Astronomy 330

Lecture 26

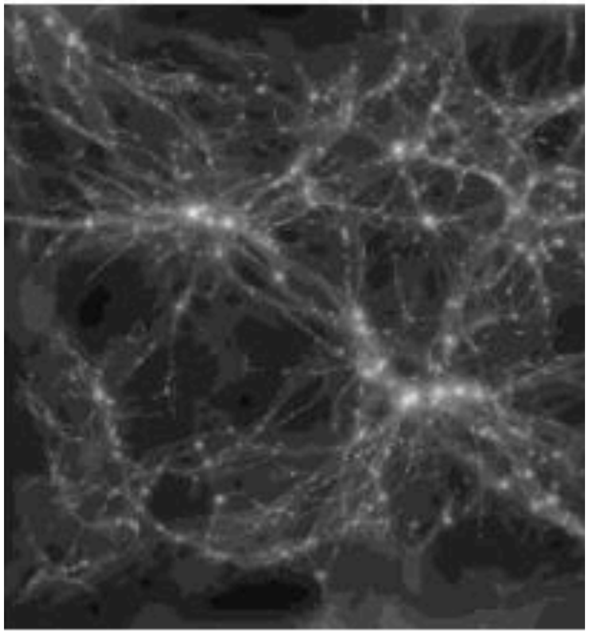
10 Dec 2010

Outline

- Clusters
  - Evolution of cluster populations
    - The state of HI sensitivity
- Large Scale Structure

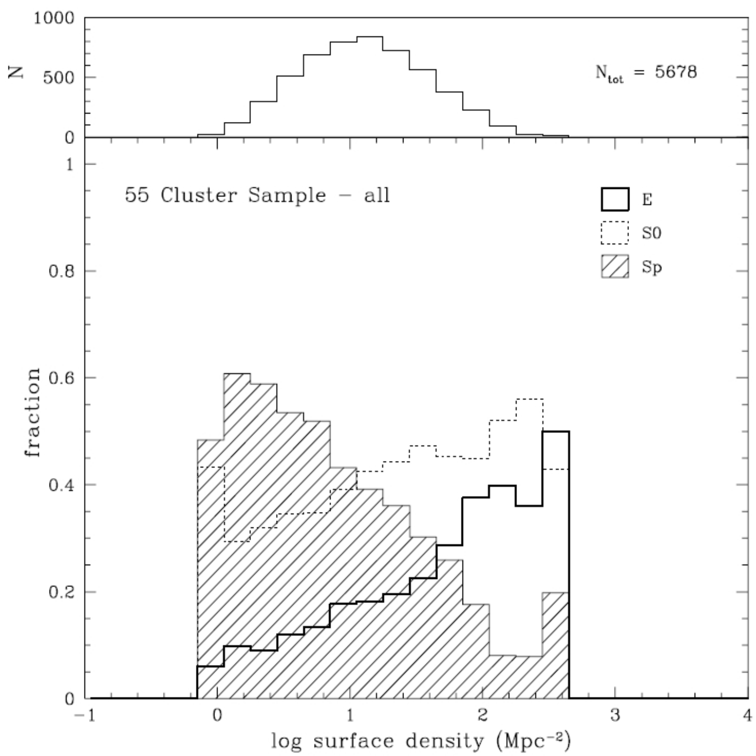
Cluster Evolution

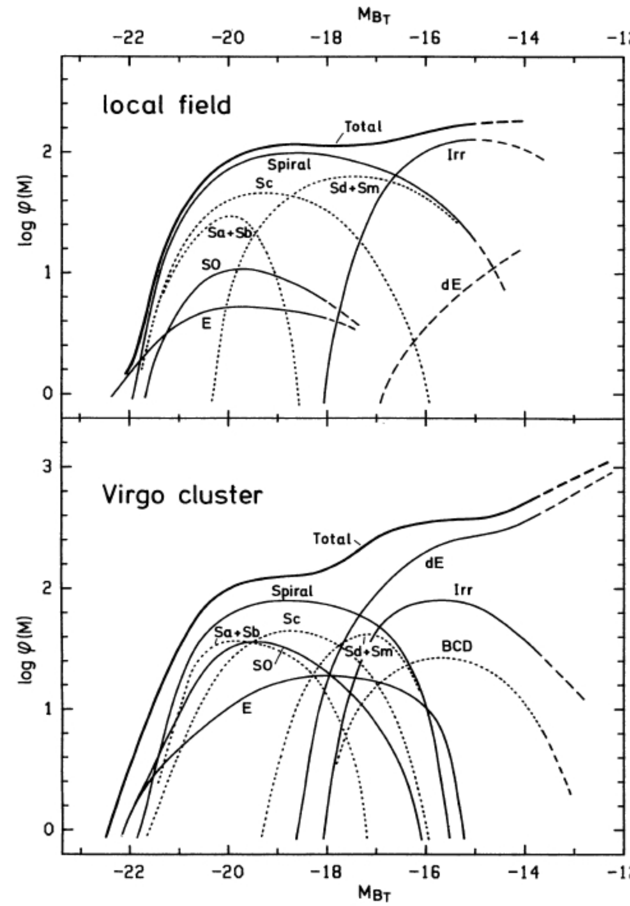
- Why might we expect it?
  - What does density determine?
- What might we expect, say, for evolutionary time-scales in dense environments relative to the field?
  - Stellar evolution?
  - Gas-consumption rates?
  - Dynamical processes (merging)?
- How would cluster selection-effects impact our assessment of evolution?
  - If density is important, what *types* of clusters will be most *easily* detected at *large* distances?
  - How about *projection* effects?



Cluster vs the field: an environmental view

- The morphology-density relationship
  - E's, S0's, and dE's more common in clusters



