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Interaction between protostellar winds and planetary magnetosphere

Y. Tamburus[1], N. F. S. Andrade[1], & V. Jatenco-Pereira[1]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas - IAG, Universidade de São Paulo
e-mail: ytamburus@usp.br, natalia.fernanda.andrade@usp.br, vera.jatenco@iag.usp.br

Abstract. We analyzed the interaction between the magnetized protostellar wind from weak-emission T Tauri stars (WTTS), guided by Alfvén waves, and the planetary magnetosphere. Our preliminary results show that most hypothetical Earth-like planets in the habitable zone of their host star can sustain their atmospheres. Although this first model has some limitations that tends to overestimate the size of the magnetospheres, it provides an initial constraint to the extension of magnetospheres associated with WTTS. We further improve the model by including a more robust estimative of the magnetosphere's size and the contribution of magnetic pressure to the interaction of wind and planetary atmosphere.

Resumo. Analisamos a interação entre o vento protoestelar magnetizado das estrelas T Tauri de linhas fracas (WTTS), guiado por ondas de Alfvén, e a magnetosfera planetária. Nossos resultados preliminares mostram que a maioria dos planetas hipotéticos semelhantes à Terra na zona habitável de sua estrela hospedeira podem sustentar suas atmosferas. Embora este primeiro modelo tenha algumas limitações que tendem a superestimar o tamanho das magnetosferas, ele fornece uma restrição inicial à extensão das magnetosferas associadas às WTTS. Melhoramos ainda mais o modelo incluindo uma estimativa mais robusta do tamanho da magnetosfera e da contribuição da pressão magnética para a interação do vento e da atmosfera planetária.

Keywords. Magnetohydrodynamics (MHD) – Planet-star interactions – Stars: winds – Stars: variables: T Tauri

1. Introduction

In the evolved stages of T Tauri stars (< 100 Myr), the weak-emission T Tauri stars (WTTS) are characterized by showing small or no trace of accretion, implying that the disk has dissipated. We also observe the presence of strong stellar winds and surface magnetic fields around kG. The current and growing search for rocky exoplanets with dimensions comparable to those of Earth make it necessary to understand better the interaction between the stellar wind and the planetary magnetosphere since it can play a role as a shield, acting against the erosion of the atmosphere by the action of the wind. See et al. (2014) performed numerical simulations to obtain the magnetospheres' dimensions of hypothetical Earth-type planets in the habitable zones of their host stars and compared them with the measurements of the Earth's magnetosphere in the Paleoarchean era (3,6 Gyr) for which the first evidence of life was registered.

2. Scientific goals

Using a sample from Güdel et al. (2007), we analyzed the interaction between the magnetized protostellar wind driven by Alfvén waves from WTTS and the planetary magnetosphere, including a constant damping mechanism in our analysis. We intend to investigate the consequent influence of the wind on the atmosphere's removal and the consequences for the habitability of the planet.

3. Models

3.1. Wind velocity profile

We use the Jatenco-Pereira & Opher (1989) model of magnetized wind. Its structure is shown in Figure (1), where it presents divergent behavior of the magnetic field lines ($S > 2$) becoming radial ($S = 2$) after the distance r_T:

$$r_T = 10^{1/(S-2)} r_0. \quad (1)$$

Equation (2) represents the wind velocity profile:

$$\frac{1}{v}\frac{dv}{dr}\left[v^2 - c_s^2 - \frac{1}{4}\left(\frac{1+3M}{1+4M}\right)\left\langle \delta v^2 \right\rangle\right] = \frac{Z}{r}\left[c_s^2 - \frac{GM_\star}{rZ} + \frac{1}{4}\left(\frac{1+3M}{1+M}\right)\left\langle \delta v^2 \right\rangle + \frac{r}{2LZ}\left\langle \delta v^2 \right\rangle\right], \quad (2)$$

while the behavior of the wind geometry is given by Equation (3):

$$Z = \begin{cases} S, & \text{para} r \leq r_T \\ 2, & \text{para } r > r_T \end{cases} \quad (3)$$

where c_s is the speed of sound, M the Alfvenic Mach number, $\left\langle \delta v^2 \right\rangle$ the mean quadratic amplitude of the velocity fluctuations and L the damping length.

3.2. Habitable Zone (HZ)

The radial distances of the HZ were calculated according to the model by Kopparapu et al. (2013a,b) using WTTS. This model checks whether there is liquid water on the surface of the Earth-type exoplanet. Therefore, the HZ is located at the following distance from the host star:

$$d = \left(\frac{L/L_\odot}{S_{eff}}\right)^{0,5} \text{ UA}, \quad (4)$$

so that S_{eff} is the effective stellar flux, i.e., a constant used to maintain a given surface temperature (Kopparapu et al. 2013a), L and $L_\odot$ are the luminosities of the WTTS and the Sun, respectively.

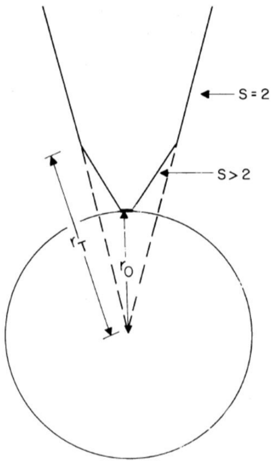

Figure 1. Geometry of the magnetic field (Jatenco-Pereira & Opher 1989).

