User Manual

SATRO

Simulation and Analysis Tool for Radio

Observations

Contents

1 Introduction

This user manual describes how to run the pipeline for simulating radio observations with a provided graphical user interface using CASA (Common Astronomy Software Application) packages and its parameters settings. The graphical user interface offers parameter selecting and setting for simulations with radio interferometer such as VLA or ALMA.
The pipeline focuses also on the output data which is generated for each iteration. The output data contains important measurements and radio images for further analysis and inspection.

The use of this application requires basic knowledge in CASA and its parameter settings. This guidance helps you to go through every single step in this application to successfully run the pipeline for simulating radio observations.

2 Quick Start Guide

This quick start guide helps you to simply set the configurations needed to run the pipeline. It shows how to select and set the parameter configurations in order to simulate radio observations.

Single Run: The following set-up for a single run:

Multiple Runs: The following set-up for multiple runs.

3 Settings

In this section you can make basic settings for simulating radio observations. The following image shows the user interface for the "Settings" where you can set the desired basic configuration.
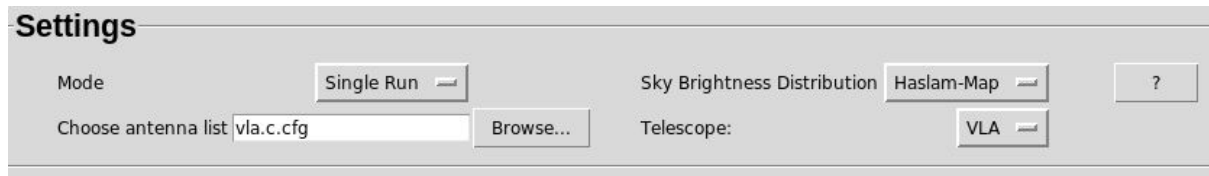
3.1 Mode

Choose the desired mode for your observation.

> *Single Run*   -- Single iteration with fixed parameter values. See definition for fixed parameter values in "Fixed Parameter Configuration".

> *Multiple Runs*   -- Multiple iterations, that use fixed parameter values and different varying parameter values that change with each iteration. See definition for varying parameter values in "Varying Parameter Configuration". This mode enables settings for "Varying Parameters Configurations".

3.2 Sky Brightness Distribution

Choose desired sky brightness distribution (Sky-model). It shows how the sky appears to the telescope.

> *Custom*   -- Customized sky brightness distribution with options to change values. When set to custom, the pipeline will create a new sky-model out of provided parameters.

> *Haslam*   -- Predefined all-sky map. The pipeline will use metadata provided in the fixed sky-model parameters and data from the sky-map of Haslam. See definition Haslam and sky parameters for further information.

Haslam

The all-sky 408 MHz map of Haslam is one of the most important total-power radio surveys. It has been widely used to study diffuse synchrotron radiation from our Galaxy and as a template to remove foregrounds in cosmic microwave background data. The map of Haslam is an atlas combining data from four different partial surveys of the sky.

3.3 Telescope

Choose the desired telescope when selected "Haslam" as sky brightness distribution. It uses the diameter of the selected telescope for further calculations.

> *VLA*   -- Telescope configuration of VLA (Very Large Array)

> *ALMA*   -- Telescope configuration of ALMA (Atacama Large Millimeter Array)

MWA   -- Telescope configuration of MWA (Murchison Widefield Array)

