ALMA Study

Total Power Map to Visibilities (TP2VIS)

Joint-Deconvolution of ALMA 12m, 7m & TP Array Data

Peter Teuben (U. Maryland)

Jin Koda (Stony Brook/NAOJ/JAO); Tsuyoshi Sawada (NAOJ/JAO);
Adele Plunkett (ESO/JAO); Crystal Brogan (NRAO)

Example Science Cases with Extended & Compact Structures

Combining data from the different ALMA arrays is a science driver for a number of topics, namely those that probe size scales of extended and compact structures simultaneously.

- Example science cases include
    - Protostar outflows and their environment
    - Evolution of AGB stars, planetary nebulae, and their winds
    - Formation of dense clumps and pre-stellar cores in molecular clouds
    - Interplay between molecular clouds and galactic structures in nearby galaxies
    - Galactic outflow & fountains
    - Analysis of the probability distribution function (PDF) from diffuse, extended emission to dense, clumpy emission.
    - Many more

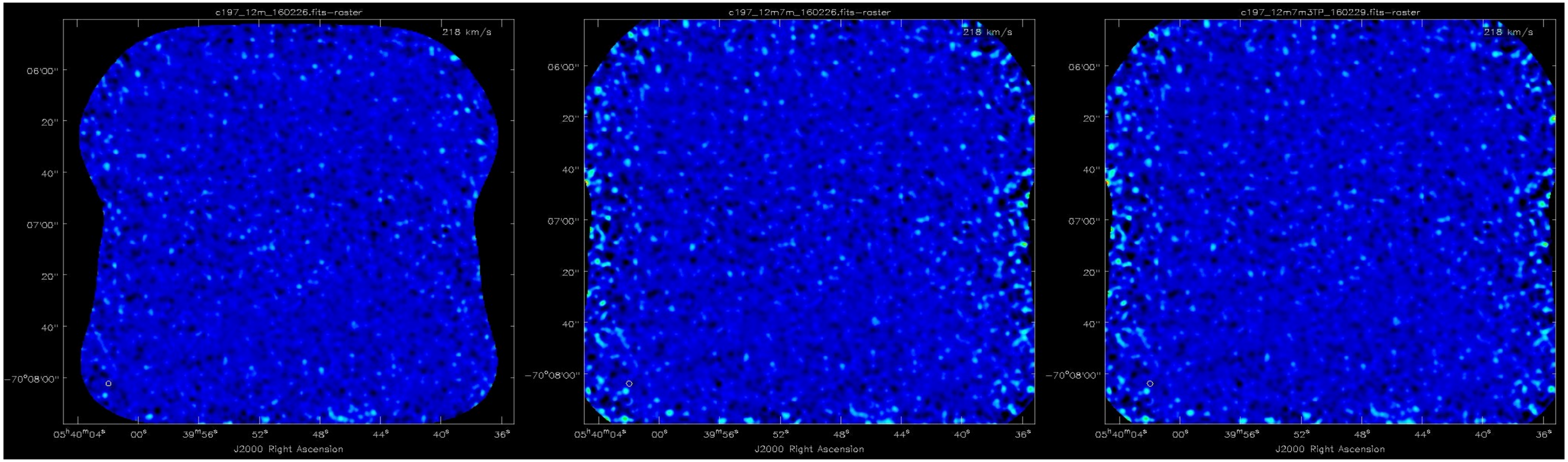
Demonstration with MIRIAD

Example: Structure in Molecular Cloud

ALMA CO(1-0) cube of a molecular cloud in Large Magellanic Cloud

“Stomach” of molecular cloud – the entire FoV should be filled with emission

12m-only 12m+7m 12m+7m+TP



ALMA 12m+7m visibilities
ALMA TP ⇒ visibilities (TP2VIS in MIRIAD) } Joint-deconvolution (CLEAN) in MIRIAD

Demonstration with MIRIAD

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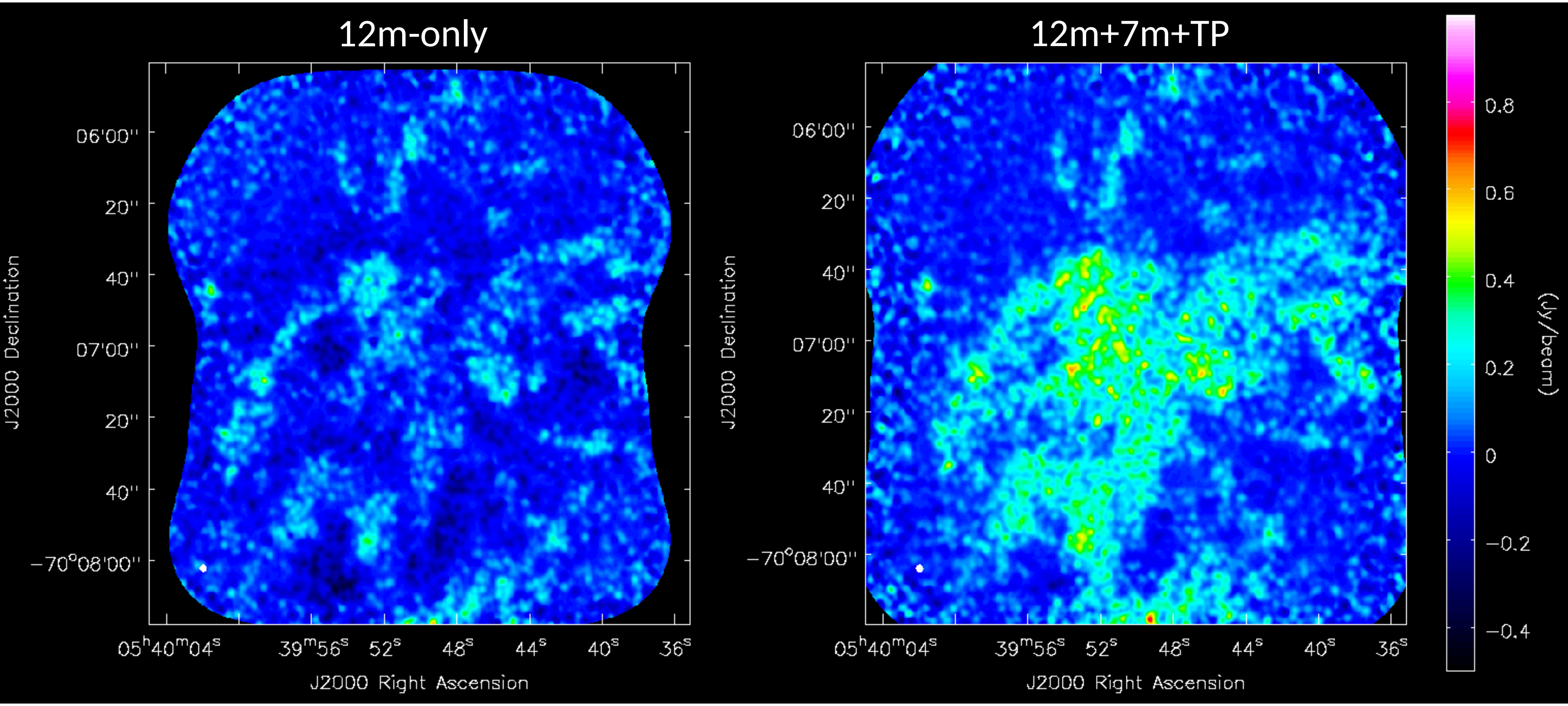


