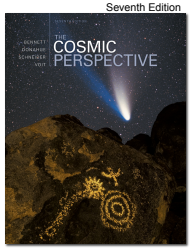
Chapter 21 Lecture

The Cosmic Perspective

Seventh Edition



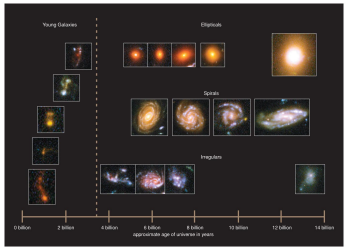
Galaxy Evolution

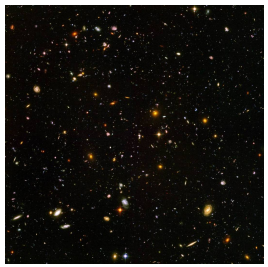
Galaxy Evolution

21.1 Looking Back Through Time

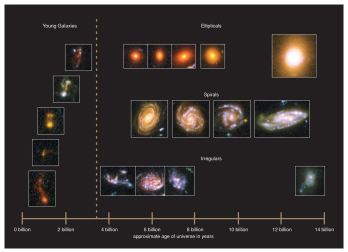
- Our goals for learning:
  - **How do we observe the life histories of galaxies?**
  - **How do we study galaxy formation?**

How do we observe the life histories of galaxies?



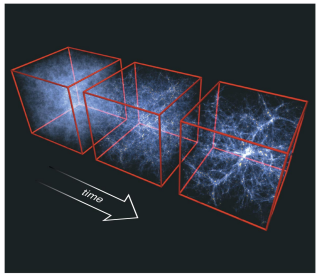


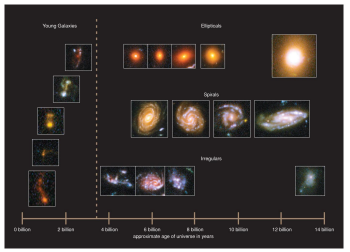
- Deep observations show us very distant galaxies as they were much earlier in time (old light from young galaxies).



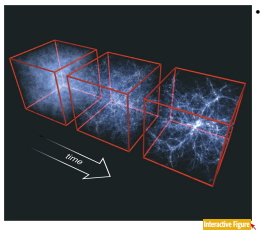
- Observing galaxies at different distances shows us how they age.

How do we study galaxy formation?





- We still can't directly observe the earliest galaxies.



- Our best models for galaxy formation assume:
  - Matter originally filled all of space almost uniformly.
  - Gravity of denser regions pulled in surrounding matter.

- Denser regions contracted, forming ***protogalactic clouds***.
- Hydrogen and helium gas in these clouds formed the first stars.

- Supernova explosions from the first stars kept much of the gas from forming stars.
- Leftover gas settled into a spinning disk due to the ***conservation of angular momentum***.

NGC 4414

M87

- But why do some galaxies end up looking so different?

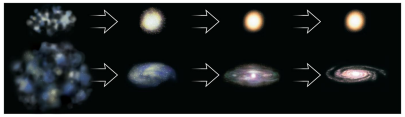
What have we learned?

- **How do we observe the life histories of galaxies?**
  - Deep observations of the universe show us the history of galaxies because we are seeing galaxies as they were at different ages.
- **How do we study galaxy formation?**
  - Our best models for galaxy formation assume that gravity made galaxies out of regions in the early universe that were slightly denser than their surroundings.

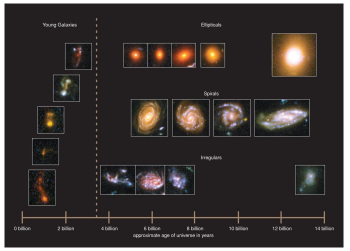
21.2 The Lives of Galaxies

- Our goals for learning:
  - **Why do galaxies differ?**
  - **What are starbursts?**

Why do galaxies differ?

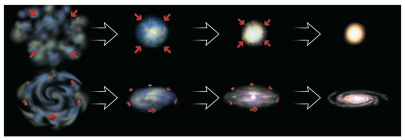


b The gas density of a galaxy's protogalactic clouds may determine whether it ends up spiral or elliptical.



