Introduction of Synthesis Imaging in Radio Astronomy

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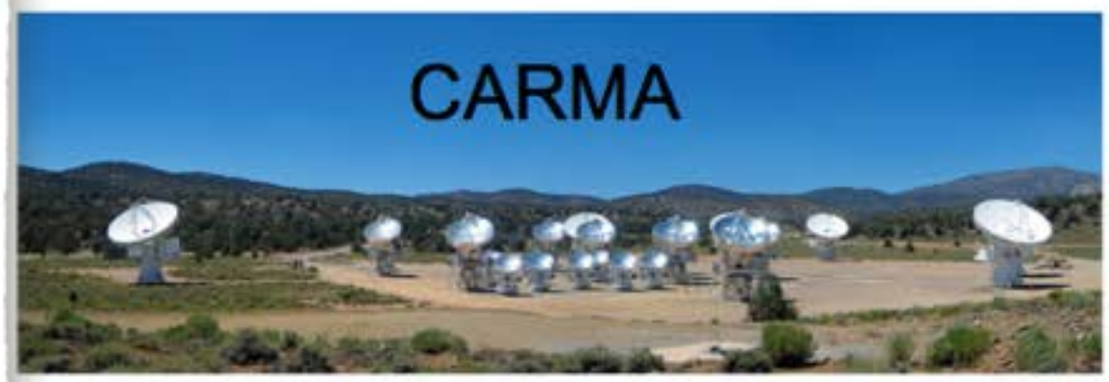
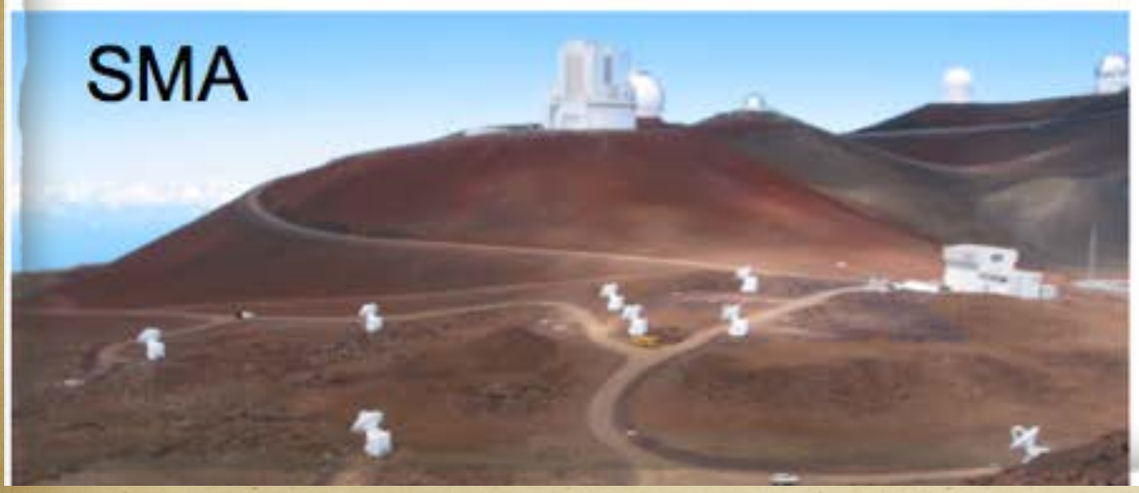
2014.10.09, Group meeting

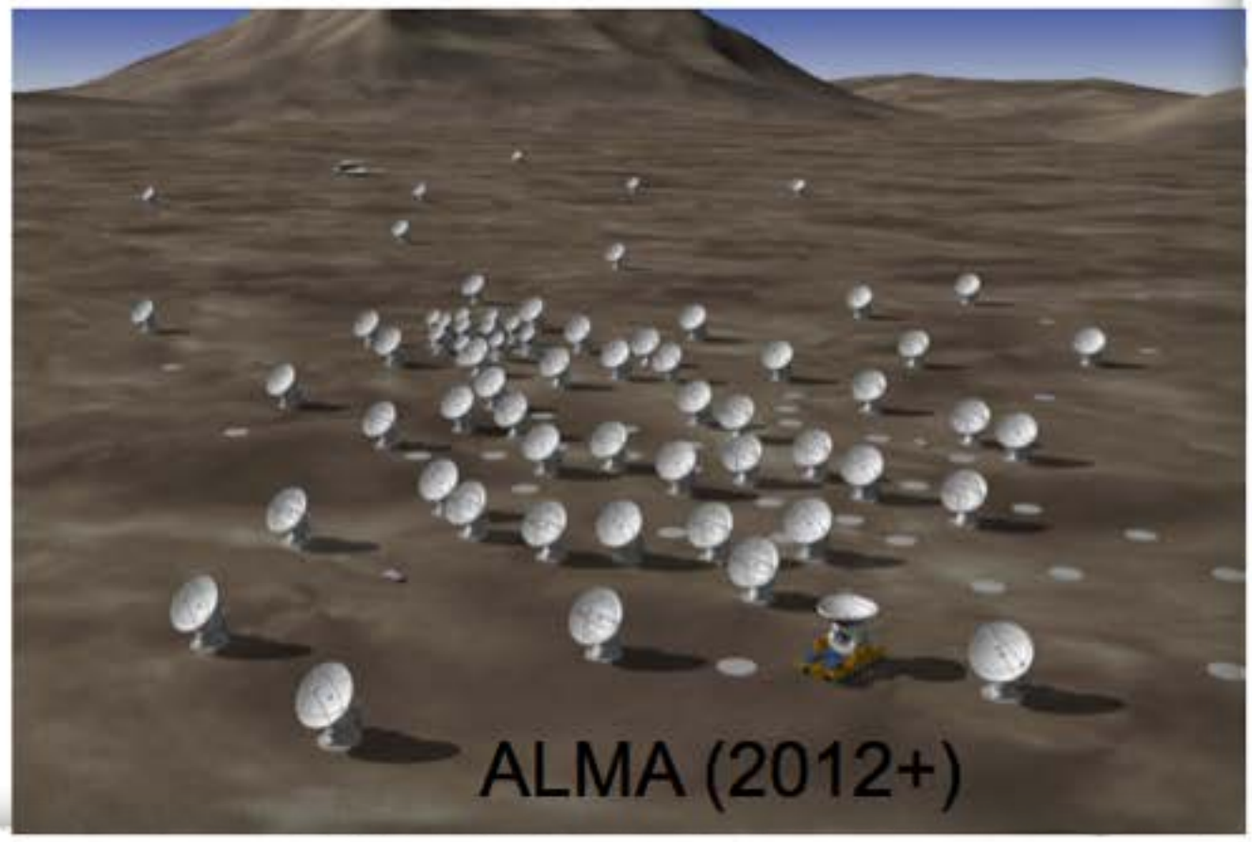

EVLA


ATCA

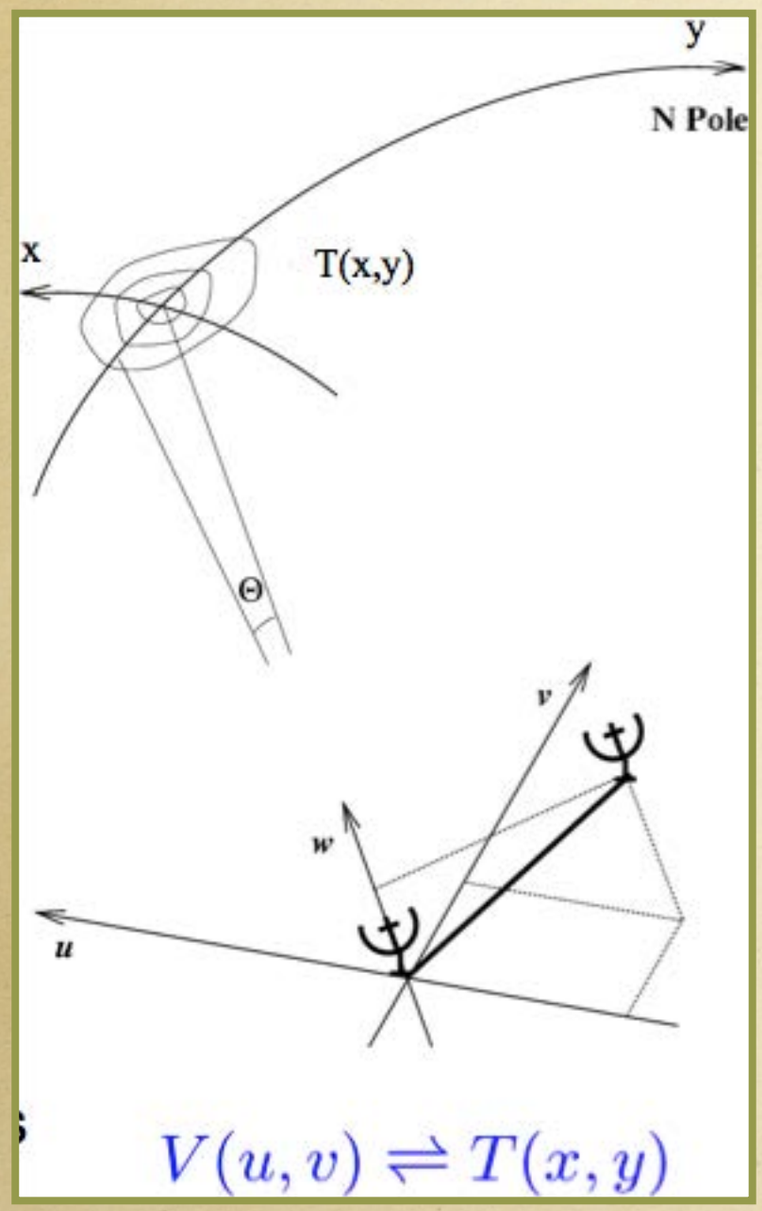

IRAM PdBI


CARMA


SMA


ALMA (2012+)

Visibility & Sky Brightness



$$V(u,v) = \int\int T(x,y) e^{2\pi i(ux+vy)} dxdy$$

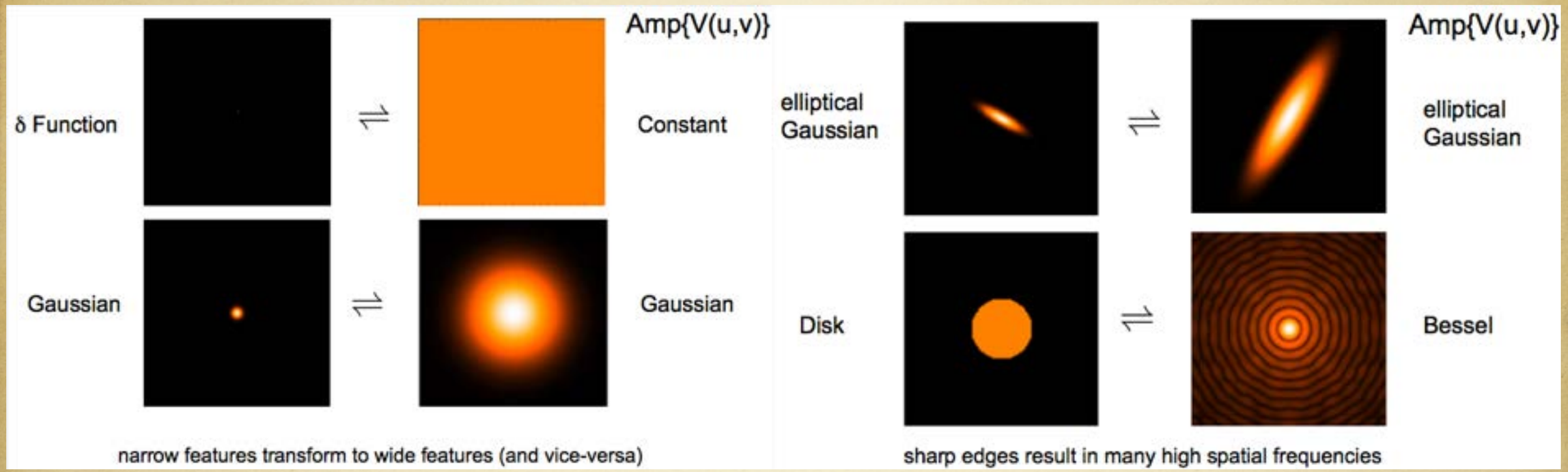
$$T(x,y) = \int\int V(u,v) e^{-2\pi i(ux+vy)} dudv$$

