Netherlands Institute for Radio Astronomy

The LOFAR Standard Imaging Pipeline (SIP)

George Heald (ASTRON/RuG)

LOFAR Data School

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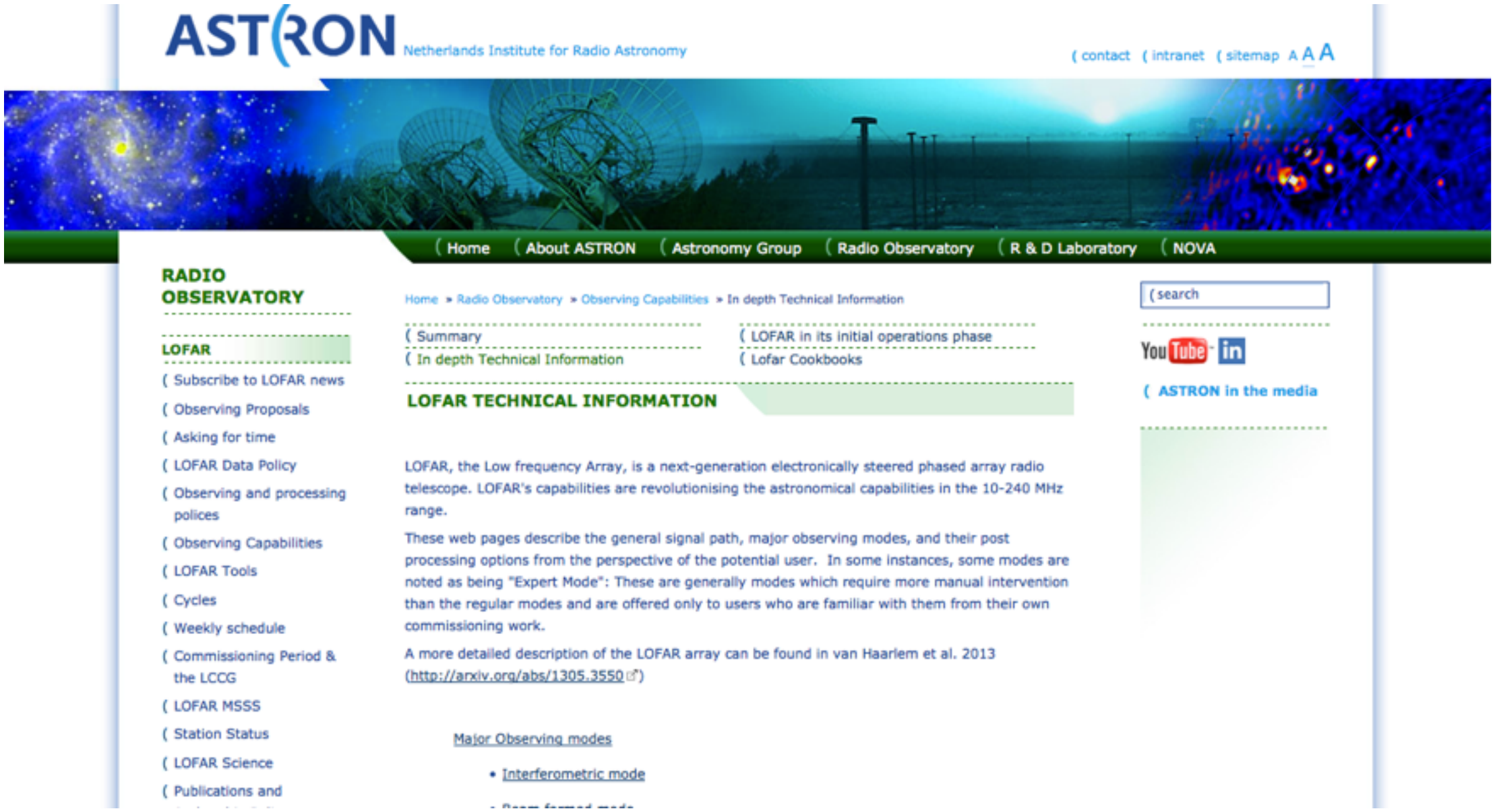
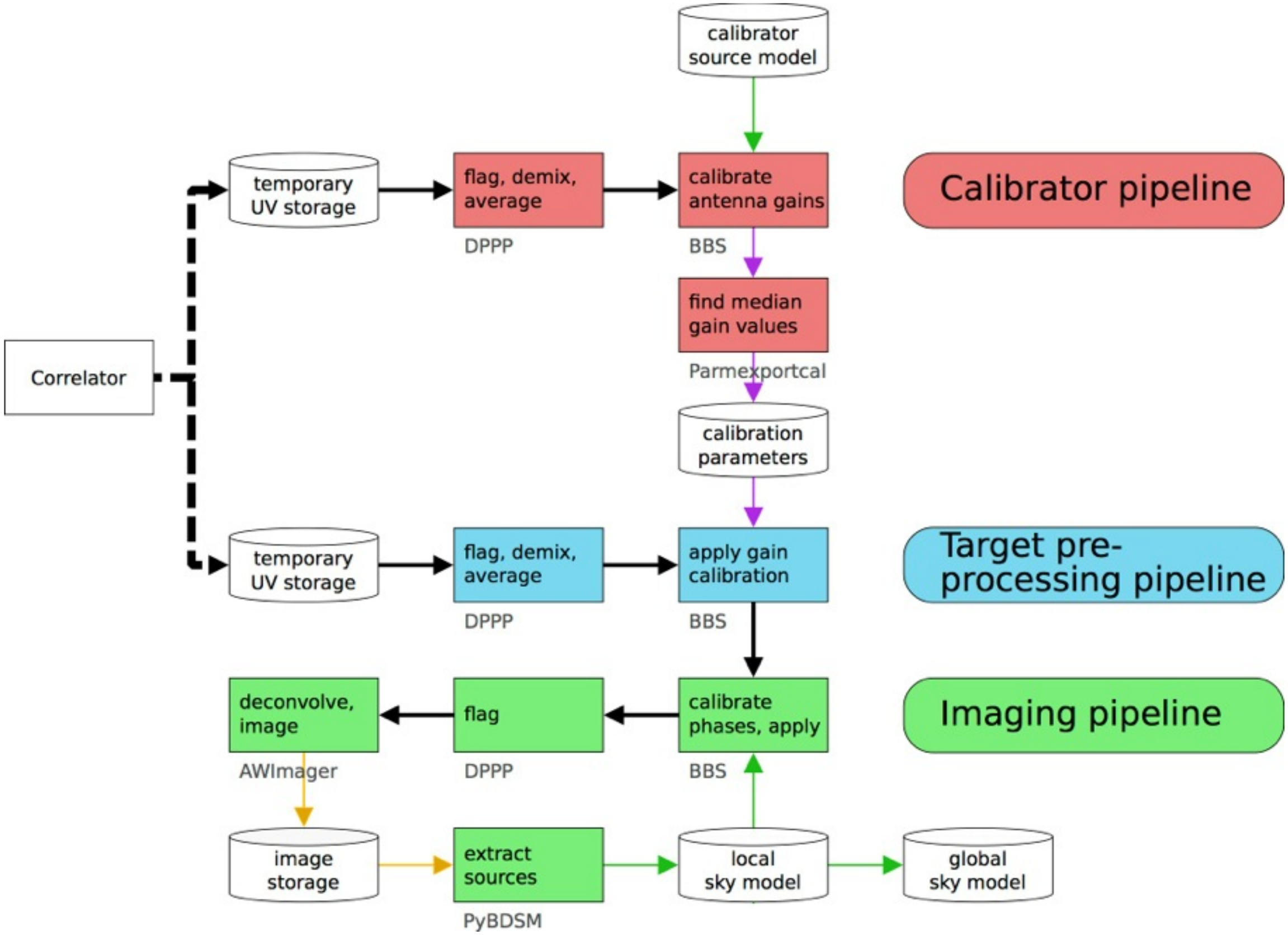
Reference materials

- LOFAR Cookbook
- LOFAR wiki
- ASTRON website, RO section

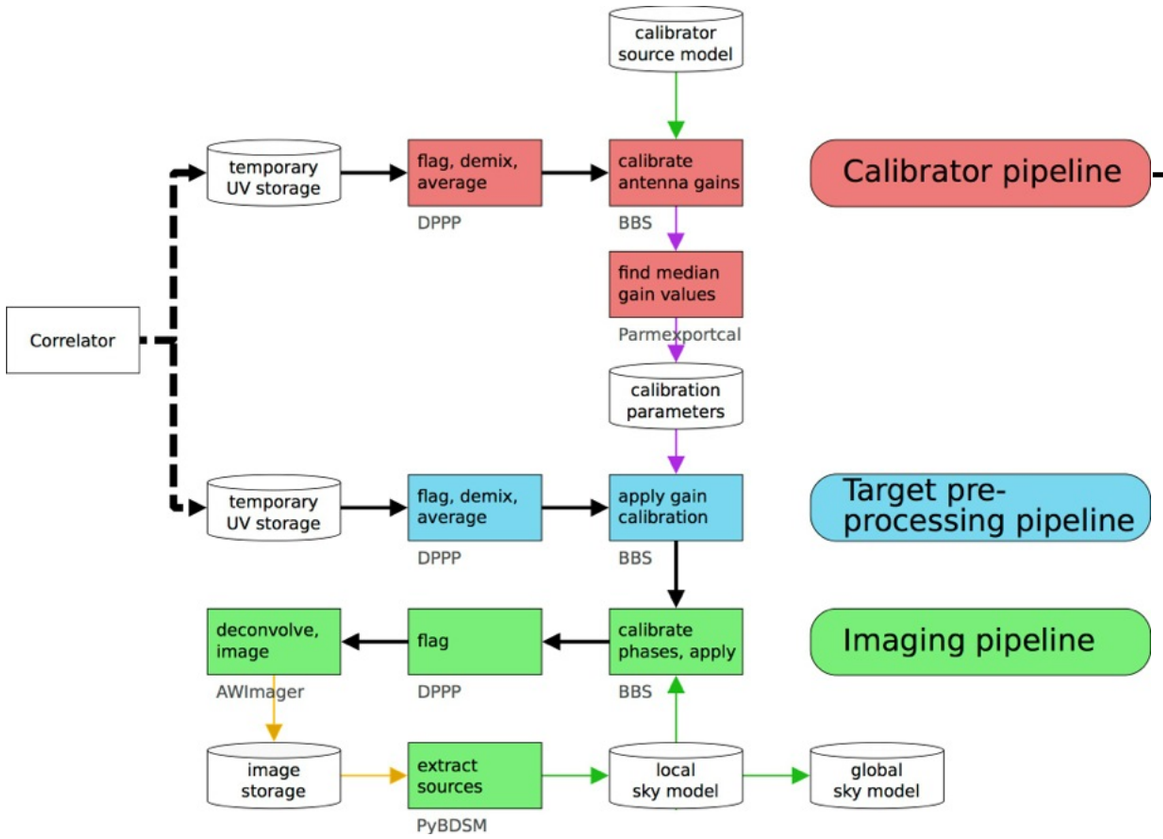


Outline

- LOFAR SIP
  - Calibrator pipeline
  - Target pre-processing pipeline
  - Imaging pipeline
- Points of interest about the SIP
- Calibration schemes
- Metrics and examples
- The future
  - Tiger Team developments
  - What to expect in the SIP



