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Polarimetry of the young Herbig Ae star HD 139614

Differences of polarimetric behaviour of Vega-type stars

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Abstract. We present optical polarimetric data of the Herbig Ae star HD 139614 and discuss its behaviour relative to similar stars. In spite of a low level of polarization (≈ 0.05–0.2%), polarimetric variability on a time–scale of days was detected during a four night synoptic study. The difference in the level of the polarization for HD 139614 relative to other Herbig Ae/Be stars such as HD 141569, HD 142666 and HD 169142 might be due to the inclinations and viewing aspects of their circumstellar disks and to their different evolutionary stages. This hypothesis is consistent with the photometric behaviour of these stars, their $v \sin i$ values and spectral energy distribution in the near and far IR.

Key words: polarization – stars: circumstellar matter – stars: individual: HD 139614 – stars: pre-main sequence

1. Introduction

HD 139614 is an early–type (A7Ve) emission–line star with infrared excess (Walker & Wolstencroft 1988, Oudmaijer et al. 1992) and has been recognized as a member of Vega–type stars (i.e. young main sequence stars) (Silvester et al. 1997 and references therein; Dunkin et al. 1997). According to Malfait et al. (1998) it is certainly a member of the young Herbig Ae/Be group (i.e. a pre–main sequence star) considering its spectral energy distribution (SED) and its single–peaked H_α emission. In reality its SED in the IR (using the IRAS data) is similar to the behaviour of Herbig Ae/Be stars or is like β Pic (a comparable young A star near the end of the pre–main sequence evolutionary phase). There is a consensus that most of the Herbig Ae/Be as well as Vega–type and β Pic–type stars are surrounded by disk–like dust envelopes (see for example Grady et al. 1996). For the case of optically thin dust distributions, any IR excess from the heated grains does not depend on the inclination of the system, whereas the value of polarization generated from the scattered stellar radiation, is sensitive to the structure of the cloud and its viewing aspect. For lenticular envelopes, the recorded polarization is likely to be at a maximum for disks which are oriented edge–on and is proportional to $\sin^2 \Theta_c$ where Θ_c is the angle between the disk's symmetry axis and the line of sight (for details, see Dolginov et al. 1995).

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Table 1. Polarimetric data for HD 139614

JD 2450000+	Filter	q	u	$\sigma_{q,u}$	p(%)	$\theta°$
226.3975	R	−0.038	+0.017	0.035	0.042	78
226.4649	V	+0.076	−0.018	0.040	0.078	173
226.4815	V	−0.025	+0.104	0.039	0.107	52
226.4958	V	−0.029	+0.036	0.039	0.046	64
226.5114	V	+0.005	+0.082	0.038	0.082	43
226.5240	V	+0.033	+0.116	0.039	0.121	37
227.4647	V	+0.060	+0.049	0.038	0.077	20
227.4794	V	+0.052	+0.016	0.038	0.054	9
228.4913	V	+0.007	+0.006	0.036	0.009	20
229.4461	V	−0.093	−0.138	0.055	0.166	118
229.4508	V	−0.104	−0.136	0.055	0.171	116
229.4557	V	−0.144	−0.159	0.055	0.215	114
229.4616	V	−0.085	−0.141	0.055	0.165	120
229.4664	V	−0.072	−0.149	0.055	0.165	122

2. Observations

V–band polarimetry of HD 139614 was undertaken on four nights at the SAAO in May 1996 (JD 2450226–2450229); on JD ...226 a single measurement was made in the R– band. The University of Cape Town photometer–polarimeter module (Cropper 1985) was used on the 0.75 m telescope. A detailed description of observational procedures and data reductions has already been presented by Clarke et al. 1998. The data are presented in Table 1. The columns give the Julian Date for the mean time of each observation, the filter used, the normalised Stokes parameters (q and u both in percent), their standard error ($\sigma_{q,u} \equiv 1\sigma$), the calculated degree of polarization ($p = (q^2 + u^2)^{1/2}$) and the position angle. The listed polarimetric parameters have been corrected for sky background and instrumental polarization and the $q,\ u$ values are plotted in Fig. 1.