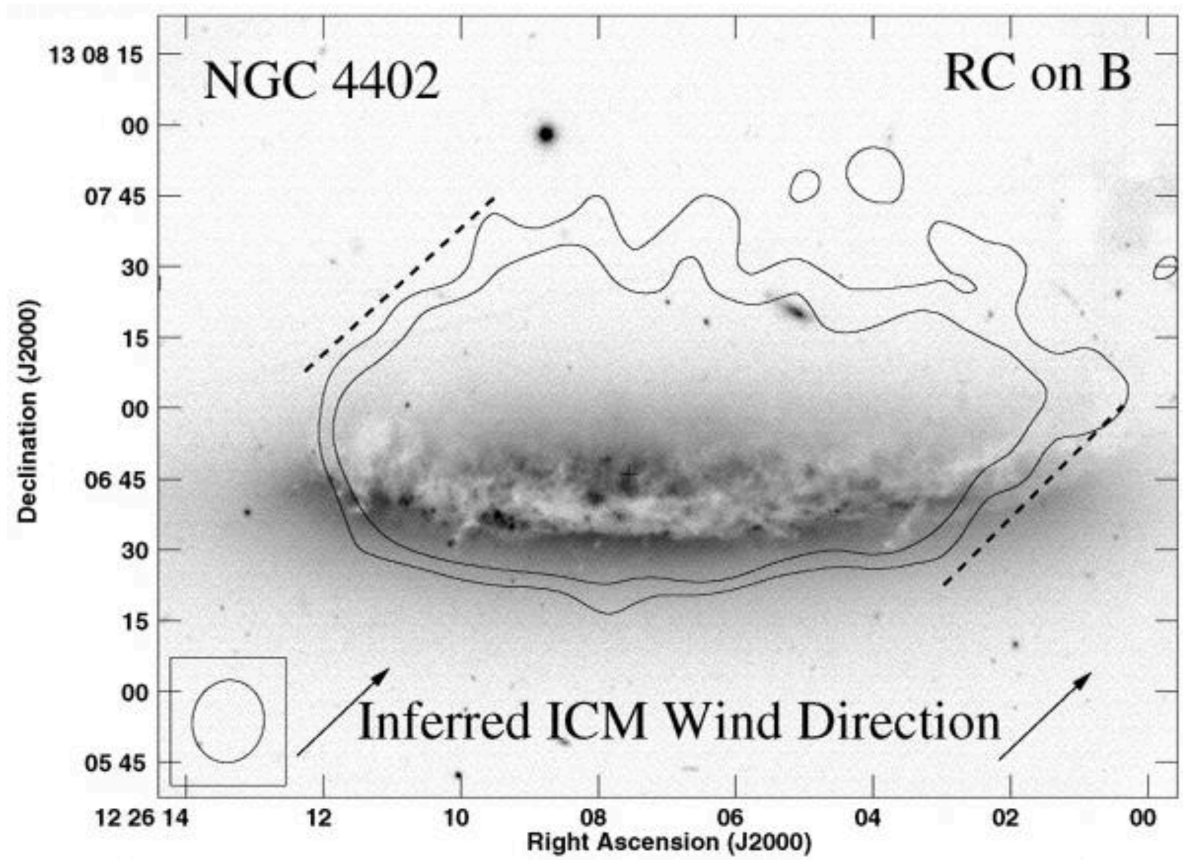


Dressler et al. '97

Binggeli et al. '88

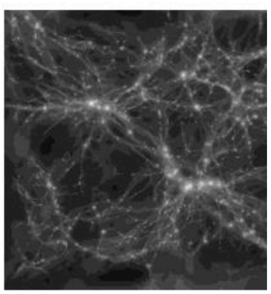
Ram-pressure stripping

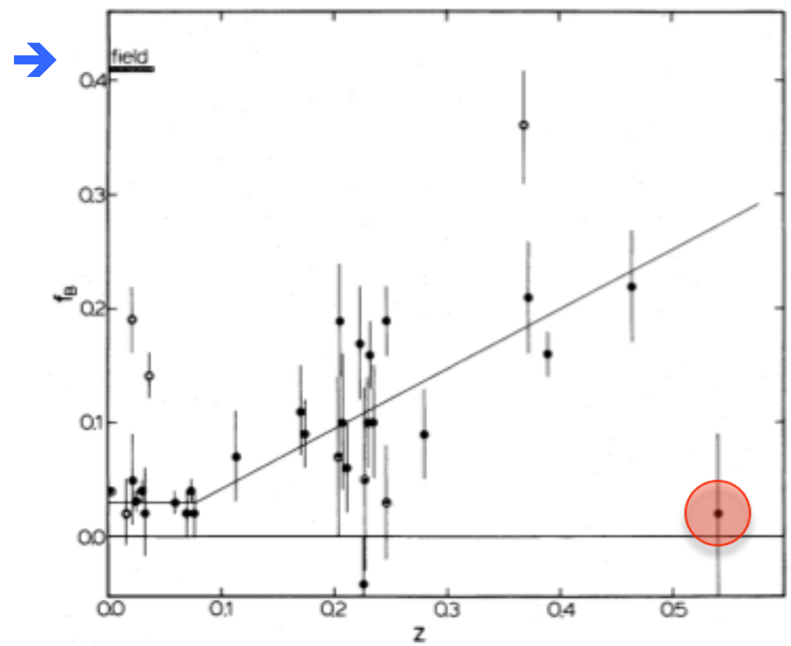
- Spirals undergo stripping, interactions in rich cluster environments
- How does this affect star-formation, galaxy colors, and morphology?



Cluster Evolution: Butcher-Oemler Effect

- (Also known as the BO or "moving target" effect)
- Original claim: (1984, ApJ, 285, 426)
  - Moderate z clusters have larger fractions of blue galaxies
- Counter examples
  - e.g., CL0016+16
- Later amended to
  - spectroscopically younger:
    - "E+A" galaxies
      - Higher velocity dispersions
      - Less centrally concentrated
    - More AGN
    - More star-bursting galaxies
- Don't forget projection!
- Sample selection?





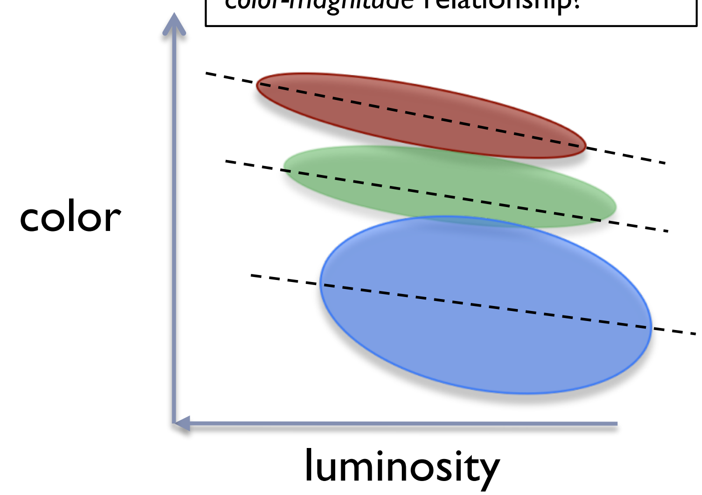
Cluster Evolution: the red sequence

- If clusters had more blue galaxies yesterday

  ➔ they have become red by today.

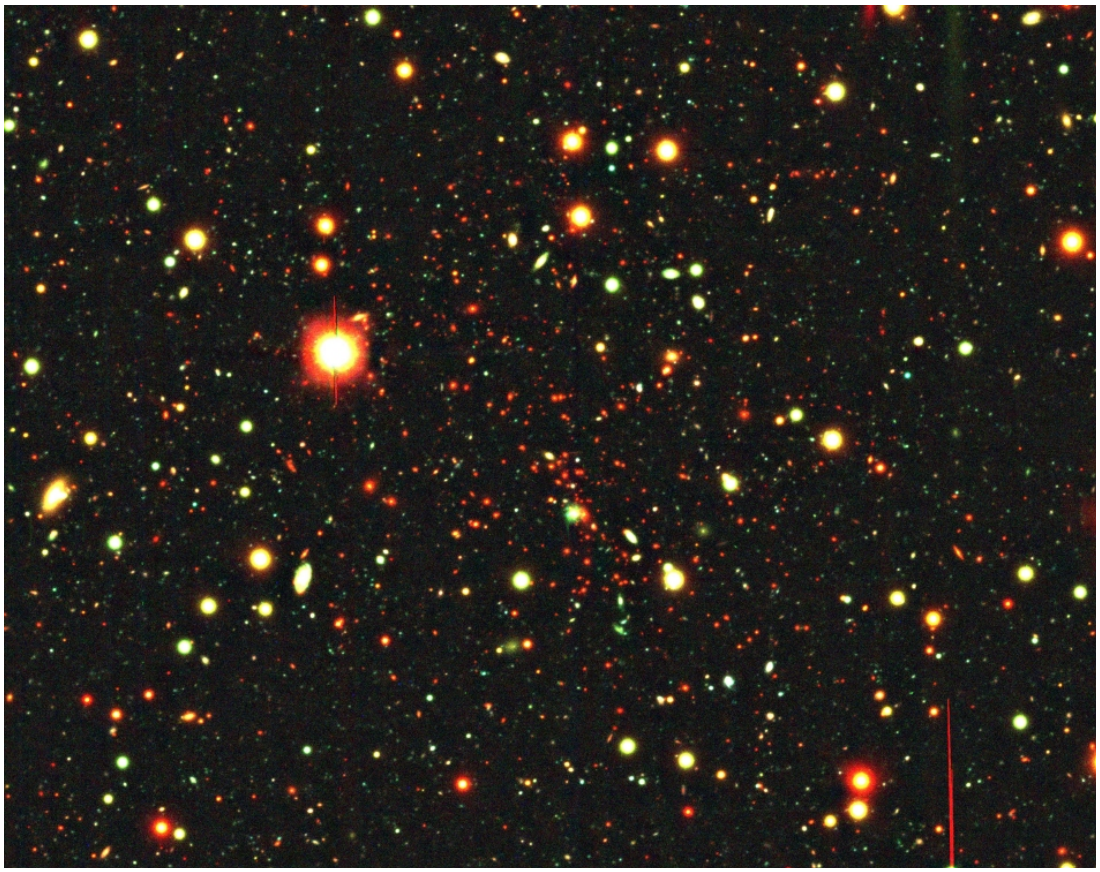
  ➔The luminosity function (LF) for different morphological or spectral types should change with time
- Specifically, the LF for red galaxies should grow with time.
  - If the LF slope changes, that tells us whether the "growth" of the red populations is for high- or low-mass objects, i.e., what the blue galaxies at higher redshift are progenitors of today.
    - Crude spectral types:
      - Red sequence
        - Red and dead (today: E's and S0's)
      - Blue cloud
        - Vigorously star-forming (today: intermediate to late-type spirals and dIrrs)
      - Green valley
        - Weakly forming stars (today: early-type spirals and some lenticulars)

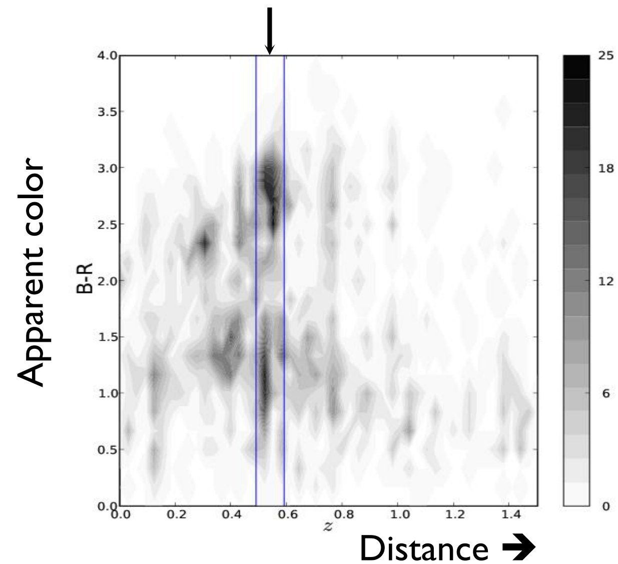
Why a slope, i.e., what is called the *color-magnitude* relationship?

