Principles of Interferometry

Hans-Rainer Klöckner

IMPRS Black Board Lectures 2014

acknowledgement

please have a look also on my "old" homepage

A small guide to AIPS [Klöckner 2010]

The Astronomical Image Processing System (AIPS) was developed by NRAO, originally to handle VLA data. It is now the most comprehensive radio image processing system available. You can not only use it for processing data optained by interferometers such as the VLA, WSRT, MERLIN, VLBA, EVN, VLBI you can also use it to work on single dish measurements and here the problem starts. Actually the variety of task (programs in AIPS) you can use to handle your radio data is sometimes confusing and on top of that you already need an idea what your radio measurements should look like.

This guide will help with your first steps in AIPS and hopefully will provide you with some confidence to calibrate your radio observations. More information and help can be found via the AIPS cookbook pages. However, once you have an idea of how AIPS works and what you should/can do with your radio data all other data processing packages use the same physical principles and are therefore easy to access even if the user interfaces appear different (e.g. Miriad).

"The first steps" describes some basic features and useful tools in AIPS. "Get your hands dirty" will guide you through a complete calibration procedure. "AIPS advanced" will (still in development) provide some useful tips how to improve images, data massaging, combine UV-datasets, program run files.

The first steps	Get your hands dirty	AIPS advanced
1.1 Start AIPS	2.1 Display data (UV-plane)	3.1 Self calibration
1.2 Get Data into AIPS	2.2 Error recognition	3.2 Data massaging [developing]
1.3 Get Information from Data	2.3 Calibrating Data	3.3 Scripts
1.4 Talking AIPS	2.4 Data handling	3.4 Source model subtraction

25.09.2014

21,960 Visitors
Since December 7, 2005

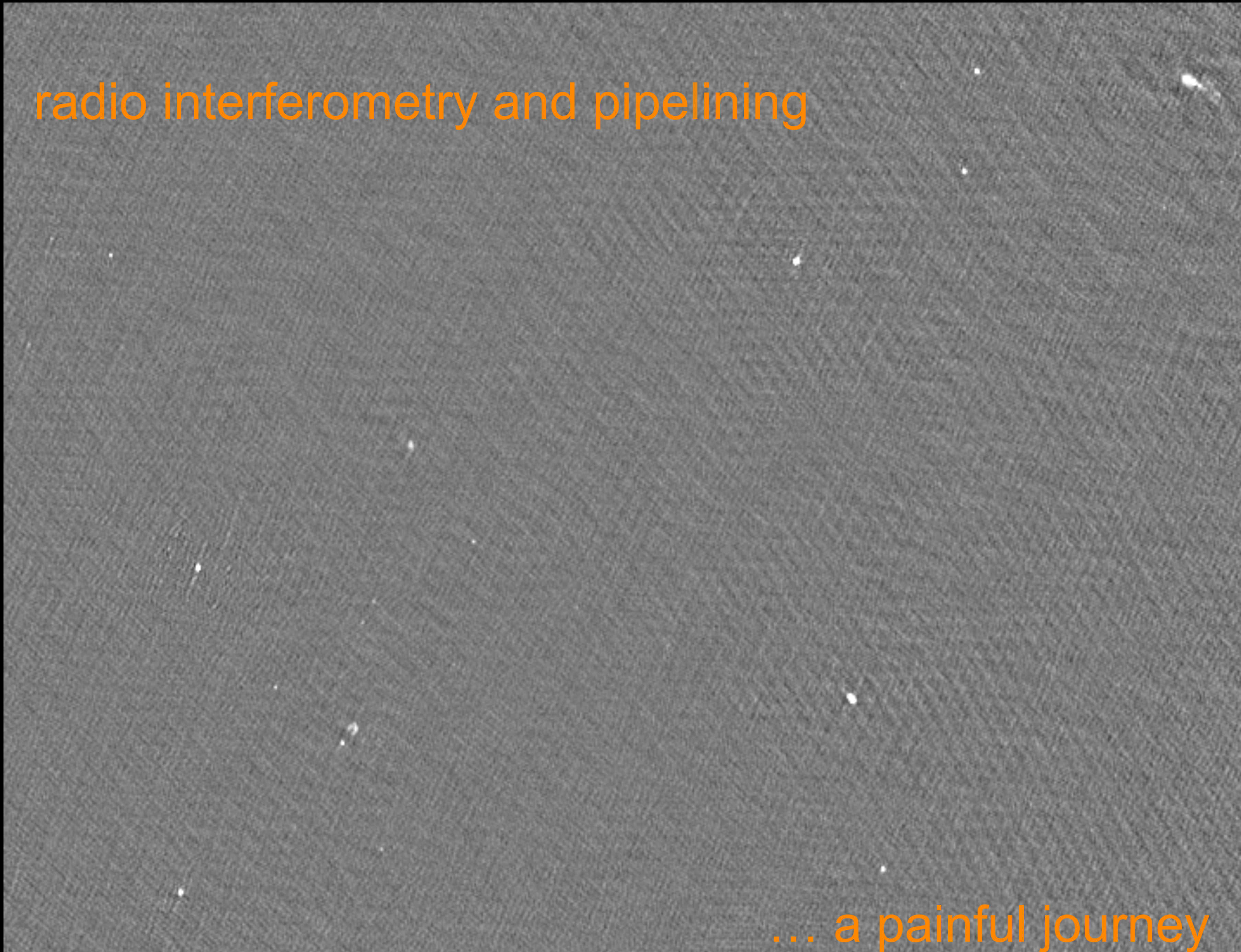
http://www-astro.physics.ox.ac.uk/~hrk/AIPS_TUTORIAL/HRK_AIPS_1.html

Lecture 6

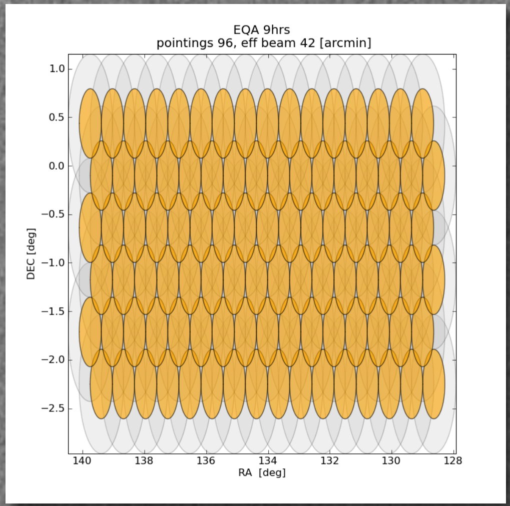
- observing with the GMRT
- investigating raw data
- evaluating calibration and self-calibration procedure
- data analysis

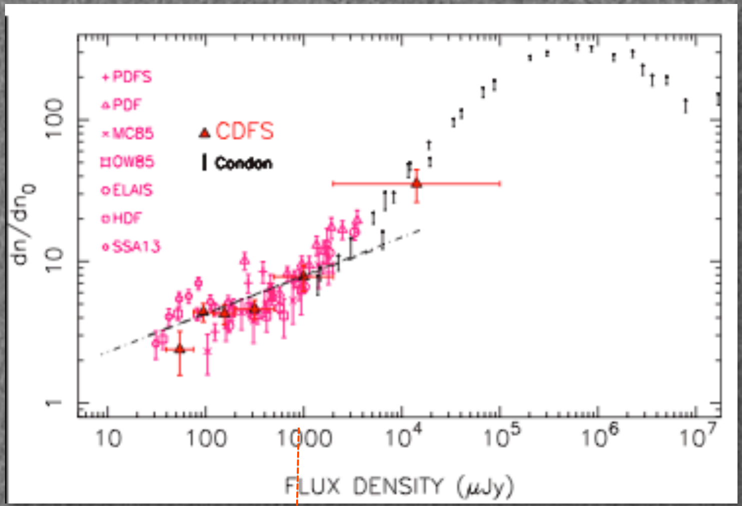

its all about dynamic range

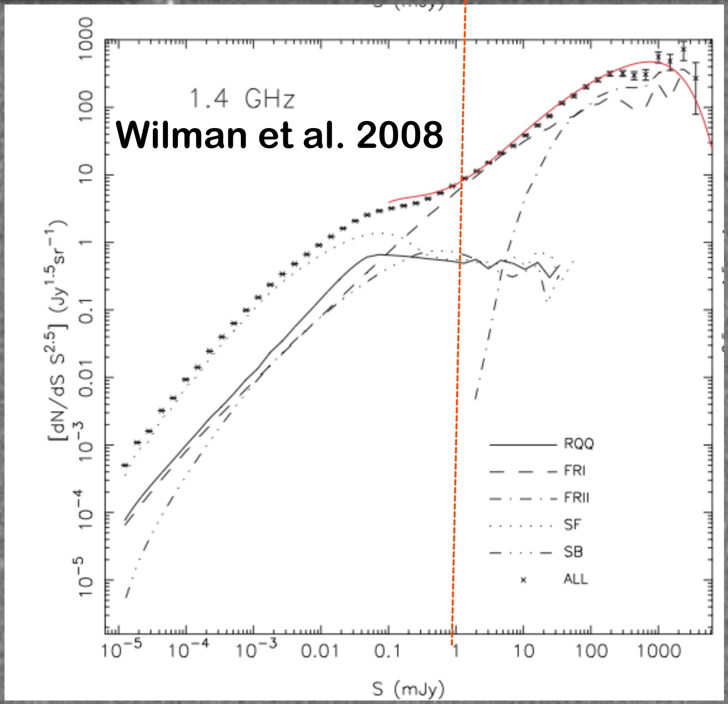
Hans-Rainer Klöckner
Max-Planck-Institut
für Radioastronomie
ERATec, Bologna 2013

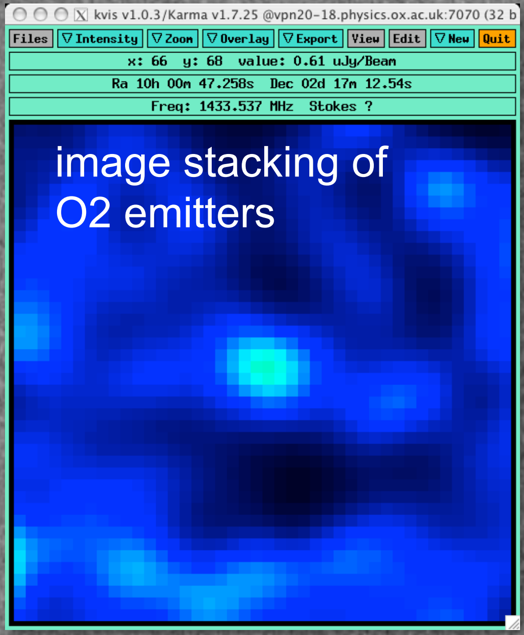

radio interferometry and pipelining
... a painful journey

what do you expect from the observations





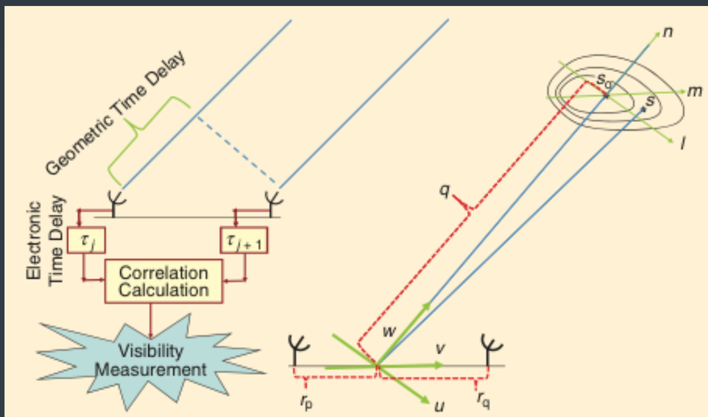


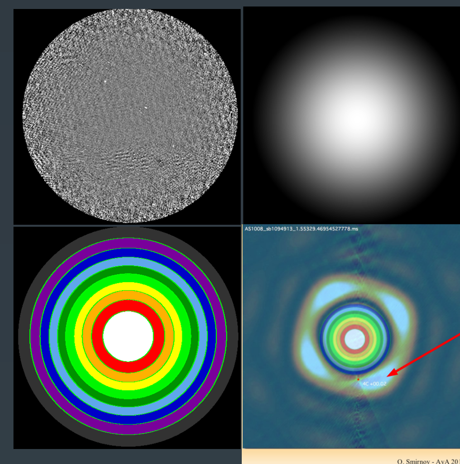


... a painful journey

interferometry – short cuts and we will suffer

Levenda & Leshem IEEE 2014





$$A = \sqrt{\mathrm{im}^2 + \mathrm{re}^2}$$

$$\phi = arctan2(\frac{\mathrm{im}}{\mathrm{re}})$$

$$V_\nu(u,v,w) = \int\int \frac{A_\nu(l,m)\cdot I_\nu^D(l,m)}{\sqrt{1-l^2-m^2}} e^{-2\pi i[ul+vm+w\sqrt{1-l^2-m^2}]} dl dm$$

$$I_\nu^D(l,m) = FT(\Pi(u,v)) \bigotimes I_\nu(l,m)$$

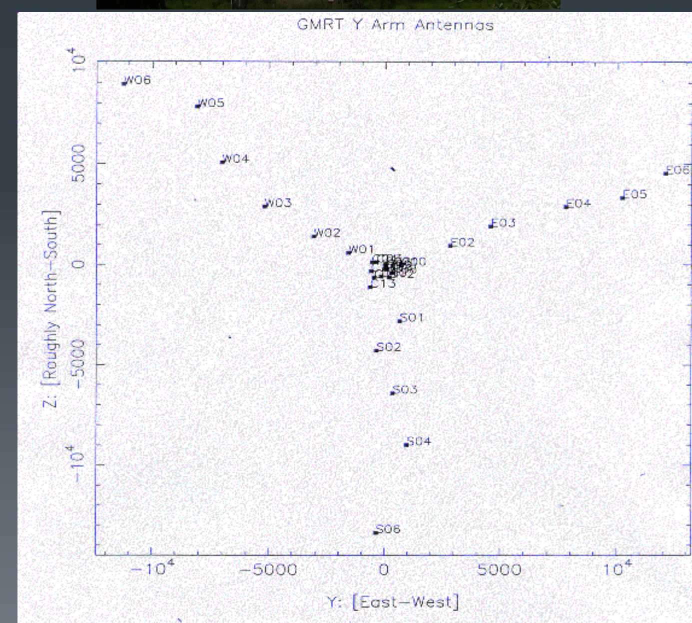
$$\widetilde{V}_{ij}(t) = g_i(t) g_j^*(t) G_{ij}(t) V_{ij}(t) + \varepsilon_{ij}(t) + \epsilon_{ij}(t)$$

$$\widetilde{V}_{ij}(t) = g_i(t) g_j^*(t) V_{ij}(t) + \epsilon_{ij}(t)$$

GMRT

Giant Metrewave Radio Telescope (GMRT)
Khodad located near (2-3 hrs by car) Pune in India

