On Galaxy Evolution Lane

- Most striking: *many galaxies experience collisions* thus becoming "interacting galaxies"
- Begin to discuss *active galaxies* and quasars
- Re-read 21.3 *Quasars and active galactic nuclei* in detail

*Third Mid-Term Exam* this Fri 20 Apr
Evening review by Nick tonight 7-9 pm

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**Clicker – Cepheids and distance**

- Two Cepheid stars, Fred and Barney, have the *same apparent brightness*. Fred has a period of 5 days, and Barney of 10 days. *Which is closer?*

  - A. Fred
  - B. Barney

**Why A. Fred?**

- Fred has a *shorter period* and so must be *less luminous*
- Less luminous but *the same apparent brightness means that Fred is closer to us*

**Distance ladder to measure universe**

Different standard candles are useful for different distances.
Hubble’s Law implies: Universe expands like raisin bread!

True for very large scales between galaxies – but not for stars, planets, us!

Use Hubble’s Law for “distances”

- Measuring distances to remote galaxies is difficult, but measuring Doppler shifts (velocities) is easier from spectra

- Use Hubble’s Law to estimate biggest distances (really LOOKBACK TIME)!

Use Hubble’s Law itself to estimate vast distances $D$

- Measure velocity, then: $D = \frac{v}{H_0}$

- Example: using $H_0 = 70$ km/sec/Mpc, and finding that $v = 700$ km/sec

$D = 700$ km/sec / 70 km/sec/Mpc = 10 Mpc = 32 million light years

Knowing distances reveals large-scale galaxy clustering

Find clusters + super-clusters: sheets and voids like ‘bubble bath’

Telescopes are “lookback” time machines

Today, we see Andromeda as she was 2.5 M years ago!
**Lookback time (in expanding universe)**

- Say it takes 400 million years for light to get from galaxy A to us in Milky Way.
- Yet during travel in spacetime, both A and MW have changed positions by expansion.
- Thus “distance” is a fuzzy concept – LOOKBACK TIME is better.

**Balloon analogy for expanding universe**

- On an expanding balloon, no galaxy is at the “center” of expansion; no edge.
- Expansion happens into a higher dimension (2-D surface into a 3-D space).
- Is our 3-D space expanding through a 4th dimension?

**Clicker on reading ahead**

**D.** What do we mean by a protogalactic cloud?

- A. It is a cloud-like halo that surrounds the disks of spiral galaxies.
- B. It was a term used historically to refer to any galaxy.
- C. It is a cloud of hydrogen gas that we detect by looking at light from quasars.
- D. It is a cloud of matter that contracts to become a galaxy.

**Making of a spiral galaxy**

- Start with a fairly uniform cloud of hydrogen.
- Gravitational collapse forms protogalactic clouds.
- First stars are born in this spheroid (such stars are billions of years old → “fossil record”).

**Small variant in spiral making …**

- Several smaller protogalactic clouds may have merged to form a single large galaxy.
- May explain slight variations in stellar ages in the MW.

**Forming a disk with spiral**

- As more material collapses, angular momentum spins it into a disk.
- Stars now formed in dense spiral arms – disk stars are younger!
Making ellipticals

- Higher density: much faster star formation uses up all the gas
- Nothing left to make a disk
- Now we see sphere of old stars

Or now a different story....

- Spiral galaxy collisions destroy disks, leave behind elliptical
- Burst of star formation uses up all the gas
- Leftovers: train wreck
- Ellipticals more common in dense galaxy clusters

Birth of galaxies in clusters

Few galaxies (none?) BORN alone

Clicker: galaxy collisions

- Why are collisions between galaxies more likely than between stars within a galaxy?
- A. Galaxies are much larger than stars
- B. Galaxies travel through space much faster than stars
- C. Relative to their sizes, galaxies are closer together than stars
- D. Galaxies have higher redshifts than stars

Collision of small galaxy with big one

Builds "bridge" and "counterarm"

Close passage: M51 + companion

NGC 4038/39 Antennae

NGC 5194 + 95

Clicker: galaxy collisions

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Close passage of two equal mass galaxies

Builds very long "tails" and wisps

Colliding galaxies – “The Antennae”

Tidal streams between galaxies

Interacting: NGC 2207 + IC 2163

Interacting system NGC 6745
Ring galaxy AM 0644-741

Many interacting galaxy systems
Very distant (big lookback time) with HST

A major puzzle: “The Mice” NGC 4676

“Mice” with HST Advanced Camera for Surveys

“Mice” in simulation 1

Rotate the “Mice”
“Mice” in finer simulation 1

Latest simulation 2 of “Mice”

Stefan’s Quintet in HST detail

It may happen to us in future!

M31 and Milky Way in future collision

M31 heading in!
Galaxies are not lonely -- many "interactions" most likely! Also curious: arcs of light?

Rich galaxy cluster

Signs of having collided: elliptical galaxy with shells

Message from galaxy interactions

1. In dense clusters, galaxy collisions (grazing or even head-on) must have been common.
2. With successive passages, spiral galaxies can tumble together to form a big elliptical.
3. Vastly increased star birth from shocking the gas and dust (star burst galaxies).
4. Start rapid feeding of supermassive black hole lurking at center of most galaxies (quasars).

NEXT

Quasars

- Quasi-Stellar Radio Source (QSO) — arise from early galaxy collisions feeding BH?
- Nuclei so bright that the rest of the galaxy is not easily seen
- First discovered as radio sources - then found to have very high redshifts!

Model for "active galaxies"

Accretion disk, supermassive BH, beams on axis