How different could stellar hydrogen burning rates be before life becomes unviable on Earth?

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Overview

Life can be sustained on planets like Earth if their ‘Sun’ is the perfect distance from them to provide the light intensity needed. We explored how this life supporting distance changed with variations in hydrogen burning as a sun-like star aged. We examined trends in Hertzprung-Russell and Kippenhahn graphs to discover that as a solar mass star ages, it becomes denser due to the fusion of hydrogen to helium and also emits a greater intensity of light. This shows that in the future, our Sun could sustain life as far as the Asteroid Belt.

Aims

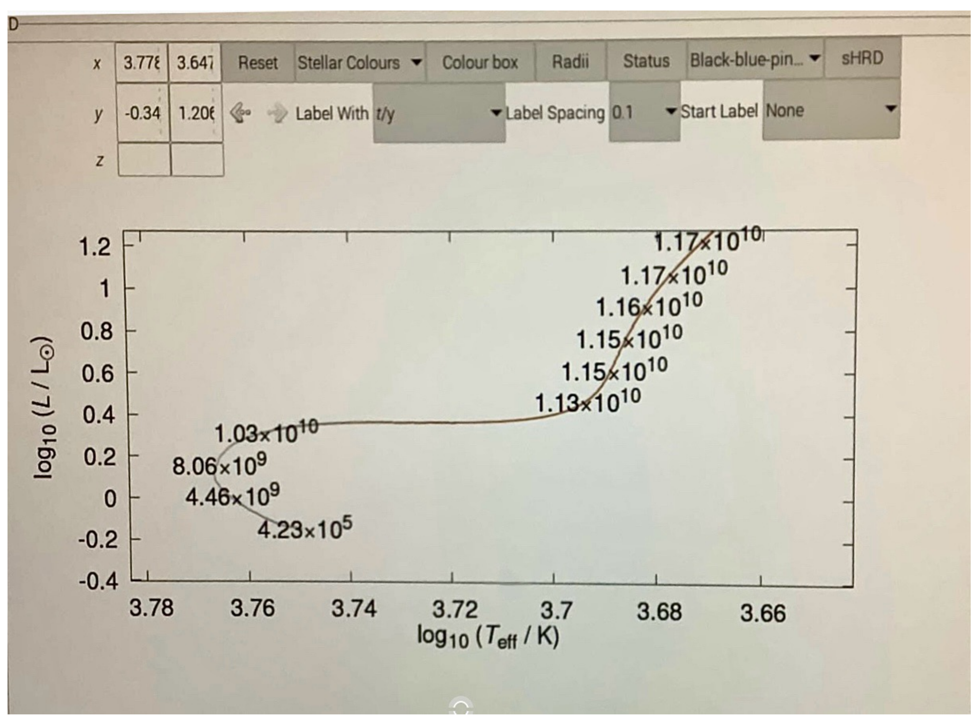
We hope to narrow the possibilities of finding habitable planets for life by calculating the luminosity and nuclear energy emission of a star and creating a metaphorical band of perfect conditions to support flora and fauna.

Background information

A star begins as a cloud of gas and dust which collapses under gravity, forming a nebula. This collapses further into a protostar. Nuclear fusion starts; hydrogen nuclei fuse to form helium, releasing a large amount of thermal energy, which balances the inward force of gravity. The light and heat the star emits radiates outwards in a ball and provides energy to potential life bearing planets. Planets in our solar system orbit the Sun in elliptical paths, so there is a point where each planet is closest to the Sun (perihelion) and furthest away (aphelion). This takes them to regions of more or less solar energy richness respectively.

Methodology

We calculated the intensity of the Sun’s light on Earth, evolved a solar mass star in ‘Window to the Stars’ and observed the resulting Hertzprung-Russell diagram. We then used the luminosity equation to calculate the orbital distance a habitable planet would need to occupy to receive the same intensity of light as the Earth. We compared our findings to the aphelions and perihelions of nearby planets and the Asteroid Belt to predict which would be habitable at different times. We also recorded the core temperatures and densities at key ages and considered how the life cycle of the star caused these changes. By forming a graph that compared the abundance of hydrogen with the star’s age, we could calculate the rate at which hydrogen fused into helium. Finally, we used a Kippenhahn diagram to compare the distance from the centre of the star and the rate of nuclear energy emitted.



A Hertzsprung-Russell diagram allowed us to find the star’s luminosity (relative to our Sun) at different points in time.

Results

Our Kippenhahn diagram revealed that nuclear fusion increases as the star evolves, this concurs with another observation that the star becomes hotter and denser as it ages. For example when our Sun’s is twice its current age its core will be 1.90 x 10^7 Kelvin and 794g/cm^3. When the Sun becomes denser the intensity of the light it emits will increase, meaning it could support life at greater distances. Hence, as the star ages, the distance Earth would have to be from the Sun to receive the current levels of light luminosity as we do now will increase.

Our results table shows trends in core temperature and density.

Age (years)	Temperature (Kelvin)	Density (g/cm^3)
4.23 x 10^5	1.32 x 10^7	71
9.65 x 10^9	1.90 x 10^7	794
1.13 x 10^10	2.50 x 10^7	25,118
1.17 x 10^10	3.00 x 10^7	100,000
1.18 x 10^10	3.89 x 10^7	251,188

A second table allowed us to compare the star’s luminosity and the orbital radius needed to sustain a life-bearing intensity.

Time (years)	Luminosity (W)	Orbital radius (m)
4.23 x 10^5	3.06 x 10^26	1.34 x 10^11
8.06 x 10^9	5.19 x 10^26	1.74 x 10^11
1.03 x 10^10	7.67 x 10^26	2.11 x 10^11
1.15 x 10^10	1.93 x 10^27	3.35 x 10^11
1.17 x 10^10	6.10 x 10^27	5.95 x 10^11

Conclusion

A star like our Sun has a very stable density and temperature in the main sequence. It also has a nearly constant rate of hydrogen burning and so a consistent level of nuclear energy emission. The star becomes a red giant when its hydrogen is depleted and a large proportion of its core has turned to helium. As helium is produced, the core gets denser and the fusion rate and energy emission falls. Additionally, our research has helped us to understand that in the next 1.296 x 10^18 years, the asteroid belt will receive the same intensity of sunlight as we do now and hence receive the energy necessary to sustain life - meaning that it could be habitable at this time!

Evaluation

We used a range of graphs; having this variety strengthens our data analysis. We also used new technology which made our data collection more efficient and relevant. Our investigation could have been improved by using only lined graphs or having automatic digital readings, allowing for a precise numerical value to be read. The graphs we collected data from were not lined, meaning people may interpret the data differently.

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