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Scattering and Diffraction in Magnetospheres of Fast Pulsars

Maxim Lyutikov

CITA 60 St. George street, Toronto, Canada

Anuj Parikh

Simon Fraser University, 8888 University Drive, Burnaby, B.C., V5A 1S6, Canada

Abstract. We show that under conditions of strong density modulation the effects of magnetospheric scintillations in diffractive and refractive regimes may be observable. The most distinctive feature of the magnetospheric scintillations is their independence on frequency. Results based on diffractive scattering due to small scale inhomogeneities give a scattering angle that may be as large as 0.1 radians, and a typical decorrelation time of 10^{-8} seconds. Refractive scattering due to large scale inhomogeneities is also possible, with a typical angle of 10^{-3} radians and a correlation time of the order of 10^{-4} seconds. Temporal variation in the plasma density may also result in a delay time of the order of 10^{-4} seconds. The different scaling of the above quantities with frequency may allow one to distinguish the effects of propagation through a pulsar magnetosphere from the interstellar medium. In particular, we expect that the magnetospheric scintillations are relatively more important for nearby pulsars when observed at high frequencies.

A number of observational results may possibly be attributed to scattering processes inside pulsar magnetospheres. The most convincing are the results of Sallmen et al. (1999) in which the the frequency independent spread and the multiplicity of the Crab giant pulses with large variations in the pulse broadening times. Other relevant observations include comparatively large size of the Vela pulsar's radio emission region (Gwinn et al. 1997), frequency independent scintillations with bandwidth 4 MHz (Gwinn et al. 1999), enhanced intensity fluctuations at very high frequencies (Kramer et al. 1997), enhanced scattering of nearby pulsars (Gupta et al. 1994, Rickett et al. 1999).

Strong magnetic fields present in pulsar magnetospheres and the unusual electrodynamics of the one-dimensional electron-positron plasma both change the familiar effects of scattering and refraction in plasma. The unusual features of scattering in such plasma may allow separation from the interstellar scattering and will serve as a tool to probe the structure of the magnetosphere itself. Typically, the frequency of the observed radio waves is much less that the cyclotron frequency $\omega \ll \omega_B$. For such frequencies the refractive index of strongly magnetized pair plasma for escaping electromagnetic modes is approximately

$$n^2 - 1 \approx \frac{\gamma_p \omega_p^2}{\omega_B^2} \equiv \delta. \tag{1}$$

Thus, the large Lorentz factor of the moving plasma effectively enhances the wave-plasma interaction on the o pen field lines. Parameter δ is the key to the scattering and diffraction effects in the pulsar magnetosphere. An important fact is that δ does not strongly depend on our assumptions about the density and the streaming Lorentz factors of the plasma.

Parameter δ, which determines refractive properties of the medium, is negligible deep inside the pulsar magnetosphere, but increases with the distance from the neutron star as $\propto r^3$. Thus, the strongest nonresonant wave-plasma interactions occur in the outer regions of pulsar magnetospheres (near the light cylinder). This allows for a considerable simplification when considering scattering and diffraction effects since one can adopt a "thin screen" approximation. We assume that emission is generated deep in the pulsar magnetosphere and then scattered in a thin screen located near the light cylinder with a typical thickness $D \approx 0.1 R_{LC}$.

Two types of inhomogeneities that should be present inside the pulsar magnetosphere: small scale inhomogeneities with a typical sizes comparable to tens of skin depth $\sim c/\omega_p$ which arize due to the plasma tubulence and large scale inhomogeneities with a typical sizes comparable to light cylinder radius which arize due to temporal and spatial modulation of the outflowing pair plasma. The two types of inhomogeneities will produce qualitatively different effects: small scale inhomogeneities will produce diffractive scattering, while large scale inhomogeneities will produce refractive scattering. Scattering inside the pulsar magnetosphere is strong (the typical phase delay $\Delta\phi \gg 1$).

The predicted characteristics of the scattering inside the pulsar magnetosphere are

diffractive scattering angle	10^{-1}
diffractive scattering time	10^{-4} sec
diffractive decorrelation time	10^{-8} sec
refractive scattering angle	10^{-3}
refractive decorrelation time	10^{-4} sec
arrival time variations	10^{-4} sec

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