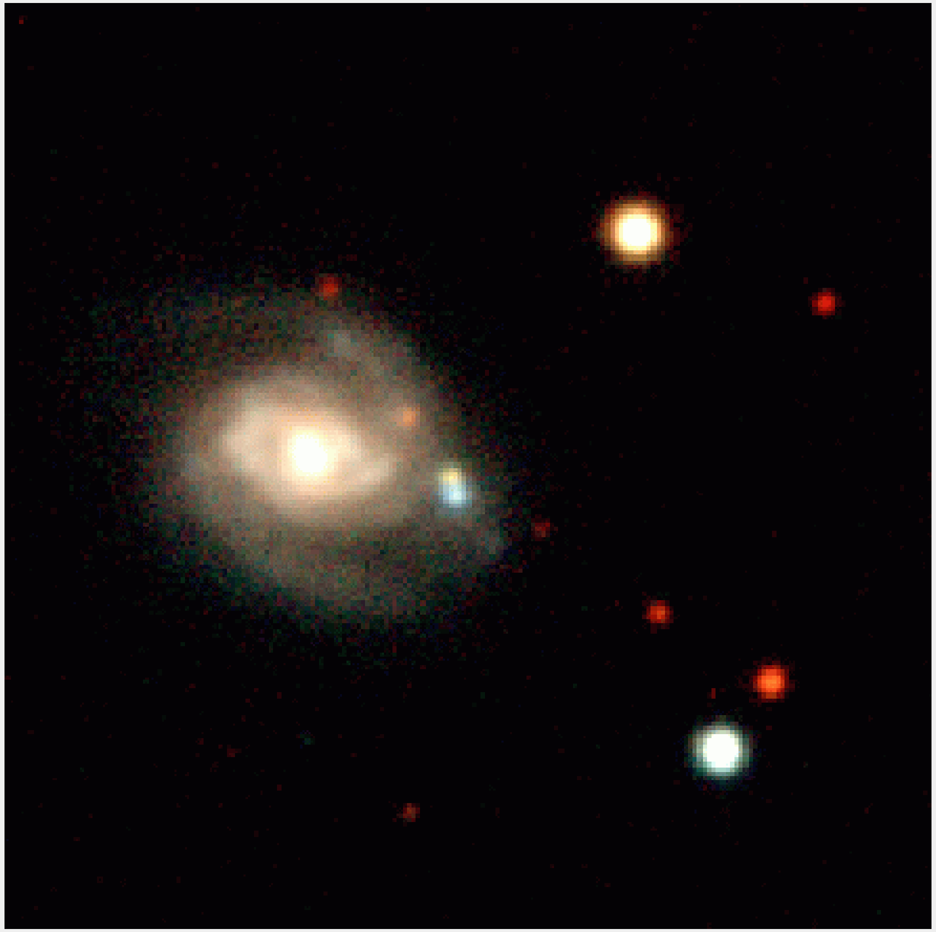
Colours and Spectral Types: Learning about stars from their spectra



Credit: Carl Hergenrother, 1997

Summary

In this Activity we will learn about the enormous amount of information contained in the **spectra** of stars. In particular, we will discuss:

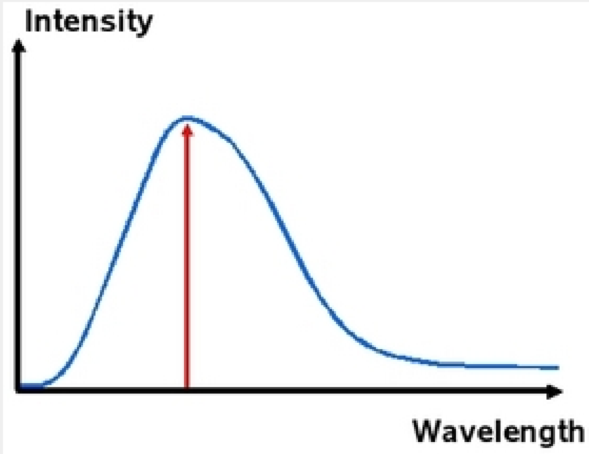
- the three types of specra - continuous, absorption and emission; and
- what spectra can tell us about the properties of stars by studying:
  - the spectral line shape;
  - spectral line shift;
  - line broadening; and
  - spectral line strength.

Stellar spectra

When we break starlight up into its component wavelengths, we can plot the *intensity* (or flux) of the light against *wavelength* to obtain the **stellar spectrum**.

We can glean a lot of information about the star by studying the overall shape of its spectrum, including the colour at which the spectrum reaches its maximum height and the overall narrowness or broadness of the spectrum. Further, the position of the spectrum, whether it is shifted toward the red or blue, and the relative strength of spectral lines provide additional information about the properties of the star.

Studying stellar spectra can tell us about the temperature, composition and motion of stars. But first, let's learn about the three different type of spectra.



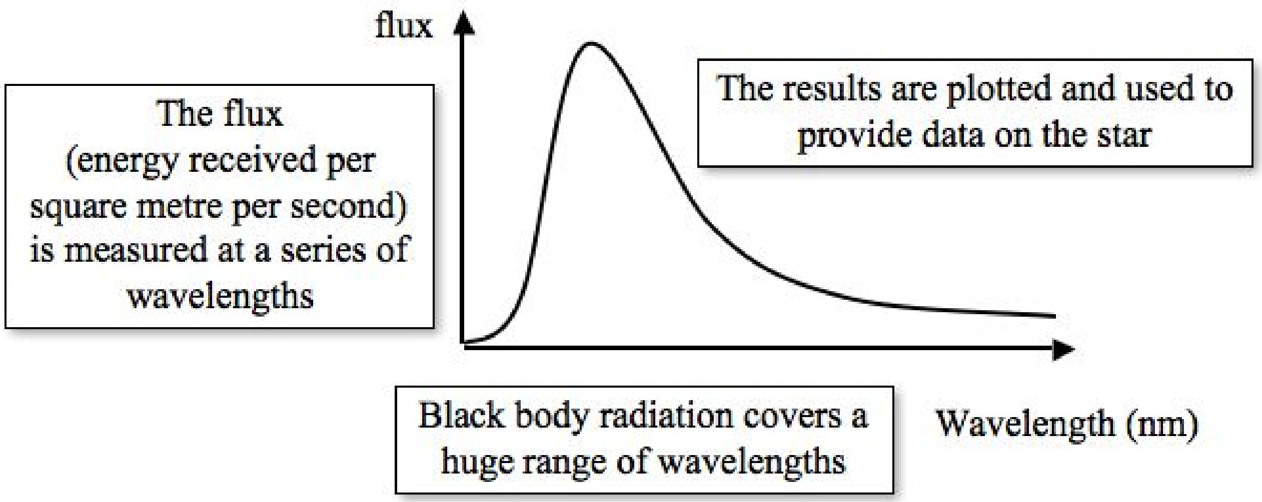
Spectrum of a star

Three types of spectra

There are three types of spectra of interest to astronomers:

