Survey of High-redshift Quasars with IMS

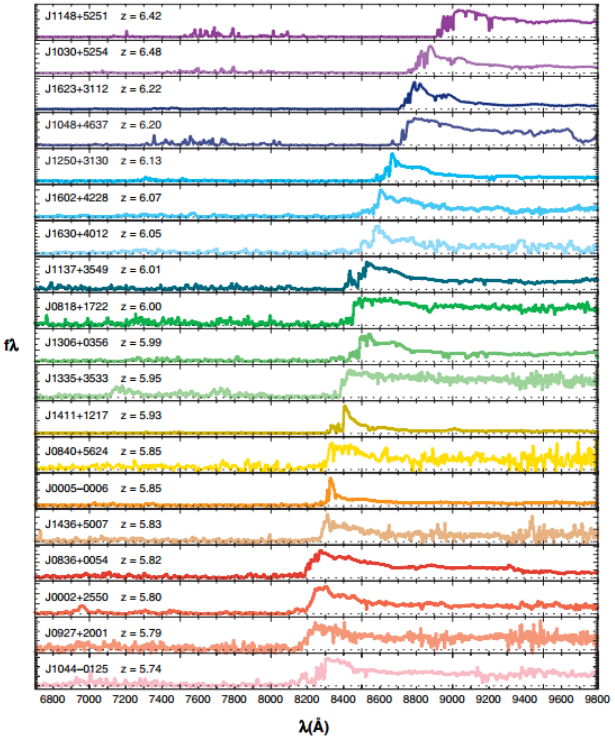
Yongjung Kim[1,2],
Myungshin Im[1,2], Yiseul Jeon[1,3], Minjin Kim[4,5], and IMS Team[1]

[1]Center for the Exploration of the Origin of the Universe (CEOU)
[2]Astronomy Program, Dept. of Physics & Astronomy, Seoul National University (SNU)
[3]LOCOOP, Inc
[4]Korea Astronomy and Space Science Institute (KASI)
[5]University of Science and Technology (UST)

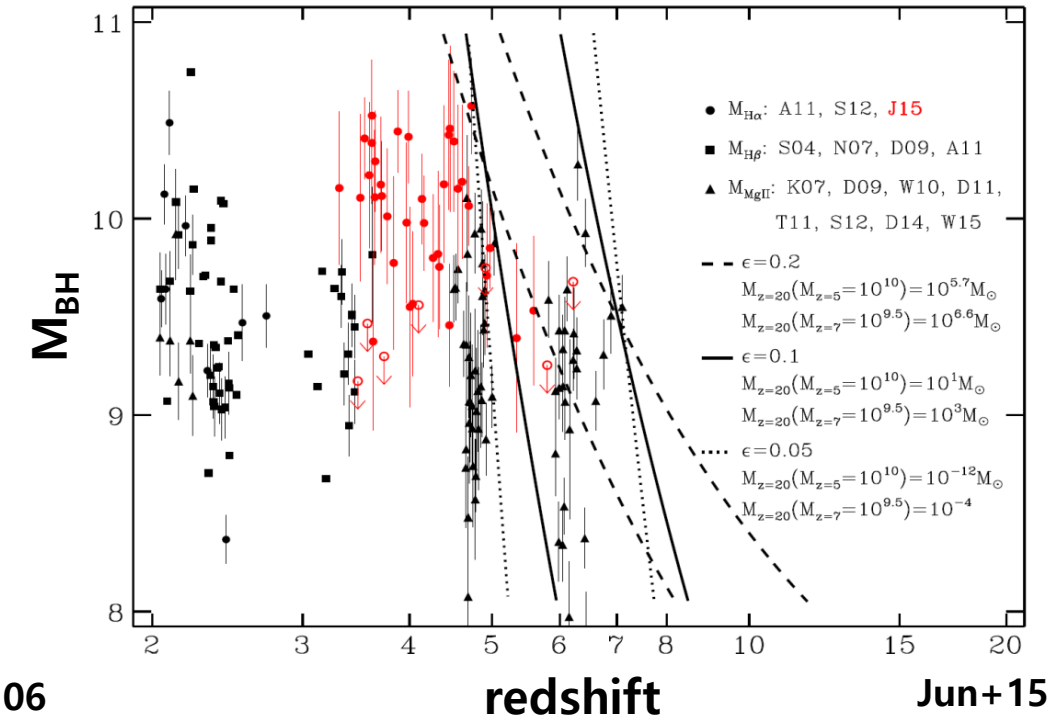
Image Credit: ESO/M. Kornmesser (http://www.eso.org/public/images/eso1122a/)

High-redshift Quasars

- **High-redshift (z>5) Quasars**
  - Quasars are energetic sources in the universe
  - Through surveys of them suggest
    - Significant fraction of intergalactic medium (IGM) is reionized
    - Formation of ~$10^{8\text{-}10}$ M_{sun} SMBHs just ~1 Gyr after Big Bang



