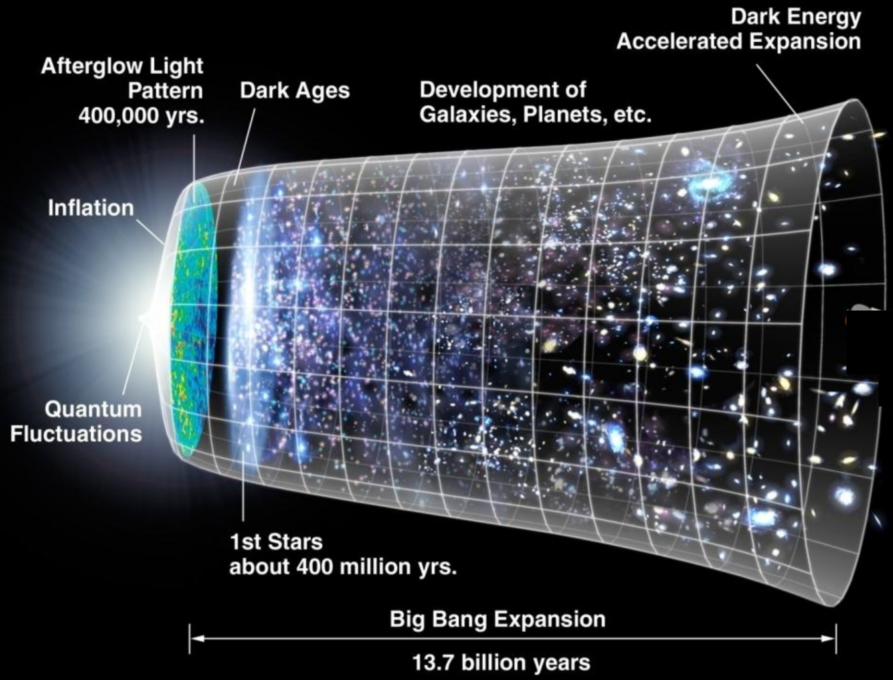
GALAXY REDSHIFTS: FROM DOZENS TO MILLIONS

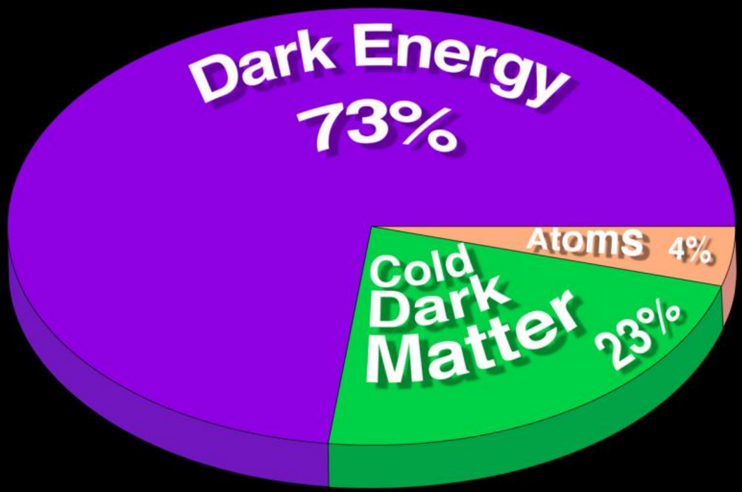
Chris Impey
University of Arizona

The Expanding Universe

- Evolution of the scale factor from GR; metric assumes homogeneity and isotropy (~FLRW).
- Cosmological redshift fundamentally differs from a Doppler shift.
- Galaxies (and other objects) are used as space-time markers.

Expansion History and Contents





The expansion history since the big bang and the formation of large scale structure are driven by dark matter and dark energy.

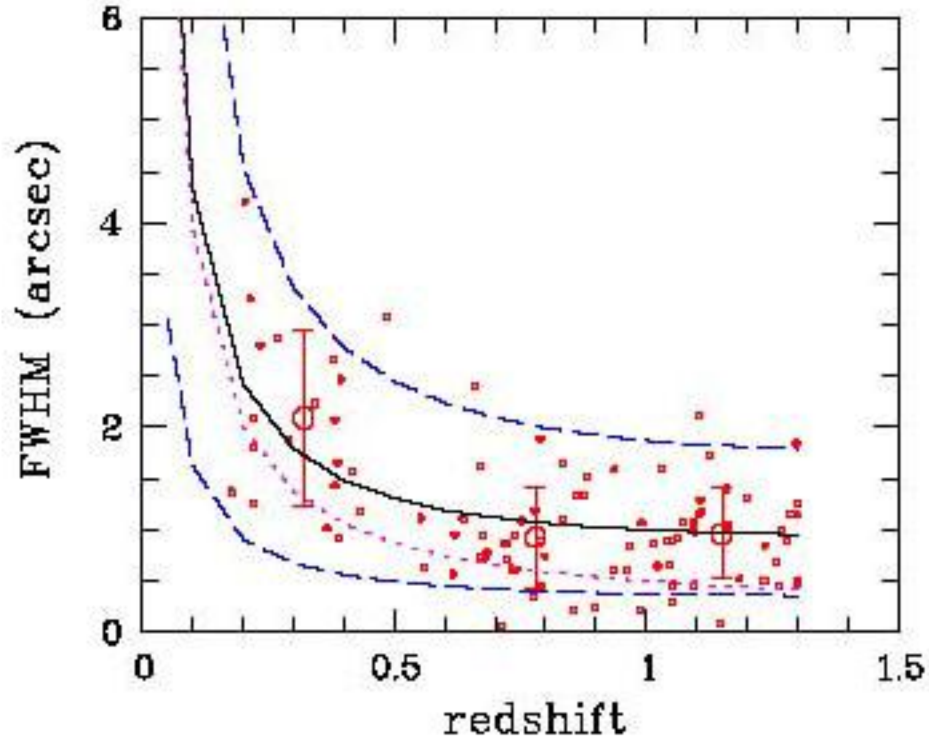
Observing Galaxies

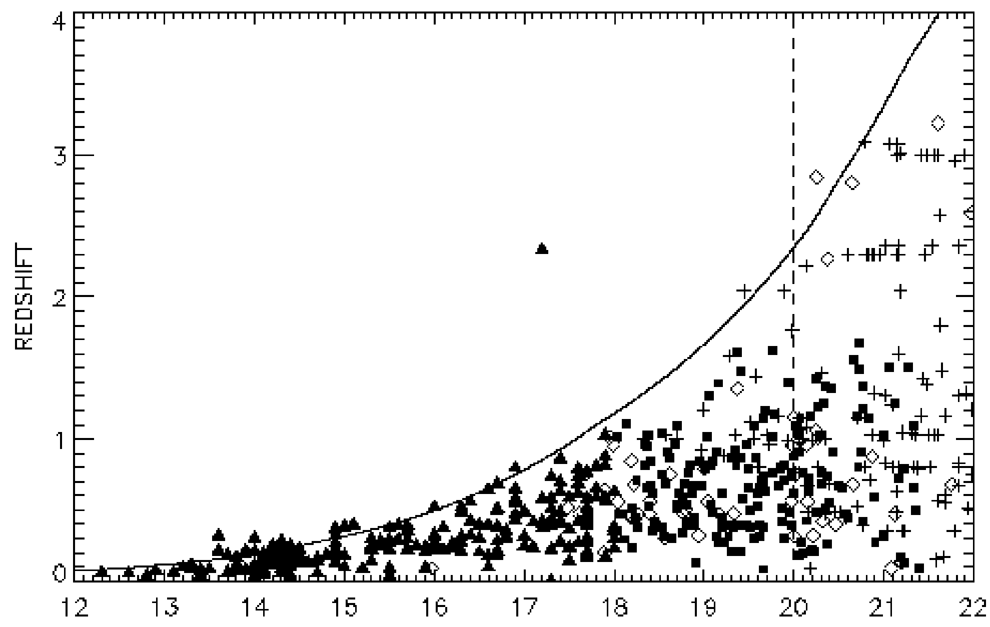
Galaxy Observables:

