POST-OUTBURST SPECTROSCOPY

OF

CLASSICAL NOVAE

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SUMMARY

SIT Vidicon spectra (3500 - 5100 Å) with time resolutions of several minutes and spectral resolutions of 6 Å have been obtained of a sample of old novae at minimum light. For comparison, spectra of SCO X-1 (V818 Sco) are also presented. Velocity-resolved image-tube spectra of RR Pic 1925 indicate Doppler variations in the He II λ4686 emission line with a period ∿ 3 hours, thus confirming the binary nature of RR Pic.

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I. INTRODUCTION

Previous investigations of the optical spectra of classical novae at minimum light indicate that the most prominent and characteristic emission features (superimposed on strong, blue continua) are the Balmer lines, He II λ4686 and the blend of C III and N III lines near λ4640 (cf. Humason 1938, McLaughlin 1953, 1960, Kraft 1963a, Greenstein 1960, Payne-Gaposchkin 1957, 1977, Warner 1976). Kraft (1963a, b) was among the first to postulate and provide the essential evidence for the binary nature of classical novae. However, other than the analyses of DQ Her 1934 (Greenstein and Kraft 1959), GK Per 1901 and V603 Aql 1918 (Kraft 1963a), no detailed spectroscopic observations of classical novae have been reported. Here we present a preliminary discussion of the optical spectra (resolution ∿ 5 Å) of five classical novae (∿ 30 to 130 yrs after outburst) and one recurrent nova (∿ 12 years after last outburst). For comparison, spectra of Sco X-1 are also presented. In addition we present radial velocity measurements of the He II λ 4686 line in spectra of RR Pic 1925 which confirm the binary nature first discovered photometrically by Vogt (1975). A more detailed discussion and analysis of our data is given elsewhere (Wyckoff 1978.)

II. OBSERVATIONS

The observations were obtained in April 1977 with the 0.9-m, 1.0-m and 1.5-m reflectors at the Cerro Tololo Inter-American Observatory (CTIO). Table 1 summarizes the observational information. Further

Table 1

Observational Instruments

Telescope	Detector	Date Obs. April 1977	Spectral		
			Range (Å)	Dispersion (Å mm^{-1})	Resoln (Å)
0.9-m CTIO	UBV Photometer	10	*	-	-
0.1-m CTIO	Image-tube Spectrograph (IIIA-J plates)	13-19	3100-7000	43	∿ 1
1.5-m CTIO	SIT Vidicon + Cassegrain Spectrograph	22-26	3600-5000	120	∿ 2

* V filter

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information concerning the CTIO SIT Vidicon is described by Osmer and Smith (1977). The SIT Vidicon spectra were obtained with an entrance slit of 8 x 110 arc sec and have been calibrated by observing Oke (1974) spectrophotometric standard stars.

III. DISCUSSION

A. SIT Vidicon Spectra of Novae at minimum

Spectra (F_ν vs. λ) of five classical novae are displayed in Figure 1 together with the spectrum of the recurrent nova T Pyx. Observational details relating to the spectra in Figure 1 are summarized in Table 2 where we have also listed V magnitudes obtained approximately two weeks prior to the spectra. Of the novae in Table 2 and Figure 1, one is a known spectroscopic binary (V603 Aql, Kraft [1963a]), and one may be an eclipsing binary (RR Pic, Vogt [1975]). We interpret the red continuum evident in the oldest known nova, V841 Oph 1848, as possible evidence for a cool stellar companion.

We note the virtual absence of hydrogen emission lines in RR Pic 1925, and suggest that this may be an indication of an abundance anomaly. In this regard it may be noteworthy that most of the weak emission features in the novae spectra in Figure 1 have tentatively been identified with ions of He, C, O and N (Wyckoff 1978).

