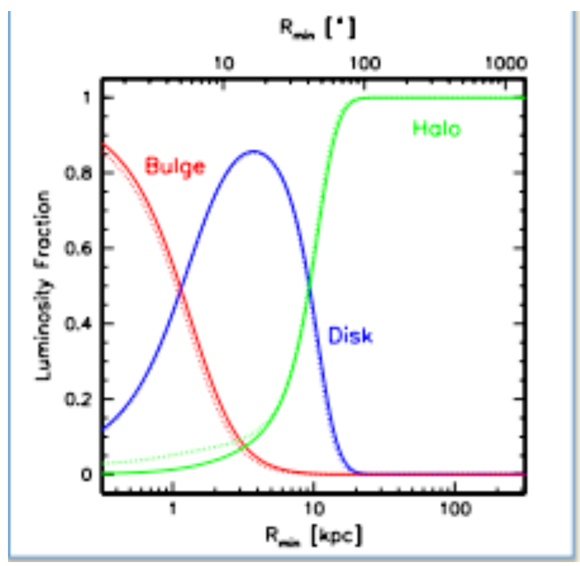
# The 'Big' Galaxies

- Opportunity to study in detail MW, M31 and M33 and onward to the rest of the universe.



# M31 and the MW

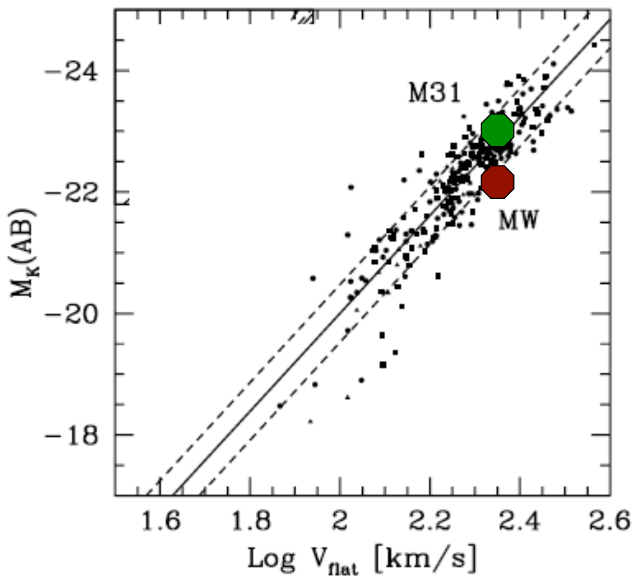
- The Milky Way and M31 have different properties
- M31 shows a lower star formation rate (SFR) than the Milky Way
- M31 appears to be a more typical spiral galaxy than the Milky Way (Hammer et al. 2007).
- M31 shows evidence for a formation and evolution history affected by merging and/or accretion events, including substructures in its halo-MW does not
- scale length of 6kpc is 3x that of the MW (2.3 kpc) but similar rotation curve.
- stellar mass $M_{star}$ ~10.3 x $10^{10} M_{\odot}$ for M31; disk 7.2x $10^{10} M_{\odot}$ and bulge 3.1x $10^{10}$ $M_{\odot}$




decomposition of M31
Courteau 2012

# Tully Fisher Relation

- The relationship of luminosity to rotation speed for spirals- (more later)
- M31 and MW have similar $v_{rot}$ but factor of 2 different luminosities and scale lengths - MW is more discrepant from large statistical samples

