Accretion Disks in Long-Period Algols

RX Geminorum

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We describe multicolor photometric solutions of the long-period Algol RX Geminorum, accretion disk kinematics deduced from phase-dependent radial velocity observations of disk Hα emission and fits to Hα profiles using a non-LTE disk model.

Keywords: accretion disk – Hα emission profiles

1 Introduction

In long-period (P > 10 days) Algols mass-transferring streams from losers miss the gainer photospheres and supply low density accretion disks. Such binaries are large, low energy analogues of cataclysmic variables and other active binaries. Depending on systemic mass loss during post main sequence evolution, some losers may be nearly stripped to their original hydrogen burning cores. While Algol accretion disks radiate weakly at Paschen continuum wavelengths, double-peaked Hα emission is often a prominent feature of their optical spectra. Disk continuum and hydrogen-line emission are diagnostics of the structure and rotation of such disks (other lines, mostly in the ultraviolet, map mass loss in jets and other structures). We describe some properties of optical disk radiation and calculate approximate non-LTE disk models for RX Geminorum, based on photometric and spectroscopic observations.

We began intermediate band *Iybvu* photometry of about a dozen long period Algols in the early 1980s, using the University of Illinois 1-m reflector at the Mount Laguna Observatory. When a CCD detector became available for the Cassegrain spectrograph in 1989, we began Hα, Hβ, MgII 4481 and OI 7774 spectroscopy. Because of low amplitudes and contamination by circumstellar matter, gainer radial velocity (RV) curves are unreliable. Weak loser lines near Hα yield undisturbed loser RV curves. Absolute binary parameters, needed for disk model calculations, rely on photometric mass ratios from these mostly semidetached binaries.

RX Gem spectra were obtained from 1990 through 1998. We obtained light and radial velocity solutions using the Wilson (1992) Eclipsing Binary Model (Olson and Etzel, 2001).

2 Basic Properties

RX Gem (HD 049512 = SAO 059533; A0 + K2; P=12.2 days) is currently a deeply but partially eclipsing binary (evidence exists of significant light curve changes during the 20th century). Hα emission is fairly weak in RX Gem, reflecting the low density of circumstellar matter, which is also consistent with the high quality of simultaneous *Iybv* photometric solutions. No third light was found, indicating high disk transparency at these wavelengths. The key to good photometric solutions is the supersynchronous rotation of the gainer (18 to 19 times the synchronous rate; equatorial velocity about 250 km s^{-1}). High rotation of at least the optically thick outer layers of the gainer results from angular momentum accretion from the disk. It is a common property of the long-period Algols in our sample. The photometrically-determined gainer rotation is significantly larger than the spectroscopic (which is 11 times synchronous in RX Gem). Similar differences are present in other Algols. A discussion of these disparities is beyond the scope of this paper.

Photometric solutions in u using the geometry from the *Iybv* solution require third light, which must be disk continuous emission. The ratio of disk to stellar light (at 3440Å) is about 0.2, so disk u light dominates loser light. This is also true in other long period Algols. Models of the accretion disk must explain both Hα profiles and ultraviolet continuous emission.

3 Hα Emission in RX Gem

Olson and Etzel (1995) observed nearly chaotic variations in Hα emission in long-period Algols. We found no obvious clues to the nature of these variations. At the time we may have been influenced by dwarf no-

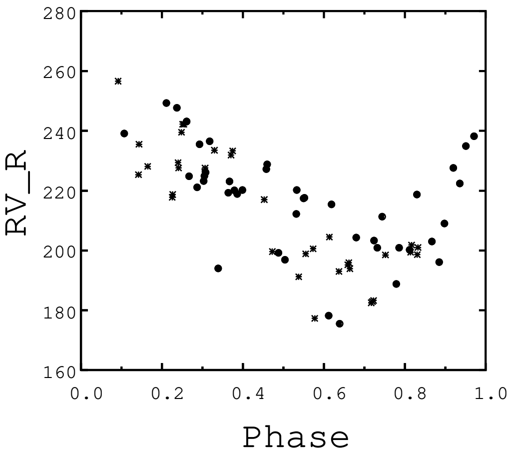

Fig. 1: Radial velocities of Hα red emission lobes relative to the hot gainer. Filled circles represent 1990 to 1996 observations; stars represent 1998 observations