The spectra of old novae in Figure 1 support the remark by Warner (1976) that the λ 4640 feature is always present in spectra of classical

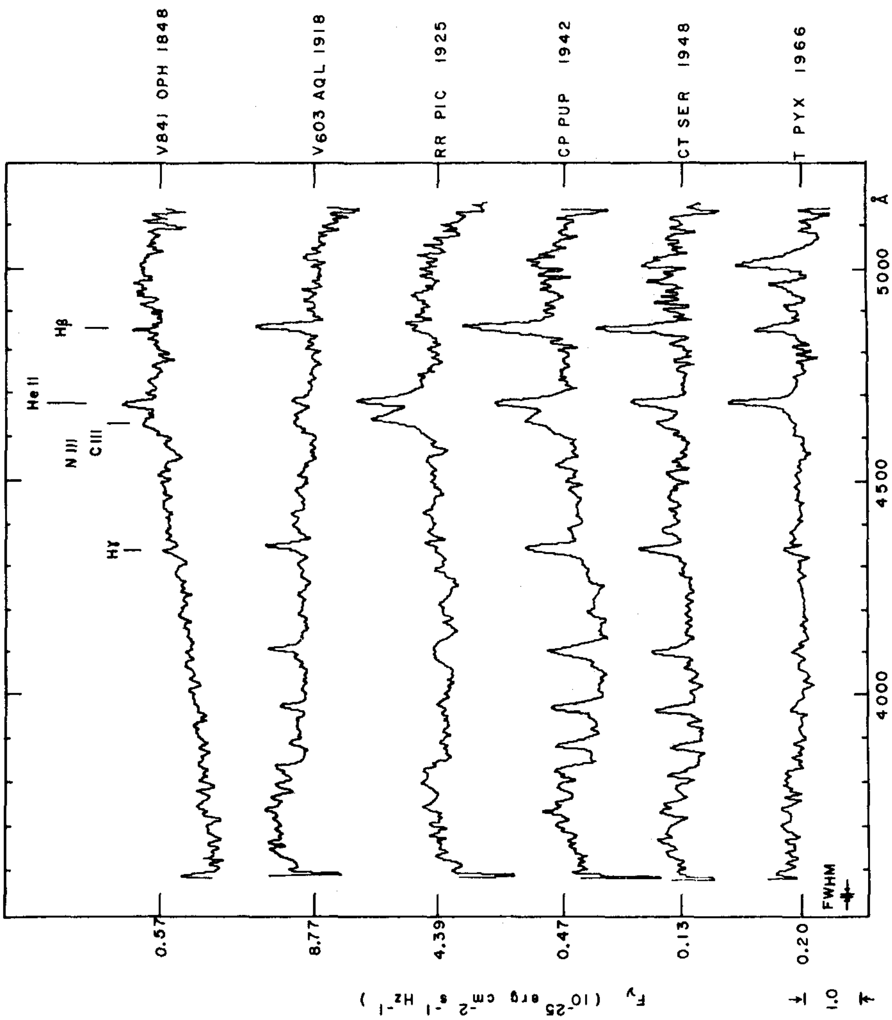

Figure 1 - Spectra (F_ν vs. λ) of old novae obtained with CTIO SIT Vidicon. The continuum fluxes for each spectrum refer to λ = 4780 Å.

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Table 2

Observational Details

Novae			SIT Spectra		Orbital Phase	Photometry	
Name	Outburst	Type	UT Date Obs. April 1977	Effective Integration Time		V	UT Date Obs April 1977
V841 Oph	1848	-	24.322	6 min	-	13.50 ± 0.03	10.26
V603 Aql	1918	v. fast	26.391	90 sec	0.979*	11.80	10.33
RR Pic	1925	slow	26.072	2 min	0.25†	(∿ 12.2:)	-
CP Pup	1942	v. fast	26.094	27 min	-	14.72	10.18
CT Ser	1948	-	26.183	60 min	-	16.24	10.24
T Pyx	1890	recurrent	24.104	20 min	-	15.70	10.22
	1902						
	1920						
	1944						
	1966						

* Phase computed from Kraft (1963a)

† Phase computed from Vogt (1975)

novae at minimum light, but is absent in recurrent novae. None of the spectra in Figure 1 shows definite evidence for absorption lines (other than interstellar). Comparison with previous descriptions of the spectra of V841 Oph 1848, V603 Aql 1918 and RR Pic 1925 (Kraft 1963a, Greenstein 1960, Vogt 1975) indicate that no gross spectral changes have occurred on timescales of years, though the intercomparisons are necessarily crude at best. In contrast with other old novae observed decades after outburst (e.g. GK Per 1901 and DQ Her 1934; Kraft [1963a]), only the recurrent nova, T Pyx (and possibly CP Pup 1942) shows evidence in our spectra for a forbidden line ([OIII] λ 5007) which is probably associated with the ejected shell. No spectroscopic characteristic seems obviously correlated with time since outburst or the timescale between outbursts except for the absence of the λ 4640 line blend and presence of forbidden lines in the spectrum of the recurrent nova, T Pyx.

