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Magnetospheric properties of the TRAPPIST-1 planets

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Abstract

We calculated the magnetic properties for all seven planets in the TRAPPIST-1 system for the first four billion years of their lifetime. We assumed a process involving the exsolution of MgO as the source of the planetary dynamo. The sizes of the magnetospheres were derived using previously modeled stellar wind parameters. We calculated the open magnetic field line regions where atmospheric escape can take place. Based on our results, we will estimate the atmospheric mass loss, which can limit habitability on the planets.

1. Introduction

The number of exoplanets in the habitable zone of M dwarfs has increased in the last few years thanks to ground-based observatories and space telescopes. M dwarfs are among the most active stars producing frequent and strong flares, strong stellar wind and high energy radiation. The habitability of these worlds strongly depends on their capability of retaining their atmospheres. Planetary magnetospheres play a crucial role in reducing atmospheric loss and thus providing a potentially habitable enviroment [1]. The M dwarf star TRAPPIST-1 is of particular interest because it hosts three Earth-sized rocky planets in its habitale zone [2]. With our current technology we are not able to detect the magnetospheres of these exoplanets. The goal of this study is to give constraints on the magnetospheric properties of the planets in the TRAPPIST-1 system and estimate the amount of atmospheric loss expected during their lifetime.

2. Magnetospheric properties

Magnetospheres are generated through the motion of conductive liquid within the planet but the mechanisms driving the planetary dynamo may change during the lifetime of planets. To calculate the magnetic field strength of the TRAPPIST-1 planets, a method based on the example of the early Earth was used, where buoyancy flux is generated by the exsolution of MgO from the core into the mantle [3]. Assuming an interior structure with different iron core sizes [4], magnetic field strength was calculated from the buoyancy flux (see Fig. 1). In order to follow the evolution of magnetic properties, we used the Virtual Planetary Laboratory to apply a thermal evolution model on the TRAPPIST-1 planets [5]. By assuming an average stellar wind for TRAPPIST-1 [6], we were able to constrain the magnetospheric standoff distances and polar cap areas for all seven planets [1]. The standoff distance is measured from the planet to the point where the stellar wind pressure is balanced by the planetary magnetic field.

3. Figure

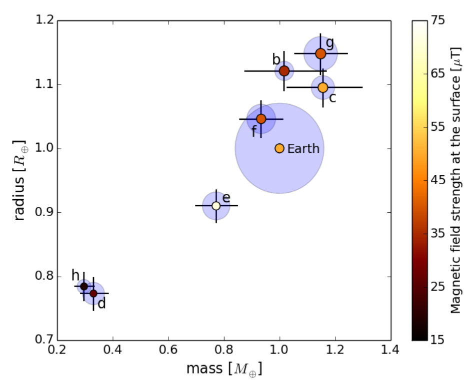

Figure 1: Magnetic properties of the TRAPPIST-1 planets four billion years after their formation. Colors indicate the magnetic field strength at the surface of the planets. Blue circles represent the standoff distances for each planet. Earth is shown for comparison. The sizes of the colored dots are relative to the Earth. Black lines show the uncertainties of planetary mass and radius [7].

4. Equations

To calculate the magnetic field strength at the core-mantle boundary (CMB) based on buoyancy flux the following scaling law can be used [8]:

$$B_{CMB}^{dipole} = \beta\sqrt{\rho\mu_0}\left(\frac{\gamma g_0 F}{\rho D}\right)^{\frac{1}{3}}, \quad (1)$$

where ρ is the density of the core, μ_0 is the vacuum permeability, D is the thickness of the dynamo region (in this case equals to the core radius), F is the buoyancy flux, g_0 is gravity at the CMB, γ describes the distribution of buoyancy in the core and β converts the internal field to dipolar field at the CMB.

Magnetic dipole moments were then calculated and used to estimate the size of the planets' magnetospheres which is described by the magnetospheric standoff distance [9]:

$$r_s = \left[\frac{\mu_0 f_0^2 M_p^2}{4\pi^2(2\mu_0 n_{sw} m_p v_{sw}^2)}\right]^{\frac{1}{6}}, \quad (2)$$

where M_p is the magnetic dipole moment, f_0 is the form factor, m_p is the proton mass, n_{sw} and v_{sw} are the stellar wind density and speed, respectively.

The polar cap area indicates the fraction of a planet's surface where magnetic field lines are open and atmospheric escape is possible. It is described by

$$\frac{A_{polar}}{A_{planet}} = (1 - cos\alpha_0), \quad (3)$$

where α_0 is the aperture of the auroral ring [1].

5. Summary and Conclusions

We calculated the magnetospheres of the TRAPPIST-1 planets for the first 4 billion years of their lifetime. Assuming their interior structure we calculated the magnetic moment and surface dipolar field strength for each of the seven planets. By assuming an average stellar wind for TRAPPIST-1, we constrained the magnetospheric standoff distances and polar cap areas for every planet. Combining our results with codes modelling atmospheric loss - such as the Virtual Planetary Laboratory - will provide information on the atmospheric evolution of these planets.

Acknowledgements

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