Closing report of NKFIH PD 131737

1. December 2019 – 31 December 2020

Habitability of exoplanetary systems around ultracool dwarf stars

Although the project officially covered 13 months, in the last 6 months I was on unpaid vacation. For this reason this report covers the progress of the period between 1 December 2019 and 30 June 2020. This period also coincides with the beginning of the pandemic (COVID-19) which made collaborations more difficult, and during which I had to work from home.

My research plan consisted of two big topics, so it is reasonable to write separately about them.

1) Stellar activity and atmospheric retention

With the active participation of Ádám Boldog (PhD student at the Eötvös Loránd University), we estimated the magnetospheric strength of the TRAPPIST-1 planets. We used the Virtual Planet Laboratory, which is an open source code, to calculate the thermal evolution of the planet interiors in the first 4 billion years after their formation. The system is believed to be ~8 billion years old (Burgasser & Mamajek, 2017), but the 4 billions year limit arises from the estimation of the magnetospheric strength. We applied the method of Badro et al. (2016) which 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. This mechanism was relevant in the first 4 billion years in the history of the Earth (Badro et al. 2016).

The interior structures of the seven planets of TRAPPIST-1 were estimated previously by Dobos et al. (2019). Using the approximate size of the iron cores, the magnetic field strength of each planet was estimated with the model of Badro et al (2016). Dong et al. (2018) estimated the stellar wind parameters of TRAPPIST-1, which was used to calculate the standoff distance (the distance between the planet and the magnetosheath in the direction of the star). The results are shown in Fig. 1, where the both the magnetospheric strength and the standoff distance of the planets are compared to those of the Earth. The values for the Earth were calculated with the same model. These results were presented at the EPSC 2020 congress (online) in a poster (Boldog et al, 2020).

The open field line regions of the planets were also estimated, through which non-thermal escape of atmospheric ions is possible (polar wind). To estimate the atmospheric escape of the planets, we chose to use the BATS-R-US model (Tóth et al., 2012). This is a very complex code, and learning how to use it takes a long time. Currently we are at this step.

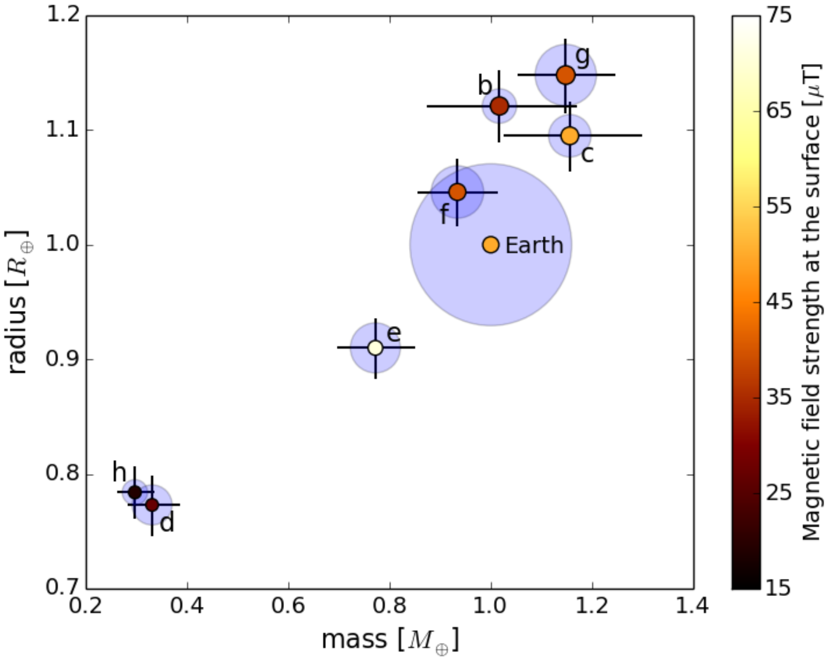

Fig. 1. Magnetospheric properties of the TRAPPIST-1 planets four billion years after their formation. Colours indicate the magnetic field strength (from brown to yellow). Earth is shown for comparison. Sizes of the coloured dots are relative to Earth. Blue circles represent the standoff distances for each planet. Black lines show the uncertainties for planetary masses and radii from Grimm et al. (2018).

