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TIME-RESOLVED ULTRAVIOLET AND OPTICAL SPECTROSCOPY OF THE PULSATING X-RAY SOURCE H2252–035

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ABSTRACT

Simultaneous ultraviolet and optical spectral measurements of the pulsating X-ray source H2252–035 have been made about its 3.6 hr binary orbital cycle with a time resolution of 30–70 minutes. A 2200 Å feature in the continuous spectral distribution of the object suggests an amount of reddening corresponding to $E(B-V) = 0.10$ with 3 σ upper and lower bounds of 0.14 and 0.02. A two-component spectrum consisting of a power law with a spectral index $\alpha = 2.74$ and a blackbody with a temperature $T = 1.34 \times 10^4$ K fits all the data on H2252–035 from 1200 to 22000 Å. The simultaneous *B* band data show a modulation with a semiamplitude of $\sim 12\%$ which is approximately in phase with previous observations of the orbital light curve. A $\sim 6\%$ semiamplitude modulation of the far-UV light curve (1200–1500 Å), observed in antiphase with the *B* band modulation, may have an instrumental origin. No modulation is detected in the near-UV light curve (1700–3100 Å). The UV spectra exhibit emission lines of N V λ1240, Si IV λ1400, C IV λ1549, and Mg II λ2800 in ratios consistent with collisional de-excitation in a plasma of temperature $T \geq 10^5$ K. The observed time-averaged ratio of the He II lines $\lambda1640/\lambda4686$ is 5.0; corrected for reddening, the ratio is ~ 7. This suggests that the helium lines are produced by recombination. In a 4 hr observation made in 1980 September, all of the UV lines, and also the optical emission lines of Hβ and Hγ, showed an intensity variation in phase with the *B* band modulation. A 50 minute observation in 1981 January, however, showed that C IV was 50% stronger than it was at about the same orbital phase in the previous observation, indicating that there is a component of variability in addition to the possible orbital modulation of the lines. A variation of the emission lines with orbital phase would suggest that at least some of this emission is associated with the inner face of the outer accretion disk rim; this atmosphere may be heated by the central X-ray source.

Subject headings: stars: pulsation — ultraviolet: spectra — X-rays: binaries

I. INTRODUCTION

Observations of the *HEAO 1* X-ray source H2252–035 (Marshall *et al.* 1979) and its orbital counterpart—a 13th magnitude, blue, emission-line star (Griffiths *et al.* 1980)—yielded an optical modulation and radial velocity variations with a 3.6 hr period (Patterson and Price 1981), a coherent optical periodicity of 858 s (Patterson and Price 1981), and a coherent X-ray periodicity of 805 s (White and Marshall 1981; Patterson and Garcia 1980). The 805 s oscillation is also sometimes seen in the optical light (Warner, O'Donoghue, and Fairall 1981). The 3.6 hr modulation is interpreted as the orbital period of the system. The optical oscillation frequency corresponds to the lower orbital sidelobe of the X-ray oscillation frequency, suggesting that H2252–035 contains a prograde-spinning, compact, magnetic star whose beamed X-radiation is reprocessed in some region fixed in the frame of reference of the binary (Patterson and Price 1981; White and Marshall 1981). The site of the reprocessing has been variously attributed to the companion star (Patterson and Price 1981) and to the mass impact region on the outer edge of the accretion disk (Hassall *et al.* 1981, hereafter HEA).

H2252–035 is distinguished from the low-mass neutron star X-ray binaries by its low ratio of X-ray to optical emission, $L_x/L_{opt} \sim 1$, which is similar to the empirically derived ratios for the accreting degenerate dwarf binaries (cataclysmic variable stars; Córdova, Mason, and Nelson 1981). This has prompted speculation that the compact object in H2252–035 might be a white dwarf (Patterson and Price 1981), rather than a neutron star. However, White and Marshall (1981) and HEA note that the observations of H2252–035 do not yet exclude a neutron star as the central source.

H2252–035 provides an excellent subject for the study of the continuous ultraviolet, optical, and infrared spectral distribution of a close binary containing a spinning, magnetized star because it is relatively bright compared with most of the pulsating neutron stars in

[1] Guest Observer with the *International Ultraviolet Explorer* satellite.

low-mass binary systems and because of the minimal contribution of its faint companion star to the optical and UV light. A single UV spectrum of H2252−035 obtained by HEA, when combined with data at longer wavelengths, showed UV and IR excesses over an unreddened blackbody spectrum with $T = 12{,}500$ K and clear evidence for only one UV line, C IV. In this paper, we report time-resolved ultraviolet spectrophotometry and simultaneous optical spectroscopy of H2252−035 around the binary cycle. We are able to resolve the UV and IR excesses with a two-component fit to a slightly reddened spectrum. We also find ultraviolet emission lines of N V, C IV, Si IV, He II, and Mg II, and absorption at Lyα. Our more extensive phase coverage allows us to search for an orbital modulation in the ultraviolet continuum and emission lines.

