ALGOL, BETA LYRAE, AND W SERPENTIS: SOME NEW RESULTS FOR THREE WELL STUDIED ECLIPSING BINARIES

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(Received 20 October, 1988 – accepted 20 March, 1989)

ABSTRACT. The properties of the eclipsing binaries Algol, Beta Lyrae, and W Serpentis are discussed and new results are presented. The physical properties of the components of Algol are now well determined. High resolution spectroscopy of the H-alpha feature by Richards *et al.* and by Gillet *et al.* and spectroscopy of the ultraviolet resonance lines with the International Ultraviolet Explorer satellite reveal hot gas around the B8V primary. Gas flows also have been detected apparently originating from the low mass, cooler secondary component and flowing toward the hotter star through the Lagrangian L1 point. Analysis of 6 years of multi-bandpass photoelectric photometry of Beta Lyrae indicates that systematic changes in light curves occur with a characteristic period of $\simeq$275 $\pm$ 25 days. These changes may arise from pulsations of the B8II star or from changes in the geometry of the disk component. Hitherto unpublished u, v, b, y, and H-alpha index light curves of W Ser are presented and discussed. W Ser is a very complex binary system that undergoes complicated, large changes in its light curves. The physical properties of W Ser are only poorly known, but it probably contains one component at its Roche surface, rapidly transfering matter to a component which is embedded in a thick, opaque disk. In several respects, W Ser resembles an upscale version of a cataclysmic variable binary system.

1. INTRODUCTION

The bright eclipsing binaries Algol and Beta Lyrae are the two best studied stars in the night sky. Algol, the namesake of IAU Colloquium 107, is the famous prototype of an entire class of semi-detached binaries composed of a hot (B to F), nearly spherical primary and a cooler, less massive companion whose surface is in contact with its Roche equipotential surface. Algols have apparently evolved from formerly detached binary systems in which the originally more massive star has evolved off the main-sequence and is transferring mass to its now more massive companion. Beta Lyrae was once considered a prototype in its own right but now has been relegated to be a peculiar member of a subset of active Algol systems known as "Serpentids". As discussed by

Space Science Reviews **50** (1989), 35–49.

Mirek Plavec at this colloquium, Serpentids, named after W Serpentis, are active Algol-type systems which display strong emission lines in the ultraviolet and are presumably undergoing vigorous mass exchange and mass loss. Beta Lyr, however, is a unique binary system with many puzzling properties even though it has been observed more frequently than Algol. Its peculiar properties are probably related to the system being caught in a rare stage of rapid mass transfer and loss. As we shall see, there is still much to be learned about this well studied system and much work and some surprises remaining. W Ser is the 9th mag prototype of the active Algol systems, the Serpentids. Although W Ser has been studied for over fifty years, the only thing that we currently know with certainty about this peculiar star is that it is an eclipsing binary with an orbital period of 14.16 days. Even its binary nature and its orbital period have been questioned in the past. Except for the deep ($\simeq$1 mag) eclipses, the light curves of W Ser have little or no resemblance to those of other Algol systems. Its light variations outside the eclipse are characterized by the appearance of humps and bumps of $\simeq$0.25 mag which change from one orbital cycle to the next. Long-term changes in the brightness of the system of over $\simeq$0.5 mag occur over one observing season and also from year to year. The variability of its light curve makes W Ser an observing challenge since a large investment of time and effort are required to define its light variability. An even greater effort may be needed before we can claim to understand this complex binary.

In the following, I will discuss the characteristics of these three famous binary systems, but space does not permit an in-depth review. Instead, I will concentrate on recent results on Algol and present, hitherto unpublished observations and results on Beta Lyr and W Ser. In discussing what is known about these systems, I also will discuss what is not well known and what needs to be done. One thing that seems appropriate for these well observed and intensively studied systems is the advice given in *Interacting Binary Stars* by Jorge Sahade and F. B. Wood which is attributed to G. E. Kron - "the more a system has been observed, the more it deserves to be observed". As we will see, this advice certainly applies today to even such well observed stars as Algol, Beta Lyrae, and W Ser.

2. ALGOL

Algol (Beta Per) is one of the best known stars in the sky and the bright prototype of a class of over 400 close, semi-detached binaries. Since its "official" discovery as a variable star in 1669 by Geminiano Montanari, Algol has been the object of numerous studies and has been observed over the entire electromagnetic spectrum, from X-rays to the radio region with a variety of techniques. In a recent compilation of notes and references to Algol made by Chen and Wood (1988), there are over 1100 entries. Even with this long-time baseline of study and the attention given to the star, some of its important properties are still not well determined.

