Introduction to Astronomy
Summary Questions Week 7

18 November 2019

1. Explain what the Hertzsprung-Russell diagram is and why it is important.

Solution: The Hertzsprung-Russell diagram (or *colour-magnitude* diagram) is a plot of *stellar temperature* against *stellar luminosity*. As a star evolves, it traces out a very well-defined track on this diagram, depending on the initial mass of the star. Consequently, the diagram can be used to *investigate stellar evolution*, or to *determine a star's age* or even its *mass*. For groups of stars that have an identical age (as for example in stellar clusters), the *age of the cluster* can be derived from the Hertzsprung-Russell diagram of its constituent stars.

2. Describe a star's evolution from initial cloud collapse to CO white-dwarf remnant by means of a Hertzsprung-Russell diagram.

Solution:

Draw an HR diagram and indicate the: *Hayashi track*, *main sequence*, *sub-giant branch*, *red giant branch*, *He flash*, *horizontal branch*, *asymptotic giant branch* and, finally, the region where white dwarfs reside. In the end, this figure should look similar to the one drawn on the blackboard during the lecture., or like the HR diagram of M13 that is linked on the course web page (except that this HR diagram doesn't show the AGB or the white-dwarf region). The stages should be described as follows:

Hayashi track: luminosity of the proto-star as it continues to contract before any nuclear fusion occurs.

Main Sequence: nuclear H burning occurs on the main sequence in the core of the star. This stage of a star's life takes by far the longest.

Sub-Giant Branch: As the helium core of the star grows, hydrogen burning gradually moves from core burning to shell burning. While this increases the outward pressure and thereby enlarges the star, the energy transport is not optimal yet, so the star's energy output doesn't increase. Consequently the outer layers cool down a bit (as they are pushed further out) and the star appears cooler with equal luminosity (i.e. the SGB is roughly horizontal).

Red Giant Branch: Eventually the star becomes fully convective which means the energy produced in the H shell burning is now moved efficiently towards the surface, i.e. the star's luminosity increases sharply.

He flash: For relatively low-mass stars ($M < 2.25 M_\odot$), Helium fusion only commences when the He core is already relatively large. As the H shell burning continues to grow the He core, at some point the gravitational pressure in the core becomes sufficient to ignite the He. This ignition increases the core pressure further, causing a runaway effect and a sudden turn-on of He burning throughout the entire He core. At this point the star suddenly jumps from the tip of the RGB to the Horizontal Branch.

Horizontal Branch: He core burning happens here. The location of a star in the HB mostly depends on the mass and metallicity. The HB is interrupted by the instability strip, where some variable stars reside.

Asymptotic Giant Branch: After the HB, He core burning moves into He shell burning around a C/O core, while the star moves along the AGB in the HR diagram. At the end of the AGB period, the most massive stars continue on to C burning etc. as supergiants, while less massive stars throw off their outer layers in a planetary nebula and their cores remain as CO White Dwarfs (which are located in the bottom-right of the diagram but don't have nuclear fusion anymore, their emission is purely blackbody radiation as they cool down).

3. Which three types of remnants may remain at the end of a star's life?

Solution: Most stars end up as *white dwarfs*, either *He white dwarfs* (for the very lightest stars) or *CO white dwarfs* (for slightly heavier stars that could sustain He burning). Heavier stars (with core masses above $1.35\,M_\odot$ but below $\sim 2\,M_\odot$ end up as *neutron stars* and the heaviest of stars become *black holes* at the end of their lives.

4. Give a rough estimate of the nuclear time scale for a solar-like star. Are the thermal and dynamical time scales shorter or longer?

Solution: The nuclear time scale for the Sun is about *10 billion years*. The thermal and dynamical time scales are *much shorter*.