II. THE OBSERVATIONS

The ultraviolet observations were made on UT 1980 September 7 and UT 1981 January 3 using the *International Ultraviolet Explorer* satellite (*IUE*) from the NASA Goddard Space Flight Center (GSFC) facility. Both the short-wavelength prime (SWP, 1150–1950 Å) and long-wavelength redundant (LWR, 1900–3100 Å) cameras were used in the low dispersion mode ($\sim$6 Å resolution for the SWP camera and $\sim$9 Å resolution for the LWR camera), together with the large ($10'' \times 20''$) aperture. The log of the UV observations is given in Table 1. During the 1980 September observing run we alternated between the short- and long-wavelength cameras with exposure times of about 30 minutes, for a total observing length of 4.0 hr, or just over one binary cycle of H2252−035. A delay time between exposures using the same camera is necessitated by the lengthy ($\sim$25 minute) readout process. To increase the time resolution during the 1980 September observations in one instance we took a "double exposure": the *IUE* telescope was moved to position the star first in one half of the large aperture and then in the other half of the aperture. The result is that two discrete spectra were obtained closely spaced in time (SWP 10040a and b). In 1981 January we took another short-wavelength double exposure (SWP 10950a and b).

The UV data were processed using software developed at Los Alamos to analyze the 55 line spatially resolved spectra that were extracted perpendicular to the dispersion by the initial GSFC processing. The *IUE* absolute calibration used is that of Bohlin and Holm (1980). The double exposures presented special problems because of the partial overlap of the discrete spectra. Figure 1 shows the flux over the entire SWP bandpass as a function of line number for SWP 10040 (Fig. 1*a*) and SWP 10950 (Fig. 1*b*). To correct for the overlap between the spectra and to allow for asymmetry in the profiles, we fitted composite Gaussian curves to these data, as shown by the solid line in Figure 1. In both of

TABLE 1

LOG OF ULTRAVIOLET OBSERVATIONS

Seq. No.	Date	UT Start	Duration
LWR 8737	1980 Sep 7	04:04:50	30 min
SWP 10038	1980 Sep 7	04:39:29	30
LWR 8738	1980 Sep 7	05:14:35	30
SWP 10039	1980 Sep 7	05:48:55	30
LWR 8739	1980 Sep 7	06:23:29	30
SWP 10040a	1980 Sep 7	07:02:28	27.7
SWP 10040b	1980 Sep 7	07:30:10	32.3
SWP 10950a	1981 Jan 3	03:31:39	25
SWP 10950b	1981 Jan 3	04:02:00	25

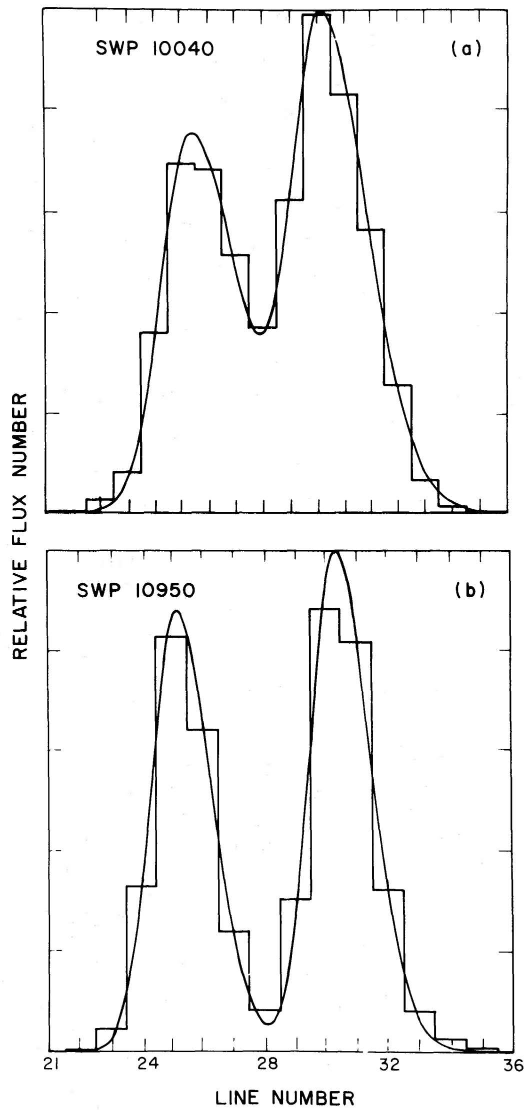

FIG. 1.—The intensity, summed over 1250–1900 Å (excluding spectral lines), in the direction perpendicular to the dispersion for the two cases in which a double exposure was taken. The star was alternately placed in the two halves of the aperture; the separation of the images was 10″.2 for SWP 10040 and 11″.2 for SWP 10950. The designations *flux number* and *line number* are defined in the *IUE* Image Processing Information Manual. The histograms are the flux numbers for each line in the 55 line spatially resolved image. The solid curves drawn through the histograms represent the Gaussians which best fit (in a minimum χ^2 sense) the data.

