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Simulations of stellar mass ejections and their effects on atmospheres of exoplanets

R. Borges Júnior & A. Valio

[1] Centro de Radioastronomia e Astrofísica Mackenzie
e-mail: reinaldo.borges@mackenzie.br, avalio@craam.mackenzie.br

Abstract. The Sun goes through periods of activity every 11 years. During the activity maximum, many mass ejections of the solar corona (CME) occur. It is believed that stars, often much more active than the Sun, also produce this phenomenon. Observations of the last 20 years have shown the existence of planets orbiting very close to their stars. This work aims to study the ejections of stellar material and their influence on the atmosphere of exoplanets. Therefore, the AMUN computational code, adapted from the case of binary stars wind interaction, will be used. This code will be modified to simulate the case of the host star and its exoplanet. The adaptation of the code will transform one of the stars into an exoplanet, the other star will have its parameters modified to study the influence of the stellar wind and mass ejections on the planet's atmosphere. The ejection of matter will be simulated numerically as a pulse in the stellar wind and we will analyze the code generated images to determine the influence of the CMEs on the atmosphere of exoplanets. Several parameters will be modified, such as the properties of stellar wind, distance between exoplanet and star, planetary radius and composition of the exoplanet atmosphere.

Resumo. O Sol passa por períodos de atividade a cada 11 anos. Durante o máximo de atividade, muitas ejeções de massa da coroa solar (CME) ocorrem. Acredita-se que as estrelas, muitas vezes mais ativas que o Sol, também produzam esse fenômeno. Observações dos últimos 20 anos mostraram a existência de planetas orbitando muito próximos de suas estrelas. Este trabalho tem como objetivo estudar as ejeções de matéria estelar e sua influência na atmosfera de exoplanetas. Para tanto, será utilizado o código computacional AMUN, adaptado a partir do caso de interação do vento de estrelas binárias. Este código será modificado para simular o caso da estrela hospedeira e seu exoplaneta. A adaptação do código transformará uma das estrelas em um exoplaneta enquanto a outra estrela terá seus parâmetros modificados, assim pretendemos estudar a influência do vento estelar e das ejeções de massa na atmosfera do planeta. A ejeção de matéria será simulada numericamente como um pulso no vento estelar e analisaremos os resultados gerados pelo código para determinar a influência dos CMEs na atmosfera dos exoplanetas. Diversos parâmetros serão modificados, como as propriedades do vento estelar, a distância entre o exoplaneta e a estrela, o raio planetário e a composição da atmosfera exoplaneta.

Keywords. Sun: coronal mass ejections (CMEs) — Planets and satellites: atmospheres

1. Introduction

Since the 90s, it is known that the main source of the disturbed solar wind are the giant ejections of matter from the solar corona (Cherenkov and Bisikalo, 2016). These giant ejections are called coronal mass ejections (CMEs) and are characterized as presenting a plasma bubble ejected in the interplanetary medium of approximately 10^{13} kg, an average ejection energy of approximately 10^{24} J and ejection velocities ranging from 100 to 2000 km/s (Zastenker & Zelenyi, 1999; Johnstone et al., 2015, Howard et al., 1985). This bubble flows into the interplanetary medium due to the large pressure difference between the CME and the interplanetary medium. This ionized plasma travels through the locally open lines of the solar magnetic field. The objective of this work is to numerically simulate the stellar mass ejections and to study their effects on the atmosphere of exoplanets.

Considering that a CME from a star hits an exopanet orbiting it, it will be subject to the action of CMEs, which could distort the initial patterns of the exoplanet: atmospheric erosion (if the exoplanet has atmosphere), changes in the magnetic field of the exoplanet and the increase of the temperature of the atmosphere, if it exists (Cherenkov and Bisikalo, 2016).

Exoplanets that are very close to their host star may suffer a strong impact, due to stellar activity, atmospheric erosion and high incidence of X-ray fluxes. Both phenomena can therefore affect the habitability of these planets.

