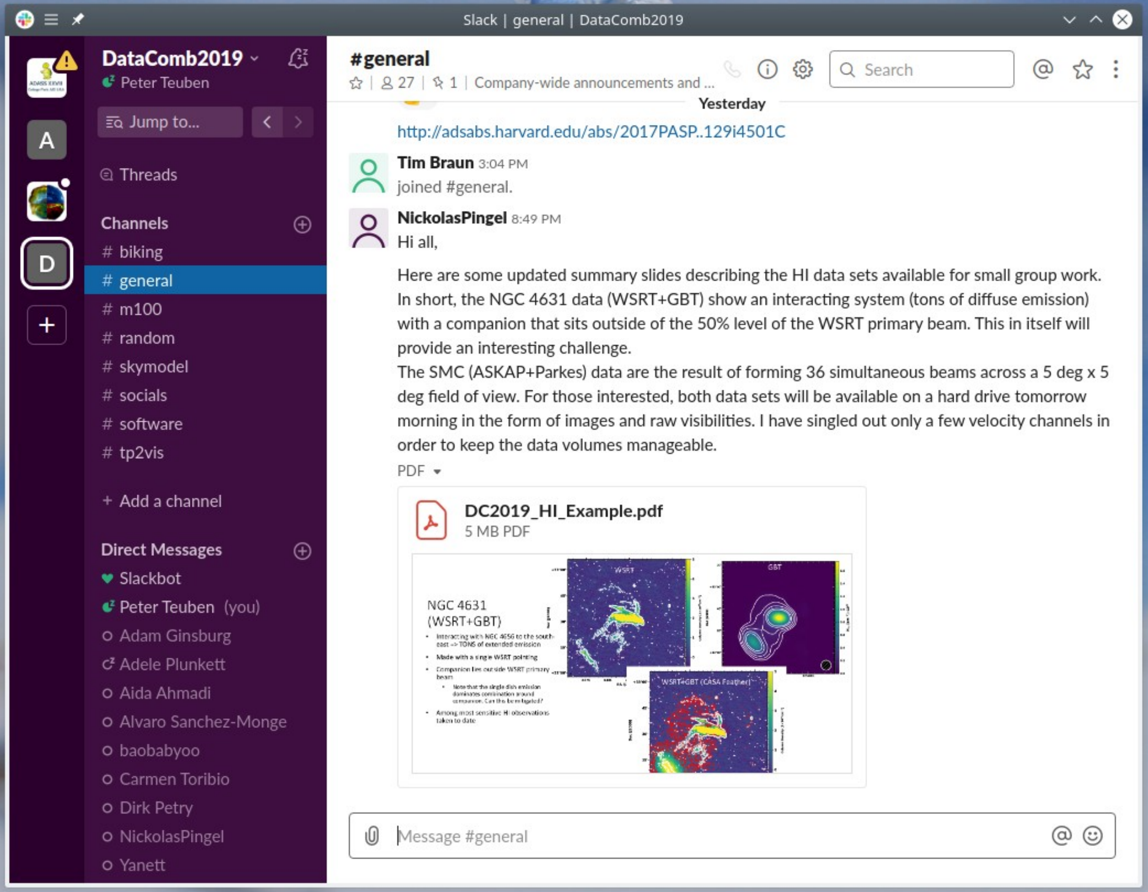
https://github.com/teuben/dc2019/blob/master/HOWTO



TP2VIS:
Total Power to Visibilities

Joint Deconvolution of ALMA 12m, 7m and TP in CASA

(ALMA Development Study)

Jin Koda*[1,2,3]*, *Peter Teuben*[4]

Tsuyoshi Sawada[2,3], *Adele Plunkett*[5,6], *Ed Formalont*[6,3]

1: Stony Brook U., ***2***: NAOJ-Chile, ***3***: JAO, ***4***: U. Maryland, ***5***: ESO, ***6***: NRAO

TP2VIS:
Total Power to Visibilities

Publications of the Astronomical Society of the Pacific, 131:054505 (16pp), 2019 May https://doi.org/10.1088/1538-3873/ab047e

CrossMark

Total Power Map to Visibilities (TP2VIS): Joint Deconvolution of ALMA 12 m, 7 m, and Total Power Array Data

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Abstract

We present a new package for joint deconvolution of ALMA 12 m, 7 m, and Total Power (TP) data, dubbed "Total Power Map to Visibilities (TP2VIS)". It converts a TP (single-dish) map into visibilities on the CASA platform, which can be input into deconvolvers (e.g., CLEAN) along with 12 m and 7 m visibilities. The TP2VIS procedure is based primarily on the one discussed in Koda et al. A manual is presented in the GITHUB repository (https://github.com/tp2vis/distribute). Combining data from the different ALMA arrays is a driver for a number of science topics, namely those that probe size scales of extended and compact structures simultaneously (e.g., protostar outflows and environment, AGB stars and planetary nebulae, molecular clouds and cores, and molecular clouds in galaxies). We test TP2VIS using model images, one with a single Gaussian and another that mimics the internal structures of giant molecular clouds. The result shows that the better *uv* coverage with TP2VIS visibilities clearly helps the deconvolution process and reproduces the model image within errors of only 5% over two orders of magnitude in flux. In the Appendix, we describe how the model image is generated.

Key words: techniques: interferometric – techniques: image processing – techniques: miscellaneous

Online material: color figures

Koda et al. 2019

tp2vis public release (V1.0)

- TP ↔ SD
- VIS ↔ INT
- Image Combination ↔ Feather
- Joint Reconstruction ↔ JD
- Start Model ?↔? Steer Cleaning

Other JD software in CASA:
- SD2VIS (Nordic ARC)
- wSDINT (Rau)

Interferometry Data
only exists between **UV_min** and **UV_max**

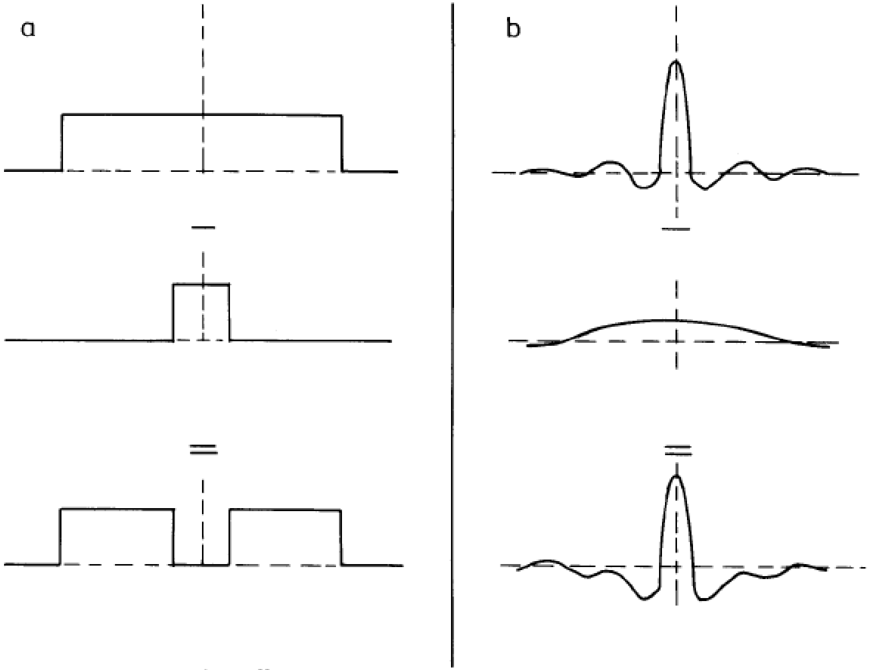
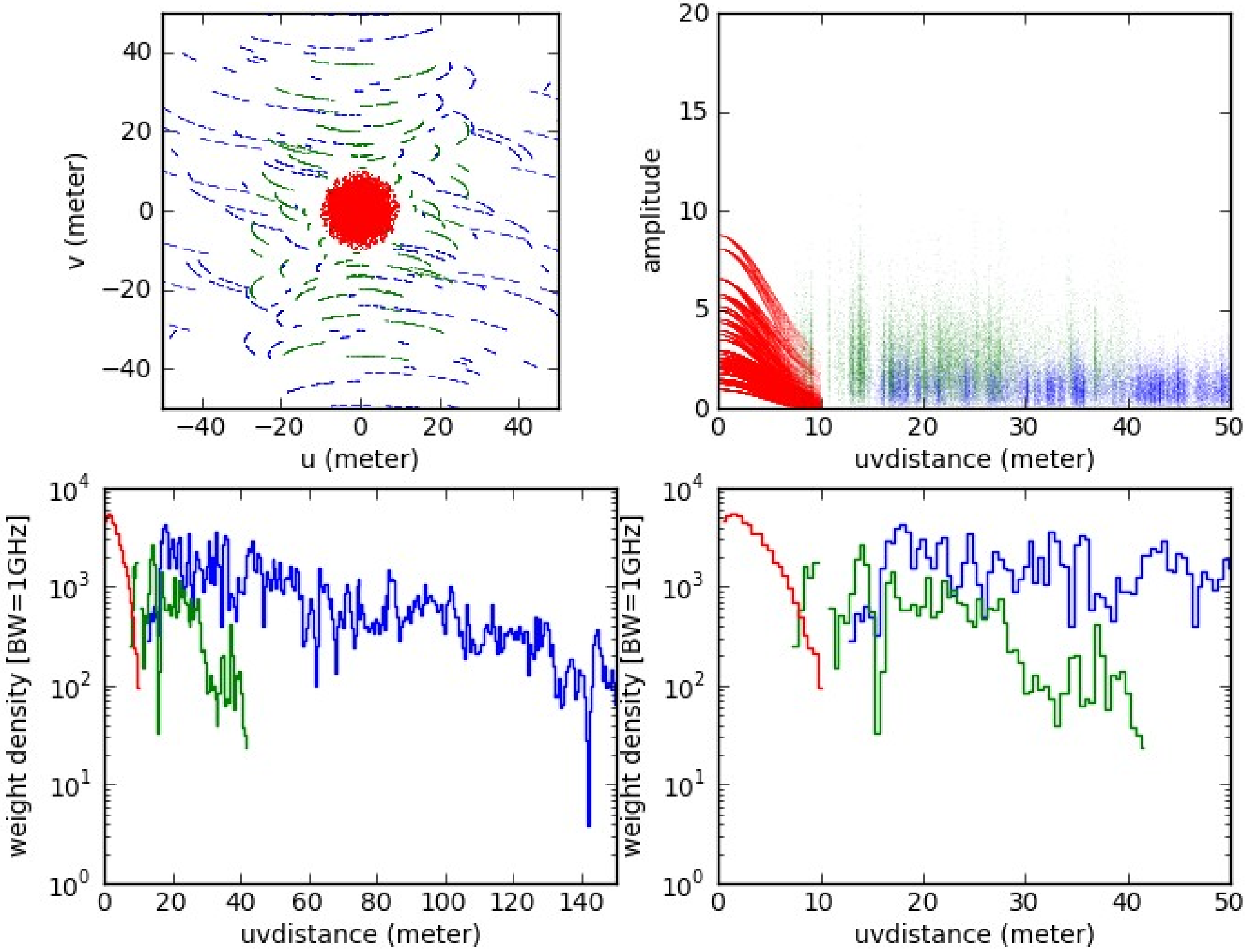


