SPECTRAL FEATURES IN C AND C-LIKE ASTEROIDS AND THE POSSIBLE PRESENCE OF PHYLLOSILICATES. D. R. Ostrowski[1], D. W. G. Sears[1,2], and K. M. Gietzen[1], C. H. S. Lacy[1,3], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, Ar 72701, USA (dostrow@uark.edu), [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Ar 72701, USA, [3]Department of Physics and Astronomy Sciences, University of Arkansas, Fayetteville, AR 72701, USA.

Introduction: Main belt asteroids (MBA) and near Earth asteroids (NEA) are classified into 26 discrete classes. The NEAs are a small fraction of the total asteroid population. For the NEAs alone there are about 4500 known, with an even smaller fraction of these that have spectra that can be classified. The large unknown population of asteroids has a need to be classified, in the mineralogical sense. For classification the mineralogically important spectral range is 0.8 – 2.5 μm. This can give the scientific community an idea of how asteroids are formed.

The C and C-like asteroids make up about 50% of the MBAs. The composition of these asteroids is unknown. It has been shown by spacecraft flybys and telescopic observations that C asteroids are possibly rubble piles. In recent experimental observation it has been suggested that these bodies generally considered to be featureless, do contain features in their relatively flat spectra [1].

Experimental: To date we have obtained seven observing runs between 2004 and 2006 on NASA's IRTF that has yielded spaectra of 35 asteroids. The spectral range observed is from 0.8 μm to 2.5 μm. The spectra were coupled with the visible wavelengths (0.4-0.9 μm) from the MIT SMASS [2-9]. The data is compared against a phyllosilicate database to check for the possible connection.

A phyllosilicate database has been built. It is separated by the three layer types; 1:1, 2:1, and 2:1:1. Spectra for this database has been acquired from the USGS spectral library [10].

Results: Of the asteroids observed, five are C and six are C-like. Figure 1 depicts the visual and infrared spectra of the C asteroids obtained and Fig 2 does this for C-like asteroids. The noise in the spectra at 1.4 and 2.0 μm is where the possible absorption features for phyllosilicates are present.

C Chondrites: The carbonaceous chondrites most closely resembling the C asteroids in their reflectivity spectra are the CI and CM chondrites, which are those most close to solar composition. Researchers agree that they consist essentially of phyllosilicates, but there is considerable uncertainty as to their exact nature; chlorite, serpentine, mica, montmorillonite, and many others have been mentioned [11]. Figure 3 displays the spectra of CI and CM chondrites [12].

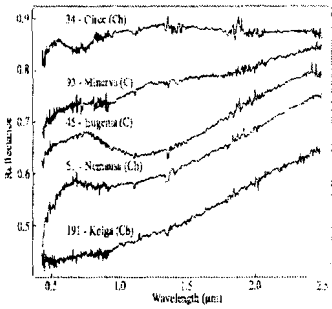


Figure 1: Visible and infrared spectrum of the observed C asteroids. Spectra are randomly stacked for visual comparison reasons.

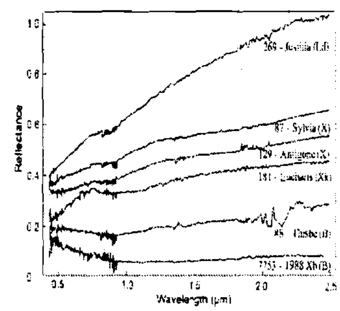


Figure 2: Visible and infrared spectrum of the observed C-like asteroids. Spectra are randomly stacked for visual comparison reasons.

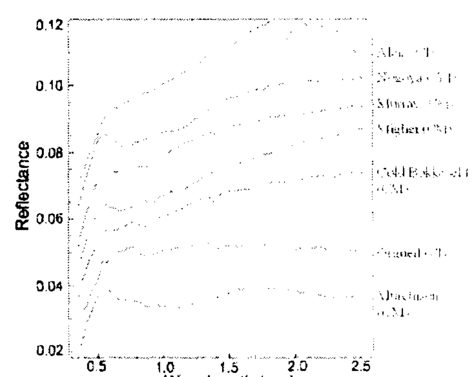


Figure 3: Visible and infrared spectra of CI and CM meteorites. The shape of the spectra is similar to that of the C and C-like asteroids.

Spectra of Phyllosilicates: The phyllosilicates are divided into three layer types: the 1:1, 2:1, and 2:1:1, which are composed of tetrahedral and octahedral

ANALYSIS OF REFLECTANCE SPECTRA OF ORDINARY CHONDRITES: IMPLICATIONS FOR ASTEROIDS.

K. M. Gietzen[1] <kgietze@uark.edu>, C. H. S. Lacy[1,2], D. R. Ostrowski[1], D. W. G. Sears[1,3], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Physics and Astronomy, University of Arkansas, Fayetteville, AR 72701 [3]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701

Introduction: Chondritic meteorites have a composition very similar to that of the photosphere of the Sun. They are classified into nine or more groups based on subtle variations in bulk phase and mineral compositions. The most abundant of these are the ordinary chondrites, which comprise ~85% of all meteorite falls and make up three of the chondrite classifications, namely H, L and LL. They are additionally sorted into petrographic types 3, 4, 5 and 6 according to the degree of metamorphism. The pyroxene structures convert from clinorhombic (CPX) to orthorhombic (OPX) form with metamorphism.

In the search for parent bodies for meteorites, asteroids have always seemed the logical solution. In particular, the S asteroid population has long been the center of the search for a connection with the ordinary chondrites due to their relative abundance to the asteroid population and the seemingly similar composition. The subtle spectral variations in the S asteroids and the ordinary chondrites and in the asteroids themselves have made this connection difficult to make. Recent work has found the clinorhombic form of pyroxene on surfaces of S asteroids which may be able to aid in the connection of these two groups of solar system bodies [1].

Experimentation: Reflectance spectra (.3 – 2.5 μm) for seven ordinary chondrites (Table 1) were obtained through the NASA Planetary Data Systems database [2]. The spectra were analyzed using the Modified Gaussian Model (MGM) [3] as were the asteroids in our earlier work.

Results: Our analysis indicated that there are absorption features in both the 1 and 2 μm regions present in all seven chondrites. This would suggest the presence of pyroxenes in all. However, there is an indication that the structure of the pyroxenes is different in the type 3 chondrites compared to the type 6 chondrites. As shown in the upper plot in Fig. 1, there is an additional absorption feature in the 2 μm region of the type 3 chondrites that is not present in the spectra of the type 6 (Fig. 1 lower plot). This additional feature represents the presence of clinorhombic pyroxenes (CPX).

Discussion: There are two or three individual absorption bands that combine to make up the 1 μm and 2 μm bands characteristic to pyroxenes which MGM can separate. The component band strength ratio (CBSR) was calculated for both the 1 and 2 μm regions using the methods of Sunshine and Pieters [3]. The CBSR allowed us to determine the percentages of clinopyroxenes relative to total pyroxenes for each chondrite (Table 1).

Table 1. Type 3 and 6 ordinary chondrites analyzed in the present study, their class and the percent clinopyroxene determined by spectral analysis[(1)]

Meteorites	Class	% CPX	
		1 μm	2 μm
Type 3 Ordinary Chondrites			
Bishunpur	LL3.1	78±5	73±5
Parnallee	LL3.3	77±2	64±1
Hedjaz	L3.7	66±6	44±5
Dhajala	H3.8	84±7	63±4
Type 6 Ordinary Chondrites			
Manbloom	LL6	84±2	[illegible]
Colby (Wisconsin)	L6	79±2	n.d.
Brudenheim	L6	76±2	n.d.

1. n.d., not detected

In the 2 μm region, we found CPX percentages to range from 44 – 73% for the type 3 chondrites and found no evidence of CPX for the type 6 chondrites. The CBSR also shows percentages for CPX in the 1 μm region for all the type 3 chondrites. In general, the 1 μm percentages are greater than those for the 2 μm for type 3. The type 6 chondrites show no indication of CPX. Other minerals such as plagioclase and olivine have absorption features in the 1 μm region in the same range as the clinorhombic pyroxenes that are responsible for these numbers. These minerals do not, however, have a 2 μm feature.

Gietzen, et al. [1] found abundant clinorhombic pyroxenes in seven of eight S asteroids ranging from 42 – 61%, similar results to what is found for the type 3 ordinary chondrites in this work. This would suggest that the surfaces of S asteroids are type 3 ordinary chondrite material and provides an explanation of the asteroid-meteorite mismatch. We are not, however, the first to observe abundant clinopyroxene in S asteroids. Gaffey et al. [4] reported finding calcic pyroxene in many of their S asteroid subclasses. They attributed it to be igneous in origin which further muddled the meteorite-asteroid connection since there is not a large

VISIBLE AND NEAR INFRARED SPECTRA OF MAIN BELT AND NEAR EARTH ASTEROIDS

K. M. Gietzen[1] <kgietze@uark.edu>, C. H. S. Lacy[1,2] <clacy@uark.edu>, [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Physics and Astromomy

Introduction: Asteroids provide unique insights into the origin and early history of the solar system. Near-Earth asteroids (NEAs) are also interesting because of the collisional hazard and value to solar system exploration as intermediate targets between the Moon and Mars. Reflectance spectra of twenty-five main belt and NEAs (Table 1) have been obtained in the near infrared (0.8 – 2.5 μm). Here we present a progress report of these studies.

Experimentation: The main belt asteroids in this study were chosen to provide a range of asteroid types while the NEAs were chosen on the basis of observability. Our spectra were obtained at Mauna Kea between 2004 and 2006 using the NASA IRTF equipped with the SpEX infrared spectrometer. The data were reduced by IRAF and other commonly used methods. The data were then coupled with spectral data in the visible wavelengths (0.4 – 0.9 μm) from the MIT SMASS [2, 3, 4, 6, 7, 8, 9, 10] database to provide a spectrum covering the visible to near infrared. The spectra were analyzed using the Modified Gaussian Model (MGM) [11] and will soon be analyzed by the other methods.

Results: Our spectra are shown in Fig. 1. The spectra of the asteroids were grouped by visual inspection. We began by placing the spectra which had absorption features in the 1 and 2 μm region together and arranging them according to the relative strengths of the two features. These were further divided according to the strength of the 1μm feature and the relative strength of the 2 μm feature. The remainder of the spectra were separated based on the presence and strength of a 1 μm feature and the basic shape of the spectra. We found seven distinct groups consistent with published taxonomies.

Discussion: The largest of these seven groups contains nine asteroids eight of which are all classified as an S, Sl, Sa or Sk in Bus and Binzel's [10] taxonomy. The ninth, asteroid 54509, has not previously been classified in this way because of the lack of a visible spectrum. The second group contains 3908, a V type asteroid, and two other as yet unclassified asteroids. Group three contains three asteroids that are classified as C or Cb asteroids. The fourth group contains one Ch and one Sl asteroid. Group five is comprised of four asteroids classified as Ld, X and C. The sixth group contains an Xk and a Ch classified asteroid and the last group also has two asteroids both classified as X. Classifications we have assigned to previously unclassified asteroids are indicated in Table 1.

Table 1

Asteroid	Type	% CPX 1 μm/2 μm	Mean Albedo
Main Belt Asteroids			
6 – Hebe	S	51/47	0.27‡
18 – Melpomene	S	61/65	0.2[illegible]‡
34 – Circe	Ch	--	0.0[illegible]‡
45 - Eugenia	C	--	0.04‡
51 – Nemausa	Ch	--	0.09‡
52 – Europa	V	--	0.06‡
63 – Ausonia	Sa	68/42	[illegible]
87 – Sylvia	X	--	0.04‡
88 – Thisbe	B	--	0.07‡
93 – Minerva	C	--	0.0[illegible]‡
129 – Antigone	X	--	0.1[illegible]‡
167 – Urda	Sk	45/42	0.2[illegible]‡
181 – Eucharis	Xk	--	0.1[illegible]‡
191 – Kolga	Cb	--	[illegible]
269 – Justitia	Ld	--	[illegible]
354 – Eleonora	Sl	Olivine	0.19‡
Near-Earth Asteroids			
1036 – Ganymed	S	41/41	0.1[illegible]†
3908 – Nyx	V	90/57	0.3[illegible]†
7753 – 1988 XB	B	--	[illegible]
1999 JV3	S	56/54	[illegible]
2003 YQ117	V*	50/51	
22771 – 1999 CU3	Sl	61/61	
54509 – 2000 PH5	S/V*	--	[illegible]
66251 – 1999 GJ2	S*	--	
68950 – 2002 QF15	V*	52/58	

*Present work , †Near-Earth Objects – Dynamic Site [12], ‡Planetary Data System [13]

In pyroxene-bearing asteroids (the first two groups in Fig. 1), there are two or three individual absorption bands that combine to make up the characteristic 1 μm and 2 μm bands which MGM can separate. The component band strength ratio (CBSR) was calculated for both the 1 and 2 μm regions using the methods of Sunshine and Pieters [11]. From this the percentage of clinopyroxenes relative to the total pyroxenes was determined for these asteroids (Table 1). In general there is agreement (within uncertainties) in the amount of %CPX calculated from each band, although asteroids 63, 354 and 3908 are exceptions. Asteroid 63, an Sa type has a spectra that is intermediate between the S type and the olivine-rich A type based on their UV slope [10]. This could indicate that asteroid 63 contains more olivine than is typical

Rosetta will be encountering the most thermally processed asteroid yet to be visited by an interplanetary spacecraft. This work was funded by the NASA Rosetta and Planetary Astronomy Programs, and was performed in part at the Jet Propulsion Laboratory under contract with NASA.

33.10

Nir Spectra And Interpretations For M-asteroids 369 Aeria And 785 Zwetana

Paul S. Hardersen[1], M. J. Gaffey[1], S. Kumar[1]
[1]*University of North Dakota.*

Systematic study of the M-asteroid population continues to reveal significant spectral and mineralogical diversity among this primarily unrelated group of main-belt asteroids. Thus far, 17 M-asteroids have been found to exhibit a variety of weak NIR absorption features indicating the presence of surficial pyroxene, olivine, or spinel. Determining the mineralogical nature of weak absorption features in NIR asteroid spectra allows tighter constraints to be placed on the geological, chemical, and thermal nature of individual asteroids, as well as identification of potential meteorite analogues. In addition, the discovery of spectral variability among the M-asteroids highlights the limitations of taxonomic identifications and interpretations.

369 Aeria and 785 Zwetana were observed at the NASA Infrared Telescope Facility (IRTF/SpeX) on April 19, 2005, UT, with the acquisition of 60 and 30 spectra, respectively. 369 Aeria exhibits weak 0.9- and 1.9-micron absorption features on an overall reddish NIR spectrum that exhibits similarities to mesosiderite spectra. Spectra were obtained across two-thirds of a rotation of the asteroid, which revealed systematic variations of the 0.9- and 1.9-micron absorptions. These band parameters change systematically with rotation of the asteroid and suggest a small, but measurable, change in orthopyroxene chemistry across the surface of the asteroid. Band Area Ratio (BAR) values for 369 Aeria are larger than 2.8, suggesting pyroxene is the significant mafic silicate on Aeria's surface. The weakness of the absorption features also suggest a significant abundance of surface metal, which weakens pyroxene absorption features.

NIR spectra of 785 Zwetana exhibit a broad, weak absorption beyond 1.30-microns without a corresponding 1-micron feature. Analysis suggests that the spectrally active phase on the surface of 785 Zwetana is spinel, which also suggests the presence of CAIs and a CO/CV-chondrite-like meteoritic analogue. This research is supported by NASA Planetary Astronomy Program Grant NNG05GH01G.

33.11 **Bull. Am. Astron. Soc, Vol. 39, p.478**

Abundant Clinopyroxene On The S Asteroids And Implications For Meteorites And Asteroid History And The Asteroid-meteorite Relationship

Katherine M. Gietzen[1], C. H. Lacy[1], D. W. Sears[1]
[1]*Univ. of Arkansas.*

Abundant clinopyroxene on the S asteroids and implications for meteorites and asteroid history and the asteroid-meteorite relationship

Abstract

We have obtained spectra for 25 asteroids in the range 0.8 - 2.5 μm using the NASA IRTF, of which eight were S asteroids. Analysis of their spectra using the Modified Gaussian Model of Sunshine and Pieters (1993) suggests that six of the eight contain significant amounts of pyroxene in the clinorhombic form (CPX), as opposed to the more common orthopyroxene, (OPX). Our pyroxene-rich targets were Hebe (%CPX = 50%), Melponeme (63%), Urda (43%), Ganymed (41%), 1999 JV3 (55%), 1999 CU3 (61%). Clinopyroxene is the low temperature form of pyroxene and is an important diagnostic feature of the primitive (least metamorphosed) ordinary chondrites. Clinopyroxene is also the form of pyroxene associated with igneous meteorites and two V asteroids in our database also contain considerable clinopyroxenes 2003 YQ 117 (50%) and 2002 QF15 (55%). Primitive and igneous meteorites are well-known and widely studied, but numerically they are very rare. The presence of this mineral phase on the surfaces of asteroids therefore has major implications for both asteroid history and the asteroid-meteorite connection.

First, the abundance of CPX on the surface of S asteroids imp[illegible] that (1) they are covered with unmetamorphosed material, consiste[illegible] onion skin model in which metamorphism is caused by internal he[illegible] the level of metamorphism experienced by the asteroid decreases [illegible] creasing distance from the center, or (2) they are covered with [illegible] material. Second, the abundance of CPX on the surface of S a[illegible] consistent with them not being related to ordinary chondrites, most o[illegible] are highly metamorphosed and contain only orthopyroxene (OPX)[illegible] weathering is therefore not the reason for the spectral mismatch be[illegible] asteroids and ordinary chondrites.

33.12

Near Infrared Spectroscopy of Jovian Trojan Asteroids: A Search [illegible] Silicate Features

Bin Yang[1], D. Jewitt[1]
[1]*Univ. of Hawaii.*

Spectroscopic studies show that the reflectance spectra of Jovian T[illegible] asteroids generally appear to be linear and moderately red (with a few [illegible] tral ones) in the optical and near infrared wavelength regions. Cruiksha[illegible] al. (2001) demonstrated that synthetic models incorporating magnesium[illegible] pyroxene (Mg, Fe SiO3) and carbon could match the low albedo and [illegible] shape of the reflectance spectrum of Trojan Hektor from 0.3 to 3.6 mic[illegible] More importantly, Spitzer thermal emission spectra of three Trojan aste[illegible] all showed an emissivity plateau near 10-micron, which was interpret[illegible] an indication of fine-grained silicates (Emery et al. 2006). Interestingly [illegible] previous survey (Howell 1995) noted that several Trojans showed a [illegible] absorption band between 1.1 and 1.25 micron based on broadband inf[illegible] colors. This possible 1 micron feature is consistent with the 1 micron sil[illegible] band that has been observed and well studied on many main belt astero[illegible]

We obtained near infrared (NIR) spectroscopy (0.8-2.5 micron) on [illegible] jan asteroids having reported silicate-related absorption bands. Also, [illegible] unique asteroid (279) Thule in the 3:4 mean-motion resonance wa[illegible] served. The observations were made with the NASA Infrared Telesco[illegible] Facility (IRTF) atop Mauna Kea. We will present the new spectra and sim[illegible] scattering models employed to constrain the surface properties of Troja[illegible] asteroids.

34: Future Missions and Instruments
Poster, Wednesday, 3:30-5:30pm, Ballrooms CDE

34.00C

Chair

Louise Prockter[1]
[1]*Applied Physics Lab.*

34.02

The Wirtanen Analysis and Surface Probe: Concept for a New Frontiers Comet Surface Sample Return Mission

Matthew Smith[1], K. Block[2], S. Byram[3], B. M. Karpowicz[4], N. Lanza[5], J. [illegible] Masiero[6], C. Miller[7], S. Singer[8], B. Smith[4], A. Winfield[9], L. Wye[10], T. [illegible] Balint[11]
[1]*University of Washington,* [2]*University of Arizona,* [3]*University of Michigan,* [4]*Georgia Institute of Technology,* [5]*University of New Mexico,* [6]*University of Hawaii,* [7]*New Mexico State University,* [8]*University of Maryland,* [9]*Auburn University,* [10]*Stanford University,* [11]*NASA Jet Propulsion Laboratory.*

The material contained within the surfaces of comets holds keys that unlock fundamental questions regarding the formation of the Solar System and life on Earth. As participants in NASA's 2007 Planetary Science Summer School at JPL, we designed for a New Frontiers (NF) class mission to return a surface sample from a comet nucleus, a goal established as a pri-

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5764

Konkoly Observatory
Budapest
10 April 2007

HU ISSN 0374 - 0676

NEW TIMES OF MINIMA OF SOME ECLIPSING VARIABLES

LACY, C.H.S.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

Observatory and telescope:
URSA: URSA Observatory at the University of Arkansas (`ursa.uark.edu`); 10-inch Schmidt-Cassegrain reflector. NFO: NFO WebScope near Silver City, NM, USA (`www.nfo.edu`); 24-inch classical Cassegrain.

Detector:	URSA: 1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) −20°C; 1.15 arcsec square pixels; 20′(N-S)×30′(E-W) field of view. NFO: 2102×2092 pixels Kodak KAF 4300E CCD cooled to (typ.) −20°C; 0.78 arcsec square pixels; 27′ square field of view.

Method of data reduction:
Virtual measuring engine (Measure 2.0) written by C.H.S. Lacy (2005).

Method of minimum determination:
Kwee & van Woerden (1956)

Times of minima:

Star name	Time of min. HJD 2400000+	Error	Type	Filter	Rem.
AP And	53733.5372	0.0001	1	V	URSA
	53736.7119	0.0004	1	V	NFO
	53916.8694	0.0003	2	V	NFO
	53998.6147	0.0002	1	V	NFO
	54009.7256	0.0002	1	V	NFO
	54017.6619	0.0002	1	V	URSA
	54021.6303	0.0002	2	V	URSA
	54021.6302	0.0002	2	V	NFO
	54028.7733	0.0001	1	V	URSA
	54029.5670	0.0001	2	V	URSA
	54032.7414	0.0001	2	V	URSA
	54048.6143	0.0002	2	V	URSA
	54051.7892	0.0002	2	V	URSA
	54052.5824	0.0002	1	V	NFO
	54059.7253	0.0002	2	V	NFO
	54063.6939	0.0001	1	V	URSA
	54067.6620	0.0003	2	V	NFO
	54071.6304	0.0003	1	V	URSA
	54071.6299	0.0002	1	V	NFO

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5670

Konkoly Observatory
Budapest
3 January 2006

HU ISSN 0374 – 0676

NEW TIMES OF MINIMA OF SOME ECLIPSING VARIABLES

LACY, C. H. S.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

Observatory and telescope:
URSA: URSA Observatory at the University of Arkansas (`ursa.uark.edu`); 10-inch Schmidt-Cassegrain reflector. NFO: NFO WebScope near Silver City, NM, USA (`www.nfo.edu`); 24-inch classical Cassegrain.

Detector:	URSA: 1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) −20°C; 1.15 arcsec square pixels; 20′(N-S)×30′(E-W) field of view. NFO: 2102×2092 pixels Kodak KAF 4300E CCD cooled to (typ.) −20°C; 0.78 arcsec square pixels; 27′ square field of view.

Method of data reduction:
Virtual measuring engine (Measure 2.0) written by C.H.S. Lacy (2005).

Method of minimum determination:
Kwee & van Woerden (1956)

Times of minima:

Star name	Time of min. HJD 2400000+	Error	Type	Filter	Rem.
AP And	53348.61894	0.00010	2	V	URSA
	53574.80780	0.00012	1	V	URSA
	53631.95039	0.00007	1	V	NFO
	53670.83898	0.00006	2	V	NFO
	53671.63281	0.00008	1	V	URSA
	53698.61653	0.00008	1	V	URSA
	53706.55315	0.00010	1	V	URSA
CO And	53314.8376	0.0003	2	V	URSA
	53358.7009	0.0005	2	V	URSA
	53360.5309	0.0004	1	V	URSA
	53634.6781	0.0003	1	V	NFO
	53676.7161	0.0004	2	V	URSA
	53687.68078	0.00020	2	V	NFO

The Astrophysical Journal, 640:1018–1038, 2006 April 1

THE ECLIPSING BINARY V1061 CYGNI: CONFRONTING STELLAR EVOLUTION MODELS FOR ACTIVE AND INACTIVE SOLAR-TYPE STARS

Guillermo Torres,[1] Claud H. Lacy,[2] Laurence A. Marschall,[3] Holly A. Sheets,[4] and Jeff A. Mader[5]
Received 2005 August 1; accepted 2005 November 30

ABSTRACT

We present spectroscopic and photometric observations of the eclipsing system V1061 Cyg ($P = 2.35$ days). A third star is visible in the spectrum, and the system is a hierarchical triple. We combine the radial velocities for the three stars, times of eclipse, and intermediate astrometric data from the *Hipparcos* mission (abscissa residuals) to establish the elements of the outer orbit, which is eccentric and has a period of 15.8 yr. We determine accurate values for the masses, radii, and effective temperatures of the binary components: $M_{\rm Aa} = 1.282 \pm 0.015\ M_\odot$, $R_{\rm Aa} = 1.615 \pm 0.017\ R_\odot$, and $T_{\rm eff}^{\rm Aa} = 6180 \pm 100$ K for the primary (star Aa), and $M_{\rm Ab} = 0.9315 \pm 0.0068\ M_\odot$, $R_{\rm Ab} = 0.974 \pm 0.020\ R_\odot$, and $T_{\rm eff}^{\rm Ab} = 5300 \pm 150$ K for the secondary (Ab). The mass of the tertiary is determined to be $M_{\rm B} = 0.925 \pm 0.036\ M_\odot$ and its effective temperature is $T_{\rm eff}^{\rm B} = 5670 \pm 150$ K. Current stellar evolution models agree well with the properties of the primary but show a very large discrepancy in the radius of the secondary, in the sense that the predicted values are ~10% smaller than observed (a ~5 σ effect). In addition, the temperature is cooler than predicted, by some 200 K. These discrepancies are quite remarkable given that the star is only 7% less massive than the Sun, the calibration point of all stellar models. We identify the chromospheric activity as the likely cause of the effect. Inactive stars agree very well with the models, while active ones such as V1061 Cyg Ab appear systematically too large and too cool.

Subject headings: binaries: close — binaries: spectroscopic — stars: evolution — stars: individual (V1061 Cyg) — techniques: spectroscopic

Online material: color figures, machine-readable tables

1. INTRODUCTION

Accurately determined properties of stars in detached eclipsing binaries provide fundamental data for testing models of stellar structure and stellar evolution (see, e.g., Andersen 1991, 1997). For stars less massive than the Sun properties such as the stellar radius and the effective temperature have occasionally been found to disagree with model predictions (see, e.g., Lacy 1977; Popper 1997; Clausen et al. 1999a; Torres & Ribas 2002; Ribas 2003). Directed efforts to find additional systems in this regime suitable for testing theory (Popper 1996; Clausen et al. 1999b) have produced a few cases, while other examples have been found serendipitously (e.g., Creevey et al. 2005; López-Morales & Ribas 2005). The present binary system is in the second category, since it was originally thought to be of a completely different nature.

The photometric variability of V1061 Cygni (also known as HD 235444, HIP 104263, RX J2107.3+5202, $\alpha = 21^{\rm h}07^{\rm m}20\overset{\rm s}{.}52$, $\delta = +52°02'58\overset{''}{.}4$ [J2000.0], spectral type F9, $V = 9.24$) was discovered photographically by Strohmeier & Knigge (1959), and the object was classified by Strohmeier et al. (1962) as an Algol-type binary with a period of 2.346656 days. Other than occasional measurements of the time of primary eclipse, the system received very little attention until the spectroscopic work by Popper (1996), who observed it as part of his program to search for eclipsing binaries containing at least one lower main sequence star (late F to K). On the basis of two high-resolution spectra and other information Popper concluded that V1061 Cyg was most likely a semi-detached system of the rare "cool Algol" class and dropped it from his program. Unlike the classical Algols, which are composed of a cool giant or subgiant and an early-type star, the mass gainer in the cool Algols is also of late spectral type (see Popper 1992). Since less than a dozen of these systems are known, V1061 Cyg was placed on the observing list at the Harvard-Smithsonian Center for Astrophysics (CfA) in 1998 for spectroscopic monitoring, and photometric observations began later. Not only did we discover that it is not a cool Algol (it is well detached, as reported by Sheets et al. 2003), but we also found that (1) it is triple lined (and a hierarchical triple), (2) the secondary in the eclipsing pair is less massive than the Sun and therefore potentially interesting for constraining models of stellar structure and evolution (Popper's original motivation for observing it), and (3) the mass ratio of the binary is quite different from unity, which makes it a favorable case for such tests. Furthermore, the comparison with theory shows a significant discrepancy in the radius of the secondary, corroborating similar evidence from other systems and providing some insight into the problem.

We describe below our observations and complete analysis of this system, including a discussion of the possible nature of the deviations from the models for low-mass stars.

2. OBSERVATIONS AND REDUCTIONS

2.1. *Spectroscopy*

V1061 Cyg was observed at the CfA with an echelle spectrograph on the 1.5 m Wyeth reflector at the Oak Ridge Observatory (eastern Massachusetts) and occasionally also with a nearly identical instrument on the 1.5 m Tillinghast reflector at the F. L. Whipple

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; gtorres@cfa.harvard.edu.

[2] Department of Physics, University of Arkansas, 226 Physics Building, Fayetteville, AR 72701; clacy@uark.edu.

[3] Department of Physics, Gettysburg College, 300 North Washington Street, Gettysburg, PA 17325; marschal@gettysburg.edu.

[4] Department of Physics and Astronomy, Dartmouth College, 6127 Wilder Laboratory, Hanover, NH 03755; holly.a.sheets@dartmouth.edu.

[5] W. M. Keck Observatory, 65-1120 Mamalahoa Highway, Kamuela, HI 96743; jmader@keck.hawaii.edu.

The Astronomical Journal, 131:2664–2672, 2006 May

Ⓔ

ABSOLUTE PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY STAR EY CEPHEI[1]

Claud H. Sandberg Lacy[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

Guillermo Torres
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; gtorres@cfa.harvard.edu

Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain; claret@iaa.es

and

John L. Menke
Menke Scientific, Ltd., 22500 Old Hundred Road, Barnesville, MD 20838; john@menkescientific.com
Received 2005 October 21; accepted 2006 January 23

ABSTRACT

We present 6907 differential photometric observations in the V filter, as well as 52 radial velocities from spectroscopic observations of the detached, eccentric 7.97 day double-lined eclipsing binary star EY Cep. Absolute dimensions of the components are determined with high precision (less than 1% in the masses and radii) for the purposes of testing various aspects of theoretical modeling. We obtain $1.523 \pm 0.008\ M_{\odot}$ and $1.463 \pm 0.010\ R_{\odot}$ for the primary and $1.498 \pm 0.014\ M_{\odot}$ and $1.468 \pm 0.010\ R_{\odot}$ for the secondary. The effective temperatures and interstellar reddening of the stars are accurately determined from the spectra, $uvby\beta$, and UBV photometry: 7090 ± 150 K for the primary and 6970 ± 150 K for the secondary, corresponding to spectral types of F0 and F0, and 0.036 mag for the color excess E_{b-y}. Spectral line widths give rotational velocities that are synchronous with the mean orbital motion in a highly eccentric orbit ($e = 0.4429$). The components of EY Cep are young main-sequence stars with an age of about 40 million years, according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (EY Cephei)

Online material: machine-readable table

1. INTRODUCTION

The discovery of EY Cep (BV 211, Tycho 4521-349-1, GSC 04521-00349; $V = 9.80$–10.57, F0+F0 V) as a variable star is due to Strohmeier (1958); see also Strohmeier et al. (1963). They gave a period of 5.51672 days (Strohmeier 1963), which we now know is incorrect, and a light curve that showed a shallow secondary eclipse, also wrong. The star was then little studied until Lacy (1985) announced the discovery of double lines in high-resolution spectra (see also Lacy 1990). Lacy continued his spectroscopic program at Kitt Peak National Observatory (KPNO) and also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. Beginning in 1995, spectrometers operated by the Harvard-Smithsonian Center for Astrophysics (CfA) were also used in an intensive campaign to obtain high-resolution spectra. Radial velocities extracted from these spectra were used to find the correct orbital period of about 7.97 days. In 2002 February, J. L. M. began photometric observations with an 11 inch (28 cm) reflector at Barnesville, Maryland. A description of his observing program has been presented (Menke 2002). By the end of 2002 December, he had obtained 504 unfiltered differential observations and 6907 differential observations in the V filter (Table 1) with a standard error of 0.012 mag. In this paper we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results to those of theory, where we find good agreement with models having a very young age of about 40 million years.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

Times of eclipse for EY Cep were determined from both the unfiltered observations and the V-band photometric data of Table 1 by the method of Kwee & van Woerden (1956). These times are listed in Table 2. Uncertainties for the eclipse timings were estimated by the method. Based on these timings, we have adopted the following linear ephemerides:

$$\text{Min. I (HJD)} = 2{,}452{,}339.60833(14) + 7.971488(6)E,$$

$$\text{Min. II (HJD)} = 2{,}452{,}342.76474(22) + 7.971488(6)E,$$

with a phase difference between the primary and secondary eclipse of 0.39596 ± 0.00004. This indicates that the eccentricity of the orbit is quite significant. The values of the periods for Min. I and Min. II have been set equal, since there is not a sufficient time base to determine whether a significant difference in period is present. The linear ephemeris for Min. I above was adopted for initial use in our spectroscopic and light curve

[1] Some of the observations reported here were obtained with the MMT, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Visiting astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.

10.07

The alpha-element Enhancement Effect On The Surface Brightness Fluctuation Magnitudes And Broad-band Colors

Hyun-chul Lee[1], G. Worthey[1], J. P. Blakeslee[1]
[1]*Washington State University.*

We present the effects due to alpha-element enhancement on surface brightness fluctuation magnitudes and broad-band colors in order to investigate the calibration zero-point. We study these effects at ages covering 0.1 to 13 Gyr and metallicities of Z=0.0003 to 0.04 using the Teramo group's isochrones, BaSTI. We show a one-to-one relationship between isochrone differences and broad-band colors and surface brightness fluctuation magnitudes because of alpha-element enhancement. Our results also illustrate a dramatic impact of the convective core overshoot assumption on the predicted broad-band colors for models with ages near 1 Gyr.

Support for this work was provided by the NSF through grant AST-0307487, the New Standard Stellar Population Model (NSSPM) project.

10.08

WIYN Open Cluster Study: UBVRI CCD Photometry Of An Open Cluster

Jessica L. Windschitl[1], H. Leckenby[1], C. P. Deliyannis[2], A. Sarajedini[3], I. Platais[4]
[1]*St. Mary's University of Minnesota,* [2]*Indiana University,* [3]*University of Florida,* [4]*Johns Hopkins University.*

We provide photometry of an open cluster in the U, B, V, R, and I filters in order to re-evaluate its fundamental properties. PSF photometry was applied using DAOPHOT II and IRAF. We discuss the reddening and metallicity, which were derived using all of the U-B, U-V, U-R, and U-I vs B-V color-color diagrams. We also discuss the distance modulus and age, which were derived from application of Yale-Yonsei isochrones.

10.09

The Composition of Horizontal Branch Stars in the Globular Cluster Messier 3

Sharina Haynes[1], C. A. Pilachowski[2]
[1]*Tennessee State University,* [2]*Indiana University.*

Moderate resolution spectra of horizontal branch and lower giant branch stars in the globular cluster Messier 3 are analyzed to determine their compositions. The spectra were obtained using the Hydra fiber positioner and Bench Spectrograph on the WIYN 3.5-m telescope. The compositions are determined using fine analysis, and are compared to the compositions of stars on the upper giant branch. Radial velocity is used to confirm membership of the stars in M3.

This material is based upon work supported by the National Science Foundation through an REU Site Program grant to Tennessee State University and Indiana University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

10.10

The Be binary star Delta Sco: Revised Orbit and Implications for the Circumstellar Disk

Robert T. Zavala[1], C. Tycner[1], J. Benson[1], D. Hutter[1], H. Schmitt[2]
[1]*US Naval Observatory,* [2]*Naval Research Laboratory.*

Delta Scorpii is a Be star and the largest member of a binary with a 10.5 year period. We have revised the orbital elements using the Navy Prototype Optical Interferometer (NPOI), published speckle and radial velocity data. The NPOI observations are the first to clearly resolve the system near periastron passage, at a separation of approximately 20 mas. We present this new orbit, and discuss the implications of the orbit on the stability of the circumstellar disk of Delta Sco. These results will be of interest for planning observations during the next periastron passage in 2011.

Session 11: Sun and Solar System
Poster, Monday, 9:20am-7:00pm, Exhibit Hall DE

11.01

Observations of Cosmic Ray Modulation with MARIE

Victor Andersen[1]
[1]*University of Houston.*

The intensity of galactic cosmic rays in the inner heliosphere is modulated by the cosmic ray's interaction with the solar magnetic field and solar wind, with lower levels of modulation generally occurring during solar minimum. During solar minimum, the intensity of cosmic rays is often observed to be periodic with a period that matches the solar rotation period, indicating that the periodicity is produced by enhanced modulation in corotating interaction regions that occur at the interface between the slow and fast solar wind. I present an analysis of low energy cosmic ray observations obtained with MARIE (an instrument aboard Mars Odyssey) for three extended time periods in 2003 during which there were no solar particle events. Comparison of these data with data from SIS aboard ACE show that are short term modulation features (timescales of days) that persist over timescales of 1 solar rotation, indicating that structures in the heliosphere are producing short term modulation effects at times far from solar minimum.

11.02 **Bull. Am. Astron. Soc, Vol. 38, p.90**

Visible and Near Infrared Spectra of Five Near Earth Asteroids

Katherine M. Gietzen[1], C. H. Lacy[1], A. S. Rivkin[2]
[1]*University of Arkansas,* [2]*The Johns Hopkins Applied Physics Laboratory.*

Reflectance spectra of five near earth asteroids (3908, 7753, 22771, 54509 and 66251) were obtained in the near infrared (.8 - 2.5 m) using the NASA IRTF equipped with the SpEX infrared spectrometer at Mauna Kea in 2004 and 2005. The data obtained was coupled with spectral data in the visible wavelengths from the SMASS database [2, 3, 4, and 5] and analyzed using the Modified Gaussian Model (MGM). The expected absorption bands at 1 and 2 m for olivines and pyroxenes were observed in a number of the asteroid spectra. However, we also found that there were asteroid reflectance spectra that were very featureless and the absorption bands that were present (if any) were very weak. Space weathering has been given by others [1] as a possible explanation for the lack of absorption features in the spectra of asteroids. This space weathering has been described to be the possible result of the processes of sputtering erosion as a result of the impacts and implantations, radiation and cosmic ray effects. Asteroid 1989 ML (10302) was also studied using SMASS observation data in the visible wavelengths. The reflectance spectra was compared to the spectra of various types of meteorites in an attempt find a match that would aid in the classification of 1989 ML

References: [1] B. Hapke (2001) J. Geophys. Res. 106, 10039-10073; [2] J.T. Rayner et al. (2003) PASP 115, 362; [3] R.P. Binzel et al. (2004) Icarus 170, 259-294; [4] R.P. Binzel et al. (2004) Meteoritics and Planetary Science 39, 354-366; [5] T.H. Burbine et al. (2002) Icarus 159, 468-499

11.03

Non-lte Multi-species Modeling of the Hydrogen Lines in Solar Chromospheric Models

Ian Short[1], B. Fuhrmeister[2], P. Hauschildt[2]
[1]*Saint Mary's Univ, Canada,* [2]*Hamburg Observatory, Germany.*

Binary Stars as Critical Tools & Tests in Contemporary Astrophysics
Proceedings IAU Symposium No. 240, 2006
W.I. Hartkopf, E.F. Guinan & P. Harmanec, eds.

doi:10.1017/S1743921307006485

Confronting Stellar Evolution Models for Active and Inactive Solar-Type Stars: The Triple System V1061 Cygni

Guillermo Torres[1], Claud H. Sandberg Lacy[2], Laurence A. Marschall[3], Holly A. Sheets[4], and Jeff A. Mader[5]

[1]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138
e-mail: gtorres@cfa.harvard.edu
[2]Dept. of Physics, University of Arkansas, Fayetteville, AR 72701
[3]Dept. of Physics, Gettysburg College, 300 North Washington Street, Gettysburg, PA 17325
[4]Dept. of Physics & Astronomy, Dartmouth College, Hanover, NH 03755
[5]W.M. Keck Observatory, Kamuela, HI 96743

Abstract.
We present spectroscopic and photometric observations of the chromospherically active (X-ray strong) eclipsing binary V1061 Cyg ($P = 2.35$ days) showing that it is in reality a hierarchical triple system. We combine these observations with *Hipparcos* intermediate data (abscissa residuals) to derive the outer orbit with a period of 15.8 yr. We determine accurate values for the masses, radii, and effective temperatures of the eclipsing binary components, as well as for the mass and temperature of the third star. For the primary we obtain $M = 1.282 \pm 0.015$ M$_{\odot}$, $R = 1.615 \pm 0.017$ R$_{\odot}$, $T_{\rm eff} = 6180 \pm 100$ K, for the secondary $M = 0.9315 \pm 0.0068$ M$_{\odot}$, $R = 0.974 \pm 0.020$ R$_{\odot}$, $T_{\rm eff} = 5300 \pm 150$ K, and for the tertiary $M = 0.925 \pm 0.036$ M$_{\odot}$ and $T_{\rm eff} = 5670 \pm 100$ K. Current stellar evolution models agree well with the properties of the primary star, but show a large discrepancy in the radius of the secondary in the sense that the observed value is about 10% larger than predicted (a 5σ effect). We also find the secondary temperature to be $\sim$200 K cooler than indicated by the models. These discrepancies are quite remarkable considering that the secondary is only 7% less massive than the Sun, which is the calibration point of all stellar models. Similar differences with theory have been seen before for lower mass stars. We identify chromospheric activity as the likely cause of the effect. Inactive stars agree very well with the models, while active ones such as the secondary of V1061 Cyg appear systematically too large and too cool. Both of these differences are understood in terms of the effects of magnetic fields commonly associated with chromospheric activity.

