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Polarimetric observations of southern hemisphere young solar-type stars

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Abstract. A report is given on some linear and circular polarimetric observations of young solar-type stars. Despite a somewhat high level of instrumental polarization, the measurements were able to detect polarizations ~ 0.0001 or 0.01%. Temporal variability has been discovered for 59 Vir with an indication that circular polarization is also present. A polarization at a level of $p \sim 1\%$ was found associated with the star SAO 251015. Marginal polarizations are also suspected for the stars HD 155555 and HD 1835. For SAO 154972 (TU Pyx), a sudden change in polarization $\sim 2\%$ occurred over some tens of minutes and an associated circular polarization was also detected.

Key words: polarization – stars: 59 Vir; HD 155555; HD 1835; SAO 251015; Tu Pyx

1. Introduction

The optical radiation from young stars at both ends of the spectral classification sequence frequently exhibits intrinsic linear polarization (Menard & Bastien, 1992, Jain & Bhatt, 1995 – and references therein). It is now well established that at least 85% (or even as many as 100%) of such stars exhibit temporal polarimetric variability on a wide range of time scales (Menard & Bastien, 1992, Yudin & Evans, 1998). These include Herbig Ae/Be stars (HAEBE spectral class from B to early F) and T Tauri type stars, ranging between later F stars to early M). There is, however, little or no information on the polarimetric properties for intermediate spectral type stars ranging between late F and early G8, the so-called solar-type stars. In catalogues of young stars (Herbig & Bell, 1988 and Thé et al., 1994) this latter category represents about 15% of the total objects and most of them have not been studied polarimetrically.

Recently it has been shown that the polarimetric properties of young stars might be considered from the point of view of their circumstellar evolution (Tamura & Sato, 1989 and Yudin, 1994). As suggested by Yudin (1994), at least one subgroup of HAEBE stars, namely those with algol-like brightness minima (Grinin, 1988), represents a late stage of circumstellar evolution with fragmented circumstellar disks forming protoplanetary condensations. Such asymmetries would affect the scattering with an associated polarization being generated in the observed light. At present this subgroup contains about 10 objects which have spectral classes mainly A. No such behaviour has been found in T Tauri type stars.

As a result of magnetic activity, young solar-type stars exhibit chromospheric disturbances which can be monitored by K-index photometry. The renowned observational program at Mt Wilson (see Vaughan et al., 1981) is a prime source of information for solar-type stars on rotation periods, typically a few days, and on magnetic cycles with periods of years. Radiation emanating from active regions is likely to be partially polarized for a variety of reasons, one such polarigenic mechanism being the integration of Zeeman split lines with differential saturation (see Leroy and LeBorgne, 1989). The expected wavelength dependence of the degree of any polarization, $p(\lambda)$, generated by this mechanism has been explored by Leroy (1989). Predictions of the magnitude of p to be observed globally from stars are generally not sanguine for the promotion of extensive polarimetric studies and there has been controvosy about some of the reported observations – see discussions in Clarke and Fullerton (1996). Fox (1995) has modelled the behaviour of star spots using Rayleigh scattering as the polarigenic mechanism and suggests that their presence might be detected with polarimetric accuracies $\sim \sigma_p = 0.005\%$, a challenging but not impossible task. On the positive and observational side, Tinbergen and Zwaan (1981) have used statistical arguments to suggest that polarimetric phenomena, at low levels, are fairly common in middle spectral type stars and with reports of polarimetric variability of individual objects (see e.g. Piirola, 1977 [χ Her – F9V] and Kemp et al., 1986 [α Boö – K1.5 III]), there is evidence for promoting further polarimetric studies of solar-type stars, albeit with the requirement of extremely high precision.

Recently, an attempt to record rotationally induced polarimetric variability has been undertaken by Gullbring & Gahm (1995) but with null results, an outcome which may have been influenced by the short run of observations and/or measurement uncertainties which were too large. Clarke and Fullerton (1996) report on novel measurements of the global radiation from the Sun near to the solar maximum and have recorded changes in p just larger than 0.0001 at the time of the appearance of large

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spots traversing the disk, promoting the possibilities of making solar-stellar connections by polarimetry.

A further dimension to polarimetry of stars in the middle part of the spectral sequence is offered by the measurements of circular polarization resulting from the presence of magnetic field structures. Kemp et al. (1987), for example, have recorded variations of the circular polarization of the RV CVn star λ And and Elias and Dorren (1990) have recorded both linear and circular polarization variations in the young solar-type star HD 129333, thought to have spots covering 6% of its surface, these being responsible for low amplitude light variations. It is important to note that, according to Bastien et al. (1989), circular polarization has been detected in most of the investigated young T Tauri stars, whereas for young HAEBE stars, circular polarization was detected for only a few objects (Yudin & Evans, 1998 – and references therein).

With the above ideas in mind, a polarimetric investigation of some southern hemisphere objects has been undertaken with aim of detecting variability in solar-type stars and the results are reported below.

