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WZ SAGITTAE: *FUSE* SPECTROSCOPY OF THE 2001 OUTBURST[1]

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ABSTRACT

The short-period cataclysmic variable WZ Sge underwent its first dwarf nova outburst in 23 years in 2001 July. Here we describe 905–1187 Å spectra obtained with the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) during the outburst and within the first few months after the outburst. The first spectrum, obtained about 7 days after the outburst began and 6.4 days past optical maximum, is dominated by a broad (50–60 Å equivalent width) feature due to O VI and can be characterized in terms of emission from a highly inclined disk modulated by the effects of a highly ionized wind. WZ Sge is fainter in later observations (starting about 45 days after optical maximum) and increasingly "red" in the far ultraviolet. The spectral shape increasingly resembles that expected from a metal-enriched white dwarf photosphere, although it seems likely that some disk contribution remains at least through the second *FUSE* observation, when the visible light curve showed the system to be undergoing a rebrightening event. The absorption lines observed on September 29 and in early November, when the visible light curve was in a fairly steady decline toward quiescence, are narrow, with widths (FWHM) of the order of 0.7–1.3 Å (200–400 km s^{-1}). The most natural explanation for these spectra is that the continuum arises from a relatively massive, slowly rotating white dwarf and that the lines are created by a combination of metals in the atmosphere and absorbing material along the line of sight to the white dwarf. If the white dwarf has $\log g = 8.5$, then the white dwarf cooled from ~25,000 K on September 29 to 23,000 K in early November.

Subject headings: accretion, accretion disks — binaries: close — novae, cataclysmic variables — stars: individual (WZ Sagittae) — stars: mass loss

1. INTRODUCTION

Cataclysmic variables (CVs) are mass-exchanging binary star systems containing a white dwarf (WD) and a relatively normal main-sequence companion. Dwarf novae are a class of CVs that exhibit outbursts lasting from a day to a few weeks, depending on the system. Usually, outburst amplitudes are 3–5 mag above quiescence, and times between outbursts range from a few weeks to a few months. The outbursts arise from a large increase in the effective temperature and optical depth of the disk that mediates the mass transfer from the normal star to the WD. All CVs, including dwarf novae, are thought to have evolved from more widely separated binaries that have passed through a common envelope phase and are thought, as a result of angular momentum loss, to evolve toward periods of about 80 minutes on gigayear timescales (Rappaport, Joss, & Webbink 1982).

Population synthesis calculations suggest that most of the CVs in the Galaxy should be at or near the period minimum. But the mass transfer rate of systems near the minimum is low. Systems near the period minimum are therefore expected to be faint in quiescence, to have larger than normal outburst amplitudes, and to have exceptionally long intervals between outbursts. As a result, detected systems near the period minimum are rare.

With a parallax-determined distance of $44^{+6.5}_{-5}$ pc (J. R. Thorstensen 2001, private communication) and an orbital period of 82 minutes, WZ Sge is the closest and best-studied example of a CV near the period minimum. The system is viewed at a relatively high inclination angle (~75°; Smak 1993); the secondary eclipses the bright spot and the outer portion of the disk, but not the WD. Prior to 2001 July, it had been observed to go into outburst only three times, once in 1913, once in 1946, and most recently in 1978. During the last outburst it was observed extensively with *IUE* (Fabian et al. 1980; Friedjung 1981; Naylor 1989). The spectra at the peak of the outburst resembled those of other outbursting systems; the spectral slope was consistent with that expected from a steady state accretion disk in outburst. After outburst, the system was not observed for about 180 days, but when observations recommenced, the spectrum had evolved into something that resembled a WD cooling from 20,500 to 15,400 K with an *e*-folding timescale of about 690 days (Slevinsky et al. 1999). WZ Sge was observed by Sion et al. (1995) with the *Hubble Space Telescope* (*HST*) in 1992. Using the data obtained, Cheng et al. (1997) estimated a temperature of 14,800 K. They also found that the WD was

[1] Based on observations made with the NASA-CNES-CSA *Far Ultraviolet Spectroscopic Explorer*. *FUSE* is operated for NASA by the Johns Hopkins University under NASA contract NAS5-32985.

rotating with $v \sin(i)$ of 1200^{+300}_{-400} km s^{-1} and that rapid rotation was coupled with abundances (most notably supersolar C) unlike those observed in any other WD in a dwarf nova system. In addition, Welsh et al. (1997) found pulsations in the UV light curve in high time resolution Faint Object Spectrograph data with a period of 28 s, in the range in which periodicities have also been observed at optical and X-ray wavelengths (Patterson et al. 1998).[2] The fact that the oscillations are not always present and are unstable in period has led to a lively debate as to whether WZ Sge is (Patterson et al. 1998) or is not (Skidmore et al. 1999) a DQ Her star, a class of CVs whose magnetic field channels material from the accretion disk onto selected regions of the WD surface.

The CV WZ Sge began a dwarf nova outburst on 2001 July 23, about 10 years earlier than predicted based on the frequency of the previously known outbursts of the system. Extensive ground- and space-based efforts were mounted in an attempt to better understand WZ Sge. These included a series of observations with the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*), which provided high-resolution ($R \sim 12,000$) spectra in the wavelength range 905–1187 Å. Here we present an initial description of those observations and an analysis of the emergence of the WD in the post-outburst spectra. A detailed discussion of the outburst spectrum will be reported elsewhere.

2. OBSERVATIONS AND QUALITATIVE DESCRIPTION OF THE DATA

The *FUSE* satellite was launched into low Earth orbit in 1999 June (Moos et al. 2000). The *FUSE* optical system consists of four optical telescopes that feed four Rowland spectrographs producing four independent spectra on two photon-counting area detectors. The optics for two of the four channels are coated with SiC optimized for shorter (905–1105 Å) wavelengths and two with Al:LiF for longer (~1000–1187 Å) wavelengths. The observatory and its operations and performance have been described in detail by Sahnow et al. (2000).

Following the announcement that an outburst of WZ Sge was underway and the approval of Director's Discretionary Time to observe WZ Sge, the *FUSE* operations staff carried out four observations of WZ Sge. VSNET and AAVSO light curves of the outburst indicate that outburst maximum occurred near 0 hr UT July 24 (JD 2,452,114.5). As shown in Figure 1, the optical outburst can be characterized by a main outburst lasting 24 days until August 16 (JD 2,452,138), a series of decline and rebrightening phases lasting until mid-September, and then a rather steady decline toward quiescence. As was typical of earlier outbursts, WZ Sge reached a peak apparent magnitude of 8.2, more than 7 mag above its quiescent brightness of 15.5 (see, e.g., Patterson et al. 2002 for a detailed discussion of the optical light curve). The first *FUSE* observations occurred about 6.4 days after outburst maximum. The second observation occurred during the decline from one of the "echo" outbursts, while the last two appear to be part of the steady decline. The November observation, which was spaced out over 5 days, was the last observation that could be scheduled until late in 2002 because of spacecraft design and operational constraints. A journal of the observations that occurred is shown in Table 1. Total exposure times varied from 3180 s in the first observation to 15,183 s in the last observation, roughly matching the decline in flux during this period.

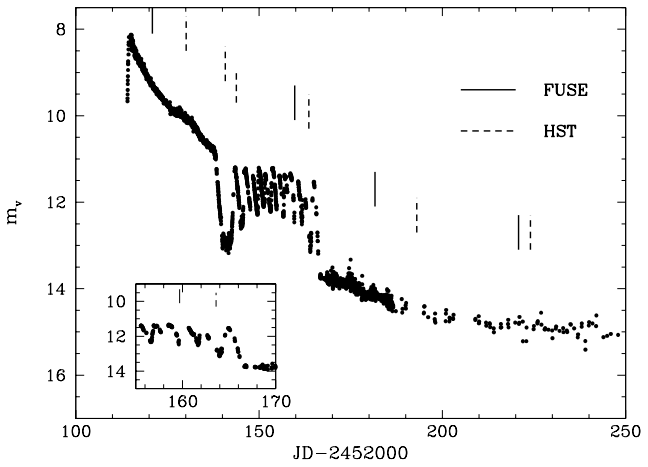


FIG. 1.—VSNET measurements of the optical light curve of the 2001 outburst of WZ Sge, as compiled by R. Ishioka et al. (2003, in preparation), with times of the *FUSE* (and the *HST*) observations indicated. An expanded view of the observations that took place when rebrightenings were occurring is shown in the inset to the figure.

