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P5 4 The Planet That Flew Too Close To The Sun

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Abstract

In 'The Sunlit Man' by Brandon Sanderson, the planet Canticle is subject to extreme solar radiation causing the rock on the daylight side of the planet to melt over a short timescale of minutes to hours. Whilst an explanation is given in the book involving the magic systems of investiture, we attempt to describe a scenario where this superheating comes purely from the incident solar flux. This model is then used to generate a plot to show the orbital radius of such a planet against the time taken to melt the surface. Suitable orbital radii are found although they lie dangerously close to the corona.

Introduction

The planet 'Canticle' in Brandon Sanderson's book, 'The Sunlit Man' [1] experiences a particularly unique day/night cycle where the day side of the planet is subject to intense stellar radiation such that "everything melts or breaks apart each day" [1]. In the book, this behaviour is explained by the in-universe magic systems, however it should be possible to provide varying orbital radii about a sun like star where these conditions are replicated. For simplicity of the model, the atmosphere of the planet is ignored, with only the incident stellar flux on the rock and the radiative cooling from the rock being considered. When not in direct sunlight, the temperatures on Canticle appear to be comparable to standard temperatures on Earth. If the stellar energy was being re radiated by the atmosphere (analogous to the greenhouse effect), the planet should heat globally to temperatures unsupportive of life. The surface material is assumed to be a standard volcanic rock like basalt since it is melted and cooled on short timescales frequently, with the material data given below in Table 1.

Property	Value
ρ	3.1×10^3 kg m^{-3}
C	1.48×10^3 J kg^{-1} K^{-1}
L	400 kJ kg^{-1}
Melting point	1570 ± 10 K

Table 1: The density of solid basalt, specific heat capacity, and specific latent heat taken from Table 1 in the Journal of Geophysical research [2]. The melting point of basalt from [3].

Results and Discussion

The total energy required to melt the basalt is:

$$Q_{heat} + Q_{fusion} = mC\Delta T + mL. \qquad (1)$$

Where Q_{heat} is the energy required to raise the temperature of a given mass of basalt to the melting temperature, and Q_{fusion} is the energy required to cause a change of state of that mass of basalt [4]. The net energy received by the

basalt is given by:

$$E_{Net} = S(F_{rad} - \sigma T^4), \tag{2}$$

where S is the surface area of the basalt exposed to the incident radiation, F_{rad} is the incident stellar flux per unit area, and the basalt is approximated as emitting as a black body (with a 100% efficiency in converting stellar flux to thermal energy). Since we assume a sun like star [5], the stellar flux is given as:

$$F_{rad} = \frac{L_\odot}{4\pi r^2}. \tag{3}$$

We examine the energy required to melt one square meter of basalt, assuming that the whole daylight side is receiving the same flux per unit area. Locally the stellar rays are parallel to the surface and so this approximation is valid. The melting timescales are split into two, one with variable temperature and the other with a constant temperature.

Varying Temperature **-** For the changing temperature:

$$mC\frac{dT}{dt} = (F_{rad} - \sigma T^4). \tag{4}$$

Rearranging and integrating gives:

$$t_1 = \int_{T_i}^{T_f} (\frac{mC}{(F_{rad} - \sigma T^4}) dT. \tag{5}$$

Where t_1 is the time for the first phase to complete, T_f and T_i are the final (1200K) and initial (293K) temperatures respectively. Integrating gives:

$$t_1 = mC[\frac{1}{4} ln|\frac{1+B}{1-B}| + \frac{1}{2}\arctan(B)\frac{1}{A^{\frac{3}{4}}\sigma^{\frac{1}{4}}}]_{T_i}^{T_f}. \tag{6}$$

Where A and B are given as:

$$A = \frac{L_\odot}{4\pi r^2}, B = \frac{\sigma^{\frac{1}{4}} T}{A^{\frac{1}{4}}}. \tag{7}$$

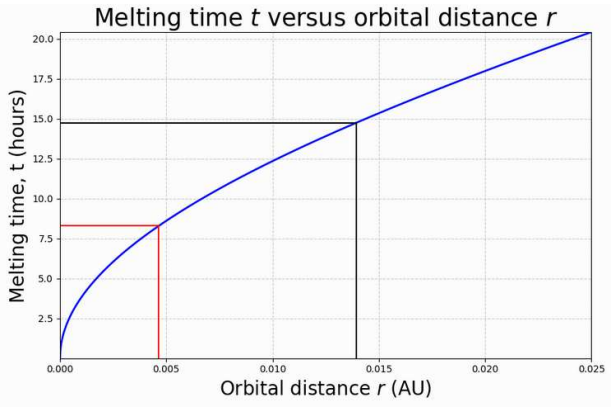


Figure 1: The solid red line indicates the boundary of the sun's surface [5], and the black line gives an estimate for the boundary of the corona of a few solar radii[6].

Constant Temperature **-** For the second phase, the temperature is constant so the time taken is:

$$t_2 = \frac{mL}{F_{rad} - \sigma T_f^4}. \tag{8}$$

The total time taken to melt is then plotted against the orbital radius in Figure 1. The mass of the basalt is approximated as a 10 cm thick slab of area 1 m^2, and density shown in Table 1, allowing melting material to cause changes in small geographical structures across the surface as described in the book.

Conclusion

We find that there is a region of orbital radii where a planet like Canticle orbiting a sun like star could experience enough solar radiation to melt its surface daily, with a melting timescale of the order of hours. The melting timescale rapidly increases with orbital radius, leaving the only viable radii just outside or inside of the corona. This poses issues with the model as it has assumed the only source of heating comes from the incident stellar radiation. The corona reaches temperatures of millions of kelvin [6], and so if a planet were in this region, the main source of heating would come from the corona itself, melting the whole planet.

References

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[6] Sakurai T.(2017), *Heating mechanisms of the solar corona.*, Proceedings of the Japan Academy, Series B Physical and Biological Sciences, `https://pmc.ncbi.nlm.nih.gov/articles/PMC5422629/`, Introduction.