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Research Note

Population I-type objects and galactic structure

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Abstract. Data on open clusters, WR stars and supernova remnants (SNRs) have been used to study the large-scale structure of the Milky Way. A comparison of the distributions of WR stars and SNRs indicates a weak correlation. It is also found that the planes of symmetry defined by open clusters, WR stars and SNRs, are inclined with respect to the formal galactic plane. The location of the Sun with respect to these planes of symmetry has been obtained. The plane of symmetry defined by SNRs is located above the Sun while the planes of symmetry defined by open clusters and WR stars are situated below the Sun.

Key words: galactic structure – population I type objects

1. Introduction

Several studies have been carried out which show that the formal galactic plane does not coincide with the planes of symmetry defined by different objects (Gum et al., 1960; Kraft and Schmidt, 1963; Fernie, 1968; Stenholm, 1975; Cohen and Thaddeus, 1977; Lockman, 1977; Lyngå, 1982, 1983; Magnani et al., 1985; Pandey and Mahra, 1987; Miyamoto et al., 1988; Pandey et al., 1988). It is also found that the Sun is situated above the planes of symmetry defined by different objects and that these planes are tilted with respect to the formal galactic plane. The neutral hydrogen layer (Gum et al., 1960), the molecular clouds (Cohen and Thaddeus, 1977), H II regions and supernova remnants (Lockman, 1977) and open clusters (Lyngå, 1983) show a variation in their mean z values with the galactocentric distance.

Pandey et al. (1988) and Janes et al. (1988) have used data on open clusters to study the galactic structure. Pandey et al. (1988) have used the data on nearby open clusters and concluded that the plane of symmetry is tilted with respect to the formal galactic plane while Janes et al. (1988) have concluded that there are no significant undulations around the plane of symmetry defined by the open clusters within 4 kpc of the Sun. However, it is possible that scatter and selection effects in their material hide evidence of an inclined plane of symmetry of the kind proposed by Pandey et al. (1988). In the present study an attempt has been made to obtain a three dimensional model of the Galaxy in rectangular coordinates (cf. Stenholm, 1975), using data on population I type objects, i.e. young open clusters, Wolf-Rayet (WR) stars and supernova remnants (SNRs). A least squares solution for the distribution of these objects in rectangular coordinates is expected to give an unbiased picture of the Galaxy; such a study has not jet been made for open clusters and SNRs.

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2. Distribution of population-I type objects in the galaxy

In the present study the following population-I type objects have been used to draw a large scale galactic structure:

(a) Young open clusters: The data for young open clusters having age $\leqq 2\ 10^8$ yr have been taken from Lyngå (1987). The weighted values given in his catalogue were used in the present analysis.

(b) WR stars: The WR stars are young and high luminosity objects, $-7 < M_V < -4$, and these can be observed further out in Galaxy than any other class of optical objects. De Loore et al. (1983) have concluded that the WR stars must be descendants from the massive O stars. The data for WR stars have been taken from Hidayat et al. (1982).

(c) Supernova remnants (SNRs): Ilovaisky and Lequeux (1972) have concluded that most of the supernovae belong to extreme population I objects. Since distances to these objects are derived from a relationship between their surface brightness observed at radio wavelengths and the diameters, therefore, interstellar absorption does not play a significant role in the study of large scale structure of the Galaxy using these objects. The data for SNRs have been taken from Allakhverdiyev et al. (1986).

2.1. *The distribution in longitude*

The histograms of the longitudinal distributions of open clusters, WR stars and SNRs within 10 kpc of the Sun are shown in Fig. 1. The longitude bin of 10° has been taken in all the histograms. A comparison of these distributions shows that the longitudinal distribution of open clusters and WR stars are more or less similar while the distribution of SNRs is somewhat different from the distributions of open clusters and WR stars.

The above mentioned longitudinal distributions might have been affected by selection effects which grow with increasing distance. To check the completeness of the data, we have plotted in Fig. 2 the number of objects against their distance from the Sun.