All of the observations were obtained using the LWRS ($30'' \times 30''$) aperture, which is least prone to slit losses due to misalignments of the four *FUSE* telescopes. Because of limitations in onboard data storage, the first two observations were obtained in histogram mode, in which spectral images are accumulated over a period of time and transmitted to the ground. A total of eight spectra with individual exposure times ranging from 392 to 403 s were obtained on July 30. For the September 7 observation, there were 16 spectra, and exposure times ranged from 460 to 593 s. However, the September 7 observation was marred by the temporary high-voltage shutdown of detector 1 because of a single bit upset event after the first four spectra were obtained, thereby eliminating half of the spectral channels and complicating somewhat the analysis of the second observation, as described below. Predicted count rates for WZ Sge were low enough in the September 29 and November observations to permit use of the high time resolution mode, in which each event time and position on the detector is recorded. There were no anomalies in either of these observations.

An overview of the time-averaged spectra obtained in each of the observations is shown in Figure 2. All of the data shown here were reprocessed using version 2.0.5 of the *FUSE* calibration pipeline; for faint sources, the flux calibration in this version of the pipeline is significantly better than that used to produce the calibrated spectra in the archive at the time of the observations. As noted above, *FUSE* has four spectroscopic apertures. During our observations, fine error sensor A, which images the LiF 1 aperture, was used to guide the telescope. It is possible because of thermal drifts between the channels for the source to drift partly or completely out of nonguiding channels.

[2] The *HST* observations of the 2001 outburst have revealed large (5%) amplitude oscillations at UV wavelengths within a month of outburst maximum (Knigge et al. 2002). This was the first time that periodicities near 15 s have been seen to be the dominant oscillation.

TABLE 1
Observation Summary

Observation	Date (2001)	Start (UT)	End (UT)	$\delta T_{\rm outburst}$[a] (days)	Start Phase[b] (cycles)	End Phase (cycles)	$T_{\rm obs}$ (s)
1.....	Jul 30	09:36:56	11:50:58	6.4	0.58	2.22	3180
2.....	Sep 7	04:42:43	11:53:02	45.3	0.94	6.21	8273
3.....	Sep 29	02:50:17	08:28:27	67.2	0.63	4.77	9319
4a.....	Nov 3	05:38:59	09:14:51	102.3	0.07	2.71	2857
4b.....	Nov 5	14:10:09	17:49:56	104.7	0.61	2.30	2857
4c.....	Nov 7	07:47:51	14:47:34	106.5	0.20	5.34	6222
4d.....	Nov 8	08:46:10	12:26:30	107.4	0.55	3.25	3877

[a] Time from outburst maximum at midpoint of observation.
[b] The orbital phases of the observations were calculated using the photometric ephemeris of Patterson et al. 1998. We applied a phase shift of −0.046 cycles to correct orbital phase zero from the photometric primary mideclipse to inferior conjunction of the secondary star (Steeghs et al. 2001).

Fortunately, the spectral regions covered by the spectral channels overlap, and therefore one can compensate for this problem. Basically, we eliminated spectra from completely misaligned channels and used the overlap regions to renormalize the remaining spectra in the SiC 1, LiF 2, and SiC 2 channels to the flux in the LiF 1 channel. To produce a final spectrum covering the full *FUSE* wavelength range, we masked low-sensitivity portions of each channel (including the so-called worm that complicates LiF 1 longward of 1134 Å) and combined the rescaled spectra. When we combined, we weighted according to the area and exposure time for that channel and then rebinned onto a common wavelength scale with, in this case, 0.1 Å resolution.

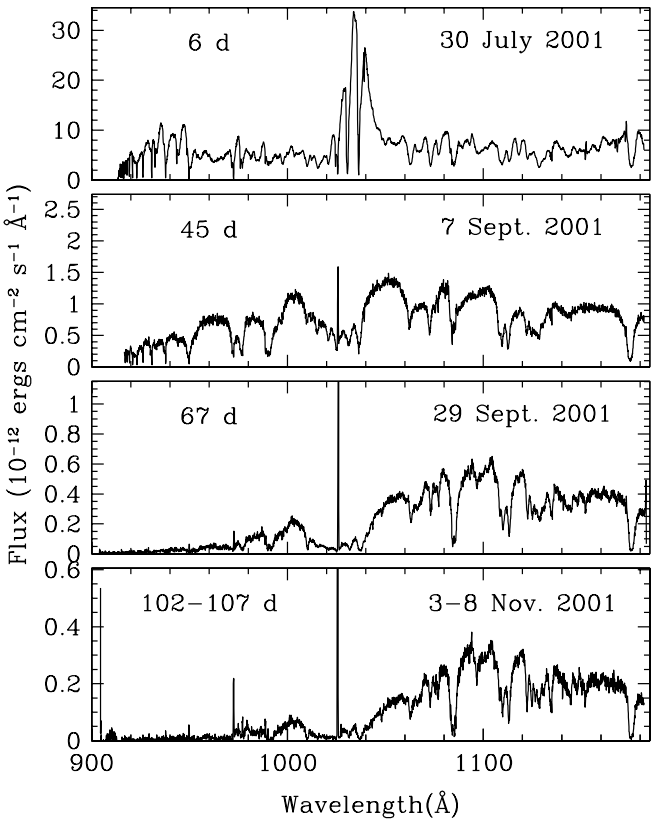


Fig. 2.—Spectra of WZ Sge as observed with *FUSE* in the summer and fall of 2001. Times past optical maximum and dates of the observations are indicated. The July 30 spectrum is scaled so that the O VI line is fully visible. The remaining spectra are scaled so that the region between 1150 and 1170 Å occupies the same portion of the plot. The very sharp emission lines seen, particularly in the November observations, are all geocoronal.

As is evident from Figure 2, there was a major evolution in both the far-UV (FUV) flux and the spectral shape of WZ Sge during the course of the four observations. The flux at 1150 Å declined from 6×10^{-12} to 9×10^{-13} to 4×10^{-13} to 2×10^{-13} ergs cm^{-2} s^{-1} Å^{-1} on July 30, September 7, September 29, and early November, respectively. The flux drop was greatest at the shortest wavelengths; on July 30 the flux at the Lyman limit was comparable to the flux at 1150 Å, but by November there was no detectable emission at the Lyman limit.

WZ Sge was observed with *HST* on August 8 (Kuulkers et al. 2002), and the flux observed with *HST* was similar to that observed with *FUSE* on July 30 in the wavelength ranges in which the spectra overlap. The flux observed on July 30 with *FUSE* was somewhat larger than the $(1–2) \times 10^{-12}$ ergs cm^{-2} s^{-1} Å^{-1} reported by Fabian et al. (1980) for the 1978 outburst using *IUE*, but the first *IUE* observation was about 15 days after optical maximum. The flux in November was comparable to that reported by Slevinsky et al. (1999) in the first postoutburst observation from the 1978 outburst, even though that observation occurred 222 days after outburst onset, while the *FUSE* observation occurred about 105 days after outburst onset.

2.1. *July 30: WZ Sge in Outburst*

The first spectrum of WZ Sge is dominated by prominent O VI emission. The entire spectrum, as shown in Figure 3, is complex. Many of the features can be identified with transitions of C III, Si III, S III, S IV, or the Lyman lines of hydrogen. Most are absorption features, although some, such as S VI, the Lyman lines of hydrogen, and C III λ1178, have associated emission wings.

Although the exact placement of the continuum is difficult to establish as a result of the complexity of the spectrum, the equivalent width (EW) of O VI is of the order of 50 Å, and the FWZI appears to be at least 30 Å, indicating a velocity spread of the order of 4000 km s^{-1}. The Lyγ profile in the first spectrum shows evidence of a red emission wing (see Fig. 3), and therefore it is possible that there is some admixture of Lyβ in what must be a predominately O VI profile. The emission feature is punctuated by several relatively narrow absorption features, or self-reversals, with cores located at 1024.6, 1025.6, 1030.6, 1036.3, and 1039.2

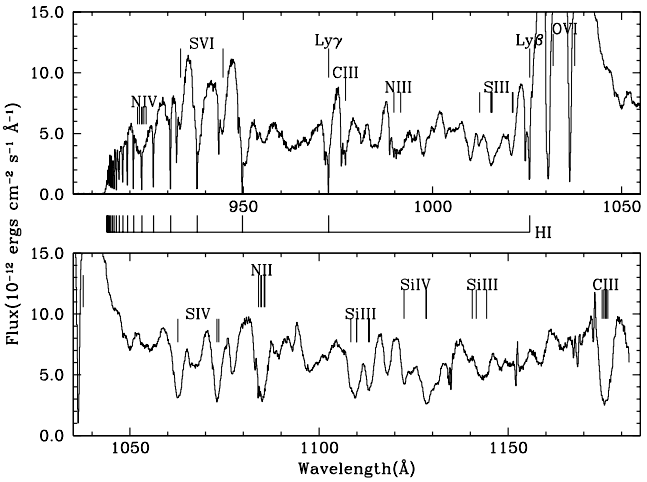


FIG. 3.—Expanded view, with lines identified, of the first *FUSE* spectrum of WZ Sge obtained on July 30, about 6.3 days after optical maximum.

