Part V
X-ray, γ-ray and millisecond pulsars

Wednesday morning. Session Chair: Wolfgang Kundt

- How do the particular properties of X-ray, γ-ray, and millisecond pulsars illuminate radio-frequency emission models?

    * Observations of the profile polarization characteristics of fast pulsars and millisecond pulsars.
    * Observations of pulse-modulation phenomena in fast and millisecond pulsars.
    * X-ray and Gamma-ray observations of radio pulsars; physical models of the X-ray and Gamma-ray emission of radio pulsars.
    * Thermal X-ray observations of pulsar polar caps.
    * Similarities and differences between the emission of fast and millisecond pulsars and that of slower pulsars.
    * Particular magnetospheric models and emission mechanisms pertaining to fast and millisecond pulsars.
    * General relativistic effects on the emission characteristics of pulsars.

This session was started by a review by G. S. Bisnovatyi-Kogan, but the paper was not submitted for publication in the Proceedings.

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ARE MILLISECOND PULSARS DIFFERENT THAN "NORMAL" PULSARS?

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Abstract

While millisecond pulsars have very different period parameters and a different evolutionary history compared to "normal" pulsars, the properties of their pulsed emission are remarkably similar to those of normal pulsars.

Are millisecond pulsars different than "normal" pulsars? The answer clearly is YES—their periods are shorter! However, there is more to this than is implied by this somewhat facetious answer. Not only are the periods shorter, but the rate at which they are increasing is much less. As illustrated in figure 1, millisecond pulsars occupy a distinct region in the period–period derivative (P–$\dot{P}$) plane. Young pulsars, and in particular those associated with supernova remnants, also are isolated on this diagram. As pulsars age, they move to the right and downward along lines of constant $P\dot{P}$ if their magnetic fields do not decay; they drop below these lines if the fields do decay. So the position on the P–$\dot{P}$ plane of the great bulk of pulsars can be accounted for by simple period evolution of young pulsars. However it is clear that millisecond pulsars must have a different evolutionary path. A clue to the probable nature of this path is provided by the observation that, compared to normal pulsars, a high proportion of millisecond pulsars are members of binary systems. Nearly half of the known millisecond pulsars are members of binary systems whereas only about one percent of normal pulsars are binary. The proportion of binary millisecond pulsars in the galactic population is likely to be even higher since observational selection discriminates against their detection. It is likely that millisecond pulsars get

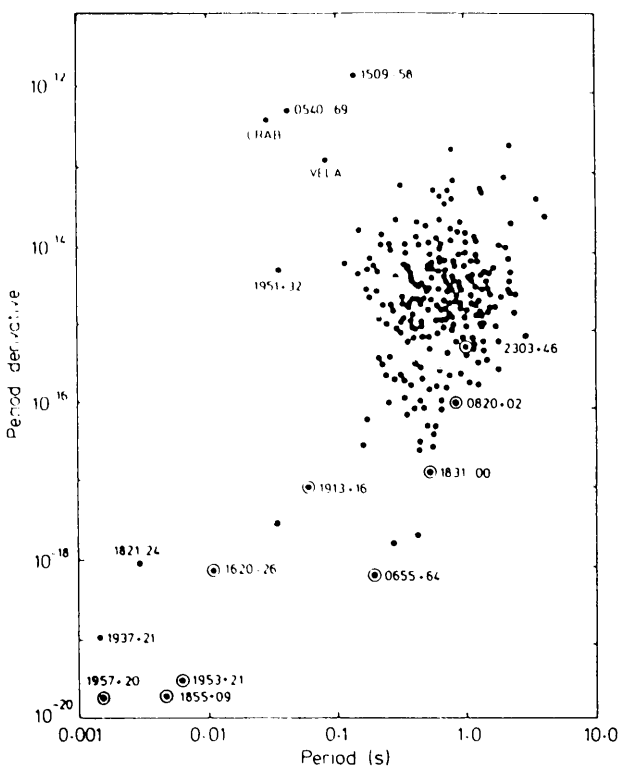

Figure 1 Distribution of pulsars on the P–$\dot{P}$ plane. Pulsars which are members of a binary system are indicated by a circle around the point. The five named pulsars in the upper-left portion of the diagram are those with a well-established association with a supernova remnant.

