Subaru Telescope and Its Prospects for Observational Cosmology

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Subaru Telescope

National Astronomical Observatory of Japan

Opening Symposium

The Institute for the Physics and Mathematics of the Universe

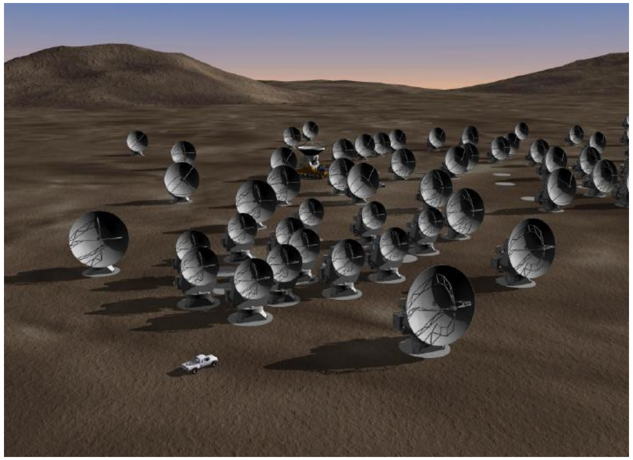
March 11, 2008

Subaru is an ancient Japanese word for the star cluster Pleiades.

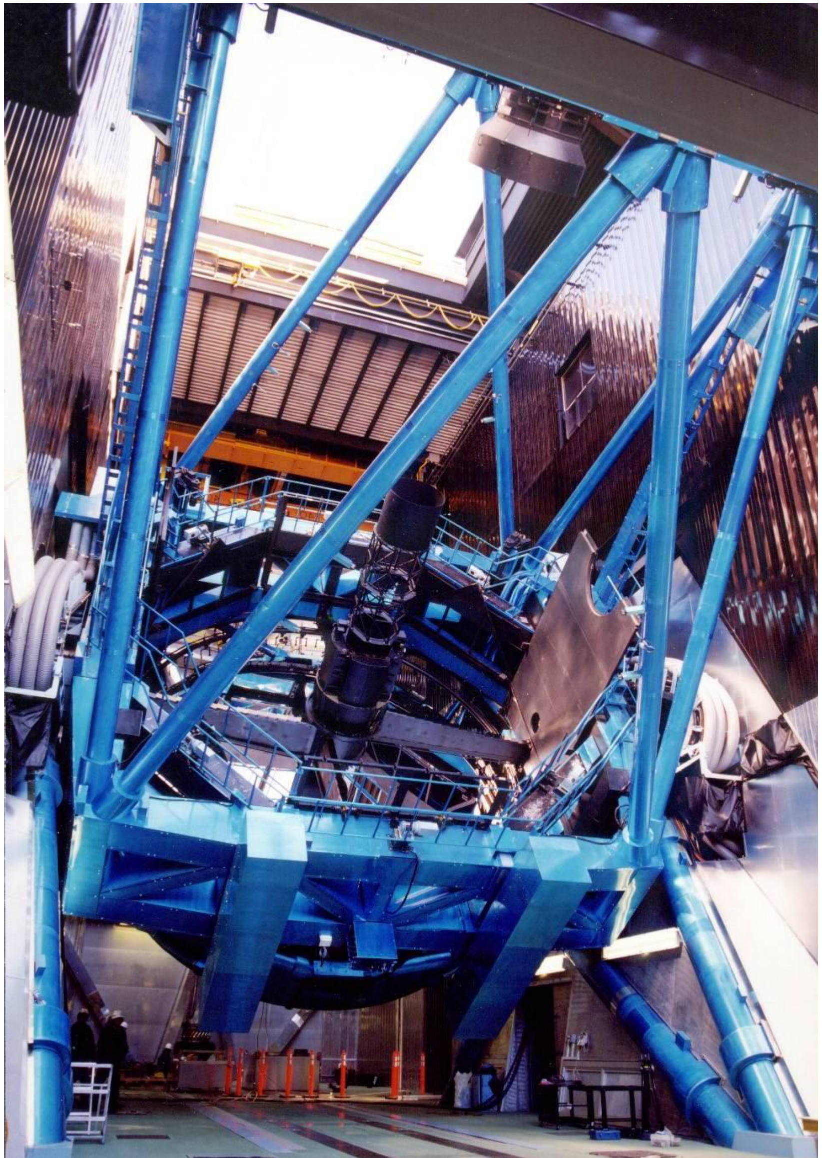
National Astronomical Observatory of Japan

National Institutes of Natural Sciences

Subaru Telescope | ALMA-J | Nobeyama | ... | ...



Overview



Construction
1991–1999 (9 years)

Total Budget
US$ 360 M (@ JYE/USD=110)

First Light
January 28, 1999

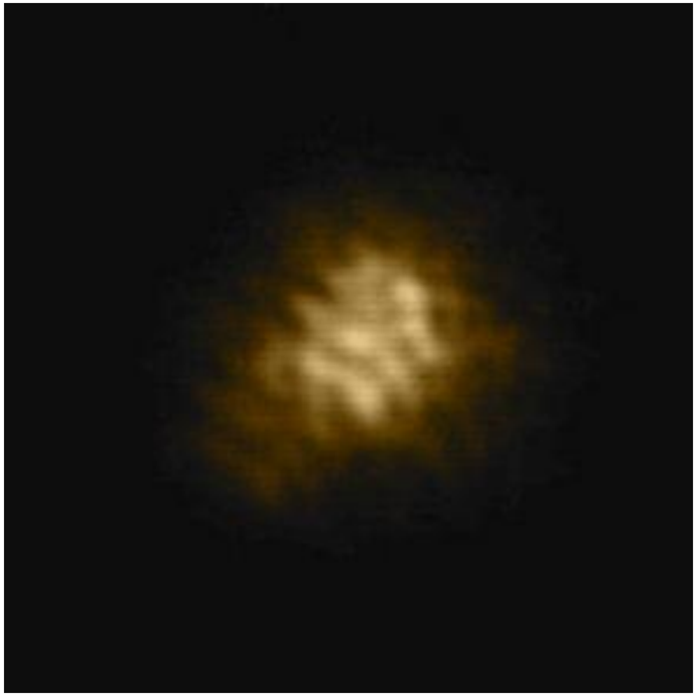
Open to Users
December 2000

Mirror Diameter
8.2 m (effective)
8.3 m (physical)

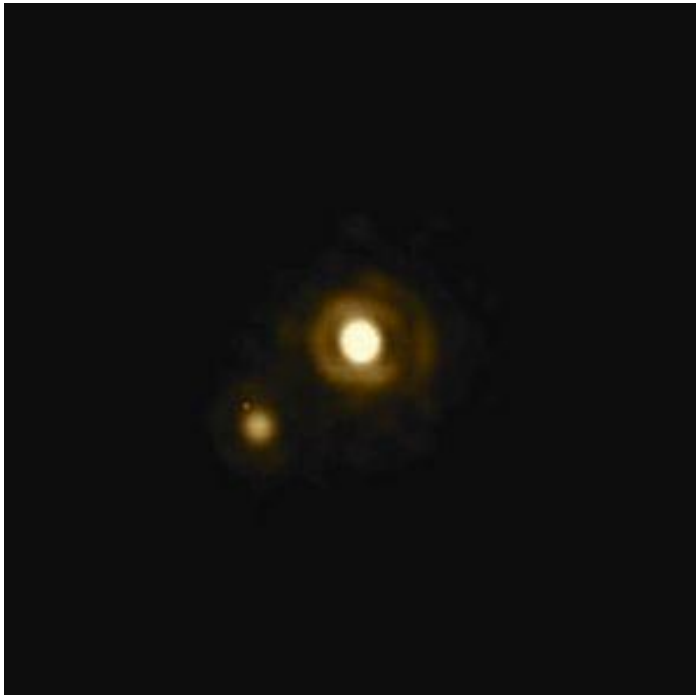
Wavelength
0.3 μm – 30 μm

Seeing
0.6″ (average at R)

Image Quality (Seeing)
an essential factor for a telescope

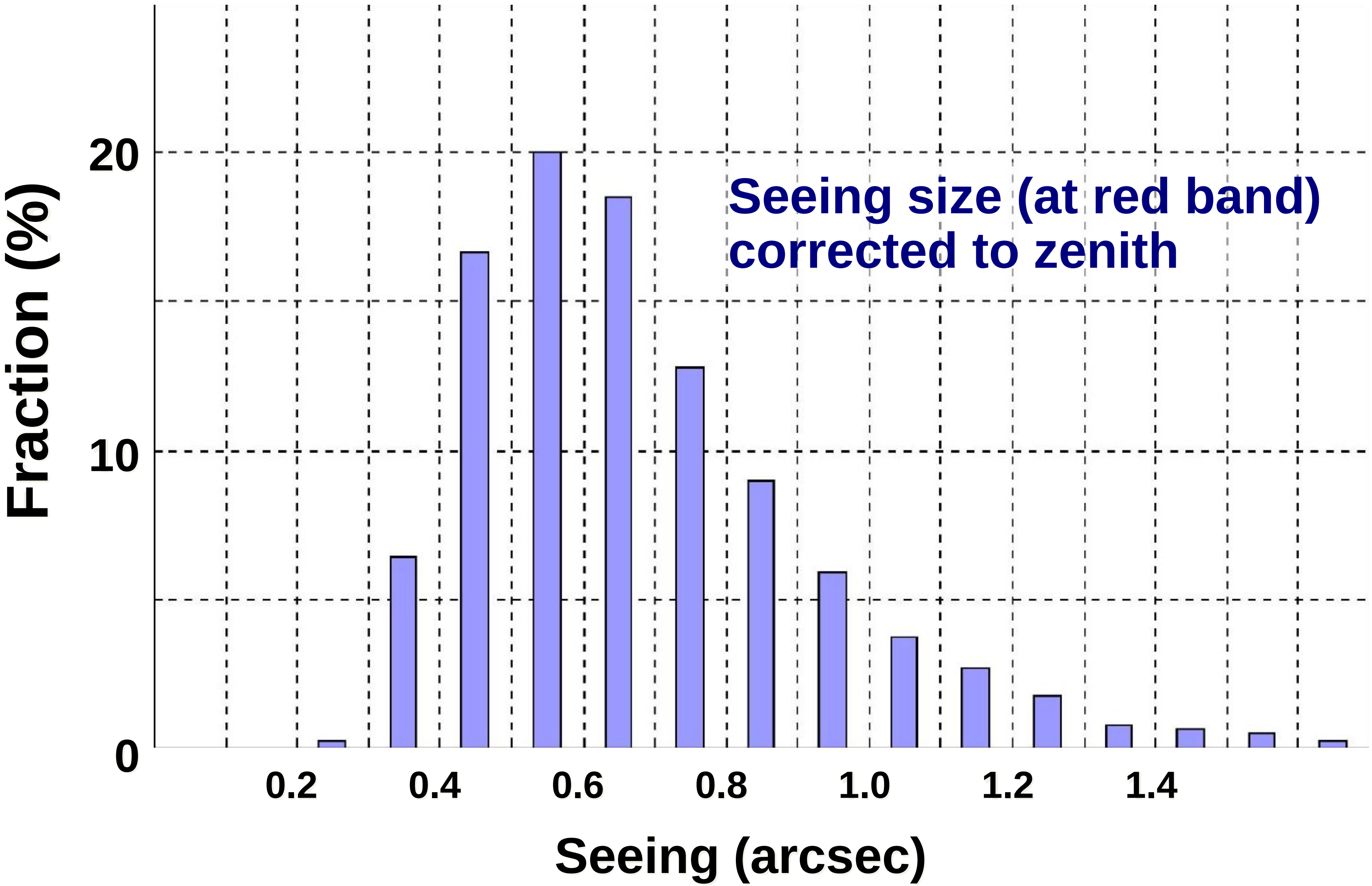


Seeing limited image. Atmospheric turbulence makes the stellar image to twinkle and blur



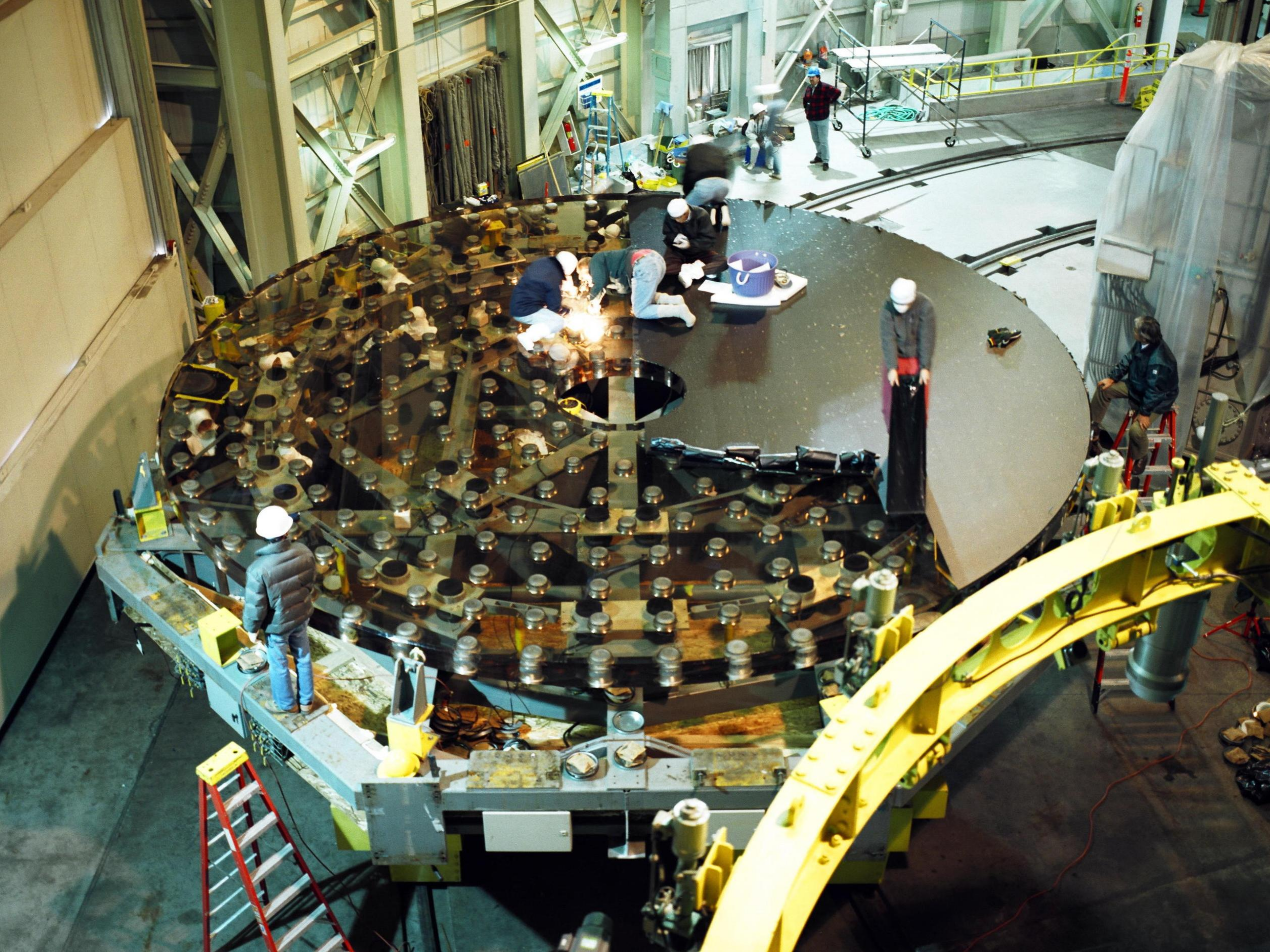
Diffraction limited image (taken with adaptive optics: currently available only at λ>1 μm)

Seeing Statistics



Excellent Image Quality

- Active optics: computer-controlled actuators with sensitive force sensors support the primary mirror at its mid-plane (center of gravity), always keeping the reflecting surface to be an ideal figure.
- Temperature control of the primary mirror and dome interior suppresses turbulence inside the dome.
- Cylindrical enclosure hampers the ground layer turbulence from coming up to the telescope level.
- Minimized telescope oscillation by finely tuned mechanical and driving systems.



