The interaction between giant Herbig-Haro flows and their surroundings

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Abstract

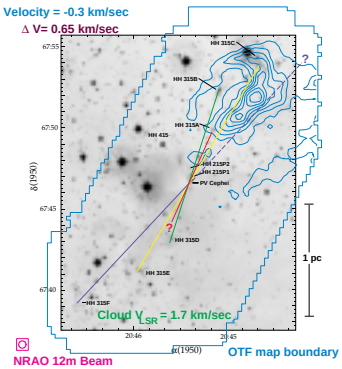
Using the on-the-fly (OTF) mapping technique with the NRAO 12m telescope, we observed a great extent of the molecular gas surrounding two giant Herbig-Haro (HH) flows. Most conventional molecular outflows studies are constrained to the immediate vicinity of the molecular outflow lobe and do not study the overall cloud gas around it. We used the advantages of the OTF technique in order to observe two molecular outflows and a large extent of their surroundings, using the CO(2-1) line, with high resolution and signal to noise, in a relatively small amount of time.

The map of the giant HH flow HH315, driven by the star PV Cephei (at a distance of 500pc) is 2 x 3.6 pc. The OTF map of the HH300 outflow, driven by IRAS 04239+2436 in B18w cloud, in Taurus, (at a distance of 140 pc) only includes the redshifted lobe, and it is 0.4 x 1.5 pc. **By observing, with high sensitivity, a bigger area than what it is usually observed of the molecular gas surrounding HH flows, we are able to study the overall effects the HH flows have on the surrounding gas in a more complete way.**

Giant Outflow HH315 from PV Cephei

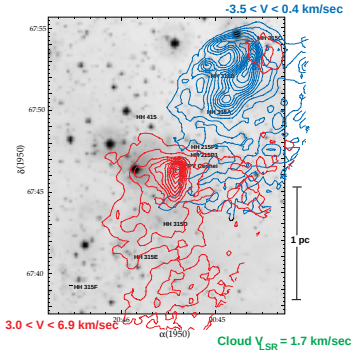
CO(2-1) data from on-the-fly mapping using NRAO 12m, overlaid on Hα + S[II] image*

Single Channel Map of HH 315 Outflow



CO (2-1) intensity contours of a single channel (velocity = -0.3 km/sec). The first contour, and all steps are 0.5 K. Notice the nice bow-shock shape the CO(2-1) emission has at this velocity, and the fact that it is coincident with the position of HH315C. Also, notice how the molecular outflow extends beyond the map boundary. HH315 is a precessing outflow, composed of several episodic outbursts. Here we show what we think are the outburst pairs. Notice how HH315A does not have a corresponding blue knot pair. We speculate that is not seen due to extinction. The corresponding red knot pair of HH315F is also missing from the optical image. This unseen knot could be responsible for the high velocity gas in the northwest corner of the map.

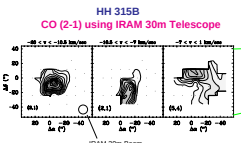
Integrated intensity contours of HH315 CO(2-1) Outflow Blue and Red-shifted lobes



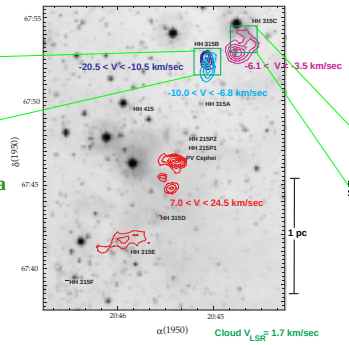
Integrated intensity contours of CO(2-1) are shown. The velocity range of integration is shown in the same color as the integrated intensity contours. The first contour is 1.5 K km/sec and steps are 1 K km/sec. Notice the redshifted gas near HH315C. This is most probably due to prompt entrainment by a bow shock, and the fact that this outflow's axis is almost parallel to the plane of the sky.

