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Scintillation and the Vela Pulsar's Magnetosphere

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Abstract. Radio-wave scattering in the Vela supernova remnant acts as an imperfect lens to resolve the pulsar's radio emission region. We use this lens to measure the pulsar's emission region. We suggest that refraction of radiation within the pulsar's magnetosphere is responsible for the observed size.

1. Obervational Approach

Strong scattering of radio waves in the interstellar medium forms a diffraction pattern on the Earth. This pattern is the convolution of the pattern for a point source, with a diffraction-limited image of the source (Goodman 1968, 1989). In principle, observations in the speckle limit (Desai et al. 1992) yield both an image of the source and the phase changes introduced by the scattering material (Cornwell & Napier 1988, Cornwell, Anantharamaiah, & Narayan 1989). Observations of the distribution of the electric field, and its moments, observed at different sites and frequencies, contain the information on the structure of the radio source (Gwinn et al. 1997b). In particular, measurements of the degree of modulation of scintillation yield a measure of the size of the spatially-incoherent emission from the source (Salpeter 1967, Cohen, Gundermann, & Harris 1967). From the modulation index for the Vela pulsar, and the distribution function of intensity, we find a size of 500 km for the emission region (Gwinn et al. 1997a).

2. Discussion

The size of the emission region may result from refraction within the pulsar's magnetosphere. The rapid rotation and strong magnetic fields of pulsars generate $\mathbf{v} \times \mathbf{B}$ forces strong enough to tear electrons from the neutron-star surface and pair-produce within a few centimeters (Goldreich & Julian 1969). The resulting electron-positron cascade provides a plausible site for the emission of the observed radio emission (Ruderman & Sutherland 1975, Arons & Scharlemann 1979, Cheng, Ho, & Ruderman 1986, Daugherty & Harding 1994). The

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electron-positron wind refracts radiation with polarization not perpendicular to the pulsar magnetic field (Blandford & Scharlemann 1976, Melrose & Stoneham 1977). In particular, radiation traveling nearly along magnetic field lines is strongly refracted (Arons & Barnard 1986) and can be "ducted" along the field for long distances. Microphysics of the plasma can amplify the radiation as it is ducted along the field lines (Lyutikov 1997). Ducting carries the radiation high into the magnetosphere; when the wave direction becomes sufficiently misaligned from the magnetic field, the ducted wave can couple to a vacuum electromagnetic wave. This picture is consistent with, and partly explains, the observed Radhakrishnan-Cooke mapping of polarization to magnetic field direction (Radhakrishnan & Cooke 1969). The resulting size is expected to be larger than the pulsar but smaller than the light cylinder, as observed.

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