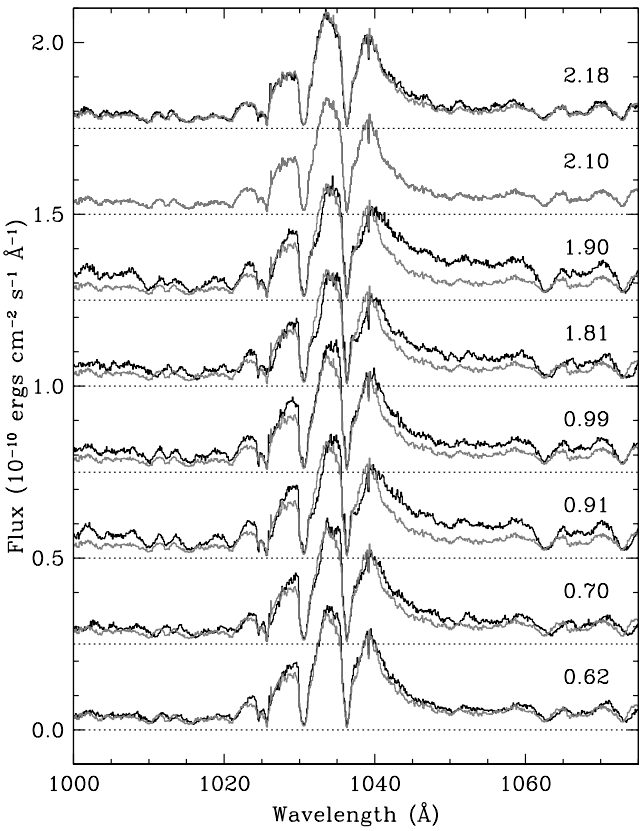


FIG. 4.—Individual LiF 1 spectra of the O VI line region as observed on July 30 in time order from bottom to top. The orbital phase associated with each spectrum is also shown. The fainter line superposed on each of the spectra is the spectrum obtained at phase 0.10 (=2.10), when the flux was least.

Å. The features at 1030.6 and 1036.3 are clearly due to O VI, blueshifted by 1.33 Å or -380 km s^{-1}. Since the γ-velocity of the system is -72 km s^{-1} (Steeghs et al. 2001), the narrow O VI features suggest material flowing out of the system toward the observer. Simple Gaussian fits to the two O VI absorption features indicate an EW (relative to the emission line) of about 1.9 Å for both features and a FWHM of about 2 Å; however, both of the lines are somewhat asymmetric in shape. The two features near 1025 Å are presumably both due to Lyβ, the longer feature being near the rest wavelength of 1025.72 Å for Lyβ, while the other is blueshifted by a similar amount to O VI. The feature is not due to He II λ1025.27, which is separated by 0.54 Å from Lyβ. A similar structure is seen in the Lyγ profile. The feature at 1039.2 Å is due to interstellar O I.

If the continuum flux level is about 5×10^{-12} ergs cm^{-2} s^{-1} Å^{-1} in the wavelength range 950–1020 Å, then there is a clear excess of emission between 925 and 950 Å. Similar excesses are observed in UX UMa (Froning, Long, & Knigge 2003) and in the quiescent or near-quiescent spectra of SS Cyg (K. S. Long et al. 2003, in preparation). The narrow absorption features in the spectrum in this region are mainly due to (interstellar) H I. Many of the narrow features have associated broader features, suggesting that H and (perhaps) He II emission are heavily involved in the overall shape of the spectrum. The two prominent peaks at 935 and 946 Å are likely to be the P Cygni emission profiles of S VI $\lambda\lambda$933, 945. The N IV λ923 multiplet, the same multiplet that appears in C III at 1175 Å, is clearly present in the outburst spectrum. There is no emission shortward of the Lyman limit.

There are variations in the *FUSE* outburst spectra on orbital timescales. This is indicated in Figure 4, which shows each of the eight LiF 1 spectra of the O VI line region. The overall flux in this region (and in the rest of the spectrum) is least during the observation obtained at phase 0.10. To illustrate the differences in the spectra, we have faintly superposed the histogram obtained at phase 0.10 over all of the other spectra. It is apparent from this comparison that the main variation is in the continuum. The peak of the O VI line is relatively constant, as are the flux levels in the centers of the line cores, especially those of Si IV $\lambda\lambda$933, 945. Given that the largest fluxes occur near orbital phase 0.90, it is tempting to associate the changing flux with an orbital hump. This suggestion has to be tempered, however, with the realization that the number of spectra is quite small, particularly near orbital phase 0, and therefore one cannot rule out the possibility that we are seeing secular variations. There are also some variations in the line profiles of O VI; in particular, in those periods in which the continuum flux is high, there is a "notch" on the red side of the O VI absorption profiles that is stronger in some spectra than in others.

2.2. *September 7: The Spectrum in the Rebrightening Phase*

The character of the spectrum changes considerably by the time of the second observation. As shown in Figure 5, the continuum is no longer flat (in F_λ) but turns down at wavelengths shorter than 1050 Å. O VI is no longer present in emission; the broad absorption profile that is present near O VI is centered on and dominated by Lyβ. O VI is still present in absorption on the red wing of the broader Lyβ profile. There are no indications of other emission features associated with S VI, C III, or the higher order Lyman lines either. The prominent lines in the spectrum have a Gaussian FWHM of the order of 1.3–1.7 Å (350–500 km s^{-1}). The lines are also blueshifted by 0.5–1 Å (150–300 km s^{-1}) compared to the interstellar lines in the spectrum; this blueshift is somewhat greater than the systemic velocity of -72 km s^{-1} (Steeghs et al. 2001).

Because of the shutdown of detector 1 during the September 7 observation, and hence the loss of the channel likely to

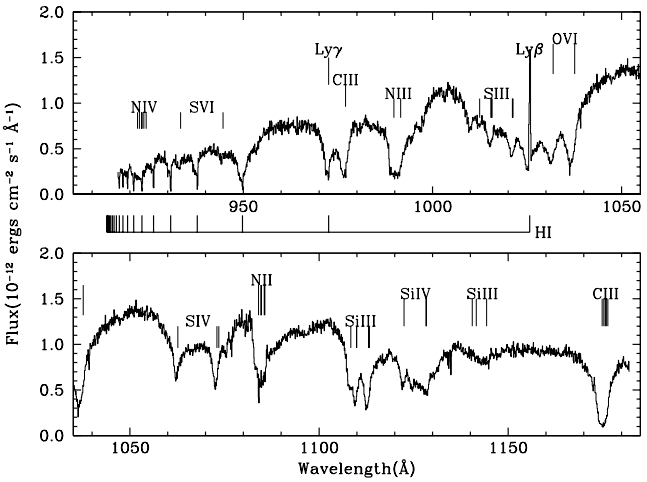


FIG. 5.—Expanded view with the stronger lines identified of the *FUSE* spectrum of WZ Sge obtained on September 7 during the rebrightening phase of the outburst, about 45 days after optical maximum.

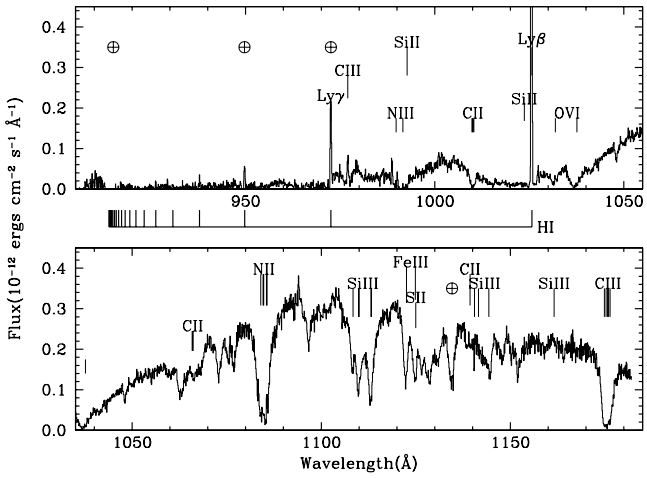


FIG. 7.—Expanded view with lines identified of the time-averaged spectrum obtained during the November *FUSE* observation, about three and a half months after the outburst began.

provide the best photometric accuracy, our ability to make judgements about temporal variability are compromised. Nevertheless, it is quite clear that the variations, if they do exist, are relatively modest. The standard deviation of the flux in the region around 1050 Å is less than 15%, with the largest deviation of the order of 30%. There are subtle variations in line shapes, but they are also quite modest.

