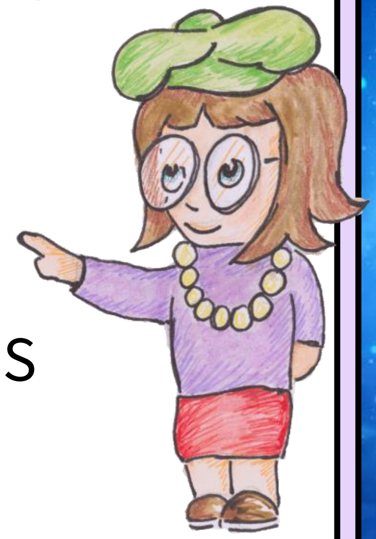
THE EXPANDING UNIVERSE



HIGHER PHYSICS

Learning Outcomes

8. The expanding Universe
I know that the Doppler effect causes shifts in wavelengths of sound and light.
I can use appropriate relationship to solve problems involving the observed frequency, source frequency, source speed and wave speed.
I know that the light from objects moving away from us is shifted to longer wavelengths (redshift).
I know that the redshift of a galaxy is the change in wavelength divided by the emitted wavelength. For slowly moving galaxies, redshift is the ratio of the recessional velocity of the galaxy to the velocity of light.
I can use appropriate relationships to solve problems involving redshift, observed wavelength, emitted wavelength, and recessional velocity
I can use appropriate relationship to solve problems involving the Hubble constant, the recessional velocity of a galaxy and its distance from us.
I know that Hubble's law allows us to estimate the age of the Universe.
I know that measurements of the velocities of galaxies and their distance from us lead to the theory of the expanding Universe.
I know that the mass of a galaxy can be estimated by the orbital speed of stars within it.
I know that evidence supporting the existence of dark matter comes from estimations of the mass of galaxies.
I know that evidence supporting the existence of dark energy comes from the accelerating rate of expansion of the Universe.
I know that the temperature of stellar objects is related to the distribution of emitted radiation over a wide range of wavelengths.
I know that the peak wavelength of this distribution is shorter for hotter objects than for cooler objects.
I know that hotter objects emit more radiation per unit surface area per unit time than cooler objects.
I know of evidence supporting the big bang theory and subsequent expansion of the Universe: cosmic microwave background radiation, the abundance of the elements hydrogen and helium, the darkness of the sky (Olbers' paradox) and the large number of galaxies showing redshift rather than blueshift.

