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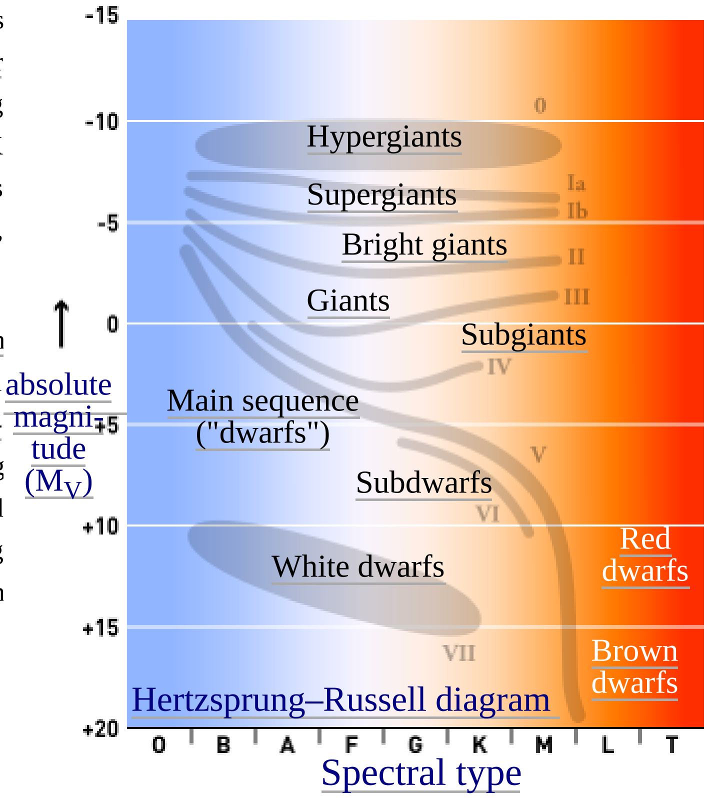
Red giant

A **red giant** is a luminous giant star of low or intermediate mass (roughly 0.3–8 solar masses ($M_\odot$)) in a late phase of stellar evolution. The outer atmosphere is inflated and tenuous, making the radius large and the surface temperature around 5,000 K (4,700 °C; 8,500 °F) or lower. The appearance of the red giant is from yellow-orange to red, including the spectral types K and M, but also class S stars and most carbon stars.



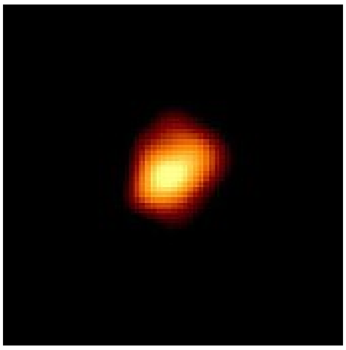
The most common red giants are stars on the red-giant branch (RGB) that are still fusing hydrogen into helium in a shell surrounding an inert helium core. Other red giants are the red-clump stars in the cool half of the horizontal branch, fusing helium into carbon in their cores via the triple-alpha process; and the asymptotic-giant-branch (AGB) stars with a helium burning shell outside a degenerate carbon–oxygen core, and a hydrogen burning shell just beyond that.

Contents

Characteristics

Red giants are stars that have exhausted the supply of hydrogen in their cores and have begun thermonuclear fusion of hydrogen in a shell surrounding the core. They have radii tens to hundreds of times larger than that of the Sun. However, their outer envelope is lower in temperature, giving them a reddish-orange hue. Despite the lower energy density of their envelope, red giants are many times more luminous than the Sun because of their great size. Red-giant-branch stars have luminosities up to nearly three thousand times that of the Sun ($L_\odot$), spectral types of K or M, have surface temperatures of 3,000–4,000 K, and radii up to about 200 times the Sun ($R_\odot$). Stars on the horizontal branch are hotter, with only a small range of luminosities around 75 $L_\odot$. Asymptotic-giant-branch stars range from similar luminosities as the brighter stars of the red giant branch, up to several times more luminous at the end of the thermal pulsing phase.