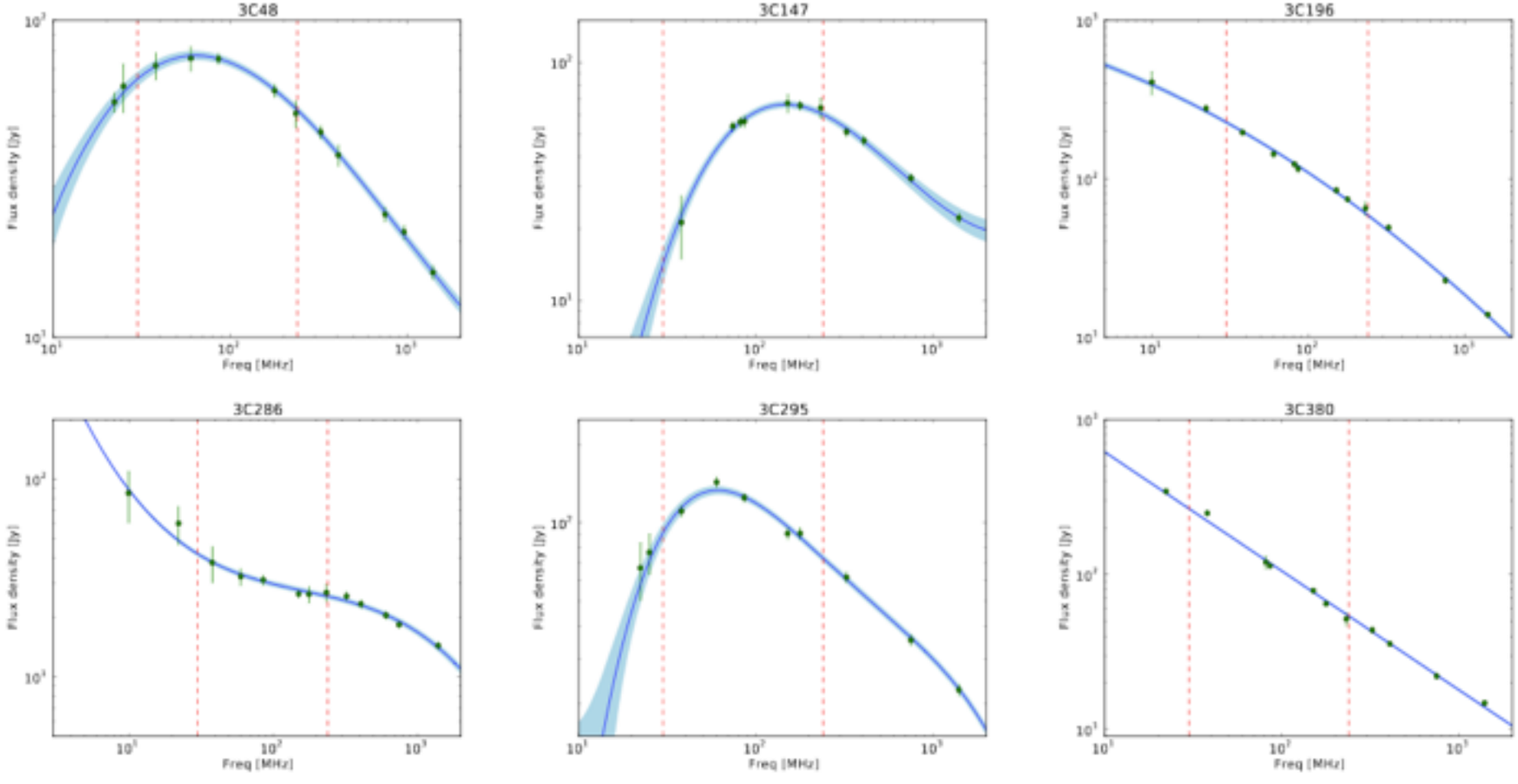
http://www.astron.nl/radio-observatory/astronomers/array-configurations/3-telescope-parameters-and-array-configurations#pipe



Calibrator pipeline

- Pre-processing
  - Flag (aoflagger)
  - optionally demix
  - average in time & freq
- Calibrate the calibrator
  - Uses BBS
  - Solutions stored

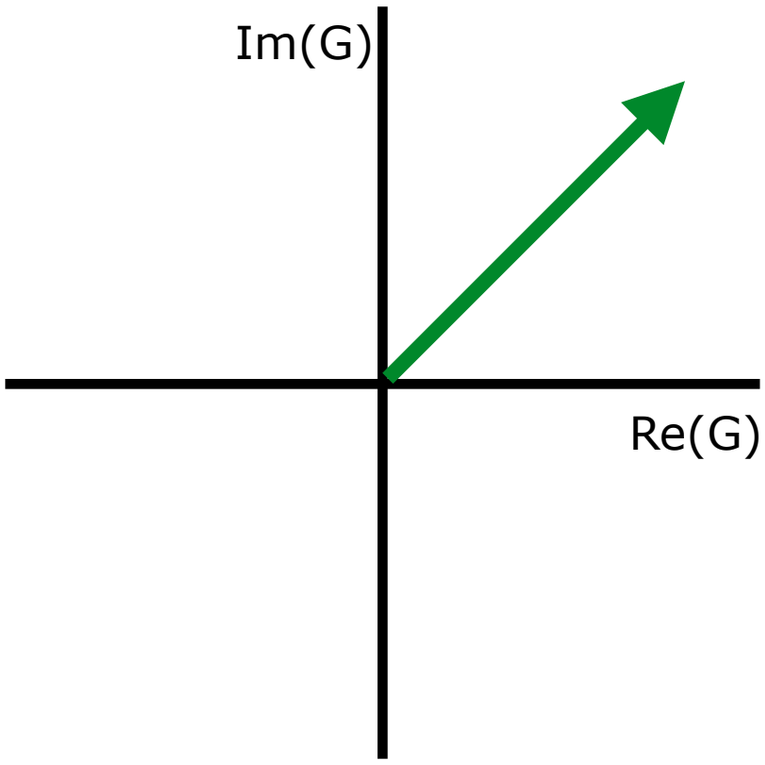
Scaife & Heald (2012)

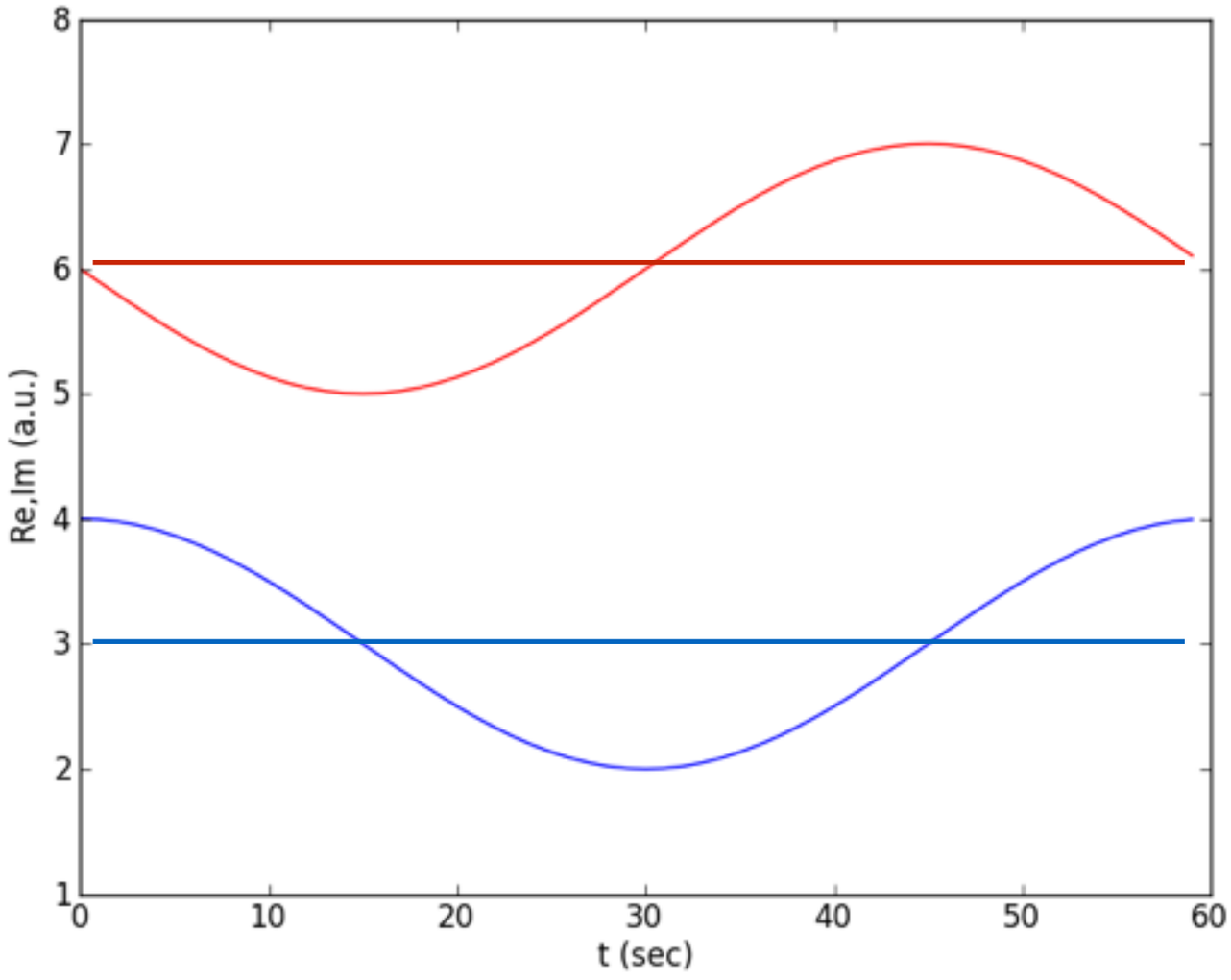


http://www.astron.nl/radio-observatory/astronomers/array-configurations/3-telescope-parameters-and-array-configurations#pipe

Gain solutions

- Why solve for a time-dependent gain and then take the median?
- Consider a smoothly varying complex gain vector, G





