Protostellar outflows mapped with ALMA and techniques to include short spacings

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I. Motivation

ALMA is known for its high angular resolution and sensitivity at sub-mm wavelengths. For a number of science cases, the combination of interferometry data with single dish observations is required, including (but not limited to):

- protostellar outflows and their environment,
- dense clumps and prestellar cores in molecular clouds (MCs),
- the interplay between giant MCs and galactic structures in nearby galaxies,
- the evolution of AGB stars,
- planetary nebulae and their winds,
- and any analysis of the probability distribution function (PDF) from diffuse emission to dense, clumpy emission.

What these have in common are both extended and compact structures spanning spatial scales over several orders of magnitude. Various methods have been developed to combine multi-scale datasets, which we list in Table I. Below (see III), we show the case study of a protostellar outflow to test two methods: feathering and tp2vis.

Table 1: A (Non-exhaustive) List of Combination Methods

Method	Domain	Input/model	CASA?	Notes
Combine-before-deconvolution	Fourier	Interferometer uv data; uv points generated for single dish data	task: tp2vis, tclean	*** "tp2vis" with joint-deconvolution; Koda et al. (2011) and NA Development Study (PI: Koda)
	Image	Dirty images; dirty beams		"Linear Combination" method by Stanimirovic et al. (2002)
Combine-during-deconvolution	Fourier	Use single dish (total power) or feathered image as tclean model ("initial guess")	task: tclean (feather for model)	http://tinyurl.com/zero-spacing by J. Kauffman
Combine-after-deconvolution	Fourier	Interferometer image; single dish image	task: feather	*** "Feather"; CASA Guide available
	Image	Interferometer image; single dish image (FITS format)	Script by Faridani	https://bitbucket.org/snippets/faridani/pRX6r; Faridani et al. (2017)

*** tp2vis and feather are two methods tested/presented in this poster.

II. Method: tp2vis

The Cycle 4 NRAO ALMA Development Study "Total Power Map to Visibilities (TP2VIS)" seeks to implement a 12m+7m+TP (Total Power) joint-deconvolution within CASA. Moreover, the availability of more than one imaging method permits the general user to check the robustness of scientific results from ALMA.

The method generates total power (TP) visibilities from TP maps as if they were observed by a virtual interferometer with very short baselines. Relative weights are applied. Finally, the uv data are "CLEANed" jointly. A schematic is shown to the right (Figure 1).

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Figure 1: tp2vis schematic

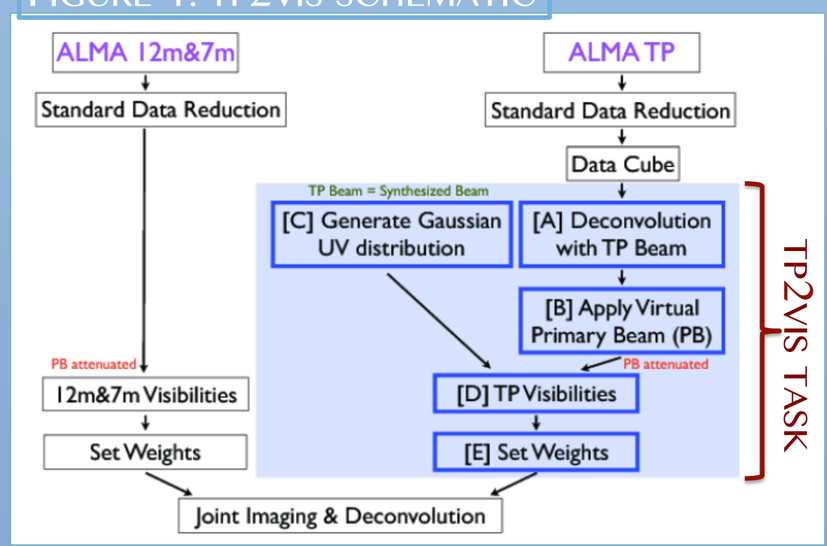
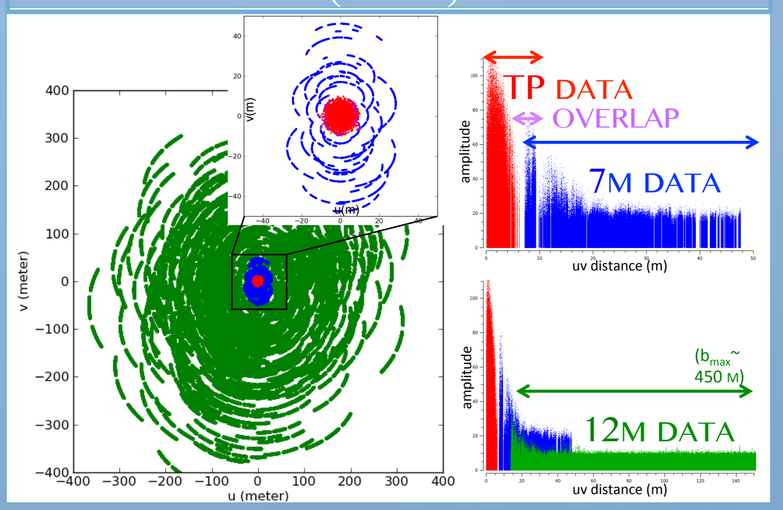


