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Accretion structures of DR Tau

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Abstract. We present some results of time series spectroscopy of the Classical T Tauri star DR Tau. Profile variability at Hδ indicates the rotation of magnetically-rigid accretion streams, and seems to be associated with a 1.5 day period. Time-lagged correlations in several emission lines are interpreted as the signatures of an accretion shock passing over the limb of the star.

1. Introduction

Classical T Tauri stars are pre-main sequence dwarfs which accrete matter from a circmstellar disk, probably via a strong stellar magnetic field (Königl, 1991). This process may well lead to the formation of rigid accretion funnels corotating with the star (e.g. Shu et al, 1994, Paatz & Camenzind, 1996). We carried out a campaign of spectroscopic monitoring of six Classical T Tauri stars in order to detect evidence for such circumstellar structures and hence constrain the magnetic properties of the systems. Here, we report the results for DR Tau. The results for the full sample are discussed in Smith et al (1999). The profile variability of DR Tau is discussed in Smith et al (1997).

2. Observations

The observations were carried out in December 1995 at the Isaac Newton Telescope at Roque de los Muchachos on La Palma. We used the INT's intermediate dispersion spectrograph, and a 300 lines/mm grating, giving a dispersion of approximately 3.3Å per pixel over a wavelength range from 3900 to 7000Å. Five

successive nights of data were obtained. Each star was observed approximately once an hour.

3. Profile variability at Hδ

Variable absorption was seen in the red wing of Hδ. for DR Tau. Figure 1 shows the time series of Hδ equivalent width. Spectra showing redshifted absorption in the red wing of Hδ are marked with downward-pointing triangles. The natural explanation for absorption in the red wing of an emission line is that it indicates that an accretion stream is aligned with the line of sight. The best interpretation of variability is that streams of infalling material are passing through the observers line of sight, carried by the rotation of the star and its magnetosphere. Three episodes of absorption are evident, on the second, third and fifth nights. These seem to repeat with a period of approximately 1.5 days. This can be contrasted with a detected 2.8 day photometric period for DR Tau found by Bouvier et al (1993). [Note that this is only one of several periods previously found for DR Tau - see also Bouvier et al, 1995]. the 1.5 day period in the absorption events might indicate a harmonic of an underlying period of approximately 3 days, which then implies two equally-spaced accretion streams. Such a configuration is suggestive of an inclined dipole geometry.

Inspection of the profiles reveals that the redshifted component lies further into the red on night 2 than on nights 3 and 5. This may indicate that on nights 3 and 5 we are seeing a region of the stream where the material is flowing more slowly, perhaps further from the star. The absorption is seen to deepen throughout nights 3 and 5, causing the equivalent widths of the lines to fall steadily. In contrast, on night 2, the absorption was roughly constant throughout the night. We can use the duration of the absorption on night 2 to place a constraint on the minimum size of the accretion stream close to the surface of the star, and hence by implication on the size of the underlying accretion shock.

This constraint is a function of the unknown rotation period of DR Tau. For an assumed rotation period of 1.5 days (corresponding to the apparent periodicity of the Hδ absorption), the stream must extend at least $1.3R_*$ across. For a 2.8 day period, the minimum stream extent is $0.75R_*$, and for a 7.3 day period (Bouvier et al, 1995), it is $0.3R_*$. Note that it is likely that the accretion shock is not circular (e.g. Mahdavi & Kenyon, 1998), and that we measure the extent of the longer axis.

4. Time lagged emission line variations

On the fourth night, between episodes of redshifted absorption, the equivalent width variability of various emission lines was seen to become decoupled. The lines varied in an apparently correlated but non-synchronous way. The time series of some of the stronger lines is shown in the left hand part of Figure 2

Cross correlation analysis reveals a time lag of 0.2 days between Hδ and Hα, Hβ and Ca II K. Cross correlation functions between Ca II K and the four detected Balmer lines are shown in the right hand part of Figure 2.