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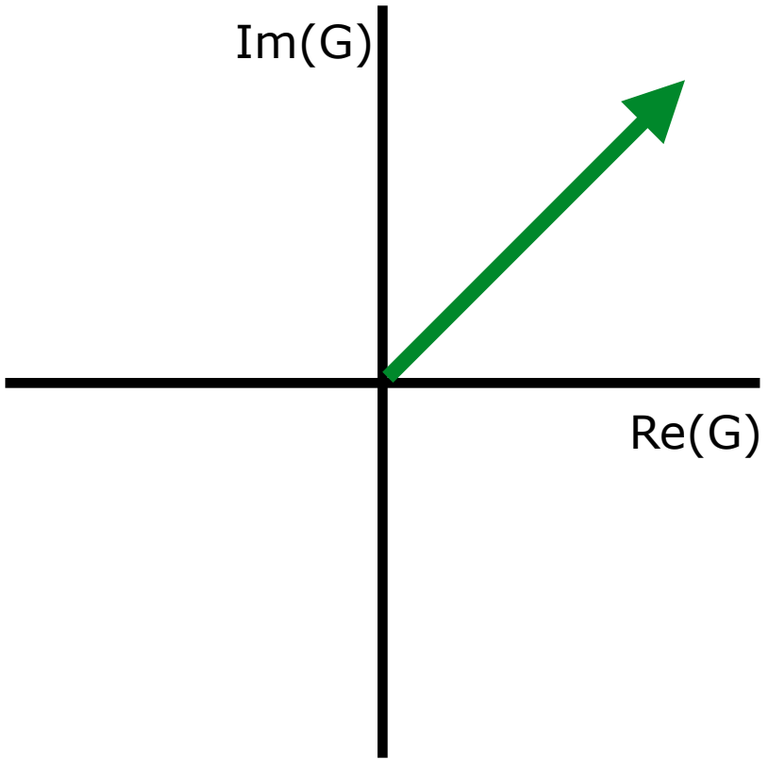
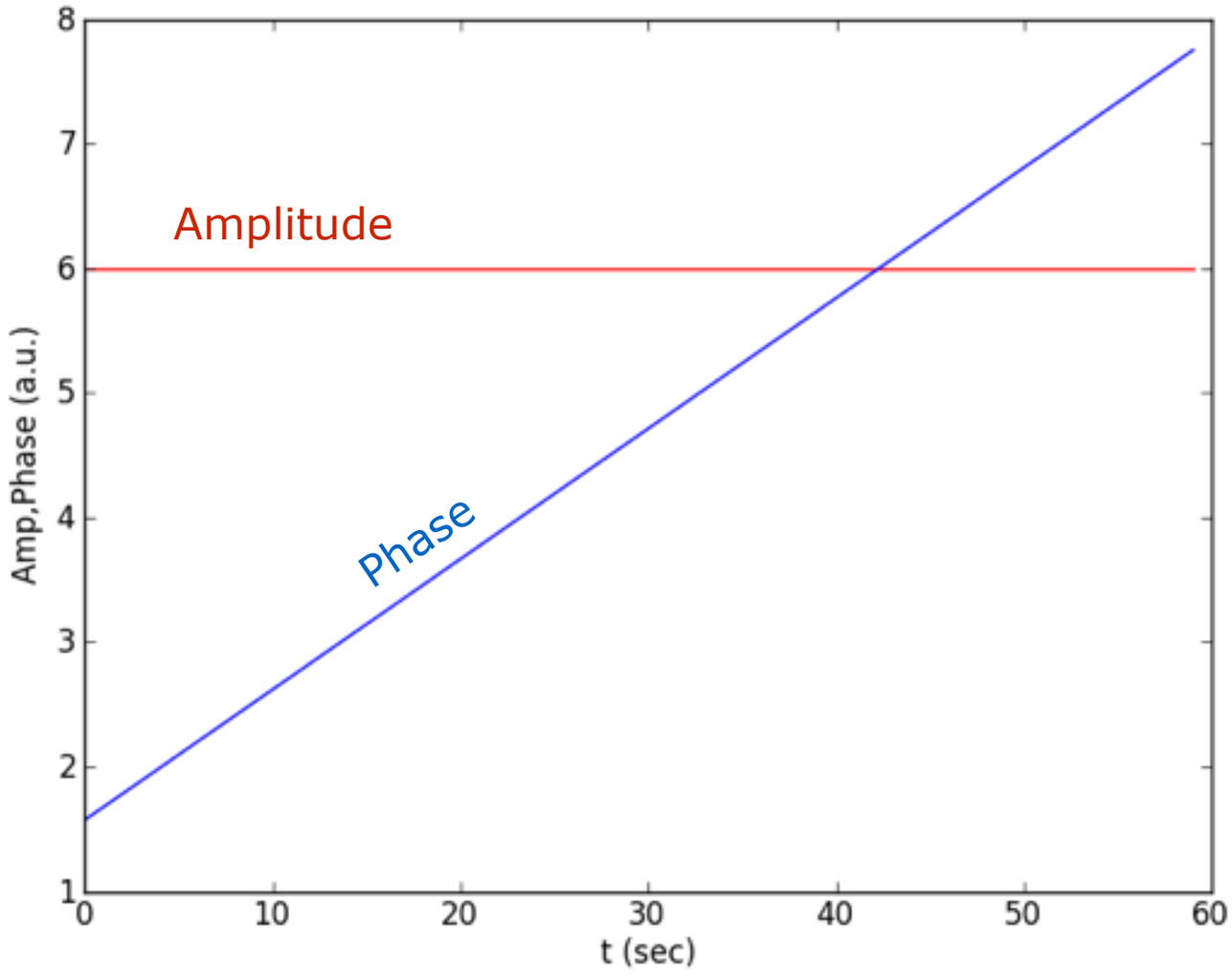
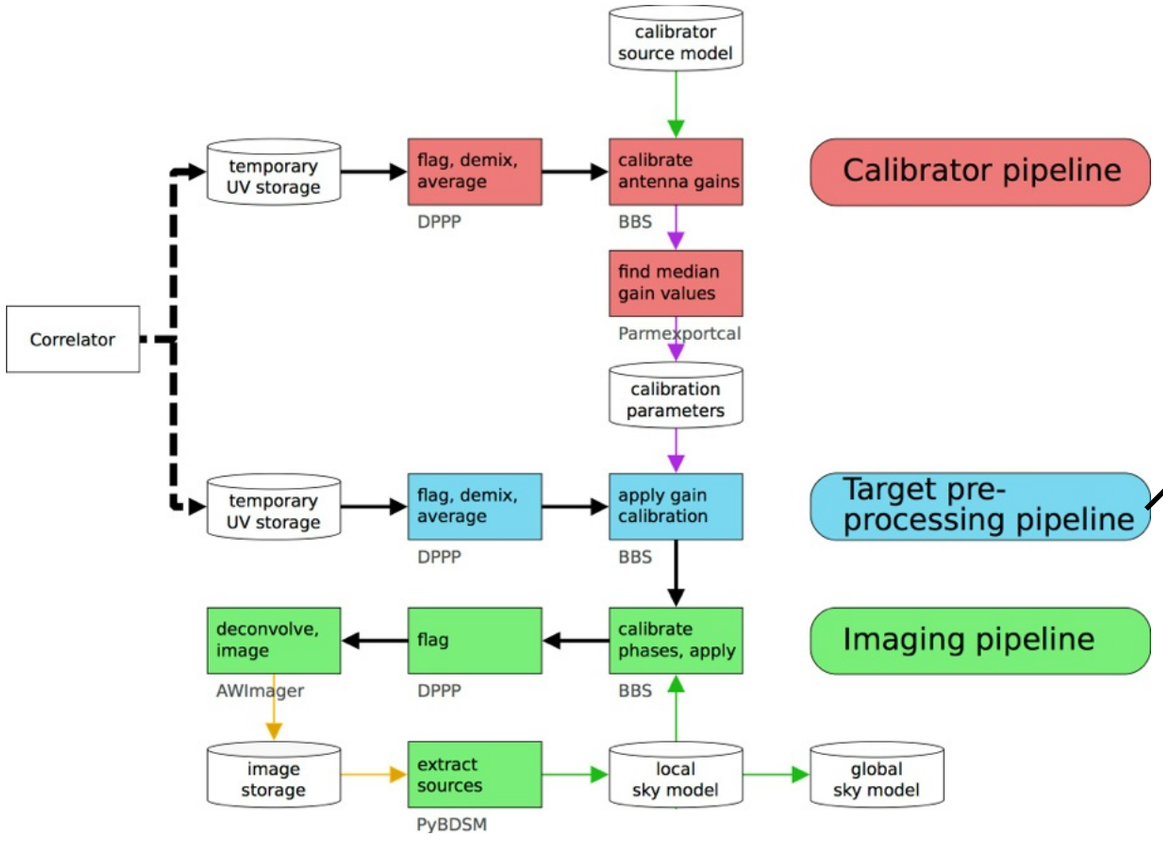






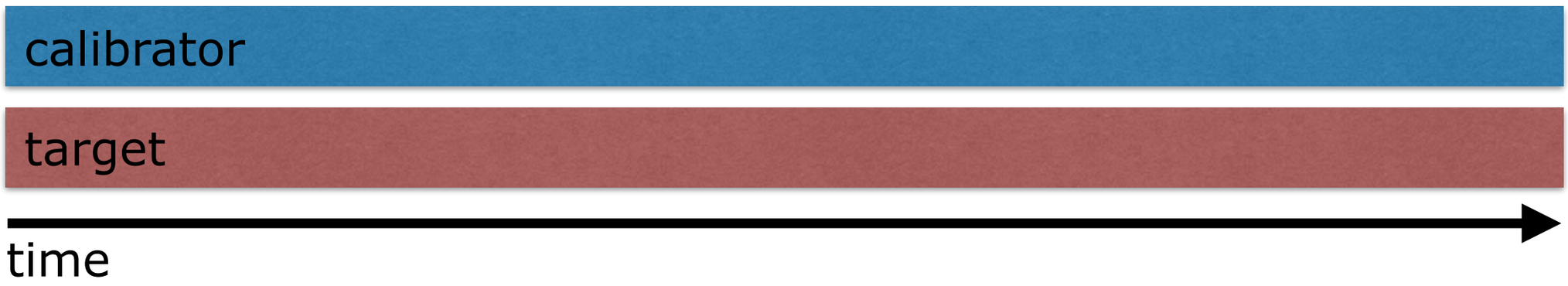
Target pre-processing pipeline

- Flag (aoflagger)
- optionally demix
- average in time & freq
- apply gain solution from calibrator pipeline

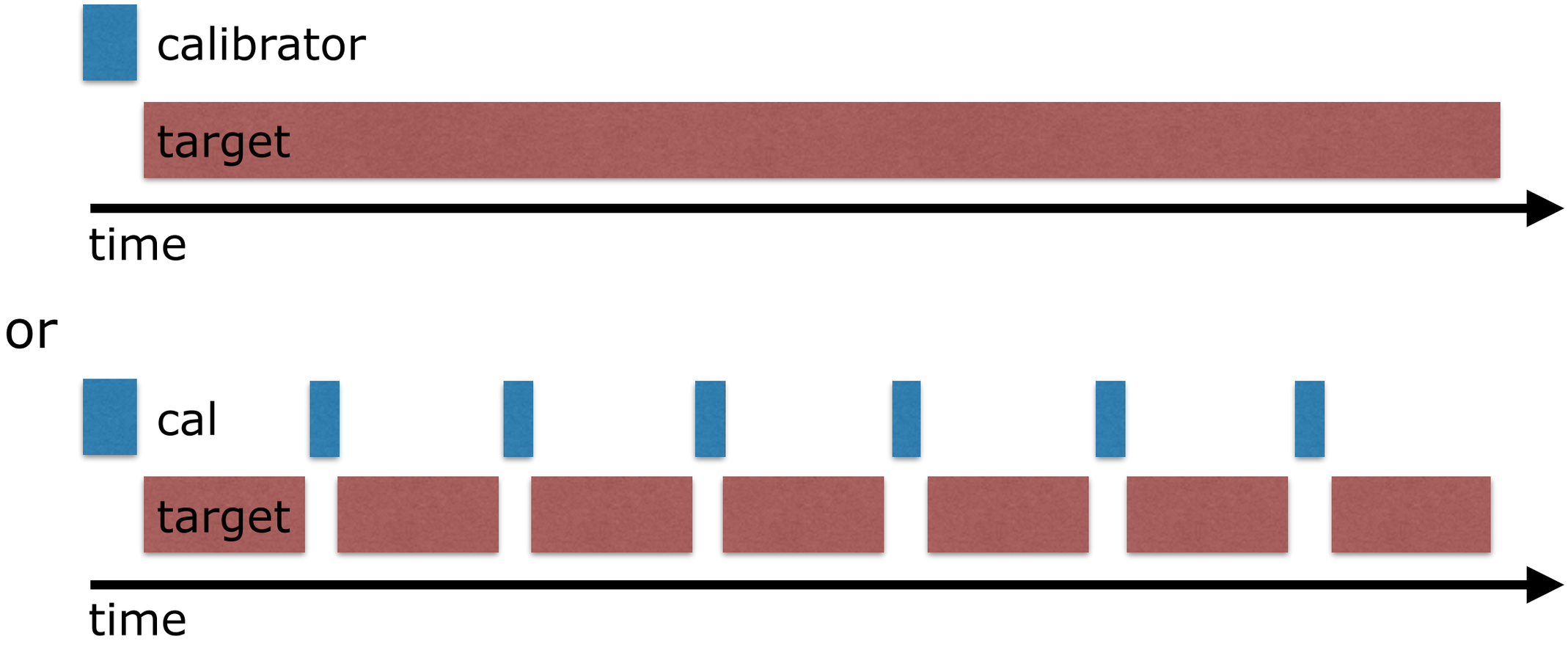
http://www.astron.nl/radio-observatory/astronomers/array-configurations/3-telescope-parameters-and-array-configurations#pipe

