31. PULSAR DISTANCES, SPIRAL STRUCTURE AND THE INTERSTELLAR MEDIUM

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Abstract. The distances of all pulsars are calculated on the assumption that they are immersed in a uniform medium of average electron density 0.06 cm^{-3}. It then appears that the pulsars are concentrated towards the local and Sagittarius spiral features and that their mean height above the plane is consistent with that of known supernova remnants. The mean distances appear to be approximately correct, but individual distances are uncertain by about a factor of two. Evidence from radio continuum results supports this model of the ionized interstellar medium.

Several attempts have been made to estimate the distances of the pulsars using theoretically based models for the free electron distribution in the interstellar medium. A different approach is to make a crude first order approximation that the pulsars are immersed in a uniform dispersing medium, calculate the distances and directions of all pulsars on this assumption and compare the results with the properties of other galactic components, particularly supernova remnants, which would appear to have a common origin. Discrepancies revealed in this comparison may then be used to refine the assumed model of the interstellar medium and improve the distance scale.

For reasons discussed later I have taken the free electron density of the uniform medium to be $n_e = 0.06\ \mathrm{cm}^{-3}$. In Figure 1 the distribution of the 40 pulsars of known dispersion measure has been plotted as projected on to the galactic plane, on the assumption that their distances are directly proportional to their dispersion measures ($\int n_e\, \mathrm{d}l$), using the value of n_e above. The pulsar parameters are given in Table I.

If the pulsars and the dispersing medium are uniformly distributed throughout the galactic disc, it would be expected that the distribution in Figure 1 would show circular symmetry. It does not. We may disregard the absence of high dispersion pulsars in the smaller sector between $l^{\mathrm{II}} = 55°$ and $l^{\mathrm{II}} = 195°$ because this area is outside the field of view of the Molonglo Radio Telescope. This instrument is responsible for the discovery of all but one of the high dispersion pulsars in the remaining sector. However, in this larger sector the distribution also does not appear symmetric and displays features which appear to be closely related to the well known H I spiral pattern.

Practically all the pulsars may be associated with the two groupings shown on the diagram which reproduce quite well in direction and distance the local and Sagittarius spiral features. The high dispersion pulsars marking extensions of these features appear to be particularly significant. This grouping appears too striking to be ascribed to chance, and the crude first order approximation to the free electron distribution would seem to be more accurate than one might reasonably expect.

With this suggestion in mind let us look briefly at some of the relevant observed properties of the interstellar medium. Firstly, it has been shown by Gould (1969) that the free-free emission and absorption processes in the ionized medium agree with

Becker and Contopoulos (eds.), The Spiral Structure of Our Galaxy, 178–181.

TABLE I

The galactic coordinates and derived distances of 40 pulsars

Designation	l (°)	b (°)	$\int n_e \mathrm{d}l$ (cm^{-3} pc)	z[a] (pc)	d[a] (pc)
MP 0031	111	−69	12	−186	70
MP 0254	271	−55	10	−137	96
CP 0328	145	0	27	0	450
MP 0450	217	−34	25	−253	346
NP 0527	184	− 7	50	−102	830
NP 0532	185	− 6	56	− 98	930
PSR 0628−28	237.0	−16.7	10	− 48	160
MP 0736	254	− 9	100	−260	1640
CP 0808	140	+34	6	+ 56	83
AP 0823+26	197	+32	19	+168	268
PSR 0833−45	264	− 3	63	− 54	1050
CP 0834	219.7	+26.3	13	+ 95	194
MP 0835	260	0	120	0	2000
MP 0940	278	− 3	145	−127	2420
PP 0943	230	+45	9.5	+112	112
CP 0950	228.9	+43.7	3	+ 34	34
MP 0959	281	− 1	90	− 26	1500
CP 1133	241.9	+69.2	5	+ 78	30
MP 1154	297	− 0.1	270	− 8	4500
AP 1237+25	250	+86	8.5	+142	10
MP 1240	302.0	− 1.0	220	− 64	3660
MP 1426	313	− 6	60	−104	1000
MP 1449	315.3	− 5.3	90	−138	1500
PSR 1451−68	313.9	− 8.6	12	− 23	198
HP 1507	90	+53	15.5.	+206	234
MP 1530	326	+ 2	20	+ 12	332
AP 1541+9	18	+46	35	+420	405
MP 1642	15	+26	40	+282	600
MP 1706	7	+15	10	+ 43	161
MP 1727	341	− 9	140	−365	2420
MP 1747	344	−11	40	−128	655
PSR 1749−28	1.6	− 1.0	51	− 15	850
MP 1818	25	+ 5	70	+103	1160
MP 1911	31	+ 7	75	+152	1240
CP 1919	55.8	+ 3.5	12.6	+ 13	210
PSR 1929+10	48	− 4	8	− 9	134
JP 1933+16	52	− 2	143	− 87	2500
AP 2015+28	68	− 4	14	− 16	233
PSR 2045−16	30.5	−33.1	11	−105	162
PSR 2218+47	98	− 8	44	−102	726

[a] In the final columns are listed $z = \dfrac{\int n_e \mathrm{d}l}{0.06} \sin b$; and $d = \dfrac{\int n_e \mathrm{d}l}{0.06} \cos b$

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radio observations of emission at high radio frequencies and absorption at low frequencies if an electron temperature of about 6000 K is assumed. There is no evidence for a significant component of low temperature electrons produced by cosmic ray ionization, except possibly in some directions of high H I concentration.

