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ULTRAVIOLET DETECTION OF THE NOVA VARIABLES V603 AQUILAE AND RR PICTORIS

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ABSTRACT

During the lifetime of the OAO-2, ultraviolet photometric observations of the old novae V603 Aql, T CrB, DQ Her, RS Oph, RR Pic, and FH Ser were attempted. Only V603 Aql and RR Pic were positively measured; and by comparing ultraviolet colors of the novae with those of normal stars we are able to deduce color temperatures of 25,000° and in excess of 35,000° K, respectively. Interpretation of the ultraviolet energy distributions are complicated by the possible presence of extended envelopes. We therefore cannot find a unique luminosity from the data but are able to estimate the minimum bolometric luminosity to be about 10 $L_{\odot}$ for both stars. The two observations of RR Pic indicated that the star varied by 0.5 mag during a time interval of 1.7 hours while the relative continuum energy distribution remained unchanged; V603 Aql was not observed to be variable.

Subject headings: novae — ultraviolet

I. INTRODUCTION

Based on measurements of Nova Serpentis 1970 made in the ultraviolet just following visual maximum, Gallagher and Code (1974) have suggested that novae could be very hot, constant-luminosity systems which, outside of a period of visual activity, normally radiate the bulk of their energy in the far-ultraviolet. As a natural test of this hypothesis could be provided by ultraviolet photometry of old novae, we have reduced and report here the OAO-2 Wisconsin Experiment Package (WEP) observations for six old novae. Although these data do not support a constant-luminosity model for novae, the measured ultraviolet energy distributions are unusual and not entirely consistent with other features of these stars.

II. OBSERVATIONS AND DATA REDUCTION

All observations were obtained with the 8-inch (20-cm) photometric telescopes in the WEP (Code *et al.* 1970). Filters with centroid wavelengths of 4250, 3320, and 2980 Å were used in stellar telescope 1, 2460 and 1910 Å in telescope 3, and 1550 and 1430 Å in telescope 4. The digital photometry data were corrected for the time-dependent dark-count background using hand-drawn curves through the dark measurements made during each photometry sequence; experience has shown this to be the most satisfactory means of reducing photometry for faint stars. The photometric measurements were then put into final form following standard WEP data reduction procedures outlined elsewhere (Doherty 1972; Gallagher and Code 1974). We have also used preliminary studies of the long-term time dependence of the photometer system responses to make approximate corrections to the most recent calibrations which refer to the early life of the satellite. Degradation was particularly severe for the stellar 4 filters which had lost nearly 2 mag in sensitivity by 3 years after launch.

For such faint stars the sky background corrections are very important. Each nova observation consists of measurements centered on a nearby blank star field as well as on the nova. Whenever possible, the sky background measured for a nova was compared with other nearby observations to check the quality of the correction. For V603 Aql, corrections for another star in the 10′ field of the photometers were necessary and are discussed in more detail below. The final data are nova minus sky background reduced to the response of the photometry system.

Of the nova systems observed, T CrB, DQ Her, RS Oph, and FH Ser (1.5 years after visual maximum) were *not* detected. A good set of measurements was obtained for V603 Aql (Nova Aquilae 1918) and fair data for RR Pic (Nova Pictoris 1925); we limit the present discussion to these measurements, although it is clear that upper limits from the other novae will provide meaningful information. Table 1 gives both a log of observations and some basic data for the detected novae.

Figures 1*a* and 1*b* illustrate the mean measured monochromatic magnitudes corrected for extinction for RR Pic and V603 Aql. The extinction corrections in the ultraviolet are large and relatively uncertain (Bless and Savage 1972). However, for these novae the estimated $E(B - V) = 0.07$ is sufficiently small that even the most strongly affected 1910 Å filter is corrected by only 0.7 mag as compared with zero extinction. If the actual extinction were much larger than we have estimated, then the corrected ultraviolet flux distribu-

TABLE 1

Observation Log and Data for Novae

Object	Distance (pc)	$E(B-V)$	V	References	Contact Orbit	Date (JD)
V603 Aql......	376	0.07	11.96	a,b	6667	2,440,661.476
					6682	2,440,662.520
					6695	2,440,663.419
RR Pic.......	480	0.07	11.99	a,c	19,186	2,441,531.899
					19,186	2,441,531.968

References.—(a) McLaughlin 1960, table 2, p. 590. (b) Landolt 1968. (c) Mumford 1971.

