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MULTI-COLOR PHOTOELECTRIC PHOTOMETRY OF THE STARSPOT ACTIVITY ON LAMBDA ANDROMEDAE DURING 1984/85

The long period RS CVn binary Lambda Andromedae (HR 8961, HD 222107; G8 IV-III; <V> = +3.88 mag) was observed photoelectrically on 30 nights from 1984 August 25 UT through 1985 February 21 UT. The observations were obtained at the Villanova University Observatory using the 38 cm Cassegrain telescope which utilizes a photoelectric photometer that is equipped with a refrigerated EMI 9658 photomultiplier tube and a microprocessor controlled integrating system. The characteristics of the intermediate-band blue, Strömgren y , Balmer H-alpha intermediate - and narrow-band filters are, respectively: λ_{max}=4530 Å, FWHM=180 Å; λ_{max}=5500 Å, FWHM=260 Å; λ_{max}=6600 Å, FWHM=272 Å; λ_{max}=6568 Å, FWHM=38 Å, It is to be noted that the bandwidth of the red intermediate-band filter is broad enough such that the included line feature does not significantly contribute to the measure. Therefore, the red intermediate bandpass measure is essentially that of the continuum centered at 6600 Å. The comparison star was Psi And (HR 9003, HD 223047; G5 Ib; V=+4.95 mag), while HR 9011 (HD 223229; B3 IV; V=+6.07 mag) served as the check star. No significant variations were detected between the check and comparison stars on the 3 nights that the check star was observed. The observing sequence was the conventional pattern of sky-comparison-variable-comparison-sky, with each measurement being approximately 40 seconds in duration. Typically, about 1 hour of data were collected per night. The effects of differential atmospheric extinction were removed using extinction coefficients determined from the observation of standard stars. Normal points were computed for the observations of each night, with up to 12 measurements forming a mean. H-alpha indices were computed from the intermediate - and narrow-band red data, forming an alpha-index that is a measurement of the net H-alpha line strength. The alpha-index is defined in the usual way, via the equation

$$\text{alpha-index} = -2.5 \log (F_n/F_i) + \text{constant}$$

where F_n and F_i are the stellar fluxes recorded by the narrow and intermediate bandpass filters, respectively. Nightly mean differential magnitudes were

computed for the λλ4530, 5500, 6600, and 6568 observations in the sense variable minus comparison. Two differential color indices were computed from the nightly mean differential magnitudes according to the following relations:

$$\Delta(b-y)_{v-c} = \Delta MAG(V-C)_{4530} - \Delta MAG(V-C)_{5500}$$

$$\Delta(b-r)_{v-c} = \Delta MAG(V-C)_{4530} - \Delta MAG(V-C)_{6600}$$

Additionally, a differential alpha-index was computed for each night using the transformation to the standard Villanova alpha system (Baliunas, Ciccone, and Guinan 1975) through the observations of standard stars. The numerical values of the blue, yellow, and red (H-alpha intermediate - and narrow-band) nightly mean differential magnitudes, as well as the nightly mean differential color and alpha indices, have been tabulated as a function of heliocentric Julian day (HJD) and have been submitted to the IAU Commission 27 Archive of Unpublished Observations of Variable Stars (Breger, 1985). The mean errors (standard deviations) for the nightly λλ4530, 5500, 6600, $\Delta(b-y)_{v-c}$, $\Delta(b-r)_{v-c}$ and $\Delta\alpha(V-C)$ data sets are, respectively: 0.007, 0.005, 0.006, 0.009, 0.009, 0.010 mag.

Figure 1 presents the blue and red light curves, along the $\Delta(b-r)_{v-c}$ and $\Delta\alpha(V-C)$ indices.The light curves exhibit the quasi-sinusoidal shape that is a characteristic of the RS CVn-type systems, believed to be produced by the rotational modulation in brightness from starspots. Assuming that the photometrically inferred (from previous studies) mean rotation period of $\approx$ 54 days is still relevant, the observations that we present here span $\approx$3.4 cycles. The light curves contain an interval of 35 days, from HJD 2445978 through 2446012 inclusive, during which we were unable to collect data as a consequence of unfavorable weather conditions. A relative light maximum may have occurred during this time. Our observations record 3 individual light maxima, occurring at approximately HJD 2445944, 2446054, and 2446104, as well as a light minimum near HJD 2446080. The interval between HJD 2446054 and 2446104 is only 50 days, differing markedly from the 54 day value one would anticipate. This discrepancy may result, in part, from the less than satisfactory phase coverage of our observations. The light variation is wavelength dependent with the blue observations having a greater light amplitude than the yellow (not shown) and the red observations. For example, during the time of greatest light variation (i.e. between HJD 2446054 and 2446080) the range of light between maximum and minimum is $\approx$0.10 mag, $\approx$0.08 mag, and $\approx$0.07 mag for the blue, yellow, and red observations, respectively.

