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Research Note

Detection of further UV-bright high-redshift QSOs*

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Abstract. We present successful UV observations with IUE of several newly discovered high-redshift QSOs from the Hamburg QSO Surveys. In addition to three previously discovered QSOs three new objects have been found to have lines of sight transparent to wavelengths as short as 1200 Å: HS 0747+4259 ($z = 1.9$, $V = 15.8$); HS 1147+6556 ($z = 2.21$, $V = 16.2$); HE 2347-4342 ($z = 2.89$, $V = 16.1$).

We also report on the discovery of HE 0515-4414 which with $z = 1.71$ and $V = 14.9$ is the brightest known $z > 1.5$ QSO in the sky and among the most luminous objects in the universe. Our IUE long wavelength observations show HE 0515-4414 to be also the UV-brightest high-redshift QSO known ($6 \cdot 10^{-15}$ erg cm^{-2} Å^{-1} s^{-1}) with a damped Ly α system at $z = 1.15$. While HE 2347-4342 has been observed spectroscopically with HST (Reimers et al. 1997), the other QSOs, in particular HE 0515-4414, are promising targets for HST and/or the Far Ultraviolet Spectroscopic Explorer (FUSE).

Since the IUE mission has come to an end, we briefly discuss the outcome of the attempts to detect with IUE UV-bright high z QSOs.

We show that the strategy that avoided QSOs with metal absorption systems and/or Lyman limit absorption already visible in low resolution optical spectra led to a detection rate at 1250 Å of approximately 35 % (5 out of 14) for QSOs with V$\lesssim$16.5 and 2$\leq z \leq$3 using whole shift IUE exposures.

Key words: quasars: general – quasars: individual: HE 0515-4414, HS 0747+4259, HS 1147+6556, HE 2347-4342 – quasars: UV radiation

1. Introduction

Spectroscopy of the intrinsic extreme ultraviolet (EUV) spectrum of high-redshift QSOs offers the possibility to study a number of astrophysically important topics. Besides the possibility to study the quasar energy distribution itself which peaks in the EUV part of the spectrum, the EUV offers the resonance lines of abundant ions like HeI, HeII, OIII-OV, NeIII-NeVIII etc. which can be used to observe the physical nature (ionization, abundances etc.) of absorbing gas clouds and of a diffuse IGM in the lines of sight of quasars (Reimers et al. 1992, Reimers & Vogel 1993, Vogel & Reimers 1995, Jakobsen et al. 1994, Reimers et al. 1997).

However, the IGM at high-redshift is relatively opaque in the UV due to Lyman continuum absorption of intervening gas clouds (Lyman limit systems,LLSs) at cosmological distances (Møller & Jakobsen 1990, Picard & Jakobsen 1993, Jakobsen 1997). On the other hand, both the detection of such UV-bright high-redshift QSOs with IUE and their subsequent spectroscopy with HST require a minimum UV flux of the order of $1 \cdot 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}.

Due to the rareness of bright ($V < 16.5$) high-redshift QSOs and absorption by the IGM up to now only three $z > 2$ QSOs with $f_\lambda > 10^{-15}$ have been detected with IUE at the shortest wavelengths, namely HS 1700+6416 (Reimers et al. 1989), HS 1103+6416 and HS 1307+4716 (Reimers et al. 1995), all from the Hamburg Quasar Survey (HQS).

We therefore intensified our attempt to find more transparent lines of sight in $z > 2$ quasars.

2. Observations

2.1. Discovery and optical spectroscopy

All QSOs are new discoveries by the HQS (Hagen et al. 1995) or the Hamburg/ESO Survey (see Reimers & Wisotzki, 1997 for further reference) which both make use of digitized objective prism plates taken with either the Calar Alto or the ESO Schmidt. Positions, magnitudes and redshifts of the QSOs discussed in this article are given in Table 1.

Follow-up spectroscopy of the semiautomatically selected QSO candidates with the aim of verification of the candidates has been performed with the Calar Alto 2.2 m telescope and with the ESO/MPIA 2.2 m telescope on La Silla. Flatfield correction and wavelength and flux calibration followed standard procedures.

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* Based on observations obtained at the VILSPA IUE Observatory of the European Space Agency, at the European Southern Observatory, La Silla, Chile, and at the German-Spanish Astronomical Center, Calar Alto, Spain

