ASTRO 310: Galactic & Extragalactic Astronomy
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Class 14    October 22, 2018
The Local Group
The Local Group

~3 large galaxies, ~40+ small galaxies (currently known) stellar mass varies by factor of ~$10^5$
3D distribution of galaxies in The Local Group

- Not randomly distributed within 3D volume
  - Most small galaxies are satellite companions to large galaxies
  - Galaxies somewhat concentrated toward a plane
Andromeda Spiral Galaxy (M31)
Stellar mass 1-2X that of Milky Way
Classified as Sb spiral (b-> moderate-size bulge)
identify 2 key things about galaxy evolution from this image!

1. galaxies form inside-out (avg age of stars older in center, younger further out)
2. small companion galaxies interact with large galaxy and sometimes accrete
the main sequence lifetime of a star at the “turn-off” point of the main sequence is equal to the age of the star cluster
Spectra of single main sequence stars

Cool + red
MS Lifetime: $10^{12}$ yr

Warm + yellow
MS Lifetime: $10^{10}$ yr

Hot + blue
MS Lifetime: $10^6$ yr
UV-NIR Spectrum of single stellar population

“single stellar population” bunch of stars formed at the same time for a given initial mass function (IMF)

Note huge change in UV light with age < 1 Gyr

Ages of stellar population given on plot in Gyr

Bruzual & Charlot 2003

GALEX FUV 1344-1786 Å
GALEX NUV 1771-2831 Å
Andromeda Spiral Galaxy (M31)
Stellar mass 1-2X that of Milky Way
Classified as Sb spiral (b-> moderate-size bulge)
M33 – spiral companion of M31

• Stellar mass ~1/3 that of Milky Way
• Classified as Sc spiral (c → small bulge)

Pink: Hα emission from ongoing star formation (HII regions)
Large Magellanic Cloud

- Stellar mass ~1/10 that of Milky Way
- Classified as *magellanic irregular galaxy* or *large dwarf galaxy*
- In class of gas-rich, star-forming galaxies
- Has some modest spiral features
- Has mass near transition between spiral galaxies (large) and dwarf irregular galaxies (small)

Pink: Hα emission from ongoing star formation (HII regions)
Small Magellanic Cloud

- Stellar mass ~1/30 that of Milky Way
- Classified as *dwarf irregular*
- Mass too low to have spiral structure (not enough differential rotation in disk, which is high in high mass galaxies)

Pink: $\text{H}\alpha$ emission from ongoing star formation (HII regions)
NGC 205, companion of M31
• Stellar mass ~1/30 that of Milky Way
• Classified as *Dwarf elliptical* (dE)
• Similar to SMC, BUT little gas & dust & no ongoing star formation
• Ongoing gravitational interaction with M31 (tidal tails)
M32, companion of M31

- Stellar mass ~1/30 that of Milky Way
- Classified as *Elliptical* (E)
- Very little gas & dust, no ongoing star formation
- Ongoing gravitational interaction with M31?
**Elliptical M32**
Compact, high central stellar density of stars
Little or no gas & star formation

**Dwarf “elliptical” NGC 205**
Not compact, low central surface density of stars
Little or no gas & star formation
E vs dE: very different light profiles

- central surface brightness: differs by 8 magnitudes (factor of 1600!)
- this is log-linear plot, so straight line of dE corresponds to exponential distribution
Surface brightness vs. luminosity for various stellar systems

NGC 205 (dwarf elliptical) and M32 (elliptical) are different types of galaxies, even though they have similar mass & no ongoing star formation. E’s are much more compact than dE’s.
NGC 205 (dwarf elliptical) and SMC (dwarf irregular) have similar stellar masses and similar stellar distributions, but differ in their gas content and amount of ongoing star formation (dIs have them, dEs have none).
Dwarf irregular (SMC)
Not compact, low central surface density of stars
Lots of gas & star formation

