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AN ULTRAVIOLET AND VISIBLE SPECTROSCOPIC STUDY OF A PULSATIONAL CYCLE OF RY SAGITTARII

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ABSTRACT

High-dispersion visible and ultraviolet spectra and *UBVRI* photometry, covering a complete pulsation of the R Coronae Borealis star RY Sgr, have been obtained. The UV spectra were the first high-dispersion data ever obtained for the star. Together these observations comprise the most complete data set covering an RCB star pulsation cycle. The cycle observed was somewhat anomalous as it was affected by a second 55 day pulsation period as well as the primary 38 day period. Howevever, the visible spectra showed the typical line splitting and radial velocity variations which have been observed previously. The simultaneous UV spectra showed much smaller, and phase-shifted, velocity variations than those seen in the visible. No evidence was seen of shock-induced emission at Mg II. These observations provide some support for the models of pulsating hydrogen deficient stars developed by Saio & Wheeler.

Subject headings: shock waves — stars: individual (RY Sagittarii) — stars: oscillations — stars: variables: other (R Coronae Borealis) — ultraviolet: stars

1. INTRODUCTION

The R Coronae Borealis (RCB) stars are a small group of hydrogen-deficient carbon-rich supergiants which undergo spectacular declines in brightness of up to 8 mag at visible wavelengths at apparently irregular intervals. The basic details of this process have been known for over 50 yr (e.g., Payne-Gaspochkin 1963). A cloud of carbon-rich dust forms along the line of sight to the RCB star and eclipses the photosphere, causing a severe drop in the brightness of the star and the appearance of a rich emission-line spectrum. As the dust cloud disperses, the star returns to maximum light. All RCB stars seem to be slightly variable at maximum light and are probably all pulsating variables (Lawson et al. 1990). These pulsations seem to be directly related to the process of dust formation in the RCB stars. The declines of RY Sgr and V854 Cen always begin at approximately the same pulsational phase (Pugach 1977; Lawson et al. 1992). This direct connection between pulsational phase and dust formation indicates that the dust may be forming very close to the star. Clayton et al. (1992, 1993) suggest that it is likely that dust is indeed forming in close proximity ($< 2R_*$) to the RCB star photosphere, based on timescales for acceleration of the dust, eclipse of the chromospheric region, and dispersal of the dust. Whitney, Balm, & Clayton (1993) point out that the temperature at which amorphous carbon forms can be as high as 4000 K and can occur in conditions far removed from thermodynamic equilibrium, as long as a mechanism exists to contain carbon atoms within a given volume. A likely form of carbon condensate is fullerenes such as C_{60}.

Shocks forming in the atmosphere of an RCB star during pulsations may provide such a mechanism for containing the carbon. But the physical role that pulsations play in dust formation is not understood. In stars such as Mira variables, the pulsations both increase the density in the outer atmosphere and decrease the temperature through adiabatic expansion thus improving conditions for the formation of dust grains which are then pushed away from the star through radiation pressure (Willson 1988). Evidence for shock heating can be seen in Mira variables where the amount of emission in Mg II rises and falls in phase with the pulsational light curve (Brugel, Willson, & Cadmus 1986). Changes in band strengths of C_2 and CN are correlated with pulsational phase in R CrB (Whitney, Clayton, & Meade 1994) and RY Sgr (Lloyd Evans 1986).

In R CrB at least two dominant pulsation periods (44 and 51 days) seem to be present at different times in the light curve (Lawson 1991). RY Sgr shows two periods of about 38 and 55 days (Lawson et al. 1990). Changes in the amplitude and/or period of pulsation, such as those seen in R CrB and RY Sgr, may affect the efficiency of the dust production (Clayton, Whitney, & Mattei 1993).

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The pulsations of RY Sgr have been particularly well studied. Analyses of photometric and spectroscopic data obtained since 1898 show the star to have a mean period of about 38 days (e.g., Alexander et al. 1972). Radial velocity variations indicate a pulsation amplitude of up to 40 km s^{-1} (Lawson, Cottrell, & Clark 1991). The nature of the radial velocity variations indicates the presence of shock waves in the atmosphere of RY Sgr. A velocity discontinuity is seen at about the time of maximum light during the pulsation cycle which is manifested as a doubling or splitting of the absorption line spectrum (Lawson 1986; Lawson et al. 1991).

High-dispersion UV spectra exist only for R CrB itself. Holm & Doherty (1988) obtained nine high-dispersion spectra of R CrB with *IUE* over a 42 day period. They were able to model continuum variations using a combination of pulsations and variable dust extinction. They were also able to measure radial velocity variations of about 6 km s^{-1}. Rao et al. (1981) suggested that emission was present at Mg II in a high-dispersion spectrum of R CrB taken at maximum light. Emission is certainly present in RCB stars at all times (Clayton et al. 1992), but it is not known whether the strength of this emission varies in concert with the pulsations.

Until now, the study of the RY Sgr pulsations has been confined to the visible part of the spectrum. We have obtained UV and visible high-dispersion spectra during a complete pulsation cycle of RY Sgr. In addition, we have *UBVRI* photometry covering the period during which the spectroscopic observations were obtained.

2. OBSERVATIONS

The observations for this program took place throughout 1991 (JD 2,448,350–2,448,600), with most of the spectroscopic observations concentrated during one pulsation cycle of RY Sgr (JD 2,448,490–2,448,540). Light and color curves for RY Sgr during 1991 are shown in Figure 1 with the times of the spectroscopic observations marked. *UBVRI* photometry was obtained throughout the year at Mount John University Observatory (MJUO). These data were acquired with a 0.6 m telescope and an automated single channel photometer. A detailed description of the observing setup and data reduction techniques is given in Lawson et al. (1990).

