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CCD B & V photometry of the young, active, late-type star PZ Telescopii

J.L. Innis[1], D.W. Coates[2], and T.G. Kaye[3]

[1] Brightwater Observatory, 280 Brightwater Rd., Howden, TAS, 7054. Email: brightwater@iraf.net

[2] School of Physics, Building 27, Monash University, VIC, 3800

[3] Spectrashift, 404 Hillcrest, Prospect Heights, IL 60090, USA

We present new CCD B and V photometry, obtained at the Brightwater Observatory in June and July 2006, of PZ Telescopii (HD 174429), a young, rapidly rotating late–type star with an active chromosphere. The CCD data were collected with a short focal–length telescope, giving a field of view near 0.80×0.55 deg, so target and comparison stars could be observed simultaneously. A periodogram analysis of the PZ Tel data returned a value of 0.94 d, consistent with earlier photometry. We found the amplitude of variation was ∼0.06 mag in B and V, with evidence for a small colour variation of between 0.01 and 0.02 mag, the star being redder when fainter. From a comparison with previously published photometry we find that the amplitude of V–light variation is amongst the smallest ever observed. There is an indication that there was a maximum in the long-term brightness level near V=8.28 around the year 2000, with the current data being several hundredths of a magnitude fainter.

Introduction

Studies of activity in late–type stars have revealed enhanced solar activity in objects ranging from very young to evolved stars (e.g. Vogt, 1983). Detailed behaviour of starspots on a small number of objects has been obtained via Doppler Imaging (Vogt & Penrod, 1983, Collier–Cameron & Unruh, 1994), often in conjunction with multi–colour photometry. However, most of our understanding of the longer–term behaviour of spotted stars has come from photometry alone, revealing evidence for stellar activity cycles (Baliunas et al. 1995), presumed to be the analogues of the solar magnetic cycle, and allowing estimates to be made of spot properties (Olah et al, 1997).

Gathering such data historically required a large investment of time of small– to medium-sized telescopes, along with observers to run them. Developments in CCDs and the availabilty of cheap computing power means that a semi–automated or even a fully automated CCD photometry system can be assembled for modest cost. Two examples that illustrate what can be done are the WASP (Kane et al. 2005) and ASAS systems (Pojmanski, 1997). These instruments use short focal–length camera lenses coupled to commercial CCDs, on mounts under computer control, and can automatically gather a large number of photometric quality CCD frames containing images of many hundreds of stars each night.

We used a semi–automated CCD system to collect B and V data on the active young dwarf PZ Telescopii. Comparing these new data to earlier observations suggests that a long–term brightening of the mean light level of PZ Tel may have peaked around the year 2000, and that the star is now fading.

The Brightwater Photometry system

The Brightwater Observatory is located in southern Tasmania, Australia, about 20 km south of Hobart in a semi-rural location. Approximate geographic co-ordinates are 147°20′ E, 43°01′ S, at 80 m elevation. The photometry system, recently commissioned, has been assembled from readily available components (Table 1).

Table 1. Brightwater Photometry System

Item	Vendor	Model/Type
CCD	S-BIG	ST7E
Filter Wheel	S-BIG	CFW8A
Filters	Schuler	*UBVRI*
Telescope	Televue	70 mm, f/6.8
Mount	Vixen	GP-E
Mount control	COAA	Win-CTC
CCD control	Cyanogen	*Maxim DL CCD*

The CCD size is 745×512 pixels, each pixel being 9μm square. At the prime focus of the 485 mm focal–length telescope we cover a field of about 0.80×0.55 degree. Each pixel subtends a 4×4 arc second area. We usually perform a 2×2 pixel binning at readout to reduce both read–out time and the size of a CCD frame on disk. We note that both the WASP and ASAS systems use a similar resolution to this.

The CCD and filter wheel are under software control via *Maxim DL CCD*. Scripts written in Visual Basic select the filter and control the exposure times. For the observations of PZ Tel reported here, exposures were limited to 30 seconds duration to remain in the linear part of the CCD response. The B, V and R filters have been calibrated to the Cousins system from observations of 14 E-region standards (Table 2).

