Astronomy 730

Environment

Outline

- Dwarfs
  - Significance
  - In the Local Group
    - Gas content
  - Types
    - Star-formation histories and feedback

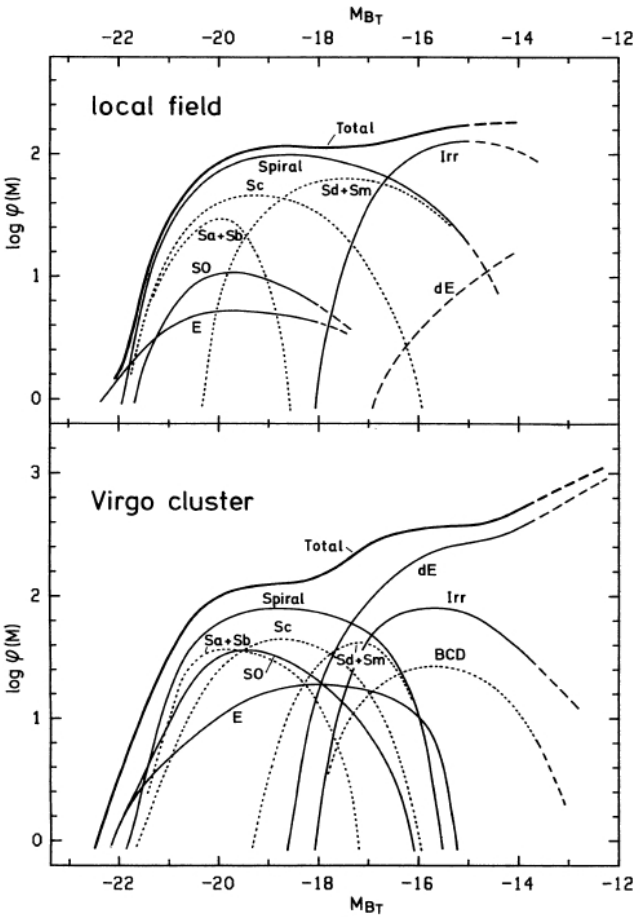
Dwarf Galaxies

Dwarf Galaxies: Galaxy formation context

- Galaxy Formation
  - Begin with some fluctuations…
    - Maximum scale: $\lambda_J = 2\pi/k_J = c_s(\pi/G\rho)^{1/2}$; $M_J = (\pi \lambda_J^3/6)\rho$
      - radiation dominated era: $M_J = 10^{11} M_\odot$
      - matter dominated era: $M_J = 10^6 M_\odot$
    - Frequency of perturbation smaller than Jeans length:
      $\omega(\lambda) = [4\pi G\rho(\lambda_J^2/\lambda^2) - 1]^{1/2}$
- Cold Dark Matter
  - 1st structures are low mass halos
  - Larger structures form via hierarchical merging
- 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 important

- Dwarfs
  - 1st to form and most numerous objects in early Universe;
  - Dominate faint galaxy counts in any deep survey;
  - Dominate luminosity function;
  - Are the building blocks of larger galaxies.
- But…
  - Those left today do not contain most of the stars and baryonic matter
  - Luminosity function depends on environment



Dwarf census in 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**

Missing dwarf problem?
10 times as many galaxies with M_{HI}~ 3 x $10^7 M_\odot$ as with $10^8 M_\odot$