Fan+06



Jun+15

High-redshift Quasars

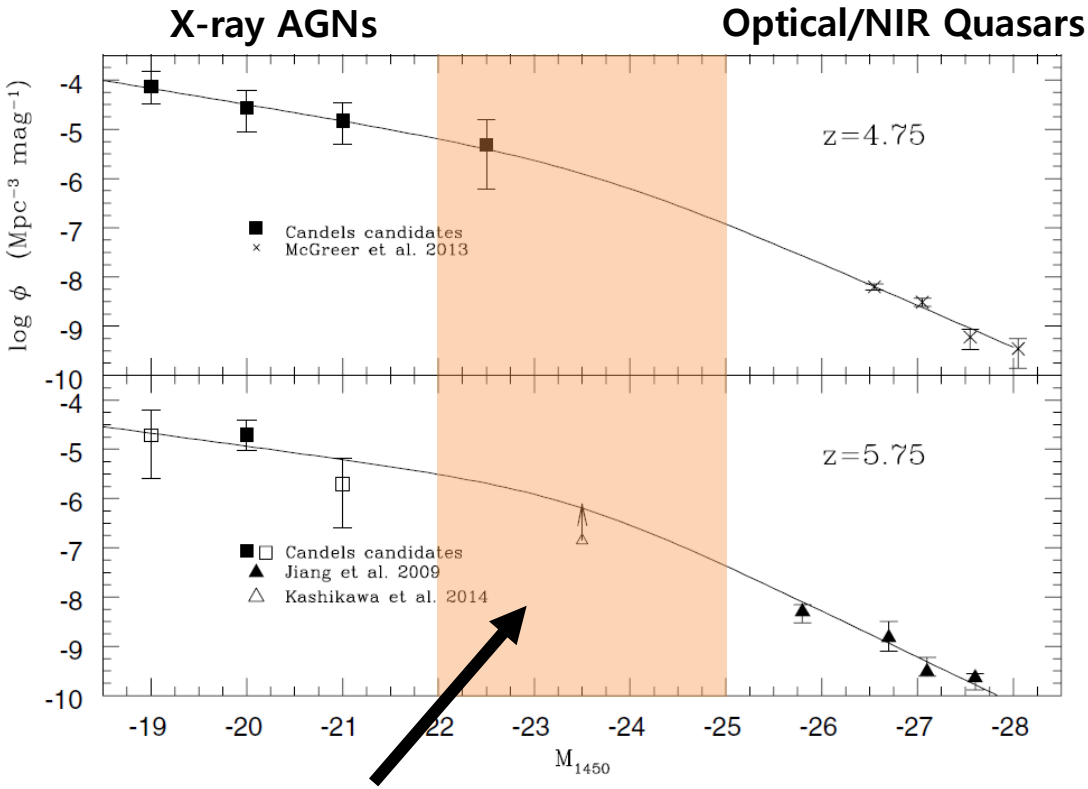
- **Unsolved Issues on High-redshift Quasars**
  - **How did high-redshift quasars contribute to cosmic reionization?**
    - Main contributors (Giallongo+15) or not (Willott+10b; Kashikawa+15)