The system is housed in a small roll-off roof observatory located at a domestic residence. It is intended to dedicate this system to intensive studies of a small number of variable stars.

Table 2: Filter transformations from 14 Cousins E-region standards

Equation	colour range	rms residual
$V = v + 0.005(B - V) + \text{const}$	$B - V$: −0.03 to 1.55	0.01 mag
$B - V = 1.177(b - v) + \text{const}$	$B - V$: −0.03 to 1.55	0.02 mag
$V - R = 1.085(v - r) + \text{const}$	$V - R$: +0.20 to 0.95	0.02 mag

PZ Telescopii

PZ Telescopii (HD 174429, $\alpha = 18^{h}53^{m}05\overset{s}{.}88$, δ = -50°10′49.″9 (J2000.0)) is a young, relatively bright ($V \sim 8.5$) and nearby ($d \sim 50$ pc) active K0 star. Attention was first drawn to it via the presence of strong Ca II emission (Bidelmann & MacConnel, 1973, Weiler & Stencel, 1979). Coates et al. (1980) presented the first optical photometry, discovering the spot–induced rotational modulation with the short period of $0^{\rm d}\!.94$. It is active at a variety of wavelengths, including detections in microwave radio (Slee et al., 1987), UV (Walter & Neff, 2006) and X-rays (Agrioffi et al. 2004). While two radial velocity measurements by Stacy et al. (1980) suggested variability, there is no evidence from the subsequent and extensive published radial velocity studies that the star is a close binary (means and standard deviations: Balona (1987): $+4.4\pm6.2$ km s^{-1}; Innis et al. (1988): -3.2 ± 3.7 km s^{-1}; Barnes et al. (2000): -0.1 ± 1.0 km s^{-1}; Nordstrom et al. (2004): -5.2 ± 5.7 km s^{-1}). A single later measurement (Soderblom et al. (1998): -13.5 ± 3.0 km s^{-1}) appears significantly different from the other data, however as noted by Barnes et al. (2000) spot–induced profile asymmetries, combined with the relatively large $v \sin i$ (e.g. Barnes et al., 2000, $\sim$70 km s^{-1}), can contribute to scatter in radial velocity measurements. Evidence of PZ Tel's youthfulness was revealed by the strong lithium λ6707 Å line (Robinson et al. 1986), and from kinematic arguments (e.g. Innis et al., 1986, Zuckerman et al., 2001). It has been the target of Doppler Imaging work by Barnes et al. (2000), who found evidence for differential rotation. The GCVS (Kholopov et al., 1985) lists the star as type RS, with a remark it is a double–lined spectroscopic binary. Presumably the SB2 designation has its origin in the Stacy et al. (1980) finding, which as noted has not been supported by subsequent studies.

A photometric compilation of several years of data and a qualitative analysis was presented by Innis et al. (1990), which demonstrated the rapid changes that take place in the light curve. Other photometry has been performed by Bopp et al. (1986), Lloyd Evans & Koen (1987), Cutispoto & Leto (1997), Cutispoto (1998), Waite (2000), and the Hipparcos mission, but in general the star does not appear to have been well observed photometrically in recent years. Some ASAS-3 data on this star exist. At present (January 2007) only a very small number of measurements are available from the ASAS-3 database.

As the star is relatively bright, and undergoes rapid changes in its spot–induced variation, it appeared as an interesting first target for the Brightwater photometer.

Observations

PZ Tel was observed for a total of 12 nights between 2006 May and July. Some nights were cloud–affected. We present data from 7 nights from the interval early June to early July. A small number of observations from late July (not shown here) do not fit the light curve defined by the earlier data, indicating a change in spot properties. Such behaviour is well documented in earlier photometry (see references cited earlier).

Exposures were taken in V and B filters, in an alternating sequence of four 30–second exposures in a given filter. Around 1000 individual CCD frames were taken in both V and B, of which about 800 of each were obtained in clear–sky conditions. Measurements from four adjacent exposures were combined into normal points representing an effective two-minute integration. Bias, dark and flat–field frames were also obtained. Flat–field exposures were made of diffusely illuminated sections of the observing hut wall. The Televue refractor telescope we use is in part designed with wide field photography in mind. We have found the field–of–view across the CCD is relatively unvignetted, with only a slight fall off of a few percent near the field edges. The flat–field exposures correct for this vignetting.