Keywords. binaries: eclipsing, binaries: spectroscopic, stars: individual (V1061 Cyg), techniques: radial velocities

1. Introduction

V1061 Cygni is a rather neglected eclipsing binary with a period of 2.35 days. It was originally thought to be an example of the rare class of "Cool Algols" (Popper 1996), a group of semi-detached systems of which less than a dozen members are known. We present here new photometric and spectroscopic observations that not only show the system to be well detached, but also reveal it to be a hierarchical triple with all three stars visible in the spectra. Furthermore, the properties of the three components turn out to be very useful for testing models of stellar evolution. In recent years compelling evidence has been presented of discrepancies in the predictions of theory for stars under a solar mass. In particular, models for such objects have been found to underestimate their radii by at least 10% (a deviation far greater than the typical uncertainties), and to overestimate

THE ASTRONOMICAL JOURNAL, 130:2838–2846, 2005 December

Ⓔ

ABSOLUTE PROPERTIES OF THE ECLIPSING BINARY STAR RW LACERTAE

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

GUILLERMO TORRES
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street,
Cambridge, MA 02138; gtorres@cfa.harvard.edu

ANTONIO CLARET
Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080
Granada, Spain; claret@iaa.es

AND

LUIZ PAULO RIBEIRO VAZ
Departmento de Física, Instituto de Ciências Exatas, Universidade Federal de Minas Gerais,
C.P. 702, 30123-970 Belo Horizonte, MG, Brazil; lpv@fisica.ufmg.br
Received 2005 May 20; accepted 2005 August 24

ABSTRACT

We present 3004 differential observations in the V bandpass measured by a robotic telescope, as well as 36 pairs of radial velocities from high-resolution spectroscopic observations, of the detached, eccentric, EA-type, 10.37 day period, double-lined eclipsing binary star RW Lac. Absolute dimensions of the components are determined with excellent precision (better than 0.7% in the masses and 0.5% in the radii) for the purpose of testing various aspects of theoretical modeling. We obtain $0.928 \pm 0.006\ M_\odot$ and $1.186 \pm 0.004\ R_\odot$ for the hotter, larger, more massive, and more luminous photometric primary (star A) and $0.870 \pm 0.004\ M_\odot$ and $0.964 \pm 0.004\ R_\odot$ for the cooler, smaller, less massive, and less luminous photometric secondary (star B). A faint, third component contributes 2.6% of the light in V but is not detected in our spectrograms. The effective temperatures and interstellar reddening of the stars are accurately determined from UBV and $uvby\beta$ photometry and from analysis of the spectrograms: 5760 ± 100 K for the primary and 5560 ± 150 K for the secondary, corresponding to spectral types of G5 and G7, and 0.050 mag for interstellar reddening E_{b-y}. The orbits are slightly eccentric, and spectral line widths give observed rotational velocities that are not significantly different from synchronous for both components. The components of RW Lac are old, somewhat metal-deficient, low-mass, main-sequence stars with an age of about 11 Gyr, according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (RW Lacertae)

Online material: machine-readable table

1. INTRODUCTION

The discovery of RW Lac (GSC 03629-00740; $V = 10.63$–11.27, G5+G7 V) as an eclipsing variable star is due to Gaposchkin (1932), who listed an orbital period of half of the true value. The first correct eclipse ephemeris was given by Martinoff (1938): Min. I $= 2{,}418{,}657.440 + 10.36922E$. He gave a photographic light curve that is not significantly different from the present one, although much less accurate. Martinoff recognized that the secondary eclipse was displaced from phase 0.5, so the system must have an eccentric orbit. Savedoff (1951) lists $e \cos \omega = -0.010$, probably not significantly different from the value today (see below). Lacy (1990) announced the discovery of double lines in a single high-resolution spectrogram taken at Kitt Peak National Observatory (KPNO) in 1989, with a line strength ratio of about 2:1 in the red, consistent with results from the light-curve analysis below. Beginning in 1995, spectrometers operated by the Harvard-Smithsonian Center for Astrophysics (CfA) were used in an intensive campaign to obtain high-resolution spectra as well. Lacy also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. In 2000 mid-November, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville (the URSA telescope) began operation with RW Lac as one of its targets. By the beginning of 2004 December, it had obtained 3004 differential observations in the V bandpass (Table 4, discussed in § 4), with a standard error of 0.0075 mag. In this paper we present the analysis of these photometric and spectroscopic data to determine very accurate measurements of the absolute properties of this low-mass, main-sequence binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results to those of two different sets of stellar models, where we find good agreement in both cases with models having an age of about 11 billion years.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

Beginning in 2000 mid-November, Lacy began photometric observations in the V bandpass with the URSA telescope. Dates of eclipses were measured by using the method of Kwee & van Woerden (1956) and are listed in Table 1 (these include

[1] Visiting astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, operated by the Associated Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

DZ Psc (NSV 223; P=0.36613 d) is a low mass ratio, high fillout W-type contact binary with two previously published light curves. We confirm the total nature of the secondary eclipse and find clear evidence of spot activity. The light curve is asymmetric between primary and secondary eclipse, with the level of secondary eclipse exhibiting a definite negative slope. We also find the light curve has changed between the 2003 and 2004 observing seasons; the depth of secondary eclipse has increased by nearly 0.04 mag in R. We will present a new light and radial velocity curve solution using Binary Maker 3 (Bradstreet & Steelman 2002) and Wilson-Devinney and compare this to the solution by Niarchos & Gazeas (2004). A period study, using newly derived and previously existing times of minimum light, will also be presented.

V842 Her (P=0.41903 d) is a W-type contact binary with two previously published light curves. The light curve exhibits a total primary eclipse and slight asymmetries in the maxima due to the presence of spots. A light curve solution has been previously published but no solutions exist that incorporate the mass ratio information from the recent radial velocity data. We present a new light and radial velocity solution using our higher precision $V\&R_c$ light curves as well as a period study.

18.10

Bull. Am. Astron. Soc, Vol. 36, p.1370

Determining Properties of the Eclipsing Binary CV Boo

S.L. Walters, C.H.S. Lacy (Arkansas-Oklahoma Center for Space and Planetary Sciences)

It is commonly believed by laymen that the majority of stars in the universe are a single-star system, like our own sun. On the contrary, researchers have found that over half of the stars in our galaxy, and presumably the rest of the universe, belong to systems containing multiple stars. Of these multiple-star systems, the majority are binary systems that contain two stars. In order to develop an accurate model of stellar evolution for binary stars, accurate data regarding binary systems need to be collected and used to reject or refine existing models.

Roughly four thousand images of the eclipsing binary star system CV Boo were taken with the URSA telescope at the University of Arkansas in Fayetteville. Using differential photometry to analyze the images, magnitude of the system was plotted as a function of time. From this, the orbital period was determined and the data were used to plot a light curve. The light curve and several known parameters of the system were input to the program EBOP. Theoretical light curves, based on a set of parameters, were generated until one exactly matching CV Boos light curve was produced, thus determining the properties of the system.

The absolute properties of the system were calculated in the usual manner. In order to determine the age of the stars, the properties of each star were compared to accurate models of chemical composition and physical properties of binary stars as they change with age. The stars in CV Boo are similar to our own sun in physical properties, but they are over twice its age. On a plot of Schallers theoretical ZAMS for binary stars, it is clear that the stars in CV Boo are leaving the main sequence.

18.11

GU Boo: a New 0.6 Msun Double-Lined, Detached, Eclipsing Binary

M. Lopez-Morales (Carnegie Institution of Washington, Department of Terrestrial Magnetism, USA), J. C. Clemens (Dept. of Physics and Astronomy, University of North Carolina - Chapel Hill, USA), I. Ribas (Institut d'Estudis Espacials de Catalunya, Spain)

We have found a new 0.6 Msun, double-lined, detached, eclipsing binary, GU Boo, among a sample of new variables from the ROTSE-I database. The system has an apparent magnitude Vph 13.7 (J 11.7) and an orbital period of 0.488728 0.000002 days. Its estimated masses and radii are M1 = 0.609 0.008 Msun, M2 = 0.599 0.008 Msun, R1 = 0.610 0.014 Rsun, and R2 = 0.639 0.015 Rsun. The radius of the secondary appears to be too large, what suggests that the system may still be young. The age and metallicity of the binary are not well determined at this point. For its mean surface temperature we have adopted a preliminary value of Teff = 3950 200 K. A comparison of the physical parameters of GU Boo to curre[illegible] models reveals that all the models underestimate the radii of th[illegible] least 10This result corroborates the findings on recent studie[illegible] low-mass binaries YY Gem, CU Cnc, and the newly discovere[illegible]

18.12

The Short Period RS CVn Binary V1034 Herculis

J. Ordway, W. Van Hamme (Florida International University)

We present new *BVRI* photometric observations of the ecl[illegible] V1034 Her (GSC0983.1044) obtained in May 2004 with th[illegible] camera and 0.9-meter telescope of the Southeastern Associa[illegible] search in Astronomy (SARA), located at Kitt Peak National Ob[illegible] 2000 and 2001, V1034 Her was observed in *V* by Kaiser et al. [illegible] 5231), who found the system to be an eclipsing binary with [illegible] about 0.815 days and with RS CVn-type light curve characte[illegible] model the previously published and new light curves with the [illegible] of the Wilson-Devinney eclipsing binary program. For each [illegible] parameters are obtained.

18.13

Solutions for eclipsing binaries of the bulge fields in OGL[illegible] the Detached Eclipsing Binary Light curve fitter (DEBiL)

J. Devor (Harvard-Smithsonian Center for Astrophysics)

We created the fully automated Detached Eclipsing Binary [illegible] fitter (DEBiL), which is designed to rapidly fit large numbers o[illegible] to a simple model. Using the results of DEBiL, light curves [illegible] be located for follow-up analysis. As a test case, we analyz[illegible] light curves within the bulge fields of the OGLE II survey [illegible] 10862 model fits. We point out a small number of extreme ex[illegible] as unexpected structure found in several of the population dis[illegible] expect this approach to become increasingly useful as light [illegible] continue growing in both size and number.

Session 19: Cataclysmic Variable Stars Poster Session, 9:20am-6:30pm Exhibit Hall

19.01

Low Resolution Spectroscopy and Classifications of Eig[illegible] Cataclysmic Variables

L. Galli (Colorado College), Dr. L. Schmidtobreick (Europ[illegible] Observatory), A. Whiting (Cerro Tololo Inter-American Ob[illegible]

Classification of candidate Cataclysmic Variables was [illegible] ing the 1.5 meter spectrograph at Cerro Tololo Observatory. [illegible] ables were selected from the Catalog of Cataclysmic Variabl[illegible] in low-resolution spectroscopy spanning roughly 6000 ang[illegible] ible and near infrared. Eight objects were observed and fou[illegible] as Dwarf Novae (Fq Mon, UY Pup, Oct (LB 9963), and Lib [illegible] 0839.1)). Wy Cma and Cet (PB 6657) were determined n[illegible] and the two other objects were indeterminable. Funding wa[illegible] Cerro Tololo REU program and National Science Founda[illegible]

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5499

Konkoly Observatory
Budapest
27 January 2004

HU ISSN 0374 - 0676

PHOTOMETRIC ORBITS OF KU AURIGAE AND SW CANCRI

LACY, CLAUD H. SANDBERG

Physics Department, University of Arkansas, Fayetteville, AR 72701, USA; email: clacy@uark.edu

I am measuring light curves in the V filter of about 3 dozen eclipsing binary stars with the aim of providing photometric orbits for systems in which the light ratio is large enough to detect double lines in the spectra with existing spectrometers. The target list was selected in a number of different ways, and sometimes I find that a binary will not be suitable for the determination of absolute dimensions and masses because the light ratio is too large to show double lines. Still, it may be useful for future studies to publish a photometric orbit for these systems. In this paper are the photometric orbits of 2 such binaries selected from the list of Popper (1996). Popper gives an estimate of the spectral type of the combined light, but not the individual spectral types. I have estimated the individual spectral types by using the central surface brightness of the secondary component and the equation in Lacy et al. (1987) that relates the central surface brightness to the difference in visual surface brightness parameter Fv. Popper (1980) gives a calibration of the visual surface brightness parameter that allows the spectral type of the secondary to be estimated from the combined spectral type.

Observatory and telescope:
URSA Observatory at the University of Arkansas (ursa.uark.edu); 10-inch Schmidt-Cassegrain reflector.

Detector:	1020x1530 pixels SBIG ST8EN CCD cooled to (typ.) -20 C; 1.15 arcsec square pixels; $20'$(N-S)$\times 30'$(E-W) field of view.

Method of data reduction:
Virtual measuring engine (Measure 1.97) written by C.H.S. Lacy in 2003.

KU AURIGAE

Name of the object:
KU Aur = GSC 02422 00020

Comparison star(s):	GSC 02422 01381

Check star(s):	GSC 02422 00931

The Astronomical Journal, 128:1340–1347, 2004 September

ABSOLUTE PROPERTIES OF THE ECLIPSING BINARY STAR V459 CASSIOPEIAE

Claud H. Sandberg Lacy[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apdo. 3004, E-18080 Granada, Spain; claret@iaa.es

and

Jeffrey A. Sabby[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu
Received 2004 May 24; accepted 2004 June 10

ABSTRACT

We present 5064 differential observations in the V filter measured by a robotic telescope, as well as 30 pairs of radial velocities from high-resolution spectroscopic observations, of the detached, EA-type, 8.46 day period double-lined eclipsing binary star V459 Cas. Absolute dimensions of the components are determined with good precision (better than 1.6% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain 2.02 ± 0.03 $M_\odot$ and 2.009 ± 0.013 $R_\odot$ for the hotter, larger, more massive and more luminous photometric primary (star A), and 1.96 ± 0.03 $M_\odot$ and 1.965 ± 0.013 $R_\odot$ for the cooler, smaller, less massive and less luminous photometric secondary (star B). The effective temperatures and interstellar reddening of the stars are accurately determined from $uvby\beta$ photometry: 9140 ± 300 K for the primary, 9100 ± 300 K for the secondary—corresponding to spectral types of A1—and 0.186 mag for E_{b-y}. The orbits are eccentric, and spectral line widths give observed rotational velocities that are much faster than synchronous for both components. The components of V459 Cas are main-sequence stars with an age of about 525 Myr according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (V459 Cassiopeiae)

Online material: machine-readable table

1. INTRODUCTION

The discovery of V459 Cassiopeiae (=BV 5, CSV 5894, GSC 04030-01001; $V = 10.33$–11.04, A1 + A1 V) as a variable star is due to Strohmeier (1955). The first eclipse ephemeris was given by Meinunger & Wenzel (1967): Min. I = 2,425,321.600 + 8.458294E. They recognized that the secondary eclipse was displaced from phase 0.5, so that the system must have an eccentric orbit. Busch (1976) summarized the dates of minima and estimated a small value of eccentricity (<0.06). Lacy (1984) announced the discovery of double lines in high-resolution spectra taken at McDonald Observatory. C. H. S. L. continued his spectroscopic program at Kitt Peak National Observatory, sustained after 1998 by J. A. S., and also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. In mid-November of 2000, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville (the URSA telescope) began operation with V459 Cas as one of its targets. By the beginning of 2004 February, it had obtained 5064 differential observations in the V filter (Table 3 below), with a standard error of 0.007 mag. In this paper, we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this main-sequence binary star system. The results are among the more accurate determinations to date for any eclipsing binary. We then compare our results with those of theory, where we find good agreement with models having an age of about 525 Myr.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

Beginning in mid-November of 2000, C. H. S. L. began photometric observations in V with the URSA telescope at Kimpel Observatory. Dates of eclipses were measured by using the method of Kwee & van Woerden (1956), as adapted to a Macintosh computer, and are listed in Table 1 along with older published CCD or photoelectric minima and those derived from photographic plates. A weighted least-squares solution for the CCD dates of primary eclipse gives the following linear ephemeris:

$$\text{Min. I} = \text{HJD } 2{,}452{,}565.67170(4) + 8.45825381(19)E.$$

The uncertainties in the last decimal place are given in parentheses. The value for the orbital period is consistent with the older published estimates based on photographic plates but is much more accurate. This linear ephemeris for primary minimum was adopted for use in all our spectroscopic and light-curve solutions below. The phase of secondary eclipse is 0.49228(2), confirming that the orbit is eccentric.

We have done an ephemeris-curve solution with the method of Lacy (1992b) to check for apsidal motion. The older photographic dates of minima were included in the analysis.

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

The Astronomical Journal, 128:1324–1330, 2004 September

ABSOLUTE PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY STAR V885 CYGNI

Claud H. Sandberg Lacy[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

Luiz Paulo Ribeiro Vaz
Departmento de Física, Instituto de Ciências Exatas, Universidade Federal de Minas Gerais, C.P. 702, 30123-970 Belo Horizonte, MG, Brazil; lpv@fisica.ufmg.br

Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apdo. 3004, E-18080 Granada, Spain; claret@iaa.es

and

Jeffrey A. Sabby[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu
Received 2004 April 23; accepted 2004 June 3

ABSTRACT

We present 4179 differential observations in the *V* filter measured by a robotic telescope, as well as 25 pairs of radial velocities from high-resolution spectroscopic observations, of the detached, EB-type, 1.69 day period double-lined eclipsing binary star V885 Cyg. Absolute dimensions of the components are determined with high precision (better than 1.5% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain $2.005 \pm 0.029\ M_{\odot}$ and $2.345 \pm 0.012\ R_{\odot}$ for the hotter, but smaller, less massive and less luminous photometric primary (star A), and $2.234 \pm 0.026\ M_{\odot}$ and $3.385 \pm 0.026\ R_{\odot}$ for the cooler, larger, more massive and more luminous photometric secondary (star B). The effective temperatures and interstellar reddening of the stars are accurately determined from $uvby\beta$ photometry: 8375 ± 150 K for the primary, 8150 ± 150 K for the secondary—corresponding to spectral types of A3m and A4m—and 0.058 mag for E_{b-y}. The metallic-lined character of the stars is revealed by high-resolution spectroscopy and $uvby\beta$ photometry. The orbits are circular, and spectral line widths give observed rotational velocities that are synchronous with the orbital motion for both components. The components of V885 Cyg are main-sequence stars with an age of about 500 Myr according to models. Our estimate of the age of this system would seem to favor the hydrodynamic damping formalism of Tassoul & Tassoul in this particular case, since both the components' spins are synchronous and the orbit is circular.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (V885 Cygni)

Online material: machine-readable table

1. INTRODUCTION

The discovery of V885 Cygni (=BD +29°3637, HBV 349, GSC 02655-01877; $V = 9.96$–10.21, A3m + A4m V) as a variable star is due to Wachmann (1964). It was initially classified as a β Lyrae type variable star (EB). The first eclipse ephemeris was also given by Wachmann: Min. I = 2,434,980.514 + 1.6947950*E*. The star was little studied until Lacy (1985) announced the discovery of double lines in high-resolution spectra. C. H. S. L. continued his spectroscopic program at Kitt Peak National Observatory, which was sustained after 1998 by J. A. S., and also obtained absolute photometry in the *UBV* and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. In mid-November of 2000, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville (the URSA telescope) began operation with V885 Cyg as one of its targets. By the end of 2003 June, it had obtained 4179 differential observations in the *V* filter (Table 3 below), with a standard error of 0.011 mag. In this paper, we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results with those of theory, where we find good agreement with models having an age of about 500 Myr.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

Only a few times of eclipse for V885 Cyg have been measured over the several decades since its discovery. The estimates from the literature are collected in Table 1 along with the first published epoch, by Wachmann (1964). Uncertainties for the eclipse timings were adopted as published or were estimated by us. A weighted least-squares solution gives the following linear ephemeris:

$$\text{Min. I} = \text{HJD } 2{,}452{,}058.8904(7) + 1.69478781(31)E.$$

The uncertainties in the last decimal place are given in parentheses. This linear ephemeris for primary minimum was

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

The Astronomical Journal, 128:1840–1846, 2004 October

ABSOLUTE PROPERTIES OF THE UPPER MAIN-SEQUENCE ECLIPSING BINARY STAR MU CASSIOPEIAE

Claud H. Sandberg Lacy[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apdo. 3004, E-18080 Granada, Spain; claret@iaa.es

and

Jeffrey A. Sabby[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu
Received 2004 April 26; accepted 2004 June 23

ABSTRACT

We present 6151 differential observations in the V filter measured by a robotic telescope, as well as 29 pairs of radial velocities from high-resolution spectroscopic observations, of the detached, EA-type, 9.65 day period double-lined eclipsing binary star MU Cas. Absolute dimensions of the components are determined with good precision (better than 2% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain $4.57 \pm 0.09\ M_\odot$ and $3.67 \pm 0.04\ R_\odot$ for the hotter, but smaller, less massive and less luminous photometric primary (star A), and $4.66 \pm 0.10\ M_\odot$ and $4.19 \pm 0.05\ R_\odot$ for the cooler, larger, more massive and more luminous photometric secondary (star B). The effective temperatures and interstellar reddening of the stars are accurately determined from $uvby\beta$ photometry: $15{,}100 \pm 500$ K for the primary, $14{,}750 \pm 500$ K for the secondary—corresponding to spectral types of B5 and B5—and 0.356 mag for E_{b-y}. The stars are located at a distance of about 1.7 kpc near the plane of the Galactic disk. The orbits of the stars are eccentric, and spectral line widths give observed rotational velocities that are synchronous with the mean orbital motion for both components. The components of MU Cas are upper main-sequence stars with an age of about 65 Myr according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (MU Cassiopeiae)

Online material: machine-readable table

1. INTRODUCTION

The discovery of MU Cassiopeiae (=BD +59°22, Son 4672, GSC 04014-01119; $V = 10.80$–11.27, B5 + B5 V) as a variable star is due to Hoffmeister (1949, p. 20); it was originally classified as a β Lyrae type (EB). The first eclipse ephemeris was given by Wenzel: Min. I = 2,427,962.509 + 3.861145E (Götz & Wenzel 1956, p. 354). We show below that this original orbital period is entirely wrong, beginning in the first decimal place! Häussler (1973) summarizes a number of early erroneous studies on this star (see also Wenzel 1972) but agrees with the original (wrong) ephemeris. The star was then little studied until Lacy (1984) announced the discovery of double lines in high-resolution spectra. C. H. S. L. continued his spectroscopic program at Kitt Peak National Observatory, sustained after 1998 by J. A. S., and also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. In mid-November of 2000, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville (the URSA telescope) began operation with MU Cas as one of its targets. By the end of 2004 February, it had obtained 6151 differential observations in the V filter (Table 3 below), with a standard error of 0.010 mag. In this paper, we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this upper main-sequence binary star system. The results are among the more accurate determinations to date for any eclipsing binary. We then compare our results with those of theory, where we find good agreement with models having an age of about 65 Myr.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

A number of photographic times of eclipse for MU Cas have been measured over the several decades since its discovery (Götz & Wenzel 1956; Häussler 1972, 1973). The observed dates of Götz & Wenzel fit the adopted ephemeris (below) quite well, though these old dates' accuracy is poor by modern standards, with a standard error of about 0.03 days. The dates of Häussler appear to be mostly spurious, corresponding to predicted times of eclipse based on the initial (wrong) eclipse ephemeris of Wenzel (Götz & Wenzel 1956).

Beginning in mid-November of 2000, C. H. S. L. began photometric observations in V with the URSA telescope at Kimpel Observatory. After a few months, it became clear that the published ephemeris was very wrong. In order to determine the true period, rough radial velocities were measured from 29 spectrograms obtained at KPNO and McDonald Observatory (see § 3 below). The Macintosh computer application Mac.Period,[2] written by C. H. S. L., was then applied

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory (NOAO), which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[2] See http://www.uark.edu/misc/clacy/BinaryStars.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5577

Konkoly Observatory
Budapest
19 November 2004

HU ISSN 0374 – 0676

NEW TIMES OF MINIMA OF SOME ECLIPSING VARIABLES

LACY, C.H.S.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

Observatory and telescope:
URSA Observatory at the University of Arkansas (ursa.uark.edu); 10-inch Schmidt-Cassegrain reflector.

Detector:	1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) −20 °C; 1.15 arcsec square pixels; 20′(N-S)×30′(E-W) field of view.

Method of data reduction:
Virtual measuring engine (Measure 1.98) written by C.H.S. Lacy (2004)

Method of minimum determination:
Kwee & van Woerden (1956)

Times of minima:

Star name	Time of min. HJD 2400000+	Error	Type	Filter	Rem.
AP And	53201.79472	0.00015	1	V	
	53205.76349	0.00019	2	V	
	53220.84197	0.00010	1	V	
	53302.5867	0.0004	2	V	
CO And	53230.7632	0.0003	2	V	
CG Aur	52990.8095	0.0003	1	V	
	53076.5867	0.0011	2	V	
	53085.6104	0.0010	2	V	
HP Aur	52985.7101	0.0010	2	V	
	53074.63505	0.00011	1	V	
	53079.61465	0.00016	2	V	
TX Boo	53104.7691	0.0009	1	V	
V381 Cas	52990.55032	0.00013	2	V	
	53003.61975	0.00025	1	V	
V389 Cas	53190.8378	0.0006	1	V	
V459 Cas	52988.58525	0.00014	1	V	
	52992.74846	0.00019	2	V	
	53026.58164	0.00014	2	V	
V651 Cas	53281.88754	0.00019	2	V	
IO Cep	52985.5526	0.0007	2	V	
	53128.9016	0.0008	2	V	
	53190.7000	0.0005	2	V	
	53198.7274	0.0003	1	V	
	53219.73559	0.00017	1	V	
	53229.62236	0.00021	1	V	

THE ASTRONOMICAL JOURNAL, 128:3005–3011, 2004 December

Ⓔ

ABSOLUTE PROPERTIES OF THE ECLIPSING BINARY STAR V396 CASSIOPEIAE

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

ANTONIO CLARET
Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain; claret@iaa.es

JEFFREY A. SABBY[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu

BEN HOOD
School of Physics and Astronomy, University of St. Andrews, St. Andrews, Fife KY16 9SS, UK; baah@st-and.ac.uk

AND

FLORIN SECOSAN
Department of Physics, University of Arkansas, Fayetteville, AR 72701; fsecosa@uark.edu
Received 2004 July 19; accepted 2004 September 8

ABSTRACT

We present 6450 differential observations in the V filter measured by a robotic telescope, as well as 28 pairs of radial velocities from high-resolution spectroscopic observations of the detached EA-type, 5.505 day period, double-lined eclipsing binary star V396 Cas. Absolute dimensions of the components are determined with good precision (better than 1% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain $2.398 \pm 0.022\ M_\odot$ and $2.592 \pm 0.013\ R_\odot$ for the hotter, larger, more massive and more luminous photometric primary (star A), and $1.901 \pm 0.016\ M_\odot$ and $1.779 \pm 0.010\ R_\odot$ for the cooler, smaller, less massive and less luminous photometric secondary (star B). The effective temperatures and interstellar reddening of the stars are accurately determined from $uvby\beta$ photometry: 9225 ± 150 K for the primary and 8550 ± 120 K for the secondary, corresponding to spectral types of A1 and A3, and 0.119 mag for E_{b-y}. The metallicity of the stars appears to be significantly less than solar. The stars are located at a distance of about 560 pc near the plane of the Galactic disk. The orbits of the stars are apparently circular, and spectral line widths give observed rotational velocities that are *not* synchronous with the orbital motion for both components. The components of V396 Cas are main-sequence stars with an age of about 420 Myr according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (V396 Cassiopeiae)

Online material: machine-readable table

1. INTRODUCTION

The discovery of V396 Cas (BD +55°2920, HD 240229, SAO 35242, GSC 04006-01219; $V = 9.56$–10.08, A1 + A3 V) as a variable star is due to Strohmeier (1962); it was originally classified as an Algol type (EA). The first eclipse ephemeris was given by Strohmeier (1962) in the discovery paper: Min I = $2{,}425{,}883.850 + 11.12576E$. We show below that this original orbital period is entirely wrong, beginning in the first decimal place! Another wrong period (15.28 days) is listed by Nha et al. (1991)! The star was little studied until Lacy (1984) announced the discovery of double lines in high-resolution spectra. Lacy continued his spectroscopic program at Kitt Peak National Observatory (KPNO), sustained after 1998 by Sabby, and Lacy also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. In 2000 mid-November, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville (the URSA telescope) began operation with V396 Cas as one of its targets. By 2003 September, it had obtained 6450 differential observations in the V filter (Table 3) with a standard error of 0.008 mag. In this paper we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this main-sequence binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results to those of theory, where we find good agreement with models having an age of about 420 Myr.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

A number of photographic times of eclipse for V396 Cas have been measured since its discovery (Strohmeier 1962; Strohmeier & Knigge 1962). These dates appear to be mostly spurious, corresponding to predicted times of eclipse based on the initial (wrong) eclipse ephemeris.

Beginning in 2000 mid-November, Lacy began photometric observations in V with the URSA robotic telescope at Kimpel Observatory on the University of Arkansas at Fayetteville campus. After a few months, it became clear that the published ephemeris was very wrong. In order to determine the true period, rough radial velocities were measured from 28 spectrograms obtained at Kitt Peak National Observatory and McDonald

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Associated Universities for Research in Astronomy under cooperative agreement with the National Science Foundation.

A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 2, Feb 2003 - Dec 2003
Issue 1

Observational Research for All Students

by **Claud H. Sandberg Lacy**
University of Arkansas, Fayetteville

The Astronomy Education Review, Issue 1, Volume 2:129-137, 2003

Abstract

Undergraduate Research Studies in Astronomy (URSA), a Web-based robotic observatory, has been in use for almost a year as part of an introductory astronomy laboratory for non-majors. The system was constructed from off-the-shelf components at a cost of around $25,000. About 500 students per year use URSA to do research-based mini-projects that follow a particular learning cycle model. Over 114,000 images have been obtained by the system to date for student and faculty research, some of which has been published. We discuss some of the lessons learned in this implementation and the extent to which our goals are being realized.

Because I am an avid observational astronomer, I want all of my students to experience for themselves the thrill of doing their own observational research. That is really the basic goal of this project. It is a worthy goal because at least some of those students will become so interested in observational work, they will want to continue to learn about astronomy, and all of the students will learn how to think scientifically about many kinds of questions. The main problem with achieving this goal is that there are about 500 students per year taking undergraduate astronomy courses at the University of Arkansas, most of them in the introductory descriptive course. There is no way to teach each individual student how to set up and use a telescope and camera system; it would take an army of teaching assistants and a football field full of equipment. My solution to this challenge is to create a Web-based robotic telescope imaging system that is as easy as possible to use, yet produces research-grade images.

I am not the first person to build a Web-based telescope. Several automated observing systems have been developed previously in the United States, three of which (the University of Iowa, the University of California at Santa Barbara, and the University of California at Berkeley) currently offer limited observing time to the general Internet community. Robert L. Mutel of the University of Iowa has developed such a system, which has both imaging and spectroscopic capabilities (Mutel 2002). The main advantage of my design is that it is made from relatively inexpensive, off-the-shelf hardware. The telescope is a Meade LX-200 10-inch f/6.3 mounted equatorially on a Superwedge; the camera is a Santa Barbara Instruments

The Astronomical Journal, 125:1448–1457, 2003 March

ABSOLUTE PROPERTIES OF THE ECLIPSING BINARY STAR RT CORONAE BOREALIS

Jeffrey A. Sabby[1] and Claud H. Sandberg Lacy[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu, clacy@uark.edu

ABSTRACT

We present an analysis of existing photometric observations in U, B, and V, and a new light curve in V, as well as spectroscopic observations, of the 5.1 day period, double-lined main-sequence eclipsing binary RT CrB. From the analysis of the light curves and radial velocity curves, we have determined the masses and radii of the components: 1.343 ± 0.010 $M_\odot$ and 2.615 ± 0.04 $R_\odot$ for the primary (hotter) component, 1.359 ± 0.009 $M_\odot$ and 2.946 ± 0.05 $R_\odot$ for the secondary (cooler) component. The formal uncertainties in the masses are both less than 1%, and the formal uncertainties in the radii are both less than 2%. Based on the analyzed light curves, as well as the combined absolute photometry of the system, we estimate effective temperatures of 5781 ± 100 K for the primary component and 5134 ± 100 K for the secondary component, corresponding to spectral types of G5 and K0, respectively. Projected rotational velocities ($v \sin i$) from the spectrograms are measured as 25 ± 2 km s^{-1} for the primary component and 33 ± 3 km s^{-1} for the secondary component and are consistent with rotation that is synchronous with the orbital motion. Evolutionary tracks from the current models are in good agreement with the observations for a system of about age 3.5×10^9 yr with a slightly nonsolar chemical composition. We also report an approximate $\Delta P/P = 3.0 \times 10^{-6}$ decrease in the orbital period over 37 years.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (RT Coronae Borealis)

1. INTRODUCTION

The discovery of RT Coronae Borealis (=HD 139588, TYC 2039-1337-1, BD +29°2690; $V = 10.21$, $\alpha = 15^h35^m59^s.993$, $\delta = +29°38'59''.31$, epoch J1960.7 and equinox J1950) as a variable star is due to Ceraski (1911). Hoffmeister, from 1914 to 1918, conducted photometric observations of RT CrB and revealed its eclipsing nature (Beyer 1935). The light elements were analyzed and the star was classified as an Algol-type binary by Beyer (1935). The light curves obtained by Hoffmeister, Beyer, and Rugemer were published by Beyer (1935). Rugemer noticed a slight variation in the depth of the secondary eclipse and suggested that the system be reclassified as an RR Lyrae type (Beyer 1935). Beyer (1943) observed RT CrB for light variation in 1935 and 1936, but the results were found to be inconclusive. For some time it appears that astronomers were not very interested in RT CrB; nevertheless, in 1970, RT CrB appeared in a list of 22 close binaries published by Popper (1970). Popper reported that these binaries were showing H and K emission outside of eclipse in at least one component and with the primary (hotter) a main-sequence or subgiant star. Popper (1976) goes on to report that these systems are showing irregularities in their light curves and that Hα emission is absent or weakly present with variable intensity. RT CrB appears in a 1976 list of "RS CVn type systems," a definition proposed by Hall (1976) for binaries that have the following characteristics: orbital periods from 1 to 14 days, strong emission in Ca II H and K lines, a hot component with the spectral type of F or G, and a luminosity class of IV or V. Hall (1976) goes on to state two more characteristics that are seen in a large portion (but not all) of the systems: H and K emission arises from either the cool star or both, and a distortion is present in the light curve outside of eclipse. Hall & Kreiner (1980) included RT CrB in a paper studying the period changes and mass-loss rates of 34 RS CVn type binaries, but because of the absence of absolute properties, no mass-loss rate for RT CrB was reported. During this period (1970–1984), RT CrB became a renewed target of several photometric observational programs, carried out by Popper & Dumont (1977) from 1972 June to 1973 June; Zhai, Zhang, & Zhang (1982) from 1978 April to July; and Ibanoğlu et al. (1985) from 1978 April to 1981 October. In addition, several spectrograms of RT CrB were collected by Popper (1990) from 1973 May to 1984 March.

The photometric data acquired by Zhai et al. (1982) showed the characteristics of a wavelike distortion in the light curve outside of eclipse, a condition mentioned by Hall (1976). A recent light curve (2001; see § 5) shows these wavelike distortions again. The previous data given by Popper & Dumont (1977) and later data given by Ibanoğlu et al. (1985) show no such wavelike distortion. Popper (1990) was the first to combine spectroscopic data with his own and previous photometric data: Popper & Dumont (1977), Zhai et al. (1982), and Ibanoğlu et al. (1985). Analyzing these data sets, Popper determined the masses and radii of the components: 1.40 ± 0.05 $M_\odot$ and 2.6 ± 0.2 $R_\odot$ for the primary (hotter) component, 1.42 ± 0.02 $M_\odot$ and 3.0 ± 0.2 $R_\odot$ for the secondary (cooler) component. Other characteristics of RS CVn type binaries (the analysis of Ca II H and K emission and Hα emission) have been reviewed by Linsky (1984), Montesinos, Giménez, & Fernández-Figueroa (1988), Strassmeier et al. (1988), de Castro et al. (1990), Strassmeier et al. (1993), Frasca & Catalano (1994), Fernández-Figueroa et al. (1994), Montes et al. (1996), and Liu, Huang, & Zhu (1997).

The evolutionary status of RS CVn type binary systems is far from clear. Hall (1972) argued that the secondary component of the systems may be in a state of

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

The Astronomical Journal, 126:1905–1915, 2003 October

ABSOLUTE PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY STAR BP VULPECULAE[1]

Claud H. Sandberg Lacy[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701;
clacy@uark.edu

Guillermo Torres
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138;
gtorres@cfa.harvard.edu

Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain;
claret@iaa.es

and

Jeffrey A. Sabby[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701;
jsabby@uark.edu
Received 2003 June 2; accepted 2003 June 25

ABSTRACT

We present 5236 differential observations in the *V* filter measured by a robotic telescope, as well as radial velocities from spectroscopic observations, of the detached, eccentric 1.9 day double-lined eclipsing binary star BP Vul. Absolute dimensions of the components are determined with high precision (better than 1% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain $1.737 \pm 0.015\ M_\odot$ and $1.852 \pm 0.014\ R_\odot$ for the primary, and $1.408 \pm 0.009\ M_\odot$ and $1.489 \pm 0.014\ R_\odot$ for the secondary. The effective temperatures and interstellar reddening of the stars are accurately determined from $uvby\beta$ photometry: 7700 ± 150 K for the primary, 6800 ± 150 K for the secondary—corresponding to spectral types of A7m and F2m—and 0.022 mag for E_{b-y}. The metallic-lined character of the stars is revealed by high-resolution spectroscopy and $uvby\beta$ photometry. Spectral line widths give rotational velocities that are synchronous with the orbital motion for the secondary component, but subsynchronous for the primary component, in a slightly eccentric orbit ($e = 0.0345$). Apsidal motion based on times of minimum light appears to be *negative* with a period of about 75 years based on recent observations of minima, but this result is not confirmed by the radial velocity measurements, and it is indeterminate when older photographic and visual data are included. The components of BP Vul are main-sequence stars with an age of about 1 Gyr according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (BP Vulpeculae)

On-line material: machine-readable table

1. INTRODUCTION

The discovery of BP Vulpeculae (=HD 352179, BD +20°4557, HIP 100745, Tycho 1644-2113-1, GSC 01644-02113; $V = 9.80$–10.52, A7m + F2m V) as a variable star is due to Hoffmeister (1935). It was initially classified as an RR Lyrae type variable star. The first eclipse ephemeris was by Illés-Almár (1960): Min. I = 2,436,860.331 + 1.938*E*. He gave an accurate photographic light curve and eclipse ephemeris with a rough estimate of the spectral type as A. Other than a few times of minimum, the star was little studied until Lacy (1985) announced the discovery of double lines in high-resolution spectra. C. H. S. L. continued his spectroscopic program at Kitt Peak National Observatory, assisted after 1998 by J. A. S., and also obtained absolute photometry in the *UBV* and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. Beginning in 1995, spectrometers operated by the Harvard-Smithsonian Center for Astrophysics (CfA) were used in an intensive campaign to obtain high-resolution spectra as well. In mid-November of 2000, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville began operation with BP Vul as one of its targets. By the end of 2002 December, it had obtained 5236 differential observations in the *V* filter (Table 5 below), with a standard error of 0.008 mag. In this paper, we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results with those of theory, where we find good agreement with models having an age of about 1 Gyr.

[1] Some of the observations reported here were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5487

Konkoly Observatory
Budapest
16 December 2003

HU ISSN 0374 – 0676

TIMES OF MINIMA OF ECLIPSING BINARY STARS

LACY, C. H. S.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

Observatory and telescope:
URSA Observatory at the University of Arkansas (ursa.uark.edu); 10-inch Schmidt-Cassegrain reflector.

Detector:	1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) −20 C; 1.15 ″square pixels; 20′(N-S) × 30′(E-W) FOV.

Method of data reduction:
Virtual measuring engine (Measure 1.97) written by C.H.S. Lacy (2003)

Method of minimum determination:
Kwee & van Woerden (1956)

Observed star(s):

Star name	GCVS type	Coordinates (J2000) RA	Dec	Comp. star	Ephemeris E 2400000+	P [day]	Source
AP And	EA/DM	23 49 31	+45 47 21	03639 00767[†]	52898.62235	1.5872920	1
CO And	EA/DM	01 11 25	+46 57 49	03268 00400	52245.65158	3.655326	2
HP Aur	EA/DM	05 10 22	+35 47 47	02401 00760	52263.62901	1.4228192	2
KU Aur	EA/SD:	06 28 04	+30 23 34	02422 01381	52263.88113	1.319577	1
CV Boo	EA/DM	15 26 20	+36 58 53	02570 00511	52321.84559	0.8469935	2
SW Cnc	EA/SD:	09 09 00	+09 35 42	00812 00083	52339.81190	1.799211	2
MU Cas	EA/DM	00 15 52	+60 25 54	01331 04014	51876.5835	9.652926	3
V381 Cas	EA/DM	00 32 52	+49 19 39	03256 01906	52968.7011	1.7459455	1
V389 Cas	EA	01 14 05	+48 58 48	03272 00102	51469.4103	4.989514	1
V396 Cas	EA/DM	23 13 36	+56 44 06	01337 04006	52180.7074	5.50545	3
V459 Cas	EA/DM	01 11 30	+61 08 48	00792 04030	51144.6845	8.458294	3
V651 Cas	EA/DM	23 48 34	+57 44 57	04009 00049	52817.87187	0.9968096	1
VZ Cep	EA/DM	21 50 11	+71 26 38	01497 04470	52054.85215	1.18336356	1
V456 Cyg	EA/DM	20 28 51	+39 09 14	03152 00323	52836.7625	0.89119220	1
V1061 Cyg	EA/DM	21 07 21	+52 02 58	03600 00278	52015.90562	2.34663383	1
HD 23642	EA/DM	03 47 29	+24 17 18	01800 01908	36096.5204	2.46113329	4
LV Her	EA/DM	17 35 32	+23 10 31	02076 00580	52490.72613	18.4359348	1
RW Lac	EA/DM	22 44 57	+49 39 28	03629 02473	52253.6669	10.36922	2
V506 Oph	EA/DM	17 41 04	+07 47 04	00993 00762	52858.6752	1.0604262	1
FO Ori	EA	05 28 10	+03 37 23	00105 02342	52275.6149	18.80058	2
V648 Ori	EA/DM	04 52 33	+06 19 24	00096 00758	52934.92834	1.626468	1
IM Per	EA/DM	03 11 42	+52 12 42	03323 01163	52902.9245	2.25422	1
V482 Per	EA/DM	04 15 41	+47 25 20	03332 00388	52266.8056	2.4467549	2
V514 Per	EB/DM	03 19 39	+50 07 12	03319 01713	52261.5563	1.819159	1
RXJ0212.3	EA	02 12 19	−13 30 41	05283 01513	52634.6593	6.709914	1

[†]Comparison star designations refer to the GSC.