- Why don't all galaxies have similar disks?

Conditions in Protogalactic Cloud?

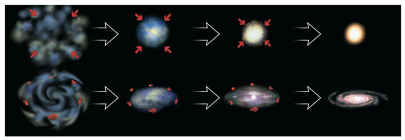


a The angular momentum of a galaxy's protogalactic-cloud system may determine whether it ends up spiral or elliptical.

Interactive Figure

- ***Spin:*** The initial angular momentum of the protogalactic cloud could determine the size of the resulting disk.

Conditions in Protogalactic Cloud?

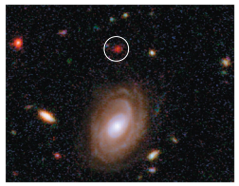


a The angular momentum of a galaxy's protogalactic-cloud system may determine whether it ends up spiral or elliptical.

Interactive Figure

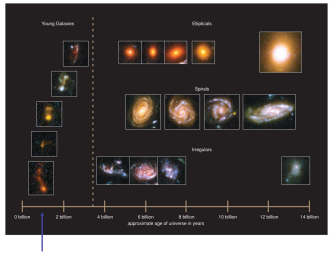
- ***Density:*** Elliptical galaxies could come from dense protogalactic clouds that were able to cool and form stars before gas settled into a disk.

Distant Red Ellipticals

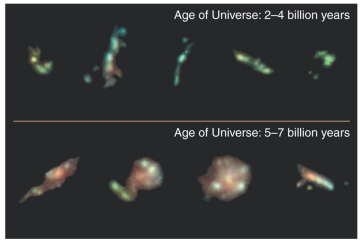


- Observations of some distant red elliptical galaxies support the idea that most of their stars formed very early in the history of the universe.

- We must also consider the effects of collisions.

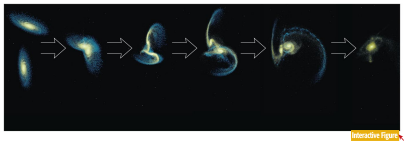


- Collisions were much more likely early in time because galaxies were closer together.



- Many of the galaxies we see at great distances (and early times) do look violently disturbed.

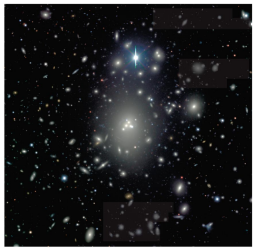
- The collisions we observe nearby trigger bursts of star formation.



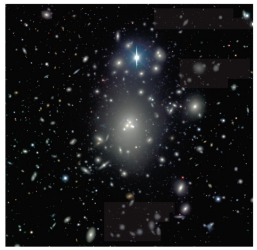
Interactive Figure

- Modeling such collisions on a computer shows that two spiral galaxies can merge to make an elliptical.

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

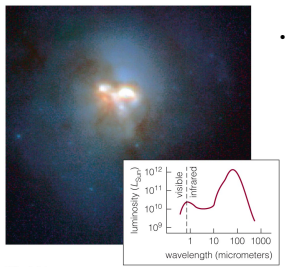


- Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together.



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

What are starbursts?

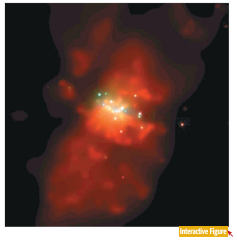


- Starburst galaxies are forming stars so quickly that they would use up all their gas in less than a billion years.

Visible-light image

Interactive Figure

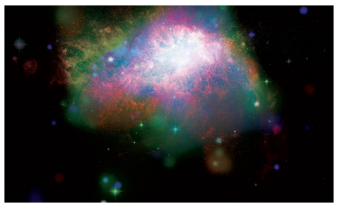
- Intensity of supernova explosions in starburst galaxies can drive galactic winds.



X-ray image

Interactive Figure

- Intensity of supernova explosions in starburst galaxies can drive galactic winds.



- A galactic wind in a small galaxy can drive away most of its gas.

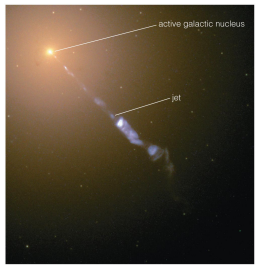
What have we learned?