A 30–second V–filter exposure resulted in a peak pixel analog-to-digital-unit (ADU)

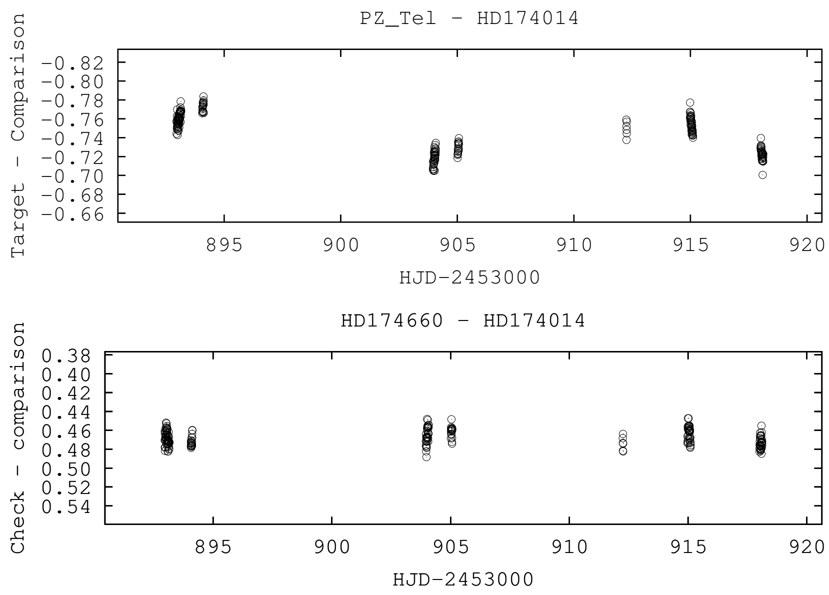

Figure 1. Instrumental v-magnitude differences for PZ Tel−HD 174014 (upper), and HD 174660−HD 174014 (lower) versus HJD. Around 200 data points (each being a 120-second total integration) are represented in each panel. The rms of the data in the lower panel is $0^{\mathrm{m}}.009$.

count near 15k (with a conversion rate of 2.3 e ADU^{-1}) , and a total ADU count near 50k in the PZ Tel profile. In the B filter the corresponding values were around 4k and 13k, due to the lower quantum efficiency of the detector and the late-type spectrum of the star. The wide field of view meant that comparison stars suitable for differential photometry were also present in the field of PZ Tel. Hence once the field was acquired and the data collection script started, the system was able to collect data unattended, although the telescope operator periodically checked on the telescope tracking and the weather, and also on the data quality in near real–time via the MUNIWIN package (`http://integral.sci.muni.cz/cmunipack`).

We selected HD 174014 as the comparison star, and HD 176440 as the check star, although we did in fact measure a number of stars in the frame. Aperture photometry measurements were performed with both IRAF and MUNIWIN. The data presented here are from MUNIWIN analysis. We used a fixed aperture of 5 pixels (∼40 arc second) radius. We measured the comparison and check star V and $B-V$ magnitudes by reference to one of the Cousins E–region standards, HD 192633, as well as measuring on one night HD 176557, which has been used as a comparison star for PZ Tel by Innis et al. (1990), Cutispoto & Leto (1997), Cutipoto (1998) and Waite (2000). We found for HD 174014: V=9.10; $B-V$=1.07, and for HD 174660: V=9.56; $B-V$=1.15. We determine the V and $B-V$ data for PZ Tel relative to these derived measurements of HD 174014.

Our V and B measurements of PZ Tel are available electronically in the html version of this paper.

The instrumental v-magnitude differences for PZ Tel − HD 174014, and HD 174660 − HD 174014, are shown in Figure 1 (upper and lower panels respectively). Just over 200 separate data points, each equivalent to a 120-second exposure, are shown in each panel. The root-mean-square deviation of the data in the lower panel (i.e. check star − comparison star) is $0^{\mathrm{m}}.009$. The scatter in the B-filter measurements is around 2 to 3 times as large, in reasonable agreement with the reduced ADU count.