2.1. *Ultraviolet Spectroscopy*

The new *IUE* observations of RY Sgr presented here are summarized in Table 1 and the times are marked in Figure 1. Eight high-dispersion LWP large-aperture spectra were obtained at 4–6 day intervals between JD 2,448,500 and 2,448,536. Table 1 lists the times of observation, LWP image number, exposure time, magnitude as measured by the Fine Error Sensor (FES), and radial velocity. An additional LWP spectrum was obtained earlier on JD 2,448,399. Figure 2 shows the spectral region from 2780 to 2880 Å with the major lines identified. The LWP spectra were reduced using a slightly modified version of the *IUE* RDAF routine IUESPEC (T. Ayres 1993, private communication). Figure 3 shows the Mg II λ2800 region for each of the nine spectra. A three-point boxcar average has been applied to the data to match the resolution of the spectrograph. The resolution of the *IUE* high-dispersion LWP spectra is about 0.3 Å, or $\lambda/\Delta\lambda \approx 9000$ at 2800 Å. The spectra have been corrected for the heliocentric and geocentric motions of *IUE* using the IUEVEL routine (Taylor 1993).

The image LWP 21213 was obtained at a different reference point within the large aperture than the other eight exposures which were all obtained at the default position. This different reference point was chosen to move the reseau marks but not introduce any velocity offset. The position was verified and the image was reprocessed by *IUE* in order to check for any velocity offset which may have been introduced. Although none was found, we have some reservations about the radial velocity derived from this spectrum (see § 3.3). All the spectra were obtained in the large aperture so that any guiding problems could have introduced spurious velocities. However, these spectra were obtained before the FES streak problems developed and good guide stars were available for all the exposures.

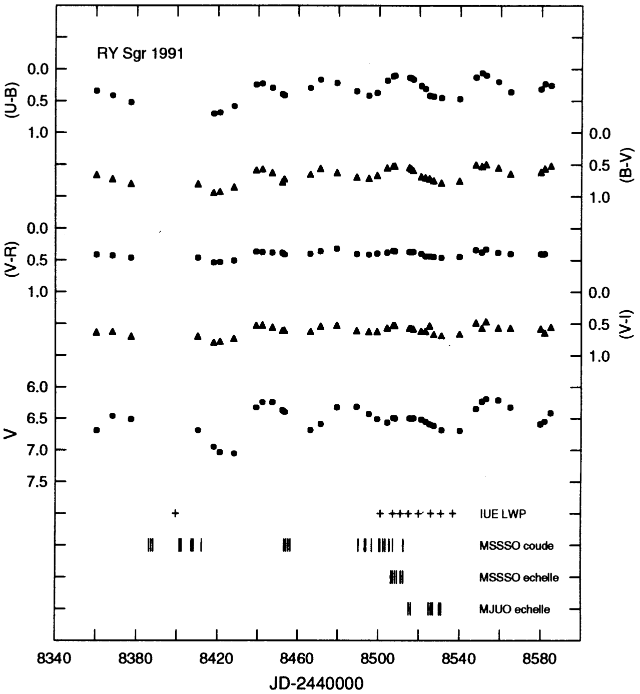

FIG. 1.—The MJUO *UBVRI* photometry obtained during 1991. The times of the UV and visible spectroscopic observations are marked.

2.2. *Visible Spectroscopy*

Spectroscopic observations were obtained at two sites. Observations of RY Sgr were made at various times throughout the year with the 1.9 m telescope at Mount Stromlo and Siding Spring Observatories (MSSSO) at the coudé focus. For most of these observations, the spectrograph was used in the regular coudé mode using the "C" grating in second order, which provides a reciprocal dispersion of 10 Å mm^{-1} at Hα.

TABLE 1

NEW *IUE* LWP OBSERVATIONS OF RY SAGITTARII

JD (2,440,000+)	LWP	Exposure Time (s)	V_{FES} (mag)	Radial Velocity (km s^{-1})
8,399.302	20427	25200	6.7	−12.0
8,500.723	21127	25200	6.7	−12.2
8,506.651	21177	23100	6.5	−17.5
8,510.636	21213	25500	6.6	−6.4
8,514.629	21245	26820	6.6	−15.6
8,519.644	21290	24600	6.7	−8.5
8,525.639	21338	25200	6.7	−5.6
8,530.611	21375	25500	6.8	−7.5
8,536.551	21427	26100	6.9	−10.0