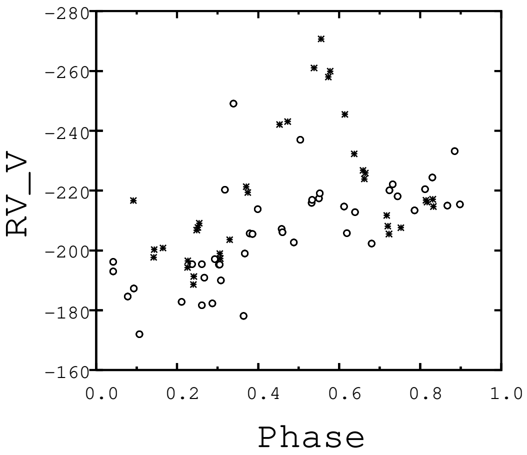

Fig. 2: Radial velocities of Hα violet emission lobes relative to the hot gainer. Open circles represent 1990 to 1996 observations; stars are for 1998

vae disks, where variations are now traced to a disk instability. More detailed consideration of Hα behavior in RX Gem and other long period Algols suggests that stream-disk impact variations probably explain Hα changes. The following observations led us in this direction.

During eight years of RX Gem Hα observations we noted three occasions when abrupt brightness increases appeared in one (red (R) or violet (V)) emission lobe. All originated in the stream impact region of the disk. In five other long period Algols, 20 of 22 such instances were also associated with stream impact. Therefore, mass transfer 'bursts' probably account for sudden Hα emission increases. Bursts also occur some short period Algols, such as U Cephei. By Occam's razor, all disk variations in long-period Algols may well be driven by transfer changes.

RVs of R and V emission lobes relative to the gainer, plotted as a function of orbital phase in Figs. 1 and 2, reveal disturbances in disk rotation that support the disk impact idea. Lobe emission profiles are asymmetrical but plots are similar, whether mean or peak lobe wavelengths are used. Circular rotation should yield constant RVs (observations when the loser partially eclipsed the disk are not plotted). Circles represent RVs from 1990 through 1996, while those from 1998 are stars. During the 1998 season Hα emission increased to the largest values we have seen in this binary.

R-lobe variations are smaller than those of V-lobes, and do not share the large temporal changes seen in the latter. Larger R-lobe RVs for phases 0.1 to 0.2 and 0.9 and 1.0 may arise from stream motion, since the stream recedes from the observer at these phases. R-lobe disk rotation may be least disturbed between phases 0.4 and 0.8, where we see that part of the disk opposite the stream impact. The apparent disk rotation at these phases ranges from 180 to 220 km s^{-1}. V-lobe and R-lobe behavior differ, reflecting the optically thick character of Hα emission.

We probably see the least disturbed disk rotation in the V lobe at phases 0.1 to 0.3, where again we view the non-impact part of the disk. Before 1998 the velocity of approach slowly rose after phase 0.3. As far as about phase 0.7, this increase may reflect an acceleration of disk rotation from stream impact. The general transfer rate was probably higher in 1998, producing markedly different V-lobe behavior. The approach velocity then rapidly increased between phases 0.2 and 0.55, reflecting the increased angular momentum from stream impact. But a well-defined decrease in approach velocity occurred between phases 0.55 and 0.7. Are we seeing the projection of still-accelerating stream material in this range? Independent of the details, it is likely that stream impact has influenced Hα emission, particularly in the V lobes. It remains to be seen if such features are present in other Algol disks.

