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Numerical MHD Simulation of Star-Planet Interaction

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Abstract

Since the first discovery of an extrasolar planetary system more than a decade ago, hundreds more have been discovered. Surprisingly, many of these systems harbor Jupiter-class gas giants located close to the central star, at distances of 0.1~AU or less. Observations of chromospheric 'hot spots' that rotate in phase with the planetary orbit, and elevated stellar X-ray luminosities, suggest that these close-in planets significantly affect the structure of the outer atmosphere of the star through interactions between the stellar magnetic field and the planetary magnetosphere. Here we carry out the first detailed three-dimensional MagnetoHydroHynamics (MHD) simulation containing the two magnetic bodies and explore the consequences of such interactions on the steady-state coronal structure. We also include the planetary orbital motion, as well as planetary outflow. The simulation results provide a better understanding of the plasma environment of such systems, as well as insight about the nature of star-planet interaction.

1. Introduction

The structure and heating of the solar corona, as well as the acceleration of the solar wind, are influenced by the structure and topology of the large-scale coronal magnetic field. On this basis, the existence of a planet at a distance of 0.1 AU or less (Mayor & Queloz 1995; Mayor et al. 2003), with a strong internal magnetic field is expected to have a significant effect on the stellar magnetosphere, which is controlled by the magnetic field structure (Cuntz et al. 2000). In recent years, some signatures of this star-planet interaction (SPI) have been observed. Shkolnik et al. (Shkolnik et al. 2003, 2005a, 2005b, 2008) have reported on modulations in the Ca ii K emission line, an indicator for chromospheric activity. They find enhancements in the line intensity that have the same period as the planetary orbital motion, though sometimes with a significant non-zero phase shift. The cause is deemed magnetic and not tidal because of the lack of an equivalent hot spot offset in phase by 180°. In addition, a statistical survey of the X-ray fluxes from stars with close-in planets has found them enhanced by 30%-40% on average over typical fluxes from similar stars with planets that are not close-in (Kashyap et al. 2008). Direct X-ray observations of the HD 179949 system (Saar et al.2008) showed that the SPI contributed 30% to the emission at a mean temperature of 1 keV. Some analytical and semiempirical arguments have been advanced to explain these observations. One posits that particles are accelerated along magnetic field lines that connect the star and planet, creating hot spots where they hit the chromospheric layer (Cuntz et al. 2000; Lanza 2008; Cranmer & Saar 2007). As a result, hot spots are observed generally in phase with the planetary orbit, but with the capacity to have large offsets, depending on the exact structure of the magnetic field between the star and the planet. Another shows that transition of field lines from a high-helicity state to a linear force-free state is energetically adequate to power the enhanced intensities (Lanza 2009). The detailed behavior of the dynamical interaction of coronal and wind plasma with two magnetic field systems is, however, very difficult to realize with idealized models. The problem properly requires simultaneous descriptions of both the stellar and the planetary magnetospheres, the planetary orbital motion, and often asynchronous stellar rotation, together with a self-consistent stellar wind solution.

Here, we describe an initial simulation of the magnetic SPI. We use idealized test cases to study the fundamental changes in the steady-state coronal structure due to the presence of the planet and its magnetic field. The dynamical interaction due to the planetary orbital motion is captured in an indirect manner.

3. Figures

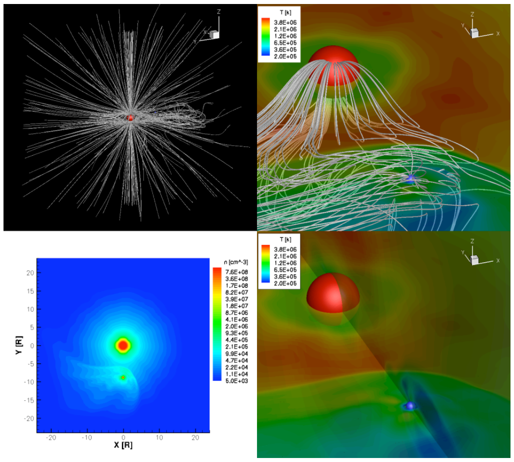

Figure 1: A snapshot from the dynamic simulation.

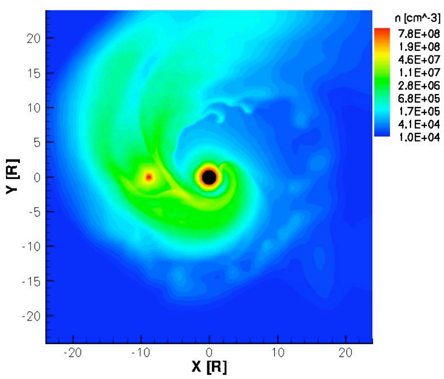

Figure 2: The equatorial plane colored with number density contours.

References

[1] Cohen et. Al, Interactions of the Magnetospheres of Stars and Close-In Giant Planets, ApJ, 704, L85-L88, 2009.