THE ASTRONOMICAL JOURNAL, 123:1013–1022, 2002 February

ABSOLUTE PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY STAR WW CAMELOPARDALIS[1]

CLAUD H. SANDBERG LACY[2,3]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu

GUILLERMO TORRES
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; gtorres@cfa.harvard.edu

ANTONIO CLARET
Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain; claret@iaa.es

AND

JEFFREY A. SABBY[3]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; jsabby@uark.edu
Received 2001 September 28; accepted 2001 November 14

ABSTRACT

We present absolute photometric observations in $uvby\beta$ and 5759 differential observations in the V filter (the most complete light curve ever obtained) measured by a robotic telescope, as well as radial velocities from spectroscopic observations of the detached, eccentric, 2.3 day, double-lined, eclipsing binary star WW Camelopardalis. Absolute dimensions of the components are determined with high precision (better than 1% in the masses and radii) for the purpose of testing various aspects of theoretical modeling. We obtain 1.920 ± 0.013 $M_\odot$ and 1.911 ± 0.016 $R_\odot$ for the primary, and 1.873 ± 0.018 $M_\odot$ and 1.808 ± 0.014 $R_\odot$ for the secondary. The effective temperatures and interstellar reddening of the stars are accurately determined from new $uvby\beta$ photometry: 8350 ± 135 K for the primary and 8240 ± 135 K for the secondary, corresponding to a spectral type of A4m for both, and 0.294 mag for E_{b-y}. The metallic-lined character of the stars is revealed by high-resolution spectroscopy and $uvby\beta$ photometry. Spectral line widths give rotational velocities that are synchronous with the orbital motion in a slightly eccentric orbit ($e = 0.0098$). The components of WW Cam are main-sequence stars with an age of about 490 Myr according to models.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (WW Camelopardalis)

On-line material: machine-readable table

1. INTRODUCTION

The discovery of WW Camelopardalis (=DM Cas = BD +64°454, Tycho 4073-1191-1, GSC 04073-01191; V = 10.14–10.84, A4m + A4m V) as an eclipsing binary star is due to Huruhata & Gaposchkin (1940). They gave an accurate photographic light curve and eclipse ephemeris with a rough estimate of the spectral type as A. Other than a few times of minimum and the $uvby$ indices (see below), the star was little studied until Lacy (1984) announced the discovery of double lines in high-resolution spectra. Lacy continued his spectroscopic program at Kitt Peak National Observatory (KPNO), assisted after 1998 by J. A. S., and also obtained absolute photometry in the UBV and $uvby\beta$ systems while he was a visitor at Mount Laguna Observatory in the autumn of 1989. Beginning in 1995, spectrometers operated by the Harvard-Smithsonian Center for Astrophysics (CfA) were used in an intensive campaign to obtain high-resolution spectra as well. In the middle of 2000 November, an automated photometric telescope at Kimpel Observatory on the campus of the University of Arkansas at Fayetteville began operation with WW Cam as one of its targets. By the end of 2001 April, it had obtained 5759 differential observations in the V filter with a standard error of 0.008 mag, more observations of an eclipsing binary than ever obtained before in less than one observing season. In this paper, we present the analysis of these photometric and spectroscopic data to determine accurate measurements of the absolute properties of this binary star system. The results are among the most accurate determinations to date for any eclipsing binary. We then compare our results to those of theory, where we find good agreement with models having an age of about 490 Myr.

2. TIMES OF MINIMUM AND THE ORBITAL PERIOD

Times of eclipse for WW Cam have been measured for nearly a century. All available estimates from the literature are collected in Table 1, along with six new measurements from the observations reported in this paper, the last six entries in Table 1 (the uncertainties of these timings are as follows: 8, 11, 10, 10, 8, and 30 × 10^{-5} days). There are 39 primary minima and 27 secondary minima, one of which gives a large residual and was excluded (it is listed in parentheses in the table). Uncertainties for the eclipse timings

[1] Some of the observations reported here were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Visiting Astronomer, Mount Laguna Observatory, San Diego State University, San Diego, CA.

[3] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Associated Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5251

Konkoly Observatory
Budapest
4 April 2002

HU ISSN 0374 - 0676

TIMES OF MINIMA OF ECLIPSING BINARIES

LACY, C.H.S.; STRAUGHN, A.; DENGER, F.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; clacy@uark.edu

Observatory and telescope:
URSA Observatory at the University of Arkansas (ursa.uark.edu); 10-inch Schmidt-Cassegrain reflector.

Detector:	1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) -15 °C; $1\farcs15$ square pixels; $20'(N-S) \times 30'(E-W)$ field of view.

Method of data reduction:
Virtual measuring engine (Measure 1.8) written by C.H.S. Lacy (2002)

Method of minimum determination:
Kwee & van Woerden (1956)

Observed star(s):

Star name	GCVS type	Coordinates (J2000) RA	Dec	Comp. star	Ephemeris E 2400000+	P [day]	Source
KP Aql	EA/DM	19 02 30	+15 48 01	00693 01585[1]	40396.4912	3.36747959	1
MU Cas	EA/DM	00 15 52	+60 25 54	01331 04014	51876.5835	9.652926	2
V396 Cas	EA/DM	23 13 36	+56 44.1	01337 04006	52180.7074	5.50545	2
V459 Cas	EA/DM	01 11 30	+61 08 48	00792 04030	51144.6845	8.458294	2
VZ Cep	EA/DM	21 50 11	+71 26 38	01497 04470	52054.8522	1.1833648	2
WW Cep	EA/DM	22 18 28	+69 51 40	00262 04467	51139.3157	4.60084540	2
RT CrB	EA/RS	15 38 03	+29 29 14	00004 02039	28273.243	5.1171590	3
RW CrB	EA/DM	15 39 15	+29 37 20	00004 02039	51931.9083	0.7264114	2
V885 Cyg	EA/DM	19 32 50	+30 01 17	01184 02655	52024.9940	1.6947950	2
V1061 Cyg	EA/D	21 07 21	+52 02 58	00278 03600	51159.3789	2.346656	2
LV Her	EA/DM	17 35 32	+23 10 31	00580 02076	52066.6996	18.4359348	4
FL Lyr	EA/DM	19 12 05	+46 19 27	00050 03542	45143.7256	2.1781542	5
CF Tau	EA/D	04 05 10	+22 29 48	00008 01814	51918.3467	2.75589	2
BP Vul	EA/DM	20 25 33	+21 02 18	01837 01644	51063.6717	1.9403491	2

Source(s) of the ephemeris:
1: Lacy (1987), 2: This paper, 3: General Catalogue of Variable Stars, Kholopov (1985), 4: Torres et al. (2001), 5: Popper et al. (1986)

[1]The names of the comparison stars are from the GSC

THE ASTRONOMICAL JOURNAL, 124:1162–1169, 2002 August

$uvby\beta$ PHOTOMETRY OF SELECTED ECLIPSING BINARY STARS

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@uark.edu
Received 2002 April 15; accepted 2002 May 8

ABSTRACT

New $uvby\beta$ observations of 51 eclipsing binary stars are presented, and outside-eclipse averages for 45 of them are given. Many of these binaries are detached main-sequence pairs that have been discovered to be double-lined spectroscopic binaries and appear suitable for determinations of accurate absolute dimensions and masses. Photometric properties are recomputed for 14 of the binaries, for which absolute properties have been published previously. Intercomparisons are made with previous photometry, when available, and notes are given for some individual systems.

Key words: binaries: eclipsing — stars: distances — stars: fundamental parameters

1. INTRODUCTION

For more than two decades, I have been working to determine accurate absolute properties of eclipsing binary stars. Some of the principal clues to the nature of these binaries are the magnitudes and color indexes outside and within eclipse. In many cases, the binaries I have studied lacked accurate color indexes, and rough spectral types from the Henry Draper Catalogue were often the only available source of this type of data. In an attempt to alleviate this problem for those systems in which I have an interest—mainly, detached main-sequence pairs I have found to be double-lined spectroscopic binaries—I measured *UBV* and $uvby\beta$ indexes during a sabbatical stay at Mount Laguna Observatory (MLO), near San Diego, California, in the autumn of 1989. The *UBV* results for 69 eclipsing binaries were published a decade ago (Lacy 1992). The $uvby\beta$ data were neglected until recently, when the results were needed for the analysis of WW Cam (Lacy et al. 2002). Results for 51 of the binaries are analyzed and discussed below.

2. OBSERVATIONS

The observations at MLO were made with the 1.0 m telescope in the autumn of 1989. A photomultiplier of the C31034C type running at 1350 V was used as the detector with a six-filter $uvby\beta$ set. The measured system dead time was 60 ns, although the observations were all obtained at count rates small enough to render the results quite insensitive to uncertainties in the assumed dead time. A diaphragm of 16″ was used for all measurements.

The observations consisted of 10–60 s integrations per filter. The usual observing sequence was a set of $uvby\beta$ integrations of the star, then the same set for blank sky near the star, then a repeat series of integrations on the star. The consistency of the repeated observations was checked during initial reductions to ensure freedom from spurious errors. Program stars and faint extinction stars were measured in random order during the night. Extinction stars were selected from the equatorial list of Crawford, Golson, & Landolt (1971). Instrumental magnitudes derived from the corrected count rates were used to measure extinction coefficients from observations made at a range of air masses. These extinction results are summarized in Table 1. The seasonal means were adopted for further use.

The $uvby\beta$ transformation stars were selected from the list of Perry, Olsen, & Crawford (1987). These transformation stars are all too bright to be observed with the same instrumental setup as the program and extinction stars. An opaque mask with about 100 holes of 1 cm diameter was placed over the telescope aperture to reduce the intensity of the starlight by about 5 mag during the transformation-star measurements. Images of the transformation stars as seen through the mask were broadened by diffraction effects and may have slightly overfilled the entrance diaphragm of the photometer. Transformation coefficients were determined by linear fits to the transformation-star data. The fitted transformation coefficients and adopted seasonal means for the slope and color terms are given in Table 2. In this table, the coefficients listed are, for V, the $b-y$ color coefficient, and for the other filters, the slopes of the instrumental-versus-standard relations. Average standard errors for a single observation of the standard stars were as follows: 0.006 (y), 0.006 ($b-y$), 0.009 ($u-v$), 0.007 ($v-b$), 0.009 (β).

In order to determine accurately the effects of the mask on the V magnitudes, two strategies were employed. Faint transformation stars for V were selected from the equatorial list of Landolt (1973), and these stars were observed in random order along with the program stars. After the extinction and transformation coefficients were determined from the masked bright transformation stars, V magnitudes of the faint transformation stars were calculated and compared with their listed standard values. The mean difference between the listed and transformed magnitudes for 15 stars was 5.187 mag, with the standard error of the mean being 0.005 mag. A second check was based on the measured outside-eclipse magnitudes of 42 eclipsing binary stars also observed by me (Lacy 1992) in the *UBV* observing program. The mean difference in this case was 5.199 mag, with the standard error of the mean being 0.003 mag. The weighted mean value of 5.195 mag due to the mask is adopted for further use. This makes the V magnitudes in this paper systematically brighter than those in Lacy (1992) by 0.004 ± 0.003 mag.

[1] Visiting Astronomer, Mount Laguna Observatory, San Diego State University, San Diego, CA 92182.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 5301

Konkoly Observatory
Budapest
2 August 2002
HU ISSN 0374 - 0676

TY Leo IS NOT AN ECLIPSING BINARY STAR

LACY, C.H.S.[1]; TORRES, G.[2]; GUILBAULT, P.R.[3]

[1] Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA; e-mail: gtorres@cfa.harvard.edu

[3] P.O. Box 287, Chepachet, RI 02814, USA; e-mail: petel199@aol.com

Discovery of the variable star TY Leo was announced by Hoffmeister (1933). He noted 5 minima and classified it as Algol-type. He included a finding chart. The eclipse ephemeris of Rugemer (1933) is Min I = 2425742.47 + 1.18466 E. Popper (1996) included the star in his program of spectroscopy of lower main-sequence eclipsing binary stars. On his 3 spectrograms, he saw no evidence of a second component, and noted that the lines are unusually sharp for the reported period of 1.2 days.

We have thoroughly observed TY Leo recently, both photometrically and spectroscopically, including visual estimates from the Harvard plate collection during the years from 1920 to 1951. We do not find it to be variable in light or radial velocity. Details of the observations are given below.

We have determined an accurate position for the star identified in Hoffmeister's finder chart from the Hubble Guide Star Catalogue: RA 10:52:27.06, Dec −05:05:17.1 (J2000). These coordinates are confirmed by measurements of the Digital Sky Survey.

CHSL observed by differential photometry with the URSA WebScope at the University of Arkansas (see Lacy et al. 2001 for a description of the observatory). Differential V magnitudes were obtained from Nov. 22, 2001 to Apr. 29, 2002 UT. A total of 1213 magnitudes were measured relative to the comparison star GSC 4920 499, which is in the same frame as TY Leo. The constancy of the comparison star was verified by differential measurements of GSC 4920 465, also in the same frame as TY Leo and the comparison star. The photometric measurements are plotted as a time series (Fig. 1) and as a light curve phased according to the ephemeris of Rugemer (1933; Fig. 2). No significant variations are seen. The standard error of an observation is 0.015 mag.

GT performed spectroscopic observations of TY Leo with an echelle spectrograph on the 1.5-m Tillinghast reflector at the F. L. Whipple Observatory (Mt. Hopkins, Arizona) over a period of 126 days. The single-order spectra cover 45 Å centered at 5187 Å, with a resolving power of $\lambda/\Delta\lambda = 35,000$. Radial velocities were obtained by cross-correlation with a synthetic template based on the latest model atmospheres by R. L. Kurucz, optimized to match the star. From this optimization an effective temperature of 6100 K was derived (SpT approximately F8V), along with a negligible rotational broadening. No significant variations are seen in the radial velocity, nor any sign of double lines in the spectra indicating binarity. The mean radial velocity is −10.20 km/s with a standard

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 5357

Konkoly Observatory
Budapest
20 December 2002

HU ISSN 0374 – 0676

TIMES OF MINIMA OF ECLIPSING BINARIES

LACY, C. H. S.

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA; e-mail: clacy@uark.edu

Observatory and telescope:
URSA Observatory at the University of Arkansas (ursa.uark.edu); 10-inch Schmidt-Cassegrain reflector.

Detector:	1020×1530 pixels SBIG ST8EN CCD cooled to (typ.) −20° C; 1.″15 square pixels; 20′(N-S)×30′(E-W) field of view.

Method of data reduction:
Virtual measuring engine (Measure 1.96) written by C.H.S. Lacy (2002)

Method of minimum determination:
Kwee & van Woerden (1956)

Observed star(s):

Star name	GCVS type	Coordinates (J2000) RA	Dec	Comp. star	Ephemeris E 2400000+	P [day]	Source
CO And	EA/SD:	$01^h11^m25^s$	$+46°57'49''$	03268 00400	52245.65158	3.655326	1
HP Aur	EA/DM	$05^h10^m22^s$	$+35°47'47''$	02401 00760	52263.62901	1.4228192	1
CV Boo	EA/DM	$15^h26^m20^s$	$+36°58'53''$	02570 00511	52321.84559	0.8469935	1
SW Cnc	EA/SD:	$09^h09^m00^s$	$+09°35'42''$	00812 00083	52339.81190	1.799211	1
MU Cas	EA/DM	$00^h15^m52^s$	$+60°25'54''$	01331 04014	51876.5835	9.652926	2
V396 Cas	EA/DM	$23^h13^m36^s$	$+56°44'06''$	01337 04006	52180.7074	5.50545	[illegible]
V459 Cas	EA/DM	$01^h11^m30^s$	$+61°08'48''$	00792 04030	51144.6845	8.458294	2
V651 Cas	EA/DM	$23^h48^m34^s$	$+57°44'57''$	04009 00049	52261.65238	0.9968096	1
VZ Cep	EA/DM	$21^h50^m11^s$	$+71°26'38''$	01497 04470	52054.8522	1.1833648	2
DV Cep	E	$20^h43^m19^s$	$+72°22'30''$	04455 00968	46763.3552	1.1619732	3
V1061 Cyg	EA/DM	$21^h07^m21^s$	$+52°02'58''$	00278 03600	51159.3789	2.346643	1
GX Gem	EA/DM	$06^h46^m09^s$	$+34°24'53''$	02444 00702	52334.75	4.0385	1
LV Her	EA/DM	$17^h35^m32^s$	$+23°10'31''$	00580 02076	52066.6996	18.4359391	4
RW Lac	EA/DM	$22^h44^m57^s$	$+49°39'28''$	03629 02473	52253.6669	10.36922	1
FO Ori	EA/DS:	$05^h28^m10^s$	$+03°37'23''$	00105 02195	52275.6149	18.80058	1
V530 Ori	EA/DM	$06^h04^m34^s$	$-03°11'42''$	04786 01469	52305.3115	6.1107799	1
V482 Per	EA/DM	$04^h15^m41^s$	$+47°25'20''$	03332 00388	52266.8056	2.4467549	1
V514 Per	EB/DM	$03^h19^m39^s$	$+50°07'12''$	03319 01713	52261.5563	1.8191	1
RXJ0212.3	E	$02^h12^m19^s$	$-13°30'41''$	05283 01513	50185.5067	6.709914	5
EN Tau	EA/SD:	$05^h56^m43^s$	$+25°14'18''$	01867 00549	52296.8535	2.4762	1
V1094 Tau	EA/DM	$04^h12^m04^s$	$+21°56'51''$	01263 00925	49701.7059	8.988487	6
AT Vul	EA/SD:	$19^h53^m59^s$	$+23°33'52''$	02140 02219	50716.3794	3.98039	7
BP Vul	EA/DM	$20^h25^m33^s$	$+21°02'18''$	01837 01644	51063.6717	1.9403491	8

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5067

Konkoly Observatory
Budapest
8 May 2001

HU ISSN 0374 - 0676

TIMES OF MINIMA OF ECLIPSING BINARIES

SANDBERG LACY, CLAUD H.; HOOD, BEN; STRAUGHN, AMBER

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA

We report times of minima of eclipsing binary stars derived from V-band photometric observations made by an automated observatory at the University of Arkansas (the URSA telescope). The URSA telescope is a 10-inch aperture Meade LX-200 $f/6.3$ with an SBIG ST8EN CCD camera (before 2000 September 1, an SBIG ST6 camera was used). Observations were made through a Bessel V filter. The observations were 60 seconds integrations followed by 30 seconds as the image was downloaded and stored on the control computer. Images were dark-subtracted and flat-fielded before being processed by a virtual measuring engine (manual measurements were made before 2000 November 14). Differential magnitudes were measured relative to a comparison star and a check star in the same $20' \times 30'$ frame. Constancy of the comparison stars on a time scale of months has been verified by comparisons with a third comparison star in the field. Pixel size was 1.15 arcsec^2. For each variable star, the ultimate measurement accuracy for differential magnitude measurements depends on the availability of suitably bright comparison stars within the same image, which is $30'$ wide E–W and $20'$ wide N–S. This ultimate accuracy can range from $0\overset{m}{.}004$ to $0\overset{m}{.}02$ for our program stars. Additionally, we sometimes observe through thin cirrus. This can double the standard errors. A sample of the observations is shown in Figure 1. Heliocentric times of minima were estimated by using the method of Kwee and van Woerden (1956) as adapted to a Macintosh computer. Uncertainties in the times of minima were estimated from the values of standard error computed by the method. In Table 1, primary eclipses are designated as type 1 eclipses, and secondary eclipses as type 2.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 5201

Konkoly Observatory
Budapest
20 November 2001

HU ISSN 0374 - 0676

THE PERIOD OF LV HERCULIS REVISITED

TORRES, G.[1]; LACY, C. H. S.[2]; GUILBAULT, P. R.[3]; DIETHELM, R.[4]; BALDWIN, M. E.[5]; LUBCKE, G. C.[6]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA, e-mail: gtorres@cfa.harvard.edu

[2] Department of Physics, University of Arkansas, Fayetteville, AR 72701, USA, e-mail: clacy@comp.uark.edu

[3] P.O. Box 287, Chepachet, RI 02814, USA, e-mail: pete1199@aol.com

[4] BBSAG, Rennweg 1, CH-4118 Rodersdorf, Switzerland, e-mail: diethelm@astro.unibas.ch

[5] 8655 N. Co. Road 775 E, Butlerville, IN 47223, USA, e-mail: mbald00@hsonline.net

[6] 3817 Patrick Henry Way, Middleton, WI 53562, USA, e-mail: gil2@ix.netcom.com

In a recent note (Torres 2000) the orbital period of LV Her (TYC 2076 − 1042 − 1; $17^h35^m32\overset{s}{.}4$, $+23°10'31''$, J2000; SpT. F9, $V = 10.9$) was reported to be 18.13120 days based on radial velocity measurements made at the Harvard-Smithsonian Center for Astrophysics (CfA). This seemed to solve the long-standing mystery about the true period of this binary, claimed originally to be 2.634 days by Zessewitsch (1944) and later revised to 5.2674 days by Zessewitsch (1954). It also seemed to solve the problem posed by the preliminary spectroscopic orbit obtained by Popper (1996), with an even longer period of 9.218 days. That orbit implied a total mass for the system of only ~1.0 $M_\odot$, which is too small for two very similar main-sequence stars of spectral type F9 or G0 in an eclipsing system.

Although the new 18.13120-day period gave a good fit to the CfA radial velocities, the report by Torres (2000) mentioned the lingering difficulty that the ephemeris did not agree with the few published times of minimum for LV Her. Continued spectroscopic observations at CfA eventually hinted at a problem with the orbit presented by Torres (2000), as additional velocity measurements began to show large residuals. In particular, new observations on the steeper portions of the velocity curves that were not well covered by the original data deviated considerably from the predictions.

Photometric (CCD) observations in the visual band by one of us (CHSL) with a robotic telescope at the Univ. of Arkansas also indicated discrepancies in the times of eclipse compared to the ephemeris by Torres (2000). It was soon found that a slight adjustment to the period of about +0.3 days gave an excellent fit to all the spectroscopic observations, as well as to the new and published eclipse timings.

Subsequently, numerous times of eclipse have been recovered from archival photographic plates going back nearly a century that are extremely valuable for confirming and improving the period of LV Her. Blue-sensitive patrol plates from the AC series at the Harvard College Observatory were measured by PRG using a sequence of steps to estimate changes in brightness. Similar material from the Sky Survey plates at the Sonneberg Observatory was measured by RD. In addition, a number of times of minimum have been

Proposal Information for 2000B-0060

PI: Jeffrey A. Sabby, University of Arkansas, jsabby@comp.uark.edu
Address: Rm 226, Fayetteville, AR 72701, USA

CoI: Claud H. Sandberg Lacy, University of Arkansas

Title: Absolute Properties of Binary Stars

Abstract: Our goals are (1) to determine the internal structure of stars over a wide range of masses in order to make critical comparisons with theoretical models, (2) to determine accurately other fundamental properties of main-sequence stars in order to make critical comparisons with theoretical models. We propose to do this by observing selected eclipsing binary stars. This is a request for coude-feed time to measure accurate radial velocity curves. The proposers are obtaining accurate light curves with an automated observing system at the University of Arkansas- Fayetteville.

National Optical Astronomy Observatory, 950 North Cherry Avenue, P.O. Box 26732, Tucson, Arizona 85726, Phone: (520) 318-8000, Fax: (520) 318-8360

Tue Mar 28 01:04:05 2000

The Astronomical Journal, 119:1389–1397, 2000 March

ABSOLUTE PROPERTIES OF THE ECLIPSING BINARY STAR FS MONOCEROTIS[1]

Claud H. Sandberg Lacy[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701
Guillermo Torres
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
Antonio Claret
Instituto de Astrofísica de Andalucía, CSIC, Apdo. Postal 3004, E-18080 Granada, Spain
Robert P. Stefanik and David W. Latham
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
and
Jeffrey A. Sabby[2]
Department of Physics, University of Arkansas, Fayetteville, Fayetteville, AR 72701
Received 1999 October 25; accepted 1999 December 9

ABSTRACT

We present photometric observations in B and V as well as spectroscopic observations of the 1.9 day–period, double-lined main-sequence eclipsing binary FS Mon. From the analysis of the light curves and radial velocity curves, we have determined the masses and radii of the components: $1.631 \pm 0.012\ M_\odot$ and $2.051 \pm 0.012\ R_\odot$ for the primary component; $1.461 \pm 0.010\ M_\odot$ and $1.629 \pm 0.012\ R_\odot$ for the secondary component. The formal uncertainties are all less than 1%. Based on our light curves as well as on the combined-light photometry of the system, we estimate effective temperatures of 6715 ± 100 K for the primary and 6550 ± 100 K for the secondary component, corresponding to spectral types of F2 and F4, respectively. Projected rotational velocities ($v \sin i$) from the spectograms are measured as 52 ± 2 km s^{-1} and 43 ± 3 km s^{-1}, respectively, from the spectrograms and are consistent with rotation that is synchronous with the orbital motion. Evolutionary tracks from current models are in good agreement with the observations for a system age of about 1.6×10^9 yr with slightly nonsolar chemical composition. We find the best match for models with a slightly lower helium abundance and a higher metal abundance than the Sun. An accurate metallicity determination for FS Mon is needed to constrain the models further.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (FS Monocerotis)

1. INTRODUCTION

FS Mon (BD $-4°1937$, Tycho 4825 2374 1, F2, $V = 9.60$) was discovered to be an eclipsing binary from photographic plates by Hoffmeister (1933). Meinunger (1962) determined an improved photographic light curve and listed 23 photographic and visual times of minima from which he derived an improved eclipse ephemeris. Lacy (1984) found the binary to be double-lined on blue spectrograms taken with the coudé spectrograph at Kitt Peak National Observatory (KPNO). He made photometric observations from Cerro Tololo Inter-American Observatory (CTIO) in 1993–1995. Spectroscopic observations with the Digital Speedometers of the Harvard-Smithsonian Center for Astrophysics (CfA) began in 1995 April.

In this paper, we present the results of our intensive spectroscopic and photometric monitoring of the system, from which we determine very accurate absolute dimensions and masses of both components. We use our determinations to test current models of stellar evolution.

2. SPECTROSCOPIC OBSERVATIONS AND REDUCTIONS

Spectroscopic observations were collected with a variety of telescopes over a period of more than 14 years. At KPNO, we used the 2.1 m and coudé feed telescopes from 1985 to 1998 with several different CCD detectors. Initial spectrograms in the blue (450 nm) proved too crowded for accurate radial velocity work, so only subsequent spectrograms in the red region have been measured. Those spectra cover a range of about 10 nm centered at 643 nm, with a resolution of 0.02 nm (2 pixels) during the year 1985. The spectra obtained during 1998 cover about 32 nm centered at 646 nm and have a resolution of 0.03 nm.

Rotational velocities ($v \sin i$) were measured from two KPNO spectra of FS Mon obtained in 1998 that had high signal-to-noise ratios. Measured line widths were compared with corresponding features in spectra of β Vir (HR 4540, F9 V), for which $v \sin i = 3$ km s^{-1} (Hoffleit 1982). The spectrograms of β Vir were synthetically broadened with the rotational profile of Gray (1992) for a range of rotational speeds until a match was found for the binary star features. The resultant values of $v \sin i$ are 49 ± 2 km s^{-1} for the hotter, larger, more luminous, and more massive primary star (star A), and 40 ± 3 km s^{-1} for the secondary star (star B).

Radial velocities were determined from the KPNO spectrograms by cross-correlation of FS Mon spectra with spectra of β Vir obtained during the same observing run.

[1] Some of the observations reported in this paper were obtained with the Multiple Mirror Telescope, which is operated jointly by the University of Arizona and the Smithsonian Institution.

[2] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

THE ASTRONOMICAL JOURNAL, 120:3226–3243, 2000 December

ABSOLUTE DIMENSIONS OF THE UNEVOLVED B-TYPE ECLIPSING BINARY GG ORIONIS[1]

GUILLERMO TORRES
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; gtorres@cfa.harvard.edu
CLAUD H. SANDBERG LACY[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@comp.uark.edu
ANTONIO CLARET
Instituto de Astrofisica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain; claret@iaa.es
AND
JEFFREY A. SABBY[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701
Received 2000 June 4; accepted 2000 August 16

ABSTRACT

We present photometric observations in B and V, as well as spectroscopic observations of the detached, eccentric 6.6 day double-lined eclipsing binary GG Ori, a member of the Orion OB1 association. Absolute dimensions of the components, which are virtually identical, are determined to high accuracy (better than 1% in the masses and better than 2% in the radii) for the purpose of testing various aspects of theoretical modeling. We obtain $M_A = 2.342 \pm 0.016\ M_\odot$ and $R_A = 1.852 \pm 0.025\ R_\odot$ for the primary, and $M_B = 2.338 \pm 0.017\ M_\odot$ and $R_B = 1.830 \pm 0.025\ R_\odot$ for the secondary. The effective temperature of both stars is 9950 ± 200 K, corresponding to a spectral type of B9.5. GG Ori is very close to the zero-age main sequence, and comparison with current stellar evolution models gives ages of 65–82 Myr or 7.7 Myr, depending on whether the system is considered to be burning hydrogen on the main sequence or still in the final stages of pre–main-sequence contraction. Good agreement is found in both scenarios for a composition close to solar. We have detected apsidal motion in the binary at a rate of $\dot{\omega} = 0^\circ\!.00061 \pm 0^\circ\!.00025$ cycle^{-1}, corresponding to an apsidal period of $U = 10{,}700 \pm 4500$ yr. A substantial fraction of this (~70%) is due to the contribution from general relativity, and our measurement is entirely consistent with theory. The eccentric orbit of GG Ori is well explained by tidal evolution models, but both theory and our measurements of the rotational velocity of the components are as yet inconclusive as to whether the stars are synchronized with the orbital motion.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (GG Orionis)

1. INTRODUCTION

The discovery of GG Orionis (HD 290842, Tycho 4767 857 1; $V = 10.4$–11.1, B9.5 V, $\alpha = 05^h43^m10^s\!.2$, $\delta = -00^\circ41'15''$, epoch and equinox J2000.0) as a variable star is due to Hoffmeister (1934), who observed the object photographically at the Sonneberg Observatory. The correct period of 6.631 days was first given by Kordylewski (1951), based on visual and photographic times of minimum. This author obtained a mean visual light curve, and established that the orbit is eccentric from the displacement of the secondary minimum.

Aside from the occasional measurement of the times of eclipse by a number of authors, GG Ori has remained until recently a rather neglected system. Double lines in the spectrum were detected by Lacy (1984), who described them as being narrow and of nearly equal strength, but no detailed spectroscopic study has been made to date. The first photoelectric light curves were published by Zakirov (1997), who presented light elements for this well-detached binary solved by the method of Lavrov (1993).

Based on the fact that the orbit is eccentric, it is expected that the system may present a measurable apsidal motion. This effect is of great interest in the study of detached eclipsing binaries because it provides information on the internal structure of stars that may be compared with predictions from theory. From its spectral type and other known properties, GG Ori was listed by Giménez (1985) as a good candidate for the study of the contribution of general relativity to the secular displacement of the line of apsides, given that the relativistic effect is expected to be dominant in this particular case.

GG Ori is located in the Orion OB1 association (see, e.g. Blaauw 1964; Warren & Hesser 1977), a complex region of star formation that has been the subject of numerous studies to determine the properties of the population of young stars and surrounding gas. The binary is located not far from the Belt of Orion, and therefore there is reason to expect that the system might also be quite young, adding to its interest.

In this paper we present new high-quality photoelectric light curves in two passbands, which we analyze together with other published photometry. We also report the results of our intensive spectroscopic monitoring of GG Ori that, combined with the light curves, enable us to derive highly precise absolute dimensions for both components of the

[1] Some of the observations reported here were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

[2] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Proposal Information for 1999B-0134

PI: Jeffrey A. Sabby, University of Arkansas, jsabby@comp.uark.edu
Address: Rm 226, Fayetteville, AR 72701, USA

CoI: Claud H. Sandberg Lacy, University of Arkansas

Title: Absolute Properties of Binary Stars

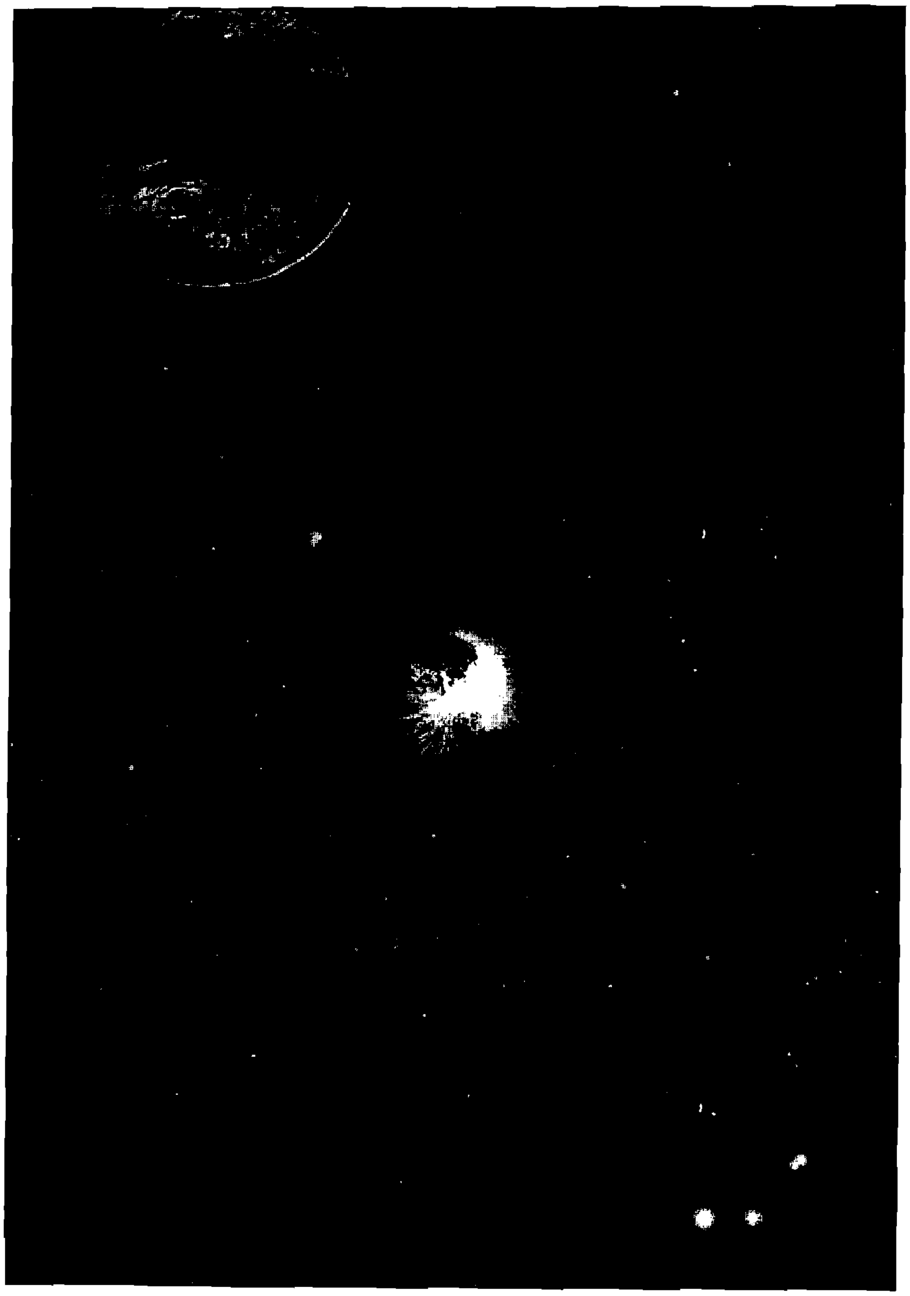
Abstract: Our goals are (1) to determine the internal structure of stars over a wide range of masses in order to make critical comparisons with theoretical models, (2) to determine accurately other fundamental properties of main-sequence stars in order to make critical comparisons with theoretical models. We propose to do this by observing selected eclipsing binary stars. This is a request for coude-feed time to measure accurate radial velocity curves. The proposers are obtaining accurate light curves with an automatic observing system at the University of Arkansas- Fayetteville.

Thu Apr 1 11:20:14 1999

Mercury, Vol. 28, no. 1, p.18

Why and How To Observe Binary Stars Tonight

The Universe is full of them – it seems to prefer them, in fact. Binary stars are of great interest to professional and amateur astronomers alike, and just a little information seems to make them even neater objects for study.



The Castor six-star system. Painting by Steven Wendell Evans (1974) and courtesy of author.

Claud H. Sandberg Lacy
University of Arkansas at Fayetteville

If you have been studying astronomy for more than just a few days, you probably already know that binary and multiple stars are pretty common. The fact is that *most* stars are contained within binary or multiple star systems: at least 50% in binary-star systems, 13% in triple-star systems, and 4% in higher multiplicities. This leaves less than a third of all stars as loners, although we know very well that *our* loner star actually has a family of planets, but more about planets later.

One of the best known *optical doubles* is Zeta and 80 Ursa Majoris, better known as Mizar and Alcor, the middle "star" in the handle of the Big Dipper (see Figure 1; also see *antwrp.gsfc.nasa.gov/apod/ap970219.html*). The ancient Arabian military used it as a test of good vision — if the recruit could see Mizar's faint, apparent companion Alcor, he had good vision. Optical doubles, you see, are stars that just happen to lie along the same line of sight; Mizar and Alcor appear close together, but they do not actually orbit one another. Interestingly, however, a telescope will uncover the fact that Mizar is a binary system, made of two stars, Mizar A and B (each of which turns out to be a spectroscopic binary system!). And Alcor? It is also a spectroscopic binary.

Binoculars and telescopes will also enable you to discover many other binary stars. Just have a look at the nearest neighbor to the Sun, the Alpha Centauri system: Visible from the southern hemisphere, this is a wide binary of nearly Sun-like stars with an orbital period of 81 years and a much more distant small, faint, red companion (Proxima Centauri, the nearest of the three stars to our Sun) that orbits the center of mass of the triple-star system with a period of hundreds of thousands of years (visit *antwrp.gsfc.nasa.gov/apod/ap960526.html* for a look).

Okay, what about the brightest star in the sky, the "Dog Star" Sirius in the constellation Canis Major? Again, a binary star, it was first detected as such in 1844 due to its wavy path through the sky as it orbits its nearly invisible companion (*antwrp.gsfc.nasa.gov/apod/ap960902.html*). It wasn't until 1862 that Alvan Clark, the famous American telescope

THE ASTRONOMICAL JOURNAL, 117:541–547, 1999 January

V907 SCORPII: A REMARKABLE BINARY STAR WHOSE ECLIPSES TURN ON AND OFF AND ON AND OFF[1]

CLAUD H. SANDBERG LACY[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@comp.uark.edu
BODIL E. HELT
Niels Bohr Institute for Astronomy, Physics and Geophysics; Astronomical Observatory, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark; bodil@ursa.astro.ku.dk
AND
LUIZ PAULO R. VAZ
Departamento de Fisica, ICEx, UFMG, C.P. 702, 30.123-970 Belo Horizonte, MG, Brazil; lpv@fisica.ufmg.br
Received 1998 September 2; accepted 1998 October 1

ABSTRACT

V907 Scorpii, near the open cluster M7, and possibly a member, is unique among all known eclipsing binary stars because its eclipses have turned on and off twice within modern history. By using all available photometric and spectroscopic data, we have discovered that it is at least a triple star and possibly a quadruple star system consisting of a visual binary with a very long orbital period, the brighter member of which is itself the triple star. The triple star contains an eclipsing binary star (B9.5 V) with an orbital period of 3.78 days and a faint, distant companion (late K, or perhaps a white dwarf) with an orbital period of 99.3 days around the center of mass of the triple star system. Radial velocity measurements allow the masses to be estimated. Because the orbital planes of the eclipsing binary and its triple companion are not coplanar, the orbital plane of the eclipsing binary shows nodal regression with a period of 68 yr. For about one-third of this time, the close binary is eclipsing; the rest of the time the inclination is too small for eclipses to occur. The earliest observations of the system in the year 1899 show eclipses; the eclipses stopped about 1918, started again about 1963, and stopped again in about 1986. We predict that the eclipses should start occurring once again in the year 2030 ± 5.

