

Molecular Outflows Driven by Young Brown Dwarfs And VLMs. New Clues from IRAM Interferometer Observations

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Abstract. The outflow phenomenon is ubiquitous in star forming regions and is now known to play an important role in the formation of both young stellar objects (YSOs) and brown dwarfs (BDs) (Whelan et al., 2012). Observations of outflows from both stars and BDs are thus essential to our understanding of the overall star & planet formation process. In 2011 and 2012 we conducted a survey with the IRAM 30 m telescope of the CO emission in the vicinity of a large sample of BDs and VLMSs to check for molecular outflows. We followed up three of the most remarkable sources namely MHO 5, BD Tau 6 and FU Tau A with high angular resolution observations with the Plateau de Bure Interferometer (PdBI). These sources were chosen because their associated CO emission showed clear evidence of an outflow and / or their spectral energy distributions (SEDs) showed strong evidence of a massive accretion disk, that we postulate to be associated with an outflow. In this paper, we present the first results of our CO(1-0) PdBI investigations of the molecular outflows of 2 of these sources, MHO5 and BD Tau 6. The signal to noise ratio on FU Tau is 3 times less than on the other sources and the results need more investigation.

1. Observations

Observations have been performed on the IRAM interferometer on a shared tracks basis from July to November 2012, with 5 or 6 antennas in a rather compact configuration, yielding a spatial resolution of $2.5''$. The cumulated time on tracks for the 2 sources presented here was 4.8 hours with 5 antennas and 3.2 hours with 6 antennas. The median sensitivities are for 0.192 MHz channels and 2 polarisations. The sensitivity reached in 156 kHz channels is 16.8 mJy. For MHO5, the best sensitivity is achieved in the 5.3 to 3.8 km/s range, and for BD Tau 6, in the 8.8 to 7.3 km/s range.

2. Results and Discussion

In figure .1 and .2, we show velocity integrated maps of the emission of the $^{12}\text{CO}(1-0)$ line observed on MHO5 and BD Tau6. On each image, the central star symbol is placed at the position of the BD, and we show in the upper right corner the CO line at the central position to emphasise the velocity ranges where we have integrated the blue & red emission.

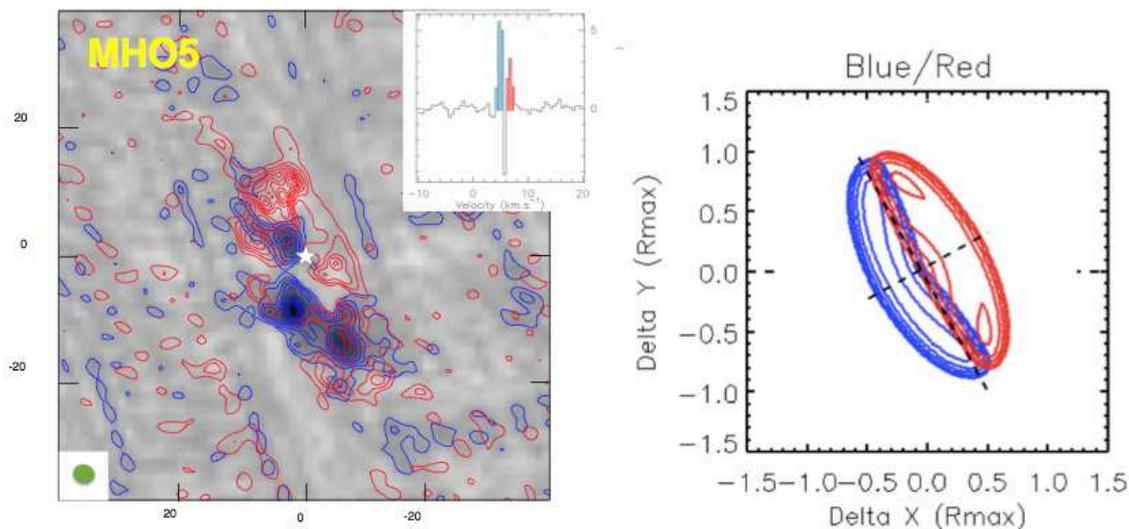


Figure .1: Left: image of the integrated emission in the velocity range Blue: 4 - 5.5 km/s and Red: 6 - 7.5 km/s for MHO5. In each colour, the contours are from 20% to 90% of the max (Blue: 0.15 Jy/beam; Red: 0.17 Jy/beam) by 10%; Right: Optically thin, density scalable model of the MHO5 flow, using a 85° opening angle cone oriented at 65° toward the observer. North is up, East is to the left.