Algol is generally assumed to be only a triple system. The AB eclipsing pair has an orbital period of 2.87 days while the third component (C) has an orbital period of 1.87 yrs about the barycenter of the triple system. The eclipsing pair consists of a nearly spherical B8V primary (M_A = 3.7M☉) and a less massive, highly distorted K2-3 IV star (M_B= 0.8M☉) in contact with its Roche equipotential surface. The third component (C) is a main sequence A5-9 m star. An excellent summary of recent photometric investigations is given by Richards *et al* (1988) and references therein. Good overviews of research on Algol are given by Sahade and Wood (1978), and here by Batten (1989). It seems now, from the study of Richards *et al.* (1988), that the orbital and physical properties of the component stars are well determined.

Although the physical properties of the component stars (masses, radii, temperatures, and luminosities) are known relatively well, the amount and distribution of gas in the system is still not well known and will be the subject of this report on Algol. Early evidence for circumstellar gas in Algol was found by Struve and Sahade (1957) who reported the presence of very weak H-alpha emission outside the eclipses. Other spectroscopic evidence of gas was reported by Fletcher (1964) who found variations in the strength of the HeI λ4472 feature.

H-alpha and H-beta wide-and-narrow band photoelectric photometry of Algol was carried out at Villanova University during 1970-1971 (Guinan *et al.* 1976). This was a student project and complete light curves were secured in the four bandpasses. H-alpha and H-beta indices were formed from these data and an analysis of these revealed the presence of circumstellar gas in the vicinity of the B8V star. As shown in Fig. 1, the differential H-alpha and H-beta indices vary systematically between 0.85 and 0.15 phase. The variations of the indices are explained by the presence of a region of hydrogen line emission located near the hotter component which becomes partially eclipsed by the cooler component shortly, after, and during the partial phases of the eclipse of the hotter star by its cooler companion.

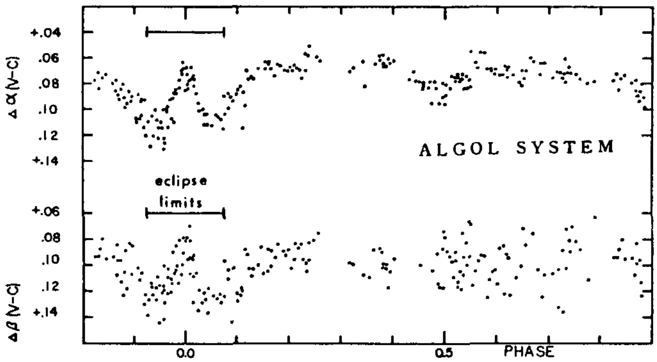

Fig. 1. The H-alpha and H-beta indices of Algol are plotted against orbital phase. Increasing net line emission is indicated by numerically smaller indices.

https://doi.org/10.1017/S0252921100087650 Published online by Cambridge University Press

The H-alpha and H-beta photometry provides a measure of only the net strength of the hydrogen line (absorption + emission) feature but provides no information on the line profile or radial velocities of the individual components making up the line feature. On the other hand, H-alpha and H-beta photometry of bright Algol systems can be done easily on a small telescope with modest equipment. The work discussed above was carried out with a 38-cm telescope by undergraduate students over 17 years ago at a site located only 15 miles from center city Philadelphia. It would be interesting to repeat these observations for Algol over several years to search for possible changes in the level of hydrogen line emission over time. It should be remembered that the observations discussed above were made during one observing season and may not apply to other epochs.

I will conclude this discussion on Algol by summarizing the results of recent high resolution H-alpha and UV satellite spectroscopic studies of the system. High resolution spectroscopic observations of the H-alpha feature around the orbit of Algol have been reported recently by Richards *et al.* (1989) and by Gillet *et al.* (1988). While Cugier and Molaro (1983; 1984) have studied the ultraviolet resonance lines of MgII, Al III, and SiIV in the high resolution IUE spectra of Algol in which these lines appear to originate in a region near the B8V primary. The H-alpha studies show the flow of cool gas (10^4K) from the inner hemisphere of the cooler toward and possibly around the primary component. During 1975/76, Richards *et al.* found strong evidence for a disk of high-rotational velocity gas around the B8V primary and a localized, variable, high density region of gas located above the inner hemisphere of this star. Gillet *et al.* (1988), however, model their data (obtained in 1985-1986) with a high density gas stream originating from the cooler component and probably flowing toward the B8 star. The IUE data are interpreted by Cugier and Molaro in terms of a mass-accretion process in which the high temperature plasma ($T \simeq 70{,}000$K) defined by SiIV absorption lines is produced by the dissipation of kinetic energy of gas accreting on the surface of the B8V primary. From these observations it appears that the SiIV lines are produced in a disk close to the surface of the B8V star while the MgII and H-alpha features originate in a plasma with a temperature of $\simeq 1 \times 10^4$K, farther away from the surface of the primary. The total picture probably is quite complex. Fig. 2 shows a scale model of the Algol system in which the location of circumstellar gas and gas flows are indicated.

