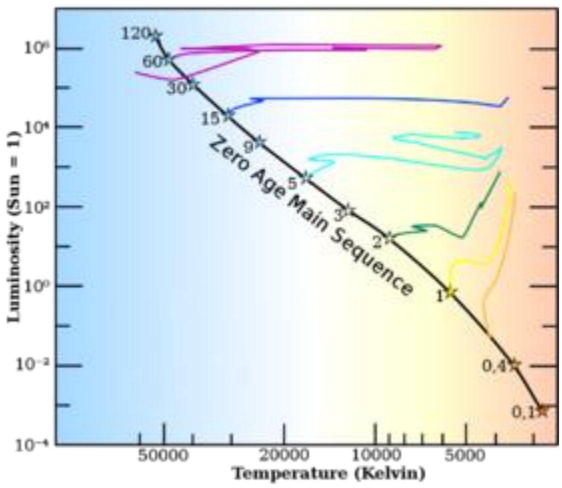
Classification and end states of Stars

1. Introduction

The **Hertzsprung-Russell (H-R)** is used as a plot of the brightness versus the temperature of stars. 1) A star is represented by a point on the graph that tells us the luminosity and temperature of the star. The horizontal axis represents the temperature of the star and the vertical axis its luminosity. See diagram below. Because the star's spectral type is determined by its temperature, instead of using the horizontal line to indicate the temperature, it can also be used for spectral type.

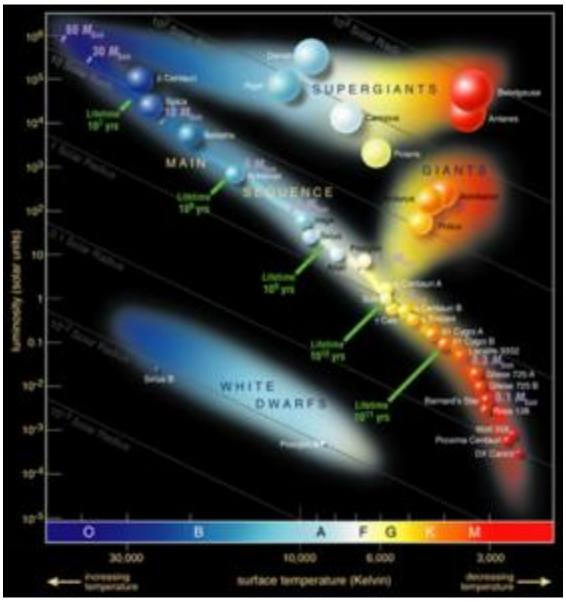


An evolutionary track of stars. The Sun=1. Credit Wikipedia.

The location of the star on the diagram changes as the star ages and its luminosity and temperature changes. The main sequence is the region of the diagram running from upper left to lower right. In the diagram above the main sequence is represented by a curved line. On the graph the hot massive sequence stars are located at the top end of the line and the smaller cooler stars at the lower right.

Below is another view which may be easier to understand.

2. Giants, supergiants and dwarfs



The hot main sequence stars are more luminous than the cool stars. In the diagram above we see that the stars at the top are larger and the stars at the bottom smaller. This is because both the temperature and size determine the star's luminosity. The Sun is located about halfway up the main sequence line. This point on the diagram represents the location of any star whose radius equals that of the Sun. (Michael A. Seeds quoted under 1).

The most important aspect of the H-R diagram is that it is a tool to identify certain families of stars. The giant stars can be found at the right above the main sequence. These stars are cool but luminous because they are 10 to 100 times larger than the Sun. The super-giants can be found at the top of the H-R diagram and are 10 to 1,000 times the size of the Sun. Betelgeuse in Orion is a super-giant.

The Stars at the lower left are hot stars but they are very faint because they are very small and they are called **white dwarfs** with a size of about the Earth. At the lower right lie the coolest main-sequence stars called **red dwarfs** and they are both small and cool.

3. Degenerate matter in stars

It is important to understand that the gas inside a star, such as the Sun, is ***ionized*** with atomic nuclei and electrons moving around freely. When the pressure of the gas is compressed to high densities, such as in the core of a giant star, the differences between these two kinds of particles should be kept in mind. See Foundations of Astronomy under 1). Two laws of quantum mechanics now become important. The first is the moving electrons inside a star's core can only have a certain amount of energy, similar to an electron in an atom can only occupy certain levels of energy.

The second quantum-mechanical law known as Pauli's exclusion principle says that two electrons having the same energy cannot occupy the same energy level. To explain it further; electrons spin in one direction or the other. It means two electrons spinning in opposite directions can occupy the same energy level. That level is then completely filled and a third electron cannot occupy the same level. It is easy to understand if we bear in mind that the third electron cannot enter because no matter in which direction it spins, its spin will be identical to one of the two electrons already occupying that level. In a dense gas there are no open spaces available for a free moving electron to drop in. If the electron can gain enough energy it can move up to a higher level where it can find an empty space on the ladder. However, in a very dense gas the movement of the electron is slowed down which will decrease its energy. When the gas is so dense that electrons cannot move around freely to exchange energies astronomers call it **degenerate matter**. There are various forms of degenerate matter.

1. Electron degeneracy

As the density of the gas increases electrons fill up the lower levels of open spaces and increasingly force electrons to fill higher levels of energy. The Pauli exclusion principle, referred to above, now causes the gas to resist any further compression because the Pauli exclusion principle prevent two electrons with the same energies to occupy the same energy level. When the electrons are stripped from their parent atoms, the gas becomes degenerate. The star becomes a **White Dwarf**, the end of sun like stars. We know that white dwarfs do not shine and the reason is that a large amount of energy is trapped. Under normal circumstances the gas will expand when it is heated but the electrons become solid. There is an upper limit on the amount of mass a white dwarf beyond which the degenerate electrons can no longer sustain the pressure. This limit is known as the Chandrasekhar limit of approximately 1.44 solar masses. Above this limit the star will form a neutron star where neutron degeneracy support a neutron star against further compression.

2. Neutron degeneracy

In a neutron star neutron degeneracy, similar to electron degeneracy in a white dwarf, but is supported by degenerate neutron gas. 2) (Potekhin A.Y. 2011. The Physics of neutron stars. Preprint quoted by Wikipedia). As the star collapses the energy of the electrons increases to produce neutrons. The result of this collapse which is predominantly extremely dense neutron gas, hence the star is called a neutron star.

3. Singularity

As the densities become greater than any of the degenerate matter described above, gravity takes over to form a black hole. The black hole has a point of no return where it is impossible for infalling matter to escape from the force of gravity called an event horizon. It is not a physical object but rather a point in spacetime where gravity takes complete control. Actually there are two event horizons; an inner and an outer event horizon, discovered by the New Zealand mathematician, Roy P. Kerr also called the Kerr black hole. Nobody knows what a singularity is. All we can say is that the force of gravity apparently becomes infinite in a singularity. We cannot observe it because light cannot escape from. Scientists have, however, learnt a great deal by observing the infalling gas and other forms of matter before it crosses the event horizon.

Black hole. Credit NASA

4. Conclusion

The classification of stars and the end states of stars, with the exception of brown dwarfs, have been described above. A brown dwarf is a star too small for the hydrogen at its core to ignite.

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2. Potekhin A.Y. 2001. The Physics of Neutron Stars. Preprint quoted by Wikipedia

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