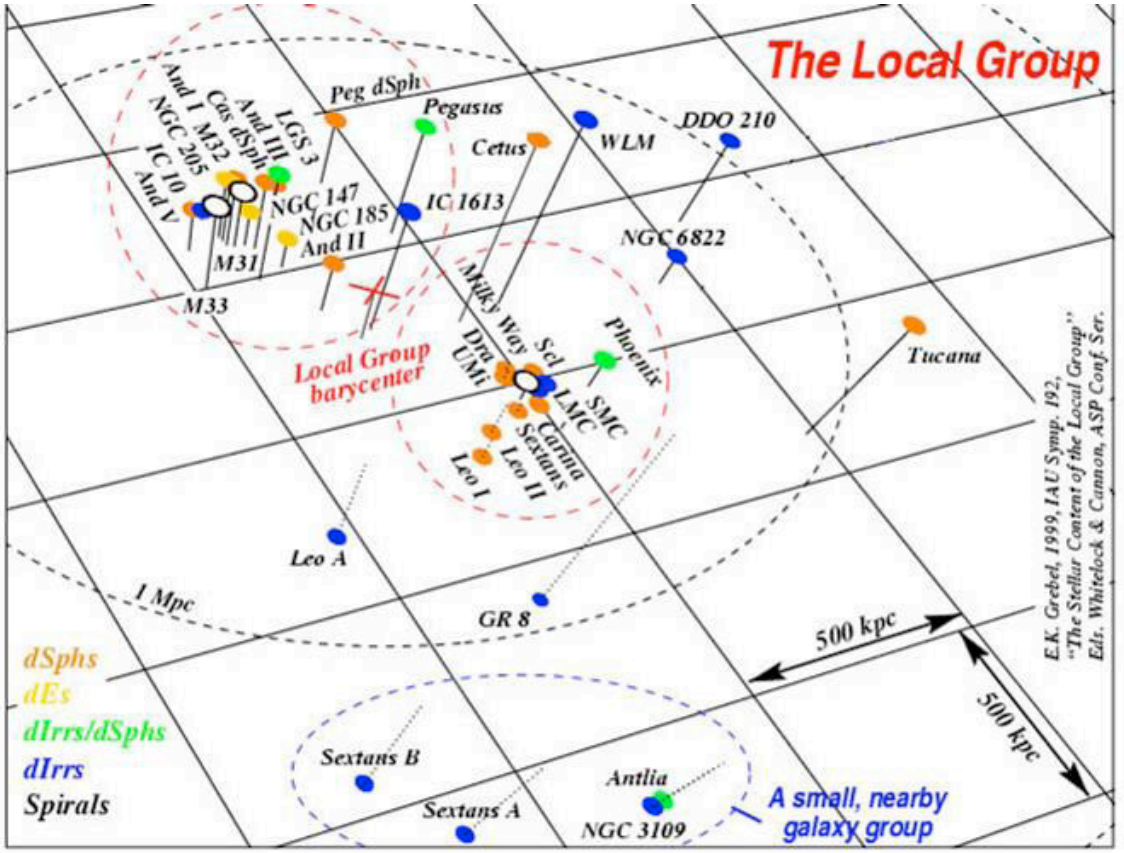
- There ought to be *many hundreds* of dwarf-mass DM haloes in the Local Group
- More detected every year!

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

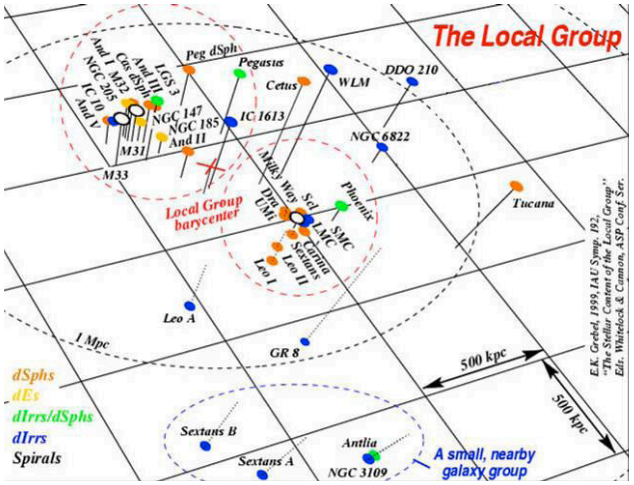
- Different types
- Clustering properties
- Gas content

