TIDAL HEATING OF EARTH-LIKE EXOPLANETS AROUND M STARS. P. E. Driscoll[1,2] and R. Barnes[1,2], [1]University of Washington Astronomy Department (Box 351580, Seattle, WA 98195), [2]NASA Astrobiology Institute, Virtual Planet Laboratory Lead Team

Introduction: The internal thermal and magnetic evolution of rocky exoplanets is critical to their habitability. We focus on the thermal-orbital evolution of Earth-mass planets around low mass M stars whose radiative habitable zone overlaps with the tidal zone, where tidal dissipation is expected to be a significant heat source in the interior (Figure 1). We focus on three geophysical habitability factors:

(1) *Prolonged magma ocean stage*. Close-in planets with a fixed high eccentricity will experience extreme tidal heating rates with hot steady state interior temperatures and mostly molten mantles. These super-tidal planets are likely inhabitable as the surface itself is partially molten or close to the silicate solidus.

(2) *Extreme volcanic eruption rates.* A modest amount of tidal heating can dramatically increase melt production rates. Even if only a fraction of this melt erupts to the surface it can easily generate extreme eruption rates that lead to rapid global resurfacing and degassing rates that make the surface environment a violent and potentially toxic place for life.

(3) *Lack of planetary magnetic field.* Planetary magnetic fields are often invoked as shields necessary to maintain life. Magnetic fields protect the atmosphere from stellar wind erosion [2] and the surface from harmful radiation [1,3]. Even before losing the dynamo entirely these planets may have magnetic fields that are too weak to hold the stellar wind above the atmosphere or surface.

Model: We develop a 1D thermal-orbital evolution model that couples tidal dissipation, with a temperature-dependent Maxwell rheology, to orbital circulation and migration.

Results: We identify thermal-orbital steady states where surface heat flow is balanced by tidal dissipation and cooling is stalled until circularization occurs. The mantle temperatures at which this balance occurs are hotter for planets with shorter orbital distances and larger eccentricities.

Orbital energy dissipated as tidal heat in the interior drives both inward migration and circularization, with a circularization time that is inversely proportional to the dissipation rate. The cooling of an eccentric planet in the habitable zone leads to a peak in the dissipation rate as the mantle passes through a visco-elastic state. Planets initially within 0.07 AU circularize before 10 Gyr, independent of initial eccentricity, and once circular cool monotonically similar to Earth.

Planets forced into eccentric orbits, for example by an additional companion, cool to a tidal steady state balance where sustained tidal heating prohibits further cooling. In the habitable zone, steady-state interior temperatures are high enough to produce a super-cooling of the core and rapid core solidification, inhibiting dynamo action for these planets.

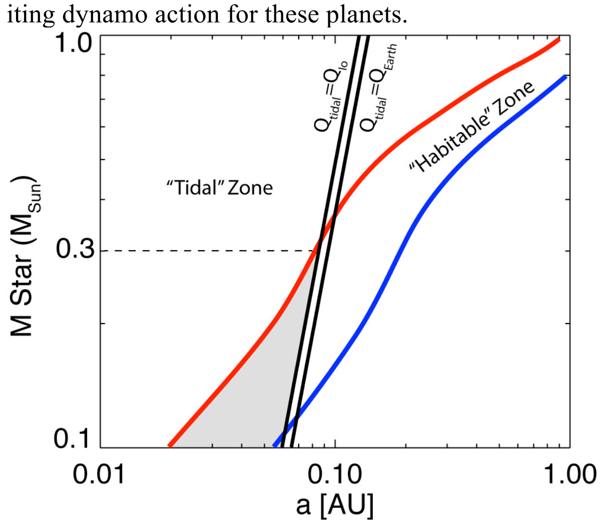

Figure 1: Comparison of the radiative "habitable" zone to the "tidal" zone. The radiative "habitable" zone is from [1]. Inside the "tidal" zone tidal heat likely dominates the internal heat budget of the planet. The tidal zone is delineated by distances from the star where an Earth-mass planet would receive an amount of heat via tidal dissipation equal to either the surface heat flow of Io (Q_{surf}=80 TW, left curve) or Earth (Q_{surf} =40 TW, right curve). Tidal heat flow assumes e=0.1 and -Im(k_2)=3x10^{-3} (k_2=0.3, Q=100). The gray shaded region denotes the zone where the planet is predicted to be radiatively "habitable" but tidally dominated, and therefore possibly not habitable.

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