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Rest-frame Optical Spectra of Quasars at z > 4: Detection of Hα Emission Lines and Implications on Distant Quasar Properties

Myungshin Im
CEOU/Department of Physics & Astronomy,
Seoul National University

Hyungsun Jun (SNU/JPL), Dohyeong Kim, Hyung Mok Lee, Myung Gyoon Lee, Jonghak Woo **(SNU),**
Y. Ohyama (ASIAA), Minjin Kim (KASI),
T. Nakagawa, H. Matsuhara, S. Oyabu, T. Takagi, T. Wada (ISAS/JAXA), X. Fan (Steward Observatory) et al.

2016 Sept. 22 - 24 East-Asia AGN Workshop, Seoul, Korea

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SMBHs over Cosmic History

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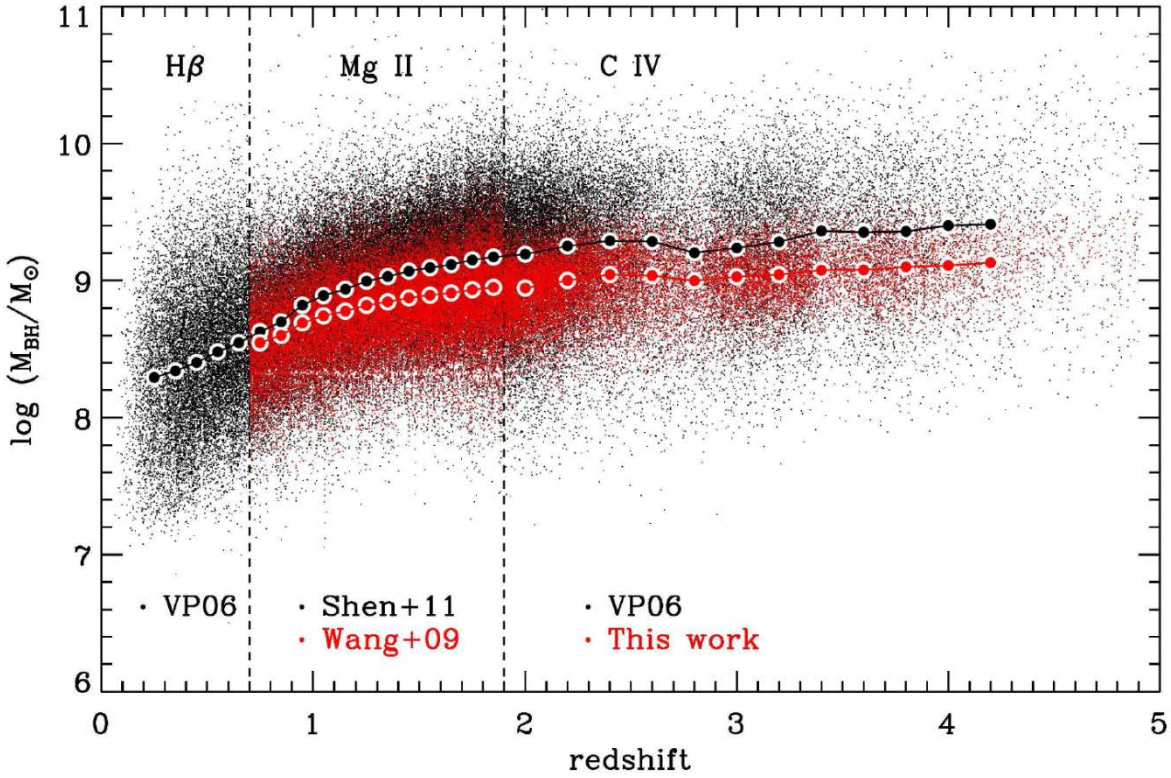
- The most massive SMBHs (M ~ 10^{10} $M_\odot$ or more) at 2 < z < 6
- ~10^9 $M_\odot$ BHs at z ~ 7.0 (t_{univ}< 1 Gyr, Mortlock et al. 2011)



More points here out to z ~ 7 from ground-based NIR spectroscopy (Jiang et al. 2007; Kurk et al. 2007; Mortlock et al. 2011; Wu et al. 2015)

Park et al. (2013)

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BHs were being made at z > 4

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- Universe age: ~1 Gyr or less
- BHs must be very young

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Questions@z > 4

- Mass – Reliable?
- Scaling relation – Universal?
- Spin – Fast or slow?

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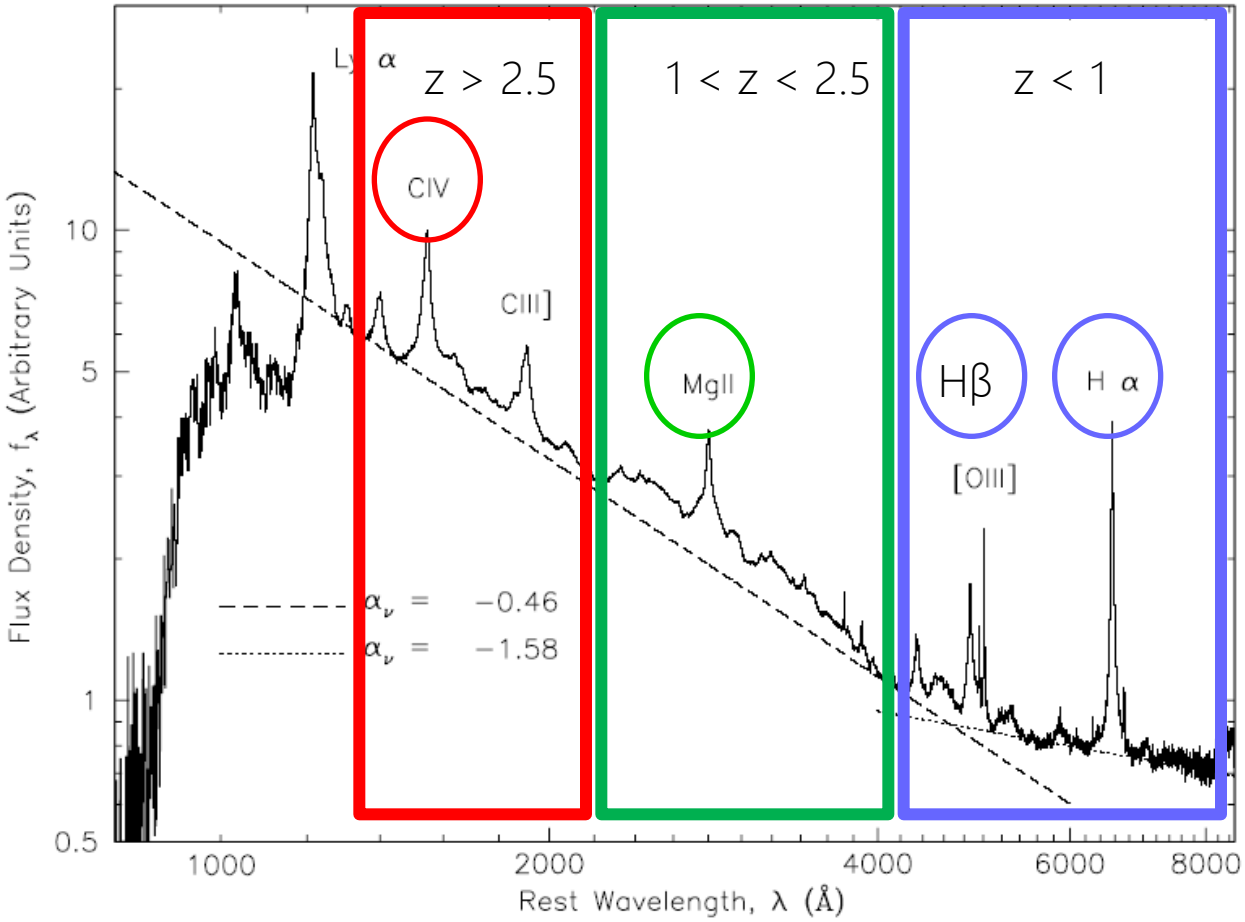
M_{BH} for High Redshift AGN



Primary

M_{BH}(Hβ or Hα)
+ L(5100, H)