- Located 19°5'47.46"N 74°2'59.07"E
- 30 x 45 m antennas (alt-z) in a Y-shape = 4.7% SKA
- baselines ~25.5 km, 435 baselines (VLA 351)
- 100 MHz - 1500 MHz (sweet spot ~ 600 MHz)



How to get GMRT data

... of course you could also take a taxi, which is less fun.

pipelining

modern datasets are to big to do this by hand

reproducible results

GMRT - pipeline

AIPS [Greisen]

ParselTongue [Kettenis]

bootstrap AIPS limitations

AIPSLite [Brouke]

enables AIPS to run on a cluster

hardware setup

Intel X5660 2.8 GHz CPUs

36 GB RAM

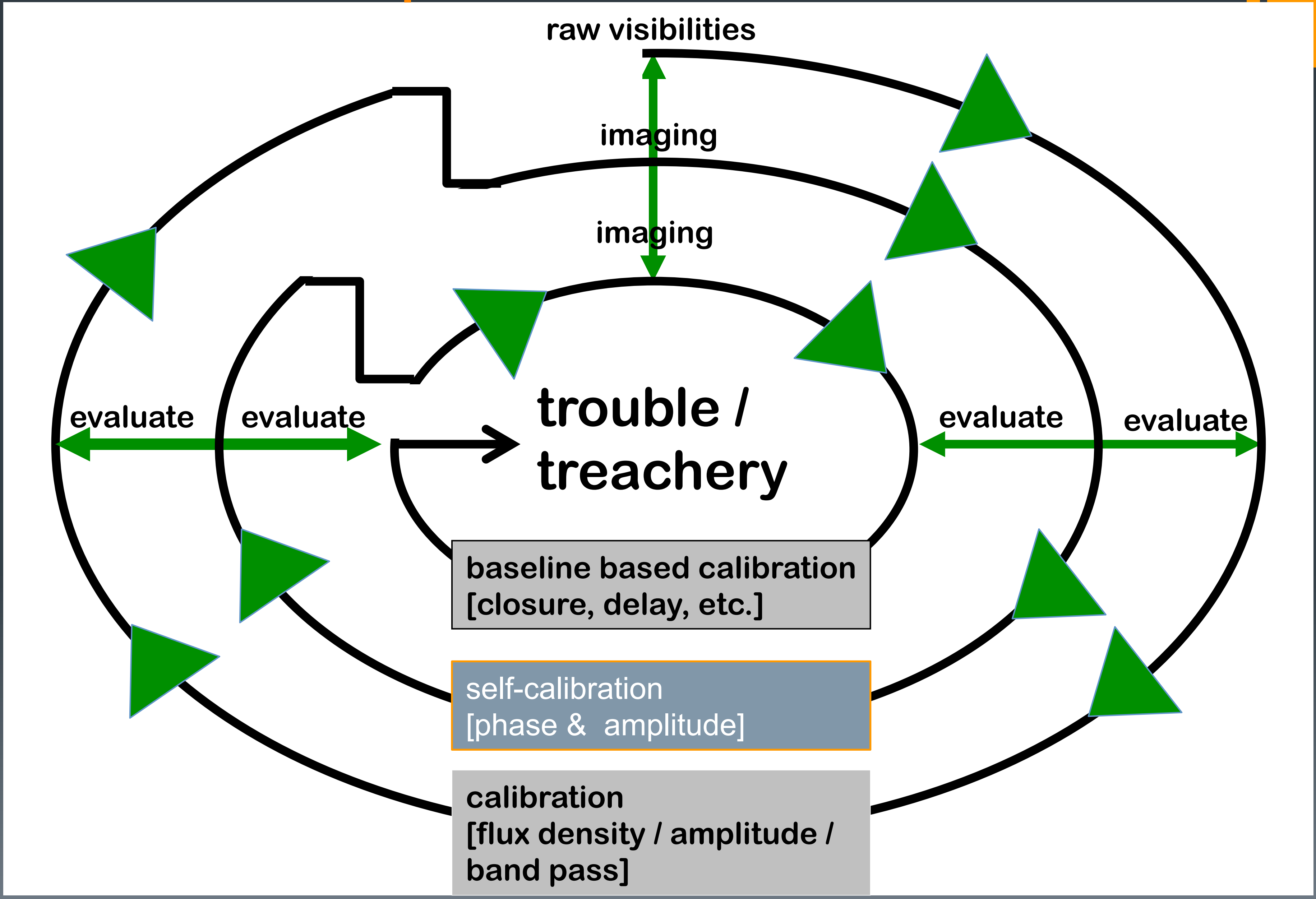
500GB locally scratch drive.

A typical run can use a maximum of about 1GB of RAM

scripts are based on individual tasks

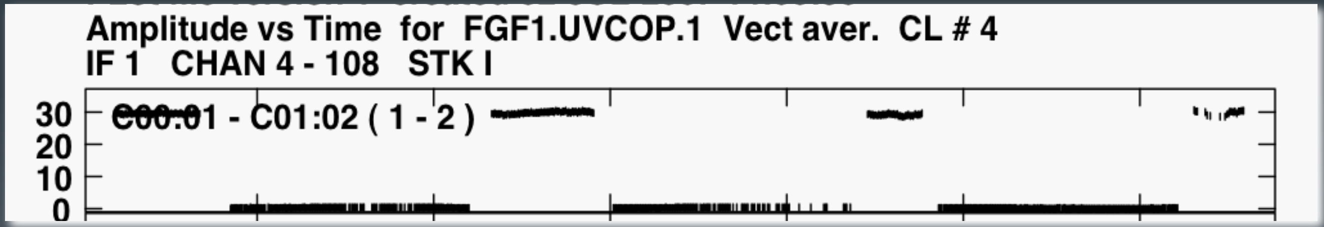
```
subgmrt "5 min" $PWD 00_GMRT_GETINFO_REPORT
```

Dante's steps of calibration

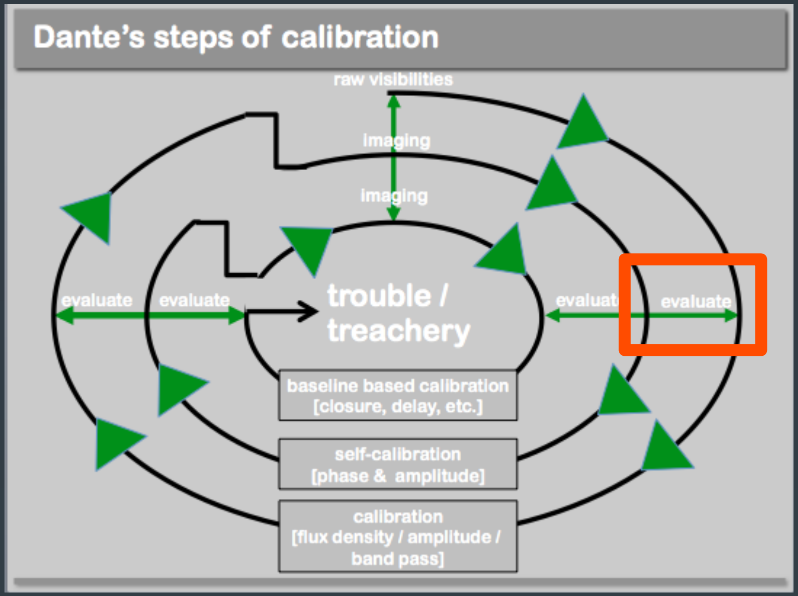


GET YOUR OBSERVATION RIGHT!

PCAL –Target – PCAL .... PCAL –Target – PCAL



PCAL needed to evaluate system performance
for other facilities meta data is needed if available

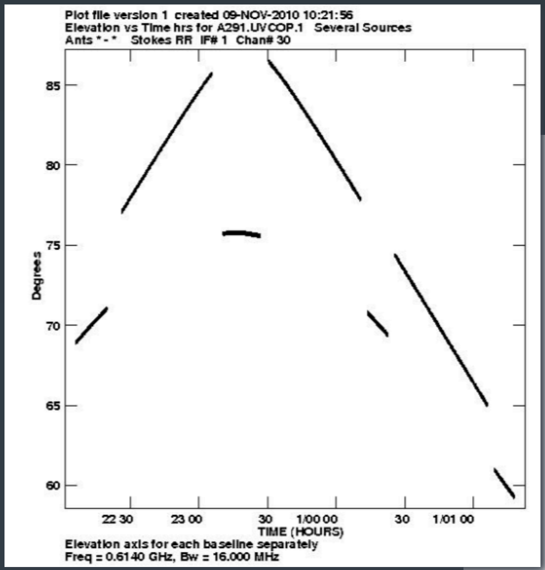


BEFORE YOU START PIPELINING

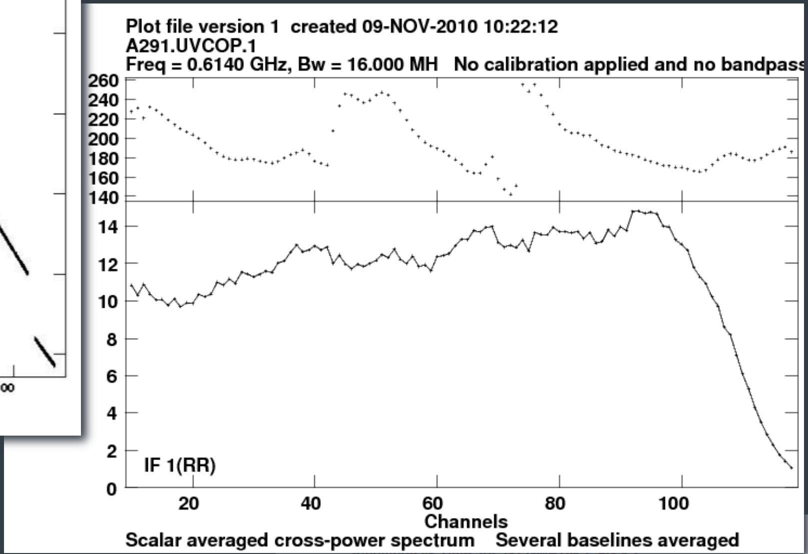
this is really not what you want !

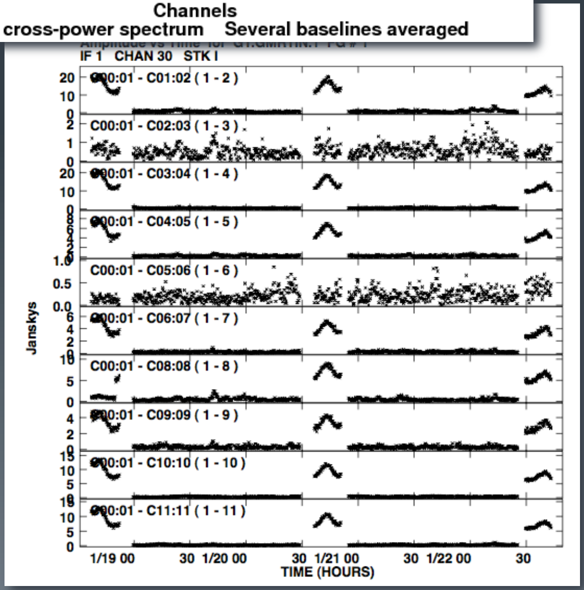
Evaluating – the classical way

Check for global & antenna problems
ONLY human interaction



careful at zenit





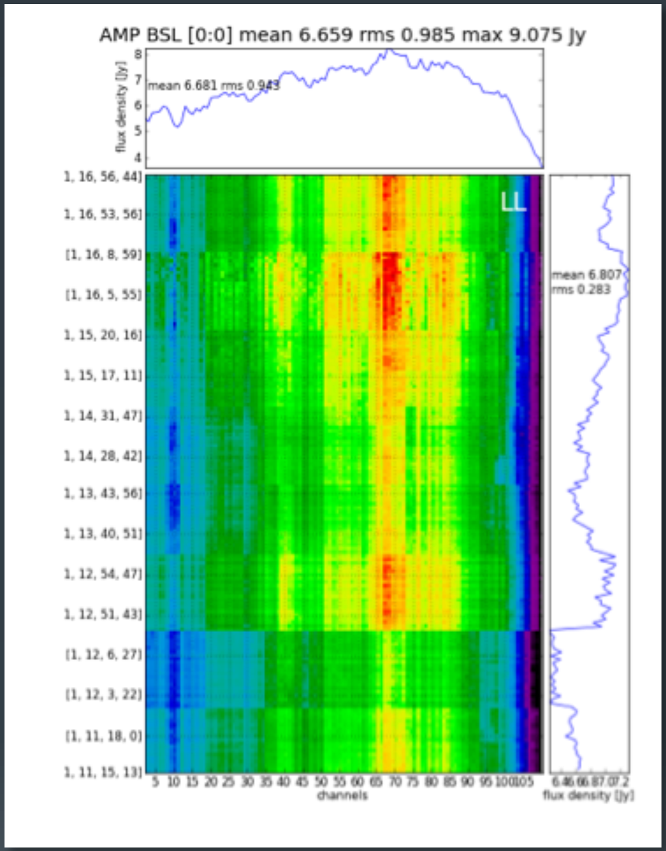
ascii output

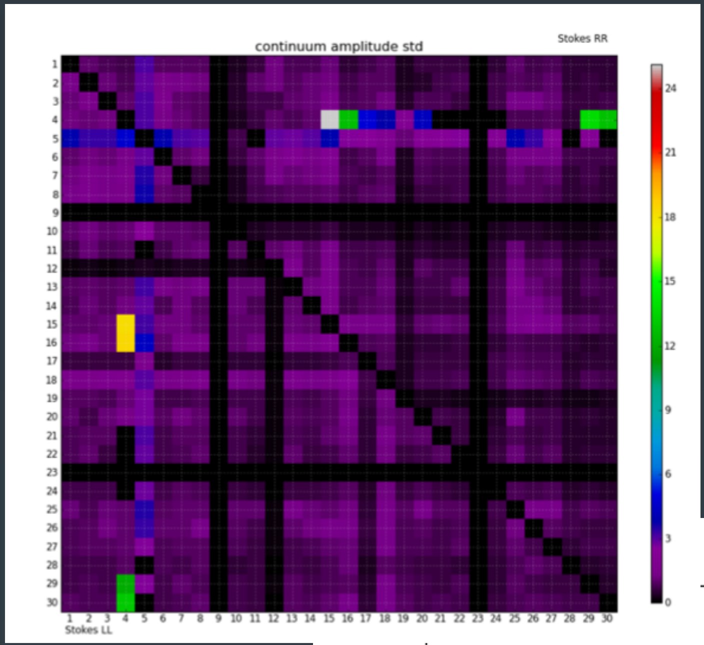
General information

of the observation

(e.g. freq, sources …)