Cameras & Spectrographs

IRCS (AO188)
Infrared imager and spectrograph ($\lambda/\Delta\lambda$=20,000)

HiCIAO (AO188)
Coronagraphic imager with differential imaging techniques

AO188
188-element curvature sensing adaptive optics system with a laser guide star capability

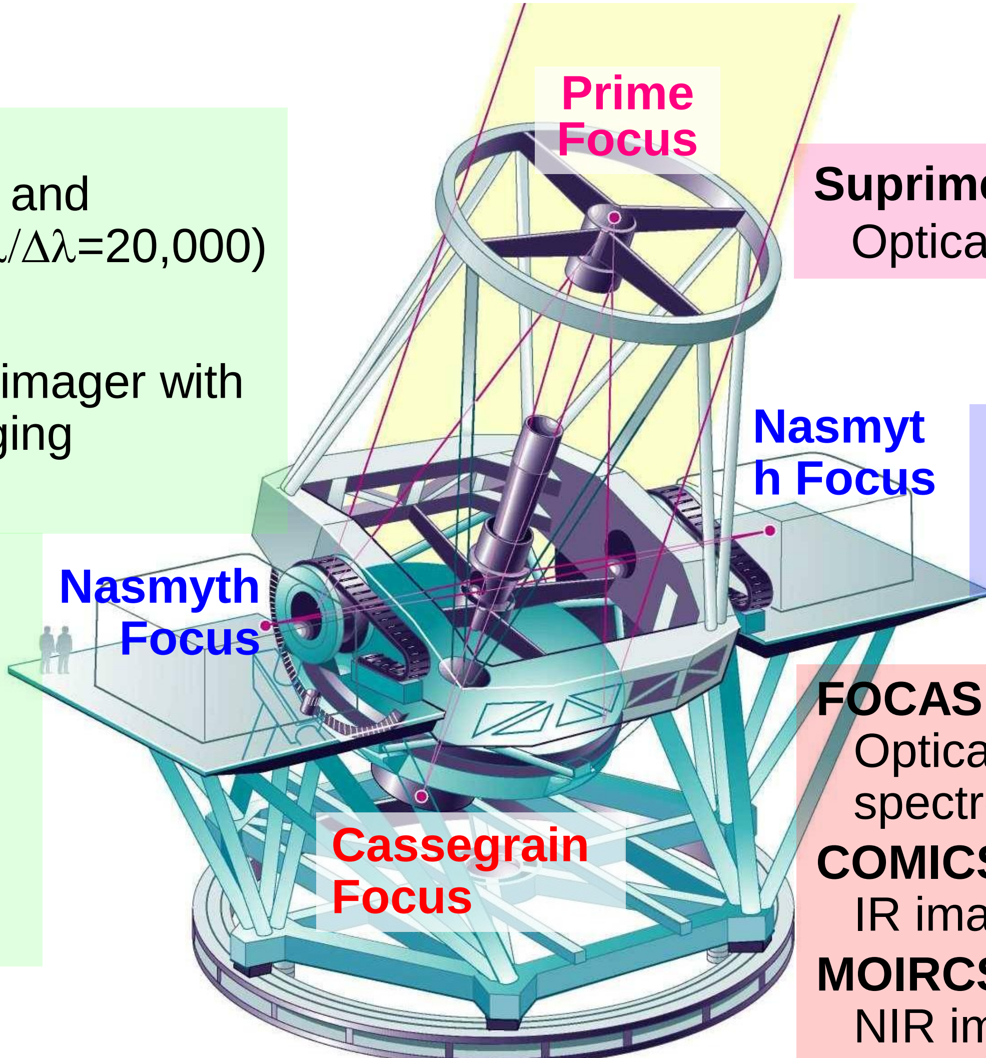


Illustration by Takaetsu Endo, taken from Nikkei Science 1996

Suprime-Cam
Optical imager ($34' \times 27'$)

HDS
Optical spectrograph ($\lambda/\Delta\lambda$=100,000)

FOCAS
Optical imager and spectrograph

COMICS
IR imager and spectrograph

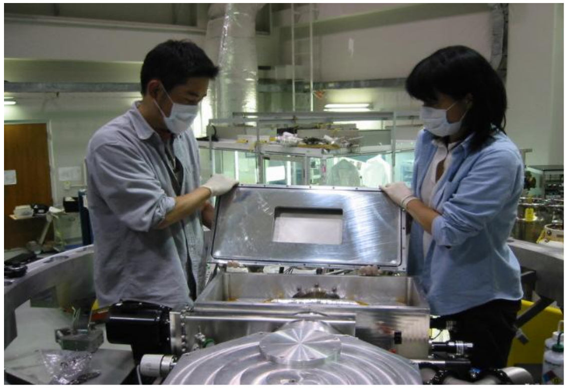
MOIRCS
NIR imager ($7' \times 4'$) and multi-object (50) spectrograph

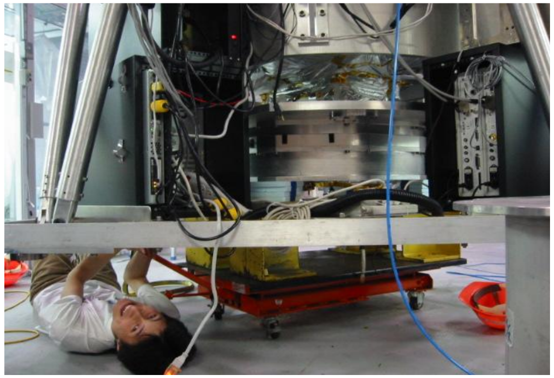
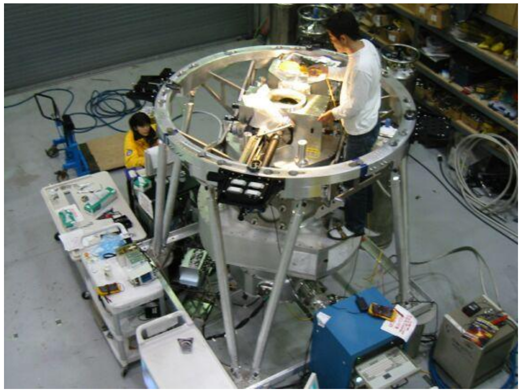
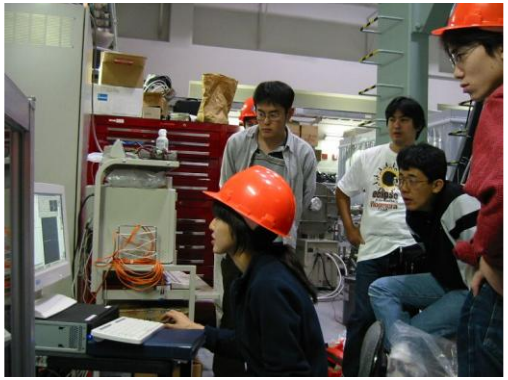
Suprime-Cam
An optical wide field imager

Developed and manufactured by NAOJ-Univ. Tokyo Collaboration

MOIRCS

An infrared wide field camera and a multi-object spectrograph

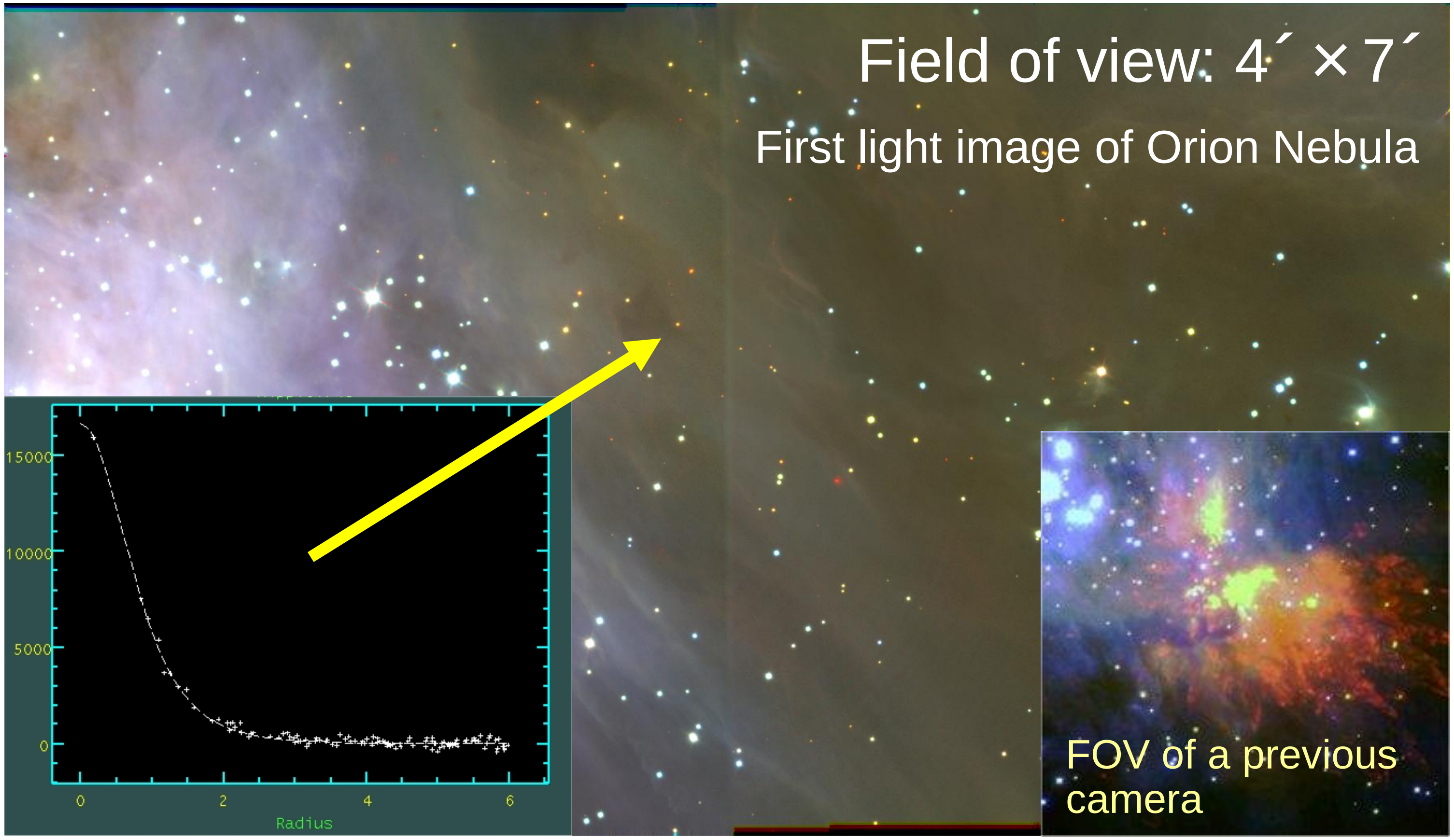



Developed and manufactured by NAOJ-Tohoku Univ. collaboration

MOIRCS

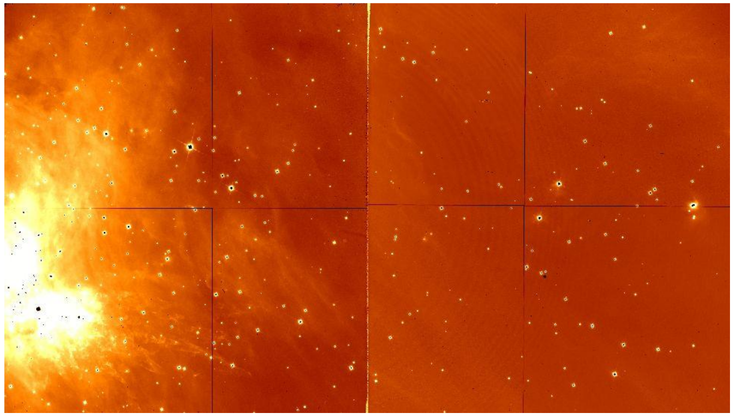
Wide field of view with superb image quality



Natural seeing: 0˝.18 (full width at half maximum)
Good image quality (0˝.2–0˝.3) is often observed.

MOIRCS

Multi-object spectrograph



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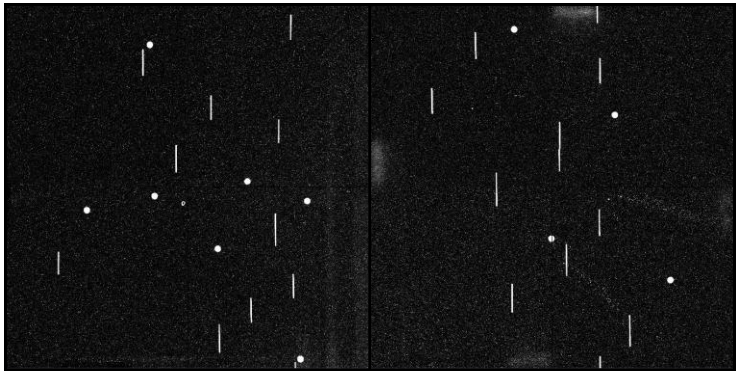
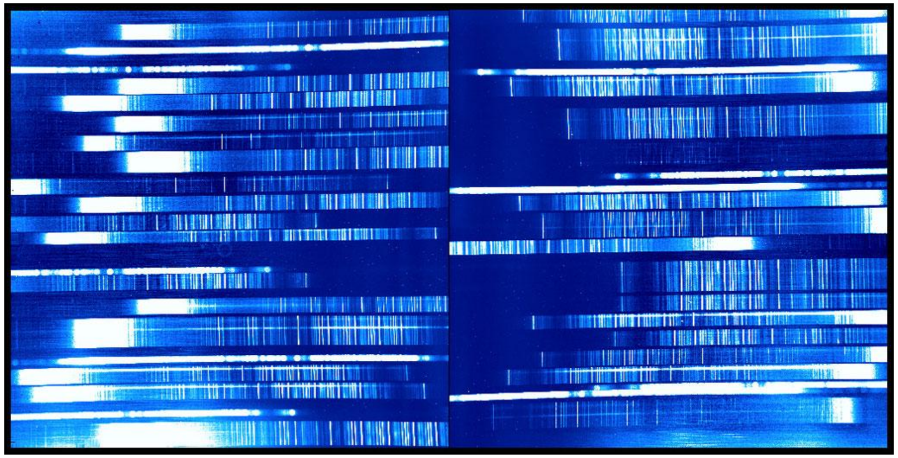


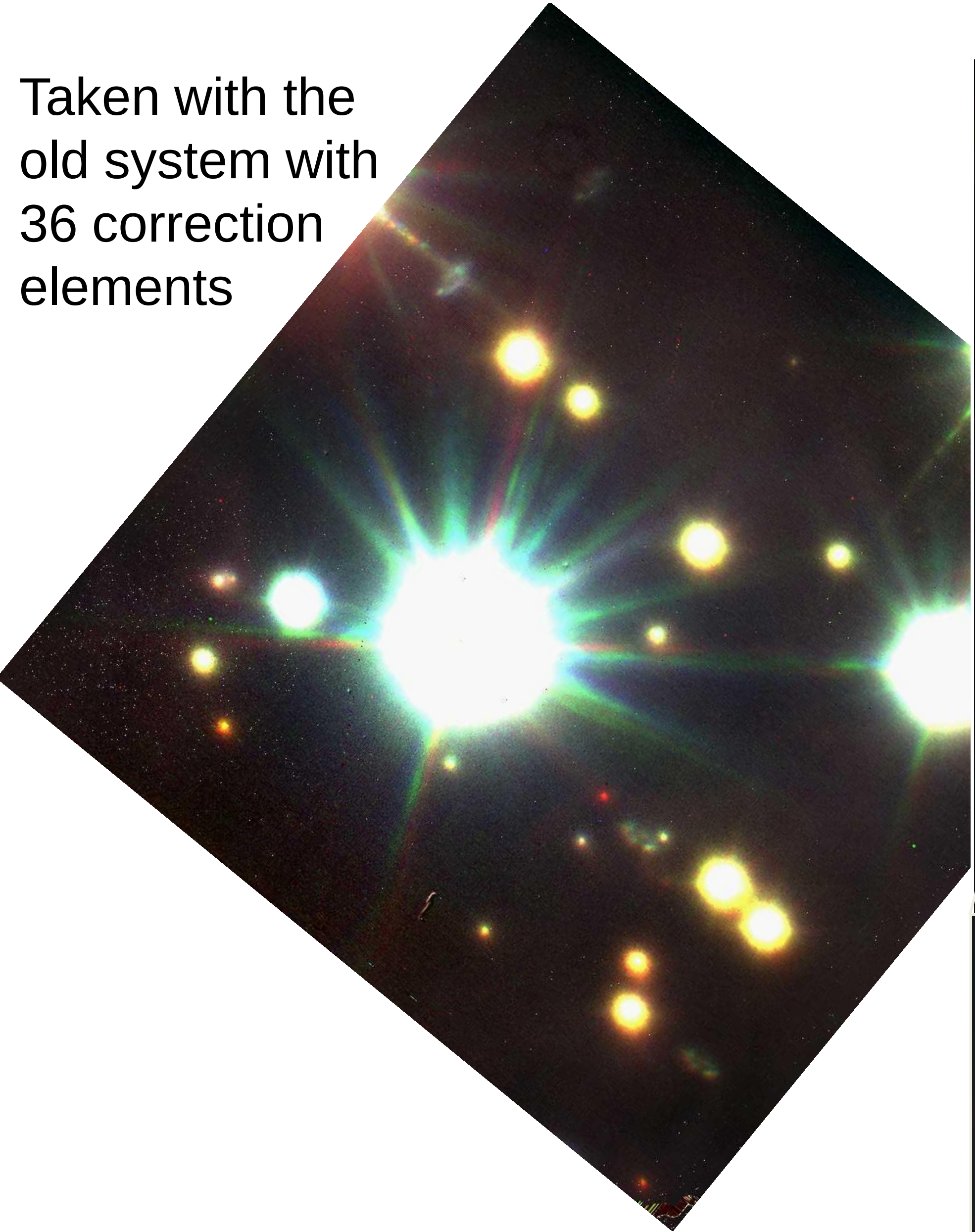
Slits or holes on targets are cut at the calculated position on an aluminum plate

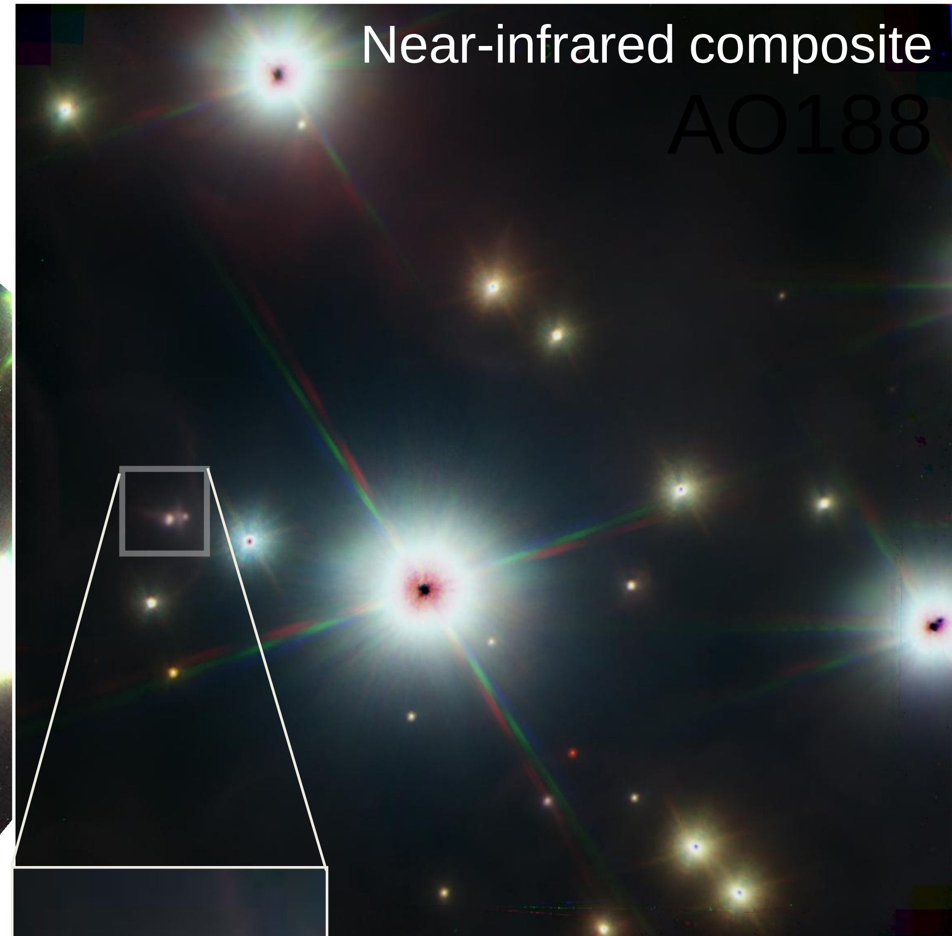
Spectra of ~30 stars (up to 50) are obtained simultaneously.

