Ten Billion Solar Mass Black Holes at the End of Re-ionization Discovered Using SDSS-WISE Photometry

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Background and Motivation

Understanding how and when supermassive black holes (SMBHs) grow is one of the key outstanding problems in extragalactic astronomy. The existence of billion $M_\odot$ BHs at the end of reionization posts significant challenges to the theory of BH formation and BH/galaxy coevolution (e.g. Volonteir 2012). Locally, BHs with masses of order 10 billion $M_\odot$ have been discovered (McConnell et al. 2011). **Do such objects exist? What's the most massive BHs in the early universe? How do they accrete and what kind of galactic environment do they live in?** Here we report the discovery of several ultra-luminous quasars with ten billion $M_\odot$ BHs. **In particular, we discovered quasar J0100+2802 with a 12 billion $M_\odot$ BH at $z = 6.3$.** These massive BHs provide unique laboratories to study BH mass assembly and BH/galaxy coevolution in the reionization-era. The extremely high luminosity nature of these quasars will allow unprecedented measurements of the temperature, ionization state and metal content of the intergalactic medium.

Challenges in Color Selections of $z > 5.1$ Quasars

High redshift quasars have been efficiently selected using a combination of optical and near-infrared colors. But it's very difficult to select $z \gtrsim 5.1$ quasars due to serious star contaminations (e.g. M dwarfs) (e.g. Fan et al. 2001, McGreer et al. 2013).

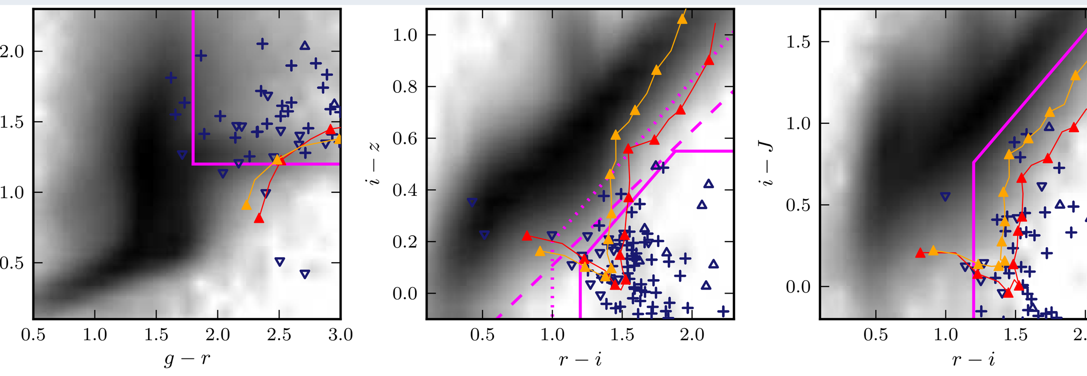

Figure 1: Typical $z \sim 5$ quasar selection method. Red ($M_{1450} = -24.5$) and orange ($M_{1450} = -26.7$) lines are the color tracks for quasars from $z = 4.5$ to $z = 5.5$, in steps of 0.1. Downward triangles denoting $z < 4.7$ quasars, upward triangles $z > 5.1$ quasars, and crosses quasars within redshift range of $4.7 < z < 5.1$. Color selection of $z \gtrsim 5.1$ quasars is not efficient with only SDSS and/or Near-IR data, especially for the most luminous quasars due to the Baldwin effect. Adapted from McGreer et al. 2013.

WISE is Very Wise

Due to the large difference in quasar and stellar SEDs in the mid-IR, the WISE W1-W2 color of high redshift quasars is markedly redder than that of late type stars. This difference makes it much easier to distinguish high-z quasars from star contaminations. Based on the optical+WISE selection, we are conducting a spectroscopy survey of $z \gtrsim 5$ quasars (see the poster of Jinyi Yang) to search for the most massive BHs at the end of reionizaion era.

