Spectral Classification and the H-R Diagram

# Stars: different colors and luminosities



In <u>physics</u> and <u>optics</u>, the **Fraunhofer lines** are a set of <u>spectral lines</u> named for the German physicist <u>Joseph von Fraunhofer</u> (1787–1826). The lines were originally observed as dark features (<u>absorption lines</u>) in the <u>optical spectrum</u> of the <u>Sun</u>.

The English chemist <u>William Hyde Wollaston</u> was in 1802 the first person to note the appearance of a number of dark features in the solar spectrum. In 1814, Fraunhofer independently rediscovered the lines and began a systematic study and careful measurement of the <u>wavelength</u> of these features. In all, he mapped over 570 lines, and designated the principal features with the letters A through K, and weaker lines with other letters.[1] Modern observations of <u>sunlight</u> can detect many thousands of lines. (Wikipedia)



Fraunhofer demonstrating the spectroscope.





### The Harvard Observatory Program to Classify Stellar Spectra

#### **Edward Pickering & Williamina Fleming**

As director of the Harvard College Observatory **Edward C. Pickering** (1846-1919) undertook the oversight for completion of the Henry Draper Catalogue. Because it was the goal of this project to <u>classify a sufficient number of stars</u> so that it would be years before anyone felt the need to repeat such an undertaking, it was Pickering's goal to classify at least <u>100,000 stars for the Henry Draper (HD) Catalogue</u>. By World War I, objective prism photography was used with telescopes at Harvard and Peru to obtain spectra of more than 250,000 stars.

Pickering was unhappy with the work performed by his male employees and declared that his maid could do a better job than they did. In 1881, Pickering did hire his maid, **Williamina Fleming** (1857-1911), to do some mathematical calculations at the Harvard Observatory. Fleming was soon promoted to work directly with the spectral classification project, although she was paid half of what the men were paid. Nevertheless, Fleming developed <u>a relatively simple classification scheme, with 22 different classes</u>, and in 1890 published the classifications for 10,000 stars as the *Draper Catalogue of Stellar Spectra*. Fleming sorted stars by decreasing Hydrogen absorption-line strength. Stars with the strongest hydrogen lines in their spectrum were designated as spectral type "A", followed by types B, C, D, etc. for stars with weaker hydrogen lines in their spectrum. Unfortunately, few of the spectral lines due to elements other than hydrogen fit into this sequence.







## Bohr model of atom

In order for atom to produce absorption line: (a) the atom should have electron orbiting it and (b) photons should have enough energy to cause excitation



### Strength of lines depends on gas temperature and on atom







Table 13.1(a) The Spectral Sequence	Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)
•	0	Stars of Orion's Belt	>30,000	Lines of ionized helium, weak	<97 nm (ultraviolet)*
	В	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*
	А	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*
	F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*
	G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)
	К	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)
	М	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong	>830 nm (infrared)

\* All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

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### **Stellar Classification**

- The spectra of stars and their colors can be used to classify their physical properties. This was recognized in the early 20th century as both Kirchhoff's Laws and the Bohr model began to be applied to stars.
- From our knowledge of blackbody radiation, we know that the color of a star is directly related to temperature where cooler stars are red and hotter stars are blue. The stellar classification system today in astronomy uses letters to signify temperatures as follows:

#### OBAFGKM

where O stars are hot (30,000 K), G stars are intermediate temperature like the Sun (5500 K), and M stars are cool (3500 K).

The distribution of spectral lines in a star are even more sensitive probes of temperature. This has to do with ionization and collisional excitation. For example, O stars have weak Balmer lines because most of the hydrogen gas is ionized in these hot stars. A stars, which have temperatures of 10,000 K, have the strongest Balmer lines. On the other hand, K and M stars have weak Balmer lines because most of the hydrogen is in the ground state and/or part of molecules in these cool stars.

### The Hertzsprung-Russell (H-R) Diagram

Danish astronomer Ejnar Hertzsprung and American astronomer Henry Norris Russell discovered that when they compared the luminosity with the type of light that was observed from stars, there were many patterns that emerged. In 1905, Hertzsprung presented tables of luminosities and star colors, noting many correlations and trends. In 1913, Russell published similar data in a diagram. It is now called the Hertzsprung-Russell Diagram in honor of these two pioneers.



Henry Norris Russell



Ejnar Hertzsprung

### The Inverse Square Law

- 1. When we look at the night sky, we see that all stars are not the same color or brightness. **Brightness** is the amount of energy per second per area that falls on a detector such as a photographic plate or on the retina of our eyes. Brightness depends upon two factors:
  - The total energy per second or *luminosity* emitted by a star or other object.
- 2. This dependence of brightness upon distance is called the *Inverse Square Law*. Once again, it is very much like the Gravity Force Law in that the brightness of a light source is proportional to  $1/R^2$ , where R is the distance between the light source and the observer.
- 3. So, when we look at a star, it may be faint because it is far away or it is low luminosity or a combination of the two.



### Properties of stars on the main sequence



### Properties of stars on the main sequence





An extremely useful tool for understanding the evolution of a star is the H-R diagram first devised in the early part of the century. It is a plot of **stellar temperature (or spectral class) on the horizontal axis versus stellar luminosity on the vertical axis.** It was found that particular types of stars lie on certain regions in this diagram according to their evolutionary state and their mass.

- The Main Sequence runs from the top left to the bottom right in the H-R diagram. These are all ``ordinary" stars, which like the Sun, are burning nuclear fuel at their centers. Stars in the upper left are luminous & have very high temperature; from the massluminosity relationship, we also know that these are the most massive main sequence stars. Stars in the lower right are low of luminosity, cool, and have masses smaller than the Sun. Notice the position of the Sun about mid-way on the Main Sequence.
- Giant & Supergiant stars lie in the upper right hand portion of the H-R diagram. These stars are luminous but have cool outer envelopes. According to our knowledge of blackbodies, a star which is cool can only be luminous if it has a large surface area (and, therefore, large radius) from which energy is emitted; thus, their position on this diagram requires such stars to be giants.
- Finally, the lower left portion of the H-R diagram contains *white dwarfs*. These stars are hot but relatively low luminosity. Again, using the same reasoning for blackbodies, such a hot star will have limited total energy emitted if it is small in radius.