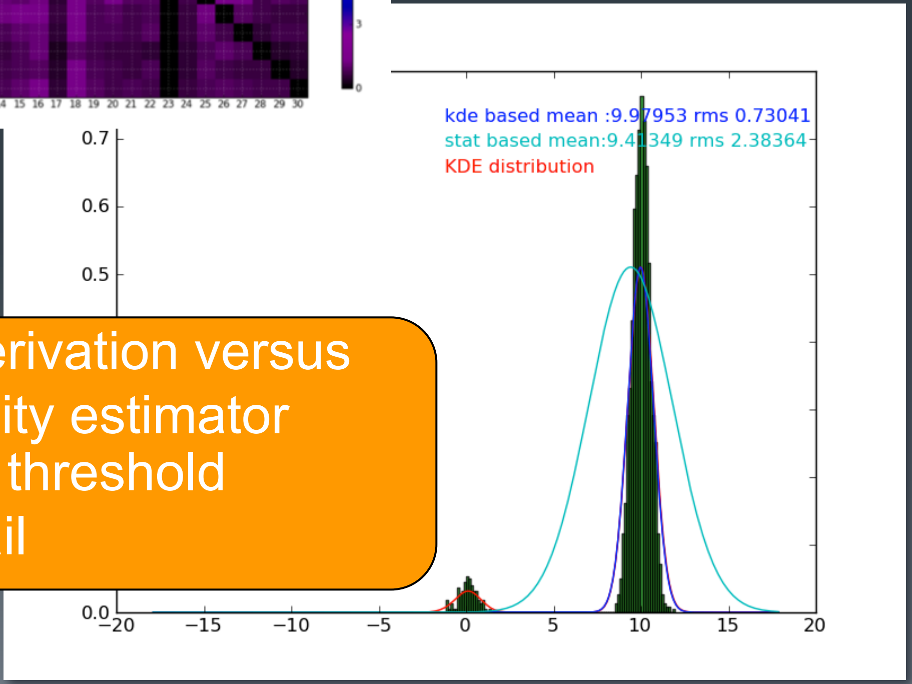
evaluating data ++





baseline based

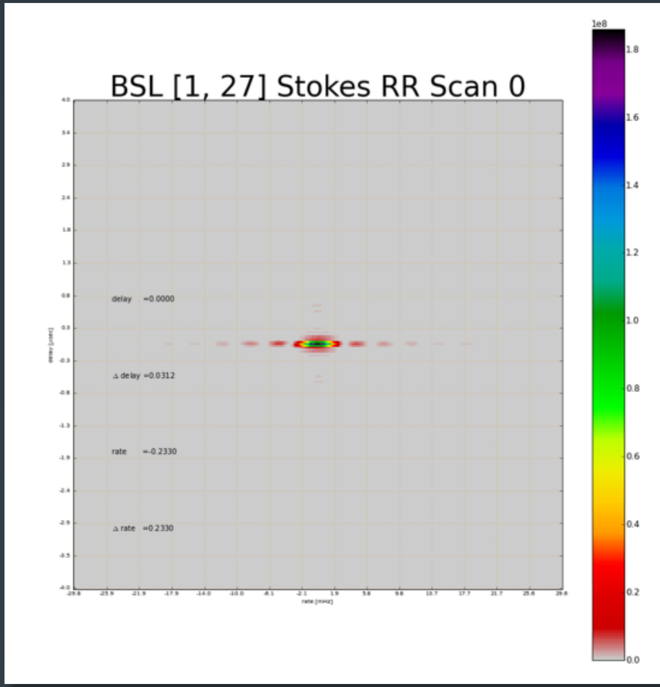
max, min, median, mean, std, nvis

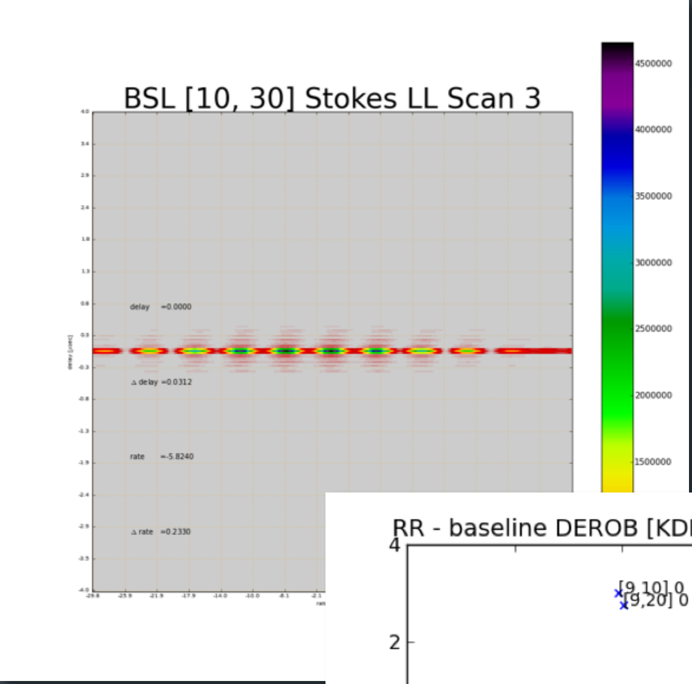


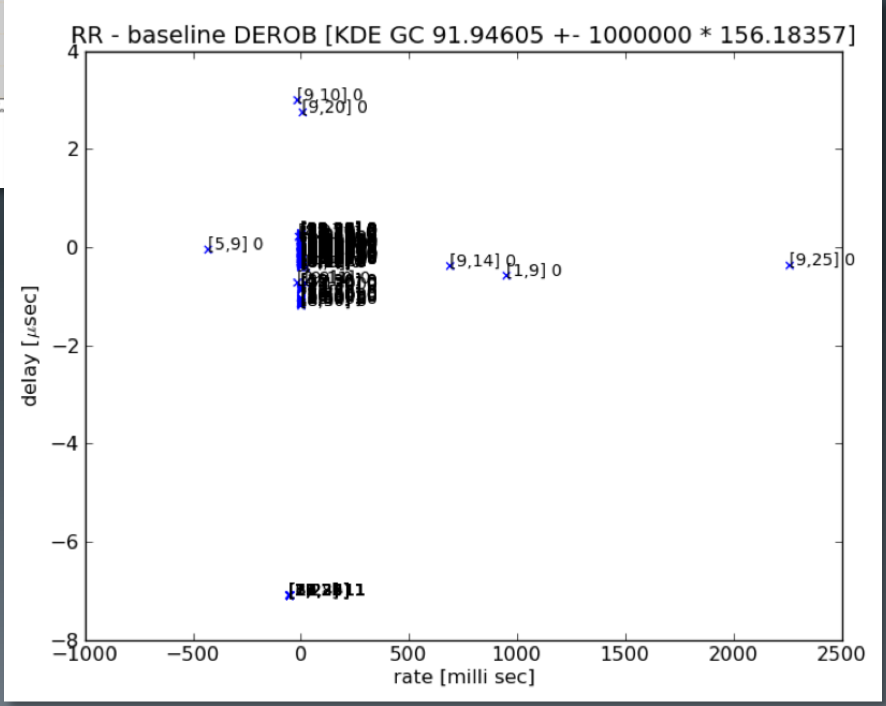
Standard derivation versus Kernel density estimator data quality threshold at 5 σ will fail

evaluating data ++

power spectrum check



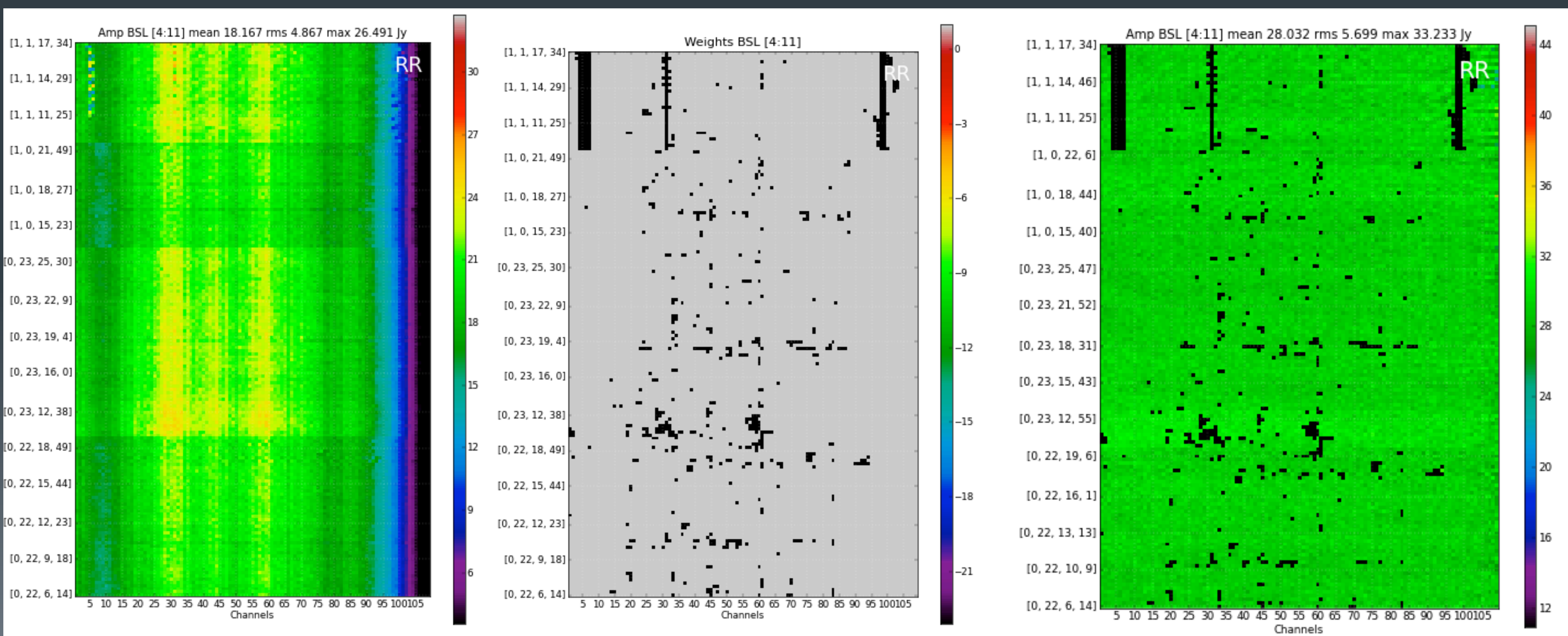


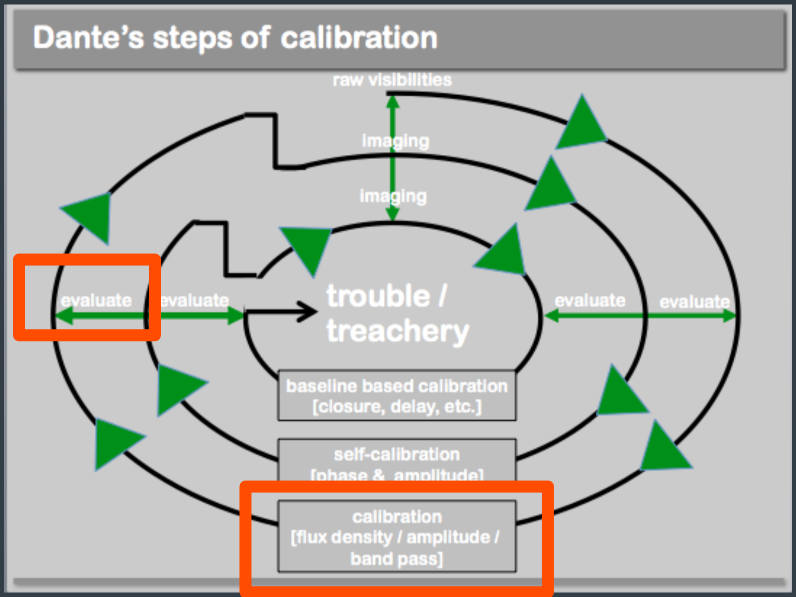


evaluating data ++

spectrum flagging

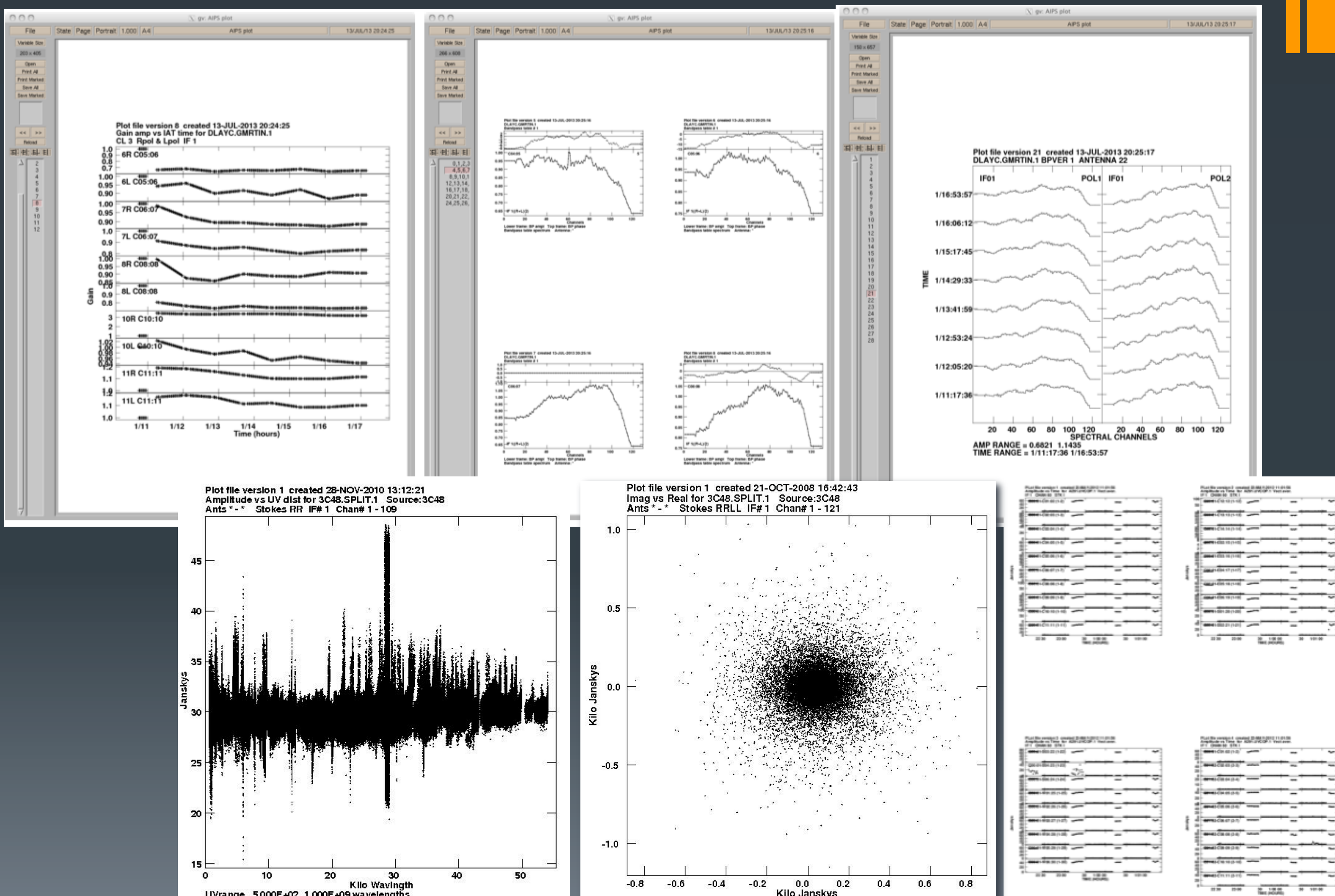
spectral filter
convolve image with
various kernels (e.g. Gauss)