Secondary

M_{BH}(MgII)/L(3000)
or
M_{BH}(CIV)/L(1350)
@ z > 1

L-Scaling Relation

M_{BH} from Hα

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Need for Better Mass Measurement

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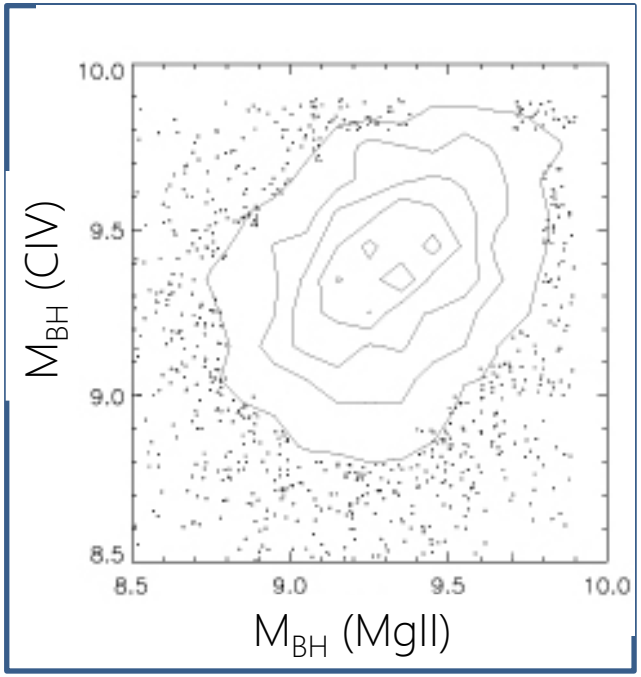
$$M_{\rm BH} = (2.0^{+0.4}_{-0.3}) \times 10^6 \left(\frac{L_{\rm H\alpha}}{10^{42}\ {\rm ergs\ s^{-1}}}\right)^{0.55\pm0.02} \left(\frac{\rm FWHM_{H\alpha}}{10^3\ {\rm km\ s^{-1}}}\right)^{2.06\pm0.06} M_\odot$$

Green & Ho (2005)



Shen et al. (2008)

- ✓ Use of CIV, MgII reliable? large scatter, metallicity evolution, extinction….
- ✓ Better if we can use optical spectral lines such as Hα or Hβ

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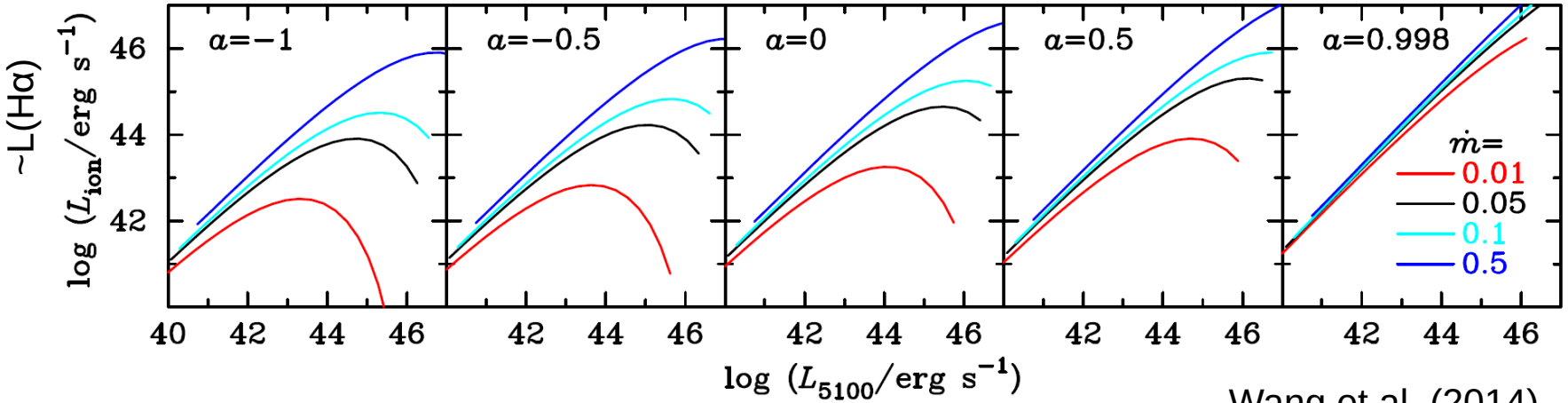
Fast Spinning BH at z > 4?

- $T_{eff,max} = f_{max}(a)\,(\frac{\dot{M}}{M^2})$ (Loar & Davis 2011)

- High M_{BH}, low spin ➔ Cold accretion disk
  ➔ Deviation in L(ion) vs L(5100) relation
  (Wang et al. 2014; Laor & Davis 2011; Trakhtenbrot 2014)

L(ion) ~ L(5100) or not?

Low spin ➔ High spin M_{BH}~10^{10} $M_\odot$ @ $\dot{m} = 0.01$



Wang et al. (2014)

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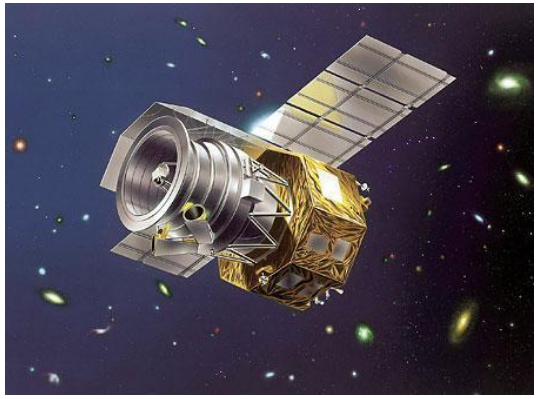
QSONG

- Quasar Spectroscopic Observation with NIR Grism [Open Time Program (PI: M Im) + Mission Program (PI: HM Lee)]
- NIR Spectroscopic Study of high-z and low-z AGNs at 2.5 – 5.0 μm with NIR grism of AKARI (R ~ 120, FWHM ~ 2500 km/sec)
- High-z study: 155 QSOs at 3.4 < z < 6.42 (Jun, Im et al. 2015)
- Low-z study: 83 nearby AGNs + red AGNs (Kim, Im, et al. 2015)



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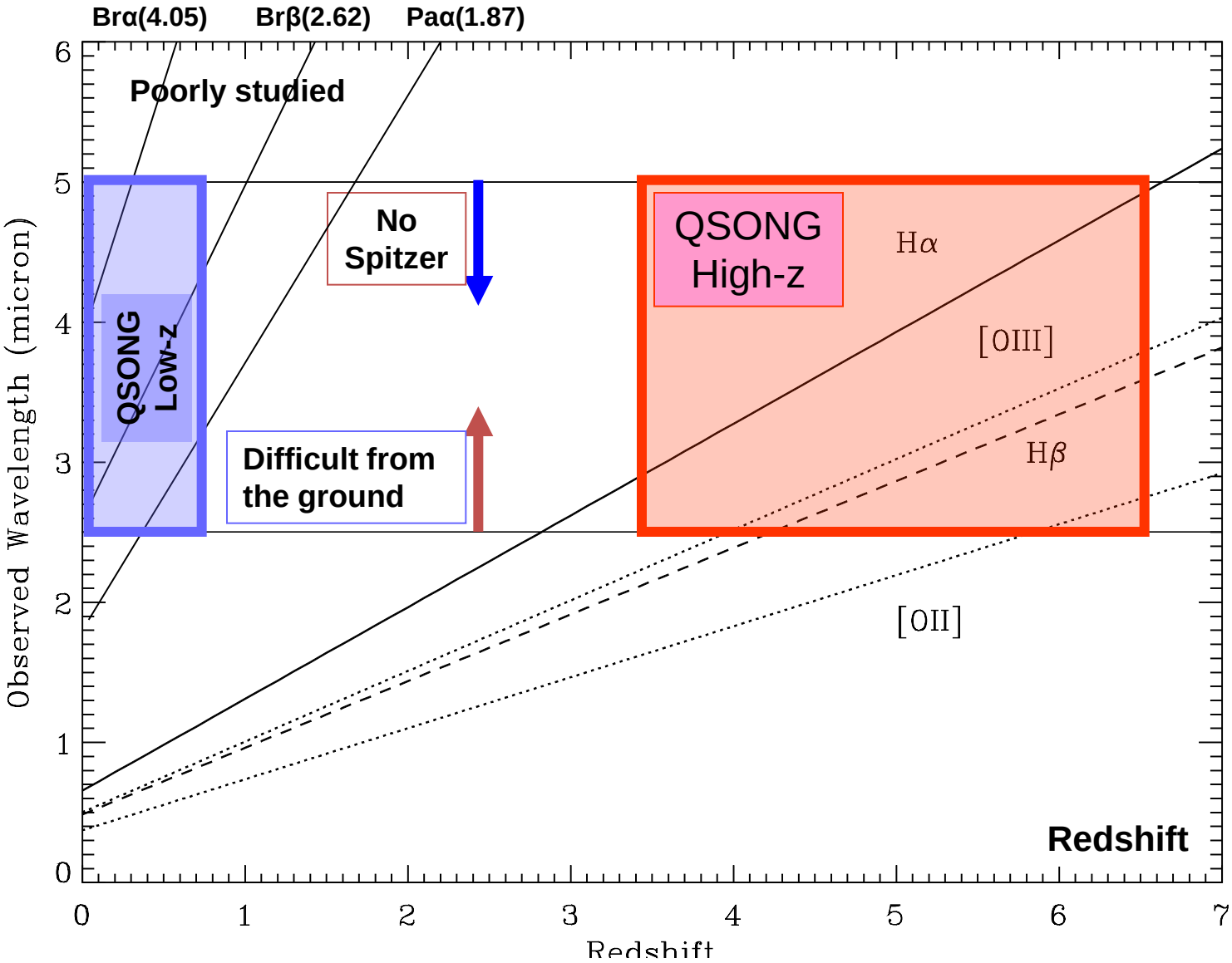
AKARI Spectroscopy at 2.5-5 MICRON



