ASTRON

Netherlands Institute for Radio Astronomy

LOFAR Calibration & Imaging Tiger Team

Overview, Progress, & Planning

George Heald

LOFAR Users Meeting

07/04/2014

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

LOFAR

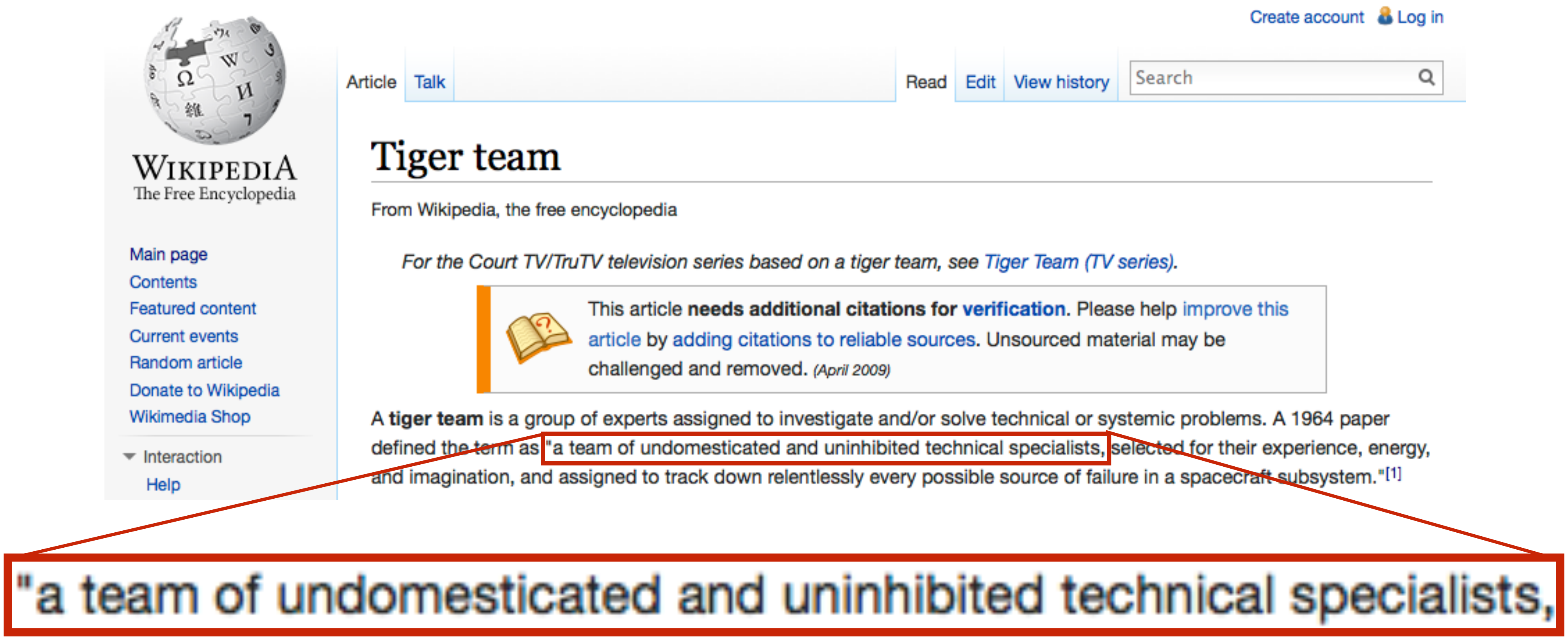
Outline

- Project motivation and scope
- Team members and development priorities
- Information exchange
- Development paths and progress: specifics
- Timeline and milestones

Project priorities:
1. Enable better quality images
2. Improve performance

So… what is a “tiger team”?

LOFAR ASTRON



- James Ballard (US Navy): “[…] a self-contained team that include[s] all the skill sets and resources needed to do the work - […] a small hand-picked, particularly skilled and capable group of ‘tigers,’ […] to plan for and/or achieve a very specific mission”

LOFAR ASTRON

- At the last LOFAR Science Workshop:

Development Overview

LOFAR ASTRON

- Development priorities for 2013
  - *Support and improve system for Cycle 0 operations*
  - *COBALT replacement of the BG/P and CEP2 upgrade*
  - *Improvements to speed and functionality of Long-Term Archive (LTA)*
  - *Enhancements to support initial responsive telescope capability*
  - *Improvements to performance and flexibility of imaging pipeline*

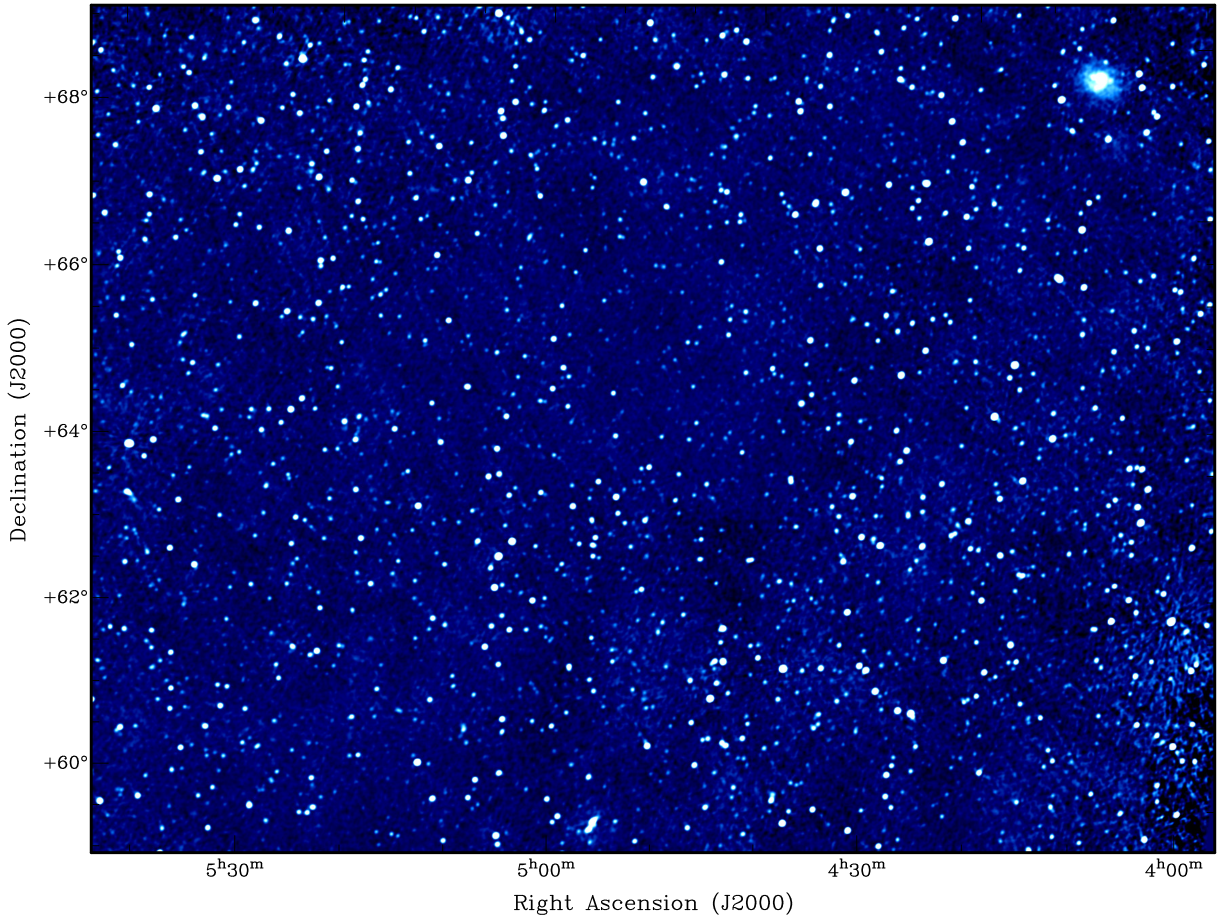
Person	Expertise	Availability
Arno Schoenmakers	Scrum leader, package support, testing	100%
Arthur Coolen	Navigator	100%
Nico Vermaas	MoM, OTB	100%
Alwin de Jong	Scheduler, XML generator	100%
Adriaan Renting	Archive ingest, data model and formats	100%
Ger van Diepen	Imager, pipeline framework, casecore	20%
Marcel Loose	Pipeline framework, software librarian	20%
Ruud Overeem	MAC, SAS, PVSS database, station control	20%
Jan David Mol	Real-time system, pulsar processing	20%
Pieter Donker	Firmware, station control	20%
Wouter Klijn	Pipeline framework, integration	20%

