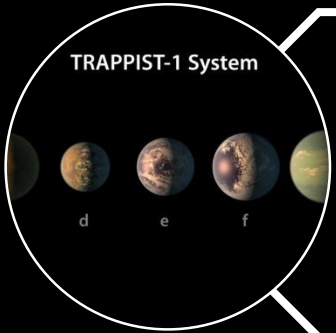
Non-thermal escape on magnetized planets in the TRAPPIST-1 system

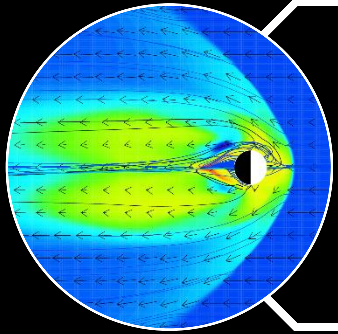
Ádám Boldog[1,2]*, Vera Dobos[3,2,4], László L. Kiss[1,5]

[1]Konkoly Observatory, Hungary, [2]MTA-ELTE Exoplanet Research Group, Hungary, [3]Kapteyn Astronomical Institute, Netherlands [4]ELTE Eötvös Loránd University, Institute of Physics, Hungary [5]Sydney Institute for Astronomy



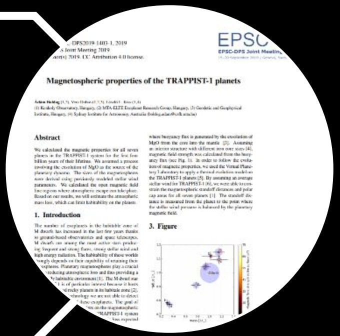
Introduction

Non-thermal escape



Magnetospheres

References

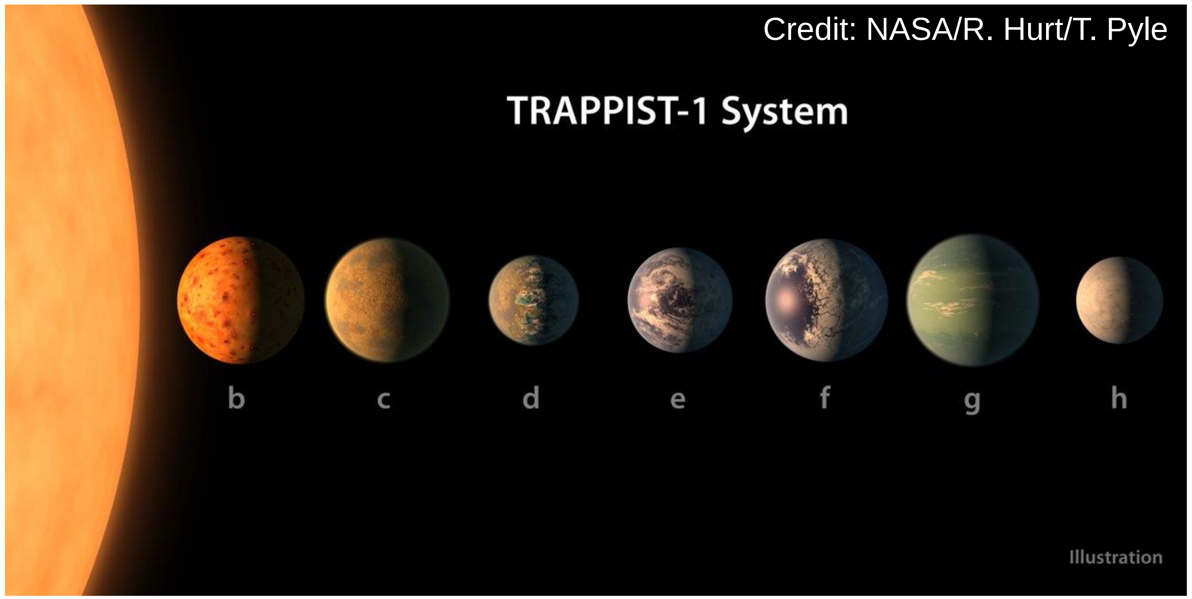


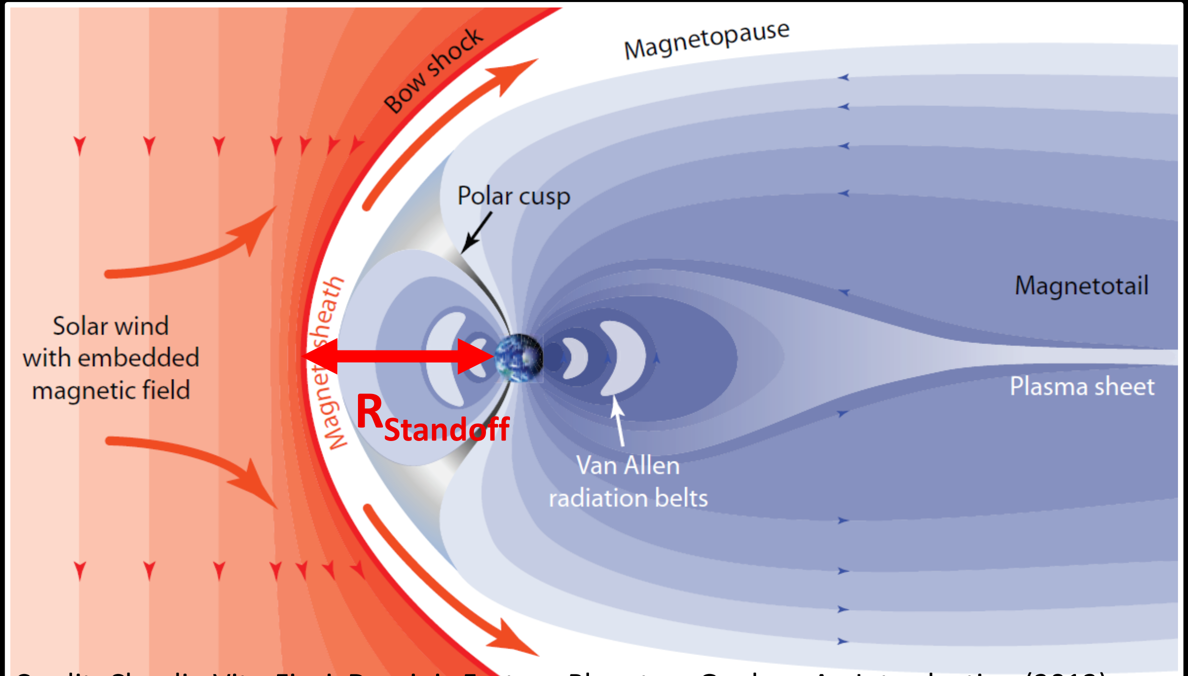
*boldog.adam@csfk.mta.hu

Introduction

TRAPPIST-1 system

The M dwarf star, TRAPPIST-1 is the host star of seven Earth-like planets, three of which resides in the habitable zone. The habitability of these planets strongly depends on their capability of retaining their atmospheres. The strong stellar wind of M dwarf stars is capable of significantly reducing the atmospheres of close-in planets through various processes (Zendejas et al. 2010.).





Credit: Claudio Vita-Finzi, Dominic Fortes - Planetary Geology An Introduction (2013)

Atmospheric escape

Atmospheric loss can occur through several processes, both thermal and non-thermal. Planetary magnetospheres can serve as protection for the planets against certain types of non-thermal escape processes, such as sputtering or ion pickup. Escape through open field lines (polar wind), on the other hand, can only occur on magnetized planets.

