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Research Note

The EUV variability of the luminous QSO HS 1700+6416

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Abstract. We report on the first observations of variations in UV (intrinsic EUV 330 Å) flux of the luminous QSO HS 1700+6416 ($z = 2.72$) over a decade. The amplitude of variations increases from ±0.1 mag in the optical (R) to up to a factor of 3 at 1250 Å. This is apparently an extension of the increase in amplitude of variations towards shorter wavelengths observed with IUE in low z AGN (Paltani & Courvoisier 1996) to the EUV. The time-scale for variations with the largest amplitudes is ≥1/2 yr to years. We briefly discuss the consequences of the observed variations on the ionizing metagalactic UV background.

Key words. galaxies: clusters: individual HS 1700+6416 – galaxies: quasars: general

1. Introduction

The origin of the UV spectral energy distribution of active galactic nuclei (AGN) and, in particular, that of luminous QSOs is poorly understood. Typically, QSOs show a steep power law type spectrum $f_\nu \sim \nu^{-\alpha}$ with $\langle\alpha\rangle = 1.8$ (e.g., Telfer et al. 2002). It is also known from the compilation of QSO UV flux distributions from the HST archive (Telfer et al. 2002) and from the FUSE archive (Scott et al. 2004) that the UV spectral index shows a broad distribution ($0 \leq \alpha \leq 3$). The four luminous QSOs, for which the energy distribution has been observed at intrinsic EUV wavelengths as short as 300 Å, are all individuals, and the spectral distribution of the so-called "big blue bump" cannot be modelled by simple power laws (cf. Fig. 2 in Reimers et al. 1998). Little is known about the intrinsic UV/EUV variability of luminous QSOs. In a systematic study of the UV variability of AGN using the IUE archive, Paltani & Courvoisier (1994) found that most AGN show flux variations whose amplitude increases from rest wavelengths 3200 Å to 1200 Å by roughly a factor of 2. Little is known about simultaneous optical variations of AGN, except in a few cases like 3C 273, NGC 4151, and NGC 5548 (see below). In this paper we report on UV (intrinsic EUV) and optical variability of HS 1700+6416 ($z = 2.72$), one of the most luminous QSOs known and also one of the few known objects where such an empirical study is possible. Discovered by the Hamburg Quasar Survey it was observed in the UV by IUE (Reimers 1989), HST (Reimers et al. 1992), HUT (Davidsen et al. 1996), and FUSE. It was also monitored in the optical in the years 1988−1995 and 1998 by the Hamburg Quasar Monitoring Program (Borgeest & Schramm 1994) and from 1995 on at the Wise observatory (Kaspi et al. 2002). While the variability of HS 1700+6416 was therefore known before, also in the UV (cf. discussion by Köhler et al. 1996), motivation for the present study came from FUSE observations taken in Feb./March 2003 when it was recognized that HS 1700+6416 had brightened by a factor of ~3 since May 2002 at FUSE wavelengths. With EUV rest wavelength observations available now at 9 epochs between 1988 and 2003 and optical R-band CCD photometry (rest wavelength 1900 Å) over several years, we can investigate the relation between the small amplitude (±10%) flux variations in the optical and the large amplitude variations in the intrinsic EUV.

2. Observations

2.1. UV data

We collected all available UV observations of HS 1700+6416 from the IUE and HST archives, most taken by ourselves. In addition, new specific UV observations were made with STIS onboard HST in May 2003 with the aim determining the QSO continuum for interpreting the FUSE intergalactic HeII 304 Å absorption spectrum. These data will be described in detail in a later paper. In Table 1 we present an overview of the UV data collected between 1988 and 2003. Flux distributions are shown in Fig. 1. In order to minimize the noise, QSO mean fluxes were formed over 100 Å intervals.

Table 1. Compilation of UV and X-ray observations of HS 1700+6416.

