The discrete charms of

Redundant Spacing Calibration (RSC)

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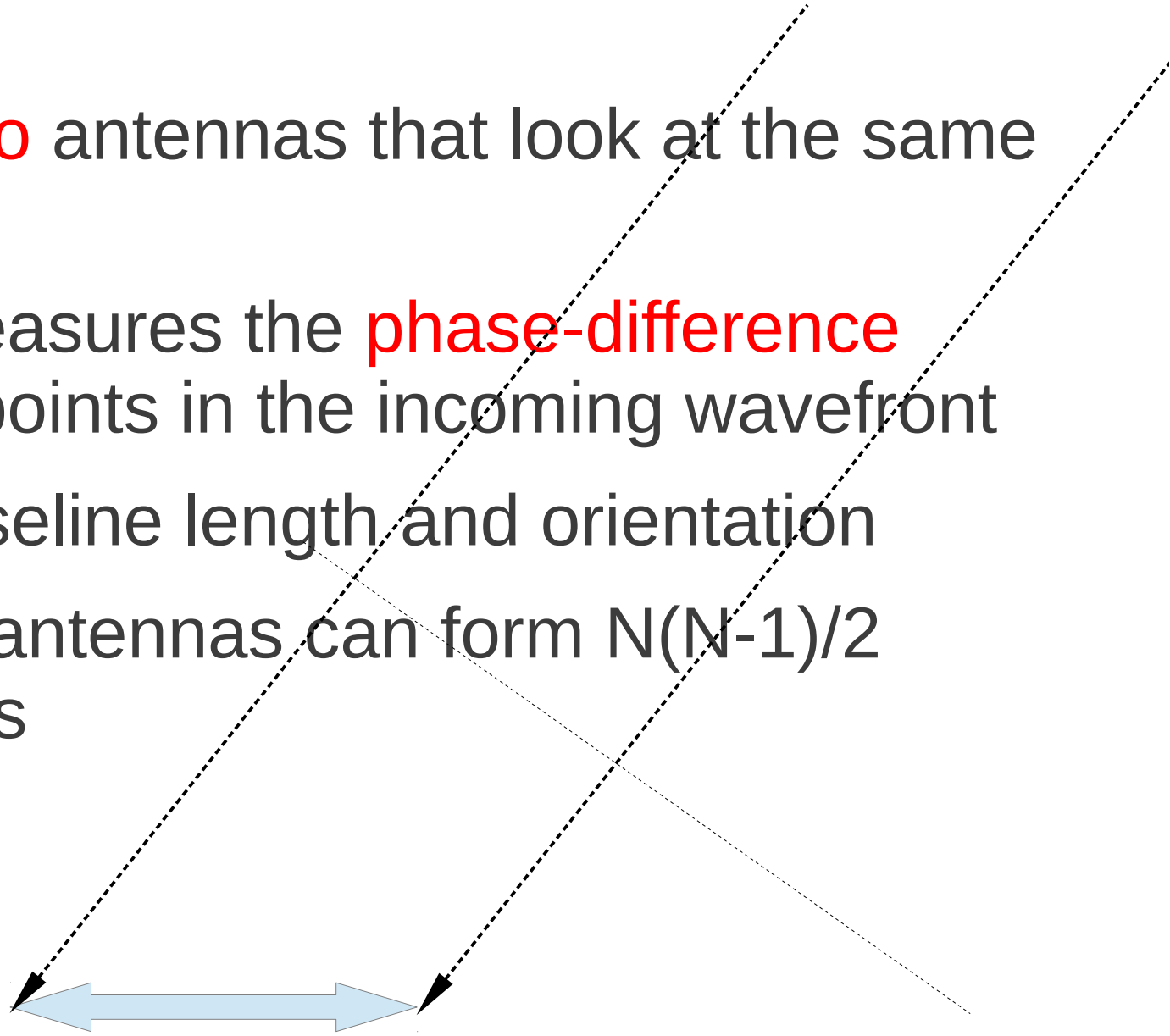
Outline

- What is RSC?
  - Advantages
  - Limitations
- The place of RSC in the GST
  - Diagnostic tool
  - Fast first calibration stage
- A second youth for RSC?
  - Built into SKA

Interferometer

- Consists of two antennas that look at the same source
- Essentially measures the phase-difference between two points in the incoming wavefront
- Important: Baseline length and orientation
- An array of N antennas can form N(N-1)/2 interferometers