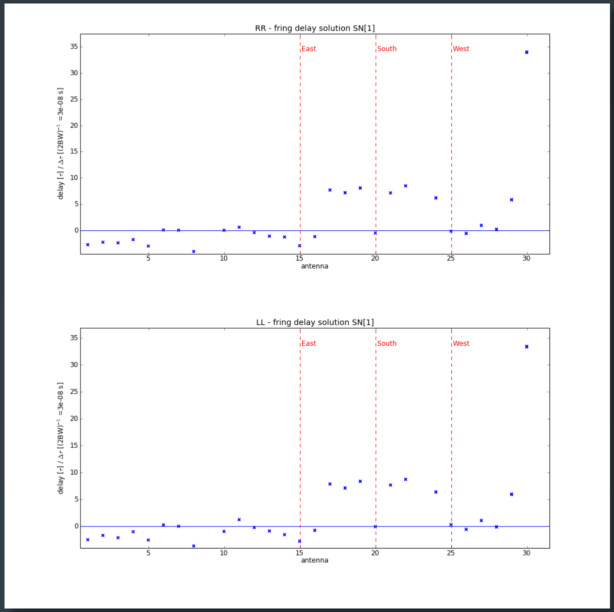


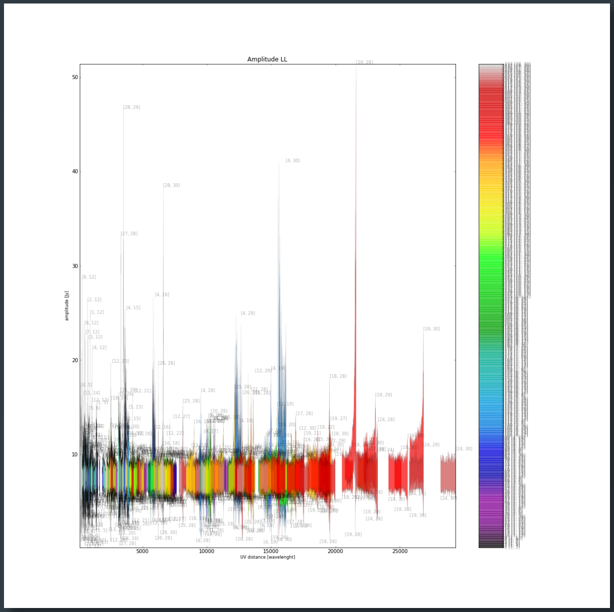
calibration [flux density / amplitude band pass]