4 Non-LTE Disk Models

We selected R-lobe emission profiles in the phase range 0.4 to 0.8 for modeling, as suggested by the RV results discussed above. Observed profiles, corrected for the underlying Hα absorption, are plotted in Fig. 3 as filled circles. Peak Hα emission is about 1.6 times the total continuum emission. The scatter in this plot derives from intrinsic intensity variations and from appreciable profile changes. The latter changes are consistent with the RV scatter of 30 to 40 km s^{-1} shown in Fig. 1. The variations in R-lobe disk rota-

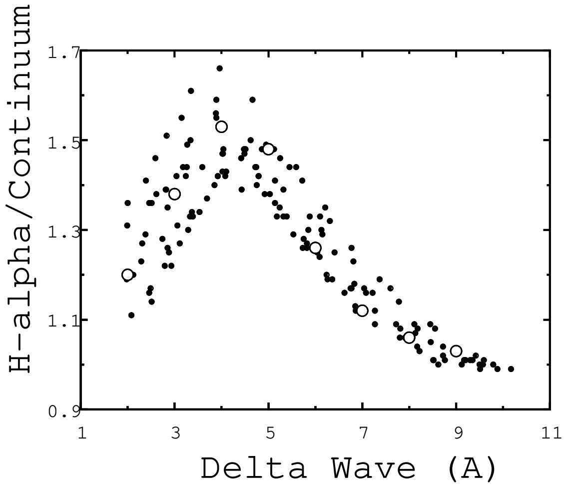

Fig. 3: Hα red-lobe emission profiles from 1998 observations (filled circles). Open circles are predictions from the non-LTE disk model described in the text

tion noted above likely produce much of the horizontal scatter in Fig. 3 profiles.

Olson (1991) described a diagnostic non-LTE code for predicting H-line and continuum emission from Algol accretion disks. This code has not been used much, because Hα emission profiles alone do not constrain models tightly. That is, calculated and observed profiles can be matched over a wide temperature range by suitable adjustments to disk pressure. However, new information on disk continuum emission from photometric solutions removes much of this uncertainty.

In this non-LTE code, temperature and pressure radial dependences are specified; they contain adjustable parameters for matching predictions to observations. Hydrostatic equilibrium in the gravitational fields of both stars obtains normal to the orbital plane. Circular Keplerian rotation is assumed (but the rotation recipe also contains adjustable parameters). Hydrogen excitation and ionization are determined in each disk integration cell by statistical equilibrium set by the stellar radiation fields, by optically thick Balmer-line radiation from the disk plane, and by electron collisions. At a fixed wavelength in the emission profile, only cells whose projected RVs shift the intrinsically narrow emission coefficients to the wavelength of interest may contribute to the emergent line radiation. Unlike LTE calculations, this code predicts small Hβ to Hα emission ratios, in qualitative agreement with observations.

Fig 3 shows the mean, predicted Hα emission profile as open circles. Circular Keplerian rotation is assumed. As already noted, departures from such rotation probably explain disagreements between model predictions and observations. Similar agreement is found for inner disk temperatures from roughly 7000 to 12,000 K (by suitably adjusting temperature gradient and pressure). However, disk continuum emission rules out models below about 10,500 K. The inner disk temperature is somewhat higher than the mean gainer photospheric temperature of 9500 K. The total disk mass (twice the R-lobe mass) ranges from 3×10^{-10} to 2×10^{-9} $M_\odot$. The disk in RX Gem is indeed of low mass. Even at modest transfer rates, disk matter is probably replaced on a time scale of a year or less.

5 Conclusions

Radial velocities of red and violet Hα emission lobes in RX Gem reveal kinematical effects of stream impact on the accretion disk. Variations in Hα brightness are probably produced by mass-transfer changes. Varying kinematical effects of such transfer changes are apparent in violet-lobe radial velocity variations. A non-LTE model of Hα disk emission, constrained by disk continuum emission inferred from photometric solutions, yields fair agreement with observations and suggests a low disk mass.

We thank the directors and staff of Mount Laguna Observatory for the considerable amount of flexibly-scheduled observing time required for full orbital coverage of photometry and spectroscopy of long period Algols. Partial support was provided by the National Science Foundation through Grants No. AST-8822351 and No. 9115033 to E.C.O. and No. AST-8822790, No. 9115104, and No. 9417035 to P.B.E. We also thank Bob Wilson for his Eclipsing Binary Computer code. E.C.O. thanks Dimitri Mihalas for assistance in beginning non-LTE calculations. Mount Laguna Observatory is jointly operated by San Diego State University and the University of Illinois at Urbana-Champaign.

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