2.3. *September 29 and Early November: Spectra from the Decline Phase*

By the time of the September 29 observation, the last rebrightening event was over, and the apparent temperature of the spectrum, as shown in Figure 6, had dropped further. As is the case in early September, the Lyman lines are quite evident, and the flux in the core of Lyβ is very small.[3] The region around O VI is fairly complex and most likely involves absorption and emission components, possibly arising from an optically thin disk. With the exception of the Lyman lines, the absorption lines are slightly narrower, with an FWHM of the order of 0.7–1.53 Å (200–400 km s^{-1}).

This trend toward lower apparent temperature continues in November, as shown in Figure 7. On September 29, emission (at a flux level of the order of 1×10^{-14} ergs cm^{-2} s^{-1} Å^{-1}) is observed to the Lyman limit, but by November there is no detectable emission at wavelengths shorter than 940 Å.

Since the September 29 and November observations were obtained in the TIMETAG mode, we divided up the exposures, constructed spectra in 200 s intervals, and searched for both secular trends and changes associated with the orbital period. Neither set of data shows large secular changes in the continuum flux, and changes in absorption-line strengths are modest. In fact, the only variability uncovered was on November 3 when the strength of the absorption-line spectrum appears to have increased during the last 2400 s of that day's observation. This is shown in Figure 8, which compares the spectrum in the LiF 1 channel, the channel used for guiding, during the period beginning at 07:13 UT with the spectrum during the rest of the November observation. The continuum appears to be unchanged, but the absorption lines are clearly deeper in this interval than during the rest of the November observations.

[3] There are some narrow emission features that become more prominent in the fluxed spectra as WZ Sge fades. However, these are all geocoronal and unassociated with WZ Sge.

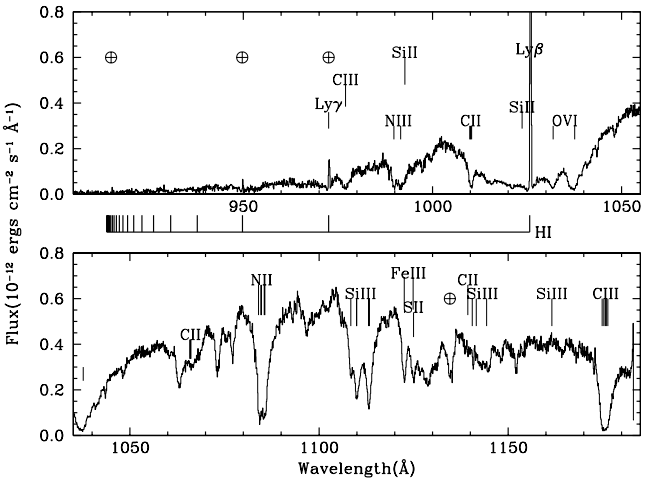


FIG. 6.—Expanded view with lines identified of the *FUSE* spectrum obtained on September 29 several weeks after the end of the last rebrightening, 67 days after optical maximum.

3. ANALYSIS AND DISCUSSION

3.1. *July 30: Outburst*

In outburst, the spectra of dwarf novae are generally understood to be dominated by disk emission. However, as has been clear since early *IUE* observations (e.g., Heap et al. 1978; Cordova & Mason 1982), most dwarf novae in outburst have spectral features (such as C IV) that reflect the scattering of disk photons in high-velocity outflows emerging from the inner disk. More recently, detailed analyses of UV spectra of some CVs (Knigge et al. 1997) and time-resolved spectroscopy of other dwarf novae (Horne et al. 1994) have made it clear that dwarf novae have additional material elevated at a significant distance above the disk plane. This material has been interpreted variously as a disk chromosphere, as a thickening of the disk at its outer edges

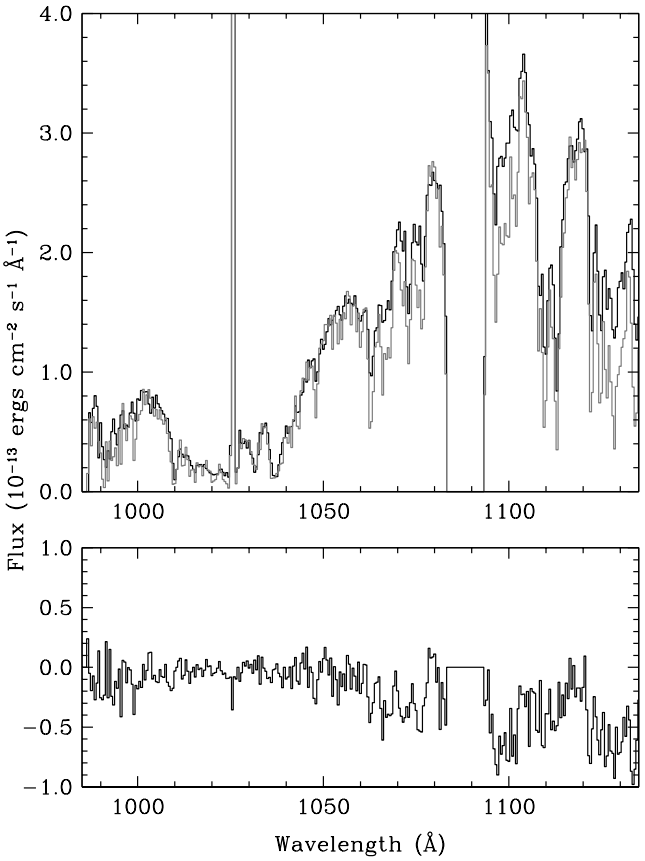


FIG. 8.—*Top*: LiF 1 spectra of WZ Sge during a 2400 s interval on November 3 (*gray*) and the rest of the November observation (*black*). Both spectra have been binned at 0.5 Å intervals. *Bottom*: Difference spectrum.

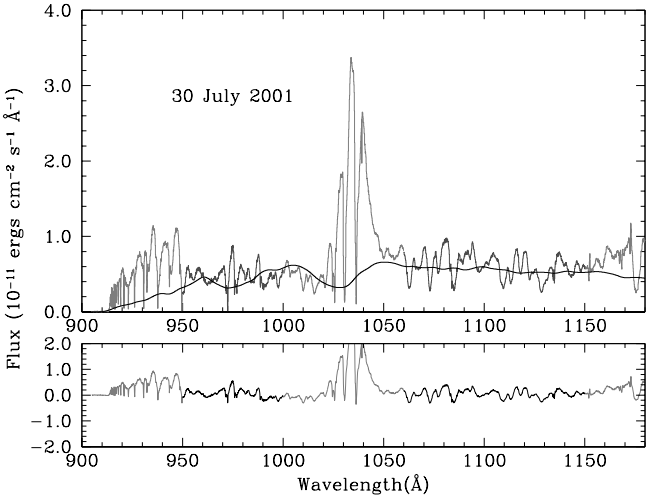


FIG. 9.—Comparison of the spectrum of WZ Sge as observed on July 28 with *FUSE* with that expected from a disk with parameters similar to that of WZ Sge and $\dot{m}_{\rm disk}$ of 8.5×10^{-10} $M_\odot$ yr^{-1} at 44 pc. This is the $\dot{m}_{\rm disk}$ that matches the flux observed from WZ Sge. *Top*: Model/data comparison. *Bottom*: Difference between the data and the model.

(or the corotation radius), or as material from the secondary overflowing the disk edge. Because of the plethora of resonance lines in the *FUSE* wavelength range, *FUSE* is quite sensitive to the existence of this material.

