EA Data Analysis Workshop – TP combination

1, Download CASA

2. Download CARTA

3. Download analysis
https://casaguides.nrao.edu/index.php?title=Analysis_Utilities

4. Edit your startup.py under ~/.casa with following lines,

```
import sys
sys.path.append("/path/analysis_scripts")
import analysisUtils as au
```

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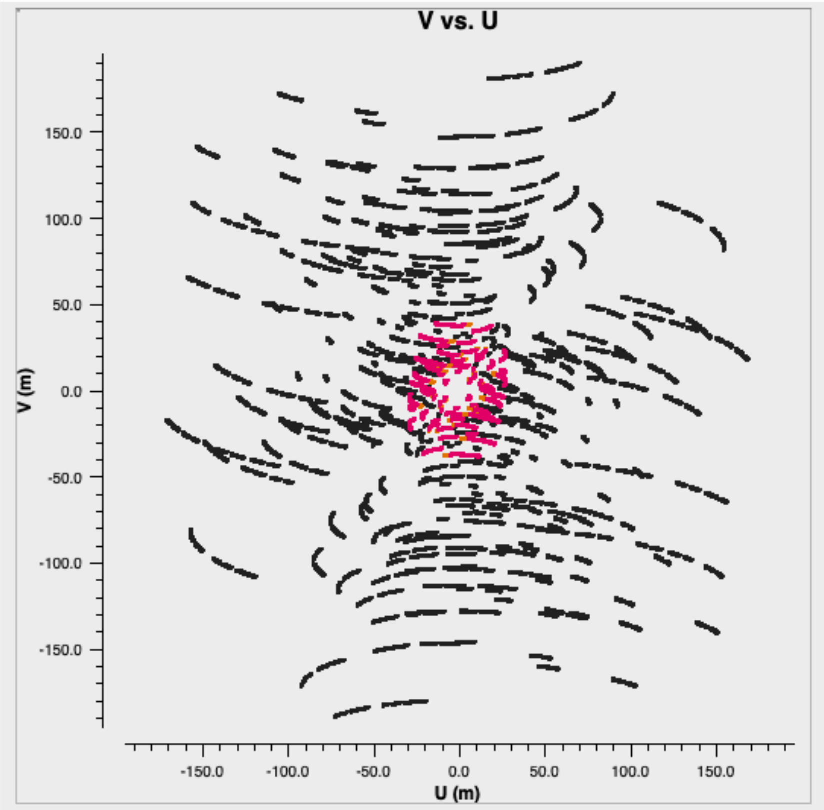
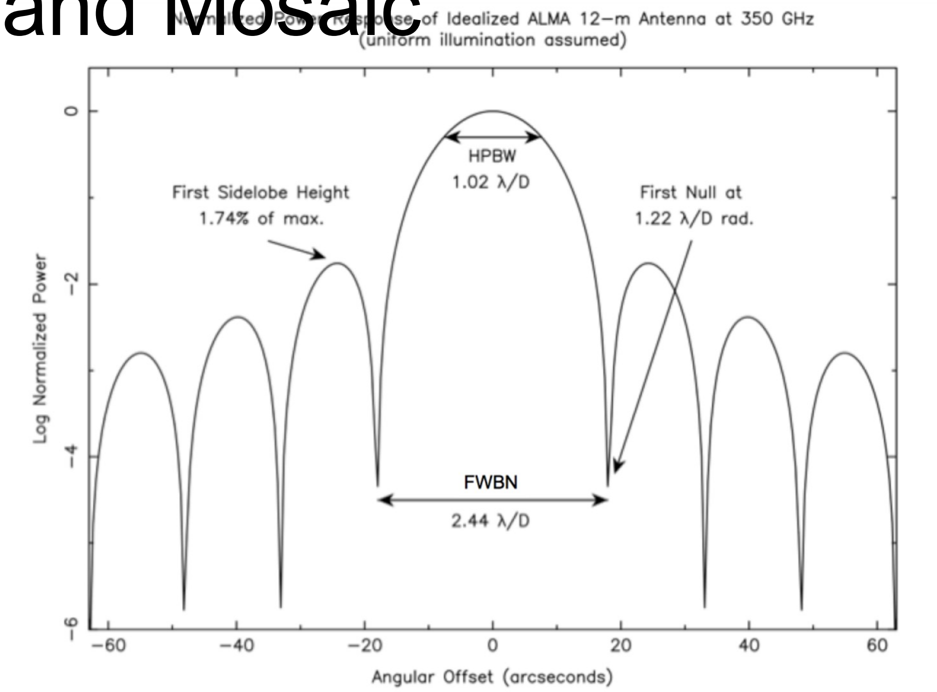
Motivation of TP Combination and Mosaic



- Short spacing: The FT of (u,v)=(0,0) means the total sum of flux. (You also can imagen that zero frequency means infinite scale structure). This 0 spacing point can never be obtained by the interferometer.

$$u = \frac{\vec{B} \cdot \vec{s}_u}{\lambda}, \quad v = \frac{\vec{B} \cdot \vec{s}_v}{\lambda}$$

Motivation of TP Combination and Mosaic



Primary Beam

The central Gaussian-like feature is called the primary beam or the antenna beam size and it has a Half Power Beam Width (HPBW) given by

HPBW Primary Beam = 1.02 × λ/D

*The angular distance between the first nulls is termed the Full Width Between Nulls (FWBN), and is given by: FWBN Primary Beam = 2.44 × λ/D.

*Half the FWBN of the primary beam, ~1.22 λ/D, is considered the Rayleigh resolution of the antenna, i.e., resolution, its ability to distinguish objects on the sky separated by some angular distance. (for the far-field diffraction pattern described using the Bessel function of first kind, 1.22 is the theoretical value of HPBW, but it was adjusted to 1.02 empirically.)

* Note that the HPBW measured for actual ALMA 12-m and 7-m antennas is ~1.13 λ/D because the illumination is not uniform.

