Study of the bright end quasar luminosity function at z~5 based on SDSS-WISE data

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Motivation

High redshift quasars are important tracers of galaxy and structure evolution in the early Universe. They become extremely rare at $z > 5.1$. A factor of greater than 2 decrease in the number density of luminous quasars from $z = 5$ to 6 than from $z = 4$ to 5 was claimed (McGreer et al. 2013). Although more than 200,000 quasars are known, only ~150 quasars at $z > 5$. There is also an obvious drop of known quasars at $z > 5.1$ because their similar optical colors with late-type stars based on optical selection alone. **However, this redshift range is one of the most important epoch of IGM evolution, black hole growth and quasar evolution in the early universe.** From the combination of SDSS DR7 quasars and Stripe 82 faint quasar sample, McGreer et al. (2013) presented the most detailed study $z \sim 5$ QLF, especially on the faint end. However, this work focused on the faint end; here are only 8 quasars with $M_{1450} < -27.3$ in their sample for QLF study. **We aim at finding more luminous quasars at $4.7 \le z \le 5.5$, and then calculate QLF and constrain the bright end slope and evolution model of high redshift quasar luminosity function.**

Quasar selection

Wide-field Infrared Survey Explorer (WISE) maps the whole sky in four bands (W1-W4) from 3.4 μm to 22 μm. The W1-W2 color of WISE can separate $z \ge 5$ quasars from stars very efficiently due to the redder W1-W2 color of high redshift quasars than that of late-type stars. We cross-matched 255,946 SDSS DR7 & DR10 quasars with ALLWISE data. We found that the ALLWISE detection rate of SDSS quasars is higher than 50% at all redshift, higher than 85% at $z < 2.0$ and higher than 80% at $4.0 < z < 5.3$. 402 of 476 $z \ge 4.5$ SDSS quasars are detected by ALLWISE dataset and the detection rate is about 84.5%, which demonstrates a high detection rate of high redshift quasars at infrared wavelength. With the whole sky coverage, high detection rate of known high redshift quasars and high efficiency of rejecting late-type stars, ALLWISE is ideal for finding luminous high redshift quasars.

At $z \sim 5$, most quasars are undetectable in u-band and g-band because of the presence of Lyman limit systems (LLSs), which are optically thick to the continuum radiation from the quasar (Fan et al. 1999). Meanwhile, the absorption systems begin to dominate in the r-band and Ly alpha emission moves to the i-band. The *r-i/i-z* color-color diagram is often used to select $z \sim 5$ quasar candidates in the previous studies (Fan et al. 1999; Richards et al. 2002; McGreer et al. 2013). With the increasing of the redshift, the *i-z* color becomes increasingly red and most $z > 5.1$ quasars enter the M star locus in the *r-i/i-z* color-color diagram, which makes it very difficult to find $z \ge 5.1$ quasars only with optical colors. As we discussed in last section, W1-W2 can be used to reject M type stars effectively. By combining SDSS and WISE photometric data, we are conducting a $z \ge 5$ quasar survey.

We use typical *u,g* drop-out method but relax the *r-i/i-z* cuts select candidates from SDSS DR10 database. We cross-match our candidates with ALLWISE database in order to use *z*-W1/W1-W2 cuts to remove star contaminations. (See details of candidate selection in Wang, F., et al. in prep.)

