



**Discovery of Primeval Large-Scale
Structures with Forming Clusters at
Redshift $z=5.7$**

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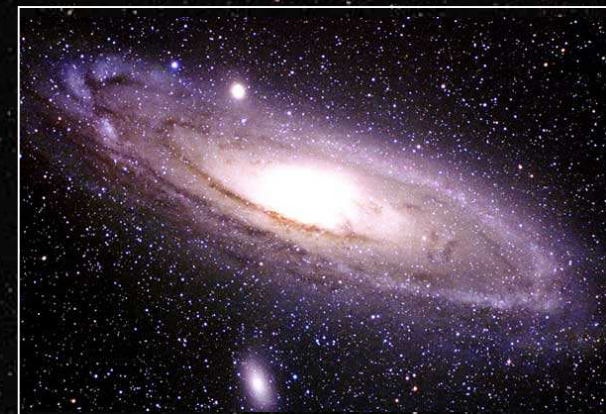
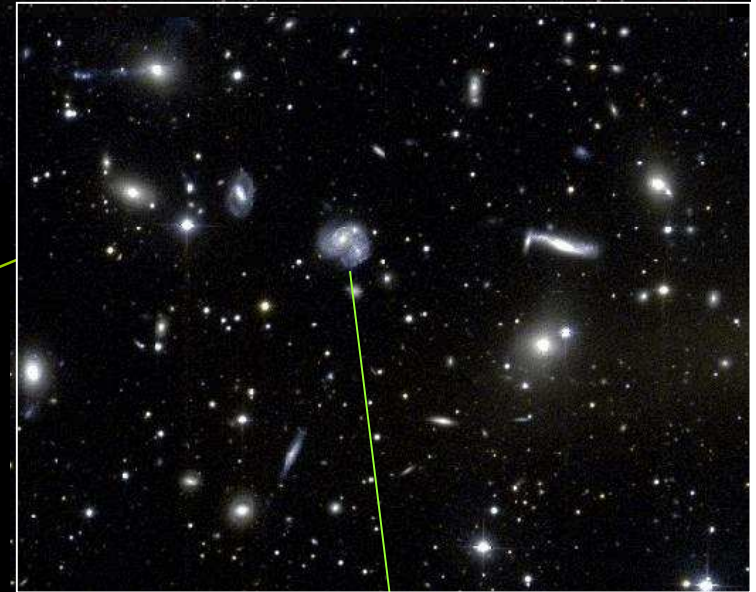
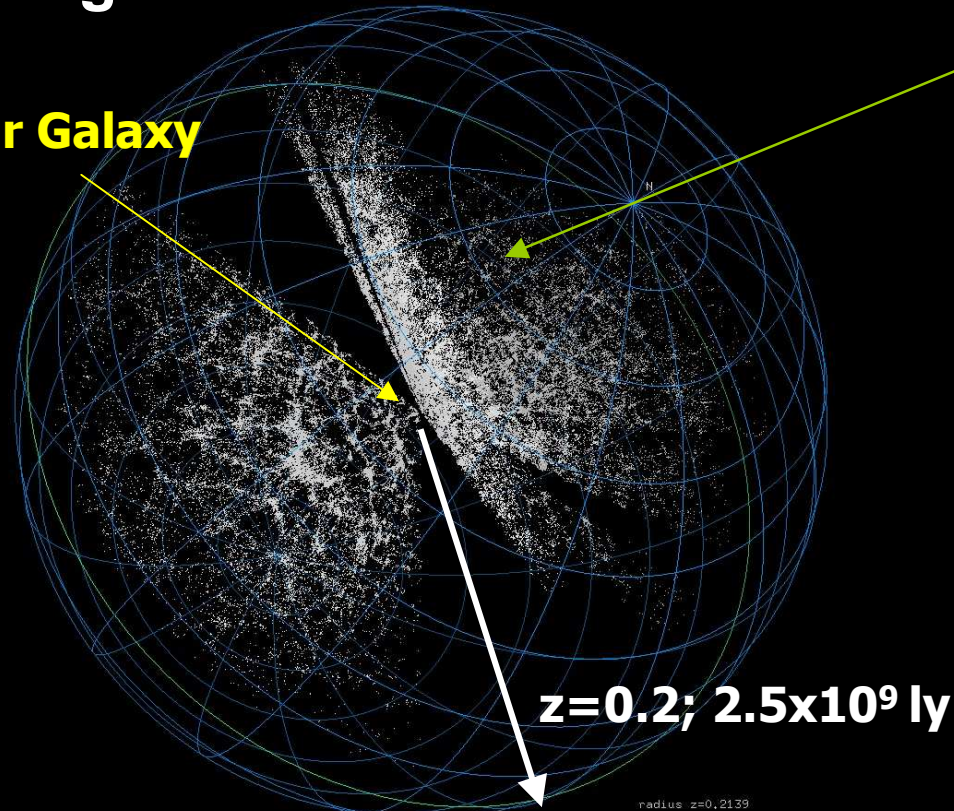
Collaborators

- **K. Shimasaku, M. Ouchi, M. Yoshida (U.Tokyo)**
- **Suprime-Cam Team (U.Tokyo + NAOJ)**
- **Subaru Deep Field (SDF) Collaboration**
- **Subaru XMM-Newton Deep Field (SXDF)
Collaboration**
- **Tohoku University Group**

Universe of Galaxies

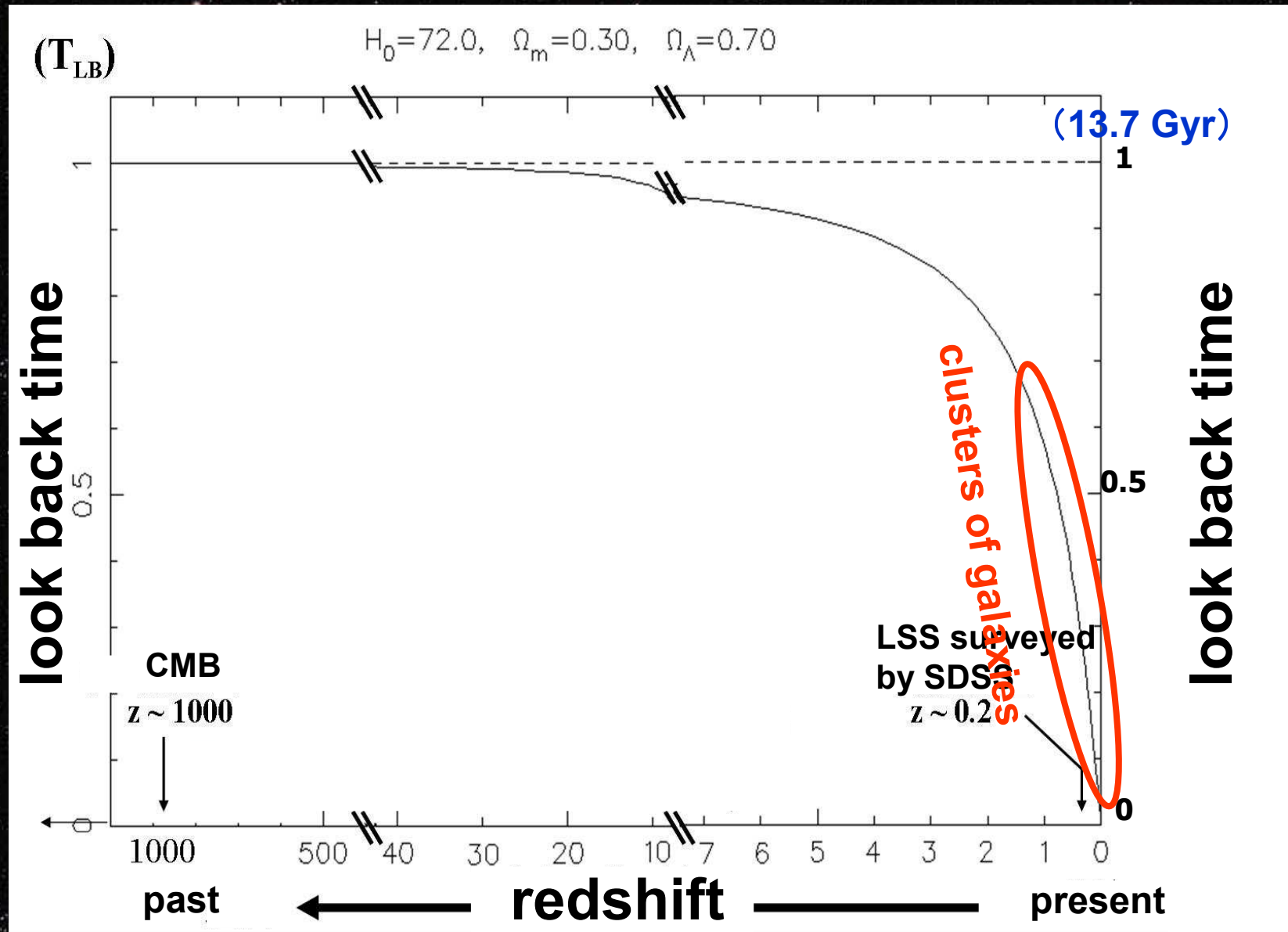
- Universe is composed of galaxies (rather than stars)
- Distribution of galaxies shows large scale structures

Our Galaxy

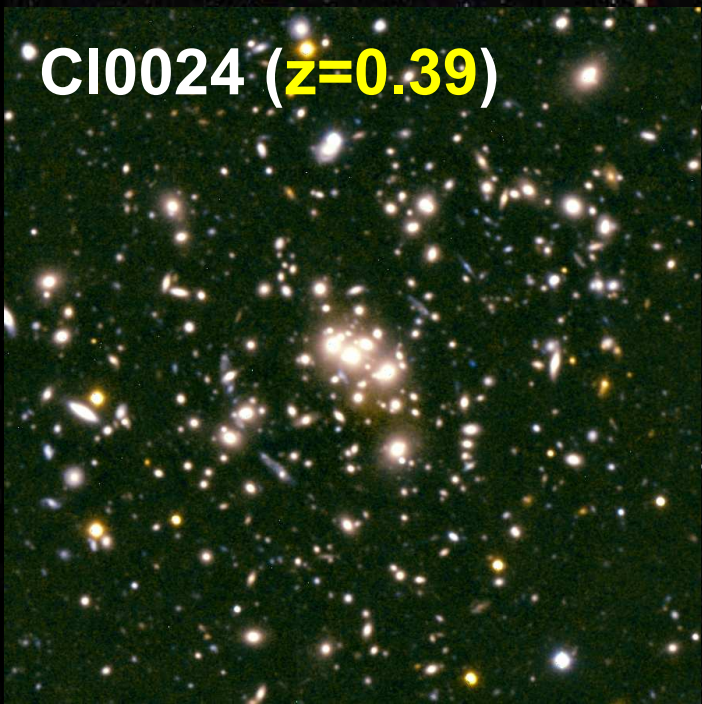


Cosmic Map by Sloan Digital Sky Survey
(distribution of galaxies up to $z=0.2$)
Courtesy: K.Mitsuhashi (U.Tokyo)