Joint-deconvolution: recovery of extended emission + virtually no negative sidelobes

Demonstration with MIRIAD

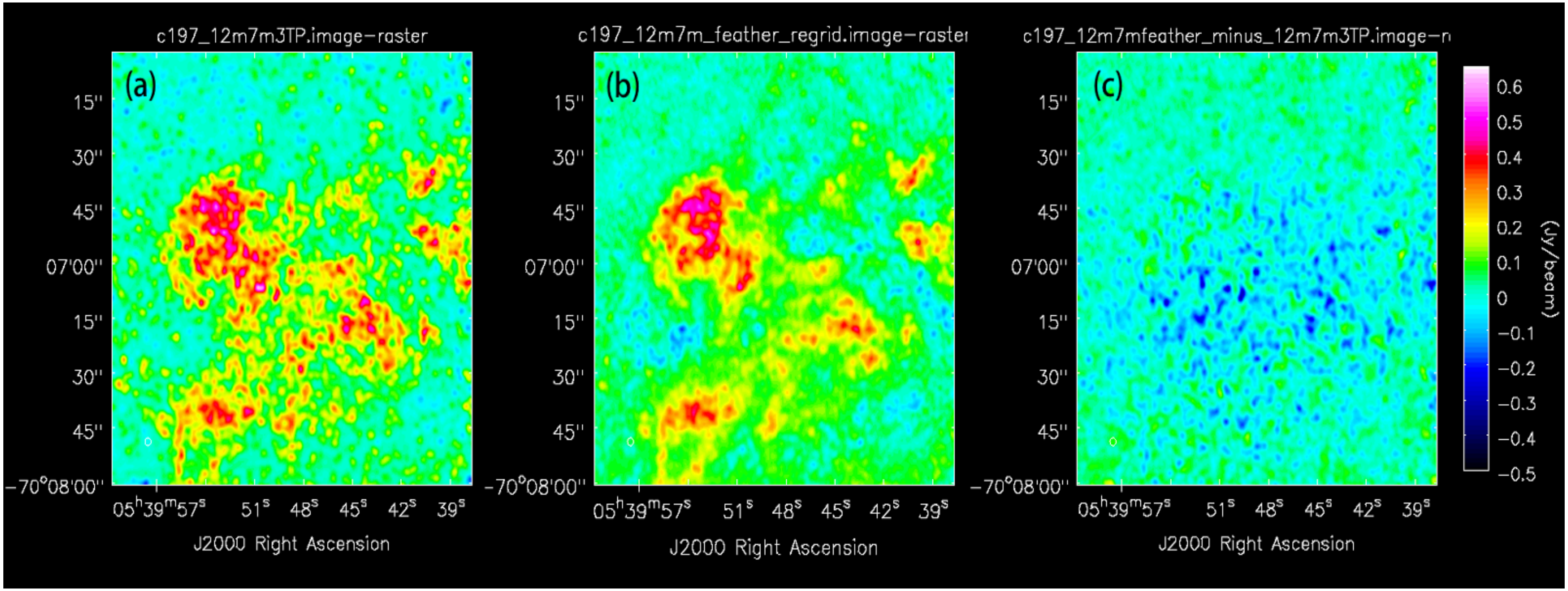
TP2VIS vs Feather

ALMA CO(1-0) Data of GMC in LMC; Reduced with MIRIAD

TP2VIS
12m+7m+TP joint-Deconvolution

Feather
12m+7m Deconvolution + TP

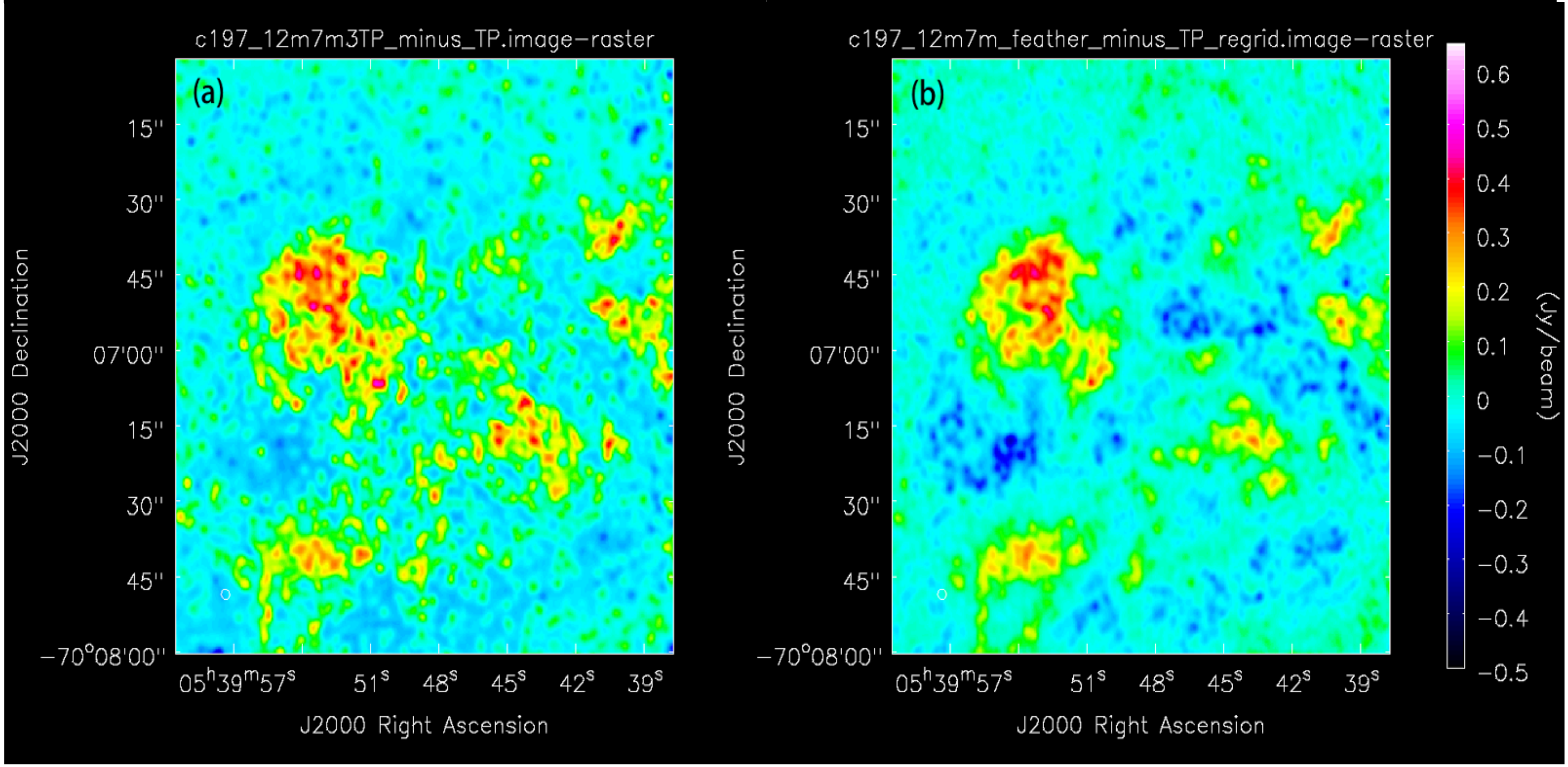
Difference
Feather – TP2VIS



Systematic difference around emission

Deconvolution with and without TP

How well deconvolution works for 12m+7m part with and without TP?



12m+7m+TP joint-Deconvolution Minus TP

12m+7m Deconvolution

Benefit for the 12m+7m part.

Joint-deconvolution: Less negative around emission! Peaks not as good? – need more tests.

ALMA Study Objectives

Our method already implemented in MIRIAD for combination of CARMA and Nobeyama 45m telescope data (Koda et al. 2011). This study will make it user-friendly in CASA.

- Developments
  - CASA-based TP2VIS tool
  - Visibility weight visualization tool
  - Benchmark simulation data
- Validations
  - Tests with simulation data
  - Tests with ALMA archival data
- User manuals

Members and Expertise

- Jin Koda (Stony Brook/NAOJ/JAO)
  - Developed TP2VIS in MIRIAD (Koda et al. 2011, ApJS, 193, 19)
  - Jump-started tests for CASA TP2VIS during his sabbatical at NAOJ Chile/JAO in Spring 2016; we will show some progress in this talk.
- Peter Teuben (U. Maryland)
  - One of the three founders of MIRIAD
  - Expertise in CASA through the ADMIT development
- Tsuyoshi Sawada (NAOJ/JAO)
  - JAO scientist
  - Expert of ALMA TP performance.
- Adele Plunkett (ESO/JAO)
  - ESO postdoc fellow at JAO
  - Extensive testing of interferometer + single-dish combination
- Crystal Brogan (NRAO)
  - CASA subsystem scientist

