Plasma physics in a neutron star magnetosphere – the effect of general relativity

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One of the main interests in neutron star research is to explain the pulsating radio emission. It originates from the open magnetic field line region of a rotating neutron star, but the process creating the radiation is still unknown. To explain the radiation, detailed models of plasma dynamics in the neutron star magnetosphere are needed. In phenomena taking place close to a neutron star, general relativity can be important.

A typical neutron star has a mass of 1.5 solar masses and a radius of 12 km – the radius is only three times the Schwarzschild radius. They rotate very fast, with periods ranging from milliseconds to 10 s. Besides the extreme density, a strong magnetic field of $10^{12} - 10^{15}$ Gauss is characteristic to neutron stars.

The aligned rotator model is a simplified but important model for the neutron star magnetosphere. The greatest simplification of this model is to assume that the axis of rotation and the magnetic dipole axis are aligned; this is not true for most of observed neutron stars. The aligned rotator model defines the light cylinder and polar cap —important concepts in neutron star physics— which can be generalized for more realistic models.

Because of the extreme density of a neutron star, general relativity is required to describe the spacetime close to it. To make plasma physics easier to handle in this environment, 3+1 split of spacetime is introduced. The spacetime is well described by the Kerr metric, which is the metric for rotating black holes. In the 3+1 split, Maxwell's equations can be rewritten with general relativistic corrections. This also leads to a modified Lorentz force law.

With these updated electrodynamics equations, we can obtain the corrections for the aligned dipole model. One important consequence is that the magnetic dipole field changes its shape close to a neutron star. This changes the size of the polar cap. By applying the electrodynamics equations with the general relativistic corrections to different models, we can see whether general relativity can be ignored in the particular model.