ASYMMETRIES IN THE GALACTIC DISTRIBUTION OF PULSARS

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The distribution of pulsars in galactocentric radius and z distance has been determined for opposite halves of the Galaxy, using data on 328 pulsars from three surveys. The distributions in galactocentric radius are found to be significantly different at positive and negative longitudes, although both show strong peaks between 5 and 6 kpc. There is also some indication that pulsars are located preferentially along spiral arms. Distributions in the z component of dispersion measure above and below the galactic plane also show asymmetry, with higher dispersion occurring at negative z. This may imply the existence of a narrow (∿ 100 pc), high electron density layer below the plane of the Sun in the inner galaxy.

INTRODUCTION

At present, 328 pulsars have been detected by various radio surveys. The three most sensitive searches, carried out at Arecibo (Hulse and Taylor 1974), Molonglo (Manchester et al. 1978) and NRAO (Damashek et al. 1978), have collectively detected all the pulsars discovered in previous less sensitive surveys plus a substantial number of new ones. The entire galactic plane and all of the sky except for the area south of $\delta = -85^o$ have been searched. With this larger, more complete sample, it has become possible to look at the galactic distribution of pulsars in more detail. Previous statistical analyses carried out on smaller samples of pulsars have assumed a distribution which is circularly symmetric about the galactic center and symmetric about the galactic plane. The present statistics allow one to drop these symmetry assumptions and thus to obtain more information on the pulsar distribution in the Galaxy. The results of this analysis reveal some significant asymmetries in both the galactocentric and the z distributions.

R DISTRIBUTION

To determine the galactocentric distribution from the observed distribution, one must correct for selection effects of the three surveys, which can all be determined to reasonable accuracy. The

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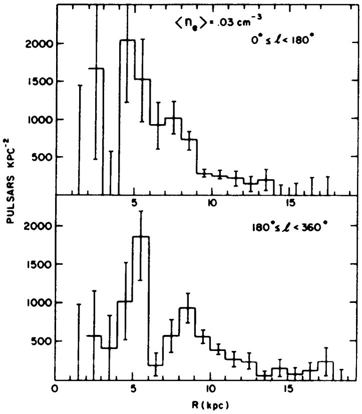

Figure 1: Surface density of pulsars versus galactocentric radius at positive and negative longitudes for a mean electron density of n_o = .03 cm^{-3}.

distribution of pulsars as a function of galactocentric radius, R, and luminosity, L, are solved for simultaneously using the method described by Taylor and Manchester (1977). Except where the distance is known independently from HI-absorption measurements, the distances are derived from the dispersion measures, which have been corrected for contributions from nearby HII regions (Prentice and ter Haar 1969). A simple exponential model for the electron density is assumed, with a mean density in the plane, n_o, and scale height h_e = 1000 pc.

The sample of 328 pulsars was divided into those with $0^o \leq \ell < 180^o$ (positive longitudes) and $180^o \leq \ell < 360^o$ (negative longitudes). These two groups contain respectively 155 and 161 pulsars having measured fluxes at 400 MHz. The R distributions for n_o = .03 cm^{-3}, in terms of the surface density of pulsars projected onto the galactic plane, are shown in Figure 1. The most obvious feature at both $+\ell$ and $-\ell$ is a peak at around 5 kpc, where surface densities are five times greater than those at the Sun. The densities seem to fall off inside 4 kpc, but the statistics are very poor and no firm conclusions can be made about pulsar densities in the inner galaxy. Even though the local density at $-\ell$ is about twice as large as at $+\ell$, the maximum densities near 5 kpc are very similar. The $-\ell$ distribution shows a secondary peak around 8 kpc and what appears to be a real deficit of pulsars between 6 and 7 kpc. It is tempting to associate this peak with the line of sight tangent to the Sagittarius arm which falls around 8 kpc. These distributions for n_o = .03 cm^{-3} bear a striking resemblance to those of other population I tracers such as CO emission (Gordon and Burton 1976, positive longitudes), galactic γ-ray emissivity (Stecker 1977), and ionized hydrogen (Lockman 1976).

The R distributions change drastically for other values of the mean electron density. The $+\ell$ distribution seems to be especially sensitive to the value of n_o assumed. The general trends are a much smaller density increase toward the galactic center for n_o = .02 cm^{-3} and a larger density increase for $n_o = .04\ \mathrm{cm}^{-3}$. The structure present in the $n_o = .03\ \mathrm{cm}^{-3}$ distributions tends to "wash out" when a higher or lower electron density is assumed. The total number of observable pulsars on each side of the Galaxy, $N_G^{\pm}$, calculated by integrating over the R distributions, come out equal within the errors only for $n_o = .03\ \mathrm{cm}^{-3}$, with $N_G^+ < N_G^-$ for $n_o = .02\ \mathrm{cm}^{-3}$ and $N_G^+ > N_G^-$ for $n_o = .04\ \mathrm{cm}^{-3}$. This result would seem to argue in favor of a mean electron density of $.03\ \mathrm{cm}^{-3}$, and the argument is reinforced when one considers the shape of the distributions and their strong similarities to other Population I tracers.