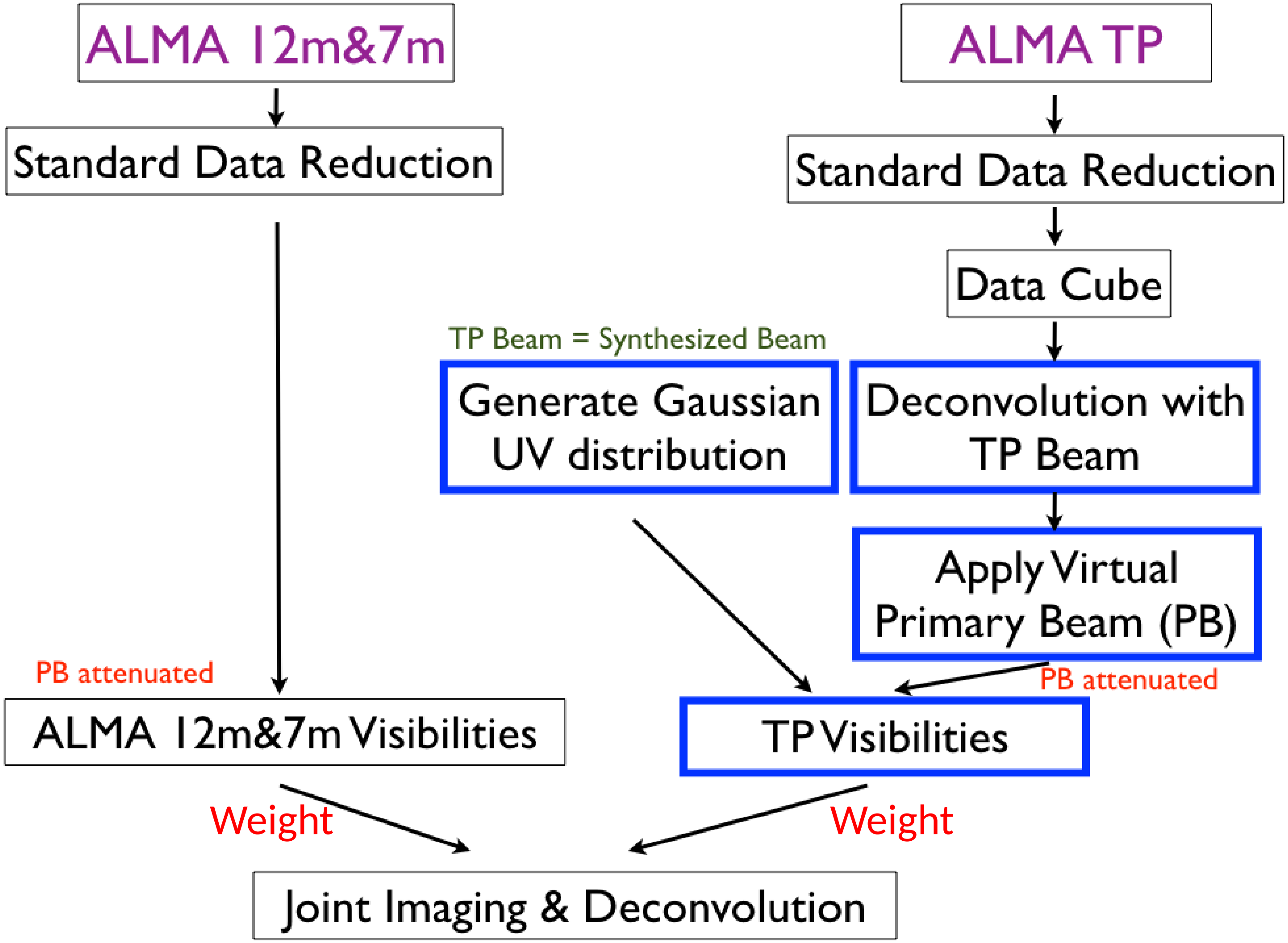
12m+7m+TP Combination Methods

1) Initial guess
    - TP map as initial guess for 12m+7m CLEAN
2) Feather
    - Add CLEANed 12m+7m map with TP map
3) Joint-deconvolution (i.e., convert TP to VIS)
    - CLEAN 12m+7m+TP simultaneously

Notes:

- CLEAN could be replaced with MEM or any other deconvolution method
- 3) can be used together with 1) or 2)

TP2VIS Flow Chart



ALMA 12m&7m

Standard Data Reduction

ALMA TP

Standard Data Reduction

Data Cube

TP Beam = Synthesized Beam

Generate Gaussian UV distribution

Deconvolution with TP Beam

Apply Virtual Primary Beam (PB)

PB attenuated

PB attenuated

ALMA 12m&7m Visibilities

TP Visibilities

Weight

Weight

Joint Imaging & Deconvolution

Converting TP map into Visibilities

- Basic parameters of each visibility
  - **U**
  - **V**
  - **W**
  - **Amplitude**
  - **Phase**
  - **Weight**
- Supplementary parameters
  - Field for mosaic
  - Primary beam shape
  - Etc.

Converting TP map into Visibilities

- Basic parameters of each visibility
  - **U**
  - **V**
  - **W**
  - **Amplitude**
  - **Phase**
  - **Weight**

Visibility distribution set manually

Coupled in a sense

From Total Power (TP) map

Depends on system parameters, integration times, etc.
Will try two approaches

- Supplementary parameters
  - Field for mosaic
  - Primary beam shape
  - Etc.

(**U, V, W**, Amplitude, Phase, Weight)

Gaussian Visibility/Weight Distribution

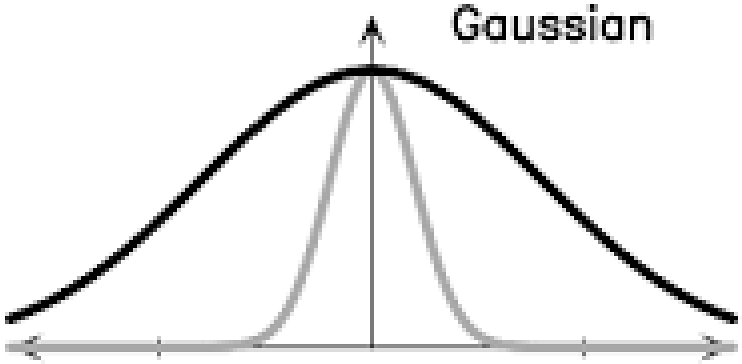
Generate the distributions of visibilities and their weights, so that their F.T. produces the TP beam pattern as synthesized beam under Natural weighting.

If the TP array has a Gaussian beam pattern,

The visibility/weight distribution should also follows a Gaussian.

$$\mathrm{Beam}_{TP} \mu\ e^{-(l^2+m^2)/2\sigma^2}$$

$$\left[\mathrm{Beam}_{TP}\right]^{F.T.} \mu\ e^{-(2\pi\sigma)^2(u^2+v^2)/2}$$



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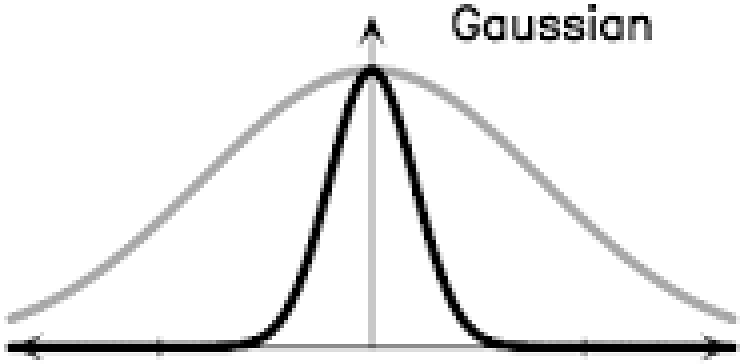


