ASTR469 Lecture 4: HR Diagram and Color-magnitude Diagrams (Still Ch. 5)

Assess yourself/study guide after lecture & reading (without peeking at notes)...

1. A star has a $B - V$ color of -1. Stars with $B - V = 0$ appear slightly blue. Does this star look more or less blue? What does that imply about its temperature? (note: similar to question in class but not exactly the same! Remember from last lecture that higher magnitude values are *fainter*; they don't quantify intensity directly.

2. Estimate the electromagnetic band (e.g. radio, infrared, optical, UV, X-ray) in which the most massive main-sequence stars would peak. Then, estimate the electromagnetic band in which a main-sequence G-class star would peak.

3. What temperature would a star have to be to have a peak in the radio waveband (say, at around 10 GHz)?

4. I know the distance to a particular star (d), and its apparent magnitude in the B and V bands. Write down the procedure you would follow to infer the approximate luminosity and radius of the star.

1 Color indices

As we saw last time, for objects emitting as blackbodies, their spectra are well-defined by the Planck function and peak at a certain wavelength. Because of this, as long as we know an object is roughly a blackbody, we don't actually have to observe a full source spectrum to quantify its temperature; observations with just two photometric filters can be used to tell us whether the magnitude is going up, roughly flat, or going down across the two wavelength bands.

We also learned before that magnitude differences correspond to flux ratios. Stars more-or-less emit as blackbodies, so their flux ratios (magnitudes) tell you about the shape of their energy distribution. Thus, the slope of the spectrum going up, roughly flat, or going down maps out which "sides" of some Planck curve you are on, telling you the approximate temperature of an object.

While many different translations for different photometric bands exist, just as an example you can infer temperature from color using:

$$T = 4600\ \mathrm{K}\left(\frac{1}{0.92(B-V)+1.7}+\frac{1}{0.92(B-V)+0.62}\right) \tag{1}$$

...where $B-V$ is the "color index." Here, B and V represent the stellar magnitudes measured in your B and V filters.

But, note that 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.

Let's talk through this in more detail. Imagine two filters placed on a blackbody curve. If the magnitude difference (flux ratio) of $m_{\mathrm{short}\lambda} - m_{\mathrm{long}\lambda}$ is large (the shorter-wavelength filter is reading much more), 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. Colors, and particular color indices, therefore tell you about the spectral shape and thus the temperature of the object.

Earlier, we said that stars are approximately blackbodies. This is obvious from Figure 1, where the U-V and B-V colors of stars are compared to those of blackbodies.

Color-magnitude diagrams

Astronomers commonly use colors as a proxy for temperatures, for example on the color-magnitude diagram, CMD. An example of this is shown in Figure 2. Using color indices in this way is very useful and makes life easier if you want to study stars; as you'll see below, simple two-color measurements can, by using CMDs, give us tons of information about stars!

The CMD has a more physical version referred to as the "Hertzsprung-Russell Diagram" (HR Diagram), show in Figure 3, which translates the observed quantities into actual physical

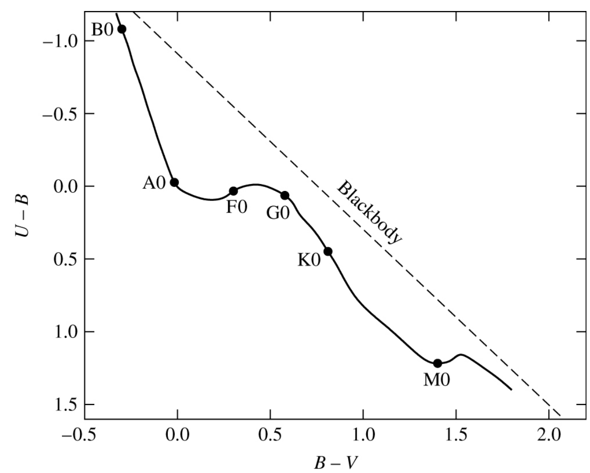

Figure 1: $B-V$ and $U-B$ colors for star of various spectral types. If you haven't encountered spectral types before, B0 is the largest and M0 are the smallest mass stars in the diagram.