Very limited new functionality for Cycle 1

Michael Wise / Dalfsen Science Workshop / March 19, 2013 12

Motivation & scope

- Automatic GSM-calibrated imaging pipeline suitable for MSSS usage



Pipeline provides good performance for a shallow, snapshot, low resolution survey

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

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

	Image rms	Typical dynamic range
LBA	1-2 mJy/beam	2000:1
HBA	0.1-0.2 mJy/beam	5000:1

CITT members and roles

George Heald
PI

Tammo Jan Dijkema
Project Manager
Calibration tools

Bas van der Tol
LOFAR Imager

Nicolas Vilchez
Selfcalibration pipeline

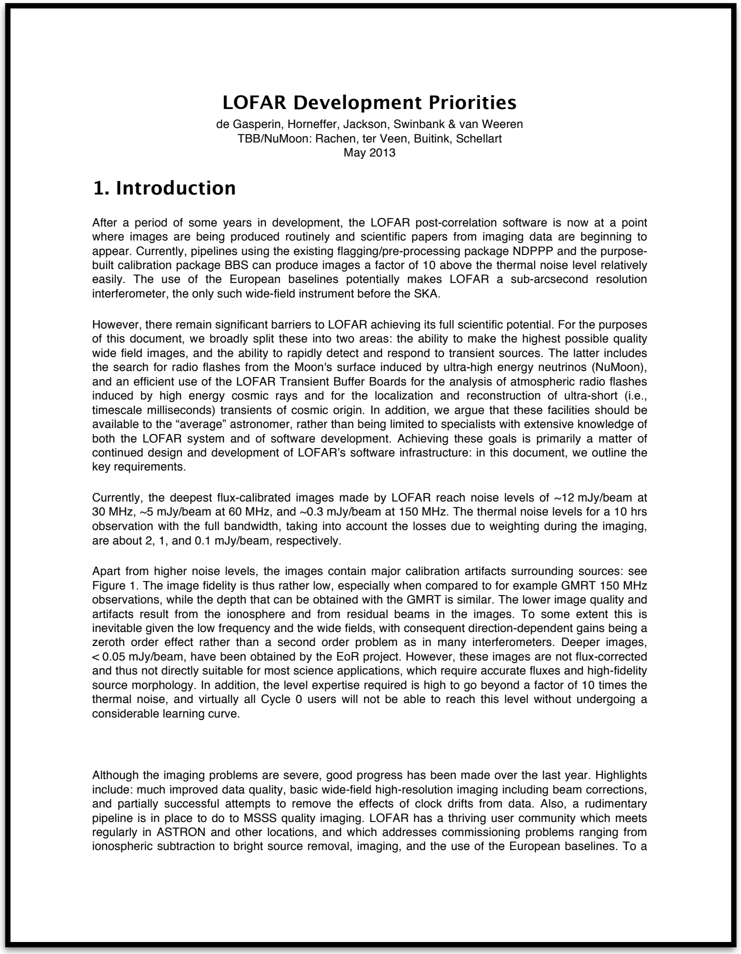
David Rafferty
Ionospheric calibration

Manu Orru &
Carmen Toribio
RO Liasons

Tiger Team Advisory Group

- Panel of external calibration & imaging experts, formed to provide valuable input to the TT and provide communication channel to science teams
  - for example: creation of `awimager` Use Cases
  - biweekly telecon schedule
- Team members:
  - Björn Adebahr (MPIfR)
  - Jess Broderick (Oxford)
  - Francesco De Gasperin (Hamburg)
  - Martin Hardcastle (Hertfordshire)
  - Maaijke Mevius (ASTRON)
  - Reinout van Weeren (CfA)



LOFAR Development Priorities

de Gasperin, Horneffer, Jackson, Swinbank & van Weeren
TBB/NuMoon: Rachen, ter Veen, Buitink, Schellart
May 2013

1. Introduction

After a period of some years in development, the LOFAR post-correlation software is now at a point where images are being produced routinely and scientific papers from imaging data are beginning to appear. Currently, pipelines using the existing flagging/pre-processing package NDPPP and the purpose-built calibration package BBS can produce images a factor of 10 above the thermal noise level relatively easily. The use of the European baselines potentially makes LOFAR a sub-arcsecond resolution interferometer, the only such wide-field instrument before the SKA.

However, there remain significant barriers to LOFAR achieving its full scientific potential. For the purposes of this document, we broadly split these into two areas: the ability to make the highest possible quality wide field images, and the ability to rapidly detect and respond to transient sources. The latter includes the search for radio flashes from the Moon's surface induced by ultra-high energy neutrinos (NuMoon), and an efficient use of the LOFAR Transient Buffer Boards for the analysis of atmospheric radio flashes induced by high energy cosmic rays and for the localization and reconstruction of ultra-short (i.e., timescale milliseconds) transients of cosmic origin. In addition, we argue that these facilities should be available to the "average" astronomer, rather than being limited to specialists with extensive knowledge of both the LOFAR system and of software development. Achieving these goals is primarily a matter of continued design and development of LOFAR's software infrastructure: in this document, we outline the key requirements.