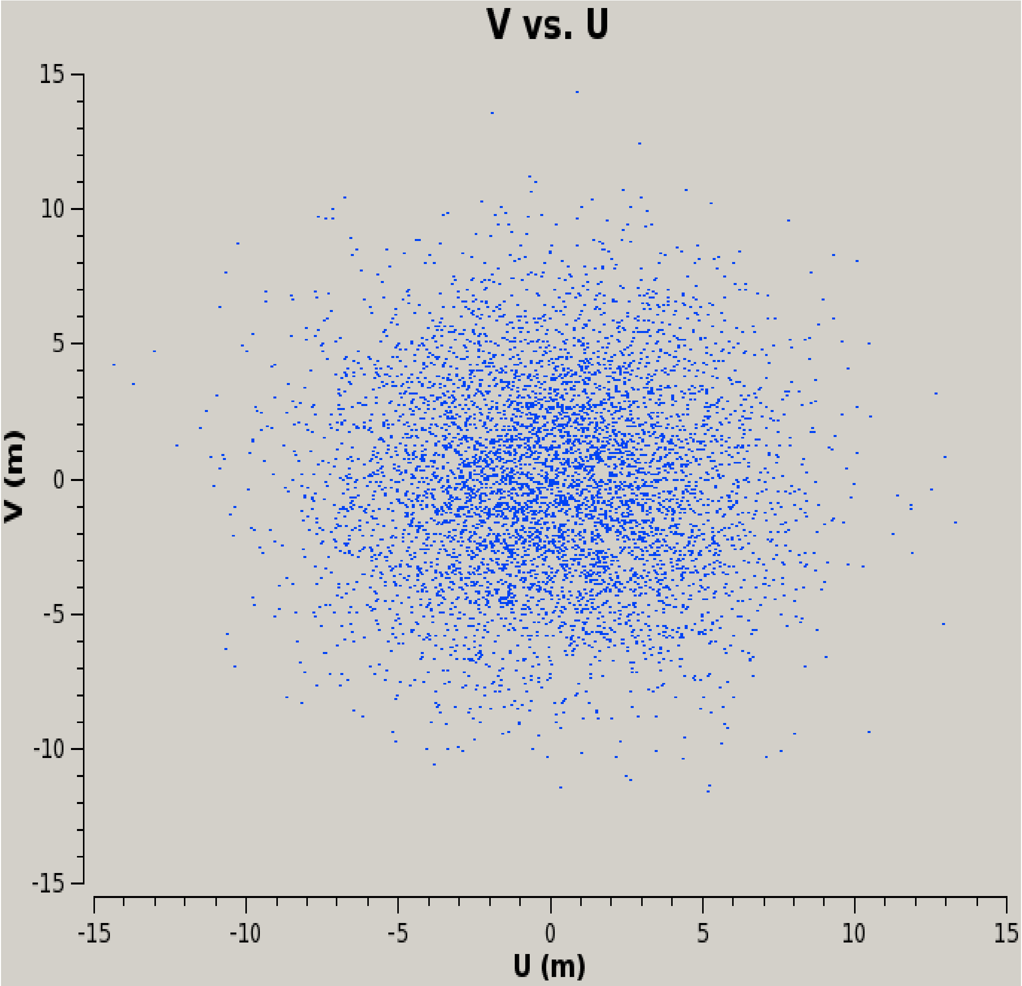
$\mathrm{FWHM}=2\sqrt{2\ln 2}\sigma$

http://www.cv.nrao.edu/course/astr534/FourierTransforms.html

(**U, V, W**, Amplitude, Phase, Weight)

Progress report I:

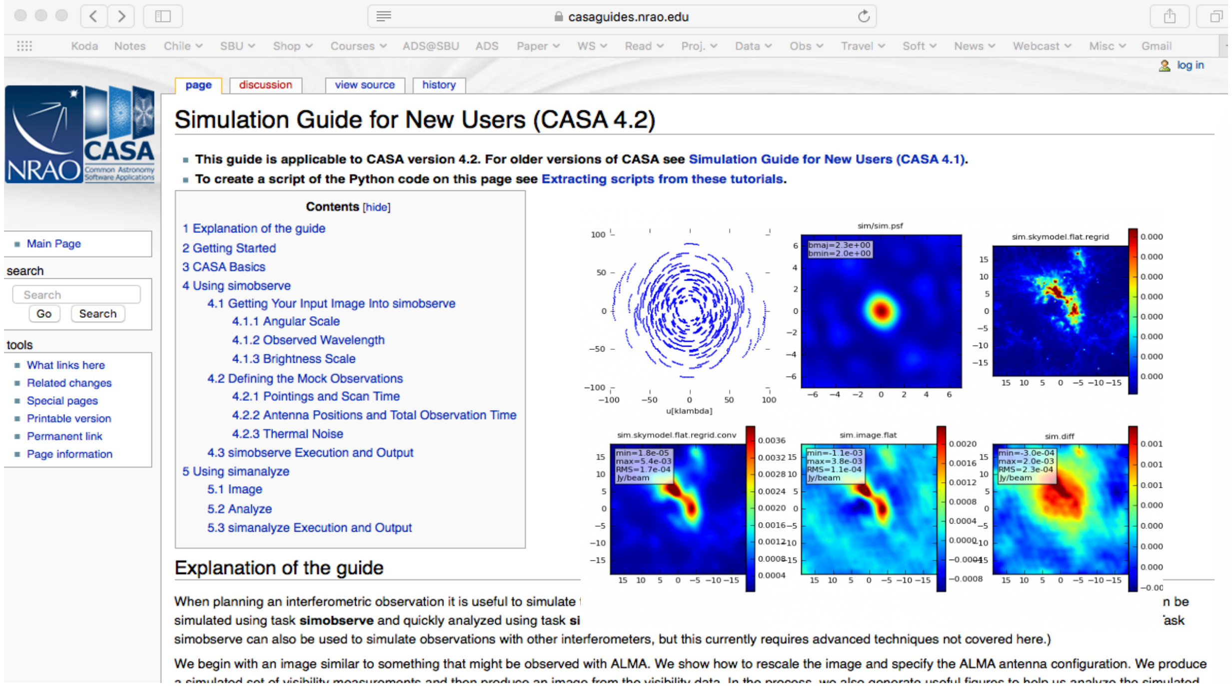
Gaussian visibility distribution in CASA measurement set



Obtain (Amp, Phase) from TP Map

- Fourier-transform TP map and read (amp,phase) at a location of each visibility.
- Learning CASAtoolkit tasks in the “simobserve” script

  ⇒ some success, but not fully yet.



Simulation Guide for New Users (CASA 4.2)

- **This guide is applicable to CASA version 4.2. For older versions of CASA see Simulation Guide for New Users (CASA 4.1).**
- **To create a script of the Python code on this page see Extracting scripts from these tutorials.**

Contents [hide]

Explanation of the guide

When planning an interferometric observation it is useful to simulate n be simulated using task **simobserve** and quickly analyzed using task **si** 'ask simobserve can also be used to simulate observations with other interferometers, but this currently requires advanced techniques not covered here.)

We begin with an image similar to something that might be observed with ALMA. We show how to rescale the image and specify the ALMA antenna configuration. We produce

(U, V, W, Amplitude, Phase, **Weight**)

Weights of TP Visibilities

- Among TP visibilities
  - Two ways to adjust
    - Adjusting visibility distribution
    - Adjusting weights of visibility points

    ⇒Already set the visibility distribution to Gaussian. All visibility points should have an equal weight.

- With respect to 12m+7m visibilities
  - Best approach
    - Still debatable
    - Need tests
  - Two approaches we plan to test
    - RMS noise-based approach
    - Matched beamsize approach

Noise-based Approach: Weight from T_{sys} and t_{vis}

Calculate noise-based weight ✉ need to the relation between sensitivity and Tsys, etc.

Idea:

Image sensitivity $\Delta S^i \mu T_{sys}$

Visibility sensitivity $\Delta S_k^v \mu T_{sys}$

share the same proportionality constant.

