2. LONG-PERIOD ECLIPSING BINARY STARS AND RELATED OBJECTS

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PHOTOMETRY OF THE RECENT ECLIPSE OF EPSILON AURIGAE

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ABSTRACT. New observations of the long period eclipsing system Epsilon Aurigae are discussed, including optical and infrared photometry, ultraviolet spectrophotometry and optical polarization. Trends are noted in the light curves and compared to previous eclipses. Comments regarding interpretation are also provided.

1. INTRODUCTION

1.1. History

The present understanding of the star Epsilon Aurigae holds that it is a binary comprised of an early F supergiant plus a large, cold disk-shaped companion. Variability in the star was first discussed by Fritsch (1824) and a 27.1 year periodicity for the 0.8 magnitude, two year long eclipse confirmed by Ludendorff (1903). Early spectroscopy of the system by Struve and Elvey (1930) could detect no sign of the secondary. It was concluded that a comparably massive companion to the supergiant existed, but it was not simply a twin because the system was not a double lined spectroscopic binary. Present consensus regarding the binary properties was summarized by Webbink (1985).

1.2. Models for the System

Interpretation of the Epsilon Aurigae data includes a set of models proposed over a fifty-year period and incorporating each new insight derived from the most recent data or allied analyses. Kuiper, Struve and Stromgren (1937) attempted to explain the eclipse properties with an "I component" which was very large, cool and semi-transparent. However, both the infrared and ultraviolet properties of such an object could not be reconciled with the data. In 1955, Struve drew upon work in interacting binary stars to propose a new model involving a complex of gas clouds streaming between the two stars, producing the eclipse effects. The I component in this model became an unimportant object, too cool to be observed. Hack (1961) proposed another solution

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involving a B star enshrouded by shells of ionized matter, building on then recent discoveries concerning shell and Be stars. Huang (1965) made the radical departure from conventional proposals by advocating a flattened disk of matter, analogous to the protosolar nebula. This model has been the most successful of those introduced to date, judged by the number of its proponents. On the basis of the most recent data, Lissauer and Backman (1985), and Eggleton and Pringle (1985) both advocated that the Huang disk is an aging accretion disk stabilized by a binary star at its center. In contrast, Saito et al. (1985) have advocated a low mass solution to the system. The modern interpretations are the subject of this Joint Discussion. It is my task here to summarize the recent photometric results, including polarimetry.

1.3. The Observing Campaign

Genet and Stencel (1981) announced the organization of an observing campaign for the 1982-84 eclipse. IAU, AAS and IAPPP endorsements were obtained. Approximately 80 participants from 15 countries were involved in actual observation, including ground- and space-based ultraviolet, optical, infrared and radio measurements. The premiere sources of photometry were from J. Hopkins and P. Schmidtke (Arizona), S. Ingvarsson (Sweden), R. Genet and L. Boyd (Ohio and Arizona), D. Boehm (Germany), J. Kemp (Oregon), Drs. Ohki and Sakai (Japan) and D. Backman (Hawaii). The participants were kept informed on the progress of the eclipse campaign with a series of 13 newsletters edited by Hopkins and Stencel. A workshop was convened in January 1985, in Tucson, Arizona to discuss the new data, and the proceedings of the workshop have been published (Stencel 1985) and distributed to libraries worldwide. Combined with the new spectroscopy, the photometric and polarimetry dataset from the recent eclipse is the most complete in the history of the study of Epsilon Aur.

2. LIGHT CURVES

2.1. UBV Photometry

The photometric coverage of the recent eclipse was excellent, particularly following first contact. The most complete summary to date has been provided by Schmidtke (1985). The UBV light curves show an 0.1 magnitude quasi-periodic variation superposed on the 0.7 magnitude eclipse. As with previous eclipses, a mid-eclipse brightening occurred, possibly more pronounced than at any previous totality. Also, an anomalous brightening (0.1 magnitude "UV flare") occurred near JD 2445700, near the start of egress. The measured eclipse depths, according to Schmidtke, were 0.686, 0.705 and 0.802 magnitudes in V, B and U respectively. Note that these are not equal (non-grey) and slightly shallower than previous eclipses.

Tables I and II compare the times of contact and duration of eclipses of Epsilon Aurigae.