Among the asymptotic-giant-branch stars belong the carbon stars of type C-N and late C-R, produced when carbon and other elements are convected to the surface in what is called a dredge-up.[1] The first dredge-up occurs during hydrogen shell burning on the red-giant branch, but does not produce a large carbon abundance at the surface. The second, and sometimes third, dredge up occurs during helium shell burning on the asymptotic-giant branch and convects carbon to the surface in sufficiently massive stars.

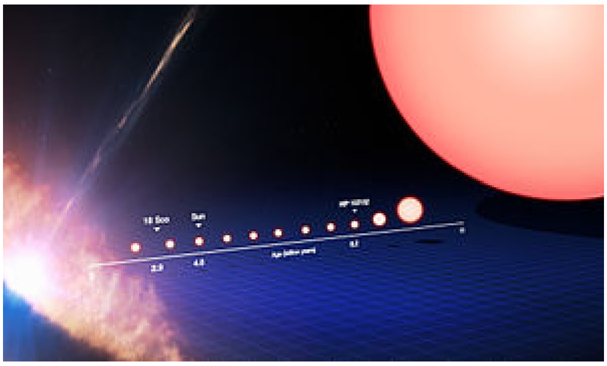


Mira, a variable asymptotic giant branch red giant

The stellar limb of a red giant is not sharply defined, contrary to their depiction in many illustrations. Rather, due to the very low mass density of the envelope, such stars lack a well-defined photosphere, and the body of the star gradually transitions into a 'corona'.[2] The coolest red giants have complex spectra, with molecular lines, emission features, and sometimes masers, particularly from thermally pulsing AGB stars.[3]

Another noteworthy feature of red giants is that, unlike Sun-like stars whose photospheres have a large number of small convection cells (solar granules), red-giant photospheres, as well as those of red supergiants, have just a few large cells, the features of which cause the variations of brightness so common on both types of stars.[4]

Evolution



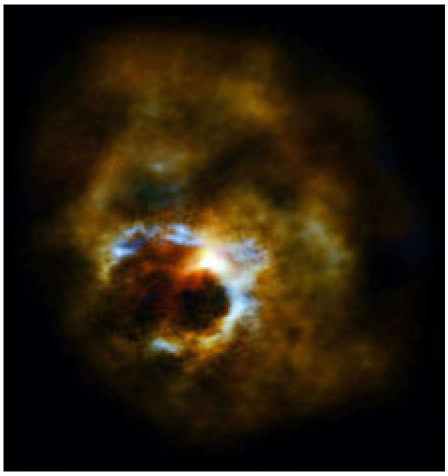
This image tracks the life of a Sun-like star, from its birth on the *left* side of the frame to its evolution into a red giant on the *right* after billions of years.

Red giants are evolved from main-sequence stars with masses in the range from about 0.3 $M_\odot$ to around 8 $M_\odot$.[5] When a star initially forms from a collapsing molecular cloud in the interstellar medium, it contains primarily hydrogen and helium, with trace amounts of "metals" (in stellar structure, this simply refers to *any* element that is not hydrogen or helium i.e. atomic number greater than 2). These elements are all uniformly mixed throughout the star. The star reaches the main sequence when the core reaches a temperature high enough to begin fusing hydrogen (a few million kelvin) and establishes hydrostatic equilibrium. Over its main sequence life, the star slowly converts the hydrogen in the core into helium; its main-sequence life ends when nearly all the hydrogen in the core has been fused. For the Sun, the main-sequence lifetime is approximately 10 billion years. More-massive stars burn disproportionately faster and so have a shorter lifetime than less massive stars.[6]

