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A2_1 Adding Fuel to the Fire

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Abstract

The Sun is approximately half way through its main sequence lifetime of 10.4 Gyr, however, this could theoretically be artificially extended by increasing its hydrogen content. We propose the notion of adding the hydrogen-equivalent mass of the four gas giants in the Solar System to the Sun, finding a maximum increase in main sequence lifetime of 125 Myr. We discuss the plausibility of accomplishing such a feat.

Introduction

The Sun is currently on the main sequence, whereby it undergoes nuclear fusion of hydrogen, which will inevitably cease. This process provides the energy required to maintain hydrostatic equilibrium - the balancing of gravity and pressure - and is released over time as luminosity [1]. The main sequence lifetime was approximated using this fact by finding the ratio of the energy generated over it's lifetime to the solar luminosity [2]. Using the same technique, we were able to approximate a new lifetime for the Sun if we were to add more hydrogen, by means of adding the gas giants present in our Solar System.

Theory

To begin the approximation, the total energy generated by the Sun over its lifetime was modelled by the equation

$$\Delta E = \eta \Delta M c^2, \tag{1}$$

where η is the efficiency of nuclear fusion of hydrogen, ΔM is the mass of hydrogen fused into Helium over the main sequence, and c is the speed of light in a vacuum. Using Eq. (1) and considering the power output as luminosity, L, of the Sun, the ratio of total energy generated to luminosity (equating to the main sequence lifetime, t_{MS}) was then found to be

$$t_{MS} = \eta \Delta M c^2 / L. \tag{2}$$

Therefore, by extension, the change in the main sequence lifetime of the Sun is the difference between the lifetimes associated with the Sun only and the addition of extra hydrogen. Assuming the increased mass has a negligible effect on the Sun's luminosity, this is given by

$$\Delta t_{MS} = \eta \Delta M' c^2 / L, \tag{3}$$

where $\Delta M'$ is the amount of hydrogen added that is converted over the main sequence.

Results

Using Eq. (2) with $\eta = 0.007$ (the nuclear burning efficiency), $\Delta M = 0.1 M_{sol}$ - assuming only 10% of the Sun's hydrogen is converted [2] - and $L = 3.828 \times 10^{26}$ W, the main sequence lifetime of the Sun was found to be 10.4 Gyr, in agreement with current predictions [3].

We then estimated the increase in the Sun's lifetime for several scenarios using Eq. (3), with $\Delta M' = 0.1M^H$, where M^H is the mass of hydrogen being added to the Sun. The results associated with Jupiter [4], Saturn [5], Uranus [6], and Neptune [7] are shown in Table 1, found by multiplying the total mass by the percentage of hydrogen present.

Gas Giant	M^H (kg)	Δt_{MS} (Myr)
All	2.40×10^{27}	125
Jupiter	1.70×10^{27}	88.7
Saturn	5.46×10^{26}	28.5
Uranus	7.21×10^{25}	3.76
Neptune	8.19×10^{25}	4.27

Table 1: The increase in the Sun's time spent on the main sequence if its hydrogen content increased by amounts equating to those of the Gas Giants.

Conclusion

Given these results, we conclude that it is theoretically possible to extend the Sun's lifetime, albeit by a relatively small amount when compared with its age. However, for an increase of only 125 Myr, the equivalent of ~ 1.26 Jupiter masses needs to be transported from over several hundred AU to the Sun, provided the transport process is not instantaneous. This in turn would require a vast amount of energy. While these calculations are beyond the scope of this paper, it is clear that such a task is highly impractical.

References

[1] `https://en.wikipedia.org/wiki/Main_sequence` [Accessed 2 October 2017]

[2] G. Wynn, 2016, *3651 Stellar Structure and Evolution*, University of Leicester

[3] `http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit2/mainseq.html` [Accessed 1 October 2017]

[4] `https://en.wikipedia.org/wiki/Jupiter` [Accessed 1 October 2017]

[5] `https://en.wikipedia.org/wiki/Saturn` [Accessed 1 October 2017]

[6] `https://en.wikipedia.org/wiki/Uranus` [Accessed 1 October 2017]

[7] `https://en.wikipedia.org/wiki/Neptune` [Accessed 1 October 2017]