

## A5\_2 Living in the Dark

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### Abstract

A body placed at the second Lagrangian point of many host planets would not experience directly incident solar radiation; however, re-emissions from the host planet would impact the satellite. This paper looks into the time taken for the satellite to reach the temperature required for liquid water. Various host planets are considered and the radius of the satellite varied to examine the effect on the heating time. The paper finds that while a satellite around Earth would provide the longest habitable period, the time frame to reach a suitable temperature is the greatest. A satellite placed around a hot Jupiter would reach habitability the fastest.

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### Introduction and Theory:

Planets in the Solar System are subject to varying levels of radiation from the Sun, depending on their orbital radius. The flux absorbed by a planet may be re-emitted, from the night-side, as the body rotates. Satellites can be located at specific orbits, such as the L1 point where the satellite will be constantly between the planet and the Sun, or the L2 point whereby the satellite will be perpetually located behind the planet. Placing a satellite in L2 orbit, we inhibit the direct impingement of solar radiation; it is then assumed that this is zero. The majority of radiation incident upon the body is therefore re-emission from the host planet. Alterations to the satellite radius vary the surface area presented and thus the quantity of incident energy. Radial variation is considered when investigating the time required for the satellite to heat to a temperature at which liquid water could be supported.

A series of planet sizes were used at varying radii from the Sun before it was concluded that the most effective place to investigate was at the mean distance of Mercury's orbit, 0.39 AU. This was shown from the calculations noted in Figure 1(i), where the time to reach a temperature for habitability at the Earth's current orbit far exceeded the time for the two considered scenarios at Mercury's orbit.

It was then assumed that the satellite would be tidally locked, much like the Moon, such that only one side would face the planet and be exposed to the re-emitted radiation. A further assumption was then made that the other side

of the satellite would be shrouded in a perfect insulator, such that no re-emission may occur, since the calculations were beyond the scope of this paper. Temperature gradients on the satellite have also been neglected in the following calculations.

Three scenarios were chosen for the investigation; Mercury and Earth at their current orbits and Jupiter at Mercury's orbital radius. Mercury and the hot Jupiter were assumed to have a rotation period similar to the Earth. Each of these have a known albedo, orbital radius, planetary radius, and mass<sup>1 2 3</sup>. From this information it is possible to calculate the distance to the second Lagrangian point and the amount of flux incident on the satellite. By varying the radius of the satellite we can then deduce the time necessary to heat it to a point where liquid water can exist and determine at which point it would become uninhabitable.

Finally, we assumed that the minimum temperature necessary for supporting life was 273K, the melting point of water, and the maximum temperature 373K, the boiling point of water. As the satellite was assumed to be fully insulated, it would continuously heat until its temperature no longer lay within this habitable range.

### Equations:

To calculate the distance to the second Lagrangian point, equation 1 is used:

$$r_{L2} = R_{orb} \sqrt[3]{\frac{M_2}{3M_1}}, \quad (1)$$

where  $r_{L2}$  is the radius from the planet to the satellite,  $R_{orb}$  is the radius of orbit of the planet about the sun,  $M_2$  is the mass of the planet, and  $M_1$  is the mass of the Sun.

To calculate the flux incident on the planet from the sun,  $f_1$ , we use the Luminosity-Radius relation, shown below in equation 2:

$$f_1 = \frac{L_{sun}}{4\pi R_{orb}^2}, \quad (2)$$

where  $L_{sun}$  is the luminosity of the sun, a researched value of  $3.846 \times 10^{23}$  Watts<sup>4</sup>.

A percentage of this flux is then absorbed by the planet and re-emitted on the night side, towards the satellite. To calculate the flux incident on the satellite,  $f_2$ , equation 3 is used:

$$f_2 = \frac{L_{sun}(1-A)r_p^2}{4\pi R_{orb}^2 r_{L2}^2}, \quad (3)$$

where  $A$  is the albedo of the planet and  $r_p$  the planetary radius. From this flux value we can calculate the length of time required to heat the satellite to the melting point of water. This time,  $t$ , is calculated by equating the energy necessary to increase the temperature by 270 K (assuming a background temperature of 3 K) and the energy gained from the incident flux, as shown in equation 4:

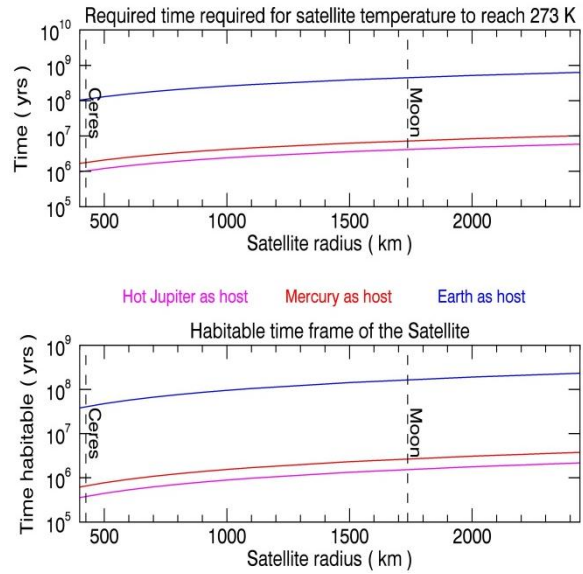
$$t = \frac{\rho r_{sat} c \Delta T}{3f_2}, \quad (4)$$

where  $\rho$  is the mean density of the planet, approximated to the density of graphite,  $r_{sat}$  is the radius of the satellite,  $c$  is the specific heat capacity of the satellite, and  $\Delta T$  is the change in temperature. The density of graphite was used due to the similarity in density to the asteroid Ceres<sup>5</sup>, taken as a good approximation to the satellite.

### Results and Conclusion:

The results show that a satellite at the L2 point of Earth would take the longest time to reach temperatures capable of supporting life, when heated solely by re-emission from the host planet. Figure 1(ii) makes apparent that once the minimum required temperature has been reached, a satellite at the L2 point of Earth will remain habitable for a far greater time than around the other host planets.

It is clear that the length of time in which the L2 point is habitable and the length of time needed to bring the system to a point of habitability are vital concerns if there was an intention for inhabiting a satellite for certain



**Figure 1(i):** Top panel - graph showing the required time for the satellite to reach a temperature of 273K with varying radii. The blue line indicates the results for Earth, red for Mercury and pink for Jupiter. The radius of Ceres and the Moon are included for reference as dashed lines.

**Figure 1 (ii):** Bottom panel – graph showing the time for which the satellite is habitable. The same colour references apply as defined for 1(i).

periods. While Figure 1(ii) shows that the best position for a satellite would be at the L2 point of Earth due to the longevity of the habitable time, Figure 1(i) demonstrates that it also takes the longest to reach a habitable temperature.

This paper notes that in similar solar systems to our own with hot Jupiters in orbit about the parent star, it would be possible for life to exist within the L2 point for periods of time. Further work could be made to investigate whether all assumptions in this paper are realistic.

### References

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All websites were accessed on 06/10/14