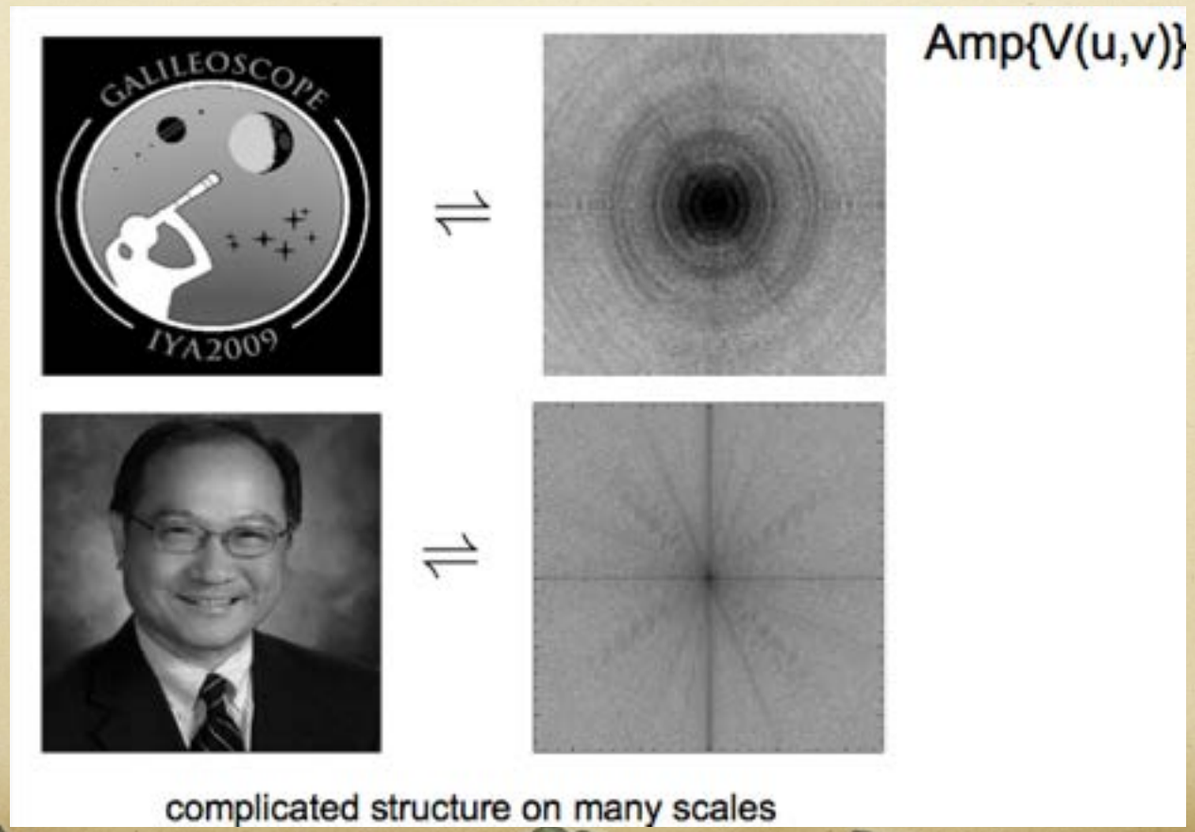
Complex Numbers:

(real, imaginary) or (amplitude, phase)

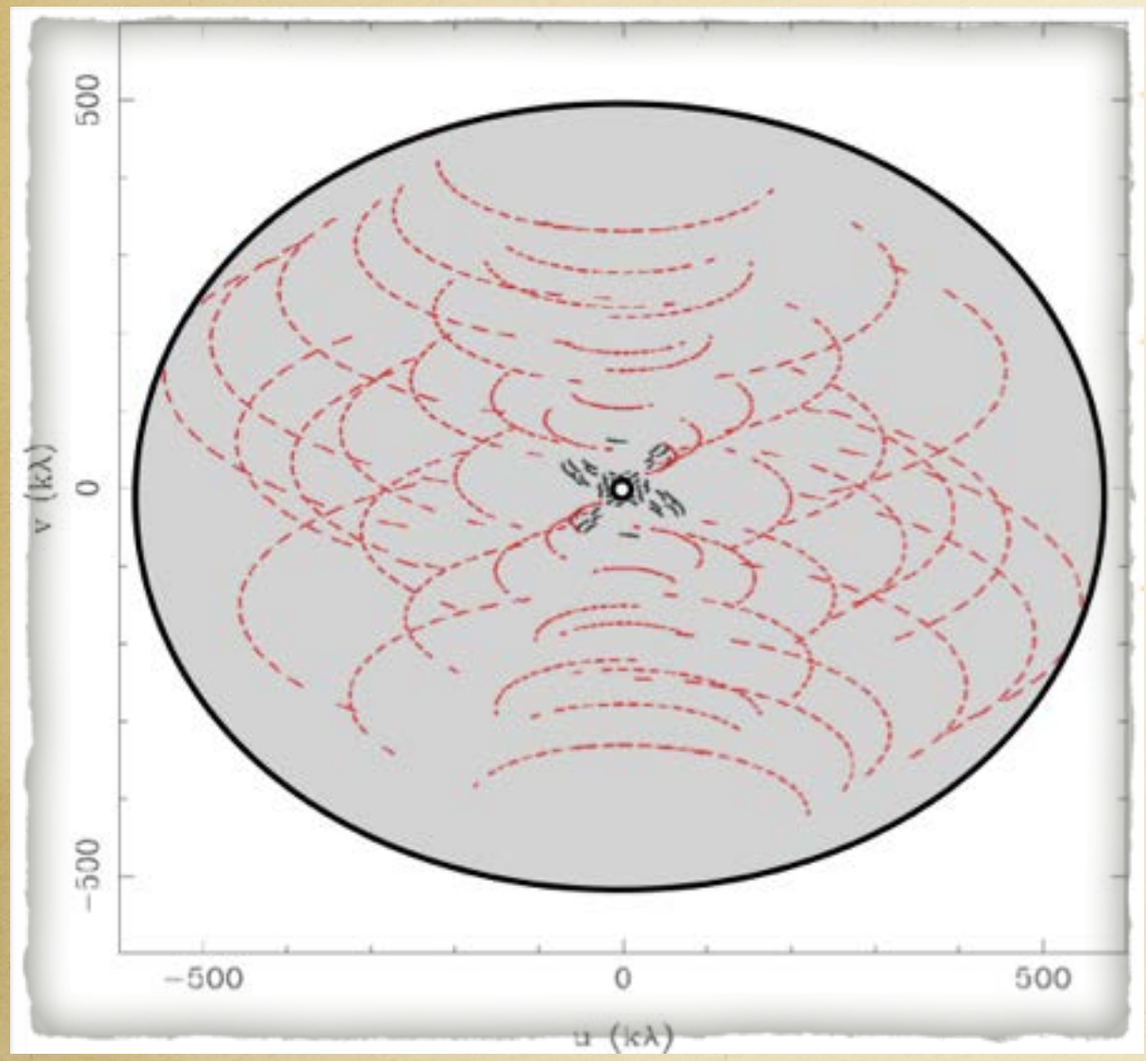
- Amplitude: "how much" of a certain frequency component
- Phase: "where" this component is located

Fourier Transform Pairs





(u, v) plane sampling



Visibilities: (amplitude, phase)

$V(u,v)$

Sample:

$B(u,v) = \sum_k (u_k, v_k)$

Inverse Fourier transform:

$$T^D(x,y) = FT^{-1}\{B(u,v) \times V(u,v)\}$$

Dirty Beam:

$$b(x,y) = FT^{-1}\{B(u,v)\}$$

Dirty Image:

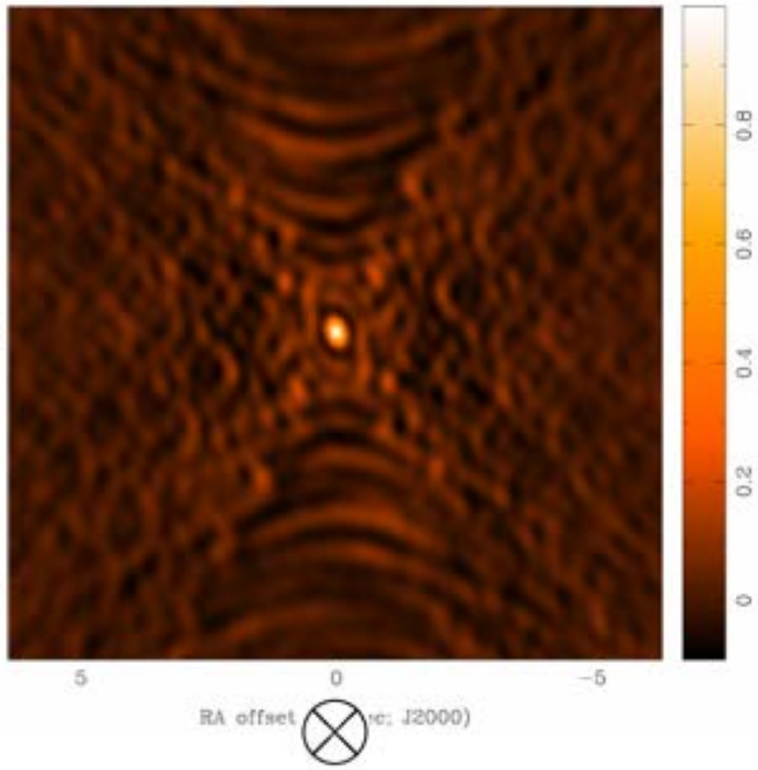
$$T^D(x,y) = b(x,y) \otimes T(x,y)$$

Limited by:

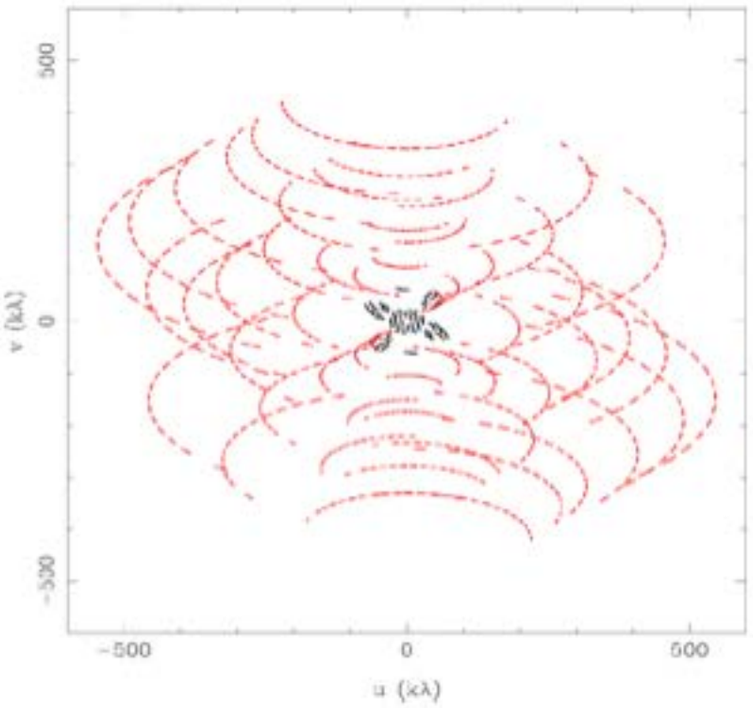
- **number of telescopes**
- **earth-sky geometry**

Dirty Beam & Dirty Image

b(x,y)
(dirty beam)

