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Fluorescence and Chromospheric Activity of V471 Tau

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Abstract. The red dwarf + white dwarf eclipsing binary V471 Tau shows a variable Hα feature that varies from absorption during eclipse to maximum emission during white dwarf transit. In 1998 we obtained simultaneous $BVRI$ photometry and Hα spectroscopy, with thorough phase coverage of the 12.5 hour orbital period. A binary star model was used with our light curve, radial velocity, and Hα data to refine stellar and orbital parameters. Combined absorption-emission profiles were generated by the model and fit to the observations, yielding a red star radius of $0.94R_{\odot}$. Orbital inclination 78° is required with this size and other known parameters. The model includes three spots 1,000 K cooler than the surrounding photosphere. The variable Hα profile was modeled as a chromospheric fluorescing region (essentially on the surface of the red star) centered at the substellar point. Additional emission seen outside our modeled profiles may be large co-rotating prominences that complicate the picture.

1. Introduction

V471 Tauri is a member of the Hyades cluster and a detached binary comprised of a tidally distorted, rapidly rotating ($P_{\rm rot} = P_{\rm orb}$) K2V red dwarf and a white dwarf in a 12.5 h orbit, and with a brown dwarf companion discovered by means of a light-time effect in eclipse timings (Guinan & Ribas 2001). The binary has been the subject of intense studies regarding common-envelope evolution, precataclysmic variables, magnetic and chromospheric activity, phase dependent Hα emission, and period changes.

Here we focus on the active K dwarf by requiring self-consistent solutions to our line profiles and light curves. Synthesized line profiles were compared to observed profiles to determine the star's radius, while model light curves were fit to the photometry. Three dark photospheric spots were needed in our light curve models to fit the data. The differential corrections (DC) routine in a binary star program (Wilson and Devinney, 1971; Wilson, 1979; 1990) was simultaneously applied to radial velocity and light curve data to refine stellar, orbital, and spot parameters. We then modeled Hα profiles for the region around the K star's substellar point where far ultraviolet light from the white dwarf is absorbed and reprocessed (*i.e.* fluorescence).

2. Observations

Simultaneous *BVRI* CCD photometry and Hα region spectroscopy were obtained at Kitt Peak National Observatory (KPNO) from October 29 to November 9, 1998. The data will be published in a forthcoming journal paper that will expand upon this preliminary note.

CCD images were acquired with the 0.9m SARA (Southeastern Association for Research in Astronomy) telescope. We imaged about 800 frames per bandpass of a 9 arc minute square field that contained V471 Tau and comparison star BD+16° 515. Exposures ranged from 7 seconds in *I* to 40 seconds in *B*. Differential magnitudes were determined with IRAF's DAOPHOT aperture photometry package.

Spectra were taken with the 0.9m Coudé Feed Telescope and F3KB CCD. Exposures of 30 minutes yielded S/N $\approx$ 70. The spectra are centered near 6525 Å, span nearly 300 Å, and have a dispersion of 0.12 Å per pixel. Wavelength calibration was with a Th-Ar lamp. Standard IRAF routines were used in the data reductions.

3. Analysis

We fit a model absorption profile to spectra taken during total eclipse of the white dwarf (Fig. 1). None of the K dwarf's illuminated chromosphere can be in view at that time so the profile should represent the non-irradiated photosphere (with spots). Rotation is the only broadening mechanism in the model. Since the star is known to rotate synchronously and the radius estimated from line profiles depends only weakly on i, adjustments in the K dwarf's size were made so as to fit the profile, leading to a radius of approximately $0.94\,R_\odot$. The inclination was accordingly changed to reproduce the observed eclipse width, given $R = 0.94\,R_\odot$, and light and radial velocities were again fit so that all parameters were consistent. Table 1 lists the results. Parameters with error estimates were adjusted by *DC* while the others were assumed. The radial velocity curves and images of the stars at key phases, with spots, are in Fig. 2. Our photometric data are compared to model light curves in Fig. 3. A similar red star size and orbital inclination were found by O'Brien, Bond, & Sion (2001) and Bond et al. (see page 239). Their stellar masses, along with the orbit size, are slightly different from our results. The discrepancy stems from their velocity analysis of each star (giving a mass ratio, q) and our assumption that $q = 1.00$. The two results agree within the reported errors.