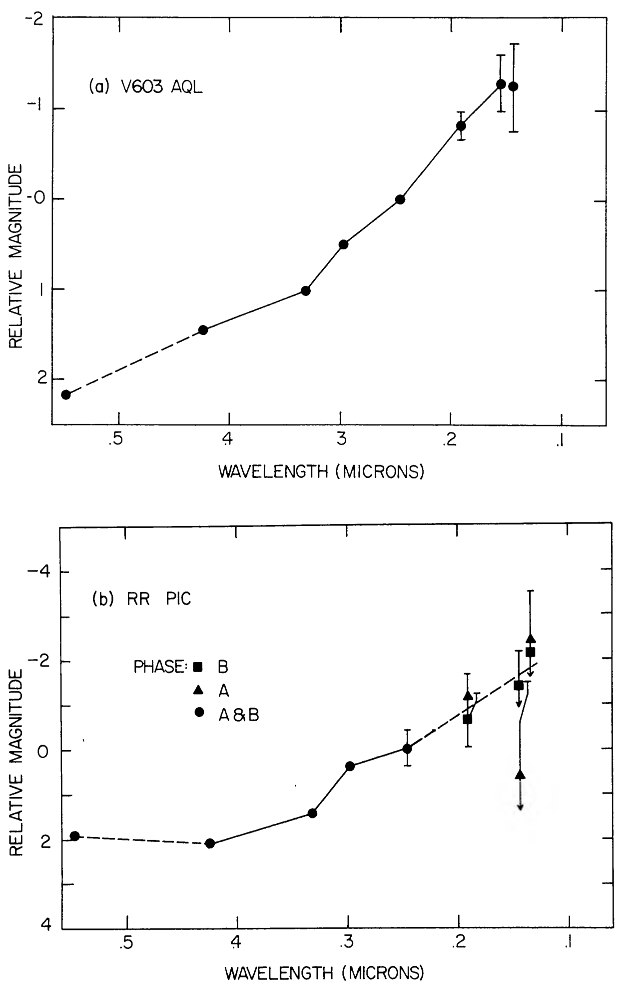

Fig. 1.—observed monochromatic magnitudes corrected for $E(B-V) = 0.07$ relative to 2460 Å for V603 Aql and RR Pic. Error bars show scatter in three observations of V603 Aql and are plotted only when larger than symbols; no estimate has been made for errors in correcting for BD+0°4022. RR Pic showed definite variability, and observations that were significantly different during the two phases are plotted as squares and triangles while overlapping observations are filled circles; the dashed line represents the estimated short-wavelength energy distribution. For both stars, the V observations are not simultaneous and are taken from table 1.

tion would no longer be smooth. As it is unlikely that any star at a distance of several hundred parsecs would be completely unreddened, we feel that a minimal extinction correction is appropriate for the discussion here. Figure 2 shows the location of these novae on an ultraviolet color-color plot; unfortunately, the mean extinction curve of Bless and Savage (1972), which was used for ultraviolet reddening corrections, is such that a reddening line runs parallel to the normal main sequence. Table 2 summarizes the observed ultraviolet colors which may be compared with colors predicted from a variety of stellar atmosphere models in table 3.

III. DISCUSSION

a) V603 *Aquilae*

Observations of this nova are complicated by the presence of the nearby star BD+0°4022 in the field of stellar telescopes 1 and 4. The photometry telescopes are not precisely aligned so that the field of telescope