Figure 2: uv coverage and amplitudes for case study (see III)



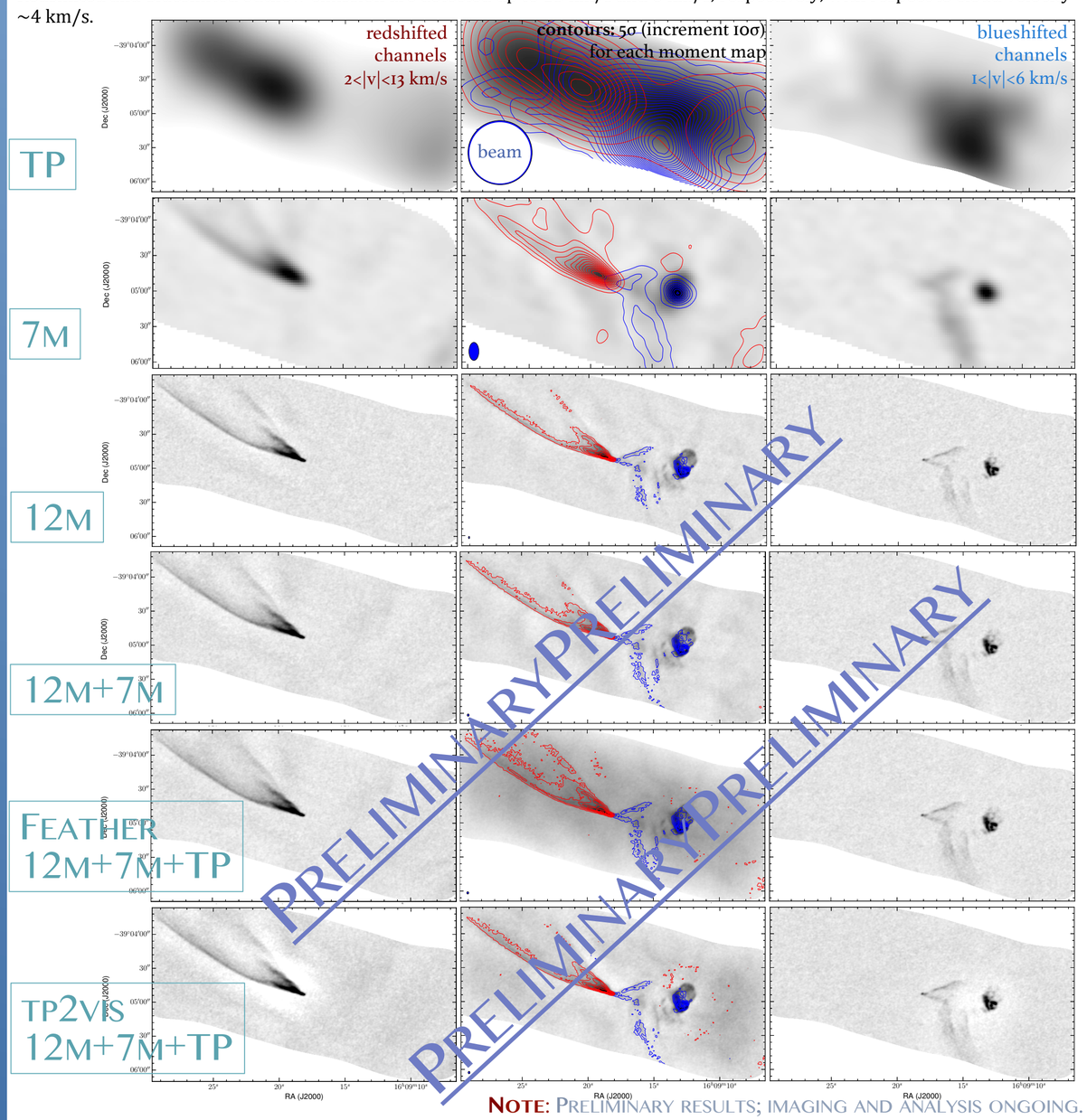
III. Case Study: Lupus 3 mms outflow

Table 2: Observations (2015.1.00306.S, PI: Plunkett)

