Cosmology with Large Surveys

(Durban, South Africa, 2016/11/19-26)

Ultra-luminous Quasars with the Most Massive Black Holes at Cosmic Down

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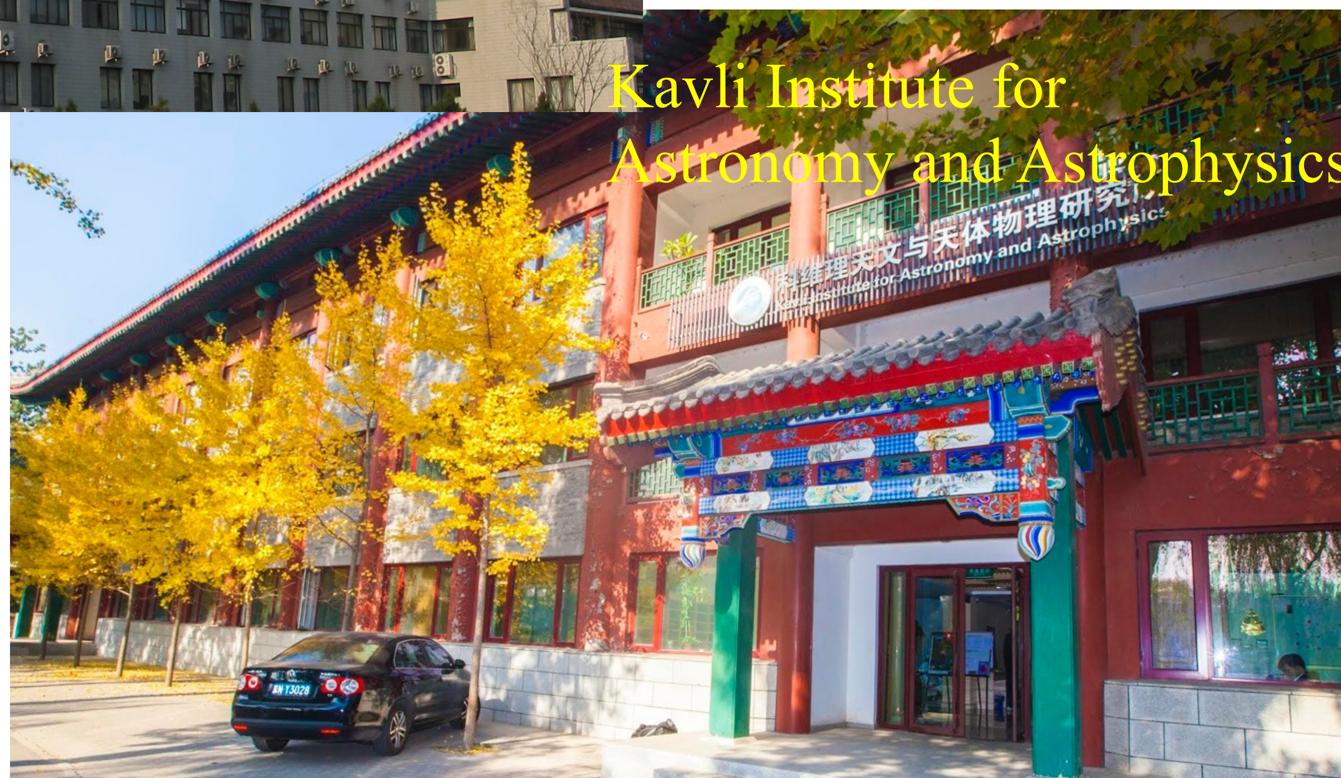
PEKING UNIVERSITY
1898

25 Faculty
20 Postdoc
60 Postgrad
100
Undergrad



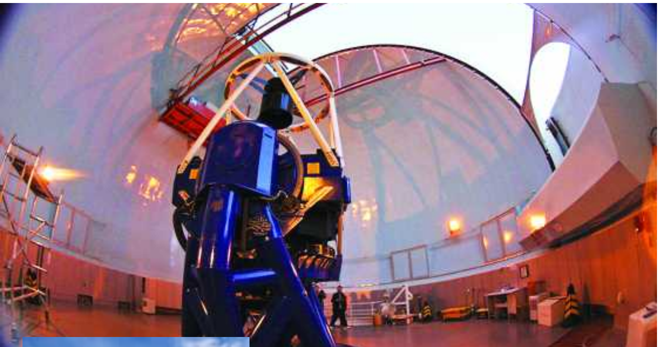
北京大学科维理天文与天体物理研究所
KIAA – PKU

Outline

- Problems in finding high-z quasars
- A survey of luminous high-z quasars with SDSS and WISE
- The most massive black hole in the early Universe
- Summary

1. Wang, Wu, Fan, et al., 2016, ApJ, 819, 24
2. Yang, Wang, Wu, et al., 2016, ApJ, 829, 33
3. Wang, Wu, Neri, et al., 2016, ApJ, 830, 53
4. Wu, Wang, Fan, et al., 2015, Nature, 518,512
5. Wang, Wu, Fan, et al. 2015, ApJL, 807, L9
6. Yi, Wang, Wu, et al., 2014, ApJL, 795, L29

Telescopes we used



2.4-m telescope, Lijiang, Yunnan, China

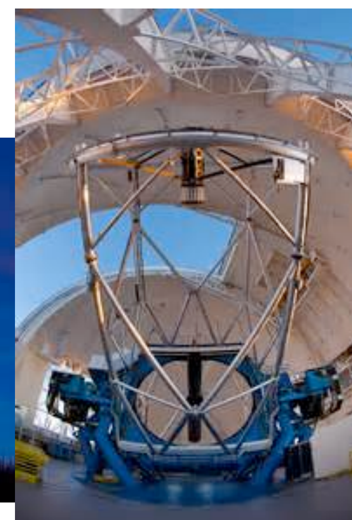
2.16-m telescope, Xinglong/ NAOC, China

Bok 2.2-m, Kitt Peak USA

ANU 2.3-m, Australia

MMT(6.5-m)

LBT(2*8.4-m)



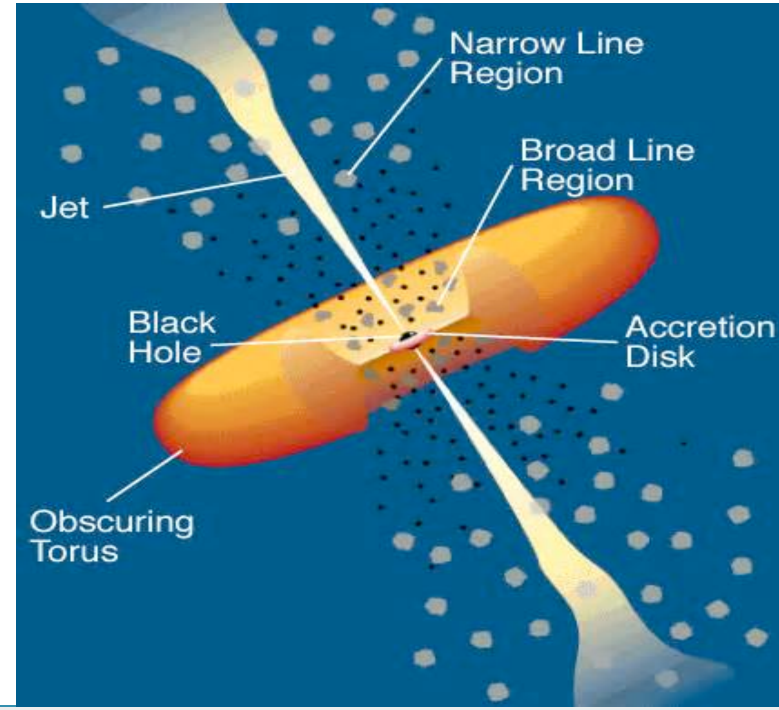
Gemini-N(8.1-m)

Magellan(6.5-m)

1. Problem in finding high-z quasars

Central Engine of Quasars

- Emit power million times higher than our Milky Way！ Not nuclear burning
- Supermassive BH(10^7-10^10 M_{sun}) ＋accretion disk＋jet
- Broad line region, dusty torus, narrow line region, host galaxy



Quasar spectrum

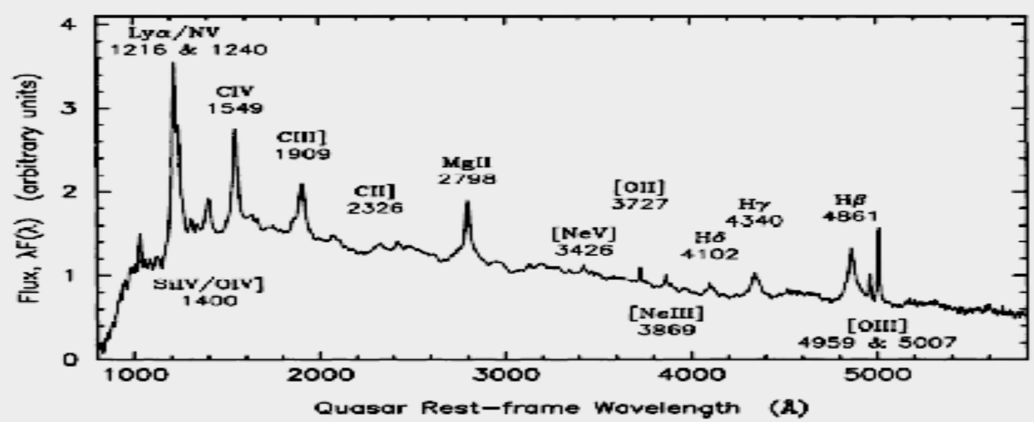
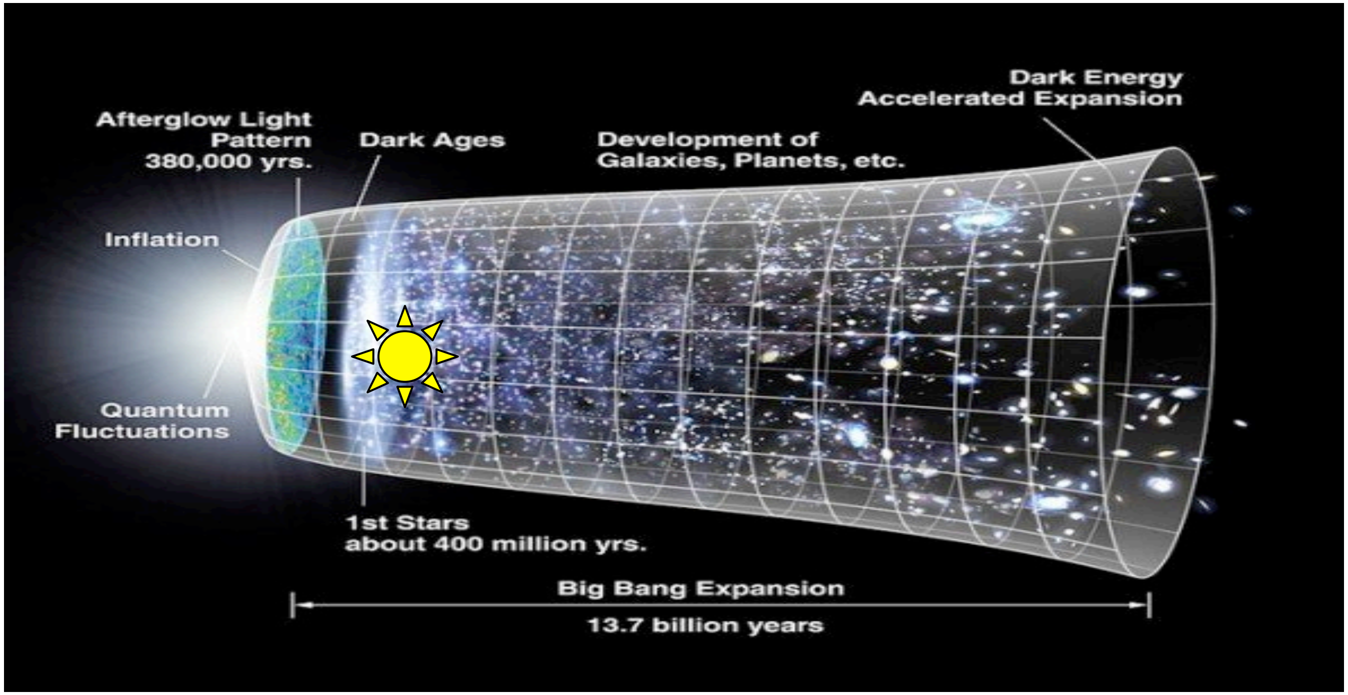
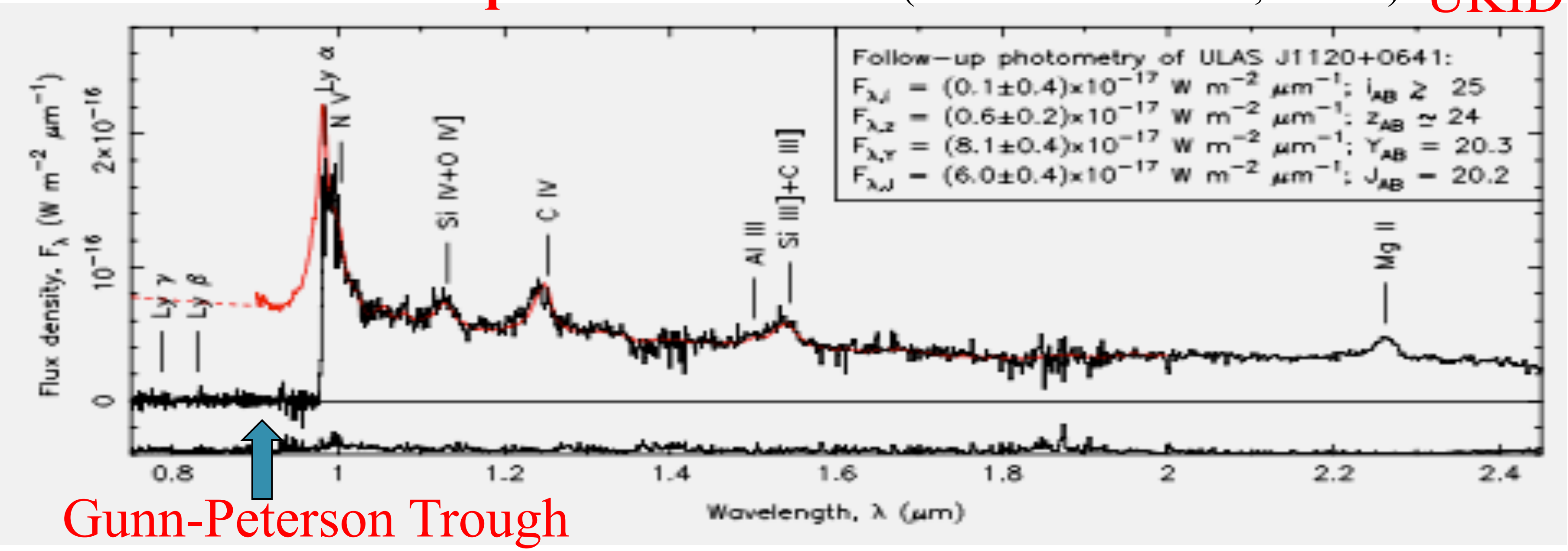


FIG. 2.—Composite spectrum plotted as $\lambda F(\lambda)$ vs. rest-frame wavelength with the principal emission features identified. The flux scale is in arbitrary units.

