Mon. Not. R. astr. Soc. (1974) **167**, 81–85.

INFRA-RED PHOTOMETRY OF SOME OLD NOVAE

M. W. Feast and I. S. Glass

(Communicated by the Radcliffe Observer)

(Received 1973 November 20)

SUMMARY

J, *H*, *K*, *L* photometry is given for some old novae. The infra-red colours of T CrB are normal for an M giant. The colours of RS Oph suggest high interstellar or circumstellar absorption. A cool component is present in the system RT Ser (slow nova). RR Tel appears similar to RT Ser except that a cool shell is needed to explain the 3·4–20 μ results of Glass and Webster. Some observations are given of V1017 Sgr, RR Pic and V603 Aql.

INTRODUCTION

Most, if not all, novae are now believed to occur in binary systems. It seems of importance to increase the number of such systems in which the secondary (the cool component) has been detected. Furthermore, there is a need for as much information as possible on these secondaries since, for instance, it is not yet entirely clear how (if at all) the nature of the secondary affects the nova outburst (except that it appears to be a necessary condition that the secondary fills its Roche lobe). This paper is concerned with the study of the secondaries of nova-binaries by infra-red photometry. We show that useful information on the nature of the secondaries and in some cases on the amount of interstellar (or circumstellar) reddening can be obtained from *J*, *H*, *K*, *L* observations. The observations are listed in Table I. They were obtained with the infra-red photometer described by Glass (1973) on either the Radcliffe 74-in. or SAAO 40-in. telescopes.

TABLE I

Infra-red photometry of old novae

Object	Date	*J*(1·2 μ)	*H*(1·6 μ)	*K*(2·2 μ)	*L*(3·4μ)
T CrB	1973 May 25	6·04 ± 0·06	5·11 ± 0·06	4·82 ± 0·05	4·68 ± 0·06
RS Oph	1973 May 10	7·74 ± 0·07	6·99 ± 0·06	6·62 ± 0·05	6·25 ± 0·11
	1973 May 26	7·61 ± 0·07	6·81 ± 0·06	6·50 ± 0·05	6·35 ± 0·09
RT Ser	1973 March 28	8·52 ± 0·08	7·57 ± 0·07	7·12 ± 0·08	7·29 ± 0·23
	1973 May 8	8·43 ± 0·08	7·35 ± 0·07	6·96 ± 0·11	(7·3 ± 0·4)
	1973 May 25	8·39 ± 0·08	7·29 ± 0·06	6·87 ± 0·05	6·65 ± 0·10
V603 Aql	1973 May 25	11·47 ± 0·23	11·8 ± 0·4	10·81 ± 0·19	
V1017 Sgr				10·58 ± 0·29	
RR Pic	1972 Sept 10		11·9 ± 0·6	11·4 ± 0·6	> 8·8

T CRB

This recurrent nova is known to be a 228-day spectroscopic binary with a gM3 secondary filling its Roche lobe (Sanford 1949; Kraft 1958, 1964). *K, L, M, N* photometry was given by Geisel, Kleinmann & Low (1970). Fig. 1 shows T CrB in a $(J-H)$, $(H-K)$ plot. Colours are shown as measured and as corrected for a reddening corresponding to $A_V = 0{\cdot}2$ which may be appropriate to T CrB at

