Protostellar jets: Numerical modeling and observational studies

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by

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Abstract

Protostellar phase is one of the earliest phases of star formation. The most important observational signature associated with this phase is the ejection of powerful bipolar jets/outflows. These jets are presumed to be the entities that enable protostellar accretion to proceed by removing excess angular momentum from the innermost radii of accretion disks. Since these jets are a by-product of accretion, various signatures of the protostellar accretion process are imprinted on the geometry, velocity structure, and symmetries of jets, which makes them powerful probes of various aspects of star formation. Large parsec-scale jets could also provide constraints on the mass-loss histories of their driving sources. Studying these jets could therefore open up an indirect window of knowledge into the evolutionary stages and activities of the protostar driving these jets.

Protostellar jets can be observed from radio to X-ray wavelengths both as continuum and spectral line emission which enable us to trace the dynamics as well as their physical and chemical conditions. However, since protostellar jets are associated with young forming stars which are enshrouded in vast amount of gas and dust, they have been extensively studied in the longer wavelengths most suitably in radio since the effect of extinction is minimal in this wavelength regime. In the first part of this thesis, our aim is to develop a numerical model to describe the radio spectra of protostellar jets. Radio continuum observations of ionized protostellar jets have shown the presence of thermal free-free emission and non-thermal synchrotron emission mechanism at play. We have therefore developed a model that incorporates both these emission mechanisms. The model flux densities include contribution from an inner thermal jet, and a combination of emission from thermal and non-thermal distributions along the edges and extremities, where the jet interacts with the interstellar medium.

We then characterize the model by carrying out a detailed investigation of the dependence of the model spectrum on the jet parameters. For each of these cases, we have calculated the turnover frequencies of the spectra and corresponding spectral indices between these turnovers, and we have carefully analyzed the behavior of these two features with variations in the model parameter values. We then discuss the potential of the model to explain the observed radio spectra of various protostellar jets and the model has been implemented to estimate physical and micro-physical parameters of these jets. The sample

of few protostellar jets to which we have applied the model are HH80-81 jet, jet driven by the young stellar object (YSO) G114.0835+02.856 and DG-Tau jet, and we have fitted the model to the observational data of these jets. For all these sources, the best fitting parameter values were estimated by χ^2 minimization.

In the second part of this thesis, we have carried out a detailed observational study of the largest known protostellar jet in the Galaxy, the HH80-81 jet, in the near-infrared (NIR) wavelengths. Here, we have explored the partially ionized and molecular regions of the jet for understanding the jet properties and estimation of its physical parameters. For this, we have utilized the emission from shocks generated by these supersonic jets. Shocks associated with jets can be best studied using emission lines in the NIR wavelength. We have, for the first time, carried out a combined 2.122 μm H_2 and 1.644 μm [Fe II] imaging followed by detailed qualitative and quantitative analysis of the HH80-81 jet. The observations were carried out using the Wide-Field Camera (WFCAM) mounted on the 3.8 m United Kingdom Infrared Telescope (UKIRT). In addition to the narrow-band filters, we have also imaged this region in the broad-band NIR J, H and K filters and the mid-infrared (MIR) L′ and M′ filters.

The morphology of emission in shock tracers can provide a resourceful gauge to examine the interaction of the jet with the ambient medium. Molecular H_2 emission is an indicator of low velocity weak C-shocks whereas, [Fe II] emission is widely used to understand fast and dissociative J-shocks caused by jets with velocities larger than 50-80 kms^{-1}. From the observed morphology of knots aligned along the jet, we segregated strong and weak shocks, and the prevalence of [Fe II] emission in the majority of knots suggests an overall dominance of strong dissociative J-shocks throughout the jet, even up to the farthest knots in the jet's southern arm. The measured H_2 and [Fe II] fluxes of the knots are in the range $0.4 - 5.2{\times}10^{-14}$ erg s^{-1} cm^{-2} and $3.1 - 13.6{\times}10^{-14}$ erg s^{-1} cm^{-2}, respectively. Following this, we used the [Fe II] luminosities to estimate mass-loss rates of the atomic component of the jet which is in the range $3.0 \times 10^{-7} - 5.2 \times 10^{-5}$ M$_\odot$ yr^{-1}. For the knots close to the central source, the values are consistent with those obtained from other tracers such as molecular gas using CO, and radio emission from ionized gas towards the central region of this jet system. The mass-loss rates of knots are also larger than those from jets of low mass YSOs ($10^{-10} - 10^{-7}$ M$_\odot$ yr^{-1}), but comparable to the [Fe II] mass-loss rate from few massive YSOs ($10^{-7} - 10^{-4}$ M$_\odot$ yr^{-1}). Additionally, the H_2 emission features identified in the central jet region include multiple groups of knots aligned linearly along outflows/jets previously identified as well as bow/arc shaped structures indicating the bow shocks arising from winds driven by two YSOs in the neighborhood of the driving source.