Several trends can be seen in Table II: totality is lengthened at the expense of egress, and the total eclipse length is slowly

TABLE I

Times of Contact (JD - 2440000)	Predicted	Schmidtke	Ohki and Sakai
First	5180	(5165)	---
Second	5315	5302	5310
Third	5709	5748	5736
Fourth	5850	5812	---

Note the delay in third contact, apparently affected by the "UV flare" near JD 2445700.

TABLE II

Duration of Phases (days)	Eclipse		
	1983	1956	Pre-1956
Ingress	137	135	182
Totality	446	394	330
Egress	64	141	203
Total Length	647	670	715

decreasing. Perhaps this is related to an increasing central concentration of the disk.

Schmidtke also pointed out several trends in the B-V and U-B colors. Both are monotonic prior to mid-eclipse, but change at and after mid-eclipse. B-V reddens and shows pulsation, as seen in the 1956 eclipse. U-B reddens and shows large UV excess at fourth contact. In general, the eclipse is "quiescent" during the first half of the eclipse, then activity increases up to fourth contact. This argues for significant asymmetries in the structure and orientation of the secondary (disk).

2.2. Infrared Observations

JHKLMNQ band photometry was reported by Backman (1985) which showed an infrared excess longward of 5 microns. The depth of the eclipse was

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clearly less at 10 and 20 microns. The inferred blackbody temperature of the secondary was 475 ± 50 K, which is only about half the equilibrium temperature expected from primary star heating. This result implies a very low luminosity for the mass of the secondary (i.e., less than 100 $L_\odot$ for 10 $M_\odot$), and could be consistent with the embedded binary core proposed by Lissauer and Backman.

Two special observations of Epsilon Aurigae were obtained with the Infrared Astronomical Satellite (IRAS: Neugebauer et al. 1984) during totality in 1983 (Backman and Gillett 1985). Detection at 10, 25 and 60 microns confirmed the 475 K temperature. This temperature combined with the IRAS flux calibration and the assumption that the secondary is opaque, imply a solid angle for the secondary of approximately 10^{-15} sr. Backman has used this result combined with eclipse duration to argue that the disk aspect ratio was very small, of order 2. In any event, it is now clear that the secondary is amenable to study at infrared wavelengths, and that continued observation may reveal the extent to which the disk is heated by the primary, as quadrature approaches.

2.3. Ultraviolet Observations

More than 100 observations have been obtained with the International Ultraviolet Explorer (IUE: Boggess et al. 1978), enabling spectrophotometry measurements over the 120-320 nm band. It was found (cf. Ake 1985) that the eclipse is highly wavelength dependent in the UV, being deepest at 160 nm (roughly one magnitude). In addition, the UV showed extraordinary brightenings just prior to first and third contacts, the latter corresponding to the JD 2445700 U-band "flare" noted above. In addition, the mid-eclipse brightening appears to be present, but not pronounced in the UV light curve.

Something of a debate has developed over the existence and nature of a UV excess shortward of 140 nm. Hack and Selvelli (1979) with an original IUE spectrum, attributed an excess to the continuum of the B star in Hack's model for the system. Ake (1985) also argued for the existence of a short wavelength continuum on the basis of the shallow eclipse at 140 nm, but deduced that it did not have B star characteristics. The IUE spectrographs however have limited dynamic range and potentially large scattered light problems for stars of type F-G-K. Altner et al. (1985) pursued a careful analysis of scattered light contributions in the short wavelength IUE spectra and concluded that a time variable UV excess probably exists. Insufficient data exist yet to clearly correlate this variable excess with the F supergiant pulsations in light. The Hubble Space Telescope will make important observations in this respect.

R. Polidan (private communication) secured a far-ultraviolet observation of Epsilon Aur in 1984 February, during the "UV flare," using the UVS instrument on the Voyager 1 spacecraft. Flux was de-detected in the 90-120 nm region, exhibiting a B star-like continuum. However, the 0.1 × 0.9 degree entrance aperture may have included light from a nearby B star in the field. A reobservation is planned with more precise aperture orientation. The Voyager flux level

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coincides with that expected near the bright extreme of the factor of 100 variation in the UV excess reported by Altner et al.