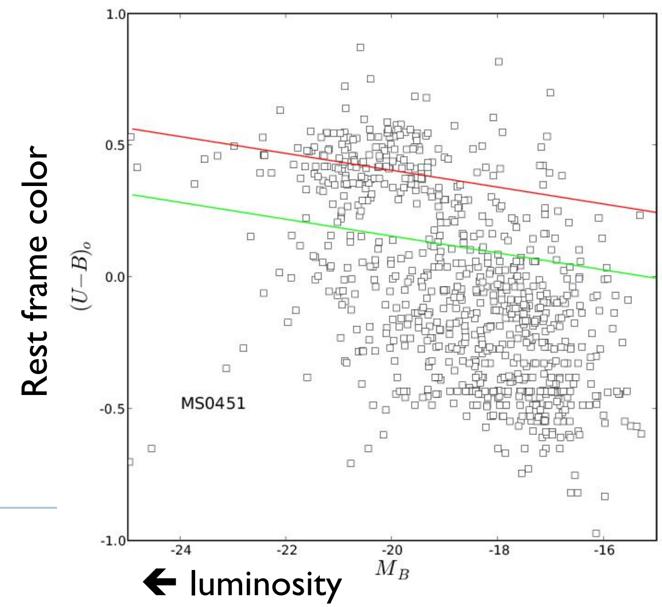


At z=0.5, the red sequence is well-formed

MS0451: z=0.54, σ=1354 km/s, L_x=40e44 ergs/s







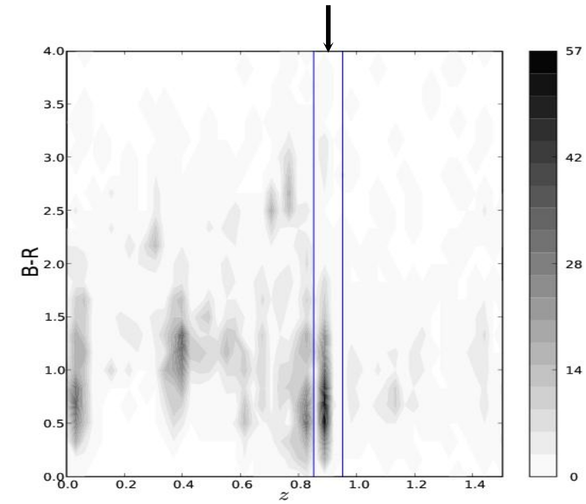
WIYN Long-Term Variability Survey

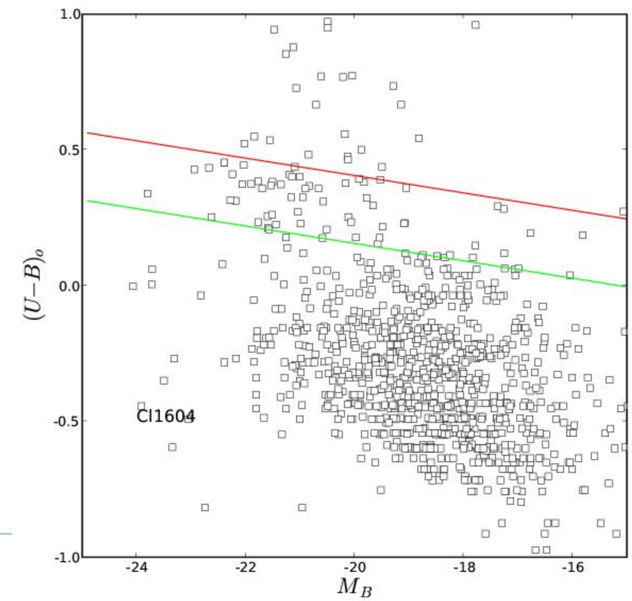
- Crawford et al. 2006, 2008

At z=0.9, the blue cloud dominates . . . even in rich clusters

CL1604: z=0.9, σ=982 km/s, L_x=2e44 ergs/s

WIYN Long-Term Variability Survey





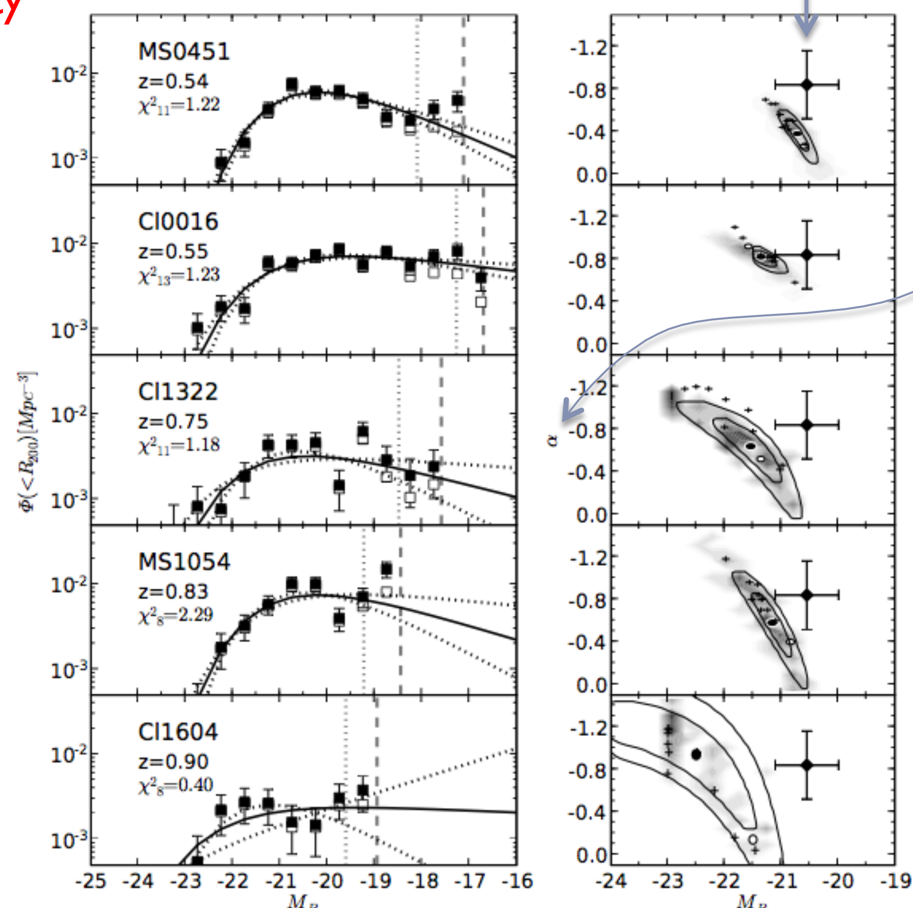
- Crawford et al. 2006, 2008

Cluster luminosity functions to z=1

Red sequence Luminosity functions (RSLF)

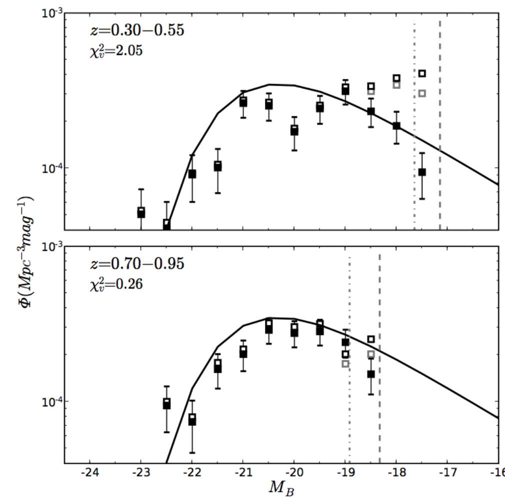
Low-z cluster values:

