Astronomy 330

Lecture 22

23 Nov 2010

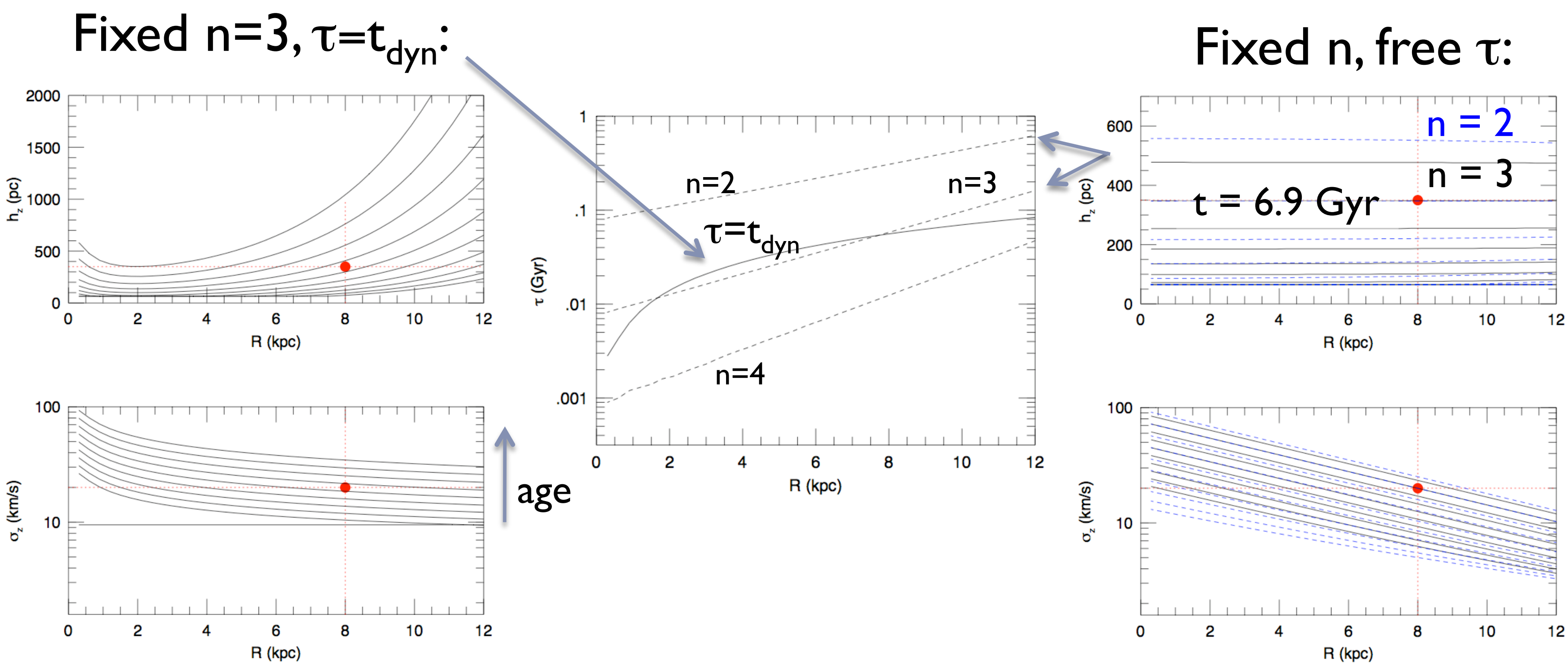
Outline

- Review:
  - Disk heating models
    - Simple diffusion model
- Dwarf galaxies
  - Context of galaxy formation
  - Content of Local Group

Review: Disk heating

- We have a plausible model for disk heating
  (via diffusion and equipartition from many two-body encounters with massive objects)
  - likely requires combination of GMCs, spiral arms, and satellites
- We expect σ to increase as $(1+t/\tau)^{1/n}$, with $2<n<3$
  - Initial conditions for σ_z and h_z : taken from cold gas today
- Diffusion theory doesn't predict the time-scale τ
  - setting $\tau = t_{dyn}$ and n=3 works ok to yield constant hz(R), and is physically motivated.
  - Fixing n or τ and letting the other vary with radius works even better, but physical motivation less clear.
- Thick disk may be created from a separate process in the early-phases of disk mass-assembly