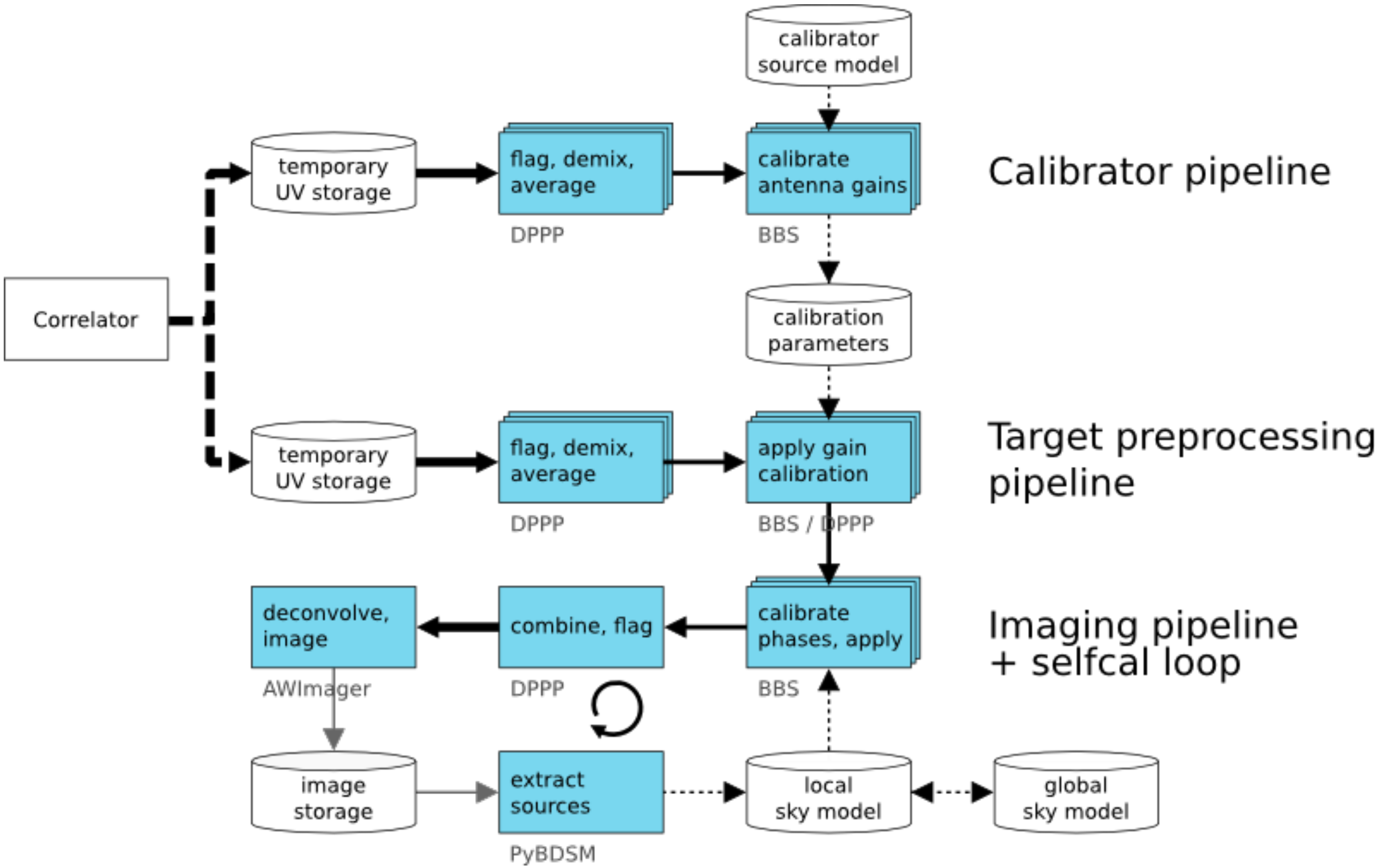
Currently, the deepest flux-calibrated images made by LOFAR reach noise levels of ~12 mJy/beam at 30 MHz, ~5 mJy/beam at 60 MHz, and ~0.3 mJy/beam at 150 MHz. The thermal noise levels for a 10 hrs observation with the full bandwidth, taking into account the losses due to weighting during the imaging, are about 2, 1, and 0.1 mJy/beam, respectively.

Apart from higher noise levels, the images contain major calibration artifacts surrounding sources: see Figure 1. The image fidelity is thus rather low, especially when compared to for example GMRT 150 MHz observations, while the depth that can be obtained with the GMRT is similar. The lower image quality and artifacts result from the ionosphere and from residual beams in the images. To some extent this is inevitable given the low frequency and the wide fields, with consequent direction-dependent gains being a zeroth order effect rather than a second order problem as in many interferometers. Deeper images, < 0.05 mJy/beam, have been obtained by the EoR project. However, these images are not flux-corrected and thus not directly suitable for most science applications, which require accurate fluxes and high-fidelity source morphology. In addition, the level expertise required is high to go beyond a factor of 10 times the thermal noise, and virtually all Cycle 0 users will not be able to reach this level without undergoing a considerable learning curve.

Although the imaging problems are severe, good progress has been made over the last year. Highlights include: much improved data quality, basic wide-field high-resolution imaging including beam corrections, and partially successful attempts to remove the effects of clock drifts from data. Also, a rudimentary pipeline is in place to do to MSSS quality imaging. LOFAR has a thriving user community which meets regularly in ASTRON and other locations, and which addresses commissioning problems ranging from ionospheric subtraction to bright source removal, imaging, and the use of the European baselines. To a

LOFAR Imaging Pipeline

- Provides first-level automatic data processing (to images), written in C++ and python .... LOFAR's "science data processor"



Calibration: Status and Plans

- Problem: BBS not fast enough for efficient pipeline calibration

- Status: Prototype of NDPPP stefcal step:
  - 15x faster (still w/o multithreading & w/o optimizations)
  - Negligible memory usage
  - Full polarization, complex calibration, beam applied
  - Shows same result within ambiguities as BBS gains using same strategy

- Plans:
  - Improve direction independent calibration
  - Investigate efficient direction dependent calibration
  - To be implemented in NDPPP or BBS

- **Short term deliverable: functional enhancement to NDPPP**

Imaging: Status and Plans

- Problem: AWImager currently not production quality software
  - Lacks key features and is too slow / memory intensive
- Status: Refactor to maintainable software
  - Link with latest Casa 4.2 ➡ wideband imaging
- Plans: Improve performance
  - Multithreading, GPU? (TBD)
  - Multiple nodes ➡ scalable performance
    - NB: imager is on the “critical path”
- **Short term deliverable: fully functional imager on new build**