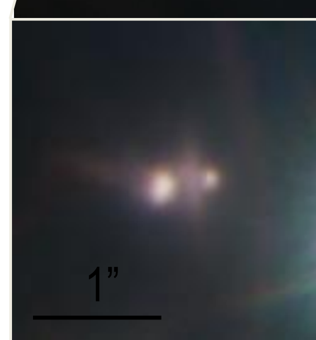


New Adaptive Optics System

Taken with the old system with 36 correction elements



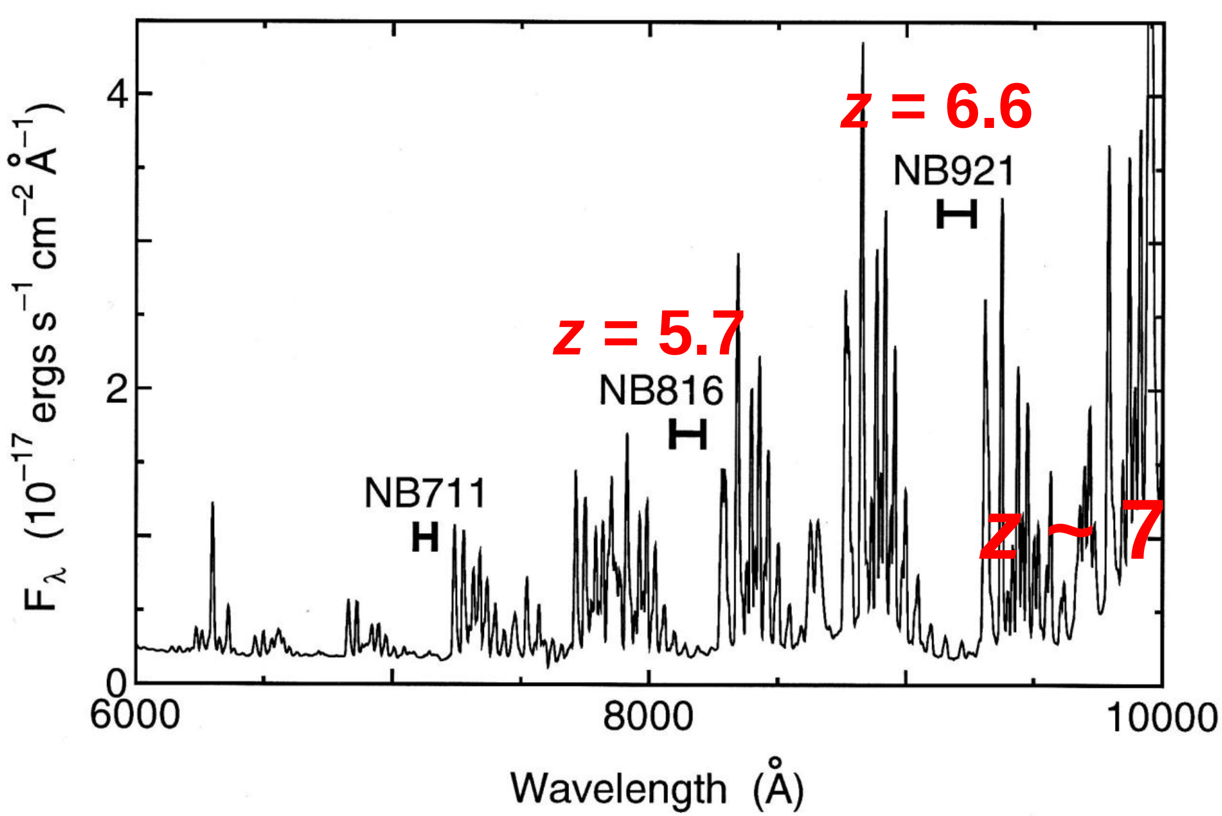




Taken with the new system with 188 correction elements

What we have seen with the Subaru Telescope

The Most Distant Galaxies

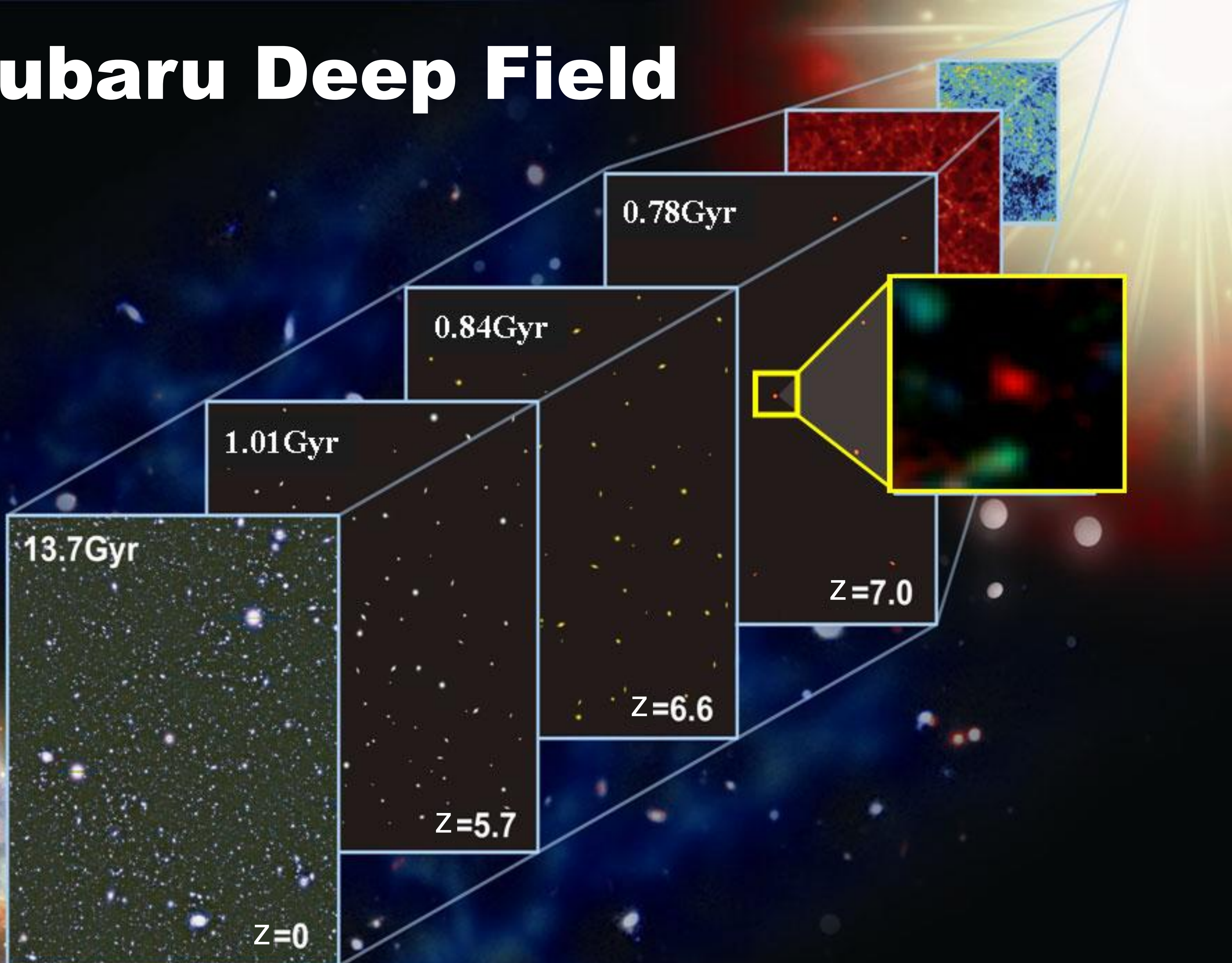


Redshift

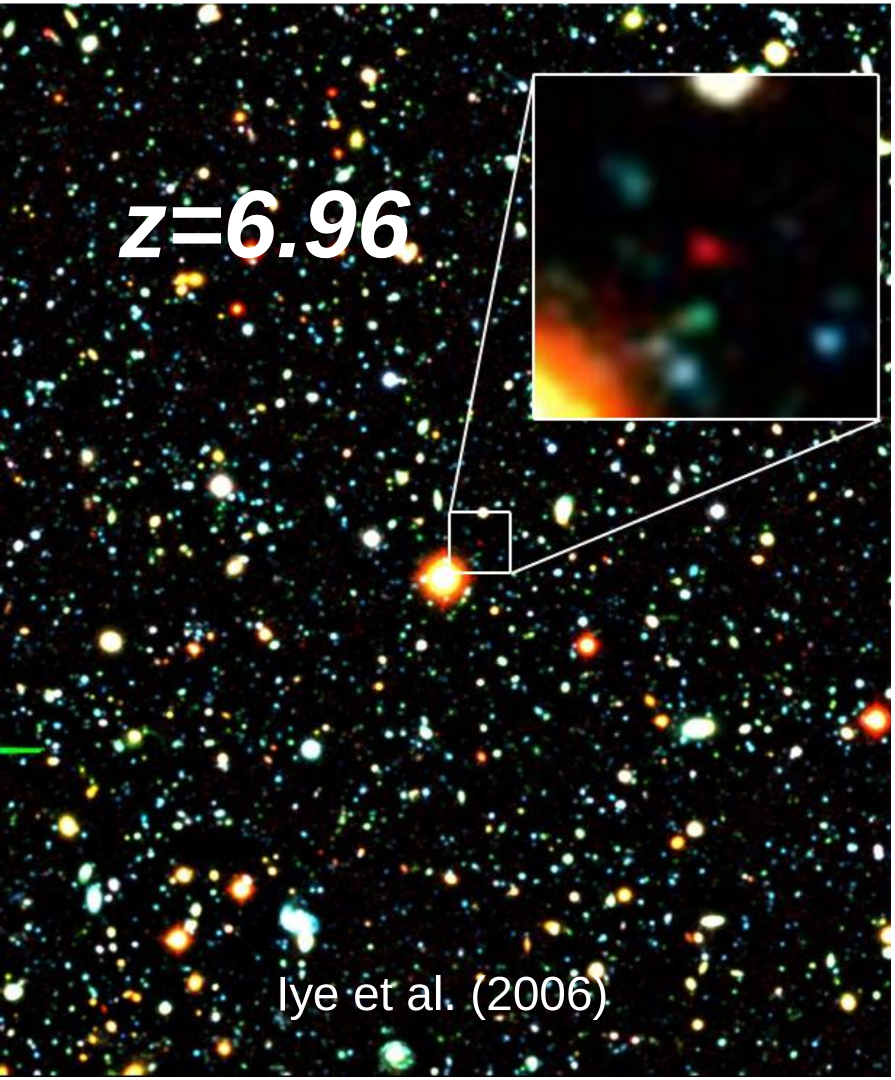
$$z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0}$$

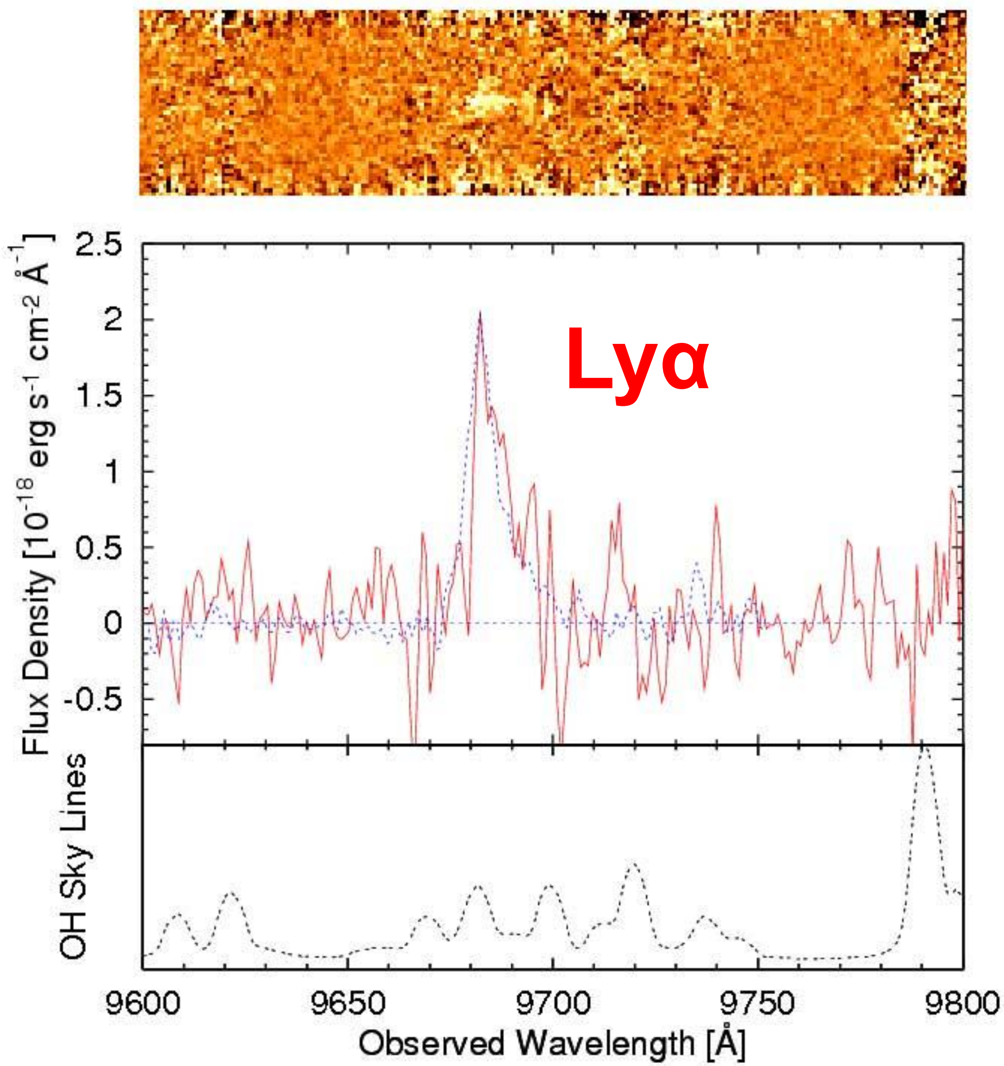
Night sky @ Mauna Kea (Alan Stockton)

Subaru Deep Field



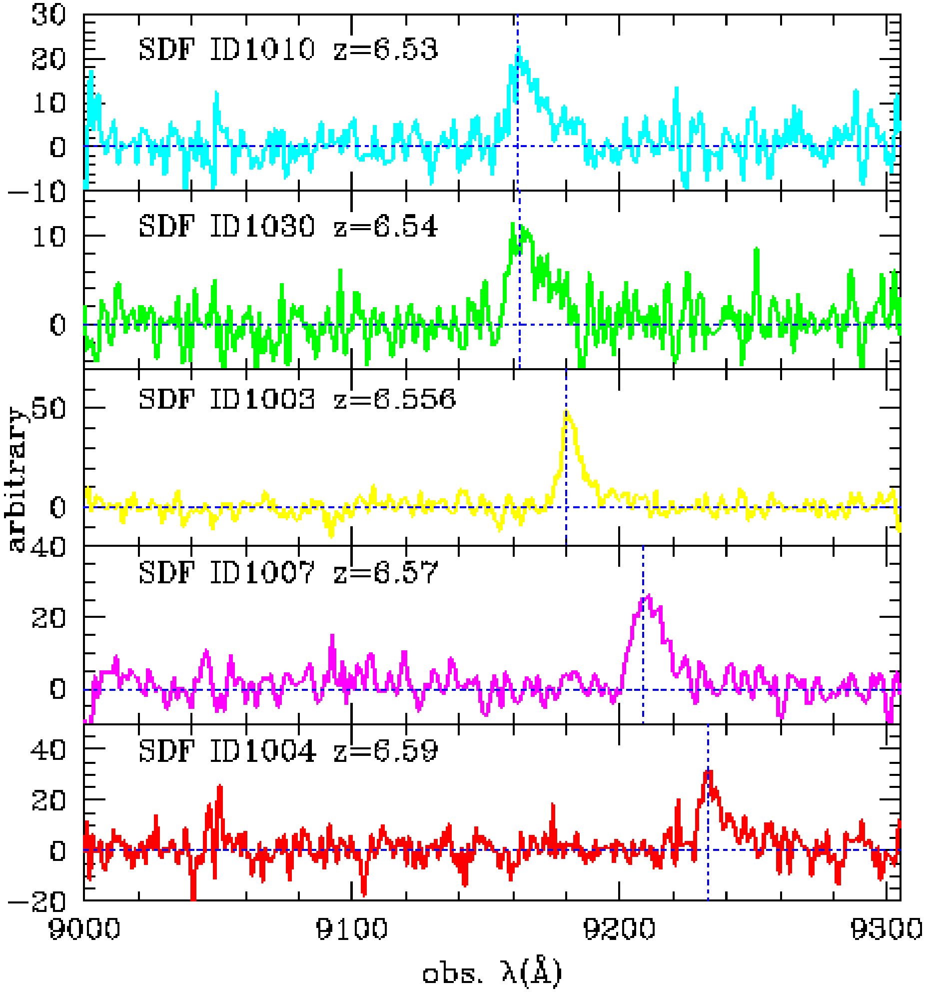
The Most Distant Galaxies





The Most Distant Galaxies

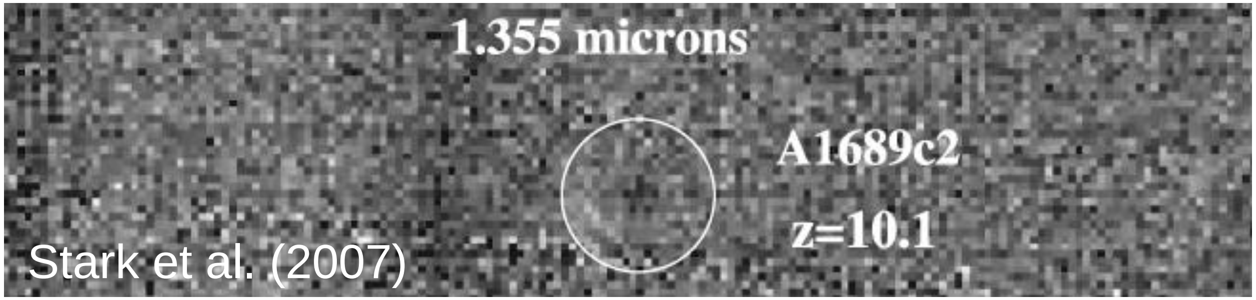
<< Galaxies with firm spectroscopic confirmation of Lyα emission >>