Redshift versus Look Back Time

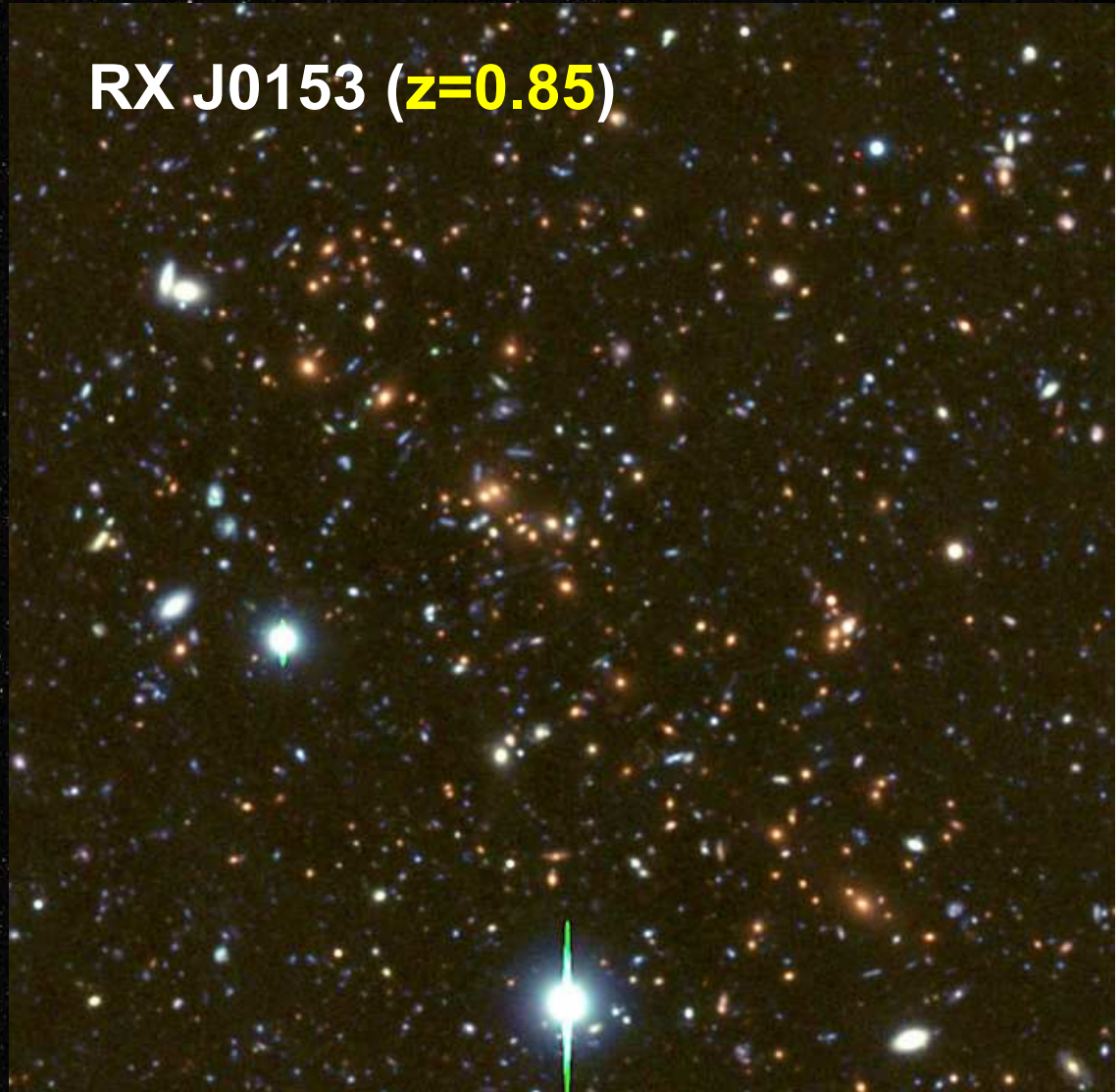


Cl0024 ($z=0.39$)

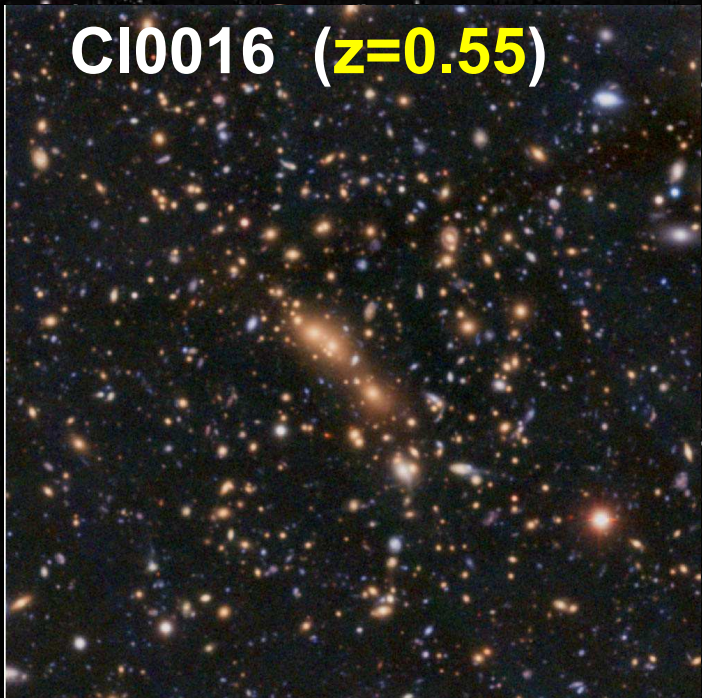


Subaru Gallery of **Distant** Clusters

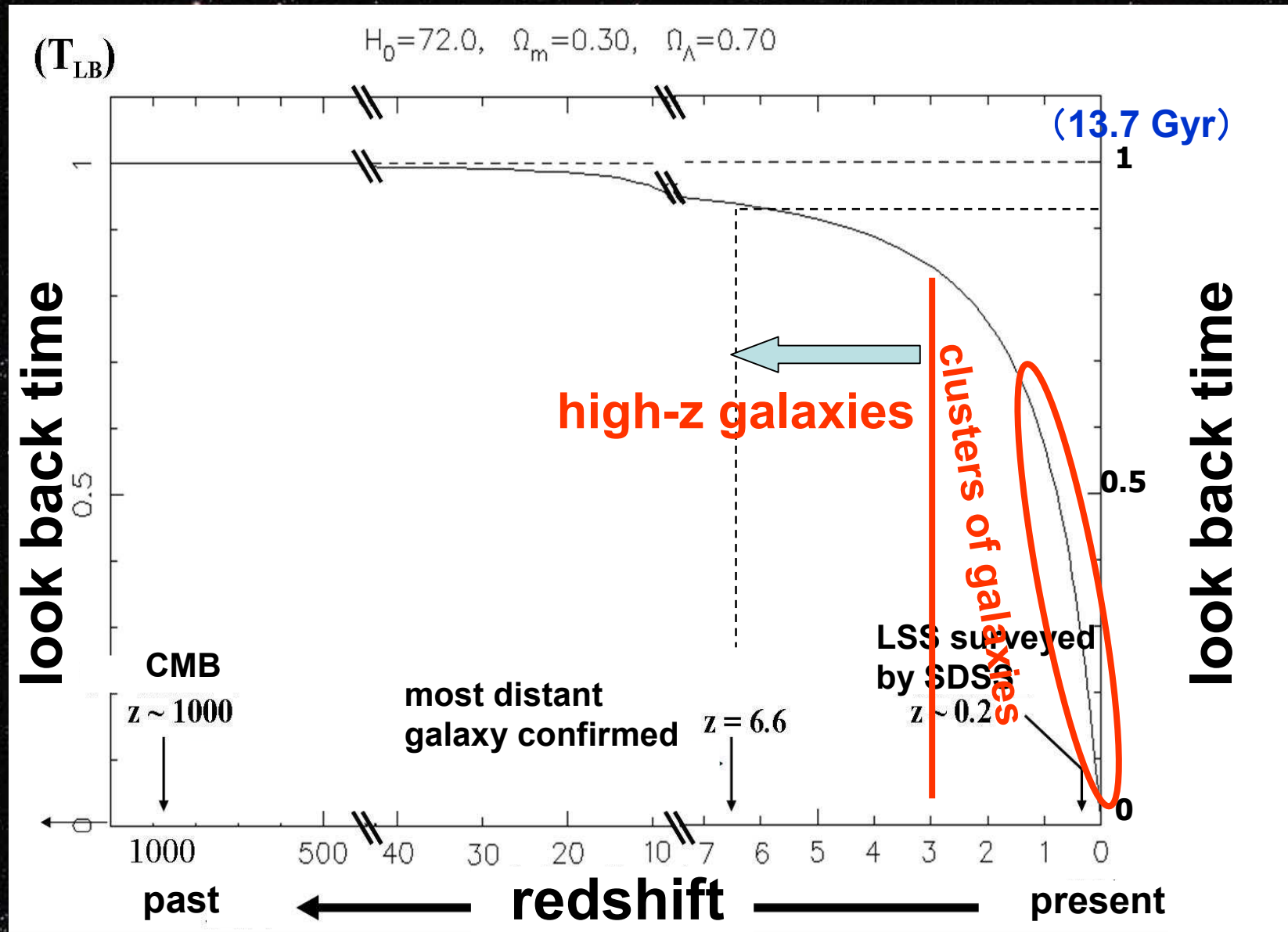
RX J0153 ($z=0.85$)



Cl0016 ($z=0.55$)



Redshift versus Look Back Time



High Redshift ($z>3$) Galaxies

Lyman Break Galaxies (LBGs)

Lyman Alpha Emitters (LAEs)

