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PZ Mon - AN ACTIVE EVOLVED STAR

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PZ Mon is a relatively little studied active K2 star, of recent interest due to discovery of a large amplitude ($\Delta m_{\rm B} \approx 1.0$) spot cycle with a period $P_{\rm cyc} \approx 50$ years (Bondar' 1995). Its spectral type is given as K2Ve by Kukarkin (1958). First noted as a result of its variable optical emission lines (Munch & Munch 1955), PZ Mon was classified a UV Ceti flare star by Petit (1959). Photometric monitoring (Cristaldi & Rodonò 1970, 1973), however, showed that flaring is quite infrequent and typically low amplitude. Longer term brightness variations also suggested it was a BY Dra variable (Wachmann 1968; Bondar' 1992). The star has been detected with *Einstein* (Agarwal et al. 1986) and IUE data (LWP14570L) show a saturated Mg II line.

In the course of a recent study of stellar dynamo cycles (Saar & Brandenburg 1998), we became interested in learning more about the star. Hipparcos data (ESA 1997) give a parallax of $\pi = 0.71 \pm 1.17$ mas, or a distance, $d \approx 1410^{+\infty}_{-880}$ pc. The maximum $m_{\rm pg} \approx 9.8$ and B$-$V = 1.10 (Bondar' 1995) implies $\rm V_{max} \approx 8.8$ (assuming $m_{\rm pg}$ = B$-$0.11), consistent with the recent (near maximum) Hipparcos value of V = 9.03. Combining $\rm V_{max}$ and π yields $M_{\rm V} \approx -1.9$ (for $d = 1410$ pc), indicating PZ Mon is clearly not a dwarf; rather, the $M_{\rm V}$ and B$-$V suggest a spectral type of ≈K0 II (e.g., Allen 1973; Gray 1992). The radius R can be expressed as $\log R = \log d - 0.164 - 2\log T_{\rm eff} - 0.2({\rm V + BC})$ (Oranje 1986), yielding $R/R_\odot \approx 45$ for $T_{\rm eff} \approx 4500$ K and $d = 1410$ pc (using the updated bolometric corrections of Flower 1996). The large errors in d, however, mean $M_{\rm V} \approx 0.2$ (for $d = 530$ pc) is also possible, which would make PZ Mon ≈K1 III with $R/R_\odot \approx 17$.

To further explore PZ Mon's evolutionary state and other properties, we obtained high resolution ($\lambda/\Delta\lambda = 125,000$, 2 pixel), moderate S/N (~ 100) spectra of PZ Mon and comparison stars with the stellar echelle spectrograph and TI CCD detector (Smith & Giampapa 1987) at the McMath–Pierce solar telescope of the National Solar Observatory. We used the 10 slice image slicer and the 180 mm transfer lens; the resulting spectra cover a 20Å interval centered near 6170 Å. The data were dark subtracted, flat-fielded, optimally extracted, and wavelength calibrated (using a quadratic fit to six Th-Ar lines).

Fig. 1 shows the PZ Mon data compared with a dwarf of similar color (HD 32147, K4V, B$-$V = 1.06) and a somewhat warmer RS CVn (λ And, G8 III-IV, B$-$V = 1.01). We convolved the HD 32147 ($v \sin i < 1$ km s^{-1}; Saar & Osten 1997) spectrum to $v \sin i = 10$ km s^{-1} with a rotational broadening function ($G(v \sin i)$; e.g., Gray 1992). The λ And spectrum was deconvolved by $G(6.5)$ to correct for its $v \sin i = 6.5$ km s^{-1} (Donati et al. 1995), convolved with $G(10)$, and filtered to suppress deconvolution noise. The wing of the strong 6162Å Ca I line is gravity sensitive, and clearly λ And is a better match near there than HD 32147. Consistent with its higher $T_{\rm eff}$, line strengths in λ And are on average slightly weaker than in PZ Mon. The radial velocity of PZ Mon at the midpoint of observations on HJD 2447834.997 was $v_r = +28.9 \pm 0.3$ km s^{-1}, based on cross-correlation of the spectrum with one of HD 32147 ($v_r = +22.2$ km s^{-1}; Eggen 1992). There is no sign of a secondary star in our spectrum (Fig. 1); if present, it must have a flux <5% of the primary at 6170 Å.