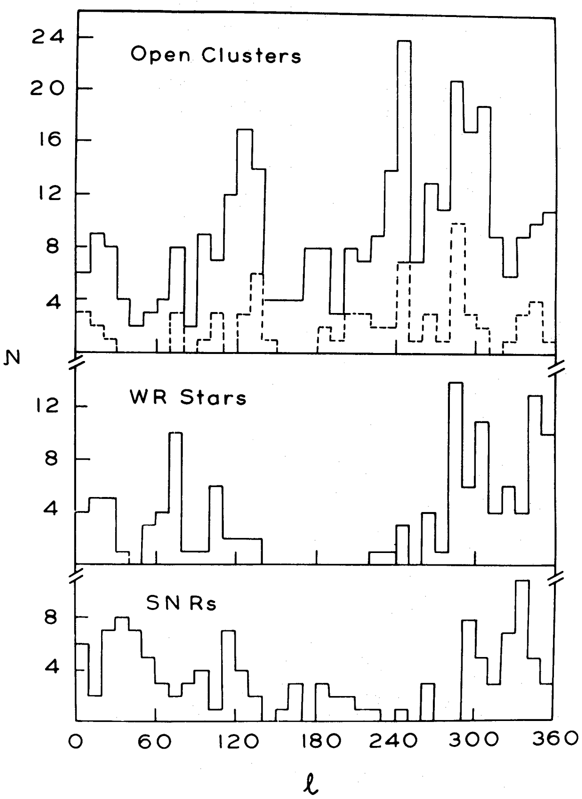

Fig. 1. The histograms of the longitudinal distribution of open clusters, WR stars and SNRs within 10 kpc of the Sun. The dashed line represents the distribution of open clusters having age $\leqq 3.2\ 10^8$ yr

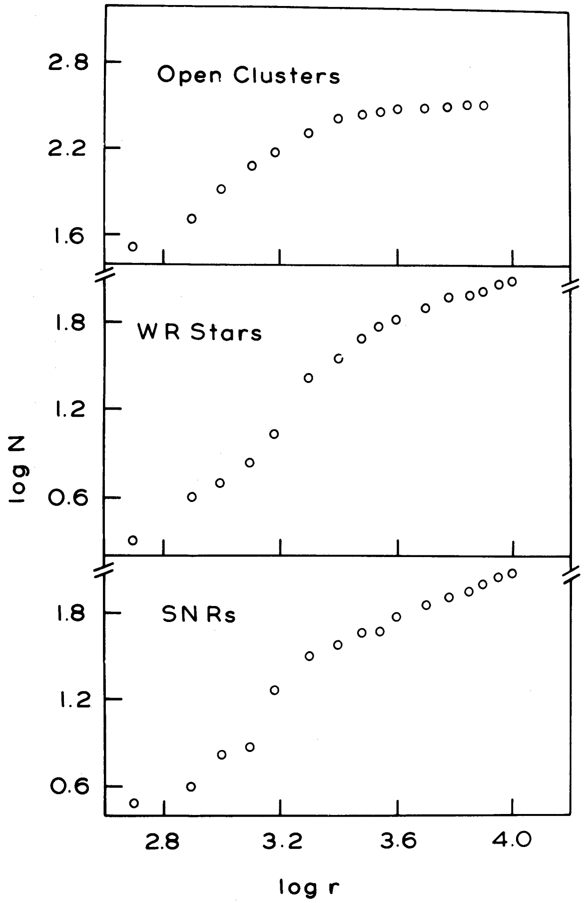

Fig. 2. The distribution of population I type objects as a function of distance from the Sun

The figures suggest that incompleteness in the data on open clusters begins at about 2.0 kpc while for WR stars and SNRs incompleteness begins at about 4 kpc. However, these estimates may have some uncertainty due to the non-uniform distribution of these objects in the galactic plane.

The histograms of the longitudinal distribution of these objects within 4 kpc of the Sun are shown in Fig. 3. A comparison of the distributions in Fig. 3 and Fig. 1 shows that open clusters and WR stars have almost similar distributions, while SNRs within 4 kpc of the Sun, show almost a flat distribution. The longitudinal distributions of open clusters and WR stars within 4 kpc of the Sun show a better resemblance than the distribution within 10 kpc.

