THE AXIALLY SYMMETRIC WIND MAGNETOSPHERE

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A central question in magnetospheric theory of pulsars is: how does a rapidly rotating magnetized neutron star manage to short-circuit its huge unipolar induction voltage? This problem is best studied in an idealized geometry like the parallel rotator. The theory must at least include basic plasma physics with relativistic particle inertia. Even the simplest model will require a global self-consistent solution of both Maxwell's equations and relativistic MHD-equations of motion. Assuming time independence, axial symmetry and charge separation, we reduce this problem to three coupled, quasilinear second order partial differential equations for three dimensionless scalar quantities Ψ, f and Γ (see Schmalz et al., 1980):

$$\Psi_{,z}^2 \Psi_{,xx} - 2\Psi_{,x}\Psi_{,z}\Psi_{,xz} + \Psi_{,x}^2\Psi_{,zz} = F_1(\Psi, f, \Gamma, \underline{\nabla}\Psi, \underline{\nabla}f, \underline{\nabla}\Gamma) \tag{1}$$

$$f_{,xx} + f_{,zz} - (1-f)(\Psi_{,xx} + \Psi_{,zz})/\Gamma = F_2(\Psi, f, \Gamma, \underline{\nabla}\Psi, \underline{\nabla}f, \underline{\nabla}\Gamma) \tag{2}$$

$$\Gamma_{,xx} + \Gamma_{,zz} - \Psi_{,xx} - \Psi_{,zz} = F_3(\Psi, f, \Gamma, \underline{\nabla}\Psi, \underline{\nabla}f, \underline{\nabla}\Gamma) \tag{3}$$

Here x and z are cylindrical coordinates measured in units of the light cylinder radius. Ψ is the stream function which is constant on stream lines, $f = x \cdot v_\phi/c$ is connected with the angular momentum (v_ϕ = toroidal velocity), and $\Gamma = 2\varepsilon\gamma = 2\varepsilon/(1 - v^2/c^2)^{1/2}$ where $\varepsilon = mc^2/(eB_o a^2\Omega)$ is a dimensionless parameter. Taking electrons (mass m, charge e) and typical neutron star parameters (radius a = 10 km, angular velocity Ω = 30/s, polar field strength $B_o = 10^8$ T), we have $\varepsilon \approx -10^{-12}$.

Closer inspection of our equations reveals that (1) is a parabolic equation while (2) and (3) are elliptic. By specifying suitable boundary conditions this problem is properly posed. The inner boundary conditions are determined by the fields inside the star. The outer boundary is the asymptotic zone far away from the star. For this region we have found a class of analytic solutions (Schmalz et al., 1979), the field of which show the universal spiral structure with a radially flowing, relativistic "pulsar wind". The numerical solution of the equations is in progress. One implication of our relativistic model is that

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the corotating zone must be drastically altered compared to the dipolar structure of the vacuum field. To show this feature we have solved our equations in the corotating domain ($\Gamma \approx 0$, $f = x^2$) by prescribing its boundary as shown in Figure 1. In summary, it seems that our equations allow a highly relativistic wind magnetosphere as suspected by Goldreich and Julian (1969) and suggested by the work of Petravić (1976).

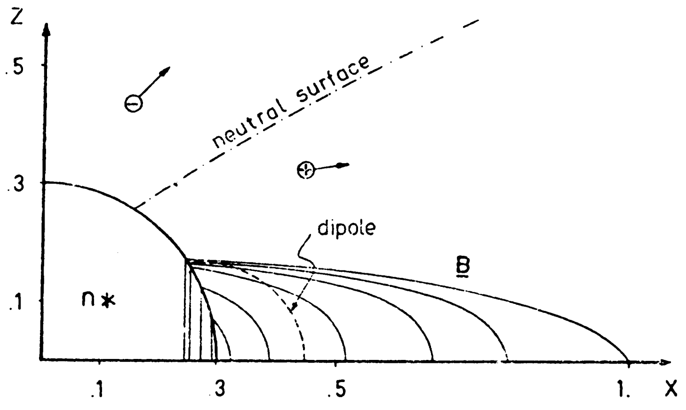

Figure 1: Numerical solution for the magnetic field $\underline{B}$ of the corotating zone. The ultimate form of the boundary as well as the neutral surface are not yet fixed.

REFERENCES

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Petravić, M.: 1976, Comp. Phys. Comm. 12, p. 9.
Schmalz, R., Ruder, H., and Herold, H.: 1979, Monthly Notices Roy. Astron. Soc. 189, p. 709.
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DISCUSSION

MESTEL: My main concerns are (1) the neglect of radiation damping from particles with such fearfully high γs, and (2) the initial choice of a markedly non-dipolar field near the star.

SCHMALZ: To (1): A fluid as we have does not radiate at all. In contrast, a single particle might radiate tremendously. We intend to solve our equations first and afterwards check whether or not radiation effects are important. We expect that the global structure will not be altered essentially. To (2): The final form of the corotating zone must emerge from the self-consistent solution.