Stellar Structure
Interpreting Blackbody Emission

We generally assume that stars emit as blackbodies, which is actually not a terrible assumption for most purposes. Let's explore the basic properties of blackbodies so we can apply this knowledge to stars.

The blackbody (Planck function) is:

$$B_\nu = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}. \tag{1}$$

or

$$B_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}, \tag{2}$$

where the function is evaluated at frequency ν or wavelength λ, and the object is at temperature T. These functions are shown in Figure 2 for different temperatures.

Students are often confused by the units: $\mathrm{erg\,cm^{-2}\,s^{-1}\,Hz^{-1}\,sr^{-1}}$ ($\mathrm{W\,m^{-2}\,Hz^{-1}\,sr^{-1}}$) for B_ν or $\mathrm{erg\,cm^{-2}\,s^{-1}\,cm^{-1}\,sr^{-1}}$ ($\mathrm{W\,m^{-2}\,cm^{-1}\,sr^{-1}}$)for B_λ, where the additional "Hz" or "cm" term is the frequency or wavelength (often given in Angstroms). This also means that it is a surface brightness or an intensity.

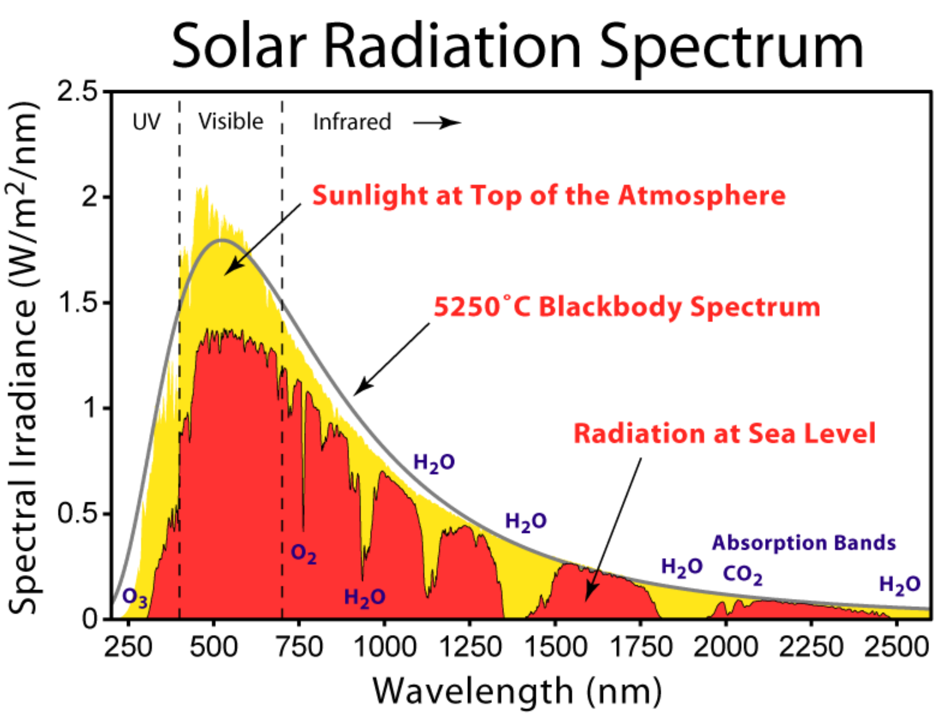

Figure 1: Comparison of Solar and blackbody spectra.