these double exposures the spectrum taken second (occupying the higher line numbers) is more intense than that taken first. This is clear in Figure 1, although the effect is magnified for SWP 10040 because of the longer exposure time on the second image (cf. Table 1). In the wavelength interval 1260–1535 Å the flux difference between the two images is ∼13% in both SWP 10040 and SWP 10950; in the interval 1800–1900 Å the difference is 2% in SWP 10040 and 13% in SWP 10950. The two observations were made in the phase intervals $\phi = 0.19$–0.47 and $\phi = 0.78$–1.03, respectively, according to the ephemeris given in § III*b*. During SWP 10040, the *V* magnitude of the star, measured using the *IUE* fine error sensor (FES) (and Lick spectrophotometry; see below), decreased by about 20%, while measurements with the FES before and after SWP 10950 indicate that the *V* band flux increased by 20%. Care must be taken, however, in interpreting the results of an *IUE* double exposure. Examination of similarly spaced double exposures of a standard star and two other cataclysmic variables of approximately the same apparent brightness as H2252−035 shows a systematic difference in intensity among the exposures, which is of comparable magnitude to that seen in the present data. As in the H2252−035 double exposures, the spectrum occupying the higher line numbers is the more intense, by an amount that ranges from ∼5% to ∼10% for the wavelength interval 1200–1500 Å and from ∼3% to ∼7% for the interval 1800–1900 Å. In addition, Clarke and Moos (1981) have reported a gradient in the profile of the diffuse Lyα emission when plotted as a function of line number, in the same sense as the effect reported here. This then suggests that at least part of the effect seen in H2252−035 may not be of astrophysical origin, although the instrumental effects that cause the difference are not presently understood.

Simultaneous optical spectrophotometric measurements were made during the 1980 September ultraviolet observations using the Robinson-Wampler Image-Tube Scanner (ITS) on the Anna Nickel 40″ (1 m) reflector at Lick Observatory. The spectral range covered was 3640–6000 Å, although the red image tube used limited the effective region covered to $\lambda > 4000$ Å. The nominal resolution of the ITS was about 3.5 Å. Scans of 8 minute length were taken starting at 04:58 until 07:58 UT alternating left and right apertures. The data were analyzed in groups of two 8 minute integrations. The three Lick Observatory flux standards observed during the run, BD +40°4032, Hiltner 102, and Feige 15, gave calibrations which agreed to within 2%, although systematic losses probably occurred due to episodes of bad seeing.

III. RESULTS

a) *The Continuous Spectral Distribution*

The gross spectral distribution of H2252−035 from 1250 to 22000 Å is illustrated in Figure 2. The ultraviolet points are from the 1980 September observations and represent an average of all the data, summed over wavelength intervals ranging from ∼50 to 100 Å and normalized to flux per angstrom. Background has been

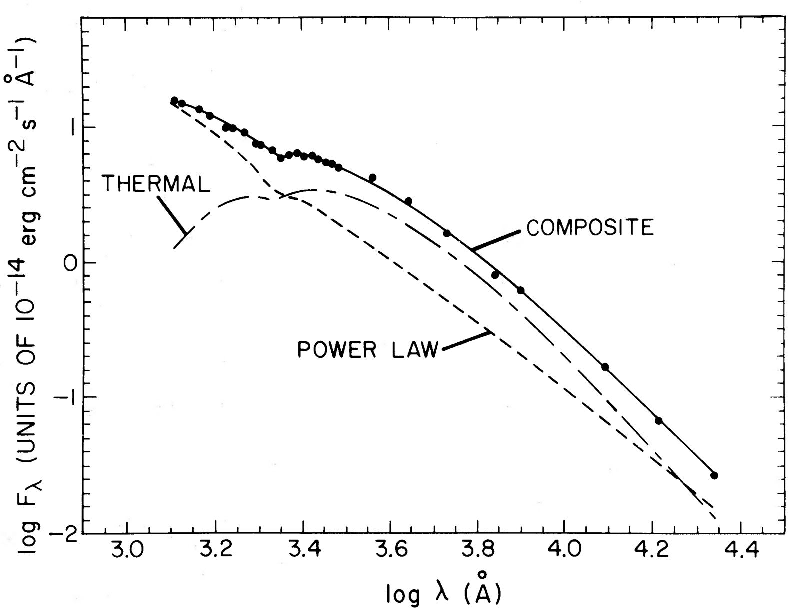

FIG. 2.—The ultraviolet, optical, and near-infrared continuum spectrum of H2252−035. The UV points are broad-band *IUE* fluxes averaged over all SWP and LWR sequence numbers listed for the 1980 September observation in Table 1. The optical and infrared data are from Hassall *et al.* (1981). The spectrum is fitted with a combination of a power-law and a thermal (blackbody) model. The power law has a slope $\alpha = 2.74$. The blackbody temperature is $T_{bb} = 1.34 \times 10^4$ K. Both models include reddening with $E(B-V) = 0.10$. The solid line is the sum of these two components.

subtracted, and spectral lines and instrumental features have been excluded. Since our optical data covered only a short wavelength span, we have combined our UV data with the optical and IR data reported by HEA and taken within about one month of our UV data. The *B*, *J*, *H*, and *K* magnitudes measured by HEA are very similar to the magnitudes obtained by Córdova, Mason, and Horne (1982) in 1981 August, suggesting that the star may be stable over relatively long-term periods at optical and IR wavelengths.