Cluster RSLF



α is faint-end slope; more negative α means steeper, upward slope

The field RSLF



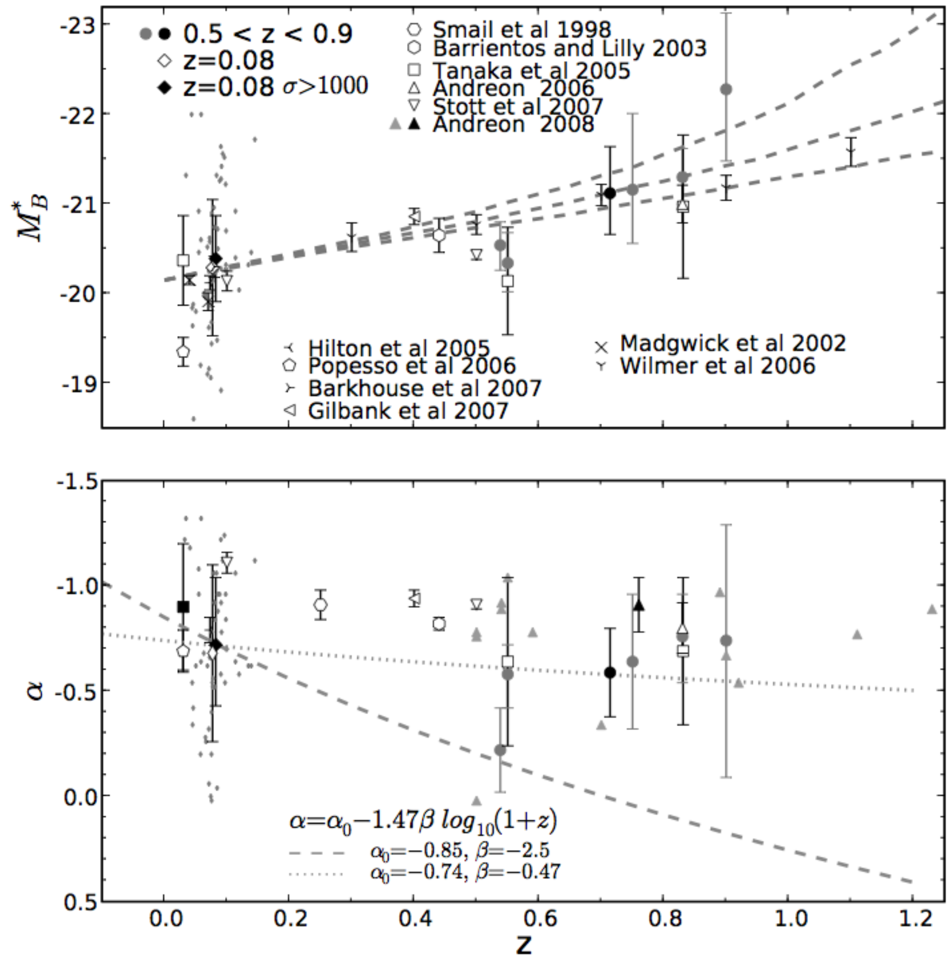
Knee of LF

Crawford et al. 2009

Luminosity Function Evolution

Consistent with *passive** luminosity evolution

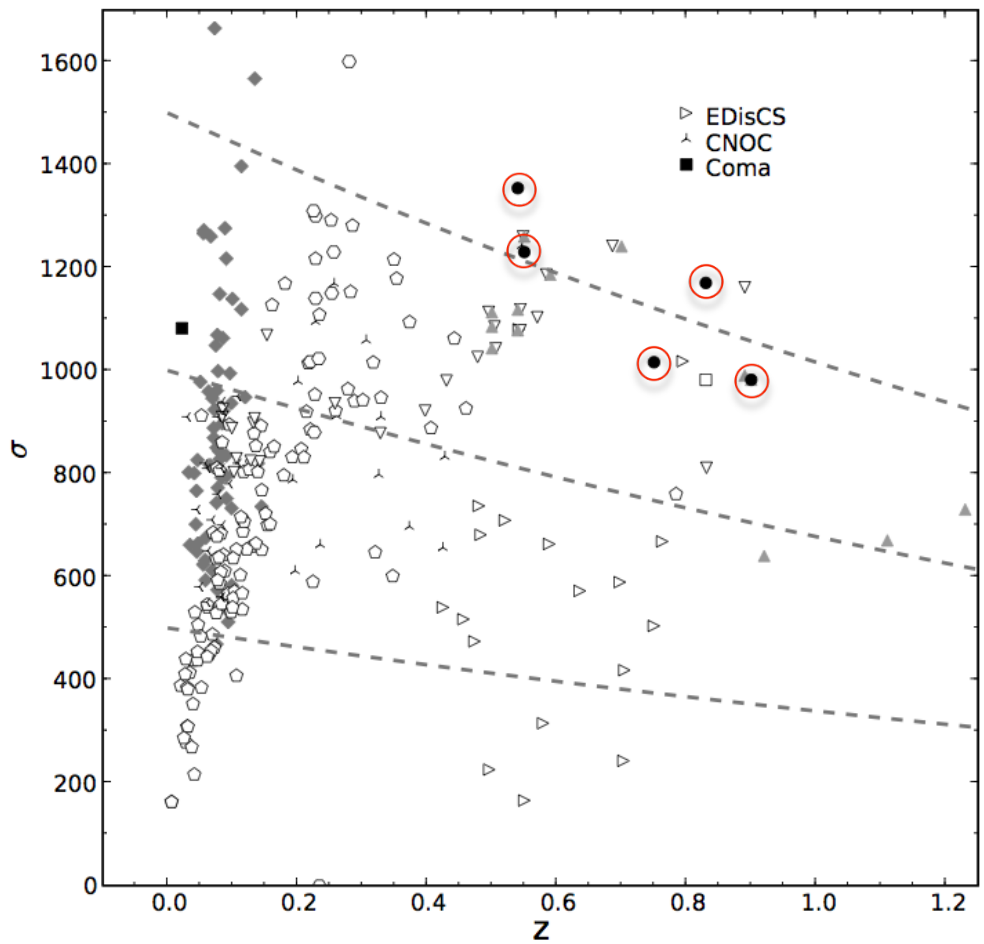
* *Passive evolution* refers to the evolution of stellar populations in the HR diagram (CMDs) in the absence of further star-formation.



Don't forget selection effects…

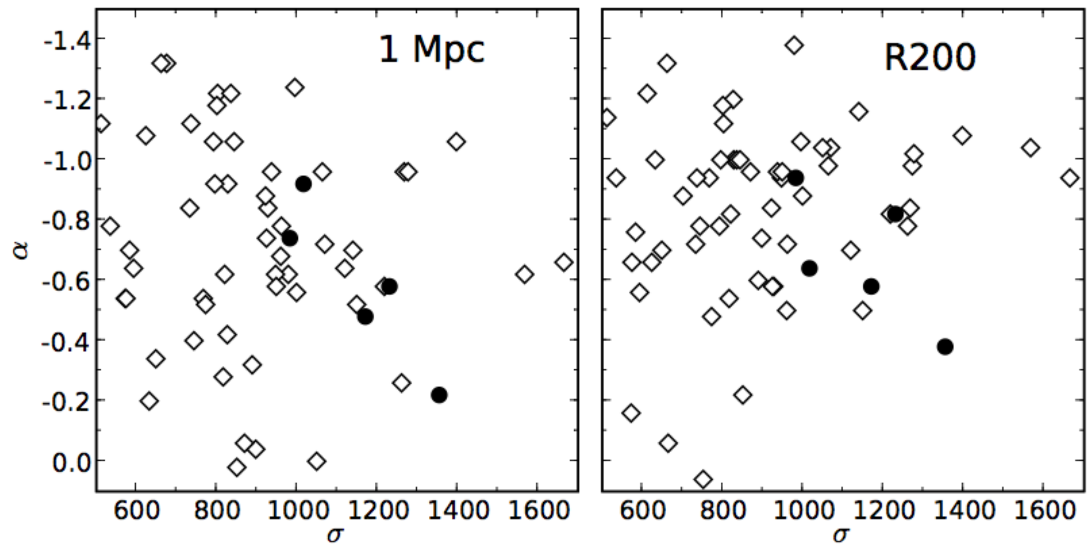
Cluster mass, or its proxy, σ, grow with time as more an more mass falls in to and virializes with the cluster potential.

The clusters studied most intensively at higher redshifts are as large or larger than most known clusters in the local volume (they are rare).



…Combined with cosmological variance

Faint-end slope of the red-sequence LF



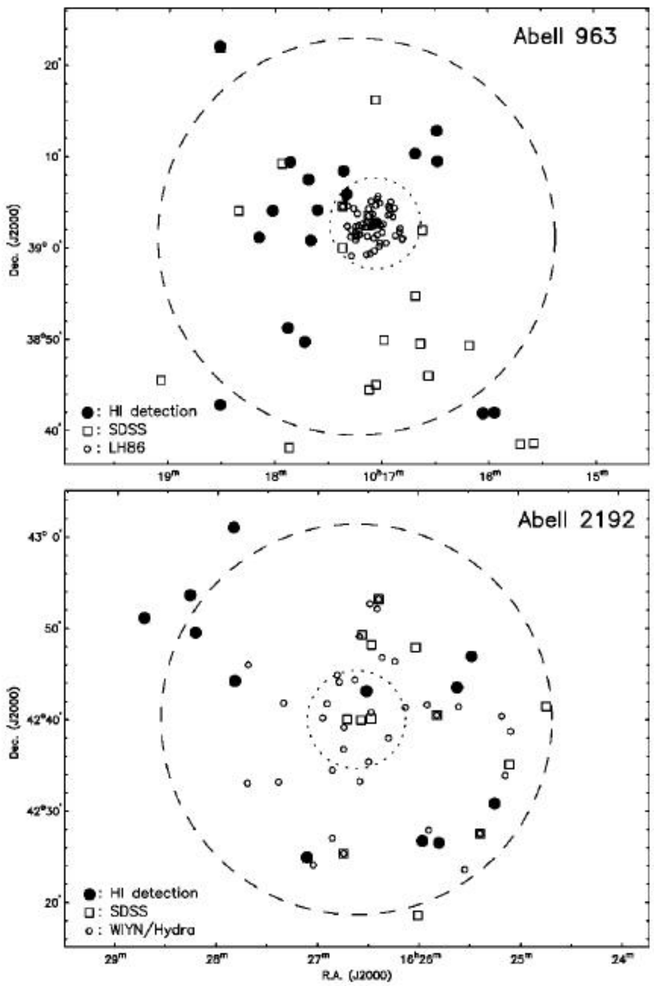
- Clusters exhibit a wide range of faint-end slopes.
- If there is a correlation with other cluster properties (there must!) it has not yet been determined.
- It does appear that the inner-cluster regions have larger (more positive) α, indicative of a relative dearth of dwarf systems.

