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Starspot coverage and differential rotation on PZ Tel

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Abstract.
We present Doppler images of the young, late-type star, PZ Tel from spectroscopic observations at two epochs. The 0.95d period necessitated dual-site observations in order to obtain full phase coverage. By making use of the large number of spectral lines available in an échelle spectrum, least squares deconvolution is used to derive a series of low noise absorption profiles. The high S:N ratio profiles enable increased latitude discrimination in Doppler imaging. The resulting maximum entropy reconstructions reveal the presence of starspots at all latitudes. Since the lifetimes of individual spots are greater than the two day gap between data sets, we cross-correlated constant-latitude strips from the images, in order to derive a measure of rotation as a function of latitude. The close agreement with the solar and AB Doradus (K0V) values, suggests that the differential rotation rate is at most only weakly dependent upon rotation rate and spectral type.

1. Introduction

The late-type single star, PZ Tel (HD 174429) is a rapid rotator with an axial rotation period of 0.94486 d (Innis , Coates & Thompson 1990) and $v\sin i = 68$ km s^{-1}. Houk (1978) classified PZ Tel as a K0 Vp and the observed UBV(RI)$_c$ colours (Cutispoto 1998) are in good agreement with those of an active G9/K0 dwarf or G9 IV/V star. A differential rotation shear consistent with the solar value was inferred by Innis et al. (1990) from a three-spot model of V-band light curves. Balona (1987) and Innis et al. (1988) found heliocentric radial velocities of $+4.4 \pm 6.2$ km s^{-1} and -3.2 ± 3.7 km s^{-1}. These measurements suggest that PZ Tel is a member of the Eggen (1975) local association or Pleiades group. The HIPPARCOS parallax of 20.14 ± 1.18 arcsec yields a distance of 49.65 ± 2.91 pc, which is lower than the Innis et al. (1988) value of ~68pc. Favata et al. (1998) found that PZ Tel lies above the main sequence, on the evolutionary track of a 1.1 $M_\odot$ star, and corresponding to an age of 20 Myr.

The study by Innis et al. (1988) revealed a strong emission core in the Ca II K line thus indicating that PZ Tel is chromospherically active, a result confirmed

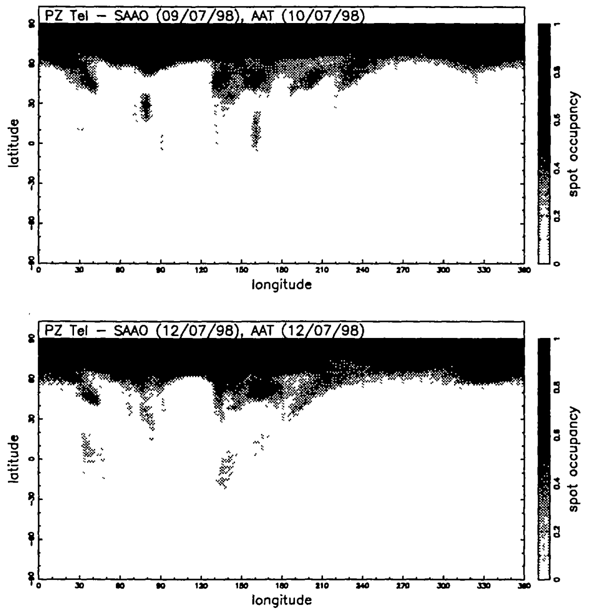

Figure 1. Max-Ent image reconstructions of PZ Tel from 09,10/07/98 (top) and 12/07/98 (bottom). Note the similarity of the two images which are effectively two rotation cycles apart.

by Soderblom et al. (1998). Innis et al. (1988) also found that H α is seen as a shallow absorption feature, being at times completely filled in.

2. Evidence for evolutionary status and physical parameters

Observations of PZ Tel were made in 1998 Jul 9, 10 & 1998 Jul 12 with the GIRAFFE spectrograph at the Sutherland 1.9 m telescope (South African Astronomical Observatory - SAAO) and UCLES at the 3.9 m Anglo Australian Telescope.

We have re-measured the lithium abundance and find N(Li) = 2.97 ± 0.06 in close agreement with N(Li) = 3.11 found by Soderblom et al. (1998). For the mass of PZ Tel, this abundance lies at the peak of the distribution of the Pleiades (~100 Myr), α Persei (~50 Myr) IC 2602 & 2391 (~30 Myr) clusters, but a little higher than the peak of the distribution for NGC 1039 (~250 Myr) & NGC 6475 (~220 Myr) clusters, indicative of PMS/early-MS status. We also derive a radial velocity of -0.2 ± 2 km s^{-1} from two orders of the SAAO data (5360 - 5440 Å and 5465 - 5545 Å were used because they both contained deep photospheric lines and negligible telluric contamination). Using HIPPARCOS data and the derived radial velocity, we derive U, V, W space motions of $U = -7.6 \pm 1.9$ km s^{-1}, $V = -16.2 \pm 1.1$ km s^{-1} and $W = -9.0 \pm 0.9$ km s^{-1}. These values are consistent with PZ Tel being a member of the young disc population (Eggen 1977).