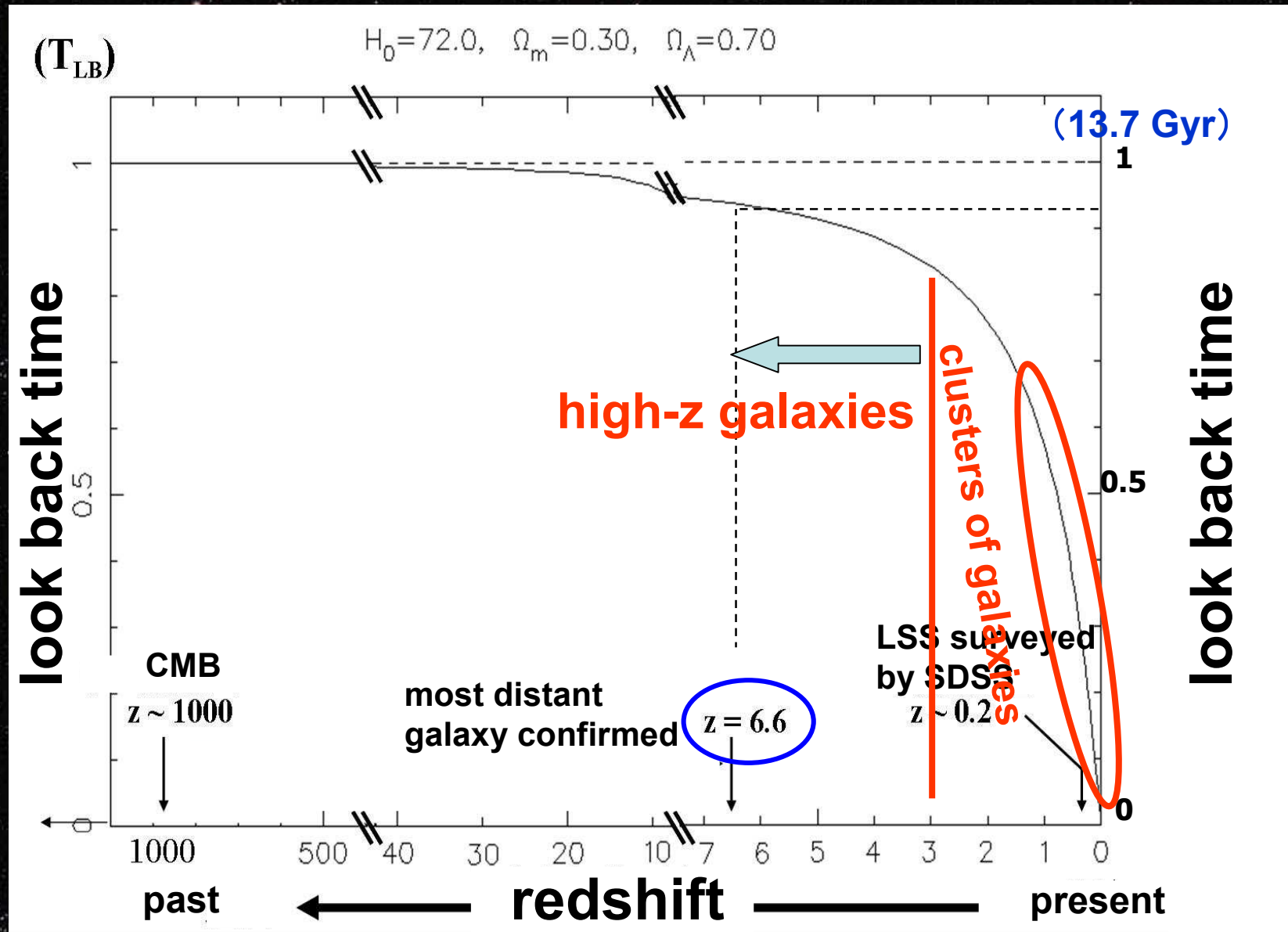


- Not classified by their nature,
but by the technique to identify them

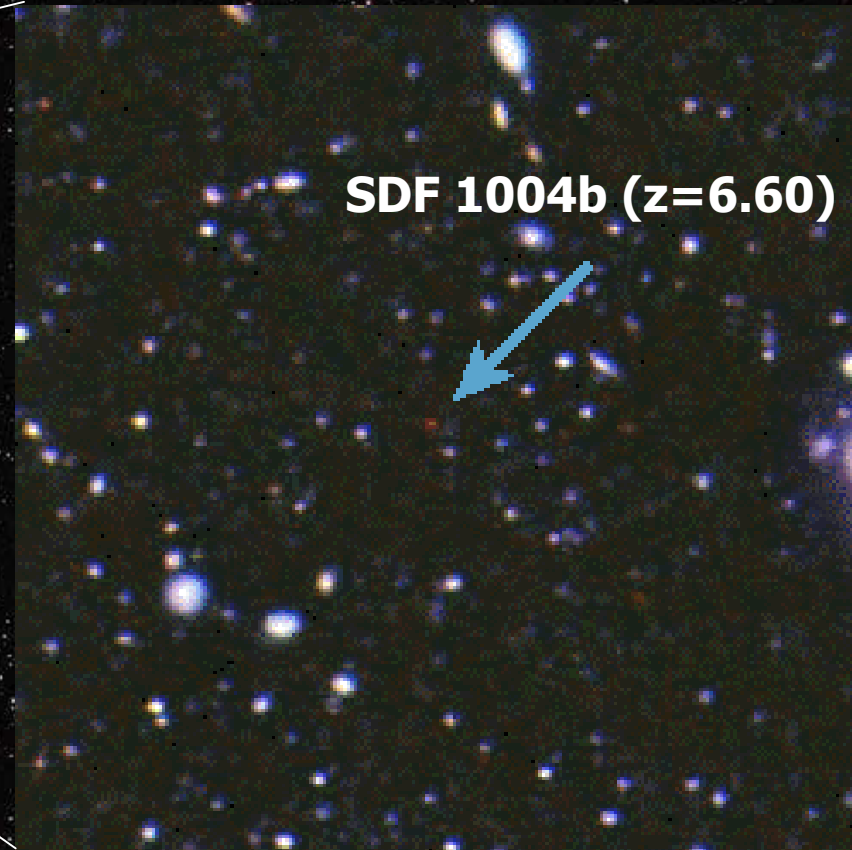
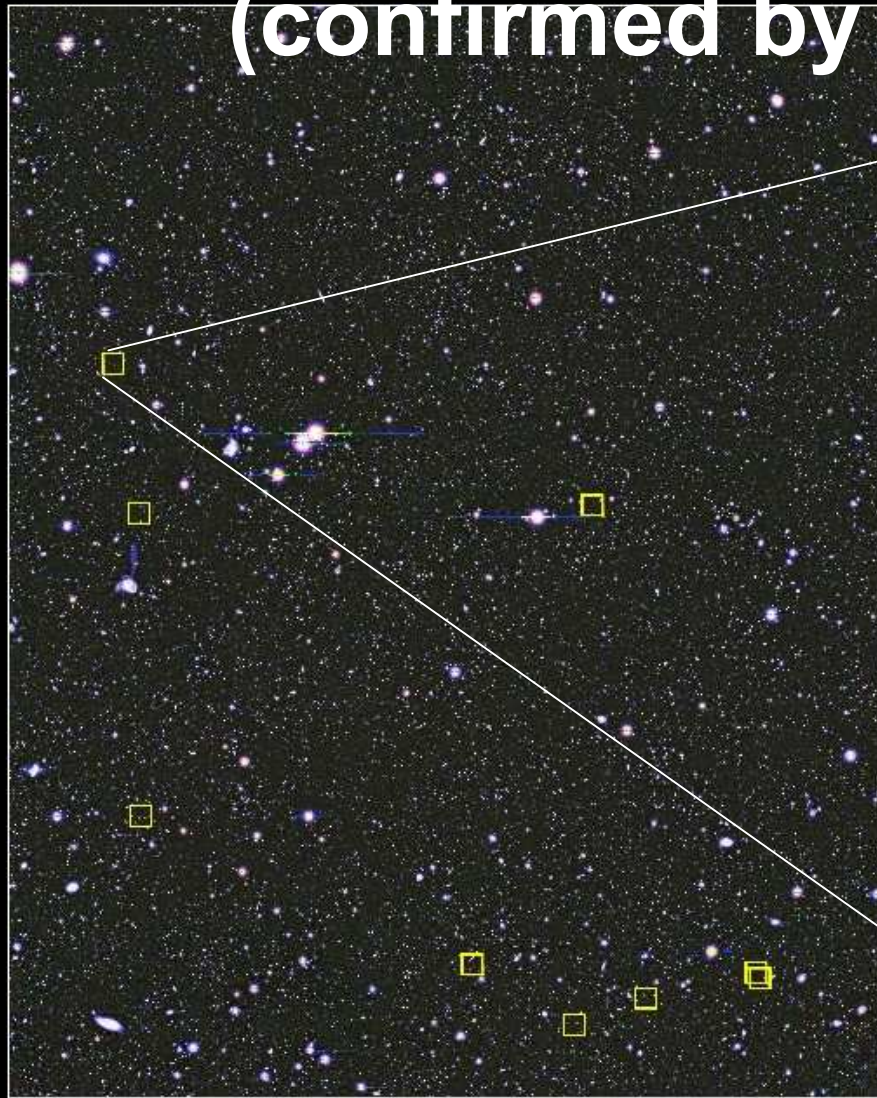
Their nature, morphology, relation to present-day galaxies are not known yet.

(Both are actively star-forming galaxies)

Redshift versus Look Back Time



Most Distant Galaxy Known (confirmed by spectroscopy)



**12.8 Gyrs ago
(0.9 Gyrs after big bang)**

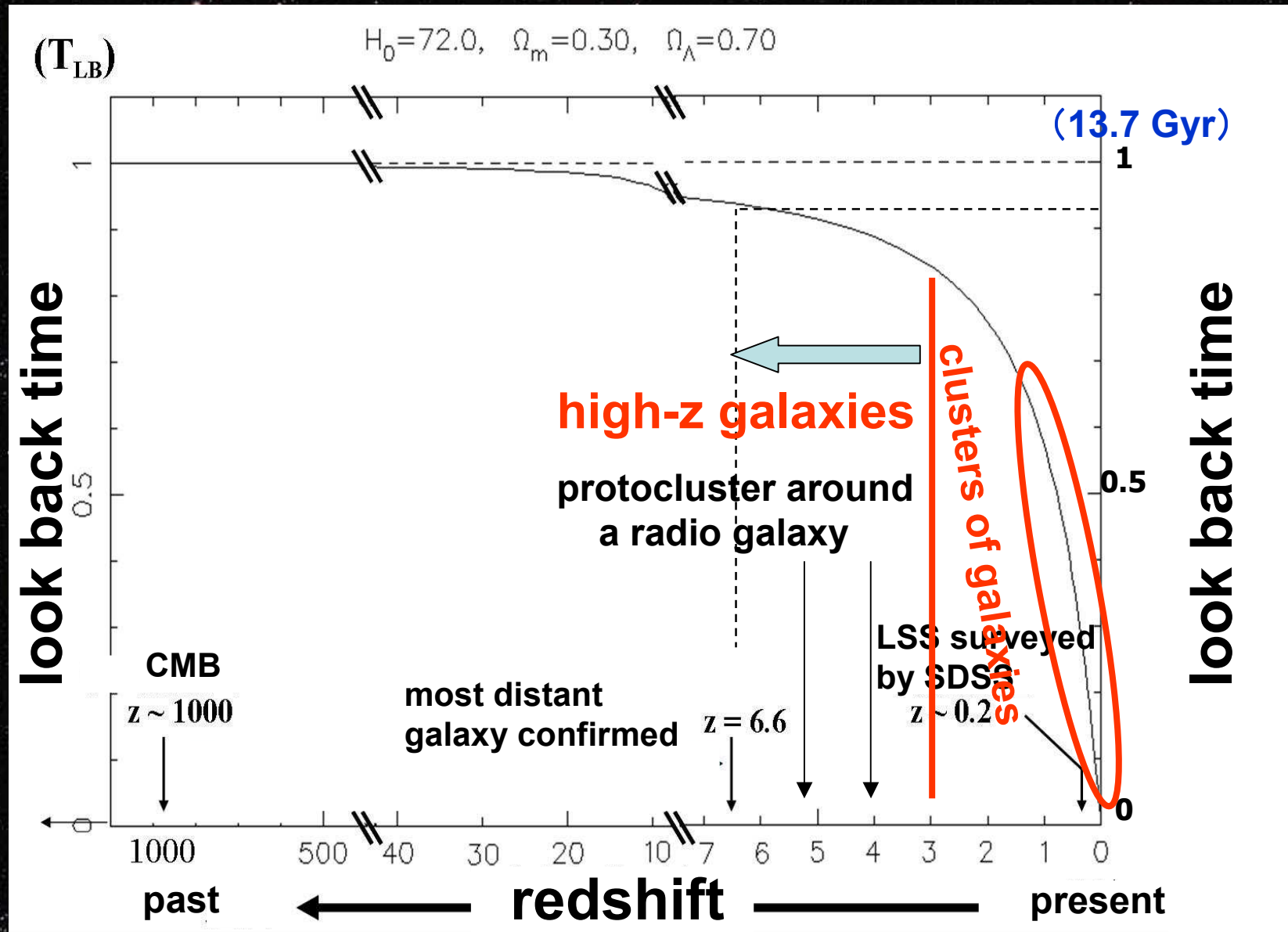


Subaru Deep Field: The Most Distant Galaxy Known
Suprime-Cam (i' , z' , 921 nm)

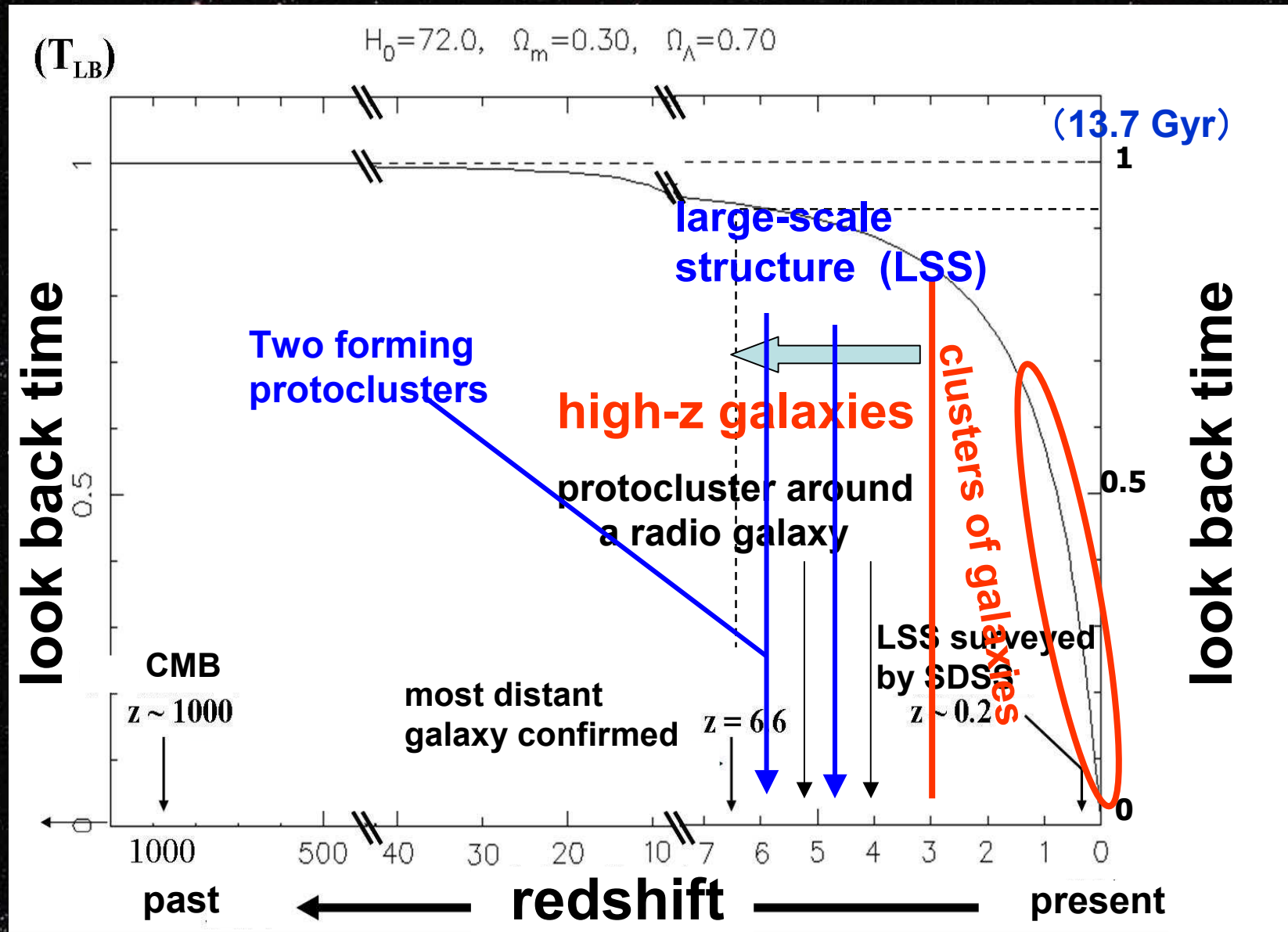
Subaru Telescope, National Astronomical Observatory of Japan March 20, 2003

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Redshift versus Look Back Time



Redshift versus Look Back Time



High Redshift ($z > 3$) Galaxies

Lyman Break Galaxies (LBGs)

Lyman Alpha Emitters (LAEs)



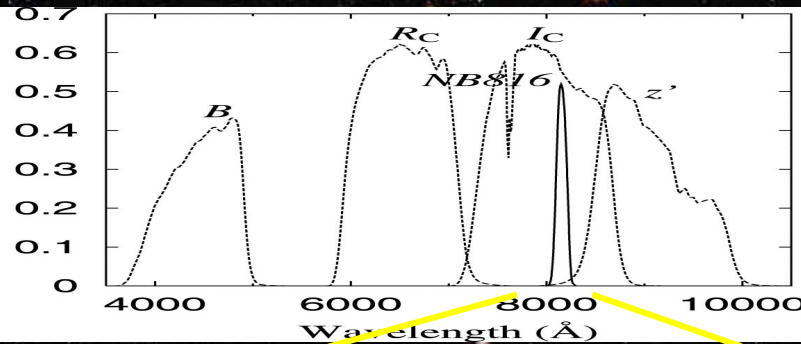
This talk

- Not classified by their nature,
but by the technique to identify them

Their nature, morphology, relation to present-day galaxies are not known yet.

