ASTRON

Netherlands Institute for Radio Astronomy

LOFAR CITT

Calibration & Imaging Tiger Team

Welcome & Beam update

George Heald (CITT1 PI)

CITT meeting, 17/9/2015

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

CALIBRATION AND IMAGING TIGER TEAM

LOFAR

Outline

- CITT1 overview
- This meeting
- Beams, flux scale, and spectra

A tiger, working hard for you

CITT1 members and roles

George Heald
PI

Tammo Jan Dijkema
Project Manager
Calibration tools

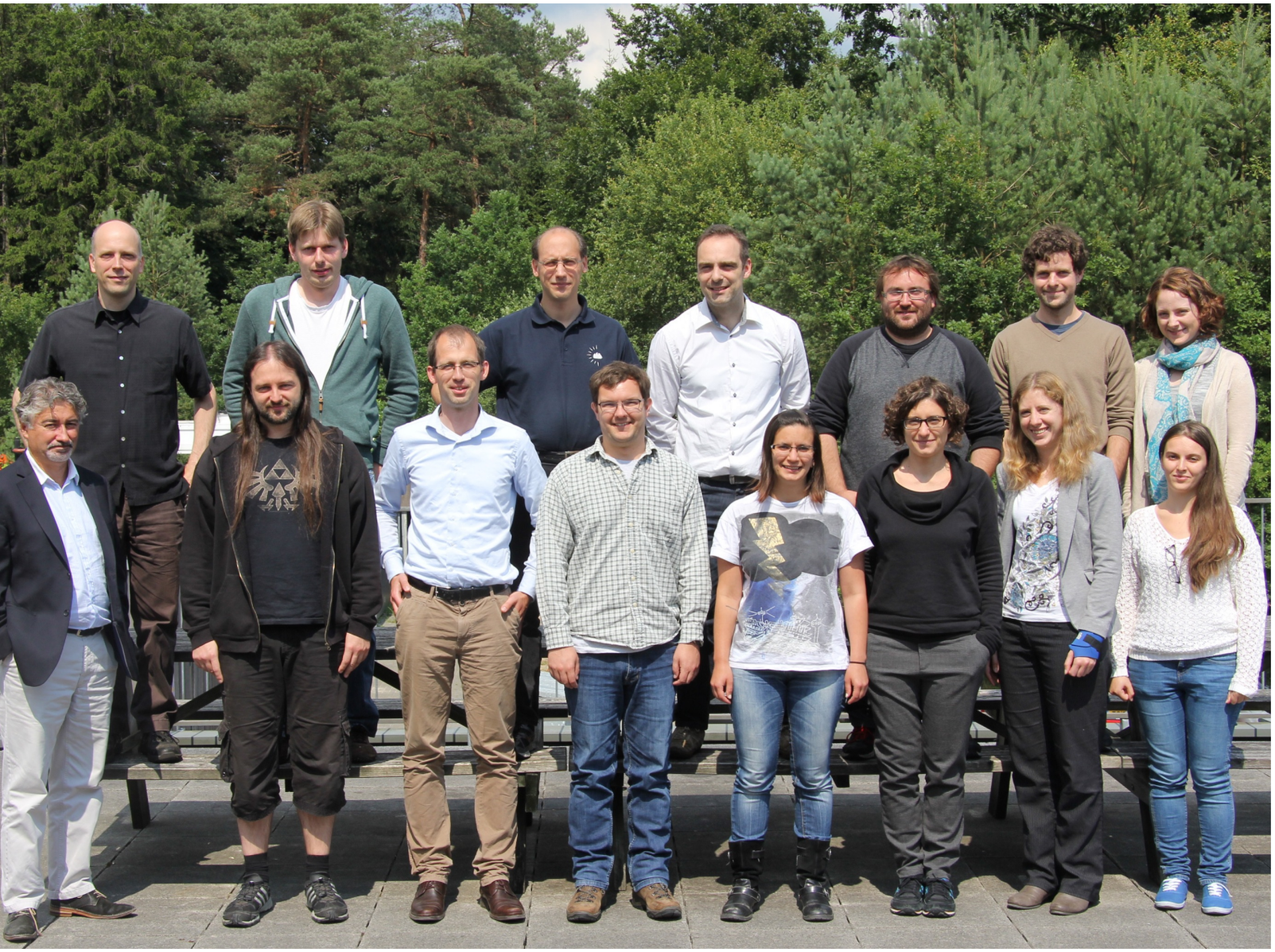
Bas van der Tol
LOFAR Imager

Nicolas Vilchez
Selfcalibration pipeline

David Rafferty
Ionospheric calibration

Stefan Fröhlich
HPC consultant

Tim Shimwell
Calibration & surveys



CITT Mid-year Progress Workshop, 2014

Manu Orru &
Carmen Toribio
RO Liasons

Summary of activity (main points)

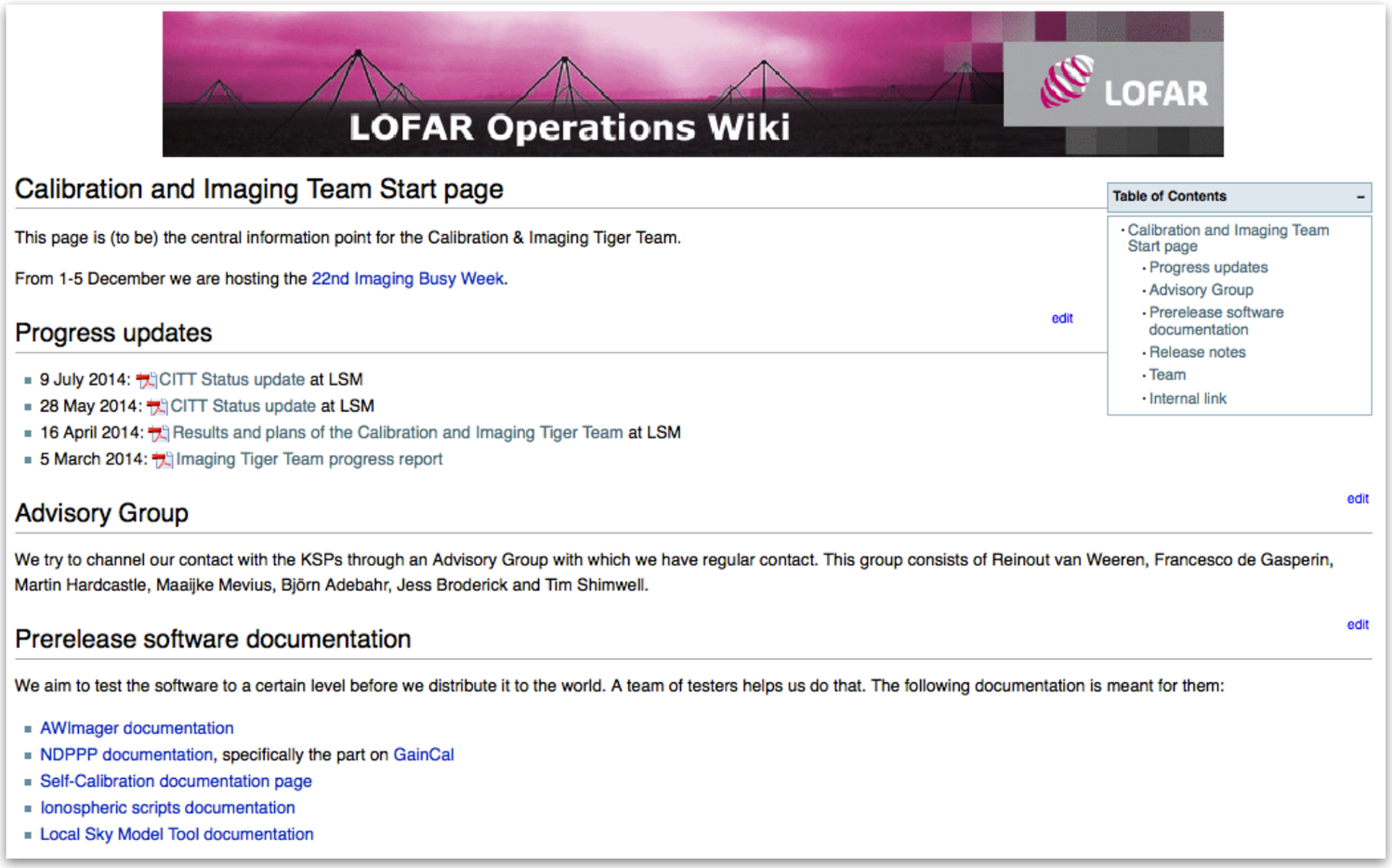
- Calibration in NDPPP/BBS
  - Demonstrated huge speedup (40x) and memory usage improvement
  - **Delivered substantially improved capability in NDPPP**
- Imaging in awimager [critical path]
  - improvements to feature set through build against casa 4.2
  - acceleration development well under way
  - **Delivered fully functional imager in new build**
- Self-calibration recipe
  - direction-independent: standalone and pipeline implementation
  - development of direction dependent version well under way
  - **Delivered functional selfcal pipeline [available on github]**
- Ionospheric / direction-dependent calibration (BBS+awimager)
  - Decision taken to transition from phase screen to extreme peeling
  - **Delivered integrated direction dependent pipeline**