When the star exhausts the hydrogen fuel in its core, nuclear reactions can no longer continue and so the core begins to contract due to its own gravity. This brings additional hydrogen into a zone where the temperature and pressure are adequate to cause fusion to resume in a shell around the core. The outer layers of the star then expand greatly, thus beginning the red-giant phase of the star's life. As the star expands, the energy produced in the burning shell of the star is spread over a much larger surface area, resulting in a lower surface temperature and a shift in the star's visible light output towards the red—hence it becomes a *red giant*. At this time, the star is said to be ascending the red-giant branch of the Hertzsprung–Russell (H–R) diagram.[6]

The evolutionary path the star takes as it moves along the red-giant branch, which ends with the complete collapse of the core, depends on the mass of the star. For the Sun and stars of less than about 2 $M_\odot$[7] the core will become dense enough that electron degeneracy pressure will prevent it from collapsing further. Once the core is degenerate, it will continue to heat until it reaches a temperature of roughly 10^8 K, hot enough to begin fusing helium to carbon via the triple-alpha process. Once the degenerate core reaches this temperature, the entire core will begin helium fusion nearly simultaneously in a so-called helium flash. In more-massive stars, the collapsing core will reach 10^8 K before it is dense enough to be degenerate, so helium fusion will begin much more smoothly, and produce no helium flash.[6] The core helium fusing phase of a star's life is called the horizontal branch in metal-poor stars, so named because these stars lie on a nearly horizontal line in the H–R diagram of many star clusters. Metal-rich helium-fusing stars instead lie on the so-called red clump in the H–R diagram.[8]

An analogous process occurs when the central helium is exhausted and the star collapses once again, causing helium in a shell to begin fusing. At the same time hydrogen may begin fusion in a shell just outside the burning helium shell. This puts the star onto the asymptotic giant branch, a second red-giant phase.[9] The helium fusion results in the build up of a carbon–oxygen core. A star below about 8 $M_\odot$ will never start fusion in its degenerate carbon–oxygen core.[7] Instead, at the end of the asymptotic-giant-branch phase the star will eject its outer layers, forming a planetary nebula with the core of the star exposed, ultimately becoming a white dwarf. The ejection of the outer mass and the creation of a planetary nebula finally ends the red-giant phase of the star's evolution.[6] The red-giant phase typically lasts only around a billion years in total for a solar mass star, almost all of which is spent on the red-giant branch. The horizontal-branch and asymptotic-giant-branch phases proceed tens of times faster


Mira A is an old star, already shedding its outer layers into space.

If the star has about 0.2 to 0.5 $M_\odot$,[7] it is massive enough to become a red giant but does not have enough mass to initiate the fusion of helium.[5] These "intermediate" stars cool somewhat and increase their luminosity but never achieve the tip of the red-giant branch and helium core flash. When the ascent of the red-giant branch ends they puff off their outer layers much like a post-asymptotic-giant-branch star and then become a white dwarf.

Stars that do not become red giants

Very low mass stars are fully convective[10][11] and may continue to fuse hydrogen into helium for up to a trillion years[12] until only a small fraction of the entire star is hydrogen. Luminosity and temperature steadily increase during this time, just as for more-massiv main-sequence stars, but the length of time involved means that the temperature eventually increases by about 50% and the luminosity by around 10 times. Eventually the level of helium increases to the point where the star ceases to be fully convective and the remaining hydrogen locked in the core is consumed in only a few billion more years. Depending on mass, the temperature and luminosity continue to increase for a time during hydrogen shell burning, the star can become hotter than the Sun and tens of times more luminous than when it formed although still not as luminous as the Sun. After some billions more years, they start to become less luminous and cooler even though hydrogen shell burning continues. These become cool helium white dwarfs[5].

Very-high-mass stars develop into supergiants that follow an evolutionary track that takes them back and forth horizontally over the HR diagram, at the right end constituting red supergiants. These usually end their life as a type II supernova. The most massive stars can become Wolf–Rayet stars without becoming giants or supergiants at all.[13][14]

Planets

Red giants with known planets: the M-type HD 208527, HD 220074 and, as of February 2014, a few tens[15] of known K-giants including Pollux, Gamma Cephei and Iota Draconis.

