

# Millimeter Interferometry Simulation Cookbook

J. Pety<sup>1</sup>, F. Gueth<sup>1</sup>, S. Guilloteau<sup>2</sup>

31-May-2005

Version 1.0

(1) Institut de Radio Astronomie Millimétrique  
300 Rue de la Piscine  
F-38406 Saint Martin d'Hères

This document presents part of the tools used to simulate Millimeter Interferometry observations.

Related information is available in:

- SIC: Command line interpreter
- GREG: Graphical possibilities
- MAPPING: Imaging and deconvolution

## Contents

<b>1</b>	<b>List of Associated Tasks</b>	<b>3</b>
1.1	millimeter-simulation . . . . .	3
1.2	ARRAY_LAYOUT . . . . .	3
1.3	ARRAY_PROJECT . . . . .	4
1.4	AZIMUTH_AVERAGE . . . . .	4
1.5	IMAGE_SAMPLING . . . . .	4
1.6	SHORT_MODEL . . . . .	4
1.7	PHASE_SCREEN . . . . .	5
1.8	SHORT_CLEAN . . . . .	6
1.9	UV_TABLE . . . . .	6
1.10	UV_MODEL . . . . .	6
1.11	UV_FMODEL . . . . .	6
1.12	UV_CCMODEL . . . . .	6
1.13	UV_CCT . . . . .	7
1.14	UV_TRACK_PHASE . . . . .	7
1.15	UV_OBSERVE . . . . .	8
1.16	UV_OBSERVE_NEW . . . . .	8
1.17	UV_POINTING . . . . .	9
1.18	UV_POINTING_NEW . . . . .	9
1.19	UV_SPLITFIELD . . . . .	10
1.20	UV_APPLYPHASE . . . . .	10
1.21	UV_SINUSPHASE . . . . .	10
1.22	UV_TIMEAVERAGE . . . . .	10
1.23	UV_TIMEBASE . . . . .	10
1.24	UV_HYBRID . . . . .	10
1.25	UV_FIDELITY . . . . .	11
1.26	UV_PLUGC . . . . .	11
1.27	UV_FCCT . . . . .	11
1.28	UV_APPLYPHASE . . . . .	11
1.29	UV_ADDNOISE . . . . .	11
1.30	UV_SOLVE . . . . .	11

## 1 List of Associated Tasks

### 1.1 millimeter-simulation

ARRAY_LAYOUT	Create an interferometer configuration file from input parameters
ARRAY_PROJECT	Undocumented...
AZIMUTH_AVERAGE	Compute the azimuthal sum and average of one plane of a data cube
IMAGE_SAMPLING	Define a sampling grid for use as input to SHORT_MODEL
SHORT_MODEL	Simulate single-dish observations
PHASE_SCREEN	Generate a 2-D phase screen to simulate atmospheric contributions
SORT_CLEAN	Sort a Clean Component Table by Intensity
UV_TABLE	Compute a Nyquist sampled UV table from a model data cube
UV_MODEL	Compute a UV table (using a template sampling) from a model data cube
UV_FMODEL	Compute a UV table (using a template sampling) from a model data cube
UV_CCMODEL	Create a model UV table from a Clean Component List.
UV_CCT	(Obsolete?, see UV_CCMODEL) Create a UV table from clean image
UV_TRACK_PHASE	Compute uv coverage + phase noise
UV_OBSERVE	Compute uv coverage + phase noise + amplitude errors
UV_OBSERVE_NEW	Compute uv coverage + phase/amplitude errors + anomalous refraction
UV_POINTING	Simulate pointing errors
UV_POINTING_NEW	Compute a UV table with pointing errors from a model data cube
UV_SPLITFIELD	Split a multi-field UV table into a series of single fields
UV_APPLYPHASE	Apply a gain solution to a UV table.
UV_SINUSPHASE	Create a model UV table with sinusoidal phase variation
UV_TIMEAVERAGE	Smooth a UV table according to time
UV_TIMEBASE	Sort a UV table into Time-Baseline order
UV_HYBRID	UV plane hybridization of two images
UV_FIDELITY	Compute Fidelity in the UV plane from two images
UV_PLUGC	Plug continuum averaged visibilities into a line UV table
UV_FCCT	Compute a UV table (using a template sampling) from a list of compact sources
UV_APPLYPHASE	Apply a gain solution to a UV table.
UV_ADDNOISE	Add noise to a UV table,
UV_SOLVE	Compute a gain solution from a calibrator UV table

### 1.2 ARRAY\_LAYOUT

#### ARRAY\_LAYOUT

This task creates a configuration file from the input parameters (number of antennas, latitude,...) and the kind of array to be used:

- 1 = compact
- 2 = disk + random
- 3 = ring
- 4 = ring + random
- 5 = reuleaux triangles
- 6 = reuleaux triangles + random

7 = spiral

### 1.3 ARRAY\_PROJECT

ARRAY\_PROJECT

### 1.4 AZIMUTH\_AVERAGE

AZIMUTH\_AVERAGE

Compute the azimuthal sums and averages as a function of radius of one plane of a data cube. The azimuthal sums and averages are computed around the central pixel (i.e.  $nx/2+1$ ,  $ny/2+1$ ).