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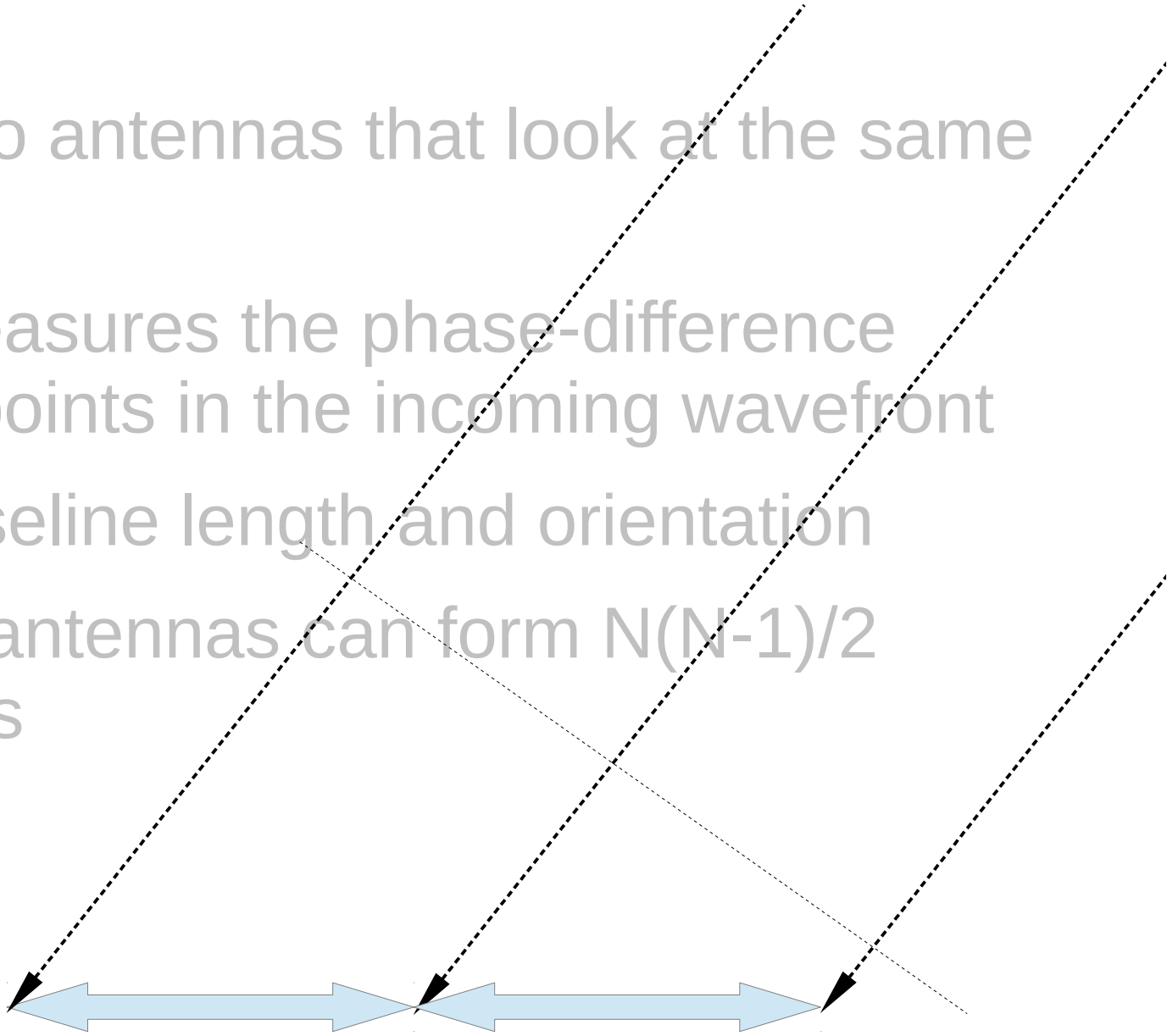
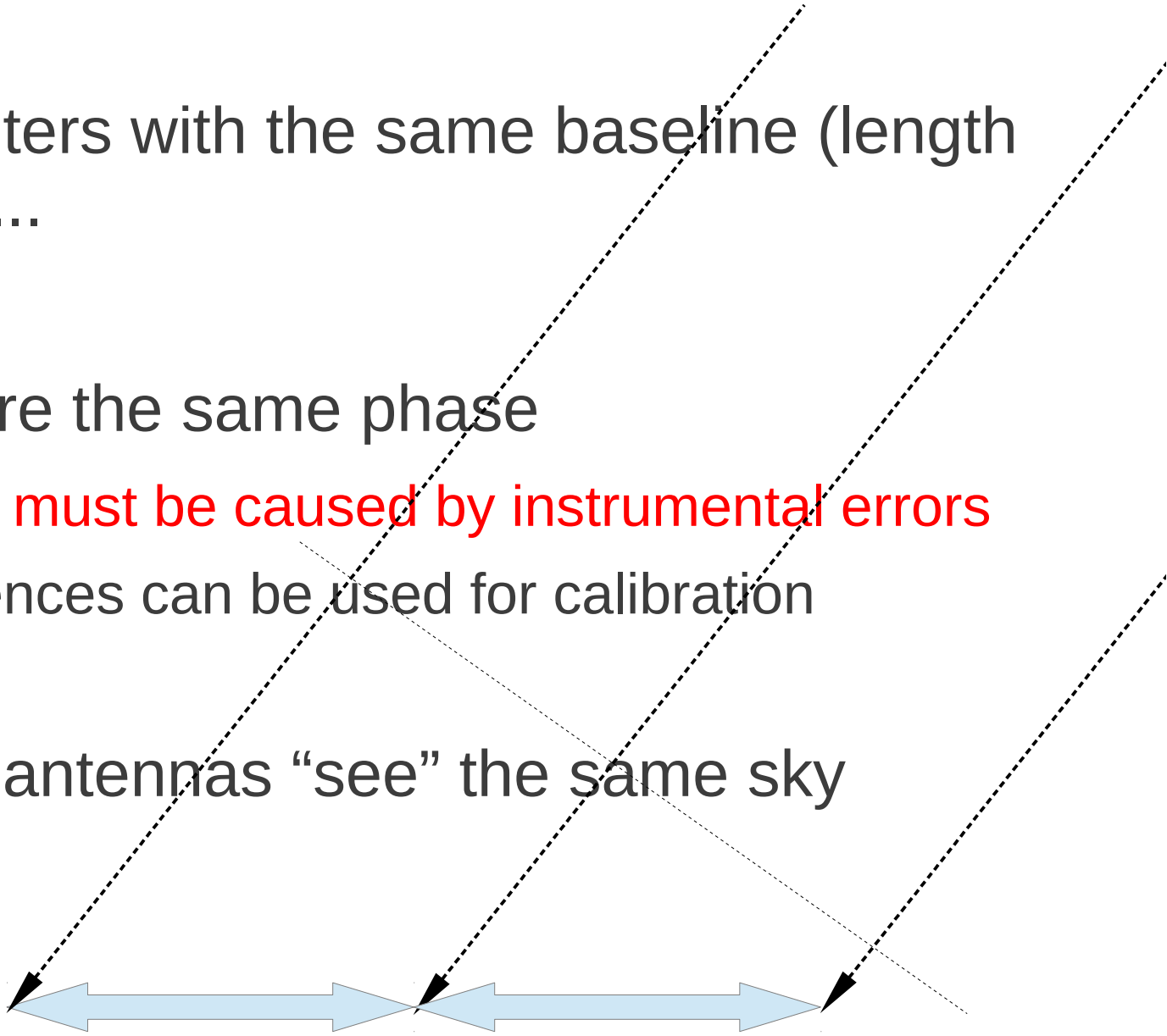


Redundant Baselines

- Two interferometers with the same baseline (length and orientation)...
-
- ...should measure the same phase
  - Any differences must be caused by instrumental errors
  - So these differences can be used for calibration
  -
- ...provided their antennas “see” the same sky



WSRT: lots of redundancy

(because CLEAN did not exist yet in 1968)

Reduction of the number of unknown antenna phases

N=2 

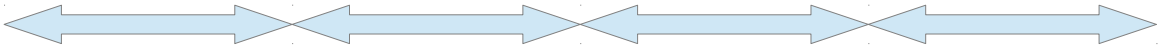
2 unknown phases (abs and gradient)

N=3 

2 unknown phases (abs and gradient)

N=4 

3 unknowns (2 abs, one gradient)