Both the H-alpha and IUE studies indicate that the amount and distribution of gas in the Algol system may be variable with time. This should not be surprising, since as discussed by Hall (1989), the cooler star is a rapidly rotating convective star and should be chromospherically active. As in the case of RS CVn variables, the cool secondary of Algol could have short-term (hours to days) enhancements in magnetic-related surface activity as well as long-term variations in activity analogous to the 11-year activity cycle present in the Sun. It would be valuable to monitor Algol over several years to investigate whether the mass loss from the cool star is variable and tied to an activity cycle. Light curves of Algol in the infrared, where the cool component contributes a larger fraction (10-25%) of light, would be useful to investigate the presence of dark starspots on the cool star.

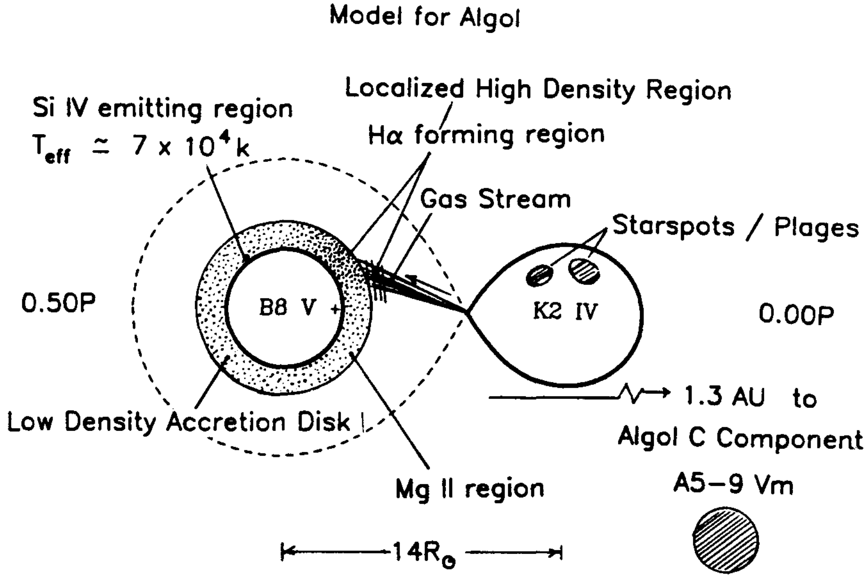

Fig. 2. A schematic representation of Algol showing the eclipsing binary components and the approximate distribution of gas in the system. The figure is adopted from the work of Richards *et al.* (1988, 1989), and Cugier and Molaro (1983, 1984).

3. BETA LYRAE

The 12.93 day period eclipsing binary Beta Lyrae was discovered as a variable star over 200 years ago by John Goodricke in 1784 and is the subject of more published papers than any other star except the Sun. An excellent comprehensive review of the system was made by Sahade (1980) while a more succinct summary is given by Sahade and Wood (1978). The current wisdom on Beta Lyrae is that it is a rapidly evolving binary composed of a B8II star in contact with its Roche lobe and a more massive B0-B2V? star surrounded by a flattened, thick disk, (Wilson 1981; Plavec 1982). Wilson (1974, 1981) estimates that the mass of the B-giant component is $\simeq$2-3M$_\odot$ while the total mass of the (disk + star) companion is $\simeq$10-12M$_\odot$. Recently, at this conference Parthasarathy has suggested that the luminous B-giant component is a helium-rich star with a B5II spectral type. The disk apparently is formed and maintained by gas flowing from the B-giant component. Period studies have been made from the 200 year data baseline which show that the orbital period is increasing with time at the rate of about 19 sec per year (Kreiner 1978). This large period increase has been interpreted as mass loss from the system at a rate of about 10^{-5} to 10^{-6} M☉/yr. This high mass loss rate inferred from the eclipse timings is in accord with the spectroscopic studies of the system carried out at visual and ultraviolet wavelengths. As discussed by Sahade (1980), Beta Lyrae appears to reside inside a large, expanding envelope of hot turbulent gas.