No.	Name	*z*	Tel.	Ref.
1	IOK1	6.96	Subaru	(1)
2	SDF132522	6.597	Subaru	(2)
3	SDF132520	6.596	Subaru	(3)
4	SDF132357	6.589	Subaru	(3)
5	SDF132432	6.580	Subaru	(2)
6	SDF132528	6.578	Subaru	(2)
7	SDF132418	6.578	Subaru	(4)
8	HCM-6A	6.56	Keck	(5)
9	SDF132432	6.557	Subaru	(3)
10	SDF132408	6.554	Subaru	(2)

(1) Iye et al. (2006), (2) Taniguchi et al. (2005), (3) Kashikawa et al. (2006), (4) Kodaira et al. (2003), (5) Hu et al. (2002)

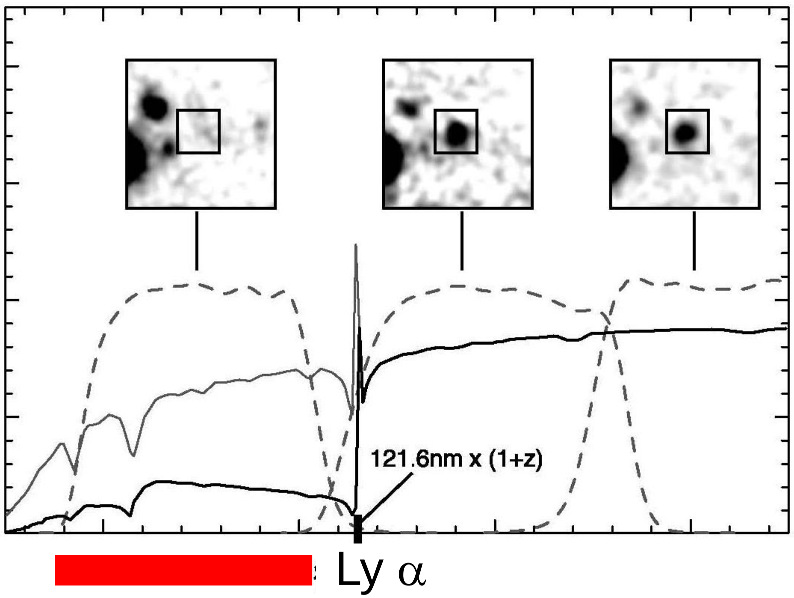
The Most Distant Galaxies



No.	Name	z	Tel.	Method	Ref.
<< Galaxies with spectroscopic evidence of possible Lyα emission>>					
1	A1689c1	10.23	Keck	GL	Stark et al. 2007
2	A1689c3	9.35	Keck	GL	Stark et al. 2007
3	A68c1	9.32	Keck	GL	Stark et al. 2007
4	A2219c1	8.99	Keck	GL	Stark et al. 2007
5	A2219c2	8.94	Keck	GL	Stark et al. 2007
6	A2219c2	8.65	Keck	GL	Stark et al. 2007
<< Galaxies with photometric evidence of large z >>					
3 J dropouts in UDF		z=8-10	HST	Blank	Bouwens et al 05
8 objects in A1835		z=7-9	VLT	GL	Richard et al. 07
5 objects in AC114		z=7-9	VLT	GL	Richard et al. 07

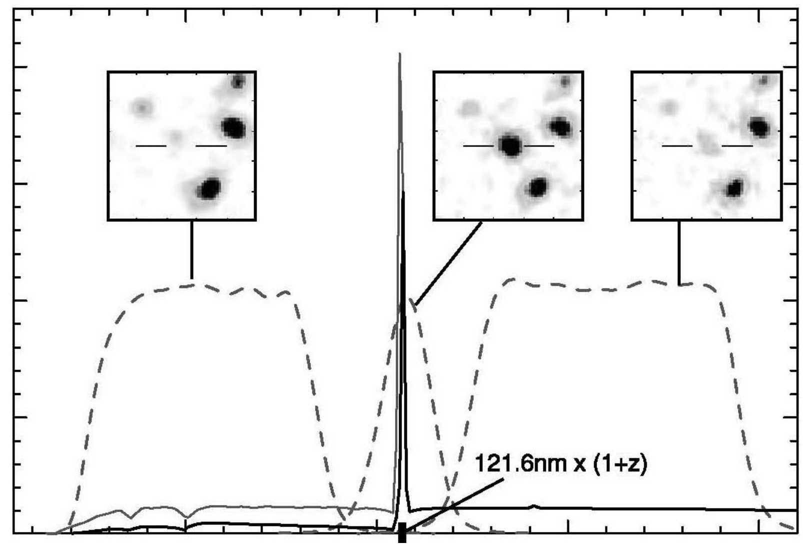
Lyman Break Galaxies vs. Lyman Alpha Emitters

Lyman Break Galaxy



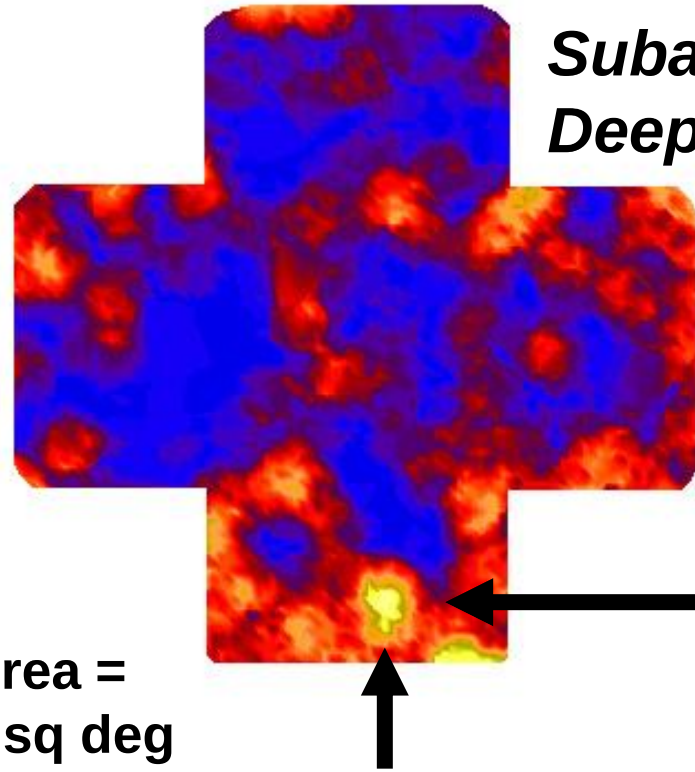
Continuum depression

Lyman Alpha Emitter



Strong Lyα

The most distant proto-cluster of LAE galaxies @ z=5.7



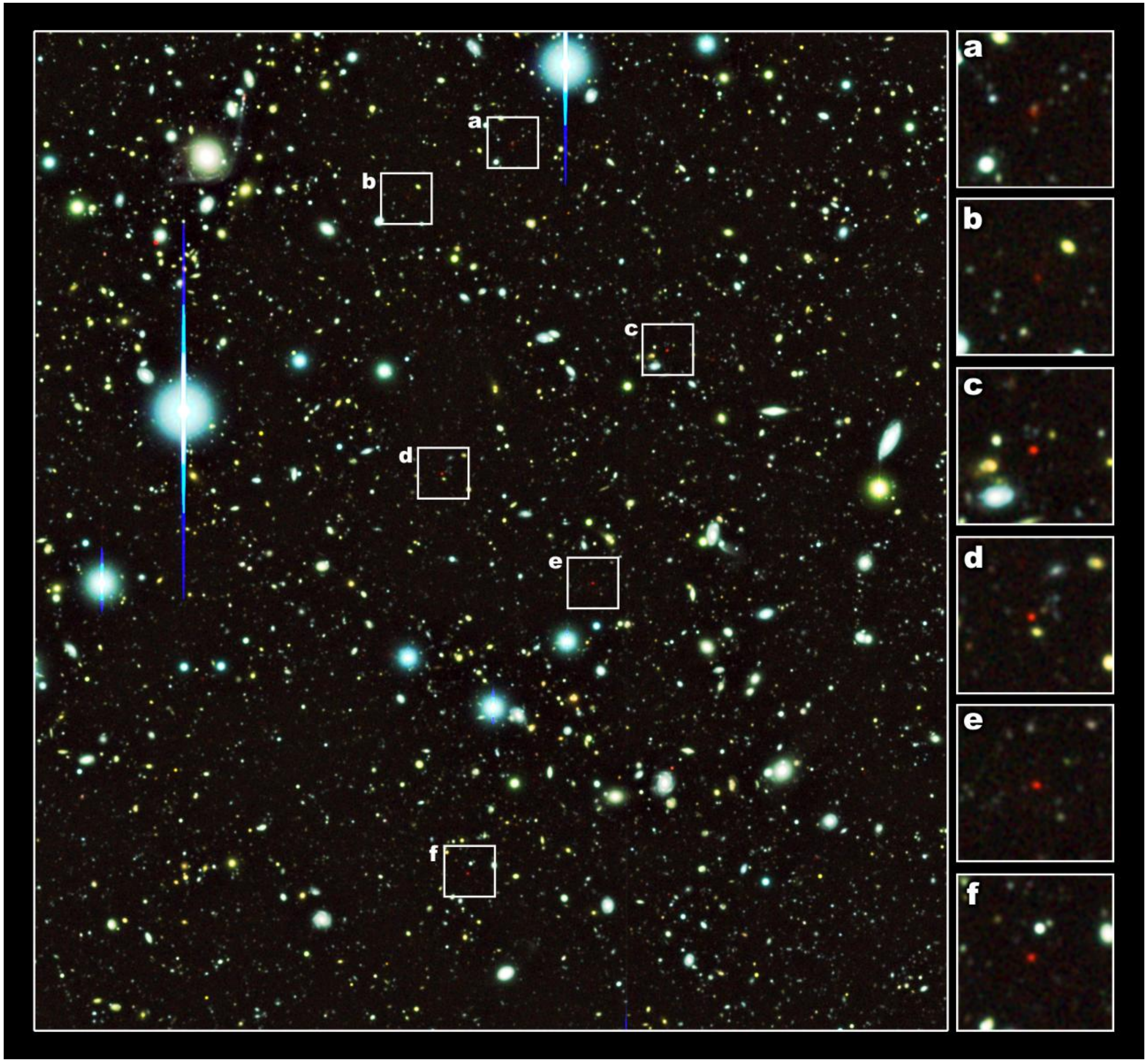
Subaru XMM-Newton Deep Survey (SXDS)

Clustering of LAEs

Area = 1.3 sq deg

Ouchi et al. (2005b)

Close up of the proto-cluster region

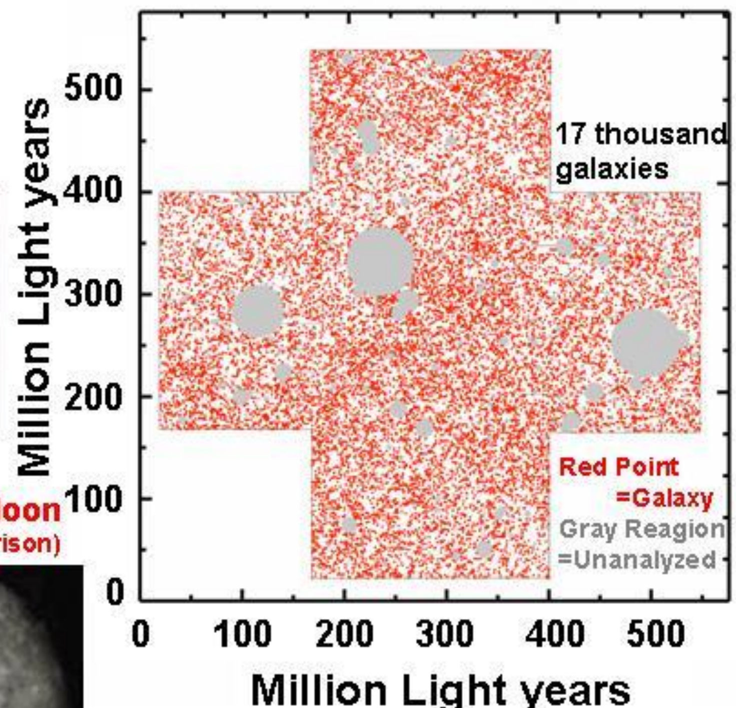


Ouchi et al. (2005b)

Lyman Break Galaxy Clustering in Dark Matter Halos

Subaru Image

Positions of Young Galaxies
12 Billion Light-Years Away



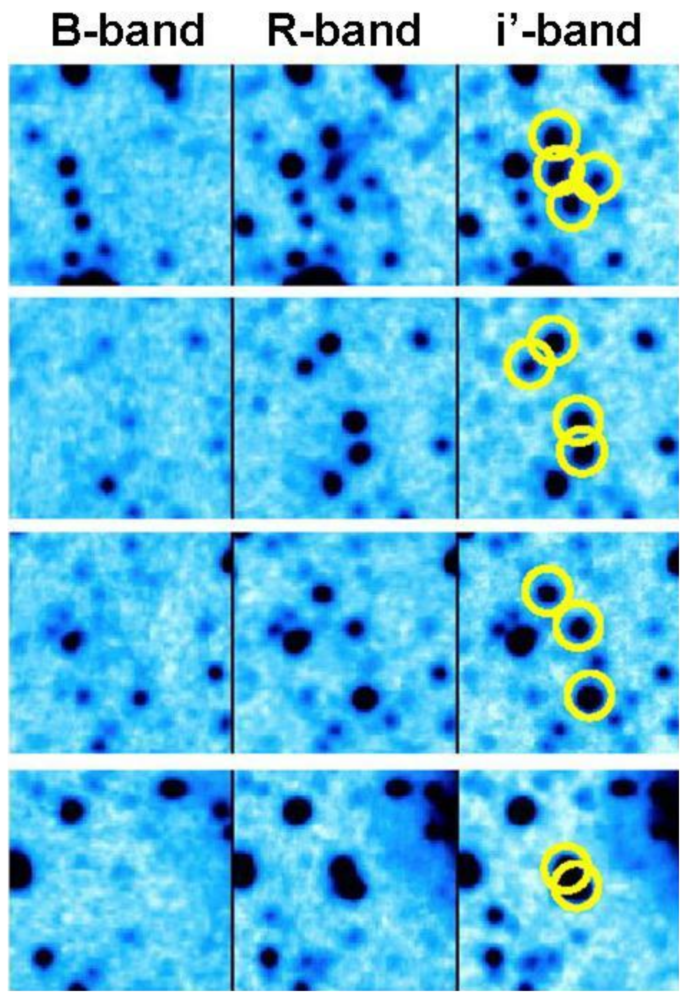
Size of Moon
(for comparison)

Subaru XMM-Newton Deep Survey (SXDS)

Ouchi et al. (2005a)

