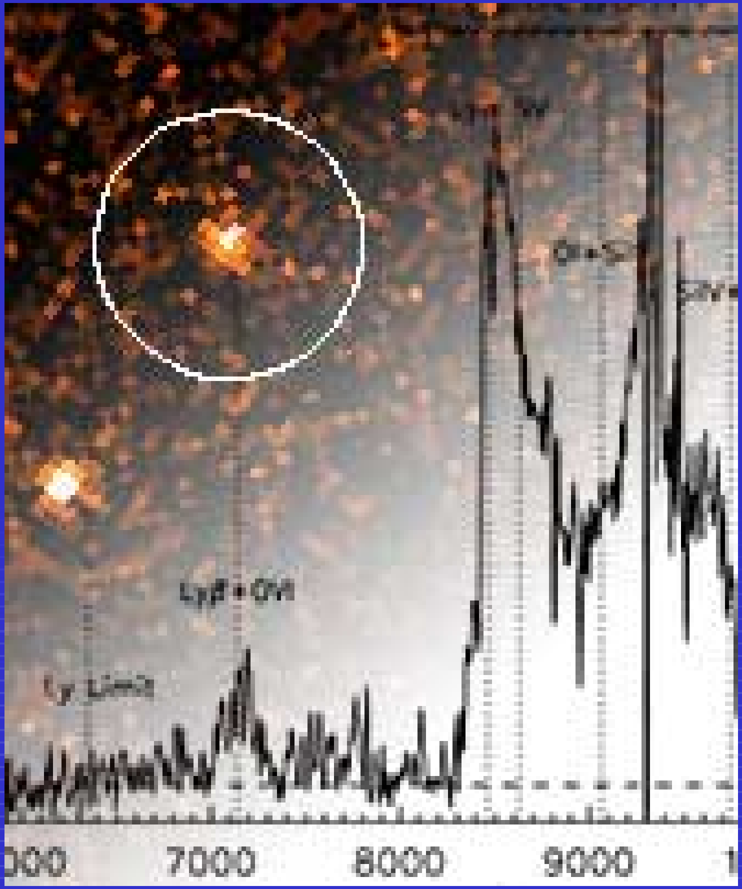
Discovery of a new QSO

z=5.96 with the Subaru telescope

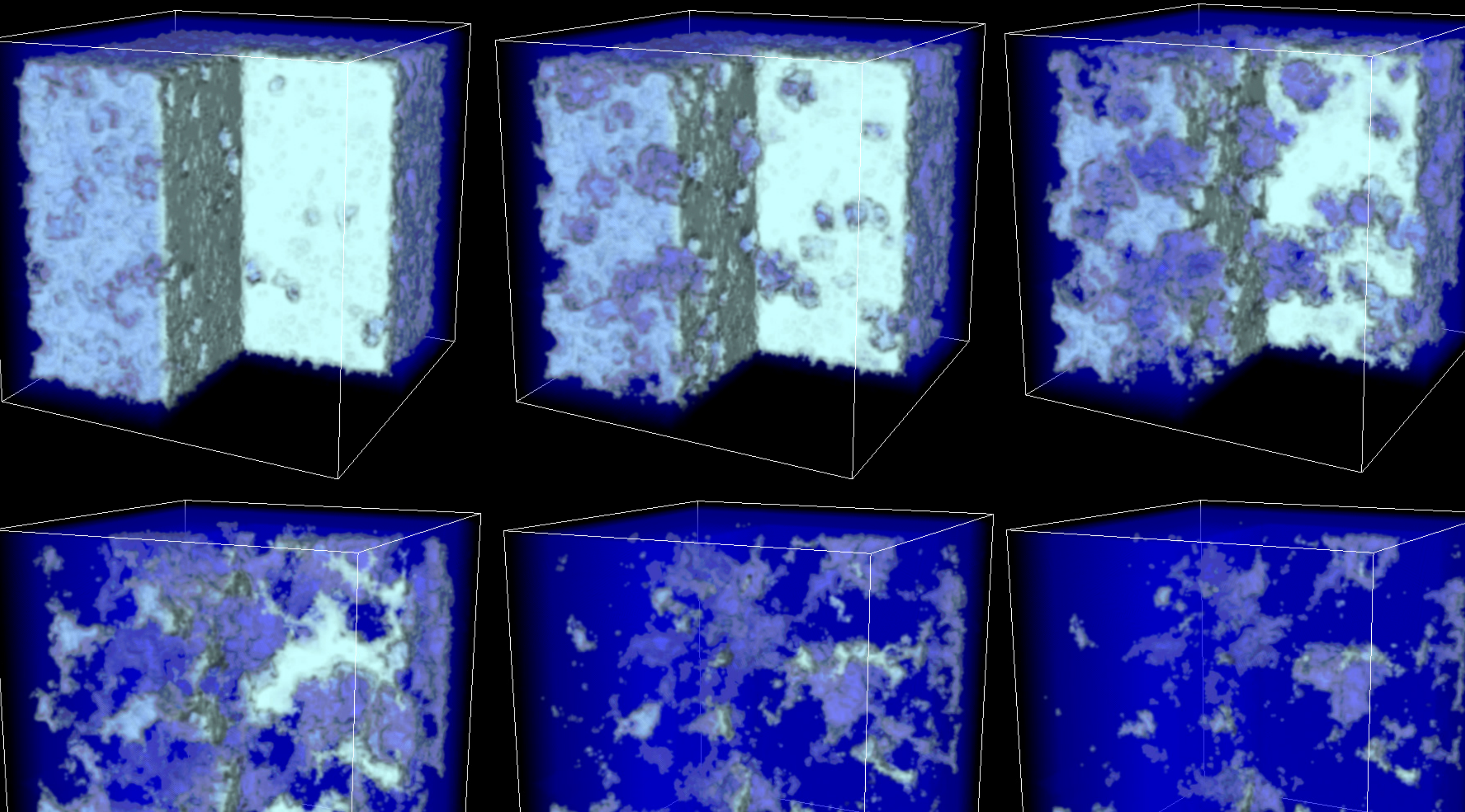


Tomo Goto (Japan Aerospace Exploration Agency)

Why high-z QSOs are important?

1. Directory prove re-ionization of the Universe
2. QSO/AGN evolution
3. Formation of super massive black holes

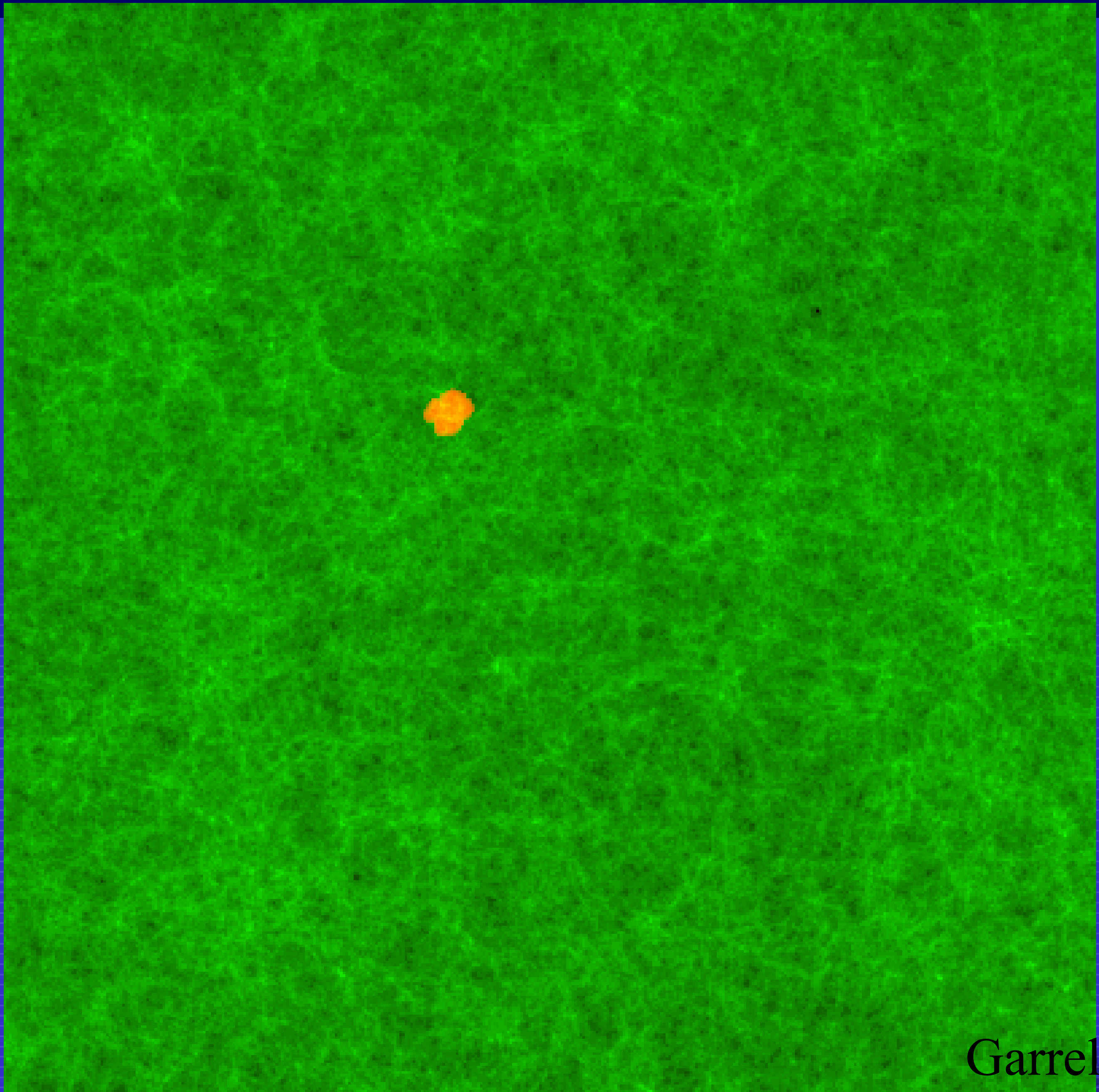
Reionization of the Universe



When and how our Universe started?

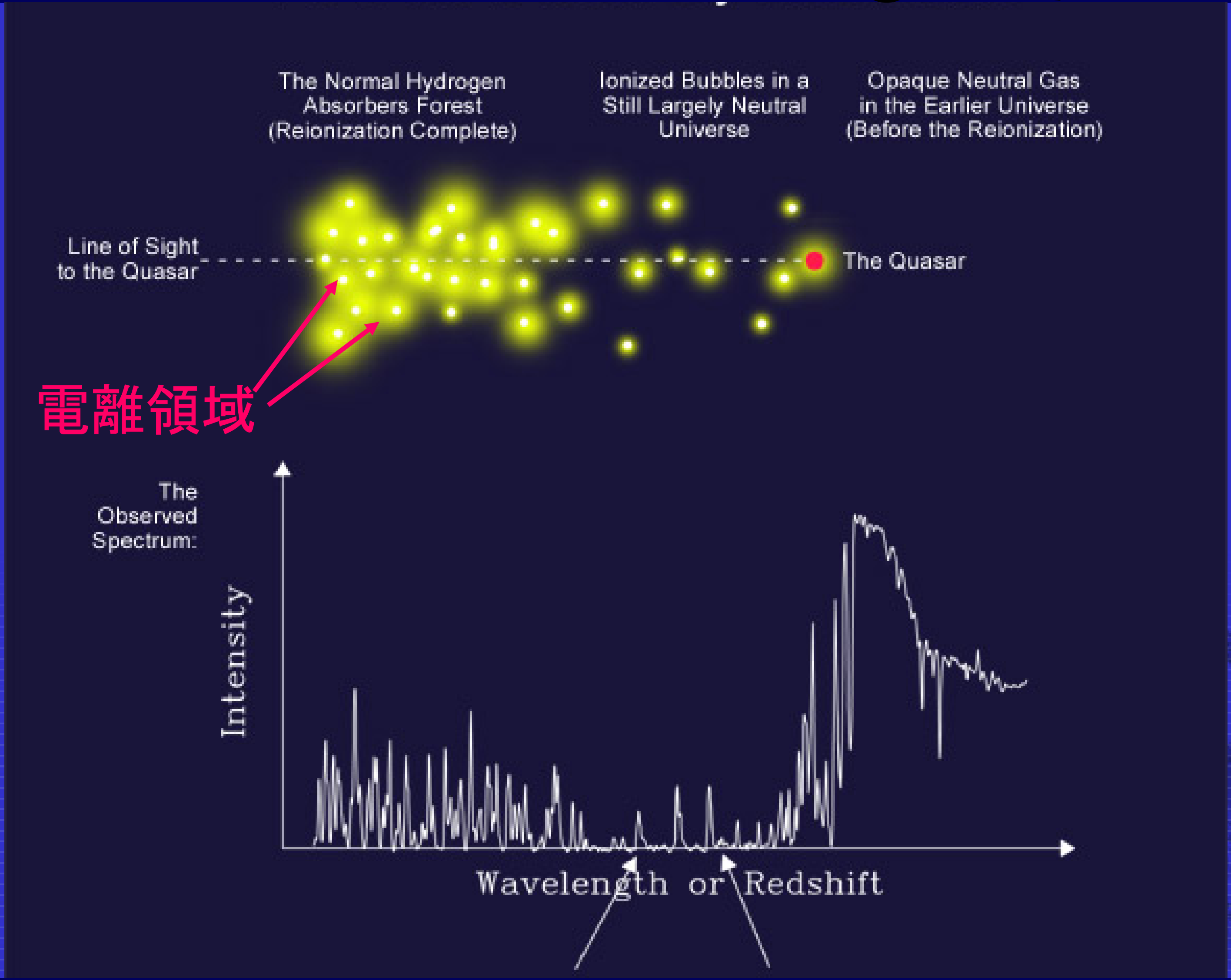
(Jelle Ritzerveld & Rien van de Weijgaert & Vincent Icke)

Visualizations of the Geometry of Reionization



Garrelt Mellema.