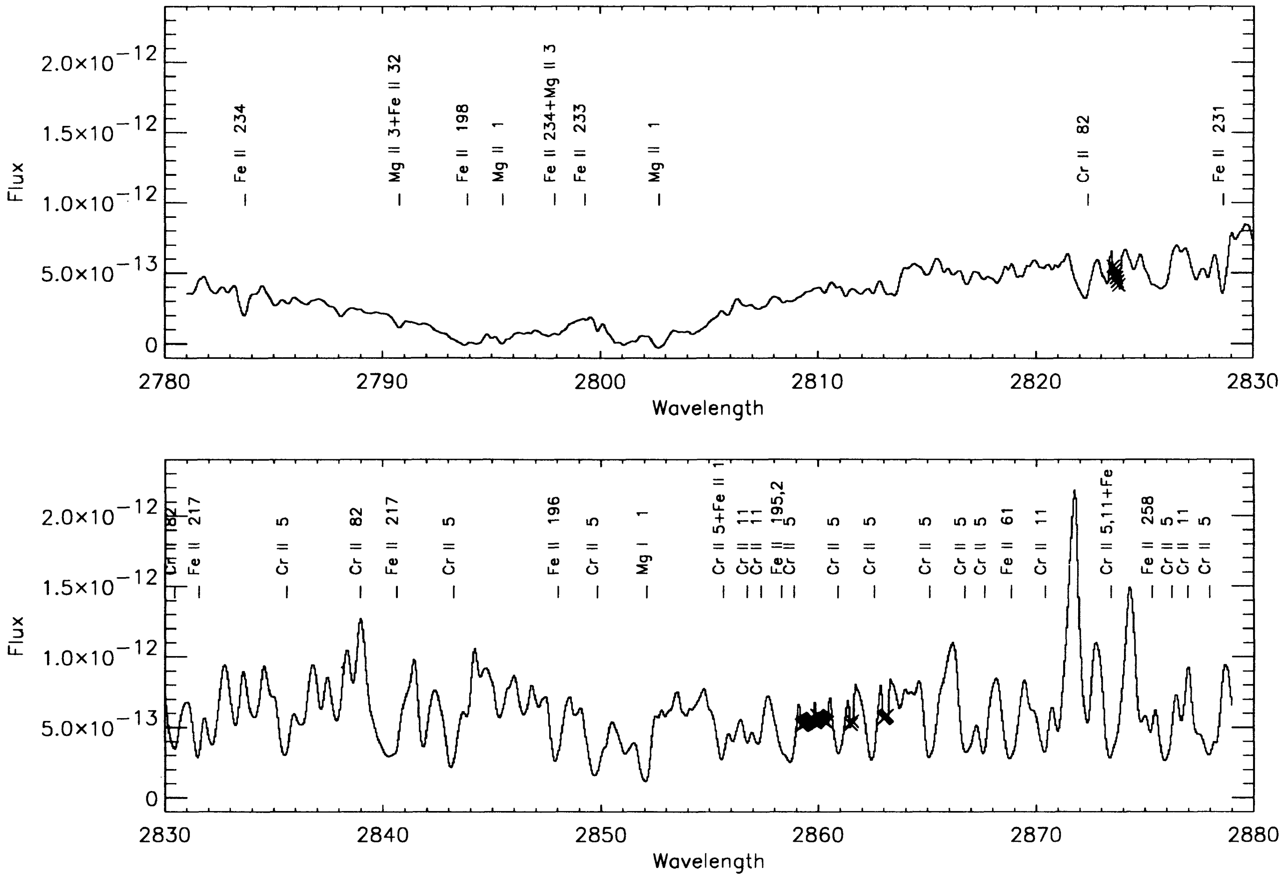

FIG. 2.—Sum of the nine *IUE* high-dispersion LWP spectra of RY Sgr obtained during 1991 showing the 2780–2880 Å spectral region. The cross is used to denote reseau marks and saturated pixels.

Spectra were obtained in the interval 6540–6655 Å or 6510–6710 Å depending on the CCD detector in use (these are denoted as mssso "short" or "long" in Table 2). At several times during the period of the *IUE* observations, the coudé was modified to operate in échelle mode at 2.5 Å mm^{-1}, covering 40 Å intervals near Hα and the Si II λ6371 line. Additional high-resolution observations were obtained with the 1 m telescope, echelle spectrograph (2 Å mm^{-1} at Hα) and CCD detector at MJUO. Intervals of 40 Å were observed in a number of orders, in particular near Hα and Si II λ6371. The dispersions of the three setups are 0.15 Å pixel^{-1} (MSSSO coudé), 0.05 Å pixel^{-1} (MSSSO échelle) and 0.04 Å pixel^{-1} (MJUO échelle), respectively. This corresponds to a spectral resolution ($\lambda/\Delta\lambda$) for the MSSSO and MJUO setups (3 pixel resolution) of ≈15,000, 45,000 and 50,000, respectively.

The times of these observations are also marked in Figure 1 and are summarized in Table 2. Figure 4 shows the MSSSO coudé spectra. Figures 5 and 6 show the MSSSO and MJUO échelle data for the Hα and Si II λ6371 regions, respectively.

3. RESULTS

3.1. *The Pulsations*

RY Sgr has the best characterized pulsation period of any RCB star. Although the light curve varies from cycle to cycle, the dominant period of ~38 days is semiregular in both duration and amplitude. Several attempts have been made to explain variations in the $O-C$ plane for RY Sgr in terms of a decreasing or varying pulsation period (Marraco & Milesi 1982; Kilkenny 1982; Lawson & Cottrell 1988, 1990). However, recently Lombard & Koen (1993) have criticized the use of $O-C$ diagrams to justify pulsation period variations and find for RY Sgr, that the observed variations in $O-C$ are random. This has reduced our ability to accurately forecast critical phases at which to obtain observations, such as during the shock wave phase. For example, the most recent pulsation ephemeris for RY Sgr (Lawson & Cottrell 1990) fails to predict the times of maxima on the light curve when the solution is extrapolated to pulsation cycles during 1991.The predicted times of maximum light on the light curve lead the observed times by 10–15 days.

From a Fourier analysis of photometry of RY Sgr obtained at MJUO during 1986–1989, Lawson et al. (1990) found an additional periodicity of ~55 days duration that seems to be irregular in amplitude. During 1988 the 55 day mode was similar in amplitude to the main 38 day cycle, but was found to be weaker by a factor of 2–4 in the other years. Amplitude spectra for the 1991 V, $(U-B)$, and $(B-V)$ data sets show this period again to be present, with the 55 day (frequency $f \approx 0.018$ day^{-1}) mode having a larger amplitude than the 38 day ($f \approx 0.026$ day^{-1}) mode in the V photometry (Fig. 7). The unusual appearance of the pulsation cycle starting around JD 2,448,500 (see Fig. 1), during which most of our spectroscopic observations were obtained, is due to the strong presence of the 55 day period.

