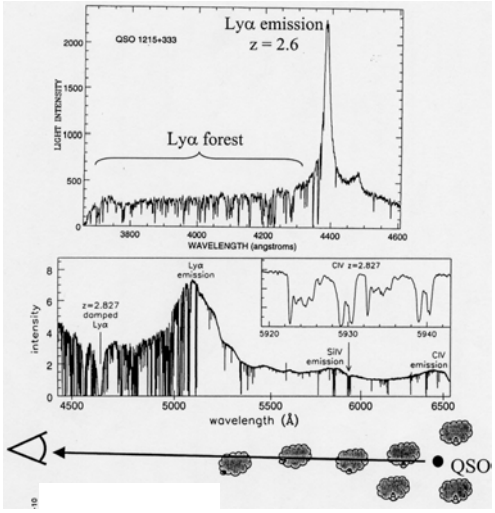
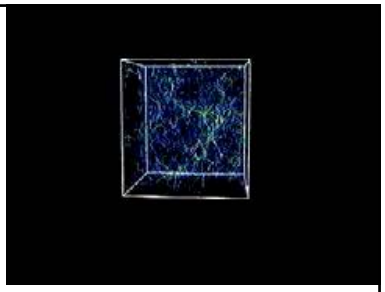
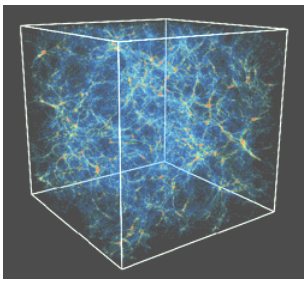
The Lyα Forest Revisted







- It's the cosmic web.
- Contains most of the baryons at high redshift.
- Contains 30% of baryons at z = 0.

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	$z \geq 10$	≤ 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	$z \geq 3$	≤ 2.19
Rich clusters of galaxies	$z \sim 2$	≤ 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.)

Bias

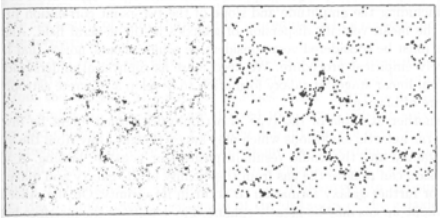
- CDM simulations ➔
  accurate predictions of CDM structure.

- 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,

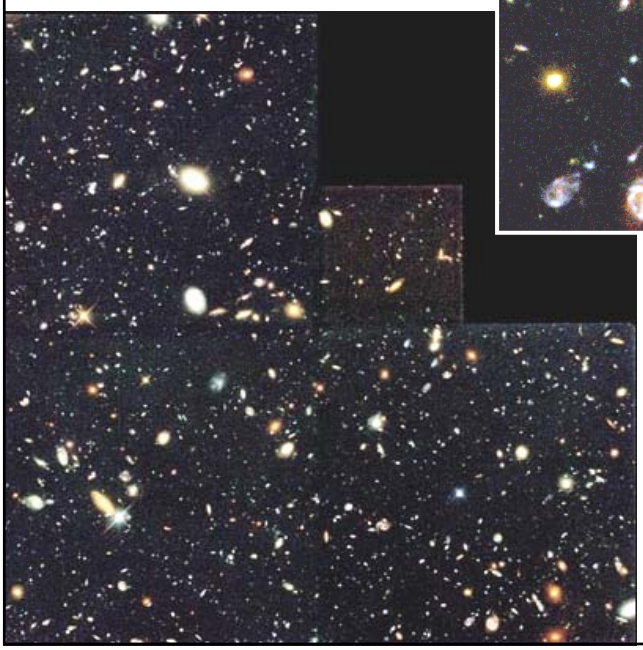
where σ_8 = variance of mass distr. in $8h^{-1}$ Mpc co-moving sphere.