Reionization through QSO



Galaxies are too faint.
GRBs disappear too quickly.

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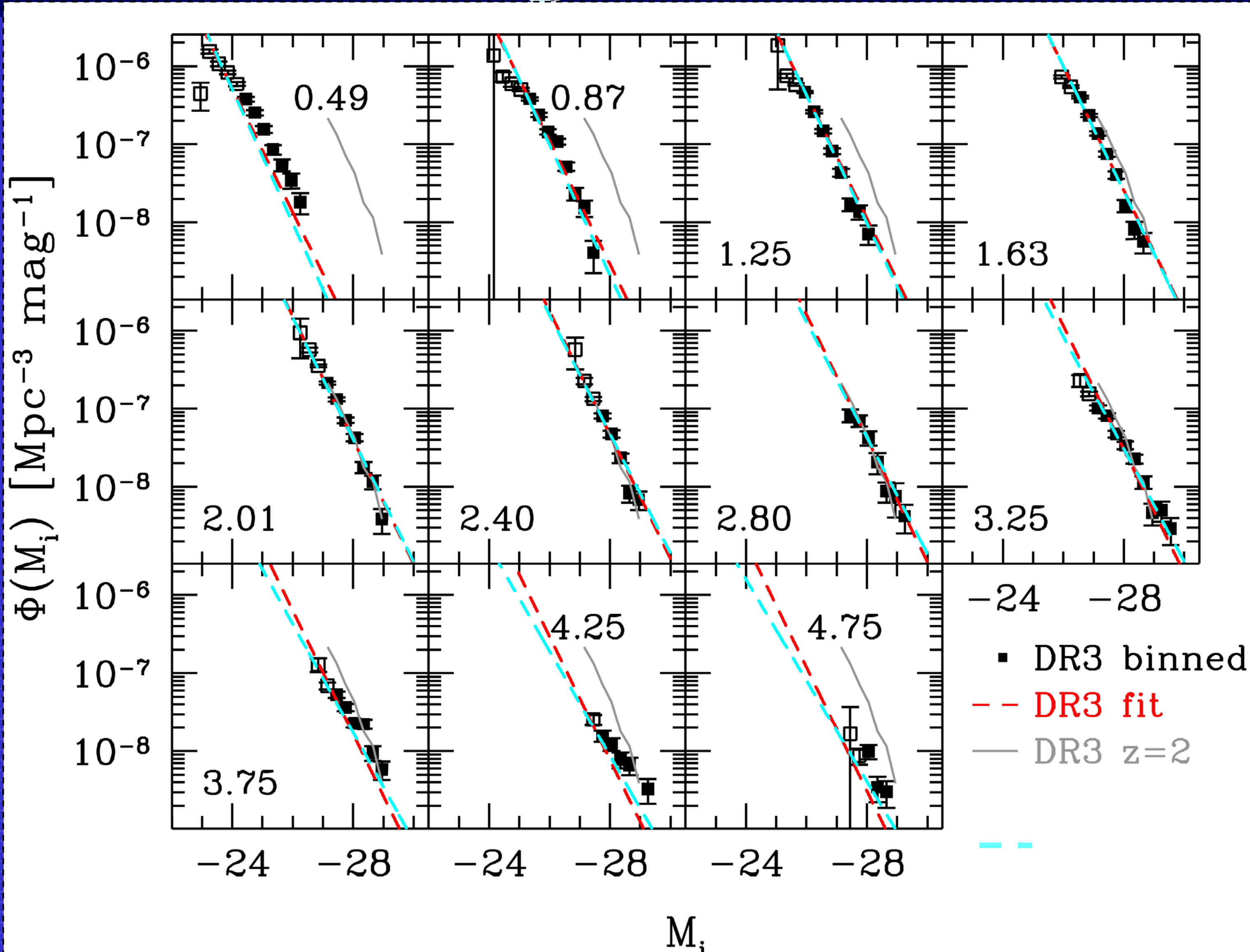
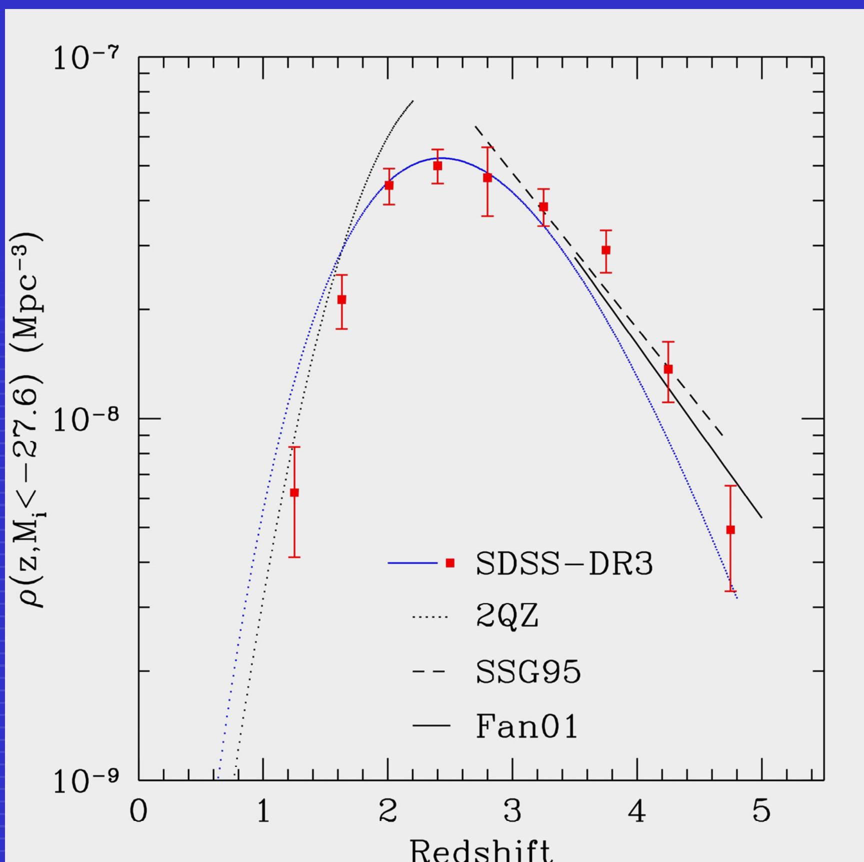
Systematic flattening of the LF above z~3

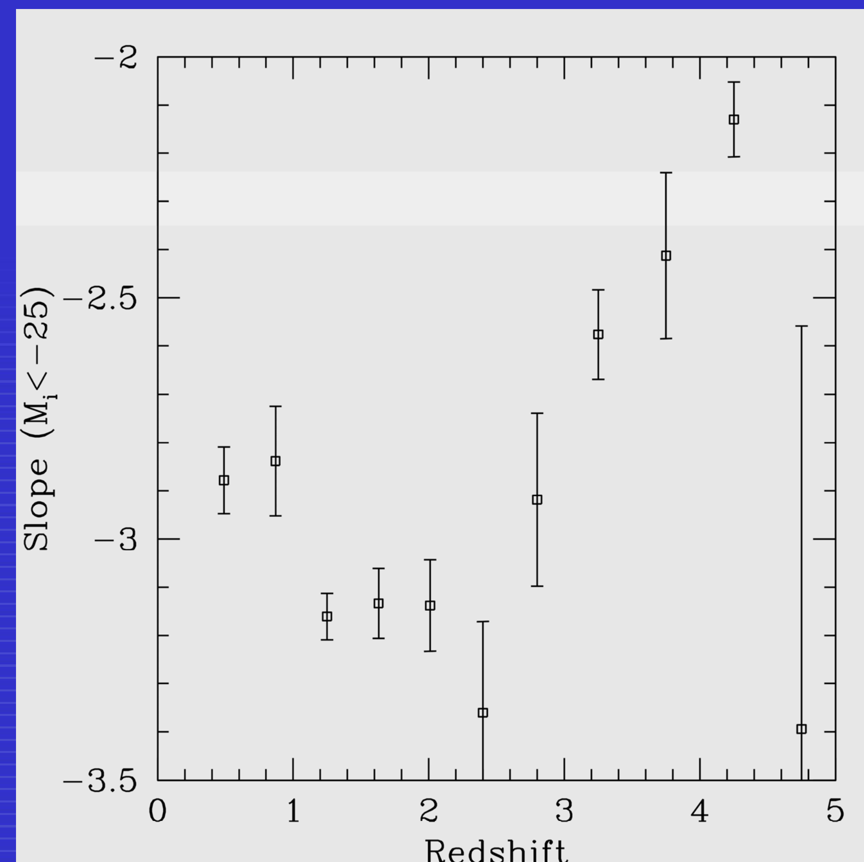


Fainter QSOs at z>5 are needed
to investigate the evolution of QSO LF

Comoving number density peaks between z=2 and 3

LF slope increases at z=3 and above.

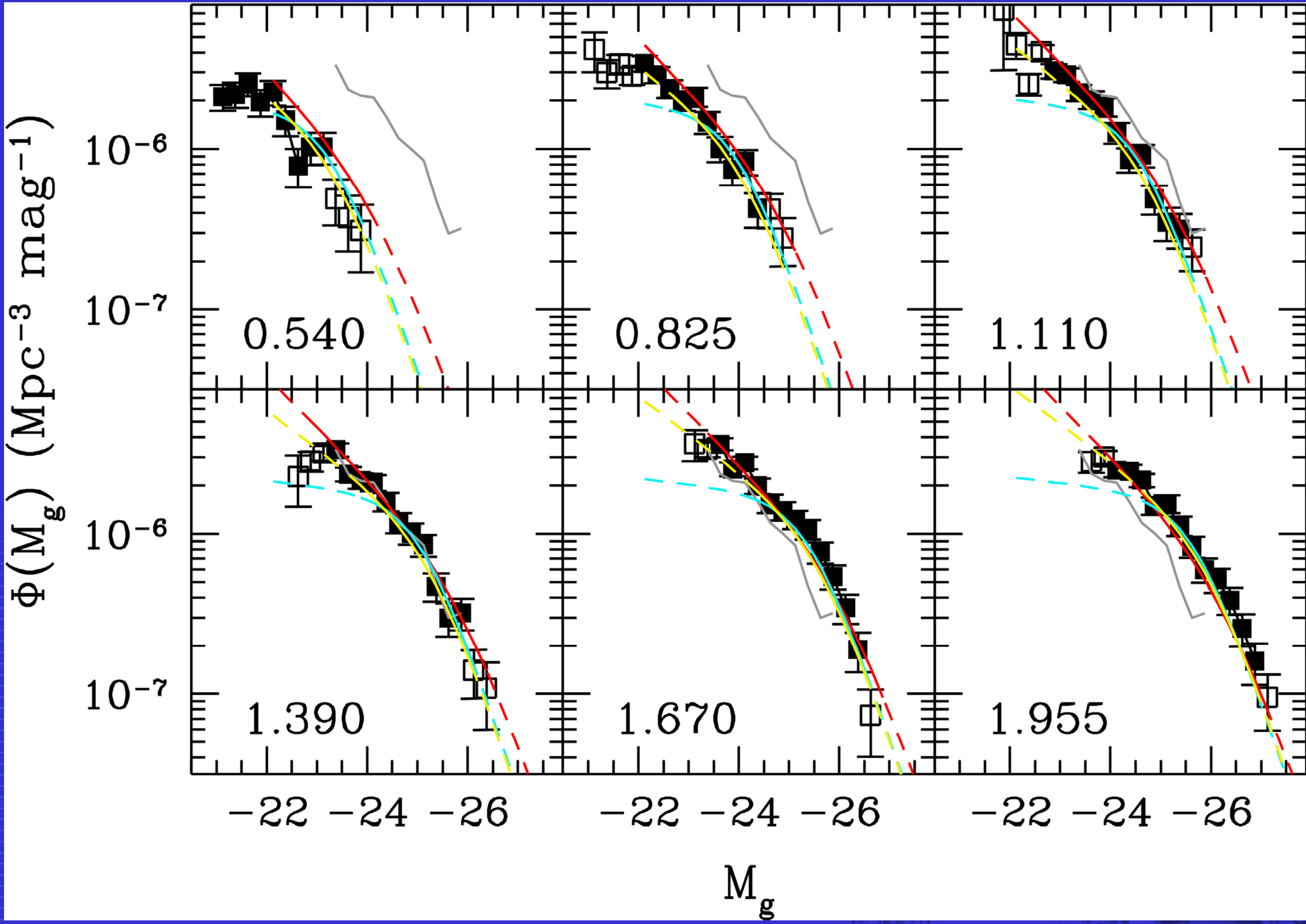




A crucial question: the shape and slope of the LF at the faint end…

5645 quasars with $g < 21.85$ selected from SDSS imaging, observed with 2dF at AAT. UV excess sources, almost all with $z < 2.5$. Best-fit slope β is -1.45 at faint end.

