Part 6
Emission and Plasma Theory

Section A. Radio Emission and Pulsar Electrodynamics

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The Superluminal Model of Pulsars

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Abstract. Salient features of the pulsar emission are all consequences of a single property of the source of this radiation: the superluminal nature of the phase speeds with which the outer parts of the distribution pattern of the emitting electric current rotate. Here we outline the principles underlying the superluminal model of pulsars, on which this claim is based, and describe a ground-based experiment currently being built that will be capable of testing, *inter alia*, the validity of this model.

Magnetic dipole radiation, at the rotation frequency ω of the central neutron star, gives rise to polarization and magnetization currents in the plasma surrounding the magnetized star whose distribution patterns likewise rotate with the frequency ω. The outer parts of the patterns in question (at cylindrical radii $r > c/\omega$) move with linear phase speeds exceeding the speed of light *in vacuo*, c. This is not incompatible with special relativity because the superluminally moving distribution pattern of the induced current is created by the coordinated motion of aggregates of subluminally moving particles.

The field that arises from each volume element, in $r > c/\omega$, of the moving distribution pattern of the induced current entails a rotating caustic that extends to the far zone (Ardavan 1998). The collection of the caustics generated by various volume elements of the source thus constitutes a focused, rotating wave packet with an anomalously large amplitude at large distances. This wave packet embodies a recurring pulse which has the same longitudinal extent as that of the source distribution, and which is beamed into a solid angle centred on the plane of rotation with the latitudinal width $2\arccos[c/(r_u\omega)]$, where r_u is the radial extent of the source distribution.

The intensity of the radiation field within the propagating caustics that embody the pulses decays like R^{-1}, instead of R^{-2}, with the distance R form the source. This result is not incompatible with the conservation of energy because the caustics in question are constantly dispersed and reconstructed out of other waves. The effect responsible for the coherence of the radio emission is this violation of the inverse square law: it implies that the intensity, and hence the brightness temperature, of the focused pulses is by a factor of the order of $R\omega/c$ greater than that of a conventional spherically decaying radiation, a factor that ranges from 10^{16} to 10^{30} in the case of pulsars.

There are volume elements in the superluminally moving distribution pattern of the source that approach the observer, along the radiation direction, with the wave speed and zero acceleration at the emission time. For these source elements the interval of retarded time δt during which a set of waves is emitted is significantly longer than the interval of observation time δt_P during which the same set of waves is received. The ratio $\delta t/\delta t_P$ is of the order of $(\omega\delta t_P)^{-\frac{2}{3}}$ and so is much greater than unity for any set of waves with a wavelength $\lambda \ll c/\omega$ which arrive at the observation point in phase, i.e. which are received during $\delta t_P \sim \lambda/c$. Any temporal fluctuation of the source in its rest frame would therefore give rise to frequencies in the spectrum of (the spherically decaying part of) the radiation that are by a factor of the order of $(\Omega/\omega)^2$ higher than the frequency Ω of the intrinsic modulation of the source.

Only the non-spherically decaying component of the present radiation is emitted at the frequencies with which the source fluctuates. The other, incoherent component of this radiation can contain frequencies in the case of pulsars that are by the factor $(\Omega/\omega)^2 \sim 10^{16} - 10^{22}$ higher than the frequencies present in the temporal variations of the magnetospheric electric current. A single emission mechanism is thus responsible for the entire spectrum of the incoherent radiation.

The large ratio $\delta t/\delta t_P \sim 10^{16} - 10^{22}$ offers an explanation also for the microstructure of the individual pulses. Since its emission time δt cannot exceed a rotation period, the signal that is detected at a given longitude (a micropulse) has a reception time interval or temporal width δt_P that is by many orders of magnitude smaller than the rotation period $2\pi/\omega$.

Like the diffraction field near a focal point, the field that arises from a superluminally moving source element undergoes a phase shift of magnitude π across its caustic. Only one of the two distinct radiation fields across the caustic is detected when we measure a component of the electric field vector at a given longitude. The vectorial addition of normal field components, at times from the same and at times from opposite sides of the caustic, thus leads to the detection of a stochastic sequence of approximately orthogonal polarization states.

An experimental device is currently being built at Oxford University that will be capable of producing a superluminally moving polarization current and thereby demonstrating the properties of the new emission mechanism invoked in the present model of pulsars. The apparatus in this experiment consists of an arc of a circular dielectric rod, an array of electrode pairs positioned opposite to each other along the rod, and the means for applying a voltage to the electrodes sequentially at a rate sufficient to induce a polarization current whose distribution pattern moves along the rod with a speed exceeding the speed of light *in vacuo*. A superluminal speed is achieved for a circular rod of diameter ~ 10 m (and arc length ~ 1 m) by an applied voltage that oscillates with the frequency ~ 10 MHz. If the amplitude of the resulting polarization current is in addition modulated at ~ 500 MHz, then the device would generate a non-spherically decaying (coherent) radiation at ~ 500 MHz, and a spherically decaying (incoherent) radiation with a spectrum that extends as far as ~ 1 THz (Ardavan & Ardavan 1998).

References

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