- **Redshift (z)**
- **Magnitude (color, SED)**
- **Angular size (morphology)**

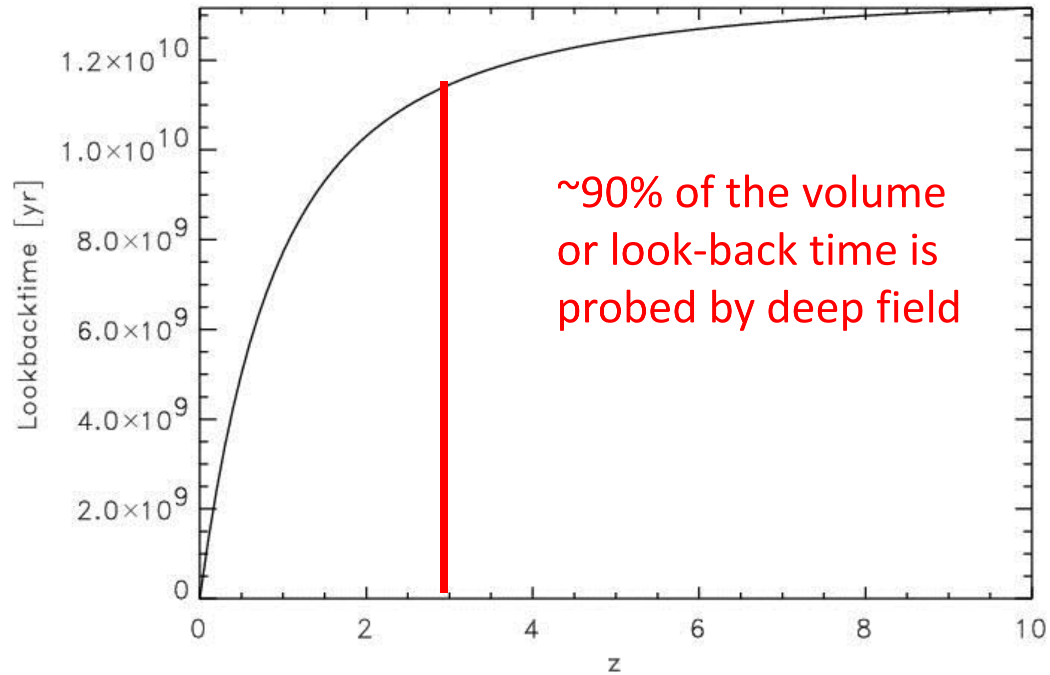
All other quantities (size, luminosity, mass) derive from knowing a distance, which relates to redshift via a cosmological model.

The observables are poor distance indicators. Other astrophysical luminosity predictors are required.



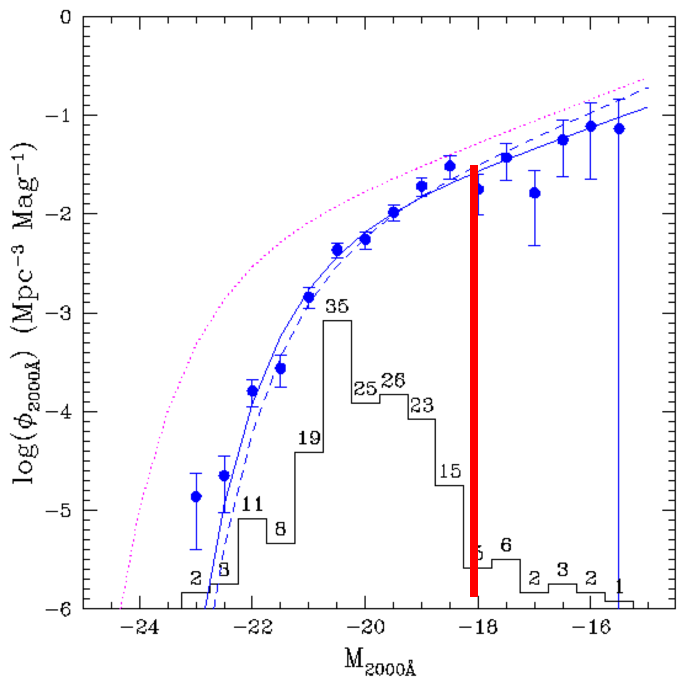


(Cowie)



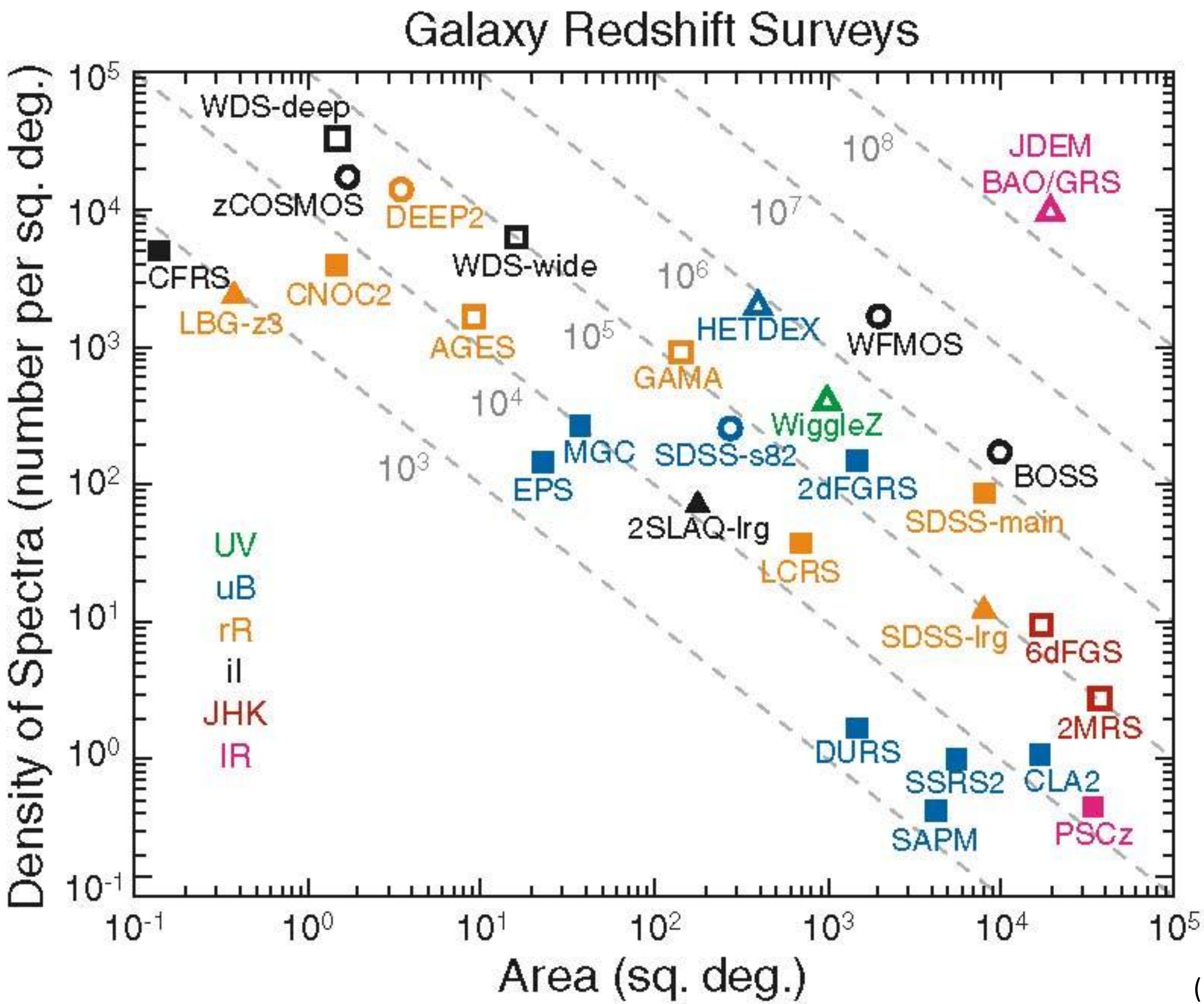
~90% of the volume or look-back time is probed by deep field

