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Tidal parameters and habitability of the TRAPPIST-1 planets

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The discovery of seven Earth-sized planets around the ultracool dwarf star TRAPPIST-1 in 2017 brought a new type of planetary system to our attention. Modelling the planets of this system and considering new physical processes may result in a more realistic description of those exoplanets that are considered to be the most habitable ones. Similar planetary systems to the TRAPPIST-1 are expected to be discovered with current and upcoming missions, and in fact, recently, two Earth-sized planet candidates were announced around the ultracool Teegarden's Star (Zechmeister et al. 2019). Detailed modelling of similar exoplanetary systems will be an important task to reveal their astrobiological potential. Until new discoveries, the TRAPPIST-1 system serves as a prototype of an ultracool M dwarf with a planetary system of Earthlike planets. For this reason, studying the TRAPPIST-1 planetary system is a pioneering work that will help in the characterization of similar systems that are yet to be discovered.

The habitability of Earth-like exoplanets around M dwarfs is becoming the forefront of exoplanetary research as the TRAPPIST-1 system is recently in the centre of attention. Tidal heating may be an important effect influencing habitability, especially for close-in planets or moons. Close-in bodies quickly become tidally locked, but if their eccentricities are excited by periodic perturbing effects of other planets or moons in the system, then varying tidal forces keep causing friction inside the body that leads to continuous heat generation (Peale et al. 1979). Some studies suggest that tidal heating may enable the emergence of life in otherwise too cold environments (Scharf 2006, Dobos & Turner 2015, Forgan & Dobos 2016, Dobos et al. 2017).

Using a Maxwell viscoelastic rheology, we computed the tidal response of the planets using the volume-weighted average of the viscosities and rigidities of the metal, rock, high-pressure ice, and liquid water/ice I layers. After determining the possible interior structures, we computed the heat flux due to stellar irradiation and tidal heating for the inner four planets (Barr et al. 2018, Dobos et al. 2019). We found that planet e is the most likely to support a habitable environment, with Earth-like surface temperatures and possibly liquid water oceans. Planet d also avoids a runaway greenhouse state (in which it would irreversibly lose all of its surface water content), if its surface reflectance is at least as high as that of the Earth. Planets b and c have heat fluxes high enough to trigger a runaway greenhouse and to support volcanism on the surfaces of their rock layers. Planets f, g, and h do not experience significant tidal heating arising from the star, and likely have solid ice surfaces with possible subsurface liquid water oceans.

We also connected dynamic evolution of planetary orbits with interior structure considerations for the inner two TRAPPIST-1 planets (Brasser et al., 2019). Based on stability considerations, and with the assumption that orbital resonances are lasting for planets b and c, lower limits can be determined for their k_2/Q tidal parameter. This parameter can further be constrained by the planets' interior structure which determines their tidal dissipation. Although the two approaches gave different results, well-constrained tidal parameters will improve the realism of orbital evolution simulations including tidal effects.