CDM structure-formation models

- Reproduce observed filamentary structure
  - Weinberg et al. astro-ph/9708213

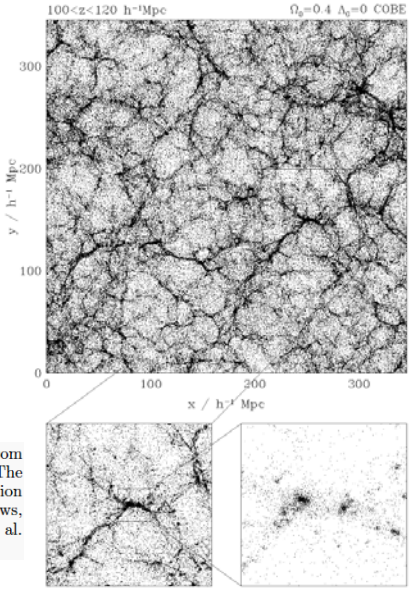
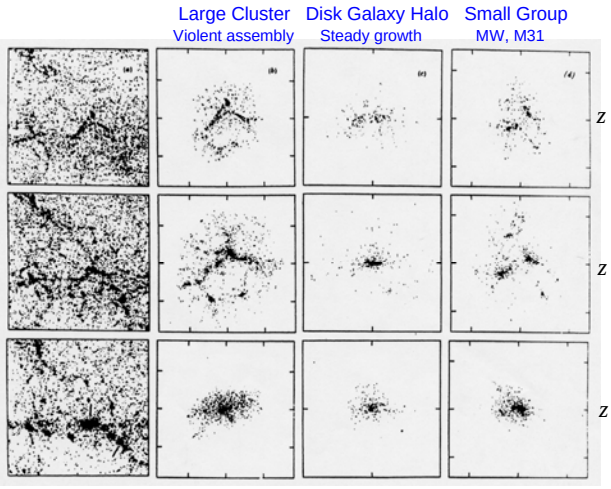
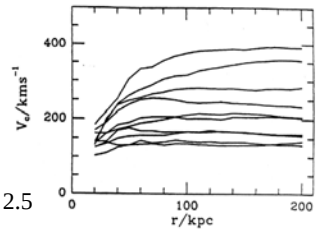


Figure 1. The particle distribution in a $20h^{-1}$ Mpc thick slice from an N-body simulation of an $\Omega_0 = 0.4$, open universe CDM model. The large panel shows the full cross section of the $360h^{-1}$ Mpc simulation box, while the two lower panels show successively expanded views, $100h^{-1}$ Mpc and $20h^{-1}$ Mpc on a side respectively. From Cole et al. (1997).

More CDM Simulations

(Frenk 1991, Physica Scripta T36, 70)





flat rotation curves reproduced

But now finding:

Galaxy dark matter halos do NOT have exactly the expected CDM density distribution (NFW profiles).

Fig. 8. Evolution of a (14 Mpc)³ volume of a flat CDM universe and of selected galactic halos that formed in it. Time increases downwards in this figure. Each row corresponds to a different redshift as follows: $z = 2.5$ (top), $z = 1$ (middle) and $z = 0$ (bottom). The column labelled (a) shows the simulation as a whole, with positions plotted in comoving coordinates; the region shown at the top of this panel is thus 4 Mpc on a side. The three clumps marked with arrows at the bottom of (a) are shown in greater detail in (b)–(d). Physical, not comoving, coordinates are used in (b)–(d) and tickmarks represent 1-Mpc intervals. The three selected halos correspond to the two most massive clumps in the simulation and to a more isolated system. (From Ref. [63].)

Bias

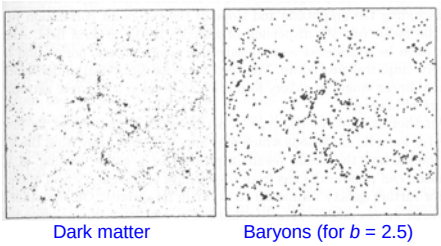
- CDM simulations ➔
  accurate predictions of CDM structure.

