

(online at [www.astro.umd.edu/~drabin/](http://www.astro.umd.edu/~drabin/))

*The truth is out there.*

**Approach**

You’ve all been exposed to magnitudes, distance moduli, spectral types, and Hertzsprung-Russell (HR) diagrams. You may not have considered luminosity functions, which work hand-in-glove with HR diagrams.

We’ll approach the HR diagram primarily from a “consumer” viewpoint—as a tool for summarizing the range of intrinsic stellar properties that we should aspire to explain with a theory of stellar structure and evolution. If we were approaching the subject primarily as observers, or as practicing model builders, we would need to look much more closely “under the hood” at the complex web of methods employed to construct HR diagrams and the uncertainties and selection effects associated with each method. As in any physical theory, the depth of the theoretical treatment is driven by the precision of the data: even apparently minute discrepancies can be worth pursuing if they are observationally significant (an example we’ll discuss later: the discrepancies between observed and theoretical frequencies of the global oscillation modes of the Sun).

**The Hertzsprung-Russell Diagram**

(O&C §8.2)

The HR diagram was introduced by E. Hertzsprung in 1905 and H. N. Russell in 1913. Russell’s original diagram plots absolute visual magnitude against spectral type.

➡ It’s not a scatterplot!

Since absolute magnitude is a measure of intrinsic luminosity, and spectral type is primarily determined by temperature,

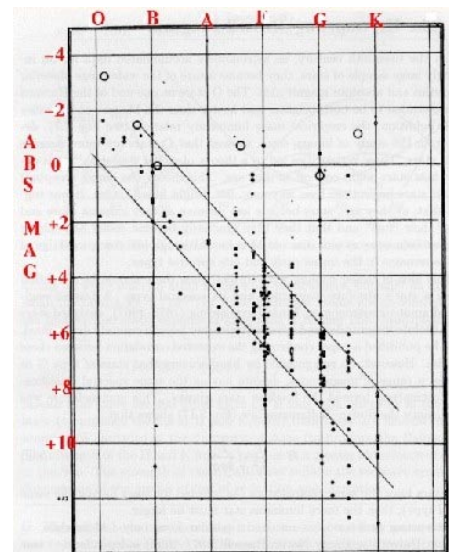


Figure 8.10 Henry Norris Russell’s first diagram, with spectral types listed along the top and absolute magnitudes on the left-hand side. (Figure from Russell, *Nature*, 93, 252, 1914.)

- Conclusion: many (but not all) stars follow a fairly well-defined relationship between luminosity and temperature.

The HR diagram is so important that we'll take a leisurely gallery tour of the many guises in which the diagram can appear. First, we'll review some of the ingredients.

## Magnitudes and photometric Systems (O&C §3.2)

Magnitude scale  $m_1 - m_2 = -2.5 \log(F_1/F_2)$

where  $F$  is flux. Just a logarithmic scale for measuring flux with the historical factor -2.5 included to make (-)five magnitudes correspond exactly to a flux ratio of 100. Smaller magnitudes correspond to brighter objects.

Absolute bolometric magnitude  $M_{\text{bol}} = -2.5 \log(L/L_{\odot}) + 4.74$

where the absolute bolometric magnitude of the Sun,  $M_{\text{bol}\odot} = 4.74$ , anchors the scale (the zero point is, ultimately, arbitrary). Note that bolometric magnitude (or luminosity) includes energy at all wavelengths.