Fitting these data simultaneously is a challenge for modern models of quasar evolution.



Richards et al. 2005a MNRAS

Fainter QSOs at high-z are needed to investigate the evolution of QSO LF

Why high-z QSOs are important?

1. Directory prove re-ionization of the Universe
2. QSO/AGN evolution
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Constraining the formation of super massive black holes.

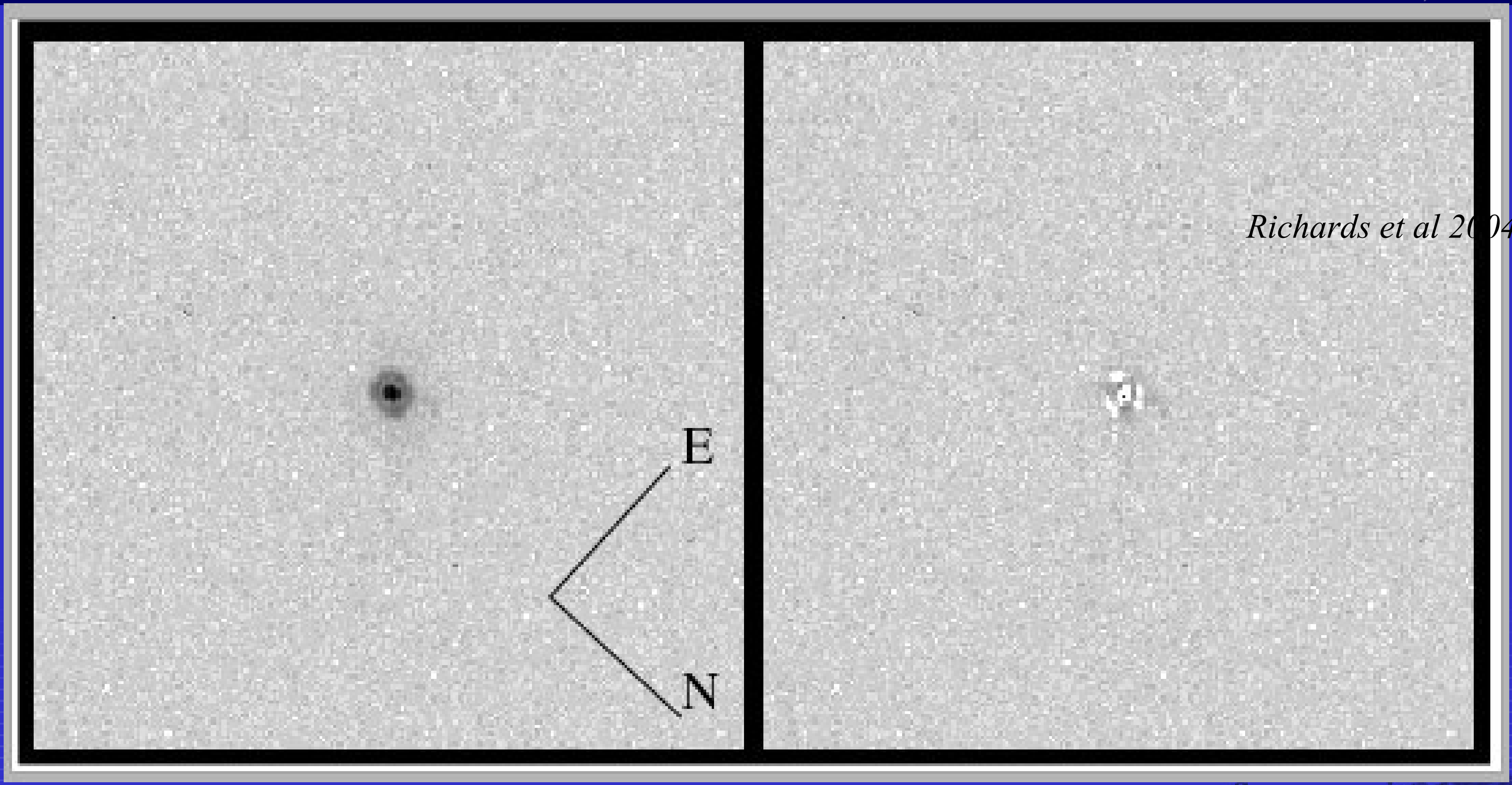
- z~6 QSOs are at the young Universe of 1Gyr old.

- M_{1450}=-27mag：Can a black hole of billion Msun be formed in 1 Gyr? Strong constraints to the black hole formation theory（Haiman 2006,MmSAI,77,629）

Are high-z QSOs gravitationally lensed (and magnified)?

If yes, luminosity/mass are overestimated.

HST ACS images are consistent with a point source.



Richards et al 2004,2005

ACS image of the quasar

Residuals after subtracting off the PSF

high-*z* QSOs do not seem to be magnified by the lens.

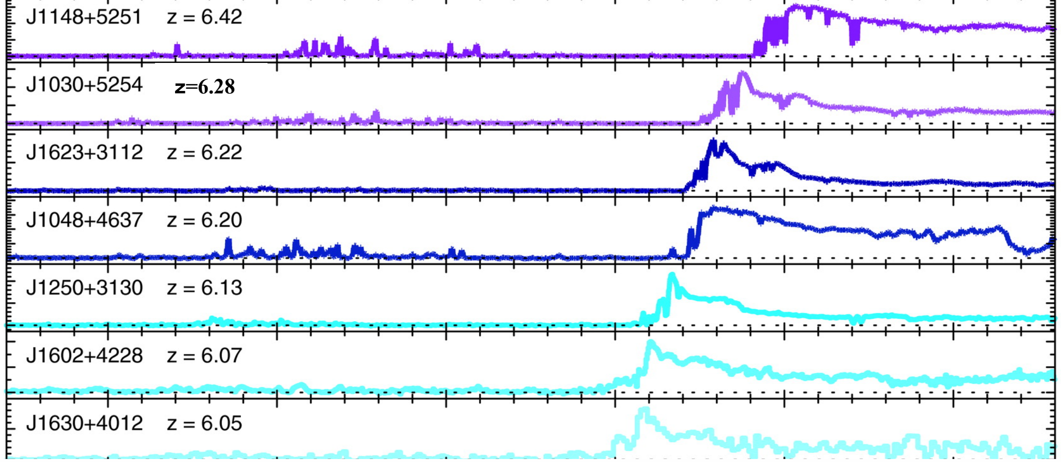
Luminosity is still～-27mag

How we form billion Msun black holes in 1 Gyr?

=> Theoretical challenge.

Current status of high-z QSO surveys

High-z QSO surveys in the past



←Remaining flux(White et al. 2003,AJ,12

←Complete Gunn-Peterson trough

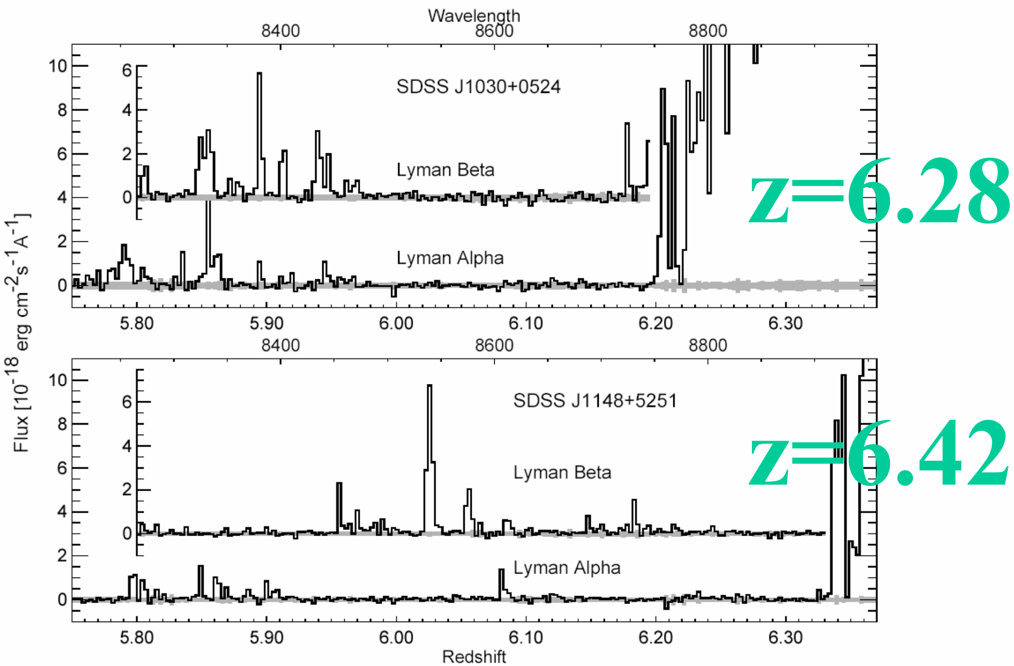


FIG. 4.—Close-up of the Lyα and Lyβ GP troughs, aligned in redshift, at a resolution of $R = 2500$ (120 km s^{-1}). Note that these spectra have not been denoised, so the pixel values are independent. The top axis shows the wavelength for Lyα, and the shaded band shows 1 σ errors. The absorption is extraordinarily black for SDSS J1030+0524, but SDSS J1148+5251 shows evidence of weak emission in the trough, especially at Lyβ. The strong peaks in the Lyβ spectrum at $z = 6.02$ and 6.06 and are discussed in the text; they could be Lyα emission from a foreground galaxy at $z = 5$.

→Reionization depends line-of-sights

→More QSOs in different line-of-sight are needed to fully probe the reionization of the Universe.

The resolution of these questions will have to wait for the discovery of additional z>6 quasars. (Richard L. White)

Fan X, et al. 2006.

Remaining flux in z=6.42 QSO coming from a foreground galaxy?

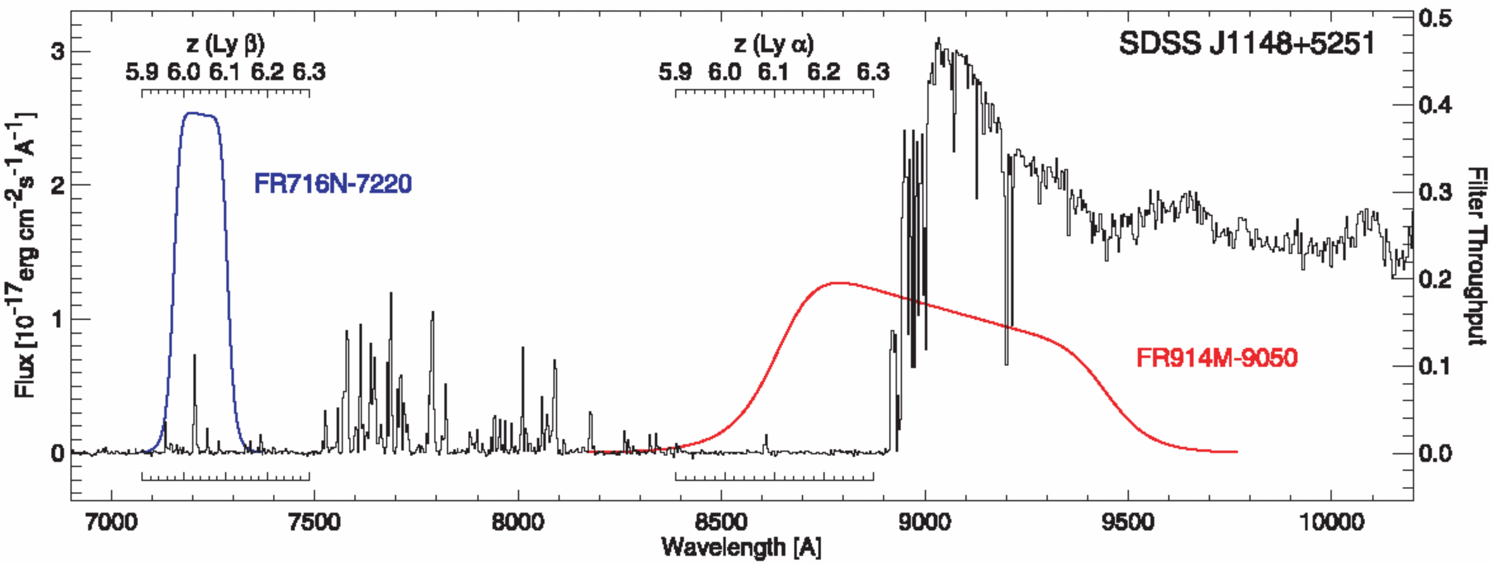


FIG. 1.—Keck Echellette Spectrograph and Imager spectrum of SDSS J1148+5251 (White et al. 2003) with the filter throughputs for our *HST* ACS observations. The narrow blue filter (FR716N-7220, $\lambda_c = 7219$ Å, and FWHM = 134 Å) is placed in the dark Lyβ absorption region around $z = 6$ and isolates the narrow emission peak at $\lambda = 7205$ Å. The broader red filter (FR914M-9050, $\lambda_c = 8980$ Å, and FWHM = 780 Å) encompasses the quasar's strong Lyα emission line and continuum and is used as a reference image.