(Both are actively star-forming galaxies)

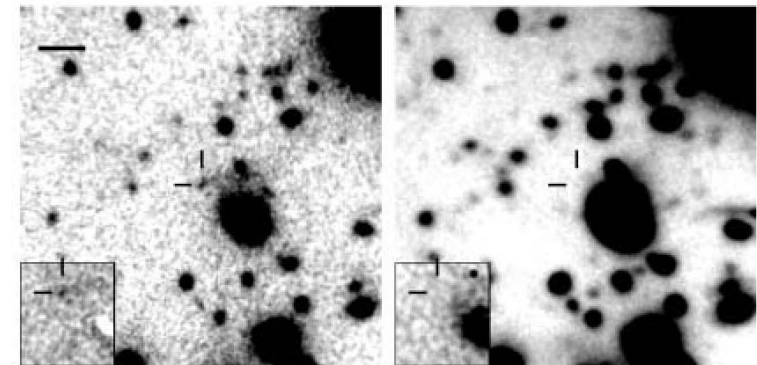
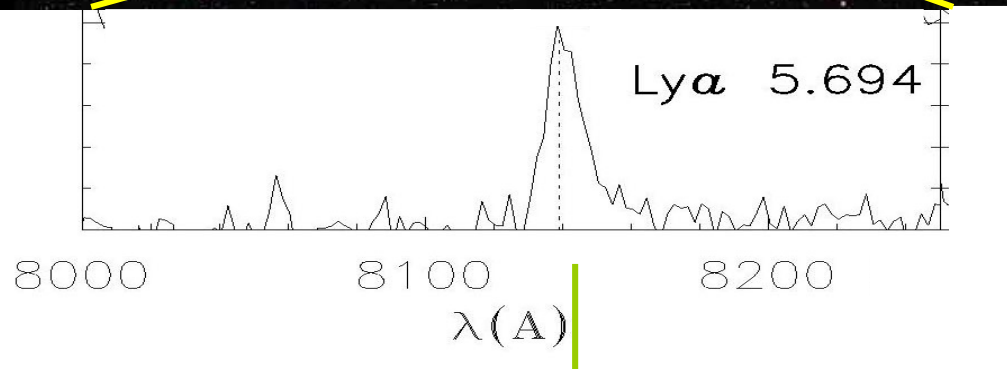
Lyman Alpha Emitters: LAEs



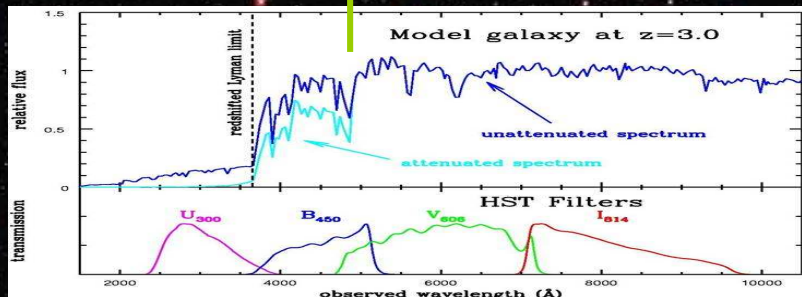
Actively star-forming
(small?) galaxies

A $z=6.56$ galaxy (LAE)

NB 912 image R band image



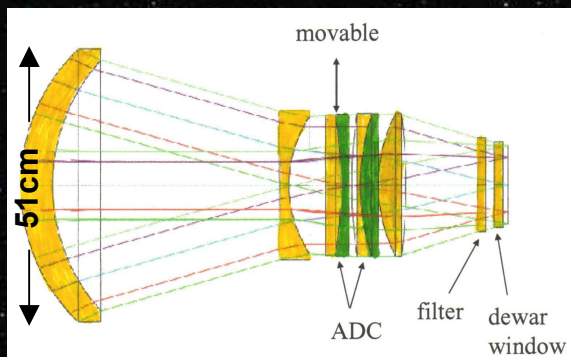
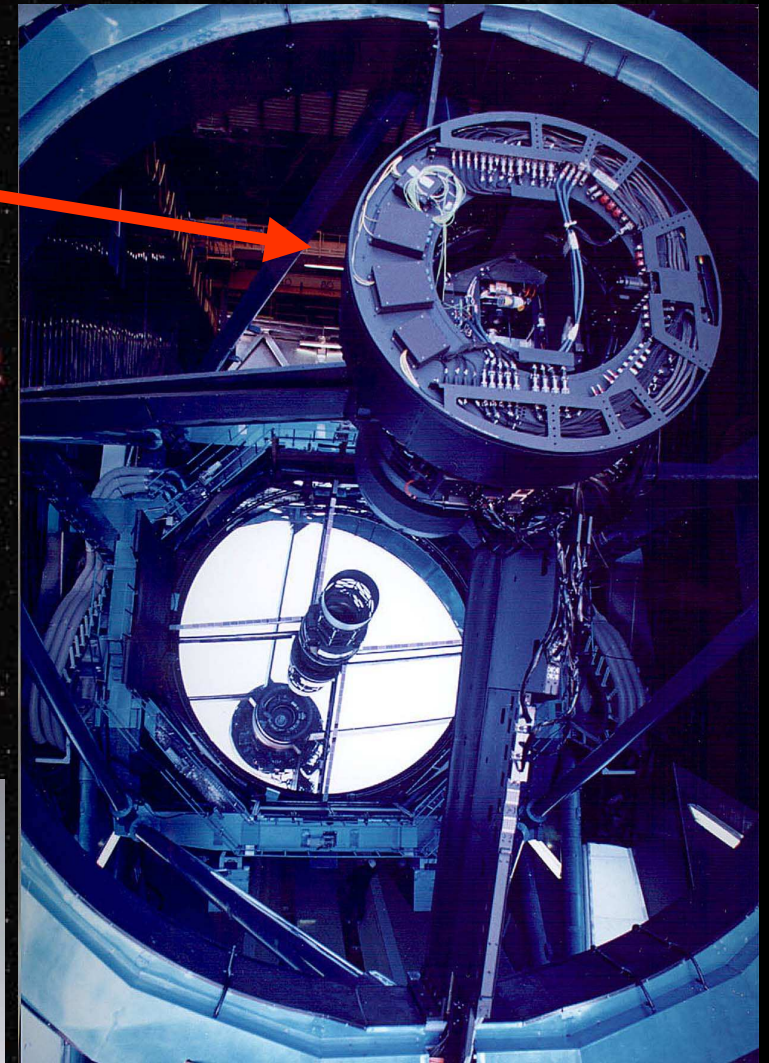
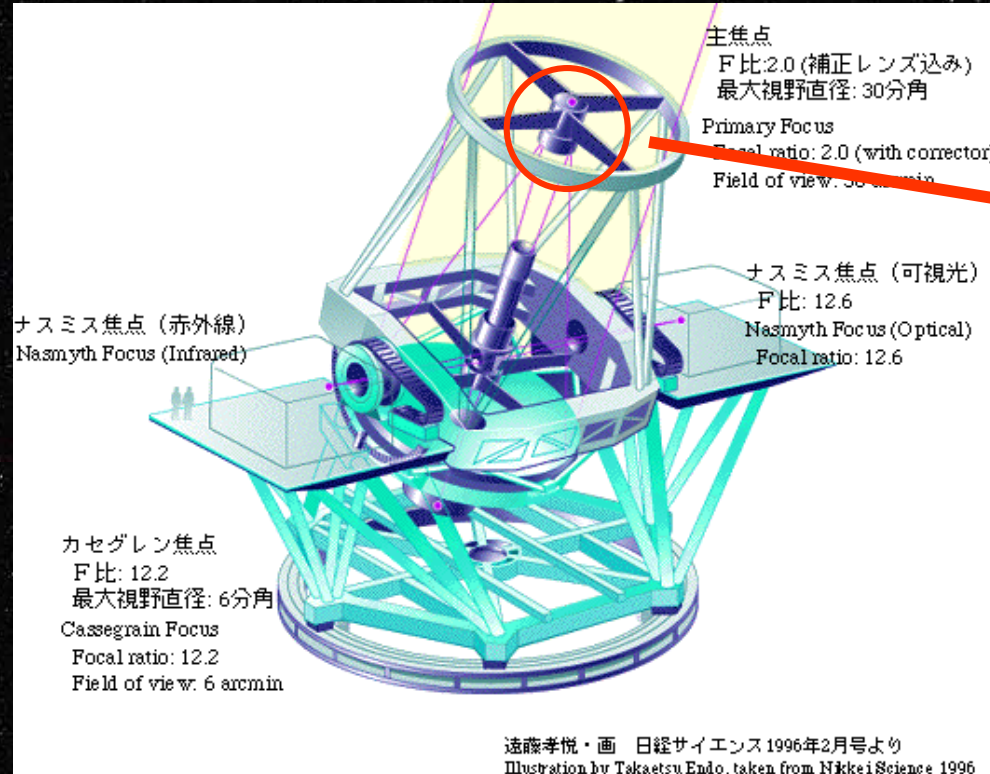
(Hu et al. 2002, ApJ, 568, L75)



cf. Lyman Break Galaxies

Suprime-Cam (1)

(Subaru Prime Focus Camera)



国立天文台すばる望遠鏡 主焦点補正光学系 1999年5月12日完成



Suprime-Cam(2)