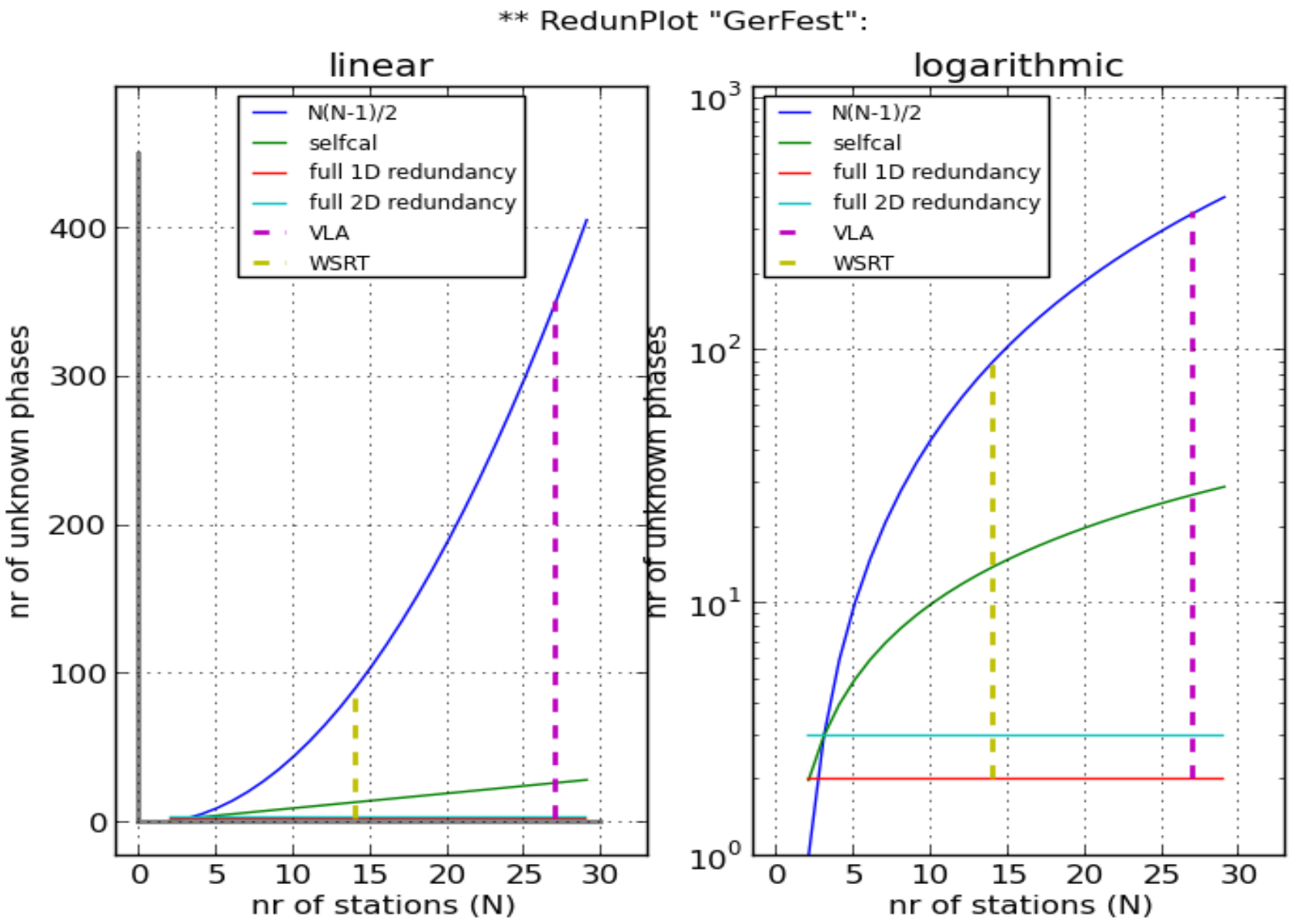
N=5 

still only 2 unknowns

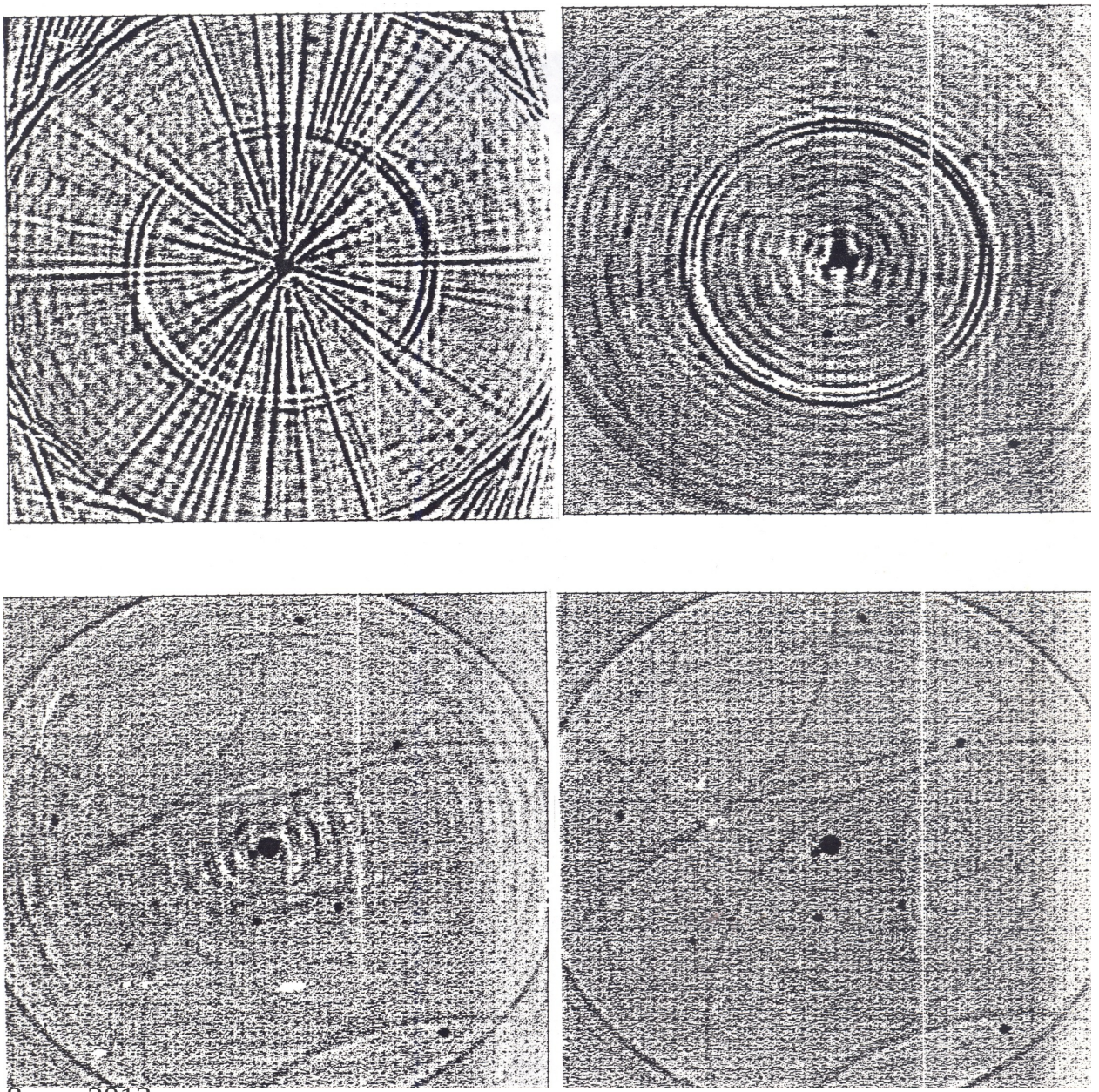
So: N(N-1)/2 (=10) data-samples share only 2 unknown phases

NB: 2D regular array: 3 parameters (abs phase and 2 gradients)