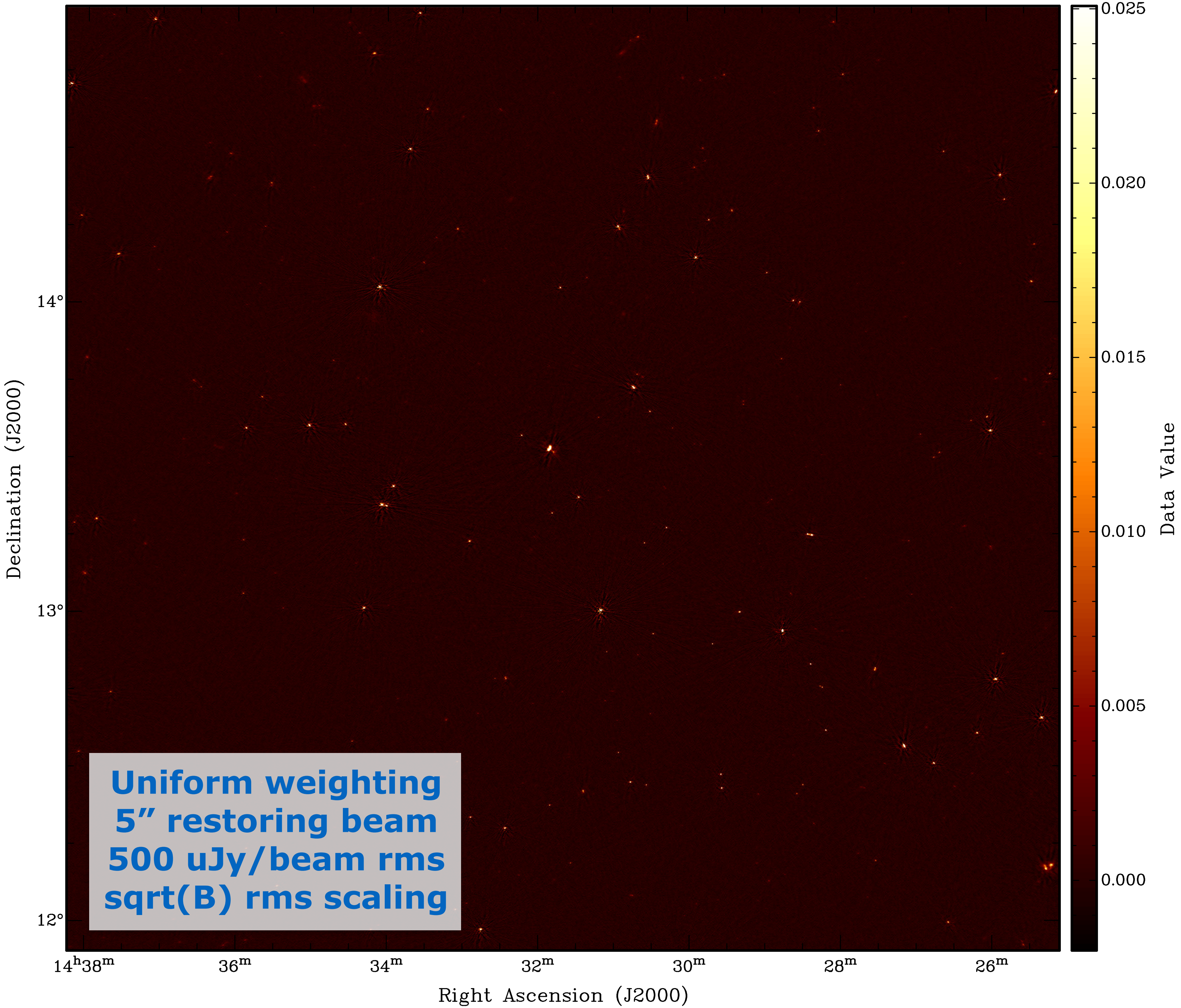
Selfcal pipeline: Status and Plans

- Problem: major cycle not closed

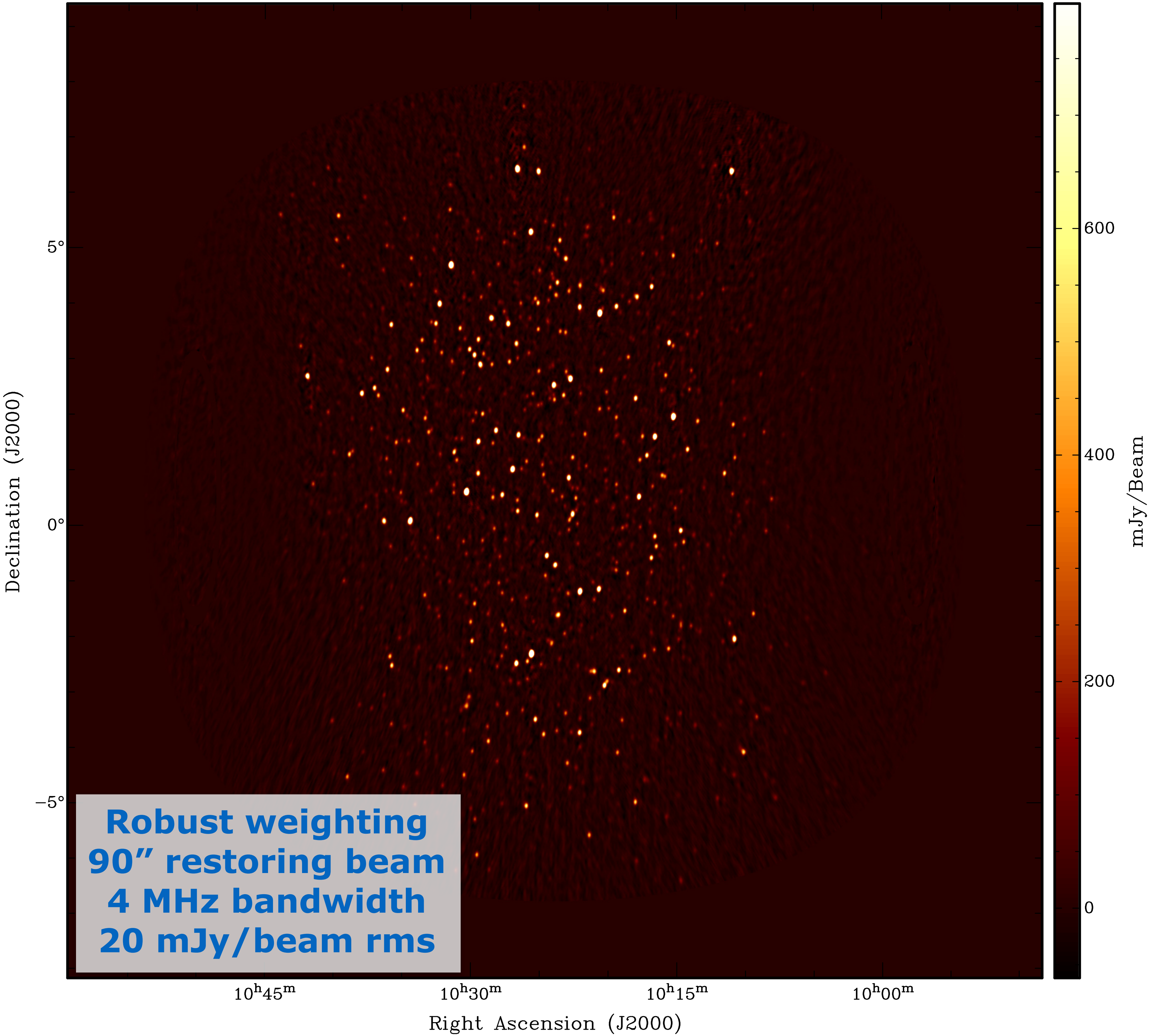
- Status: Standalone selfcal pipeline available
  - Demonstrated in HBA low, LBA, and HBA high
  - HBA low: 15x lower noise, 500 μJy/beam in full band
  - Description in newest version of cookbook

- Plans: Enhance capability
  - Incorporate direction dependent effects
  - Merge enhanced tools as they become available

- **Short term deliverable: Enhanced selfcal w/ simple peeling**



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


Robust weighting
90” restoring beam
4 MHz bandwidth
20 mJy/beam rms
Declination (J2000)
5°
0°
−5°
Right Ascension (J2000)
10h45m
10h30m
10h15m
10h00m
mJy/Beam
600
400
200
0