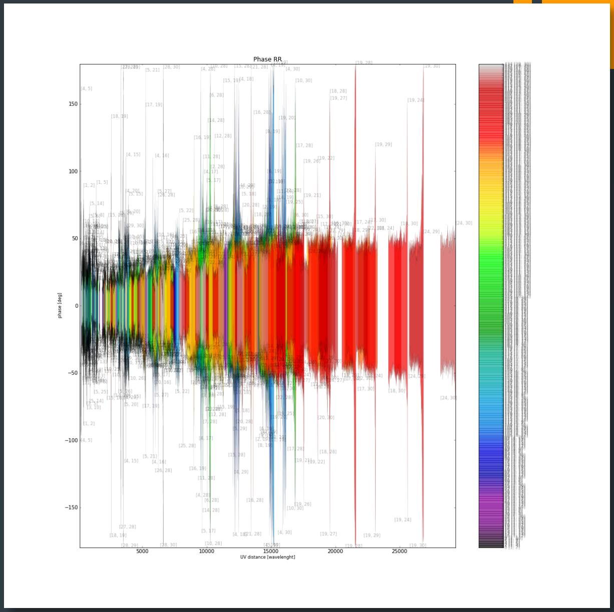
Evaluating – the classical way

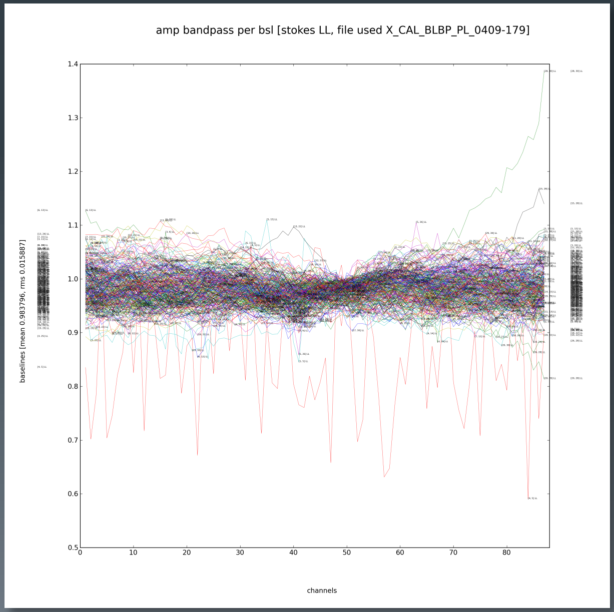


evaluating data ++





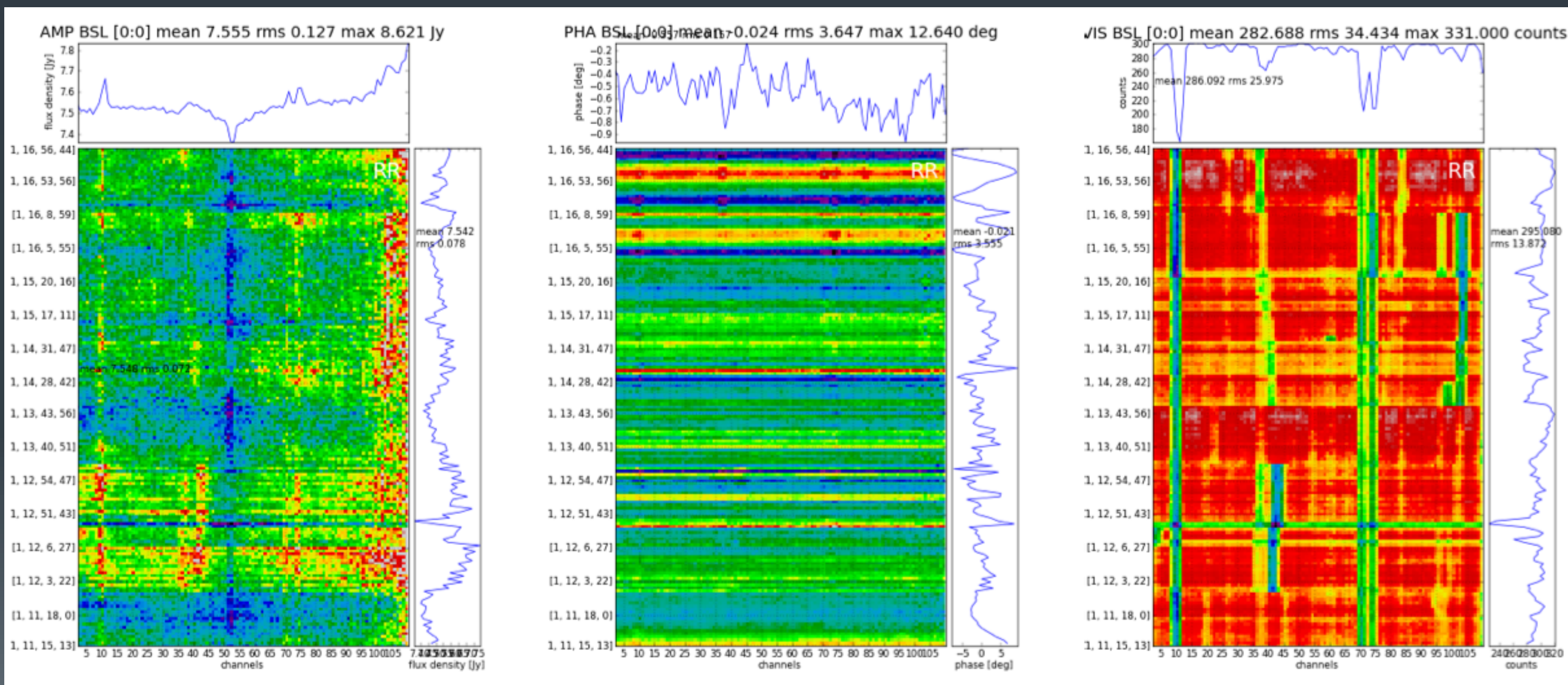


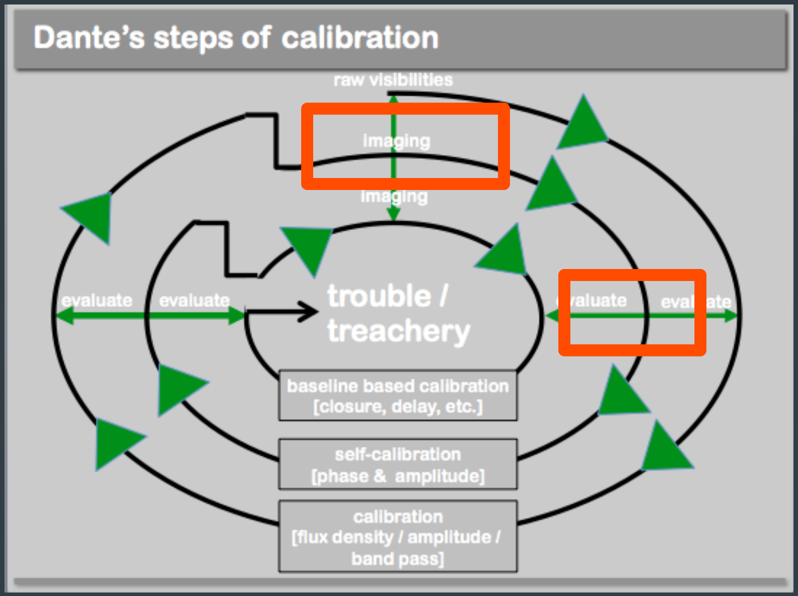


evaluating data ++

integrated spectra entire dataset

amplitude phase number of vis

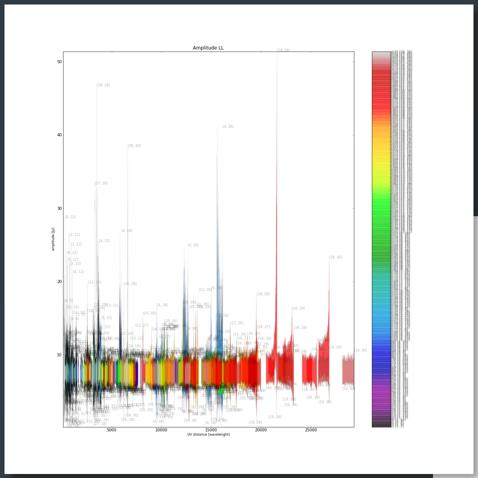


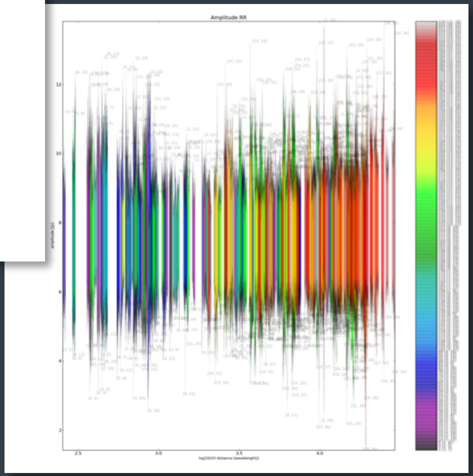


imaging
evaluating

dirty image no cleaning used

image large field of view





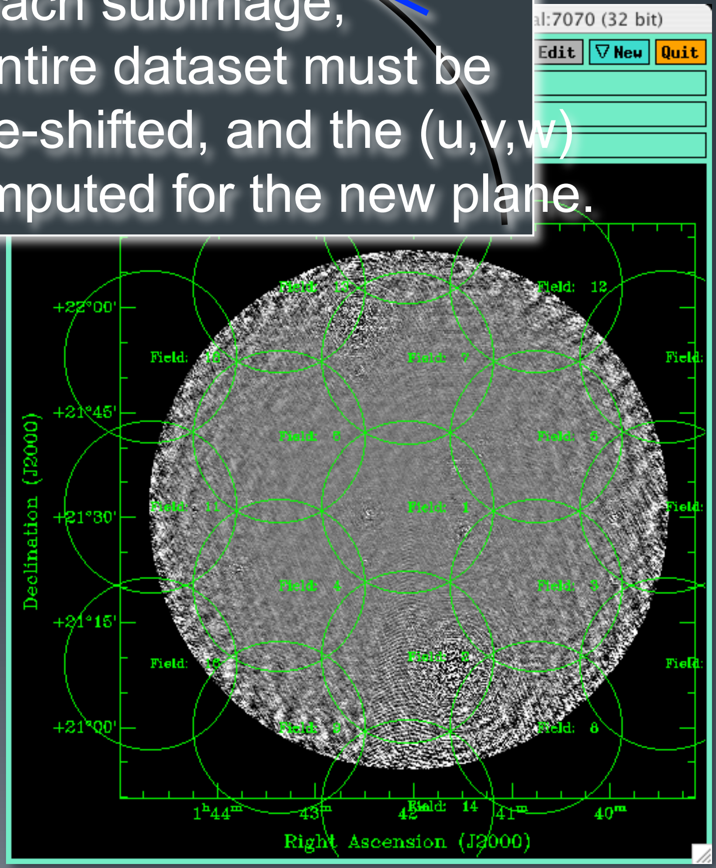
multi-facet

610 MHz 19 sub images

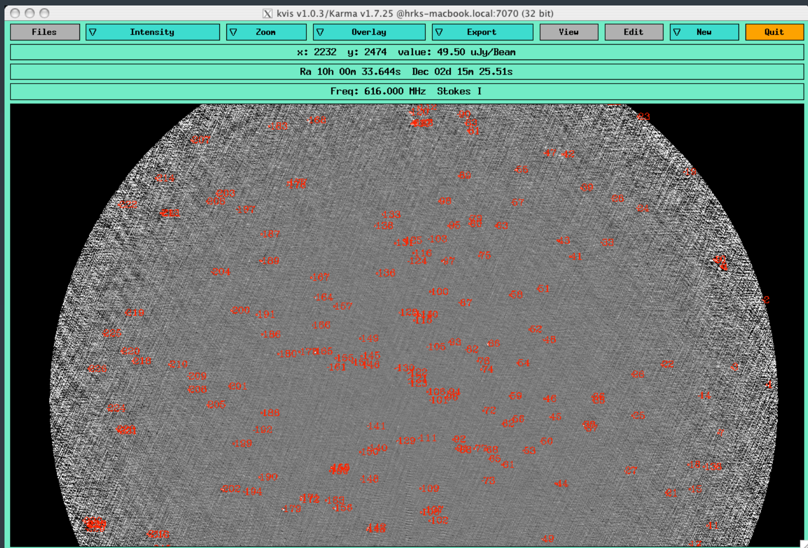
244 MHz ~200 sub-images

facet

For each subimage, the entire dataset must be phase-shifted, and the (u,v,w) recomputed for the new plane.

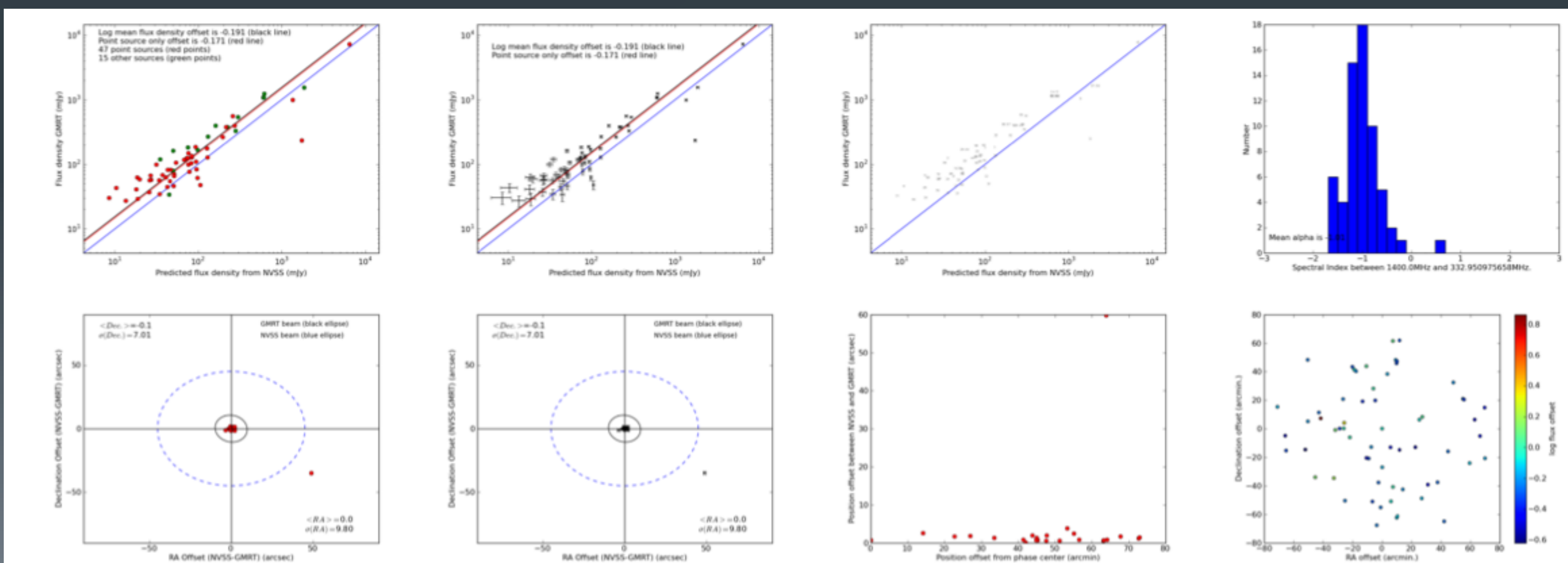


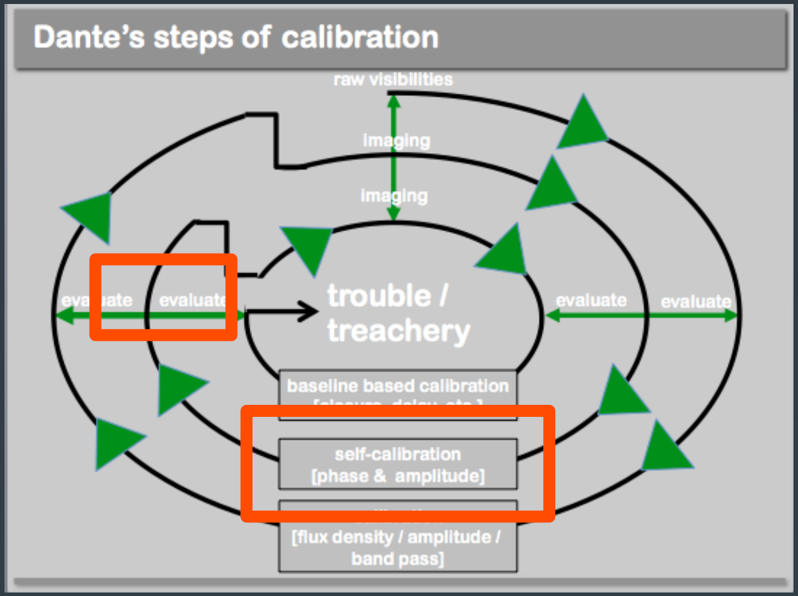
dirty image & cataloging & pseudo LSM



ASCII
VO table

NVSS, FIRST,
WENSS, SUMSS



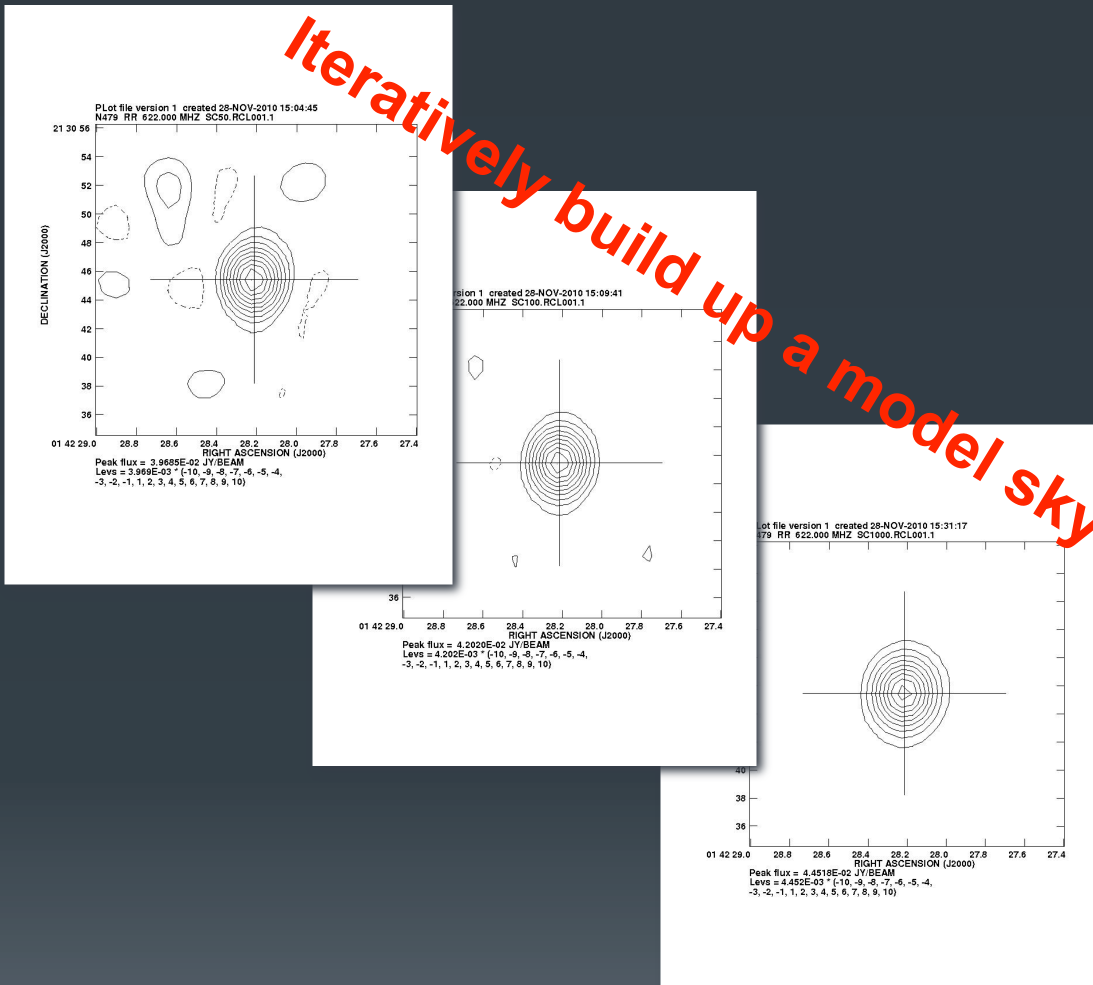


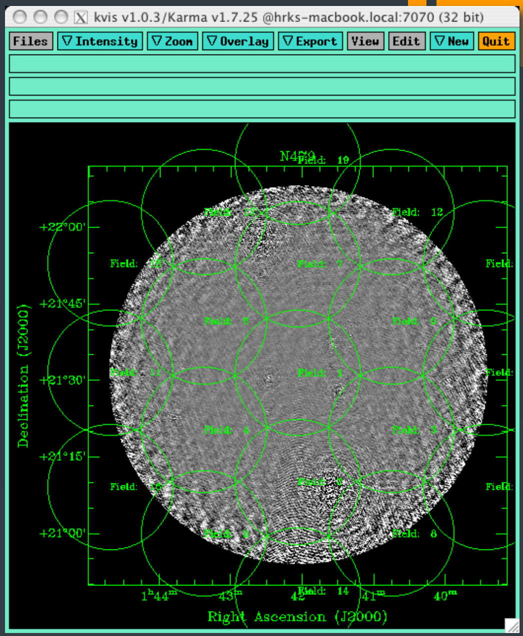
self-calibration [phase & amplitude]

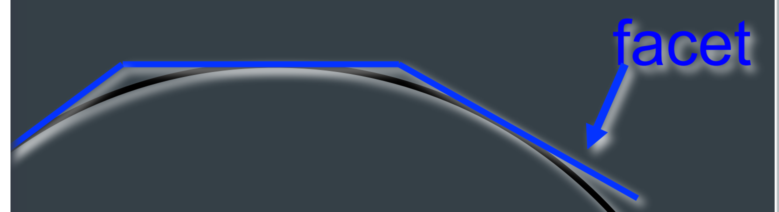
building up the LSM /
... beating the chicken and the egg problem

multifacet self-calibration

Iteratively build up a model sky







each subimage, the entire dataset must be phase-shifted, and the (u,v,w) recomputed for the new plane.

SELFCAL STEP

- increase # of cc components (niter)
- decrease averaging time (solint)

some output

Selfcal performance

dynamic range	selfcal type	selfcal niter(#CC)	solint (min)
289	P	50	60
371	P	100	30
481	P	500	15
713	P	1000	7
942	P	2000	3
1702	P	14274	1
1739	A&P	15861	10
1237	A&P	20392	3
1913	A&P	28549	1

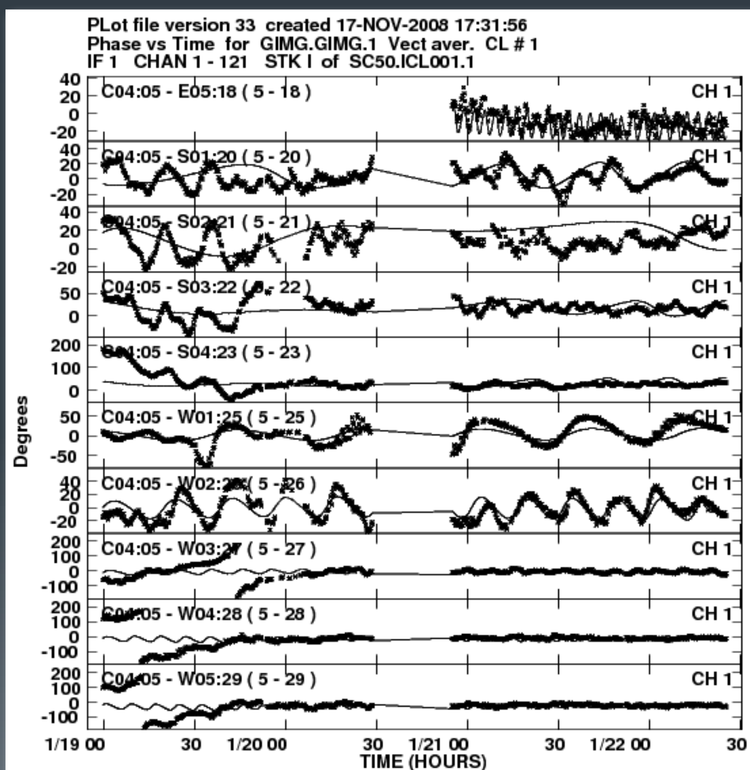
```
CALIB1: FACSET: 1.004184 Jy found from 5 components
CALIB1: FACSET: 1.255884 Jy found from 5 components
CALIB1: FACSET: 1.573940 Jy found from 8 components
CALIB1: FACSET: 2.160819 Jy found from 34 components
CALIB1: FACSET: 2.389948 Jy found from 40 components
CALIB1: FACSET: 2.869350 Jy found from 114 components
CALIB1: FACSET: 2.946990 Jy found from 129 components
CALIB1: FACSET: 2.803550 Jy found from 104 components
CALIB1: FACSET: 3.032050 Jy found from 147 components
```