Apparent magnitude  $m$   $m - M = 5 \log(d/10 \text{ pc})$

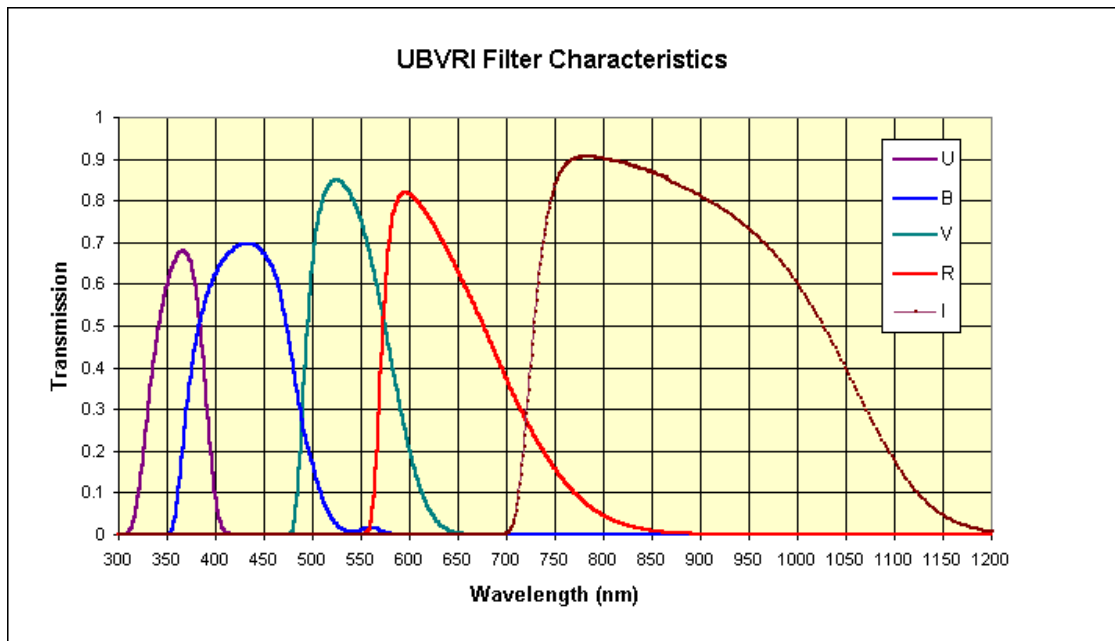
Where  $m - M$  is called the *distance modulus*. By definition, then, the apparent and absolute magnitudes coincide for an object at a distance of 10 pc (and with no interstellar absorption). Apparent and absolute magnitude scales both involve an arbitrary constant, but those constants must be linked by this relationship.

Bolometric luminosity is not easily measured, since it includes all wavelengths. More commonly, the wavelength range is restricted by the sensitivity of the detector or intentionally (with filters, for example) to provide crude spectral resolution. A calibrated restriction of this kind is called a *photometric system*. The sensitivity function  $R(\lambda)$  gives the fraction of flux  $F(\lambda)$  incident on the detector system (which may include the telescope) that is ultimately measured. A general photometric system will be defined by

Apparent photometric magnitude  $m_s$   $m_s = -2.5 \log \left( \int_0^{\infty} F(\lambda) R(\lambda) d\lambda \right) + C_s$

where  $C_S$  is an arbitrary constant. Early photometric systems were visual (response of the human eye) or photographic (tied to a photographic emulsion—the absolute magnitudes in Russell’s HR diagram would be of this type). Today, all commonly used photometric systems are specified by precisely defined filter pass bands and constants  $C_S$ . An extension of the classical *UBV* (Ultraviolet/Blue/Visual) to *Red* and *Infrared* is shown below. Other infrared filters (*JHKLMN*, out to 10  $\mu\text{m}$ ) are increasingly used; they are better matched to cool objects and are less affected by interstellar absorption.

**P** A star of what  $T_e$  peaks ( $B_\lambda$ ) at the peak wavelength of the *L* filter, 3.55  $\mu\text{m}$ ?



Astronomers convert between photometric and bolometric magnitudes with a bolometric correction,