Disk heating models




Dwarf Galaxies
Don’t look here

Dwarf Galaxies: Galaxy formation context

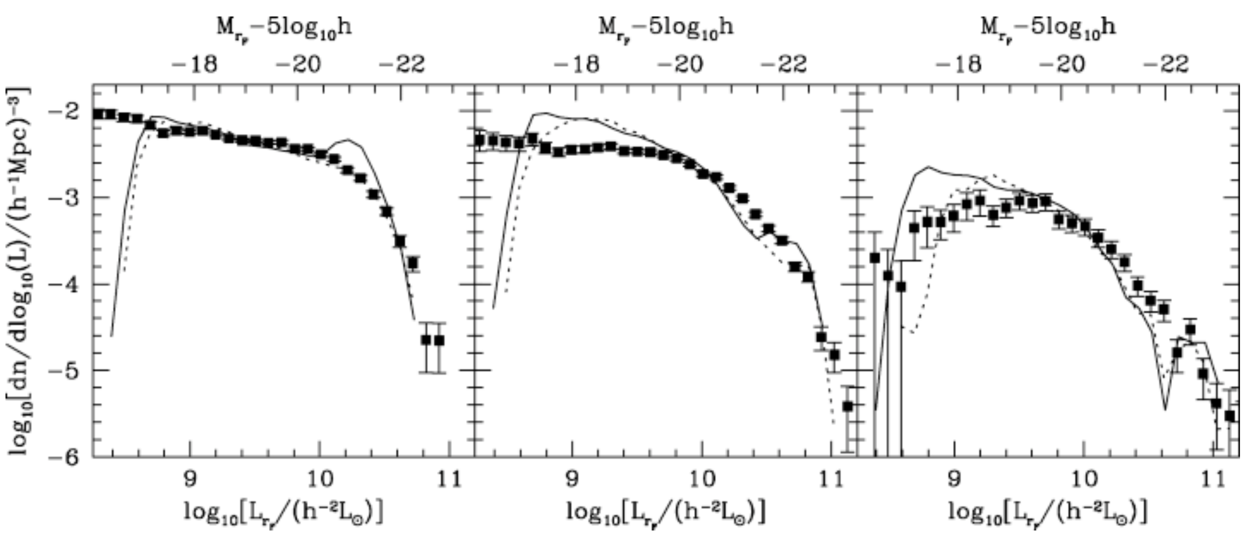
- Galaxy Formation I
  - Begin with some fluctuations…
    - Max. scale: $\lambda_J = 2\pi/k_J = c_s(\pi/G\rho)^{1/2}$
    - Freq. of perturbations: $\omega = [4\pi G\rho(\lambda_J^2/\lambda^2) - 1]^{1/2}$
    - For perturbations smaller than Jeans length
  - Imagine a sphere with the Jeans length
    - $M_J = (\pi\lambda_J^3/6)\rho$
    - In radiation dominated era: $M_J = 10^{11} M_\odot$
    - In matter dominated era: $M_J = 10^6 M_\odot$
- Cold Dark Matter
  - 1st structures are low mass halos
  - Larger structures form via hierarchical merging

Galaxy formation (continued)

- Cooling
  - Initial fluctuations are warm post-recombination (1000's of degrees)
  - What does the cooling?
    - No metals, so it must be some form of H
    - In situ formation of H_2
  - Results (e.g. Hutchings et al. 2002)
    - 1st structures to cool have $M_{virial} \sim 9 \times 10^5 M_\odot$
- Simulations/Semi-Analytic Models
  - Remember "cosmology" yields a spectrum of density fluctuations
  - Fluctuations = regions of overdensity ➔ growth of dark matter halos ➔baryon infall ➔make stars ➔feedback ➔result is a prediction of the distribution/population of galaxies at high redshift

Why Dwarf Galaxies are so important

- Dwarfs
  - are 1st to form and the most numerous objects in the early Universe;
  - dominate faint galaxy counts in any deep survey;
  - should dominate local galaxy luminosity function;
  - Are the building blocks of larger galaxies.
- But…
  - They do not contain most of the stars and baryonic matter