- Problems describing baryon response.
  - Observations ➔ preference for galaxies to form in denser regions.

$$\left(\frac{\delta\varrho}{\varrho}\right)_{\mathrm{B}} = b\left(\frac{\delta\varrho}{\varrho}\right)_{\mathrm{D}}$$ in CDM simulation ➔

$$b^2 = \frac{\sigma_8^2(\mathrm{galaxies})}{\sigma_8^2(\mathrm{mass})}$$ from observations,

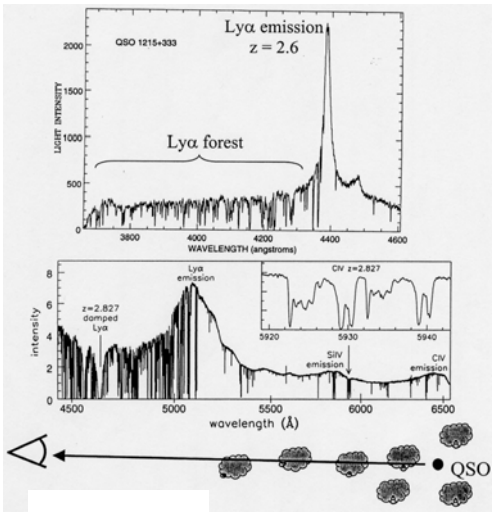
where σ_8 = variance of mass distr. in $8h^{-1}$ Mpc co-moving sphere.

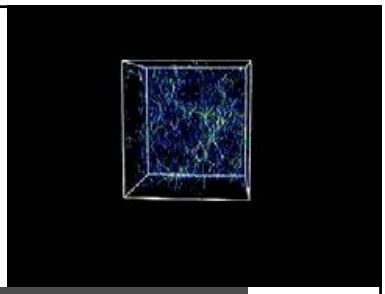


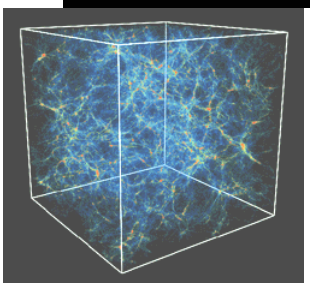
Dark matter Baryons (for b = 2.5)

- So arbitrary assumptions are needed to describe the observable galaxies.

The Lyα Forest Revisted







- It's the cosmic web.
- Contains most of the baryons at high redshift.
- Currently: ~1/2 baryons still in web, but heated to 10^6 K.

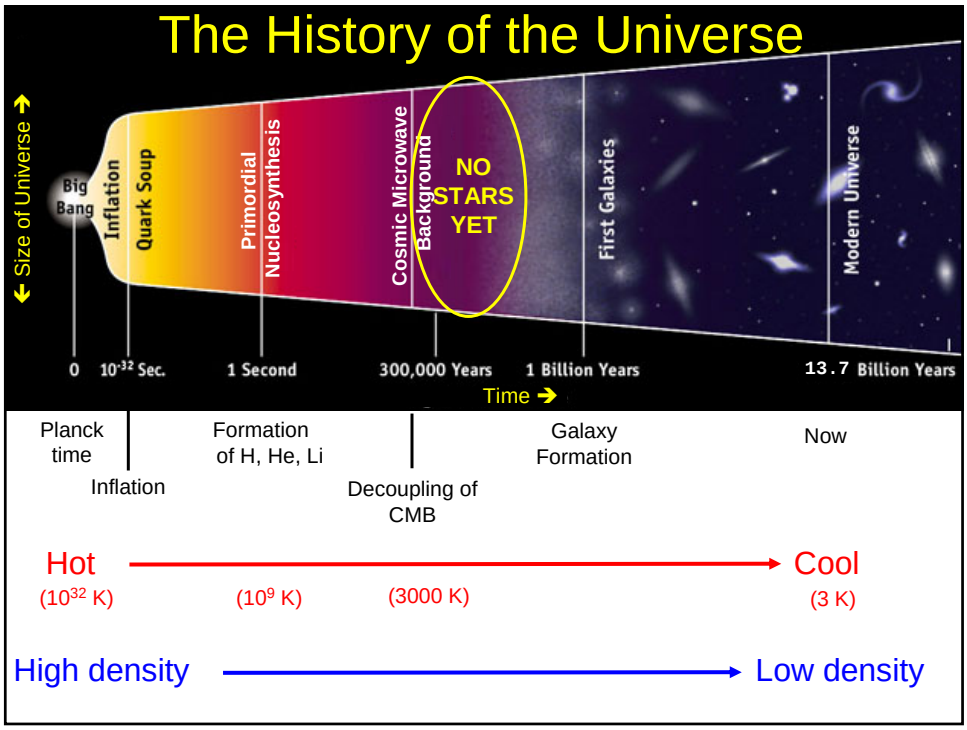
Warm-Hot Intergalactic Medium (WHIM)