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High-z QSONG
(H. Jun, M. Im, et al. 2015, ApJ)

- 155 Type-1 QSOs at $3.4 < z < 6.42$ (mostly SDSS QSOs)

- z-band magnitude limit:
  $z_{AB} < \sim 19$ for $z < 5.5$
  $z_{AB} < \sim 20$ for $z > 5.5$

- L_{bol} limit ~ 10^{47} erg s^{-1}
- M_{BH} limit ~ 10^{9} $M_{\odot}$

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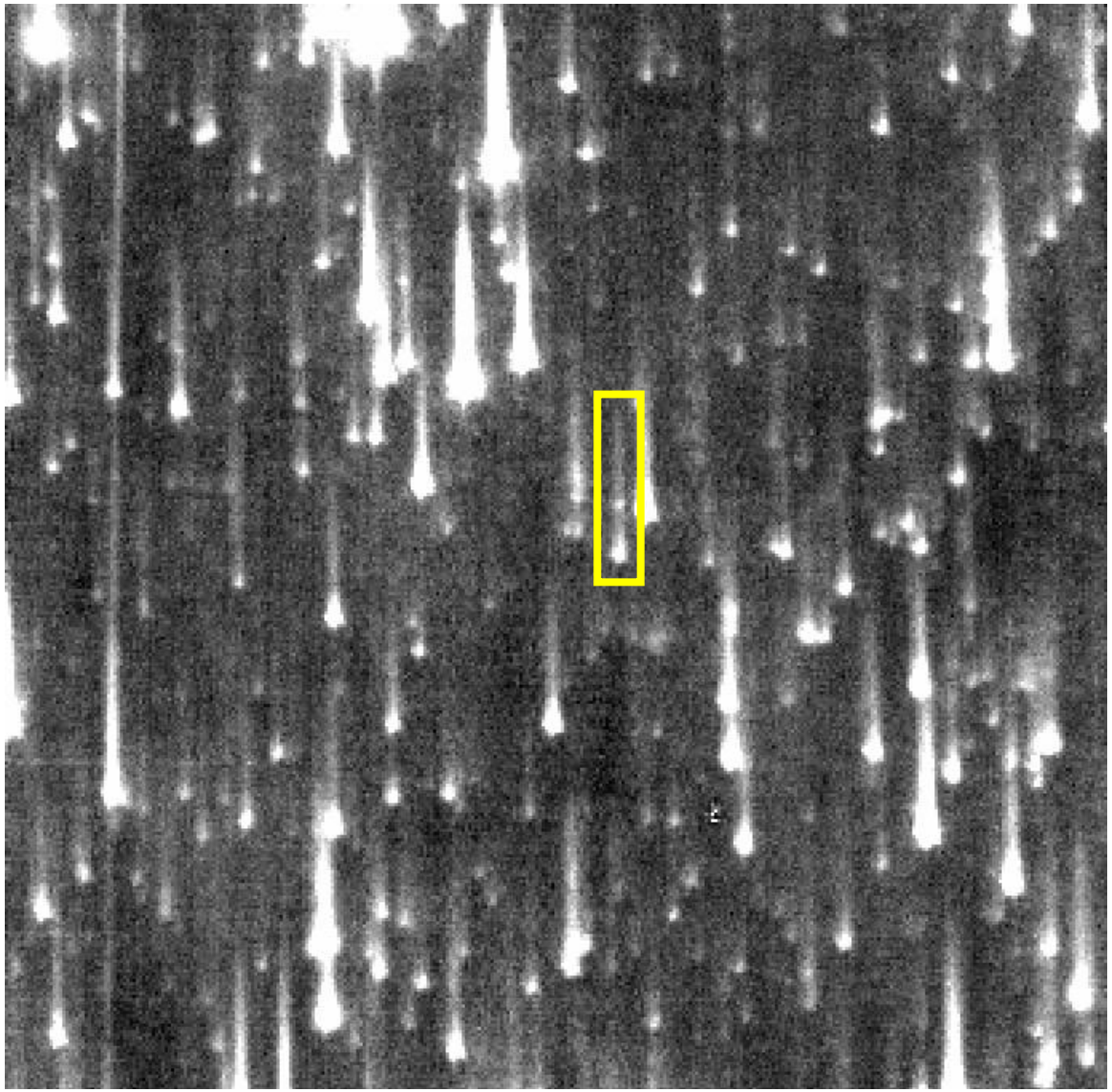
NIR Prism Observation



