The Doppler Effect

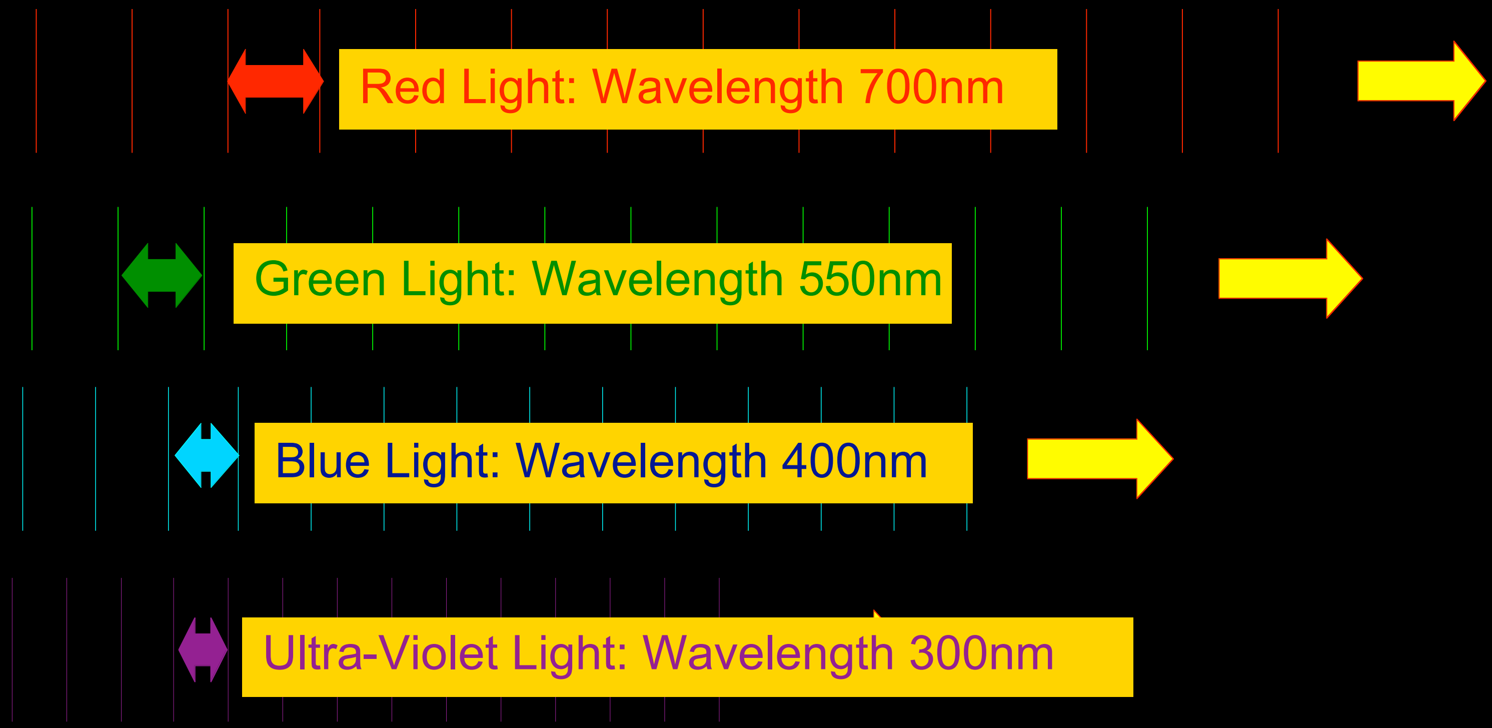
ASTR1001

Spectroscopy

- When the media covers astronomy, they nearly always show pretty pictures. This gives a biassed view of what astronomers actually do: well over 70% of all observations are not pictures - they are spectra.
- Spectra are the most vital tool of astronomy - without them we'd be lost. However, they are slightly more complicated to understand than pictures (and nothing like as pretty), so the media ignores them.
- Light is made up of waves of entwined electricity and magnetism. This applies to all types of light, including radio waves and X-rays. The general term for these waves is "Electromagnetic Waves".
- These waves always travel at the same speed: 300,000 kilometres per second.