Dark matter Baryons (for b = 2.5)

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

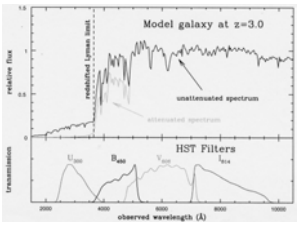
The Hubble Deep Field

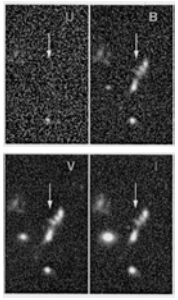


Northern field:
- 10 days, 150 orbits
  - WFPC2 camera
  - 5.3 arcmin^2
- 5000 objects
  - 20 stars
  - rest are galaxies

Southern field:
- 70 hours
- QSO in center

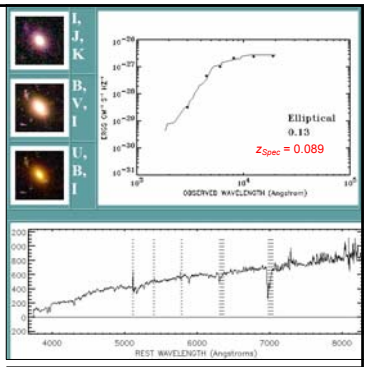
Photometric Redshifts

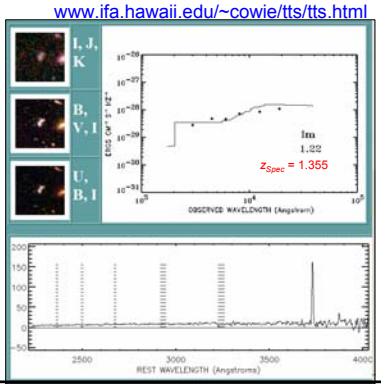


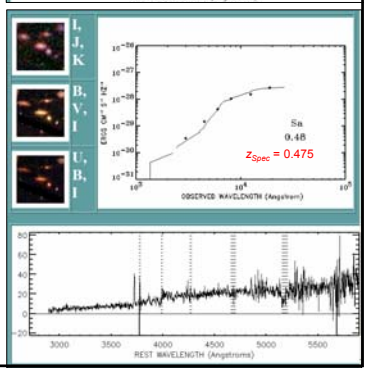


www.ifa.hawaii.edu/~cowie/tts/tts.html

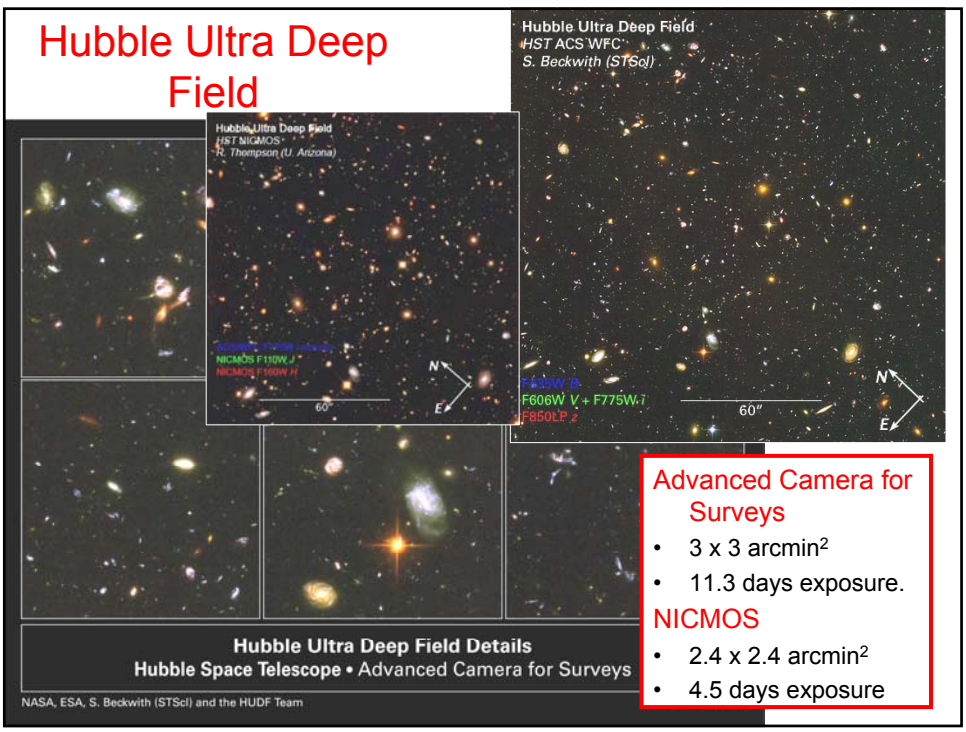
- Pioneered by Loh & Spillar 1986
- Used with HDF and most deep surveys since.
- Reasonable redshift accuracy.
- Reasonable ability to classify galaxies.
- Only need a few broad-band images, not spectra.







Hubble Ultra Deep Field



Advanced Camera for Surveys

- 3 x 3 arcmin^2
- 11.3 days exposure.