Table 2. Some properties of the group of Vega–type stars discussed in our study. Estimates of spectral classes were taken from Dunkin et al. (1997). L_{IR}/L_*–ratio is taken from Silvester et al. (1996); * – the value from Malfait et al. (1998);** – the value derived from Hipparcos data.

Name	Sp class	E(B−V) (mag)	A_V (mag)	$v \sin i$ (kms^{-1})	Δm_V (mag)	NIR excess (mag) E(V−J)	E(V−K)	E(V−L)	L_{IR}/L_*
HD 139614	A7Ve	0.03	0.09	24±1	0.05	0.2	1.1	2.0	0.39
HD 142666	A8Ve	0.31	0.96	70±2	1.2–2.5	1.0	2.2	3.2	0.34
HD 141569	A0Ve	0.1^{**}	0.31^{**},0.47^{*}	236±9	0.2	0.2	0.3	0.4	$8.4\ 10^{-3}$
HD 169142	A5Ve	0.14	0.43	55±2	0.13	0.4	1.2	2.0	0.088

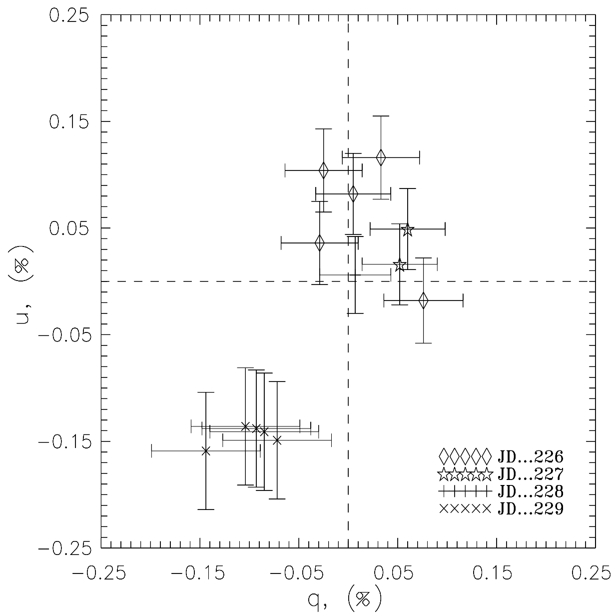

Fig. 1. V band polarization measurements of HD 139614 plotted in the qu–plane.

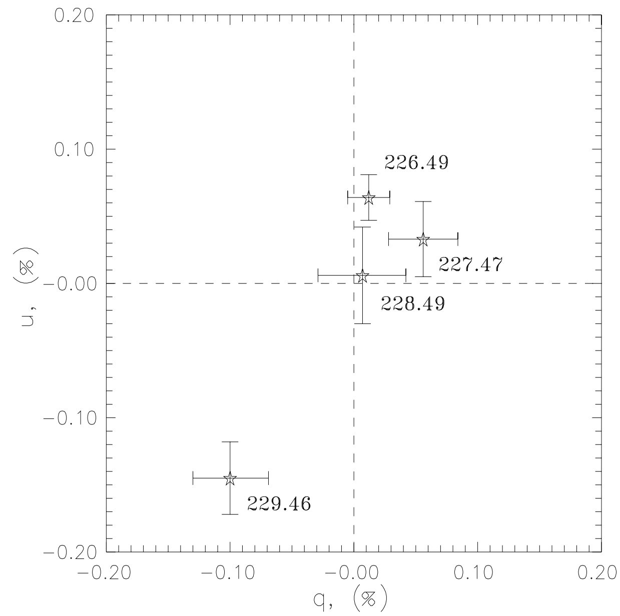

Fig. 2. The qu-diagram of weighted nightly mean V band polarization measurements of HD 139614.

3. Discussion

3.1. Polarization of HD 139614

It can be seen immediately from both Table 1 and Fig. 1 that HD 139614 exhibits low levels of polarization of 0.05%–0.2% changing from night-to-night with JD . . . 228 showing a level close to zero.

To investigate the presence of polarization for this star the q, u–plane projection technique was applied, allowing determination of confidence intervals (see Clarke & Stewart 1986 for details). The measurements show a presence of polarization at the 68% confidence level on JD. . . 226 and JD . . . 227 whereas on JD . . . 229 significant polarization was detected at the 99% confidence level. On JD . . . 228 no statistically significant polarization was detected even at the 68% confidence level. Note that the data on JD. . . 226 and JD. . . 229 lie in the first and third quadrants respectively. Application of the Welch test (see Brown & Forsythe 1974) indicates a temporal variability greater than the 99% confidence level for the nightly mean values on JD . . . 226 and JD . . . 229.