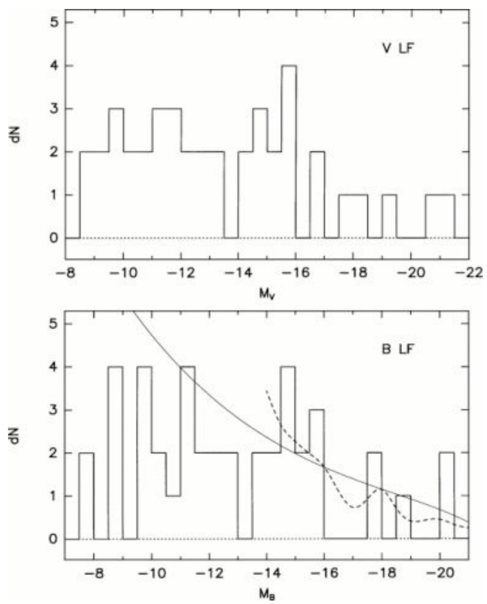


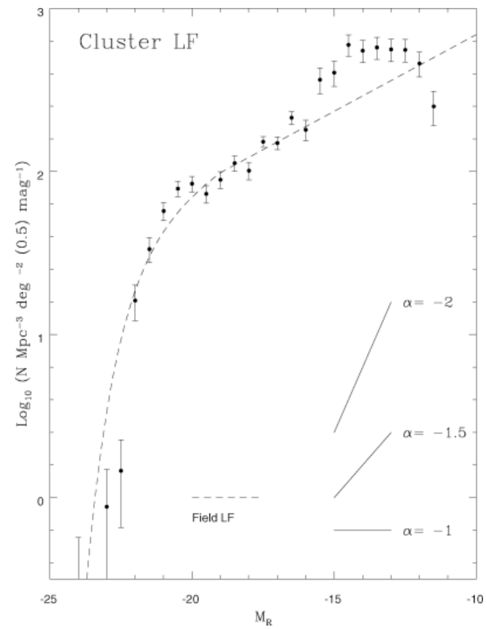
Luminosity function

Rising slope at faint luminosities ➔lots of dwarf galaxies

Galaxy luminosity function

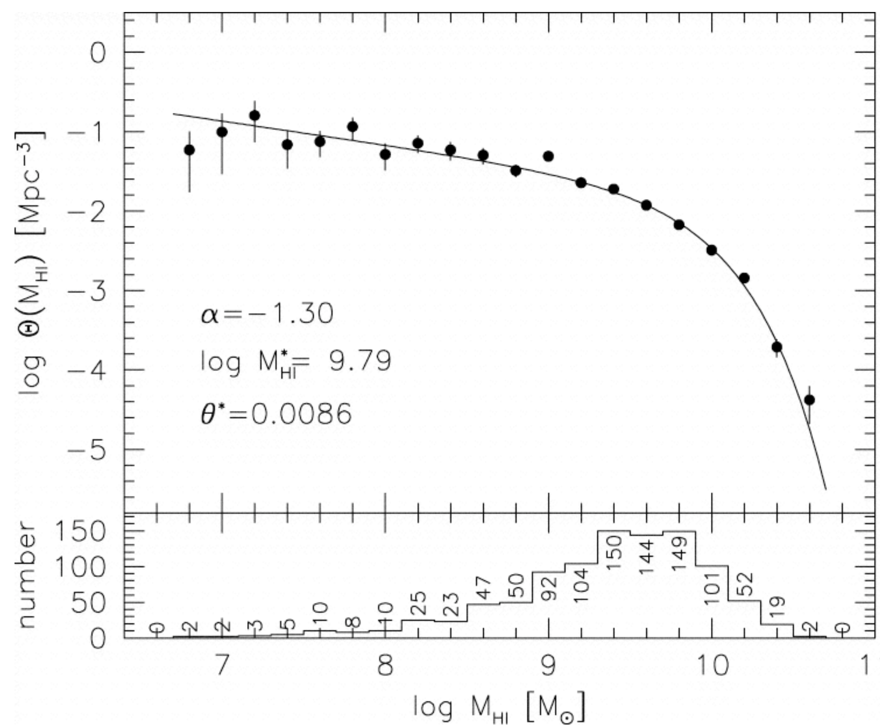
- LF varies a bit with environment
  - Virgo: faint end slope is steep ➔ dEs are > 50% of all galaxies (Trentham et al)
  - Local Group: steeply rising at low luminosities (Mateo)
- HI mass function is similar





Galaxy luminosity function

- HI mass function
  - In the field



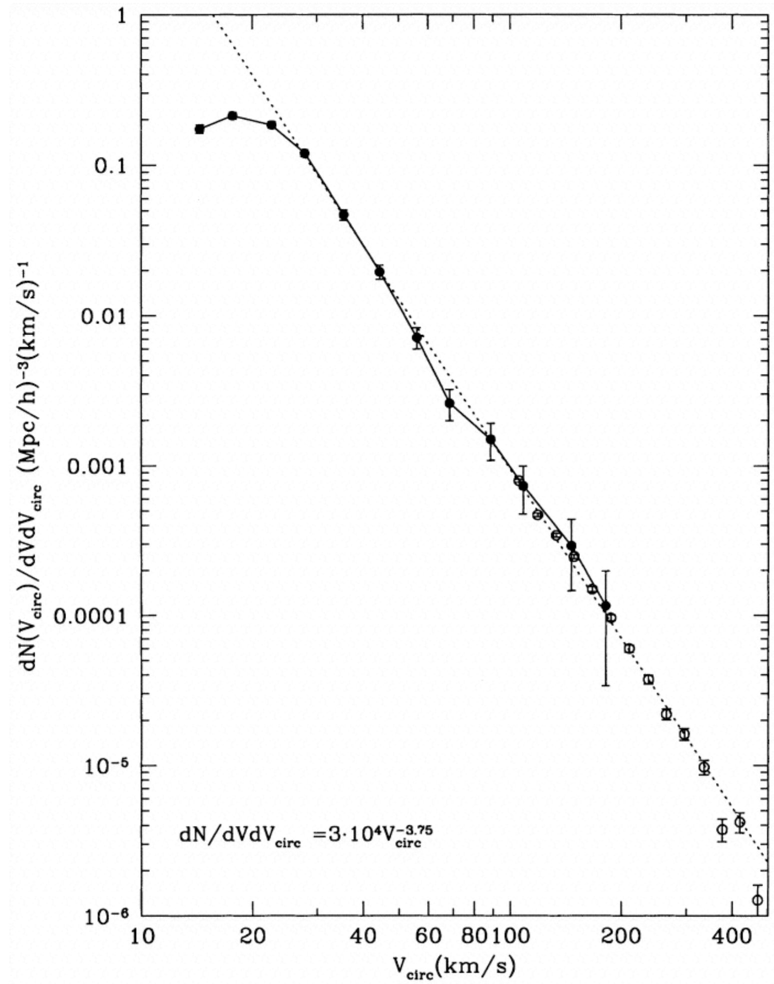
Zwaan et el. (HIPASS)

Dwarf Census in the Local Group

- Mateo (1998) ARAA, 36, 435
- Total number of dwarfs: ~40
  - Magnitude limits: (fainter than ~ −18)
    - Ursa Minor ~ −7.6
    - NGC 205 ~ −16.0
  - Mass (dynamical)
    - DDO 210 ~ 5.4 x $10^6 M_\odot$
    - M32 ~ 2.1 × $10^9 M_\odot$
  - M_{HI} / M_{TOT}
    - Several < 0.001
    - Leo A ~ 0.72
- Morphology – Distribution Correlation