Motivation of TP combination and Mosaic

$$\mathcal{V}(u,v) = \iint \mathcal{A}(l,m) I(l,m) e^{-2\pi i(ul+vm)} dl dm.$$

- Primary beam: the power responses of antenna on the sky: Airy function A (unobstructed, uniformly illuminated aperture). The HPBW of the primary beam serves as the “field-of-view” of the single-pointing interferometric image.
- The measured visibility is the Fourier transform of the sky brightness distribution multiplied by the antenna power response.
- In the last step of image processing, primary beam correction should be performed to recover the sky brightness.

Mosaic

To counteract the angular fall-off of sensitivity due to the primary beam response, or even to sample emission over areas on the sky larger than the primary beam.

In radio astronomy, when conducting a mosaic survey where multiple pointings are used to cover a larger field of view, the concept of Nyquist sampling is critical to ensure that the spatial sampling of the sky is adequate to reconstruct the image without loss of information due to undersampling. Nyquist sampling in the context of a mosaic involves a specific spacing between adjacent pointings that relate to the beamwidth of the telescope.

Hexagonal Mosaic

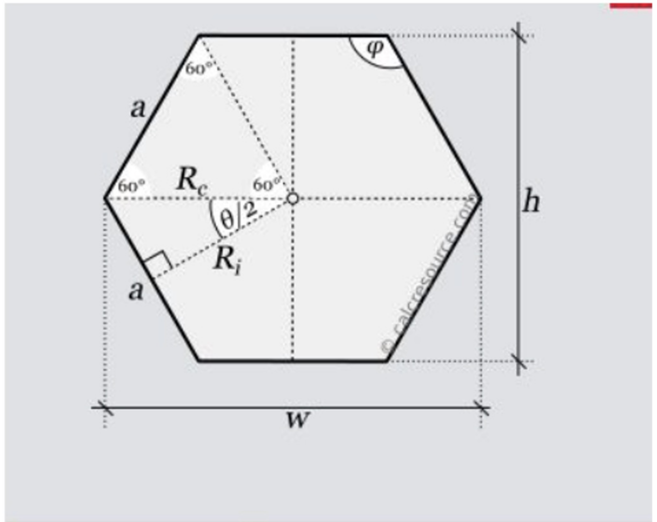
FWHM (ALMA)=1.13 λ/D

$$\theta_{hex} = \frac{\lambda}{D\sqrt{3}} = 0.511 \times FWHM.$$

Separation along RA (X-offset)

The positions observed are arranged in a grid of equilateral triangles spaced by λ/(√ 3D), where D is the diameter of the antenna.

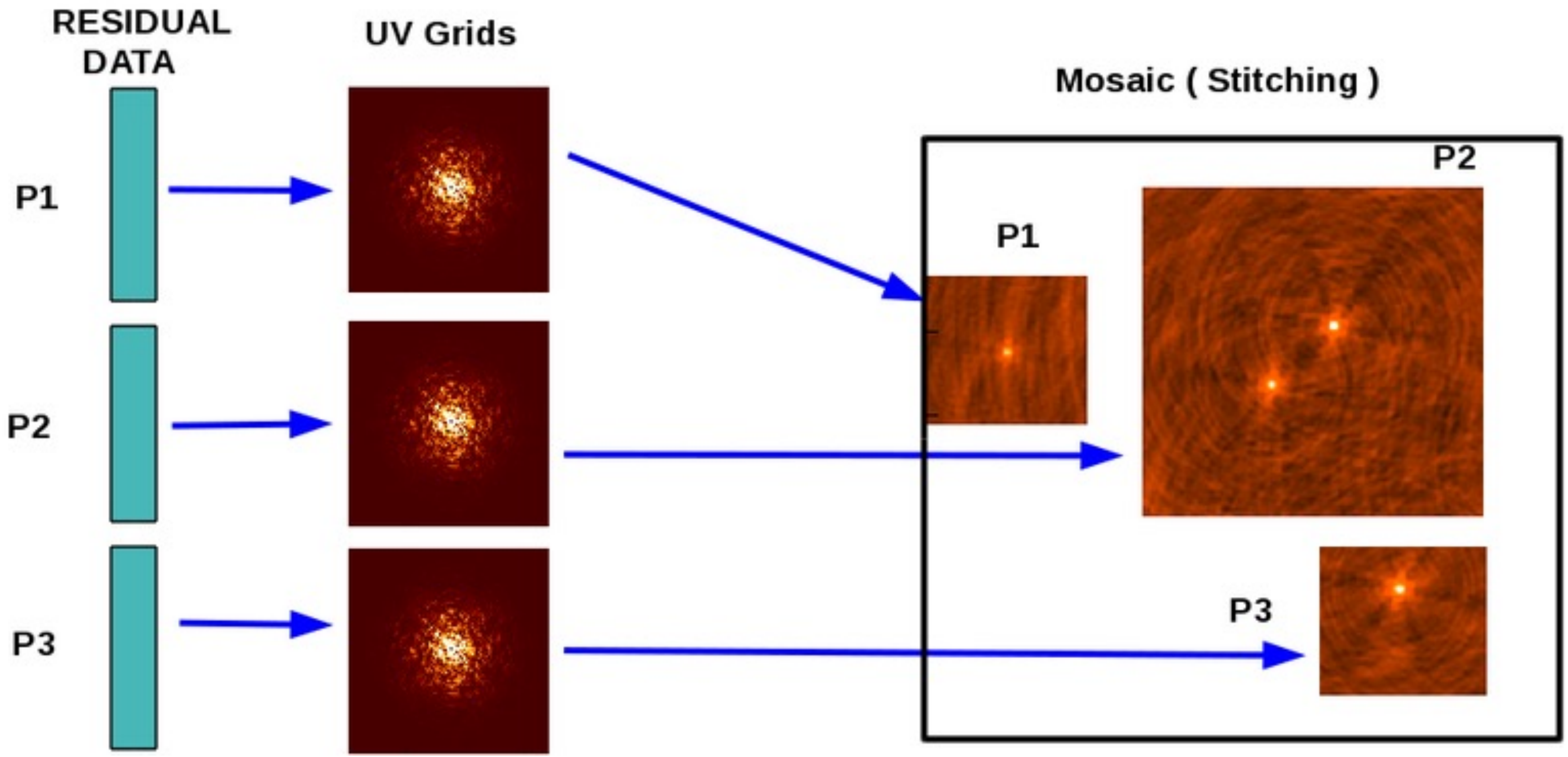
Uniform sensitivity can be obtained across the primary beam of a single pointing but requires a minimum of six other pointings around the single pointing. These six pointings are arranged in a hexagonal pattern with each vertex spaced λ/(√ 3D) from each other (and the single pointing).