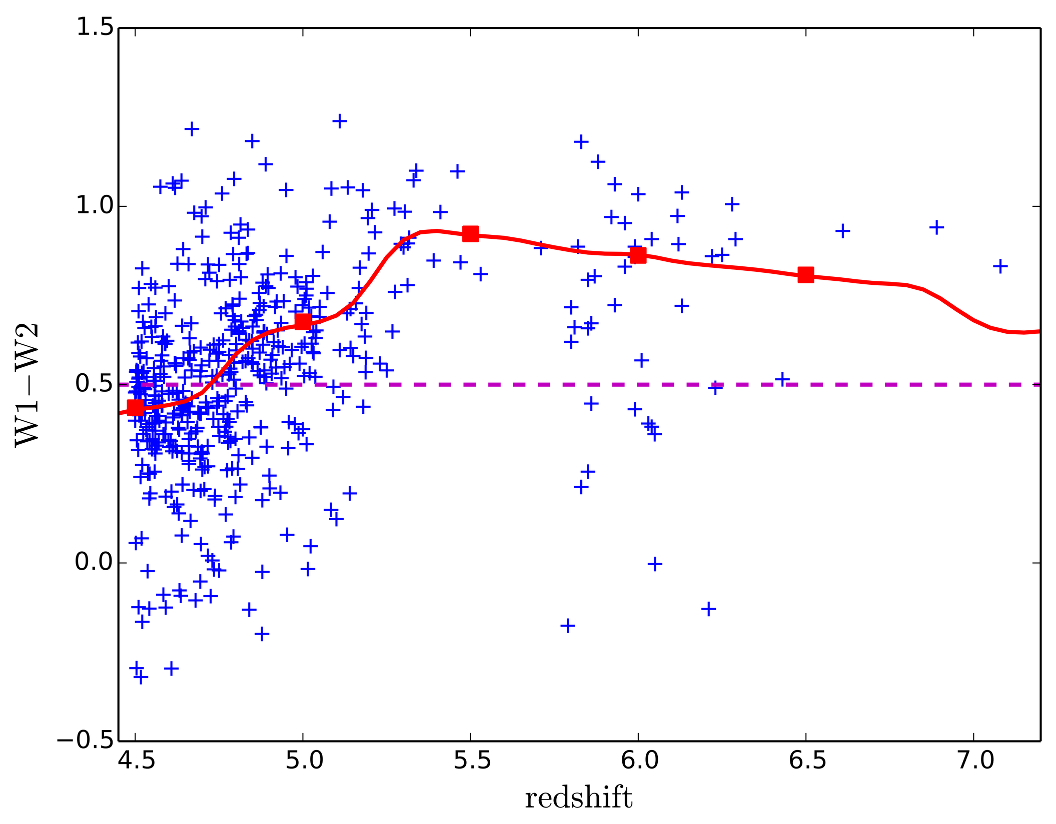

Figure 2: The W1-W2 vs. redshift diagram. The purple dashed line represents W1-W2=0.5. The red solid line represents the color-z relation predicted using the SDSS composite quasar spectra. The solid squares mark the color tracks of quasars from z = 4.5 to 6.5, in steps of 0.5. The blue crosses represent ALLWISE detected $z \geq 4.5$ quasars.

Three Ten Billion Solar Mass BHs

J0100+2802 at $z = 6.30$. It has a bolometric luminosity $L_{bol} = 1.62 \times 10^{48}$ ergs s^{-1} ($\sim 4.3 \times 10^{14}\ L_\odot$) and a BH mass $M_{BH} = 1.24 \times 10^{10} M_\odot$. It is the only quasar with $L_{bol} > 10^{48}$ ergs s^{-1} and $M_{BH} > 5 \times 10^9 M_\odot$ yet known at $z \gtrsim 6$. It is comparable to he most luminous quasar with the most massive BH at any redshift (Fig. 4). The discovery of this ultra-luminous quasar over the entire SDSS footprint is broadly consistent with the extrapolation of SDSS $z \sim 6$ quasar luminosity function. Its existence strengthens the claim that supermassive black hole at early Universe probably grows much quickly than its host galaxy, as argued from the molecular gas study of $z \sim 6$ quasars.

The equivalent width of the Lyα + NV emission lines is roughly 10Å, suggesting that J0100+2802 is a weak-line quasar (WLQs). Submm observations of this quasar could shed light on the nature and evolutionary stage of WLQs at high redshift. On the basis complete Gunn-Peterson absorption, we estimate the proper proximity zone size to be about 8 Mpc, larger than found with other quasars at $z > 6.1$, its large proximity zone size is expected from the higher level of photo-ionization dominated by quasar radiation..

