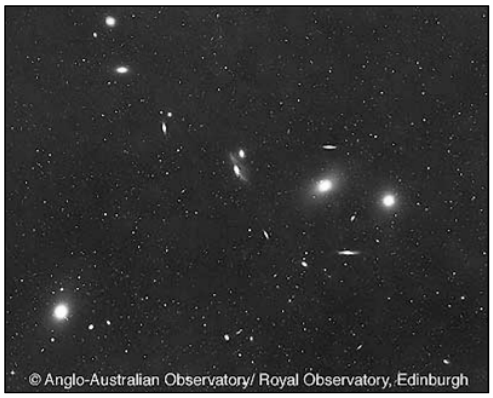
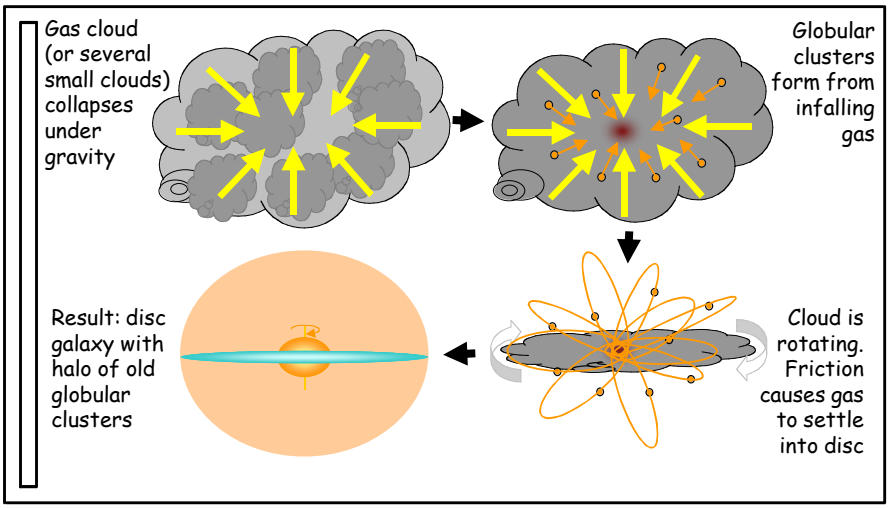
Galaxy evolution

- Why do galaxies come in such a wide variety of shapes and sizes?
- How are they formed?
- How do they evolve?



From gas cloud to galaxy



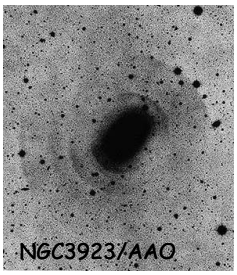
What do we expect?

- From this scenario
  - globular clusters should contain the oldest stars
  - the disc should rotate and should contain all the remaining gas
  - dark halo probably spherical, not disc-shaped (no friction)
- Looks reasonable for spiral galaxies — but what about ellipticals?

Making elliptical galaxies

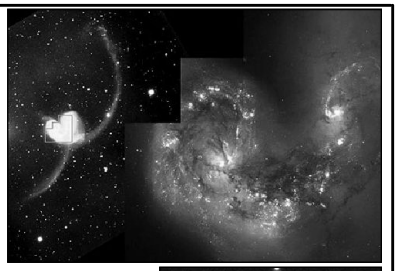
- Elliptical galaxies have little gas
  - used up? lost somehow?
- The stars have much less ordered motion
  - original disc disrupted?
- They are much more common in galaxy-rich environments
  - nearby galaxies needed?
- They often show faint "shells" of increased star numbers
  - produced by interactions with other galaxies?

➔ Are elliptical galaxies the result of galaxy collisions?

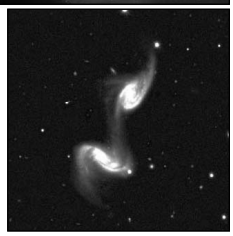


Colliding galaxies

- Pairs of colliding galaxies can be seen in the night sky
  - the collision sets off a burst of star formation
  - and produces "tidal tails" of gas and stars
- Discs and spiral arms are clearly disrupted
  - resulting merged galaxy will not be a spiral



