Revisiting the IR line decrements of T Tauri stars with magnetospheric accretion models.

Jesús V Díaz[1,3], María José Colmenares[1,3] ,Nuria Calvet[2], Thanawuth Thanathibodee[2], Gladis Magris[3] , James Muzerolle[4]

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Introduction

We use magnetospheric accretion, Figure 1, to explain and constrain the observations presented by Bary et al. (2008). That work used recombination models to find that temperatures below 5000 K are necessary in order to fit the Balmer and Paschen decrements for a set of CTTS in the Taurus-Auriga star forming regions. However, magnetospheric models can explain the observations using higher temperatures, from 8000 K to 11000 K. These magnetospheric models have successfully explained the emission line profiles from brown dwarfs (Muzerolle et al. 2003) to Herbig Ae/Be (Muzerolle et al. 2004)

Objectives

- Understand more about the limitations and physical conditions required for different magnetospheric accretion models.
- Compare available models with a set of observations in order to test the validity of the models and interpret the results.

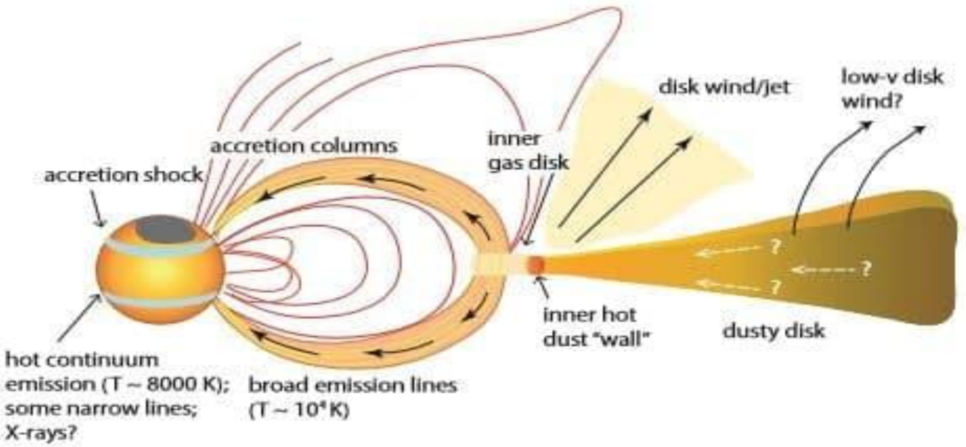

Figure 1: A representation of magnetospheric accretion. Matter from the disk falls onto the star following the magnetic field lines. From Hartmann et al. (2016)

Click on each heading to review the desired section.

References

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Model

Observations

Results

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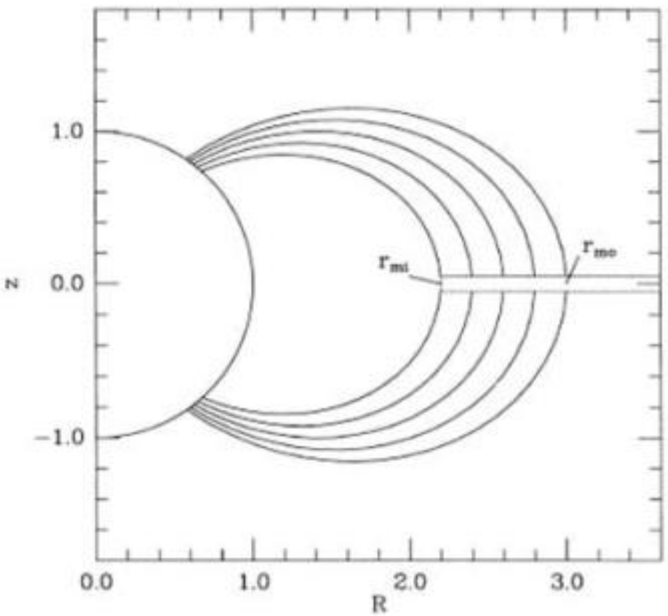

Figure 2: Different Geometries for magnetospheric accretion.