Since PZ Mon is evolved, active, rapidly rotating (for a K giant/bright giant) and spotted, it seems likely to be an RS CVn system. The K1III+? classification (putting $d \sim 500$ pc) is then perhaps slightly preferred, since few RS CVn systems are bright giants (Strassmeier et al. 1993). Further v_r data can help determine whether it is a binary.

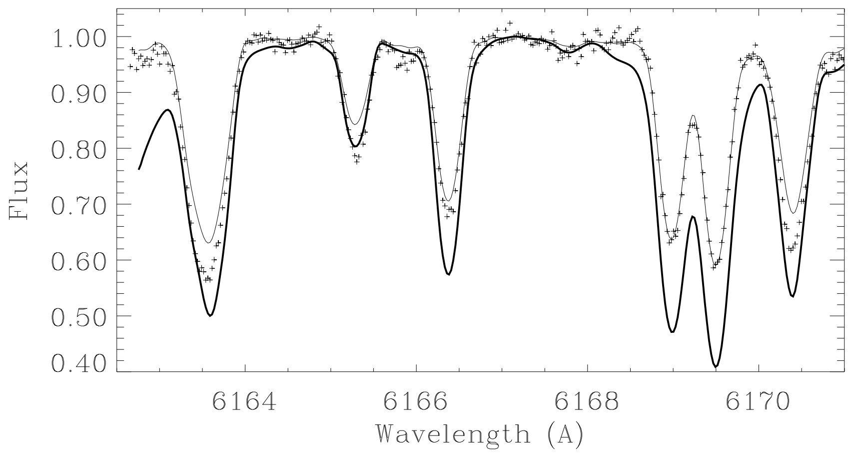

Figure 1. McMath–Pierce data of PZ Mon (+; 0.0245 Å pixel^{-1}, $\lambda/\Delta\lambda = 125,000$, S/N $\approx$ 100) compared with HD 32147 (K5V; heavy solid) and λ And (G8III-IV; thin solid), both convolved to $v \sin i = 10$ km s^{-1}). All spectra have been shifted to the laboratory λ scale.

Since neither of the comparison stars was a perfect match, we also fit selected line profiles using a simple radiative transfer model (Saar & Osten 1997) to confirm the $v \sin i$. The average results for 4 relatively unblended lines (Fe I 6165, 6180 Å, Ca I 6166 Å, Ni I 6175 Å; Fig. 2) was $v \sin i = 10.2 \pm 0.4$ km s^{-1}, close to results using a comparison star (Fig. 1), and a (radial-tangential) macroturbulent velocity $v_{\rm mac} = 5.5 \pm 0.8$ km s^{-1}. This $v_{\rm mac}$ is normal for a K1 III star ($\langle v_{\rm mac} \rangle \approx 5.0$ km s^{-1}; Gray 1992, his Fig. 18.9), though perhaps slightly enhanced due to activity (Saar & Osten 1997). The magnetically sensitive (Landè $g_{\rm eff} = 2.5$) Fe I 6173Å line is best fit by $v \sin i = 9.9$ km s^{-1} and $v_{\rm mac} = 7.1$ km s^{-1}; the excess broadening in the wings (enhanced $v_{\rm mac}$) suggests the presence of significant magnetic flux (cf. Saar & Linsky 1986).