Fig. 1a and b. The effect on instrumental response of missing short spacings. **a** Observed spatial frequencies and **b** the corresponding instrumental response

UV LM

Braun & Walterbos (1985)

M100 real and pseudo visibilities



	Band	3	4	5	6	7	8	9	10
	Frequency (GHz)	100	150	185	230	345	460	650	870
Configuration									
7-m	θ_{res} (arcsec)	12.5	8.35	6.77	5.45	3.63	2.72	1.93	1.44
	θ_{MRS} (arcsec)	66.7	44.5	36.1	29.0	19.3	14.5	10.3	7.67
C43-1	θ_{res} (arcsec)	3.38	2.25	1.83	1.47	0.98	0.735	0.52	0.389
	θ_{MRS} (arcsec)	28.5	19.0	15.4	12.4	8.25	6.19	4.38	3.27
C43-2	θ_{res} (arcsec)	2.3	1.53	1.24	0.999	0.666	0.499	0.353	0.264
	θ_{MRS} (arcsec)	22.6	15.0	12.2	9.81	6.54	4.9	3.47	2.59
C43-3	θ_{res} (arcsec)	1.42	0.943	0.765	0.615	0.41	0.308	0.218	0.163
	θ_{MRS} (arcsec)	16.2	10.8	8.73	7.02	4.68	3.51	2.48	1.86
C43-4	θ_{res} (arcsec)	0.918	0.612	0.496	0.399	0.266	0.2	0.141	0.106
	θ_{MRS} (arcsec)	11.2	7.5	6.08	4.89	3.26	2.44	1.73	1.29
C43-5	θ_{res} (arcsec)	0.545	0.363	0.295	0.237	0.158	0.118	0.0838	0.0626
	θ_{MRS} (arcsec)	6.7	4.47	3.62	2.91	1.94	1.46	1.03	0.77
C43-6	θ_{res} (arcsec)	0.306	0.204	0.165	0.133	0.0887	0.0665	0.0471	0.0352
	θ_{MRS} (arcsec)	4.11	2.74	2.22	1.78	1.19	0.892	0.632	0.472
C43-7	θ_{res} (arcsec)	0.211	0.141	0.114	0.0917	0.0612	0.0459	0.0325	0.0243
	θ_{MRS} (arcsec)	2.58	1.72	1.4	1.12	0.749	0.562	0.398	0.297
C43-8	θ_{res} (arcsec)	0.096	0.064	0.0519	0.0417	0.0278	-	-	-
	θ_{MRS} (arcsec)	1.42	0.947	0.768	0.618	0.412	-	-	-
C43-9	θ_{res} (arcsec)	0.057	0.038	0.0308	0.0248	0.0165	-	-	-
	θ_{MRS} (arcsec)	0.814	0.543	0.44	0.354	0.236	-	-	-
C43-10	θ_{res} (arcsec)	0.042	0.028	0.0227	0.0183	0.0122	-	-	-
	θ_{MRS} (arcsec)	0.496	0.331	0.268	0.216	0.144	-	-	-

Table 7.1: Resolution (θ_{res}) and maximum recoverable scale (θ_{MRS}) for the 7-m Array and 12-m Array configurations available during Cycle 7 as a function of a representative frequency in a band. The value of θ_{MRS} is computed using the 5$^{\text{th}}$ percentile baseline (L05) from Table 7.2 and Equation 7.7. The value of θ_{res} is the mean size of the interferometric beam obtained through simulation with CASA, using Briggs (u, v) plane weighting with *robust=0.5*. The computations were done for a source at zenith; for sources transiting at lower elevations, the North-South angular measures will increase proportional to 1/sin(ELEVATION).

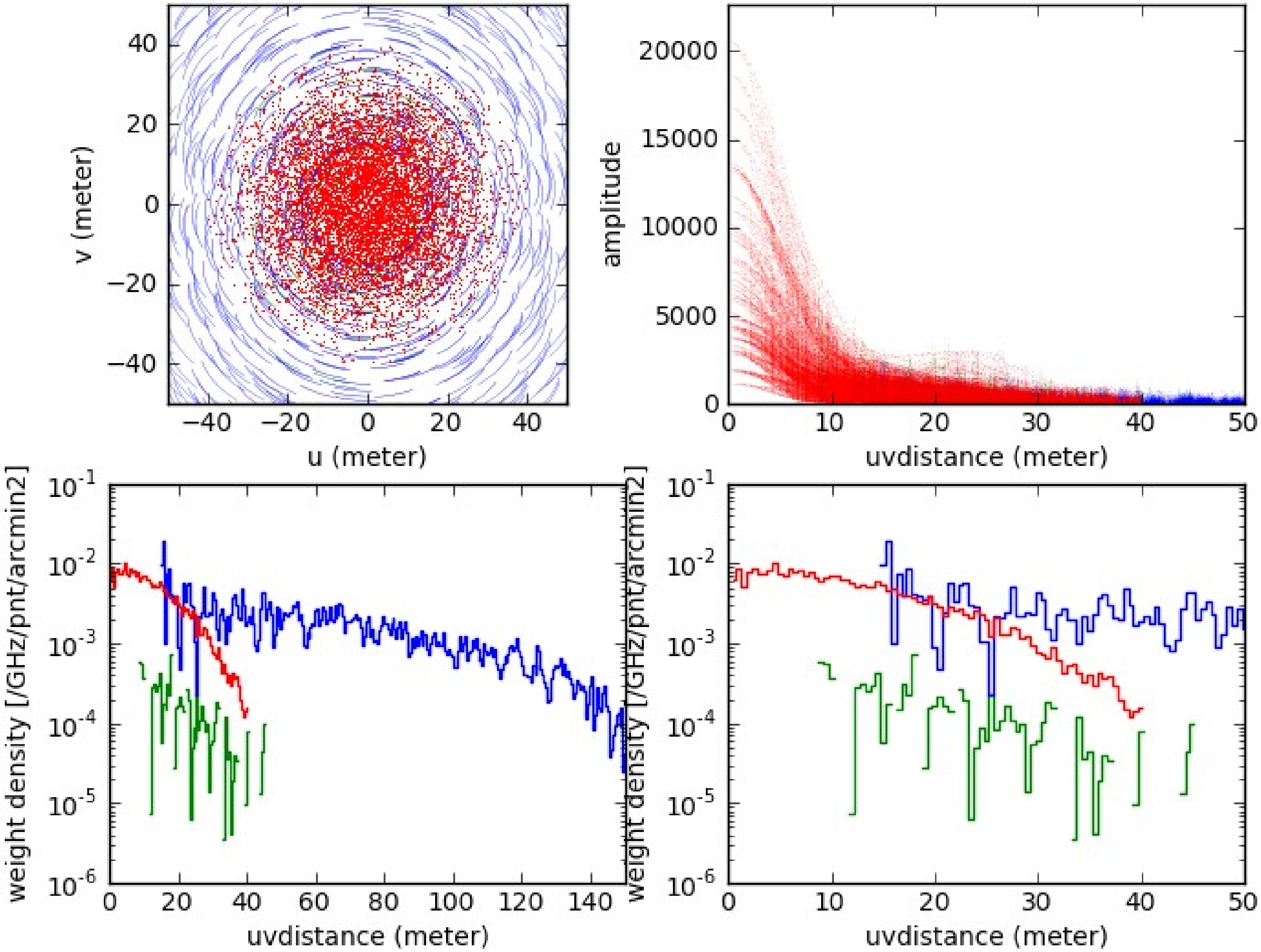
Configuration	7-m	C43-1	C43-2	C43-3	C43-4	C43-5
Minimum baseline (m)	8.7	14.6	14.6	14.6	14.6	14.6
5th percentile or L05 (m)	9.1	21.4	27.0	37.6	54.1	90.9
80th percentile or L80 (m)	30.7	107.1	143.8	235.4	369.2	623.8
Maximum baseline (m)	45.0	160.7	313.7	500.2	783.5	1397.9
Configuration	C43-6	C43-7	C43-8	C43-9	C43-10	
Minimum baseline (m)	14.6	64.0	110.4	367.6	244.0	
5th percentile or L05 (m)	148.6	235.2	427.3	746.9	1228.1	
80th percentile or L80 (m)	1172.5	1673.1	3527.3	6482.6	8685.9	
Maximum baseline (m)	2516.9	3637.8	8547.7	13894.2	16194.0	

Table 7.2: Basic parameters of the 7-m Array configuration and the ten 12-m Array configurations offered

ALMA Array Configurations:
C43-1 … C43-10

3” … 0.04” at 3mm

How about ALMA with a bigger TP dish ?



