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THE UNUSUAL ULTRAVIOLET VARIABILITY OF THE QSO 3C 232

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ABSTRACT

After examining ultraviolet *IUE* spectra of 18 QSOs with $z > 0.35$, we find that one object, 3C 232 ($z = 0.533$), stands out as exhibiting highly unusual spectral and continuum variability. The H I–Lyα shows at least 50% variability on a time scale of roughly a month, while the ultraviolet continuum exhibited approximately a factor of 2 decrease in a day. The magnitude of the UV continuum variability is reminiscent of that seen in the optically violent variables at visual wavelengths. Several spectral features at wavelengths shortward of H I–Lyα in the rest frame are identified. A brief discussion comparing the spectrum of 3C 232 with those of other QSOs in our *IUE* sample at wavelengths shortward of 1216 Å is also presented.

Subject headings: quasars — ultraviolet: spectra

I. INTRODUCTION

In a survey of archival data obtained by the *International Ultraviolet Explorer* (*IUE*) of QSOs, representing over 45 spectra, with redshift $z > 0.35$, we find that one QSO, 3C 232, exhibits both dramatic continuum and spectral variability unlike that seen in any other object in our sample. (The results of our survey will appear elsewhere.) In this *Letter* we will describe the unusual ultraviolet variability of 3C 232. Also, we will briefly discuss how 3C 232 compares with other QSOs based upon preliminary results of our survey of spectral features shortward of H I–Lyα (1216 Å).

II. DATA

The data for 3C 232 were all acquired using the *IUE* at low dispersion (~ 7 Å resolution) using the large 10″ × 22″ aperture. The *IUE* data are briefly summarized in Table 1, where the image number, date of observation, and total exposure time, as well as relevant comments are presented. In all, six *IUE* images (four SWP and two LWR) were included in our analysis of 3C 232. The QSO 3C 232 was observed on two other occasions, resulting in the images SWP 5144 and LWR 6242, which were not included. One of these images, SWP 5144, was an extremely short exposure, only 20 minutes, while data for the other image, LWR 6242, could not be easily obtained. Unlike LWR 2752 and 4680, LWR 6242 was not acquired near the time of a SWP image and could not provide information on short time variability of 3C 232.

The spectra of all six images were reextracted from the spatially resolved (line-by-line) data files which are supplied by the *IUE Observatory*. Corrections were made to ensure that the proper Intensity Transfer Function was used on all the data. We carefully examined each line-by-line file, as well as the photowrites, to remove charged-particle "hits" or other blemishes. Often, weak radiation hits fell on the spectrum of the quasar and were not evident as radiation hits from the inspection of the photowrites. These hits could be erroneously interpreted as real features, but they would not coincide with the emission peak of the H I–Lyα and continuum of the quasar perpendicular to the spectral dispersion in the line-by-line data. In such events, these features were labeled as hits and did not contribute to the final reextracted *IUE* spectrum. All of the remaining reextraction, with the exception of flagging bad data, was accomplished using the standard parameters used by the *IUE Observatory*. Although no perceptible differences were seen in the general net flux levels, the apparent signal-to-noise levels were noticeably improved in many cases.

a) The Observed Spectral Features

Usually, *IUE* observations of quasars require long exposure times and the resulting images often yield low signal-to-noise ratios and exhibit many charged-particle "hits". The data for 3C 232 are typical of the *IUE* data composing our survey. Extreme care must be taken to ensure proper analysis of such data.

Aware of these problems, we developed a set of guidelines in identifying spectral emission features in quasars, and in 3C 232. These guidelines consist of the following:

1. Identification of features was only attempted in the reextracted *IUE* spectra.

2. Any identified features had to be common in other quasar spectra of our survey.

[1]Guest Investigators with the *International Ultraviolet Explorer*.

TABLE 1

IUE DATA FOR 3C 232

IUE Image Number	Observation date (yr/day)	Exposure (minutes)	Comments
SWP 3173	1978/300	420	Several pronounced emission lines
LWR 2752	1978/302	435	
SWP 5169	1978/128	865	H I–Lyα is very strong
SWP 5435	1979/153	180	See Fig. 2
LWR 4680	1979/154	230	See Fig. 2
SWP 8825	1980/116	369	

3. Finally, we insisted that all identifications be physically reasonable.

In Table 2, we list the spectral features which we have identified in 3C 232. (See also Fig. 1.) These features do not necessarily appear in all the *IUE* images and strongly suggest variability.