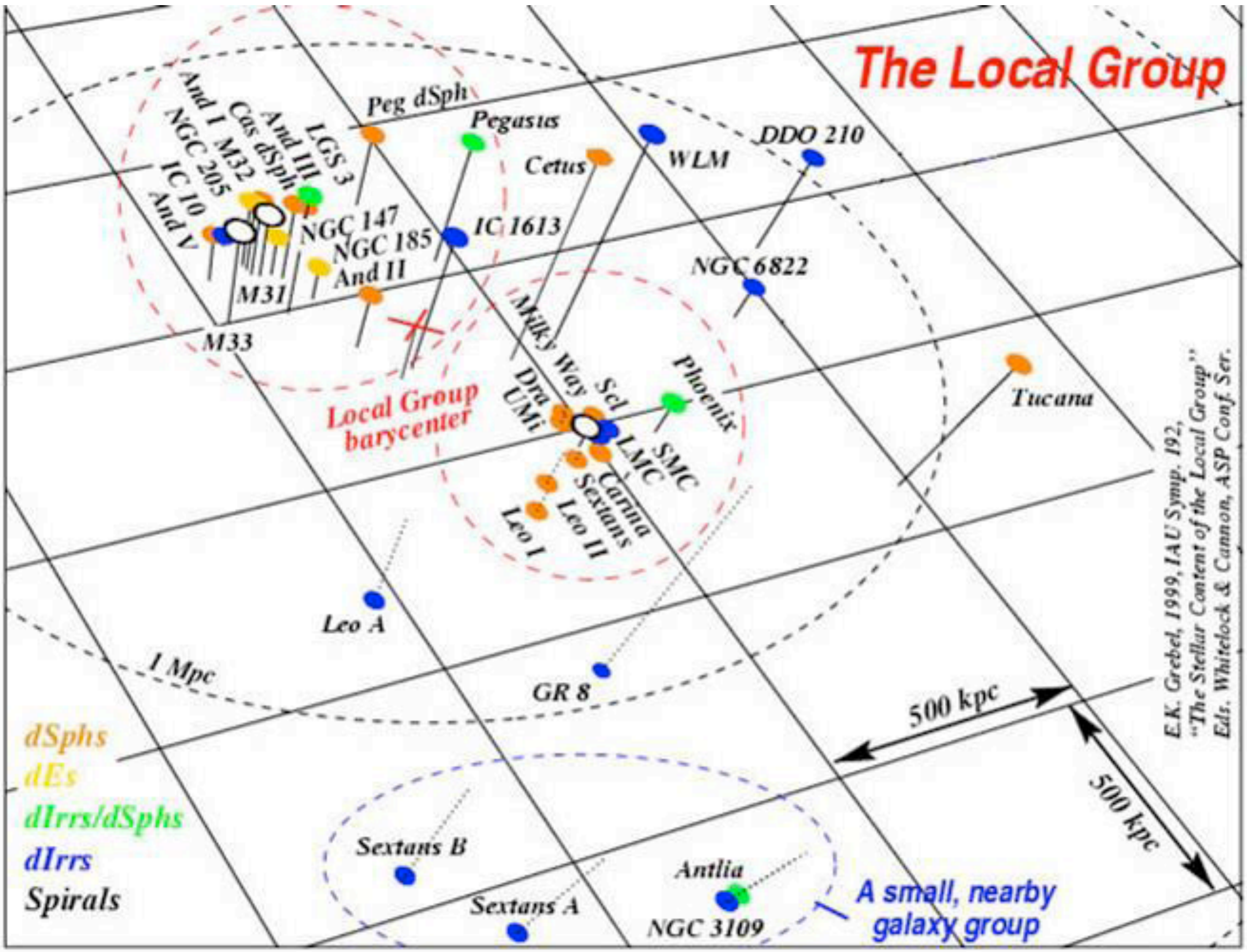
Local Group dark-matter halos

- Cumulative distribution function for DM halos in the simulated Local Group (Klypin et al.).
- Empirical fit from observations:
  - Log (M_{HI}) = 1.97log(V_{circ}) + 4.96
    - 100 km/s = 8 x $10^9 M_\odot$
    - 50 km/s = 2 x $10^8 M_\odot$
    - 20 km/s = 3 x $10^7 M_\odot$
- **10 times as many galaxies with M_{HI}~ 3 x $10^7 M_\odot$ as with $10^8 M_\odot$**



