Setting the Scene

For workshop 3GC-II (Portugal)
On Station Beamshapes
Modelling, Measurement, Application

J.E.Noordam
(noordam@astron.nl)

Standing on the Shoulders of...

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Standing on the Shoulders of...

His notes will be shown at the end

3^{rd} Generation Calibration (3GC)

- 1GC: Rely on instrumental stability (1:100)
  - Enough for the great discoveries of the 70's
- 2GC: Selfcal (2 parameters per antenna)
  - >1:1.000.000 (WSRT/NEWSTAR)
  - The easiest telescope to calibrate (36 years)
- 3GC: Direction-Dependent Effects (DDE)
  - More parameters, more processing, more equations
- 4GC: Statistical analysis of the residuals

3GC-I (Nancay, 2009)

- Delightfully primitive and isolated
- First of a new style of workshops
  - Preparation/selection, 2 full weeks, continue afterwards
  - Encouraged by SKADS and RadioNet
- The concept still needs to be tweaked:
  - Narrowed scope (just beamshapes, no ionosphere)
  - Proven software now exists (OMS, WSRT)
  - The world is more aware of the 3GC problem

The Topic of 3GC-II: Station Beamshapes

- Modeling (2x2 parametrized expressions)
  - Topic chair: Isak Theron
- Measurement (open-loop vs closed-loop)
  - Topic chair: Stephen Bourke
- Application (aw-projection vs facet imaging)
  - Topic Chair: Cyril Tasse

I will repeat this talk once or twice

for the newcomers
and to remind you

This talk was given at ASTRON in March 2011, to plead for using the existing WSRT system for measuring the Apertif beamshapes

Measuring Actual Station Beamshapes

As a function of time and frequency
In full polarization

J.E.Noordam

(noordam@astron.nl)

Why are beamshapes important?

- Steve Rawlings said (airily): "... once we have subtracted the foregrounds..."
- Unfortunately, this requires:
  - Very high Dynamic Range
  - Over a very wide field
  - Full polarization
  - Accurate spectral calibration
- Crucial: station beam shapes (i,l,m,f,t,pol)

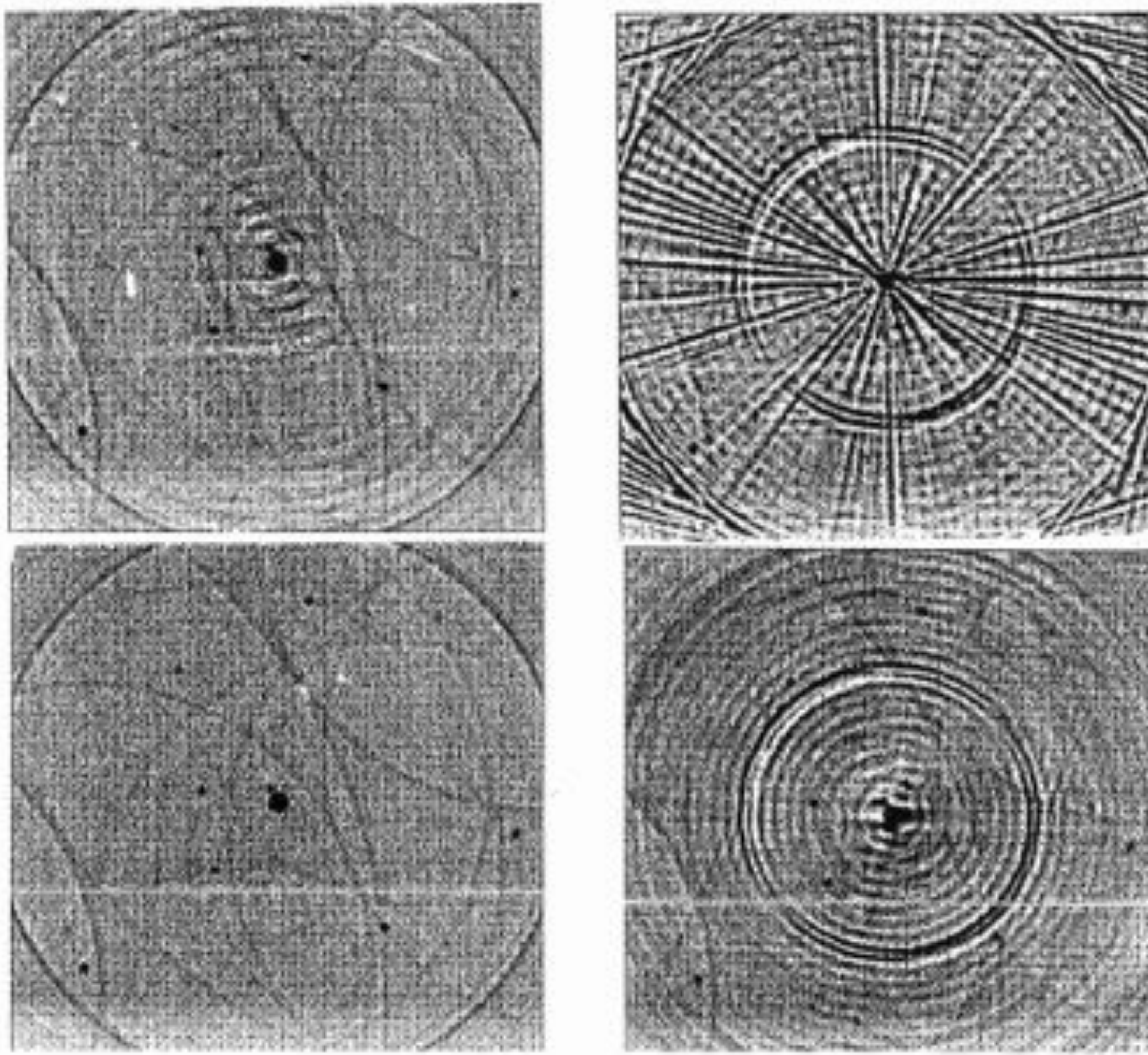
Calibration: The ability to subtract bright foreground sources with high accuracy