Distant quasars can help probe the cosmic reionization



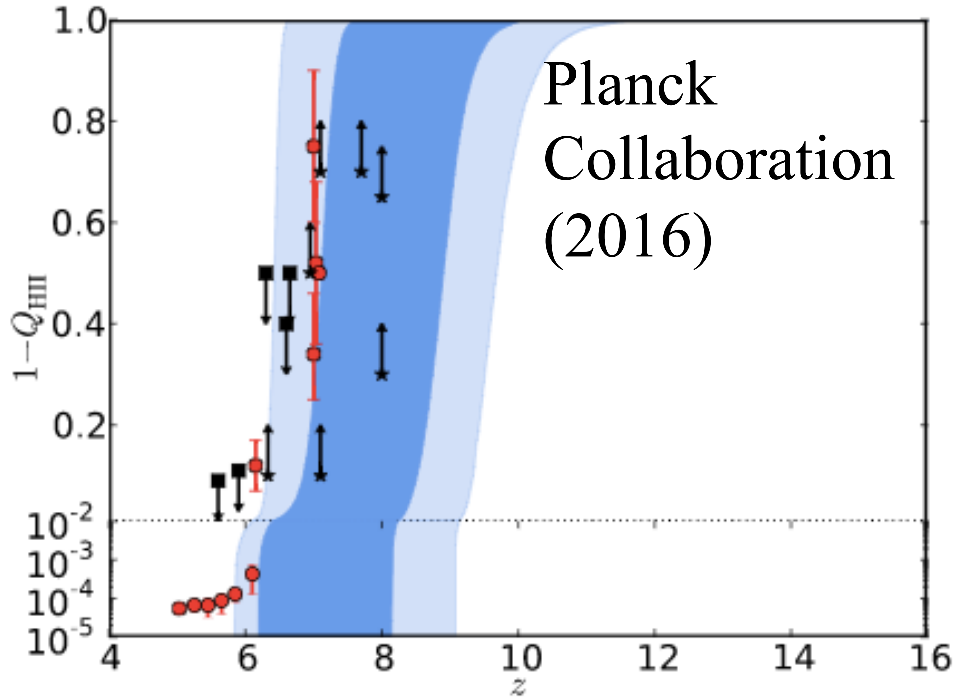
The most distant quasar at z=7.085 (Mortlock et al. 2011, Nature) UKIDSS

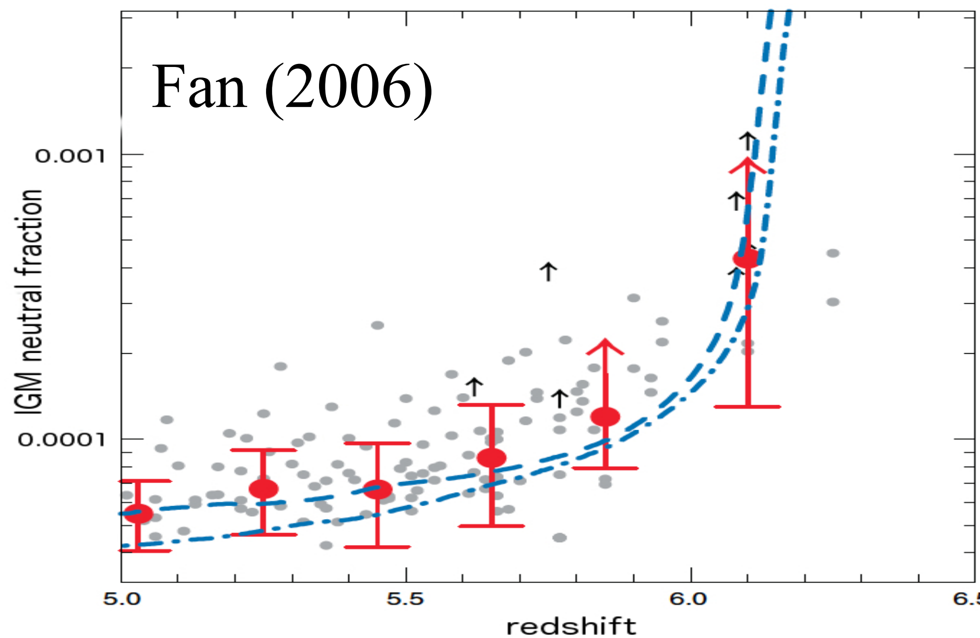


- **The peak of reionization around *z~9*; from CMB observations (Planck)**

- **Reionization ends at *z~5-6*; from high-z quasars**

- **The neutral fraction of IGM increases rapidly at z>6.**

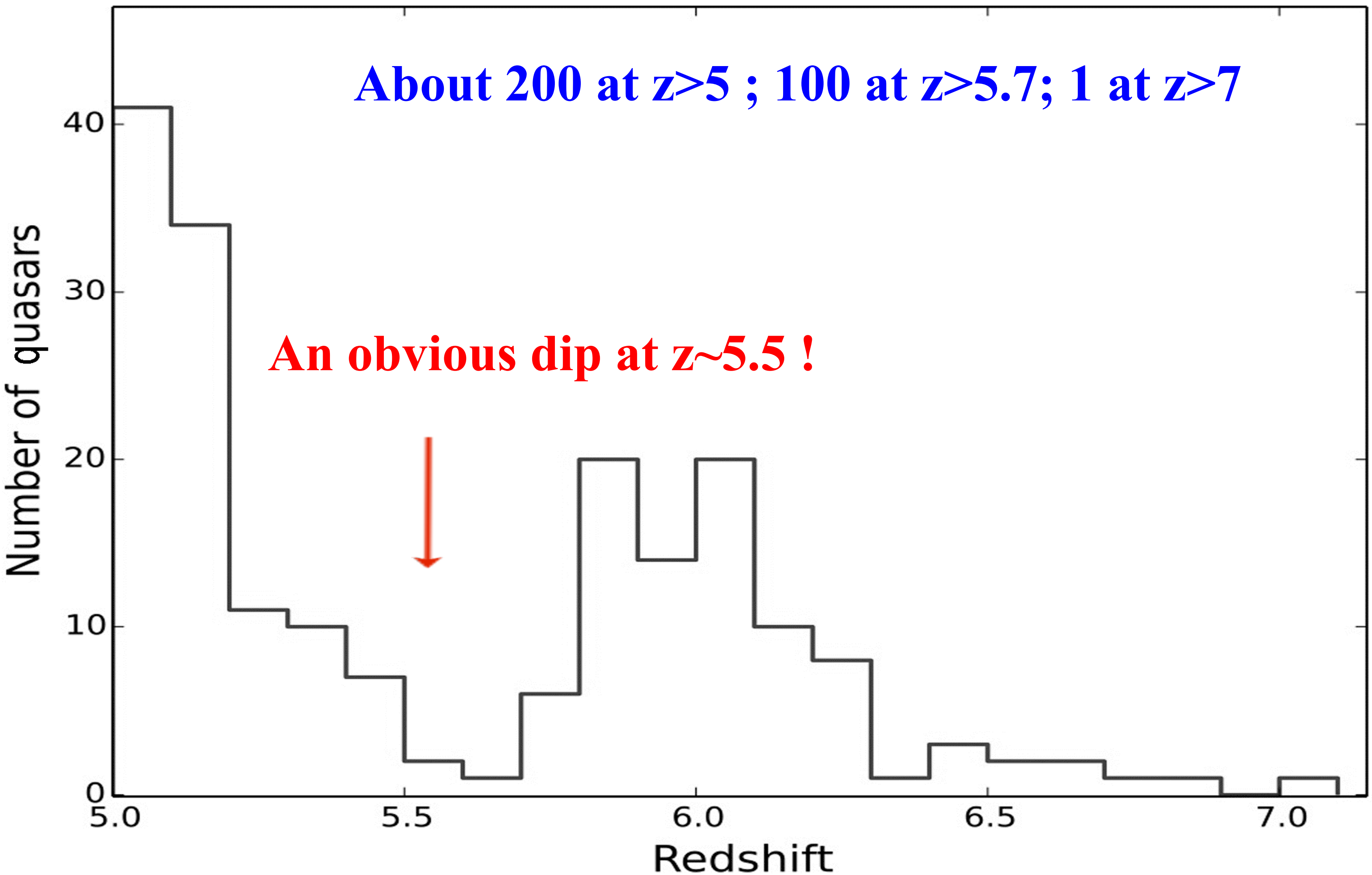




Weighing BH in distant quasars

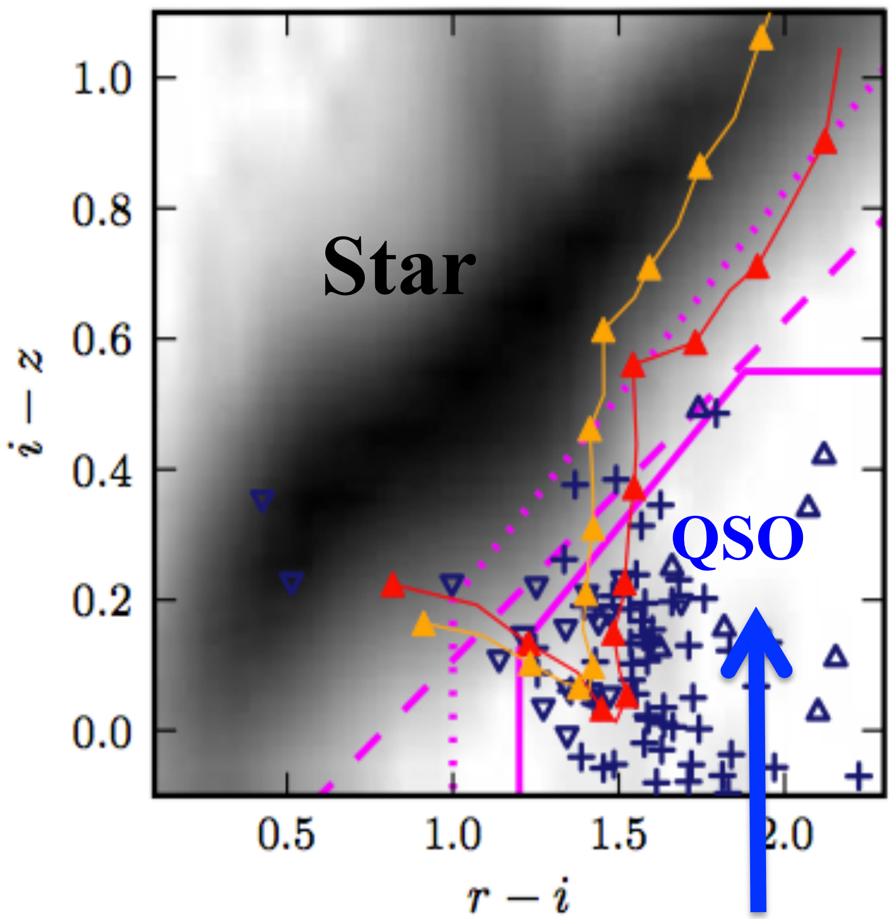
- **BH mass can be estimated with some empirical relations（$M_{BH} \sim V^2R \sim V^2L^{1/2}$, V and L can be measured from the broad emission line width and continuum luminosity in quasar spectrum）**
- **Quasar at z=6-7 host SMBHs with masses of about one billion solar masses. How can the SMBHs grow in a time within 1 Gyr ? This is a big challenge to theorists**

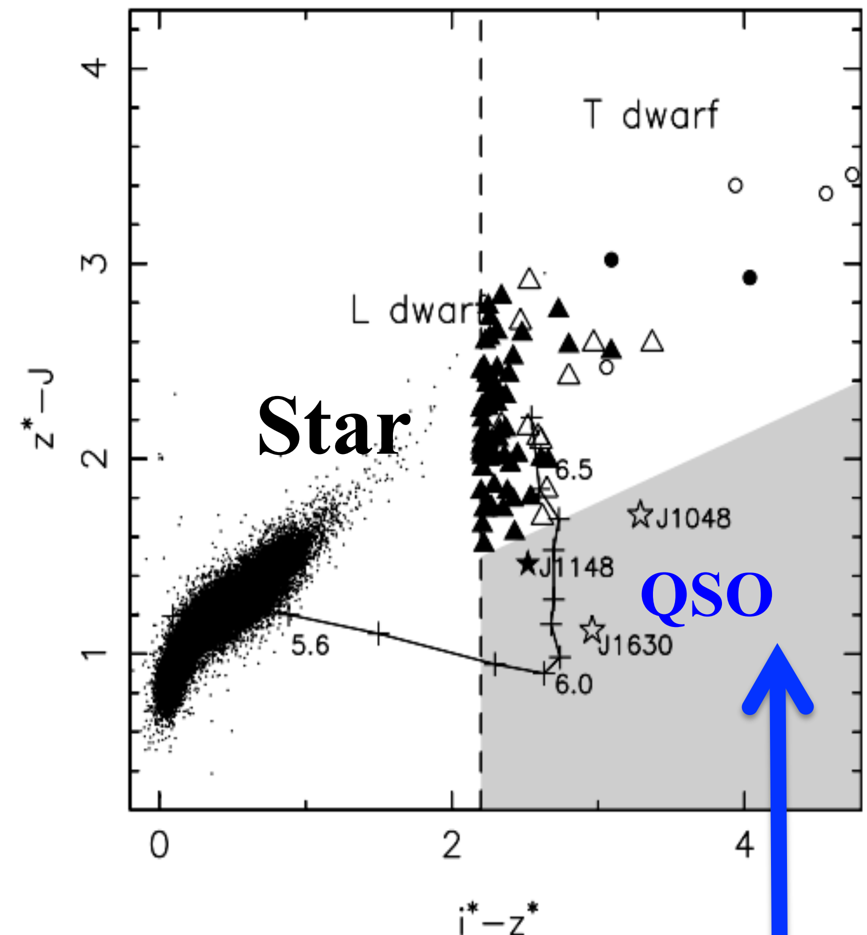
Redshift distribution of z>5 quasars



Why is it difficult to find z~5.5 quasars?

(M star contaminations！)