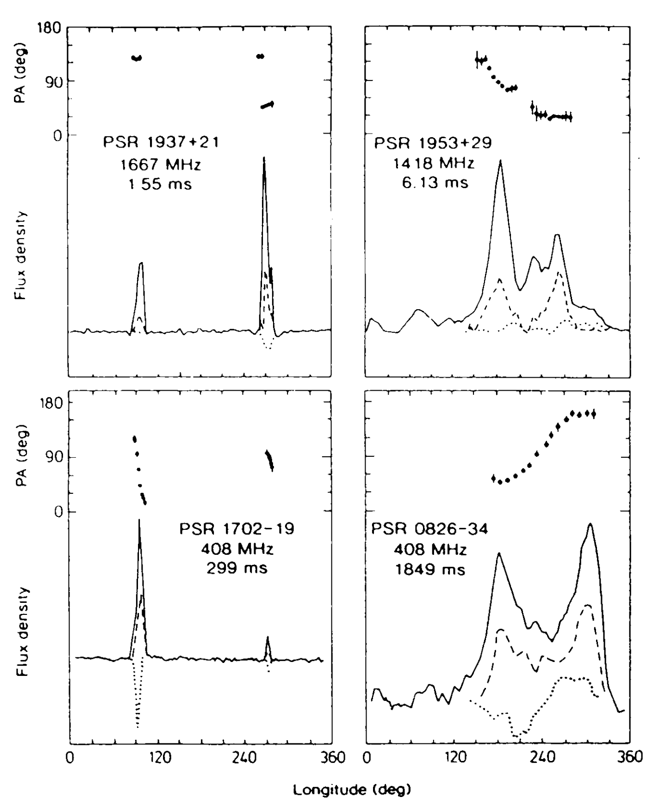

Figure 2 Integrated pulse profiles and polarization parameters for two millisecond pulsars, PSR 1937+21 and PSR 1953+29 (adapted from Thorsett and Stinebring 1990) and for two longer period pulsars, PSR 1702−19 and PSR 0826−34 (adapted from Lyne and Manchester 1988).

their rapid spin rate by accretion of material from a companion star. (See van den Heuvel 1984, for a review.)

Perhaps a more relevant question to the subject of this Colloquium is as follows: Is the pulse emission mechanism in millisecond pulsars different to that in normal pulsars? Here, the evidence is that the answer is NO. Since the radius of the light cylinder for PSR 1937+21 is a factor of 3000 smaller than that of the longest-period pulsars, this implies a remarkable insensitivity of the emission process to conditions at the light cylinder.

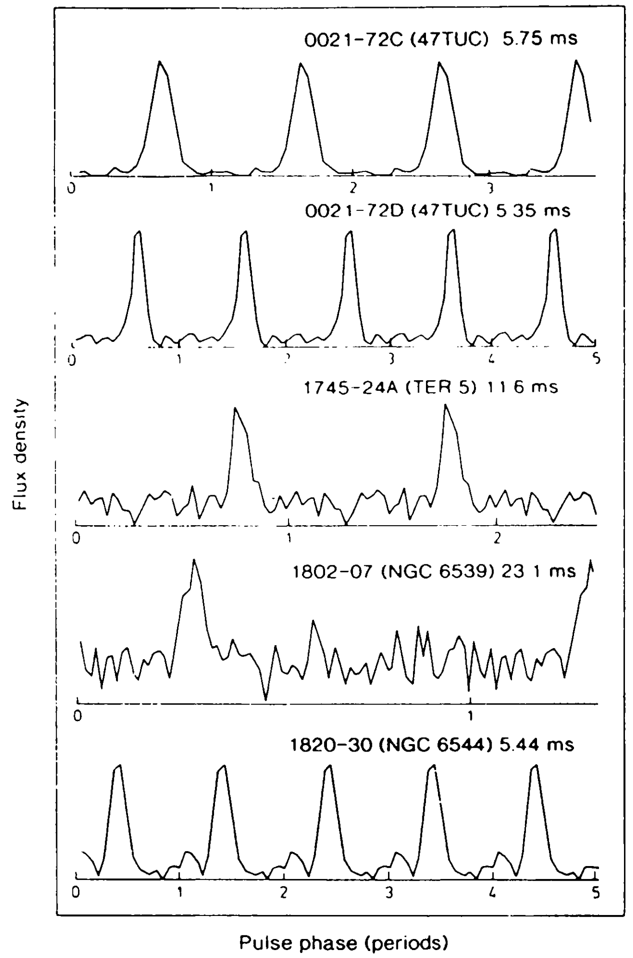

Figure 3 Integrated pulse profiles of five recently discovered globular cluster pulsars, each of which has a pulse period of less than 25 ms. None of these pulsars has an interpulse.

