THE BIRTHPLACES OF PULSARS

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Abstract. With the refinement of the estimates of electron density in the Galaxy it is clear that pulsars have *z* distances away from the galactic plane of a few hundred parsec. There is now a very strong indication that young pulsars lie at small *z* distances, suggesting that pulsars originate in a small *z* population and are given velocities of about 100 km s^{-1} at birth.

Earlier in this symposium it was demonstrated that the *z* distribution of pulsars is well-defined and substantially independent of distance from the Sun out to at least 5 kpc. The electron distribution is smooth enough for the dispersion measure to be quite a good measure of distance, and the mean electron density in the plane cannot be far different from 0.03 cm^{-3}. Figure 1 shows the distribution of pulsars off the plane in units of dispersion measure. The mean distance off the plane is about seven of these units, or 230 pc using a value of 0.03 for the mean electron density.

How did they get there? Do pulsars originate from a stellar population having a similar distribution to the one we see now, or from a much narrower one? The ideas

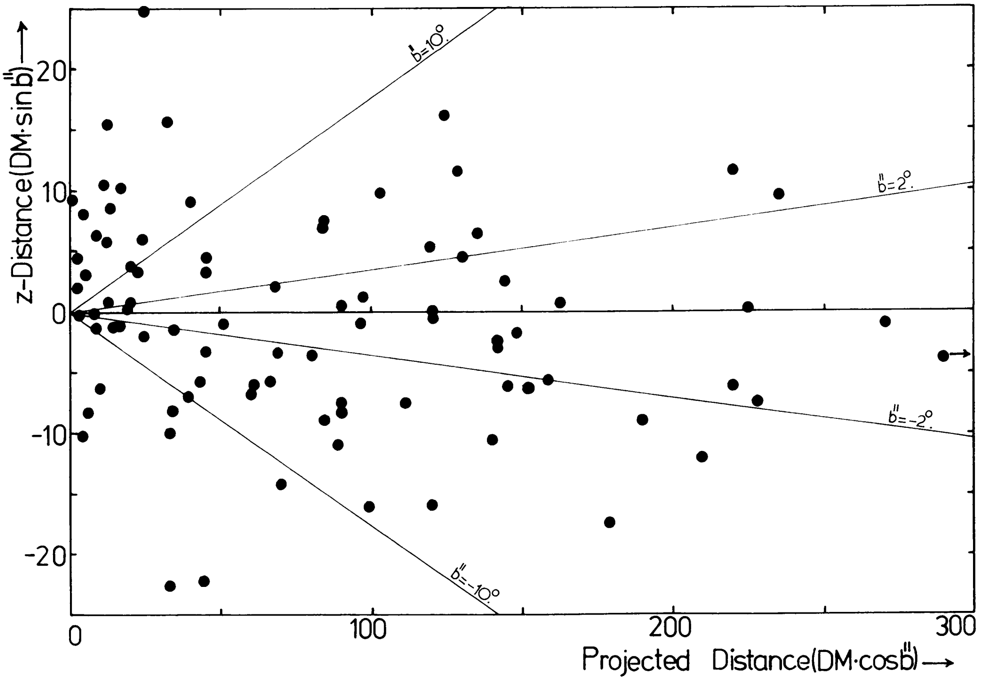

Fig. 1. The derived *z* distances of pulsars plotted against the distances along the galactic plane from the Sun. The units of both quantities are in units of dispersion measure, pc cm^{-3}.

F. J. Kerr and S. C. Simonson, III (eds.), Galactic Radio Astronomy, 369–372.

I am going to present are not entirely new (see, for instance, Gold and Newman, 1970 and Prentice, 1970) but I think we can now investigate them more critically with the present data.

The notion that pulsars originated from very close to the plane can be investigated from the ages of pulsars, young pulsars appearing closer to the plane than old ones. The age as measured from the derivative of the period is available at the moment only for a minority of pulsars. However, we can use period as a crude measure of age. If we plot a pulsar in a graph of period, P, against time, t, it will follow one of a family of curves. These curves will be parabolae in the case of magnetic braking and will take the general form $P \propto t^{1/2}$ as indicated in Figure 2a. Which of the curves a pulsar follows is determined by the strength of the braking.

If the pulsar at birth is given a kick, for instance due either to the disruption of a binary system or an asymmetric supernova explosion, the velocity normal to the plane will remain essentially constant during the lifetime of the pulsar, since this lifetime of about 10^7 yr is small compared with the period of oscillation across the plane (Oort, 1965). Thus z would be a crude measure of time, the crudeness depending upon the dispersion in velocity and direction of the velocity.

Because of the dispersion in braking, velocity and direction we should not expect to find a very strong relationship. Whether the effect exists can be judged from Figure 2b, which shows period plotted against z distance for the 100 pulsars which have reliable dispersion measurements. The mean z of the dozen or so shortest period objects is about 3 pc cm^{-3} while that of the rest is something over 7 pc cm^{-3}. I think that this lends some support to the model I have described, but the evidence is by no means concrete. By early next year, period derivatives for the majority of pulsars