Key words: binaries: close — binaries: eclipsing — binaries: spectroscopic — stars: individual (V907 Scorpii)

1. INTRODUCTION

The eclipsing binary V907 Sco = BV 549 = CoD −34°12293 = HD 163302 (9.0 mag, A0) was discovered by Strohmeier, Knigge, & Ott (1964) on photographic plates taken at the Bamberg Observatory Southern Station. The photographic amplitude of the eclipses is listed as 0.4 mag at the time of discovery in 1963. The first time of eclipse listed by the Bamberg group (Bauernfeind 1968; Rahe & Schöffel 1976) is in the year 1963.5, although the Bamberg Southern Sky Patrol began taking plates in 1961. Bauernfeind (1968) used the Harvard plate collection to improve ephemerides for variables found by the Bamberg group. He also used times of minima from the Sonneberg survey. For V907 Sco, he concluded that the period was variable. The data available to him covered 68 yr, although it is clear that his ephemeris was based solely on the Bamberg data. He displayed his ephemeris results for V907 Sco in an $O-C$ graph, where there are about 40 points near the upper left-hand side (early in the century, from the Harvard plates), 14 points on the lower right-hand side clustered around zero residual (the Bamberg observations), and a single point of half-weight labeled "Sonneberg" in the middle of what appears to be a wide and otherwise empty discontinuity between the two groups of points. As Bauernfeind shows in his diagram, this anomalous point is dated at a time covered by the Harvard plates when no eclipse could be detected on them. We have tried to trace the origin of the Sonneberg point because it disappears in the later work. We suspect that it was obtained at the German research station in Windhoek, South Africa, and that it was rejected by Rahe & Schöffel (1976) owing to its low weight. The ephemeris determined by Bauernfeind (1968) turned out to be wrong for two reasons: first, his period is about one-half the true period—a common mistake in this kind of work; and second, as discovered by Rahe & Schöffel (1976), his period was incorrect by one-half a cycle over about 25,000 days.

In April and May of 1975, photometric observations were made with the ESO 50 cm telescope at La Silla, Chile by the group at Remeis Observatory, Bamberg. Primary eclipses with an amplitude of 0.6 mag were observed (we will show later that these were in fact secondary eclipses). Combining all times of minima from plates taken at Boyden Observatory, South Africa, Mount John Observatory, New Zealand, Bauernfeind's (1968) results (minus the Sonneberg point), and the photoelectric times, Rahe & Schöffel (1976) determined an ephemeris of

$$\text{Min I} = \text{JD } 2{,}414{,}862.585 + 3.776277E\ .$$
$$\pm 0.012 \qquad \pm 0.000003$$

The uncertainties are mean errors. Their ephemeris results are also displayed in an $O-C$ diagram, again showing the periods of time covered by the Harvard plate collection and

[1] Based in part on observations obtained at the Danish 50 cm telescope (SAT) at ESO, La Silla, Chile. The original *uvby* observations may be obtained from the CDS.

[2] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4737

Konkoly Observatory
Budapest
23 July 1999

HU ISSN 0374 – 0676

TIMES OF MINIMA OF ECLIPSING BINARIES

CLAUD H. SANDBERG LACY[1], KYLE MARCRUM[1], CAFER IBANOGLU[2]

[1] Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA

[2] Astronomy & Space Sciences Department, Ege University, Izmir, Turkey

We report times of minima of eclipsing binaries derived from photometric observations made by CI at the Ege University Observatory in Turkey in Johnson B, V filters, and at the University of Arkansas (unfiltered CCD observations made by KM). Heliocentric times of minima were estimated for each filter by using the method of Kwee and van Woerden (1956) as adapted to a Macintosh computer. The adopted time of minimum was then the average over both filters for Ege data. In all cases the times of minima in different filters were concordant. Uncertainties in the times of minima were estimated from the values of standard error computed by the method and from differences in times derived from the various filters used. In Table 1, primary eclipses are designated as type 1 eclipses, and secondary eclipses as type 2.

Table 1

Star	JD of Min – 2400000	Type	Observatory	Notes
WW Cam	51134.7232 ± 0.0004	1	Arkansas	
V459 Cas	51144.6845 ± 0.0005	1	Arkansas	
WW Cep	51141.6161 ± 0.0005	2	Arkansas	1
RW Lac	51076.6925 ± 0.0005	2	Arkansas	2
V530 Ori	51199.2593 ± 0.0005	1	Ege	3
BP Vul	51063.6717 ± 0.0003	1	Arkansas	
	51128.645 ± 0.005	2	Arkansas	
	51129.646 ± 0.001	1	Arkansas	

Notes:

1. The period listed in the GCVS is almost exactly 1/3 of the true period found by Torres (1998) from spectroscopic observations as 4.600843 ± 0.000054 days. From dates of minima found in the eclipsing binary minima database at the web site

`http://www.oa.uj.edu.pl/ktt/index.html`

we find

$$\mathrm{Min\ I} = 4.600841 \times n + 2449218.4631.$$

From the zero epoch in the GCVS and our observation, assuming a circular orbit (consistent with published dates of minima), we find a period of 4.600849 days, in agreement with the spectroscopic value. The origin of the error in the GCVS period is unknown.

101.10

Classical Novae at Apache Point Observatory

J. Johnson, J. J. Hoffman, T. E. Harrison (NMSU)

We have an ongoing program of observing current and past classical novae using the 3.5m telescope at the Apache Point Observatory. We have obtained both high and low resolution optical spectra, and infrared spectra. We present samples of our datasets, including a time-series of high resolution spectra of Nova Cas 1995, and spectra of Nova Sco 1997 and CI Cam during outbursts, as well as other recent novae. We discuss the differences and similarities of the objects we have observed.

101.11

The Infrared Spectroscopic Parallaxes of Three Dwarf Novae

E. Harrison, B. J. McNamara (NMSU), P. Szkody (U. Wash.), A. ...mola (UCO Lick), R. L. Gilliland (STScI)

We are nearing completion of a project to measure precise (± 1 mas) parallaxes for three dwarf novae (SS Cyg, U Gem, and SS Aur) using the Fine Guidance Sensors (FGS) on the HST. One goal of this program is to calibrate the technique of infrared spectroscopic parallax. To accomplish this, we have obtained moderate resolution (R = 5000) K-band spectroscopy of all three dwarf novae in quiescence using CRSP on the KPNO 2.1 m. We find that the spectral types of the secondary stars derived from the infrared spectroscopy are similar to, but slightly earlier than previous determinations. Using new infrared photometry, and recent calibrations of the infrared luminosities of late-type dwarf stars, we estimate the distances to these three dwarf novae for future comparison with the parallaxes that will be derived from the HST FGS measurements.

...12

...tations on Luminosity Classification of Red Stars using BVI (...n-Cousins) Photometry

...Robertson (Ball State University)

...database has been constructed which contains UBVRI photometry on ...ron-Cousins system for approximately 2500 stars. The database in... only observations made with photoelectric photometers and filters ...ed to reproduce the Kron-Cousins R and I magnitudes. These data ...een used to construct (B-V) - (V-I) diagrams for red stars to evaluate ...itations of luminosity classification using this diagram. For this ap...on observations of known binary and double stars were removed. Stars ...rouped by luminosity class and mean polynomial relations for giant ...warf star sequences were computed. An algorithm for computing lu...ity class from the photometry was computed. Problems associated with variability, multiplicity, interstellar reddening and chemical abun... variations are discussed in the context of the application of this dia... for luminosity classification.

...ion-Dependent SPH Simulation Time Series of Superhump ...ions

...ood (Florida Inst. of Technology), C. J. Burke (Yale University), ...mpson (Computer Sciences Raytheon)

...culate superhump light curves as a function of system inclination ...ng the method of smoothed particle hydrodynamics and a simple ... method. For inclination angles $i \leq 45°$ the power is dominated ...perhump period, whereas for larger angles the light curve has a ...ctional amplitude and is dominated by higher frequencies which ...be linear combinations of the orbital and superhump period — i.e., ...ics are blueshifted relative to the fundamental, as observed. These ...gest that the harmonic complexity of superhump light curves can ...ependent constraints on the system inclination. Our simulations, which are fully three-dimensional, reveal a low-density bulge normal to the midplane in the disk sector undergoing the largest oscillations. This bulge precesses at the disk precession frequency of ~ 30-100 orbits, and may explain the color changes observed on the precession timescale in high-inclination systems.

Session 102: Binary Stars
Display Session, 9:20am-4:00pm
Exhibit Hall 1

Bull. Am. Astron. Soc, Vol. 30, p.1401

102.01

V907 Sco Eclipses Turn On and Off and On and Off

C.H.S. Lacy (U. Arkansas), B.E. Helt (Niels Bohr Inst.), L.P.R. Vaz (UFMG)

V907 Sco is discovered to be unique among all known eclipsing binary stars because its eclipses have turned on and off twice within modern history. The system is at least a triple star consisting of a (sometimes) eclipsing binary star (B9.5V) with an orbital period of 3.78 days, and a faint, distant companion with an orbital period of 99.3 days. Radial velocity measurements allow the masses to be estimated. Because the orbital planes of the eclipsing binary and its triple companion are not co-planar, the orbital plane of the eclipsing binary shows nodal regression with a period of 68 years. For about 1/3 of this time, the close binary is eclipsing. The earliest observations of the system in the year 1899 show eclipses; the eclipses stopped about 1918, started again about 1963, and stopped again in about 1986. We predict that the eclipses should start occurring once again in the year 2030.

102.02

Cool Companions to Hot White Dwarfs

P.J. Green (SAO), B. Ali (U. Rochester)

We describe a near IR photometric search for cool red dwarf companions to hot white dwarfs (WDs). IR photometry offers a sensitive test for low mass main sequence (MS) companions, and our sample of EUV-detected WDs offers a threefold advantage over previous (largely proper motion-selected) samples: (1) the high WD temperatures insure excellent IR flux contrast with cool dwarfs (2) the range of evolutionary parameter space occupied by the WDs is considerably narrowed and (3) the random effects of the intervening ISM provides a complete but reasonably-sized sample.

We use detailed DA model atmosphere fits to optical spectra to predict WD K magnitudes and distances, against which we contrast our near IR observations. Our photometric survey reveals several DAs with a K excess, which is most likely caused by a cool, low mass dwarf companion. A few such composites have been found optically among WDs detected in recent EUV All-Sky Surveys. However, IR techniques can probe further down the MS, and to wider separations, where a significantly larger number of companions is expected.

Systems showing an IR excess will be followed up to determine the mass and spectral type of the cool companions, leading to better estimates of 1) the low mass MS luminosity function (2) the fraction of WDs with MS companions and (3) the mass ratio distribution in binaries. WD+MS systems are the progenitors of novae, CVs, symbiotics, Ba and CH giants, Feige 24-type systems, dwarf carbon stars, and other interacting binaries.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 4755

Konkoly Observatory
Budapest
26 August 1999

HU ISSN 0374 - 0676

ABSOLUTE PROPERTIES OF ZZ URSAE MAJORIS

CLAUD H. SANDBERG LACY AND JEFFREY A. SABBY

Department of Physics, University of Arkansas, Fayetteville, AR 72701 USA

Radial velocities have been measured on 27 spectrograms obtained with the Kitt Peak National Observatory coude-feed CCD spectrometer between May 1989 and May 1999. A typical spectrogram is shown in Fig. 1. Radial velocities were obtained by cross-correlation with suitably broadened spectra of the radial velocity standard β Vir (RV = 4.3 km/s, Mayor & Maurice 1985). The radial velocities are listed in Table 1.

We have adopted an eclipse ephemeris based on the dates of minima of Mallama (1980) and Hanzl (1991):

$$\begin{array}{ll} \text{Min I} = 2^{d}\!.2992599n + \text{JD } 2447967.4134 \\ \qquad\quad \pm 0.0000005 \qquad\qquad \pm 0.0004 \end{array}$$

We have fitted a circular spectroscopic orbit, given in Table 2. The fitted orbit is displayed in Fig. 2. The residuals from both the primary and secondary orbits were 1.1 km/s. We have combined our spectroscopic orbits with the photometric orbit of Clement et al. (1997); the results are shown in Table 2.

Table 1: Heliocentric radial velocities of ZZ UMa.

HJD − 2400000	RV (km/s) Primary	Secondary	HJD − 2400000	RV (km/s) Primary	Secondary
47651.6661	18.7	−165.2	51246.8659	−154.6	38.0
47652.7547	−144.8	24.7	51246.9082	−149.5	33.8
47655.6915	−109.7	−14.4	51247.9057	28.8	−176.7
47656.7073	5.3	−149.0	51248.9040	−154.2	40.1
48013.6395	−124.1	3.8	51249.9436	9.2	−153.4
48017.7156	2.8	−141.0	51309.7210	9.1	−151.3
48018.7101	−154.2	39.4	51309.8099	21.6	−165.0
49485.7416	−140.7	23.3	51312.6475	−18.6	−120.2
49486.7165	27.6	−175.0	51313.6480	−140.6	25.1
49488.7593	17.3	−162.1	51313.6900	−133.3	16.7
50938.7165	−157.9	44.0	51313.7331	−124.9	8.0
50939.6885	26.4	−172.4	51314.7072	22.7	−169.3
50940.7404	−147.1	31.4	51315.7079	−160.5	47.2
50944.7106	−7.4	−133.0			

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 4782

Konkoly Observatory
Budapest
2 November 1999

HU ISSN 0374 - 0676

NEW ANALYSES OF V909 CYGNI LIGHT CURVES

CLAUD H. LACY[1], MAMNUN ZAKIROV[2], G.C. ARZUMANYANTS[2], N.R. BAIRAMOV[2], A.S. HOJAEV[2]

[1] Department of Physics, University of Arkansas, Fayetteville, AR 72701, USA

[2] High Altitude Maidanak Observatory, Astronomical Institute, Tashkent 700052, Uzbekistan

Lacy (1997) reanalyzed the photometry of Gülmen et al. (1988) and combined the results with his spectroscopic orbit to determine the absolute properties of this triple star. He found anomalies in the absolute properties of this system. The primary component appeared to be very small for its mass, and the secondary appeared to be less massive, but considerably larger than the primary, which seemed to imply it might be a pre-main-sequence object. A new set of B, V light curves is now available for this system. They were obtained at the High Altitude Maidanak Observatory in Uzbekistan with a 0.6-m reflector. Times of minima derived from these data have been reported (Lacy et al. 1998). From these times of minima and those of Gülmen et al. (1988) we find an improved ephemeris: Min I = $2.80538720(60)n + 2450305.3731(20)$, where the uncertainty in the last digits is shown in parentheses. We have now fit an orbit to these new data and find significant differences with the previous photometric orbit.

The new data were analyzed with the NDE model (Etzel 1981, Popper & Etzel 1981) as were the older data. The results are presented in Table 1 and shown in Fig. 1 and 2.

Table 1: Analyses of V909 Cyg Light Curves

Parameter	Gülmen et al. (1988) Data		Maidanak Data	
	B	V	B	V
J_s	0.719 ± 0.006	0.760 ± 0.007	0.744 ± 0.009	0.798 ± 0.008
r_p	0.117 ± 0.002	0.113 ± 0.001	0.122 ± 0.002	0.125 ± 0.001
k	1.01 ± 0.04	1.08 ± 0.02	0.95 ± 0.03	0.93 ± 0.02
i (deg)	89.1 ± 0.2	89.5 ± 0.5	89.7 ± 0.7	89.9 ± 1.9
L_A	0.447 ± 0.016	0.401 ± 0.008	0.473 ± 0.017	0.454 ± 0.009
L_C	0.230 ± 0.008	0.248 ± 0.008	0.218 ± 0.012	0.234 ± 0.011
u_A	0.550	0.500	0.280	0.470
u_B	0.599	0.539	0.315	0.498
s.e. (mag)	0.010627	0.011908	0.024486	0.020515
N	720	696	523	536

Note: $L_A + L_B + L_C = 1$.

Some of the parameters are consistent across all analyses: the orbital inclination i, and the third light L_C. All other parameters differ significantly. The ratio-of-radii, for instance, is less than 1 in the analysis of the newer data, which would remove the anomalies

THE ASTRONOMICAL JOURNAL, 118:1831–1844, 1999 October

ABSOLUTE DIMENSIONS OF THE A-TYPE ECLIPSING BINARY V364 LACERTAE[1]

GUILLERMO TORRES
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; gtorres@cfa.harvard.edu
CLAUD H. SANDBERG LACY[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701; clacy@comp.uark.edu
ANTONIO CLARET
Instituto de Astrofísica de Andalucía, CSIC, Apdo. Postal 3004, E-18080 Granada, Spain; claret@iaa.es
MAMNUN M. ZAKIROV, G. C. ARZUMANYANTS, N. BAYRAMOV, AND A. S. HOJAEV
High-Altitude Maidanak Observatory, Astronomical Institute, Tashkent 700052, Uzbekistan; mamnun@astro.gov.uz
ROBERT P. STEFANIK AND DAVID W. LATHAM
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; rstefanik@cfa.harvard.edu, datham@cfa.harvard.edu
AND
JEFFREY A. SABBY[2]
Department of Physics, University of Arkansas, Fayetteville, AR 72701
Received 1999 May 5; accepted 1999 June 15

ABSTRACT

We present photoelectric observations in B and V, as well as spectroscopic observations of the 7.3 day period double-lined eclipsing binary V364 Lacertae. From the analysis of the light curves and the radial velocity curves we have determined the absolute dimensions of the components with high precision ($\lesssim 1\%$). The masses for the primary and secondary are $M_A = 2.333 \pm 0.015\ M_\odot$ and $M_B = 2.296 \pm 0.025\ M_\odot$, respectively, and the radii are $R_A = 3.307 \pm 0.038\ R_\odot$ and $R_B = 2.985 \pm 0.035\ R_\odot$. We derive also effective temperatures of $T_{\rm eff}^A = 8250 \pm 150$ K and $T_{\rm eff}^B = 8500 \pm 150$ K, and projected rotational velocities of $v_A \sin i = 45 \pm 1$ km s^{-1} and $v_B \sin i = 15 \pm 1$ km s^{-1}. Evolutionary tracks from current stellar evolution models are in good agreement with the observations for a system age of $\log t = 8.792$ (6.2×10^8 yr) and for solar metallicity. Hints of a lower metallicity from spectroscopy and photometry appear to be ruled out by these models, but a definitive comparison must await a more accurate spectroscopic abundance determination. Analysis of all available eclipse timings along with our radial velocities of this moderately eccentric system ($e = 0.2873 \pm 0.0014$) has revealed a small but significant motion of the line of apsides of $\dot\omega = 0.00258 \pm 0.00033$ deg cycle^{-1}, corresponding to an apsidal period of $U = 2810 \pm 360$ yr. The contribution from general relativity effects is significant ($\sim 17\%$). A comparison with predictions from interior structure models shows the real stars to be less concentrated in mass than expected. Our measurements of the projected rotational velocities indicate that the primary star is essentially pseudosynchronized (synchronized at periastron), while the secondary is spinning 3 times more slowly and is not yet synchronized. Both the rotational status of the stars and the nonzero eccentricity of the orbit are consistent with the predictions from tidal theory, specifically for the radiative damping mechanism.

Key words: binaries: eclipsing — binaries: spectroscopic — stars: evolution — stars: fundamental parameters — stars: individual (V364 Lacertae)

1. INTRODUCTION

Detached double-lined eclipsing binaries provide an opportunity to determine the physical properties of stars with high accuracy and high precision, most importantly the mass and the radius. When those determinations are such that the uncertainties are $\lesssim 1\%$ and when supplemented with accurate measurements of the metal abundance, the observations allow for critical tests of stellar evolution theory that offer important insight into issues such as the opacities and the treatment of convection, among others (Andersen 1991, 1998). There are currently a few dozen cases suitable for this type of test, distributed across much of the H-R diagram. Additional information is available in eccentric systems that show apsidal motion. These cases allow one to probe the interior structure of the stars and to compare findings with predictions from theory regarding the degree of mass concentration. In favorable systems both the classical terms of the apsidal motion and the general relativistic contributions can be tested. Another aspect of theory that can be confronted with observations is that of tidal evolution. Tidal forces tends to circularize the orbits and to synchronize the rotation of the components with the orbital motion, and they are very sensitive to the dimensions and the internal structure of the stars. The binary system discussed in this paper is particularly interesting in that it can serve to test each of the above-mentioned areas of theoretical modeling.

V364 Lac (also HD 216429, HIP 112928, BD+37 4713, SAO 72799; $V = 8.3$–9.0, $\alpha = 22^{\rm h}52^{\rm m}14\overset{\rm s}{.}8$, $\delta = +38°44'45''$, epoch and equinox J2000.0) was discovered as a photo-

[1] Some of the observations reported in this paper were obtained at the Multiple Mirror Telescope Observatory, a facility operated jointly by the University of Arizona and the Smithsonian Institution.

[2] Visiting astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

THE ASTRONOMICAL JOURNAL. 115:801–808, 1998 February

ABSOLUTE DIMENSIONS AND MASSES OF V541 CYGNI AND THE GENERAL THEORY OF RELATIVITY

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas at Fayetteville, Fayetteville, AR 72701; clacy@comp.uark.edu
Received 1997 July 28; revised 1997 October 13

ABSTRACT

Absolute dimensions and masses of V541 Cyg (B9.5 V + B9.5 V) have been computed from its first spectroscopic orbit and the excellent light curve published by Khaliullin in 1985. This binary has a long period (15.34 days) and a highly eccentric orbit ($e = 0.479$), with very small stars relative to their separation. It shows apsidal motion of $0.^\circ60 \pm 0.^\circ10$ per 100 years, significantly slower than the rate predicted by theory [$0.^\circ89 \pm 0.^\circ03$ (100 yr)$^{-1}$]. In this system the rate of apsidal motion due to general relativistic effects is 5 times that from the classical Newtonian causes (tidal and rotational distortions of the stars). The discrepancy in the apsidal motion rate is difficult to explain, and is in the same sense as the discrepancies found for two other eclipsing binaries, DI Her and AS Cam, in which the relativistic contributions to apsidal motion are also significant.

Key words: binaries: eclipsing — stars: individual (V541 Cygni)

1. INTRODUCTION

The eclipsing binary V541 Cygni (=BD +30°3704; B9.5 V + B9.5 V, $V = 10.35$, $B-V = 0.35$) is a detached pair of stars with a highly eccentric orbit ($e = 0.479$) and a long orbital period (15.34 days). Its variability was discovered by Kulikowski (1948), who also realized that its orbit must be eccentric (Kulikowski 1953). Photographic observations of the system were obtained by Karpowicz (1961) and Wachmann (1961). McCuskey & Seyfert (1950) measured the spectral type outside eclipse as A0. Khaliullin (1985) was the first to obtain a photoelectric light curve of V541 Cyg and analyze it. The light curve consists of 531 observations in the V band. My reanalysis of this light curve (discussed below) confirms Khaliullin's photometric orbit. Khaliullin (1985) estimated the rate of apsidal motion from his own observations of times of minima and from times of minima obtained by reanalysis of the photographic observations of Karpowicz (1961). He estimated a rate of apsidal motion of $0.^\circ90 \pm 0.^\circ13$ per 100 years based on these two epochs, not significantly different from the rate predicted from theory. My own results, discussed below, and those of Wolf (1995) and Guinan, Maley, & Marshall (1996), which are based on more numerous accurate eclipse timings than were available to Khaliullin, show that the observed rate of apsidal advance is significantly slower than initially estimated by Khaliullin (1985) and is, in fact, significantly slower than expected by theory.

Spectrograms obtained from 1984 to 1994 at McDonald Observatory and at Kitt Peak National Observatory (KPNO) are analyzed below, and the spectroscopic results have been combined with the photometric results to yield for the first time the absolute properties of the system. Accurate times of minimum from photoelectric or CCD observations have been analyzed to determine the apsidal motion rate observed for this system. When this rate is compared with the theoretical rate expected due to classical and general relativistic causes, it is found that there is a discrepancy, in that the observed rate is significantly slower than predicted. This discrepancy is in the same sense as two other results for eclipsing binaries in which the relativistic contribution to the apsidal motion is significant, DI Her and AS Cam (Guinan & Maloney 1985; Maloney, Guinan, & Mukherjee 1991; Guinan, Marshall, & Maloney 1994). Since the general relativistic rate is 5 times the classical rate in this system, suspicion falls on the general theory of relativity, an otherwise well confirmed theory.

2. LIGHT-CURVE REANALYSIS AND COLOR INDICES

I deemed it prudent to reanalyze the light curve of Khaliullin (1985) with the NDE method of Etzel (1981) and Popper & Etzel (1981). The first element needed in the analysis was an estimate of the effective temperature of the system. Khaliullin's (1985) results indicated that the two stars have very nearly the same effective temperature. The Q-method of Johnson & Morgan (1953) was used with the all-sky UBV indices of Lacy (1992a) to determine an unreddened color index of $(B-V)_0 = -0.034 \pm 0.005$, corresponding to a spectral type of B9.5 V ($E_{B-V} = 0.069 \pm 0.009$, $A_V = 0.22 \pm 0.03$) and to an effective temperature of 9940 ± 60 K (Popper 1980), consistent with the estimate by Guinan et al. (1996) of 9900 ± 400 K. The adopted UBV indices of Lacy (1992a) do not agree with those of Khaliullin (1985), who derived from his photometry spectral types of B8.5 V + B8.7 V for the components. This result of Khaliullin (1985) is certainly wrong since my spectrograms of the system show only a faint hint of the 4471 Å He I line, which is well developed in stars of spectral type B9 V and earlier (see Fig. 6 below). I conclude that the UBV indices of Khaliullin (1985) are seriously in error.

Auxiliary quantities needed in the analysis include a convective gravity-brightening coefficient, from Martynov (1973; 0.18), and a limb-darkening coefficient, from Wade & Rucinski (1985; 0.41). The eclipse ephemeris of Khaliullin (1985) was used to compute phases. The NDE program converged successfully, but there was a slight but significant lack of fit in the minima. This lack of fit was eliminated when the limb-darkening parameter was allowed to vary. The average residual decreased from 0.011883 to 0.011863 mag as a result of the improved fit within minima. Param-

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.

motely, and filters, field of view and exposure times can be changed easily. The MicroObservatory Net consists of five of these telescopes. They are being deployed around the world at widely distributed longitudes for access to distant night skies during local daytime. Remote access to the MicroObservatories over the Internet has been available to select schools since 1995. The telescopes can be controlled in real time or in delay mode, from any computer using Web-based software. Individuals have access to all of the telescope control functions without the need for an on-site operator. After a MicroObservatory completes a job, the user is automatically notified by e-mail that the image is available for viewing and downloading from the Web site. Images are archived at the Web site, along with sample challenges and a user bulletin board, all of which encourage collaboration between schools. The Internet address of the telescopes is http://mo-www.harvard.edu/MicroObservatory/.

The telescopes were designed for classroom instruction by teachers, as well as for use by students and amateur astronomers for original scientific research projects. In this talk, we will review some of the experiences we, students and teachers have had in using the telescopes.

Support for the MicroObservatory Net has been provided by the NSF, Apple Computer, Inc. and Kodak, Inc.

91.06

The University of Iowa Robotic Observatory

R. L. Mutel (University of Iowa)

The University of Iowa has recently completed construction of a 0.5m fully robotic telescope in southern Arizona. The telescope is computer controlled and is operated from campus in Iowa City via the Internet. It is primarily used by undergraduates in astronomical laboratory projects and for research projects such as asteroid rotation studies, supernova searches and binary star light curves. A typical night's observing consists of 600-800 images generated from 30-50 separate observing programs. On clear nights we typically reach a limiting magnitude $V \sim 19.5$ in 30 seconds with a [illegible]ing disk of FWHM ~ 2.5 arcsec. I will describe our experience in using [illegible]is facility as part of the undergraduate laboratory curriculum as well as for individual student research projects.

91.07 **Bull. Am. Astron. Soc, Vol. 30, p.1385**

Binary Star Software for Teaching

C.H.S. Lacy (U. Arkansas)

Educational software for Macintosh computers to aid in teaching binary star concepts is now available free from my web site http://www.uark.edu/misc/clacy/BinaryStars/. Four programs are available to teach binary star concepts such as orbital period, orbital phase, eclipsing binary star, dates of minima, semi-major axis, eccentricity, longitude of periastron, orbital inclination, Keplers laws, and observing seasons. These programs may be used in a teaching laboratory setting, or for personal use. Both student manuals and instructor manuals are provided.

91.08

Simulations and Experiments in Astronomy and Physics

F. P. Maloney, P. A. Maurone, L. E. DeWarf (Villanova)

There are new approaches to teaching astronomy and physics in the laboratory setting, involving the use of computers as tools to simulate events and concepts which can be illuminated in no other reasonable way. With the computer, it is possible to travel back in time to replicate the sky as Galileo saw it. Astronomical phenomena which reveal themselves only after centuries of real time may be compressed in the computer to a simulation of [illegible]al minutes. Observations simulated on the computer do not suffer from [illegible] vagaries of weather, fixed time or geographic position, or nonrepeatability. In physics, the computer allows us to secure data for experiments which, by their nature, may not be amenable to human interaction. These could include experiments with very fast or very slow timescales, large number of data samples, complex or tedious manipulation of the data which hides the fundamental nature of the experiment, or data sampling which would need a specialized probe, such as for acid rain. This innovation has become possible only recently, due to the availability and affordability of sophisticated computer hardware and software. We have developed a laboratory experience for non-scientists who need an introductory course in astronomy or physics. Our approach makes extensive use of computers in this laboratory. Using commercially available software, the students use the computer as a time machine and a space craft to explore and rediscover fundamental science. The physics experiments are classical in nature, and the computer acts as a data collector and presenter, freeing the student from the tedium of repetitive data gathering and replotting. In this way, the student is encouraged to explore, to try new things, to refine the measurements, and to discover the principles underlying the observed phenomena.

91.09

Introducing the AAS Education Office Online

D. K. Duncan, G. Brissenden (AAS Education Office), T. F. Slater (Montana State U., Bozeman)

The AAS Education Office has just placed its new interactive web site online. The web site features resources to support AAS members creating effective Education and Public Outreach plans, an interactive database to search and add high-quality educational resources useful to AAS members, an annotated bibliography of research in astronomy education, an automated name exchange to link astronomers interested in education with teachers needing partner scientists, and reports and programs from the AAS Education Office.

91.10

Simulations in the Introductory Astronomy Laboratory: Six Years of Project CLEA

L.A. Marschall (Gettysburg College)

Since 1992, Project CLEA (Contemporary Laboratory Experiences in Astronomy) has been developing introductory computer-based exercises aimed at the introductory astronomy laboratory. These exercises simulate important techniques of astronomical research using digital data and Windows- based software. Each of the 9 exercises developed to date consists of software, technical guides for teachers, and student manuals for the exercises. CLEA software is used widely at many institutions, and at a variety of setting from middle school to upperclass astronomy classes. The current design philosophy and goals of Project CLEA will be discussed, along with the results of both formal and informal assessments of the strengths and weaknesses of is approach. Plans for future development will be presented. Project CLEA is supported by grants from Gettysburg College and the National Science Foundation

Session 92: Clusters of Galaxies
Oral Session, 2:00-3:30pm
Room 9 (A and B)

92.01

Projection, Correlation, and Anisotropy in the Abell Catalog

C. Miller, K. Slinglend, D. Batuski (UMaine), J. Hill (Steward Obs.)

An analysis of $R > 0$ Abell clusters is presented for samples containing recent redshifts from the MX Northern Abell Cluster Survey. The newly obtained redshifts from the MX Survey, as well as those from the ESO Nearby Abell Cluster Survey (ENACS), provide the necessary data for spatial analyses of the largest (in number and in volume) sample of rich clusters in the entire sky (excluding the galactic plane). The MX Survey, undertaken primarily to provide data for large-scale structure studies, has also provided a large compilation of galaxy redshifts within Abell cluster fields for the

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4597

Konkoly Observatory
Budapest
3 June 1998

HU ISSN 0374 - 0676

TIMES OF MINIMA OF ECLIPSING BINARIES

CLAUD H. SANDBERG LACY[1], JAMES L. CLEM[1], MAMNUN ZAKIROV[2], G.C. ARZUMANYANTS, N.R. BAIRAMOV[2], A.S. HOJAEV[2]

[1] Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, USA

[2] High Altitude Maidanak Observatory, Astronomical Institute, Tashkent 700052, Uzbekistan

We report times of minima of eclipsing binaries derived from photometric observations made at the High Altitude Maidanak Observatory in Uzbekistan in Johnson B,V filters, and at the University of Arkansas (unfiltered CCD observations; all but one of the Arkansas minima were observed by JLC). Heliocentric times of minima were estimated for each filter by using the method of Kwee and Van Woerden (1956) as adapted to a Macintosh computer. The adopted time of minimum was then the average over both filters for Maidanak data. In all cases the times of minima in different filters were concordant. Uncertainties in the times of minima were estimated from the values of standard error computed by the method and from the differences in times derived from the various filters used. In Table 1, primary eclipses are designated as type 1 eclipses, and secondary eclipses as type 2.

Table 1

Star	JD of Min -2400000	Type	Observatory
KP Aql	50670.6586 ± 0.0008	1	Arkansas
WW Cam	50319.3520 ± 0.0005	2	Maidanak
	50667.3343 ± 0.0004	2	Maidanak
	50675.3063 ± 0.0005	1	Maidanak
	50843.6054 ± 0.0002	1	Arkansas
	50852.7028 ± 0.0003	1	Arkansas
	50868.6209 ± 0.0004	1	Arkansas
AY Cam	50847.7598 ± 0.0004	1	Arkansas
IT Cas	50848.6032 ± 0.0009	1	Arkansas
PV Cas	50321.4771 ± 0.0006	2	Maidanak
V459 Cas	50307.3162 ± 0.0005	1	Maidanak
EK Cep	50311.3135 ± 0.0004	1	Maidanak

THE ASTRONOMICAL JOURNAL VOLUME 113, NUMBER 3 MARCH 1997

ABSOLUTE DIMENSIONS AND MASSES OF YY SAGITTARII AND V526 SAGITTARII

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
and Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
Electronic mail: clacy@comp.uark.edu

Received 1996 September 24; revised 1996 December 10

ABSTRACT

Accurate masses and radii have been determined from new spectroscopic observations and previously published photometric orbits of YY Sgr (B5+B6) and V526 Sgr (B9.5+A2), two Southern eclipsing binaries with eccentric orbits and measured apsidal rotation. The measured properties, including apsidal rotation rate, are compared with recent theoretical predictions. The models indicate ages near 30 million and 200 million years for YY Sgr and V526 Sgr, respectively. The agreement between theory and observations is not entirely satisfactory for V526 Sgr.
[S0004-6256(97)01803-7]

1. INTRODUCTION

YY Sgr (B5+B6) and V526 Sgr (B9.5+A2) are Southern eclipsing binary stars whose orbits have been known to be eccentric and to exhibit apsidal motion since early in this century. I have previously summarized their history and analyzed recent photometric observations and dates of minima (Lacy 1993a, 1993b). A complete comparison with theoretical predictions of the stars' properties could not be made before spectroscopic orbits were determined. These orbits are analyzed below and a comparison with theory is carried out.

2. OBSERVATIONS AND ANALYSIS

The radial velocity observations have been made with a variety of telescopes and coude spectrometers at McDonald Observatory and Kitt Peak National Observatory (KPNO); these include a Digicon detector at McDonald Observatory and various CCD detectors at KPNO. The McDonald Observatory 2.7 m observations are the earliest ones, ending in 1983 August. At KPNO the 2.1 m reflector was used from 1983 August to 1985 December, and the coude-feed telescope after that. The detection of doubled lines was announced by Lacy (1984, 1985). The measured spectra typically covered about 10 nm centered at a wavelength of 450 nm, and at a resolution of about 0.03 nm. Typical spectra are shown in Figs. 1 and 2. Wavelengths were calibrated with comparison spectra (Fe-Ne or Th-Ar). Radial velocities were extracted by using the IRAF cross-correlation routine FXCOR (Tonry & Davis 1979). The comparison star used was o Peg (HR 8641, A1 V), for which a radial velocity of 8.4 km/s was adopted, based on measurements of Fekel (1990). Rotational velocities ($v \sin i$) of the components were estimated by comparisons with artificially broadened profiles of o Peg; these are listed in Tables 1 and 2. All cross-correlation analyses used comparison star profiles artificially broadened to match that of the variable stars. The measured radial velocities are listed in Tables 3 and 4. Amplitudes of the radial velocity curves were then fitted by using a program of Daniels (1966). Auxiliary quantities such as the eccentricity, longitude of periastron, anomalistic orbital period, and rate of apsidal motion were fixed at values derived from previous analyses (Lacy 1993a, 1993b). Residuals from these fits are given in Tables 3 and 4, and displayed in Figs. 3 and 4. Orbital parameters are shown in Tables 1 and 2. Residual standard errors were 5.7 and 8.3 km/s for the primary and secondary of YY Sgr, and 6.1 and 4.9 km/s for V526 Sgr. The center-of-mass velocities of the primary and secondary component of YY Sgr may be significantly different, which is unexpected and unexplained.

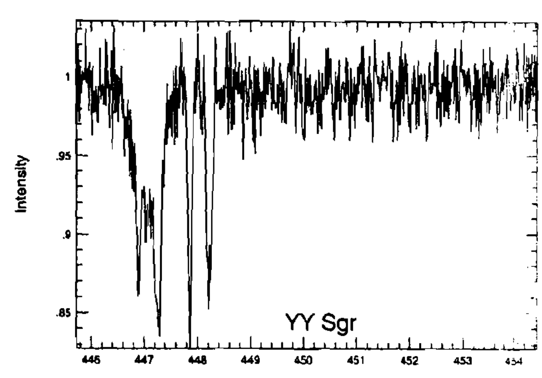


FIG. 1. Typical spectrum of YY Sgr. The exposure was made with KPNO coude-feed spectrograph on 1994 May 16 and lasted 1 hour. The most prominent features are the doubled lines of He I at 4471 Å and Mg II at 4481 Å.

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

THE ASTRONOMICAL JOURNAL VOLUME 113, NUMBER 3 MARCH 1997

THE SPECTROSCOPIC ORBIT OF Π CETI

C. H. S. LACY[1]
Department of Physics, University of Arkansas, Fayetteville, Arkansas, and Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
Electronic mail: clacy@comp.uark.edu

F. C. FEKEL[1]
Center of Excellence In Information Systems, Tennessee State University, Nashville, Tennessee 37203
Electronic mail: fekel@coe.tnstate.edu

R. D. MATHIEU[1]
Department of Astronomy, University of Wisconsin, Madison, Wisconsin 53706
Electronic mail: mathieu@astro.wisc.edu

N. I. MORRELL[1]
Facultad de Ciencias Astronomicas y Geofisicas, Universidad Nacional de La Plata, Argentina
Electronic mail: nidia@fcaglp.fcaglp.unlp.edu.ar

J. A. MORSE[1]
Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, Colorado 80303
Electronic mail: morsey@casa.colorado.edu

G. TORRES
Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
Electronic mail: gtorres@cfa.harvard.edu

D. WILLMARTH
National Optical Astronomy Observatories, Tucson, Arizona 85726
Electronic mail: dwillmarth@noao.edu

Received 1996 October 21; revised 1996 November 20

ABSTRACT

π Ceti (HR 811, B7 V) has been known to be variable in its radial velocity for almost a century, but its relatively long period and small amplitude have conspired against a determination of its orbit. We have combined in an optimal fashion observations from early in this century with modern measurements to find the spectroscopic orbit with high accuracy. The orbit has a period of 7.45 years and a semiamplitude of 4.3 km/s. The measured eccentricity of $e=0.00\pm0.07$ is indistinguishable from circular, surprising for such a long period. The 76 radial velocity observations available extend over 12 cycles of the orbit. © *1997 American Astronomical Society.* [S0004-6256(97)00303-8]

1. INTRODUCTION

The first observation of the radial velocity of π Ceti (HR 811, B7 V) was made at Lick Observatory with the Mills spectrograph on the 36-inch refractor on 1903 October 20 (Table 1). The variability of its radial velocity was suspected by J. H. Moore after the third plate, taken nearly two years later, showed a significant change in radial velocity. A fourth plate, taken a year after that, confirmed the variability. The variability was announced by Campbell & Albrecht (1909) and by Campbell (1910). The early observations at Lick were published by Campbell (1928), and those of the Yerkes observers by Frost *et al.* (1926), who surmised that the amplitude of variability was probably small.

π Ceti has often been used as a late-B reference star in photometric and spectrophotometric studies (Manfroid *et al.* 1995; Griffin *et al.* 1993; Smith & Dworetsky 1993; Bastiaansen 1992; Roby & Lambert 1990; Cousins 1989; Kilkenny & Menzies 1986). The best determination of its spectral type is that of Garrison & Gray (1994), who have classified it as B7 IV. From high-resolution spectrograms Adelman (1991) confirmed that it is a relatively normal late-B star with mostly near-solar abundances. Its spectrum is relatively narrow lined with a $v \sin i$ value of about 19 km/s (Day & Warner 1975; Hoffleit 1982; Adelman 1991). It is a weak x-ray source (Cash *et al.* 1979; Cash & Snow 1982; Grillo *et al.* 1992).

[1]Visiting Astronomers, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Reserach in Astronomy, Inc., under contract with the National Science Foundation.

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARY STARS: THE ANOMALOUS TRIPLE STAR V909 CYGNI

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72703
Electronic mail: clacy@comp.uark.edu

Received 1997 July 14; revised 1997 August 6; accepted 1997 August 6

ABSTRACT

V909 Cygni is found to be a triple star (A0+A2+A1) with some anomalous properties. The A0+A2 eclipsing binary has a very small primary for its mass, although, within the observational errors, it is not inconsistent with a zero-age star according to some models. The secondary star of the eclipsing binary, however, is less massive but considerably larger than the primary. Since the binary is well detached, mass exchange looks unlikely as an explanation. It may be that the secondary is a pre-main-sequence object. The observed rotational velocities are significantly faster than synchronous, which would be expected if the secondary star were as young as a pre-main-sequence object. This system deserves further study. © *1997 American Astronomical Society.* [S0004-6256(97)02511-9]

1. INTRODUCTION

The eclipsing binary V909 Cygni=BD+27°3441 (A0, P=2.80 days, V=9.505 mag) is a detached close binary. Its variability was discovered photographically by Wachmann (1963). Photoelectric light curves in B and V filters were obtained and analyzed by Gulmen *et al.* (1988). These authors could not obtain convergent photometric solutions using the WINK computer program (Wood 1971), but produced a grid of solutions by assuming values of the radius ratio k consistent with preliminary estimates of the luminosity ratio based on some spectrograms of this author. I have reanalyzed the photoelectric observations by using the NDE model (Etzel 1981; Popper & Etzel 1981). This analysis revealed that a good fit to the photometry can only be obtained by assuming the existence of a significant amount of third light. Thus it appears that the V909 Cyg system is at least triple. Spectrograms obtained at McDonald Observatory and at Kitt Peak National Observatory have been analyzed and the results have been combined with those of the photometry to yield absolute properties of the system. As discussed below, the properties of the eclipsing binary appear to be anomalous relative to other eclipsing binary star results, and also anomalous relative to some theoretical predictions.