LSM performance

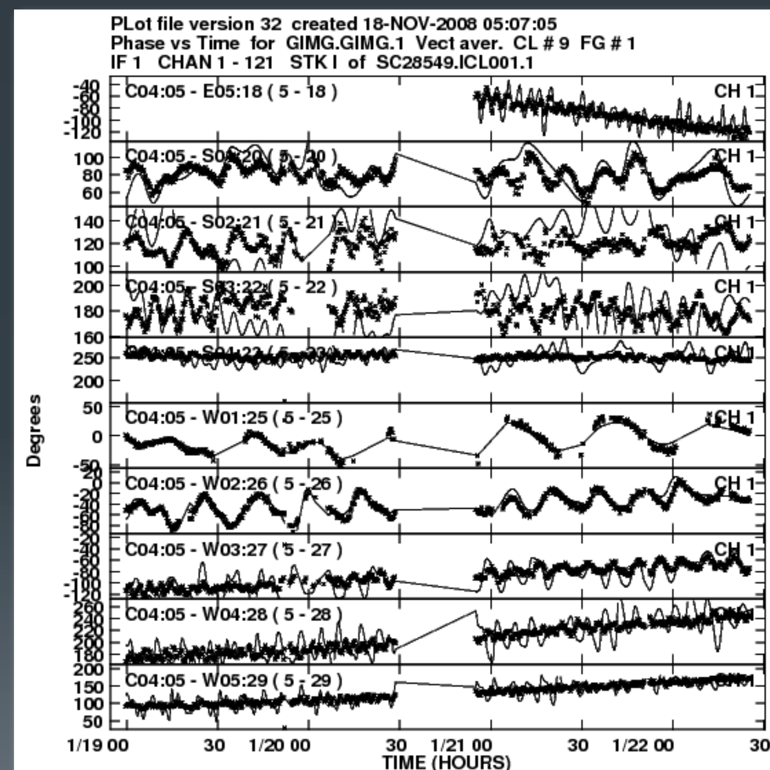
How good is the sky model

Image - select good cc components - phase calibration

1st scal step



final scal step

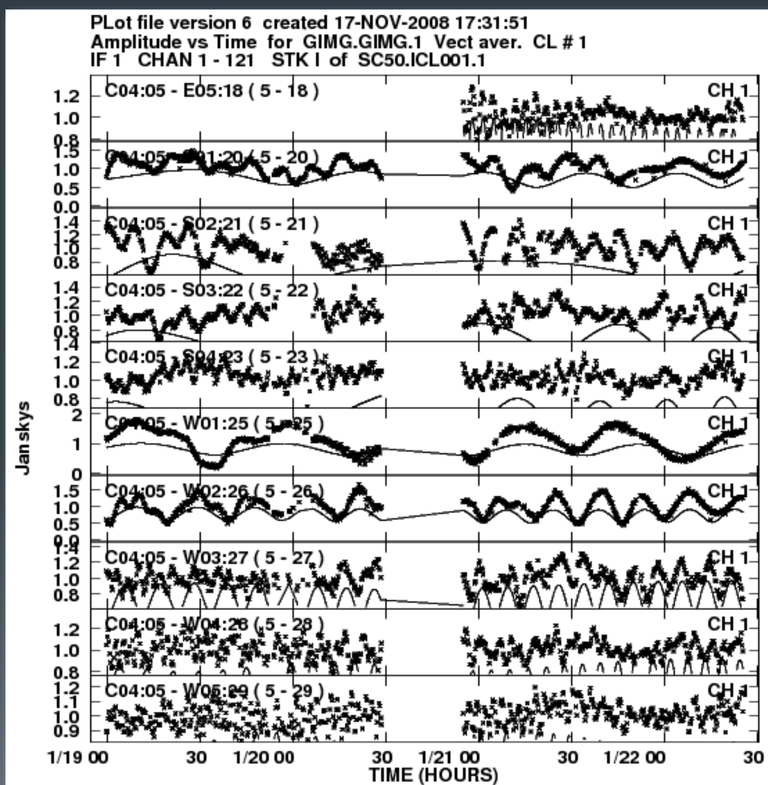


LSM performance

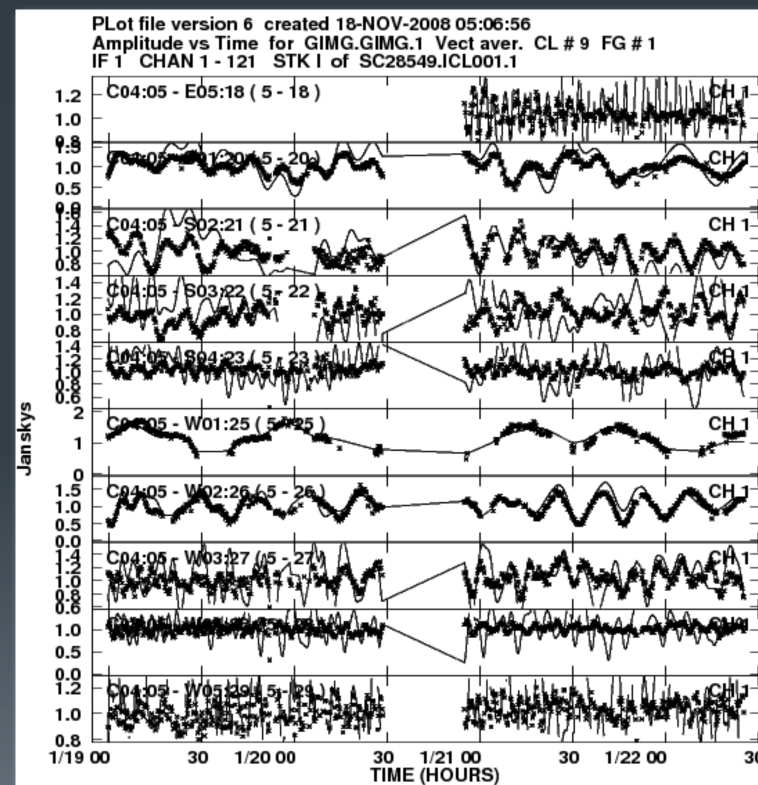
How good is the sky model

Image - select good cc components - amplitude calibration

1st scal step



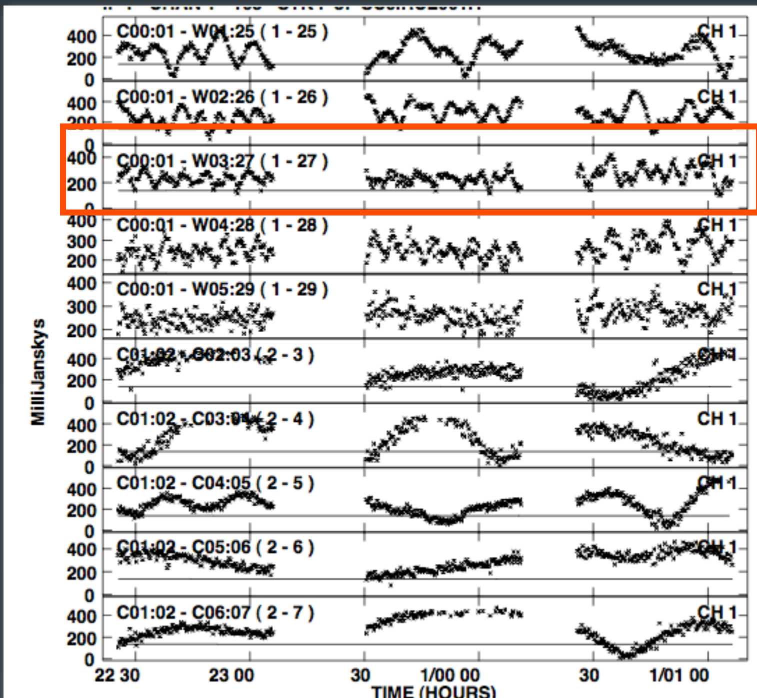
final scal step



A 10° phase error is as bad as a 20% amplitude error.