2. The measurements

Seven nights were allocated for May 1996 on the 0.75m SAAO telescope at Sutherland using the University of Cape Town Polarimeter. This instrument, designed by Cropper (1985), operates with a single channel and filter set to provide UBVRI measurements. The modulator comprises oppositely rotating quarter-wave and half-wave (achromatic) phase plates at 10 revs s^{-1}, the oscillatory signal providing means of determining both the linear and circular components simultaneously, the system being ideal for polarimetry of solar-type stars. Pulse counting is employed with the recorded photons being binned into computer memory according to the phase of the modulator. Polarimetric accuracies limited only by photon counting statistics can be achieved under good working conditions. For the purpose of making data comparisons, the normalised linear Stokes components q and u were calculated with the degree of linear polarization, $p = (q^2 + u^2)^{1/2}$, together with the normalised circular Stokes parameter, v.

As the emphasis of the study was towards high accuracy, early experience indicated that the best results accrued by concentrating the observational effort on measurements in the B and V bands. With these passbands, the photon count rates were sufficient to achieve $\Delta p \sim \pm 0.0001$ in about 20mins. For the brighter stars, a 2.5D neutral density filter was introduced into the beam after the polarizer to keep the count rate to acceptable levels so that dead-time errors were unimportant (see Clarke and Naghizadeh-Khouei, 1994). To establish a data set, repeated records for the degrees of linear and circular polarization and brightness levels (photon counts and magnitudes) were obtained using a preset integration time typically several tens of seconds. Telescope tracking reliability was checked from the quality of the polarimetric modulated signal and at interruptions of the sequence for visual inspections. From the collection of records contributing to a mean measurement, it was later possible to undertake internal statistical analyses of the behaviour of the data sets. Following the observing run, the data were cleaned with integrations removed which were obviously distorted by cloud or inadequate telescope tracking. The measurements were also honed to remove the effects of the sky background although they proved to be inconsequential at the achieved polarimetric accuracy.

Table 1. The observed program stars including unpolarized and polarized standards.

Star Identification	Other Name	Mag	Spectral Type	Notes
SAO 154972	TU Pyx	8.7	G0	
SAO 251015		8.1	G0	
HD 100623		6.0	K0V	Unpol Std.
HD 115383	59 Vir	5.23	F8V	3.$^{\mathrm{d}}$3 P
HD 128400		6.7	G5V	
HD 147084	o Sco	4.6	A5II-III	Pol Std.
HD 155555	V824 Ara	6.67-6.84	G5	Sp 1.$^{\mathrm{d}}$682
HD 160529		6.7	A2Ia	Pol Std.
HD 202940		6.6	G5V	Unpol Std.
HD 1835	9 Cet	6.44	dG2	8$^{\mathrm{d}}$ P

It was hoped to relate any polarimetric variations of a star to magnitude changes but, without the full procedure involving observations of photometric standard stars, this was not possible. At no time were the conditions “photometric” and on some nights the effects of buoyancy waves on the atmospheric extinction were clearly seen.

The list of observed stars is given in Table 1. The main program stars were selected by having spectral classification around G5V, for their comparative youth, by having known estimates of their rotation period, by having some known variable characteristic and by having sufficient brightness to allow high accuracy polarimetry in short integration times. In addition to the program stars, observations were made of two listed unpolarized standard stars (HD 100623 and HD 160529 – in Appendix 1 and 2 respectively of Serkowski, 1974) to allow investigation of the instrumental polarization and two recognised polarized stars (HD 147084 and HD 160529 – in Appendix 3 of Serkowski, 1974) to check out the modulator efficiency and the orientation of the polarimeter’s reference axes relative to equatorial co-ordinates.

3. The results

3.1. Statistical analyses

At the stage of reducing the data and also assessing if any star is exhibiting temporal variability or if there are polarimetric differences between sets of stars, various statistical tests were performed.

The first procedure involved checking that the normalised Stokes parameters, q, u and v, generated by repeated integrations could be considered as coming from the same parent Normal distribution. This exercise was useful to check for any spurious records and to search for any drifts in the underlying mean values during the data accumulation caused either by effects in the instrument or in the stellar radiation itself. Normality checks were performed by determining the skewness and kurtsosis coefficients and comparing the resulting values with those in tables presented by Brooks et al. (1994).

In order to test if there were polarimetric differences between mean values of q, u and v, the Welch statistic (see Brown and Forsythe, 1974) was applied to the data assemblies providing the individual means. The test was performed covering groups of data sets from different stars, particularly those which might be considered as being unpolarized sources, and on groups of data sets from individual stars to see if there were any temporal changes between their accumulation. Features of the Welch test are that it can be applied to several data sets simultaneously and that the number of values constituting any of the data sets can be small. The only prerequisite is that each of the compared data sets should be indistinguishable from having a Normal distribution, such tests being performed as a matter of course as outlined above.

3.2. The unpolarized reference

From the kinds of stars selected for the program, it was anticipated that any measured polarizations, other than the polarized standard stars, would be fairly small. One of the basic questions to be asked of each star is whether the measurements are consistent with the radiation being unpolarized by comparison with data from unpolarized standard stars, assuming the latter to be designated correctly.

Early in the observing run it was apparent that the system displayed a high level of instrumental polarization and that its value was strongly wavelength dependent. This has no consequence on deciding whether there are differences in the low levels of polarization between compared stars but imposes restrictions on its absolute description (amount and position angle). Such a problem cannot be resolved without spending an inordinate amout of observing time calibrating this off-set with many more “unpolarized” stars being measured to provide a larger statistical base.