The physical parameters $v\sin i = 68$ km s^{-1} and inclination $i = 60° - 65°$ are derived from minimisation of χ^2 using our imaging code DOTS. TiO bandhead strengths on active cool stars reveal a high fraction of global spot coverage of

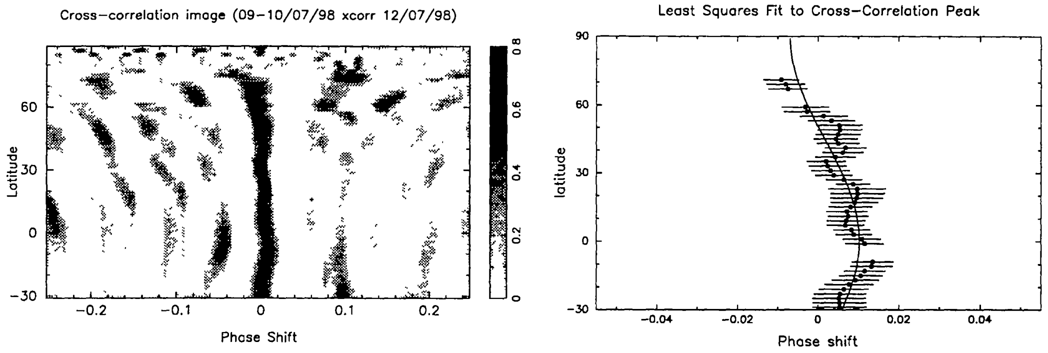

Figure 2. Left: Cross-correlation image of the two Max-Ent reconstructions. Right: Least squares fit to cross-correlation peak (see text).

typically $\alpha = 0.1$ -0.5 (O'Neal, Neff & Saar 1998). The lack of evidence for such a high spot filling in Doppler images suggests that such features are beyond the resolution of this technique. The presence of spots on the stellar surface blocks flux from leaving the star. The deeper layers of the convection zone heat up until the surface luminosity returns to its original value on the Kelvin-Helmholtz timescale ($t_k \simeq 2 \times 10^5$ yrs). As a result, the star has a larger radius and surface temperature (Spruit 1982). Neglecting to include this effect leads to systematic underestimation of the stellar radius from the Barnes-Evans method (Barnes et al. 1978). However, the increased radius and spot temperature offset the colour change due to a global spot coverage. Assuming negligible effects of short lived starspots ($< t_k$) on the mean photometric colours, it is possible to determine the corrected V magnitude and V-I colour to obtain a new Barnes-Evans estimate. Using Monte-Carlo simulations, we find $i = 60° - 65°$ in good agreement to the maximum entropy minimisation method used above.

3. Results

The images of PZ Tel from the two epochs (two day separation) were calculated using our maximum-entropy imaging code, and are shown in Fig. 1. The similarity of surface structure in the two images affords the chance to cross-correlate constant latitude strips in an attempt to measure possible latitude-dependent surface differential rotation. The resulting cross-correlation image is shown in Fig. 2. The solar-type differential rotation of PZ Tel is described to first order as

$$\omega(l) = 6.650 \pm 0.054 sin^2(l) \mathrm{day}^{-1} \tag{1}$$

by fitting a $\sin^2(l)$ function (Fig. 2) to the cross-correlation peaks. The equator laps polar-regions once every 116 ± 19 days, and as such is entirely consistent with the equivalent solar value of 120 days and that found for the K1 dwarf AB Doradus (Donati 1997) (110 days) using the technique described here.

4. Discussion and Conclusion

The Mount Wilson survey (Wilson 1978 and Baliunas et al. 1995) of the variable Ca II H & K chromospheric emission cores in solar type stars was begun in 1966. The emission line strengths vary with magnetic field strength, and are thus excellent indicators of stellar analogues to the 11 yr solar magnetic cycle. Of the stars which show a regular activity cycle, the main concentration of periods are in the range 5 - 11 yrs, with none of the periods classified as good or excellent being shorter than 7 yrs. If the same magnetic dynamo process is at work in all (pre-) main-sequence stars we may also expect to see a common differential rotation rate. The models of Kitchatinov & Rüdiger show that absolute differential rotation (the equator lap pole time) is indeed independent of rotation period in the range 1 day to the solar rotation period. These models also show a weak dependence on spectral type in the range considered (G2V to K5V).

The magnitude of the differential rotation on single (pre-) main-sequence stars is known only for the Sun, AB Dor and PZ Tel. Doppler imaging is currently the best tool with which to measure differential rotation in rapid rotators. The sample of stars for which the differential rotation is known must be increased, with a greater range of spectral types and rotation periods before any firm conclusions can be reached.

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