Antennae: B. Whitmore/ NASA



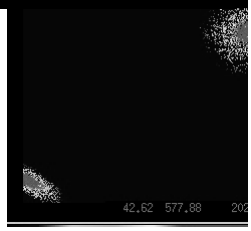
Arp 240: SDSS

Susan Cartwright *Our Evolving Universe* *5*

Simulation of galaxy collision

- Physics of galaxy collisions is simple (gravity)
  - very large numbers of objects (stars, dark matter, gas, etc.)
  - use supercomputers to simulate
- Simulations reproduce observed phenomena well
  - support idea that large ellipticals form from mergers

Hernquist, Dubinski, Mihos

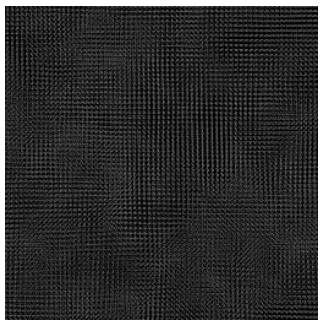


Chris Mihos

Susan Cartwright *Our Evolving Universe* *6*

Galaxy clusters

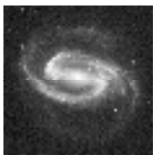
- Rich clusters such as Coma usually have a supergiant elliptical galaxy at the centre
  - simulations show how such galaxies form by consuming smaller members of the cluster
  - these interactions may also explain why so few spirals survive in cluster centres



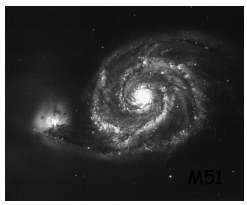
John Dubinski, CITA/Toronto

Discs and spirals

- What makes and maintains spiral structure?
  - it's not always the same stars
    - spiral arms are seen in short-lived massive stars
    - spiral arms would wind up
  - probably a "density wave" of increased gas density (like sound wave)
    - induces star formation
    - perturbs orbits of existing stars
  - what generates this wave?
    - bar
    - satellite
    - close encounter

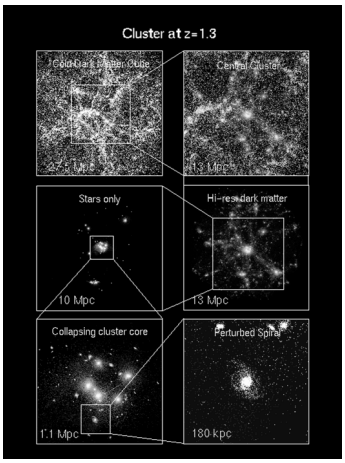


NGC 1300



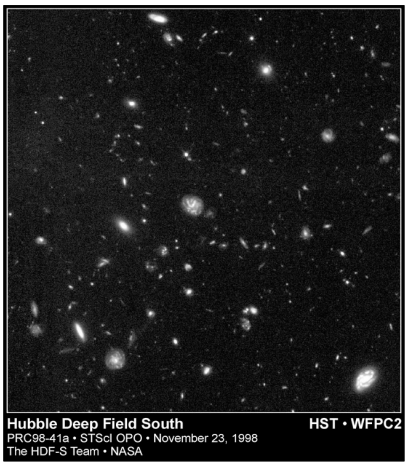
Theory and observation

- Summary so far:
  - disc galaxies form from collapse
  - elliptical galaxies are produced by mergers
  - spiral structure is maintained by a density wave triggered by bar, companion or close passage
- How can we test these ideas?
  - need to look at galaxies in the process of formation



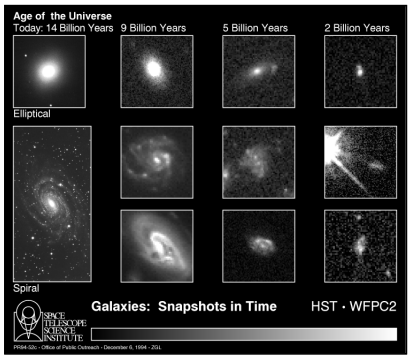
Looking back in time

- Light from a distant galaxy takes time to get here
  - M31 is 2 million light years away
  - we see it as it appeared 2 million years ago
    - 2 million years is a short time
    - but looking at very distant galaxies we see them as they were billions of years ago

