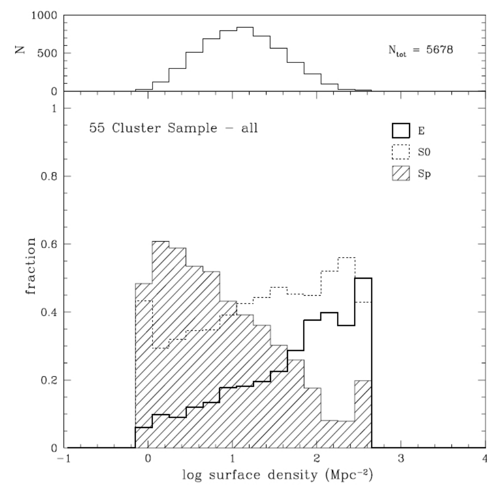
Astronomy 330

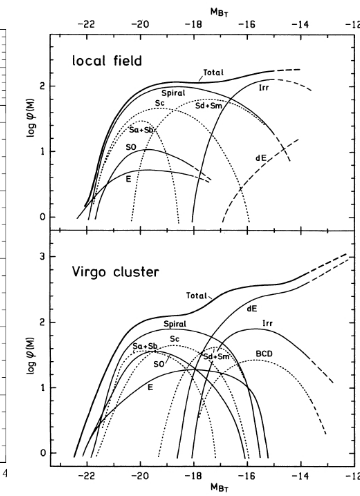
Lecture 27

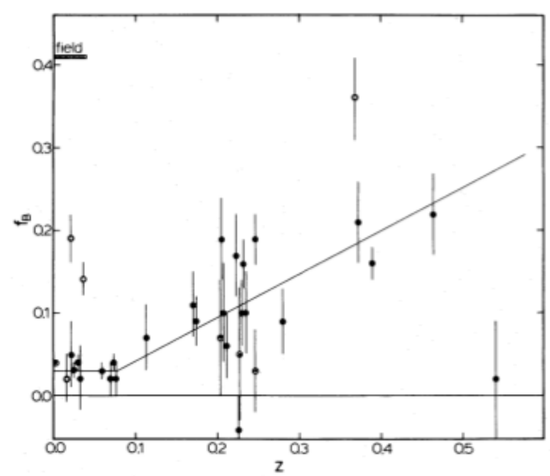
15 Dec 2010

Outline

- **Review:**
  - Cluster evolution
    - Morpholgy-density relations:
      - early vs late; dwarf vs giant
    - Evolution of cluster populations
      - BO: field-contamination?
      - RS-LF growth
        - Luminosity evolution: ***yes***
        - Number-density evolution: ***yes***
        - Luminosity-dependent density evolution: **?**
    - The state of HI sensitivity: pitiful
- Large Scale Structure
- The high-redshift Universe

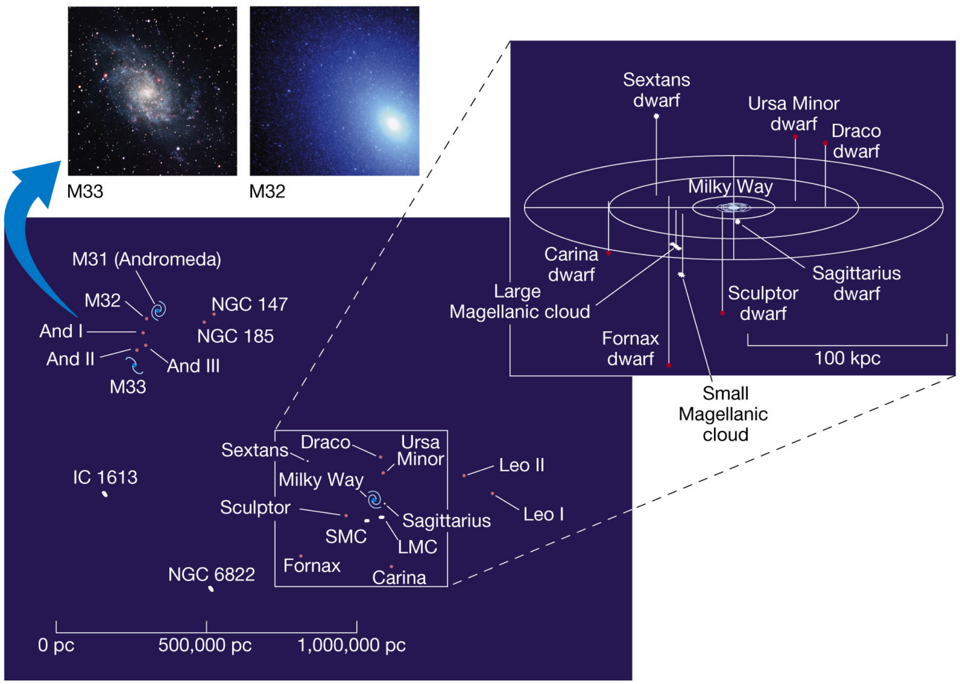


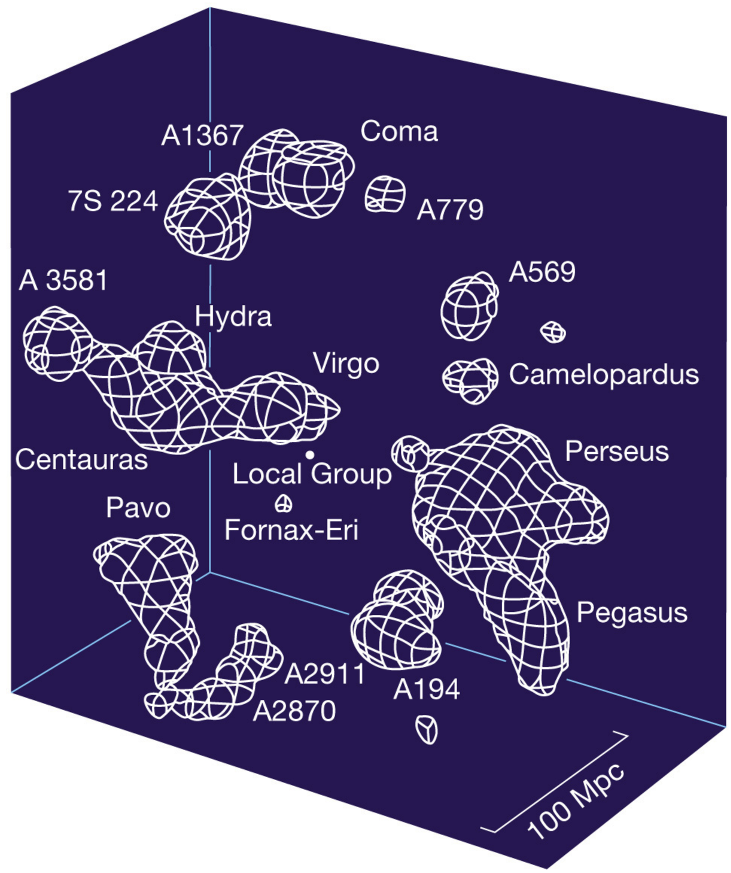




Large Scale Structure: revisited

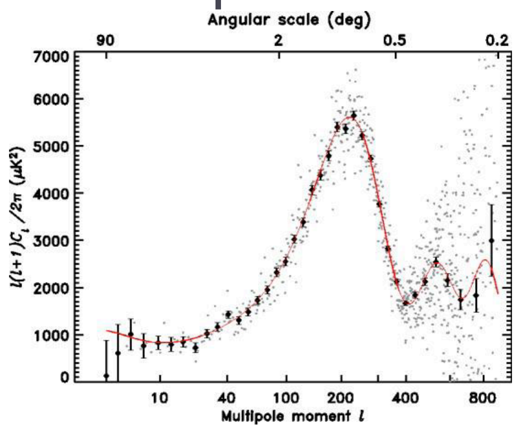
- Local Group (1 Mpc):
- Local volume (100 Mpc):