TP2VIS in miriad also still works!

(Koda et al. 2011)

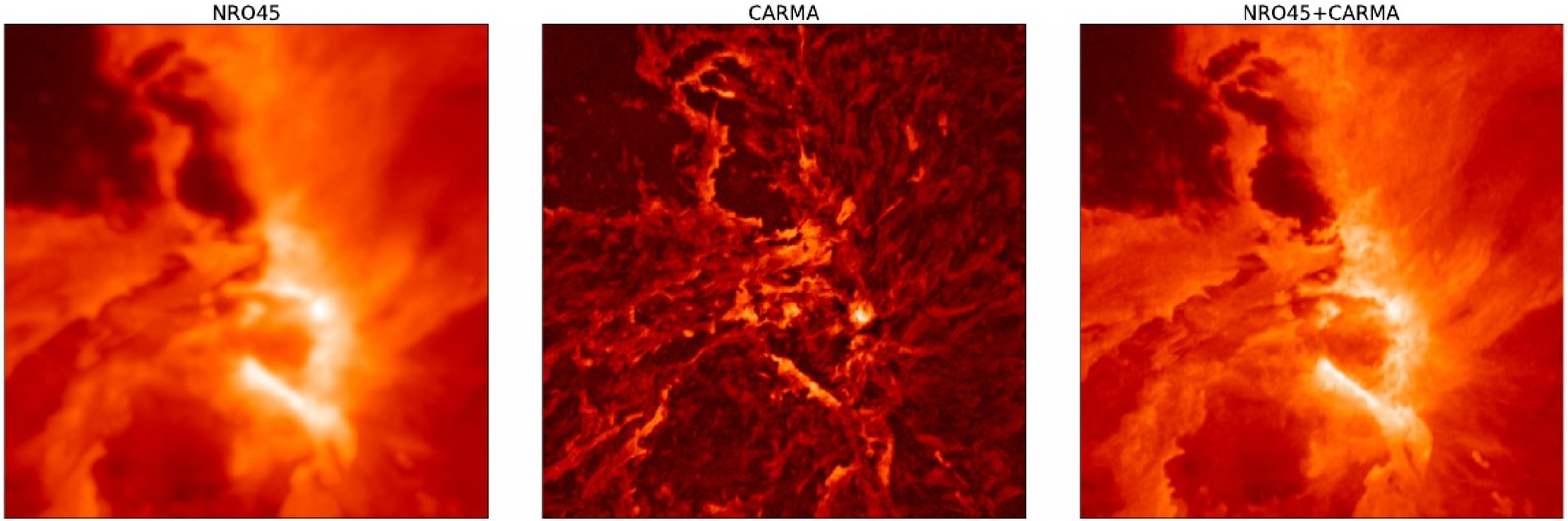
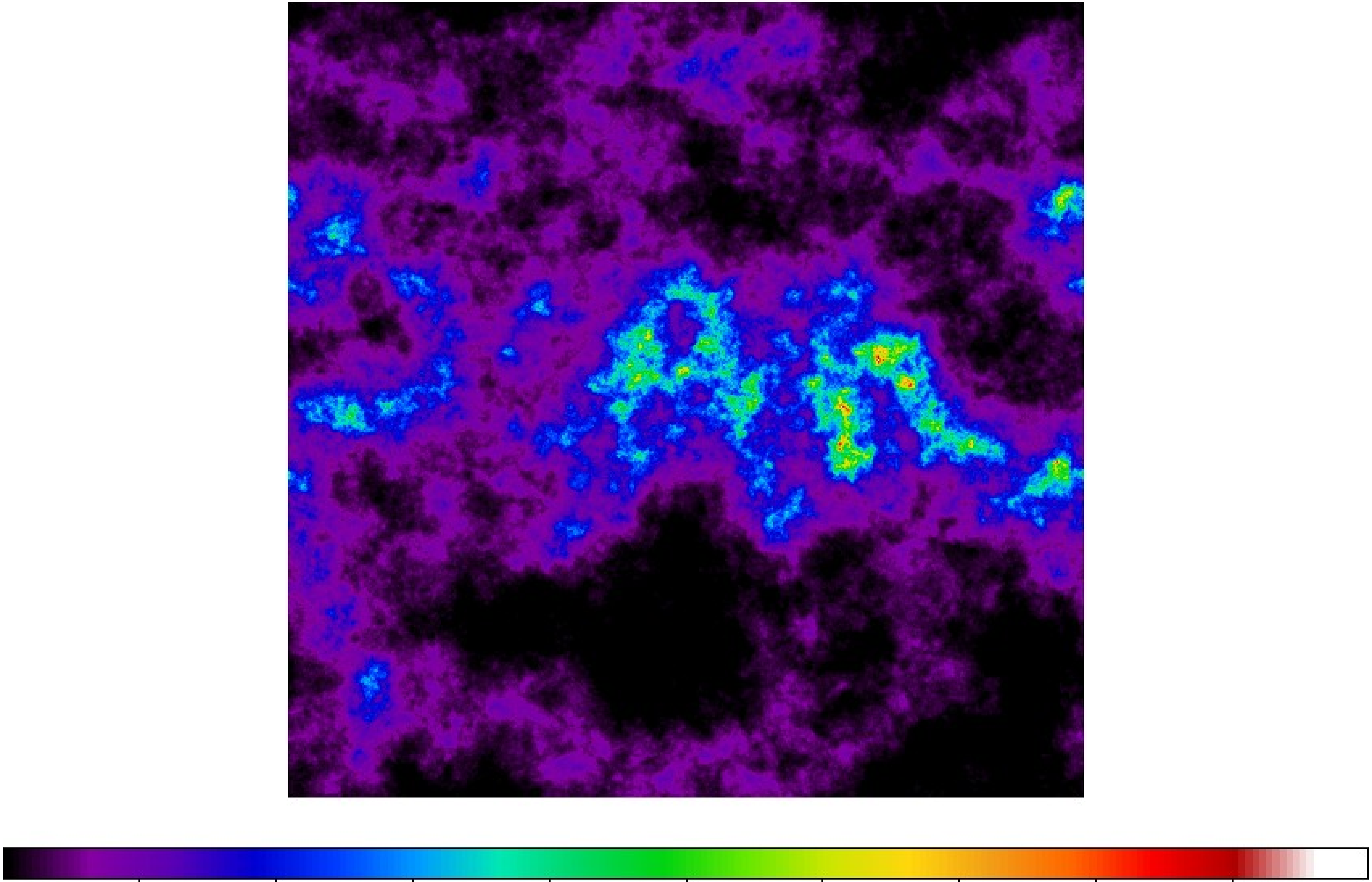


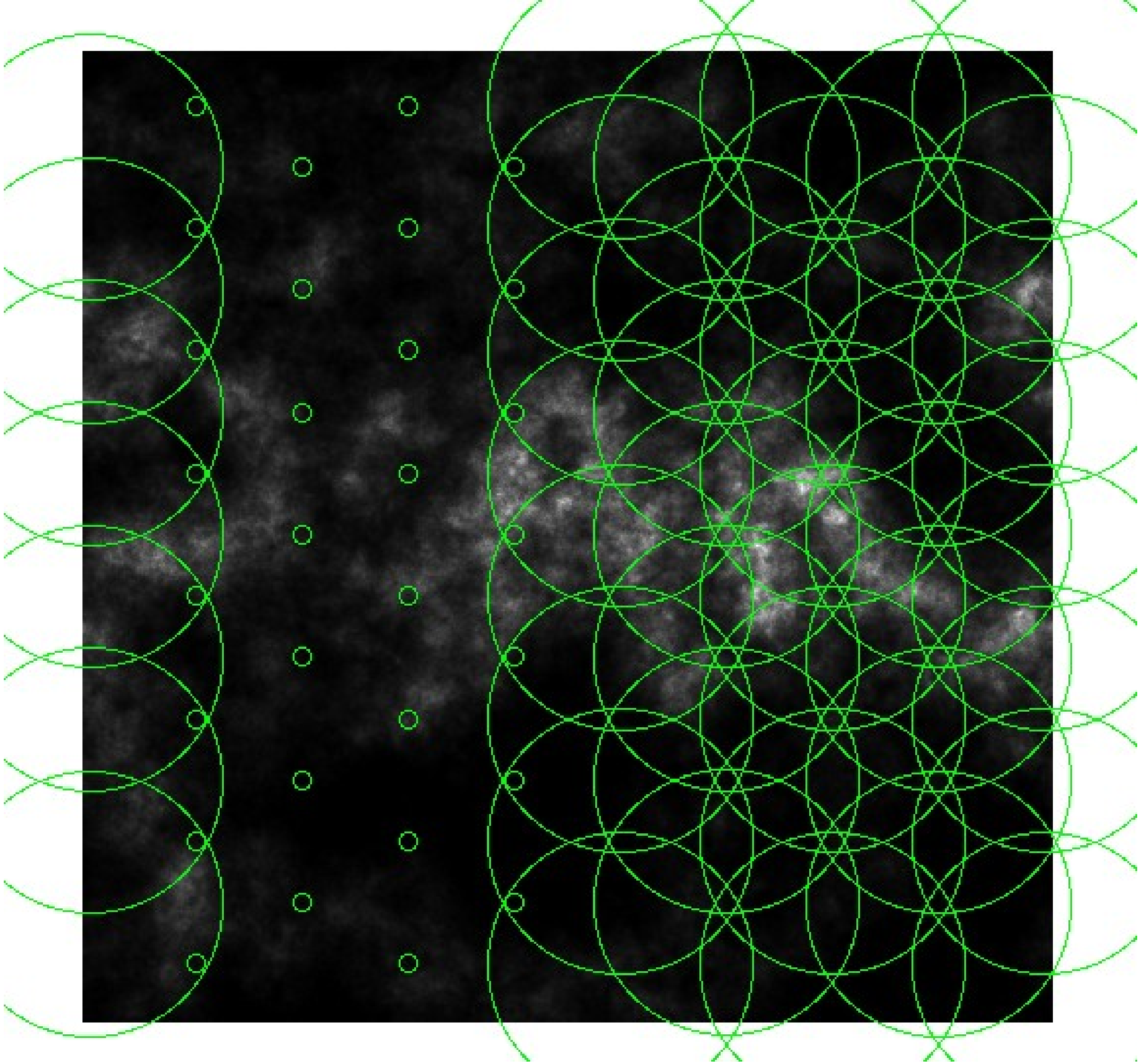
Figure 2. Sample comparison of the NRO45, CARMA, and combined maps. (Left) ^{12}CO peak intensity maps from NRO45, (middle) CARMA, and (right) the combined CARMA+NRO45 data sets. All panels show the same $19'.0 \times 18'.7$ (2.21 pc $\times$ 2.17 pc) area centered around the ONC and Orion KL region and includes the Orion Bar. The increased sharpness of the extended images when the CARMA observations are combined with those from NRO45 is immediately clear.