The
EOR
is
hidden
in
the
noise

The discovery of selfcal

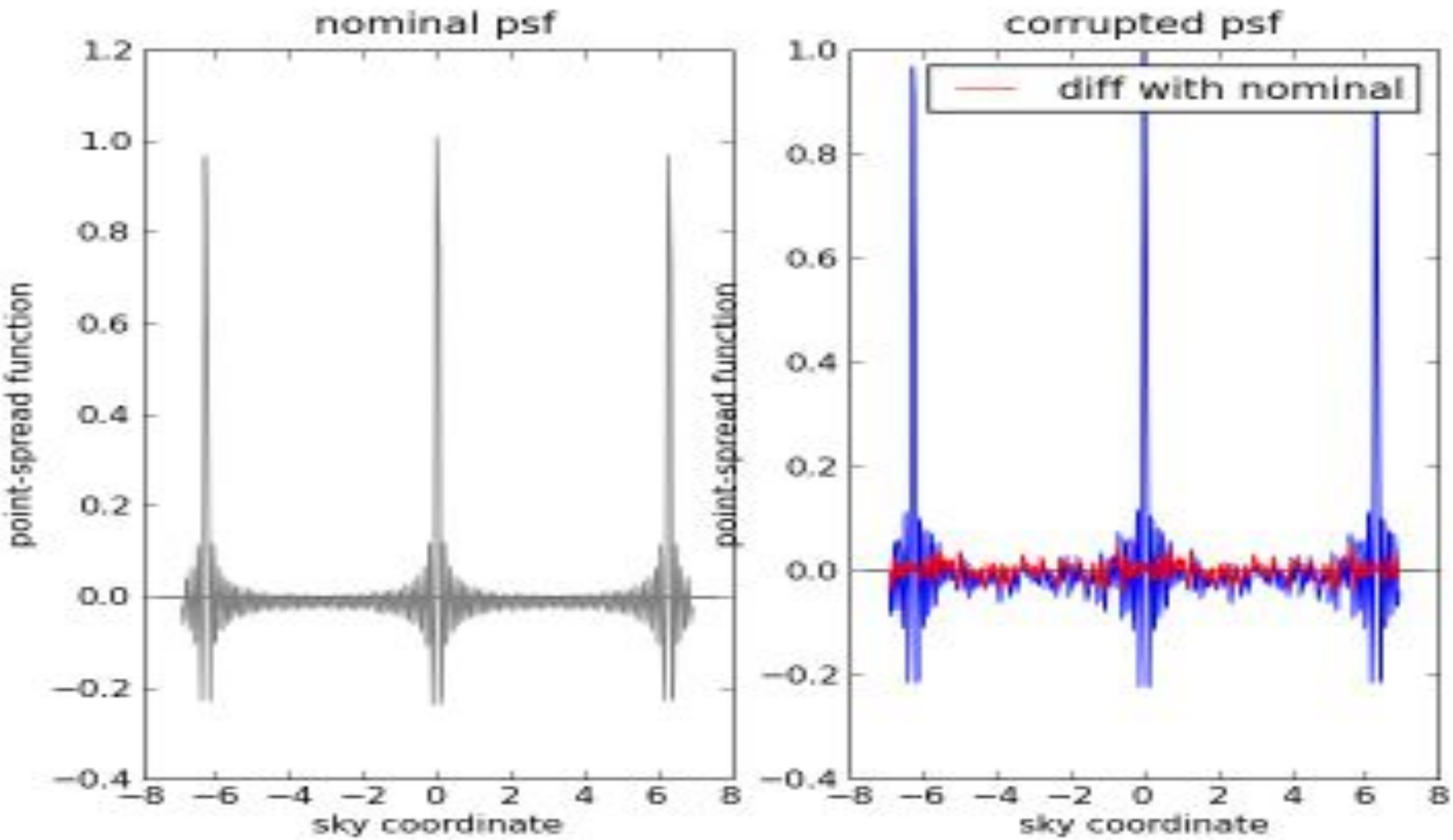
DR 1:100

WSRT
3c48
RSC
1980

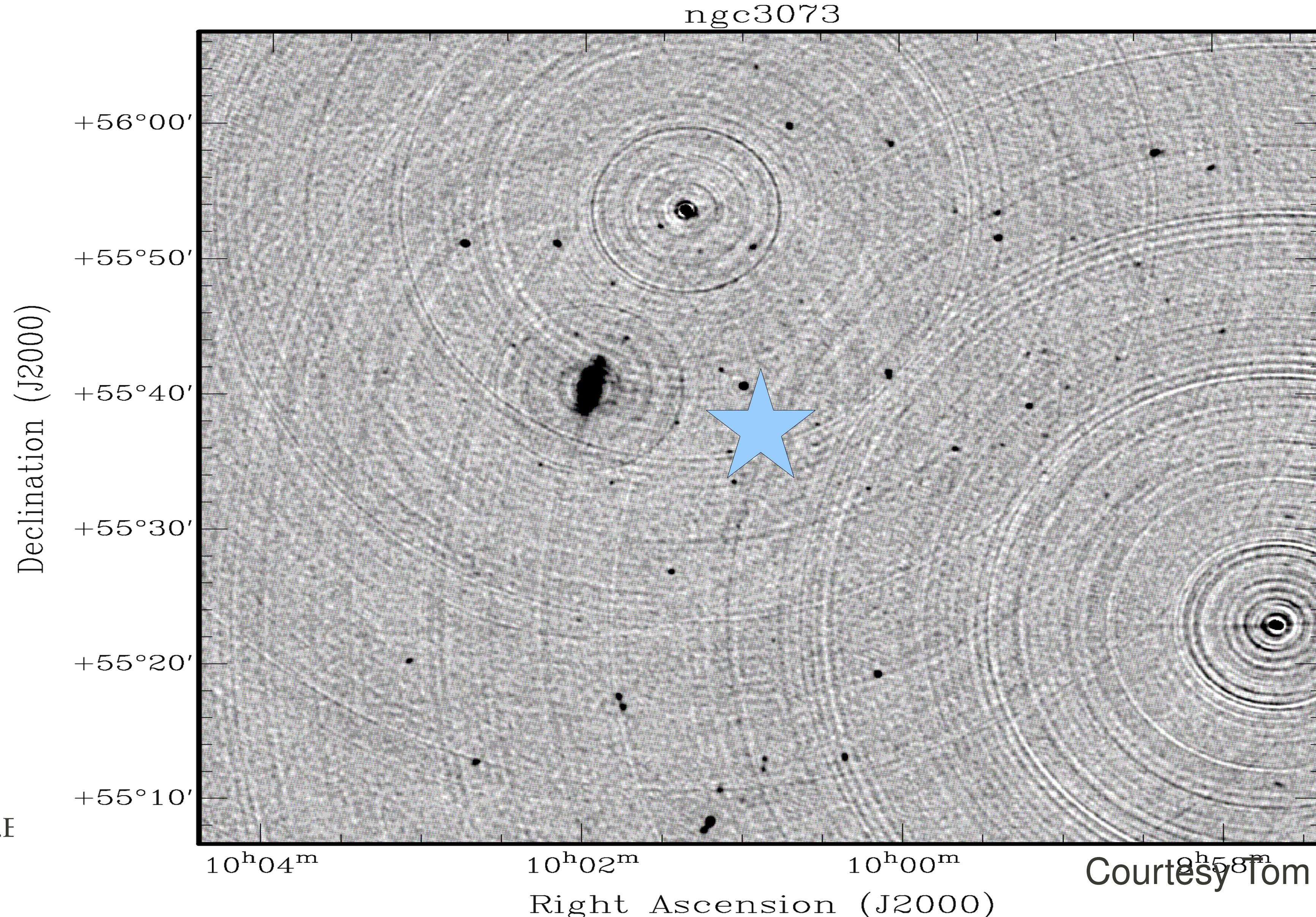


DR 1:10.000

Source Subtraction requires accurate knowledge of the PSF