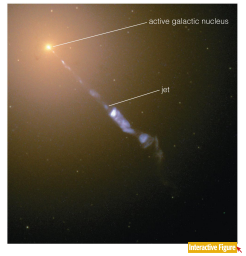
- **Why do galaxies differ?**
  - Some of the differences between galaxies may arise from the conditions in their protogalactic clouds.
  - Collisions can play a major role because they can transform two spiral galaxies into an elliptical galaxy.
- **What are starbursts?**
  - A starburst galaxy is transforming its gas into stars much more rapidly than a normal galaxy.

21.3 Quasars and Other Active Galactic Nuclei

- Our goals for learning:
  - **How are quasars powered?**
  - **Do supermassive black holes really exist?**
  - **How do quasars let us study gas between the galaxies?**

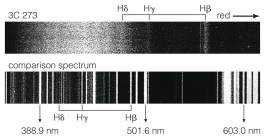
How are quasars powered?





Active nucleus in Galaxy M87

- If the center of a galaxy is unusually bright, we call it an ***active galactic nucleus.***
- Quasars are the most luminous examples.



- The highly redshifted spectra of quasars indicate large distances.
- From brightness and distance we find that luminosities of some quasars are greater than $10^{12}\ L_{Sun}$.
- Variability shows that all this energy comes from a region smaller than our solar system.

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.

Thought Question

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

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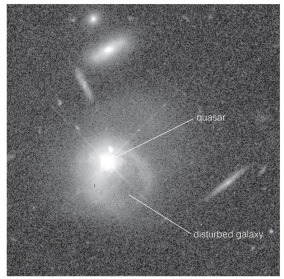
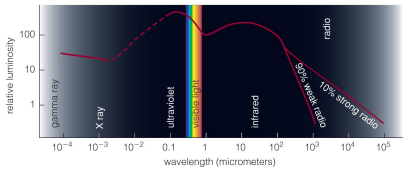
C. Galaxy collisions might turn them on.
D. Nearby galaxies might hold dead quasars.

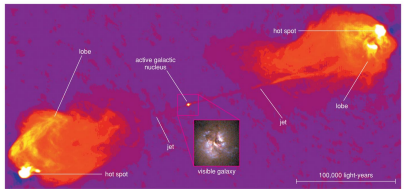
All of the above!



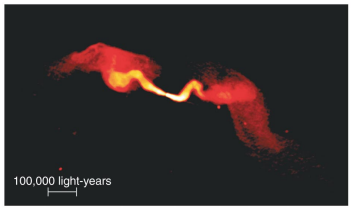
- Galaxies around quasars sometimes appear disturbed by collisions.



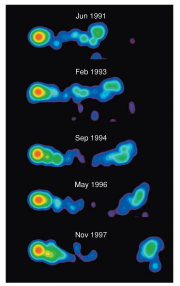
- Quasars powerfully radiate energy over a wide range of wavelengths, indicating that they contain matter with a wide range of temperatures.



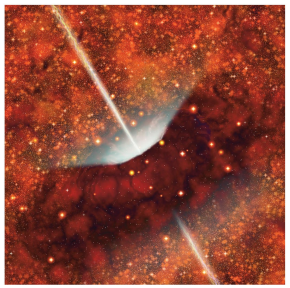
- ***Radio galaxies*** contain active nuclei shooting out vast jets of plasma that emits radio waves coming from electrons that move at near light speed.



- The lobes of radio galaxies can extend over hundreds of thousands of light-years.



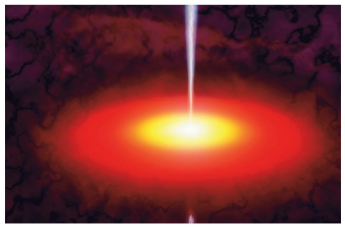
- An active galactic nucleus can shoot out blobs of plasma moving at nearly the speed of light.
- These ejection speeds suggests the presence of a black hole.