When did galaxy formation occur?

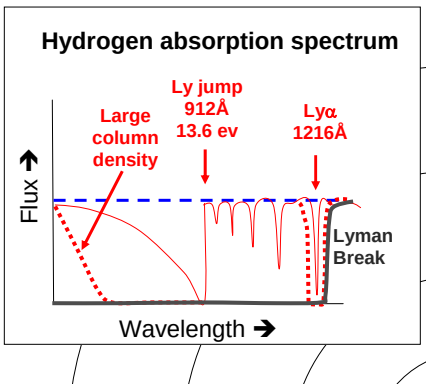
Ned Wright's Cosmology Calculator

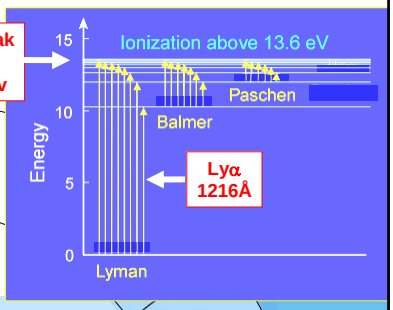
Structure	Redshift	Age of U. (Gyr)
Density fluctuations in CMB	$[z_{dec}]_{WMAP} = 1089$	0.00018
Spheroids of galaxies	$z \sim 20$	0.18
The first engines of active galactic nuclei	$z \geq 10$	$\leq$ 0.48
The intergalactic medium	$z \sim 10$	0.48
Dark halos of galaxies	$z \sim 5$	1.20
The first 10% of heavy elements	$z \geq 3$	$\leq$ 2.19
Rich clusters of galaxies	$z \sim 2$	$\leq$ 3.34
Thin disks of spiral galaxies	$z \sim 1$	5.93
Superclusters, walls, and voids	$z \sim 1$	5.93

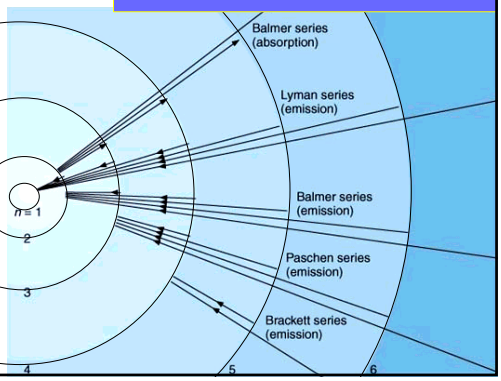
TABLE 30.3 Redshifts for Structure Formation. Approximate redshifts at the time of the formation of various structures. (Adapted from Peebles, *Principles of Physical Cosmology*, Princeton University Press, Princeton, NJ, 1993.)



The Gunn – Peterson Effect







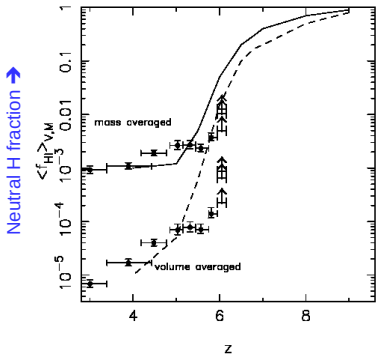
- Expect Ly continuum absorption from Inter-Galactic Medium to completely block all radiation with $\lambda < 912$Å or 1215Å.
- Why doesn't it?

