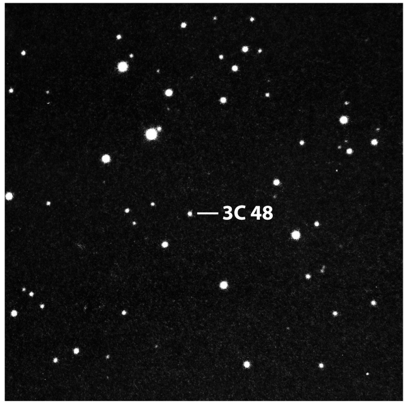
Lecture 13: Galaxies and their environments

- Active galaxies
- The environment of our Galaxy
- Galaxy clusters and dark matter
- Large scale structure
- The effects of environment on galaxies
- Galaxy formation - spirals and ellipticals

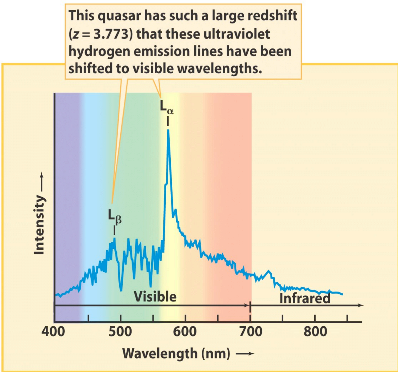
Quasars

- Quasars ("quasi-stellar objects") look like faint stars.

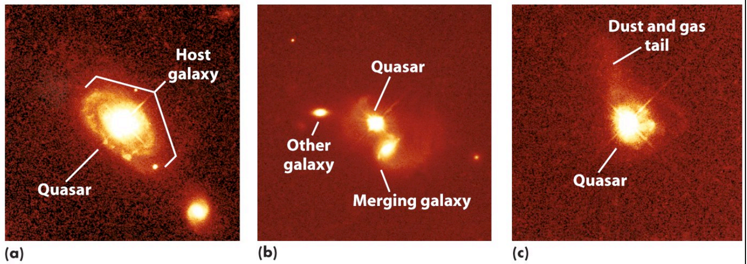


Quasars

- Quasars ("quasi-stellar objects") look like faint stars.
- However, their spectra reveal large redshifts, showing that they are very distant extragalactic objects
- They must therefore be very luminous, radiating ~1000 times more power than an ordinary galaxy



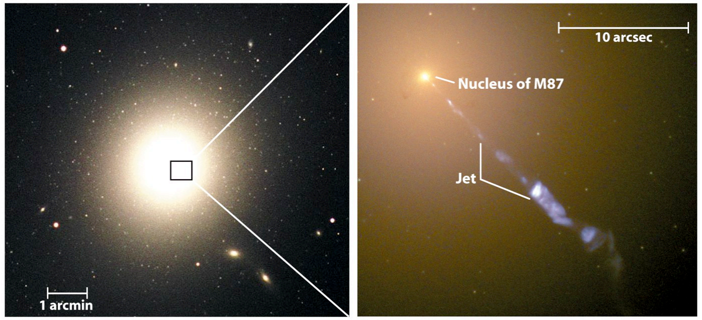
The nature of quasars



Sensitive high resolution observations eventually showed that quasars are actually ultraluminous nuclei of galaxies.

Many of the galaxy hosts seem to be interacting, or the products of galaxy mergers.

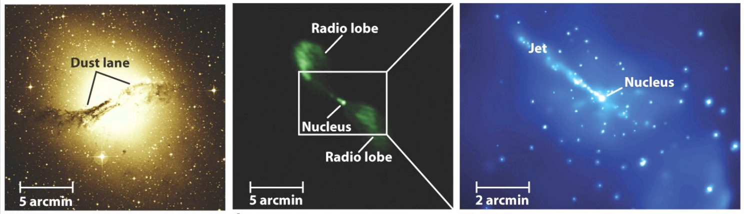
Other active galactic nuclei (AGN)



(a) The giant elliptical galaxy M87 (b) A shorter exposure reveals M87's jet

- Many other galaxies have active nuclei which are less luminous than quasars. M87, in the core of the Virgo cluster, is an example.
- AGN may exhibit jets, which can be one or two-sided.