(If we figure one out, we know the other one.)

In fact, with natural weighting the noises of each visibility and of final image are related simply:

$$\left(\frac{1}{\Delta S^i}\right)^2 = \sum_k \left(\frac{1}{\Delta S_k^v}\right)^2$$

	ALMA 12m, 7m	ALMA Total Power
Visibility sensitivity ΔS^v	(1) $\Delta S_k^v = C_{ij}\sqrt{\frac{T_{sys,i}T_{sys,j}}{B \cdot t_{vis}}}$	(3) $\Delta S_k^v = C_{TP}\sqrt{\frac{T_{sys}T_{sys}}{B \cdot t_{vis}}}$
Image sensitivity ΔS^i	(2) $\Delta S^i = C_{ij}\sqrt{\frac{T_{sys,i}T_{sys,j}}{B \cdot t_{tot}}}$	(4) $\Delta S^i = C_{TP}\sqrt{\frac{T_{sys}T_{sys}}{B \cdot t_{tot}}}$

$t_{tot} = N_{vis} t_{vis}$

For 12m, 7m visibility

$$C_{ij} = \frac{2k_B}{\sqrt{(\eta_{a,i}A_i)(\eta_{a,j}A_j)}}\frac{1}{\sqrt{2}\eta_q}$$

For TP map

$$C_{TP} = \frac{2k_B}{\eta_{mb}\eta_a\eta_q A} \longrightarrow$$

Use this for TP visibilities

(U, V, W, Amplitude, Phase, **Weight**)

Noise-based Approach: Parameters for weights

Noise of TP single-dish map: $\Delta S^i = C_{TP}\sqrt{\frac{T_{sys}T_{sys}}{B \times t_{tot}}}$

Known or measurable

$$C_{TP} = \frac{2k_B}{\eta_{mb}\eta_a\eta_q A}$$

ΔS^i = RMS-noise from emission-free channels

T_{sys} = typical Tsys from observations

$$\left.\begin{matrix} C_{TP} \\ \Delta S^i \\ T_{sys} \end{matrix}\right\} t_{tot} \xrightarrow{} t_{vis} = \frac{t_{tot}}{N_{vis}}$$

$$\uparrow N_{vis}$$

Arbitrarily-chosen number of visibilities
Should be large enough to fill UV-space smoothly

These give the sensitivity (or noise-based weight) of each visibility point: $\Delta S_k^v = C_{TP}\sqrt{\frac{T_{sys}T_{sys}}{B \times t_{vis}}}$

(U, V, W, Amplitude, Phase, **Weight**)

Matched Beamsize-based Approach

With TP data, the beam area and emission have non-zero values.

Dirty map $\xrightarrow{\text{CLEAN}}$ CLEAN components + Residual

Unit: Jy/Ω_{dirty} Jy/Ω_{CLEAN} Jy/Ω_{dirty}

$\Omega_{dirty} \neq \Omega_{CLEAN}$ could cause inconsistency in flux in a CLEANed map

---

We want to have $\Omega_{dirty} = \Omega_{CLEAN}$ for flux conservation

Depend only on weight at (u,v)=(0,0)

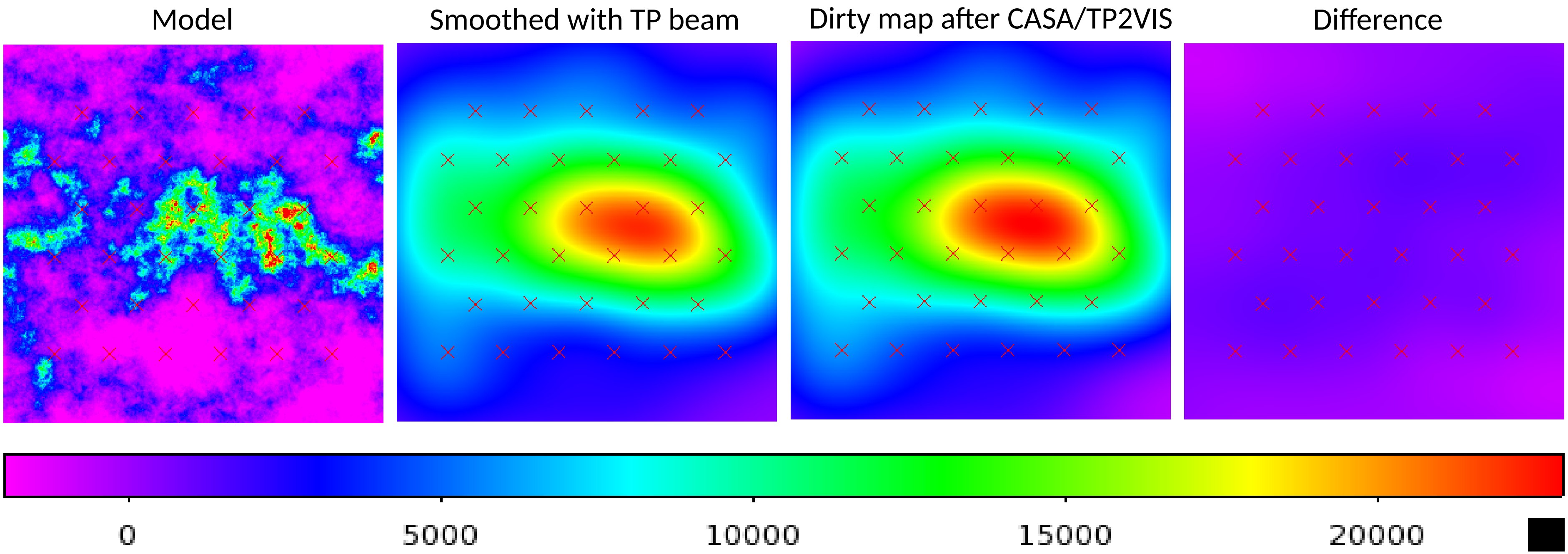
$$\Omega_{dirty} = \iint B(l,m)\,dl\,dm = W(0,0)$$

Depend on weight distribution in uv-space (e.g., on how extended the uv distribution is)

→ Set the weight of TP data to satisfy $\Omega_{dirty} = \Omega_{CLEAN}$

Progress Report II

We can generate (U,V,W, Amp, Phase), but not yet other parameters



Model

Smoothed with TP beam

Dirty map after CASA/TP2VIS

Difference

33 pointing mosaic: x – pointing centers

We can at least make a Gaussian visibility distribution for TP. Still, banging head for many issues: for example, CASA CLEAN/TCLEAN do not accept our TP visibilities together with 12m+7m visibilities …

Benchmark Model Data

- Need model data for benchmark test for TP2VIS and other combination methods in future.

