AR PAVONIS: THE ROSETTA STONE OF THE SYMBIOTICS

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1. Early History and Observations

With Mayall's discovery of the eclipsing nature of AR Pavonis = CD-66°3307, a nearby unique opportunity to directly probe the structure of the symbiotic binary became available. Few eclipsing systems have been detected among the symbiotics and AR Pav is fortunately bright enough to be observed spectroscopically at Coudé dispersions.

Due to the dominance of the giant component over the optical region, it has been difficult to reliably derive the properties of the hot companion from optical studies alone. The light curves published by Mayall (1937) and more recently by Andrews (1974), in addition to the detailed spectroscopic studies undertaken by Thackeray (1959) and Thackeray and Hutchings (1974), were used to determine the binary properties. At a distance of approximately 3.8 kpc, the system appears to consist of an M3III secondary and a subluminous primary ($T_e \simeq 30,000$ K) embedded in an accretion "shell". The binary model proposed for AR Pav by Thackeray and Hutchings is reviewed in light of recent ultraviolet, infrared, and radio observations.

2. The Light Curve

Using extensive Harvard plate collection, Mayall (1937) published a photographic light curve for AR Pav, spanning the period from 1889 to 1936. A skewed primary eclipse ($\delta m_{pg} = 2.5$ mag) is clearly present, lasting approximately 100 days from initial ingress to final egress. No convincing evidence for a secondary eclipse is discernible. The eclipse depth is variable, showing "bright" eclipses where the level at minimum light is nearly 0.5 mag above that seen at "quiescent" eclipses. The system brightness outside of eclipse is also variable, with a quasi-periodicity of approximately seven years. There is no apparent correla-

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tion between "bright" eclipse minima and an elevated light level between eclipses.

Andrews (1974) presented UBV observations over the period 1967–1973, refining Mayall's value for the eclipse period (605 days) to P_{ecp}= 604.6 days. Eclipses were observed in 1967, 1969, 1970, and 1972; the mean "quiescent" eclipse profile derived from the observations displays a marked asymmetry at ingress, exhibiting a "stillstand" near phase = 0.9. The eclipse minima are not flat, indicating the non-stellar appearance of the primary object. The U-B index changes abruptly by –0.3 mag following the stillstand into eclipse, and returns to the pre-eclipse value of –0.60 mag upon egress.

During a "bright eclipse", the stillstand apparently disappears and the time of mid-eclipse advances to phase 0.98. While the eclipse duration remains essentially the same, the central depth of a bright eclipse is about 0.5 mad deeper than for a quiescent eclipse.

3. Spectroscopic Properties

In 1900–1901 the earliest spectra of AR Pav showed P Cygni line profiles, with HeII 4686 A and NIII 4640 A emission lines appearing in addition to the Balmer series (Mayall 1937). Sahade (1948) obtained additional spectra and identified emission from MgII, FeII, HeI, CIII, [OIII], and [NeIII], superimposed on an early-type absorption spectrum.

The most detailed spectroscopic studies remain those of Thackeray (1959) and Thackeray and Hutchings (1974). The rich emission line spectrum and its behaviour throughout the eclipse cycle was the subject of the first paper. The Balmer lines of Hγ and Hδ were resolved into two components, whose separation decreased by 34 km/s during eclipse from 114 km/s seen outside of eclipse. Both the helium and hydrogen lines weakened in eclipse relative to the [OIII] 4363 A nebular line; HeII 4686 A virtually disappeared at mid-eclipse. TiO absorption was seen only during the eclipse. The stratified nature of the emission producing region is indicated by this behaviour, where the high excitation lines appear to be concentrated towards the central region.

In the later paper, Thackeray and Hutchings discuss the radial velocity and emission line intensity variations across the eclipse cycle, using an extensive set of spectra spanning a twenty year period. From the ratio of [OIII] (4959+5007)/4363 the mean electron density in the nebula was estimated to be log $N_e \sim 7$, substantially higher than found in the planetary nebulae.