NICMOS

- 2.4 x 2.4 arcmin^2
- 4.5 days exposure

Other deep surveys:

- Chandra Deep Fields
  - North (Centered on HDF North)
  - South (New location; no QSO; but HUDF now centered here)
- GOODS (Great Observatories Origins Deep Survey)
  - Less deep survey, but over wider area
  - Incorporates HST, Chandra, Spitzer, XMM Newton + ground-based observations.
  - Fields centered at:
    - Hubble Deep Field North (same as CDF North)
    - Chandra Deep Field South (same as HUDF)

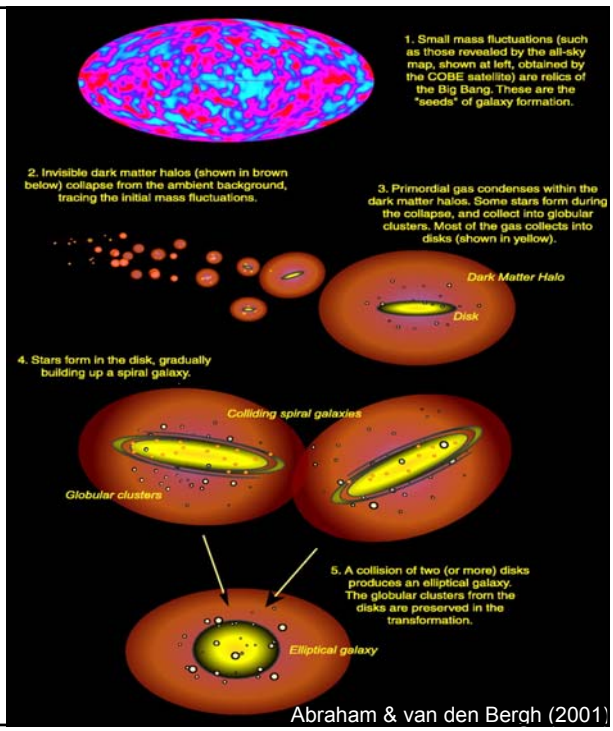
Basic idea behind galaxy formation - objects start small and grow by merging

Do galaxies form this way?

Does star formation occur before, during or after mass assembly?

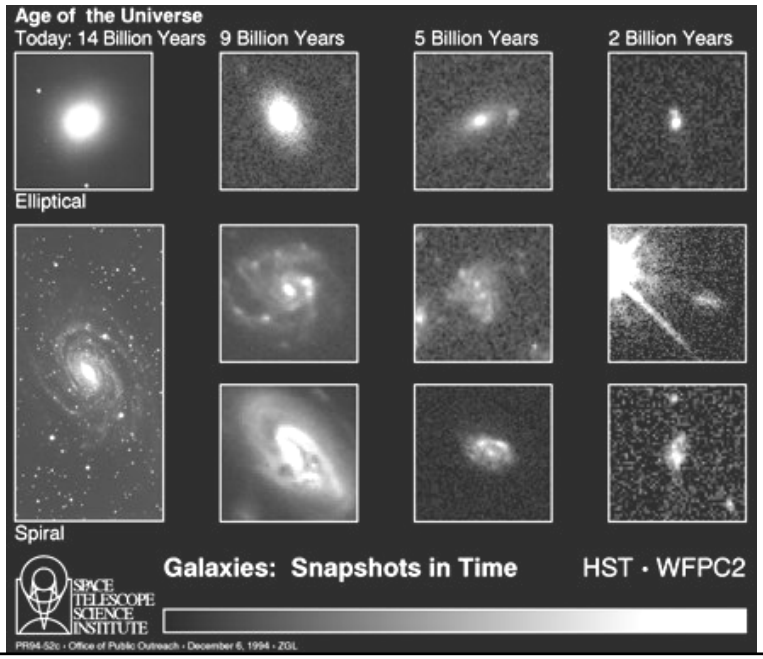
When and how do Hubble Types form?