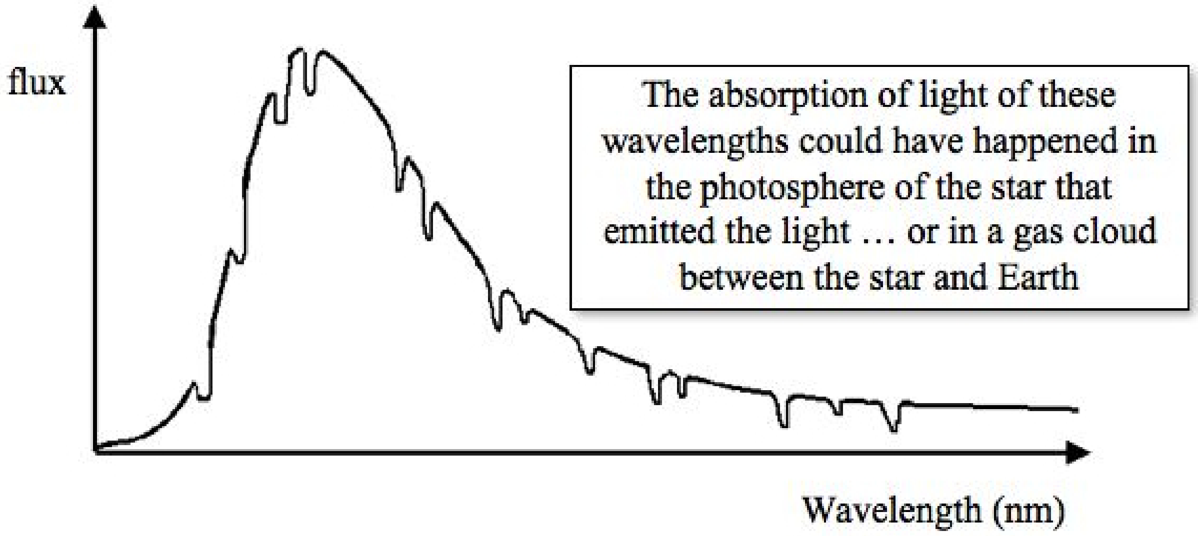
1. Continuous spectrum

This is the overall hill-shaped spectrum of electromagnetic radiation emitted by a black body.



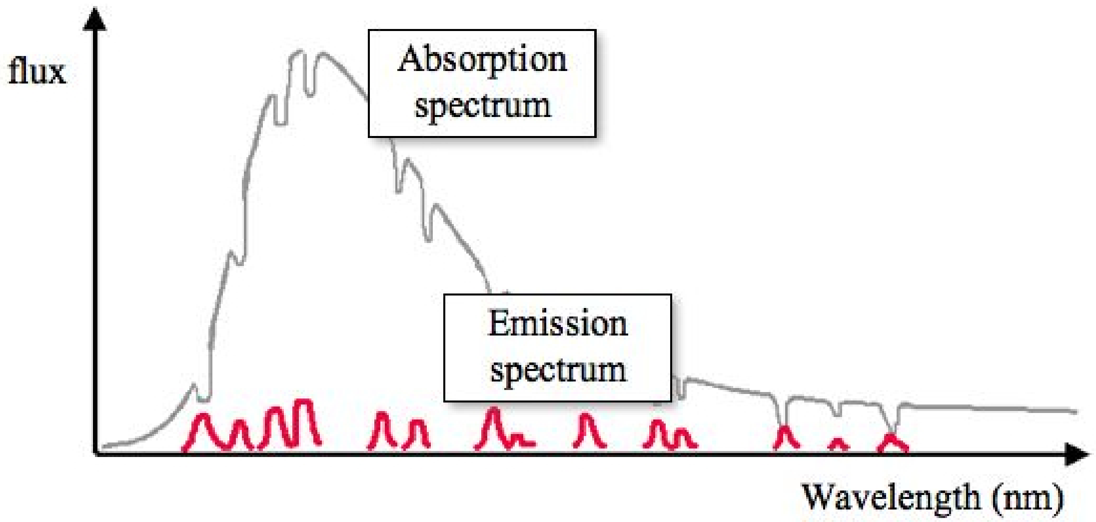
2. Absorption spectrum

The absorption spectrum is a continuous spectrum, but with the flux of certain frequencies reduced because something absorbed them between the source and Earth.



3. Emission spectrum

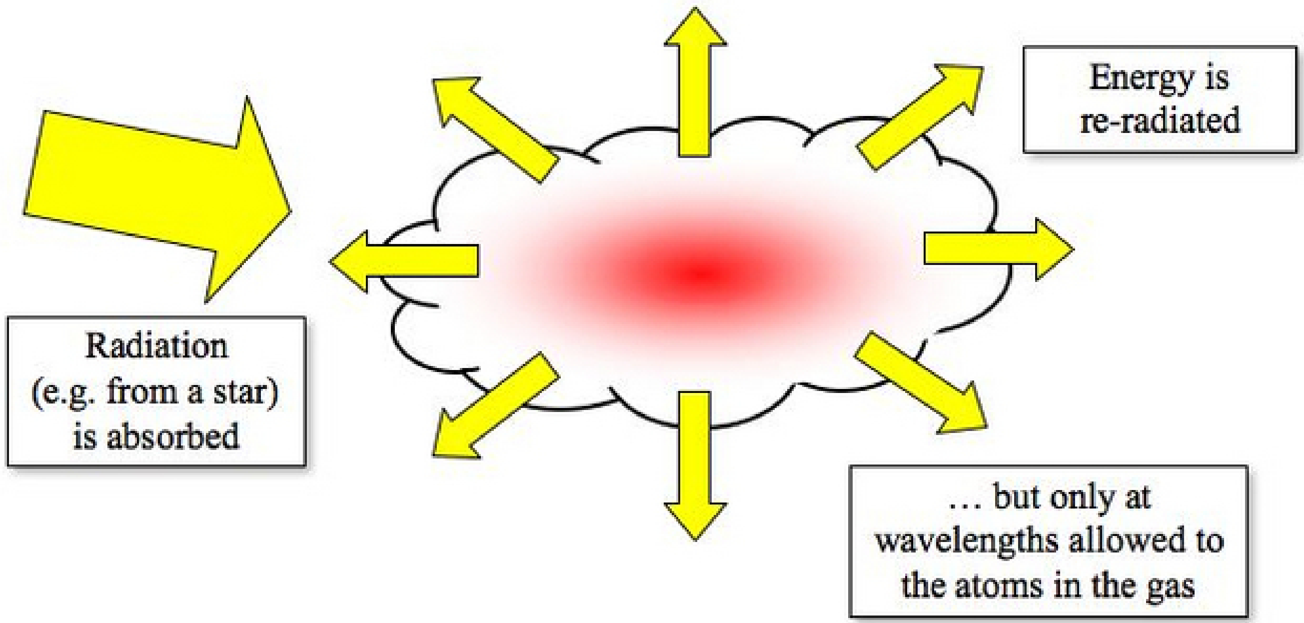
An emission spectrum looks very different: Rather than a continuous spectrum, we see emission at specific wavelengths.
You will see the spectrum shown below in red. Why ?



