Lecture 2: Cosmological Redshift and Galaxies

Galaxies

Galaxies are the basic structures of the Universe at large scales. They are "cities" of stars.

Our Milky Way Galaxy weighs about 1,000 billion times the mass of our Sun, has about 400 billion stars and is 100,000 light years in radius. It is a large galaxy, although the largest galaxies known are about 5 times heavier still. When seen edge on, the Milky Way appears like a thin disk, but if seen face on it has a majestic spiral shape.

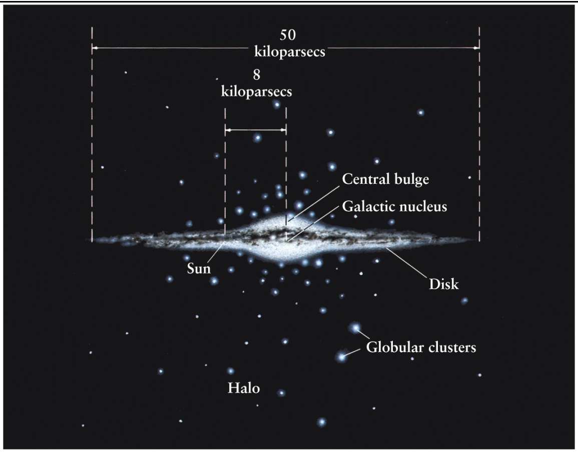


Diagram illustrating the disk shape of our Milky Way Galaxy when seen edge-on. The Sun lies in the mid plane of the disk, about 1/3rd of the way from the core to the edge.

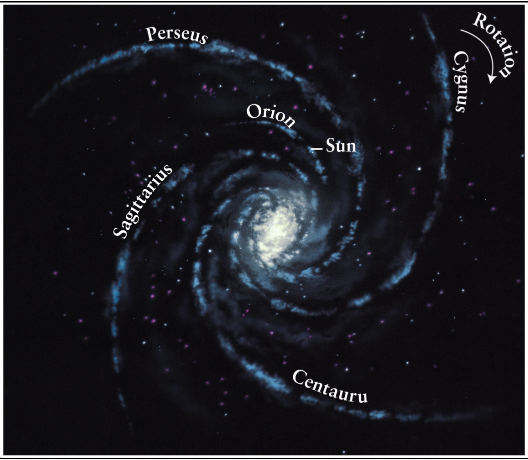
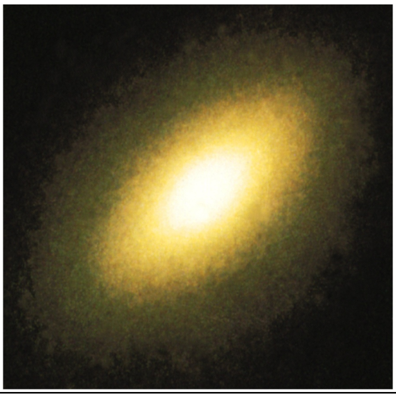


Diagram showing what the Milky Way would look like if seen face-on. Four spiral arms are clearly seen. The Sun lies in a lesser arm, known as the Orion spur.

There are three principal types of galaxy that are found: spirals, ellipticals and irregular galaxies – named after their characteristic shapes.

The three principal types of Galaxy

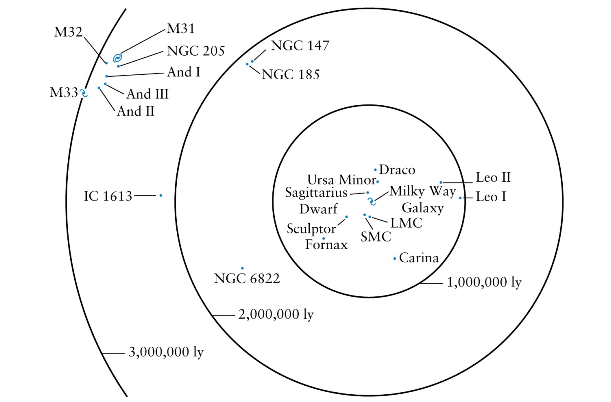
Spiral galaxy – with both young and old stars. The young stars are found mostly in the spiral arms where stars are still forming. The Milky Way is a spiral.



Elliptical galaxy – with virtually all old stars, and very few young stars. The largest galaxies known are elliptical galaxies and are found in the centres of vast clusters of galaxies.

Irregular galaxy – with no clearly defined shape. Often because they are being torn apart by tidal forces from larger galaxies. Generally contain a mix of young and old stars.

