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THE SPOTTED YOUNG SUN – HD 129333 (= EK Dra)

HD 129333 (= EK Dra) is a young, single, solar-type star with a rotational period of approximately $2\overset{d}{.}7$. Its U, V, W space velocity components (+3, −29, −17) (km/s) are very close to those of the Pleiades cluster (+9, −27 −12), making it a probable member of the Pleiades moving group of young stars with an age of ≈ 70 Myr (Soderblom & Clements, 1987). This star is part of a program being carried out at Villanova University called *The Sun in Time*. The program involves multiwavelength observations of single G0-G5 V stars with ages ranging from ≈ 70 Myr to ≈ 9 Gyr. These stars are suitable proxies for the sun at several stages of its life history from the zero age main sequence (ZAMS) to the very late (terminal) main-sequence (TAMS) phase (Dorren & Guinan, 1994a).

HD 129333 (dG0, B−V = +0.61, T_{eff} = 5930 K, age ≈ 70 Myr) provides a look at the sun shortly after it arrived on the main-sequence (Dorren & Guinan, 1994b). It has a very active chromosphere and transition region, which are consistent with its youth and rapid rotation. Furthermore, in 1991, HD 129333 was detected as an X-ray source during ROSAT pointed observations, with an X-ray luminosity of L_x (0.2-2.4 keV)$\sim 9\times10^{29}$ erg/s, or about 300 times stronger than the Sun (Dorren & Guinan, 1992). The X-ray emission probably originates from the stellar corona, while the UV emission features are associated with the chromosphere-corona transition region of the star (Dorren & Guinan, 1994b). The best fit to the X-ray energy distribution indicates a two-temperature component corona with $T_1 = 1.3 \times 10^6$ K and $T_2 = 9.6 \times 10^6$ K (Dorren, Güdel & Guinan 1994).

In 1983 this star was discovered to have low amplitude (Amp(V) ≈ 0.05) light variations with a period of $\sim 2\overset{d}{.}7$ (Dorren & Guinan, 1994b). These periodic $2\overset{d}{.}7$ variations increase in amplitude with a decrease in wavelength and are assumed to be rotational modulation due to the presence of cool starspots. In that case, the photometric period ($\sim 2\overset{d}{.}7$) represents the stellar rotational period. HD 129333 now has a variable star designation of EK Draconis (Kazarovets, Samus & Goranskij, 1993).

Photoelectric photometry was obtained from 1990/91 to the present for HD 129333 in *UBV*, *ubvy* and Hα *wide* and *narrow* bandpasses with Automatic Photoelectric Telescopes (APTs) located at Mt.Hopkins, Arizona. The data presented in this report has come from the Four College Consortium (FCC) 0.8m APT. The photoelectric observations were carried out relative to the nearby comparison star HD 129390 (V = +7.5; B−V = +0.4; F2) and check star HD 127821 (V = +6.09; B−V = +0.41; F4 IV) and followed the usual pattern of *sky-comparison-check-variable-comparison-sky*, with each measure lasting 10 seconds. 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. Typically, each normal consists of 4-5 individual 10 sec measurements.