Although Dultzin-Hacyan, Salas, and Daltabuit (1982) have previously analyzed two images of 3C 232 (SWP 3173 and LWR 2752), we drew different conclusions about some of the features identified in these images. Dultzin-Hacyan *et al.* identified a feature as H I–Lyγ at 971 Å; we find it instead is due to a charged-particle event, producing a so-called comet, which runs across the camera face and intersects the spectrum. We note that they also identified the Lyman series through Lyδ at 939 Å in SWP 3173. We only find H I–Lyα and possibly Lyβ, which, if present, is blended with the O VI doublet (1032, 1038 Å) and possibly C II (1036, 1037 Å). Although we do not attempt to identify any feature at 940 Å, a feature at 940 Å is quite common in quasars in our data sample. A more likely identification in these instances is S VI, rather than H I–Lyδ.

Certainly, examination of other quasars in our sample indicates that a feature near 1032 Å in the rest frame is extremely common in quasars (also see Green *et al.* 1981). The wavelength centroids of the observed emission in our quasar sample suggest that H I–Lyβ generally provides, at most, a minor contribution to the 1032 Å feature. Also, the strength of this feature, when observed, correlates well with that of the N V resonance doublet (1238, 1242 Å), which appears on the longward wing of H I–Lyα. We do note that in 3C 232 the 1032 Å feature only appears in SWP 3173 where N V is the strongest. The UV continuum in this image is the lowest of the four SWP exposures, which may have increased the contrast of the emission features relative to the continuum.

We find C II 902 Å to be another quite common feature in the QSOs of our *IUE* data sample, and its presence should also imply that resonance transitions of C II at 1335 Å are strong. Dultzin-Hacyan *et al.* also identify C II 902 and 1335 Å in images SWP 3173 and LWR 2752, respectively, while Lynds and Wills (1968) find emission due to redshifted C II] 2325 Å at optical wavelengths. However, our more conservative line identification criteria, and the spectral variability of 3C 232, does not allow us at present to make any further deductions about the presence of C II 1335 Å which lies in the insensitive region of the images acquired with the LWR camera.

Other lines are also present in 3C 232 which may or may not exhibit variability. Of particular interest is the feature at 834 Å, which is below the Lyman limit and can be seen, although not prominently, in all four available *IUE* spectra of 3C 232 (see Fig. 1). The position of this feature corresponds to 1280 Å in the observed frame, coinciding with an artifact feature sometimes seen in SWP images (Hackney, Hackney, and Kondo 1982). However, in most QSO spectra of our sample, where this wavelength region is accessible and where this feature corresponds to a different redshift, the 834 Å feature is seen. It is identified as O II with possibly some contribution from O III (see Table 2). Results indicate that charge transfer should be extremely important in producing the observed emission at nebular conditions like that implied for QSOs (Butler, Heil, and Dalgarno 1980).

The charge transfer reaction O III + H I → O II + H II (Butler, Heil, and Dalgarno 1980) is very strong, with a rate 10^{-9} cm^3 s^{-1}. This reaction highly populates the $2s2p^4$ (^4P)

TABLE 2

SPECTRAL FEATURES IN 3C 232

Ions	Laboratory Wavelengths (Å)	F_{obs}[a] (10^{-14} ergs cm^{-2} s^{-1})	Central Rest Wavelengths (Å)	Comments
O II	832.8, 833.3, 834.5	4 ± 3	834	Most likely O II due to charge transfer
O III	832.9, 833.7, 835, 835.3			
C II	903.6, 903.9, 904.1, 904.5	12 ± 3	904	
O VI	1031.9, 1037.6	18 ± 6	1034	Negligible contribution from H I–Lyα
C II	1036.3, 1037			
?...........	?	8 ± 4	1147	Feature exists in many quasar spectra
H I	1215.7	44 ± 10	1216	
N V	1238.8, 1242.8	20 ± 8	1240	
Si III][b]	1892	10 ± 3	1909	Mostly C III]?
C III][b]	1909			
Mg II[b]	2795, 2802		2800	Absorption from the Galactic halo?

[a] The observed line fluxes (F_{obs}) are measured from images SWP 3173 and LWR 2752. The error estimates for the observed fluxes only reflect the contrast to the apparent noise in the reextracted spectra. They do not take into account any unrecognized radiation hits, camera artifacts, background irregularities, and other unidentified systematic effects. The C IV 1549 Å feature falls in the insensitive region of the LWR camera and is not detected.