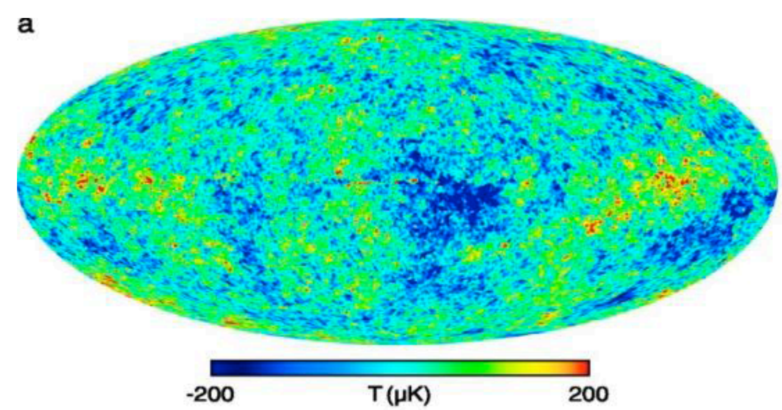




From CMB to Large Scale Structure (LSS)

- 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

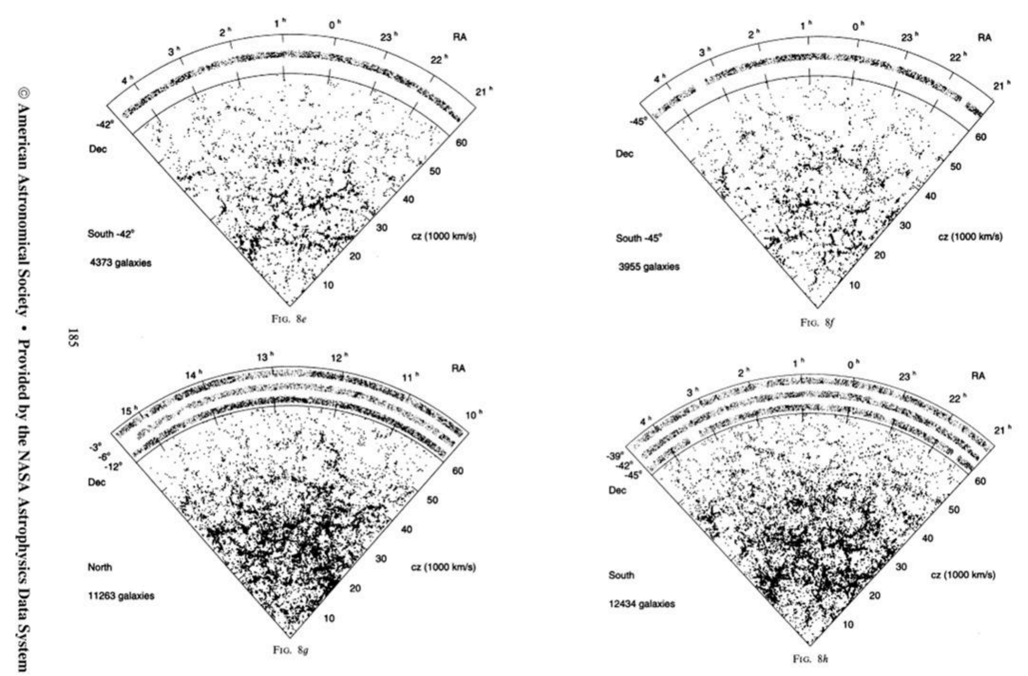




Scales of structure today

- 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:

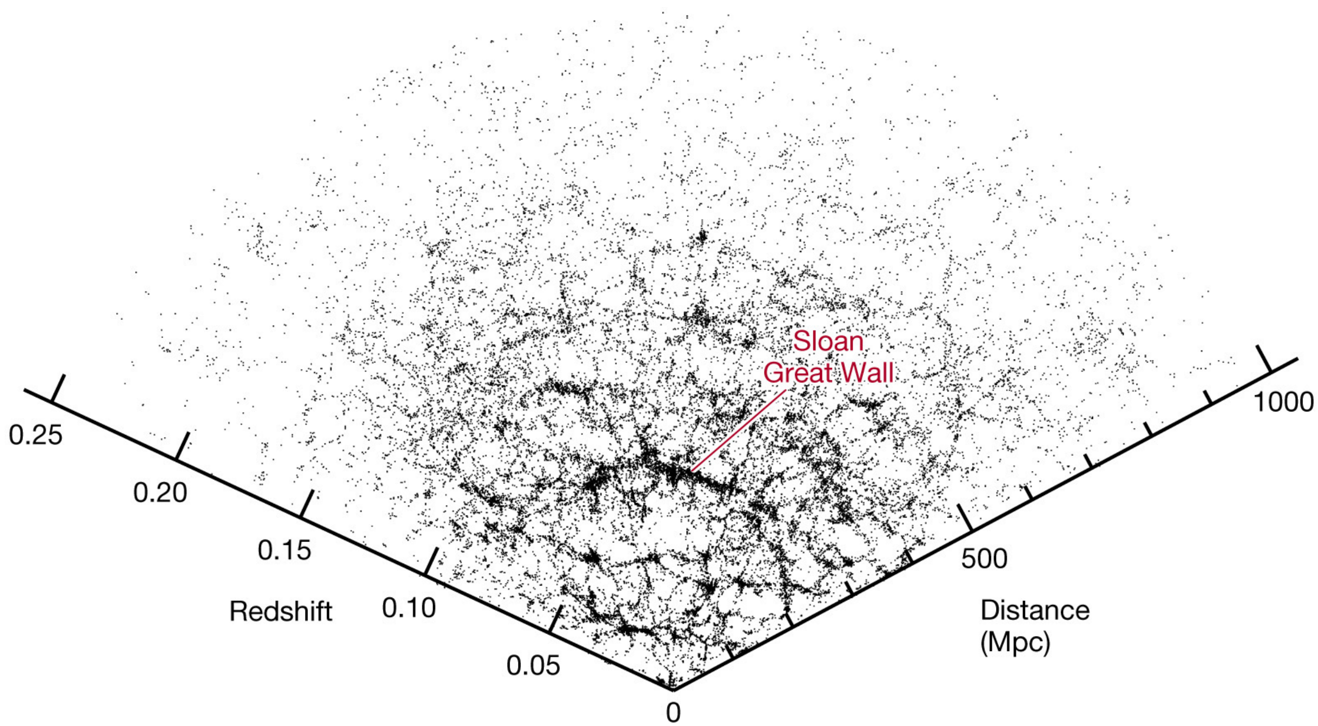


Sloan Digital Sky Survey

- 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

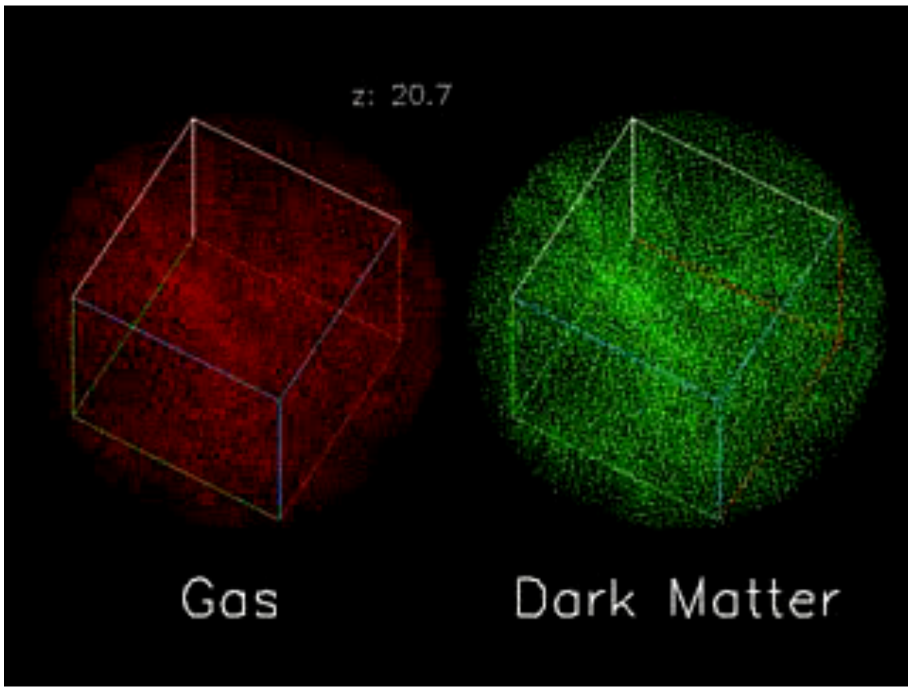
Large Scale Structure: revisited

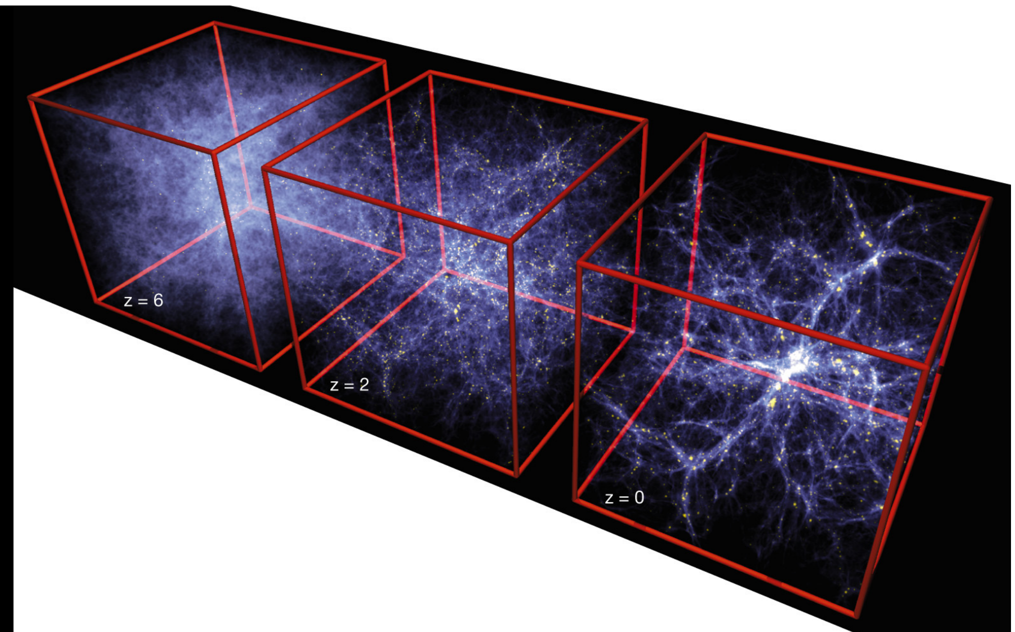
- Filaments and voids
  - Great Attractor
  - Characteristic scales: 40-120 Mpc



Large scale structure of the Universe

- Fly-through of the Cosmic Web





Filamentary Structure

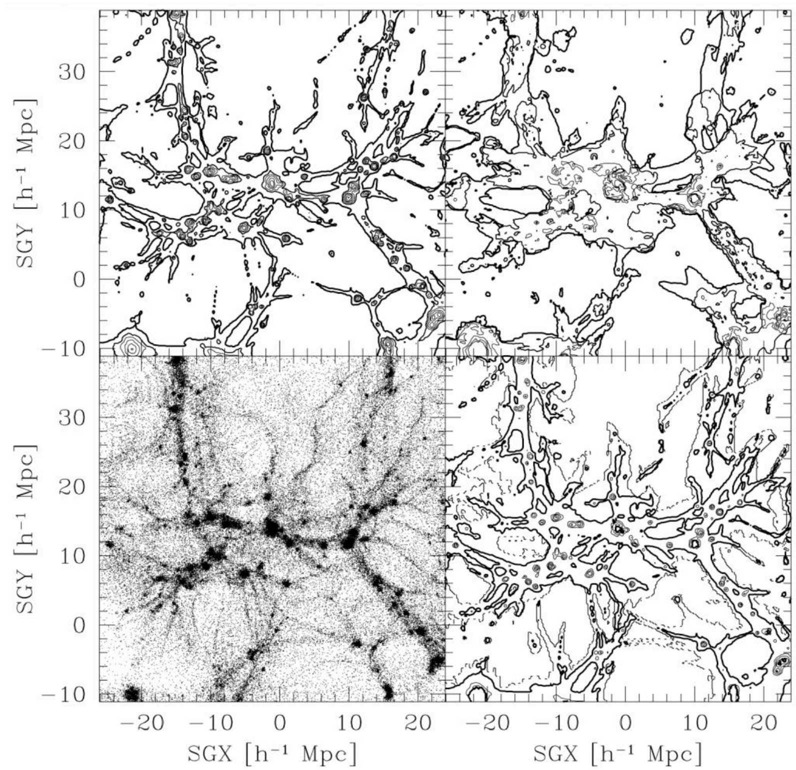
- How do we know?
  - Redshift surveys (optical): large numbers of galaxies over a large volume
    - Wide-field, multi-object spectroscopy to get redshifts
    - Emission/absorption line galaxies