Array	Dish size (airy)	N_{ant}	Mosaic Ptgs	Primary Bm	HPBW
12m	10.7m	44	29	51"	2"x1" (-73°)
7m	6.25m	11	11	87"	15"x9" (83°)
Total Power (TP)	10.7m				56"

Figure 3: Sample moment 0 maps

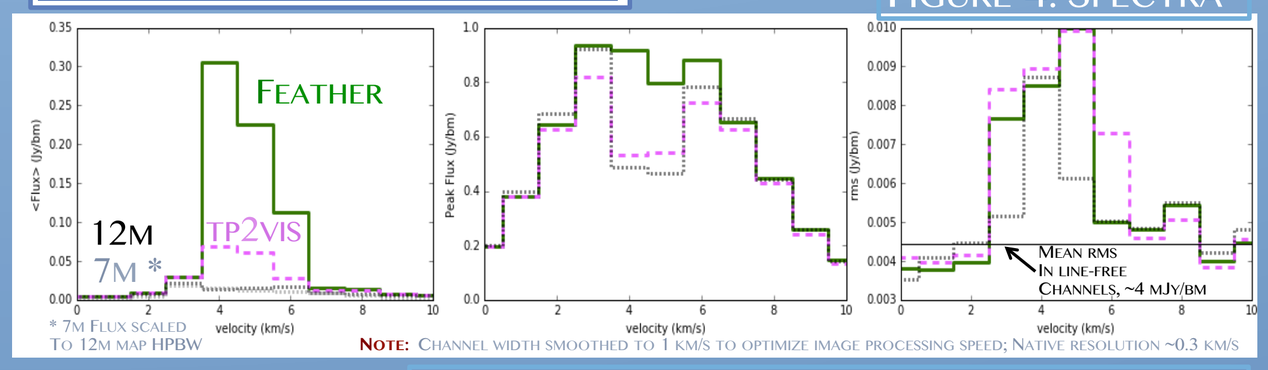
Here we show moment 0 maps of redshifted and blueshifted channels (grayscale in left and right columns, respectively, and contours in central column). Grayscale in central column corresponds to moment 0 integrated emission of all channels. Redshifted and blueshifted outflow emission are detected up to 13 km/s and 6 km/s, respectively, with respect to cloud velocity ~4 km/s.



NOTE: Preliminary results; imaging and analysis ongoing.

IV. Diagnostics and Inspection

Figure 4: Spectra



NOTE: Channel width smoothed to 1 km/s to optimize image processing speed; Native resolution ~0.3 km/s

Figure 5: Comparing methods, by channel

Inspecting by eye, recovered emission depends on method, and varies by channel. Possible issues may include:

- Insufficient CLEANing, either in imaging prior to feather, or when CLEANing after tp2vis.
- Errors in the weights of relative arrays and total power.

NOTE: Auto-masking in tclean (usemask="auto-multithresh") is a useful tool for complex, channel-dependent emission.

contours: 5σ (increment 20σ) for each moment map; dotted lines show -4σ

V. Conclusions

- Feathering and tp2vis were tested for the case study Lupus 3 mms outflow. Both methods can be implemented in CASA.
- Depending on the distribution of emission (different channels), either tp2vis or feathering seem to recover the expected structures (with lower-level negatives).
- Tp2vis and feather are not mutually exclusive methods, but rather can be used together to improve uv coverage and imaging.

Considerations for a Large Aperture Submm/mm Telescope

Ideally, a LAST would have the largest diameter possible to optimize combination with ALMA interferometry data, specifically:

- Better compare the fluxes (weights) in the overlap region
- Increase single dish (total power) sensitivity

These considerations seem to be independent of combination technique.

References

Faridani, S., Bigiel, F., Floeer, L., Kerp, J., & Stanimirovic, S. 2017, arXiv:1709.09365 • Koda, J., Sawada, T., Wright, M.C.H., et al. 2011, ApJS, 193, 19 • Kurono, Y., Morita, K.-I., & Kamazaki, T. 2009, PASJ, 61, 873 • Stanimirovic, S. 2002, Single-Dish Radio Astronomy: Techniques and Applications, 278, 375

Want to Try?

v0.7, for expert users/testers:
https://github.com/tp2vis/distribute
Official release coming soon!