UV Emissivity

$\epsilon \propto \phi \times L$

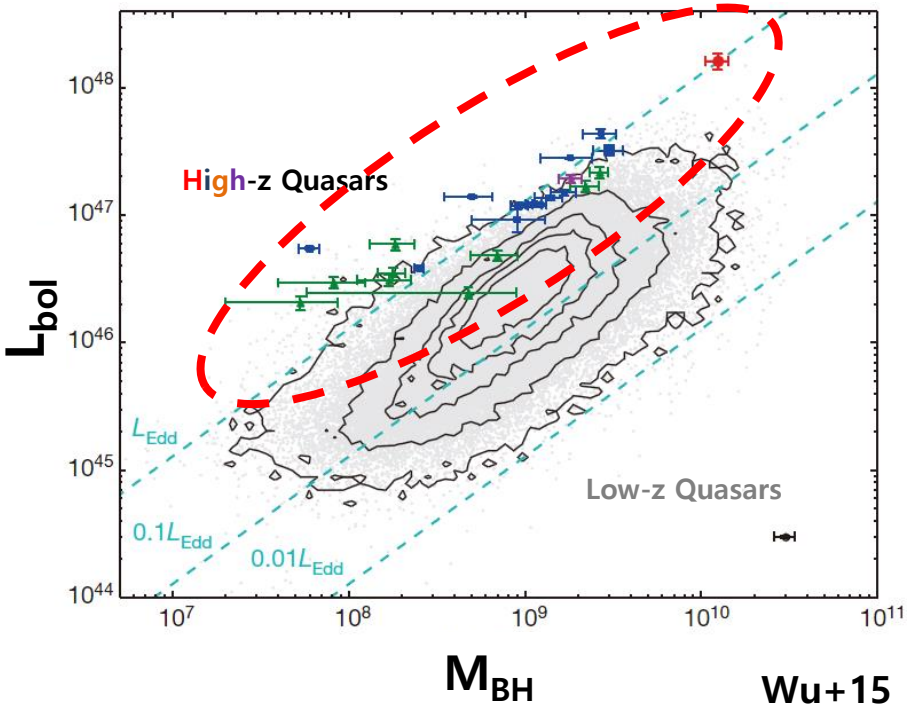
ϕ: QLF L: luminosity

Maximum at
M_{1450} ~ -23.5 mag

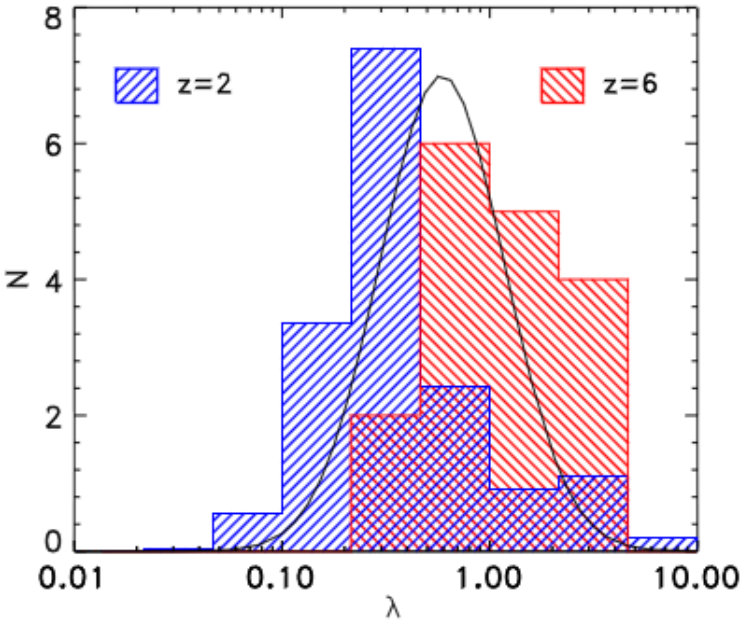


High-redshift Quasars

- **Unsolved Issues on High-redshift Quasars**
  - **Are high-redshift quasars growing fast**? Or simply a tip of iceberg?
  - High Eddington ratio (λ_{Edd}) of high-redshift quasars
    - Key to solve theoretical challenges on the growth to 10^9 Msun?
    - Result of bias?



Wu+15



Willott+10a

[1]

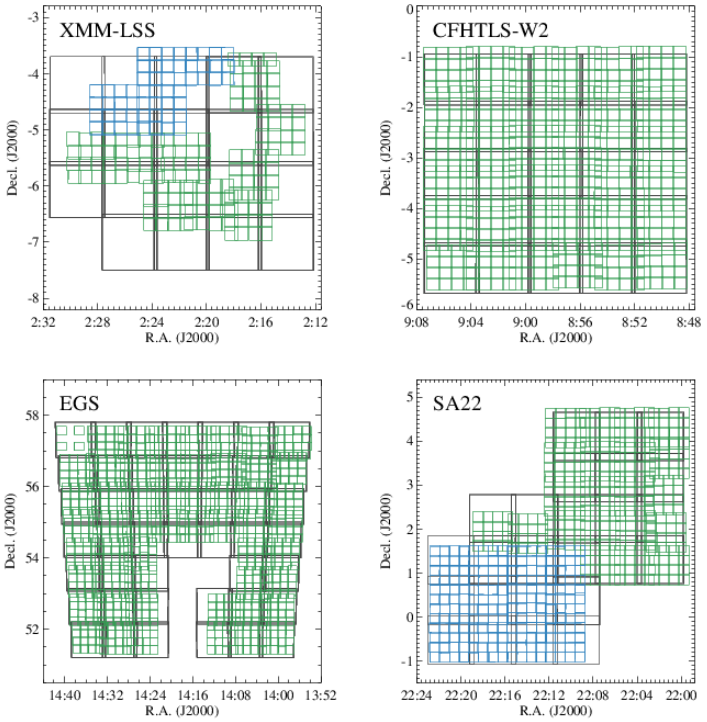
How Did High-redshift Quasars Contribute to Cosmic Reionization?

[2]

Are High-redshift Quasars Growing Fast?

Infrared Medium-deep Survey (IMS)

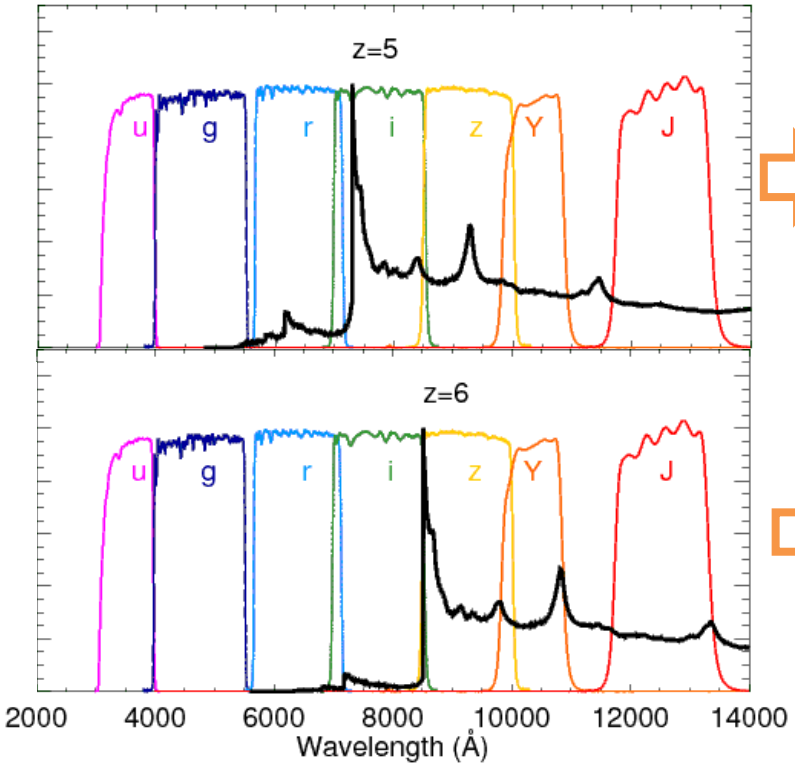
- **Description of IMS**
  - Imaging survey at J_{AB}<23 mag, 120 deg^2 (+Y-band data)
  - **UKIRT WFCAM** observation (2009-2013)
  - CFHT Legacy Survey optical data (ugriz, ~25 mag)
  - Discovery of high-z quasars, galaxy clusters, and transients