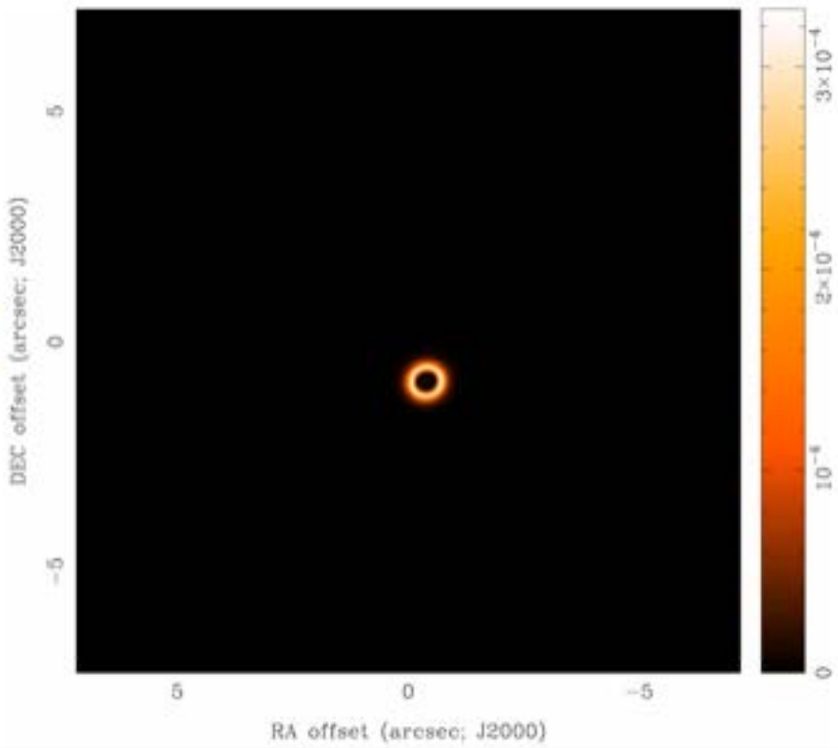


⇂↾



B(u,v)

T(x,y)



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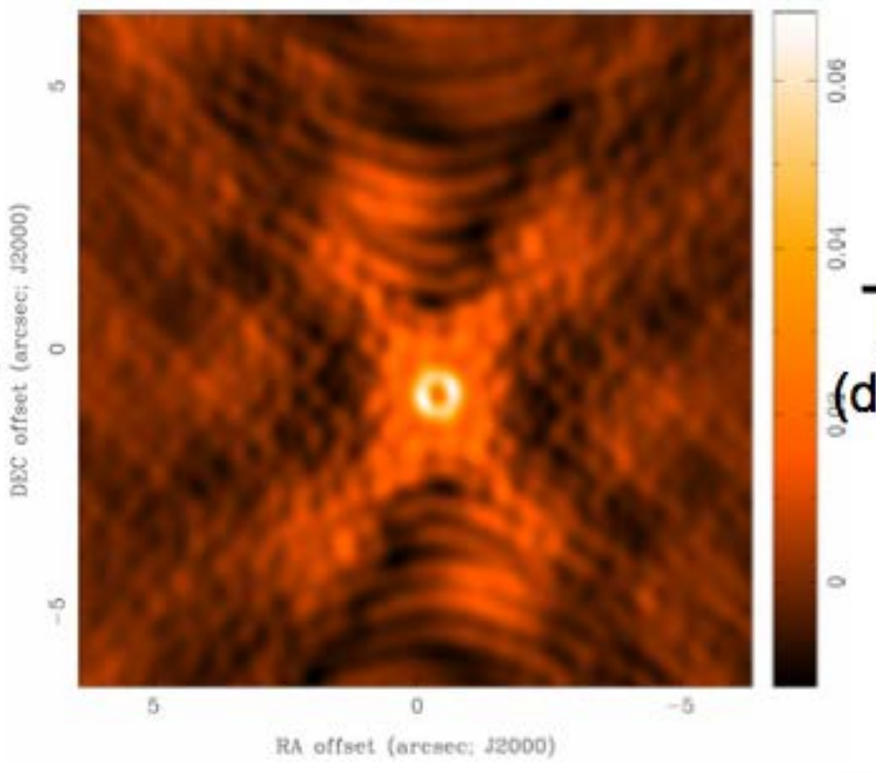


$T^D(x,y)$
(dirty image)

Visibilities

$V(u,v)$

$B(u,v) = \sum_k (u_k, v_k)$

Synthesis
Calibrations

Fourier transform

$b(x,y) = FT^{-1}\{B(u,v)\}$

Dirty Beam -> Clean Beam
Dirty image -> Model

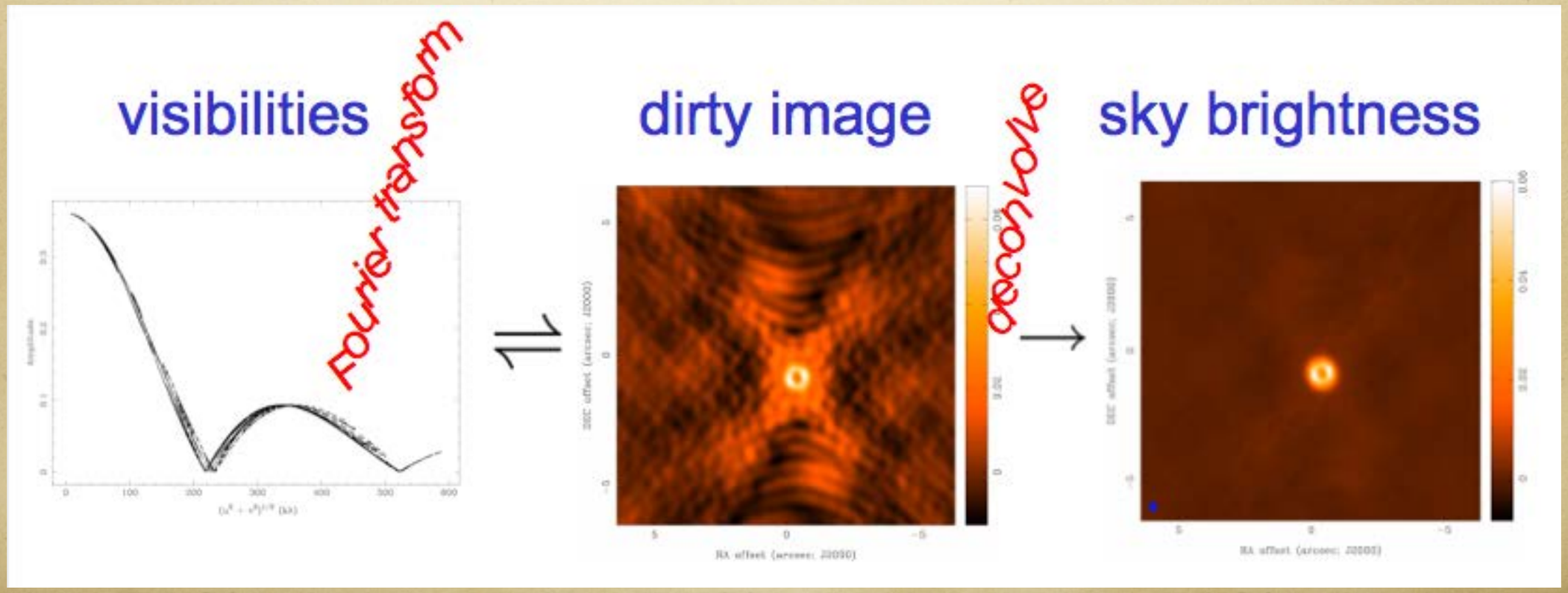
$T^D(x,y) = b(x,y) \otimes T(x,y)$

Deconvolve

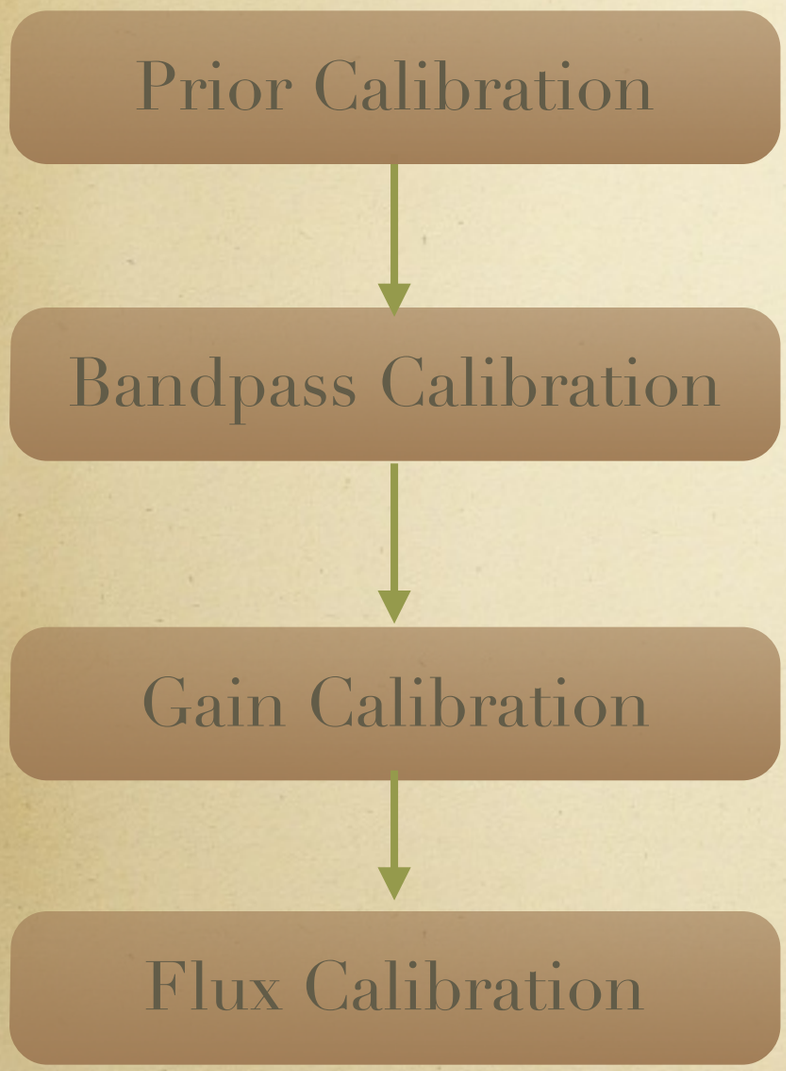
Clean

Clean Image

Analysis



Synthesis Calibrations (to visibility data)



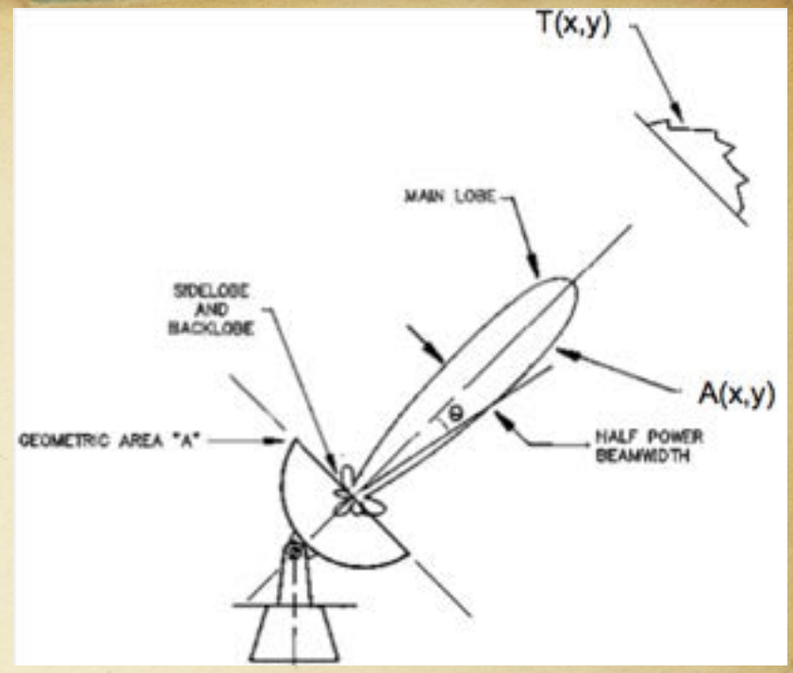
Bandpass Calibrator —> Freq.

