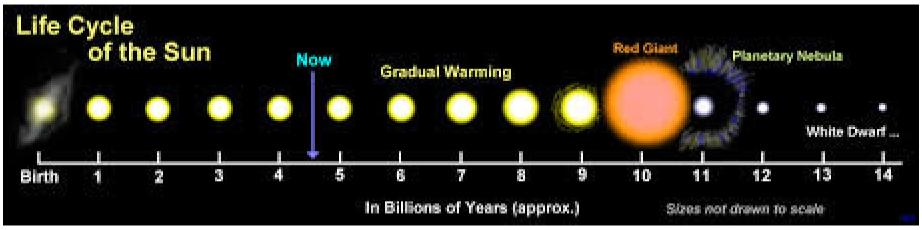
Sun – Part 29 - Life cycle



Solar life cycle

Formation The Sun formed about 4.567 billion years ago from the gravitational collapse of matter within part of a giant molecular cloud. This was possibly triggered by shockwaves from a nearby supernova. Evidence for this is the high abundance of heavy elements eg gold, uranium in the solar system. Particle impact initiated rotation of the mass, which resulted in most of the mass becoming concentrated at the centre, the rest flattening out into a disk that would become the solar system planets. Over time, gravity and pressure at the centre caused the central mass to became increasingly hot, hot enough to eventually initiate nuclear fusion. The Sun was born.

Main sequence The Sun is now roughly middle aged, and described as being about half way through its main sequence stage, the time in its life when it shines by converting hydrogen to helium at its core. Every second, more than 4 million tonnes of matter are converted into energy within the core, producing solar radiation and neutrinos. So far, the Sun has converted around 100 times Earth's mass into energy, about 0.03% of its own total mass. It is currently about half way through the most stable part of its life, the 8-10 billion years in the main sequence.

Over time, the Sun is gradually becoming hotter because the helium atoms in the core occupy less volume than the hydrogen atoms they replace. The shrinking core also allows the outer layers of the Sun to move closer to the centre and experience a greater gravitational force according to the inverse square law. This stronger force increases pressure on the core, which is resisted by a gradual increase in the rate of fusion and a resultant increase in energy emission. This process speeds up as the core gradually becomes denser and the Sun is about 30% brighter now than it was in its distant past. Its brightness increases by about 1% every 100 million years.

Later life stages After about another 4.5 billion years, hydrogen supply in the core will become exhausted and hydrogen fusion will stop. At his point, the Sun will, by definition, leave the main sequence, causing large internal and external changes. Although core hydrogen is exhausted, the Sun will still have hydrogen reserves in layers surrounding the core. The core will heat up this shell until it is hot enough for the hydrogen to be fused into helium. Using this reserve has a price, however, as the energy source is not dense, and its utilisation initiates the process which will convert the Sun to a red giant. During this time, its outer layers will expand as the final available hydrogen is consumed and the core contracts and heats up. The colour change towards red is a consequence of the Sun's exterior cooling as the star expands. The red giant Sun will be sufficiently large to engulf Mercury, Venus and, perhaps, Earth. During that process, its luminosity will have nearly doubled. The red giant stage will last around 2 billion years.

The gradual conversion to a red giant involves various stages. Initially, as it begins burning its hydrogen reserves, the Sun will start to expand into the sub-giant phase and slowly double in size over about 0.5 billion years. Then it will expand more rapidly over another 0.5 billion years until over 200 times larger than today, and 2,000 times more luminous.

Then the red-giant-branch (RGB) phase will begin. During a timespan of approximately 1 billion years, the Sun will lose around a third of its mass. After the RGB, it will have about 120 million years of active life left.

During that brief time, much will happen. The dense core, full of degenerate helium, will become increasingly hotter until it ignites violently in the so-called helium flash, during which 6% of the core (itself 40% of the solar mass) will be converted into carbon within minutes. Then the Sun will shrink to about 10 times its current size, and 50 times the luminosity, with a temperature a little lower than that of today.

Now in the red clump or horizontal branch (HB) phase, the Sun will become moderately larger and more luminous over about 100 million years as it continues to burn the remaining helium in the core and any remaining shell hydrogen. When core helium is exhausted, it will repeat the expansion which happened after hydrogen was exhausted as it resorts again to using shell reserves, except much faster and it will become even larger and more luminous. This is the asymptotic giant branch (AGB) phase.

After about 20 million years in the AGB, the Sun will become increasingly unstable as its fusion processes become progressively inefficient, undergoing rapid mass loss and thermal pulses that increase the size and luminosity for a few 100 years every 100,000 years or so. Thermal pulses become larger each time, later pulses increasing luminosity to as much as 5,000 times current levels, and widening the radius of the dying Sun to over 1 AU. Four thermal pulses are predicted for the Sun before it completely loses its outer envelope and starts forming a planetary nebula. By the end of the AGB phase, the Sun will only be about half its current mass.

During the rapid planetary nebula stage, luminosity will stay largely constant, as the temperature increases, with the ejected half of the Sun's mass becoming ionised into the nebula as the exposed core reaches 30,000 K. The final naked core temp will be over 100,000 K. The planetary nebula will disperse in about 10,000 years and the remnant will cool to becomes a white dwarf. The cooling white dwarf will survive for trillions of years before fading into a black dwarf.

Sources: Ridpath, I (Ed) (2012) Oxford dictionary of astronomy 2nd ed rev, www.en.wikipedia.org, www.astrophysics.org