3.3. Ram pressure, thermal pressure and magnetic pressure

It was considered that the WTTS wind has ram pressure (Equation 5), thermal pressure (Equation 6), and magnetic pressure (Equation 7):

$$P_{ram} = \rho_{c\star} f \tilde{\rho}(r) v^2(r), \quad (5)$$

$$P_{term} = \rho_{c\star} f \tilde{\rho}(r) c_s^2, \quad (6)$$

$$P_B = \frac{B^2}{8\pi} = \frac{B_0^2}{8\pi} \left(\frac{r_0}{r_T^S}\right)^2 \left(\frac{r_T}{d^2}\right)^2, \quad (7)$$

where $\rho_{c\star}$ is the stellar coronal density, f a normalization factor, $\tilde{\rho}$ the normalized density and B_0 the inicial magnetic field.

3.4. Magnetospheric dimension

The magnetosphere sizes of hypothetical Earth-type planets were calculated from the model by Grießmeier et al. (2004). An assessment of the T Tauri's wind pressure and the planet's magnetic pressure was carried out:

$$r_{MP} = \left[\frac{\mu_0 f_0^2 M_E^2}{8\pi^2 (P_{ram} + P_{term} + P_B)}\right]^{1/6}, \quad (8)$$

where μ_0 is the Earth's magnetic permeability, f_0 a factor that considers the Earth's non-spherical shape and $M_E = 8 \times 10^{26}$ A cm^2 is the Earth's magnetic moment. The field of the hypothetical planet is the same as the Earth's.

4. Results

A simulation between the pressure balance of the stellar wind (Figure 2a: ram, thermal, and magnetic; Figure 2b: ram and thermal) and the planets (magnetospheric) located in the HZs. The coloring of the graphs was done according to the chromospheric activity of the star. Furthermore, the present day and the Paleoarchean magnetospheric sizes are shown, where Tarduno et al. (2010) say it is reasonable to assume that during this period, it would already be able to contribute to the planet's defense.

We did a comparison to verify if the magnetospheric dimension is proportional to the radial distance from the habitable zone, as seen in Figure (3).

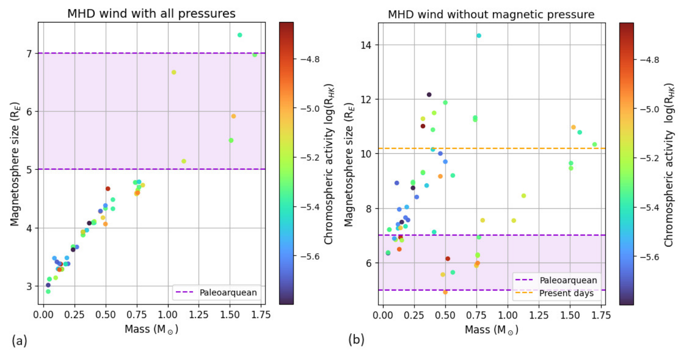

Figure 2. Relation between magnetospheric dimension as a function of stellar mass, considering (a) ram, thermal, and magnetic pressures in the wind; (b) only ram and thermal pressures.

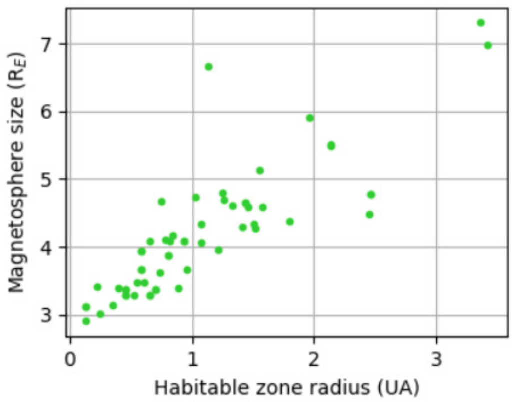

Figure 3. Relation between the magnetospheric dimension as a function of the radius of the habitable zone.

5. Conclusions

We notice that magnetic wind pressure significantly influences the size of magnetospheres because, in Figure (2a), only some planets can sustain their atmospheres. Although in Figure (2b), when magnetic pressure is disregarded, almost all planets have magnetospheres greater or equal to the Paleoarchean size. And we verify a dependence between the magnetosphere's size and the radius of the habitable zone, as shown in Figure (3) (Jardine & Cameron 2008).

References

Grießmeier, J. M., et al. 2004, A&A, 425, 753.
Güdel et al. 2007, AAS, 39, 753.
Jardine, M., & Cameron, A. C. 2008, A&A, 490, 843.
Jatenco-Pereira, V., & Opher, R. 1989, MNRAS, 236, 1.
Kopparapu, R. K., et al. 2013a, ApJ, 765, 131.
Kopparapu, R. K., et al. 2013b, ApJ, 770, 82.
See et al. 2014, A&A, 570, A99.
Tarduno, J. A., et al. 2010, Science, 327, 1238.