Agarwal et al. (1986) detected PZ Mon with *Einstein* at 0.021 IPC counts s^{-1}. The star appears to be variable in X-rays: SIMBAD lists a detection at 0.014 IPC counts s^{-1}. Assuming a coronal temperature of 10^7 K and an ISM column of $\log n_H \approx 21.32$ (equal to HD 48279, 1°.4 distant at $d = 1635$ pc; Shull & Van Steenberg 1985), using PIMMS,

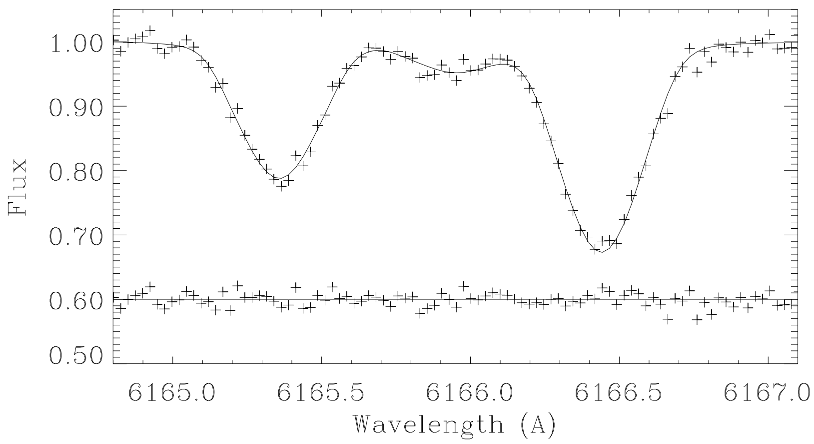

Figure 2. McMath–Pierce data of PZ Mon (+) near the Fe I 6165.3 Å and Ca I 6166.4 Å lines, fit with a simple radiative transfer model (solid), with residuals offset below. Average results for four lines are $v \sin i = 10.2 \pm 0.4$ km s^{-1}, and $v_{\rm mac} = 5.5 \pm 0.8$ km s^{-1}; $\sigma_{\rm fit} = 0.011$.

the Agarwal et al. flux works out to $f_X \approx 5 \times 10^{-13}$ ergs cm^{-2} s^{-1} (0.2-4.0 keV) at earth. Using the calibration of (Oranje 1986), the ratio of surface fluxes (at star/at earth) is $\log F/f \approx 18.3$, implying $\log F_X = 6.0$ ergs cm^{-2} s^{-1} and $\log F_X/F_{\rm bol} = \log L_X/L_{\rm bol} = -4.2$, and $\log L_X = 31.8$ ergs s^{-1} (if $d \approx 1410$ pc) or $\log L_X = 30.9$ ergs s^{-1} (if $d \approx 530$ pc). These values are typical of RS CVn systems (e.g., Dempsey et al. 1993).

The shift of PZ Mon from a dwarf to a giant classification is consistent with its very low level of flaring (RS CVns show few optical flares; Henry & Newsom 1996). It is also consistent with its non-detection by the ROSAT EUVE survey (Tsikoudi & Kellett 1997) – the larger ISM column due to greater d would absorb much of the EUV flux. The combined properties of the star suggest it may be a distant analog to σ Gem (K1III+?, B$-$V = 1.12, $v \sin i = 25$ km s^{-1}, $\log L_X \approx 31.4$; Strassmeier et al. 1993). As PZ Mon is now an active giant, V833 Tau (Hartmann et al. 1981; Bondar' 1995) appears to reclaim the title of the dwarf star with the largest photometric spot cycle amplitude. PZ Mon becomes one of the relatively few evolved stars with a well determined starspot cycle.

In summary, an Hipparcos parallax and new high-resolution spectra show that PZ Mon, long considered a spotted UV Ceti flare star, is actually a distant active giant (probably $\sim$K1III+?) with $v \sin i \approx 10$ km s^{-1} and $v_r = +28.9$ km s^{-1} on HJD 2447834.997. It is likely an RS CVn variable, similar to σ Gem in many respects. The recalibrated X-ray properties of PZ Mon are consistent with RS CVn systems.

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