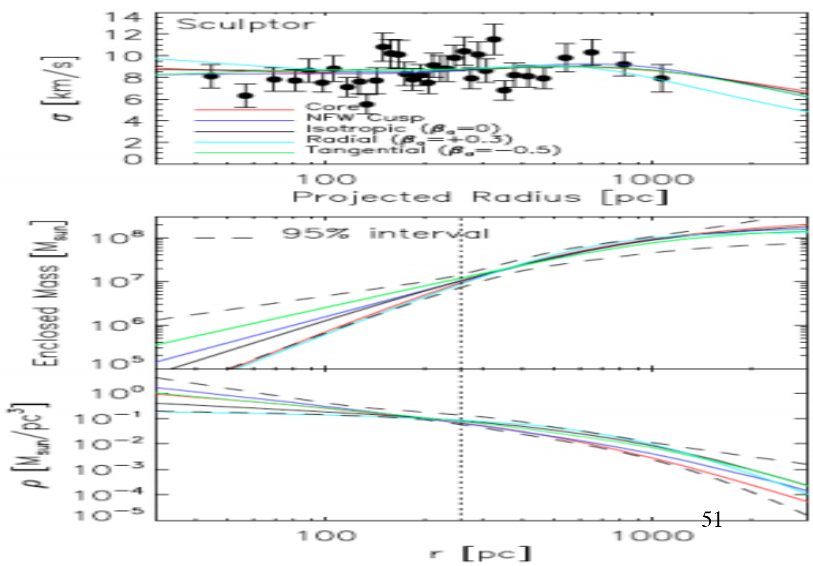
Dwarfs

- Have VERY low internal velocity dispersion~10km/sec, r_{scale}~50-1000pc
- IF mass follows light- very dark matter dominated- but precise mass is not well determined even with ~3000 stars individually measured (!)
- - using Jeans method: all solutions (different

shapes of the potential or orbital distributions) are ok- **mass well determined**



51

Mass Models For M31

- Several different potential forms give reasonable fits to velocity data; differ in 'total' mass by <50%- probable detection of drop in v_{circ} at large R.

- the merging history of a galaxy, together with its star formation history, and mass re-arrangement (such as gas flows or stellar radial migration) is written in its structure, stellar ages, kinematic and chemical-elemental abundance distribution functions.

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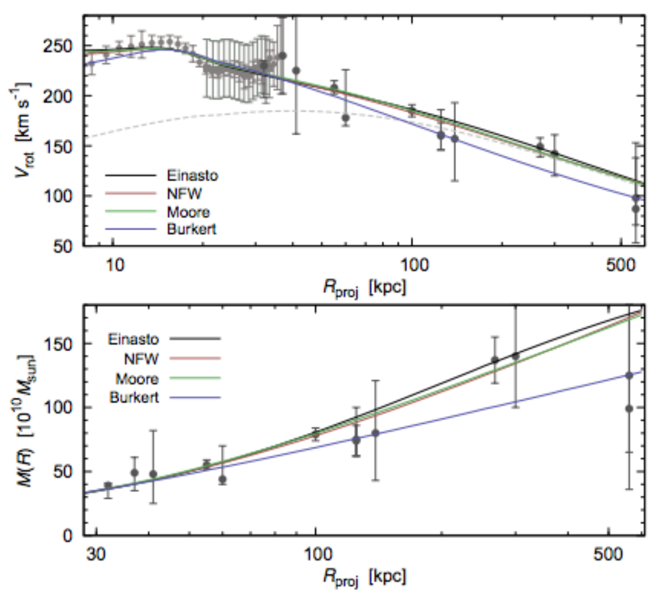
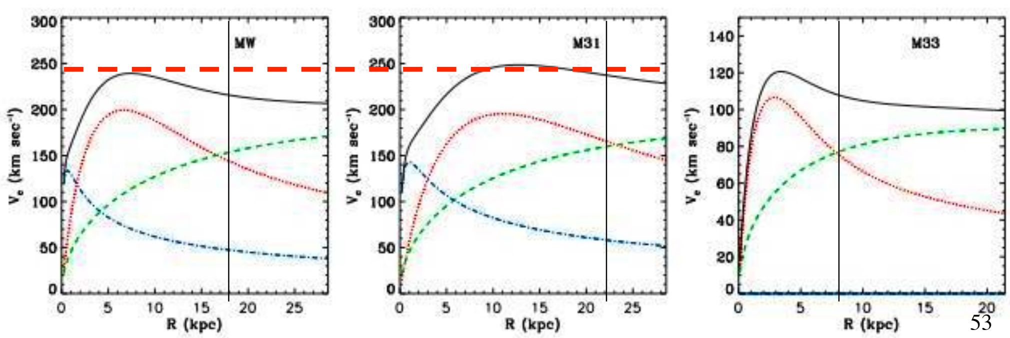


