Preliminary Results from an Open Cluster Polarimetric Survey

Orsatti[1,2], A. M.; Vergne[1,2], M. M.; Feinstein[1,2], C. and Martínez[1,2], R. E.

1: Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina. 2: Instituto de Astrofísica de La Plata, Conicet.

Contact: mvergne@fcaglp.unlp.edu.ar

Abstract

We present preliminary results from an Open Clusters Polarimetric Survey which is being developed at La Plata Observatory (Argentina).

The aim of this Survey is to provide clues about the characteristics of the dust responsible for extinction and polarization in the light from member stars of Open Clusters, about its galactic distribution and also to confirm or reject possible memberships of cluster members.

At the present stage we have studied a total of 17 Open Clusters with galactic longitudes between 294° < l < 16° in the Southern Milky Way, with a range in distance of about 800-2300 pc from the Sun and a sample of about 500 observed individual stars.

In each one of these clusters, we have been able to detect the presence (if any) of intracluster dust and interstellar dust on direction to the cluster, with auxiliary observations of nonmember stars. Also, we got from these observations the distribution, size and efficiency of the dust grains which polarize the starlight and the changing directions of the Galactic magnetic field on the line of sight to each cluster. A very important byproduct of these studies is the isolated stars that are candidates for having an intrinsic component of polarization (with a non-interstellar origin).

Special applications have been found, as for example in help discussing membership of Cepheids in some open clusters, or detecting the location of energetic phenomena occurred in the past history of a cluster.

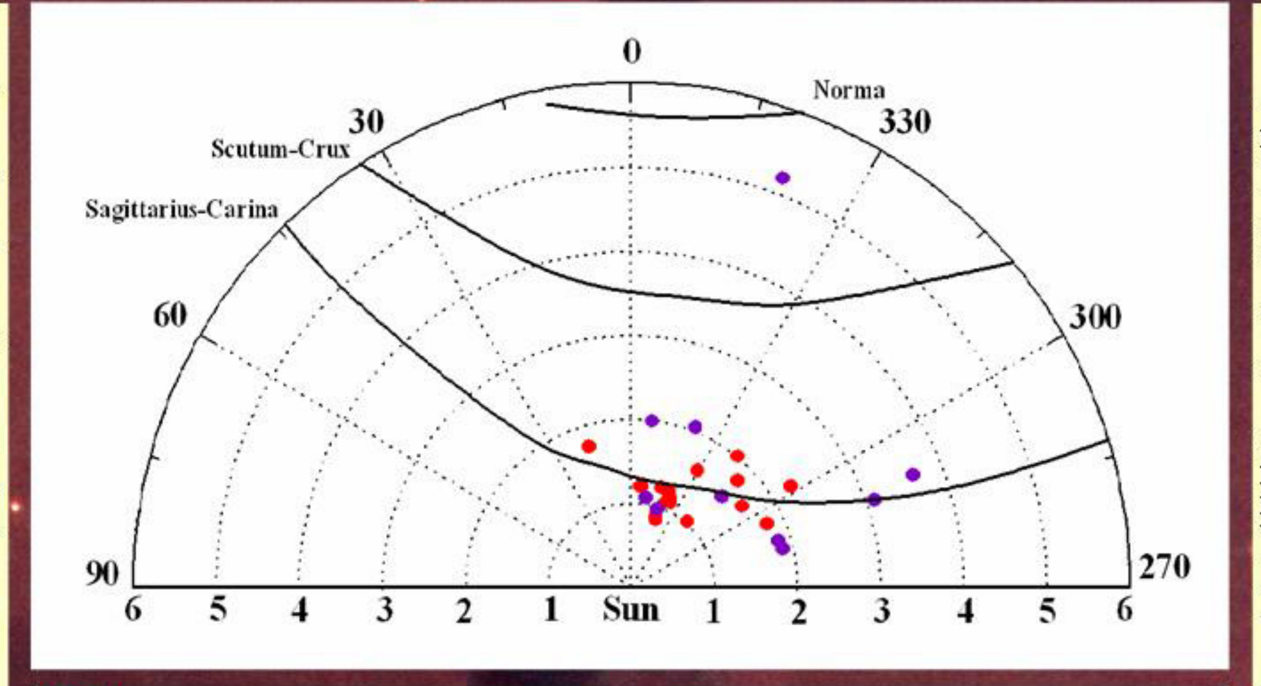

FIG. 1- Third and fourth quadrants of the Milky Way are represented, centered in the Sun. Red dots represent Open Clusters studied and violet dots represent Open Clusters only observed but not analysed. The figure includes Sagittarius-Carina, Scutum-Crux and Norma arms, in full line.

