Discovery of a Faint Quasar at z~6 and Implications for Cosmic Reionization


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Introduction

- **Quasars in the Early Universe**
  - Energetic sources in the universe
  - A unique sample to study
    - Formation of the first supermassive black holes (SMBHs)
    - Host galaxies at the epoch of cosmic reionization

- **Optical/NIR Survey for High-z Quasars**
  - SDSS (Fan+06; Jiang+08,09), CFHQS (Willott+07,09,10),
    UKIDSS (Mortlock+09,11), VIKING (Venemans+13,15),
    Pan-STARRS1 (Banados+14)

ULAS J1120+0641, z=7.085 quasar (Mortlock+11)
Introduction

- Cosmic Implication of Discovered Quasars
  - Formation of $10^{8-10} \, M_{\odot}$ SMBHs just $\sim 1$ Gyr after Big Bang
  - Accreting mass at maximal rates (Willott+10; Jun+15)
  - Paucity of hot dust emission (Jiang+10; Jun & Im 13)
  - Significant fraction of intergalactic medium (IGM) is reionized
    - Strong Gunn-Peterson troughs (Gunn & Peterson 65; Fan+06)
Introduction

- Lack of Faint Quasars at $z > 6$ ($M_{1450} > -24$ mag)
  - Biased sample of currently discovered quasars
    - High luminosities and high accretion rates

Venemans+15
Introduction

- Lack of Faint Quasars at $z > 6$ ($M_{1450} > -24$ mag)
  - The faint end of the quasar luminosity function (QLF)
  - Significant contribution to reionization (Giallongo+15) or not (Willott+10)

UV Emissivity

$$\epsilon \propto \phi \times L$$

$\phi$: QLF  $L$: luminosity

Maximum at $M_{1450} \sim -23.5$ mag
IMS and CFHTLS Data

• **Infrared Medium-deep Survey (IMS)**
  - Infrared imaging (Y/J) survey for seven extragalactic fields (~120 deg$^2$) with UKIRT/WFCAM (Im et al. in prep)
  - Detection limit (5σ) : ~23.5 AB mag (Karouzos+14)

• **Canada-France-Hawaii Telescope Legacy Survey (CFHTLS)**
  - Optical imaging (ugriz) survey with CFHT/MegaCam
  - Completeness limit (80%) : ~24-25 AB mag (Hudelot+12)

• **Data Analysis**
  - Focus on **SA22** field (~12.5 deg$^2$)
  - Source detection in z’-band images by SExtractor
  - Dual mode with the identified z’-band sources

SA22 Field Coverage
Quasar Candidate Selection

• Spectral Energy Distribution of z~6 Quasars
  • Lyα break (1216 Å) redshifted to λ~8500 Å
  • Blue continuum beyond Lyα break

• Selection Criteria
  • \((i' - z') > 2\)
  • \((i' - z') - 1.5 (z' - J) > 0.6\)
  • No detection (2σ) in \(u', g', \) and \(r'\) (Willott+09)

IMS J2204+0112

\[
\begin{align*}
F_v (\mu Jy) & \\
\text{Wavelength(Å)} & \\
0.1 & 1 & 10 & 100 \\
2000 & 4000 & 6000 & 8000 & 12000 & 14000 & 16000
\end{align*}
\]
Spectroscopic Observation

• Gemini/GMOS-S Observation (2015A)
  • Supported by K-GMT Science Program of KASI
  • Instrument: Gemini Multi-Object Spectrograph (GMOS)

• Technical Description
  • Nod & Shuffle longslit (1” width) mode with R150_G5326 grating
  • 4x4 binning $\rightarrow$ 7.72 Å/pixel ($\sim$290 km/s)
  • RG610_G0331 filter to avoid the order-overlap

• Exposure Time
  • 12 sequences of 968 s ($\sim$3 hr)
  • Use five frames ($\sim$1.3 hr) with seeing < 1”
Discovery of a Faint Quasar at $z \approx 6$

- **Spectrum of IMS J2204+0112**
  - Clear break at $\sim 8443$ Å (identified as Ly$\alpha$)
  - Fit the SDSS composite quasar spectrum, considering IGM attenuation (Vanden Berk+01; Madau+96)
  - $z = 5.944 \pm 0.002$, $M_{1450} = -23.59 \pm 0.10$ mag

- **Emission lines**
  - Ly$\alpha$ $\lambda 1216$, N V $\lambda 1240$, Si IV $\lambda 1400$

- **(Possible) absorption lines**
  - Si II $\lambda 1260$, C II $\lambda 1335$
  - Absorber at $z \approx 5.71$

- **Lower limit of $M_{BH}$**
  - $M_{BH} > 10^8$ $M_{\odot}$ ($\lambda_{Edd} = 1$)
Expected Number of Quasars in SA22

• Expected Number in SA22 Field at $M_{1450} = -23.5$
  • Hard to constrain the faint end with only one quasar
    • Optical/NIR AGNs (Willott+10, Kashikawa+15) : 1.4
    • Faint X-ray AGN candidates (Giallongo+15) : $\sim40$

• Fraction of Required UV Photons for Reionization
  • AGNs at $M_{1450} \sim -23.5$
    • Giallongo+15: $\sim60\%$
    • Willott+10, Kashikawa+15: $\sim3\%$
    • Our result: $<15\%$

![Graph showing expected number of quasars vs. $M_{1450}$ magnitude](image)
IMS as a Survey for High-z Quasars

- **Survey for Faint Quasars in the Early Universe**
  - Can be identified efficiently with IMS
  - Analysis of full IMS data → more faint quasars at $z \sim 6$

- **Large Sample of Faint Quasars**
  - Constrain the faint end of QLF
  - Determine $M_{BH}$ & Eddington ratio
  - Understand low-luminous quasar population
Thank You