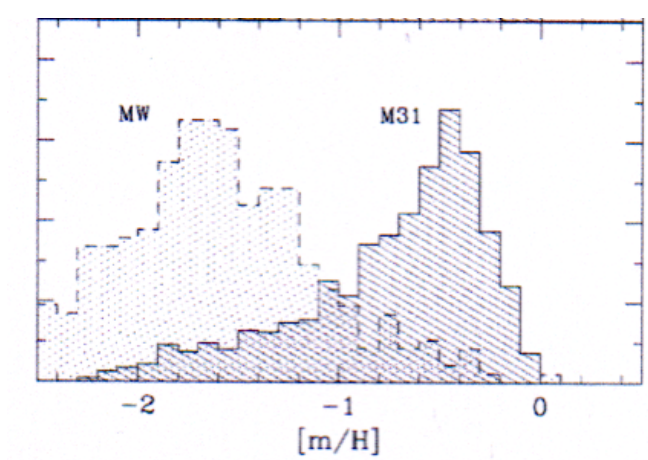



M31, compared to the Milky Way, has 2 x more stellar mass and 2.5 x more specific angular momentum Hammer 2007



# Comparison of Metallicity of Halo Stars in M31 and MW

- The vastly different chemical compositions of the halo of MW and M31 indicate different formation histories or processes EVEN in the Local Group
- Comparison of observed metallicities to theoretical yields from a closed box approx (S+G 4.13-4.16) indicates outflow of enriched material




- Halo of M31 = Andromeda (Durrell et al. 2001)
- Halo of the Milky Way (Ryan & Norris 1991)

# 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.

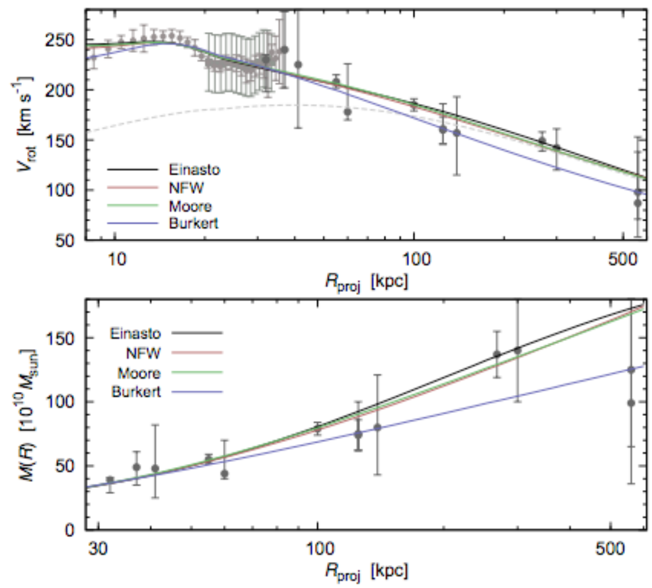
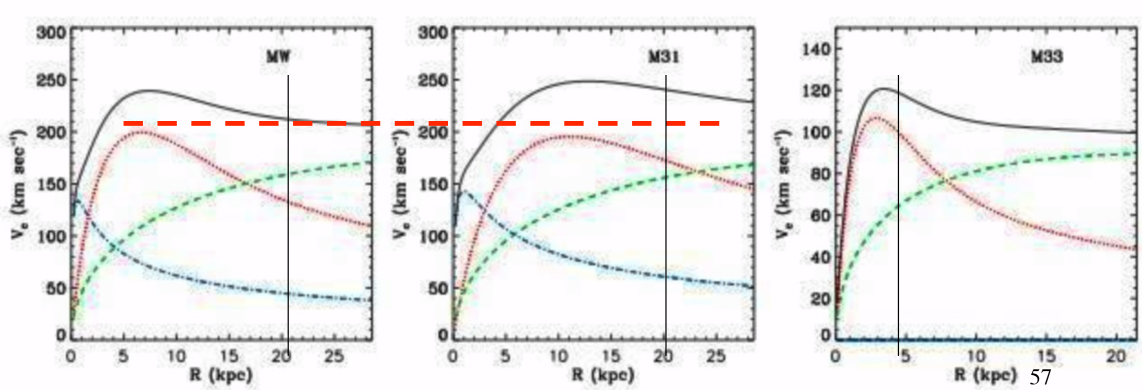