I - Introduction

Studies of interstellar polarization are important for two reasons: they provide information on the dust responsible of the polarization and it is a mean to trace the Galactic magnetic field. Comparison of polarization and extinction data in the same lines of the sight provides tests for models of extinction and alignment of the grains. This alignment involves several processes acting simultaneously, but on different time-scales. The rotating dust grains get substantial magnetic moment that allows them to precess fast about magnetic field lines. As the result, the grains preserve their orientation to magnetic field when the magnetic field direction fluctuates, forcing grain axes to be aligned in respect to the grain angular moment (Lazarian & Cho 2005). Therefore, the observed polarization vector map the mean field direction projected on the plane of the sky. This allows us to investigate the structure of both the macroscopic field in our Galaxy (Mathewson & Ford 1970; Axon & Ellis 1976) and the local field associated with the individual clouds (Goodman et al. 1990).

The polarimetric technique is a very useful tool to obtain significant information from the dust located in front of a luminous source. In particular, young open clusters are very good candidates to carry out polarimetric observations, because previous photometric and spectroscopic studies of these clusters have provided detailed information on the colour and luminosity of the main sequence stars of the cluster. Thus, we can compute the physical parameters of the clusters and then, with the polarimetric data, we can study the distribution, size and efficiency of the dust grains which polarize the starlight and the different directions of the Galactic magnetic field in the line of sight to the cluster. As some of the open clusters spread within a certain area, it is possible to analyse the evolution of the physical parameters of the dust all over the region.

For some years now, we have been carrying out systematic polarimetric observations in a large number of Galactic Open Clusters. The principal aim of this Survey is to develop, in the near future, a new catalog containing the polarimetric parameters associated with them. Hence, this is the first polarimetric survey devoted not to isolated stars, as in other catalogs, but to a stellar group at a certain location, immersed in a particular interstellar medium whose characteristics can be revealed through polarimetry.

II a - Observations

Data on linear optical polarimetry were obtained, for 17 Open Clusters (see Table 1 and Fig. 1), at the Complejo Astronómico "El Leoncito" (CASLEO) in San Juan, Argentina. The observations were carried out using the Torino five-channel photopolarimeter (Scaltriti 1994) attached to the 2.15-m telescope. The individual stars were observed simultaneously through the Johnson-Cousins broad band UBVRI filters (λ_{Ueff}=0.360µm, λ_{Beff}=0.440µm, λ_{Veff}=0.530µm, λ_{Reff}=0.690µm, λ_{Ieff}=0.830µm). Standard stars for null polarization and for zero point of the polarization position angle were observed times each night for calibration purposes. Each observation in each filter was corrected for sky polarization and calibrated in the angle in the equatorial system with the proper correction obtained by the data of the angle standards. No correction was done by instrumental intrinsic polarization because it was found to be insignificant in the observations of null polarization stars. For further information on the instrument, data acquisition and data reduction see Scaltriti (1994).

Table 1

Cluster	ℓ	b	E_{B-V}	Distance (kpc)	Age (x 10[7])
IC2944	294.85	-1.65	0.32	1.79	0.66
Hogg 15	302.05	-0.24	1.09	2.26	0.60
Stock 16	306.25	0.06	0.49	1.64	0.82
NGC 5606	314.84	0.99	0.47	1.81	1.20
NGC 5749	319.53	4.55	0.38	1.03	5.35
Pismis 20	320.52	-1.20	1.18	2.02	0.73
Lynga 6	330.37	0.32	1.25	1.60	2.69
NGC 6167	335.22	-1.43	0.78	1.11	7.71
NGC 6193	336.71	-1.57	0.47	1.16	0.60
Hogg 22	338.56	-1.14	0.65	1.22	0.60
NGC 6204	338.56	-1.04	0.43	1.09	3.60
NGC 6250	340.68	-1.92	0.35	0.87	2.60
NGC 6124	340.80	6.00	0.80	0.56	10.00
Lynga 14	340.92	-1.09	1.43	0.88	0.52
NGC 6231	343.46	1.18	0.44	1.24	0.70
Trumpler 27	355.06	-0.74	1.19	1.21	1.16
NGC 6611	16.95	0.79	0.78	1.75	0.77