- **Number of galaxies in observable universe: about 100 billion**
- **Number of stars in the observable universe: about 10^{22}**



~90% of the galaxies in the volume are counted

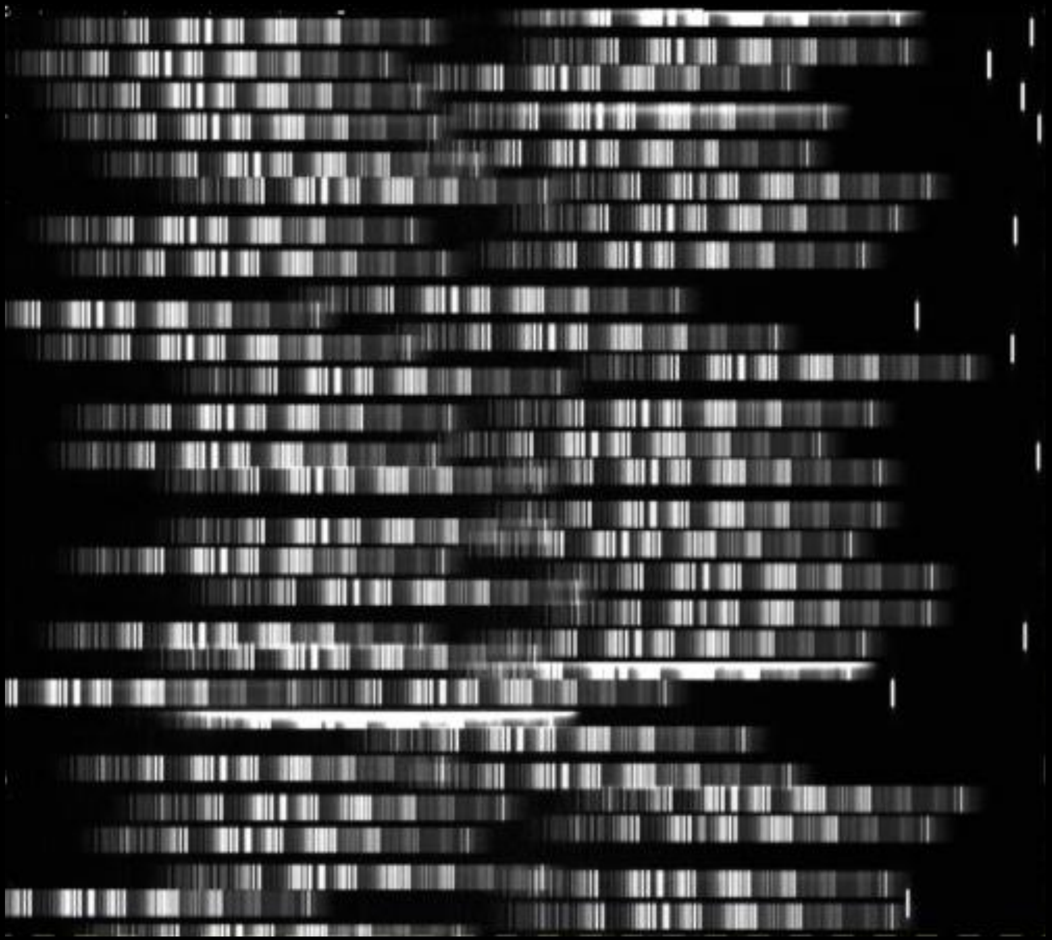
Heading for 100 Million



(Baldry/Eisenstein)

Multiplex Advantage

Cannon (1910)



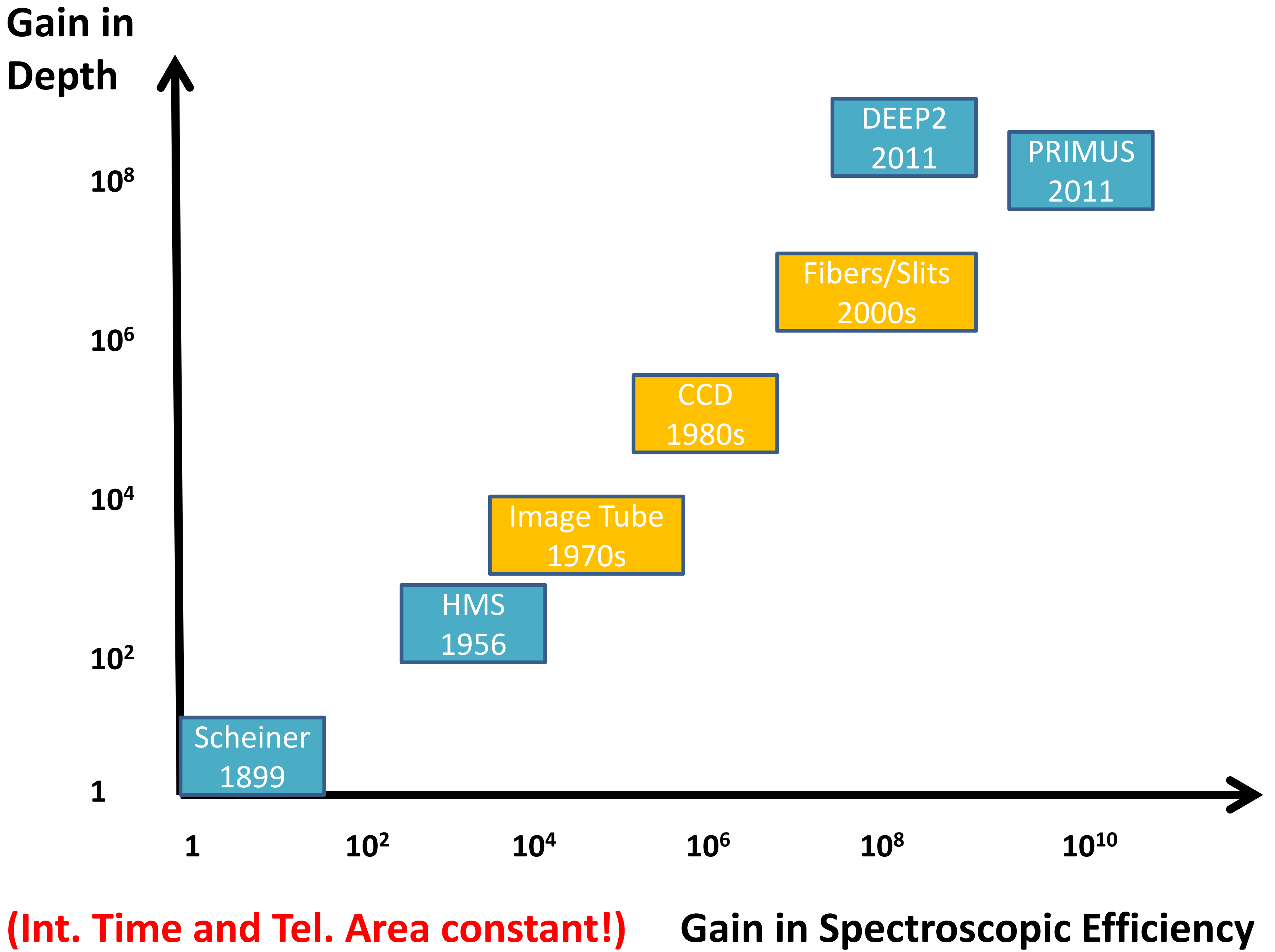
Gemini/GMOS (2010)

Sluggish,
Spacious,
Reliable.