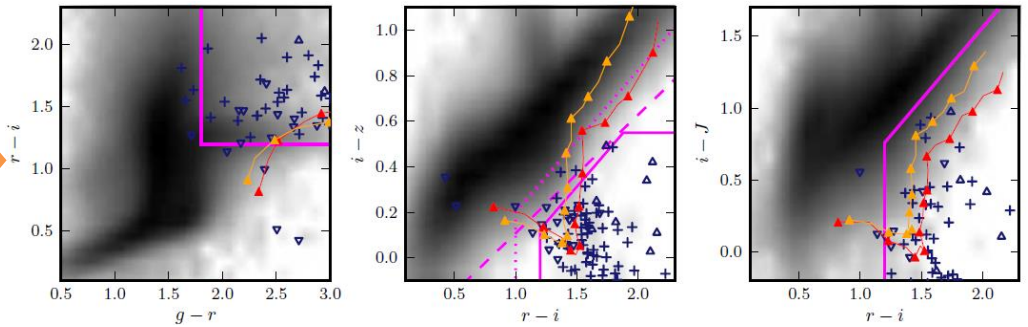


CFHTLS
IMS
DXS

Discovery of High-redshift Quasars

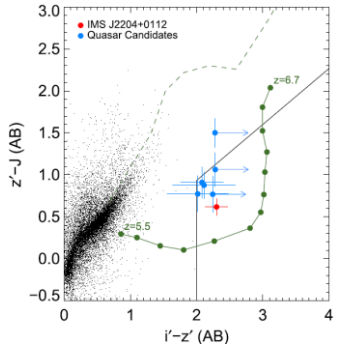
- **Color Selection Method**
  - **Red colors** due to Lyman break with Intergalactic Medium (IGM) attenuation
    - (i-z) for z~6 quasars, and (r-i) for z~5 quasars
  - Robust sample from broad-band data (**CFHTLS + IMS**)





grizJ selection by McGreer+13

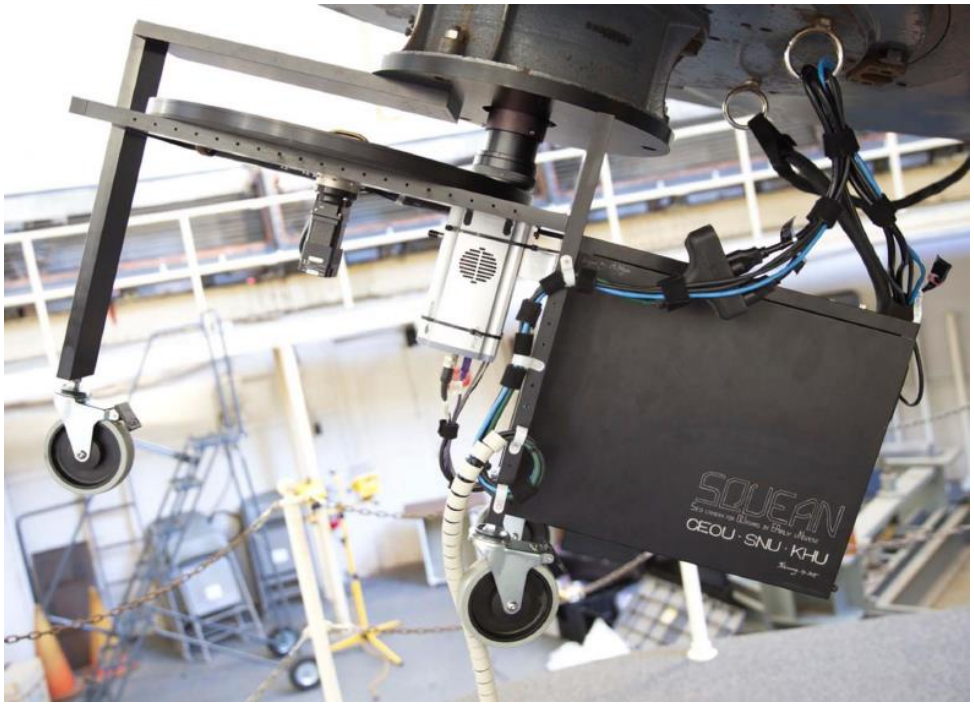
No detection in u,g,r bands +



Kim Y.+15

Discovery of High-redshift Quasars

- **Color Selection Method**
  - Follow-up **medium-band** observations
  - **SQUEAN** (SED camera for QUasars in the Early Universe; Kim S.+15)
    - On Otto Struve 2.1m Telescope, McDonald Observatory, TX
    - Improve identification rates from 60% (broad band) to 90%