II b - Sky projection of the V-band polarization

Commonly in a typical Open Cluster the polarization vectors have a similar mean orientation of the polarization angle (see Fig 2a), and the individual stars show little scatter over this fixed direction (≈ ± 10°, Waldhausen et al. 1999; Feinstein et al. 2000, 2003). But there is a small amount of Open Clusters in which the distribution of the polarization angles is abnormal (NGC 6231, see Fig 2b).

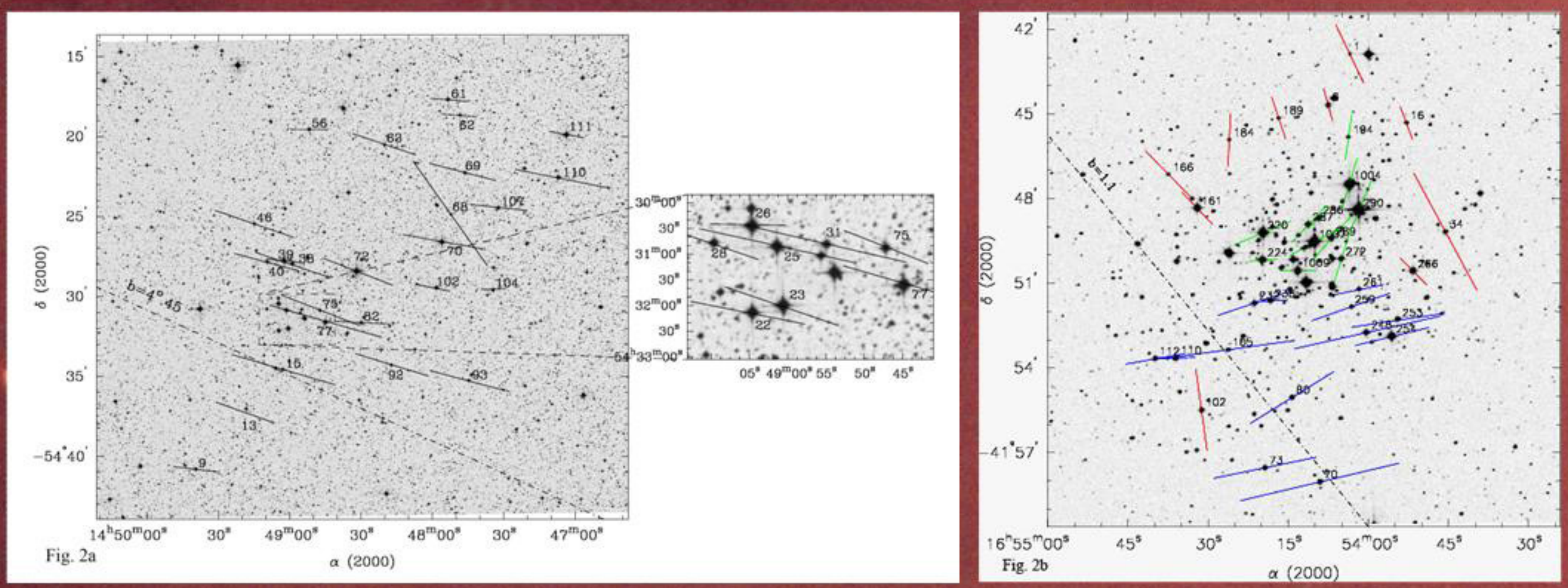

FIG. 2- Projection on sky of the polarization vectors (Johnson V filter) of the stars observed, indicating the dot-dashed line the galactic parallel in the region. *(a)* It corresponds to stars observed in the region of NGC 5749 (near the south-western edge of the Lupus constellations), and it is a typical distribution of the polarization vectors (Vergne et al. 2006). *(b)* It corresponds to stars observed in the region of NGC 6231 (Ara region). In this case, we observe three groups, according to location and the angle of the polarization vectors (abnormal distribution). To the North the polarization angles are dominated by the direction of the galactic disk and to the South are perpendicular to this orientation. Close to the core they are well organized in a pattern semicircular which we suppose that is the result of the shock on the local ISM due to an energetic event (probably a supernova) occurred in the history of the cluster (Feinstein et al. 2003).

III a - Analysis

The polarimetric observations in the five filters (UBVRI) were fitted in each star using Serkowski's law of the interstellar polarization (Serkowski 1973)

$$\frac{P_\lambda}{P_{\lambda_{max}}} = e^{-K\ln^2(\lambda_{max}/\lambda)} \quad \text{with} \quad K = 1.66\lambda_{max} + 0.01$$

