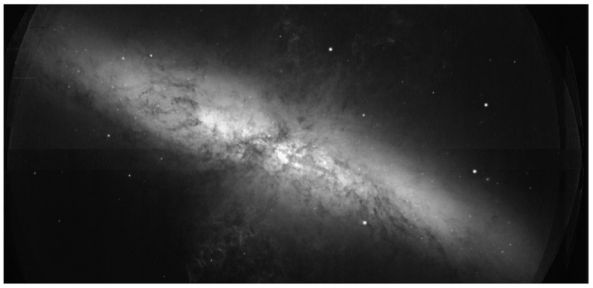
Chapter 21
Galaxy Evolution



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Preview: Evolution of Structure in the Universe

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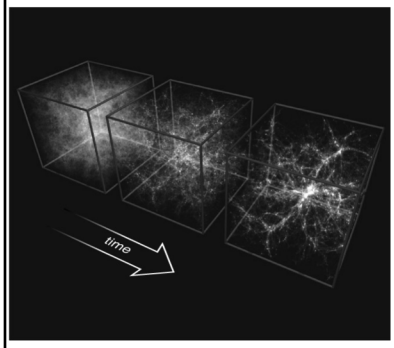

Our best models for galaxy formation assume:

- Matter originally filled all of space almost uniformly
- Gravity of denser regions pulled in surrounding matter

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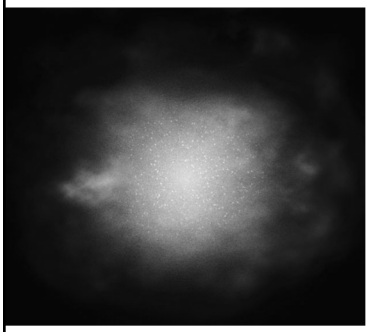

Denser regions contracted, forming ***protogalactic clouds***

H and He gases in these clouds formed the first stars

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Supernova explosions from first stars kept much of the gas from forming stars

Leftover gas settled into spinning disk

Conservation of angular momentum

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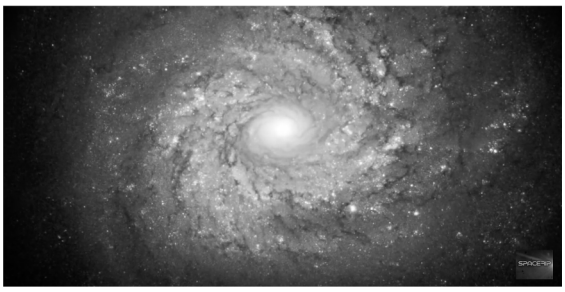
Models: Evolution of Galaxy Interactions



https://www.youtube.com/watch?v=Xu3-0Ubhiwo

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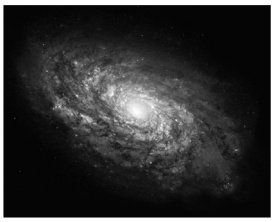
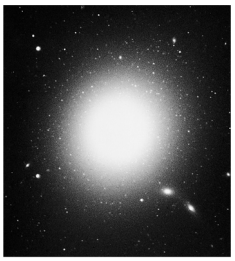
NGC 4414



M87



But why do some galaxies end up looking so different?

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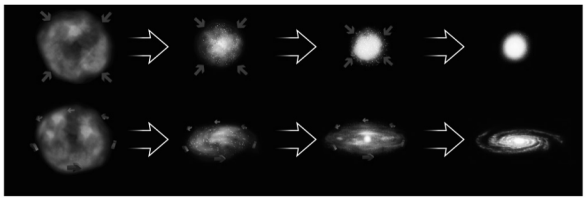
Conditions in Protogalactic Cloud?



Spin: Initial angular momentum of protogalactic cloud could determine size of resulting disk

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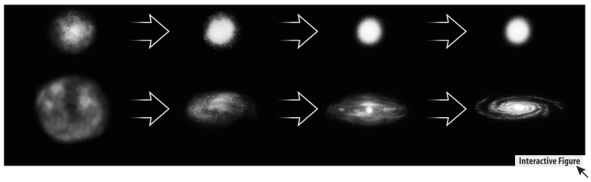
Conditions in Protogalactic Cloud?



Density: Elliptical galaxies could come from dense protogalactic clouds that were able to cool and form stars before gas settled into a disk

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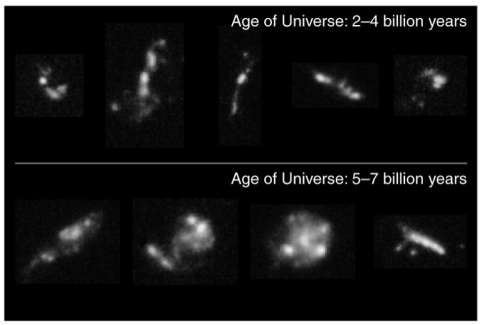

Collisions were more common in early smaller Universe. Many of the galaxies we see at great distances (and early times) indeed look violently disturbed.

