Hα OBSERVATIONS OF ALGOL-TYPE INTERACTING BINARY SYSTEMS

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ABSTRACT

An observational study of the Hα feature in Algol type binary systems has revealed the presence of emission in nearly all systems with periods greater than 6 days. The disks which produce this emission are generally thin and can extend out to 90% of the Roche surface of the primary star. If emission is found in the systems of shorter period, it tends to be transient, lasting only a few orbital cycles. In several systems, there is evidence of mass loss from the vicinity of the primary at phase 0.5.

1. INTRODUCTION

In this paper, initial results are presented from a study of the Hα feature in interacting binaries of the Algol type. Algol systems displaying a wide range in period are being observed at Kitt Peak National Observatory in order 1) to look for the presence of emission in Hα which implies the existence of a circumstellar disk of relatively low density ($N_e \simeq 10^{10} cm^{-3}$) and 2) to look for and interpret phase dependent profile variations in Hα which provide information on the dimensions of the Hα emitting disks, the extent of the asymmetry in the disks, and whether there is evidence of mass outflow in the systems. Since circumstellar disks radiate most strongly at Hα, this feature can reveal more information about the geometry of and physical conditions in these disks than the other emission features which the pioneering researchers on Algol disks (i.e. A. H. Joy and O. Struve) analyzed.

The data base for this investigation include 1) Varo image tube spectrograms (11 - 33 A mm^{-1}) obtained at Lick Observatory during 1973 - 1976 in collaboration with Drs. M. Plavec and R. S. Polidan and 2) Carnegie image tube plates recently obtained at Kitt Peak National Observatory with the 0.9 m Coudé Feed telescope. To date nearly 50 systems have been observed at least once and we have good phase coverage for about 10 systems. About half of the sample are "short" period systems ($P \simeq 3^d$) while the other half have periods > 5^d.

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 287–292.

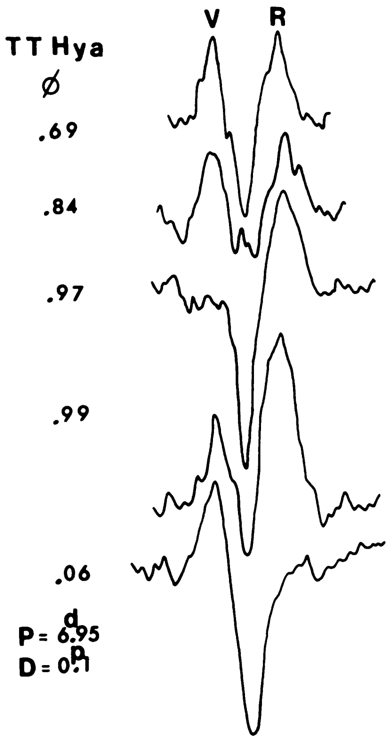

Fig. 1. Phase dependent Hα profile variations in TT Hya.

2. RESULTS

This investigation has revealed that Hα emission is common in systems with periods greater than 6 days. Furthermore, this emission persists for a large number of orbital cycles (≳100). However, there appears to be no correlation between the intensity of the Hα emission and the period of the system. In fact, one system, V889 Aql (P = $11^d.1$) shows no trace of Hα emission, even during eclipse. Alternatively, Hα emission is rare in systems with periods less than 6 days. If emission is found, it tends to be transient, lasting only a few orbital cycles or less.

Let us now direct our attention toward the long period systems. Shown in Figure 1 is a series of Hα profiles observed in TT Hya, a system which displays strong ($I \simeq 1.3 I_c$) Hα emission. These profiles illustrate the type of phase dependent variations frequently seen in long period Algols. Near quadrature, we observe a two component feature which is formed in a disk which co-rotates with the primary. In TT Hya, the width of the emission feature implies that the Hα emitting region is located $7.5R_\odot$ ($3.75R_p$) from the primary. As the disks of Algol primaries undergo eclipse, we typically observe the type of Hα profile variation shown in the latter three profiles in Figure 1. The fact that one observes a complete occultation of the V and R lobes in systems such as