[b] Seen in LWR 2752 and LWR 4680.

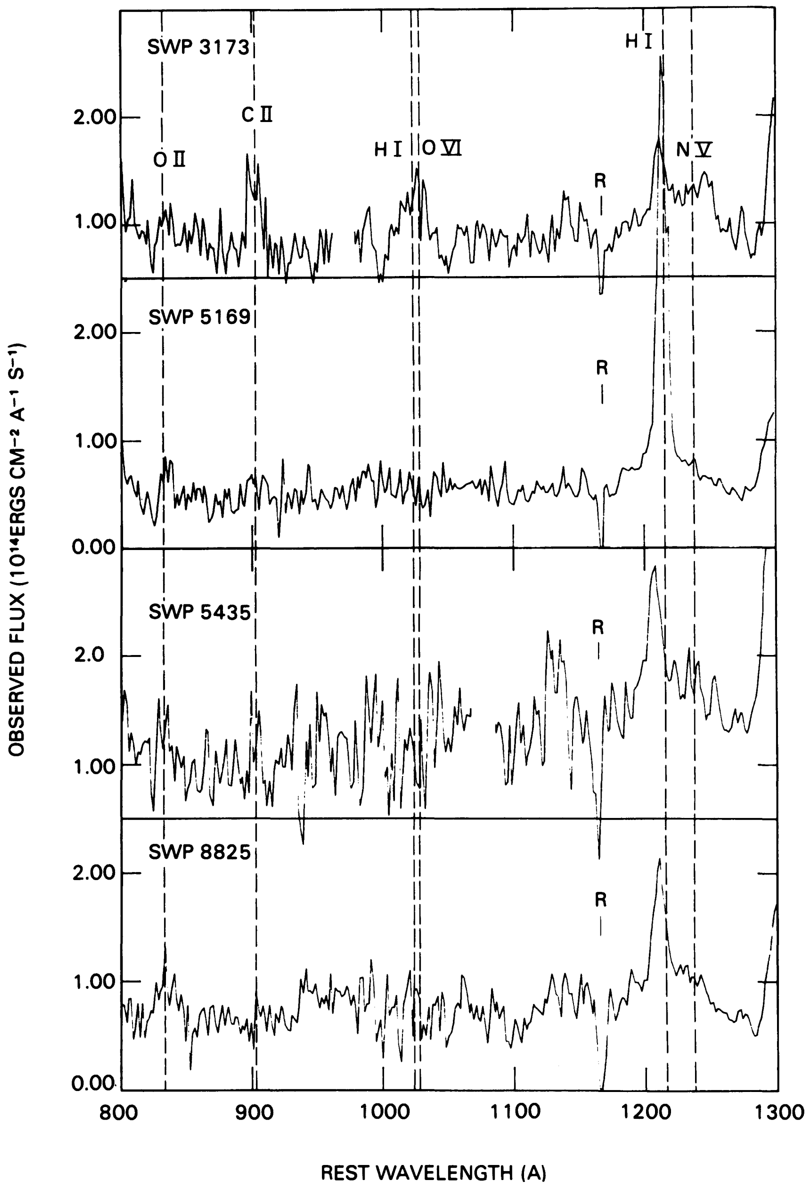

FIG. 1.—Four reextracted *IUE* spectra of 3C 232 acquired with the Short Wavelength Prime (SWP) camera. The wavelength scale is that of the rest frame of the QSO, assuming a $z = 0.533$. The vertical lines denote laboratory wavelengths of ionic transitions indicated in the top panel. The *IUE* image numbers are given in the upper left in each panel. The spectral features, most notably that of H I–Lyα, may not be perfectly aligned since the quasar may not necessarily be centered on the dispersion axis of the large aperture. Wavelength shifts as large as 4–5 Å might be expected. The peak intensity of H I–Lyα in SWP 5169 is somewhat uncertain since the pixels near the peak flux of this feature are affected by saturation.

level, resulting in strong emission in the UV1 multiplet of O II.