Circumradius:	$R_c = a$
Inradius:	$R_i = \frac{a}{2\tan(30^\circ)} = \frac{\sqrt{3}}{2}a$
Height:	$h = 2R_c = 2a$
Width:	$w = 2R_i$
Area:	$A = \frac{3a^2}{2\tan(30^\circ)} = \frac{3\sqrt{3}}{2}a^2$
Interior angle:	$\varphi = 120^\circ$
Central angle:	$\theta = 60^\circ$
Approximations:	$R_i = 0.866a$ $w = 1.732a$ $A = 2.598a^2$

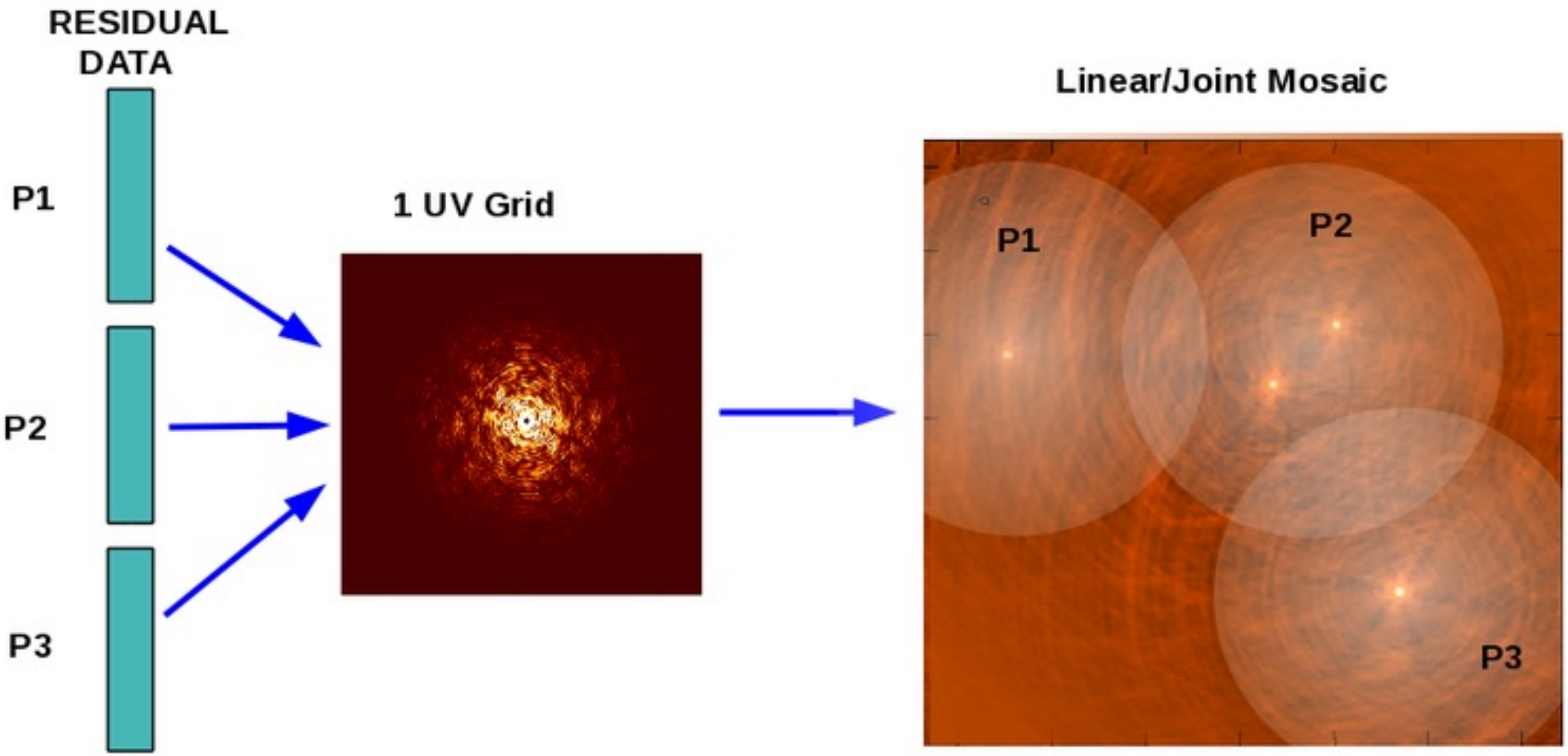
更多

Imaging: Linear Mosaic (stitched mosaic)



Making images of each pointing separately and using task such as *immath* to stitch the images.

Imaging: Joint Mosaic (non-linear mosaic)



The joint mosaic was performed at a given (u,v) point but a varying phase center (x+xp, y+yp).