Kong et al. 2018: Orion Molecular Cloud

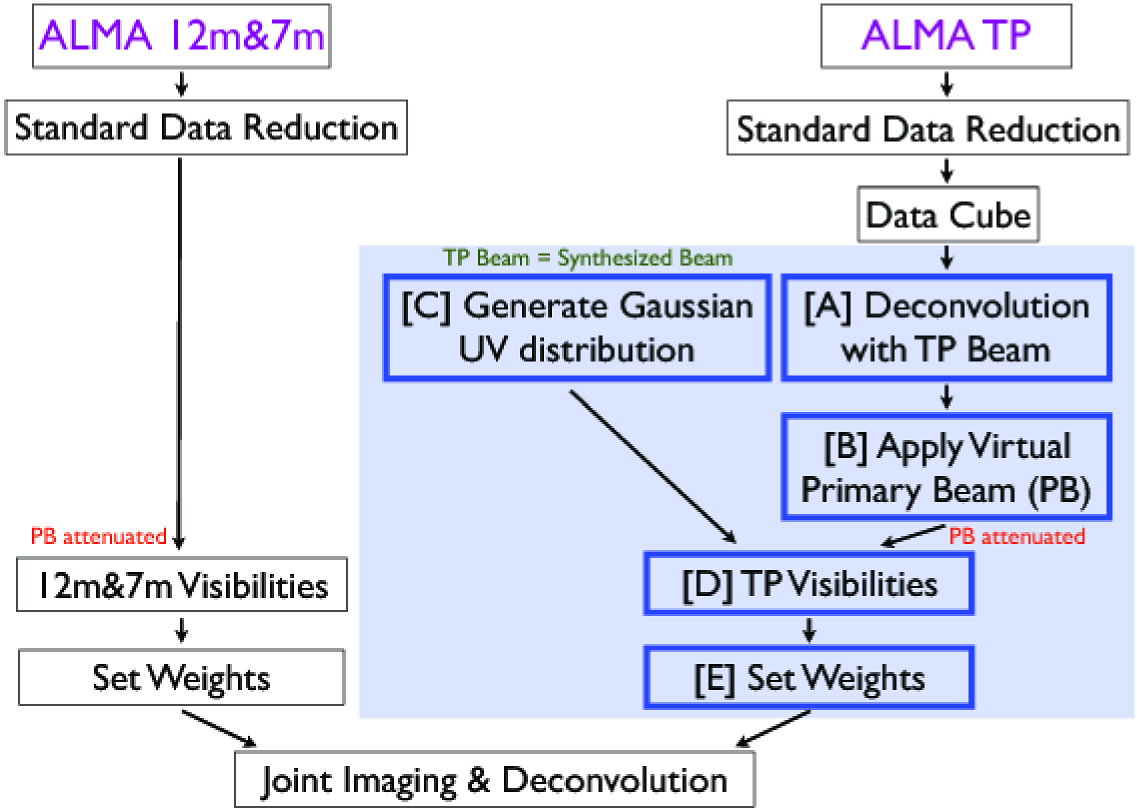
Abbreviations

- SPP = Short Spacing Problem
- SSC = Short Spacing Correction
  - SD = Single Dish
  - TP = Total Power
  - OTF = On The Fly map (“gaussian smoothing”)
  - VP = Voltage Pattern
  - PB = Primary Beam (PB = VP**2)
  - MS = Measurement Set
    - Pseudo-Visibilities or Virtual Visibilities
    - Visibilities (Re/Im from the correlator)
  - JD = Joint Deconvolution



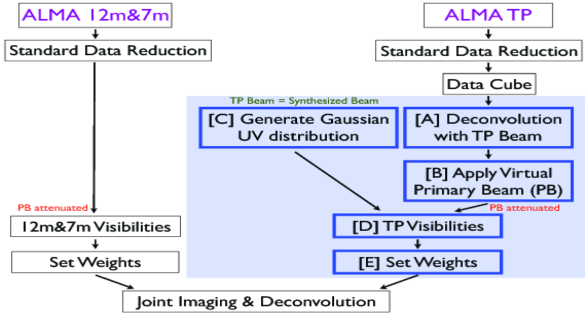


Flow Chart of the **TP2VIS** procedure



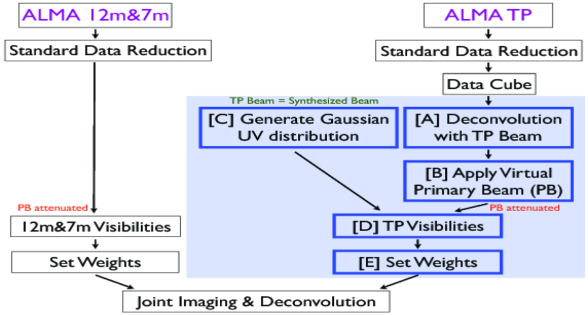
Step A:
Deconvolution with TP beam

- Input TP map is sky convolved with TP beam →
- Map needs to be deconvolved with TP beam for input to the virtual interferometer
  - ALMA: gaussian 56.6” at 115.2 GHz
    - Accurate models for PB are needed
  - Non-ALMA (e.g. GBT, VLA) can also be used
    - To the rescue: VP manager?



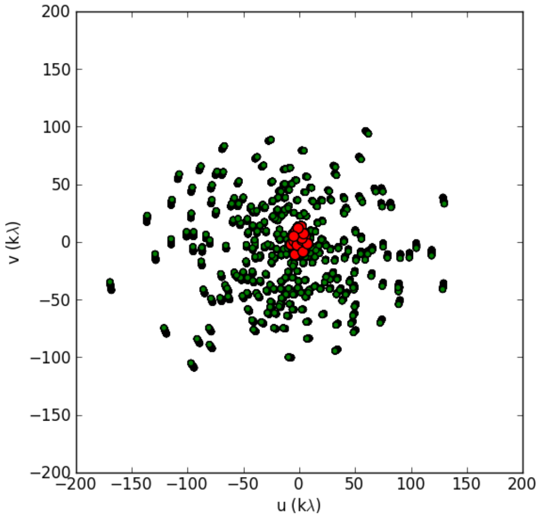
Step B:
Apply Virtual Primary Beam

- A selected virtual primary beam is applied to all pointings selected for "observing"
- Pointings can be picked from:
  - Another (interferometric) data set (MS)
  - An ascii file with RA,DEC positions
  - An auto-filled set of pointings e.g. using hex-pattern nyquist sampling

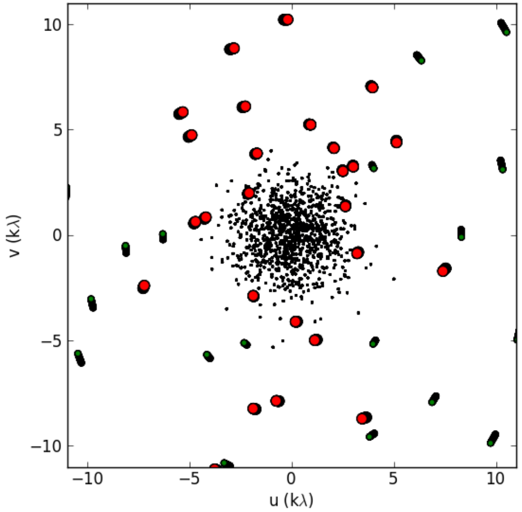


Step C:
Generate Gaussian UV Distribution

- Random gaussian distribution UV points, including (0,0) for the total flux
- Fourier transform of these points should represent the TP beam

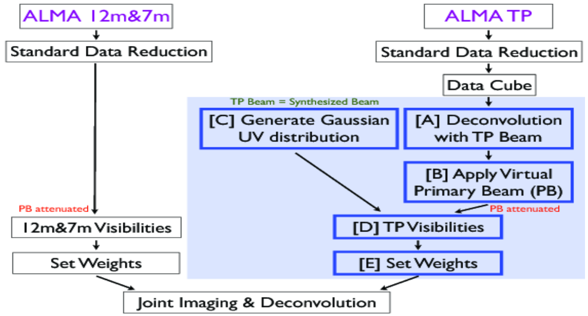


7m (red) + 12m (green) + TP (black)



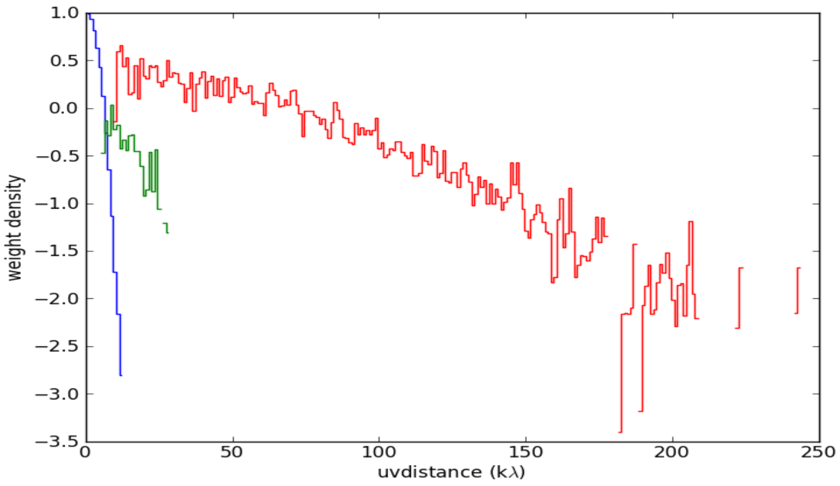
Step D:
Fill Visibility Amplitudes and Phases

