TOMOGRAPHY OF THE INNER EDGE OF PROTOPLANETARY DISKS.

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Getting insights in the geometry of the inner edge of protoplanetary disks surrounding T Tauri stars is very challenging, even with the advance of near-infrared interferometers. In some specific configurations, when the disk is seen close to edge-on, we observe the central star trough the magnetospheric cavity and the photometric and polarimetric variations of the light curves give access to a better understanding of the structure of the inner disk.

Indeed, the current paradigm suggests that the accretion disk is disrupted at a few stellar radii by the strong stellar magnetic field and that accretion onto the star follows the magnetic field lines, at free-fall velocities. These accretion streams of disk material impact the stellar surface at magnetic poles and produce bright spots. Models also suggest that the interaction of the disk with the stellar magnetosphere results in a warp at the inner edge of the disk (Terquem & Papaloizou, 2000). This orbiting wall of circumstellar material could produce eclipses when the disk is seen close to edge-on.

We present here a study of two stars, seen with this particular inclination, AA Tau and RY Lup, for which we observe quasi-periodic eclipses of the stellar photosphere by orbiting circumstellar material, anti-correlated with an increase of the linear polarization rate : when the star is bright, polarization is low ; and when the star is fainter, polarization is larger.

The effects of a warp at the inner edge of the accretion disk and of hot spots on the stellar surface on the photometric and polarimetric light curves of the T Tauri stars AA Tau and RY Lup are studied via a Monte Carlo radiative transfer code, MCFOST (pinte et al., 2006). It is shown that the main features of photopolarimetric variations can be explained by the presence of a wall and that simultaneous modeling of the photometry and polarimetry is a powerfull to constrain the disk parameters. In this abstract, we summary the results for the case of AA Tau.

AA Tau's photopolarimetric light curves

AA Tau presents a quite unusual light curve with recurrent deep and wide brightness minima, with a period of about 8.2 days. One the most important characteristic is the lack of color variations as the system brightness varies with a maximum of 0.2 magn for the V-I indices. In addition to variations on time-scale of years, the eclipses can vary from a period to another and can even almost disappear to reappear the following period, *i.e.* skip an eclipse. The polarization rate increases as the magnitude decreases : starting from 0.5% in the bright state, polarization becomes maximum with a level around 2% when the system is faintest.

Confirmation of circumstellar extinction

This model of a wall of circumstellar material producing quasi-periodic eclipses of the star can explain all the characteristics of AA Tau light curves : the shape of the eclipses, the neutral color during the fadings, the increase of polarization as the system dims. The increase of polarization can be understood as follows : as the wall occults the photosphere, the relative fraction of scattered (and hence polarized) light increases which leads to a stronger polarization at minimum brightness. These results, in good agreement with observations (Fig. 1), allow us to confirm the interpretation of Bouvier at al (1999).

Constraints on disk and wall parameters

Wall optical depth : The absence of color variations during the eclipses implies a strong wall opacity. $\tau = 3$ is the smallest optical depth that does not generate reddening at minimum brightness. For a fixed eclipse's depth, the polarization rate decreases as τ grows, from which we deduce the optical depth should be close to $\tau = 3$.

Maximum size of grains : The grain sizes are distributed according to $\mathrm{d}n(a) \propto a^{-3.7}\,\mathrm{d}a$ between $a_{\min} = 0.03\,\mu$m and $a_{\max}$. The ISM value $a_{\max} = 0.9\mu$m leads to a maximum polarization around 1%. The best fits were obtained with $a_{\max} = 0.45\mu$m.

System geometry : The light curves can only be reproduced if we see the disk with a *grazing incidence*. Using the smallest values generally observed for the scale height and mass of other accretion disks we derive a maximum inclination of $i_{\max} \approx 76^{\circ}$. As the inclination decreases, the polarization decreases and $i_{\min} \approx 68^{\circ}$ is a lower limit.

Non-steady magnetospheric accretion

The observations of Bouvier et al (2003) show that the AA Tau system sometimes skips an eclipse. To explain this behaviour as part of the magnetospheric accretion theory, we have to assume that the accretion is non steady and that the wall is not replenished immediately as it empties via magnetospheric funnels. In order for the wall to reappear one period after its destruction, the accretion rate must be sufficiently important. From our new constraints on the wall parameters, we can derive an estimation of the necessary accretion rate to generate the wall in one rotational period : $9\,10^{-9} M_{\odot}.\mathrm{yr}^{-1}$, in agreement with the average accretion rate measured for TT Tauri Stars (Hartmann et al, 1998).

