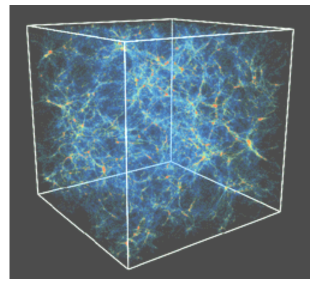
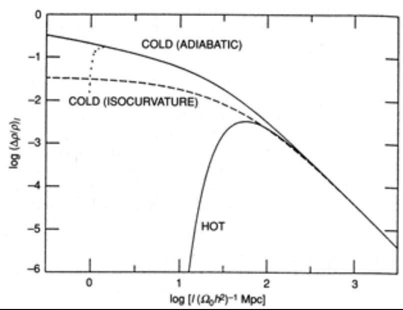
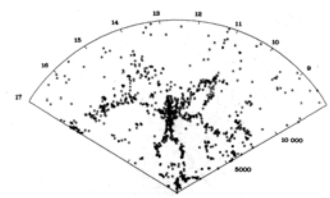
# Cosmology ➔ Bottom-Up formation of structures

Recent calculations from the National Center for Supercomputing Applications.

Flythrough NCSA
Growth of structure NCSA



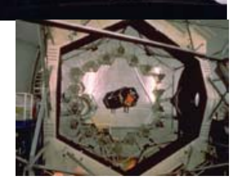


# Some large ground-based optical telescopes

**Lick 36” Refractor**
**1888**

**Mt. Palomar 200” Reflector**
**1948**

Light-gathering power

$\propto$ (mirror area)

$\propto$ (mirror diameter)$^2$

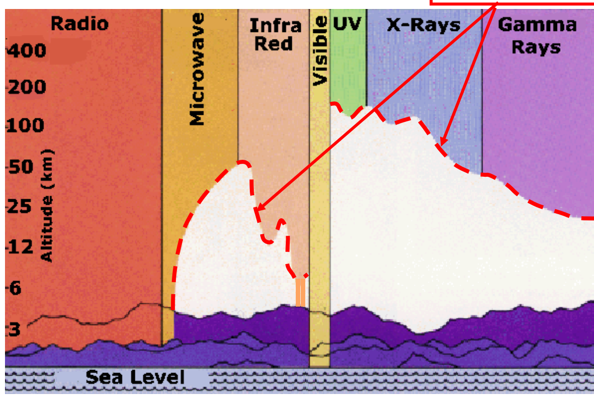
Technological advances

- Lenses ➔ mirrors
- Thick mirrors ➔ thin mirrors
  passive ➔ active support
- Now working on designs for 30m and 100m diameter telescopes.

**Europe’s Very Large Telescope**
**(Four 8m telescopes)**

**Mirror for Gemini 8m Telescope**

Light from outer space cannot penetrate below this altitude.

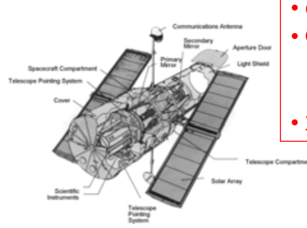


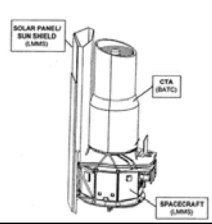

←Wavelength of light

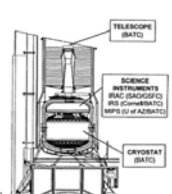
# NASA's "Great Observatories

- Compton Gamma Ray Observatory
  - Mission completed in 2000
- Chandra X-Ray Observatory
  - In orbit
  - High sensitivity
  - High angular resolution
- Hubble Space Telescope
  - Ultraviolet, optical, near IR wavelengths
  - High angular resolution
  - 2.4 meter dia. mirror
- Spitzer
  - a.k.a. Space Infra-Red Telescope Facility (SIRTF)
  - 0.85m aperture
  - Launched summer 2003
  - 2-5 yr lifetime.