Emission spectra explained

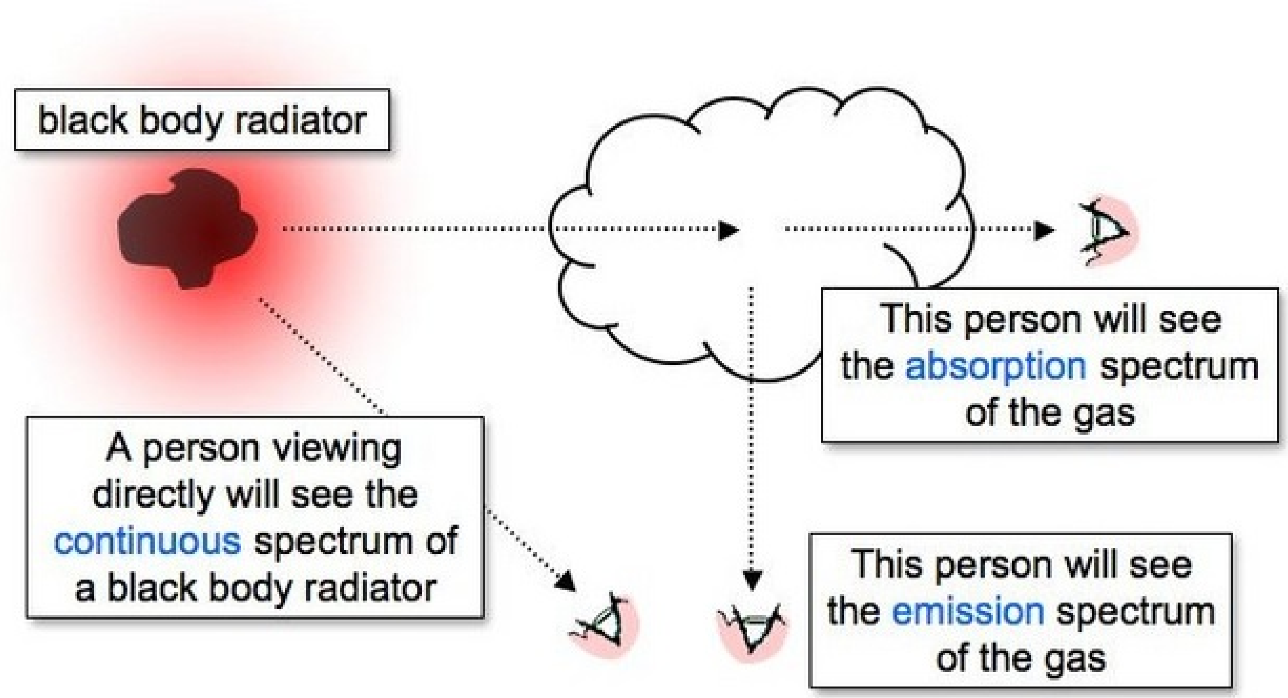
An emission spectrum is made by an object such as a cloud of gas emitting radiation rather than absorbing it.

It can only emit those same wavelengths that it can absorb, and those wavelengths will depend on the atoms comprising the gas.



Emission versus absorption spectra

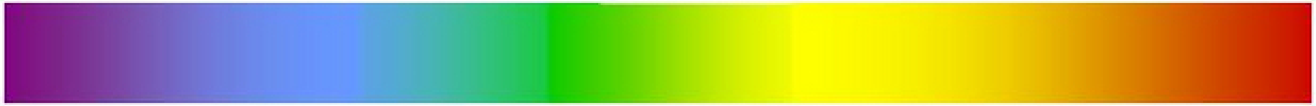
The type of spectrum you see will depend on how the source, the cloud of gas and how you are all arranged.



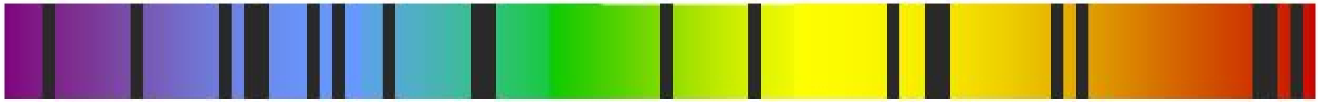
The three spectra

Here are simplified versions of the three spectra as they might be observed on photographic film.

1. Continuous spectrum



2. Absorption spectrum



3. Emission spectrum

In the real world, we always see a mixture of all three!

Two important assumptions

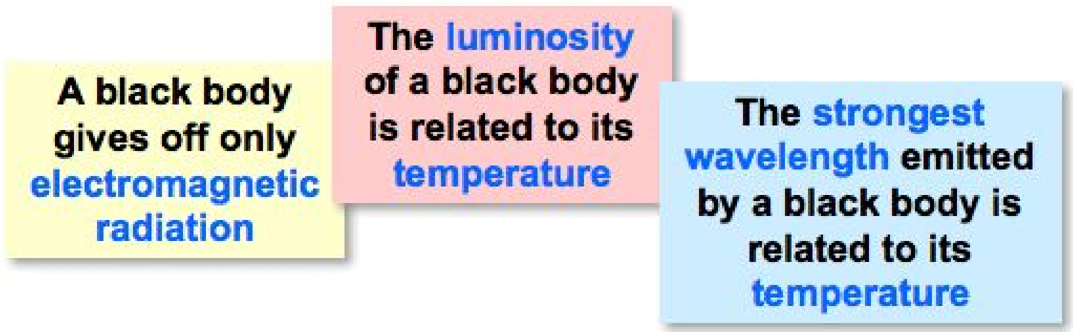
Stellar spectra can be extremely powerful, providing a great deal of information about stars. For example, if we know the distance to the star (by parallax methods) and we have the spectrum of the star, we can detremine the motion of the star, the size of the star, and the its temperature.

However, we need to make two important assumptions.

Assumption 1: Blackbody radiation

As we saw in the Activity ***Magnitudes and Colours of Stars***, it is assumed that a star behaves like a **blackbody**[1] and emits a spectrum that is well described by various equations and laws of thermal physics.

This assumption is made so that the overall shapes of spectra and the position of their maxima can be compared quantitatively, and is based on what we know about the Sun and nearby stars.