Satellite/instrument	Date	Flux at 1250 [10^{-15} erg s^{-1} cm^{-2} Å^{-1}]
IUE	1988/7/15	1.6
IUE	1988/11/15 11/17	2.4
HST/FOS	1992/2/17	3.5
HST/GHRS	1994/7/26	1.1
HUT	1995/3/4-10	1.15
HST/GHRS	1996/5/29,28	1.5
HST/STIS	1998/7/23-25*	1.4
HST/STIS	2003/5/14,18	2.1
		Flux
FUSE (1050 Å)	2003/2/27	2×10^{-15} erg s^{-1} cm^{-2} Å^{-1}
RASS	1990/12-1991/1	0.0115 cts/s
ROSAT PSPC	1992/11/13	0.0088
ROSAT PSPC	1993/7/22	0.0158

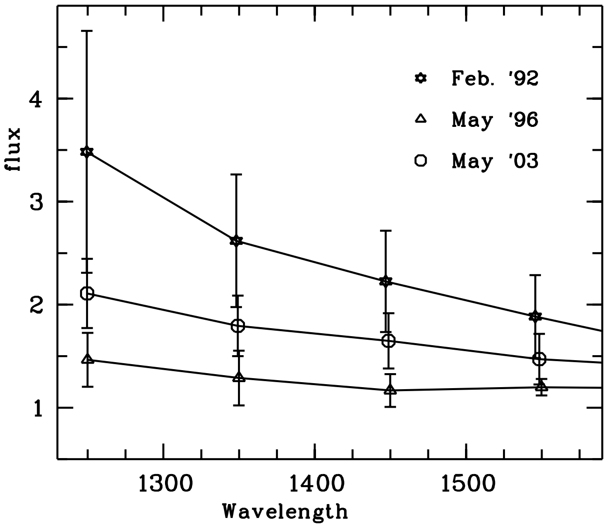

Fig. 1. Ultraviolet energy distribution of HS 1700+6416 [10^{-15} erg s^{-1} cm^{-2} Å^{-1}] for selected epochs (cf. Table 1).

As expected, and briefly discussed already by Köhler et al. (1996), the amplitude of the flux variation increases to shorter wavelengths and reaches a factor of ≥3 at 1250 Å, while at ~1600 Å the factor is less than 2.

2.2. Optical monitoring

HS 1700+6416 was monitored photometrically between the end of 1988 and mid 1995 by the Hamburg Quasar monitoring program (Borgeest & Schramm 1994) in the Johnson R-band using the Calar Alto 1.23 m telescope. All available HS 1700+6416 data from the HQM monitoring program are shown in Fig. 2. HS 1700+6416 varies erratically on time-scales of several months to a few years with a full amplitude of ΔR = 0.2 mag. Variations within a few days appear to be ≤0.02 mag and within a month typically less than 0.05 mag. We mention these maximum amplitudes on short time-scales explicitly, since while our UV data from space and the data from optical CCD photometry are not always strictly simultaneous, we wish to use the closest (in time) optical measurement for a comparison with space data. The typical rise time to maximum brightness (May 90 and Feb. 92) is ~6 months.

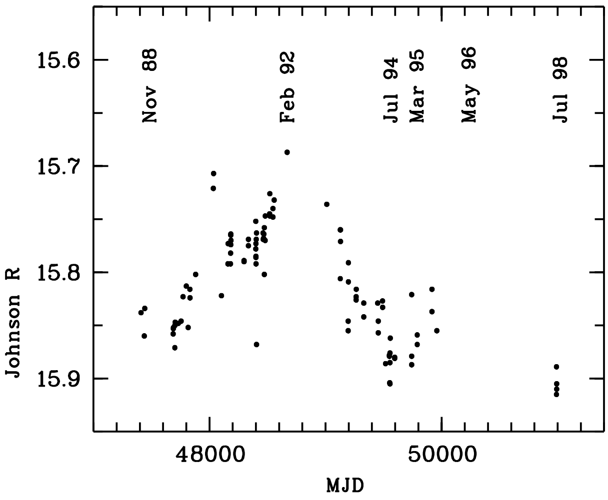

Fig. 2. Light curve of HS 1700+6416 from the Hamburg Quasar monitoring program (Borgeest & Schramm 1994). The dates of (quasi) simultaneous UV observations are indicated.

