PULSARS AS A GALACTIC POPULATION

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Recent pulsar surveys have increased the number of known pulsars to well over 300, and many of them lie at distances of several kpc or more from the sun. The distribution of pulsars with respect to distance from the galactic center is similar to other population I material such as HII regions, supernova remnants, and carbon monoxide gas, but the disk thickness of the pulsar distribution is rather greater, with $<|z|>\simeq 350$ pc. Statistical analysis suggests that the total number of active pulsars in the Galaxy is a half million or more, and because kinematic arguments require the active lifetimes of pulsars to be $\lesssim 5\times 10^6$ years, it follows that the birthrate required to maintain the observed population is one pulsar every ~10 years (or less) in the Galaxy.

This contribution is intended to serve as an update on what is known about the galactic distribution of pulsars. This subject has received much attention in the past year or so (see for example, Lande & Stephens 1977; Davies, Lyne & Seiradakis 1977; Taylor & Manchester 1977; Manchester & Taylor 1977). All of these studies have concluded that the number of pulsars in the Galaxy, considered together with the estimated active lifetime of pulsars, requires a pulsar birthrate of one every ~6 years in the Galaxy. This computed mean interval between births is somewhat less than (but not grossly inconsistent with) recent estimates of the rate of occurrence of galactic supernova outbursts (Tammann 1977).

In the past 18 months, the number of known pulsars has increased from 148 to 320, thanks largely to 155 pulsars discovered in a sensitive, systematic survey of the entire sky between declinations -85° and +20°, carried out with the Mills Cross antenna at Molonglo, Australia (Manchester, Lyne, Taylor, Durdin, Large & Little 1978). A complementary survey of the northern sky is now underway, and has detected 17 new pulsars (Damashek, Taylor & Hulse 1978). The distribution of all presently known pulsars is shown in equal area galactic coordinates in Figure 1. This picture is unlikely to change markedly in the foreseeable future, because of sensitivity limitations of existing radio telescopes, and it is interesting to note in passing that spiral structure in the pulsar

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distribution is now suggested by a clumping of pulsars near the "tangential" longitudes 280°, 310°, and 330°.

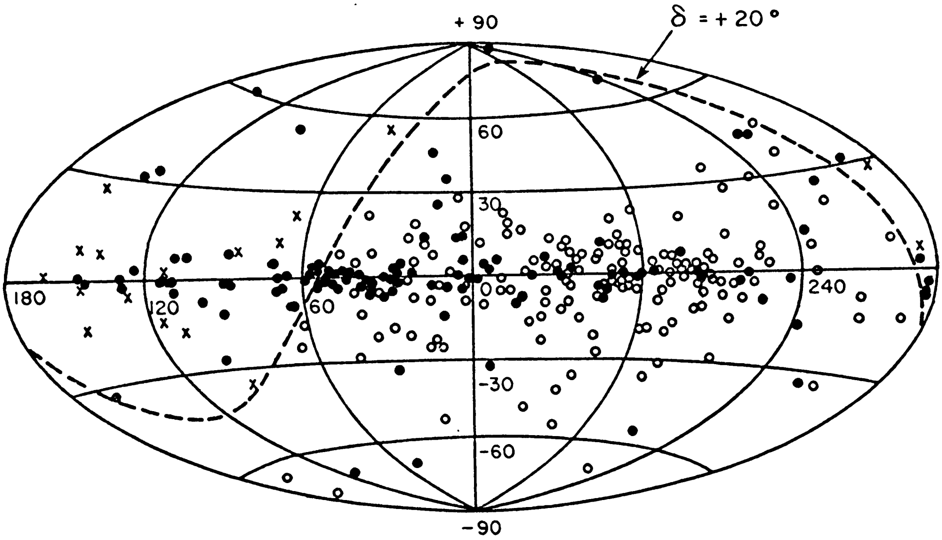

Figure 1. The distribution in galactic coordinates of all pulsars known as of June 1978. Sources newly discovered in the second Molonglo survey (Manchester et al 1978) are denoted by open circles, and those discovered by Damashek, Taylor and Hulse (1978) by crosses. In crowded regions, a few symbols have been omitted for clarity.

A three-dimensional description of the galactic pulsar distribution requires knowledge of pulsar distances. Dispersion measure (the integral of electron density n_e along the line of sight) is for pulsars a directly measurable quantity that is approximately proportional to distance, because n_e has been shown to be reasonably constant throughout much of the galactic disk (see, for example, Ables and Manchester 1976). Therefore pulsar distances can be estimated directly from the observed dispersion measures; such distances are thought to be statistically reliable to within 20 or 30 percent, although individual distances may be in error by a factor of 2 or more because of excess dispersion caused by intervening HII regions.