The *FUSE* spectrum of WZ Sge in outburst needs to be interpreted in this context. Qualitatively, the *FUSE* spectrum is somewhat similar to that obtained of the novalike variable UX UMa (Froning, Long, & Knigge 2003) and quite different from the two long-period dwarf novae in outburst that we have studied (U Gem: Froning et al. 2001; SS Cyg: K. S. Long et al. 2003, in preparation). In particular, the outburst spectra of WZ Sge in the *FUSE* region are complex, with narrower absorption lines than expected from a steady state accretion disk viewed at high inclination. However, to our knowledge, the prominence of O VI makes the WZ Sge spectrum unique. Both the O VI line and the other features are likely to be due to a wind and/or corona vertically extended above the disk in WZ Sge, and the strength of O VI may be due to ionization of the wind by X-rays created in the hot boundary layer (Kuulkers et al. 2002). It is ultimately our intention to model the outburst spectra of WZ Sge in detail in an attempt to determine the kinematic and ionization structure of the line-producing regions, but this will require significant effort.

Here, we limit ourselves to an approximate estimate of the accretion rate. Specifically, we have compared the observed spectrum with model spectra created for steady state disks. The model spectra themselves were constructed from summed, area-weighted, Doppler-broadened stellar atmospheres, assuming a standard steady state temperature distribution in the disk (see, e.g., Froning et al. 2001). For the parameters of the system, we assumed a nonrotating 0.8 $M_\odot$ WD (Skidmore et al. 2000), a disk inclined at 75° (Smak 1993), and a boundary layer that did not contribute significantly to the continuum.

We have made estimates of the accretion rate both from the flux observed, assuming a distance of 44 pc, and from the shape of the spectrum. For the July 30 observation, the flux is consistent with an overall accretion rate of 8.5×10^{-10} $M_\odot$ yr^{-1}, while a fit to the spectral shape indicates a value roughly 3 times larger.[4] While the model shown in Figure 9 is not a good fit to the data, it does have a slope that plausibly could underly a more complicated spectrum. It is also painfully obvious that standard disk models will not accommodate the narrow features in the spectrum. This is because features in the disk photosphere are broadened by the Doppler rotation of the inner disk at the inclination appropriate for WZ Sge. Nonetheless, we believe it is significant that the values of the disk accretion rate $\dot{m}_{\rm disk}$ are lower than is often estimated for dwarf novae in outburst but are consistent with its relatively modest brightness compared to other dwarf novae at well-known distances. For example, U Gem has an astrometric distance of 96.4 ± 4.6 pc (Harrison et al. 1999) and an inclination angle of $67° \pm 3°$ (Long & Gilliland 1999), similar to WZ Sge. *FUSE* spectra obtained of U Gem during the peak of an outburst in 2000 March show a flux of 1.8×10^{-11} ergs cm^{-2} s^{-1} Å^{-1} at 1150 Å, roughly 3 times that of WZ Sge. Froning et al. (2001) estimated the mass accretion rate to be 7×10^{-9} $M_\odot$ yr^{-1}, almost 10 times that of the flux-based estimate for WZ Sge (and 3 times greater than the spectral shape-based estimate). This conclusion has to be mitigated somewhat because of the fact that WZ Sge had already declined from maximum by about 1.1 mag by

[4] These fits were made for an assumed WD mass and radius appropriate for a nonrotating WD. Larger values of the accretion rate would result if the WD were of lower mass, both because the gravity is less and because the radius of a lower mass WD is larger.

July 30. This *FUSE* spectrum was the first obtained of the outburst, and one cannot state with confidence that the flux was not significantly higher earlier. On the other hand, there was very little evolution of the UV flux between July 30 and August 8, when the first *HST* observation took place and the optical magnitude had declined by an additional 0.9 mag.

3.2. *September 29 and Early November: Postoutburst Spectra*

As discussed in § 1, the UV spectra of WZ Sge in quiescence have been interpreted in terms of emission from a rapidly rotating WD that cooled from about 20,500 K about 180 days after outburst to about 15,000 K 15 years later (Slevinsky et al. 1999; Cheng et al. 1997).

The observed flux in November was comparable to that reported by Slevinsky et al. (1999) in the first postoutburst observation in 1978. Therefore, it is reasonable to expect that FUV flux from WZ Sge is dominated by the WD in the September 29 and early November observations. The main problem with this hypothesis is that the Cheng et al. (1997) analysis of *HST* Goddard High Resolution Spectrograph (GHRS) observations suggest that the WD in WZ Sge is rotating rapidly [$v \sin(i) = 1200$ km s^{-1}]. If that is correct, then the metal lines that are observed in the *FUSE* spectra cannot arise in the WD photosphere, since they have a velocity width of the order of 200–400 km s^{-1}. As a result, there are at least three possibilities to explore:

1. The WD is slowly rotating. If this is correct, then it seems most likely that the interpretation of the GHRS data was flawed, presumably because of the limited signal-to-noise ratio (S/N) of the data and the fact that there were only a few line features being fitted and that these were relatively shallow.
2. The WD is rapidly rotating and the narrow lines are due to material along the line of sight to the WD. If this is correct, then the narrow lines that are observed in the September and November observations do not arise from the surface of the WD but from material somewhere in the WZ Sge system along the line of sight to the WD. In that case, as the system approaches "complete" quiescence, the narrow features should disappear, and broad features from the rapidly rotating WD should become apparent.
3. The WD is slowly rotating, and some but not all of the lines are due to overlying material.

In an attempt to distinguish between these choices and to help extract information about the WD in the event that the lines do not originate in the WD photosphere, we have created a new grid of model WD spectra using I. Hubeny's TLUSTY and SYNSPEC codes (Hubeny 1988; Hubeny & Lanz 1995). The new grid has temperatures from 13,000 to 80,000 K, $\log g$ from 7.5 to 9, and rotation rates ranging from no rotation to 1500 km s^{-1}. It contains models for pure hydrogen atmospheres and for atmospheres with metal abundances ranging from 0.01 solar to 10 times solar. To identify the models that best fit the data, we have conducted standard χ^2 fits to the data.

Unless otherwise noted, we have attempted to fit the entire spectrum, omitting only regions contaminated by airglow or by obvious emission features, e.g., O VI and C III λ977. All results are quoted in terms of χ^2 per degree of freedom, or χ^2_ν.

We have concentrated our initial spectral fits on the time-averaged November observation in the hope that contributions from the disk and any other material in the system would be minimized then. The best χ^2 fit, assuming $\log g = 8.5$, is shown in Figure 10. The model has a temperature of 23,200 K, a rotation rate of 190 km s^{-1}, and metal abundances that are 2.2 times solar ratios. Qualitatively, the model approximates the overall shape of the spectrum fairly well, although χ^2_ν is large, 16.9. Assuming that the distance is 44 pc and that the WD is fully visible, the normalization implies a radius for the WD of 4.8×10^8 cm. This radius would suggest that the mass of the WD is $\sim$1.2 $M_\odot$ (or that the gravity is actually greater than $\log g = 8.5$) but is in any event consistent with a relatively massive WD. The value of χ^2_ν is large mainly because of the discrepancies associated with the lines in the models. There is a correlation between gravity and temperature in model fitting of this type (because both gravity and temperature affect the width and depth of the Lyman features). When the gravity is set to $\log g = 8.0$, the best-fitting temperature becomes 21,500 K, the best rotation rate remains 190 km s^{-1}, and the best metal abundance becomes 1.75 solar. As a result of the fact that the temperature is lower, the normalization implies a somewhat larger radius, 5.3×10^8 cm. The fits with $\log g = 8$ are slightly worse in a statistical sense, $\chi^2_\nu = 17.6$.