Table 2 lists the basic polarimetric determinations for the two observed catalogued unpolarized stars. The mean values q_o, u_o and v_o are the normalised Stokes parameters as calculated directly by the reduction process with their 1σ uncertainty obtained from the fitting of the coefficients of the harmonics describing the polarimetric modulation and from the combination of repeated measurements used to determine the quoted means. The data for each star suggest that the underlying distribution of measurements in the q, u plane have circular symmetry and that the variances of the individual Stokes parameters are equal to each other. Each listed 1σ value has been taken from the mean of the sample variances obtained for the q and u parameters individually.

A statistical comparison (Welch tests) of the measurements showed that, for a given passband, no distinction could be made between the mean values of the stars or between measurements made on different nights. To act as a reference for all other measurements, the data sets and mean values of HD 2902940 were taken as their quality was far superior to those of HD 100623. Thus the assumed instrumental linear polarization was

U: $q = +0.00594$, $u = -0.00387$: $\equiv p = 0.00709 \pm 0.00177$
B: $q = +0.00151$, $u = -0.00235$: $\equiv p = 0.00279 \pm 0.00011$
V: $q = +0.00047$, $u = -0.00085$: $\equiv p = 0.00097 \pm 0.00007$
R: $q = +0.00015$, $u = -0.00046$: $\equiv p = 0.00048 \pm 0.00011$
I: $q = -0.00171$, $u = -0.00098$: $\equiv p = 0.00197 \pm 0.00146$.

It may be noted that the values for the U and I bands are from single measurements carrying low accuracy and are only listed for reference in respect of the general spectral trend of the instrumental polarization, clearly seen over the B, V and R bands, being in the same quadrant in the Stokes parameter plane and exhibiting a progessive reduction.

The weighted mean values for the circular polarization were

B: $v = -0.00001 \pm 0.00007$
V: $v = -0.00019 \pm 0.00004$
R: $v = -0.00007 \pm 0.00007$.

These data suggest that for the V band, circular polarization has nominally been detected, this probably originating within the telescope, although it cannot be ruled out as being present in the stellar radiation. This is the first time HD 202940 has been measured for circular polarization. In fact it is always difficult to obtain firm offset calibrations for v as a catalogue of reliable standards is not available. For the B and R bands the measurements provide null values with uncertainties of $\pm 0.007\%$.

3.3. The polarized reference stars

Table 3 summarises the measurements made of the two polarized standard stars HD 147084 (o Sco) and HD 160529. Following the subtraction of the proposed instrumental values, the reduced values for q and u are consistent with the polarimeter's axes being set at angle of $1^\circ\!.45$ for the B band and $0^\circ\!.4$ for V, the difference being caused by the dispersion in the principal axis of the achromatic modulator.

The values of the degree of polarization as calculated in the instrumental and corrected frames may also serve as a check on the suggested instrumental values by comparison with measurements listed in the literature serving as “standards”. Table 4 provides the degree of polarization based on the mean values of q and u for the B and V bands with respect to the instrumental (p_o) and corrected frames (p) together with measurements ($p_{\rm HB}$) taken from Hsu and Breger (1982). For o Sco, the correction procedure has converted the raw values from being marginally less than the standard values to being marginally greater. For HD 160529 the raw value for B is already greater than the standard value and the correction increases the disparity; for the V band the outcome is similar to that for o Sco.

Thus for the V band it might be construed that the instrumental polarization has been marginally overestimated while for the B band the picture is inconclusive. Based on this very limited data, it was decided not to reconsider any reworking of the reductions for the program stars with alternative values for

Table 2. The measurements of the unpolarized standard stars according to the mean Julian Date ($245+$) and the filter passband. The headings q_o, u_o, and v_o correspond to the raw normalised Stokes parameters in the instrumental frame, with the standard error (1σ) attached. The number of integrations is designated by N, each with integration time of T seconds.

HD 100623

JD	Band	q_o	u_o	σ	v_o	T	N
0229.239	R	-0.00033	-0.00014	±0.00031	$+0.00025 \pm 0.00022$	120	4
0229.216	V	$+0.00029$	-0.00056	±0.00037	-0.00058 ± 0.00026	120	4

HD 202940

JD	Band	q_o	u_o	σ	v_o	T	N
0225.606	U	$+0.00594$	-0.00387	±0.00177	-0.00200 ± 0.00125	120	1
0225.608	B	$+0.00142$	-0.00328	±0.00068	-0.00024 ± 0.00048	120	1
0225.585	V	$+0.00024$	-0.00057	±0.00045	-0.00071 ± 0.00032	120	1
0225.616	R	-0.00074	-0.00242	±0.00127	-0.00175 ± 0.00090	120	1
0225.623	I	-0.00171	-0.00098	±0.00146	-0.00001 ± 0.00103	120	1
0226.653	B	$+0.00173$	-0.00263	±0.00029	-0.00047 ± 0.00020	750	1
0226.621	V	$+0.00027$	-0.00072	±0.00012	-0.00010 ± 0.00009	750	2
0229.556	B	$+0.00152$	-0.00240	±0.00017	$+0.00004 \pm 0.00012$	180	10
0229.565	V	$+0.00053$	-0.00103	±0.00011	-0.00023 ± 0.00008	180	10
0230.542	B	$+0.00143$	-0.00211	±0.00018	$+0.00015 \pm 0.00013$	180	10
0230.544	V	$+0.00062$	-0.00078	±0.00012	-0.00018 ± 0.00008	180	10
0230.603	R	$+0.00016$	-0.00044	±0.00011	-0.00010 ± 0.00008	180	6