Ionosphere: Status and Plans

- Problem: LOFAR images strongly limited by ionospheric effects

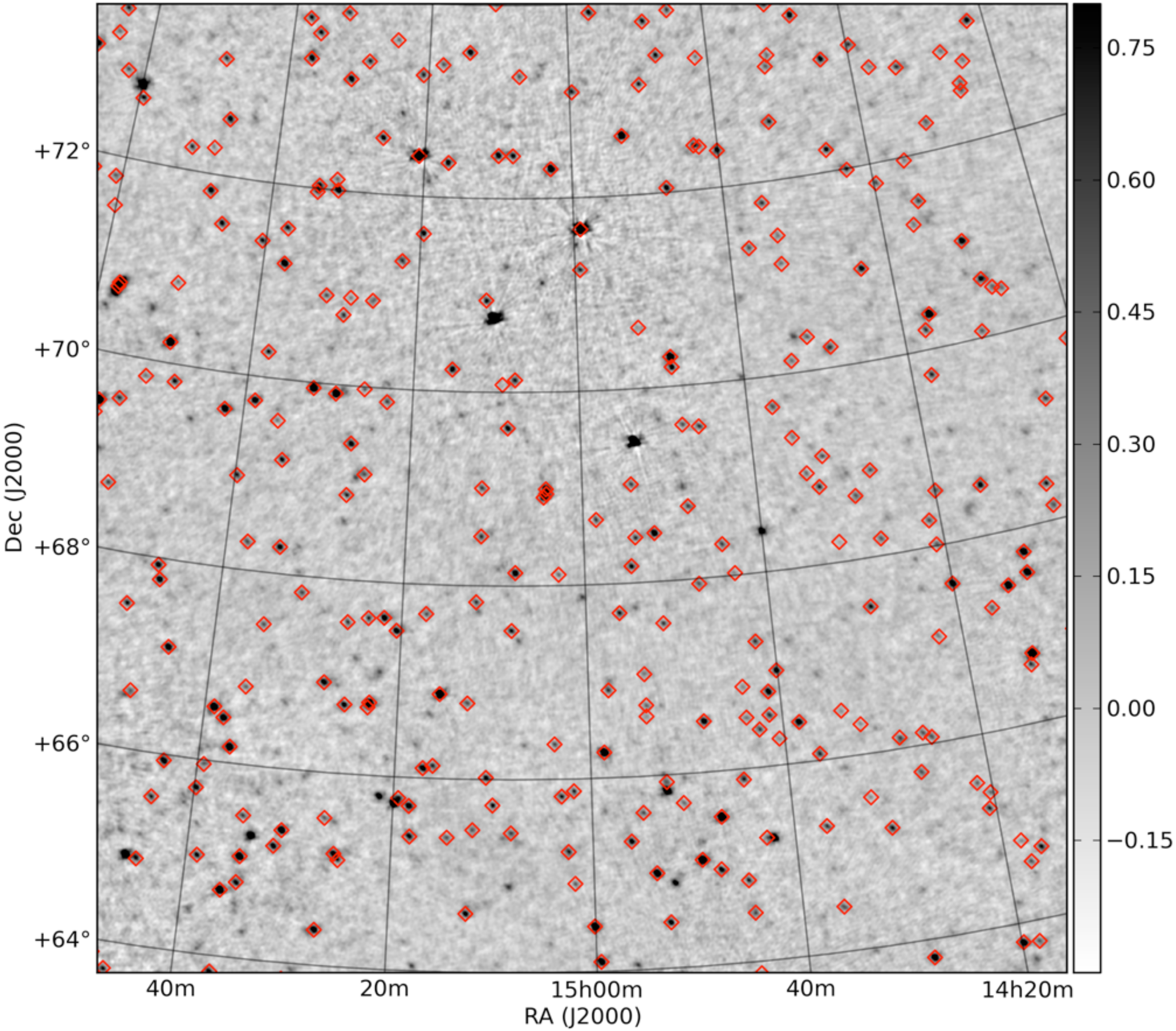
- Status: Handcrafted tools in use now
  - Demonstrated improvement on MSSS LBA images
  - Uses BBS and existing awimager

- Plans: Move toward an automatic recipe
  - Verify general applicability of the scheme (LBA and HBA)
  - Translate manual aspects to automatic tools
  - Merge enhanced tools as they become available

- **Short term deliverable: Ionospheric recipe for LOFAR data**

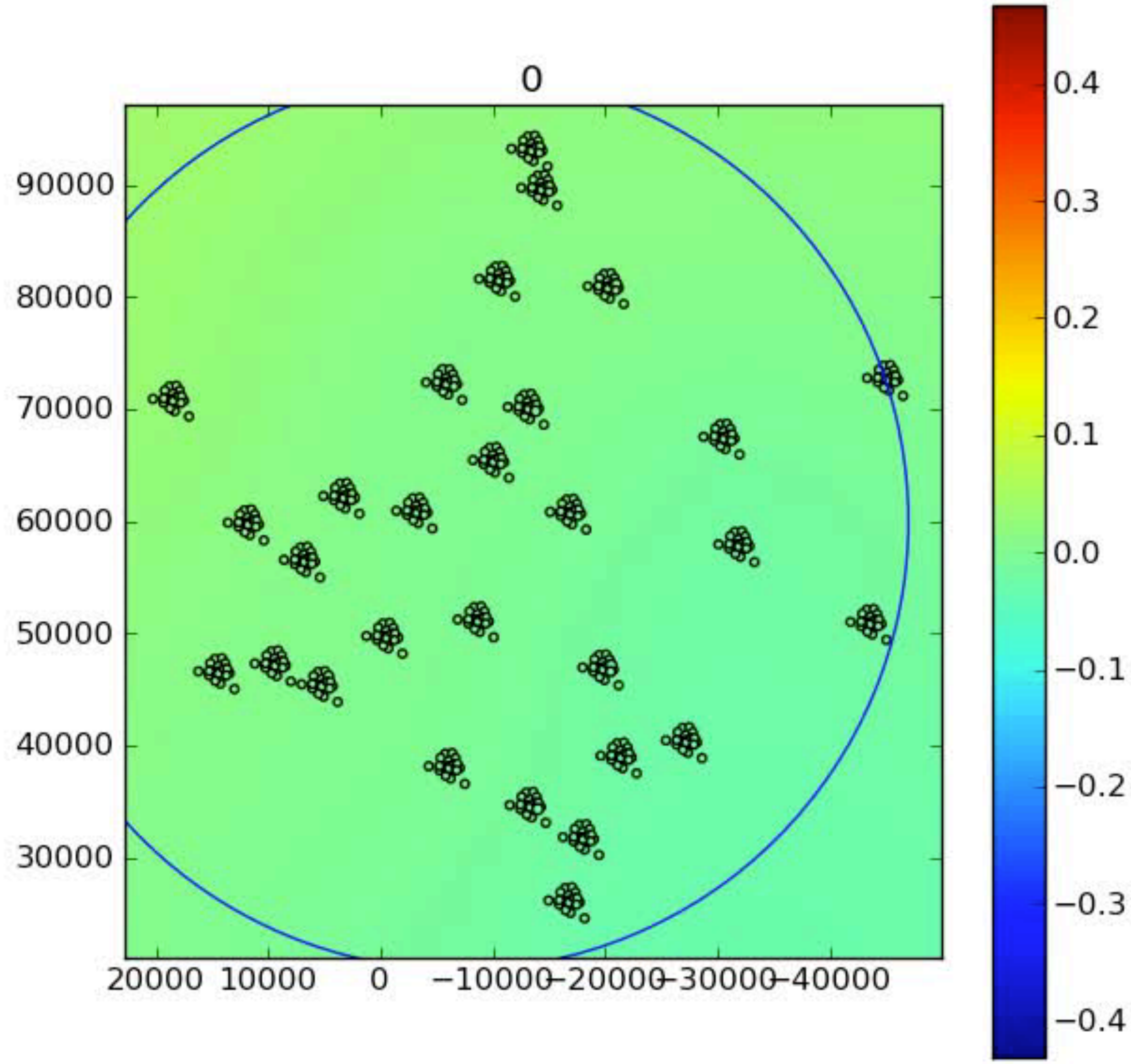
MSSS Verification Field (MVF)