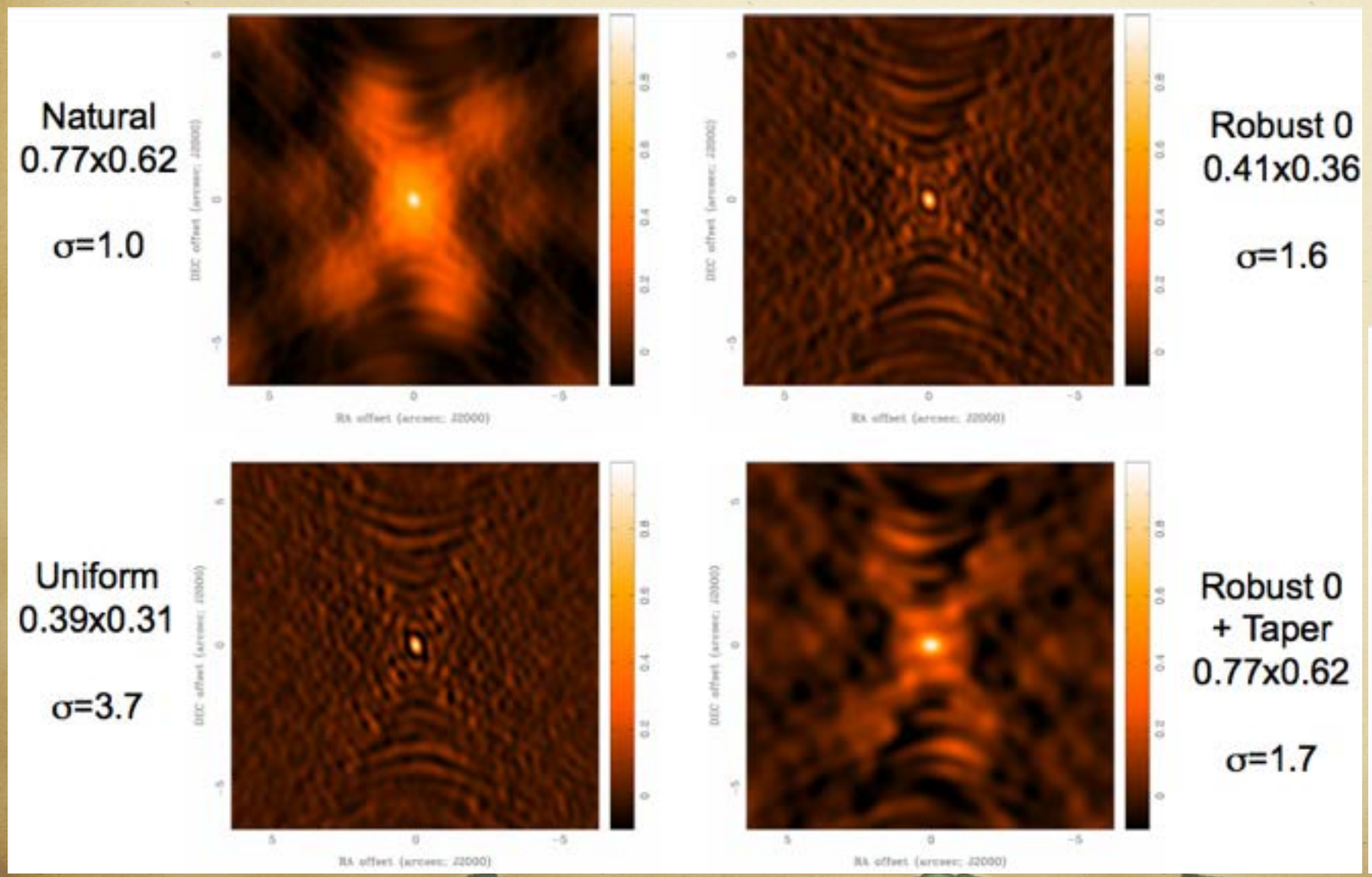
Gain Calibrator(s) —> phase & amp.

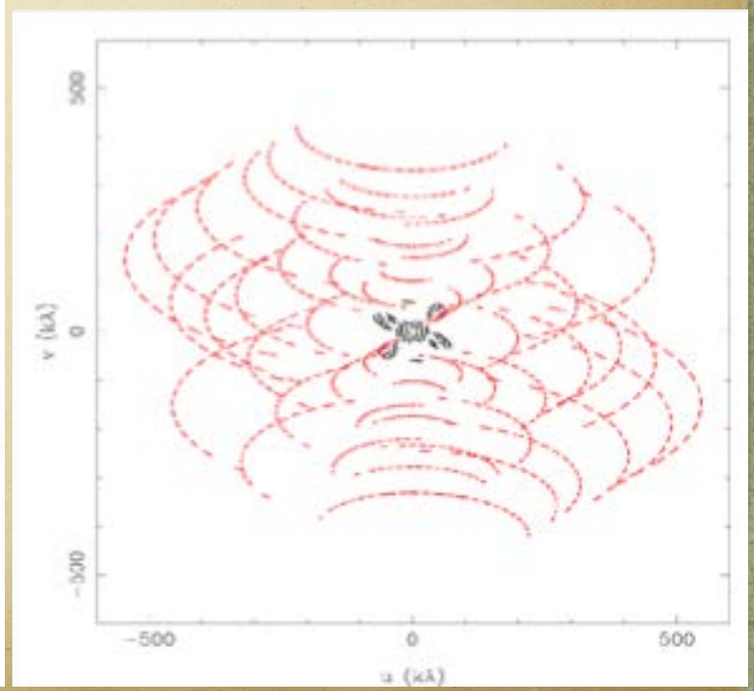
Flux Calibrator —> Flux

Beam

- Primary Beam —> Field of View (for one single pointing)
- Dirty Beam
  - Weighting —> Resolution

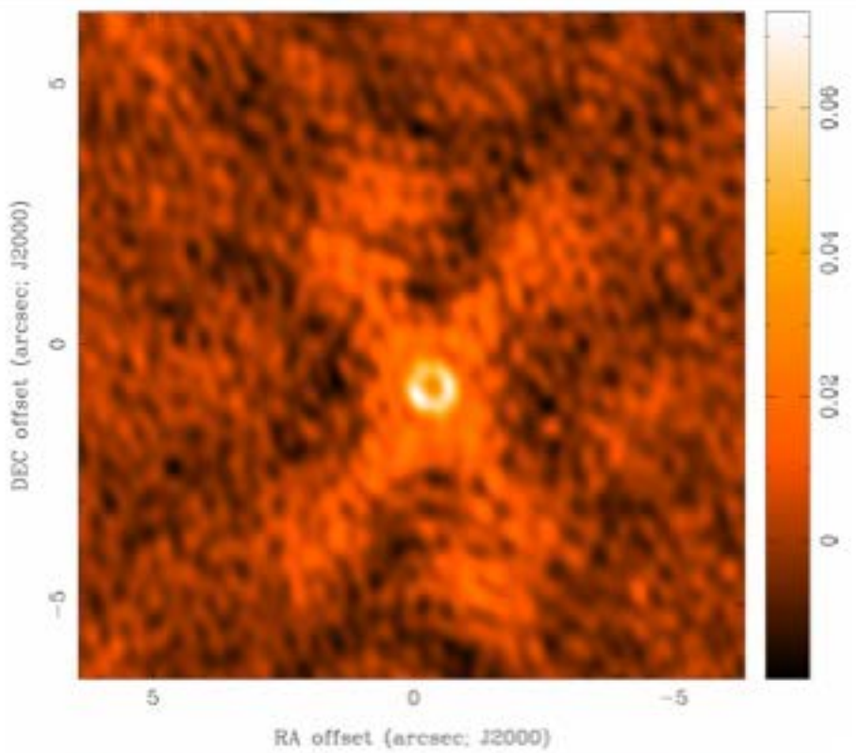




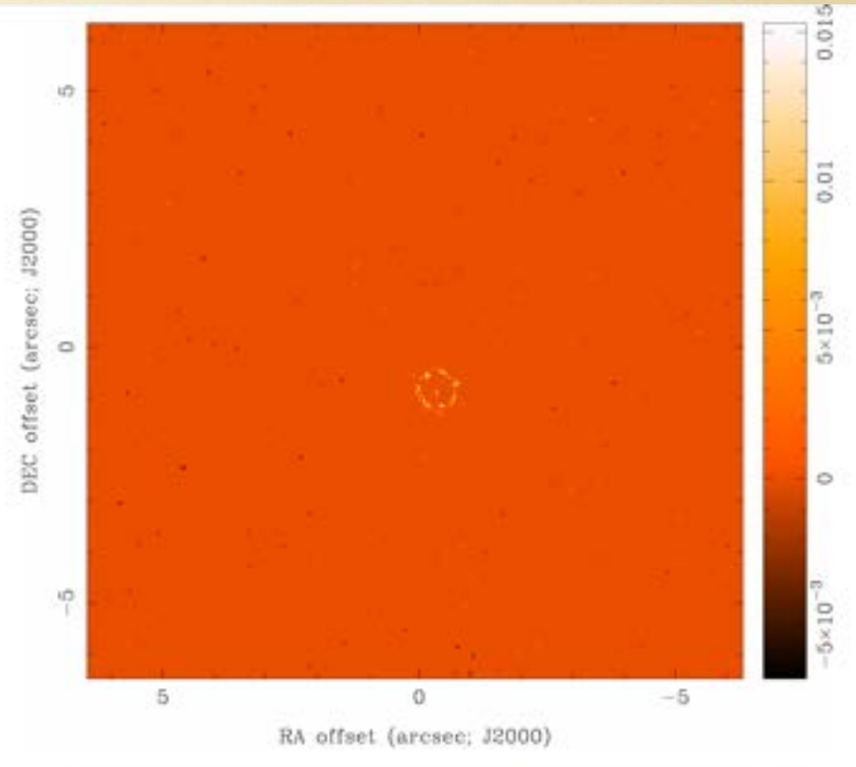


Clean

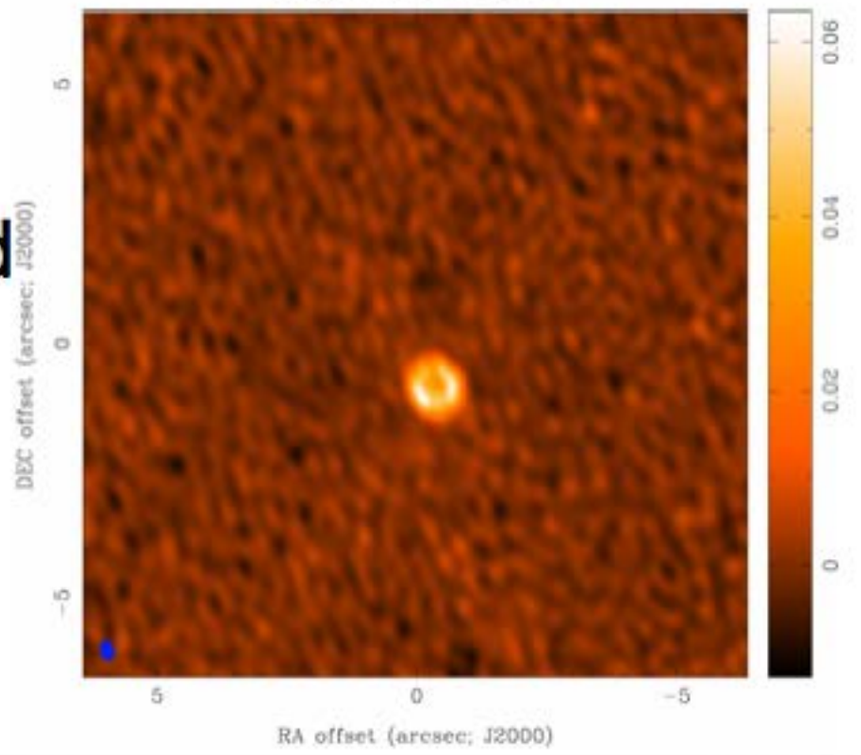
$T^D(x,y)$



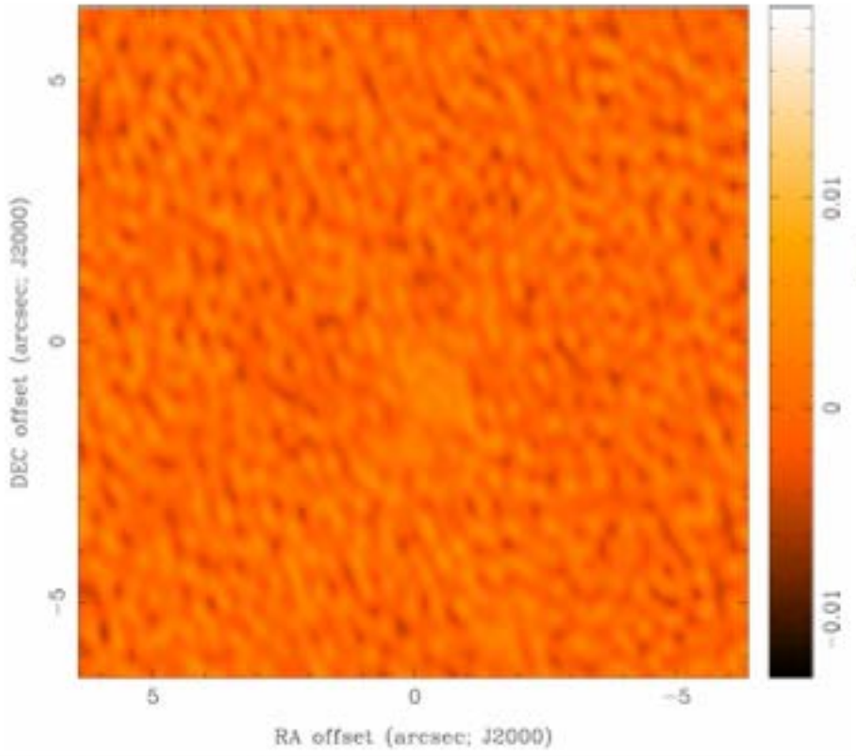
CLEAN model



restored image



residual map



CASA Tutorials

- Basic Commands
- Data Structure: Measurement Set (MS)
- Data Reduction
  - Examination
  - Flagging
  - Prior Calibration
  - Main Calibration
  - Clean
- Image Analysis