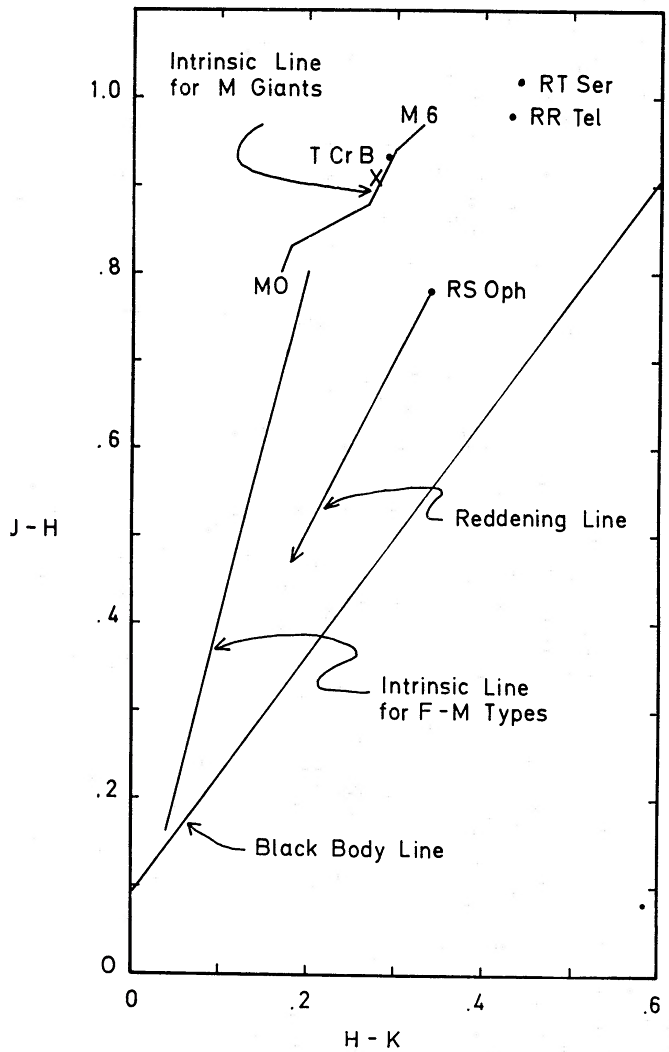

FIG. 1. *The $(J-H)$, $(H-K)$ diagram (filled circles) for some of the stars discussed in the text. The cross is the estimated unreddened position of T CrB.*

galactic latitude 48°. Also shown in the diagram are the blackbody line, the intrinsic relation for M giants (Lee 1970) and a preliminary calibration of the intrinsic line for giants and dwarfs of types F to M (Glass, in preparation). It is evident that the infra-red colours indicate the presence of a cool star. With the adopted reddening the colours suggest a type of about M4, consistent with the visual classification. In addition with $V = 10{\cdot}2$ (Geisel *et al.* 1970) and on the reasonable assumption that the secondary dominates the visual region, we have $(V-K)_0 = 5{\cdot}20$ which again is consistent with type M4 (*cf.* the intrinsic colours of Lee 1970). If one insisted on even closer agreement with the spectral classification M3 this could be achieved by adopting greater reddening. The secondary of T CrB is losing mass through its inner Lagrangian point and therefore cannot, *a priori*, be expected to be normal. It is therefore of interest to see: (i) T CrB falls close to the normal giant relation in the $(J-H)$, $(H-K)$ diagram indicating a normal M giant (note that M dwarfs (Lee 1970) and Mira Variables (Glass & Feast 1973) deviate from this relationship): (ii) Lee (1970, Fig. 2) finds that there is a (weak) luminosity discrimination between giants and supergiants in the $(K-L)$ $(J-H)$ diagram. In this diagram T CrB falls with the giants which is a useful confirmation of its luminosity.

RS OPH

This recurrent nova has a very complicated spectroscopic behaviour. At times an absorption spectrum is seen but it appears that this is due to a shell and that the secondary has not been detected spectroscopically (Wallerstein 1963; Kraft 1964). The H, K photometry of Swings & Allen (1972) agrees well with that in Table I. In the $(J-H)$, $(H-K)$ plot (Fig. 1) its position is similar to that occupied by some Mira variables (Mendoza 1967; Glass & Feast 1973).