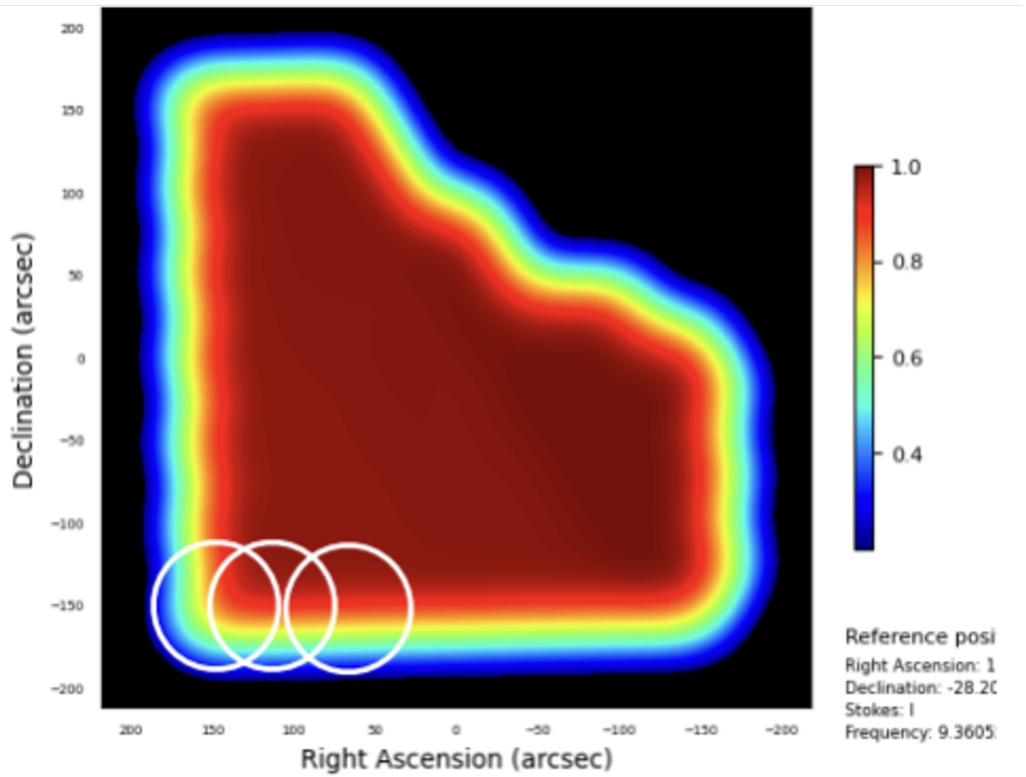
$$V(u+u_p, v+v_p) = \frac{[\mathrm{FT_p}(V_{\mathrm{mes}})]\,(u_p, v_p)}{T(u_p, v_p)}$$

Tclean parameters for mosaic observations

- gridder='mosaic' (cf 'standard') (12m+12m, etc.)
- mosweight (bool=True) - Independently weight each field in a mosaic (True) or average weight of whole fields (False).
- pblimit (double=0.2) - PB gain level at which to cut off normalizations
- restoringbeam='common'

Noisy edges

Mosaics are Nyquist sampled to have uniform noise over the mosaic area.



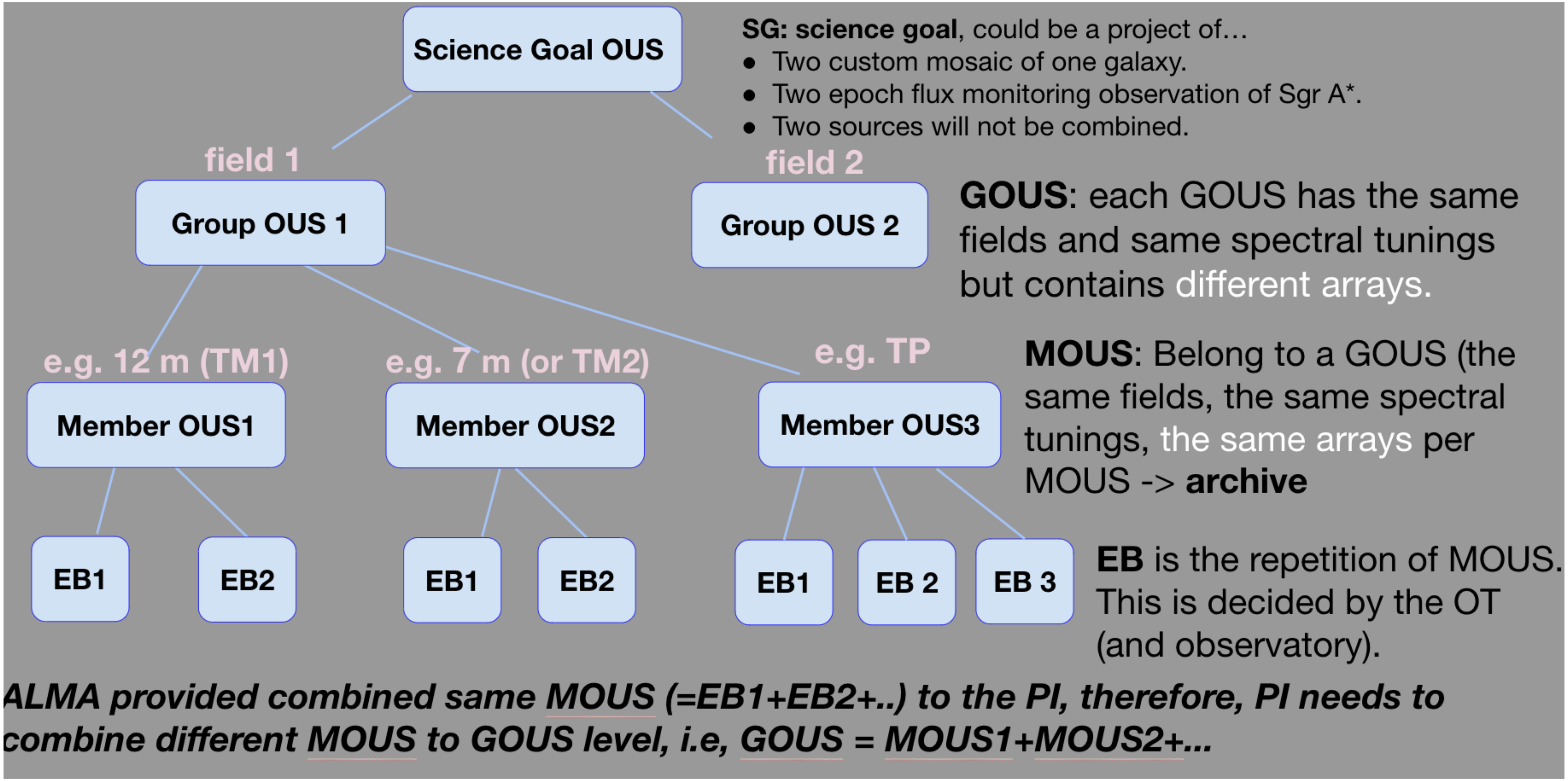
ALMA Proposer's guide – Array combination