Table 3. The measurements of the polarized standard stars according to the mean Julian Date (245 +) and the filter passband. The headings q_o, u_o, and v_o correspond to the instrumental normalised Stokes parameters with their standard errors (1σ) attached. The number of integrations is designated by N, each with integration time of T seconds. Columns identified by q and u contain the values of the normalised Stokes parameters corrected for instrumental polarization but in the instrumental frame; the uncertainties of these values are taken as being the same as the basic measurements without the inclusion of the estimate of any systematic effect from the subtraction of the instrumental polarization.

HD 147084

JD	Band	q_o	u_o	σ	v_o	T	N	q	u
0225.421	U	$+0.01390$	$+0.03093$	±0.00284	-0.00129 ± 0.00202	120	1	$+0.00796^*$	$+0.03480^*$
0225.423	B	$+0.01576$	$+0.03217$	±0.00099	-0.00159 ± 0.00070	120	1	$+0.01425$	-0.03452
0225.427	V	$+0.01684$	$+0.03786$	±0.00056	$+0.00038 \pm 0.00039$	120	1	$+0.01637$	-0.03871
0225.432	R	$+0.01860$	$+0.04095$	±0.00043	$+0.00024 \pm 0.00030$	120	1	$+0.01845$	-0.04141
0225.440	I	$+0.02108$	$+0.04183$	±0.00041	-0.00001 ± 0.00029	120	1	$+0.02279$	-0.04281
0228.455	B	$+0.01330$	$+0.03113$	±0.00046	$+0.00053 \pm 0.00032$	160	1	$+0.01179$	-0.03348
0228.462	V	$+0.01724$	$+0.03805$	±0.00027	-0.00033 ± 0.00019	160	1	$+0.01677$	-0.03890
0228.474	R	$+0.01773$	$+0.04067$	±0.00021	-0.00033 ± 0.00015	160	1	$+0.01758$	-0.04113

* Poorly determined instrumental polarization offset in the U band

HD 160529

JD	Band	q_o	u_o	σ	v_o	T	N	q	u
0225.673	V	$+0.05825$	$+0.04791$	±0.00044	-0.00058 ± 0.00031	120	1	$+0.05778$	-0.04876
0225.678	R	$+0.05382$	$+0.04578$	±0.00036	-0.00011 ± 0.00026	120	1	$+0.05367$	-0.04876
0225.680	I	$+0.04522$	$+0.04268$	±0.00102	-0.00002 ± 0.00073	120	1	$+0.04693$	-0.04366
0229.525	B	$+0.05386$	$+0.04767$	±0.00031	-0.00043 ± 0.00022	180	5	$+0.05235$	-0.05002
0229.547	V	$+0.05633$	$+0.04908$	±0.00015	-0.00030 ± 0.00011	180	5	$+0.05586$	-0.04990

the instrumental polarization, but to bear it in mind that their reported values may carry small systematic errors, adding complications to discussions on whether individual stars do or do not display low levels of polarization.

For o Sco, raw circular polarization was not detected in any of the bands, with the weighted mean values of v being insignificant in relation to their uncertainties. Measurements made by Kemp and Wolstencroft (1972) indicate that, for the B band, the value of v is ~ -0.00030 being of the same order of accuracy as the reported measurements; the values obtained by Kemp and Wolstencroft for the V and R bands progressively approach zero and are certainly smaller than the detectivity used here. Circular polarization is nominally detected for HD 160529 in the V band with a weighted mean value of -0.00033 ± 0.00010.

Table 4. The determined raw (p_o) and corrected (p) values of the degree of linear polarization for comparison with the standard values ($p_{\rm HB}$) of Hsu and Breger (1982).

	p_o	p	$p_{\rm HB}$
o Sco			
B	3.42±0.04	3.58	3.50
V	4.17±0.02	4.23	4.18
HD 160529			
B	7.19±0.03	7.24	6.97
V	7.26±0.03	7.52	7.31

It is impossible to say, however, if this originates in the stellar radiation (e.g. an interstellar component), or if it is the same offset as recorded for the unpolarized standard stars, or if there is some linear-to-circular conversion by the telescope, this star exhibiting a high value of p.

3.4. The program stars

Table 5 summarises the reduced measurements of the program stars. The quoted q and u values have been corrected for the sky background, the instrumental polarization and have been rotated from the instrumental frame to the equatorial co-ordinate frame. It has been assumed that the underlying distribution of measurements in the q, u plane have circular symmetry and that their variances are equal to each other and are independent of the chosen co-ordinate frame. Any inter-star data comparison to decide on polarimetric differences is unaffected by the reduction and transformation procedures.