Wide-Field Source Subtraction
The PSF varies over the field



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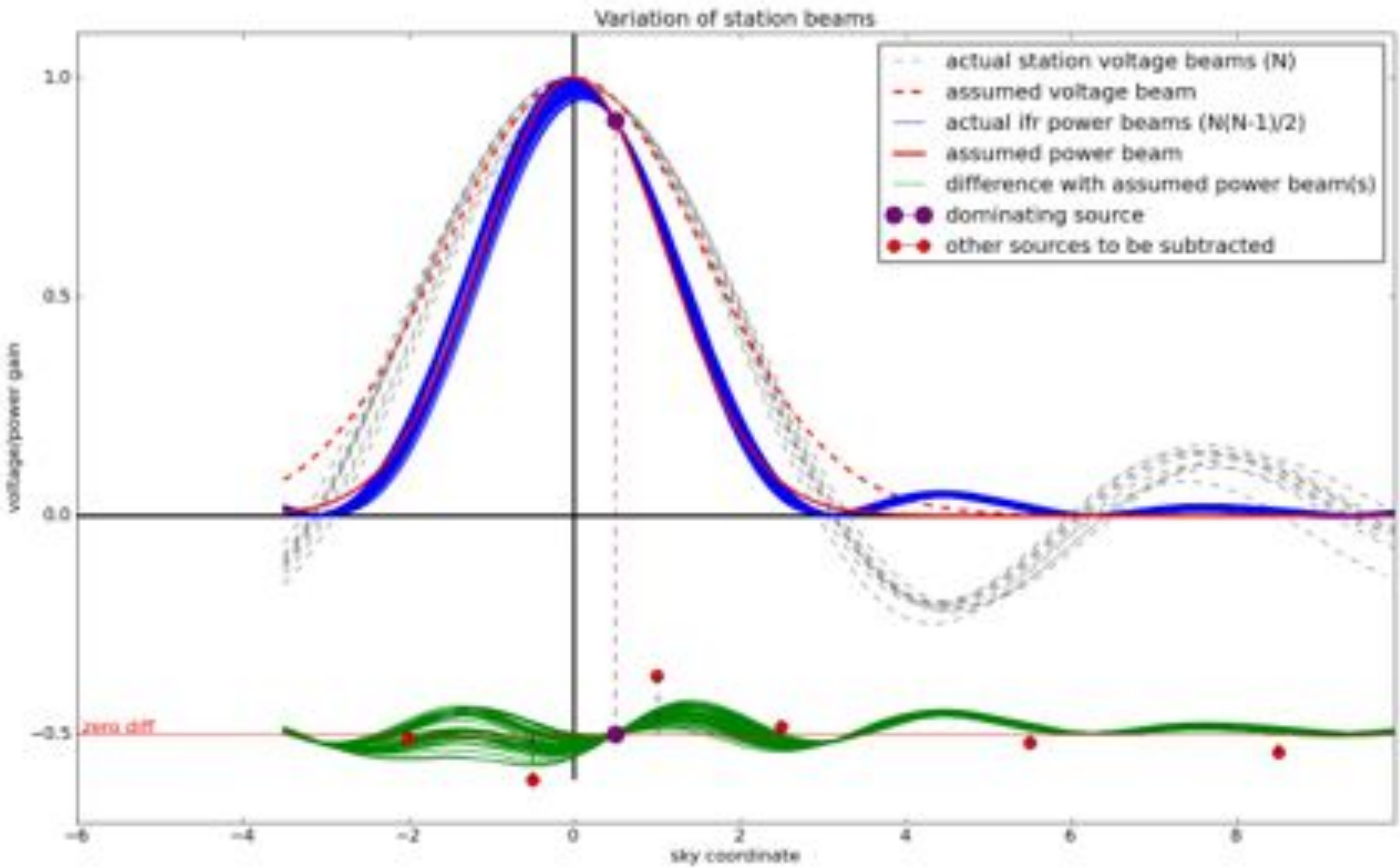
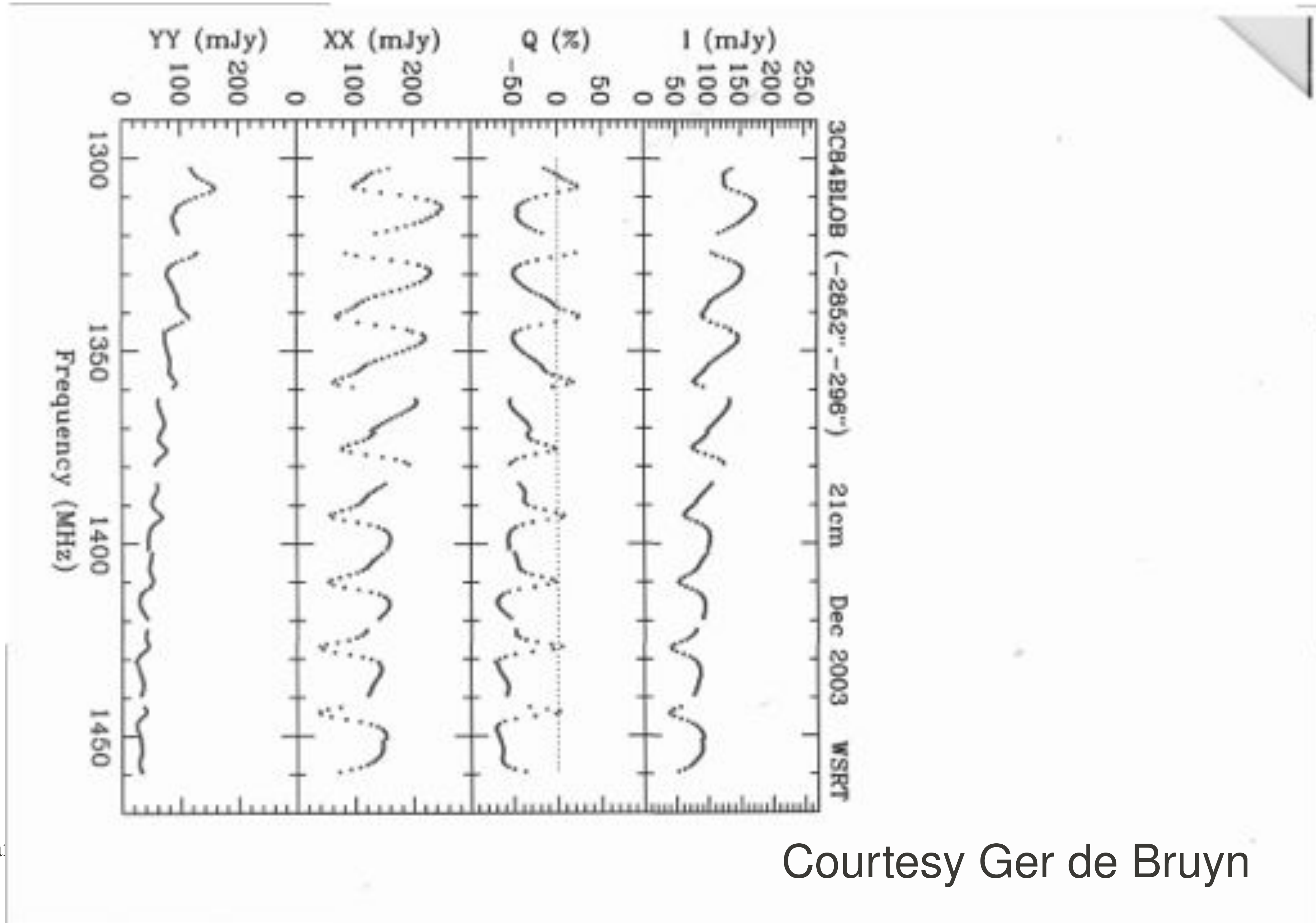
Courtesy Tom Oosterloo

Station Beams are NOT identical!