No foreground galaxy.

The flux really comes from the QSO through IGM.

Remaining flux in z=6.42 QSO coming from a foreground galaxy?

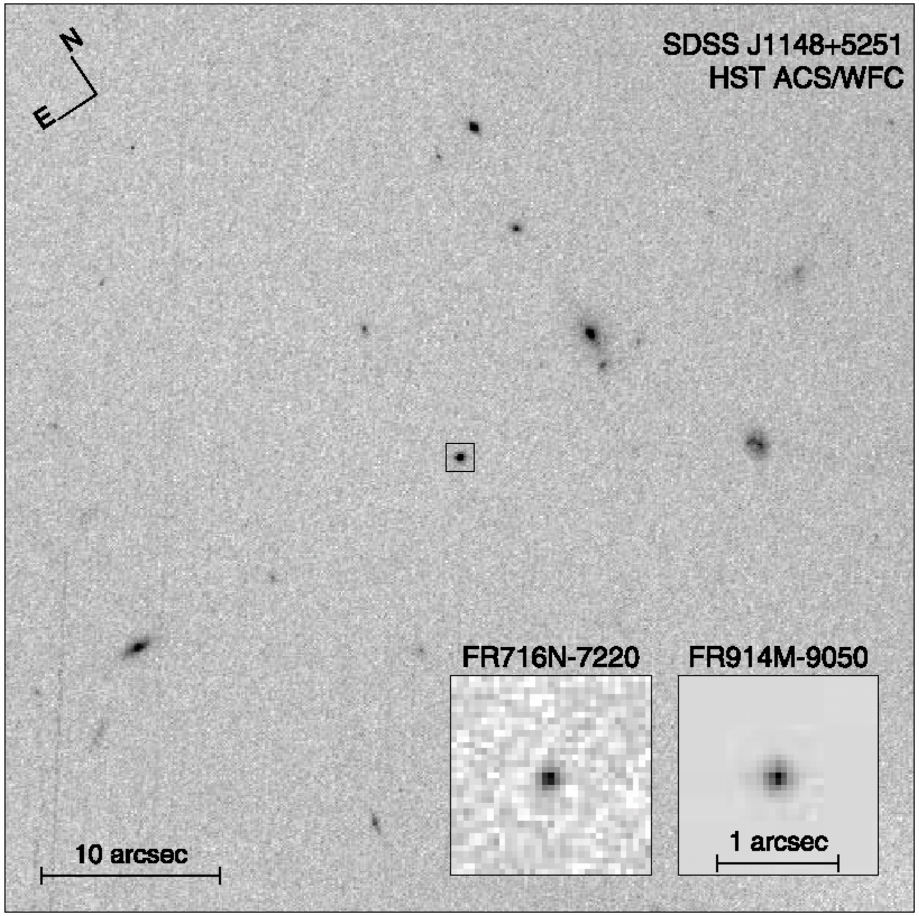
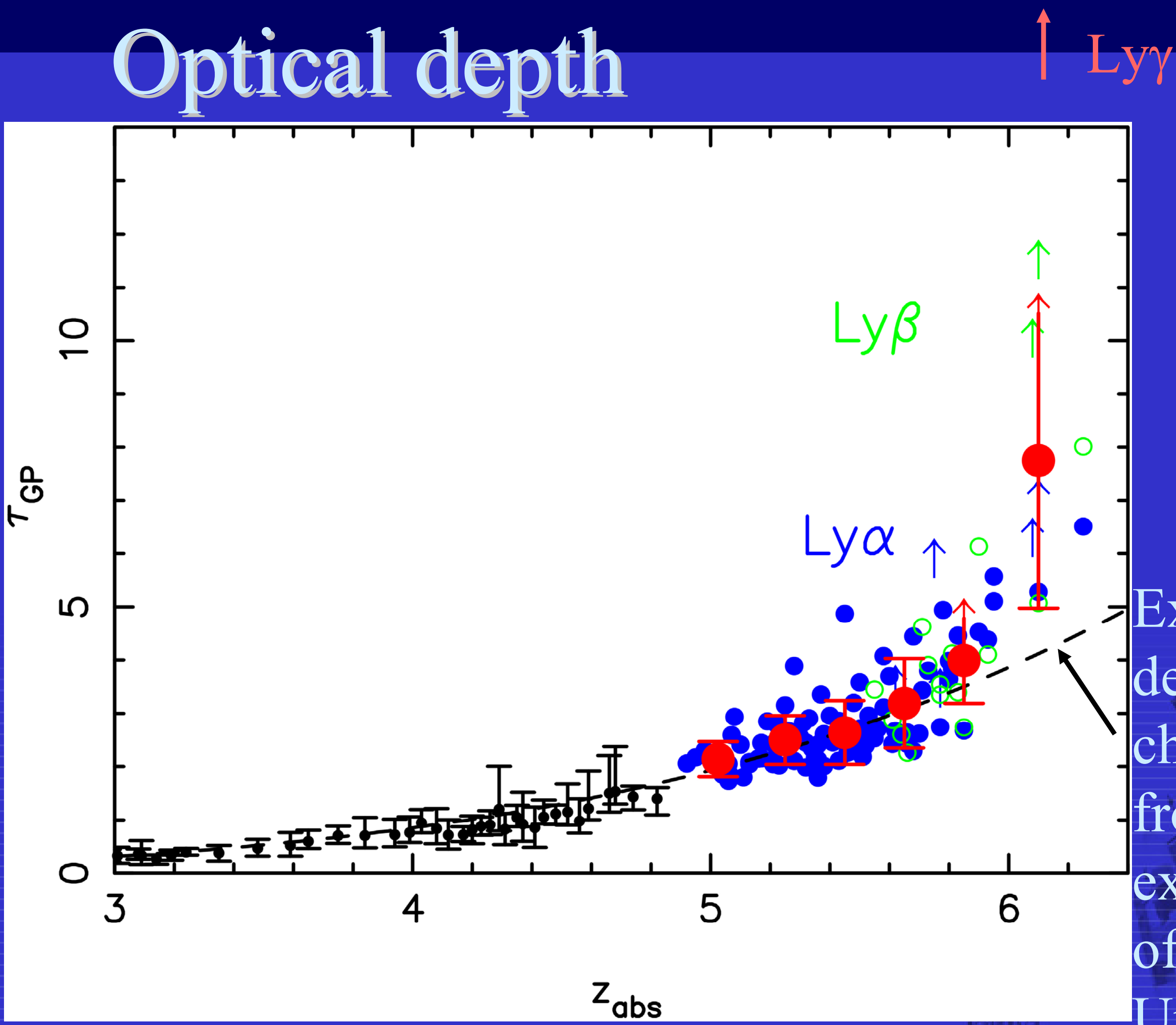


FIG. 2.—The *HST* ACS / WFC images of SDSS J1148+5251. The large image shows the detection image (a combination of the two filters), while the insets depict the quasar image in the two filters. The quasar appears unresolved, and the images coincide to high accuracy.

No foreground galaxy.

The flux really comes from the QSO through IGM.

Optical depth



Expected density change from the expansion of the Universe.

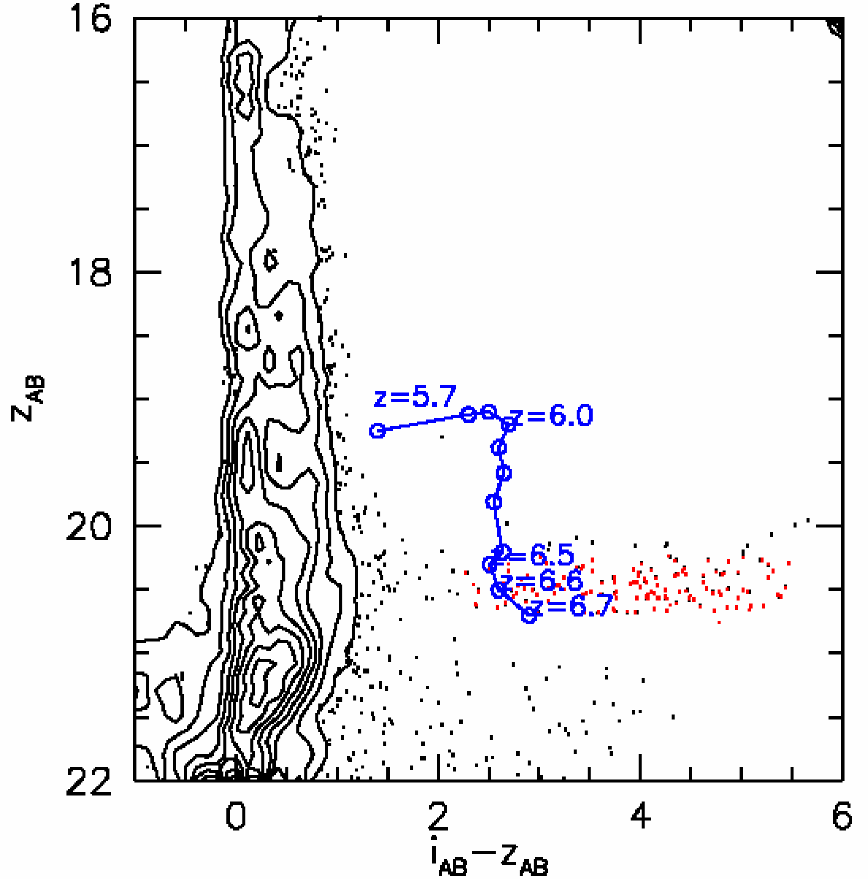
Quick change at z~5.7 ! ?

We need more QSOs at z>5.7

We need more $z>6$ QSOs.

→How do we search？

Our strategy : fainter、 toward higher redshift (z>20.2)



By product : fainter z~5.8 QSO, important to investiage LF slope.

Figure 1. (left). The $i_{AB} - z_{AB}$ vs z_{AB} color-color diagram for point sources in the SDSS. The median track of simulated $i_{AB} - z_{AB}$ color and z_{AB} magnitude for QSOs with $M_{1450} = -27$ is shown in the blue line as a function of redshift. Our candidates of highest redshift QSOs are emphasized in red dots, which are well-separated from the stellar locus ($i_{AB} - z_{AB} \sim 0.5$) and from spurious objects at $z_{AB} > 22$, forming a good targeting region to find highest redshift QSOs. In the dense regions of stellar locus $i_{AB} - z_{AB} \sim 0.5$, dots are replaced with contours for clarity. The median track illustrates that in order to find QSOs at $z > 6.43$, it is necessary to go fainter and to target objects with $z_{AB} > 20.2$, justifying the use of the 8m Subaru telescope.