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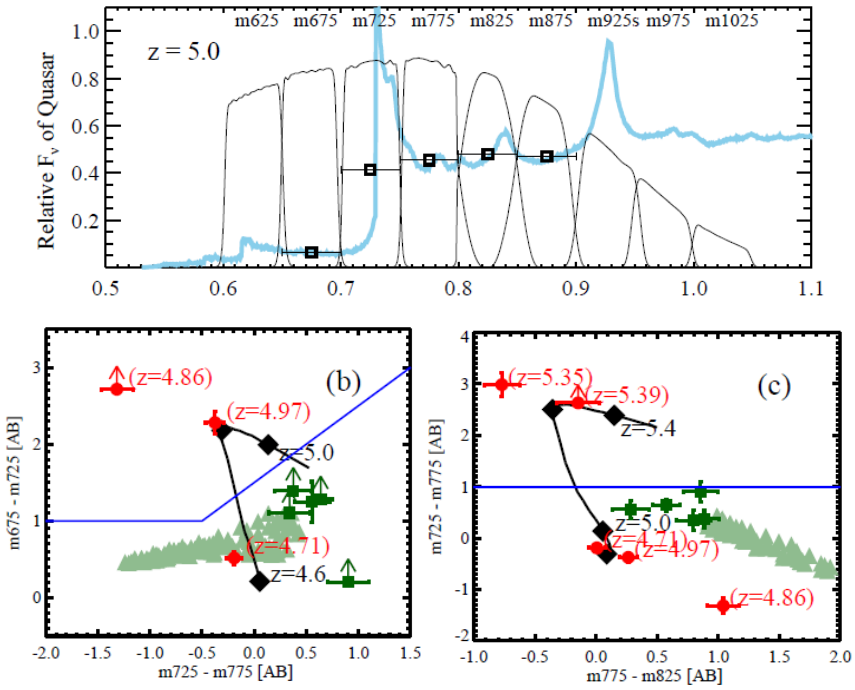

Jeon+16

Discovery of High-redshift Quasars

- **Spectroscopic Identification of Quasars**
  - GMOS/Gemini 8 m Telescope
  - IMACS/Magellan Baade 6.5 m Telescope
- **Discovered Quasars with IMS So Far**
  - 3 quasars at z~6 (a quasar newly discovered)
  - ~30 quasars at z~5 (~10 quasars newly discovered)

Supported by
KASI 한국천문연구원
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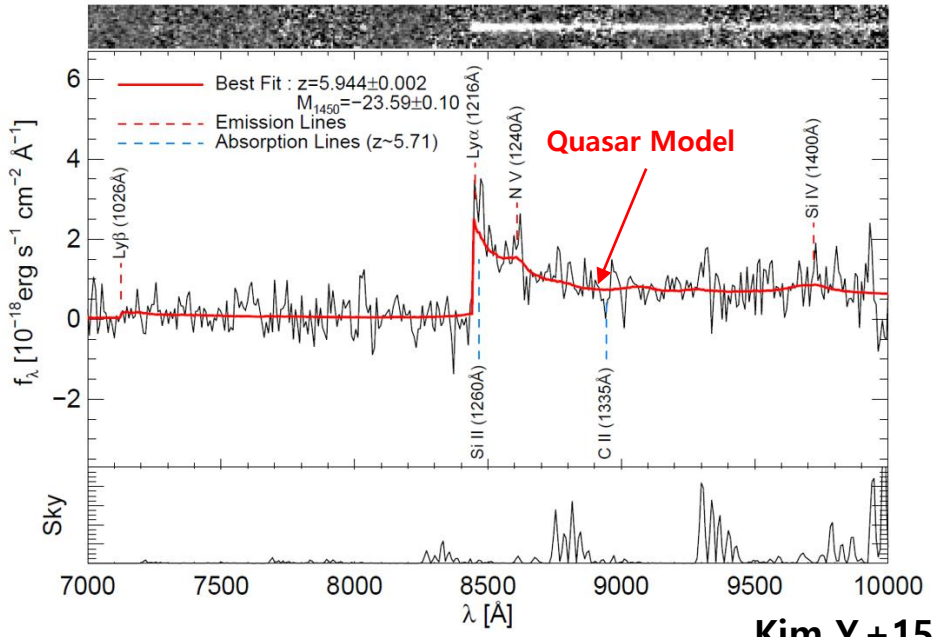

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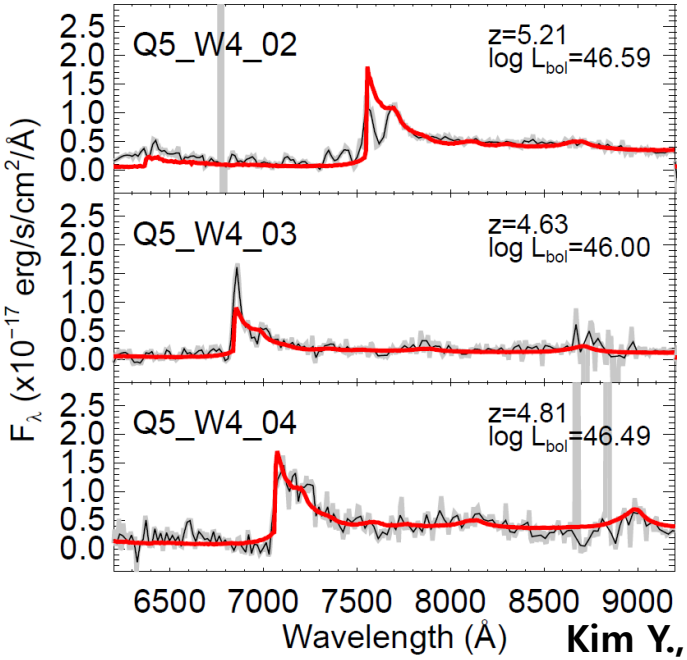