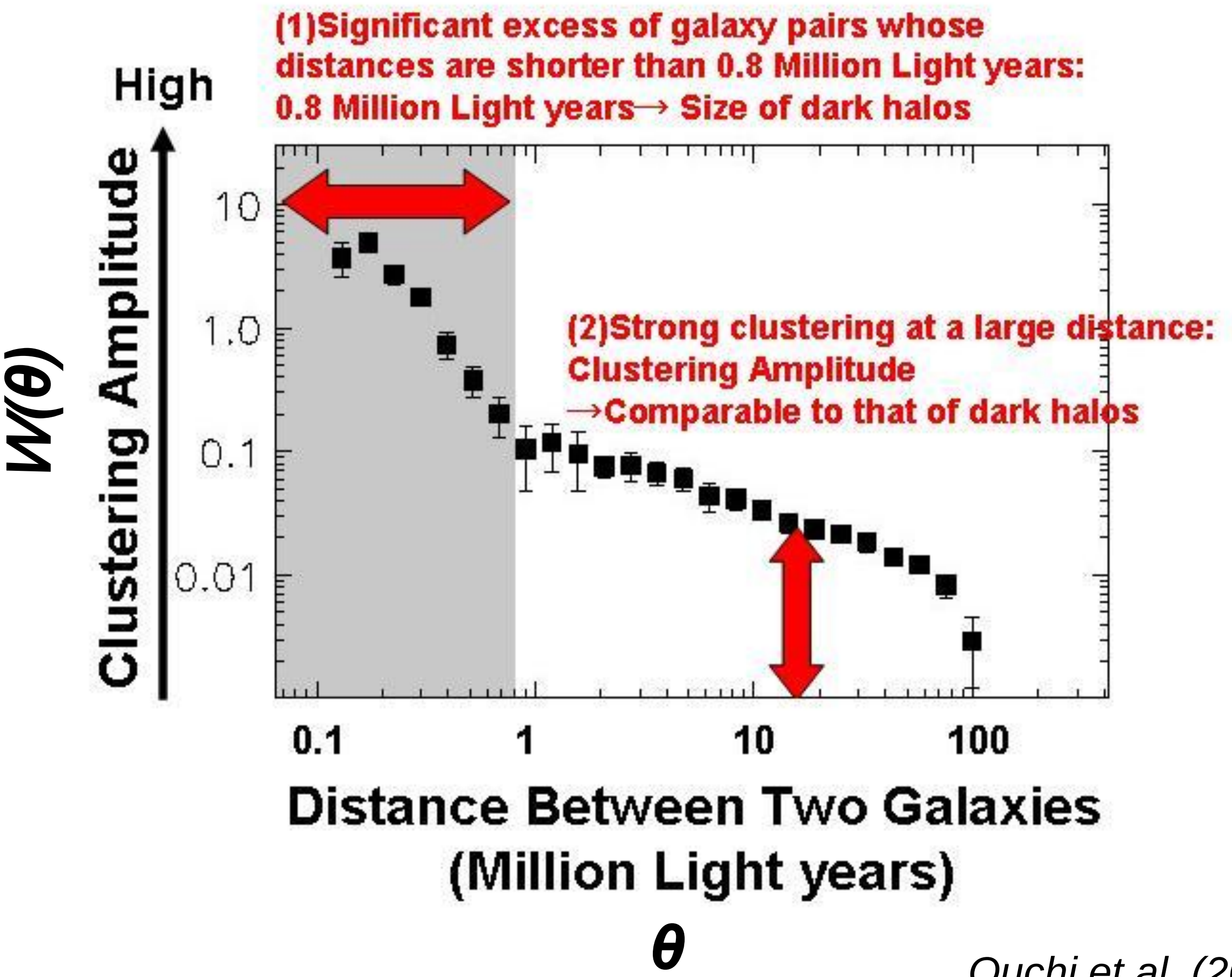
Lyman Break Galaxy Clustering in Dark Matter Halos

17,000 LBGs @ z ~ 4 – 5 in SDF/SXDS



Ouchi et al. (2005a)

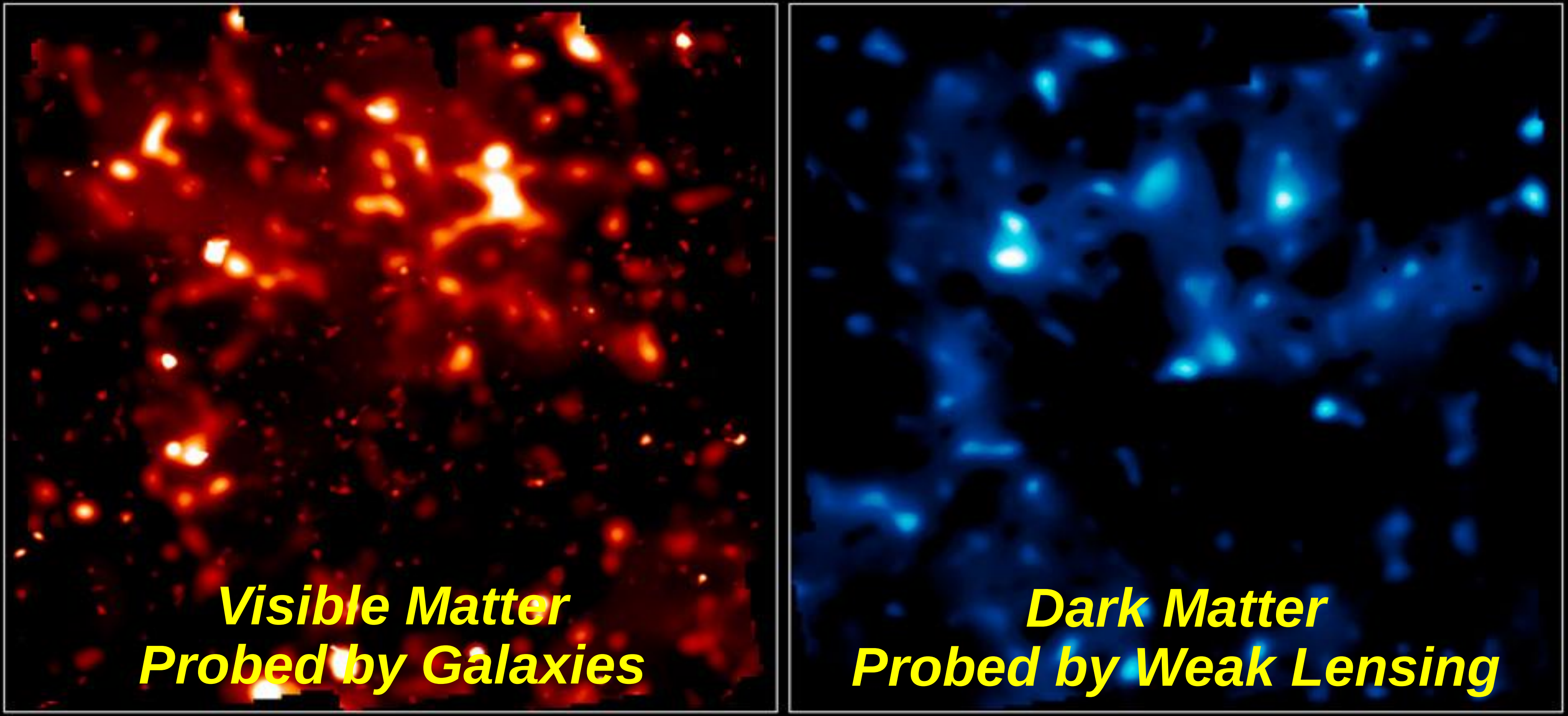
Lyman Break Galaxy Clustering in Dark Matter Halos



Distinctive transition from large- to small-scale clustering of Lyman break galaxies at z~4: galaxy clustering in dark matter halos

Ouchi et al. (2005a); Kashikawa et al. (2006)

COSMOS: COSMIC Evolution Survey



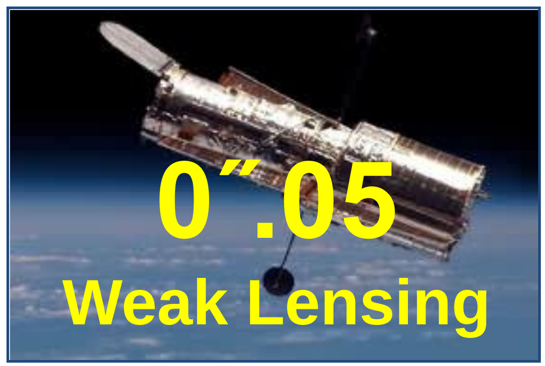
Distribution of Visible and Dark Matter
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, and R. Massey (California Institute of Technology)

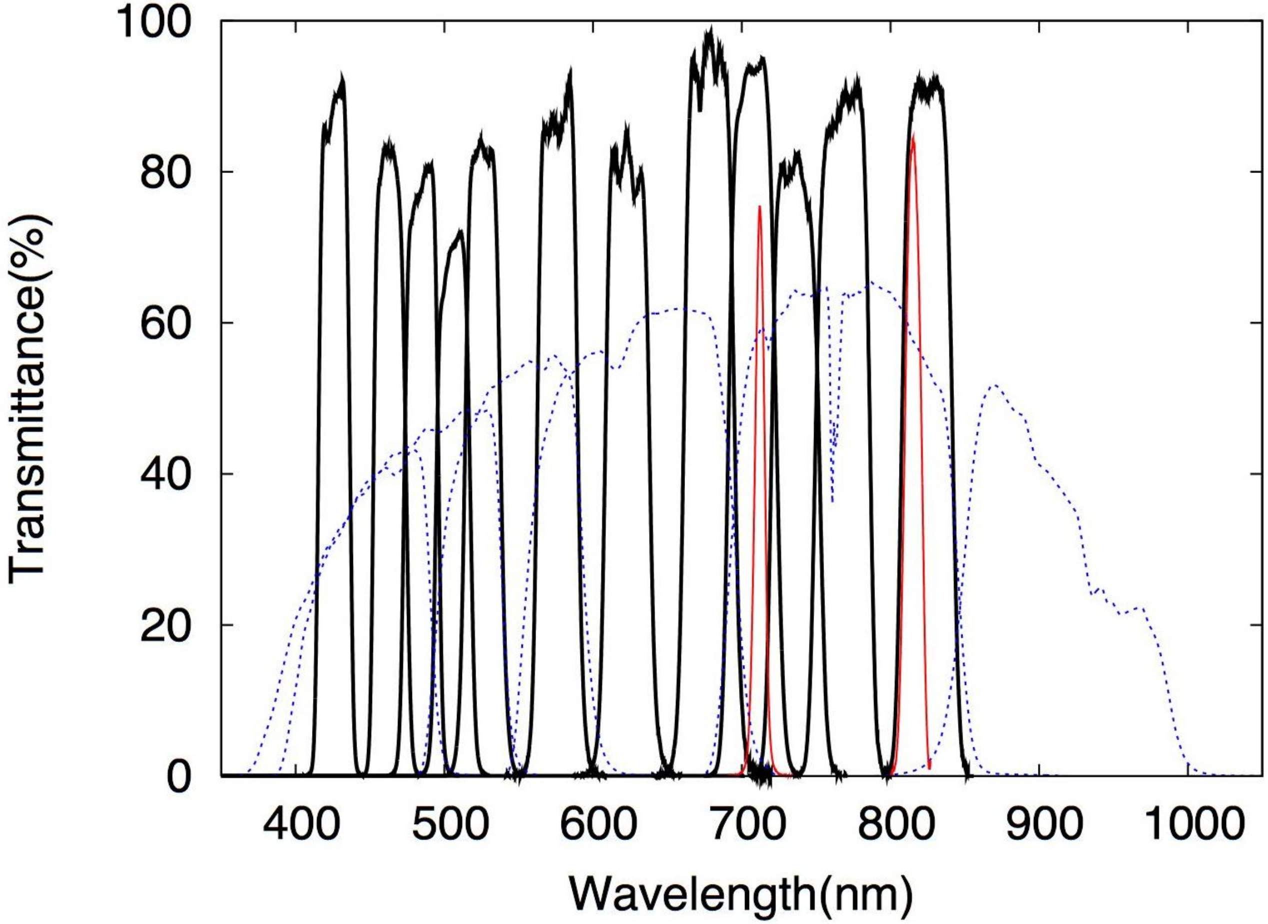
STScI-PRC07-01b

Redshift range : $0.1 < z < 1$

Multi-λ Strategy
with Great Observatories



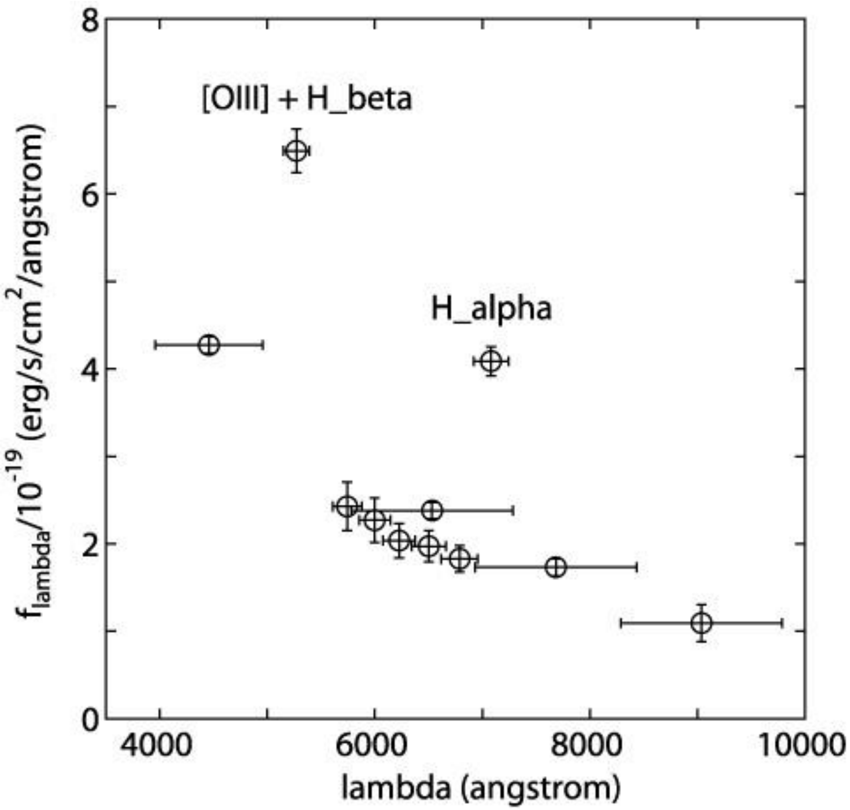
COSMOS-20

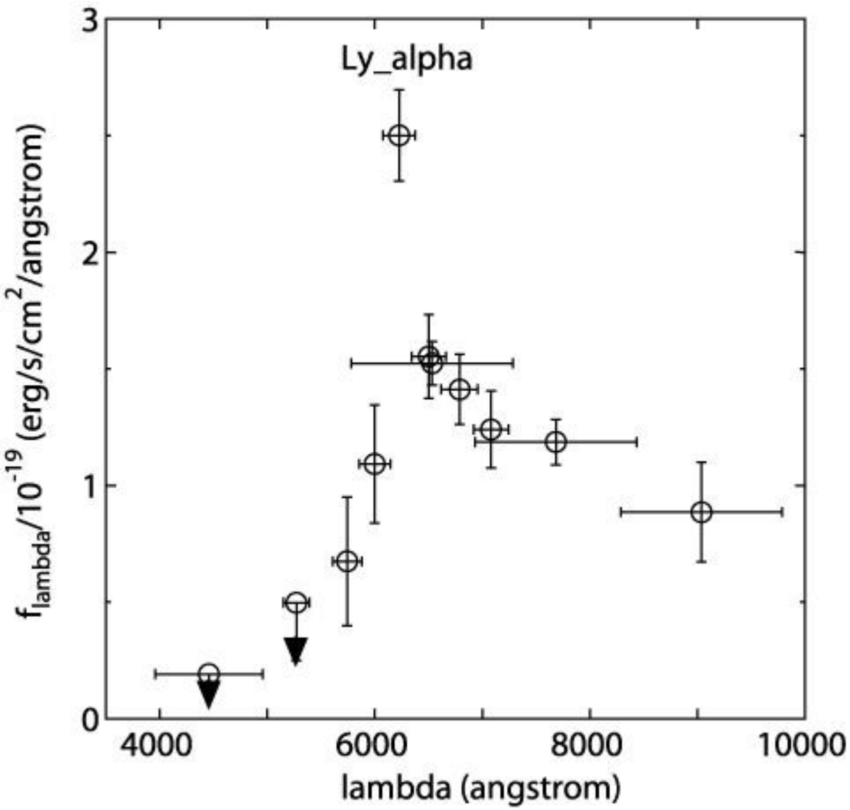


6 broad + 2 Narrow +12 Intermediate Filters

Taniguchi et al. (2008)

Photo-z

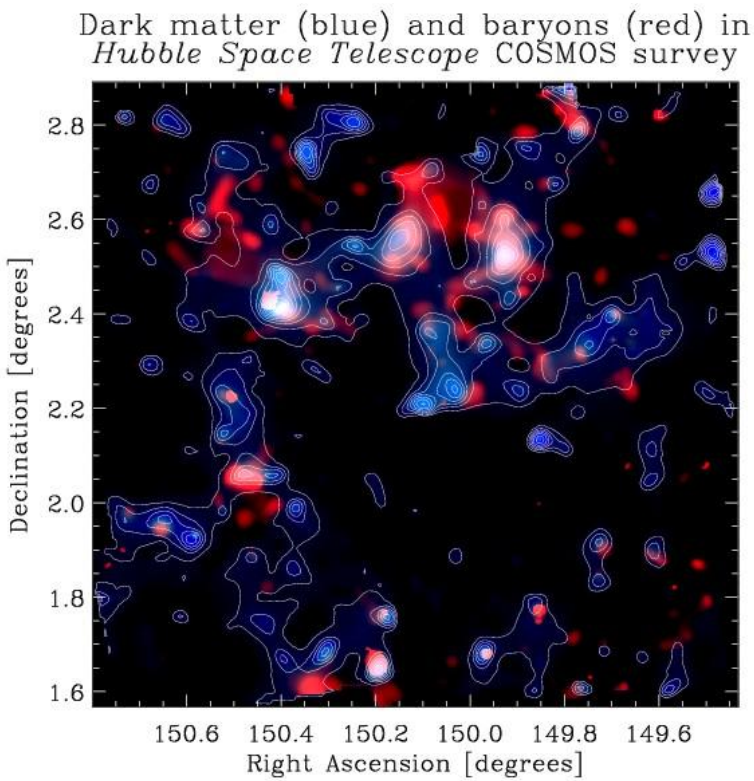


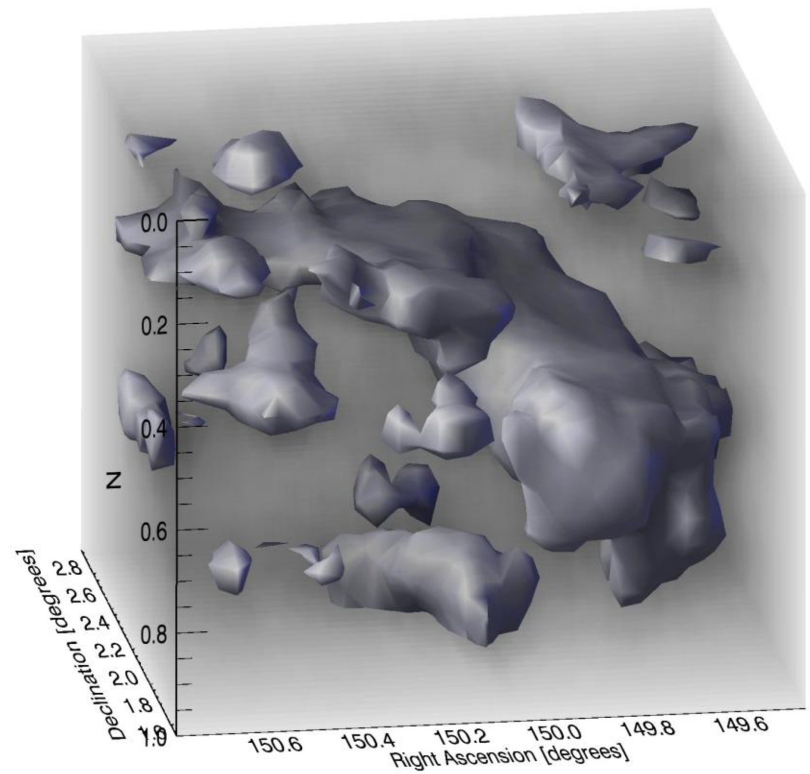


z (photo) = 0.05 ***z (photo) = 4.13***

Yamada F. S. et al. (2005)