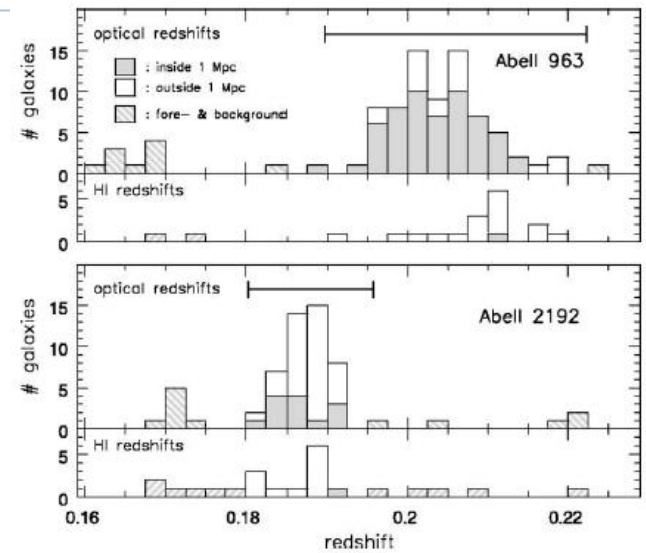
- **What's the cold gas doing?**

HI View: State of the Art:

Verheijen et al. 2007 (van Gorkum)

45’

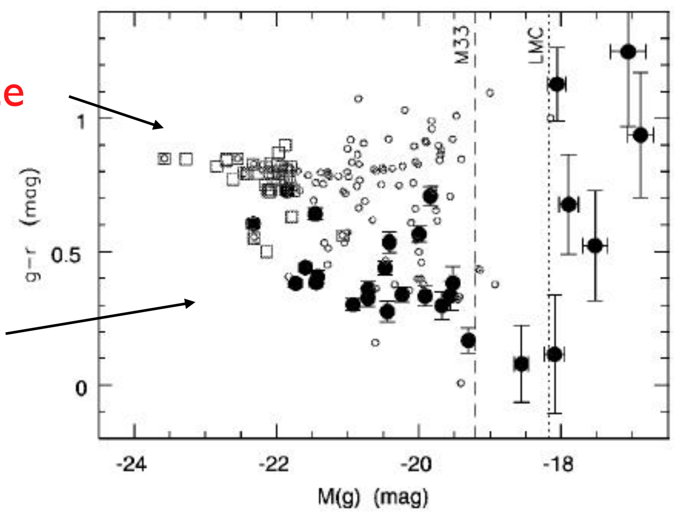




z=0.2

Red sequence

Blue cloud



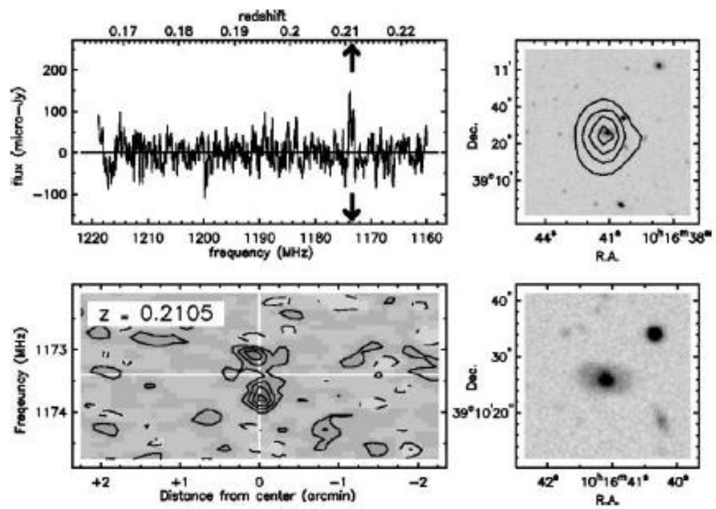
- Westerbork

NB: 200h of 1000h *total to come*!

HI View: State of the Art

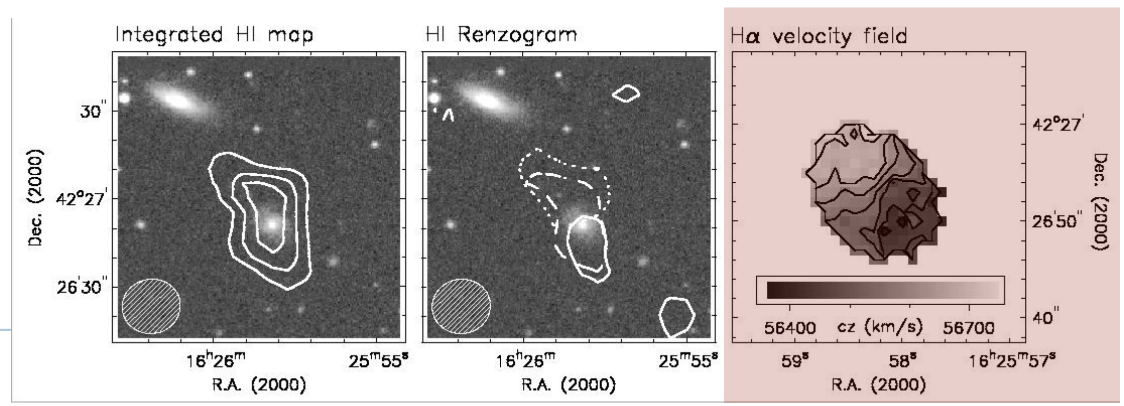
- Solid detections for 42 sources in 2 x 0.4 deg^2 fields
  - expect 200 sources in 1000h
- Limited spatially-resolved kinematic information
- Hα offers detailed kinematic supplement + SFR map
  - t=80 min, 3.5m telescope (CA)
  - 16x16 array of 1” fibers (PMAS)

A963 - Westerbork



A2192 (z=0.19) - VLA

M_{HI}=7x10^9 M_{sun}



Verheijen & Dwarakanath ‘08

The State of HI Sensitivity

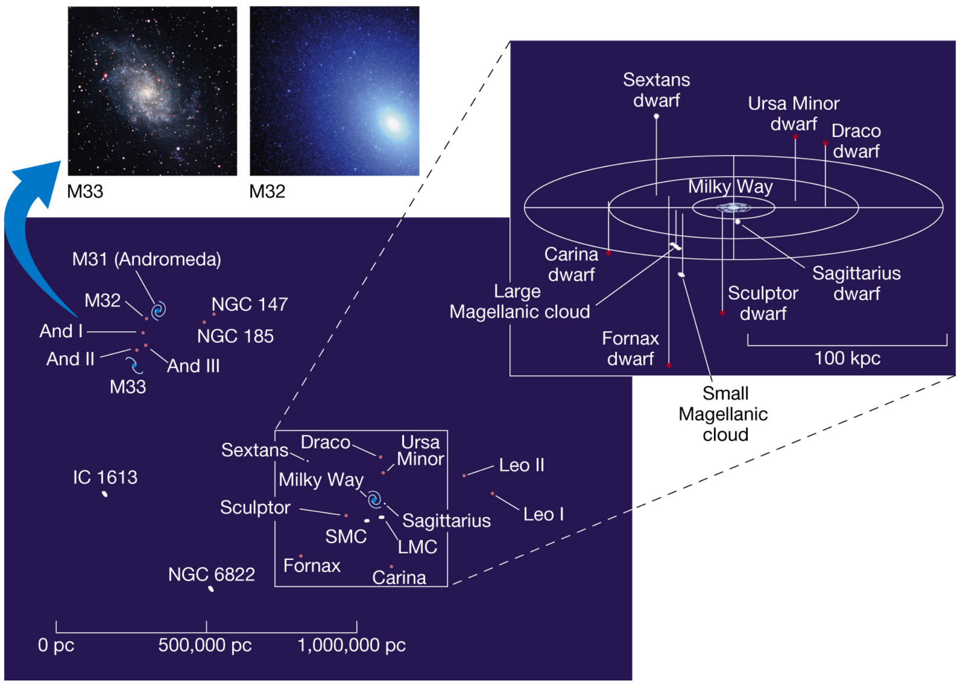
- Heroic efforts
- Awesome data
- … but sensitivity is pitiful compared to optical and infrared data