2.2. The distribution in latitude

In Fig. 4 we have plotted the running mean values of galactic latitude $\bar{b}$ taken over 60° intervals of longitude, against the mean longitude of that interval, for the population I type objects used in the present study. From Fig. 4 it is obvious that the population I type objects used in the present study are unevenly distributed with respect to the formal galactic plane and show systematic variation with l. If the planes of symmetry defined by these objects are tilted with respect to the formal galactic plane, the mean b values will show a systematic variation with longitude. The

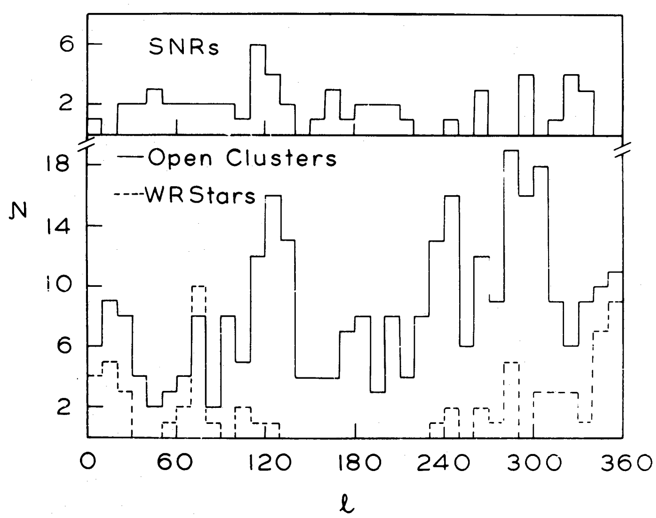

Fig. 3. The histograms of the longitudinal distribution of the objects within 4 kpc of the Sun

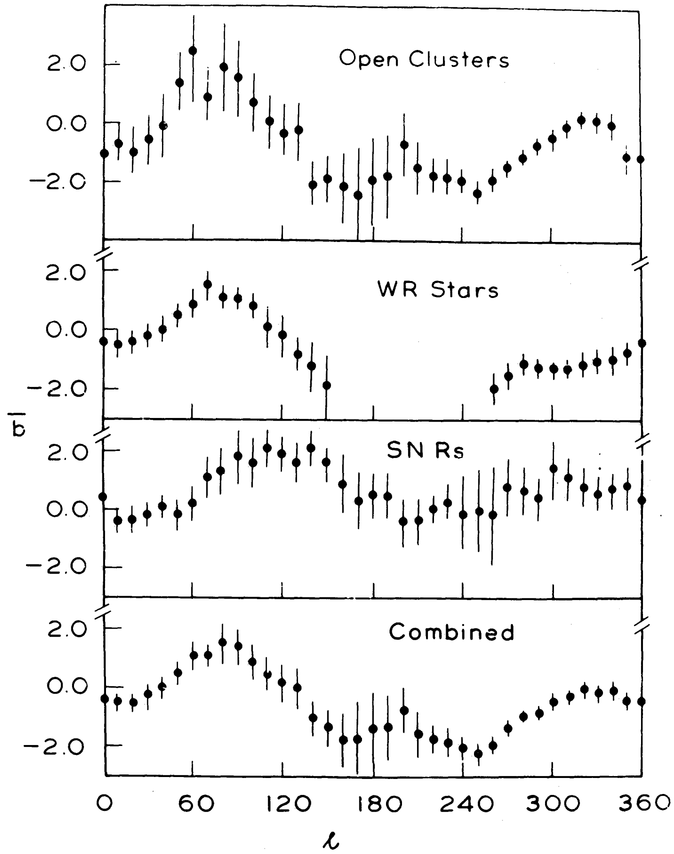

Fig. 4. Running mean of latitude, $\bar{b}$, for 60 intervals of galactic longitude as a function of mean longitude of that interval. The error bar represents the standard error of the mean which is defined as $\pm\sigma/\sqrt{N}$, where σ is the standard deviation and N is the number of objects in each interval

distribution of open clusters shows approximately a sinusoidal variation with galactic longitude. However, the open cluster in the vicinity of longitudes, $l \sim 20°–40°$ shows a lower value of $\bar{b}$. Pandey and Mahra (1987) have found that the maximum interstellar absorption occurs towards $l \sim 50°$ and that additionally, towards this direction the concentration of interstellar matter is maximum above the formal galactic plane. Therefore, the $\bar{b}$ values of the clusters in the vicinity of longitudes 20°–40° might have been affected due to selection effects in this region. In case of WR stars and also the SNRs, the distributions are rather complicated. The WR stars and the SNRs do not define a plane like that of open clusters but these show a rather warpy surface.