Other supporting activities

- Smart demixing
  - Required for good quality HBA data to enter the pipeline
  - New scheme not yet verified
  - Testing started with new dataset (Horneffer)
- Beam model adjustments
  - For now, normalization (HBA flux scale)
    - Further improvements will need commitment at ASTRON
- Continued support of software packages (BBS etc), ~20% time
- Fast rollout of improvements to the community
  - e.g. gaincal, awimager, support of LoSoTo, LSM tool, …
- Engagement with the RO to implement software in operational system (to come: pipeline structure)
- Support release of casacore 2.0 (now for NRAO and LOFAR)

Documentation

- Documentation can always be improved, but we've kept usage information up to date as we move along (cookbook & wiki):



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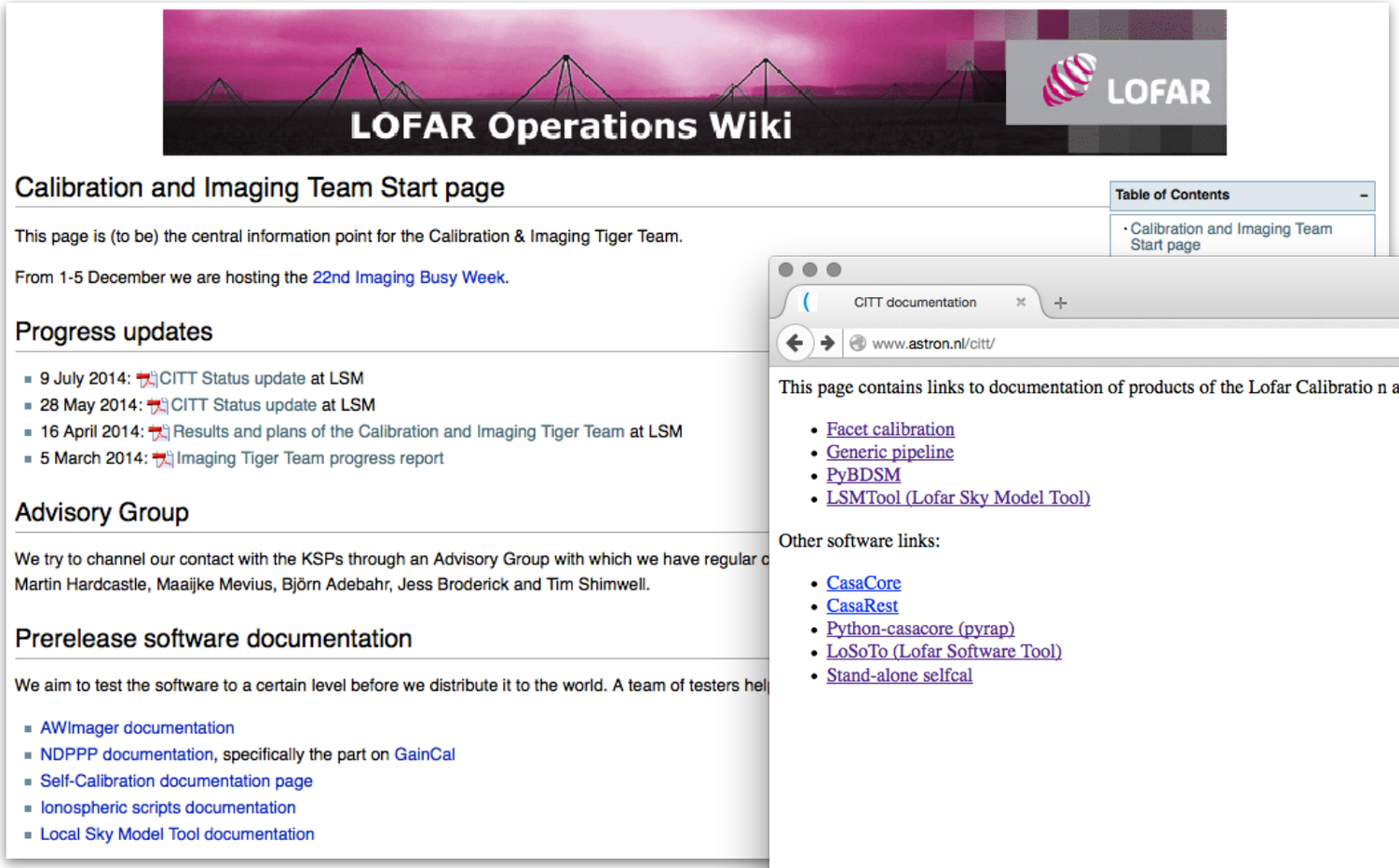