2.4. Polarization Observations

A unique set of data was obtained during this eclipse by Kemp (1985) who measured the linear polarization of Epsilon Aur in the UBV bands. He found a background 2% level of polarization consistent with interstellar effects over 1 kpc. He also found the polarization to be color-independent, and a strong 100 day oscillatory variation. Again, the light curve was asymmetric about mid-eclipse: larger variations past mid-eclipse, possibly complicated by the JD 2445700 "UV flare." Kemp et al. (1985) have advanced an interesting interpretation of all of this. The polarization is ascribed to "limb polarization" which is light scattered near the F star limb only partially cancelled during eclipse. The light curve asymmetries require a non-central eclipse (tilted disk) and a tilted primary star with a hot pole. Finally the primary is a non-radial pulsator. In addition to replicating the polarization light curves, this model also agrees with asymmetries noted in the UV light curves. This model deserves further discussion.

3. COMMENTARY

The new interpretation of Epsilon Aur reflects the new discoveries. First, there is evidence for secular changes on an orbital timescale, suggesting evolution of the secondary/disk structure. Second, the multi-spectral data show convincingly that the eclipse is NOT grey, particularly in the UV and IR.

The importance of continued monitoring of this star prior to the next eclipse (in 2009 A.D.) should be stressed. UBV and polarization observations will better define the nature of the F star's Cepheid-like pulsations. IR observations should be able to detect the gradual appearance of the heated side of the disk as quadrature approaches. I am pleased to note that several individuals have stated intention to pursue their observations toward these ends. Further, the important role performed by serious amateurs, worldwide, in obtaining light curves during this eclipse campaign deserves emphasis. As Douglas Hall noted, during the 1955-57 eclipse, virtually none of the photometry reported by Gyldenkerne (1970) was provided by amateurs, whereas during the recent eclipse, a significant contribution was made by such persons. This is a positive development, deserving of appreciation by all professional astronomers.

Finally, I am pleased to acknowledge the diligence of many colleagues who helped to make the observing campaign successful. Much of my effort in coordinating this work occurred during a tour of duty at the Astrophysics Division, NASA Headquarters, while on leave from the Joint Institute for Laboratory Astrophysics at the University of Colorado. I am grateful to NASA and JILA for institutional support of this work.