Moreover, it may be suggested that nightly mean values, as plotted in the qu–plane, possibly forms a locus along an arc, being part of a closed phase curve (see Fig. 2). If this notion is correct, the full period of polarimetric variation is about 8–10 days and probably results from some kind of rotational modulation (see discussion below). Whether this is the case or not, the observations clearly reveal the presence of a variable intrinsic polarization.

3.2. Evolutionary stages of some Vega–type stars

It is interesting to compare the polarimetric data for HD 139614 presented here with those obtained by one of the authors (RVYu) for other Herbig Ae stars: HD 141569, HD 142666 and HD 169142 (Yudin & Evans 1998). Like that for HD 139614 all of these stars are also recognized as Vega–types by Silvester et al. (1996) and Harvey et al. (1996).

Table 2 summarises some properties of the above mentioned stars. Taking into account the colour–colour diagrams of near infrared data, (J−H)/(H−K) and (H−K)/(K−L) (see Figs. 3 and 4 of Silvester et al. (1996)), we conclude that HD 139614, HD 142666 and HD 169142 are located in a transition zone between young Herbig Ae/Be stars and the oldest – but still young main sequence Vega–like stars (including the 'prototypes', e.g.

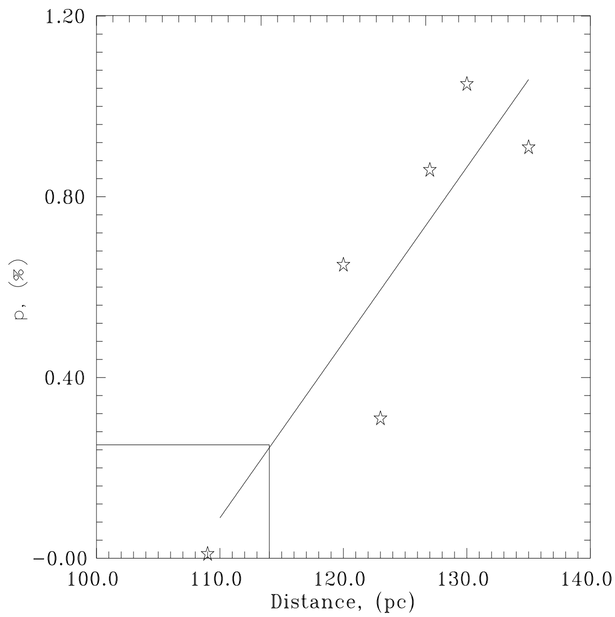

Fig. 3. Polarization–distance dependence in the vicinity of HD 142666

Vega, Fomalhaut and β Pic). It may be noted that the same conclusion for HD 142666 was made by Coulson et al. (1998). In contrast to HD 139614, HD 142666 and HD 169142 the star HD 141569 has no near IR excess and is likely to be a real member of the Vega–like group. This suggestion is supported by comparison of the L_{IR}/L_{*}–ratio for selected stars, where L_{IR} is the total energy radiated in the IR/sub-mm wavelength region by the dust and L_{*} is the stellar luminosity. Note that for HD 141569 the ratio L_{IR}/L_{*}=8.4 10^{-3} and for 'prototypes' β Pic, Vega and Fomalhaut this ratio is 2.6×10^{-3}, 2.3×10^{-5} and 8×10^{-5} respectively (Dunkin et al. 1997). Malfait et al. (1998) noted that the inner part of a dust disk "evolves more rapidly than the outer disk, and as a result, only the far IR excess remains" agreeing with the data for HD 141569 as well as for the 'prototypes'. On the other hand, perturbation of dust in the outer disk is reflected by the spectral energy distribution in the far infrared (see Yudin & Evans 1998 and references therein). Both near and the far IR data suggest a possible evolutionary sequence: "Herbig Ae/Be stars (i.e. pre–main sequence stars) $\Longrightarrow$ Vega–like stars with near–IR excess (i.e. young stars near the end of the pre–main sequence evolutionary phase) $\Longrightarrow$ Vega–like stars without near–IR excess but with some far–IR excesses (i.e. young main–sequence stars) $\Longrightarrow$ main sequence stars without near– and far–IR excesses".