2) Tidal heating in planets and moons

During the seven months of the project, I made calculations with a bachelor student, András Haris-Kiss (Eötvös Loránd University) on the topic of habitable exomoons on stable orbits. The work is based on a paper that is under review and which investigates stable orbits around known exoplanets (Dobos et al., under review). As a continuation of this project, we applied my tidal heating code (Dobos & Turner, 2015, Dobos et al. 2017) to those cases where moons (if exist) are likely to be on stable orbits. The code calculates the surface flux of the hypothetical moons considering different energy sources: stellar irradiation, reflection from the planet, thermal radiation of the planet and tidal heating in the moon. The preliminary result is shown in Fig. 2, which is part of the diploma work of András (which he successfully defended in June 2020). I call this a *preliminary result*, because we will need to rerun all the calculations, due to changes made in the preceding paper during the referee process. Upon the acceptance of the paper we will make our calculations again and publish the results.

The coloured dots in Fig. 2 show the habitability rate, or in other words, the fraction of habitable moons around a planet. There are many planets outside the circumstellar habitable zone (the borders are indicated by green curves) with relatively high habitability rate. This is in part due to eccentric orbits of the planets (the planet–moon pair periodically receives higher stellar irradiation), and in part due to tidal heating arising in the moon.

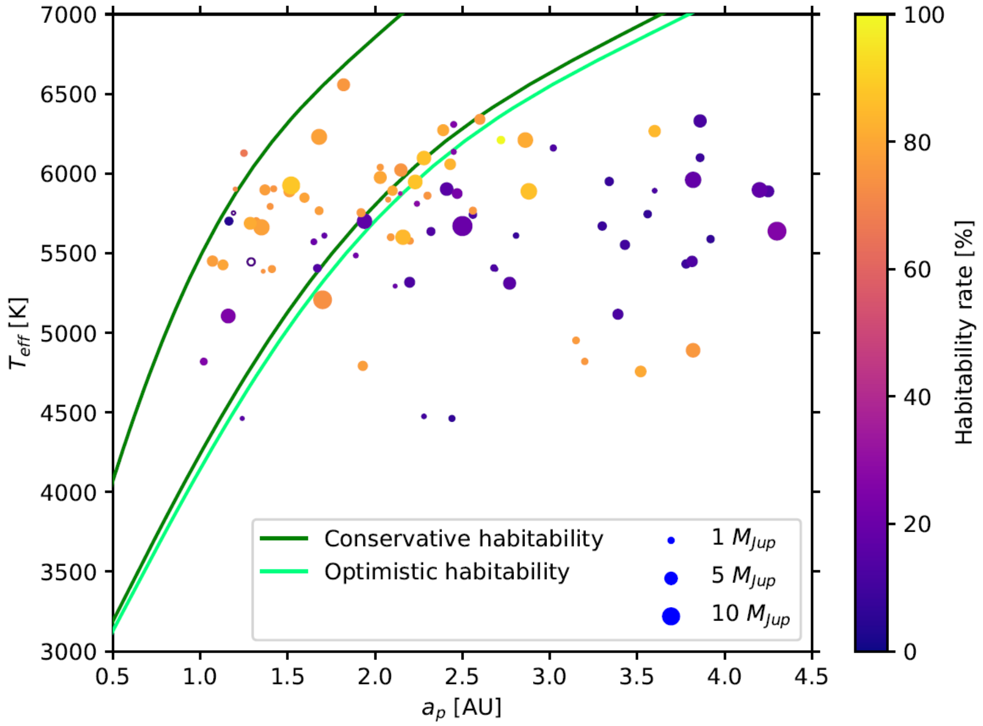

Fig. 2. Habitability rate of hypothetical exomoons around known exoplanets as functions of the semi-major axis of the planet, and the effective temperature of the host star. The size of the dots is proportional to the mass of the host planet (which is proportional to the mass of the hypothetical moon). Green curves show the inner and outer boundaries of the conservative and optimistic circumstellar habitable zone (calculated with the formula given by Kopparapu et al., 2013).

References

Badro J., Aubert J., Hirose K. et al. 2018, Geophysical Research Letters 45, 13-240

Boldog Á., Dobos, V., Kiss L.L. 2020, EPSC2020-702

Burgasser A., Mamajek E.E. 2017 ApJ 845, 110

Dobos V., Barr A., Kiss L.L. 2019, A&A 624, A2

Dobos V., Charnoz S., Pál A., Roque-Bernard A., Szabó Gy.M. 2021, PASP, under review

Dobos V., Heller R., Turner E.L. 2017, A&A 601, A91

Dobos V., Turner E.L. 2015, ApJ 804, 41

Dong C., Jin M., Lingam M. et al 2018, PNAS 115, 260

Grimm S.L., Demory B.-O., Gillon M. et al 2018, A&A 613, A68

Kopparapu R.K., Ramirez R., Kasting J.F. et al 2013, ApJ 765, 131

Tóth G., van der Holst B., Sokolov I.V. et al. 2012, Journal of Computational Physics 231, 870