We performed a period search on the data shown in the top panel of Figure 1. We used both the phase dispersion minimisation method of Stellingwerf (1978) and the string length method of Dworetsky (1983) and found identical results. The best–fit period was $0^{d}.94$, effectively identical, given the limited time-span of these current data, with the value of $0^{d}.94486$ obtained by Innis et al. (1990) from several seasons of observations. Phase plots of the transformed V and B data are shown in the top and middle panels of Figure 2, using the period and epoch from Innis et al. (1990).

We binned the V and B data separately into phase bins of width 0.01, and looked for changes in $B - V$ with rotation phase. A plot of these data is shown in the lower panel of Figure 2. The mean $B - V$ for PZ Tel was found to be 0.78 (with a standard deviation of $0^{m}.01$ mag). There is an indication of a colour change, with the star being redder when fainter. The solid curve is a best-fit line, and suggests a colour change of around $0^{m}.01$ or $0^{m}.02$ over a rotation. If we split the data into V brighter than 8.36 (39 points) and V fainter than 8.36 (31 points), we find the corresponding $B-V$ mean values and standard errors are 0.777±0.002 and 0.784±0.002 respectively, also suggestive of a small but systematic change. Small colour changes (of order $0^{m}.02$) have occasionally been seen on PZ Tel (Cutispoto, 1998, Innis, 1986). The larger scatter in these current B data compared to the V data tend to mask small colour changes. In future we intend to make longer integrations in the B band to reduce the observational uncertainties.

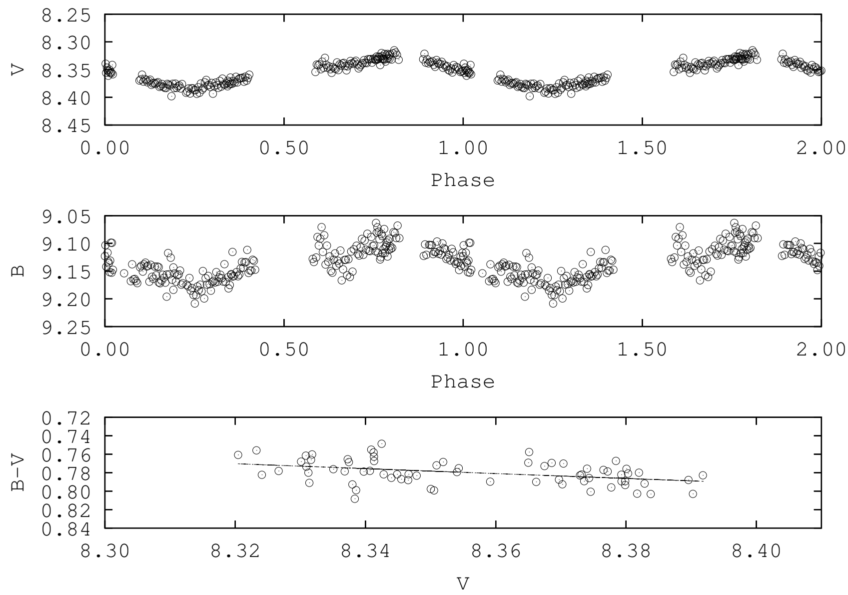

Figure 2. PZ Tel phase plots and $B - V$ colour measurements for data obtained at the Brightwater Observatory in 2006 June and July. The phase plots use the epoch HJD 2444179.256 and period $0^{d}.94486$ from Innis et al. (1990). Upper: V data phase plot; middle: B data phase plot; lower: $B - V$ versus V for phase-binned data. The solid curve is a best-fit line. A small colour change is apparent.

Discussion

We plot in Figure 3 the V photometric history of PZ Tel (from references cited in the previous section). The dominant cause of the varying amplitudes, and changes in mean light levels, is probably starspot activity. The contribution to the overall light-level from bright plage–like areas, and any other possible long–term secular variation, is much more uncertain.

