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SPECTROPHOTOMETRY OF AR LACERTAE

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Abstract. Spectrum scans of the RS CVn-type eclipsing binary star AR Lac at different phases in the wavelength range $\lambda\lambda$3200–7600 Å taken through Hilger and Watts monochromator equipped with 104-cm telescope of Uttar Pradesh State Observatory, Naini Tal, have been presented and discussed. By subtracting the reduced fluxes of the spectrum scan obtained during the totality of the primary eclipse from the fluxes of the spectrum scans obtained outside the eclipse, the continuum energy distribution data of the primary star of AR Lac have been derived.

1. Introduction

AR Lac ($P = 1\overset{d}{.}98$) is a binary system in which a K-type giant star eclipses a brighter F- or G-type star. The variability of AR Lac was discovered by Leavitt (1903), an eclipsing binary by Jacchia (1929) and Loreta (1930). Several investigators have discussed its photometric and spectroscopic data. Harper (1933) and Sanford (1951) have derived the spectroscopic elements while photometric elements have been derived by Chambliss (1976) and Srivastava (1981). Oliver (1974) and Hall (1975) classified AR Lac as a member of the RS CVn group.

Wood (1946) noted the intrinsic light variation in the primary component of the system. From his photoelectric observations Kron (1947) noted the irregularities during the partial phases and, first proposed an explanation based on the presence of 'star spots' on the photosphere of the primary component. Chambliss (1976) analysed 2000 *UBV* photometric observations of the system and found intrinsic light variations of the order of $0\overset{m}{.}04$ in the light curve. Hall *et al.* (1976) found persistent wave-like distortion in the light curve outside eclipse which migrates slowly towards decreasing orbital phase.

Wyse (1934) classified the spectra of the system as G5 and K0 and noted that the K0 component had sharp H and K emission lines of Ca II, superimposed on broad absorption. Struve (1952) discussed the spectra of the system in the light of turbulent spot hypothesis. Hjellming and Blankenship (1973) reported variable radio emission from the system. Gibson and Hjellming (1974) observed a relatively strong radio flare at 2695 and 8085 MHz. Srivastava (1985) observed the optical flares in *U*, *B*, and *V* filters.

This interesting eclipsing system AR Lac was included in our spectrophotometric observing programme in 1983, to study the continuum energy distributions of the component stars of eclipsing binary system. The purpose of this paper is to present the spectrophotometric observations of the system AR Lac and to discuss the results.

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2. Observations

The spectrophotometric observations of AR Lac were taken in the wavelength range $\lambda\lambda 3200-7600$ Å on 10 November 1983, with the 104-cm telescope of Uttar Pradesh State Observatory, Naini Tal. The Hilger and Watts spectrum scanner was used at the Cassegrain focus ($f/13$) for obtaining the spectral scans. An exit slit of 50 Å width was used. The standard d.c. technique was used for detecting and recording the signal. A total of 10 scans (2 scans at outside the eclipse phases, 6 during the partial primary eclipse, and 2 within the totality of the primary minimum light) have been taken. We have also observed 6 photometric standard stars listed in Table I, as comparison stars.

TABLE I

A list of stars observed for comparison

HR	HD	Spectral type	m_V
437	9270	G8	3.62
1829	36079	G5	2.85
2693	54605	F8	4.84
3043	63660	G0	5.33
46271	2382	K0	5.83
69267	3249	K4	3.53

Along with these, the spectrophotometric standard star α Lyr was observed many times during the same night for deriving the extinction coefficients and converting the observations into standard monochromatic magnitudes. The absolute calibrations of α Lyr, given by Taylor (1984) was adopted. The standard deviation of the observations does not exceed $\pm 0^{m}_{\cdot}03$ in the whole wavelength region. The observed standard magnitudes of AR Lac at phases $0^{p}_{\cdot}90$ and $0^{p}_{\cdot}00$ against wavelengths are given, respectively, in Figures 1 and 2. The phases have been computed with the ephemeris (Srivastava 1981)

$$M(E)\ \text{J.D. (Hel.)} = 2442716.1986 + 1^{d}_{\cdot}983198E\,. \tag{1}$$

3. Result and Discussion

The spectral scans of AR Lac observed during the total primary eclipse represents the spectrum of the secondary component of the system. This spectrum scan enables us to classify the secondary star of AR Lac by matching its flux distribution to those of late-type giant stars and also to derive the effective temperature by matching the continuum energy distribution with that obtained from model atmosphere.