A single time-slot



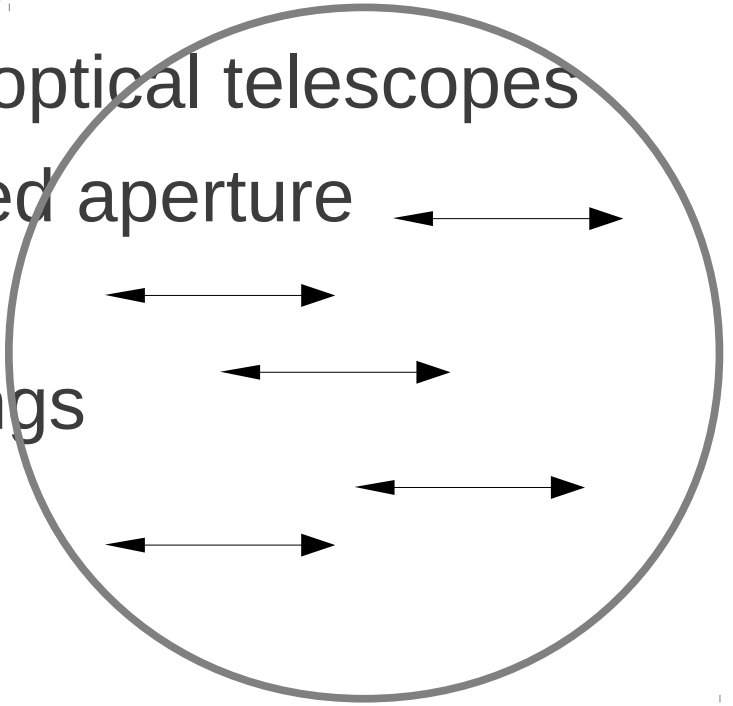
The WSRT Dynamic Range skyrocketed



3C48
~1980
WSRT
610 MHz
1:10000

Some serendipity:
RSC gave you WIFI (!)

- Hamaker, O'Sullivan, Noordam (JOSA, 1977)
  - Only one of these three got rich
-
- Triggered by Muller and Buffington (JOSA, 1976)
  - The use of sharpness criteria in optical telescopes
  - They work best for a fully sampled aperture
    - Like a lens or a mirror
  - Because it has redundant spacings

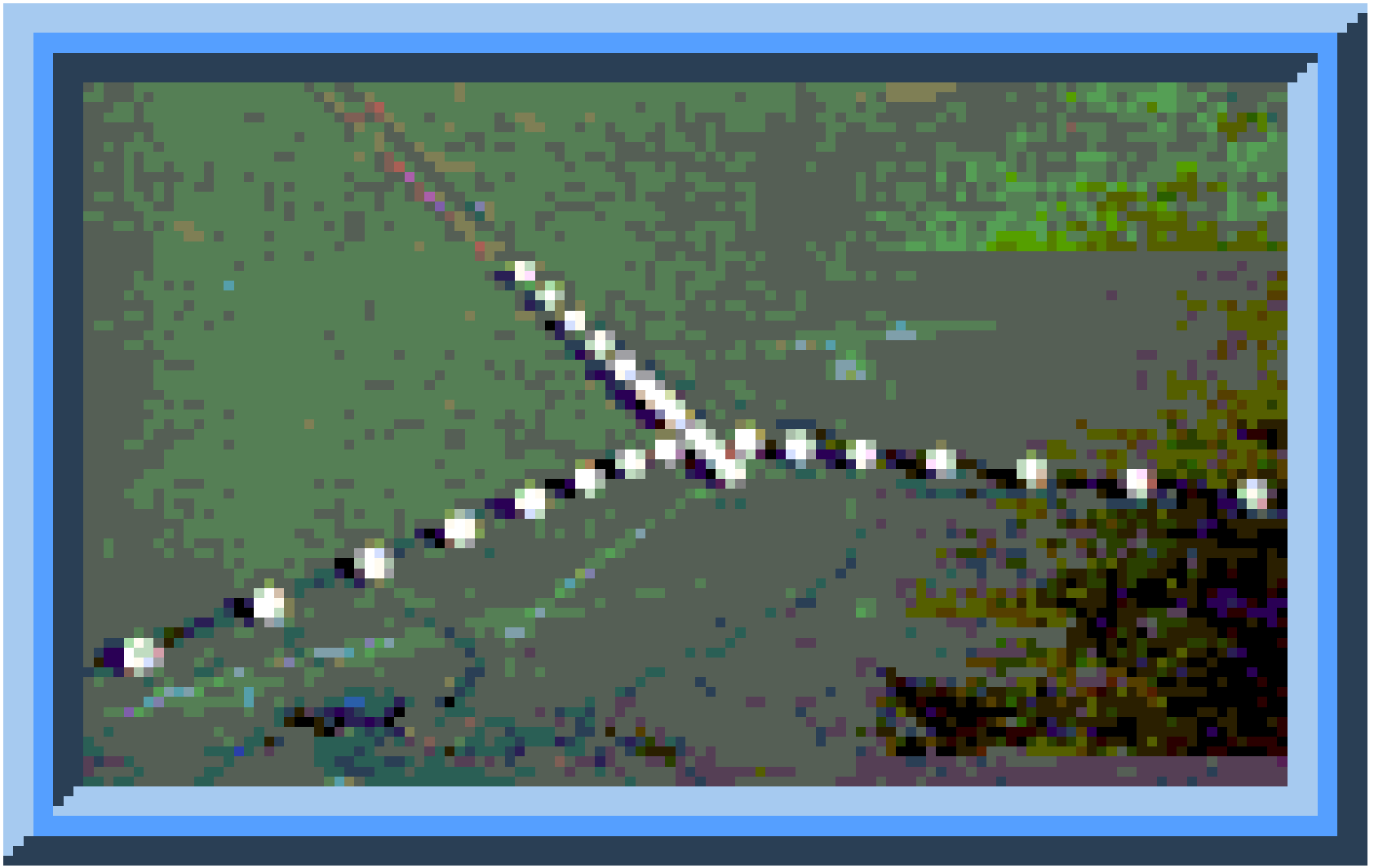


The Blue Riband
of Macho Imaging

- 1980: WSRT and “redundancy”: DR = 10.000
- 1990: WSRT and NEWSTAR: 1.000.000
- 2010: WSRT and MeqTrees: 2.000.000
- 2013: EVLA and MeqTrees: 3.000.000
- 201x: LOFAR and SageCal....?
-
- … but RSC did not play much of a role in all this...
  - (generalised selfcal with good sky models is enough)

VLA: no redundancy

(N=27: 351 different baselines, closure errors)



Self-calibration (selfcal)

- Solving for (antenna-based!) instrumental errors by comparing the measured data with predicted values from a model of the observed field.
- Selfcal was a game changer technique:
  - it saved the VLA, and made VLBI possible
  - “generalised” selfcal is the basis of all these wonderful LOFAR images
- Invented by Cornwell and Wilkinson (Jodrell Bank, ~1980)
  - Selfcal, “hybrid mapping” and “closure phase” are all the same thing
- Locally stumbled upon by yours truly, by way of RSC
  - with help from John O'Sullivan, Johan Hamaker and Ger de Bruyn
  - (we initially missed it because of Wim's frugality)