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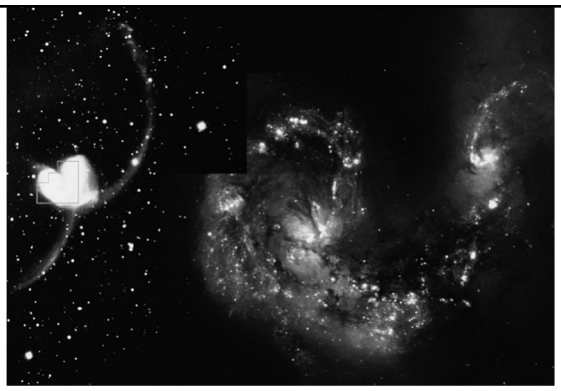

Stars miss but gas collides triggering bursts of star formation

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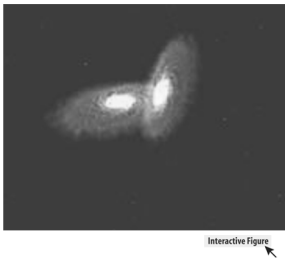

Modeling such collisions on a computer shows that two spiral galaxies can merge to make an elliptical:
Milky Way – Andromeda collision in the future
https://www.youtube.com/watch?v=mzgGhpAu2_I

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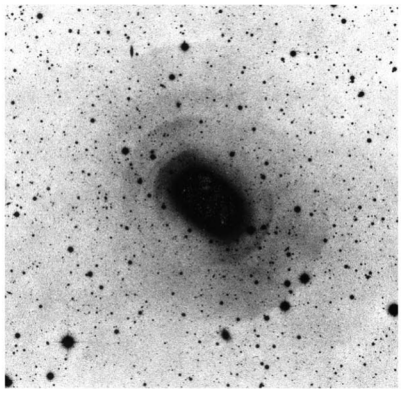

Shells of stars observed around some elliptical galaxies are probably the remains of past collisions

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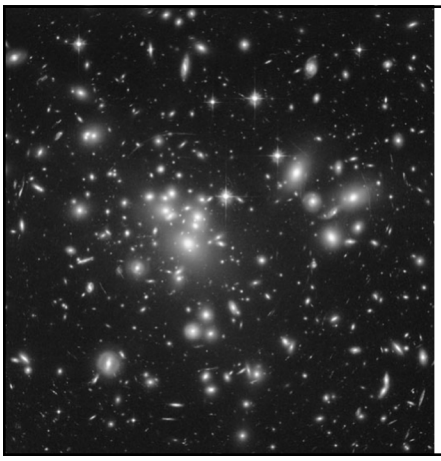

Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together

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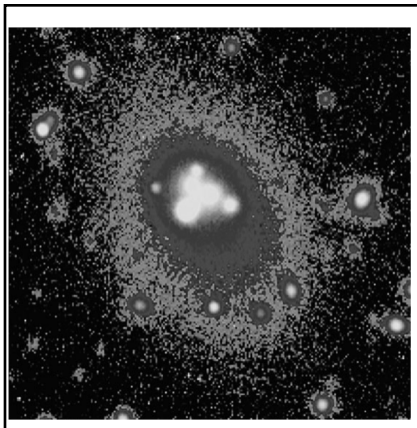

Giant elliptical galaxies at the centers of clusters seem to have consumed a number of smaller galaxies

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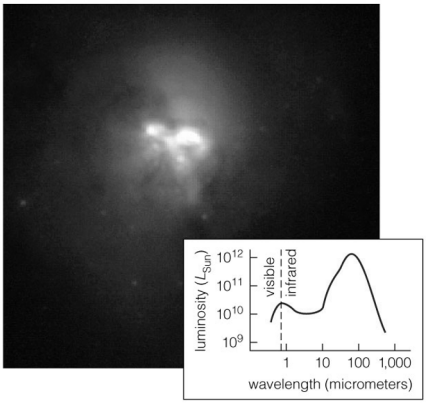

Collisions may induce *Starburst Galaxies*; form stars so quickly they would use up all their gas in less than a billion years

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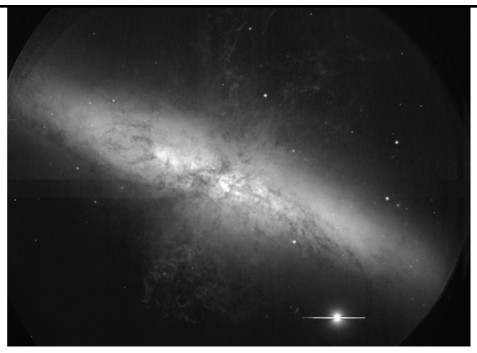