The 38 day period is an average period and in any individual cycle may be different by 20% or more. Also, as shown in

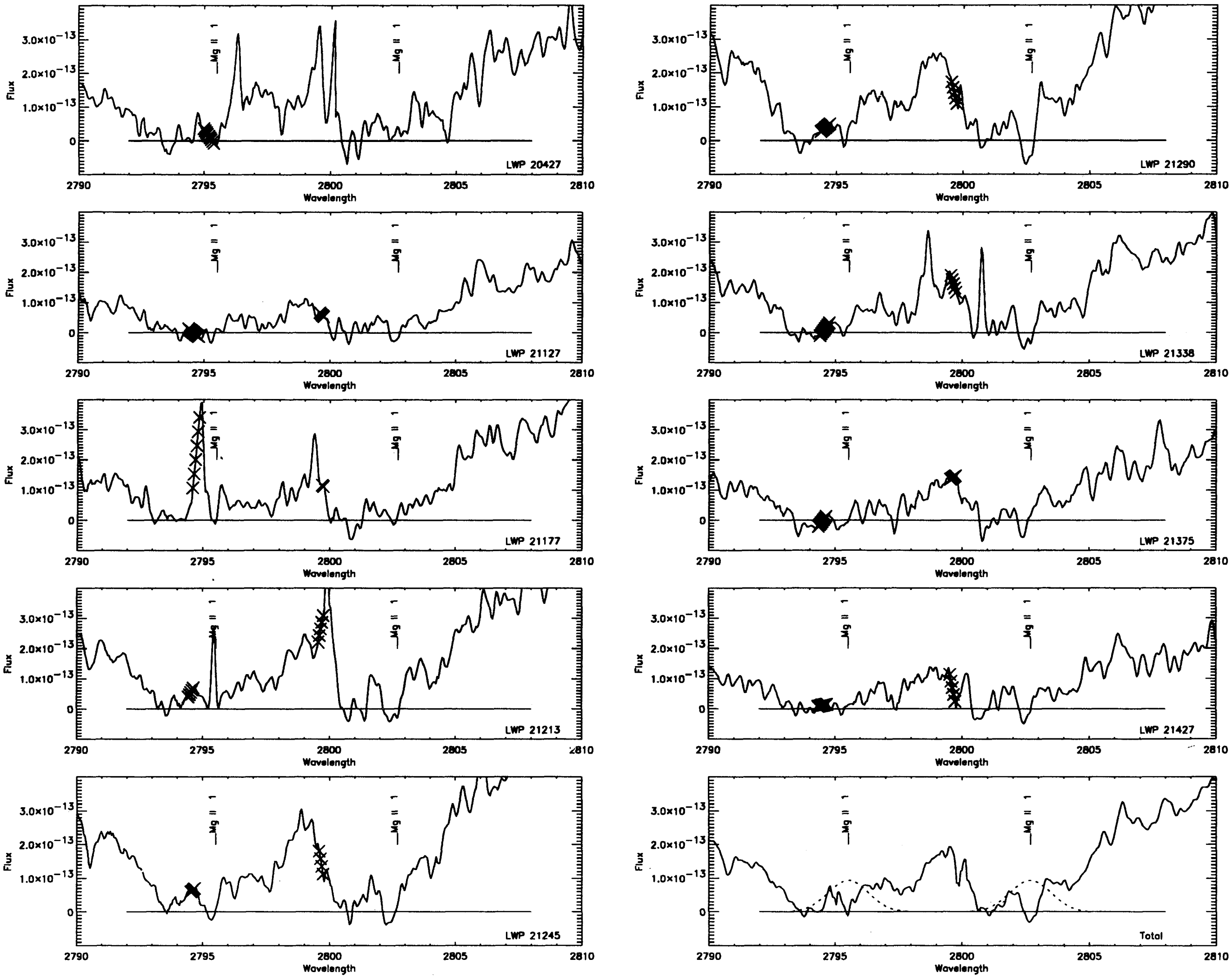

FIG. 3.—The Mg II λ2800 spectral region for the individual high dispersion LWP spectra. The cross is used to denote reseau marks and saturated pixels. Also shown in the bottom right-hand panel is the sum of the nine spectra with the expected Mg II emission plotted in dashed lines (see § 3.2.2 for discussion).

Figure 7, the 55 day period is strongly present in 1991. However, it does appear that there are maxima separated by about 40 days at ~JD 2,448,365, 2,448,405, 2,448,445, and 2,448,485. The following cycle, which should have a maximum around JD 2,448,525, is very strange in appearance and is apparently affected by the 55 day period. The color variations appear more regular. The times of the color maxima lead the light maxima by typically 4 days as is normal. Even during the strange light cycle around JD 2,448,525, the color behavior seems to indicate a normal cycle of about 40 days duration. Note that the amplitude spectra for the $(U-B)$ and $(B-V)$ data sets are dominated by the 38 day period even though the 55 day period is also present.

3.2. *Spectroscopic Variations*

3.2.1. *Visible*

Line splitting in RY Sgr spectra was first noted by Danziger (1963). Cottrell & Lambert (1982) found that the absorption lines split at certain phases and apparently were related to the 38 day period of the star. From observations of RY Sgr obtained in 1984, Lawson (1986) showed that the line splitting occurred around maximum light on the pulsation cycle due to shocks in the atmosphere of the star. He found that many strong lines are split. Among them are C I, Ba II, Fe II, Si II, and Ti II. Weak lines did not appear to split but this may be a S/N effect. Just before the lines split, the spectrum took on a "washed-out" look. The spectrum returned to normal after the line splitting. The timescale of the event was about 10 days or ~0.25 of a period.

Cottrell, Lawson, & Smith (1988) reported similar results for data on RY Sgr from 1986. The onset of the splitting phase occurred near the $(B-V)$ maximum which led the time of visual maximum by 4–8 days. In a more comprehensive study, Lawson et al. (1991) found that the line splitting event may last 16–20 days (0.4–0.5 of a cycle), using data obtained at MJUO during 1988.