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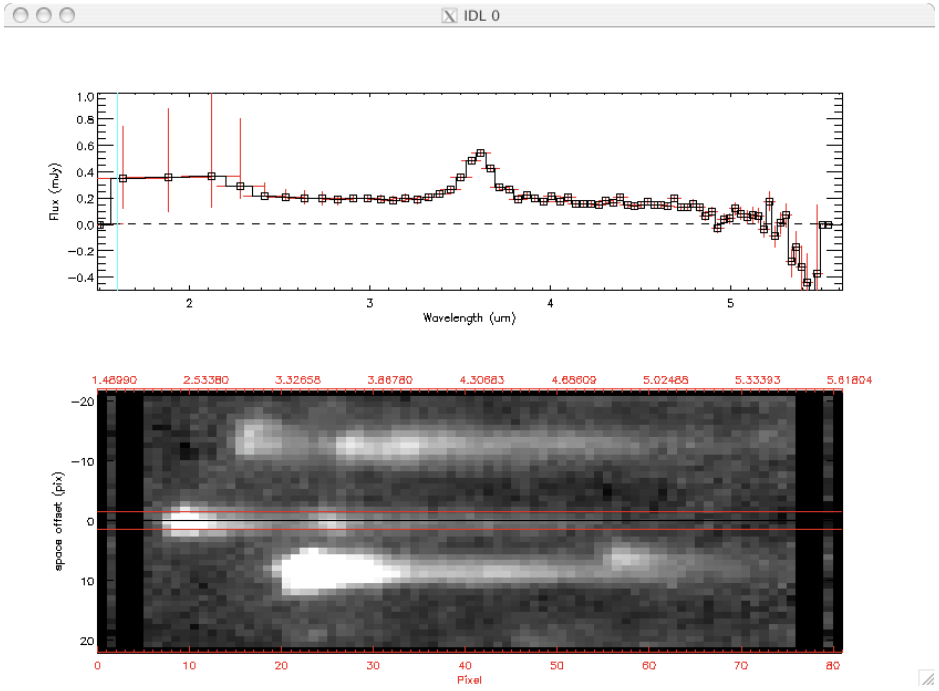
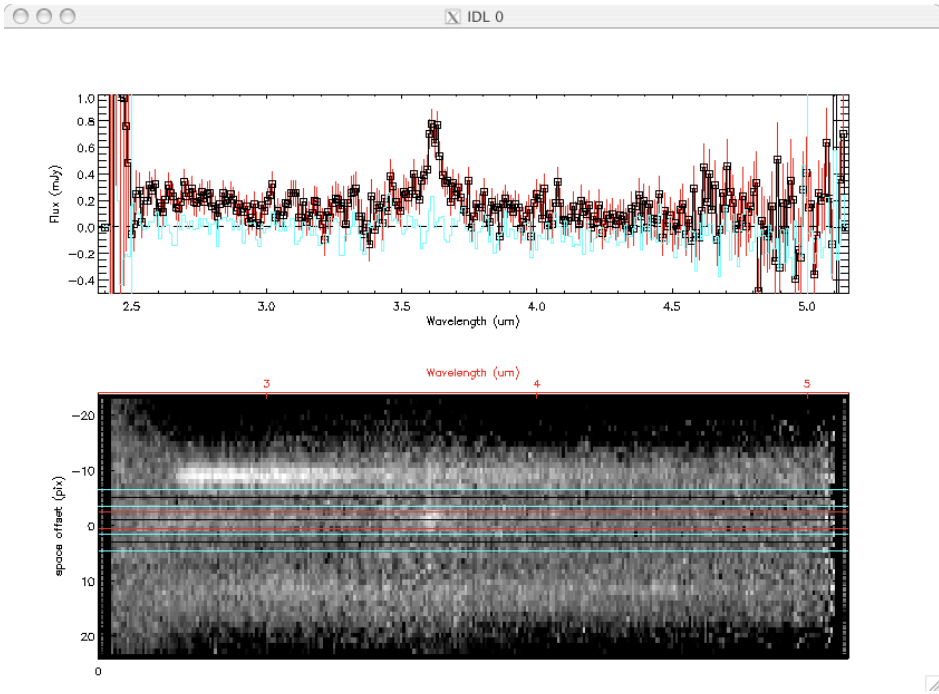
BR 0006-6208 (z=4.49)





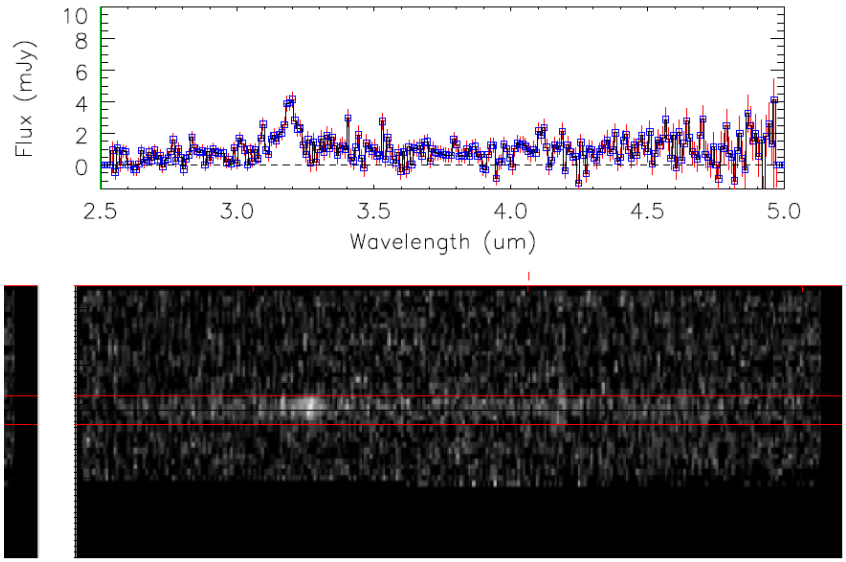
NP

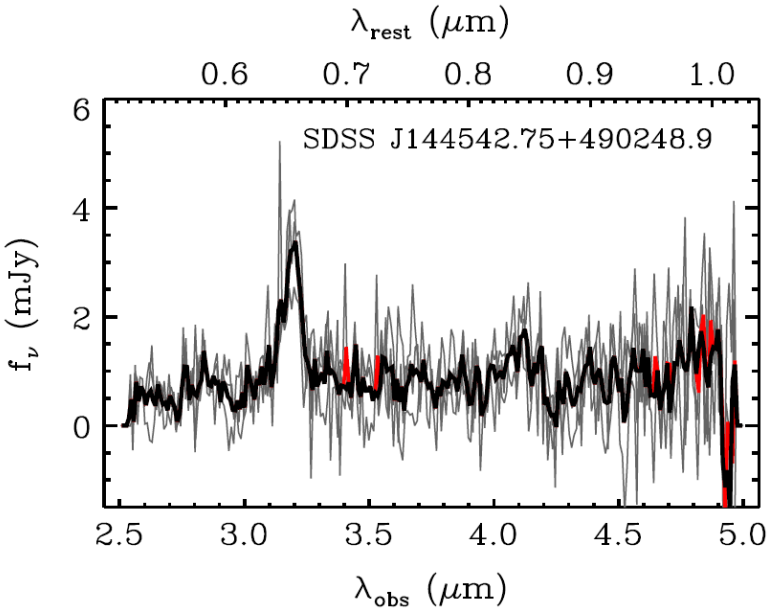
NG

FWHM(CIV) = 11,000 km/sec vs. ?

Log[M_{BH}(CIV)] = 10.48 +- 0.24 vs. ?

QSO@z=3.88





FWHM(CIV) = 3,100 km/sec vs. ?

Log[M_{BH}(CIV)] = 9.52 +- 0.20 vs. ?

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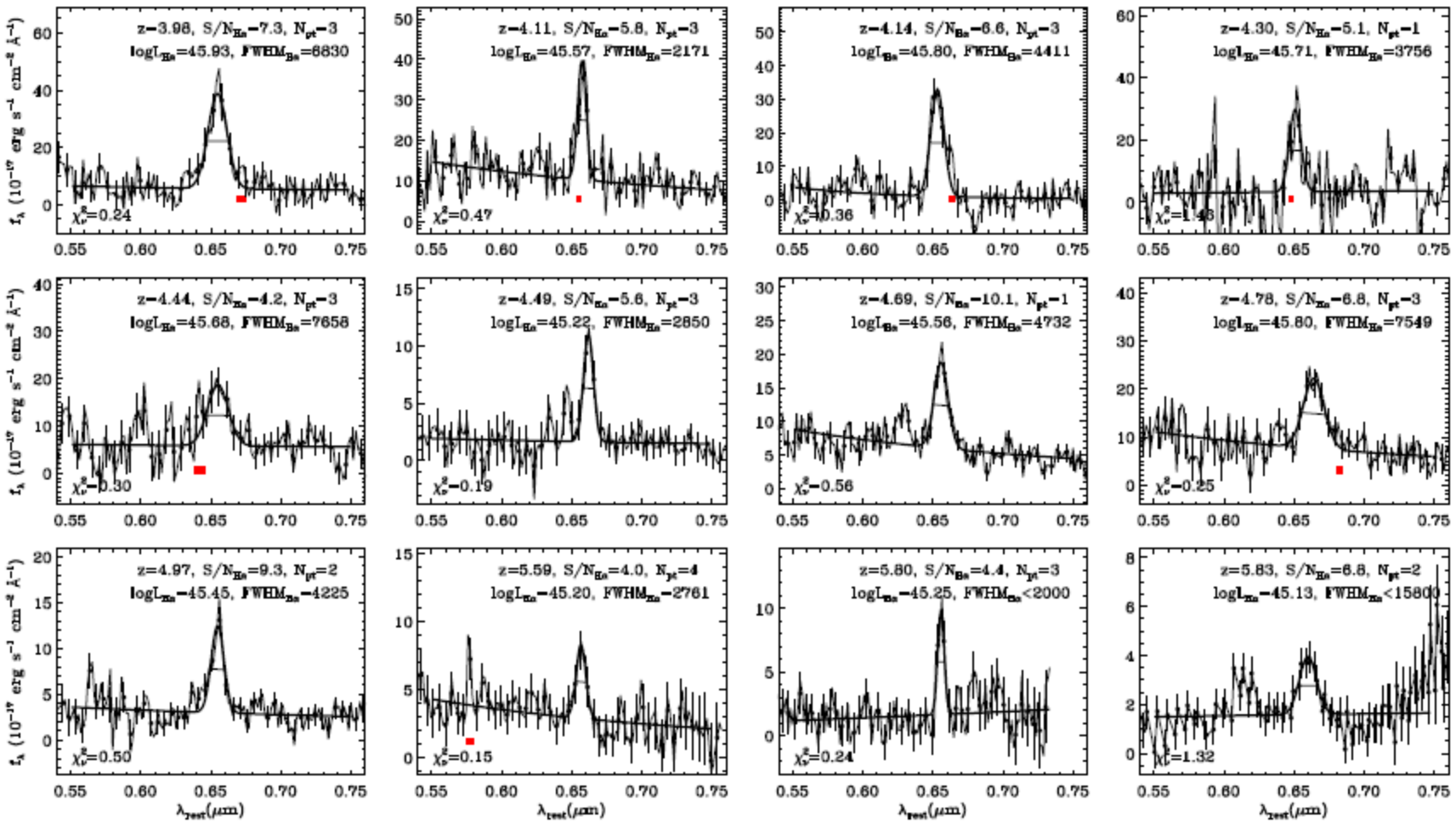
Hα DETECTION IN 72 QUASARS (S/N > 2)