2. REANALYSIS OF PHOTOMETRY

The existing photometric observations were fitted with the NDE model. The first element needed in the analysis was an estimate of the effective temperature of the system. The Q-method of Johnson & Morgan (1953) was used with the main-sequence color indices of Deutschman *et al.* (1976) and the all sky UBV indices of Lacy (1992) to determine a Q-value of 0.026±0.008 and an unreddened color index of $(B-V)_0$=0.021 (+0.029±0.016) corresponding to a spectral type of A1 (E_{B-V}=0.123±0.03, A_V=0.400 mag). An effective temperature of 9350 K was adopted from the Popper (1980) calibration. Auxilliary quantities needed for the analysis include convective gravity-brightening coefficients from Martynov (1973) (0.23 in B, 0.19 in V), and limb-darkening coefficients from Wade & Rucinski (1985) (0.53 in B, 0.44 in V). The eclipse ephemeris of Gulmen *et al.* (1988) was used to compute phases: Min I =2445204.3730+2.805399 E. The NDE program did not converge successfully, and limiting solutions indicated a serious lack of fit in the minima. The residual errors are significantly improved, however, by the addition of a third-light parameter to the models. The existence of a third light source in the system was therefore suspected. General solutions for the B and V light curves including third light converged successfully (see Table 1). Spectroscopic information was available to limit the photometric solution in the B-band. Figure 1 shows a typical spectrogram of the V909 Cyg system. Absorption lines due a third component are not evident in any of my spectrograms, nor is a third component evident in the cross-correlation analysis for radial velocities. It is possible, however, that a third component does exist, but is a shallow broad line centered near the center-of-mass velocity, and causing only a shallow depression of the relatively narrow eclipsing binary absorption lines. This possibility is not inconsistent with the appearance of the available spectrograms. In the analysis to follow, I have assumed that the third component's spectral features are extremely broad due to rapid rotation, and do not produce systematic effects on the radial velocities. By comparison with line profiles of stars of similar spectral type and known rotational velocities it was found that the $v \sin i$ values for the components were 35±2 km/s for both the primary and the secondary component. These rotational velocities are significantly faster than the synchronous values of 26.4±0.3 and 28.4±0.6 km/s.

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc. under contract with the National Science Foundation.

THE ASTRONOMICAL JOURNAL VOLUME 113, NUMBER 4 APRIL 1997

ABSOLUTE DIMENSIONS AND MASSES OF AD BOOTIS

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701, and Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
Electronic mail: clacy@comp.uark.edu

Received 1996 October 8; revised 1997 January 2

ABSTRACT

Accurate masses and radii have been determined from new spectroscopic observations and previously published light curves of AD Boo (F6+G0 from the color indices). The measured properties are compared with recent theoretical models. The observed properties match the theoretical models at an age of about 1.3 billion years. © *1997 American Astronomical Society.* [S0004-6256(97)01504-5]

1. INTRODUCTION

AD Boo (BD+25° 2800, G0) was discovered to be an eclipsing binary by Strohmeier *et al.* (1963), but they incorrectly assigned an orbital period near 1.0344 days, about half the true period found by Zhai *et al.* (1982, 1983). The star is of special interest because its relatively late spectral type is rare among the eclipsing binaries. For this reason Popper (1993, 1996a) included it in his program which concentrates on low-mass eclipsing binaries. He has given preliminary values of the masses (1.37 and 1.17 solar masses) that are somewhat smaller than those of this study. The reason for the differences is unknown, but the differences may not be significant (see discussion below).

2. OBSERVATIONS AND ANALYSIS

The radial velocity observations have been made with the 2.1 m reflector and the 1.0 m coude-feed telescopes and coude spectrometer at Kitt Peak National Observatory (KPNO); these observations were made with a variety of CCD detectors and spectrometer configurations. The 2.1 m reflector was used from 1984 June to 1985 December, and the coude-feed telescope after that. The detection of doubled lines was announced by Lacy (1985). The measured spectra typically covered about 10 nm centered at a wavelength of 642 nm, and at a resolution of about 0.03 nm. A typical spectrogram is shown in Fig. 1. Wavelengths were calibrated with Th-Ar hollow cathode emission tubes. Radial velocities were extracted by using the IRAF cross-correlation routine FXCOR (Tonry & Davis 1979). The comparison star used was β Vir (HR 4540, F9 V), for which a radial velocity of 4.3 km/s was adopted based on the work of Mayor & Maurice (1985). Rotational velocities ($v \sin i$) of the components were estimated by comparisons with artificially broadened profiles of β Vir; these estimates are listed in Table 1, and they are consistent with synchronous rotation of the components. All cross-correlation analyses used comparison star profiles artificially broadened to match those of the variable stars. Comparison star observations used for the cross correlations were made during the same night as the variable star observation with which they were cross correlated.

I have searched for systematic errors in my radial velocities measured with FXCOR within and between observing runs, such as those errors found by Popper & Jeong (1994). I found significant variations of, in the largest case, 1.2 km/s in the radial velocity zero point of the run (referenced to a particular observation of β Vir) in measurements of bright standard radial velocity stars (o Peg, ι Psc, 5 Ser, 10 Tau, β Vir) between runs. No significant errors were found from night to night within an observing run. No significant differences were found in calculating the velocities from a pixel-only cross correlation versus interpolating to a log-lambda scale before cross correlating. Standard errors in standard star observations within a run averaged 0.2–0.7 km/s per observation using my adopted methods.

Initially, each AD Boo spectrogram was cross correlated with the template (β Vir) to measure the radial velocity. The

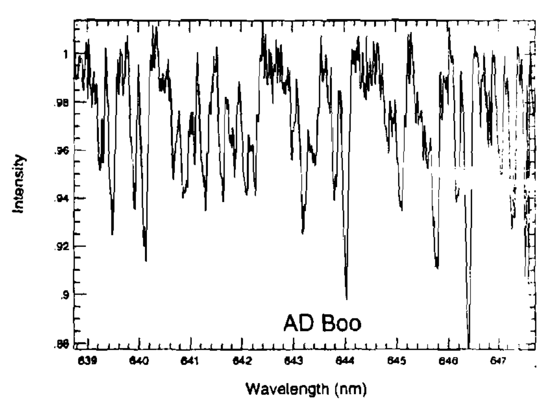


FIG. 1. Typical spectrum of AD Boo. The exposure was made with the KPNO 2.1 m coude spectrograph on 1985 July 2 and lasted 0.5 hours.

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

ABSOLUTE DIMENSIONS AND MASSES OF SW CANIS MAJORIS

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Electronic mail: clacy@comp.uark.edu

Received 1997 January 14; revised 1997 March 13

ABSTRACT

SW CMa (BD $-22°$ 1712, HD 54520) is a detached double-lined eclipsing binary with a very eccentric (e=0.3179) orbit and a long orbital period (10.09 days). New photometric and spectroscopic data have been obtained and analyzed. The results indicate that the binary consists of a pair of A5 main sequence stars with an age of about 700 million years, which puts the pair near the upper boundary of the main sequence band. The measured rate of apsidal motion due to relativistic and Newtonian causes is poorly determined by the available data, but is consistent with the theoretically predicted rate (U=14 000 years). © *1997 American Astronomical Society.* [S0004-6256(97)02706-4]

1. INTRODUCTION

SW CMa (BD $-22°$ 1712, HD 54520) was discovered to be an eclipsing binary by Hoffmeister (1932). Initial investigation was hampered by the facts that its period is relatively long (10.09 days), and is almost an integral multiple of a day (Florja 1937). Early spectroscopic work was done by Struve (1945) who found that the system was double-lined within a narrow phase interval during its orbit. He determined preliminary elements (e=0.50, γ=+40 km/s, K_1 = 90 km/s, K_2 = 90 km/s) with the note that "the elements do not represent the observations very satisfactorily." As will be shown below, his elements are not too far off the mark. He estimated the combined spectral type as A8. Employing higher spectral resolution, Lacy (1984) found that the double lines could be resolved during much of the orbit. A number of photographic observations of dates of minima in the literature (Florja 1937; Wenzel 1952; Ziegler 1965) as well as more accurate photoelectric observations (Lacy & Fox 1994) are potentially valuable for determining the apsidal rotation period and putting observational constraints on the internal structure constants of the component stars.

2. OBSERVATIONS AND ANALYSIS

Differential and all sky photometric observations have been made from Cerro Tololo Inter-American Observatory with the 0.6 m Lowell telescope during the Southern Hemisphere summers of 1993–4 and 1994–5. Photomultipliers with S-20 photocathodes were used with a set of UBV filters for all observations. Differential observations were made in B and V, and all-sky observations were made in U, B, and V. All-sky observations were calibrated with standard stars of Landolt (1973). Observations and reductions were made in the same manner as described by Lacy (1992a, 1993a, 1993b, 1993c). Photometric data for the variable and comparison stars are shown in Table 1. Differential observations of the comparison and check stars showed no night-to-night variations at the level of 0.002 mag standard error.

Differential photometric observations (428 per filter) are listed in Tables 2 and 3. From these it was possible to determine accurate times of minima. These times of minima have been given by Lacy & Fox (1994). For computing orbital phases, I have adopted the eclipse ephemeris of Ziegler (1965), but with the zero epoch of Lacy & Fox (1994):

$$\text{HJD Min I} = 10.091948n + 2449352.6453.$$

The photometric observations have been analyzed with the Nelson-Davis-Etzel (NDE) model (Etzel 1981; Popper & Etzel 1981). Auxiliary quantities needed in the analysis include gravity-brightening coefficients from Martynov (1973) (0.26 in B, 0.21 in V, convective) and limb-darkening coefficients from Wade & Rucinski (1985) (0.53 in B, 0.46 in V). The individual B and V light curves were analyzed, then mean values for the geometrical quantities were adopted and the radiative quantities were determined from these. The results are given in Table 4 and shown in Figs. 1 and 2.

Spectrographic observations were made from 1982 to 1989 with a variety of coude spectrometers at McDonald Observatory and at Kitt Peak National Observatory. Detectors included Digicon and CCD arrays. Observations were made typically in a 10 nm band centered at 450 nm wavelength, with a spectral resolution of 0.03 nm. Wavelengths were calibrated with observations of Fe-Ne or Th-Ar hollow-

TABLE 1. Photometric data for SW CMa and comparison stars.

Star	V	B−V	U−B	Obs.
SW CMa (variable)	9.126	0.189	0.189	5
	±0.012	±0.005	±0.009	
−22° 4063 (comparison)	9.166	0.230	0.143	3
	±0.009	±0.002	±0.004	
−22° 4073 (check)	9.181	−0.037	−0.260	3
	±0.006	±0.002	±0.004	

[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

THE ASTRONOMICAL JOURNAL VOLUME 114, NUMBER 2 AUGUST 1997

THE ECLIPSING DOUBLE-LINED SPECTROSCOPIC BINARY SYSTEM V505 PERSEI

LAURENCE A. MARSCHALL
Department of Physics, Gettysburg College, Gettysburg, Pennsylvania 17325
Electronic mail: marschal@gettysburg.edu

ROBERT P. STEFANIK
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138
Electronic mail: stefanik@cfa.harvard.edu

CLAUD H. LACY
Department of Physics, 226 Physics Building, University of Arkansas, Fayetteville, Arkansas 72701
Electronic mail: clacy@comp.uark.edu

GUILLERMO TORRES
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138
Electronic mail: torres@cordoba.harvard.edu

DAVID B. WILLIAMS
9270-A Racquetball Way, Indianapolis, Indiana 46260
Electronic mail: Dbwilymuz@aol.com

FRANZ AGERER
Private Observatory, D-84184 Zweikirchen, Germany
Electronic mail: Agerer.Zweik@t-online.de

Received 1997 February 4; revised 1997 April 25

ABSTRACT

The recently-discovered eclipsing double-lined spectroscopic binary V505 Persei (SAO 23229) consists of two nearly identical F5 main sequence stars in a 4.2 day orbit. We have obtained both spectroscopic and photometric observations of the binary that densely sample the complete cycle of radial velocity and light variations. These observations have been used to determine the elements of the orbit, to determine individual masses of the stars in the system to a precision of better than 1%, and to estimate an age for the system. The derived properties agree well with current stellar structure models and provide fundamental data for tests of stellar evolution theory. © *1997 American Astronomical Society.*
[S0004-6256(97)00508-6]

1. INTRODUCTION

Although one might have thought that all the bright, large amplitude variable stars had been discovered long ago, a number of these systems have been found in recent years. Among these is the 7th magnitude eclipsing binary star SAO 23229 (V505 Persei; HD 14384; $\alpha(2000.0)=02^h21^m12.7^s$ $\delta(2000.0)=54°30'36''$; $V=7.3$), whose sizable eclipses (0.5 mag in depth) were discovered by amateur astronomer Daniel Kaiser in 1989 September (Kaiser 1989; Kaiser *et al.* 1990; MacRobert 1990).

The initial observations of Kaiser suggested a photometric period of about 2.1 days. Subsequent spectroscopic observations at the Oak Ridge Observatory of the Harvard-Smithsonian Center for Astrophysics (Marschall *et al.* 1990) revealed that the system was a double-lined binary with two components of approximately equal luminosity, and that the reported 2.1 day period, half the true period of 4.2 days, represented the time between nearly-equal secondary and primary eclipses.

Such double-lined eclipsing binary systems are our primary source of fundamental data on stellar masses and a powerful tool for testing theories of stellar structure and evolution (Andersen 1991; Latham *et al.* 1996). Since V505 Persei was so bright, it was clear that this could be a valuable target for a highly-precise mass determination. Therefore, in 1990, a program of spectroscopic radial velocity observations was begun by two of the authors (Marschall and Stefanik) at the Center for Astrophysics (CfA), while photometric observations were undertaken by two other authors (Williams and Agerer).

2. SPECTROSCOPIC OBSERVATIONS AND ANALYSIS

Sixty-three spectra of V505 Persei were obtained between 1990 February and 1992 August using CfA echelle spectrographs mounted on the 1.5 m Wyeth Reflector at the Oak

THE ASTRONOMICAL JOURNAL VOLUME 114, NUMBER 3 SEPTEMBER 1997

ABSOLUTE DIMENSIONS AND MASSES OF IT CASSIOPEIAE[1]

CLAUD H. SANDBERG LACY[2]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Electronic mail: clacy@comp.uark.edu

GUILLERMO TORRES AND DAVID W. LATHAM
Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
Electronic mail: gtorres@cfa.harvard.edu, dlatham@cfa.harvard.edu

MAMNUN M. ZAKIROV AND G. C. ARZUMANYANTS
Astronomical Institute Astronomicheskaya, Taskent 700052 Uzbekistan, CIS
Electronic mail: mamnun@astro.gov.uz

Received 1997 May 9; revised 1997 June 17

ABSTRACT

Accurate masses and radii have been determined from new spectroscopic and photometric observations and from previously published photometric observations and times of minima of this pair of F5 V stars. Previous reports of δ Scuti variations by the components appear to be erroneous. IT Cas has an eccentric orbit, but existing observations cover too small a fraction of the apsidal motion variations to fit an accurate apsidal period, which is estimated to be 2200 years based on theoretical models. These models give an age near 2 billion years for the binary star. There is a small amount of color excess due to interstellar reddening. © *1997 American Astronomical Society.* [S0004-6256(97)04109-5]

1. INTRODUCTION

The eclipsing binary IT Cas (F5, $P=3.90$ days, $e=0.085$, $V=11.15$ mag) is a detached main-sequence system. The history of the scientific study of IT Cas has been summarized recently by Holmgren & Wolf (1996). Only one modern photoelectric light curve of IT Cas has been published (Khaliullin & Kozyreva 1989), and phase coverage of that one was very sparse, consisting almost entirely of observations on only 2 nights. No radial velocity curves of the system have been published previously. We have obtained new photoelectric light curves in U, B, V, and R filters and an accurate radial velocity curve. We analyze the existing data below. As a result of our analysis, we now know the absolute properties of this system very accurately.

2. OBSERVATIONS AND ANALYSIS

New light curves in Johnson B, V, U, and R filters have been obtained with the 1.0 and 0.6 m reflectors at the Maidanak Observatory, located in the mountains in the south of Uzbekistan at an altitude of 2600 m. These observations are listed in Tables 1–4. The magnitudes and color indices are based on comparisons with photometric standards in Selected Area 112 (Landolt 1983). The comparison star used in the differential photometry was BD+50°4121. Heliocentric dates of minima were extracted from these data by using the method of Kwee & van Woerden (1956) as we have done previously (Lacy *et al.* 1995). These new dates are listed in Table 5. The average eclipse ephemeris between 1982 and 1995 is Min I$=2445167.3157+3.8966494n$ based on the zero epoch of Khaliullin & Kozyreva (1989). Table 5 also lists observed times of minima previously published. We have tried to estimate the accuracy of these dates [illegible] published results and our previous experience. The dates and uncertainties have been analyzed with the method of Lacy (1992b). Our results are listed in Table 6 and shown in Fig. 1. The solution was somewhat sensitive to the size of the finite differences used to estimate partial derivatives in the numerical algorithm, but the solution listed in Table 6 is stable over a wide range of assumed values of finite differences. Note that the value of the apsidal motion period (U) is very poorly determined (essentially undetermined) by the available dates of minima because of the small fraction of the apsidal period covered by the available observations. The fitted value of U is consistent with theoretical estimates (see Sec. 3 below).

Our ephemeris curve results do not agree with those of Holmgren & Wolf (1996). They made the assumption that all photoelectric times of minima had a standard error of 0.0052 days, an order of magnitude larger than typical errors in our experience. The sensitivity of the numerical algorithm to the size of the finite differences used in calculating derivatives may also contribute to this difference in results.

The photometric observations were fitted with the Nelson–Davis–Etzel (NDE) model (Etzel 1981; Popper & Etzel 1981). Auxiliary quantities needed in the analysis in-

[1]Some of the observations reported here were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.
[2]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc. under contract with the National Science Foundation.

THE ASTRONOMICAL JOURNAL VOLUME 114, NUMBER 1 JULY 1997

THE MACHO PROJECT LMC VARIABLE STAR INVENTORY. V. CLASSIFICATION AND ORBITS OF 611 ECLIPSING BINARY STARS

C. ALCOCK,[1,2] R. A. ALLSMAN,[3] D. ALVES,[1,2,10] T. S. AXELROD,[4] A. C. BECKER,[7] D. P. BENNETT,[1,2] K. H. COOK,[1,2] K. C. FREEMAN,[4] K. GRIEST,[2,5] C. H. S. LACY,[12] M. J. LEHNER,[2,5] S. L. MARSHALL,[1,2] D. MINNITI,[1,2] B. A. PETERSON,[4] M. R. PRATT,[2,6,7] P. J. QUINN,[4,11] A. W. RODGERS,[4] C. W. STUBBS,[2,7] W. SUTHERLAND,[8] AND D. L. WELCH[9]

(The MACHO Collaboration)

Received 1996 June 23; revised 1997 April 15

ABSTRACT

We report the characteristics of 611 eclipsing binary stars in the Large Megallanic Cloud found by using the MACHO Project photometry database. The sample is magnitude limited, and extends down the main sequence to about spectral type A0. Many evolved binaries are also included. Each eclipsing binary is classified according to the traditional scheme of the *General Catalogue of Variable Stars* (EA and EB), and also according to a new decimal classification scheme defined in this paper. The new scheme is sensitive to the two major sources of variance in eclipsing binary star light curves—the sum of radii, and the surface-brightness ratio, and allow greater precision in characterizing the light curves. Examples of each type of light curve and their variations are given. Sixty-four of the eclipsing binaries have eccentric, rather than circular, orbits. The ephemeris and principal photometric characteristics of each eclipsing binary are listed in a table. Photometric orbits based on the Nelson–Davis–Etzel model have been fitted to all light curves. These data will be useful for planning future observations of these binaries. Plots of all data and fitted orbits and a table of the fitted orbital parameters are available on the AAS CD-ROM series, Vol. 9, 1997. These data are also available at the MACHO home page (http://wwwmacho.mcmaster.ca/). © *1997 American Astronomical Society.* [S0004-6256(97)03607-8]

1. INTRODUCTION

There have been two previous large surveys for eclipsing binary stars in the Large Magellanic Cloud (LMC). The first was that of the Harvard workers, summarized by Payne-Gaposchkin (1971) and Gaposchkin (1972). They list characteristics of 78 LMC eclipsing binaries (10 of these stars are also included in this survey). Their discoveries resulted from the visual examination of about 2000 photographic plates. The second was that of the EROS project (Grison *et al.* 1995). They list characteristics of 79 LMC eclipsing binaries (23 of these stars are also included in this survey). Their discoveries resulted as a byproduct of a gravitational microlensing survey of the bar of the LMC.

The MACHO Project photometry database contains photometric data for approximately 37 000 variable stars discovered during the first 400 days of observations in 22 LMC fields as part of the microlensing survey. An early rough estimate of the number of eclipsing binary stars in the database was 1200. Operationally, the observed color–magnitude space was divided into a number of independent bins: main sequence, Cepheids, RR Lyr, long-period variables, and others. This paper is a result of selecting relatively bright, large-amplitude eclipsing binaries from the main sequence ($V-R<0.3$) and Cepheid ($0.3<V-R<0.6$) bins. The distribution of the selected eclipsing binaries in color-magnitude space is shown in Fig. 1. The R magnitude limit for selection from the main-sequence bin (from preliminary magnitude estimates) was set at 18.0; for the Cepheid bin it was 18.5. Only those variables with photometric amplitudes greater than 0.2 mag were selected.

2. ANALYSIS AND RESULTS

Variable stars were visually identified as being eclipsing binaries, rather than some other type of variable star, by examining plots of their light curves based on the three best

[1]Lawrence Livermore National Laboratory, Livermore, CA 94550; Electronic mail: alcock, alves, bennett, dminniti, kcook, stuart@igpp.llnl.gov
[2]Center for Particle Astrophysics, University of California, Berkeley, CA 94720.
[3]Supercomputing Facility, Australian National University, Canberra, ACT 0200, Australia; Electronic mail: robyn@mso.anu.edu.au
[4]Mt. Stromlo and Siding Spring Observatories, Australian National University, Weston, ACT 2611, Australia; Electronic mail: tsa, kcf, peterson, alex@mso.anu.edu.au
[5]Department of Physics, University of California, San Diego, CA 92093; Electronic mail: kgriest, jguem, mlehner@ucsd.edu
[6]Department of Physics, University of California, Santa Barbara, CA 93106.
[7]Departments of Astronomy and Physics, University of Washington, Seattle, WA 98195; Electronic mail: becker, mrp, stubbs@astro.washington.edu
[8]Department of Physics, University of Oxford, Oxford OX1 3RH, U.K. Electronic mail: w.sutherland@physics.ox.ac.uk
[9]Department of Physics and Astronomy, McMaster University, Hamilton, ON L8S 4M1, Canada; Electronic mail: welch@physics.mcmaster.ca
[10]Department of Physics, University of California, Davis, CA 95616.
[11]European Southern Observatory, Karl-Schwarzchild Str. 2, D-85748, Garching, Germany; Electronic mail: pjq@eso.org
[12]Department of Physics, University of Arkansas, Fayetteville, AR 72701; Electronic mail: clacy@comp.uark.edu

60.04

Hubble Space Telescope FGS Transfer Function Observations of L726-8

P.J.Shelus (McD Obs.), O.G.Franz, L.H.Wasserman (Lowell Obs.), G.F.Benedict, R.L.Duncombe, P.D.Hemenway, W.H.Jefferys, B.McArthur, E.Nelan, D.Story, A.L.Whipple (UTx), W.F.van Altena (Yale), L.W.Fredrick (UVa)

The M dwarf visual binary L726-8 is an interesting astrophysical object and one of the nearest stellar systems to the Sun. Almost 50 years of ground-based photographic and visual observations of position angle and separation now exist. The system is a difficult one to observe and its components are now rapidly nearing closest approach. At the present time the separation of the components is less than 1.5 seconds of arc. Periastron passage is predicted to occur in early 1998. It is also an important candidate to search for orbital perturbations that might be caused by extra-Solar System planets. As such, L726-8 is an excellent object for HST FGS attention. Because of the binary nature of the system and the extreme scarcity of suitable background reference objects, we are choosing to observe this object with HST Fine Guidance Sensor #3 in transfer function mode. Beginning in the summer 1995 a number of observational sets have been obtained, using Astrometry Science Team Guaranteed Time Observations. It is expected that HST observations of L726-8 will continue in this mode until at least July 1997. In this poster we are presenting the available HST observations and some analytical results, alone and co- mingled with ground-based observations, that furnish dynamical information of the system. Eventually, and only when a sufficiently accurate and precise orbit is obtained, we will examine the residuals for indications of a perturbation in the system, possible evidence of one or more unseen companions.

60.05

UZ Tau E: A New Classical T Tauri Spectroscopic Binary

R.D. Mathieu (U. Wisconsin, Madison), E.L. Martin (Inst. de Astrofisica de Canarias), A. Maguzzu (Oss. di Catania)

We have monitored spectroscopically the classical T Tauri star UZ Tau East. Most observations were obtained with the Intermediate Dispersion Spectrograph at the Isaac Newton Telescope in La Palma Observatory. Several additional spectra were obtained with other telescopes at La Palma, ESO and Lick observatories. Radial velocities were measured via cross correlation with UZ Tau West. In total we have so far 18 radial velocity measurements spanning 2627 days (Nov 1988 – March 1996).

The radial-velocity data are well fit (σ=2.3 km s^{-1}) with a single-line orbit solution having a period of 19.1 days, an eccentricity e=0.28, and a K of 17 km s^{-1}. The projected primary semi-major axis is a sini = 0.03 AU. The orbit parameters are not yet definitive because the phase sampling is not thorough.

After GW Ori and DQ Tau, UZ Tau E is the third classical T Tauri spectroscopic binary for which an orbit has been derived. A massive (0.06 $M_{\odot}$) circumbinary disk has been resolved at millimeter wavelengths (Jensen *et al.* 1996, ApJ, in press). Interestingly, UZ Tau E has a power-law infrared spectral energy distribution with no evident dip suggesting an inner region cleared by the binary. In addition, UZ Tau E is spectroscopically active with both veiling and emission lines, indicative of active accretion at a stellar surface despite the close companion.

With this discovery UZ Tau becomes a quadruple system, as UZ Tau West is a speckle binary with a projected separation of 50 AU.

60.06

The Radial Velocity Curves of the Two Components of the Spectroscopic Binary GJ 372AB, a Double M-Dwarf System

J.J.B. Harlow (PSU)

GJ 372 was recently found to be a spectroscopic binary (Upgren, A.R. and Harlow, J.J.B. 1996, PASP 108, 64). It has an orbital period of 48 days and radial velocity semi-amplitudes of 31 kms^{-1} for the primary and 39 kms^{-1} for the secondary. The radial velocity curves of both components of GL372AB are presented for the first time. The mass ratio of the two components is measured to be 1.28 $\pm$ 0.04. The flux ratio at 5300Å of 2.39 $\pm$ 0.71 implies a spectral class difference of 1$\pm$0.3 subclasses. Photometry and parallax measurements from the literature suggest a spectral class for the primary of M1.5V $\pm$ 1 subclass, and a corresponding range for the secondary of M2.5V $\pm$ 1 subclass.

Bull. Am. Astron. Soc, Vol. 28, p.920

60.07

The Eclipsing Spectroscopic Binary System V505 Persei

L.A. Marschall (Gettysburg Coll.), R.P. Stefanik (CfA), C.H. Lacy (Univ. of Arkansas), D.B Williams (Indianapolis, IN), F. Agerer (Zweikirchen, Germany)

We have obtained extensive spectroscopic and photometric observations of the bright double-lined eclipsing binary V505 Persei (SAO 23229) discovered in 1989 by Kaiser. The system consists of two nearly identical F5 main sequence stars in a 4.2 day orbit. The observations enable us to derive high precision (< 1stellar masses, along with other properties of the binary system. These values agree well with current stellar structure models, and add to the growing base of fundamental stellar data applicable to tests of stellar evolution theory.

60.08

Multiband Photometry of Southern Very Short Period Eclipsing Binaries. I. V676 Centauri

J.D. Gray, R.G. Samec, S.L. Woissol (Millikin U.)

In this paper, we extend our study of solar-type binariés near the the low period limit to include Southern hemisphere systems. Observations are being taken at Cerro Tololo Inter-American Observatory, Chile. Here, we report B,V,R,I observations of V676 Centauri. Our three nights of data were taken in May of 1991 with a dry ice cooled Ga-As photometer attached to the 1.0-m reflector. Two new primary and two secondary epochs of minimum light were determined from the observations, and more than 100 minima were collected from the literature. Our period study spans some 35 years. The light curves show a rather large difference in eclipse depths for a W UMa binary. An O'Connell effect lends evidence of spot activity in this very short period (0.291 d) system. A preliminary photometric analysis of the light curves is presented.

60.09

Continuing the Search for Short Period EEB's: The Analysis of HW Persei

R.J. McDermith, R.G. Samec (Millikin University, Visiting Astronomer, Lowell Observatory), B.J. Carrigan (Millikin University)

In our continuing campaign to obtain light and radial velocity curves of short period eccentric eclipsing binary (EEB) candidates, we have obtained complete UBV observations of the neglected system, HW Persei. They were taken at Lowell Observatory in January 1996. Three new epochs of minimum light have been determined. A preliminary period study, spanning some sixty years of timings (with a 24 year gap), result in the following improved linear ephemeris, 2450097.7836(70) + 0.6348285(4)d X E. A quadratic fit was also calculated. This gave a marginally significant quadratic term of 8(6)X10-11 which translates to a period increase of 5(4)X10-8 d/yr. The U, B, V light curves formed from the present precision observations show that HW Per is a near or shallow contact system. Contrary to earlier reports that HW Per has a displaced secondary eclipse, our secondary eclipse falls at phase 0.5. A complete analysis of the synthetic light curve is presented and discussed.

This research was supported by funds from the National Science Foundation.

THE ASTROPHYSICAL JOURNAL, 459:721–728, 1996 March 10

EE PEGASI REVISITED: A SPECTRUM SYNTHESIS AND NEW LIGHT SYNTHESIS STUDY

A. P. LINNELL[1]
Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824
I. HUBENY[2]
NASA Goddard Space Flight Center, Greenbelt, MD 20771
AND
C. H. S. LACY[3]
Department of Physics, University of Arkansas, Fayetteville, AR 72701
Received 1995 June 16; accepted 1995 September 20

ABSTRACT

A self-consistent physical model, described in an earlier paper by Linnell & Hubeny, has permitted fits of synthetic spectra to observed spectra of EE Pegasi. The synthetic spectra determine abundances for iron, calcium, and silicon. The same model has been the basis of an optimized light synthesis solution of an accurate light curve by Ebbighausen. The solution, requiring use of a model atmospheres option to represent the component star radiative properties, agrees with the standard solution by Lacy & Popper. The derived component parameters place them on an isochrone, determine a compositional Z, and are in accordance with evolution tracks by Schaller et al. The model is not restricted to systems with small distortion.

Subject headings: binaries: eclipsing — stars: evolution — stars: individual (EE Pegasi)

1. INTRODUCTION

EE Pegasi (HD 206155, SAO 126971, +08°4714) is one of the stars included in the list by Andersen (1991) of stars with accurately known masses and radii. Popper (1980, 1981) lists it in his review article on stellar masses and in a subsequent rediscussion article. Popper notes that the primary (more massive) component is a metallic-line A3m object. Lacy & Popper (1984, hereafter LP) report the discovery that EE Peg is a triple system. LP also analyzed the Ebbighausen (1971) *B* photometry (normal points), using EBOP, described, e.g., by Etzel (1993), and obtained absolute dimensions and other parameters of the binary components. EE Peg consequently is one of the stars fundamental to a comparison between derived parameters and results of stellar evolution models.

Linnell & Hubeny (1994, hereafter LH) have recently completed a spectrum synthesis program for binary stars. A motivation in the development of that program was the recognition that both T_{eff} and log g vary over the photospheres of tidally and rotationally distorted binary components, and that, as a consequence, a synthetic spectrum calculated with single values of those parameters cannot accurately represent the true spectrum of a distorted binary component. The LH program represents an extension of the light synthesis program developed by Linnell (1984, hereafter L84). Both programs are based on the Roche model geometry, described in detail in L84, and permit any degree of distortion, up to and including contact configurations.

The distortions of the EE Peg components are small, and the importance of the system invites its study as a first application of the LH program. The spectroscopic observational material includes 26 spectra of EE Peg obtained by Lacy at the 2.7 m telescope at McDonald Observatory with the coudé Reticon spectrometer.

2. SPECTRUM SYNTHESIS

Briefly, the LH procedure uses an interface program, ACPGF2, to calculate the synthetic spectra of the individual components and the combined system synthetic spectrum at a specific orbital longitude and orbital inclination. The L84 program package supplies ACPGF2 with files for the two components containing data for each (stellar surface) segment, hereafter indicated simply by the word "segment," on the two component photospheres. (Segment sizes are set in the L84 package.) The data include segment area, cosine of the angle between the surface normal and line of sight to the observer, radial velocity (combined orbital and rotational), T_{eff}, log g, and a visibility key indicating whether that segment is visible to the observer. Additionally, program SYNSPEC (Hubeny, Lanz, & Jeffery 1994) provides ACPGF2 with a group of synthetic spectra for specific values of T_{eff} and log g that bridge the extremes of T_{eff} and log g of the L84 data. The SYNSPEC synthetic spectra have sufficiently close spacing in T_{eff} and log g to permit accurate linear interpolation among them. ACPGF2 then produces a synthetic spectrum for each component, with due allowance for Doppler shifts and eclipse effects, as well as the total system synthetic spectrum.

SYNSPEC uses a model atmosphere, a specified wavelength range, specified chemical composition, and a line list to calculate a synthetic spectrum. We used the recent Kurucz (1993) model atmospheres, although specially calculated atmospheres using TLUSTY (Hubeny 1988; Hubeny & Lanz 1995) could equally well have been used. Our line list is a subset of the Kurucz list and includes of order 10^6 lines. SYNSPEC solves the radiative transfer

[1] Visiting Scholar, Astronomy Department, University of Washington, Seattle, WA 98195; linnell@pa.msu.edu.

[2] Universities Space Research Association; hubeny@stars.gsfc.nasa.gov.

[3] E-mail: clacy@comp.uark.edu.

60.06 Bull. Am. Astron. Soc, Vol. 27, p.1372

A Spectrum Synthesis and new Light Synthesis Study of EE Pegasi

A.P. Linnell (MSU), I. Hubeny (GSFC), C.H.S. Lacy (UArk)

EE Peg is among the binary systems with accurately known masses and radii (Andersen 1991, Astron. Astrophys. Rev., 3, 91). With component masses of 2.15 $M_\odot$, 1.33 $M_\odot$ and an orbital period of 2.63^d, this low distortion system is an excellent first test case for application of a new spectrum synthesis program for binary stars (Linnell & Hubeny 1994, ApJ, 434, 738). The existing standard light curve solution is by Lacy & Popper (1984, ApJ, 281, 268), analyzing an excellent B light curve by Ebbighausen. That paper also includes component mass determinations to 1%, based on spectra by Lacy.

Our synthetic spectrum fits determine an iron abundance of log Fe=3.0x solar, and a calcium abundance of Ca=0.5x solar, consistent with the Am spectral type of the primary component.

Calculation of a synthetic spectrum depends on prior knowledge of component dimensions and $T_{\rm eff}$ values. Consequently there is an interdependence with the light curve solution. Our light curve solution applied the light synthesis program by Linnell (1984, ApJS, 54, 17). We found that use of the Planck Law to represent component radiative properties, a common procedure, produced a B-V component difference in strong disagreement with Popper's calibration of flux and $T_{\rm eff}$ for main sequence stars. A program modification permitted direct use of our synthetic spectrum results to represent the component radiative properties, with improved results.

Since our program is applicable to systems of any distortion, successful analysis of EE Peg invites future discussion of distorted systems for which single values of $T_{\rm eff}$ and log g are inadequate.

Session 61: Russell Prize Lecture
Invited Session, 11:40am-12:30pm
La Villita Assembly Building, 1st Floor

61.01

Abundance Inhomogeneities and Other Abundance Anomalies Among Globular Cluster Stars

R.P.Kraft (UCO/Lick Observatories)

Stars within a given "monometallic" globular cluster often exhibit wide variations in the abundances of C, N, and O as well as certain light metals, particularly Mg, Na and Al. Such variations are generally less pronounced as cluster metallicity increases, and are also less pronounced at a given metallicity in field halo giants. In general, these variations tend to be of two types: (1) those related to evolutionary state and (2) variations among stars in the same evolutionary state. The abundances of C and N and of O and N often prove to be anticorrelated, and most recently it has been found that there exists a "universal" anticorrelation between O and Na, as well as a correlation between Al and Na. These results are discussed in terms of competing scenarios, one in which the anomalies are driven by deep mixing associated with stellar evolution as opposed to another picture in which the variations reflect the primordial state of the cluster gas.

Recent observations of r-process species in omega Cen (Smith *et al.* 1996) and Na abundances among giants in M13 and the halo field (Pilachowski *et al.* 1996) are discussed in connection with these hypotheses.

Session 62: X-ray Astronomy: New Discoveries
Oral Session, 2:00-3:30pm
La Villita Assembly Building, 1st Floor

62.01

Iron-line Spectroscopy of AGN

A.C. Fabian (IoA, UK)

Seyfert galaxies commonly show Fe-K line emission. X-ray spectra fro[illegible] ASCA now enable the line to be resolved. In Seyfert 1 galaxies the line [illegible] often found to be broad, and in the best observed cases is skew, with a sha[illegible] drop at the higher energies (~6.5−7 keV) and a long tail to lower energ[illegible] (4−5 keV). The line is best modeled by fluorescence from the innermo[illegible] regions (less than about 20 Schwarzschild radii) of an accretion disk about [illegible] massive black hole. The profile and time variation of the iron line in MC[illegible] −6−30−15 will be discussed, together with results from some other Se[illegible] fert 1 galaxies. Additional emission from outer gas in both Seyfert 1 and [illegible] galaxies is used to constrain the overall geometry. Finally, the prospects [illegible] understanding the near environment of black holes through iron-line spe[illegible] troscopy will be outlined.

62.02

ASCA Observations of the Galactic Center

K. Koyama (Kyoto U., Japan)

X-ray imaging spectroscopic observations near the Galactic Center reg[illegible] in the 0.5-10 keV band were carried out with the ASCA satellite. Two bri[illegible] spots close to the Galactic Center (Sgr A*) are found; one is a hot pl[illegible] with strong line emissions of highly ionized iron and the other is a ne[illegible] discovered eclipsing X-ray burster with a largely absorbed spectrum. [illegible] probable that the previous reports on the X-ray flux from the Galactic Ce[illegible] were contaminated by this X-ray burster. Further extended hot plasma [illegible] K- shell transition lines of highly ionized silicon sulfur argon and iron is [illegible] found. Spatially resolved spectra from the Center region are found [illegible] identical from place to place, except for the amount of low energy absor[illegible] and the absolute flux. Another remarkable discovery is 6.4 keV line e[illegible] sions of low ionization iron atoms near the Sgr B2 cloud and the Radio [illegible] region. We interpret that the 6.4 keV line originates from the florescent [illegible] the gas cloud irradiated by strong X-ray beams, which is now quiet bu[illegible] been active until the recent past. The origin of the hot plasma may also [illegible] related to the past possible activity at the Galactic Center.

62.03

X-ray Emission from Clusters of Galaxies - A Cosmological Labo[illegible] tory

R.Mushotzky (NASA/GSFC)

In the last 5 years our knowledge of the x-ray emission from clust[illegible] exploded with high quality Rosat image and ASCA spectra. We are now [illegible] to obtain detailed measurements of the mass and mass distribution of cl[illegible] out to radii of 2 Mpc for relaxed systems.over a a mass range [illegible] 10^13-4^15 solar masses. In addtion the abundances of O, Si, S, and Fe [illegible] be reliably obtained over the same mass range. For massive cluste[illegible] elemental ratios strongly indicate that type II supernova were responsib[illegible] most of the metals. However less massive systems may have a subs[illegible] contribution from type Is. The total mass of alpha burning elements st[illegible] indicates that most galaxies went through a extremely luminous early [illegible] which resulted in the ejetion of 1/2 of their total mass. The Fe abund[illegible] a function of redshift shows little if any change out to redshifts [illegible] confirming the early enrichment of the intergalactic medium in cl[illegible] Detailed temperature maps for merging systems have shown direct evi[illegible] for interaction and allow modeling of these complex systems.

Briefly Noted

Powers of Ten, Philip Morrison, Phylis Morrison, and the Office of Charles and Ray Eames (Scientific American Library, 1994). 160 pages. ISBN 0-7167-6008-8. $19.95, paperbound.

The 1977 film *Powers of Ten: A Film Dealing with the Relative Size of Things in the Universe and the Effect of Adding Another Zero* by Charles and Ray Eames has become a classic for envisioning the universe. In 1982 Philip and Phylis Morrison wrote a book based on the film, and it is now available in its first paperback edition.