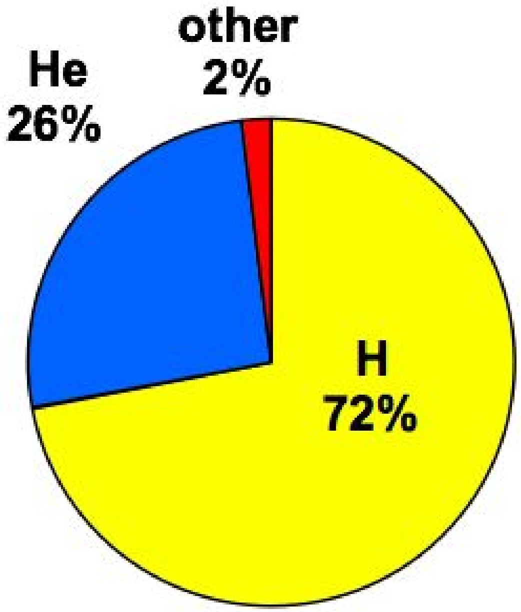


[1] To learn more about blackbody radiation, click here.

Assumption 2: Same composition

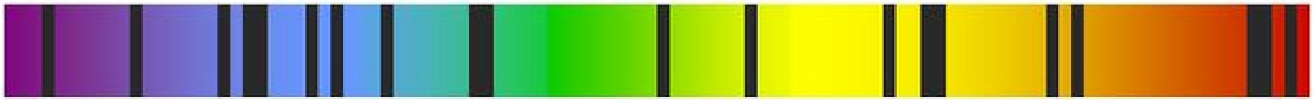
It is assumed that almost all stars have the same *initial* composition: Mostly **hydrogen** (H), some **helium** (He), and traces of other elements (mostly light elements).

As far as we can tell, this is true; stars seem to be made up of much the same kind of stuff.



Why assume the stars have the same initial composition?

Because radiation leaving the inner regions of a star forms a **continuous** spectrum. However different particles in the photosphere absorb particular wavelengths as the radiation passes through it. As a result there are gaps in the spectrum - **spectral lines** - and the results is an **absorption** spectrum.



If the photospheres of stars have pretty much the same in composition, then these lines should occur in the absorption spectra for all stars.

The same should apply to **emission** spectra.

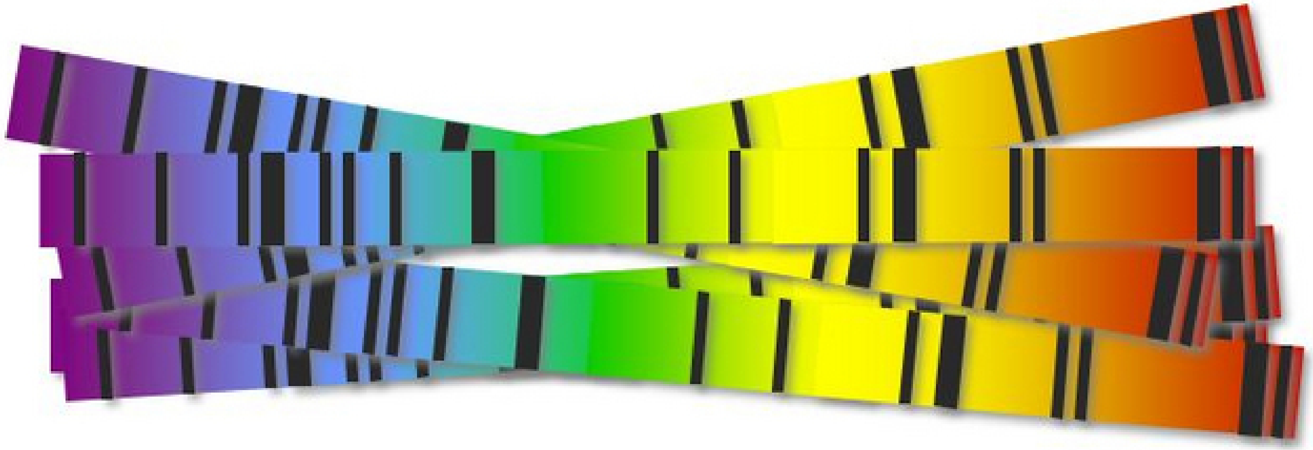
These two assumptions are made so that the overall shape of spectrum, and the position, width and strength of absorption or emission lines within the spectra of different stars can be compared.

In reality, there are differences both in the overall continuous spectrum and in the fine detail of the absorption and emission lines.

It is these differences that help astronomers to find out more about stars.

Comparing stellar spectra

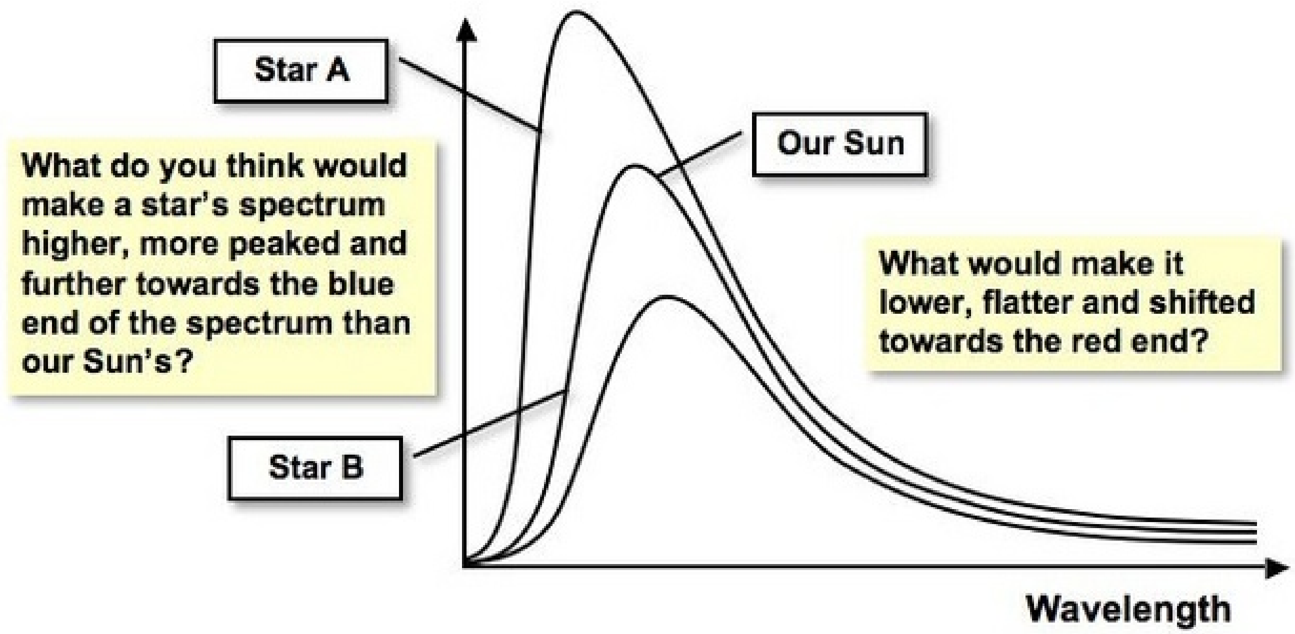
Let's have a look at some of the differences between the spectra of stars, and see what information can be deduced.