There is no particular reason to believe that the metals present in the photosphere are solar abundance ratios. One might hope that a proper choice of abundances could bring the model more into alignment with the data. As a result of this, we have experimented with fitting models in which abundances of individual elements are varied from the average value of 2.2. The model grids we created for this purpose had $\log g = 8.5$ and a rotational velocity of 190 km s^{-1}. The only element for which there was a major improvement was for N. Allowing the ion abundance of this element to vary improved the value of χ^2_ν to 15.4 (from 16.9). The improvement in χ^2_ν was due primarily to improvements in fitting

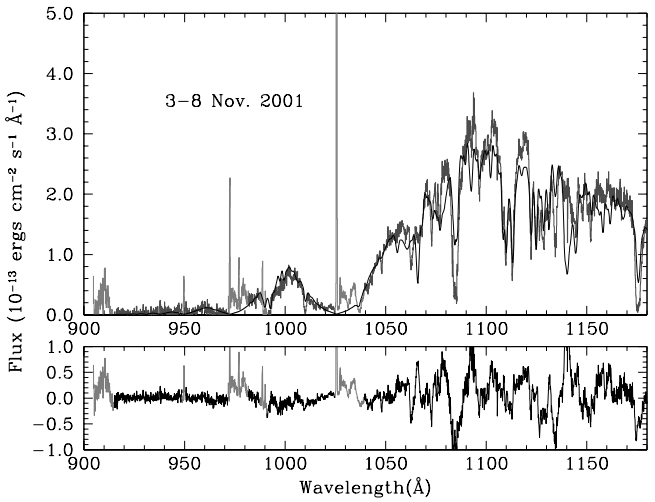


FIG. 10.—Comparison of the spectrum of WZ Sge as observed in November with that expected from a $\log g = 8.5$ WD with $v \sin(i)$ of 190 km s^{-1}, a temperature of 23,200 K, and metal abundances that are 2.2 times solar. As described in the text, this was the best-fitting WD model, in which $\log g$ was constrained to be 8.5 and the overall abundance was allowed to vary. The data that were used in the fit are plotted in black; the data that were omitted, most notably the region around C III λ978, O VI, and various geocoronal lines, are in gray.

lines at 990, 1084, and 1135 Å, which arise from N III, N II, and N I, respectively. The best-fit value for the abundance was 12.5 times solar; the best-fit temperature was essentially unchanged at 23,100 K, as expected, since the overall continuum shape is not affected very much by a simple abundance change. Fitting models in which C, Si, S, or Fe were varied did not result in either large changes in χ^2_ν or a qualitative improvement in the fits. Unlike the situation with N, the best-fit abundances were not very far from the value derived when all of the abundances were varied together. For example, if the abundance of C was allowed to vary, the best fit was for an abundance of 2 times solar. Inspection of the features that are sensitive to the C abundance shows that C III λ1178 is too weak in the best-fit model, but those associated with C II at 1140 and 1162 Å are too strong.

In addition to problems with specific metal lines, there is also a discrepancy between the data and the model in the region between 1050 and 1080 Å and also between 990 and 1005 Å; these are regions where quasi-molecular H features are expected. In our models, the Lyβ quasi-molecular features in the 1050–1080 Å region are included, using data from Allard et al. (1999). Similar data are not yet available for the Lyγ features between 990 and 1005 Å. Since the theory of the quasi-molecular H lines has not yet been tested thoroughly in the *FUSE* wavelength range, we have checked and determined that best-fitting values of temperature and metallicity are not altered significantly if these regions are ignored in fitting the data.

We conclude that if both the continuum and line spectrum of WZ Sge in the FUV arise in the WD atmosphere, then (1) the WD must be slowly rotating [$v \sin(i) \sim 200$ km s^{-1}], and (2) the atmospheric abundance of N is enhanced relative to that of other metals. Both of the results are in conflict with the findings of Cheng et al. (1997). On the other hand, the abundance pattern we find would fit with that expected from CNO-processed material, which has been reported in other WDs in CVs, such as U Gem (Long & Gilliland 1999) and VW Hyi (Sion et al. 2001).

The extreme alternative to the hypothesis that all of the lines in the *FUSE* spectrum are photospheric is to assume that all of the lines are created by material along the line of sight to the WD but that the WD spectrum is relatively featureless. The technical problem associated with this hypothesis is that there are no physically based models for this material. We do not know for certain whether it is more likely that this is material splattered by the disk stream interaction or if it is somehow associated with the WD itself. Since light from the WD probes a "pencil beam," the absorbing material could be located almost anywhere along the line of sight. Therefore, as an initial attempt, we have elected to model the absorption in terms of one or more slabs of overlying material, each of which we assume to be in LTE. For each slab, there are three parameters, the temperature T_s of the slab, the column density $N_{\rm H}$ of the slab, and the (presumably) turbulent velocity v_s of the slab. To model the effect of each slab, we have calculated the opacity of LTE material using TLUSTY/SYNSPEC, convolved the opacities with the appropriate velocity-dependent Gaussian to create a smoothed opacity, and created grids of optical depths as a function of column density. This approach is very similar to that developed by Horne et al. (1994) to model 1150–2500 Å *HST* spectra of the high-inclination dwarf nova OY Car in quiescence in terms of a 16,500 K WD and an "Fe II curtain." Our grid included temperatures from 5000 to 30,000 K, densities from 10^9 to 10^{13} cm^{-3}, turbulent velocities from 50 to 500 km s^{-1}, and column densities from $\log N_{\rm H}$ of 18 to 22. To restrict the total number of models, only slabs with solar abundance ratios were considered.

Attempts to fit the data with a model consisting of a DA WD and a single slab were unsuccessful. The fits were qualitatively and quantitatively worse than fits made assuming the lines arise in a metal-enriched WD photosphere. The absorption spectrum of a single slab is simply not rich enough to mimic the lines in the November *FUSE* spectrum of WZ Sge. (For this reason, it is unlikely that plausible changes in abundances could substantially improve the fits.)

On the other hand, as shown in Figure 11, models constructed from a DA WD and two slabs of overlying material do reproduce the data at least as well as the best models based on WD photospheres. This particular model was obtained assuming a velocity broadening of 200 km s^{-1} and a density of 10^{13} cm^{-3} in both slabs. The temperature of the underlying $\log g = 8.5$ DA WD is 23,300 K, essentially identical to that derived for the metal-enriched $\log g = 8.5$ WD. The two slabs have temperatures of 9000 and 15,000 K and column densities of 1×10^{20} and 3×10^{20} cm^{-2}, respectively. The value of χ^2_ν is 10.9, which is considerably better than any of the metal-enriched photosphere models. Fits obtained from models assuming lower densities are almost identical to those shown in Figure 11; the column densities of the slabs are about the same, but the temperatures of the slabs are somewhat lower. The temperature change is a simple reflection of our assumption of LTE, implying that the ionic abundances are determined by the Saha equation.

Models constructed from a DA WD and two slabs with lower velocity dispersion fitted the data considerably less well, as might be expected, since the measured line widths are of the order of 200 km s^{-1}. The sound speed for a plasma with a temperature of 15,000 K is about 15 km s^{-1}, much less than the velocity width of the lines. This is a challenge that would have to be overcome in the creation of a physical model based on overlying absorption. Most probably, one

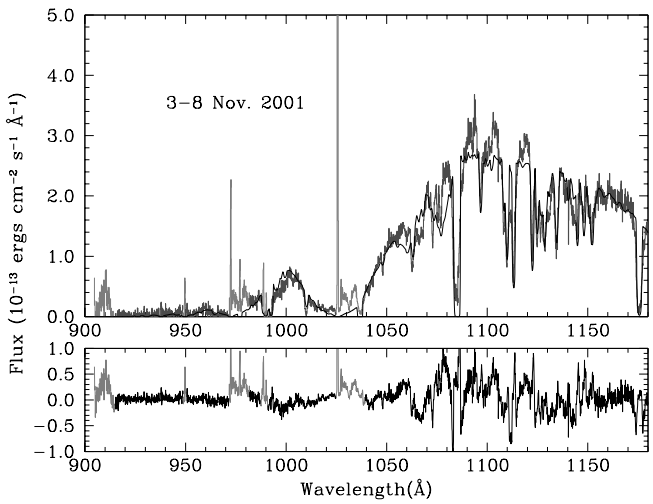


FIG. 11.—Comparison of the spectrum of WZ Sge in November with that expected from a DA WD and overlying material. Here, the overlying material was represented in terms of two slabs, assumed to have densities of 10^{13} cm^{-3} and turbulent velocities of 200 km s^{-1}. The resulting fit yielded temperatures of 9000 and 15,000 K and column densities, measured in terms of $N_{\rm H}$, of 1×10^{20} and 3×10^{20} cm^{-2}, respectively, for the two slabs.

would need to invoke velocity gradients along the line of sight, since a turbulent plasma with a characteristic velocity of 200 km s^{-1} would be so supersonic that one would expect shocks to quickly raise the temperature and hence the ionization state of the plasma beyond what is observed in WZ Sge. An alternative is that the absorbing material lies just above the WD surface. This would help to explain the absence of strong orbital modulations of the lines, but in this picture, which might actually be described as a WD with an extended atmosphere, one would expect photospheric lines as well.