Velocities were measured for the permitted and forbidden emission lines, as well as for the absorption lines of TiII, ScII, and SrII. Orbital solutions were independently calculated for each set of velocities. The permitted line (PE) solution, identified with the primary, gave a semi-amplitude of $K = 13.0 \pm 1.6$ and an eccentricity of $e = 0.11$

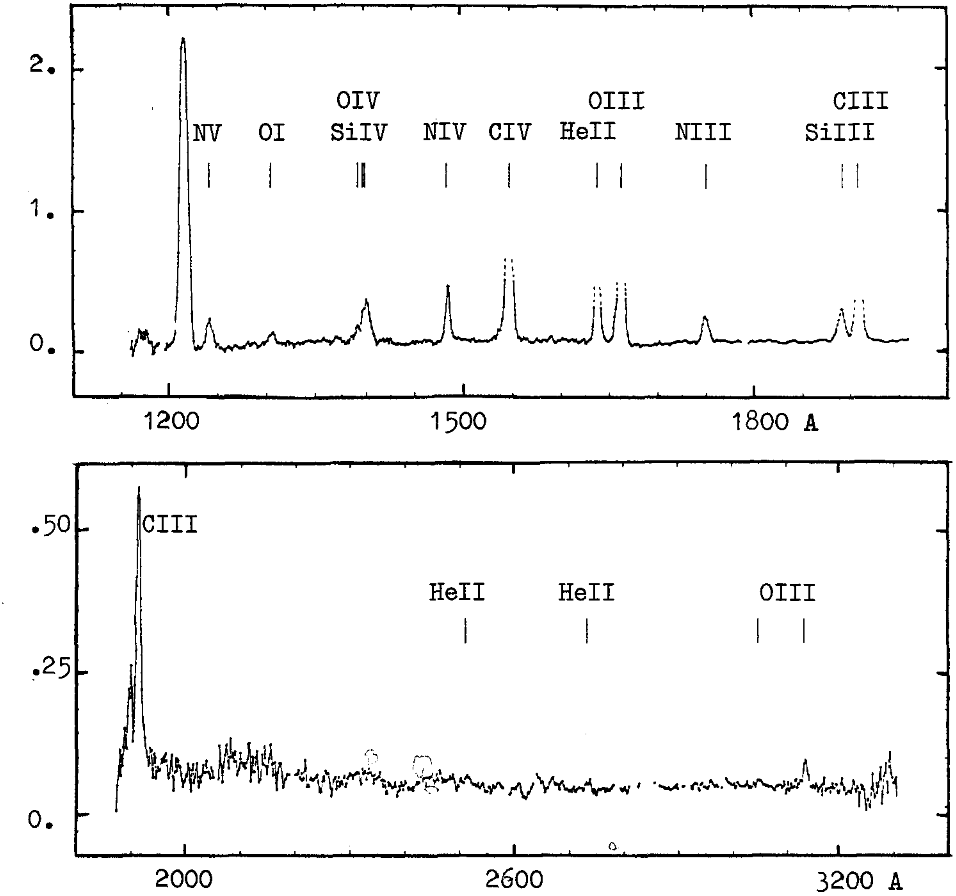

Figure 1. Low resolution IUE spectra of AR Pavonis. Ordinates are fluxes in 10^{-11} erg $cm^{-2}s^{-1}A^{-1}$ dereddened for E(B-V) = 0.30.

± 0.11. The absorption line (A) solution, associated with the late type secondary, yielded values of K = 26.4 ± 11.2 and e = 0.45 ± 0.39. The forbidden line (FE) solution indicates that these velocities only weakly reflect the orbital motion (K = 6.4 ± 2.1 and e = 0.53 ± 0.20), having a phase shift of 0.1 from the A and PE solutions. The large scatter of the individual velocity measurements (± 5.7 km/s) suggests that the streaming velocities in the line forming regions are significant compared to the orbital motion.

From the PE and A solutions, Thackeray and Hutchings (1974) estimate a mass ratio $q = M_1/M_2 \approx 2$, yielding probable masses of $M_1 = 2.5\ M_\odot$ and $M_2 = 1.2\ M_\odot$ for the primary and secondary respectively, assuming the eclipse is total.