**Fig. 6.** Outer rotation curve observations and models (*upper*



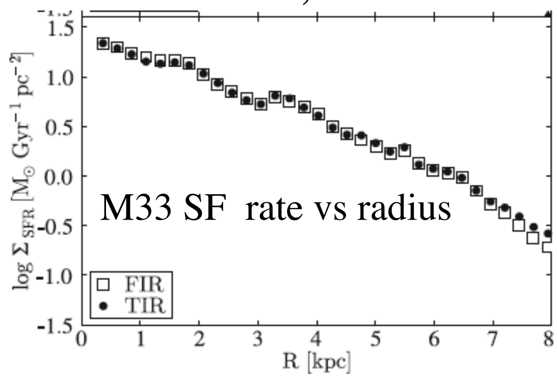
# Comparison of Rotation Curve for MW, M31, M33

- Black is total curve, blue is bulge (*notice no bulge in M33*), green is DM and red is disk
- observed maximum circular velocity for each galaxy: $V_c \approx 239$ kms at the solar radius for the MW, $V_c \approx 250$km/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

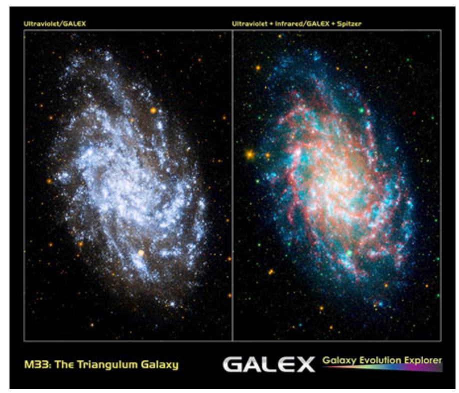


# Present Day Star Formation in M31,M33

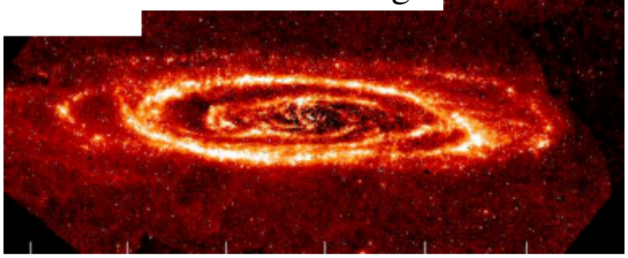
- the specific star formation rate (SFR) in M31 is less than in the MW with a present rate of ~0.6M/yr.
- the SF is concentrated in a ring 10kpc out
- M33 on the other hand is vigorously forming stars 0.45M/yr all over




M33 UV and IR images




M31 IR SF rate image



# Past Star Formation in M31 and Increase in Metallicity with Time (Williams et al 2017)

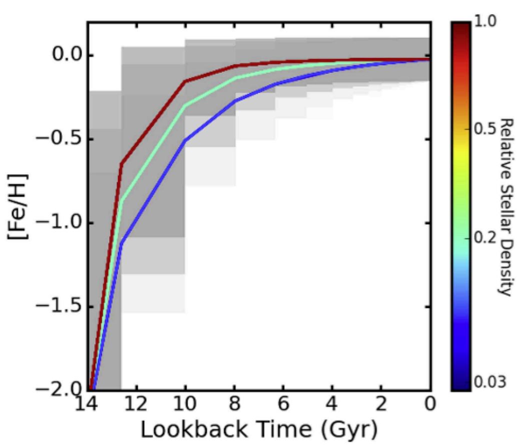
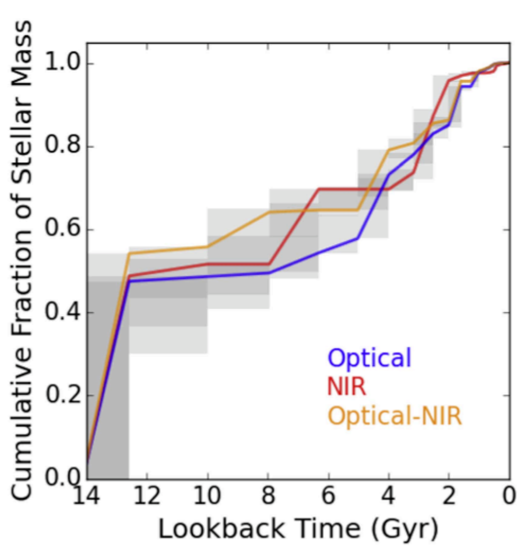