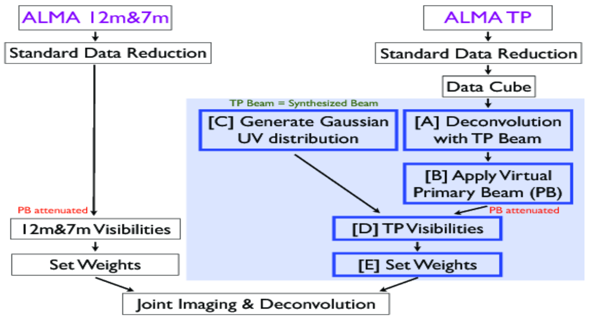
- Sky brightness from step B and spacings from step C can now predict what visibilities are “observed”
- Cleaning these visibilities with a natural weighting scheme should now result in reproducing the input image
- Weights are needed to combine with 7+12m



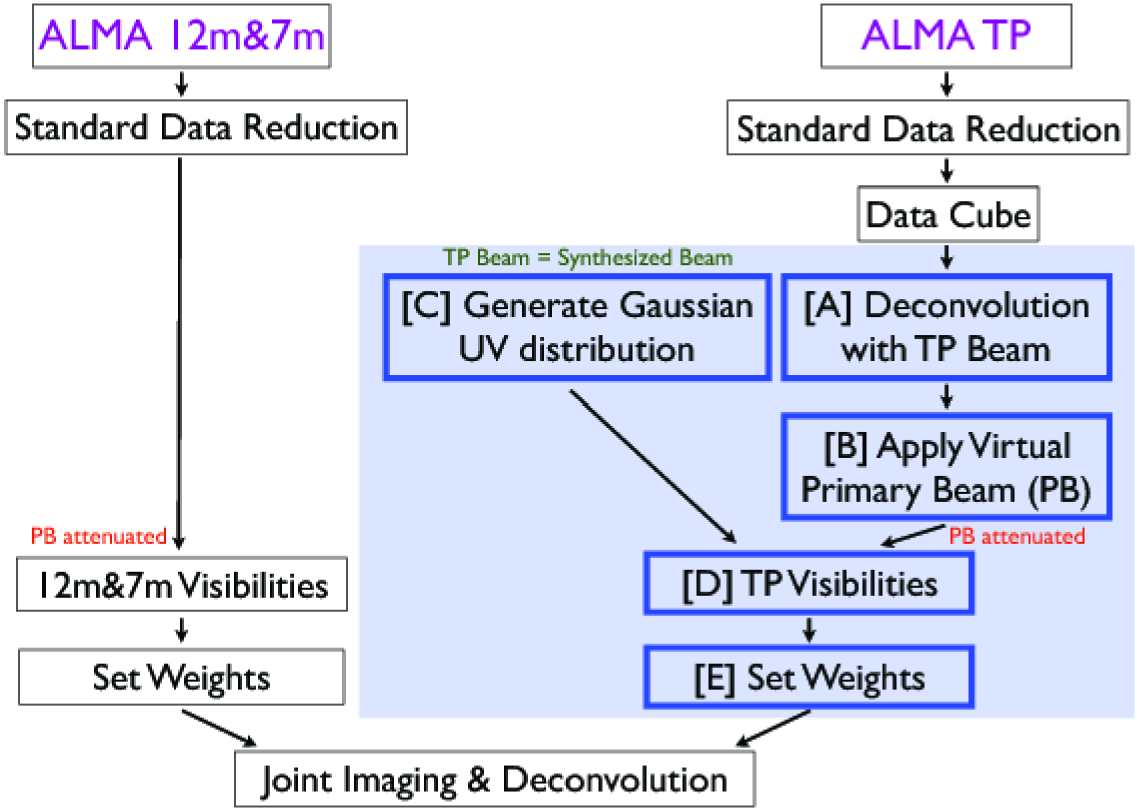
Step E:
Set Weights of TP Visibilities

- By default weights will be set consistent with the RMS noise in the TP cube
- "**tp2viswt**" can set different weights, e.g. match dirty beam area to the beam solid angle





Flow Chart of the **TP2VIS** procedure



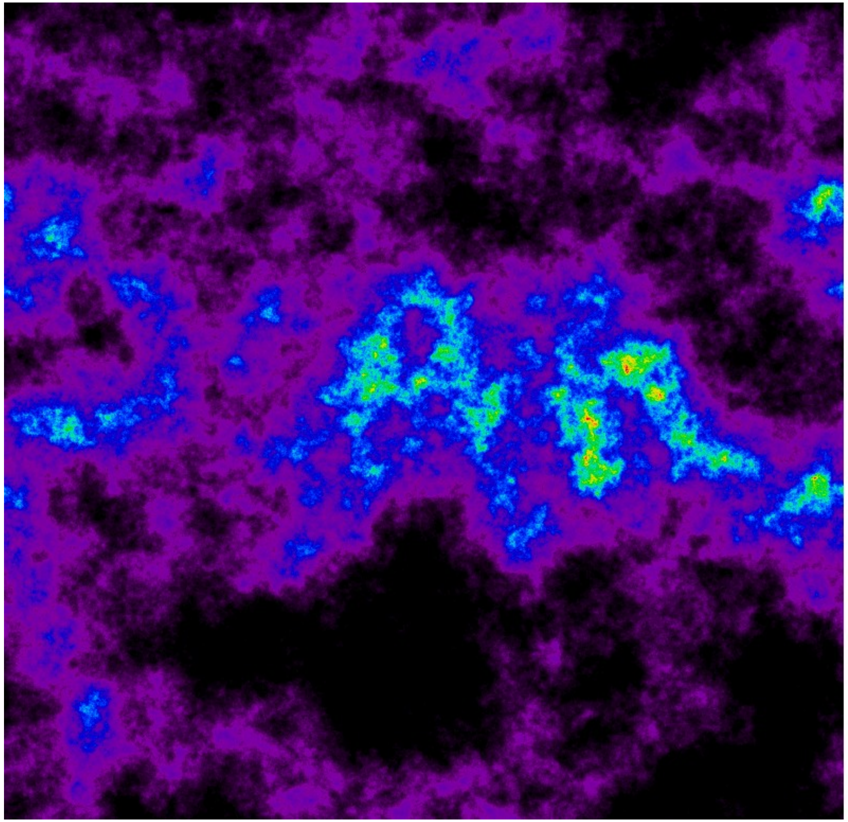
TP2VIS for CASA users is now simple!

```
#  load TP2VIS  (can also use the ~/.casa/init.py trick)
execfile('tp2vis.py')

#  convert Image to Visibilities
tp2vis('alma_tp.im', 'alma_tp.ms', ptg='alma_12m.ms', rms=0.7)

#  joint deconvolution using standard CASA task
tclean(vis=['alma_7m.ms','alma_12m.ms','alma_tp.ms'], imagename='alma_all',
    niter=1000, imsize=[512,512], cell=['0.5arcsec'])
```

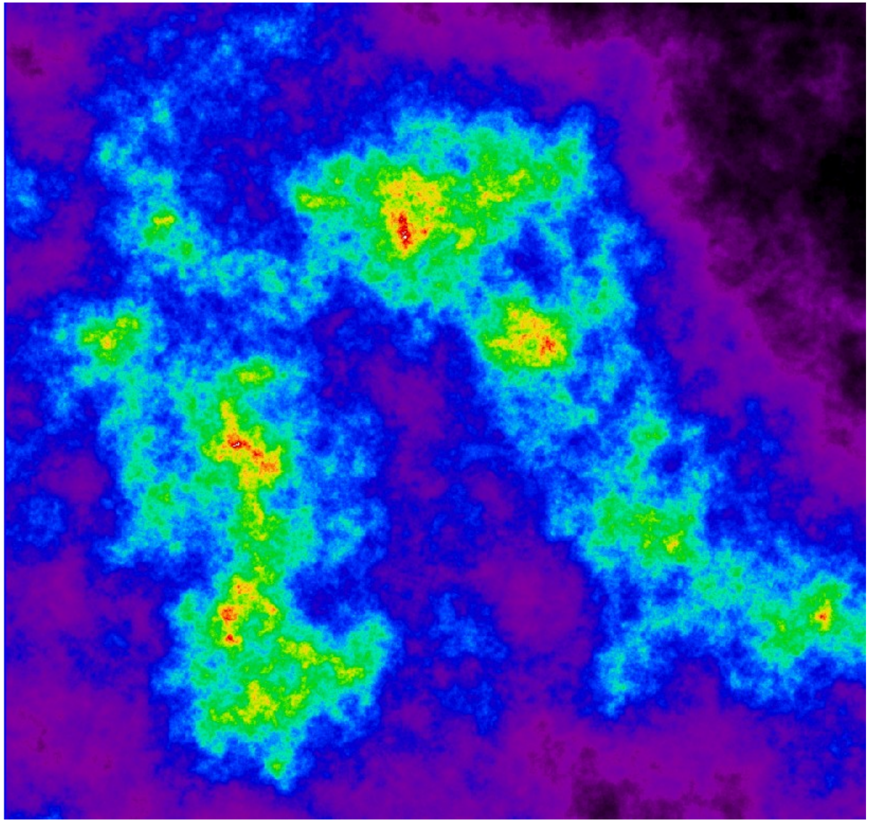
feather in CASA is also easy to use!

```
#  get two identically gridded image, lowres and highres

feather(imagename = 'final.image',
        highres   = 'highres.image',
        lowres    = 'lowres.image')
```