I will report on some new results obtained on Beta Lyrae from a photometric program being conducted at Villanova University. This work is being carried in collaboration with George McCook and Ted Bergin (Villanova University), Craig Robinson and Sallie Baliunas (CFA) and Andrew Theokas (Harvard). The photometry is being carried out with our 38-cm reflector and with a 25-cm automatic photoelectric telescope (APT) located at Mount Hopkins, Arizona. The photometry at Villanova Observatory was conducted during 1970-1974 and again during 1985-1988. The star was observed at Villanova with H-alpha and H-beta filter sets and intermediate-band blue (λ4530) and yellow (λ5500) filters. BVRI filters were used with the APT. The comparison star was Gamma Lyr. The differential magnitudes for the H-alpha wideband filter are plotted against orbital phase in Fig. 3. These observations were obtained during 1970 to 1974 and different symbols are used for each observing season in the plot. As discussed earlier, this light curve and the others show large amounts of scatter. This is especially true with primary minimum which varies in depth by $\simeq$0.25 mag. Examination of the data obtained during other years showed similar behavior. Moreover, upon closer scrutiny, systematic variations in the light curves appeared to be occuring on a time scale of months. These changes are clearly seen in Fig. 4. which shows a plot of observations obtained within primary eclipse from March through October 1972. Different plot symbols are used to distinguish observations made during different parts of the same observing season. As shown in the figure, the brightness of primary eclipse varies systematically with time. During March/April the eclipse is apparently deep and progressively becomes shallow until July/August when it is brightest. After that time the brightness of the primary minimum decreases again until in October/November it is near the same level as observed during March/April. The overall change in brightness of primary minimum is about 0.25 mag. The time for the brightness of the primary minimum to return to its original value is about 9 months or $\simeq$275 days.

Examination of the remainder of the data reveals that systematic changes in the light level of the rest of the light curve occurs concurrently with those larger changes seen in the primary minimum. When the primary is deep, the light level of the rest of the light curve is lower by $\simeq$0.07 mag than when the primary minimum is shallow. Secondary eclipse is not covered very well, but it appears the changes in its depth may be relatively small ($\simeq$0.03 mag). The 1985-1987 data obtained at Villanova and at Mount Hopkins with the APT confirm this behavior.

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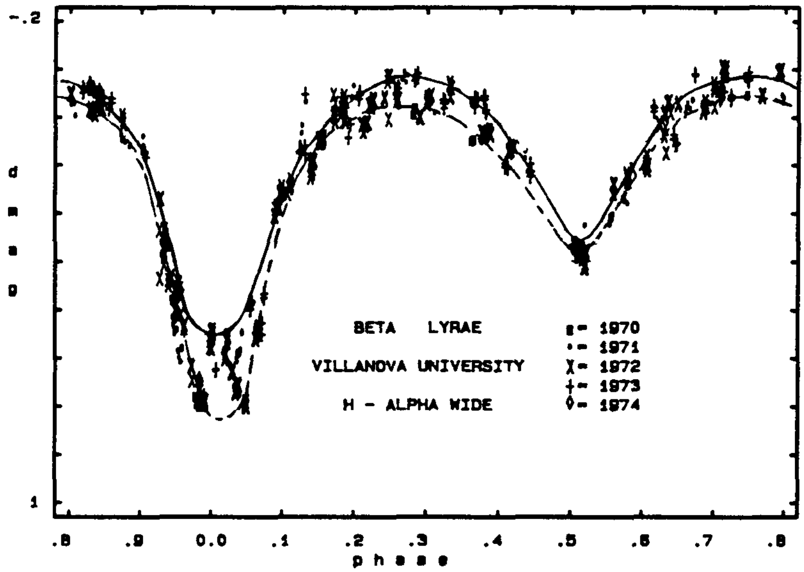

Fig. 3. The H-alpha wideband (6585A) observations of Beta Lyr conducted at Villanova during 1970-1974. The observations are plotted against orbital phase. The scatter in the light curve is not random but caused by cyclic changes in the system's brightness. The curves are drawn through the data to show the binary in its two extreme states.

