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Spectrophotometry of RR Telescopii

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Summary. The strongest emission lines in the nova-like variable RR Telescopii were measured during late 1974 using a spectrum scanner. The wavelength range 3350–7700 Å was scanned with a resolution of 50 Å. The results are compared with published spectrophotometry covering the period 1961–72, with the conclusion that few changes have taken place in the last 6 yr. No evidence was found that suggested the existence of a cool star, nor was there any indication of night-to-night changes in the emission line intensities. The spectrophotometry of the past 15 yr is consistent with an expanding shell, the emission from this shell being caused by high-energy radiation from an underlying star.

1 Introduction

Extensive spectrophotometry of RR Tel, covering the period 1961–72, has been published by Aller & Keyes (1974). As part of a programme studying spectral line variations in symbiotic stars, RR Tel was scanned during observing runs at the South African Astronomical Observatory, Sutherland, in 1974 July, October and November. The analysis below is similar to that given by Aller & Keyes so that comparisons can readily be made.

2 Observations

The spectrum scans were obtained using a NOVA minicomputer controlled spectrum scanner whose design and performance are described by Walker (1976). The instrument is of the rapid scanning type and under conditions of good seeing provides a resolution of 50 Å over a wavelength range of up to 3000 Å. The data presented here were obtained with telescopes of aperture 50 and 100 cm using uncooled Amperex 56DVP (S-11) and RCA 8644 (S-20) photomultipliers as detectors. The spectra were reduced to the zenith using mean extinction coefficients and then normalized to the standard star grid established by Hayes (1970) together with the absolute calibration of α Lyrae given by Oke & Schild (1970). The line intensities thus obtained were then normalized such that $I(\mathrm{H}\beta) = 100$. Measurement errors resulting from inaccuracies in the photometry amount to about 10 per cent. Blending with faint lines and uncertainty in the location of the continuum will cause the true errors to be somewhat larger than this. Since examination of the extensive line list given by Aller, Polidan & Rhodes (1973) showed that blending corrections are in general small for the strongest lines, no corrections were made. Cases where blending corrections are likely to be important are specifically mentioned.

3 Results

3.1 VARIABILITY

No changes in the relative fluxes of the emission lines were detected that were greater than the measurement errors, both on a night-to-night basis and over the three observing runs. Visual observations of RR Tel made by the Royal Astronomical Society of New Zealand (Bateson 1974) show that the star remained between 10.0 and 10.5 mag throughout late 1974 apart from a period of greater activity than usual in July and August when the star was at times as bright as 9.5 mag. Both visual estimates made at the telescope and Hα measurements from the scans suggest that the star was at much the same brightness throughout the series of observations made here.

3.2 RELATIVE LINE INTENSITIES

The line intensities given by Aller & Keyes (1974) cover the wavelength range 3340–6678 Å, with a resolution of 10 Å shortward of 6000 Å. The number of lines measured by these authors is considerably greater than measured here due to the difference in resolution. The results are presented in Table 1, the data under the headings 1961, 1968 and 1972 are adapted from Tables 1 and 3 of Aller & Keyes.

3.2.1 *Balmer lines*

In all of the results Hα is too strong relative to the rest of the hydrogen lines, the theoretical I(Hα) being about 280 relative to I(Hβ) = 100. Between 1968 and 1974 Hα was between 1.3

Table 1. Line intensities for RR Tel.

	Identification	1961	1968	1972	1974
3426	[Ne V]	249	280	310	301
3868–3896	[Ne III], H9, H8, He II	132	68	83	83
4101	Hδ	33	30	24	20
4340–4363	Hγ, [O III]	90	95	81	81
4686	He II	68	80	61	71
4861	Hβ	100	100	100	100
4959–5007	[O III], [O III]	315	167	162	171
5721	[Fe VII]		16	19	18
5876	He I		18	13	7
6087	[Fe VII]		30	35	23
6300	[O I]		10	6	7
6563	Hα		363	575	420
6830	?				9
7065	He I				15

Notes:

(i) The data for 1961, 1968 and 1972 are from Aller & Keyes (1974).

(ii) Only the major contributors to a blend are included in column 2.

and 2.0 times as intense as the theoretical prediction. This may be due to collisional ionization or excitation, or else is caused by selectively absorbing material in the line of sight. If circumstellar dust is responsible then the absorbed radiation should be re-emitted in the infrared. RR Tel has an unusually shaped infrared continuum that may well be caused by a combination of dust emission and a late-type star (Feast & Glass 1974). The reddening required to produce the observed Balmer decrement is about $E(B-V) = 0.7$. An attempt was made to estimate the reddening using the [Fe II] line intensities given by Aller *et al.* (1973) and the method described by Pagel (1969). There was very little wavelength trend apparent in the [Fe II] curve of growth, the reddening required to produce the wavelength dependence was $E(B-V) = 0.1 \pm 0.5$, probably not sufficient to explain the large Balmer decrement. A similar result was found for Henize 2-177 by Webster (1974).