Comparison of observed pulsar flux densities with the estimated distances shows that pulsar luminosities (crudely defined for this purpose as $L=Sd^2$, where S represents flux density and d represents distance) range over at least 6 orders of magnitude. The observed distribution of luminosities is such that most observed pulsars lie in the medium-to-high range, but consideration of the volumes of space effectively surveyed for different luminosities shows that far more pulsars exist with low L than high L. In fact, the pulsar luminosity function is approximately a power law, with the number of pulsars per logarithmic luminosity interval inversely proportional to luminosity.

Analysis of the pulsar distribution in terms of distance R from the galactic center shows a curve that increases sharply inside the solar circle, reaching a peak at 4 to 6 kpc from the galactic center. The radial distribution curve is very similar to those obtained for the distributions of ionized hydrogen, supernova remnants, carbon monoxide gas, and γ-radiation, and all of them differ markedly from the neutral hydrogen distribution (see Burton 1976 for a review). On the other hand, the pulsar distribution in height above the galactic plane, z, is rather different from the other population I constituents. Whereas the scale height of the other types of material mentioned above is $\lesssim$100 pc, we find the pulsar scale height to be approximately 350 pc. This difference is a direct result of the high velocities that pulsars acquire at birth: proper motion studies show that pulsar peculiar velocities are typically $\gtrsim$200 km s^{-1} (see for example, Taylor & Manchester 1977), and thus,

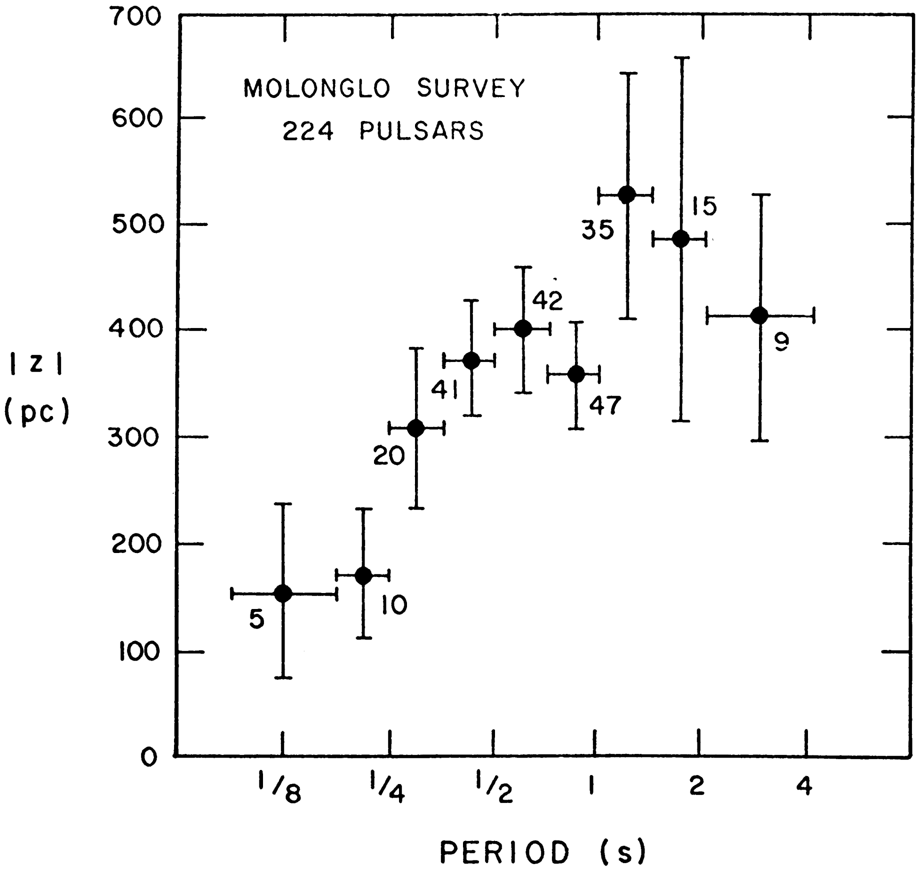

Figure 2. Average distance of pulsars from the galactic plane, plotted as a function of period, for nine period ranges.

although most pulsars are no doubt born at heights $|z|\lesssim 150$ pc, they disperse to considerably greater distances from the plane within a few million years. Some new direct evidence of this effect is illustrated in Figure 2, which is based on the uniform sample of 224 pulsars detected in the second Molonglo pulsar survey. The short-period pulsars, which are known to be the younger ones, have a markedly narrower z-distribution than their older cousins.