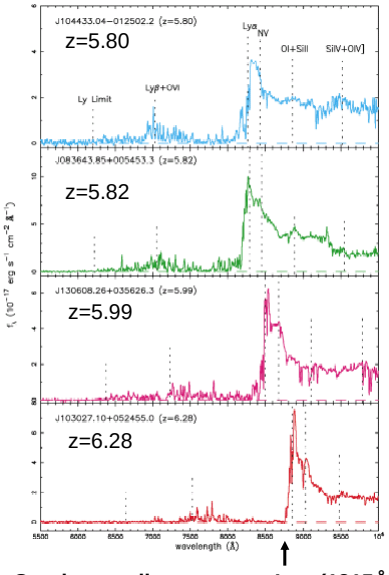
IGM is ionized. *Re-ionized.*

Re-ionization = end of Dark Ages

When did re-ionization occur?

- We see QSOs at z ~ 6 with Gunn-Peterson absorption.



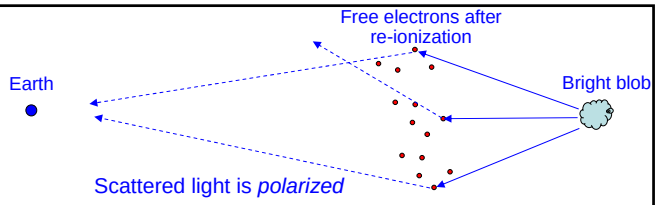


Continuum disappears at Lyα (1215Å)

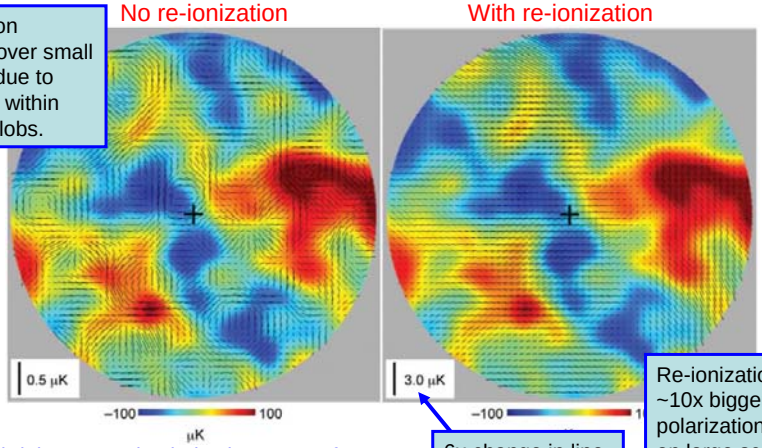
- But WMAP finds *z* =11.0 ±1.4 (420 Myr) for re-ionization
  - From polarization of CMB.

➔ patchy re-ionization?

CMB Polarization due to electron scattering by re-ionized gas.



Polarization structure over small scales is due to scattering within emitting blobs.



Simulated brightness and polarization maps of CMB. Length & direction of lines show polarization.

6x change in line-length scale!!