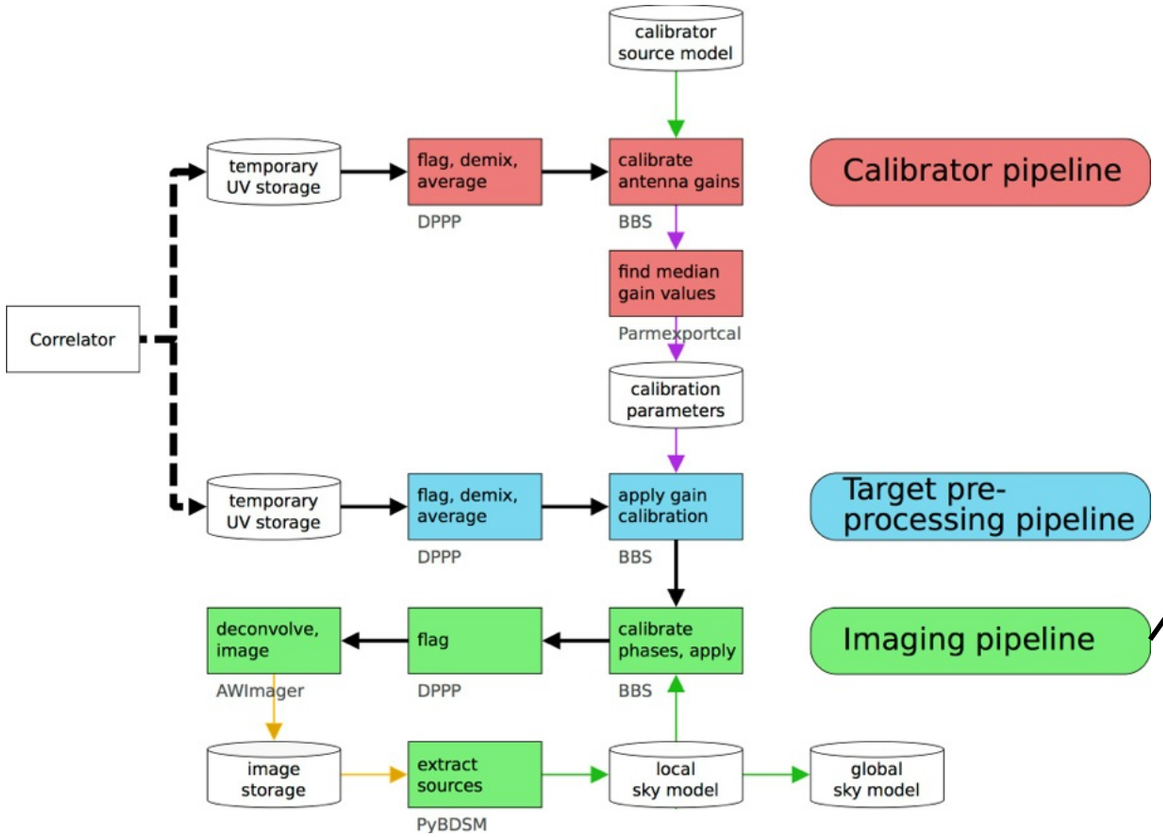
Calibration schemes

- The SIP knows how to deal with three “recipes”:
  - LBA simultaneous (half & half BW) calibration



  - HBA serial calibration (2 modes; simultaneous also allowed)





Imaging pipeline

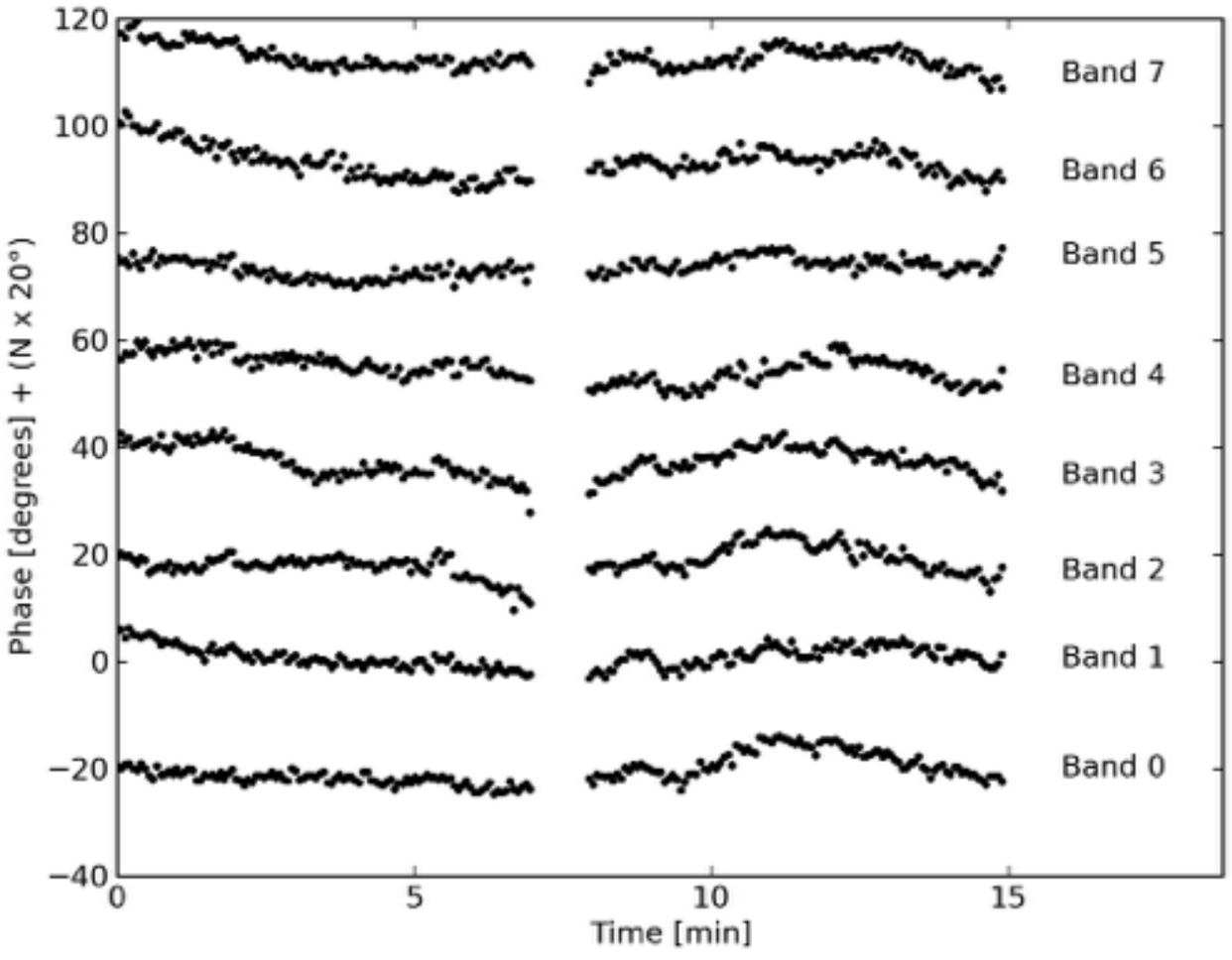
- Subbands collected and concatenated (default 2 MHz)
- Flagging
- Phase calibration using GSM-based model (VLSSr, later to be derived from MSSS)
- AWimager
- Source finding (PyBDSM)
  - Updated LSM generated
- In future: selfcal loop

http://www.astron.nl/radio-observatory/astronomers/array-configurations/3-telescope-parameters-and-array-configurations#pipe

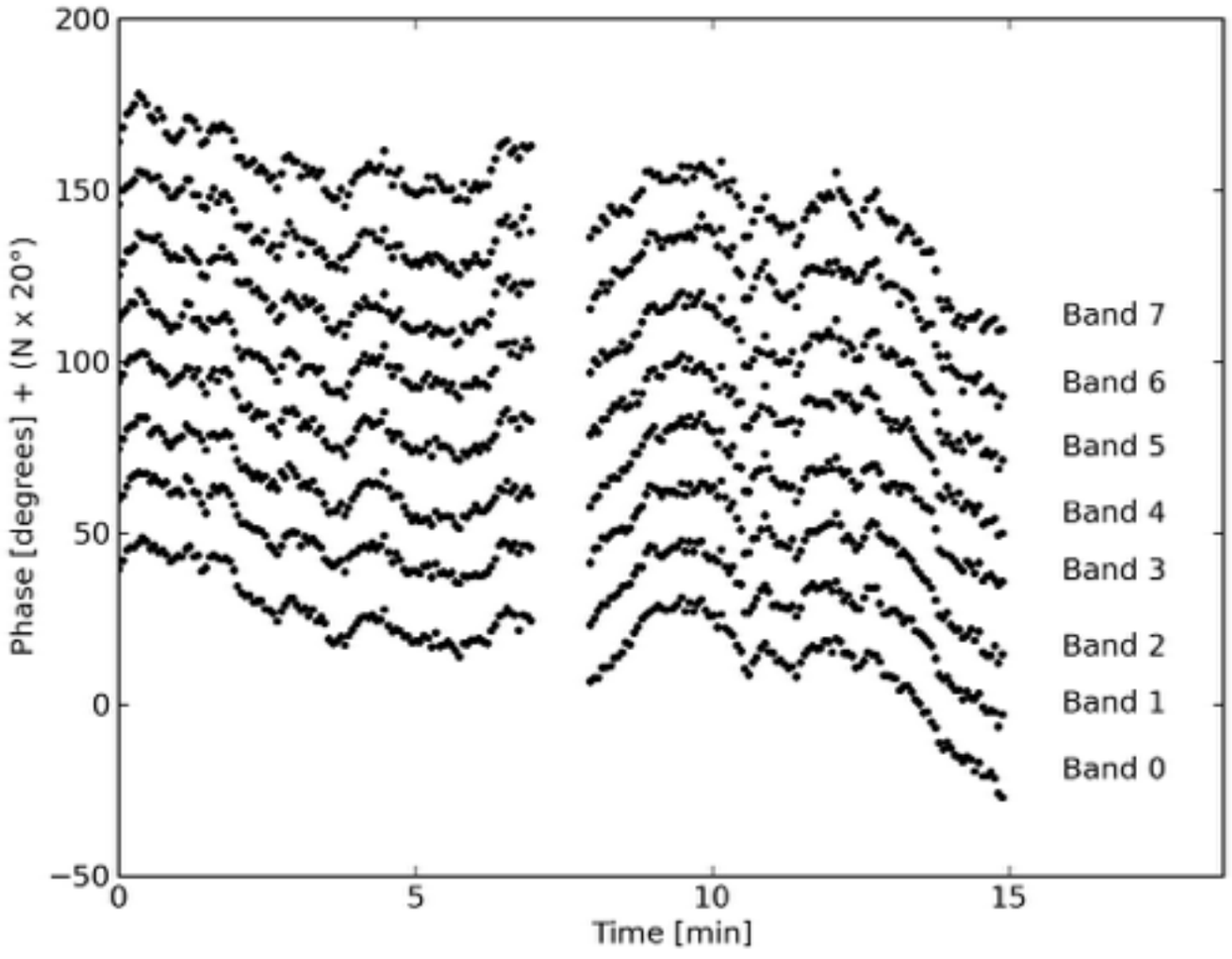
Example phase solutions

- From MSSS (HBA)