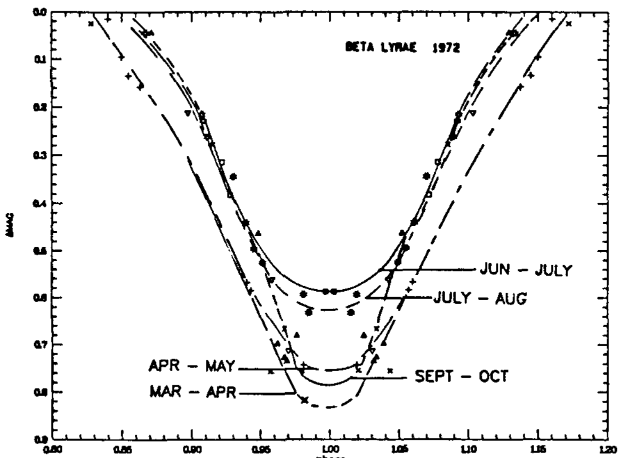

Fig. 4. The H-alpha wideband observations of Beta Lyr, obtained at Villanova during March to October of 1972, are plotted. The observations are separated into 40 to 80 day intervals and plotted with different symbols to show systematic changes in the depth of primary eclipse with time. The data are reflected about 0.0 phase to fill in the light curve.

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Figure 5 is a plot of the brightness of primary minimum versus time obtained from photometry during late 1971, 1972, and early 1973. The brightness estimates of the maxima of the light curve from the same data set are plotted against time in the figure. As shown, a clear ≃275 ± 20 day cyclicity is apparent in the data. The observations obtained during the same time by Landis *et al.* (1973) also were found to display the same 275 day period. Furthermore, the 1985-1987 data also show a similar periodicity.

An investigation of the colors and H-alpha and H-beta indices indicates that the star is slightly bluer and the H-alpha emission is significantly weaker when the light curve is high and the primary minimum is shallow. Currently, we are entering all of the published B and V observations of Beta Lyr into the computer so that a more complete data set can be studied.

At present it is difficult to identify with much certainty the source of the observed cyclic changes in the light curve of Beta Lyr. One possibility is that the light changes occur from periodic (or quasi-periodic) pulsations of the B giant component which are accompanied by mass loss and exchange as the star perhaps overflows its Roche lobe. Another possibility is that the observed light curve changes arise from the periodic changes in the disk. These changes could be due to variations in its opacity, size or shape. We plan to analyze the two extreme light curves to try to solve this problem. It is surprising that the possible 9 month periodicity in the light has not been reported previously. It is somewhat embarrassing that we did not find it earlier in the 1970-1974 data set. Perhaps it would be worthwhile to search for other periodicities in the photometry and spectroscopy using Fast Fourier Transform techniques.

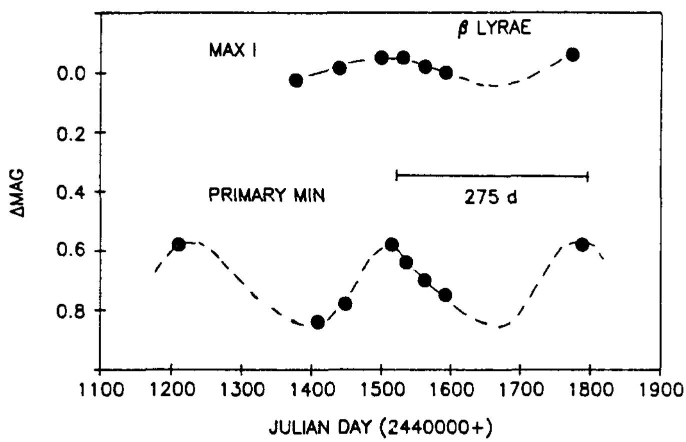

Fig. 5. The height of Max I (0.25P) and the depth of primary minimum are plotted against Julian date. These observations were obtained during late 1971, 1972, and early 1972 and show a possible 275 ± 20 day periodicity.

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4. W SERPENTIS

W Serpentis is the very peculiar prototype of an already peculiar subset of active Algol-type systems which are characterized by strong ultraviolet emission lines of CIV, CII, HeII, NV, and SiIV, etc. (Plavec 1980; 1982a 1982b; 1989). The optical spectrum has been extensively studied by Sahade and Struve (1957). The spectrum is complex and displays a combination of absorption and emission features which have been interpreted as arising from mass transfer and mass loss from a rapidly evolving binary system. Photometric studies have been carried out by McLaughlin (1961), O'Connell (1937), Gaposchkin (1937), Fresa (1957), Lynds (1957), and Young and Snyder (1982). The light curves are bizarre (see Figs. 6 , 7 , and 8) with little or no resemblance to other eclipsing systems except for the repetitive 1 mag eclipse occuring every 14.16 days.

From ground-based and ultraviolet spectrophotometry, Plavec (1989) has classified the visible spectrum of W Ser as F2-F5. However, according to Plavec, this F2-F5 spectral classification does not appear to correspond to a photosphere of a star but to the "pseudophotosphere" of a luminous, opague disk seen nearly edge-on. As in the case of Beta Lyr, the orbital period of W Ser is rapidly increasing at a rate of +14 sec/yr (Koch and Guinan 1978). This period change implies rapid mass transfer and mass loss.

