EPSC Abstracts
Vol. 12, EPSC2018-241, 2018
European Planetary Science Congress 2018

Effective induction heating inside exoplanets orbiting strongly magnetized M dwarfs

Kristina Kislyakova (1,2), Lena Noack(3), Colin Johnstone (1), Luca Fossati (2), Helmut Lammer (1), Manuel Güdel (1), and the PATH team
(1) University of Vienna, Department of Astrophysics, Vienna, Austria, (2) Space Research Institute, Austrian Academy of Sciences, Graz, Austria, (3) Freie Universität Berlin, Berlin, Germany

Abstract

We suggest electromagnetic induction heating as an energy source inside terrestrial planets orbiting late M dwarfs with strong magnetic fields. Induction heating arises due to varying magnetic field flux penetrating the planet. We show that for close-in planets, induction heating can be stronger than the tidal heating occurring inside Jupiter's satellite Io; namely, it can generate a surface heat flux exceeding $2\,\mathrm{W\,m^{-2}}$. An internal heating source of such magnitude can lead to extreme volcanic activity on the planet's surface, possibly also to internal local magma oceans, and to the formation of a plasma torus around the star aligned with the planetary orbit.

1. Introduction

Many M dwarfs have been observed to host strong dipole-dominated magnetic fields of a few kG and more [1]. Induction heating arises when a changing magnetic field induces currents in a conducting medium which then dissipate to heat the body, mostly within an upper layer called the skin depth. For induction heating to be substantial, the planetary orbit has to be inclined with respect to the stellar rotation and dipole axes, or (if the planet orbits in the stellar equatorial plane) the stellar dipole axis has to be inclined with respect to the rotation axis (Fig. 1). In this case, stellar magnetic field penetrating the planet varies periodically, which leads to generation of eddy currents in the conducting planetary mantle. Under these conditions, induction heating can be substantial.

2. Methods

In our model, the planet is assumed to be a sphere made up of concentric layers; each layer has a uniform conductivity which is different for different layers. We solve the induction equation in every layer and calculate the magnetic field strength and current. Knowing the current and conductivity, we find the energy release within each layer (see [2], for details). We assume by default an Earth-like mantle conductivity profile, but in the papers we have also considered a case of a molten mantle with increased conductivity. After calculating the heating, we model its influence on interiors and estimate the increase in volcanic activity using the code CHIC [4].

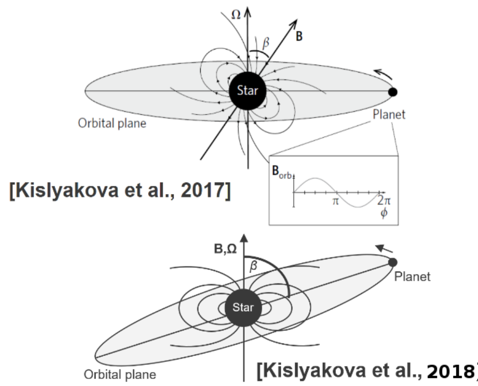

Figure 1: Sketch of the induction heating mechanism. The planet continuously experiences magnetic flux changes in its interior along its orbital motion. The change of the magnetic field arises due to the planetary orbital motion, stellar rotation, and/or stellar dipole tilt. The change of the magnetic flux penetrating the planet generates eddy currents which dissipate and heat the planetary mantle [2, 3].

3. Results

Fig. 2 presents an example calculation of induction heating inside and Earth-sized Earth-mass planet or-

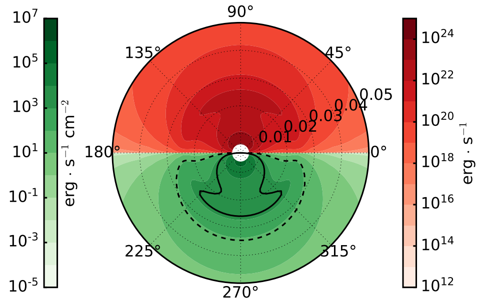

Figure 2: Total energy release inside an Earth-radius and Earth-mass planet (upper half, in red) and surface heat flux (lower half, in green) as a function of distance to WX UMa (concentric dotted rings) and orbital inclination. The solid and dashed black lines mark the surface heat fluxes of 2×10^3 erg cm^{-2} s^{-1}, which corresponds to the surface heat flux on Io due to tidal heating, and 80 erg cm^{-2} s^{-1}, which corresponds to the total heat flux of modern Earth [3].

biting WX UMa on an inclined orbit, a 0.12 $M_\odot$ star with a dipole-dominated magnetic field of 7.3 kG [1]. There is a region close to the star where the surface heat flux due to induction heating exceeds 2×10^3 erg s^{-1} cm^{-2} (2 W m^{-2}) by up to two orders of magnitude. This value corresponds to Io's heat flux induced by tidal heating, which makes this Jovian satellite the most volcanically active body in the solar system. Even at larger orbital distances, induction heating is still more powerful than the modern Earth energy release due to radioactive decay.

4. Summary and Conclusions

We show that for stellar magnetic fields above 2-3 kG, at some orbital distances energy release due to induction heating is so high that it exceeds the surface heat flux of Io, the most volcanically active body in the solar system. Energy release of such magnitude can lead to the formation of a magma ocean beneath the solid surface. Induction heating is strong also for planets with a molten mantle. Induction heating is the strongest close to the star, but it can be substantial even as far as in the habitable zone of an M dwarf, leading to increased levels of volcanic activity and potentially influencing the conditions for habitability on planets, for instance, in the TRAPPIST-1 system [3]. Therefore, it is likely that the planets orbiting magnetized M dwarfs may experience extreme volcanism and the possible formation of a plasma torus along their orbits, which may be observable in the strong far-ultraviolet OI triplet at about 1304 Åby Hubble Space Telescope or especially by a telecope of a new generation such as LUVOIR. This heating, together with the tidal heating, can be a very powerful energy source for rocky planets orbiting strongly magnetized M dwarfs and should be taken into account among other heating sources when addressing the interior evolution of such planets.

Acknowledgements

We acknowledge the support by the Austria Science Fund (FWF) NFN project S116-N16 and the subprojects S11607-N16 and S11604-N16.

References

[1] Shulyak, D., Reiners, A., Engeln, A., et al: Strong dipole magnetic fields in fast rotating fully convective stars, Nature Astronomy, Vol. 1, id. 0184, 2017.

[2] Kislyakova, K.G., Noack, L., Johnstone, C.P., et al.: Magma oceans and enhanced volcanism on TRAPPIST-1 planets due to induction heating, Nature Astronomy, Vol. 1, pp. 878-885, 2017.

[3] Kislyakova, K.G., Fossati, L., Johnstone, C.P., et al.: Effective induction heating around strongly magnetized stars, ApJ, Vol. 858, p. 105, 2018.

[4] Noack, L., Rivoldini, A., and Van Hoolst, T.: Modeling the Evolution of Terrestrial and Water-rich Planets and Moons, International Journal on Advances in Systems and Measurements, Vol. 9 no 1&2, 2016.