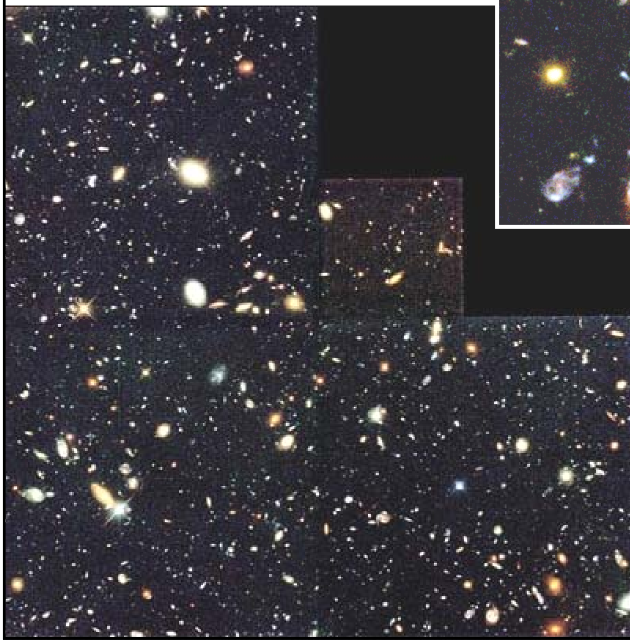
Coming attraction:
James Webb Space Telescope
- 6 meter mirror
- Optimized for infrared observations of primeval galaxies.
- 2010 launch?





# The Hubble Deep Field



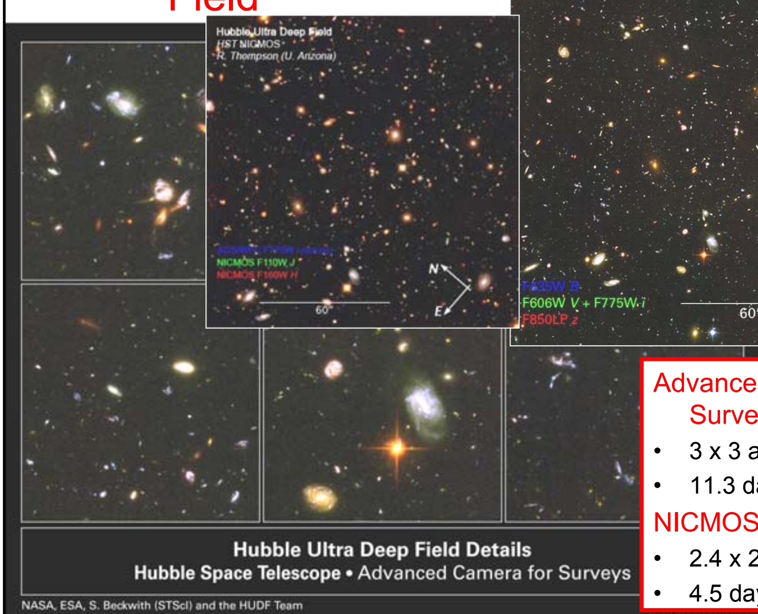
Northern field:

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

Southern field:

- 70 hours
- QSO in center

# Hubble Ultra Deep Field


Advanced Camera for Surveys

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

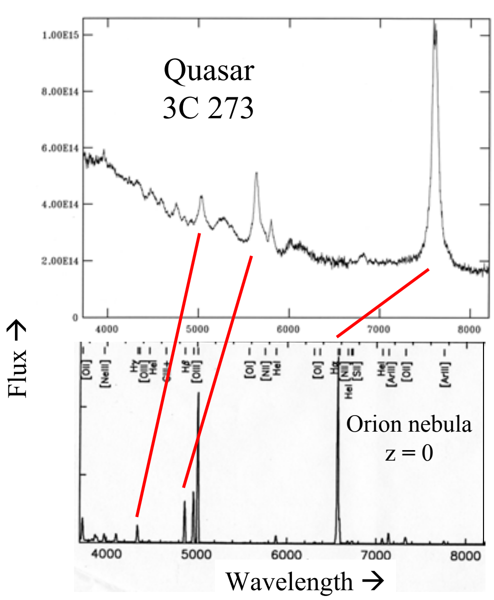
NICMOS

- 2.4 x 2.4 arcmin$^2$
- 4.5 days exposure

# Other very 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)

# Determining Redshifts




- Measure Doppler shift from emission or absorption lines:

  Redshift $z = \Delta\lambda/\lambda = v/c$

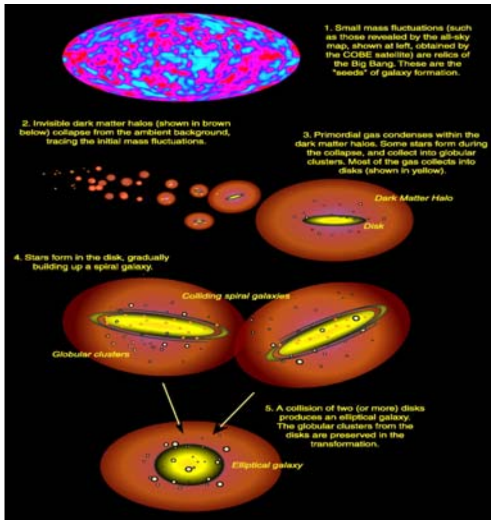
- Plug into equations for luminosity or angular size distance as needed (Ned Wright's Cosmology Calculator)

## 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?




Abraham & van den Bergh (2001)

With available data we can start answering these questions

**From a talk by Chris Condalice Caltech**

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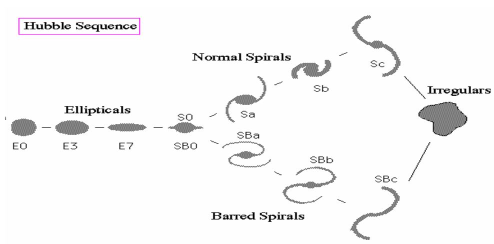
**Chris Condalice**

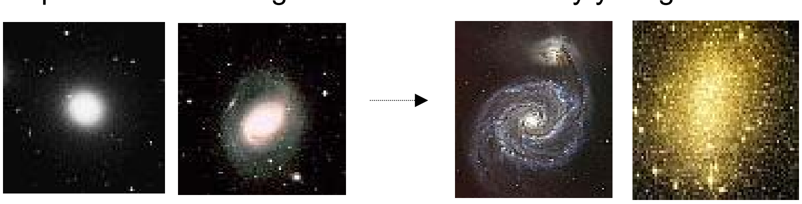
## Hubble Types

98% of all nearby bright galaxies can be placed into a Hubble type




Hubble types are the z = 0 final state of bright galaxy evolution

Ellipticals have old stellar populations, spirals have both old and young components while irregulars are dominated by young stars



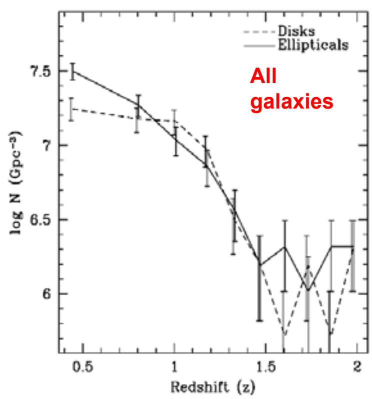
Old stars

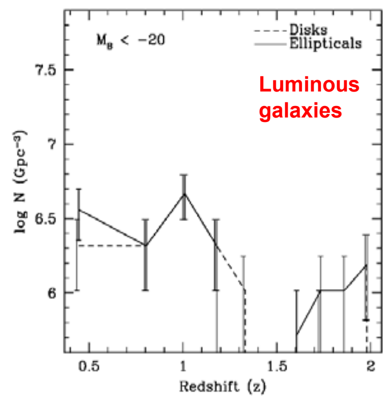
Young stars

A significant amount of star formation must have occurred in the past for Es, but some young stars clearly exist in spirals

**Chris Condalice**

Co-moving density of Hubble Types with Redshift

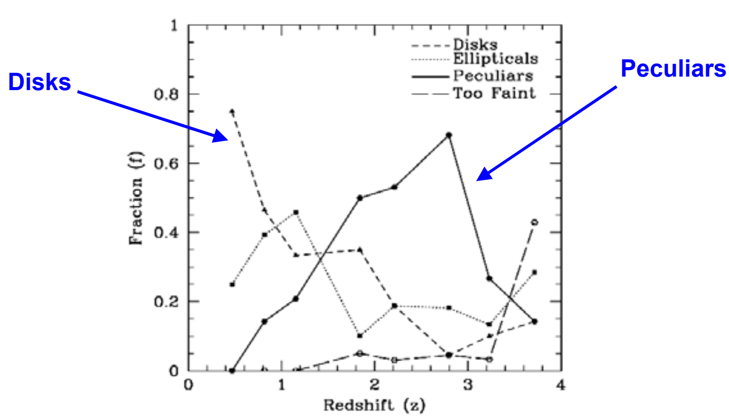



Co-moving density drops from z ~ 1 to 1.5, even when considering only bright galaxies