Figure 4 shows that all the three population I type objects are not distributed symmetrically with respect to the formal galactic plane. The distributions of open clusters and WR stars suggest that the Sun is located above the planes of symmetry defined by these objects, while the distribution of SNRs shows that the Sun is situated below the plane of symmetry defined by SNRs. However, the distribution of these population I type objects combined together shows that the Sun is located above the plane of symmetry. Another conclusion drawn from the Fig. 4 is that the plane of symmetry defined by these objects are tilted with respect to the formal galactic plane.

2.3. *Three dimensional picture of the Galaxy*

An unbiased method of determining the plane of symmetry defined by the stellar objects is a least squares solution for the distribution of these objects (Stenholm, 1975). A plane of symmetry, in rectangular coordinate system is defined by the equation:

$$Z = a_0 + a_1 X + a_2 Y; \qquad (1)$$

where,

$X = r \cdot \sin l \cdot \cos b$;
$Y = -r \cdot \cos l \cdot \cos b$; and
$Z = r \cdot \sin b$.

The coefficients in Eq. 1 are determined by the least squares method and the value of a_0 thus obtained corresponds to the distance of the Sun from the plane of symmetry. The tilt of the plane with respect to the formal galactic plane and the longitudinal direction of the tilt are computed using Eq. 1 and the results of least squares solutions for various limiting distances are given in Table 1. The limiting distance, the number of objects, a_0, tilt angle and direction of the maximum tilt for open clusters, WR stars, SNRs, and for combined data have been given in Table 1.

Considering that the observed tilt between the formal galactic plane and the planes of symmetry defined by these objects may be a result of local selection effect produced by the presence of Gould's belt, we have also carried out an analysis by excluding the objects within 1 kpc of the Sun and the results thus obtained are given in Table 2. A comparison of the results given in Table 1 with Table 2 further supports that the plane of symmetry defined by population I type objects are tilted with respect to the formal galactic plane.

Pandey et al. (1988) have studied the distribution of young open clusters within 1500 pc of the Sun and concluded that the plane defined by the young open clusters is inclined to the formal galactic plane by an angle of $0.^\circ5 \pm 0.^\circ4$ and shows a maximum upward tilt towards $l \sim 50°$. The distribution of these nearby clusters does not show any relationship with the Gould belt, a ring of O and B stars inclined approximately 18° to the galactic plane and lies within 1 kpc of the Sun (Taylor et al., 1987).

One striking feature in the distribution of these population I type objects is that the plane of symmetry defined by SNRs, is located above the Sun, while other two distributions suggest that the Sun is situated above the plane of symmetry. A comparison of the distributions of the WR stars and the SNRs suggests that these two distributions are quite different and leads to the conclusion that the SNRs may not have WR stars as their progenitors. Gorden (1983) has also expressed a similar doubt regarding the relation between SNRs and WR stars.

From the results given in Table 1, we find that the longitudinal direction of upward tilt is different for open clusters, WR stars and SNRs and the direction of upward tilt shifts considerably as we add objects at farther distances. We conclude that these objects do not define simple planes of symmetry but probably show radial undulations with respect to the formal galactic plane. Lyngå (1983), based on the distribution of open clusters with respect to the formal galactic plane, has also concluded that there seems to be a radial undulation of the galactic disc, similar to that discussed by Lockman (1977) for H II regions.