2. Methods

A two-dimensional numerical hydrodynamic (HD) model is used to study, in time and space, the structures of CMEs (coronal mass ejections) originating in the solar corona that propagate through the interplanetary medium. The computational simulations for the accomplishment of such study were done with the AMUN code, entirely written in FORTRAN, developed by Grzegorz Kowal (Kowal, 2007).

This code was adapted to simulate the case of a host star and its exoplanet, as well as the study of the influence of mass ejections in the atmosphere of this planets. The ejection of matter is simulated numerically as a pulse of the star's wind, so by imaging it is possible to study the influence of CMEs in the atmosphere of exoplanets. Several parameters were modulated, such as stellar wind properties, distance between the exoplanet and the star, planetary radius and composition of the exoplanet atmosphere. For our study we use the 2D hydrodynamic code AMUN, with the following equations HD.

One of the applications of this code is for the interaction of the stellar winds of a binary system. This code will be modified for a host star and an exoplanet, where the star is active and produces CMEs. Simulations will be repeated for different system parameters, for such as temperature and/or velocity. For example, radius of the planet and density of its atmosphere, distance between the planet and its star, initial properties of the CME.

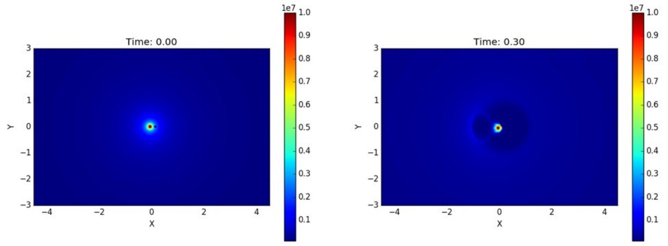

Figure 1. Left figure shows a CME pulse being created in the vicinity of an exoplanet, while the figure on the right shows the event after a certain time.

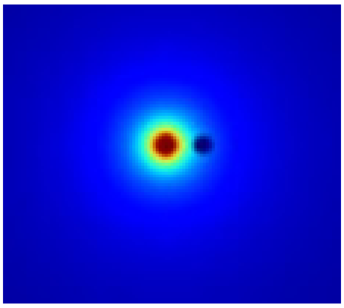

Figure 2. The figure shows the initial time of the CME pulse.

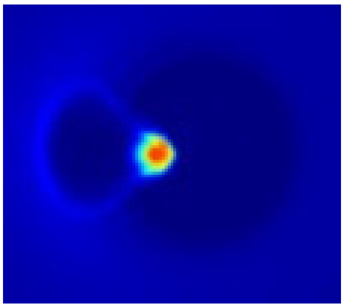

Figure 3. This figure illustrates the CME after a time t.

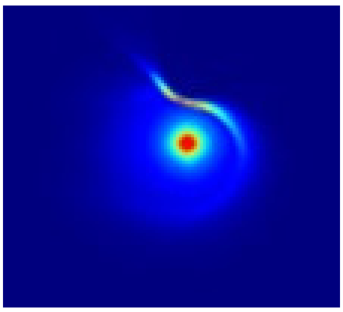

Figure 4. The figure shows the CME and its propagation at an instant after t.

3. Partial Results

After performing some simulations and studying the AMUN code, simulations were performed for the case of binary stars, with a pulse of CME. The following images (Fig. 1) show results of the propagation of a pulse of CME as a function of time (considered from 0 to 0.3, with units of the code). The vertical bar indicates the density of the CME.

Figures 2, 3 and 4 show three enlarged images of the results obtained for three different instants after a pulse of CME.

4. Conclusions

In order to complete the work, one must follow what happens to the atmosphere of simulated exoplanets when hit by CMEs of their host stars. Such changes in the atmosphere can be perceived by loss of mass of the atmosphere, increase of surface temperature and changes of magnetic field. The graphs generated in the computational simulations will be used and, from there, the impacts will be measured. The results show that the code used is able to simulate the effects of CMEs in exoplanet atmosphere. Therefore, the AMUN code is able to achieve the purpose of this work.

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