4. Discussion

4.1. SAO 154972 – TU Pyx

Although the measurements of this star are relatively few, it displayed by far the largest temporal changes. In the V band the nights of JD 0226 and 0227 had too few internal values to warrent full Normality tests but the nights of JD 0229 and 0230 provided Normally distributed data sets. However, for the night of JD 0231 the data were distinctly non-Normal with an approximately 3σ change occuring over the course of an hour. A Welch test concluded that the data sets for JD 0229, 0230 and 0231 could not be considered as being generated from the same parent distribution with the night of JD 0231 being the deviant. The measurements indicate an intrinsic polarization of about 0.5% which suddenly increased to $\sim 2\%$ on the night of JD 0231. Fig. 1 depicts the movement of the polarization vector in the q, u plane. Of the six separate measurements made on this night, the first three are grouped together with a low level of polarization, while the latter three are similarly grouped together but with the much higher value of p. Although a full photometric procedure was not performed during the observations, there was no commensurate change in the star's brightness as recorded in the raw photon count.

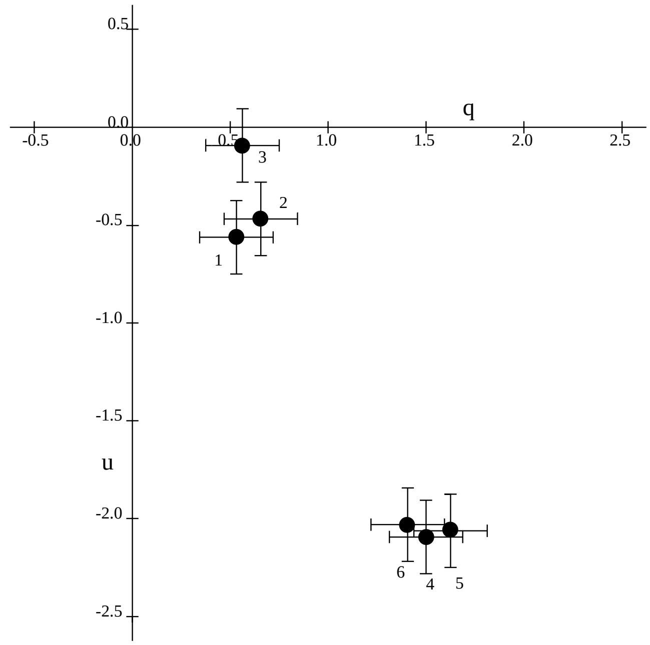

Fig. 1. The Stokes parameter plot (q, u in $\%$) displays the six V band polarization measurements of TU Pyx made on the night of JD 0231. The time sequence covering about 20 minutes shows that the first three are bunched close to the origin while the final three display $p \sim 2\%$.

It is also noteworthy that, for the V band, the values of v are persistently positive with an overall weighted mean of $+0.00037 \pm 0.00016$. On the night of JD 0231 the mean value was $+0.00095 \pm 0.00058$, the first value of the six measurements, prior to the sudden change in the linear polarization being $+0.00210 \pm 0.00137$. All other stars provided negative values of v — see measurements of the unpolarized reference above and all the monitored stars below.

Although the weighted mean value for all the measurements in the R band is -0.00019 ± 0.00009 signifying the detection of a weak linear polarization, this cannot be differentiated from measurements made of the unpolarized standard stars.

According to the General Catalogue of Variable Stars (Kholopov, 1987) TU Pyx is classified as a semi-regular variable (SRB), spectral type M5, with a nominal period of 88 days and displaying a magnitude variation from 10.7 to 9.9. It was included in a ground based infrared photometric synoptic study of such stars by Kerschbaum (1995) and also in a study of H_2O maser emission of irregular variables by Szymczak and Engels (1997). However, according to the lists of SAO stars with infrared excess in the IRAS Point Source Catalog (see Oudmaijer, et al., 1992), this star is classified as G0 with $V = 8.7\,{\rm mag}$, reflecting a better match to the telescopic visual impression at the time of the observations reported here. Its catalogued entry suggests the presence of a circumstellar dust shell with a temperature of 1200 K.

Scattering of the stellar radiation by such dust with some kind of non-spherical distribution would give rise to an intrinsic polarization but it is very difficult to provide the means whereby such a large polarimetric change could occur without any no-

Table 5. The measurements of the program stars according to the mean Julian Date (245 +) and the filter passband. The headings q, u, and σ are the corrected normalised Stokes parameters (equatorial frame) and 1σ uncertainty. The raw value of v_o, with its uncertainty, is also tabulated. The number of integrations is designated by N, each with integration time of T seconds.