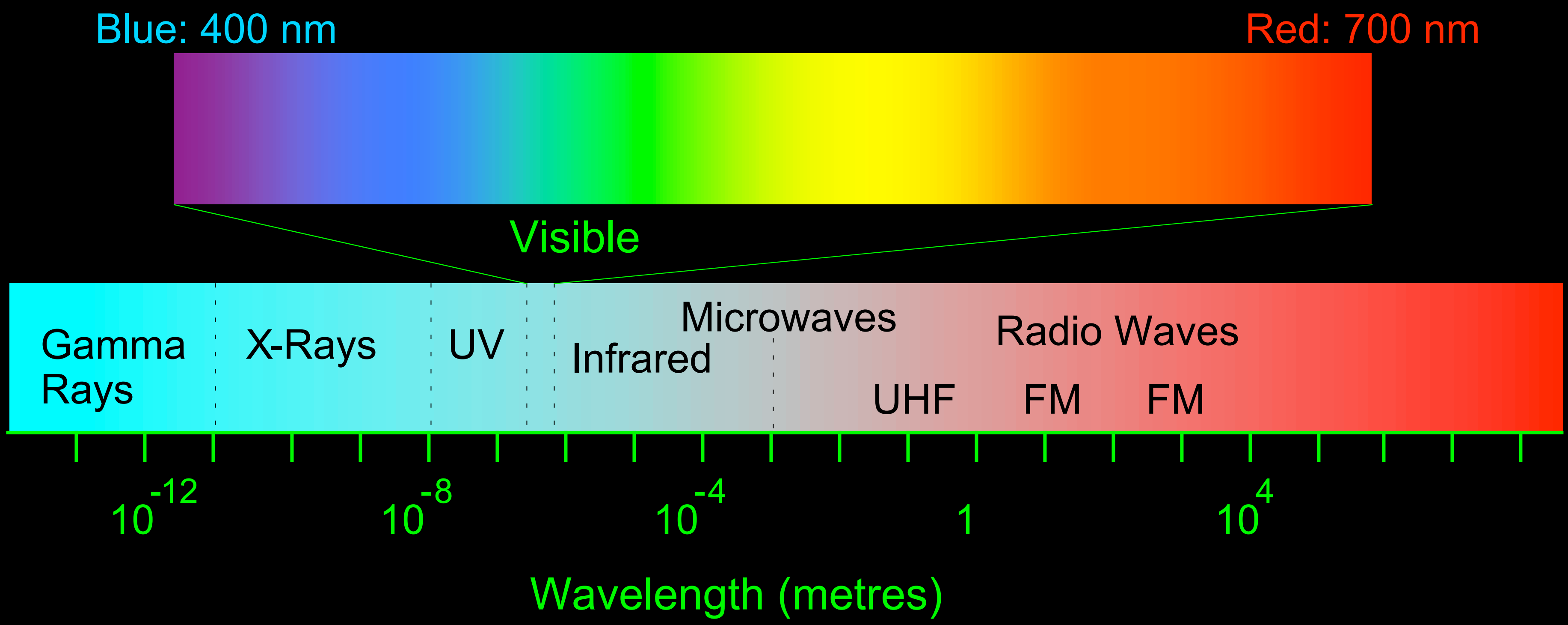
Wavelengths

- Electromagnetic waves, while all travelling at the same speed, can have different wavelengths (the distance between the crest of one wave and the next).
- It is the wavelength that determines what type of light you have.



