So How Do Radio Pulsars Slow-Down?

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In 1983 our team have shown that for zero longitudinal electric current circulating in the pulsar magnetosphere the energy losses $W_{\text{tot}}$ vanish for any inclination angle $\chi$ [1]. This effect (confirmed later by L. Mestel group [2]) results from full screening of the magneto-dipole radiation by magnetospheric plasma. This implies that the pulsar braking results fully from impact of the torque $K$ due to longitudinal currents.

On the other hand, rotating magnetized star can be slowed down only due to the action of the Ampère force connecting with surface currents $J_s$: $W_{\text{tot}} = -\dot{\Omega}K$, where

$$K = \frac{R^4}{c} \int J_s(Bn) \, do = \frac{R^3}{4\pi} \int \{ [n \times B^{(3)}](B^{(0)}n) + [n \times B^{(0)}](B^{(3)}n) \} \, do. \quad (1)$$

Here the indices $(0, 3)$ correspond to expansion powers on small parameter $\varepsilon = \Omega R/c$. Careful analysis for vacuum magneto-dipole radiation surprisingly shows that in Landau-Lifshits solution both terms play the role while in Deutsch solution only the first one (giving, certainly, the same well-known result).

Returning to magnetosphere filling with plasma, one can find that the torque acting on the star by surface currents $J_s$ closing the longitudinal electric currents [1] $K_{\text{sur}} \parallel \approx -m_2 \Omega^3 c^3 i_s$, $K_{\text{sur}} \perp \approx -m_2 \Omega^3 \left( \frac{\Omega R}{c} \right) i_a$, $I_s \dot{\Omega} = K_{\parallel}^A + (K_{\perp}^A - K_{\parallel}^A) \sin^2 \chi$, \quad (2)

corresponds to first term in (1). Here we introduce two components of the torque $K$ parallel and perpendicular to the magnetic dipole $m$. Besides, dimensionless current $i = j / j_{\text{GJ}}$ (normalization to ‘local’ Goldreich-Julian current density $j_{\text{GJ}} = |\Omega \cdot B| / 2\pi$ with scalar product) also separated into symmetric and antisymmetric contributions, $i_s$ and $i_a$, depending upon whether the direction of the current is the same in the north and south parts of the polar cap, or opposite.

Hence, to satisfy Spitkovsky’s relation $\dot{\Omega} \propto (1 + \sin^2 \chi)$ we should have to assume too large antisymmetric current $i_a \sim \varepsilon^{-1}$ while in reality $i_a \sim \varepsilon^{-1/2}$. Thus, it is necessary to assume additional contribution resulting from mismatch between magneto-dipole and magnetospheric radiation and corresponding to the second term in (1)

$$K_{\perp}^{\text{mag}} = -A \frac{B_0^2 \Omega^3 R^6}{c^3} i_a. \quad (3)$$

For $i_a \sim \varepsilon^{-1/2}$ we obtain $A \sim \varepsilon^{1/2}$. This implies that for local GJ current $i_s \approx 1$ for most inclination angles one can neglect the additional term $K_{\perp}^{\text{mag}}$, as was done in [1].

References