Radiative outbursts in pulsar emission and collective plasma instabilities: The potential of kinetic plasma simulations

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ABSTRACT: Radiative outbursts in pulsar emission such as the Crab's Giant Radio Pulses (GRPs) are paradigmatic because of two distinguished qualities:
(i) GRPs proceed on time scales characteristic for kinetic plasma instabilities. In general the radiative cooling times for non-thermal emission in fully ionized collisionless astrophysical plasmas are not directly related to the dynamic time scales of collective plasma motion.
(ii) GRPs relate to a highly coherent emission process, as is inferred from associated brightness temperatures exceeding T=10^{30} K. Consequently such outbursts indicate the interdependence of collective plasma motion and coherent emission.
The quest for a valid description of pulsar radio outbursts stimulated theoretical work for more than two decades. Reviewing these activities we focus on the models dealing with the interaction of pair plasma shells in the polar cap regions, the analytical studies of the sustained modes in an intrinsically relativistic plasma, and the proposed emission mechanisms. We further specialize on the mechanism of collisionless bremsstrahlung, which is independent from the individual geometry of the emission zone and is tractable in kinetic plasma simulations. Kinetic simulations were successfully applied to study the non-linear dynamics of scenarios like reconnection and beam instabilities. In the context of pulsar GRPs, such simulations gain the unprecedented potential to explore the dynamics of collective plasma motion/coherent emission and the impact of non-linear radiative back-reaction.