宇宙を捉える電子の眼

～すばる望遠鏡ファーストライトを担った観測装置～

Suprime-Cam

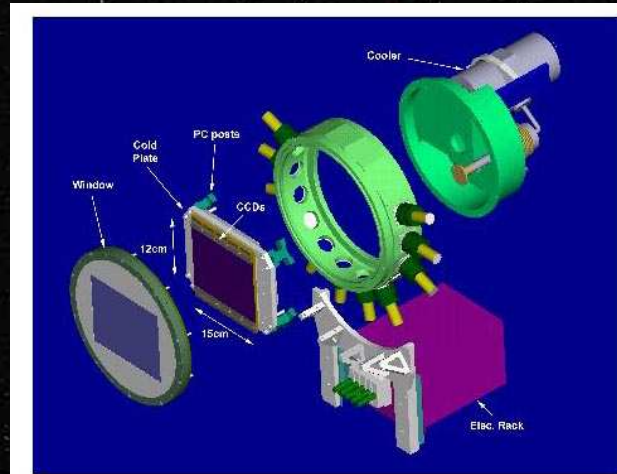
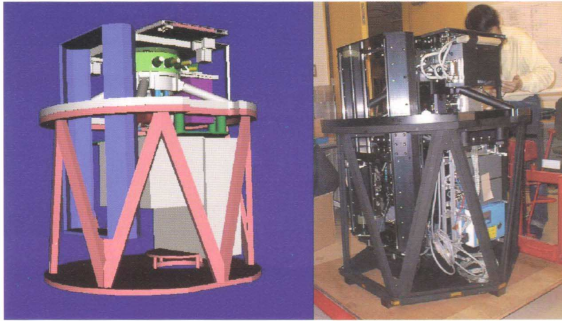
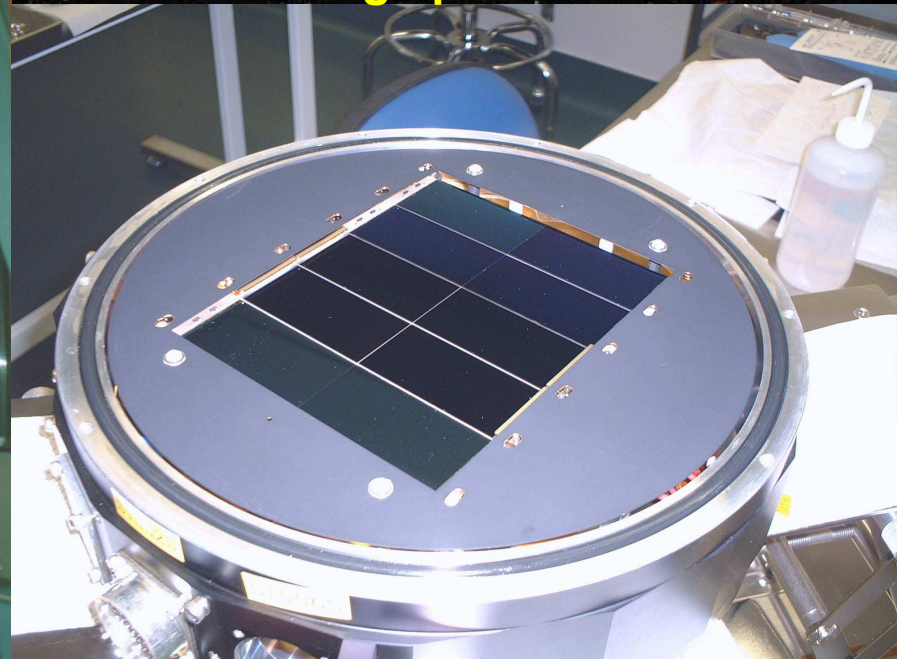
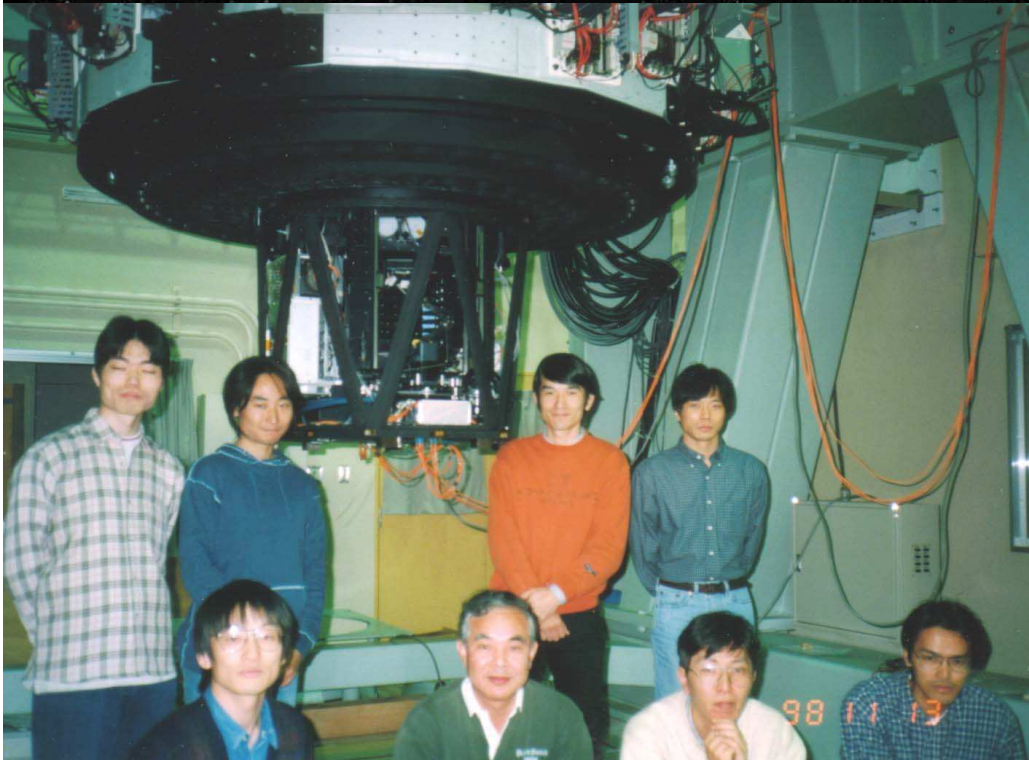

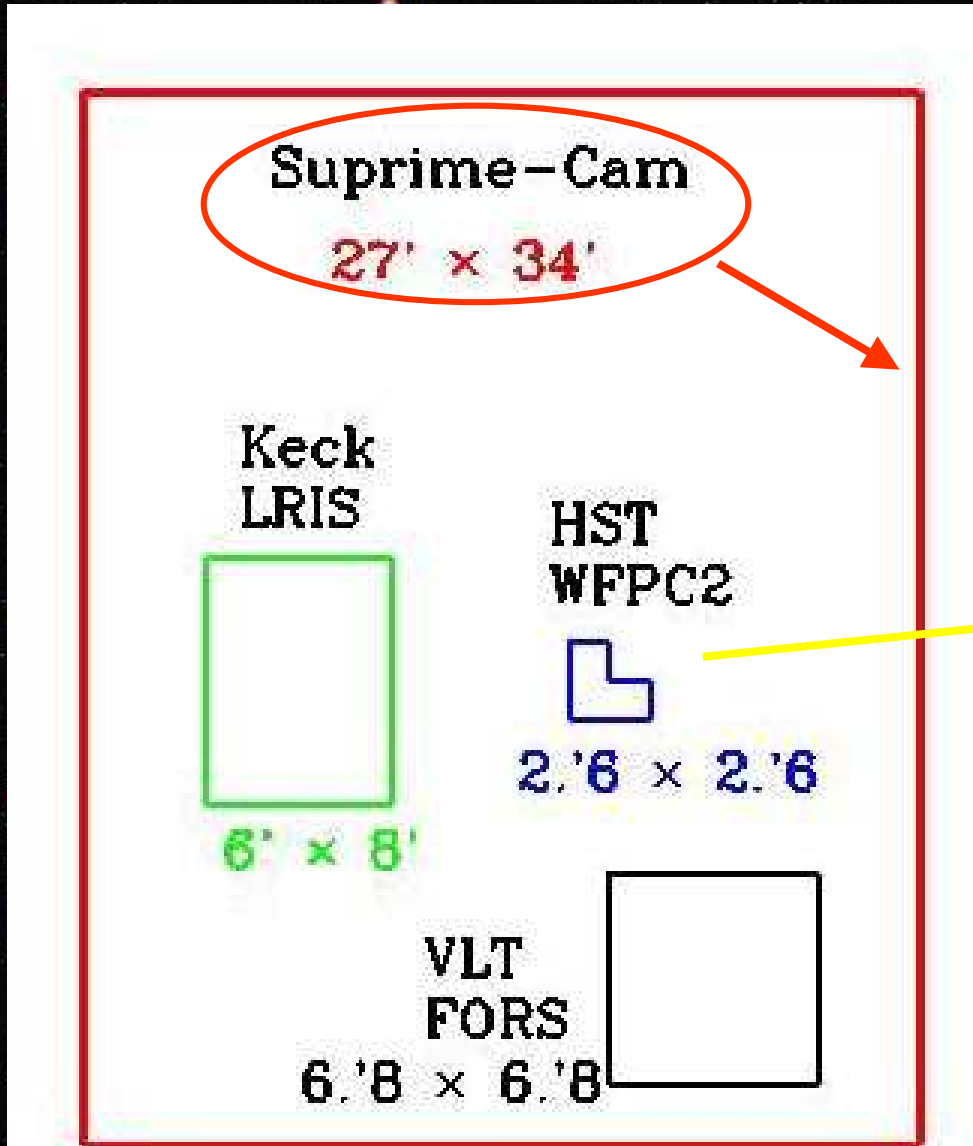


Fig. 9.— Exploded view of vacuum dewar of Suprime-Cam

2048x4096pixelsx10chips =
80 Mega pixels

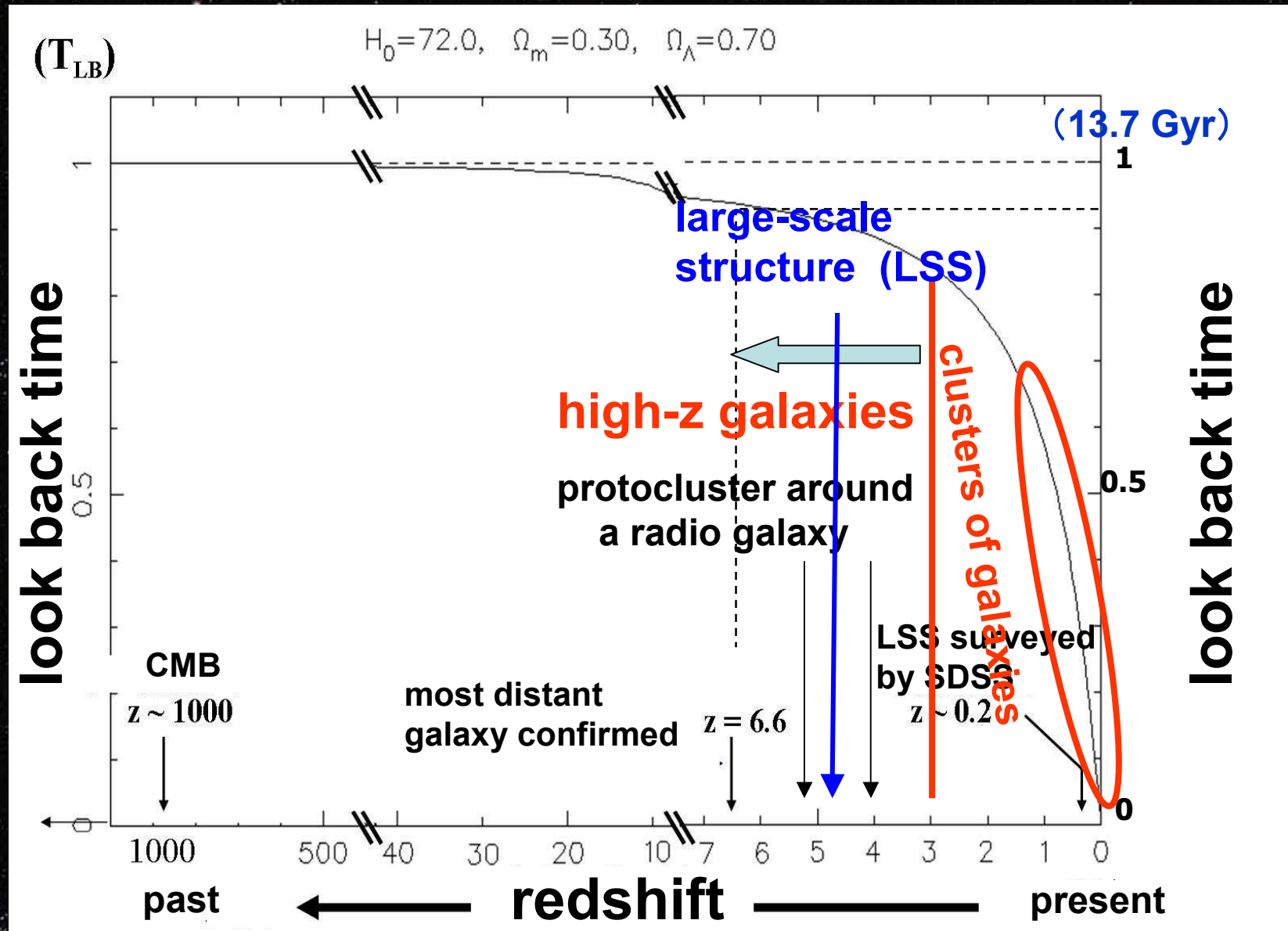


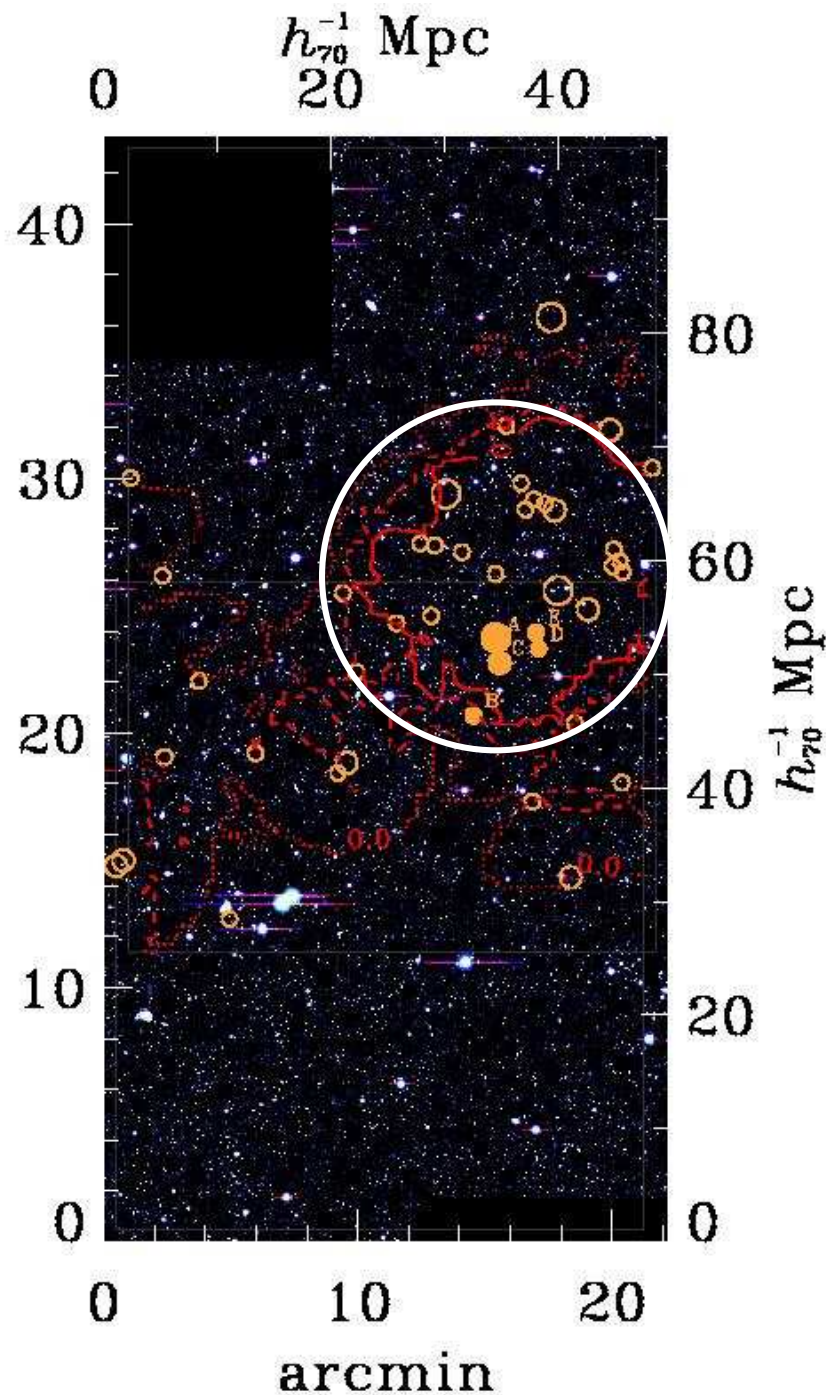
Comparison of Field of View



HST ACS
 $3.3' \times 3.3'$
(2002/3-)