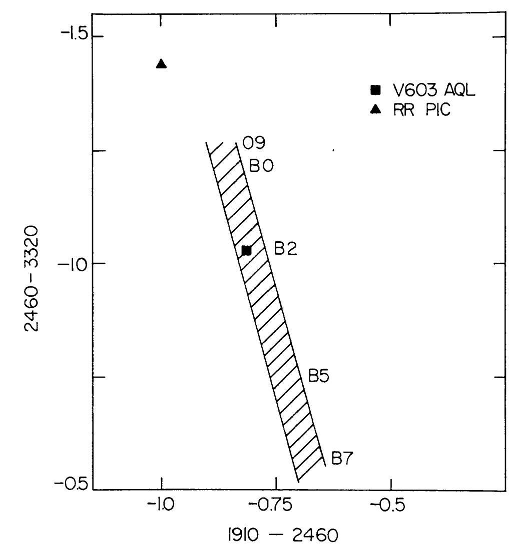

Fig. 2.—the locations of V603 Aql and RR Pic are shown on this ultraviolet color-color plot. An empirical main sequence is shown by the hatched area. The empirical color temperatures were found by comparing ultraviolet colors with those of early-type stars.

TABLE 2

OBSERVED MAGNITUDES AND COLORS CORRECTED FOR EXTINCTION

Nova	2460*	1550−3320	1910−2460	1550−1910
V603 Aql.....	9.55	−2.32	−0.81	−0.5
RR Pic, phase A....	10.38	<−2	−1.2	<+1.8
RR Pic, phase B....	9.87	−2.8:	−0.7	−0.7

* The 2460 magnitude is defined by (see Doherty 1972)

$$2460 = -2.5 \log \left[\frac{\text{NET COUNTS}}{\text{CAL} - \text{DK}} f(t)\right] + C_{2460} ,$$

where $f(t)$ corrects for the time-dependent spacecraft response. Here C_{2460} has been chosen such that $V-2460 = 0.00$ for an equal energy source.

TABLE 3

THEORETICAL COLORS

Model Temperature (°K)	Type	Source*	1550−3320	1910−2460	1550−1910
100,000.....	PP	1	−3.09	−0.96	−0.87
50,000.....	PP	1	−2.79	−0.86	−0.76
30,000.....	PP	1	−2.60	−0.82	−0.70
37,500.....	SPH	2	−2.09	−0.64	−0.59
48,900.....	SPH	2	−2.37	−0.77	−0.61

* SOURCES: (1) Hummer and Mihalas 1970 models 205, 214, 233. (2) Cassinelli 1971 models 1 and 2; T refers to $\tau = \frac{2}{3}$; curvatures are given by the ratio of $R(\tau = 0.001)/R(\tau = \frac{2}{3})$ which is 1.95 for the 37,500° K model and 1.89 for the 48,900° K model.

3 does not include this star. Dr. H. Abt obtained a classification spectrum of BD+0°4022 with the 84-inch (2.1 m) Cassegrain spectrograph; the spectral type is A7 V and the estimated visual magnitude about 10. Corrections could then be made in the V603 Aql data by scaling observations of the A7 stars, HD 68457 and α Cep, to give the predicted count rate for a similar 10th magnitude star. The expected contribution to the stellar telescope 4 data from BD+0°4022 is zero, and thus the 1910−2460 and 1550−1910 colors should be little affected by the accuracy of the correction. In figure 1*a* we have illustrated the corrected monochromatic magnitudes and errors based on the scatter from the mean of the three sets of independent measurements. V603 Aquilae remained constant in brightness to within experimental accuracy during our observations.

In figure 2, V603 Aql lies near the left edge of the main sequence. Based on this plot and on the other ultraviolet colors, the empirically estimated temperature is about 25,000° K. This temperature is lower than that implied by visual spectral features such as the lack of a pronounced Balmer discontinuity or the presence of He II λ4686 in emission (Greenstein 1960; Kraft 1964). One possible mechanism that would lead to a disparity between colors and the observed spectral features is the presence of an extended envelope, which could result from mass exchange in this close binary system. A major effect of an extended atmosphere is to lower the color temperature of the star at wavelengths longward of the peak in the flux distribution, and it is then also impossible to go directly from the observed color temperature and flux to a bolometric luminosity (Cassinelli 1971; Heap 1972). For the purposes of comparison, we have included two of the Cassinelli models in table 2 and we note that while the 37,500° K model produces colors close to those observed, models with other curvatures and temperatures could be chosen to give equally good or better fits.

