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VARIATIONS IN THE EFFECTIVE TEMPERATURE AND THE BALMER JUMP OF THE Ap STAR 41 Tauri

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The magnetic Ap-Si star 41 Tau (GS Tau, B9p Si) was found to be variable by Rakoš (1962) with a period of around 12 days. Blanco and Catalano (1972) also confirmed this periodicity. Subsequently, Abt and Snowden (1973) discovered the spectroscopic binarity of 41 Tau and determined an orbital period of $7^{\rm d}.227424$, a value also adopted by Wolff (1973). The investigation of the visible spectrum by Wolff established the synchronism between rotation and revolution for this star. Moreover Wolff (1973) recorded Zeeman spectrograms of this star and determined the variations of the effective magnetic field, suggesting a maximum near phase 0.6. These spectrograms also yielded variations of Si II, Sr II and Ti II lines and showed that the Si II minimum, near phase 0.4, coincides approximately with the maximum brightness whereas Sr II and Ti II minima occur near phase 0.0. Moreover Artru and Freire-Ferrero (1988), who observed 41 Tau with the IUE satellite, confirmed the results of Wolff (1973). They showed that the minimum of silicon absorption occurs at phase 0.47, just before the gallium maximum at phase 0.59. More recently, Gonzalez and Artru (1994) used the visible spectra to derive variations of the O I lines at $\lambda\lambda$ 7771.95, 7774.17 and 7775.39 Å and found that there must be an accumulation of oxygen around the positive magnetic pole of 41 Tau.

A new method of determination of the effective temperature ($T_{\rm eff}$) of the chemically peculiar stars using the Balmer continuum slope near the Balmer jump was proposed by Sokolov (1998). Using this method it is possible to measure the size of the Balmer jump (D) as well (see Sokolov 1995). To check the reliability of this method the star 41 Tau was selected, because there is evidence for variability in the size of the Balmer jump for this star (Adelman 1983). Fourteen continuum energy distributions in the spectra of 41 Tau were taken from the paper Adelman (1983). The scans have seven measurements in the Balmer continuum that allowed to calculate the $T_{\rm eff}$ from the slope of spectra in the Balmer continuum with reasonable accuracy. To determine the continuum shape at both sides of the Balmer jump, an iterative procedure was used. The Balmer jumps of 41 Tau were calculated, by extrapolating the two fitted curves to λ = 3700 Å, as described by Sokolov (1995). The errors on effective temperatures and on size of the Balmer jumps were computed according to the formula for the standard error propagation theory. The phases for the observational data in our investigation were computed using the ephemeris adopted by Abt and Snowden (1973).

The variations in the effective temperature and Balmer jump of 41 Tau are plotted on the middle and bottom panels of Fig. 1, respectively. As one can see from Fig. 1, both

$T_{\rm eff}$ and D reveal clear variation with phase for 41 Tau. Although the statistical error of the $T_{\rm eff}$ determinations for individual scans is large enough (up to 800 K). In order to find the amplitude of the $T_{\rm eff}$ and D variations a linearized least-squares method was used, which was described by North (1987). A least-squares fit by one-frequency cosine curve was applied both to the $T_{\rm eff}$ and to the D variations. The fitted curves are plotted as the solid lines in Fig. 1. The computations give the minimum of the $T_{\rm eff}$ (12650 K) and D (0.292 dex) at the phases 0.45 and 0.42, respectively. Also, the maximum of the $T_{\rm eff}$ (13240 K) is at phase 0.95 and is consistent with the maximum of D (0.319 dex) at phase 0.92.

