TEMPERATURE DISTRIBUTIONS ON TIDALLY-LOCKED HOT EXOPLANETS. A. L. Ganesan[1], L. T. Elkins-Tanton[1], S. Seager[1,2] [1]Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Sciences, [2]Massachusetts Institute of Technology, Department of Physics, 77 Massachusetts Avenue, Cambridge MA 02139 (aganesan@mit.edu)

Introduction: The discovery of over 250 exoplanets, many of which exist in conditions unlike any Solar System bodies, has motivated researchers to study these planets and place them within the greater context of planetary science. Of these discovered exoplanets, most are massive (Jupiter masses) and orbit very close to the parent-star, with orbital periods on the order of several days [1]. Additionally, near Earth-mass planets orbiting in habitable zones of other solar systems are being discovered with new detection techniques. The planet GI 581c, discovered in 2007, is an example of such a planet [2]. Atmospheres have been detected on giant exoplanets and with the advent of new telescopes and techniques, will also be detected on smaller planets. We primarily focus on hot super-Earth planets, rocky planets up to 20 Earth masses that orbit close to the parent star. The closest analog in our solar system to these hot exoplanets is Mercury, a planet with a composition whose exact nature remains to be determined [3].

We present a preliminary computational method to understand possible surface and interior temperatures and atmospheric compositions of hot, rocky exoplanets by modeling solid-state heat transfer using conductive and radiative transport. These methods allow us to characterize these planets and provide a theoretical context for observational data.

Methods: We use the finite element code SSAXC, a spherical axisymmetric version of ConMan (Convection in the Mantle) to study heat transfer in tidally-locked planets. The code uses the Petrov-Galerkin finite element method to solve the time-dependent two-dimensional heat equation for an axially symmetric geometry [4]. The code is modified to include heat flux onto and radiative heat loss from the surface at each time interval to compute the steady-state temperature profile. This code can accomodate both conductive and convective cases for a variety of planetary conditions and materials, though in this preliminary study, only the conductive case is considered. In the case of exoplanets, various planetary radii, orbital distances, and parent-star types and fluxes will be considered. We will be considering planets up to 20 Earth masses with varying metallic core size and surface compositions.

Results: A steady-state temperature profile was computed for a conductive planet with stellar heating as the sole heat source. The pole is the axis of symmetry and represents the point closest to the star. Stellar heat flux is treated with latitudinal dependence, as it drops off as a cosine function from the pole. A core region is treated at a constant temperature that is 10% (T=0.1) of the surface polar temperature (T=1). Temperatures and radii have been normalized, such that R = 1 represents the planet radius and T =1 is the peak temperature (Fig. 1).

At steady-state, there are regions where the planet may exist in a molten state that could be depleted of volatile materials that have either escaped or are constituents of an atmosphere. Future laboratory experiments will elucidate information of what materials would preferentially evaporate from a range of possible silicate compositions.

Additionally, there are regions of intermediate temperature that could be considered habitable even on a hot exoplanet.

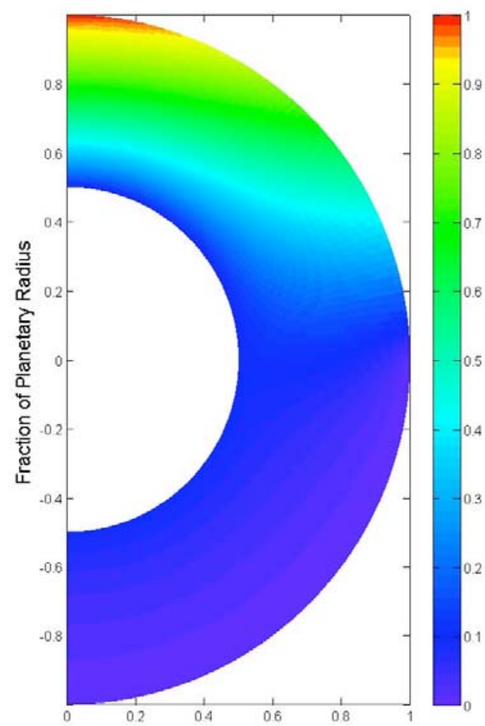

Fig. 1: Steady-state temperature profile of a tidally-locked planet with constant stellar heating and conductive heat transfer. Temperatures and radii are normalized, such that R = 1 is the planet radius and T = 1 is the peak temperature.