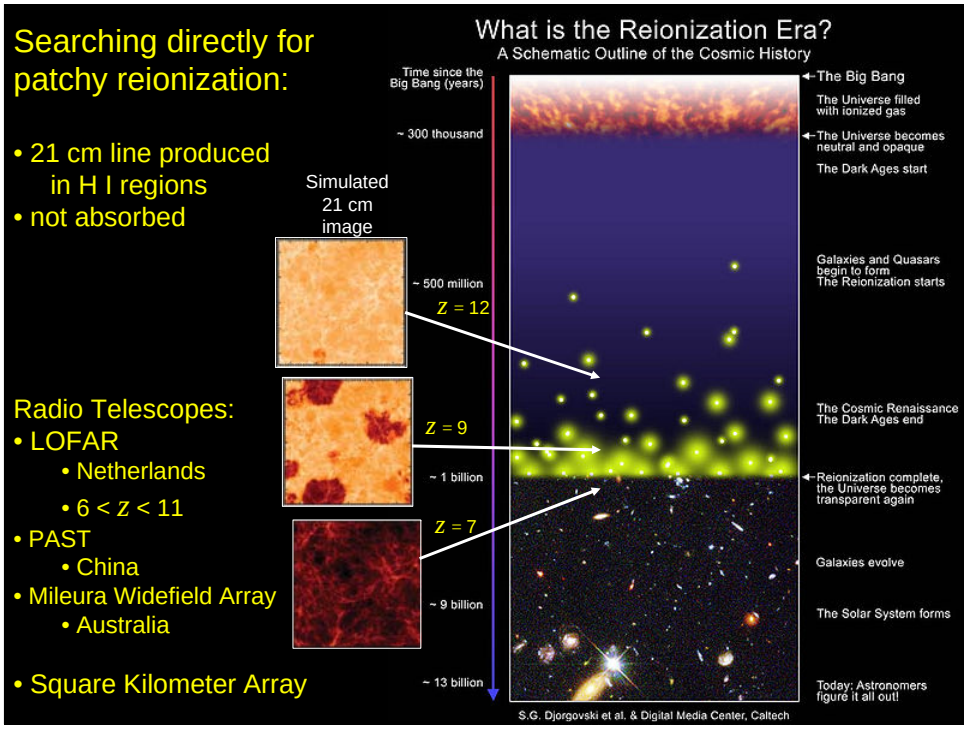
Re-ionization ➔ ~10x bigger polarization signal on large scale lengths.

Searching directly for patchy reionization:

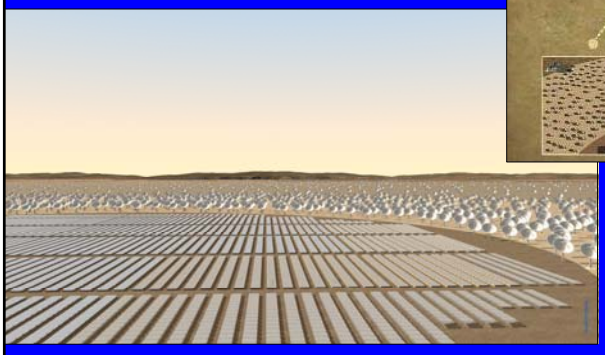
- 21 cm line produced in H I regions
- not absorbed

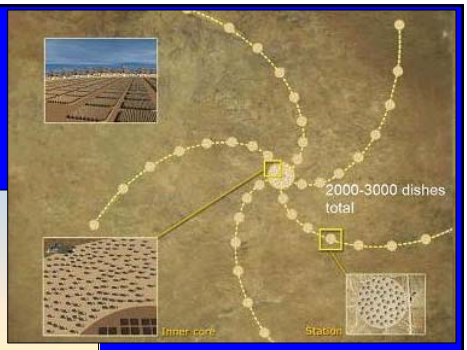
Radio Telescopes:
- LOFAR
  - Netherlands
  - $6 < z < 11$
- PAST
  - China
- Mileura Widefield Array
  - Australia

- Square Kilometer Array



The SKA
Square Kilometer Array





- 1 km^2 *collecting area.*
- 50% in central 5 km dia.
- Rest out to 3000 km.
- Start construction 2012.
- start science in 2014.

z = 7 galaxy ?

Gravitationally lensed galaxy observed at Keck by Ellis et al.