Intensity of supernova explosions in starburst galaxies can drive galactic winds

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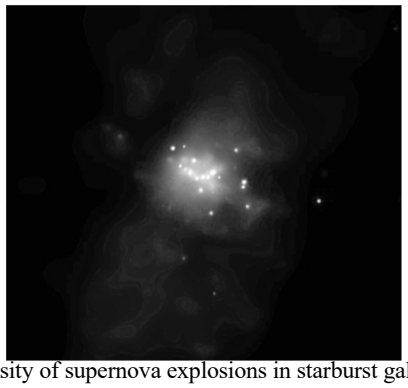

X-ray image

Intensity of supernova explosions in starburst galaxies can drive galactic winds

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Next Time: Active galactic nuclei

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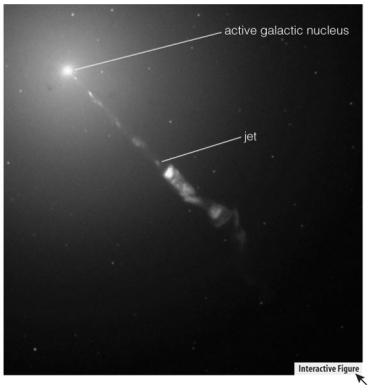

Active Nucleus in M87

If the center of a galaxy is unusually bright we call it an ***active galactic nucleus***

Quasars are the most luminous examples; large redshifts (Hubble's Law)

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Characteristics of Active Galaxies

- Luminosity can be enormous (>10^{12} L_{Sun})
- Luminosity can rapidly vary (comes from a space smaller than solar system)
- Emit energy over a wide range of wavelengths (contain matter with wide temperature range)
- Some drive jets of plasma at near light speed

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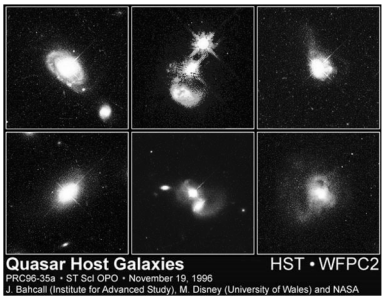

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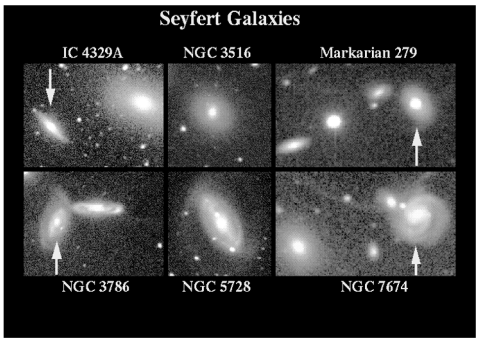

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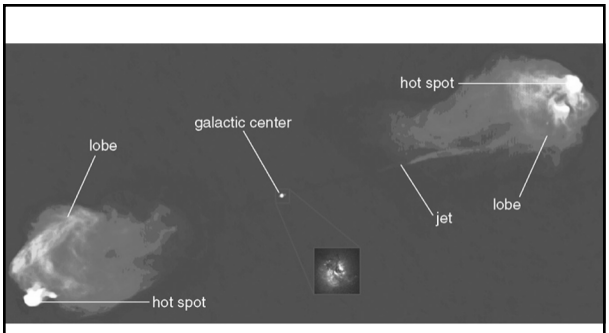

Radio galaxies contain active nuclei shooting out vast jets of plasma that emits radio waves coming from electrons moving at near light speed

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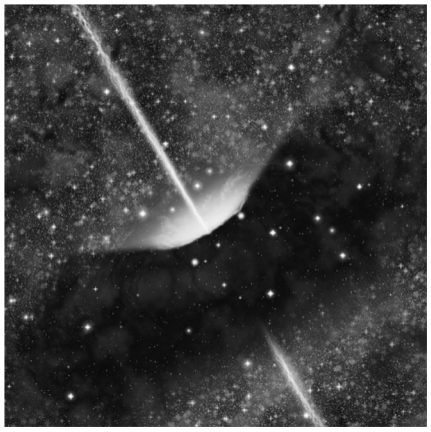

Radio galaxies don't appear as quasars because dusty gas clouds block our view of accretion disk

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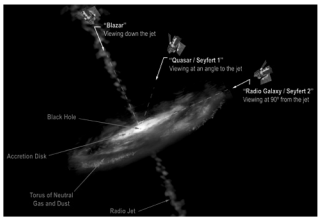
Blazar