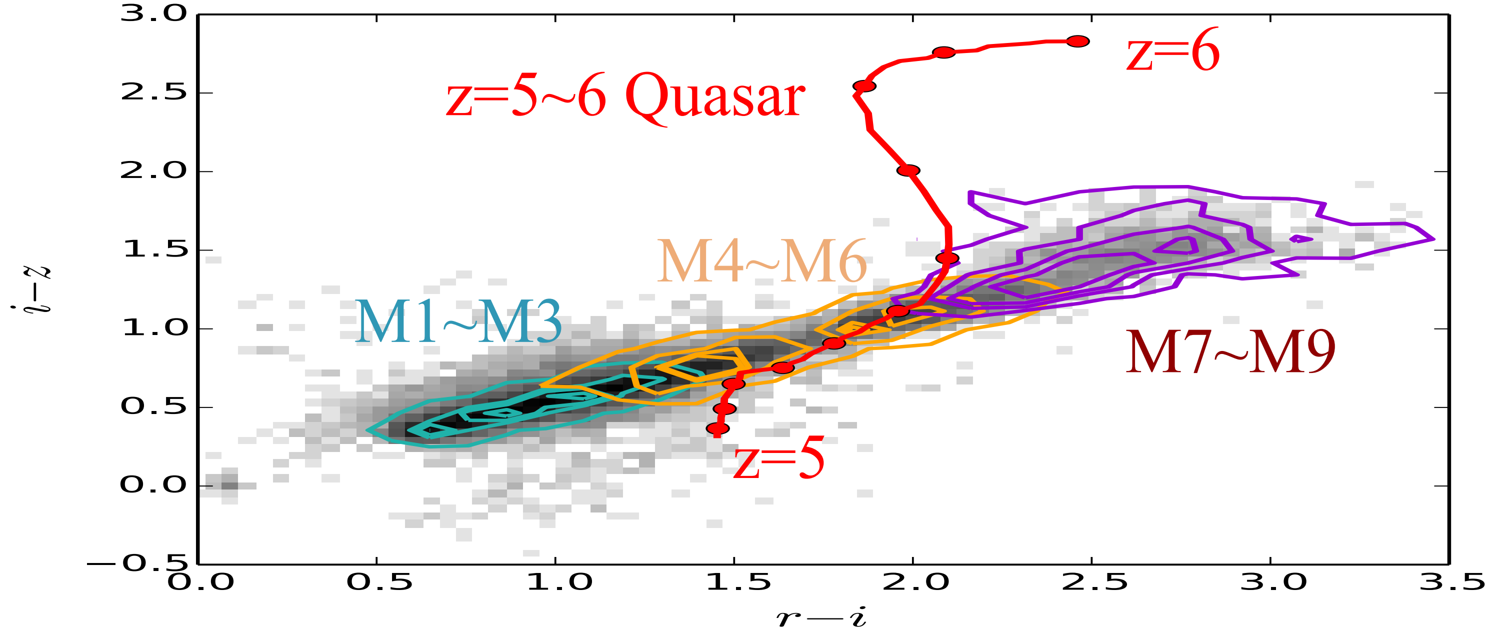


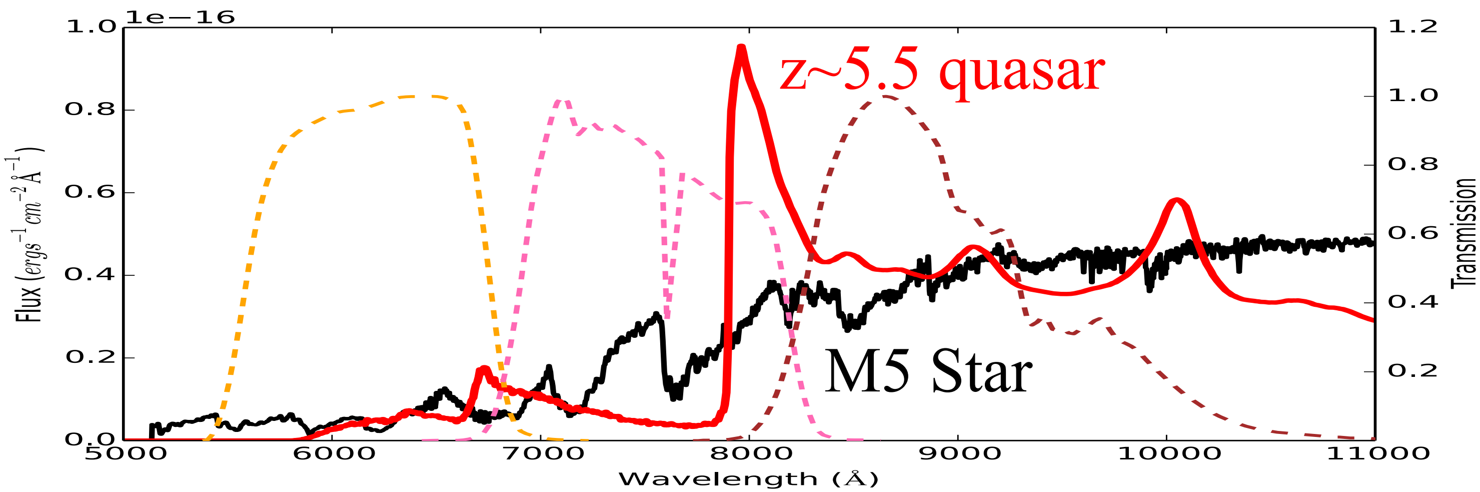


McGreer et al. 2013;
Effective: 4.7< z < 5.1

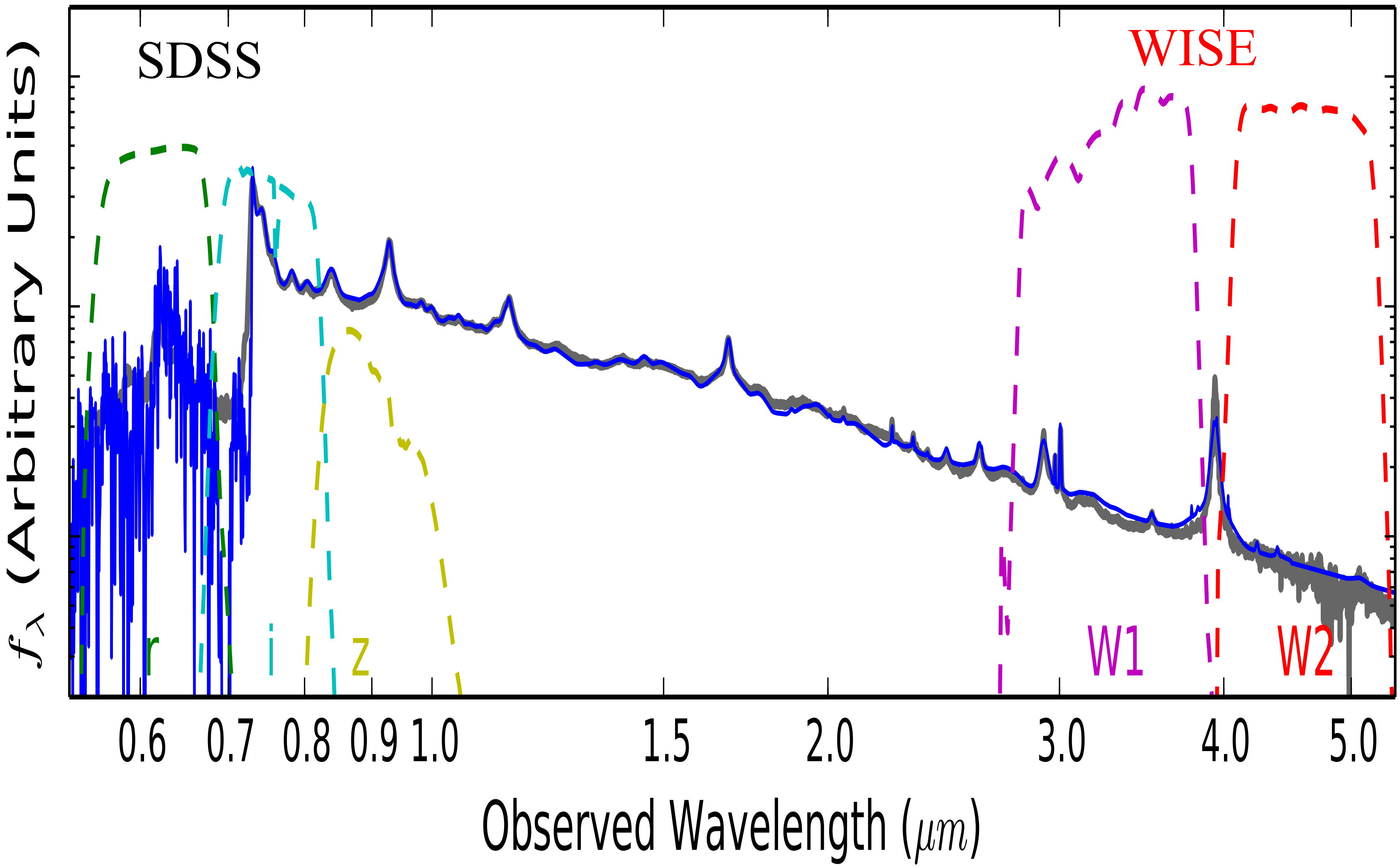
Fan et al. 2001, 03, 04, 06
Jiang et al. 2008, 09;
Effective: z > 5.8

Using optical colors can hardly separate z~5.5 quasars and M stars (Yang, Fan, Wu, et al., 2016)





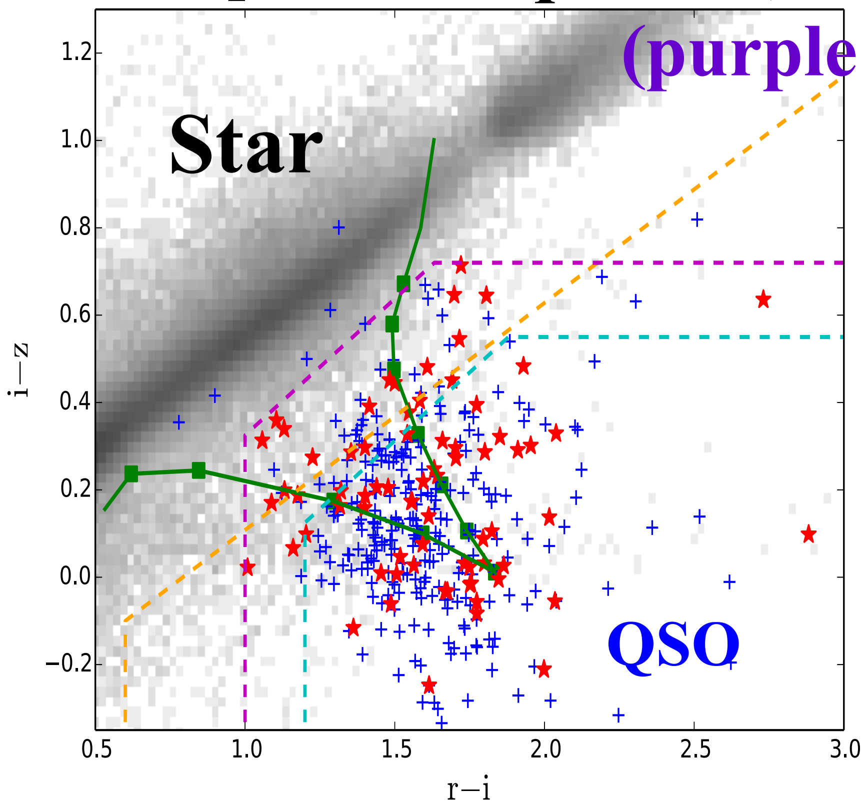
z~5 quasar spectrum

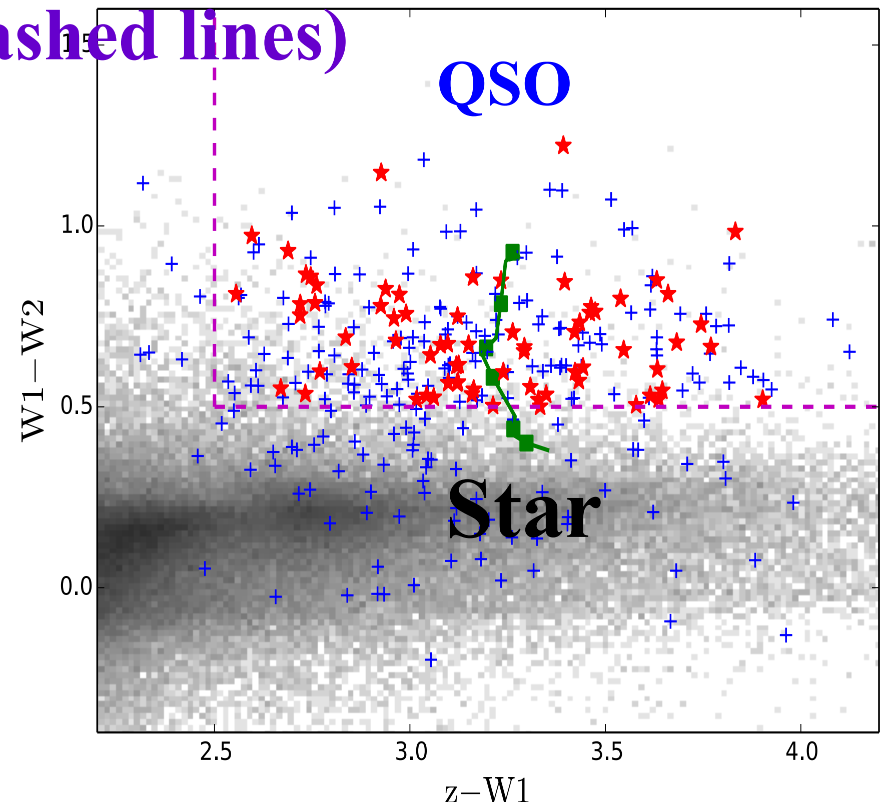


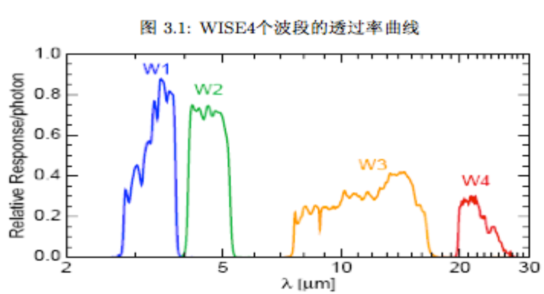
2. A survey of luminous high-z quasars with SDSS and WISE

Select high-z quasar candidates with SDSS-WISE

Because WISE detection rate of z>4.5 quasars is 75%, using WISE can help find z~5 quasars; revised selection criteria (purple dashed lines)

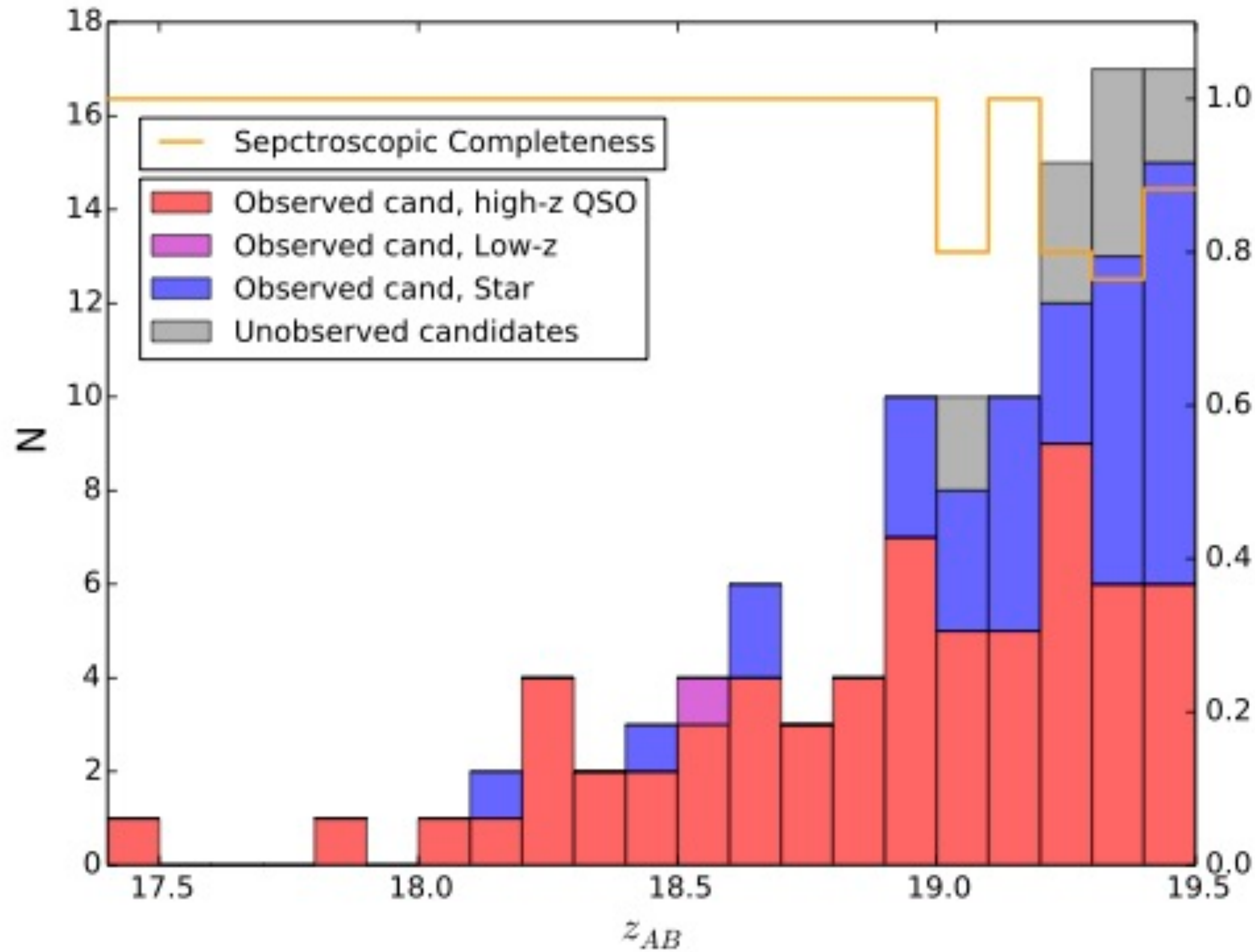




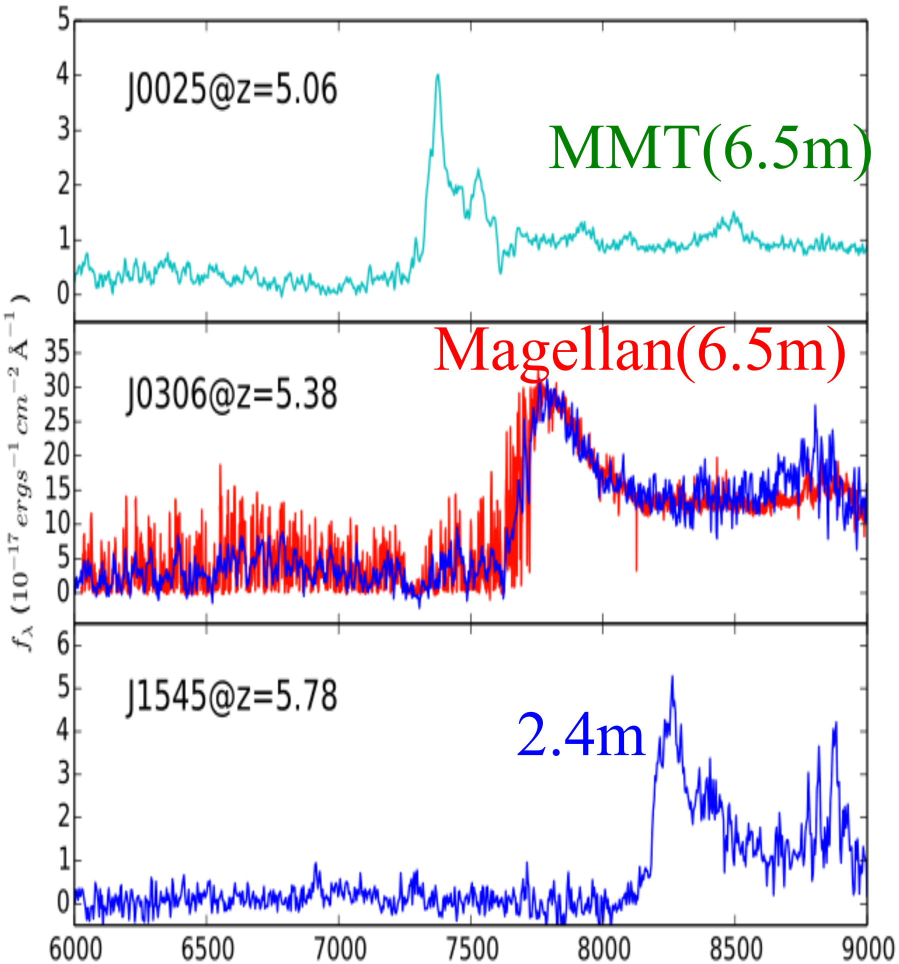


(Wang F., Wu, X.-B., et al. 2016, ApJ)