On the other hand, charge transfer of O IV + H I → O III + H II would result in the population of the $2p3p\ ^1P$ level and many emission lines, none being from the UV1 multiplet of O III 833–835 Å (Dalgarno and Sternberg 1982). Thus, if charge transfer is the dominant means of producing the observed 834 Å feature, then it must be predominantly due to O II. The strength of this feature would be linked directly to the abundance of H I and, as such, might prove a useful diagnostic of neutral hydrogen in quasar spectra. This is because radiative recombination of O III would proceed at a rate ~ 10^{-12} cm^3 s^{-1} and as long as the neutral fraction of hydrogen n(H I)/n(H II) > 10^{-3}, charge transfer of O III with H I would proceed faster than radiative recombination. Power-law ionizing flux in a QSO would result in a neutral fraction l > 10^{-3} throughout the ionized region (Davidson 1972). Our conclusions concerning the 834 Å feature in the spectrum of 3C 232 is the first direct evidence that charge transfer population of the O II levels is important in QSOs.

Other features might be present in the spectrum of 3C 232. Specifically, we see what appears to be an emission complex near 1147 Å. This complex seems to be present in three of the four SWP spectra and is also seen in most of the QSO spectra that we have examined from our sample. At present, we have been unable to identify this feature, but the only reasonable identification that we can make is the UV2 multiplet of N I near 1135 Å. Although this multiplet may be present in QSO spectra, the wavelengths of these transitions seem too far from that of the observed feature at 1147 Å.

We also attempted to identify features seen in the LWR camera. The only ones that we could identify with some degree of confidence were C III] 1909 Å emission of 3C 232 and resonance absorption of Mg II, which appears at 2800 Å in the observed frame. This we attribute to interstellar absorption arising in the galactic halo (see Table 2).

Although the *IUE* data presented here are of limited signal-to-noise ratio, Figure 1 illustrates that spectral line variability is quite pronounced in 3C 232. The most dramatic example is seen for H I–Lyα. Even though Lyα is saturated in SWP 5169, comparisons with the other images obviously show that this feature was much stronger at this time than during the other three exposures of 3C 232.

Even though the pixels of the peak of the H I–Lyα profile in SWP 5169 are saturated, the line-by-line data files in which the data sampling this feature are not saturated clearly indicate that Lyα is exceedingly strong. Comparisons with similar data for SWP 5435 show that the Lyα fluxes are at least 50% higher in SWP 5169 than in SWP 5435 acquired 25 days later.

b) *Short-Term Continuum Variability*

Much tighter constraints can be placed upon continuum variation. For example, two of the SWP exposures 3173 and 5169 were followed by LWR exposures LWR 2752 and 4680, respectively, within 2 days. The continuum flux levels derived from the images SWP 3173 and LWR 2752 as discussed by Dultzin *et al.* indicate that a single continuous power law with no breaks can fit the flux data, $F(\nu)$, in both cameras. This is also reflected in our reextracted data seen in Figure 2. On the other hand, the reextracted data for SWP 5435 and LWR 4680 cannot be fitted with a single continuous power law. The data in Figure 2 indicate that the continuum flux level around Lyα dropped by a factor of 2 within a 24 hr period. Not only does one see decidedly different flux levels in the two spectra, but the spectral index of LWR 4680 is less steep than in the shorter wavelength data obtained 1 day earlier. However, a