20.2<z<21.0 still secure

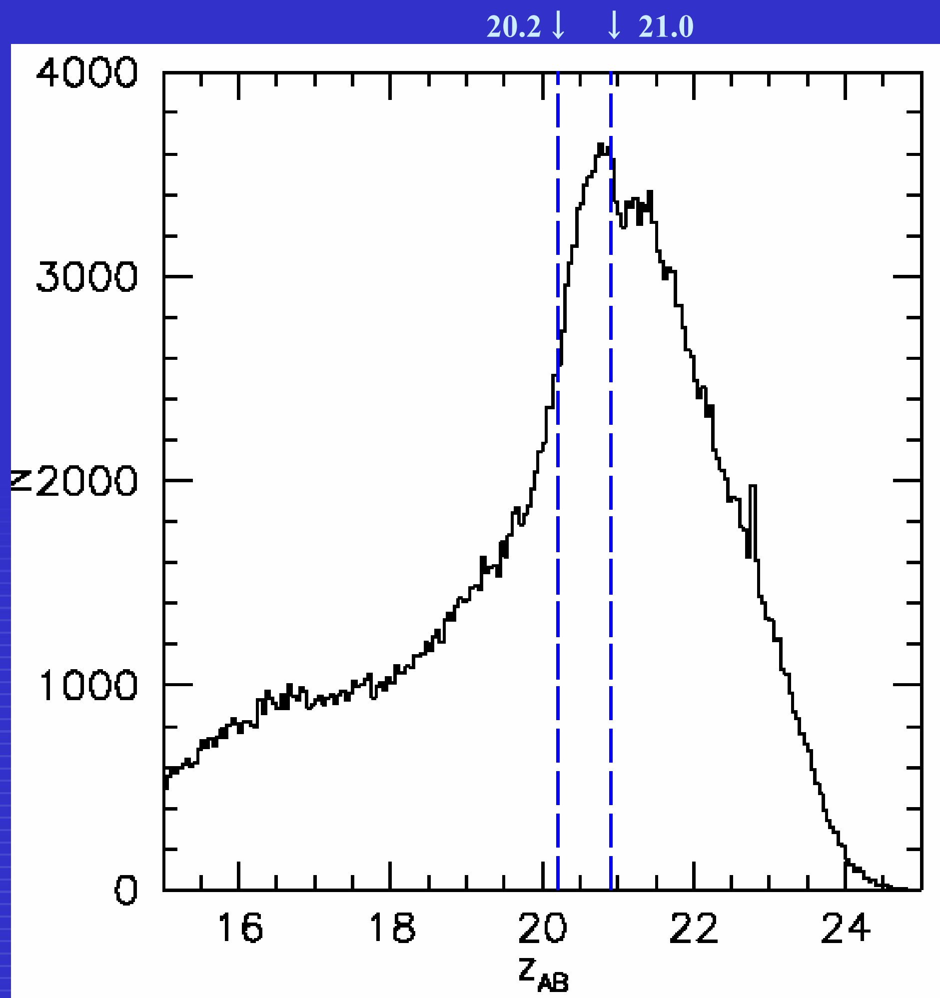


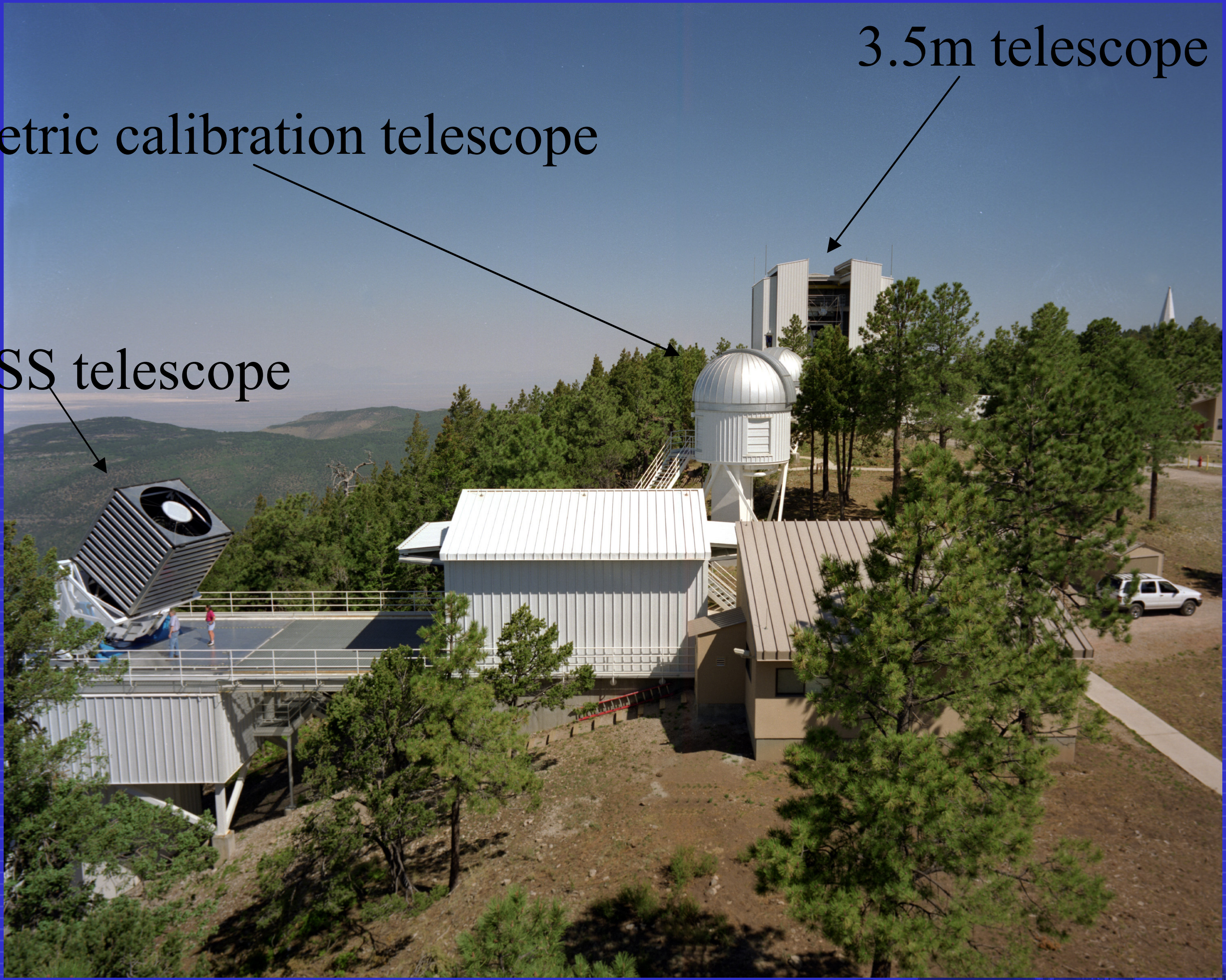
Figure 2. (right). Number counts of point-like sources in the SDSS z_{AB}-band. The magnitude range of our targets (20.2 < z_{AB} < 21.0) is shown as a region surrounded by the blue dotted lines. Note that the number counts does not drop until z_{AB} > 21.0, showing that the z_{AB}-band detection is still reliable in our magnitude range.

Method:

1800 million objects to a few dozen candidates

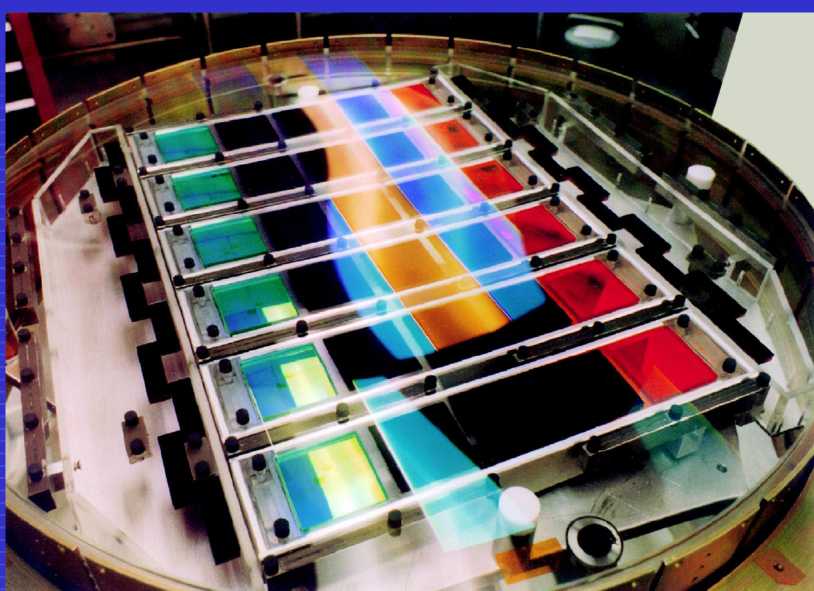
1. ***z***-band only detections in the SDSS
2. Cosmic-ray rejection（important）
3. J-band imaging to reject brown dwarfs (brown dwarfs are also interesting objects.)
4. Spectroscopy with the Subaru

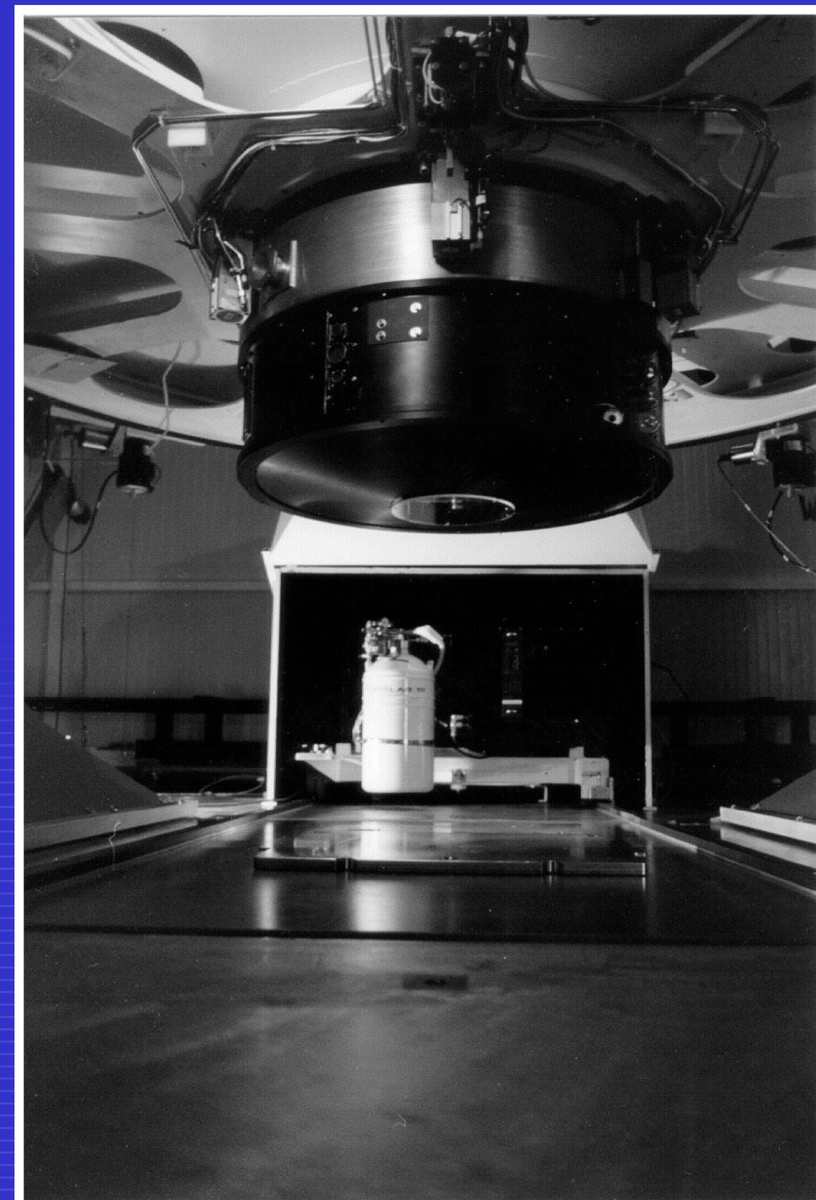
The Apache Point Observatory
Sunspot, New Mexico



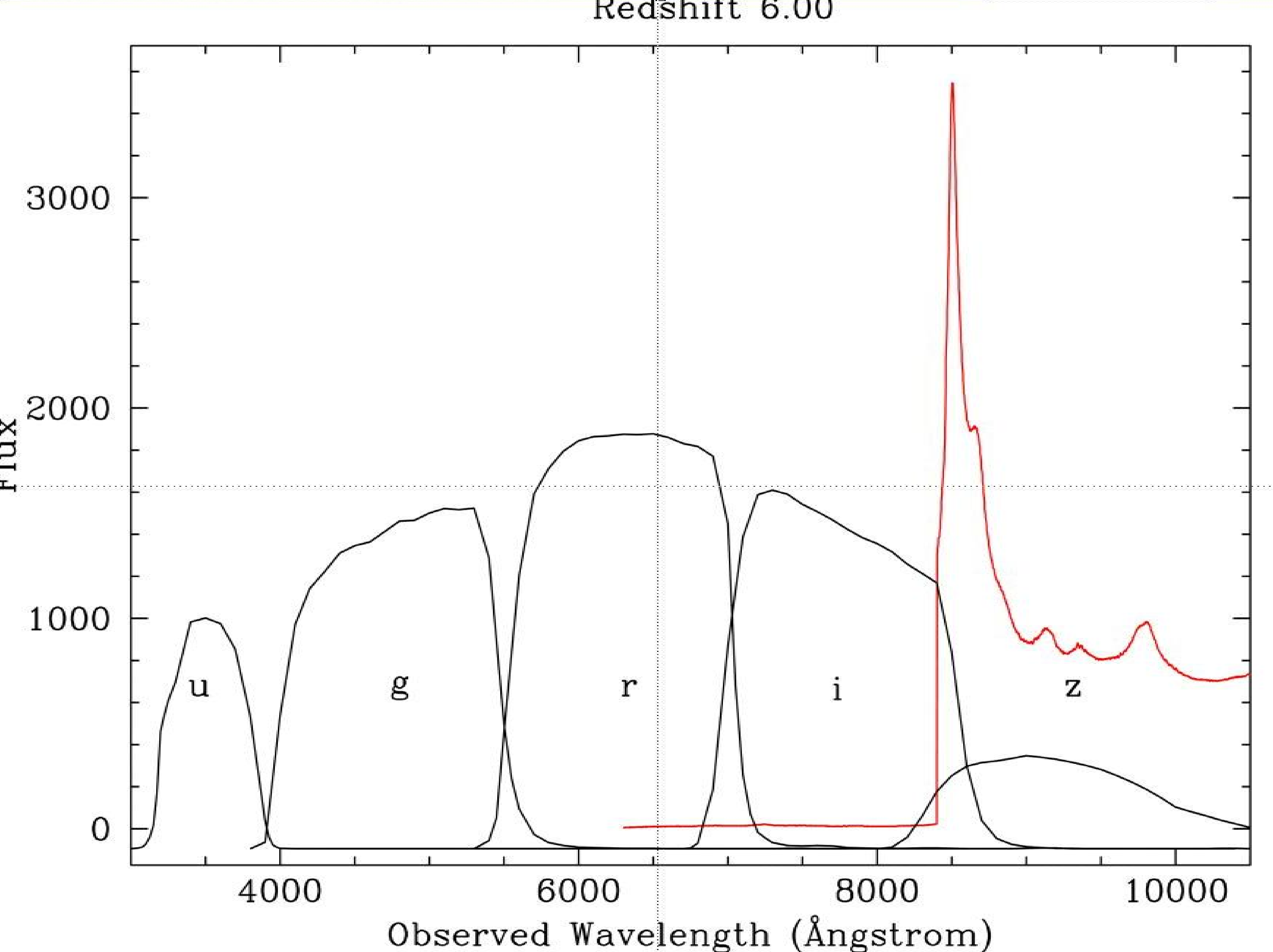
SDSS imaging camera

Interior view of the camera, showing the filters on the corrector plate.