Most millisecond pulsars are too weak for detailed study of individual pulses, so the evidence comes mainly from integrated pulse properties. What is this evidence? Firstly, integrated pulse profiles for millisecond pulsars have the same general character as those for normal pulsars. This is illustrated in figure 2 in which the pulse profiles and polarization parameters for two millisecond pulsars, PSR 1937+21 and PSR 1953+29, are compared with those for two "normal" pulsars. From the pulse shape and polarization data alone, it

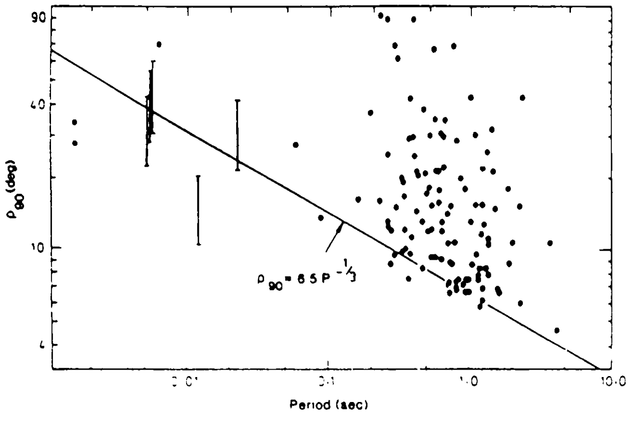

Figure 4 Period-pulse width relation from Lyne and Manchester (1988) supplemented by pulse widths for five recently discovered millisecond pulsars. The new pulsars are represented by a vertical bar with the top of the bar being at the observed pulse width and the lower end a factor of two down, approximating the uncertainty due to the unknown angle between the observer's sight line and the pulsar magnetic axis.

would not be possible to tell which of these pulsars has a period in the millisecond range. The millisecond pulsars exhibit all the properties familiar to us from the study of longer period pulsars. Some pulse profiles are wide, some are narrow. Some pulsars have interpulses, some do not. Profiles are predominantly linearly polarized with a sweep of position angle through the pulse. The orthogonal polarization flip seen in the main pulse of PSR 1937+21 is identical in character to those seen in many longer period pulsars.

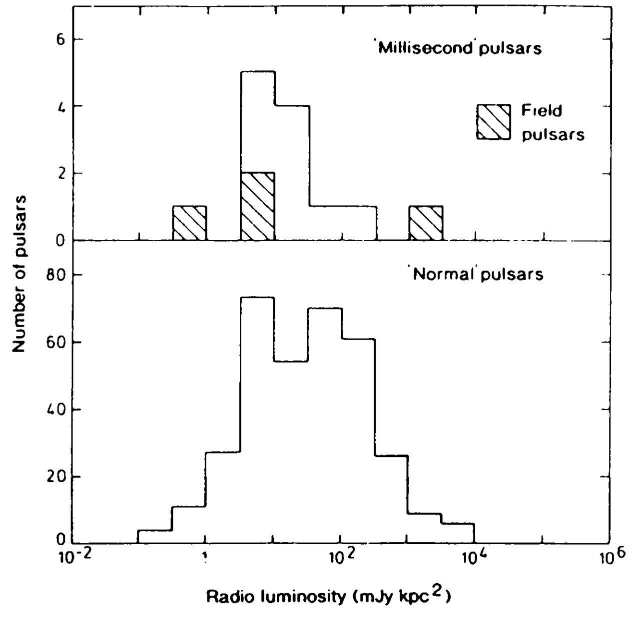

Figure 5 Distribution of observed radio luminosities (approximated by $S\,d^2$ where S is the mean pulse flux density at about 400 MHz and d is the pulsar distance, in most cases estimated from the dispersion measure) for pulsars with period less than 25 ms (top) and longer period pulsars (bottom, from Lyne, Manchester and Taylor 1985).

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While the two pulsars with the shortest known periods (PSR 1937+21 and PSR 1957+20) have strong interpulses and the proportion of interpulses is higher among millisecond pulsars than in normal pulsars, recent discoveries have shown that the proportion is not as high as was first thought. Mean pulse profiles for five recently discovered millisecond pulsars are shown in figure 3. None of these pulsars has a detectable interpulse. Of the 13 pulsars with periods less than 25 ms and with published pulse profiles, only four have interpulses. The millisecond pulsars, on average, have wider pulse profiles than longer period pulsars. However, as shown in figure 4, these pulse widths are generally consistent with the $P^{-1/3}$ relation found by Lyne and Manchester (1988). This suggests that the altitude of the pulse-emission region above the polar cap is roughly independent of period and that the increase in pulse width is due to the wider opening angle of the open field lines at that altitude.

Figure 5 shows that the distribution of observed radio pulse luminosities for millisecond pulsars covers the same range as that for longer period pulsars. The distribution for millisecond pulsars is affected by the fact that most of these pulsars have been found in deep searches for pulsars in globular clusters. Searches for "field" or galactic millisecond pulsars have so far covered only a small proportion of the celestial sphere, so low luminosity pulsars are under-represented in the top part of the figure. So far only a few millisecond pulsars have reliable spectral index values. These values tend to be at the steep (more negative) end of the distribution for normal pulsars but not outside it.

In summary, the observed properties of the pulsed radio emission from millisecond pulsars are remarkably similar to those of longer period pulsars and there is no reason to suggest that the pulse emission mechanism in millisecond pulsars is fundamentally different to that in longer period pulsars.