A100–Exploring the Universe: Evolution of Galaxies

Martin D. Weinberg
UMass Astronomy
weinberg@astro.umass.edu

November 29, 2012
Announcements

- Exam #3: Thu 6 Dec (last class)
- Final exam: Hasbrouck 20 (here!) on Wednesday 12 December at 8:00am

Read: Chaps 21, 22
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Today: Galaxy formation and evolution

- How do we observe the life histories of galaxies?
- How did galaxies form?
- Why do galaxies differ?
- How do galaxies evolve?
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Today: Galaxy formation and evolution

- How do we observe the life histories of galaxies?
- How did galaxies form?
- Why do galaxies differ?
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Questions?
How did galaxies form?

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

H and He gases in these clouds formed the first stars

Denser regions contracted, forming protogalactic clouds

H and He gases in these clouds formed the first stars
Supernova explosions from first stars kept much of the gas from forming stars

- Leftover gas settled into spinning disk
- Conservation of angular momentum
Why do some galaxies end up looking so different?

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Red ellipticals
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Tidal interactions
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Ring/Splash
Cartwheel galaxy
Galactic Cannibalism
Future: Andromeda and the Milky Way
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Starbursts
Galactic Wind
Summary

b NGC 4414, a spiral galaxy whose disk is somewhat tilted to our line of sight.

a M87, a giant elliptical galaxy in the Virgo Cluster, is one of the most massive galaxies in the universe. The region shown is more than 120,000 light-years across.

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Why do some galaxies end up looking so different?

Why don’t all galaxies have similar disks?
Spin: Initial angular momentum of protogalactic cloud could determine size of resulting disk.
Density: Elliptical galaxies could come from dense protogalactic clouds that were able to cool and form stars before gas settled into a disk.
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.

Read: Chaps 21, 22
Many of the galaxies we see at great distances (and early times) indeed look violently disturbed.
Galaxy interactions

- Clustering: galaxies tend to be found in the vicinity of other galaxies
- Galaxies are large compared to the distances between them
  - Significant fraction of the galaxy is beyond their luminous component (dark matter)

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  - Most stars are separated by $10^7$ times their diameters
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Galaxies are likely to encounter other galaxies!
Galaxies interact through gravitation

Two galaxies passing near each other raise mutual tides

Tides distort the shapes of the galaxies

Gives rise to dramatic effects without direct collision

Many *peculiar* galaxies are interacting pairs
How do tides work in galaxies?

- Just as in Earth-Moon system
- Tidal stretching along the line between the two galaxies
  - Near side feels stronger gravitational pull from the companion
  - Far side feels weaker gravitational pull and lags behind the near side
Galaxy interactions are very slow

- Timescale: billions of years

Physical insight from computer simulations:

- Solve Newton’s laws of motion for stars and gas
- Compare predictions with observed properties of interacting galaxies

Advanced computing techniques: parallel computation, supercomputing
Rare direct collisions have more dramatic effects:

- Stars and gas stripped by tidal force
- Forms *tidal* arms and bridges
- Stars do not collide
- Gas clouds *do* collide
- Huge burst of star formation in disk
Galaxy collision example
Galaxies may initially have escape velocity
- Exchange energy and angular momentum
- Can dissipate enough orbital energy to become bound!
  - Wreckage merges into a single galaxy
  - Gas clouds collide and form new stars
  - Some stars and gas may be ejected from the system
    - Carrying away angular momentum and energy

Mergers may play a pivotal role in the formation of galaxies

Evidence: clusters have more elliptical galaxies than spirals
A fast-moving smaller galaxy passes through the center of a larger disk galaxy

- Results in a tidal ring
  - Circular density wave moving outward through large galaxy
  - Wave triggers star formation in the disk gas
- Interloping galaxy passes on through

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Example: Cartwheel galaxy
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Galactic Cannibalism

- Slow encounter between a large and small galaxy
  - Smaller galaxy gets torn apart by tides from larger galaxy
  - Gas and stars incorporated by larger galaxy
  - Nuclei of the galaxies slowly spiral together

- May be the way giant elliptical galaxies grow

Read: Chaps 21, 22
The collisions we observe nearby trigger bursts of star formation.
Future: Andromeda and the Milky Way

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Future: Andromeda and the Milky Way

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

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

The central region of elliptical galaxy NGC 3923 is surrounded by several distinct shells of stars. These stars probably formed after gas was stripped out of the galaxy during a past collision. The image is a negative in which starlight is black and space is white because it makes it easier to see faint details.
Collisions and Clusters

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.
This visible-light photograph (from the Hubble Space Telescope) shows violently disturbed gas (red) blowing out both above and below the disk.
Starburst galaxies are forming stars so quickly they would use up all their gas in less than a billion years.
Intense supernova explosions in starburst galaxies can drive galactic winds.

*This visible-light photograph (from the Hubble Space Telescope) shows violently disturbed gas (red) blowing out both above and below the disk.*

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Starbursts

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This X-ray image from the Chandra X-Ray Observatory shows the same region as the visible-light photograph in (a). The reddish region represents X-ray emission from very hot gas blowing out of the disk. The bright dots in the galactic disk probably represent X-ray emission from accretion disks around black holes or neutron stars produced by recent supernovae.

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A galactic wind in a small galaxy can drive away most of its gas.
How do observe the history of galaxies?

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- Deep observations of the universe are showing us the history of galaxies because we are seeing galaxies as they were at different ages.

How do galaxies form?

- Our best models for galaxy formation assume that gravity made galaxies out of regions of the early universe that were slightly denser than their surroundings.
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.
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- Some of the differences between galaxies may arise from the conditions in their protogalactic clouds.
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What are starbursts?

- A starburst galaxy is transforming its gas into stars much more rapidly than a normal galaxy.