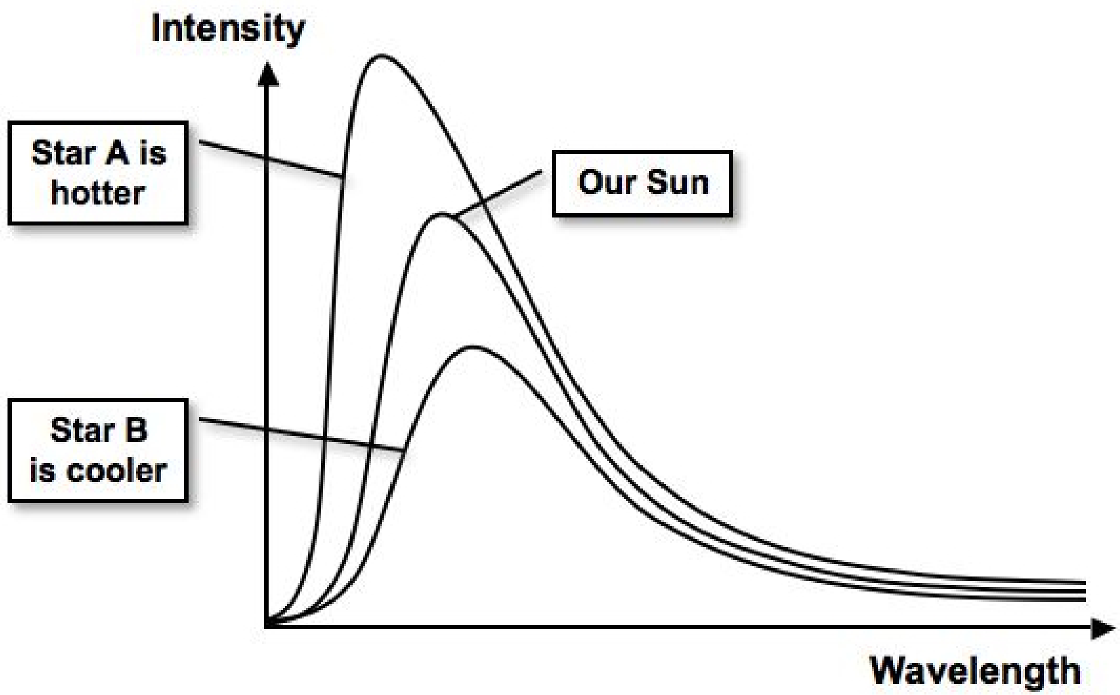
We will start off with the differences that you can see in the overall shape and position of the spectrum.

1. "The whole spectrum has stretched, and the peak has moved..."

One of the most common differences between spectra is the **position** of the peak with respect to wavelength, combined with an overall change in **steepness**.



According to the rules governing blackbody radiation, the spectrum of a **hotter** star will have a **higher, sharper peak** closer to the **blue** end of the spectrum.

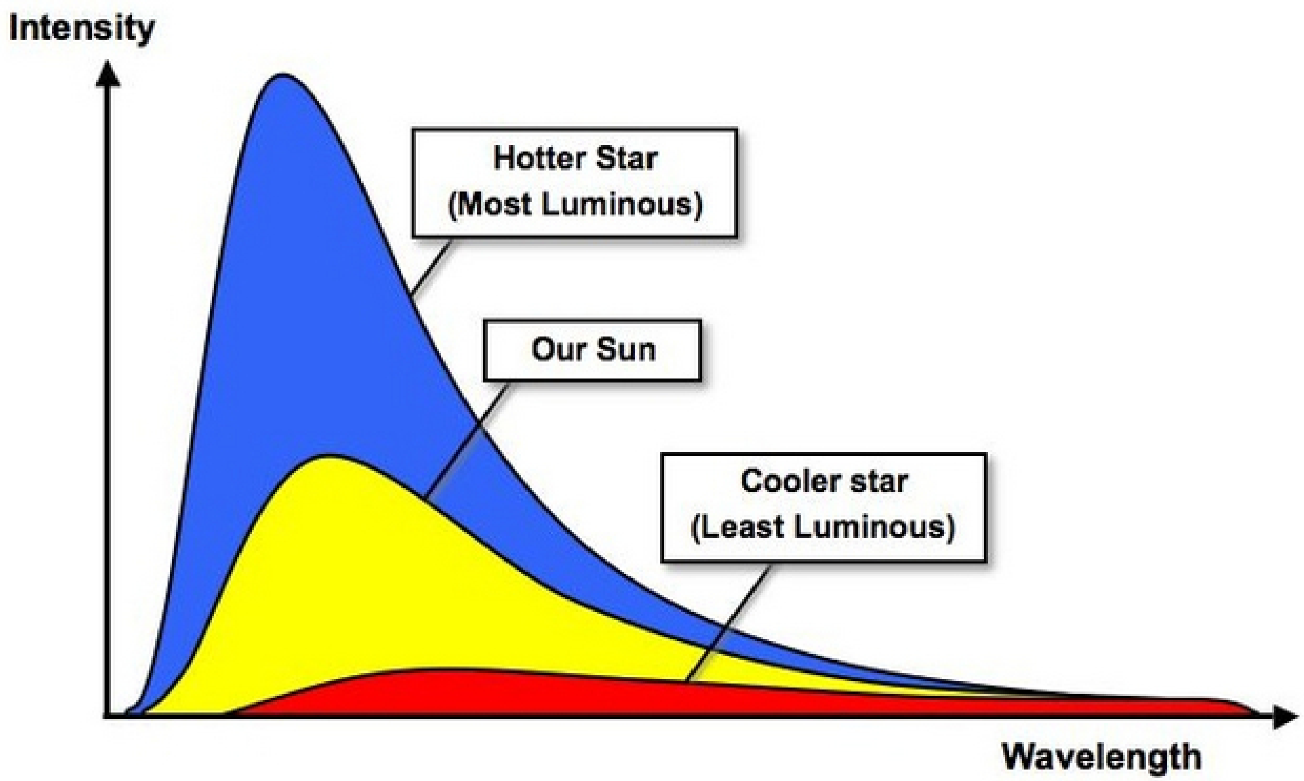


A cooler star will have a lower, flatter peak closer to the red end of the spectrum.

(Strictly speaking, every blackbody spectrum has the same functional form, but the total area varies with size and temperature and the peak obey's Wien's law, peaking at a shorter wavelengths with increasing temperature.)

The **total energy** radiated is proportional to the **area under the graph multiplied by the frequency of the light**.

