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Proton acceleration in pulsar magnetospheres

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Due to their huge rotational energy and large magnetic fields, pulsars have been proposed as candidate sources of high-energy cosmic rays. However, a precise description of the acceleration processes at play is still to be established.

Using particle-in-cell simulations, we study proton acceleration in axisymmetric pulsar magnetosphere. In these numerical experiments, electrons and protons are injected from the neutron star surface, and electrons and positrons are produced through pair production process. We focus on the influence of pair production, which has a crucial impact on the structure of the magnetosphere and the unscreened electric field, and thus on particle acceleration.

In all our simulations, protons are accelerated and escape. The acceleration sites are different for the protons and the pairs. Protons gain most of their kinetic energy below the light-cylinder radius within the separatrix current layers, and are not confined within the equatorial current sheet. As shown in previous studies, pairs are accelerated to their highest energies at the Y-point and in the equatorial current sheet.

Rescaling the simulation results to describe the proton maximum Lorentz factor and luminosities in realistic astrophysical objects is not straightforward. Therefore, in addition to the impact of pair production, we study the impact of the magnetic field and the stellar radius, which are downscaled in our simulations. Our estimates support that millisecond pulsars could accelerate cosmic rays up to PeV energies and that new born millisecond pulsars could accelerate cosmic rays up to ultra-high energies.

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