The new data presented here from 1991 show much the same behavior. The radial velocity variations are easily visible in Figures 4–6, as are the line-splitting events. Figure 4, which follows RY Sgr during the early part of 1991 (JD 2,448,386–2,448,512) shows clear splitting in the Ti II λ6559 line from JD 2,448,401 to 2,448,412. Figures 5 and 6 cover the pulsation cycle (JD 2,448,506–2,448,531) where we also have *IUE*

TABLE 2

New Ground-based Observations of RY Sagittarii

JD (2,440,000+)	Telescope/ Spectrograph	Wavelength	Radial Velocity (km s^{-1}) High χ	Low χ
8,386.113	mssso coudé	Short	−23	−21
8,387.109	mssso coudé	Short	−15	−23
8,388.148	mssso coudé	Short	−13	−14
8,401.152	mssso coudé	Long	−33	−44
8,401.700	mssso coudé	Long	−37	−47
8,402.152	mssso coudé	Long	−34	−48
8,403.089	mssso coudé	Long	−39	−49
8,407.199	mssso coudé	Long	−28	−41
8,408.043	mssso coudé	Long	−26	−38
8,412.109	mssso coudé	Long	−21	−33
8,453.066	mssso coudé	Long	−17	−26
8,454.125	mssso coudé	Long	−15	−25
8,455.082	mssso coudé	Long	−16	−25
8,456.043	mssso coudé	Long	−16	−23
8,493.040	mssso coudé	Long	−6	−23
8,493.700	mssso coudé	Long	9	3
8,496.600	mssso coudé	Long	10	1
8,500.125	mssso coudé	Short	11	−2
8,500.602	mssso coudé	Short	16	4
8,502.066	mssso coudé	Short	25	7
8,503.094	mssso coudé	Short	16	4
8,505.066	mssso coudé	Short	17	4
8,506.016	mssso echelle	Hα/Si II	−7	−12
8,506.973	mssso coudé	Short	−9	−21
8,506.984	mssso echelle	Hα/Si II	−7	−10
8,508.008	mssso echelle	Hα/Si II	−11	−9
8,508.953	mssso echelle	Hα/Si II	−11	−10
8,510.969	mssso echelle	Hα/Si II	−11	−9
8,511.945	mssso echelle	Hα/Si II	−13	−10
8,512.035	mssso coudé	Short	−25	−12
8,514.907	mjuo echelle	Hα/Si II	−20	−33
8,515.909	mjuo echelle	Hα/Si II	−25	−32
8,524.841	mjuo echelle	Hα/Si II	−21	−26
8,525.877	mjuo echelle	Hα/Si II	−21	−27
8,526.850	mjuo echelle	Hα/Si II	−20	−25
8,529.914	mjuo echelle	Hα/Si II	−22	−22
8,530.924	mjuo echelle	Hα/Si II	−17	−19

spectra. Both figures show the "washed-out" type spectra from about JD 2,448,514 to 2,448,516 and then distinct line splitting from JD 2,448,524 to 2,448,531 where the coverage ends. As described above, it is very difficult to determine the pulsational phase in 1991 because of the unusual light curve. However, using the $(B-V)$ curve which appears fairly normal, the line-splitting events at JD 2,448,400 and 2,448,515 appear to occur just after the $(B-V)$ maximum as previously observed in 1984, 1986, and 1988. The duration of the events cannot be ascertained due to the spectroscopic coverage, but they both last at least 10 days, again in keeping with the previous studies.

3.2.2. *Ultraviolet*

Early and late in a decline, strong shell absorption components sometimes appear showing velocities of −200 to −300 km s^{-1}, indicating gas moving away from the star. Feast (1986) suggests that absorption lines due to this material may be detectable even at maximum light in high-resolution spectra. Observations in the UV have shown that emission lines are always present around RCB stars but are generally seen only during declines when the photosphere is obscured (Holm & Wu 1982). The C II λ1335 line is visible even at maximum light because there is no stellar continuum at that wavelength to obscure the line. However, at Mg II λ2800, the emission is obscured except when the RCB star is in decline. Rao et al. (1991) suggested that some Mg II emission is measurable in a high-dispersion *IUE* spectrum of R CrB obtained at maximum light, but the spectrum is of very low S/N. We have no information on how the emission at Mg II may be varying with pulsational phase. This line is an important coolant in chromospheres. The best measurement of the driving amplitude of the pulsation is the emission from material behind the shock (Brugel et al. 1986). Much of this emission comes from the hydrogen Balmer lines and Mg II *h* and *k*. Due to the paucity of hydrogen in the RCB stars, the importance of Mg II may increase. In Mira variables, the Mg II emission strength rises and falls in phase with the pulsational period (Bookbinder, Brugel, & Brown 1989). As the shock moves outward from the photosphere, the Mg II emission increases sharply at first and then falls as the density and the shock velocity decrease (Willson 1988).

