Classification of stars

Basic properties of stars include the mass M, radius R, total (bolometric) luminosity L (total rate of energy output integrated over all wavelengths, units erg s^{-1}), and the spectrum.

For the Sun:

$M_\odot = 1.989 \times 10^{33}$ g

$R_\odot = 6.96 \times 10^{10}$ cm

$L_\odot = 3.83 \times 10^{33}$ erg s^{-1}

Solar spectrum can be roughly approximated as a black body:

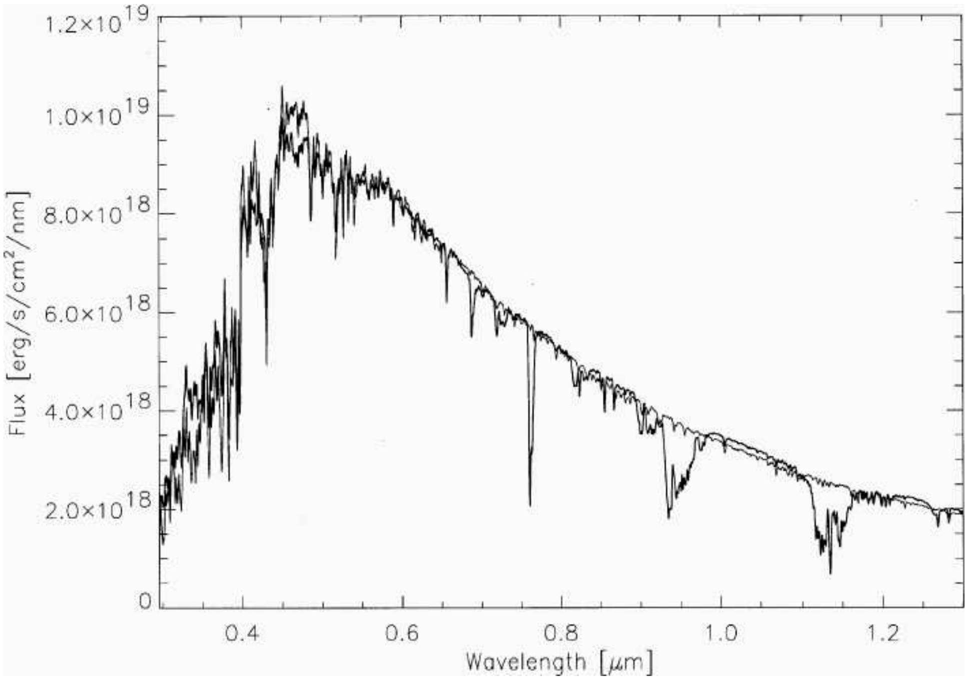


Figure from Hauschildt, Allard & Baron (1999)

+ absorption lines (looking at hotter layers of the Sun through the cooler outer layers). Stars substantially hotter or cooler than the Sun depart more from black body spectrum.

Recall that for a black body,

$$B_\nu(T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1} \text{ erg cm}^{-2}\text{ s}^{-1}\text{ Hz}^{-1}\text{ sr}^{-1}$$

which peaks at,

$$h\nu_{\text{max}} \simeq 2.8kT$$

For any spectrum, define **effective temperature** T_e of a star as the temperature of a black body with the same luminosity / unit surface area as the star. Stefan-Boltzmann law gives,

$$L = 4\pi R^2 \sigma T_e^4$$

where $\sigma = 5.67 \times 10^{-5}$ erg s^{-1} cm^{-2} K^{-4}.

Where stars lie in the L vs T_e plane is of the greatest interest theoretically.

Observationally, L may not be known (if the source is at unknown distance), and the only spectral information may be color. Because of this, and for historical reasons, need to introduce extra nomenclature.

Magnitudes and colors

For a star at distance d with an observed flux $l = L/(4\pi d^2)$ (integrated over some range of wavelengths, units erg cm^{-2} s^{-1}), apparent magnitude,

$$m = -2.5 \log l + \text{constant}$$

i.e. a star that is 5 magnitudes brighter (smaller magnitude) has 100 times the flux. For two stars with fluxes l_1, l_2, apparent magnitudes m_1, m_2,

$$\frac{l_2}{l_1} = 10^{-(m_2-m_1)/2.5} = 2.512^{m_1-m_2}$$

Central wavelengths λ and full widths at half maximum W for common bands are:

Band	U	B	V	R	I
λ / nm	365	445	551	658	806
W / nm	66	94	88	138	149

i.e. broadband filters have width of around 20% of the central wavelength. Sirius has $m_V = -1.45$.