**Chris Condalice**

Evolution in the relative fraction of types out to z ~ 4 in the HDF

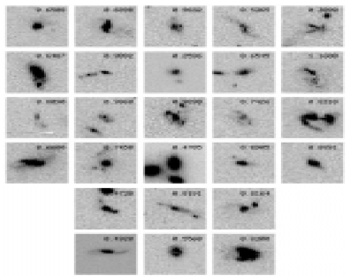



Did peculiar galaxies merge to form today's massive E and S galaxies?

**Chris Condalice**

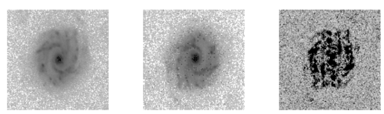
## What are these high redshift peculiar galaxies? Are they mergers?

Want to find a method to determine if a galaxy is undergoing a major merger. Traditional method uses pairs of galaxies:



LeFevre et al. (2000)

Morphological methods finds objects that have already merged



I R abs(I–R)

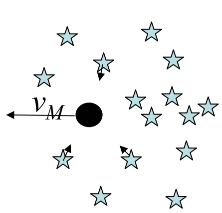
$$A = \frac{\text{abs}(I-R)}{I}$$

Rotate and subtract and image and quantify the residuals as a number

# Merger Processes [*READ* CO 24.1]

- **Dynamical Friction -** A slow accretion process.
  - Massive body moving through uniform distribution of stars
    - Pulls stars in behind it.
    - Creates high-density wake.
    - Gravitational pull from wake slows down massive body.
    - If massive body is in orbit in a galaxy, it will gradually spiral into the center.
    - Force on massive body is $f_d \simeq C \frac{G^2 M^2 \rho}{v_M^2}$ ⇨ $t_c = \frac{2\pi v_M r_i^2}{CGM}$

$$r_{\max} = \sqrt{\frac{t_{\max} CGM}{2\pi v_M}}$$




$r_i$ = initial distance from center of galaxy.

$t_c$ = time to spiral into center due to dynamical friction.

$r_{max}$ = max radius for capture within age of universe. (= 4 kpc for M31 and $t$ = 17 Gyr)

**Homework:**
**CO 24.1, 24.2, 24.4**
**Due Wednesday**

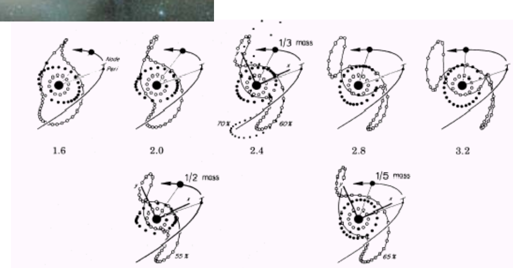
- *You're invited!*
  - SOAR Telescope dedication ceremony
  - Saturday April 17, 6:30 PM in BPS Atrium.
  - But please RSVP by THIS WEDNESDAY to (517) 432-4561.
- These powerpoint slides are on the web at www.pa.msu.edu/courses/ast308

**Homework:**
**CO 24.1, 24.2, 24.4**
**Due Wednesday**

# The Antennae Galaxies

NGC 4038
NGC 4039

- **Galaxy collisions** – "impacts".
  - Numerical simulations
  - Toomre & Toomre, 1972, ApJ 178, 623.
    - Tidal tails, etc.