Planetary magnetospheres

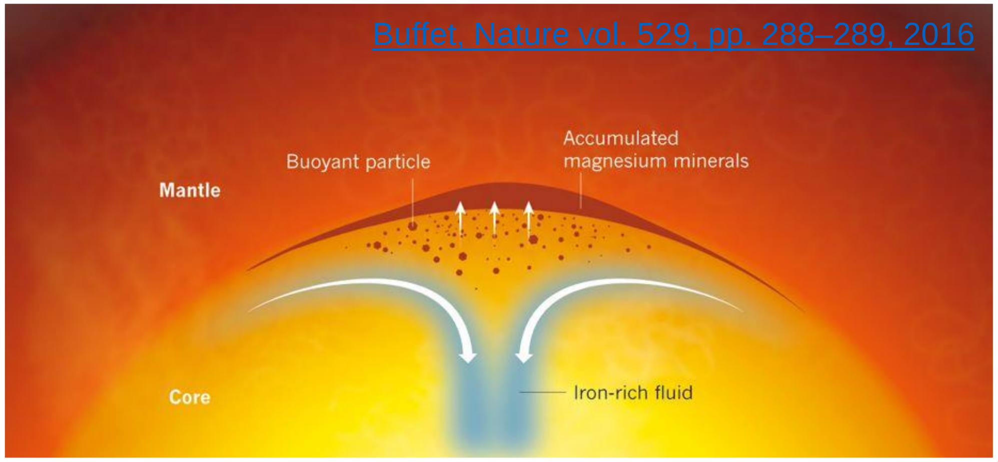
Planetary magnetospheres are generated through dynamo mechanisms, which in turn are fueled by the motion of conductive, liquid material inside the planet. The magnetospheric standoff distance ($R_{standoff}$, see the figure to the left) depends on both stellar wind and planetary properties.

Previous slide Next slide

Magnetospheres

Our goal is to:

- Calculate the magnetospheric properties of the TRAPPIST-1 planets assuming different iron core sizes from Dobos et al 2019. (See also this poster).



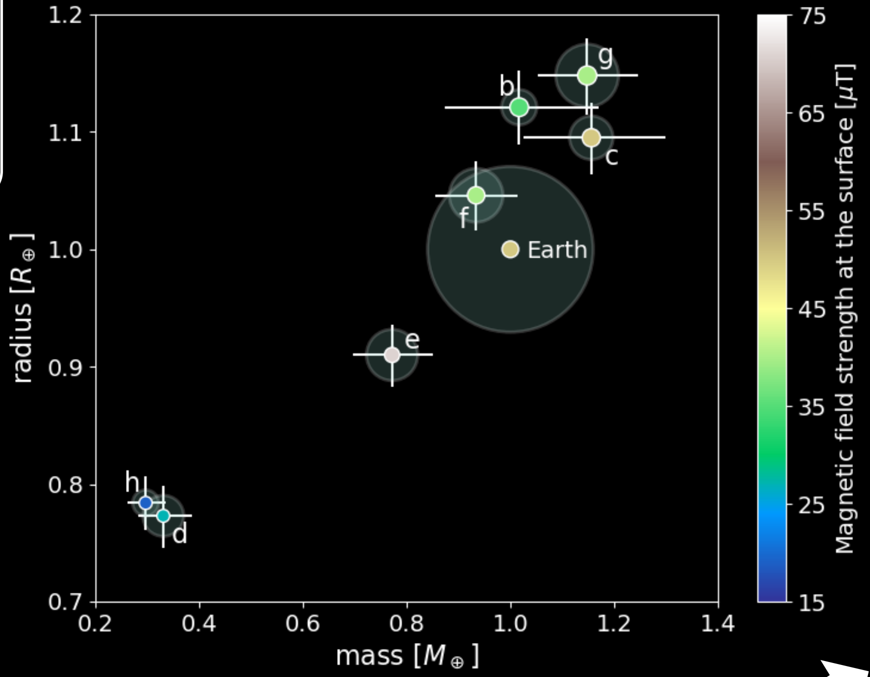


Figure shows the magnetospheric properties of the TRAPPIST-1 planets four billion years after their formation. Colours indicate the magnetic field strength. Green circles represent the standoff distances for each planet. Earth is shown for comparison. Sizes of the coloured dots are relative to Earth. White lines show the uncertainties for planetary masses and radii from Grimm et al. 2018.

Geodynamo

First, we calculated the magnetic dipole moments of all seven planets. Our calculations are based on the method presented by Badro et al. 2018. Their method describes a dynamo mechanism based on the early Earth, where bouyancy flux is generated by the exsolution of MgO from the core into the mantle.