Galaxies are found in groups. Some, like our "Local Group" have just a few tens of members. Others, like the Virgo cluster, can contain several thousand galaxies.

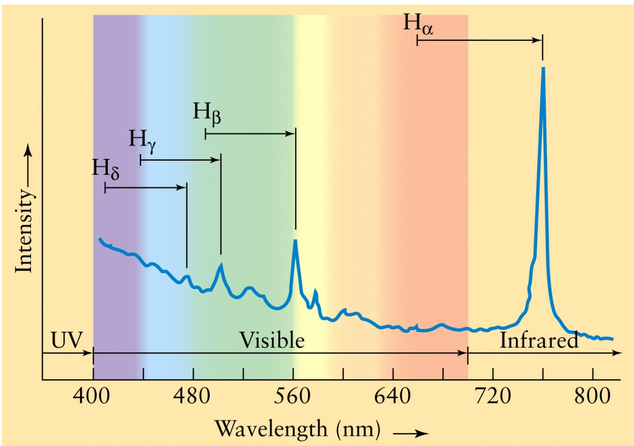


Map of our "Local Group" of galaxies, dominated by the Milky Way and the Andromeda galaxy (M31), roughly 2 million lights years away. Both are spiral galaxies.

The Virgo cluster of galaxies, dominated by two giant ellipticals known as M84 and M86. Virgo contains about 2,000 galaxies and is 16 Mpc (megaparsecs) away from us. The Local Group is falling towards Virgo with a speed of about 750 km/s.

Cosmological Redshift

We can measure spectral lines from galaxies, as for stars. This lets us work out how fast they are moving away or towards us.



Spectrum measured for a galaxy which is redshifted. The wavelengths of the hydrogen lines are shifted to longer wavelengths (i.e. to the "red"). The galaxy is thus moving away from us.

We define the Cosmological Redshift, z, as before by $z = \frac{\Delta\lambda}{\lambda}$.

However (this is the tricky bit!): the redshift is a result of *space expanding between us and the distant galaxy*!

i.e. the distance between Earth and the galaxy is increasing, and not that the galaxy is moving away from us.
[Actually there will be a small component due to the motion of the galaxy too, but this is relatively minor for distant galaxies.]

When the velocity of expansion is small, i.e. $v << c$ or $v/c << 1$, then we can show that the cosmological redshift is given by

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

This is the very same formula as for the Doppler redshift, but now the interpretation is that space is being stretched at speed v.

This is equivalent to the galaxy moving away from us, as per the Doppler redshift, with a speed of *v*.

Examples:

1. The Local Group is falling towards the Virgo cluster at 745 km/s. What is the redshift parameter? What would the wavelength of a hydrogen line emitted at 656.3 nm from Virgo be when observed with a telescope on Earth?

   The redshift parameter is $z=v/c=745/300{,}000=0.0025$. Since we are falling towards Virgo the spectral lines will be blue-shifted. From the redshift formula we then have

   $$\Delta\lambda=\lambda.z=656.3 \text{ nm} \times 0.0025=1.6 \text{ nm}.$$

   Since the line is blueshifted the wavelength observed is 656.3-1.6=654.7 nm.

2. The Coma cluster of galaxies has been measured to have a redshift of $z=0.0231$. At what speed is it receding from us?

   As above, $z=v/c$, hence $v=cz=0.0231 \times 300{,}000$ km/s = 6,930 km/s.

Note: there is an exact formula for the cosmological redshift given by (*you don't need to know this for A Level Physics, though*):

$$1 + z = \gamma(1 + \frac{v}{c}) \text{ where } \gamma = 1/\sqrt{1 - \left(\frac{v}{c}\right)^2}$$

When $v/c << 1$ then $\gamma \approx 1$ and we recover the original redshift formula, $z=v/c$.

e.g. If $v/c=0.1$ then $\gamma = \sqrt{1 - 0.1^2} = \sqrt{0.99} = 0.995 \approx 1$

However, as the velocity approaches the speed of light, i.e. $v \to c$ then $\gamma \to \infty$ and hence the redshift tends towards infinity.

For "nearby" galaxies, such as Andromeda, the motion is dominated by the Doppler redshift.

For distant galaxies the motion is dominated by the cosmological redshift; i.e. by the stretching of space.

Doppler redshift applies for:

- motions of planets in our Solar System
- motions of stars in our Galaxy
- motions of nearby galaxies

Cosmological redshift applies for:

- the stretching of space to distant galaxies.