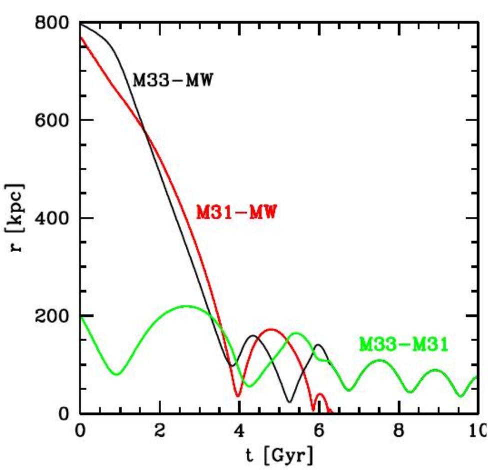

**Figure 8.** Enrichment models adopted for three radial divisions, using the same color coding as in Figure 1. Gray areas show the spread in metallicity allowed in each epoch. The inner regions enrich faster earlier, while the outer regions have more constant enrichment.



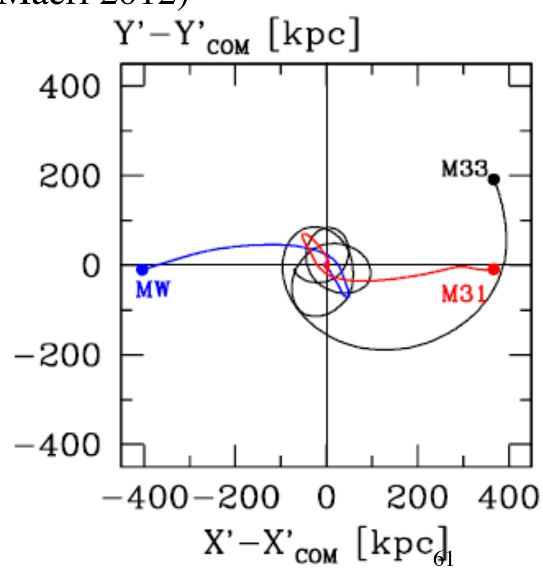


# The future of the local group (S+G 4.5)

- 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)

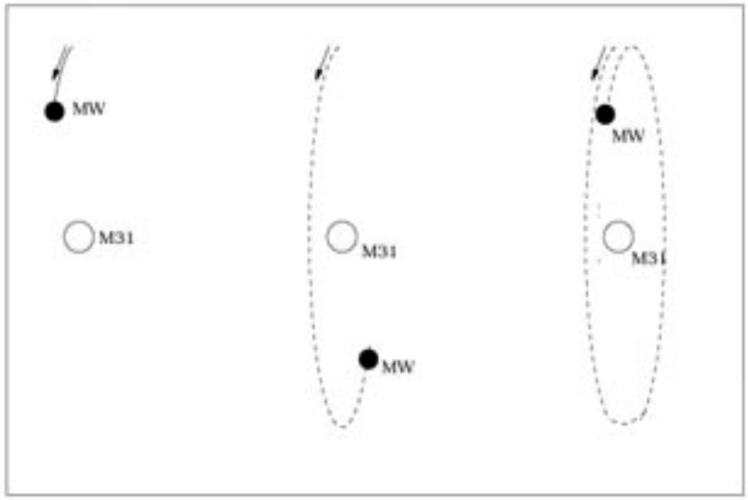



/ separations in the MW-M31-M33 system as function



# Timing Argument for Mass of MW and M31

- the two galaxies are now approaching each other. assume that (i) the two galaxies were formed close together, (ii) that their combined mass was sufficient to make them a bound unit, and (iii) that they have performed the larger part of at least one orbit with a period of no more than 15 Gyr.
- Simple radial orbit and simple Keplerian dynamics shows that the mass of the (M31–Milky Way) system is about 20 times larger than the masses of the stars of the two galaxies.