The smallest V–range shown in Figure 3 is $0\overset{m}{.}03$, from 1985.5 (near JD 2446250), from the data of Bopp et al. (1986). However only approximately 0.5 of a rotational phase was observed at this epoch. The smallest amplitude seen in a light curve with near complete phase cover is $0\overset{m}{.}04$, in late 1990 (Cutispoto & Leto, 1997). The range in V light of PZ Tel in the current data from mid 2006 of $0\overset{m}{.}06$ is therefore amongst the smallest seen. For reference, the median amplitude of PZ Tel in V is $0\overset{m}{.}1$.

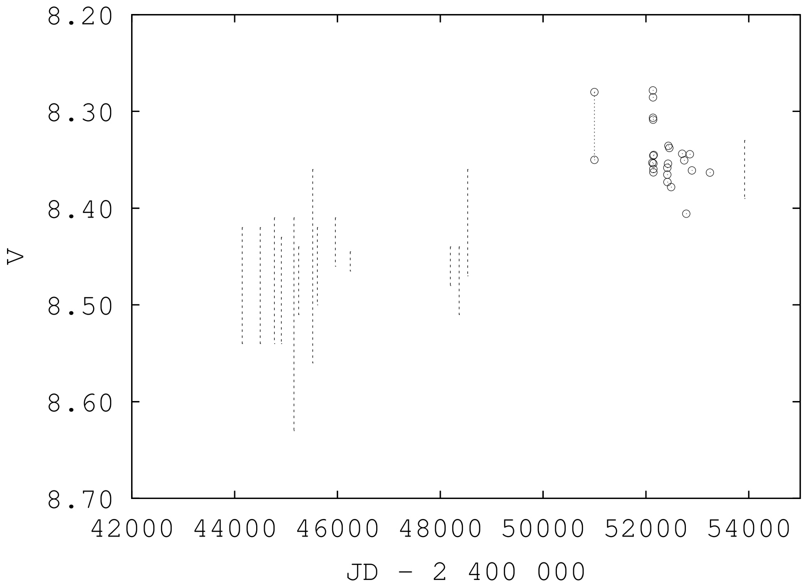

Figure 3. PZ Tel V range versus epoch of observations. Data are from Bopp et al. (1986); Lloyd Evans & Koen (1987); Innis et al. (1990); the Hippacos mission transformed to V; Cutispoto & Leto (1997); Cutispoto (1998); the unpublished thesis of Waite (2000) (points joined by line); ASAS data (individual points); and data from the current work.

The photometric history of PZ Tel spans some 27 years, although there are gaps in the record. There is no obvious indication of a periodicity in the V light levels of this star. In contrast, the very similar star AB Dor exhibits a strong suggestion of a ∼25 year periodicity in mean V light, however as only about 30 years of photometric data exist only one putative cycle has been observed (Jarvinen et al. 2005). For PZ Tel, there may be an indication that a maximum in the long-term V magnitude occurred near JD 2451000 (i.e. near the year 2000), with the current data suggesting a decline has commenced. We consider it very worthwhile to continue to monitor this star to follow the future behaviour. It would be of interest to understand why PZ Tel and AB Dor differ in their long-term photometric properties, given they are otherwise so similar.

Conclusion

B and V light curves of the active late-type star PZ Tel were obtained via a semi-automated CCD photometer system, using a 70-mm diameter, short-focal-length telescope. The wide field of view allowed target and comparison stars to be observed simultaneously. The root-mean-square deviation between the check and comparison stars (both of $V \sim 9^{m}$) for the time series of 120-second exposures was slightly below $0\overset{m}{.}01$ in V, and around twice this in B, which we take as the precision in the determination of the magnitude of PZ Tel. A period analysis of around 200 V measurements for PZ Tel returned a best period of $0\overset{d}{.}94$, effectively identical with a previous determination for this star from multi-year photometry. The amplitude of the V variation was near $0\overset{m}{.}06$, which is amongst the smallest this star has exhibited. There is an indication of a small colour change, with the star being redder when fainter. Inspection of the long-term V light levels of PZ Tel leads us to speculate that a maximum may have been reached around the year 2000, with the current data possibly showing the beginnings of a decline. Further observations will reveal if this is in fact the case.

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