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Stars, Companions, and their Interacions: A Memorial to Robert H. Koch

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Constraining the Mass Loss Geometry of Beta Lyrae

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Massive binary stars lose mass by two mechanisms: jet-driven mass loss during periods of active mass transfer and by wind-driven mass loss. Beta Lyrae is an eclipsing, semi-detached binary whose state of active mass transfer provides a unique opportunity to study how the evolution of binary systems is affected by jet-driven mass loss. Roche lobe overflow from the primary star feeds the thick accretion disk which almost completely obscures the mass-gaining star. A hot spot predicted to be on the edge of the accretion disk may be the source of beta Lyrae's bipolar outflows. I present results from spectropolarimetric data taken with the University of Wisconsin's Half-Wave Spectropolarimeter and the Flower and Cook Observatory's photoelastic modulating polarimeter instrument which have implications for our current understanding of the system's disk geometry. Using broadband polarimetric analysis, I derive new information about the structure of the disk and the presence and location of a hot spot. These results place constraints on the geometrical distribution of material in beta Lyrae and can help quantify the amount of mass lost from massive interacting binary systems during phases of mass transfer and jet-driven mass loss.

Keywords: binaries, jet-driven mass loss, accretion disk, beta Lyrae, mass transfer, hot spot

1. INTRODUCTION

Beta Lyrae is an eclipsing, semi-detached, binary star system. The primary star is a B6-8 II giant that is losing material through Roche lobe overflow. The secondary, B0.5 V main sequence star is surrounded by an opaque accretion disk created by the mass transfer process (Hubeny & Plavec 1991). Bipolar outflows have also been detected in the system (Harmanec et al. 1996, Hoffman et al. 1998). A 'hot spot,' due to the mass stream impacting the edge of the disk, has been theorized to exist but light curves of the system have not revealed its existence.

Recent work by Ak et al. (2007) and Zhao et al. (2008) support our current understanding of the beta Lyrae system. Interferometric images of the system clearly show the disk and primary star as separate objects (Zhao et al. 2008), and the results of an analysis of a larger number of spectra are consistent with the presence of a disk and bipolar outflows (Ak et al. 2007).

Since the system's two stars are hot, gas in the outflows and disk is at least partially ionized. Therefore, the system's observed polarization is due to electron scattering. This process retains geometric information about the scattering region. Consequently, polarimetry can be used to probe the geometric structure of the disk and outflows to determine whether the theorized hot spot exists, since it would create a disruption in the otherwise smooth structure of the disk edge. Polarimetry can also help constrain the location of the source of the bipolar outflows.

2. OBSERVATIONS

Three spectropolarimetric data sets were used in this study. The first data set was originally published in Appenzeller & Hiltner (1967) and taken between 1964 and 1966. The second set of observations was taken with the Flower and Cook Observatory (FCO)'s photoelastic modulating polarimeter instrument between 1987 and 1992. The last consists of 6 years of new and recalibrat-

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ed observations taken with the University of Wisconsin's Half-Wave Spectropolarimeter (HPOL) between 1992 and 1998, a portion of which was originally published in Hoffman et al. (1998).

Each data set has been corrected for interstellar polarization effects and rotated to the average position angle of 164°. This places the majority of the polarimetric variations in the new projected %*q* direction, while the %*u* polarization averages to zero. Only the projected %*q* data are presented here.

The phase for each observation was calculated using the ephemeris

$$T_{pri} = \mathrm{JD}2408247.966 + 12.91378\,E + 3.87196\times10^{-6}\,E^{2}$$

where *E* is the total number of orbits since the primary eclipse that occurred at JD 2408247.966 (Harmanec & Scholz 1993).

3. *V* BAND RESULTS

The %*q* plot (Fig. 1) shows three main morphological features. First, there is a maximum in polarization at primary eclipse when the primary star, a major source of unpolarized light, is being eclipsed by the disk. This reduction in the total unpolarized light causes the percentage of observed polarized light to increase. The second feature is local maxima at the quadrature phases due to light scattering off the disk edge. The third feature is a secondary eclipse in polarized light that occurs before the secondary eclipse in total light (phase 0.483 compared to phase 0.5). It has a corresponding position angle rotation away from 164°. A position angle of 164° is consistent with the system's axis on the sky and indicates the *V* band light is being polarized in the system's disk while the rotation away from 164° implies something is different about the scattering process at phase 0.483. Therefore, we have interpreted this feature as evidence of a hot spot on disk edge.