## Local Group timing argument sec 4.5 S&G, problem 4.11

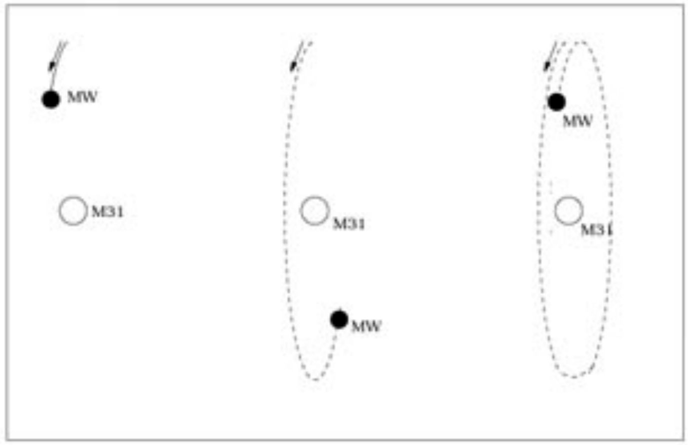
- Use dynamics of M31 and the MW to estimate the total mass in the LG.
- the radial velocity of M31 with respect to the MW ~-120km/sec e.g. towards MW presumably because their mutual gravitational attraction has halted, and eventually reversed their initial velocities from the Hubble flow.
- neglect other galaxies in LC, and treat the two galaxies as an isolated system of two point masses.

- assume orbit is radial, then Newton's law gives $dr^2/dt^2=GM_{total}/r^2$
- Period of orbit less than age of the universe:
  - Kepler's Law $P^2=4\pi a^3/GM$
- radial orbits (no net ang Mom) so $GM/2a=[GM/d]-E_k$; d=distance to center of mass and $E_k$ is KE/unit mass

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

# timing argument

- $M_{total}$=3.66x10$^{12}$ $M_{\odot}$and mass 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

- 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

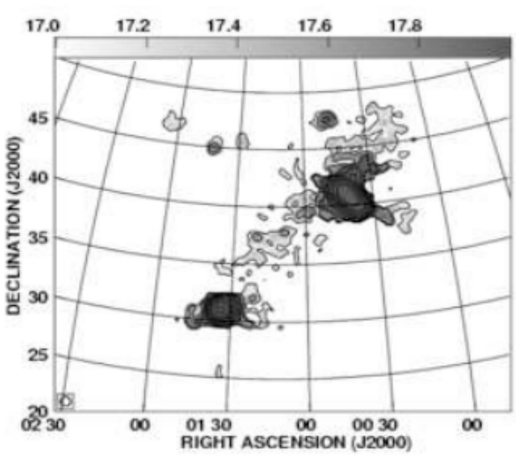



**Fig. 9.** Integrated H I emission from the subset of detected features apparently associated with M31 and M33. The grey-scale

$M_{disk,stellar}$~3.8x10$^9$$M_{\odot}$
$M_{bulgek,stellar}$~1x10$^8$$M_{\odot}$
$M_{virial}$~2.2x10$^{11}$$M_{\odot}$