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

Characteristics of Active Galaxies

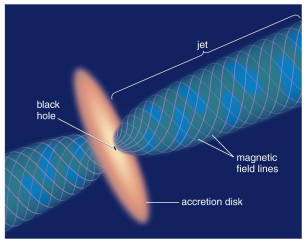
- Their luminosities can be enormous (>$10^{12}\ L_{Sun}$).
- Their luminosities can rapidly vary (come from a space smaller than solar system).
- They emit energy over a wide range of wavelengths (contain matter with a wide temperature range).
- Some galaxies drive jets of plasma at near light speed.



- Accretion of gas onto a supermassive black hole appears to be the only way to explain all the properties of quasars.

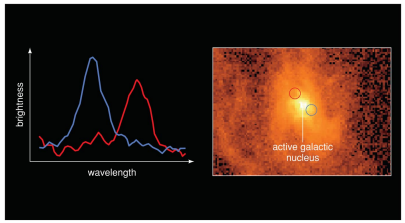
Energy from a Black Hole

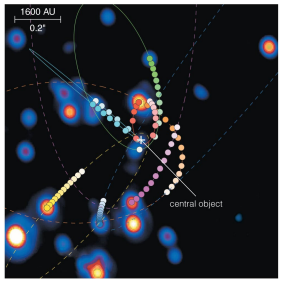
- Gravitational potential energy of matter falling into black hole turns into kinetic energy.
- Friction in an accretion disk turns kinetic energy into thermal energy (heat).
- Heat produces thermal radiation (photons).
- This process can convert 10 to 40% of $E = mc^2$ into radiation.



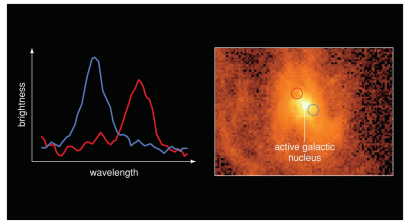
- Jets are thought to come from twisting of magnetic field in the inner part of accretion disk.

Do supermassive black holes really exist?





- Orbits of stars at center of Milky Way stars indicate a black hole with mass of 4 million M_{Sun}.

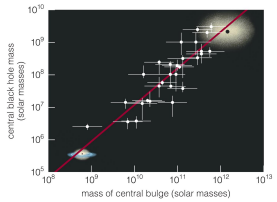


- The orbital speed and distance of gas orbiting the center of Galaxy M87 indicate a black hole with mass of 3 billion M_{Sun}.

Black Holes in Galaxies

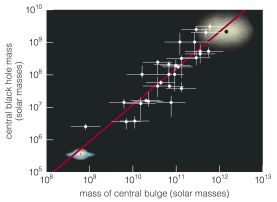
- Many nearby galaxies—perhaps all of them—have supermassive black holes at their centers.
- These black holes seem to be dormant active galactic nuclei.
- All galaxies may have passed through a quasar-like stage earlier in time.

Galaxies and Black Holes



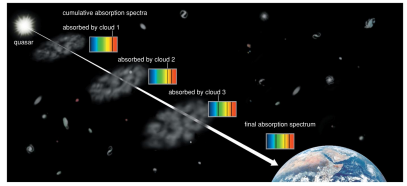
- The mass of a galaxy's central black hole is closely related to the mass of its bulge.

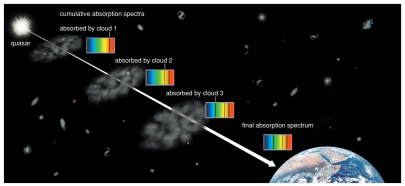
Galaxies and Black Holes



- The development of the central black hole must be somehow related to galaxy evolution.

How do quasars let us study gas between the galaxies?





- Gas clouds between a quasar and Earth absorb some of the quasar's light.
- We can learn about protogalactic clouds by studying the absorption lines they produce in quasar spectra.

What have we learned?

- **How are quasars powered?**
  - Active galactic nuclei are very bright objects seen in the centers of some galaxies, and quasars are the most luminous type.
  - The only model that adequately explains the observations holds that supermassive black holes are the power source.

What have we learned?

- **Do supermassive black holes really exist?**
  - Observations of stars and gas clouds orbiting at the centers of galaxies indicate that many galaxies, and perhaps all of them, have supermassive black holes.
- **How do quasars let us study gas between the galaxies?**
  - Absorption lines in the spectra of quasars tell us about intergalactic clouds between those quasars and Earth.