If the polarization is produced by aligned interstellar normal dust particles, the observed data will follow this law and each star will have $P_{\lambda max}$ and λ_{max} values (see Table 2).
To quantify the departure of our data from this "theoretical curve", we computed the unit weight error of the fit (σ_1, Orsatti et al. 1998), given by:

$$\sigma_1 = \frac{\sum (r_\lambda/\varepsilon_{p_\lambda})^2}{(m-2)} \quad \text{with} \quad r_\lambda = P_\lambda - P_{\lambda max}e^{-K\ln^2(\lambda_{max}/\lambda)}$$

where m is the number of colors.

Table 2. Polarimetric parameters

Open cluster	Observed stars	Members (confirmed)	Stars with P_i (*)	$<P_{\lambda max}>$ (%) Observed	$<\lambda_{max}>$ (µm) Observed	OUR REFERENCES
IC 2944	30	21	11	1.70 ± 0.03	0.55 ± 0.02	AJ 108, 1834, 1994
Hogg 15	23	12	4	3.18 ± 0.48	0.60 ± 0.04	AJ 116, 266, 1998
Lynga 14	15	10	0	1.89 ± 0.30	0.65 ± 0.08	AJ 116, 266, 1998
NGC 6167	50	---	---	3.22 ± 0.36	0.57 ± 0.07	AJ 117, 2882, 1999
NGC 6193	31	---	---	1.30 ± 0.21	0.51 ± 0.05	
Trumpler 27	30	25	4	5.79 ± 1.87	0.58 ± 0.06	AJ 120, 1906, 2000
NGC 6611	32	28	14	3.74 ± 0.88	0.57 ± 0.04	A&AS 144, 195, 2000
Lynga 6	16	8	5	5.90 ± 0.54	0.61 ± 0.03	A&A 380, 130, 2001
NGC 6231(#)	34	23	4	----------	----------	ApJ 578, 349, 2003
Pismis 20	20	15	6	A: 4.31±0.50 B: 6.08±0.80	0.64 ± 0.10 0.57 ± 0.02	A&A 408, 135, 2003
Stock16	26	12	3	2.24 ± 0.22	0.57 ± 0.04	A&A 409, 933, 2003
NGC 6204	33	15		2.00 ± 0.21	0.61 ± 0.05	A&A 419, 965, 2004
Hogg 22		9		2.10 ± 0.28	0.57 ± 0.02	
NGC 5606	56	26	8	3.20 ± 0.33	0.59 ± 0.09	in preparation
NGC 5749	31	24	3	1.70 ± 0.30	0.62 ± 0.06	A&A (in press)
NGC 6250	32	18	2	1.79 ± 0.10	0.60 ± 0.06	in preparation
NGC 6124	32	13	8	2.40 ± 0.32	0.57 ± 0.02	in preparation

(*) Candidates in the observed stars for having an intrinsic component of polarization.
(#) $<P_{\lambda max}>$ and $<\lambda_{max}>$ cannot be to compute due its peculiar polarimetric characteristics.

