# Effects of the luminosity dependence of quasar spectra on the completeness estimates

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## 1. Introduction

It is important to understand the cosmological evolution of SMBHs, and a critical key to tackle this issue is the redshift evolution of the quasar luminosity function.

Here the completeness correction is required to derive the quasar luminosity function from the observational data, and usually the "typical" quasar spectrum is used for this correction (Fig. 1).

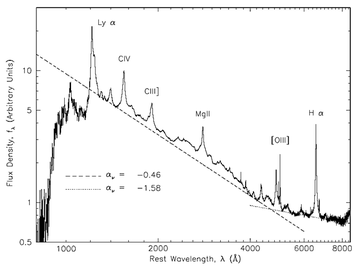



Fig. 1. SDSS composite spectra (Vanden Berk et al. 2001)

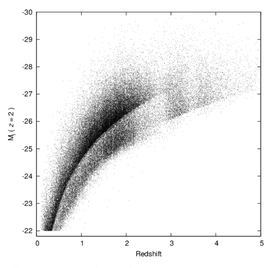



Fig. 2. The distribution of DR7 quasars in luminosity-redshift space

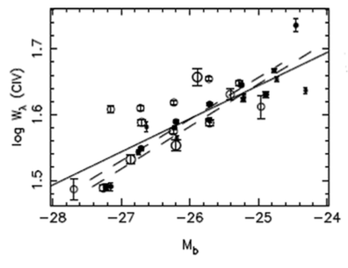



Fig. 3. The Baldwin effect for CIV (Croom et al. 2002)

Actually the quasar spectrum depends on the quasar luminosity, known as the Baldwin effect (i.e., a negative correlation between the emission-line EWs and the continuum luminosity; Fig. 3).

QUESTION: Can we adopt the "typical" quasar spectrum for correcting the completeness to derive the quasar luminosity function in a wide luminosity range?

This could be important especially for the coming HSC survey, since we would want to give constraints on quasars with a significantly lower luminosity than the SDSS quasars!

## 2. Sample

catalog・・・SDSS DR5 quasar catalog (77429objects : Schneider et al. 2007)

- $z > 2$
- $\log L_{1350}$ given in Shen et al. (2008)
- non-BAL quasar

9584 objects → making composite spectra as functions of $z$ & $L_{1350}$

46 composite spectra made

($\Delta\log L_{1350} = 0.25$ for $45.25<\log L_{1350}<47.00$, $\Delta z = 0.25$ for $2<z<4.5$)

The stacked spectra show significant dependence on $L_{1350}$ but not on $z$

Re-combining the stacked spectra to make high-S/N luminosity-dependent composites ($45.25<\log L_{1350}<47.25$, $\Delta\log L_{1350} = 0.25$)
→ 9 composite spectra (Fig. 4)

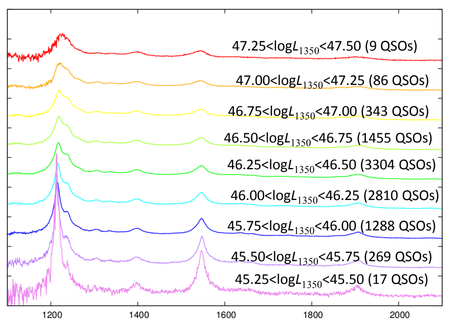
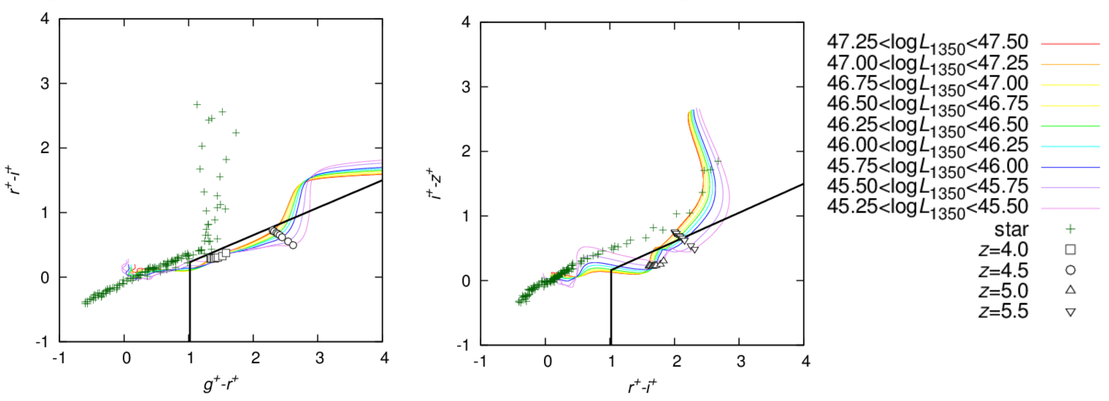