2 km SW

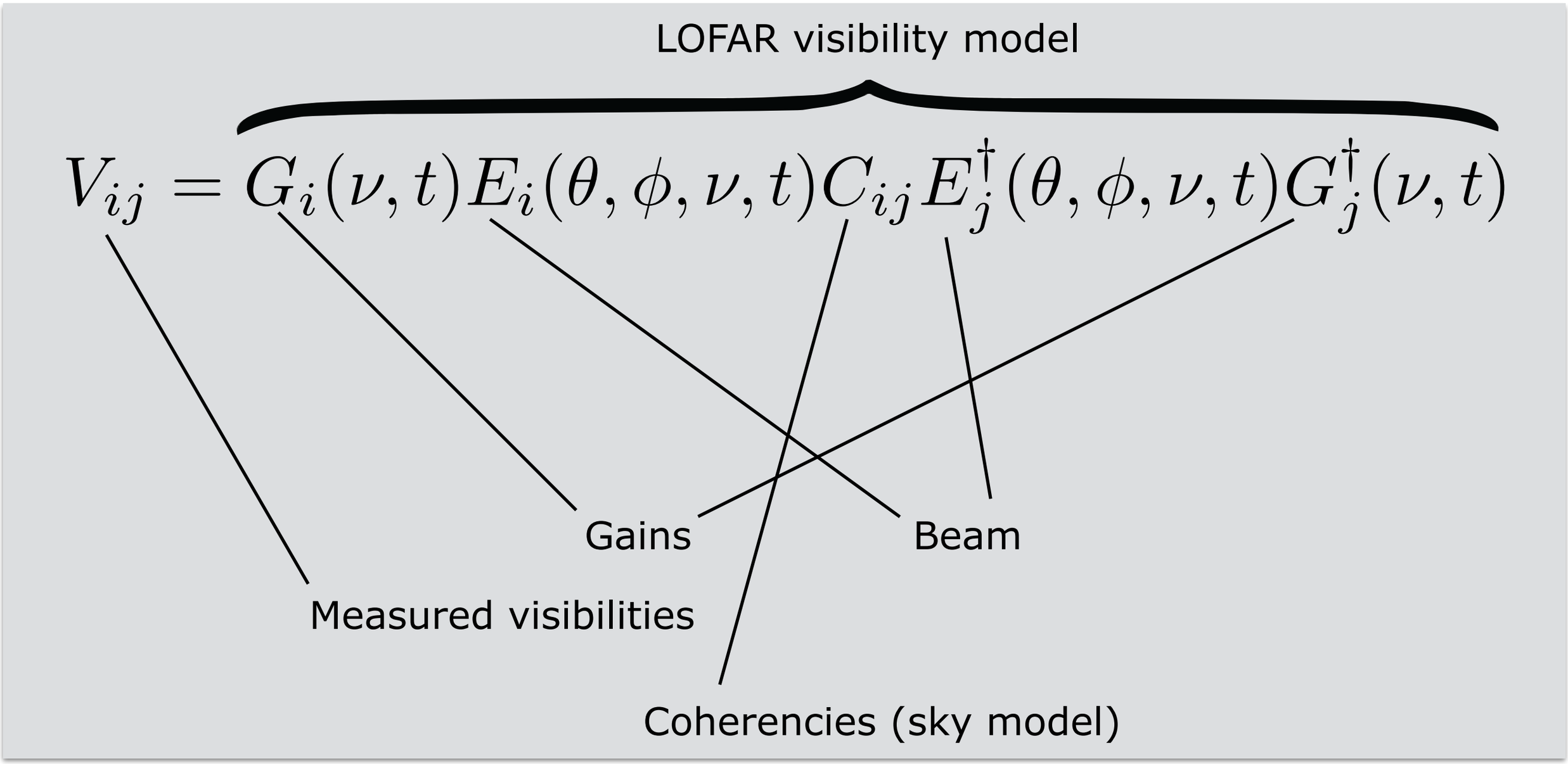


15 km W



Where the beam goes in the SIP

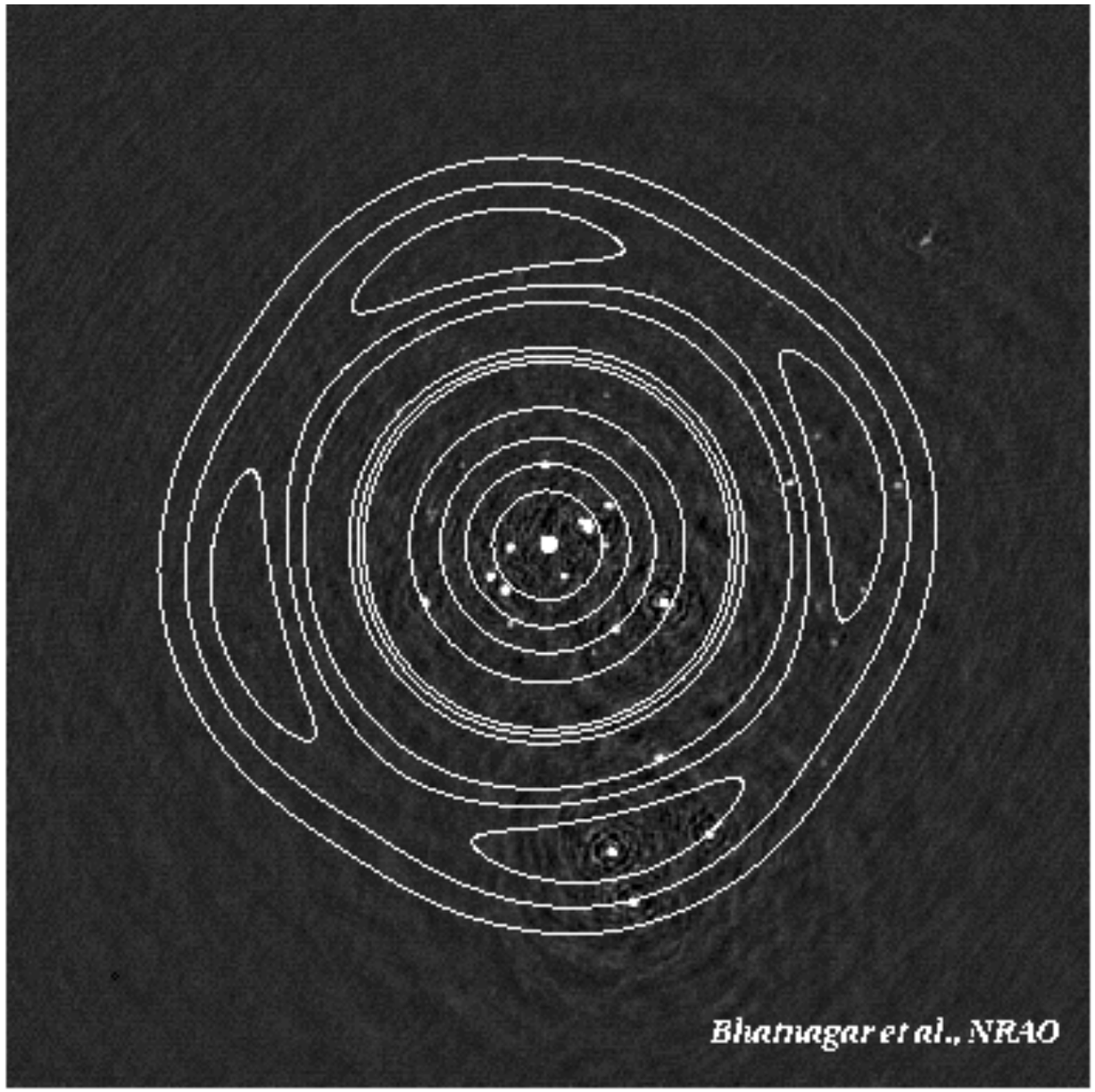
- Calibration: beam needed to properly match data to model



- See also John McKean's lecture
- Note that beam should only be ***applied*** once! (see e.g. Tutorial 2)

Where the beam goes in the SIP

- Awimager (see Bas van der Tol's lecture)
- Cannot be applied at the end as (normally) with VLA, WSRT, etc (LOFAR beam is time dependent…)



SIP performance (as "P/O")

- Pre-processing stage: limiting factor is demixing

Type	Nr Demixed Sources	Nr SB	P/O ratio
LBA	0	244	0.6
LBA	2	244	1.6
LBA	0	80	0.2
LBA	1	80	0.3
LBA	2	80	1.0
HBA	0	244	1.0
HBA	2	244	4.5
HBA	0	122	0.9
HBA	1	122	1.0
HBA	0	366	1.4
HBA	1	366	2.2
HBA	0	380	1.5
HBA	0	480	1.4

Table 4: Pre-processing performance for >2h observations with different observation parameters and settings for demix for HBA and LBA. Although the case of 3 demixed sources has not been characterized, a large increase of the P/O ratio for both LBA and HBA is expected.

- Smart demixing should dramatically improve this situation!

SIP performance

- Imaging stage: limiting factor is Field of View

	B < 3.5 km Large FoV	B < 50 km Moderate FoV	All remote Small FoV
LBA P/O Imaging	0.8 (FoV 12°)	1.2 (FoV 8°)	“feasible” (FoV 3°)
HBA P/O Imaging	0.9 (FoV 5°)	1.3+ (FoV 5°)	“feasible” (FoV 3°)

SIP output structure

- Important outputs:
  - Calibrator pre-processing pipeline: uncalibrated visibilities (MS)
  - Calibrator pipeline: gains (INST) & calibrated visibilities (MS)
    - INST can be saved but not in LTA
  - Target pre-processing pipeline: uncal & cal visibilities (MS)
  - Imaging pipeline: images (hdf5 format)
    - FITS and source lists can be saved but not in LTA

- Be sure to request needed LTA storage and saving of additional products as necessary…!

SIP output structure

- Calibrator pipeline example

```
--------- locus091 ---------
104K    /data/scratch/lofarsys/Observation250336/L250292_SAP000_SB079_uv.MS.bbs.sourcedb
48M     /data/scratch/lofarsys/Observation250336/L250292_SAP000_SB079_uv.MS.dppp
452K    /data/scratch/lofarsys/Observation250336/L250292_SAP000_SB079_uv.MS.dppp.bbs.parmdb
60K     /data/scratch/lofarsys/Observation250336/L250292_SAP000_SB079_uv.MS.dppp.parmdb
13M     /data/scratch/lofarsys/Observation250336/L250292_SAP000_SB079_uv.MS.dppp.sourcedb
```

- Target pipeline example

```
--------- locus091 ---------
356M    /data/scratch/lofarsys/Observation250338/L250294_SAP000_SB079_uv.MS.dppp
13M     /data/scratch/lofarsys/Observation250338/L250294_SAP000_SB079_uv.MS.dppp.sourcedb
60K     /data/scratch/lofarsys/Observation250338/L250294_SAP000_SB079_uv.MS.parmdb
96K     /data/scratch/lofarsys/Observation250338/L250294_SAP000_SB079_uv.MS.sky
```

