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P5_4 What if Earth orbited VY Canis Majoris.

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Abstract

In this paper we explore what would happen to the Earth if the Sun were replaced by one of the largest stars ever discovered, VY Canis Majoris, such that it has the same angular diameter in the sky as our current Sun does. We find the Earth would orbit the star at 1420 ± 120 AU, with an orbital period of $13,000 \pm 3,500$ years. Earth would have an effective temperature of -120 ± 8.7°C, but factoring in the greenhouse effect the real temperature would be -35 ± 2.3 °C, thus we would most likely expect Earth, in this system, to be non-habitable.

Introduction

VY CMa (VY Canis Majoris) has a radius of 1420 ± 120 $R_\odot$ and a luminosity of $270,000 \pm 40,000$ $L_\odot$ [1] making it one of the most massive and most luminous red supergiants in the Milky Way. Due to its size, Earth would have to orbit at a far greater distance for the star to have the same angular diameter in the sky as the Sun. Given this condition, we explore what effects such a large star would have on the Earth.

Theory

For VY CMa to take up the same space in the sky as the Sun currently does, and assuming both stars can be approximated as spheres, we require the two stars to have the same angular diameter in the sky. Angular diameter is expressed in equation 1 [2], where D is the distance to the star and r is the radius of the star, both in SI units.

$$\delta = 2 \arctan{(r/D)} \tag{1}$$

Solving equation 1 simultaneously for the Sun and VY CMa, it can be shown that in order for VY CMa to have the same angular diameter as the Sun, the radius of Earth's orbit would have to be 1420 ± 120 times greater.

Using Kepler's third law [3] (equation 2) we can find P, the orbital period of Earth around VY CMa,

$$P = 2\pi\sqrt{D^3/GM} \tag{2}$$

where D is the radius of the Earth's orbit around VY CMa, M is the mass of VY CMa (17 ± 8 $M_\odot$ [1]), and G is the universal gravitational constant, all in SI units.

Earth receives most of its energy from solar radiation [4]. The amount of solar radiation incident on the Earth will change if the luminosity of the Sun or distance from the Sun changes. To find how the power of the radiation received by the Earth has changed in our VY CMa system, we use equation 3 to find the radiative flux [5],

$$S = \frac{L}{4\pi D^2} \tag{3}$$

where L is the luminosity of the star (given in the introduction), and D is the radius of Earth's orbit, both in SI units.

The effective temperature, T_e, shown in equation 4 [6], is the temperature at the surface of the Earth, if you ignore the greenhouse effect and model the Earth to have no atmosphere.

$$T_e = \left(\frac{(1-a)S}{4\sigma} \right)^{1/4} \tag{4}$$

Where a is the albedo of Earth (~ 0.3 [7]) and σ is the Stefan-Boltzmann constant.

Since the greenhouse effect is a significant factor when considering a planet's surface temperature, we alter equation 4 by introducing a factor GHF (Greenhouse flux) to approximate the real average surface temperature of the planet as can be seen in equation 5 [8].

$$T = \left(\frac{GHF}{\sigma} + \frac{(1-a)S}{4\sigma} \right)^{1/4} \tag{5}$$

Where GHF is 150.75 W/m^2 [8].

Liquid water is thought to be the most important condition required for life [9]. Thus, using the temperature calculated in equation 5, we can speculate the possibility of liquid water, and hence life on Earth in the VY CMa system.

Results

Earth's orbit in the VY CMa system would have a period of $13,000 \pm 3,500$ years. We calculated the radiative flux to be 180 ± 41 W/m^2, which corresponds to an effective temperature of -120 ± 8.7 °C. This is significantly lower than -18 °C for the Earth in its usual configuration [8]. Factoring in the greenhouse effect, we approximated a real temperature of -35 ± 2.3 °C. This is much lower than the Earth's usual average temperature of 15 °C [8], and is significantly below the freezing point of water.

Conclusion

In the VY CMa system the Earth's orbit would have a period of $13,000 \pm 3,500$ years. We also approximated that the Earth in this system would have a surface temperature of -35 ± 2.3 °C. This temperature is significantly below the freezing point of water, thus we would not expect the planet to be habitable.

More research required to understand how a such a significant change in temperature would effect the atmosphere and hence the greenhouse effect, and what effects geological activity might have on the planets surface temperature. It has been theorised extremophiles could live in subsurface oceans on Enceladus [10], this could also be the case for our system.

References

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