A better fit than for any simple metal-enriched WD photosphere, even when abundances are allowed to vary, can also be obtained by assuming that both photospheric lines and absorption by a single slab contribute to the spectrum. There are a number of possibilities, depending on whether one assumes that the WD rotational velocity and the so-called turbulent velocity of the veil are identical or not. Restricting ourselves to the simplest case, the best-fitting model with a $\log g = 8.5$ WD with solar abundances, rotating with $v \sin(i) = 200$ km s^{-1}, and a slab with a turbulent velocity of 200 km s^{-1} and a density of 10^{13} cm^{-3} is shown in Figure 12. The temperature of the WD is 23,100 K, very close to the value in the models involving a normal-abundance WD and the DA WD plus slab. The temperature of the slab is 15,800 K, and the column density is 8.5×10^{19} cm^{-2}. The value of χ^2_ν is 12.4, compared to 15.4 for our best model based on a metal-enriched WD photosphere alone.

We have also carried out the same analysis of the September 29 observation of WZ Sge. Qualitatively, the results are similar. As shown in Figure 13, the best fit to a WD photosphere with $\log g$ fixed at 8.5 yielded a temperature of 25,200 K, abundances that were 3.4 times solar, and a rotational velocity [$v \sin(i)$] of 250 km s^{-1}. The normalization implies a WD radius of 5.1×10^8 cm. The value of χ^2_ν is 20.2, slightly greater than for the November observations, but this can be attributed to the higher S/N in the September 29 observations. Models with elevated N abundances improve the fits. In particular, if all of the heavy-element abundances are

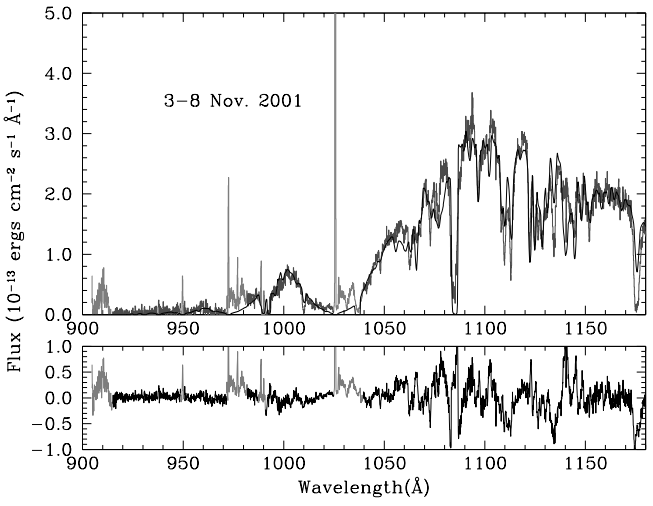


FIG. 12.—Comparison of the November WZ Sge spectrum with a model consisting of a normal-abundance WD and a slab. The WD is assumed to have $\log g = 8.5$, and the veil is assumed to have a density of 10^{13} cm^{-3} and a turbulent velocity of 200 km s^{-1}. The best fit has a WD temperature of 23,100 K, a slab temperature of 15,800 K, and a slab column density of 8.5×10^{19} cm^{-2}.

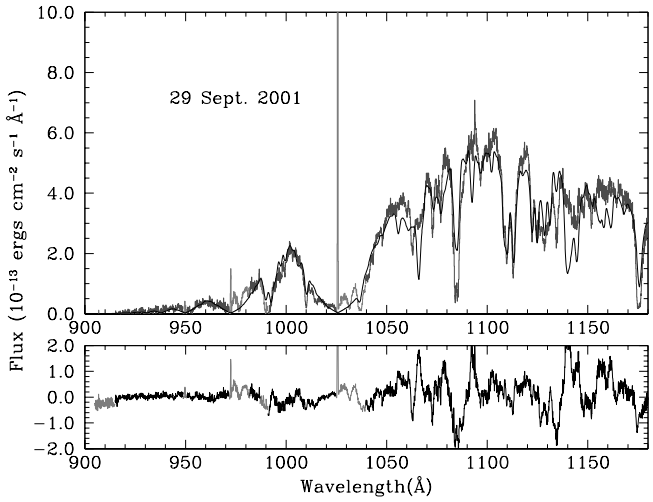


FIG. 13.—Comparison of the spectrum of WZ Sge as observed at the end of September with that expected from a WD photosphere. For the fit, $\log g$ was fixed at 8.5, and the temperature and overall metal abundance were allowed to vary.

fixed at 3.4 times solar except N, then the best-fitting $\log g = 8.5$, $v \sin(i) = 250$ km s^{-1} model has a temperature of 25,000 K, a N abundance of 20 times solar, and a χ^2_ν of 18.3. For the September 29 observation, a better fit (χ^2_ν of 15.8) can be obtained with the normal-abundance WD photosphere and slab. The temperature of the WD is 25,100 K, the temperature of the slab is 16,300 K, and the column density is 1.0×10^{20} cm^{-2} if a $\log g = 8.5$ WD and a slab density of 10^{13} cm^{-3} are assumed.

An important point is that for $\log g = 8.5$ models, the WD temperature is always close to 25,000 K, regardless of whether a DA WD, a simple normal-abundance WD, or a WD plus slab is assumed. Thus, there is clear evidence of cooling of the WD of approximately 2000 K in a month. If the WD is less massive, the temperatures of the best fits are lower. If a $\log g = 8$ WD is assumed, then the temperature of the best-fit normal-abundance WD plus slab model is 23,500 K on September 29 and 21,000 K in early November. If a $\log g = 9$ WD is assumed, then the temperature is 26,200 K on September 29 and 24,300 K in November. The fits themselves do not distinguish strongly between the various gravities. This is similar to our analysis of *HST* data, which suggests that the WD cools from 23,000 K on October 10 to 19,000 on November 10 (Sion et al. 2003).

In addition to the WD in the spectra of WZ Sge on September 29 and in November, there are emission lines due to C III λ1177 and to O VI. A careful inspection of the spectra shows that the two C III features are centered close to the rest wavelength of C III but that the two obvious features associated with O VI are not. Instead, the two obvious features near 1030 Å are actually centered at 1032 Å, which is very close to the rest wavelength of the shorter wavelength line of the O VI doublet. The separation of the O VI doublet is large enough that a portion of the profile associated with O VI is actually buried in the continuum near 1038 Å. Gaussian fits to the profiles indicate widths of 2–3 Å (600–900 km s^{-1}), except for the peak at 1034 Å, which, presumably because of contributions from both components of the doublet, has an FWHM of nearly 4 Å. Assuming that the two peaked structures represent Doppler rotation, the separation of the C II line, 5 Å, implies that $v \sin(i)$ for the emission

region is of the order of ± 750 km s^{-1}, consistent with a location in the outer disk. It is possible, but far from clear, that the same material provides for absorption elsewhere.

3.3. *The Rebrightening Phase Spectrum*

As noted previously, the September 7 observation of WZ Sge took place during a time in which the disk, or at least part of it, was in an optical high state. As a result, it is unclear whether one should expect the FUV spectrum to be dominated by the WD or by the disk. Accordingly, we have attempted to fit the data obtained on September 7 with both synthetic WD spectra and synthetic disk spectra. Examples of the fits, in which the fitted regions were limited to relatively line-free portions of the spectrum, are shown in Figure 14. While neither model is a good fit to the data statistically, both do have overall shapes that plausibly resemble an underlying continuum. It is also evident that neither model produces (or could produce) a good fit to all of the data without additional components, such as a veil or a chromosphere.

The relative contributions from the disk and the WD are not straightforward to determine in the September 7 spectrum. On the one hand, the spectrum shows absorption lines from the higher order Lyman series up to at least Lyη ($n = 7$), as expected from a relatively hot WD; however, the flux does not go to zero near the line center, as is predicted by the WD model. At 1100 Å, the flux from WZ Sge on September 7 was 1.2×10^{-12} ergs cm^{-2} s^{-1} Å^{-1}, 2.4 times greater than it would be on September 29. Assuming that the WD was at least as bright on September 7 as on September 29, then the WD must have contributed at least 40% of the flux at 1100 Å on September 7, even though the system was in the rebrightening phase.

To better characterize the WD, under the assumption that the FUV flux was dominated by the WD on September 7, we have fitted the data to the $\log g = 8.5$ grid of synthetic WD spectra, allowing the temperature, metallicity, and rotation rate to vary and using the same wavelength regions that were used to fit the September 29 and November spectra. The best fit has a temperature of 38,600 K, a rotation rate of 430 km s^{-1}, and metal abundances that are 10 times solar, the maximum in our grid. The normalization implies a WD radius of 4.0×10^8 cm, which is somewhat (10%), but not grossly, smaller than values found for the radius when the disk appears optically to be in quiescence. The value of χ^2_ν was 26.0 for this fit, not noticeably worse than similar fits to the September 29 spectra. If the WD dominated, then the WD photosphere would need to cool by about 15,000 K in the 3 weeks between September 7 and September 29. However, the metal abundances seem extreme. If the same fits are performed, but the abundances are constrained to be solar, then the best fit has a somewhat higher temperature of 42,000 K, a lower rotation rate of 270 km s^{-1}, a WD radius of 3.3×10^8 cm, and χ^2_ν of 36.

