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Studying the Outflow-Core Interaction with ALMA Cycle 1 Observations of the HH46/47 Molecular Outflow

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Abstract. We present preliminary analysis of ALMA cycle 1 12m array ^{12}CO /^{13}CO /C^{18}O data of the HH 46/47 molecular outflow. ^{13}CO and C^{18}O trace relatively denser outflow material than ^{12}CO and allow us to trace the outflow to lower velocities than what it possible using only the ^{12}CO emission. Interestingly, the cavity wall of the red lobe can be seen at velocity as low as 0.2 km/s. Using C^{18}O, we are now able to estimate the optical depth of ^{13}CO, and then use the corrected ^{13}CO emission to further and better correct the ^{12}CO emission and estimate the mass, momentum, and kinetic energy of the outflow. Moreover, C^{18}O reveals a flattened rotational structure at the center, likely to be a rotational envelope infalling onto an inner Keplerian disk.

The outflow feedback on the protostellar core may be responsible for finally dispersing it and setting the core-to-star efficiency. Therefore it is crucial to accurately estimate the mass, momentum and kinetic energy of the outflow, especially at low velocities where the data often suffers from high CO opacities. Here we present ALMA cycle 1 12m array data of the HH 46/47 molecular outflow driven by a low-mass Class 0/I source at 450 pc. ALMA cycle 0 observations of ^{12}CO(1-0) showed that the molecular outflow is formed by the entrainment of the gas by a jet and/or a wide-angle wind (Arce et al. 2013). ^{13}CO and C^{18}O trace relatively denser and slower material than ^{12}CO and are only detected within ~1 km/s from the cloud velocity (Figure 1). This allows us to trace the outflow to lower velocities than what it possible using only the ^{12}CO. Interestingly, the cavity wall of the red lobe can be seen at outflow velocity as low as ~0.2 km/s. Furthermore, using C^{18}O we are able to study the dependence of the ^{13}CO opacity on velocity.

The second panel of Figure 2 shows the emission ratio between these tracers, which is close to 0 when optically thick, and reach the abundance ratio of two tracers when optically thin. We can see that ^{13}CO is optically thick within ~ 0.8 km/s. The corrected ^{13}CO emission is then used to further and better correct the ^{12}CO emission (first panel of Fig. 2) and estimate the mass spectrum of the outflow (right four panels). Such correction significantly increased the estimated outflow mass within about 4km/s. With the high sensitivity and resolution we actually are able to study such velocity dependence of opacities for each sub-region (central part, extended outflow, etc.). In addition, C^{18}O reveals a flattened rotational structure around the central source, likely to be a rotational envelope infalling onto an inner Keplerian disk. With the full data set (which includes 12m array, ACA and total power data of ^{12}CO, ^{13}CO and C^{18}O)

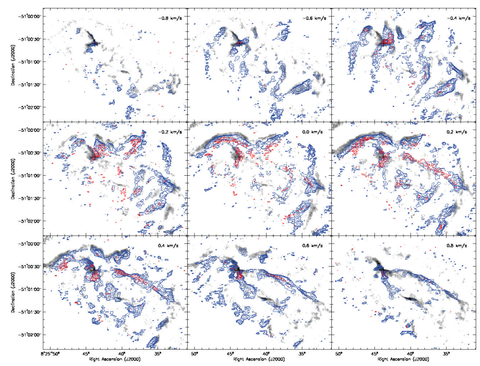

Figure 1. Channel maps for ^{12}CO (grey), ^{13}CO (blue), and C^{18}O (red). The synthesized beams are $1.47'' \times 1.42''$ for ^{12}CO, and $3.1'' \times 1.6''$ (PA=-85°) for others.

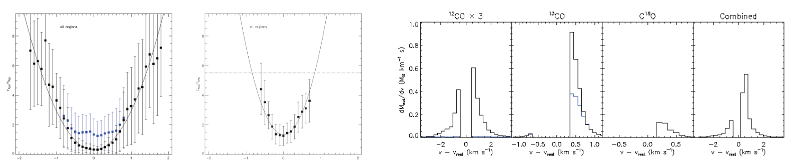

Figure 2. The left two panels show the ^{12}CO/^{13}CO and ^{13}CO/C^{18}O brightness temperature ratios which are used to estimate the opacities. Blue and black data points in the first panel are before and after correcting ^{13}CO opacities. The line is a polynomial fit which allows to extend the correction to higher velocities where not every tracer is detected. The right panels show gas mass in unit velocity interval) estimated from different tracers (note the ^{12}CO curves are scaled up by 3) and combined. Blue and black are before and after opacity corrections. [H_2]/[^{12}CO]=10^4, [^{12}CO]/[^{13}CO]=62, [^{13}CO]/[C^{18}O]=5.5, and $T_{\rm ex}$=15K are assumed.

soon to be obtained and analyzed, we expect to have a better understanding of how this outflow interacts with and even eventually disperses its parent core.

References

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