Meerkat   -- Telescope configuration of Meerkat

3.4 Antenna list

Choose an antenna configuration in your file system for the observation. Default value is vla.c.cfg.
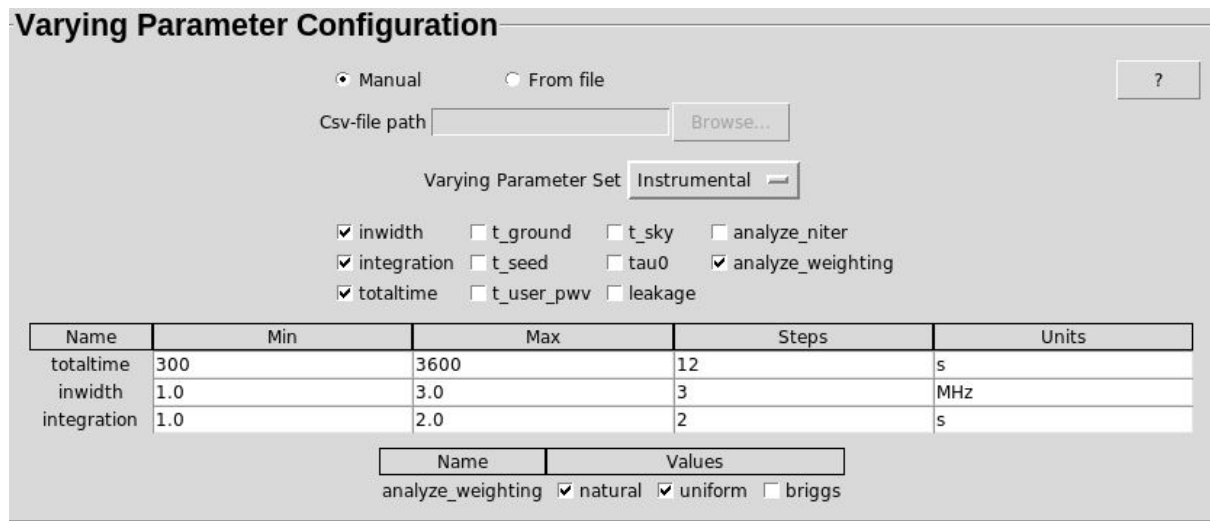
vla.c.cfg   -- Antenna configuration for Very Large Array (Radio Interferometer)

This configuration file contains information about the antenna list such as coordinates (x,y,z) and dish diameter of each antenna. All antenna configurations of CASA can be found in the "Antennalists" folder.

4 Varying Parameter Configuration

In this section you can select desired varying parameters and set their values and units. The following image shows the graphical user interface for the "Varying Parameter Configuration" where you can set the desired values.

> *Varying parameter* -- Parameter values are going to be varied in each iteration. Varying parameters are divided in three different sets: Instrumental, Sky-model and Sources. Further description of the parameters can be found in the next section "Fixed Parameter Configuration".

4.1 Manual

Select and set for values/units of varying parameters manually.

4.2 From file

Select csv with predefined varying parameter values. Note that the parameters "sm_shape", "sp_shape" and "weighting" cannot be read from this file and have to be entered manually.

> *csv-file path* -- Select csv-file on your file system

4.3 Varying Parameter Set

Select desired varying parameter set.

> *Instrumental* -- Telescope-based parameters (radio telescope configurations) used by the CASA tasks simobserve and simanalyze.

> *Sky-model* -- Sky-based parameters (corresponding to Sky-model values to vary distribution of sources, flux, shapes, etc.) used by CASAs utility tools componentlist, coordinate system, image analysis and quanta.

Sources — Sky-based parameters (additionally adding sources to Sky-model. Corresponding to source values to vary distribution of sources, flux, shapes, etc.) used by the componentlist utility tool from CASA.

Instrumental & Sky-model -- Combination of Instrumental and Sky-model parameter sets

Instrumental & Sources -- Combination of Instrumental and Sources parameter sets

Sky-model & Sources -- Combination of Sky-model and Sources parameter sets

Enter values for the parameters in the chosen varying parameter set.

Name -- Name of varying parameter

Min -- Minimum value of varying parameter

Max -- Maximum value of varying parameter

Steps -- Steps between minimum and maximum value of one varying parameter. Number of steps corresponds to number of Iterations.

Values -- Values of varying parameter that can be checked or unchecked

Example: inwidth
- Minimum value is 1.0
- Maximum value is 2.0
- Steps is 3
- Units "GHz".

Varying parameter values for the iterations are: 1.0GHz, 1.5GHz, 2.0GHz

5 Fixed Parameter Configuration

In this section you can adjust values and units for the fixed parameters. The following image shows the user interface for the "Fixed Parameter Configuration" where you can set the desired values.

> *Fixed parameter* -- Parameter default value that does not change with each iteration while doing multiple runs. Except this parameter is also selected as a varying parameter then the values of the fixed parameters will not be used. Fixed parameters are divided in three different sections: Instrumental, Sky-model and Sources.

5.1 Choose from file

Select csv with predefined fixed parameter values. It is very important that the csv file has the same structure for each parameter set and that no parameters are omitted.