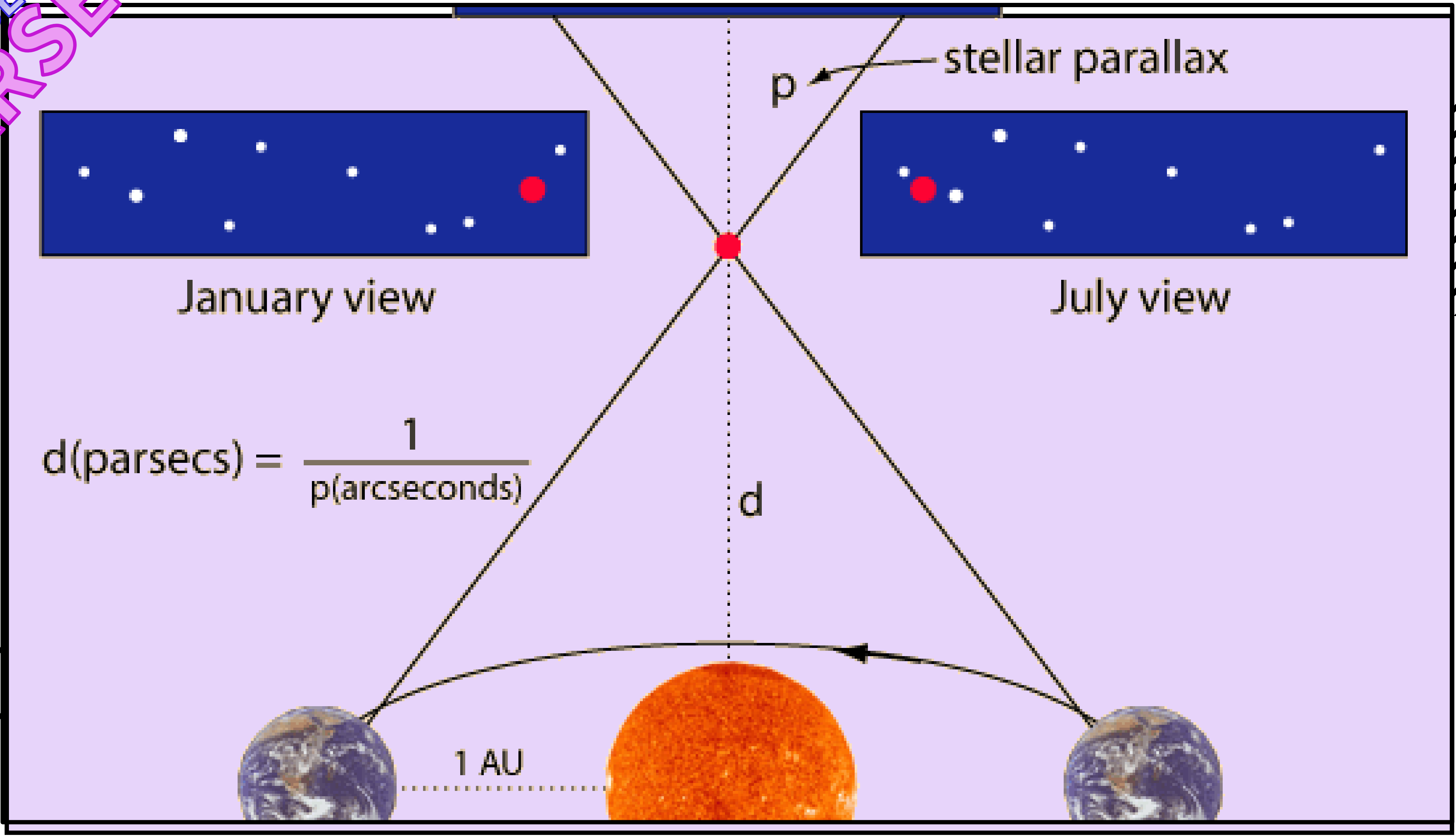
Distance units- AU

- Astronomers use many different units to describe distances in space. You met the light year- the distance light travels in one year at National 5. Astronomers also use the Astronomical Unit (AU) and the parsec (pc).

- ASTRONOMICAL UNIT

- **Astronomical Unit: a unit of measurement equal to 149.6 million kilometres, the mean distance from the centre of the earth to the centre of the sun**.

PARSEC



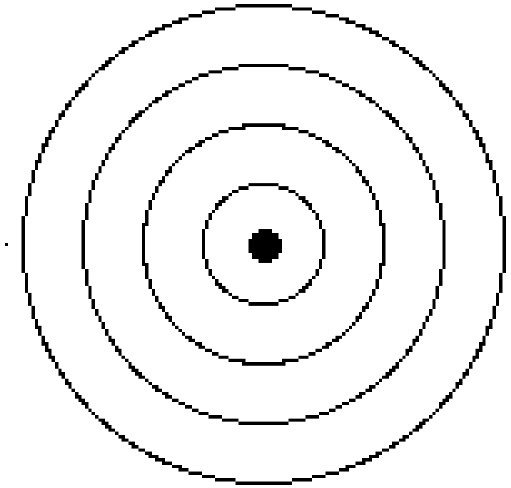
http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/para.html

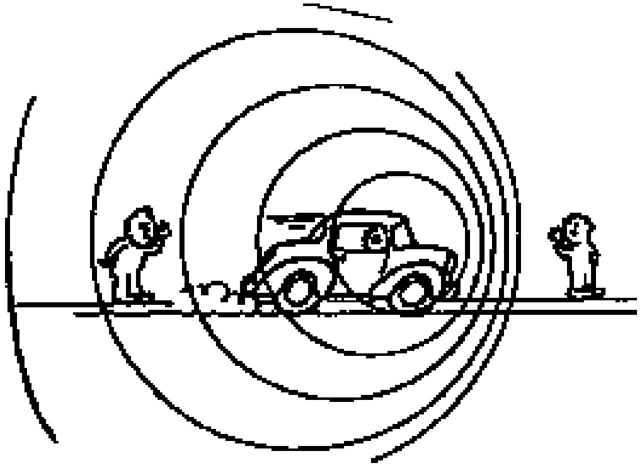
Doppler Effect

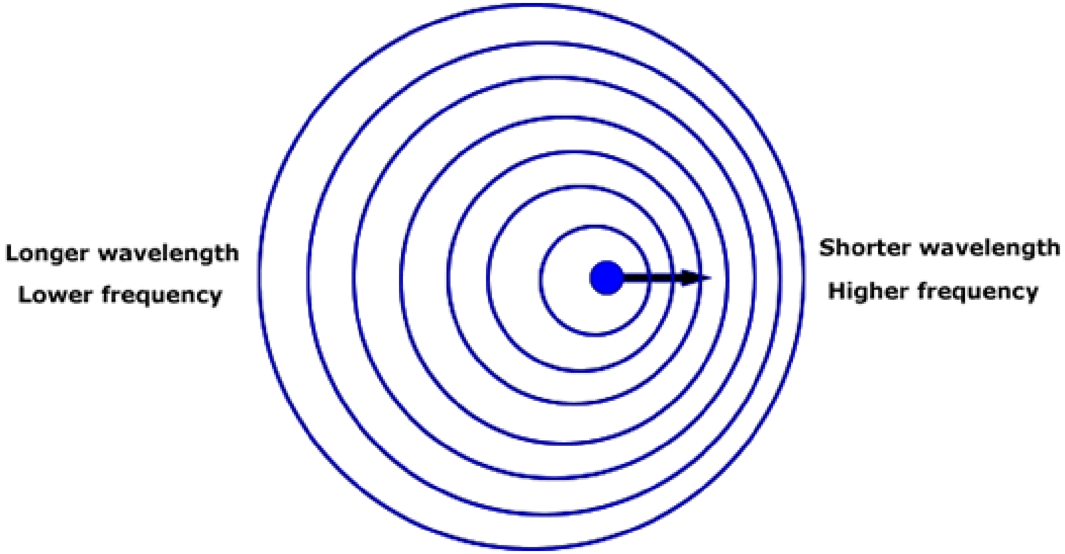
- **Definition:**
- **The Doppler Effect is the apparent change in frequency of a wave when the source and observer are moving relative to each other.**