However in the $(J-K)$, $(K-L)$ diagram RS Oph, with $J-K = 1{\cdot}12$ and $K-L = 0{\cdot}37$ lies near the normal giant or supergiant sequence and not in regions characteristic of Mira variables (*cf.* Glass & Feast 1973, Fig. 4). This result is essentially independent of reddening since the intrinsic and reddening lines are practically parallel in this diagram. This result suggests that we are dealing with an object of normal stellar colours. The $J-H$, $H-K$ diagram (Fig. 1) then indicates heavy reddening. Because the angle between the intrinsic and reddening lines in this diagram is quite small only a rough estimate of the absorption can be obtained. Using the usual ratios of total to selection absorption (corresponding to van de Hulst's curve 15 (Johnson 1968)) we find $A_V \sim 5{\cdot}5$ but this may be uncertain by 1 or 2 mag. It has in fact long been suspected that RS Oph suffers heavy reddening. The diffuse interstellar bands are strong in the spectrum and the (emission) Balmer decrement is very steep (Wilson & Williams 1934; Griffin & Thackeray 1958; Dufay & Bloch 1964). The latter authors derived a reddening equivalent to $A_V = 4{\cdot}7$. The further independent evidence for heavy absorption that we have found is of value since the results derived from the interstellar bands and the Balmer decrement have not been universally accepted (see the discussion following the paper by Dufay & Bloch 1964). It should be noted that there remains an uncertainty as to whether the infra-red radiation arises in a cool secondary or is connected with the shell-like absorption spectrum mentioned earlier.

RT SER

This slow nova ($10{\cdot}6 - < 16$ pg) has been fairly extensively studied spectroscopically (e.g. Grandjean 1952). So far as we are aware the secondary has not been previously detected. However the magnitudes of Table I show that a red component is present in the system. Further work is required to properly define the nature of this component. In the $J-H$, $H-K$ diagram (Fig. 1) the star falls in a region occupied by some Mira variables (*cf.* Glass & Feast 1973, Fig. 3). However within the errors of the photometry this diagram would also be satisfied with alternative interpretations as (i) a moderately reddened M giant or (ii) a very heavy reddened (A_V 6^m–7^m) G star. In all cases the predicted V magnitude of the secondary is 14^m–15^m which is probably consistent with the magnitude of RT Ser at minimum. The mean K–L (= +0·02) is unusual (with J–K = 1·46) although some Miras do fall relatively close to these colours (Glass & Feast 1973; Fig. 4). However the two determinations of K–L differ (−0·17 and +0·22) and there is also some evidence for variability in the magnitudes of Table I. Evidently a fairly extensive set of observations is desirable.

RR TEL

In view of the above results it is of interest to discuss again the observations of another well known slow nova, RR Tel (extensively studied spectroscopically by Thackeray 1955; 1969 etc.). The photometry of RR Tel by Glass & Webster (1973) shows it to have similar J, H, K colours (but not K–L) to RT Ser. Glass & Webster found that the flux (F_ν) of RR Tel was nearly constant from J (1·2 μ) to Q (20 μ). They were able to fit this distribution by considering contributions from free-free and free-bound atomic processes. However the contribution of these processes to the visual region would be much too great, as they show. The position is considerably changed by the discovery of absorption TiO bands in the spectrum (Webster 1974). We may therefore anticipate a contribution to the infra-red from a cool star. In order to explain the fact that F_ν is nearly constant it is then necessary to add an infra-red excess at the longer wavelengths. The results would for instance be satisfied by the combination of an M5 III star which dominates at J and a 700 K blackbody which dominates at N. Infra-red excesses in the 10–20 μ region have been found in some novae including RS Oph (Geisel *et al.* 1970) and also, e.g. in some Mira variables so that a low temperature infra-red source as well as a cool star in RR Tel seems not unreasonable. RR Tel is included in Fig. 1 although the colours will depend not only on the cool component but on the low temperature shell. In particular H–K will probably be $\sim 0^{\mathrm{m}}\cdot 1$ larger than appropriate to the cool component alone.