Selfcal and RSC

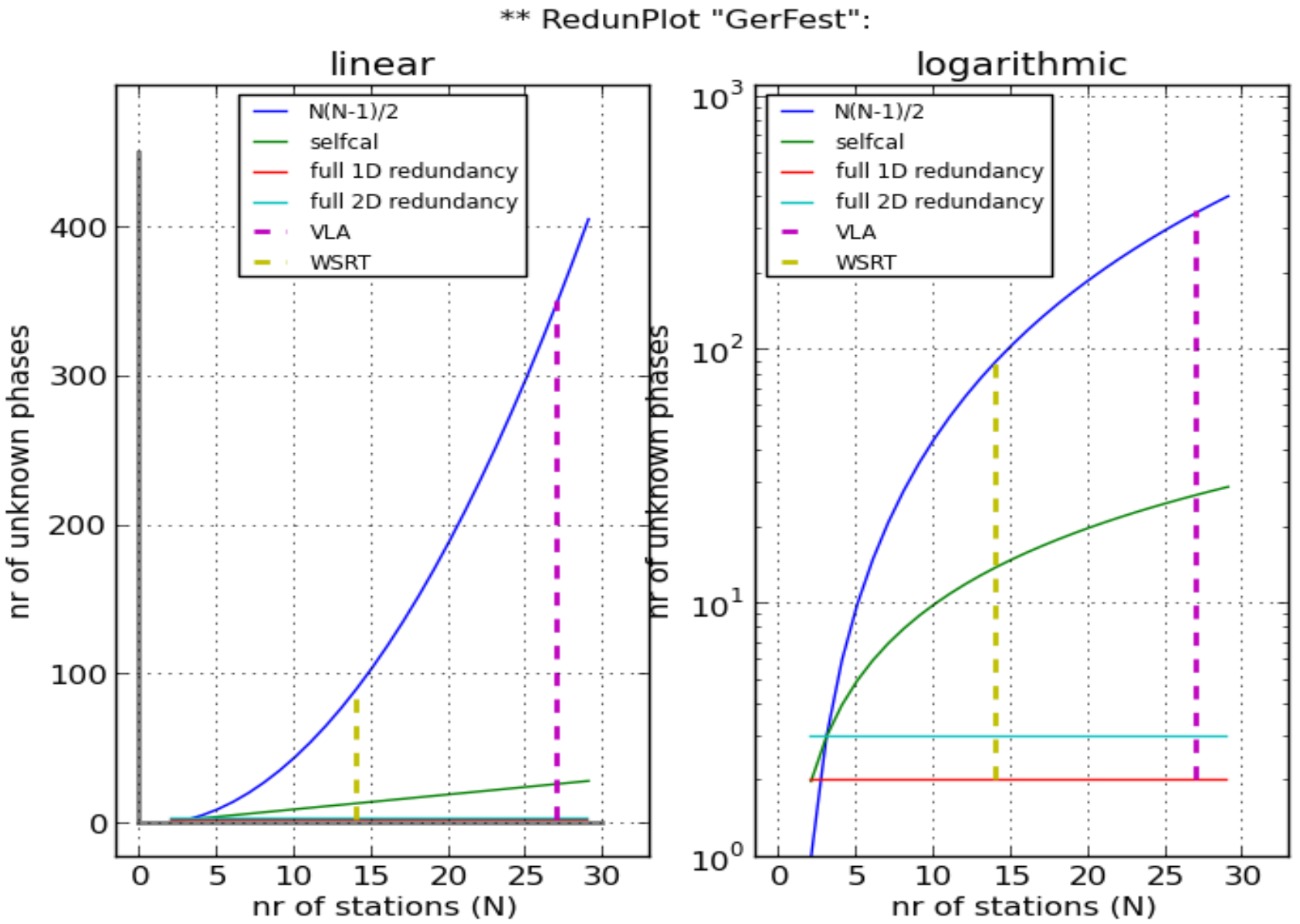
- Both require the assumption of antenna-based instrumental errors
  - To reduce the number of unknowns
  - RSC has even fewer unknowns than selfcal (2 vs N)
- RSC is supposed to be sky-model-independent
  - Which makes it fast and “safe”
  - But RSC does still need a model to align time-slots
    - i.e. to equalise their position and total flux
    - We tried to use the centre-of-flux of the entire field for that
- RSC may be seen as an extra constraint on selfcal

Problems with RSC

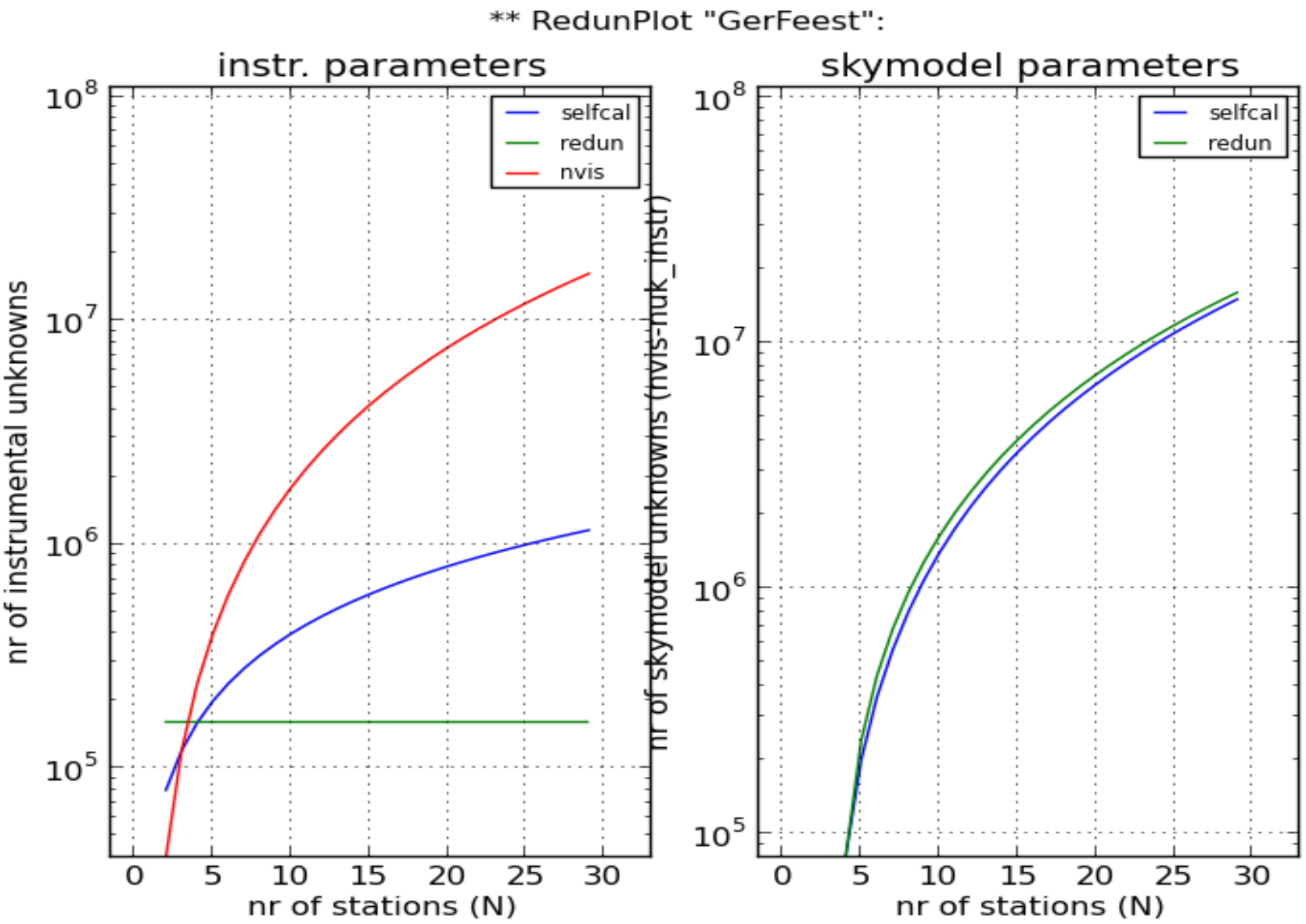
- Different antennas “see” a different sky
  - More so for more ambitious (macho) imaging
- RSC can't deal with Direction Dependent Effects (DDE)
  - E.g. station beam-shapes, or the ionosphere
- Redundant baselines reduce the uv-coverage
  - Only a problem for arrays with few elements