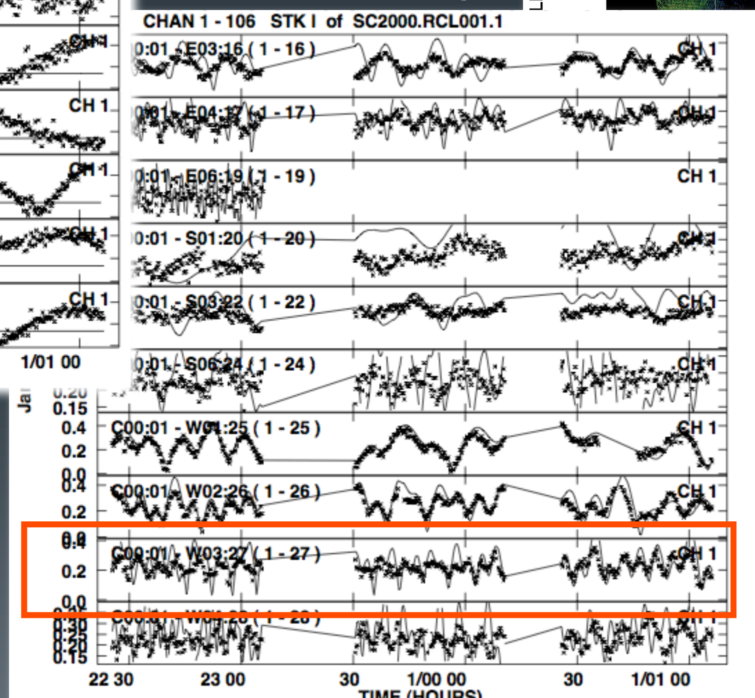
LSM performance

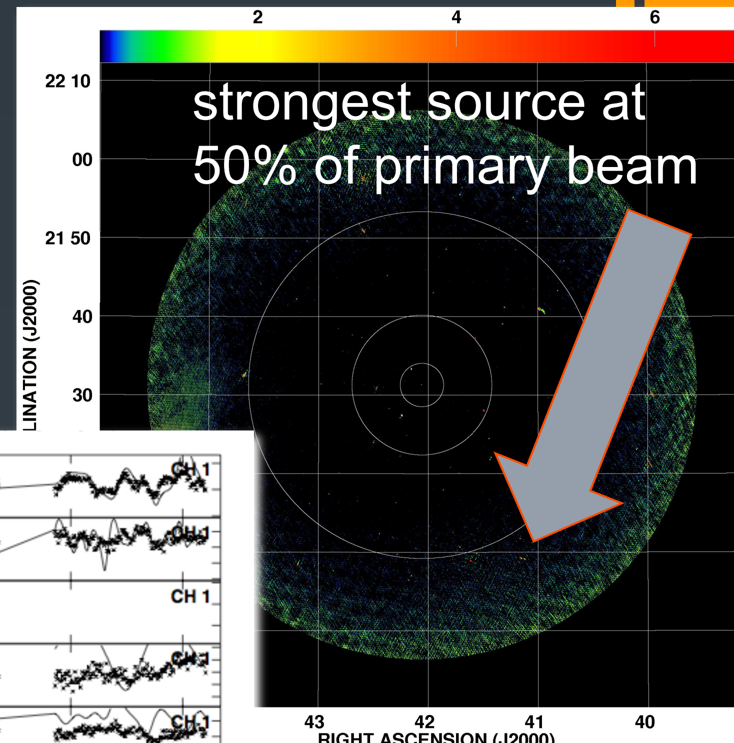
final scal step



long baselines
can not be calibrated

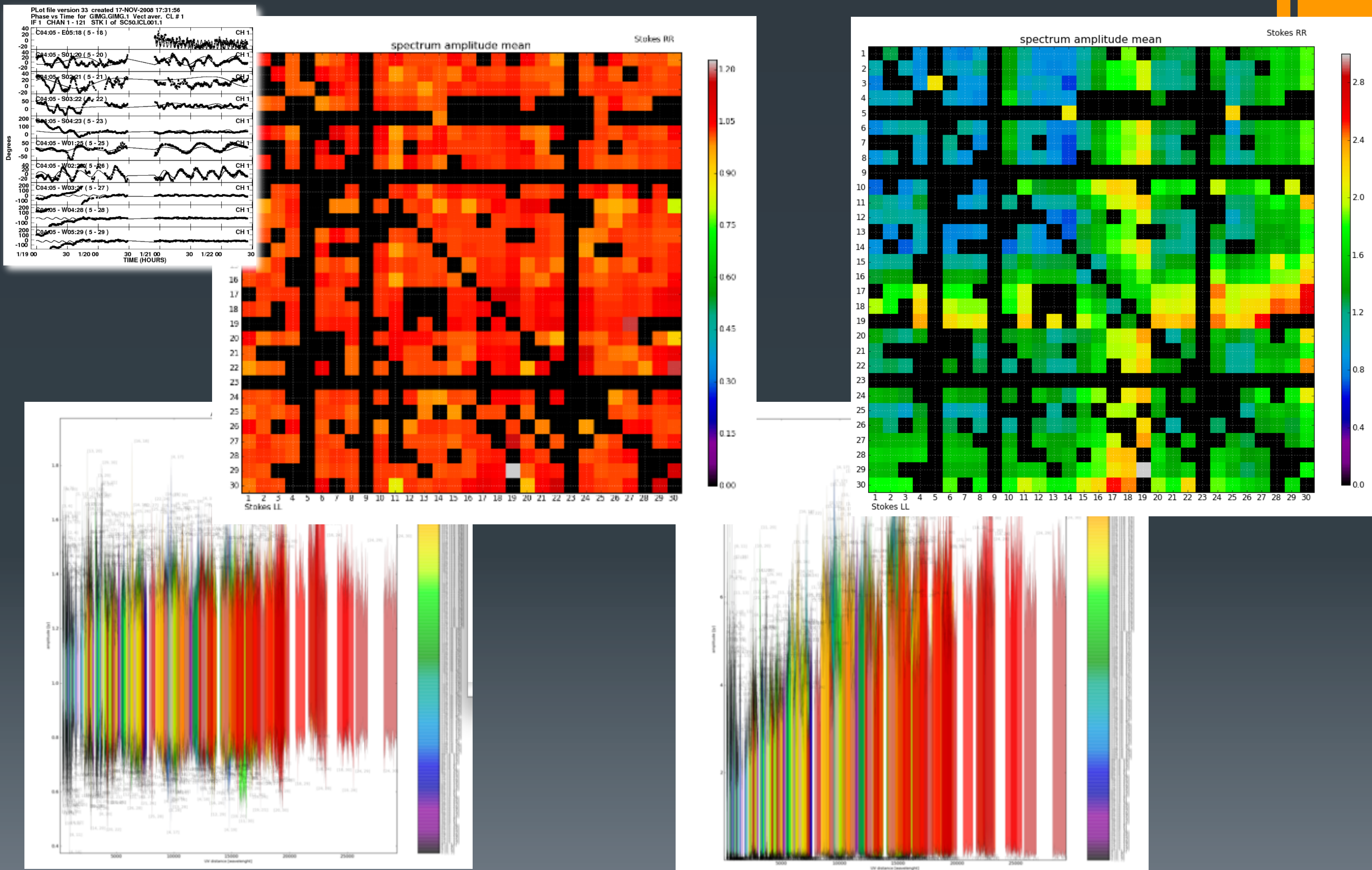
final scal step



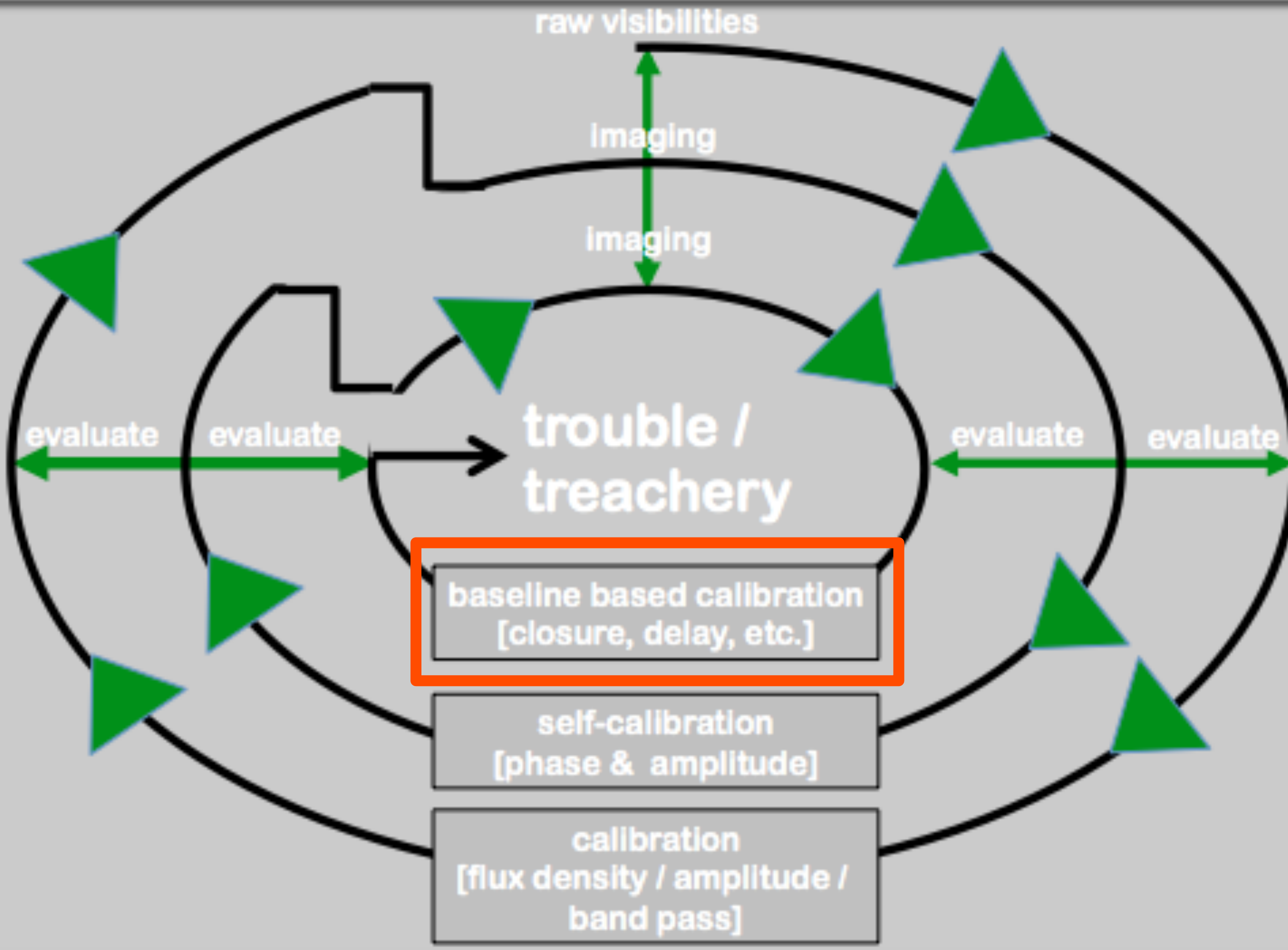


shift the phase centre

LSM performance – visibilities div / sub model



Dante’s steps of calibration



further steps into Dante's hell

or we are lucky and end up in heaven

calibration up to now based on antenna solutions

LSM based calibration

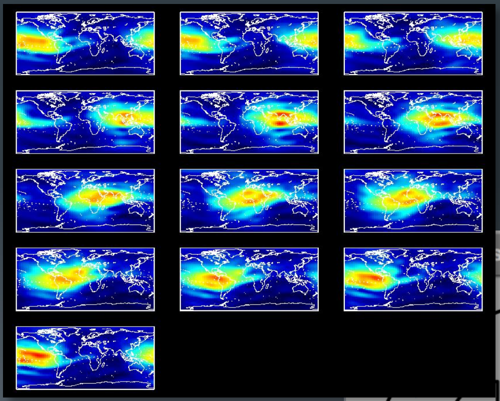
- closure relation
- baseline based fringe fit

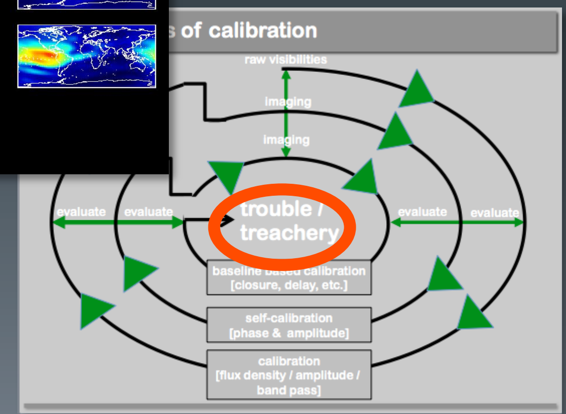
NO physical model needed

LSM based calibration

- TEC measurements,
- primary beam models
- directional dependent calibration Meq

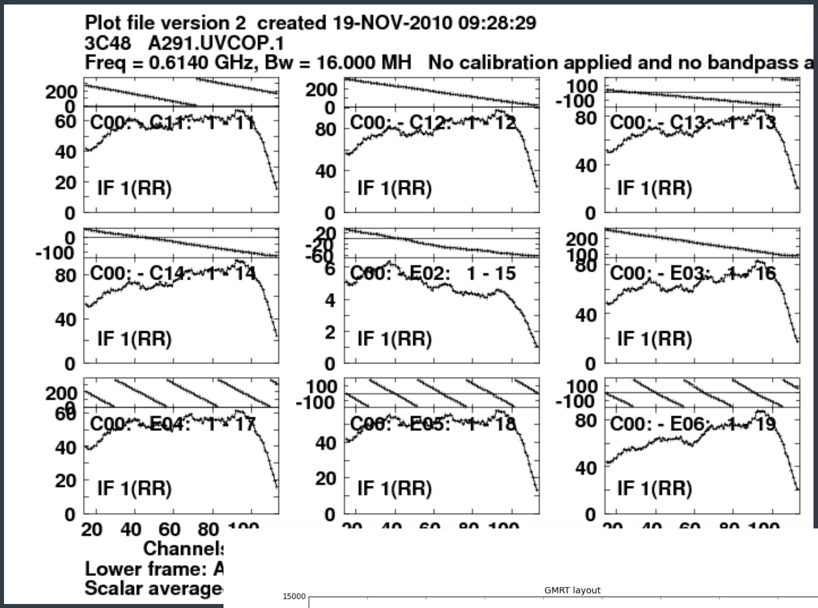
physical [either sky or array] model needed !!!

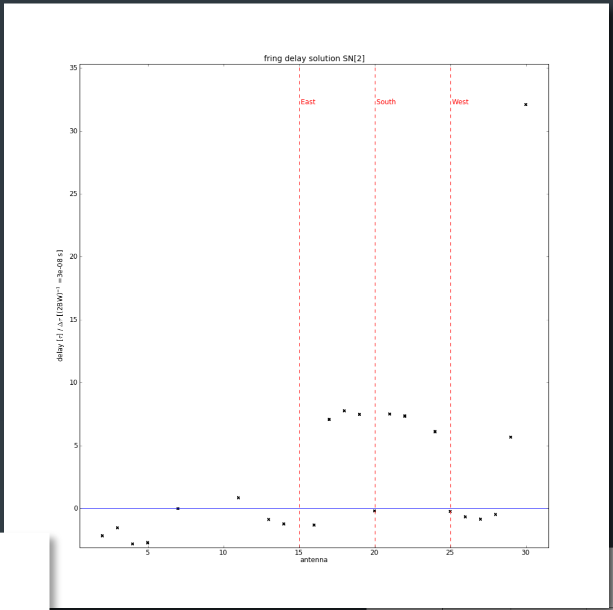


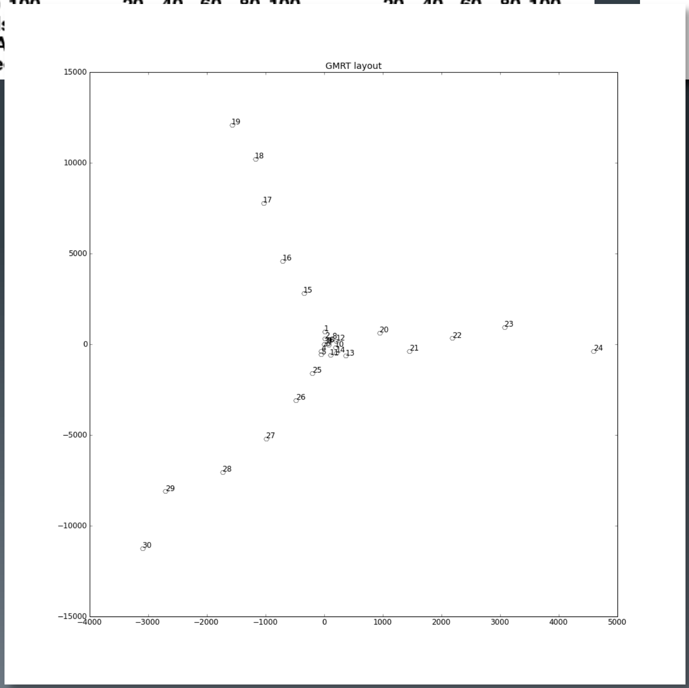


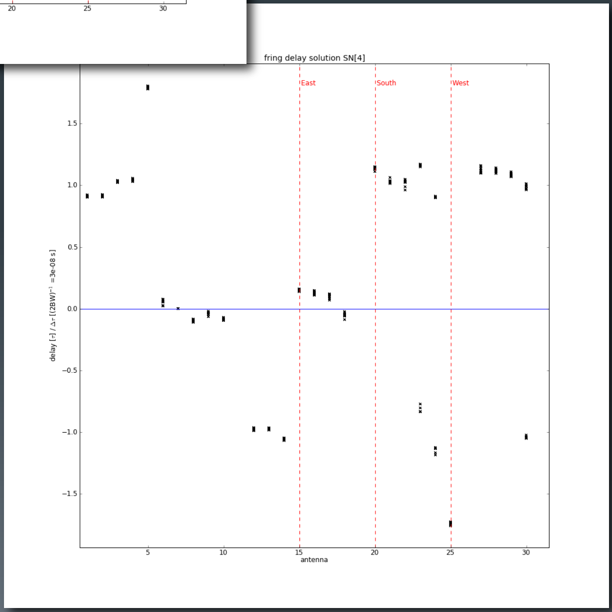
issues

GMRT - issues

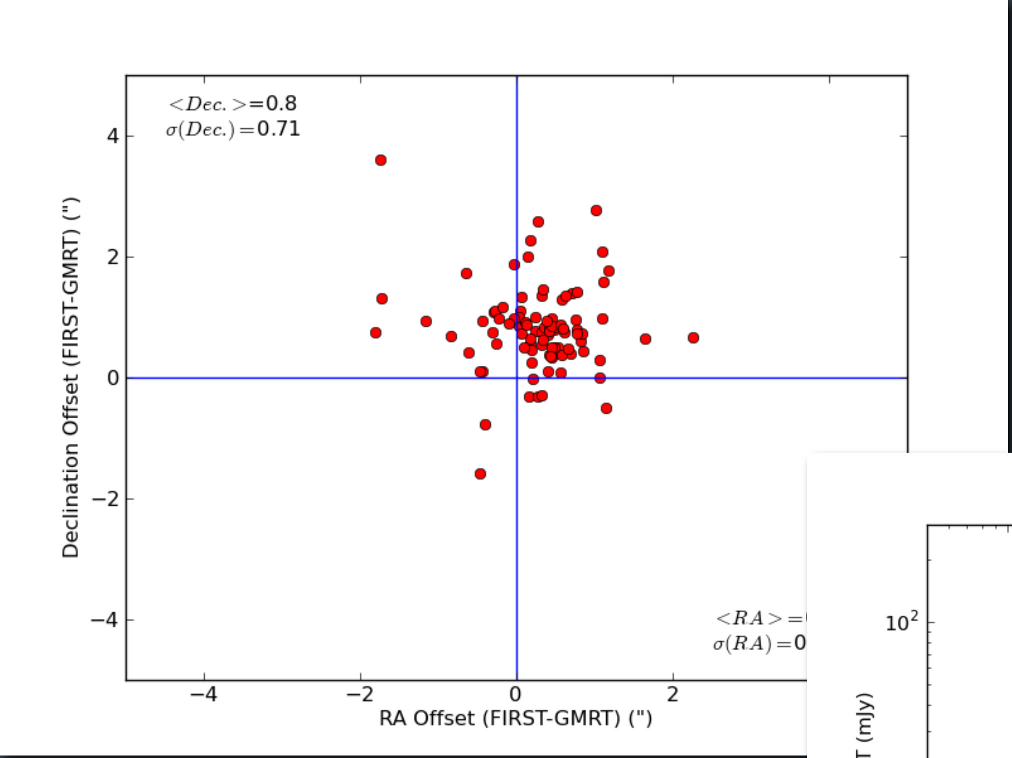

Plot file version 2 created 19-NOV-2010 09:28:29
3C48 A291.UVCOP.1
Freq = 0.6140 GHz, Bw = 16.000 MH No calibration applied and no bandpass a
C00: - C11: 1 - 11
C00: - C12: 1 - 12
C00: - C13: 1 - 13
C00: - C14: 1 - 14
C00: - E02: 1 - 15
C00: - E03: 1 - 16
C00: - E04: 1 - 17
C00: - E05: 1 - 18
C00: - E06: 1 - 19
IF 1(RR)
Channel
Lower frame: A
Scalar average