https://www.youtube.com/watch?v=h4OnBYrbCjY

Doppler in pictures

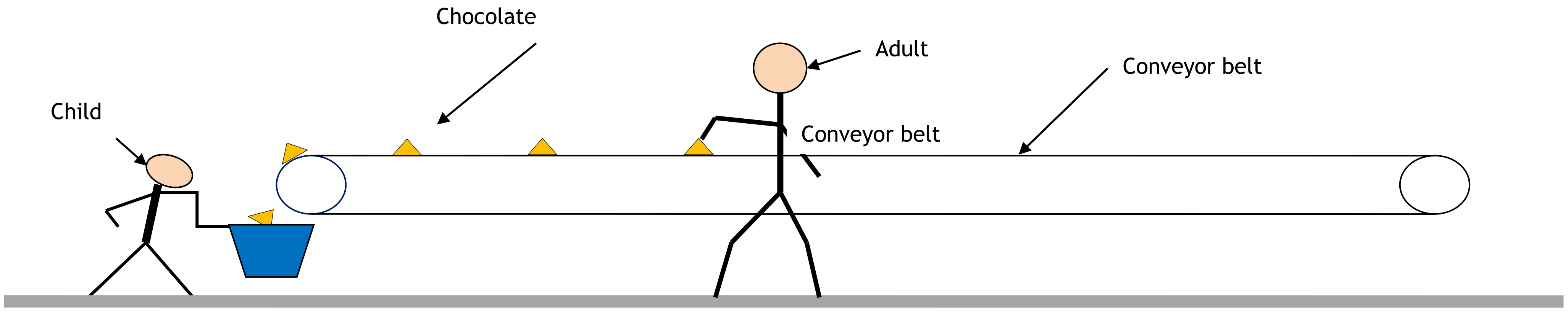






We only deal with moving objects and stationary observers

Doppler Analogy

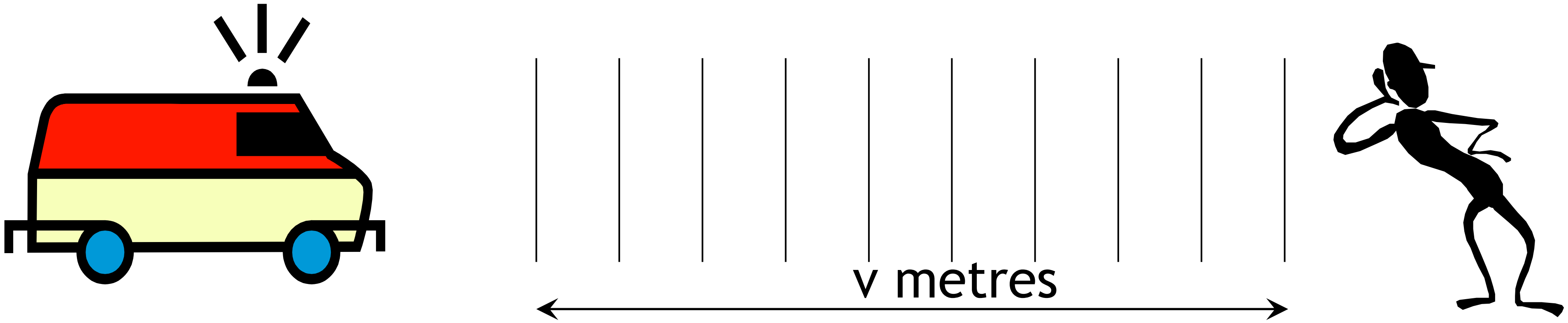


Chocolates on conveyor belt

DERIVING THE DOPPLER EQUATION

- These are the symbols that the SQA use to define the terms. Most other books use the same symbols but use them to represent different terms so the equation can look different.

  - ***speed of sound = v*** ***speed of source = v_s***
  - ***frequency source = f_s*** ***observed frequency = f_o***