JD	Band	q	u	σ	v_o	T	N
SAO 154972							
0226.240	V	−0.00077	−0.00296	±0.00068	+0.00045 ± 0.00045	750	1
0227.218	V	−0.00093	−0.00248	±0.00046	−0.00010 ± 0.00033	750	2
0227.245	R	−0.00077	−0.00284	±0.00023	−0.00036 ± 0.00016	750	2
0229.206	V	−0.00170	−0.00591	±0.00043	+0.00072 ± 0.00030	240	4
0229.222	R	−0.00055	−0.00267	±0.00029	−0.00026 ± 0.00015	240	4
0230.266	V	+0.00036	−0.00423	±0.00053	+0.00016 ± 0.00037	360	4
0230.299	R	+0.00108	−0.00304	±0.00024	+0.00009 ± 0.00017	360	4
0231.231	V	+0.01011	−0.01167	±0.00082	+0.00095 ± 0.00058	120	6
SAO 251015							
0225.334	U	+0.00403	−0.00016	±0.01734	−0.00194 ± 0.01219	120	1
0225.335	B	−0.01184	+0.02024	±0.00666	−0.01186 ± 0.00471	120	1
0225.342	V	−0.01126	+0.00562	±0.00131	−0.00017 ± 0.00093	120	1
0225.344	R	−0.01248	+0.00335	±0.00063	+0.00054 ± 0.00045	120	1
0225.352	I	−0.00776	+0.00403	±0.00039	+0.00038 ± 0.00028	120	1
HD 115383							
0226.249	B	−0.00021	+0.00015	±0.00010	+0.00010 ± 0.00007	750	3
0226.330	V	−0.00022	−0.00027	±0.00022	−0.00020 ± 0.00016	750	2
0227.351	B	−0.00039	−0.00003	±0.00029	−0.00007 ± 0.00021	180	1
0227.353	V	−0.00027	−0.00113	±0.00065	−0.00047 ± 0.00046	180	1
0227.374	V	−0.00018	+0.00103	±0.00046	−0.00089 ± 0.00033	750	1
0227.388	V	−0.00016	+0.00064	±0.00032	−0.00060 ± 0.00022	750	1
0227.406	B	+0.00018	+0.00046	±0.00014	+0.00006 ± 0.00010	800	1
0227.427	B	−0.00042	+0.00027	±0.00015	−0.00025 ± 0.00010	800	1
0229.000	B	+0.00048	−0.00017	±0.00014	+0.00006 ± 0.00010	180	4
0229.368	V	+0.00148	−0.00054	±0.00031	−0.00071 ± 0.00022	180	4
0230.382	B	+0.00066	+0.00027	±0.00015	+0.00037 ± 0.00010	180	4
0230.387	V	+0.00013	+0.00080	±0.00033	−0.00040 ± 0.00023	180	4
HD 128400							
0229.411	B	+0.00038	+0.00017	±0.00027	+0.00016 ± 0.00019	180	5
0229.414	V	+0.00032	−0.00011	±0.00017	−0.00009 ± 0.00012	180	5
0230.426	B	−0.00070	−0.00045	±0.00020	+0.00036 ± 0.00014	180	10
0230.428	V	+0.00056	+0.00095	±0.00013	−0.00024 ± 0.00009	180	10
HD 155555							
0225.465	U	−0.00388	−0.00404	±0.00178	−0.00016 ± 0.00126	120	2
0225.467	B	+0.00050	+0.00017	±0.00065	+0.00035 ± 0.00046	120	3
0225.473	V	+0.00007	+0.00021	±0.00021	−0.00039 ± 0.00012	120	3
0225.475	R	+0.00047	−0.00039	±0.00030	+0.00048 ± 0.00021	120	2
0225.481	I	+0.00259	−0.00006	±0.00032	−0.00016 ± 0.00023	120	2
0227.521	V	+0.00035	+0.00043	±0.00020	−0.00036 ± 0.00014	960	1
0229.478	B	+0.00053	−0.00077	±0.00030	+0.00007 ± 0.00021	180	5
0229.480	V	+0.00057	−0.00044	±0.00018	−0.00024 ± 0.00013	180	5
0230.485	B	−0.00010	−0.00036	±0.00022	+0.00037 ± 0.00016	180	9
0230.487	V	+0.00036	−0.00035	±0.00014	+0.00000 ± 0.00010	180	9
HD 1835							
0229.639	B	+0.00013	−0.00076	±0.00023	+0.00013 ± 0.00016	180	5
0229.663	V	−0.00029	+0.00017	±0.00015	−0.00003 ± 0.00010	180	5
0230.635	B	+0.00048	−0.00069	±0.00021	+0.00006 ± 0.00015	180	6
0230.637	V	−0.00011	−0.00011	±0.00014	−0.00033 ± 0.00010	180	6

ticeable change in the brightness and on a time scale of a matter of minutes. In view of the indication that circular polarization might be associated with this star and the recorded outburst of linear polarization, it is important that TU Pyx should be monitored further.

4.2. SAO 251015

Measurements of this star were made on one night only with moderate accuracies. Nonetheless, linear polarization appears to be present at a level just greater than 1% being significantly greatest in the B band, suggesting a polarigenic mechanism associated with the abundance of metal lines in this waveband. However it may be noted that this star has an infrared excess (Oudmaijer, 1992), suggesting the presence of a circumstellar cloud. From the recorded $p(\lambda)$ data and from the location of this star, it is suggested that the polarization is intrinsic rather than having an interstellar origin. The raw measurements of v suggest null detections, except perhaps for the B band, but the absolute value of the uncertainty associated with this measurement is large. From this preliminary study, it is important that this star should be included in any future monitoring program.