In order to do this, we have corrected the observed continuum of the secondary star (Figure 2) in AR Lac for reddening by taking the value of $E(B - V) = 0^{m}_{\cdot}05$ (Chambliss, 1976). The reddening at the visual magnitude (A_V) was determined by adopting the mean value of total to selective extinction $R = 3.25$ (Moffat and Schmidt-Kaler, 1976). The

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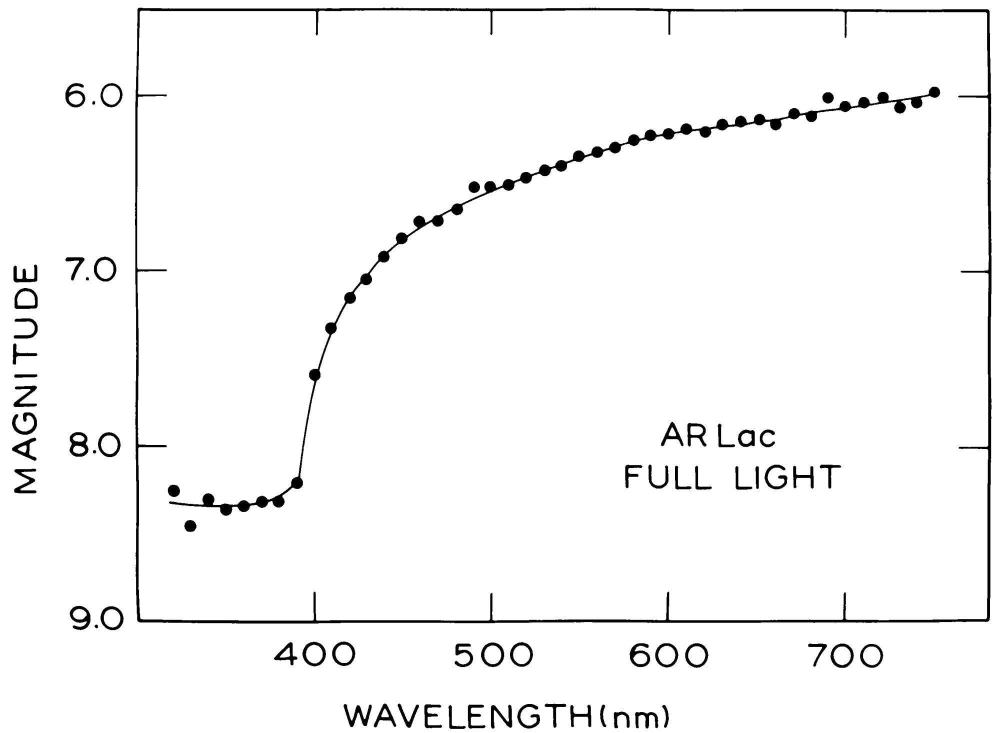

Fig. 1. Observed continuum of AR Lac (filled circles) at 0ᴾ90.