Redshift versus Look Back Time





Large Scale Structure at $z=4.86$

**43 LAE candidates in SDF
(contamination $\sim 20\%$)**

Highly non-uniform

**Progenitor of a cluster?
Overdensity ~ 2**

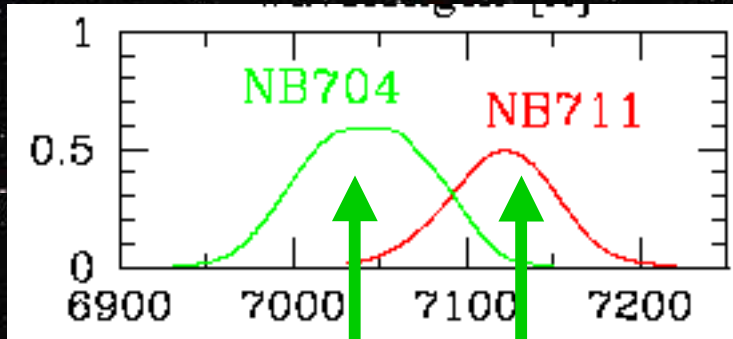


**Large bias between dark
matter and LAEs: $b \sim 6$**

(Shimasaku et al., 2003, ApJ, 586, L111)

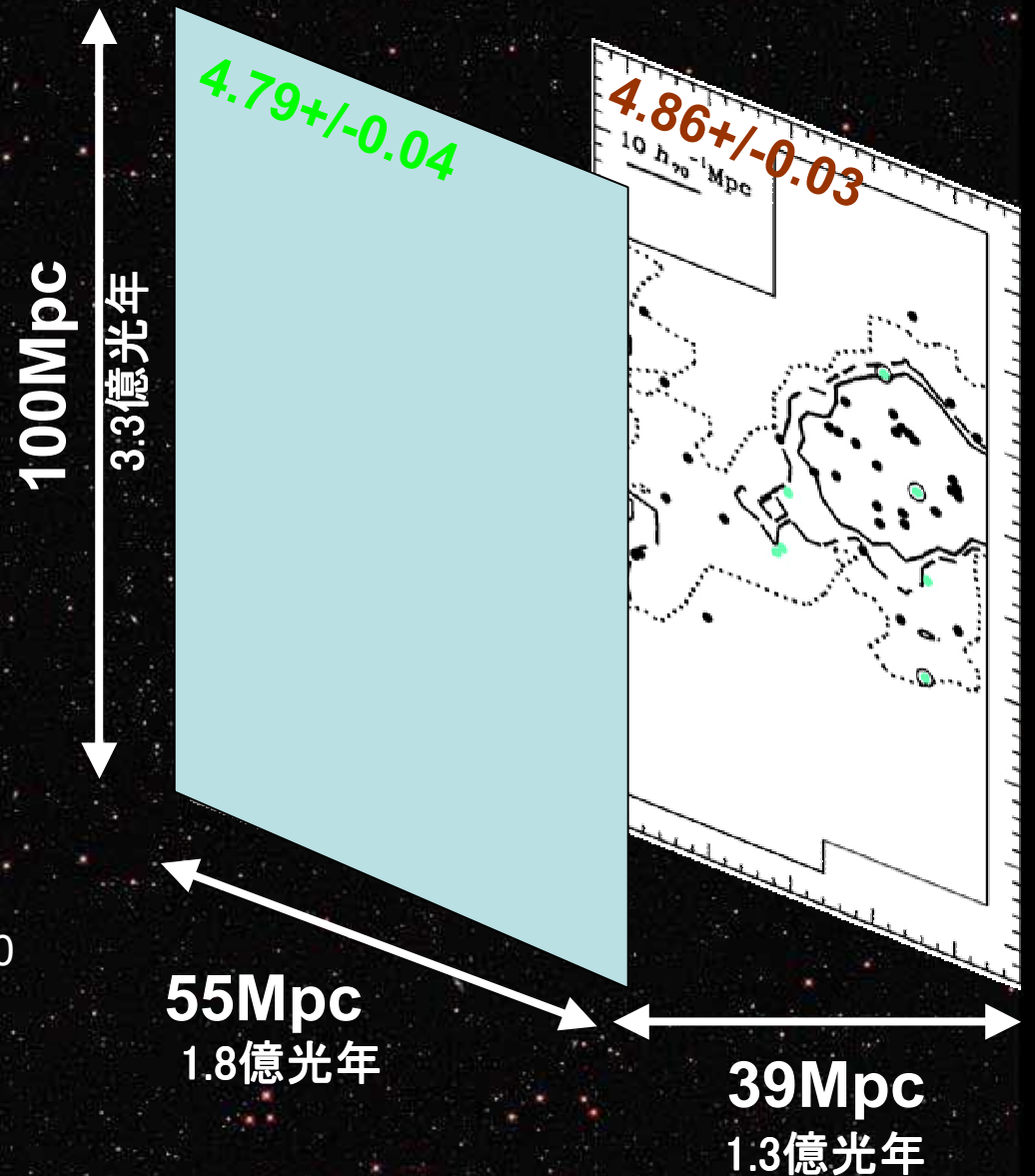
Large Scale Structure at $z \sim 5$

Two slices in the $z \sim 5$ universe



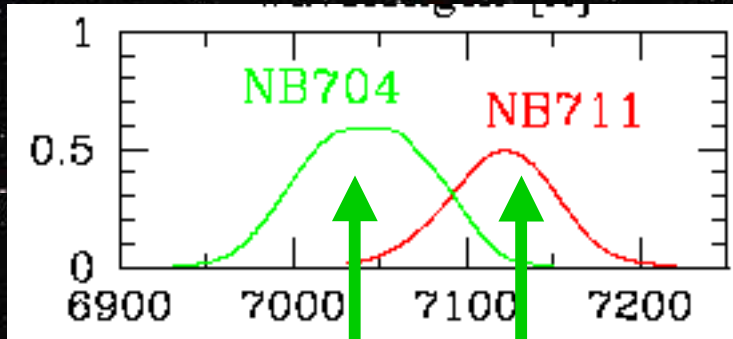
redshift: 4.79 ± 0.04 4.86 ± 0.03

$\Delta \text{ distance} = 40 \text{ Mpc}/h_{70}$



