Abstract

Around 10% of galaxies that present Active Galactic Nuclei (AGN) produce relativistic jets. These jets are collimated relativistic outflows of plasma and magnetic fields. Jets, among other high-energy astrophysical phenomena, such as gamma-ray bursts, and pulsar wind nebulae, present non-thermal emission signatures originating from non-thermal particle energy distributions. These particle distributions result from non-thermal acceleration in low-density collisionless plasma environments. In addition, from observations of synchrotron emission, magnetic fields are thought to play a fundamental role in the particle acceleration and radiation processes. These two conditions, low densities and strong magnetic fields, imply relativistic magnetizations, which means that the magnetic energy density dominates the rest-mass energy density of matter.

For a long time, it has been under debate which dissipation mechanism (in particular shock waves or magnetic reconnection) best suits the observed emission signatures, how efficient it is, and where exactly it happens. It has been only during the last years when kinetic simulations became available to investigate from first principles the effects of instabilities beyond their linear phases in relativistically magnetized plasmas, the results of those simulations are being adapted to emission models in order to explain observations.

The main topic of this thesis is the analysis of two particle acceleration mechanisms in relativistically magnetized jets through particle-in-cell (PIC) kinetic simulations. The mechanisms studied are: (1) the steady-state relativistic magnetic reconnection, and (2) the current- and pressure-driven instabilities of cylindrical magnetized jets.

Chapter 2, which consists of the paper Ortuño-Macías and Nalewajko (2020), presents the results of 2D PIC simulations of radiative relativistic magnetic reconnection in pair plasma, where the steady-state was achieved by means of open boundaries, that allows for unimpeded outflows. We included radiation reaction due to the synchrotron process and we regulated the radiative cooling efficiency by the choice of initial plasma temperature. We confirmed the anti-correlation between plasmoid size and plasmoid velocities found in Sironi et al. (2016), hence small plasmoids are relatively fast and large plasmoids are slow. We observed that the relativistic outflows between plasmoids (minijets) have small contribution to observed radiation because of their low densities. We found that main contributors to the observed emission are large/slow plasmoids with the major part of the radiation originating from their central cores. The obtained synchrotron lightcurves show conspicuous signatures in the form of rapid bright flares that we identified as being produced at tail-on merger events between small/fast and large/slow plasmoids.

The second paper Ortuño-Macías et al. (2022), contained in Chapter 3, presents the results of 3D kinetic simulations of cylindrical relativistically magnetized jets populated with electron-positron pair plasma. Our simulation setup was designed to bridge between the two models considered before, the

pressure balanced configuration studied by Alves et al. (2018), and the force-free configuration studied by Davelaar et al. (2020), using a single parameter that defines how much pressure is asserted by the gas over the pressure and tension of the toroidal component of the magnetic field. We also investigated the effect of the power-law index of the radial profile of the toroidal magnetic field. We argue that the particle energy limit found by Alves et al. (2018) is due to the finite duration of the fast magnetic dissipation phase. For any of the configurations studied, we found a rather minor contribution of the parallel electric field (associated with guide-field magnetic reconnection events) to particle acceleration. In all investigated cases kink modes arise from the central core of the jet. In the gas pressure-dominated cases, we also observe a comparable contribution of the pinch modes. We argue that pressure-driven modes are important where enough gas pressure is produced by other dissipation mechanisms.