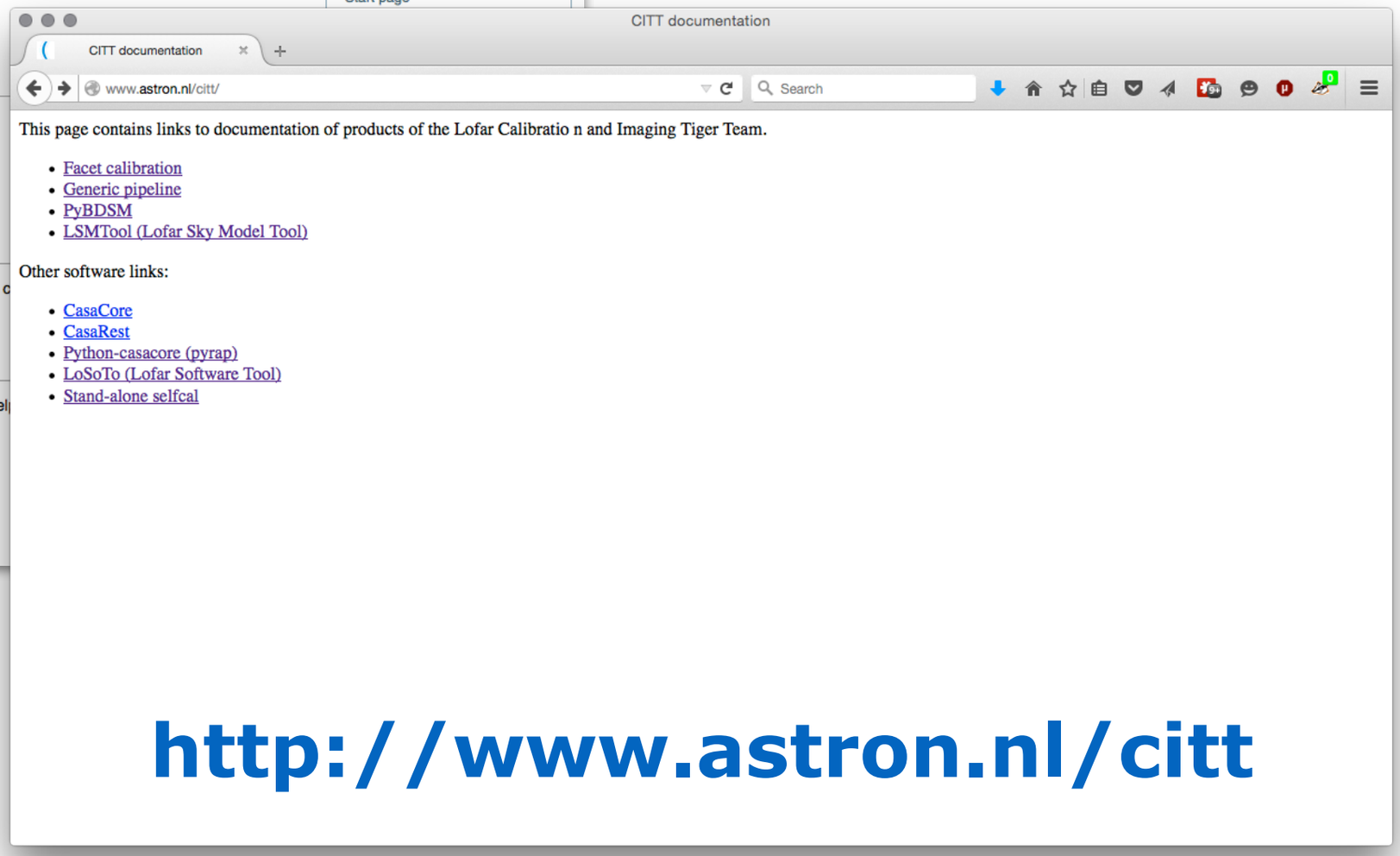

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This meeting

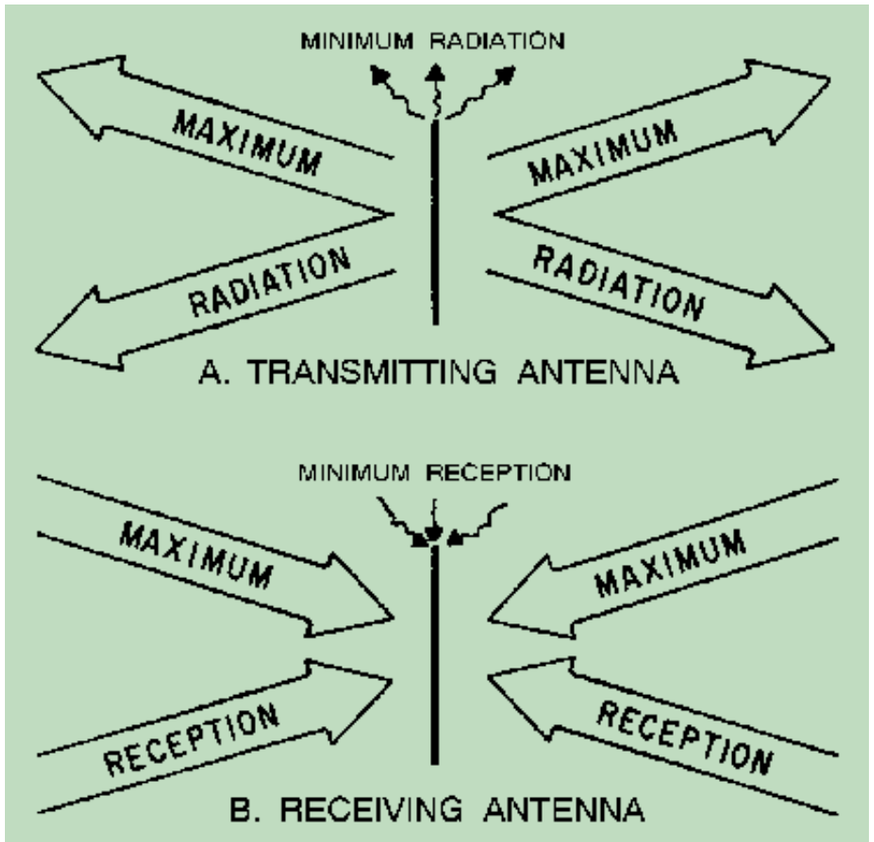
- Review CITT1 progress and status
- Advertise availability of documentation
- Instruct community in use of CITT products
  How to get Tiger Team products on your desktop!

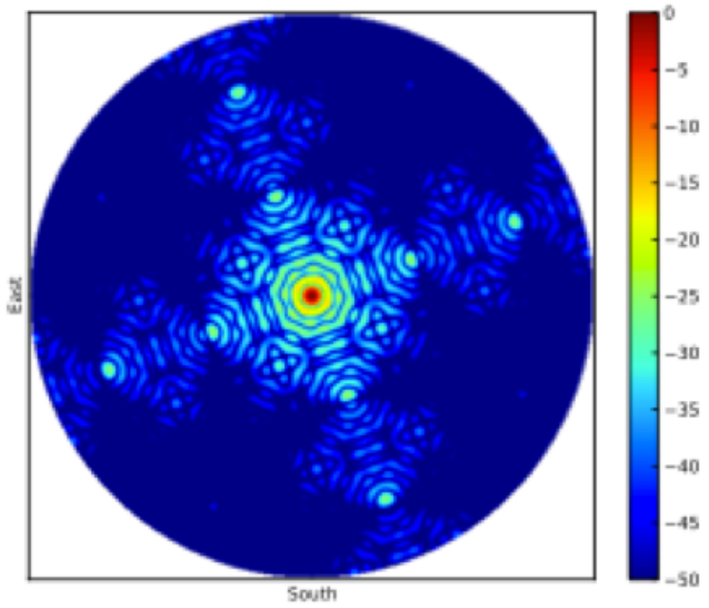
- Forward look & plan for CITT2!

Flux scale

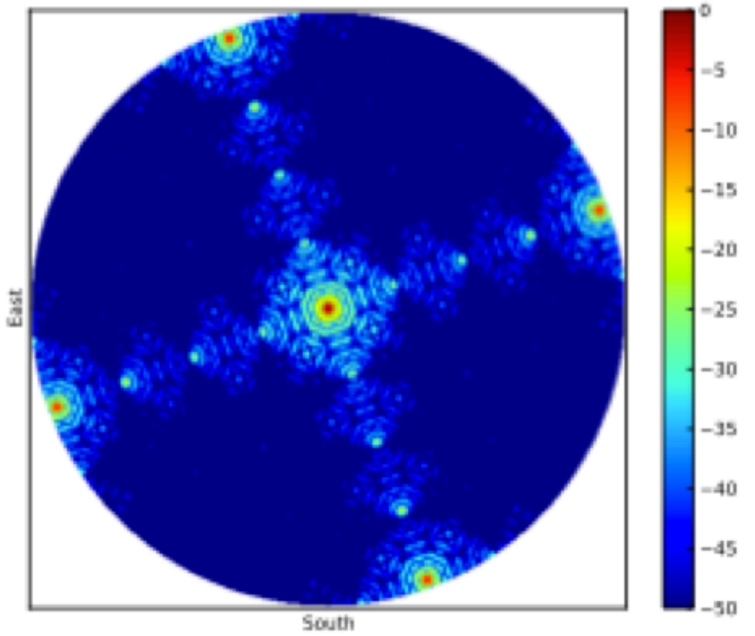
Unmodeled beam effects

- Aspects not included in LOFAR's standard beam model
  - power in grating lobes
  - mutual coupling
- These can lead to strong frequency dependent effects





150 MHz



240 MHz

Beam images from Michiel Brentjens

Bruteforce correction: beam integrals

- Adjust beam model with empirical normalization values:

$$A_d(\theta,\phi) = C_d \sum_i a_i \, e^{ik\vec{r}_i\cdot\hat{r}} \equiv C_d \, A'_d(\theta,\phi)$$

Heald et al (in prep)

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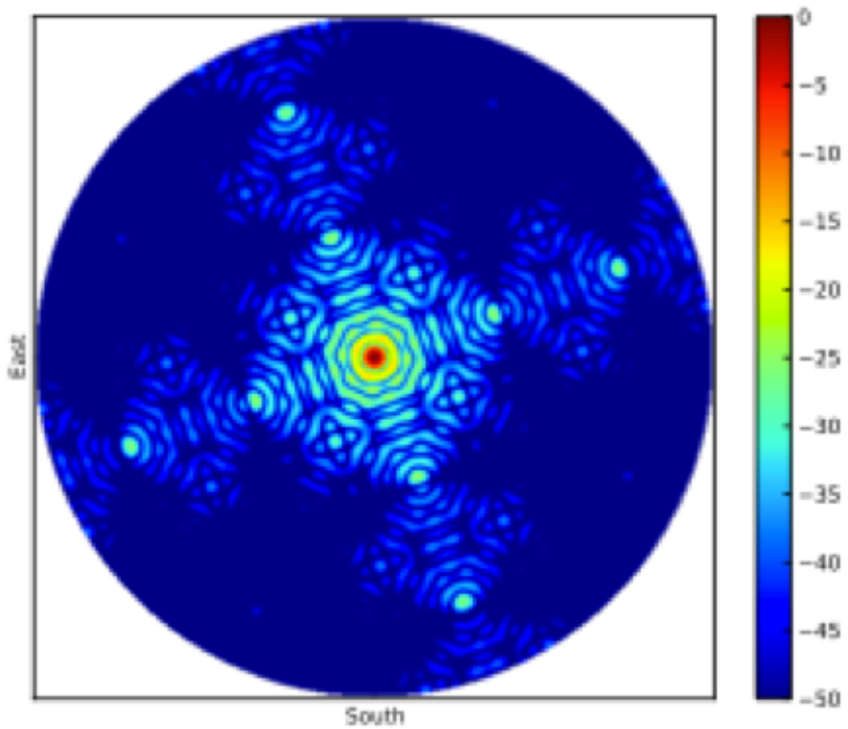
C_d (el=0, 150 MHz) = $\int$ dl dm



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Implementation & verification

- Beam integrals computed and stored in 3D FITS cube
  - Computed for CS002HBA1 (rotation=0)
  - All other stations are rotated version of CS002HBA1 (assuming HBA_DUAL_INNER and neglecting intl stations)
  - Stored in wcs horizon coordinates and frequency ($\Delta\nu$=5 MHz)
  - Mode 5 ready; mode 7 in progress
  - FITS cubes read by modified beam model and used to normalize digital beam response