Fig. 4. The 9 composite spectra made by us

## 3. The luminosity dependences on the two-color diagrams

Fig. 5. Quasar color tracks on the two-color diagrams




Significant luminosity dependences are seen in the quasar model tracks on two-color diagram, suggesting that the luminosity dependence of the quasar spectrum is important in the completeness estimates!

what is the cause of the difference in the color tracks?

Baldwin effect of Lyα, CIV

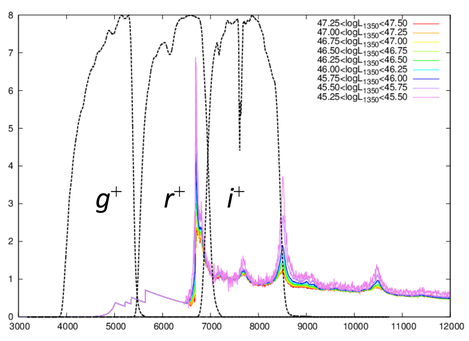



Fig. 6. Filter transmission curves overlaid on the composite spectra redshifted to $z$~4.5. Significant luminosity dependences of emission-line EWs affect the broad-band colors, that results in the luminosity-dependent quasar color tracks.

## 4. Completeness estimation: Case study in the COSMOS field

### Method of the calculation

1. generating "simulated spectra" taking account of L-dependent EWs and intrinsic dispersions in EWs and power-law slope
2. calculating $g^+$, $r^+$, $z^+$ mag for various $i^+$ mag and redshifts from the generated sim. spectra
3. putting point sources having the calculated mag into the COSMOS SCam image
4. detecting them using SExtractor, and calculating the "pseudo-observed" colors of sim. quasars
5. calculating the completeness (how fraction of input point sources satisfy the quasar criteria)

### Result of the "revised" completeness

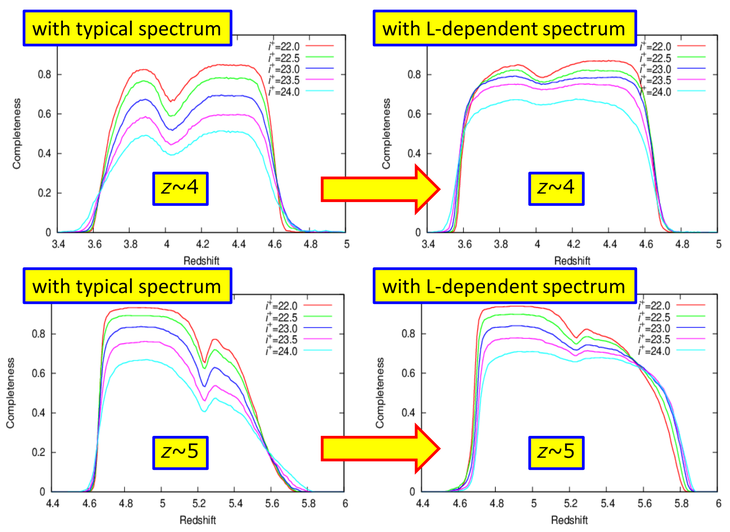



Fig. 7. Simulated completeness in the COSMOS field, in the cases of using typical spectrum (left) and L-dependent spectrum (right) at $z$~4 (upper) and $z$~5 (lower). The completeness using the typical quasar spectrum is given in Ikeda et al. (2011, 2012)

The luminosity dependence of the quasar spectra actually affects the completeness calculations!!

## 5. Revised Quasar luminosity function in the COSMOS field

To derive the QLF, we calculated the effective comoving volume adopting the derived completeness, and then derived the quasar space density at $z$~4-5.

$$V_{\rm eff}(m_{i'}) = d\Omega \int_{z=0}^{z=\infty} C(m_{i'}, z)\frac{dV}{dz}dz$$

$d\Omega$= 1.64 deg$^2$ (COSMOS)
$C(m_{i'}, z)$ : completeness

$$\Phi(M_{1450}, z) = \frac{\Phi(M^*_{1450})}{10^{0.4(\alpha+1)(M_{1450}-M^*_{1450})} + 10^{0.4(\beta+1)(M_{1450}-M^*_{1450})}}$$

