Neutron escape from microquasar jets

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Abstract / The launching mechanism and composition of astrophysical jets are still open problems. If relativistic protons are present in these jets, then energetic neutrons should be produced. Since neutrons are not affected by magnetic fields, they should escape the jet and decay outside. In this work we introduce the relativistic neutron component in the model of a microquasar jet. We find that observable signatures are too weak for current instruments, but a steady escape of secondary charged particles from the decay region might contribute to the population of Galactic cosmic rays.

Keywords / stars: jets — relativistic processes

1. Introduction

Astrophysical jets are collimated flows of matter and radiation. They are present in several astrophysical sources such as active galactic nuclei, microquasars (MQs), and gamma-ray bursts. The launching mechanism and composition of these jets are still not well understood. One approach to study the composition of these systems consists in modelling the spectral energy distribution that different particle populations in the jet would produce. Previous works (e.g., Pepe et al., 2015) usually include mainly relativistic protons and electrons. Neutrons, however, would be produced by the interaction of energetic protons with ambient ones. The dynamics of this component is different from that of charged particles, because neutrons do not interact with the magnetic field that collimates the flow. Therefore, they may escape freely, decaying outside the jet, and possibly giving rise to a rich phenomenology. In this work, we introduce the neutron component in MQ jet models, and explore the observable consequences.

2. General scheme

Our jet model is based on that of Romero & Vila (2008). We consider a lepto-hadronic model in which relativistic protons and electrons of energy E_i are injected in the jet at a rate $Q_i(E_i) \propto E_i^{-\alpha} \exp(-E_i/E_{\max,i})$, for $i = e, p$, with maximum energy $E_{\max,i}$ and spectral index α. The fraction of the jet kinetic power in relativistic particles is 10%, most of which is carried by protons. Protons radiate via synchrotron and pion decay from proton-proton collisions. Relativistic neutrons are introduced through the interaction channel $p+p \to p+n+\pi^+ +(...)$. Charged-particle populations may evolve also through escape and advection, whereas neutrons may escape and decay. The steady spectral density for the three species is obtained by solving the system of three coupled transport equations, as described in Escobar et al. (2018).

Almost all neutrons escape from the jet. These free neutrons inject energetic particles in the interstellar medium (ISM) through beta decay, following an exponential law in distance from the source. We study the propagation and emission of these particles considering synchrotron radiation of electrons, proton-proton inelastic collisions with the ambient medium, as well as diffusion and thermalization by coupling with matter and waves in the ISM.

3. Results and conclusions

We apply the model to a typical microquasar system (Cygnus X-1, e.g., Pepe et al., 2015). Neutrons carry only about 10^{-7} of the power of the jet, and decay at typical distances of $10^{16} - 10^{17}$ cm, far from the source (whose typical size is $\sim 10^{12} - 10^{13}$ cm). As the jet bulk velocity is non-relativistic (Lorentz factor $\Gamma \sim 1.25$), we consider the neutron flux to be spherically symmetric. Because of the low ISM magnetic field ($\sim 10^{-5}$ G), the synchrotron spectrum of secondary electrons peaks at a much lower energy than that of the jet. However, even at low energies the jet flux is still higher, and secondary-electron emission would not be observable. The main energy-loss mechanism of secondary protons is elastic Coulomb scattering, producing no radiation.

Both secondary protons and electrons travel long distances before cooling. Therefore, they would escape from the system with some fraction of their initial energy, and propagate through the interstellar medium. This result suggests that microquasars may be cosmic-ray sources (cf. Heinz & Sunyaev, 2002). Future work will focus on the main features of this cosmic-ray population, and its impact on the surrounding medium.

References

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