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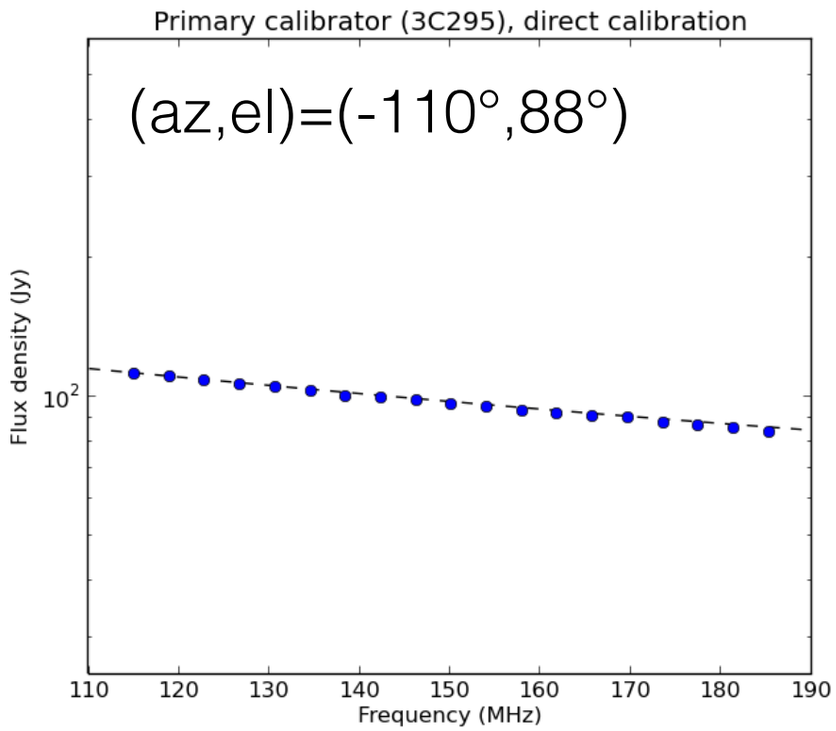
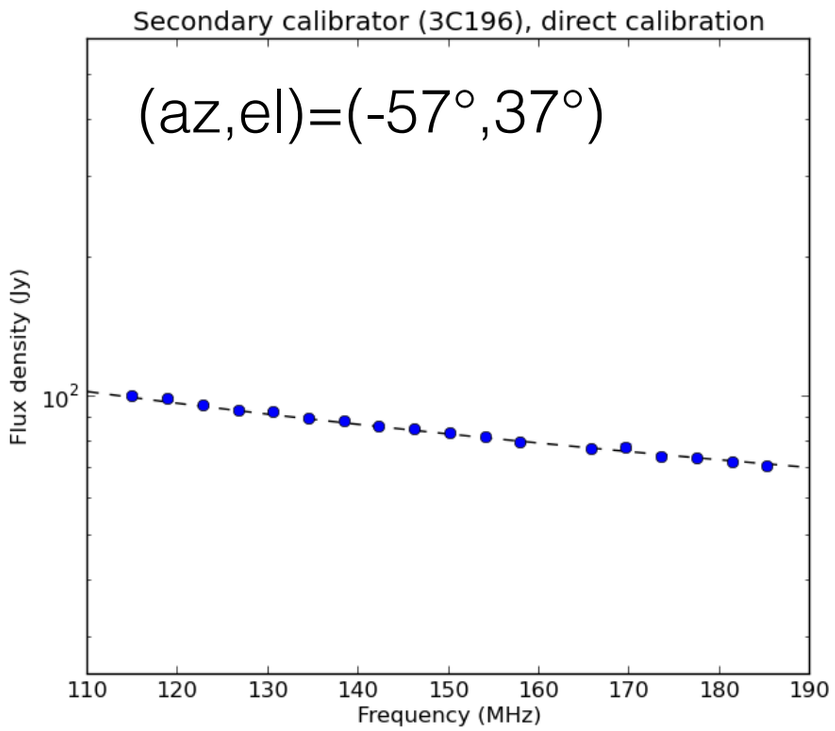
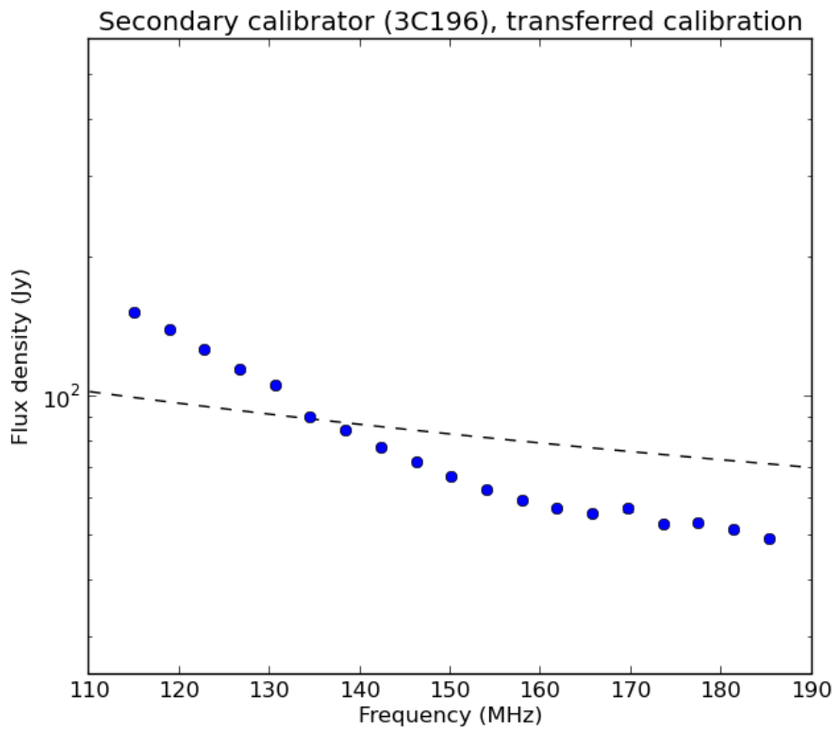
  - Mode 5 ready; mode 7 in progress
    - FITS cubes read by modified beam model and used to normalize digital beam response
- Being verified through LC1_014 (Scaife, Heald & Perley)
  - 24-hour sequence of 3-minute calibrator snapshots
  - LBA_INNER, HBA_DUAL_INNER modes 5 and 7
  - Parallelized cross-calibration script developed to determine quality of correction (takes ~12 minutes per calibrator pair)

Verification: results

- Example: 3C295 calibrating 3C196







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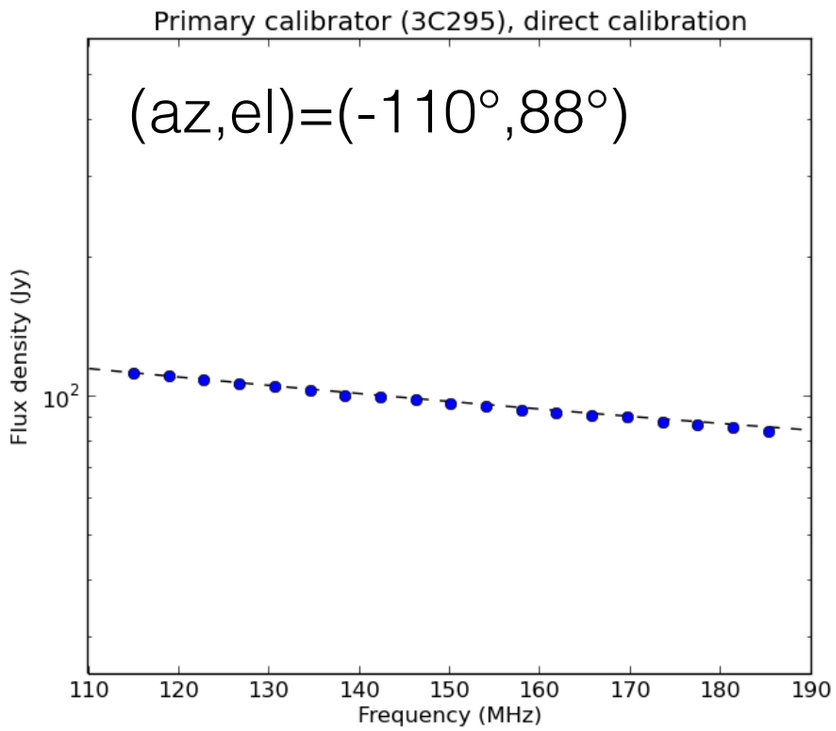

