Contribution ID: **6**

Type: **not specified**

Kinetic model of pair cascades in pulsar polar caps

Thursday 1 September 2022 11:15 (25 minutes)

Time-dependent discharges of electron-positron pairs have recently been proposed as a primary ingredient to explain the nature of pulsar radio emission, a long-standing open problem in high-energy astrophysics. During these discharges - positive feedback loops of gamma-ray photon emission via curvature radiation by TeV electrons and positrons and pair production - the plasma self-consistently develops inductive waves that couple to electromagnetic modes capable of escaping the pulsar dense plasma.

However, a full kinetic model that could predict the growth rate of the cascade, the screening time, and the subsequent emissions is still lacking. First, we show how the kinetic equations can be used to provide such predictions in two setups: (i) uniform electric field and a more realistic vacuum-gap space-time dependent electric field. We show also that the full QED differential probability rates can be approximated by a heuristic rate for photon emission and pair creation. All analytical results are illustrated with particle-in-cell simulations performed with OSIRIS. Second, these results are used to interpret new multidimensional simulations including an ab initio description of the Quantum Electrodynamics (QED) effects responsible for hard photon emission and pair production in pair discharges. It is shown that the electromagnetic modes generated during pair discharges present direct imprints of QED and plasma kinetic effects in properties (e.g. frequency, polarisation and Poynting flux angular distribution) that are consistent with observations.

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Session Classification: Astrophysics and Cosmology

Track Classification: Strong-field QED: Astrophysics & cosmology