Lecture 31: Interacting Galaxies and Active Galactic Nuclei

Readings: Sections 26-7, 27-1, 27-2, 27-3, 27-4 and 27-5

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 ~20 times their diameters
- By comparison, most stars are separated by ~10^7 times their diameters

Galaxies are likely to encounter other galaxies a few times over their histories.

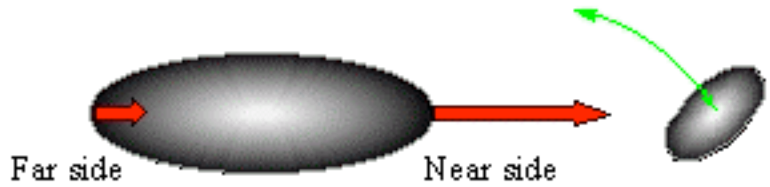
Tidal Interactions

Galaxies interact via *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 *without* direct collison

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.mpagarching.mpg.de/~volker/gadget/index.html (scroll down towards the bottom.) 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.

Computer simulation of Milky Way and Andromeda courtesy of Dr. Dubinski.

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

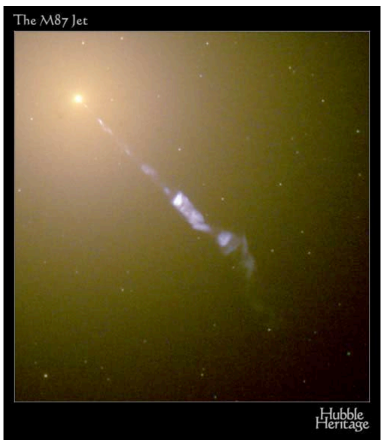
Black Hole accretion is very efficient

- Up to 10% efficiency
- ~1 Myr/year needed for a bright AGN
- Get “fuel” from surrounding gas and stars

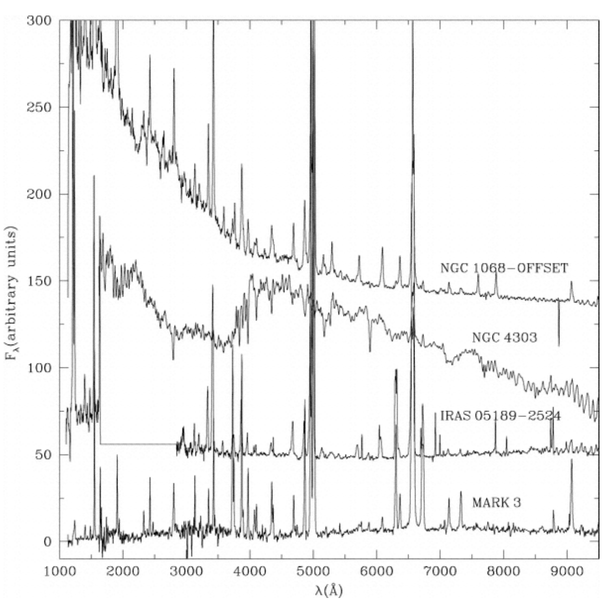
Rapidly Spinning Black Hole:

- 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 3×10^6 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.