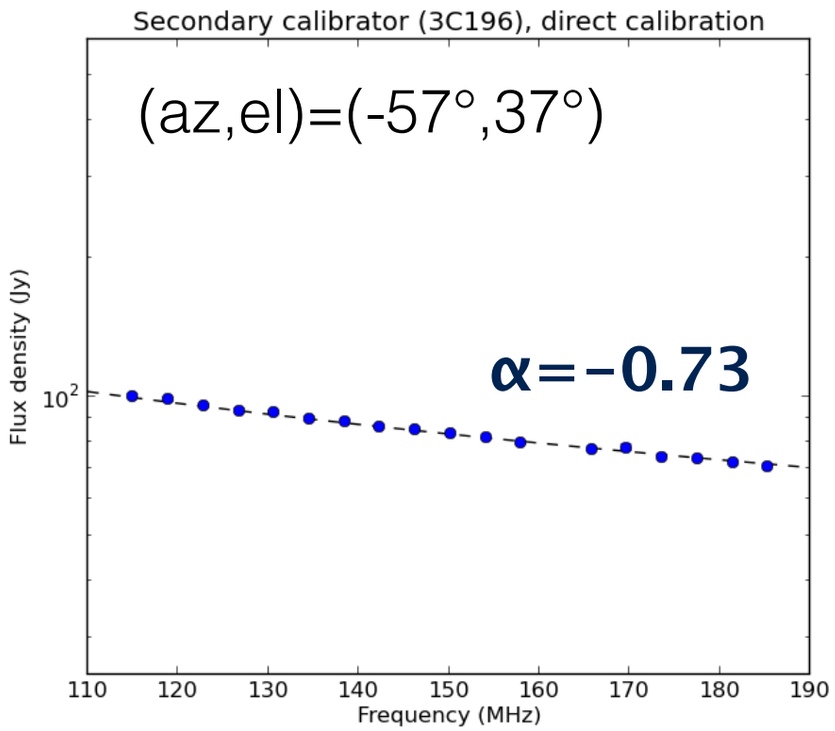

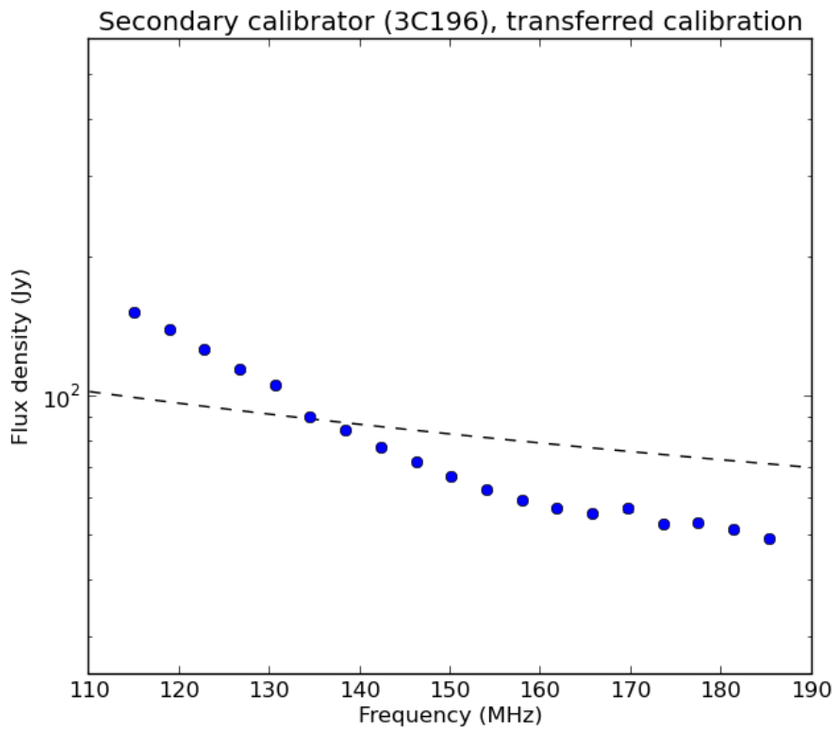

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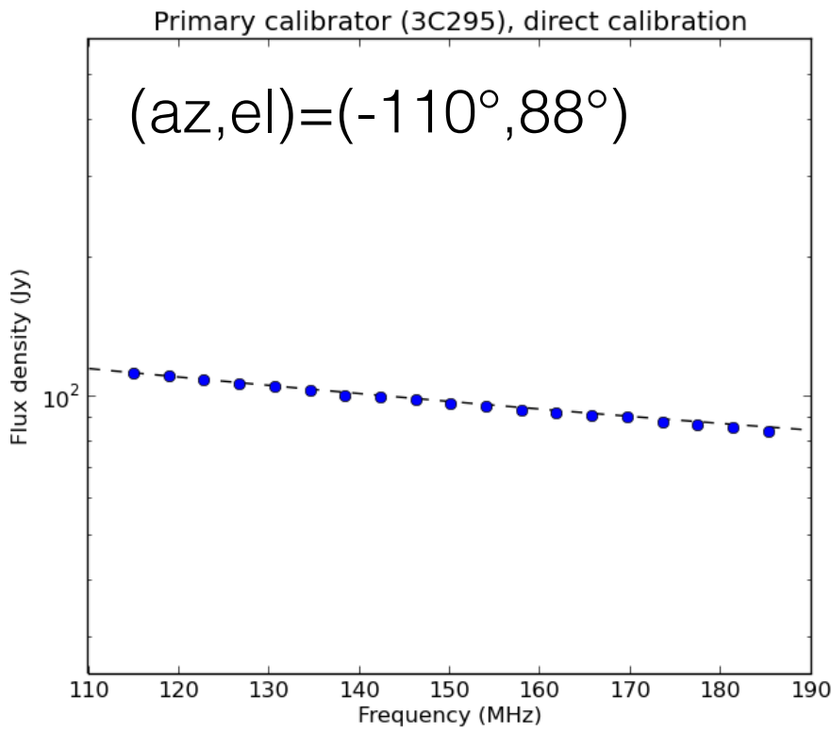