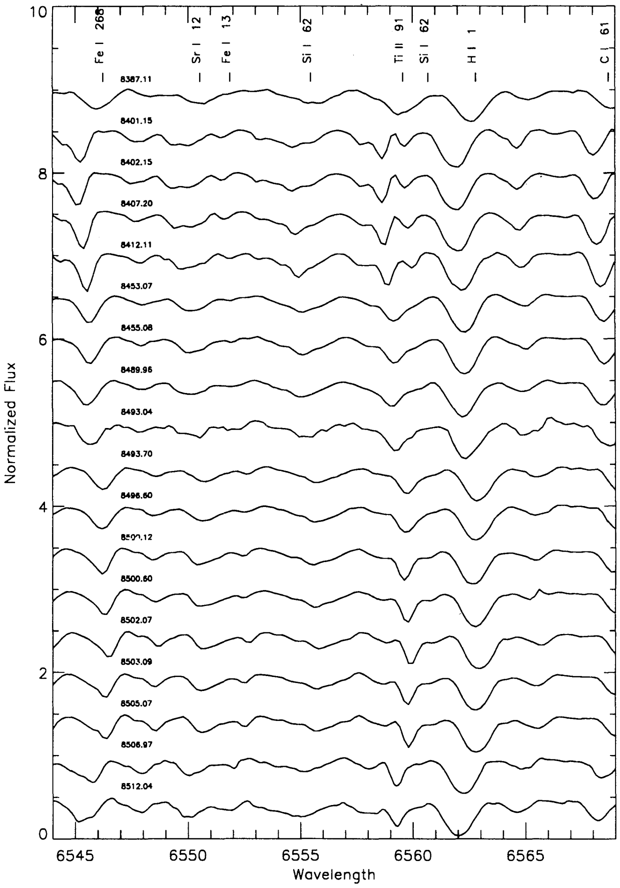

FIG. 4.—MSSSO coudé spectra showing the Hα region, 6545–6570 Å

We do have information on how strong an emission line might be expected at Mg II. The emission strength was measured during a decline of RY Sgr in 1990 (Clayton et al. 1992). The net flux in Mg II (both components are blended in the low-dispersion spectrum) was about ~3 × 10^{-13} ergs s^{-1} cm^{-2} Å^{-1}. The Mg II lines are thought to originate in the broad-line emission region (Clayton et al. 1992) which implies a FWHM of ~200 km s^{-1}. Therefore, we can calculate the expected emission in the Mg II lines using the measured flux and assumed FWHM. Figure 3 shows the Mg II region for each of the nine spectra. The bottom right-hand panel shows the

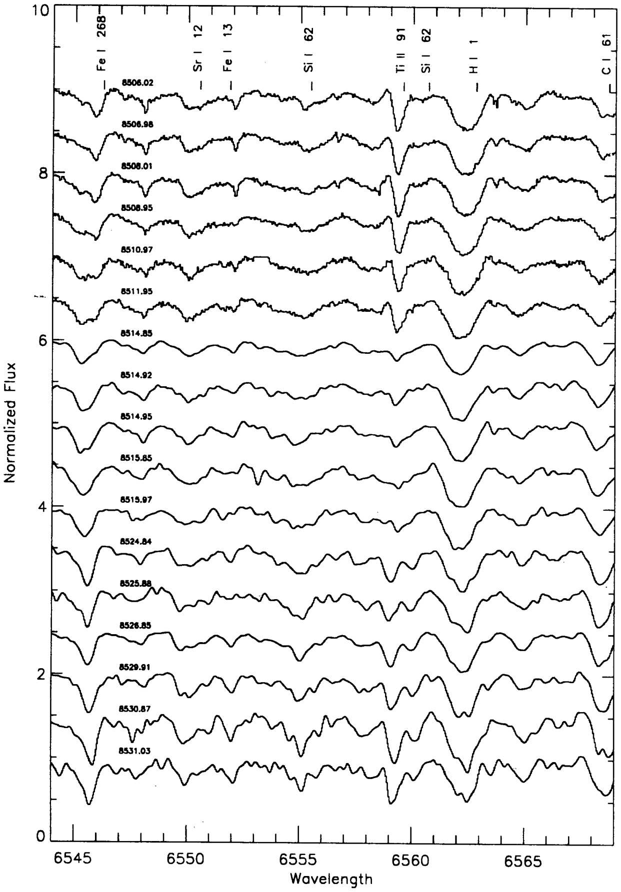

FIG. 5.—MSSSO and MJUO echelle data obtained in the Hα region, 6545–6570 Å.

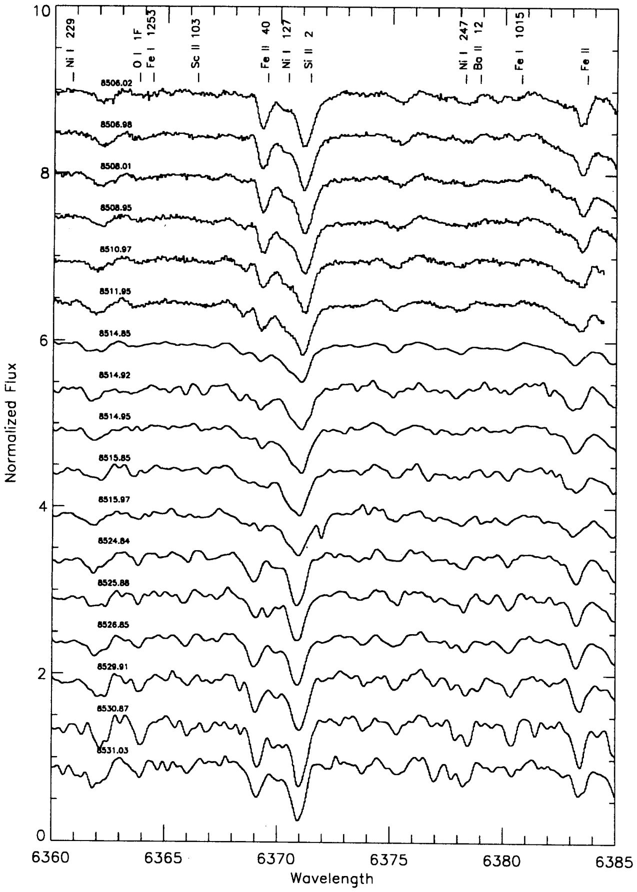

FIG. 6.—MSSSO and MJUO echelle data for the Si II λ6371 spectral region, 6360–6385 Å.

sum of the nine spectra with the calculated Mg II emission lines superposed. The individual spectra are of low S/N in the bottom of Mg II. While features do seem to come and go, they are probably noise spikes. They seem much too narrow, and appear and disappear in a random manner. The summed spectrum is of more interest. Note the similarity of the two components of Mg II. There seem to be two absorption components or perhaps a single emission component, but it seems likely that the former is the case. There is an absorption around zero velocity which may be interstellar. In addition there is an absorption from about -100 to -200 km s^{-1}. This corresponds well to the blueshifted absorptions seen at times in RCB stars. The Mg II region of R CrB shows a similar absorption feature. These features may be associated with gas being dragged along with the dust as it is blown away from the star by radiation pressure or perhaps by a stellar wind.