- 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

Dark matter

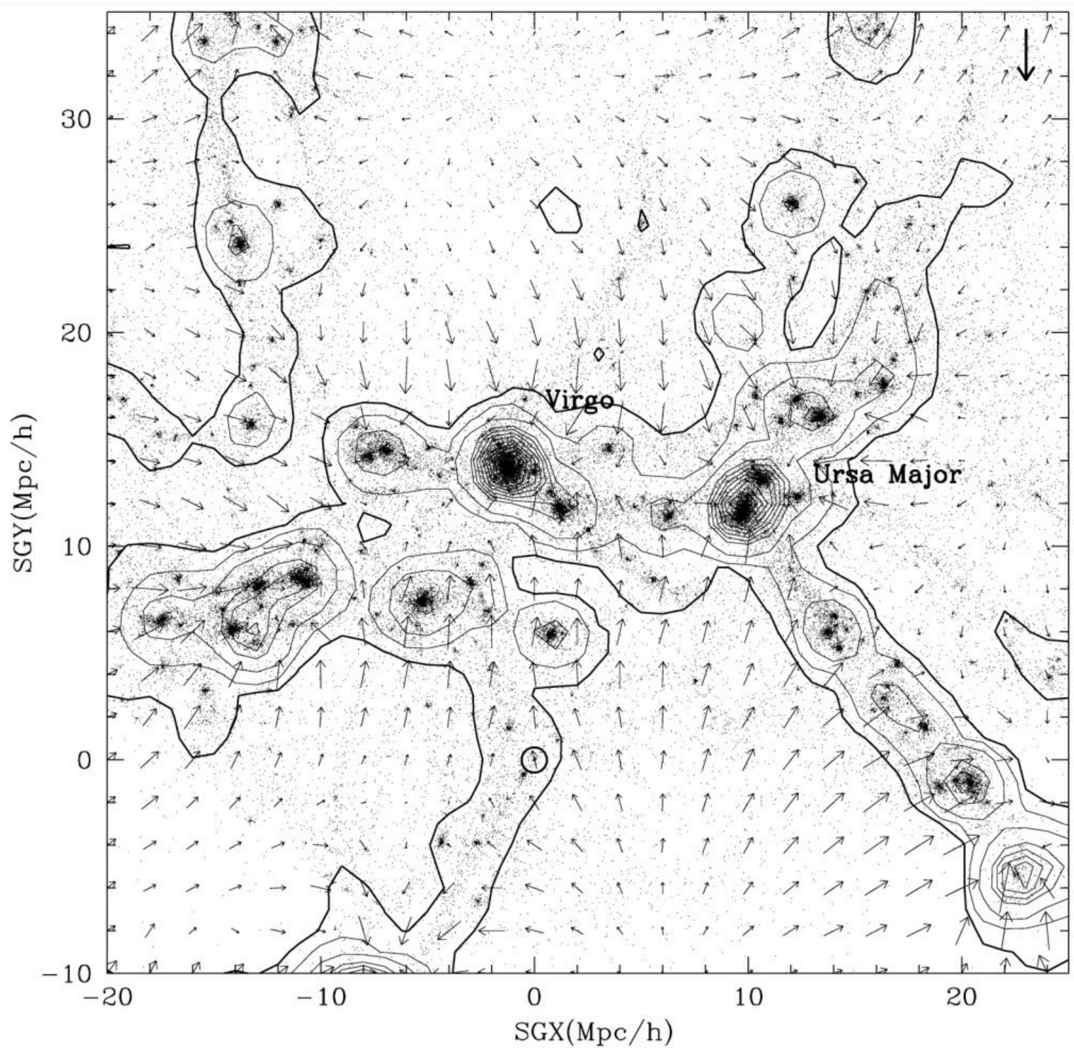


T/10^6 K

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

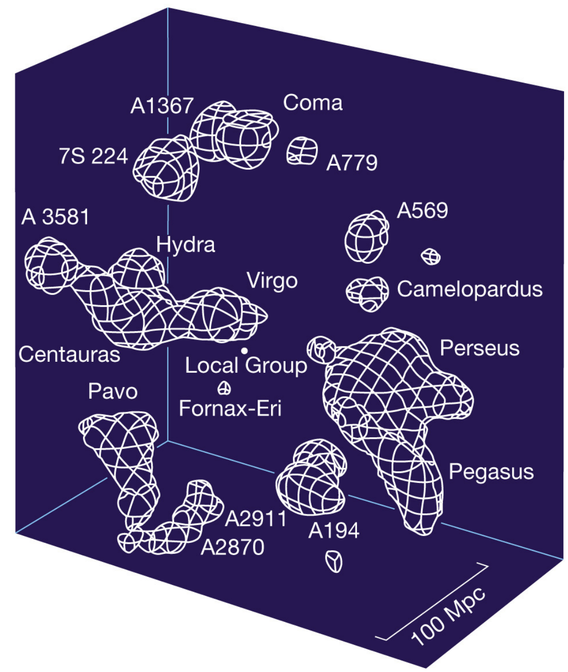


- What does H_0 mean?
  - Over what scales (spatial)?
  - What kinematic scales?