The illuminated (fluorescent) area is determined by the geometry and covers an angular radius of 76° as measured from the center of the K star. We fit the emission level of our model to the observed fluorescing chromosphere at quadrature since an additional, more Doppler shifted, source is apparent (Fig. 1). Phase redundancy shows this emission to vary in strength and wavelength with the orbit, so it may be a co-rotating source such as a prominence. The

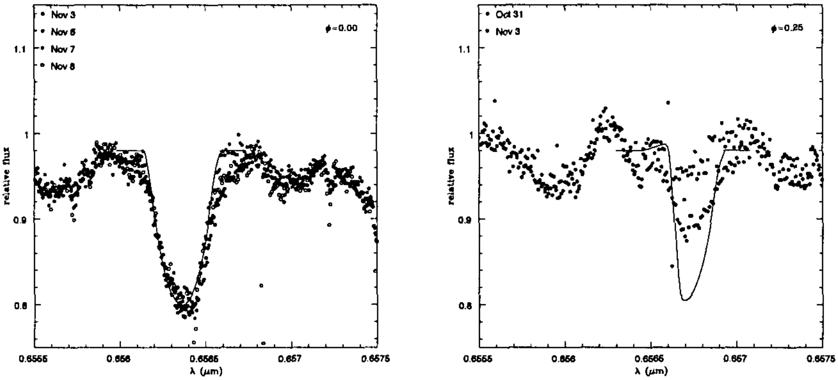

Figure 1. Observed spectra of V471 Tau (dots) and the modeled Hα profile (continuous line). The observations are binned at every $0.^P01$ phase, in bins $0.^P01$ wide. Telluric lines have not been removed but in general appear shifted, as the spectra are Heliocentric. (Left panel): spectra taken during eclipse for which we fit a model absorption profile that sets the photospheric contribution of the K star. (Right panel): spectra at quadrature (the illuminated chromosphere is approaching). The emission level of our profile model is set to the fluorescing region, which appears to be the small blue shifted bump. Stronger emission is seen further blue shifted.

Table 1. V471 Tau parameter solutions.

Parameter	Value
T_0 (HJD_0)	2451119.7274±0.0002
P	0.52118334 days
e	0.00
q	1.00
a	$3.172 \pm 0.008\, R_\odot$
V_γ	$40.5 \pm 0.3\,\mathrm{km\,s^{-1}}$
i	77°.5
T_{wd}	32,400 K
T_{rd}	5,000 K
M_{wd}	$0.79\ M_\odot$
M_{rd}	$0.79\ M_\odot$
R_{wd}	$0.009\ R_\odot$
R_{rd}	$.936\ R_\odot$

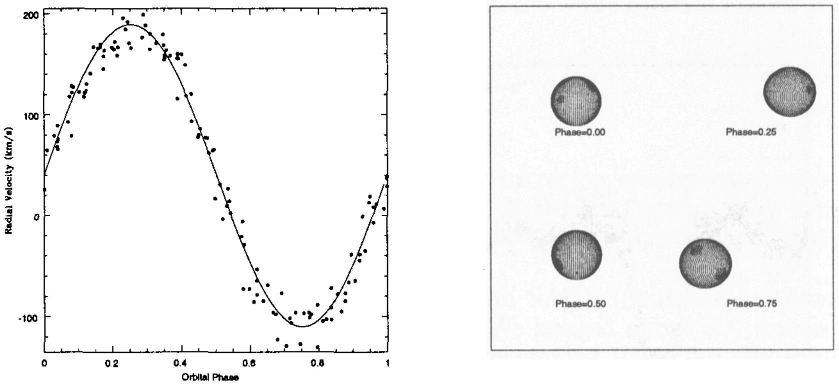

Figure 2. (Left panel): K star radial velocity curves of our data (points) and the model fit (solid line). (Right panel): Scaled pictures of the binary showing the spots.

wavelength displacement of the excess is consistent with an extended structure about 10^5 km above the surface. This structure could be associated with the spot seen near the substellar point (see the bottom left of the right panel in Fig. 2). UV absorbing material above spots has been noted by Guinan & Carroll (1990). Similar structures have been detected on the rapidly rotating, non-interacting K dwarf AB Dor (Cameron & Robinson 1989). The excess emission contaminates the chromospheric fluorescence during white dwarf transit and is red shifted further than expected for the receding illuminated region at phase 0.75 (Fig. 4). Our model profile at phase 0.5 indicates that the absorption is little more than filled in by the fluorescence, consistent with the *non-emission* detection made in 1992 by Rottler et al. (1998).

4. Conclusions

It is clear from the spots and excess Hα emission that V471 Tau was active during 1998. A possible connection exists between the excess emission and the spot modeled on the inner-facing hemisphere. This makes it difficult to fit our model to the emission level of a profile expected from the fluorescing chromosphere alone. The activity history favors an 11 – 12 yr cycle. We might expect quiescence in 2003/4 if the 1992 lack of emission (Rottler et al. 1998) represents a minimum. Large prominences may provide mechanisms for mass loss, exchange, and angular momentum loss via magnetic braking, all of which may contribute to orbital period changes.