A dip in the observed spectrum of H2252−035 at 2200 Å suggests interstellar reddening of the source (see Fig. 2). We find, using the dereddening procedure described in Mason and Córdova (1982), that the best fit value of the color excess is $E(B-V) = 0.10$ with 3 sigma upper and lower bounds of 0.14 and 0.02. $E(B-V) = 0.0$ can be excluded at the 3.9 sigma confidence level.

HEA fit the UV to IR spectral distribution of H2252−035 with an unreddened blackbody model having a temperature $T_{bb} = 1.25 \times 10^4$ K. They note the presence of UV and IR excesses over this model. We find that the fit to the data in the ultraviolet and infrared is considerably improved by the addition of a single power-law component ($F_\lambda \propto \lambda^{-\alpha}$) to the blackbody. The best fit is obtained with $T_{bb} = 1.34 \times 10^4$ K, $\alpha = 2.74$, and $E(B-V) = 0.1$. Both spectral components and their sum are shown in Figure 2. The total flux in the dereddened blackbody component from 1250 to 22000 Å is 2.3×10^{-10} ergs cm^2 s^{-1}; for the power-law component the flux in this interval is 2.5×10^{-10} ergs cm^{-2} s^{-1}.

b) *The Ultraviolet and Optical Light Curves*

The continuum intensity as a function of time and orbital phase during the 1980 September observation is illustrated for various wavelength intervals in Figure 3. The phase is calculated using a revised orbital period, $P_{rev} = 0^d.149627$ (Patterson 1981, private communication; Córdova, Mason, and Horne 1982); the epoch of maximum light is that of Patterson and Price (1981).

The *B* band light curve peaks at phase 0.1, roughly consistent with the above ephemeris. The modulated fraction of the *B* band light is about 25%. A modulation similar in phase and intensity was observed with the FES visual photometer on *IUE*. The long-wavelength ultraviolet light curve, in contrast, is flat to within a few percent. For example, the ratio of the summed flux of LWR 8739 to LWR 8738 is 1.04, compared with the value of 1.20 for the *B* band in the same time intervals. The flux in the longest wavelengths ($\lambda > 1700$ Å) of the SWP exposures also shows no significant modulation. In the 1260–1535 Å band there is a 12% step in intensity between the two exposures that comprise SWP 10040 (in antiphase with the *B* band modulation). As noted in § II, it may be that no more than a small fraction (i.e., ≤ 7%), if any, of this effect is astrophysical.

c) *The Emission-Line Spectrum and Variability*

The short-wavelength UV spectra, shown in Figure 4 (1980 September 7) and Figure 5 (1981 January 3), consistently exhibit emission lines of N v λ1240, Si iv λ1400, C iv λ1549, and He ii λ1640. To ascertain whether

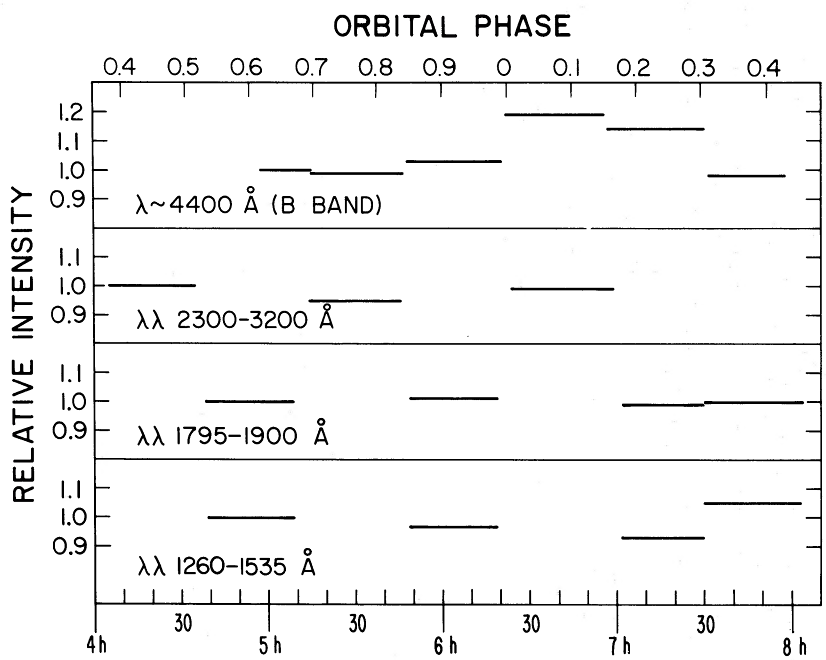

FIG. 3.—Continuum light curves of H2252−035 as a function of wavelength. The data have been normalized to the flux value of the first point in time for each wavelength band. The *B* band data have been summed over intervals corresponding to the UV exposure sequences. Orbital phase is calculated from an epoch JD=2,444,428.873 using a period of $0^d.149627$. As cautioned in the text, the apparent 12% difference between the last two points of the 1260–1535 Å light curve may be largely an instrumental effect.