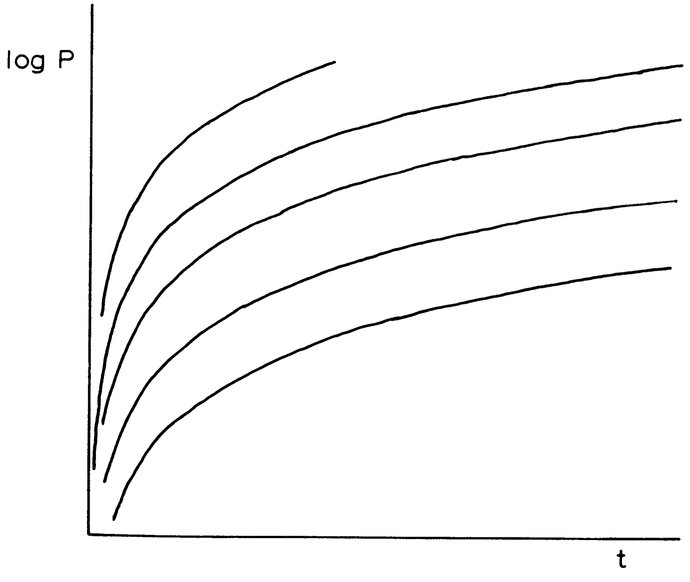

Fig. 2a. A schematic evolution of the periods of pulsars with time.

https://doi.org/10.1017/S0074180900026681 Published online by Cambridge University Press

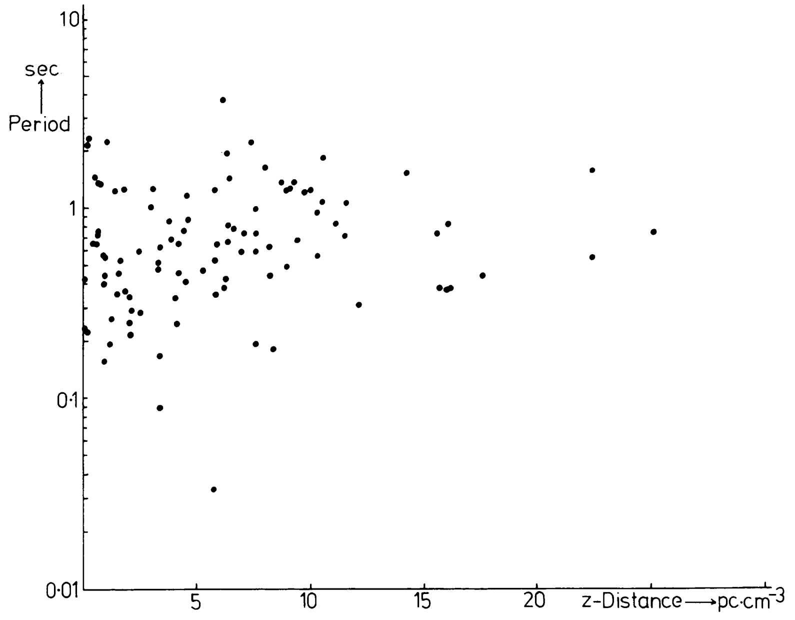

Fig. 2b. The observed distribution of pulsars in period and z distance.

should be available and this should remove one of the main decorrelating influences in this diagram.

This suggests that the pulsars are born in a population having a scale height of very much less than the estimated 230 pc of the observed distribution. Possibly they originate in population I objects. Supernova remnants (Poveda and Woltjer, 1968) as well as many other populations have scale heights of less than 100 pc. The distribution in longitude lends some support to this.

Let me pursue the argument further and now assume that pulsars are born on the plane and attempt to compute the velocity they must have in order to have reached their present heights off the plane during their lifetime as pulsars. The mean age of the two dozen or so objects with measured derivatives is about 3×10^6 yr. This leads to an estimate of the mean velocity normal to the plane of 70 km s^{-1}. Provided that the velocity distribution is isotropic in space, then from the Earth we will observe pulsars to have velocities normal to the line of sight of 95 km s^{-1} and total mean velocities of 125 km s^{-1}.

That pulsars may have high velocities has been suggested by Gunn and Ostriker (1970) and by Prentice (1970) and others. The velocities of the order of 100 km s^{-1} suggested here are an order of magnitude lower than suggested by these authors. However, they are consistent with estimates of velocity from observations of the interstellar scintillation patterns (Rickett, 1970; Downs and Reichley, 1971; Ewing *et al.*, 1970; Lang and Rickett, 1970; Galt and Lyne, 1972).

The present indications are therefore that the pulsars originate in a small z

https://doi.org/10.1017/S0074180900026681 Published online by Cambridge University Press

distance galactic population, possibly type II supernovae, and are given velocities of the order of 100 km s^{-1} at birth.

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DISCUSSION

Sutton: For the 24 or so pulsars with measured d*P*/d*t*, have you made any preliminary diagrams of age vs *z* distance?

Lyne: No; however, a few months ago with 18 pulsars there was only a very weak effect in such a diagram.

Milne: When you extrapolate these values back toward the plane, do you find a supernova remnant there? For example, IC 443 – is the pulsar moving in the right direction?

Lyne: From this data all we know is the component of velocity normal to the plane, and normal to the line of sight. We don't know what the other two components are, so it is difficult to do that. I'm not saying that the velocities are always moving away from the plane. The simple assumption that I've made here is that they were born at zero height off the plane. In fact, they are presumably born a few tens of parsecs away from the plane.

Smith: You might make it clear though, that it is possible to measure the velocities, including the velocity vector. Exactly what you suggest could be done for IC 443. I made that remark earlier on.

Van Woerden: Goss and Schwarz (*Nature Phys. Sci.* **234** (1971), 52) have shown that the weak extended radio source near pulsar CP 1919 has a shell structure. They now find, from more sensitive observations, a second shell source overlapping the first and again having the pulsar close to its edge. The discrepancies of age and of distance remain as severe as they were. Maybe several events have happened in this region?