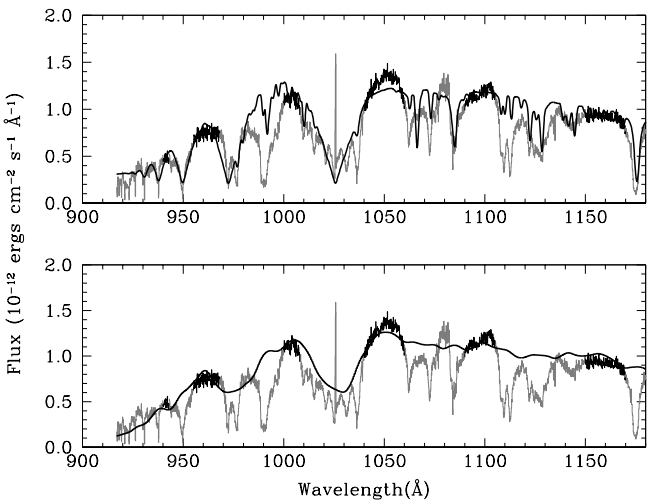


FIG. 14.—Comparison of the spectrum of WZ Sge as observed on September 7 with that expected from a WD (*top*) and a disk (*bottom*). The portions of the spectrum considered in the fit are shown in black. Thus, the fits are intended to match regions without obvious line absorption. Other fits for WDs in which fits were made to the entire spectrum are discussed in the text. Here, a rotation rate for the WD of 200 km s^{-1} and normal abundances were assumed. For the WD, the temperature was 41,200 K; for the disk, $\dot{m}_{\rm disk}$ was $2.3 \times 10^{-10}\ M_\odot$ yr^{-1}.

The WDs of dwarf novae do respond to dwarf nova outbursts, and a variety of mechanisms (see, e.g., Godon & Sion 2002) have been suggested to explain their responses. Temperatures of 39,000–42,000 K are comparable to the temperature of U Gem at the end of a normal outburst (Froning et al. 2001) and TT Ari in quiescence (Gänsicke et al. 1999) and somewhat lower than the value of $\sim$50,000 K for the WD in the novalike variable and SW Sex star DW UMa (Knigge et al. 2000; Araujo-Betancor et al. 2003). Therefore, such temperatures for WZ Sge would not be unprecedented. However, it is unclear whether the normally lower average temperature of a WD in these short-period systems can be raised to this high level. (We do note in passing that if the accretion energy at the WD surface could heat the surface uniformly, then the accretion rate required would be quite small, coincidentally similar to the value of the disk accretion rates below.) In the case of U Gem, the WD temperature declines by about 10,000 K in several months, but here we would require the WD to cool by 13,000–16,000 K in 3 weeks. VW Hyi may be a better analog. After a superoutburst, the WD cools with an *e*-folding timescale of 9.8 days, considerably more rapidly than is observed in U Gem (Gänsicke & Beuermann 1996). But the peak temperature for the WD in VW Hyi is 26,400 K, and the total temperature change is 7090 ± 430 K, considerably less than required for WZ Sge. On the other hand, the main, or plateau, phase of the WZ Sge outburst was considerably longer than in a typical dwarf nova, suggesting that the temperature rise of the WZ Sge WD might be larger than in a typical dwarf nova system.

If, alternatively, the FUV flux was dominated by the disk, then, the overall spectral shape suggests an $\dot{m}_{\rm disk}$ of about $1.1 \times 10^{-9}\ M_\odot$ yr^{-1}, not very different from that during the July 30 observation. However, the flux on September 7 was lower, and the rate required to match the flux at 1100 Å is $2.3 \times 10^{-10}\ M_\odot$ yr^{-1} for a system comprised of a 0.8 $M_\odot$ WD and a disk inclined at 75°. A model based on summed stellar atmospheres with this accretion rate would underestimate the flux at the shortest wavelengths and, if one were confident of the shape of disk spectra in the FUV, would be a fairly strong argument against a disk origin for the bulk of the FUV emission. Unfortunately, there is no consensus on the shape of the spectrum of a steady state disk in the *FUSE* wavelength range. Even if there were, the disk in WZ Sge is unlikely to be in a steady state during the rebrightening outbursts.

Some combination of disk and WD emission is also possible. Model fitting does not help, because there are no simple disk plus WD models that match the features that dominate χ^2. At present, we do not believe one can determine the fraction of emission due to the disk precisely, since it seems likely that most of the line features are not created directly above the FUV photosphere of either the WD or the disk. On the other hand, it is difficult to believe that the WD was intrinsically fainter on September 7 than on September 29. If that is true, then the WD had to have been contributing of the order of 40% at 1150 Å in early September. WD domination in the FUV would not be completely unprecedented, since Froning et al. (2001) found that the WD in U Gem dominated the *FUSE* spectrum during the decline from outburst.

4. SUMMARY

We have observed WZ Sge four times during the outburst of 2002. In that time the spectrum evolved from a disk-dominated to a WD-dominated system. Our principle conclusions are as follows:

1. At least in the FUV, the outburst luminosity of WZ Sge is low compared to that of other (mostly longer period) systems for which there are good distance and inclination estimates. Based on the strength of the O VI feature, however, the excitation spectrum is high compared to these systems, suggesting that the boundary layer may be relatively luminous.

2. The O VI profile in the outburst spectrum shows clear evidence of outflow, based on the blueshift of the absorption cores, even in the absence of a classic P Cygni profile. In addition to O VI, the outburst spectrum is rich in absorption lines of moderate ionization state ions of common elements; this indicates material relatively far from the WD, suggesting that the disk (or more likely a tenuous layer above the disk) must be vertically extended.

3. By early September, in the observation occurring during the early rebrightening phase, the high excitation lines had weakened significantly. It is not obvious from spectral fits whether disk or WD emission dominates in the *FUSE* wavelength range at this time. It seems likely that the spectrum arises from a combination of disk and WD emission, with a minimum contribution of 40% from the WD.

4. In the September 29 and early November observations, both of which occurred after the last rebrightening event in the WZ Sge outburst, the WD dominates the continuum spectrum. The combination of a parallax distance of 44 pc, the observed UV flux, and the derived temperature of the WD on September 29 and in November implies that the WD in WZ Sge is relatively massive, at least 0.8 $M_\odot$, in agreement with the conclusions of Skidmore et al. (2000) and Steeghs et al. (2001), and possibly larger. It is interesting that Knigge et al. (2002) report weak 6.5 s as well as 15 s oscillations in *HST* spectra of WZ Sge; if the shorter periodicity is associated with material rotating at Keplerian velocities, the minimum mass of the WD is 1.03 $M_\odot$. For $\log g = 8.5$, the WD declines by about 2000 K, from 25,100 K on September 29 to 22,600 K in early November.

5. The lines in the September 29 and early November spectra are narrow, with velocity widths of the order of 200–400 km s^{-1}. If some or all of these are created in the WD photosphere, as seems natural, then the WD in WZ Sge is rotating relatively slowly, in contrast to the conclusion of Cheng et al. (1997). However, it also possible, at least on the basis of the fits, that all of the lines are created by material located somewhere along the line of sight to the WD photosphere. (The main problem with assuming that material along the line of sight dominates the absorption spectrum is that there is no physical model for this material. In the absence of such a model, one suspects that one could produce good fits to the spectra of almost any WD in a dwarf nova system, thereby bringing into question a considerable body of research.)

This has been a first analysis of the early *FUSE* observations of the outburst of WZ Sge in 2001 July. A similar campaign was conducted with *HST* (Knigge et al. 2002; Sion et al. 2003). These, along with continued observations of WZ Sge with *FUSE* and with *HST*, will eventually resolve the question of the rotation of the WD and with that the degree to which material along the line of sight to the photosphere contaminated our view of the WD in the fall of 2002. Ultimately, we will obtain a clear picture of the UV properties of one of the nearest and shortest period dwarf novae.

We gratefully acknowledge the efforts of the *FUSE* operation team and the *FUSE* project scientist George Sonneborn in making timely observations of the WZ Sge outburst possible. Our analysis effort was supported by NASA through grants NAG5-9283 and NAG5-10338. B. T. G. was supported by a PPARC advanced fellowship.

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