Fig. 6. Outer rotation curve observations and models (*upper*

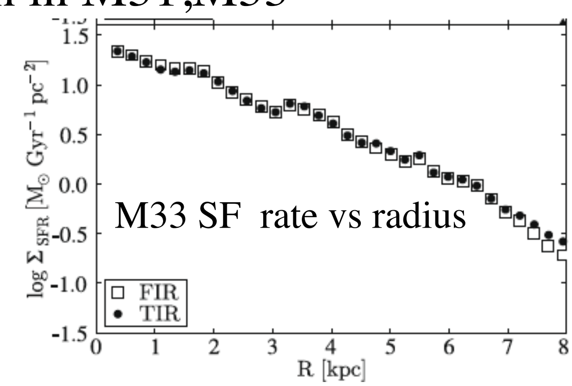
Comparison of Rotation Curve for MW, M31,M33

- Black is total curve
- blue is bulge (*notice no bulge in M33*), green is DM and red is disk (data from van der Maerl 2012)
- observed maximum circular velocity for each galaxy: $V_c \approx$ 239 kms at the solar radius for the MW, $V_c \approx$ 250km/s for M31 $V_c \approx$ 120 kms M33
- S+G says that M31 has a higher rotation velocity, latest data on MW has changed that ! Notice where DM becomes dominant- 22 kpc for M31, 18kpc for MW, 8kpc for M33
- Virial mass of M33=$2.2x10^{11}M_\odot$

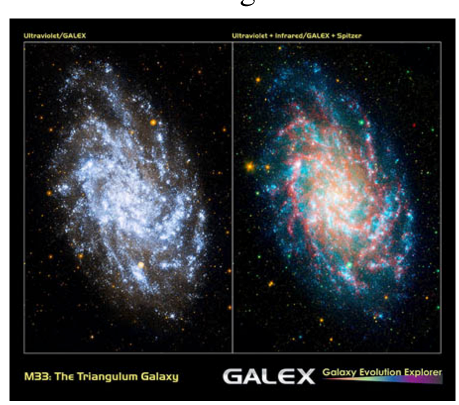


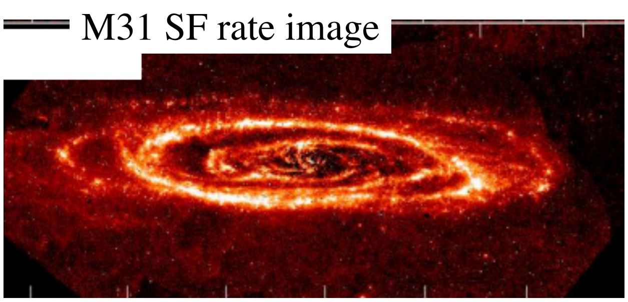
Star Formation in M31,M33

- the specific star formation rate in M31 is less than in the MW with a present rate of ~0.6M/yr.
- the SF is concentrated in a ring 10kpc out
- M33 on the other hand is vigorously forming stars 0.45M/yr all over (why??)