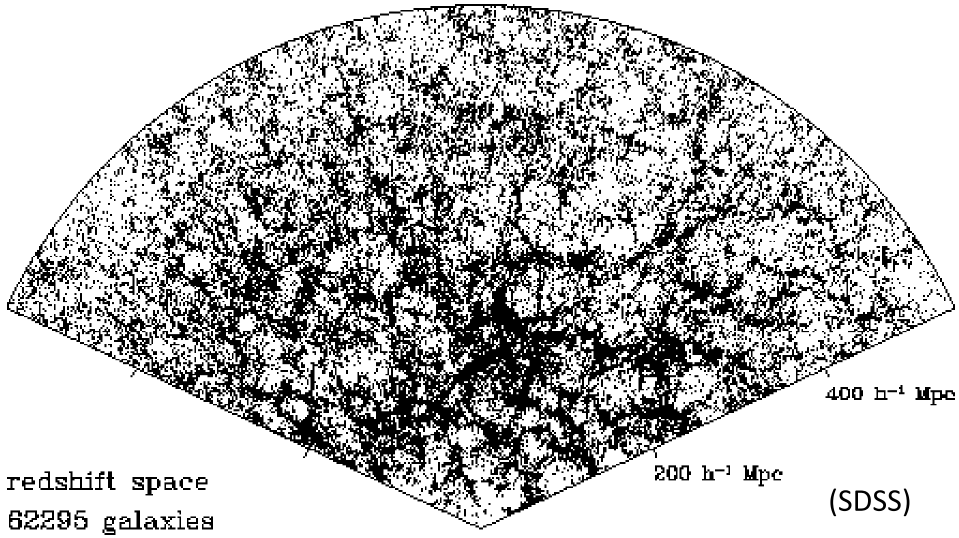
Speedy,
Cramped,
Finicky.

100 Years of Measuring Galaxy Redshifts

Who	When	# Galaxies	Size	Time	Mag
Scheiner	1899	1 (M31)	0.3m	7.5h	V = 3.4
Slipher	1914	15	0.6m	~5h	V ~ 8
Slipher	1917	25	0.6m	~5h	V ~ 8
Hubble/Slipher	1929	46	1.5m	~6h	V ~ 10
Hum/May/San	1956	800	5m	~2h	V = 11.6
Photographic	1960s	1	~4m	~2.5h	V ~ 15
Image Intensifier	1970s	1	~2.5m	~15m	V ~ 15
CCDs	1980s	1	2-4m	~1h	V = 16-18
Fibers/Slits	2000s	100s	4-10m	~1h	V = 18-22
CfA	1982	2400	1.5m		B < 14.5
LCRS	1996	26,000	2.5m		R < 17.5
CNOC2	2000	6,000	4m		R < 21.5
SDSS	2002	700,000	2.5m		R < 17.8
2dF	2003	220,000	4m		B < 19.5
DEEP2	2003	38,000	10m		R < 24.1
VIMOS	2005	100,000	8m		I < 22.5
DEEP3	2011	~50 (R = 2000)	10m	~1h	R < 24.4
PRIMUS	2011	~2000 (R = 200)	6.5m	~1h	I < 23.5

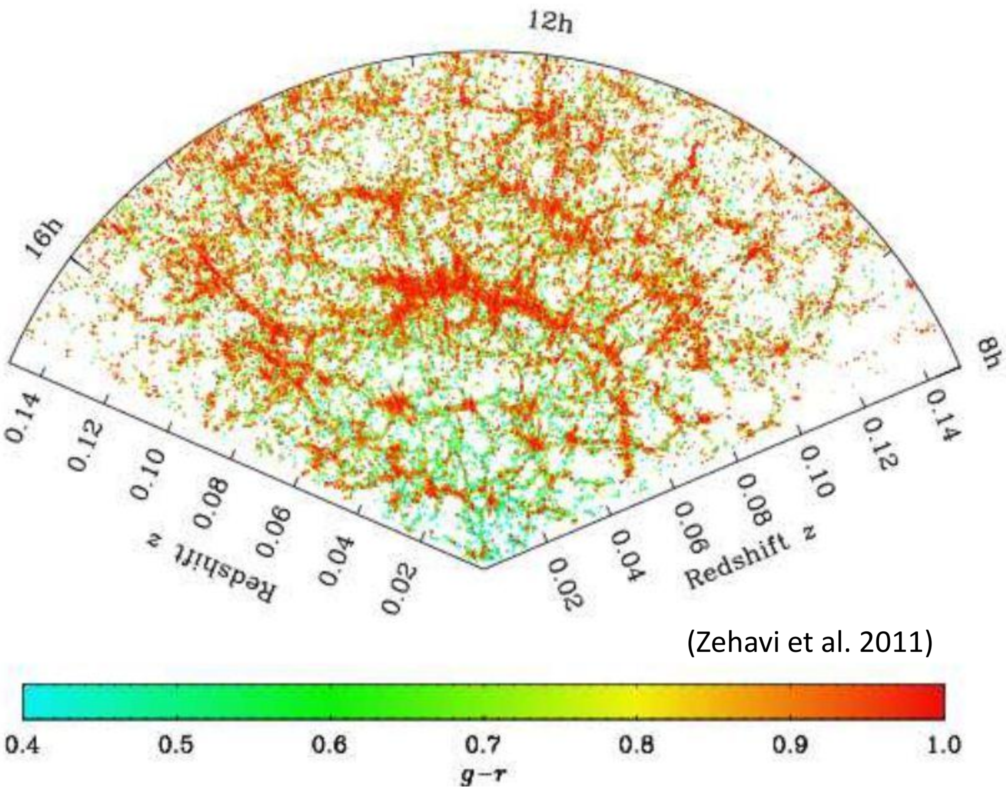

Gain in Depth
10^8
10^6
10^4
10^2
1
DEEP2 2011
PRIMUS 2011
Fibers/Slits 2000s
CCD 1980s
Image Tube 1970s
HMS 1956
Scheiner 1899
1
10^2
10^4
10^6
10^8
10^10
(Int. Time and Tel. Area constant!)
Gain in Spectroscopic Efficiency

Understanding Large Scale Structure



(SDSS)

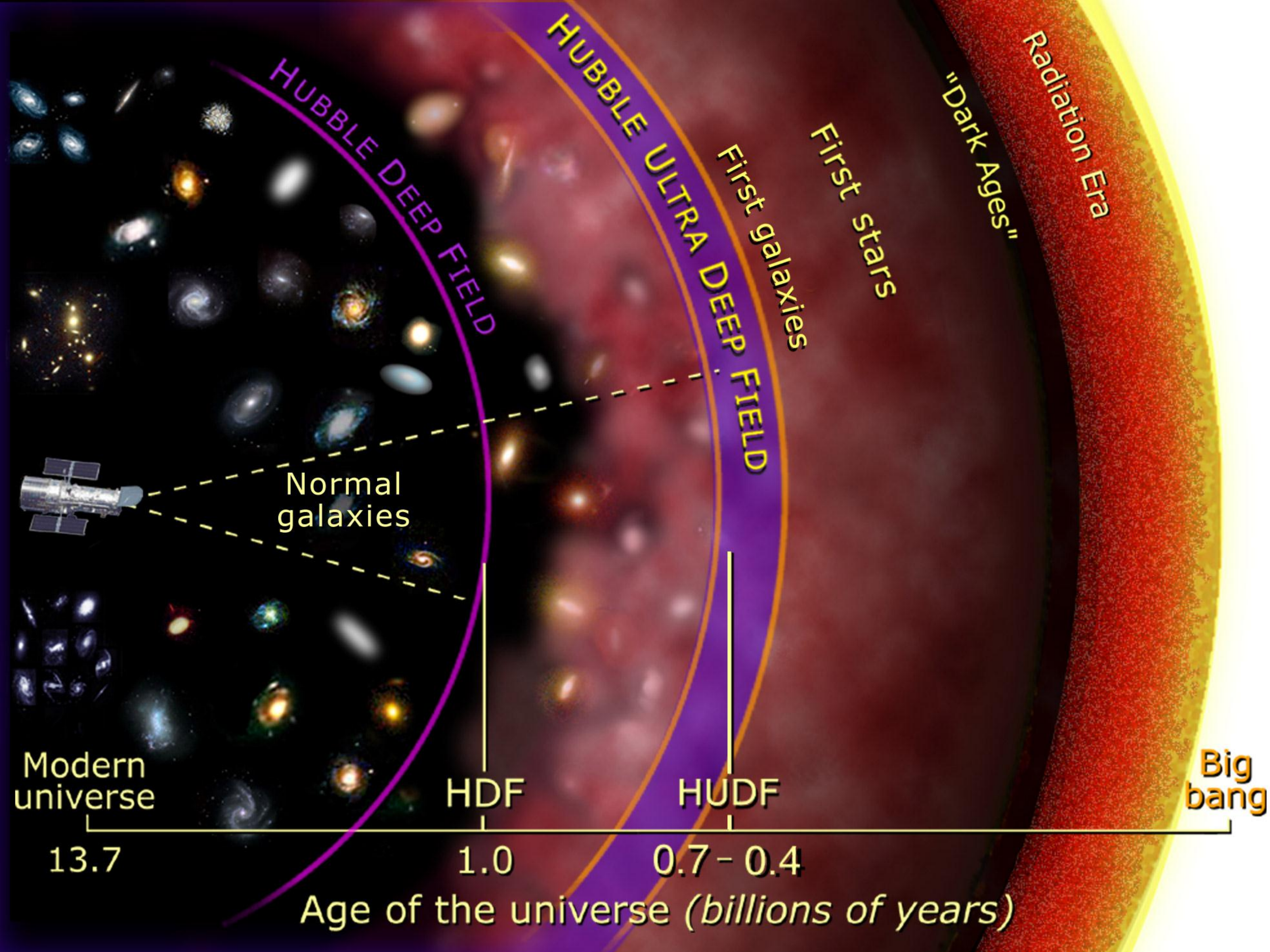
Simulations of structure formation dominated by cold dark matter predict smooth initial conditions and hierarchical growth.