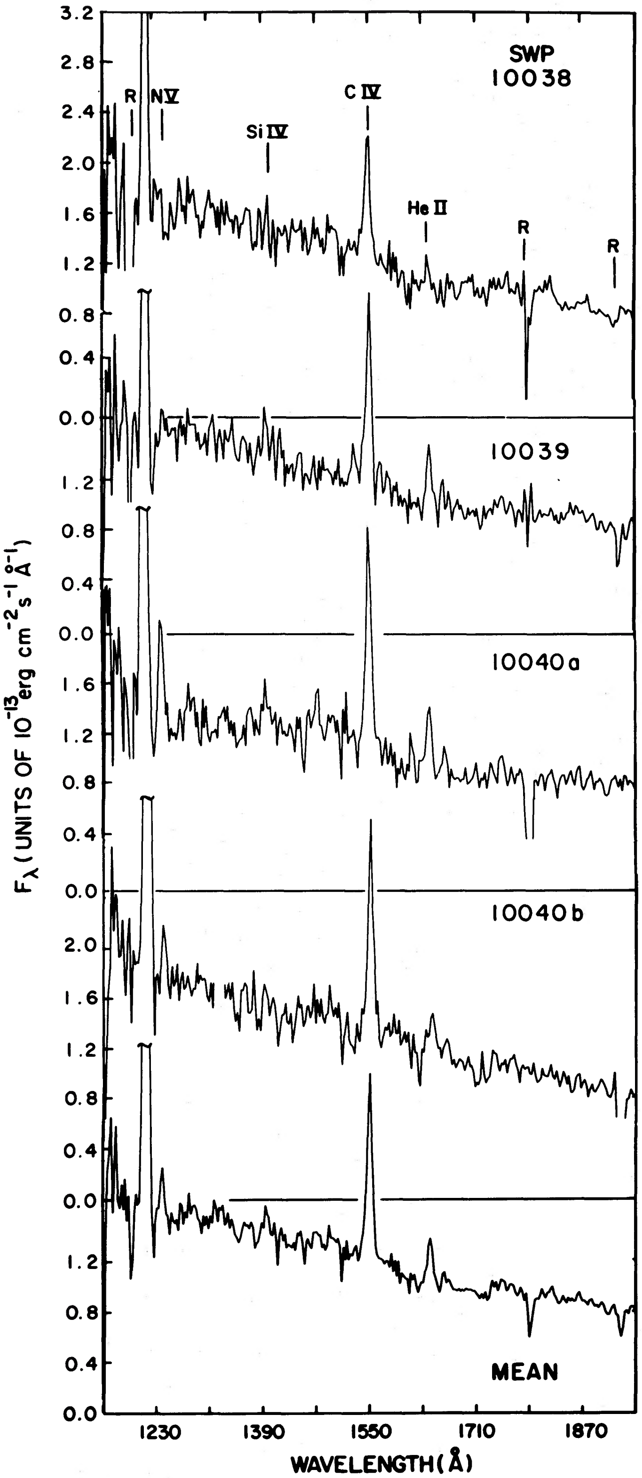

FIG. 4

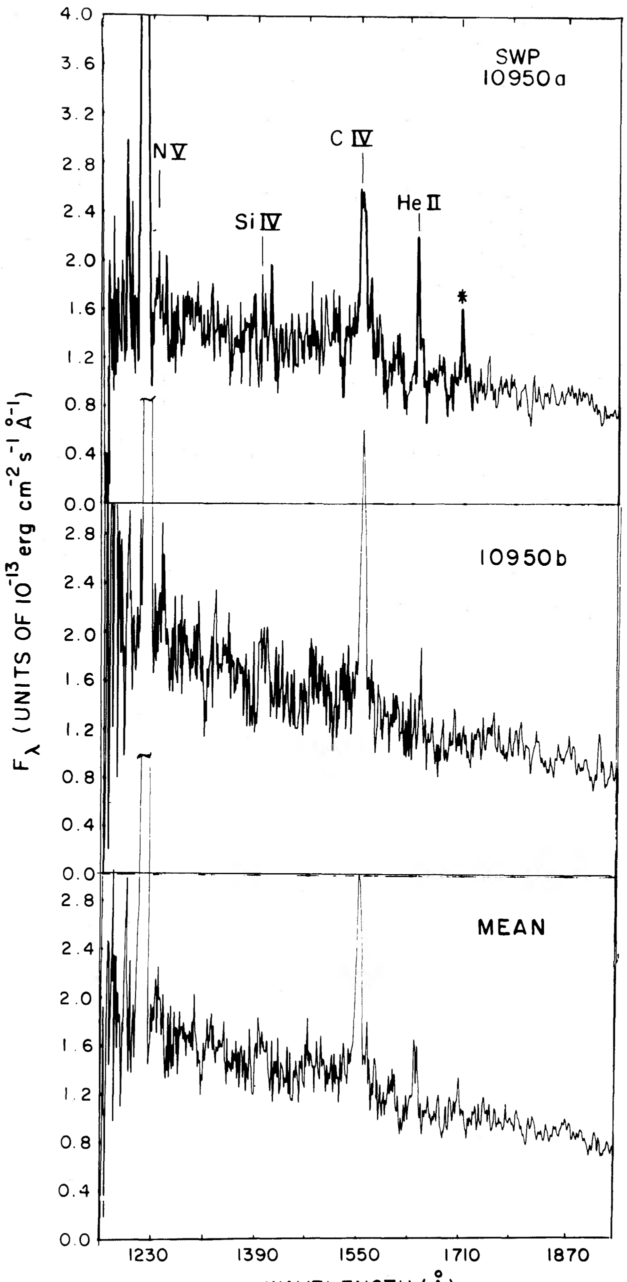

FIG. 5

FIG. 4.—Reduced short-wavelength (SWP) spectra of H2252−035 taken on 1980 September 7. The bottom panel shows the mean of all the individual spectra. The prominent emission lines have been marked. Features labeled "R" are due to camera reseaux.