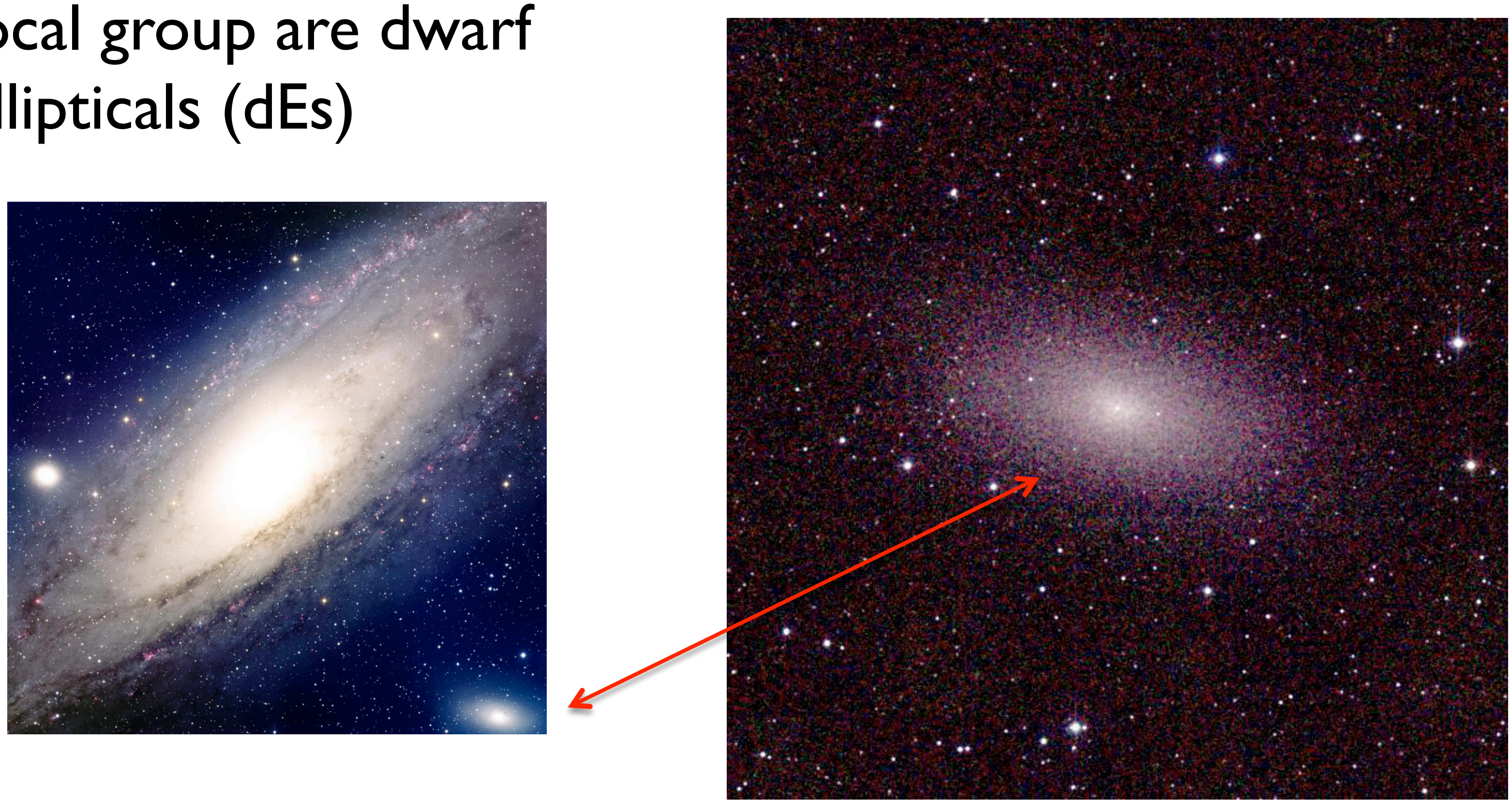
Distribution of Dwarfs in the Local Group

- Dwarf Ellipticals (dEs)
  - concentrated around M31
  - M32, N147, N205, N185
  - Little gas, old stellar pops
  - N147, N185, N205 rotationally supported
- Dwarf Irregulars (dIrr, Sdm)
  - All over, even at outskirts
  - Lots of gas (HI), mixed stellar pops
  - Rotationally supported
- Intermediate/Transition
  - Some gas, some SF, some with very few old stars
  - Probably not rotationally supported
- Dwarf Spheroidal (dSphs)
  - Satellites of MWG, M31
  - Complex SFH
  - gas?
  - Glorified globular clusters, but with dark matter
  - High σ /Vrot


The Local Group
Peg dSph
Pegasus
Cetus
WLM
DDO 210
And V
IC 10
NGC 205
And I
M32
Cas dSph
And III
LGS 3
NGC 147
NGC 185
IC 1613
And II
M31
M33
NGC 6822
Local Group barycenter
Milky Way
Dra
UMi
Scl
Phoenix
LMC
SMC
Carina
Sextans
Leo II
Leo I
Tucana
Leo A
GR 8
1 Mpc
500 kpc
500 kpc
E.K. Grebel, 1999, IAU Symp. 192, "The Stellar Content of the Local Group" Eds. Whitelock & Cannon, ASP Conf. Ser.
dSphs
dEs
dIrrs/dSphs
dIrrs
Spirals
Sextans B
Sextans A
Antlia
NGC 3109
A small, nearby galaxy group

Dwarf Elliptical Galaxies

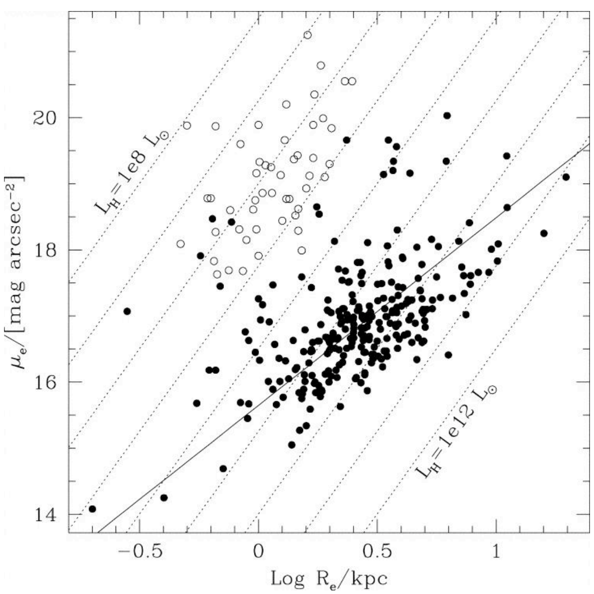
- All of the ellipticals in the local group are dwarf ellipticals (dEs)