COSMOS

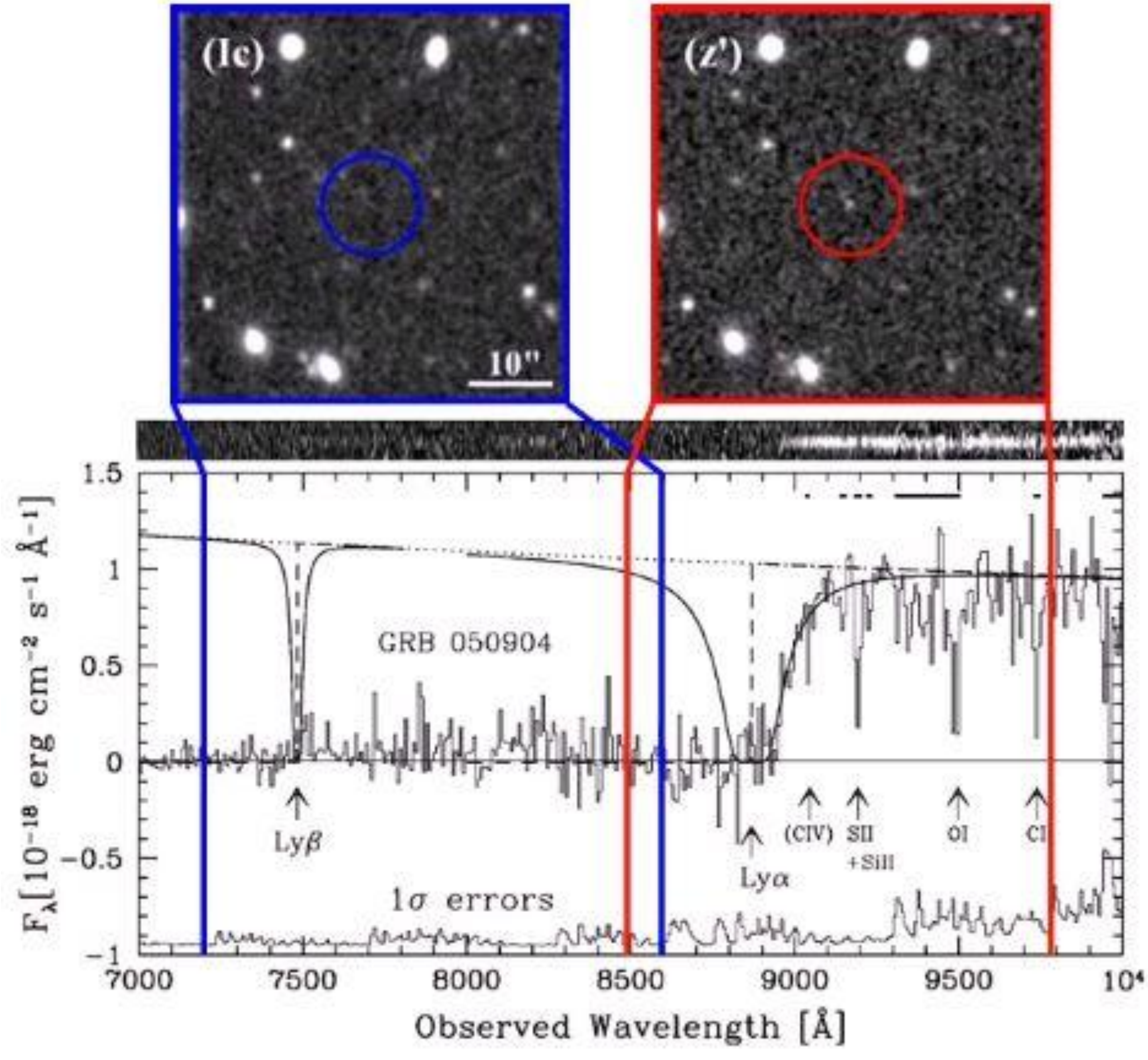




Suprime-Cam data was used to measure the photometric distances to 500,000 galaxies in order to estimate the distances to dark matter features that cause weak lensing effect to these galaxies. The resultant 3D map shows for the first time the large scale structure of the dark matter, within which lies the large scale structure of galaxies, confirming the scenario that galaxies formed in cold dark matter halos.

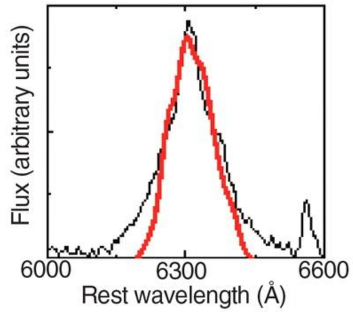
Massey et al. (2007)

The Most Distant Gamma-Ray Burst @ z = 6.3



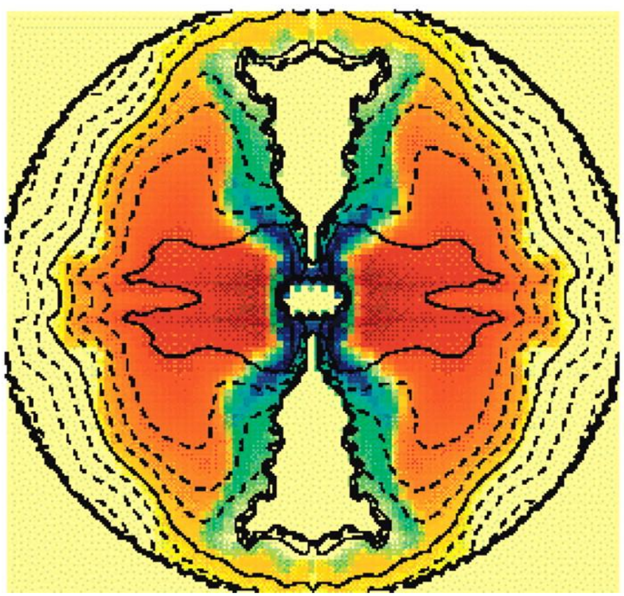
Kawai et al. (2005)
Totani et al. (2006)

Origin of Gamma Ray Bursts



GRB

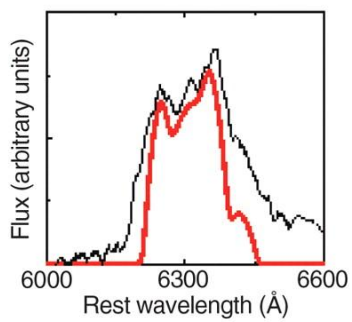
1998bw



2003jd

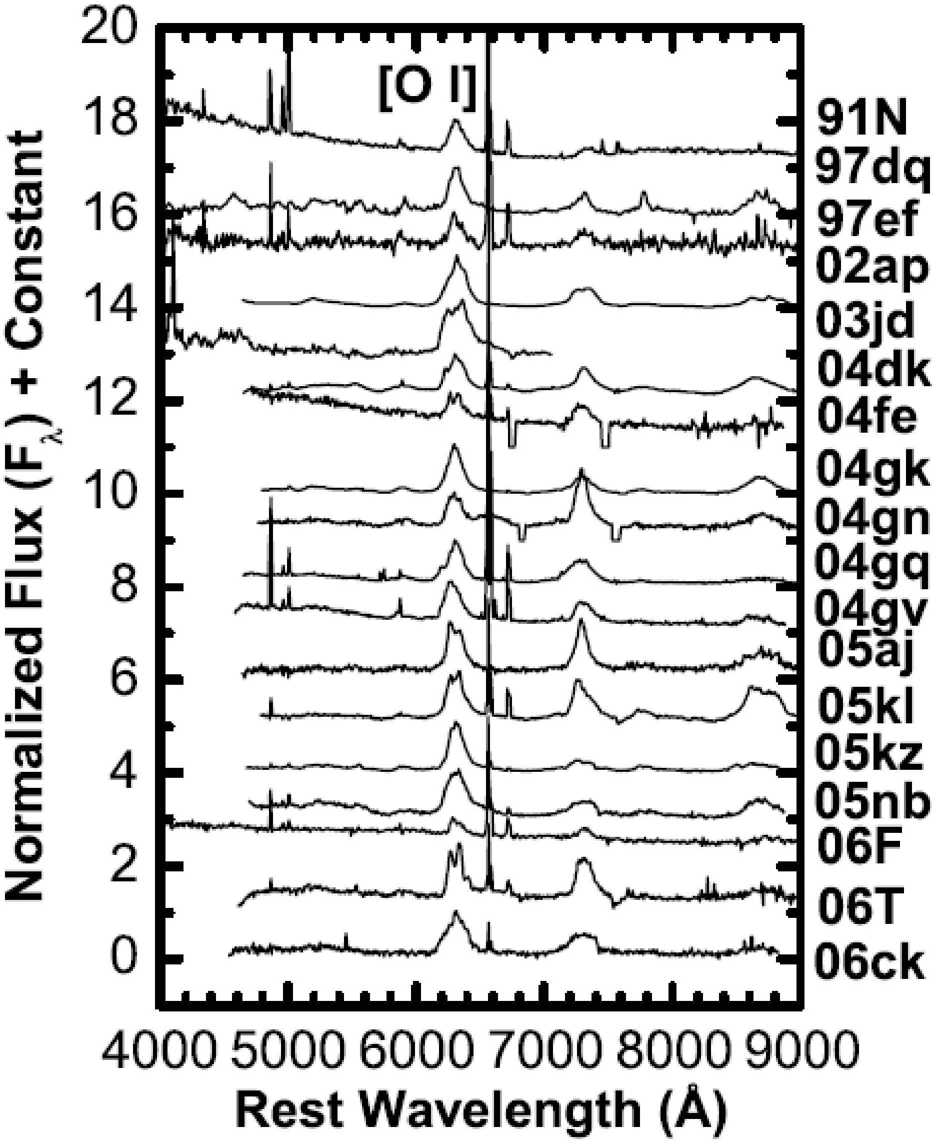
Non-spherical explosion models predict ejection of oxygen to equatorial direction, suggesting that double peak [OI] emission is observed for off-axis supernovae, as observed for SN2003jd

non-GRB



Mazzali et al (2005)

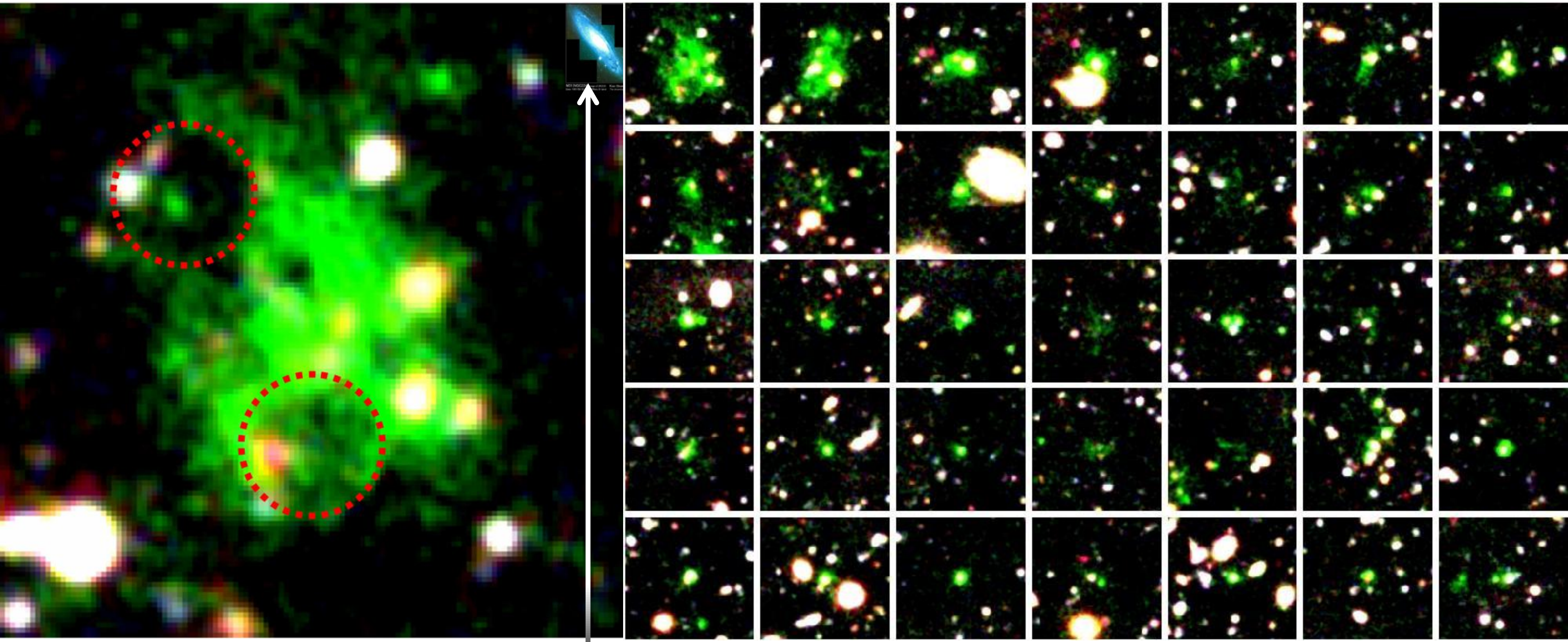
Origin of Gamma Ray Bursts



Maeda et al. (2008) studied [OI] line profiles of 18 supernovae (nebulae phase) whose progenitors lost their envelopes ("stripped supernovae"), showing that the double peaked [O I] line profile (=non-sphericity) is a generic property.

Non-sphericity is a key to explosion mechanism, although not all stripped supernovae are GRB sources.