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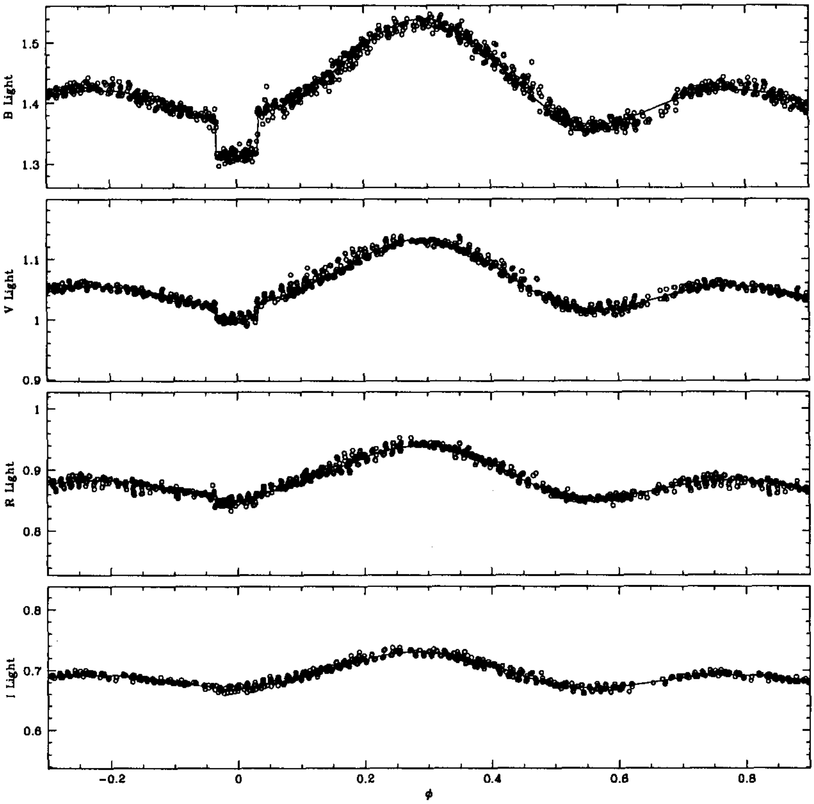

Figure 3. BVRI light curves of our data (points) and the model fit (solid line). The plots are in *light* vs. phase.

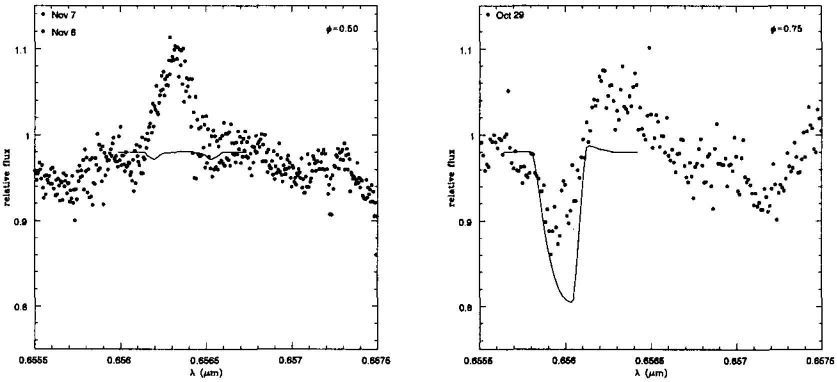

Figure 4. (Left panel): Hα emission during white dwarf transit. The excess appears to overlap and dominate the expected fluorescing region, appears narrower than expected from the illuminated chromosphere alone, and is still a bit on the blue side of the K star's line center. (Right panel): The excess emission recedes and is red shifted more than the modeled fluorescent zone.

References

Cameron, C., & Robinson, R. 1989, MNRAS, 238, 657

Guinan, E., & Carroll, S. 1990, in Active Close Binaries, ed. C. İbanoğlu (Dordrecht: Kluwer), 7

Guinan, E. F., & Ribas, I. 2001, ApJ, 546, L43

O'Brien, M., Bond, H., & Sion, E. 2001, ApJ, 563, 971

Rottler, L., Batalha, C., Young, A., & Vogt, S. 1998, BAAS, 30, 920

Wilson, R. E. 1979, ApJ, 234, 1054

Wilson, R. E. 1990, ApJ, 356, 613

Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605