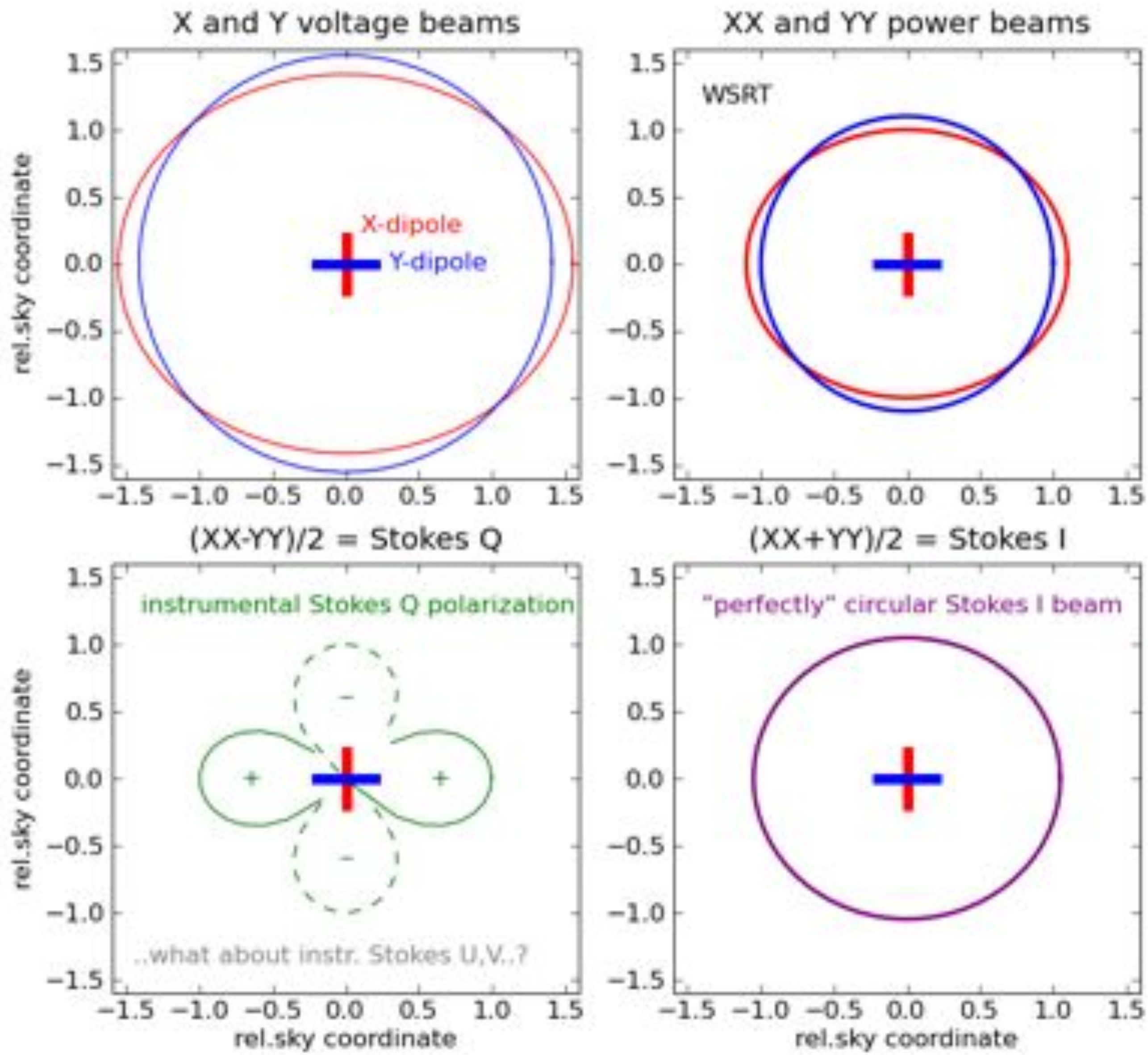


Frequency Dependence



Courtesy Ger de Bruyn

Instrumental Polarization



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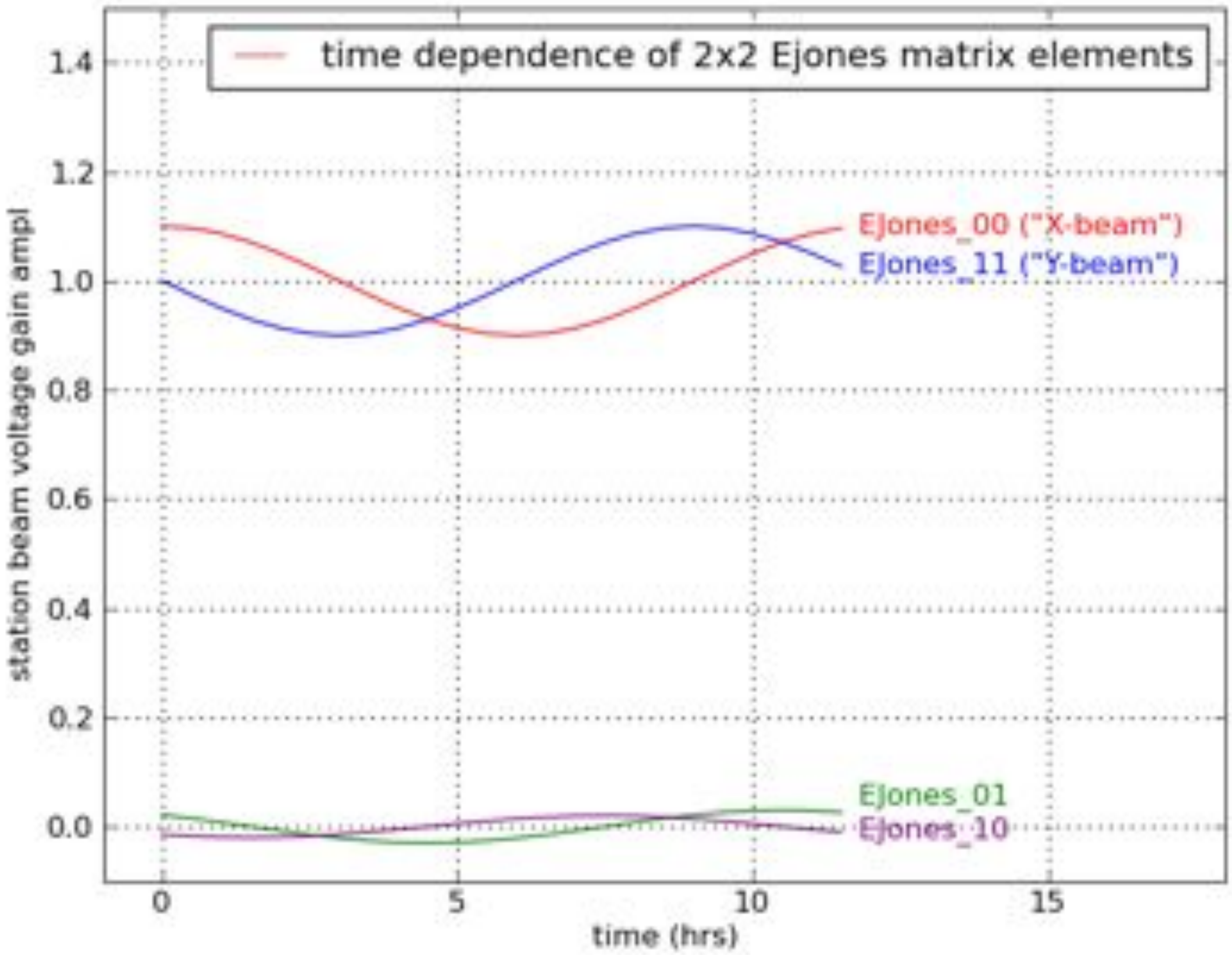
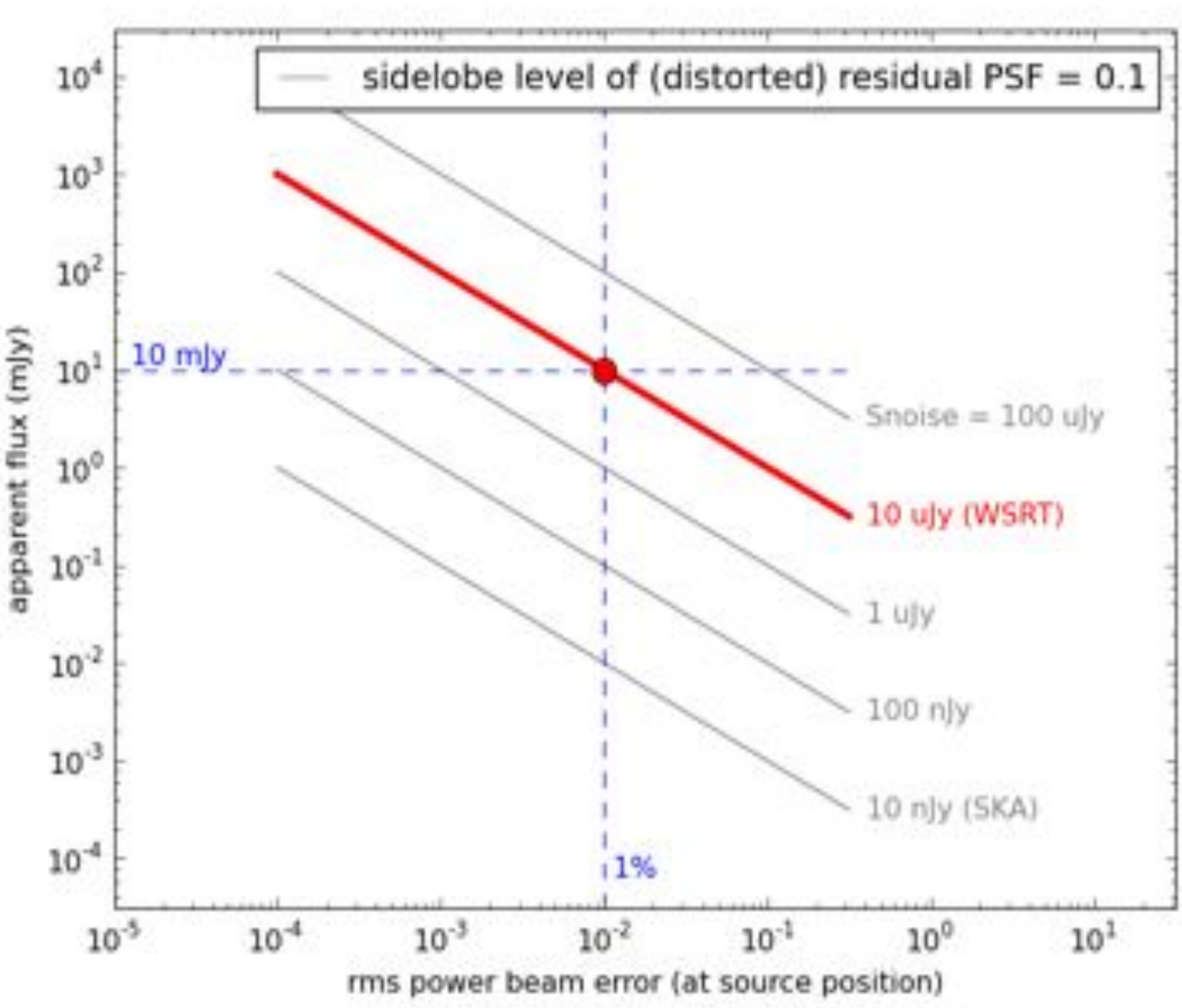
Time Dependence