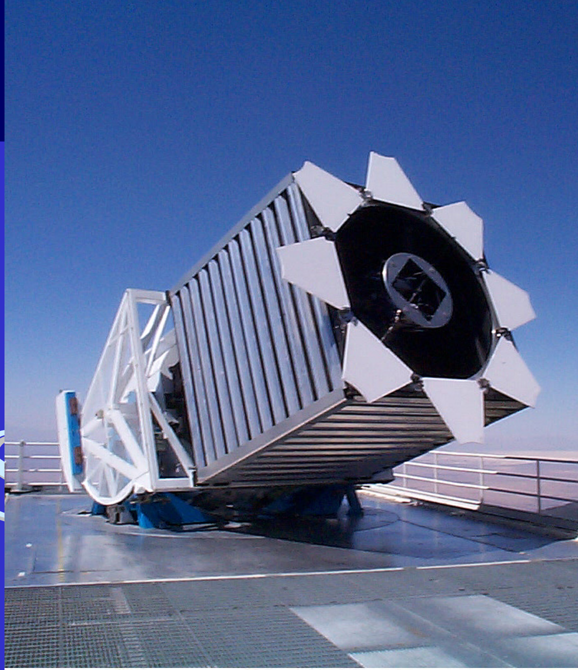
Z-band filter is essential for the QSO search.

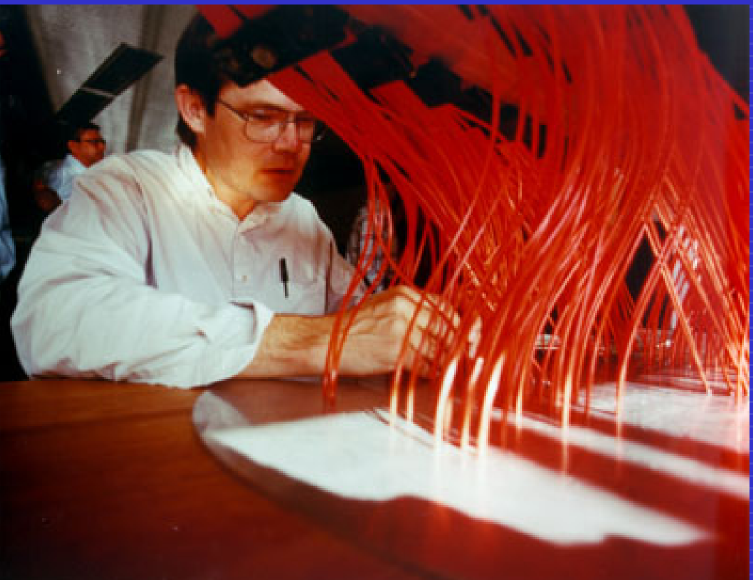


Redshift 6.00
Flux
3000
2000
1000
0
4000
6000
8000
10000
Observed Wavelength (Ångstrom)
u
g
r
i
z

Find z-band only detections among 1800 million objets in the SDSS

*TDI（drift scan）imaging is not particularly advantageous for QSO search.





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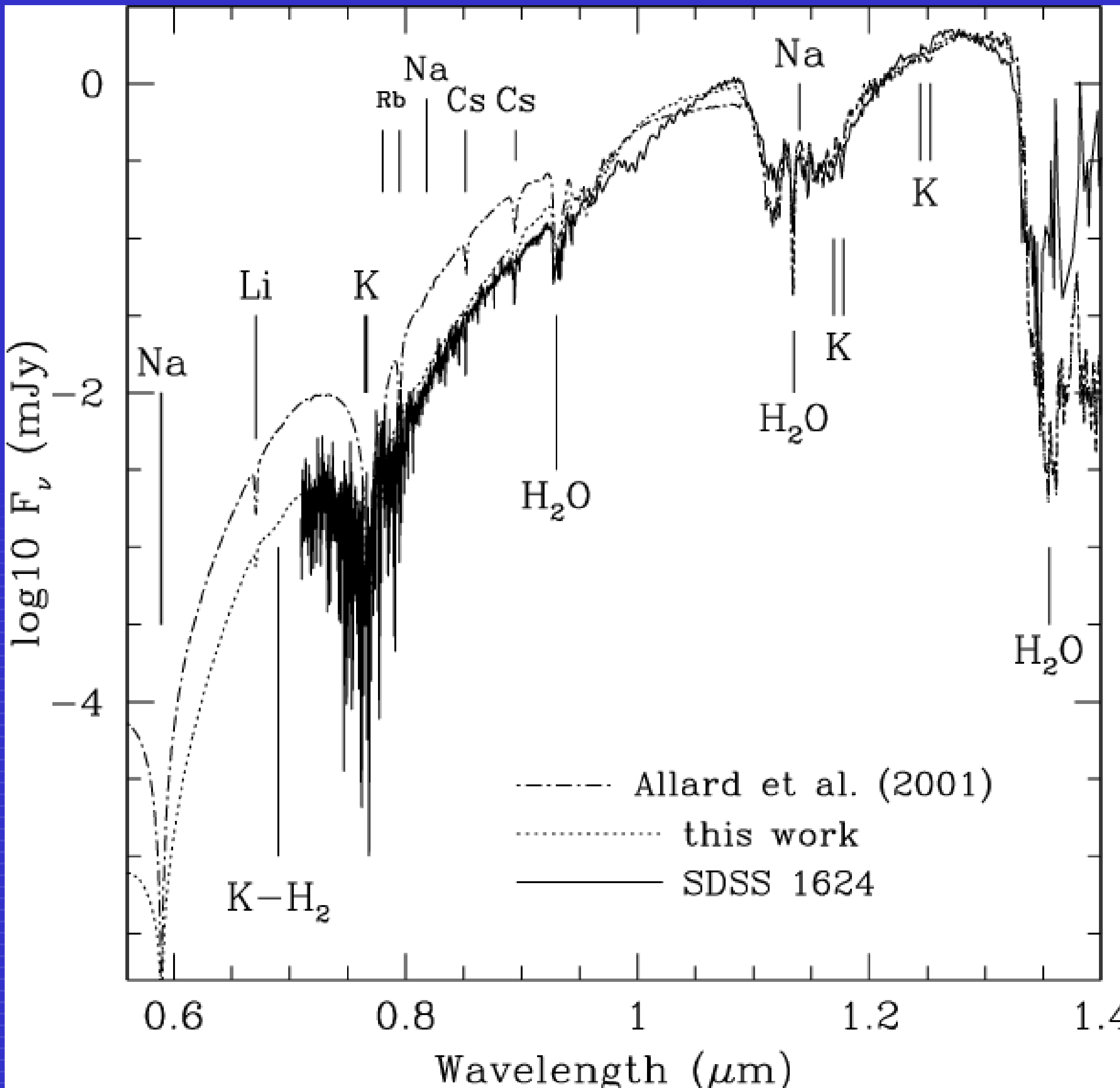
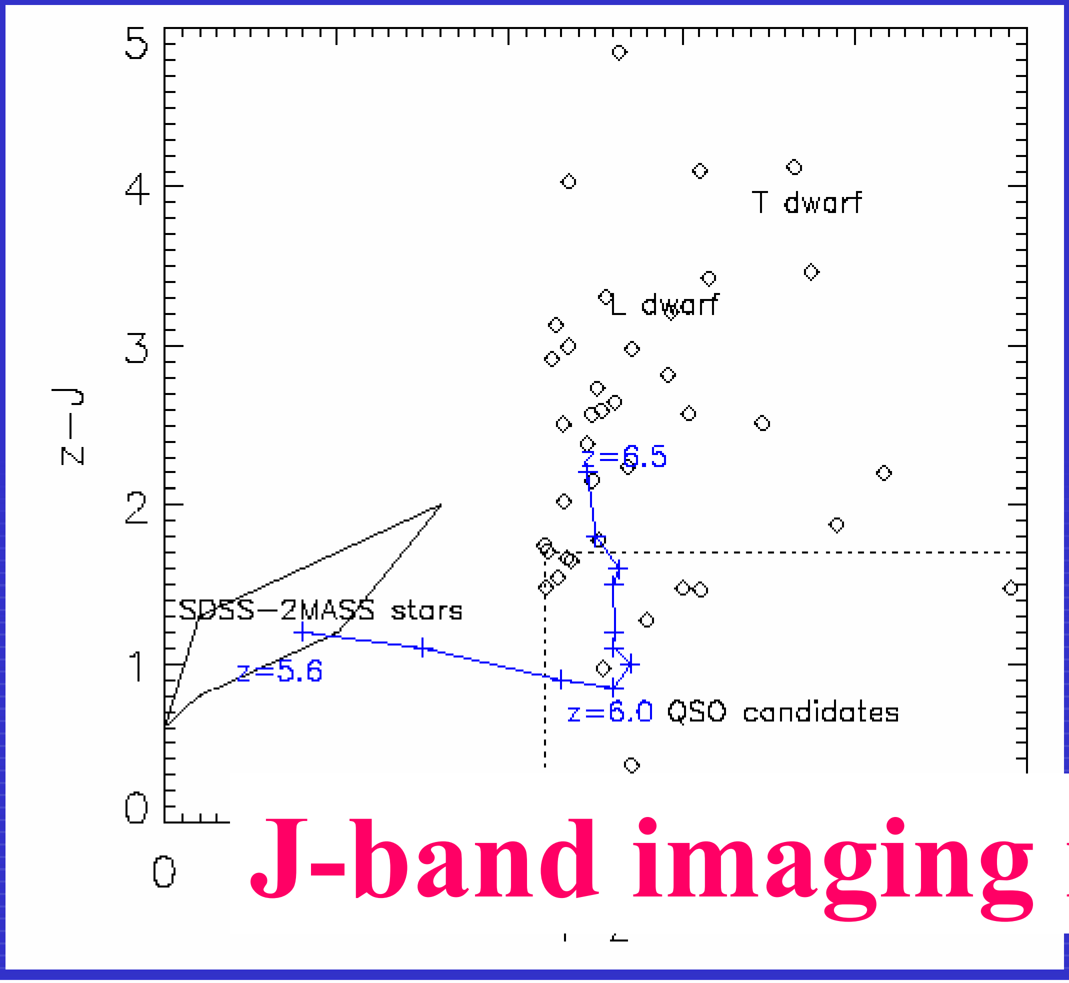
QSOs and brown dwarfs have the same i-z color→We need J-band imaging



Telescope time spend on brown dwarfs won't be wasted.