> *csv-file path* -- Select csv-file on your file system

5.1.1 Csv-file for Instrumental Parameters:

Note that this csv-file must contain exactly three column headers (Name, Value, Units) with following instrumental parameter:

Name	Value	Units
incenter	1.0	GHz
compwidth	1.0	GHz
incell	1.0	arcsec
inwidth	1.0	MHz
integration	1	s
totaltime	3600	s
mapsize	5.0	arcmin
thermalnoise	tsys-atm	
t_ground	269	
t_sky	260	
leakage	0.0	
t_seed	11111	
t_user_pwv	0.5	
tau0	0.1	
analyze_niter	0	
analyze_imsize	1000	
analyze_weighting	natural	
analyze_cell	1.0	arcsec
analyze_stokes	I	
analyze_threshold	0.0	mJy/beam

5.1.2 Csv-file for Sky-model Parameters:

Note that this csv-file must contain exactly three column headers (Name, Value, Units) with following Sky-model parameters:

Name	Value	Units
sm_flux	1.0	
sm_fluxunit	Jy	
sm_polarization	Stokes	
sm_direction_ra	180.0	
sm_direction_dec	-30.0	
sm_size	1000	
sm_cellsize	0.1	arcsec
sm_shape	Gaussian	
sm_majoraxis	0.5	arcmin
sm_minoraxis	0.5	arcmin
sm_positionangle	0.0	deg
sm_frequency	1.0	GHz
component_frequency	1.0	GHz
frequency_increment	128	MHz
sm_index	1.0	
sm_spectrumtype	spectral index	
sm_label		

5.2 Number of Sources

In section "Sources" you can select how many sources you want to add to the Sky Brightness Distribution.

Parameter	Source1	Source2	Source3
sp_flux	1.0	2.0	2.5
sp_fluxunit	Jy	Jy	Jy
sp_direction_ra	180.0	180.01	180.02
sp_direction_dec	-30.0	-30.02	-30.04
sp_shape	point	point	point
sp_majoraxis	0.5arcmin	0.5arcmin	0.5arcmin
sp_minoraxis	0.5arcmin	0.5arcmin	0.5arcmin
sp_positionangle	0.0deg	0.0deg	0.0deg
sp_frequency	1.0	1.0	1.0
sp_frequency_unit	GHz	GHz	GHz

5.3 Instrumental Parameters

These parameters are used for the CASA-tasks "simobserve" and "simanalyze" and are split into those. Visit the official CASA documentation for further information. Note that the input of parameters is handled differently than in CASA, as their values are concatenated with units.

5.3.1 Simobserve

Name	Type	Units	CASA-equivalence (simobserve)	Description
incenter	float	GHz or MHz	incenter	Frequency to use for the center channel (or only channel, if the skymodel is 2D). - Subparameter of skymodel Example: 1.5GHz
compwidth	float	GHz or MHz	compwidth	Bandwidth of components. - Subparameter of complist If simulating from components only, this defines the bandwidth of the MS and output images. Example: 1.0GHz
incell	float	arcsec	incell	Set new cell/pixel size. - Subparameter of skymodel Example: 1.0arcsec
inwidth	float	GHz or MHz	inwidth	Set new channel width. - Subparameter of skymodel Example: 1.0MHz
integration	integer	s	integration	Time interval for each integration. Example: 1s

totaltime	integer	s	totaltime	The total time of an observation. Example: 900s
mapsize	float	arcmin	mapsize	Angular size of of mosaic map to simulate. Example: 5.0arcmin
thermalnoise	string	-	thermalnoise	add thermal noise. - Options: tsys-atm, tsys-manual, "" See [casadocs](#) for further information. Example: tsys-atm
t_ground	float	-	t_ground	Ground/spillover temperature in K. - Subparameter of thermalnoise = 'tsys-atm|tsys-manual' Example: 269.0
t_sky	float	-	t_sky	Atmospheric temperature in K. - Subparameter of thermalnoise = 'tsys-manual' Example: 260.0
leakage	float	-	leakage	Add cross polarization corruption of this fractional magnitude. Example: 0.0
t_seed	integer	-	seed	Random number seed. - Subparameter of thermalnoise = 'tsys-atm|tsys-manual' Example: 11111
t_user_pwv	float	-	user_pwv	Precipitable water vapor if constructing an atmospheric model (in mm). - Subparameter of thermalnoise = 'tsys-atm' Example: 0.5
tau0	float	-	tau0	Zenith opacity at observing frequency. - Subparameter of thermalnoise = 'tsys-manual' Example: 0.1