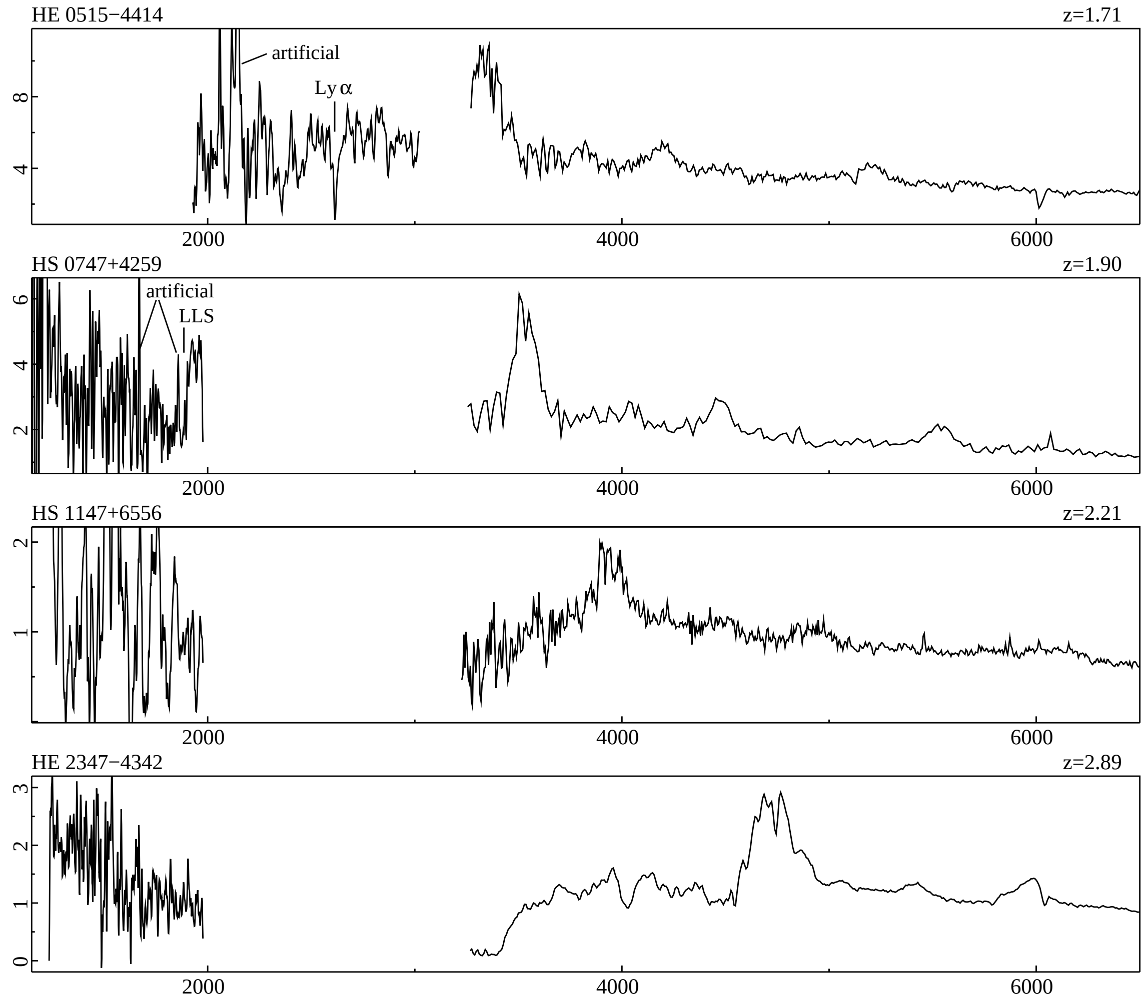

Fig. 1. Combined ultraviolet and optical spectra. Flux units are 10^{-15} erg cm^{-2} s^{-1} Å^{-1}.

Table 1. Basic data for the QSOs detected with IUE

Object	α (1950)	δ	V	z
HE 0001-2340	00 01 11.5	-23 40 37	16.7	2.28
HE 0515-4414	05 15 37.7	-44 14 06	14.9	1.71
HS 0747+4259	07 47 25.7	+42 59 58	15.8	1.90
HS 1147+6556	11 47 53.9	+65 56 10	16.2	2.21
HE 2347-4342	23 47 57.5	-43 42 40	16.1	2.89

2.2. IUE observations

Our strategy for finding transparent lines of sight with high-redshift QSOs was to inspect the optical spectra carefully: If there was the slightest evidence for LLS absorption in the optical ($\lambda > 3100$ Å) or for metal lines (CIV, MgII) visible already in low resolution optical spectra, any QSO which due to its brightness (V$\lesssim$16.5) would be otherwise a candidate for IUE follow-up observations was discarded.

All IUE images have been photometrically corrected and wavelength calibrated with the NEWSIPS processing software. Optimal extraction of the onedimensional spectra has been done using a modified version of the extraction algorithms in NEWSIPS and new noise models for the IUE cameras (Rodriguez-Pascual et al., in preparation).

Individual objects:
HE 0001-2340: Observed for the first time on October 28, 1994 for 315 min. with the long wavelength prime camera (LWP). Since the particle background was so high that the camera background was saturated for $\lambda > 3000$ Å, it was decided to repeat the observations on July 24, 1995. In the new image, there is a weak trace of spectrum at $\lambda > 2940$ Å with $f_{3000\,Å} = 1.1(\pm 0.1) \cdot 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}. The lack of a detectable signal at 2800 Å suggests the presence of a LLS at $z = 2.2$.

