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What is the pulsar radio emission mechanism?

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Over 50 years since pulsars were discovered, there is no agreement on the radio emission mechanism. It is widely accepted that the mechanism involves one or more plasma instabilities in a pulsar plasma, defined as a highly relativistic, one-dimensional (1D), electron-positron plasma flowing outward on open ("polar-cap") magnetic field lines. There are three mechanisms (e.g., Eilek & Hankins 2016), referred to here as coherent curvature emission (CCE), relativistic plasma emission (RPE) and anomalous Doppler emission (ADE), that continue to attract both supporters and critics.

The favored versions of RPE and CCE are based on resonant beam-driven instabilities in which waves with phase speed $z = \omega/k_\parallel c$ grow due to a beam with speed speed $\beta_b > z$ or $\gamma_b = (1-\beta_b^2)^{-1/2} > \gamma_\phi = (1-z^2)^{-1/2}$. I identify the following difficulties. (a) The distribution function chosen for relativistically streaming ($\gamma_b \gg 1$) particles artificially favors relatively large growth. (b) The waves are assumed to be Langmuir-like, but there are no Langmuir-like waves in pulsar plasma. (c) The growth rate is estimated in the rest frame of the plasma, and the growth rate in the pulsar plasma, where the important constraint applies, is orders of magnitude smaller.

(a) The distribution function for relativistically streaming particles should be constructed by applying a Lorentz transformation to a plausible distribution in the rest frame. The default choice in the rest frame should be a Jüttner distribution, $g(u) \propto \exp(-\rho\gamma)$, with temperatures $T = mc^2/\rho$, (e.g., Wright & Hadley 1975). A conventional choice of a streaming Gaussian, $g(u-u_b) \propto \exp[-(u-u_b)^2/u_{th}^2]$ (e.g., Asseo & Melikidze 1998), is much narrower than a Lorentz-transformed distribution, as illustrated in Figure 1 with the two Gaussians corresponding to $u_{th}^2 = 1/\rho$ and $1/\rho^2$; the choice can lead to misleading results in the highly relativistic case.

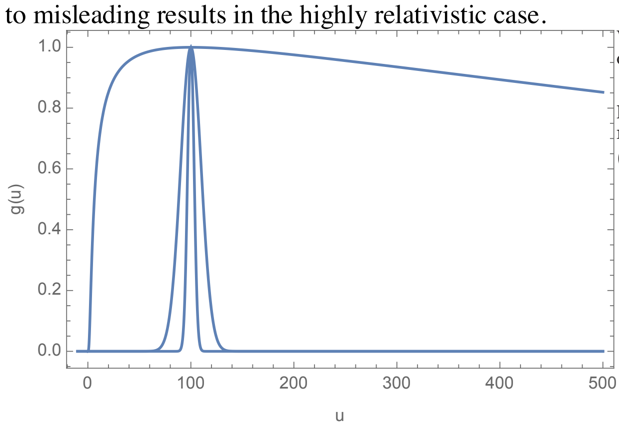

Figure 1 Comparison of the shapes of a Lorentz-transformed Jüttner distribution and two streaming Gaussian distributions with ρ=0.1 and u_b=100.

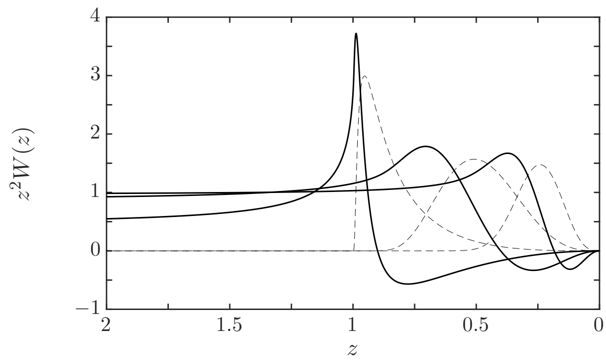

Figure 2 Real (solid) and imaginary (dashed) parts of $z^2W(z)$ for, from top to bottom at the left margin, ρ = 50, 10 and 1, showing development of sharp peak.

(b) The relativistic plasma dispersion function (RPDF) is shown in Figure 2 for a Jüttner distributions showing how a peak develops at subluminal phase speeds $z = \omega/k_\parallel c$ just below unity for small ρ. The dispersion relation for longitudinal waves is $\omega = \omega_p z^2 W(z)$, where ω_p is the plasma frequency. For a highly relativistic plasma, $\rho \ll 1$, the peak value is $2.7/\rho$ at $1-z = 0.013\rho^2$. The RPDF is negative for $1-z = 0.14\rho^2$ so that there are no solutions and no "Langmuir-like" waves for $z < 1-0.14\rho^2$.

(c) A growth rate is usually calculated in the rest frame of the plasma, but the wave growth needs to be discussed in the pulsar frame in which the plasma is flowing outward, with Lorentz factor $\gamma_s \gg 1$, and the growth rate in this frame is smaller by a factor $1/2\gamma_s$.

These various difficulties are so severe that they lead me to conclude that none of the presently favored pulsar radio emission mechanisms is tenable. At least one of the assumptions made must be changed substantially.

I argue that the assumption of beam-driven wave growth be abandoned. An alternative source of wave energy involves long-wavelength (or quasi-temporal) oscillations generated directly by the electrodynamics, as the plasma attempts to screen the parallel inductive electric field associated with the rotating magnetic field.

References

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