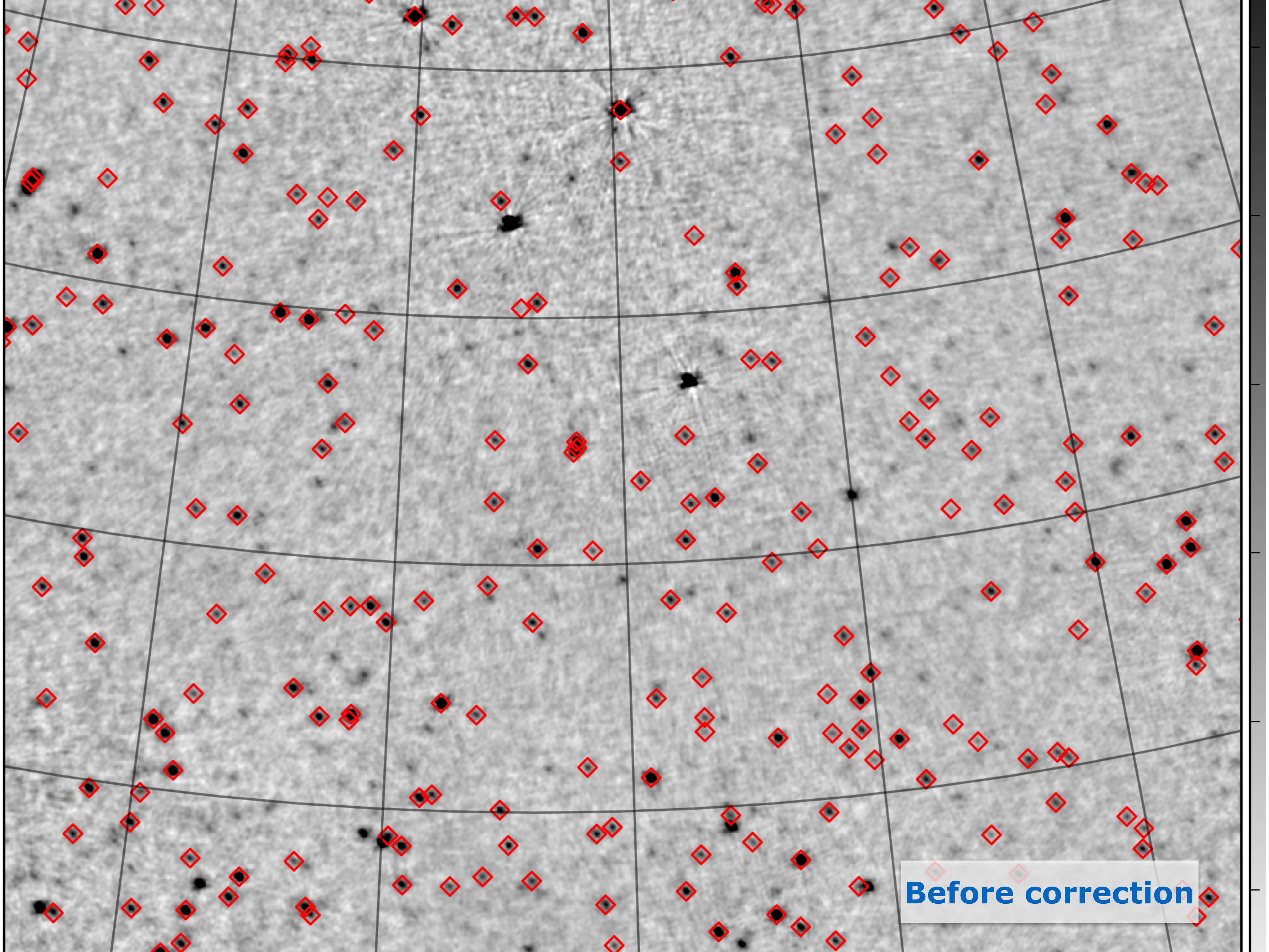
- LBA 46 mJy/beam, 2′ resolution

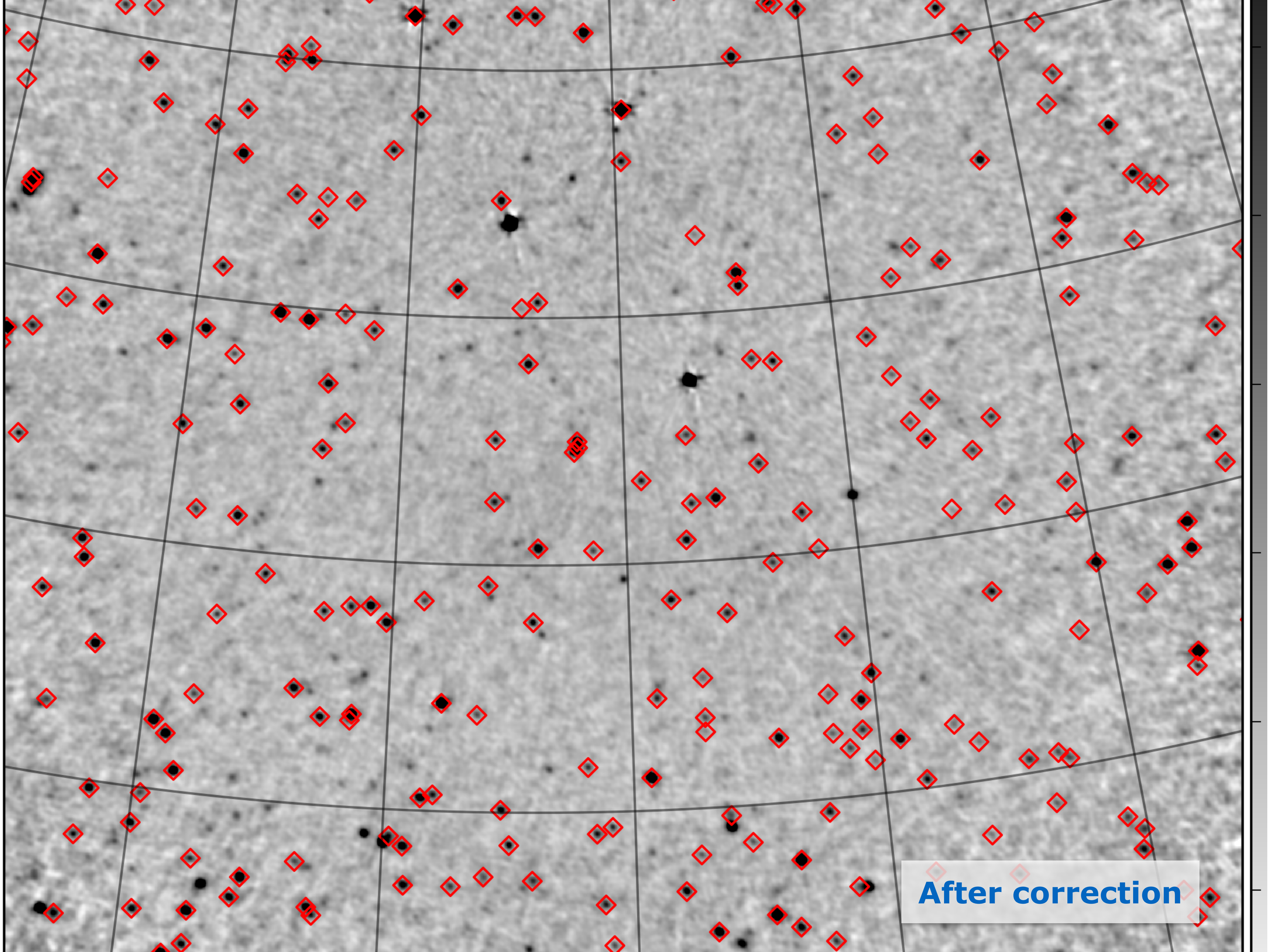


Determination of MVF phase screens

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

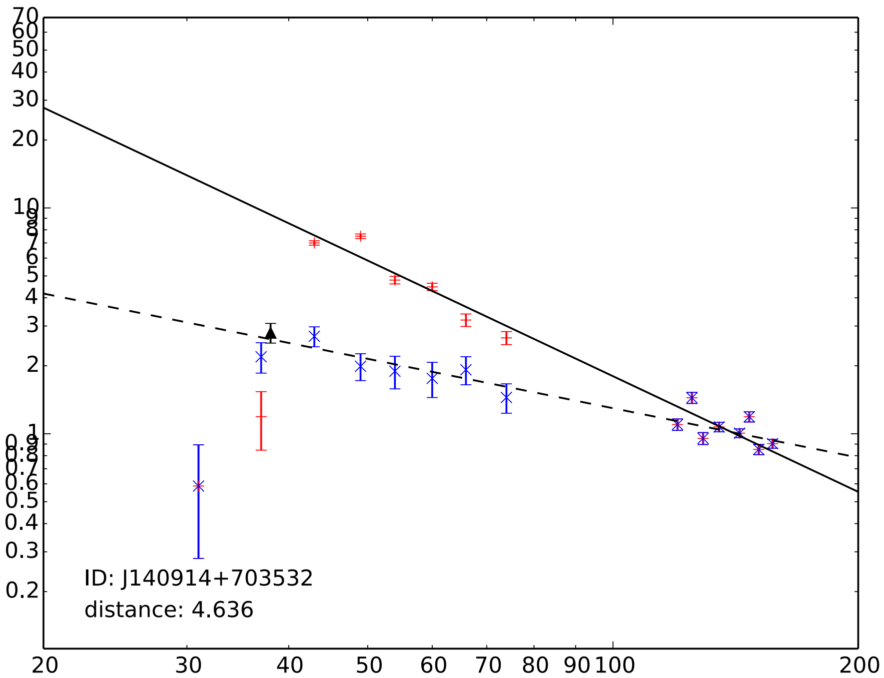


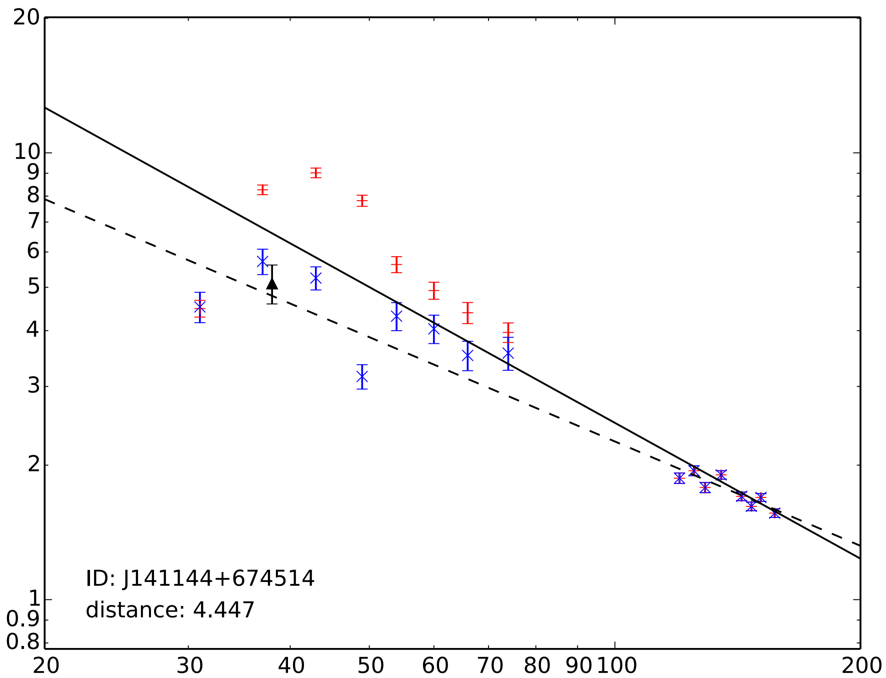

Before correction


After correction

Ionospheric corrections