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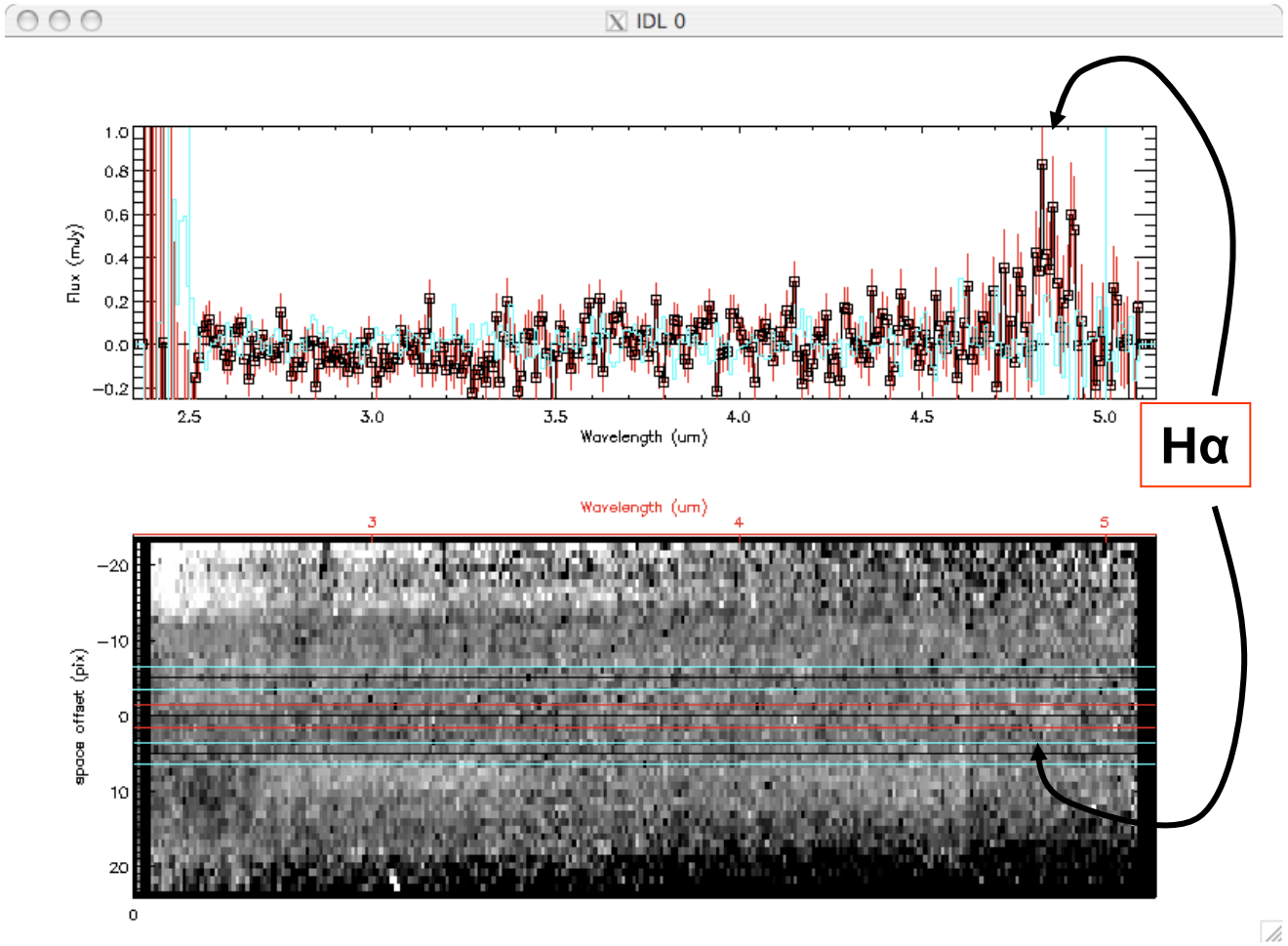
SDSS J 114816+525150 at z=6.42



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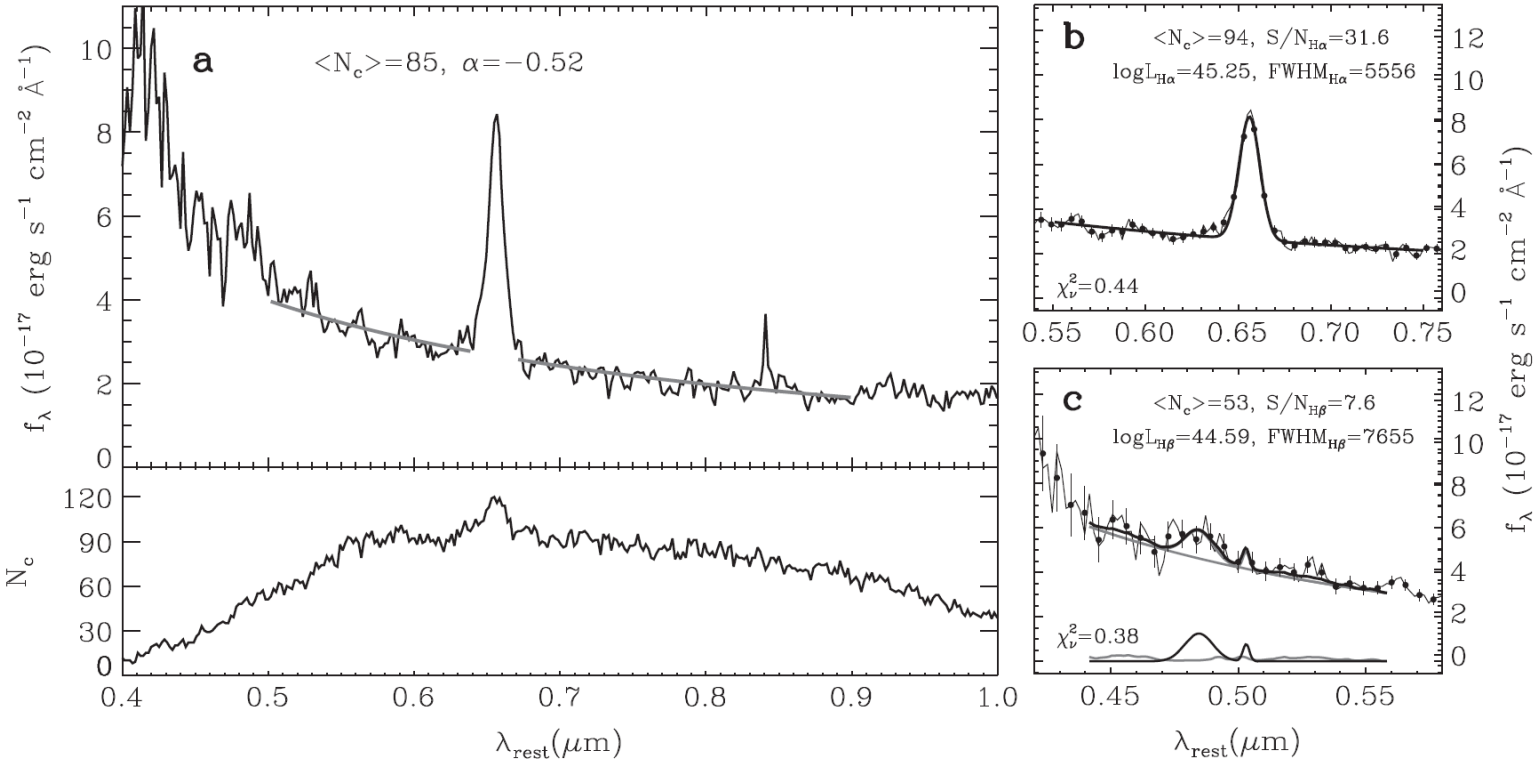
Composite Spectrum