- Internal structure
  V_{rot} / σ
- Complex stellar populations



HI Content of the Local Group

- Gas-rich spirals
  - M31 (log $M_{HI}/M_{\odot}$~ 9.76)
  - MWG (log $M_{HI}/M_{\odot}$~ 9.60)
  - M33 (log $M_{HI}/M_{\odot}$~ 9.18)
  - LMC (log $M_{HI}/M_{\odot}$~ 8.85)
- Gas-rich irregulars
  - SMC (log $M_{HI}/M_{\odot}$~ 8.81)
  - IC 10 (log $M_{HI}/M_{\odot}$~ 8.18)
  - WLM (log $M_{HI}/M_{\odot}$~ 7.90)
  - Sextans A (log $M_{HI}/M_{\odot}$~ 7.90)
  - IC 1613 (log $M_{HI}/M_{\odot}$~ 7.78)
  - Leo A (log $M_{HI}/M_{\odot}$~ 7.30)
  - *Gas-rich irregulars tend to lie at large distances*
- Tidal Debris/HVCs
  - Magellanic Stream
  - M31/M33 bridge (Braun & Thilker2004)
  - HVC system



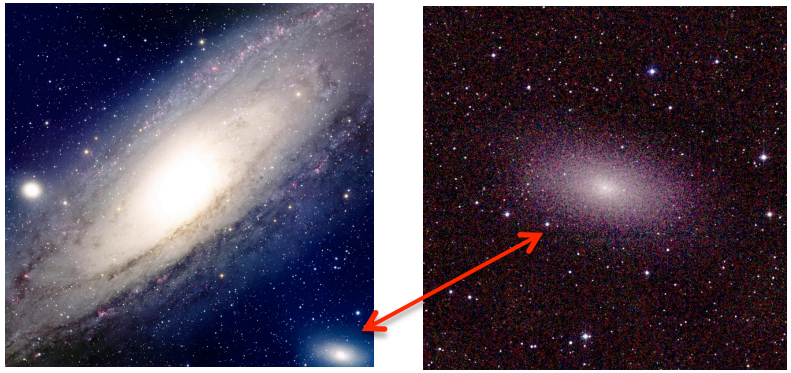
Total HI Mass
log $M_{HI}/M_{\odot}$ ~ 10.13
~ 10% $M_{stellar}$
≤ 1% of $M_{dynamical}$

Pure HI galaxies?

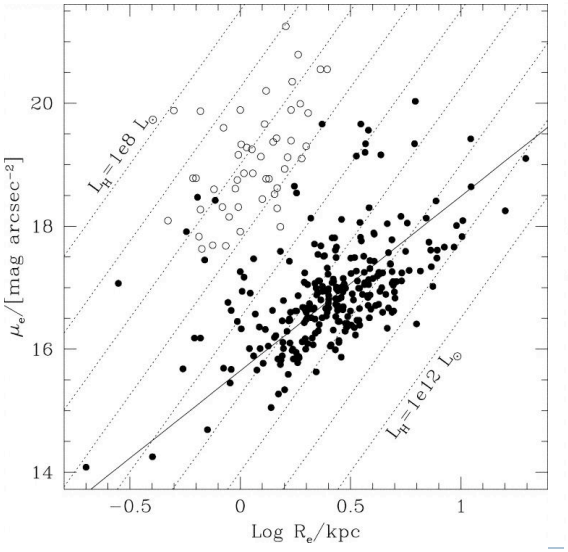
- There is no indication of a population of pure HI clouds (HVCs) in the intra-group medium.
- The HI mass function in the group environment is flat at the low mass end.
- Intra-group medium in "intermediate" groups is populated with tidally stripped HI as groups evolve