Klypin et al. 2003

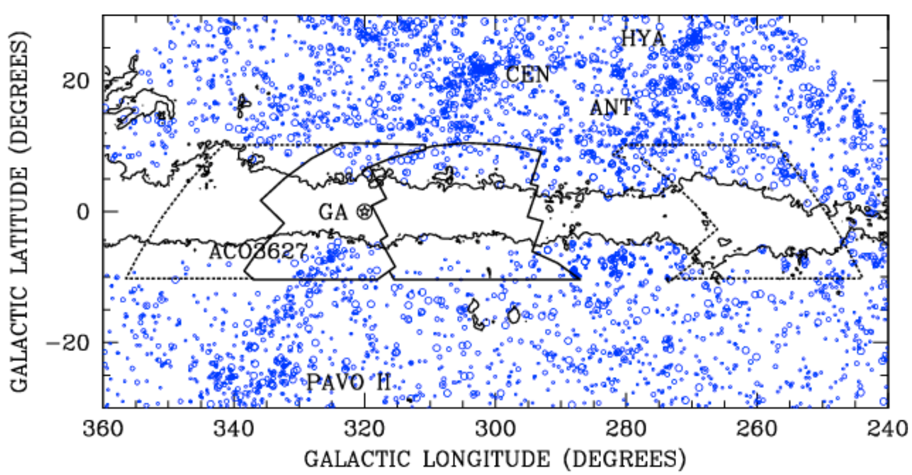
Superclusters

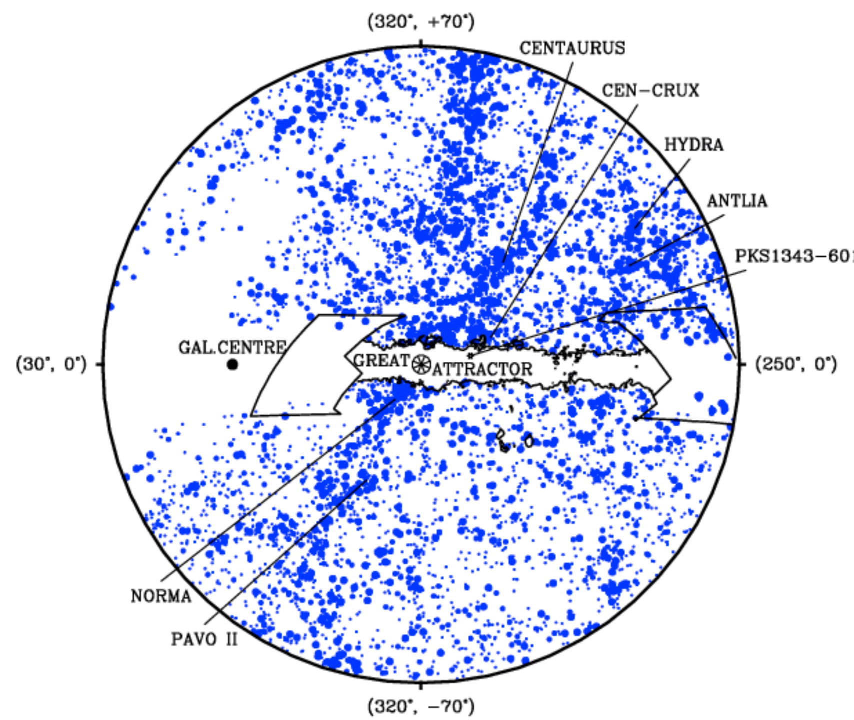
- The Peculiar Velocity Field and the Great Attractor
  - Motions: Earth, Sun, Milky Way, Local Group, Virgo!
    - The observed motion of the Virgo Cluster implies something extremely massive in the direction of the southern Milky Way
    - ➔ The Great Attractor
- Observed Superclusters
  - There are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



The Great Attractor

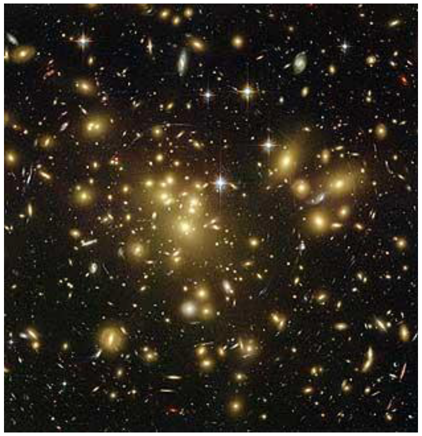
- Problem –its behind the Milky Way in the Zone of Avoidance (ZOA)!





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)



How we think structure formed

- Process:
  - Start with distribution of fluctuations (i.e. dark matter halos)
  - Fill with baryons and let "gastrophysics" happen
    - Virialization of gas
    - Radiative cooling ➔ disk formation
    - Photoionization from background
    - Star-formation ➔ feedback
    - Chemical evolution

Jeans mass and length:
$M_J = (\pi\lambda_J 3/6)\,\rho$
$\lambda_J = (c_s/(3)^{1/2})(3\pi/8G\rho)^{1/2}$

- What is the dark matter: *hot, warm, or cold?* (how long relativistic?)
- Hot Dark Matter (*top down*)
  - Neutrinos w/ E~10 eV ➔ $mc^2 = 3k_BT$ (non-relativistic) occurs at $z \sim 2\times10^4$
    ➔ Universe is hot, Jeans mass is large ➔ $M \sim 10^{15} M_\odot$ (i.e. cluster masses)
    ➔ density fluctuations < $10^{15} M_\odot$ are damped out
  - 1st structures to form are large clusters
  - galaxies form from fragmentation of larger structures (like star-formation)

Zeldovich pancakes

- Cold Dark Matter (*bottom up*)
  - Post recombination temperature ➔ $M_J \sim 10^5 M_\odot$
  - 1st structures to form were small

What we expect

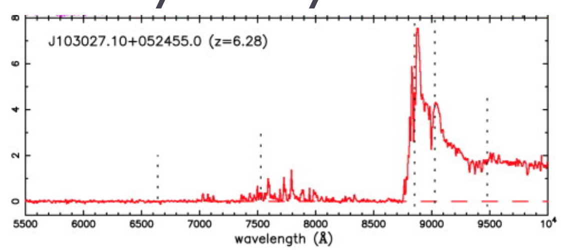
- Well, Hot or Cold?
  - Hot ➔ hard to make stars/galaxies so much younger than clusters
    - we also see evolution/growth in galaxy clusters at $z \sim 0.7$
  - Hot ➔ too easily makes large flattened things
  - Cold ➔ structure on all scales forms at same time
  - Cold ➔ matches galaxy two-point correlation
- CDM the winner
  - Hierarchical formation ➔ building galaxies via merging of large numbers of small galactic systems ➔ described via a "merger tree"

What do galaxies look like at high-z?

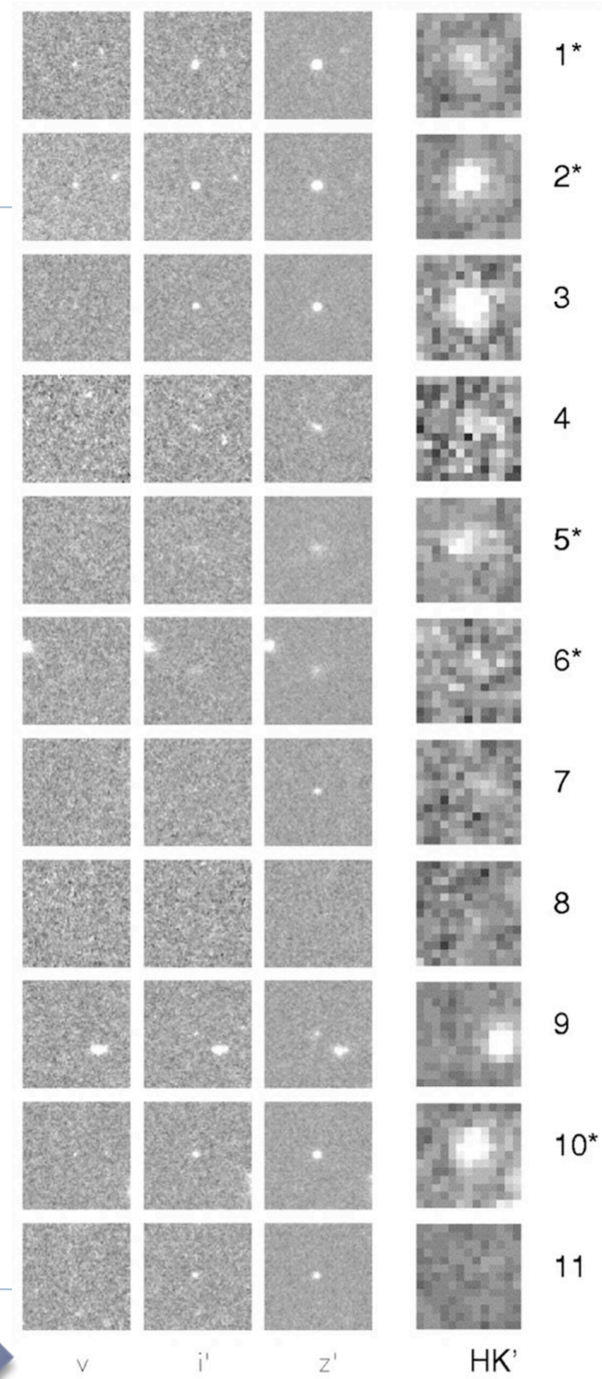
- Cosmological distances
  - Because the
    - Universe is smaller in the rest frame
    - Photons have lost energy along the way
  - $d_L = (1+z)R(t_0)r_{cm}$ (r_{cm}= comoving distance)
  - $d_A = R(t_0)r_{cm}$
- "k-correction"
  - $k(z) = 2.5\log_{10}(1+z) - 2.5\log_{10}\{ (\int L_\lambda[\lambda/(1+z),t_0]d\lambda) / \int L_\lambda [\lambda,t_0]d\lambda \}$
    - Accounts for changes in wavelength of light due to z
- Redshift issues
  - Rest frame vs observed
  - Varying metallicity/extinction
  - Real distance determination

