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Radio emission from close-in giant planets around young stars

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Abstract

Since the first discovery of extrasolar planets, more than 400 planets have been detected, many of them located very near the host star. Because of such extreme proximity, interaction of the planet with the star is expected to give rise to a variety of phenomena. The stellar wind is expected to directly influence the planet and its atmosphere, e.g., by changing the configuration of the planet's magnetosphere, producing nonthermal planetary magnetospheric radio emissions, etc. So far, the few theoretical works investigating the influence of the stellar wind on the magnetosphere of planets were based on simplified treatments of the stellar winds. We developed three-dimensional magnetohydrodynamics models of stellar winds from young stars which enabled us to determine self-consistently the characteristics of the impacting wind on the planet. Under realistic stellar wind conditions, we estimated the power released from the magnetic interaction (reconnection) between a magnetized wind and the magnetosphere of a close-in giant planet. We found that a close-in Jupiter-like planet orbiting at 0.05 AU presents a radio power that is ~ 5 orders of magnitude larger than the one observed in Jupiter, which suggests that the stellar wind from a young star has the potential to generate strong planetary radio emission that could be detected in the near future with LOFAR.

1. Introduction

The stellar wind of a host star is expected to directly influence an orbiting planet and its atmosphere. The interaction of a magnetized wind with a magnetized planet can give rise to reconnection of magnetic field lines. For example, the solar wind interaction with the magnetic planets of the Solar System (SS) generate electrons that propagate along the planet magnetic field lines, producing electron cyclotron radiation at radio wavelengths [10]. By analogy to the SS, predictions have been made that extra-solar planets should produce cyclotron maser emission [1, 4, 3, 2, 8], if they harbor intrinsic magnetic fields.

The consideration of a realistic wind is crucial to determine how such interaction occurs. Using the 3D, time-dependent, MHD wind models of weak-lined T Tauri stars (WTTSs) developed in [9], we investigate the planet-wind interaction and estimate the radio power released.

2. Wind modeling and planetary radio emission

The stellar wind simulations are performed using the 3D magnetohydrodynamics (MHD) numerical code BATS-R-US [7], which solves the ideal MHD equations. Details of the grid construction, choice of boundary and initial conditions can be found in [9].

The adopted star has $0.8\ M_\odot$, $R_\star = 2\ R_\odot$, and is considered to be rotating as a solid body with a period of rotation $P_0 = 1$ day. Its axis of rotation lies in the z-direction. The surface magnetic moment vector is considered to be that of a dipole, tilted with respect to $\hat{z}$ at an angle $\theta_t = 30^\circ$. As the magnetic field is anchored on the star, in one stellar rotational period, the surface magnetic moment vector draws an imaginary cone, whose central axis is the z-axis. Because of that, in the simulations with oblique magnetic geometries, the boundary conditions are time-dependent and the simulations achieve a *periodic* configuration. Therefore, the wind impacting on the planet varies during one full period of the star.

The MHD solution is evolved in time from the initial dipolar configuration for the magnetic field to a fully self-consistent non-dipolar solution. We assume that the magnetic field intensity at the magnetic poles of the star is 1 kG, the temperature at the base of the wind is 10^6 K and the density is 10^{-11} g cm^{-3}. Figure 1 presents a meridional cut of the radial wind velocity for such simulation after 10 stellar rotations. Black lines represent magnetic field lines.

Our simulations of stellar winds of WTTSs provide a powerful tool to investigate the planet-wind interac-

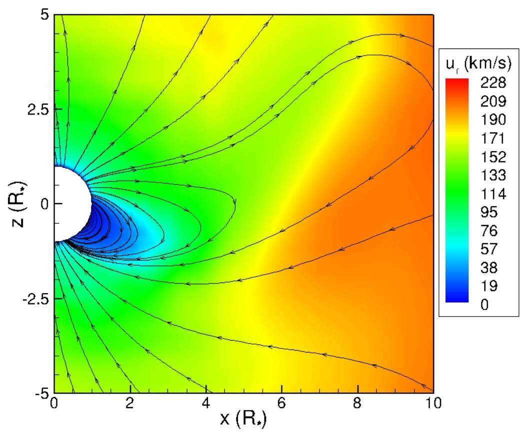

Figure 1: Radial velocity of the wind.