III b - Polarization efficiency

The ratio of polarization to extinction at some wavelength is a measure of the mean polarization efficiency of the dust along a line of sight. Therefore, using the derived color excesses E_{B-V}, we calculated the polarization efficiency $P_{\lambda max}/E_{B-V}$ (see Fig. 3). The empirical "upper limit" relation for the polarization efficiency, assuming normal interstellar material characterized by R=3.2, is given by

$$P_{\lambda_{max}} = RA_V \approx 9E_{B-V} \quad \text{(Serkowski et al. 1975)}$$

The observed "normal" efficiency of the polarizing properties of the dust is represented by

$$P_{\lambda_{max}} = 5E_{B-V} \quad \text{(Serkowski et al. 1975)}$$

There is a new estimate of the average efficiency, made by Fosalva et al. (2002), valid for $E_{B-V} < 1$ mag, and given by

$$P_{\lambda_{max}} = 3.5E_{B-V}^{0.8}$$

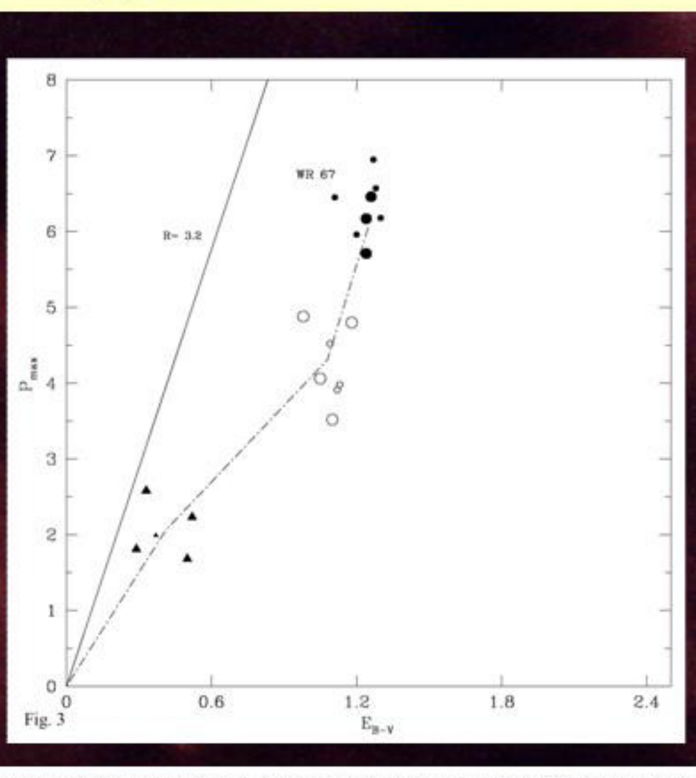

FIG. 3 - Polarization efficiency diagram for stars observed on direction to the open cluster Pismis 20. This parameter depends mainly on the alignment efficiency and the magnetic field strength. The continuous line (maximum efficiency) shows the empirical upper limit. If the stars lie to the right of the interstellar maximum line, the observed polarization is mostly due to the interstellar material. In this particular case, the polarimetric observations helped in segregating three groups: one of them belonging to the Local arm, and two other groups. The dash-dotted line shows the change in dust efficiency between the three groups.

III c - Stokes parameters

In our study we express the polarization in terms of the Stokes's parameters. These are used extensively in the literature because of their additive properties. In terms of magnitudes they are given by the relations

$$Q = P\cos 2\theta \qquad U = P\sin 2\theta$$

where θ is the position angle of the E-vector with respect to the North Galactic Pole, and P is the degree of polarization expressed in magnitudes (see Serkowski 1962). Therefore, Q and U are the equatorial coordinates of the polarization vector. The Q vs. U plot provides useful information on variations in interstellar environments: if the light from individual stars of the region where the Open Cluster is located has gone through a common sheet of dust, their representative points will concentrate on a given region in the Q vs. U plot, indicating similar optical characteristics in the polarizing dust, both for member and nonmember stars (located behind a dust layer). For that, if the representative point of any member star is located out of the corresponding point to the members of the cluster. This should be considered as a possible nonmember. An accurate application of this plot for membership issues requires a previous identification and exclusion of any star with intrinsic polarization (see Fig. 4).