3.3. *Radial Velocity Variations*

Because of the large velocities in the RY Sgr shock in the visible, individual lines can be accurately measured to look for depth effects in the shock wave. For pulsations of RY Sgr during 1988, Lawson et al. (1991) found that the higher excitation lines ($\chi > 8$ eV) showed a lower shock amplitude (~ 20 km s^{-1}) compared to the lower excitation lines ($\chi < 3$ eV) (~ 35 km s^{-1}). There also appeared to be a small phase difference between the high and low excitation lines with the low excitation line velocities lagging behind those of high excitation. The amplitude and phase differences may be due to the lower excitation lines being formed in the outer parts of the stellar atmosphere relative to the higher excitation lines.

Two techniques were employed here to measure radial velocities: the measurement of individual lines, and the measurement of groups of lines using cross correlation techniques. For the UV data, we have measured velocities using cross correlation because of the lower spectral resolution of these data and concerns about line blending. A technique similar to that used by Holm & Doherty (1988) was applied to each *IUE* spectrum in the wavelength interval 2780–2880 Å. Velocities can be measured using this technique to an accuracy of ~ 3 km s^{-1} (Holm & Doherty 1988). The UV lines used in the cross-correlation lying between 2780 and 2880 Å are Cr II and Fe II lines with excitation potentials mostly between 5 and 8 eV (Moore 1952). The ground-based data have superior spectral resolution and individual lines can easily be measured. We also wished to investigate any difference in velocity between high and low excitation lines. The lines used to derive radial velocities from the MSSSO coudé and MJUO/MSSSO échelle spectra are summarized in Table 3. Average velocities derived from the measurements of the individual lines have uncertainties of typically 5 km s^{-1}. For a comparison with the UV results, the cross correlation technique was also applied to the visible spectral data.

Since individual lines were measured in the visible, it was possible to put the cross correlation results on an absolute

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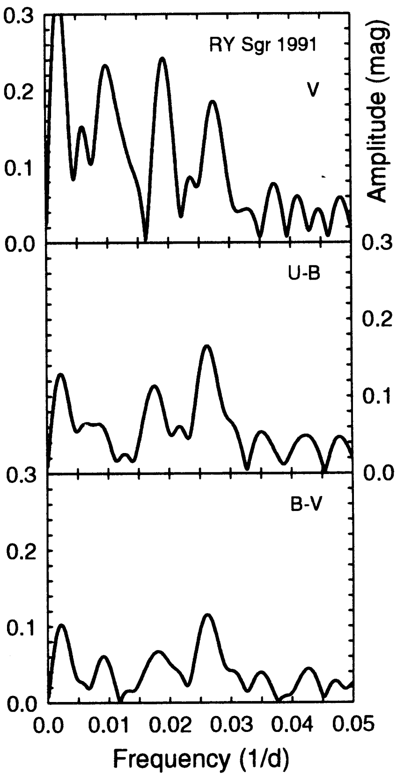

FIG. 7.—Amplitude spectra of the 1991 V, $(U-B)$ and $(B-V)$ data sets of RY Sgr. Note that a 55 day mode ($f \approx 0.018$ day^{-1}) is strongly present in the data sets, in addition to the usual 38 day mode ($f \approx 0.026$ day^{-1}).

velocity scale directly. However, in the UV the spectra were cross-correlated with a simulated spectrum whose lines were at zero velocity. The UV (cross correlation) and visible (individual line measures) velocities are listed in Tables 1 and 2. The measured velocities for RY Sgr in the 1991 data are plotted in Figure 8. The top three panels are (*a*) the velocity measured from individual lines of high and low χ, (*b*) the velocity measured from the cross correlation of lines in the Hα region, 6545–6568 Å, and (*c*) the velocity from cross correlation of lines in the UV in the Mg II spectral region, 2780–2880 Å. The bottom panels show the $(B-V)$ and V photometry for comparison.

In Figure 8, we can see that the top two panels showing the visible velocity variations are in good agreement. The amplitude of the variations are ~40 km s^{-1} which is typical for RY Sgr. There is no discernible phase difference between the high- and low-χ lines which had been previously noted (Lawson et al. 1991). There does seem to be a velocity offset between the two χ groups at all times with the high-χ lines having the more positive velocities. The two pulsation cycles with velocity coverage in Figure 8 (near JD 2,448,400 and 2,448,500) have similar behavior but different velocities. The cycle around JD 2,448,400 shows velocities which are ~10 km s^{-1} more negative. The radial velocity variations are quite similar to those seen in the previous studies of RY Sgr. Both cycles show a marked discontinuity around the time of $(B-V)$ maximum attributed to shocks.

TABLE 3

SPECTRAL FEATURES MEASURED FOR RADIAL VELOCITIES

Line	λ (Å)	χ (eV)	Spectrograph
	High χ		
Si II	6371.360	8.12	Echelle
Ni II	6541.190	15.00	Coudé/echelle
Si I	6555.470	5.98	Coudé
C I	6556.955	8.54	Echelle
C I	6568.708	9.00	Echelle
	Low χ		
Ti I	6366.356	1.46	Echelle
Fe II	6369.463	2.89	Echelle
Fe I/Ti I	6546.250	2.76/1.43	Coudé/echelle
Si I	6550.278	2.69	Echelle
Ti II	6559.576	2.05	Coudé
Ti II	6569.576	2.05	Echelle

