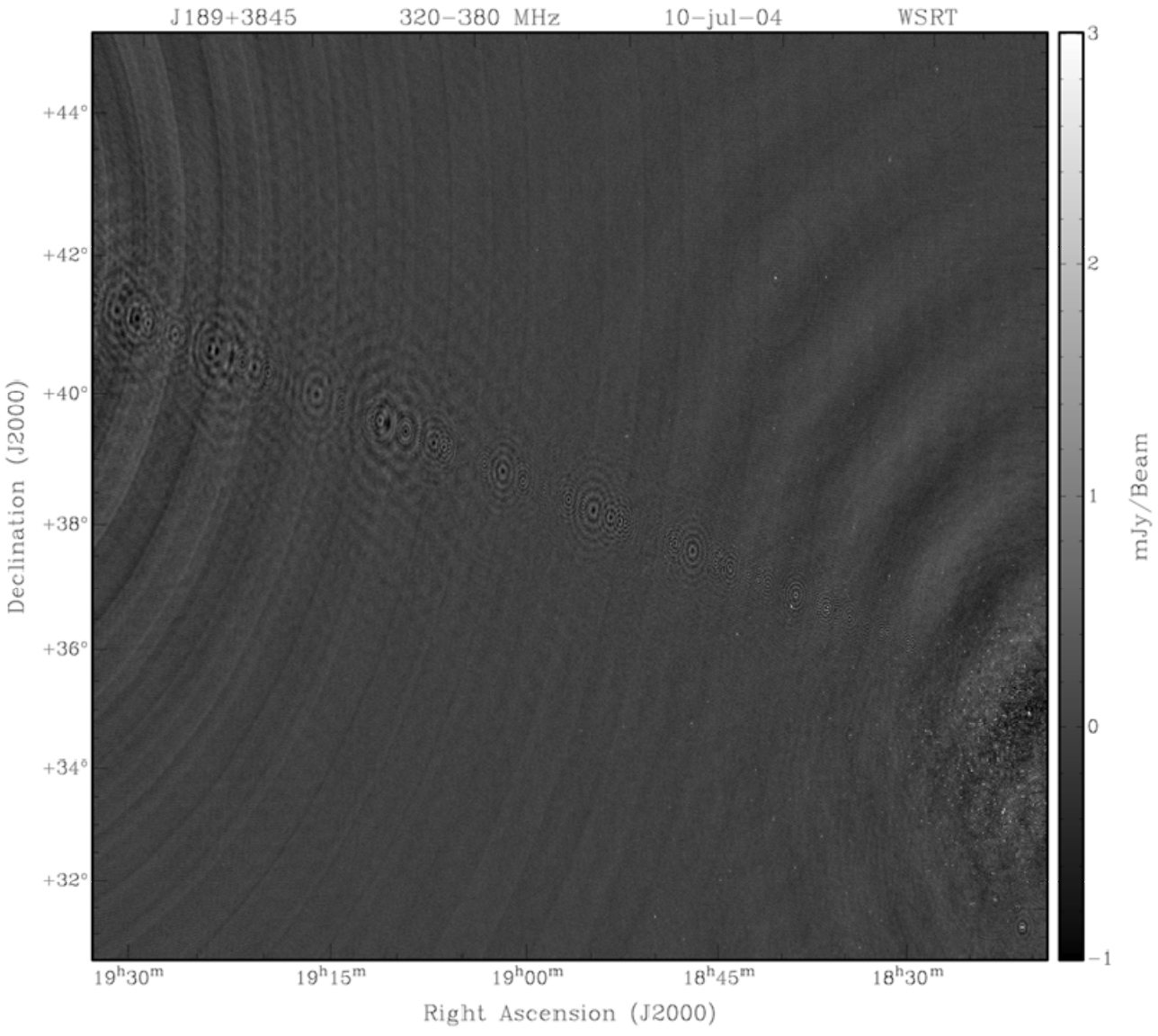
Ghostbusters: The Unknown Unknowns Of Selfcal