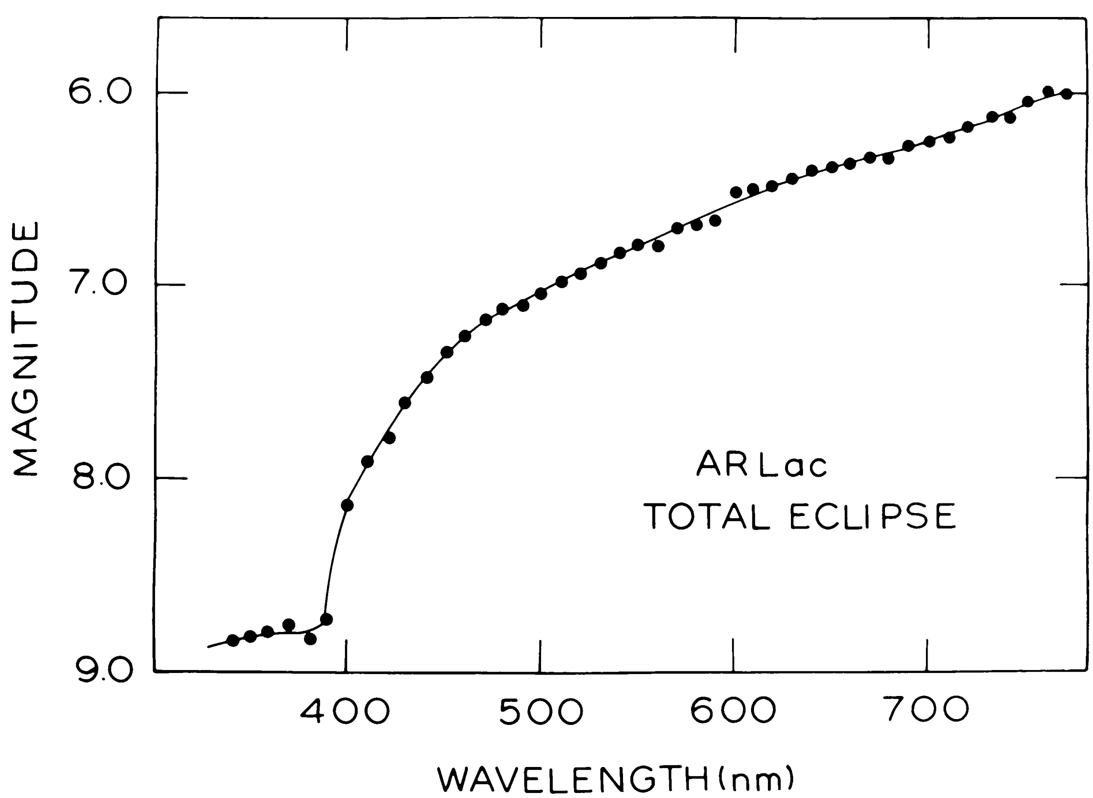

Fig. 2. Observed continuum of AR Lac (filled circles) at 0ᴾ00.

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reddening corrections at different wavelengths were worked out by using the value of A_V and extrapolated reddening law by Lucke (1980). The de-reddened continuum flux distribution of the secondary star indicates an effective temperature, below the lower limit in the Kurucz's grid of model atmospheres. Therefore, we are unable to derive the effective temperature of the secondary star in AR Lac.

In order to determine the spectral type of the secondary star in AR Lac. We have compared its observed de-reddened normalized monochromatic fluxes with the observed de-reddened normalized monochromatic fluxes of some phtometric standard late type giant stars as listed in Table I. It is found that the flux distribution of the continuum of secondary star matches well with the flux distribution of the continuum of photometric standard star 12 Mon (K0) in the whole wavelength range from $\lambda\lambda$3200–7600 Å.

The spectrum of the primary star of the eclipsing binary system AR Lac may be constructed from the intensity tracings, by substracting the intensity of the spectral scan of the secondary star as observed at the totality from the intensity of the composite spectral scan of the system as observed outside the eclipse. In order to get the continuum flux distribution of the primary star the observed magnitudes of both the spectra (Figures 1 and 2), at the interval of 10 nm, were converted into fluxes with the aid of the equation (Hayes *et al.*, 1975):

$$m_\lambda = -2.5 \log F_\lambda + 21^{m}.17 , \tag{2}$$

where m_λ and F_λ are, respectively, the monochromatic magnitude and flux at wavelength λ.

As in practice, further in all our calculations, we need normalized monochromatic magnitudes, therefore, the extracted monochromatic fluxes of the primary star were converted into normalized magnitudes with the help of the equation

$$nm_\lambda = -2.5 \log F_\lambda / F_{550} , \tag{3}$$

where *nm*, is the normalized magnitude at wavelength λ and F_{550} is the monochromatic flux at wavelength $\lambda = 550$ nm. In this way, the continuum flux distribution curve obtained for the primary star is given in Figure 3.