The optical brightness of HS 1700+6416 for May 2003 was derived from the STIS target acquisition exposures.

2.3. X-ray observations

Does the variability continue to even shorter wavelengths? ROSAT observations of HS 1700+6416 at 3 epochs (RASS, and 2 epochs observed by Reimers et al. 1997) show variations apparently out of phase with the optical data. However, since no strictly simultaneous X-ray and optical observations are available, no safe conclusions are possible, except that HS 1700+6416 varies also in the ROSAT – band by nearly a factor of ~2. The X-ray flux varies on much shorter time-scales. A 16 ks observation with the ROSAT PSPC on Nov. 13, 1992, distributed over ~21 h shows that the flux varied by a factor of ~2 within a day, so that no relation between X-ray and optical / UV fluxes could be established.

3. Interpretation and discussion

The question is whether luminous QSOs behave like Sy1 galaxies in how the amplitude of variability increases towards shorter wavelengths. In Fig. 2 we marked the epochs of UV observations along the R-light curve of HS 1700+6416. While we have barely any strictly simultaneous observations, we notice that when the QSO is bright in R (Feb. 92), it is bright at 1250 Å and vice versa. The close relation between the flux at 1250 Å ($\lambda_{\rm rest} \simeq 335$ Å) and the flux in the Johnson R-band

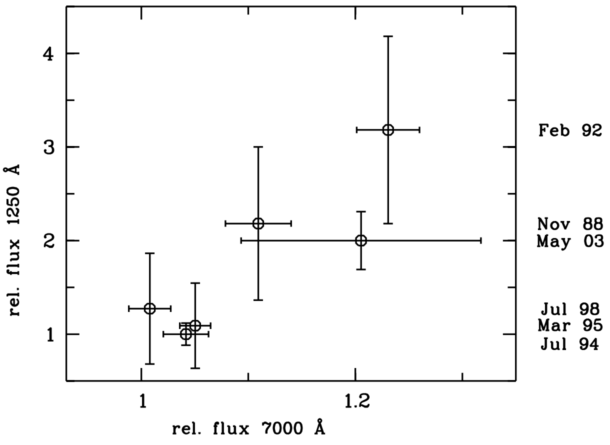

Fig. 3. Flux at 1250 Å (in units of 1.1×10^{-15} erg s^{-1} cm^{-2} Å^{-1}) versus R band flux (in units of 7.5×10^{-16} erg s^{-1} cm^{-2} Å^{-1}).

($\lambda_{\rm rest}$ = 1900 Å) is shown in Fig. 3. Although the optical CCD photometry in R is typically only within a month (except the maximum on Feb. 17, 1992 where we have a simultaneous measurement) the tendency is clear. An amplitude of ~20% at $\lambda_{\rm rest}$ = 1900 Å steepens to an amplitude of a factor of ~1.8 at $\lambda_{\rm rest}$ = 420 Å and a factor of ~3 at $\lambda_{\rm rest}$ = 330 Å. At face value this looks like a continuation of the trend known from Sy1 nuclei (Paltani & Courvoisier 1994) where the amplitude of variations increases by typically a factor of 2 between $\lambda_{\rm rest}$ = 3200 Å and $\lambda_{\rm rest}$ = 1200 Å. A detailed variability study of 25 000 SDSS quasars by Vanden Berk et al. (2004) has also shown that quasars are about twice as variable at 1000 Å as at 6000 Å.

The behaviour of HS 1700+6416 at intrinsic EUV wavelengths is similar to the EUV behaviour of the few Sy 1 AGN observed so far, but it is not as variable at longer wavelengths. In NGC 5548 the amplitude of variations increases from visible wavelengths through the ultraviolet to the extreme ultraviolet. In the visible, variations have an amplitude of ~50% from maximum to minimum, increasing to about a factor of 2 in the far-ultraviolet (Korista et al. 1995), which is much larger than the variability seen in HS 1700+6416 at comparable rest wavelengths. EUVE observations of NGC 5548 at rest wavelengths of ~80 Å also show factor of 2 variations (Marshall et al. 1997; Chiang et al. 2000). The EUV variability of the narrow-line Seyfert 1 galaxy Mrk 478 has a comparably large amplitude (Marshall et al. 1996).