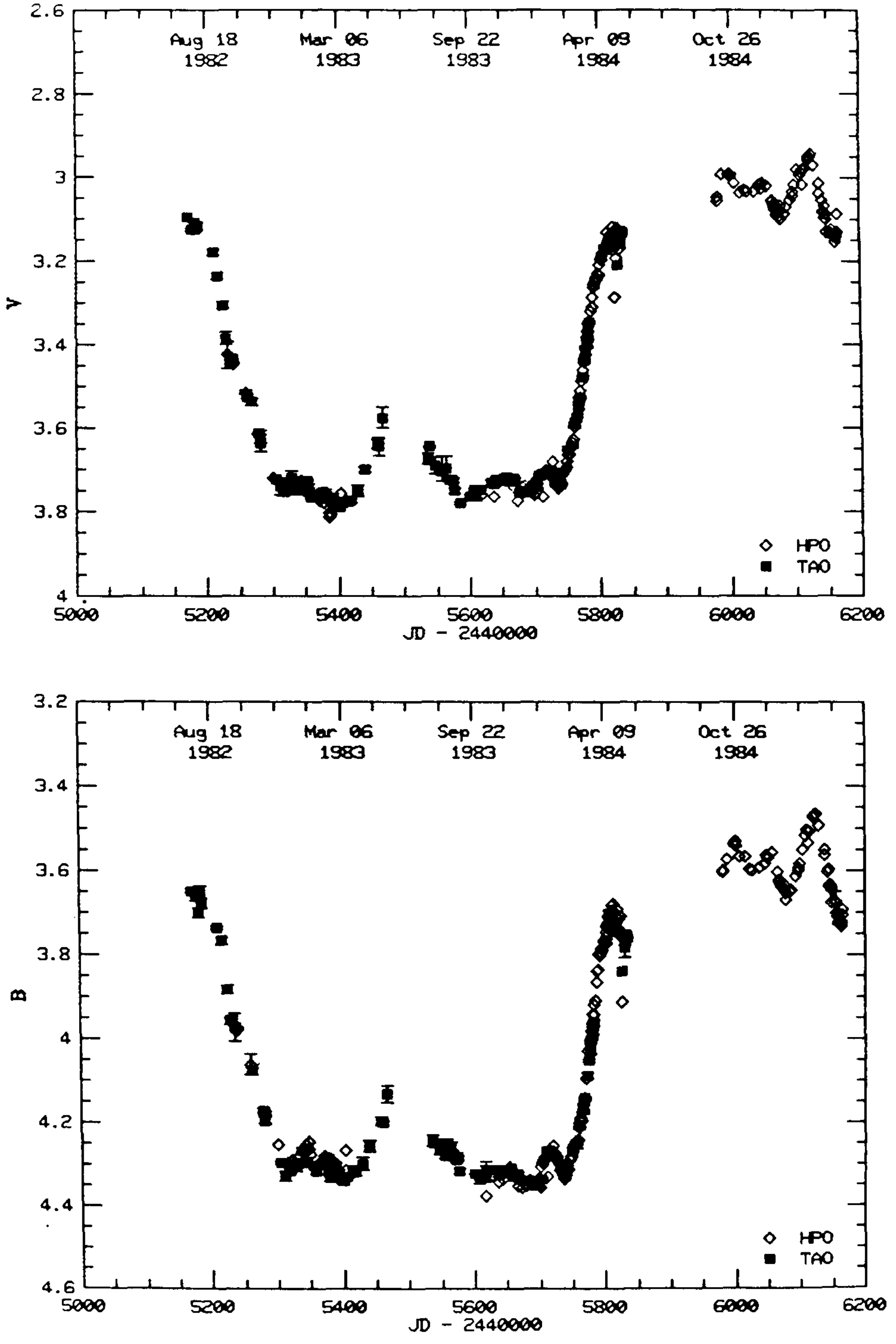

Figure 1. V and B photometric light curves for Epsilon Aurigae.

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4. REFERENCES

Ake, T. -- see Stencel (1985).
Altner, B., Chapman, R., Kondo, Y. and Stencel, R. -- see Stencel (1985).
Backman, D. 1985 -- see Stencel (1985).
Backman, D. and Gillett, F. 1985, Ap. J. (Letters) Dec. 15 issue.
Boggess, A. et al. 1978, Nature 278, 1.
Eggleton, P. and Pringle, J. 1985, Ap. J. 288, 275.
Fritsch, J. M. 1824, Berlin. Jahrbuch., p. 252.
Genet, R. and Stencel, R. 1981, B.A.A.S. 13, 804.
Gyldenkerne, K. 1970, Vistas Astron. 12, 199.
Hack, M. 1961, Mem. Soc. Astron. Ital. 32, 351.
Hack, M. and Selvelli, P. 1979, Astron. Astrophys. 75, 316.
Huang, S. S. 1965, Ap. J. 141, 976.
Kemp, J. -- see Stencel (1985).
Kemp, J., Henson, G., Kraus, D., Beardsley, I., Carroll, L., Ake, T., Simon, T. and Collins, G. 1985, Ap. J. (Letters), submitted.
Kuiper, G., Struve, O. and Stromgren, B. 1937, Ap. J. 86, 570.
Lissauer, J. and Backman, D. 1985, Ap. J. (Letters) 286, L39.
Ludendorff, H. 1903, Astr. Nachr. 164, 81 (Nos. 3918-3920).
Neugebauer, G. et al. 1984, Ap. J. (Letters) 278, L1.
Saito, M., Kawabata, S., Saijo, K. and Sato, H. 1985, P.A.S.J., submitted.
Schmidtke, P. 1985 -- see Stencel (1985).
Stencel, R. E. 1985 (Editor) "The 1982-1984 Eclipse of Epsilon Aurigae," NASA Conf. Publ. 2384 (available from National Technical Info. Service, Springfield, VA 22161 U.S.A.).
Struve, O. 1955, P.A.S.P. 68, 27.
Struve, O. and Elvey, C. T. 1930, Ap. J. 71, 136.
Webbink, R. 1985 -- see Stencel (1985).

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