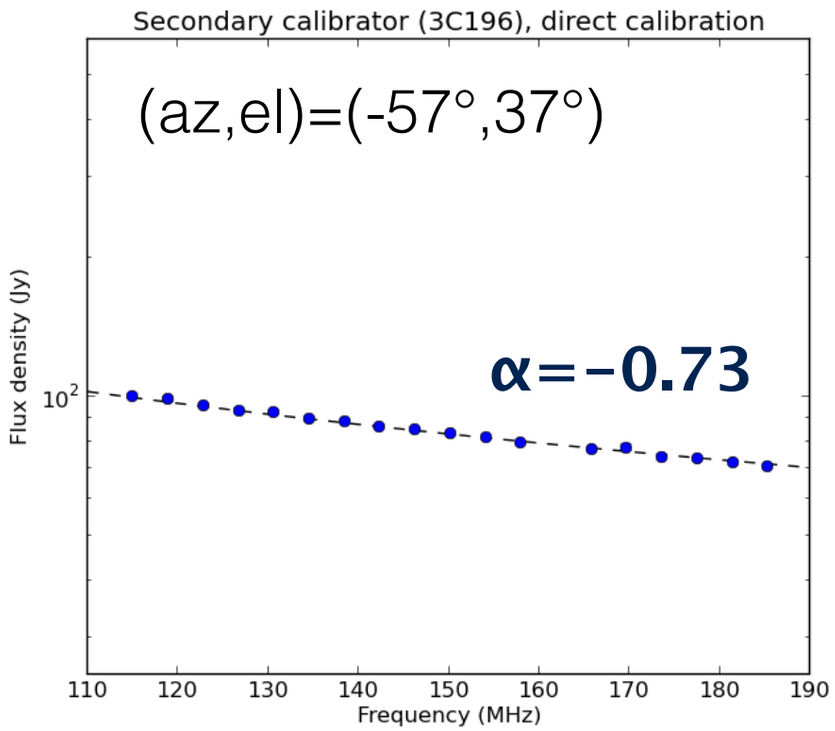

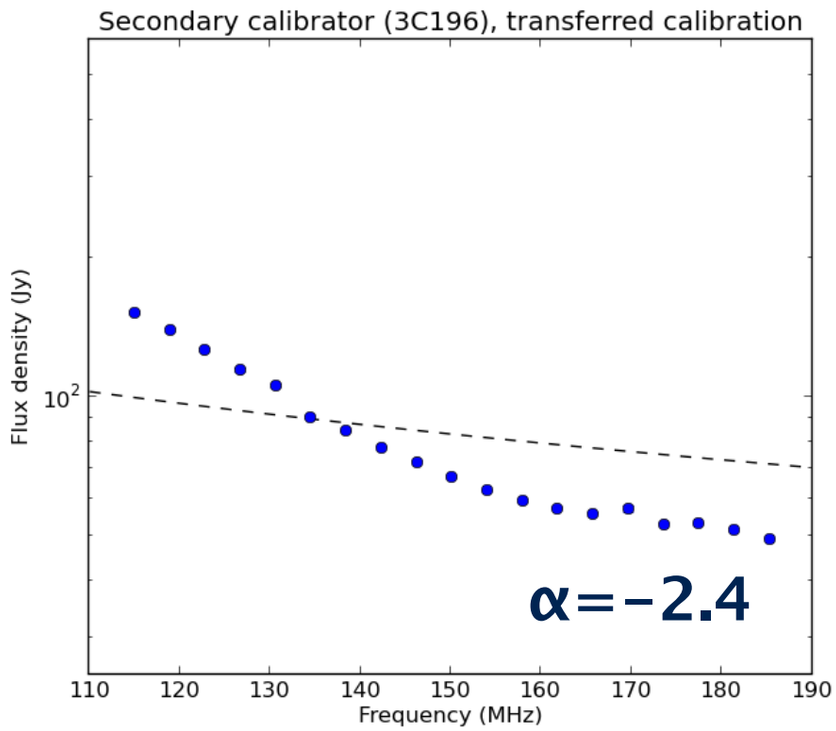

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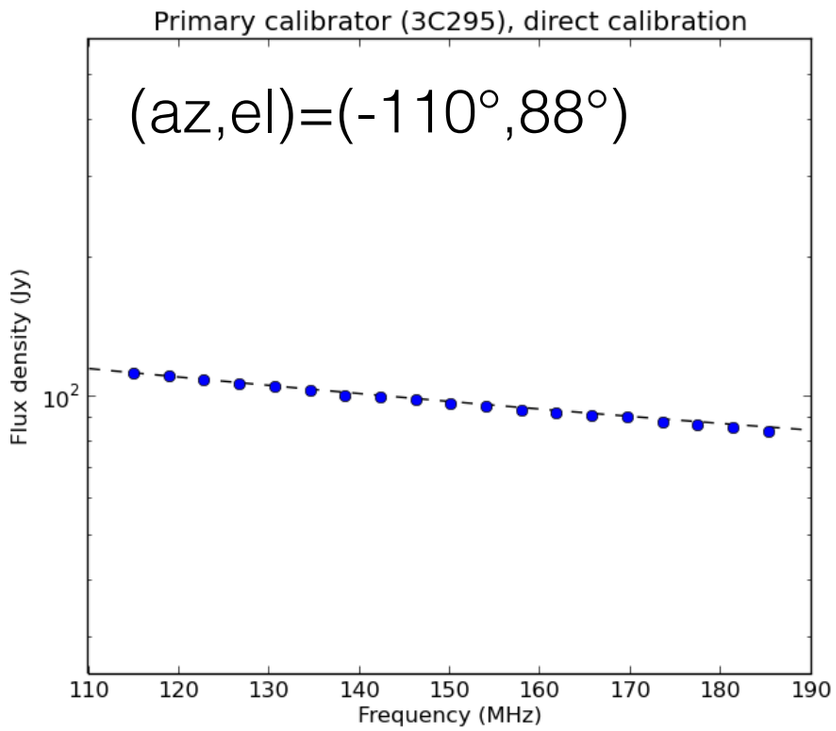
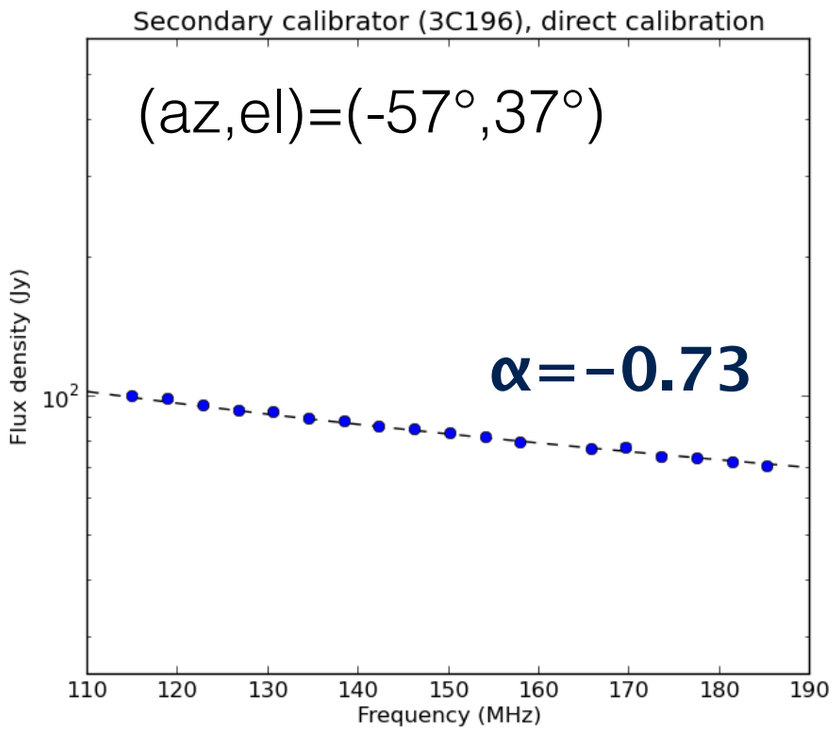
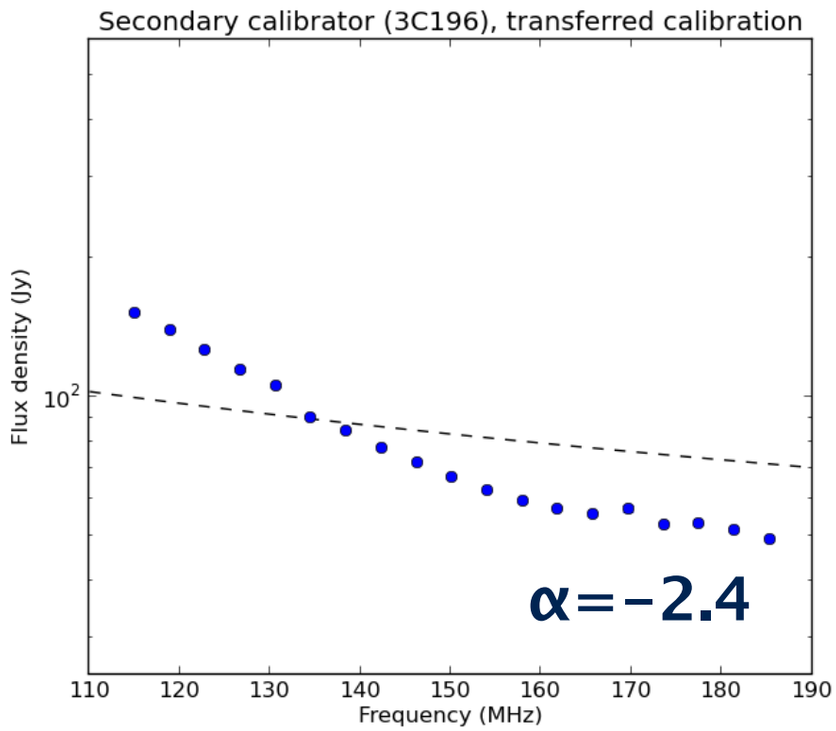


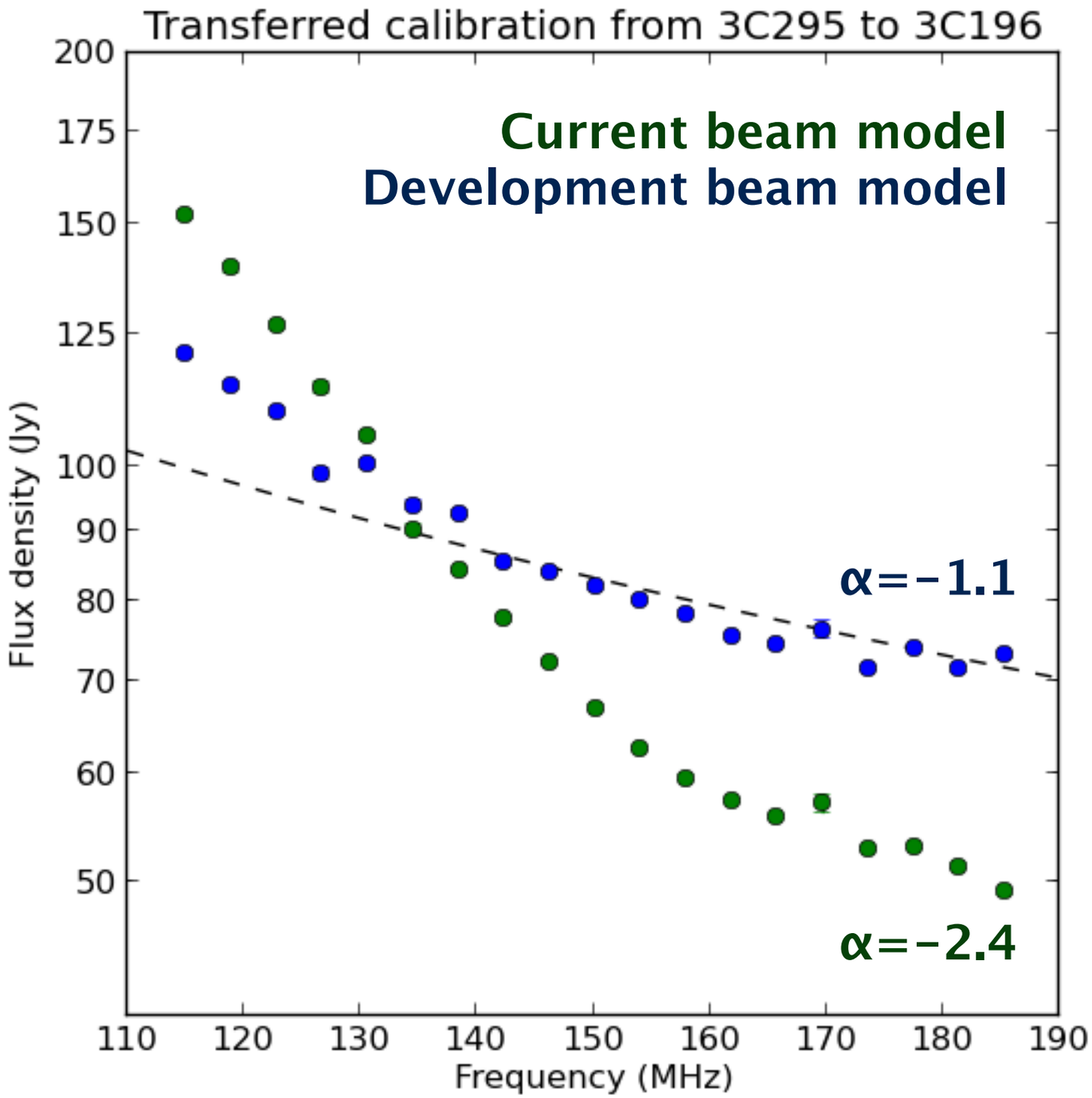




- Old situation:
  - in-band spectral index incorrect (often far too steep)
  - for observations ~120-160 MHz, average flux density at ~140 MHz is approximately correct