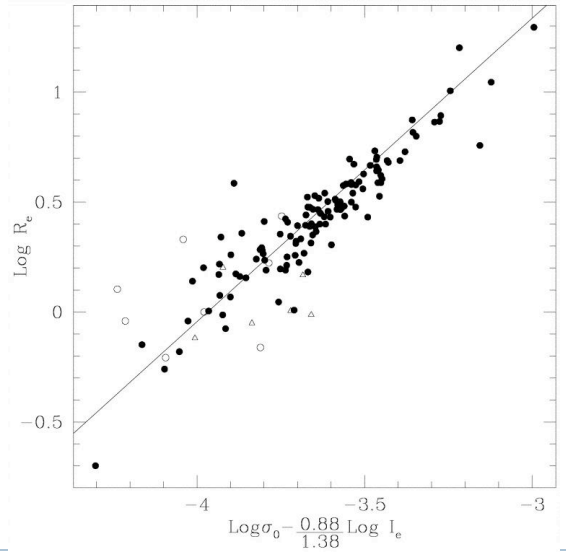
Dwarf Elliptical Galaxies

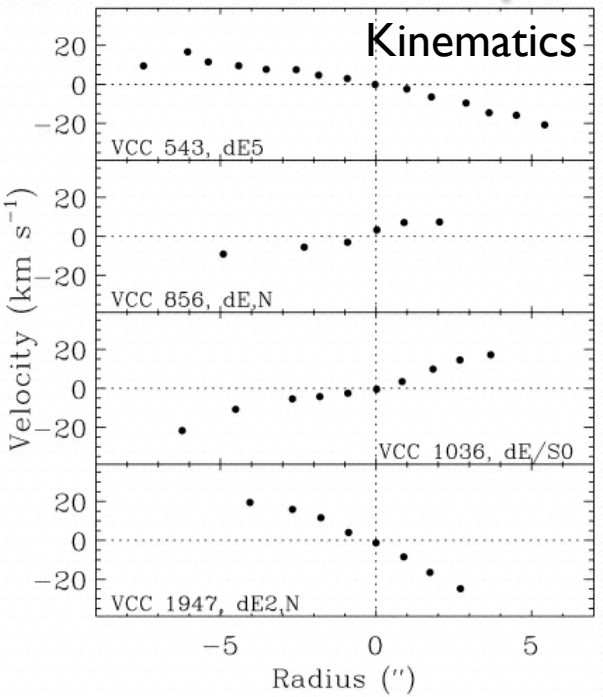
- All of the ellipticals in the local group are dwarf ellipticals (dEs)



- 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:





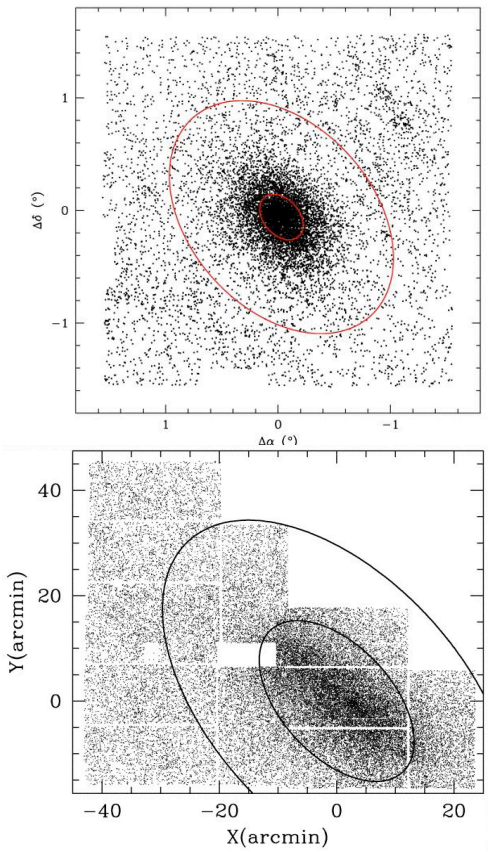


- Open circles = dwarf ellipticals; Filled circles = large ellipticals

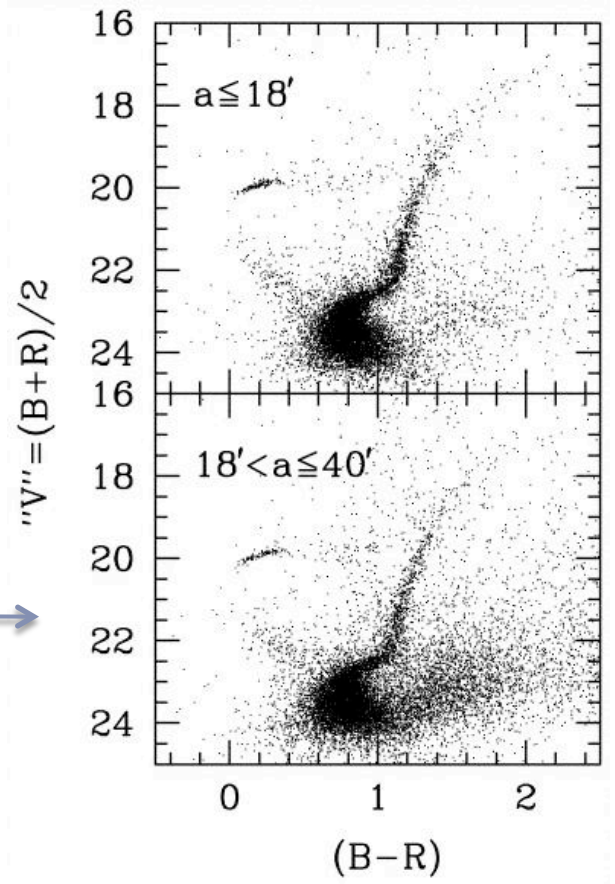
Dwarf Spheroidals

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

Fornax dSph



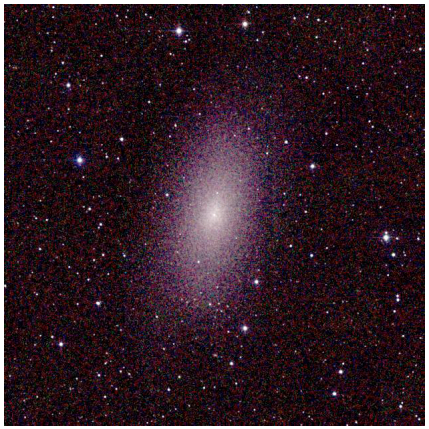
Ursa Minor



Dwarf Irregulars

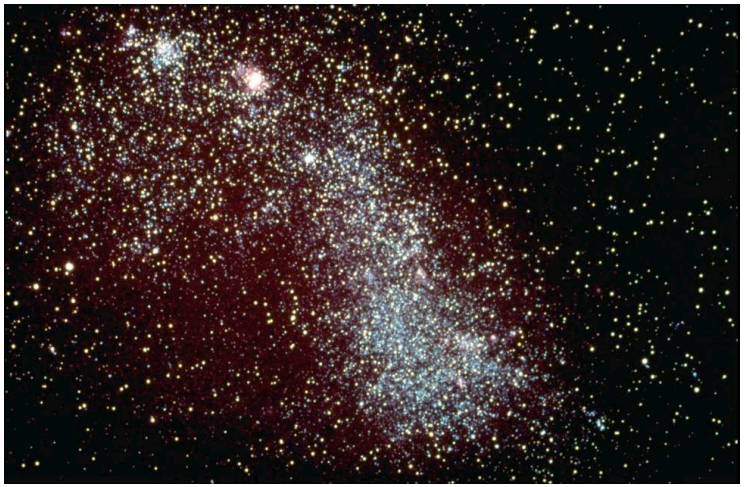
- Obvious difference?