$z$~4 quasar space density

Ikeda et al. 2011

| $M_{1450}$ (mag) | $N_{cor}$ | $\Phi$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) | $\sigma(\Phi)$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) |
|---|---|---|---|
| −23.59 | 4.67 | 3.93 | 1.82 |
| −22.59 | 6.07 | 6.64 | 2.69 |

this work

| $M_{1450}$ (mag) | $N_{cor}$ | $\Phi$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) | $\sigma(\Phi)$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) |
|---|---|---|---|
| −23.59 | 4.67 | 3.18 | 1.47 |
| −22.59 | 6.07 | 4.44 | 1.80 |

$z$~5 quasar space density

Ikeda et al. 2012

| $M_{1450}$ (mag) | $N_{cor}$ | $\Phi$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) | $\sigma(\Phi)$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) |
|---|---|---|---|
| −24.02 | < 1 | < 1.67 | — |
| −23.02 | ≦2 | < 3.65 | — |

this work

| $M_{1450}$ (mag) | $N_{cor}$ | $\Phi$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) | $\sigma(\Phi)$ ($10^{-7}$ Mpc$^{-3}$mag$^{-1}$) |
|---|---|---|---|
| −24.02 | <1 | < 1.40 | — |
| −23.02 | ≦2 | < 2.77 | — |

~20-30% lower Phi !

How is the QLF affected accordingly?

The best-fit parameters $z$~4 QLF

Ikeda et al. (2011)
$\Phi(M^*_{1450}) = 3.1\ (+0.3, -0.2) \times 10^{-7}$ Mpc$^{-3}$ mag$^{-1}$,
$M^*_{1450} = -24.40\ (+0.05, -0.07)$, $\beta = -1.60\ (+0.23, -0.18)$

this work
$\Phi(M^*_{1450}) = 3.0\ (+0.3, -0.2) \times 10^{-7}$ Mpc$^{-3}$ mag$^{-1}$,
$M^*_{1450} = -24.40\ (+0.05, -0.07)$, $\beta = -1.37\ (+0.24, -0.18)$

Here $\alpha$ is fixed to be $\alpha = -2.58$ based SDSS results and $\Phi^*$, $M^*$, $\beta$ are derived through the least squares method.
The QLF parameters are actually affected by the completeness treatments!!

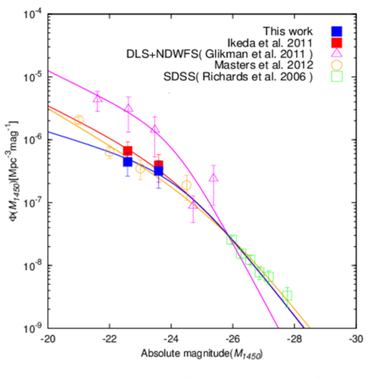



Fig. 8. $z$~4 QLF, based on the previous (red square) and new completeness estimate (blue square)

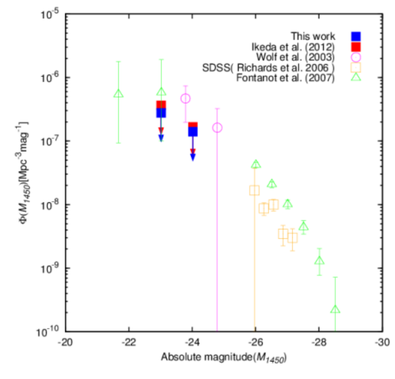



Fig. 9. Same as Fig. 8 but for $z$~5 QLF

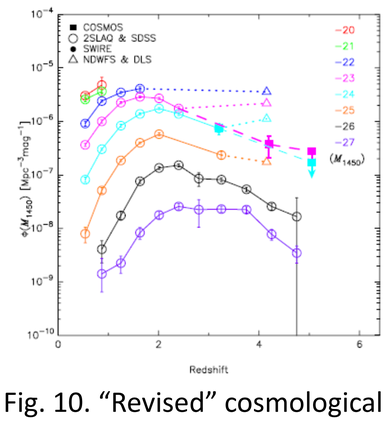



Fig. 10. "Revised" cosmological evolution of the quasar space density

## 6. Summary

We examined possible effects of the L-dependence of quasar spectra on the survey completeness estimates. The revised quasar space density, taking this effect into account, is 20-30% smaller than the previous work adopting only "typical" spectrum for the completeness estimates. This result seems important in the coming HSC survey, in which a wider range of quasar luminosity will be examined.