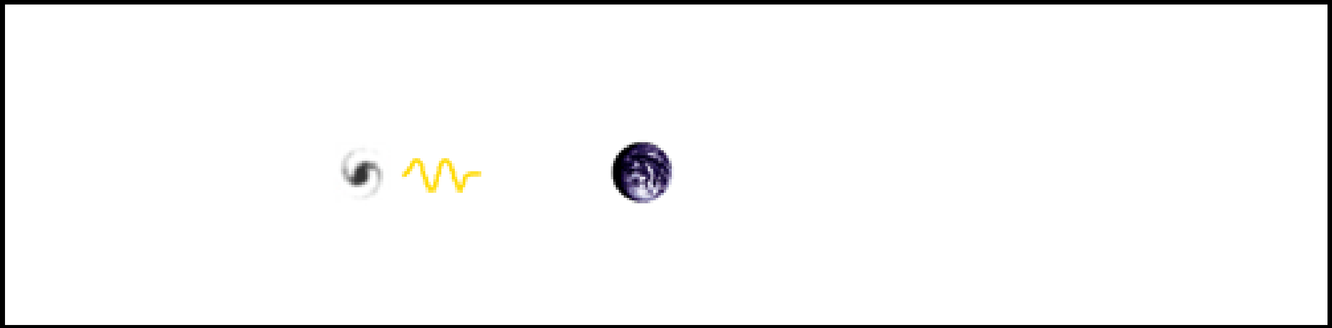


(Zehavi et al. 2011)

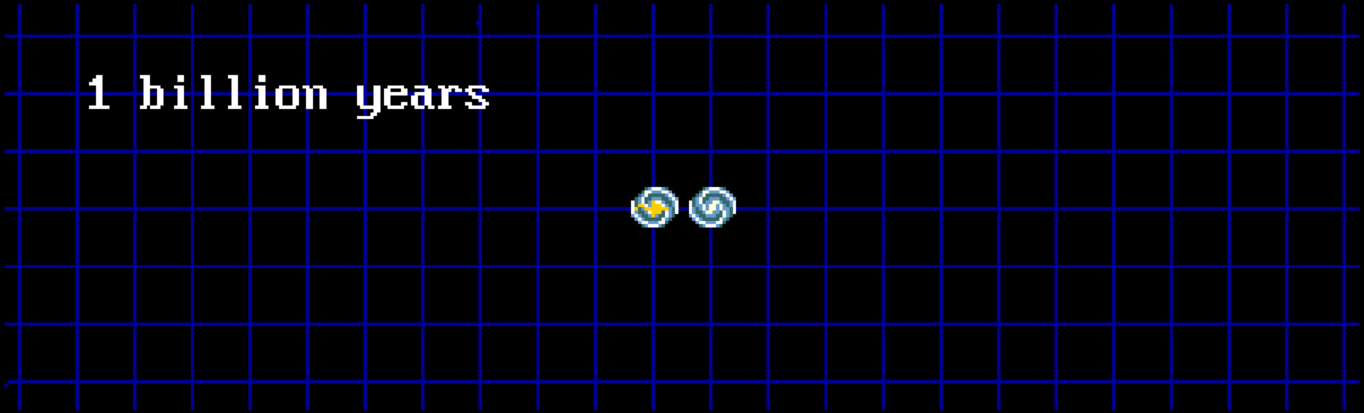
Observing the luminous tracers agrees with CDM implying galaxies formed first and then merged to create larger structures.

Towards the Big Bang

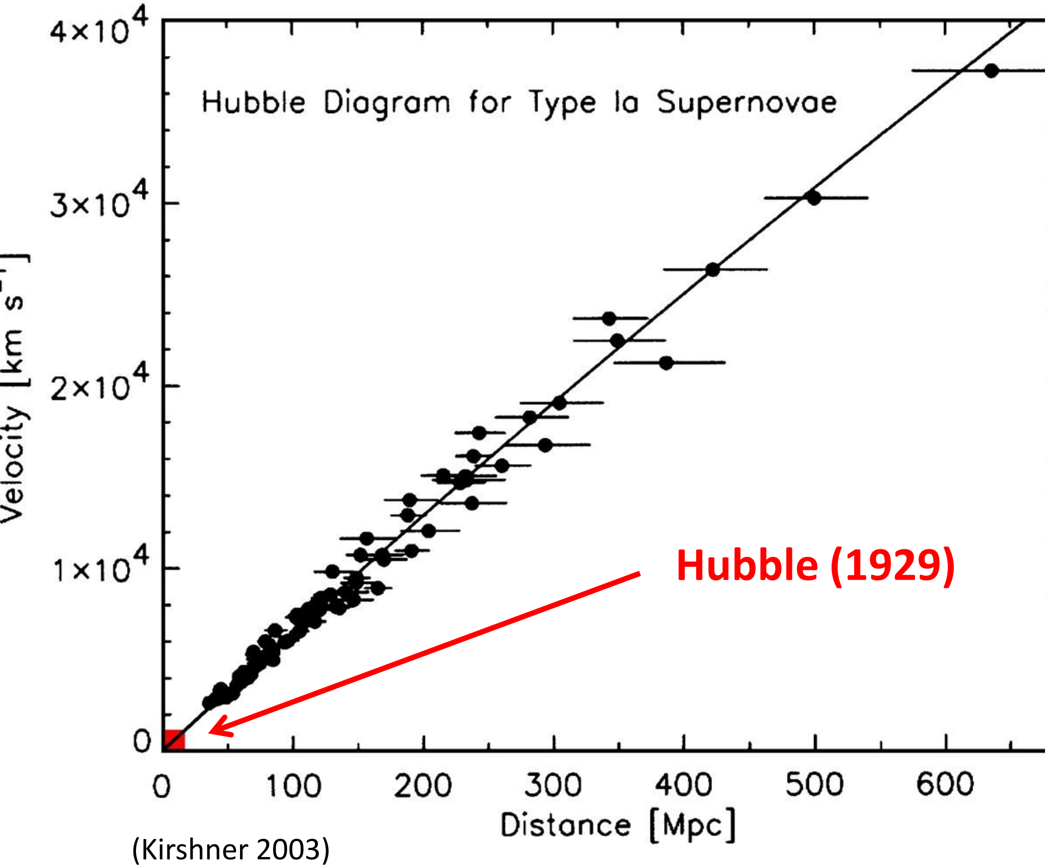

HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)



