

Magnetic field variability of BP Tau over a decade of observations

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Abstract. The study of classical T Tauri stars allows for the investigation of the Sun’s past and stellar magnetic evolution. However, few have had their magnetic fields directly measured over extended periods of time. This work examines the star BP Tau, a classical T Tauri monitored between 2006-2014 (ESPaDOnS/CFHT) and 2019-2024 (TESS). Our objective is to understand the early development of stellar magnetism and infer how the solar dynamo may have operated in the past. We analyze the emission lines (He I, $H\alpha$, $H\beta$, Ca II) in the ESPaDOnS spectra, detecting variability in accretion at specific epochs. The LSD technique allowed for the derivation of average Stokes I and V profiles and the calculation of the longitudinal magnetic field. Its evolution over nearly a decade enabled the investigation, for the first time, of magnetic variability on a timescale comparable to a solar cycle. We will discuss the refinement of the star’s rotation period and the search for signatures of long-term variability that may be associated with a stellar magnetic cycle.

Resumo. O estudo das estrelas T Tauri clássicas permite investigar o passado do Sol e a evolução magnética estelar. No entanto, poucas tiveram seus campos magnéticos medidos diretamente em longos intervalos de tempo. Este trabalho estuda a estrela BP Tau, uma T Tauri clássica monitorada entre 2006-2014 (ESPaDOnS/CFHT) e 2019-2024 (TESS). Nosso objetivo é compreender o desenvolvimento inicial do magnetismo estelar e inferir como o dínamo solar pode ter operado no passado. Analisamos as linhas de emissão (He I, $H\alpha$, $H\beta$, Ca II) nos espectros do ESPaDOnS, detectando variabilidade na acreção em épocas específicas. A técnica LSD permitiu derivar perfis médios de Stokes I e V e calcular o campo magnético longitudinal. Sua evolução ao longo de quase uma década possibilitou investigar, de forma inédita, a variabilidade magnética em uma escala comparável a um ciclo solar. Discutiremos o refinamento do período de rotação da estrela e a busca por assinaturas de variabilidade de longo prazo que possam estar associadas a um ciclo magnético estelar.

Keywords. magnetic field – star formation – pre-main sequence

1. Introduction

T Tauri stars are young, low-mass objects in the pre-main-sequence phase. Classical T Tauri stars are those that still possess an accretion disk and exhibit strong emission lines (Figure 1), whereas in weak-lined T Tauri stars the accretion process has ceased. These stars host intense magnetic fields that truncate the disk and are responsible for channeling material onto the stellar surface along accretion funnels. The accretion shock generates an additional continuum component that is superimposed on the stellar continuum, thereby reducing the depth of photospheric absorption lines, a phenomenon known as veiling.

The aim of this work is to analyze spectropolarimetric data of the classical T Tauri star BP Tau in order to investigate the evolution and impact of stellar magnetic fields during the early stages of star formation.

2. Methodology

The spectropolarimetric data sets were obtained in 2006, 2011, 2012, and 2014 with ESPaDOnS, a high-resolution instrument covering the optical wavelength range from 370 to 1050 nm, installed at the Canada–France–Hawaii Telescope (CFHT).

In order to enhance the detection of polarization signals in photospheric lines, we employed the Least-Squares Deconvolution (LSD) technique (Kochukhov et al. 2010), which extracts common information from selected spectral lines and derives mean Stokes I and Stokes V profiles with a high signal-to-noise ratio. These profiles enable measurements of the radial velocity and the longitudinal magnetic field at the stellar surface (Figure 2).

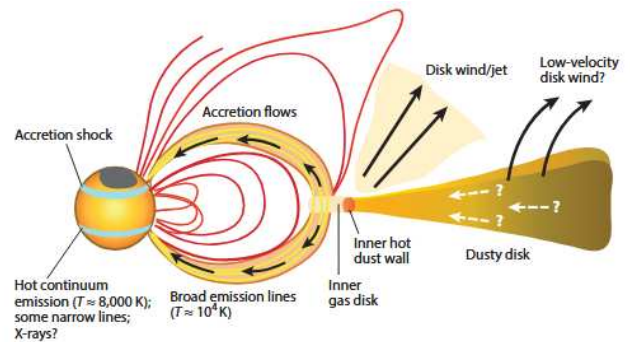


FIGURE 1. Schematic illustration of the magnetospheric accretion process, showing the disk region and the stellar magnetic field. Hartmann et al. (2016)

The longitudinal magnetic field is calculated using the first-order moment of the Stokes V profile, as described by the following equation:

$$\langle B_l \rangle = -7.145 \times 10^6 \frac{\int v V dv}{\lambda_0 \bar{g}_0 \int I dv}, \quad (1)$$

where λ_0 is the central wavelength of the line, \bar{g}_0 is the effective Landé factor, and the magnetic field is measured in Gauss.