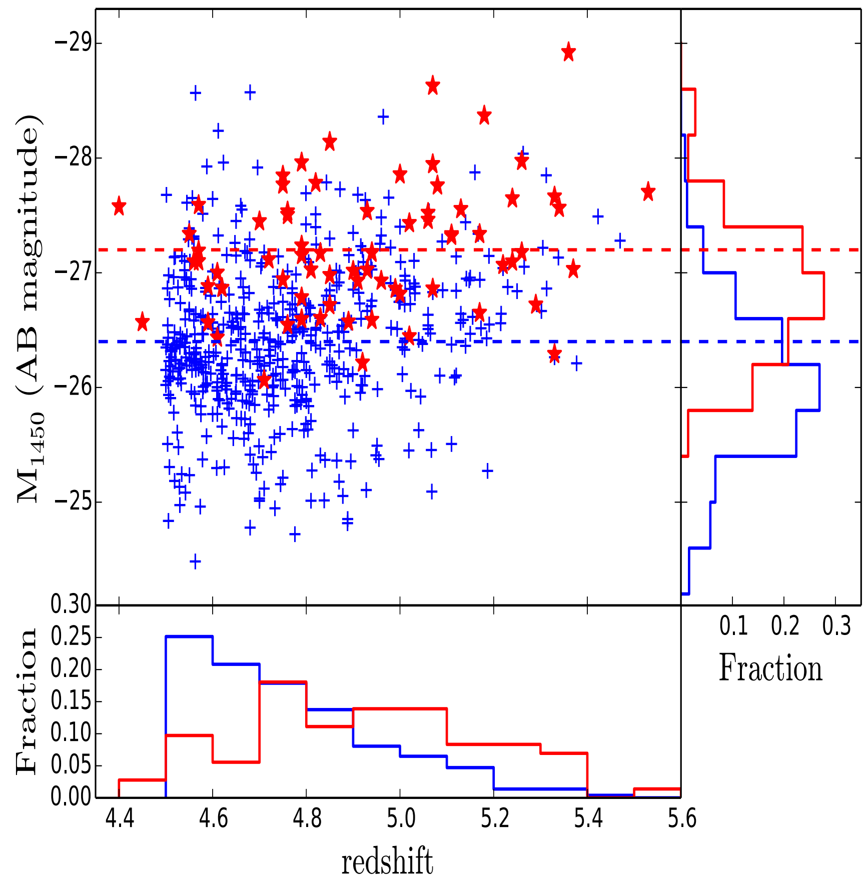
Observational Results of 110 candidates (z_{AB}<19.5)



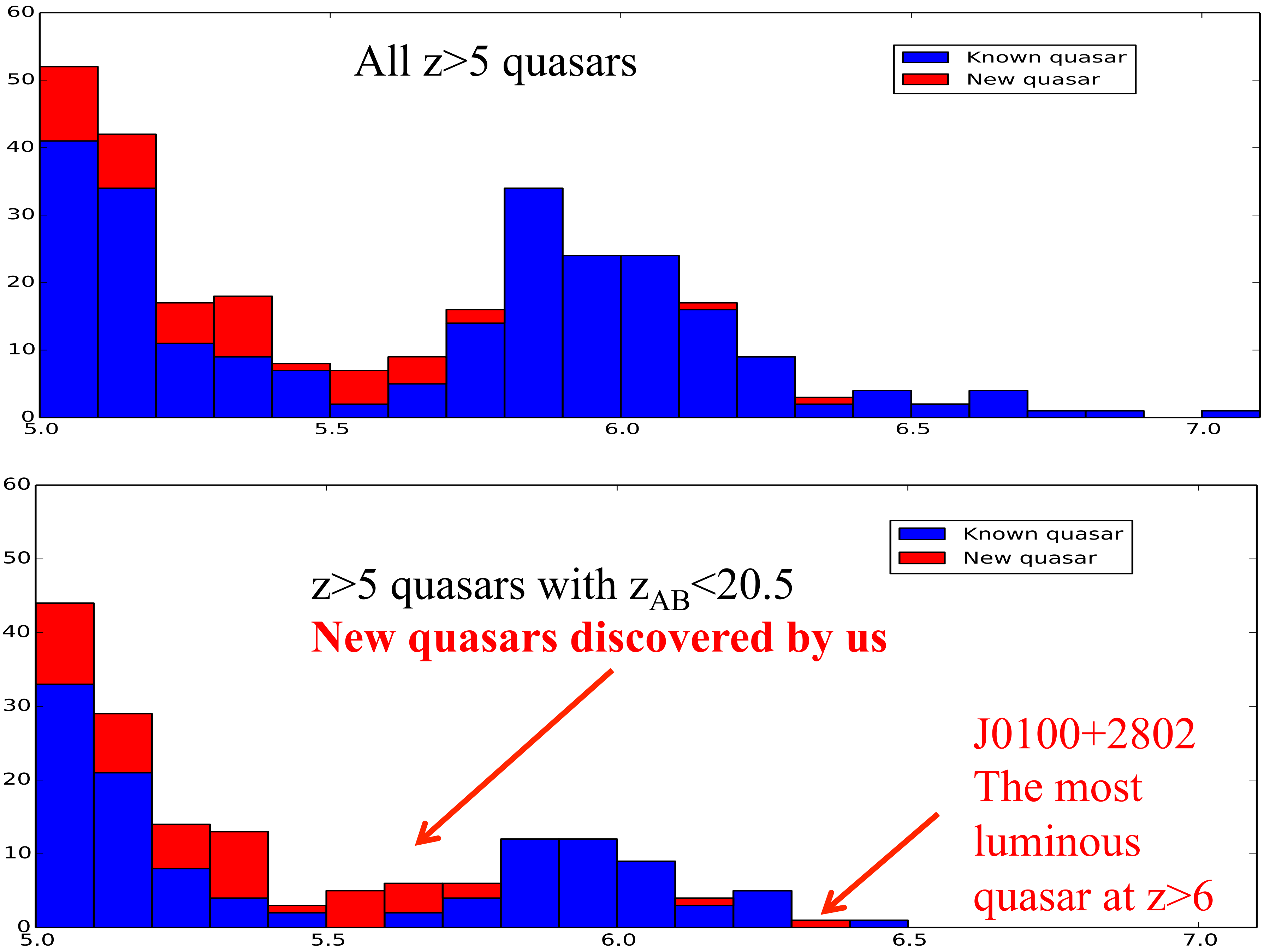
SDSS-WISE High-z Quasar Candidates



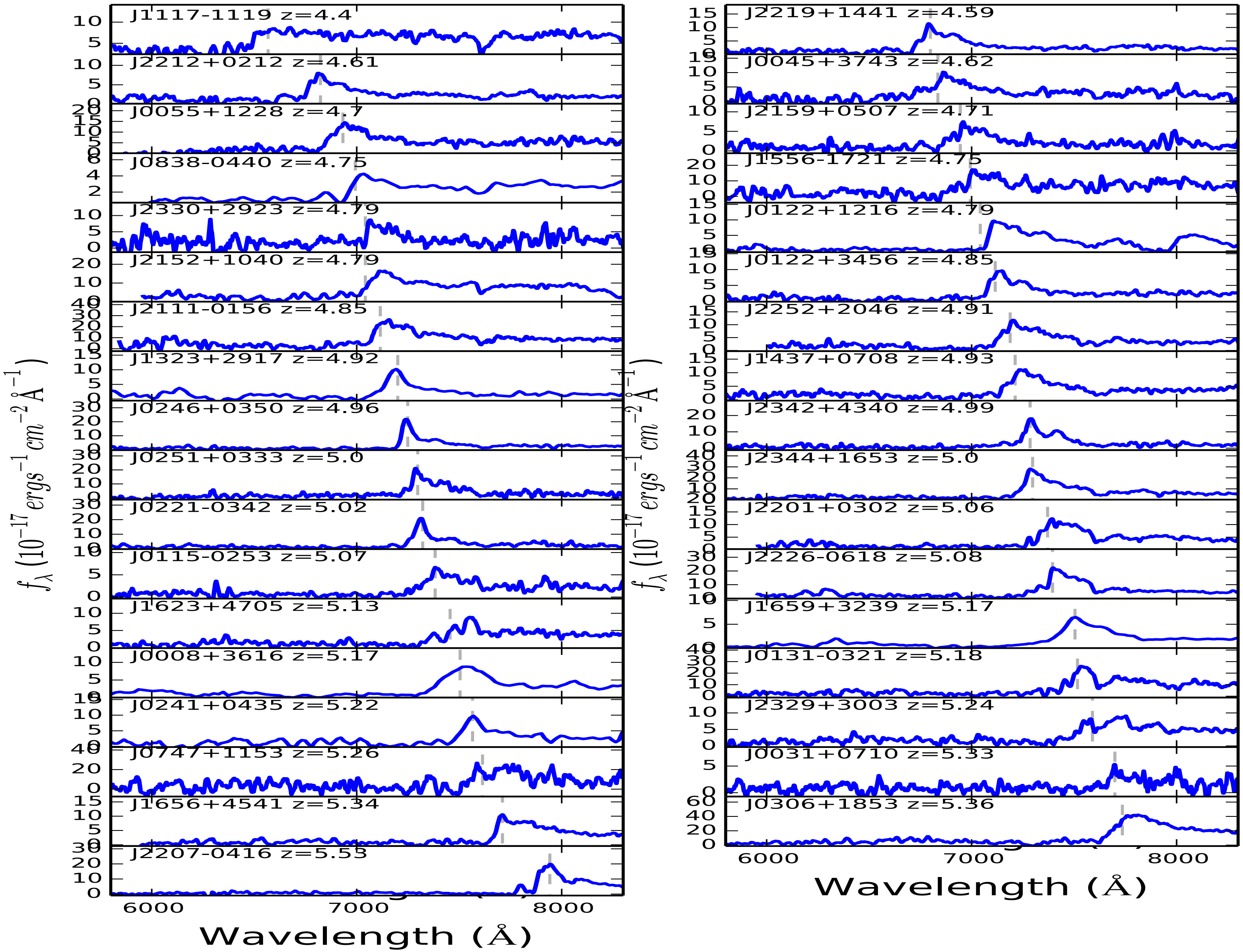
76 new quasars (some are very bright)



(Wang Feige et al. 2016, ApJ)

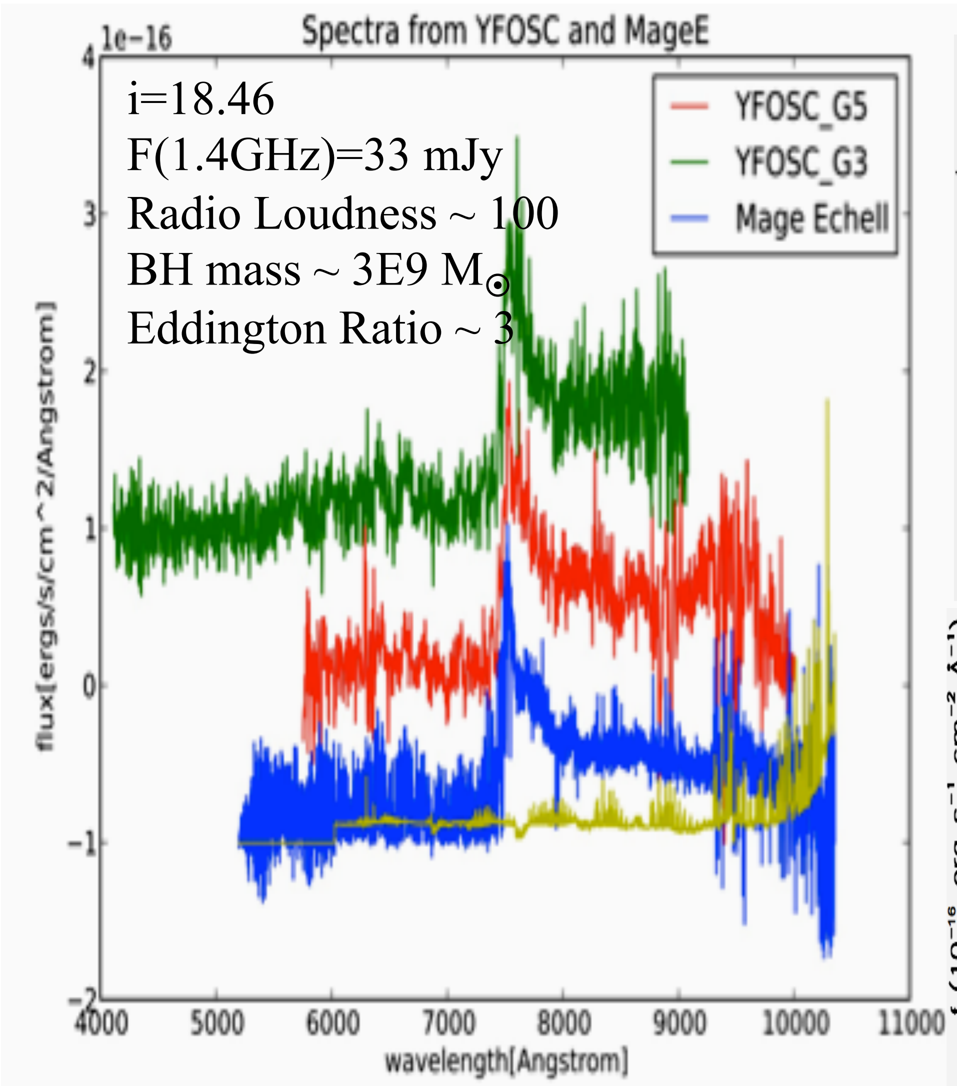

All z>5 quasars
Known quasar
New quasar
60
50
40
30
20
10
0
5.0
5.5
6.0
6.5
7.0
Known quasar
New quasar
z>5 quasars with z_{AB}<20.5
New quasars discovered by us
J0100+2802
The most
luminous
quasar at z>6

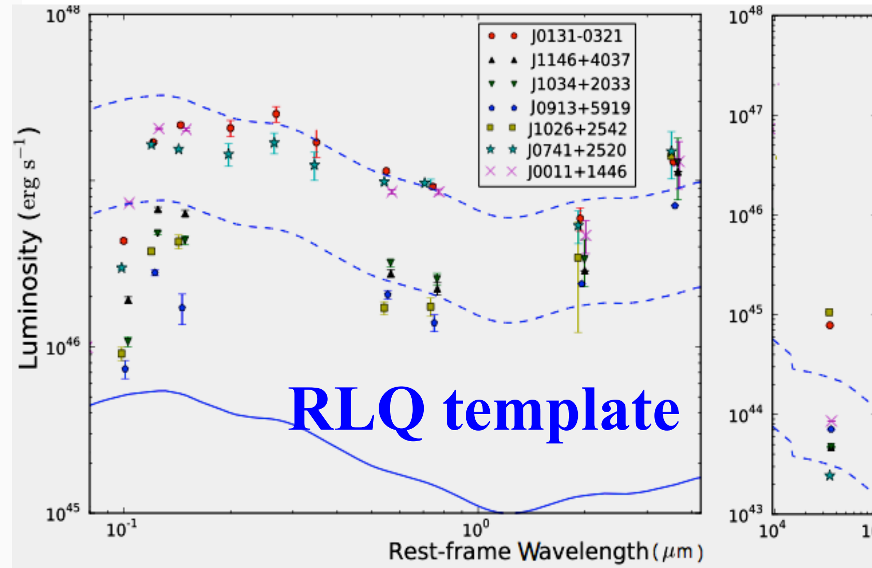
35 z~5 quasars found by 2.4-m

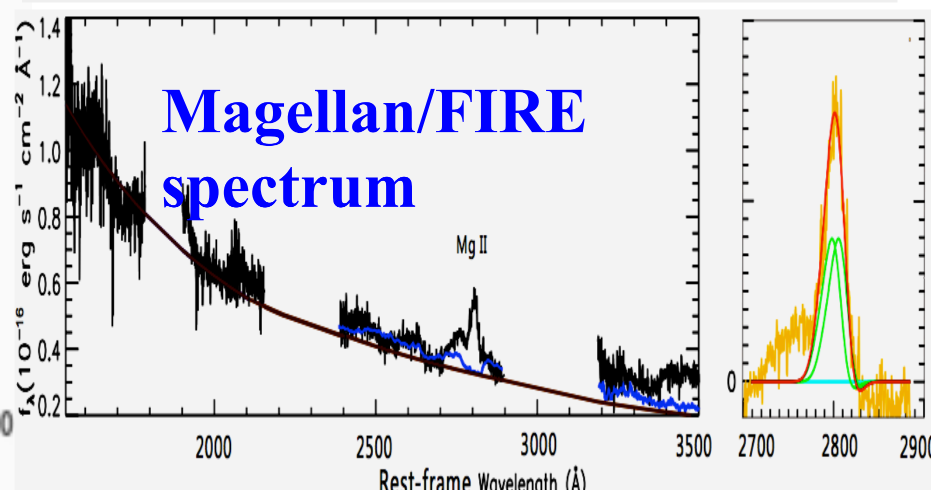


A rare z=5.18 radio-loud quasar

(Yi W.-M., Wang F., Wu, X.-B. et al. 2014, ApJL)