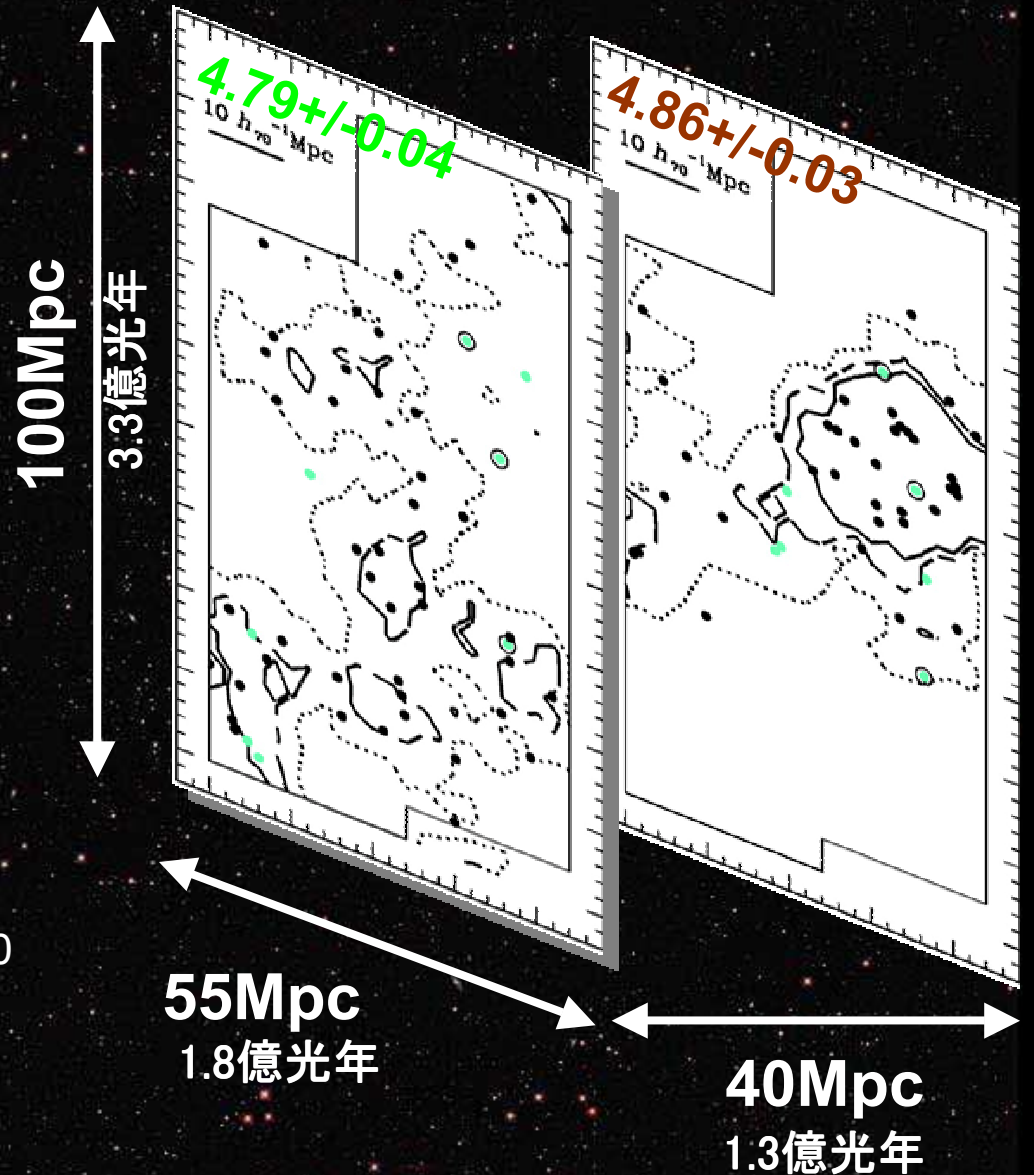
Large Scale Structure at $z \sim 5$

Two slices in the $z \sim 5$ universe

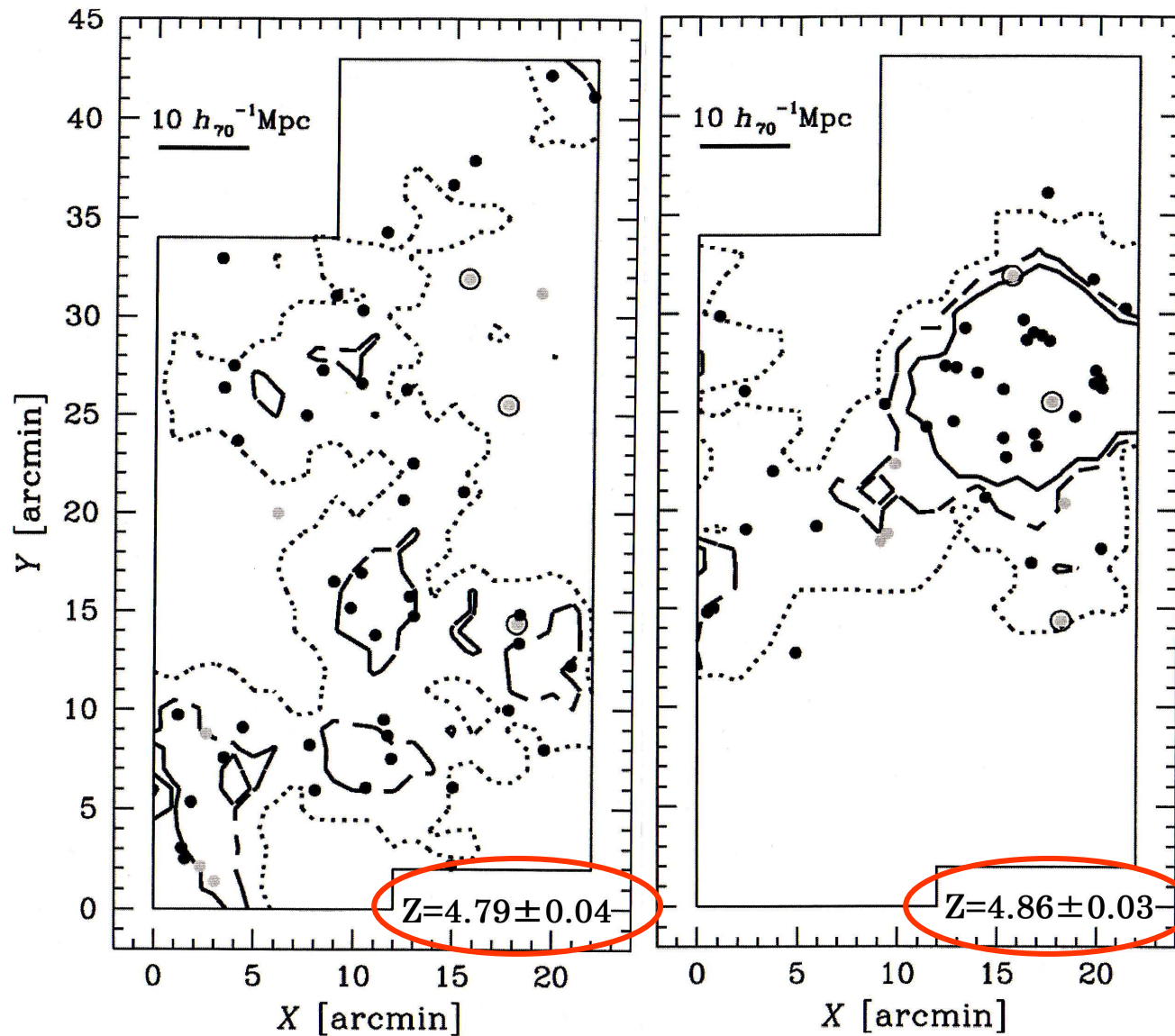


redshift: 4.79 ± 0.04 4.86 ± 0.03

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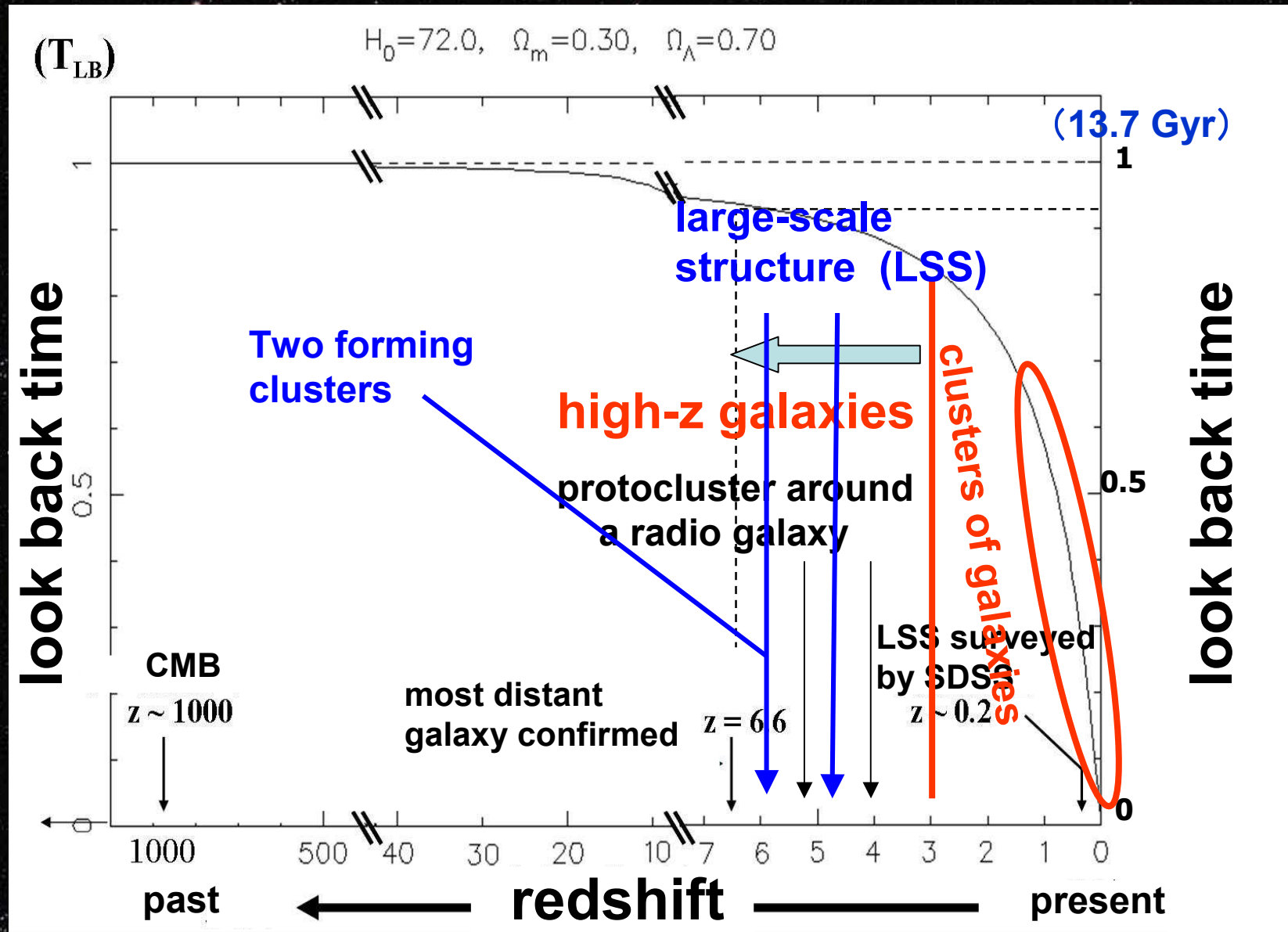
Distribution of LAEs in the Slices



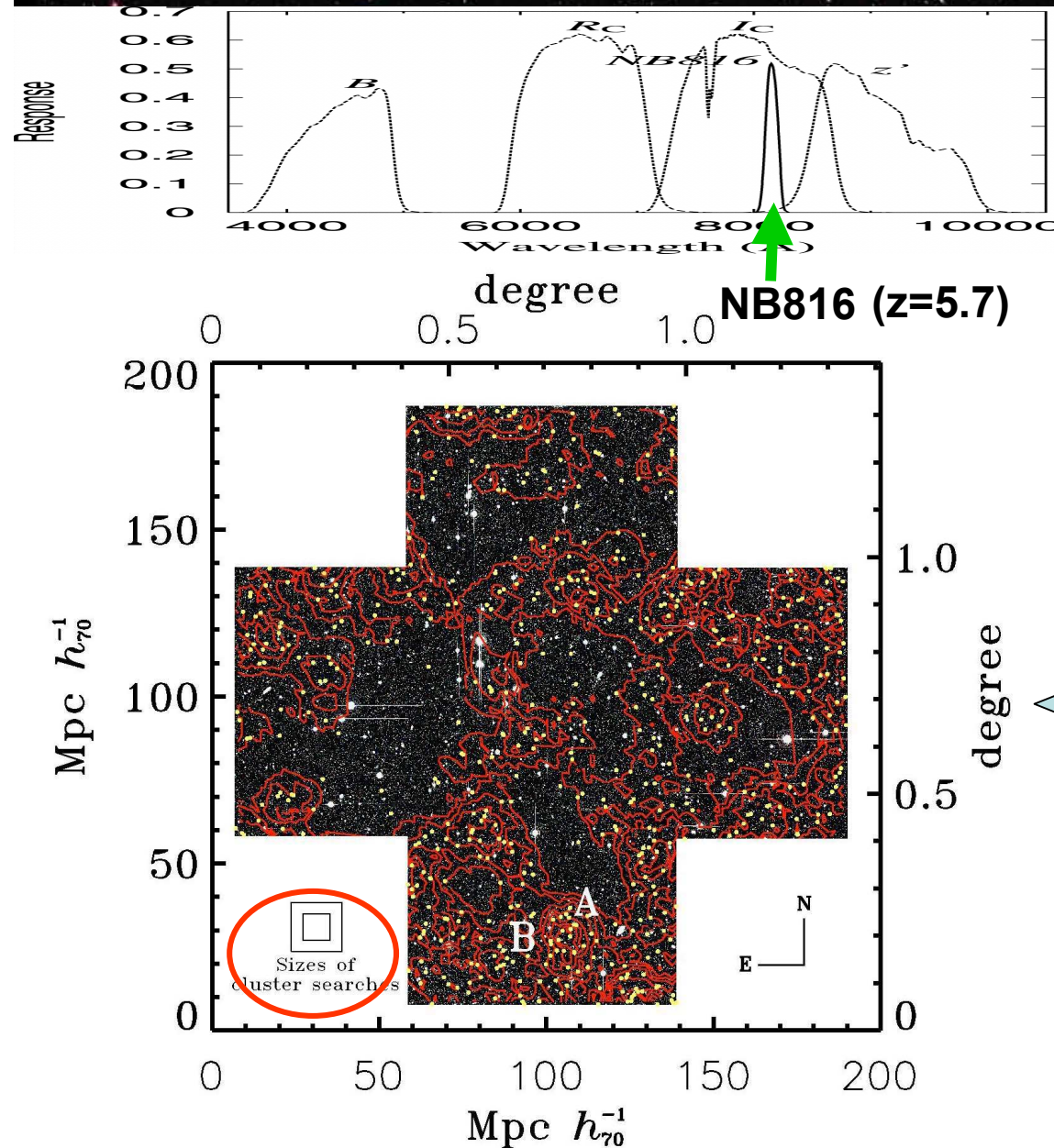
Shimasaku et al.
2004, ApJ, 605,
L93

**Large
Cosmic
Variance?**

Redshift versus Look Back Time



Large Scale Structure at $z=5.7$ (1)



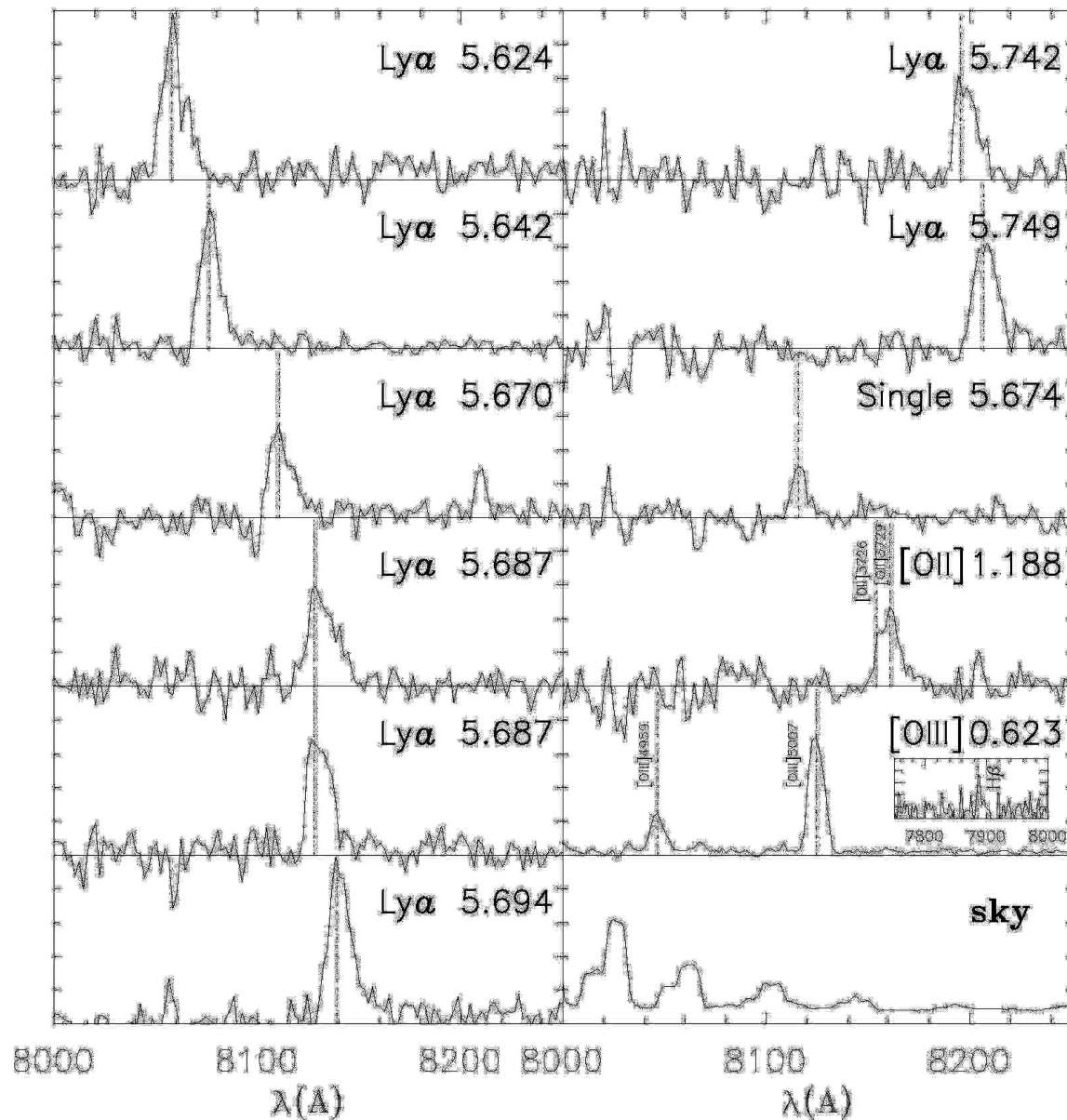
large area
(SXDF field)