Basic Commands

- **startup**
  - casapy / casapy nologer
  - casalogger
  - casapy-YYYYMMDD-HHMMSS.log
  - casapy logfile otherfile.log
  - columns
    - Time: generated time
    - Priority: priority level
      - casalog.filter('...')
    - Origin: Task::Tool::Method
    - Message: actual text
- features
  - Search
  - Filter
  - View
  - Insert message
  - Copy
  - Open

- **exit**
  - quit (ask 'y or n')
  - exit
  - CTRL-D
- **help**
  - task?
  - %pdoc task (cleanest)
  - help task
  - help 'task'
  - help tool.methd
  - help
- **history**
- **Terminal commends**
  - !rm -r mydata.ms
  - rm -r mydata.ms
  - os.system('rm -r mydata.ms')
  - rmtables('mydata.ms')

- **View the task parameters**
  - inp task
  - tget task & inp
- **execute tasks**
  - task
  - go
  - task(...)
  - execfile('myscript.py')
  - execfile 'myscript.py'
  - run myscript.py
  - run task.last
  - $: casapy -c 'myscript.py'

Measurement Set (MS)

- Data structure: Measurement Set (MS)
  - browserdata
  - $: casabrowser .

Table Browser

day2_TDEM0003_10s_norx | SOURCE | FIELD | ANTENNA

table data | table keywords | field keywords

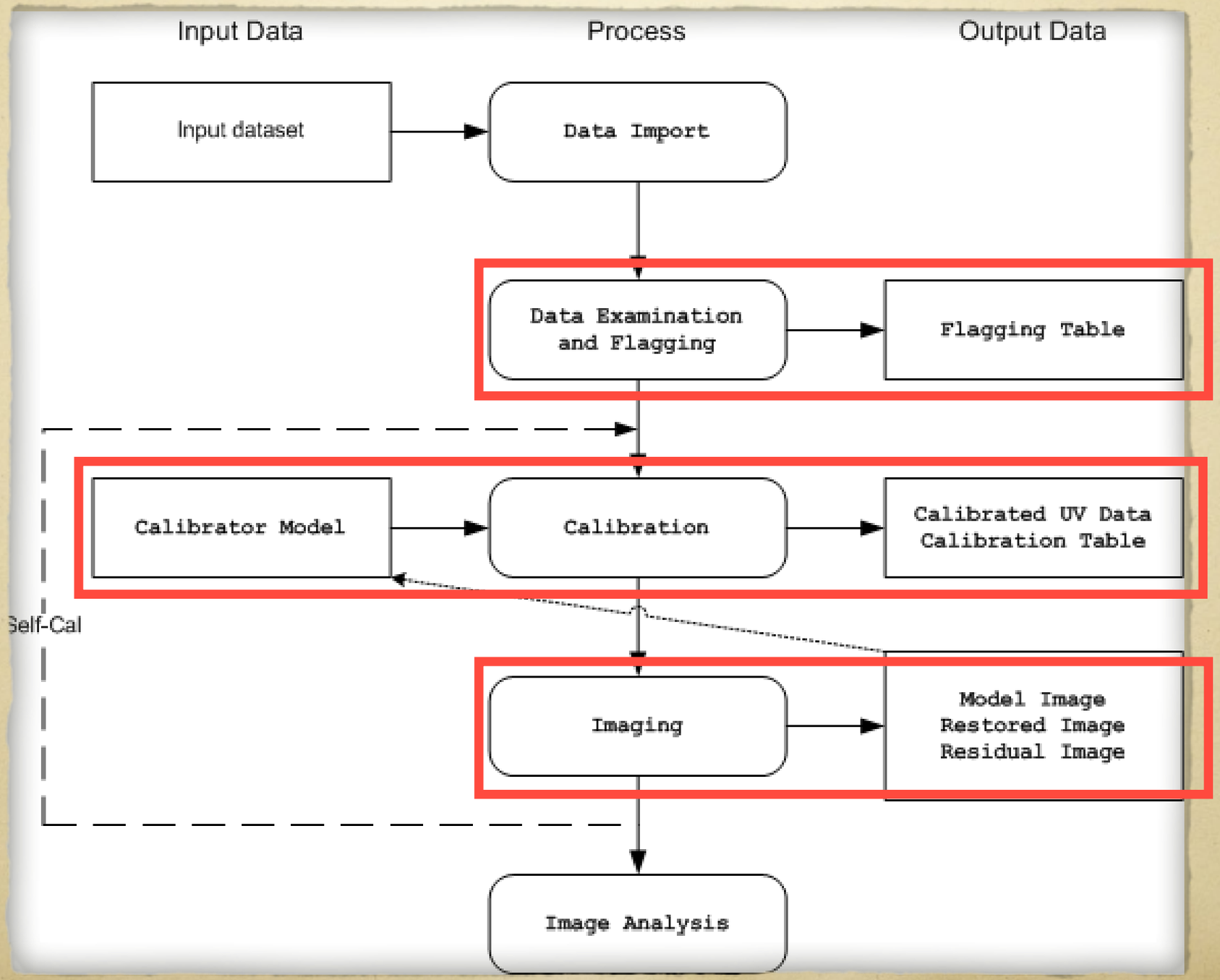
	UVW	FLAG	FLAG_CATEGORY	WEIGHT	SIGMA	ANTENNA1	ANTENNA2	ARRAY_ID	DAT/
0	[-501.927, -321.749, 15...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	1	0	0
1	[-1011.35, -121.001, 16...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	2	0	0
2	[-466.751, -300.157, 14...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	3	0	0
3	[-416.223, -591.091, 22...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	5	0	0
4	[-460.127, -338.154, 15...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	6	0	0
5	[-910.536, -160.84, 160...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	8	0	0
6	[-230.612, -169.454, 79...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	9	0	0
7	[-345.837, -254.113, 11...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	10	0	0
8	[-428.009, -523.148, 20...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	11	0	0
9	[-473.348, -262.158, 13...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	12	0	0
10	[-437.921, -466.209, 19...	[4, 64] Boolean	[0, 0, 0] Boolean	[7, 7, 7, 7]	[0.377964, 0.377964, 0....	0	13	0	0

Restore Columns | Resize Headers

PAGE NAVIGATION First << [1 / 291] >> Last 1 Go Loading 1000 rows.

Opened saved view.

Data Reduction (Flow Chart)



Load the data to CASA

- importuvfits (UVFITS, visibility data)
- importvla (VLA data)
- importasdm (ALMA data in ASDM format)
- importevla (JVLA/EVLA data in SDM format)
- importfits (FITS, image)

1. Import

Data Examination

- listobs (summarize)
- plotants
- plotms (visibility data)
- viewer (image)
- plotcal (calibration solutions)
- vishead

2. Examination

Examination: listobs

Fields: 4

ID	Code	Name	RA	Decl	Epoch	SrcId	nRows
2	D	J0954+1743	09:54:56.823626	+17.43.31.22243	J2000	2	65326
3	NONE	IRC+10216	09:47:57.382000	+13.16.40.65999	J2000	3	208242
5	F	J1229+0203	12:29:06.699729	+02.03.08.59820	J2000	5	10836
7	E	J1331+3030	13:31:08.287984	+30.30.32.95886	J2000	7	5814

Spectral Windows: (2 unique spectral windows and 1 unique polarization setups)

SpwID	Name	#Chans	Frame	Ch0(MHz)	ChanWid(kHz)	TotBW(kHz)	Corrs
0	Subband:0	64	TOPO	36387.229	125.000	8000.0	RR RL LR LL
1	Subband:0	64	TOPO	36304.542	125.000	8000.0	RR RL LR LL

Sources: 10

ID	Name	SpwId	RestFreq(MHz)	SysVel(km/s)
0	J1008+0730	0	0.03639232	-0.026
0	J1008+0730	1	0.03639232	-0.026
2	J0954+1743	0	0.03639232	-0.026
2	J0954+1743	1	0.03639232	-0.026
3	IRC+10216	0	0.03639232	-0.026
3	IRC+10216	1	0.03639232	-0.026
5	J1229+0203	0	0.03639232	-0.026
5	J1229+0203	1	0.03639232	-0.026
7	J1331+3030	0	0.03639232	-0.026
7	J1331+3030	1	0.03639232	-0.026

Observer: Mark J. Mark Claussen Project: T.B.D.
Observation: EVLA
Data records: 290218 Total integration time = 10016 seconds
Observed from 26-Apr-2010/03:21:56.0 to 26-Apr-2010/06:08:52.0 (UTC)