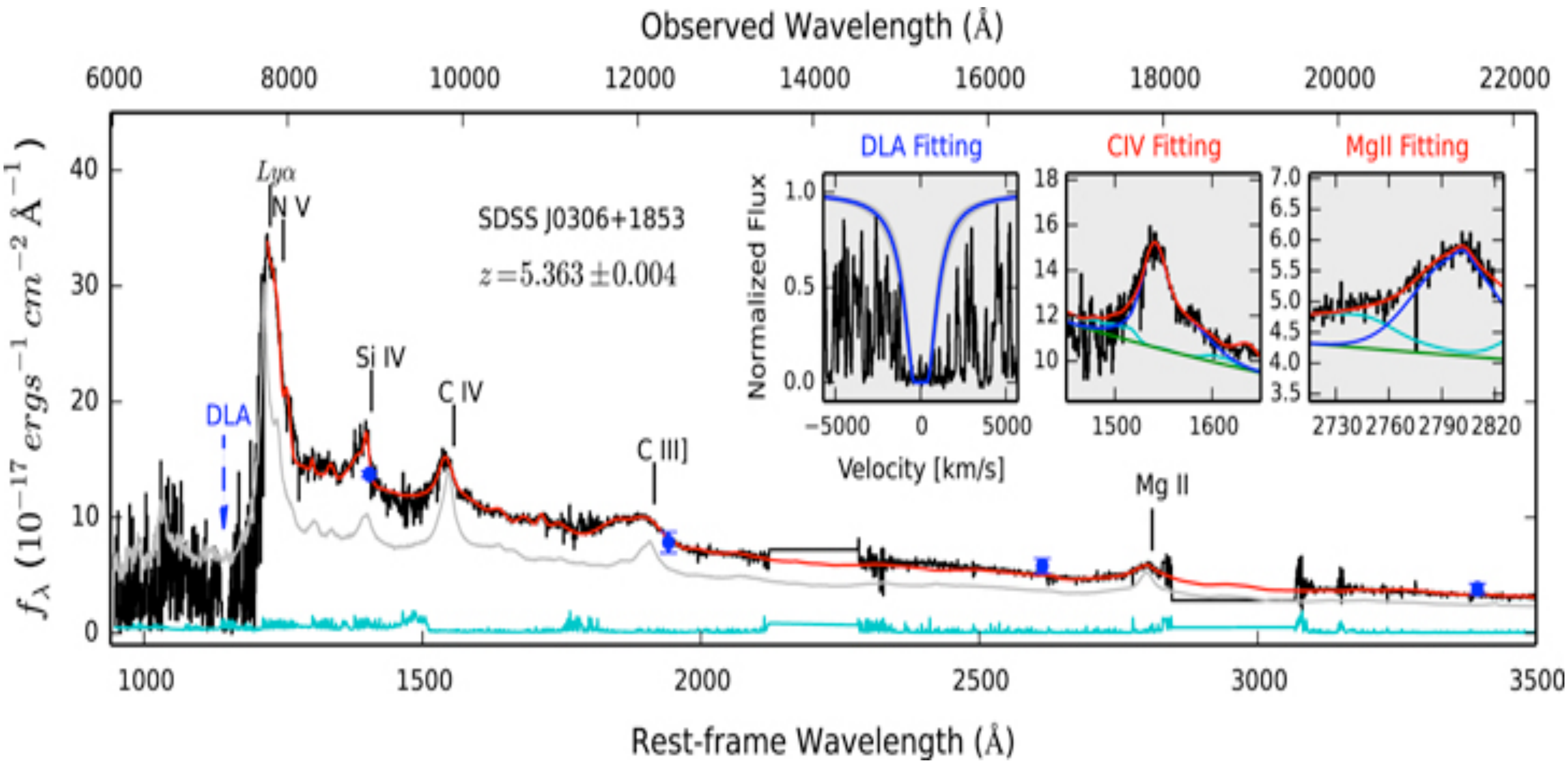




AN ULTRA-LUMINOUS QUASAR AT z = 5.363 WITH A TEN BILLION SOLAR MASS BLACK HOLE AND A METAL-RICH DLA AT $z \sim 5$

（Wang Feige, Wu, Xue-Bing, Fan Xiaohui et al. 2015, ApJL）

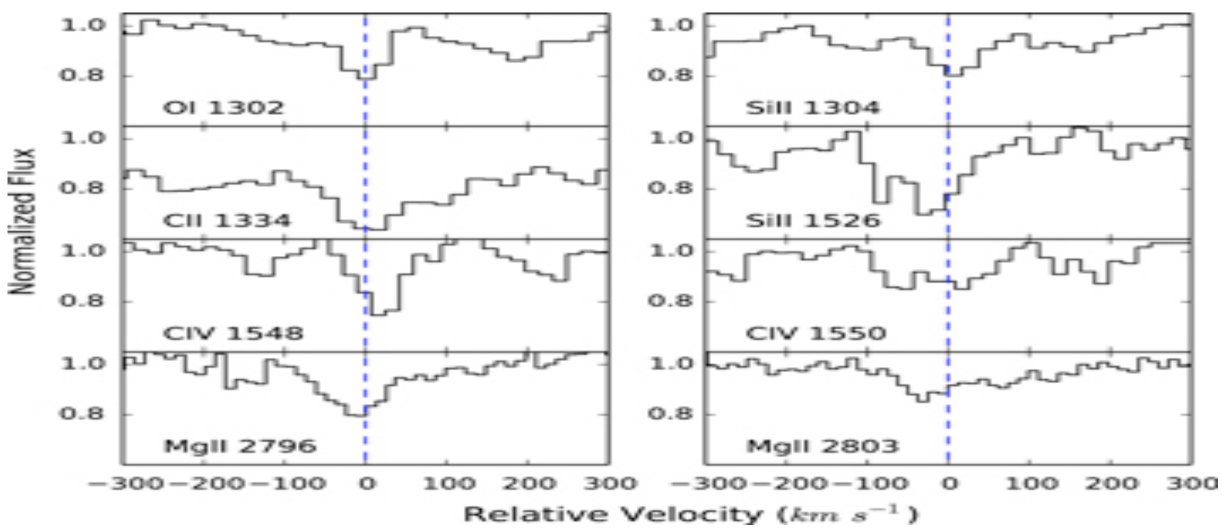
The first low-resolution optical spectrum of this source was obtained with the Lijiang 2.4 m telescope using the YFOSC on 2013 November 25 (UT), then follow-up by Magellan.



A rare DLA system at z~5 !

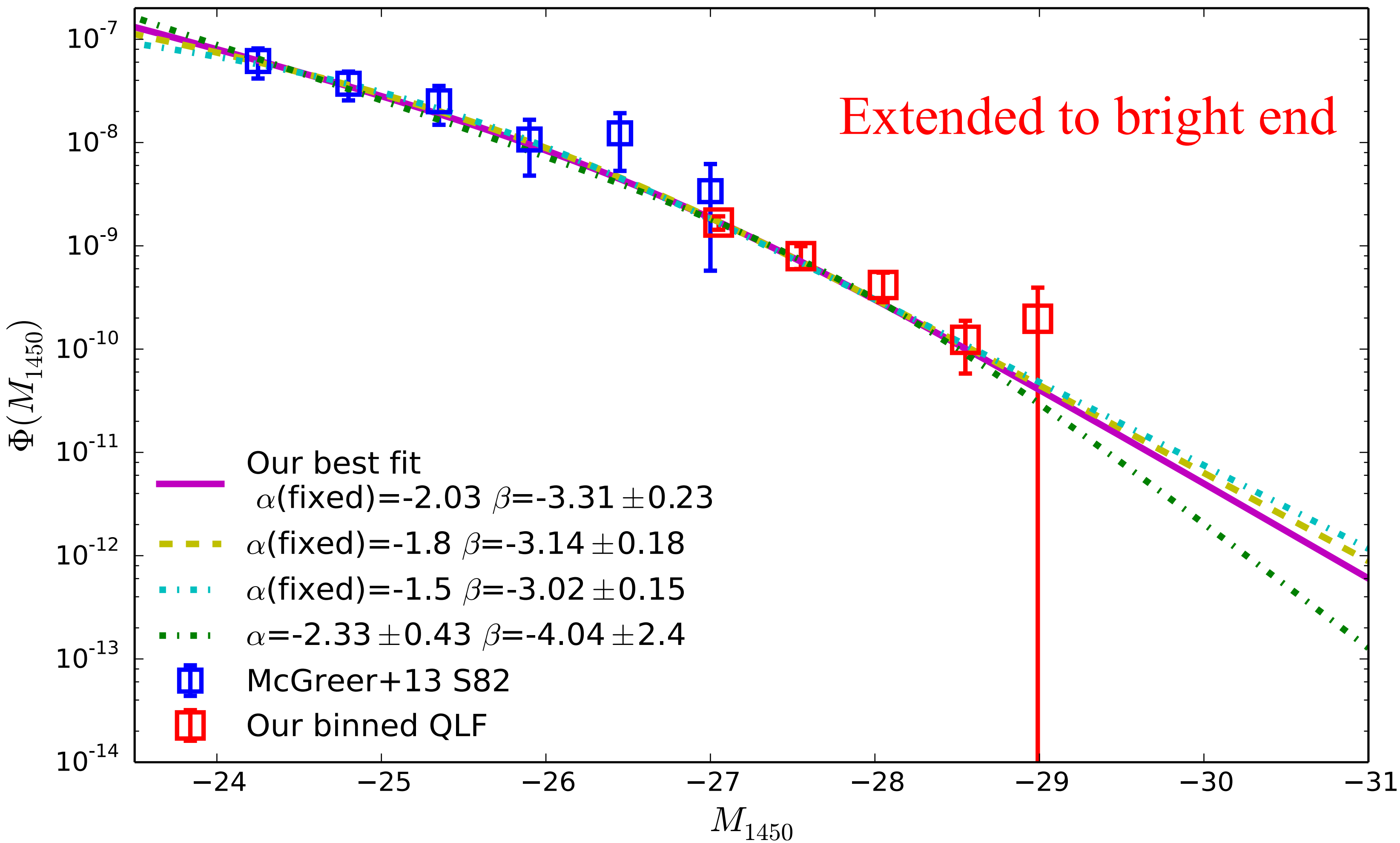
- DLAs are atomic hydrogen gas clouds measured in absorptions to background quasars with a column density higher than 2E20/cm^2, which are unique laboratories for understanding the conversion of neutral gas into stars at high redshift (Wolfe et al. 2005).
- However, the number of known high-redshift DLAs is very rare and only about 10 DLAs have been discovered at z>4.7 (Rafelski et al. 2012).
- The studies of metallicities of these high-redshift DLAs suggest a rapid decline in metallicity of DLAs at z~5 (Rafelski et al. 2012, 2014).

- The DLA is also associated with a number of corresponding metal lines, including C II λ1334, Si II λ1304, λ1526, O I λ1302, C IV λ1548, λ1550, and Mg II λ2796, λ2803
- Although the metallicity of the DLA in J0306+1853 ([M/H]=-1.3) is about 0.7 dex higher than the average metallicity of other z~5 DLAs, the existence of such a system is still consistent with the rapid decline in metallicity of DLAs at z>=5 (Rafelski et al. 2014).

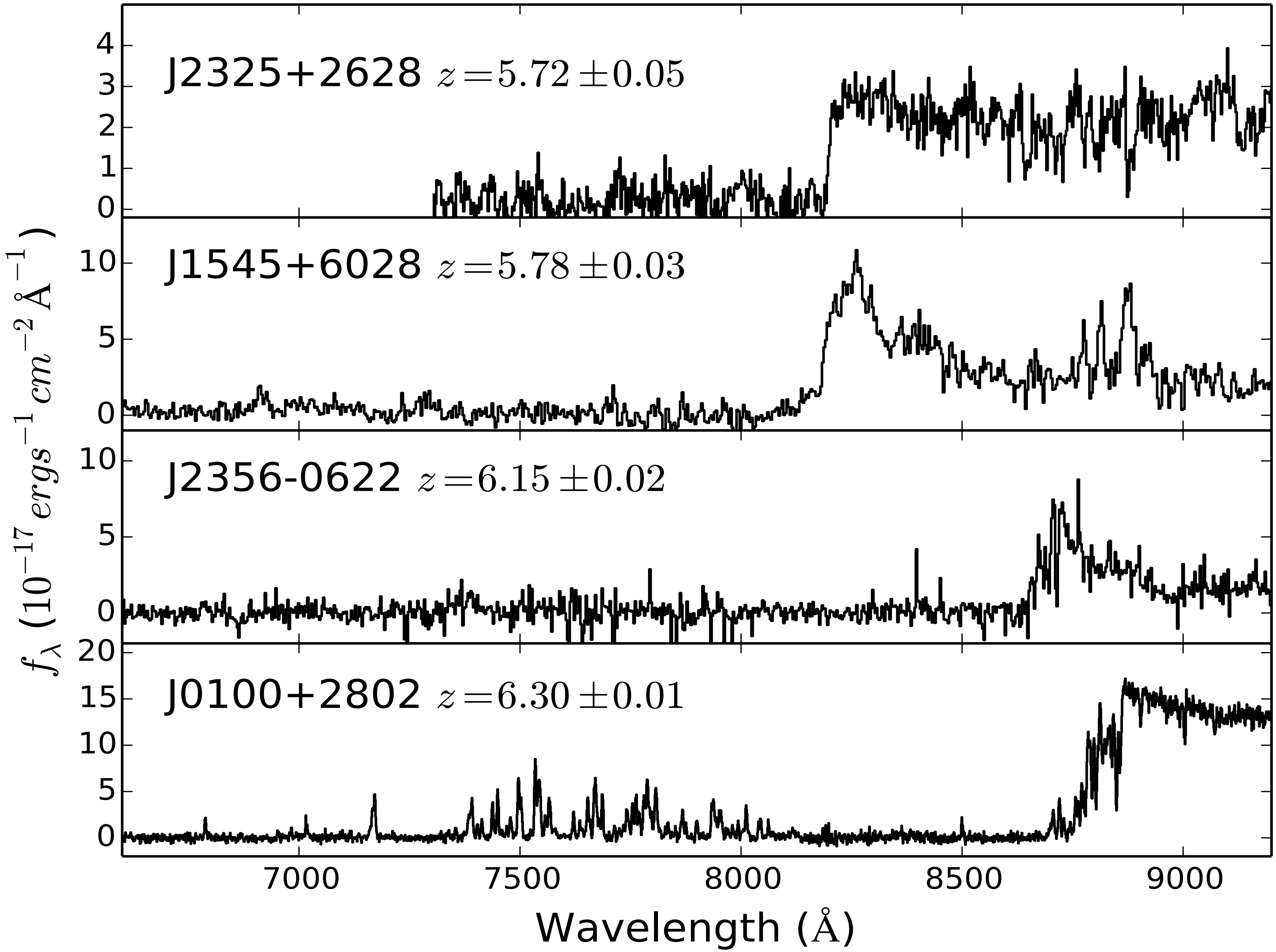


Quasar Luminosity Function at z~5

Yang J., Wang, F., Wu, X.-B. et al. 2016, ApJ, 829, 33

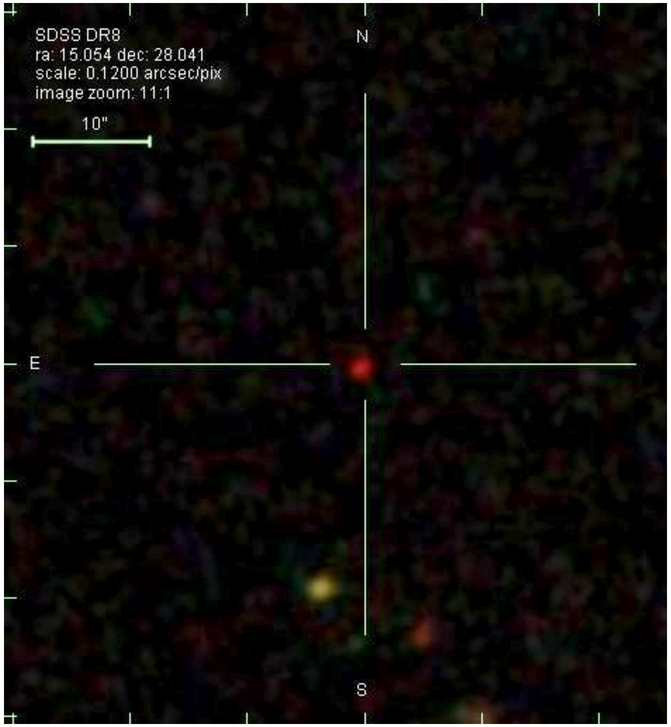


4 new z>5.7 quasars



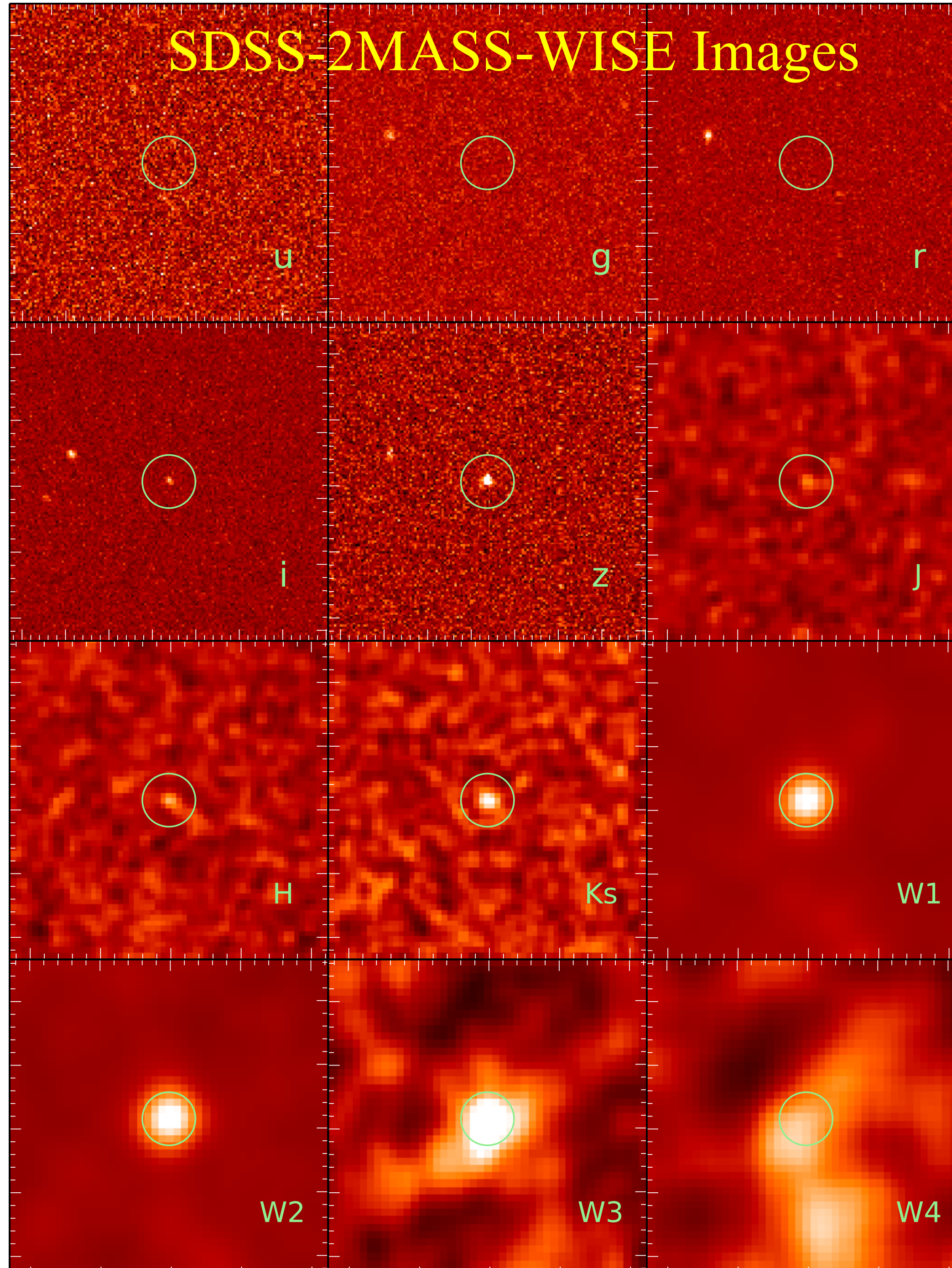
3. The most massive black hole in the early Universe