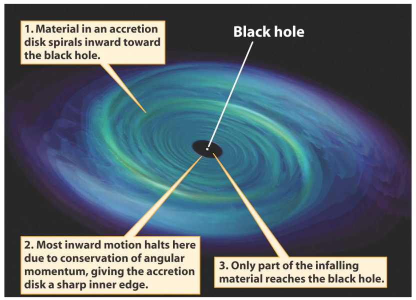
Other active galactic nuclei (AGN)

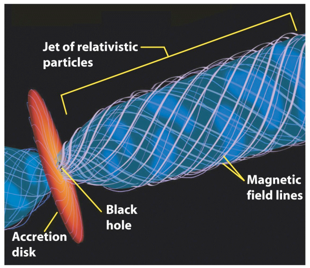


(a) Centaurus A: light from stars (b) Centaurus A: radio lobes (c) An X-ray-emitting jet emanates from the nucleus

- In radiogalaxies, such as Cen A, jets are seen to lead to two large radio lobes.
- Radio emission is produced by charged particles spiralling in a magnetic field (synchrotron emission).

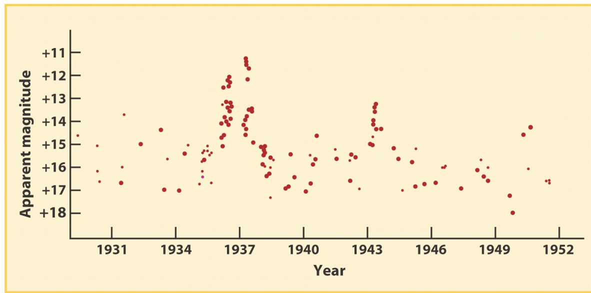
A model for AGN - supermassive black holes





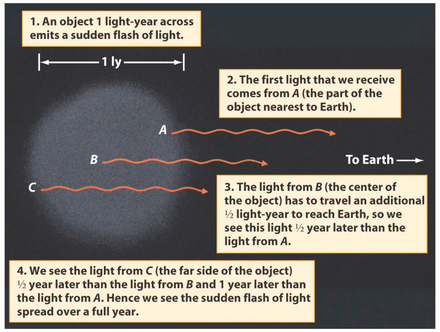
- It is widely accepted that the power source for AGN is a supermassive black hole at the centre of the galaxy, into which material spirals via an accretion disk (as in X-ray binaries, but without the binary companion).
- Some material is ejected perpendicular to the plane of the disk, via electromagnetic processes, forming a jet of relativistic particles.

Variability and size constraints



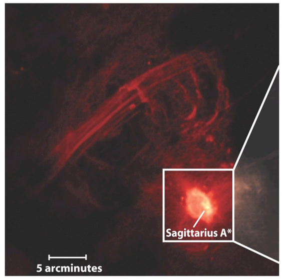
- Some AGN are extremely variable - here the system 3C 279 is seen varying by large factors on a timescale ~ 1 year.

Variability and size constraints

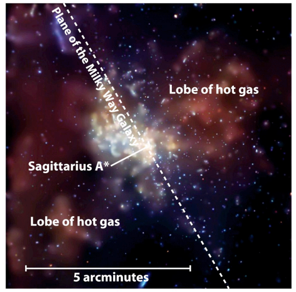


- The variability timescale sets an upper limit to the size of the region from which the (very large) luminosity is being emitted. In the case of 3C 279, this is ~ 1 light year.
- It is hard to envisage anything other than a black hole which could generate a luminosity greater than that of a whole galaxy, from such a small volume.

A black hole at the centre of our own Galaxy



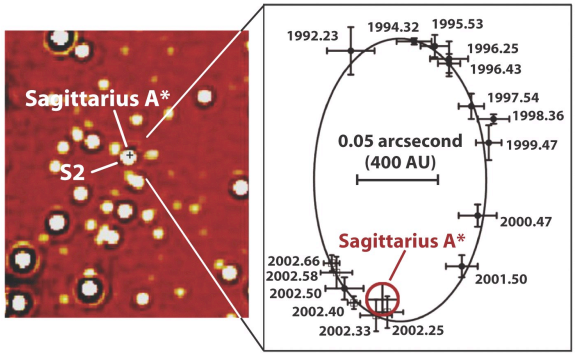
A radio view of the galactic center



An X-ray view of the galactic center

- Sagittarius A* is a bright, variable radio source located at the very centre of our Galaxy.
- A close-up (right) of this region in X-rays, shows two lobes of ~10^7 K gas which appear to have been ejected perpendicular to the Galactic plane.