Dwarf “elliptical” NGC 205
Not compact, low central surface density of stars
Little or no gas & star formation
both dI’s and dE’s have similar, \textasciitilde exponential light profiles
at least some dE’s are dI’s that lost their gas
Leo A
• Stellar mass $\sim 1/3000$ that of Milky Way
• Classified as \textit{dwarf irregular}
• has gas & dust & ongoing star formation
Leo I

- Stellar mass ~1/3000 that of Milky Way
- Classified as *dwarf spheroidal* (lower mass version of dwarf elliptical)
- has NO gas & dust & ongoing star formation
Dwarf spheroidal galaxy vs. globular cluster

47 Tuc globular star cluster
Stellar Mass: $7 \times 10^5 \, M_\odot$

Leo I dwarf spheroidal galaxy
Stellar mass: $\sim 10^7 \, M_\odot$
How are small dwarf galaxies different from large (globular) star clusters?

A. star formation history
B. central concentration of stars
C. central concentration of dark matter
D. number of stars
How are small dwarf galaxies different from large (globular) star clusters?

A. star formation history
B. central concentration of stars
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D. number of stars
Dwarf spheroidal galaxy vs. globular cluster

**Globular cluster**
- Generally fewer
- compact, small extent
- Single episode
- NO

**Dwarf spheroidal**
- Generally more *BUT OVERLAP*
- diffuse, large extent
- Multiple episodes
- YES

*Number of stars:*
*Concentration & size:*
*Star formation history:*
*Dark matter concentration:*
Dwarf spheroidal galaxy vs. globular cluster
to
~correct scale

47 Tuc
globular star cluster
stellar mass: $7 \times 10^5 \, M_\odot$

Leo I dwarf spheroidal galaxy
galaxy
stellar mass: $\sim 10^7 \, M_\odot$
Dwarf spheroidal galaxy vs. globular cluster

The dwarf galaxy looks like a big loose fluffy thing – why does it stay together? *it is bound by its total mass, and most of the mass is dark matter* -- roughly 99%. So the total mass of the galaxy is \( \sim 10^9 \text{ M}_\text{Sun} \).

47 Tuc
globular star cluster
stellar mass: \( 7 \times 10^5 \text{ M}_\text{Sun} \)
total mass: \( 7 \times 10^5 \text{ M}_\text{Sun} \)

Leo I dwarf spheroidal galaxy
stellar mass: \( \sim 10^7 \text{ M}_\text{Sun} \)
total mass: \( \sim 10^9 \text{ M}_\text{Sun} \)
The smallest dwarf galaxies have the same stellar mass as the largest globular star clusters, but much lower stellar densities.
Carina dwarf color-magnitude diagram

Carina
Stellar mass ~1/30,000 that of Milky Way
Classified as dwarf spheroidal (dSph)
has NO gas & dust & ongoing star formation

explain the distribution of stars
in the color-magnitude diagram!
HR diagram of nearby stars

HR diagram of globular cluster

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Range of ages

All the same age
Carina dwarf color-magnitude diagram

3 concentrations of stars with distinct main sequence turnoffs
→ 3 main episodes of star formation
Andromeda Spiral Galaxy (M31)
Dwarf galaxies are satellites of large galaxies, orbit around them and gravitationally interact with them
Milky way galaxy in optical (0.4 - 0.7mm)(B V R)

Milky way galaxy in infrared (1.2, 1.6, 2.2μm)(J H K)(2MASS)
The 2 Magellanic Clouds are gravitationally interacting with each other and the Milky Way.
Milky way galaxy in optical (0.4 - 0.7 mm) (B V R)

Milky way galaxy in infrared (1.2, 1.6, 2.2 µm) (J H K) (2MASS)
Some halo globular clusters originate from the disrupted Sagittarius dwarf galaxy, currently merging with the Milky Way.
Simulation of Sgr dwarf galaxy gravitationally interacting with Milky Way Galaxy
Sgr dwarf galaxy & Milky Way interaction: viewing “current” timestep in simulation from different angles
Important 1st step in understanding dynamical state of system: ask what physical processes *might* be occurring. How long does it take for this process to occur for average particle? Some of the key processes take place on one of these timescales:

