The Present, The Past, And The Future of The Milky Way
The World of Galaxies

- Galaxies come in three main types:
  - Spirals (like the Milky Way and Andromeda)
  - Ellipticals (they mostly live in large clusters)
  - Irregular (often small, look like mess)
Hubble’s Classification

- Edwin Hubble developed a classification scheme that is still in use.
- Many spirals have **bars** – the Milky Way has too.
The Milky Way Bars

A bar *in* the Milky Way

A bar *of* the Milky Way
Hubble classification is thought to reflect the evolution of galaxies. Ellipticals are called early type, and spirals are called late type galaxies. The bulges of spiral galaxies look exactly like elliptical galaxies. So, structurally, a spiral galaxy is an elliptical galaxy with a disk.

Which way does the evolution go?

A: Elliptical galaxies evolve from spiral galaxies by losing their disks.

B: Spiral galaxies evolve from elliptical galaxies by growing a disk.
Review Question

What are the 3 main constituents of the Milky Way?

- **A**: gas, dust, stars
- **B**: dark matter, stars, gas
- **C**: planets, stars, nebulae
- **D**: milk chocolate, corn syrup, sugar
Galaxy Evolution Fact I

- The key to galaxy evolution is the different dynamics of dark matter, stars, and gas.
- Dark matter *always* forms a quasi-spherical halo, for *all* galaxies.
- Gas *always* forms a disk, because it...
  - A: always keeps cooling.
  - B: gets compressed by dark matter.
  - C: contains cosmic dust.
  - D: glows in the dark.
  - E: forms stars.
Galaxy Evolution Fact II

- Dark matter does not cool (by definition!). The "gas of stars" does not cool too (star collide very rarely).
- Stars form from the gas, so young stars are always located in the
  - A: stellar halo.
  - B: bulge.
  - C: disk.
When galaxies collide (merge), orbits of stars in the disk get disrupted and randomized. The “gas of stars” gets “heated”, stars turn into a bulge (= elliptical galaxy).

What happens when two bulges (or two elliptical galaxies) collide and merge?

- **A**: Stars “cool off” to form a disk.
- **B**: Nothing happens, just a bigger bulge forms.
- **C**: A stellar halo forms – the energy of collision “heats” the bulges.
Galaxy Evolution Fact IV

- The first galaxies must be
  - A: large, made mostly of stars (and DM).
  - B: small, made mostly of stars (and DM).
  - C: large, made mostly of gas (and DM).
  - D: small, made mostly of gas (and DM).

- Dwarf galaxies today should resemble the early “building” blocks of larger galaxies.
- Indeed, they are mostly gaseous disks.
Galaxy Evolution: Cartoon

- Baby Milky Way: just a gas disk (DM is always there; an edge-on view).
Galaxy Evolution: Cartoon

- Young stars form in the gas disk.
We merge with someone else.
Two stellar disks crash into each other, forming a bulge. Gas disk reforms rapidly.
Galaxy Evolution: Cartoon

- Bulge ages, new stars form in the gas disk.
Galaxy Evolution: Cartoon

- We merge with someone else again (last time: about 10 Gyr ago).
Galaxy Evolution: Cartoon

- Stellar halo forms from collided bulges; younger stars added to the bulge.
Stellar halo and bulge age; new stars form in the gas disk. Here we are!
Galaxy Evolution: Cartoon

- Keep going: in about 2Gyr we will consume the rest of our gas.
Galaxy Evolution: Cartoon

- Disk stars will quickly age.
We will then collide with something (something being Andromeda).
Galaxy Evolution: Cartoon

Local Group will become a **fossil group** (a group with a single large elliptical galaxy).
Milky Way Movie
Simulating the World of Galaxies

- Modern supercomputers are powerful enough to model a large region of the universe with millions of galaxies in exquisite detail.
- They produce model galaxies that look *almost* like real ones.
- One example of such a project: Illustris (there are also EAGLE, MAGIC, MUFASA, etc).
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Simulating the World of Galaxies: Illustris Project
Brightest Cluster Galaxies

- Biggest galaxies are central ellipticals in clusters of galaxies. They can be 30 times more massive than the Milky Way.
Active Galactic Nuclei

- Many galaxies have active nuclei, with jets, X-ray and gamma-ray emission.
- Spectral lines show large Doppler shifts, indicating velocities up to 10 - 20% of the speed of light.

Centaurus A
Centaurus A

The peculiar radio galaxy Centaurus A

Visible

Near infrared
What could be the source of energy for such violent activity?

- **A**: a supernova
- **B**: a black hole
- **C**: an interstellar nuclear war
- **D**: large number of supernovae in a small region of space
Quasars

- There are many types of AGN: DRAGNs, Seyfert galaxies, quasars.
- **Quasars** are the most powerful of AGN.
Most large galaxies are believed to have supermassive black holes at their centers (we have found no galaxies without one).

Largest ones reach 3 billion $M_\odot$ (ours is 3.3 million $M_\odot$, Andromeda’s is 20 million $M_\odot$).

The bigger the galaxy, the larger the black hole. Somehow, galaxies know how big a black hole they must have – this is known as “$M-\sigma$” relation.

But black holes are very small compared to galaxies, there shouldn’t be any connection between them. It remains unexplained.
Black Holes Masses

Black hole masses are measured by the same old Kepler’s law.
Believe it or not, black holes are the brightest objects in the universe!

- As gas falls into a black hole, it can turn up to 15% of its rest energy ($mc^2$) into radiation (stars only do 0.7%, and only in the core).