The Electromagnetic Spectrum

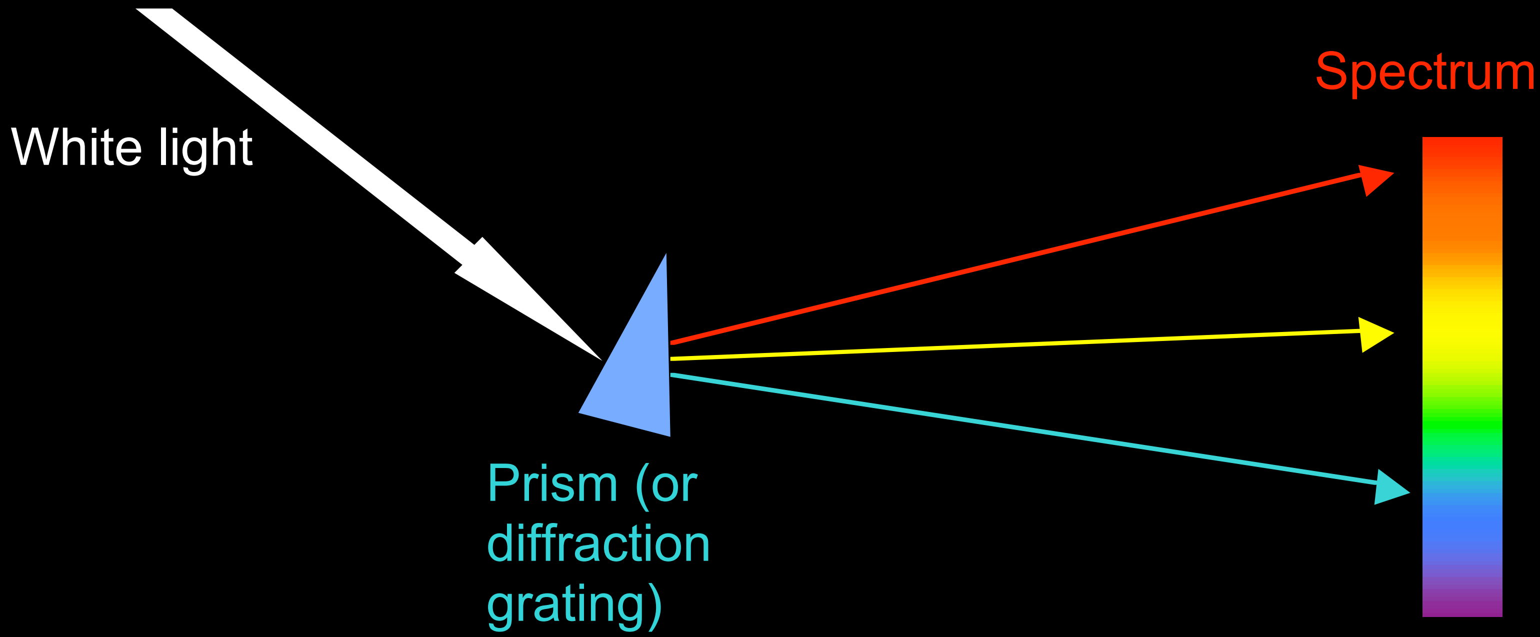
- Electromagnetic waves can have any wavelengths at all: anywhere from picometres to light-years.