CO (2-1) Integrated Intensity High-Velocity Components of the HH315 Outflow

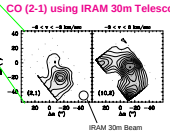
HH 315B
CO (2-1) using IRAM 30m Telescope



High Resolution CO(2-1) Data of HH315C and HH315B using IRAM 30m



HH 315C
CO (2-1) using IRAM 30m Telescope



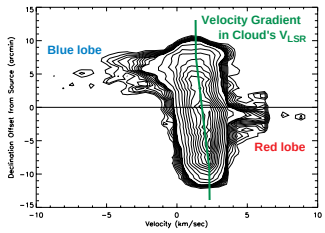
Integrated intensity contours of CO(2-1) are shown. The velocity range of integration is shown in the same color as the integrated intensity contours. The first contour and all steps are 0.5 K km/sec. Notice how most contours are right on top of an optical HH knot. The cloud's local standard of rest (LSR) velocity is given in green. The squares around HH315B and HH315C denote the area observed with the IRAM 30m telescope.

Using P-V diagram on right:

1) We detect a 1.4 km/sec/pc gradient in the cloud along the outflow's major axis presumably caused by the outflow

2) $\rho_{high} V_{low} = \rho_{low} V_{high}$

Position-Velocity Diagram of HH315 Outflow

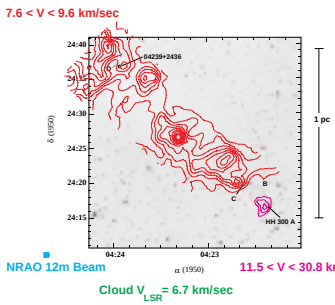


The position-velocity (PV) diagram obtained by integrating the spectra of a 12' wide strip along the major axis of HH315 (P.A.=-26 deg). Contours are at 1,1.5,2, 2.5,3,3.5,4,4.5,5,5.5,6,10,15,20,25,30,35,40,45,50,55,60,65 K km/sec. The horizontal line at zero denotes the position of PV Cephei along the cut. The green line is a fit, by eye, to the velocity value of the peak contour. It appears that the outflow has managed to modify the bulk motion of the cloud, a necessary step in the clearing of the gas surrounding the young star.

Giant Outflow HH300 in Taurus

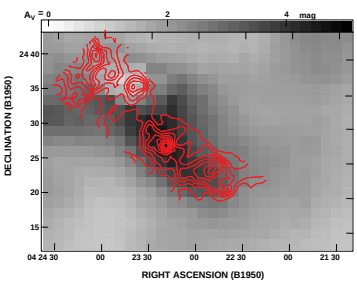
CO(2-1) data from on-the-fly mapping using NRAO 12m, overlaid on Hα + S[II] image* and A_V image

CO (2-1) Integrated Intensity Contours of the Red-Shifted Lobe of the HH300 Outflow



Integrated intensity contours of CO(2-1) are shown. The velocity range of integration is shown in the same color as the integrated intensity contours. The first red contour value is 2 K km/sec, and steps are 1 K km/sec. The first magenta contour is 0.5 K km/sec, and steps are in 0.5 K km/sec. Notice how the magenta contour is right on top of HH300A and how their is a maximum in the red integrated intensity contours on top of HH300C. The cloud's LSR velocity is given in green.

Outflow Aligned with Dark Cloud's Major Axis



Could it be that dust entrained by the outflow has created an enhancement in the extinction along the outflow axis, or is it just coincidence?

What do you think???

Integrated intensity contours of CO(2-1) are shown overlaid on an optical extinction (A_V) greyscale map. The contours show the redshifted lobe of the HH300 outflow integrated over 7.6 < V < 9.6 km/sec. The extinction map was obtained using IRAS 100 and 60 micron images. The extinction "hole" on the upper left corner of the greyscale map is not real, it is caused by the presence of an IRAS source (IRAS 04239+2436, this outflow's source).

Preliminary Results

1) This is the first time that HH300 has been mapped in CO, and the first time that HH315 has been fully mapped in CO(2-1). We find the HH315 outflow to be bigger than was originally thought.

2) Both molecular outflows have density-velocity structure suggestive of their being formed by (bow-shock) prompt entrainment.

3) Both molecular flows have a mass which is 10 to 20% that of the mass of the ambient gas in the same area where the flow lies.

4) We find unresolved high-velocity components in CO(2-1) at the same position as several of the optical HH knots. In particular, the IRAM 30m data shows very interesting position and velocity structure in both HH315B and HH315C.

5) From the position-velocity diagram of HH315 it is evident that the outflow has modified the velocity structure of the cloud.

6) We find that HH300's redshifted lobe is aligned to its parent dark cloud's major axis. Is this coincidence, or the outflow's doing?

More information available at:
http://www-cfa.harvard.edu/~harce/thesis

* CCD image from Reipurth et al. 1997, AJ, 114, 278