5.3.2 Simanalyze

Name	Type	Units	CASA-equivalence (simanalyze)	Description
analyze_niter	integer	-	niter	Maximum number of iterations of [clean task](#) (0 for dirty image) Example: 1000
analyze_imsize	integer	-	imsize	Output image size in pixels (x,y) or set to 0 to match model (default) Example: 1000
analyze_weight	string	-	weighting	This parameter sets the weighting

				that is to be applied to the visibility data. Options: ● natural ● uniform ● briggs See [casadocs](#) for further information. Example: natural
analyze_cell	float	arcsec	cell	Cell size of the image with units or when unset (default) model cell size will be used. Example: 1.0arcsec
analyze_stokes	string	-	stokes	Specifies stokes parameter for resulting images. Example: I
analyze_threshold	float	mJy	threshold	Sets the upper threshold for cleaning. Example: 0.0mJy/beam

5.4 Sky Parameters

These parameters are used by the componentlist utility tool from CASA using mainly "[addcomponent](#)" to create a sky-model and sources to it. Visit the official CASA documentation for further information. Note that the input of parameters is handled differently that in CASA, as their values are concatenated with units. For the map of Haslam only following Sky-model parameters are used for the simulation:
- sm_direction_ra
- sm_direction_dec
- sm_size
- sm_cellsize.

5.4.1 Sky-model

Name	Type	Units	CASA-equivalence (cl.addcomponent)	Description
sm_flux	float	-	flux	The flux value. Example: 1.0
sm_fluxunit	string	-	fluxunit	The units of the flux. Any string with the same dimensions as the Jansky. Example: Jy
sm_polarization	string	-	polarization	The polarization of the value field. "Stokes", "linear" or "circular". Example: Strokes
sm_direction_ra	float	-	dir	The direction measure of the source. it is entered in units of degree, but converted internally in quantities of right ascension. This parameter will

				be concatenated with sm_direction_dec to represent the full direction value from CASA. Example: 180.0
sm_direction_dec	float	-	dir	The direction measure of the source. it is entered in units of degree, but converted internally in quantities of declination. This parameter will be concatenated with sm_direction_ra to represent the full direction value from CASA. Example: -30.0
sm_shape	string	-	shape	The new shape type. A string that is either 'point', 'Gaussian', 'disk', or 'limbdarkeneddisk'. Example: Gaussian
sm_majoraxis	float	arcmin	majoraxis	The width (FWHM in the case of a Gaussian) of the larger axis. A quantity with angular units. Example: 0.5arcmin
sm_minoraxis	float	arcmin	minoraxis	The width (FWHM in the case of a Gaussian) of the smaller axis. A quantity with angular units. Example: 0.5arcmin
sm_positionangle	float	deg	positionangle	The rotation of the axes with respect to the reference frame. A quantity with angular units. Example: 0.0deg
component_frequency	float	GHz	freq	The reference frequency of the component. A quantity with units equivalent to the 'Hz' and frame or a frequency measure, e.g ['TOPO', '1.6GHz'], or simply default frame (LSRK) '1.6GHz'. Example: 1.0GHz
sm_spectrumtype	string	-	spectrumtype	The spectrum type, a string that is either 'constant' or 'spectral index'. Example: spectral index
sm_index	float	-	index	The spectral index. Example: 1.0
sm_label	string	-	label	The label for the component.
sm_size	integer	-	-	The size of the sky-model image in pixels. The image will be a square with a side length of sm_size pixels. Example: 1000
sm_cellsize	float	arcsec	-	The cell size and units of the sky-model image. A quantity with angular units. Example: 0.1arcsec

| sm_frequency | float | GHz | - | The channel width in units of Hz.
Example: 1.0GHz |

5.4.2 Sources

They can be added to Sky Brightness Distribution additionally to simulate the effect of having one or more sources on this image.