From a talk by Chris Conselice

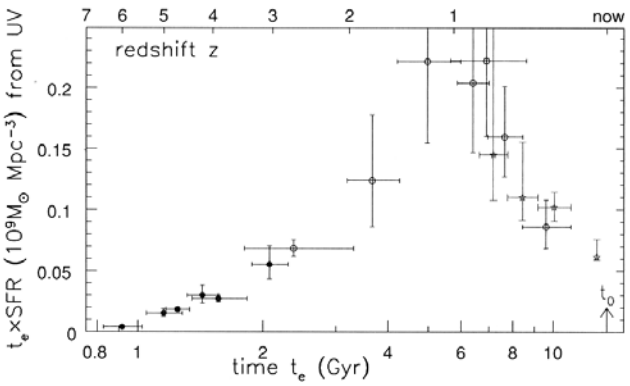


Abraham & van den Bergh (2001)

From the HST PR dept:



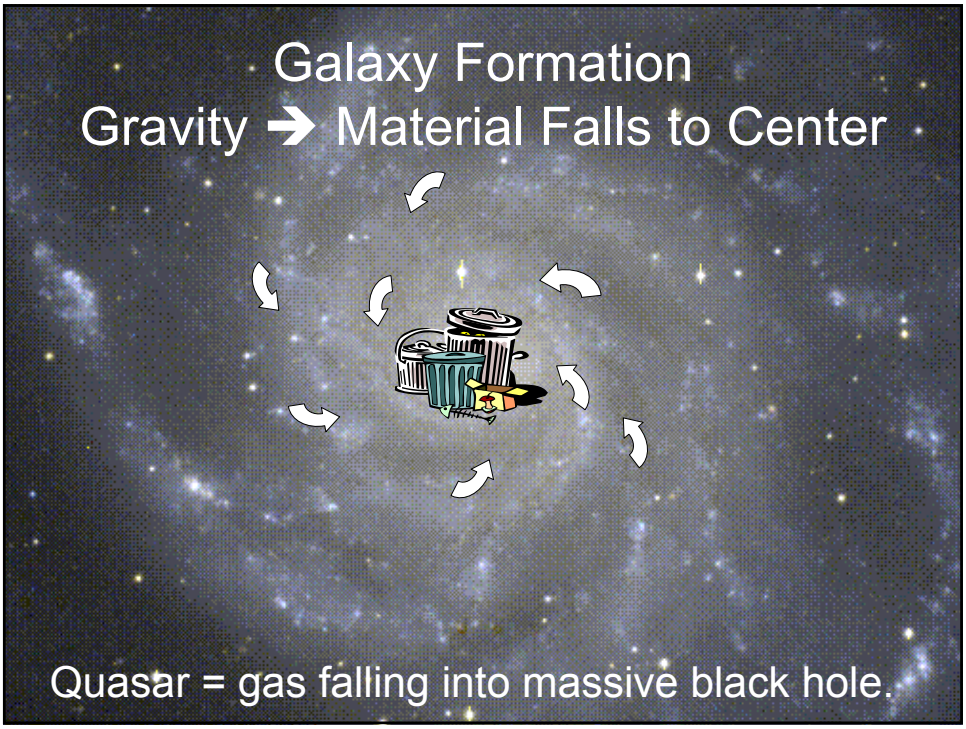
Star formation rate as a function of time



Measured from

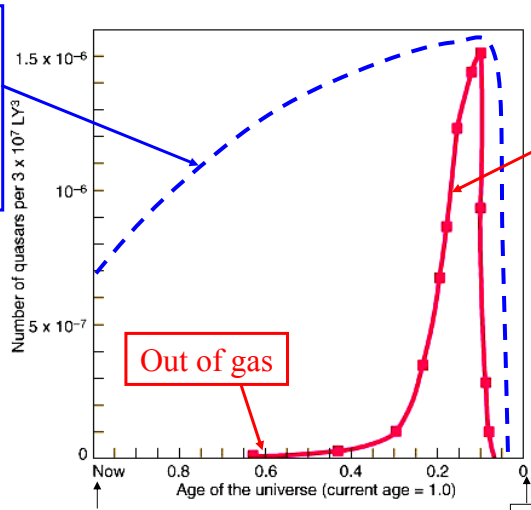
- Blue light (O star continuum)
- Hα emission (H II regions)

"Madau diagram"



Most Quasars Lived and Died Long Ago

Rate at which stars are formed in galaxies.



Number of Quasars per unit volume

Out of gas

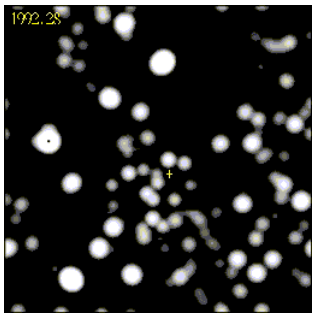
Conclusion:
Quasars are events in young galaxies.

