Origins: From the Protosun to the First Steps of Life
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Electromagnetic induction heating of planets orbiting late M dwarfs

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Abstract. We propose induction heating of planetary interiors as an energy source in the planetary mantles. Induction heating arises when a changing magnetic field induces currents in a conducting planetary mantle which then dissipate to heat the planet, mostly within an upper layer called the skin depth. This physical process can play a role in planetary interiors around strongly magnetized stars such as low mass M dwarfs with kG magnetic fields, which are common among these stars.

Keywords. planets and satellites: general, stars: magnetic fields, stars: late-type

1. Introduction

Internal energy sources play a big role in the evolution of exoplanets, their interiors and habitability. Important energy sources include: radioactive decay, mantle differentiation, core and inner core formation, and tidal heating. We show that planets orbiting magnetically active M stars are also subject to induction heating, which can similarly to tidal heating change the temperature profile of the planetary mantle and sometimes even melt it, and lead to increased volcanic activity. For induction heating to be substantial, the planet has to experience constant variations of the stellar magnetic field along its orbit. Fig. 1 illustrates how large scale variable magnetic field can be generated around the planet if the host star has a dipole dominated magnetic field.

2. Model and results

We consider a planet to be a sphere made up of concentric layers with uniform conductivity (Kislyakova *et al.* 2017). We solve the induction equation in every layer and calculate the energy dissipation. Late M dwarfs have measured magnetic fields which often exceed some kilogauss (Shulyak *et al.* 2017), which make electromagnetic induction effects very important for planets orbiting them. We use the interior model CHIC (Noack *et al.* 2016) to model magmatic effects and estimate the increase of volcanic outgassing due to an additional heating source.

Fig. 2 shows the energy release calculated for an Earth-mass, Earth-sized planet orbiting WX UMa, a very active late M dwarf with a mass of 0.1 $M_\odot$ and a dipole-dominated magnetic field of 7.3 kG (Shulyak *et al.* 2017). For inclinations higher than ≈30° induction heating is very efficient for a variety of orbital distances including the habitable zone (HZ) of this star. Strong heating of planetary interiors can lead to formation of magma oceans beneath the planetary surface (Kislyakova *et al.* 2017). The middle of the HZ of WX UMa is located at 0.046 au.

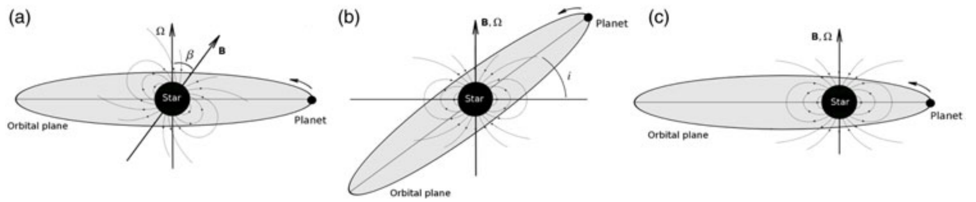

Figure 1. Three possible mechanisms to generate a varying magnetic field along the planetary orbit due to an inclination of the stellar dipole field (a), planetary orbit (b), and orbital eccentricity (c).

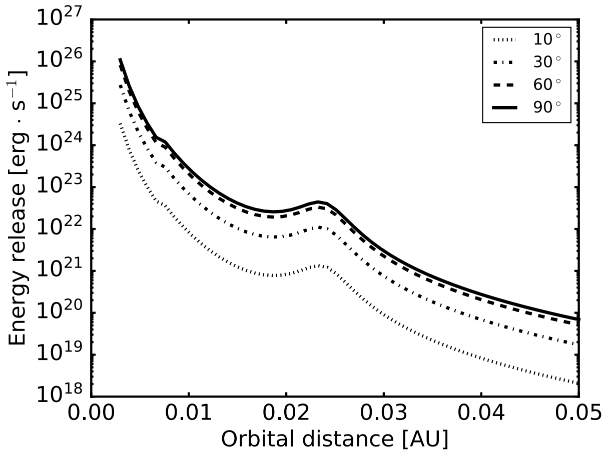

Figure 2. Energy release inside a putative Earth-sized, Earth-mass planet orbiting WX UMa on an inclined orbit (Kislyakova *et al.* 2018). We assumed an Earth-like electrical conductivity profile for the planetary mantle.

3. Implications for planetary evolution and habitability

Volcanoes can eject gases composed mainly of SO_2, CO_2, H_2O, and S_2. The exact composition depends on the redox state and volatile abundances in planetary interiors, and also on the surface pressure (Gaillard *et al.* 2014). On planets orbiting late M dwarfs, volcanic activity would resemble the one on Io, the most volcanically active body in the solar system. Severe volcanic activity can be detrimental for habitable conditions as it can lead to acid rains, ozone layer depletion, and abrupt warming from greenhouse gas emissions. However, excess outgassing can also replenish the atmosphere lost during the early active phase of the evolution of the host star. Our results are presented in more details in (Kislyakova *et al.* 2017, 2018).

References

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