4. Recent Observations

Over the last decade, observations of AR Pav at infrared, radio and

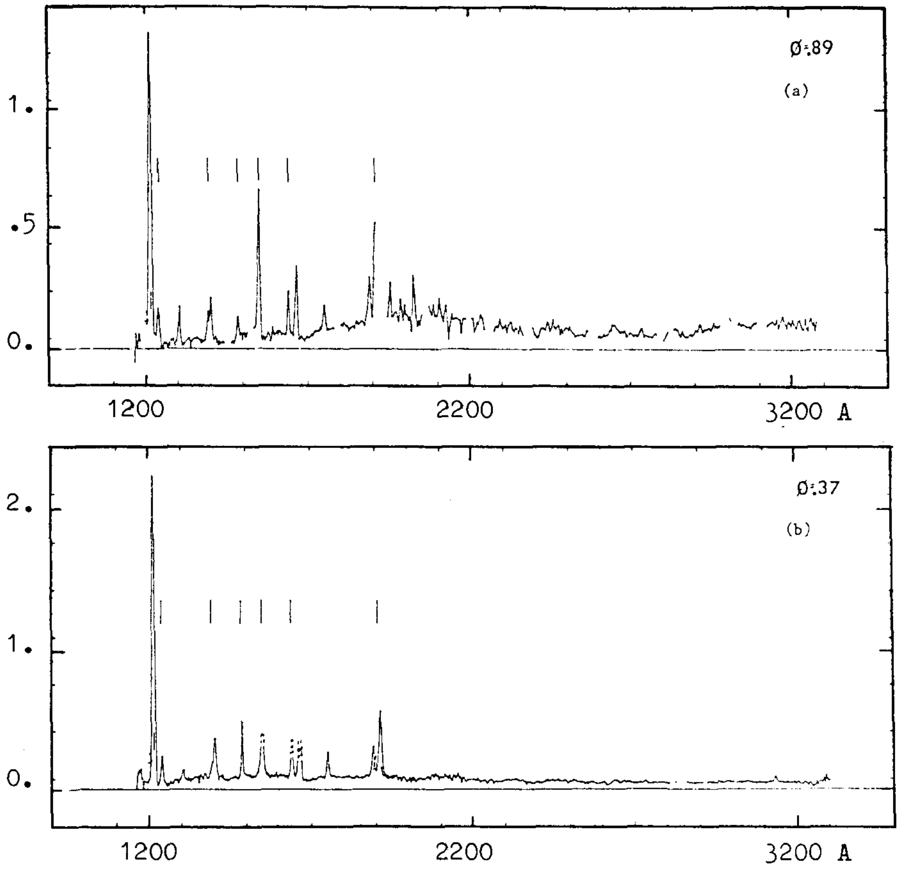

Figure 2. Combined SWP and LWR spectra of AR Pavonis at (a) eclipse ingress, and (b) outside of eclipse. Ordinates as in figure 1.

ultraviolet wavelengths have been obtained. In the infrared Glass and Webster (1973) and recently Allen (1978) have published broad-band Johnson JHKL photometry. The infrared properties do not differ markedly from normal non-variable giant stars, and Allen (1978) subsequently classified AR Pav as an S, or stellar type symbiotic. AR Pav was included, but not detected, in the 2.1 cm continuum survey of Wright and Allen (1978). The lack of detectable radio emission is consistent with its S type classification.

Low resolution ultraviolet IUE spectra have been obtained for AR Pav at eclipse ingress (Ø = 0.89) and outside of eclipse (Ø = 0.37) (Slovak 1981). The SWP and LWR spectra at phase 0.37 are seen in figure 1. Prominent lines of NIV], CIV, HeII, OIII], NIII] and CIII] dominate the SWP bandpass. The LWR spectrum shows a strong Balmer continuum with few emission features. The interstellar 2200 A feature was used to estimate a value of the reddening $E(B-V) = 0.30$ substantially higher than the value of $E(B-V) < 0.1$ determined by Andrews (1974) from UBV observations of surrounding stars in the field.