The introduction of polarimetry as a diagnostic, with its ability to provide information on the optical thickness and geometry of scattering material in the vicinity of this group of stars, is critically important in considering such an evolutionary sequence.

3.3. Interstellar components of polarization

Before the measured polarization values for selected stars can be discussed, estimates for the presence of interstellar polarization should be made and corrections applied. A standard procedure for this is to investigate the field star data from available polarization catalogues. Using the VizieR Service at Centre de Donnés Astronomiques de Strasbourg, we selected the stars with polarimetric measurements from Mathewson & Ford (1970) and Axon & Ellis (1976) in a circle of 3° around each of our objects taking into account the distances derived from the Hipparcos data (ESA 1997). The results of this exercise are presented in Table 3.

Although the polarimetric data for field stars are not numerous and homogeneous, suggestions on the interstellar components of polarization have been made as follows:

HD 139614: Even if an interstellar polarization component exists, it cannot exceed 0.04%. It is likely that all the observed polarization is intrinsic to the star.

HD 142666: Field stars in the vicinity of the object possibly show a correlation between the distance and polarization (see Fig. 3). At the distance corresponding to HD 142666, the component of interstellar polarization is about 0.3% with a position angle about 100°. Using this estimate we calculate the component of intrinsic polarization for the object: $p_{intr} \approx 0.5\%$, $\theta_{intr} \approx 70°$.

HD 141569: Four stars in the vicinity of the object also possibly show a correlation between the distance and polarization. Using this dependence, the interstellar component for the star is estimated as: $p_{is} \approx 0.5\%$, $\theta_{is} \approx 85°$; the intrinsic component is therefore very small: $p_{intr} < 0.15\%$, $\theta_{intr} \approx 105°$.

HD 169142: Seven of the eight stars in the vicinity of the object show a position angle of about $115°$ and six of them have polarization $p \approx 1.2\%$. For the majority, Hipparcos data is insufficient to derive distances. Estimates of their distances lead to the conclusion that at least some of the field stars are probably located at 4× the distance of HD 169142. This provides an estimate of interstellar polarization of $p \approx 0.2\%$. Note that according to Yudin & Evans (1998), HD 169142 shows $\theta \approx 120°$ at the low state of polarization (i.e. when $p_V < 0.2\%$) this being in agreement with the above estimate of the interstellar component. Thus the intrinsic component of polarization for the star varies from 0.2% to 0.7% with an intrinsic position angle close to 175°.

3.4. Circumstellar shells around the considered stars

Detailed comparison of the photometric behaviour of HD 139614 and HD 142666 has been described recently by Meeus et al. (1998) who discussed evidence for circumstellar disks around these stars. According to Silvester et al. (1996), the total extinction towards HD 142666 is significantly larger than towards HD 139614 (see Table 2). Meeus et al. (1998) noted that both stars have almost identical spectral types, UV–optical

Table 3. Polarization data for field stars with respect to the considered stars. R is the angular projected distance of a field star from the object. The determined intrinsic polarizations of the stars discussed in the paper are also tabulated in summary rows.

