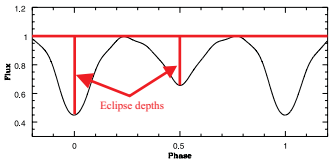
Constraining Disk Properties in Binary Star-Disk Systems

Jennifer L. Hoffman, Kenneth H. Nordsieck (UW-Madison), Barbara A. Whitney (SSI)

ABSTRACT

We have created a Monte Carlo radiative transfer code that models the observed flux andpolarization variations of a binary-disk system. Especially in cases where some system parameters are known from light-curve analysis, studying families of models can help constrain the geometrical and optical characteristics of the circumstellar material. We illustrate this technique by applying it to the disk around the secondary star in the famous eclipsing Algol binary β Lyr.

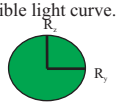
1. Light Curve Analysis



V-band Fourier-fit light curve of β Lyr from Harmanec et al. 1996 (A&A, 312, 879).

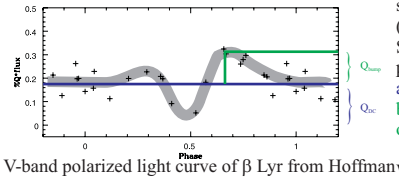
We started with a simple model geometry: an ellipsoidal primary star and an opaque disk shaped like a spherical wedge. Using a geometrical analysis similar to that of Huang 1965 (ApJ, 141, 976), we solved for sets of system parameters (α and R_z) that yielded the correct eclipse depths in the visible light curve.

(inner star not included in light curve calculation)



(R_z/R_y ratio of 0.85 simulates a Roche lobe)

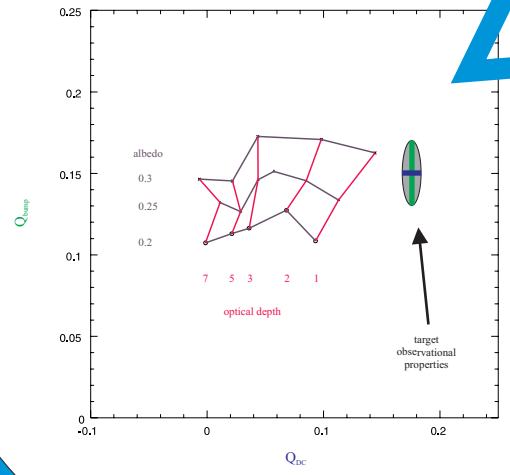
2. Polarization Analysis



V-band polarized light curve of β Lyr from Hoffman et al. 1998 (AJ, 115, 1576), with gray curve drawn by hand to guide the eye.

The polarized light curve has two characteristics we would like to match: A roughly constant "DC" signal and "bumps" at near-quadrature phases. (Here, we use "Q" to refer to polarized flux in Stokes Q, along the system axis.) Based on our previous modeling results, we assume the DC signal arises from self-scattering of disk emission, and the bumps are due to light from the outer star scattering off the edge of the disk.

We calculated Q_{DC} and Q_{bump} from our observed polarized light curves, and used these as benchmarks for analyzing the success of our models.



3. Model Grid Construction

Using a set of geometrical parameters found in step 1 (to ensure an approximate light-curve fit), we constructed a grid of Monte Carlo models of the star-disk system. The models consider electron scattering plus bound-free absorption. (For a description of the code, see Hoffman 2000, ASP Conf. Ser. 214, 464.) We varied two optical parameters: the optical depth and the albedo (≡scat/(scat+abs)) of the disk material--both of which we took to be constant throughout the disk--and calculated the resulting Q_{DC} and Q_{bump} for each combination. Different geometrical parameters from step 1 yielded similar results to the ones shown here.

We found that Q_{bump} is relatively insensitive to optical depth, but varies directly with albedo. Albedos of 0.25 to 0.3 yield good matches for Q_{bump}. We prefer high optical depths because they result in better fits o the light curve (since we assumed an opaque disk in step 1). However, lower optical depths come closer to matching Q_{DC} than do higher values. But even an optical depth of 1 does not result in high enough DC polarization levels from the disk alone.

Therefore, we believe (for this simplified picture) the inner mass-gaining star must contribute to the polarized light, even though spectroscopic studies have shown that it does not contribute appreciably to the total system light.

4. Conclusions

Our model results lead us to the following conclusions:

- ★ Q_{bump} is a good indicator of disk albedo.
- ★ Q_{DC} increases with decreasing disk optical depth.

Comparing model results with observations of β Lyr shows that

- ★ Disk self-scattering alone cannot produce the observed DC level of polarized light. Therefore, the interior star must contribute to Q_{DC}.
- ★ Since Q_{DC} requires a low optical depth but the interior star is not seen in the spectrum, the disk cannot have a uniform optical depth. It may be that a disk midplane region of high optical depth hides the direct light from the inner star, while a surrounding region of low optical depth produces the observed Q_{DC}.

Future Directions:

In future models, we will investigate the effects of the interior star on the polarized light curve, and also test the disk with nonuniform optical depth proposed above. We will assess the extent to which our models yield reasonable physical disk properties by using our albedo and optical depth solutions to calculate disk density and temperature. Finally, we will use polarimetric observations at other wavelengths to constrain our models of the disk structure.