4.3. HD 115383 – 59 Vir

Previous U band observations of this star over three consecutive nights have been made by Leroy and Le Borgne (1989) but with a null result. The reported measurements here on four nights for the B and V bands suggest, however, that a variable polarization is present. The nightly mean values are plotted in Fig. 2, there being similarity of the locations in the q, u plane for the two colours. The p value in the V band for JD 0229 achieves $\sim 0.15\%$ and Welch tests in association with measurements of the unpolarized standard, HD 202940, confirm the significant difference in their q parameters on this occasion, this being the component dominating the polarization. It is interesting to note that the raw value of v for the V band on this night is also statistically significant. In fact the overall weighted value of v from the four nights is -0.00046 ± 0.00009. No doubt some of this apparent circular polarization is instrumental as the measurements of the standard unpolarized star and of all the other stars below suggest, but this value is an extreme which is statistically significant.

Inspection of Fig. 2 suggests that the temporal behaviour of the data for the B and V bands is coherent with the V band displaying a larger scale movement in the locus path. If the origin of the q, u plot has been correctly determined, the impression is that the underlying locus may be an elliptical figure with the origin towards an extreme end of the major axis (see, for example, Fig. 2(b) in Clarke and McGale, 1986). This is in keeping with a star exhibiting spot activity in its equatorial belt with the inclination, i, of the rotation axis being close to $90°$. According to Donahue et al. (1996), 59 Vir displays a photometric rotational signature which has been persistent over five seasons.

Although the Normality tests suggested that the polarization values were noisy or drifting during the time span of the measurements on JD 0230, the data set was insufficiently large to be able to confirm this. It is noteworthy, however, that if the locus of the data is following the suggested ellipse in the q, u plane, the phase associated with JD 0230 (see the points labelled 6 in Fig. 2) corresponds to a time when it is moving at its fastest rate.

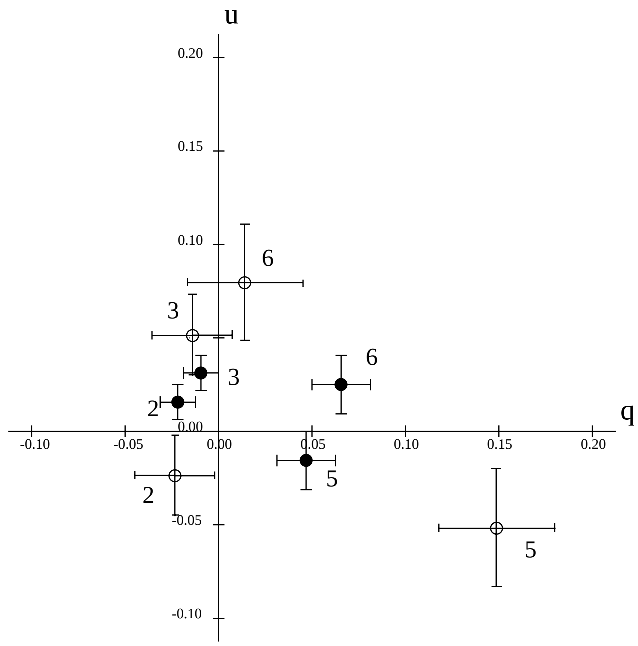

Fig. 2. The Stokes parameter plot (q, u in $\%$) of the B ($\bullet$) and V ($\circ$) band measurements made of 59 Vir on four different nights indicate polarimetric changes that may be related to its associated photometric period. The numbers 2, 3, 5, 6 refer respectively to the nights of JD 0226, 0227, 0229 and 0230.

It is important that the detected polarimetric variability for 59 Vir should now be monitored more comprehensively to check on its coherence with its well established photometric period. Investigation of the circular polarization also needs a more thorough approach with the application of longer integration times.

4.4. HD 128400

On JD 0229 neither sets of data (B and V) were distinguishable from being representative of an unpolarized source. However, on JD 0230 Welch tests indicate a departure from the unpolarized reference in u just greater than the 90% confidence level for the B band and a similar significance of departure in q for the V band. However, polarization is not detectable in any of the data at the 99% confidence level. Even if the 90% level is taken as being acceptable for polarization detection, it would be difficult to reconcile why it should display inconsistent position angles for the two colours.

The weighted mean value for the two nights for the raw v measure in the V band indicates a detection (-0.00019 ± 0.00007) which is consistent with an instrumental offset.

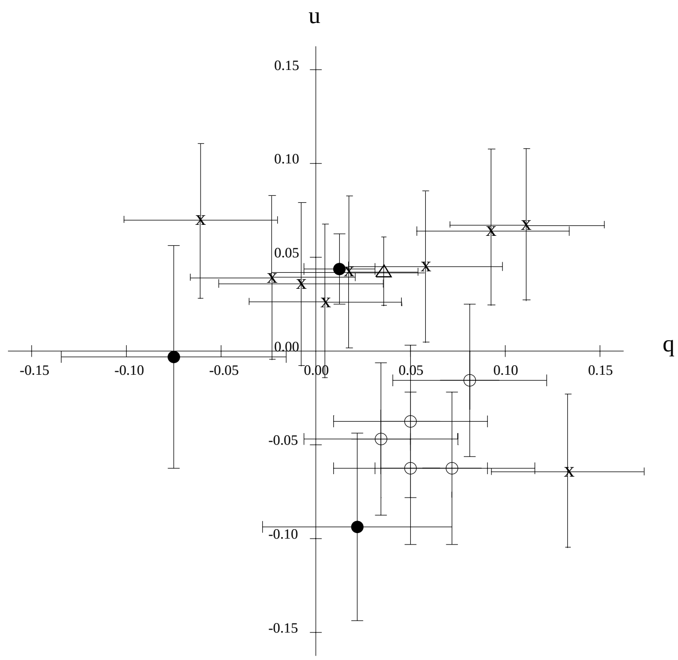

Fig. 3. The Stokes parameter plot $(q, u \text{ in } \%)$ depicts the V band polarimetric values for HD 155555 for each integration period on the four nights of observation; $\bullet$ = JD 0225, $\triangle$ = JD 0227, $\circ$ = JD 0229 and $\times$ = JD 0230. It may be noted that for JD 0229, all the data lie in the fourth quadrant and Welch tests indicate variations in the parent distributions from which the night-to-night data have been sampled suggesting a low level of polarimetric variability.