Lyman α Blobs @ z=3.1



LAB1 found by Steidel et al. (2000)

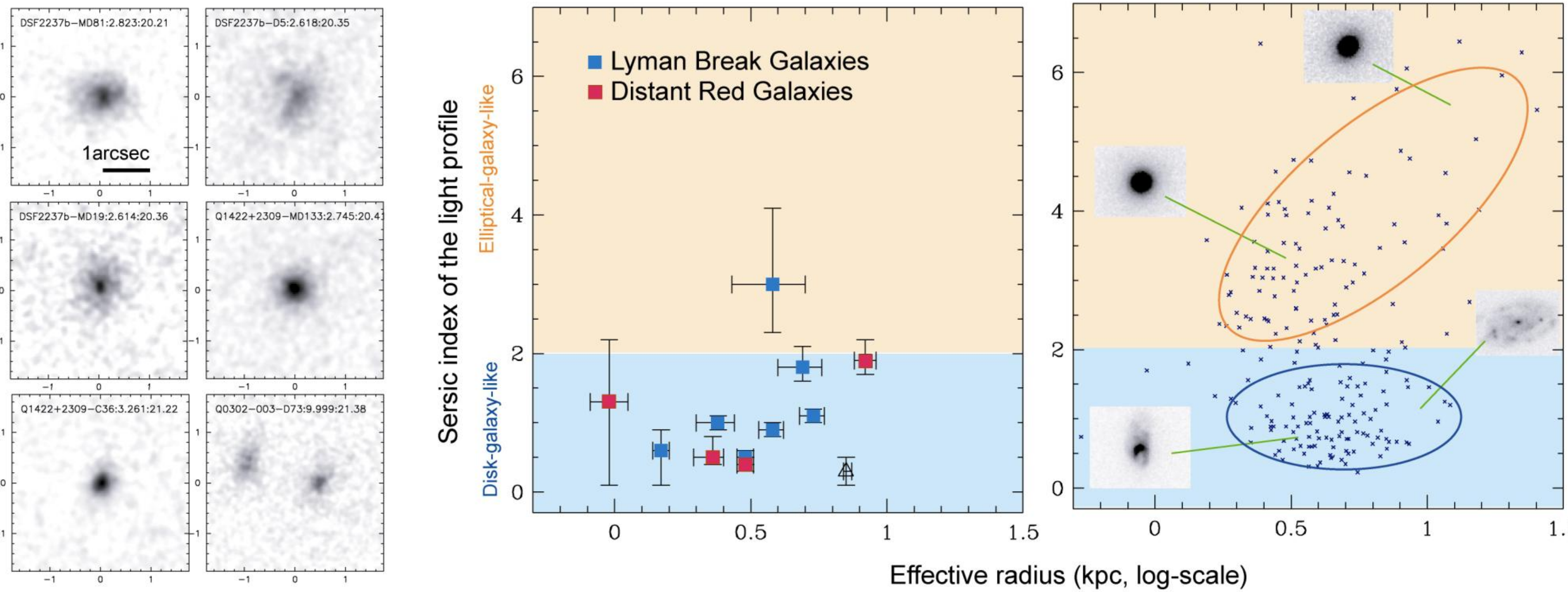
Size of the Andromeda galaxy at 12 billion light years away

Matsuda et al. (2004, 2005, 2006)

Morphology of z~3 Galaxies

AO deep observation (FWHM~0.2"~1.6kpc@z=3) results of z~3 galaxies

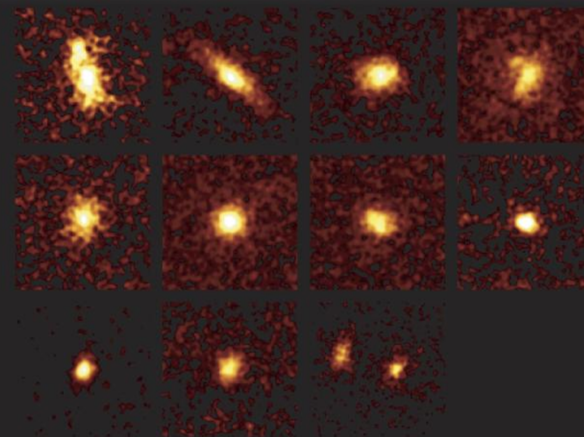
Simulated images of galaxies



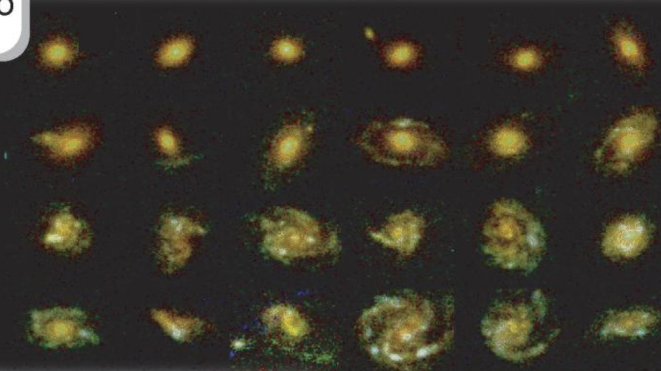
- K-band adaptive optics imaging has revealed for the first time detailed rest-frame V-band morphology of z~3 galaxies.
- All but one galaxies have flat brightness profiles similar to those of disk galaxies in the local universe. Highly concentrated elliptical galaxies are rare at z~3.
- The disk-like galaxies at z~3 are formed from merging of gas rich halos and are expected to evolve into elliptical galaxies through gas poor merging by the time z=1.

Akiyama et al. (2007)

Galaxies at 11 billion years ago



Galaxies at 8 billion years ago



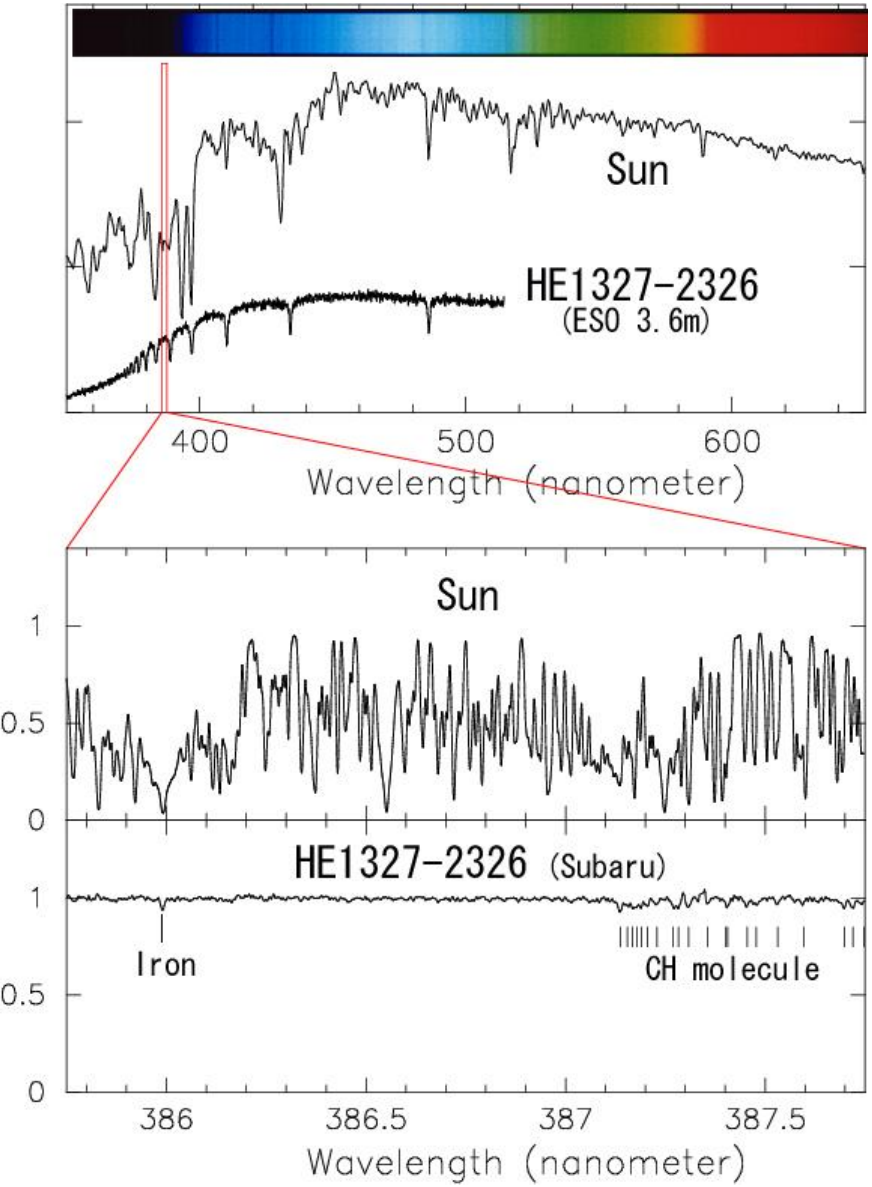
Galaxy collisions and mergings were frequent between 11 and 8 billion years ago, and elliptical galaxies were formed.

Galaxies in the current universe

The evolution of morphology of galaxies were mild between 8 billion years ago and the current.

Akiyama et al. (2007)

The Most Metal Deficient Star



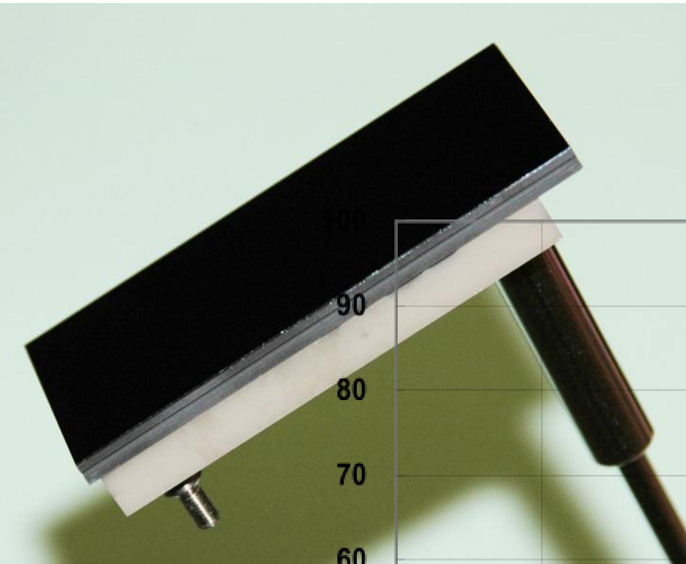
Frebel et al. (2005)
Aoki et al (2006)

(Fe/H) = (Fe/H)$_{\odot}$ / 250,000
but with excess carbon abundance

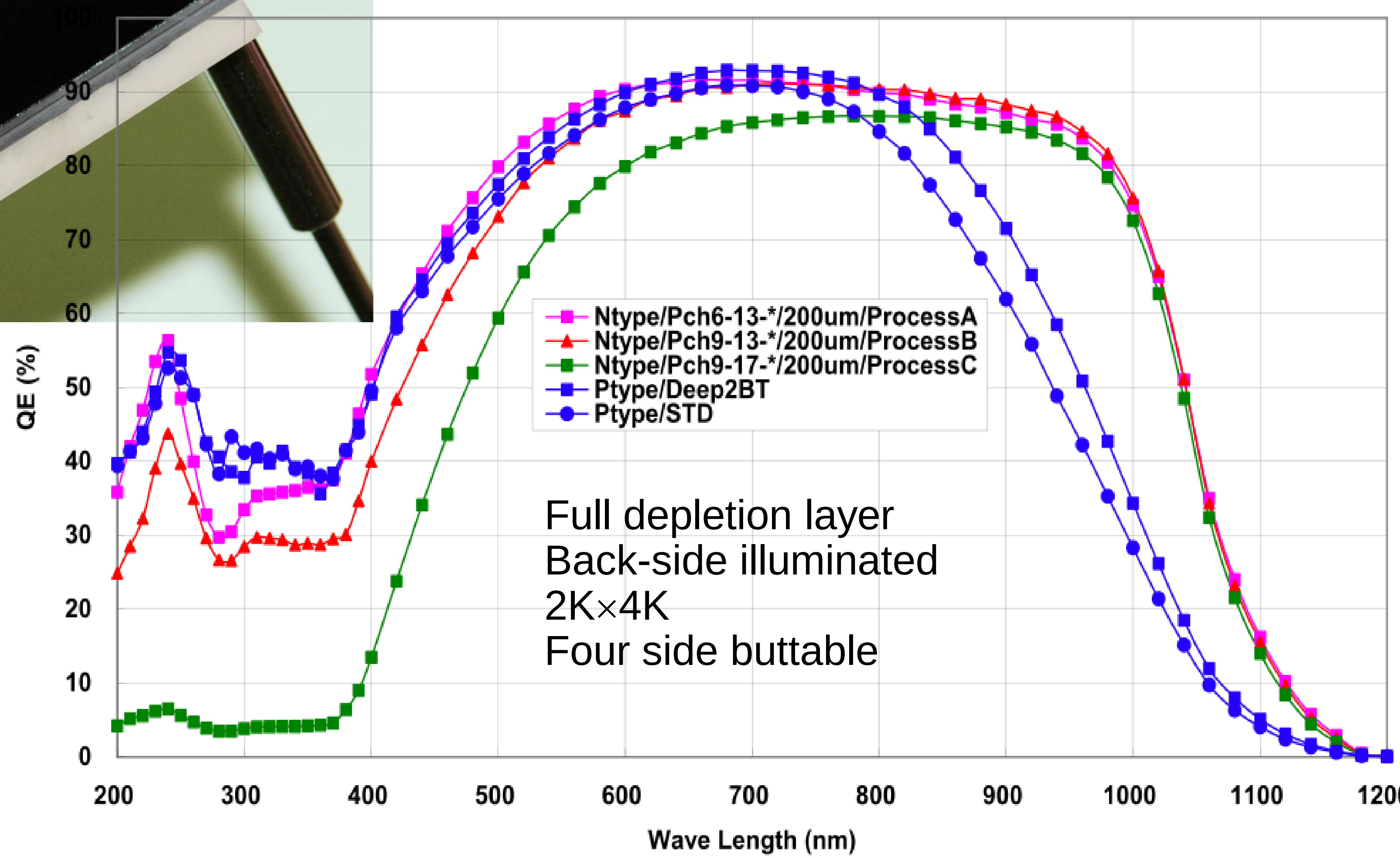
Aspherical supernova explosion (Iwamoto et al. 2005) or mass-loss from rotating massive stars (Meynet et al. 2006) of first-generation stars may be the origin of the high C abundance of HE1327-2326.

What will come next for the Subaru Telescope?