Sun Moon: Myths, Tales, and Visions, Diana Landau, editor (The Nature Company, 1994). 160 pages. $29.95, paperbound. (Available exclusively at Nature Company stores, through its mail-order catalog, or by calling 800-227-1114.)

Impressions of the Sun and Moon are presented with essays and sayings from a variety of scientists, poets, and philosophers in this unusual "dual" text, richly illustrated with paintings and photographs. The two-books-in-one binding has one half dealing with the Sun, then by flipping the book over, you have the second half about the Moon.

Where Next Columbus? Valerie Neal, editor (Oxford University Press, 1994). 231 pages. ISBN 0-19-509277-5. $35.00.

This look ahead to the possible future of humankind in space was inspired by an exhibit at the National Air and Space Museum in Washington, D.C. Beginning with early exploration of the Earth, the text proceeds through the Apollo missions and robotic planetary surveys to the future of space exploration. Contributing authors include Timothy Ferris, Robert L. Forward, Carl Sagan, Harrison H. Schmitt, and Edward C. Stone.

Venus Explorer, John Hinkley (Virtual Reality Laboratories, Inc.). CD-ROM for IBM and Macintosh computers. $69.95. (Available from Sky Publishing Corp.)

View Venus as charted by the radar of the Magellan spacecraft. Use a small-scale index map to select areas between latitude 52° north and 52° south to examine the planet in detail (at maximum magnification 1 inch equals approximately 1°). Adjust brightness, color, and contrast, and search for named features.

Binary Star, Claud Lacy (Gemini Software, 502 Holly, Fayetteville, AR 72703). Software for fast Macintosh computers. $37.50. Site licenses available.

Examine binary star systems by changing any of 15 orbital parameters and seeing the results in six animated diagrams (view from Earth, view from orbital pole, brightness versus phase, radial velocity versus phase, luminosity versus temperature, and radius versus mass). Work with real stars or experiment with imaginary systems to gain an intuitive understanding for binaries. Intended for college laboratory use.

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4194

Konkoly Observatory
Budapest
18 May 1995
HU ISSN 0374 - 0676

TIMES OF MINIMA OF EIGHT ECLIPSING BINARIES

We report times of minima of eccentric eclipsing binaries derived from photometric observations made at Ege University Observatory in Turkey and at Cerro Tololo Inter-american Observatory (CTIO) in Johnson B and V filters, and at the High Altitude Maidanak Observatory in Uzbekistan in Johnson U,B,V,R filters. Heliocentric times of minimum were estimated for each filter by using the method of Kwee and Van Woerden (1956) as adapted to a Macintosh computer. The adopted time of minimum was then the average over all filters. In all cases the times of minimum in different filters was concordant. Uncertainties in the times of minima were estimated from the values of standard error computed by the method and from the differences in times derived from the various filters used. Primary eclipses are designated as type 1 eclipses, and secondary eclipses as type 2.

We would like to acknowledge financial support of our work by the American Astronomical Society through the Edith J. Woodward Award and from the Margaret Cullinan Wray Charitable Lead Annuity Trust.

Claud H. SANDBERG LACY
Department of Physics
University of Arkansas
Fayetteville, Arkansas 72701
USA

Cafer IBANOGLU
Z. TUNCA
S. EVREN
C. AKAN
V. KESKIN
Ege University
Bornova-Izmir
Turkey

Mamnun ZAKIROV
G. ARZUMANYANTS
R. ISHANKULOV
V. KHARCHENKO
High Altitude Maidanak Observatory
Astronomical Institute
Tashkent 700052
Uzbekistan

Reference:

Kwee, K.K., and van Woerden, H., 1956, *B.A.N.*, **12**, 327

COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4009

Konkoly Observatory
Budapest
24 March 1994

HU ISSN 0324 - 0676

TIMES OF MINIMA OF NINE ECLIPSING BINARIES

We report times of minima of eclipsing binaries derived from photometric observations made with the 0.4 m reflector at Droke Observatory near Fayetteville, Arkansas, and with the 0.6 m Lowell Telescope at Cerro Tololo Interamerican Observatory in Chile. Both photometers used pulse-counting techniques and the observations were corrected system deadtime and atmospheric extinction. Heliocentric times of minimum were estimated by bisecting chords drawn across the minima. Uncertainties were estimated from differences in the timings in the two filters used - V and R at Droke Observatory and B and V at CTIO - and also differences between independent estimates of the times of each eclipse. Primary eclipses are designated as type 1 eclipses, secondary eclipses as type 2.

Table 1

Star	JD of Min -2400000	Type	Observatory	Observer
SW CMa	49345.6754 ± 0.0006	2	CTIO	Lacy
	49352.6453 ± 0.0004	1	CTIO	Lacy
EK Cep	49248.6416 ± 0.0007	1	Droke	Fox
V477 Cyg	49251.7117 ± 0.0006	1	Droke	Fox
V1143 Cyg	49234.6144 ± 0.0006	1	Droke	Fox
DI Her	49225.6702 ± 0.0012	2	Droke	Fox
FS Mon	49343.7953 ± 0.0005	1	CTIO	Lacy
GG Ori	49355.7327 ± 0.0005	2	CTIO	Lacy
V530 Ori	49341.5832 ± 0.0005	1	CTIO	Lacy
	49353.8048 ± 0.0006	1	CTIO	Lacy
DR Vul	49228.7300 ± 0.0007	2	Droke	Fox

tification of the Islamic star and crescent symbol with a conjunction of the moon and Venus (Ahmad 1989, B.A.A.S., 21, 1217) has been expanded to consider lunations other than June-July 610. We find that a conjunction in the July-August lunation is much closer than that observable from Mecca in the preceding month. Further, the July-August lunation occurred in the Islamic month of Ramadan, in line with tradition. Because the traditions state that the event occurred on an odd numbered date of the month, the issue of lunar visibility is critical and bears on the historically important issue of calibrating the Islamic calendar (Ahmad, 1988, B.A.A.S., 19, 1011). We consider the possible dates of an actual lunar sighting and its implications for the date of the Islamically important date of "the Night of Power." We report the results of preliminary calculations of the astronomical configurations in the dawn sky of possible dates. Our earlier conclusion that caution must be exercised in imputing astronomical conclusions from mythological, literary, and religious sources is confirmed.

Session 34: HAD
Oral Session

34.03
Back To The Future

David H. DeVorkin (Smithsonian)

This talk reviews how astronomers responded to the prospect of government funding in the decade following World War II. Specifically I relate how astronomers organized themselves in response to an invitation by the Office of Naval Research to advise the Navy on the needs of American astronomy. I will also address how leaders of the American astronomical community envisioned the future of their discipline as they expressed their needs first to ONR, and then to NSF; and, above all, examine their fears as they faced the prospect of governmental patronage.

34.04
Creating a Network of Astronomical Couples: The Harvard College Observatory 1920-1940

P.A. Kidwell (Smithsonian)

Under the administration of Harlow Shapley, the Harvard College Observatory became a center of an international network of astronomers who wed one another. This paper traces the origins of this network in the graduate programs at Radcliffe College and Harvard University, and outlines some of its ramifications.

Bull. Am. Astron. Soc., Vol. 26, No. 1, p. 790

Session 88: Teaching Astronomy
Display Session

88.11
Teaching Binary Star Concepts

C.H.S.Lacy (U.Ark.)

I will summarize the currently available resources for teaching elementary to advanced binary star concepts to college students. Some of these concepts are: orbit, center of mass, orbital period, orbital phase, stellar eclipse, time of minimum, light curve, radial velocity curve, angular separation, position angle, and various orbital parameters. Sources include [illegible] videos, and print materials. New computer programs for th[illegible] of computers will be described which have been written recent[illegible] use in introductory astronomy laboratories. These include M[illegible] finding tool, and Mac.chart, a visualization tool to accompany [illegible] distributing these programs through the CLEA Anonymous ftp [illegible] describing how to acquire the programs may be obtained [illegible] clacy@uafsysb.uark.edu.

88.12
Why are Star Images Round?

Stephen M. Pompea (Steward Observatory, Universty of Ariz[illegible]

Stephen M. Pompea, Steward Observatory, University [illegible] William G. Weller, Gemini 8-Meter Telescopes Project.

The observation that stars look circular when viewed throu[illegible] often taken by students as conclusive evidence that stars are [illegible] the round appearance is evidence that the telecope aperture [illegible] produces the characteristic diffraction pattern of a circular ape[illegible] demonstration shows students the nature of diffraction pattern[illegible] shaped apertures, and provides a good introduction to diffractio[illegible]

Session 89: HEAD I-ASCA

89.03
ASCA Observations of Binaries

N. E. White (LHEA/GSFC)

The first results from the Japanese/US X-ray astronomy satellite [illegible] merly Astro D) on binary stars are presented. The improved spectral [illegible] and collecting area of this mission have revealed many new and exc[illegible] from both coronally active stars, and accretion powered X-ray sour[illegible] observation of the RS CVn system AR Lac shows an X-ray eclipse [illegible] keV band. The X-ray spectrum can be well fit by a two-temperat[illegible] model, but only if the abundances of the medium-z elements are [illegible] third the solar photospheric value. Observations of the 4.8 hr X-ray [illegible] X-3 reveal Helium-like and Hydrogen-like iron K lines, as well as [illegible] species from Sulphur and silicon. Red and blue shifted S, Si and Fe [illegible] lines are clearly resolved from the jets of SS433. These and other re[illegible] will be presented.

Session 96: HEAD II-SN 1993J

96.01
X-Ray Observations (ROSAT, ASCA and OSSE) of SN 1993J

W. H. G. Lewin (M.I.T.), ()

X-ray Observations (ROSAT, ASCA and OSSE) of SN 1993J.

Abstract: X rays were observed from SN 1993J as soon as the observa[illegible] started, only 5 days after the "explosion". I will review the results inclu[illegible] the flux changes and the spectral changes as observed with ROSAT, ASC[illegible] OSSE, and I will make a modest attempt to interpret these data.

did not specify any of the detailed conventions required to convey the complexities of actual image projections. Building on conventions in wide use within astronomy, this paper proposes changes to the simple methods for describing coordinates and proposes detailed conventions for describing most of the methods by which spherical coordinates may be projected onto a two-dimensional plane. Simple methods for converting from the existing coordinate conventions are described. This paper does not attempt to address the politically sensitive questions of frequency/velocity coordinates, nor does it address various other types of coordinates, such as time.

9.02

The Scientific Visualization Studio at the NASA/Goddard Space Flight Center

R.A. White, J.E. Strong, D.E. Pape, H.G. Mitchell (NASA/GSFC), A. McConnell (Pix/GSFC), J.M. Cavallo, R.L. Twiddy (HSTX/GSFC), H. Rais (MDSSC/GSFC)

The Scientific Visualization Studio is a part of the Scientific Applications and Visualization Branch of the Space Data and Computing Division at the NASA/Goddard Space Flight Center. It is tasked to provide advanced data visualization support to users of the NASA Center for the Computational Sciences and other NASA funded scientific researchers in both the space and Earth Sciences. Such support includes providing both software and expertise in visualizing large, complex, multidimensional data sets, and in creating videos, films, and other forms of hardcopy of the results. Hardware and software tools include a Cray Y/MP, a Convex C3240, a MasPar MP-1, a family of SGI workstations, video disks and recorders in all the international standards, color printers, photographic and movie transfer tools, and IDL, AVS, and FAST.

We demonstrate these capabilities, as applied to various Earth and space science data sets, through a variety of annotated images and a video.

Session 10: Teaching of Astronomy
Display Session
Pauley

10.01
Astronomy Day at a Science Museum

C. M. Brunello

On May 1st, 1993, the Don Harrington Discovery Center in Amarillo, Texas, and the Amarillo Astronomy Club celebrated Astronomy Day. Many activities were planned for children, and there was a variety of information on astronomy available for adults. A star party was planned for that evening, with a back-up date in the event of bad weather. Information on the event was sent out to the media one month in advance.

This paper will discuss the day's events--its shining successes and dismal failures--based on attendance, media response, and public evaluation. Visuals and descriptions of the day's activities will be presented, along with suggestions on how they could have been improved. Our main goal is to increase the public's interest in astronomy; an attempt will be made to evaluate how successful we were.

10.02

"The Active Sun": Educational Videotapes on Solar Physics for College Astronomy

N. Hurlburt, A. Title, T. Tarbell, Z. Frank, K. Topka and R. Shine (Lockheed Solar and Astrophysics Laboratory)

We present a series of short, educational documentaries on solar physics aimed at college-level general astronomy courses. These tapes highlight recent advances in high-resolution solar astronomy and in theoretical and computational modeling of solar physics with particular focus on dynamical phenomena. The relevant physical mechanisms, theoretical interpretations and observational techniques are discussed. These include granulation, the theory of convection, five-minute oscillations, sunspots, magnetic fields, seeing and dopplergrams. VHS tapes are available to researchers and educators through a variety of distributors.

This work supported by Lockheed Independent Research Funds.

Bull. Am. Astron. Soc, Vol. 25, p.809

10.03
A Period-Finding Tool

C.H. Sandberg Lacy (U Ark)

My first real research job in astronomy was finding the orbital periods of eclipsing binary stars. I worked for Balfour S. Whitney as an undergraduate research assistant at the University of Oklahoma Observatory in 1967. We used hand-drawn plots of eyeball estimates of the brightness of star images on astrograph plates and calculated orbital phases from trial estimates of the period by using a Merchant mechanical calculator to do the 10-digit arithmetic (Balfour wore out 3 of these calculators in his time). It was a slow and exacting process, and getting a good period took many hours of work. I did learn a lot about binary stars and real data in the process, however. The task of period-finding is still a good way to introduce students to binary-star astronomy. The processes of light curve calculation and display can be accomplished by a modern microcomputer so rapidly that many trial periods can be checked quickly, and a numerical measure of the quality of the trial period (the "scatter") allows quantitative selection of the best trial period. The tool I have developed has an interactive graphical user interface and is very easy to use -- I have developed a lab exercise that employs it in my introductory liberal-arts astronomy class -- yet it is powerful enough to be used for research as well. The program shows its greatest advantage in determining periods from unequally sampled data when the period is shorter than the average sampling interval. I will demonstrate the program on a Macintosh computer.

10.04

The UCSB Remote Access Astronomy Project: Image Processing for High School and Undergraduate Students

Jatila van der Veen (ACHS), Erin O'Connor (UCSB,SBCC), Ted Smith (UCSB), Chris Bosso (UCSB), Carlos Alexandre Wuensche (UCSB,CNPq(Brazil),INPE(Brazil)), Philip Lubin (UCSB,CfPA)

The Remote Access Astronomy Project (RAAP) at the University of California, Santa Barbara is a computerized image data base, remotely-operated telescope with CCD camera, and electronic mail system. Students and teachers can download high quality images and curricula for physics, astronomy, chemistry, and earth science courses, as well as exchange ideas and e-mail over the bulletin board. The telescope is now available on a limited basis for remote

THE ASTRONOMICAL JOURNAL VOLUME 105, NUMBER 3 MARCH 1993

THE PHOTOMETRIC ORBIT AND APSIDAL MOTION OF V526 SAGITTARII

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Received 25 August 1992; revised 14 October 1992

ABSTRACT

Improved photometric orbits and apsidal motion parameters are derived from new observations of V526 Sgr (B9.5+A2). The new orbits are consistent with previous work on this system, but have much higher accuracy. Further improvement in our knowledge of this system must await completion of spectrographic work.

1. INTRODUCTION

The history of observations and analysis of V526 Sgr (HD 177994, CoD $-31°16374$, CPD $-31°5894$, SAO 210970) now spans almost a century. It was one of the first binaries recognized to show the effects of apsidal motion in the times of its eclipses. The early history of work on this binary was summarized by O'Connell (1967, hereafter referred to as OC), who was the first to analyze photoelectric light curves for it. He fitted a photometric orbit and also estimated the apsidal motion. My own work on this system began in 1983 August with the detection of double lines in the binary's spectra with a dual-array Digicon detector on the coudé spectrograph of the 2.7 m reflector at McDonald Observatory. This discovery was announced by Lacy (1985). A program of differential and all sky photometric measurements of this binary was also begun in 1988 with the Lowell 0.6 m telescope at Cerro Tololo Inter-American Observatory (CTIO). Results of the photometric program are discussed below. The spectroscopic analysis is not yet completed.

2. PHOTOMETRIC OBSERVATIONS AND ANALYSIS

Photometric observations of V526 Sgr began 1988 August 5 with a pulse-counting photometer on the 0.6 m Lowell telescope at CTIO. All observations were made with this equipment during the northern-hemisphere summers of 1988–1990. Photomultipliers of the ITT FW130 type with S-20 photocathodes were used with a *UBV* filter set. Typically, a diaphragm of 25 arcsec was used in good seeing conditions. The differential observations consisted of 30 s integrations per filter through the V and B filters. The variable star, its comparison star, and blank sky near the variable were observed at zenith distances corresponding to less than 2.0 airmasses of extinction. Observations of blank sky were made only every 20–30 min. The comparison star showed no detectable sign of night-to-night variability in the observations of OC, so no check star was used.

The interpretation of all photometric data for V526 Sgr is complicated by the presence of two significantly bright companions within 14 arcsec of the eclipsing binary itself [see Fig. 1 (Plate 58)]. Only the brightest and closest of these was recognized by OC. On 1990 June 27 (JD 2448069.531, orbital phase 0.846), at the author's request, Elizabeth D. Siciliano obtained CCD (TEK [illegible]) images of V526 Sgr with the 0.9 m Yale reflector at CTIO. The filters were meant to mimic Johnson V and B. The IRAF QPHOT routine was used to measure the magnitudes and positions of the variable and companion stars on the reduced frames. The results are summarized in Table 1. My results for stars A and B are consistent with those of OC. OC states that star B was included in his observations, but it is not known whether star C was included as well. Star B is probably a physical companion of the eclipsing binary; star C probably is not a physical companion of the V526 Sgr (A+B) system. The orbital period of the AB system is probably on the order of 10^5 yr. Two previous measures of positions of AB were given by OC. These measures and my own ($\delta=8.81$ arcsec, P.A.$=8°.2$ at 1990.5) probably are not inconsistent with the assumption of no detectable orbital motion during the last 80 yr.

All sky photometry on the *UBV* system was also obtained for V526 Sgr and its comparison star. Details of the observations and reductions have been discussed by Lacy (1992a). The diaphragm included stars A, B, and C. The results are shown in Table 2. The comparison star [illegible] (CoD $-31°16384$) is the same one used by OC. The photometric indices have been dereddened with the Q method of Johnson and Morgan (1953), and the photometrically estimated spectral types are shown in parentheses.

In 1989 August, at the author's request, Charles L. Perry included V526 Sgr in his extensive program of $uvby\beta$ observations with the 1.0 m reflector at CTIO. His results (Perry 1989) for observations outside eclipse are:

V	$b-y$	m_1	c_1	β
9.68	0.109	0.142	0.917	2.885

with standard errors of about 0.008 mag for the color indices. Previous estimates of the spectral type of V526 Sgr based on classification-dispersion spectrograms from the HD (A0) and by Houk (1982) (A0 V) are consistent with both sets of color indices.

The differential photometric observations were reduced

[1]Visiting Astronomer, Cerro Tololo Inter-American Observatory, operated by AURA, Inc. under contract to the National Science Foundation.

THE PHOTOMETRIC ORBIT AND APSIDAL MOTION OF V523 SAGITTARII

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

Received 29 July 1992; revised 18 September 1992

ABSTRACT

Improved photometric orbits and apsidal motion parameters are derived from new observations of V523 Sgr (F0 + F0). The new orbits are consistent with previous work on this system, but have much higher accuracy. Further improvement in our knowledge of this system must await additional spectrographic work.

1. INTRODUCTION

The history of observations and analysis of V523 Sgr (HD 176754, CoD $-29°15641$, CPD $-29°5846$, SAO 187605) now spans almost a century. It was one of the first binaries recognized to show the effects of apsidal motion in the times of its eclipses. Jones (1938) was one of the first to study it, and she recently published the first photoelectric light curves and summarized the history of this system (Woodward & Koch 1989, hereafter referred to as WK). My own work on this system began in May, 1983 with observational attempts to detect double lines in the binary's spectra with a dual-array Digicon detector on the coudé spectrograph of the 2.7 m reflector at McDonald Observatory. Because of very poor luck with the weather initially, and because of its very shallow and moderately broad absorption lines, double lines were not detected unambiguously until observations taken in May, 1989 with the coudé spectrograph of the coudé-feed telescope at Kitt Peak National Observatory (Lacy 1990). A program of differential and all sky photometric measurements of this binary was also begun in 1988 with the Lowell 0.6 m telescope at Cerro Tololo Inter-American Observatory (CTIO). Results of the photometric program are discussed below. Not enough spectrograms are available yet for a definitive spectroscopic analysis.

2. PHOTOMETRIC OBSERVATIONS AND ANALYSIS

Photometric observations of V523 Sgr began 5 August 1988 with a pulse-counting photometer on the Lowell telescope at CTIO. All observations were made with this equipment during the Northern-hemisphere summers of 1988–1990. Photomultipliers of the ITT FW 130 type with S-20 photocathodes were used with a *UBV* filter set. Typically, a diaphragm of 25 arcsec was used in good seeing conditions. The differential observations consisted of 30 s integrations per filter through the *V* and *B* filters. The variable star, its comparison and check stars, and blank sky near the variable were observed at zenith distances corresponding to less than 2.0 airmasses of extinction. Usually, observations of the check star were made only during a few cycles near the beginning of the night, and observations of blank sky were made only every 20–30 min. The comparison and check stars showed no detectable sign of night-to-night variability at a level of 0.01 mag standard error.

All sky photometry on the *UBV* system was also obtained for V523 Sgr and its comparison stars. Details of the observations and reductions have been discussed by Lacy (1992a). The results are shown in Table 1. The comparison stars I used were not the same as those used by WK. The photometric indices have been dereddened with the Q-method of Johnson & Morgan (1953), and the photometrically derived spectral types are shown in parentheses.

In August 1989, at the author's request, Charles L. Perry included V523 Sgr in his extensive program of $uvby\beta$ observations with the 1.0 m reflector at CTIO. His results (Perry 1989) for observations outside eclipse are

V	$b-y$	m_1	c_1	β
9.56	0.282	0.163	0.711	2.761

with standard errors of about 0.008 mag for the color indices. These data imply a slightly larger value for the interstellar reddening than do my *UBV* observations or those of WK, but also point to an average spectral type of F0 for the binary. Previous estimates of spectral type based on classification–dispersion spectrograms from the HD (A5) and by Houk (1982) (A3/5 II/III) are inconsistent with all three sets of photometric values for unknown rea-

TABLE 1. Photometric data for V523 Sgr and comparison stars.

Star	V	B-V	U-B	n	Q	$(B-V)_0$	Sp
V523 Sgr	9.570 ±0.004	0.418 ±0.002	0.133 ±0.005	10	-0.168 ±0.006	0.31 ±0.01	(F0)
-29°15649 (comparison)	9.101 ±0.003	0.072 ±0.002	-0.047 ±0.004	10	-0.099 ±0.005	-0.05 ±0.01	(B9.5)
-29°15655 (check)	10.166 ±0.006	0.400 ±0.003	0.088 ±0.004	11	-0.200 ±0.006	0.34 ±0.01	(F1)

[1]Visiting Astronomer, Cerro Tololo Interamerican Observatory, operated by AURA, Inc. under contract to the National Science Foundation.

 0004-6256/93/020630-07$00.90

Complementary Approaches to Double and Multiple Star Research, IAU Colloquium 135, ASP Conference Series, Vol. 32, 1992
Harold A. McAlister and William I. Hartkopf (eds.)

Ultra-High Accuracy Masses of Eclipsing Binary Stars

CLAUD H. LACY
Physics Department, University of Arkansas, Fayetteville, AR 72701, USA

New observational spectroscopic methods have made it possible to obtain radial velocities of eclipsing binary star components with unprecedented accuracy. Most of the improvement in accuracy is due to two techniques: (1) The use of optical fibers to scramble the spatial distribution of stellar brightness at the input end of the spectrometer, and to allow the spectrometer to be located off the telescope where its temperature and position can be stabilized. (2) The simultaneous exposure of the comparison emission-tube light through a separate fiber or pair of fibers adjacent to the stellar fiber continuously during the stellar exposure. Any changes in the response of the spectrometer during the exposure then affect the stellar and adjacent comparison spectra in almost exactly the same way.

I have used these techniques to obtain radial velocities with typical accuracy of 0.2–0.3 km s^{-1} per observation and have in hand data projected to yield 0.1–0.2 km s^{-1} when fully analyzed. Simulation studies done recently (Lacy 1992) in the Robotic Observatories Symposium have shown that the observations now in hand should likely yield masses of 0.05–0.10% accuracy. This accuracy is an order-of-magnitude better than what has been achieved before.

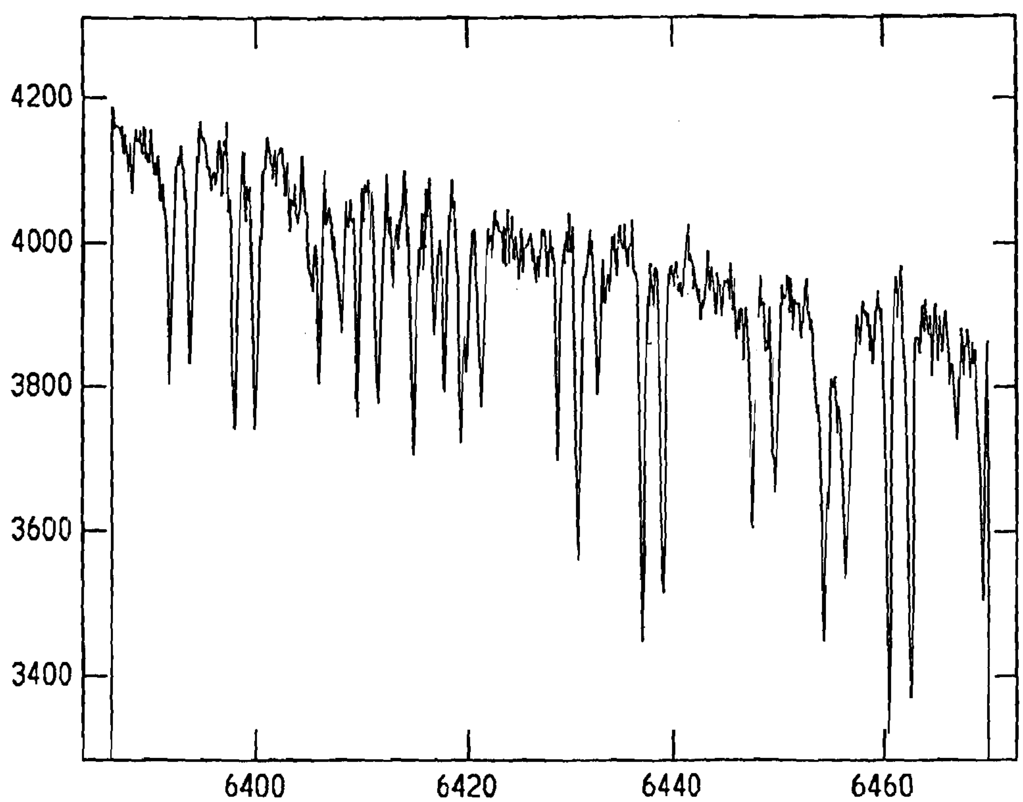


FIGURE 1. Spectrum of ZZ Boo, from the 1-m coudé-feed spectrograph at KPNO

1993AJ....105..637L

THE PHOTOMETRIC ORBIT AND APSIDAL MOTION OF YY SAGITTARII

CLAUD H. SANDBERG LACY[1]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Received 6 August 1992; revised 5 October 1992

ABSTRACT

Improved photometric orbits and apsidal motion parameters are derived from new observations of YY Sgr (B5+B6). The new orbits are consistent with previous work on this system, but have much higher accuracy. Further improvement in our knowledge of this system must await additional spectrographic work.

1. INTRODUCTION

The history of observations and analysis of YY Sgr (HD 173140, BD−19°5148, HV 3080) now spans almost a century. It was one of the first binaries recognized to show the effects of apsidal motion in the times of its eclipses. The early history of work on this binary was summarized by Keller & Limber (1951, hereafter KL), who were the first to obtain an unfiltered (1P21) photoelectric light curve for it. They fitted a photometric orbit and also estimated the apsidal motion period. Woodward & Koch (1992, hereafter WK) recently published their observations and analysis. My own work on this system began in May 1983 with the detection of double lines in the binary's spectra with a dual-array Digicon detector on the coudé spectrograph of the 2.7 m reflector at McDonald Observatory. This discovery was announced by Lacy (1984). A program of differential and all sky photometric measurements of this binary was also begun in 1988 with the Lowell 0.6 m telescope at Cerro Tololo Interamerican Observatory (CTIO). Results of the photometric program are discussed below. The spectroscopic analysis is not yet completed.

2. PHOTOMETRIC OBSERVATIONS AND ANALYSIS

Photometric observations of YY Sgr began 5 August 1988 with a pulse-counting photometer on the 0.6 m Lowell telescope at CTIO. All observations were made with this equipment during the Northern-hemisphere summers of 1988–1990. Photomultipliers of the ITT FW130 type with S-20 photocathodes were used with a *UBV* filter set. Typically, a diaphragm of 25 arcsec was used in good seeing conditions. The differential observations consisted of 30 s integrations per filter through the *V* and *B* filters. The variable star, its comparison and check stars, and blank sky near the variable were observed at zenith distances corresponding to less then 2.0 airmasses of extinction. Usually, observations of the check star were made only during a few cycles near the beginning of the night, and observations of blank sky were made only every 20–30 min. The comparison and check stars showed no detectable sign of night-to-night variability at a level of 0.004 mag standard error.

All sky photometry on the *UBV* system was also obtained for YY Sgr and its comparison stars. Details of the observations and reductions have been discussed by Lacy (1992a). The results are shown in Table 1. The comparison star I used (BD−19°5140) is one of those used by KL (comp. star D), and is also the one used by WK. The photometric indices have been dereddened with the Q method of Johnson & Morgan (1953), and the photometrically estimated spectral types are shown in parentheses.

In August 1989, at the author's request, Charles L. Perry included YY Sgr in his extensive program of *uvbyβ* observations with the 1.0 m reflector at CTIO. His results (Perry 1989) for observations outside eclipse are:

V	$b-y$	m_1	c_1	β
10.02	0.175	0.057	0.489	2.771

with standard errors of about 0.008 mag for the color indices. These data imply a slightly smaller value (by 0.025 mag) for the interstellar reddening than do my *UBV* observations, but also point to an average spectral type of B5.7 for the binary. Previous estimates of spectral type based on classification–dispersion spectrograms from the HD (A0) and by Houk 1988 (B8/9II) are inconsistent with both sets of color indices. Strong He I 4471 Å lines show that both components are mid-B stars. From my own initial high-resolution observations in a 100 Å band of the 4500 Å region, I estimated spectral types of B8+B8 (Lacy 1984), probably the origin of the entry in the *General Catalogue of Variable Stars* (Kholopov 1987). According to Perry (1989), the binary's m_1 index indicates that the star is metal-weak. These photometric and spectroscopic data

TABLE 1. Photometric data for YY Sgr and comparison stars.

Star	V	B-V	U-B	n	Q	$(B-V)_0$	Sp
YY Sgr	10.033 ±0.004	0.193 ±0.003	-0.311 ±0.006	12	-0.450 ±0.008	-0.145 ±0.010	(B5.7)
-19°5140 (comparison)	9.585 ±0.003	0.274 ±0.003	0.174 ±0.005	12	-0.023 ±0.007	-0.004 ±0.010	(A0)
-19°5137 (check)	8.924 ±0.003	0.304 ±0.002	0.185 ±0.003	10	-0.034 ±0.005	-0.007 ±0.010	(A0)

[1]Visiting Astronomer, Cerro Tololo Interamerican Observatory, operated by AURA, Inc. under contract to the National Science Foundation.

 0004-6256/93/020637-09$00.90

THE ASTRONOMICAL JOURNAL VOLUME 104, NUMBER 6 DECEMBER 1992

AN EXACT SOLUTION OF THE EPHEMERIS-CURVE PROBLEM

CLAUD H. SANDBERG LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

Received 27 May 1992; revised 28 July 1992

ABSTRACT

A new method is presented for the determination of apsidal motion parameters from observed times of minima of eccentric eclipsing binary stars. Previous methods have relied on approximations which, in the most accurate case, include terms up to the fifth power of the eccentricity. The new method is exact—no approximations are used. Instead, iterative numerical methods are used to solve the transcendental equations to arbitrarily high precision. A Levenberg–Marquardt method is used to obtain simultaneously the optimum values of all fitting parameters and their mean errors. As an example, the method is used to analyze the apsidal motion of V523 Sgr.

1. INTRODUCTION

The history of apsidal motion studies based on observations of times of minima of eclipsing binary stars is long and interesting. It began with the recognition by Dunér (1892) that there were two separate types of minima of Y Cyg with significantly different periods, and he correctly attributed this effect to a rotating line of apsides. It is interesting to read of the excitement generated by these early discoveries. The observers sometimes went to great lengths to observe predicted eclipses. Dugan (1931) abstracts observations of Chandler on "20 nights Dec. 1886–Jan. 1887 (*some of them made on a railroad train*)." The cause of the apsidal motion was initially attributed to the gravitational influence of a third body. Russell (1928) was the first to recognize that rotational and tidal distortion of the stars would themselves be sufficient to cause the apsidal motion, and he used the available observations of Y Cyg to determine the interior stellar mass distribution. Russell's theory was improved by Cowling (1938) and Sterne (1939). About the same time, Levi-Civita (1937) discussed the general relativistic contribution to the rate of apsidal advance.

The motivation for apsidal rotation studies has always been to test the theories of stellar structure and/or general relativity. Initial comparisons indicated quite significant disagreement between observationally and theoretically derived stellar structure constants. This disagreement persisted until relatively recently (Stothers 1974) when improvements in the theories of stellar structure and evolution and new tables of opacities made possible reasonable agreement between theory and observation. The most recent comparisons (Giménez *et al.* 1987) show that the best available observational determinations can now be used to discriminate critically between competing theories of stellar structure and evolution. Observations of times of minima have also led to the discovery of at least one apparent anomaly with the general theory of relativity. Guinan & Maloney (1985) show that in the case of DI Her the apsidal motion is not consistent with theory and argue that alternative theories of gravitation may be needed to explain the discrepancy. This is a controversial point of view however, and other explanations within the framework of standard theories are possible (Company *et al.* 1988). One of the strongest tests of general relativity is possible with pulse timings of binary pulsars (Taylor & Weisberg 1989), and the most recent results show good agreement between the theory and observations in the best case.

The problem of analyzing times of minima to determine orbital parameters, which I will call the *ephemeris-curve* problem (after deKort 1956), has traditionally been approached by using truncated series expressions to approximate the solution of the transcendental equations that are involved. Early works found that series to the second power of the eccentricity were sufficient (Dugan 1931), and also include the assumption that the orbital plane was seen exactly edge-on. Todoran (1972) made this approach more general and extended the series approximations to terms with the third power of the eccentricity. Finally, Giménez & Garcia-Pelayo (1983), hereafter referred to as GG-P, extended this approach to terms with the fifth power of eccentricity. The equations involved in this approximation are rather long, including approximately 50 terms. Indeed, my main motivation for seeking a better approach was the difficulty of verifying the published expressions (there are at least several misprints). In the new method, no approximations are used. Instead, the transcendental equations are solved to arbitrarily high precision by using iterative numerical techniques. This is now a viable approach due to advances in computing technology; it would have been totally impractical in the days when computations were done by hand. There is no longer much justification, however, for using truncated series approximations to solve the ephemeris-curve problem, except, perhaps, to estimate first-guesses at the parameters.

[1]Visiting Astronomer, Cerro Tololo Interamerican Observatory, operated by AURA, Inc. under contract to the National Science Foundation.

THE ASTRONOMICAL JOURNAL VOLUME 104, NUMBER 2 AUGUST 1992

UBV PHOTOMETRY OF SELECTED ECLIPSING BINARY STARS

CLAUD H. LACY[1]

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

Received 19 March 1992

ABSTRACT

New *UBV* observations of 69 eclipsing binary stars are presented, and outside-eclipse averages are given. Many of these binaries are detached main-sequence pairs that have been discovered to be double-lined spectroscopic binaries and appear suitable for determinations of accurate absolute dimensions and masses. Revised photometric properties of five of the binaries are computed, for which absolute properties have been published previously. Intercomparisons are made with previous photometry, when available, and notes are given for some individual systems.

1. INTRODUCTION

For more than a decade I have been working to determine accurate absolute properties of eclipsing binary stars. Many of the systems fainter than 10th magnitude do not have accurate color indices; even some of the brighter stars lack them. In these cases one must rely on the rough spectral types available; until recently those from the Henry Draper Catalogue were often the only ones available. In an attempt to alleviate this problem for those systems in which I currently have an interest—mainly detached main-sequence pairs—I have measured *UBV* indices of 69 eclipsing binaries. Many of these have been discovered to the double-lines eclipsing binaries (Lacy & Evans 1979; Lacy 1984, 1985, 1990). In some cases the light and radial velocity curves have been analyzed and published without access to good color indices, thus rendering the quantities that are dependent on these indices somewhat uncertain.

In Sec. 2 the methods and equipment used in obtaining the data are discussed. In Sec. 3 the results for individual systems are analyzed.

2. OBSERVATIONS

The allsky-type photometry was obtained at Cerro Tololo Inter-American Observatory (CTIO) in Chile and at Mount Laguna Observatory (MLO) near San Diego, California. The CTIO observations were made during three observing runs in the summers of 1988–1990 with the Lowell 0.6 m telescope. Photomultipliers of the ITT FW130 type with S-20 photocathodes were used with a *UBV* filter set. Typically, a diaphragm of 20 arcsec was used in good seeing conditions. The observations at MLO were made in the autumn of 1989 with the Smith 0.6 m telescope. A photomultiplier of the EMI 6256 type with an S-4 photocathode was used with a *UBV* filter set. Typically, a diaphragm of 24 arcsec was used in good seeing conditions.

The observations consisted of 10–30 s integrations per filter. The usual observing sequence was a set of *UBV* integrations of the star, then the same set for blank sky near the star, then a repeat series of integrations on the star. The consistency of the repeated observations were checked during initial reductions to insure freedom from spurious errors. Program stars, standard stars, and extinction stars were observed in random order during the night. Standard stars were from the equatorial list of Landolt (1973). Extinction stars were from the equatorial list of Crawford *et al.* (1971). Typically, one pair of extinction stars was observed four or five times over a range of more than 1 airmass, and about 20 transformation stars were observed per night. Measured system deadtimes of typically 29 ns (CTIO) and 60 ns (MLO) were used to correct the raw data, although the observations were all obtained at counting rates small enough to render the results quite insensitive to uncertainties in the assumed deadtimes. Instrumental magnitudes derived from the corrected counting rates were used to measure extinction coefficients from the extinction-star observations. These are summarized in Table 1. Only first-order coefficients were used since inclusion of second-order coefficients did not improve the transformation-star residuals. Transformation coefficients were determined by linear fits to the transformation-star data. The fitted slopes were stable within each season. These slopes are listed in Table 2. Average standard errors for a single observation of the standard stars at CTIO were as follows: 0.010 (V), 0.010 ($B-V$), and 0.016 ($U-B$). At MLO they were as follows: 0.014 (V), 0.011 ($B-V$), and 0.025 ($U-B$).

Special checks were made to attempt to detect the following effects during the reduction of each night's data: nonlinearity in the photomultiplier response; zero-point

[1]Visiting Astronomer, Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by AURA, Inc. under contract to the National Science Foundation, and at Mount Laguna Observatory, operated by the Departments of Astronomy, San Diego State University and the University of Illinois.

...ure and Superionization in the Wind ...del for Be Stars

...P. Cassinelli (U. Wisconsin)

...elli (1991) have developed a 2-D model for ... wind which originates on a rapidly rotat- ... This model predicts the formation of a dense ... rapidly rotating B stars. The high den- ... shock compression of the wind as it enters ... and the ram pressure of the wind confines ... narrow equatorial zone, producing a "wind ... we present an approximate calculation ... which we use to predict the shock temper- ... temperature is sufficient to produce the ...rionization in the winds of Be stars. Fur- ...cation explains the observations of Grady ... K.S. Bjorkman (1989) which indicate that ...wards the equator at small radii. We also ...elation of shock temperature with rotation ...hest observed ionization stage will depend ... the star.

... Helium-Strong Star δ Orionis C

...lker (UBC), C.T. Bolton (UT)

... the helium-strong star δ Orionis C (= HD ...nce of double-peaked Hα emission in this ...netic B3V star. The emission is variable ..., and the profile variations are periodic ... of 1.5 days. When strongest the peaks ...tely 10% of the continuum level at about ... line center, and emission is apparent to ... assume that the magnetic field forces the ...id rotation about the star.

...variability is very similar to that of the ...ar σ Orionis E. However, the inclination ... C must be $\approx 10°$ in order to account for ... $v\sin i$ of 30 kms^{-1}. The low inclination ...tion in the observed longitudinal magnetic ... $i \approx 90°$. δ Ori C therefore provides us ...ity to investigate the cool components of ... of the helium-strong stars from a unique

...Accretion onto ONeMg White Dwarfs ...tion Network

...SU), J. W. Truran (UI), W. M. Sparks ... Garching)

... which examine the consequences of ... ONeMg white dwarfs with masses of ... In these studies we used our Lagran- ...ensional computer code that now ...uclei up to ^{40}Ca, elemental diffusion, ...ons of state. Our initial abundance ... Weiss and Truran (*A&A*, **238**, 178, ... Starrfield (*ApJ*, **369**, 440, 1991) and ...ure that was enriched to 50% in ... Arnett and Truran: *ApJ*, **157**, 339, 1969). The evolution of the TNR on the 1.35M$_\odot$ WD was the most interesting because the peak temperature in the shell source exceeded 300 million degrees. This sequence produced significant amounts of ^{22}Na (8.8 x 10^{-3} [mass fraction]) via proton captures onto ^{20}Ne and significant amounts of ^{26}Al (5.4 x 10^{-3} [mass fraction]) via proton captures on ^{24}Mg as was predicted in the above nucleosynthesis papers. This sequence ejected 5.2 x 10^{-6}M$_\odot$ moving with speeds from ~100km/s to ~2300km/s. Light curves produced by the ejected material will be shown as will the results from the studies at the other WD masses. We are currently extending these calculations to additional WD masses and accretion rates. We will also include elemental diffusion (using the algorithm described in Iben and MacDonald: *ApJ*, **296**, 540, 1985) in those sequences where the time scales are sufficiently long for diffusive mixing to become important.