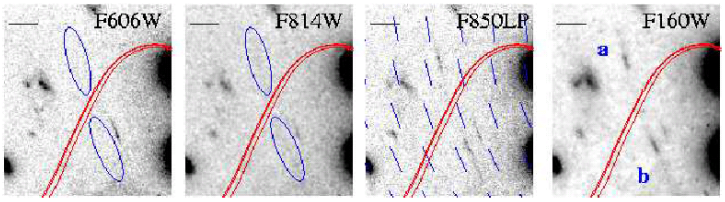
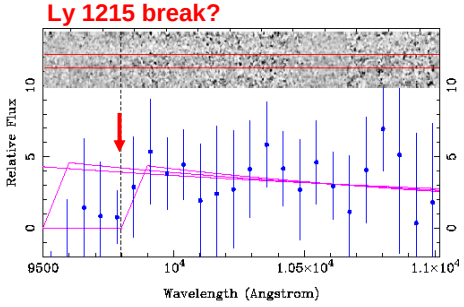
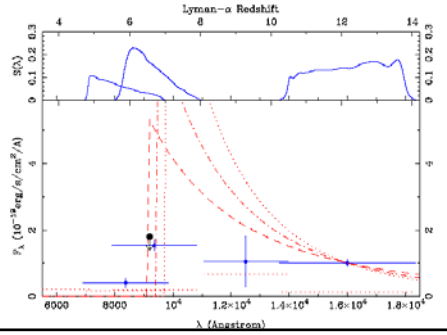


Figure 1: *WFPC2*-F606W, *WFPC2*-F814W, *ACS*-F850LP and NICMOS-F160W images of Abell 2218 of the new faint pair in the lensing cluster Abell 2218 (z=0.175). The signals redward of the *WFPC2*-F814W observation suggests a marked break occurs in the continuum signal at around 9600Å . Red lines correspond to the predicted location of the critical lines at z_s=5,6.5 and 7 (from bottom to top, the latter two being almost coincident). The scale bar at the top left of each image represents 2″. The predicted shear direction (thin blue lines) closely matches the orientation of the lensed images.

Ly 1215 break?



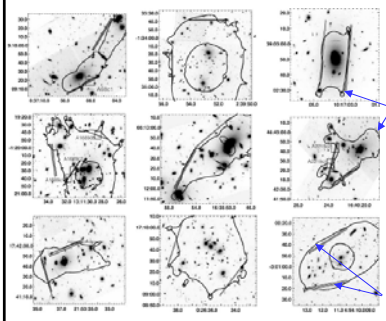


Z ~ 10 galaxies?

A KECK SURVEY FOR GRAVITATIONALLY-LENSED LYMAN α EMITTERS IN THE REDSHIFT RANGE 8.5<Z<10.4: NEW CONSTRAINTS ON THE CONTRIBUTION OF LOW LUMINOSITY SOURCES TO COSMIC REIONIZATION

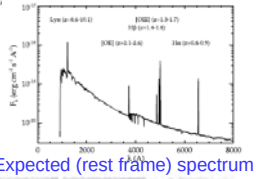
DANIEL P. STARK[1], RICHARD S. ELLIS[1], JOHAN RICHARD [1], JEAN-PAUL KNEIB [1,2], GRAHAM P. SMITH [1,3], MICHAEL R. SANTOS [4]

Draft version January 10, 2007

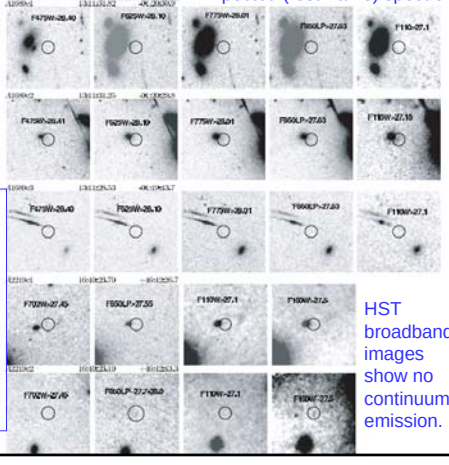


Grav. lensing critical lines.

Keck NIRSPEC slit positions



Expected (rest frame) spectrum



INFRARED SPECTA
6 possible Lyα emission lines (circled)
z ~ 8.5 – 10.4

2 best bets are z ~ 10

HST broadband images show no continuum emission.