dE (NGC 205)



vs

dIrrs

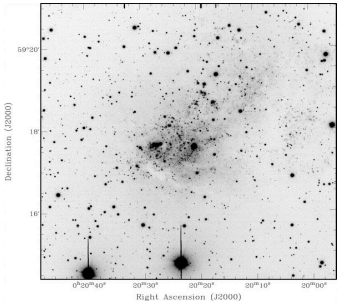


SMC

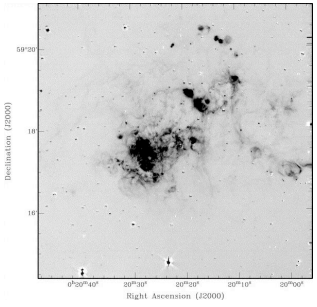
vs

IC 10

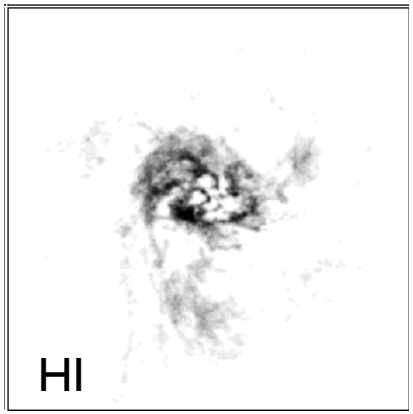
- dIrrs (only?)
- $M_{HI} \sim 10^6$–$10^9 M_\odot$
- Distribution:
  - Holes/shells
- Rotation
- Large extents?



blue

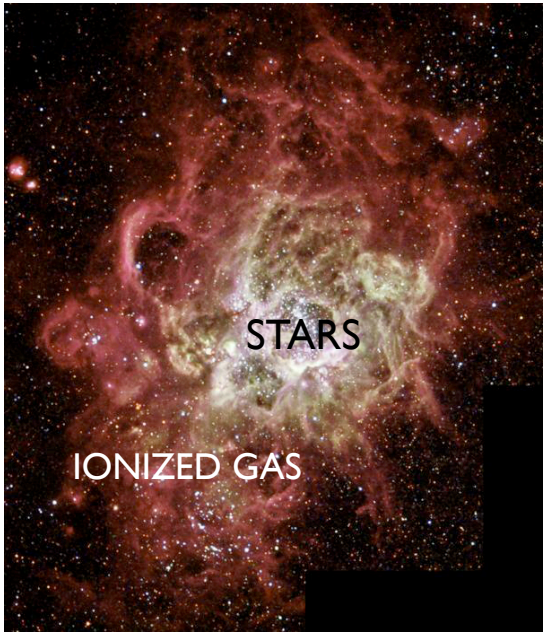


H α



Feedback in Dwarf and Spirals

- 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}
- Ionized gas is "stirred up" ➔ $\sigma_{H\alpha}$ = 80-100 km/s
  - Correlated with star-formation intensity
- 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!***



IC 1613

- No observed loss of *cool* ISM
  - HI holes not necessarily correlated with HII regions/OB associations/diffuse X-ray emission
- Kinematics of ionized/cool gas cannot account for energy deposition from stellar-winds/SNe
  - Mechanical energy deposited by stars/Sne's is ***a factor of 10 higher*** than can be accounted for in the kinematics of the neutral and ionized gas ➔ most energy escapes with hot gas to halo (fountains)
- Ultimate fate
  - Removal of gas content? ➔ unlikely except in extreme cases
  - Loss of metals? ➔ *likely*
    - Enough to pollute the IGM? (e.g., hot gas leaving NGC 1569 is metal rich; Martin et al. 2002)

Summary: Feedback, Stellar Pops & Abundances

- CMDs from HST reveal
  - complex SFH
  - all galaxies have some old stars (I Zw18 extreme)
- Spectroscopy reveals:
  - low stellar abundance correlated with luminosity (and plausibly mass)
- Multi-wavelength imaging reveals:
  - SF has enough energy to blow out *all* gas
  - All gas is not always blown out (dIrr's)
  - SF and gas holes not always co-incident
- Inferences on *feedback* in dwarfs:
  - Energy from star-formation preferentially blows out enriched gas local to the clumpy star-formation.
  - Inefficient for blowing out all gas, particularly cold gas.
  - ➔ SF is on-going, but metal poor.