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.
Galaxies are too faint.
GRBs disappear too quickly.
Why high-z QSOs are important?

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Systematic flattening of the LF above $z \sim 3$

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 $\beta$ is -1.45 at faint end. Fitting these data simultaneously is a challenge for modern models of quasar evolution.

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Constraining the formation of super massive black holes.

- $z \sim 6$ QSOs are at the young Universe of 1 Gyr old.

- $M_{1450} = -27$ mag: 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 $\sim -27$ mag

How we form billion Msun black holes in 1 Gyr?

$=>$ Theoretical challenge.
Current status of high-z QSO surveys
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)

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 Ly$\beta$ 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 Ly$\alpha$ emission line and continuum and is used as a reference image.

No foreground galaxy.
The flux really comes from the QSO through IGM.
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Optical depth

Quick change at $z \sim 5.7$ !

Expected density change from the expansion of the Universe.

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 \(z\sim5.8\) QSO, important to investigate LF slope.
20.2 < z < 21.0 still secure

Figure 2. (right) Number counts of point-like sources in the SDSS u-r-band. The y-axis range of ourCatalogue is shown as a region surrounded by the blue dotted lines. Note that the number counts drop off quickly as the magnitude increases.
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

- 2.5m SDSS telescope
- Photometric calibration telescope
- 3.5m telescope
Interior view of the camera, showing the filters on the corrector plate.

Z-band filter is essential for the QSO search.
Find z-band only detections among 1800 million objects 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.
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
Apach Point Observatory
3.5m

Hard!  J-band imaging
Himalayan Chandra Telescope

Hard!  J-band imaging
Hard!  J-band imaging

Okayama 1.88m
Hard!  J-band imaging

NTT3.6m
A Happy New Year @La Silla
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.
$i, z, J$ images: a good candidate
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We found a z=5.96 QSO

\[ M_{AB,1450} = -26.9 \]

\((H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}, q_0 = 0.5)\)
Remaining flux at 8000–8300 Å. The Universe was already ionized in this line-of-sight at $z = 5.58–5.82$. **Escaping flux**
Summary

• We are searching for cosmologically important $z \sim 6$ QSOs.
• 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.