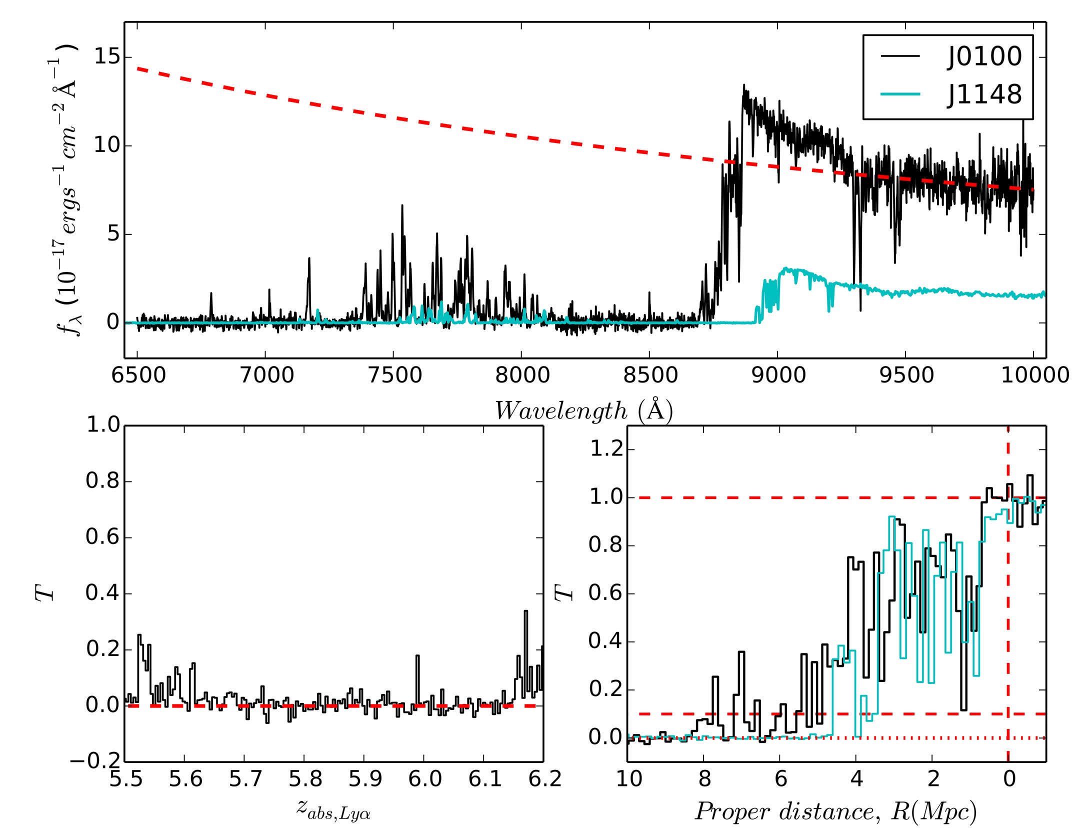

Figure 3: Upper: LBT optical spectra of J0100+2802. Lower: Transmission in absorption troughs and the proximity zone of J0100+2802. It is a weak-line quasar with continuum luminosity five times higher than that of J1148+5251, the archetype $z > 6$ quasar. The optical spectrum exhibits a deep Gunn-Peterson trough and a significant transmission peak at z = 5.99. The proper proximity zone for J0100+2802 (in black) extends to 7.9 ± 0.8 Mpc, much larger than those of other $z \sim 6$ quasars, including 4.9 ± 0.6 Mpc for J1148+5251 (in cyan), consistent with its higher UV luminosity.

J0306+1853 at $z = 5.36$. It has a MgII based $M_{BH} = 1.18 \times 10^{10} M_\odot$ and a CIV based $M_{BH} = 2.23 \times 10^{10} M_\odot$. A $z \sim 5$ Damped Lyα system with metallicity [M/H]$= -1.3 \pm 0.1$ is shown in the spectra. The existence of J0306 sets strong constraints on the quasar luminosity function and BH mass function.