One interesting target

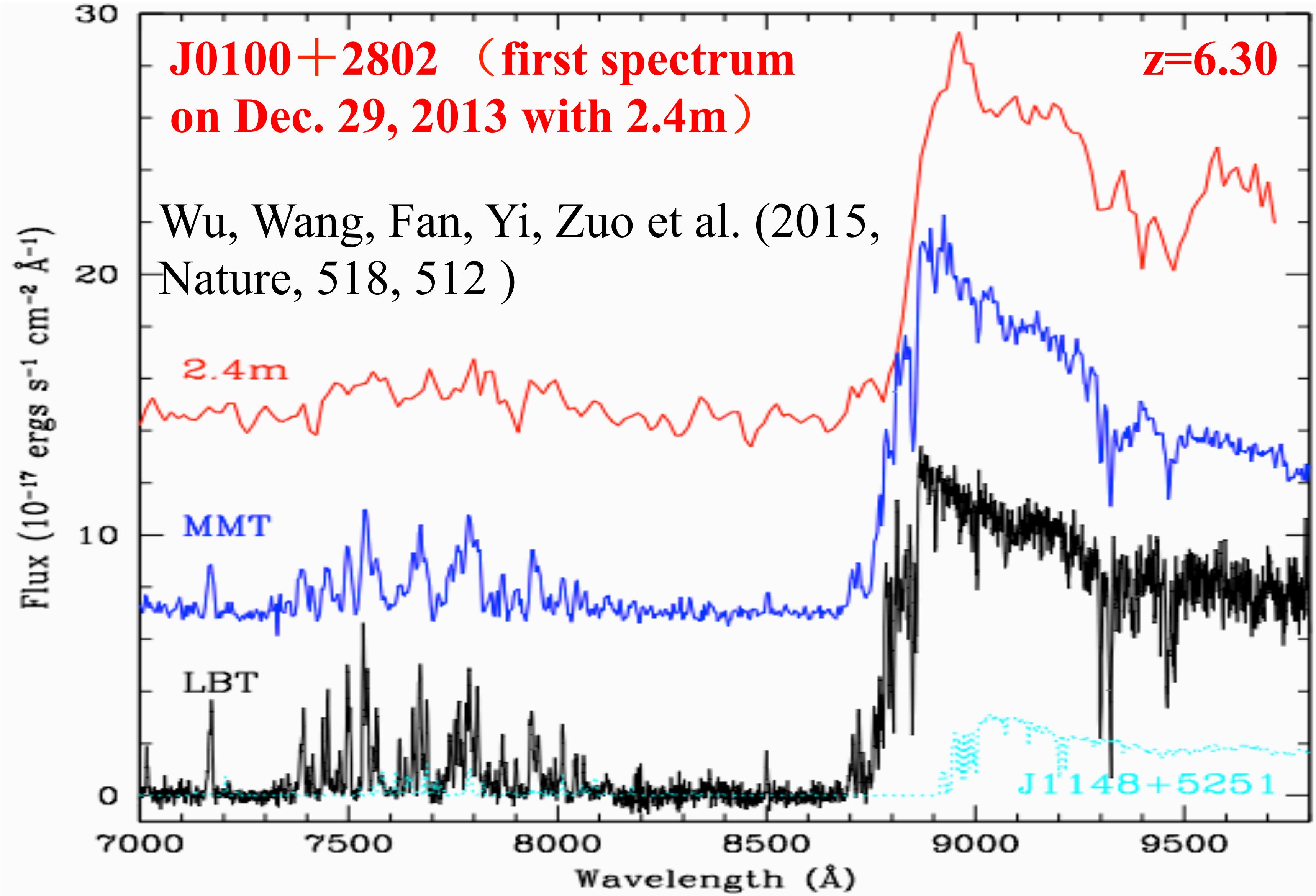


i=20.84 z=18.33
J=17.00 H=15.98
Ks=15.20
W1=14.45 W2=13.63
W3=11.71 W4=8.98

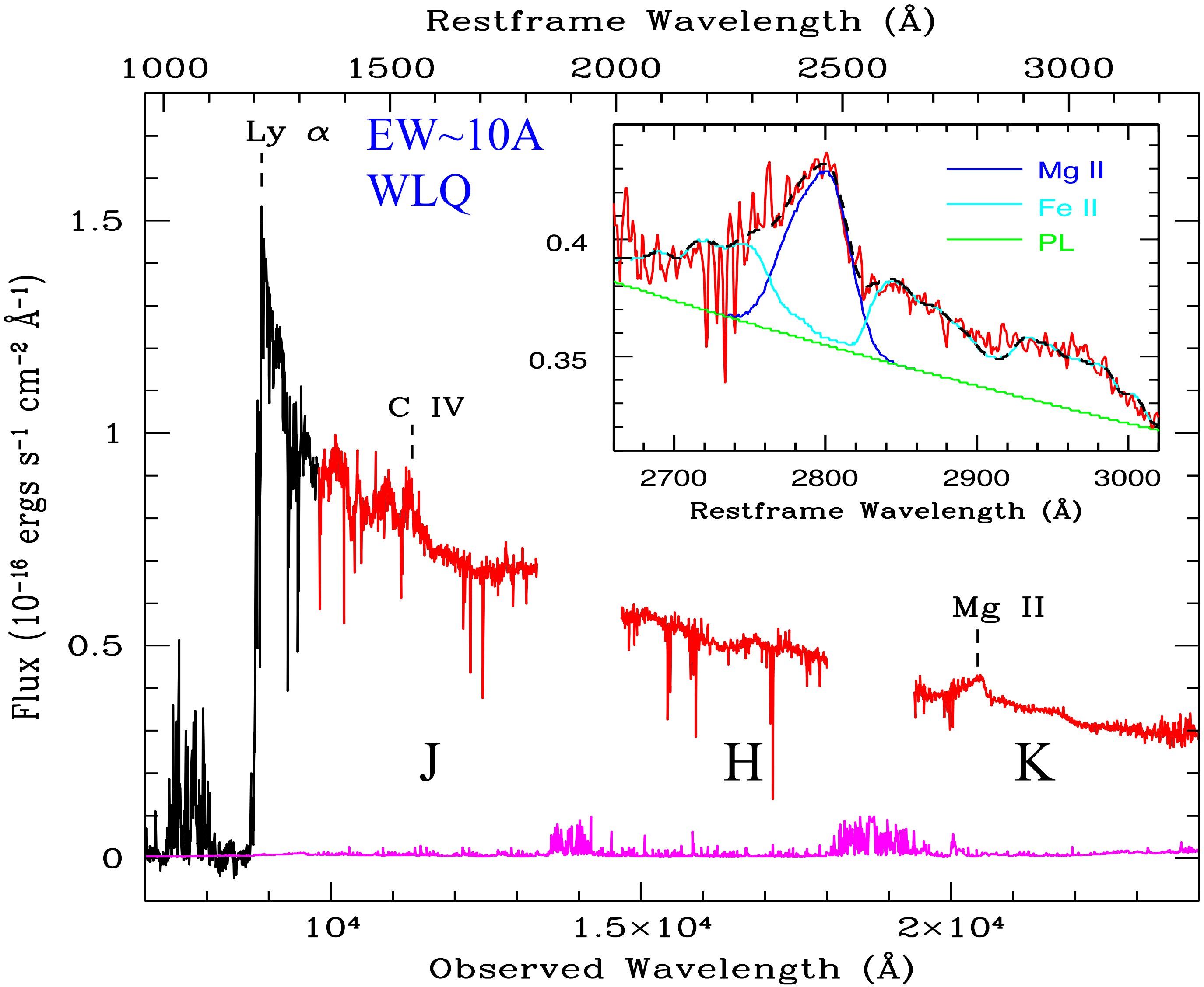
Photo-z ~ 6.3!



The highest redshift quasar we discovered with 2.4m telescope



Near-IR Spectroscopy (Jan.-Oct., 2014)

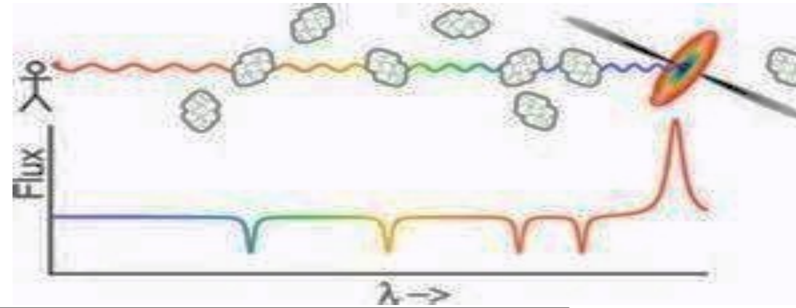


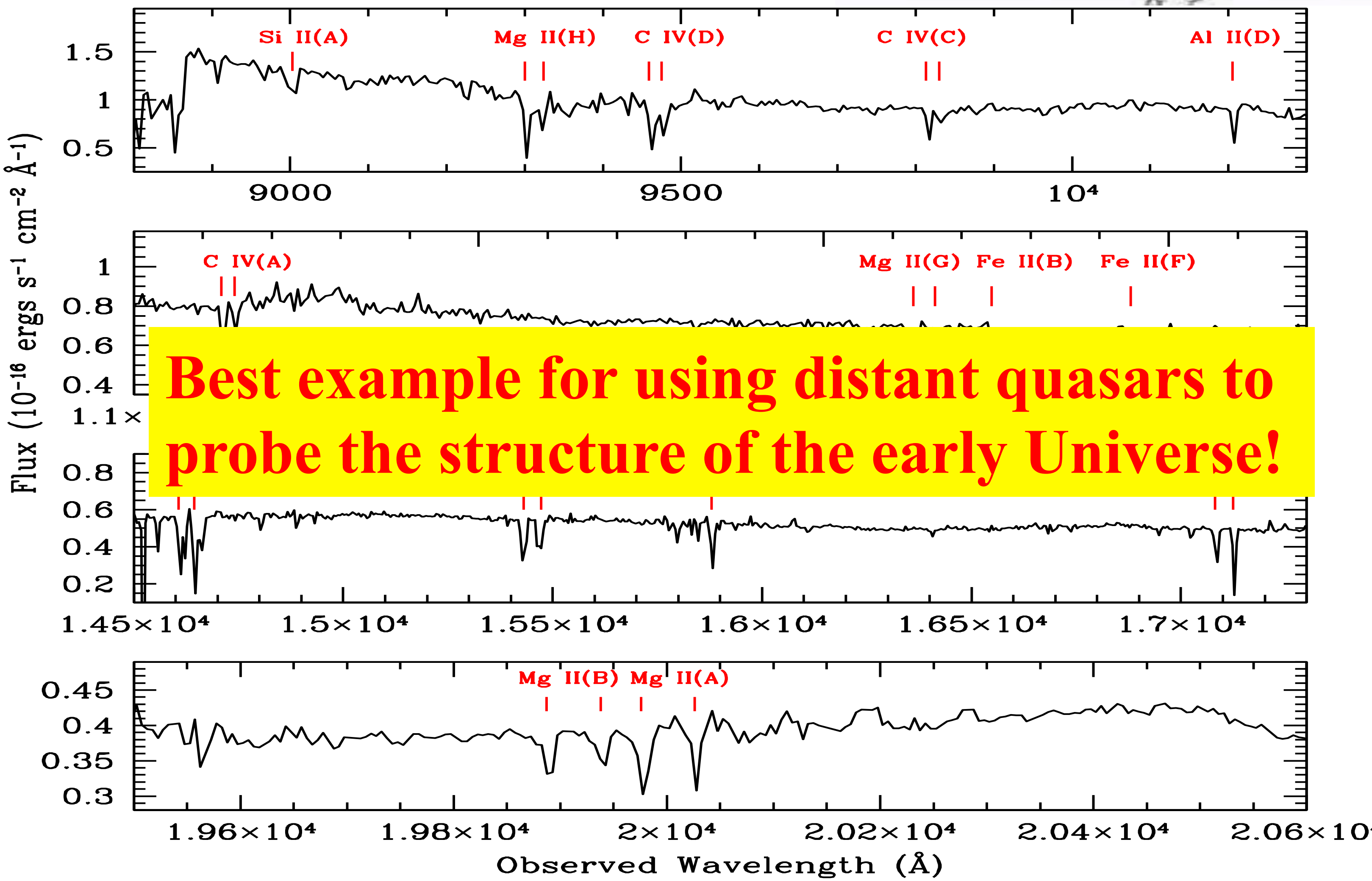
LBT(8.4-m; Jan.)
Gemini (8.1-m;Aug.)
Magellan(6.5m; Oct.; R~6000, S/N>30)

MgII FWHM ~ 5130 km/s
L_{3000}~3.15E47 erg/s

Following MD04 & VP06
-->BH mass ~ **12 billion solar masses**

Many Absorption Systems at z=2.2 to 6.1 !



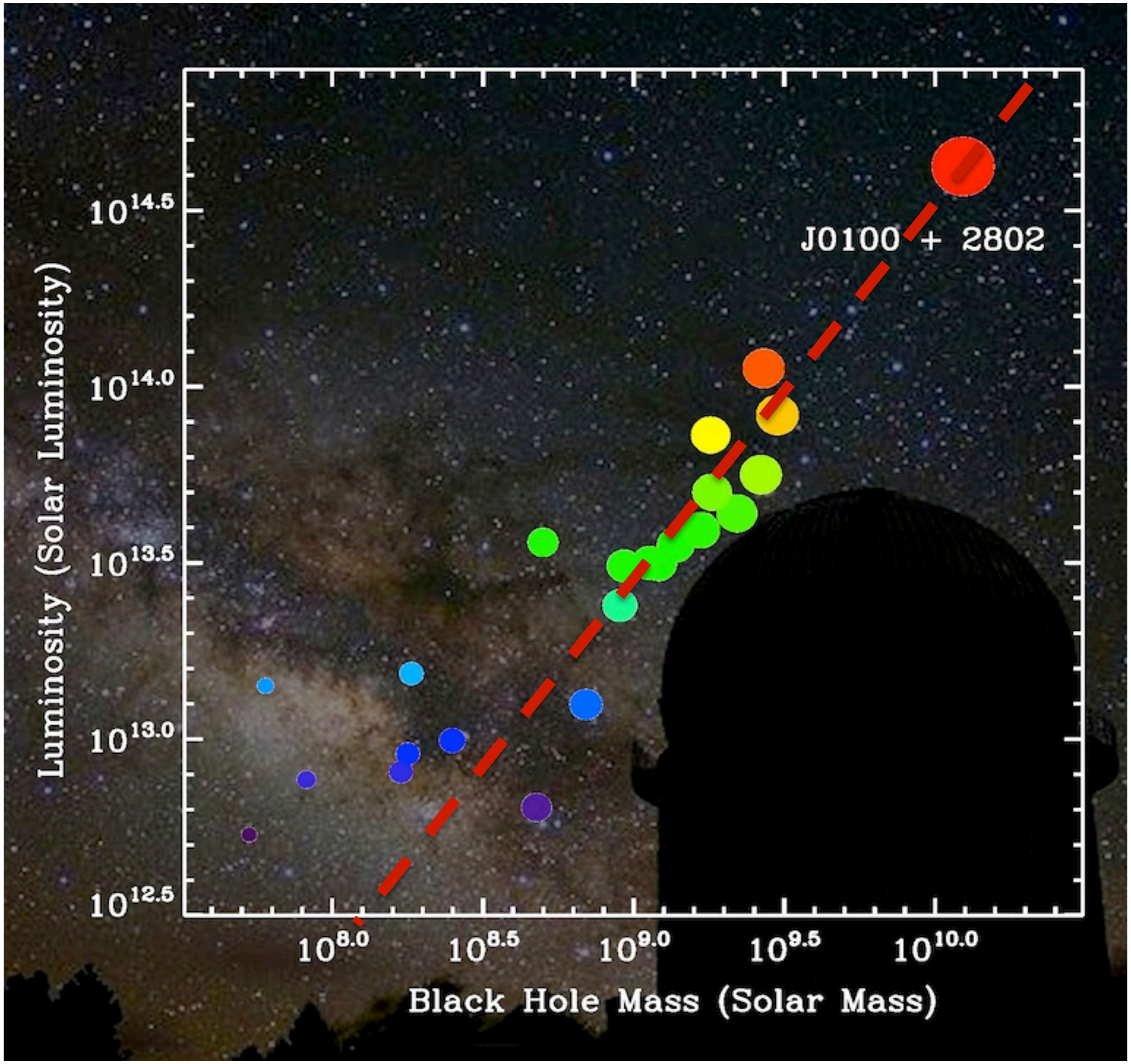


Best example for using distant quasars to probe the structure of the early Universe!