MHO5: the source line shows at a velocity close to the one of the surrounding extended cloud emission (≈ 6 km/s), and the central velocity channel is suppressed by the interferometer. This is not a real problem as the signal we are looking for is the one in the wings, well outside from the cloud emission. The velocity integrated blue and red emission appear

distributed on an ellipsis with lobes symmetrical with respect to the central source. This result is more complex although apparently consistent with the one of Phan-Bao (2011). The estimated mass in each of the blue / red lobes is $\approx 2 \cdot 10^{-5} M_{\odot}$. We model the MHO5 emission in the form of a cone oriented at 65 degree in the plane of the sky. Such an almost edge-on situation could explain why MHO5 is so dim, and it could also explain the low radial (blue-shifted) velocity of the OI6300 line of ≈ 20 km/s. We downloaded this HIRES spectra from the Keck Observatory Archive (KOA), and the spectra were reduced using standard IRAF routines. This spectra was originally discussed in Muzerolle et al. 2003, and we discuss here for the first time the radial velocity of [OI]6300 line.

Many questions remain concerning the validity of our model, as we use a cone with an opening angle $\approx 80 - 90^{\circ}$, i.e. almost along the plane of the disk.

BD Tau 6: the integrated blue and red emission lobes are almost superimposed at $\approx 10''$ to the SW from the central source. This result is surprising, and is already visible on our lower spatial resolution results obtained during our 30 m observations. The geometry of the emission is difficult to reconcile with an outflow originating from the central source. We have estimated the integrated column density present in each of the blue / red emission on BD Tau 6, and find $\approx 6 \cdot 10^{-6} M_{\odot}$ of H_2 gas in each lobe. Such a value is of the order of what was observed in FU Tau by Monin et al. (2013).

In none of the two sources we detect the continuum emission. The upper limit reached from the sensitivity of these observations is consistent with the one published by Schaefer et al. 2009 (7.8 mJy @ 2.6 mm).

More complete results will be published in a forthcoming paper (Monin et al., 2014).

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References

- Monin, J.-L., Whelan, E. T., Lefloch, B., Dougados, C., & Alves de Oliveira, C. 2013, A&A, 551, L1
- Monin, J.-L., et al., 2014, in prep
- Phan-Bao, N., Lee, C.-F., Ho, P. T. P., & Tang, Y.-W. 2011, ApJ, 735, 14
- Whelan, E. T., Ray, T. P., Comeron, F., Bacciotti, F., & Kavanagh, P. J. 2012, ApJ, 761, 120
- Schaefer, G. H., Dutrey, A., Guilloteau, S., Simon, M., & White, R. J. 2009, ApJ, 701, 698

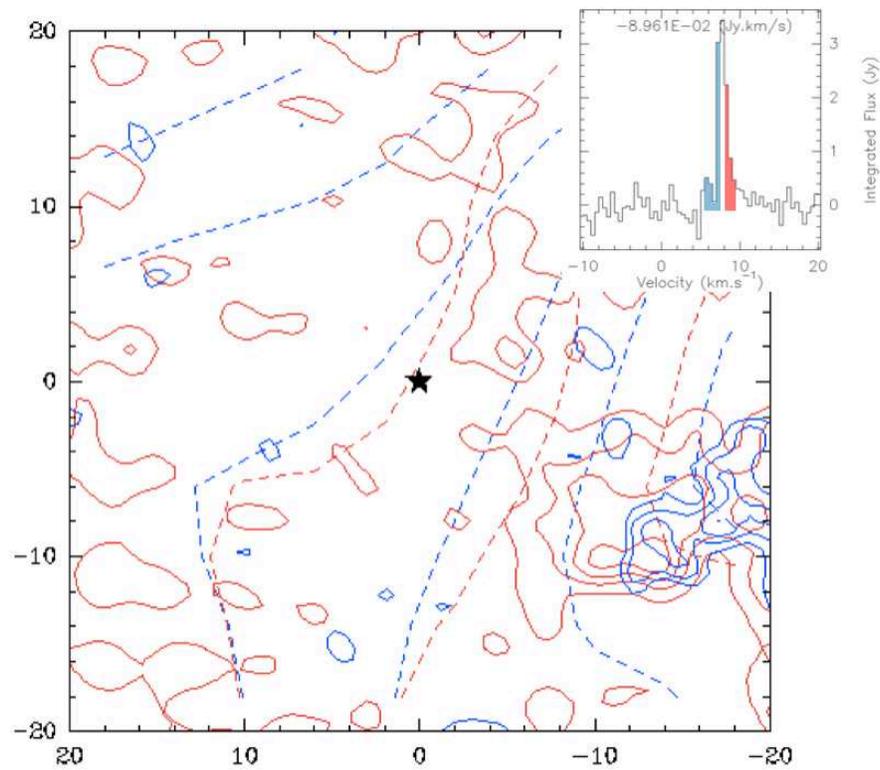


Figure .2: Superimposition of 30 m (dashed lines) and PdBI (solid lines) integrated emission in the same velocity range: Blue 6 - 7.5 km/s and Red 8 - 9 km/s for BD Tau 6. In each colour, the contours are from 30% to 90% of the max (Blue: 0.05 Jy/beam; Red: 0.09 Jy/beam) by 20%.



Ruth Angus (left) and Sarah Ballard during the Grand Canyon outing on Wednesday afternoon.