Jun, Im, et al. 2015, ApJ

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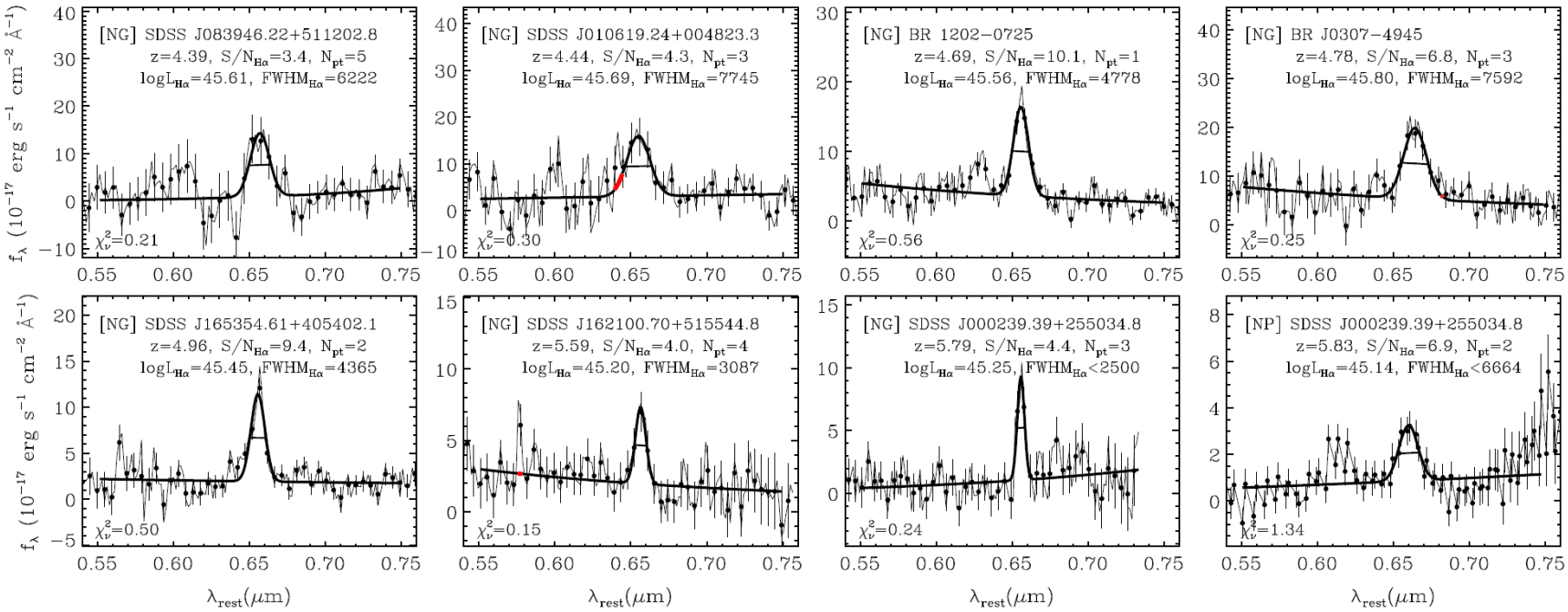
Spectral Fitting

- Line luminosities, line widths are derived for 72 Quasars



Jun, Im, et al. 2015, ApJ

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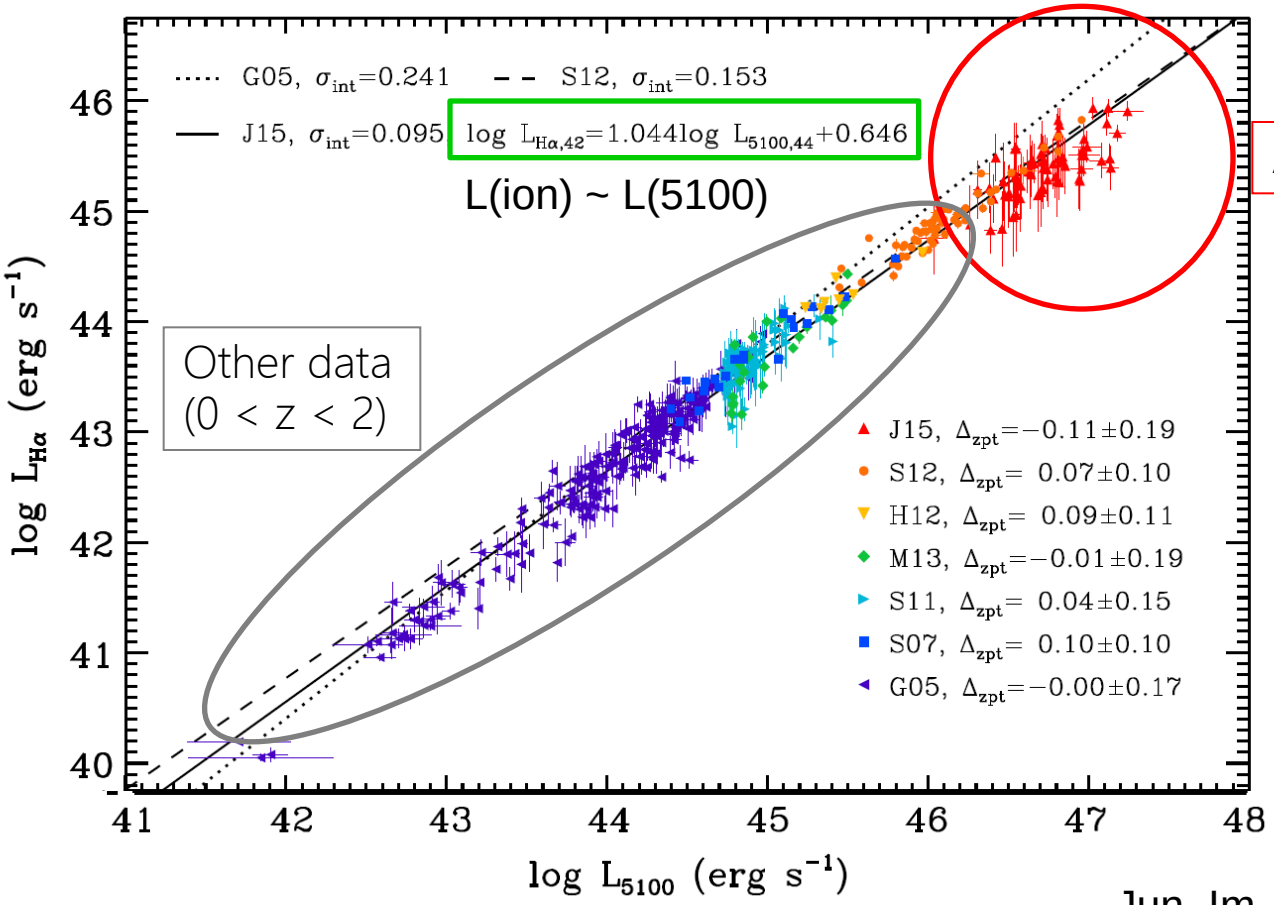
L(Hα) VS L(5100) RELATION
- NO DEVIATION FROM LOW Z RELATION
- RAPIDLY SPINNING BH