## Life in the fastlane…

## Colliding galaxies

Meanwhile, in a galaxy close, close to home…

**The Milky Way Meets Andromeda**

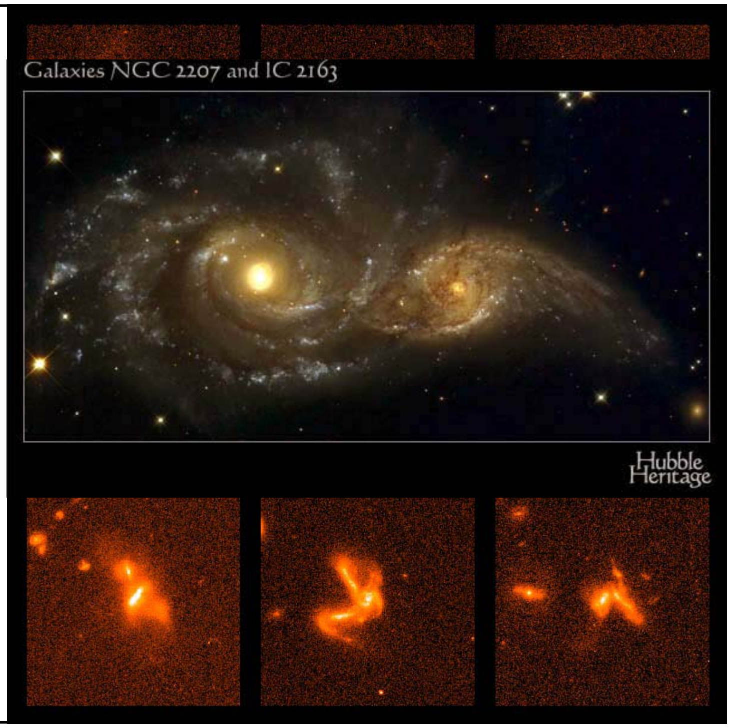
2.5 million ly away

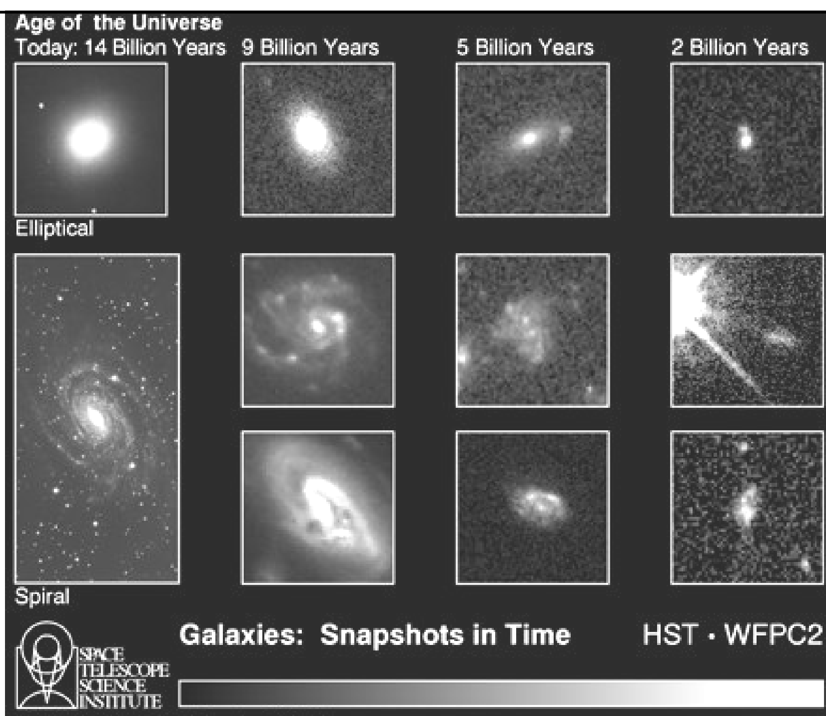
Approaching at 500,000 km/hr

➔ Collision in 3 billion yrs

Movie lasts 1.3 billion yrs.

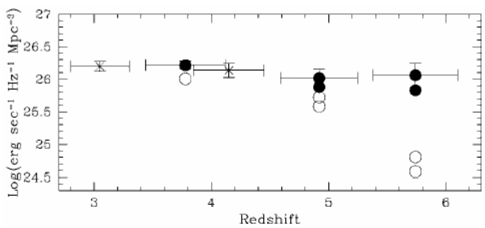
play



# Recent results from GOODS

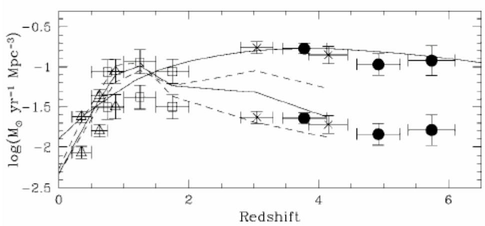
(Giavilisco, et al. 2004, ApJL, 600, L103.)