Table 1. Identification for the Geometries.

ID	Rmi(R_*)	Rmo(R_*)
G01	2	2,5
G02	2	3
G03	3,5	4
G04	3,5	4,5
G05	5	5,5
G06	5	6

The magnetospheric accretion model.

In the magnetospheric accretion model it is assumed that the magnetic field of the star truncates the disk at a few stellar radii, after which point the material from the disk is accreted following the magnetic field lines. Emission lines are generated in the accretion flows. We followed the method in Muzerolle et al. (2001) to calculate a grid of models with the following parameters:

- The geometry of the inner and outer magnetic dipolar field lines which can be seen in Figure 2 and Table 1.
- The maximum temperature (Tmax) from 8000 K to 11000 K.
- The mass accretion rates ($\dot{M}$) shown in Table 2.

Models results are shown in Figure 3.

Table 2. Identification for the mass accretion rates.

ID	M01	M02	M03	M04
$\dot{M}(M_\odot yr^{-1})$	10^{-10}	10^{-9}	10^{-8}	10^{-7}

We show models for a K7 star with R= 2 $R_\odot$, M= 0.5 $M_\odot$ and , varying the parameters from M01, M02, M03, M04, different geometries for the magnetic field, from G01, G02, G03, G04, G05, G06, and the maximum temperatures. All for an inclination of 60°.

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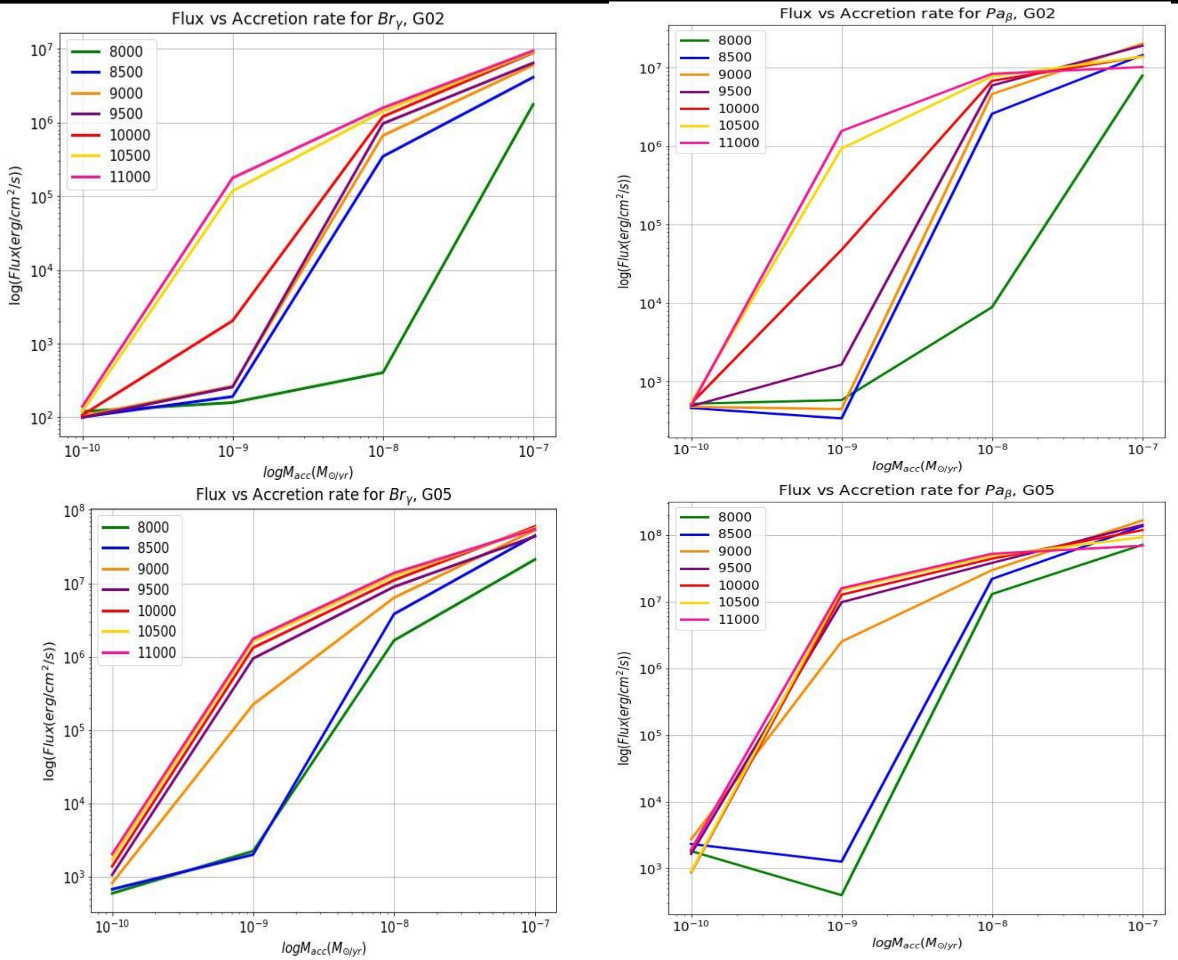

