THE VERY UNUSUAL ULTRAVIOLET SPECTRA OF R ARAE

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Abstract

The high resolution ultraviolet spectra of the 4.4-day period binary R Arae, observed in 1980 with the International Ultraviolet Explorer (IUE), show that its continuum flux level varied outside of eclipse by more than a factor of two in ten days, and by over 50 percent within a same orbital cycle. The flux level varied non-monotonically at different wavelengths. The resonance lines of Mg II and Si IV exhibited shortward-shifted absorption components near phase 0.4, indicating the presence of a gas stream toward the observer at a velocity of some −450 to −500 km s^{-1}. Our observations of R Arae with the Einstein satellite show it to be an X-ray source.

1. Introduction

R Arae is a relatively bright (m_V at maximum = 6.5) eclipsing binary with a period of about 4.4 days. Its primary component is classified as B9p, but its secondary component is spectroscopically unidentified (Sahade 1952). He derived a mass function of 0.10 $M_\odot$ but cautioned about large uncertainties involved. Taking the mass of the primary to be 4.0 $M_\odot$, Sahade derived an estimated mass for the secondary of 1.4 $M_\odot$. If it is a main-sequence star, it is an F-type object. He also noted a number of peculiarities in the ground-based spectra of this binary.

We have included this binary in our study of the mass flow and evolution in close binary system, which is being conducted with the IUE. The IUE has been described in detail by Boggess _et al_. (1978).

2. Observations

In all, four exposures with the far ultraviolet SWP camera covering the 1150–1900Å range and six exposures with the mid-ultraviolet LWR

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camera covering the 1900–3200Å range, were obtained in the high-resolution mode ($\lambda/\Delta\lambda = 10^4$) using the large spectrograph entrance aperture. The pertinent information is given in Table 1. The spectra were obtained during a 12 day period in May through June 1980. All except those for phase 0.13 were obtained during the same orbital cycle.

3. Discussion

3.1 Spectra

The resonance lines of C II (1335Å), Si IV (1393, 1402Å), Si II (1526Å), Fe II (2599Å) and Mg II (2795, 2802Å) were observed as P-Cygni features. The emission in those P Cygni features varied significantly but no clear-cut changes were detected in the absorption equivalent widths. The radial velocities in the absorption lines showed small (10 to 50 km s^{-1}) but real deviations from what is expected for the orbital velocities of the B star; the deviation was in the direction of short wavelengths. Near phase 0.41, the Mg II and Si IV resonance doublets showed edge velocities of -440 and -500 km s^{-1}, respectively, indicating that a gas stream was approaching toward the observer at the time of observation. Unless the gas was located very close to the B star, the observed velocity was probably in excess of the escape velocity from the star and possibly even out of the binary system. A somewhat analogous gas streaming was observed in a 2.4-day binary U Cep and reported by Kondo, McCluskey and Stencel (1980) and Kondo, McCluskey and Harvel (1981).

The presence of the Si IV resonance doublet indicates a temperature higher that that appropriate for a B9 star. The Si IV lines probably originated in the gas stream and possibly also in a hot spot on the B star resulting from the accretion of infalling matter; if accretion on to the B star is occurring, then it is the secondary component that is losing the matter. The resonance doublets of Si IV and C IV (1548, 1550Å) were also observed in U Cep, whose hotter component is classified as a B8 star; these Si IV and C IV lines were interpreted in the above-mentioned work as evidence of mass accretion onto the B8 star in U Cep. However, no emission feature was detected in U Cep.

3.2 Flux Variations

It became apparent as the exposures were being taken, that the continuum flux was varying significantly outside eclipse. In order to study the variation quantitatively, we selected the regions of flat continuum that were free of any emission or absorption features for several angstroms. After normalization for different exposure times for each spectrum, the ratios of flux levels were taken with respect to those at phase 0.28, which we took arbitrarily as standard; thus, the flux ratio = F_λ (phase X)/F_λ (phase 0.28). The uncertainty in these ratios is estimated to be 10 to 15 percent.