Name	Type	Units	CASA-equivalence (cl.addcomponent)	Description
sp_flux	float	-	flux	The flux value. Example: 1.0
sp_fluxunit	string	-	fluxunit	The units of the flux. Any string with the same dimensions as the Jansky. Example: Jy
sp_direction_ra	float	-	dir	The direction measure of the source. it is entered in units of degree, but converted internally in quantities of right ascension. This parameter will be concatenated with sm_direction_dec to represent the full direction value from CASA. Example: 180.0
sp_direction_dec	float	-	dir	The direction measure of the source. it is entered in units of degree, but converted internally in quantities of declination. This parameter will be concatenated with sm_direction_ra to represent the full direction value from CASA. Example: -30.0
sp_shape	string	-	shape	The new shape type. A string that is either 'point', 'Gaussian', 'disk', or 'limbdarkeneddisk'. Example: point
sp_frequency	float	-	freq	The reference frequency of the component. A quantity with units equivalent to the 'Hz' and frame or a frequency measure, e.g ['TOPO', '1.6GHz'], or simply default frame (LSRK) '1.6GHz'. Example: 1.0
sm_frequency_unit	string	-	-	The unit of sp_frequency ('Hz') Example: GHz

6 Menu Bar

The application has several features and tools which can be used. These features are listed in the menu bar on the top of the graphical user interface.

6.1 Save Configuration

This feature allows you to save the current selected options in the settings and the configurations of the parameter values as pkl-file.

6.2 Load Configuration

With this feature you can load a pkl-file with saved configurations into the GUI.

6.3 Output Analysis

The tool "Output Analysis" allows you to view the generated output data from a simulation. It also shows important metrics that are relevant to quantify the quality of an image. The images are read as FITS-files, hence they are exported as such by the pipeline.
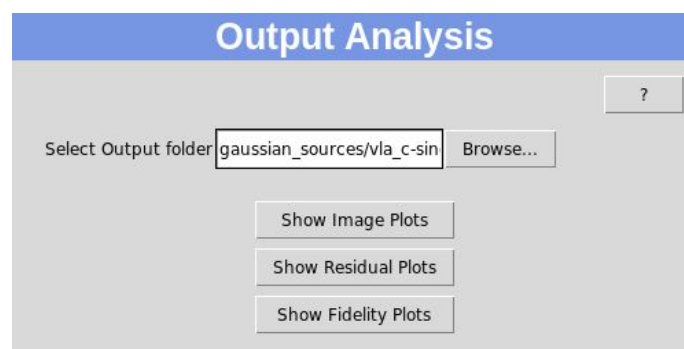

6.4 Image Comparison

Image comparison allows you to quickly display the difference between two FITS images. The images are required to have the same brightness unit (unit of the pixel values) and shape excluding empty dimensions. The tool shows residual after the subtraction which is defined as:

$$I1 - I2, \text{ where } I1 \text{ is the first selected FITS image and } I2 \text{ the second one}$$

6.5 Matplotlib Controls

"Output Analysis" and "Image Comparison" display different matplotlib plots. Those plots have some navigation controls that the matplotlib library provides. Visit the official matplotlib documentation for further information.
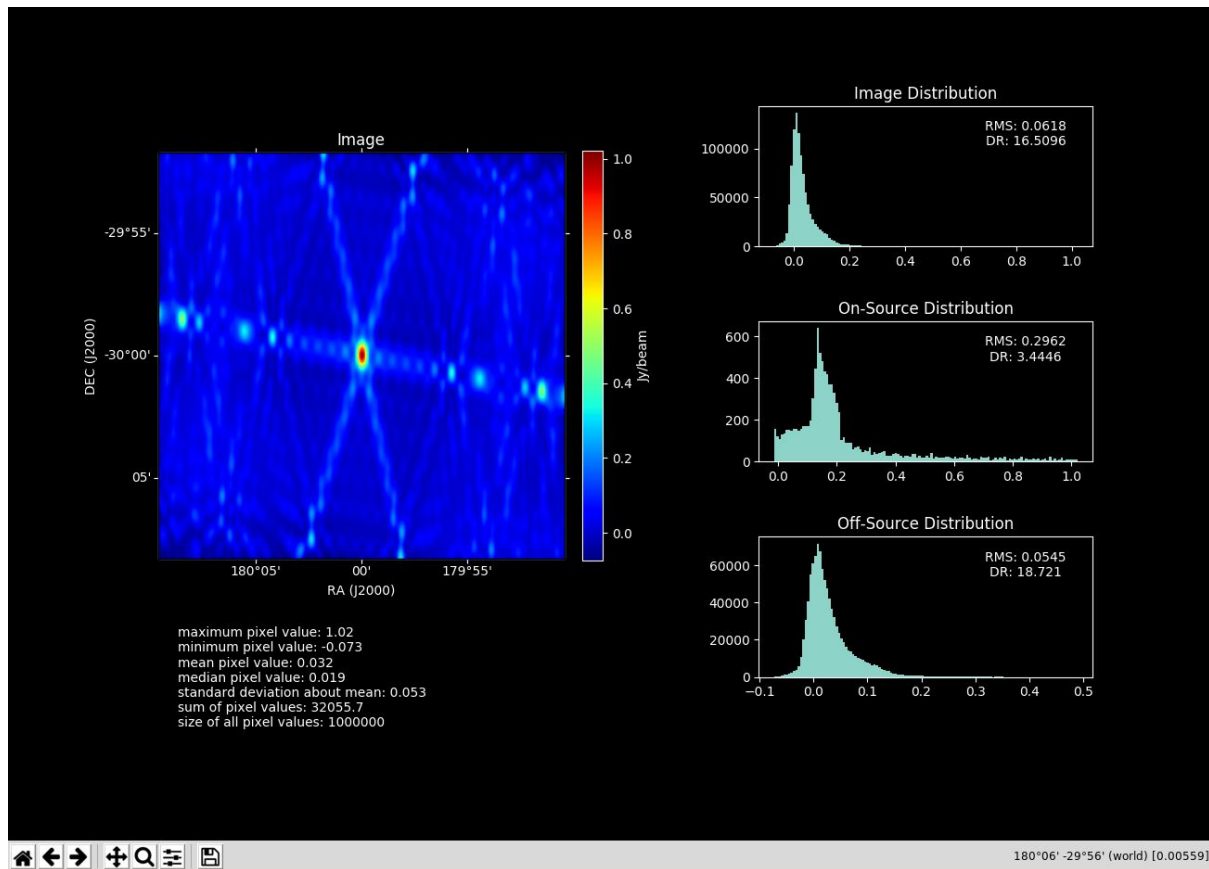
Some basic navigation controls are the following ones:

Home/Reset	**h** or **r** or **home**
Back	**c** or **left arrow** or **backspace**
Forward	**v** or **right arrow**
Pan/Zoom	**p**
Zoom-to-rect	**o**
Save	**ctrl + s**
Toggle x axis scale (log/linear)	**L** or **K** when mouse is over an axes
Toggle y axis scale (log/linear)	**l** when mouse is over an axes

7 Summary Page

After you have entered the desired settings and parameter value configurations, a summary page appears when clicking the next button in the bottom area of the user interface.
The summary page lists all selected and entered configurations. It also shows the number of iterations for the simulation. Furthermore the page shows you how long the estimated time for a simulation will be. Before running the pipeline by clicking the "Run"-button you can define a desired output folder path. Otherwise it will take a default output folder path.

8 Output

In this chapter the output of the pipeline such as naming convention and folder structure will be explained.

8.1 Naming Convention

The pipeline creates data for the observation and analysis. This data will be saved in a directory with following naming convention example:

vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0

1   2   3   4   5   6   7   8

1) Antenna list
2) Mode
3) Varying parameter set (if mode is mult)
4) Incenter value and unit
5) Inwidth value and unit
6) Integration value and unit
7) Sky brightness distribution
8) Varying parameter name and iteration (if mode is mult)

8.2 Folder Structure

The folder structure of the output will be explained with following example:

```
FITS_Files
Skymodel
Taskfiles
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.diff
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.fidelity
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.flux
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.image
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.image.flat
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.model
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.ms
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.noisy.ms
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.psf
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.residual
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.skymodel
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.skymodel.flat
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.skymodel.flat.regrid
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.skymodel.flat.regrid.conv

pipeline-20200806-114251.log
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.analysis.png
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.clean.last
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.image.png
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.observe.png
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.ptg.txt
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.simanalyze.last
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.simobserve.last
vla_c-mult-sim-f_1.0GHz-df_1.0MHz-dt_1s-sm_custom-analyze_niter0.skymodel.png
```

Skymodel: The sky-model image and sky-model fits-file will be stored in this sub-folder. As well as the sources.pkl file.

Taskfiles: The log-files for the CASA-tasks will be stored in this sub-folder. Those files show all used parameters for the tasks "simobserve", "simanalyze" and "exportfits".

Log-File: The log-file reports different steps with time measurements during each simulation.

Other folders: The task "simobserve" and "simanalyze" produce measurement-set and different radio images that will be stored directly as different sub-folders.

PNG-Files: The output-images of simobserve and simanalyze will be stored as png-files.

See simobserve and simanalyze for detailed output description.