Figure 3.Flux for the magnetospheric accretion models vs their dependence of mass accretion rate, for geometries G02 and G05 from lines Paβ and Brγ.

The magnetospheric accretion model.

Figure 3 shows the dependency of the model flux for lines Paβ and Brγ, on different parameters presented for two different geometries of the magnetic field, small and wide geometry (G02), and a large and narrow geometry (G05).

In each plot, lines connect points of equal maximum temperature for the given geometry. The flux values are plotted against the range of mass accretion rates presented in Table 2.

A correlation between the maximum values of the flux and the geometries can be seen from Figure 3. It is also clear that the higher the accretion rate the higher the flux. It can also be seen in Figure 3, that as the maximum temperature increases so does the flux. In particular, a big difference, for a maximum temperature of 8000 K with M03, can be seen between the G02 and G05 geometries.

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Observations

We use observations from Bary et al. (2008). The IR spectra were obtained with CorMass (Cornell-Massachusetts) spectrograph in the Vatican Advanced Technology Telescope (VATT). The resolution was R~300 and the spectra coverage from 0.8 to 2.5 μm, which allowed for simultaneous measurements of various Paschen and Brackett lines.

The line fluxes were corrected for reddening using Av values from White & Ghez (2001) and Kenyon & Hartmann (1995) along with the standard extinction law from Cardelli et al. (1989).

We derived the ratios for the Paschen and Brackett series lines using a single epoch of observation for DR Tau. This was decided in order to get consistent data without having to worry about the variability of the star. In addition, since DR Tau is a strong accretor (see Table 3), (Calvet & Gullbring 1998), the emission lines are strong, providing a better test of magnetospheric accretion.

The measured lines in the Paschen series were Paβ, Paγ, Paδ, Pa8, Pa9, Pa10, Pa11, Pa12 and Pa14. For the Brackett series the measured lines were Brγ, Br10, Br11, Br12, Br13, Br14, Br15 and Br16.

Table 3. Data for DR Tau .