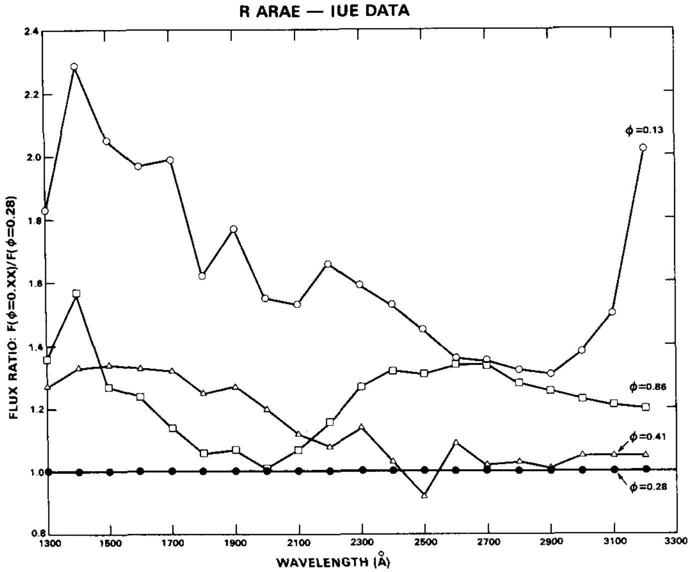

Figure 1. IUE Flux Ratios of R Arae

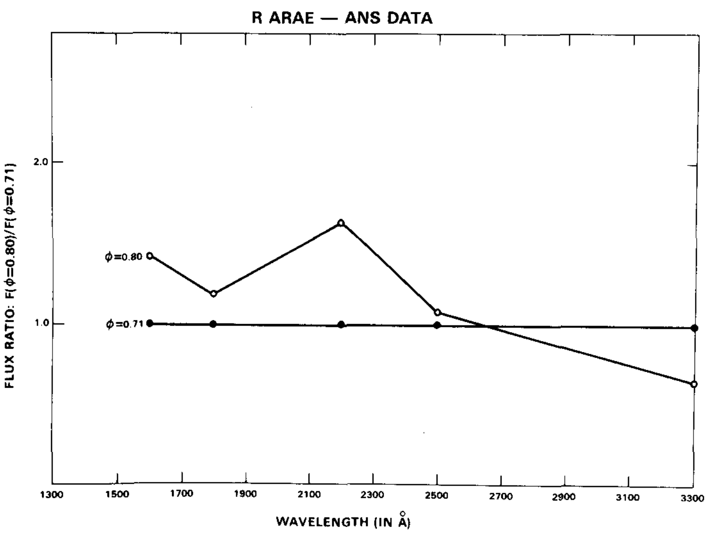

Figure 2. ANS Flux Ratios of R Arae

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The flux level at phase 0.13, the only data taken at another orbital cycle 10 days apart, was higher by a factor of up to two. During one orbital cycle, the highest variation observed was up to 50 percent. However, it is not clear from the current data whether the variation was a phase dependent phenomenon or a secular one. We note that the changes recorded for a pair of LWR spectra, taken practically next to each other with an interspacing of only one SWP exposure in between, were quite small and within the errors of determination. Such a pair of exposures were taken twice at phases 0.13 and 0.86; the flux levels given for these two phases were, therefore, taken to be an average of the two in each case.

The important point to note is that the flux did not increase or decrease monotonically with wavelength. Of course this apparently peculiar manner of variation might be in part due to the peculiarity of the comparison continuum flux at phase 0.28. Still, a similar peculiarity was also observed in the ultraviolet photometric data obtained with the Astronomical Netherlands Satellite (ANS), as will be discussed below. The change cannot be interpreted simply as variation in the temperature or in the size of the emitting area in the source. The apparent absence of correlation between the absorption equivalent widths and the observed flux levels present an additional challenge in interpreting the data. The correct interpretation might lie in a combination of several factors, such as an uneven variation in the temperature of the emitting plasma and in the source size. The plasma causing the variation could pertain to the B star, in which case hot or cool spots as well as an unstable expanding or contracting optically thick outer atmosphere might be involved. The variation might in part be caused by optically thick, variable gas streams or disks.