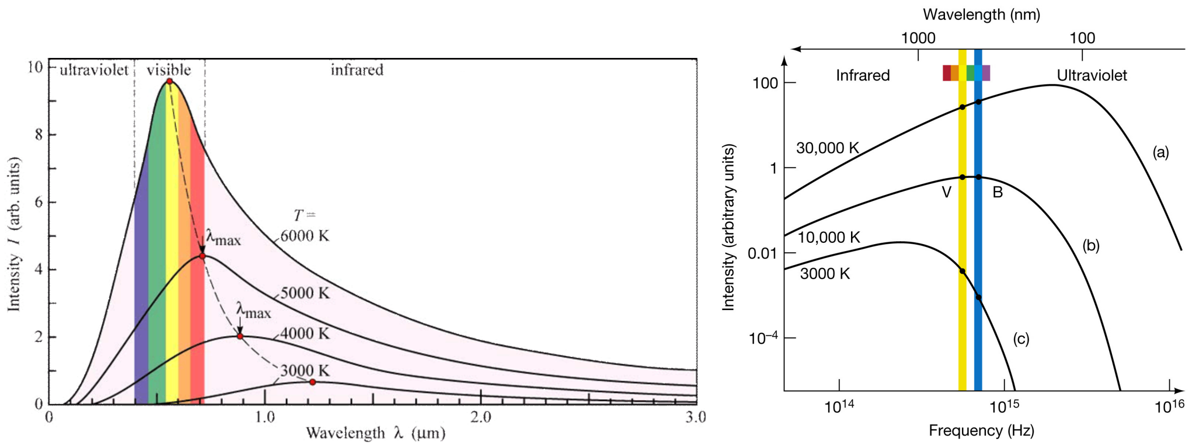

Figure 2: Blackbody curves in linear (left) and log (right)-space. Wien's Law can clearly be seen.

As we learned last lecture, the fundamental observational quantity in astronomy is the specific intensity I_ν. But under what conditions is $I_\nu = B_\nu$? When something called the "optical depth" τ is high. To answer this, we have to review a little radiative transfer. The fundamental textbook for RT is "Radiative Processes in Astrophysics" by Rybicki and Lightman.

Using Blackbodies

We can usually assume that stars emit similarly to blackbodies, in which case we know their approximate spectral shape for a given temperature. Therefore, observations of stars using astronomical filters can give you information about the temperatures of those stars. Since the temperature and mass are related, we can get a proxy for mass.

The flux (or magnitude) that we measure depends on the filter used. In the optical we may use the U, B, and V filters. We measure the convolution of the filter transmittance and the source spectrum.

Imagine two filters placed on a blackbody curve. The flux ratio of these filters will give you some information about how the intensity is changing. For example, if the flux ratio is large (the longer-wavelength filter is reading much less), the decrease is steep and we must be on the long wavelength side of a high temperature peak. If the flux ratio is small, we must be on the short wavelength side of a low temperature peak. From our discussion of magnitudes, we know that flux ratios are called colors. Colors therefore tell you about the spectral shape, and the temperature of the object.

That colors are useful relies on the fact that stellar spectra are similar to that of blackbodies. This is obvious from Figure 3 below (Figure 3.11 in Carroll

& Ostlie), where the U-V and B-V colors of stars are compared to those of blackbodies.

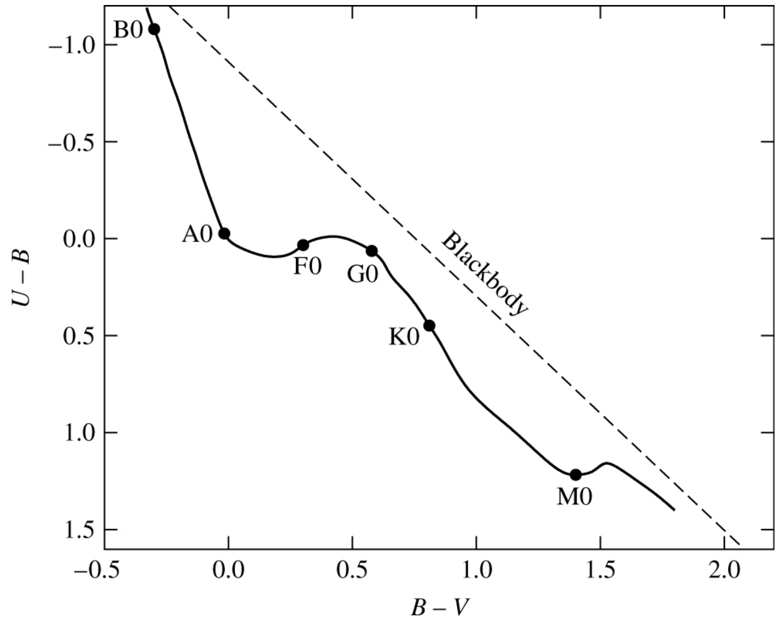

Figure 3: $B - V$ and $U - B$ colors for star of various spectral types. B0 is the largest and M0 are the smallest mass stars in the diagram.