### 1.5 IMAGE\_SAMPLING

IMAGE\_SAMPLING

Define a sampling grid for use as input to SHORT\_MODEL. The sampling grid is a regular rectangular grid large enough to cover the size of the input sky image. It is better than Nyquist sampled, i.e. the pixel size is the beam width divided by POINT\_PER\_BEAM\$. One grid point either pass through the sky image center or the reference pixel available in the sky image.

To better mimic On-The-Fly observations the grid should have Nyquist sampling perpendicular to the scanning direction.

The grid nod positions are given in radian as offsets compared to the reference position of the sky image. The grid is duplicated by the number of Single-Dish antenna simultaneously observing. The output table has the following format: Number of position x Number of antenna x 2 (Lambda and Beta coordinates).

### 1.6 SHORT\_MODEL

SHORT\_MODEL

This task simulates observations performed with single-dish antennas, to be used later on as short spacings information. The model image is convolved by the antenna lobe (via Fourier Transform) and the intensity is then estimated at (i) the position of the mosaic fields, and (ii) on an externally defined grid (see IMAGE\_SAMPLING documentation). If the required position does not coincide with a pixel center, a bilinear interpolation from the neighbor pixels is performed.

Pointing errors can be simulated by estimating the intensity at a slightly wrong position. This task can generate simple kind of pointing errors but it can also read an input pointing error table (enabling to simulate much more complex kind of pointing errors).

Thermal noise can then be added to the data, and the corresponding weight is stored. Finally, a calibration error can be simulated: the observed intensities are multiplied by a random factor whose mean value (different from 1 if a systematic error is present) and rms can be specified. In this case, we obtain: `results = cal_rr*(model+thermal0ise)`.

The error on the amplitude gain is modeled as the sum of an offset and a drift with time. The offset and drift values are randomly reset at each calibration for each antennas. In addition, an offset common to all the antennas can also be added to the amplitude gain.

Intensity unit of input image is supposed to be Kelvin. The output table has the following format: 4 columns x Number of antenna x (NFIELD\$ + Number of observed positions). Column 1 is the X offset in radian, column 2 the Y offset in radian, column 3 the weight and column 4 the flux in Jy. The first NFIELD\$ lines of the model are the position of the mosaic for use by UV\_ZERO and all the other ones are the nod of the externally defined grid (by IMAGE\_SAMPLING) for use by UV\_SINGLE. This complex line layout comes from historical reasons (as usual)...

Limitation: only image can be processed (i.e. \*no\* data cube) meaning that this task can not (yet) handle spectra cubes.

## 1.7 PHASE\_SCREEN

### PHASE\_SCREEN

Warning: This task is encapsulated into the "phaseeen.map" procedure which enables an easy viewing of the result.

To compute the atmospheric phase errors, this task generate a 2-D phase screen on a grid with sufficient spatial resolution to sample the antenna diameter (typically 4-m pixels for ALMA, and 4-m pixels for Bure). The phase screen is generated in the Fourier plane with the constraint that its 2nd order structure function is a combination of 3 power laws in 3 different spatial ranges. The resulting phase screen is averaged over the effective dish diameter. Because of the size limitation imposed by the FFT, very long phase screen are built as a linear combination of independently generated screens. This is correct since atmospheric path-length variations are completely uncorrelated at large distances.

Dynamic (anomalous) refraction is directly proportional to the phase gradient. This task thus computes the phase gradient associated to the phase screen, in order to obtain a coherent derivation of the dynamic refraction term. As the phase screen, the phase gradient is averaged over the effective dish diameter.

## 1.8 SORT\_CLEAN

SORT\_CLEAN

Sort a Clean Component Table in decreasing order of intensity.

## 1.9 UV\_TABLE

UV\_TABLE

Compute a UV table from an input image (3-D data cube are allowed). It differs from UV\_MODEL in producing UV data on a critically sampled rectangular grid rather than along user specified tracks. It is typically used to analyse image plane observational data with UV tools.