Observed 1500A luminosity density

Proper correction for sensitivity

Wrong correction

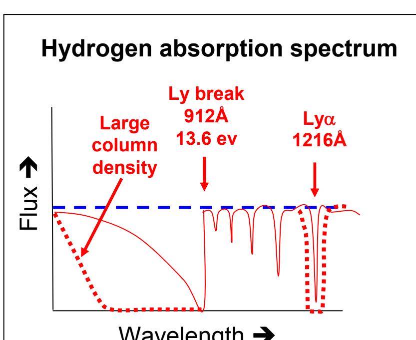


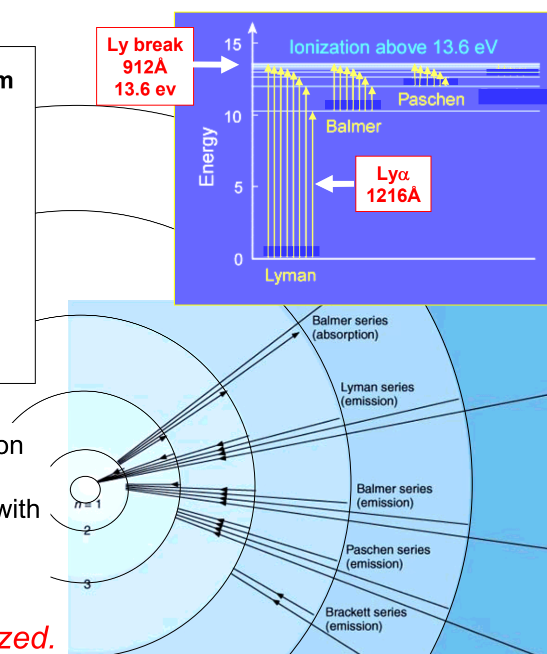

Converted to star formation rate

Corrected for dust extinction

Not corrected

# The Gunn – Peterson Effect



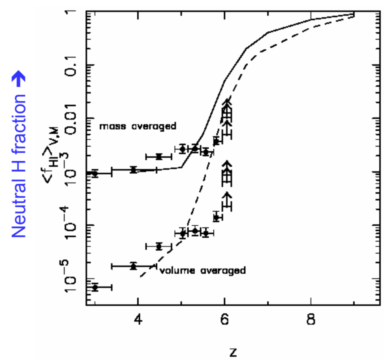

- Expect Ly continuum absorption from Inter-Galactic Medium to completely block all radiation with $\lambda < 912$Å
- Why doesn't it?

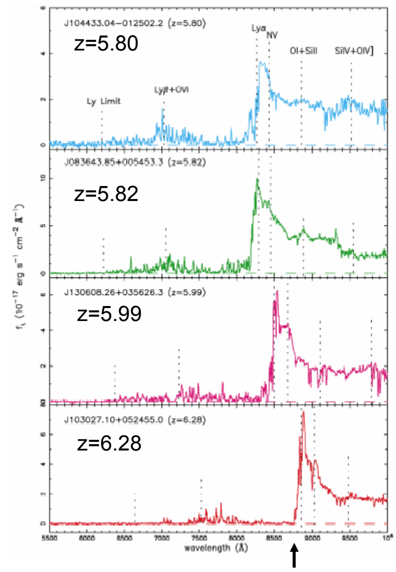
*IGM is ionized.* *Re-ionized.*

# The dark ages

## When did re-ionization occur?

- Seem to be finding QSOs at z ~ 6 with Gunn-Peterson absorption.




**Continuum disappears at Lyα (1215Å)**

- But WMAP finds z = 20 (180 Myr) for re-ionization
  - From polarization of CMB.

➔ patchy re-ionization?

# z = 7 galaxy ?

Gravitationally lensed galaxy observed at Keck by Ellis et al.