This research was supported by NSF grants 88-18215 (ASU), 89-17442 (Illinois), and the DOE.

73.08

Optical Polarization Position Angle Variations of V Hya

S. J. Shawl (U. Kansas)

V Hya, a star of variable type SRb and a period of 529 days, was extensively observed polarimetrically by Serkowski (posthumous publication of his entire extensive data set for cool stars is in preparation). The percent polarization in the blue reaches a maximum of 3% with position angle variations between $-10°$and $+20°$. In the (Q,U) plane, the locus of points for consecutive observations is counterclockwise during one time interval, and clockwise at another. Models which allow one to understand such odd behavior are presented.

Bull. Am. Astron. Soc., Vol. 23, p.1265

73.09

The Eccentric Eclipsing Binaries YY Sgr, V523 Sgr, and V526 Sgr

C.H. Lacy (UA Fayetteville)

Light curves in B and V have been obtained for the eccentric eclipsing binaries YY Sgr, V523 Sgr, and V526 Sgr with the Lowell 0.6 m telescope at CTIO. These binaries have also been discovered to be double-lined spectroscopic binaries with the coude feed spectrograph at KPNO. It will therefore be possible to determine accurate absolute dimensions and masses for these stars. Apsidal motion has been detected and reasonably accurate apsidal motion periods have been calculated. Internal structure constants can therefore be accurately estimated for these spectral-type B, A, and F main-sequence pairs.

73.10

Photometric Binary Stars in Praesepe

M. Bolte (DAO/Lick Obs.)

In a number of well-studied open clusters and a few globular clusters, there are stars with colors and magnitudes that place them above the zero-age main sequence for single stars. Of the several explanations for these 'second sequence' objects, the most likely has been thought to be that they are binary systems that are not spatially resolved. This hypothesis has been tested by a program monitoring radial velocities of the second sequence objects in the nearby cluster Praesepe (=M 44, NGC 2632). For Praesepe, 10 of 17 binary candidates show velocity variations which indicate they are binary systems. In 5 of the binaries the full amplitude for the velocity variations is greater than 50 km/sec. These results are reported in full the Astrophysical Journal Aug 1 1991.

This work has been supported in part by NASA through grant #HF-1002.01-90A awarded by STSCI.

COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS
Number 3448

Konkoly Observatory
Budapest
27 March 1990
HU ISSN 0374 - 0676

NEW DOUBLE-LINED ECLIPSING BINARIES

High-resolution coudé spectrometric observations have been continued during the past 5 years as part of a program to determine accurate absolute properties of eclipsing binary stars. Previous progress reports (Lacy and Evans 1979, Lacy 1984, Lacy 1985) have discussed 45 of the stars in this program. Observations of an additional 8 eclipsing binaries are discussed here. These observations were obtained with either the 2.1 m reflector or the coudé feed telescope at Kitt Peak National Observatory (N.O.A.O.) and the coudé CCD spectrometer. Typically 100 Å in the blue (4500 Å) or red (6430 Å) were observed at a resolution of 0.2-0.3 Å. The individual binaries are discussed below.

Double-Lined Eclipsing Binaries

Name	V	Spec	P(days)	Name	V	Spec	P(days)
WW Cep	10.63	G3*	1.53*	RW Lac	10.65	F2*	10.37
EY Cep	9.79	A5*	5.52	V530 Ori	9.87	G0	6.11
NN Cep	8.10	A5*	2.06	V523 Sgr	9.56	A5*	2.32
V498 Cyg	9.83	B1:III:	3.49	TY Tau	12.01	K0V	1.08

* See notes below.

Only V523 Sgr and NN Cep have good photoelectric light curves. Photoelectric observers are encouraged to observe these systems in at least two well-calibrated colors in order to make possible the most accurate determinations of absolute stellar properties.

The V magnitudes listed above are preliminary results of UBV all-sky photometry obtained at Mt. Laguna Observatory in the Fall of 1989, except for V523 Sgr (see below). The spectral types and orbital periods are those listed in the *General Catalogue of Variable Stars* (1985). Notes on the individual systems are listed below.

WW Cep: Double lines were first detected in a spectrogram taken July 2, 1985. Preliminary color indices are consistent with a slightly reddened G9 main-sequence star.

THE ASTRONOMICAL JOURNAL VOLUME 97, NUMBER 3 MARCH 1989

PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY UZ DRACONIS

CLAUD H. LACY[a)]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

ÖMÜR GÜLMEN, NECDET GÜDÜR, AND CENGIZ SEZER
Ege Univesity Observatory, Bornova-Izmir, Turkey
Received 20 June 1988; revised 30 November 1988

ABSTRACT

Radial velocities, line profiles, and B,V photometry of UZ Dra (F7 + G0) are analyzed to obtain the fundamental properties of this detached main-sequence binary.

I. INTRODUCTION

UZ Dra = BD + 68° 1065 was discovered to be an eclipsing binary by Wright (1937). The light elements of Dugan and Wright (1939) indicated a period of 1.63066 days, nearly half the modern value. This mistake undoubtedly occurred because both the primary and secondary eclipses of UZ Dra are deep and it was assumed that both were primary eclipses, with the secondary eclipse being undetectably shallow. The doubled period of 3.261304 days was first adopted by Tsesevich (1954) based on his photovisual observations. The value of the period was improved to its presently accepted value of 3.2613024 days by Koch and Koch (1962). Gulmen, Gudur, and Sezer (1986) have summarized all existing observations of minima, including their recent photoelectric determinations. Their results:

$$\text{JD Hel Min I} = 2446227.4238 + 3^{\mathrm{d}}2613024\,E,$$

are adopted for our study of this binary. Imbert (1986) presented the first spectroscopic study of this system based on photoelectric radial-velocity measurements with the *Coravel* instrument at l'Observatoire de Haute-Provence.

In Sec. II, we discuss and analyze new spectroscopic data obtained with solid-state array detectors. In Sec. III, we discuss and analyze the first photoelectric light curves of the binary in two colors. The resulting orbital elements are combined to yield absolute properties of the components and a comparison with stellar-evolution theory in Sec. IV.

II. SPECTROSCOPY

Sixteen digital spectrograms of UZ Dra have been obtained in the 6400 Å region of the spectrum during the interval 1981–1985. The coudé Reticon and Digicon detectors of the 2.7 m reflector at McDonald Observatory (described by Vogt, Tull, and Kelton 1978) were used until August 1983; afterwards, Texas Instruments 800×800 CCD detectors were used with the coudé spectrograph of the 2.1 m reflector at Kitt Peak National Observatory. Spectrograms typically covered 100 Å centered on 6420 Å at resolutions of 0.3–0.6 Å. Spectrograms of iron or thorium–argon hollow-cathode lamps were used as comparison sources near the times of observations, and the standard stars ι Psc (F7 V) or o Aql (F8 V) were observed for use in the cross-correlation analysis employed to obtain radial velocities. The radial-velocity reductions follow the precepts of Lacy (1981). We have adopted a radial velocity of $+5.3$ km s^{-1} for o Aql (Pearce 1955) and have determined velocities of the components of UZ Dra differentially with respect to them. Unblended lines of Fe I and Ca I were used to determine the differential velocities. Sections of two spectra near opposite quadratures are shown in Fig. 1. The resulting radial velocities are listed in Table I and displayed in Fig. 2. Circular spectroscopic elements fitted to the orbits are listed in Table II and shown in Fig. 2.

Also shown in Table II is the spectroscopic orbit obtained by Imbert (1986). For both components, the radial-velocity amplitudes of Imbert are about 2% smaller than those based on our data. This difference amounts to 3 and 4 standard deviations for the two components, a rather large difference. A Student's t test indicates that differences as large as those found here would be expected to occur by chance about 20% of the time for each component. However, *both* components have differences this large, and this would be expected only 4% of the time by chance. We consider these odds small enough that the difference is probably not due to chance. Since the results of our methods have previously been checked against independently determined orbits for the same stars without significant differences (Lacy 1981; Lacy and Popper, 1984), we believe our methods are sound. The reason for the systematic differences is therefore unknown. Under these circumstances, we have decided to base our calculations of absolute properties on the spectroscopic orbit derived from our own data. For the purpose of this study, we have chosen not to use the orbits of Imbert (1986).

Equivalent widths and rotational velocities of both components have been measured from unblended line profiles on 16 spectrograms. Profiles of the sharp-lined star ι Psc were synthetically broadened with the rotational broadening function of Gray (1976) for a variety of values of $v \sin i$. These synthetically broadened profiles were then matched to the observed profiles of the binary star components to yield rotational velocities of 20 ± 1 km s^{-1} for the primary and 19 ± 1 km s^{-1} for the secondary. These values do not differ significantly from the synchronous velocities of 20.2 ± 0.5 and 17.7 ± 0.3 km s^{-1} derived from the absolute dimensions (Sec. IV).

Spectrophotometric light ratios provide powerful constraints on photometric-light-curve analyses, and both Imbert (1986) and we have obtained them. From the *Coravel* correlation peaks, Imbert found an observed line ratio of 0.70 ± 0.05 in the blue (approximately 4500 Å). We have measured the equivalent width of two strong lines in our spectrograms: the 6400.0 Fe I and 6439.1 Ca I lines were measured from the nine best unblended spectrograms. The resulting equivalent widths are, for λ 6400, 0.095 ± 0.002

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by AURA, Inc., under contract to the National Science Foundation.

Colloquium on Critical Observations Versus Physical Models for Close Binary Systems, p. 49- 53

DETACHED MAIN-SEQUENCE ECLIPSING BINARIES WITH G-TYPE COMPONENTS

D.M. POPPER
University of California, Los Angeles

C.H. LACY
University of Arkansas, Fayetteville

J. TOMKIN
University of Texas, Austin

The first reliable masses and radii of main-sequence G-type stars have been obtained for the components of the eclipsing binaries HS Aur, FL Lyr, EW Ori, and α CrB. The significance of the results is discussed briefly.

Our investigations of four eclipsing systems have led to the first evaluations of the properties of main-sequence G stars with a reliability approaching that of the better-studied A and F stars. The photometric observations of FL Lyr, EW Ori, and HS Aur were obtained by Lacy and his co-workers at the McDonald Observatory, while the photometric observations of α CrB analyzed are those of Kron and Gordon (1953). The spectrographic orbits of EW Ori and HS Aur are based on image-tube spectrograms obtained by Popper at the Lick Observatory. The Reticon spectrometer at McDonald was used by Lacy for FL Lyr and by Tomkin for the secondary component of α CrB. The velocities of the primary are those of the K dwarf and when the white dwarf is behind the K dwarf. The terminal velocity appears to be $\approx$800 km/s and we estimate a mass loss rate three to four orders of magnitude higher than the solar mass loss rate. To our knowledge this is the first direct evidence of mass loss from a K or M dwarf. The blue-shifted absorption velocities coincide with that of an expanding circum-binary shell discovered by Bruhweiler and Sion (1986, Ap.J. 304, L21). The braking action of this wind may cause this post-common envelope, pre-cataclysmic binary to begin Roche lobe overflow and thus cataclysmic variable evolution in less than 10^8 years. Calculations of magnetic braking and the possible role of the wind, in accretion by the white dwarf and in explaining the 555 second EXOSAT X-ray/optical oscillations are presented. This research has been supported by NASA grant NAG5-343 and in part by NSF grant AST85-17125, both to Villanova.

22.02

The Radio Light Curve of V471 Tauri

J.–P. Caillault (U. Georgia), J. Patterson (Columbia U.), D. Skillman (GSFC)

We have observed the white dwarf – K dwarf eclipsing binary system V471 Tauri with the VLA. On Jan 22/3, 1987 the source was weak and slowly varying, but the Jan 26/7, 1987 observation showed a brighter, flaring source with an interesting dip centered near phase zero (the phase of white dwarf eclipse). We have considered three possible explanations for this dip: (1) the eclipse of a large radio–emitting cloud centered on the presumably magnetic white dwarf; (2) the self–eclipse of a large radio–emitting cloud anchored to a particular spot on the secondary, namely the sub–white dwarf point; and (3) random variability.
We think that (2) is the leading possibility, because our nearly simultaneous optical light curve showed the optical wave minimum to be near phase 0.5. If, as is widely believed, this is a result of the presence of a dark starspot, then the "spot", and any structures associated with it, would suffer a broad eclipse near phase zero — consistent with the radio light curve.
Additional VLA time is scheduled this quarter to verify if this is a reproducible feature of the light curve. The favorable geometry and the very promising first observation makes it rather likely that we really will learn the size and location of the radio emission relative to the starspot – a crucial link that has not yet been securely established for any stellar radio source.

22.03

The Masses and Helium Abundance of the Population II Binary Star μ Cassiopeiæ

J.W. Haywood, D.J. Hegyi (U. Michigan)

We have obtained accurate measurements of the separation and position angle of the Population II astrometric binary star μ Cas using a direct imaging CCD camera. Speckle interferometric observations at 810 and 858 nm were made at 4 epochs between 1983.7 and 1985.9 using the McGraw-Hill 1.3-m telescope.

Combining these data with each of the two most recently published astrometric orbits for μ Cas yielded two solutions for the masses of the primary and secondary which were incompatable. However, it was possible to bring the solutions into agreement by using our observations and another recent measurement of the separation and position angle to determine the semimajor axis of the orbit and a new value for ω. These solutions lead to weighted averages for the masses of the primary and secondary of $0.731 \pm 0.049\mathcal{M}_\odot$, and $0.1692 \pm 0.0082\mathcal{M}_\odot$.

In addition, we find the temperature of the secondary to be 2977 ± 42 K, and the difference in bolometric magnitude between the secondary and primary to be 4.66 ± 0.08. Depending on the value used for the system parallax, the bolometric magnitude of the secondary lies between 10.2 and 10.3.

Using the mass of the primary quoted above and the measured metal abundance $Z = 0.002$, we find the helium abundance of the primary to be 0.24 ± 0.05 for an age of 12 Gyr and 0.22 ± 0.05 for an age of 16 Gyr.

Bull. Am. Astron. Soc., Vol. 20, p.707

TUESDAY

22.04

Absolute Properties of the Eclipsing Binary UZ Dracouis

C.H. Lacy(U. Arkansas)

The 10th magnitude eclipsing binary UZ Draconis has an HD spectral type of F8 and an orbital period of 3.26 days. Spectroscopic observations of the binary were obtained with the Reticon and Digicon coudé spectrograph of the 2.7 reflector at McDonald Observatory and the CCD coudé spectrograph of the 2.1 m reflector at Kitt Peak National Observatory. The spectrograms show double lines. Radial velocities derived from the spectrograms were analyzed to yield spectroscopic orbits. These indicate minimum masses of 1.34 and 1.24 M. for the components. Photometric observations of this system have been carried out by O. Gülmen of Ege University. The observations trace out a well-defined light curve with minima of 0.8 and 0.5 mag depth. The light curve was fitted with the WINK light curve modelling program. The photometric and spectroscopic orbits have been combined to yield absolute dimensions and masses of the components.

22.05

Optical Spectrophotometry of Several Yellow Supergiants

R.S. Patterson (SW Missouri St. U.)

Spectrophotometric observations of 50 F, G, and K spectral class supergiant and bright giant stars are presented. The observed flux distributions in the wavelength regions 3500-6300 Å at 10.3 Å resolution, and 5900-7350 Å at 5.4 Å resolution were corrected for instrumental effects and atmospheric and interstellar extinction. The resulting intrinsic flux distributions have been compared to theoretical models given by Kurucz (1979) in order to assign effective temperatures.

22.06 (Dissertation)

The Starpatch on the G8 Dwarf ξ Boo A

C.G. Toner and D.F. Gray (U. Western Ontario)

The chromospherically active G8 dwarf ξ Boo A has been spectroscopically monitored for four observing seasons. The data were analyzed for variations in the mean line asymmetry, line strength, and line broadening, using a combination of line bisector and Fourier techniques. Systematic variations in all quantities were found, which repeat with a period of 6.43 ±0.01 days. The line broadening variations show no evidence of being magnetic in nature, and there is no evidence of a change in period or phase shift over the four seasons.

THE ASTRONOMICAL JOURNAL VOLUME 94, NUMBER 6 DECEMBER 1987

PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY AY CAMELOPARDALIS

CLAUD H. LACY[a)]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Received 10 July 1987; revised 3 August 1987

ABSTRACT

Radial velocities and line profiles of AY Cam are analyzed, and the results are combined with previous light-curve analyses to yield absolute properties of this binary. Comparison of the properties of these stars with theoretical models of stellar evolution indicates that the primary component is significantly beyond the point of core-hydrogen exhaustion and the secondary is near the point of core-hydrogen exhaustion.

I. INTRODUCTION

AY Cam ($V=9.69$, $B-V=+0.33$) was discovered photographically by Strohmeier and Knigge (1961), who classified it as an Algol-type eclipsing variable with no perceptible secondary minimum and a period of 1.367485 days. Tempesti (1969) studied the system photoelectrically and found that the period was actually twice that found by Strohmeier and Knigge (1961). Tempesti (1969) obtained a good V light curve of the binary and the color index $B-V$ outside eclipse. He also obtained photometric orbital elements by use of the nomograms of Russell and Merrill (1952). Al-Naimiy (1977) and Milano and Russo (1979) have reanalyzed Tempesti's (1969) light curve by using modern computer techniques of analysis.

Lacy (1984a) announced the detection of double lines in the spectra of AY Cam. He found that the spectrum of the primary was consistent with late A spectral type. Digital spectrograms of AY Cam were obtained by the author in the interval May 1980–December 1983. Radial velocities obtained from these provide the basis for a determination of the absolute dimensions and masses of the system.

II. SPECTROSCOPIC OBSERVATIONS

High-resolution spectrograms of AY Cam were obtained with the coudé Reticon and Digicon detectors of the 2.7 m reflector at McDonald Observatory (described by Vogt, Tull, and Kelton 1978) until August 1983; afterwards, an RCA CCD detector was used with the coudé spectrograph of the 2.1 m reflector at Kitt Peak National Observatory. Spectrograms typically covered 100 Å centered on 4505 Å at resolutions of 0.3–0.5 Å. Spectrograms of iron or thorium-argon hollow-cathode lamps were used as comparison sources near the times of observation, and the standard stars θ Leo (A2 V) and 68 Tau (A2 IV) were observed for use in the cross-correlation analysis employed to obtain radial velocities. The radial-velocity reductions follow the precepts of Lacy (Lacy 1981, 1982, 1984b; Lacy and Frueh 1985). The radial velocities adopted for the standard stars are $+7.8$ km s^{-1} for θ Leo (Moore 1932) and $+38.0$ km s^{-1} for 68 Tau (Fekel 1981). Unblended lines of Fe II and Ti II were used to determine the differential velocities. The resultant radial velocities are listed in Table I and displayed in Fig. 1. Circular spectroscopic elements fitted to the orbits are listed in Table II and shown in Fig. 1.

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by AURA, Inc., under contract to the National Science Foundation.

Equivalent widths and rotational velocities of both components have been measured from unblended profiles on 19 blue spectrograms. Profiles of the sharp-lined star 68 Tau were synthetically broadened with the rotational broadening function of Gray (1976) for a variety of values of $v \sin i$. These synthetically broadened profiles were then matched to the observed profiles of the binary star components to yield rotational velocities of 52 ± 3 km s^{-1} for the primary and 40 ± 3 km s^{-1} for the secondary. These values do not differ significantly from the synchronous values of 51.1 ± 0.7 km s^{-1} for the primary and 39.4 ± 1.6 km s^{-1} for the secondary as derived from the absolute dimensions (Sec. III).

Because the two components of AY Cam are similar in spectral type, the ratio of equivalent widths of spectral lines should closely match the light ratio of the adopted photometric orbit at the wavelength of the lines. This provides a powerful constraint on the photometric elements. Equivalent widths of the 4508.3 Fe II, 4515.4 Fe II, and 4549.5 Ti II–Fe II lines were measured on all spectrograms. The mean ratio of measured equivalent widths, 0.61 ± 0.04, compares favorably with the value from the photometric solution 0.603 ± 0.008, but it should be pointed out that the line ratio was measured in the B band and the photometric solution was in the V band.

TABLE I. Radial velocities of AY Cam.

JD − 2440000	Orbital[a] phase	Primary RV (km s^{-1})	Primary O − C	Secondary RV (km s^{-1})	Secondary O − C
4362.618	0.807	107.4	4.2	− 113.0	3.5
4366.638	0.277	− 106.0	1.4	124.4	0.8
4571.983	0.358	− 82.4	2.2	93.9	− 3.7
4626.832	0.413	− 62.3	− 5.9	57.4	− 8.1
4627.888	0.799	101.2	− 3.8	− 122.9	− 4.4
4678.659	0.363	− 82.7	− 0.1	95.6	0.2
4678.728	0.388	− 69.7	0.7	82.2	0.8
4974.885	0.673	99.1	1.5	− 108.9	1.2
4976.887	0.405	− 64.9	− 4.1	67.8	− 2.7
4978.871	0.131	− 77.0	2.6	90.2	− 1.7
5100.640	0.654	91.6	0.9	...	...
5102.627	0.380	− 78.4	− 4.2	90.3	4.5
5269.001	0.213	− 104.5	1.4	122.1	0.2
5271.987	0.304	− 105.0	− 2.4	124.9	6.7
5273.018	0.681	99.7	− 0.3	− 109.8	3.1
5275.023	0.414	− 59.2	− 3.7	55.0	− 9.5
5337.859	0.389	− 69.5	0.0	82.4	2.0
5476.645	0.134	− 77.5	3.8	101.3	7.4
5685.056	0.337	− 87.3	5.7	106.9	− 0.3

[a] $C = 2.7349658n + 2439385.5084$.

 0004-6256/87/061670-03$00.90

PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY KP AQUILAE

CLAUD H. LACY[a)]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701
Received 9 June 1987; revised 10 August 1987

ABSTRACT

Radial velocities and line profiles of KP Aql (F0 + F0) are analyzed, and the results are combined with those of the light-curve analysis of Ibanoglu and Gulmen to yield absolute properties of this main-sequence binary. Comparison of the properties of these stars with theoretical models of stellar evolution indicates an age of approximately 8×10^8 yr.

I. INTRODUCTION

KP Aql is an eclipsing binary with deep, nearly equal primary and secondary eclipses. The near equality of the eclipses led to confusion as to whether the system was an Algol type eclipsing binary with nearly equal components and a period near 3.367 type days or an Algol-like eclipsing binary with deep primary eclipses and a period near 1.684 days. This confusion was not resolved until the photoelectric work of Ibanoglu and Gulmen (1974), who give references to the early work on this binary. They found the binary consisted of nearly equal components. Spectroscopic observations of the binary were reported by Cailliatte (1951). The spectral types were found to be A in primary minimum and K in maximum light, clearly not consistent with nearly equal components. Lacy and Evans (1979) found from high-dispersion spectrograms that the system consists of nearly equal early F stars.

II. SPECTROSCOPIC OBSERVATIONS

High-resolution spectrograms of KP Aql were obtained in the interval 1978–1985. The coudé Reticon and Digicon detectors of the 2.7 m reflector at McDonald Observatory (described by Vogt, Tull, and Kelton 1978) were used until August 1983; afterwards, RCA and Texas Instruments CCD detectors were used with the coudé spectrograph of the 2.1 m reflector at Kitt Peak National Observatory. Spectrograms typically covered 100 Å centered at 4505 Å at resolutions of 0.3 to 0.5 Å. Two spectrograms were centered at 6420 Å. Spectrograms of iron or thorium-argon hollow-cathode lamps were used as comparison sources near the times of observation, and the standard stars *o* Peg (A1 V), *o* Aql (F8 V) and 5 Ser (F8 IV–V) were observed for use in the cross-correlation analysis employed to obtain radial velocities. The radial-velocity reductions follow the precepts of Lacy (1981,1982). We have adopted a radial velocity of $+7.5$ km s^{-1} for *o* Peg (Fekel 1981), $+0.1$ km s^{-1} for *o* Aql, and $+53.5$ km s^{-1} for 5 Ser (Pearce 1955). *o* Aql and 5 Ser were used as standards for the two observations of KP Aql in the 6420 Å region, and *o* Peg was used as the standard for the bulk of the observations in the 4505 Å region. *o* Peg is not an "official" standard star, but appears to have constant velocity. Unblended lines of Ca I, Fe I, Fe II, and Ti II were used to determine the differential velocities. The resulting heliocentric Julian dates and radial velocities are listed in Table I and displayed in Fig. 1. The period and epoch of Ibanoglu and Gulmen (1974) has been used for the phases. A zero-eccentricity orbit was adopted based on the photometric results of Ibanoglu and Gulmen (1974). Circular spectroscopic elements fitted to the orbits are listed in Table II and shown in Fig. 1.

Equivalent widths and rotational velocities of both components have been measured from unblended profiles on 11 blue spectrograms. Profiles of the sharp-lined star 68 Tau were synthetically broadened with the rotational broadening function of Gray (1976) for a variety of values of $v \sin i$. These synthetically broadened profiles were then matched to the observed profiles of the binary star components to yield rotational velocities of 28 ± 2 km s^{-1} for the primary and 29 ± 2 km s^{-1} for the secondary. These values do not differ significantly from the synchronous velocity of 27.5 ± 1 km s^{-1} derived from the mean absolute dimensions (Sec. III).

Because the photometric results show that the two components of KP Aql are almost equal in size and brightness, the ratio of equivalent widths of spectral lines should closely match the light ratio of the adopted photometric orbit at the wavelength of the lines. This provides a powerful constraint on the photometric elements. Equivalent widths of the 4549 Ti II–Fe II blend were measured on all spectrograms in the blue. The mean ratio of measured equivalent widths, 0.94 $\pm$ 0.04, compares favorably with the value from the photometric solution of Ibanoglu and Gulmen (1974), 0.95.

III. ABSOLUTE PROPERTIES

The photometric solution of Ibanoglu and Gulmen (1974) shows that the two components are essentially equal in size and brightness, but indicates that primary eclipse is an

TABLE I. Radial velocities of KP Aql.

JD − 2440000	Orbital[a] phase	Primary RV (km s^{-1})	Primary O − C	Secondary RV (km s^{-1})	Secondary O − C
3741.667	0.377	− 113.5	2.2	31.3	0.5
3742.733	0.693	51.8	− 3.0	− 139.0	3.7
4040.828	0.215	− 148.2	− 3.7	56.7	− 3.4
4042.772	0.792	55.8	− 1.9	− 146.0	− 0.3
4096.651	0.792	54.0	− 3.7	− 146.7	− 1.0
4175.631	0.246	− 146.6	0.4	61.9	− 0.8
4178.593	0.125	− 117.1	− 0.4	35.9	4.1
4449.789	0.659	49.0	4.2	− 133.2	− 0.6
5187.841	0.830	53.3	4.8	− 137.2	− 0.8
5274.546	0.577	7.0	1.2	− 94.6	− 1.7
5566.752	0.350	− 125.4	1.6	43.3	1.0
5567.727	0.640	38.2	0.9	− 124.3	0.7
6248.844	0.903	14.4	− 2.4	− 105.5	− 1.4

[a] Computed dates of primary eclipse $C = 2440396.4912 + 3.36747959n$.

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by AURA, Inc., under contract to the National Science Foundation.

 0004-6256/87/061673-02$00.90

THE SURFACE-BRIGHTNESS ANOMALY IN ECLIPSING BINARIES

CLAUD H. LACY
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

MARIAN L. FRUEH AND ANDREW E. TURNER[a]
McDonald Observatory, University of Texas, Austin, Texas 78712
Received 26 May 1987; revised 29 June 1987

ABSTRACT

Surface-brightness ratios of the eclipsing binaries V477 Cyg, TX Her, CM Lac, RR Lyn, and EE Peg are determined from new *V*, *R* light curves. Along with the previously determined values for IQ Per, these ratios are used as probes for the $B-V$ and $V-R$ surface-brightness calibrations in a region of low data density. An anomaly is found in the sense that if the primaries are assumed to lie on the calibration curve, then the secondaries are less bright than expected, or if the secondaries are assumed to lie on the calibration curve, then the primaries are brighter than expected. It does not seem possible at this time to find an unambiguous interpretation of this anomaly.

I. INTRODUCTION

One of the fundamental quantities obtained in solutions of eclipsing binary light curves is J_c/J_h, the ratio of surface brightnesses of the cooler and hotter components. From well-observed light curves, this quantity can be determined to an accuracy of better than 1%. The surface brightnesses themselves are not determined in this way unless the distance to the system is known. Surface brightnesses of individual stars have been determined by interferometry, lunar occultations, and other methods that measure stellar angular diameters. A summary of surface-brightness determinations is given by Barnes, Evans, and Moffett (1978). They show that there is a strong correlation between the stellar surface brightness and the color index $V-R$ over the entire range of stellar types. They also find a strong correlation with the color index $B-V$ but only over a limited range of stellar types, from spectral type O to K. Popper (1980) also lists a different calibration of surface brightness versus color indices and spectral types. Both these calibrations are based on very few observed points over the range from A7 to K2. Barnes, Evans, and Moffett (1978) draw a noticeable "bump" in this region to fit the few available data.

The present study was inspired by the idea that one could probe the region of the bump by using main-sequence eclipsing binaries with primaries outside the bump and secondaries in the bump region. If the surface brightnesses of the primaries were assumed to fall on the calibration curve, then the secondaries' surface brightnesses could be computed from the known ratio J_c/J_h, thus providing additional information on the behavior of the surface-brightness relation in the bump region.

In order to carry out this study, a list of suitable candidate stars was drawn up. For all of the candidates, $B-V$ indices of the components were known, but $V-R$ indices of the components were not known. An observational program was therefore begun at McDonald Observatory to obtain light curves in *V* and *R* for use in determining the photometric elements and component colors. The results of this program are discussed below.

II. OBSERVATIONS AND ANALYSIS

Photoelectric observations of program stars were carried out with the 30 and 36 in. reflectors at McDonald Observatory. An EMI 9658 R photomultiplier and the set of glass filters recommended by Fernie (1974) was used. New *VR* light curves of the program stars were obtained during 1979–1982. Differential observations of the program stars were made with respect to the nearby comparison stars listed in Table I. Typically, 10 s observations through a 16 arcsec diaphragm were used. The observations were corrected for the measured deadtime of the photometer (60 ns) and for differential extinction effects. Extinction coefficients were determined from observations of standard stars. The resultant extinction-corrected instrumental magnitudes were transformed to the *VR* system with transformation equations determined from observations of a number of the stars observed by Johnson *et al.* (1966). The *UBVRI* photometric system has no "official" standard stars for *R* and *I* magnitudes, so a wide selection of the stars in Johnson *et al.* (1966) must be used in order to minimize the effects of the 0.01–0.02 mag observational errors present in the *R* magnitudes listed by Johnson *et al.* (1966). Details of the transformations are discussed by Lacy and Frueh (1985). The resultant light curves are shown in Figs. 1–5. The light curve of IQ Per has been analyzed previously by Lacy and Frueh (1985).

The adopted ephemerides are shown in Table II. That of V477 Cyg is based on the period of O'Connell (1970) and our observed dates of primary minima: JD 2445106.9368 ± 0.0002 and 2445139.7944 ± 0.0002. Sources are listed for the other ephemerides.

The light curves have been analyzed with the Nelson-Davis-Etzel program EBOP (Etzel 1981; Popper and Etzel 1981). The resulting theoretical curves are shown as solid lines in Figs. 1–5. The photometric elements are listed in Tables III–VII, where J_s/J_p is the ratio of central surface brightnesses of the secondary and primary, k is the ratio of radii, r_p, r_s are the relative radii of the primary and secondary, i is the orbital inclination, L_p is the luminosity of the primary, and σ is the standard error of one observation. All observations were assumed to have unit weight. In many cases, it was necessary to assume that some or all of the geometrical elements had values given by previous investiga-

[a] Now at Orbit Dynamics Section, Ford Aerospace and Communications Corporation, Palo Alto, California 94303.

 0004-6256/87/041035-08$00.90

THE ASTRONOMICAL JOURNAL VOLUME 94, NUMBER 3 SEPTEMBER 1987

PROPERTIES OF THE MAIN-SEQUENCE ECLIPSING BINARY V442 CYGNI

CLAUD H. LACY[a)]
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

MARIAN L. FRUEH
McDonald Observatory, University of Texas, Austin, Texas 78712

Received 4 May 1987; revised 2 June 1987

ABSTRACT

Radial velocities, line profiles, and *V*, *R* photometry of V442 Cyg (F1 + F2) are analyzed to obtain the fundamental properties of this detached main-sequence binary. The minima in the light curve (0.56 and 0.49 mag) are deep enough for definitive photometric orbits, despite the relatively small number of observations within eclipses. Comparison of the properties of these stars with theoretical models of stellar evolution shows a good match at an age of 1.3×10^9 yr and a composition of $x = 0.7$, $z = 0.03$. The primary is very near the end of its core-hydrogen-burning lifetime.

I. INTRODUCTION

There are only a few references to V442 Cyg in the literature. It was discovered to be an eclipsing binary from photographic work by Wachmann (1939), later elaborated by Loreta (1940). The ephemeris quoted in the third edition of the *General Catalog of Variable Stars* (JD 2428745.249 + 1.1929738 E) is due to Ikauniex (1946), who correctly guessed "It is probable that the above given period is equal to one half of the true one." This guess was probably based on the appearance of the photographic light curve, which showed a deep, narrow primary eclipse and no sign of a secondary eclipse. This can happen in systems with nearly equal primary and secondary eclipses and circular orbits when half the true orbital period is assumed. The correctness of Ikauniex's guess was verified in 1978 when CHL began high-resolution spectroscopy of this system and found strong double lines in the spectra. First results were reported by Lacy and Evans (1979). Photometric work on this binary was begun by CHL in 1979 and continued by MLF. Analysis of the photometry is discussed in Sec. II and that of the spectroscopy in Sec. III. Absolute properties of this binary and a comparison with stellar evolution theory are presented in Sec. IV.

II. PHOTOMETRY

Photometry of the binary in an instrumental *v*, *r* system was carried out with the 36 in. and 30 in. reflectors at McDonald Observatory in the years 1979–1982. The procedures, including reduction to the Johnson *V*, *R* system, are described by Lacy and Frueh (1985) and Popper, Lacy, Frueh, and Turner (1986). Properties of the binary and comparison stars are listed in Table I. No sign of variability was seen between the comparison and check stars. A summary of the differential observations is contained in Table II and the light and color curves are shown in Fig. 1. Secondary eclipse is covered by photometry on three nights, but primary eclipse is covered well only once.

A revised ephemeris has been determined from our date of primary minimum (JD 2444919.561 $\pm$ 0.002) and the zero epoch of Ikauniex (1946): Primary minimum = JD 2444919.561 + 2.3859437 E. The new period is estimated to be uncertain by 3×10^{-7} days based on a guess as to the uncertainty of the earlier epoch (± 0.002 days).

The Nelson-Davis-Etzel program (Etzel 1981; Popper and Etzel 1981) has been employed exclusively in the analysis of the differential photometry. It has been shown that this program yields accurate solutions for the photometric elements in cases such as this one when the separation of the stars is large compared to their radii and the oblateness is small.

Equal weights were used for each observation. Limb-darkening coefficients for the *V* and *R* bands (0.60 and 0.47) are taken from Al Naimiy (1978). The observations are not adequate for the inclusion of limb darkening as an adjustable parameter in the analysis. The spectroscopic mass ratio, 0.902, is employed, as are gravity-brightening coefficients of 0.34 in *V* and 0.28 in *R*, one-third the blackbody radiative values.

Preliminary fits were made to the data in order to fix the values of the adjustment of the phase of primary minimum and the value of $e \cos \omega$. It was found that the value of $e \cos \omega$ (-0.00006 ± 0.00013) is not significantly different from zero. Likewise, the value of $e \sin \omega$ (-0.00002 ± 0.0030) was found to be not significantly different from zero, and both values were fixed at zero for the remainder of the analysis.

[a)] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by AURA, Inc., under contract to the National Science Foundation.

TABLE I. Properties of the variable and comparison stars.

Star	Designation	Spec[a]	V	$V-R$	Nights[b]
V442 Cyg	HD 334426	F4	9.72 ± 0.01	0.40 ± 0.01	5
Comparison	HD 334431	F5	9.66 ± 0.01	0.40 ± 0.01	5
Check	HD 334448	F6	9.72 ± 0.01	0.42 ± 0.01	5

[a] Spectral class listed in the HD catalog.
[b] Star compared directly with *V*, *R* "standards."

 0004-6256/87/030712-11$00.90

THE ASTRONOMICAL JOURNAL VOLUME 91, NUMBER 2 FEBRUARY 1986

PROPERTIES OF MAIN-SEQUENCE ECLIPSING BINARIES: INTO THE G STARS WITH HS AURIGAE, FL LYRAE, AND EW ORIONIS

DANIEL M. POPPER
Department of Astronomy, University of California, Los Angeles, California 90024

CLAUD H. LACY
Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

MARIAN L. FRUEH AND ANDREW E. TURNER[a)]
McDonald Observatory, University of Texas, Austin, Texas 78712
Received 9 September 1985

ABSTRACT

Radial velocities and V, R photometry of HS Aur (G8 + K0), FL Lyr (F8 + G8), and EW Ori (G0 + G5) are analyzed to obtain the fundamental properties of the components of these detached binaries. They are the first main-sequence eclipsing binaries with G-type components having properties known about as well as those of numerous binaries of earlier types. The minima in the light curves of HS Aur (0.7 and 0.55 mag) and EW Ori (0.75 and 0.6 mag) are deep enough for definitive photometric orbits despite the relatively small number of observations within eclipses. The minima of FL Lyr are less deep (0.5, 0.25 mag), so that the luminosity ratio obtained from spectra is required in order to solve its light curve. Comparison of the properties of these stars with predictions from evolutionary models is inconclusive because of differences between different sets of models. Having a mass ratio significantly different from unity (0.79), FL Lyr is of particular interest, both for comparison with interior models and for its potential contribution to the flux and temperature scales. The slope of the mass-luminosity relation, $\Delta \log L / \Delta \log m$, for FL Lyr (and for α Cen) is close to the value, 4.8, predicted by interior models for masses in the solar range, and is considerably larger than values near 3.9 usually quoted.

I. INTRODUCTION

While there are numerous F-type main-sequence eclipsing binary stars with well-established properties (e.g., Popper 1980), main-sequence G and K stars are notable by their near absence. One may group main-sequence G-type eclipsing binaries into three categories according to their periods. The group with shortest periods, less than 0.5 days, comprises the W UMa systems, nearly all in contact configurations, so that the properties of the components are strongly influenced by their mutual interactions. There is not complete agreement on the previous history of these systems. Next, there is a small group of double-lined, detached systems with periods between 0.5 and 1.0 days, including UV Leo ($P = 0^{d}60$), CG Cyg ($P = 0^{d}63$) and UV Psc ($P = 0^{d}86$). Rotational broadening of the lines in the crowded spectra of these systems, as well as instabilities in the light curves, presumably a consequence, in part, of spottedness of their surfaces, makes definitive determination of their properties difficult. It is to members of the third group, with periods significantly longer than one day, and having no important spectroscopic or photometric anomalies, that we address ourselves.

Obvious selection effects are responsible for the sharp falloff in numbers from the F-type binaries. Surveys to a given magnitude limit include fewer G- and K-type main-sequence stars than F-type stars because of their intrinsic faintness, which more than compensates for their increased numbers per volume of space. In addition, the smaller sizes of stars of the later types decrease the chances of eclipses for a given linear separation. Indeed, in two of the systems in the present study, HS Aur and EW Ori, the components have smaller relative radii than the primary component of any system listed in the compilations of Koch, Plavec, and Wood (1970) and of Cester *et al.* (1979) except for the white dwarf in V471 Tau. Another selection effect has been against investigation of systems with large-magnitude differences between the components. The use of spectrometers with low-noise, solid-state detectors allows this selection effect to be less restrictive than in the past.

A survey of the properties of G-type eclipsing binaries with periods longer than one day shows that the great majority of them have at least one component evolved outside the main-sequence band. These systems, generally showing RS CVn characteristics, are not our concern here.

In this paper we analyze our spectrographic and photometric observations of three detached main-sequence systems with one or both components of type G: HS Aur, FL Lyr, and EW Ori. Information on these systems is given in Table I. The magnitudes and color indices at maximum light are derived from the McDonald photometry, while the spectral types of the more luminous components are based on 16 Å mm^{-1} Lick spectrograms of the photographic region. These types cannot be in error by more than one subclass. Magnitudes and color indices on the Strömgren system are available for FL Lyr and EW Ori outside eclipses. For FL Lyr (Hilditch and Hill 1975), the values of V and $b-y$ are 9.30 and +0.363. The latter value corresponds to $V-R = +0.48$. Unpublished photometry of EW Ori by R. W. Hilditch and by J. Andersen gives $V = 9.91$ and 9.93, respectively, and $b-y = +0.386$ and +0.395. The color indices correspond to $V-R = +0.50$ and +0.52. There are no inconsistencies.

The H and K lines of Ca II are not seen in emission in any of our spectrograms of the three binaries. It was this lack of

[a)] Now at Systems Engineering Department, Ford Aerospace and Communications Corp., Palo Alto, California 94303.

