WJEC (Wales) Physics A-level

Topic 1.6: Using Radiation to Investigate Stars

Notes

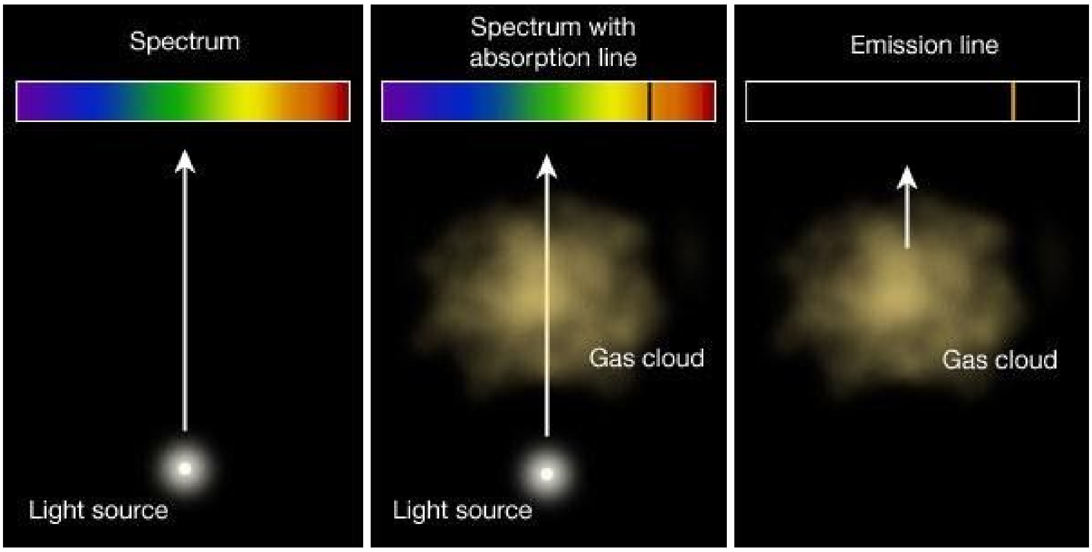
Emission and Absorption Spectra

Emission

All stars emit a **continuous (no gaps) spectrum** of electromagnetic radiation which arises from the surface of the star.

Absorption

When emitted radiation passes through a star's atmosphere a line absorption spectrum is produced where atoms **absorb certain wavelengths** of the electromagnetic spectrum.



http://www.insideastronomy.com/index.php?/topic/790-spectroscopy-101-whats-up-with-the-squiggly-graphs/

In the diagram above, the light source produces a continuous spectrum. The gas cloud then absorbs one specific wavelength (the black line) and then emits that wavelength in the emission spectrum (the orange line).

Black Bodies

A **black body** is the name given to a body which absorbs all incoming radiation. **Stars** are not quite black bodies but can be **approximated as block bodies very accurately**.

The continuous spectrum that stars emit (mentioned at top of page) is a black body spectrum.

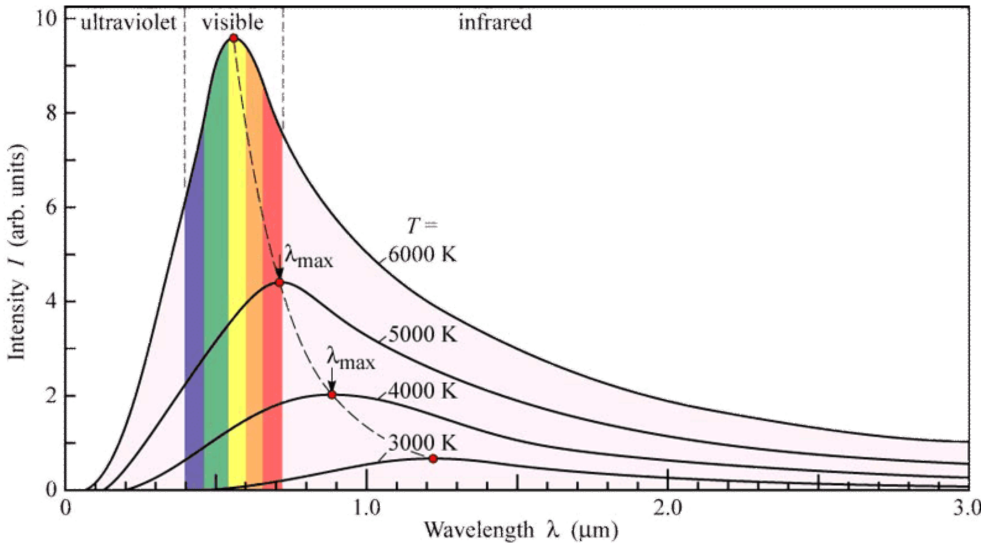
Black Body Spectrum

The black body spectrum is the spectrum of radiation emitted from a black body at a given surface **temperature** (the temperature of the surface from which the radiation is emitted).