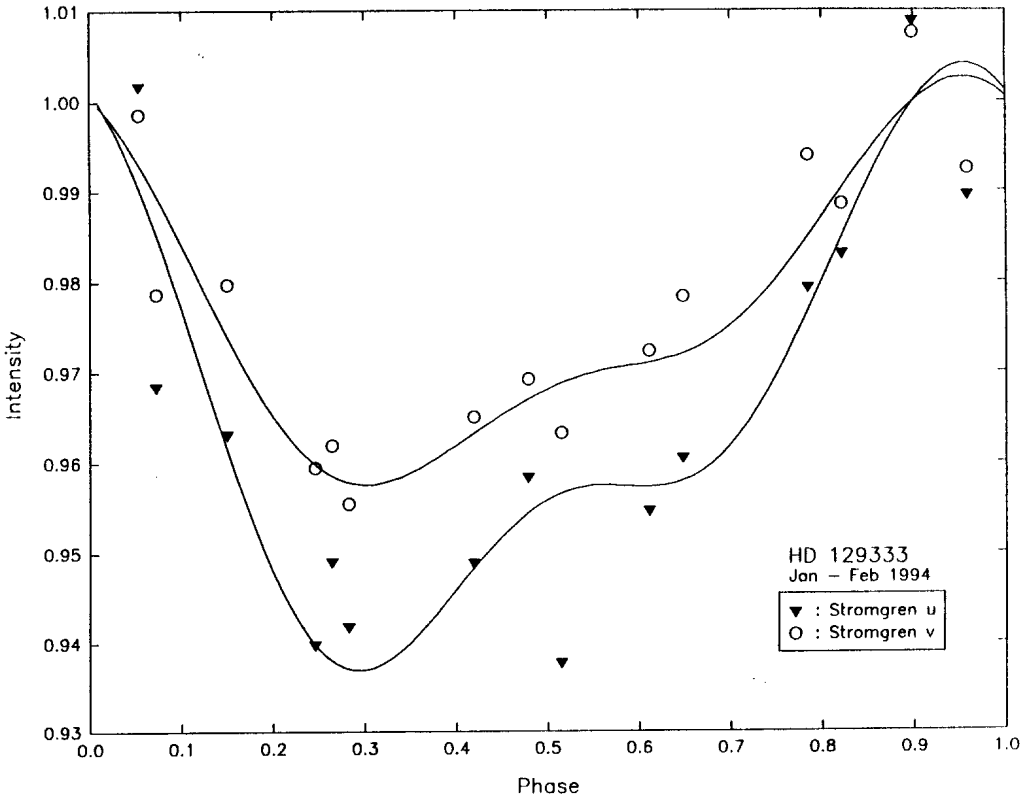

Figure 1: Photometric variations of HD 129333 versus phase. Each filter was fit with a model (solid lines on figure) using Binary Maker 2.0.

Table 1. Spot Parameters for HD 129333

Assumed Quantities

Inclination $i = 60°$

$P_{rotation} = 2.74$d

$T_{photosphere} = 5930$ K[a]

Limb-Darkening Coefficients[b]

x(λ3700) = 0.76

x(λ5500) = 0.62

Determined Quantities

	Temperature (K)	Radius	Longitude	Latitude
Spot 1	5470 ± 40	$20.5° \pm 1.5°$	$240° \pm 5°$	$+40° \pm 5°$
Spot 2	5470 ± 40	$24.5° \pm 1.5°$	$100° \pm 5°$	$+38° \pm 5°$

Total Spotted Area[c] = $7.4\% \pm 0.5\%$

[a] From dG0 spectral type.

[b] Al-Naimiy (1978).

[c] In terms of the total surface area of the star.

The data discussed here represents 15 nights over the period 1994 January 24 UT through 1994 February 26 UT. Nightly means were calculated and phases were computed using an arbitrary starting heliocentric Julian Date and a period of $2\overset{d}{.}74$. The data were then normalized to intensity units and plotted in intensity versus phase.

Figure 1 shows the nightly mean differential magnitudes for the y-band (5500 Å) and the u-band (3600 Å). The differential yellow light curve has a broad primary minimum extending from $\approx$ 0.10P to $\approx$ 0.60P. The light amplitude of the yellow curve is $\simeq$ 0.040 mag. For the u-filter (λ3600), the shape is very similar to the yellow curve but the light amplitude is greater ($\simeq$ 0.062 mag). The intermediate filters (violet 4100 Å and blue 4400 Å) have similar shapes and amplitudes which fall between the yellow and ultra-violet curves.

The fits for HD 129333 were done using Binary Maker 2.0, a synthetic modeler for binary star systems (Bradstreet, 1993), with the second component essentially *turned off* (given a very low mass and temperature) in order to model a single rotating star. The model consists of two large, mid-latitude spots separated by 140° in longitude. The total area spotted is about 7.4% of the stellar surface area. The spots were assumed to be circular and to have the same temperature. Table 1 gives a summary of the spot parameters used in the model.

The temperature difference between the spots and the photosphere was determined to be 460 ($\pm$40) K. The model was fit for several different starspot temperatures and radii in the y-band (5500 Å) and then compared with the u-band (3600 Å) to cover the full range of wavelength dependence in the data. The models that best fit to both colors were in the range 420-500 K. This solution was found to fit the other light curves at the intermediate wavelengths. The uncertainty in the value results from the scatter in the data and ambiguities in the model.

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