Strömgren $\underline{u}$, $\underline{v}$, $\underline{b}$, $\underline{y}$ and H-alpha photometry of W Ser was conducted at Biruni Observatory, Shiraz, Iran during 1977 and 1978. (During 1977 the star was observed with only the $\underline{b}$ and $\underline{y}$ filters.) The observations were obtained by Javad Siah and myself using a 51-cm reflector. Because of clear summer skies in southwest Iran, good phase coverage of the system was obtained. The $\underline{y}$ and (b-y) observations are plotted against time in Fig. 6 for the two seasons. As shown, the light curve changes from one cycle to the next and from one year to the next.

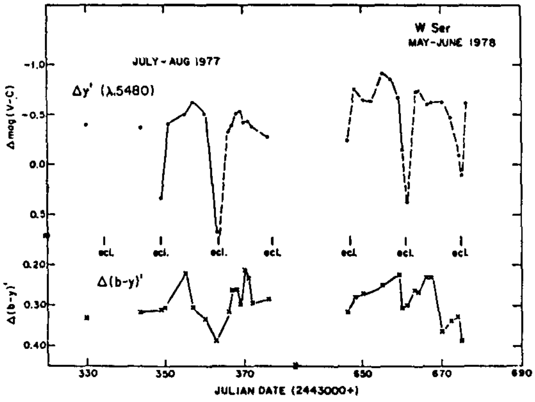

Fig. 6.

The differential y and (b-y) observations of W Ser obtained at Biruni Observatory during 1977 and 1978, are plotted against time. The primary eclipse times are indicated.

The light curves obtained during 1978 show the most interesting effects. Fig. 7 shows the blue (b) and ultraviolet (u) light curves obtained during May and June. The observations have been coded by date so that the changes with time can be more readily followed. As shown, a large increase in light occurs between 0.6 and 0.9 phase between May 26 and May 30. This increase in brightness is over 0.5 mag for the u observations and decreases with increasing wavelength. During the next orbit, this enhancement is gone and the system is significantly fainter.

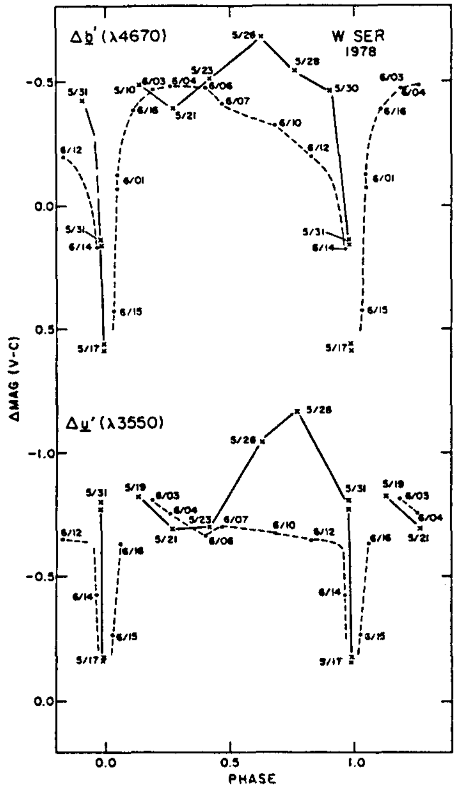

Fig. 7. The differential blue (b) and ultraviolet (u) observations of W Ser are plotted against orbital phase. The observations were made during May and June 1978 and have been labeled with the date of observation.

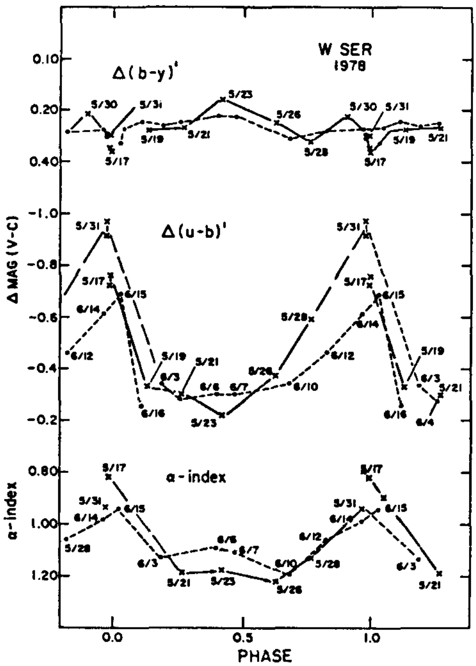

Fig. 8. The differential (unstandardized) (b-y) and (u-b) color indices and the standardized H-alpha indices for W Ser are plotted against orbital phase.