It is clear from Figure 3 that the primary star in AR Lac is an early-type star. To determine its spectral class, the flux distribution (Figure 3) was matched with the flux distribution of standard stars as listed in Table I. It is found that the continuum of the primary star of AR Lac can be determined by using the synthetic spectra constructed by Kurucz (1979).

Kurucz (1979) computed models assuming plane-parallel geometry, hydrostatic equilibrium, local thermodynamic equilibrium, assuming no molecular formation in the equation of state and radiative plus convective energy transports. Line blanketing was included through a statistical distribution function which includes the opacity of almost 1 000 000 atomic lines. We have already used Kurucz models for single stars of early spectral types (Singh and Chaubey, 1987).

Kurucz's grid of model atmospheres with solar abundances and microturbulence

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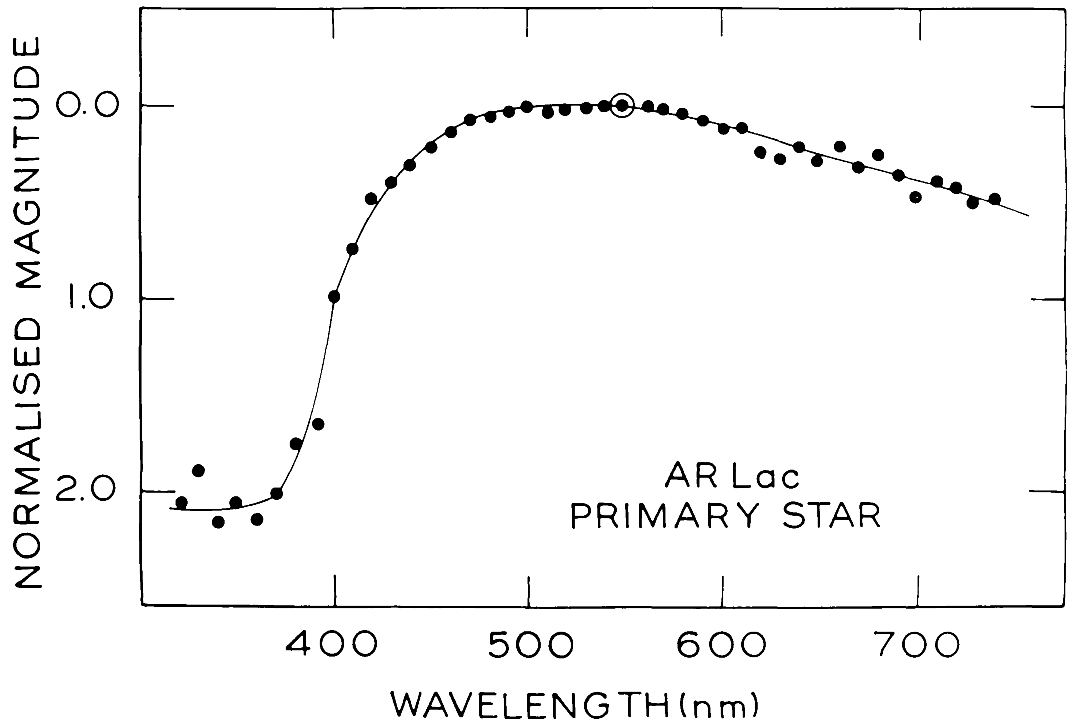

Fig. 3. Comparison of the continuum of primary star in AR Lac (dots) with the Kurucz (1979) model for $T_{\rm eff}$ = 6000 K and log g = 4.0 (continuous curve).

velocity of 2 km s^{-1} were superimposed on the observed spectra (Figure 3) for deriving the effective temperatures. It is found that the flux distribution data of primary star matched well with the model atmosphere having $T_{\rm eff}$ = 6000 K and log g = 4.0. The model (solid continuous curve) fitted with the observations is also shown in Figure 3.

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