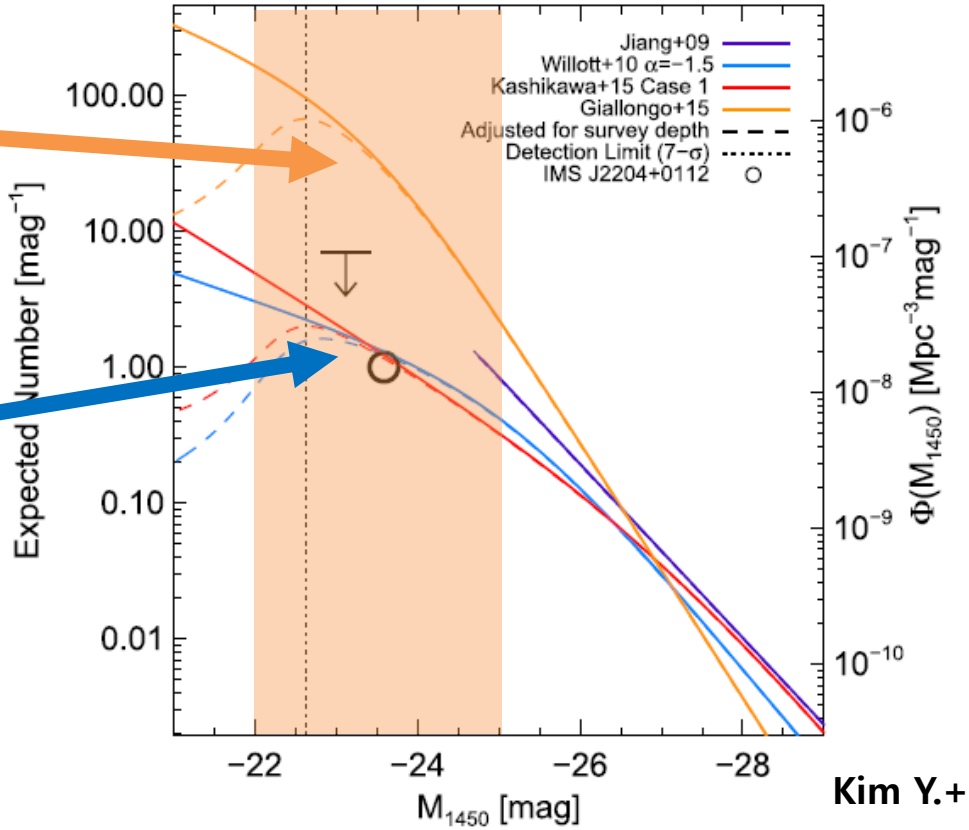
Kim Y., in prep

Discovery of High-redshift Quasars

- **Constraints on Cosmic Reionization at z~6**
  - Expected number of quasars in SA22
  - Fraction of required UV photons for Reionization
    - It is likely to be **<15%** of ionizing photons