515 candidates out of
305,012 objects
(contamination $\sim 30\%$)

**First map at $z > 2$
covering an
area larger than
100 Mpc.**

(Ouchi et al., 2005,
Ap.J., 620, L1)

Large Scale Structure at $z=5.7$ (2)



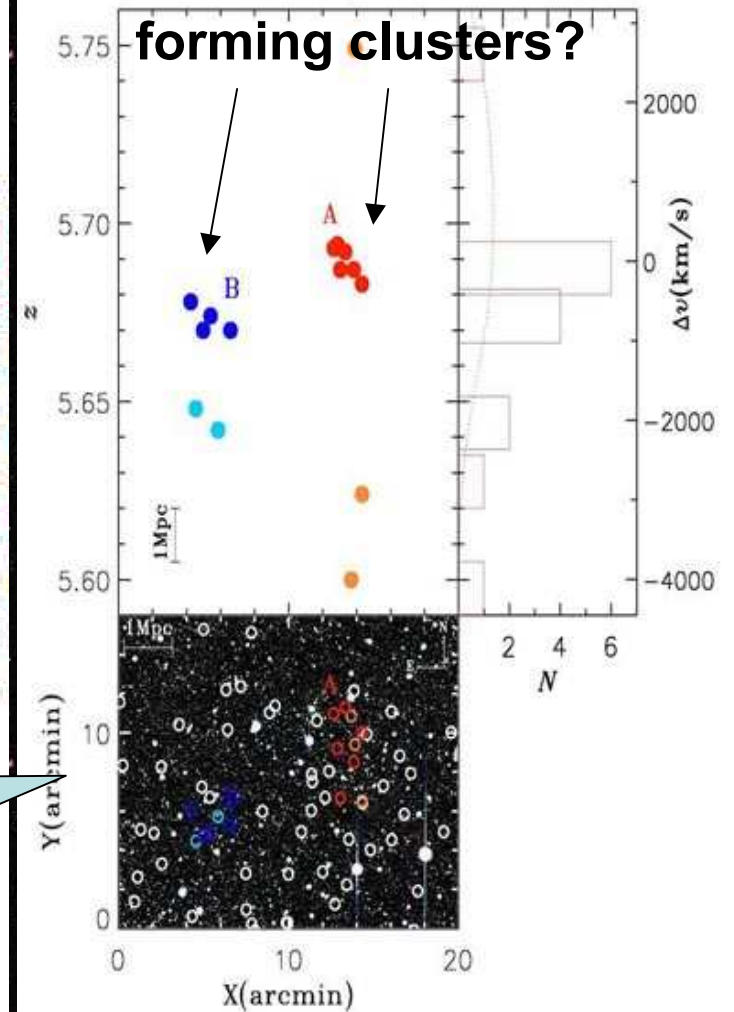
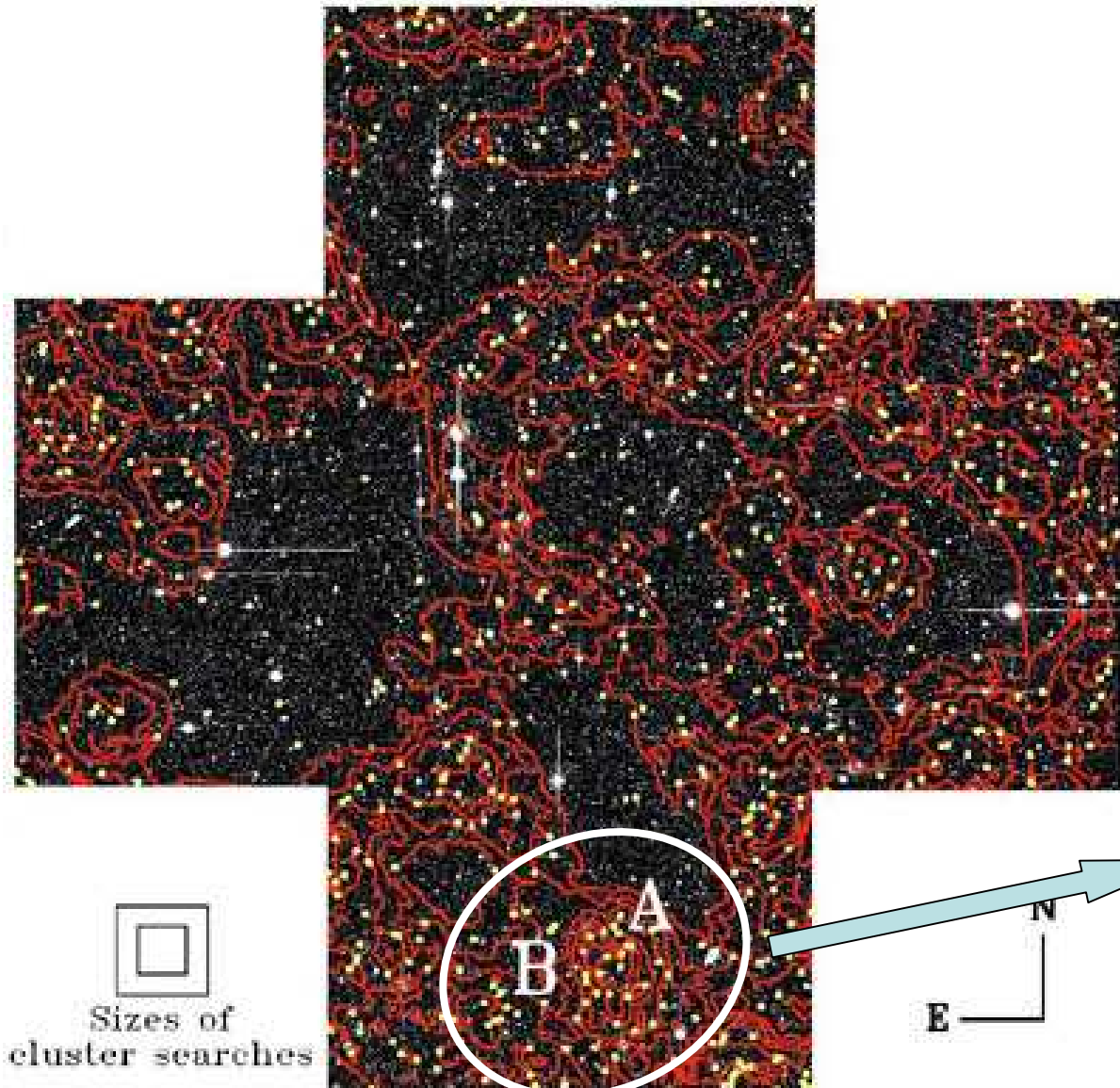
Spectroscopic
observation
(2003 Dec.)



**19/22 are LAEs
at $z=5.7$ (86%)**

Large Scale Structure at $z=5.7$ (3)

(Ouchi et al., 2005, Ap.J., 620, L1)



Properties of Clumps A and B

	clump A	clump B
Velocity disp.	180 km/s	150 km/s
Virial mass	1×10^{13} Msun	8×10^{12} Msun
3-D density contrast	average 80 (100-200 for present-day clusters)	

SFR density contrast ~130

Survey volume 9×10^5 Mpc³

two massive clusters with mass $(1-3) \times 10^{14}$ Msun

Summary

Large samples of Lyman α Emitters at $z\sim 5$ and $z\sim 6$

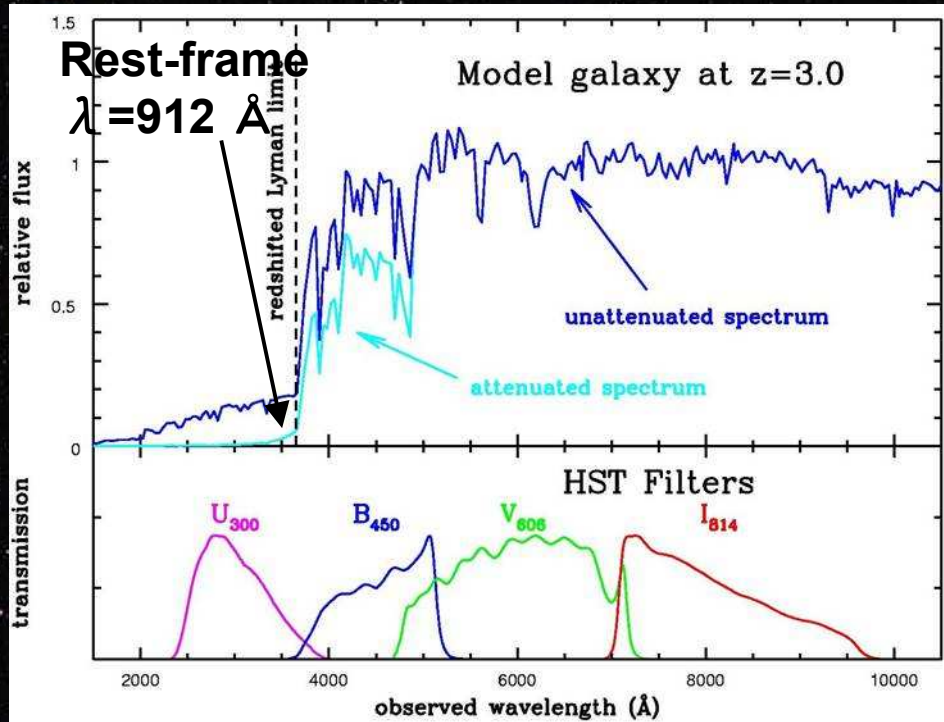


- LSS already present at $z=5.7$, when the age of the Universe was less than 10% of the present age
- Two forming clusters (protoclusters) at $z=5.7$
- Distribution of LAES at $z\sim 5$ shows large cosmic variance

A deep space photograph of a galaxy cluster, likely the Abell 1689 cluster, showing numerous galaxies of various shapes and sizes, including spiral, elliptical, and irregular forms, set against a dark background filled with stars. The text "Thank you very much" is overlaid in the center in a white, sans-serif font.

Thank you very much

Lyman Break Galaxies: LBGs



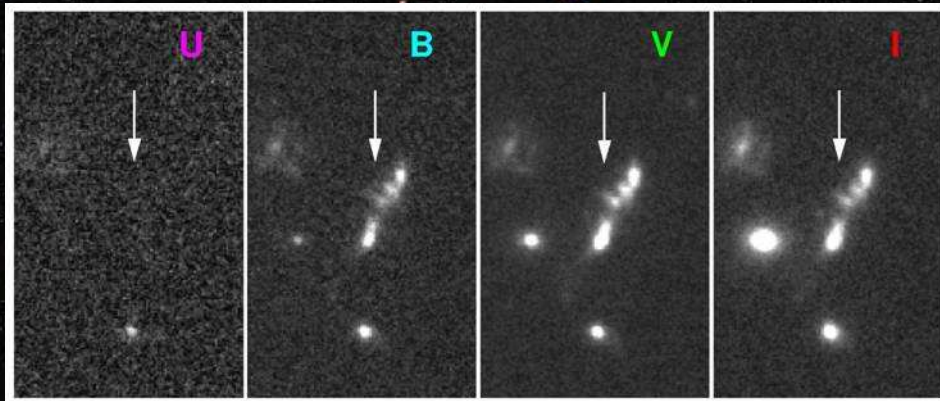
Actively star-forming
(large) galaxies

U-Drop Out

$$(1+z) \times 912 \text{ \AA} > 3500 \text{ \AA}$$



$$z > 3$$



Dickinson 1997, Proc. STScI symp.

Narrow Band Filters for LAE Search

