Multiwavelength study of parsec scale outflows associated with low mass young stellar objects

Irena Stojimirovic, *University of Massachusetts Amherst*

Abstract

A multi-wavelength, multi-telescope observational study of recently discovered parsec-scale Herbig-Haro flows associated with the earliest stages of low mass protostellar formation is presented. Improvements in optical observational capabilities allowed the discovery of the new class of parsec scale HH flows. Similar improvements at millimeter wavelengths allowed for faster, more sensitive mapping at multiple frequencies of parsec-scale outflows in nearby protostellar regions. ^ Using the availability of large-format heterodyne arrays at millimeter wavelengths and the availability of "on-the-fly" mapping capabilities at the FCRAO 14 m telescope, a sensitive, fully sampled survey of fifteen parsec-scale HH flows has been completed in ^{12}CO and ^{13}CO J=1→0 over their full extents. A smaller subset of these sources has been observed in ^{12}CO J=3→2 at the HHT 10 m telescope. Complementary optical data are also available for most sources. The use of the combined millimeter and submillimeter CO isotopic transitions allows a better determination of the physical characteristics of outflows, such as mass, energetics, and excitation temperature. The combination of CO and optical data provides morphological relation between different tracers of the shock processes that arise during the interaction of the material launched from the star with its surrounding ambient cloud. By comparing the observational findings to theoretical predictions different outflow entrainment models are distinguished. ^ The outflow sources L1551 and L1228 are found to possess molecular outflow over the full parsec-scale HH flow extent, whereas outflows in Haro 6-10 and L1617 do not. We also study molecular parsec scale outflows in NGC 2071 region who show only single HH object but are associated with parsec-scale H_2 shocked emission. Comparing the observational characteristics of the outflows to the characteristics of different jet and wind driven theoretical models we find that many outflows have features characteristic of both types of models. The main outflow in L1551 region has M(v) spectral indices and position-velocity features characteristic of the jet entrained outflows, while its low-velocity shell-like morphology is associated with wind models. L1228 is an interesting outflow with two asymmetric outflow lobes. M(V) indices point toward jet entrainment while position-velocity plots are inconclusive. Both outflows in L1228 and L1551 are very energetic and have a strong impact on their host cloud. The outflow activity in the L 1551 has triggered formation of new stars while outflow in L1228 has set its cloud core into motion. Our sensitive mapping allowed us to discover outflow in the Haro 6-10 which has a poor molecular flow with jet-like characteristics. We also report two new outflows in NGC 2071 and we find many features of the main NGC 2071 outflow to be best explained by jet driven models. Since neither theoretical model can produce all of the observed outflow features and both jet and wind features are often present in the same outflows, our results support the growing notion that there must be a unified model for the outflows where jet and less collimated component are coexistent at all time. ^

Subject Area

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