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MAGNETIC POLES AND THE POLARIZATION STRUCTURE OF PULSAR RADIATION

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Comparison of the polarization structure of PSR 0833–45 at different frequencies leads to the conclusion that pulsar radiation must emanate from the neighbourhood of magnetic poles. The recent jump in periodicity of this pulsar was not accompanied by any gross changes in its magnetic field structure.

INTRODUCTION

The polarization properties of the pulsar PSR 0833–45 at 1420 MHz have been compared with previous observations at 1720 and 2700 MHz (Radhakrishnan *et al.* 1969). The more comprehensive measurements at 1720 MHz showed that the pulse was linearly polarized 95 ± 5 per cent at the peak. During the pulse the plane of polarization rotated almost linearly with time through a range of position angles, close to 90°. The new observations at 1420 MHz were undertaken to study the frequency dependence of the polarization structure. The measurements are compared in detail and the implications for pulsar models are discussed.

OBSERVATIONS

The measurements were made with the Parkes 210-ft telescope. At 1420 and 1720 MHz the receiver bandwidth was restricted to 100 kHz to remove any effects of dispersion, but at 2700 MHz the 500 MHz effective passband of the receiver broadened the pulse appreciably. A time-constant of 0.1 msec was used, and averages were taken over 1 000 pulses. The results are summarized in Table I.

The change of polarization angle with frequency in pulsars has been attributed to Faraday rotation (e.g. Smith 1968). In the absence of an established theory which requires all frequencies to have the same polarization at the source it is necessary to demonstrate the validity of this assumption. The position angle of polarization of the pulse peak at the three frequencies is shown in Figure 1 plotted against λ^2. The position angle is a linear function of λ^2, as would be expected for Faraday rotation, thus making it reasonable to assume that all frequencies were generated with an intrinsic position angle of 47°. The unambiguous rotation measure of $+42 \pm 4$ rad m² derived here confirms the earlier estimate (Radhakrishnan *et al.* 1969).

The rotation of the plane of polarization through a large angle within the pulse at 1720 MHz prompted the suggestion byRadhakrishnan *et al.* (1969) that the radiation emanated from the neighbourhood of a magnetic pole. On the basis of comparison with incomplete observations at 2700 MHz it was assumed that differential Faraday rotation effects were not responsible for the observed pattern of polarization. That this assumption was justified is demonstrated in Figure 2. The lower portion of the figure shows the difference in position angles at 1420 and 1720 MHz as a function of time. The

TABLE I
Polarization Characteristics of PSR 0833–45

Percentage linear polarization at pulse peak,		
	1420 MHz	95%±5%
	1720 MHz	>95%
Position angle of pulse peak,	1420 MHz	154°±5°
	1720 MHz	120°±5°
Rotation measure (1420 → 2700) MHz		$+42 \pm 4$ rad m^{-2}
Intrinsic angle of polarization		~47°
Total rotation of position angle within pulse		~90°
Rate of rotation of position angle within pulse		~25° msec^{-1}