At phase 0.483, the primary star has already begun its eclipse of the disk and the mass stream should lead the loser as it moves across the edge of the disk (Lubow & Shu 1975). The polarized secondary eclipse should thus occur when the area disrupted by the hot spot and eclipsed by the primary star is maximized. Simple estimates for the size of the hot spot can be made using this new information. Assuming the orbits are circular and the hot spot's height is the same as that of the disk edge, a simple geometric analysis of the polarized light curve gives an estimated maximum hot spot width of approximately 30 solar radii (roughly equal to the disk radius). A similar analysis of the position angle rotation yields a larger estimate. A third estimate utilizes a simple model of the polarized flux of the system. Assuming the polarization of the disk is uniform across the disk edge, this model produces an estimate similar to the geometric analysis of the polarized light curve (about 30 solar radii). Full modeling of the polarized light curves will also help to better constrain the hot spot size.

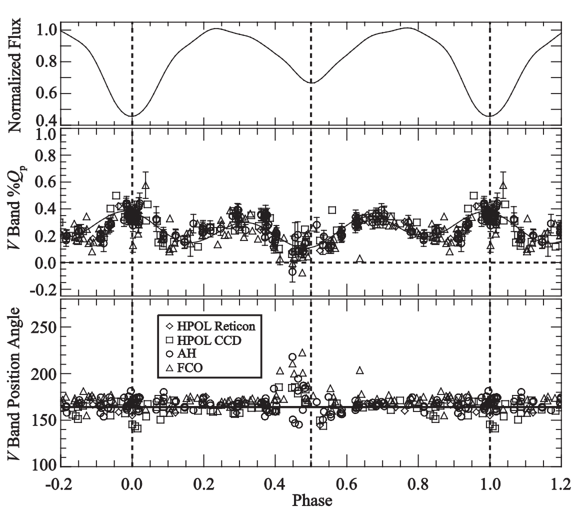

Fig. 1. *V* band polarization of beta Lyrae. *From top:* normalized Fourier fit *V* band light curve (Harmanec et al. 1996), projected *%q* curve, and position angle (degrees) versus phase. The solid curve in the middle panel represents a Fourier fit to the data. The solid line in the bottom panel represents the average position angle of 164°.

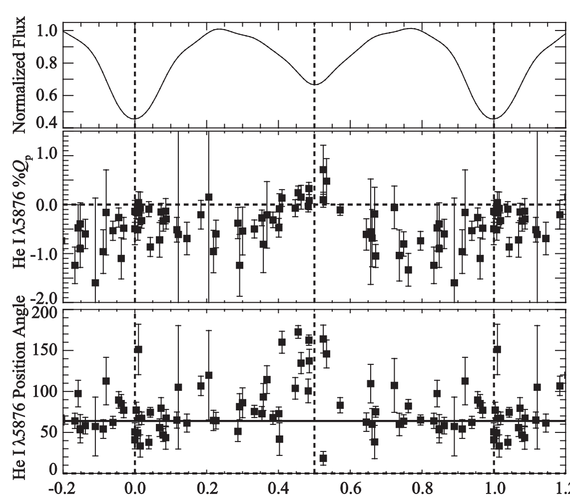

Fig. 2. He I (5,876 Å) line polarization of beta Lyrae. *From top:* normalized Fourier fit *V* band light curve (Harmanec et al. 1996), projected *%q* curve, and position angle (degrees) versus phase. Only HPOL charge-coupled device data are represented here. The solid line in the bottom panel represents the average position angle of 64°.

4. HE I (5,876 Å) LINE RESULTS

The He I (5,876 Å) line is polarized at a position angle (64°) perpendicular to the *V* band polarization and has both a primary and secondary eclipse (Fig. 2) in the projected %*q*. This suggests that the primary scattering region is associated with the bipolar jets and is located close to the plane of the system. The eclipses are also centered on phases 0.0 and 0.5. This is possible if the bipolar outflows do not originate from the hotspot, but rather from a location within the disk near the mass-gaining star. However, future observations with better signal-to-noise and improved phase coverage will allow for stronger constraints on the source of the bipolar outflows.

5. FUTURE WORK

Full results of this study, including *BVRI* band polarimetric analysis, will be presented in an upcoming paper (Lomax et al. 2011).

Long-term periodic behavior has been detected in the beta Lyrae system (Harmanec et al. 1996). However, due to the uneven time coverage of our combined data set, advanced period-finding techniques are required to find such periodicity in the polarization results.

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