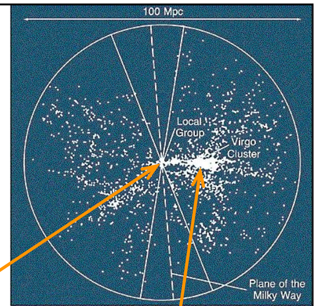
A black hole at the centre of our own Galaxy



The dynamics of stars orbiting close to Sgr A* confirm that a large mass (~3.7×10^6 $M_\odot$) must be concentrated into a very small volume here.

The local environment of our Galaxy

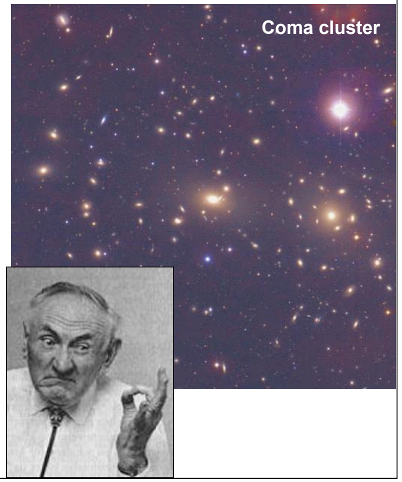
The Milky Way is part of the Local Group of galaxies, this is part of a local supercluster, which includes the nearest large galaxy cluster - the Virgo Cluster.



Galaxy clusters and dark matter

- The virial theorem (see lecture 7) can be applied to the motion of galaxies within a cluster.
- This means that the total gravitational binding energy is related to the kinetic energy of the galaxies.
- In 1933, Fritz Zwicky applied this to the Coma cluster, and concluded that it must contain ~10 times more mass than is visible in the galaxies of the cluster.

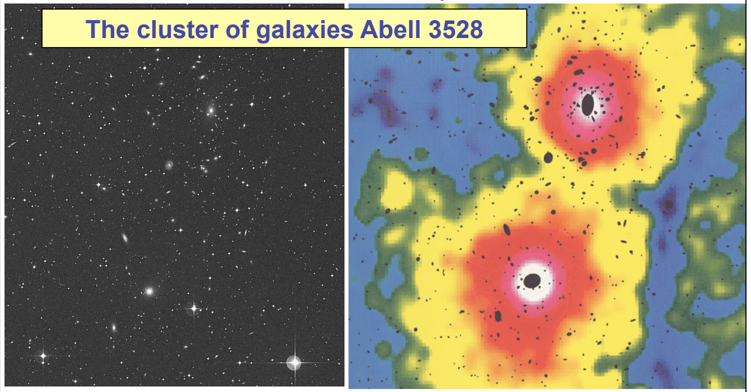
"Dark Matter"



A galaxy cluster at two wavelengths

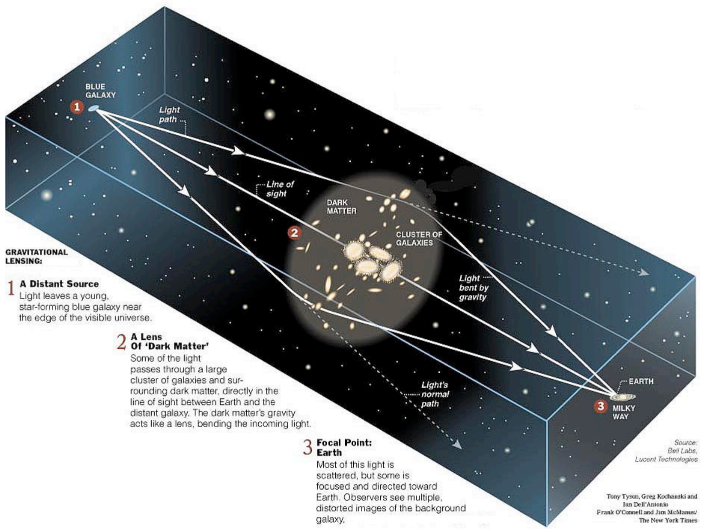
Some of this mass has been discovered by X-ray telescopes in the form of hot (>10^7 K) gas pervading the space between the galaxies.

However, most of the dark matter remains mysterious.

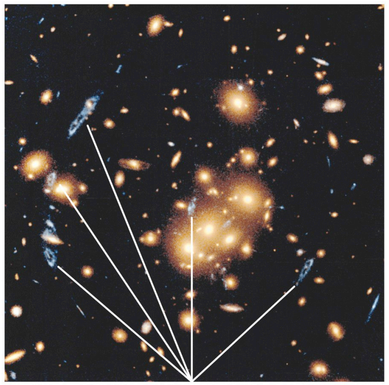


Light from galaxies

X-rays from hot gas (galaxies in black)



Gravitational lensing

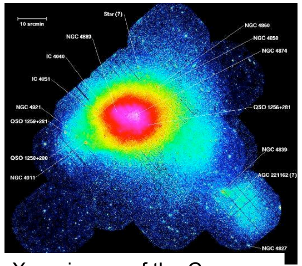


All of these blue arcs are images of the same distant galaxy.