Hγ is blended with [O III] at 4363 Å at low resolution, so the relative intensities had to be found indirectly. The Balmer decrement for Hβ, Hγ and Hδ appears to have changed only slowly since 1961. Extrapolation from the data provided by Aller & Keyes (1974), and the known intensities of Hβ and Hδ, enables the ratio $I(\mathrm{H}\beta)/I(\mathrm{H}\gamma) = 2.7$ to be found. Thus $I(\mathrm{H}\gamma) = 37$ and $I(4363) = 44$. The relative intensities of the first four Balmer lines are given in Table 2. In general, the changes in intensity are slow and regular. Tables of the Balmer decrement as a function of electron density and temperature have been computed by Brocklehurst (1971). Examination of these tables shows that the theoretical decrement for the lower members of the series varies only slowly over a wide range of densities and temperatures. The data for Hβ, Hγ and Hδ are consistent with a model with T_e between 5000 and 20 000 K and $\log N_e$ between 4 and 6.

Table 2. Relative intensities of the Balmer lines.

Line	1961	1968	1972	1974
Hα		363	575	420
Hβ	100	100	100	100
Hγ	34	52	42	37
Hδ	33	30	24	20

3.2.2 *[O III] lines*

The intensities of the [O III] lines are given in Table 3, again normalized to $I(\mathrm{H}\beta) = 100$. The values for $I(5007)$ and $I(4959)$ have been forced to fit the theoretical ratio $I(5007)/(4959) = 3$. The line intensities changed drastically between 1961 and 1968 and have remained almost constant ever since. The intensity ratio $I(4363)/I(5007)$ is a very sensitive indicator of electron temperature and density. The observed ratio of 0.34 corresponds to the section of Table 5 in Nussbaumer (1971) where $\log N_e$ is between 6 and 7 and T_e between 10 000 and 20 000 K.

Table 3. Relative intensities of the [O III] lines.

Line	1961	1968	1972	1974
4363	53	39	38	44
4959	72	41	37	43
5007	215	120	110	128
$\frac{I(4363)}{I(5007)}$	0.25	0.32	0.34	0.34

3.2.3 *[Fe VII] and [Ne V]*

Nussbaumer & Osterbrock (1970) found a relation between electron pressure and temperature, and the line intensities [Fe VII] at 6087 Å and [Ne V] at 3426 Å.

The line ratio was found to be 0.08, not significantly different from the value of 0.11 in 1968 and 1972, since both [Ne V] and [Fe VII] are blended with other moderately strong lines (Thackeray, private communication) and extinction corrections are uncertain this far in the ultraviolet. As the two lines are formed under similar excitation conditions it is reasonable to assume that in the part of the shell where they are formed all the iron exists as Fe^{6+} and all the neon as Ne^{4+}. The cosmic abundance of neon is $\log N(\mathrm{Ne}) = 7.92$ on a scale with $\log N(\mathrm{H}) = 12.00$ (Allen 1973). Using Nussbaumer & Osterbrock's (1970) relation, $\log N_e = 6$, $T_e = 20\,000\,\mathrm{K}$, then $\log N(\mathrm{Fe}) = 6.92$ for the intensity ratio 0.08, a value lower than the generally accepted cosmic iron abundance, $\log N(\mathrm{Fe} = 7.60$ (Allen 1973), but probably not significantly so due to the blending, uncertain extinction and even more uncertain reddening.

3.2.4 *6830 Å*

This strong feature remains unidentified. A similar 'line' also occurs in Henize 2-177 (Webster 1974) while a strong unidentified line at 6827 Å has been seen in RS Oph and RT Ser (Swings 1970).

3.3 COOL STAR

The TiO bandheads at 7054, 7088 and 7126 Å were not seen, although blending with He I (7065 Å), and the low quantum efficiency of the S-20 photomultiplier at wavelengths longer than 7000 Å would make detection difficult unless the bands were quite strong. The failure to detect the bands places an upper limit of $V \sim 12$ on the magnitude of a possible M star, about 1 mag (if M6) to 4 mag (if M0) fainter than required to produce the infrared excess observed over the J to L bands.

Conclusion

There is no reason to modify the conclusion reached by Aller & Keyes (1974) that the emission line spectrum of RR Tel is due to an expanding inhomogeneous shell exposed to a flux of high temperature radiation from an underlying star, presumably the source of the 1944 nova explosion. Conditions in this shell now appear to be changing only slowly, in contrast to the rapid changes that took place in the first 20 yr following the nova outburst, summarized by Thackeray (1969).

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