Our spectra of the classical novae in Figure 1 and Table 2 indicate changes in the continuum and in the emission lines on timescales as short as several minutes. For RR Pic and V603 Aql we detect changes in emission line strengths (after correcting for continuum changes) of Hβ and He II λ 4686 which correlate weakly with orbital phase (Wyckoff 1978). The short-term, essentially random changes in the emission-line strengths are probably indicative of a highly non-uniform distribution of gas in the line-emitting regions of old novae.

None of the spectral changes we have observed in old classical novae have been as dramatic as the changes observed in the Balmer line strengths of Sco X-1 (cf. Crampton et al. 1976). In Figure 2 we present spectra of Sco X-1 obtained on two different nights with the CTIO SIT

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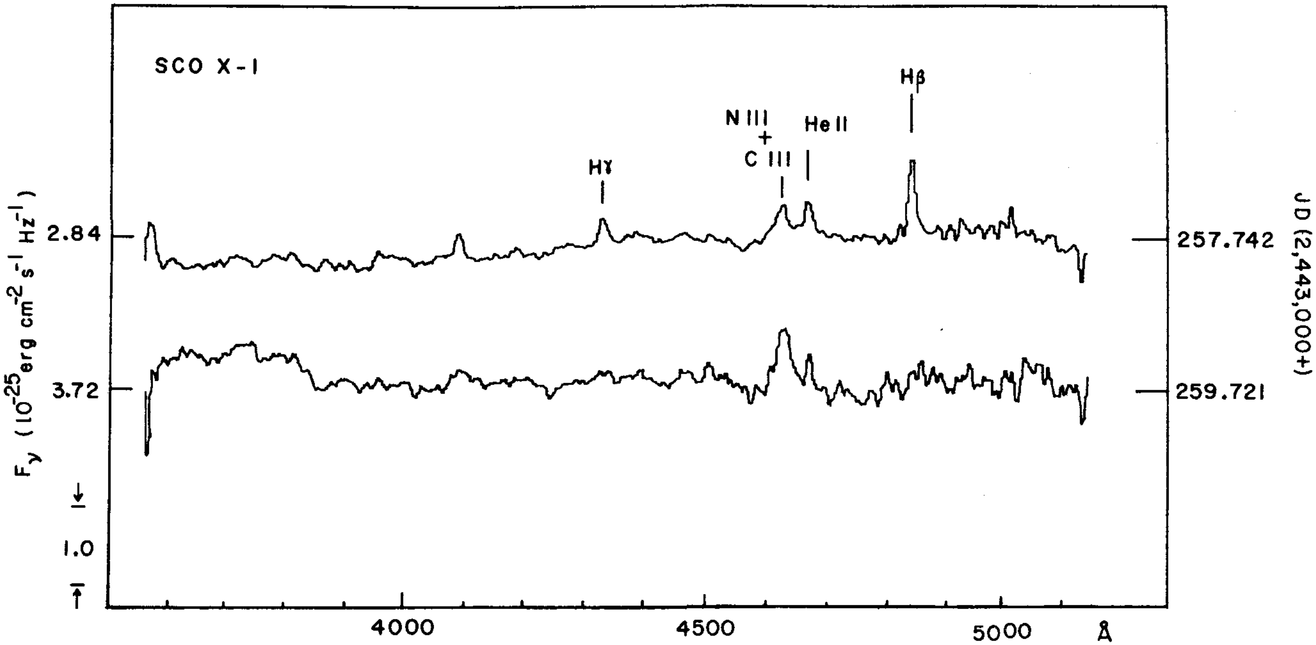

<u>Figure 2</u> - Spectra (F_ν vs. λ) of X-ray source Sco X-1 obtained on two different nights. Note changes in Balmer emission line strengths. Continuum fluxes refer to λ = 4780 Å.