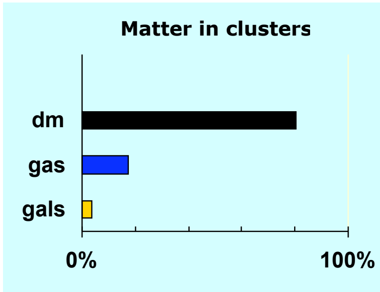
The masses of clusters inferred from models of gravitational lenses also imply the presence of large quantities of dark matter in clusters.

Galaxy clusters and dark matter

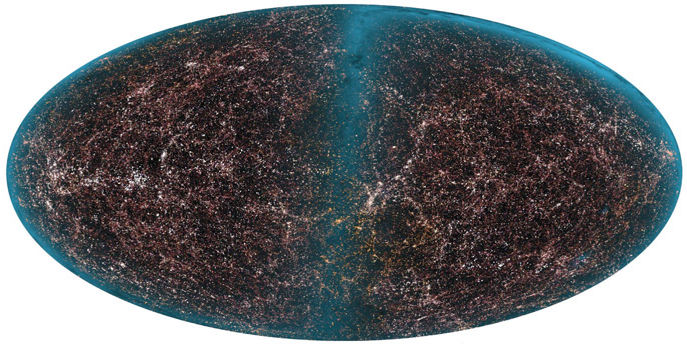
- The pressure of the hot X-ray emitting gas can also be used to infer the mass of clusters.
- All three methods (galaxy speeds, lensing and hot gas) imply that there is much more mass than can be accounted for by the galaxies or the hot gas – this is strong evidence for the reality of dark matter.
- Proportions are approximately 80:17:3.



X-ray image of the Coma cluster from XMM-Newton

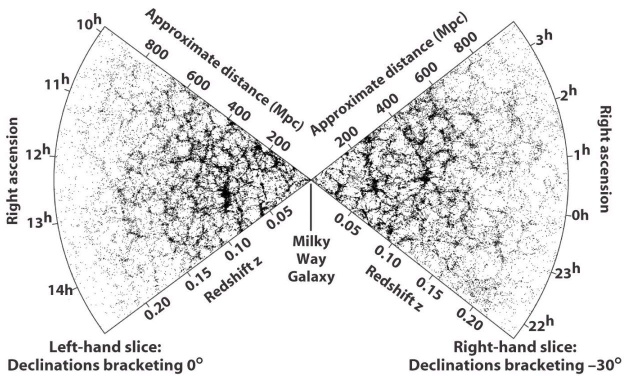


Large scale structure of the Universe



All-sky image in the near infrared from the 2MASS survey

Large scale structure

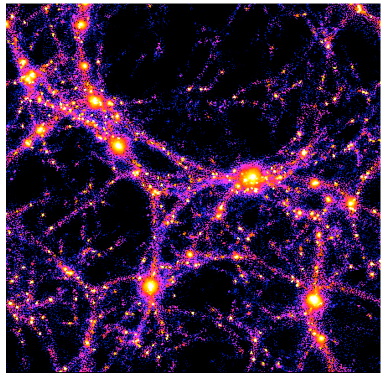


The 2dF galaxy survey

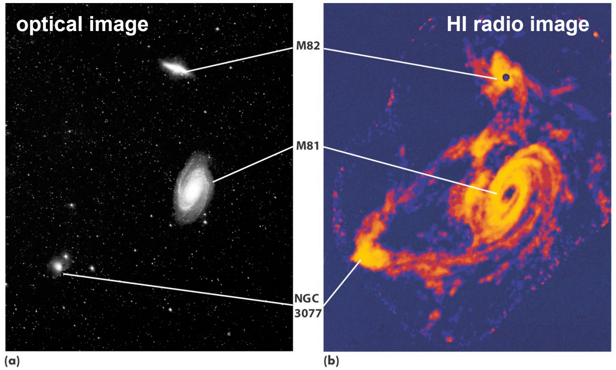
Redshift surveys such as 2dF show even more clearly that galaxies are not scattered randomly throughout the universe, but arranged in filaments, with groups and clusters at their intersections.