2.4. *Spiral arm structure of the Galaxy*

Since the objects used in the present study, are considered as spiral arm tracers, therefore, these objects must show a pattern of spiral arms. An $X-Y$ plot of these objects is shown in Fig. 5. The apparent distribution of these population I type objects projected

Table 1. Results from least squares solutions for equation of plane of symmetry

Object	Distance limit (kpc)	Number of objects	a_0 (pc)	Inclination: Angle (θ) (degrees)	Inclination: Longitudinal direction of upward tilt (degrees)
Open clusters	3	261	−19±4	0.6±0.2	25±20
	4	284	−20±5	0.7±0.1	35
	5	295	−20±4	0.3±0.1	50
	6	302	−20±5	0.3±0.1	60
WR stars	3	50	−38±16	2.1±0.4	70±25
	4	67	−36±15	1.5±0.1	55
	5	82	−50±15	1.7±0.1	50
	6	96	−27±17	0.8±0.5	105
	7	100	−27±18	0.7±0.5	120
	8	109	−23±19	1.1±0.4	105
	9	118	−39±21	1.0±0.5	100
	10	124	−50±31	0.8±0.4	70
SNRs	3	47	31±16	0.5±1.0	125±25
	4	60	31±15	0.9±0.7	130
	5	73	36±19	0.7±0.6	165
	6	81	37±19	0.9±0.4	180
	7	90	38±17	0.7±0.4	185
	8	103	41±16	0.6±0.3	190
	9	111	40±17	0.6±0.3	165
	10	120	44±16	0.5±0.3	170
Combined data	3	358	−12±4	0.6±0.2	75±20
	4	411	−13±4	0.8±0.1	70
	5	450	−13±5	0.6±0.1	80
	6	479	−14±5	0.5±0.2	115
	7	492	−15±5	0.5±0.2	120
	8	514	−13±5	0.6±0.2	105
	9	531	−16±6	0.7±0.2	105
	10	546	−16±7	0.5±0.2	95

Table 2. Results (excluding objects within 1 kpc of the Sun) from least squares solutions for equation of plane of symmetry

Object	Distance limit (kpc)	Number of objects	a_0 (pc)	Inclination: Angle (θ) (degrees)	Inclination: Longitudinal direction of upward (degrees)
Open clusters	$1<r\leqq 6$	226	−22± 6	0.3±0.2	60
WR stars	$1<r\leqq 10$	119	−52±33	0.8±0.4	70
SNRs	$1<r\leqq 10$	109	45±18	0.5±0.2	170
Combined	$1<r\leqq 10$	454	−18± 9	0.5±0.2	95

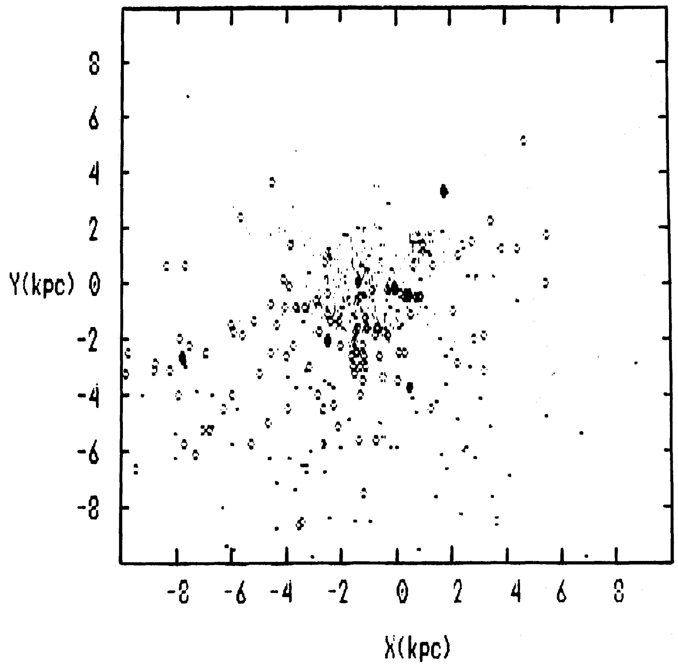

Fig. 5. The distribution of young clusters (|), WR stars (ϕ) and SNRs (□) projected on the galactic plane

on the galactic plane does not follow the expected spiral arm patterns. Janes and Adler (1982) have also concluded that the frequently designated spiral arms are the results of attempts to impose a pattern on a picture composed partly of selection effects caused by patchy distribution of absorption and partly of regions of recent star formation which may or may not follow a regular spiral pattern.

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