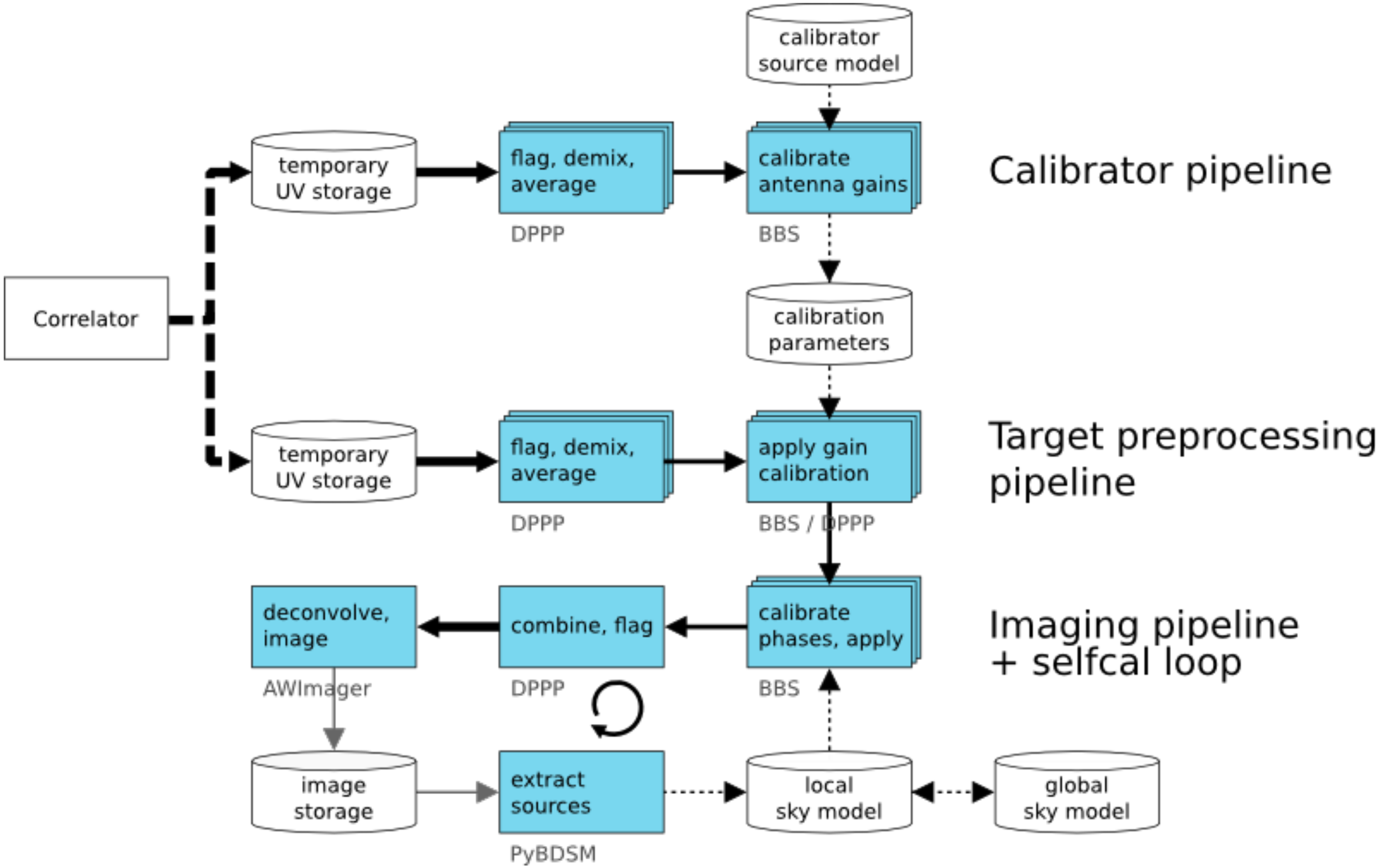
- Determined on basis of BBS direction-dependent gain solutions
- TEC screen fitted using specialty, but generalizable, procedure
- TECs applied in awimager to directly produce corrected images
- Little improvement in image rms, but 50% more sources detected at lowest frequencies … and with more reliable fluxes & positions