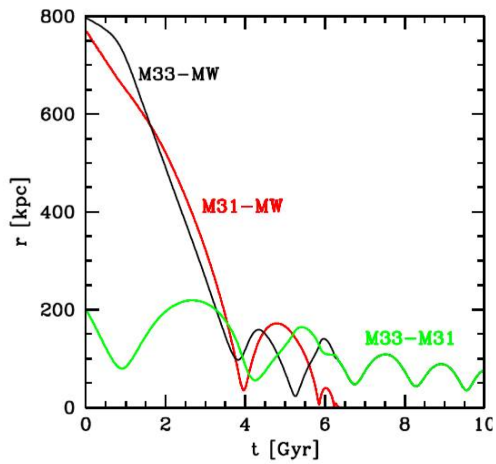
M33 UV and IR images



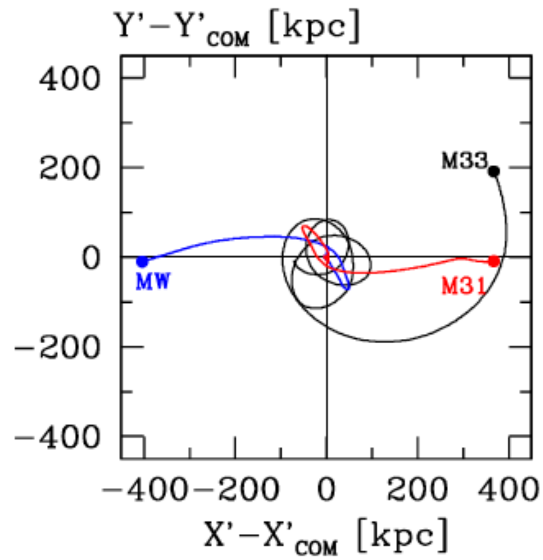


The future of the local group (S+G 4.5)

- It seems clear that M31 has had a much more active merger history than the MW- so beware of close by objects
- given what we know about the mass of M31, M33 and MW they will all merge in~6Gyrs (van den Maerl 2012)



/ separations in the MW-M31-M33 system as function



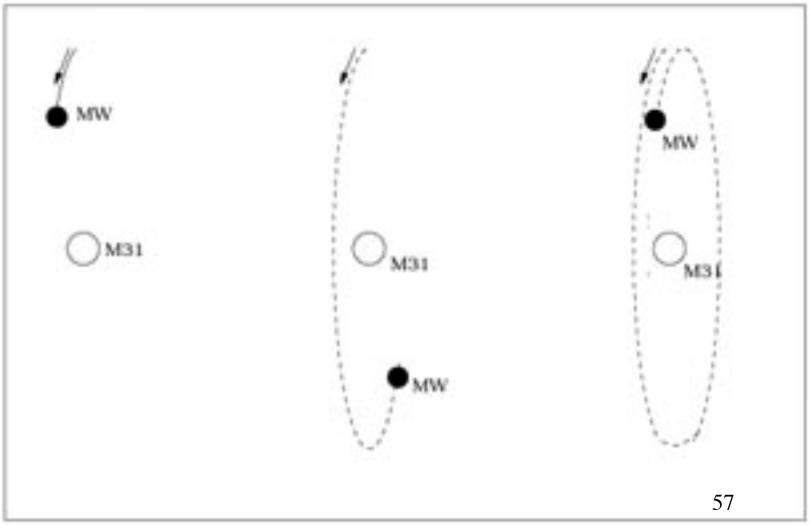
Local Group timing argument

- Use dynamics of M31 and the MW to estimate the total mass in the LG.
- the radial velocity of M31 with respect to the MW ~-120km//sec e.g. towards MW presumably because their mutual gravitational attraction has halted, and eventually reversed their initial velocities from the Hubble flow.
- neglect other galaxies in LC, and treat the two galaxies as an isolated system of two point masses.
- assume the orbit to be radial, then Newton's law gives $dr^2/dt^2=GM_{total}/r$
- Period of orbit less than age of the universe: Kepler's Law $P^2=4\pi a^3/GM$
- Assume purely radial orbits (no ang Mom) so GM/2a=GM/dE; d=distance to center of mass and E is KE/unit mass

derive total $M>1.8x10^{12}M_\odot$

Timing Argument

- M_{total}=3.66x10^{12} $M_\odot$ and mass of MW ~1/3 of total
- R_{halo} =GM_{MW}/V^2_c =G*10^{12}/(220km/s)^2 =90kpc
- If, the rotation speed drops at large R, then R_{halo} is even bigger



M33- this slide was skipped in lecture

- M33 is almost unique in having very tight constraints placed on the presence of a supermassive black hole in its nucleus.
- It is probably tidally involved with M31-220kpc away

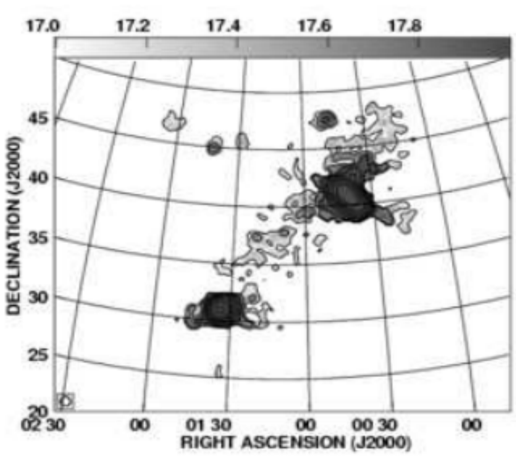


Fig. 9. Integrated H I emission from the subset of detected features apparently associated with M31 and M33. The grey-scale

