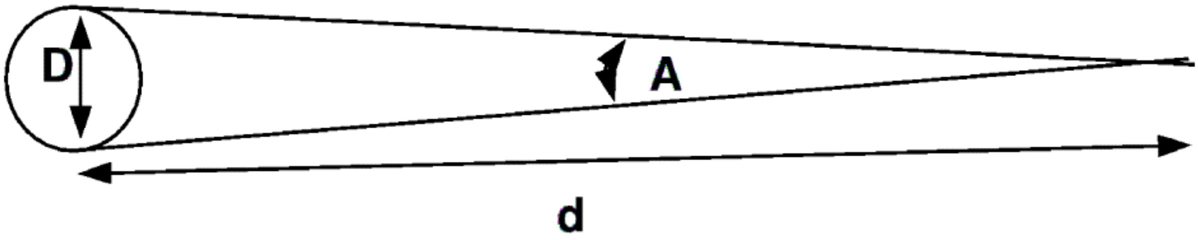
1. The small angle formula that relates angles to physical distances is this:



A=(D/d)x206,263 arc sec

If the Hubble Space Telescope can measure angles as small as 0.05 arcseconds, and the Moon is 384,000km away, then what would be the smallest object that you could detect on the Moon using the Hubble Space Telescope? (2)

Putting the values that we know into the small angle formula:

$$0.05 = \frac{D}{384000} \times 206263$$

Then, rearranging to find D:

$$\begin{aligned} D &= \frac{0.05 \times 384000}{206263} \\ &= 0.093\text{km} \\ &= 93\text{m} \end{aligned}$$

So the smallest object that you could resolve with the Hubble Space Telescope on the Moon would be 93m across

2. The largest crater on the Moon's surface is called Bailly, and it has a diameter of 295km. The human eye can resolve objects as small as one arcminute across. Can you see Bailley with the naked eye? (2)

To calculate the apparent size of Bailley, put the numbers we know into the equation:

$$\begin{aligned} A &= \frac{295}{384000} \times 206263 \\ &= 158.5\, arcseconds \\ &= 2.64\, arcminutes \end{aligned}$$

So, if the human eye can resolve objects an arcminute across, then we should be able to

see Bailly with the naked eye. (In practise it would be very difficult to see, because it is close to the lunar limb, and very old and eroded)

3. The distance between the Earth and the Sun is 150,000,000km (an Astronomical Unit). How far away from the Solar System would you have to be for the Earth and Sun to appear one arcsecond apart? (2)

Putting the numbers into the equation:

$$1 = \frac{150{,}000{,}000}{d} \times 206263$$

Rearrange to get d, the distance required:

$$\begin{aligned} d &= 150{,}000{,}000\, x\, 206{,}263 \\ &= 3.09 \times 10^{13}\, km \\ &= one\ parsec \end{aligned}$$

This is the definition of a parsec

4. Give two reasons why collisions between stars are extremely rare. Explain why these two reasons don't apply to galaxies. (4)

Stellar collisions are extremely rare because the distances between stars are very large compared to the sizes of stars – eg, the diameter of the Sun is about 1.5 million kilometres, while the distance to the nearest star, Proxima Centauri, is 1.3 parsecs, or $4 x 10^{13}$km. This is millions of times larger than the diameter of the Sun.

In addition, in galaxies, stars in a particular region will generally be moving in similar orbits around the centre of mass of the galaxy. In our spiral arm of the Milky Way, all the stars are moving in the same direction in their orbits around the galaxy.

Galaxy collisions are much more frequent. Firstly, the sizes of galaxies are large compared to the distances between them – for example, the Milky Way and the Andromeda Galaxy are both around 100,000 light years across, and the distance between them is about 2.2 million light years, so the separation is only about 20 times their size.

And galaxies within clusters are not orbiting in the ordered way that stars in the Solar neighbourhood are orbiting – their motions are much more random, and their paths much more likely to intersect.