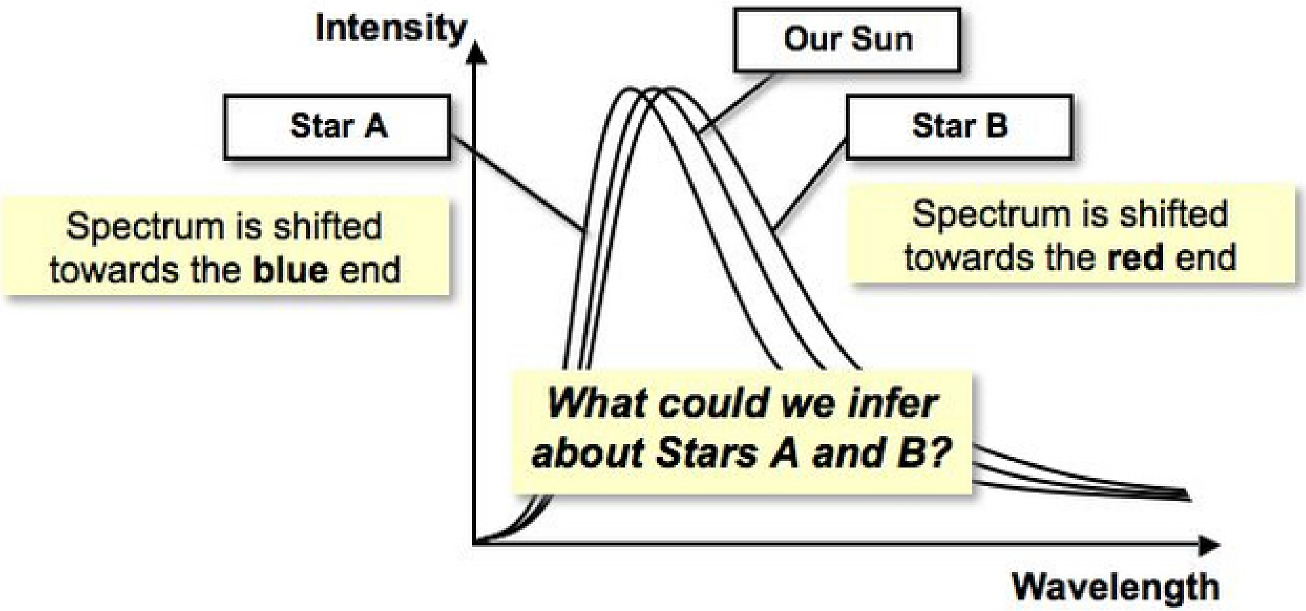
For the diagram below, we can clearly see that a hot star must radiate more energy than a cool star.



2. "The entire spectrum is shifted"

Sometimes the spectrum of a star is like that of our Sun (or another known star)... except that the **entire spectrum** is moved towards the red end or the blue end.

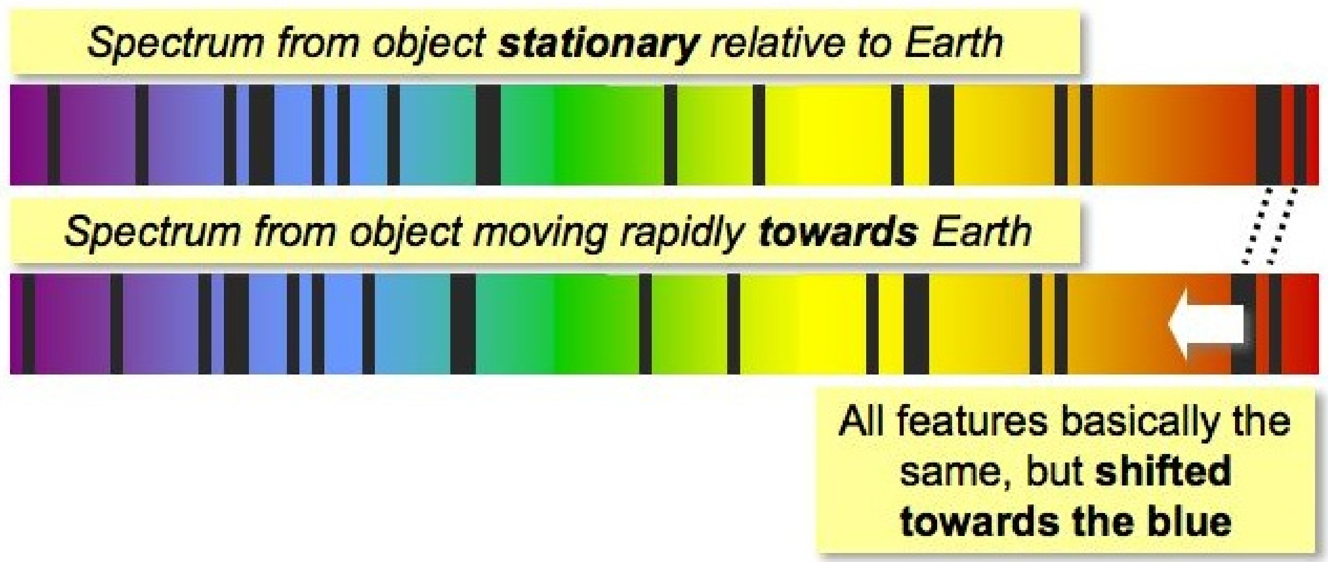
There isn't much change in "steepness" or intensity, just in position.



This effect is due to stellar motions - stars moving towards us will have their spectrum shifted to the blue end, and those moving away will have their spectrum shifted towards the red end.

