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Non-Dipolar Magnetic Fields in Pulsars

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Abstract. Several bright pulsars have position angle sweeps which are not consistent with a simple dipole field in the radio emission region. The data are now good enough to justify modelling of deviations in the field structure in these stars, and the effect of these deviations on the radio emission. As a first step, we consider the effect of quadrupoles, and of polar currents, on the observed polarization and emission signatures.

1. Is the Field Dipolar?

One of the basic tenets of pulsar study is that the magnetic field is a simple dipole, tied to the rotating star. This picture has proven very useful in understanding many aspects of pulsar observations. However, it does not explain all phenomena found in the data. We are therefore revisiting this picture, and considering how it can be extended. In particular: are there stars with significant non-dipolar fields?

Polarization is our only measure of the geometry of the magnetic field — with the caveat that we must assume the linear polarization direction is uniquely tied to **B** (either perpendicular or parallel, depending on the emission model). If the latter assumption is true, a dipolar field has a unique signature in the polarization angle (PA) sweep (Radhakrishnan & Cooke 1969, "RC"). Deviations from this signature are then signs of a non-dipolar field in the emission region. In addition, the standard pulsar model assumes all radio emission comes from the open field line region above the polar cap, and thus predicts a clear relation of the emission and PA behavior with pulse phase. Deviations here are also important: they are either signs of a non-dipolar field, or signs of problems with the standard emission picture.

We find several stars with one or both of these deviations; details are given in Eilek & Hankins (2000). Some stars have PA tracks (established in single pulse data) which quantitatively disagree with the RC predictions. A few stars appear to have two different, non-orthogonal PA tracks. Two stars that we know of, B1929+10 and the Crab pulsar, have PA tracks which can be fit by an RC model, but which are seriously offset in phase from the emission profile.

These difficult stars are the most interesting ones. They are telling us the ways in which the simple model is limited, if only we can understand their message. While we hardly claim to have determined the field geometry in the emission region, we have begun work on two simple approaches which we find promising.

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2. Models of Non-Dipolar Fields

The formal way to extend the dipolar model is to introduce a quadrupole component. There are, of course, two possible quadrupolar field configurations (*e.g.* Jackson 1975). When they are added to a dipolar field, we find a wonderful range of possible field structures. One example is shown in Figure 1.

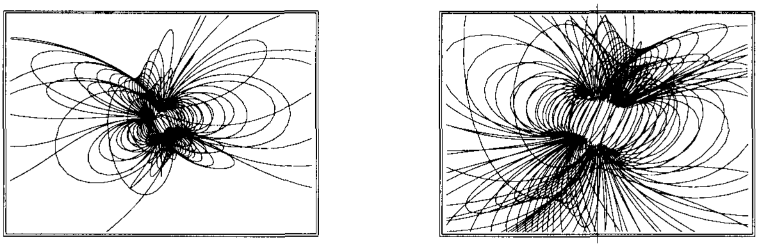

Figure 1. Two views, distant and "zoom", of a magnetic field in which both quadrupoles are added to the dipole component. This illustrates the complexity possible of such fields.

Can such structures account for the unusual PA signatures? We think not. The field lines in our model are not significantly distorted at low altitudes in the open field line regions (where we believe the emission arises). PA tracks from such fields should be very close to the RC prediction. However, we note that these fields are very asymmetric, and allow the possibility of open field line regions which are asymmetrically placed on the star's surface. Such configurations may give rise to the offset emission seen in B1929+10 or in the Crab pulsar. We are exploring this possibility *via* further numerical simulations.

On the other hand, PA sweeps which deviate from RC require field line distortions on small scales in the radio emission region. Formal quadrupoles are unlikely to do this; a much higher "pole" must be added. We have experimented with one possibility: a current flowing out along the open field lines. We have used very simple current models, assuming a constant charge density within the open field line region, and a current returning in a thin layer on the edge of this region; and have simulated their effect on the PA sweep (details and simulated PA tracks are presented in Eilek & Hankins 2000). A current density that is a few times the Goldreich-Julian current will produce interesting and observable effects in the PA sweep. These are no more than toy models, but our results seem to warrant further analysis.

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