Verification: results

- Example: 3C295 calibrating 3C196



Further examples

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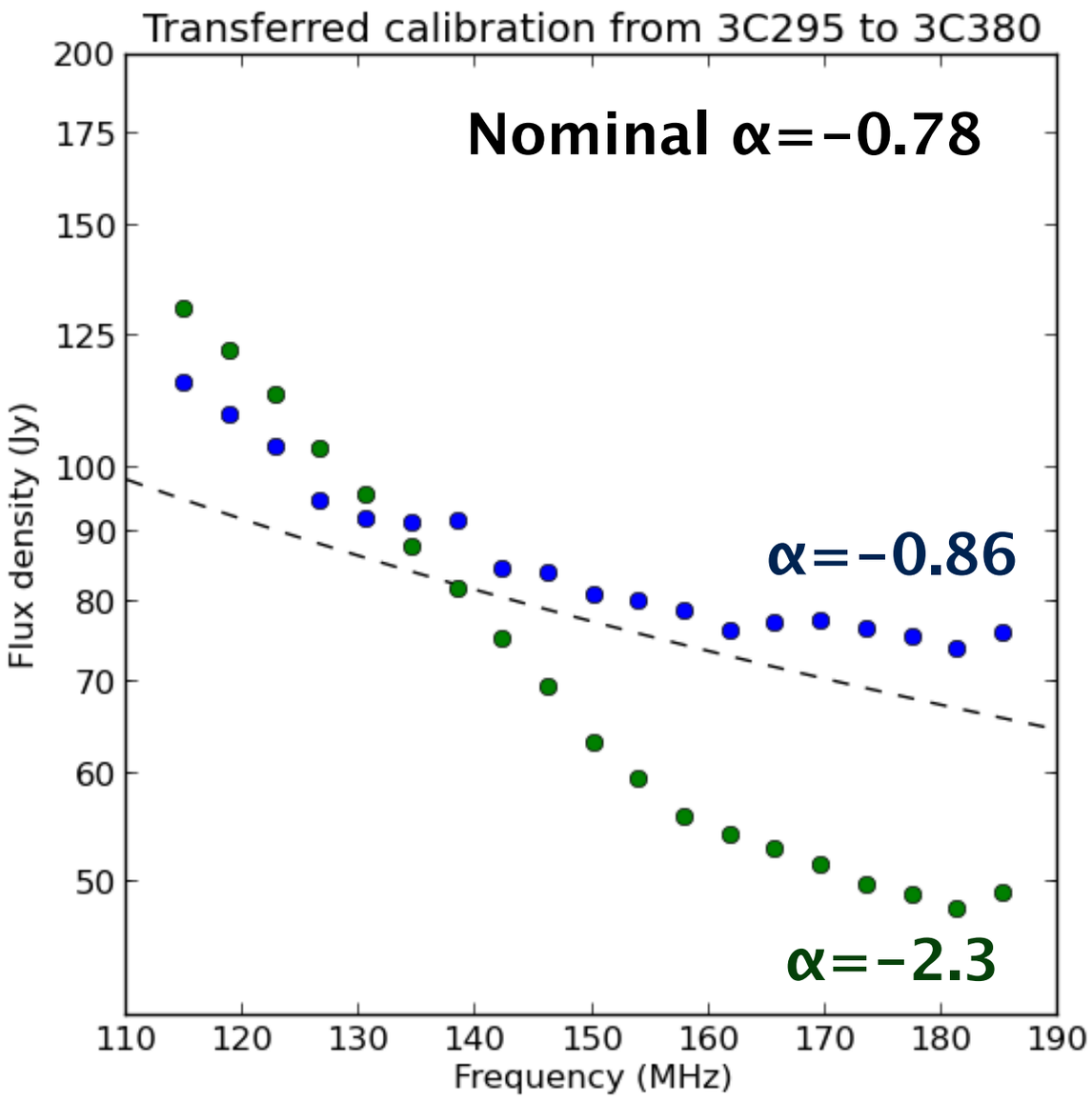
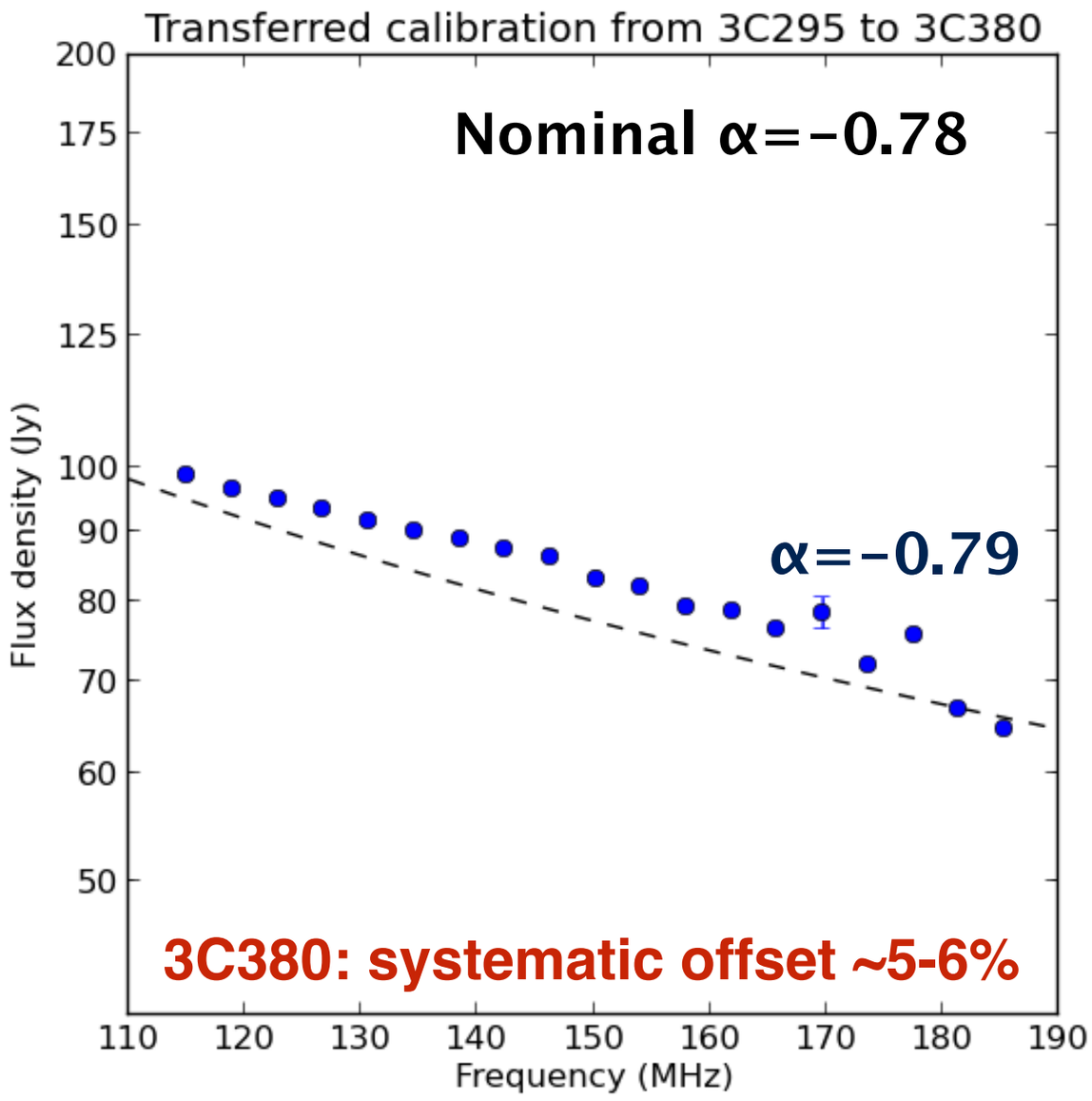
  - indicative of remaining element beam uncertainties?
  - perhaps possible to bootstrap remaining errors using LC1_014