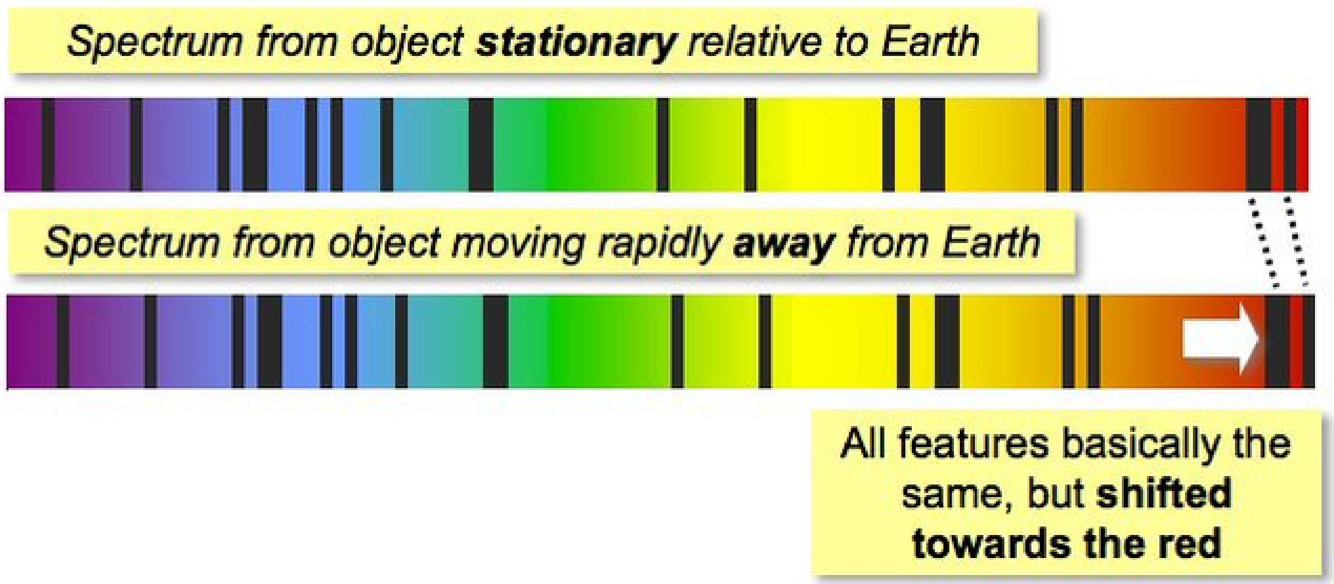
Blue shift

If the spectrum (emission or absorption) were compared to a known, calibrated spectrum for a similar object which is not moving relative to Earth, then the same features would be there but would all be shifted towards the blue end of the spectrum.



Red shift

Similarly, if an object emits light as it moves rapidly away from us, then its light is “stretched” and all features of the spectrum are shifted towards the red end of the spectrum.



Red/blue shift

So if a star or galaxy or other object is zooming towards the Earth at any significant speed, that speed can easily be calculated by checking the spectrum of the star.

The entire spectrum will be shifted towards the blue end. The shift in wavelength and the “original” unshifted wavelength are related by:

$$\frac{\text{shift in wavelength}}{\text{unshifted wavelength}} = \frac{\text{star's speed towards Earth}}{\text{speed of light}}$$

Exactly the same sort of equation is used to work out the speed of an object if it is racing away from Earth. In that case the light will be red shifted.

Reading between the lines

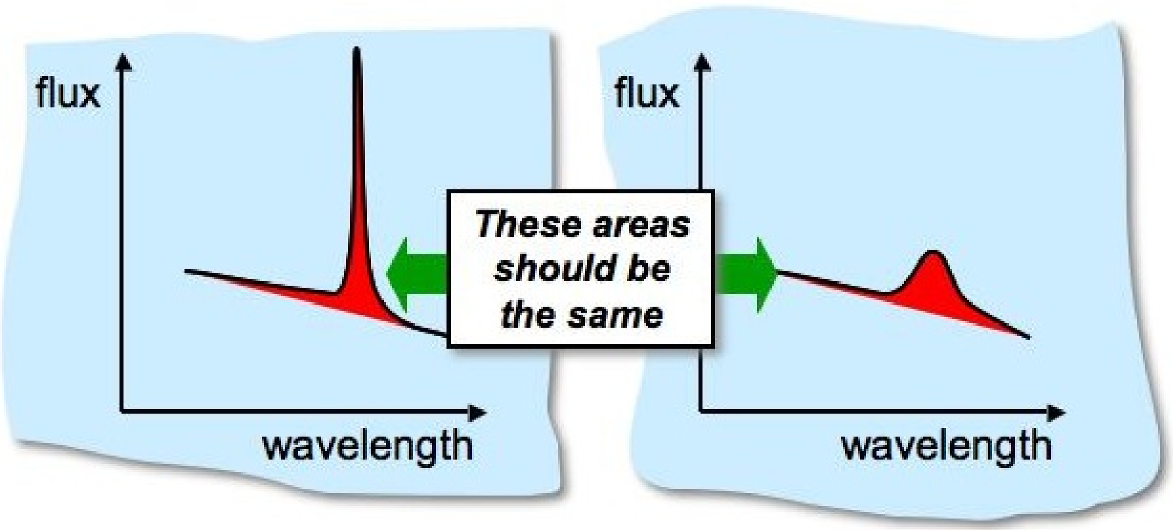
You can do more than examine the peak position and height of a spectrum, and check it for red or blue shift.

It is also possible to read ”between the lines” in astronomy! That is, you can study the individual lines within a spectrum and gain information from them.

We will now look at some of the variations that are found.

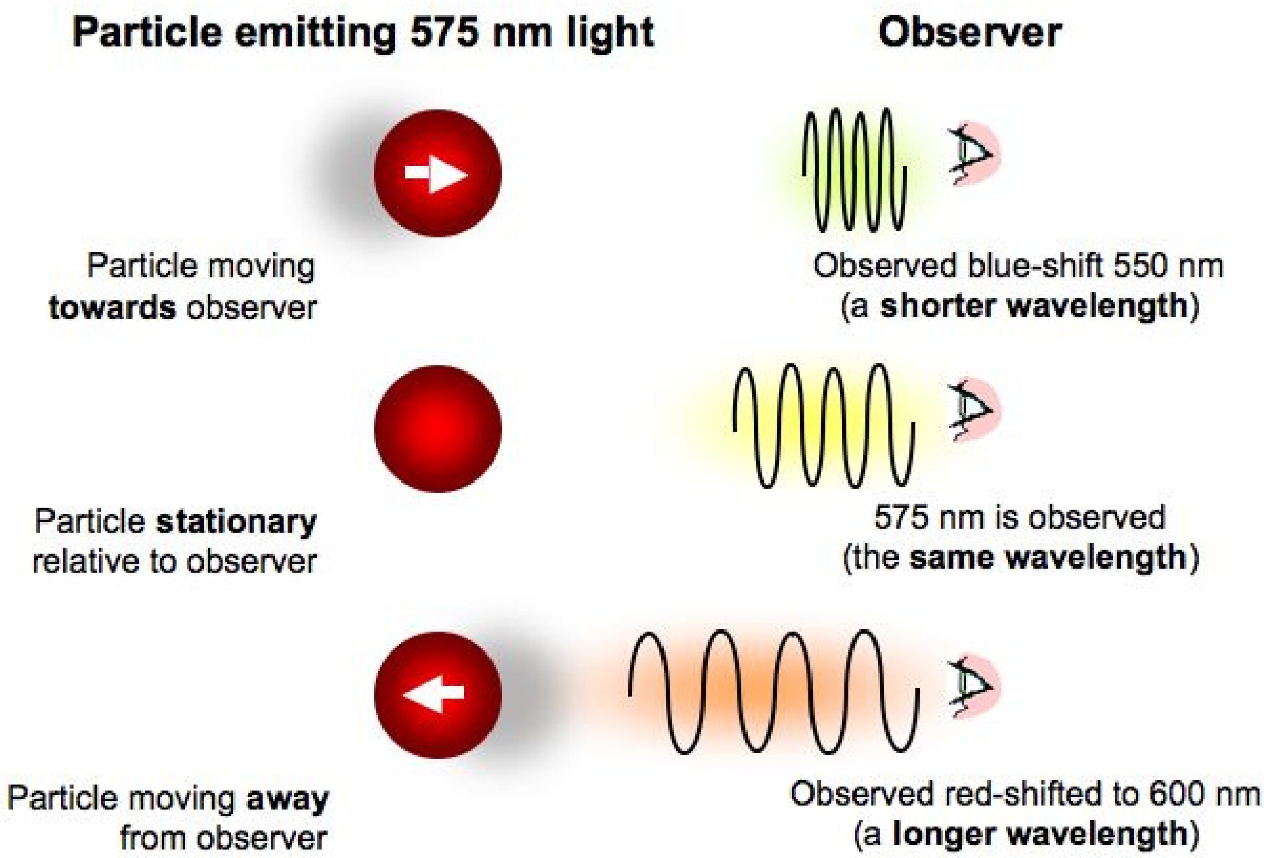
3. ”Why aren’t my lines sharp?”