- Not so good data with emission distribution and dynamic range, e.g., like in molecular clouds.

- This ALMA study will develop a set of benchmark model data with compact & extended emission.

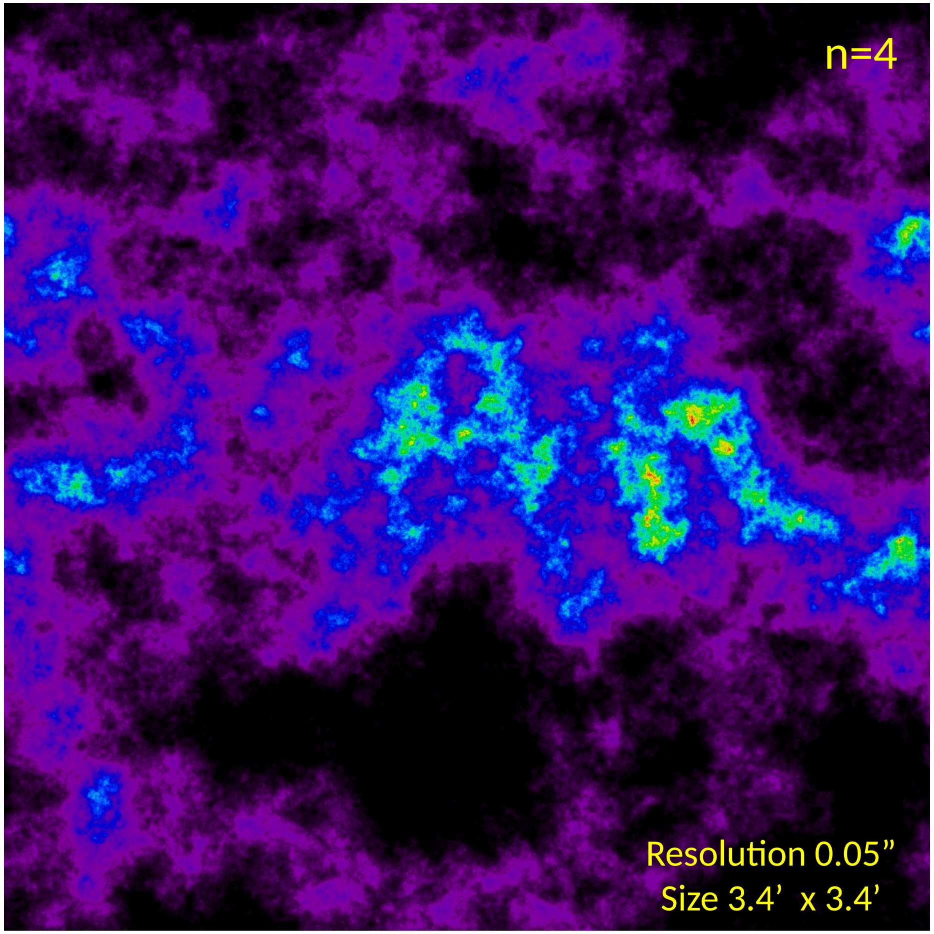
Benchmark Model Data: Example

Molecular cloud with power spectrum density fluctuation

- Power spectrum amplitude

$$P^{3D}(k)\,\mu\,k^{-n}$$

- Random phase



- Test script ok, but slow (~1 week to generate the right on a fast PC).
- Include more coherent structure, such as spiral arm, outflow, etc.

Benchmark Model Data: Example

Molecular cloud with power spectrum density fluctuation

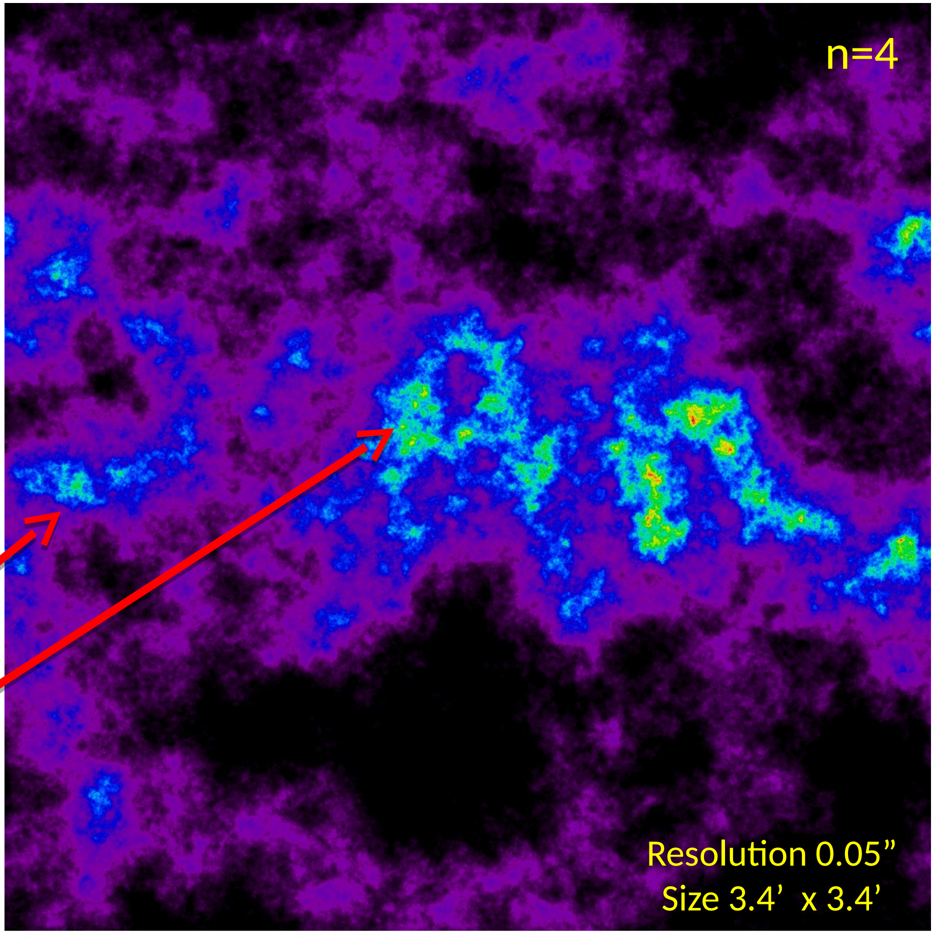
- Power spectrum amplitude

$$P^{3D}(k) \mu k^{-n}$$

- Random phase

One interesting caveat
to those who identify filaments/shells.