Magnetospheric properties

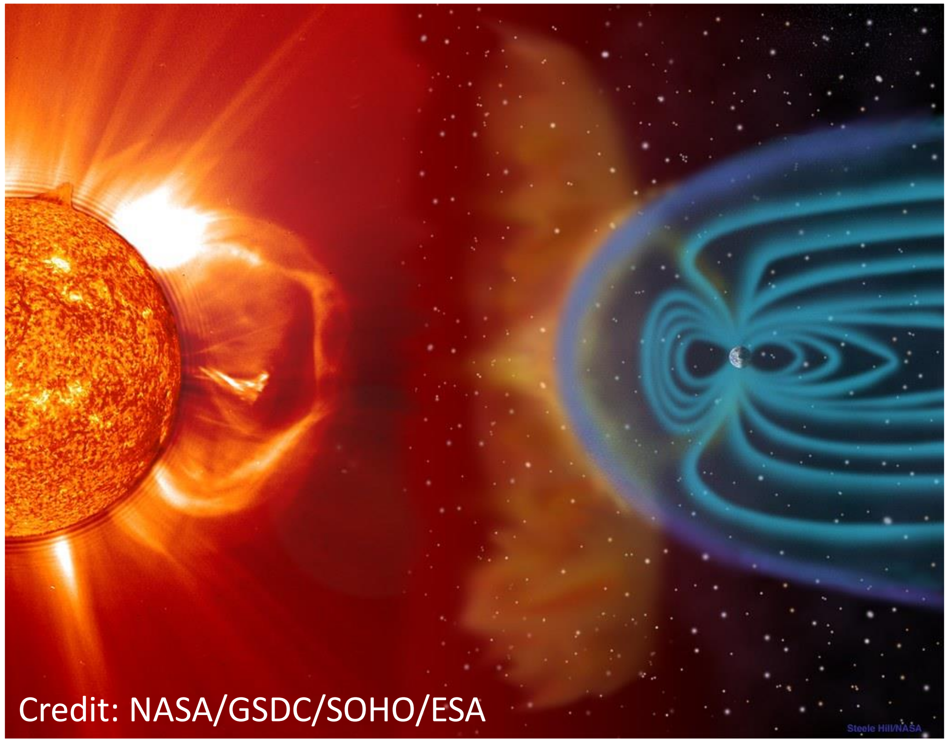
Using the acquired magnetic field strength and stellar wind parameters from Dong et al. 2018. we calculated the standoff distances for all of the planets and estimated the open field line regions, where non-thermal escape of atmsopheric ions through polar wind is possible.

Previous slide Next slide

Non-thermal escape

Our goal is to:

- Estimate the amount of atmospheric loss through non-thermal processes.



Credit: NASA/GSDC/SOHO/ESA

Non-thermal atmospheric escape

Non-thermal processes include sputtering, charge exchange, ion pickup and polar wind. Although an existing magnetosphere could reduce loss in the case of the first three processes, escape through polar wind, on the other hand can only occur on magnetized planets. We use the BATS-R-US model (Tóth et al. 2012.) to estimate the atmospheric escape rate through non-thermal processes.

Input parameters

In our simulations the stellar wind of TRAPPIST-1 is assumed to be constant and all planets are magnetized. Dipole moments are strongly dependent on the planetary iron core sizes. We run multi-species simulations where escape rates of the different atmospheric species are calculated individually and then summed up.

Simulations with BATS-R-US

BATS-R-US is now part of the SWMF (Space Weather Modeling Framework, Tóth et al. 2005.). For our simulations we use the Global Magnetosphere module of BATS-R-US coupled with the Ionosphere Electrodynamics (Ridley et al. 2002.), Inner Magnetosphere and Polar Wind modules. GM and IM calculates the outer and inner magnetospheres of the planet using our input parameters. Simulations are run until a steady state solution is achieved.

Previous slide Next slide

References

- Badro, J. et al., Geophysical Research Letters, Vol. 45, 2018.
- Dobos, V. et al., A&A, Vol. 624, id.A2, 2019.
- Dong, C. et al., Proceedings of the National Academy of Sciences, Vol. 115, Issue 2, pp. 260-265, 2018.
- Grimm S. L. et al., A&A, Vol. 613, id.A68, 2018.
- Ridley, A.J. and Liemohn, M.W., Journal of Geophysical Research, 107, A8, 2002.
- Tóth, G. et al, Journal of Geophysical Research, 110, A12226, 2005.
- Tóth, G. et al, Journal of Computational Physics, 231, 870-903, 2012.
- Zendejas, J. et al., Icarus, Vol. 210, 539-544, 2010.

Previous slide