Z DISTRIBUTION

There is also an asymmetry in the distribution of pulsars in the z component of dispersion measure, DMsinb, above and below the plane. If an exponential model is used to describe both electrons and pulsars, the expected number of pulsars in each DMsinb interval can be calculated as a function of h_e, n_o, and the pulsar scale height, h_p (Taylor and Manchester 1977). A least squares fit of this function to the data (dispersion measures are those corrected for effects of nearby HII regions) for assumed values of $h_e = 1000$ pc and $n_o = .03\ \mathrm{cm}^{-3}$ yields a significantly larger value for the pulsar scale height below the plane (Fig. 2).

One explanation for this asymmetry, short of invoking real asymmetries in the pulsar distribution, is that the Sun is displaced north of the plane defined by the electron and pulsar distributions and that there is also a high density disk component of electrons in the plane. The resulting electron distribution would be:

$$n_e(z) = \begin{cases} n_o + n_e^D & |z+z_\odot| \leqq \Delta z \\ n_o \exp(-|z+z_\odot|/h_e) & |z+z_\odot| > \Delta z \end{cases}$$

where n_e^D and Δz are the density and half width of the disk component, $z_\odot$ is the Sun's distance above the plane, and $\Delta z \ll h_e$. The DMsinb distribution expected in this model can be fit to the data if values for n_o, h_e and $z_\odot$ are assumed. The values of n_e^D and Δz are then determined by requiring that the pulsar scale height be equal above and below the

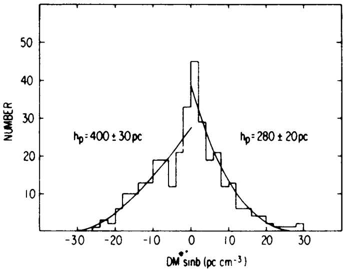

Figure 2: Distribution of pulsars in z component of dispersion measure and the least squares fits for + and − z. Dispersion measures have been corrected for effects of HII regions within 1 kpc of the Sun.

plane. The best fit to the uncorrected dispersion measure distribution for $n_o = .03\ \mathrm{cm}^{-3}$, $h_e = 1000$ pc and $z_\odot = 20$ pc, gives a disk half width $\Delta z = 40$ pc and density $n_e^D = 0.1\ \mathrm{cm}^{-3}$. The resulting pulsar scale height is 340 pc. If $z_\odot$ is left as a free parameter, then the general solution is $\Delta z = 2z_\odot$ and $n_e^D = 2\ \mathrm{pc\ cm}^{-3}/z_\odot$, with the same pulsar scale height.

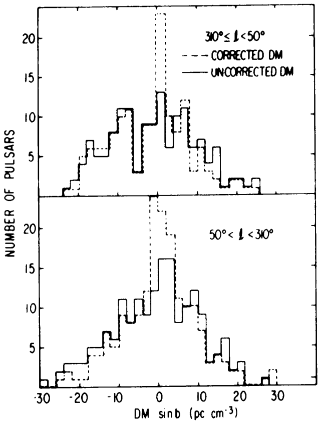

Figure 3: Corrected and uncorrected dispersion measure distributions for longitude intervals 310° ≦ ℓ ≦ 50° and 50° < ℓ < 310°.

There is evidence for a longitude dependence of this asymmetry. If, as shown in Figure 3, the pulsars are further divided into those with $|\ell| \leqq 50°$ and those with $|\ell| > 50°$, then the uncorrected DMsinb distributions show a slightly greater asymmetry toward the galactic center. However, if the dispersion measures are corrected for effects of local HII regions, then the asymmetry becomes more pronounced toward the galactic center and tends to disappear in the opposite direction. Apparently, the asymmetry in the $|\ell| \leqq 50°$ data is a large scale effect which is somewhat masked by local enhancements of electron density. The absence of a large scale asymmetry for $|\ell| > 50°$ implies that the disk component exists only inside the solar circle and probably has an R dependence. The local effects which show up in the uncorrected data suggest that the nearby HII regions have a distribution similar to Gould's Belt.

High electron densities in the inner galaxy have also been evidenced through distance determinations to pulsars using HI absorption measurements (Ables and Manchester 1976, Weisberg et al. 1980). The disk component needed here to explain the asymmetry in the z distribution would be consistent with those observations. Since the high density layer is so narrow and is probably R dependent, the mean electron density in the plane will be n_o in most directions. Dispersion measure derived distances will be strongly affected for only a small number of pulsars, and the R distribution should not change significantly.

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DISCUSSION

RICKETT: Have you included the pulsars discovered in the sensitive Arecibo survey in your analysis? These pulsars are concentrated over a narrow range of galactic longitudes and latitudes.

HARDING: Yes, they were included, but the increased sensitivity in that part of the sky covered by the survey was taken into account in calculating the distributions. It would be interesting, though, to see what effect removing the Arecibo pulsars from the sample has on the R distribution at positive longitudes.

FERGUSON: Do you find peaks in the longitude distribution of pulsars along tangents to the spiral arms?

HARDING: The longitude distribution shows broad peaks around 30° and 330° which would correspond to the 5 kpc peaks in the R distributions. The longitude resolution is not good enough to show a feature corresponding to the secondary peak at negative longitudes.