Many Quasars:
Ionizing Sources

Few Quasars:
Not main contributors

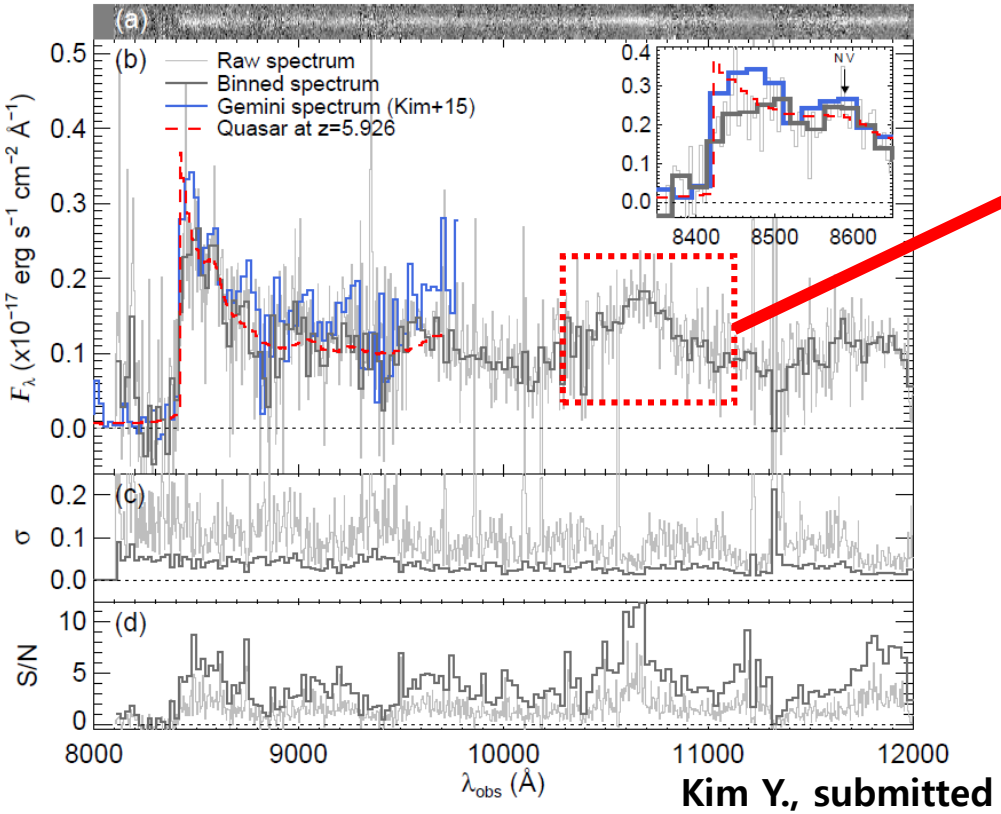


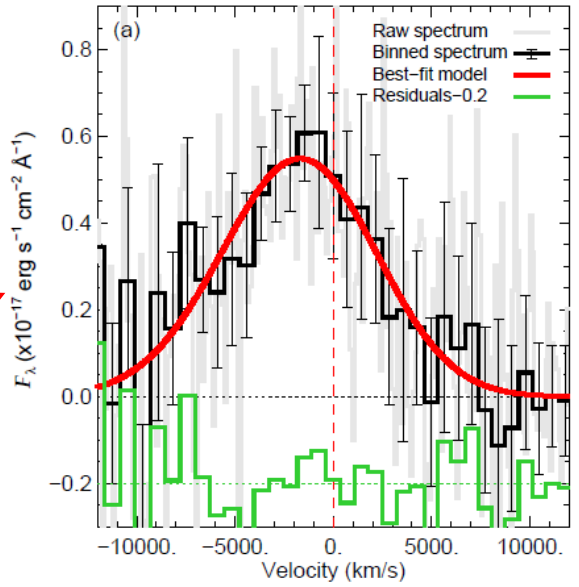
Kim Y.+15

Discovery of more faint quasars is consistent with this result
(e.g., Matsuoka+17)

BH Growth in the Early Universe

- **Deep NIR Spectroscopy of IMS J2204+0112**
  - **IMS J2204+0112**: One of the Faint quasars at z~6 (L_{bol}~10^{46} erg/s)
  - FIRE on Magellan Baade 6.5 m Telescope
    - 5.0 hrs exposures for **CIV λ1549** detection





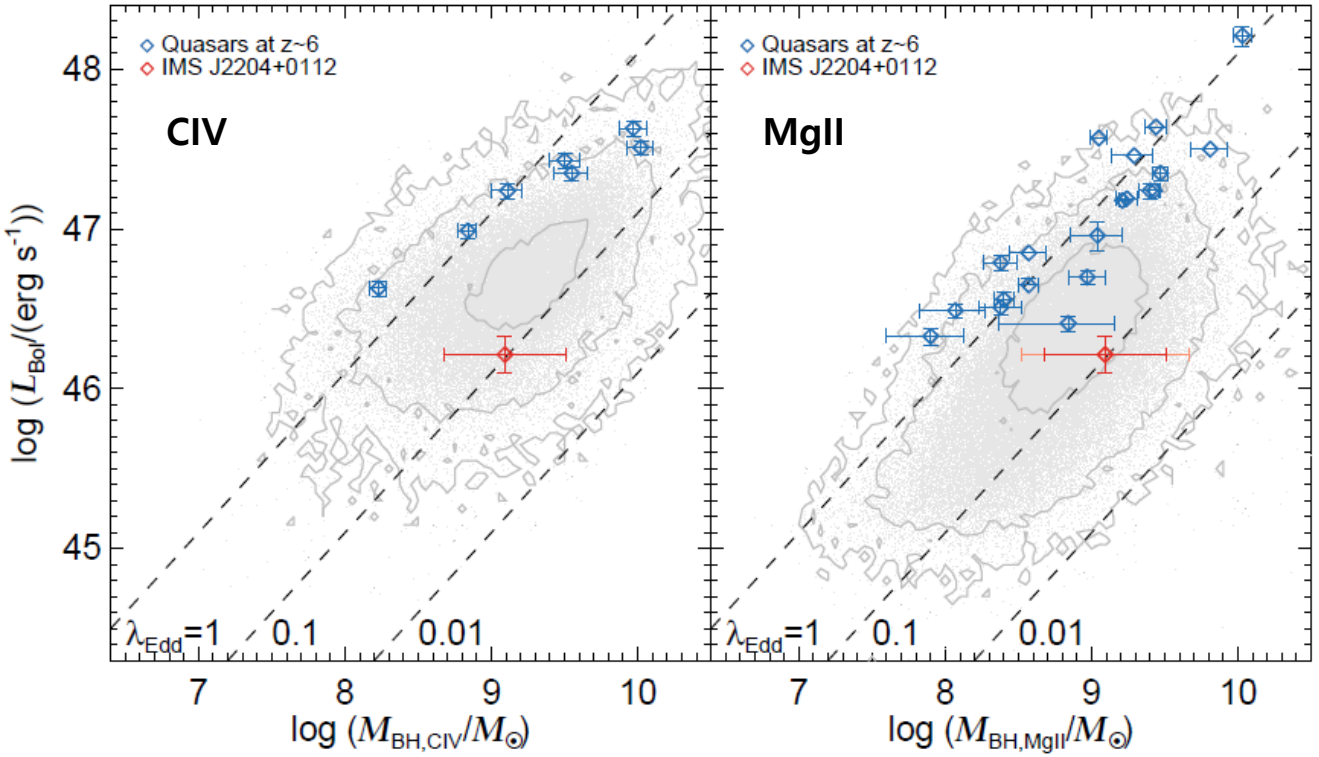
$$\log\left(\frac{M_{\rm BH,CIV}}{M_\odot}\right) = A + \log\left\{\left(\frac{L_{1350}}{10^{44}\ {\rm erg\ s^{-1}}}\right)^{\beta}\left(\frac{\rm FWHM_{CIV}}{1000\ {\rm km\ s^{-1}}}\right)^{\gamma}\right\}$$