O. Smirnov

Football: 18:30 at De Borken

2004: The Ghosts of Cyg A



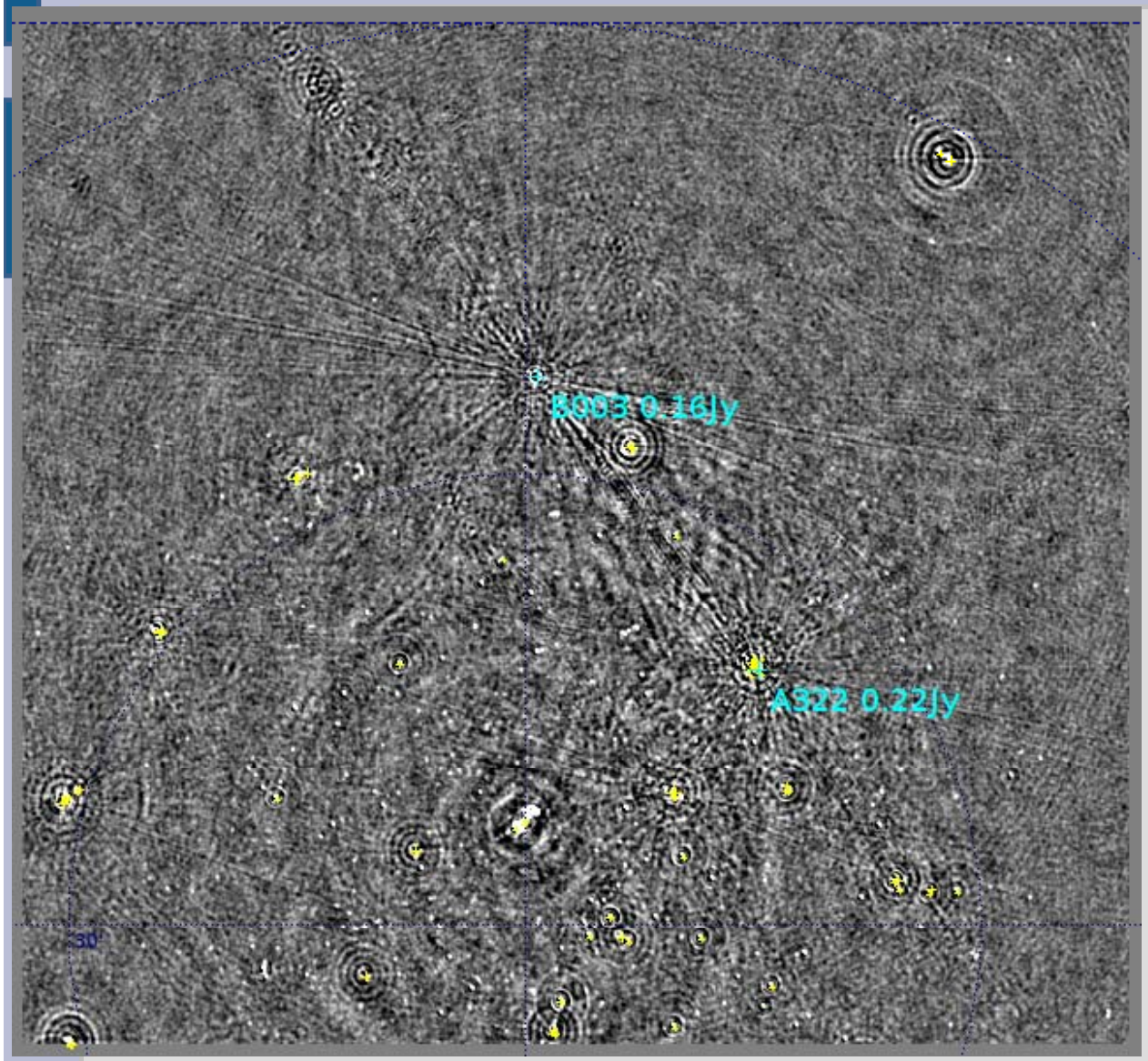
WSRT 92cm observation of J1819+3845 by Ger de Bruyn

- String of ghosts from brightest source to CygA (20° away!)

- Perfectly circular
- Present in all 8 bands
- Position and size distribution does not depend on frequency
- Wasn't clear if they were “in the data”, or a

2008: LOFAR Ghosts

2010: QMC2
(The Field That Keeps On Giving)