Zero points are different for each band – need to look these up as required.

Absolute magnitude M is defined as the apparent magnitude the star would have at a fixed fiducial distance (10 pc).

Let l_{10} be flux when star is at 10 pc, mag M
Let l_d be flux when star is at distance d, mag m

Then,

$$\frac{l_{10}}{l_d} = \left(\frac{d}{10\ \mathrm{pc}}\right)^2 = 10^{-(M-m)/2.5}$$

$$m - M = 5 \log\left(\frac{d}{10\ \mathrm{pc}}\right)$$

$m - M$ is the distance modulus.

To compare with theory, most interest in the **bolometric magnitude** M_{bol} – the absolute magnitude that would be measured by a bolometer sensitive to all wavelengths.

Define the **bolometric correction** via,

$$\mathrm{BC} = M_{\mathrm{bol}} - M_{\mathrm{V}} = m_{\mathrm{bol}} - m_{\mathrm{V}}$$

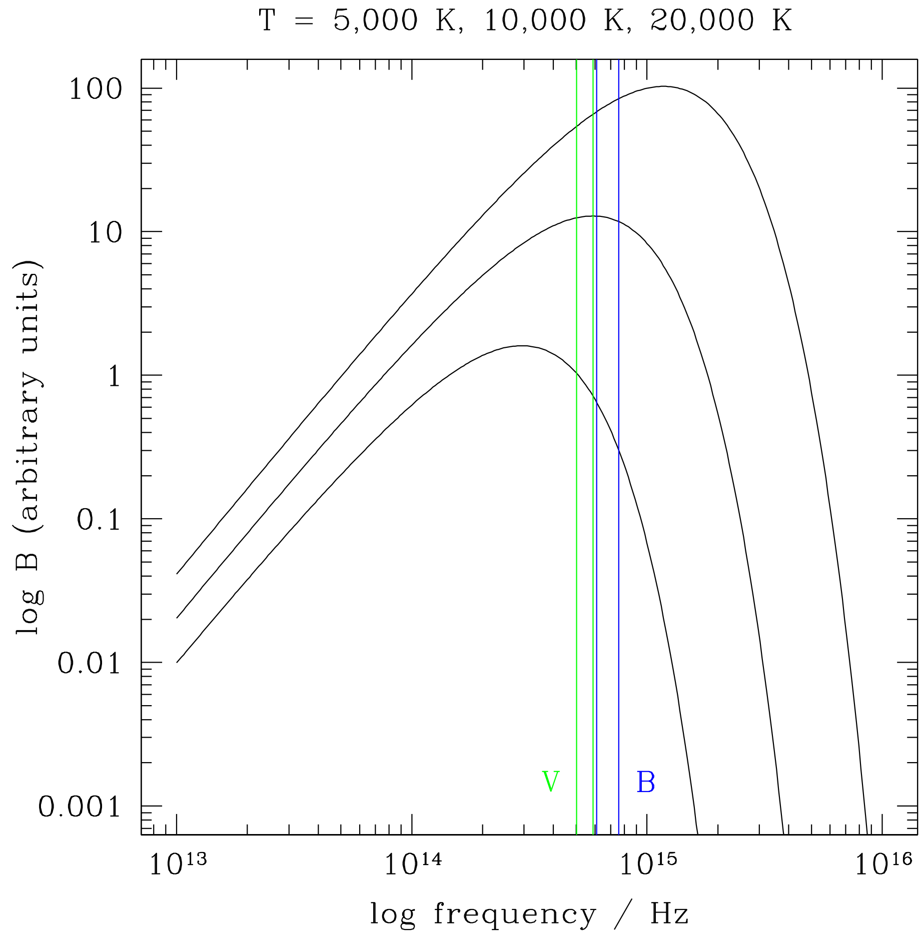
The BC is zero for a star with $T_e \simeq 6,600$ K, and varies with effective temperature.

Colors

Define color indices, e.g.

$$B - V = m_B - m_V.$$

Colors are distance independent, and are related to the effective temperature because stars radiate approximately as black bodies:



Colors are zero for a Vega-like star with $T_e \simeq 9,500$ K. Then $(B - V) < 0$ for hotter temperatures, $(B - V) > 0$ for cooler stars.