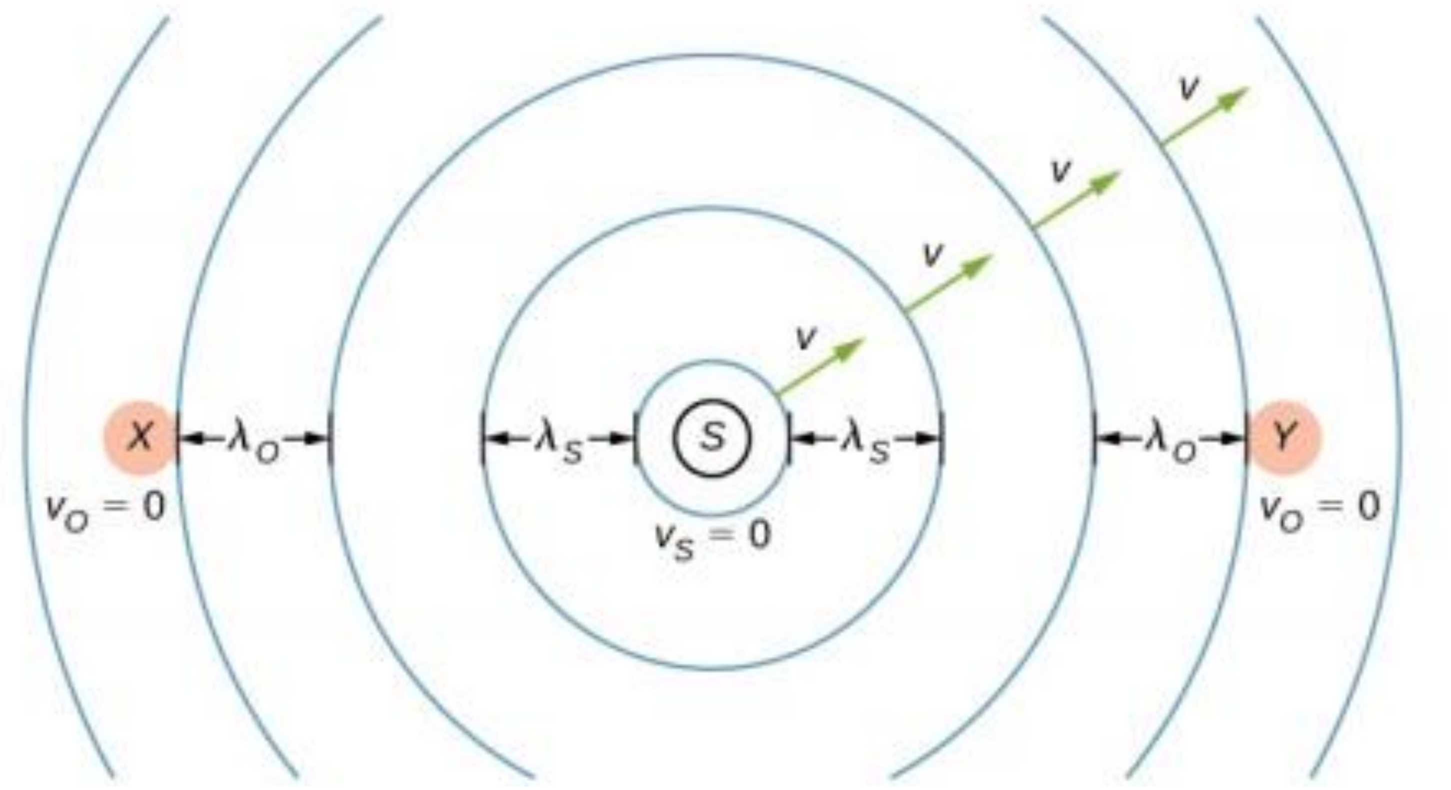
- Stationary: in 1 second there will be f_s waves produced. The sound will travel a distance of *v* metres in *1 second*. This means there are f_s waves in a distance of *v* metres.
  Moving at speed v_s: In the same way as above, in 1 second f_s waves will cover a **distance** of **($v - v_s$)** metres.
  As

$$v = \frac{d}{t}$$

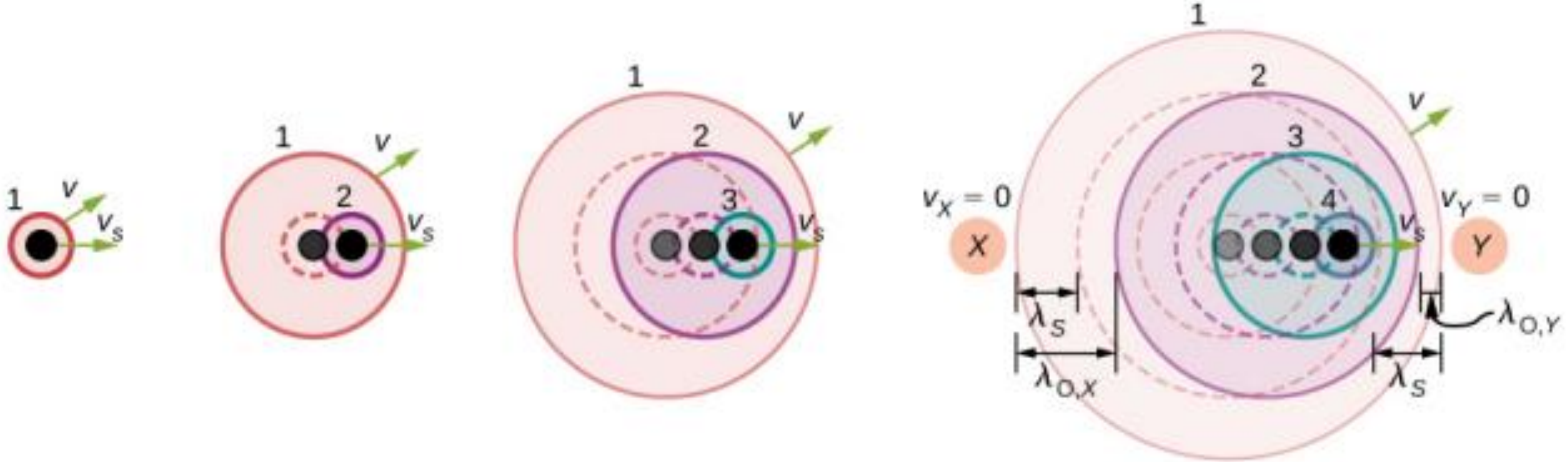
then numerically in one second the value of *v* is equal to the value of *d*

Derivation: read through don't learn!

- Consider two stationary observers X and Y in the Figure, located on either side of a stationary source. Each observer hears the same frequency, and that frequency is the frequency produced by the stationary source.



A stationary source sends out sound waves at a constant frequency fs, with a constant wavelength λs , at the speed of sound v. Two stationary observers X and Y, on either side of the source, observe a frequency fo = fs, with a wavelength λo=λs .



