Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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The activity evolution of Solar-like stars with age and its planetary impact

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Abstract. The age-dependent activity of a star dictates the extent of its planetary impact. We study the interaction of the stellar wind produced by Solar-like stars with the magnetosphere of Earth-like planets using three dimensional (3D) magnetohydrodynamic (MHD) simulations. The numerical simulations reveal important features of star-planet interaction e.g. bow-shock, magnetopause, magnetotail, etc. Interesting phenomena such as particle injection into the planetary atmosphere as well as atmospheric mass loss are also observed which are instrumental in determining the atmospheric retention by the planet.

Keywords. Sun: solar wind, MHD, magnetic fields, shock waves

1. Introduction

The age of a star determines its activity which in turn affects the planetary magnetic field. The stellar activity evolution is thus relevant for determining the mechanism and variability of star-planet interactions. The habitability of a planet [Garraffo *et al.* (2017)] depends on its ability to retain an atmosphere around itself which is dictated by whether the rate of particle injection into the atmosphere is greater or lesser than the atmospheric mass loss. We carry out 3D full MHD simulations of the interaction between the wind produced by a Solar-like star and the magnetosphere of an Earth-like planet. Specifically in this work, we compare the magnetopause distances obtained for different configurations of the wind with the expected values and also study the mechanism of particle injection and mass loss from the planetary atmosphere.

2. Simulations & Results

We carry out three dimensional full MHD simulations using the PLUTO code [Mignone *et al.* (2007)]. The magnetosphere is assumed to be a simple dipole while the properties of the incoming solar wind are calculated using the Rankine-Hugoniot conditions to resemble a pure shock. The computational domain contains the planet in the interplanetary medium which is initially in hydrostatic equlibrium [Matsakos *et al.* (2015)]. The left x boundary is customized to simulate the traveling solar wind while the other boundaries are made force-free with outflow conditions.

The numerical simulations reveal many interesting features of the star-planet interaction. The contour map of the x component of velocity (v_x) [Fig. 1(a)] depicts the formation of a bow shock in front of the magnetopause. The white contour line in the magnetotail shows the region of negative component of v_x and hence, plasma inflow towards the planet indicating stellar particles' injection. The contour map of tracer density

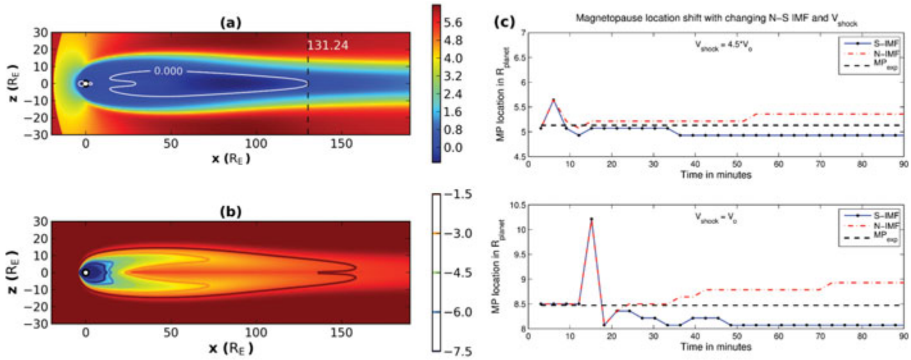

Figure 1. (a) Contour map of the x component of velocity (v_x). The white contour line (marked '0.000') bounds the region of inflow. The velocity of the incoming solar wind (v_{shock}) is in the positive x direction. (b) Contour map of the tracer density of the incoming solar wind depicting particle injection from the right. (c) Comparison of the temporally-varying magnetopause distances obtained using a wind with a magnetic field directed southwards (blue line with black dots) and northwards (red dashed dotted line) with the expected value (black dashed line). The upper and lower plots are for two different shock velocities of the incoming wind. V_0=350 km/s.

of the solar wind [Fig. 1(b)] along with [Fig. 1(a)], confirms the injection of particles from the wind into the planetary atmosphere through the magnetotail. The Fig. 1(c) shows the time evolution and finally, the deviation from the expected value for the case of southward and northward directed wind magnetic field for two different wind velocities ($V_{\rm shock} = 4.5V_0$ and V_0). The equilibrium state is reached in less than 90 minutes. As expected, a higher wind velocity decreases the magnetopause distance and vice-versa.

3. Conclusions

We conclude that the phenomenology of star-planet interaction is critical in determining the habitability of the planet. Our simulations show that particle injection into the planetary atmosphere is possible although it depends greatly on the properties of the incoming wind and the mechanism of magnetic field reconnections [Cohen *et al.* (2014)]. A comparison of magnetopause distances show that a very strong wind can push the magnetopause location inside the planet which in turn can kill the atmosphere. The magnetopause locations change for different magnetic field orientations of the wind.

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