## 1.10 UV\_MODEL

UV\_MODEL

Compute a UV table from an input image (3-D data cube are allowed) and a reference UV table used to specify the UV sampling. Task UV\_FMODEL will do the same, but faster, by using an intermediate FFT plus resampling rather than the direct Sin and Cos.

Related task UV\_TABLE will do the same for a regular output UV grid rather than on the sampling of a template table.

## 1.11 UV\_FMODEL

UV\_FMODEL

Compute a UV table from an input image (3-D data cube are allowed) and a reference UV table used to specify the UV sampling. This is the fast version of UV\_MODEL, which uses an intermediate FFT plus resampling rather than the direct Sin and Cos.

## 1.12 UV\_CCMODEL

UV\_CCMODEL

Use a Clean Component Table produced by WRITE CCT (in Mapping) to compute a UV table from an input UV coverage. It can also be used to subtract the Clean Components from a UV table to compute the residuals.

### 1.13 UV\_CCT

UV\_CCT

Compute a UV table from a Clean Component Table. See also UV\_CCMODEL.

### 1.14 UV\_TRACK\_PHASE

UV\_TRACK\_PHASE simulates the uv coverage of an observation specified by the source, observatory, and hour angle range. The output is a uv table that can be used as input for tasks such as UV\_FMODEL. Caution: this uv table is not standard, as it includes two additional columns (#11 with elevation, #12 with integration time).

The weight column (#10) is filled with as realistic as possible estimates of the actual weights (derived from Trec, Tau, elevation).

The visibilities columns (#8 and #9) are filled with a point source (amplitude = 1, phase = 0). Random phase noise can be added, to simulate atmospheric phase noise.

If DO\_SCREEN = YES, a phase screen is used to simulate phase noise: this file contains a statistically correct spatial distribution of the phase perturbation induced by the atmosphere. This screen moves above the array at the wind velocity. The correct phase value is computed each antenna at each time dump.

If DO\_CALIB = YES, the observations of a calibrator are simulated, assuming a loop calibrator-source-calibrator-source. The corresponding uv table is created.

If DO\_RADIOM = YES, a phase correction based on WVR measurements is simulated.

UV\_TRACK family of tasks (in order of increasing complexity):

- UV\_TRACK: uv coverage + random phase noise
- UV\_TRACK\_PHASE: phase noise from atmospheric screen + observations of calibrator + WVR correction
- UV\_OBSERVE: also includes amplitude noise

- UV\_OBSERVE\_NEW: also includes anomalous refraction

### 1.15 UV\_OBSERVE

UV\_OBSERVE simulates the uv coverage of an observation specified by the source, observatory, and hour angle range. The output is a uv table that can be used as input for tasks such as UV\_FMODEL. Caution: this uv table is not standard, as it includes two addition columns (#11 with elevation, #12 with integration time).

The weight column (#10) is filled with as realistic as possible estimates of the actual weights (derived from Trec, Tau, elevation).

The visibilities columns (#8 and #9) are filled with a point source (amplitude = 1, phase = 0). Amplitude calibration errors (offset + drifts) can be included. Random phase noise can be added, to simulate atmospheric phase noise.

If DO\_SCREEN = YES, a phase screen is used to simulate phase noise: this file contains a statistically correct spatial distribution of the phase perturbation induced by the atmosphere. This screen moves above the array at the wind velocity. The correct phase value is computed each antenna at each time dump.

If DO\_CALIB = YES, the observations of a calibrator are simulated, assuming a loop calibrator-source-calibrator-source. The corresponding uv table is created.

If DO\_RADIOM = YES, a phase correction based on WVR measurements is simulated.

UV\_TRACK family of tasks (in order of increasing complexity):

- UV\_TRACK: uv coverage + random phase noise
- UV\_TRACK\_PHASE: phase noise from atmospheric screen + observations of calibrator + WVR correction
- UV\_OBSERVE: also includes amplitude noise
- UV\_OBSERVE\_NEW: also includes anomalous refraction

### 1.16 UV\_OBSERVE\_NEW

UV\_OBSERVE\_NEW simulates the uv coverage of an observation specified by



the source, observatory, and hour angle range. The output is a uv table that can be used as input for tasks such as UV\_FMODEL. Caution: this uv table is not standard, as it includes two addition columns (#11 with elevation, #12 with integration time).

The weight column (#10) is filled with as realistic as possible estimates of the actual weights (derived from Trec, Tau, elevation).