$M_{disk,stellar}$~3.8x$10^9 M_\odot$
$M_{bulgek,stellar}$~1x$10^8 M_\odot$
M_{virial}~2.2x$10^{11} M_\odot$

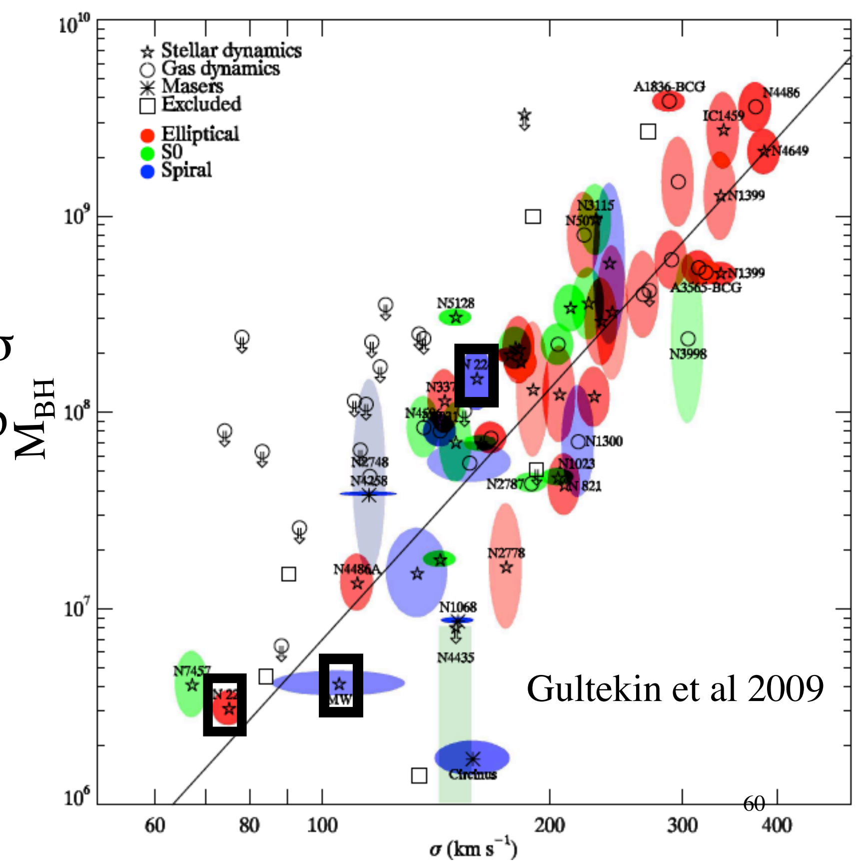
HI image of sky around M33
notice connecting stream to M31