Wien's Displacement Law

This law states that the peak wavelength (highest intensity) of a black body spectrum is inversely proportional to the absolute temperature. It is also sometimes called just Wien's law. The absolute temperature is the temperature measured in kelvin (K). To convert from Celsius to kelvin,

$$T\,(K) = \theta\,(^{\circ}C) + 273.15$$



Mathematically, Wien's displacement law is given by the following equation,

$$\lambda_{max} = \frac{b}{T}$$

where b is a constant of proportionality called the Wien's displacement constant. It is roughly equal to $2.9\times10^{-3}\ m{\cdot}K$. The unit here is **metre-kelvins** NOT millikelvin.

Stefan's Law

Stefan's law (often called the Stefan-Boltzmann law) states that the power per unit area emitted by a black body in radiation is proportional to its temperature to the fourth power. It can be extended to say that the **luminosity (total power) of the black body is proportional to the product of its surface area and its temperature to the fourth power**.

$$L = \sigma A T^4$$

The constant of proportionality σ, is the Stefan-Boltzmann constant which is approximately equal to $5.7\times10^{-8}\ Wm^{-2}K^{-4}$. This can be applied to stars accurately but for spherical bodies the law can be adapted further,

$$L = \sigma A T^4 = \sigma 4\pi r^2 T^4$$

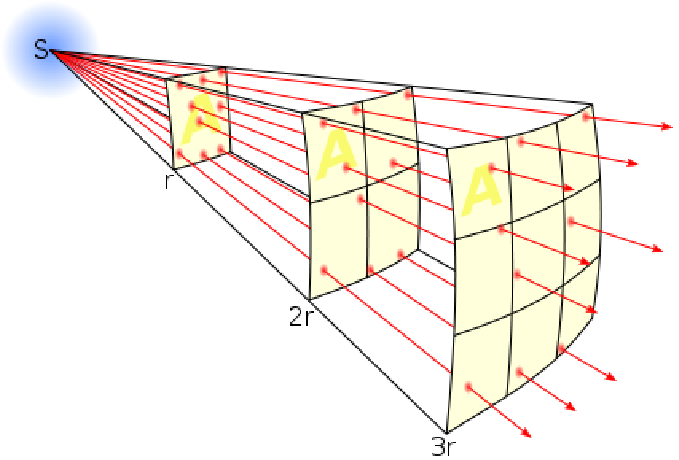
where $4\pi r^2$ is the surface area of the body if r is its radius.

Inverse Square Law

The inverse square law says that the **intensity of radiation received from a star is inversely proportional to the squared distance** away from it.

The diagram below shows why this is the case. As you increase your distance away, the total area over which the radiation is spread out increases with the square of that distance. As the radiation is spread out over a larger area the intensity falls.

The radiation is spread over a sphere with radius equal to the distance between the observer and the body because it is emitted in all directions. Therefore, the intensity is equal to the luminosity divided by the surface area of that sphere ($4\pi r^2$).



Classifying Stars

The three laws mentioned above can be used together to try to find out properties of certain stars including their luminosity, size, temperature and distance in order to classify them.

Luminosity

If the distance of a star from you is known, the intensity of incident radiation from that star can be measured, and the inverse square law used to **calculate the luminosity**.

For example, if the intensity of the sun's radiation arriving at the Earth is about $1360\ Wm^{-2}$ and the distance to the sun is $1.49\times10^{11}\ m$ then the luminosity can be given as:

$$I = \frac{L}{4\pi d^2}$$

$$L = 4\pi I d^2 = 4\pi\,(1360)\left(1.49 \times 10^{11}\right)^2$$

$$L = 3.79 \times 10^{26}\ W$$

Temperature

We can work out the surface temperature of a star by measuring its black body spectrum and finding the peak wavelength of emission (about 500nm). Then, Wien's displacement law can be applied to find its temperature.

$$\lambda_{max} = \frac{b}{T}$$

$$T = \frac{b}{\lambda_{max}}$$

$$T = \frac{2.90\times10^{-3}}{500\times10^{-9}} = 5800K$$

Size

Knowing the luminosity and temperature, the size of the star (it's radius) can be calculated using Stefan's law, using the Stefan-Boltzmann constant as $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$:

$$L = \sigma 4\pi r^2 T^4$$

$$3.79 \times 10^{26} = \left(5.67 \times 10^{-8}\right)(4\pi)(r^2)(5800)^4$$

$$r^2 = \frac{3.79\times10^{26}}{\left(5.67\times10^{-8}\right)(4\pi)(5800)^4} = 4.70 \times 10^{17}$$

$$\Rightarrow r = 6.86 \times 10^8 m = 686,000km\ \ (3sf)$$

This method is surprisingly accurate.

Distance

If the radius of the star and its temperature are known, it's luminosity can then be used to find the distance away. This is done by measuring the star's intensity from Earth and using the **inverse square law** to find the distance.

There are many other ways to find, in this example, the Earth-Sun distance such as using Newton's law of **gravitation**, **parallax** angles etc.

Multiwavelength Astronomy

Often, we cannot see electromagnetic radiation from bodies in the universe because they emit radiation with wavelengths too long or too short to see (outside the visible region).

By observing areas of the universe using instruments **sensitive to other parts of the spectrum** such as gamma-rays, x-rays, infrared, and ultraviolet we can attempt to understand other processes that are going on which do not emit visible light.

For example, pulsars are neutron stars which emit radio waves in pulses as they rotate. Using radio wave images, we can see these pulses of radio waves and confirm we have a pulsar.