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Titre: Calculation of the Galactic gamma-ray and neutrino emissions at very high energies

The origin of very-high-energy (VHE) Galactic cosmic rays (CR) is one of the most important unsolved questions in particle astrophysics. We know that astrophysical particle accelerators in our Galaxy can accelerate CRs up to at least a few PeV, but the nature of these sources (called "PeVatrons") still remains elusive. Historically, supernova remnants – the remnants of stellar explosions – were thought to be the sources of these VHE CRs. However, in recent years, theoretical studies and observations have cast strong doubts over this assumption. In particular, the LHAASO Collaboration has now measured the VHE gamma-ray emission from our Galaxy above 100 TeV, allowing to place stringent constraints on the nature of PeVatrons. Several LHAASO measurements are intriguing, and new theoretical insights are needed to explain them. A number of alternative PeVatron candidates have emerged over the last few years, such as supernovae in dense winds, stellar clusters, or microquasars with their black holes and relativistic jets. Complementary constraints now exist thanks to the recent IceCube measurement of the diffuse VHE neutrino emission from our Galaxy.

Galactic CR propagation codes simulate numerically the injection and propagation of CRs in the Milky Way, and provide theoretical sky maps of the Galactic VHE gamma-ray and neutrino emissions, produced by the interaction of CRs with the interstellar gas. Our group is developing a new Galactic CR propagation code, which allows for a more realistic simulation of the Milky Way at VHE, thanks to two improvements compared with existing codes: First, the transient nature of PeVatrons is taken into account through stochastic injection of CRs in the Galactic disc; Second, CR propagation in the interstellar medium is treated through first principles, by calculating the individual trajectories of particles in 3D models of the Galactic magnetic field.

The PhD candidate will have the possibility to lead, and contribute to, the development of this new code, by implementing additional features (such as the gamma-ray emission from CR electrons, more realistic PeVatron characteristics/distributions in the Milky Way, or more realistic gas distributions, Galactic magnetic field models, etc.). The candidate will also use their code to make theoretical predictions under different scenarios and compare them with existing CR, gamma-ray and neutrino measurements, from e.g. LHAASO and IceCube experiments. This will allow them to place novel constraints on important unknown or poorly-known quantities, such as the frequency and distribution of PeVatrons in our Galaxy, the properties of the Galactic magnetic field and of CR propagation in the interstellar medium. The research topics are flexible and will be adapted to the PhD candidate's preferences. For instance, the candidate may choose to focus more on particle propagation by studying extended gamma-ray sources or the CR anisotropy, or the candidate may choose to focus more on studying particle acceleration mechanisms at given types of astrophysical sources. The candidate may also make predictions for KM3NeT, CTA and SWGO experiments.

A large fraction of the work will involve numerical simulations. Prior basic experience with programming in C (or Python, or Fortran) would be preferable, although not required.

An M2 internship is also welcome.