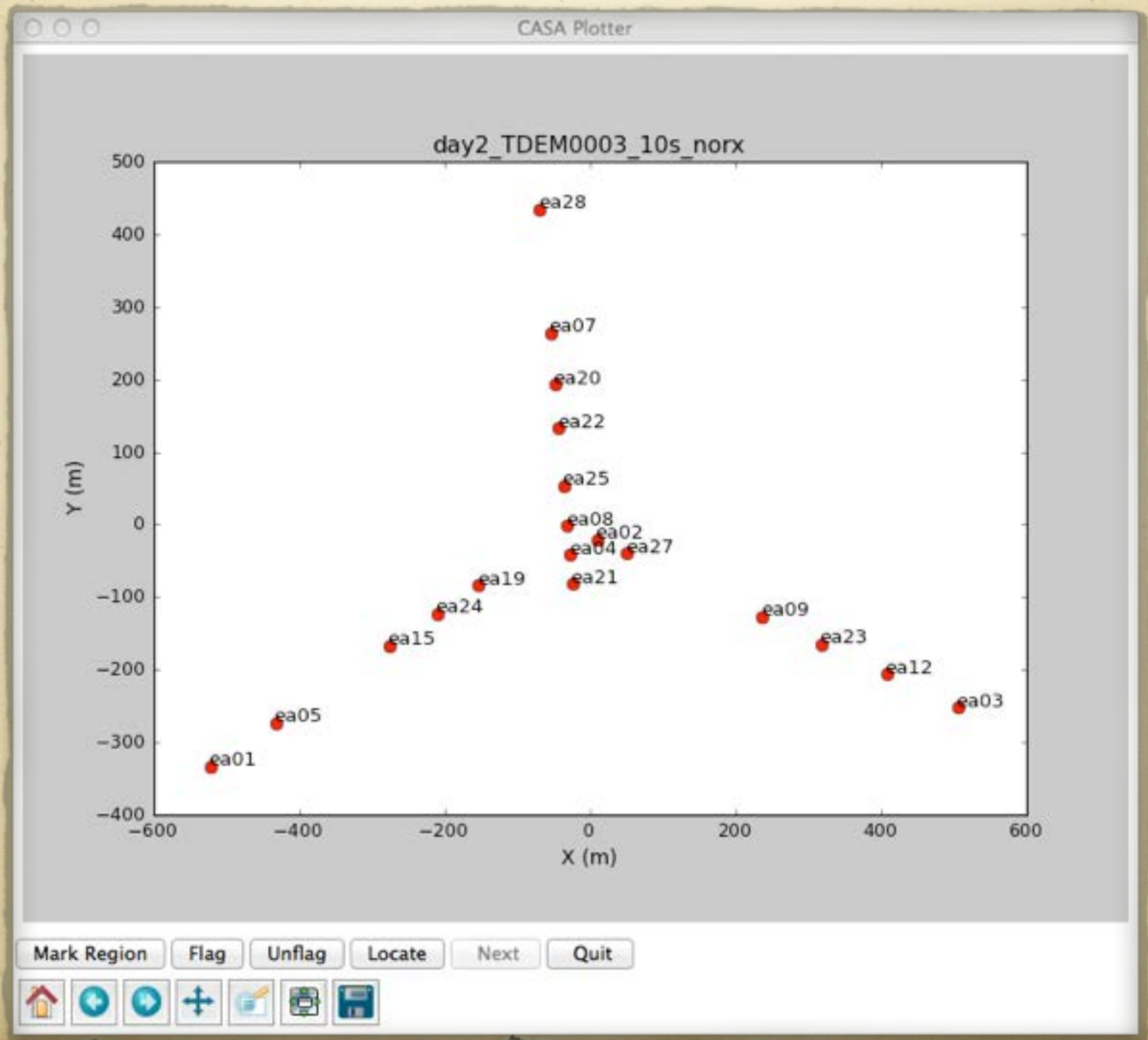
ObservationID = 0 ArrayID = 0

Date	Timerange (UTC)	Scan	FldId	FieldName	nRows	SpwIds	Average Interval(s)	ScanIntent
26-Apr-2010	03:21:51.0 - 03:23:21.0	5	2	J0954+1743	2720	[0, 1]	[10, 10]	
	03:23:39.0 - 03:28:25.0	6	3	IRC+10216	9918	[0, 1]	[10, 10]	
	03:28:38.0 - 03:29:54.0	7	2	J0954+1743	2700	[0, 1]	[10, 10]	
	03:30:08.0 - 03:34:53.5	8	3	IRC+10216	9918	[0, 1]	[10, 10]	
	03:35:07.0 - 03:36:23.0	9	2	J0954+1743	2736	[0, 1]	[10, 10]	
	03:36:37.0 - 03:41:22.5	10	3	IRC+10216	9918	[0, 1]	[10, 10]	
	03:41:35.4 - 03:42:51.5	11	2	J0954+1743	2700	[0, 1]	[10, 10]	
	03:43:05.8 - 03:47:51.5	12	3	IRC+10216	9918	[0, 1]	[10, 10]	
	03:48:04.4 - 03:49:20.5	13	2	J0954+1743	2700	[0, 1]	[10, 10]	
	03:49:34.9 - 03:54:20.5	14	3	IRC+10216	9918	[0, 1]	[10, 10]	
	03:54:33.0 - 03:55:49.6	15	2	J0954+1743	2496	[0, 1]	[10, 10]	

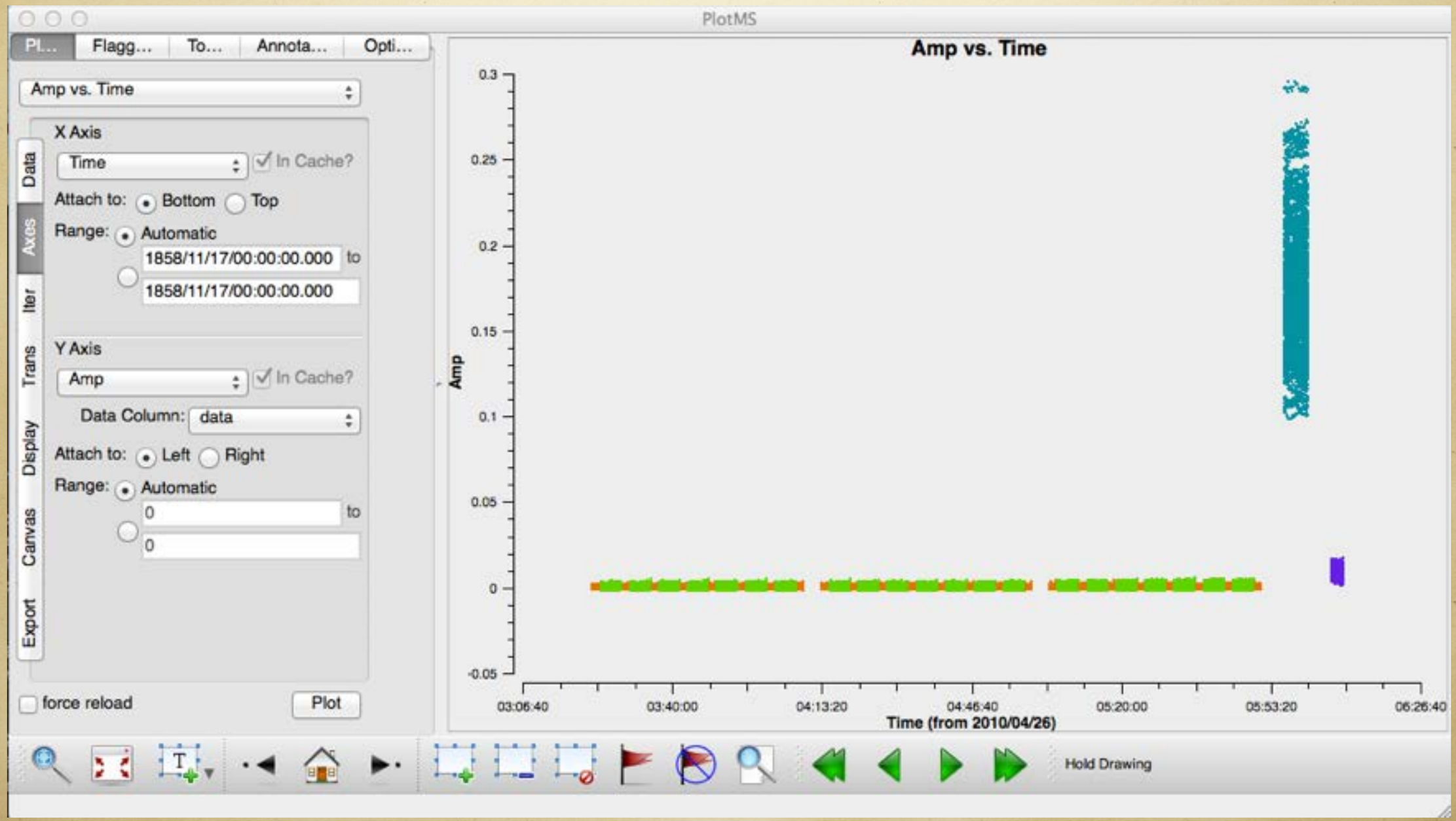
Antennas: 19:

ID	Name	Station	Diam.	Long.	Lat.	Offset from array center (m) East	Offset from array center (m) North	Offset from array center (m) Elevation	ITRF Geocentric coordinates (m) x	ITRF Geocentric coordinates (m) y	ITRF Geocentric coordinates (m) z
0	ea01	W09	25.0 m	-107.37.25.2	+33.53.51.0	-521.9407	-332.7782	-1.1977	-1601710.017000	-5042006.928200	3554602.355600
1	ea02	E02	25.0 m	-107.37.04.4	+33.54.01.1	9.8247	-20.4292	-2.7808	-1601150.059500	-5042000.619800	3554860.729400
2	ea03	E09	25.0 m	-107.36.45.1	+33.53.53.6	506.0591	-251.8666	-3.5832	-1600715.948000	-5042273.187000	3554668.184500
3	ea04	W01	25.0 m	-107.37.05.9	+33.54.00.5	-27.3562	-41.3030	-2.7418	-1601189.030140	-5042000.493300	3554843.425700
4	ea05	W08	25.0 m	-107.37.21.6	+33.53.53.0	-432.1158	-272.1493	-1.5032	-1601614.091000	-5042001.655700	3554652.509300
5	ea07	N06	25.0 m	-107.37.06.9	+33.54.10.3	-54.0667	263.8720	-4.2292	-1601162.593200	-5041829.000000	3555095.890500