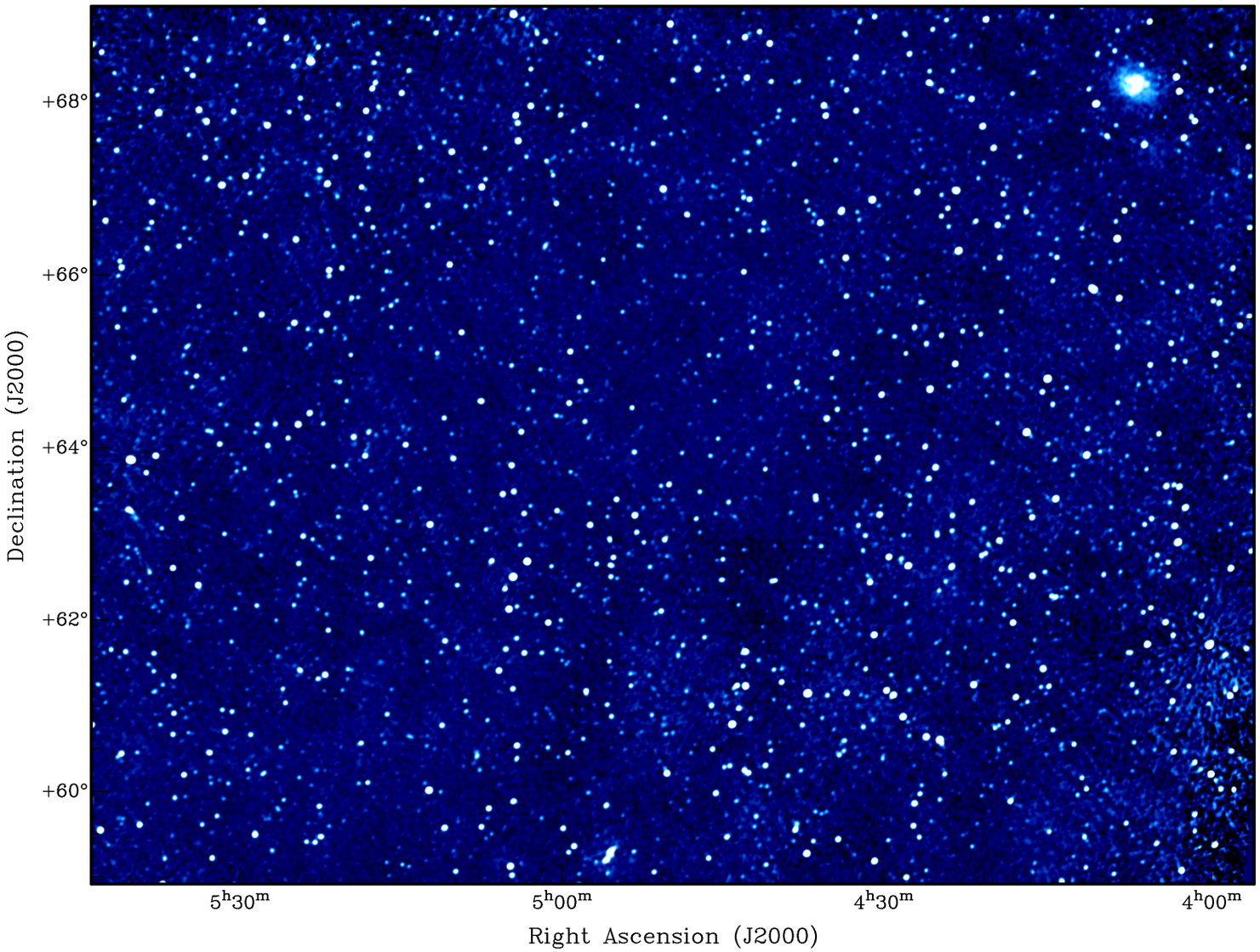
SIP output structure

- Imaging pipeline example

```
--------- locus090 ---------
213M    /data/scratch/lofarsys/Observation250380/awimage_cycle_0
4.0K    /data/scratch/lofarsys/Observation250380/awimager.log_prop
17M     /data/scratch/lofarsys/Observation250380/bdsm_output.img_0
17M     /data/scratch/lofarsys/Observation250380/bdsm_output.img_1
17M     /data/scratch/lofarsys/Observation250380/bdsm_output.img_2
17M     /data/scratch/lofarsys/Observation250380/bdsm_output.img_3
17M     /data/scratch/lofarsys/Observation250380/bdsm_output.img_4
8.0K    /data/scratch/lofarsys/Observation250380/concat.ms
180K    /data/scratch/lofarsys/Observation250380/concat.ms.sourcedb
8.0K    /data/scratch/lofarsys/Observation250380/concat.ms.sourcedb.temp
0       /data/scratch/lofarsys/Observation250380/JAWS_products
4.0K    /data/scratch/lofarsys/Observation250380/makesourcedb.log_prop
4.0K    /data/scratch/lofarsys/Observation250380/NDPPP.log_prop
0       /data/scratch/lofarsys/Observation250380/pipeline_process.log
39G     /data/scratch/lofarsys/Observation250380/subbands
49G     /data/scratch/lofarsys/Observation250380/time_slices
```

Current SIP capability

- Automatic GSM-calibrated imaging pipeline suitable for MSSS usage



Pipeline provides good performance for a shallow, snapshot, low resolution survey (resolution ~1-2', DR up to ~1000)

Further work needed for deep, high angular resolution imaging work

- Requirement for an improved imaging pipeline that produces ***competitive, science-quality image performance***
  led to identification of resources for a specialized development team

What is the Tiger Team working on?

What new features will the SIP have?

Motivation & scope

- Need a functioning (automatic) self-calibration loop, including:
  - Direction dependent effects (ionosphere)
  - Speedups & improvements to all involved tools
- Assumptions:
  - Single imaging tracks (8–10 hrs), standard calibration setup
  - Distant from A-team sources and/or smart demixing available

Table 1 SIP goals

Property	Value (HBA)	Value (LBA)
Integration time	8 h	8 h
Bandwidth	48 MHz	48 MHz
Image depth	$100\,\mu$Jy beam^{-1}	1 mJy beam^{-1}
	$\sim 4 \times \sigma_{\text{thermal}}$	$\sim 2 \times \sigma_{\text{thermal}}$
Resolution	$10''$	$30''$
Field of view	$11\,\square^{\circ}$ (HBA_DUAL_INNER)	$12\,\square^{\circ}$ (LBA_OUTER)
	$\cong 15000 \times 15000$ $3''$ pixels	$\cong 5000 \times 5000$ $10''$ pixels
Dynamic range	$5 \times 10^4 : 1$	$1 \times 10^4 : 1$
	for a 5 Jy source	for a 10 Jy source

CITT members and roles

George Heald
PI

Tammo Jan Dijkema
Project Manager
Calibration tools

Bas van der Tol
LOFAR Imager

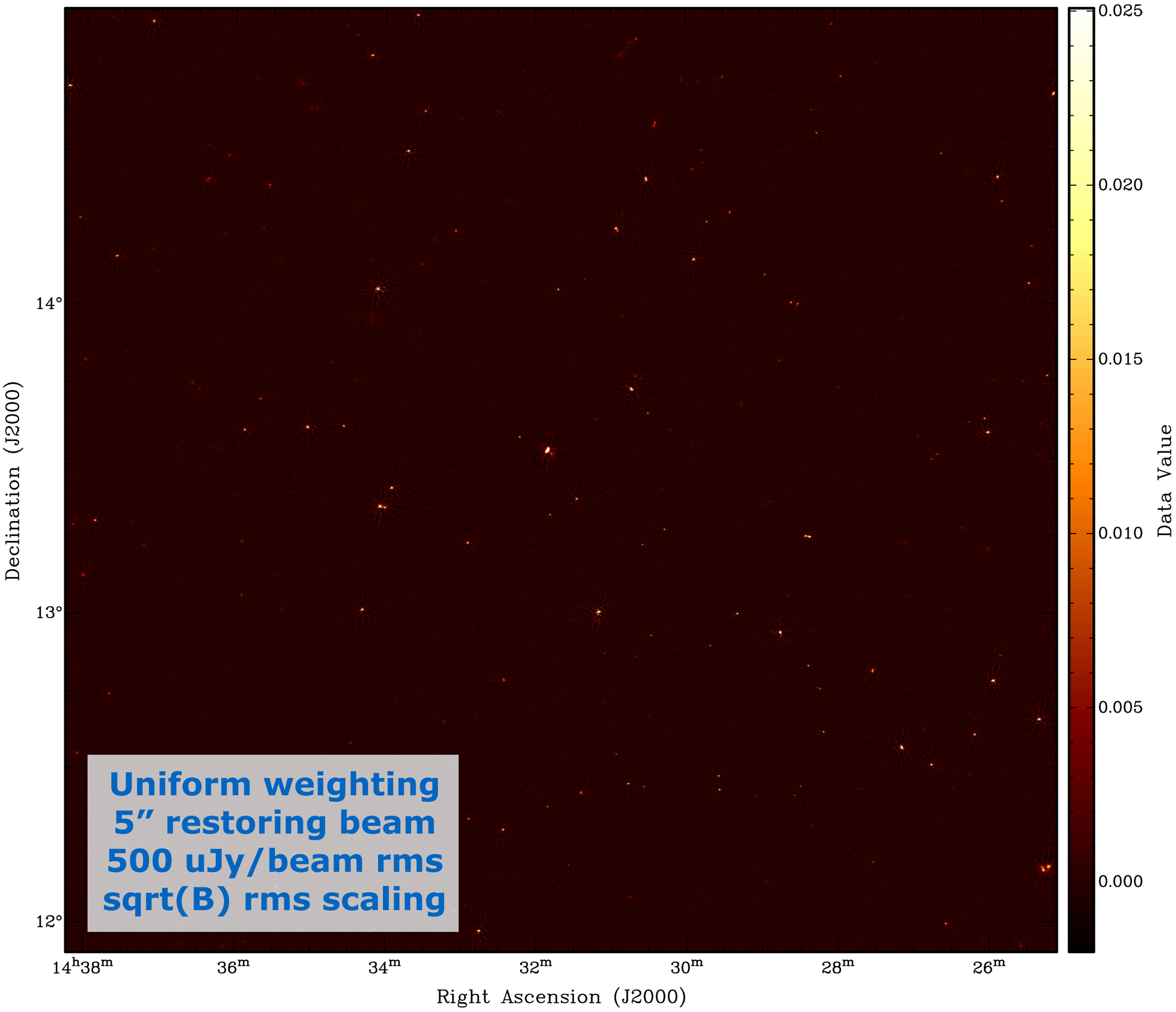
Nicolas Vilchez
Selfcalibration pipeline

