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P3_3 Stardew Planet

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Abstract

In this paper we discuss the orbital and stellar requirements for a planet with Earth like conditions but with an orbit of only 112 days as demonstrated in the game Stardew Valley. We determine that an orbit of 0.388 Au, with a star of mass 0.623 Solar Masses, luminosity of 0.151 Solar Luminosity, radius 0.623 Solar Radii and a surface temperature of 4580K is the most likely configuration for these conditions.

Introduction

The game Stardew Valley is a farming game where you obtain a farm in the eponymous Stardew Valley. The game simulates a year using 4, 28 day seasons, before starting a new year. This means that the Stardew Valley cannot be on Earth. The most obvious solution, therefore, is to have the valley be on a planet with an orbit of 112 days. However, we also know that the planet has Earth-like conditions, so it cannot merely be orbiting closer to it's parent star, otherwise it would be removed from the Goldilocks Zone.

Assumptions

We must make some assumptions in order to calculate characteristics about the planet and it's star. Firstly, we are assuming that the Stardew planet is receiving near identical flux from its star when compared to Earth. This is justified by the fact that flora and fauna in the game are identical to those on Earth. Secondly, we assume that the planet is following a near circular orbit, justified by the fact that in game season changes are extremely similar to our own, and not exaggerated by orbital effects. Thirdly we are assuming a day on Stardew Planet is the same length as a day on Earth, justified by noting that actions in game take equivalent time as they might do on Earth.

Theory

We start by calculating the solar flux in coming at 1AU. This is simply,

$$L_e = L_s/4\pi r^2 \tag{1}$$

L_e is the net flux at Earth, L_s is the luminosity of the Sun (taken to be $3.90 \times 10^{26} W$), and r^2 is the elliptical semi major axis which is simply 1 Au. This gives us a values of $L_e = 1390 W m^{-2}$

We then need two equations, the reduced form of Kepler's third law and the mass-luminosity relationship for stars. For the mass-luminosity relationship we have taken a, the exponent, to be 4. The exponent changes for various factors including chemical content of the star and age but Henry and McCarthy[1] suggests a higher exponent for stars of the mass we are expecting ($0.5M_s - 1M_s$)than the standard 3.5 so a value of 4 was chosen. This give us,

$$a^3/T^2 = GM_S/4\pi^2 \tag{2}$$

and,

$$L_{star}/L_S = (M/M_S)^4 \quad (3)$$

where a is the elliptical semi major axis (we are presuming near circular orbits so this is just taken as radius) of Stardew Planet, T is orbital period which for our planet is 112 days, G is the gravitational constant, $6.674 \times 10^{-11} m^3 kg^{-1} s^{-2}$, M_s is the mass of the Sun $1.989 \times 10^{30} kg$, M is the mass of the Stardew star, L_s is the luminosity of the sun, and L is the luminosity of the Stardew star.

Rearranging (2) gives us,

$$a^3 = GMT^2/4\pi^2 \quad (4)$$

and rearranging (3) gives us,

$$M = M_s(L_{star}/L_s)^{1/4}. \quad (5)$$

Combining the two grants us,

$$a^3 = GM_sT^2(L_{star}/L_s)^{1/4}/4\pi^2. \quad (6)$$

Returning to equation (1) and rearranging gives us an equation for L_{star}

$$L_{star} = 4L_p\pi a^2 \quad (7)$$

where L_p is this time the net flux to Stardew Planet, though we are taking this to be identical to L_e.

Adding this into (6) gives,

$$a^3 = GM_sT^2(4L_p\pi a^2/L_s)^{1/4}/4\pi^2 \quad (8)$$

We then rearrange this equation to give us,

$$a = (4^{-3}\pi^{-7}(GM_sT^2)^4(L_p/L_s))^{1/10} \quad (9)$$

We know all of the values required here and putting in the constants and our calculated L_p gives us,

$$a = 5.81 \times 10^{10} m = 0.388 Au \quad (10)$$

Using this and equation (7) gives us a values for L,

$$L_{star} = 5.89 \times 10^{25} W = 0.151 L_s \quad (11)$$

and again into (5)

$$M = 1.239 \times 10^{30} kg = 0.623 M_s \quad (12)$$

We can use these calculated values to determine the mass and temperature of the star. Unfortunately the mass-radius relationship is less defined than the mass-luminosity relation. However, we do have a candidate star extremely similar to our currently calculated star and conditions which we can use as a reference. Kepler-442 has a mass of $0.61 M_s$ and a radius of 0.60 Solar Radii [2]. Using this we can see that for a similar star the ratio is about $Radius = Mass$ in Solar Units. Thus we can reasonably say $R \approx 0.623 R_s$.

Using the Stefan-Boltzman and the Solar Radius ($696340 km$) law we can then calculate the temperature,

$$T_e = \left(\frac{5.89 \times 10^{25}}{(4\pi \times 0.623 \times 696000 \times 10^3 \times \sigma)}\right)^{1/4} \quad (13)$$

$$T_e = 4578^o K \approx 4580^o K \quad (14)$$

Conclusion

In conclusion, the most likely orbit for a planet receiving identical incoming net flux from it's star, yet having a 112 day orbit, would be at $a = 0.388 Au$. The most likely stellar properties would be a mass of $m = 0.623 M_s$, a luminosity of $L = 0.151 L_S$, a radius of $R = 0.623 R_s$, and a temperature of $T = 4560^o K$.

References

[1] [Henry and McCarthy(1993)] 1993AJ ....106..773H Henry, T. J., McCarthy, D. W. 1993. The Mass-Luminosity Relation for Stars of Mass 1.0 to 0.08M(solar). The Astronomical Journal 106, 773. doi:10.1086/116685

[2] [Torres et al.(2015)]2015ApJ...800...99T Torres, G. and 25 colleagues 2015. Validation of 12 Small Kepler Transiting Planets in the Habitable Zone. The Astrophysical Journal 800. doi:10.1088/0004-637X/800/2/99