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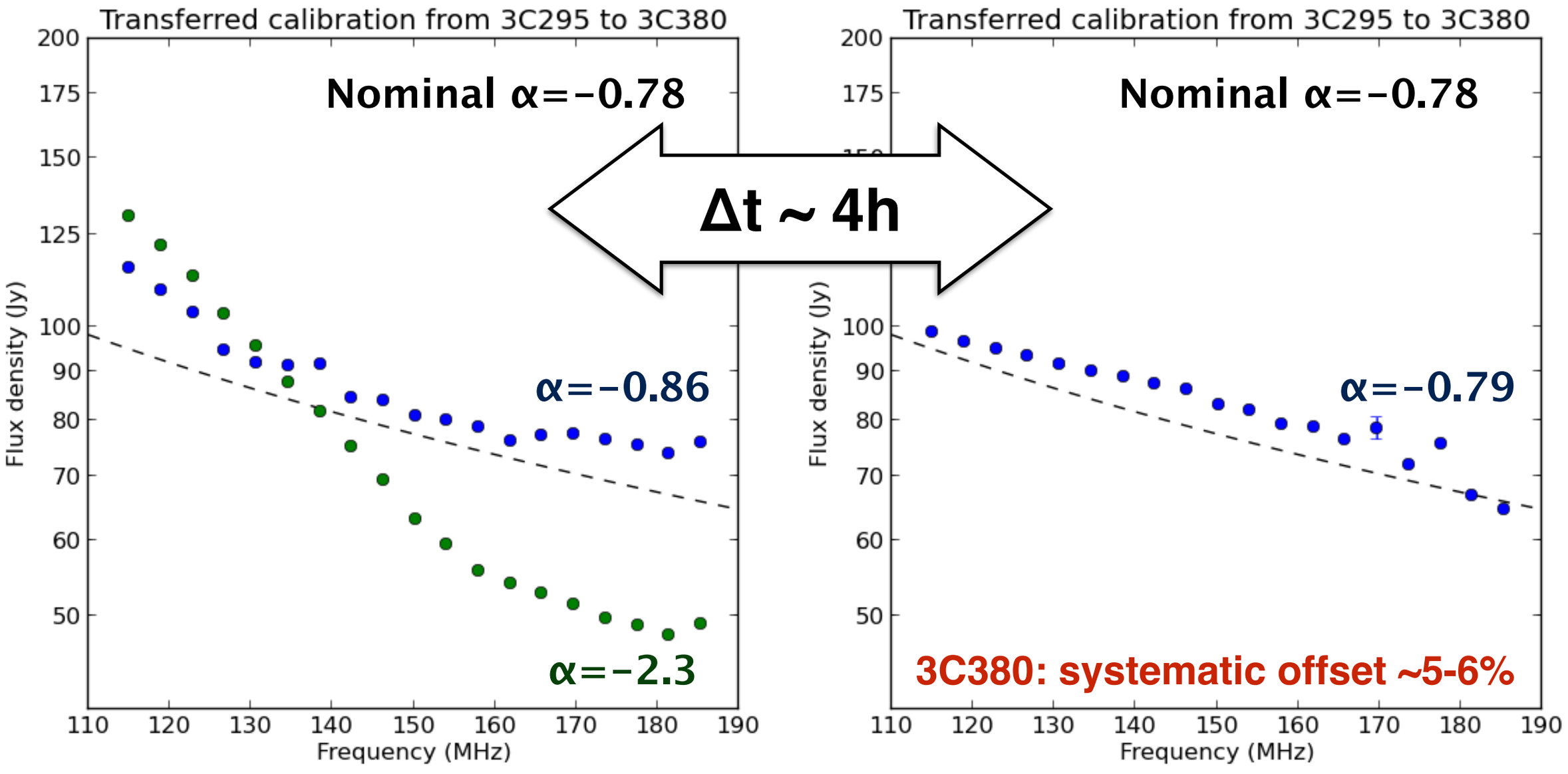

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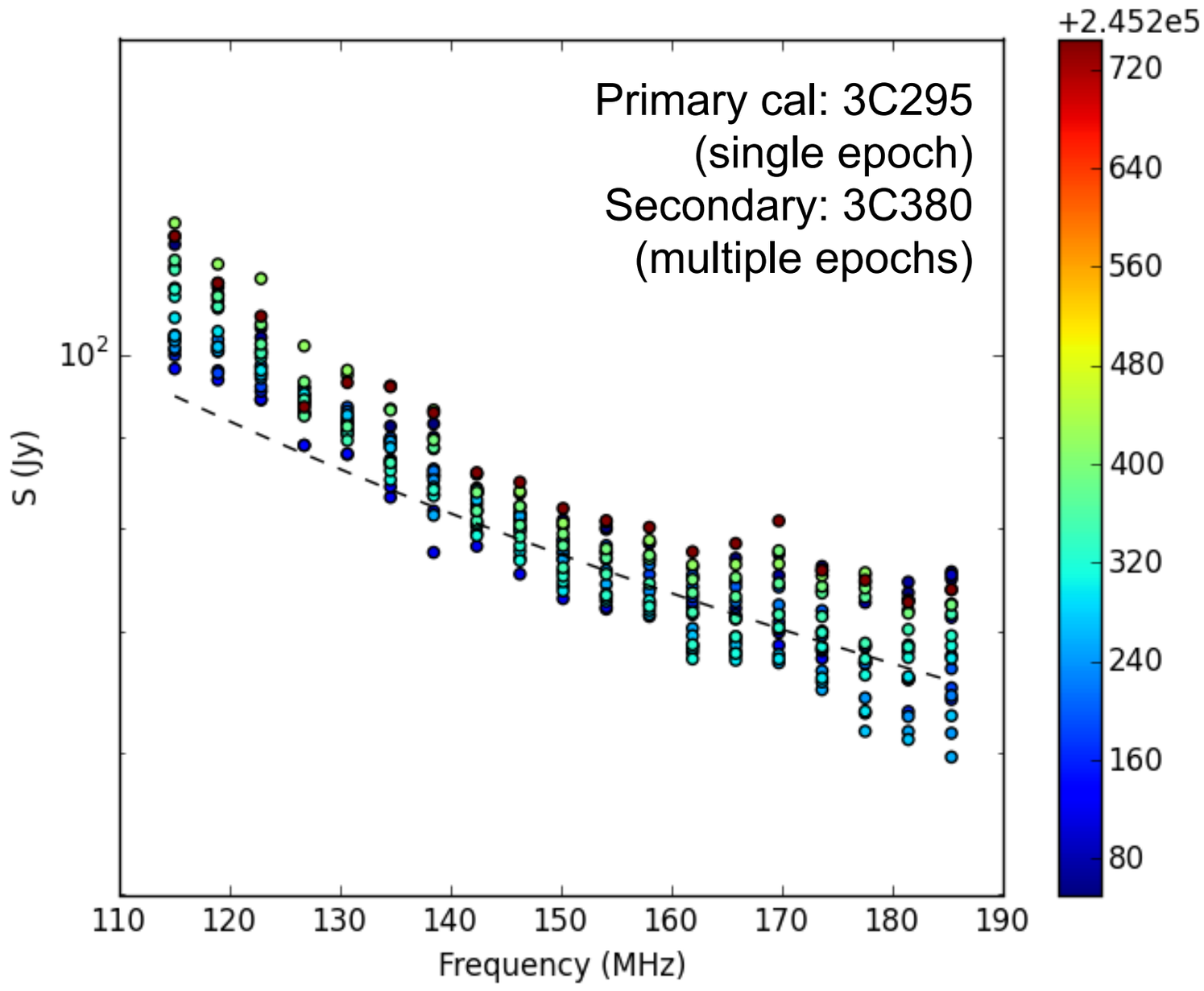

Plans for the beam

- Technical paper describing implementation and demonstrating current calibratability of the flux scale

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Implementation of a normalized LOFAR digital beam model

George Heald[a,b], Tammo Jan Dijkema[a]

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[b] *Kapteyn Astronomical Institute, PO Box 800, 9700 AV Groningen, the Netherlands*

Abstract

Reliable flux calibration of LOFAR imaging data requires a properly normalized model of the beam. This is particularly difficult above 100 MHz where the sparse station layout is regular, resulting in strong grating lobe response that reduces the sensitivity in the pointing direction. In this paper we develop a correction for the LOFAR beam model that implements a suitable normalization factor. We verify this improvement on the basis of measurements of standard calibrator sources.

Keywords: something, something, something

1. Introduction and Context

The Low Frequency Array (LOFAR; van Haarlem et al., 2013) is a large-scale radio interferometer based on a hierarchical phased array design. The basic receiving elements are simple antennas (dipole pairs) that are fixed on the ground. In contrast to many other modern radio telescopes, these antennas are not physically pointed. Instead, they are grouped into concentrated arrangements that are combined electronically at a co-located digital processing unit to focus the sensitivity in one or more directions of

16 antennas are referred to as "tiles"; the combined signal from each tile is used as the input to the digital beamformer. HBA stations have a regular layout: the antennas are on a regular 4×4 grid within each tile, and the tiles are themselves arranged on a regular grid within each antenna field. This regularity results in strong grating lobe responses in the formed beam. To mitigate the effect on astronomical observations by reducing the sensitivity to far off-axis sources, the layout of individual stations is rotated to an arbitrary angle. LBA stations are also rotated with respect to each other, but it is less important in that

Plans for the beam

- Technical paper describing implementation and demonstrating current calibratability of the flux scale
- Release detailed information to the community along with updated beam model and tools for computing the effect in various circumstances
- Fix MSSS flux scale and publish corresponding catalog
- Longer term: develop full EM models of stations and further improve flux scale

Final remarks

- CITT1 developments widely used in the community
  - Basic tools (NDPPP, awimager)
  - Pipelines (selfcal, Factor)
- Documentation for all aspects available on the CITT website

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- CITT1 developments widely used in the community
  - Basic tools (NDPPP, awimager)
  - Pipelines (selfcal, Factor)
- Documentation for all aspects available on the CITT website
- CITT1 has been a success!

Thanks to all the team members for their hard work!

Thanks to the community for testing and feedback!

Thanks to ASTRON for supporting this project!