Full Depletion Layer CCDs

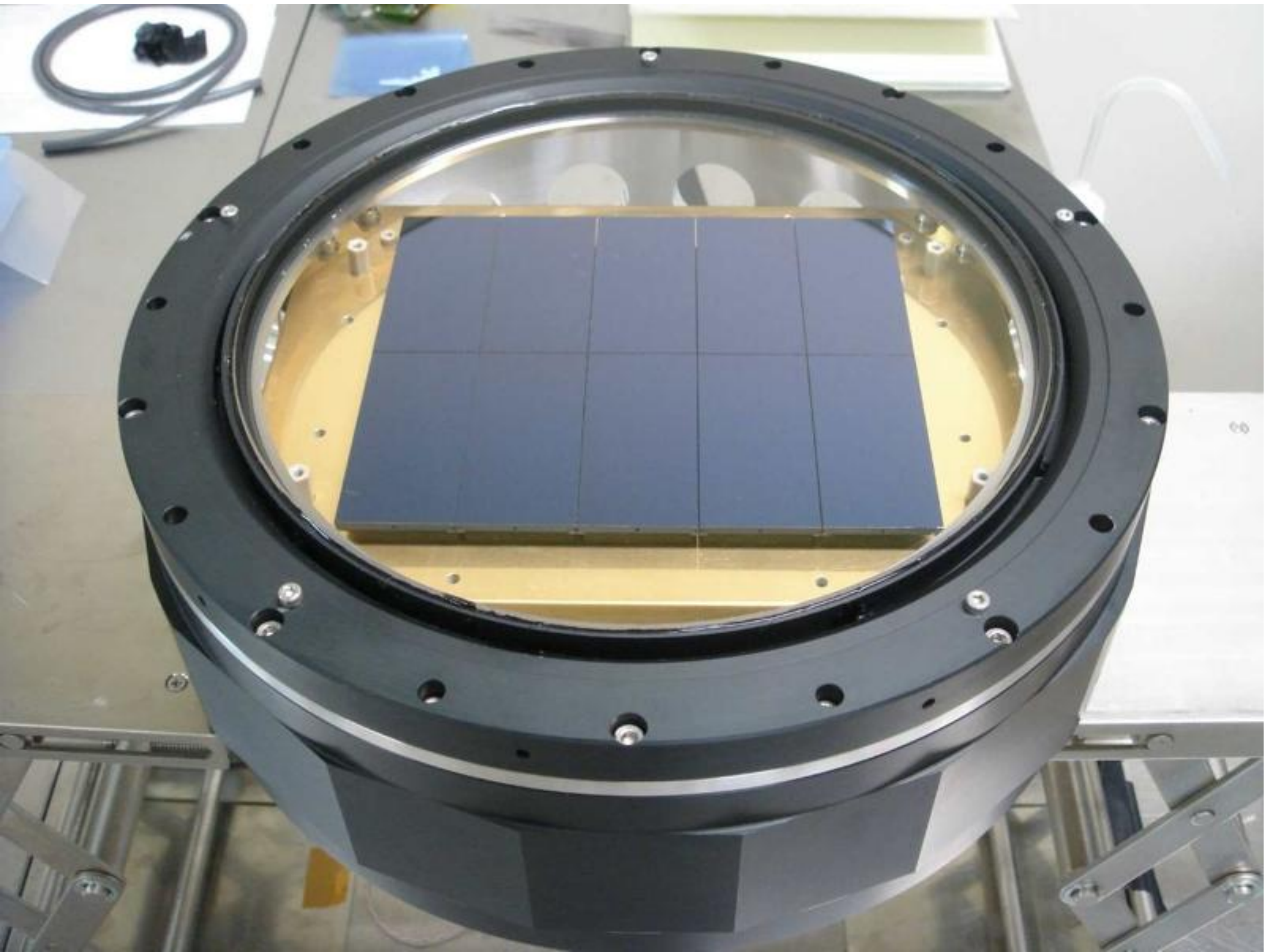


Developed by Hamamatsu Photonics-NAOJ collaboration



Full depletion layer
Back-side illuminated
2K×4K
Four side buttable

Suprime-Cam with Full Depletion Layer CCDs

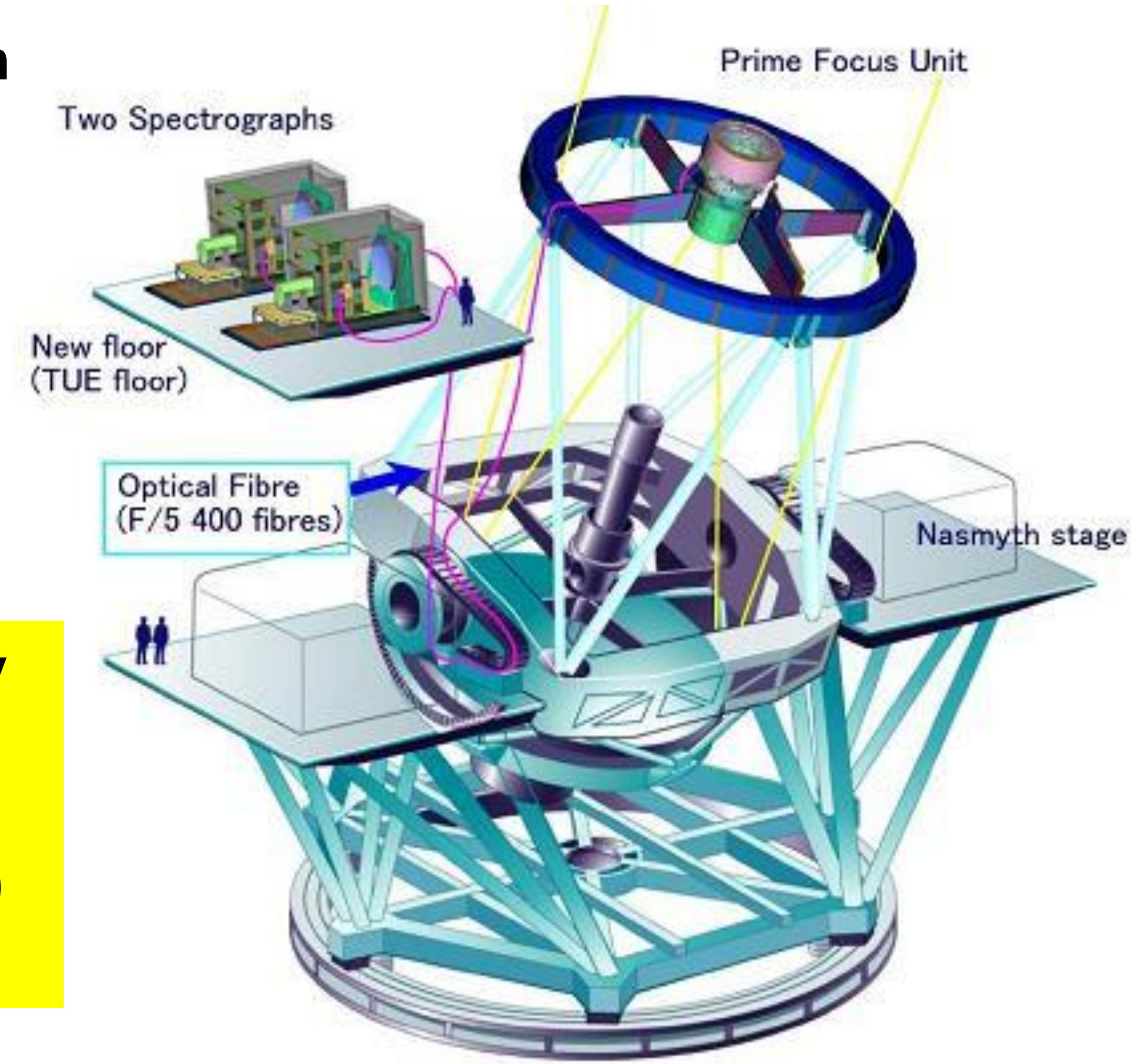


Available from summer 2008

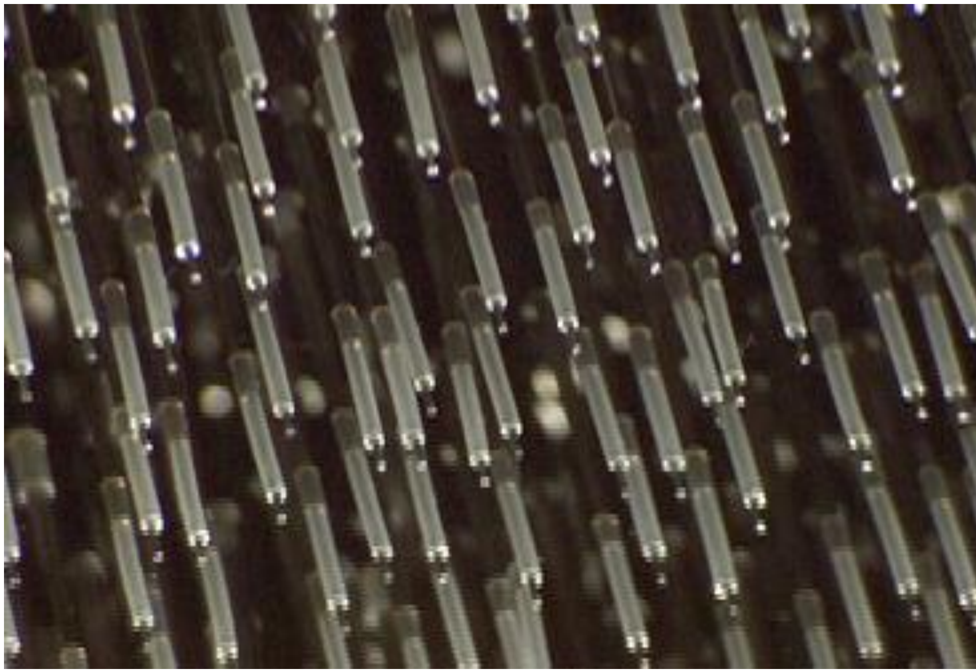
FMOS
Fibre Multi-Object Spectrograph

Wavelength: **0.9 – 1.8 μm**
Field of View: **30 arcmin**
Multiplicity: **400 spectra**
OH-airglow suppression
Spectral resolution:
R=500 & 2200

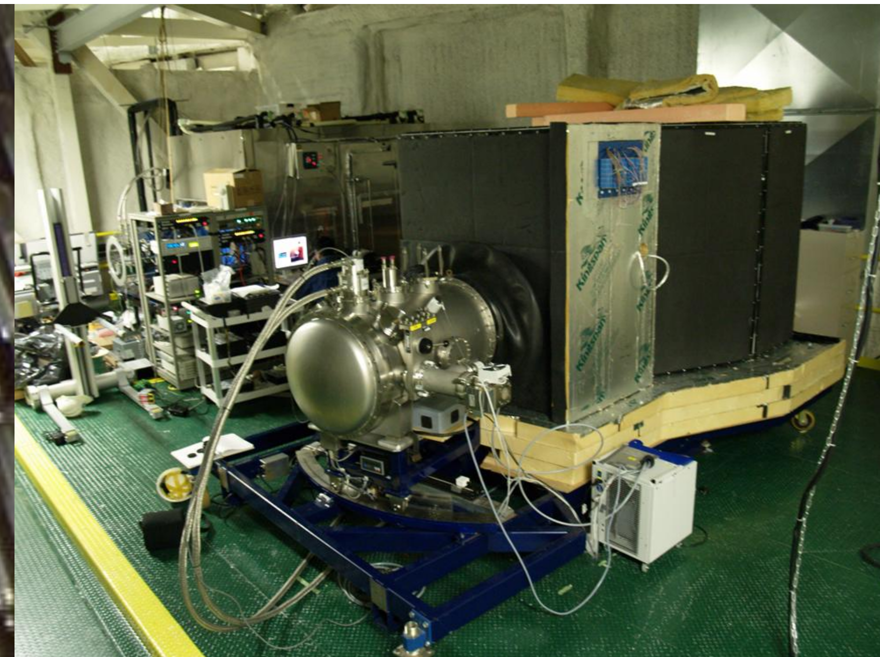
FMOS will be the only instrument that can make near-infrared spectroscopy of >100 objects at a time.



FMOS

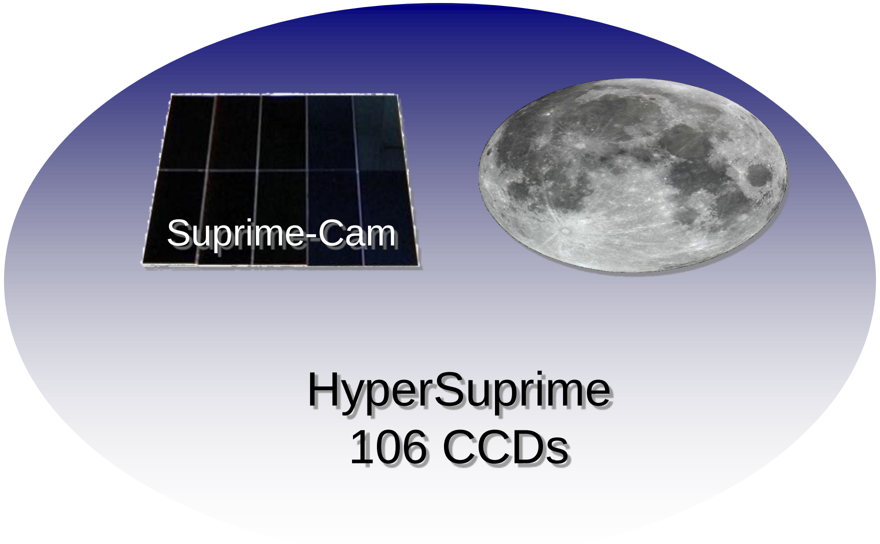


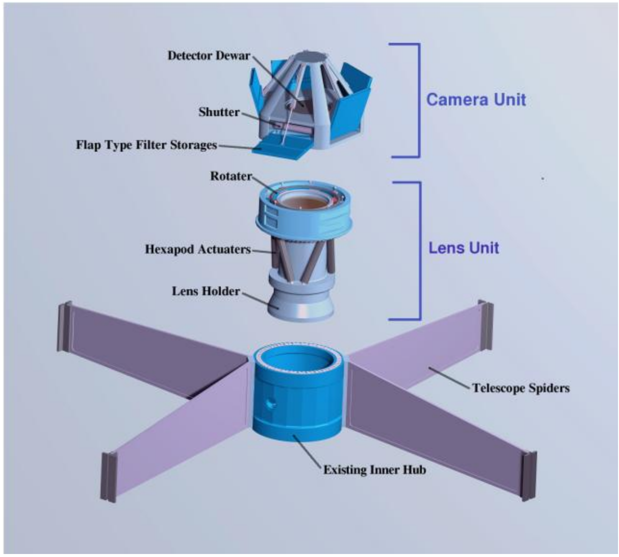
Echidna, a 400 fibre positioner



Two spectrographs for 400 spectra

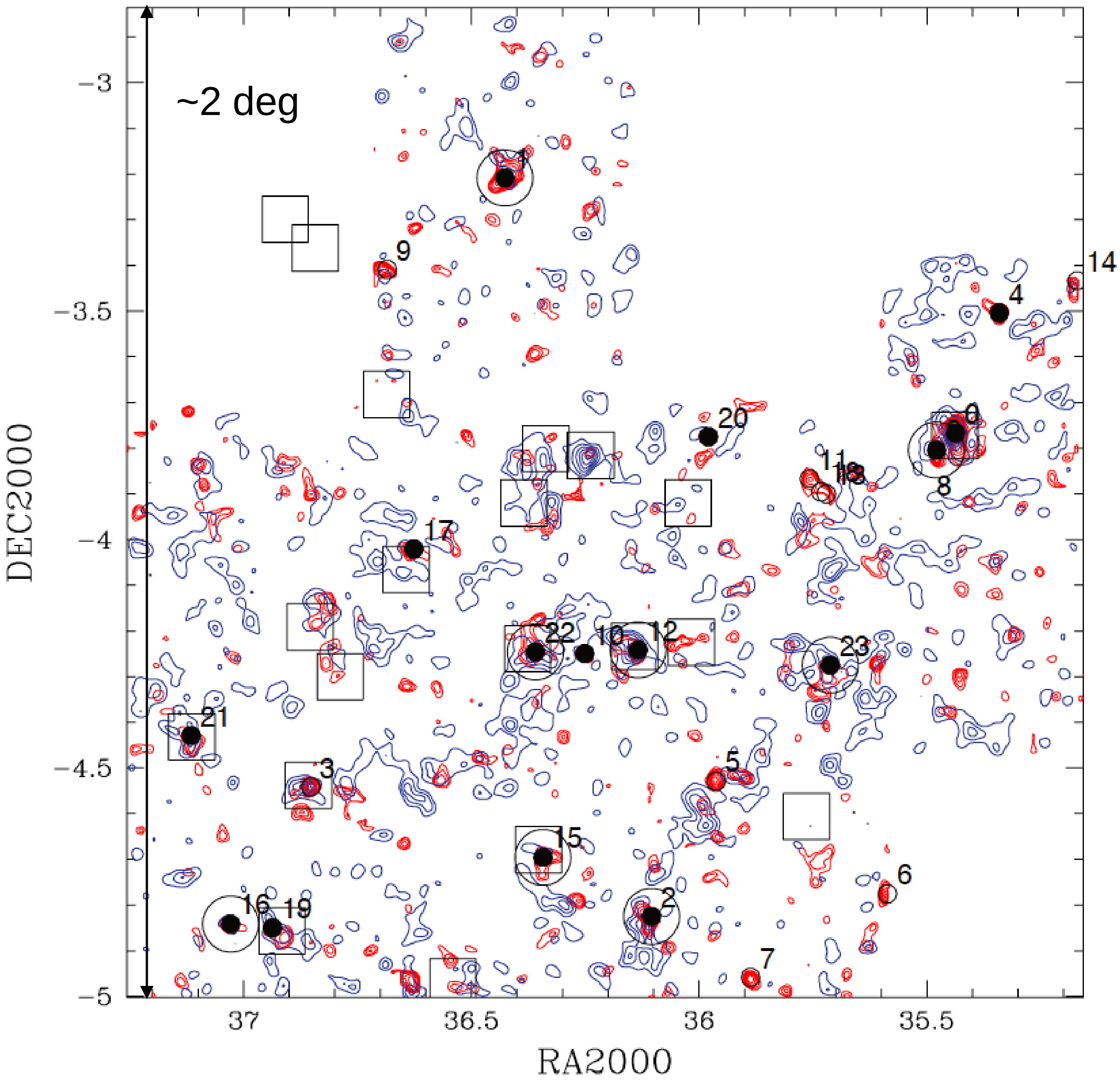
Hyper Suprime-Cam





- Conceptual design studies of the camera and top unit modification are underway
- Conceptual design review in a few months
- FOV: 1°.5
- Collaboration with the University of Tokyo, KEK, ASIAA (Taiwan) and Princeton University.

A Blind Cluster Search



Peaks of mass distribution probed by weak lensing agree with those of galaxy distribution

Mass

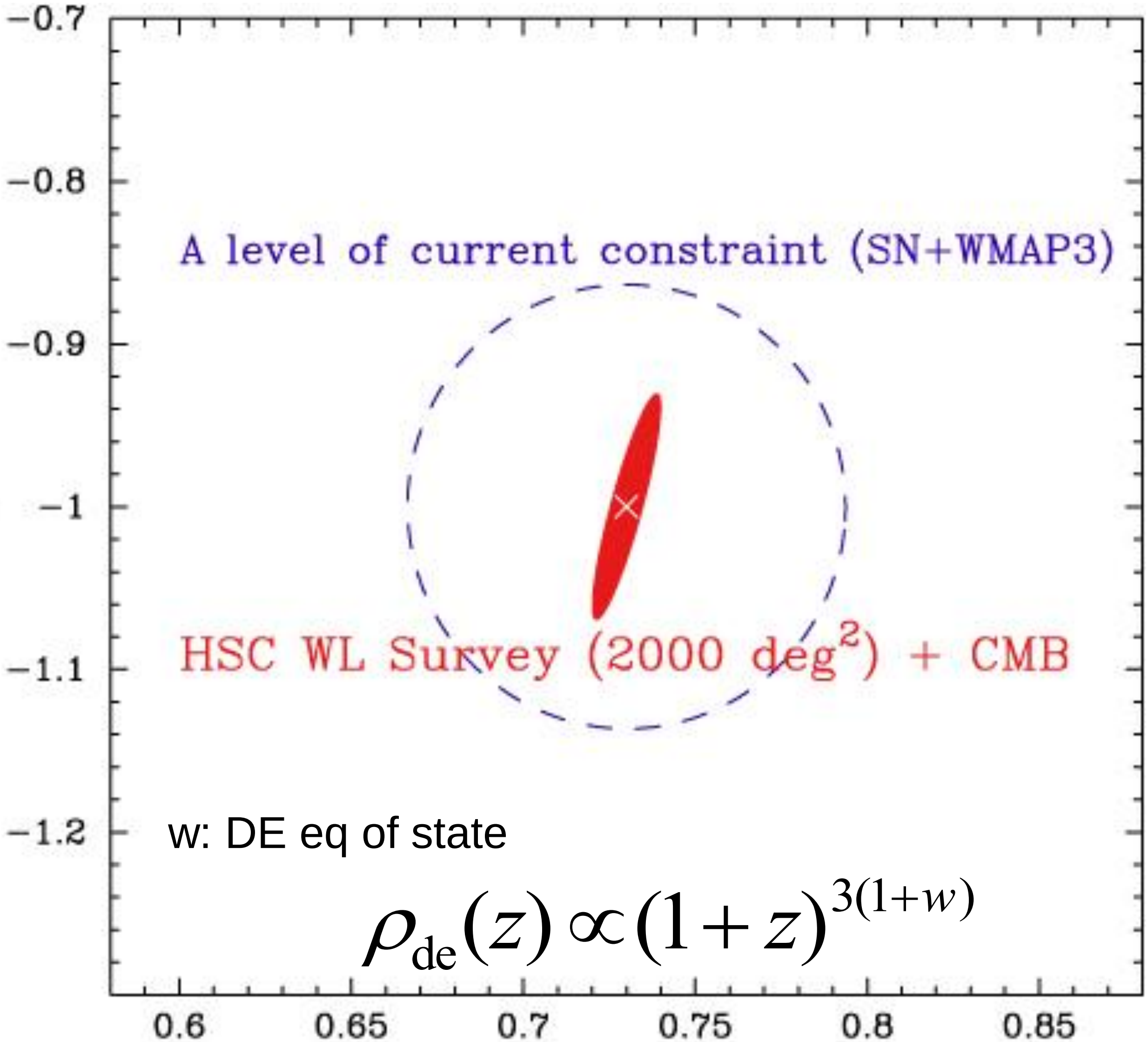
Light (galaxies)

Secure halos

X-ray selected

Miyazaki et al. (2007)

Expected Dark Energy constraint



w: DE eq of state

$$\rho_{\mathrm{de}}(z) \propto (1+z)^{3(1+w)}$$

DE equation of state: w

DE density parameter: Ω_de

Takada & Jain (2004)

Summary

- Subaru Telescope has a unique capability in wide field imaging with excellent image quality among the current 8-10 m class optical-infrared telescopes
- Essential contribution has been made with Subaru Telescope in the field of observational cosmology such as the discoveries of the most distant objects (galaxies, clusters, GRBs, ...), oldest stars, dark matter distribution in 3D, etc.
- Subaru Telescope will play an important role in understanding the dark matter and dark energy through its future surveys with unique instruments.