HI image of sky around M33 notice connecting stream to M31

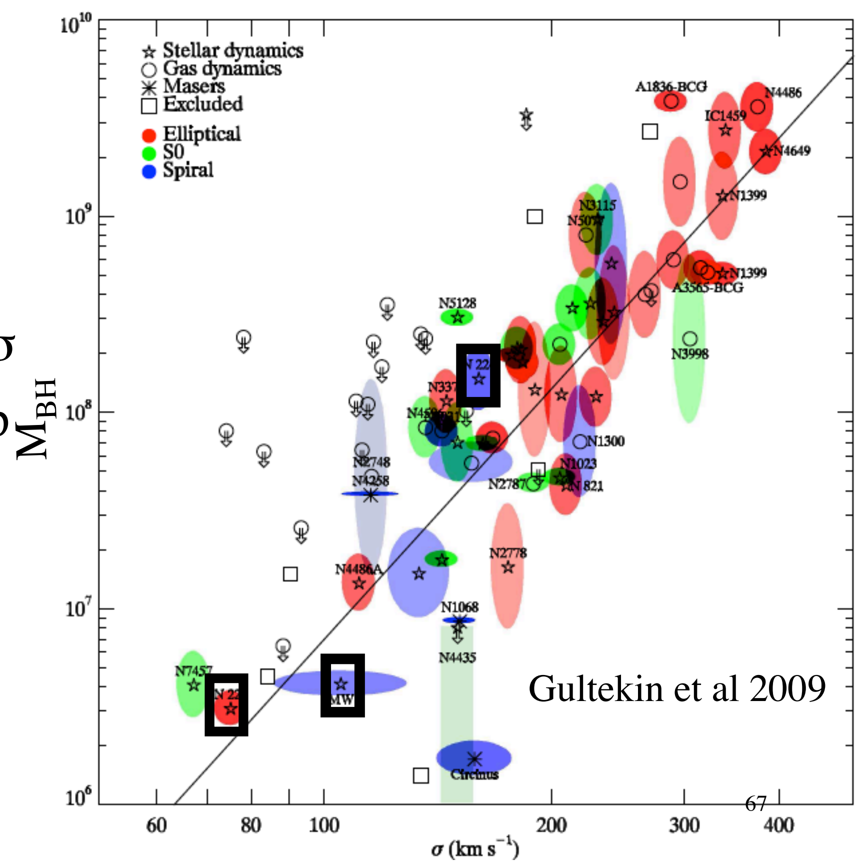
# Black Holes

- 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)

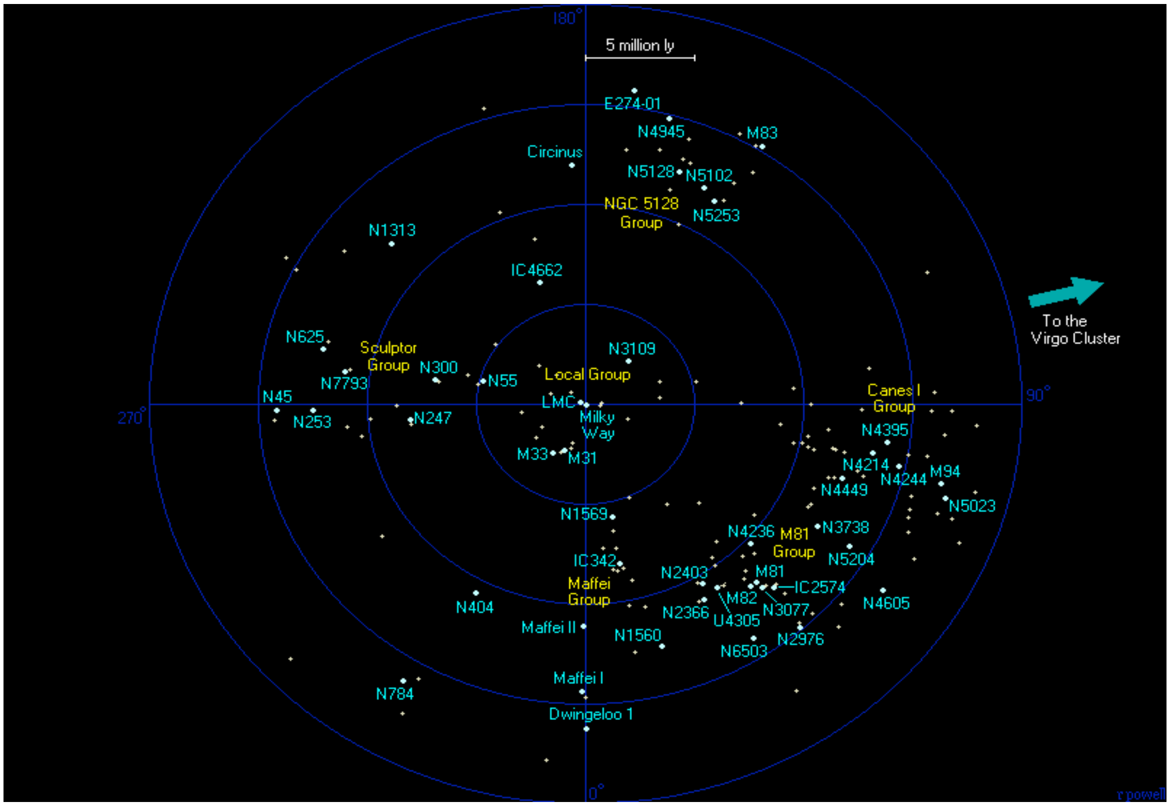
| | | $M_{BH}(M_\odot)$ | $M_{bulge}(M_\odot)$ | |
|---|---|---|---|---|
| M33 | Scd | $< 3 \times 10^3$ | $1.5 \times 10^8$ | |
| NGC205 | E | $< 2.4 \times 10^4$ | $2.7 \times 10^8$ | satellite of M31 |
| M32 | E | $\sim 2.5 \times 10^6$ | $\sim 2.5 \times 10^8$ | satellite of M31 |