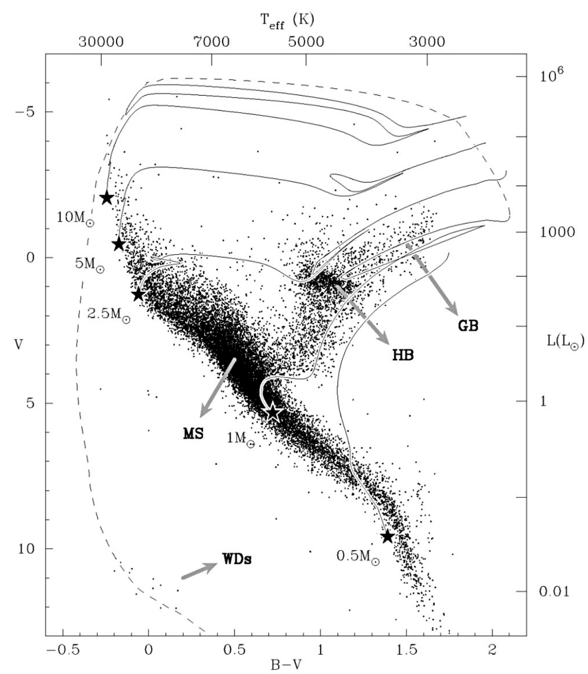

Figure 2: A Color-Magnitude Diagram (CMD). Each dot corresponds to one star. Shown are the main sequence (MS), location of white dwarfs (WD), the Horizontal Branch (HB), and the Giant Branch (GB). With time, stars evolve off the main sequence, go up into the giant branch, back down into the horizontal branch, and eventually become white dwarfs. The evolutionary tracks for stars of various masses are also shown.

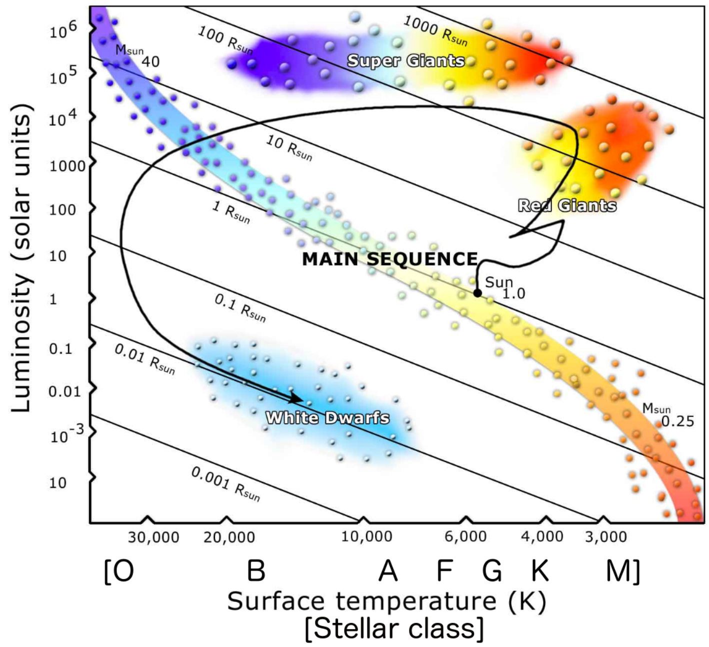

Figure 3: The HR diagram. Note that the horizontal axes can reflect both temperature and spectral type.

properties: luminosity and surface temperature. In this particular figure, the eventual path over the lifetime of the Sun is shown; as with the CMD, stellar sequences for particular stars can be linked here.

An important note: apparent vs. absolute mags and extinction

As we've said in the past, apparent magnitudes reflect the light we see, while absolute magnitudes should reflect the intrinsic luminosity of the emitter. Apparent magnitude depends on the distance of the star, while absolute magnitude should not.

CMDs are plotted by astronomers using EITHER apparent or absolute magnitude; there is no particular standard.

However, in the future we will discuss extinction. In the atmosphere and in the interstellar medium of a galaxy, dust attenuates star light, and this attenuation is often measured in magnitudes. Each kpc in our Galaxy produces about a magnitude of visual extinction. Star formation regions can have visual extinctions of 100, so a star would have $2.512^{100} = 10^{40}$ times less light than it would if extinction were not present. Extinction generally decreases with increasing wavelength, so it is less in the infrared and essentially absent in the radio. Thus, sometimes apparent magnitudes must be corrected for BOTH distance and extinction if they are to reflect absolute magnitude.

2 Stellar properties and the HR Diagram

Figure 3, and its similarities with the equivalent Figure 2, demonstrate in a few ways how useful simple measurements of temperature (two apparent magnitudes) and luminosity (absolute magnitude, or apparent magnitude and distance) can be.

First, let's make some observations. The "main sequence" of stars is visible as the curvy, diagonal band across the plot. This shows the birthplace of stars. High-mass stars tend to be younger (and more luminous, and bluer). The observable properties of main sequence stars, such as their surface temperature, luminosity, and radius, are all related to the mass of the star. Thus, the position along the main sequence can be considered as related to mass.

You'll also note that there are bands of constant radius marked. That is because of the Stefan-Boltzmann law, discussed last lecture, which relates temperature, luminosity, and radius.