For a planet of composed of basalts and peridotite, temperatures of 1100 to 1200 ºC (at 1 atm. pressure) are required for melting of the silicate material [5,6]. Evaporation temperatures are not well known but will begin at temperatures lower than the solidus. To achieve an equilibrium temperature that would allow melting of these silicates, orbital distance has been computed for a planet orbiting various types of main-sequence stars (Fig. 2).

The planet HD 190360c, discovered in 2005, orbits a class IV subgiant star. The planet is approximately 18 Earth masses, and orbits the star with a 17 day period. It is possible that this body could have an equilibrium temperature greater than the melting temperature of basalt and peridotite [7]. Additionally, as shown in Figure 1, some planets may have localized regions that are molten.

Discussion: This research has implications for the search for molten and hot exoplanets. Due to the mechanisms of current detection techniques, planets orbiting close to the star are more likely to be detected. This method will elucidate compositional information for surfaces that are both hot enough to evaporate volatiles from the solid state without melting, as well as surfaces that are hot enough to melt. Planets that are fully or partially molten are unlike any solar system bodies, and thus provide insight into a new class of planets.

There could exist an annulus on the surface of a hot tidally-locked exoplanet corresponding to a habitable region, where temperatures are intermediate between those resulting from the intense stellar heating and the cold, dark side. This has broad implications for the search for extraterrestrial life, in that these planets should also be considered. In the example from Figure 1, if the nondimensional temperature scaled to 1 corresponds to 1000°C, then a region in the planet at temperatures between 20 and 40°C exists permanently at the surface close to the equator, and extends into the planet at higher latitudes and greater depths.

On very hot, tidally-locked planets, the efficiency of heat removal on the dark side (Fig. 1) indicates that the planet could be molten to some tens of even hundreds of kilometers at its pole, as a sort of magma pond. The low density of this magma and the relatively low viscosity of surrounding warm silicates create conditions conducive to isostatic rebound. During isostatic rebound the solid silicate mantle will rise to match gravitational stability in the sphere, and force the molten surface material to flow out of its original region onto the cold adjacent planetary surface.

Future Work: This research could also provide a compositional context for the mass and radius relationship of exoplanets. For example, if a silicate magma ocean can be detected, ruling out an outer water layer will constrain the planet's composition.

A similar theoretical study will be performed for Mercury to examine the volatilization of oxides from possible Mercury basaltic crustal compositions. Comparisons of these results will be made with measurements taken on the *MESSENGER* mission to Mercury.

We also plan a laboratory study to determine the order and amounts of elements volatilized from a solid crystalline planetary surface by solar heating.

Further research can identify key spectral signatures to aid in the search of exoplanets. As more space-based telescopes with higher resolution become available, surface and atmospheric spectral features will be resolved. This research can provide tools to relate possible compositional profiles to observational data. The *Kepler* mission, to be launched in 2009, and the *Corot* mission, will find many of these smaller, rocky planets.

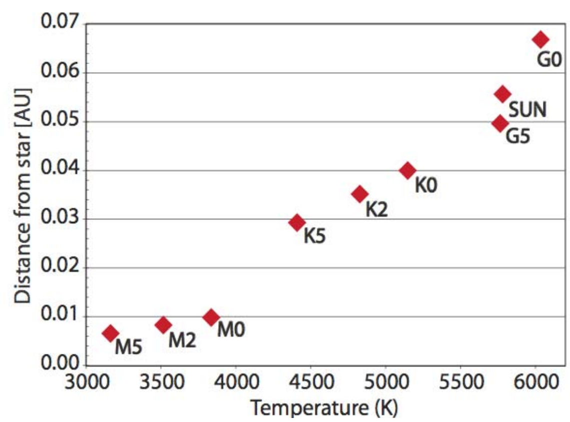

Fig. 2: Maximum orbital distance from main sequence stars where planets can have equilibrium temperatures needed to melt basalts and peridotite. Values are computed for a perfectly absorbing, tidally-locked body, with heat reradiating from one side.

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