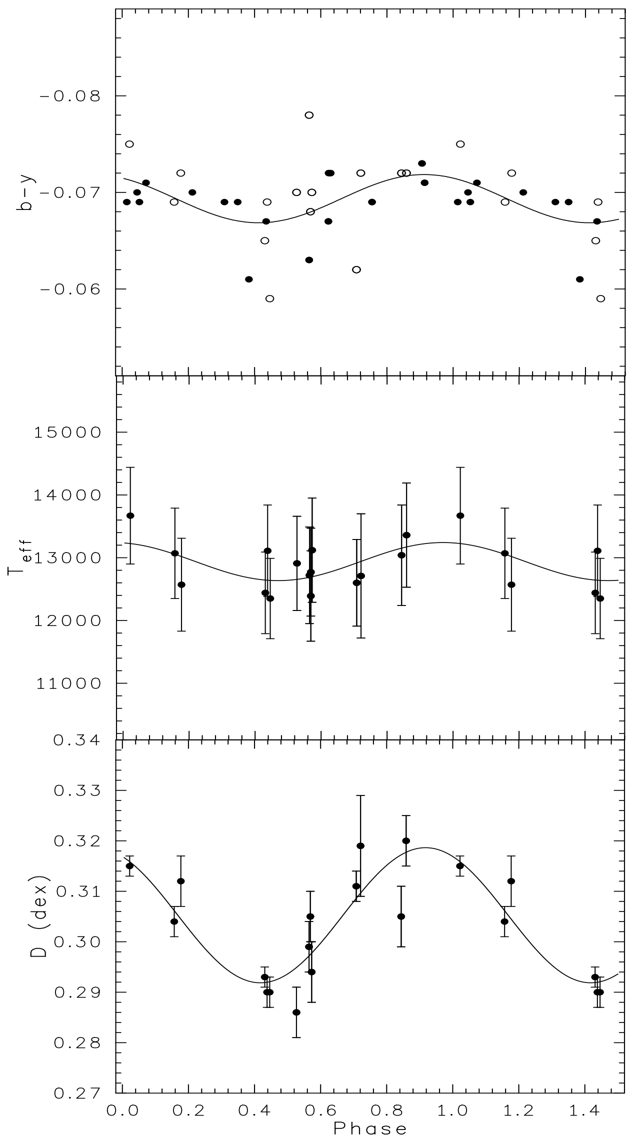

Figure 1. The variations in the $b-y$ color index, effective temperature and Balmer jump for 41 Tau. The top panel shows the $b-y$ color index variations observed by Wolff (1973) (filled circles) and synthesized from spectrophotometry by Adelman (1983) (open circle s). The middle panel shows the effective temperature variations. The bottom panel displays the Balmer jump variations. The solid lines are least squares fit.

It is well-known that the $u-b$ and $b-y$ color indices of Strömgren photometry measures the size of the Balmer jump and the slope of the Paschen continuum, respectively. Adelman (1983) established the changes in the size of the Balmer jump from the $u-b$ index variations and two scan comparisons. Moreover he noted that the $b-y$ index can be described as constant although the values suggest low amplitude variability, but the slope of the Balmer continuum is not quite correct.

To test the validity of the obtained phase diagrams of the $T_{\rm eff}$ and the D variations, the $u-b$ and $b-y$ indices were used. The correlation between the D and the $u-b$ index variations is excellent, as is illustrated by Fig. 1 and by Fig. 4 from the paper by Adelman (1983). It should be noted that the minimum of D corresponds to the maximum of the light both in the Paschen continuum and in the Balmer continuum (see Wolff 1973).

The slope of the Paschen continuum is a good estimator of $T_{\rm eff}$ for hot CP stars in the visual spectral region. To investigate the correlation between variations of the slope of the Paschen continuum and the variations of $T_{\rm eff}$ derived from the slope in the Balmer continuum the $b-y$ color index was used. The top panel of Fig. 1 shows the $b-y$ index variations of 41 Tau. The solid line is a least squares fit by a one-frequency cosine curve. The fitted curve confirms the low amplitude variability of the $b-y$ color index for this star, although the scattering of the points in the top panel of Fig. 1 is large. The correlation between the slope in the Paschen continuum and the $T_{\rm eff}$ derived from the slope in the Balmer continuum variations appears to be very good, as is illustrated by Fig. 1. The minimum of the $b-y$ index is at phase 0.42 and is consistent with the minimum of the $T_{\rm eff}$. This supports the reliability of the obtained phase diagram for the $T_{\rm eff}$ variations. On the other hand, the minimum of the $T_{\rm eff}$ corresponds to the maximum light. Moreover the observations of 41 Tau show that Si minimum coincides with maximum light at the phase 0.4 (Wolff 1973). However Mantegazza et al. (1990) found that the shape of the light curve of 41 Tau is variable on the timescale of a few years.

In conclusion, the present analysis of 41 Tau shows that the method proposed by Sokolov (1998) is of sufficient accuracy to study the effective temperature and the Balmer jump variations with phase for Ap stars.

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