- a stationary observer X with a source moving away from the observer with a constant speed vs < v. At time t = 0 , the source sends out a sound wave. This wave moves out at the speed of sound v. The position of the sound wave at each time interval of period T_s is shown as dotted lines. After one period, the source has moved $\Delta x = v_s T_s$ and emits a second sound wave, which moves out at the speed of sound. The source continues to move and produce sound waves, as indicated by the circles numbered 3 and 4. Notice that as the waves move out, they remained centered at their respective point of origin.

A source moving at a constant speed vs away from an observer X.

- The moving source sends out sound waves at a constant frequency fs, with a constant wavelength λs , at the speed of sound v. Snapshots of the source at an interval of T's are shown as the source moves away from the stationary observer X. The solid lines represent the position of the sound waves after four periods from the initial time. The dotted lines are used to show the positions of the waves at each time period.
- The observer hears a wavelength of $\lambda o = \lambda s + \Delta x = \lambda s + vsTs$.

We know that

$$v = \frac{d}{t}$$

If we take the time as the period (time for one wave to be produced) then the distance would equal 1 wavelength so,

$$vt = d$$

$vT = \lambda$ *for an object moving away*

$$\lambda_o = \lambda_s + \Delta x$$
$$vT_o = vT_s + v_s T_s$$

As $T = \frac{1}{f}$ we can substitute $T_o = \frac{1}{f_o}$ and $T_s = \frac{1}{f_s}$

$$\frac{v}{f_o} = \frac{v}{f_s} + \frac{v_s}{f_s}$$

Taking out the common factor in the fraction addition calculation we can write this as

$$\frac{v}{f_o} = \frac{v + v_s}{f_s}$$

- Tip upside down

$$\frac{f_o}{v} = \frac{f_s}{v + v_s}$$

- Multiple through with *v* and cancelling

$$\frac{\cancel{v} f_o}{\cancel{v}} = \frac{v f_s}{v + v_s}$$

- Gives

$$f_o = f_s \left(\frac{v}{v + v_s} \right)$$

We know that

$$v = \frac{d}{t}$$

If we take the time as the period (time for one wave to be produced) then the distance would equal 1 wavelength so,

$$vt = d$$

$vT = \lambda$ *for an object moving toward*

$$\lambda_o = \lambda_s - \Delta x$$

$$vT_o = vT_s - v_s T_s$$

As $T = \frac{1}{f}$ we can substitute $T_o = \frac{1}{f_o}$ and $T_s = \frac{1}{f_s}$

$$\frac{v}{f_o} = \frac{v}{f_s} - \frac{v_s}{f_s}$$

Taking out the common factor in the fraction addition calculation we can write this as

$$\frac{v}{f_o} = \frac{v - v_s}{f_s}$$

- Tip upside down

$$\frac{f_o}{v} = \frac{f_s}{v - v_s}$$

- Multiple through with *v* and cancelling

$$\frac{\cancel{v} f_o}{\cancel{v}} = \frac{v f_s}{v - v_s}$$

- Gives

$$f_o = f_s\left(\frac{v}{v - v_s}\right)$$

If vehicle TOWARD -this gives an observed frequency that is **higher/greater** than that of the source

- If the source is moving away from the observer then the frequency observed will be **lower/smaller** than that of the source.

$$f_o = f_s \frac{v}{(v + v_s)}$$

- Frequency increases as they come towards you and frequency decreases as they move away.
  - **Remember the correct formula from ADD when the object moves AWAY**
  - **and TAKE AWAY (subtract) when the object comes TOWARDS**