In order of Trouble

- WSRT (no sky rotation, on-axis SPR)
- ASKAP/Apertif (no sky rotation, on-axis PAF)
- AAT/GMRT (sky rotation, on-axis SPR)
- VLA (sky rotation, off-axis SPR)
- ATA/GBT/MeerKat
  - sky rotation, widely off-axis SPR
- AA (LOFAR, Embrace)
  - sky rotation, elongation, polarization

Required Beam Accuracy



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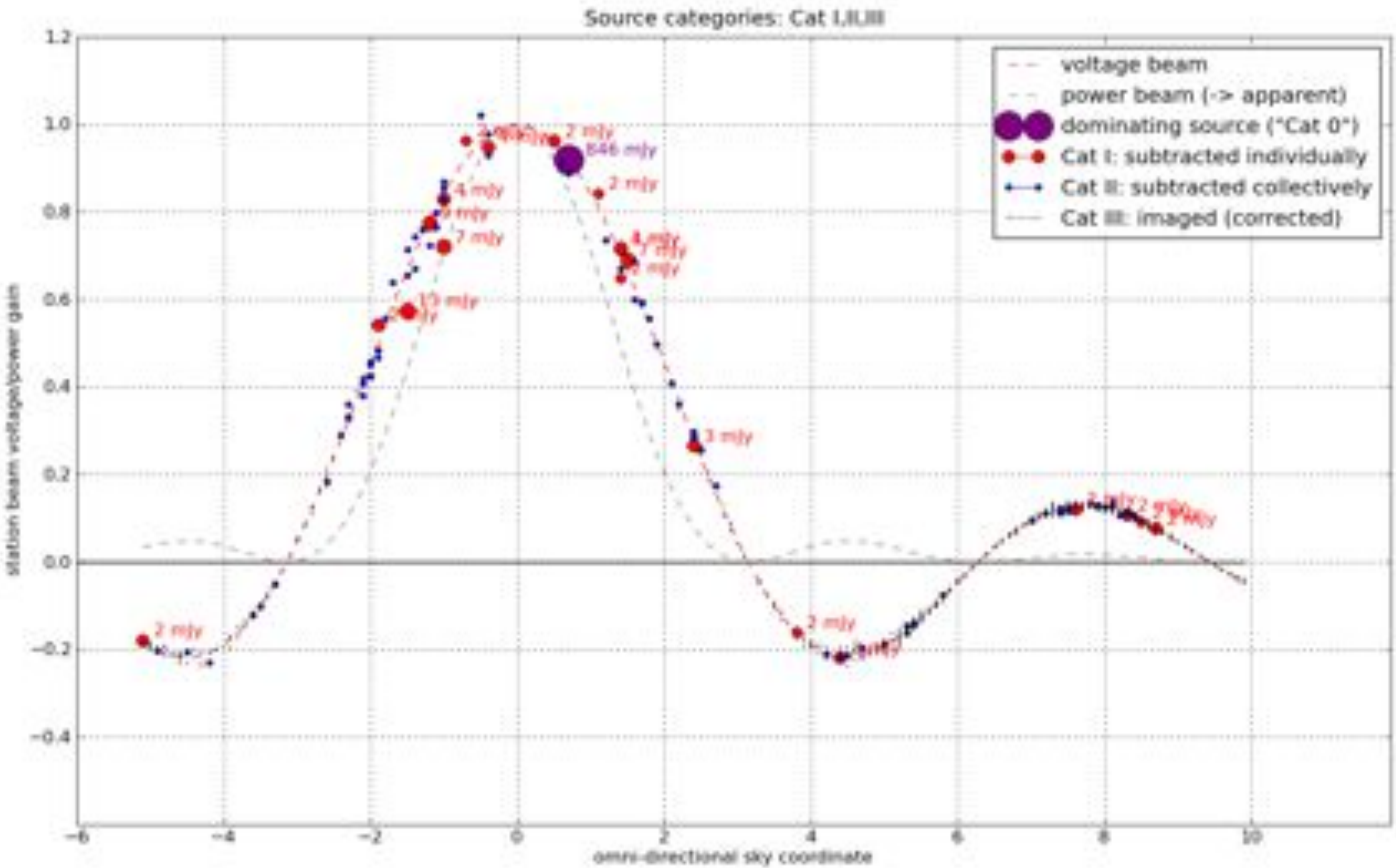
How are Station Beamshapes used?

Source Categories (I,II,III)



Source Categories

- Cat "0": The dominating source (if any)
  - Used to calibrate rapidly varying errors
- Cat I: The 10-20 calibration beacons
  - Estimated and subtracted individually
  - Used to estimate beamshapes
- Cat II: The 100-1000 fainter LSM sources
  - Subtracted collectively, using interpolated beamshapes
- Cat III: The many "one-sigma" sources
  - Imaged after correcting the uv-data for beamshapes

So, how do we get to know our beamshapes with sufficient accuracy?

Open-loop vs Closed-loop

- Open-loop:
  - Use a theoretical beamshape model
  - Measured the beamshapes once and for all, e.g. by scanning through a bright source
- Closed-loop:
  - Continuous measurements during the observations
  - Using the sources in the field
  - Time, frequency and polarization
  - Like selfcal