The current view of UV and EUV emission in AGN is that the broad peak of emission in the UV, the "big blue bump", is primarily due to thermal emission from an accretion disk, and that variations are induced by a varying X-ray flux irradiating the disk. Observations showing that flux variations in the Seyfert 1 NGC 7469 show progressively longer lags at longer wavelengths relative to the UV suggest that the disk radiation is due to reprocessed radiation from the inner parts of the disk (Collier et al. 1998; Kriss et al. 2000). Nandra et al. (2000) account for the complicated relationship among the time-variable X-ray, EUV, and UV fluxes from NGC 7469 by describing the thermal disk radiation as a variable seed distribution of soft photons that are Compton scattered to create the X-ray flux. These X-rays are in turn absorbed and reprocessed by the disk to create the observed UV and EUV flux. Since the EUV radiation arises from the exponential Wien tail of the flux radiated by the disk, slight changes in disk temperature can lead to large variations in flux (Marshall et al. 1997). In the context of this picture, we suggest that the lower amplitude of UV and optical variations in a luminous quasar such as HS 1700+6416 is due to its lower X-ray to optical luminosity ratio. It is firmly established that the X-ray to optical luminosity ratio of AGN is anticorrelated with bolometric luminosity (e.g., Kriss & Canizares 1985). Since the X-ray radiation in luminous AGN is energetically less important, we would expect that X-rays illuminating the disks of these objects would play a smaller role in determining the radiative output of the disk.

The strong UV variability of luminous QSOs may also have an impact on both the neighbouring IGM and on the metagalactic EUV background that ionizes H and He II. While for the immediate neighbourhood the influence of the QSO consists of additional ionization of the Lyα forest "clouds" (Bajtlik et al. 1988), this proximity effect has been proven only statistically with large QSO samples, since not each QSO shows the expected effect (Bechthold 1996; Scott et al. 2000). None are shown by HS 1700+6416, one of the most luminous QSOs in the universe where one would expect a strong proximity effect. Among the possible reasons are a finite lifetime of the present QSO phase insufficient to build up an HII region or a particularly dense environment in which the QSO resides. The short term variability that we observed in HS 1700+6416 should have no observable influence.

A further aspect is the recent observation of the HeII 304 Å Lyα forest with FUSE in the lines of sight of HE 2347-4342 (Kriss et al. 2001; Shull et al. 2004) and of HS 1700+6416 (Reimers et al. 2004). The column density ratio N(HeII)/N(HI) = η, which is roughly proportional to the flux ratio $f(911)/f(228)$ of the ionizing background at the corresponding ionization edges, varies between $\eta \approx 1$ and $\eta \approx$ several 10^2 on the scale of 1 Mpc h_{70}^{-1} (Shull et al. 2004). This behaviour is not understood and could be a mixture of radiation transfer effects in the "cosmic web" on the radiation of QSO with a large range of spectral shapes (see above). Another effect would be the finite lifetime of QSOs (with light echos of the width of the lifetime in the surrounding medium) or strong variations of the flux ratios $f(911)/f(228)$ on even shorter timescales. While in HS 1700+6416 we have not directly observed the corresponding wavelengths (3418 Å and 854 Å), we estimate from the present observations that $f(911)/f(228)$ may vary by a factor of 4 in six months. According to the energy distribution corrected for reddening, Lyman limit systems and the cumulative effect of the Lyman α forest shown for the 1994 epoch in Reimers et al. (1998), the effective η caused by HS 1700+6416 varies between 7 (bright phase) and 28 (faint phase). On longer time-scales (10^6 yr) this amplitude could be even higher and might be part of the explanation for small scale variations in the ionizing background. Ionization and recombination times for HeII/HeI are both in the order 10^6 yr. This implies that, while the ionization equilibrium may not be representative of the instantaneous spectrum, short term variations will not lead to deviations from the ionization equilibrium.

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