Pulsars : Problems & Progress
ASP Conference Series, Vol. 105, 1996
S. Johnston, M. A. Walker and M. Bailes, eds.

Wave Propagation in Pulsar Magnetospheres and Interstellar Interferometric Observations

Yves A. Gallant

Astronomical Institute, Utrecht University, Netherlands

1. Interstellar interferometric observations

Using a refractive scintillation event of PSR 1237+25, Wolszczan & Cordes (1987) inferred a projected displacement of the emission region of order 10^8 cm across the pulse. Gupta (these proceedings) inferred a lower separation limit of a few times 10^7 cm from a similar event for PSR 1133+16. In both cases the projected displacement was also a nonmonotonic function of pulse phase.

Neither these large separations nor the nonmonotonic behavior can be explained in a simple model which assumes that the emission originates parallel to the field lines of a magnetic dipole, at a fixed altitude across the open field zone, and propagates in a straight line to the observer. There is considerable circumstantial evidence for dipolar fields from polarization sweep and pulse morphological studies. Time delays due to different emission altitudes could produce asymmetries in pulse profiles and projected displacements, but cannot explain the large separations if the emission originates well within the light cylinder.

2. Wave propagation in pulsar magnetospheres

The dispersion relation for radio-frequency waves in the dense, relativistically outflowing pair plasma which is thought to be present in the open field zone above pulsar polar caps has been investigated by several authors. There are two orthogonal polarizations: the X-mode, which in a superstrong magnetic field has a light-like dispersion relation, and the O-mode, which under the same conditions separates into two branches, subluminous and superluminous.

Barnard & Arons (1986) examined the propagation of O-mode waves in an inhomogeneous model magnetosphere composed of a pair plasma flowing out with constant Lorentz factor γ along dipolar field lines. They found that for proper frequencies low relative to the proper plasma frequency, the subluminous branch of the O-mode propagates along field lines (is magnetically "ducted"), while to lowest order the wave vector $\mathbf{k}$ preserves its initial direction.

3. "Ducting" and large separations at small pulse phases

This propagation behavior allows a wave emitted close to the polar cap to travel large distances outward along the field while approximately preserving its initial $\mathbf{k}$-vector direction, hence the rotation phase at which it will be seen (Figure 1). But in order to escape the plasma and be observed, the subluminous O-mode must be converted to the superluminous branch. Such mode conversion is most

https://doi.org/10.1017/S0252921100042032 Published online by Cambridge University Press

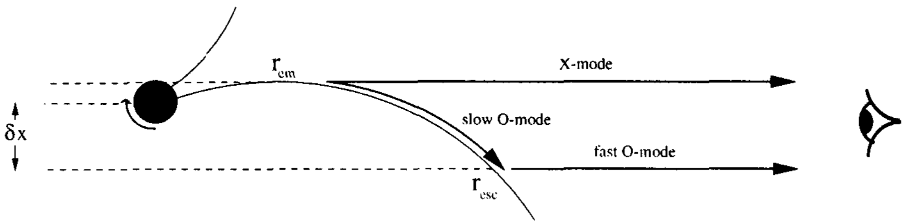

Figure 1. Schematic geometry for O and X-mode propagation.

likely to occur near the proper plasma frequency, corresponding to $\omega \approx 2\sqrt{\gamma}\omega_p$ for nearly parallel propagation. The implied frequency dependence of the escape radius $r_{\rm esc}$ has been proposed as an explanation of the pulse width to frequency mapping by Barnard and Arons (1986). Emission might alternatively occur directly in the superluminous branch, which at low frequencies has similar ducted propagation properties. This mode would then smoothly become light-like near the same $r_{\rm esc}$ without requiring mode conversion.

4. Birefringence and nonmonotonic displacements

The nonmonotonic behavior of the displacement can be understood if X-mode waves are also emitted above the polar cap. Assuming its initial **k**-direction is exactly preserved, the projected displacement of the O-mode ray is

$$\delta x = r_{\rm esc}\,\theta_{\rm em}\left(\sqrt{\frac{r_{\rm esc}}{r_{\rm em}}} - \frac{3}{2}\right)$$

(see Figure 1). For low-altitude emission and typical pulsar parameters, $r_{\rm esc}/r_{\rm em}$ can be several hundreds, accounting for the large observed δx's. The X-mode case is obtained by putting $r_{\rm esc} = r_{\rm em}$, which yields a δx of the opposite sign. This might explain the nonmonotonic behavior of δx if the outer edges of the pulse are predominantly O-mode and the inner parts X-mode. Such separation of the O and X-modes has also been suggested by McKinnon (these proceedings) to explain pulse profile broadening and depolarization.

While the precise details of the transition from magnetically ducted to light-like propagation require further study, the essential conclusion of this work is that the large projected displacements inferred from interstellar interferometric observations can be explained by propagation effects in the inner magnetosphere. More observations of this type might yield inferences on magnetospheric conditions, in particular the pair plasma density and Lorentz factor which determine the escape radius, and indications on the nature of the wave modes emitted independent of any subsequent depolarization or mode mixing.

References

Barnard, J. J., & Arons, J. 1986, ApJ, 302, 138
Wolszczan, A., & Cordes, J. M. 1987, ApJ, 320, L35

https://doi.org/10.1017/S0252921100042032 Published online by Cambridge University Press