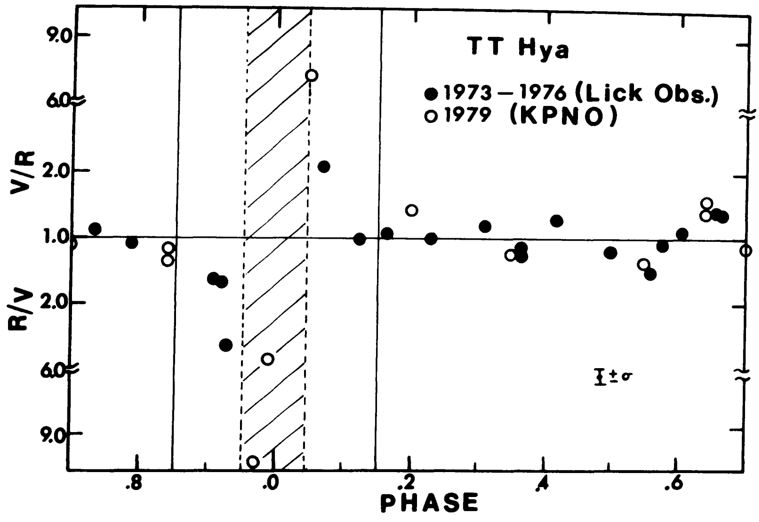

Fig. 2. V/R in Hα versus phase for TT Hya. The thin vertical lines between 0.85 < ϕ < 0.15 delineate the domain where the secondary occults the Roche surface of the primary. The cross-hatched region indicates the duration of primary eclipse.

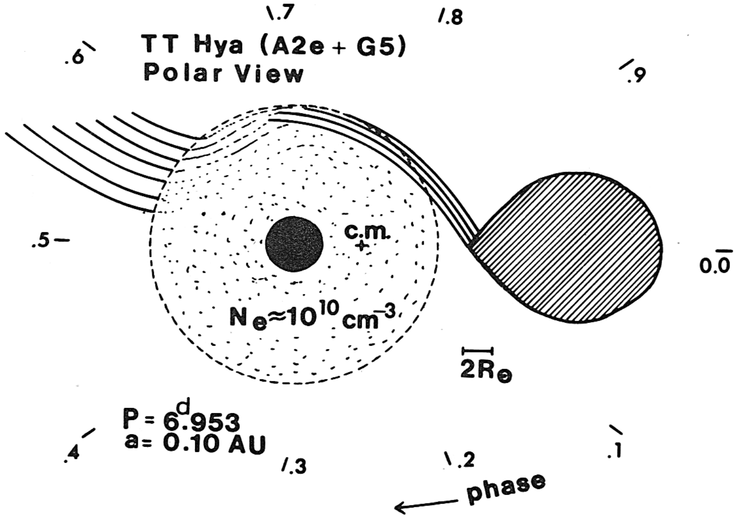

Fig. 3. A model suggested for TT Hya based upon the Hα observations discussed in this paper. The system is drawn to scale using the masses and radii given by Popper (1979).

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TT Hya and RX Gem which barely display a total eclipse, implies that the disks are thin, $\simeq 1R_p$, in vertical extent. The emission observed at central eclipse is from the periphery of the disk. If the particles are in stable Keplerian orbits about the primary, the width of the Hα feature implies that the disk extends out to $10.4R_\odot$. As the radius of the Roche surface of the primary in TT Hya is $10.5R_\odot$, the observations suggest that the disk extends out to this limit. The latter result is supported by the general phase dependent behavior of the Hα profile. In Figure 2, we see that the V lobe of Hα begins to weaken at $\phi = 0.85$, the phase at which one would expect occultation to commence if the disk extended out to the Roche surface. Also notice that the receding part of the disk appears to be less extended than the approaching side. Outside of primary eclipse, $V/R \simeq 1.0$, except for the region around $\phi = 0.5$ where $V<R$. Observations of both TT Hya and RX Gem reveal the presence of deep, blue-shifted cores ($v \simeq -30$ km s^{-1}) near $\phi = 0.5$. In TT Hya, the strength of the core suggests a mass outflow from the vicinity of the primary of $2.5 \times 10^{-8} M_\odot$ yr^{-1}. Finally, it can also be seen from Figure 2 that the cyclic profile variations have persisted for at least six years. Variations recently observed at KPNO are identical to ones seen in the earlier Lick Observatory data.