Name	α_{1950}	δ_{1950}	R($^\circ$)	p(%)	θ ($^\circ$)	Distance(pc)	A_V
HD 139614	15 37 23	-42 20 14	0	0–0.2	20–120	84	0.09
HD 139127	15 34.7	-42 24	0.499	0.04	15.0	72	0
HD 138769	15 32.4	-44 47	2.607	0.08	65.5	182	0.06
HD 140861	15 44.1	-40 02	2.628	0.03	128.1	126	0
HD 139614	p_{intr}=0–0.2%		θ_{intr}=20–120°		see text for details		
HD 142666	15 53 43.3	-21 53 00	0	0.63	78	114	0.96
HD 143275	15 57.4	-22 29	1.042	0.31	120.0	123 ± 12	0.5
HD 142096	15 50.4	-20 01	2.021	0.00	0.0	109 ± 12	0.6
HD 142184	15 51.0	-23 50	2.048	0.65	64.0	120 ± 17	0.6
HD 142165	15 50.9	-24 23	2.583	0.86	56.0	127 ± 17	0.5
HD 144217	16 02.5	-20 32	2.670	0.91	99.0	135 ± 19	0.7
HD 144470	16 03.9	-20 32	2.730	1.05	119.0	130 ± 14	0.6
HD 142666	p_{intr} ≈0.5%		θ_{intr} ≈70°		see text for details		
HD 141569	15 47 20.2	-03 46 12	0	0.6	90	99 ± 8	0.31–0.47
HD 141513	15 47.0	-03 16	0.510	0.07	167.0	48 ± 2	0.1
HD 142863	15 54.0	-02 64	1.970	1.72	84.7	140 ± 27	0
HD 140873	15 43.5	-01 38	2.341	0.92	83.8	126 ± 11	0.3
HD 143396	15 57.6	-04 57	2.816	1.79	88.0	134 ± 28	1.3
HD 141569	p_{intr} <0.15%		θ_{intr} ≈105°		see text for details		
HD 169142	18 21 18.0	-29 48 28	0	0.1–0.6	120–180	145	0.43
HD 169100	18.21.2	-30 10	0.359	1.35	103.6		0.9
HD 168785	18 19.6	-30 10	0.514	1.20	95.7	588	0.8
HD 167775	18 14.8	-29 17	1.508	0.31	117.6		0.4
HD 170638	18 28.6	-30 06	1.608	0.42	62.7	612	0
HD 167402	18 13.1	-30 09	1.808	1.09	95.4		1.0
HD 169435	18 22.7	-31 47	1.998	1.06	119.5		0.6
HD 167665	18 14.3	-28 18	2.148	0.04	41.9	30 ± 8	0
HD 167599	18 14.0	-31 19	2.178	1.23	115.8		1.0
HD 169872	18 24.9	-32 30	2.800	1.28	140.9		0.2
HD 169142	p_{intr}=0.2–0.7%		θ_{intr} ≈175°		see text for details		

SEDs and observed IR excesses. However, they pointed out that HD 142666 has a substantial amount of circumstellar material in the line of sight, while HD 139614 shows no evidence for material in the line of sight. In terms of a model proposed by Meeus et al. (1998) for HD 142666, the irregular brightness variations are caused by dense nodules in the dust clouds which occasionally cross the projected stellar disk, i.e. the disk is being viewed edge–on. The non–variable photometric behaviour of HD 139614 suggests a more pole-on orientation of a disk.

Dunkin et al. (1997) have discussed the orientation of circumstellar disks around the stars from our sample based on the comparison of their $v \sin i$ values. Let us consider the rotational velocities the stars in context with their polarimetric behaviour.

The $v \sin i$ value for HD 142666 is much larger than for HD 139614 (see Table 2) and, together with its higher level of polarization and larger amplitude of photometric variability, supports the hypothesis that this star exhibits a circumstellar disk with edge–on aspect. Consideration of the polarization data obtained here and of Yudin & Evans (1998) for HD 142666 is perfectly consistent with the above descriptive model. The estimate of intrinsic polarization for HD 142666 shows a value ≈0.6%, much larger than any of the values obtained for HD 139614. Note that the behaviour of $p(\lambda)$ for HD 142666 is unlike that of interstellar polarization with p probably increasing in the red. Thus the polarization is again intrinsic to the stellar system. Moreover, the visual magnitude of HD 142666 at the time of the polarimetry was about $8\overset{m}{.}7$, i.e. the star was observed at maximum light. One can predict the detection of a much larger value of polarization for this star in minima because, according to Malfait et al. (1998) (132 observations), its amplitude of photometric variability is about $1\overset{m}{.}2$ in the V band or even may reach 3^{m} (see Bogaert & Waelkens (1990)). It may well be a member of Herbig Ae/Be stars with Algol–like minima of brightness (Meeus et al. 1998).

Two other Ae stars (HD 141569 and HD 169142) also show evidence of intrinsic polarization (Yudin & Evans 1998). HD 169142 displays night-to-night polarimetric variability from 0.1% to 0.6% (i.e. the amplitude of variability being greater than that for HD 139614 reported here). Dunkin et al. (1997) noted that HD 139614 and HD 169142 have the lowest $v\ \sin i$ values from all Vega-type stars in their sample and suggested that the disks around these stars may be closer to pole–on.