Simulated Data
(power spectrum of sources)

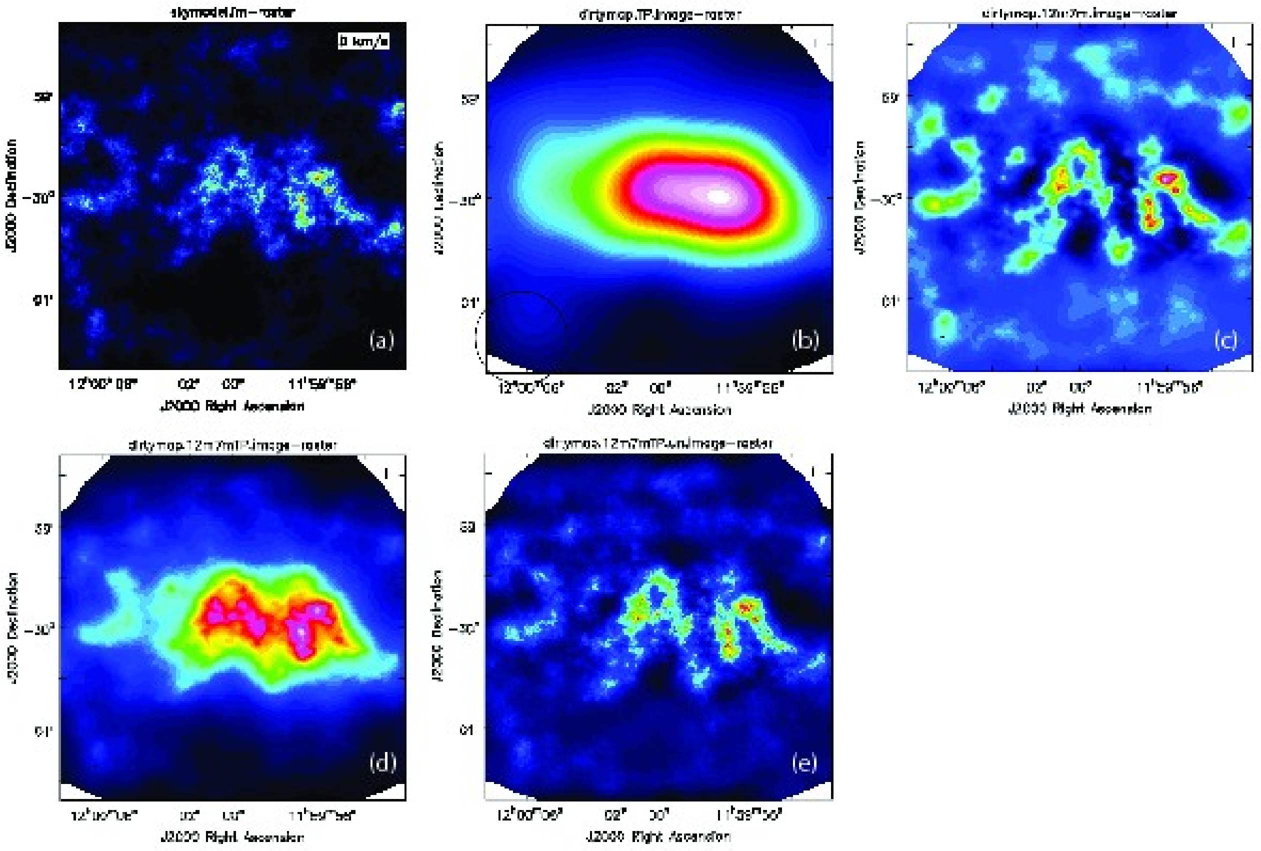


4096 x 4096



Zoom
(middle right)