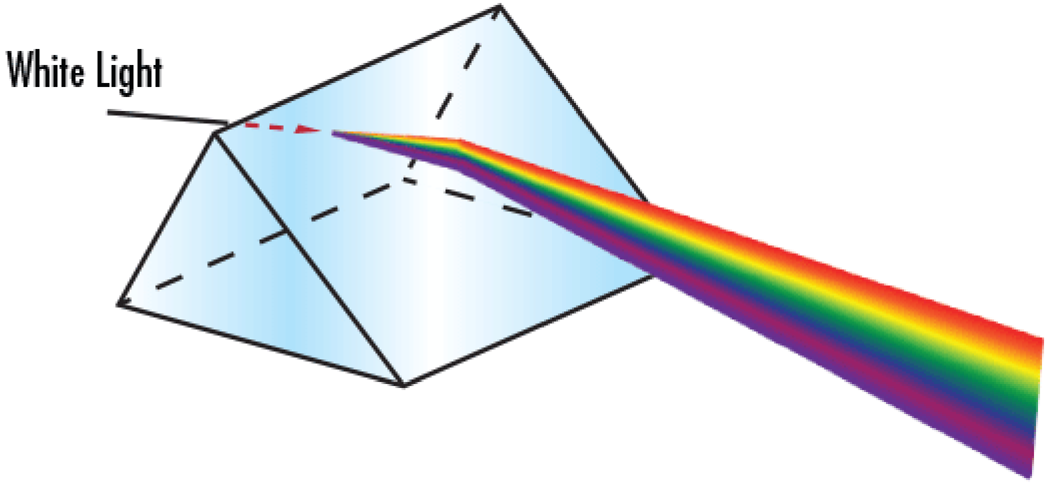
Doppler and the Universe

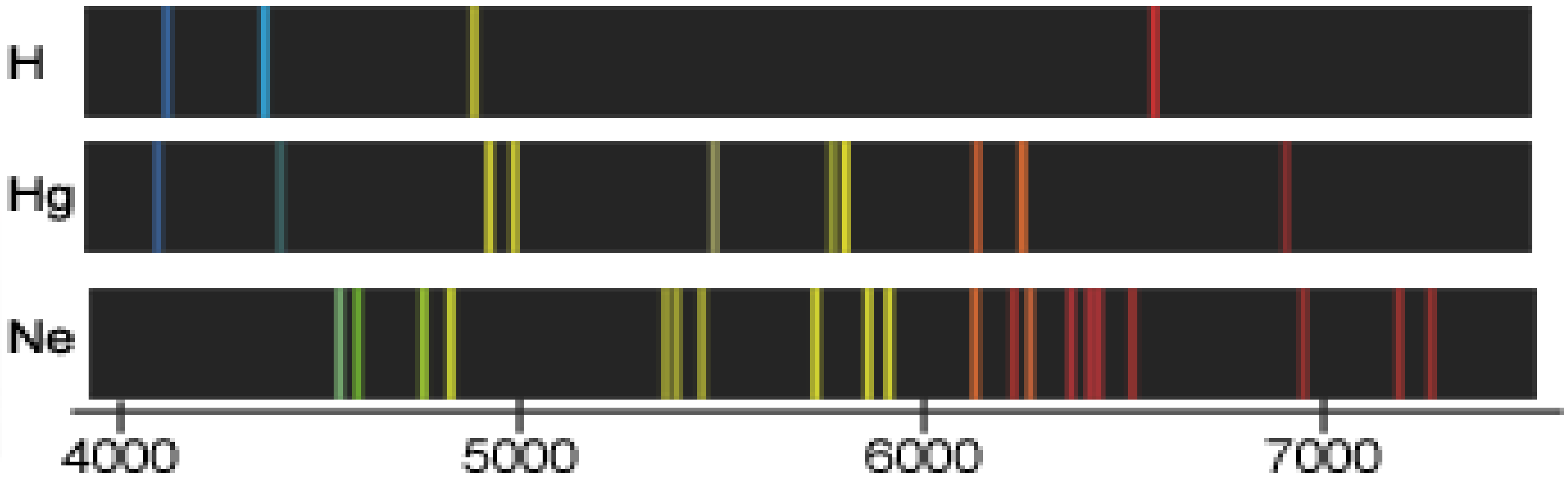
- It appears that the Doppler Effect is important in things in the Universe too, and can give us an indication of the relative motion of objects.

https://www.youtube.com/watch?v=y5tKC3nEx2I

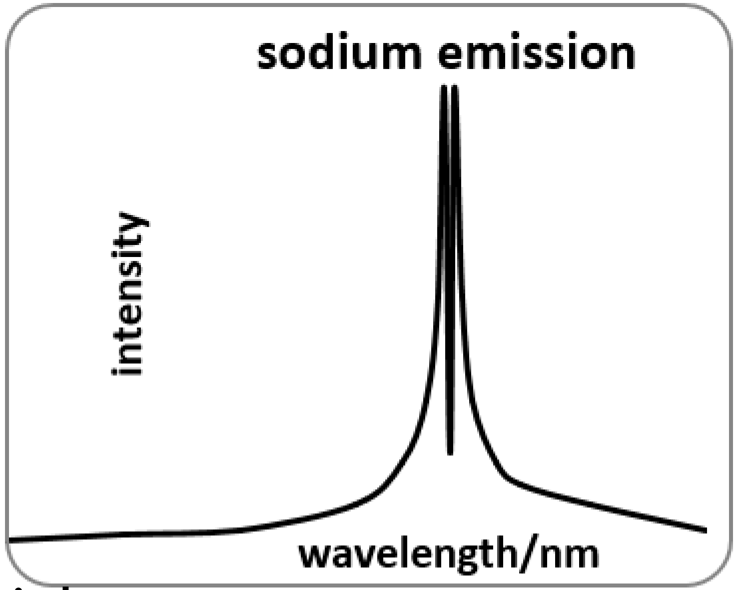
https://www.youtube.com/watch?v=-mQ41yA6LaA