The visibilities columns (#8 and #9) are filled with a point source (amplitude = 1, phase = 0). Amplitude calibration errors (offset + drifts) can be included. Random phase noise can be added, to simulate atmospheric phase noise.

If DO\_SCREEN = YES, a phase screen is used to simulate phase noise: this file contains a statistically correct spatial distribution of the phase perturbation induced by the atmosphere. This screen moves above the array at the wind velocity. The correct phase value is computed each antenna at each time dump.

If DO\_CALIB = YES, the observations of a calibrator are simulated, assuming a loop calibrator-source-calibrator-source. The corresponding uv table is created.

If DO\_RADIOM = YES, a phase correction based on WVR measurements is simulated.

UV\_TRACK family of tasks (in order of increasing complexity):

- UV\_TRACK: uv coverage + random phase noise
- UV\_TRACK\_PHASE: phase noise from atmospheric screen + observations of calibrator + WVR correction
- UV\_OBSERVE: also includes amplitude noise
- UV\_OBSERVE\_NEW: also includes anomalous refraction

## 1.17 UV\_POINTING

UV\_POINTING

Fast pointing error simulation based on gridded interpolation from the Fourier Transform of an image

## 1.18 UV\_POINTING\_NEW

UV\_POINTING\_NEW

Compute a UV table from an input image (2-D images only) and a reference UV table used to specify the UV sampling. Pointing errors are added from an independant table. This task can be used to model a mosaic observation with or without pointing errors.

### 1.19 UV\_SPLITFIELD

UV\_SPLITFIELD

Use for ALMA simulation. Splits a special UV table containing data for overlapping fields into separate, single field UV tables.

### 1.20 UV\_APPLYPHASE

UV\_APPLYPHASE

Apply phase correction to a UV table. The first UV table contains the gain correction, the second the visibilities to be corrected. Works only for one channel for the time being...

### 1.21 UV\_SINUSPHASE

Used in ALMA simulator during its debugging, and perhaps in some version still nowadays...

UV\_SINUSPHASE

### 1.22 UV\_TIMEAVERAGE

Smooth a UV table according to time.

### 1.23 UV\_TIMEBASE

UV\_TIMEBASE

### 1.24 UV\_HYBRID

UV\_HYBRID

Compute a synthetic images from two input ones which contain information on different scales.

## 1.25 UV\_FIDELITY

UV\_FIDELITY

Compute Fidelity in the UV plane from two images

## 1.26 UV\_PLUGC

UV\_PLUGC puts a time average continuum UV table into the last channel of a spectral line one. It is intended for specific purposes where having the continuum and line data in the same table is required. The weights of the continuum data is kept also.

## 1.27 UV\_FCCT

UV\_FCCT

Compute a UV table from a list of Clean Components (for several channels) and a reference UV table used to specify the UV sampling. This is the fast version of UV\_CCT, which uses an intermediate FFT plus resampling rather than the direct Sin and Cos.

## 1.28 UV\_APPLYPHASE

UV\_APPLYPHASE

Apply phase correction to a UV table. The first UV table contains the gain correction, the second the visibilities to be corrected. Works only for one channel for the time being...

## 1.29 UV\_ADDNOISE

UV\_ADDNOISE

Add noise to a UV table, according to the weights of a specified channel, with an optional scale factor.

## 1.30 UV\_SOLVE

UV\_SOLVE

Compute a gain solution from a calibrator UV table

## Index

ARRAY\_LAYOUT, 3  
ARRAY\_PROJECT, 4  
AZIMUTH\_AVERAGE, 4  
  
IMAGE\_SAMPLING, 4  
  
millimeter-simulation, 3  
  
PHASE\_SCREEN, 5  
  
SHORT\_MODEL, 4  
SORT\_CLEAN, 6  
  
UV\_ADDNOISE, 11  
UV\_APPLYPHASE, 10, 11  
UV\_CCMODEL, 6  
UV\_CCT, 7  
UV\_FCCT, 11  
UV\_FIDELITY, 11  
UV\_FMODEL, 6  
UV\_HYBRID, 10  
UV\_MODEL, 6  
UV\_OBSERVE, 8  
UV\_OBSERVE\_NEW, 8  
UV\_PLUGC, 11  
UV\_POINTING, 9  
UV\_POINTING\_NEW, 9  
UV\_SINUSPHASE, 10  
UV\_SOLVE, 11  
UV\_SPLITFIELD, 10  
UV\_TABLE, 6  
UV\_TIMEAVERAGE, 10  
UV\_TIMEBASE, 10  
UV\_TRACK\_PHASE, 7