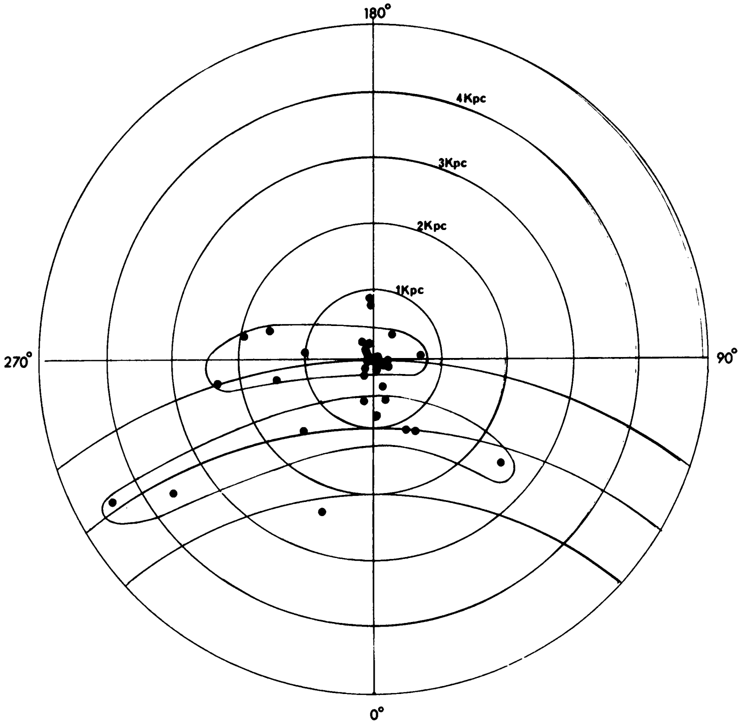

Fig. 1. The distribution of pulsars in the galactic plane on the assumption of a uniform dispersing medium of density $\langle n_e \rangle = 0.06\ \mathrm{cm}^{-3}$.

Gould also finds that the local value of the mean square electron density $\langle n_e^2 \rangle \simeq 0.06\ \mathrm{cm}^{-6}$. However, we have seen that a plausible distribution of pulsars is yielded by $\langle n_e \rangle = 0.06\ \mathrm{cm}^{-3}$ or $\langle n_e \rangle^2 = 0.0036\ \mathrm{cm}^{-6}$. Distances derived from this value of n_e are also consistent with a common origin for pulsars and supernova remnants. The former have a mean height above the plane, $\langle |z| \rangle \simeq 110$ pc, while for the supernova remnants in the same part of the Galaxy $\langle |z| \rangle \simeq 85$ pc according to a recent tabulation of Milne (1969). In view of the uncertainty in both distance scales the agreement is good and the distributions in $|z|$ otherwise appear very similar. The identifications of the Vela (PSR 0835-45) and Crab (NP 0532) pulsars with the corresponding supernova remnants yield $\langle n_e \rangle \simeq 0.1$ and $\langle n_e \rangle \simeq 0.03$ respectively. Accordingly, there appears little doubt that, in the interstellar medium, $\langle n_e^2 \rangle \gg \langle n_e \rangle^2$. This inequality implies that the distribution of the ionized medium is very irregular, but we have seen that the dispersion measures appear to give a good indication of pulsar distances. We must suppose that the free-free processes ($\propto \langle n_e^2 \rangle$) are dominated by dense clouds and the

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pulsar dispersions ($\propto\langle n_e\rangle$) by a much more uniform tenuous intercloud medium. The temperature of the ionized intercloud medium cannot be substantially less than that of the clouds or its effects would be more apparent in the low frequency absorption measurements. Thus ionization by dilute UV radiation seems very likely.

Further evidence for a hot intercloud medium comes from some recent H-line observations of Radhakrishnan and Murray (1969), who find that the intercloud hydrogen atoms are at a very much higher spin temperature than those in the H I clouds responsible for the greater part of the observed galactic emission and absorption of the H-line. In one direction at least the spin temperature exceeds 1000 K.

A plasma with $\langle n_e\rangle \simeq 0.06\,\text{cm}^{-3}$ and $T \simeq 6000\,\text{K}$ is unlikely to be closely confined to the galactic plane, certainly not if there is any tendency towards equipartition of turbulent energies. Ultraviolet ionization would be possible to great heights and, in general, one might expect such a plasma to exist at heights at least as great as those to which the magnetic fields extend. A measure of this extent is given by the galactic distribution of synchrotron radiation which is much wider than that of the H-line emission, for which the mean height $\langle |z| \rangle$ is similar to that of the pulsars. Accordingly, the assumption that all pulsars lie within the dispersing layer appears to be very reasonable. If this were not so it would be difficult to explain the resulting very high z distances of some of the pulsars.

A better fit to the Sagittarius arm distance and the Vela and Crab supernovae is obtained if it is assumed that, within the spiral arms, the mean electron density is greater than $0.06\,\text{cm}^{-3}$ and, between the arms, it is less. However, the small amount of available data does not appear to justify the assignment of actual numbers at this stage. Even if improved statistical distances can be obtained there appears little prospect of appreciably reducing the uncertainty in the distances of individual pulsars, indeed the only refinement which appears justifiable is an allowance for the dispersion measure of known H II regions when they lie in front of a pulsar. Only two of the pulsars, PSR 0833-45 and MP 0736, are obviously affected but the H II region has low surface brightness and is believed to be very close so that corrections should not be large. Quantitative information is not at present available.

To conclude, it appears that the simplest possible model for the dispersing medium yields distances which are probably individually accurate to a factor of two and yields the pulsar statistics with much greater accuracy. There is a striking association of a group of ten pulsars with the accepted location of the Sagittarius spiral arm. The great majority of the remainder appears to be associated with the local spiral feature. This interpretation of the data follows from the assumption of a fairly uniform distribution of free electrons extending to much greater heights above the plane than the dense H I clouds.

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