The expansion of the sun into the orbit of Earth

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Introduction

The survival of the human species largely depends on the existence of our sun. It heats our Earth just enough for us to live, but not too much so that we would be burnt alive. It makes photosynthesis and hence plant life possible, which in turn enables animals and humans to survive. However, our sun is not unchanging, and at some point in the future, it will move onto the next phase of its life and expand into the orbit of Mercury, Venus, and then, our planet Earth, engulfing these planets as a whole.

This implies that the human race is in a race with time. We have to be capable of expanding into the farther reaches of space before this happens in order to survive. Will this impending doomsday catch up to us first, or will we be on different planets saluting the end of the planet that we came from?

How Stars Shine

There are two major forces that determine the size of a star. The inward collapsing gravitational force, and the outward thermal pressure generated by nuclear fusion. When these two forces are balanced, the star is known to be in hydrostatic equilibrium and the size of the star stabilizes.

Nuclear fusion is the process of fusing smaller atomic nuclei into larger atomic nuclei, which generates energy in stars. This process is exclusively found in the cores of stars naturally, as it requires extremely high heat and high pressure to initiate this reaction, with the lowest threshold temperature for fusion reactions being around 4×10^6 K[7]. At the same time, this process also provides an outward thermal pressure to balance the inward gravitational force. In other words, it stops stars from collapsing into itself due to its own gravity. In the case of our sun, the dominant type of nuclear fusion reaction occurring is called the proton-proton chain reaction[2], which fuses hydrogen nuclei, or protons, into helium nuclei through a multi-step chain reaction (Refer to Figure 1). Stars that are fusing hydrogen into helium are categorized as main-sequence stars, as this is the lengthiest phase in a star's active lifetime - about 90% of stars are currently in the main sequence.[9]

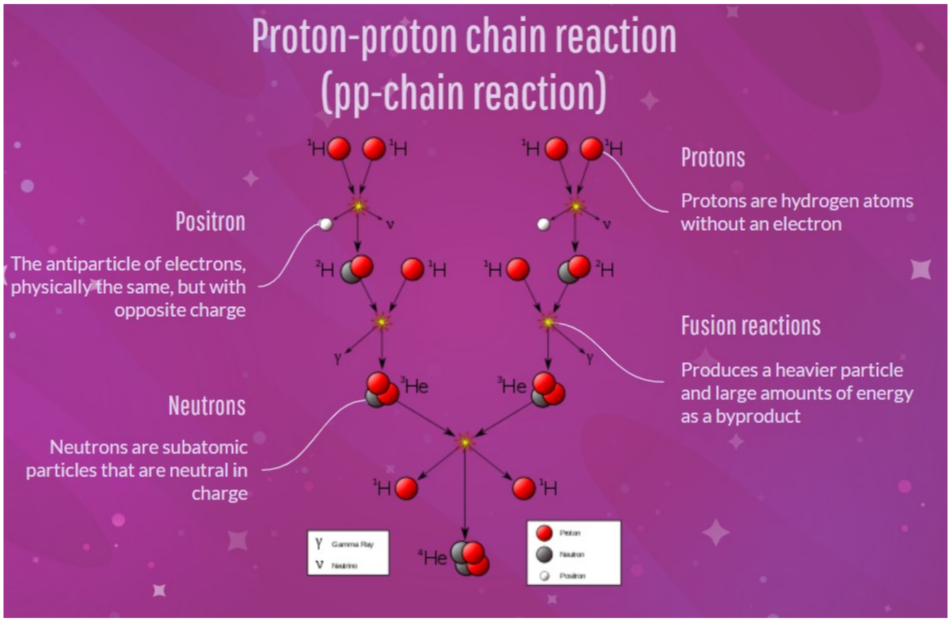

Figure 1: A diagram showing the Proton-Proton chain reaction

Evolutionary Stages of our Sun

However, as you may imagine, the hydrogen supply within our sun is not infinite. As time goes on, the protons in the core of our sun will be depleted. Our sun will lose its fuel supply and start collapsing into itself due to the force of gravity. As our sun continues to collapse, unfused hydrogen just outside the core will be ignited due to the increased pressure and temperature, forming a hydrogen-burning shell outside of the helium core[3] (Refer to Figure 2). When this ignition happens, our sun will enter the red giant phase, and the explosive pressure from the hydrogen-burning shell will cause our sun to expand. However, the helium core will continue to collapse until the repulsion between helium nuclei can support the gravitational forces. The estimated radius of our red giant sun is 0.75 AU[1], which means Mercury and Venus will be engulfed by the sun[8].

As the our sun expands, the density of the outermost layers will drop drastically, and the gravitational forces will be significantly weaker there. Hence, our sun will slowly lose about one-third of its mass in the red giant phase, and the Earth's orbit will also increase to about 1.5 AU[8]. At this time, although Earth has yet to be engulfed, the surface climate will have changed drastically as we will be receiving much more energy from the sun due to its closer distance and increased luminosity. If we were to sustain any kind of life on Earth, we would have to reflect the excess energy back into space, isolate ourselves in climate-controlled domes or develop underground cities.

