Lecture 31: Interacting Galaxies and Active Galactic Nuclei

Key Ideas:
Tidal Interactions between Galaxies:
   Close Tidal Encounters
   Galaxy-Galaxy Collisions
   Splash encounters
Starbursts Induced by Interactions
Mergers & Galactic Cannibalism
Fate of the Milky Way & Andromeda?

Active Galactic Nuclei
   Powerful energy sources in some galaxy nuclei
Power source
   Accretion of matter by Supermassive Black Holes
Types of Active Galaxies
   Quasars
   Seyfert Galaxies
   Radio Galaxies

Elbow Room
Galaxies are large compared to the distances between them:
   Most galaxies are separated by only \( \sim 20 \) times their diameters
   By comparison, most stars are separated by \( \sim 10^7 \) times their diameters
Galaxies are likely to encounter other galaxies a few times over their histories.

Tidal Interactions
Galaxies interact via \textit{Gravitation}.
   Because of their large sizes, two galaxies passing near each other raise mutual tides.
   These tides distort the shapes of the galaxies
   Dramatic effects \textit{without} direct collision

Most “peculiar galaxies” are interacting pairs.
Raising Tides

Tidal stretching along the encounter line
- Near side feels stronger gravitational pull from the comparison
- Far side feels weaker gravitational pull and lags behind the near side

Overlapping Galaxy Pair

Credit: Hubble Space Telescope

Computer Simulations
Galaxy Interactions are very slow
- Timescales of ~ 1 billion years
Much of what we know comes from computer simulations
- Solve Newton’s Laws of Motion for gas & stars
- Compares predictions to observed galaxies
Requires the fastest supercomputers

Galaxy Collisions
Direct collisions have more dramatic effects:
- Tides raised are stronger, giving greater tidal distortion
- Tear off huge “Tidal Tails” of stars and gas
- Stars pass through without colliding, but
Gas clouds collide, leading to a massive starburst in the galaxy disks.
Example: “The Mice” (NGC 4676)

Credit: Hubble Space Telescope

Witness a computer simulation of the formation of “The Mice” at Dr. John Dubinski’s web site www.cita.utoronto.ca/~dubinski/nbody/ . Also present are other nifty simulations, including the collision of Andromeda and the Milky Way.

Starbursts
Case of intense star formation in a galaxy
- Gas compresses, causing enhanced star formation
- Millions of O&B stars greatly enhance the brightness of the galaxy
- Exhausts the available gas in a few Myrs.
- Many supernovae can drive fast “superwinds” blowing out of the galaxies.

The most intense starbursts occur in violently interacting galaxy pairs.

Example:
Starburst in “The Antennae”

Mergers
If two colliding galaxies can dissipate enough orbital energy:
- Wreckage merges into a single galaxy
- Gas clouds collide and form new stars
- Some portion of the old stars are ejected from the system (carry off orbital energy)

Mergers appear to play a pivotal role in the formation (“assembly”) of galaxies. In particular, mergers of two spirals = ellipticals?

Computer simulations of spiral-spiral mergers resulting in an elliptical galaxy courtesy of Dr. Volker Springel at www.mpa-
They are similar to observations made of merging galaxies.

Galactic Cannibalism
Slow encounter between a large and a small galaxy
  Smaller galaxy gets torn apart by the tides from the larger galaxy
  Gas and stars get incorporated into the larger galaxy
  Nuclei of the galaxies slowly spiral together
May be the way that giant Ellipticals grow.

Milky Way: Guilty of Galactic Cannibalism
Milky Way currently munching the Sagittarius dwarf spheroidal. The Sag dSph is spiraling into the Milky Way, and huge tidal tails are appearing leading and trailing the dwarf.

The Milky Way & Andromeda
The Milky Way (us) & Andromeda are perhaps on a collision course:
  Moving toward each other at ~120 km/sec
  In ~3-4 Gyr, they will have a close encounter
  Tidally distort and merge after ~1-2 Gyr
Eventually, only 1 galaxy would remain behind, most likely a medium-sized Elliptical.

Active Galaxies & Quasars

Galactic Nuclei
Galaxy Nucleus:
  Exact center of a galaxy and its immediate surroundings
  If a spiral galaxy, it is also the center of rotation
Normal Galaxies:
  Dense central star cluster
  A composite stellar absorption-line spectrum
  May also show weak nebular emission lines
Image of the nucleus of the Milky Way (see Figure 25-22c)

3.7 x 10^6 M_{Sun} Black Hole at the Center of the Milky Way. Found by the velocities of stars near the Galactic center. Some emission from gas swirling into the black hole, but not particularly bright.

**Active Galactic Nuclei (AGN)**

About 1% of all galaxies have bright active nuclei

**Bright, compact nucleus**

- Sometimes brighter than the entire rest of the galaxy
- Strong, broad emission lines from hot, dense, highly excited gas

**Rapidly Variable**

- Small, only a few light days across

In general, about 30%-50% of spiral galaxies show some level of activity in their nuclei, but only 1% are truly dominated by nuclear activity.

**What powers AGNs?**

Properties that need to be explained:

- **Powerful:**
  - Luminosities of Billions to Trillions of suns
  - Emit from Radio to Gamma rays

- **Compact:**
  - Visible light varies on day timescales
  - X-ray can vary on a few hour timescales!

**The Black Hole Paradigm**

The energy source is accretion of matter by a supermassive Black Hole

- “Supermassive”=10^6-10^9 M_{Sun}
- Schwarzschild Radii: ~0.01-10 AU

Infalling matter releases gravitational binding energy:

- Infalling gas settles into an accretion disk
- The hot inner parts of the disk shine very brightly, especially at X-rays

Diagrams of the accretion disk and jet in Figure 27-19, 20, and 21.
The Central Engine
Black Hole accretion is very efficient
  Up to 10% efficiency
  ~1 Myr/year needed for a bright AGN
Get “fuel” from surrounding gas and stars
Rapidly Spinning Black Hole:
  Acts like a particle accelerator
  Leads to the jets seen in radio-loud AGNs
Example: M87, an elliptical galaxy with an AGN and a Jet

Examples of Spectra from Active Galactic Nuclei

Credit: Spinelli et al. 2006
The AGN Zoo
While all the same basic phenomena, AGN are traditionally grouped into 3 basic types:

Quasars: “Quasi-Stellar Radio Sources”
See Figure 27-2 for quasar 3C 48
Most luminous AGN, outshine entire galaxies.

Seyfert Galaxies
Low-luminosity Quasars

Radio Galaxies
AGN unusually strong at radio wavelength
Many show large-scale radio jets

Example: Radio Galaxy, Cygnus A (see Figure 27-1)

Some Nagging Questions:
How do supermassive black holes form?
We don’t really know for sure, but it appears to be coupled to galaxy formation

How are they fueled?
Galaxy interactions might dump gas into the nuclear regions to feed the Black Hole.
Stellar bars might funnel gas into the nucleus from the disk of the galaxy
Cannibalism of gas-rich dwarf?

With HST, we see the host galaxies of quasars. Many of them are interacting, providing ways for fuel to get down to the nuclei.
(see Figure 27-24)

Why don’t all galaxies have active galactic nuclei?
Nearly all spirals show some level of activity
Dynamical evidence for massive black holes in many nearby “inactive” galaxies.
Milky Way has a 3x10^6 M_{Sun} black hole, but lacks strong activity
Many more AGNs in the distant past, but few today—where are all the dead quasars?
Need fuel – supplied by interaction/merging?
Finding answers is an active area of research.