Line Spectra

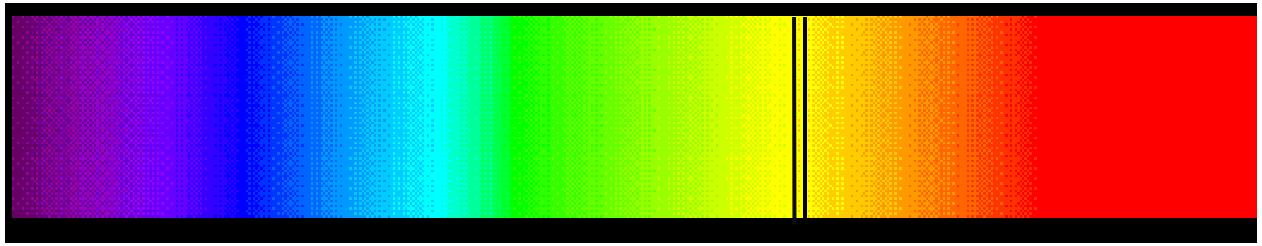


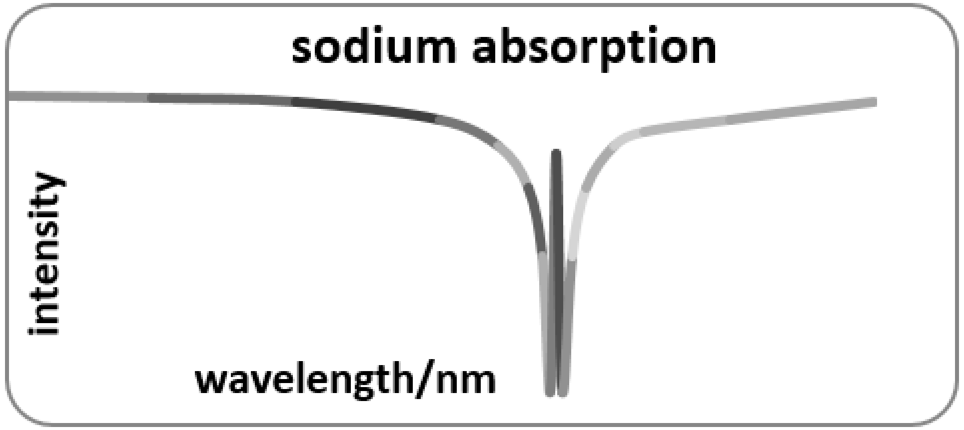


Scientists have used line spectra to discover new elements. The element helium was discovered by studying line spectra emitted by the Sun.



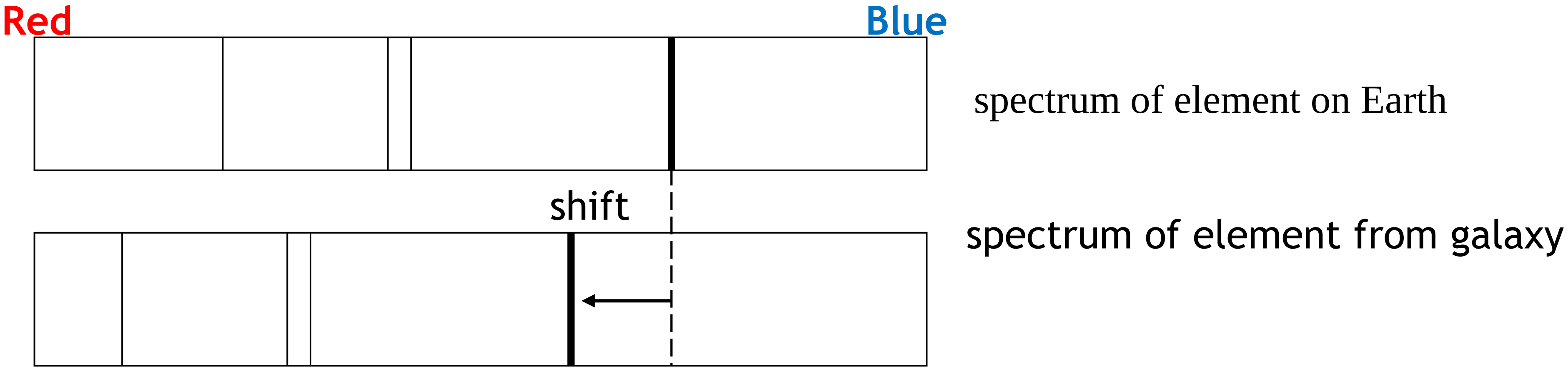
Sodium absorption spectrum, produced when white light is passed through sodium gas.



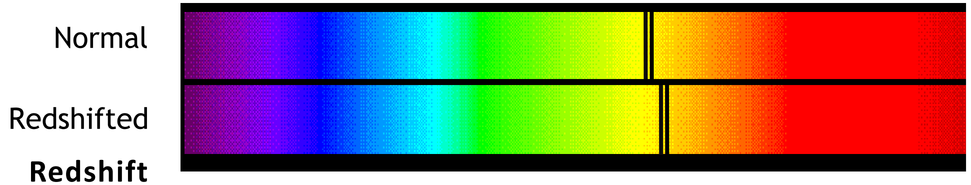


Redshift, z

Redshift is the term given to the change in frequency of the light emitted by stars, as observed from Earth, due to the stars moving away from us.



Redshift of a galaxy



Redshift, z, of a galaxy is defined as the change in wavelength divided by the original wavelength, and given the symbol z.
So, redshift

$$z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$

Where *z = redshift,* λ_{obs} = *observed wavelength*
λ_{rest} = *wavelength of the source*

Note: Redshift is a dimensionless quantity since it is a ratio of two lengths.

- *Example*
- *An astronomer observes the spectrum of light from a star. The spectrum contains the emission lines for hydrogen. The astronomer compares this spectrum with the spectrum from a hydrogen lamp. The line, which has a wavelength of 656 nm, from the lamp is found to be shifted to 663 nm in the spectrum from the star. Calculate the redshift for this light.*