If the J, H, K magnitudes of RR Tel are primarily due to a late M-type star then we anticipate the V magnitude of this star to be about 10^{m}–11^{m}. This is probably consistent with the magnitude at the epoch of Webster's discovery of TiO (though accurate V magnitudes at that epoch are probably not available). However at minimum RR Tel reaches 16·5 pg and this presumably indicates that at that time not only is the primary (nova component) much fainter than at present but also the secondary. Before the 1944 outburst RR Tel was classified as a long-period semi-regular variable, though possibly with some peculiarities (Gaposchkin 1952). The evidence of the present paragraph that the cool component of RR Tel has varied with time makes it reasonable to suppose that the long period variability of the object prior to 1944 was due to a semiregular variation of the cool component.

V1017 SGR, V603 AQL, RR PIC

V1017 Sgr is a recurrent nova with a well-developed spectrum of the secondary (G5 IIIp) in the visible (Kraft 1964). If we take V = 13·6 (Mumford 1971) as referring mainly to this secondary we have V–K = 3·07. This agrees with Kraft's spectral type (*cf.* Johnson 1966) if $A_V \sim 1·0$.

Kraft (1964) used the life–luminosity relation together with the magnitude of the system at minimum to predict that the secondary of V603 Aql (Nova 1918) has $M_V \geqslant 5{\cdot}0$ (i.e. a dwarf of type G5 or later). Our value of J–$K \sim 0{\cdot}7$ is that of a middle K dwarf, consistent with this prediction, though the errors are large. The secondary of RR Pic (Nova 1925) is near the limit of detection.

ACKNOWLEDGMENTS

We wish to thank Dr B. L. Webster and Dr A. D. Thackeray for helpful discussions.

M. W. Feast:
Radcliffe Observatory, Pretoria

I. S. Glass:
South African Astronomical Observatory, Cape
On leave from Royal Greenwich Observatory, Herstmonceux

REFERENCES

Dufay, J. & Bloch, M., 1964. *Ann. Astrophys.*, **27**, 462.
Gaposchkin, S., 1952. *Harvard Ann.*, **115**, 22.
Geisel, S. L., Kleinmann, D. E. & Low, F. J., 1970. *Astrophys. J.*, **161**, L101.
Glass, I. S., 1973. *Mon. Not. R. astr. Soc.*, **164**, 155.
Glass, I. S. & Feast, M. W., 1973. *Mon. Not. R. astr. Soc.*, **163**, 245.
Glass, I. S. & Webster, B. L., 1973. *Mon. Not. R. astr. Soc.*, **165**, 77.
Grandjean, J., 1952. *Ann. Astrophys.*, **15**, 7.
Griffin, R. & Thackeray, A. D., 1958. *Observatory*, **78**, 245.
Johnson, H. L., 1966. *A. Rev. Astr. Astrophys.*, **4**, 193.
Johnson, H. L., 1968. *Nebulae and interstellar matter*, p. 167, eds B. M. Middlehurst & L. H. Aller, Chicago University Press.
Kraft, R. P., 1958. *Astrophys. J.*, **127**, 625.
Kraft, R. P., 1964. *Astrophys. J.*, **139**, 457.
Lee, T. A., 1970. *Astrophys. J.*, **162**, 217.
Mendoza, E. E., 1967. *Bol. Tonantzintla Tacubaya*, **4**, 114.
Mumford, G. S., 1971. *Astrophys. J.*, **165**, 369.
Sanford, R. F., 1949. *Astrophys. J.*, **109**, 81.
Swings, J. P. & Allen, D. A., 1972. *Publ. astr. Soc. Pacific*, **84**, 523.
Thackeray, A. D., 1955. *Mon. Not. R. astr. Soc.*, **115**, 236.
Thackeray, A. D., 1969. *Les Transitions Interdites dans les Spectres des Astres* (1968 Liege Colloquium), p. 327. Institute d'Astrophysique, Liege.
Wallerstein, G., 1963. *Publ. astr. Soc. Pacific*, **75**, 26.
Webster, B. L., 1974. *I.A.U. Symposium No.* 59 (Canberra 1973), in press.
Wilson, O. C. & Williams, E. G., 1934. *Astrophys. J.*, **80**, 344.