The thickness of the pulsar disk, together with the observed pulsar velocities, yields an estimate of the mean pulsar lifetime, $<|z|>/<|v_z|>$ ≈ 350 pc/100 km $s^{-1} \approx 3 \times 10^6$ years. Integration of the density distributions with respect to R and z suggests a total of at least 10^5 potentially observable pulsars in the Galaxy at the present time. To maintain such a steady-state population would require a pulsar birth at least every ~30 years, and if beaming effects make some ~80% of pulsars unobservable from Earth, the required birthrate would increase to one every ~6 years or so. The well calibrated nature of the recent pulsar surveys will allow the uncertainties on these estimates to be reduced significantly, and work is now underway on a full statistical analysis of the new data.

REFERENCES

Lande, K., and Stephens, W.E.: 1977, Astrophys. Space. Sci., 49, pp. 169-177.
Davies, J.G., Lyne, A.G., and Seiradakis, J.H.: 1977, Mon. Not. Roy. Astron. Soc. 179, pp. 635-650.
Taylor, J.H., and Manchester, R.N.: 1977, Astrophys. J. 215, pp. 885-896.
Manchester, R.N., and Taylor, J.H.: 1977, "Pulsars," W.H. Freeman & Co., San Francisco.
Tammann, G.A.: 1977, Annals N.Y. Acad. Sci. 302, pp. 61-80.
Manchester, R.N., Lyne, A.G., Taylor, J.H., Durdin, J.M., Large, M.I., and Little, A.G.: 1978, Mon. Not. Roy. Astron. Soc. (in press).
Damashek, M., Taylor, J.H., and Hulse, R.A.: 1978, Astrophys. J. (Letters) (in press).
Ables, J.G., and Manchester, R.N.: 1976, Astron. Astrophys. 50, pp. 177-184.
Burton, W.B.: 1976, Ann. Rev. Astron. Astrophys. 14, pp. 279-306.

DISCUSSION

Tinsley: The expected relative numbers of SNR and pulsars depend of course on their relative lifetimes. What do you find for the mean pulsar lifetime? And how does the pulsar birthrate then compare with the formation rate of SNR?

Taylor: The most assumption-free estimate of the average pulsar lifetime is based on kinematics: the observed z-distribution of pulsars is consistent with the observed proper motion velocities of ∿100 km s^{-1} only if the mean age is not more than a few million years. The corresponding pulsar birthrate (if only ∿20% of pulsars are potentially observable because of beaming effects) is one every five years or less. Only a small fraction of pulsar-producing events can result in long-lived supernova remnants.

Innanen: Is the decline in pulsar density with galactocentric distance exponential or a power law?

Taylor: The experimental uncertainties are not small enough to warrant any conclusions beyond the simple statement that the density distribution falls off rather sharply over the range 5 to 10 kpc from the galactic center.

Stecker: Some workers, in analyzing the radial distribution of SN remnants in the Galaxy, have found a monotonic increase all the way to the galactic center; other analyses have yielded a radial distribution peaking in the 5-kpc annulus similar to the pulsar distribution shown by Dr. Taylor. Do you have any comments on this apparent discrepancy?

Wielebinski: It is difficult to see SNR in the direction of the center. Maybe we should recall Berkhuijsen's work on M31: the SNR distribution in M31 does not follow the distribution of the ratio continuum radiation.

Mathewson: The apparent discrepancy between the number of pulsars and the number of supernova remnants in the Galaxy would be removed if there was a region of low electron density in the local neighborhood.

Taylor: I agree completely. The distance scale for nearby pulsars is crucial in this regard; some direct parallax measurements would be nice.

Terzian: We should remind ourselves that $\langle n_e \rangle$ is not really constant in all directions in the Galaxy, consequently distances of pulsars derived on the assumption of constant $\langle n_e \rangle$, say ∿0.03, can have errors of factors of 3 or more. Similarly the derived luminosities and $|z|$-distribution will have large errors.

Taylor: I agree that individual pulsar distances estimated from dispersion measures may sometimes be in error by a factor of 2 or 3. Statistically, however, I believe that the distance scale is much better than this, and that the composite distribution functions are reasonably well determined.