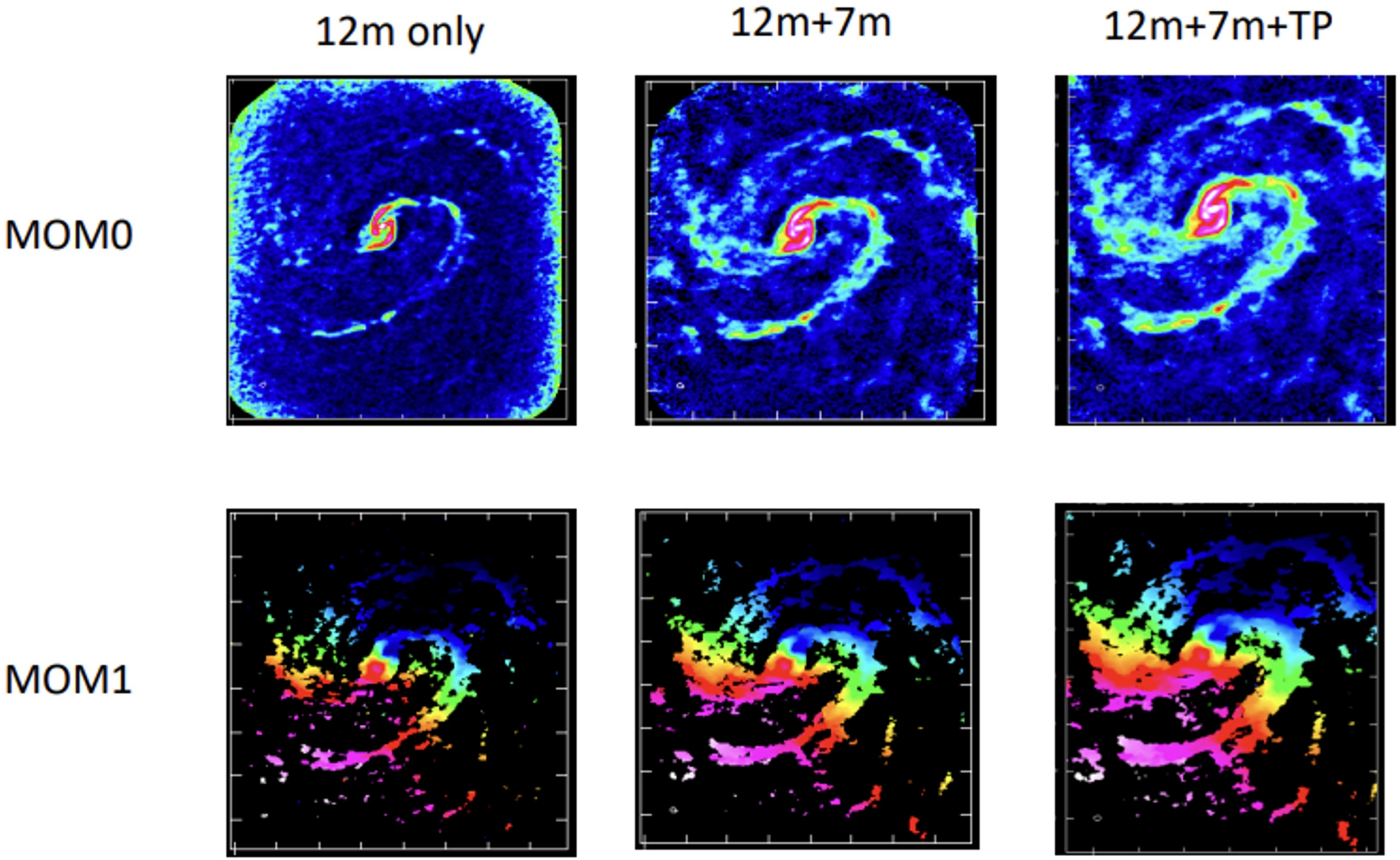
The final factor in the time estimate is the possible addition of configurations needed to reach the LAS specified by the user. The LAS is compared to the "Maximum Recoverable Scale" (MRS) of the configurations that best match the requested range of angular resolutions. The MRS for each configuration is listed in Table A-1. If the LAS exceeds the MRS of all matching configurations, then additional configurations, if allowed (Section A.4), are added with a time estimated using the multipliers given in Table A-2. If the array combinations are not allowed (Section A.4), the ALMA OT will give a validation error. If the LAS can be achieved with one or more of the best-matching configurations, the remaining configurations meeting the angular resolution but not the LAS request will not be considered.

Most Extended configuration	Allowed Compact configuration pairings	Extended 12-m Array Multiplier	Multiplier if compact 12-m Array needed	Multiplier if 7-m Array needed	Multiplier if TP Array needed and allowed (with 7-m Array in 4x4-bit mode)	Multiplier if TP Array needed and allowed (with 7-m Array in 2x2-bit mode)
7-m Array	**TP**			1	1.7	1.4
C-1	**7-m Array & TP**	1		7.0	11.9	9.5
C-2	**7-m Array & TP**	1		4.7	7.9	6.3
C-3	**7-m Array & TP**	1		2.4	4.1	3.3
C-4	**C-1 & 7-m Array & TP**	1	0.34	2.4	4.0	3.2
C-5	**C-2 & 7-m Array & TP**	1	0.26	1.2	2.1	1.7
C-6	**C-3 & 7-m Array & TP**	1	0.25	0.6	1.0	0.8
C-7	**C-4**	1	0.23			
C-8	**C-5**	1	0.22			
C-9	**C-6**	1	0.21			
C-10	–	1				