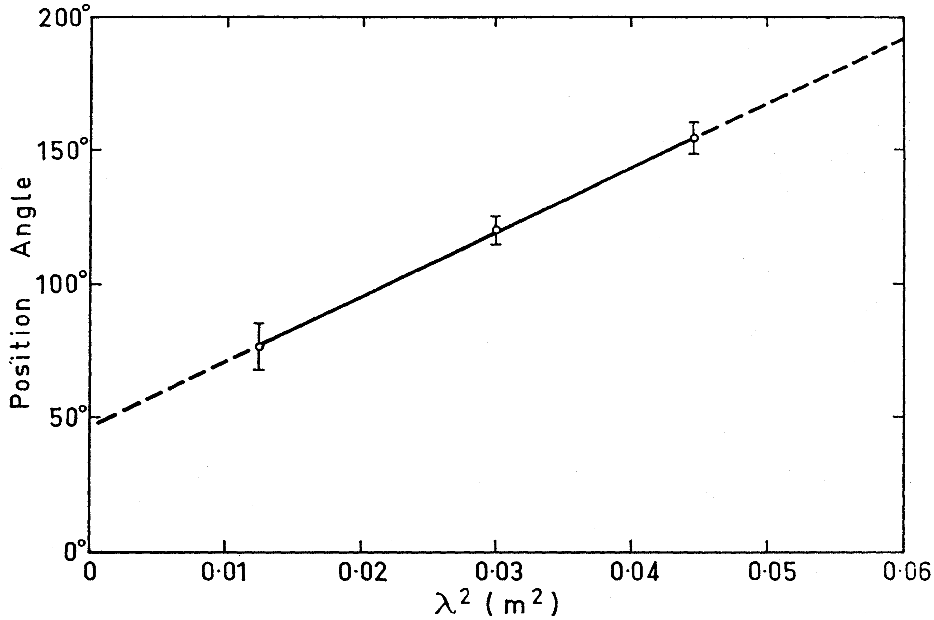

FIG. 1. The position angle of the peak of the pulse at 2700, 1720, and 1420 MHz plotted against the square of the wavelength. The slope of the line corresponds to a rotation measure of $+42 \pm 4$ rad m^{-2}.

difference is constant, and close to 34° for the duration of the pulse. In the upper half of the figure we have interleaved measurements at the two frequencies, removing the mean difference of 34°. Any differential Faraday rotation would have produced a greater spread at the lower frequency and so a progressive misalignment of the position angles.

DISCUSSION

The data from which Figure 2 was drawn show that the plane of polarization changes almost linearly with time over the full width of the pulse. The position angle rotates through a range of about 90° at the rate of 25° per millisecond. As the period of the pulsar is 89 msec, the pulsar rotates on its own axis through an angle of 4° for every millisecond of time. If the directed quantity determining the polarization is the magnetic field, the projected field lines, as seen by the observer, must rotate during the pulse at the rate of about 6° in position angle per degree of pulsar rotation. The conclusion that the radiation originates in the neighbourhood of a magnetic pole is a compelling one. In the case of this particular pulsar we can go further and state that the line joining the observer and the region of radio emission must intersect the surface of the star within 10° of a pole. For a dipole model the absence of an interpulse from the other magnetic pole then requires that the inclination of the magnetic dipole to the axis of rotation be less than 80°. A model satisfying these requirements is represented in Figure 3. For PSR 0833–45 the angle $\beta < 10°$, $\alpha < 80°$, and $\beta \approx 10 \sin \alpha$ degrees. The line of sight has been drawn below the magnetic pole to satisfy the further requirement that the plane of polarization rotate almost linearly with time through a large angle (see Figure 4). Consideration of the geometry of Figure 4 will show that, in this case, the locus of the intersection of the line of sight with the surface will have the same sense of curvature as the small circles of magnetic latitude.

In the case of the Crab Nebula pulsar, the inclination of the magnetic dipole, α, will now have to be closer to 90° to bring the other pole into partial view to produce the interpulse. Since the optical radiation shows the same sense of polarization rotation in both the main and subsidiary pulses (Warner *et al.* 1969), the angle β will have the opposite sign to α. The line of sight will then intersect the surface further from the rotational equator than the magnetic pole.

In addition to the optical measurements referred to above, the radio radiation from several other pulsars also exhibits polarization rotation during the pulse (Clark and Smith 1969; Komesaroff, Morris, and Cooke, private communication). This characteristic of the radiation and the relatively