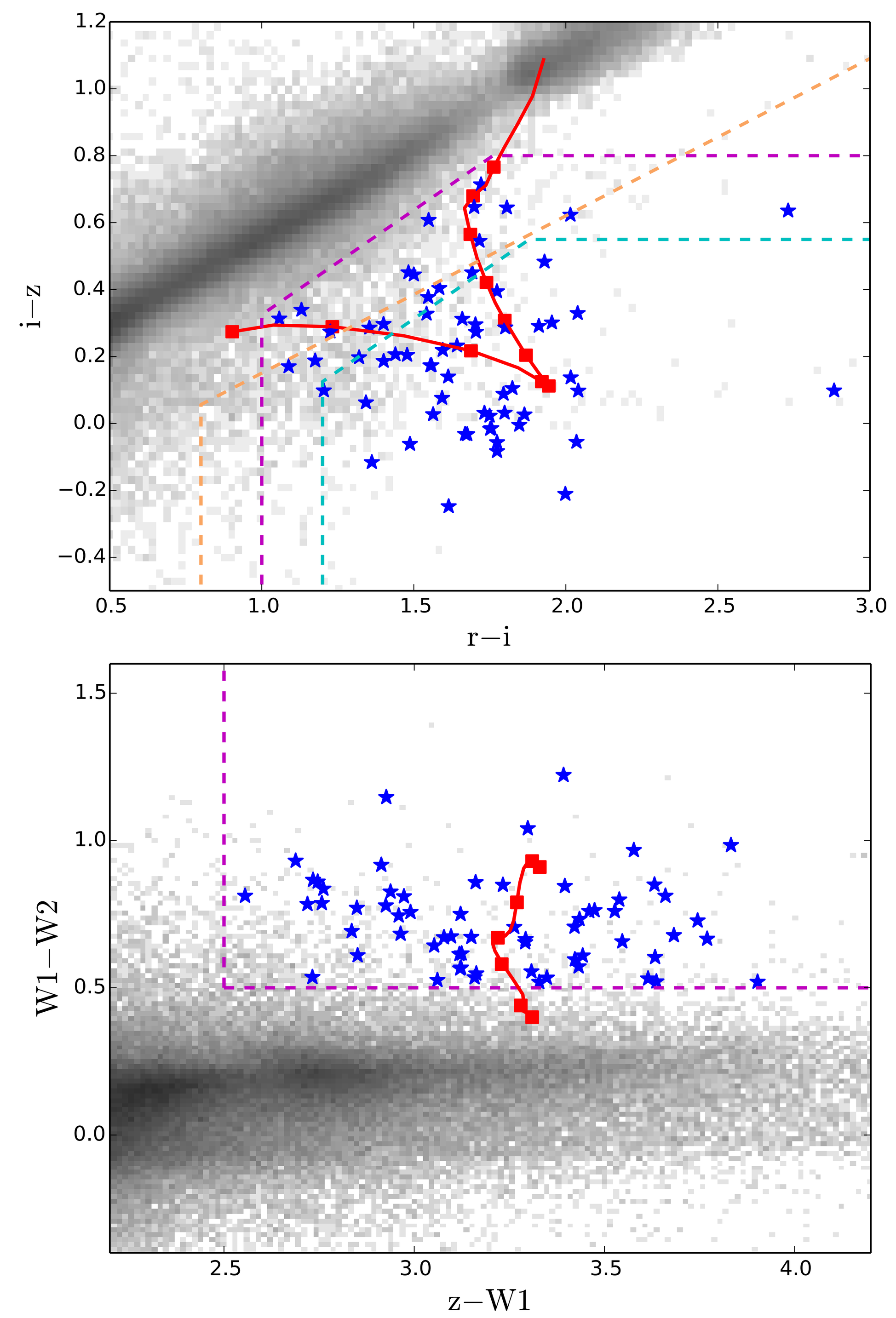

Figure 1.***Upper***: The $i - z / r - i$ color-color diagram. The purple dashed line represents our selection criteria for quasar candidates. The orange and cyan dashed line represent the selection criteria of Fan et al. (2000) and McGreer et al. (2013). The red solid line represents the color-z relation predicted using $z \sim 5.0$ SDSS quasar composite spectra. The solid squares mark the color tracks for quasars from z = 4.4 to z = 5.4, in steps of $\Delta z = 0.1$. The grey map denotes SDSS stars, the blue stars denote our new discovered quasars. ***Bottom:*** The z −W1/W1−W2 color-color diagram. The purple dashed line represents our selection criteria for quasar candidates. The solid squares mark the color tracks for quasars from z = 4.4 to z = 5.6, in steps of $\Delta z = 0.2$.

Spectroscopic Observations

Up to date, we have identified ~120 candidates using:

- Lijiang 2.4m, in 2013 Nov. and 2014 Apr., Oct., Nov.
- MMT Red channel, in 2014 May
- Bok 2.3m, in 2014 Oct. and Nov.
- ANU 2.3m, in 2014 Oct. and Dec.

Our observations are continuing in 2015.

Result

We discovered ~ 70 new quasars within a redshift range of $4.5 < z < 5.8$. There are 43 quasars with redshift range of $4.7 < z < 5.4$ and z band magnitude brighter than 19.5. There are also 57 known quasars that satisfy our selection. Three of our new quasars are brighter than any previously known quasars at $z > 5$. Figure 2 shows the distribution of our new discovered quasars and known quasars at $4.7 < z < 5.4$ and SDSS $z < 19.5$. It is obvious that our discovery significantly expand the $z \sim 5$ luminous quasar sample, which is expected to set strong constraints on the bright end of quasar luminosity function and the massive end of black hole mass function.