M_{BH} = $10^{9.09\pm0.40}$ M_{sun}

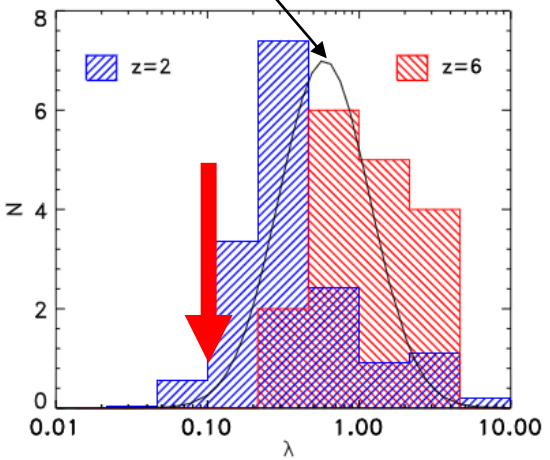
Kim Y., submitted

BH Growth in the Early Universe

- **The lowest Eddington Ratio (λ_{Edd}) Quasar at z~6**
  - **λ_{Edd} ~ 0.1** of IMS J2204+0112
    - **Only chance of 0.03% (3.5σ)** with the intrinsic λ_{Edd} distribution from Willott+10



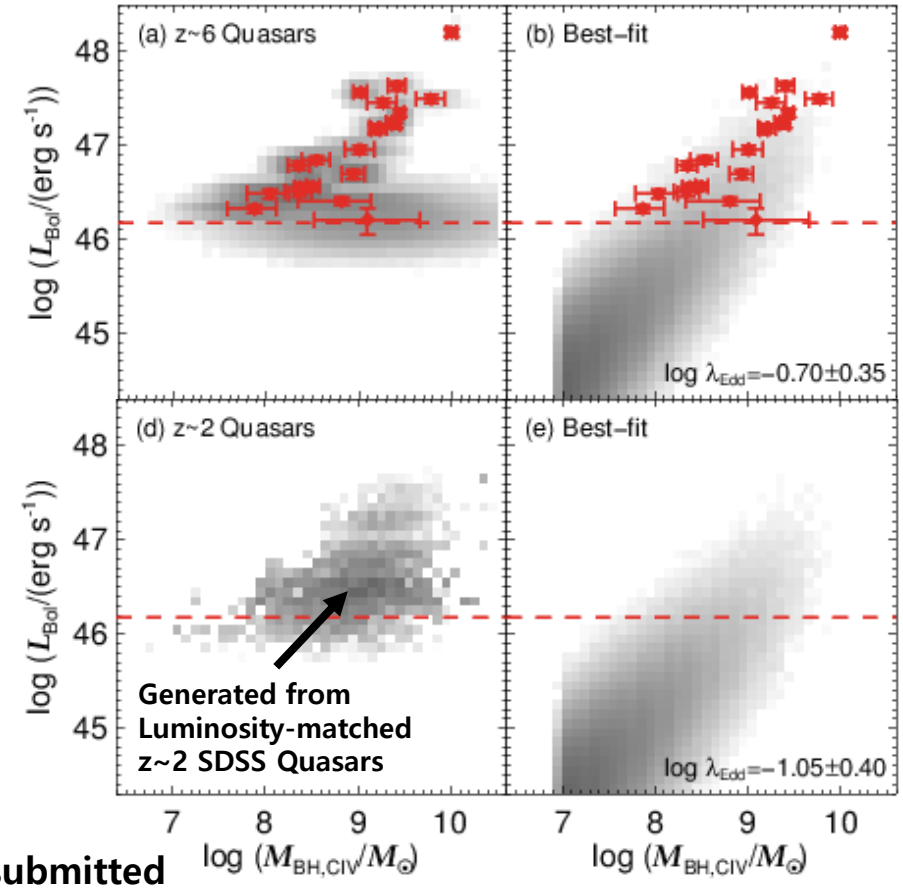
Kim Y., submitted



Willott+10a

BH Growth in the Early Universe

- **What is the Intrinsic λ_{Edd} Distribution of z~6 Quasars?**
  - 2D fitting for density map on M_{BH}-L_{bol} plane
    - QLF-adapted observations vs. Mock 10^6 quasars
  - λ_{Edd} at z~6 could be lower than before, but still slightly **higher (0.35 dex)** than λ_{Edd} at z~2
- **Implications for SMBH Evolution?**
  - For ~10^2 M_{sun} seed BH,
    - Episodic high super-Eddington accretion (λ_{Edd} > 10) within short time scale
  - For ~10^5 M_{sun} seed BH,
    - Eddington-limited accretion until z~7, and then reduces to λ_{Edd} ~ 0.2 at z~6



Kim Y., submitted

Summary

- **Faint High-redshift Quasars**
  - IGM ionization source
  - SMBH growth probe
- **Survey with IMS**
  - We discovered one z~6 quasar and ~10 of z~5
  - M_{BH} & λ_{Edd} measurements
- **High-redshift Quasars for Cosmic Reionization?**
  - **They are probably too few to fully account for the IGM ionization at z ~ 6**
- **High-redshift Quasars for Early SMBH Growth?**
  - **Not all quasars are accreting materials at maximal rates**