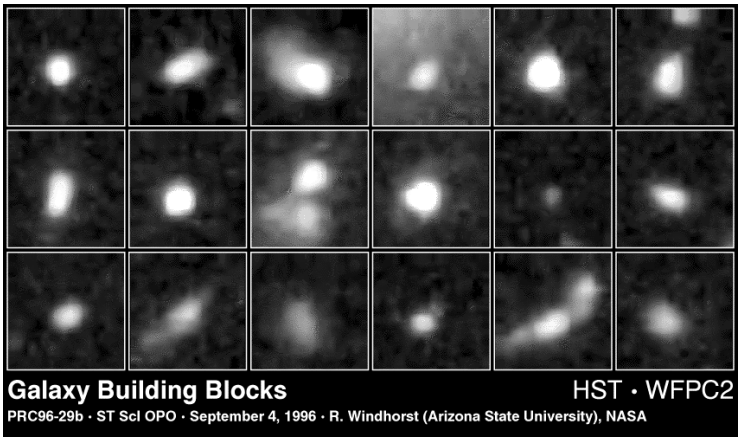


Results from "deep fields"

- Images of very distant galaxies contain
  - large numbers of interacting galaxies (up to 25% — now 1%)
  - more disrupted and irregular galaxies rather than "modern" spirals
  - some apparently normal elliptical galaxies
    - results of early collisions?
  - many small, blue objects
    - which will merge to form larger modern galaxies?

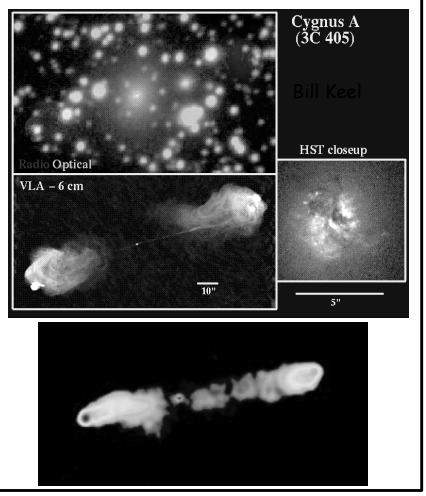


Baby galaxies



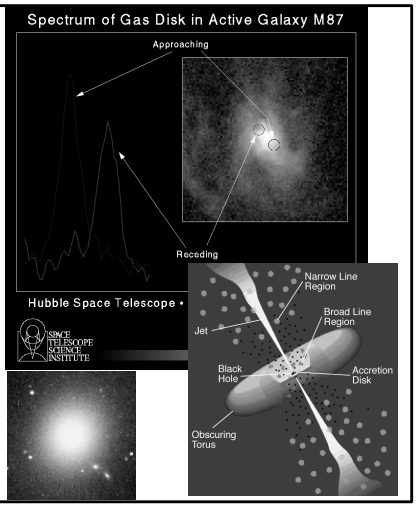
Wild youth: active galaxies

- The light from some galaxies isn't just stars
  - enormous amounts of "extra" luminosity in radio, X-rays, etc.
  - sometimes associated with huge "jets" extending over millions of light years
  - much more common in distant objects, i.e. when galaxies were young
  - galaxies responsible often disrupted ellipticals
    - activity associated with galaxy interactions?



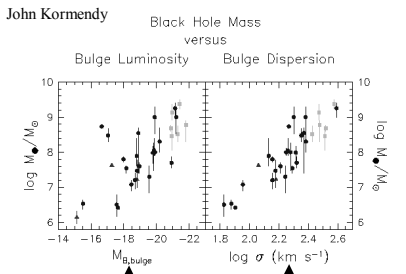
Active galaxies & black holes

- Huge luminosities of active galaxies powered by very small object in centre
  - probably supermassive black hole
  - energy generated by gas heated up by friction as it falls into black hole
  - eventually black hole runs out of accessible gas, becomes quiet (like ours)
    - many modern galaxies should contain black holes



Black holes in galaxy centres

- Most large galaxies do seem to contain black holes
  - detected by applying Newton's laws to motion of stars and gas in central region of galaxy
- The more massive the galaxy's central bulge, the larger the black hole
  - cause or effect? or bias??



bulge brightness and orbital speeds of bulge stars are both measures of the mass of the bulge

What have we learned?

- Pre-galactic gas clouds are quite small
  - could form dwarf galaxies or merge to form galaxies like the Milky Way
  - spirals could form when most merging occurs early
    - they take time to settle down: early galaxies are more irregular
  - ellipticals may result from collisions between fully-fledged galaxies
    - simulations support this
- Spiral structure may be due to a density wave
  - started by bar, companion or close encounter
  - causes star formation
- Many galaxies contain central black holes
  - when the galaxy is young these can power nuclear activity

To go beyond galaxies we need to consider the whole universe

… next lecture!