Even this random realization shows apparent

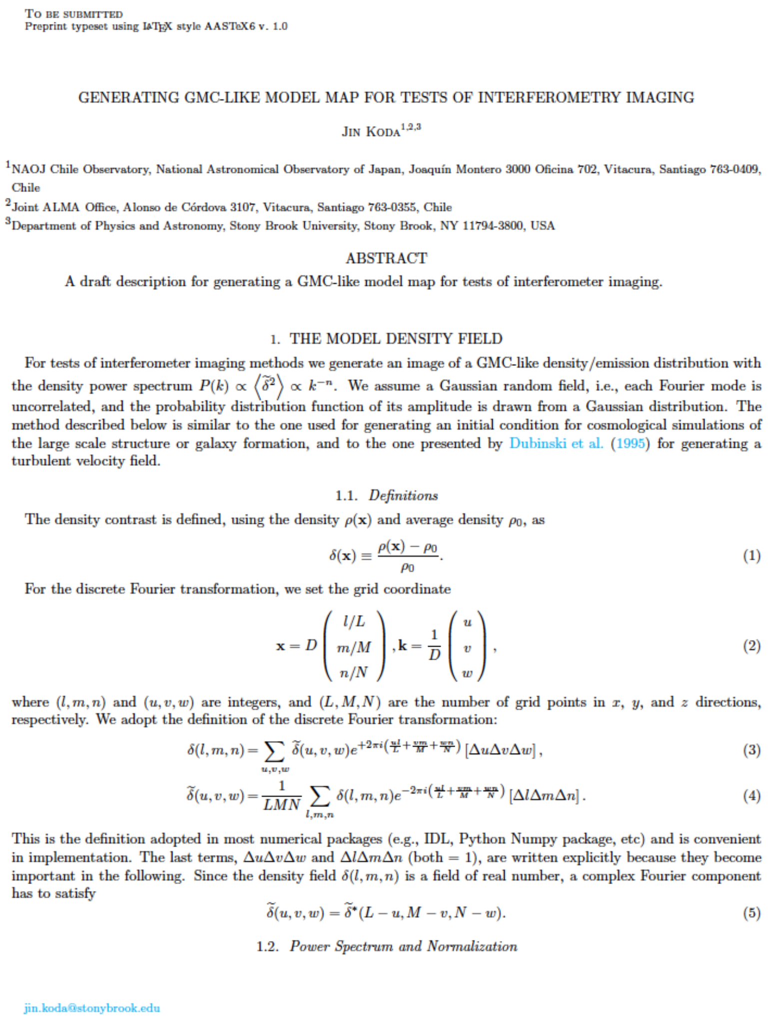


Filament
Shell

Documentation & User Manual

- Final product include
  - Description of the method
  - User manual

Example description of the power-spectrum model



To be submitted
Preprint typeset using LaTeX style AASTeX6 v. 1.0

GENERATING GMC-LIKE MODEL MAP FOR TESTS OF INTERFEROMETRY IMAGING

Jin Koda[1,2,3]

[1]NAOJ Chile Observatory, National Astronomical Observatory of Japan, Joaquín Montero 3000 Oficina 702, Vitacura, Santiago 763-0409, Chile
[2]Joint ALMA Office, Alonso de Córdova 3107, Vitacura, Santiago 763-0355, Chile
[3]Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794-3800, USA

ABSTRACT

A draft description for generating a GMC-like model map for tests of interferometer imaging.

1. THE MODEL DENSITY FIELD

For tests of interferometer imaging methods we generate an image of a GMC-like density/emission distribution with the density power spectrum $P(k) \propto \left\langle \widetilde{\delta}^2 \right\rangle \propto k^{-n}$. We assume a Gaussian random field, i.e., each Fourier mode is uncorrelated, and the probability distribution function of its amplitude is drawn from a Gaussian distribution. The method described below is similar to the one used for generating an initial condition for cosmological simulations of the large scale structure or galaxy formation, and to the one presented by Dubinski et al. (1995) for generating a turbulent velocity field.

1.1. *Definitions*

The density contrast is defined, using the density $\rho(\mathbf{x})$ and average density ρ_0, as

$$\delta(\mathbf{x}) \equiv \frac{\rho(\mathbf{x}) - \rho_0}{\rho_0}. \tag{1}$$

For the discrete Fourier transformation, we set the grid coordinate

$$\mathbf{x} = D \begin{pmatrix} l/L \\ m/M \\ n/N \end{pmatrix}, \mathbf{k} = \frac{1}{D} \begin{pmatrix} u \\ v \\ w \end{pmatrix}, \tag{2}$$

where (l,m,n) and (u,v,w) are integers, and (L,M,N) are the number of grid points in x, y, and z directions, respectively. We adopt the definition of the discrete Fourier transformation:

$$\delta(l,m,n) = \sum_{u,v,w} \widetilde{\delta}(u,v,w) e^{+2\pi i\left(\frac{ul}{L}+\frac{vm}{M}+\frac{wn}{N}\right)} \left[\Delta u \Delta v \Delta w\right], \tag{3}$$

$$\widetilde{\delta}(u,v,w) = \frac{1}{LMN} \sum_{l,m,n} \delta(l,m,n) e^{-2\pi i\left(\frac{ul}{L}+\frac{vm}{M}+\frac{wn}{N}\right)} \left[\Delta l \Delta m \Delta n\right]. \tag{4}$$

This is the definition adopted in most numerical packages (e.g., IDL, Python Numpy package, etc) and is convenient in implementation. The last terms, $\Delta u \Delta v \Delta w$ and $\Delta l \Delta m \Delta n$ (both $= 1$), are written explicitly because they become important in the following. Since the density field $\delta(l,m,n)$ is a field of real number, a complex Fourier component has to satisfy

$$\widetilde{\delta}(u,v,w) = \widetilde{\delta}^*(L-u, M-v, N-w). \tag{5}$$

1.2. *Power Spectrum and Normalization*

jin.koda@stonybrook.edu

Summary of the New ALMA Study

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Our method already implemented in MIRIAD for combination of CARMA and Nobeyama 45m telescope data (Koda et al. 2011). This study will make it user-friendly in CASA.

- Developments
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