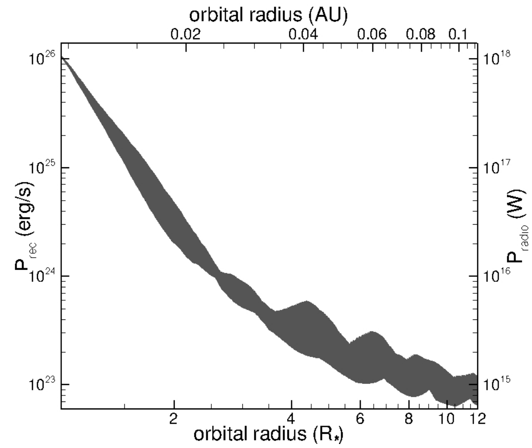

Figure 2: Estimated dissipated power and radio power.

tion, as they allows us to consider the effects of a more realistic wind and obtain key insights on the detectability of radio emission from extrasolar planets.

The planetary radio emission depends on the planet's magnetic field intensity and on the stellar wind power: in general, it implies that the stronger the stellar wind is, the more radio-luminous should the planet be. So far, such radio signatures from stars hosting hot Jupiters have not yet been detected [6]. In the next evaluations, we adopt that the planet's magnetic field is a dipole, with maximum intensity of 100 G.

The power released with the reconnection event $P_{\rm rec}$ can be decomposed into a power released from the dissipation of kinetic energy carried by the stellar wind P_k and a power released from the magnetic energy of the wind P_B [1, 11]: $P_{\rm rec} = aP_k + bP_B$, where a and b are efficiency ratios. Observations of the SS suggest $a \simeq 7 \times 10^{-6}$ and $b \simeq 3 \times 10^{-3}$ [11]. Without a better guess, we adopt a and b as in the SS.

According to our stellar wind models, we find that $aP_k \sim bP_B$ for $r < 0.11$ AU, which means approximately equal contributions from the kinetic flow and the magnetic powers to the power released in the reconnection. At, for example, 0.05 AU, this yields a total power $P_{\rm rec} \sim 1.5 - 4 \times 10^{23}$ erg/s. The range of values exists because the wind impacting on the planet changes characteristics depending on the stellar rotational phase. Part of this released energy can be used to accelerate electrons, generating radio emission: $P_{\rm radio} = \eta P_{\rm rec}$, where η is the conversion efficiency. Assuming $\eta = 10\%$ [5], we present the power released in the reconnection and the radio power as a function of planetary orbital radius in Figure 2.

For Jupiter, $P_{\rm radio} \sim 10^{10.5}$ W, which means that, for our assumed giant planet orbiting our fictitious star at 0.05 AU, the radio power released is ~ 5 orders of magnitude larger than for Jupiter. This result suggests that stellar winds from young stars have the potential to generate strong planetary radio emission.

The radio flux detected on Earth is: $\Phi_{\rm radio} = \frac{P_{\rm radio}}{d^2 w (f_c/2)}$, where w is the solid angle of the conical emission beam, d is the distance to the star, $\Delta f = 0.5 f_c$ is the emission bandwidth, and f_c is the frequency of the cyclotron emission [1]. Adopting $d \sim 10$ pc and a beamed emission with a conical aperture of $45^{\rm o}$, $w \sim 1.8$ sr, the radio flux detected at Earth would be $\Phi_{\rm radio} \sim 6 - 16$ mJy at $\Delta f = 140$ MHz. In this case, our hypothetical planet could be observable by LOFAR.

References

[1] Farrell, W. M., et al. 1999, J. Geophys. Res., 104, 14025

[2] Grießmeier, J.-M., et al. 2007, Pl. Space Sci., 55, 618

[3] Grießmeier, J.-M., et al. 2004, A&A, 425, 753

[4] Ip, W.-H., et al. 2004, ApJ, 602, L53

[5] Jardine, M., & Cameron, A. C. 2008, A&A, 490, 843

[6] Lazio, T. J. W., & Farrell, W. M. 2007, ApJ, 668, 1182

[7] Powell, K. G., et al. 1999, J. of Comp. Phys., 154, 284

[8] Stevens, I. R. 2005, MNRAS, 356, 1053

[9] Vidotto, A. A., et al. 2010, ApJ, submitted

[10] Zarka, P. 1998, J. Geophys. Res., 103, 20159

[11] Zarka, P., et al. 2001, Ap&SS, 277, 293