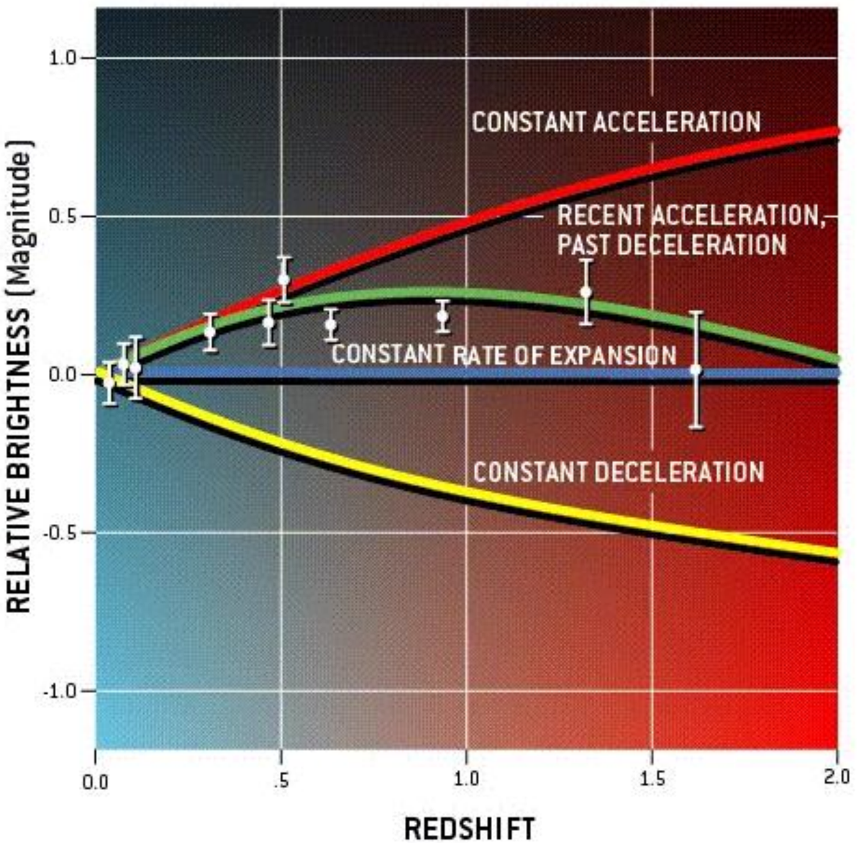
Photons from distant objects are redshifted by expansion since time of emission. At the highest redshifts, galaxies were receding at ~2.5c and the entire universe was 10 times smaller and hotter, and 1000 times denser.



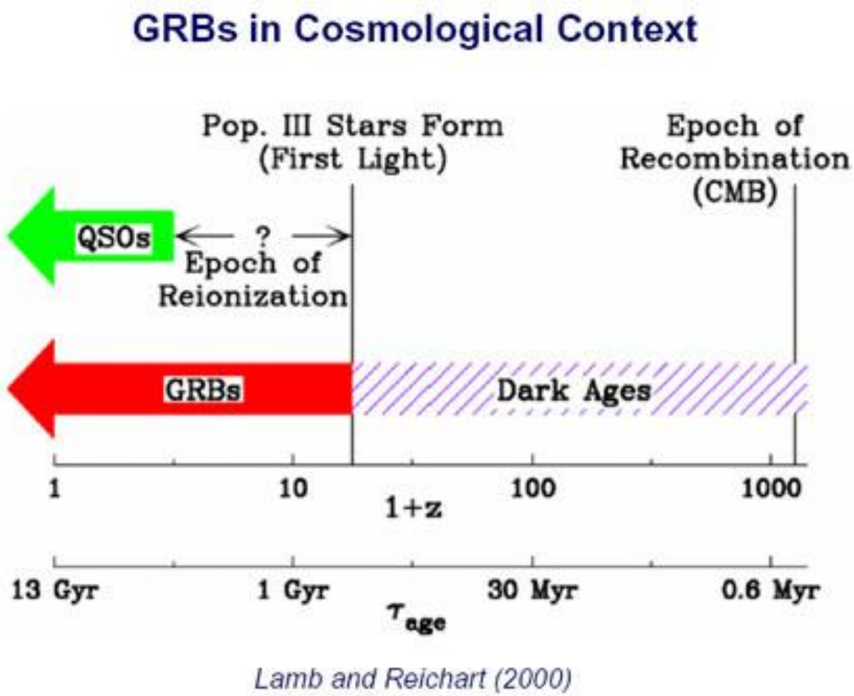
Expansion via Stellar Cataclysms I

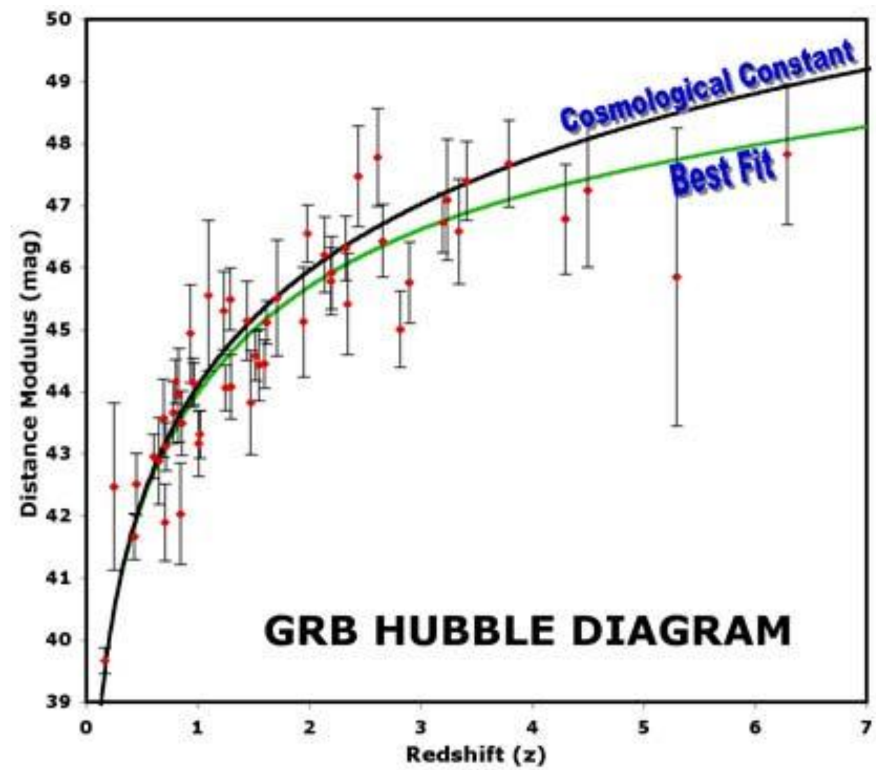


(Kirshner 2003)