Now
= 14 billion yrs

← time

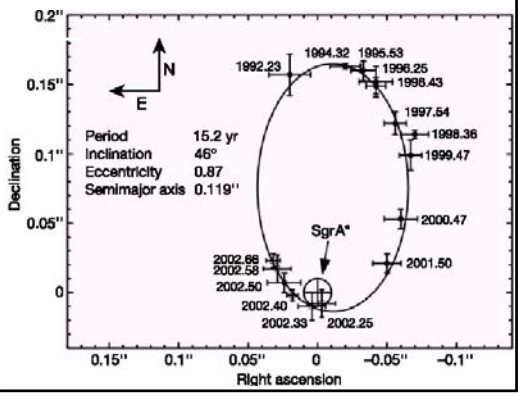
Formation of universe

Sidetrack: The Black Hole at the the Galactic Center



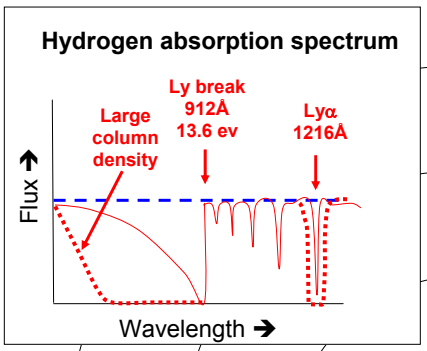
Infrared observations over 6 years.

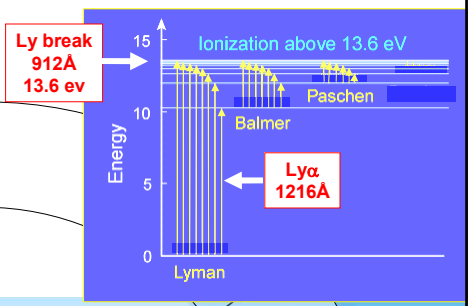
Velocities of stars in very center
➔ 1 million $M_\odot$ black hole
at position of Sagittarius A*

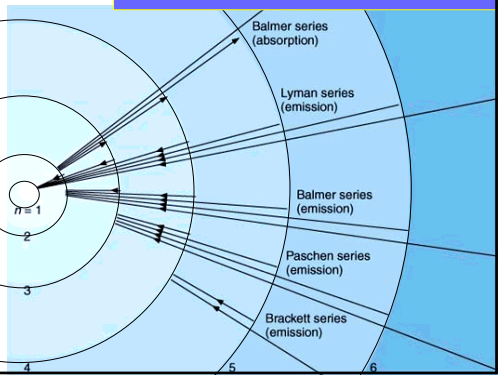


Follows complete orbits to within 60AU from black hole.

The Gunn – Peterson Effect







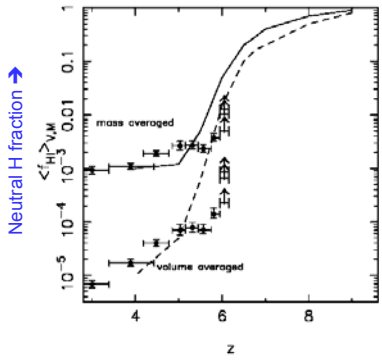
- Expect Ly continuum absorption from Inter-Galactic Medium to completely block all radiation with $\lambda < 912$Å
- Why doesn't it?

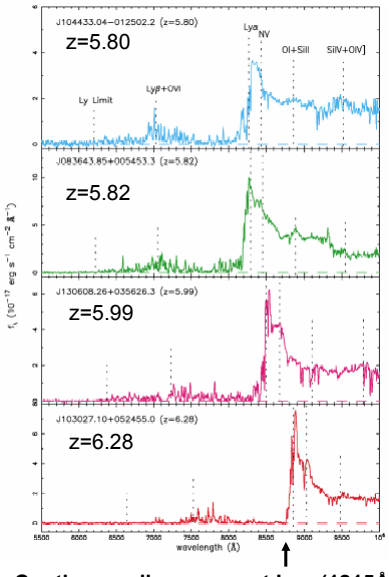
IGM is ionized. *Re-ionized.*

The 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 $z = 10.9^{+2.7}_{-2.3}$ (420 Myr) for re-ionization
  - From polarization of CMB.

➔ patchy re-ionization?

z = 7 galaxy ?