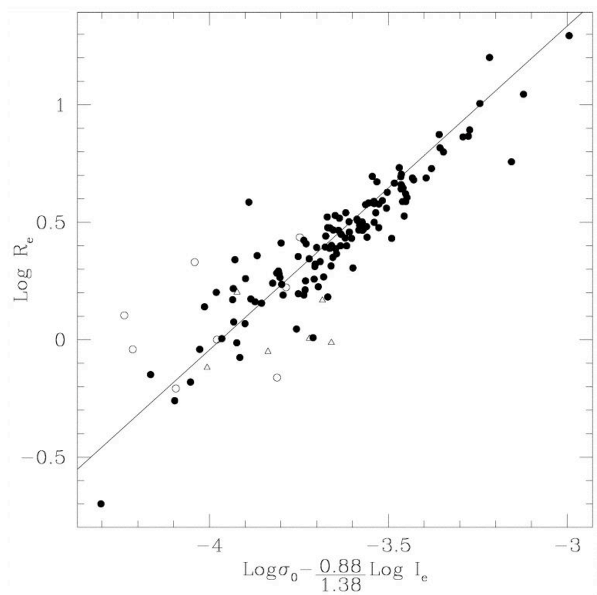


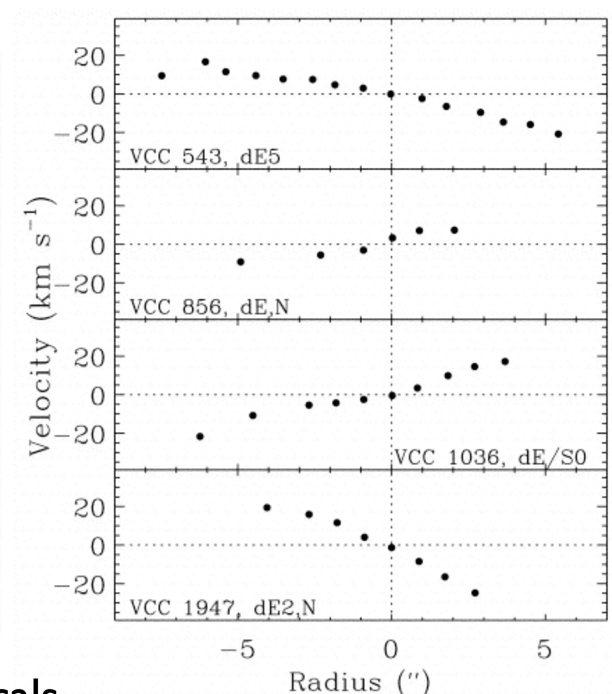
Dwarf Ellipticals

- Are they just scaled down versions of giant ellipticals?
  - Most are dominated by velocity dispersion
  - A few are rotating
  - Most lie on the fundamental plane: ➜

Kinematics





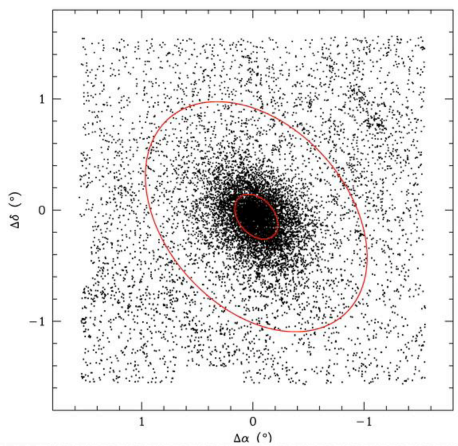


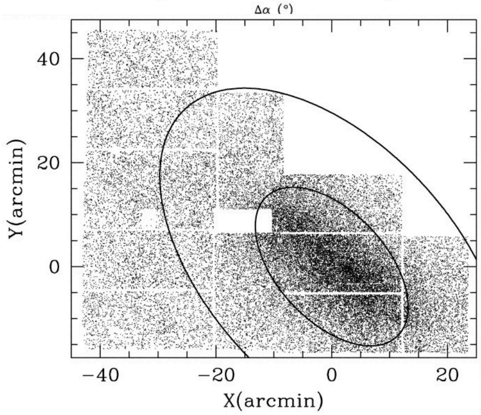
Open circles = dwarf ellipticals; Filled circles = large ellipticals

Dwarf Spheroidals

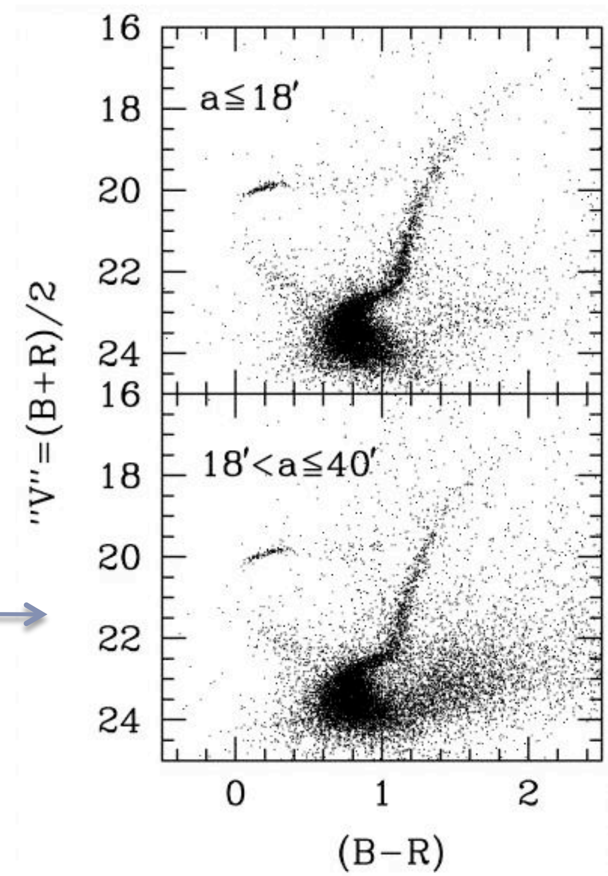
- What's the difference between a dSph and a dE?