The primary eclipse is relatively sharp and narrow beginning at about 0.94 - 0.95 phase and ending near 0.05 - 0.06 phase. The relative depth of the eclipse (measured with respect to the mean light level at 0.10 - 0.15 phase) is a function of wavelength. The relative eclipse depths are 0.74 mag at λ6580 (H-alpha wide), 1.03 mag at λ5470 (y), 1.05 mag at λ4670 (b), and only about 0.67 mag at λ3500 (u). However, the measure with the H-alpha wide filter does include the H-alpha emission feature and is not a true continuum measure. The u-bandpass contains the Balmer continuum shortward of the Balmer limit at λ3647. The shallow depth of the eclipse in the ultraviolet is most unusual, but is also seen the UBV observations of the system by Lynds (1957).

The differential (b-y) and (u-b) color indices (not standardized) and the H-alpha indices measured during May and June 1978 are plotted against orbital phase in Fig. 8. As shown in the figure, there are only small variations with time and phase of the (b-y) color index. However, the (u-b) index undergoes huge ($\simeq$0.6 mag) changes with orbital phase and with time. The ultraviolet flux is strongest near 0.0 phase and weakest between 0.20-0.50 phase. Also, the ultraviolet flux is enhanced relative to the blue flux during May 28-May 31.

The lower plot in Fig. 8 shows the hydrogen-alpha index plotted against phase. This index is a measure of the net strength of the Balmer H-alpha (emission + absorption) line. The alpha-index is numerically smaller for stars with strong H-alpha-line emission. For W Ser the values for the alpha-index are abnormally small for a stellar source and indicate intense H-alpha emission similar in strength to strong emission line sources such as Be stars, novae, and nebular sources. A phase dependent variation in the strength of the H-alpha emission is inferred from the data which shows the H-alpha emission to be strongest near 0.0 $\pm$ 0.1 phase and weakest near 0.50 $\pm$ 0.25 phase. An interesting feature of the H-alpha index plot is that no significant change in H-alpha emission occured when the light curve showed the large enhancements in the blue and ultraviolet.

At present, it is not possible to model the light curves of W Ser because they deviate so much from light changes expected from the usual binary star interaction (ellipticity + reflection) effects. Some conclusions can, however, be drawn from the observations without detailed modeling.

1. From the spectroscopic studies the object eclipsed at primary minimum is the luminous F2-F5, presumed disk component.

2. The primary eclipse is relatively sharp and narrow, indicating that the fractional radii of the components are probably less than r < 0.15.

3. The primary minimum is deep, indicating an orbital inclination greater than $\gtrsim$ 80 degrees.

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4. The spectrum of the fainter component is not seen from ultraviolet to optical wavelengths. Also, there is no detectable secondary eclipse in the light curves. Combined with (2), we infer that the secondary component (the mass losing star) is a star cooler and smaller than the more luminous component.

5. If we assume that the source of the strong ultraviolet and H-alpha line emissions is gas around the accreting star, (analogous with other Algol-type systems), the unseen star is in contact with its Roche lobe and losing and transfering mass.

6. The copious amounts of gas in the system and the large rate of increase in the orbital period imply that the system is in a very rapid stage of binary star evolution. And if the less luminous component has a small fractional radius, and in contact with its Roche lobe, it probably has already lost an appreciable amount of mass and has a smaller mass than its companion.

7. The cause (or more likely causes) of the large variations in the light curves with time are difficult to explain. Fast Fourier Transform (FFT) analyses of the available photoelectric data (especially those of Fresa (1957)) have been carried out by Craig Robinson at CFA. Interestingly enough, significant periods were uncovered having the following values: 114 days, 60 days, and 1/2, 1/3, and 1/4 the 14.16 day orbital period. Further analyses are needed to ascertain the significance of all or even some of these periods. If real, they could arise from several causes, such as pulsations of the luminous (disk) component and/or instabilities in the disk or variations in the circumstellar gas in the system.

8. The large augmentation in brightness at short wavelengths observed during May 26-31, 1978, could be produced as material from the mass losing component impacts on the outer edge of the accretion disk causing kinetic heating, and producing a "hot spot". This phenomenon is quite common in cataclysmic binaries where the "hot spot" produces a large hump in the light curve.

9. The peculiar wavelength dependence of the relative depth of primary eclipse could be partially explained if there were sources of ultraviolet flux which do not partake in the eclipse. Hot spots on the edge of disk or a large source of continuum ultraviolet flux from an extended envelope surrounding the system are two possibilities. I am sure there are several more possibilities.