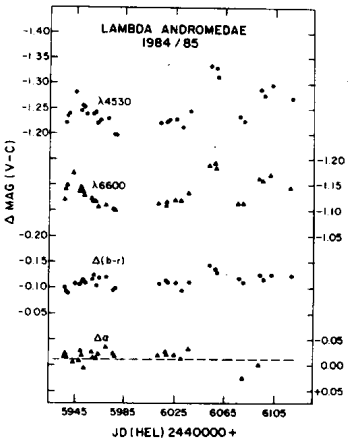

Figure 1: The photoelectric observations of Lambda Andromedae made with respect to the comparison star, Psi Andromedae during 1984-85. The differential blue (λ4530) and red (λ6600) magnitudes are plotted along with the differential (b-r) and αindices. More negative values of Δαindicate a net weakening of the Balmer Hα absorption feature. The level of no net Hα emission is indicated in the figure by a broken line.

A weak correlation exists for both the $\Delta(b-r)_{v-c}$ and $\Delta(b-y)_{v-c}$ (not shown) color indices in that they are bluest near HJD 2446054, corresponding to the light maximum which has the largest amplitude of the 3 recorded maxima. The correlation is more pronounced for the $\Delta(b-r)_{v-c}$ data than for the $\Delta(b-y)_{v-c}$ data. The mean values for the $\Delta(b-r)_{v-c}$ and the $\Delta(b-y)_{v-c}$ data sets are, respectively, -0.114 mag and -0.104 mag.

No apparent correlation exists between the light curve variations and the differential H-alpha index. Based upon the spectral types for Lambda And and Psi And (the comparison star), $\Delta\alpha$(V-C) $\gtrsim$-0.015 mag corresponds to no H-alpha emission. The mean value for the $\Delta\alpha$(V-C) data set is $\approx$-0.016 mag. Note that the data point recorded at HJD 2446079 deviates most from the mean, revealing the strongest H-alpha absorption of our observations.

The photometric behavior of Lambda And prior to autumn 1983 was distinguished by large amplitude (typically 0.20 mag at λ 5500), quasi - sinusoidal waveforms, occasionally possessing two maxima per rotation cycle. Bopp and Noah (1980), Dorren, Guinan, and Paczkowski (1982), and Dorren and Guinan(1984) have explained the ever changing shape and amplitude of the light curves as being due to the rotational modulation of 2 large circular spots or spot complexes. Unpublished observations obtained at Villanova University from late 1983 through July 1984 reveal that the light output from Lambda And was essentially constant. In the context of the starspot model, such behavior can be explained by either the spots being located near the star's rotational pole, or, the fragmentation of the 2 large spots into numerous, smaller spots which are evenly distributed across the visible stellar surface.

As shown in the figure, the light curves vary in shape and light amplitude with time. These cycle-to-cycle variations are similar to those found previously for this star (Boyd et al. 1983, Dorren and Guinan 1984), and have been interpreted as arising, in part, from differential rotation of one spot complex relative to the other (Dorren and Guinan 1984). Furthermore, the wavelength dependence of the amplitudes of our light curves is consistent with the presence of dark starspots 800 degrees cooler than the surrounding photosphere (Bopp and Noah 1980, Dorren and Guinan 1984). With respect to the photometric behavior of Lambda And between late 1983 and July 1984 explained in the previous paragraph, the observations presented here may be indicative of longitudinal concentration of the spot complexes coupled with latitudinal migration away from the pole. Continued monitoring throughout the 1985/86 observing season should help bring clarity towards understanding the current surface and atmospheric activity of Lambda And.

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