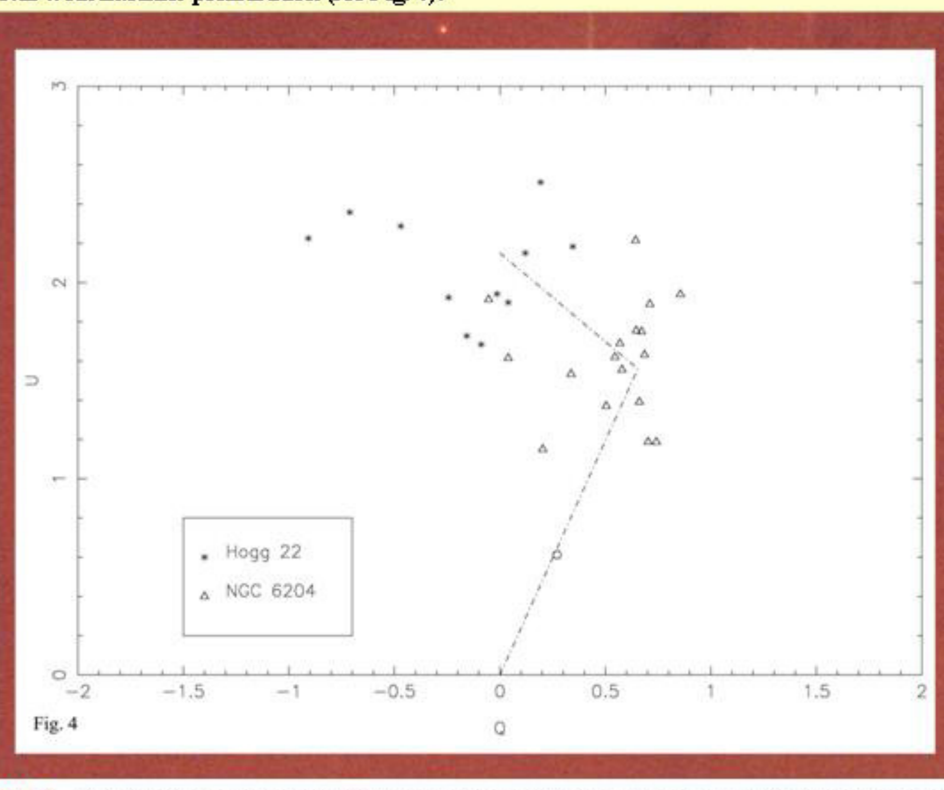

FIG. 4 – U vs. Q (Stokes parameters) for the stars of NGC 6204 and Hogg 22. The dot-dashed lines show the variation of the polarization produced by the dust layer on the line of sight to the clusters.

III d - Intrinsic component of polarization

In our scheme we use three indicators to detect the presence of a non-interstellar component in the polarization of a star. They are:

- A value of σ1 lower than 1.5.
- A value of λ_{max} much lower than 0.545µm (the average value of the interstellar medium).
- A value of the dispersion of the position angle for each star, normalized by the average of the position angle errors, higher than 3σ.

(see Fig. 5)