The Known Unknowns

(for a single time-slot)

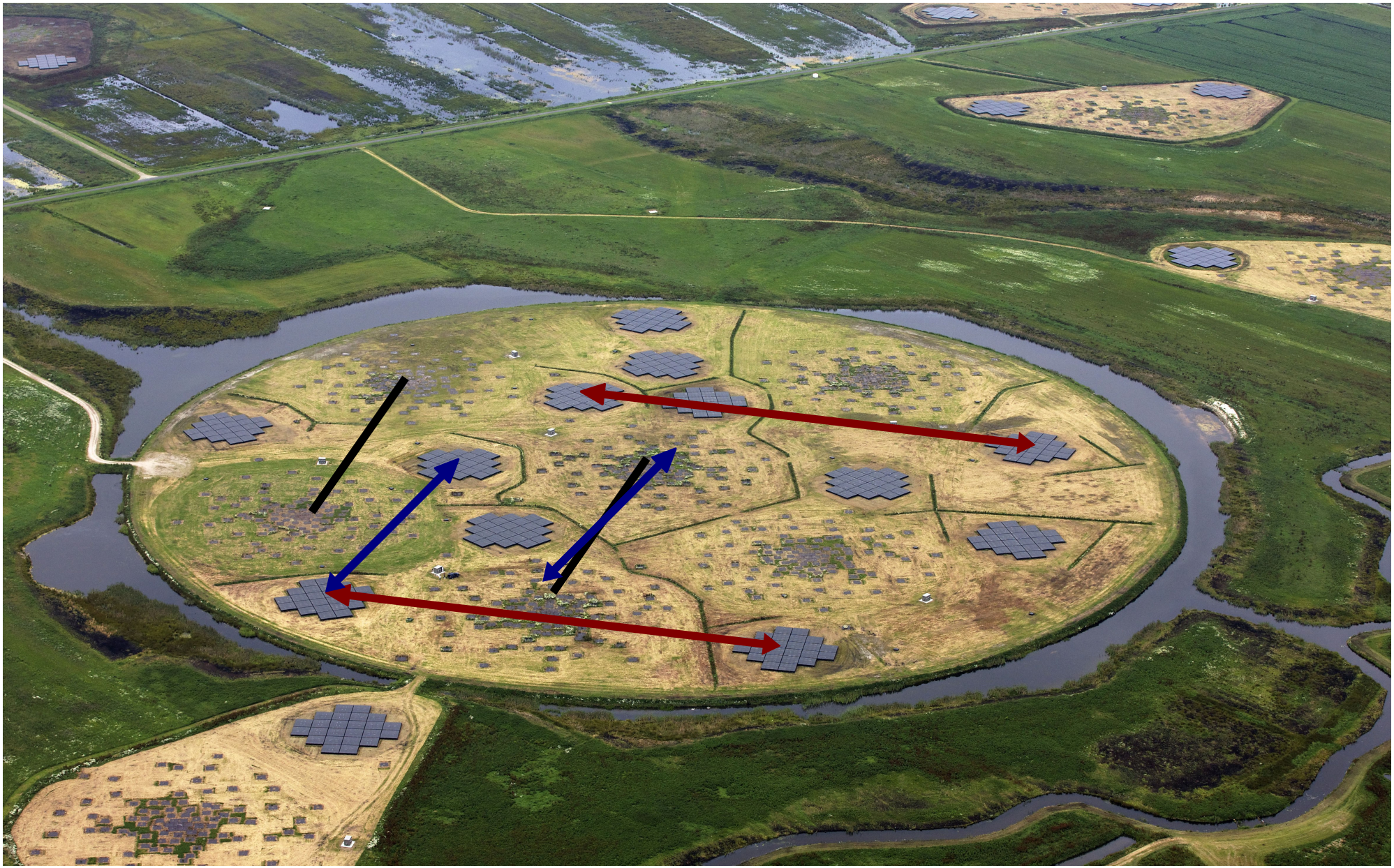


The Unknown Knowns
(for an entire observation)



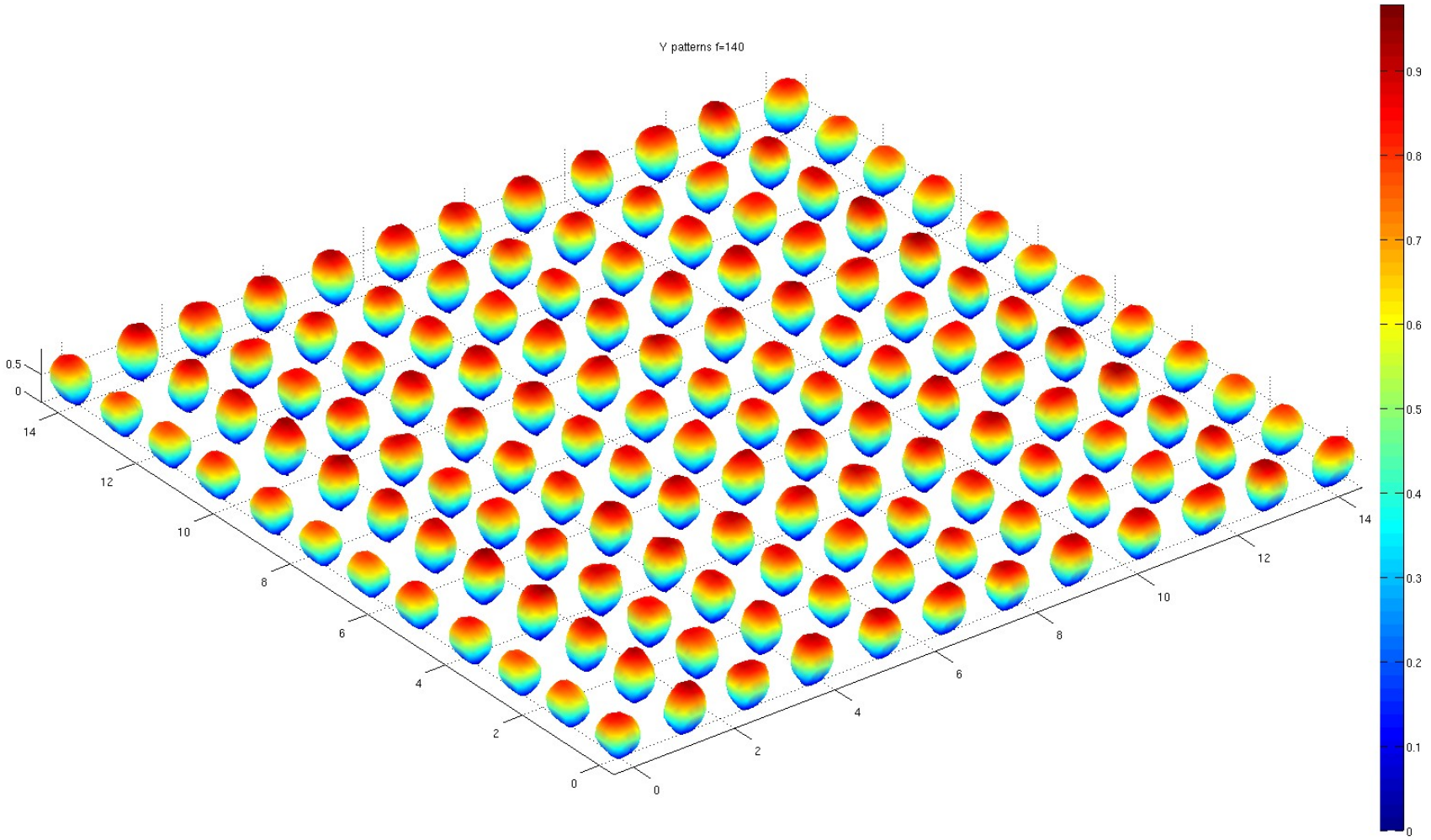
A second youth for Redundant Spacing Calibration?