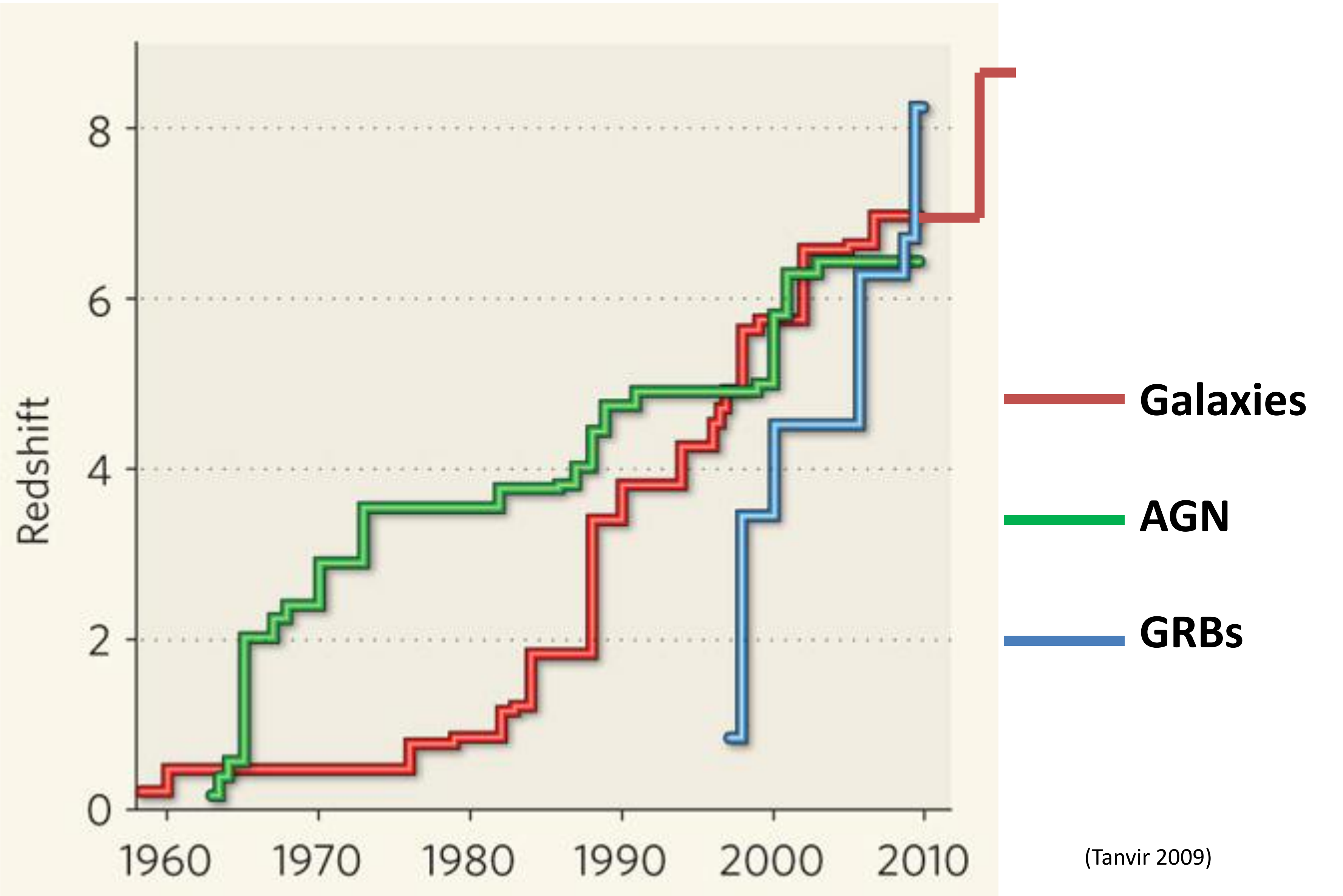
Expansion via Stellar Cataclysms II





(Shaefer 2011)

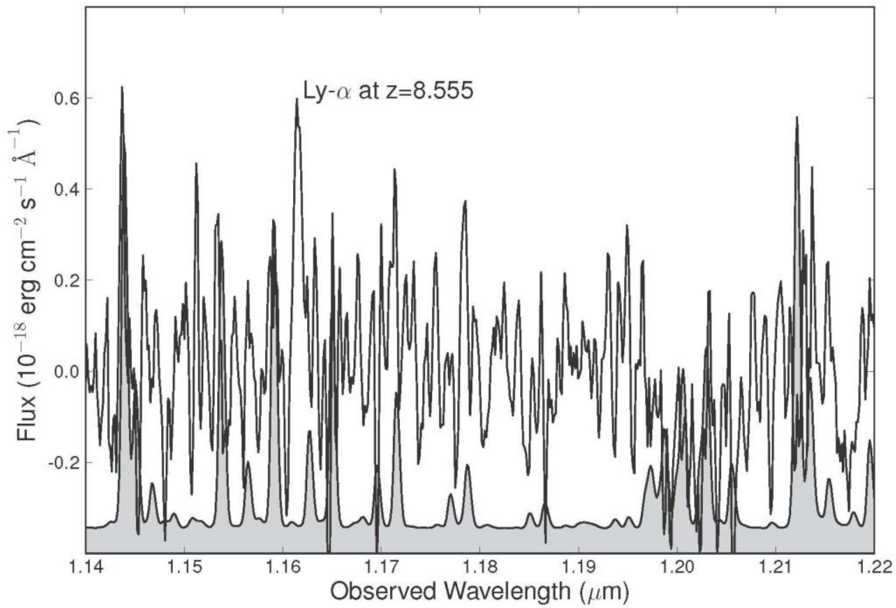
Redshift Records



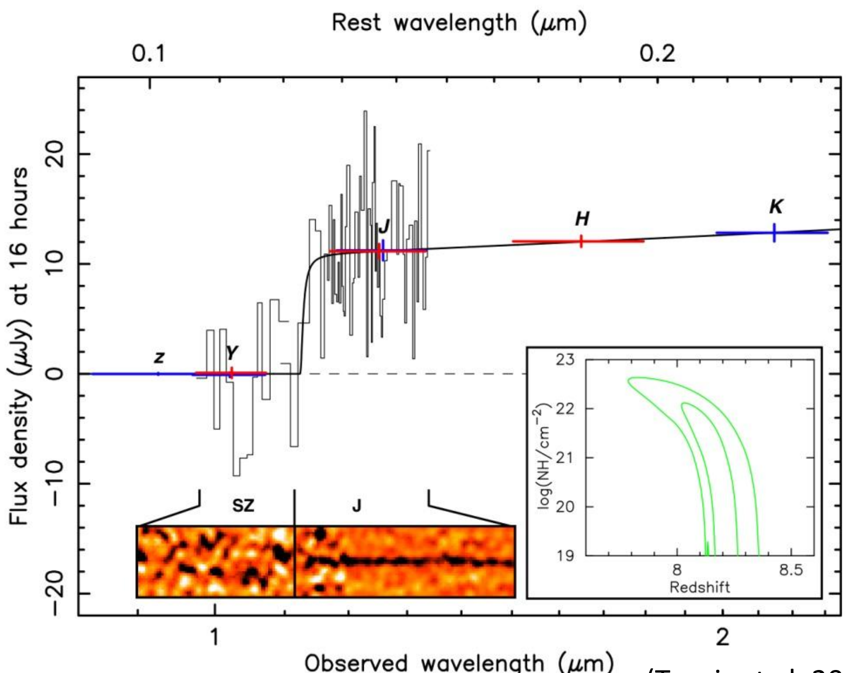
(Tanvir 2009)

Highest Redshifts:

Each took about 15 hours on the 8m VLT

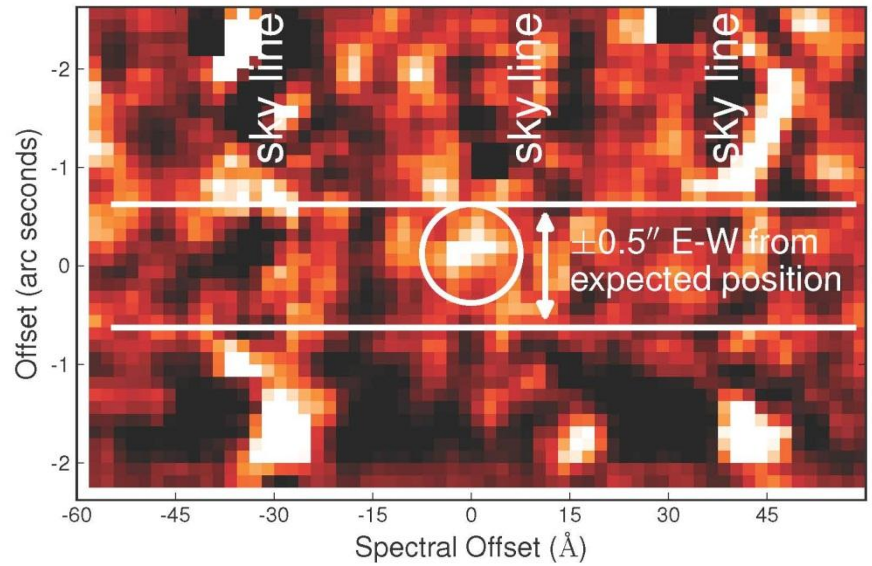


GRB at z = 8.3



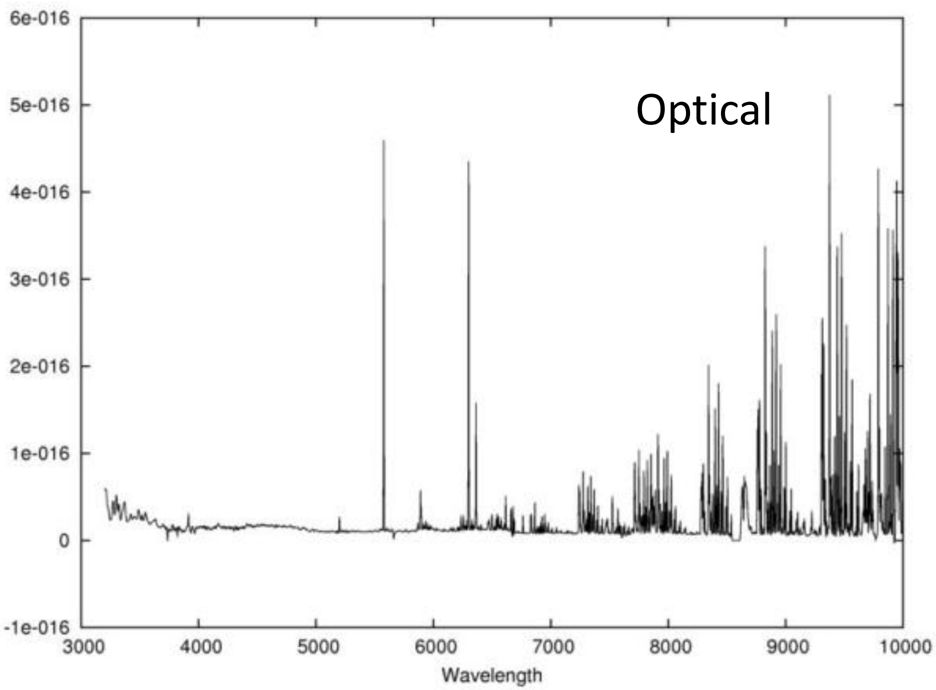
(Tanvir et al. 2009)

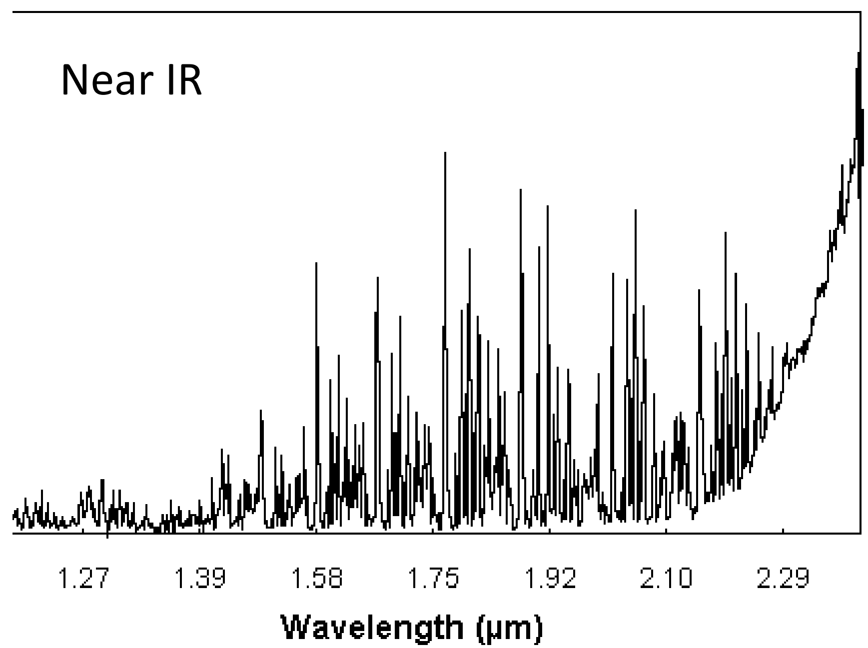
Galaxy at z = 8.6



(Lehnert et al. 2011)

Sky Spectrum



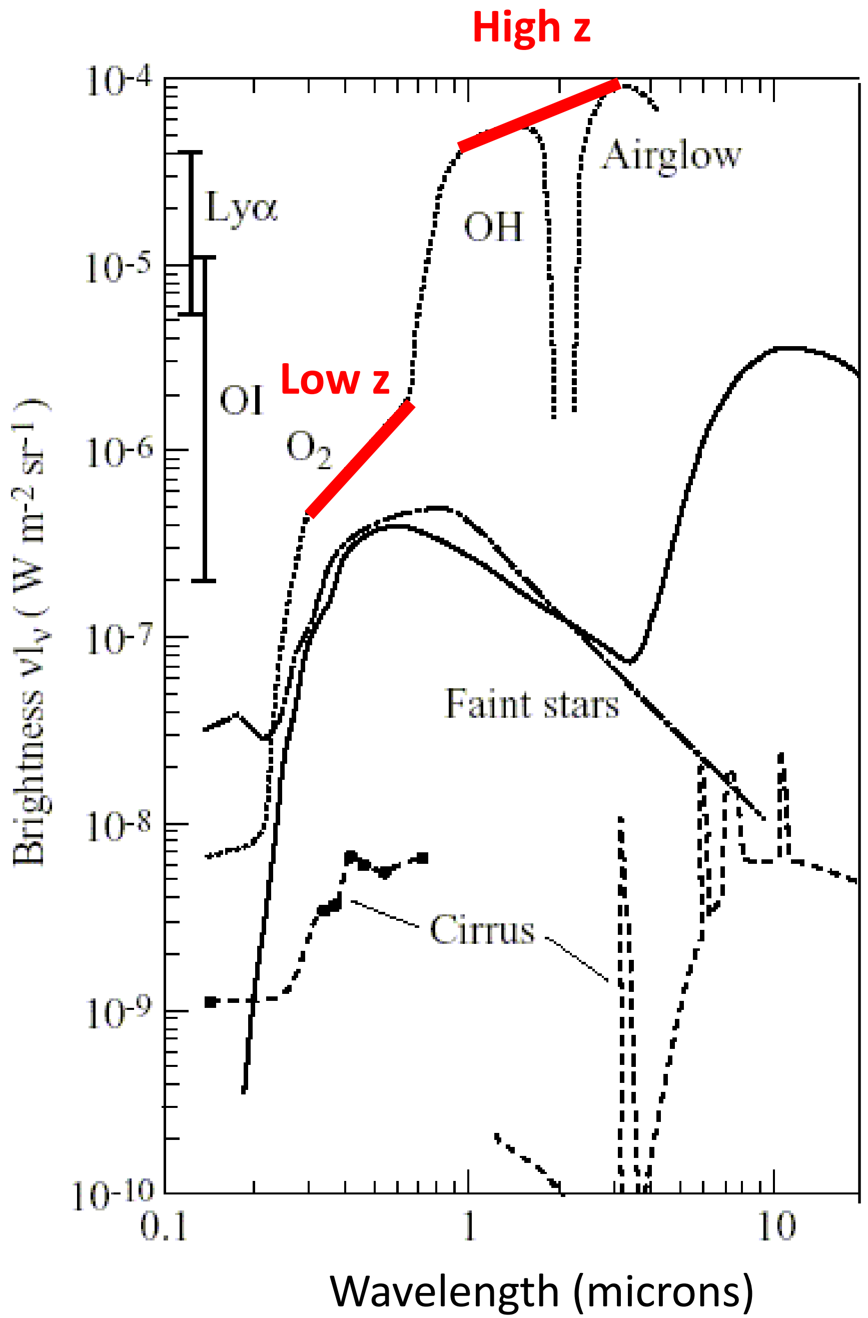


Galaxy features **z =1** **z = 2** **z = 3** **z = 4**

Observing challenge:

For the highest redshift galaxies, only 1 in 10^{54} photons are collected using a 10m telescope.

That's 50 photons per second at R = 25, with 1000 times more light coming from night sky.



Photons from the Dawn of Time

Hubble Lectures Colleagues On His Many Accomplishments