Detecting High-z Galaxies

- "Dropouts" (Steidel, Pettini, Hamilton 1995)
  - Lyman break at 912 A ➔ dropoff in continuum flux, just shortward of Ly α line ➔ select filters accordingly
  - Absorption generated by the Ly α forest

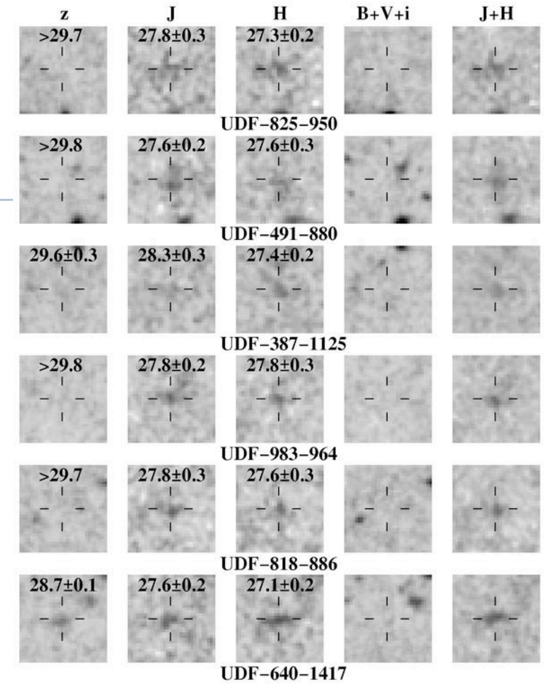


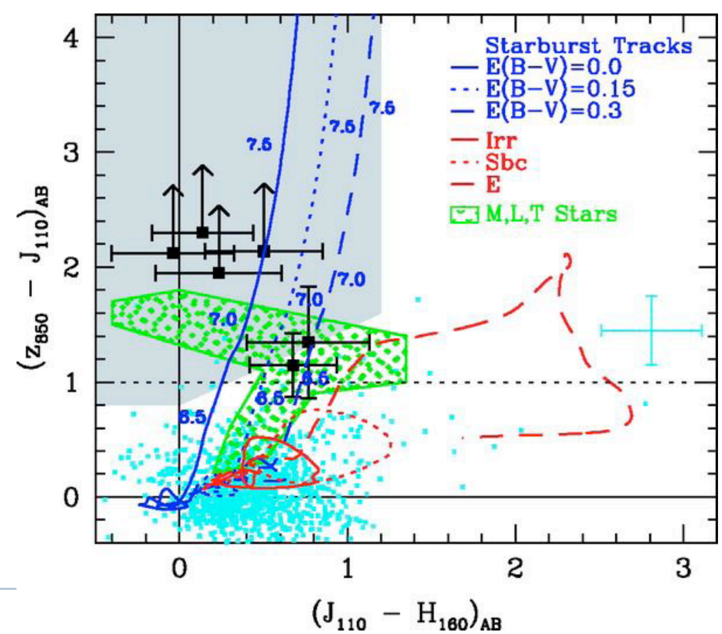
- Examples
  - Stanway et al (2005) ➔ surface density of i-band dropouts (HST, Keck)
    - z~6 star-bursting galaxies
    - No X-ray detections ➔ no quasars
    - Tiny sizes ~ 1.5 kpc
    - SFR ~ 10-25 M yr-1