Spectral classification

Lines seen in a stellar spectrum depend upon the temperature in the atmosphere. Ionization potentials I for several relevant species:

H	He I	He II	Ca I	Ca II	Fe I
13.6 eV	24.6 eV	54.4 eV	6.1 eV	11.9 eV	7.9 eV

As a rough rule of thumb, ionization occurs in a stellar atmosphere when,

$$kT_{\text{ion}} \sim \frac{1}{10} I$$

i.e. at *much lower* temperatures than you would naively expect from expressing I in temperature units (why?). Numerically,

$$T_{\text{ion}} \sim 11,600 \left(\frac{I}{10 \text{ eV}} \right) \text{ K}$$

Appearance of lines of a given element reaches a maximum when T_e in the atmosphere is comparable to T_{ion}, e.g.,

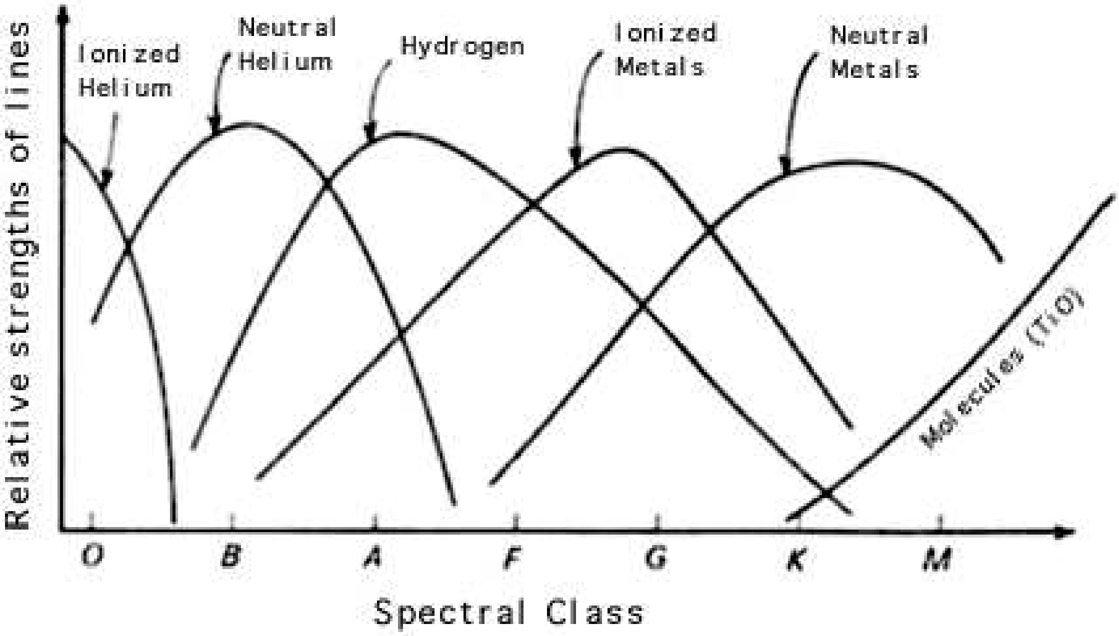
$T > 20,000$ K → all H ionized, no lines

$T < 5,000$ K → all H in $n = 1$ state, no Balmer lines from transitions to $n = 2$ state

Presence of specific lines in spectrum is an observational indicator of T_e – basis of **spectral class** classification.

Spectral class

Classification of stars based on the absorption line spectrum:



Examples of temperatures corresponding to different classes,

O	B	A	F	G	K	M
40,000K	20,000K	10,000K	6,700K	5,500K	4,500K	3,500K
Early	*type*				*Late*	*type*

L and T dwarfs are cooler, and generally substellar.

Each class is divided into subclasses e.g. Sun is G2. The bolometric correction is zero for F5. U=B=V for A0.

Luminosity class

Spectral class does not directly depend upon luminosity – a giant and a dwarf star with same T_e will show similar lines in spectrum.

Details of spectral lines do depend upon the size of the star (large stars have lower surface acceleration, less dense atmospheres, and narrower lines).

Indicated by the luminosity class:

I	II	III	IV	V
Supergiants	Luminous giants	Giants	Subgiants	Dwarfs

None of the above mentions abundances. Comparison of theoretical atmosphere models with observed spectra yield relative abundances of elements.

Additional classification for evolved stars that show unusual patterns of elements in their spectra – mostly not of interest to us here.