SDSS J0100+2802, a quasar with largest BH mass and highest luminosity at z>5.7

$L_{bol} = 5.15 \times L_{3000} = 1.62 \times 10^{48}$ erg/s

$M_{1450} = -29.26$



--- Eddington Luminosity

Credits: Zhaoyu Li (SHAO); background photo (2.4m dome) provided by YNAO

LETTER

doi:10.1038/nature14241

An ultraluminous quasar with a twelve-billion-solar-mass black hole at redshift 6.30

Xue-Bing Wu[1,2], Feige Wang[1,2], Xiaohui Fan[2,3], Weimin Yi[4,5,6], Wenwen Zuo[7], Fuyan Bian[8], Linhua Jiang[2], Ian D. McGreer[3], Ran Wang[2], Jinyi Yang[1,2], Qian Yang[1,2], David Thompson[9] & Yuri Beletsky[10]

Wu et al. 2015, *Nature*, 518, 512

REUTERS

NATIONAL GEOGRAPHIC

The Washington Post

新华网

Los Angeles Times

NEWS

CBSNEWS

CNN

CCTV 中国中央电视台 CHINA CENTRAL TELEVISION

TIME

http://www.sabc.co.za

Scientists discover black hole so big it contradicts growth theory

Thursday 26 February 2015 06:38

REUTERS

An artist's illustration shows a supermassive black hole with millions to billions times the mass of our sun at the centre.(REUTERS)

Scientists say they have discovered a black hole so big that it challenges the theory about how they grow.

Scientists said this black hole was formed about 900 million years after the Big Bang.

But with measurements indicating it is 12 billion times the size of the Sun, the black hole challenges a widely accepted hypothesis of growth rates.

"Based on previous research, this is the largest black hole found for that period of time," Dr Fuyan Bian, Research School of Astronomy and Astrophysics, Australian National University (ANU), told Reuters on Wednesday.

http://www.iol.co.za

Massive black hole stymies scientists

SPACE / 27 February 2015, 12:30pm

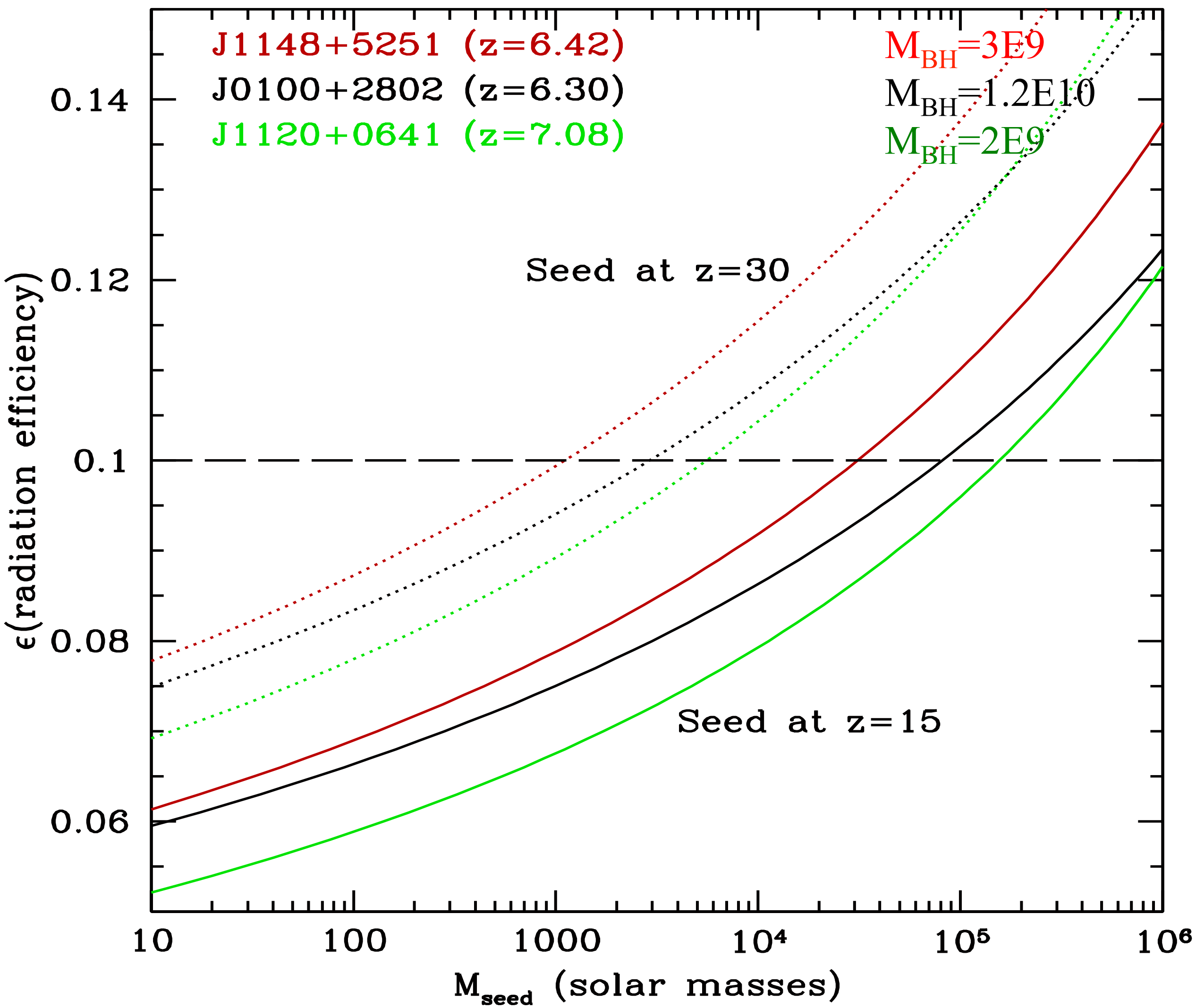
Irene Klotz

An artist's illustration shows a supermassive black hole with millions to billions times the mass of our sun at the centre. Pic: Reuters/NASA/JPL-Caltech

Cape Canaveral – A black hole 12 billion times as massive as the sun has been found in a glowing quasar that existed when the universe was just a fraction of its current age, scientists said on Wednesday.

The discovery challenges theories that black holes and their host galaxies grew in relative lockstep over the eons.

Constraints on seed BH & growth

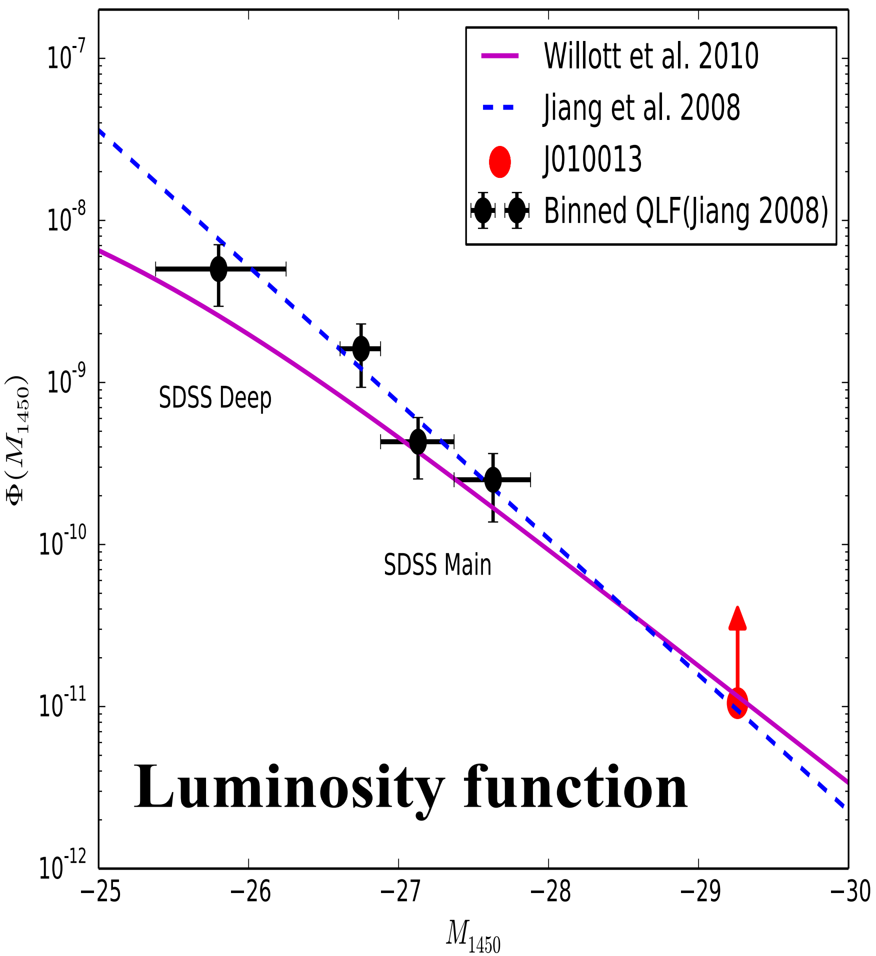


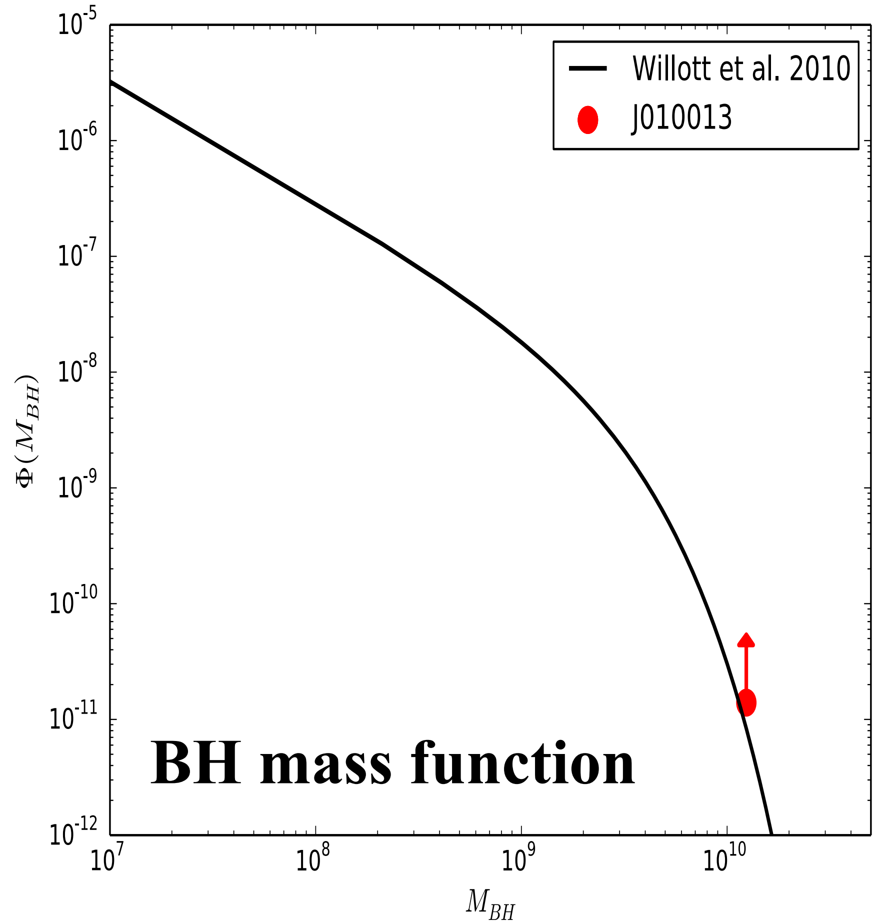
Assumptions:
Eddington accretion;
Duty cycle=1

Seed BH mass >10^5 solar masses!

Direct collapse? (Latif & Volonteri 2015)
Or super(hyper)-Eddington accretion ? (Inayoshi, Haiman & Ostriker 2016)

Constraints on high-z quasar luminosity function and BH mass function





X-ray fellow up observation of J0100

- Chandra 14.8ks on Oct. 16, 2015

  (Ai, Du, Fan, et al., 2016, ApJ, 823, L37)

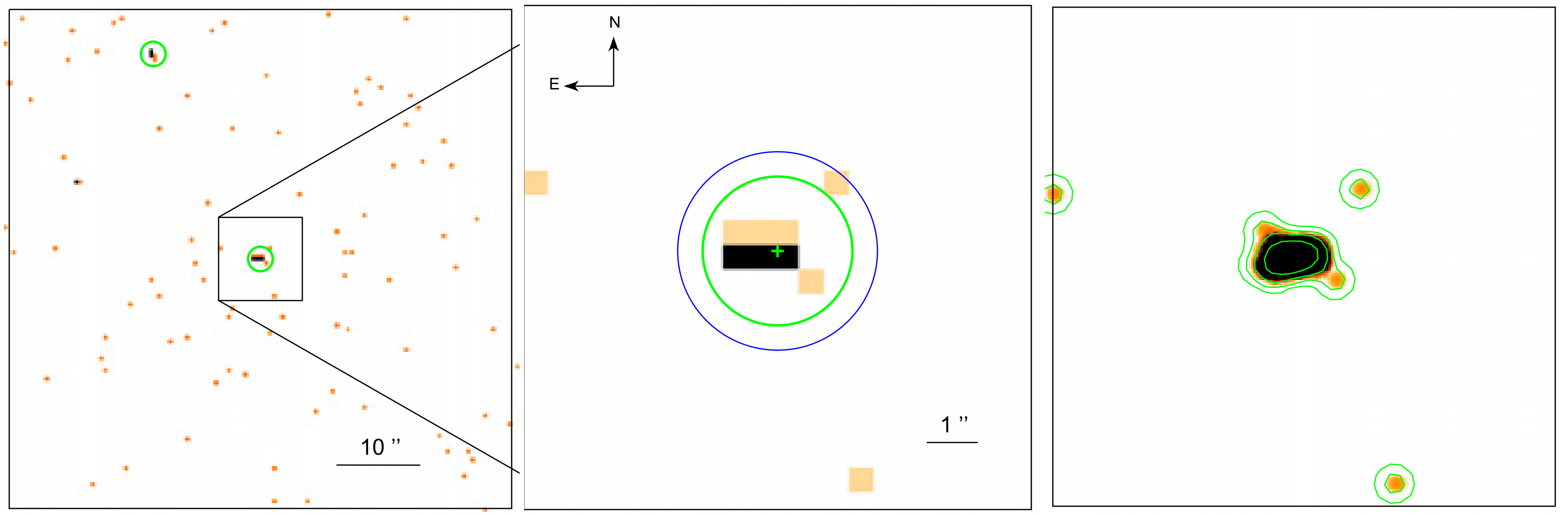
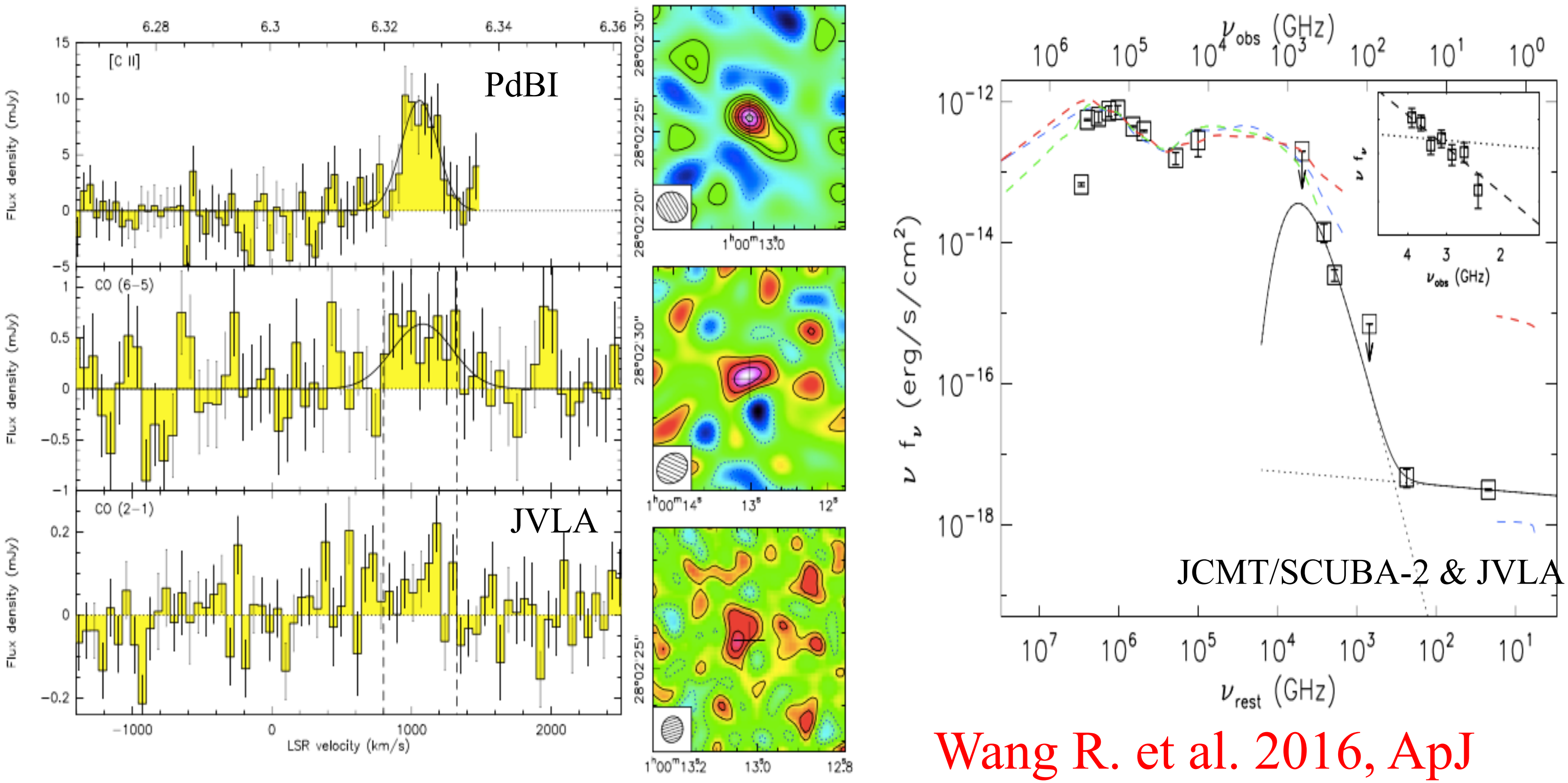