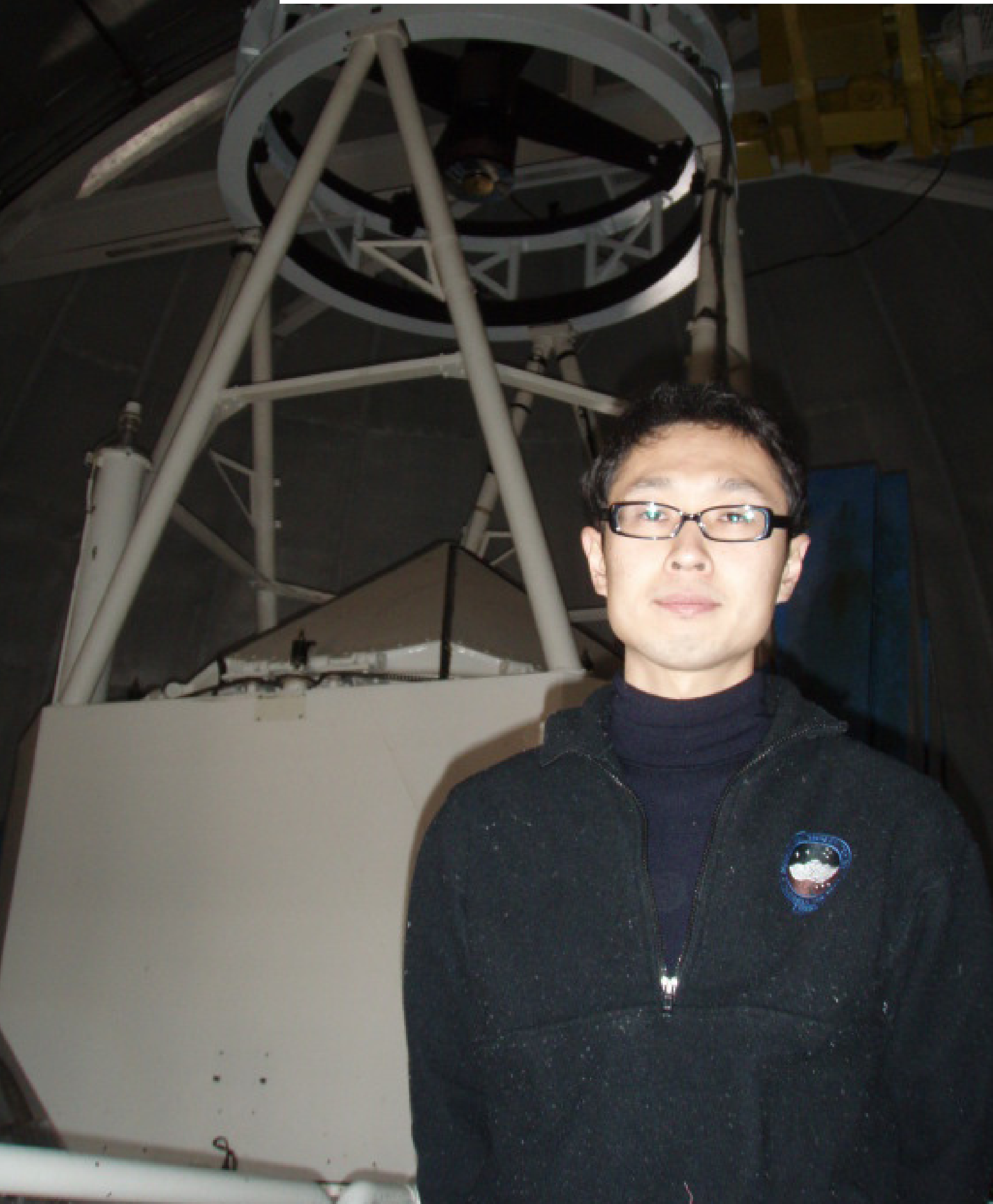
z-J can separate QSOs and brown dwarfs



J-band imaging is important.

Figure 4. (right) The $i-z-J$ color-color diagram. Using 32 nights of 2-4m telescopes for J-band imaging, we have found many high-z QSO candidates with $z-J < 1.7$ & $i-z > 2.2$ (dots in the lower right region). The simulated track is plotted with the blue line. These candidates are highly likely to be QSOs, waiting to be discovered by the Subaru/FOCAS.