Based on the above discussion, Fig. 9 shows a tentative model of the W Ser binary system. This model is proposed only as a starting point and incorporates the semi-detached model common to all Algol-type stars but with the gas stream, accretion disk, and bright spot used to explain features of cataclysmic binary systems.

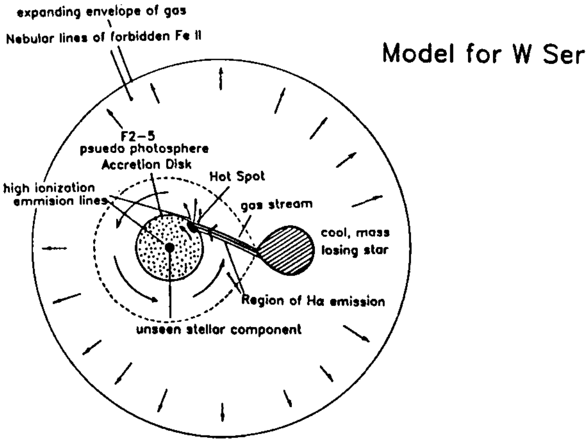

Fig. 9. A very tentative schematic model of W Ser is shown.

5. CONCLUSIONS

As shown in this report and in other contributions at this colloquium, there is still much to be learned from the continued observations of Algol systems. It would be important to carry out truly synoptic, multi-frequency spectroscopic, photoelectric, polarimetric observations of a number of crucial systems. I would recommend organizing international campaigns similar to those carried out nearly 30 years ago with Beta Lyr and SX Cas. With two weeks of concerted effort, most of the important systems could be covered over their orbits from X-ray with Ginga, in the EUV with Voyager, in the FUV with IUE or maybe with HST, in the optical region with several ground-based telescopes, in the IR with the telescopes in Hawaii, and maybe from the air with the Kuiper Airborne Observatory, and into the radio region perhaps with the VLA. Well, why not! Maybe that old adage "the more a system has been observed, the more it deserves to be observed" is true, and we would certainly make giant strides in understanding these complex stars and the astrophysical process taking place by more coordinated intensive observing programs at all wavelengths.

ACKNOWLEDGEMENTS

This paper is dedicated to Dr. F. B. Wood who first stimulated and encouraged my interest in eclipsing binary stars nearly 25 years ago at the University of Pennsylvania. I also wish to acknowledge support from a *William and Flora Hewlett Foundation Grant of Research Corporation*. Also, I wish to thank the Smithsonian Institution for a Visiting Scientist summer appointment at the Harvard Smithsonian Center for Astrophysics. I am also grateful to Joan Feuer for carefully preparing the manuscript for publication.

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DISCUSSION

Plavec showed spectra of W Ser, as they were seen in 1982, both in full light and in primary eclipse. He pointed out that although the spectrum resembled that of an F-type star the helium D_3 line could be seen in emission. The eclipse depth was roughly constant at long wavelengths, but decreased towards the UV. He suggested that the visible spectrum was of a disk rather than a star. In response to a request from Smak, Guinan stated that the subsidiary periodicities he had found in W Ser were $4^{d}_{.}69$ and $3^{d}_{.}54$ - close to one-third and one-quarter of the orbital period of $14^{d}_{.}16$. Parthasarathy suggested that W Ser and BL Tel might prove to be systems in the same evolutionary phase.

Polidan said that _Voyager_ observations of β Lyr show that the disk is highly variable. He believed that perhaps the system contained no BO star - for reasons that he would elaborate in his own paper (p.85). He spoke of plans for an observing campaign by many spacecraft in February and March 1989 when, unfortunately the system would be difficult to observe from the ground. Guinan, who follows the system photoelectrically from Villanova and Arizona, thought it might be possible to join in March.

Olson commented that one could hardly speak of an activity _cycle_ in U Cep. Brightness variations, he thought, were perhaps produced by the kind of S-wave migration seen in RS CVn stars. Bolton pointed out that the variations seen at Hα in Guinan's photometry coincided in phase with the changes from emission to absorption described in the poster paper by Richards, himself and Mochnacki (p.358). He felt they were to be explained by changes in the perspective from which we viewed the "localized region" rather than in terms of Hα emission filling the Roche lobe. Parthasarathy suggested that the variations in the light-curve of β Lyr might be the result of pulsations of the primary star, as were found in the system of υ Sgr. Guinan replied that the variations did not resemble pulsations since the system is not bluer when it is brighter. Moreover, the observed period of 275^{d} was unusually long for pulsations of such a star.