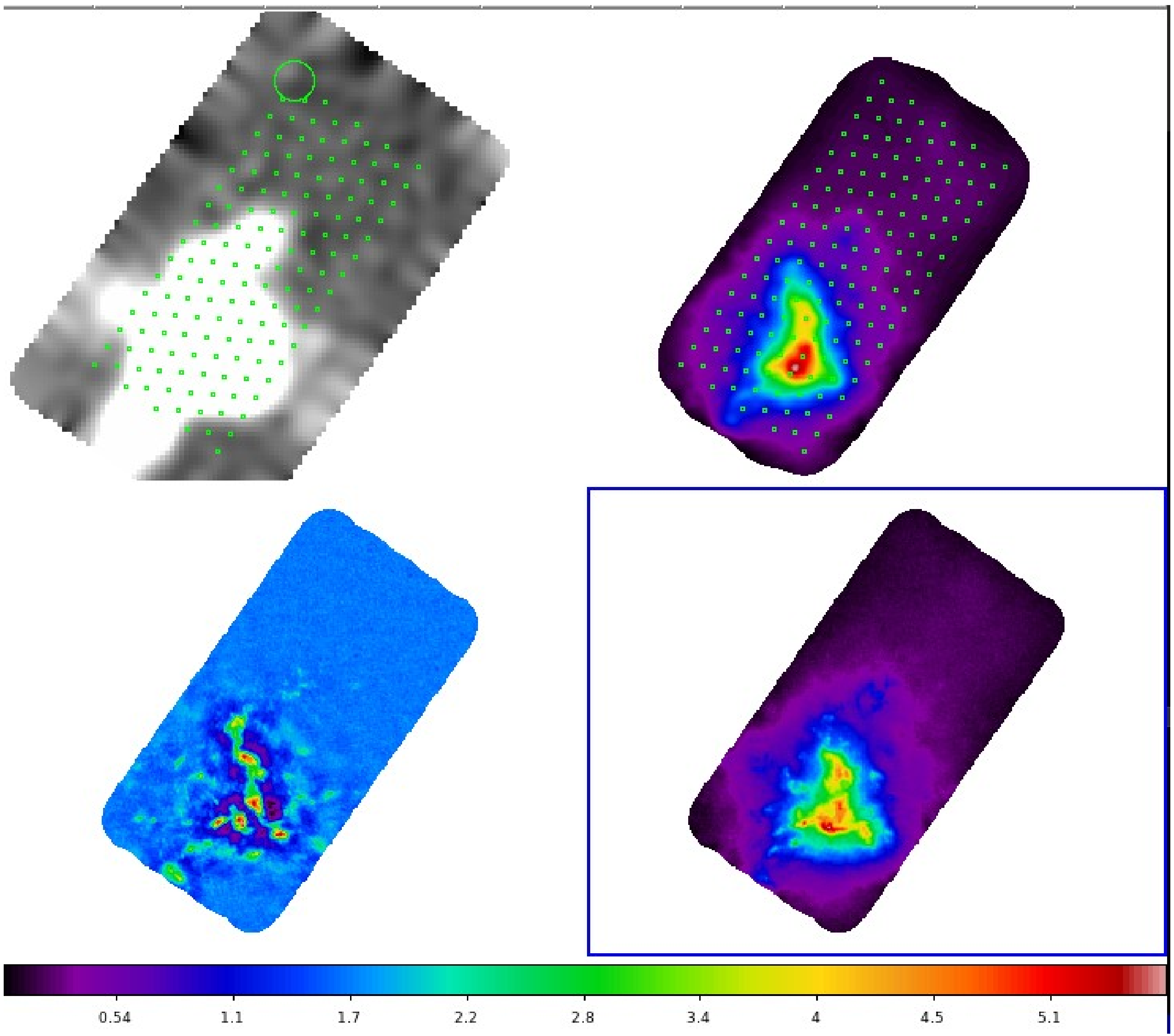
Examples: simulated GMC



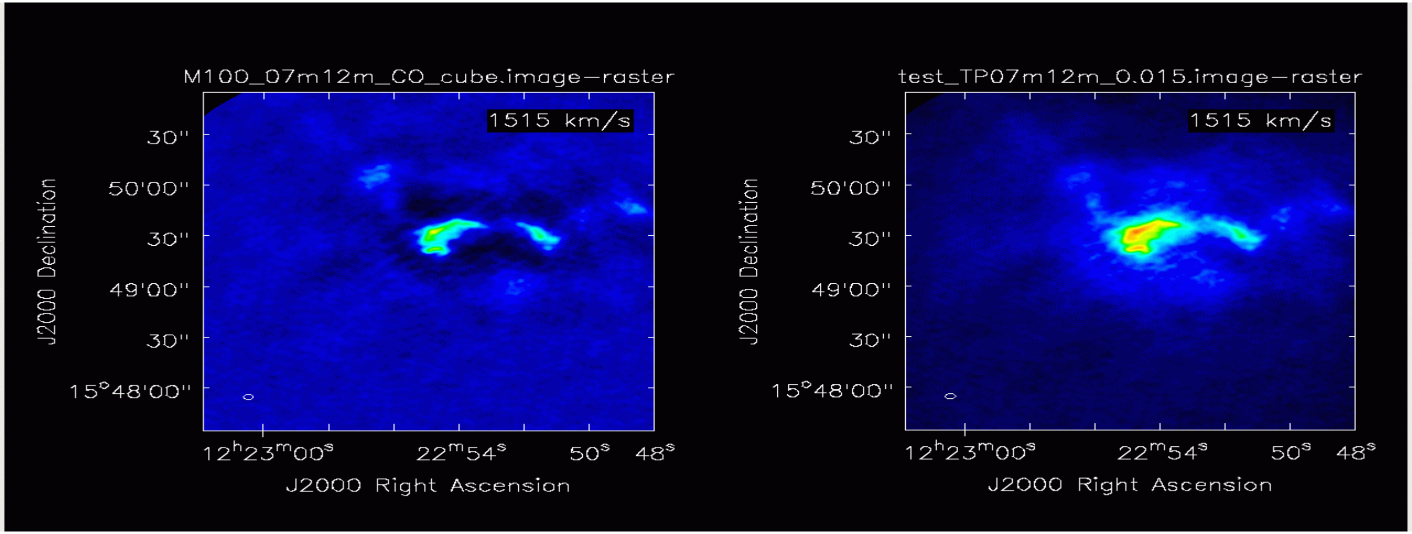
Weights

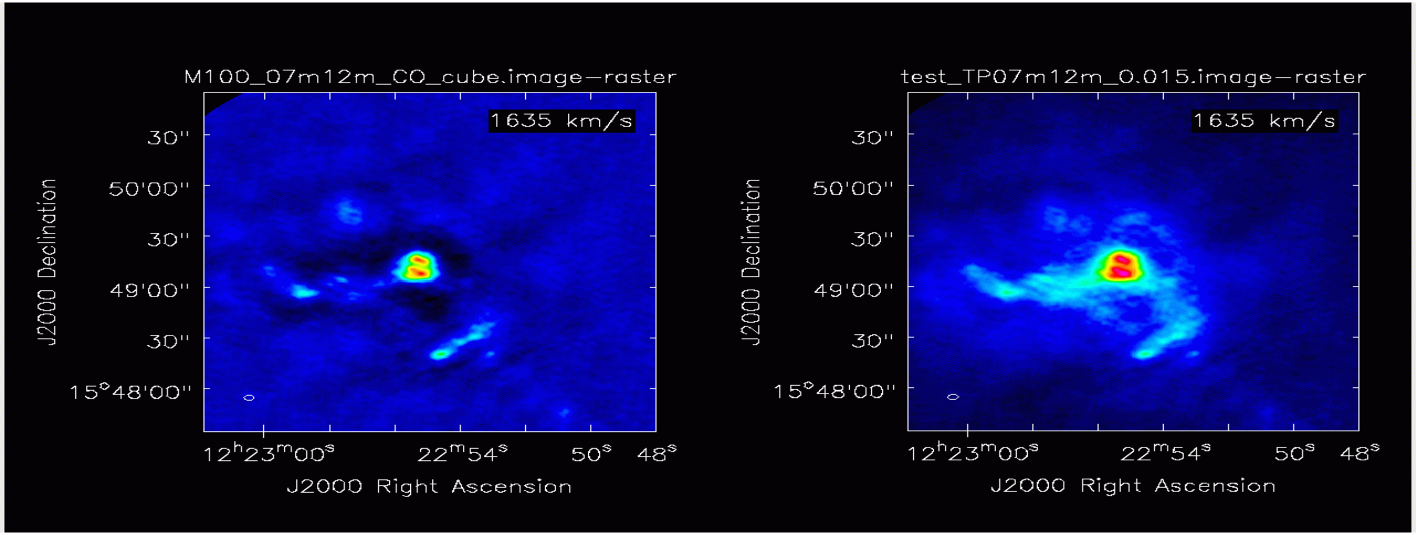
- CLEAN uses weights to give preference to certain data.
  - “natural” vs. “uniform” vs. “Briggs robust”
- We experiment with three different weights for the TP visibilities:
  - RMS from cube based (default in “tp2vis”)
  - Match synthesized beam to beam solid angle
  - Manually adjusting weights

$$\sigma_{ij}(Jy) = \frac{2k}{\eta_q \eta_c A_{eff}} \sqrt{\frac{T_{sys,i} T_{sys,j}}{2\Delta\nu_{ch} t_{ij}}} \times 10^{26}$$

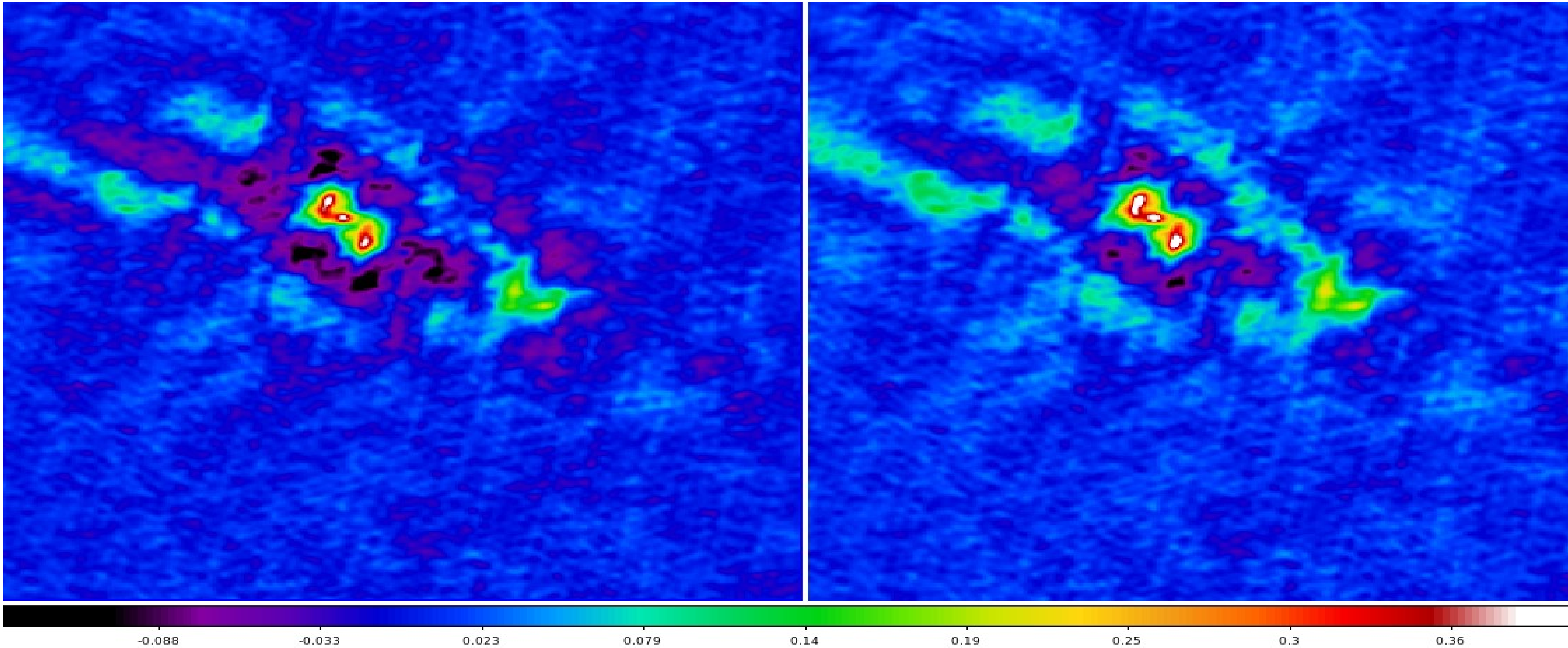


0.54
1.1
1.7
2.2
2.8
3.4
4
4.5
5.1


M100_07m12m_CO_cube.image−raster
1515 km/s
J2000 Declination
J2000 Right Ascension
30"
50'00"
30"
49'00"
30"
15°48'00"
12h23m00s
22m54s
50s
48s
test_TP07m12m_0.015.image−raster
1515 km/s
J2000 Declination
J2000 Right Ascension

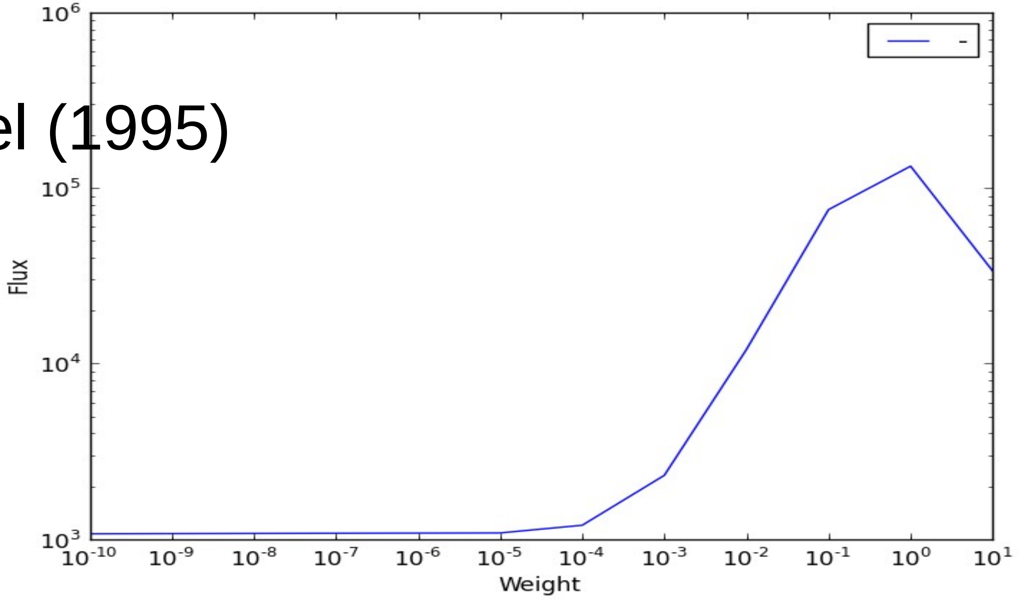

M100_07m12m_CO_cube.image−raster
1635 km/s
J2000 Declination
J2000 Right Ascension
30"
50'00"
30"
49'00"
30"
15°48'00"
12h23m00s
22m54s
50s
48s
test_TP07m12m_0.015.image−raster
1635 km/s
J2000 Declination
J2000 Right Ascension

ALMA vs. TPALMA – channel 36 – no deconvolution



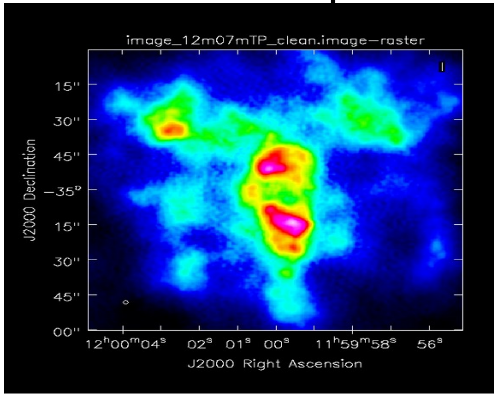
Issues – Conserving Flux

- imstat()['flux'] = imstat()['sum'] * Δv / Nppb
- Nppb = 1.1331 * (Bx*By)/(px*py)
- But what are really Bx and By?
  - Gauss fit to peak of PSF
- See also Jörsäter & van Moorsel (1995)
- Implemented in AIPS::IMAGR
- See also tp2vistweak()



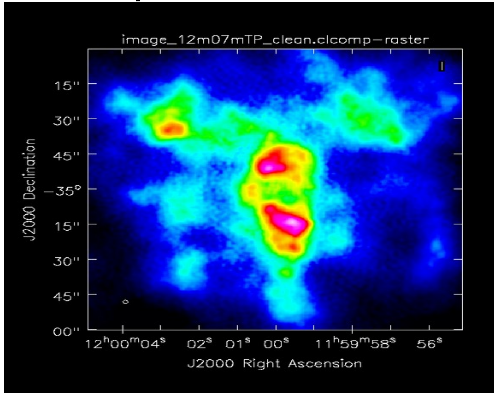
Beam-size Mismatch – What is Jy/beam?

