**Title**
Study of the non-relativistic astrophysical jet flows with the help of coupled MHD and PIC simulations : application to laboratory astrophysics experiments.

**Summary**
The acceleration of charged particles by magnetic fields embedded in a plasma is a major research topic in astrophysics. In addition to space observations, numerical and theoretical work, a recent development is the unexpected observation of high-energy particles in scaled, laboratory astrophysics experiments of MHD jet-like flows.
The PhD student will work on integrating a kinetic-ion module in our existing 3D MHD code and on building the simulations and theoretical framework to understand particle acceleration in these laboratory plasmas, and the implication for astrophysical plasmas.

**Context**
The acceleration of energetic charged particles is a universal phenomena in astrophysical and laboratory plasmas, and it is usually associated with events such as magnetized shocks, magnetic reconnection, or plasma disruption by instabilities. For example, cosmic rays with energies up to a few PeV are thought to originate in supernovae shocks through a combination of diffusive shock acceleration and streaming instabilities which greatly amplify the magnetic filed (Bell 2004). At much lower energies the turbulence in the ISM can locally accelerate particles by repeated scattering by magnetic inhomogeneities. Magnetic reconnection is another mechanism that may be responsible for the acceleration of these particles (Zweibel 2009). In the environment of young stars observations of polarized synchrotron emission in stellar jets indicate the presence of relativistic electrons. Although the acceleration mechanism is unknown, it is thought to be capable to accelerate low energy protons as well (carrasco-Gonzalez et al 2010). The existence of local sources of non-thermal particles in the environment of young stars has important consequences on the local chemistry and ionization of the molecular cloud, with fundamental implications for the coupling of magnetic field with the poorly ionized plasma, and thus on star and disk formation itself (Padovani et al 2014).
In addition to space observations, numerical and theoretical work, laboratory plasma experiments can also help to disentangle the physics of particle acceleration. A recent, yet theoretical unexplored new development, is the observations of energetic charged particles in scaled laboratory experiments of astrophysical jets (Suzuki-Vidal et al 2013). Time-integrated imaging and spectra indicate that high-energy protons with power-law distribution up to a few-MeV are accelerated during the evolution of these super-Alfvenic jets and are spatially localized in the regions where kink-like instabilities rapidly develop. Simulations have shown that these instabilities lead to a chaotic, time-varying magnetic field (Ciardi et al 2007), which may naturally lead to magnetic reconnection events or Fermi-type acceleration.

**Work and Applications** .
The focus of the PhD is to build the numerical tools and to develop the theoretical framework needed to fully investigate these exciting new results, and planned future experiments. This work has potentially far reaching implications in elucidating the mechanisms leading to particle acceleration in rapidly evolving MHD flows, in both space and laboratory plasmas.
The PhD student will work within a long-standing collaboration between the laboratories LERMA and LPP, and the experimental plasma physics group MAGPIE at Imperial College London, where the experiments are actually carried out.

**Method**
Much of our understanding of the acceleration of particles, their transport and related instabilities relies on numerical modeling done within the framework of kinetic particle-in-cell codes. However these models are limited to relatively short time- and length-scales, and are unable to provide a coherent picture of both the large-scale MHD dynamics and the small-scale physical processes. To capture the global evolution of these plasmas, a combination of kinetic-PIC and MHD techniques is thus necessary as demonstrated in the work of Bai et al 2015.
The PhD student will work on extending our existing single-fluid, two-temperature resistive MHD code GORGON. This code is extensively used to model high-energy density laboratory astrophysics experiments done on laser and pulsed-power installations.
The student will integrate in the code GOROGN the physics of a collisionless population of charged particles. This will involve the implementation of a parallelized, PIC (Particles In Cell) module which allows individual ion trajectories to be followed (electrons will stay as a neutralising fluid). The module will also include a self-consistent feedback of the particles on the magneto-fluid. Furthermore, the initial injection in the computational domain of low-energy, non-thermal particles (i.e. a seed ions which are then further accelerated) requires the exploration of different injection methods. Part of the student's work will be to develop appropriate models based on theoretical work, experimental data and kinetic-PIC simulations.
The experimental data can provide vital information on the spatial distribution of the magnetic field and its evolution, the ionic and electronic temperatures and flow velocities, spatial and energy data on the accelerated particles. Therefore, an important aspect of the student's work will be to develop the necessary synthetic diagnostics, for both the particle and fluid components of the plasma, to extensively compare the 3D simulations to the experimental data.

**Integration within the group**
The PhD student will join the eXtreme Laboratory Astrophysics group where work is carried out on a series of high-energy density laboratory astrophysics areas. These include accretion flows, shocks and related instabilities, protostellar jets, and ion streaming instabilities.

**Skills required**
The student should be comfortable with

- working at the interface between astrophysics and high-energy density plasmas physics
- programming, computer languages, Linux OS;
- written and oral English.

**Supervision**
The student will work under the supervision of Philippe Savoini (LPP, Ecole Poly. and UPMC) and Andrea Ciardi (LERMA, Obs. de Paris and UPMC).
Andrea Ciardi is an expert in the MHD modelling of high-energy density plasma with applications to astrophysics.
Philippe Savoini is an expert in the kinetic modelling of astrophysical non-relativistic plasmas.
The student will work in the eXtreme Laboratory Astrophysics group at LERMA, Sorbonne University on the Paris campus of Jussieu.