4.5. HD 155555

Welch tests applied to the overall set of B band measures show that they can be considered as belonging to the same parent distribution and cannot be differentiated from data of the unpolarized standard. For the V band, however, Welch tests suggest that the measurements of the u parameter on JD 0229 are deviant. The q, u plot (Fig. 3) of the data for the separate integrations from each night displays bunching with all of the five values appearing in the fourth quadrant. From its high Li/H ratio, HD 155555 has been classified as an active close binary system with both stars not having completed their contraction to the main sequence (see Pasquini et al., 1991). Cutispoto (1990) has included HD 155555 in UBVRI photometric studies of active southern hemisphere stars. It is of interest to note that his data shows that it is also the V band which displays by far the largest rotationally modulated signal with a variation of ~ 0.1 mag associated with a period of $= 1.^{\rm d}68$. Unfortunately the reported polarimetric data are insufficient to consider any correlation of its suspected variability with the photometric behaviour but the star is a prime candidate for further high accuracy studies.

HD 155555 was included in circular spectropolarimetric studies by Donati et al. (1997) and clear magnetic signatures have been detected with the high signal-to-noise records they were able to obtain. Although the weighted mean values for the raw v measurements in the V band reported here indicate a detection (-0.00021 ± 0.00006), again this can only be considered as an instrumental effect.

4.6. HD 1835

The hour angle of this star was such that it could only be observed at large zenith distance just before sunrise and consequently the time coverage was insufficient to investigate any possible rotational modulation. In the V band the two sets of measurements could not be distinguished from representing unpolarized radiation. In the B band there is a marginal suggestion that the star may exhibit a polarization $\sim 0.07\%$. HD 1835 has been a prime target in the Mt Wilson K-index programme (see Donahue et al., 1996) exhibiting photometric variations with periods ranging from $7.^{\rm d}23$ to $8.^{\rm d}30$ due to changes in the mean latitude of the active regions and effects of surface differential rotation. These preliminary measurements are sufficiently encouraging to promote a more intensive high precision polarimetric study.

Yet again, weighted mean values for the raw v measurements in the V band indicate a detection (-0.00018 ± 0.00007) but this can only be considered as an instrumental effect.

5. Conclusion

A preliminary synoptic study has been made of a sample of young solar type stars with the aim of detecting activity via polarimetry. Previous studies, both theoretical and observational, suggest that the levels of any polarization are likely to be small. As the stars are effectively solar type in terms of their luminosity and display high apparent brightness, they are relatively close and unlikely to be contanimated by interstellar polarization.

For the work reported here, both the linear and circular components have been investigated with typical measurement uncertainties in $q, u \text{ and } v \sim \pm 0.0003$. This high level of accuracy causes problems with the assessment and removal of instrumental polarization due to the inadequacy of the catalogued unpolarized and polarized standard stars. In addition, even if the reference stars provided well calibrated values, an in-ordinate amount of time from the observational run would be required to perform the measurements to the required levels of accuracy. Consequently the tabulated polarimetric values for the programme stars may be subject to systematic errors of the order of the uncertainties of their measurements but this in no way negates the investigations and detections of any variable intrinsic polarization. There is no evidence of any instability in the instrumental polarization which could erroneously be interpreted as stellar variability.

The sample of investigated stars is small and the time window for the measurements is very limited. Of the stars suspected of displaying polarimetric variability, there are no similarities of behaviour. The most remarkable recorded event was for SAO154972 (TU Pyx) which displayed a sudden change in polarization from a level $\sim 0.5\%$ to $\sim 2.0\%$ in a time interval of about 15 minutes. There is also a strong indication of circular polarization associated with this star, suggesting the presence of magnetic activity. It is important that this star be included as a prime target in future polarimetric programmes.

Measurements of HD 115383 (59 Vir) on four nights display polarization variations $\sim 0.1\%$ which are coherent in the B and V bands, confirming that this originates in the star. The fact that the variation in V has larger amplitude than for B emphasises the notion that the behaviour truly occurs in the star and is not caused by any experimental instability, the instrumental polarization being much smaller in V than in B.

There is also evidence for a detection of circular polarization in the V band. The data for HD 155555 also display night-to-night variations in the V band but not in B; these may be related to previously monitored photometric variability which is also most strongly apparent in the V band.

The data for HD 1835 are very limited but there is marginal evidence for detection of a weak polarization in the B band.

All of these stars require further observations to characterise their polarimetric behaviour and to confirm that the observed effects are related to active regions traversing the projected disk as a result of stellar rotation or to other causes.

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