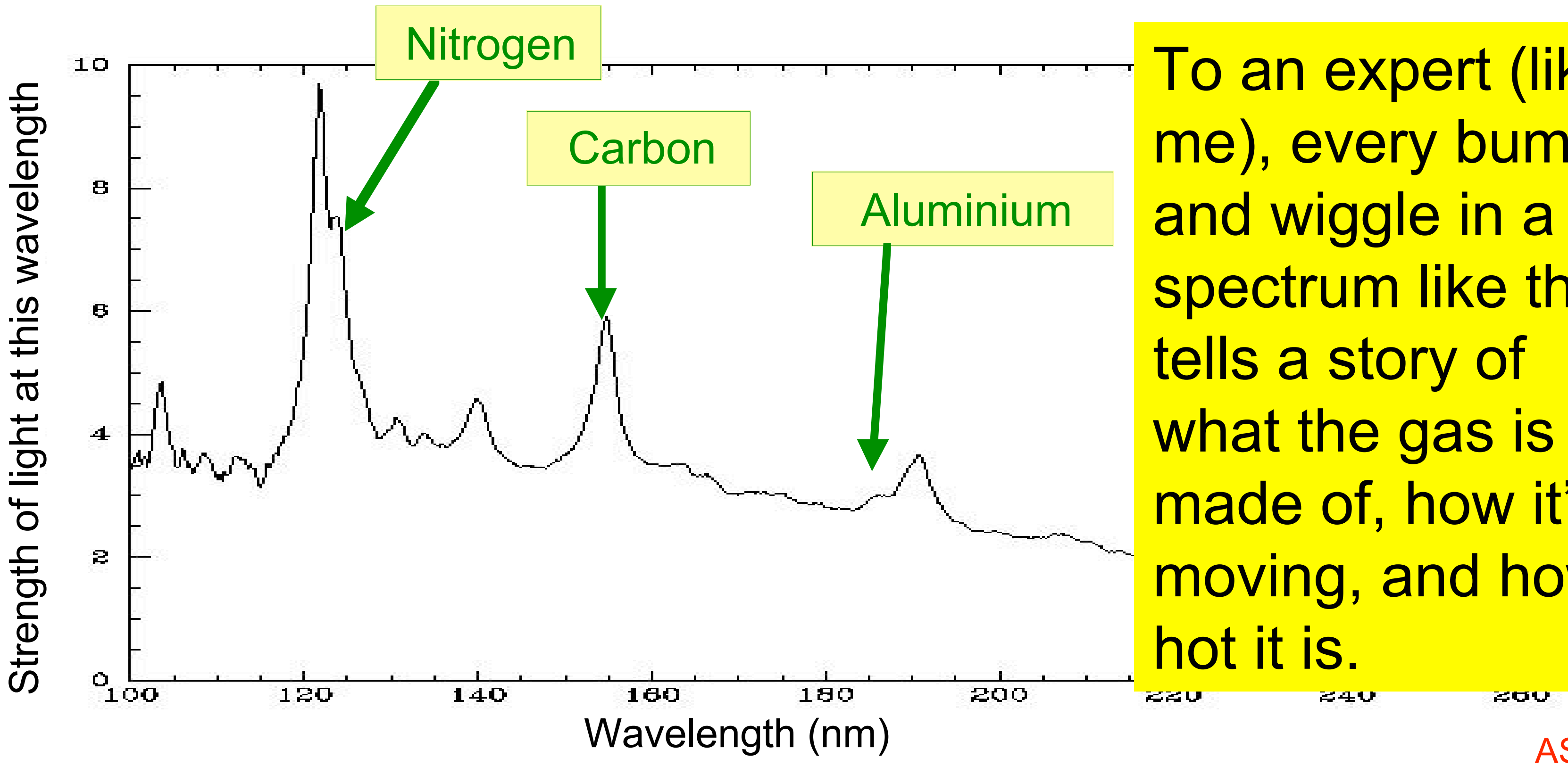
- These are all basically the same things: waves of entwined electricity and magnetism flying through space: the only thing that's different is the wavelength. You also get waves longer than radio and shorter than Gamma Rays - but these are very rare, and as far as we know useless (at present). Our eyes are only sensitive to visible light.

Spectrographs

- A spectrograph separates light out into its component wavelengths: separating the long wavelength light from the short.
- They can either use a prism or a device called a diffraction grating (like the bottom of a cd).



- We plot spectra as graphs: graphs showing precisely how much power the thing we are looking at emits at each precise wavelength.
- Spectra are incredibly useful. Luckily, all chemicals emit and absorb light at certain very specific wavelengths. A typical spectrum (like this spectrum of gas spiraling into a black hole) can be used to identify the composition of the gas.