Fornax dSph





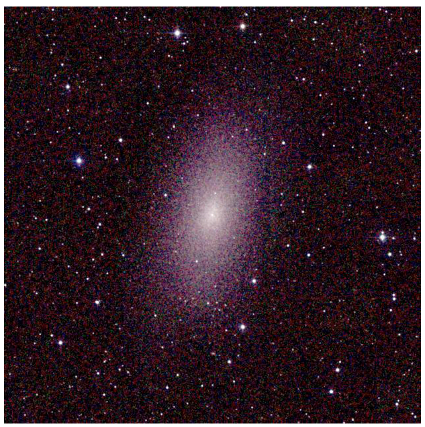
← Ursa Minor →



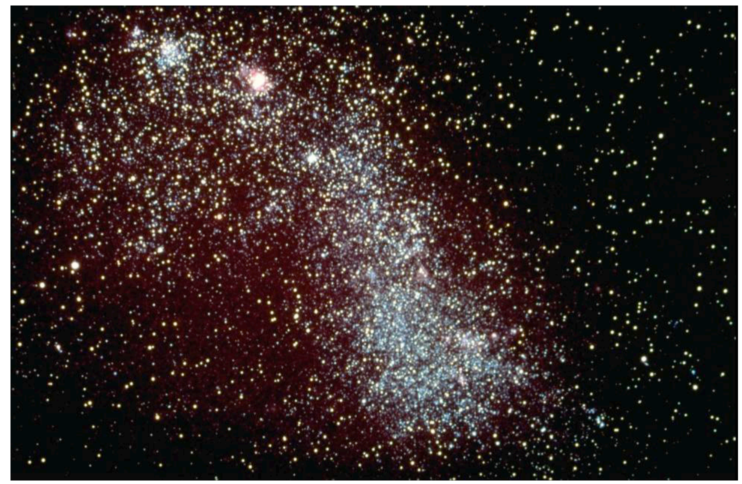
Dwarf Irregulars

- Obvious difference?

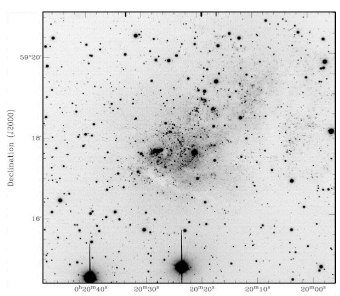
dE (NGC 205)



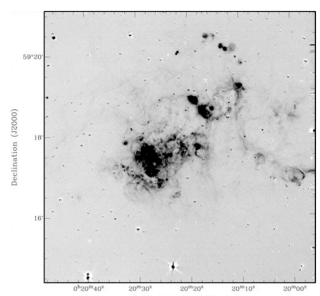
dIrrs (SMC)