5. Give three pieces of evidence that suggest that the universe began with a Big Bang. (3)

1. **All clusters of galaxies outside the Local Group are observed to be receding from Earth, and the speed at which they are receding is proportional to their distance. This means the universe must once have been much smaller than it is today.**

2. **In all directions, microwave emission is detected, almost perfectly uniform in its intensity, and with a temperature of about 2.7 K. This is the thermal radiation from a young hot universe, which has expanded and cooled over time.**
3. **The amounts of helium and lithium observed in the universe today closely match the predictions made by theories of how the elements would form in a big bang.**

   Other observations which rule out a 'steady state' universe include the fact that the constituents of the universe are not uniformly distributed throughout it. Some objects, like quasars, are only seen at large distances and not near by.

6. The positions of astronomical objects on the sky are measured in Right Ascension and Declination. Define what these terms mean. (4)

Right Ascension is the distance eastwards from the First Point of Aries (that is, the point on the celestial equator where the apparent path of the Sun through the sky crosses from the southern hemisphere to the north) to a celestial object. It is measured in hours, minutes and seconds. Once the First Point of Aries has crossed the meridian, then the time until a given object crosses the meridian is equal to its RA.

Declination is the angular distance of an object from the celestial equator. Objects in the northern hemisphere have positive declinations, and those in the southern hemisphere have negative declinations.

7. Why do we have to specify what year a given Right Ascension is valid in? (2)

The First Point of Aries is unfortunately not a permanently fixed point in the sky. It isn't even in Aries any more! It moves because the gravitational pull of the Moon and Sun on the Earth cause the direction that the Earth's rotational axis points to slowly change, and so the point where the Sun crosses from the southern celestial hemisphere to the northern slowly moves. This effect is called *precession*.

8. What is the definition of a Solar day? What is the definition of a sidereal day? Why are these days not the same length? (3)

A solar day is the time between successive upper meridian transits of the Sun. A sidereal day is the time between successive upper meridian transits of the First Point of Aries. They are not the same length because the movement of the Earth in its orbit around the Sun changes the position of the Sun relative to the stars: the Sun takes about four minutes longer than the First Point of Aries to move between successive upper transits.

9. Why do solar and lunar eclipses not occur at every new moon and full moon respectively? Why are total solar eclipses much less frequently seen from a given place on the Earth's surface than total lunar eclipses? (5)

The moon's orbit around the Earth and the Earth's orbit around the Sun are not in the same plane – the Moon's orbit is inclined by about five degrees to the plane of the Earth's orbit around the Sun. So, most of the time, the alignment between the three bodies at new or full moon is not perfect and no eclipse occurs. An eclipse will only occur if the three bodies lie on (or very close to) the line of intersection between the planes of the orbits – the *line of nodes*.

Solar eclipses can only be seen from a very small part of the Earth's surface, because the shadow of the Moon only just reaches the Earth (and for part of its elliptical orbit, the Moon is too far away for its shadow to even reach the Earth). Total lunar eclipses, on the other hand, can be seen from any part of the Earth from which the Moon can be seen – that is, the entire night side of the Earth, during a lunar eclipse. So, from a given location, lunar eclipses are seen much more frequently than solar eclipses.

10. Why will total solar eclipses eventually stop occurring as seen from Earth? (3)

The gravitational pull of the Moon raises tides in the Earth – a huge bulge of water is raised. But the Earth rotates much faster than the Moon orbits, and so the bulge of water is 'carried ahead' of the line joining the Earth and Moon. The gravity of the bulge pulls on the Moon, accelerating it into a slightly larger orbit. This causes the Moon to recede from the Earth by about 3.8cm per year. Eventually, this effect will mean that the Moon is too far away for its shadow ever to reach Earth, and total solar eclipses will no longer occur.

At the same time, throughout its life as a *main sequence* star, the Sun will get slowly larger. This will also reduce the frequency with which total solar eclipses occur.