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

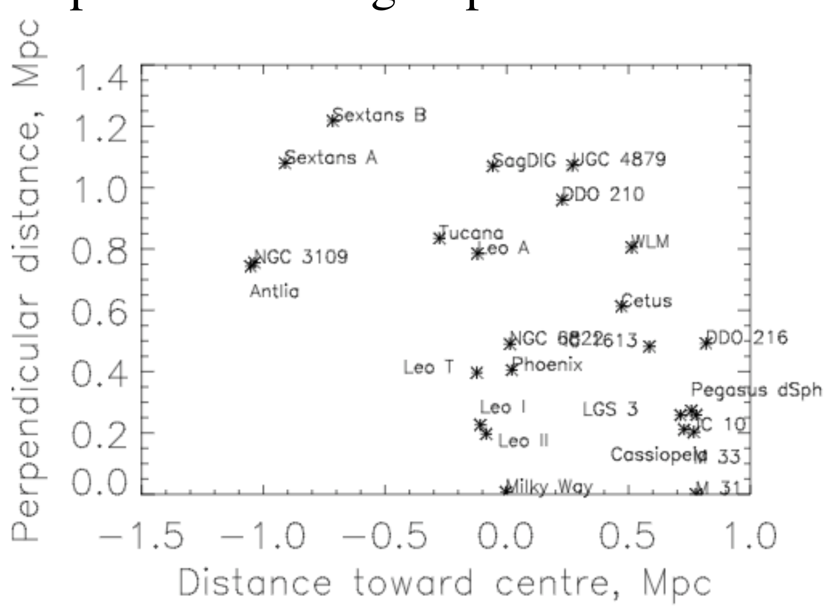


# Beyond the Local Group




# Map of the Local group

- the kinematics of the Local Group is not well-sampled by the visible galaxies.
- their sparseness and asymmetry managed to fool statistical techniques of moderate sophistication (Whiting 2014)