The value of $v\ \sin i$ for HD 169142 is, however, 2× larger than for HD 139614, indicating a difference in the inclination of the circumstellar disks of these two stars. The disk edge of HD 169142 from time to time may screen the stellar radiation, inducing the large polarimetric variability ($\Delta p \approx$0.5%) observed for this star. Moreover, Yudin & Evans (1998) noted that HD 169142 shows strongly increasing polarization to shorter wavelengths (see their Fig. 23) and discussed this fact in terms of Rayleigh scattering by small grains in the circumstellar envelope. This behaviour agrees well with the results of Sylvester et al. (1997) who modelled the near–IR emission for a sample of Vega–type stars (including of HD 169142) by the presence of small (with radius ≈10–50 Å) dust grains in their circumstellar environments.

The star HD 141569 has one of the largest values of $v\ \sin i$ among Vega–type stars and its disk may be close to being edge–on. However, its intrinsic polarization is very small (see Sect. 3.3). This is not surprising because, as suggested above, the star is an analog of 'prototype' Vega–like stars. Polarimetric data for 'prototypes' which are available in the catalogue of Leroy (1993) are as follows:

	0.020%±0.008%	for	β Pic,
	0.007%±0.004%	for	Vega
and	0.005%±0.005%	for	Fomalhaut.

Thus the polarization for 'prototypes' has a very low level even for β Pic's edge-on disk and for Fomalhaut with i about 60°(Harvey et al. 1996). Small polarizations associated with Vega–like 'prototypes' is also in agreement with the conclusion of Yudin (1988) that the dust grains with temperature of about 900–1000 K (i.e. the dust grains which are mainly responsible for near–IR excess) is a main agent of optical polarization of young Herbig Ae/Be stars. For 'prototypes' exhibiting no near–IR excess, the expected value of the polarization is small.

However, in the case of an exact pole–on orientation of an homogeneous disk with an axially symmetric distribution of dust and in the absence of any other polarigenic mechanisms other than scattering, the expected value of p is zero. In addition, from the lack of photometric variability, we can only suppose that the inclination of a disk around HD 139614 is such that from our viewpoint, it does not affect the direct radiation from the star.

Even for a close to pole–on orientation of the circumstellar disk, it is easy to explain the small but variable polarization of HD 139614 by the presence of dust clouds and/or planetesimal (comet–like) bodies orbiting the star within the circumstellar envelope. Such a scenario was discussed for β Pic by Beust et al. (1991) and for UX Ori–type stars by Grinin et al. (1996). In general, the cloud orbits the star in a plane whose normal makes an angle i to the line of sight. For i=0° (i.e. a pole–on orientation) and a circular orbit, only variability in the position angle, θ, should be observed, leading to a circular track in the qu–plane. In the case of elliptical orbits within the cloud, or departure of i from 0°, giving an ellipse for the projection of the disk on the sky–plane, variability of p should also take place. Because of the larger amounts of stellar flux being intercepted by an incoming planetesimal, the overall observed polarization measured from the system would increase when the cloud approaches the star. As discussed by Grinin et al. (1996), a large planetesimal (comet–like) would fragment at about $10R_*$ for an A–type star and this process will be connected with ejection of small dust particles that can produce variations of intrinsic polarization. Note also that Grinin's calculations on the time scale for this process is about few days. For i=90°(i.e. edge–on orientation of a cloud orbit) the formation of the dust in the vicinity of a star will be accompanied by simultaneous variations in polarization and brightness (like those observed in the UX Ori–type stars Grinin et al. 1996). In this case, however, the variations in the qu–plane would tend to follow a linear path. The model discussed above is consistent with the data for HD 139614 reported here, namely with polarimetric variability and a possible qu–plane locus along an arc and, with the absence of photometric variability, indicating a close to pole–on orientation of the disk. It may be noted that the 'planetesimal' hypothesis is also applicable to HD 169142.