FIG. 5.—Similar to Fig. 4, but for 1981 January 3. The sampling frequency is twice that of Fig. 4 (a result of GSFC improvements to the extraction of low-dispersion spectra between the time of the two observing runs, thus making full use of the ~6 Å spectral resolution possible). This increases the noise by ~1.4 but allows us to observe that the He II λ1640 line is possibly double, with the shortward wing predominating during 10950a and the longward wing during 10950b. The mean spectrum shows the two peaks clearly. The asterisk denotes an ion hot spot.

H2252−035 contributes some of the Lyα flux in the spectra, we analyzed the flux distribution in the direction perpendicular to the dispersion using the spatially resolved spectral files. Measurement of the Lyα flux of H2252−035 proved difficult because of the very large contribution from geocoronal Lyα. Only spectra containing one image of the source could be used (i.e., SWP 10038 and 10039). We find that Lyα is present in absorption in H2252−035 and that the absorbed flux is $\sim 1.5 \times 10^{-12}$ ergs cm^{-2} s^{-1}.

There are peaks above the local noise in single spectra at λ1527 (Si II?), λ1613 (Al III?), and λλ1661, 1666 (O III]?), but all may be spurious. The 1981 January spectra have better wavelength resolution than those taken in 1980 September because of improvements in the GSFC extraction procedure between the two runs. With the enhanced spectral sampling rate, SWP 10950 shows that the He II λ1640 line may be double. All the long-wavelength *IUE* spectra (not shown) exhibit weak Mg II λ2800 emission.

The optical spectra exhibit Hβ, Hγ, Hδ, and He II λ4686 emission lines, and occasionally the λ4640 blend (C III/N III/O II) in emission. The summed spectrum is shown in Figure 6. The width of the spectral lines has been measured by calculating the rms moment for the line.[2]

[2] Width (km s^{-1}) $= (2c/\lambda_0)\{[\sum I(\lambda_i)(\lambda_i - \lambda_0)^2]/[\sum I(\lambda_i)]\}^{1/2}$, where the $I(\lambda_i)$ are the intensities (above the continuum) at each discrete value of λ; λ_0 is the centroid of the line; and c is the speed of light. For a Gaussian-shaped line, this width is equivalent to 2 σ.

For Hβ, He II λ4686, Hγ, and Hδ, the widths so derived are in units of km s^{-1}, 900 ± 100, 1100 ± 100, 1000 ± 100, and 1300 ± 200, respectively.

The fluxes and equivalent widths of the UV and optical lines, averaged over all spectra for each of the two observing runs, are listed in Table 2. No correction for reddening has been applied to the fluxes. The observed ratios (averaged over *all* SWP spectra) for N V:Si IV:C IV:Mg II are 1.0:1.0:4.4:0.5 (or 1.0:0.9:4.1:0.4 when corrected for $E(B-V) = 0.10$). These ratios compare favorably with the collisionally excited line emissivities predicted in the limit $T \geq 10^5$ (Jameson, King, and Sherrington 1980). The average ratio of the He II lines λ1640/λ4686 for the 1980 September observation is 5.0; corrected for reddening this ratio is $7.3^{+1.2}_{-2.0}$ (where the errors correspond to the 3 σ limits on the reddening). This is consistent with the theoretical ratio for a recombination spectrum (Seaton 1978).

In Figure 7 we have plotted the fluxes of the brighter emission lines as a function of time during the 1980 September observation. The UV line fluxes and Hβ appear to be modulated in phase with the *B* band light (cf. Fig. 3). To quantify the relative amplitude of the variability in each line, we compute the ratio of the line flux in SWP 10038 to that in the first exposure of SWP 10040 (or the equivalent time interval in the case of the optical spectrum). This ratio is 2.6:2.2:1.6:>1:>5, respectively, for the Hβ, He II λ1640, C IV λ1549, Si IV λ1400, and N V λ1240 lines. The He II λ4686 line does