Prospects for habitability

Although traditionally it has been suggested the evolution of a star into a red giant will render its planetary system, if present, uninhabitable, some research suggests that, during the evolution of a 1 $M_\odot$ star along the red-giant branch, it could harbor a habitable zone for several times 10^9 years at 2 AU out to around 10^8 years at 9 AU out, giving perhaps enough time for life to develop on a suitable world. After the red-giant stage, there would for such a star be a habitable zone between 7 and 22 AU for an additional 10^9 years.[16] Later studies have refined this scenario, showing how for a 1 $M_\odot$ star the habitable zone lasts from 10^8 years for a planet with an orbit similar to that of Mars to 2.1×10^8 yr for one that orbits at Saturn's distance to the Sun, the maximum time

(3.7×10^8 yr) corresponding for planets orbiting at the distance of Jupiter. However, for planets orbiting a 0.5 $M_\odot$ star in equivalent orbits to those of Jupiter and Saturn they would be in the habitable zone for 5.8×10^9 yr and 2.1×10^9 yr respectively; for stars more massive than the Sun, the times are considerably shorter.[17]

Enlargement of planets

As of June 2014, 50 giant planets have been discovered around giant stars. However, these giant planets are more massive than the giant planets found around solar-type stars. This could be because giant stars are more massive than the Sun (less massive stars will still be on the main sequence and will not have become giants yet) and more massive stars are expected to have more massive planets. However, the masses of the planets that have been found around giant stars do not correlate with the masses of the stars; therefore, the planets could be growing in mass during the stars' red giant phase. The growth in planet mass could be partly due to accretion from stellar wind, although a much larger effect would be Roche lobe overflow causing mass-transfer from the star to the planet when the giant expands out to the orbital distance of the planet.[18]

Well known examples

Many of the well known bright stars are red giants, because they are luminous and moderately common. The red giant branch variable star Gamma Crucis is the nearest M class giant star at 88 light years.[19] The K0 red giant branch star Arcturus is 36 light years away.[20]

Red-giant branch

- Aldebaran (α Tauri)
- Arcturus (α Bootis)
- Gacrux (γ Crucis)

Red-clump giants

- Hamal (α Arietis)
- κ Persei
- δ Andromedae[21]

Asymptotic giant branch

- Mira (o Ceti)
- χ Cygni
- α Herculis

The Sun as a red giant

In about 5 to 6 billion years, the Sun will have depleted the hydrogen fuel in its core. It will shrink, with the hydrogen outside the core able to compress enough for hydrogen there to fuse, and will begin to expand into a subgiant. Eventually, the pressure builds up so much that the core will begin to fuse helium, and will expand even more into a red giant. At its largest, its surface (photosphere) will approximately reach the current orbit of Earth. It will then lose its atmosphere completely; its outer layers forming a planetary nebula and the core a white dwarf. The evolution of the Sun into and through the red-giant phase has been extensively modelled, but it remains unclear whether Earth will be engulfed by the Sun or will continue in orbit. The uncertainty arises in part because as the Sun burns hydrogen, it loses mass causing Earth (and all planets) to orbit farther away. There are also significant uncertainties in calculating the orbits of the planets over the next 5–6.5 billion years, so the fate of Earth is not well understood. At its brightest, the red-giant Sun will be several thousand times more luminous than today but its surface will be at about half the temperature.

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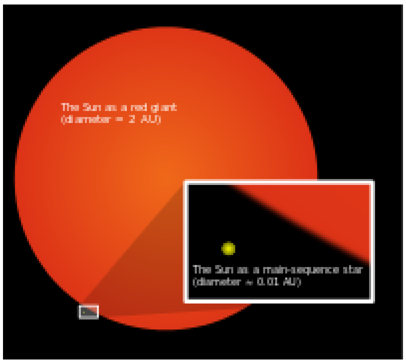

The current size of the Sun (now in the main sequence) compared to its estimated maximum size during its red-giant phase in the future

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