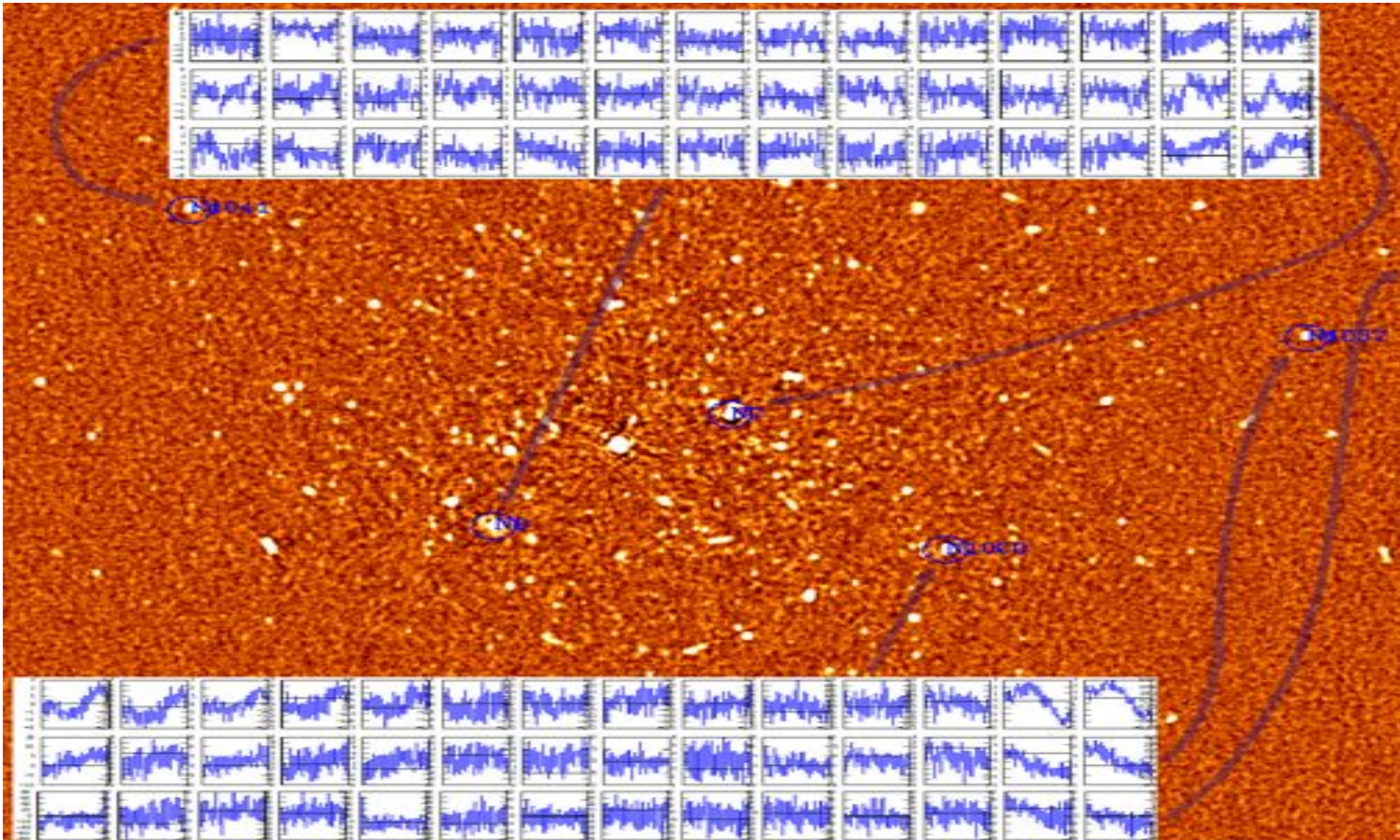
TINA

- There Is No Alternative to closed-loop
  - If we want to deliver on our promises
-
- Fortunately, this seems to be possible
  - Enough calibration beacons (information)
  - Enough equations to solve for the extra unknowns
-
- The price: It will require a lot of extra processing

The Differential Gains Method

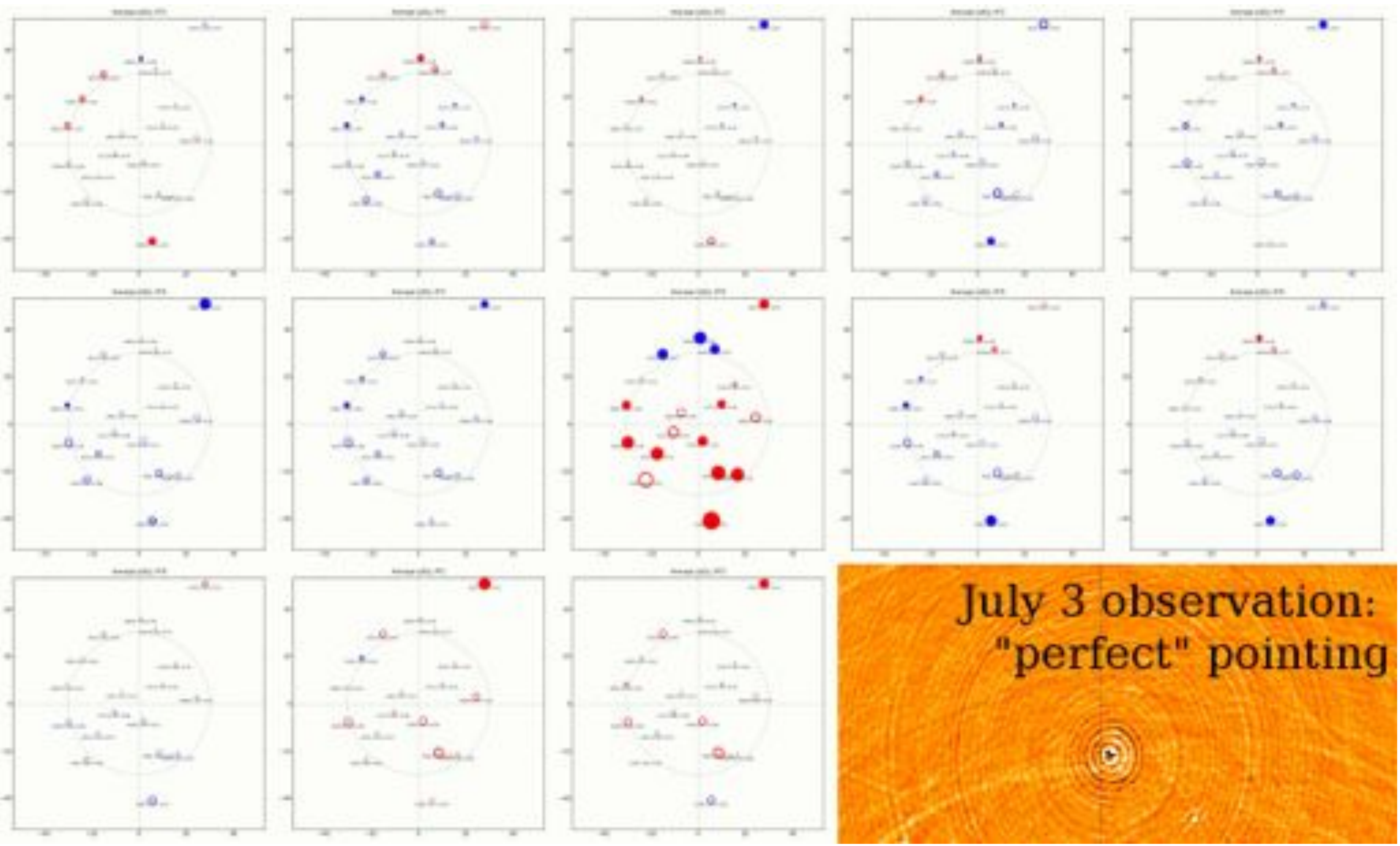
- Use the dominating source to take out the rapidly varying instrumental errors (2GC)
- Estimate the slowly varying differential gains in the direction of 10-20 calibration beacons
  - Integration time: >30 minutes
- Estimate beamshape parameter values (i,f,t)
  - Use these to subtract Cat II sources
  - Use these to correct residual uv-data while imaging

