Uncovering episodic outflows and their feedback in protostellar clusters

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Motivation

Outflows are a bridge for feedback from individual protostars to their nascent cluster environment.
Outflow morphology and efficiency of momentum transfer between jet-outflow-cluster likely determine the extent to which outflows provide significant feedback to regulate ongoing star formation.

Here we present a case study of the protostellar cluster Serpens South:
- Early, active phase of star formation
- Low- to intermediate-mass protostars
- Relatively nearby, d = 415 pc

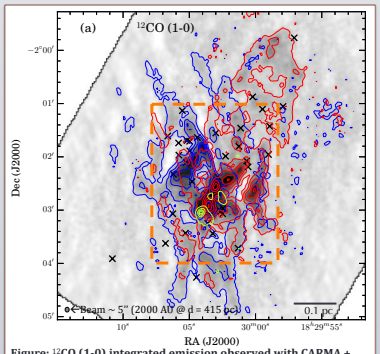


Figure: ^{12}CO (1-0) integrated emission observed with CARMA + IRAM (Plunkett et al. 2015a). For mass, momentum, and energy calculations, ^{13}CO was also critical to correct for optical depth of the ^{12}CO line; we used ^{12}CO J=1-0 and J=3-2 (from CSO observations) to estimate excitation temperature. Identifying individual outflows required follow-up at higher resolution and sensitivity with ALMA.

Observational Objective

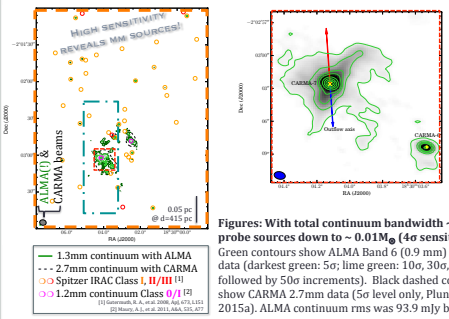
Can we identify individual outflows within such a complex region (see previous observations to left), while still recovering extended outflow and cloud emission?

ALMA has the valuable capability to observe the same region with its different arrays – **12-m, 7-m, and Total Power (TP)** – hence probing different spatial scales that in this case correspond to the sizes of cores and outflow structure (hundreds of AU) to clusters (few parsec).

Band 6 ALMA Observations

Array	Date	Pointings	Primary beam/FOV	Angular resolution
12-m	2014 Mar	137	25.3"	1.0"x0.6"
7-m	2014 Jan-Jun	53	43.3"	7.7"x4.3"
Total Power	2015 Aug	[map]	3' x 4'	28.25"

A case study: CARMA-7 is the brightest continuum source in Serpens South, and it is located in a dense region where the protostar fraction reaches ~90%.



Figures: With total continuum bandwidth ~1 GHz we probe sources down to ~ 0.01M$_\odot$ (4σ sensitivity). Green contours show ALMA Band 6 (0.9 mm) continuum data (darkest green: 5σ; lime green: 10σ, 30σ, 50σ, 70σ, followed by 50σ increments). Black dashed contours show CARMA 2.7mm data (5σ level only, Plunkett et al. 2015a). ALMA continuum rms was 93.9 mJy bm^{-1}.

An episodic, bipolar outflow: 22 outflow ejecta comprise an episodic, bipolar outflow north-south of CARMA-7.

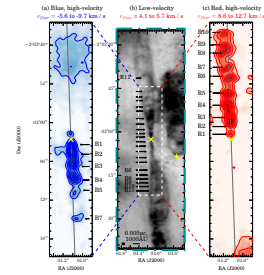


Figure: ^{12}CO (2-1) moment map of CARMA-7 outflow. Lower-velocity (b) outflow forms a cavity around high-velocity (a, c) bullet-like ejecta. We achieved a ^{12}CO RMS of 9 mJy beam^{-1} ch^{-1} (channel width of 0.16 km s^{-1}).

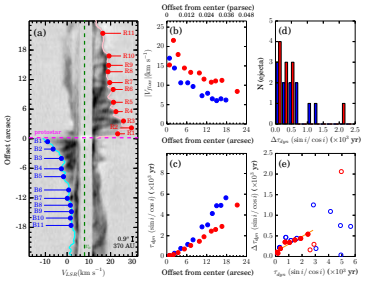


Figure: (a) PV map along outflow lobes, with 22 ejecta identified. Panels (b-e) show trends among ejecta: specifically related to outflow velocity (V_{flow}), dynamic timescale (τ_{dyn}), and the time since previous ejection ($\Delta\tau_{dyn}$).

Rotating, infalling envelope

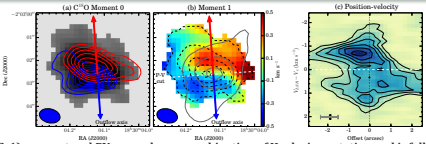
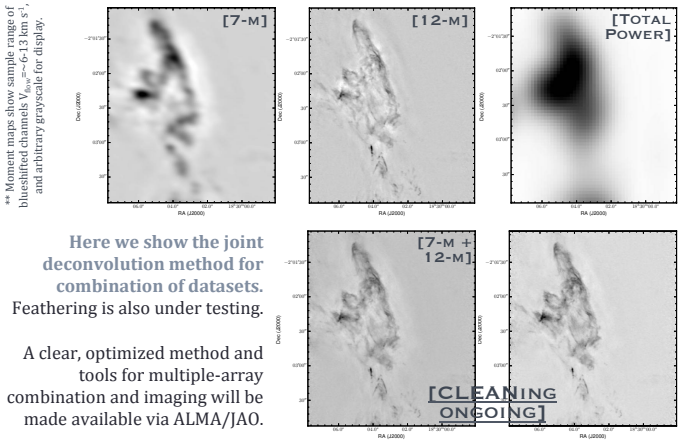


Figure: C^{18}O (2-1) moment and PV maps show a combination of Keplerian rotation and infall. We note early signs for disk formation perpendicular to the outflow axis (arrows). C^{18}O RMS was 8 mJy beam^{-1} ch^{-1} (channel width of 0.16 km s^{-1}).

Conclusions (Plunkett et al. 2015b, *Nature*):

- CARMA-7 shows evidence that an episodic, accretion-driven outflow begins in the earliest phase of protostellar evolution.
- Further, the outflow remains intact in a very clustered environment, probably providing efficient transfer of momentum to drive turbulence.
- Analysis is ongoing for the nearby ~10 continuum sources detected here for the first time, as well as diverse outflow emission throughout the map.

ALMA array combination



Here we show the joint deconvolution method for combination of datasets. Feathering is also under testing.

A clear, optimized method and tools for multiple-array combination and imaging will be made available via ALMA/JAO.

Takeaway points

- We present one example of a collimated, episodic bipolar outflow in Serpens South, with analysis of the full map ongoing.
- We utilize ALMA's powerful capability to observe with its different antenna arrays: 12-m, 7-m, and Total Power.
- This suite of observations provides constraints for simulations of protostellar outflows in clusters that (should) include episodic accretion and outflow-driven turbulence.
- **Ongoing work:** Measure mass, momentum, and energy of individual outflows utilizing the full ^{12}CO, ^{13}CO, and C^{18}O ALMA datasets. Follow-up on envelope/disk characteristics of CARMA-7 (in ALMA Cycle 3/4).

This poster is based on 2 papers:

- Plunkett, A. L., et al. 2015a, ApJ, 803, 22 (arXiv:1503.01111)
- Plunkett, A. L., et al. 2015b, Nature, 527, 70 (arXiv:1511.01100)

And ALMA observations: #2012.1.00769.S