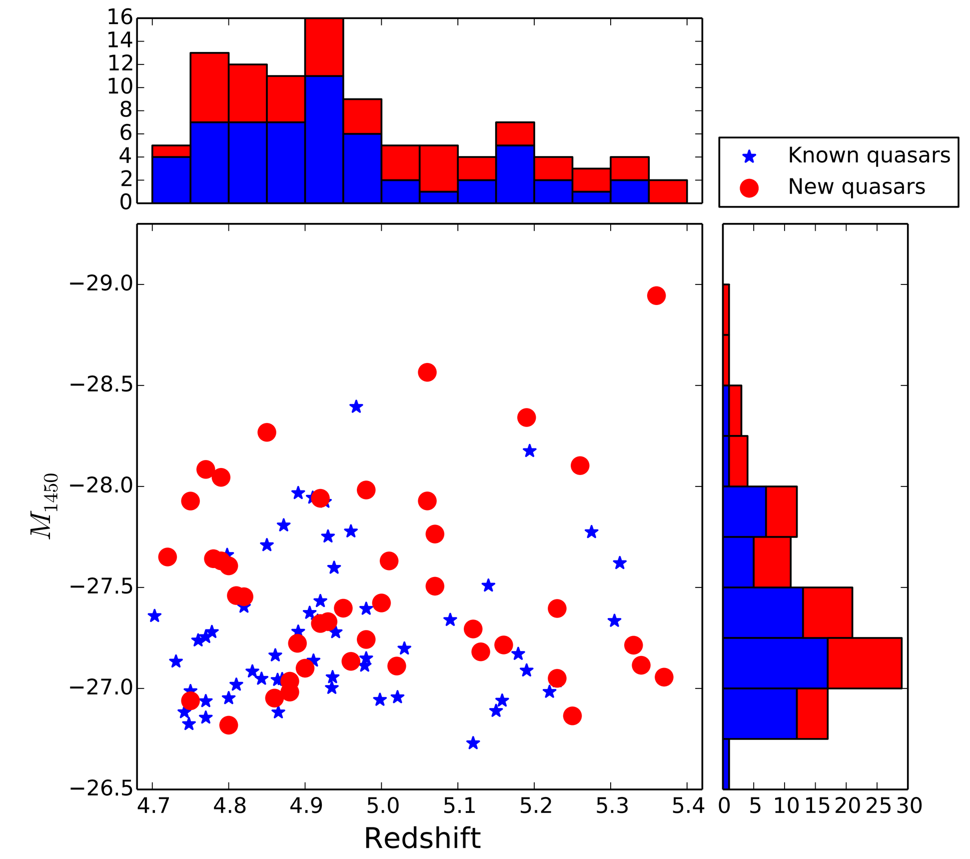

Figure 2: Distribution of new discovered quasars and all known quasars at $4.7 < z < 5.4$ and SDSS $z < 19.5$. Red dots and red filled parts in histogram denote new discovered quasars. It is obvious that we add a large number of luminous z ~ 5 quasars.

In order to compare with the result from McGreer et al. (2013; See Figure 3), we want to cover two bins at the bright end of their QLF. So we select all quasars with $4.7 < z < 5.4$ and $M_{1450} < -27.3$ from the sample discussed above to calculate our QLF. There are 48 quasars with $4.7 < z < 5.4$ and $M_{1450} < -27.3$. 25 of them are our new discovered quasars. We divide these quasars into two redshift bins ($4.7 < z < 5.05$ and $5.05 < z < 5.4$) and four M_{1450} bins. We use ~ 30000 simulation quasars which are generated used an updated version of quasar spectral model (McGreer et al. 2013) to build our selection function and use $1/V_a$ method to calculate our QLF. We correct the z ~ 4.9 best fit QLF from McGreer et al. (2013) into z ~ 5.2 based on a steep decline with redshift (Fan et al. 2001) for our high redshift bin.

As shown in Figure 3, in both low redshift bin ($z \sim 4.9$) and high redshift bin ($z \sim 5.2$), our result show an agreement with the best fit QLF of McGreer13. Therefore, based on our luminous $z \sim 5$ quasar sample, we suggest that the bright end slope of z ~ 4.9 and z ~ 5.2 QLF is $\beta \sim -4$, which is consistent with McGreer13.