fring delay solution SN[2]
East
South
West
antenna


GMRT layout

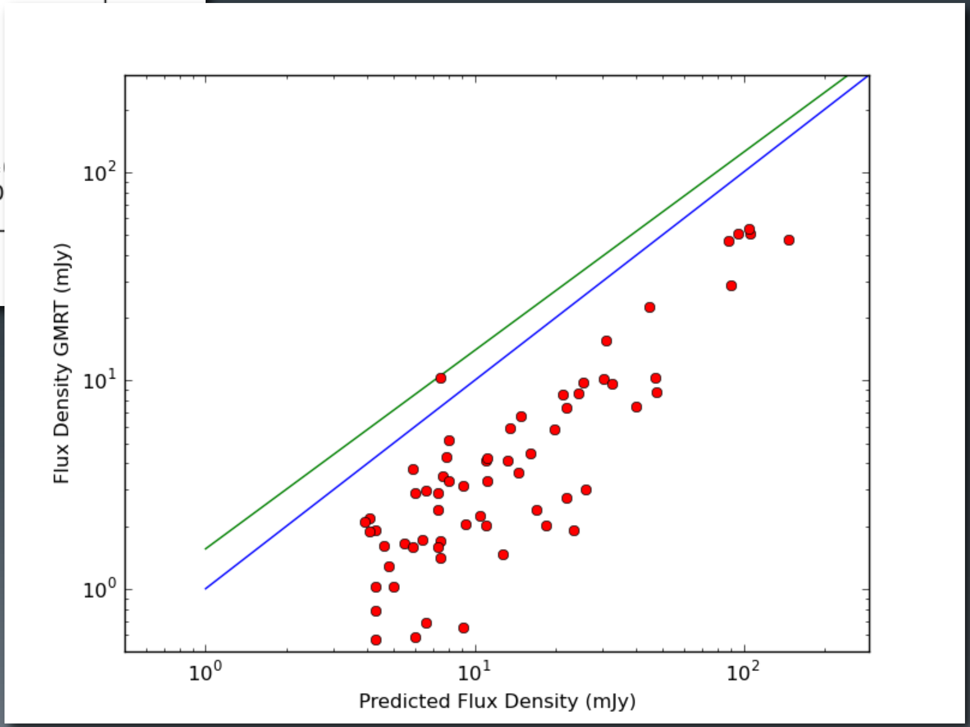

fring delay solution SN[4]
East
South
West
antenna

GMRT - issues

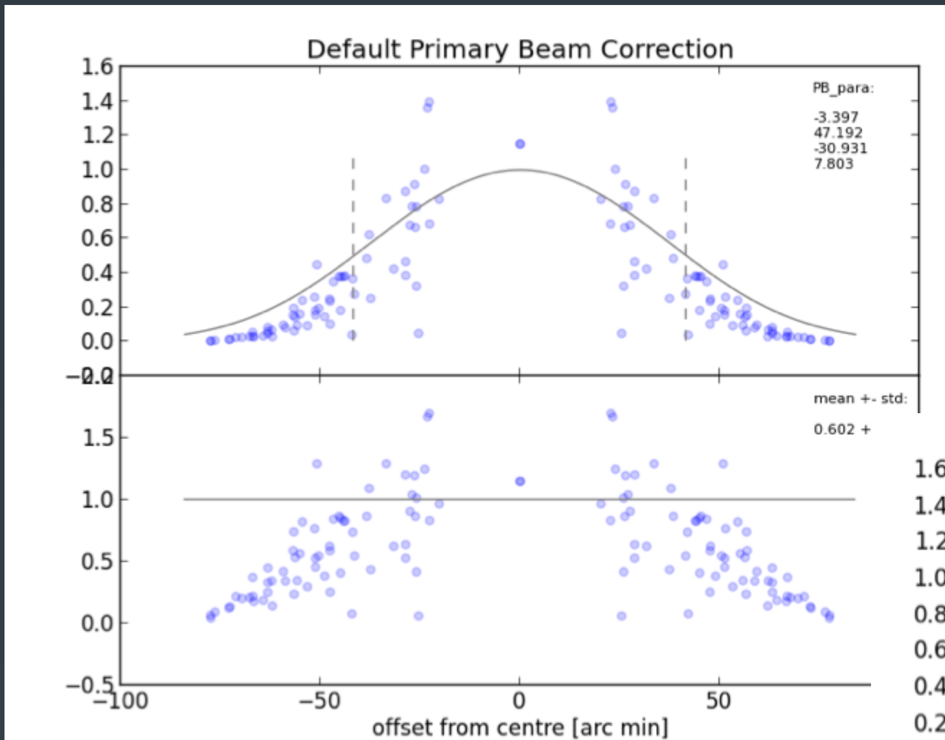


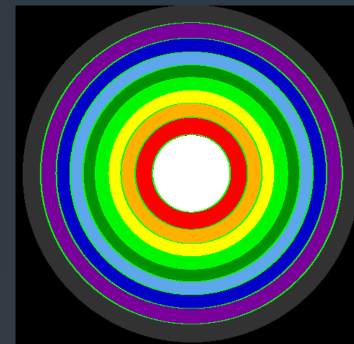
self-calibration

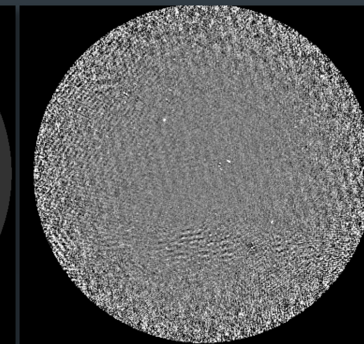
cleaning / bias

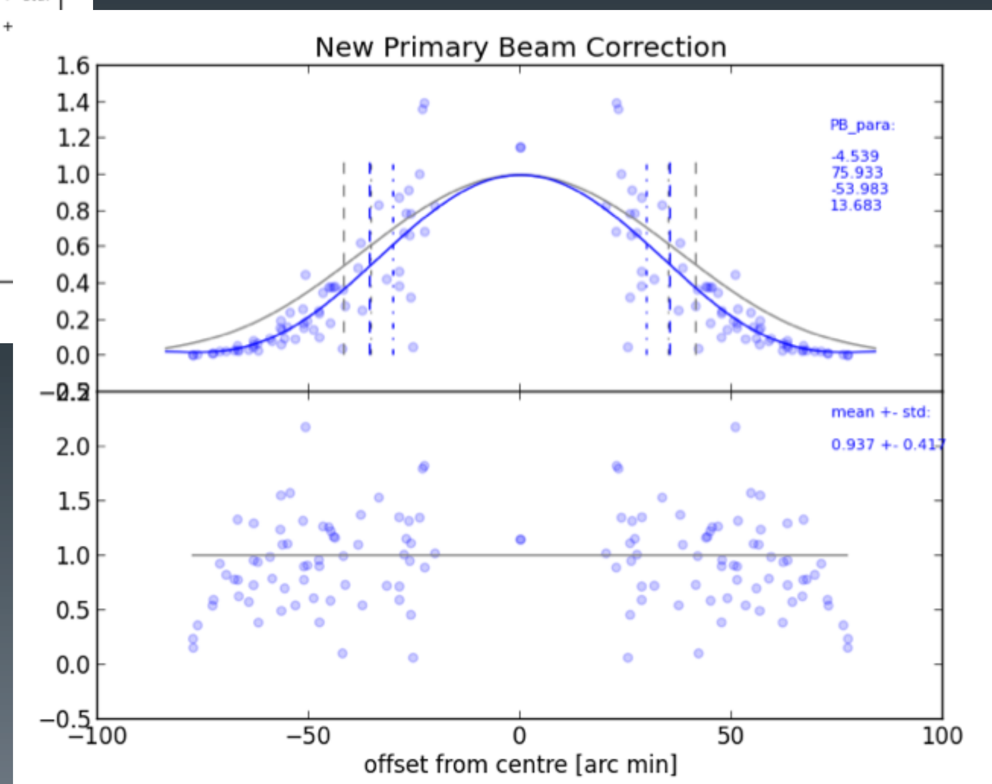


GMRT – primary beam









NVSS, FIRST,
WENSS, SUMSS

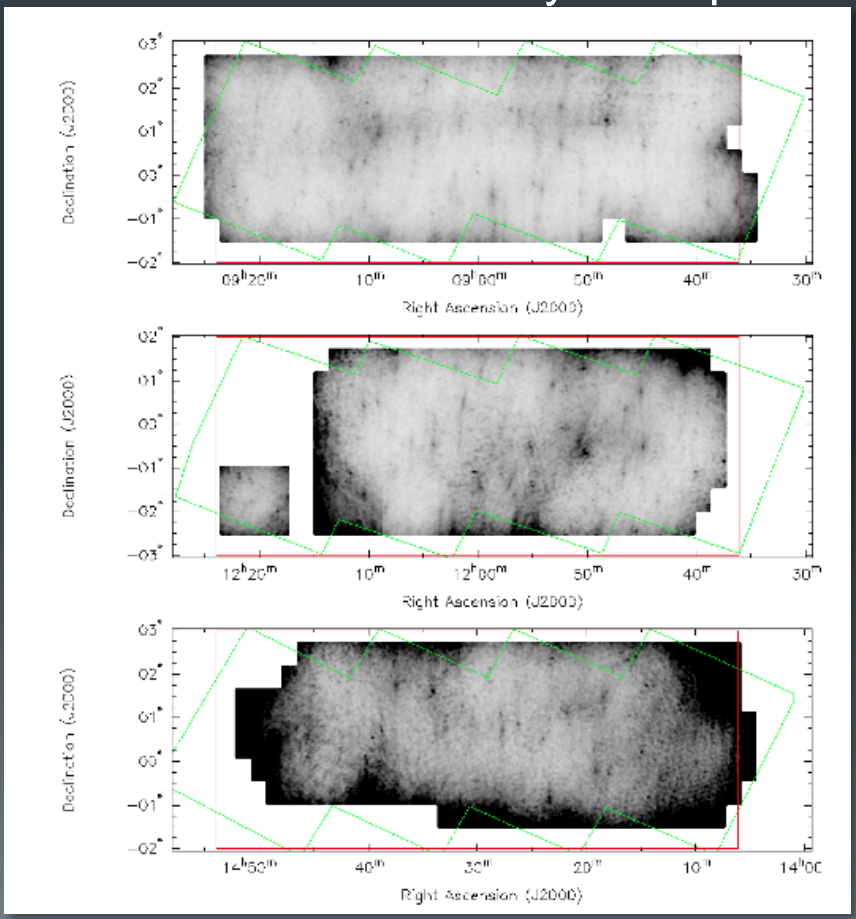
Herschel-ATLAS/GAMA fields

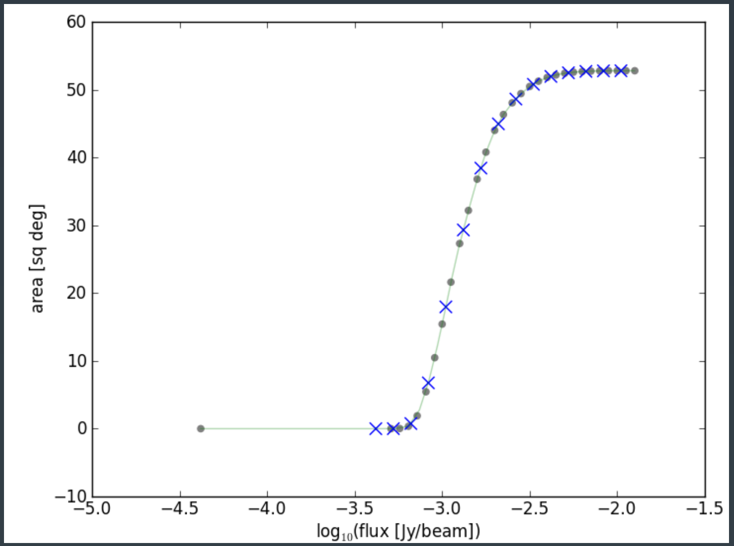
90 sq. deg^2 ~ 360 full moons

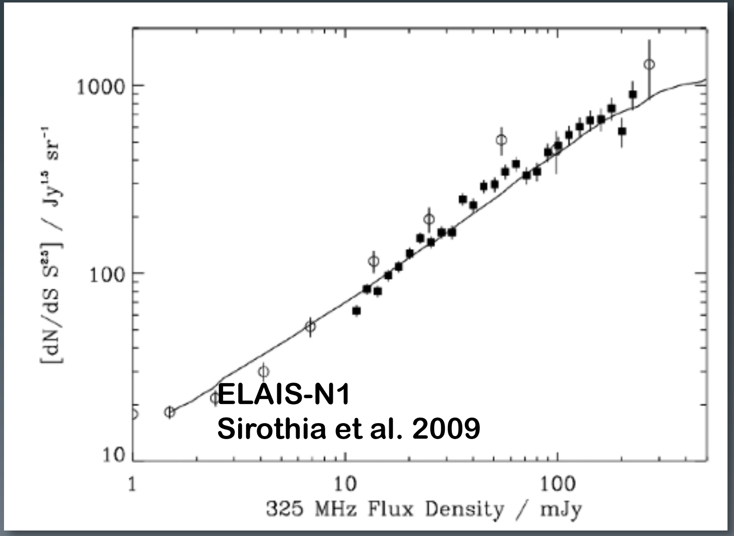
212 x 10 min/per pointing

1 mJy/beam

survey noise pattern







thank you for listening and enjoy synthesis imaging after all its fun to get an image out of the data and do science with it