LOFAR superterp redundancy



LOFAR HBA station redundancy

(used for HBA station calibration)

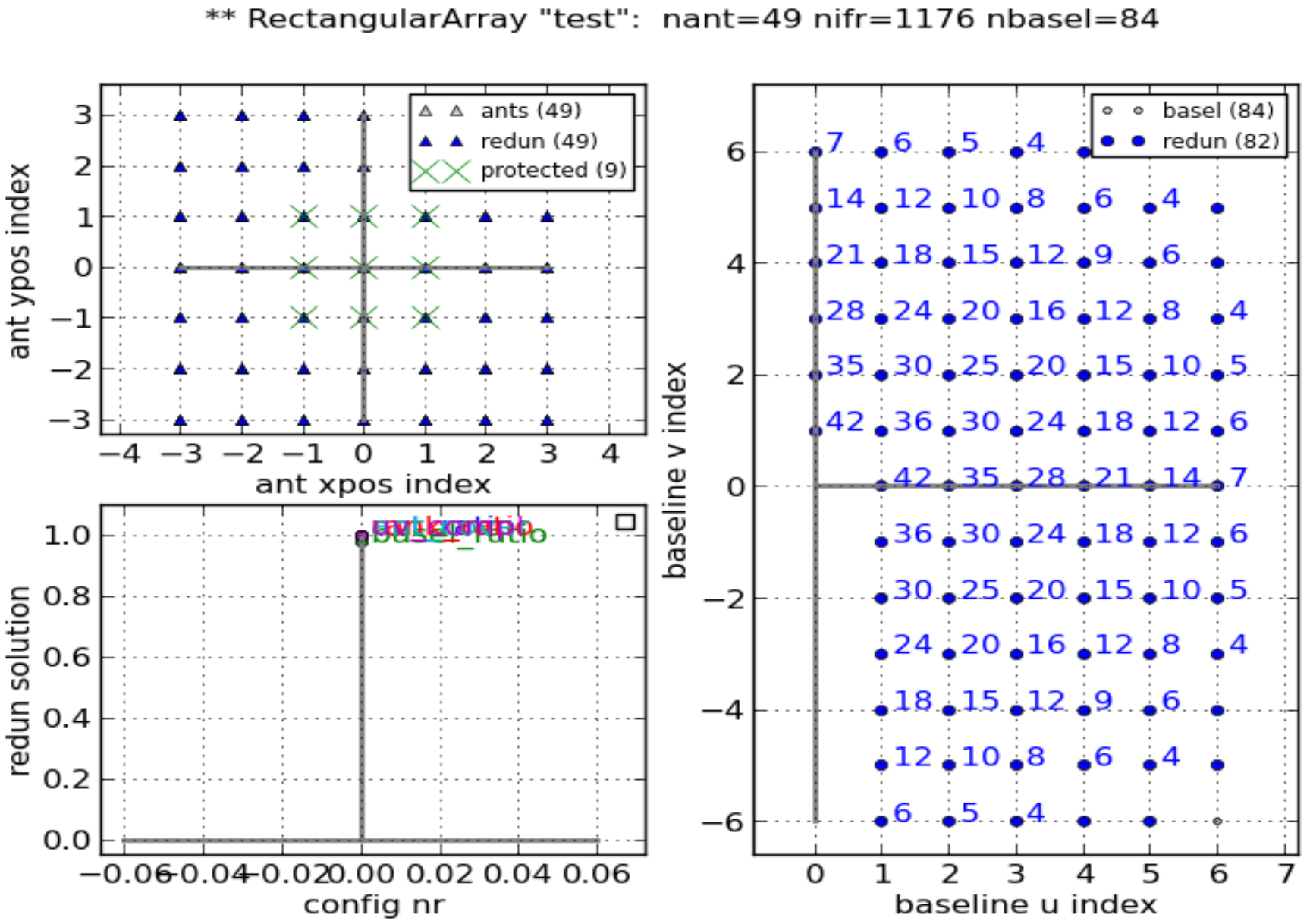


2D array of 144 antennas that share only 2 unknown phases!