J0131-0321 at $z = 5.18$. A radio loud quasar ($R \sim 100$) with MgII based $M_{BH} = 4.0 \times 10^9 M_\odot$ and big blue bump fitting based $M_{BH} = 1.1 \times 10^{10} M_\odot$. It's also detected in X-ray with $F_{0.3-10keV} = 1.4 \times 10^{-13}$erg cm^{-2}s^{-1} and could be a blazar candidate.

Key Results

Remarkably, our $z \gtrsim 5$ quasar survey has resulted in the discovery of several ultra-luminous quasars with around ten billion $M_\odot$ BHs. Figure 4 shows the distribution of BH mass and bolometric luminosity for both low-z and high-z quasars. The three new quasars we have discovered are close to the most massive and luminous systems at any redshift. The yellow stars in the plot denote another four new identified ultra-luminous quasars with BH mass measurements in our sample. The existence of such objects would set strong constraints on the growth of supermassive black holes.

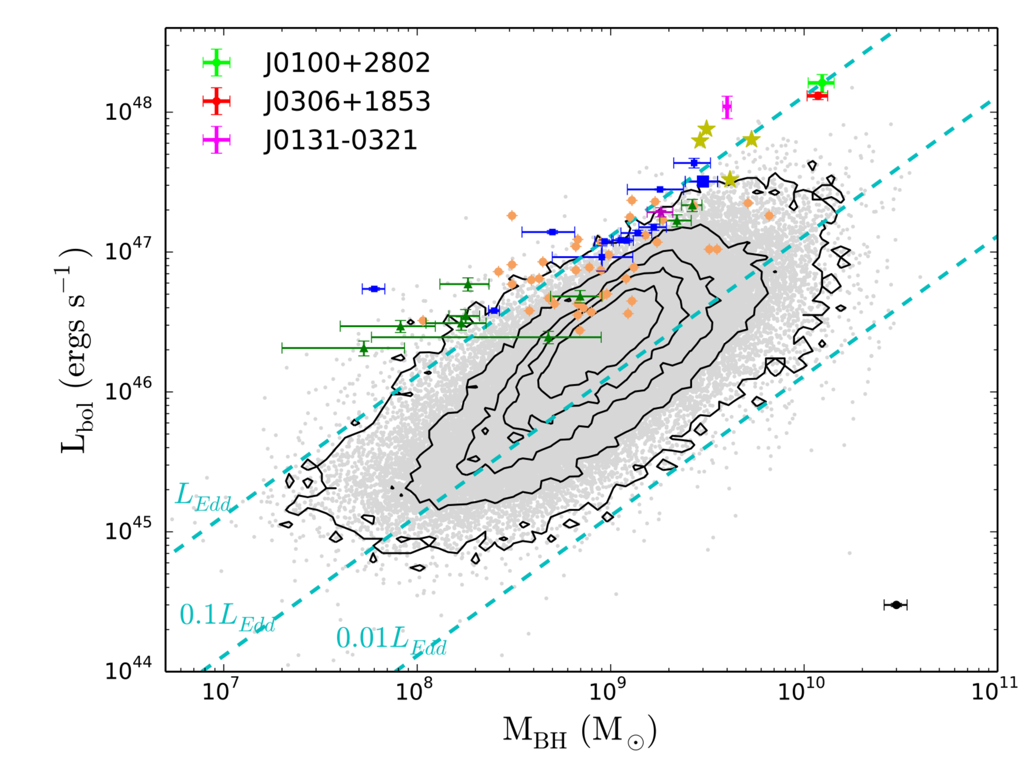

Figure 4: Distribution of quasar bolometric luminosities and MgII based BH masses. The brown points denote $z \sim 4.8$ quasars from Trakhtenbrot et al. (2011), blue squares denote SDSS $z \gtrsim 6$ quasars, the green triangles denote CFHQS $z \gtrsim 6$ quasars, purple square denotes the most distance quasar ULAS J1120+0641 at z=7.085, black contours and grey dots denote SDSS low redshift quasars from Shen et al. (2011). The yellow stars denote four other new identified quasars with BH mass measurements.

References:

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