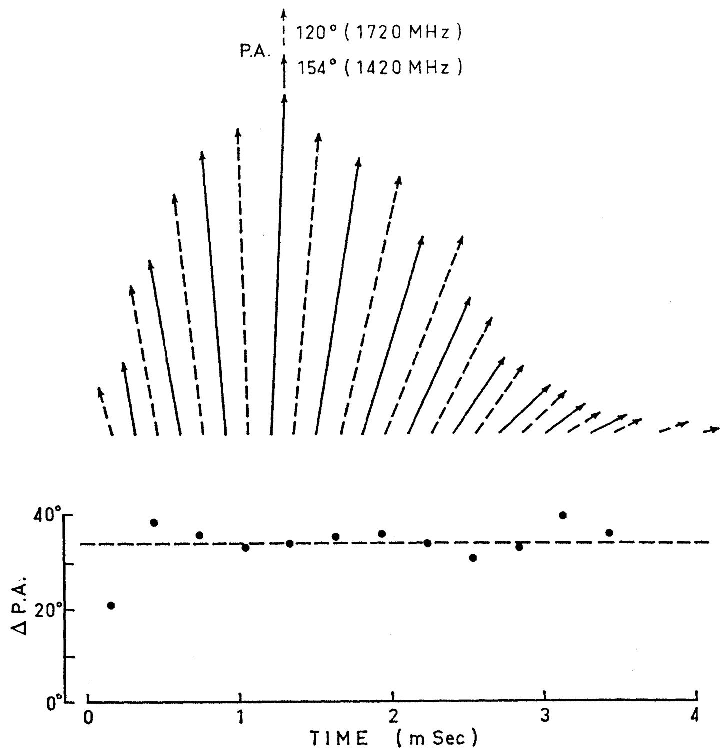

FIG. 2. The difference in the position angles of polarization at 1420 and 1720 MHz plotted against time (lower). The dotted horizontal line is drawn at 34°. Measurements at 1420 and 1720 MHz have been interleaved in the upper figure by removing the 34° mean difference in the position angles at the two frequencies. The length and orientation of the arrows represent the polarized flux and the position angle. The amplitude scales have been adjusted to agree on the average.

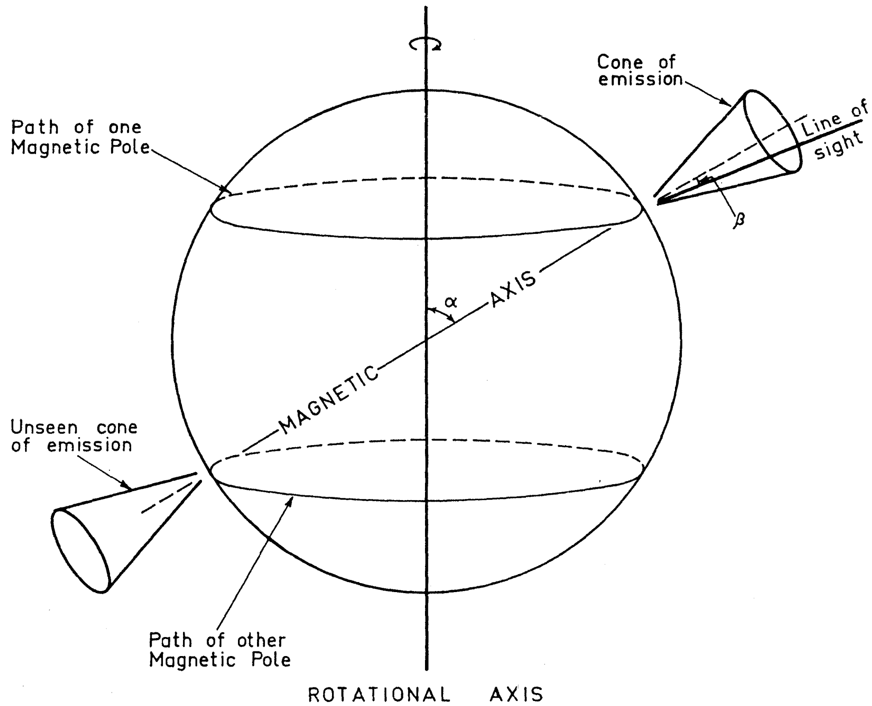

FIG. 3. Representation of a possible model for PSR 0833–45. α is the inclination of the magnetic dipole to the rotational axis and β is the inclination of the line of sight to the magnetic dipole. The line of sight has been drawn in only to indicate β and is not meant to suggest that it passes through the magnetic pole. To adapt this model for the Crab pulsar, α will have to be increased to almost 90° and the line of sight moved to be above the magnetic pole.