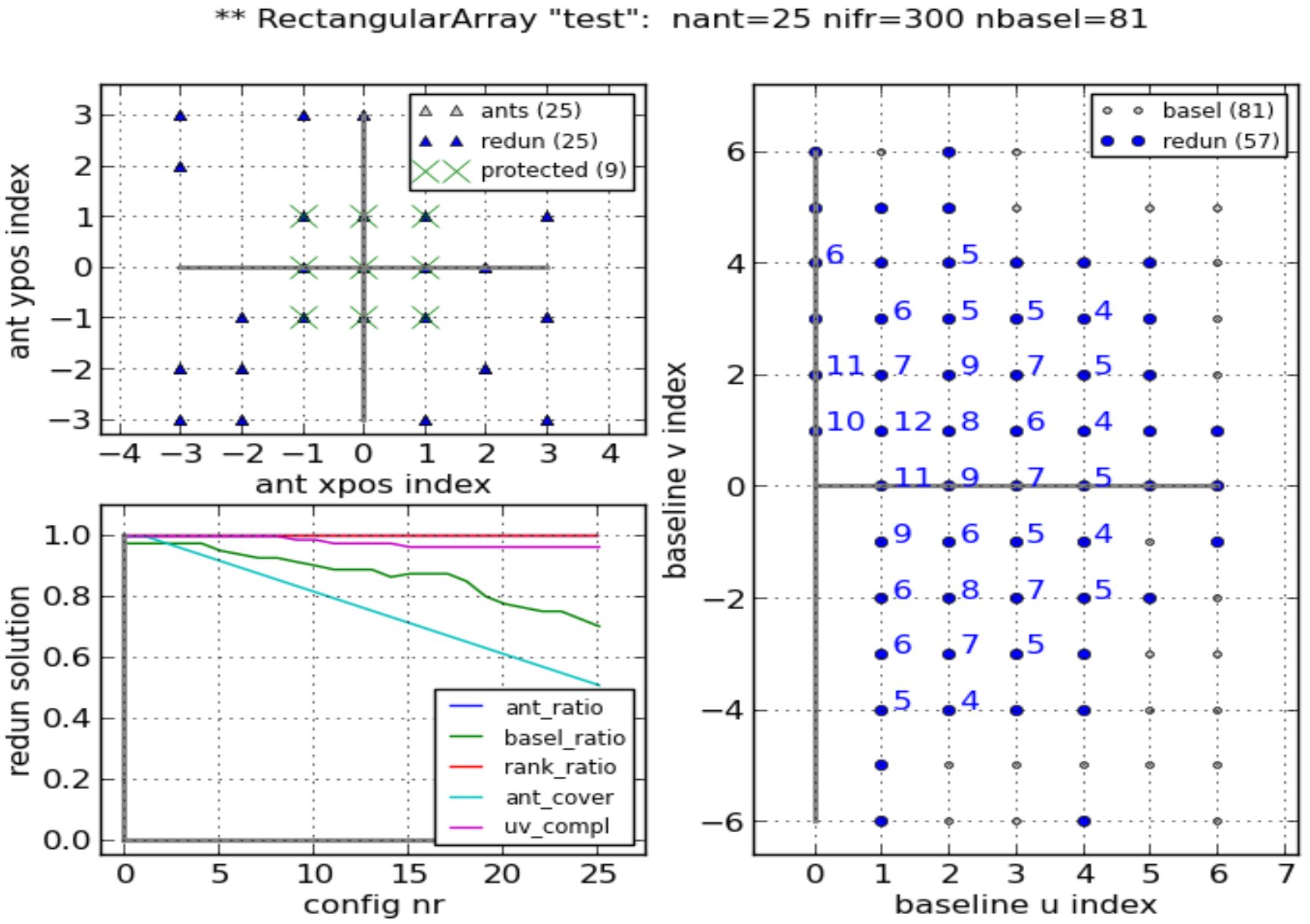
Redundancy for SKA?
(advocated by the Man Himself)

- Easily achieved for the central 3 km or so
- Stations (and even antennas) on single flat grid
  - Fully filled grid: sensitivity
  - Fully sampled uv-plane: imaging
- Powerful diagnostic tool
- Rapid initial calibration
- The idea of an “FFT telescope” (Tegmark and friends)
  - No gridding needed (except to apply DDE's...?)

Rectangular Array

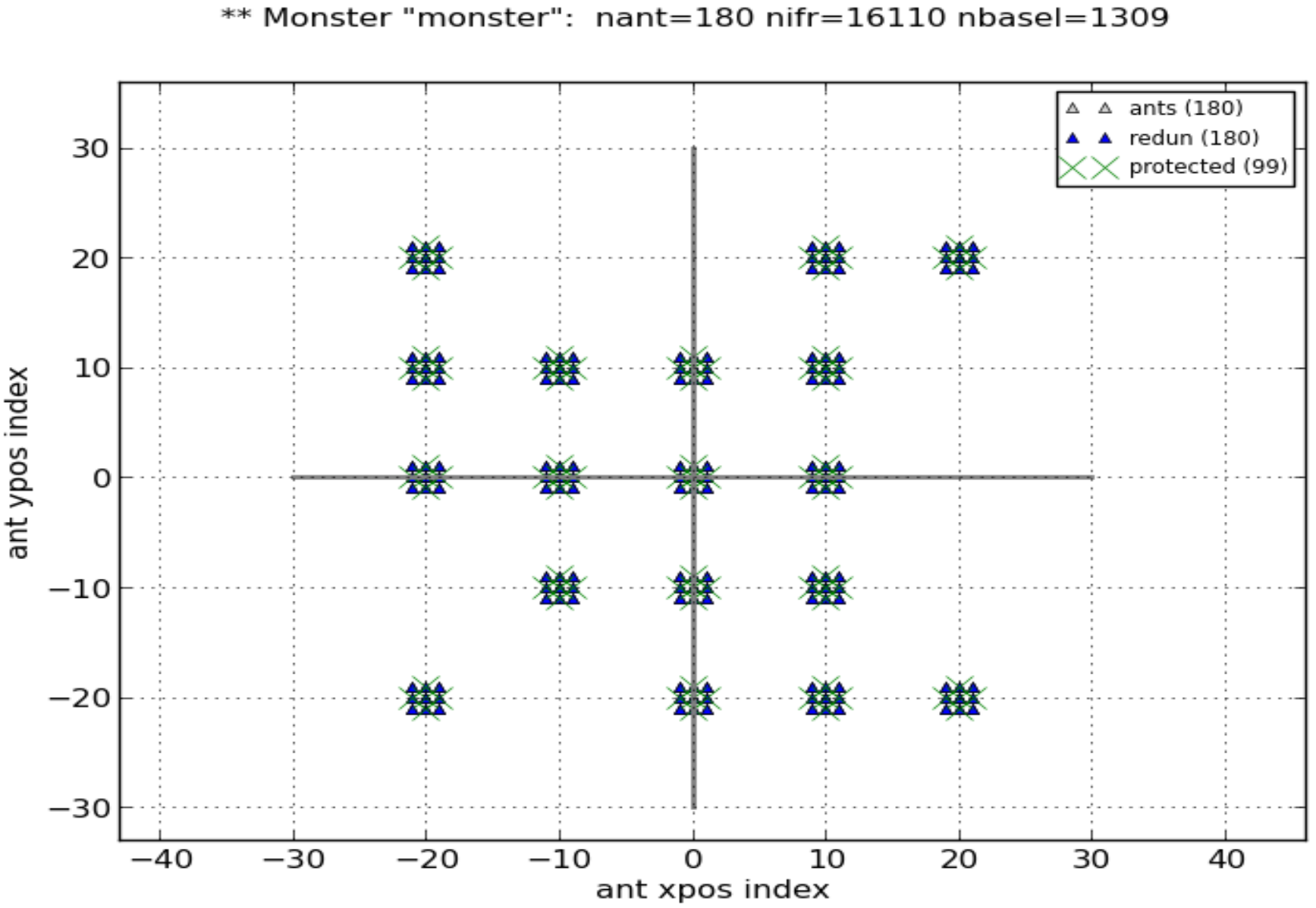


Optimised


** RectangularArray "test": nant=25 nifr=300 nbasel=81
ants (25)
redun (25)
protected (9)
ant ypos index
ant xpos index
redun solution
config nr
ant_ratio
basel_ratio
rank_ratio
ant_cover
uv_compl
basel (81)
redun (57)
baseline v index
baseline u index

Stations and Antennas

all on the same grid



Enjoy...