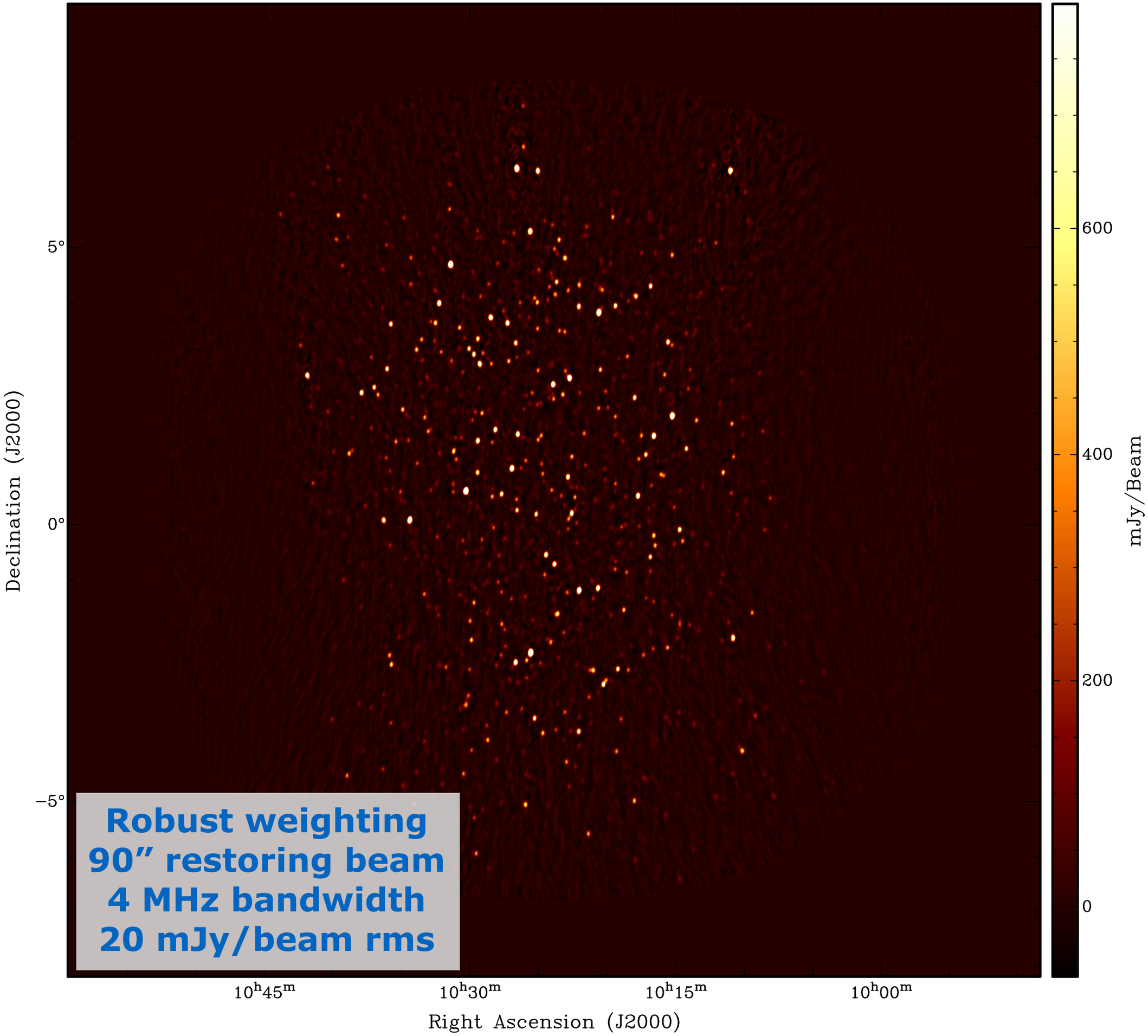
David Rafferty
Ionospheric calibration

Manu Orru &
Carmen Toribio
RO Liasons

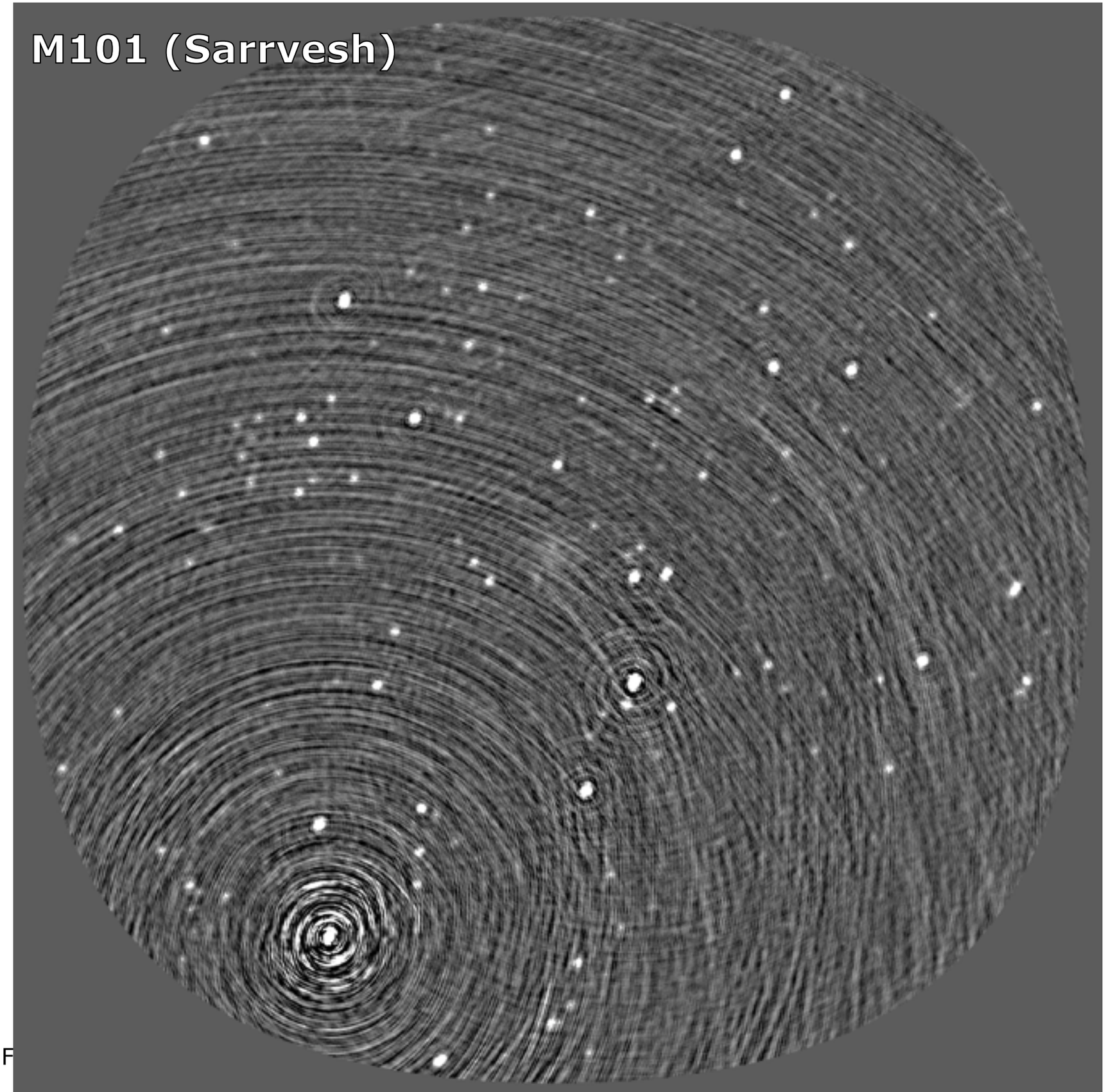
Development threads

- Calibration in NDPPP/BBS
  - Demonstrated 15x speedup and massive memory usage improvement
  - **New capability: functional enhancement to NDPPP**
- Imaging in awimager [critical path]
  - improvements to feature set through build against casa 4.2
  - new awimager now ready for test release
  - **New capability: fully functional imager on new build**
- Self-calibration recipe
  - direction-independent major cycle closed in standalone tool and demonstrated improvements in LBA, HBA (modes 5,7)
  - **Short term deliverable: Enhanced selfcal w/ simple peeling**
- Ionospheric / direction-dependent calibration (BBS+awimager)
  - Improvements demonstrated in LBA; soon to start HBA testing
  - **Short term deliverable: Ionospheric recipe for LOFAR data**

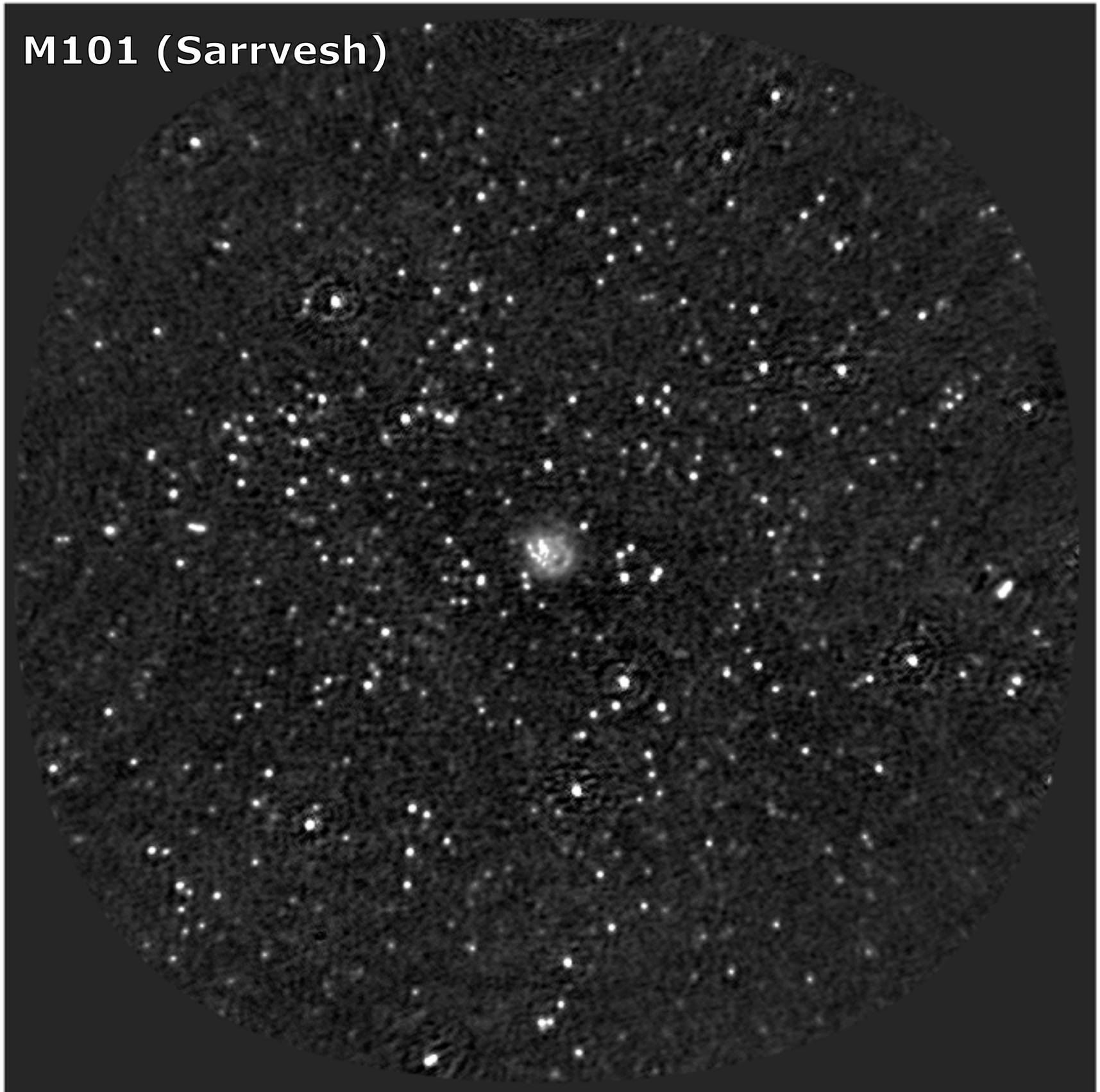

14°
13°
12°
Declination (J2000)
14h38m
36m
34m
32m
30m
28m
26m
Right Ascension (J2000)
0.025
0.020
0.015
0.010
0.005
0.000
Data Value
Uniform weighting
5” restoring beam
500 uJy/beam rms
sqrt(B) rms scaling


5°
0°
−5°
Declination (J2000)
10^h45^m
10^h30^m
10^h15^m
10^h00^m
Right Ascension (J2000)
600
400
200
0
mJy/Beam
Robust weighting
90” restoring beam
4 MHz bandwidth
20 mJy/beam rms

Next: peeling (see Elizabeth's lecture)



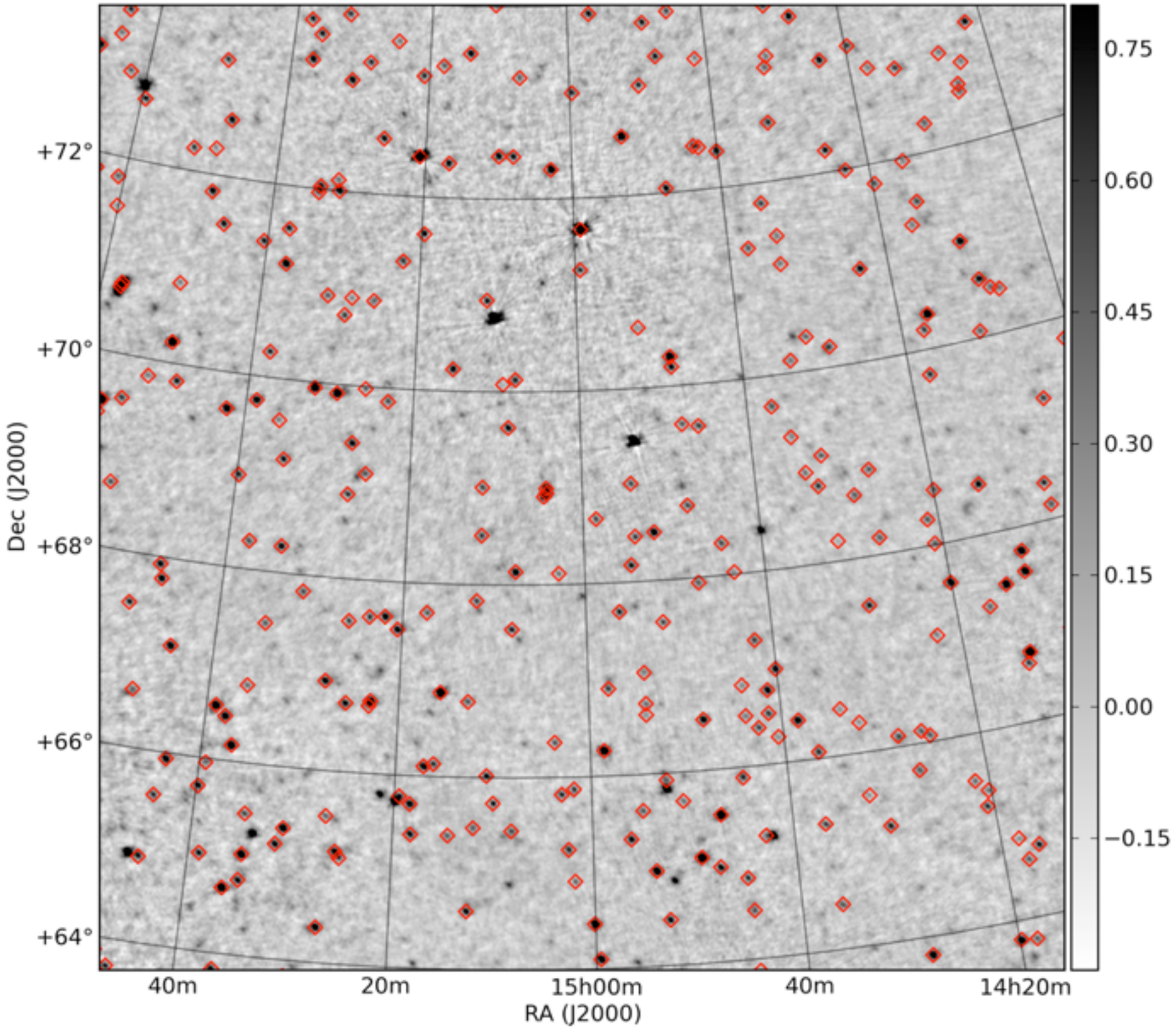
Next: peeling (see Elizabeth's lecture)



