THE LOCATION, SPECTRUM AND BEAMWIDTH OF PULSAR RADIATION FROM POLAR CAP MODELS

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In the rotating "lighthouse" interpretation of pulsars, the average radio pulse profile is generally assumed to be a section through the average beam shape radiated by a spinning neutron star. The radio emission received in any one particular period usually differs markedly from the average profile. Such variations have been classified as subpulses ($\sim$ 3 ms) and micropulses ($\sim$ .3 ms); see Cordes (1979) for examples. However, there is not general agreement as to whether these variations are caused by the rotation of a steady narrow beam or by temporal variations of a wider beam. We first discuss these questions independently of the emitting particle location, and then apply them to a particular model.

We review evidence in (a)-(d) that subpulses are due to angular beams and in (e) that micropulses are due to temporal modulation:
(a) The widths of the average profiles typically vary as $\nu^{-.3\pm.2}$ over 100-1000 MHz, showing that average beamwidths vary in the same way. Bartel et al. (1980) show that subpulse widths and separations (P_2) also tend to vary in the same way. This similarity suggests that subpulses are narrower beams which lie within the average beamshape and share its frequency dependence. (b) Although a vibrating model for P_2 can be constructed, the drifting subpulse bands rather suggest beams which drift through the average beam (see also Bartel et al. 1980).
(c) Excluding the 90° flips, the polarization angle normally continues its steady rotation across individual subpulses, also implying a beamed origin. (d) In PSR 1133+16 Boriakoff (1980) finds that individual subpulses are wideband and that their separations take part in the $\nu^{-.3}$ scaling; again a beamed origin for the subpulse is implied. (e) In contrast to (d) we have found that the separation of micropulses from PSR 0950+08 do not take part in the widening of the average profile. We conclude that the micropulses are thus temporal variations of the subpulse and average beams.

We now narrow the discussion to models involving plasma flow from the "polar cap". This does not exclude "light cylinder" models, but similar arguments should be applied to them. We adopt the general

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geometry of the polar cap models (e.g. Ruderman and Sutherland 1975) in which plasma flows relativistically out along the "open" field lines. Emission is by curvature radiation.

In order to explain the frequency dependence of the average beam-shape two extreme hypotheses can be advanced. In radius-to-frequency mapping the emission is concentrated near the edge of the flaring cone of open field lines and at a radial distance which varies with frequency $r(\nu) \propto \nu^{-a}$. If the field is dipolar this leads to a beamwidth $\propto \nu^{-a/2}$ and so observations require $a \sim .6 \pm .4$. By contrast longitude-to-frequency mapping may be responsible. Here emission is concentrated at a fixed radius but its spectrum depends on the longitudinal separation from the magnetic axis, high frequencies coming from nearer the axis than low frequencies. We find that geometrically satisfactory models with radius-to-frequency mapping can be constructed but that no longitude-to-frequency model can be found to satisfy all of (b), (d) and (e).

We, consequently, narrow the discussion to polar cap models with radius-to-frequency mapping, explaining the three regimes as follows. Subpulses are beams from current filaments along flux tubes within the open field lines which define the average profile. A current filament whose origin slowly moves across the polar cap is responsible for a drifting band, while the existence of P_2 requires a characteristic separation of the filaments. Micropulses are caused by modulations along the length of a filament, causing time modulations at a particular radius. Since the particles are relativistic these time variations will be nearly simultaneous for an outside observer; so no differential retardation should be detectable for micropulses. However, the subpulses and average profiles should be retarded by a time difference $\Delta t_{12} = [r(\nu_2) - r(\nu_1)]/c$ between frequencies ν_1 and ν_2. We have observed just such a difference for PSR 0950+08. If the 111 MHz and 318 MHz profiles are aligned so that the micropulses are simultaneous, the point of symmetry of the double profile is .4±.2 ms earlier at 111 MHz. If the symmetry point is where the observer is closest to the magnetic axis and the field is dipolar, we conclude that $r(318) \sim 10^7$ cm ± 50% $\sim 10\ r_{star} \sim 0.01\ r_{LC}$.

In summary we have proceeded from a general geometrical argument about angular beaming and temporal modulation to a particular polar cap model. In such a model we conclude that some degree of radius-to-frequency mapping is required but that the coherence could still be either narrow band, as from a wave at the local plasma frequency, or broad band as from a small charge clump emitting up to some ν_{max} which varies with radius.

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DISCUSSION

FERGUSON: There seem to be several arguments against microstructure being a time modulation. Among these are:
(1) the polarization changes often observed within and at the edges of micropulses;
(2) the complete decorrelation of microstructure between 400 and 1400 MHz seen in PSR 1133+16;
(3) the observed symmetry of micropulses and their frequency independent time scales and separations, while dispersion within the exciting waves in travel from one radius to another will act to destroy these properties.
Could you comment on these questions?

RICKETT: (1) In the point of view which I have presented, rapid changes of polarization have to be explained as propagation phenomena, though this may be avoiding the issue.
(2) The decorrelation of microstructure presents no problem if the radial modulation which causes microstructure changes slowly as it travels out from the star. Indeed, in order to explain the relative weakness of microstructure at high frequencies the radial modulation must grow as it travels from the 1 GHz-emitting height to the 0.1 GHz height. If the structure rearranges somewhat as it travels, the microstructure will be correlated over a reduced range of frequencies only.
(3) The third question concerns the polar cap model in particular and the physics of plasma flow along a flux tube. A consideration of this physical question may reject the model, but time modulation is still the simplest explanation for the frequency independence of widths and separations.

BORIAKOFF: As a contrast to temporal modulation do you exclude thin flux tubes as the cause of microstructure and why?

RICKETT: My expectation of thin flux tubes is that they would spread apart with increasing radius and give rise to frequency dependent widths and separations — in contradiction with the measurements. The only alternative that I can see is to propose that microstructure is a separate emission mechanism or comes from a different region with different spectrum and beamwidth. I would try hard to avoid such an extra ad-hoc assumption.