4. Conclusions and future perspectives

Our main conclusions may be summarised as follows:

1. In spite of a low level of polarization (≈ 0.05–0.2%), polarimetric variability on a time–scale of days was detected for HD 139614. This variability may be explained in terms of a model of a close to pole–on circumstellar disk with the presence of dust clouds and/or planetesimal (comet–like) bodies moving on different trajectories in the circumstellar envelope around the star.
2. The difference in the level of the polarization for HD 139614 relative to other Herbig Ae/Be stars such as HD 142666 and HD 169142 might be due to the inclinations and viewing aspects of their circumstellar disks. This hypothesis is consistent with the photometric behaviour of these stars and their $v\ \sin i$ values.
3. The small intrinsic polarization for another star from the Vega–like group, HD 141569, for which the disk may be oriented close to edge–on is explained in terms of its different evolutionary stage (akin to the 'prototype' Vega–like stars: β Pic, Vega and Fomalhaut).

It is important to undertake precise multicolour observations to investigate the $p(\lambda)$ behaviour of HD 139614 for the detection of small dust grains in the circumstellar envelope and to obtain a longer time series of measurements to confirm the periodicity of the polarimetric variations. More generally, it is also important to extend photometric and polarimetric studies of Herbig Ae/Be stars with approximately the same IR excesses and physical properties (spectral types and brightness) and Vega–like stars to allow better interpretation of the model and the role that disk orientation plays on their observed behaviour. In addition, polarimetric measurements for groups of stars of different evolutionary stages (like that of Vega–like stars with and without near–IR excesses) are also desirable to study polarimetric behaviour in connection with evolution of circumstellar shells. For example, as was mentioned above, the dust structure around young objects will evolve as a result of break up of the disks caused by planet formation (see Malfait et al. 1998). The possible presence of giant planets around some Vega–like stars without near–IR excesses may also generate periodic polarimetric variability which might be similar to the behaviour observed in HD 139614. However, such observations require very high accuracy ($\sim$ 0.005%).

Finally, it is important to investigate the polarimetric behaviour in the context of the 'planetesimal' hypothesis quantitatively (mass involved, implication on system life–time, timescales, etc.) but this is beyond the scope of our present report.

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References

Axon D.J., Ellis R.S., 1976, MNRAS 177, 499
Beust H., Vidal-Madjar A., Ferlet R., Largange-Henry A-M., 1991, A&A 247, 505
Bogaert E., Waelkens C., 1990, In: Jaschek C., Andrillat Y. (eds.) The infrared spectral region of stars. Cambridge Univ. Press, p. 345
Brown M.B., Forsythe A.B., 1974, Techometrics 16, 129
Clarke D., Smith R.A., Yudin R.V., 1998, A&A 336, 604
Clarke D., Stewart R.A., 1986, Vistas Astron. 29, 27
Coulson I.M., Walther D.M., Dent W.R.F., 1998, MNRAS 296, 934
Cropper M., 1985, MNRAS 212, 709
Dolginov A.Z., Gnedin Yu.N., Silant'ev N.A., 1995, In: Propagation and polarization of radiation in Cosmic Media. Gordon and Breach Publishers
Dunkin S.K., Barlow M.J., Ryan S.G., 1997, MNRAS 286, 604
Hipparcos and Tycho Catalogues, 1997, ESA SP-1200
Grady C.A., Perez M.R., Talavera A., et al., 1996, A&AS 120, 157
Grinin V., Nata A., Tambovtseva L., 1996, A&A 313, 857
Harvey P.M., Smith B.J., Difrancesco J., Colome C., 1996, ApJ 471, 973
Leroy J.L., 1993, A&AS 101, 551
Malfait K., Bogaert E., Waelkens C., 1998, A&A 331, 211
Mathewson D.S., Ford V.F., 1970, Mem. R. Astron. Soc. 74, 139
Meeus G., Waelkens C., Malfait K., 1998, A&A 329, 131
Oudmaijer R.D., van der Veen W.E.C.J., Waters L.B.F.M., et al., 1992, A&AS 96, 625
Silvester R.J., Skinner C.J., Barlow M.J., Mannings V., 1996, MNRAS 279, 915
Silvester R.J., Skinner C.J., Barlow M.J., 1997, MNRAS 289, 831
Walker H.J., Wolstencroft R.D., 1988, PASP 100, 1509
Yudin R.V., Evans A., 1998, A&AS 131, 402
Yudin R.V., 1988, SvA 32, 652