1. crossing time
2. collision time
3. relaxation time

If a process takes longer (for an average particle) than the age of the system, then the process is not important for the overall behavior and evolution of system.
timescales of Local Group
a small loose group of galaxies

calculate timescales ..but now “particles” are galaxies not stars!
N = 3 (# of large galaxies)
R = 0.5 Mpc
n = 10 gal Mpc$^{-3}$
$\sigma$ = 200 km/s

t$_{\text{cross}}$ = $2 \times 10^9$ yr
$\text{t}_{\text{relax}}$ = $10^9$ yr
$t_{\text{coll}}$ = $10^{10}$ yr
timescales of Local Group
a small loose group of galaxies

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\[ t_{\text{cross}} = 2 \times 10^9 \text{ yr} \]
\[ t_{\text{relax}} = 10^9 \text{ yr} \]
\[ t_{\text{coll}} = 10^{10} \text{ yr} \]

what are the physical implications of each of these timescales?
timescales of Local Group
a small loose group of galaxies

calculate timescales ..but now “particles” are galaxies not stars!
N = 3 (# of large galaxies)
R = 0.5 Mpc
n = 10 gal Mpc$^{-3}$
$\sigma = 200$ km/s

t$_{\text{cross}} = 2 \times 10^9$ yr $< t_H$ so group should be virialized
t$_{\text{relax}} = 10^9$ yr $< t_H$ so 2-body encounters have changed orbits
t$_{\text{coll}} = 10^{10}$ yr $\sim t_H$ so collisions & mergers important in groups

all timescales short so galaxy-galaxy gravitational encounters
(both direct collisions & near misses) important in galaxy groups
Geometrical cross section

Cross section augmented by gravitational focusing
direct galaxy collisions

- for direct collision, $\Sigma = \pi (2r_{\text{cross}})^2 = 4 f_c \pi r_{\text{gal}}^2$
- $r_{\text{gal}} \sim 20$ kpc for large spiral
- $f_c$ = correction factor for gravitational focusing (depends on velocities – larger $f_c$ for smaller velocities) $\sim$ few-10
- $\Sigma = 40\pi (20 \text{ kpc})^2 \sim 40000$ kpc$^2$

gravitational focusing enhances collision cross-section
direct galaxy collisions

t_{\text{coll}} = \frac{\lambda}{v_{\text{rand}}} = \frac{1}{(n\Sigma v_{\text{rand}})} = 10^{10}\text{ yr}

- \Sigma = 40\pi (20\text{ kpc})^2 \sim 40000\text{ kpc}^2
- v_{\text{rand}} = \sqrt{3}\sigma = 350\text{ km/s}
- n = 10\text{ gal Mpc}^{-3}

t_{\text{coll}} = 10^{10}\text{ yr} \text{ is about the same as the age of universe} \rightarrow
many groups have had direct collisions of large galaxies \rightarrow collisions & mergers are important in groups!

very different from stars in star clusters & galaxies, where
star-star collisions extremely rare and completely unimportant in evolution of system
Galaxy groups are generally older than several crossing times, so they are in (or close to) virial equilibrium. Which galaxy system is younger than 1 crossing time?

A) equal mass pair of galaxies
B) compact groups of galaxies
C) clusters of galaxies
D) supercluster filament
Galaxy groups are generally older than several crossing times, so they are in (or close to) virial equilibrium. Which galaxy system is **younger** than 1 crossing time?

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C) clusters of galaxies  
D) supercluster filament
Superclusters: filaments of ‘cosmic web’

Length $\sim 50$ Mpc
Width $\sim 3$ Mpc
Velocity dispersion $\sim 300$ km/s
$\tau_{\text{cross}} \sim 10^{11}$ yr (length)
$\tau_{\text{cross}} \sim 10^{10}$ yr (width)

Age $\sim 10^{10}$ yr is $\leq \tau_{\text{cross}}$
so galaxies have crossed supercluster $\leq$ once!

Superclusters:
not yet virialized
still in process of formation
still in process of initial collapse