Figure 1. Detection of X-ray emission of J0100+2802. Left: $1' \times 1'$ *Chandra* image centered on J0100+2802 in 0.5–7 keV. The circles show the two sources detected by CIAO task WAVDETECT; Middle: central $10'' \times 10''$ of the image. The plus sign shows the optical position given by SDSS. 14 counts are detected in the 3 pixel radius aperture (green), and one more count in the 4 pixel radius aperture (blue). Right: rebinned image in the middle panel to 0.1 ACIS pixel and smoothed with a $0\farcs492$ Gaussion filter. The size of the ACIS CCD pixel is $\sim 0\farcs492$.

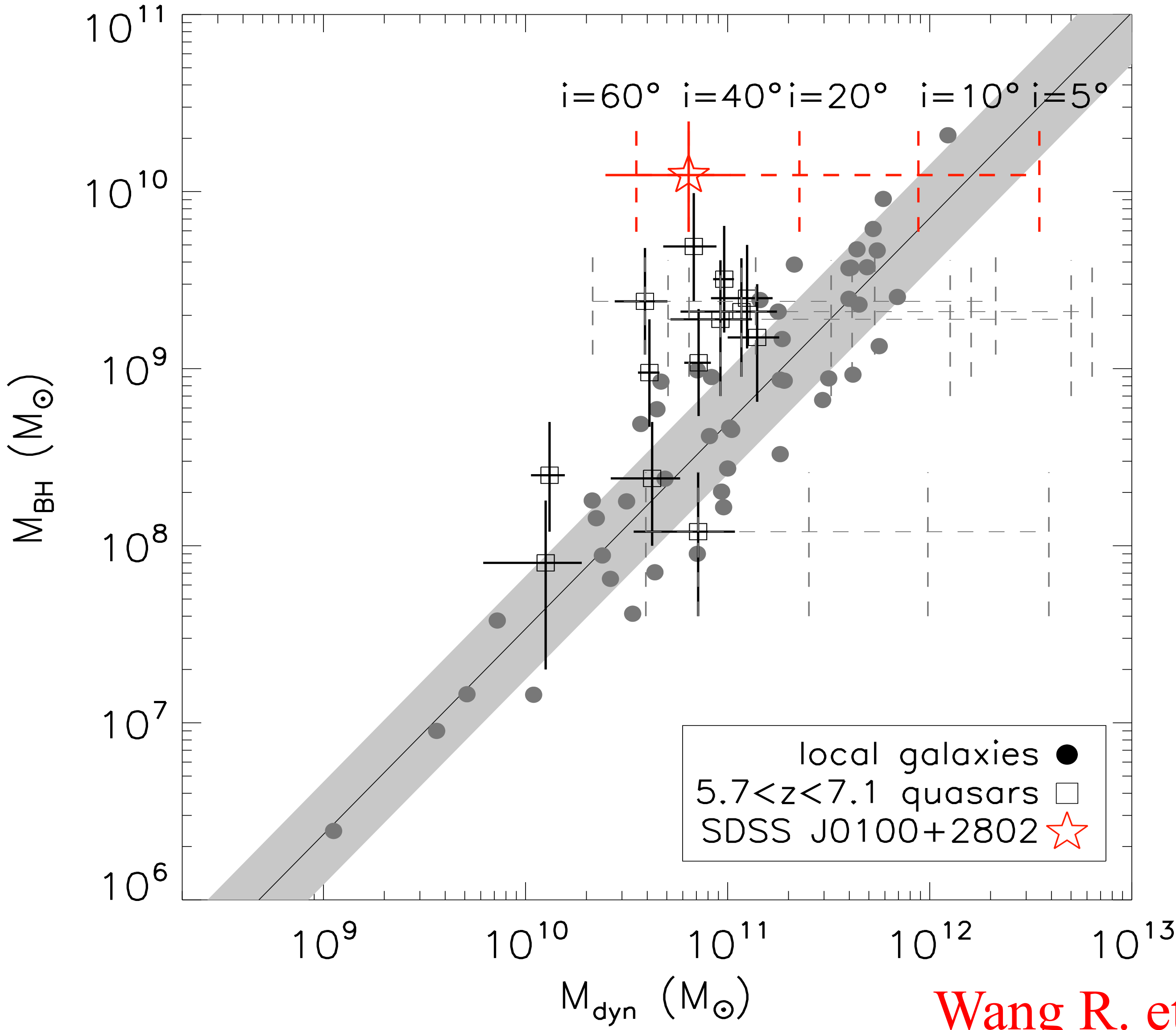
mm/radio observations on J0100+2802
(IRAM/PdBI, JCMT/SCUBA-2, JVLA)



Wang R. et al. 2016, ApJ

Detect the [C II] 158µm fine structure line and molecular CO(6-5) line and continuum emission at 353 GHz, 260 GHz, and 3 GHz → active star formation!

BH-Host Relation

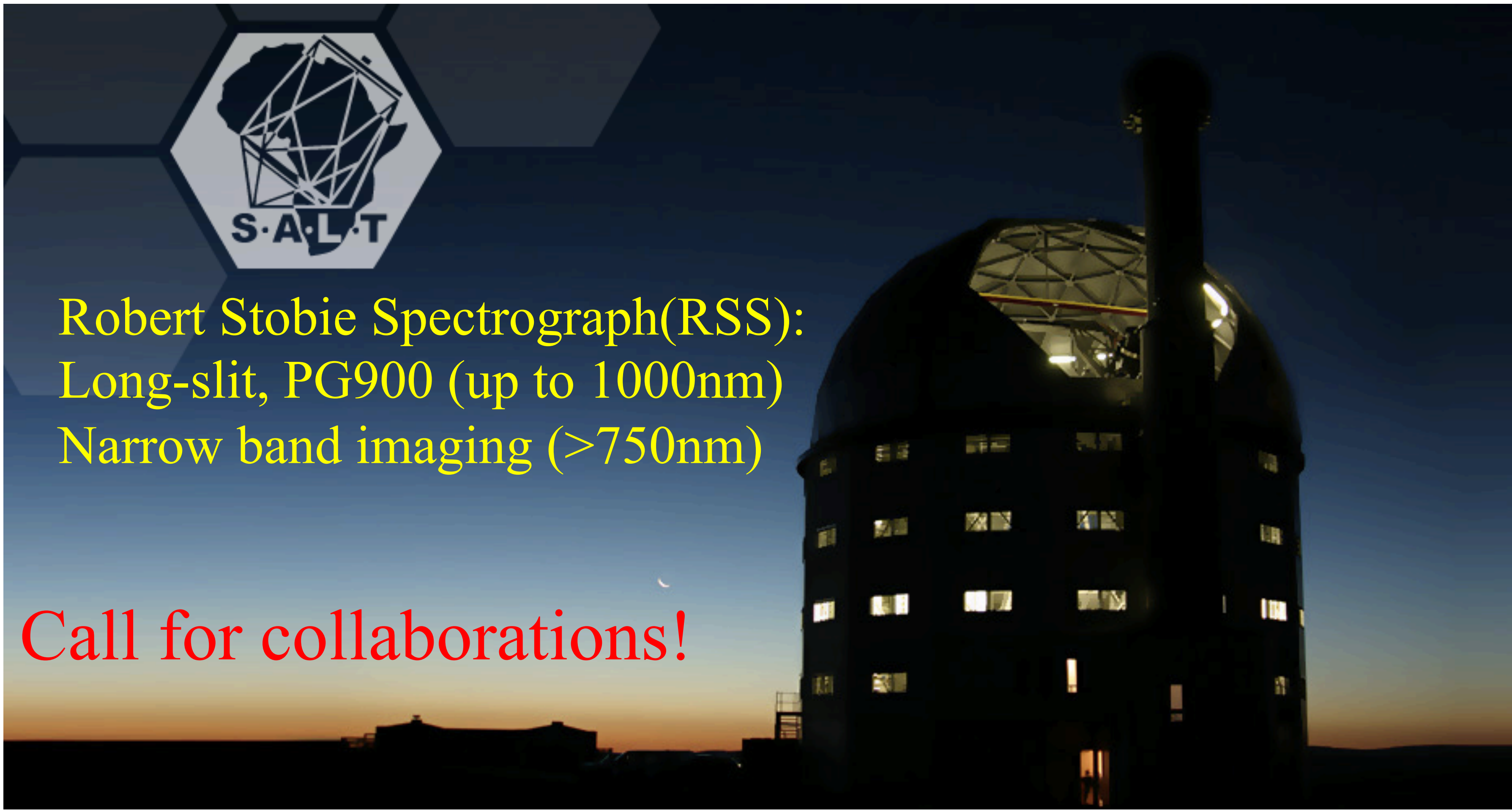


J0100 lies above the local SMBH-galaxy mass relationship, unless we are viewing the system at a very small inclination angle.

Wang R. et al. 2016, ApJ

Southern African Large Telescope ?

(See Ted Williams & Petri Vaisansen's talks)

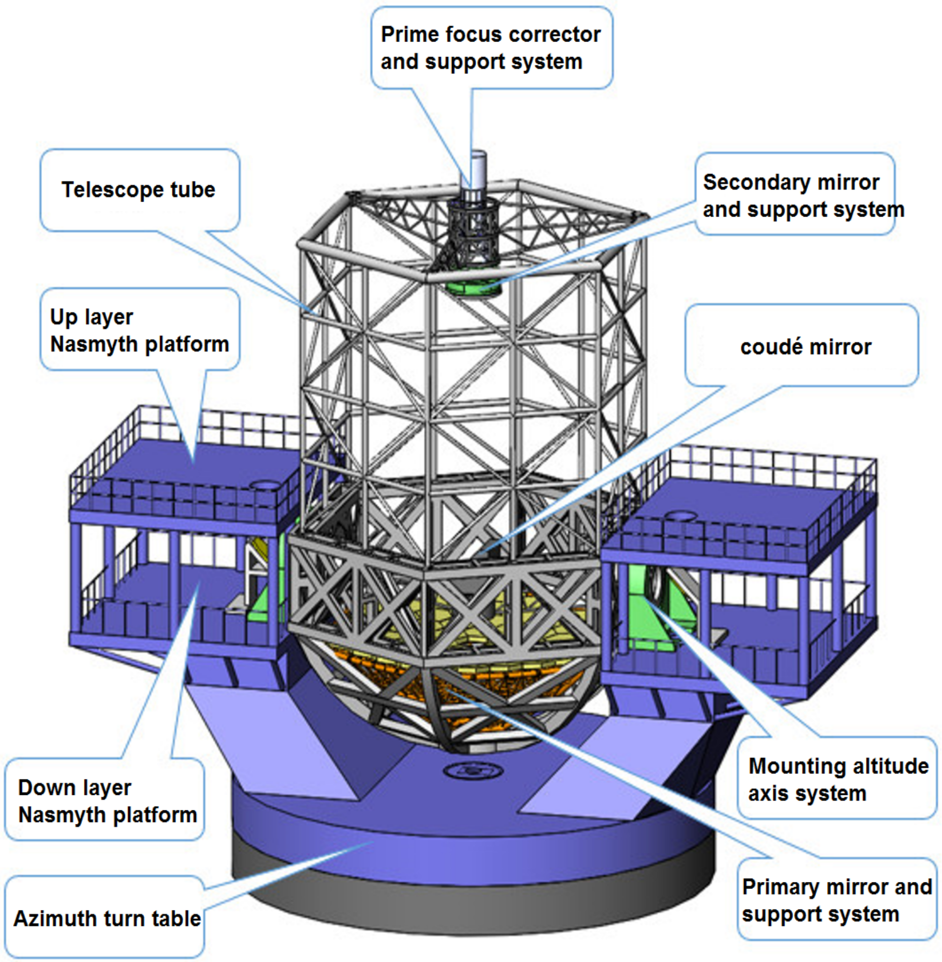


Robert Stobie Spectrograph(RSS):
Long-slit, PG900 (up to 1000nm)
Narrow band imaging (>750nm)

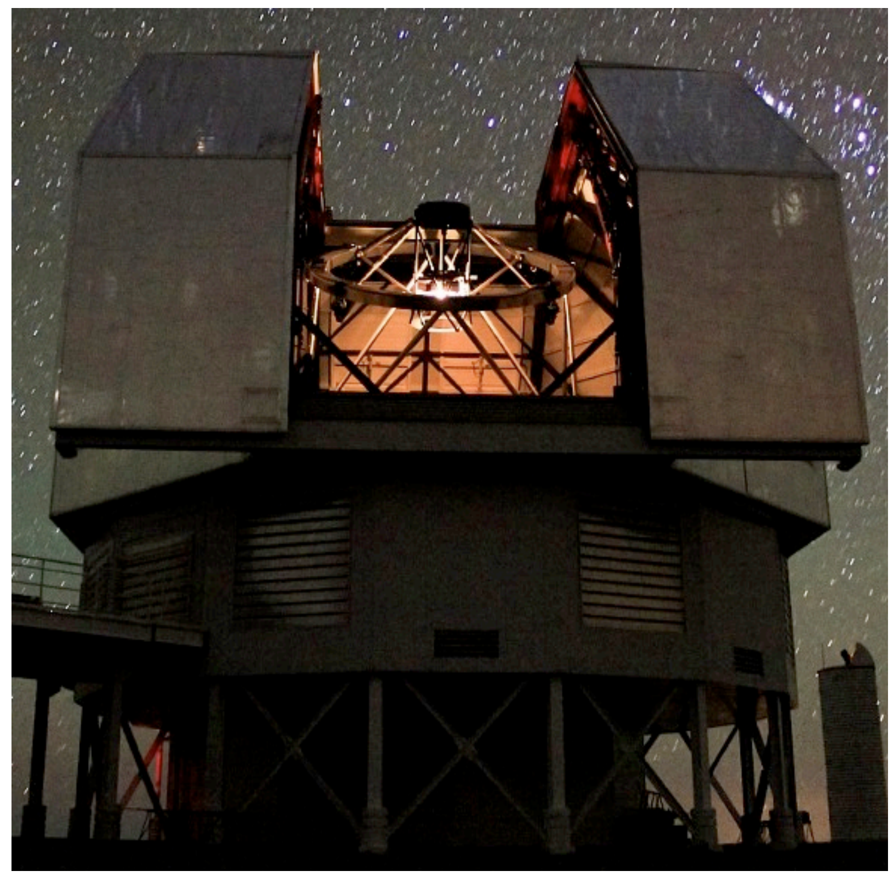
Call for collaborations!

Future Large Optical/IR Telescopes in China (~2023?)

LOT(12-m)



AST(6.5-m)



4. Summary

- Discovering more high-z quasars is crucial to study the evolution of quasars/galaxies and BH growth at cosmic dawn
- We proposed new selection criteria in finding high-z quasars with SDSS & WISE, and are carrying out a large program in identifying luminous quasars at z>5
- An ultra-luminous z=6.3 quasar with the most massive BH (12 billion solar masses) was discovered, which challenges the theories of black hole growth and galaxy formation in the epoch of cosmic reionization
- A lot of follow-up observations on high-z quasars and new programs are ongoing
- Welcome collaborations from SA astronomers