Even then, this new orbit for Earth will not be stable for long. Having the sun so much closer to

[1] AU, or astronomical unit, is the distance between sun and Earth. 1 AU = $1.496 \times 10^{1}1$ m or 9.296×10^{7} mi

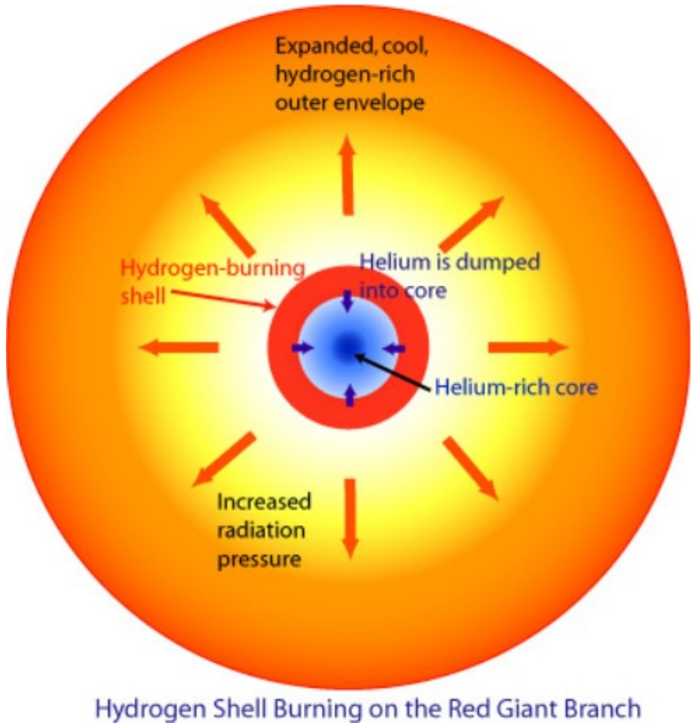

Figure 2: A diagram of the hydrogen burning shell

Earth means that the gravitational pull on the sun-facing side of Earth will be significantly higher than the opposite side, causing Earth to slowly orbit in, and finally into the chromosphere of the sun at about the end of its red giant phase, eventually suffering the same fate as Mercury and Venus.[8]

Are we doomed?

Now that we know how planet Earth will end, how likely are humans as a species to tackle this problem? First of all, let us look at the timescale of these events. Lower mass stars have smaller gravitational forces, hence they do not need as much thermal pressure as more massive stars to stay in hydrostatic equilibrium. Hence hydrogen in lower mass stars can be fused at a slower pace, prolonging their main sequence lifetime[1]. Our sun is a relatively small star compared to most other stars in the universe, and we estimate our sun to have a main sequence lifetime of 10 billion years. Well, how much of these 10 billion years do we have left? Scientists have estimated that our sun was formed about 4.8 billion years ago[10], meaning we have little over 5 billion years left in the main sequence. If we need it, the sun will also stay in the red giant phase for around a billion years[8], meaning we have about 6 billion years in total before Earth truly gets engulfed by the sun.

There is one other possibility that may cause our sun to age much quicker than we expect it to, and that is the collision with another star. That being said, the probability of our sun even coming close to another star is less likely than being eaten by a shark in a desert. First of all, we are located at the outskirts of the Milky Way galaxy, meaning the stellar density is much lower than the galactic nucleus, hence local fluctuations in the galactic structure will not cause collisions[4]. The chances of a stray star coming across the Milky Way and heading towards us directly is also unimaginably low. And to top it all off, the expansion of the universe is increasing the distance between stars that are outside of our local group, making it even more unlikely for us to come across anything at all. The only chance for a collision to even occur is the Andromeda Galaxy collision with the Milky Way galaxy in 4.5 billion years' time[5]. But even then, since stars are so far apart in galaxies, it is still extremely unlikely any real collisions between stars or planets will happen.

As we can see, we do have quite a lot of time left before we need to face this problem head-on. The first written language was invented only about 5000 years ago, and since then human civilization has not stopped improving, with new inventions and breakthroughs made every single year. The first successful spacecraft was launched in 1944, which was an artificial satellite named Sputnik 1. As of July 2022, there are over 9000 individual satellites are orbiting our planet, over 300 crewed space missions, and over 30 currently active solar system probes[6]. We are making progress, if not good progress, in terms of space exploration and developing spaceships.

SpaceX, one of the largest space exploration organizations today, has announced that they aim to have crewed missions on Mars by 2030. In the past 10 years, they have revolutionized space exploration with a rapid and reusable launch capability, largely reducing to cost of a space mission or launching a satellite into space. With their surprisingly fast pace in developing, testing, and then achieving something never done before, they have a reasonable chance of fulfilling their goal. On the other hand, the James Webb Telescope has also recently been launched into orbit around the second Lagrangian point and has already started sending data of the early universe back to us. Being 100 times more powerful than its predecessor, the Hubble Telescope, we are sure to obtain groundbreaking images and improve our understanding of the universe itself in the coming years.

Conclusion

The sun is still very stable at the moment, and extinction by a dying sun should be the least of our worries. We should first put our attention to other first-world problems, including but not limited to, climate change, world hunger, clean water and sanitation, etc. The sun will continue to be here for the next 5 to 6 billion years, while these other problems could potentially kill us thousands of times over. In conclusion, human extinction will be extremely unlikely to be caused by our sun expanding into the Earth's orbit, as we would either be extinct for a different reason or have become a space-faring interstellar civilization by the time it happens.

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