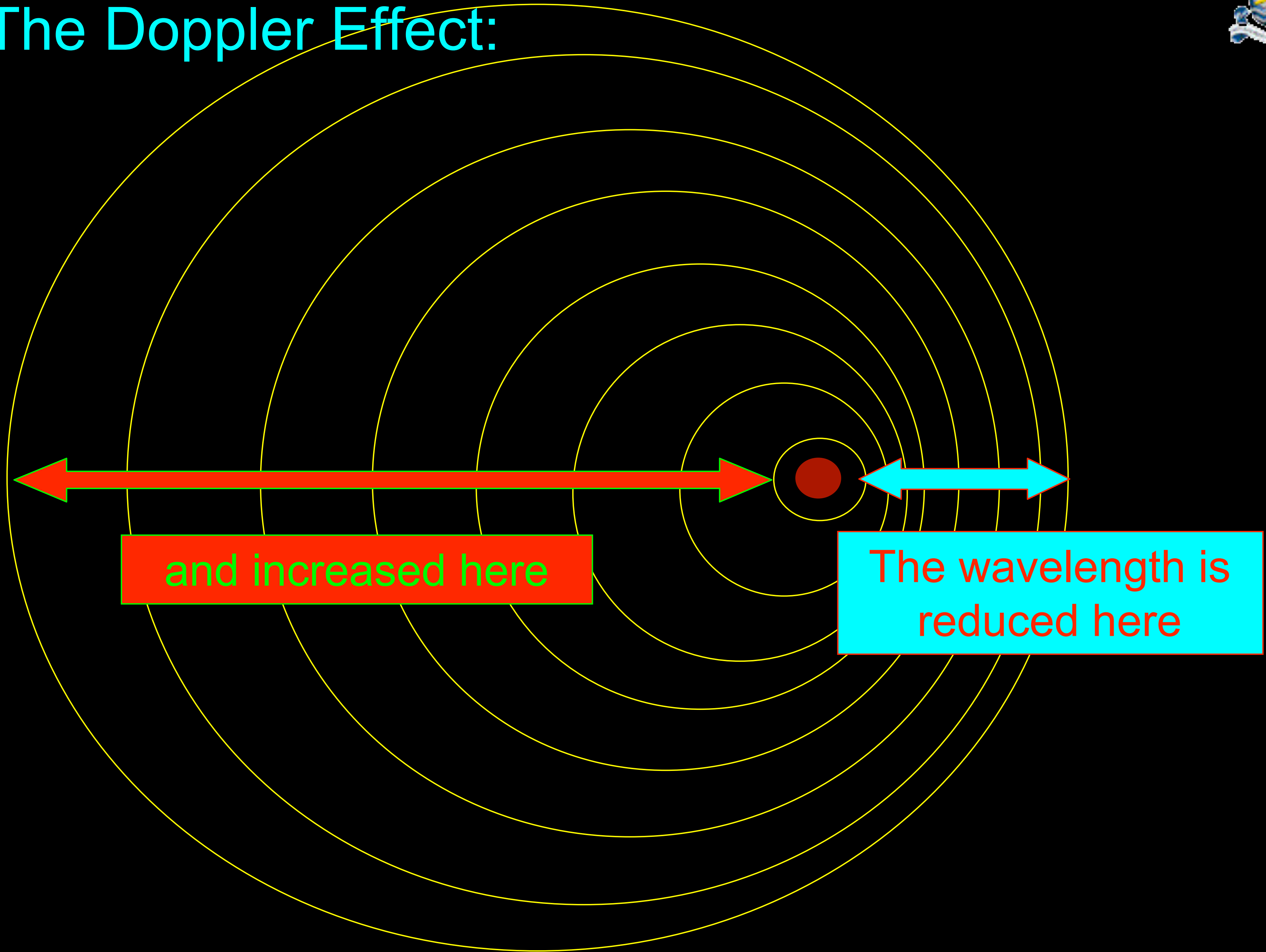


To an expert (like me), every bump and wiggle in a spectrum like this tells a story of what the gas is made of, how it's moving, and how hot it is.