The Differential Gains Method

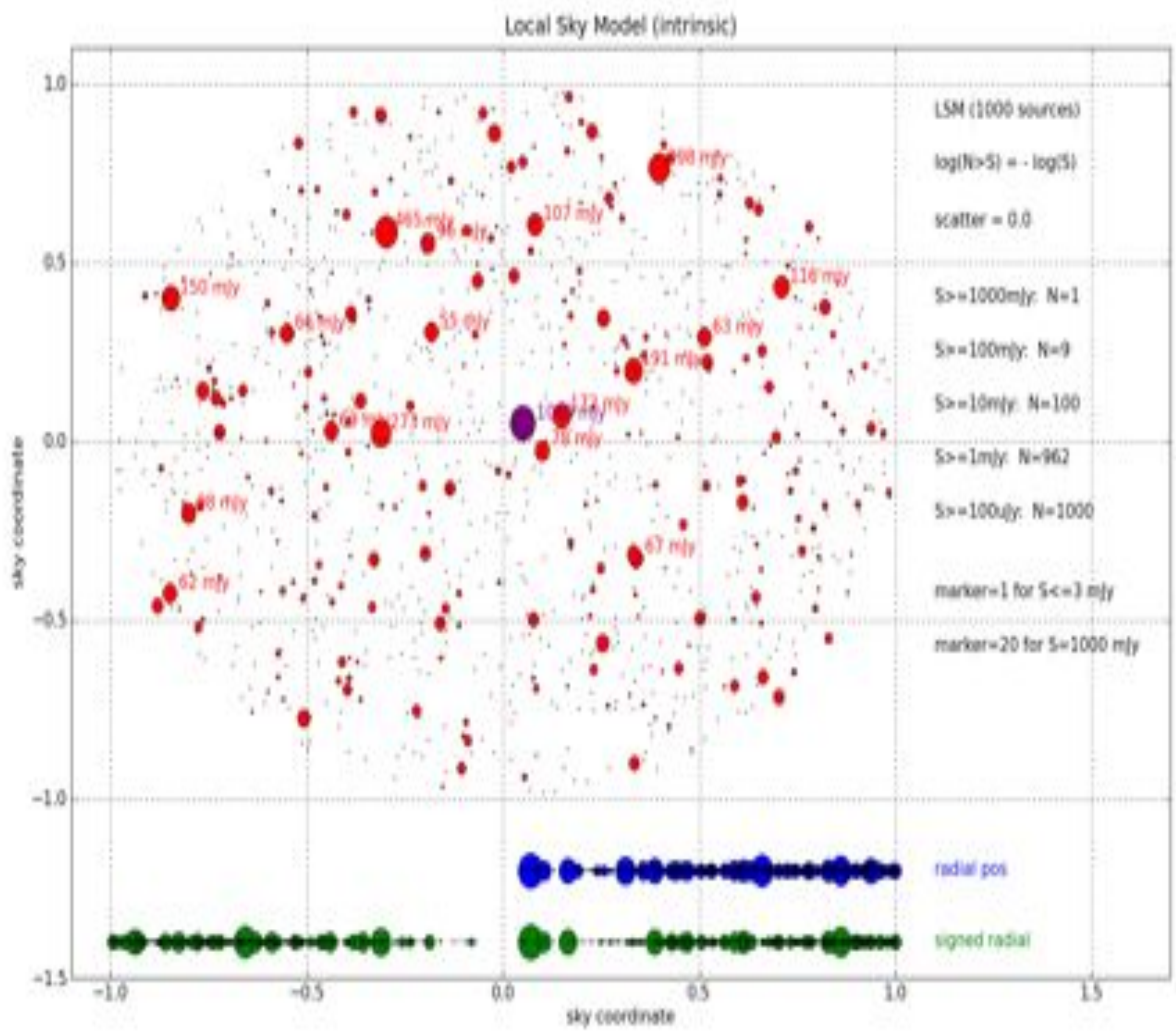


Courtesy Oleg Smirnov

Differential Gains in action



Calibration Beacons
Intrinsic Source Fluxes



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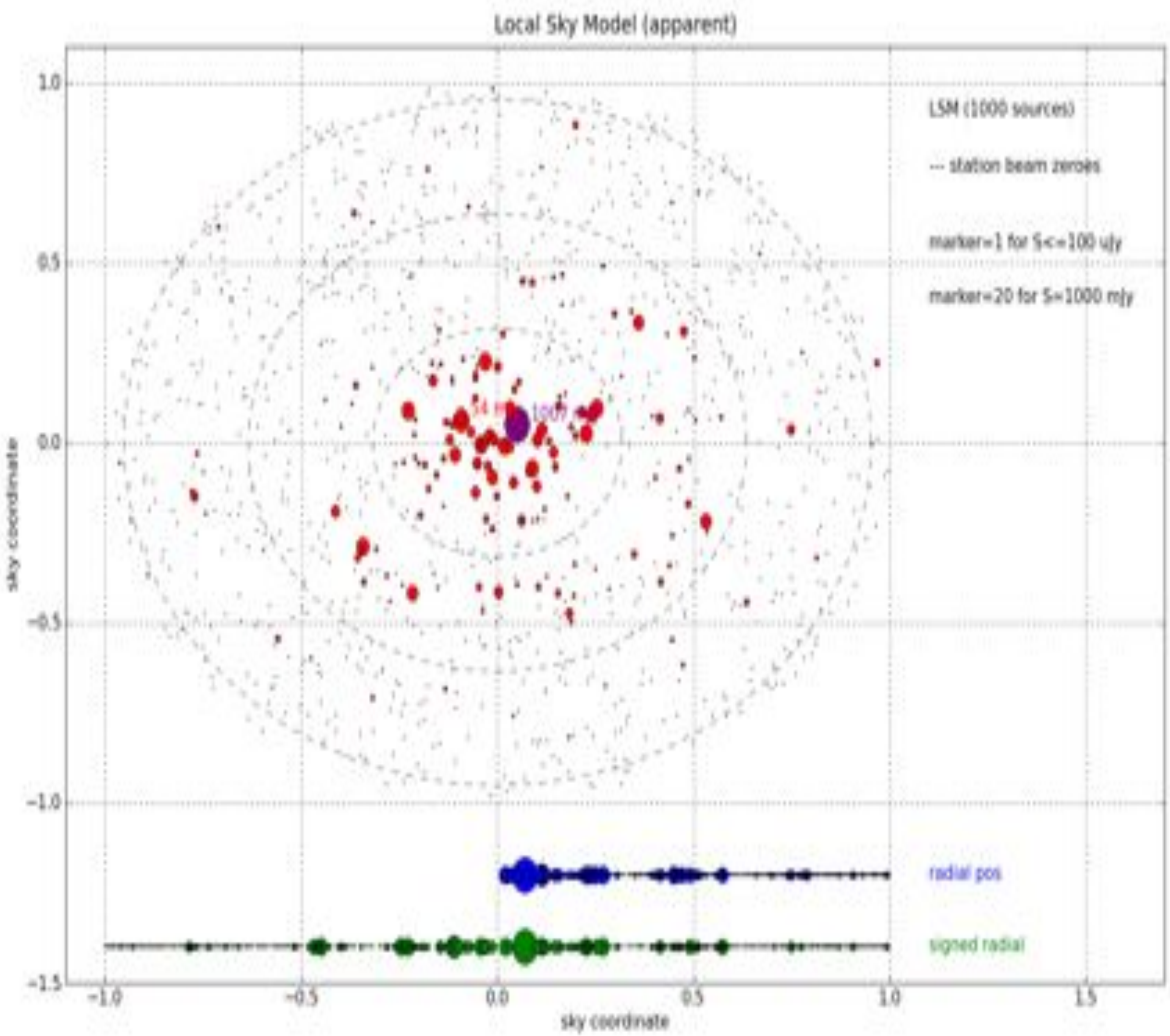
Calibration Beacons
Apparent Source Fluxes