Black Holes

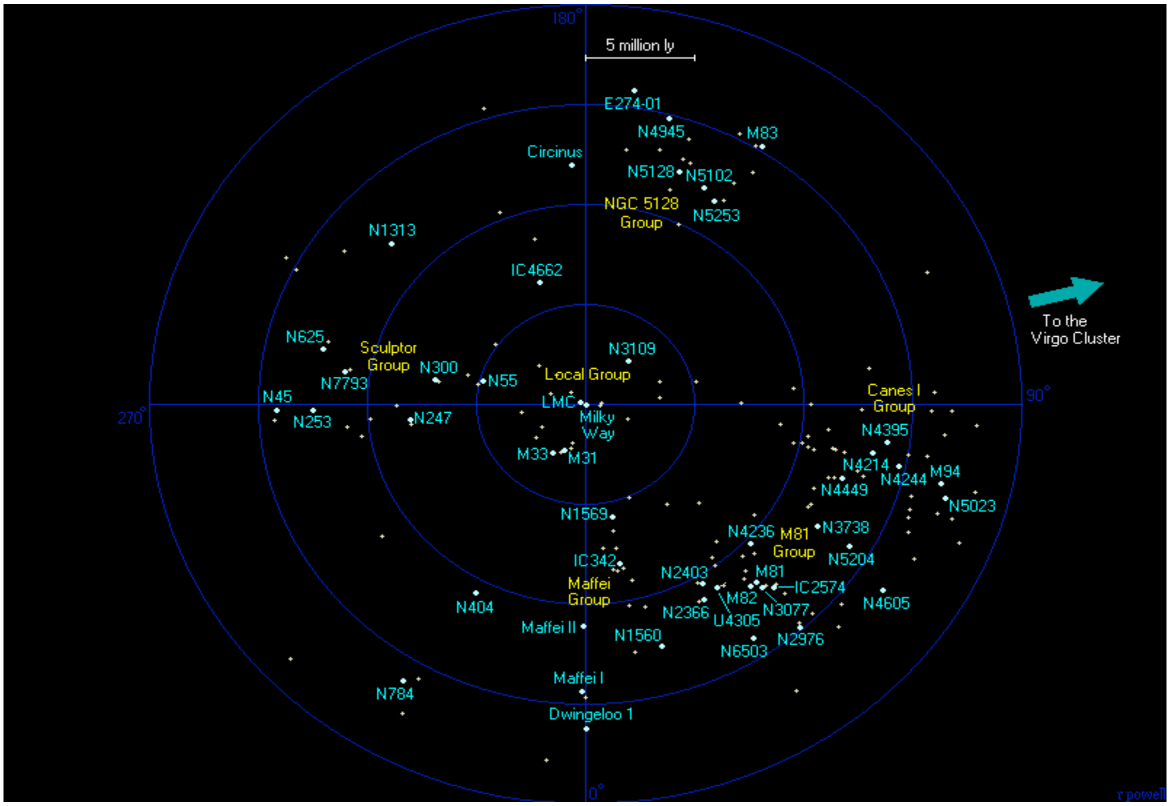
- It is now believed that 'all' massive galaxies have super massive black holes in their nuclei whose mass scales with the bulge properties of the galaxies
- What about the smaller galaxies in the local group?
- Search for BHs 2 ways
  - dynamics
  - presence of an AGN (active galactic nucleus)
- None of the Local group galaxies host an AGN (today)
- Of the small galaxies only M32 shows *dynamical* evidence for a black hole (van der Maerl 2009) of $M \sim 2.5 \times 10^6 M_\odot$ for a galaxy of luminosity -16.83 compared to -21.8 for M31 (100x less luminous) **which has a similar mass BH**- M32 is spheroidal (all bulge)

		$M_{BH}(M_\odot)$	$M_{bulge}(M_\odot)$	
M33	Scd	$< 3 \times 10^3$	1.5×10^8	
NGC205	E	$< 2.4 \times 10^4$	2.7×10^8	satellite of M31
M32	E	$\sim 2.5 \times 10^6$	$\sim 2.5 \times 10^8$	satellite of M31

- Black hole mass vs bulge velocity dispersion σ
- Local group galaxies



Beyond the Local Group



- "The orbits of Virgo, Fornax, Antlia and Virgo~W clusters are represented by large spheres colored red, gold, black, and purple, respectively. The Milky Way and M31 are shown by smaller spheres colored yellow and green,

Local Volume of Space

As indicated by CDM simulations the universe is lumpy

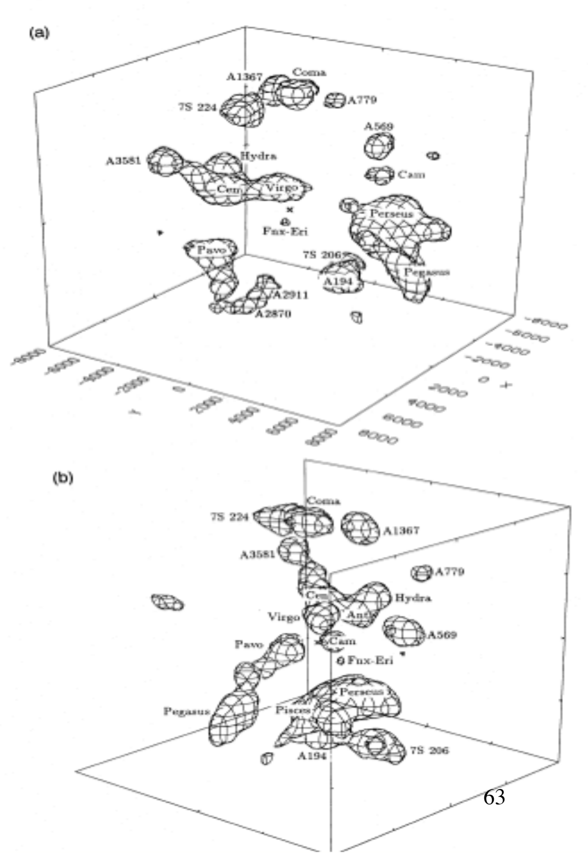
Here is a 'map' (Hudson 1994) of the nearby universe