A model has been developed for the TT Hya system based solely on the Hα observations. This model is shown, drawn to scale, in Figure 3. An Hα emitting disk of density $10^{10} cm^{-3}$ extends to the Roche surface of the primary; it is less than $1R_p$ in vertical extent. The density was obtained from the equivalent width of Hα with the aid of a formula developed by Wellman (quoted in Pagel 1960). We assume the secondary fills its critical Roche surface. The nature of the gas stream should be regarded as speculative. Its thickness and angle are based upon the assumption that it is similar to the stream observed in HR 2142 (Peters 1976). The streamlines near $\phi = 0.5$ represent the observed mass loss discussed above.

All long period Algol systems observed to date with sufficient phase coverage display the same type of profile variations observed in TT Hya. Some minimum sizes deduced for disks (in terms of the Roche radius) are: RX Gem (0.9), AU Mon (0.6), V393 Sco (0.3), AD Her (0.5), and AW Peg (0.4). Recent theoretical studies by Lubow and Shu (1975) suggest that the disks should be small (<0.3) while Paczynski (1977) predicts that the disks can extend out to 90% of the Roche surface of the primary. The Hα observations discussed in this paper are more compatible with the latter.

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COMMENTS FOLLOWING PETERS

Shu: A number of developments of the past few years have convinced me that accretion disks are often larger than what Lubow and I had proposed in 1975. Nevertheless, I would like to make the following cautionary remark. The densities you and other speakers this morning have deduced refer to relatively low density material. This material might well contribute to most of the emission lines and polarization, but it may tell us little about what most of the mass is doing.

Peters: I agree. Perhaps the detailed analysis of the sharp absorption features will make my analysis more complete.

Hall: Since Hα emission must come from optically thin regions, your observations probably have outlined the maximum extent of the thin, outer parts of the disk. It is possible that the disk may be optically thick closer in, in which case it would appear as part of the "radius" in a standard solution of UBV light curve, for example. That prompts me to point out that radii of the mass-gaining star in most long-period Algols (listed in Acta Astronomica 24, 215) fall clearly above the main sequence in an M vs. R diagram. I suggest that a fuller picture will be given if the wide-band and narrow bands are looked at together.

Peters: Such a photometric project would be a nice supplement to a spectroscopic one such as the one I described.

Smak: Could you estimate the inner radii of disks?

Peters: The density in the disk most assuredly increases uniformly toward the primary star. It is the gas which has a (low) density of 10^{10} cm^{-3} which produces most of the Hα emission we observe. I intend to analyze the detailed Hα profile (emission plus sharp absorption) as a function of phase throughout eclipse and perhaps this analysis will provide information on the density and extent of the denser inner disk.

Whelan: Could you directly determine the electron density, N_e, from the Balmer decrement, rather than using estimates of the volume of the disc?

Peters: Yes, upon making a number of assumptions about the gas in the disk (e.g. radiative transfer in the functional form of the density gradient in the disk, whether LTE prevails, etc.); currently my data base does not include the higher Balmer lines but I intend to supplement my Hα data with "blue" spectrograms and ultimately use Balmer decrements as well as the strengths of other Balmer lines to obtain a better estimate for N_e in the disk.

Bolton: What was the velocity separation of the Hα emission peaks in the spectra you showed us?

Peters: It is 500 km s^{-1} outside of eclipse and 400 km s^{-1} during central eclipse when the material with a higher velocity of rotation is occulted by the secondary star. Incidentally, the velocity separation during eclipse is compatible with the disk extending out to the Roche surface of the primary if it is assumed that the emitting H atoms are in Keplerian orbits.

Bolton: The emission profiles are lying on top of a rapidly varying continuum--the absorption profiles of the underlying stars. If this continuum can be rectified by subtracting the absorption profiles, you can extract considerable kinematical information even outside eclipse. My experience with Algol and other stars indicates this is a worthwhile procedure.

Peters: I intend to model these systems by analyzing the complex $H\alpha$ feature as a function of phase.