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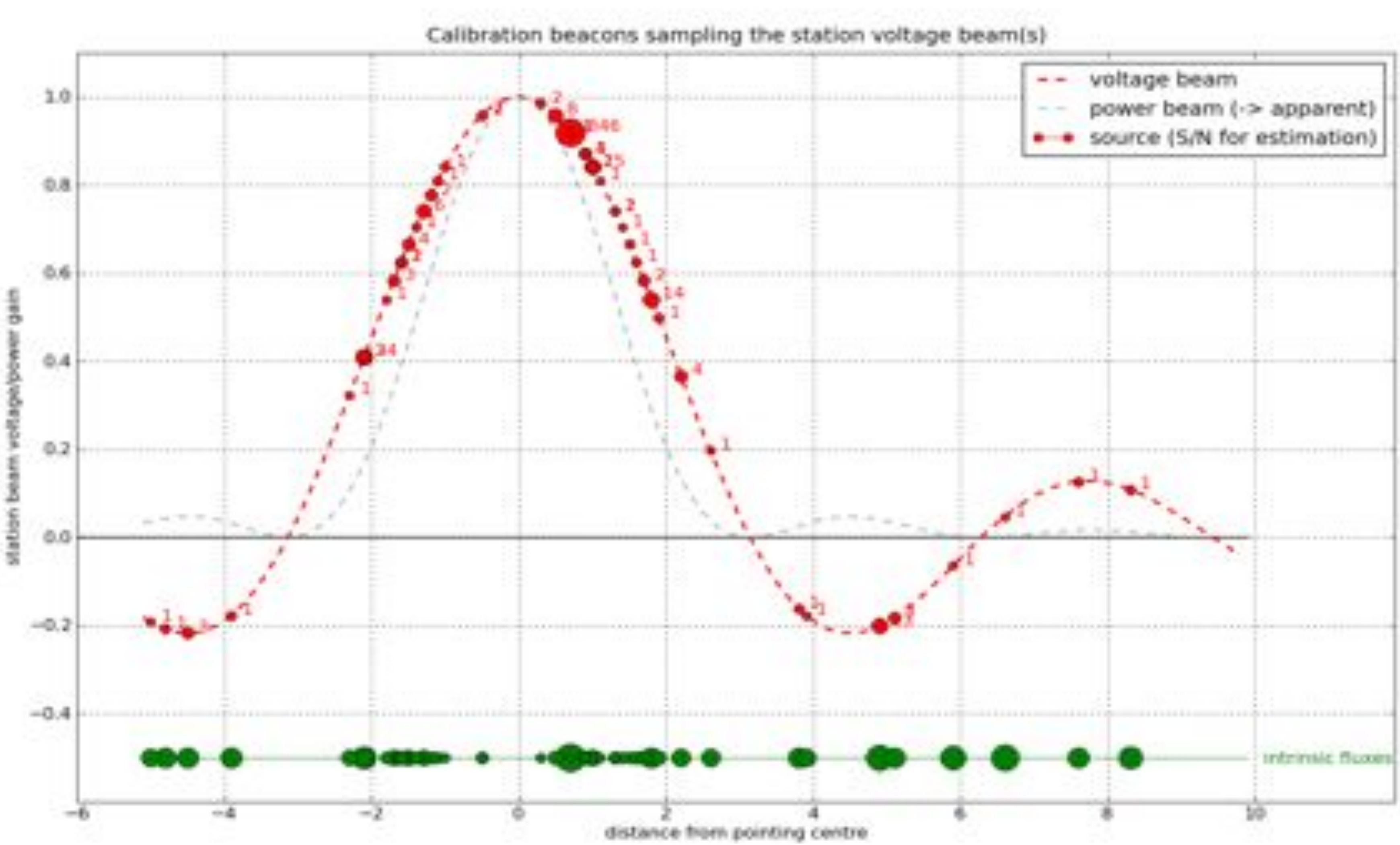
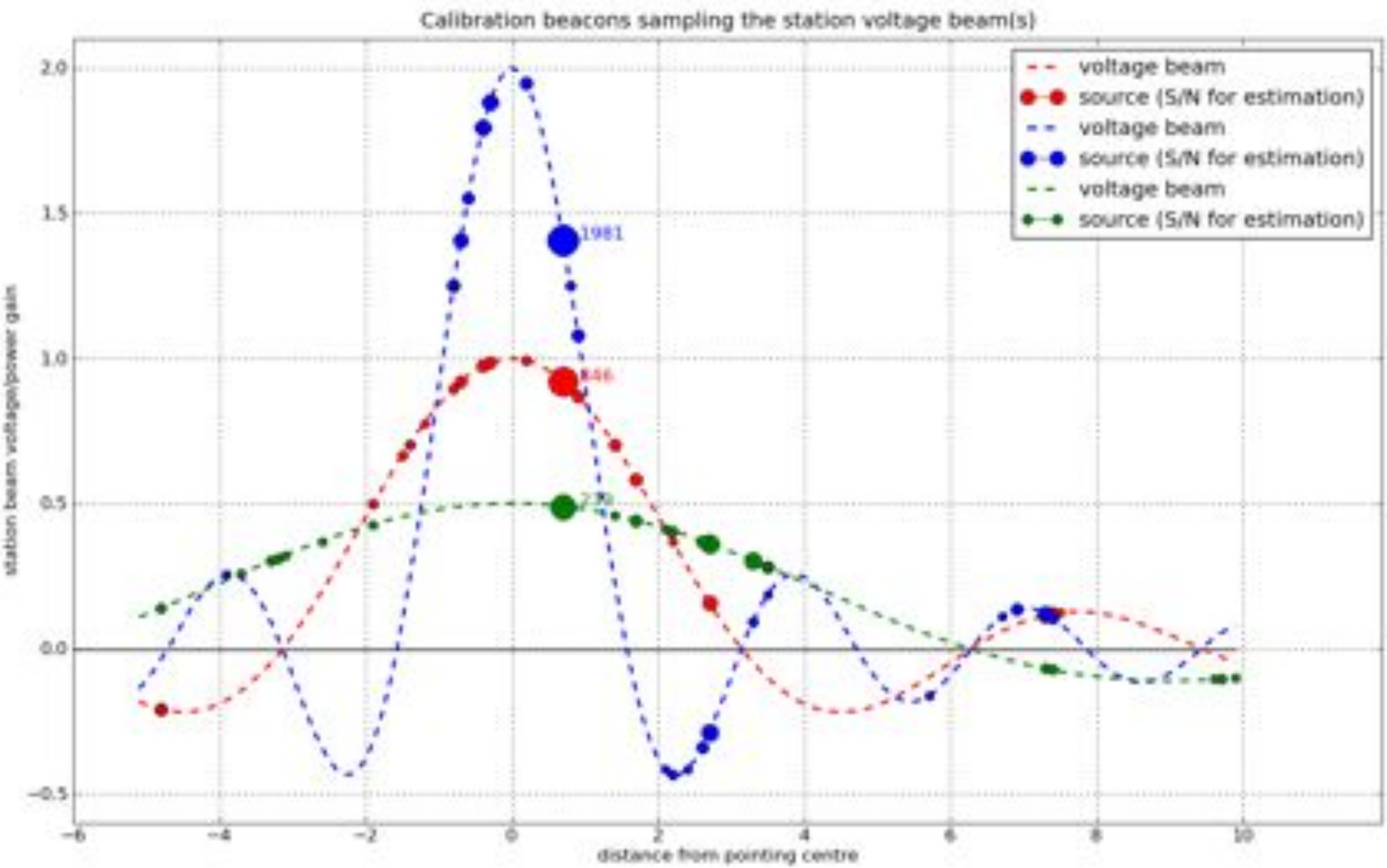
Calibration Beacons sample the beamshape



Independent of Station Diameter (to first order)



The Good News for SKA

- There seem to be enough calibration beacons in a typical 21cm WSRT field
- To first order, this is independent of station diameter
- It gets better for longer wavelengths
    - Wavelengths < 21 cm could be problematic

The Good News for SKA

- There seem to be enough calibration beacons in a typical 21cm WSRT field
- To first order, this is independent of station diameter
- It gets better for longer wavelengths
  - Wavelengths < 21 cm could be problematic
- This should be a huge relief to the SKA community

The Bottom Line

If you know your station beams (i,l,m,f,t,p)

Your DR problem reduces to the WSRT problem

You can have 1:000.000 too

And perhaps more...

The WSRT as a Test Bed for prototype stations

- Assuming the use of calibration beacons
- The 3km spatial resolution is needed to distinguish the beacons from each other
- The more telescopes in the array, the better
- The WSRT is highly stable and very well known
  - This allows absolute measurements
  - NB: The recent closure errors have been solved
- It allows a gradual path to the full Apertif

EMBRACE/AAVP

- We should exploit the opportunity offered by the EMBRACE-WSRT combination
  - It is there (it just needs to be a little bigger)
  - The software exists
  - It just needs an interface with the WSRT
- This will give an imaging Result within a year
  - And a string of other results as by-products
- It should establish AA's as the “realistic approach”

EMBRACE @WSRT

Apertif

- The same arguments apply for testing a single Apertif prototype
- It allows a gradual low-risk implementation of the full 14-station Apertif

Conclusions

- It is time to start measuring our station beams
  - For all kinds of reasons
  - For the first time in history
- A method exists (Differential Gains)
  - available to all
- It has been “demonstrated” that a typical field @21cm contains enough calibration beacons to measure the beam during the observations