This behaviour is unusual; the lines were seen to vary synchronously for most stars most of the time. We know from the lack of Hδ absorption that no

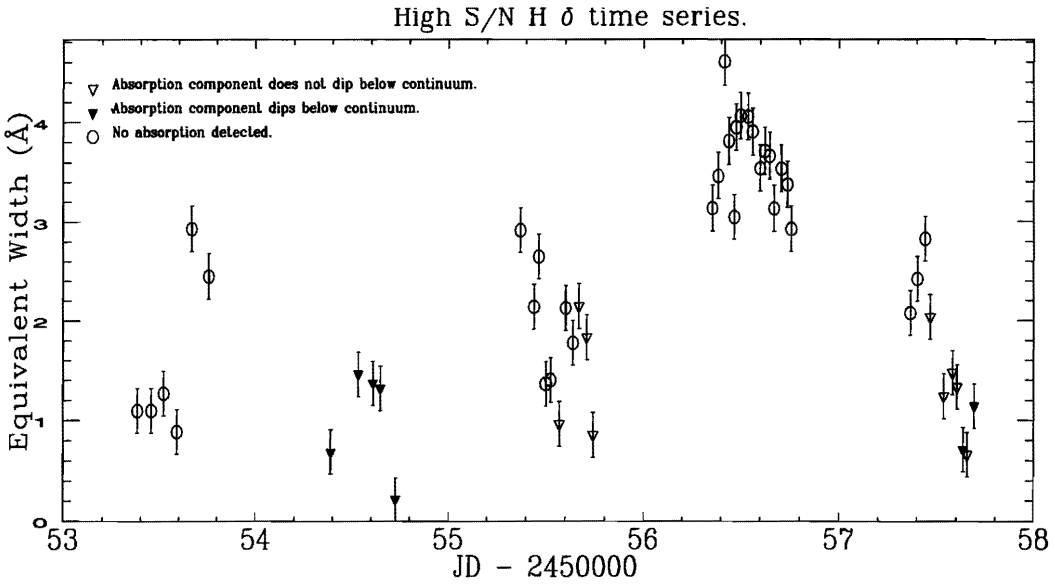

Figure 1. Time series of Hδ equivalent width. Open circles represent profiles with no absorption component. Solid triangles represent profiles with redshifted absorption dipping below the continuum, and open triangles profiles with absorption not dipping below the continuum.

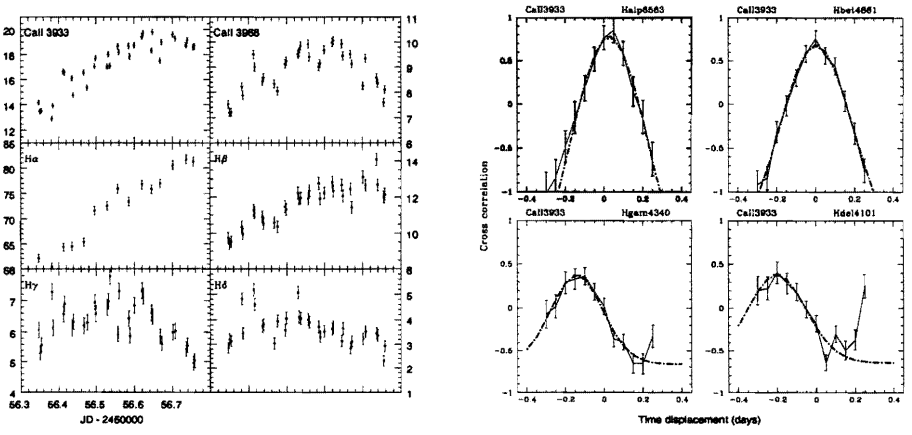

Figure 2. (Left) Equivalent width time series for six strong lines on night 4. (Right) Cross correlations between the time series of Ca II K (3933Å) and the four Balmer lines, with Gaussian fits.

accretion stream is aligned with the line of sight at this time. In the case that there are two streams and the star rotates with a 2.8 day period, this night would correspond to the phase at which one stream is seen at the limb of the star. The time lagged line variability could then be due to an optical depth effect as an accretion shock travels over the limb of the star. This possibility is currently the subject of an ongoing modelling project.

5. Summary

Continuous spectroscopic monitoring of DR Tau over a timescale comparable to the rotation timescale of the star can be used to constrain the magnetically dominated circumstellar environment. The interpretation is problematic, because of the complexity of the system, and various assumptions have been made in order to construct the picture we present. Future modelling work will allow a clearer picture to be developed. In particular, we need to investigate the behaviour of various emission lines from an accretion shock seen in different orientations.

References

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