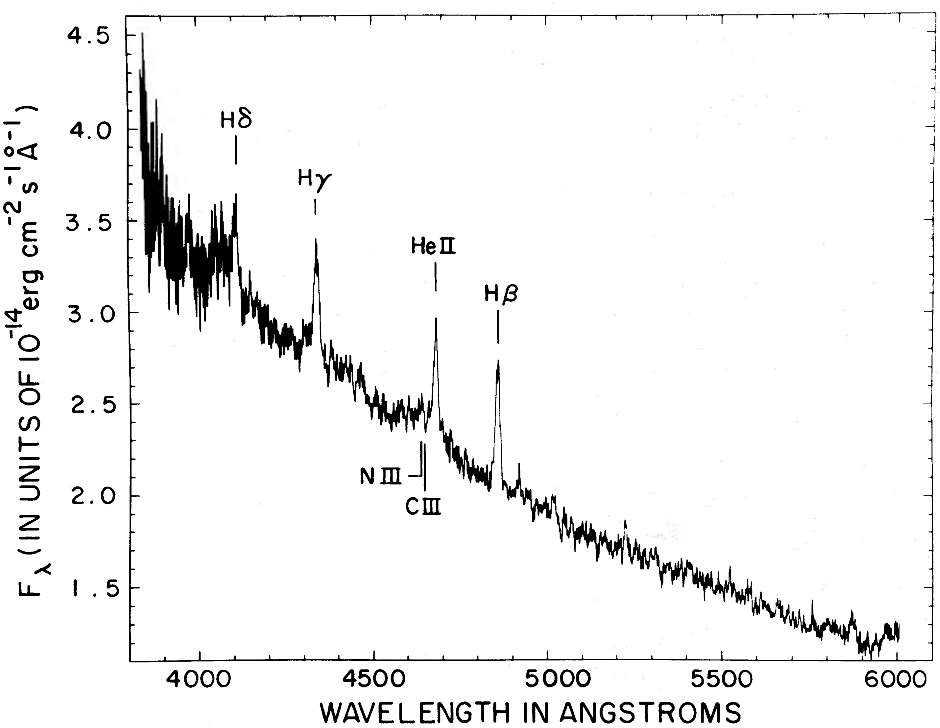

FIG. 6.—An optical spectrum of H2252−035, which is averaged over all the spectra that were taken simultaneously with the *IUE* observations of 1980 September 7. The total exposure time in this spectrum is 168 minutes.

TABLE 2

Line Fluxes and Equivalent Widths of H2252−035

Line	⟨Flux⟩[a] (10^{-13} ergs cm^{-2} s^{-1})		⟨Equivalent Width⟩ (Å)	
	1980 Sep 7[b]	1981 Jan 3[c]	1980 Sep 7[b]	1981 Jan 3[c]
Lyα λ1215	15.0[d]	...	8.7[d]	...
N v λ1240	3.4	5.9	2.3	3.2
Si iv λ1400	4.0	4.9	3.1	3.5
C iv λ1549	15.6	22.6	13.3	17.9
He ii λ1640	4.2	5.4	4.4	5.4
Mg ii λ2800	2.2	...	4.0	...
He ii λ4686	8.4	...	3.1	...
Hβ λ4861	9.8	...	4.7	...
Hγ λ4340	9.6	...	3.4	...
Hδ λ4101	7.1	...	2.2	...

[a] Not dereddened.
[b] The 1980 September data are averaged over all binary phases.
[c] The 1981 January data are averaged over only phases $\phi = 0.8$–1.0.
[d] Lyα is the only line detected in absorption, rather than emission. Values for Lyα are approximate owing to difficulty in subtracting geocoronal Lyα.

not vary in strength by more than 30%. The Hγ line (not shown in Fig. 7) behaves similarly to Hβ. The mean ratio Hβ:Hγ is $\sim$1 and also does not vary by more than 30% during the observation.

The short SWP observation of H2252−035 by HEA was centered at phase $\phi = 0.75$. We estimate that the equivalent width of C iv in their spectrum is about a factor of 2 larger than that quoted by them (cf. their

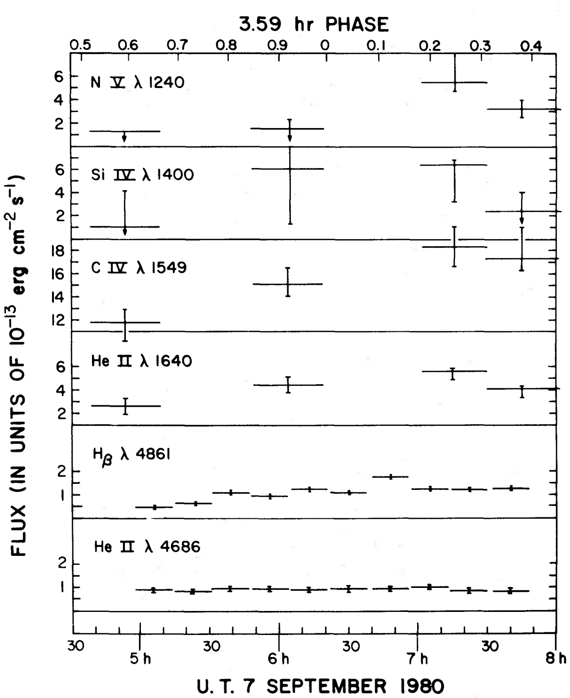

Fig. 7.—The emission-line fluxes of the prominent UV and optical lines observed in 1980 September as a function of time and orbital phase. The optical data are plotted at 16 minute intervals; the UV data are plotted for the intervals listed in Table 1. A downward arrow signifies a value for the flux compatible with zero.

