Journal of Physics Special Topics

An undergraduate physics journal

P4_6 A Brown Sun?

R. Latif, S. Rizvi, J. Lamb, G. Pugh

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 20, 2019

Abstract

We created a scenario where the Sun is replaced by a brown dwarf (Teide 1), which would have a much lower effective temperature and a lower mass compared to the Sun. We investigated the effect of such a swap on Earth's effective temperature and found that the Earth's orbital radius would increase as a result of the swap, and the effective temperature of Earth would be about 16 K. However, if the Earth is to maintain its current effective temperature of 255 K, then the orbital distance of Earth from the brown dwarf has to be equal to 1.17×10^{10} m.

Introduction

Brown dwarfs, unlike stars like our Sun, are not massive enough to fuse hydrogen in their cores [1] which is why they are often referred to as 'failed stars'. However, brown dwarfs do fuse deuterium inside them, but have much lower surface temperatures than main sequence stars [1]. We are going to consider a scenario in which our Sun is replaced by a brown dwarf. We will explore the effects it will have on the Earth and whether it could have a habitable environment.

Theory

We are going to assume that the Sun is replaced by Teide 1, which is a brown dwarf of spectral class M8 [2]. By combining Kepler's third Law with the definition of angular momentum, we get :

$$L_{\text{orb}} = M_{\oplus}(GM_{\odot}D)^{1/2}, \tag{1}$$

where $M_{\oplus}$ is the mass of the Earth, $M_{\odot}$ is the mass of the Sun and D is the orbital radius of Earth which is around 1.5×10^{11} m [3]. Using equation 1 and data from table 1, we calculated the orbital angular momentum of the Earth orbiting around the Sun, which was found to be equal to 2.68×10^{40} $\text{kgm}^2\text{s}^{-1}$. Assuming that angular momentum will be conserved, we can use equation 1 again to calculate the subsequent orbital distance between Teide 1 and Earth after the swap, which is 2.72×10^{12} m. The power radiated by a spherical blackbody is given by:

$$P_{\odot} = (\sigma T_{\odot}{}^4)(4\pi R_{\odot}{}^2), \tag{2}$$

where σ is the Stefan-Boltzmann constant, $T_{\odot}$ is the effective temperature and $R_{\odot}$ is the radius of the object. The power emitted by Teide 1 was found using equation 2 to be 2.37×10^{24} watts. The energy absorbed by the Earth at a particular orbital distance is given by:

$$P_{\oplus,\text{abs}} = (1-\alpha)P_{\odot} \times (\frac{\pi R_{\oplus}{}^2}{4\pi D^2}), \tag{3}$$

where α is Earth's albedo or reflectivity coefficient which is on average about 0.3 [4] and $R_{\oplus}$ is the radius of Earth. Using equation 3, the power absorbed by earth is found to be 2.7×10^{12} watts and the temperature of the Earth at this orbital

	Mass (kg)	Radius (m)	Effective Temperature (K)
Sun	2×10^{40} [5]	7×10^{8}[5]	5772 [5]
Earth	6×10^{24} [3]	6.37×10^{6} [3]	255 [6]
Brown Dwarf (Teide 1)	1.1×10^{29} [7]	2.7×10^{8} [7]	2600 [8]

Table 1: Characteristics of Sun, Earth and Teide 1.

distance from Tiede 1 is found to be 16 K using equation 2.

Discussion

The effective temperature of the Earth is around 255 K [6]. Comparing this to the effective temperature of the Earth in our scenario which is around 16 K, we can see that in such extremely low temperatures Earth would only exist as a frozen ball of ice and rock, which won't be able to sustain life. However, for the Earth to have a similar effective temperature of around 255 K, the distance between Earth and Teide 1 would have to be equal to 1.17×10^{10} m .

Brown dwarfs fuse deuterium instead of hydrogen in their cores which is responsible for most of their energy output. However, this deuterium fuel is present in much lower quantities as compared to the hydrogen. The primordial ratio of deuterium to hydrogen in the universe is about $(2.31\pm0.24)\times10^{-5}$ [9]. Hence, Teide 1 would run out of fuel quicker compared to a main sequence star, cooling slowly afterwards which would affect its energy output considerably and result in a shorter window of desirable temperatures for life on Earth.

The luminosity of brown dwarfs is mostly in the infrared and red optical wavelength bands which will affect the habitat of the Earth regardless of the suitable effective temperatures. For example, plants would need to photosynthesize primarily in the red and near infrared regions of light to absorb the oncoming radiation efficiently.

Conclusion

Replacing the Sun with a Teide 1 does not bode well for life on Earth since the expansion in its orbit and the lower radiative flux on it as a result of that swap, would result in the Earth freezing over. To match its current temperature, Earth would have to be much closer to the brown dwarf around the orbital radius (2.72×10^{12} m) between Mercury and Venus [3]. Even if the Earth is at an optimal distance from brown dwarf to have effective temperatures of 255 K, due to the changes in the radiative output between the Sun and the brown dwarf, life would have to majorly adapt and evolve over the years to thrive on a planet that orbits a brown dwarf.

References

[1] *The Deuterium-Burning Mass Limit for Brown Dwarfs and Giant Planets, arXiv:1008.5150*

[2] `https://jgagneastro.com/list-of-ultracool-dwarfs/`

[3] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/`

[4] `https://earthobservatory.nasa.gov/images/84499/measuring-earths-albedo`

[5] `https://arxiv.org/abs/1203.4898`

[6] `https://eesc.columbia.edu/courses/ees/climate/lectures/radiation/index.html`

[7] *Mid-IR Observations of the Pleiades Brown Dwarfs Teide 1 and Calar 3, 2000ASPC..212...82L*

[8] `http://www.exoplanetkyoto.org/exohtml/A_All_Exoplanets.html`

[9] `https://web.archive.org/web/20100715200549/http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html`