$$BC_S = m_{\text{bol}} - m_S$$

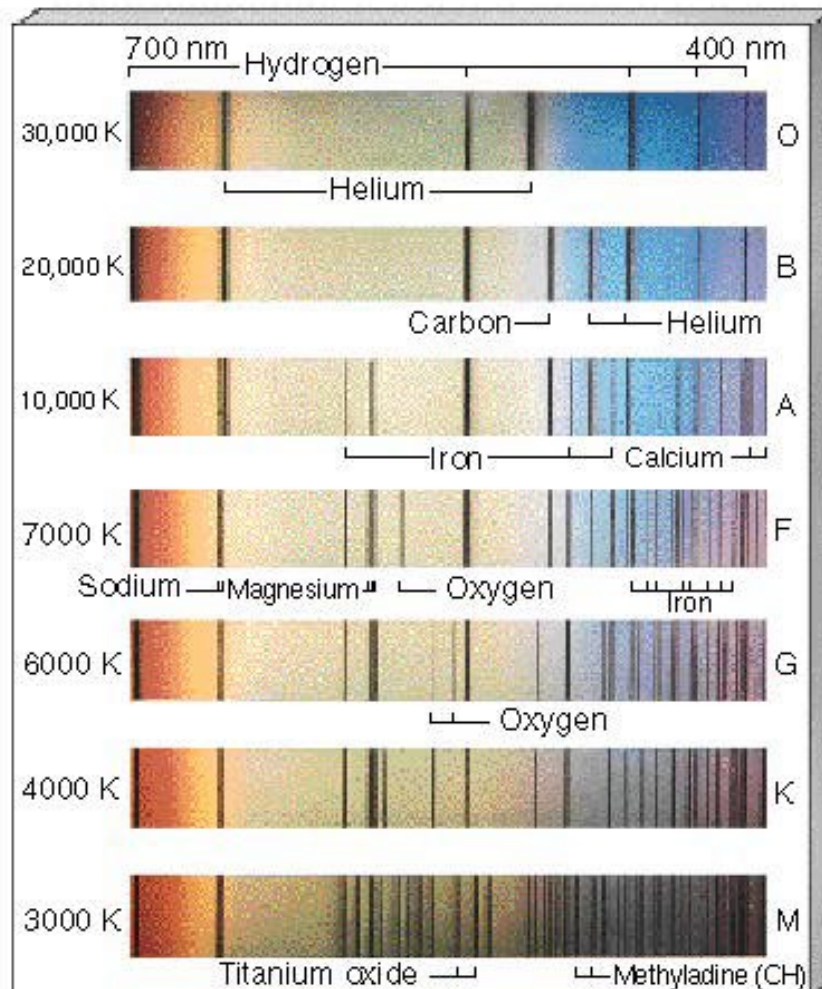
Note that the correction  $BC_S$  is specific to a given band  $S$  (even though you will often see “the” bolometric correction used as if it were universal).

Color index  $B - V$

$$B - V = m_B - m_V = M_B - M_V$$

Where  $B \equiv m_B$ . Any other photometric pass bands may be substituted for  $B$  or  $V$ . The constants  $C_B$  and  $C_V$  in the definitions of  $m_B$  and  $m_V$  were chosen historically to make  $B - V \approx 0$  for an A0 dwarf star (in fact,  $B - V \approx U - B \approx V - R \approx R - I = 0.00 \pm 0.02$  for spectral type A0 V).

## Spectral classification (O&C §8.2)



➡ Spectral class (class and type are used interchangeably) is primarily determined by temperature (Saha and Boltzmann equations). A single basic type (say, G) can be reliably divided into several subtypes (e.g., G0, G2, G5, G8) on the basis of the observed spectrum. Not all possible subtypes are used in practice. There are also more exotic types used for cool stars (e.g., C for “carbon” stars showing strong molecular bands of  $C_2$ , CN and CH).

➡ Smaller differences—in absorption line widths and line-strength ratios—among stars of the same basic spectral type can distinguish *luminosity classes*.

The standard system for two-dimensional (temperature-luminosity) spectral classification is called MK after two of its originators. Note that the MK system is based on spectral characteristics in the “classical” wavelength region, roughly 380–700 nm. For very hot or very cool stars, the ultraviolet or infrared spectrum often provides stronger discriminators than the visible/near-IR spectrum.

**TABLE 17.2 Stellar Spectral Classes**

<b>SPECTRAL CLASS</b>	<b>SURFACE TEMPERATURE (K)</b>	<b>PROMINENT ABSORPTION LINES</b>	<b>FAMILIAR EXAMPLES</b>
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7,000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6,000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4,000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3,000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2), Barnard's Star (M5)

### Luminosity classes

- Ia most luminous supergiants
- Ib less luminous supergiants
- II luminous giants
- III normal giants
- IV subgiants
- V dwarfs (main sequence)

**P** Is the spectrum actually sensitive to the luminosity (radiative output) of the star? If not, what is the physical effect behind luminosity classes? How much does that effect vary among stars?