THE ASTROPHYSICAL JOURNAL, 295: 569–579, 1985 August 15

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARIES. V. IQ PERSEI

CLAUD H. LACY
Department of Physics, University of Arkansas, Fayetteville

AND

MARIAN L. FRUEH
McDonald Observatory, University of Texas, Austin
Received 1984 November 9; accepted 1985 February 25

ABSTRACT

New photometric and spectroscopic observations of the 1.7 day eclipsing binary IQ Persei (B8 + A6) have been analyzed to yield very accurate fundamental properties of the system. Reticon spectroscopic observations obtained at McDonald Observatory were used to determine accurate radial velocities of both stars in this slightly eccentric large light-ratio binary. A new set of *VR* light curves obtained at McDonald Obervatory were analyzed by synthesis techniques, and previously published *UBV* light curves were reanalyzed to yield accurate photometric orbits. Orbital parameters derived from both sets of photometric observations are in excellent agreement. The absolute dimensions, masses, luminosities, and apsidal motion period (140 yr) derived from these observations agree well with the predictions of theoretical stellar evolution models. The A6 secondary is still very close to the zero-age main sequence. The B8 primary is about one-third of the way through its main-sequence evolution.

Subject headings: stars: eclipsing binaries — stars: individual

I. INTRODUCTION

IQ Persei (BD +47°920 = HD 24909) was discovered to be variable star by Hoffmeister (1949). It is a fairly bright ($V = 7.7$ mag) star outside eclipse and is the brighter member of a visual binary with BD +47°921 ($V = 9.3$ mag) at 39″.3 separation. Hall, Gertken, and Burke (1970) obtained complete *UBV* light curves of IQ Per and found an orbital period of 1.7435673 days. They found that secondary eclipse was a total occultation and was displaced because of a slightly eccentric orbit. They derived a photometric orbit by using the methods of Russell and Merrill (1952) and estimated an apsidal motion period of ~70 yr based on the theory of Schwarzschild (1958). They estimated the spectral classes of the components as B7 + A2 reddened by $E(B-V) = 0.15$ mag based on their color indices. Meisel (1968) had classified IQ Per as B8 Vp: and estimated the rotational velocity as 100 km s^{-1}. The visual companion appears to be physically associated with the eclipsing binary at a separation of at least 11000 AU.

Young (1975) was the first to attempt to determine a spectroscopic orbit for IQ Per. Eleven Cassegrain and coudé plates were obtained at dispersions of 39.5 and 13.4 Å mm^{-1}, respectively. On five of these plates, lines of the secondary were barely detectable at Mg II λ4481 and Ca II λ3933 only. Radial velocities were measured and orbits were fitted to the measurements. Residuals from the primary star's orbit had a very large standard error of 13 km s^{-1}, and for the secondary 15 km s^{-1}. Young stated that "the quoted results for the secondary star must be taken as no better than provisional." Our conclusion below is that Young's estimate of the radial velocity semi-amplitude (K_2) was ~14% too small.

Lacy began the present study in 1978 with the coudé Reticon spectrometer of the 2.7 m reflector at McDonald Observatory. This detector has been described by Vogt, Tull, and Kelton (1978). Since Young had been able to detect lines of the secondary with photographic techniques, IQ Per seemed an easy target for a high signal-to-noise ratio detector like the Reticon, and this belief was quickly confirmed.

For two reasons, IQ Per was also included in a program of *VR* differential photometry carried out by M. L. F. First, we wished to determine how well modern photometric orbits of this system determined by independent investigators would agree. This is important as a check on the accuracy of the error estimators of the analytical methods. Second, we wished to determine accurately the *UBVR* color indices of the components of IQ Per and the difference in visual surface brightness in order to check the accuracy of visual surface brightness versus color calibrations. The secondary star was expected to be in a region of low data density in these calibrations, while the primary was in a region of high data density. A differential comparison of the surface brightness scales would then be possible.

II. SPECTROSCOPIC OBSERVATIONS AND ANALYSIS

Spectroscopic observations of IQ Per were obtained by Lacy from 1978 to 1983 with a 1024 element Reticon photodiode array. The observations were centered at 4500 Å and have a width of ~100 Å. The spectrometer slit typically projected onto five diodes, or 0.55 Å, on the detector array at a dispersion of 4.4 Å mm^{-1}. The signal-to-noise ratio was typically 300 to 1. Observations of a hollow cathode iron-neon source were made after each observation of the variable star, and observations of the radial velocity reference stars π Cet (B7 V) and 68 Tau (A2 IV) were obtained to establish the radial velocity zero point and to serve as templates in the cross-correlation analysis employed to obtain radial velocities. The radial velocity reductions followed the precepts of Lacy (1981, 1982, 1984).

We have adopted a radial velocity of +15.3 km s^{-1} for π Cet based on Wilson's (1953) value of +15.4 km s^{-1} and Fekel and Tomkin's (1982) value of +15.2 km s^{-1}. Because 68 Tau has been suspected of being a low-amplitude radial velocity vari-

THE ABSOLUTE DIMENSIONS AND MASSES OF IQ PERSEI

Claud H. Lacy

Department of Physics, University of Arkansas

ABSTRACT. High signal-to-noise ratio spectrometric observations of the large light-ratio eclipsing binary IQ Per (B7 + A2) have been obtained with the coudé Reticon spectrograph of the 2.7 m reflector at McDonald Observatory. Absorption lines of the secondary are seen at the 4481 Å MgII line and the 4549 Å TiII + FeII blend. Radial velocities of both components have been measured by cross-correlation techniques and spectroscopic orbits have been computed. The fitted orbits have an eccentricity (0.075 $\pm$ 0.007) that is consistent with the photometric orbit of Hall, Gertken and Burke (1970). Young's (1975) "provisional" estimate of K_2 is about 14% too small. Absolute dimensions and masses have been computed from Hall et al.'s (1970) photometric orbit and the new spectroscopic orbit. Additionally, V-R photometric observations obtained by M. Frueh at McDonald Obs. have been analysed by Popper with light curve synthesis techniques (WINK and EBOP). The relative radii of the new photometric orbits differ by less than 2% from the previous orbits, and the other orbital elements also show excellent agreement. The absolute dimensions and masses are (3.51 ± 0.04 $\mathfrak{M}_\odot$, 2.46 ± 0.04 $R_\odot$) for the primary and (1.73 ± 0.02 $\mathfrak{M}_\odot$, 1.50 ± 0.03 $R_\odot$) for the secondary. Both stars are near the zero-age main sequence. The value of ω has changed significantly between the epoch of Hall, Gertken, and Burke's (1970) observations and my own due to apsidal motion. The apsidal motion period is estimated to be in the interval $90 \leq \tau \leq 180$ yr.

REFERENCES

Hall, D. S., Gertken, R. H. and Burke, E. W. Jr. 1970, Publ. Astron. Soc. Pacific, 82, 1077.

Young, A. 1975, Publ. Astron. Soc. Pacific, 87, 717.

D. S. Hayes et al. (eds.), Calibration of Fundamental Stellar Quantities, 389.

COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS
Number 2685

Konkoly Observatory
Budapest
18 March 1985

HU ISSN 0374 - 0676

ADDITIONAL DOUBLE-LINED ECLIPSING
BINARIES OBSERVED WITH CCD DETECTORS

High resolution coudé spectrometric observations have been made during the past six years as part of a continuing program to determine accurate absolute properties of eclipsing binary stars. Previous progress reports (Lacy and Evans 1979, Lacy 1984) have discussed 36 of the stars in this program. Observations of an additional 9 eclipsing binaries are discussed here. These observations were obtained with the 2.1 m reflector at Kitt Peak National Observatory (NOAO) and the coudé CCD spectrometer. Typically 100-200 Å in the blue (4500 Å) or red (6400 Å) were observed at a resolution of 0.3-0.4 Å. The individual binaries are discussed below:

Double-Lined Eclipsing Binaries

Name	Mag.	Spec.	P(days)	Name	Mag.	Spec.	P(days)
AD Boo	9.8	G0	2.06	V643 Ori	10.6	G-K	52.4
EY Cep	10.1	A5	5.52	V526 Sgr	9.7	A0	1.92
RT CrB	10.2	G0	5.12	FV Sco	7.9	early B	5.73
V885 Cyg	9.9	B9	1.69	BP Vul	10.1	A7	1.94
GM Hya	11.0	G2	12.19				

The listed data is generally as stated in the General Catalogue of Variable Stars (GCVS), except as noted below. Of the systems listed, only AB Boo and V526 Sgr have adequate multicolor photoelectric light curves. Photoelectric observers are encouraged to observe the other binaries in at least two well-calibrated colors in order to make possible the most accurate determinations of absolute stellar properties.

AD Boo: This star has moderately narrow double lines in the red. The line strength ratio is about 2:1. My spectra are consistent with the primary's G0 spectral type from the GCVS. Recently Sheng, Xian, and Tong (1983) obtained a good B,V lightcurve and found the period to be twice its older value. This is an important solar-type system.

EY Cep: Narrow double lines are seen in the blue with a line strength ratio of about 3:2. The late-A appearance of my spectra is consistent with the GCVS spectral type of A5.

CORRECTION TO I.B.V.S. No. 2489

"In the discussion of FT Ori I should have noted that J. Tomkin was, in fact, the first to observe line doubling in that system. I am collaborating with him in the analysis of our spectroscopic material."

C.H. LACY

THE ASTROPHYSICAL JOURNAL, 281: 268–275, 1984 June 1

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARIES. IV. EE PEGASI IS A TRIPLE STAR

CLAUD H. LACY
Department of Physics, University of Arkansas

AND

DANIEL M. POPPER
Department of Astronomy, University of California, Los Angeles
Received 1983 September 19; accepted 1983 December 8

ABSTRACT

A previously unknown faint companion with an orbital period of about 4 years has been discovered orbiting the 2.6 day eclipsing binary in the EE Pegasi system. The third star was discovered by its effects on the radial velocities and times of primary eclipse of the eclipsing pair. Spectroscopic observations of very high quality were obtained with the Reticon spectrometer of the 2.7 m reflecting telescope at McDonald Observatory. Radial velocities of high precision have been obtained for both stars of the eclipsing pair in this well-known, large light ratio, eclipsing binary system. Spectroscopic orbits derived from a three-body fit to the radial velocities have been combined with photometric orbits from photoelectric light curves to find very accurate masses and radii for components of the eclipsing binary: ($2.15 \pm 0.02\ M_{\odot}$, $2.09 \pm 0.03\ R_{\odot}$) for the A3m primary and ($1.33 \pm 0.01\ M_{\odot}$, $1.31 \pm 0.01\ R_{\odot}$) for the F5 secondary. The uncertainties are conservative standard errors. Theoretical evolutionary tracks indicate an age of about 3×10^8 years based on the observed masses, radii, and luminosities. The F5 secondary of the eclipsing pair is still very close to the zero-age main sequence. The A3m primary is about halfway through its main sequence lifetime. Both are rotating synchronously with the orbital period. The third star is probably a low-mass main-sequence star of spectral type K or M.

Subject headings: stars: eclipsing binaries — stars: evolution — stars: individual — stars: rotation

I. INTRODUCTION

EE Pegasi (HD 206155, SAO 126971, +08°4714) was discovered to be an eclipsing binary by Hoffmeister (1935). In the half-century since its discovery, EE Peg has been studied by many photometric and spectroscopic investigators, and our knowledge of its properties has gradually improved. From visual observations, Gomi (1940) found that the original estimate of the orbital period was twice the true value. Wellmann (1953) obtained both visual brightness estimates and photographic radial velocities of the primary and derived the first orbits. Bakos (1965) improved the orbits by obtaining additional radial velocities and the first photoelectric photometry of this system. Catalano and Rodonó (1970) published improved photoelectric light curves and a better photometric orbit and ephemeris. An excellent blue light curve obtained by Ebbighausen (1971) has been reanalyzed by Linnell (1973), who also gave an improved ephemeris, and by Mezzetti *et al.* (1980). Popper (1981) was able to measure radial velocities from the D lines of both components on 11 Å mm^{-1} spectrograms photographed on high signal-to-noise ratio plates at the Lick Observatory between 1973 and 1980. On the basis of these velocities and his discussion of Linnell's analysis of the light curve, the properties of the components were derived. These properties were included in the review of stellar masses (Popper 1980), although it was realized that small systematic effects might be present in the velocities of the secondary component because of possible blending in the D lines.

The coudé Reticon spectrometer of the 2.7 m telescope at McDonald Observatory was brought to bear on EE Peg in 1979 in the hope that weak lines of the secondary could be measured in the 6400 Å region, as had been possible for the similar large light ratio system YZ Cas (Lacy 1981). Lines of the secondary were easily found in spectra with a signal-to-noise ratio of about 300. Preliminary results were announced by Lacy and Evans (1979), Fekel, Lacy, and Tomkin (1980), and Lacy (1983). This series of Reticon observations has now been completed, and the data are discussed and analyzed in § II. Because we have found from that analysis that the EE Peg system is in fact a triple star, it is necessary to consider the effect of the light of the third component on the photometric orbits mentioned above. This is done in § III. The results of the new photometric and spectroscopic analyses are combined and interpreted by application of theoretical models in § IV.

II. SPECTROSCOPIC OBSERVATIONS AND ANALYSIS

Spectroscopic observations of EE Peg were obtained by Lacy with the Reticon spectrometer of the 2.7 m telescope at McDonald Observatory from 1979 to 1983. Vogt, Tull, and Kelton (1978) have described this device. The observations were centered at 6420 Å and have a width of about 100 Å. The spectrometer slit projected onto 4 diodes, or 0.44 Å, on the detector array at a dispersion of 4.4 Å mm^{-1}. Observations of a hollow cathode iron-neon source and the standard radial velocity stars *o* Peg and *ι* Psc were also made just before or after EE Peg was observed in order to fix the radial velocity zero point and to provide templates in the cross-correlation analyses employed to obtain radial velocities. The radial velocity reductions followed the precepts of Lacy (1981, 1982). The resultant radial velocities are listed in Table 1. Small portions of two representative observations are shown in Figure 1.

COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS
Number 2489

Konkoly Observatory
Budapest
7 March 1984
HU ISSN 0374 - 0676

NEW DOUBLE-LINED ECLIPSING BINARIES FOUND
WITH RETICON, DIGICON, AND CCD DETECTORS

High resolution coudé spectrometric observations have been made during the past five years as part of a continuing program to determine accurate absolute properties of eclipsing binary stars. A previous progress report (Lacy and Evans 1979) discussed nine of the stars in this program (KP Aql, CW CMa, YZ Cas, V442 Cyg, TX Leo, FL Lyr, EE Peg, V906 Sco, and TX UMa) which were observed with a Reticon detector on the 2.7 m McDonald Observatory reflector. The completed analyses of the observations of CW CMa, YZ Cas, and EE Peg already have been published (Lacy 1982, 1981, and Lacy and Popper 1984). Observations of an additional 27 eclipsing binaries are discussed here. These observations were obtained with the coudé Reticon and Digicon detectors on the 2.7 m reflector at McDonald Observatory and the coudé CCD spectrograph of the 2.1 m reflector at Kitt Peak National Observatory. The binaries have been divided into two groups (double-lined systems and others) and are discussed in detail below:

Double-Lined Eclipsing Binaries

BW Aqr*	IT Cas*	V541 Cyg*	GG Ori*
HS Aur*	MU Cas*	V909 Cyg	IQ Per
BW Boo*	PV Cas	UZ Dra*	YY Sgr*
WW Cam*	V396 Cas*	FS Mon*	V907 Sco*
AY Cam	V459 Cas*	EW Ori*	RW UMa*
SW CMa*	WX Cep	FT Ori	BD +37°4713

Systems with an asterisk (*) either do not have a photoelectric light curve or need to have additional photometric coverage. Photoelectric observers are encouraged to observe these systems in at least two well-calibrated colors in order to make possible the most accurate determinations of absolute stellar properties.

14.03 Combined X-ray, Ultraviolet and Ground-based Observations of the Symbiotic Star AG Draconis at Quiescence, M. H. SLOVAK, U. Wis., C. M. ANDERSON, U. Wis., J. P. CASSINELLI, U. Wis., D. L. LAMBERT, U. Tex.
AG Draconis was observed with the IUE and Einstein satellites before its latest eruption in late 1980. We have combined these data with ground-based optical and infrared observations to derive the quiescent energy distribution from 41 A to 5 microns. We interpret the continuum and emission-line spectrum using a three-component model, consisting of a hot subdwarf primary (T = 191,000 K; L = 192 $L_\odot$) with a cool giant secondary (T = 3800 K; L = 144 $L_\odot$) companion, embedded in a warm, high density circumsystem nebula (T_e = 20,000 K; log n_e = 8 cm^{-3}). We argue that the X-ray flux is thermal emission from the primary and is detectable, unlike most other symbiotics, because of the close proximity (d = 700 pc). and low obscuration (b = +41^o). The inferred parameters of the primary are consistent with those for the central stars of planetary nebulae (CSPN) and indicate that the primary may be in a rapid state of evolution, preceding its descent along a Harmann-Seaton track to become a white dwarf.

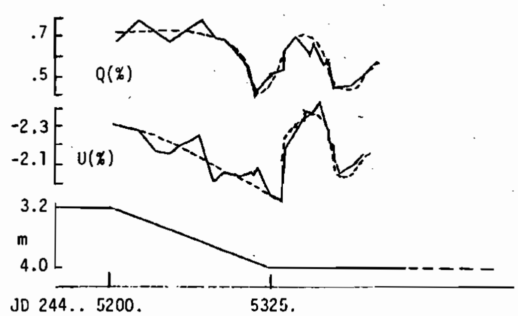
Bull. Am. Astron. Soc., Vol. 15, p.665

14.04 EE Pegasi Is A Triple Star, C. H. LACY, U. Ark. High resolution (0.3 Å) coudé Reticon spectral scans of the eclipsing binary EE Peg have been obtained over the last 4 years using the 2.7 m reflector at McDonald Observatory. Weak lines of the secondary have been detected in the 6400 Å region. Radial velocities of the primary and secondary have been measured using a cross-correlation technique and spectroscopic orbits have been determined. Residuals from these orbits show a low amplitude (4 km/s half-amplitude) variation with a period of about 1450 days. This variation is also shown in Popper's (1981) radial velocities and is interpreted as orbital motion of the center of mass of the eclipsing binary produced by a third orbiting body in the system. Published photoelectric eclipse timings show the light-time effect produced by this orbital motion in observed times of primary minima. Accurate absolute dimensions and masses of the eclipsing components have been computed and limits have been placed on the properties of the third body. This work has been supported in part by joint NSF grants to the University of Arkansas, Claud H. Lacy, Principal Investigator, and to the University of Texas, David S. Evans, Principal Investigator.

14.05 Composite Photometry of Close Visual Binaries, - R.L. WALKER, U.S.N.O. Flagstaff Station. -- Composite UBV photometry of 301 close visual binaries has been obtained. To determine the position of these systems on the two-color diagram theoretical curves have been computed using a range of magnitude differences and color combinations. Most of the binaries lie on these theoretical curves, but positions of some deviate by an amount significant enough to warrant further attention.

14.06 Variable Polarization in the Eclipse of Epsilon Aurigae. G.D. HENSON, J.C. KEMP, and D.J. KRAUS, Physics Dept., Univ. of Oregon - Variable polarization in the U, B, and V bands has been observed during the recent ingress into eclipse and throughout the first months of totality. A slow variation with an amplitude of 0.3% is seen over the course of ingress. An extraordinarily rapid transition of 0.3% occurred in 24 hours during 28-30 December 1983, presumably associated with second contact. A sine wave-like variation of 0.2 - 0.3% on a time scale of 60-80 days appears to continue during totality (the flat bottom portion of the eclipse). There is no indication of a very significant color dependence, although there are some differences between U, B, and V. Our observations will continue through and beyond eclipse.

Below are shown the average UBV polarization curves in terms of normalized equatoral Stokes parameters; and the schematic light curve.



14.07 **Ultraviolet Emission Line Variability in Two Active F Star Binaries: σ Cor Bor and ω Dra, R.A. STERN, Lockheed Palo Alto Research Laboratory. The two spectroscopic binaries σ Cor Bor (P=1.1) and ω Dra (P=5.3) have been repeatedly observed over a 5-day interval with the International Ultraviolet Explorer. Low dispersion short wavelength (1150-2000Å) and high dispersion long wavelength (2000-3200Å) spectra were obtained for each observation. σ Cor Bor shows clear variability (~ 50%) in the C IV λ1549 line and probable variability in several other chromospheric and transition region lines. In contrast, the less active ω Dra system shows little or no UV line variability. In both binaries, Mg II h and k reversals are present, but vary little in total flux. There is evidence, however, for changes in the h and k line profiles of σ Cor Bor which correlate with orbital velocity, suggesting that both stars in the system have active chromospheres. The above results will be discussed in light of previous X-ray detections of these and other active cool star binaries. This work was supported by NASA Contract NAS7-100 and the Lockheed Independent Research Program.**

Lowell Observatory Bulletin (ISSN 0024-7057), no. 167, 1983, p. 108-112; Discussion, p. 113.

YZ CAS ± 0.5%

Claud H. Lacy
University of Arkansas at Fayetteville

I will discuss one of the results of a continuing program to determine accurate masses and radii of stars in eclipsing binaries. This program actually began in 1976 with my work on the faint M-dwarf system CM Dra (Lacy 1977). By faint I mean $B = 14^m.5$. I needed high-dispersion spectra to get radial velocities, and an intensified solid state array detector called the Digicon, which had recently been installed on the coude spectrometer of the 2.7m reflector at McDonald Observatory, turned out to be the answer. 30 minute integrations were sufficient to get accurate radial velocities from the Hγ emission lines. The Digicon is very good at getting crumby spectra of faint objects fast. By crumby, I mean signal-to-noise ratio of less than 100.

My Reticon, solid state array studies began in 1978 in collaboration with David Evans. Regular observations of YZ Cas and about two dozen other systems have been made since then on the 2.7m and 2.1m reflectors at McDonald Observatory. The Reticon is a high signal-to-noise ratio detector and is therefore complimentary to the Digicon. The Reticon is very good at getting really marvelous spectra of bright stars fast.

The Reticon and Digicon are both mounted on a sliding table at the camera focus. Changing detectors is a matter of only a few minutes now. Both Reticon and Digicon use a solid state array, but in the Digicon the array is at the back end of an image tube and detects photoelectrons rather than photons. A coude Reticon system has also been installed at the 2.1m Struve reflector. This system was used for a few of my observations of YZ Cas, but most of the observations were taken with the 2.7m Reticon system.

The only photoelectric light curves for YZ Cas were taken by Gerald Kron in the late 1930's. Kron normalized the light just preceeding or following eclipse to eliminate differences in the optical path of his photo-comparator, but was unable to do so between eclipses.

Kron's 1939 and 1942 light curves of YZ Cas have been re-analyzed in at least 8 other studies. All studies are in good agreement.

I have adopted a weighted average of the 8 photometric orbits for the purposes of this study. I estimate the average relative radii to be uncertain by about 1% and the inclination by $0^\circ.2$.

Single-lined spectroscopic orbits for YZ Cas have been done by Plaskett (1926) and Perry and Stone (1966). Since the light ratio is roughly 10 to 1 for YZ Cas, features due to the secondary

THE ASTROPHYSICAL JOURNAL, **270**: 123–139, 1983 July 1

THE TYPE I SUPERNOVA 1981b IN NGC 4536: THE FIRST 100 DAYS

DAVID BRANCH
Department of Physics and Astronomy, University of Oklahoma
C. H. LACY
Department of Physics, University of Arkansas
MARSHALL L. MCCALL
Mount Stromlo and Siding Spring Observatories
P. G. SUTHERLAND[1]
Department of Physics, McMaster University
A. UOMOTO
Department of Astronomy, University of Michigan
AND
J. C. WHEELER AND B. J. WILLS
Department of Astronomy and McDonald Observatory, University of Texas at Austin
Received 1982 August 9; accepted 1982 December 14

ABSTRACT

High-quality optical spectra of the Type I supernova 1981b in NGC 4536 from the time of maximum light to 116 days later are presented. This supernova is compared photometrically with the Type I supernova 1972e in NGC 5253, and the two are found to be very similar. Synthetic spectra based on resonance scattering lines superposed on a continuum give excellent fits to the data. The spectra after maximum light are dominated by blends of permitted Fe II lines. The continuum temperature, as a function of time, is determined by optical and infrared fluxes. This allows a determination of the angular size of the continuum photosphere, which is found to increase until 30 days after maximum light and then to decrease. Analysis of the photometry and spectroscopy, together with the assumption that the explosion occurred 15 days before maximum light, leads to a distance of 28 ± 8 Mpc. Implications of this for the extragalactic distance scale are presented. We also discuss the implications of the observations for models of Type I supernovae.

Subject headings: galaxies: individual — line identifications — stars: supernovae

I. INTRODUCTION

On 1981 March 2, Tsvetskov (see Aksenov 1981) discovered a 12th magnitude Type I supernova (SN I) in NGC 4536, a spiral galaxy in the southern extension of the Virgo Cluster complex. A coordinated program of spectroscopy and optical photometry was begun at the McDonald Observatory on March 6, shortly before the supernova reached its maximum brightness. Photometry covering the first 80 days after maximum light has been reported by Buta and Turner (1983), and the spectrum at maximum light has been interpreted by Branch *et al.* (1982, hereafter Paper I). In this paper we present all of the spectra obtained during the first season of observations, which extended to 1981 July 1, 116 days after maximum light. We interpret these spectra as P Cygni–type line profiles superposed on a thermal continuum from a photosphere. Spectra obtained during the second season, beginning 1981 December 2, 270 days after maximum light, will be presented in a later paper. By the beginning of the second season the ejecta had become optically thin, and a different interpretation is needed.

[1] Alfred P. Sloan Foundation Fellow.

The spectra of SN 1981b are presented in § II. In § III, the broad-band photometry of SN 1981b is compared with that of SN 1972e in NGC 5253. These two well-observed SN I are shown to have been very similar photometrically. Comparison of energy distributions with Planck curves is then used to infer the angular size of the photosphere as a function of time. In § IV, synthetic spectra are used to establish line identifications and to investigate the chemical composition and the evolution of the velocity at the photosphere. The distance to the supernova is estimated in § V, and the implications of our results for models of SN I are explored in § VI.

II. OBSERVATIONS

a) *Instruments and Reductions*

The supernova was observed at the University of Texas McDonald Observatory with the 2.7 m and 2.1 m reflectors. The IDS spectrometer was used with the 2.7 m telescope as described by Branch *et al.* (1981), and standard reduction procedures were used.

The April 11 and 25 observations were made at the 2.1 m Struve reflector using a non-intensified Reticon diode array as the detector. The spectrograph is the same

16.09 Analysis of the Light Curves of FK Comae with the Starspot Model. J.D. DORREN, University of Pennsylvania, E.F. GUINAN and G.P. MC COOK, Villanova University.

Photoelectric observations of the very rapidly rotating G giant star, FK Comae (=HD 117555) have been carried out at Villanova University Observatory, starting in March 1982. Previous photometric studies were made by Chugainov in 1966 and 1974 and more recently by Rucinski during 1977. The star is variable with a photometric period of $P = 2\overset{d}{.}400$. The light amplitude in V found previously was about $0\overset{m}{.}08$. Our 1982 observations of this star indicate that changes in the light curve have taken place. The light curve shape and amplitude are different, and the phase at which minimum light occurs has advanced. In addition we find evidence from our Hα photometry that flaring activity is taking place. An analysis of our 1982 light curves, together with the previous light curves has been made on the assumption that the light variations are produced by the presence of starspots on this rapidly rotating star. The results of this analysis and new insights into the nature of this object will be presented.

16.10 Evolution and Analysis of the Complex Light Curves of λ And using the Starspot Model. J.D. DORREN, University of Pennsylvania, E.F. GUINAN and B. PACZKOWSKI, Villanova University.

We present five years of intermediate band photoelectric photometry of the long period RS CVn binary λ Andromedae and discuss these data in the context of the starspot model. The spots are found to be about 800°K cooler than the photosphere, in agreement with previous results for this star. The light curve exhibits cycle-to-cycle changes. The photometric period of ~ 54d is not constant, but varies from 52^d to 56^d in a systematic way. Much of the general evolution of the light curve is suggestive of the effects of differential rotation on spot groups at different latitudes, but a detailed understanding of the changes in the spot configuration in this complex and difficult system is elusive.

Bull. Am. Astron. Soc, Vol. 14, p.634

16.11 Absolute Dimensions and Masses of CW CMa, C. H. LACY, U. Ark. The eclipsing binary CW CMa has been found to be strongly double-lined on high signal-to-noise ratio digital spectral scans obtained with the Reticon and Digicon spectrometers of the 2.7 m reflecting telescope at McDonald Observatory. Absorption lines of both components are of nearly equal strength in the 4500 Å region, and radial velocities of high precision have been obtained for both stars. Spectroscopic orbits derived from these data have been combined with the photometric orbit of Williamon (1976) to give very accurate masses and radii: ($2.09 \pm 0.02\ M_\odot$, $1.89 \pm 0.04\ R_\odot$) for the primary and ($1.98 \pm 0.02\ M_\odot$, $1.79 \pm 0.07\ R_\odot$) for the secondary. The uncertainties are conservatively estimated standard errors. An analysis of the line profiles of both components indicates that they are synchronously rotating with the orbital period. A limited range of theoretical evolutionary tracks can be fitted simultaneously to both stars of CW CMa. The approximate age of this system is 2×10^8 years.

16.12 IUE Observations of Phase-Dependent Spectral Variations in WR Binaries, L.H. AUER, G. KOENIGSBERGER, Penn State U. Spectra of five Wolf-Rayet binaries (WN+OB) with high orbital inclinations have been obtained with the IUE with the purpose of reconstructing structural information about the gas in the systems. The phase-dependent variations found in all of the observed systems are of similar nature and their magnitude is such that they are easily seen even in low dispersion spectra. In particular, N IV 1718 is mostly in absorption when the OB star is behind the WR component and goes into relatively strong emission when it is infront. This implies a higher ionization state on the side of the WR facing the OB star, generalizing the conclusion reached in the case of V444 cyg from optical observations.

16.13 A Search for Light-Time Effects in Binary Cepheids: AW Persei, N. REMAGE EVANS, David Dunlap Observatory, U. of Toronto. A search for light-time effects in classical cepheids which are known spectroscopic binaries is being undertaken. The extensive work of Szabados (1980, Mitteilungen der Sternwarte der Ungarischen Akademie der Wissenschaften, 76, 1) provides phase residuals from light curves ("O-C diagrams") which sometimes appear to be periodic. However, in the case of SU Cygni, the phase residuals do not agree with the light-time delay computed from the binary orbit (Evans, N.R. 1980, Bull.A.A.S., 12, 862). Tests have been performed on the photoelectric observations of AW Persei to determine how accurately phase shifts, as well as small zero-point corrections, can be determined. The phase residuals from the last thirty years have decreased and then increased again, confirming Szadabos' result. Though the radial velocity observations during this period are scarce, they do establish approximately the time of minimum phase residual and the amount of phase delay ($0\overset{d}{.}1$). The observed phase residuals are in agreement with these estimates. If the light-time interpretation is correct, observations in the next decade should show that the phase residuals are periodic.

Five radial velocities obtained at David Dunlap Observatory in 1981 and 1982 (12 Å/mm), together with five from the previous decade, indicate that the orbital velocity has recently decreased 4 km/sec, and put limits on the orbital period.

Supported by an N.S.E.R.C. Research Grant to Dr. J.R. Percy.

Session 17: Quasars and Supernovae 0940–1630 (Room 232) (Display Presentation)

17.01 The Morphology and Energetics of Discrete Optical Events in Compact Extragalactic Objects, J. T. POLLOCK, Appalachian St. U. All available optical variability data for compact extragalactic objects were assembled. For objects showing evidence for one or more discrete events, this information was digitized, composite light curves generated and discrete events identified. All event data were converted to rest frame 2500 Å monochromatic luminosities. The base luminosity was determined for and subtracted from each set of event data, and normalized event luminosity curves were generated. The morphology of these events was examined, both for single events and for groups of events.

THE ASTROPHYSICAL JOURNAL, 261:612–616, 1982 October 15

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARIES. III. CW CANIS MAJORIS

CLAUD H. LACY
Department of Physics, University of Arkansas
Received 1982 January 18; accepted 1982 April 19

ABSTRACT

The eclipsing binary CW CMa has been found to be strongly double-lined on high signal-to-noise ratio digital spectral scans obtained with the Reticon and Digicon spectrometers of the 2.7 m reflecting telescope at McDonald Observatory. Absorption lines of both components are of nearly equal strength in the 4500 Å region, and radial velocities of high precision have been obtained for both stars. Spectroscopic orbits derived from these data have been combined with the photometric orbit of Williamon to give very accurate masses and radii: (2.09 ± 0.02 $M_\odot$, 1.89 ± 0.04 $R_\odot$) for the primary and (1.98 ± 0.02 $M_\odot$, 1.79 ± 0.07 $R_\odot$) for the secondary. The uncertainties are conservatively estimated standard errors. An analysis of the line profiles of both components indicates that they are synchronously rotating with the orbital period. A limited range of theoretical evolutionary tracks can be fitted simultaneously to both stars of CW CMa. The approximate age of this system is 2×10^8 years.

Subject headings: stars: eclipsing binaries — stars: evolution — stars: individual

I. INTRODUCTION

The two previous papers in this series (Lacy 1977, hereafter Paper I; Lacy 1981, hereafter Paper II) dealt with double-lined eclipsing binaries which were either too faint (CM Dra) or had too large a light ratio (YZ Cas) to be observed successfully with traditional photographic spectroscopic techniques. CW CMa, however, probably *could* be observed successfully with photographic methods, albeit with much greater observational difficulty than that encountered with a solid state array detector. The southerly declination of CW CMa ($-23°.6$) and, until recently, its lack of an accurate light curve may have helped discourage observation in the past by observers in the northern hemisphere.

The light variations of CW CMa (HD 57802, SAO 173554, $-23°5335$) were studied photographically by Deurink (Van Hoof 1949) and photoelectrically by Williamon (1976). The orbital period is about 2.1 days, the HD spectral type is B9, and the eclipses are of nearly equal depth, about 0.4 mag. The only photoelectric photometry of the system appears to be that of Williamon (1976), who found $V = 8.58$, $B - V = 0.14$, and $U - B = 0.07$ outside eclipse. Williamon's light curves have been analyzed by Williamon using the methods of Russell and Merrill (1952) and by Mezzetti *et al.* (1980) using Wood's (1972) WINK computer program. No previous radial velocity work has been done on this system.

II. OBSERVATIONS AND ANALYSIS

Digital spectral scans of CW CMa were obtained mainly using the Reticon detector on the coudé spectrometer of McDonald Observatory's 2.7 m reflector. This device has been described by Vogt, Tull, and Kelton (1978). A smaller number of scans were obtained using the dual-array Digicon mounted on the same sliding table as the Reticon. The Reticon scans consist of 1024 data words corresponding to photodiodes on the array spaced at 25 μm between centers. The Digicon scans consist of pairs of 936 data words corresponding to the two adjacent arrays of photodiodes, each array having a diode spacing of 30 μm between centers. The scans were obtained in the blue region of the spectrum at a central wavelength of approximately 4505 Å and a dispersion of 4.4 Å mm^{-1}, or 0.11 Å per diode for the Reticon and 0.14 Å per diode for the Digicon. A projected slit of 0.55 Å or 0.66 Å was used in all cases.

It was possible to use a slit this broad because the rotational broadening was approximately 1 Å for both components, so the additional instrumental broadening had only a small effect on the ability to resolve stellar absorption lines. Each scan covered about 100 Å for the Reticon and 125 Å for the Digicon. The signal-to-noise ratio of the scans was typically 100. Two Reticon scans taken at opposite quadratures are shown in Figure 1. The lines of both components are well resolved near quadratures, but crowding is a problem (as always) in this blue spectral region.

THE ASTROPHYSICAL JOURNAL, 251:591–596, 1981 December 15

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARIES. II. YZ CASSIOPEIAE

CLAUD H. LACY
Department of Physics, University of Arkansas
Received 1981 May 11; accepted 1981 July 7

ABSTRACT

Absorption lines of the F2 V secondary star of YZ Cas have been detected for the first time in high signal-to-noise ratio digital spectral scans obtained with the Reticon spectrometer of the 2.7 m reflecting telescope at McDonald Observatory. Radial velocities of high precision have been obtained for both the primary and secondary stars in this well known large light-ratio eclipsing binary system. Spectroscopic orbits derived from these data have been combined with a photometric orbit derived from Kron's photoelectric light curve to give very accurate masses and radii: ($2.31 \pm 0.01\ M_\odot$, $2.53 \pm 0.03\ R_\odot$) for the primary and ($1.35 \pm 0.01\ M_\odot$, $1.35 \pm 0.02\ R_\odot$) for the secondary. The uncertainties are conservatively estimated standard errors. Theoretical evolutionary tracks indicate an age of about 4×10^8 years based on the observed masses and radii. The primary star is near core hydrogen exhaustion and is rotating about 20% faster than the synchronous rotational velocity. The secondary is rotating synchronously.

Subject headings: stars: eclipsing binaries — stars: evolution — stars: individual — stars: rotation

I. INTRODUCTION

Over the last decade a number of new types of spectrometric detectors have been developed for use on coudé spectrometers of large telescopes. Solid state array detectors such as the Reticon or its intensified version, the Digicon, are especially well suited for this application (Vogt, Tull, and Kelton 1978). Spectral scans of several classes of binary stars may be obtained with these detectors much more efficiently than with conventional methods. The first paper in this series (Lacy 1977) demonstrated the advantages of the Digicon for obtaining spectra of a very faint eclipsing binary (CM Dra, $B = 14.5$) with nearly equal components. Spectral scans adequate for determining accurate radial velocities of both components were obtained with exposures of typically 30 minutes duration at a resolution of 0.6 Å.

While the Digicon is most efficient in applications requiring a small signal-to-noise ratio such as faint binaries with nearly equal components, the Reticon is most efficient in applications requiring large signal-to-noise ratio. The optimal systems for study with the Reticon are therefore bright, large light-ratio binaries such as the Algol-like systems or large mass-ratio main sequence binaries. This type of system cannot be studied easily using conventional photographic or image tube methods because of the limited dynamic range of photographic emulsions in conventional spectrographs.

YZ Cas (HD 4161, BS 192, 21 Cas, +74°27, ADS 624 A) is a well known bright ($V = 5.66$) large light-ratio eclipsing binary which is single lined on the best photographic spectrograms. Olson (1975) has confirmed the metallic line character of the primary. Popper (1979) failed in a concerted effort to find D lines of the secondary photographically. The single-lined spectroscopic orbit of Perry and Stone (1966) is listed by Batten, Fletcher, and Mann (1978) as class *a*. The only published photoelectric light curves of YZ Cas are those of Kron (1939, 1942). Kron (1942) derived photometric orbits based on Russell's (1912) model. Kron's data have been reanalyzed by a number of authors (see Table 1). Koch, Plavec, and Wood (1970) cite the mean of Kron's (1942) and Kitamura's (1965) orbits as class A with the comment that Kron's observations "are frequently cited as composing the most accurate binary light curves, but night corrections of considerable size have been added to some blue observations and the phase coverage between the eclipses is rather sparse." Kron (1939) did not display his complete light curve, only the eclipses. The complete blue light curve based on his data is shown in Figure 1. Kron adjusted his observations within eclipse such that the outside eclipse data just preceding or following the eclipse had the same mean value. This was justified by Kron because of the small night-to-night changes in the optical path of the photocomparator used in his observations. This can be plainly seen in the observations between eclipses, which could not be corrected for this effect.

For the purposes of this study I have adopted a weighted average of the eight photometric orbits cited in Table 1, all of which are based on Kron's observations. The uncertainties in the adopted solution reflect primarily the degree of consistency shown by the various solutions and should be interpreted as standard errors. I

OBSERVATIONS OF SPECTROSCOPIC BINARIES WITH A SOLID-STATE DETECTOR

Francis Fekel, Jr., Claud H. Lacy, and J. Tomkin
Department of Astronomy and McDonald Observatory
The University of Texas, Austin, Texas 78712

The recent installation of a solid-state 1024-element silicon photodiode array detector (Reticon) at the coude focus of the 2.7 m McDonald Observatory reflector has greatly extended its limits of observation for binary and multiple systems which have weak and/or broad-lined components. This detector can produce extremely high signal-to-noise ratio observations and has high quantum efficiency over the wavelength region 3000-11000Å. The observational programs of three users of this device are described below.

1. RETICON OBSERVATIONS OF ECLIPSING BINARIES BY J. TOMKIN

Secondaries of Algol-type eclipsing binaries are being observed by J. Tomkin. Most of the stars in his program have evolved secondaries although a few main-sequence pairs are also included. The sensitivity of the Reticon in the red and near-infrared--where the secondaries are relatively brighter than in the photographic part of the spectrum and blending problems are less severe--are advantages. The outstanding advantage, however, is the large signal-to-noise ratio that can be obtained. This is particularly true of bright objects. The detection of the NaD lines of the secondary of Algol (Fig.1) is an example.

Studies of δ Lib, Algol and U Sge have been published. A preliminary analysis of U Cep gives a K_2 of 200 km s^{-1}. Batten had suggested a tentative value of 180. The secondaries of RZ Cas, S Cnc, U CrB, Alpha CrB, AI Dra and EK Cep, have also been detected and further observations of these systems are underway.

J. Tomkin, D. Lambert and M. Parthasarathy are studying abundances in eclipsing binaries. An investigation of the metal abundances of the secondary of U Cep shows that they are not significantly different from solar. A preliminary analysis of the secondary of U Sge shows that it also has solar metal abundances. These results do not support the conclusions of earlier investigations by narrow-band photometry which had indicated large metal-deficiencies in evolved Algol-type secondaries. An investigation of carbon, nitrogen and oxygen abundances in primaries and secondaries is planned.

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 53–57.