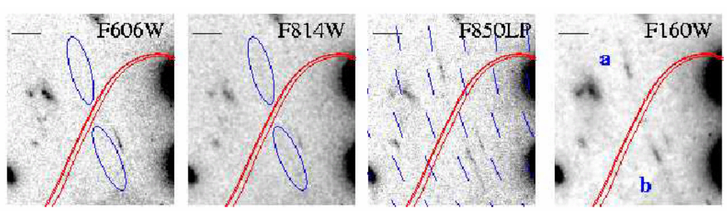
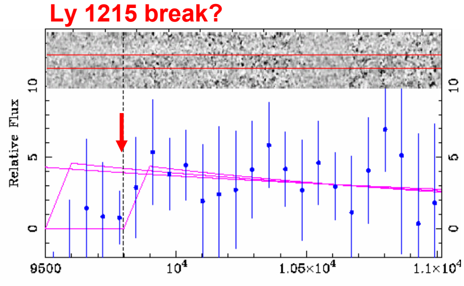
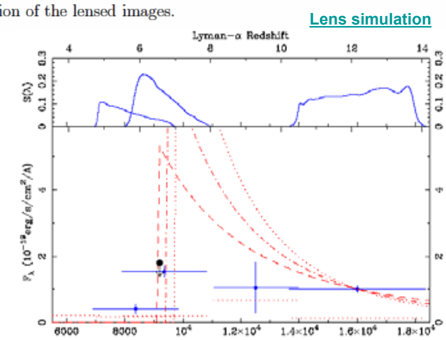



**Figure 1:** *WFPC2*-F606W, *WFPC2*-F814W, *ACS*-F850LP and NICMOS-F160W images of Abell 2218 of the new faint pair in the lensing cluster Abell 2218 ($z$=0.175). The signals redward of the *WFPC2*-F814W observation suggests a marked break occurs in the continuum signal at around 9600Å . Red lines correspond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

Lens simulation

**Ly 1215 break?**

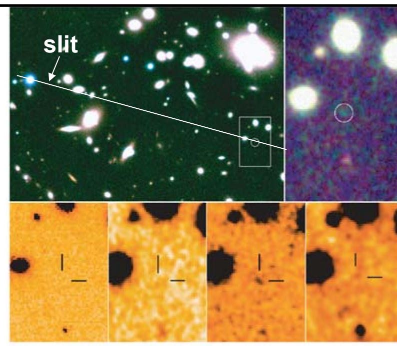


# z = 10 galaxy ?

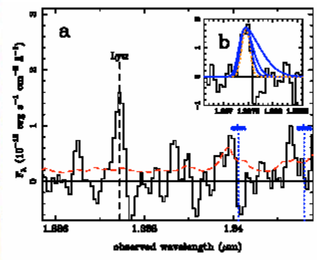
Gravitationally lensed galaxy observed at VLT by Pelló et al.

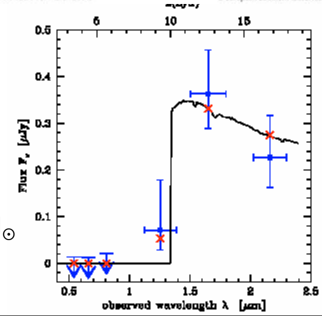
- $\geq$ 25x magnification.
- mag 28 unlensed.
- size ~ 1 kpc
- Star Formation Rate = 20-120 $M_\odot$ / yr
- Total mass in stars ~ $10^7$ $M_\odot$
- Total mass including dark matter ~ 5 x$10^8$ $M_\odot$
- Observed 460 Myr after Big Bang.

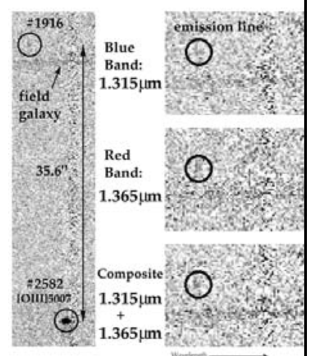



Abell 1835 IR1916 - the Farthest Galaxy - Seen in the Near-Infrared
(VLT ANTU + ISAAC)

ESO PR Photo 05a/04 (1 March 2004)
© European Southern Observatory




Two-dimensional Spectra of Abell 1835 IR1916
(VLT ANTU + ISAAC)

ESO PR Photo 05b/04 (1 March 2004)
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