Fig. 2), and thus the flux in the C iv line is 1.1×10^{-12} ergs cm^{-2} s^{-1}. HEA's spectrum is similar in appearance to our SWP 10038, which was centered at a similar orbital phase, $\phi = 0.6$. The continuum flux level of H2252−035 was also about the same during the two observations. The differences between our summed spectrum and that of HEA, taken one month apart, are thus no larger than would be expected if the line variability found in 1980 September were a function of orbital phase.

In 1981 January the continuum level was about 5% higher than during 1980 September, while the C iv λ1549 line was 50% stronger than at the same orbital phase in September. The remaining UV lines appear on average to be slightly stronger in January than in September, but the differences are less significant than for C iv. The changes in the C iv line demonstrate that the lines do vary in strength over and above any effect that might be related to orbital phase.

The observed ratio He ii $\lambda1640/\lambda4686 \sim 5$ derived by us differs considerably from the ratio of less than unity reported by HEA from their nonsimultaneous UV and optical measurements of H2252−035. As noted above, the He ii λ1640 line appears in all six of our short-wavelength spectra, although it is variable by a factor of 2.5. We also measure the average flux of the He ii λ4686 line to be more than a factor of 2 smaller than that reported by HEA. It is thus likely that orbital or stochastic variability, compounded by the nonsimultaneity of HEA's UV and optical observations, has contributed to the discrepancy between our measurements and HEA's measurement of the He ii ratio.

IV. DISCUSSION

a) Summary

The ultraviolet data presented here constitute a factor of 10 more exposure time on H2252−035 than the previous UV measurement by HEA. With the additional data we are able to determine that the source is reddened, with $E(B-V)=0.10$ giving the best fit. We have decomposed the continuous spectrum from 1200 to 22000 Å into two components: a blackbody with a temperature of 13,400 K, similar to that measured by HEA, and a power-law component ($F_\lambda \propto \lambda^{-\alpha}$) with $\alpha = 2.74$. The latter component fits the UV and IR excesses noted by HEA. The slope of the power law is close to the $\alpha = 2.33$ distribution expected of an infinitely large, optically thick, steady-state accretion disk (Lynden-Bell 1969); the $\alpha = 2.74$ value is consistent with a disk model having a slight curvature because of its finite extent (e.g., see Bath, Pringle, and Whelan 1980).

The equivalent widths of the UV lines in H2252−035 are about a factor of 5 less than those of the magnetic variables AM Herculis and 2A 0311−227; in these binaries the compact, accreting star is thought to be corotating with its companion, and there is no evidence that there is a significant accretion disk (see references in Córdova and Mason 1982). The equivalent widths of the emission lines in H2252−035 are similar to those of some disk-accreting dwarf novae during outbursts (e.g., see Szkody 1981). This information, plus the model fit to the continuum, suggests that H2252−035, too, might have an appreciable disk.

The emission-line intensities of H2252−035 are variable by about a factor of 2. Our continuous observations around one binary cycle suggest that some of the variability could be accounted for by a modulation in phase with the optical continuum binary modulation. Additional, although much shorter, observations at a different time reveal that there must also be variability in the lines unrelated to the orbital modulation.

b) Models

In the model of H2252−035 proposed by Patterson and Price (1981) the 858 s reprocessed X-ray pulsation, the optical emission lines, and the 3.6 hr variation are all attributed to the heated face of the mass-transferring companion star. This model is consistent with the phasing of the latter two variations, but, as pointed out by HEA, it is not compatible with the constraints imposed by the amplitudes of the continuum and radial velocity variations and with the measured 13,000 K blackbody spectrum. According to HEA, a more likely reprocessing site, which is in agreement with the data, is a locally thick region (or bulge) on the outer edge of the disk, where the mass stream from the companion impacts it. By analogy with the model of Patterson and Price, the 3.6 hr optical modulation may be due to the changing aspect of the bulge with orbital phase. However, our UV orbital phase data are inconsistent with the modulated source being a 13,000 K blackbody. For the observed 25% (peak to peak) modulation at 4400 Å (see Fig. 3) such a spectrum predicts a 16% variation at 2500 Å and a 9% variation at 1800 Å. Yet longward of 1700 Å our UV light curves are not modulated by more than 5%. Simultaneous multicolor optical and UV photometry around the orbit are required to more accurately measure this spectrum. Such observations may also permit us to improve on the simple model used to describe the mean continuum.

What could cause an orbit-related variation in the emission lines? One possibility is that the line-emitting region is associated with an atmosphere above the *inner* disk, and the modulation caused by an occultation by the bulge at phase 0.5. In such a model, though, the UV continuum associated with the inner disk would be modulated even more than the extended emission-line region. Our upper limit on a modulation in the UV continuum argues that the emission-line variation must be produced in another way. A more viable possibility is that the emission lines are associated with the inner face of the disk rim (which has the greatest projected area when the bulge is viewed in the direction of phase 0.0: maximum *B* light). The lines may be produced in an optically thin atmosphere on the inside of the disk rim, which is probably heated by the central X-ray source. As previously discussed, the temperature of this optically thin gas has to be $T \geq 10^5$ K to reproduce the observed UV line ratios.

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