AKARI points

Jun, Im, et al. 2015, ApJ

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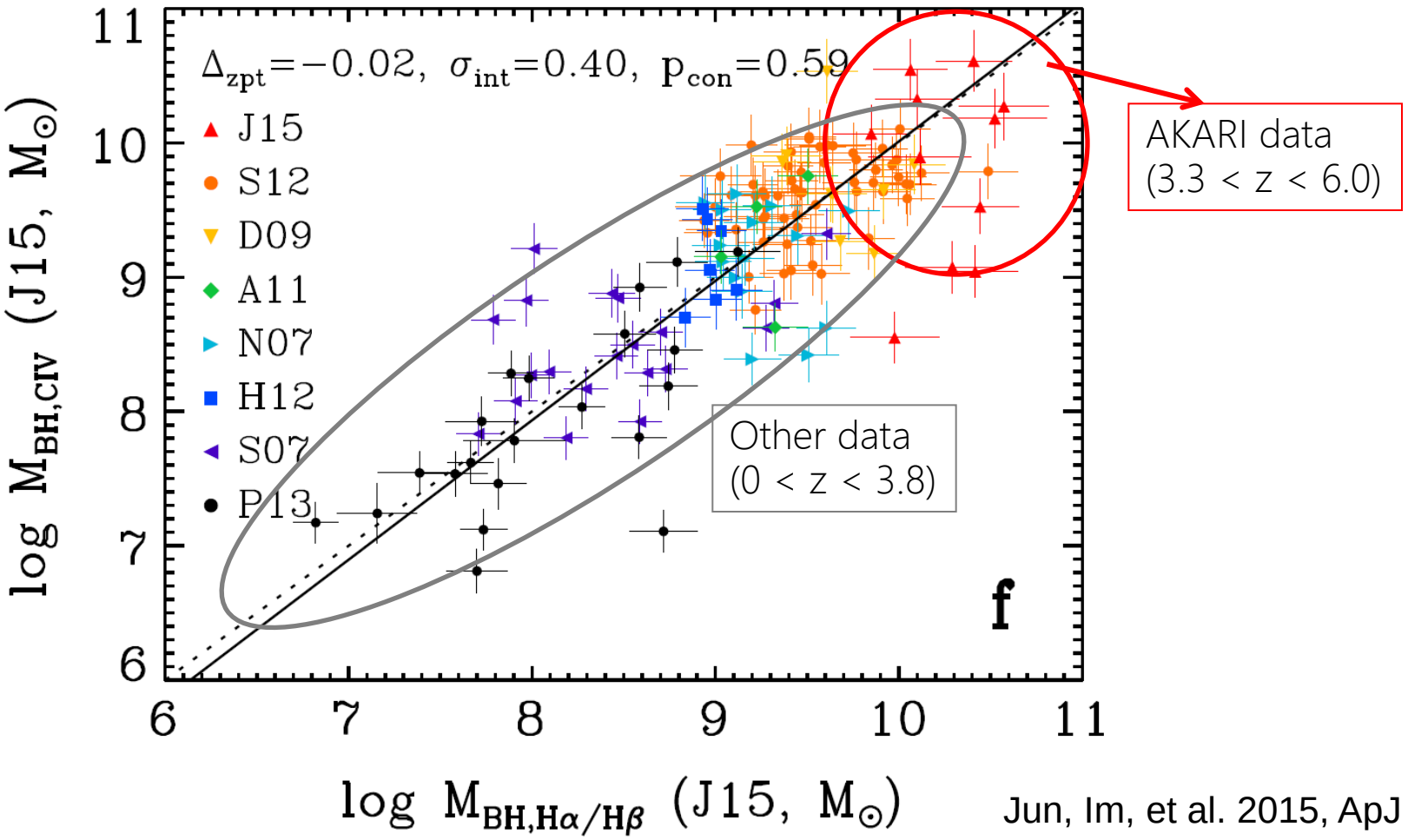
M_{BH}(CIV) vs M_{BH}(Hα,Hβ)

- Large Scatter

- Some Quasars: M_{BH}(Hα,Hβ) > M_{BH}(CIV)



Jun, Im, et al. 2015, ApJ

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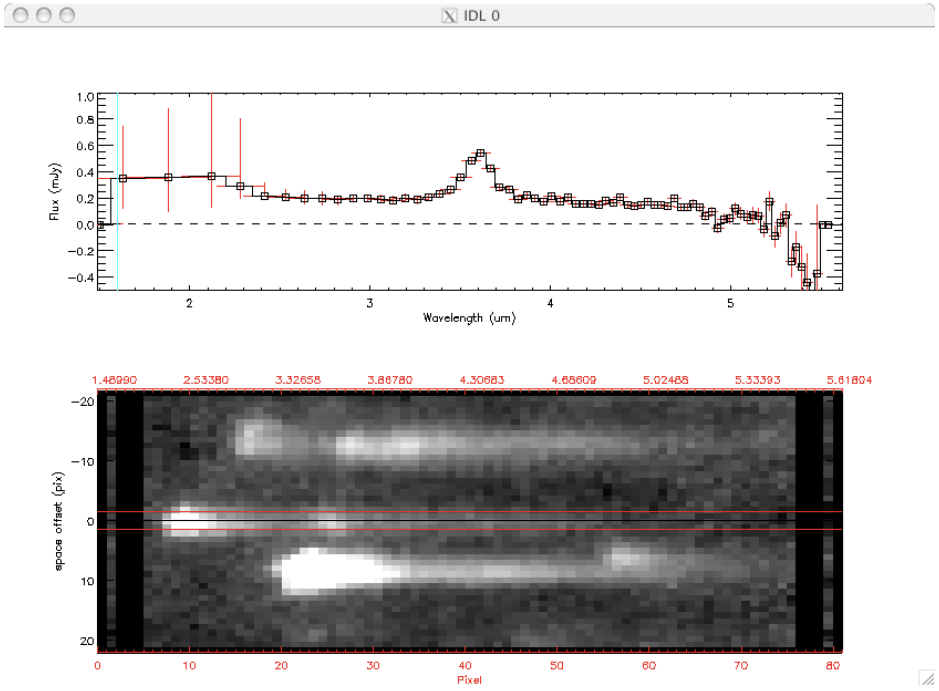
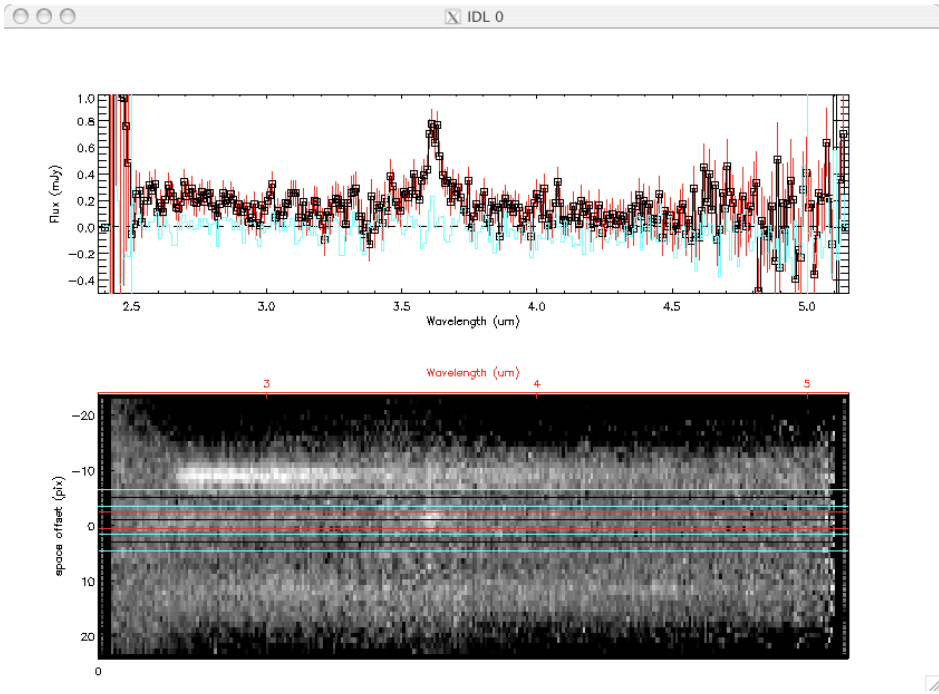