- Really need SKA

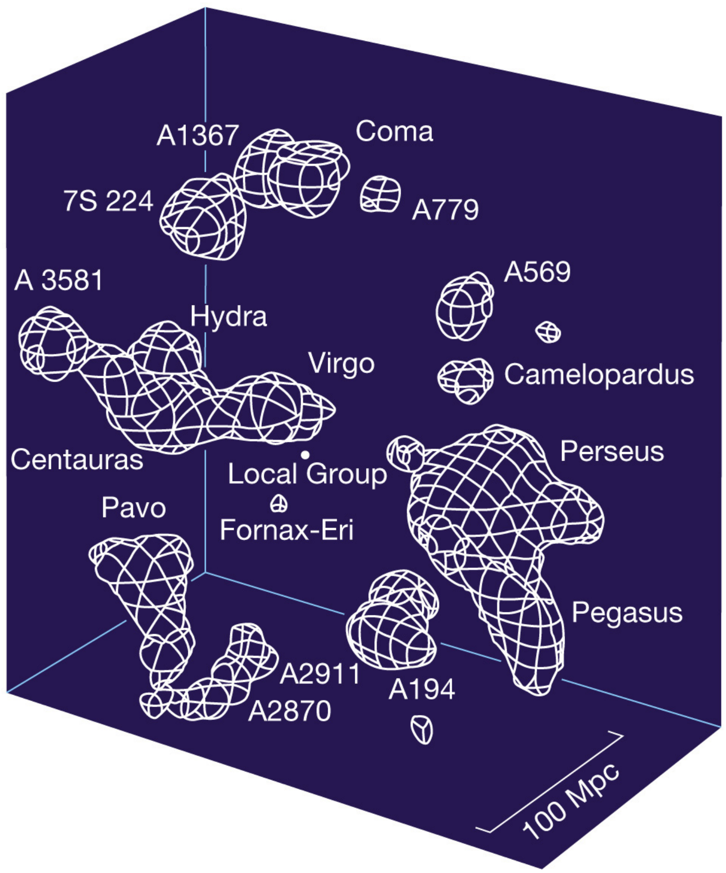
Stopped here

Large Scale Structure: revisited

- Local Group (1 Mpc):

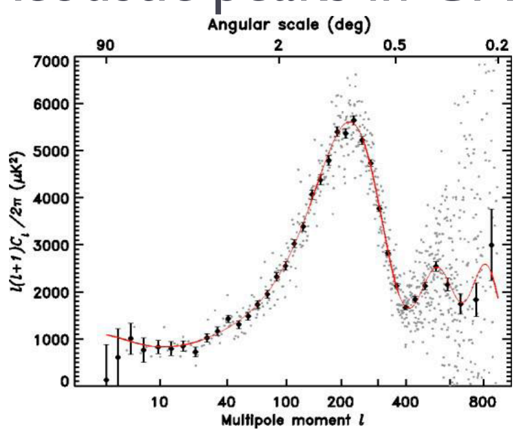


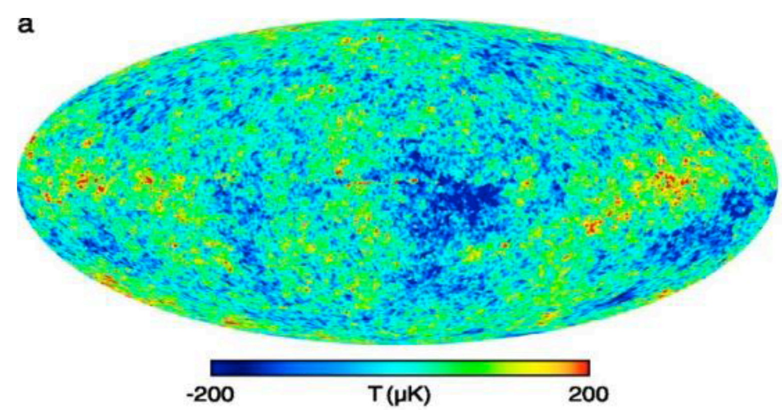
- Local volume (100 Mpc):



From CMB to Large Scale Structure (LSS)

- CMB: 2.728±0.02 deg (K)
  - 0.03% deviations
- Very smooth but there are distortions
- Fluctuations on different scales
  - Angular scale corresponds to spatial scale today
- Power spectrum of fluctuations
  - Acoustic peaks in CMB

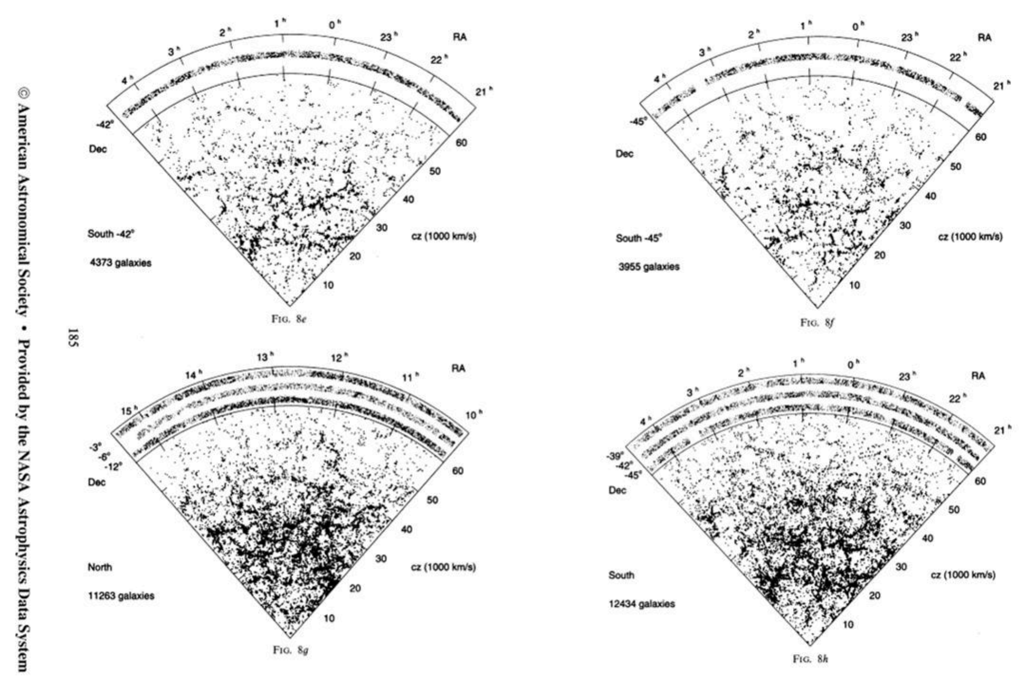




Scales of structure today

- Individual galaxies ➔ 0.2-0.5 Mpc
- Galaxy groups ➔ 1-2 Mpc
- Clusters of Galaxies ➔ 2-4 Mpc
- Superclusters ➔ 5-10 Mpc
- Filaments ➔ tens of Mpc

Optical redshift surveys:

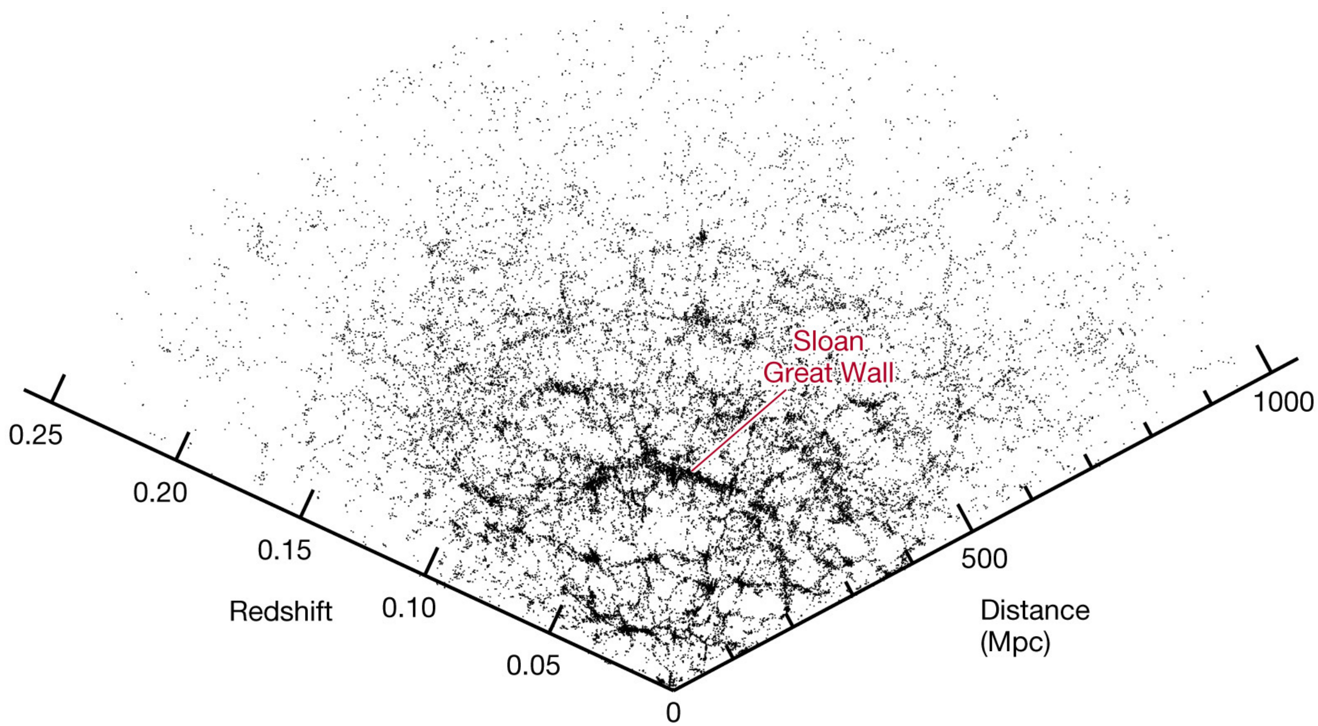


Sloan Digital Sky Survey

- 200,000 galaxy redshifts → 3D map of galaxy distribution traces true baryonic matter distribution
- Power spectrum (scales over which galaxies are spatially correlated) reflects matter distribution
- Caveats: redshifts reflect deviation from Hubble flow
- Variation with morphological type → "gastrophysical processes" only act on Mpc-scales
  - Tegmark et al. 2004 ApJ 606 702