# Local Volume of Space

As indicated by CDM simulations the universe is lumpy

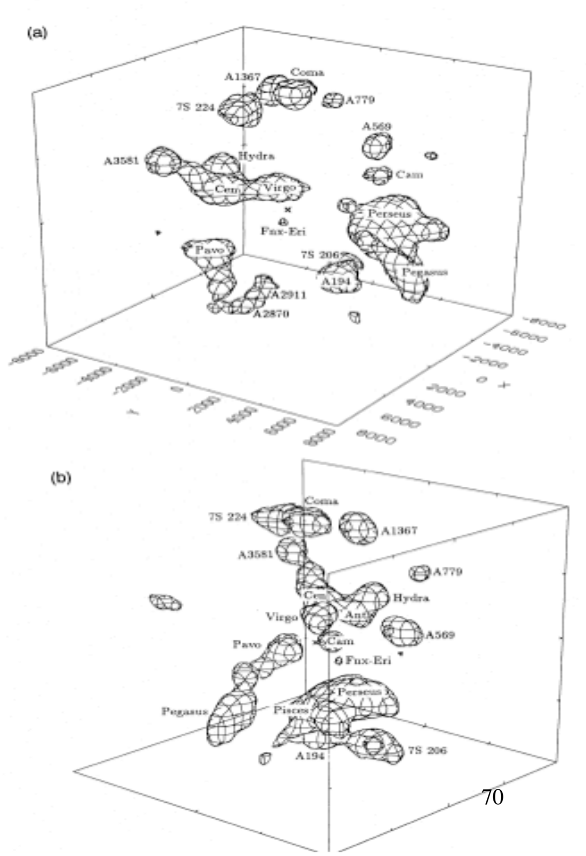
Here is a 'map' (Hudson 1994) of the nearby universe

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)

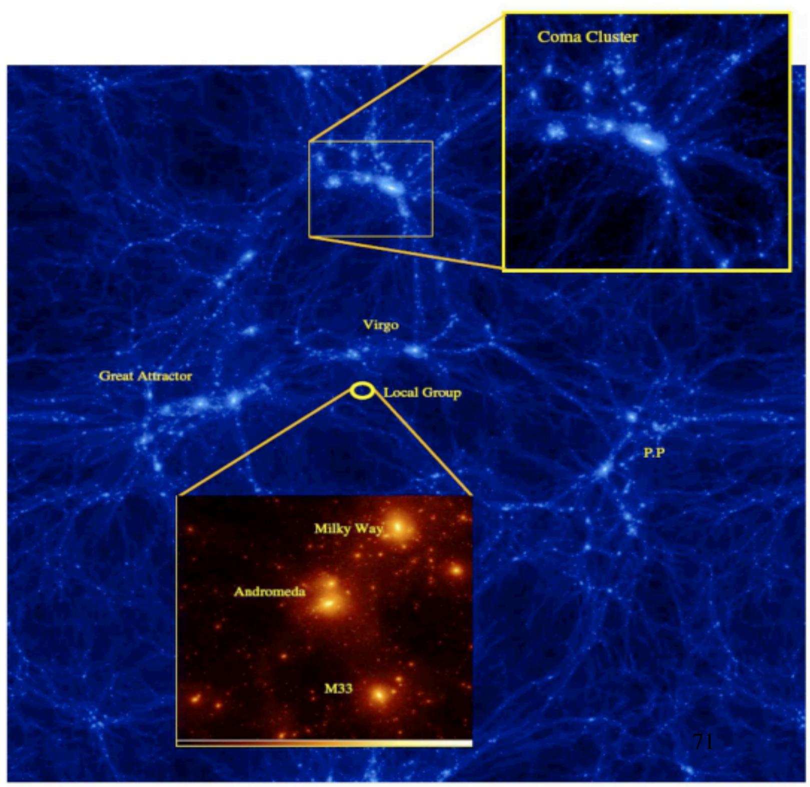
Notice filamentary structure.






# 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



# Where is the Local Group

- This visualization shows our "Local Universe", as simulated in the constrained realization project.
- The Local Group is in the centre of the sphere. In the initial orientation of the sphere, the Great Attractor is on the left, and the Cetus Wall on the lower right.
- Credit: Volker Springel
- Simulation code: Gadget



# Summary of Today's Lecture Local Group

- Introduction of Tully-Fisher scaling relation- how to compare galaxies- much more in discussion of spirals next week.
- 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