Large scale structure

- Cosmological simulations of the development of the Universe show that gravitational attraction leads the dark matter to clump into filamentary structures very similar to those seen in redshift surveys.
- The majority of space consists of empty voids.

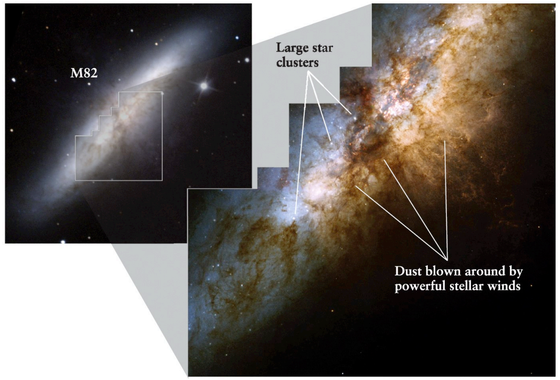


The effects of environment on galaxies



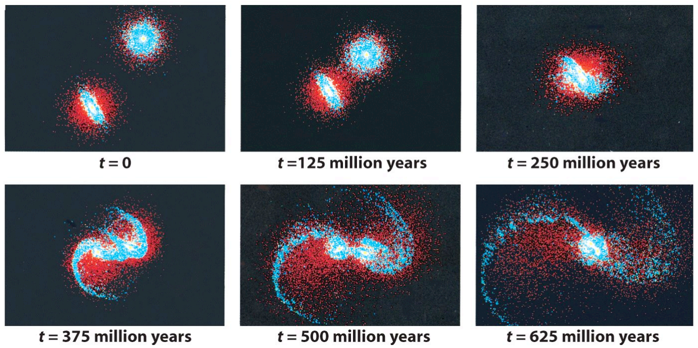
- Many galaxies do not evolve in isolation, but are affected by interactions with their environment.
- When galaxies interact, gas may be removed by tidal forces, as here in the M81/M82 system.

The effects of environment on galaxies



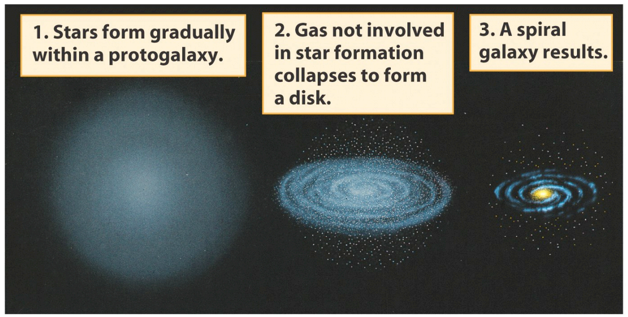
Interactions can also cause orbiting gas within spiral disks to lose angular momentum and fall the centre of the galaxy, where it may fuel a starburst - as in M82.

The effects of environment on galaxies



- Galaxy collisions will normally result in a merger.
- Stars do not collide directly (they are too small), but many may be pulled off to form tidal tails, during the pre-merger encounter.
- Gas in the galaxies *does* collide, triggering massive star formation.

The formation of galaxies

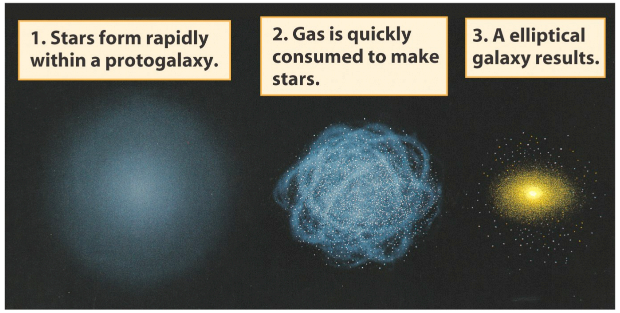


Formation of a spiral galaxy

Understanding galaxy formation is one the main aims of modern astronomy.

Spiral galaxies are believed to form from progressive star formation within a rotating disk of gas, contained within a dark matter halo.

The formation of galaxies



Formation of an elliptical galaxy

The formation of elliptical galaxies is still a subject of debate.

In one model, ellipticals form in a rather similar way to spiral galaxies, except that star formation is much more rapid, so the the gas has no time to settle into a flattened rotating disk.

Elliptical formation through spiral galaxy mergers

An alternative is that elliptical galaxies form through galaxy mergers.

Numerical simulations show that the merger of two spiral galaxies results in a relatively featureless assembly of stars looking like an elliptical galaxy.

This is now the most popular hypothesis for the way ellipticals form.