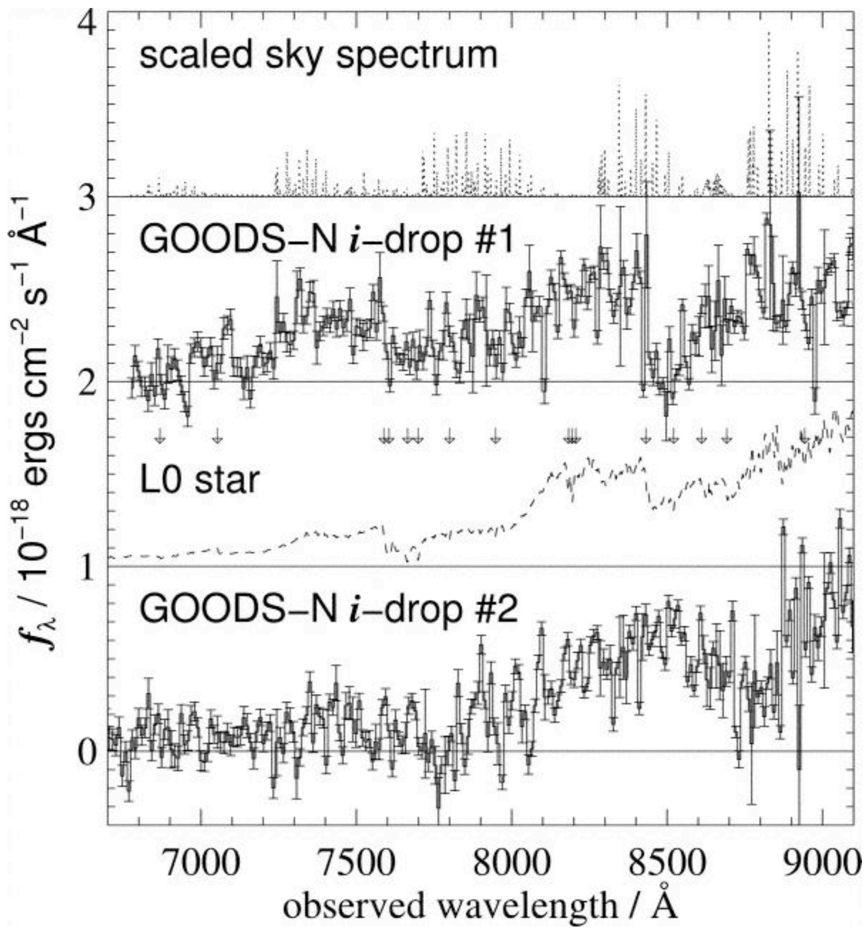
Detecting High-z Galaxies

- "Dropouts"
  - Lyman break at 912 A ➔ dropoff in continuum flux, just shortward of Ly α line ➔ select filters accordingly
- Examples
  - Bouwens et al (2005) ➔ Near-IR spectrophotometry
    - z–J > 0.85 mag
      - z filter at 8500 A = 0.85 microns
      - J filter at 1.1 microns
    - no detection below 8500 A (z~7.3)
    - 5 sources with H (1.6microns) ~ 27 mag
      - Corresponds to rest-frame UV ➔ L*-like galaxies
    - No luminosity evolution as compared to z~3.8 sample
      - Account for redshift distance/size



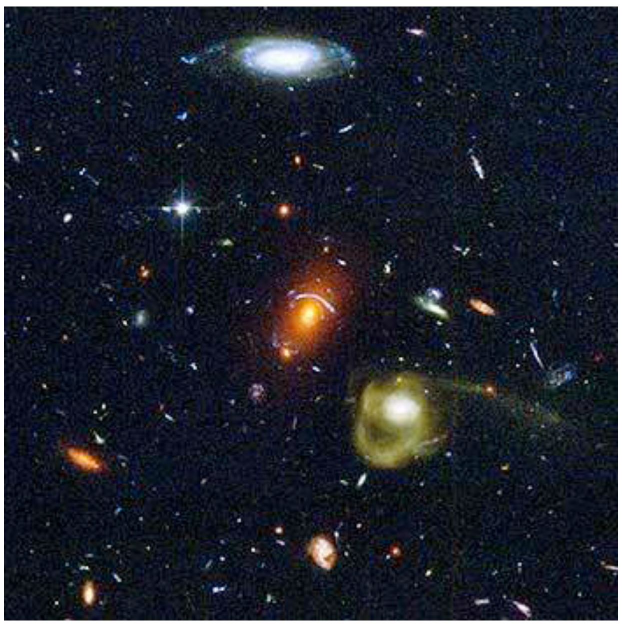


Contamination: cool stars

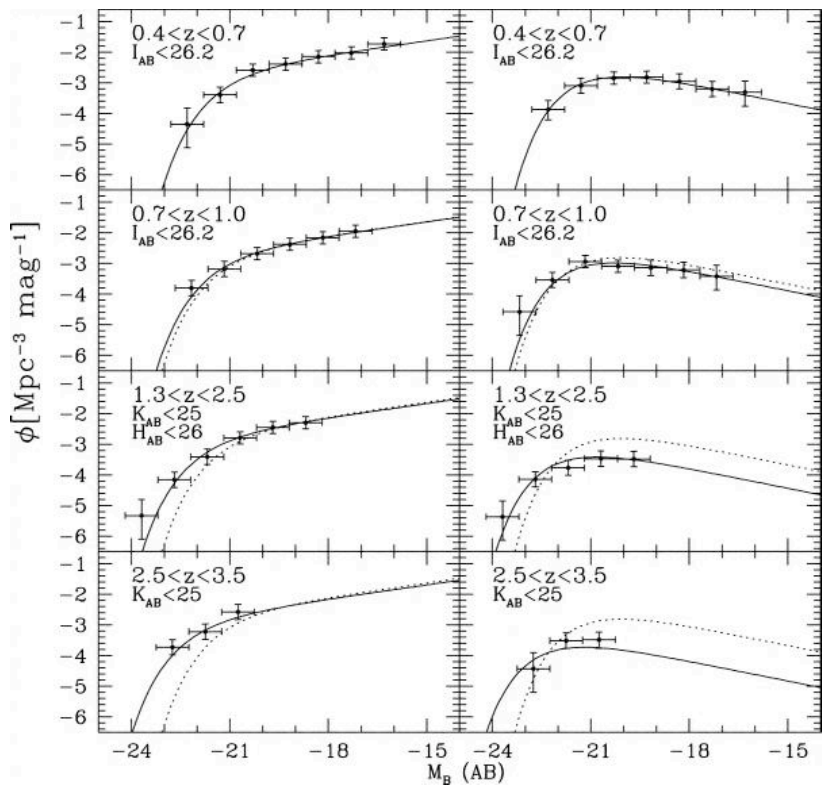


Metrics of evolution

- Luminosity function/mass function
- Size distribution (i.e. how big are individual galaxies?)
  - Morphology distribution
- Star formation/stellar mass

