

# Role of the Sun as a Stellar Evolution Pattern

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**Abstract**— The sun is a G-type main-sequence star and it is located at the center of our solar system. Besides being the source of the energy that keeps the earth alive, the sun encapsulates the life cycle of an average star as it began its life about 4.6 billion years ago from a molecular cloud that was collapsing and will end its life several billion years from now. In the light of this, the paper digs into the birth of the sun, its present constitution and the source of its energy, as well as the stages through which it will pass in dying, stressing its important role as a stellar evolution pattern.

**Keywords** — Sun; Formation; Death; Solar System; Stellar Evolution.

## 1. Introduction

The Sun is the epicenter of the solar system and nearly accounts for 99.86% of the mass of the entire system. Accordingly, it is the major contributor to the gravitational forces that orchestrate the movements of all celestial bodies, planets included [1]. Being a star of average size in the main sequence, its life and alteration serve as an open book to the laws of physics governing stars and the lifetime of the same kind in the universe. Consequently, getting to grasp the Sun's birth and losing it in the end is tantamount to figuring out the way stellar evolution works, and in addition, it allows us to foresee the distant future of our solar system.

## 2. Formation of the Sun

### 2.1 The Solar Nebula Hypothesis

The solar nebula hypothesis is the most convincing scenario that explains how our Sun came into being. Roughly 4.6 billion years ago, a molecular cloud of hydrogen, helium, and small amounts of heavier elements, spanning a vast area, started to collapse due to its own gravity [2]. It is quite possible that a supernova shock wave passing nearby caused the collapse. As the cloud shrank, it kept changing its angular momentum, hence it flattened out and began spinning, forming a disk that is now referred to as the protoplanetary disk. The area with the greatest density was at the center of the disk, thus the birth of the protostar —the early sun -was imminent.

### 2.2 Protostar Development and Nuclear Fusion

On top of that, less than timely the protostar's gravitational energy was converted into heat with the core temperature going up by leaps and bounds. The moment

the temperature hovered around 10 million degrees Kelvin was the time when the fusion of hydrogen nuclei into helium through the proton-proton chain reaction started [3]. The ignition of nuclear fusion was the defining moment that saw the sun come into the main sequence phase which entails hydrostatic equilibrium—gravitational contraction is counterbalanced by the outward radiation pressure.

## 3. Structure and Energy Production

The Sun's composition is layered as follows:

**Core:** The very central part of the Sun, where the nuclear fusion takes place and the temperature is approximately 15 million K.

**Radiative Zone:** The energy is moving layer after layer via radiation and the process takes a few thousands of years.

**Convective Zone:** The energy here is transferred by convective currents of plasma.

**Photosphere:** The Sun's visible surface, the place where the temperature is around 5800 K.

**Chromosphere and Corona:** The Sun's outer atmospheric layers, the latter is only visible during total solar eclipses and it has very high temperatures.

Most of the Sun's luminosity is derived from the fusion of about one-half billion tons of hydrogen into helium every second, with the energy released being consistent with Einstein's mass-energy equivalence,  $E = mc^2$  [4].

## 4. Current Stage: Main Sequence

The age of the Sun is estimated to be about 4.6 billion years, and it is now at the middle of its main sequence life, which is around 10 billion years [5]. The Sun uses hydrogen to make helium, and as a result, it is able to produce light and heat in a stable manner. The Sun is stable because the forces of gravity acting inwards are balanced by the thermal pressure going outwards. There is a little magnetic activity on the Sun; the number of spots and flares varies with the strength of the magnetic field.

## 5. The Death of the Sun

### 5.1 The Red Giant Phase

After the Sun uses up the last unit of hydrogen in its core, the fusion will stop in the core but will go on in the shell surrounding it. The core will shrink and heat up, but the atmosphere will get bigger and cooler, i.e., the Sun will become a red giant [6]. At this point in time, the Sun's radius will be able to go beyond the Earth's orbit, and so, it will be able to engulf the closest planets to the Sun for sure – Mercury and Venus and maybe Earth as well.

### 5.2 Helium Burning and Planetary Nebula

As the core gets smaller, the temperature will rise to about 100 million K and at that point helium will start fusing into carbon and oxygen. After the helium is used up, fusion will go dark, and as a result, the Sun will throw its outer layers away into the space, thus giving rise to a shining planetary nebula - a cloud of gas that is lit up by the leftover core [7].

### 5.3 White Dwarf Remnant

The leftover core that can no longer support fusion will become a white dwarf, a stellar remnant of high density, that is about the size of the Earth but with half the mass of the Sun. This white dwarf will slowly cool down and after billions of years, it will turn into a black dwarf, which is not the case yet as the universe is not sufficiently aged [8].

## 6. Implications for the Solar System

The stages of the Sun's change will totally reshuffle the solar system. The expansion during the red giant phase will most probably lead to the complete vaporization of the oceans and the atmosphere of Earth. Jupiter and Saturn being at a far distance from the Sun may witness changes in their orbits due to the solar mass loss. The matter that gets thrown out from the planetary nebula will be merged with the interstellar medium, thus starting the cycle of elements that are needed for the birth of new stars and planets [2], [6].

## 7. Conclusion

Sun's existence from the moment it was born in a collapsing molecular cloud and till it turned out to be a white dwarf, is basically the life cycle of a medium-sized star. Its origin and extinction are the major steps that ensure the ongoing cosmic renewal process which is the reusing of stellar material for the formation of new systems. Research through such missions as NASA's Parker Solar Probe and

ESA's Solar Orbiter keep on enlightening us concerning the solar dynamics and the fate of our star.

## References

- [1] B. W. Carroll and D. A. Ostlie, *An Introduction to Modern Astrophysics*, 2nd ed. Cambridge, U.K.: Cambridge Univ. Press, 2017.
- [2] E. Chaisson and S. McMillan, *Astronomy Today*, 9th ed. Boston, MA, USA: Pearson Education, 2021.
- [3] D. Prialnik, *An Introduction to the Theory of Stellar Structure and Evolution*, 3rd ed. Cambridge, U.K.: Cambridge Univ. Press, 2020.
- [4] A. Einstein, "Does the inertia of a body depend upon its energy content?" *Annalen der Physik*, vol. 18, no. 13, pp. 639–641, 1905.
- [5] R. Kippenhahn, A. Weigert, and A. Weiss, *Stellar Structure and Evolution*, 2nd ed. Berlin, Germany: Springer, 2012.
- [6] NASA, "The Life and Death of the Sun," NASA Solar System Exploration, 2023. <https://solarsystem.nasa.gov>
- [7] ESA, "Solar Evolution and Planetary Nebulae," European Space Agency, 2024. [https://www.esa.int/Science\\_Exploration](https://www.esa.int/Science_Exploration)
- [8] F. Shu, *The Physical Universe: An Introduction to Astronomy*, Mill Valley, CA, USA: University Science Books, 1982.