Spectral Types

As mentioned in *Handout* II, the dark absorption lines in stellar spectra (see Fig. 1) provide information about the stars' effective temperatures. At the beginning of the 20th century, Annie Jump Cannon devised a classification scheme that assigns stars a *spectral type* from the sequence O-B-A-F-G-K-M[1], on the basis of the strength of various absorption lines. This sequence forms a temperature progression, with O-type stars the hottest and M-type stars the coolest. In the modern form of this scheme, each type is further subdivided into sub-types, indicated by a number, with smaller indicating earlier (hotter) in the sequence. The Sun is a G2 star.

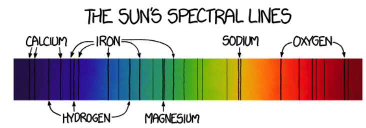

Figure 1: A schematic visible-light spectrum of the Sun, showing the dark absorption lines that arise from certain elements within the solar photosphere. Adapted from the XKCD comic strip at `https://xkcd.com/1733/`.

[1] The sequence is not alphabetical for historical reasons. Earlier attempts at devising a classification scheme focused only on the strength of hydrogen lines, with A-type stars showing the strongest lines and O-type the weakest. Cannon re-ordered this sequence to follow temperature, and eliminated many of the letters.

The Hertzsprung-Russell Diagram

Building on Cannon's spectral classification scheme, Ejnar Hertzsprung and Henry Norris Russel independently developed a diagram that plots the spectral type of stars against their absolute magnitude. This *Hertzsprung-Russell* (HR) diagram remains the most important visualization tool in stellar astrophysics.

Fig. 2 shows an early HR diagram created by Russell. The stars are not uniformly distributed across the diagram, but tend to cluster into distinct regions:

- *main-sequence* stars, lying along a diagonal band running from top-left to bottom right;
- *giant* stars, lying in the upper right;
- *white-dwarf* stars, lying in the lower left.

The names 'giant' and 'dwarf' already hint at the distinction between these regions. To understand them further, we must place the HR diagram on a more quantitative footing.

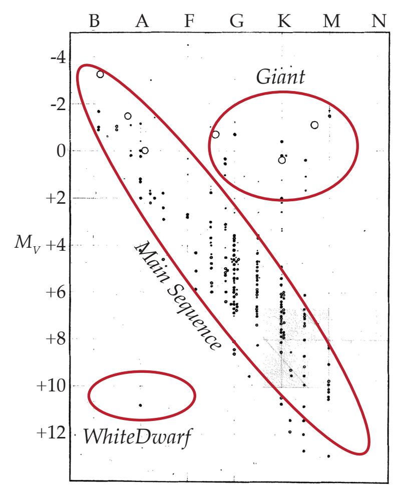

Figure 2: An early HR diagram, created by Russell (1914, *Pop. Ast.*, **22**, 331) for nearby stars having measured parallaxes. The regions containing the main-sequence, giant and white-dwarf stars have been highlighted by the red ellipses, and the axes have been reworked to make them legible.

Quantitative HR Diagrams

Although the original HR diagrams used spectral type and absolute luminosity for their axes, equivalent diagrams can be constructed using temperature (or a proxy such as color) along the horizontal axis and luminosity along the vertical. Fig. 3 shows one of these HR diagrams, plotting $\log T_{\mathrm{eff}}$ versus $\log L$ for a selection of stars out to a distance 30 pc. In keeping with the layout of the original HR diagrams, temperature *decreases* from left-to-right in the diagram.

The main sequence can be clearly seen in the diagram, together with a sprinkling of giant stars and a couple of white dwarfs. The

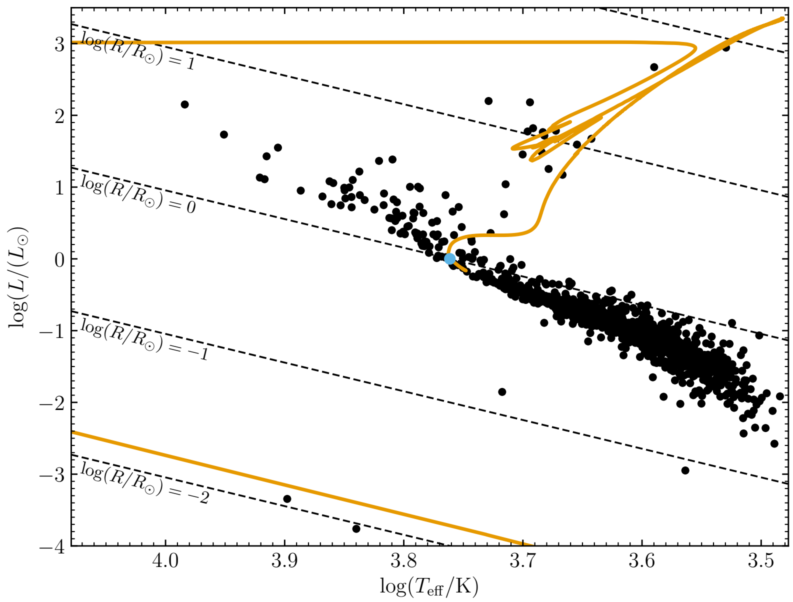

Figure 3: An HR diagram for stars within 30 pc of the Earth, comprising 1130 main-sequence stars, 16 giants and 2 white dwarfs (taken from the *Exocat-1* catalog compiled by Margaret Turnbull). The dashed lines mark contours of constant stellar radius, labeled with reference to the solar radius $R_\odot = 6.957 \times 10^{10}$ cm. The orange line shows the evolutionary track of the Sun, calculated using the *MESA* software; toward the end of the Sun's life, the track disappears off the top-left of the diagram, before reappearing at the bottom left. The blue dot shows the present-day position of the Sun, on the main sequence

logarithm of the Stefan-Boltzmann law applied to stars is

$$\log L = 4 \log T_{\rm eff} + 2 \log R + \log(4\pi\sigma); \qquad (1)$$

therefore, contours of constant R appear as straight lines in this HR diagram, with slope $\mathrm{d}\log L/\,\mathrm{d}\log T_{\rm eff} = 4$.

From these contours, we see that giants have radii $R \gtrsim 10\,\mathrm{R}_\odot$; in fact, the largest giants — known as *supergiants* — can be as large as $R \simeq 10^3\,\mathrm{R}_\odot$. Likewise, white dwarfs exhibit typical radii $R \simeq 0.01\,\mathrm{R}_\odot$, about the same size as the Earth. Main-sequence stars lie between these extremes, with typical radii in the range $0.1\,\mathrm{R}_\odot \lesssim R \lesssim 10\,\mathrm{R}_\odot$.

Evolution in the HR Diagram

The different regions of the HR diagram represent stars at different stages in their *evolution*. Stars spend most of their lives on the main sequence, converting hydrogen into helium in their cores via nuclear fusion. When their supplies of hydrogen are exhausted, they evolve to lower temperature but larger radius and luminosity, carrying them into the giant region of the HR diagram. Eventually, they shed their outer layers, and move across and then down in the HR diagram to become a white dwarf. The curve plotted in Fig. 3 shows the *evolutionary track* that will be followed by the Sun as it passes through these stages.

Further Reading

Ostlie & Carroll, §§8.1,8.2; *Prialnik*, §1.4.