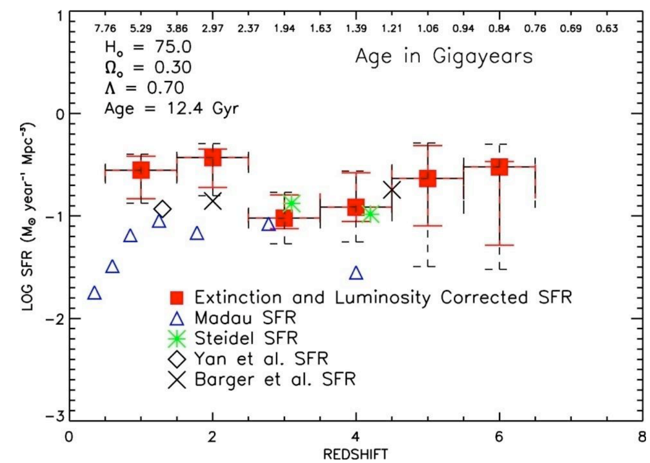


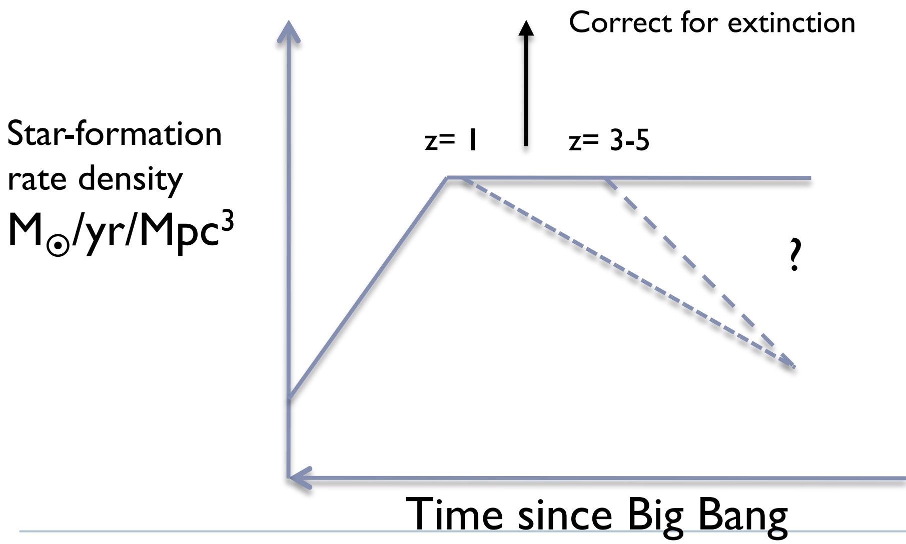
blue red

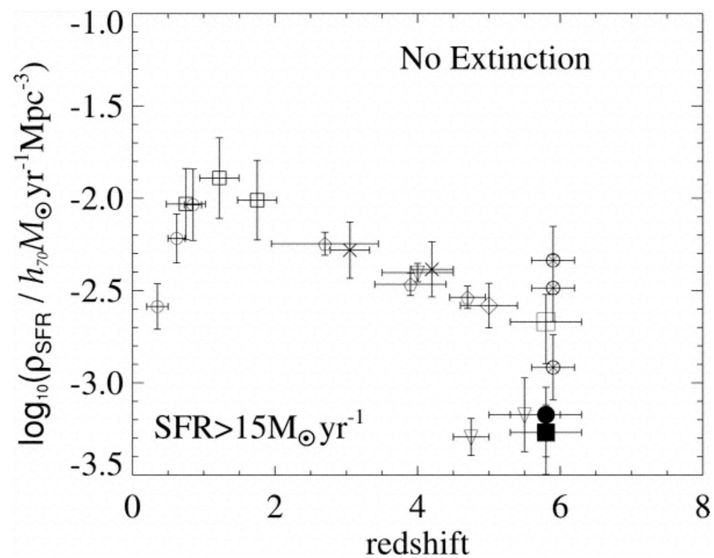


Star Formation History of the Universe

- What fraction of stars formed when?
- Measure SFR at a variety of redshifts
  - Metrics for measuring the SFR….
    - H α , radio continuum ➔ local
    - [O II]3727 at intermediate redshifts ➔ z ~ 3
    - UV continuum at high redshifts
    - (SKA will use radio continuum)



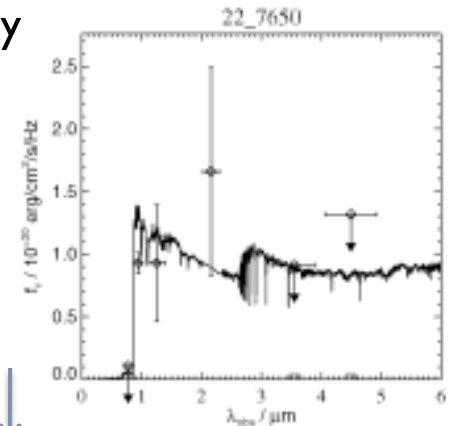




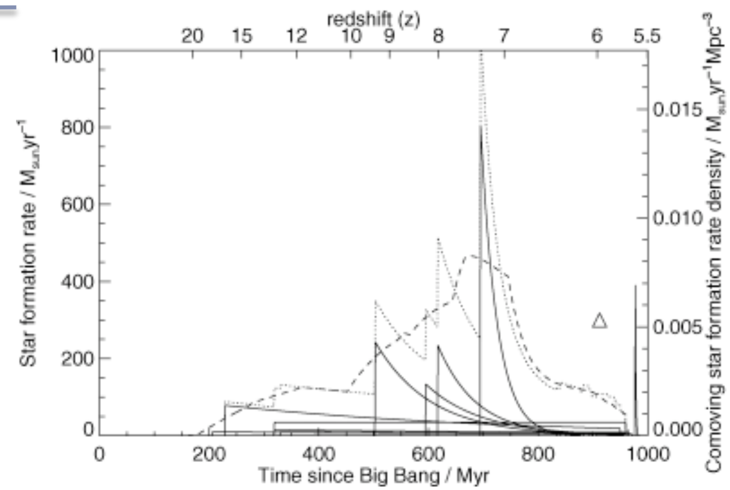
Growth of stellar mass

(a) Optical-NIR photometry + redshifts for many galaxies; here's one typical example.

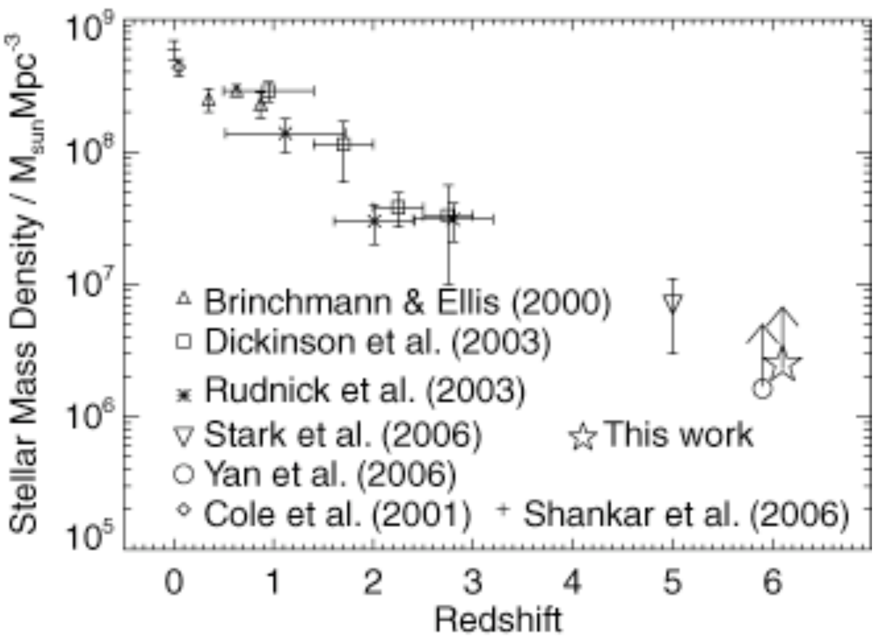
(b) Model SFR history for each individual galaxy



(c) Estimate ensemble SFR history



(d) Sum up contributions to total stars formed



- Eyles et al. 2006 MNRAS

What we think we know

- At high redshift galaxies were
  - Smaller, lumpier, and presumably more gas rich
  - Bluer…
    - More actively forming stars (per unit mass)…
  - Not as concentrated in clusters…
- What we'd like to know:
  - When and how quickly did gas settle into dark matter potentials?
  - When, where, and how did the gas get converted into stars?
  - When and how did the merging process of galaxies develop?
  - What is the relative importance of gas accretion *versus* merging?
  - How rapidly are galaxies still (trans)forming today?

- The door is wide open for you to make giant leaps in our understanding of how galaxies formed and evolved.