Quasar or Seyfert Galaxy



Radio Galaxy

What we see depends on orientation

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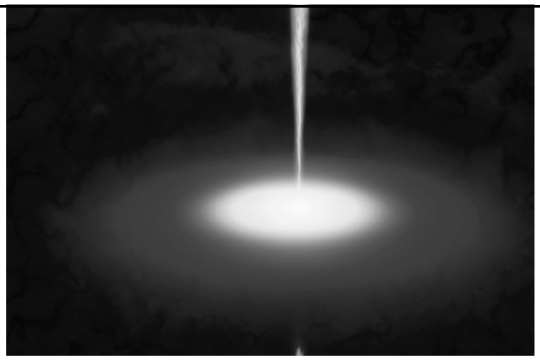

Accretion of gas onto a supermassive black hole produces friction, heat, radiation, jets (10-40% of mass-energy can be converted to radiation on approach to event horizon).

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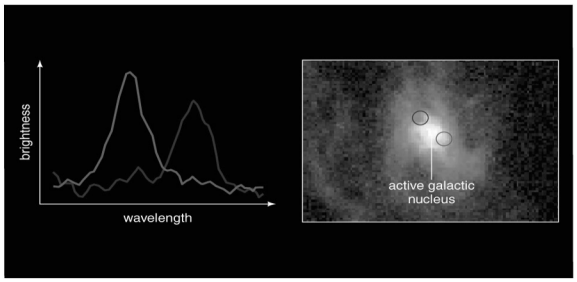

Orbital speed and distance of gas orbiting center of M87 indicate a black hole with mass of 6 billion M_{Sun}

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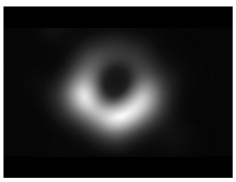
Event Horizon Telescope

- Array of radio telescopes around the world
- Gathered data on distant giant galaxy M87
- Final image reveals the central black hole shadow: first picture of a black hole
- https://www.youtube.com/watch?v=oLeKFDfCrTg



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Thought Question

What can you conclude from the fact that quasars usually have very large redshifts?

A. They are generally very distant
B. They were more common early in time
C. Galaxy collisions might turn them on
D. Nearby galaxies might hold dead quasars
E. All of the above

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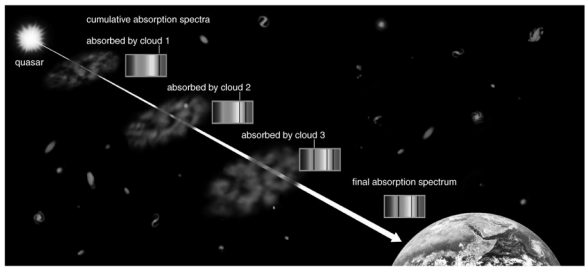

Gas clouds between a quasar and Earth absorb some of a quasar's light

We can learn about protogalactic clouds by studying the absorption lines they produce in quasar spectra

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Black Holes in Galaxies

- Many nearby galaxies – perhaps all of them – have supermassive black holes at their centers
- These black holes seem to be dormant active galactic nuclei
- All galaxies may have passed through a quasar-like stage earlier in time
- Even found in very distant galaxies at times when Universe was less than one billion years old

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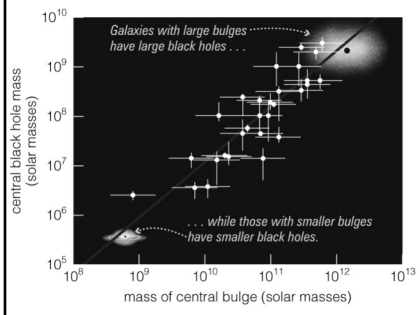
Galaxies and Black Holes



- Mass of a galaxy's central black hole is closely related to mass of its bulge

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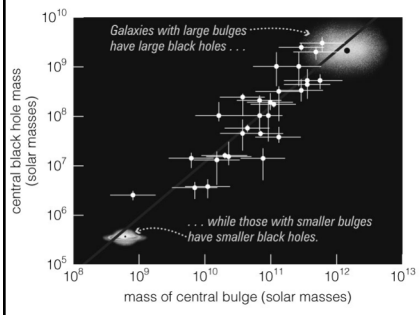
Galaxies and Black Holes



- Development of central black hole must be somehow related to galaxy evolution

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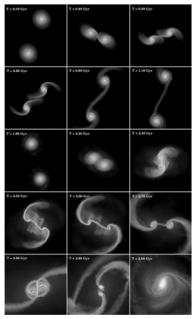
How did supermassive black holes form?



- Collisions of galaxies and gas infall
- Explosions of clusters of massive stars
- Concentrating stars in the centers of star clusters
- Very dense locations https://rh.gatech.edu/news/616736/birth-massive-black-holes-early-universe-revealed

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