Star	$\dot{M}(M_{\odot} yr^{-1})$	Sp Type
DR Tau	1×10^{-7}	K7

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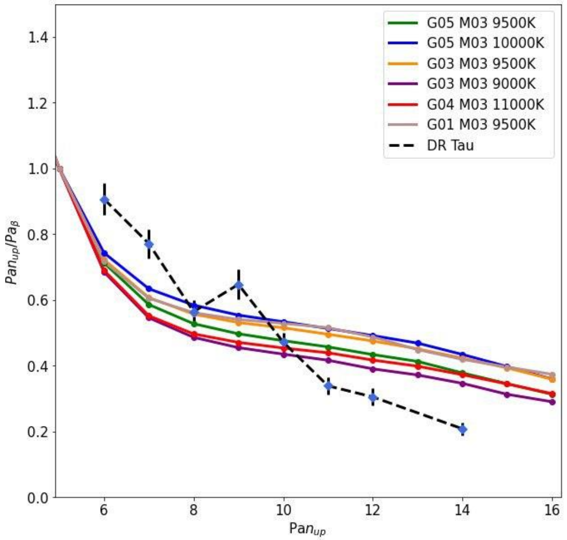
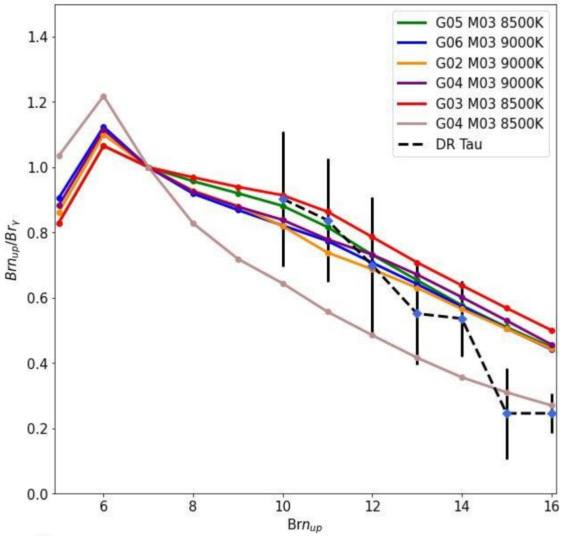
Results

We fit the models to the observed Pan/Paβ, Brn/Brγ, Brγ/Pan DR Tau flux ratios using χ^2 as a merit function to measure the goodness of fit. $\chi^2 = \sum_i (O_i - M_i)^2$, where O_i is the observed flux ratio and M_i is the model flux ratio corresponding to the geometry, Tmax, $\dot{M}$ set of parameters.

The distribution of parameters weighted by the likelihood, $\mathcal{L} \propto \exp(-\chi^2/2)$, allows us to conclude:

- Both, Pan/Paβ and Brγ/Pan flux ratios strongly favor models with 8000 K < Tmax < 9000 K . Although more weakly, Brn/Brγ also favors Tmax < 9000 K.
- All the studied ratios indicate M03 ($\dot{M}$ = $10^{-8}\ M_\odot yr^{-1}$). These results are consistent with Muzerolle et al. (2001), who found that low maximum temperatures are expected for high $\dot{M}$.
- The geometry of the magnetic field is weakly constrained by the studied ratios, and slightly favors a large magnetosphere G05, G06.
- **In any case, the Br and Pa line fluxes are consistent with a magnetospheric accretion model with maximum temperature not lower than 8000 K.**





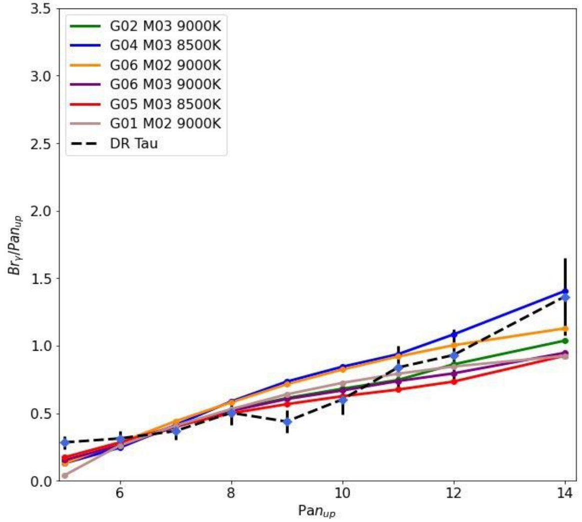


Figure 4. Observed DR Tau and model line flux ratios: Upper-Left: Pan/Paβ, Upper-Right: Brn/Brγ, Lower-Right:/Pan. Color coded lines connect models of indicated equal geometry, $\dot{M}$, and Tmax. Dashed lines connect observed ratios, the error bars represent observational uncertainties.

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