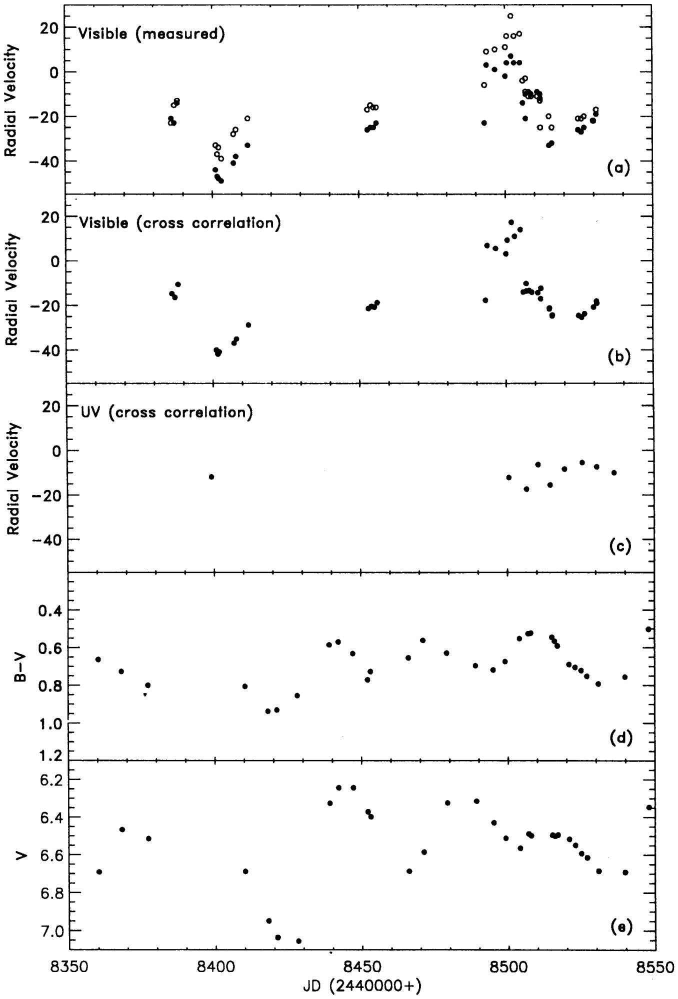

FIG. 8.—Radial velocity variations in RY Sgr. The top three panels are (*a*) velocities measured from individual lines of high (*open circles*) and low (*filled circles*) χ, (*b*) velocities from cross correlation of lines in the Hα region, 6545–6570 Å, and (*c*) velocities from the cross correlation of lines in the UV spectra. The bottom panels show the $B-V$ color and V magnitude photometry for comparison.

The new UV data show a much smaller range of radial velocity variations (~13 km s^{-1}). The observation obtained on JD 2,448,510 (LWP 21213) shows a sudden velocity change. As discussed in § 2.1, every effort was made to discover whether a velocity offset may have been introduced due to the different observing setup used to obtain this spectrum, but no such effect could be found. Therefore, this velocity change may be real. Generally, the behavior of the UV velocity curve seems to be a mirror of the visible data. Some models for hydrogen-deficient stars (e.g., model 7 of Saio & Wheeler 1985) show more distant regions of the stellar atmosphere (where the UV lines are most likely forming) pulsating at a lower amplitude and lagging up to 0.3 of a cycle behind the photospheric layers. In addition, whereas a photospheric shock is evident in model 7, a shock is not observed in the outer layers. However, photospheric shocks may not be essential for mass loss in RCB stars. R CrB itself has a radial velocity amplitude of only 10–15 km s^{-1} (Fernie & Lawson 1993) which may not exceed the sound speed in the photosphere. There are no apparent discontinuities in the radial velocity curve for R CrB that might indicate shocks are occurring.

We note that the UV velocity amplitude found for RY Sgr exceeds that observed in R CrB (6 km s^{-1}; Holm & Doherty 1988) by about a factor of 2, roughly the ratio of observed velocity variations in the visible (25–40 km s^{-1} for RY Sgr compared to 10–15 km s^{-1} for R CrB). Fernie & Lawson (1993) also point out that the ratio of velocity amplitude to V light amplitude is similar in both stars. Thus, other than the amplitude of the variations, the behavior of both stars appears to be similar. If photometric variations at maximum light reflect radial velocity variations, as suggested by the comparison between RY Sgr and R CrB, then RY Sgr represents an extreme in pulsational behavior since it has the largest pulsation-related photometric variations of any known RCB star (see Lawson et al. 1990). RCB stars with semiregular photometric variations similar to R CrB are more common.

4. SUMMARY

We have presented a large number of new high-dispersion spectra of RY Sgr. Most importantly we have obtained the first UV spectra covering a pulsation cycle of RY Sgr along with simultaneous visible spectra and photometry. Together these observations comprise the most complete data set covering an RCB star pulsation cycle. From these data we can reach the following conclusions:

1. The behavior of the visible spectral lines during the pulsation of ~JD 2,448,500 appears very similar to those previously observed in other cycles of RY Sgr over the last 10 yr. The spectral lines become washed out in appearance around the time of the $(B-V)$ maximum, followed by splitting in the strong lines which lasts at least 10 days.
2. The behavior in the visible spectra appears normal despite the strange appearance of this pulsation cycle in V. The light curve is affected strongly by the interaction between the primary 38 day period and a second 55 day period which was present in 1991. Since we believe the 38 day mode is the primary radial pulsation mode for RY Sgr, the 55 day mode must be nonradial.
3. The radial velocity variations are much smaller in the UV. It is possible that at the lower resolution, any line-splitting event is not evident in the data. There is a good correspondence between the observed visible and UV velocity behavior in RY Sgr and some models for pulsating hydrogen deficient stars.
4. No emission is seen at Mg II. It is probable that the emission, which is likely to be present, is too weak to measure. Therefore, it is not possible to infer whether some or all of the emission seen during declines is due to shock heating as in the Mira stars. It is likely that the emission reported by Rao et al. (1981) is not significant. A blueshifted absorption trough is seen at Mg II indicating a possible wind of 100–200 km s^{-1}.

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