Sometimes the lines within a spectrum are spread out, moved towards ***both*** the red end and the blue end of the spectrum at the same time. What does this mean?

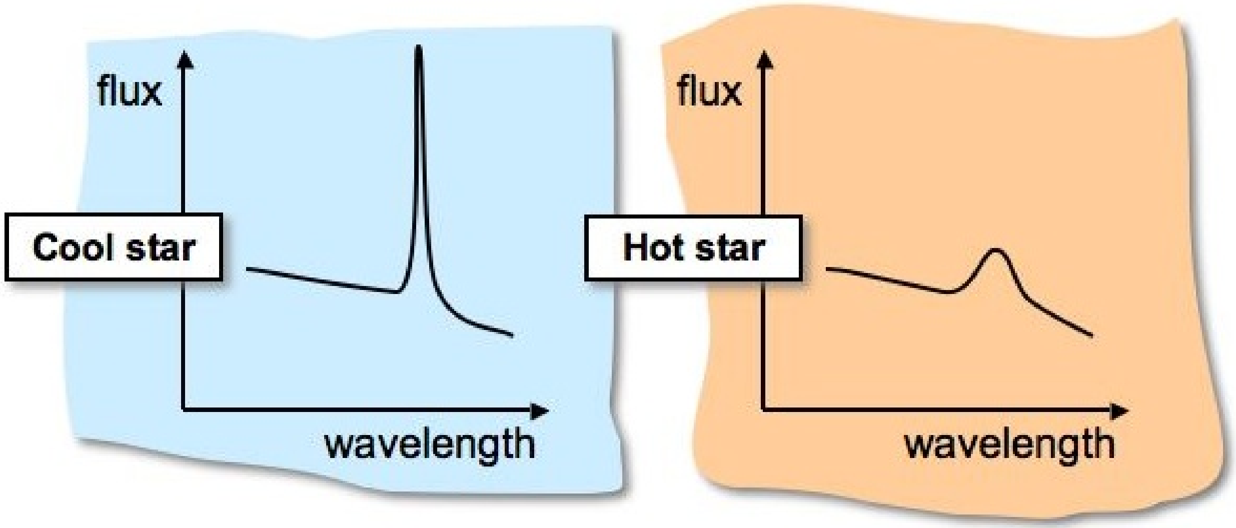


Gas particles, when in an interstellar cloud or in the photosphere of a star, are moving at random as they emit light.

The hotter the gas, the more likely it is that some fast-moving particles will emit light which reaches us blue- or red-shifted.

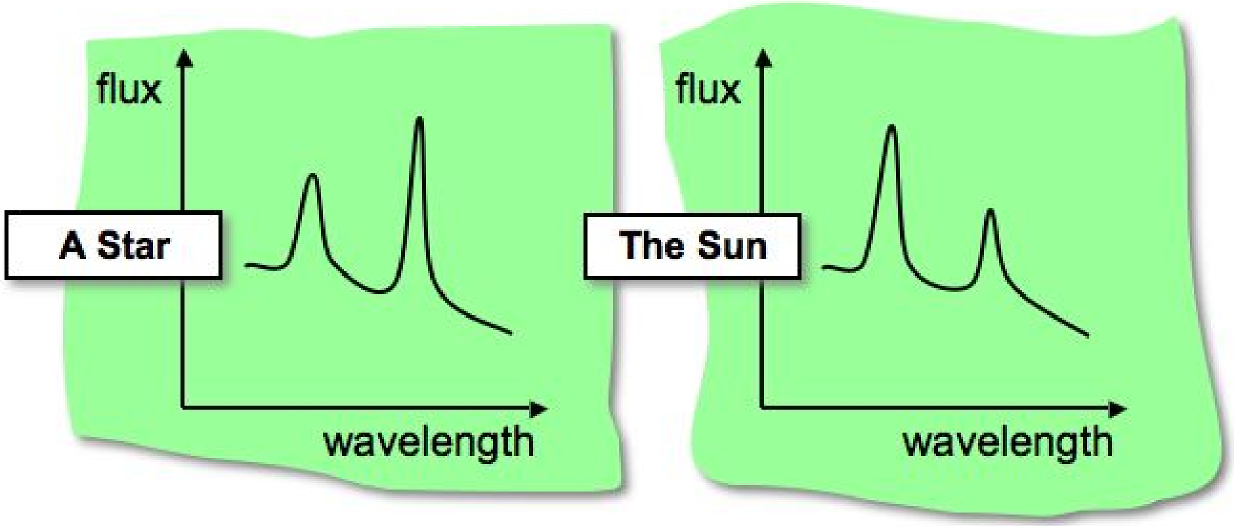


So a spectral line that would be expected to be very thin (confined to just one particular wavelength) is in fact spread across neighbouring wavelengths as well due to the random motion in a hot gas. This is called “**broadening**”.



4. ”Why are the lines different strengths?”

What if the strength of the lines differs between the spectrum of a star and that of the Sun?



This is yet another indication of temperature. If temperature in a gas varies, the sorts of processes which allow light to be emitted also vary: some processes get stronger and others get weaker.

Different line strengths can also be due to changes in the relative chemical abundance between two stars. The chemical composition of the star and relative elemental abundances can also affect the line strengths. The more Carbon present at the surface of the star, the more strength its carbon lines will possess.

In the next Activity, we will study the most important of these processes: in particular, the **Balmer series**.

Summary

In this Activity, we have learnt about three different types of spectra - continous, absorption and emission. We also learnt how a star's properties can affect its spectrum and in particular that

- **hot stars** will have a high spectrum peaked towards the blue end;
- **cool stars** will have a low, flat spectrum peaked towards the red end;
- if a star is **moving** rapidly towards us (or away from us), then **the entire spectrum is shifted** towards the blue (or the red) end of the spectrum;
- that very hot stars will have broadened spectral lines; and
- that the relative **line strength** of absorption or emission lines can also indicate the temperature of the star.

In the next Activity, we will learn more about line strength, the Balmer series, and how stars are classifed according to their spectral type.