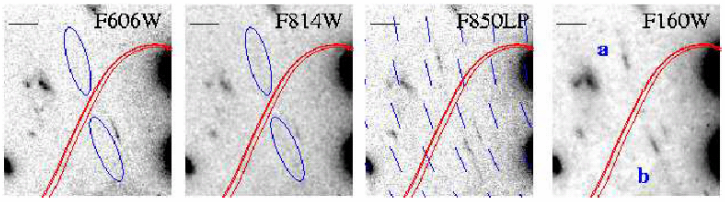
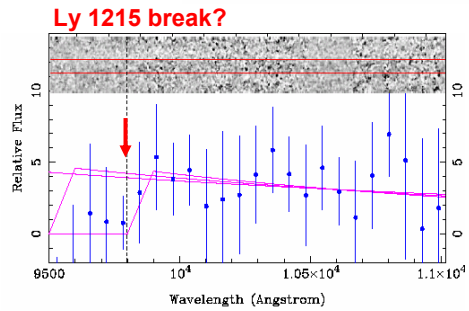


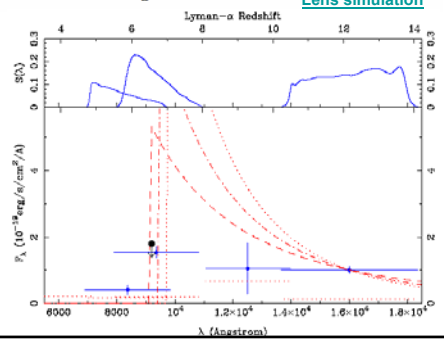
Figure 1: *WFPC2*-F606W, *WFPC2*-F814W, *ACS*-F850LP and NICMOS-F160W images of Abell 2218 of the new faint pair in the lensing cluster Abell 2218 (z=0.175). The signals redward of the *WFPC2*-F814W observation suggests a marked break occurs in the continuum signal at around 9600Å . Red lines correspond 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.

Gravitationally lensed galaxy observed at Keck by Ellis et al.

Lens simulation

Ly 1215 break?



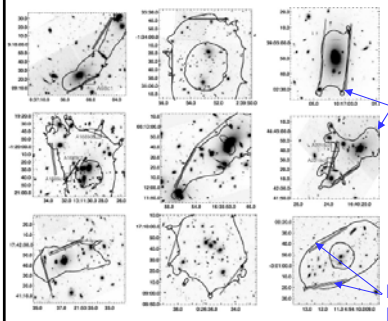


$z \sim 10$ galaxies?

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

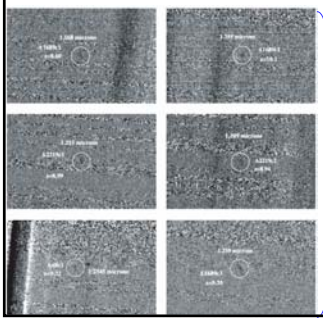
DANIEL P. STARK[1], RICHARD S. ELLIS[1], JOHAN RICHARD [1], JEAN-PAUL KNEIB [1,2], GRAHAM P. SMITH [1,3], MICHAEL R. SANTOS [4]

Draft version January 10, 200



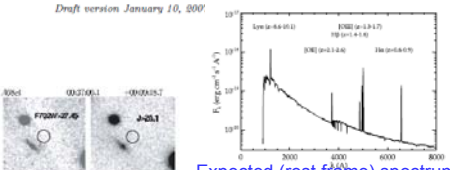
Conjugate caustics

Keck NIRSPEC slit positions

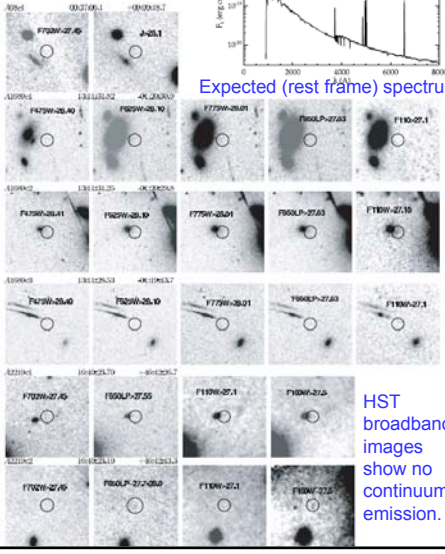


6 possible Lyα emission lines (circled)
$z \sim 8.5 - 10.4$

2 best bets are $z \sim 10$



Expected (rest frame) spectrum



HST broadband images show no continuum emission.