Accretion onto complex stellar fields

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Abstract: Observations of accretion in T Tauri stars suggest the presence of accretion funnels where a complex stellar magnetic field channels the infalling material into discrete streams. We present models of this infall for realistic field geometries that are determined by extrapolating the 3D structure of the star's corona from Zeeman-Doppler images of the surface magnetic field. Both the positions of the resulting hot spots and the mass accretion rate can be influenced significantly by the structure of the star's magnetic field.

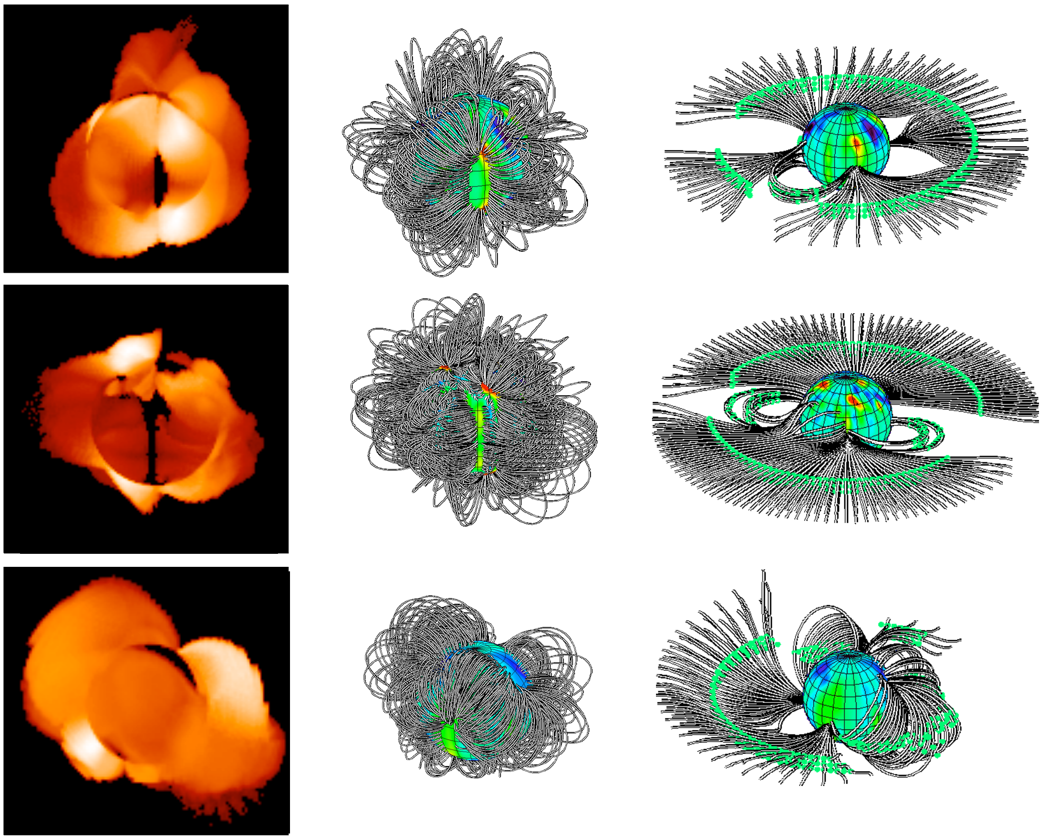


Figure 1: Three sample coronal fields extrapolated from Zeeman-Doppler images of LQHya in Dec 2001 (top), AB Dor in Dec 1996 (middle) and a combined map of LQHya from Dec 2001 and Dec 1993 (bottom). We show simulated X-ray emission images for a temperature of 2×10^6K (left), sample closed magnetic fields lines (middle) and accreting field lines (right), where the green dot denotes the point at which the field line would intersect a disk.

Introduction

Recent observations of magnetic fields on T Tauri stars (e.g. Valenti & Johns-Krull, 2004) have suggested that their fields are more complex than the simple dipolar geometry assumed in early models of magnetospheric accretion. We will soon be in a position to determine the coronal structure of T Tauri stars from Zeeman-Doppler images obtained with the new spectro-polarimeter ESPaDOnS. Using such surface magnetograms obtained for the young stars AB Dor and LQHya (Donati & Collier Cameron 1997, Donati et al 1999, 2003) we show here the types of accretion geometries that are possible with realistically complex stellar magnetic fields. We demonstrate that the field geometry can have a significant effect on the accretion signatures and the mass accretion rate.

Technique

We extrapolate the surface magnetic field using the *potential field source surface* method (Altschuler & Newkirk 1969, Jardine et al 2002a,b). We assume that the field is potential and is forced open by the stellar wind at the *source surface*. If we write the field in terms of the gradient of a flux function Ψ, then the condition that the field is divergence and curl free reduces to Laplace's equation with solution in terms of spherical harmonics:

$$\Psi(r,\theta,\phi) = \sum_{l=1}^{N} \sum_{m=-l}^{l} \left(a_{lm} r^{l} + b_{lm} r^{-(l+1)}\right) Q_{lm}(\theta) e^{im\phi}$$

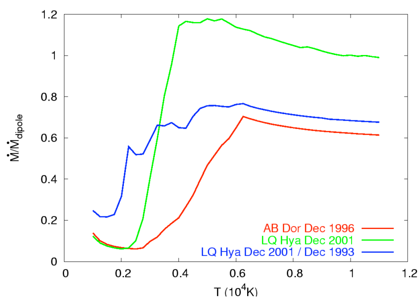
where $Q_{lm}(\theta)$ denotes the associated Legendre functions. We make a conservative estimate of the position of the source surface by calculating the radius at which the pressure of the coronal gas contained in a purely dipolar field would exceed the magnetic pressure. The source surface shrinks as either the coronal temperature rises or the surface field strength falls and may be inside or outside the co-rotation radius. Along each field line we determine the isothermal pressure and the velocity from conservation of mass, magnetic flux and momentum:

$$\rho v \propto B \qquad p = p_0 \exp\left[\frac{1}{c_s^2}\left(-\frac{1}{2}\left(v^2 - v_0^2\right) + \int \mathbf{g.ds}\right)\right]$$

The right-hand panels of Fig. 1 show field lines that can support an accretion flow that accelerates through the sonic point on to the star. All other field lines are either open or in hydrostatic equilibrium. We note that the gas pressure is set to zero along open field lines or those where the gas pressure exceeds the magnetic pressure. We compute the simulated X-ray images shown in the left panels of Fig. 1 using a Monte Carlo radiative-transfer code.

Results

We find that the pattern of accretion differs markedly from what would be found if these stars had dipolar magnetic fields aligned with the rotation axis. Discrete accretion footpoints are often at mid to low latitudes where they would suffer significant rotational modulation. By contrast, for an aligned dipole field, accretion footpoints are at the pole and hence are never rotationally eclipsed. The mass accretion rate and hence the accretion luminosity both vary significantly relative to dipolar accretion, particularly at low accretion temperatures.



As the disk temperature T increases, the sonic point moves towards the star where, for the highly complex fields shown here, the number of field lines available to accrete increases significantly. This causes the steep rise shown above in the mass accretion rate once the sonic point is sufficiently close to the star.

References

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