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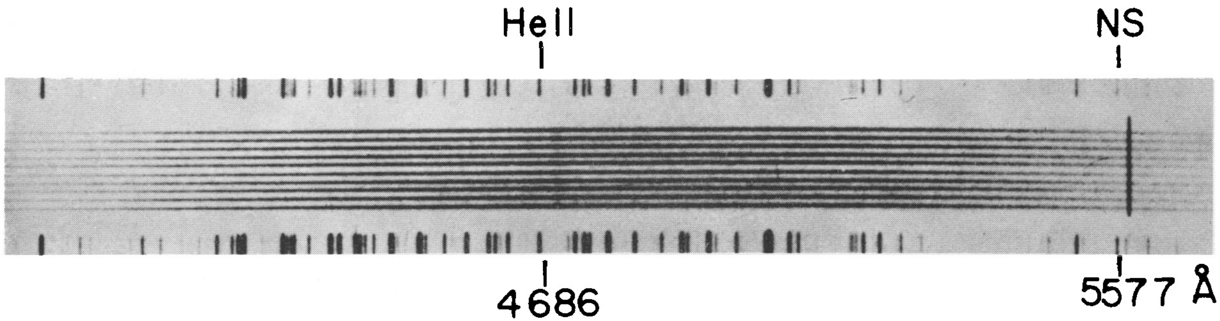

Figure 3 - *Image-tube spectrogram of old nova RR Pic 1925 (original* dispersion ∿ 40 A mm^{-1}) obtained with the 1-m CTIO reflector. Exposure times of untrailed spectra ∿ 6 min; time between mid-exposures ∿ 7 min. Total time interval covered by the 10 untrailed spectra ∿ 60 min. Note Doppler shift due to orbital motion in He II λ 4686 emission line.

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Vidicon. (Integration times were $\sim$ 1 min for each spectrum in Fig. 2.) When the Balmer emission lines are absent the λ 4640 complex is strong; when the Balmer lines are present the λ 4640 complex is weak.

B. Radial Velocity Curve of RR Pic

Vogt (1975) has observed light variations in RR Pic 1925 with a period of $\sim$ 0.15 days. Measurements of time-resolved image-tube spectra obtained with the CTIO 1-m image tube spectrograph provide confirmatory evidence for the binary nature of RR Pic 1925. A representative spectrum is displayed in Figure 3 where 10 untrailed spectra (6 min exposure each) of RR Pic are shown. The slit was oriented east-west and the telescope was moved $\sim$ 15 arc sec in declination (southward) between spectra. In this way very accurately timed, velocity-resolved spectra of RR Pic were obtained. The average time between mid-exposures was $\sim$ 7 minutes. The first untrailed spectrum in Figure 3 (bottom) was obtained at phase (Vogt 1975) $\sim$ 0.611 and the last (top) at phase 0.906. Measurements of the He II λ 4686 line obtained from spectra ($\sim$ 100 exposures), such as displayed in Figure 3, over 5 nights indicate velocity variations with an amplitude K $\sim$ 120 km s^{-1}. Only the He II line was strong enough to be measured on our plates. The resulting radial velocity curve (assuming light elements given by Vogt [1975]) is plotted in Figure 4 where the mean error of a single measurement is $\sim \pm$ 20 km s^{-1}. The scatter in the radial velocity curve is caused by intrinsic, random changes in the He II line profiles (Wyckoff 1978). Nonetheless, a periodic change in radial velocity is clearly evident in Figure 4: We interpret this as orbital motion of the HeII emission region associated with RR Pic 1925.