Objects labled 'A' are rich clusters

other massive clusters are labeled Virgo Coma, Cen, Perseus

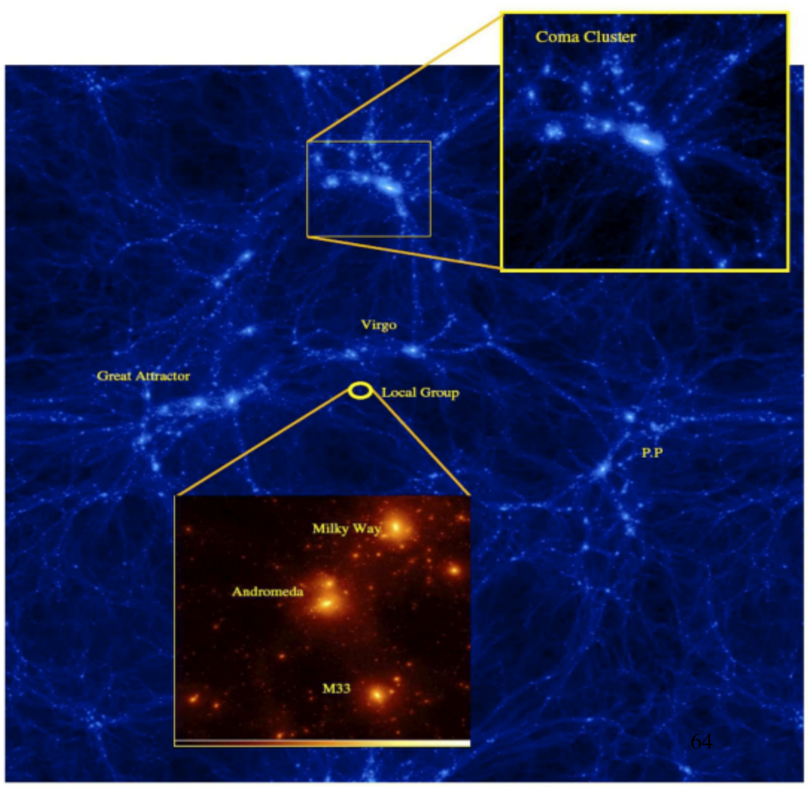
of galaxies from Abells catalog - axis are labeled in velocity units (km/sec)

Notice filamentary structure.



Constrained Realization

- In order for numerical galaxy formation models to 'work' properly need to sample a large volume of space.
- Constrained to have properties of Local group



Local Group Summary

- What is important
  - local group enables detailed studies of objects which might be representative of the rest of the universe (e.g CMDs of individual stars to get SF history, spectra of stars to get metallicity, origin of cosmic rays etc)
    - wide variety of objects -2 giant spirals, lots of dwarfs
  - chemical composition of other galaxies in local group (focused on dwarfs and satellites of the MW) similar in gross terms, different in detail; indications of non-gravitational effects (winds); went thru 'closed box' and 'leaky box' approximations, allowed analytic estimate of chemical abundance distribution and its evolution.
  - dynamics of satellites of MW (Magellanic clouds) clues to their formation, history and amount of dark matter
    - dwarfs are the most dark matter dominated galaxies we know of- closeness allows detailed analysis.
    - dwarf galaxy 'problem' are there enough low mass dwarfs around MW??- leads to discussion later in class about galaxy formation and Cold dark matter models

Summary of Today's Lecture Local Group

- Discussion of detailed properties of M31, M33 comparison to MW; differences in how they formed; MW very few 'major mergers' M31 more; not all galaxies **even those close to each other do not have the same history.**
- Dynamics of local group allow prediction that M31 and MW (and presumably the Magellanic clouds) will merge in ~6 gyr
- A supermassive black hole exists in the centers of 'all' *massive* galaxies- properties of BH are related to the bulge and not the disk of the galaxy
- Use 'timing argument' to estimate the mass of the local group (idea is that this is the first time MW and M31 are approaching each other and the orbit is radial) use 'simple' mechanics to get mass
- Local group is part of a larger set of structures- the 'cosmic web' galaxies do not exist in isolation