Final map



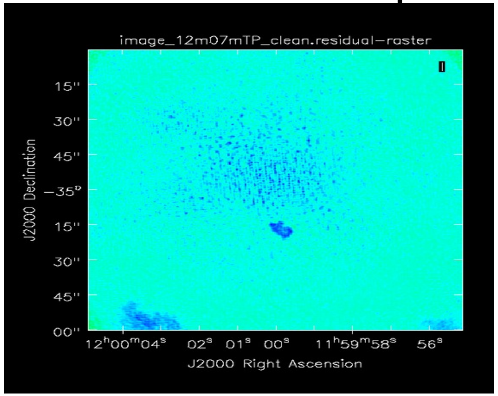
=

Clean component (Model) map



+

Residual map



Jy/(“ **beam**”)

Jy/(“**conv. beam**”)

Jy/(**syn. beam**)

“Convolution beam” is typically adopted.

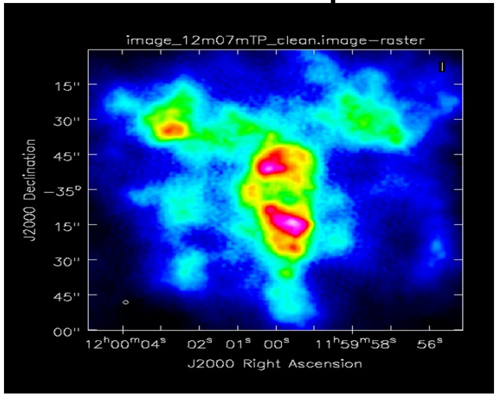
The units of clean component map and residual map are not consistent.

Convolution beam: $\Omega_{conv} = \frac{\pi(b_{maj} \times b_{min})}{4\ln 2}$ ... depends mainly on *longest baselines*

Synthesized beam: $\Omega_{syn} = \int B(l,m)\,dl\,dm = W(0,0)$ ... depends on *zero baseline*

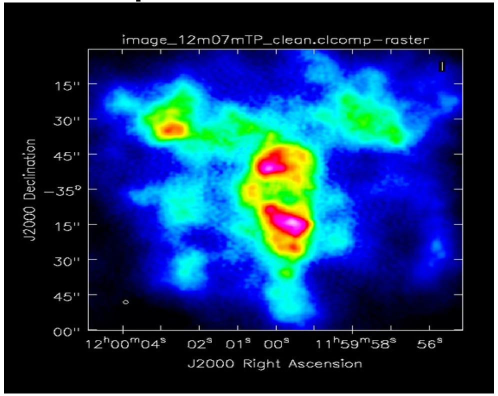
Residual Rescaling: tp2vistweak()

Final map



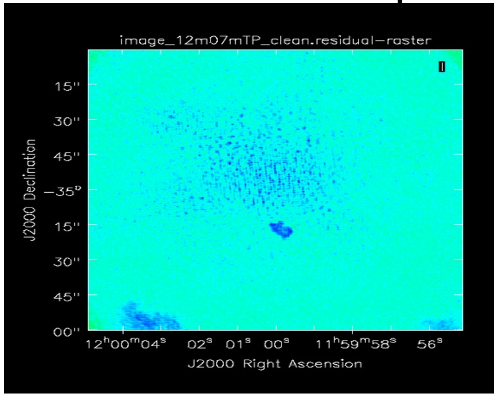
=

Clean component (Model) map



+

Residual map



Jy/("**beam**")

Jy/(conv. beam)

Jy/(syn. beam)

Re-scale this by beam ratio

Cleaned Final map

$$\left[\frac{F}{(\mathrm{Jy}/\Omega_{conv})}\right] = \left[\frac{M}{(\mathrm{Jy}/\Omega_{conv})}\right] + \left[\frac{R}{(\mathrm{Jy}/\Omega_{syn})}\right]$$

Dirty map

$$\left[\frac{D}{(\mathrm{Jy}/\Omega_{syn})}\right] = \left[\frac{I}{(\mathrm{Jy}/\Omega_{syn})}\right] + \left[\frac{R}{(\mathrm{Jy}/\Omega_{syn})}\right]$$

$$\frac{\Omega_{conv}}{\Omega_{syn}} = \frac{F - R}{D - R}$$

Issues – CASA

- mstransform() seems to loose first and/or last channel sometimes
- vpmanager: can’t set a private VIRTUAL?
  - But: being tested with VP=1
- concat() needed before tclean([ms1,ms2]) to prevent a crash out of CASA
- But no concat() for simulator data, or it will crash CASA
-

Simplistic classification

A Variety of Combination Methods

Combination	Fourier domain	Image domain
Before Deconvolution	*Generate psuedo visibilities* • Vogel et al. 1984 • Rodriguez-Fernandez 2008 • Kurono et al. 2009 • Pety & Rodriguez-Fernandez 2010 • Koda et al. 2011 • Koda et al. 2019 (TP2VIS)	*Combine dirty map/beam* • Stanimirovic et al. 1999 • Urvashi Rau, in prep.
During Deconvolution	*Single dish map as initial model* • Cornwell 1988 • Dirienzo et al. 2015	
After Deconvolution	*"Feather" and its predecessors* • Herbstmeier et al. 1996 • Weiβ et al. 2001 • Blagrave et al. 2017	*"Feather" in image domain* • Faridani et al. 2018

TP2VIS public release via Github

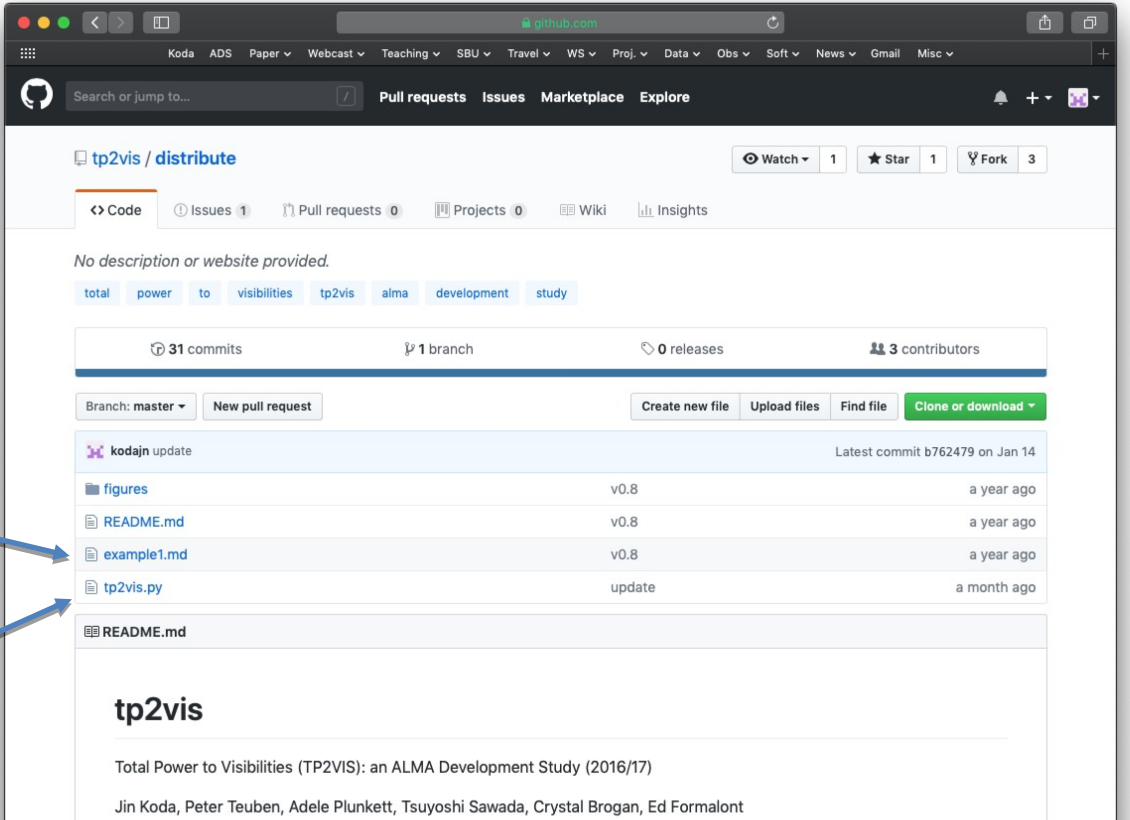
https://github.com/tp2vis/distribute - or just google “tp2vis”

Koda et al. 2019, PASP . Also, ALMA Memo 615

It works!

Example
the spiral galaxy M100

Download “tp2vis.py”



Concluding

- TP2VIS is easy to use, but:
  - May need tp2vistweak()
  - Developed and works for ALMA (12m TP)
  - May need CASA workarounds for some issues
  - Usage of VP not well tested, but should work for non-ALMA