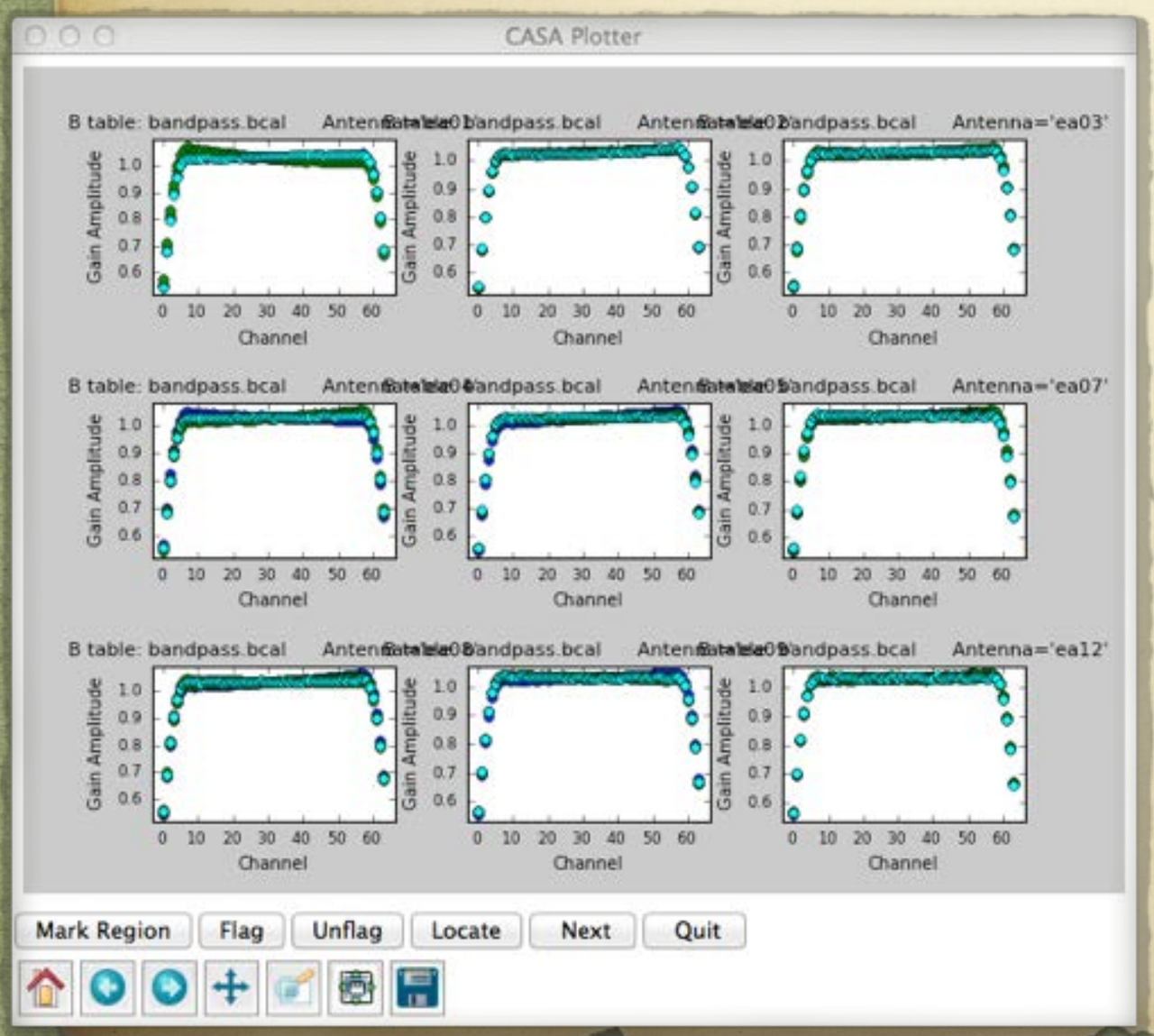
Examination: plotants

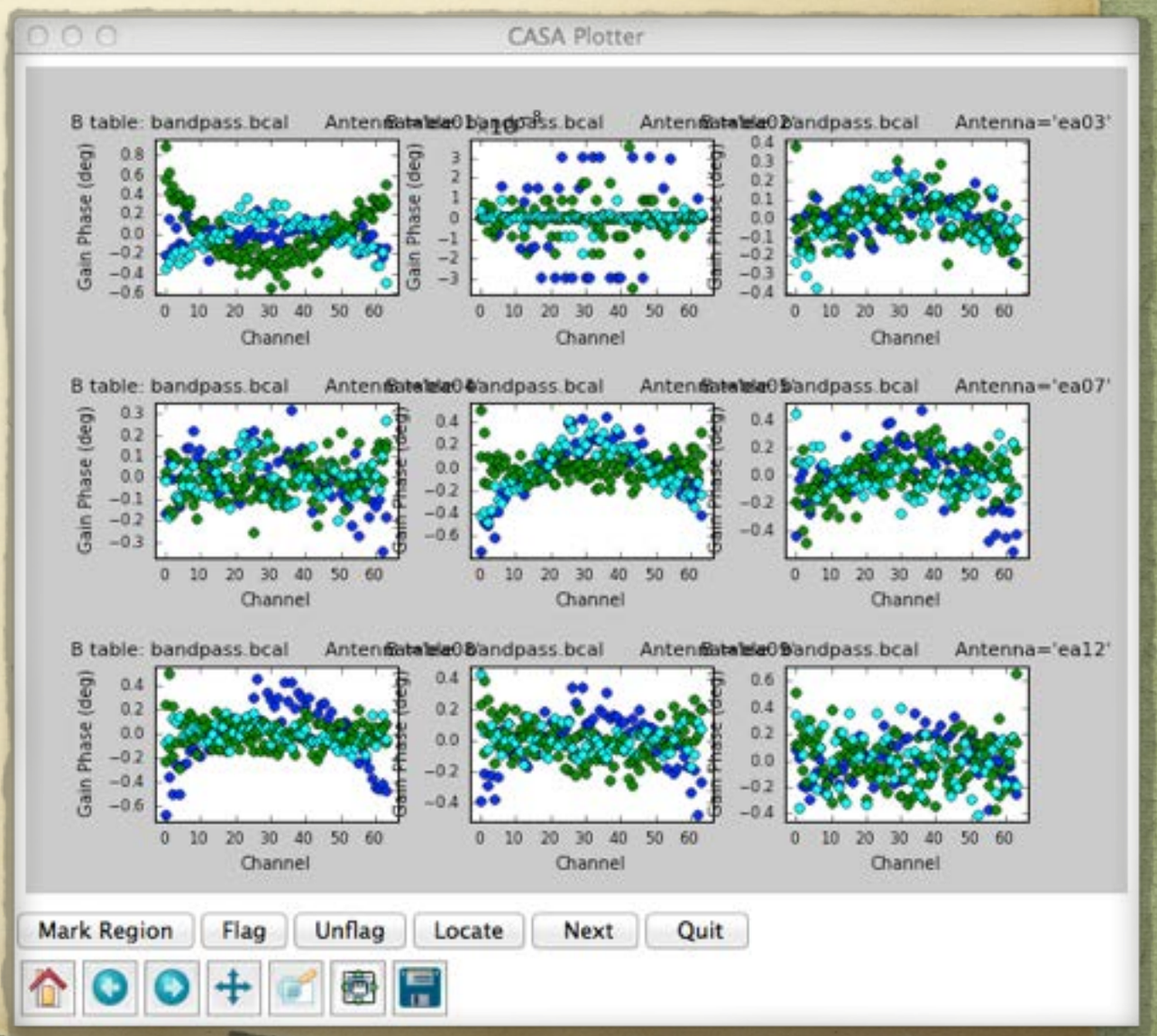


Examination:
plotms (Visibility Data)

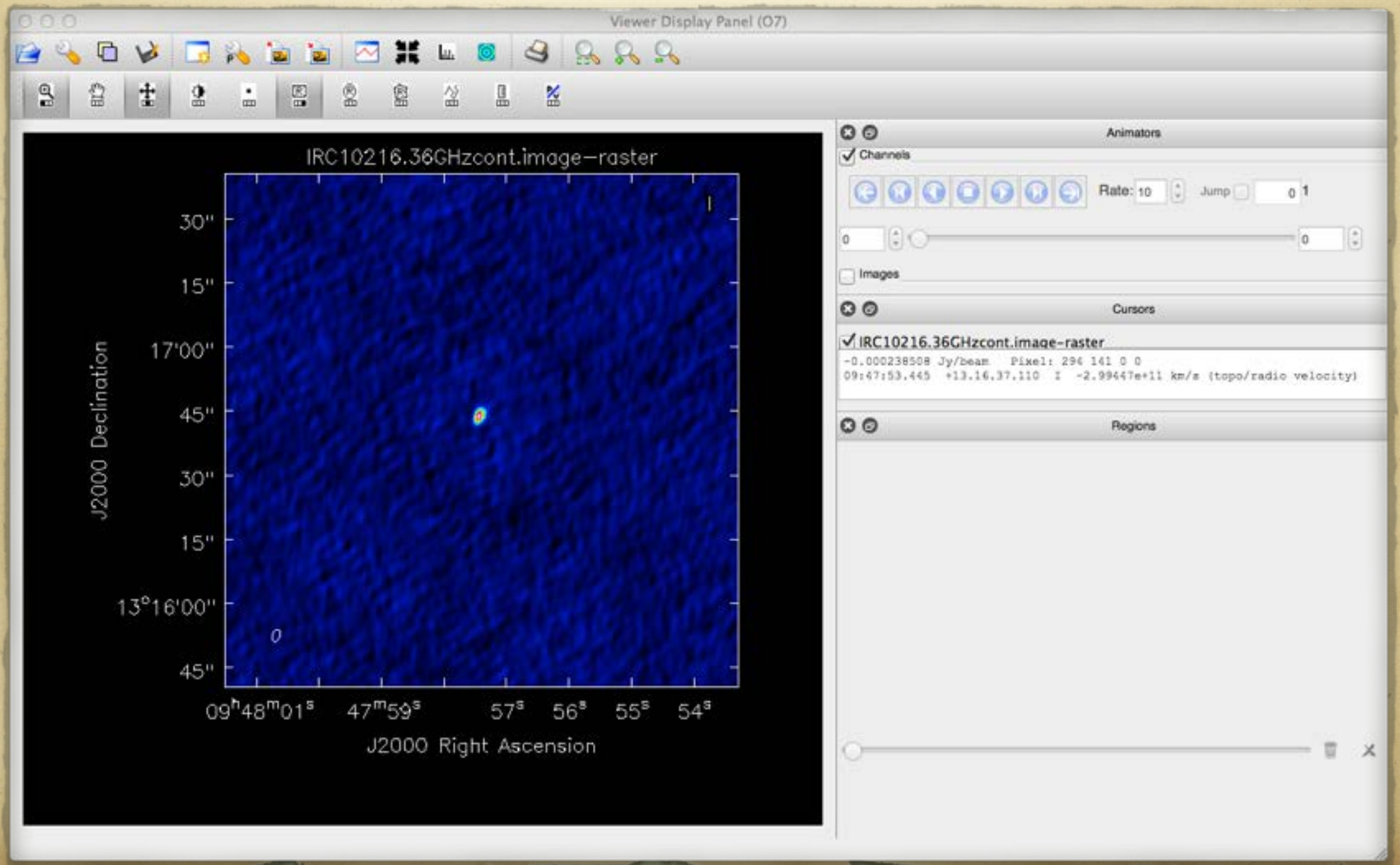


Examination:
plotcal (calibration solutions)





Examination:
viewer (Image Data)

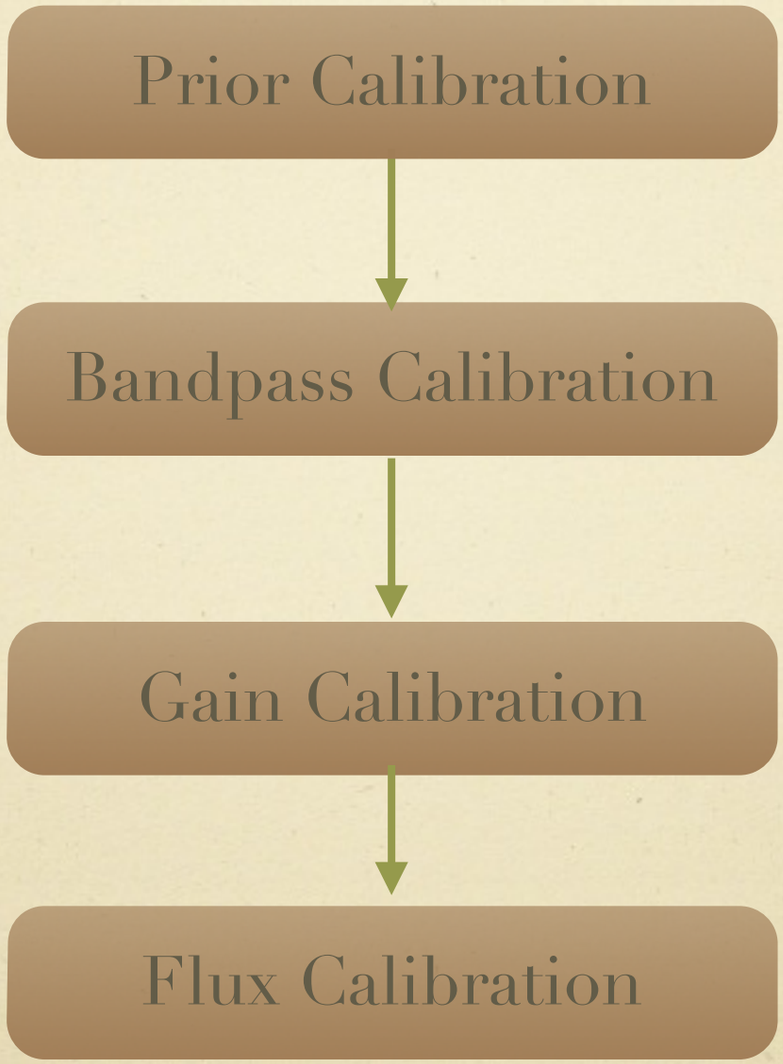


3. Flagging

Data flagging

- flagdata
  - mode='manual'
  - mode='list'
  - mode='unflag'
  - mode='summary'
  - mode='clip' ('quack','shadow','elevation','tfcrop','rflag','extend')
- flagmanager (MS)
  - mode='list'
  - mode='save'
  - mode='restore'
  - mode='delete'
  - mode='rename'
- flagcmd
  - action='apply' ('unapply','list', 'plot','clear','extract')
- Interactive flagging (backup before do that)
- Auto-RFI flagging
  - flagdata: mode='rflag'

4. Synthesis Calibrations



Prior Calibration

↓

Bandpass Calibration

↓

Gain Calibration

↓

Flux Calibration

System Temperature & Switched-Power Correction

Flux Density Scale (model)

Antenna Gain-Elevation Curve Calibration

Atmospheric Optical Depth Correction

Antenna-based Delay (sbd, mbd)

Antenna position offset Correction

Prior Calibration

Bandpass Calibration

Gain Calibration

Flux Calibration

Phase-only ('int')

Antenna-Based ('inf')

Baseline-Based ('inf')