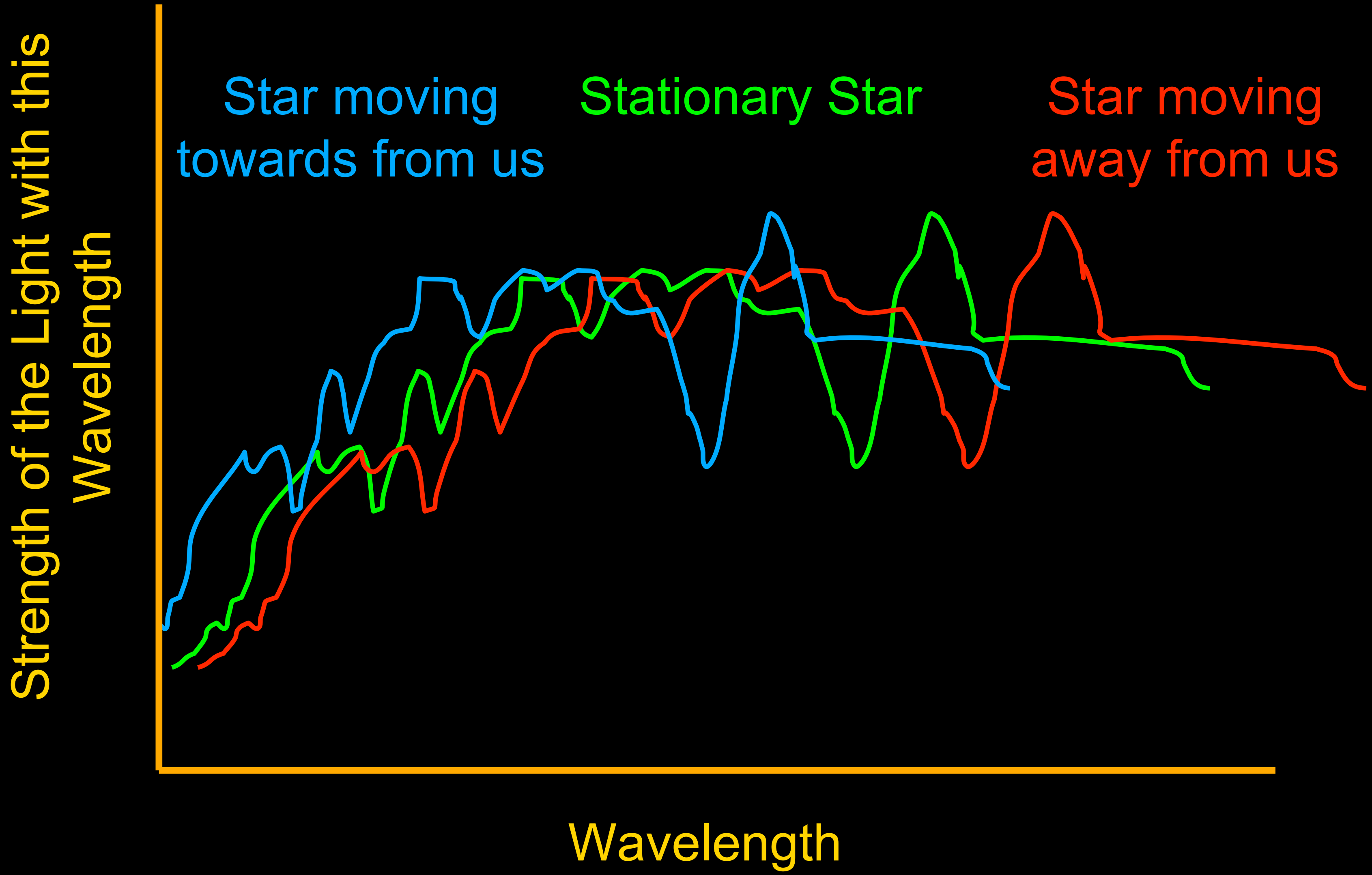
What's this got to do with velocities?

- Well, the waves of electromagnetic radiation coming from some distant object can be used to see whether that object is moving away from us or towards us.
- If the waves are bunched unusually close together, the object must be moving towards us. This would mean that all the bumps and wiggles in a spectrum would appear to be at slightly shorter wavelengths than usual.
- If they are unusually spread apart, the object must be moving away from us. All the bumps and wiggles will be at slightly longer wavelengths than usual.
- This effect is called the "Doppler Effect". It is widely used on Earth, for such things as radar and speed traps.

The Doppler Effect:



How does this affect the spectra?



The Maths

- How big is this effect? A full account requires relativity, but as long as your velocity is a small fraction of the speed of light, the fractional shift in wavelength is equal to the velocity divided by the speed of light.

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f} = \frac{v}{c}$$

∀ Where Δλ is the change in the wavelength of some spectral feature, Δf is the change in its frequency, v is the radial velocity, and c the speed of light.

Example.

- If, for example, a particular emission line is normally seen at a wavelength of 10 nm, but we observe it in the spectrum of a star at 9nm, then $\Delta\lambda = (10-9)$. $\Lambda=10$, so $\Delta\lambda/\lambda = 1/10$.
- This star must therefore be travelling towards us at 10% of the speed of light.