Astronomers use colors as a proxy for temperatures, for example on the color-magnitude diagram, CMD. The CMD looks almost exactly like the H-R diagram because there is such a clean mapping between colors and temperatures. Why use the CMD? The quantities are entirely observable. In the H-R diagram, we often do not know the luminosity and temperature, but we can easily measure magnitudes for a bunch of stars.

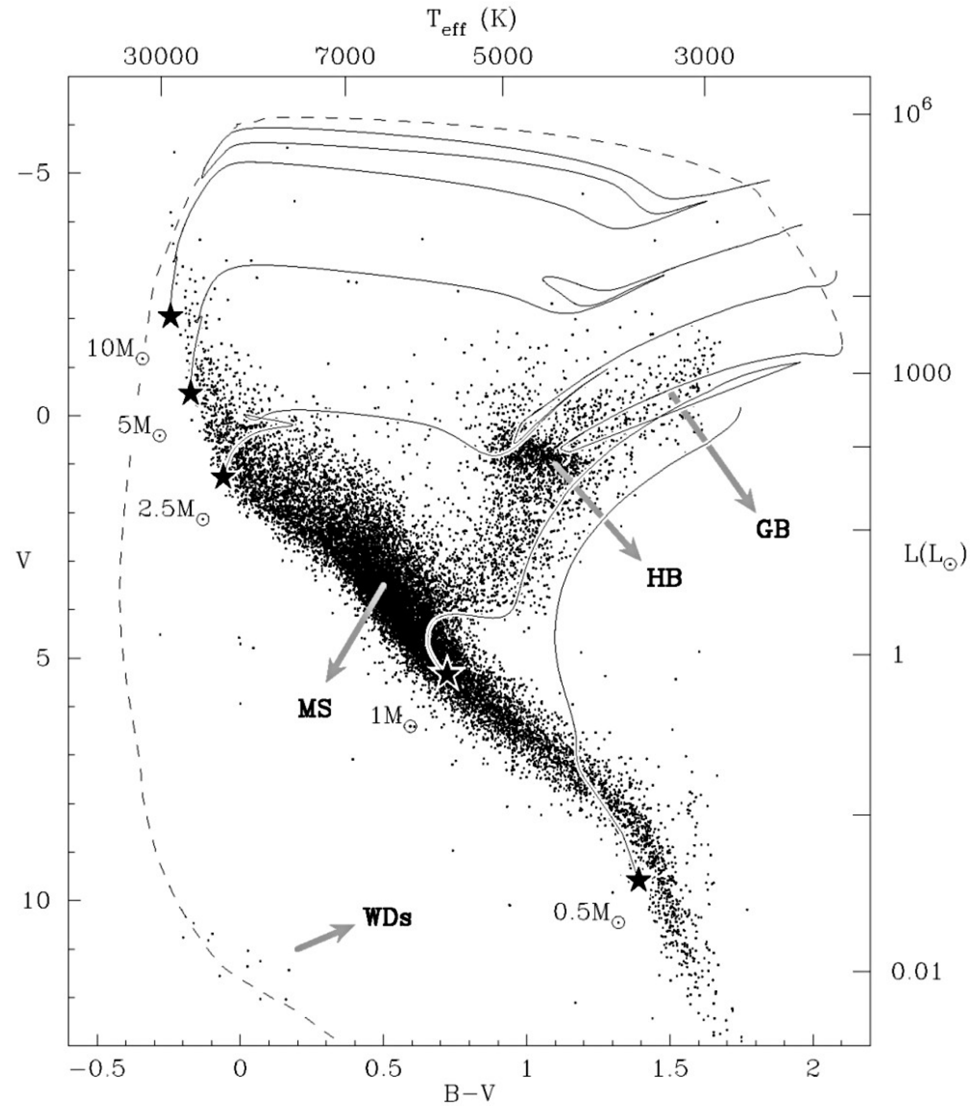

Figure 4: A Color-Magnitude Diagram (CMD). Each dot corresponds to one star. Shown are the main sequence (MS), location of white dwarfs (WD), the Horizontal Branch (HB), and the Giant Branch (GB). With time, stars evolve off the main sequence, go up into the giant branch, back down into the horizontal branch, and eventually become white dwarfs. The evolutionary tracks for stars of various masses are also shown.