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Dissertation Summary

Nonthermal Emission and Particle Acceleration in Protostellar Jets

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Since the first studies at radio frequencies in star-forming regions, the emission of jets ejected by young stellar objects (YSOs) has been exclusively considered to be of thermal origin. The presence of a nonthermal component in this kind of jet is a recent and outstanding discovery, which implies the existence of relativistic particles interacting with magnetic fields. This in turn requires the action of a mechanism able to efficiently accelerate particles in these low-energy systems.

The aim of this dissertation is to present the main results obtained during my PhD research, devoted to deepen the understanding of this topic through a multifrequency study of the radio continuum emission of two emblematic YSOs with different masses: (1) the triple radio continuum source in Serpens (intermediate mass), the first YSO for which the presence of synchrotron emission has been proposed Rodriguez et al. (1989); and (2) The system HH 80–81 (high mass), one of the most powerful protostellar jets known, and the only one (so far) for which linearly polarized centimeter emission has been detected (Carrasco-González et al. 2010), thus confirming the synchrotron origin of the radiation. The study of these objects was mainly based on new high-sensitivity data obtained with the Karl G. Jansky Very Large Array radio interferometer from the National Radio Astronomy Observatory (NRAO), in a wide range of wavelengths (3–20 cm). In both cases, radio continuum images and spectral index maps (α, with $S_\nu \propto \nu^\alpha$, being S the flux density at the frequency ν) allowed to characterize the emission nature in different regions and structures of the jet, i.e., being $-0.1 \leqslant \alpha \leqslant +0.6$ consistent with partially optically thin free–free emission (Reynolds 1986), and $\alpha < -0.1$ associated with optically thin synchrotron emitters in star-forming regions Rodriguez et al. (1993). The results were analyzed in the context of particle acceleration, exploring the possible scenarios to produce diffusive shock acceleration (DSA) in strong shocks of the jet with the ambient medium. A detailed discussion can be found in Rodríguez-Kamenetzky et al. (2016) and Rodríguez-Kamenetzky et al. (2017).

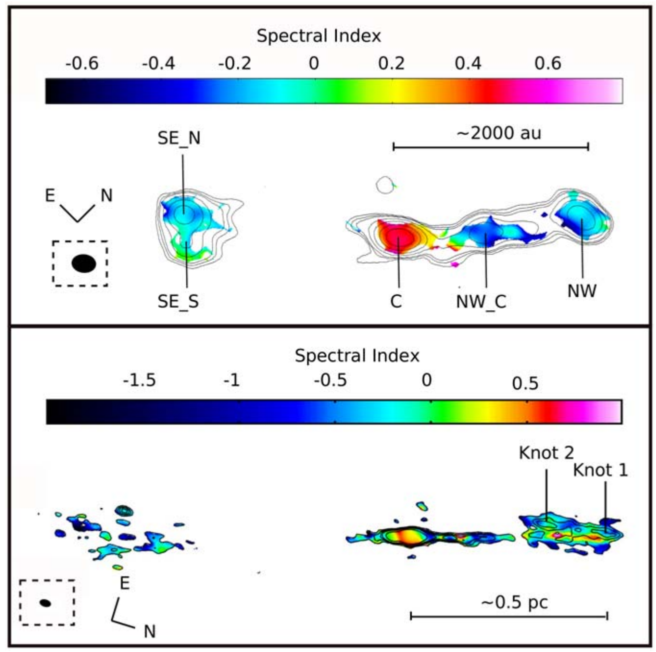

Figure 1. Upper panel: the triple source in Serpens. Combined radio continuum emission at 13, 6, and 3 cm (contours) over a spectral index map (color scale). The beam size is 1.07″ × 0.80″ (PA of-58°). The central source, C, and the radio knots are labeled. Bottom panel: the HH 80–81 jet internal region (up to 0.5 pc from its driving source). Combined radio continuum emission at 20, 13, and 6 cm (contours) over spectral index map (color scale). The beam size in 2.37″ × 1.46″ (PA = 4°). Figures are adapted from Rodríguez-Kamenetzky et al. (2016) and Rodríguez-Kamenetzky et al. (2017).
(A color version of this figure is available in the online journal.)

The triple source in Serpens: the spectral analysis revealed a clear difference in the emission nature of the jet itself and its driving source (nonthermal and thermal, respectively); see Figure 1, upper panel. The **HH 80–81 jet:** high-resolution images revealed morphological characteristics that resemble those observed in relativistic jets, e.g., a highly collimated region ending in an extended lobe-like structure,

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with presence of high-intensity knots (hot spots). In addition to this complex structure, the mixed distribution of spectral indices indicates the existence of both thermal and nonthermal emission. The hot spots present in the lobe-like structure (knots 1 and 2 in Figure 1, bottom panel) revealed their nonthermal nature.

In both cases, the radio knots trace interactions of the jet with the ambient medium, that give rise to two shocks: one moving downstream (forward shock), and one moving upstream (reverse shock or Mach disk). By analyzing the physical conditions given in each systems, it was found that the Mach disk could be a nonradiative shock and produce efficient particle acceleration via DSA, under certain conditions (see Rodríguez-Kamenetzky et al. 2016, 2017). Complementary studies in the Herbig-Haro objects HH 80 and HH 81 are consistent with the formation of a radiative frontal shock, and an adiabatic reverse shock (Rodríguez-Kamenetzky et al. 2018).

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