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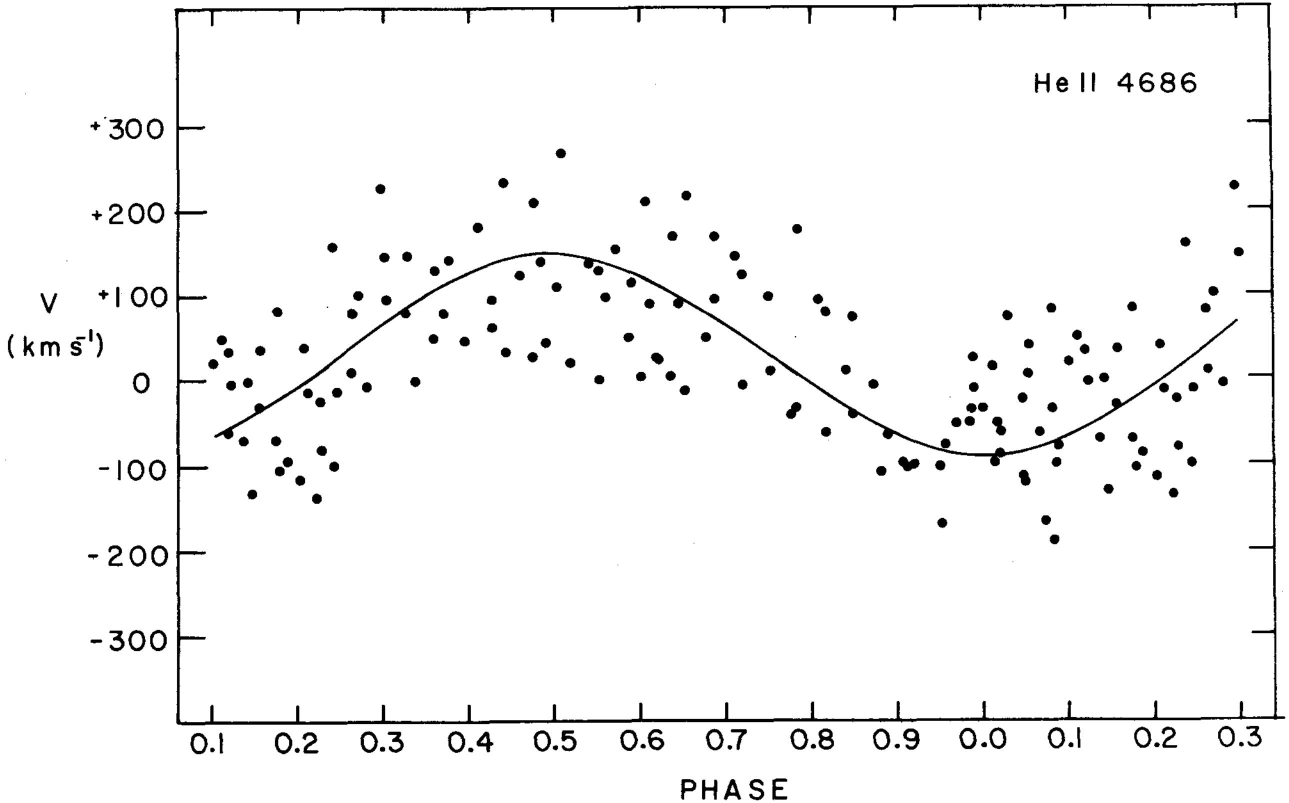

Figure 4 - Radial velocity curve of RR Pic 1925 determined from spectra such as shown in Figure 3 over 5 nights. Phases computed from Vogt's (1975) elements. K ∿ 120 km s^{-1} and γ velocity is ∿ + 40 km s^{-1}.

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D I S C U S S I O N of paper by WYCKOFF and WEHINGER:

BIERMANN: How did you determine the radial velocity from such complicated spectral line profiles as shown in the last slide?

WYCKOFF: As I have already mentioned, the radial velocities were measured from the spectra in Figure 3, using "classical techniques".

KRAFT: Do you have photographic spectra of CP Pup from which the orbit could be obtained?

WYCKOFF: No. But this is probably the best candidate for a binary of the sampled old novae which we observed. It has quite broad emission lines. We also suspect that the spectrum is composite.

BIANCHINI: I should like to remark that the red emission component of RR Pic is in your data usually fainter than the blue one, as is the case for GK Per I have observed. Do you have an explanation for the behaviour of Hβ emission intensity throughout the orbital cycle?

WYCKOFF: Yes, in our spectra too, we generally observe the red component is weaker than the blue component when an emission line profile is asymmetric. The changes in the line profiles however, correlate only weakly with orbital phase. In answer to your second question, there seems to be a trend for the Hβ line strength to be weakest near phase 0.0. However, this is not strictly true for each cycle.

APPENZELLER: Are the two emission peaks of the Hβ and the He lines in the spectra of RR Pic (averaged over the period) symmetric relative to the systemic velocity?

WYCKOFF: No. The HeII 4686Å line is asymmetric over most of each cycle. The Hβ line is much weaker, but is probably asymmetric over most of the cycle also.

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