Cleaning up requires direction dependent effects

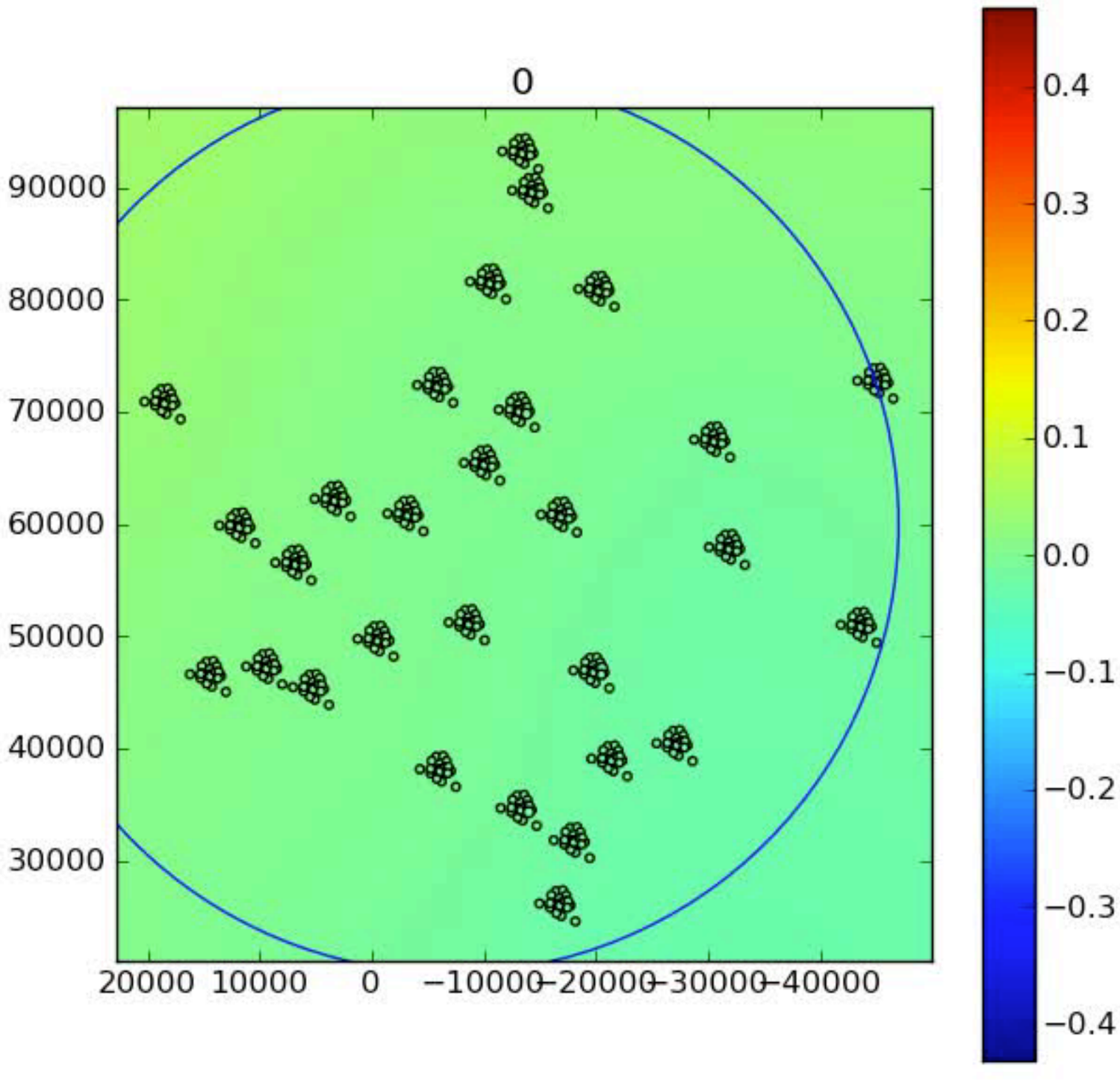
MSSS Verification Field (MVF)

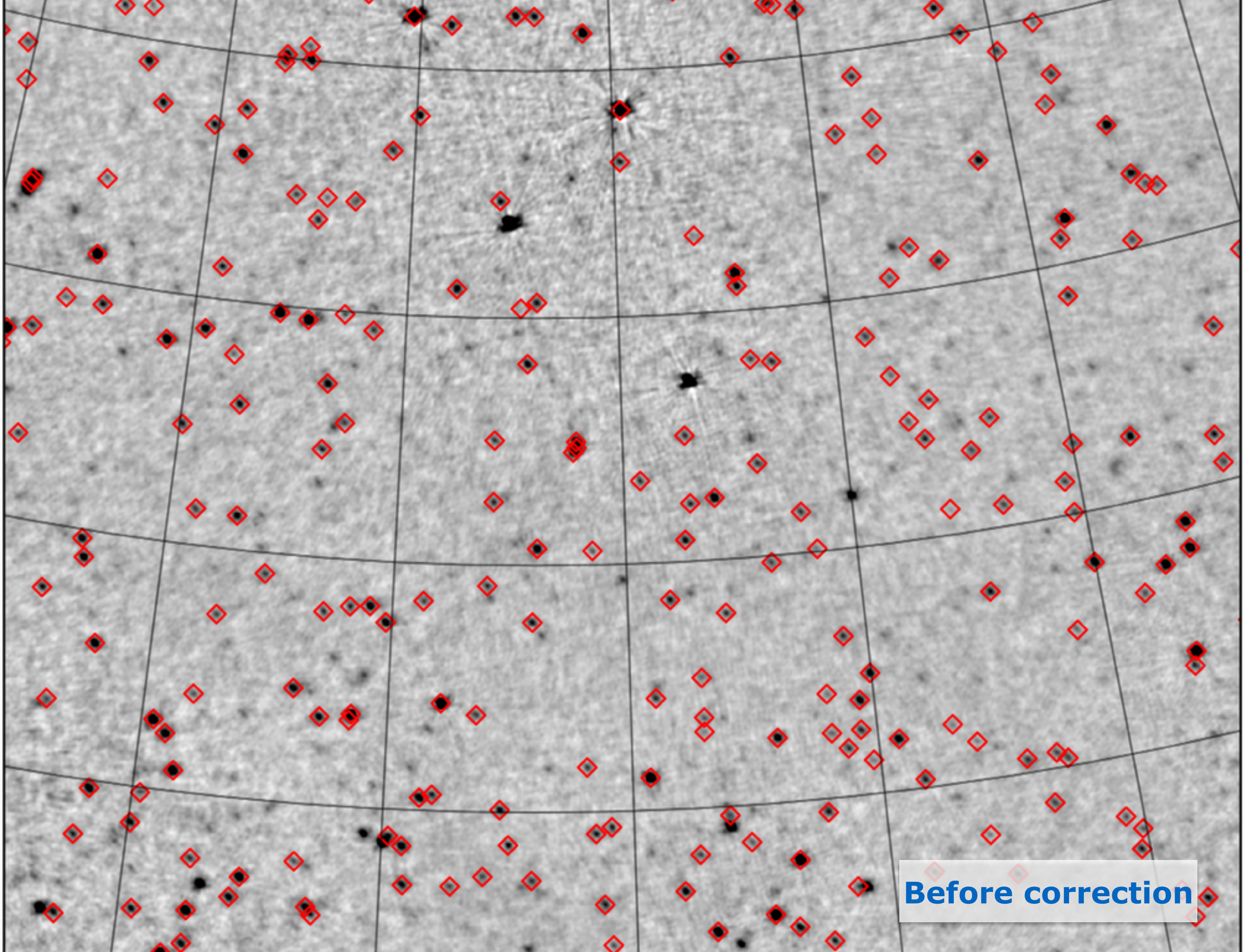
- LBA 46 mJy/beam, 2’ resolution



Determination of MVF phase screens

- Using BBS direction-dependent gain solutions, now on patches
- Up to 30 directions in FoV with good-quality phases

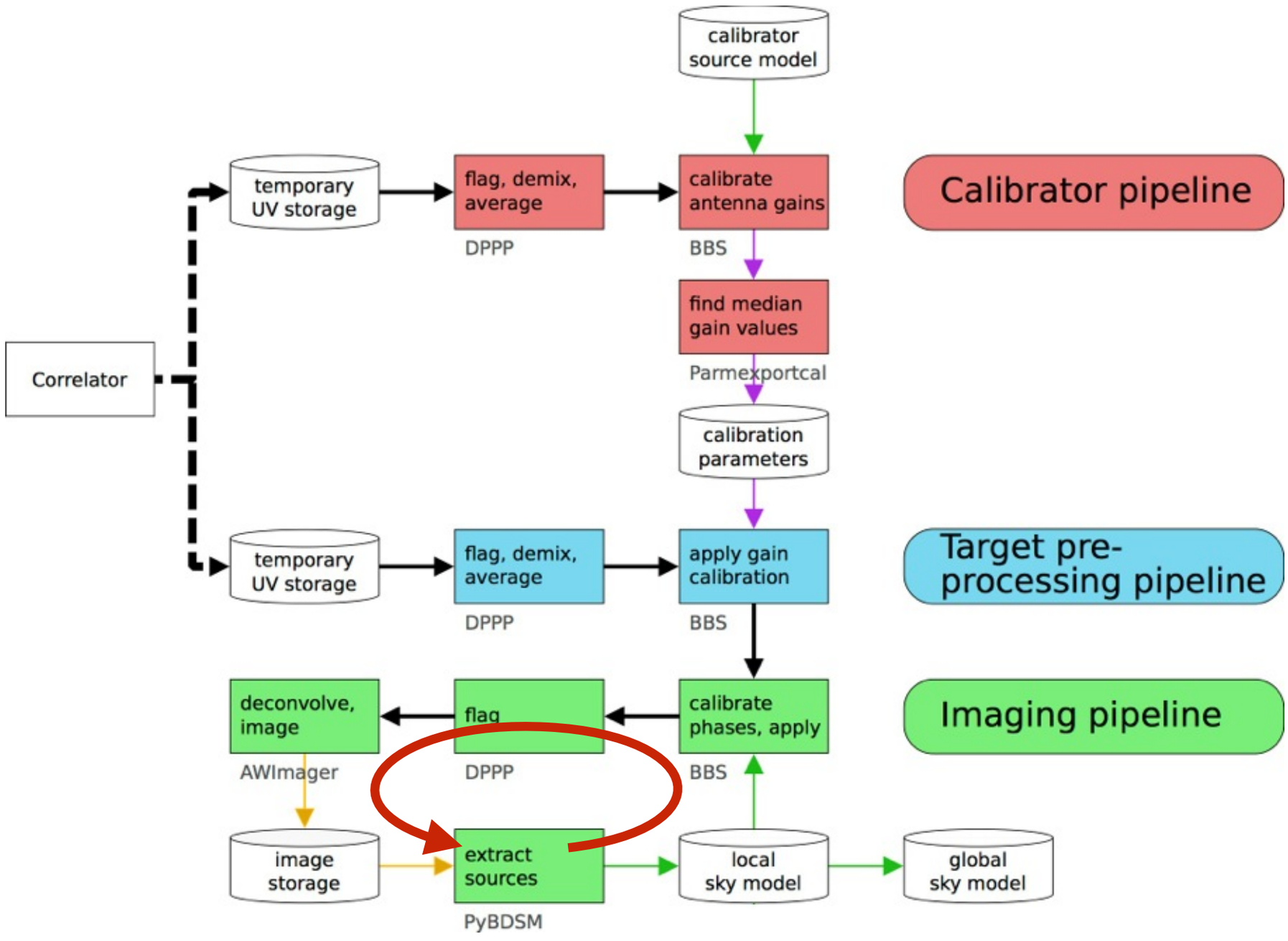



Before correction

After correction

Looking forward

- Ultimate aim is to merge these development streams and produce a fast pipeline with a functional major cycle including direction dependent calibration along with a capable imager



Join us at our next busy week!