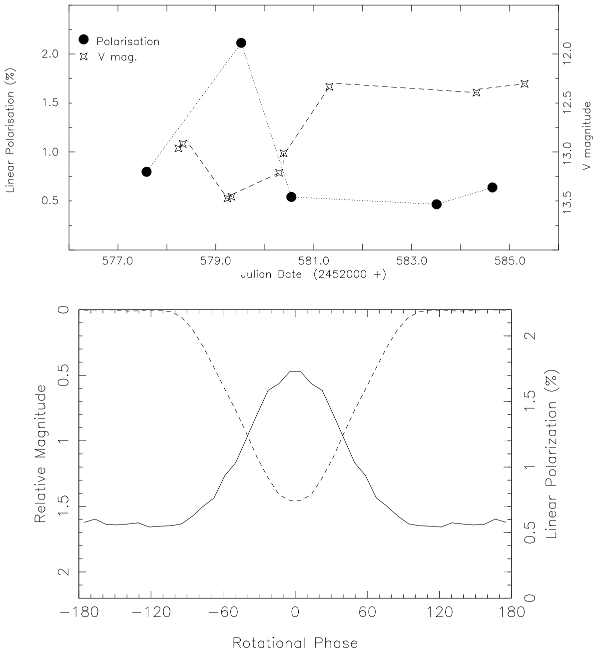

Figure 1: Comparison of observed (top) and computed (bottom) AA Tau's photometric (dashed line) and polarimetric (full line) light curves.

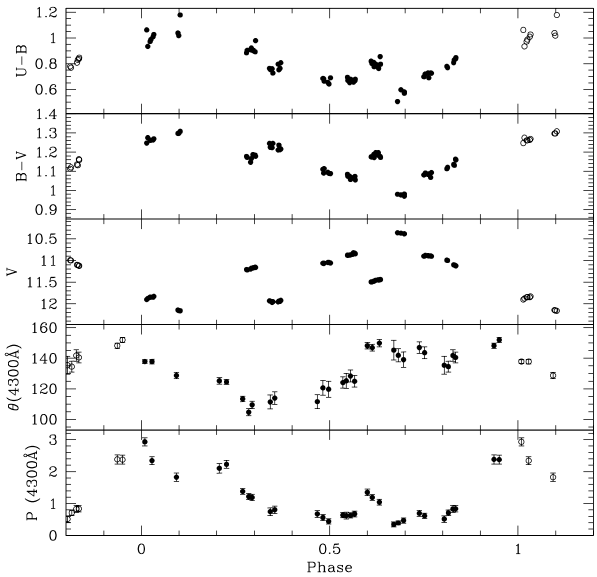

Figure 2: Photometry and polarimetry (observed polarization, *i.e.* intrisic + interstellar) of RY Lup at 4 300 Å as a function of phase with a period of 3.75 days.

RY Lup

Ry Lup shows light curves very reminiscent of those of AA Tau with large periodic photometric variations $\Delta V = 1.2$ mag, anti-correlated with variations of the observed polarization $\Delta P = 2.3\,\%$ at B band and $\Delta P = 1.8\,\%$ at V band (Fig. 2).

Contrary to AA Tau, the star becomes redder during eclipses with $\Delta(B - V) = 0.25$ mag and $\Delta(U - B) = 0.37$ mag.

The larger polarization and color variations of RY Lup are interpreted in our model by a smaller opacity of the occulting material.

Conclusion

The AA Tau's light curves are well reproduced by our multiple scattering model. These results allow us to confirm that extinction by circumstellar dust is responsible for quasi-periodic brightness fadings and polarization increases and give us new constraints on the magnetospheric structure in the very first tenths of AU from the central star.

AA Tau and RY Lup are typical CTTS and their quite unusual light curves are the result of their particular inclinations. The constraints derived on the structure of the accretion zone should apply to other CTTS and we can expect to detect the presence of a "wall" in other systems, and not only in systems seen close to edge-on.

References

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