A comparison of the IUE observations at eclipse ingress and outside of eclipse is seen in figure 2 (a) and (b) respectively. The ratios of CIV/NIII] and HeII/NIII] weaken as the eclipse progresses while the ratio NIV]/NIII] remains relatively constant. This behaviour is consistent with the optical counterparts of these ratios. The peak continuum flux also moves from $\lambda \sim 2000$ A near eclipse to $\lambda \sim 1500$ A outside eclipse, reflecting the contribution of the hot primary.

5. Review of the Binary Model

The recent observations serve to confirm the validity of the binary model proposed for AR Pav by Thackeray and Hutchings (1974). The secondary appears as an M3 giant showing normal infrared properties. The nature of the hot primary, however, remains uncertain as it appears obscured by an accretion "shell" both during and outside of eclipse.

These comments are reinforced by the absolute energy distribution shown in figure 3. Absolute mean fluxes are compared to an intrinsic composite stellar distribution derived from a BOV star (T_e = 28,000 K) combined with an M3III star. A reasonable fit is achieved beyond one micron, but shortward of 3300 A the distribution is dominated by Balmer continuum radiation. Thus the accretion shell dominates the UV region, and significantly alters the eclipse appearance when bright.

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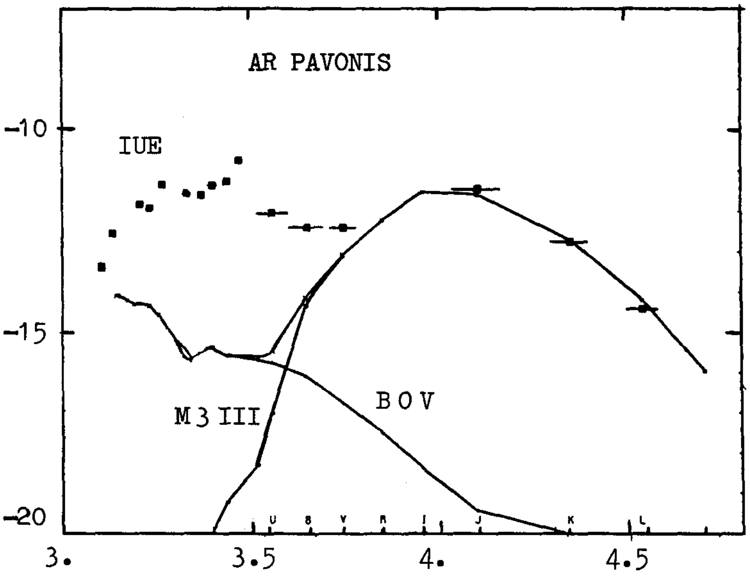

Figure 3. Absolute energy distribution for AR Pav. Abscissae: log wavelength in angstrom. Ordinates: log flux in erg $cm^{-2}s^{-1}A^{-1}$. Filled squares (▪): IUE, optical and IR photometry of AR Pav. The absolute energy distributions of M3III, B0V stars, and the combined distribution are also indicated.

DISCUSSION ON AR PAVONIS

Plavec: I would like to call your attention to the bulge seen in the continuum of AR Pav at approximately 1900A. This bulge is seen in all Serpentids (that are strongly interacting binaries with strong emissions of NV, CIV, SiIV, etc.), notably in β Lyrae. Since β Lyrae and the other Serpentids show strong emissions of FeIII, and since FeIII has usually many lines just in the region about λλ1850-2300 A, it was suggested that the bulge in the continuum is caused by a suprposition of numerous faint FeIII emission lines. However, there are no FeIII emissions visible in AR Pav. This support my opinion, based on my work on β Lyrae, that the bulge is not due to FeIII emission, but is of a different nature, completely (in AR Pav) or at least predominantly (as in β Lyrae), namely, that it is due to a peak in the continuous bf + ff radiation of a hydrogen cloud in the system.