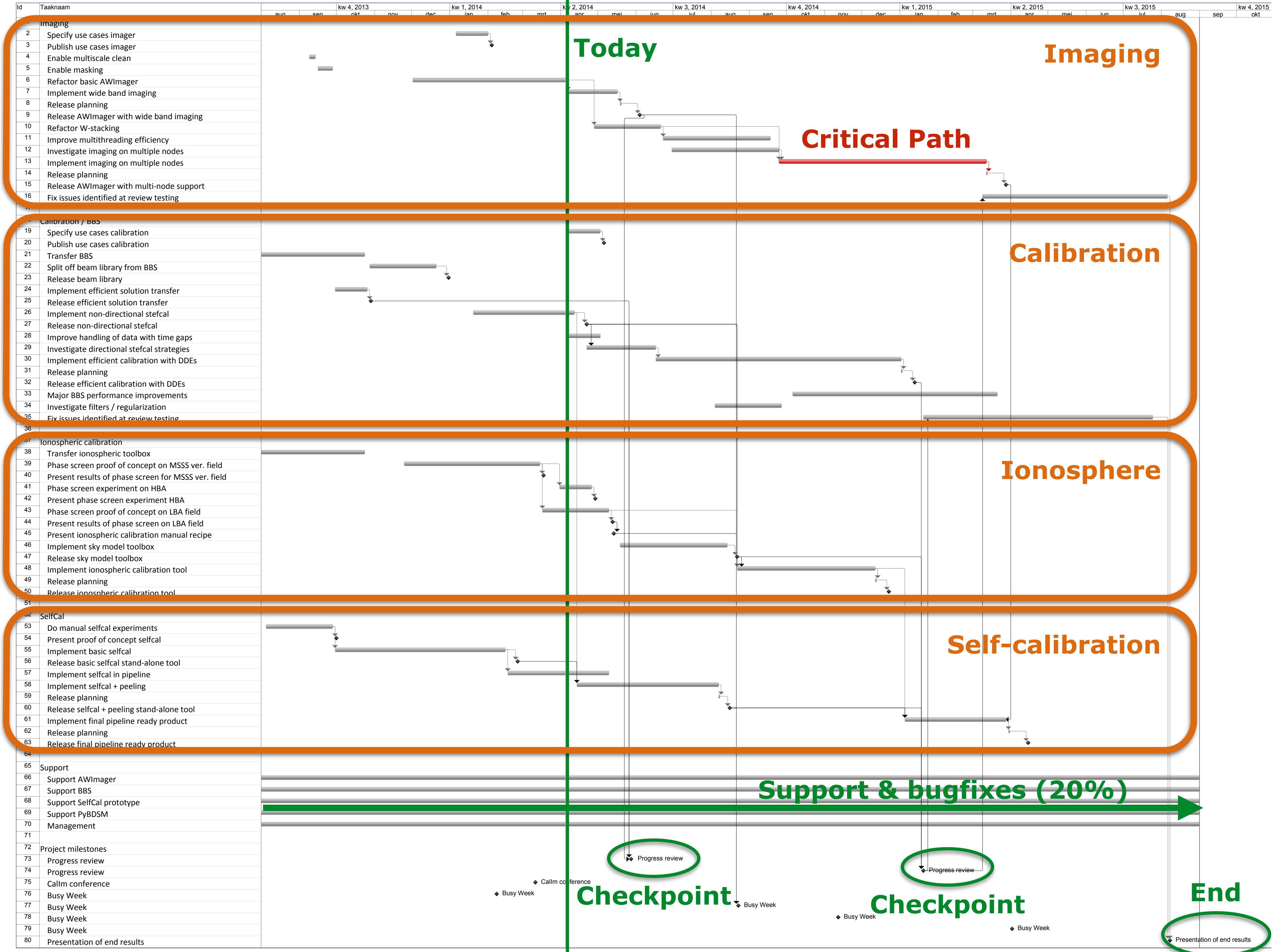




Looking forward

- Ultimately merging these development streams to produce a fast pipeline with a functional major cycle including direction dependent calibration and a capable imager




Id
Taaknaam
kw 4, 2013
kw 1, 2014
kw 2, 2014
kw 3, 2014
kw 4, 2014
kw 1, 2015
kw 2, 2015
kw 3, 2015
kw 4, 2015
Imaging
2 Specify use cases imager
3 Publish use cases imager
4 Enable multiscale clean
5 Enable masking
6 Refactor basic AWImager
7 Implement wide band imaging
8 Release planning
9 Release AWImager with wide band imaging
10 Refactor W-stacking
11 Improve multithreading efficiency
12 Investigate imaging on multiple nodes
13 Implement imaging on multiple nodes
14 Release planning
15 Release AWImager with multi-node support
16 Fix issues identified at review testing
Calibration / BBS
19 Specify use cases calibration
20 Publish use cases calibration
21 Transfer BBS
22 Split off beam library from BBS
23 Release beam library
24 Implement efficient solution transfer
25 Release efficient solution transfer
26 Implement non-directional stefcal
27 Release non-directional stefcal
28 Improve handling of data with time gaps
29 Investigate directional stefcal strategies
30 Implement efficient calibration with DDEs
31 Release planning
32 Release efficient calibration with DDEs
33 Major BBS performance improvements
34 Investigate filters / regularization
35 Fix issues identified at review testing
Ionospheric calibration
38 Transfer ionospheric toolbox
39 Phase screen proof of concept on MSSS ver. field
40 Present results of phase screen for MSSS ver. field
41 Phase screen experiment on HBA
42 Present phase screen experiment HBA
43 Phase screen proof of concept on LBA field
44 Present results of phase screen on LBA field
45 Present ionospheric calibration manual recipe
46 Implement sky model toolbox
47 Release sky model toolbox
48 Implement ionospheric calibration tool
49 Release planning
50 Release ionospheric calibration tool
SelfCal
53 Do manual selfcal experiments
54 Present proof of concept selfcal
55 Implement basic selfcal
56 Release basic selfcal stand-alone tool
57 Implement selfcal in pipeline
58 Implement selfcal + peeling
59 Release planning
60 Release selfcal + peeling stand-alone tool
61 Implement final pipeline ready product
62 Release planning
63 Release final pipeline ready product
65 Support
66 Support AWImager
67 Support BBS
68 Support SelfCal prototype
69 Support PyBDSM
70 Management
72 Project milestones
73 Progress review
74 Progress review
75 Callm conference
76 Busy Week
77 Busy Week
78 Busy Week
79 Busy Week
80 Presentation of end results
Today
Imaging
Critical Path
Calibration
Ionosphere
Self-calibration
Support & bugfixes (20%)
Progress review
Progress review
Callm conference
Busy Week
Busy Week
Busy Week
Busy Week
Checkpoint
Checkpoint
End
Presentation of end results

Timeline: milestones

- August 2013: Project start
- February 2014: Busy week testing CITT developments
- June 2014: Progress review [**Goal: deliver enhanced capability**]
    - Imager with wideband/multiscale imaging, built against casa 4.2
    - Manual recipe for direction-dependent ionospheric calibration
    - Direction-independent stefcal
    - Selfcal tool with simple peeling scheme
- August 2014: Busy week testing CITT developments
- November 2014: Busy week testing CITT developments
- February 2015: Progress review [**Goal: more capability & speedups**]
    - Functioning prototype pipeline with ionosphere
- July 2015: Project end [**Goal: full capability & performance**]
    - Pipeline-ready end product