$$z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$

$$z = \frac{\lambda_o - \lambda}{\lambda}$$

$$z = \frac{663n - 656n}{656n}$$

z=0.0107

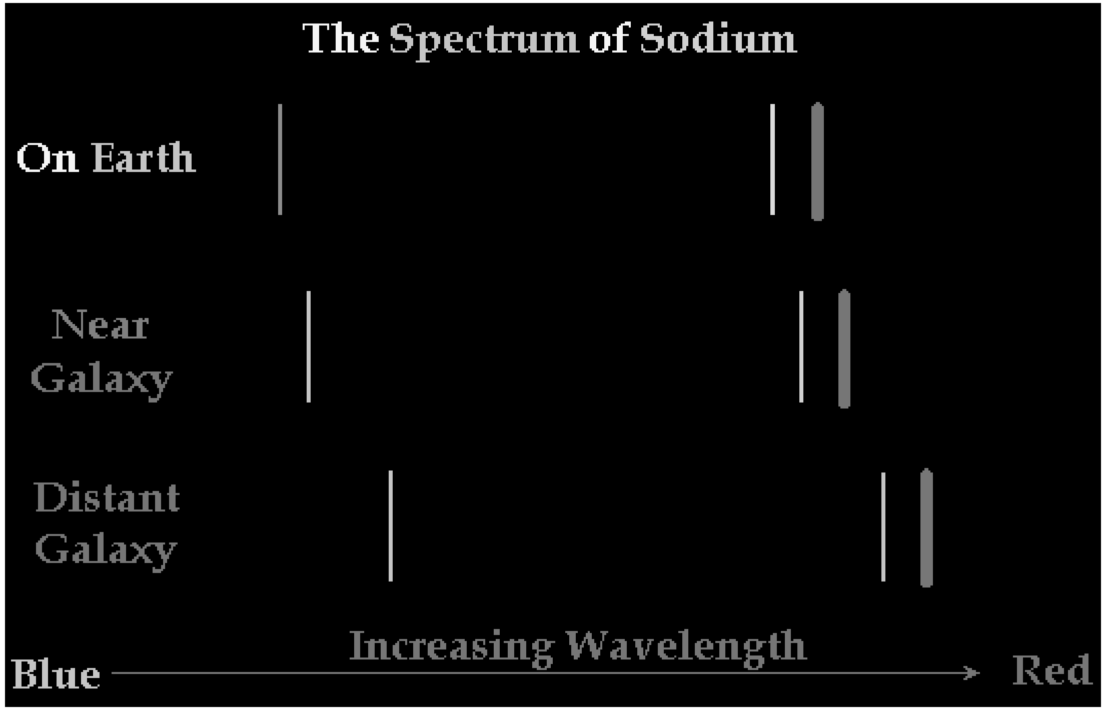
NB Make sure you quote to the correct sig fig

Recessional Velocity, *v*

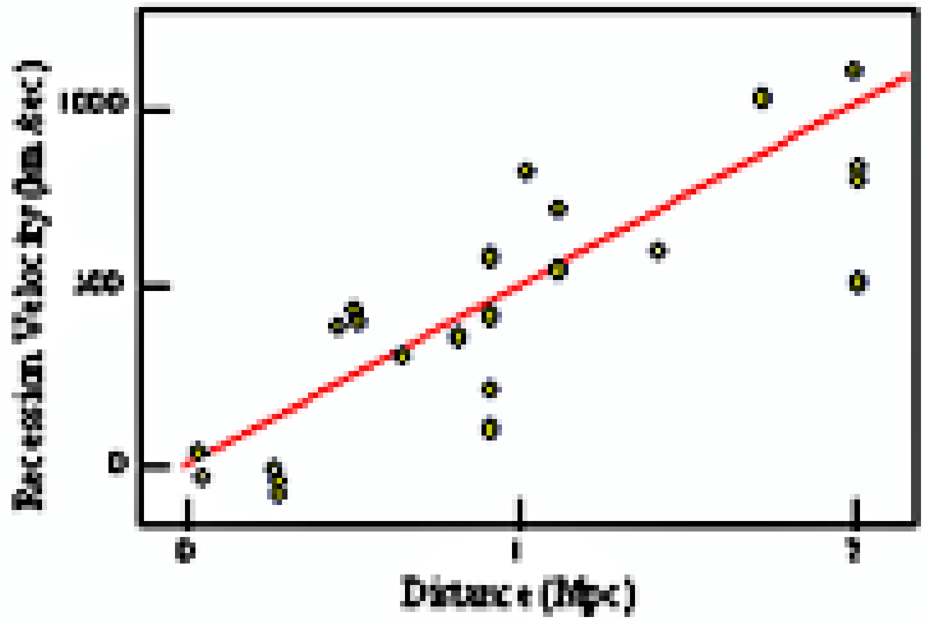
- Recessional velocity is the rate at which an astronomical object is moving away, typically from Earth.
- It can be measured by shifts in spectral lines or estimated by general reddening of a galactic spectra.

Hubble's Law

Galaxies are moving away from the Earth and each other in all directions, which suggest ....

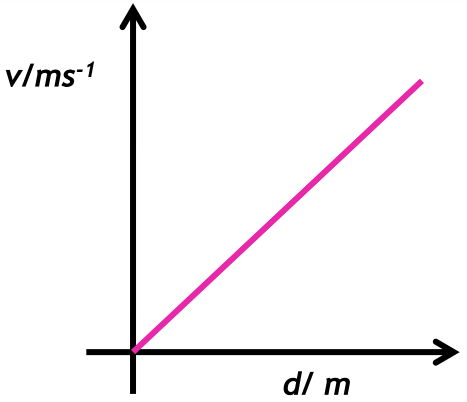


Hubble's Data (1929)



The graph plots the data collected by Hubble giving the relationship between the velocity of a galaxy (recessional velocity) and its distance from us

$$\boldsymbol{gradient = \frac{v}{d} = Hubble\ contant}$$



From the equation for $v = \frac{d}{t}$

$$rearranging \Rightarrow \frac{v}{d} = \frac{1}{t}$$

The gradient of this graphs is called the Hubble Constant and has units of s^{-1}.

If we take the inverse of the Hubble constant we should be able to predict the age of the Universe.