A direct integration of the V603 Aql measurements corrected for $E(B - V) = 0.07$ over λλ1430–5480 give a luminosity of about 8 $L_\odot$ for $V = 11.96$ (Landolt 1968). If the empirically estimated color temperature of 25,000° K is used, then the bolometric luminosity is 12 $L_\odot$ if V603 Aql has an atmosphere similar to a normal main-sequence star. To illustrate the increase in the bolometric correction when an extended atmosphere is present, the total luminosity becomes about 50 $L_\odot$ if the spherical 37,500° K model is used to compute corrections. Clearly our observations can give only a lower limit to the total luminosity.

b) *RR Pictoris*

The remnant of Nova RR Pic is apparently an eclipsing binary with a blue amplitude of 0.1–0.3 mag and subject to superposed irregular variations on the order of tenths of a magnitude (van Houten 1968; Mumford 1971). Using the period listed by Mumford, we find that a phase difference of about 0.5 exists between our two observations of RR Pic, although the period is not known with sufficient precision to determine an absolute phase. However, our data do indicate that for wavelengths of 2460 Å and longer, the nova was about 60 percent brighter at phase B than phase A. The star was probably also brighter at shorter wavelengths, but filter degradation had caused such a decrease in sensitivity as to make this data rather uncertain. As can be seen from figure 1, the energy distribution remains the same for $\lambda \geq 2460$ at phases A and B, and to within rather large experimental error it may remain the same to 1910 Å and to even shorter wavelengths. In figure 2 we see that the mean colors of RR Pic place it above the extreme upper main sequence. The observed ultraviolet energy distribution of RR Pic, unlike that of V603 Aql, differs from that of a normal star, and the empirical color temperature is therefore more difficult to estimate. Since our hottest comparison stars have $T \sim 35{,}000°$ K, we have chosen this temperature as a lower limit for RR Pic.

The total flux observed between 1430 and 5460 Å has been integrated for RR Pic by assuming that

$V = 12$ (Mumford 1971) and that the ultraviolet energy distribution below 2460 Å is given by the dashed line in figure 1*b*. The measured luminosity is about 10 $L_\odot$, and we again find a lower limit to the total luminosity of 15 $L_\odot$ by estimating the bolometric correction from a plane-parallel atmosphere.

IV. CONCLUSIONS

On the basis of visual spectral region observations, it has been determined that many old novae have properties commensurate with most of the light arising from the hot, blue component of a binary system (McLaughlin 1953; Greenstein 1960; Kraft 1964). The ultraviolet measurements presented here are in qualitative agreement with this picture, although in particular the ultraviolet energy distribution of V603 Aql implies lower color temperatures than would be predicted from visual-region spectral features. We have suggested that this is an effect due to geometrically extended atmospheres in the novae and that such an atmosphere might be found in a binary system where mass exchange is occurring. If such atmospheres are indeed present, then one could argue that the higher color temperatures found for RR Pic could either result from a real difference in luminosity or merely indicate that the envelope of RR Pic is less extended than that of V603 Aql. Because of these types of ambiguities introduced by this interpretation, we have used our data to directly estimate only lower limits of 10 $L_\odot$ for V603 Aql and 15 $L_\odot$ for RR Pic. If even a moderately extended envelope is present, these luminosities could be increased by about a factor of 5. However, it seems unlikely that the bolometric correction to the total measured fluxes could much exceed a factor of 10, and thus the present novae are considerably less luminous than at maximum visual light when $L >$ 10,000 $L_\odot$.

The ultraviolet properties of V603 Aql and RR Pic can also be compared with the last photometric measurements made of FH Ser (Nova Serpentis 1970) 54 days after visual maximum (Gallagher and Code 1974). The measured luminosity of FH Ser at that time was about 10^4 $L_\odot$, and the ultraviolet colors on the mean corresponded to lower temperatures than we have found for the old novae. We therefore suggest that the final evolution of a nova in the post-maximum stage is toward a relatively hot star with $M_{\rm bol} \sim 0$ and that it would be interesting to isolate the period during which the nova returns to lower luminosity.

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