HE 0515-4414: The LWP spectrum (220 min.) shows a clear detection for $\lambda > 2000$ Å at a level of $6 \cdot 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}. For $\lambda > 3000$ Å there is a contamination with solar straylight. Notice the strong (damped) Ly α absorption line at ~ 2615 Å. High-resolution optical spectra (de la Varga & Reimers, 1997) are consistent with a damped Ly α metal line system at $z = 1.15$. This system with log $N_H \simeq 20.3$ is also responsible for the nondetection in the short wavelength prime camera (SWP) exposure. The feature at $\sim$ 2140 Å is not real since the camera sensitivity is low in that wavelength range, and the S/N is approximately 1. HE 0515-4414 is for $\lambda > 2000$ Å the UV brightest known QSO with $z > 1.5$.

HS 0747+4259: This QSO is detected all along the SWP range (1200 - 1880 Å) in a 340 min. exposure. The two features at 1670 and 1860 Å are camera artefacts. The break at 1900 Å is real and suggests the presence of a LLS at $z \simeq 1.1$ with a HI column density of $\sim 10^{17}$ cm^{-2}.

HS 1147+6556: has also been detected in the whole SWP range in 315 minutes. A cosmic ray hit complicates the extraction of the spectrum below 1400 Å. The flux level at 1850 Å is $\sim 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}.

HE 2347-4342: was observed twice (580 and 712 min.) with deep SWP exposures and detected all along the SWP range. In order to improve the quality of the extracted spectra, some bright spots have been removed after visual inspection of the images. The average spectrum does not show any feature in the range 1230 - 1950 Å and the flux increases monotonically from $\sim 10^{-15}$ at the long wavelength end to $> 2 \cdot 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1} at 1230 Å. The spectrum appears to be cut off at $\sim$1188 Å. In the meantime HE 2347-4342 has been observed spectroscopically with HST (Reimers et al. 1997), the break in the spectrum is confirmed and found to be caused by redshifted HeII 303.8 Å absorption. HE 2347-4342 is the UV-brightest high-redshift QSO detected so far at wavelengths as short as 1200 Å.

Further IUE observations of bright QSOs: We finally mention briefly a number of nondetections of high-redshift QSOs with IUE ($f_\lambda > 1 \cdot 10^{-15} erg\, cm^{-2} s^{-1}$ Å^{-1} at 1250 Å). These are HS 1946+7658 ($z = 3.05$, Hagen et al. 1992; SWP), HS 1833+5811 ($z = 2.02$, Hagen et al. in prep.; SWP), HS 0119+1432 ($z = 2.9$, Hagen et al. in prep.; SWP) and Q 1442+2391 ($z = 2.67$, Sanduleak & Pesch 1989; SWP).

3. Discussion

After the end of the IUE mission, the success of IUE observations in detecting high-redshift QSOs at the shortest wavelengths can be summarized: In Table 2 we present an overview using the data from the IUE archive (Courvoisier & Paltani 1992), from our earlier paper (Reimers et al. 1995) and from this paper. No quasar with $z > 3$ has been detected with IUE with the SWP camera ($\sim$ half a dozen have been tried), contrary to earlier claims in the literature, consistent with only 2 detections at 1300 Å at the 10^{-16} erg cm^{-2} s^{-1} Å^{-1} level among more than 110 $z > 3$ QSOs observed with the FOC onboard HST (Jakobsen 1996).

The threshold for a positive detection with IUE was roughly f_λ (1250 Å) $> 1 \cdot 10^{-15} erg\, cm^{-2} s^{-1}$ Å^{-1} for a whole shift (400 min.) exposure. A quasar with B = 17 ($f_\lambda = 10^{-15}$) with $f_\lambda \sim \lambda^{-1}$ is then just at the detection threshold with an IGM transparency of 30 % at 1250 Å . According to Picard & Jakobsen (1993), only 15 % of all QSOs at z = 2.5 should have lines of sight with > 30 % transparency. Our own $\sim$ 35 % detection rate (5 out of 14, see Table 2) for $2 < z < 3$, compared to the zero detection rate in the IUE archive, is apparently due to the careful selection of potential IUE targets.

Table 2. Number of IUE detections/nondetections at 1250 Å of QSOs as a funtion of redshift z.

	Archive		Hamburg	
QSO z range	Detections at 1250 Å	Nondet. at 1250 Å	Detections at 1250 Å	Nondet.
2 - 3	0	12*	5	9
1.5 - 2	3	8	2	1
1 - 1.5	10	11	1	0

* 6 non detections in SWP, 6 with LLS in LWP (SWP not observed)

We are not able to give more quantitative numbers since IUE has never observed a complete sample of QSOs with specified brightness limits and exposure times. At the de facto end of the IUE mission (Feb. 1996), we had surveyed approximately 50 % of the extragalactic sky ($\sim$ 11 000 deg^2) for bright $z > 2$ QSOs suitable for IUE follow-up observations. We shall finish the remaining part of the extragalactic sky (in total 13 600 deg^2 in the north and 9000 deg^2 in the south) until the end of 1998. We expect therefore to be able to detect further half a dozen UV bright $z > 2$ QSO, provided follow-up spectroscopy with HST or FUSE is granted. The importance of such work cannot be overemphasized, since our present UV bright sample contains, e.g., the only two *bright* QSOs for which HeII 304 Å absorption by the IGM has been observed, with implications for the thermal history of the IGM and the reionization of the universe (Davidsen et al. 1996, Jakobsen 1997,Reimers et al. 1997).

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