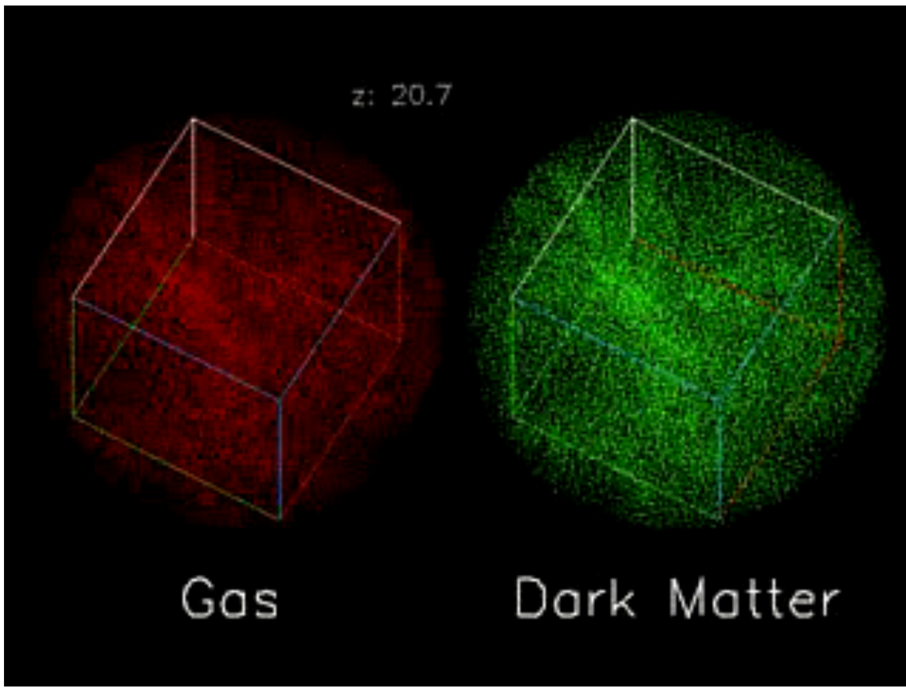
Large Scale Structure: revisited

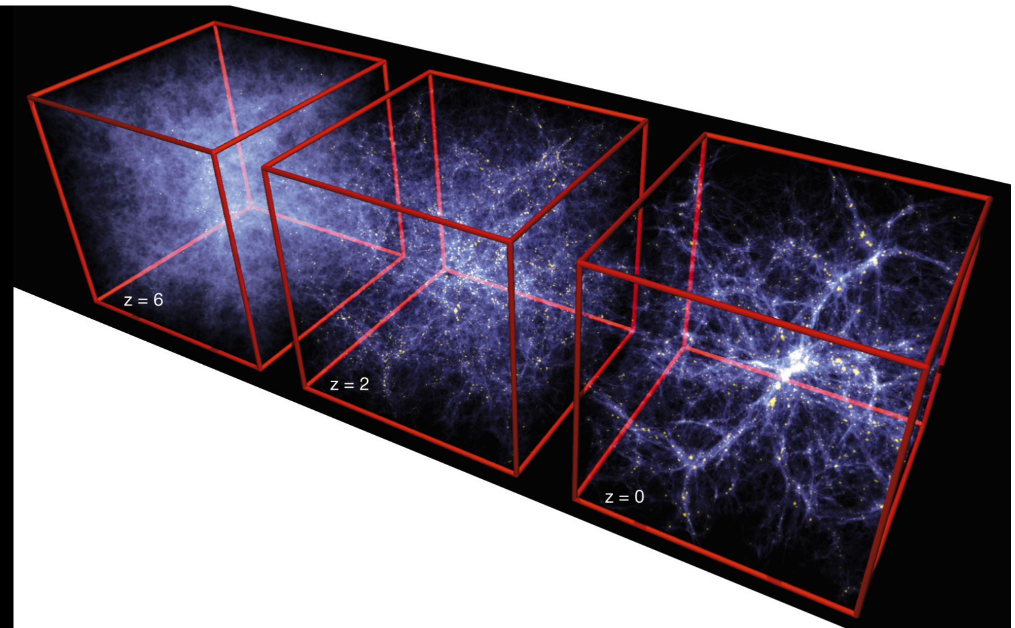
- Filaments and voids
  - Great Attractor
  - Characteristic scales: 40-120 Mpc



Large scale structure of the Universe

- Fly-through of the Cosmic Web





Filamentary Structure

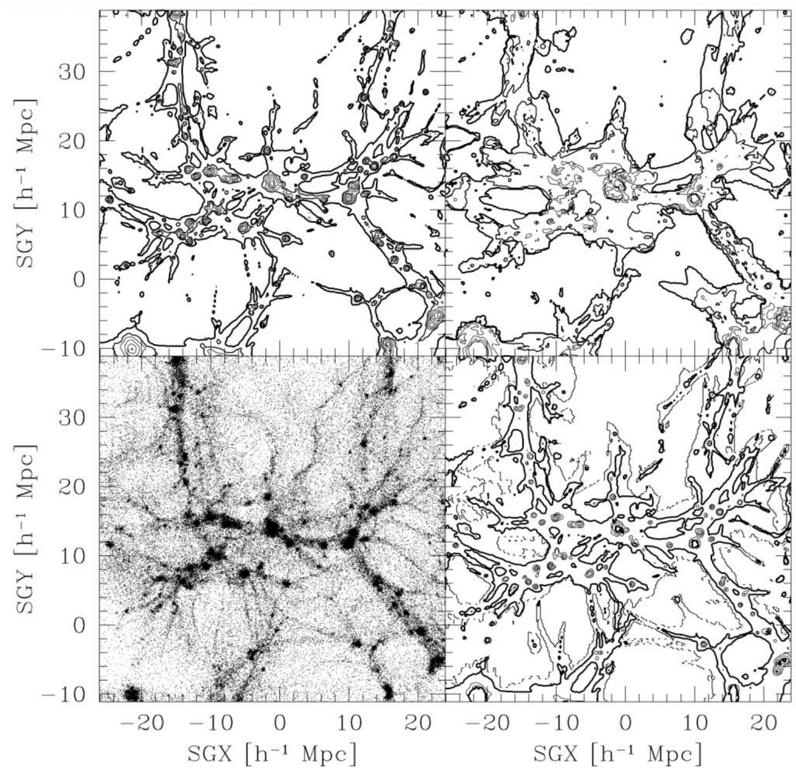
- How do we know?
  - Redshift surveys (optical): large numbers of galaxies over a large volume
    - Wide-field, multi-object spectroscopy to get redshifts
    - Emission/absorption line galaxies

- How big are filaments?
  - Largest length scale is 70-80 Mpc
- What's going on in the filaments?
  - Galaxy groups line the filaments
  - Giant clusters reside where filaments intersect