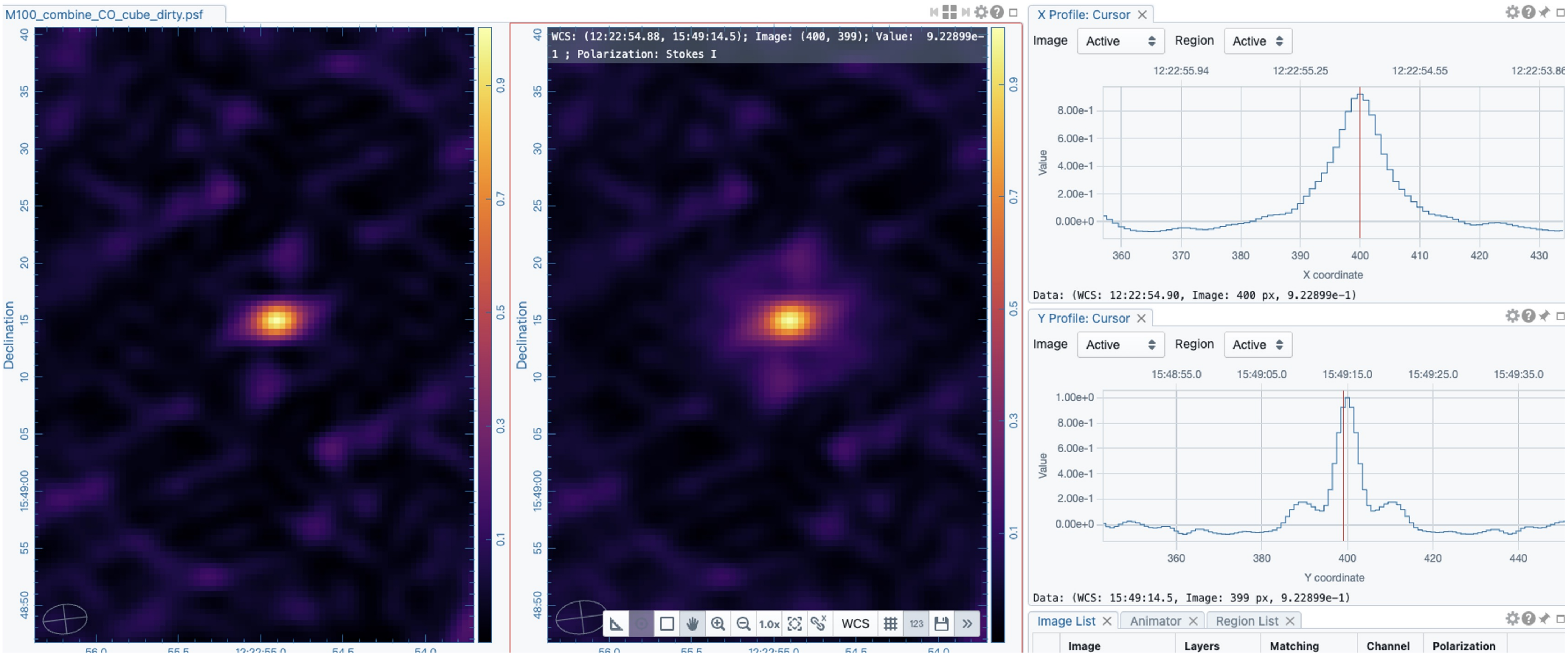
Table
also see table 7.5 in THB

Separate Scheduling Blocks (SBs) will be prepared during Phase 2 (Section 6.1) for each required configuration. These will be observed independently




12m only
12m+7m
12m+7m+TP
MOM0
MOM1

Point spread function of 7m and 12m combined data (non-single Gaussian)



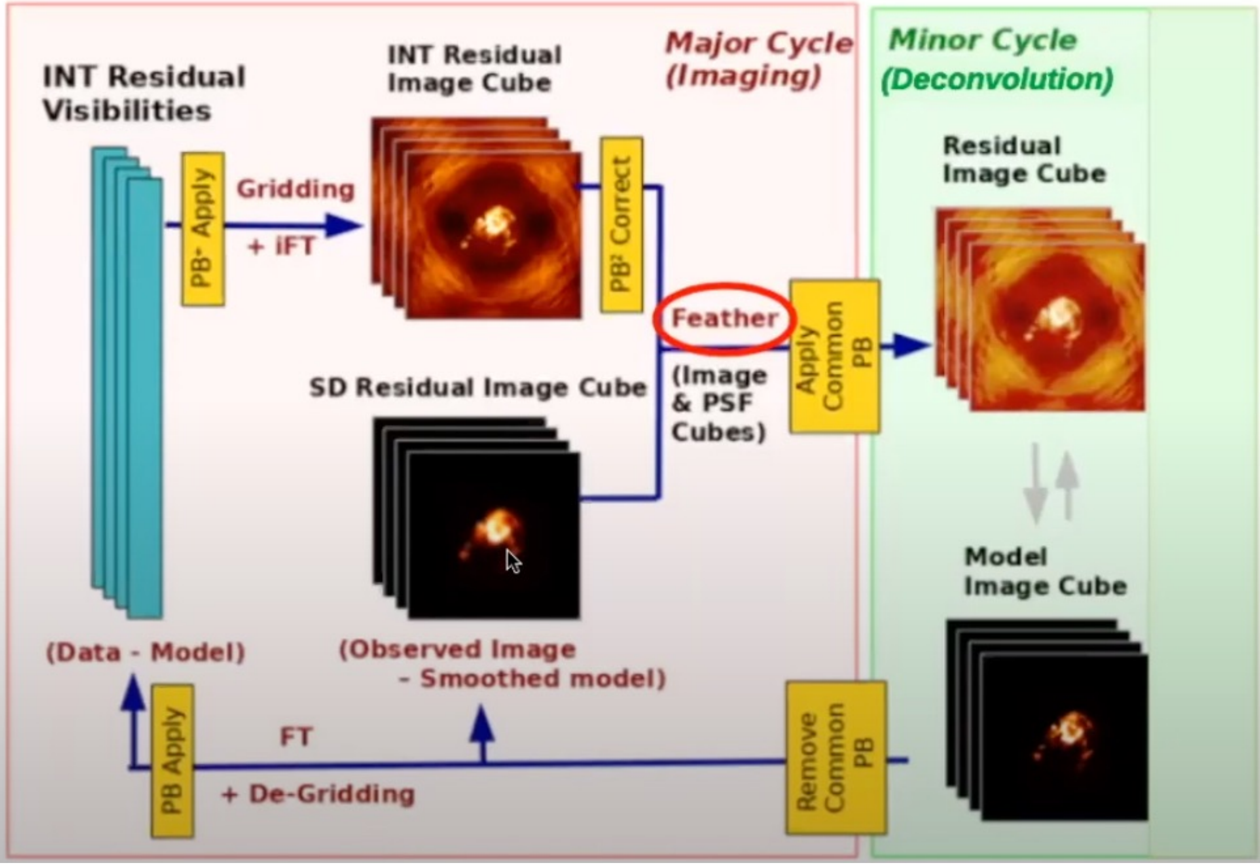
TP combination

- Imaging based: feather (cleaned int. map + SD map)
- Visibility based: TP2VIS (Jin Koda)
- *Sdintimaging: feather is performed during tclean process*
- *Feather: feather is performed after tclean process*
    - *sdfactor*: Value by which to scale the Single Dish image. Default is 1.0. Basically modifying the flux scale of the SD image.