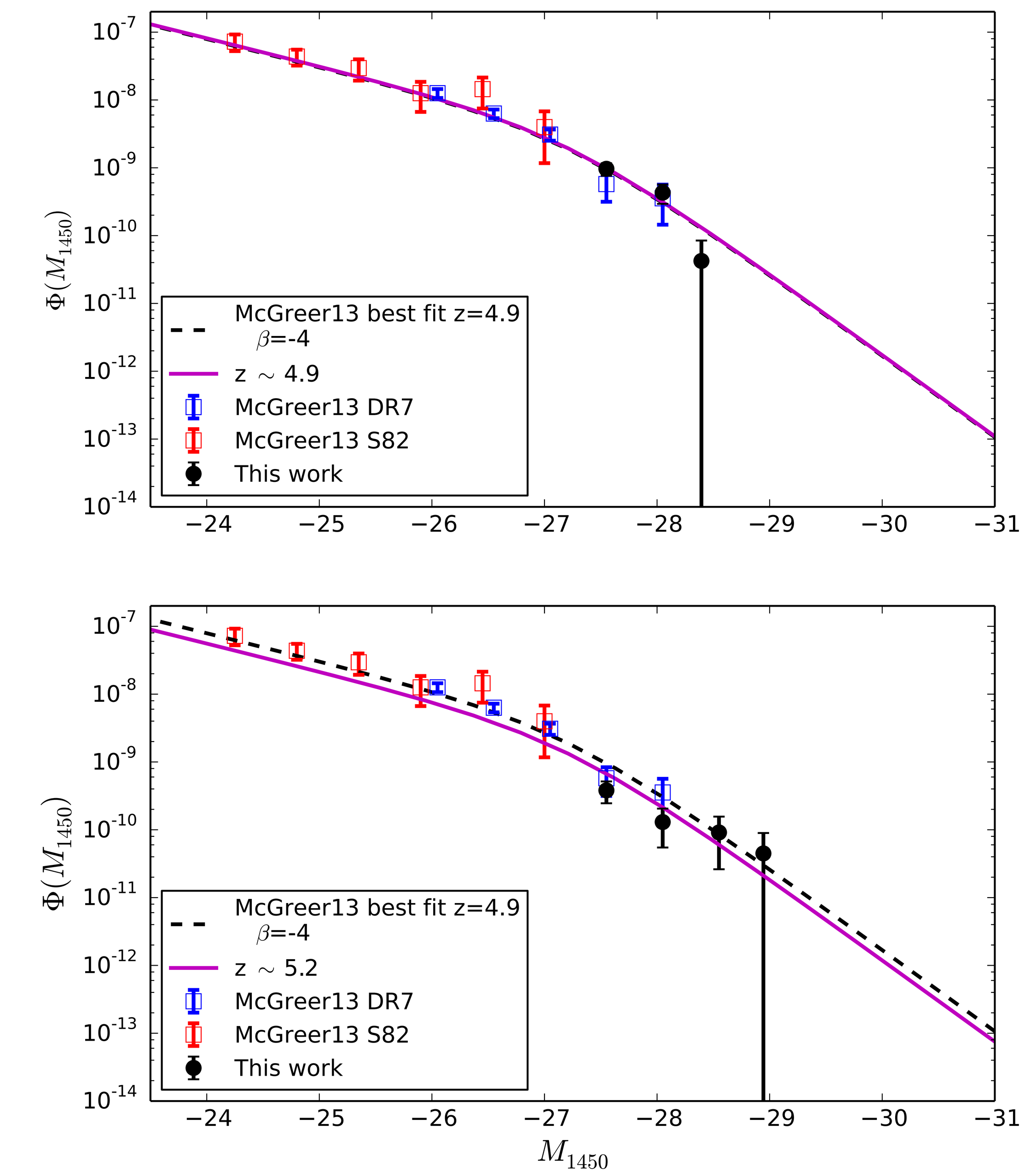

Figure 3: The preliminary binned QLF result(black dots) at z~4.9 bin (*upper*) and z~5.2 bin(*bottom*), comparing with McGreer's binned QLF and best fit QLF (McGreer et al. 2013). We correct the z~4.9 best fit QLF into z~5.2 based on a steep decline with redshift (Fan et al. 2001).

Summary

- **We combined SDSS & ALLWISE photometry data to construct a highly effective $z \sim 5$ quasar selection criteria. ALLWISE data is key in this new high redshift quasar selection method.**
- **We discovered ~70 new z~5 quasars and used 48 quasars with $4.7 < z < 5.4$ and $M_{1450} < -27.3$ to study the bright end of z~5 quasar luminosity function.**

Reference

Fan, X., 1999, AJ, 117, 2528 •Fan, X., et al., 2000, AJ, 119, 1 •Fan, X., et al. 2001, AJ, 122, 2833 •McGreer, I., et al., 2013, ApJ, 768, 105 •Richards, G. T., et al. 2002, AJ, 123, 2945 •Wang, F., et al., in prep.

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