3. Discussion

In order to validate our analysis, the longitudinal magnetic field was computed using the LSD Stokes V profiles of photospheric lines and of several emission lines ($H\alpha$, $H\beta$, He I) for the 2006

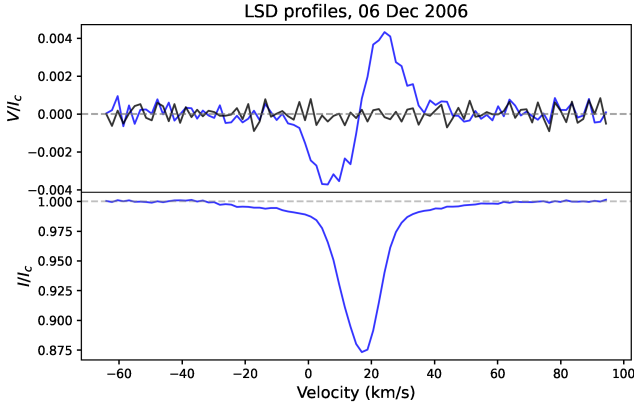


FIGURE 2. LSD profiles of Stokes V (circularly polarized) and Stokes I (unpolarized) of BP Tau are shown in blue in the upper and lower panels, respectively. In black, in the upper panel, we show the null spectrum, which allows verification of the absence of spurious polarization in the observed data.

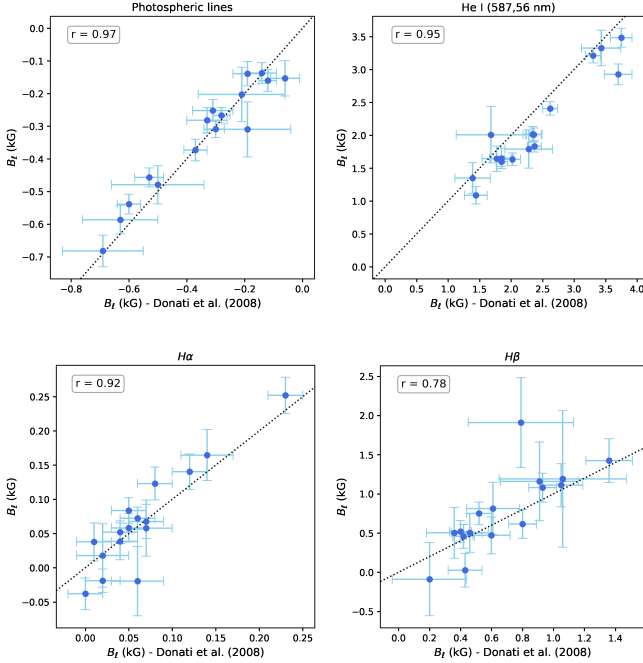


FIGURE 3. Comparison between the longitudinal magnetic field values calculated in this work (vertical axis) and those reported by Donati et al. (2008), using Stokes V profiles of photospheric lines and emission lines ($H\alpha$, $H\beta$, and He I 587.56 nm). In all panels, the dotted line represents the identity function.

epoch, applying Equation 1. Figure 3 presents a comparison between the values obtained in this work and those published by Donati et al. (2008). We find a good correlation between the results and therefore extend our analysis to the remaining observing epochs.

Our results for the year 2014 reveal a periodic modulation in the longitudinal magnetic field variability (Figure 4), which allowed us to determine the rotation period of BP Tau as $P_{\text{rot}} = 8.3 \pm 0.2$ days ($\text{FAP} = 0.000002$).

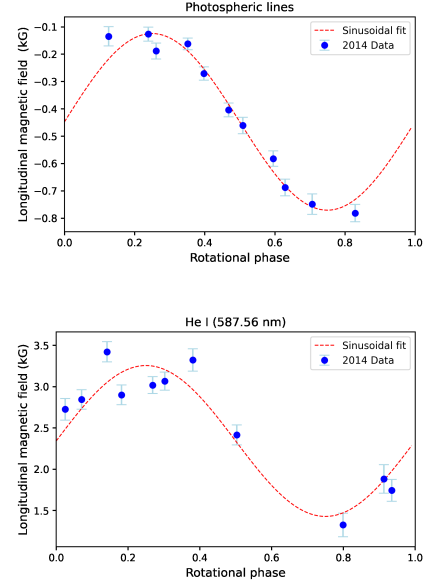


FIGURE 4. Sinusoidal fit, with a period of 8.3 days, to the longitudinal magnetic field values derived from the LSD profiles of photospheric lines (left panel) and from the He I 587.56 nm line (right panel).

4. Conclusion

We computed the longitudinal magnetic field for four observing epochs, which enabled the monitoring of its temporal variability. The analysis of the 2014 data allowed us to determine the rotation period of BP Tau, which had previously been subject to substantial uncertainty in the literature, with reported values ranging from 7 to 11 days.

Following the calculation of veiling, we are concluding this work by estimating the mass accretion rate of BP Tau, with the aim of investigating its variability over a decade, a timescale comparable to that of the magnetic cycles observed in the Sun.

References

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