Prior Calibration

Bandpass Calibration

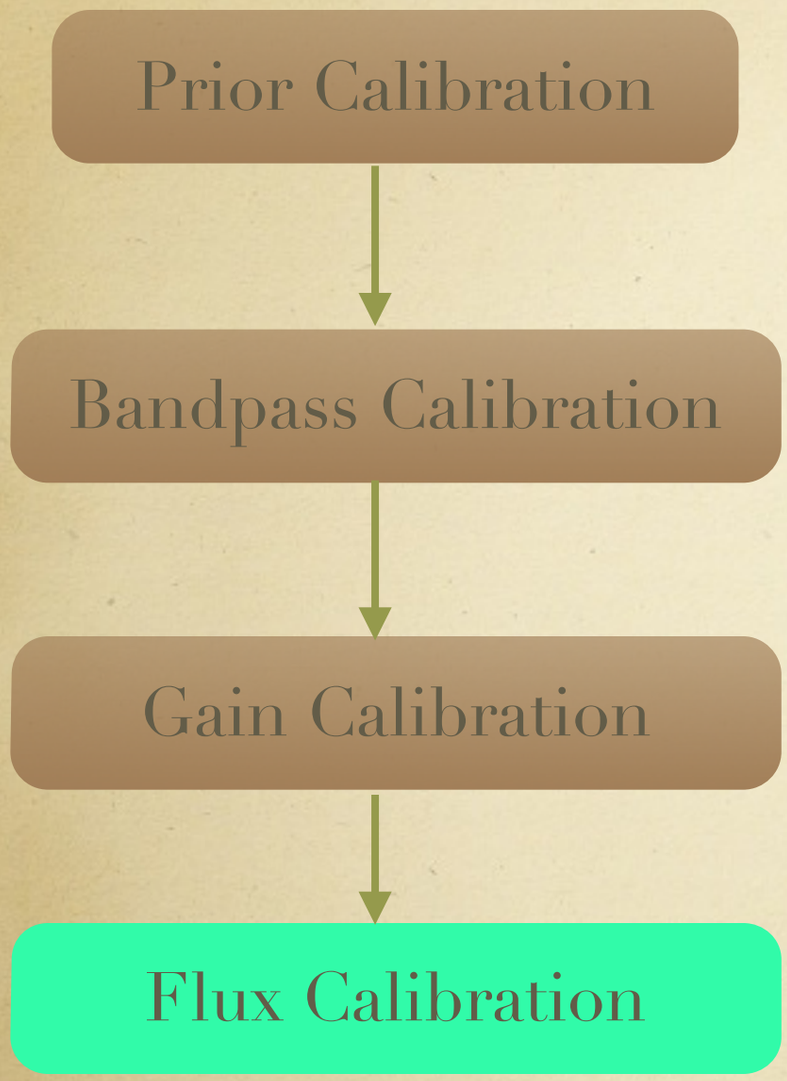
Gain Calibration

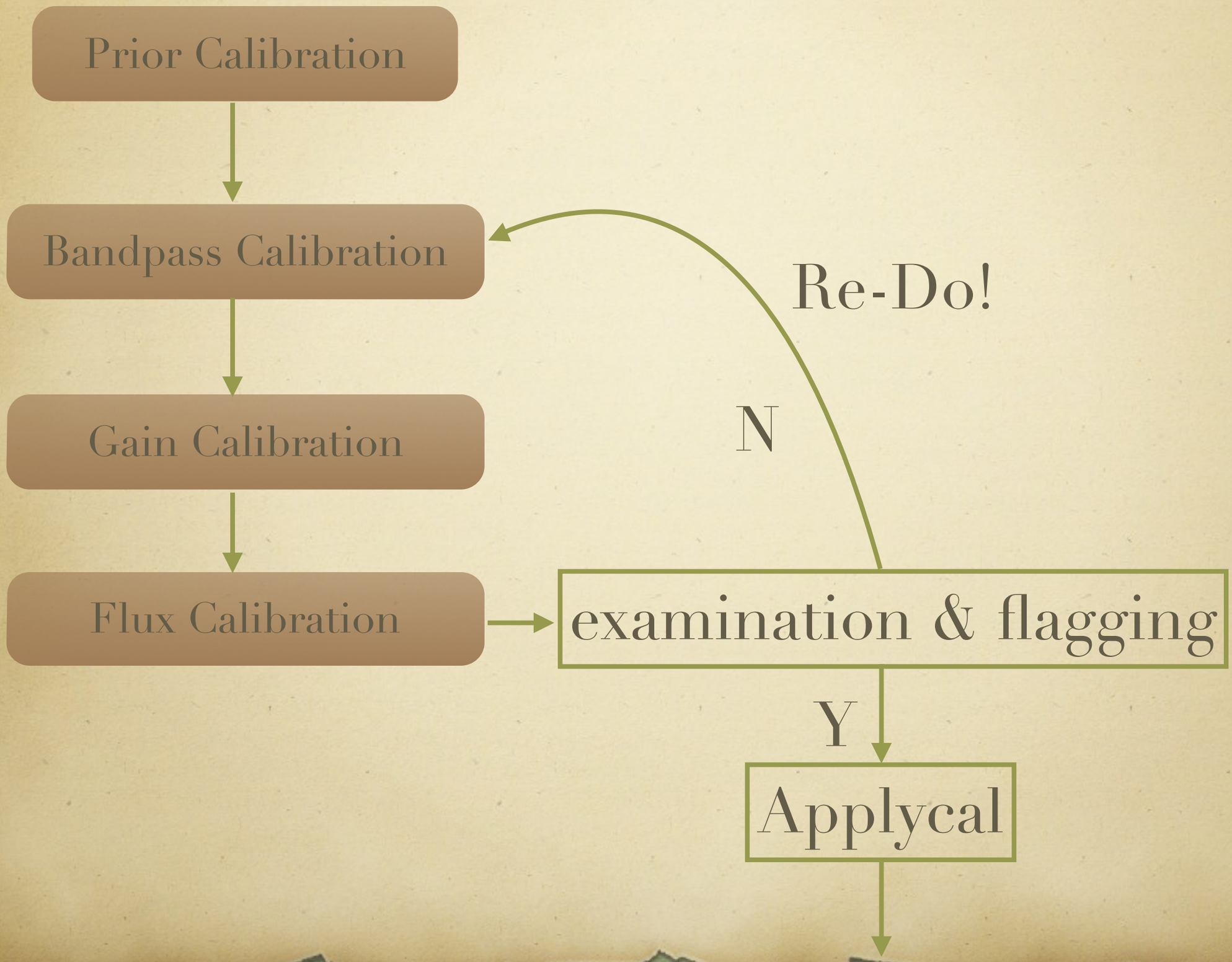
Flux Calibration

Phase-only ('int')

Phase-only ('inf')

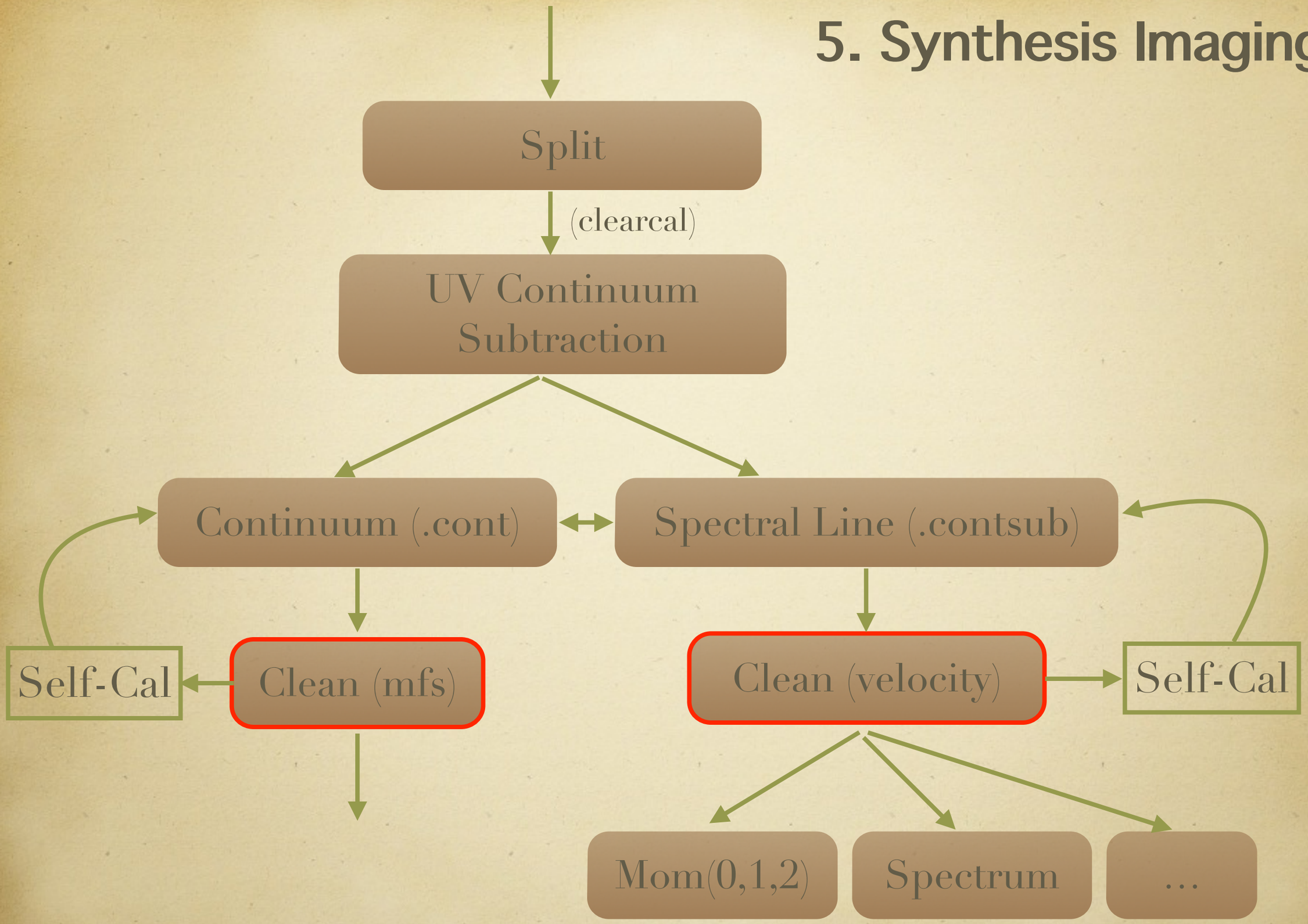
Phase & Amplitude ('inf')


Prior Calibration
Bandpass Calibration
Gain Calibration
Flux Calibration


Prior Calibration
Bandpass Calibration
Gain Calibration
Flux Calibration
examination & flagging
Re-Do!
N
Y
Applycal

- Important Tips:
  - check & check
  - take a note
  - backup

5. Synthesis Imaging



Clean

- **cell:** pixel size
- **imsize:** 10*2^n (n=1,2,3,4,5,6….)
- **weighting**
  - natural $w_i = \omega_i = \frac{1}{\sigma_k^2}$
  - uniform & superuniform $w_i = \frac{\omega_i}{W_k}$.
  - radial $w_i = \omega_i \cdot \sqrt{u_i^2 + v_i^2}$.
  - briggs $w_i = \frac{\omega_i}{1 + W_k f^2}$ $f^2 = \frac{(5 * 10^{-R})^2}{\frac{\sum_k W_k^2}{\sum_i \omega_i}}$
    - robust: -2(uniform) 2.0(natural)
- **mode**
  - mfs
  - velocity/channel/frequency
- **psfmode**
  - 'clark' algorithm (default)
  - 'hogbom' algorithm
- **imagermode**
  - csclean
  - mosaic
- **threshold:** rms
- **niter**
- **gain:** 0.1
- **multiscale**
- **mask**
- **interactive**

- **imagename.image** > restored image
- **imagename.flux** > effective response
- **imagename.flux.pbcoverage** > PB coverage (ftmachine='mosaic')
- **imagename.model** > model image (Jy/pix)
- **imagename.residual** > residual image
- **imagename.psf** > synthesized (dirty) beam

- **Image analysis & viewing (image cube)**
  - moment (immoment)
  - spectral line fitting (specfit)
  - P-V diagram (impv)
  - image-component fitting (imfit)
  - image convolution (imsmooth)
  - continumm subtraction (imcontsub)
  - (imhead)
  - statistics (imstat)
  - math (immath)
  - regride (imregrid)
  - redefine the velocity frame (imreframe)
  - ...

- **Self-calibration**
- **Mosaic**
  - **task 'clean'**
    - imagermode='mosaic'
    - ftmachine='ft' —> slow (weighted combination of images)
    - ftmachine='mosaic'(default)
      —> fast (gridded onto a single uv-plane —> single output image)
      —> needed primary beam correction
      —> twice as big as necessary to encompass the mosaic
  - minpb
  - phasecenter
- **Toolkit 'MEM'**

Thanks!