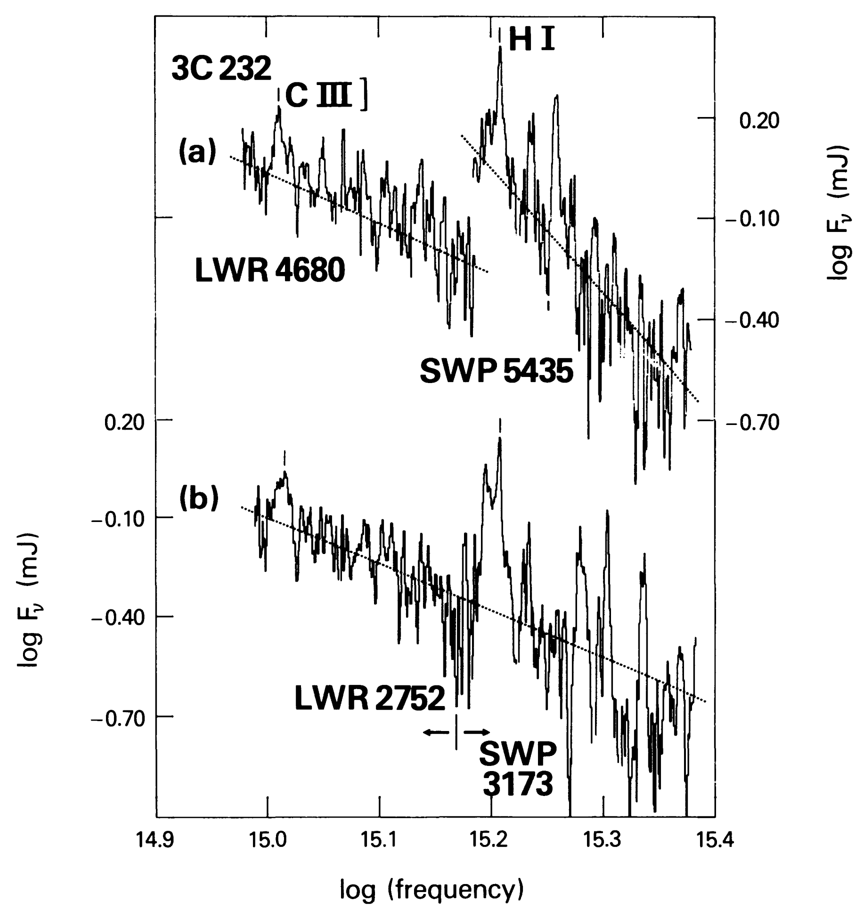

FIG. 2.—Flux distributions for 3C 232. The images SWP 3173 and LWR 2752 were acquired on days 300 and 302 in 1978, while SWP 5435 and LWR 4680 were obtained on days 153 and 154 in 1979. Approximate power-law fits were made to the data sets from both *IUE* cameras. These fits are represented by dotted lines. The features C III] 1909 Å and H I–Lyα are also denoted. These data clearly indicate that the flux near H I–Lyα has decreased by a factor of 2 between the acquisition of SWP 5435 and LWR 4680, roughly 24 hr later. The data for image LWR 4680 also show a much shallower power-law slope than do those for SWP 5435. The data for SWP 3173 and LWR 2752 show no hint of flux variation between the two exposures. The false "comet" feature corresponding to 940 Å in SWP 3173 (See Fig. 1 and text) has not been removed.

significant fraction of the quasars in our survey sample shows what appears to be a curvature or change of slope at wavelengths shortward of Lyα. (Also see Green *et al.* 1980.)

We examined the possibility that extreme overexposure of the SWP camera prior to SWP 5169 may have left a slowly decaying residual phosphorescent spectrum. If there had been such an exposure, it would have resulted in SWP derived fluxes that would be too high. Perusal of the *IUE* logbook did not reveal any extreme overexposure prior to SWP 5169 that would have affected the derived flux levels in that *IUE* image.

We have further examined the agreement of the fluxes derived from other QSOs in our sample where both SWP and LWR exposures were made within a couple of days of each other. Several of these sources had comparable total flux levels and exposure times to those of SWP 5485 and LWR 4860. We found no serious discontinuities like that exhibited in 3C 232 (Fig. 2). Agreement in these cases was within 20% and it usually was not as good at much longer timescales, presumably a result of longer time scale variability.

III. DISCUSSION AND CONCLUSIONS

To the authors' knowledge, the dramatic UV continuum and spectral line variability seen in 3C 232 has no other known analogs in the UV. This variability might imply that this object is similar to the optically violent variables (OVV) identified at optical wavelengths. The increase of 0.8 mag in 24 hr seen in 3C 232 is large, similar to changes that have been seen in OVVs (Penston and Cannon 1970; McGimsey *et al.* 1975). Rapid changes of 0.3 mag hr^{-1} have been photoelectrically recorded by Angione (1971) for 3C 354.3, and analysis of Harvard plate material (Angione 1973) recorded changes of 0.9 mag per day for 3C 351.

Moore and Stockman (1981) find a high correlation between high optical polarization and dramatic QSO photometric variability. However, there are many exceptions to this correlation. In this regard, the results of Stockman, Moore, and Angel (1983) show 3C 232 to be a low-polarization quasar. Even though 3C 232 is a fairly strong radio source and has a flat spectrum (Miley 1971; Potasch and Wardle 1979; Pilkington and Scott 1965) which suggest properties similar to OVV quasars, it lacks high polarization, uncharacteristic of OVV quasars.

Yet, a spectroscopic study at visual wavelengths by Lynds and Wills (1968) revealed 3C 232 to possess a very unusual spectrum compared with the other five QSOs studied. They found that features due to [Mg v] at 2786 and 2931 Å were unusually strong relative to other observed lines.

In any event, we find no basis to question the observed spectral and rapid continuum variability seen in 3C 232. Further observations, especially those obtained simultaneously at multiple bandpasses, should provide important clues to the nature of 3C 232 and active galactic nuclei.

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