The Cosmic Web

Density

T/10^6 K

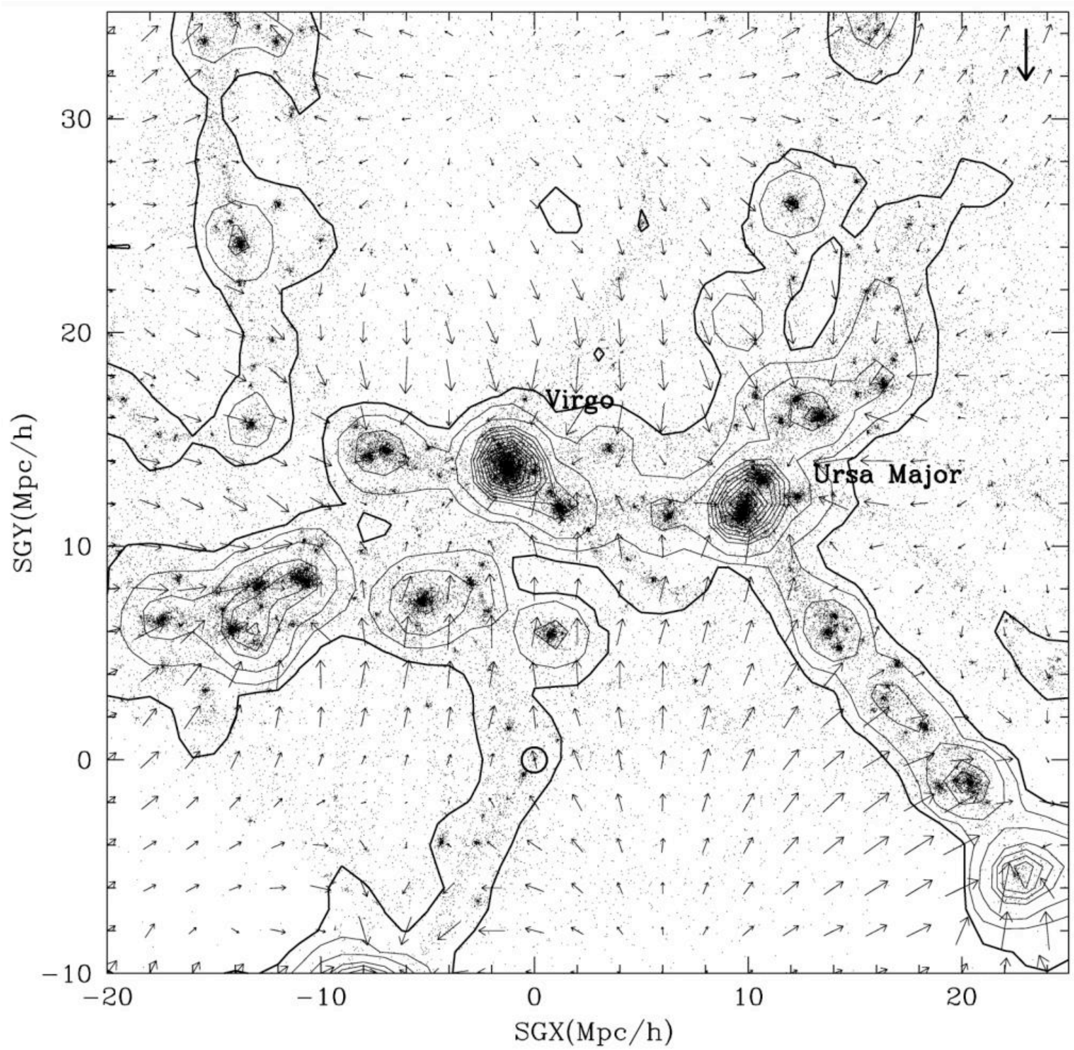


Dark matter

WHIM: Warm/ hot itergalactic medium

- WHIM: Claimed to contain the bulk of normal matter (baryons) in the universe
    - but this is based on scant number of QSO absorption lines-of-sight
- How was the WHIM produced? (structure/galaxy formation)
- How has it been kept at 10^6 K degrees over a Hubble time?
- Is there cold gas too? (how do you detect it?)

Cosmic Streaming

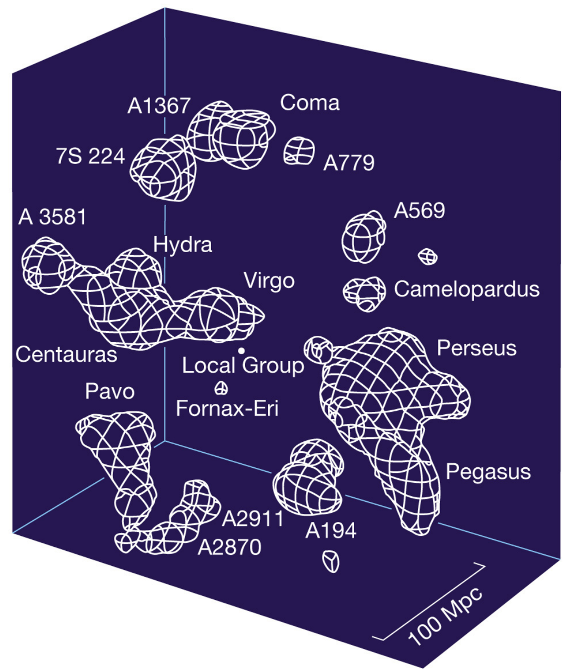


- What does H_0 mean?
  - Over what scales (spatial)?
  - What kinematic scales?

Klypin et al. 2003

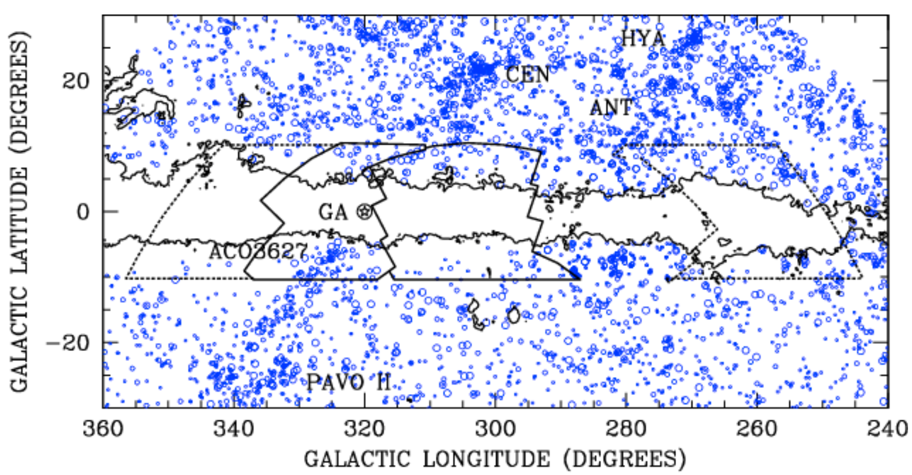
Superclusters

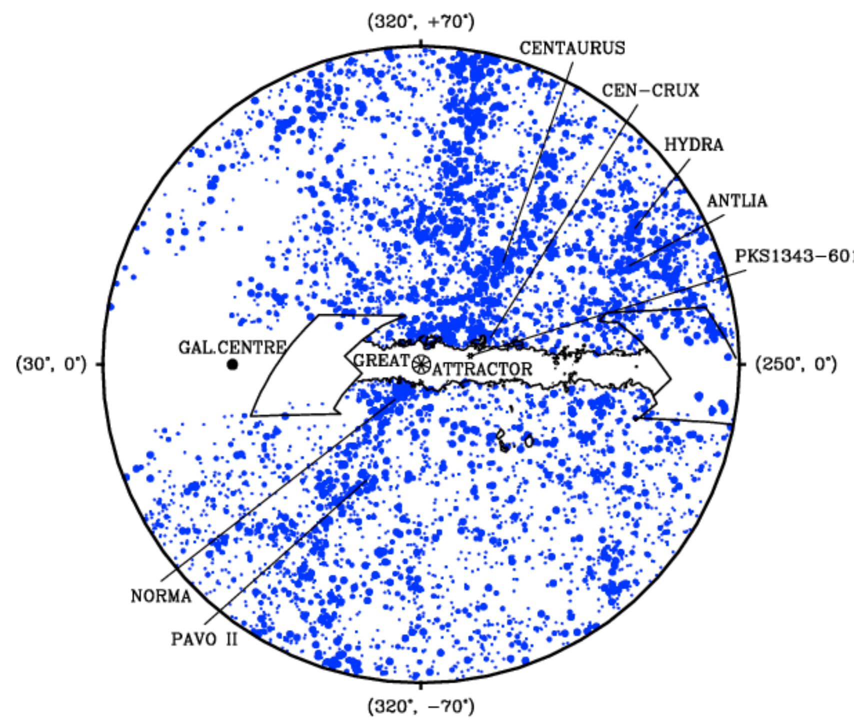
- The Peculiar Velocity Field and the Great Attractor
  - Motions: Earth, Sun, Milky Way, Local Group, Virgo!
    - The observed motion of the Virgo Cluster implies something extremely massive in the direction of the southern Milky Way
    - ➔ The Great Attractor
- Observed Superclusters
  - There are collections of clusters in the nearby Universe (Perseus-Pisces ridge); usually not spherical (like individual clusters)



The Great Attractor

- Problem –its behind the Milky Way in the Zone of Avoidance (ZOA)!





Finding galaxies behind the MW ZOA

- Deep optical galaxy searches (using existing sky surveys)
- NIR: 2MASS survey (H,J,K) and DENIS (I,J,K)
- HI surveys
  - unaffected by extinction (ZOA transparent)
  - immediate redshifts/linewidths
  - uniform flux limited sample
  - BUT:
    - no early-type galaxies (which we would expect in rich clusters)
    - no galaxies with -250 $\leq v \leq$ 250 km/s
    - lower detection rate for $|b| \leq 1.5°$(HI-ZOA)