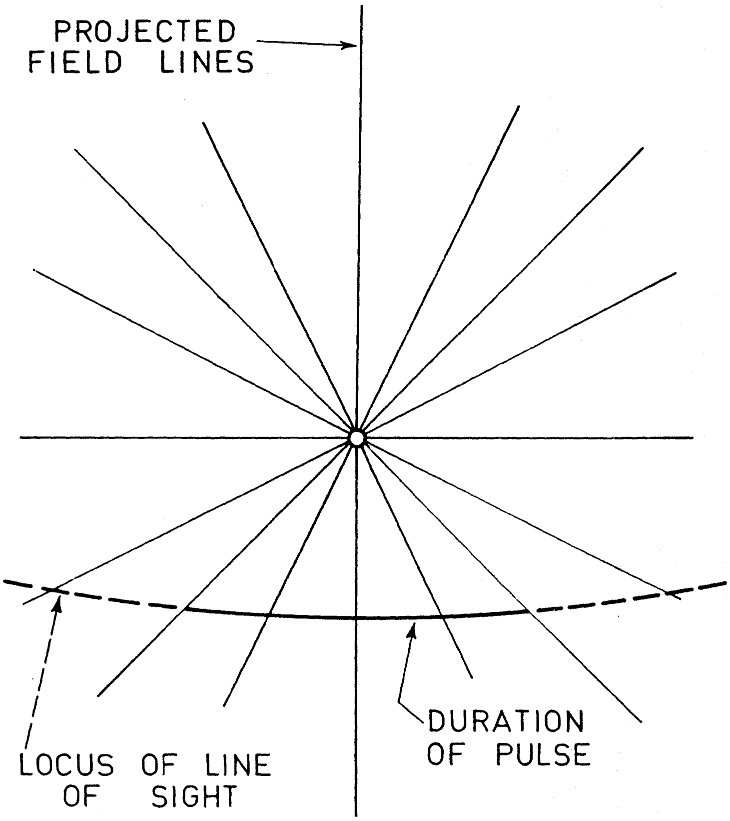

FIG. 4. Locus of the line of sight in the neighbourhood of the magnetic pole. During the pulse the inclination of the field lines changes by 90°.

small spread of the duty cycles in all observed pulsars (3 to 10 per cent) together constitute, in our view, the two most important clues to the radiating mechanism of pulsars. Few of the theoretical papers published so far on this subject have attempted to incorporate both the above-mentioned features.

The hypothesis that the radiation must emanate from a magnetic polar region goes a long way towards explaining the characteristics of pulsar radiation. Goldreich (1969) has shown that in rotating neutron stars with strong magnetic fields, charged particles must be accelerated to extremely high energies along the polar field lines. His treatment was restricted to the axisymmetric case, but it is likely that it applies to inclined dipoles as well. If part of the energy of the charged particles is converted to radio frequency radiation, the radiation pattern will be limited by the geometry of the field lines in polar regions. A cone of radiation limited in this way would automatically produce pulses with a duty cycle independent of the speed of rotation of the pulsar. As discussed earlier, the polarization rotation within the pulse can be explained quite naturally. In connection with this last point, we should like to emphasize that the exact angle between the plane of polarization and the field lines responsible is of no consequence as long as it is relatively constant. In the case of the Crab Nebula pulsar, one now has an opportunity to compare the radio and optical radiation mechanisms. A measurement of the radio polarization at several frequencies could, by extrapolation, provide a value for the intrinsic angle of radio polarization which could then be compared with the optical value (Warner *et al.* 1969).

In the course of making the observations reported in this paper it was discovered that PSR 0833–45 had suffered a sudden change in period of 2 parts in 10^6 some weeks earlier (Radhakrishnan and Manchester 1969, Reichley and Downs 1969). In comparing the present observations with those made in December 1968, prior to the event, we have been aware of the possibility of a change in the magnetic field configuration accompanying the event. The absence of any major differences in the two sets of observations is, of course, the basis of the conclusions drawn in this paper. Further observations at the same frequency (1720 MHz) as the December 1968 measurements are required to permit the detection of a possible small change in the polarization structure of the pulses.

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