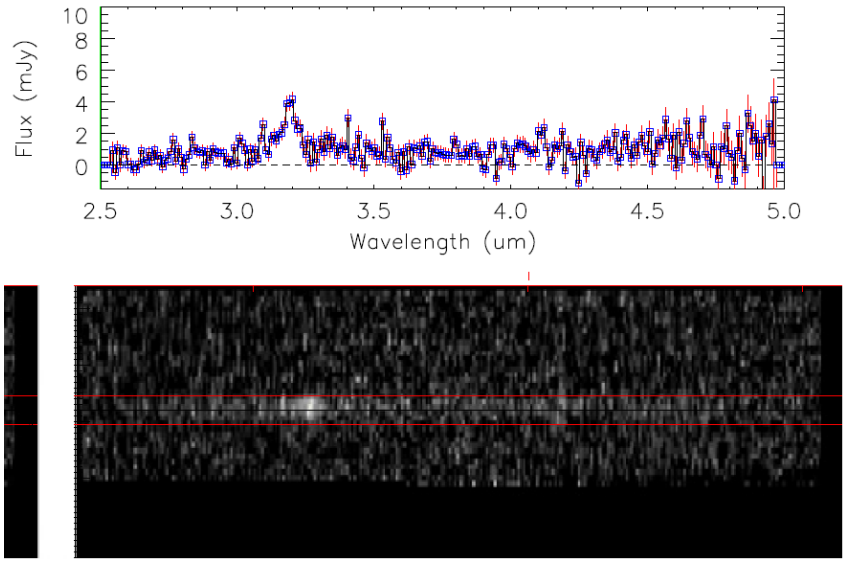
NP

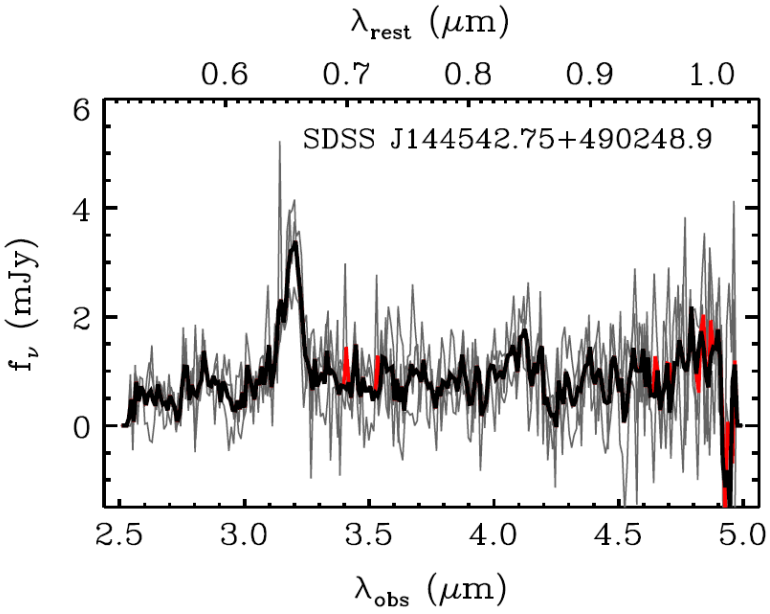
NG

FWHM(CIV) = 11,000 km/sec vs. FWHM(Hα)= 2,900 km/sec

Log[M_{BH}(CIV)] = 10.48 +- 0.24 vs. Log[M_{BH}(Hα)]=9.46 +-0.31

QSO@z=3.88





FWHM(CIV) = 3,100 km/sec vs. FWHM(Hα)= 6,600 km/sec

Log[M_{BH}(CIV)] = 9.52 +- 0.20 vs. Log[M_{BH}(Hα)]=10.44 +-0.21

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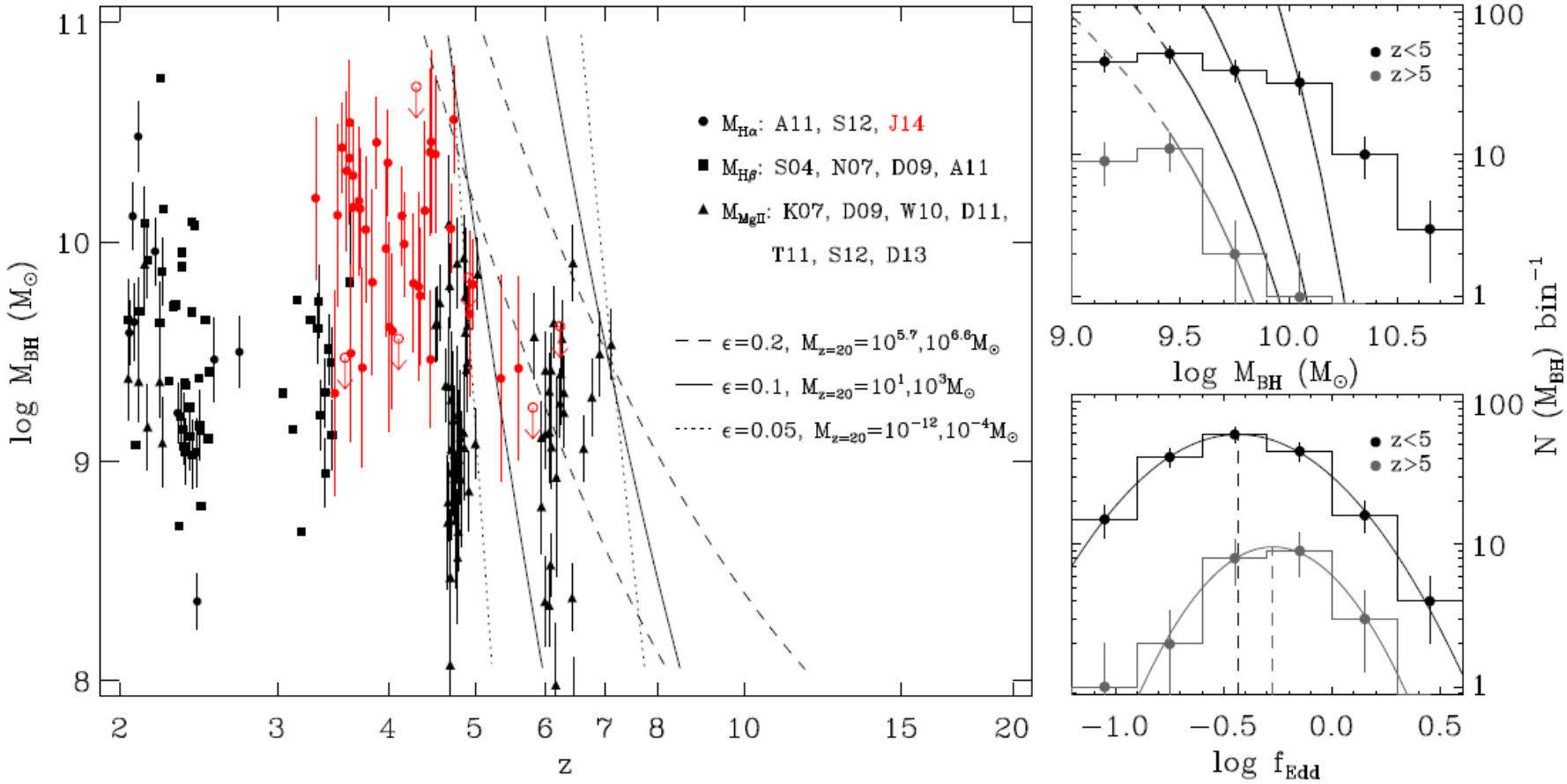
10^{10} $M_\odot$ SMBH exist at z < 5



Jun, Im, et al. 2015, ApJ

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Summary

- AKARI NIR (2.5-5 micron) Spectroscopy of 72/155 high redshit QSOs ($3.4 < z < 6.4$)
- Rest-frame optical spectra for high redshift QSOs
  First detection of Hα lines at QSOs $z > 4.5$ (before JWST)
- Existence of ~10^9 $M_\odot$ SMBHs out to $z \sim 6$, confirmed
- L(Hα) – L(5100) valid out at $0 < z < 6$ and $10^{42} < L(5100)/[erg/sec] < 10^{47}$
- Fast spin of SMBHs formed in the first Gyr