      For ALMA, the flux calibration of single dish has been monitored, and the conversion factor of Jy/beam and Kelvin is also regularly calibrated. (The original unit of flux is Kelvin for single dish observation). In principle, we can trust the flux of single dish. However, you might need to change the sdfactor if the flux of single dish is not correct (if the flux correction is not reliable for example). This is one of the uncertainty for TP combination.

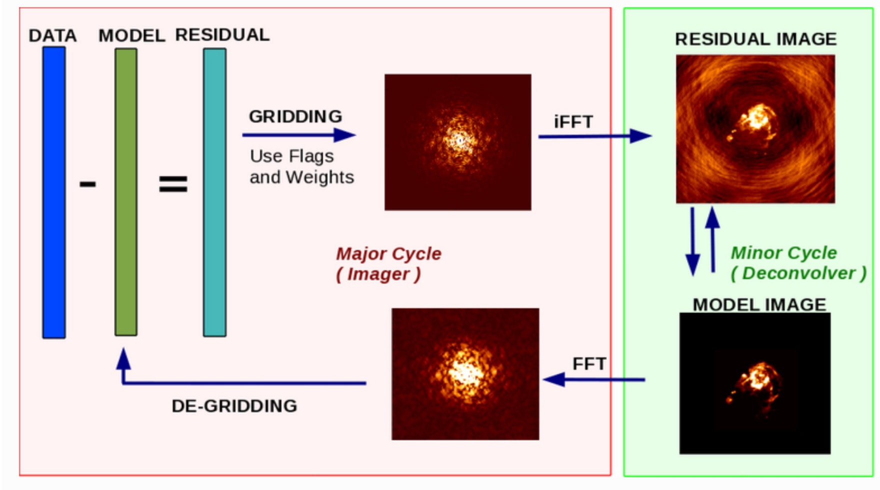
SDINT (CASA task "sdintimaging", algorithm: Rau, Naik & Braun 2019)

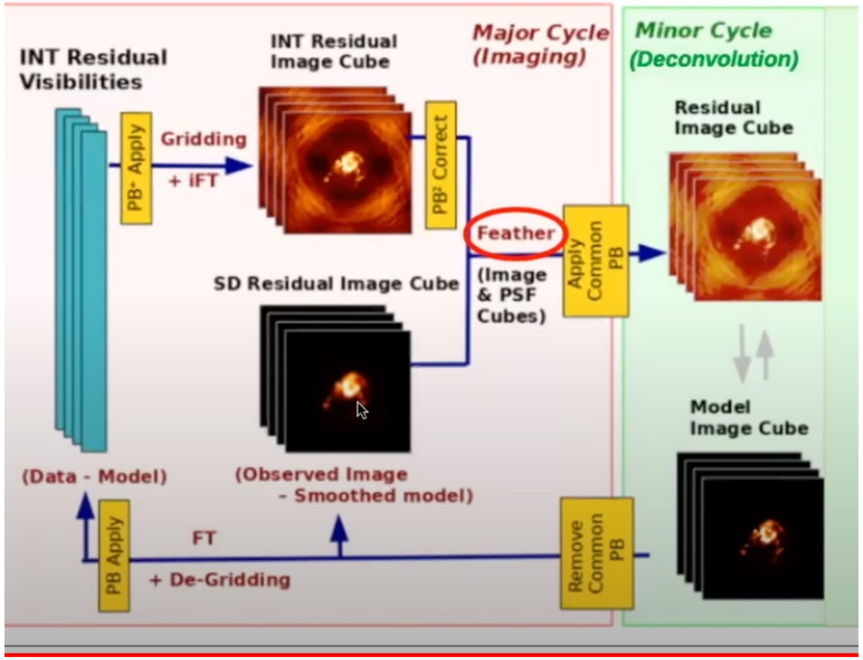
- joint deconvolution of visibilities and SD image via CLEAN
- uses Feather internally before every CLEAN minor cycle to combine SD and INT residual
- main parameter: ***sdgain*** controls *relative* SD weight in feather step



Tclean (major and minor cycles):

- The tclean was performed for both major and minor cycles. In the major cycle, it does (1) gridding in the uv-plane and (2) inverse FFT of the visibility to images. In the minor cycle, it does image-based deconvolution to remove the effect of the dirty beam from the dirty map. It also selects "clean components (1 pixel)" as the models *(.model), convolves this one-pixel model with the dirty beam (*.psf), subtracts it from the dirty map, and creates a residual map (*.residual), i.e., map_dirty.residual = map_dirty.image – (map_dirty.model X map_dirty.psf)
- In the major cycle, the model and residual map will be FFT to visibility, and the model visibility will be subtracted from the visibility of the residual map. After this major cycle subtraction, the residual visibility will be IFFT again to the image and continues on the minor cycles.
- For sdintimaing, the SD map and SD PSF are feathered with the int. residual map and int. PSF, respectively in the major cycle.