Hard! J-band imaging

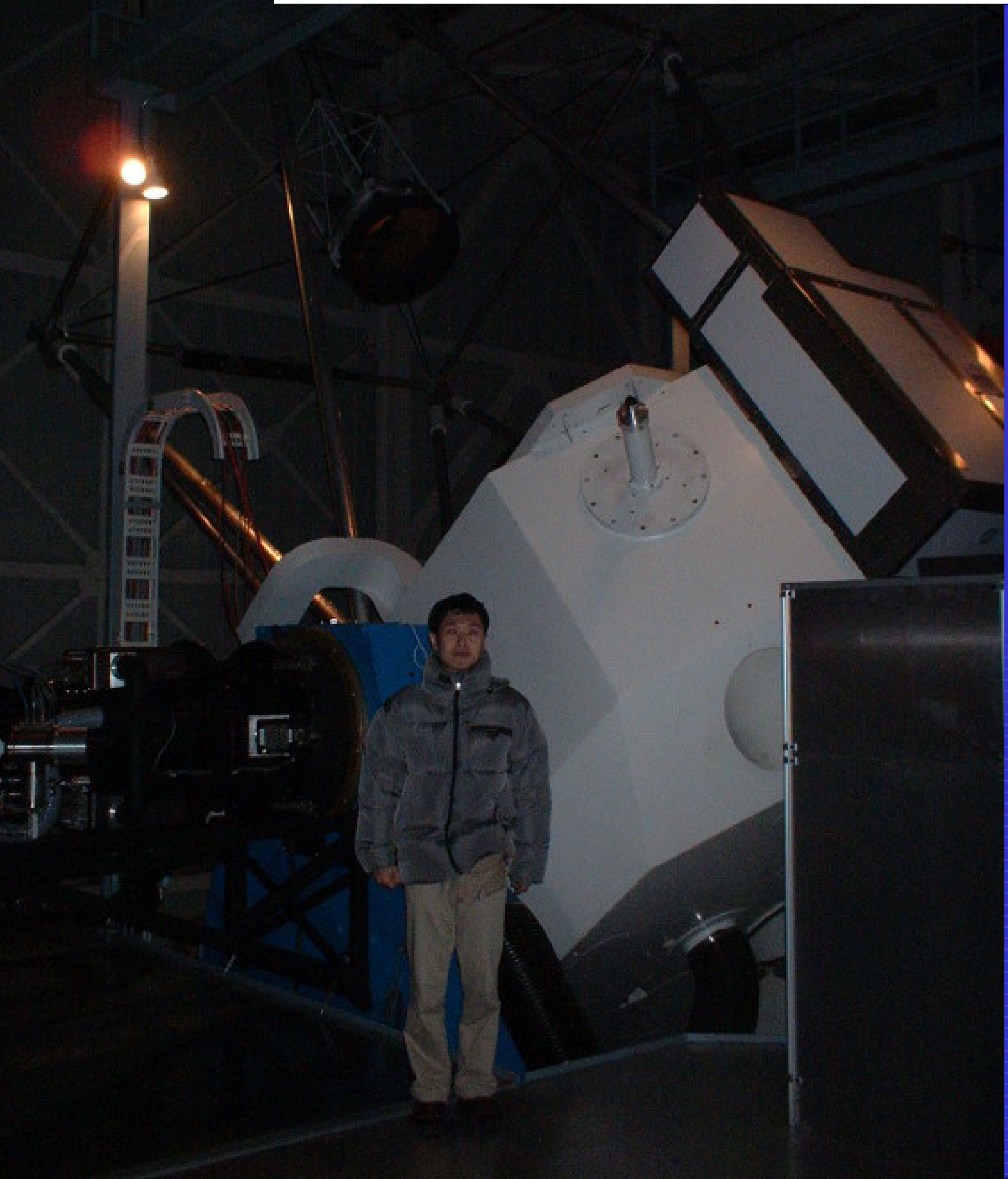


Kitt Peak 2m telescope

Hard! J-band imaging

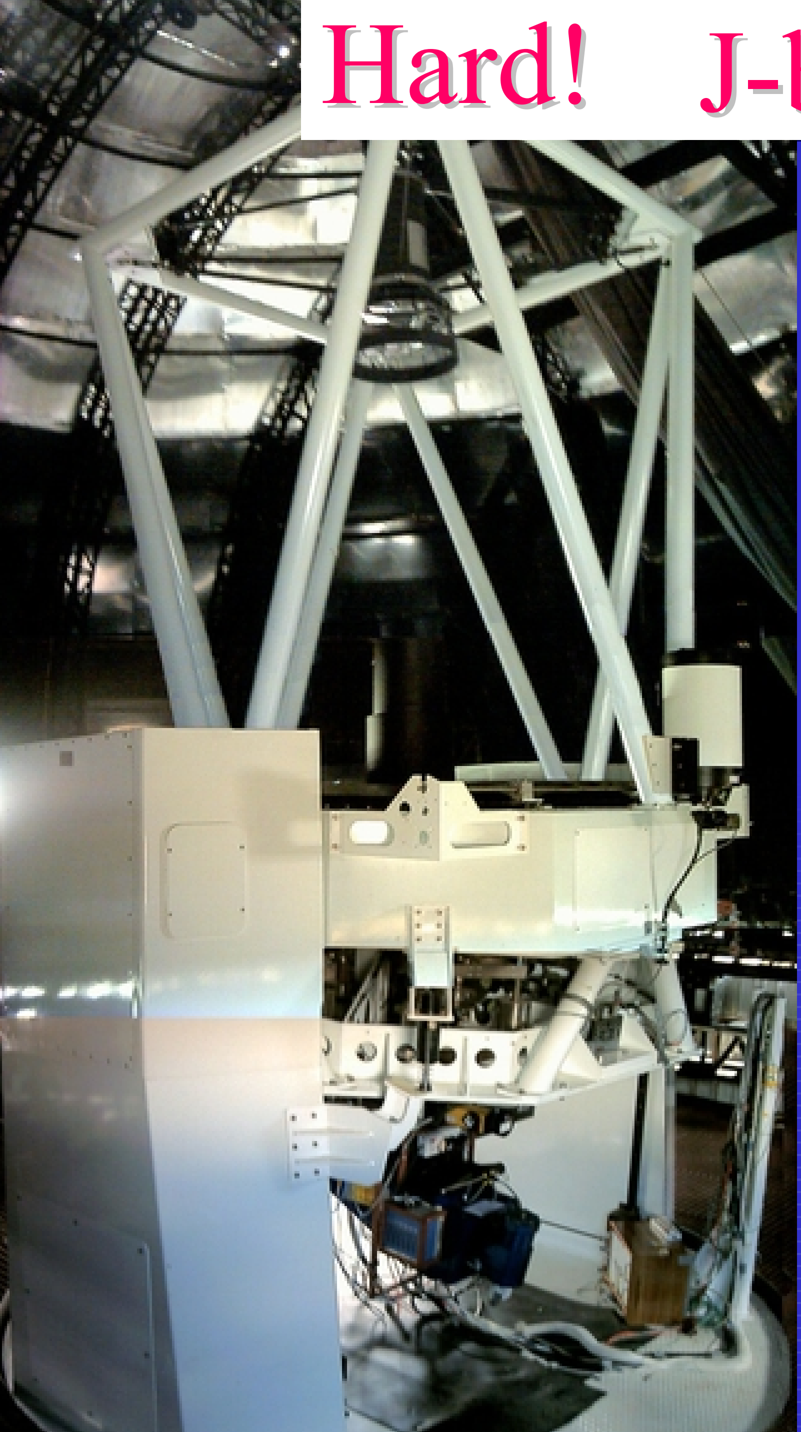
UKIRT3.8m

Hard!   J-band imaging



Apach Point Observatory 3.5m

Hard!   J-band imaging



Himalayan Chandra Telescope

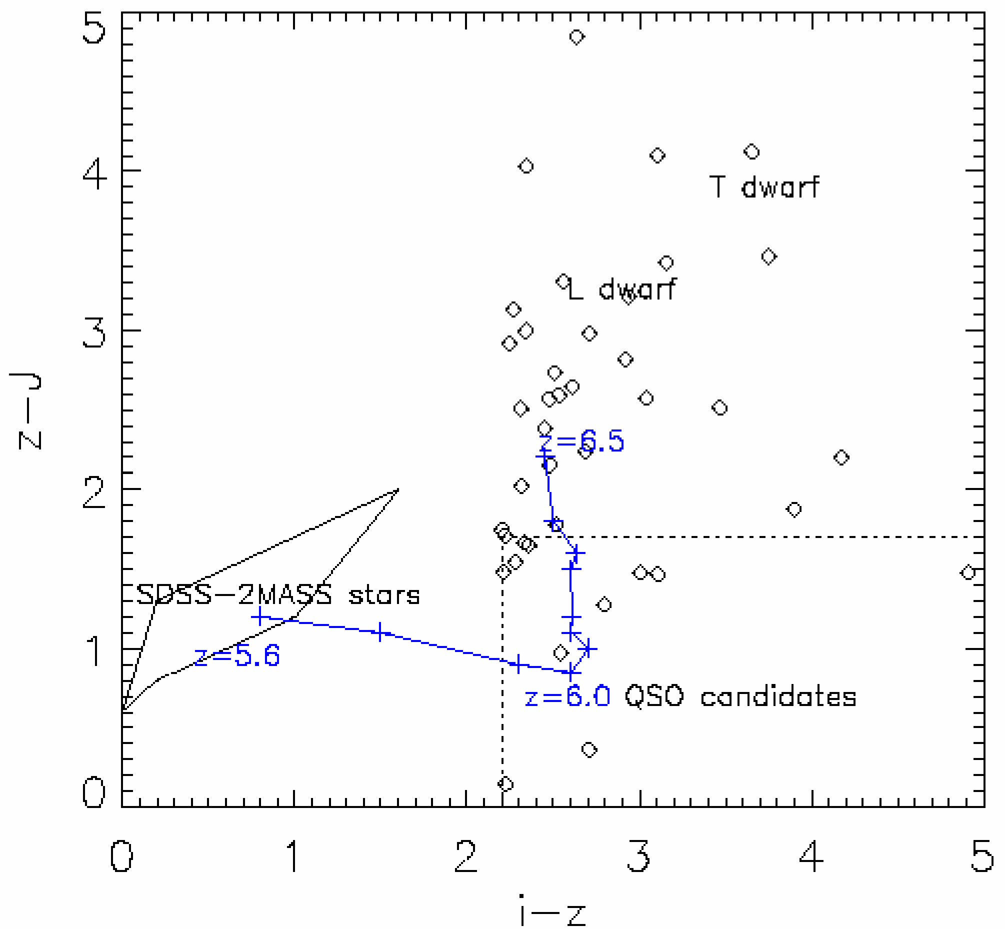
Hard!   J-band imaging

Okayama 1.88m

Hard!   J-band imaging


A Happy New Year @La Silla

QSO candidates



←good QSO candidates

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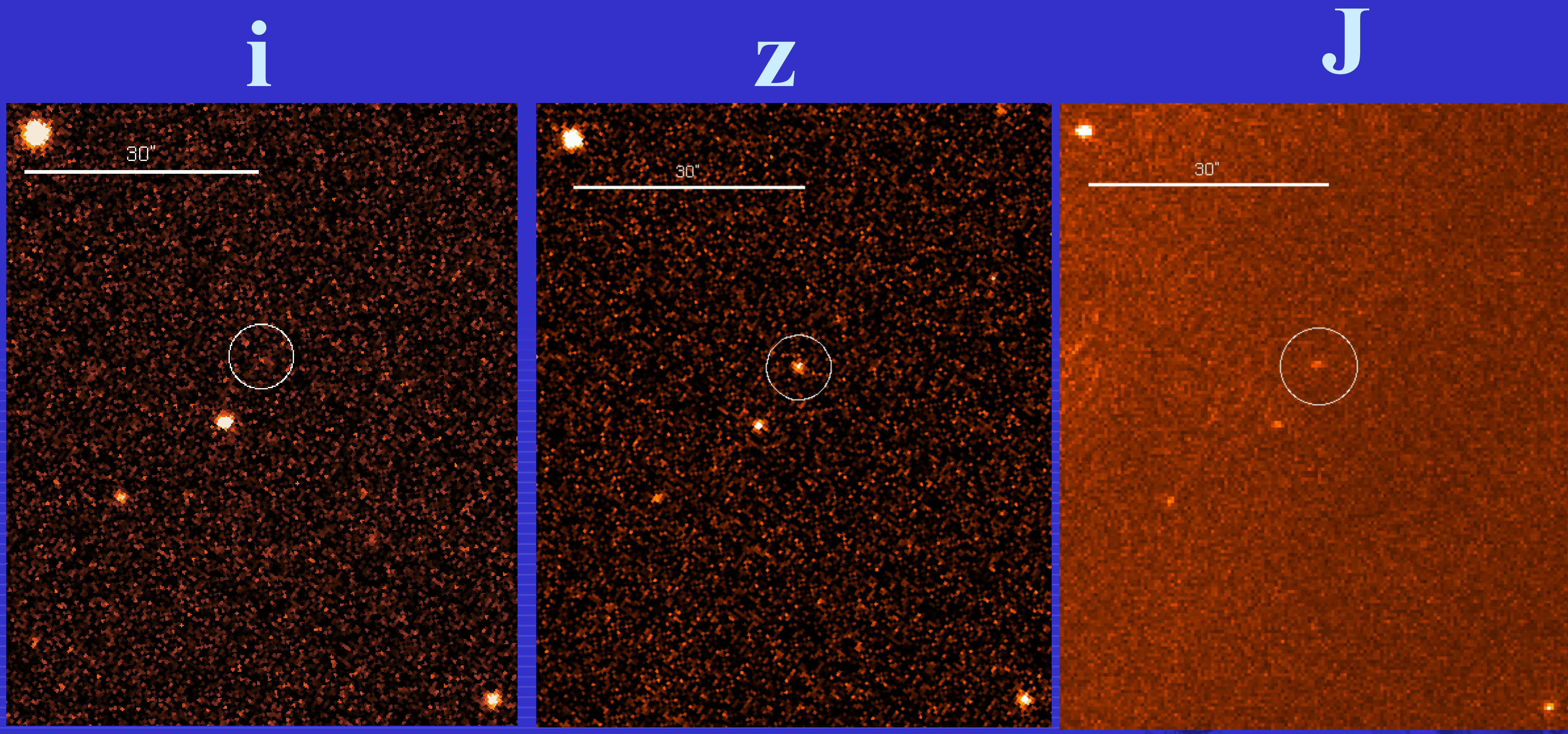
i,z,J images : a good candidate



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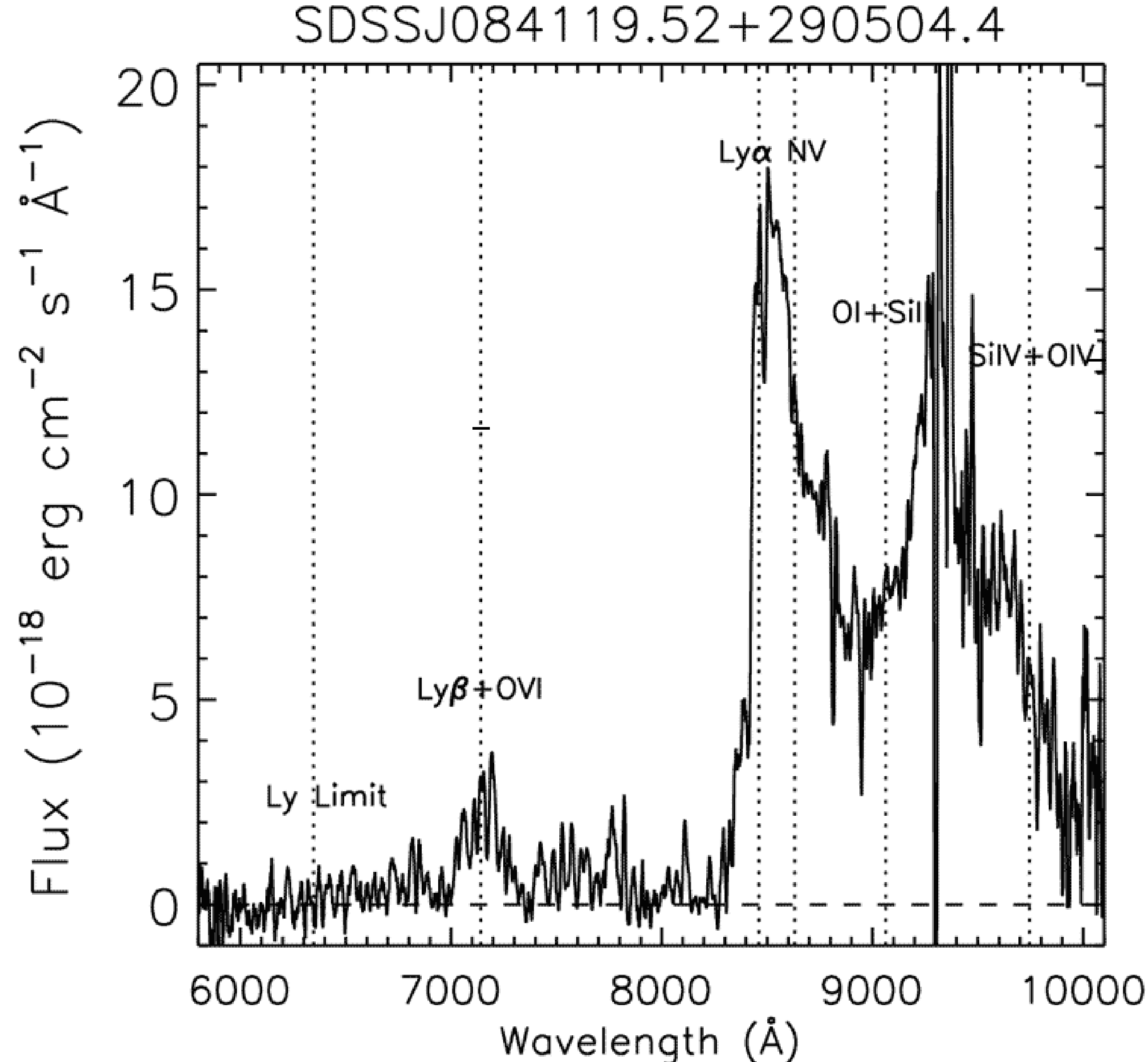
Subaru

Feb.2006

FOCAS spectrum

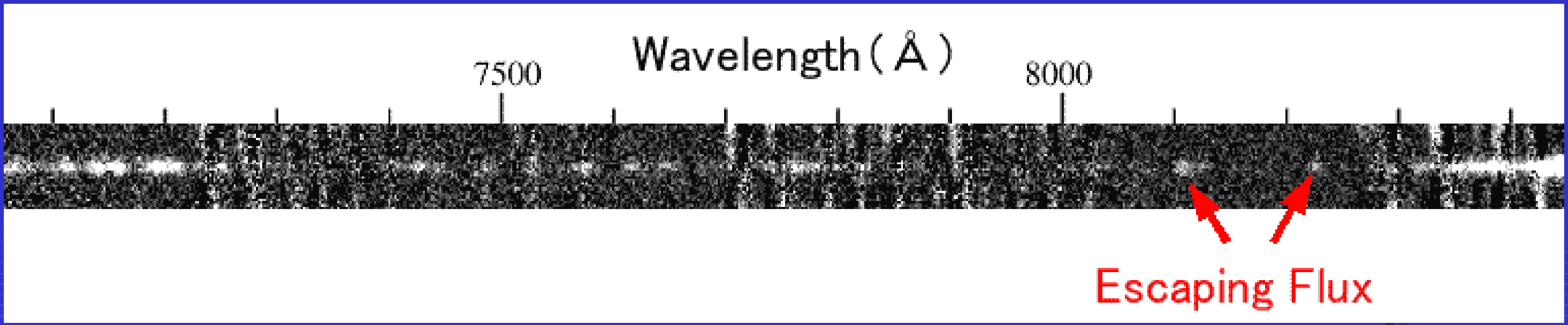
We found a z=5.96 QSO



Lyα + N v 、Lyβ + O vi→z=5.96

$M_{AB,1450} = -26.9$ (H_0 = 50 km s ^{1} Mpc ^{1}, q_0 = 0.5).

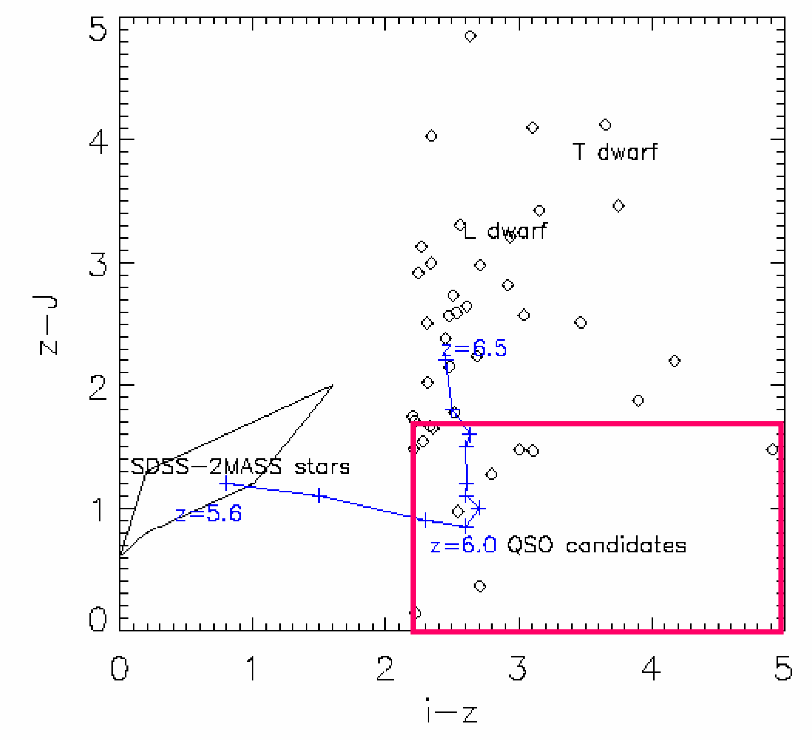
Escaping flux



Remaining flux at 8000–8300 Å . The Universe was already ionized in this line-of-sight at z＝ 5.58–5.82

Summary

- We are searching for cosmologically important z~6QSOs
- We found a new QSO at z = 5.96 (Goto 2006 MNRAS,371,769), showing our targeting strategy works.
- There was escaping flux at 8000–8300 Å、The Universe was already ionized at z＝5.58–5.82 in this direction
- More QSO candidates are waiting to be discovered.



←good QSO candidates waiting to be discovered with the Subaru