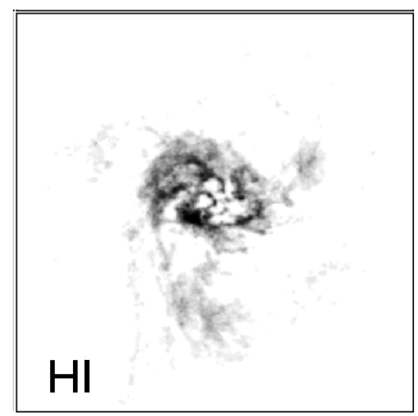
IC 10



blue

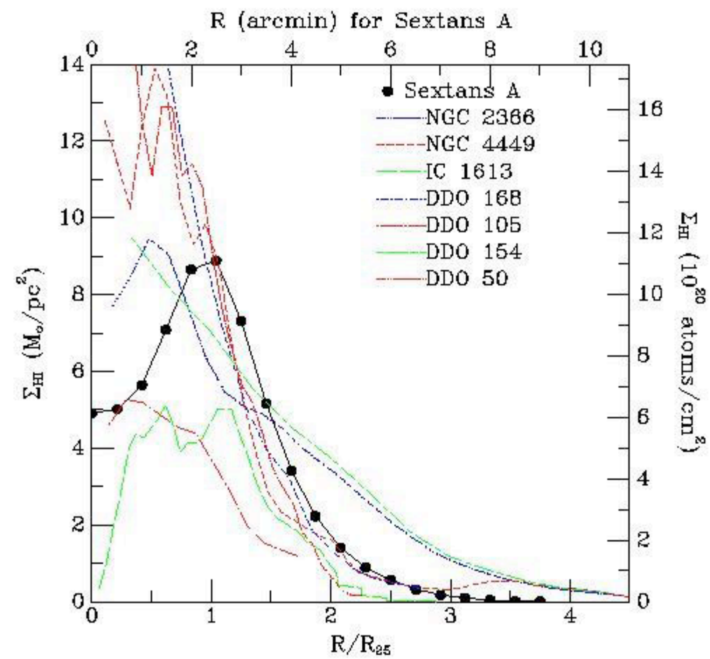


Hα



HI Content of Dwarfs

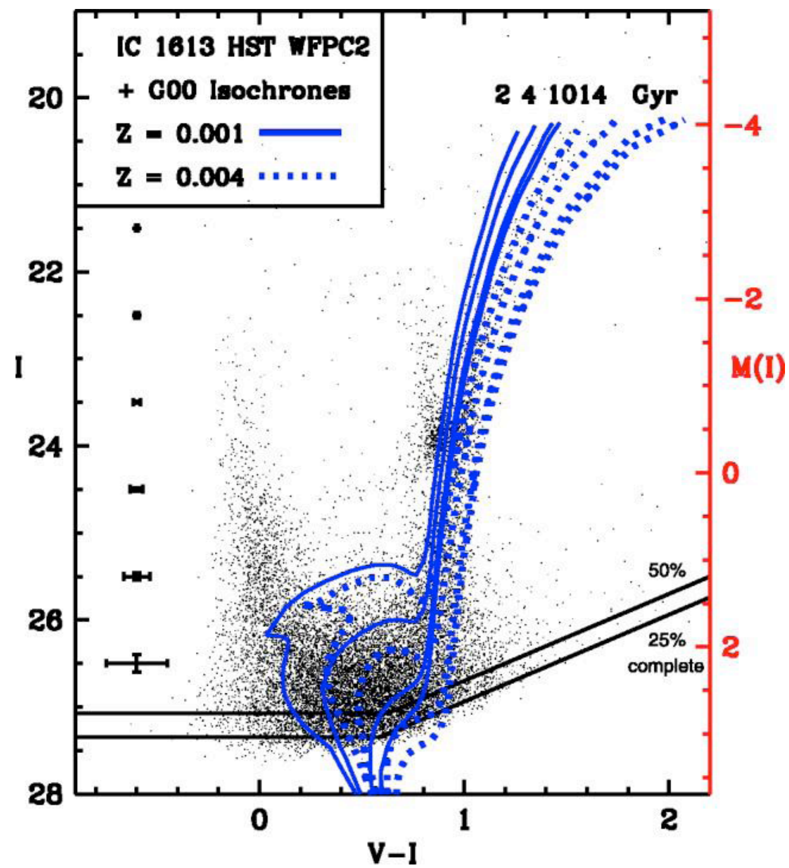
- dIrrs (only?)
- $M_{HI} \sim 10^6 – 10^9 M_\odot$
- Distribution:
  - Holes/shells
- Rotation
- Large extents?



Wilcots & Hunter

Stellar Populations

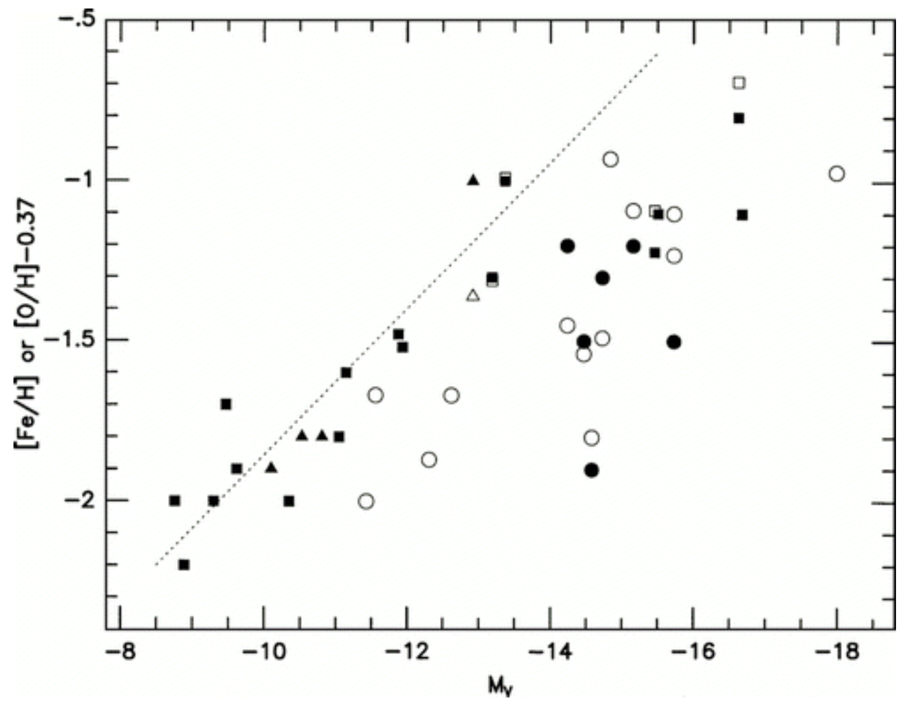
- Many CMDs from HST imaging
- Complex SFH
- All galaxies have some old stars
- A few dwarfs have very few old stars (e.g. I Zw 18)



IC 1613: Dohm-Palmer et al

Abundances

- [Fe/H] low
- [O/H] low
  - Why [O/H]?
- Trend w/ M_V
- Lowest Z galaxies are dwarfs
  - BCDGs
  - Why?



Feedback in Dwarf Galaxies

- Massive stars deposit energy into ISM
  - L_W ~ (mass loss rate) × (wind-velocity)^2
  - Create hot bubble (R ~ 60-200 pc)
  - SNe ➔ 10^{38} erg s^{-1} ➔ total E ~ 10^{50} erg
    - Shock heats gas to 10^6 K
    - Bubble expands at 10-100 km s^{-1}
- Dwarfs have "shallow" potentials
  - Low mass ➔ low V_{esc} (~40 km s^{-1})
- Loss of ISM ➔effects Luminosity Function?
  - Enough to hamper future SF?
    - M_{gal} = $10^6 M_\odot$ ➔ should lose all their ISM
    - but dSphs have had multiple episodes of SF!
- Loss of metals
  - Enough to pollute the IGM?
  - Hot gas leaving NGC 1569 is metal rich (Martin et al. 2002)