After the current IUE observations were obtained, the 5-band ultraviolet photometric data of R Arae obtained with the ANS became available. The data, obtained during one orbital cycle in 1974, are reported elsewhere by Kondo, McCluskey and Wu (1981). The ANS observations are plotted in Figure 2. The uncertainties in the ANS data are at a few percent level and are smaller than those for the IUE data.

3.3 X-ray Observations

On a guest observer program with the Einstein (HEAO-2) satellite, we observed R Arae. The Einstein IPC data show this binary to be an X-ray source. If the B9 star is a main-sequence object with $M_V = 0$, R Arae is at the distance of about 160 pc. Then, the X-ray luminosity of R Arae is 6.5×10^{30} erg s^{-1}. If R Arae is a luminous supergiant with $M_V = -7$, the binary is at the distance of 4000 pc. The X-ray luminosity, then, is 3.5×10^{33} erg s^{-1}.

If the foregoing considerations are correct, R Arae is not a strong X-ray source.

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4. Concluding Remarks

The close binary R Arae exhibits very unusual ultraviolet spectra. So far as we are aware, no other close binary system, observed with any of the orbiting satellites, show outside-eclipse ultraviolet continuum flux variations of this nature. The apparent "seesawing" of the continuum level with respect to the reference spectrum is puzzling. The shortward shifted absorption component in the Si IV and Mg II resonance doublet with a Doppler velocity of some -500 kms s^{-1} indicates probable mass loss from the system. In addition, the possible existence of hot spots is hinted by the presence of the Si IV doublet.

Clearly, this binary is passing through a very unusual stage in its evolutionary path. The current results suggest the presence of an optically thick plasma that vary as a function of the phase, or secularly, or both. The plasma causing these variations could involve gas streams, circumstellar or circumbinary disks or an unstable outer atmosphere of the B component.

From the currently available data, we are unable to infer the exact nature of this binary. However, several possibilities, including the following, may be considered. (A) R Arae is in that much talked about but never observationally verified state in which the originally more massive component is currently losing mass. (B) The binary is just entering or coming out of the short-lived dynamic phase of mass transfer, which β Lyr is purportedly undergoing. (C) The spectroscopically undetected companion is a compact object; this would place the binary in an advanced stage of evolution. If so, the weakness of its X-ray emission might be explained as the result of blanketing of the inner X-ray emission by feeding of the matter at the super-critical rate of 10^{-6} solar mass per year or more.

Clearly, much more observations are needed in all spectral ranges, including hitherto unobserved infrared and radio regions. In particular, we need continuous ultraviolet observations during one orbital cycle. Since the IUE telescope time is quite valuable, one practical approach may be to obtain a set of SWP and LWR spectra at high-resolution twice daily for 4.4 days, thus providing a coverage approximately at an interval of one-eighth the period. In addition, a few additional exposures several orbital cycles later will be helpful in investigating possible secular variations.

New spectroscopic and photometric observations from Southern Hemisphere observatories will also be of much value. Of course, except from an Antarctic observatory, it will not be possible to cover this binary continuously during one orbital cycle. Infrared and radio observations would likely add to our information base. For instance, infrared observations might help us pin down the nature of the secondary component; it might at least impose more

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Table 1
IUE Observations of R Arae

Exposures (min.)	JD2444300+	Phase
LWR 7781 (6)	77.3338	0.127
SWP 9026 (18)	77.3542	0.132
LWR 7782 (11)	77.3698	0.135
LWR 7869 (20)	86.8696	0.282
SWP 9138 (30)	86.8911	0.287
LWR 7877 (30)	87.4329	0.409
SWP 9144 (50)	87.4703	0.418
LWR 7888 (34)	89.4161	0.857
SWP 9151 (55)	89.4503	0.865
LWR 7889 (25)	89.4815	0.872

strict conditions on its nature. Radio observations would augment our knowledge of the non-thermal emissions from this binary. Finally, a continuous monitoring of this object in the X-ray region, when a satellite observatory for such purposes becomes available again, would certainly be of much interest.

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