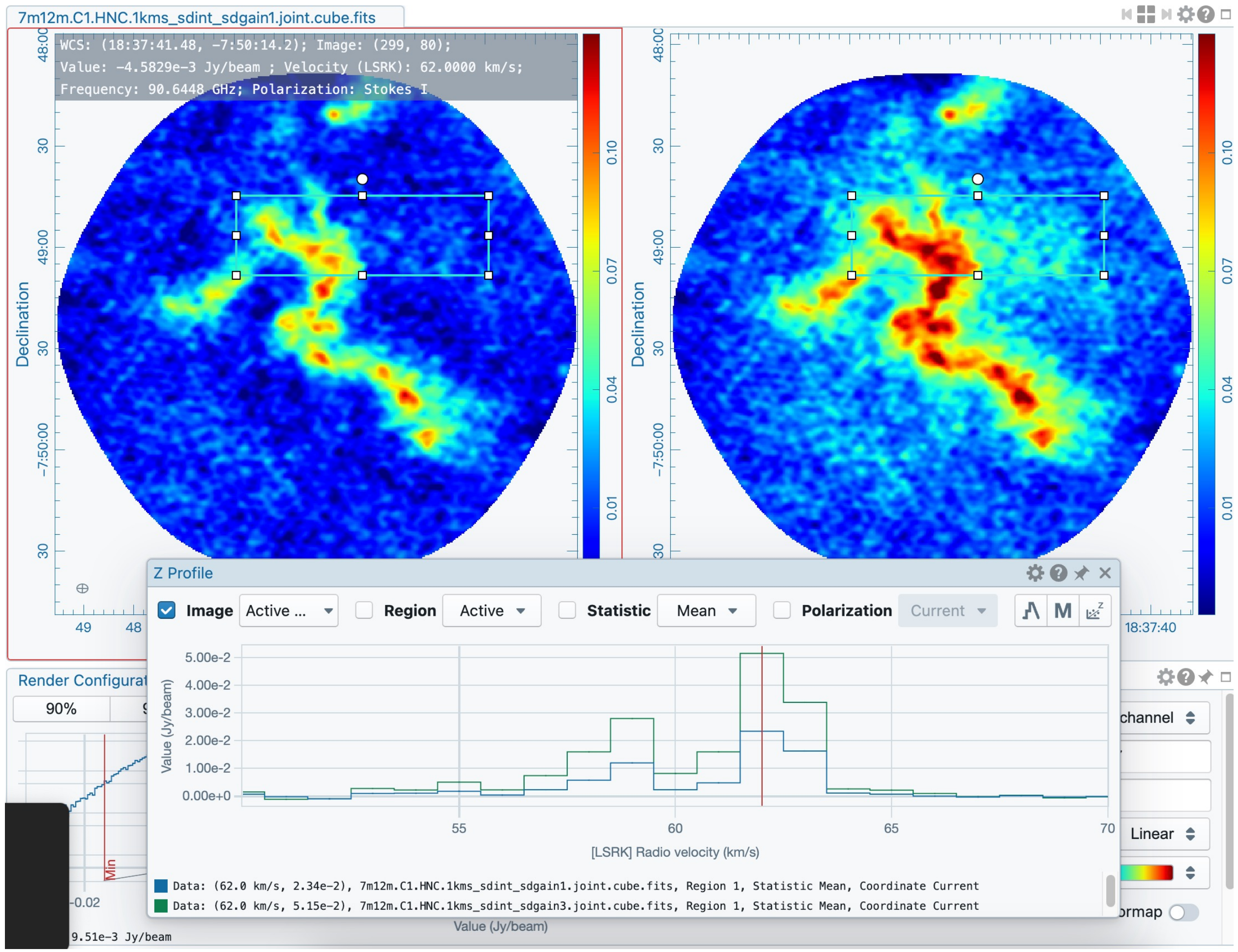
Important parameters for sdintimaging - sdgain

- sdgain: default is 1, but you can tune this number to optimize the tclean.

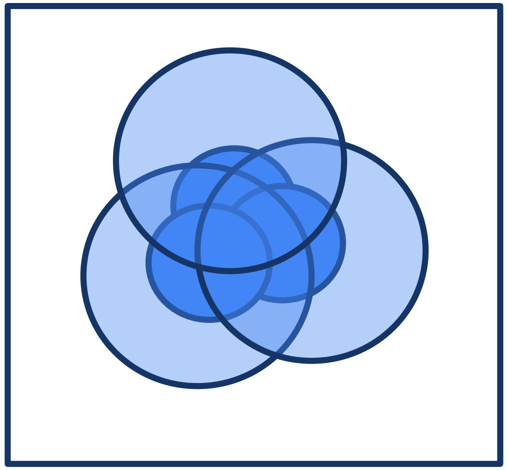
Left: sdgain=1

right: sdgain=3

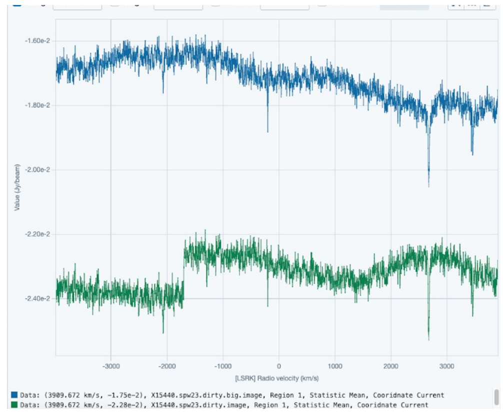
- How to choose a good sdgain? I think the most important thing is to make sure the flux is correct after adding the TP image. So maybe you can smooth your combined map to the same beam as the TP map and compare the spectra to see if the flux is consistent with each other.



Some more parameters for TP combination



- Feather the images before/after primary beam correciton
  - Int(PB corrected) feather TP image -> already PB corrected
  - (Int(non-PB correct) feather (TP image X Int_PB))/ Int_PB
- Changing image size of the 12m+7m joint mosaic
  - Are the flux differing a lot?
- Different approach for feather
  - Feather 7m and TP first, then feather (7m+TP) with 12m map (be careful of the primary beam response. 7m also has it’s own primary beam efficiency.
- Changing weighting ratio in task “concat”
  - If you raise the weight of 7m data, how does the rms and the map looks like?



https://casaguides.nrao.edu/index.php/DataWeightsAndCombination

The purpose of this guide is to describe the CASA visibility weights, and how they relate to data combination. If you are trying to combine ALMA data from Cycles 0, 1, and/or 2, you should be aware of the issues described here. Only data calibrated in >=CASA 4.2.2 pipeline, or manual reduction in >=CASA 4.3 are free from any issues. All of the data to be combined must be in a consistent weight state.