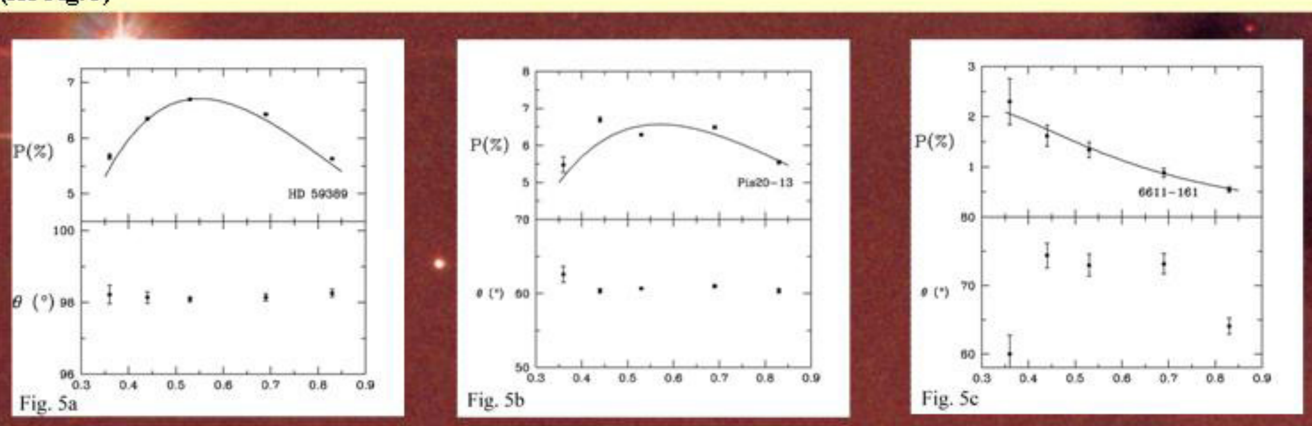

FIG. 5 - Polarization and position angle dependence on wavelength for HD 59389 (polarisation standard, Fig. 5a) and for two stars with indications of intrinsic polarization (Fig. 5b,c). The continuous line represents the Serkowski's curve corresponding to given P_{max} and λ_{lambda} values. The intrinsic polarization in the light from a star can be identified as a mismatch between observations and the Serkowski's curve fit and/or variable position angle. The first situation can be seen in the Fig. 5b for star 13 in Pismis 20, while strong variable position angles can be seen in the Fig. 5c for star 161 in NGC 6611.

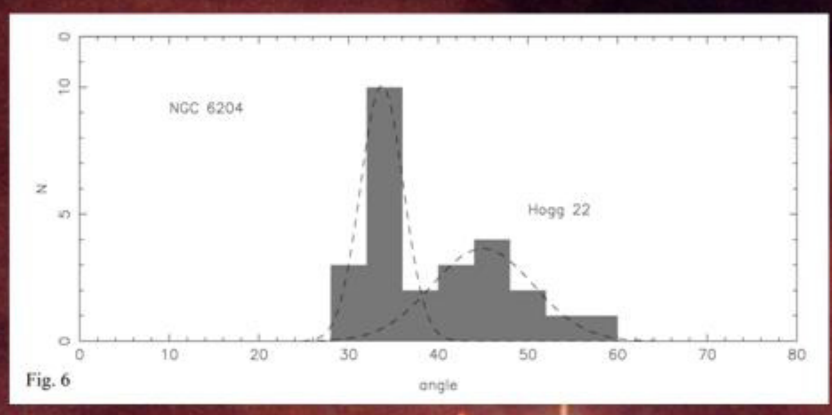

FIG. 6- Histogram of the polarization angles θ_V for all observed stars in the region of Hogg 22 and NGC 6204 (Ara region). The continuous line is the Gaussian fit to the data of each cluster. This plot shows how polarimetric data separate adequately the two clusters (Martínez et al. 2004).

Our findings

1. The polarimetric observations are excellent tools to determine membership in Galactic Open Cluster, in particular when field stars have colors which are similar to those of cluster members (see, eg., figs. 4 and 6).
2. In every investigation, dust clouds close to the Sun have been identified and their polarization characteristics have been determined. These clouds produced polarizations with values below 1%, in most cases, with distances up to 300 pc from the Sun. The e-vectors are aligned with the projection of the local Galactic magnetic field vectors.
3. In some clusters, we have found intracluster dust component of variable characteristics.
4. The use of the σ_1 polarimetric parameter has led to the identification of stars whose light displays a polarization of non interstellar origin: that is, stars with extended atmospheres (like Be stars), dust associated to possible binary systems, or surrounding the star (due to evolution or as a formation remnant).
5. Polarimetry helps in solving particular situations as, for example, in discussing Cepheids' membership in a given Open Cluster, or detecting the location of an energetic phenomena occurred in the past history of a cluster (see, eg., fig. 2b).

The Catalog

The Catalog will provide identifications, positions, percent polarization in the UBVRI bands and their uncertainties, polarization angles, the detection of intrinsic polarization (and the origin, if it is possible), visual magnitudes, spectral types and accepted distance.

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