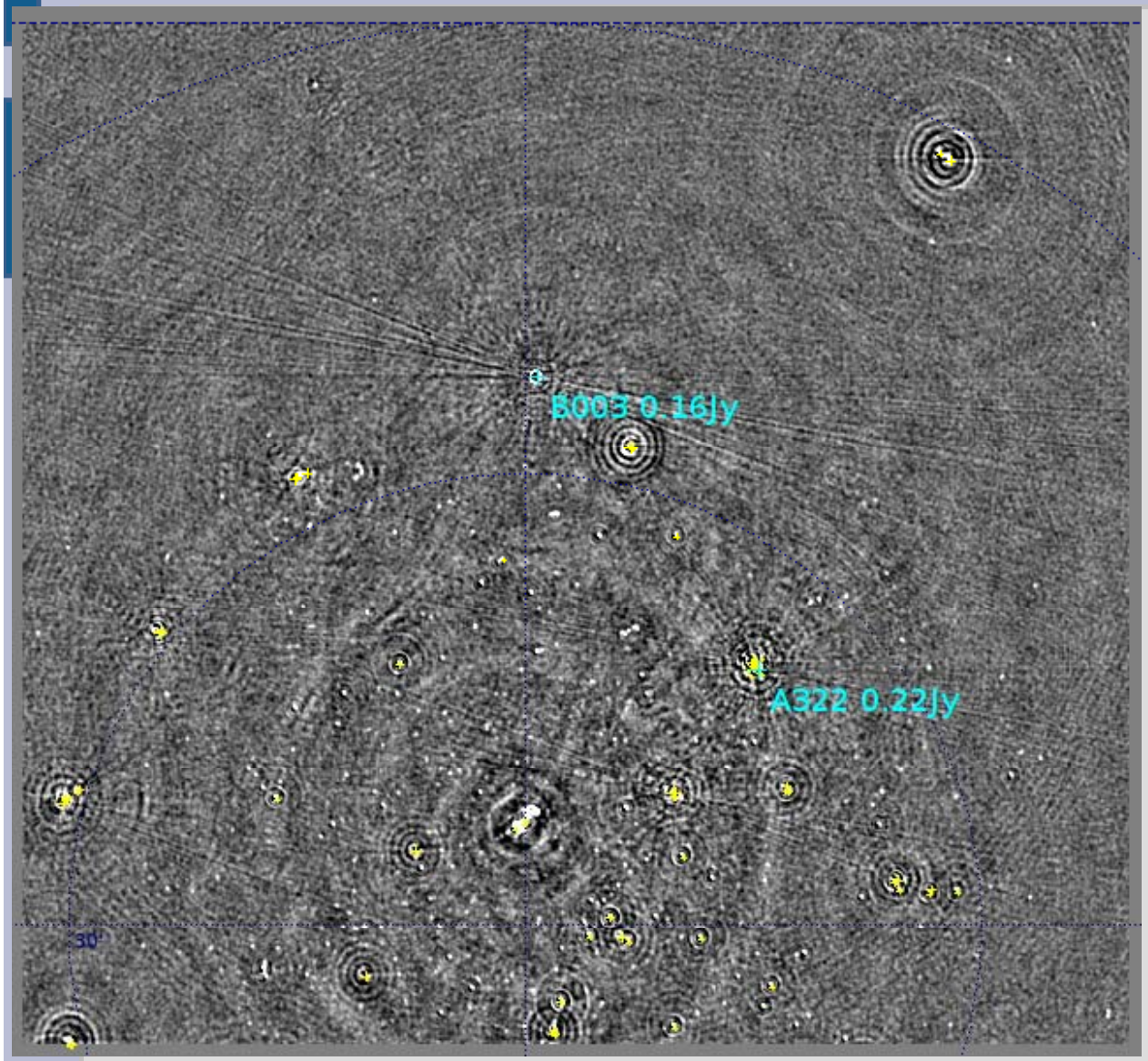


WSRT 21cm observation

- String of ghosts connecting dominant sources A (220 mJy) and B (160 mJy)
- Second, fainter, string from source A towards NNE *(Do not cross the streams!)*
- Qualitatively similar to
- 2004 ghosts

2010: QMC2

Busted!



...and then I busted them.

"Maybe now you'll never slime a guy with a positron collider!"
– Dr. Peter Venkman

To Bust Something Is To Understand It?

- QMC2 calibration steps:
  - Selfcal
  - Differential gain solutions for A, B, and 6 other sources
  - Repeat selfcal ← **ghosts disappear**
- Repeated selfcal for J1819+3845 observation, with a *frequency-dependent* differential gain on Cyg A: ghosts busted
- Independently, Ger de Bruyn repeated selfcal using an improved Cyg A model: ghosts busted

Poll: Who Understands Selfcal?

- *"If you are not completely confused by quantum mechanics, you do not understand it."*

  – <John Wheeler|Niels Bohr>
- *"It is safe to say that nobody understands quantum mechanics"*

  – Richard Feynman

- Second Law Of Smirnov:
  You do not understand selfcal.

Ghostbusters: The Movie

Ghosts = Selfcal Contamination

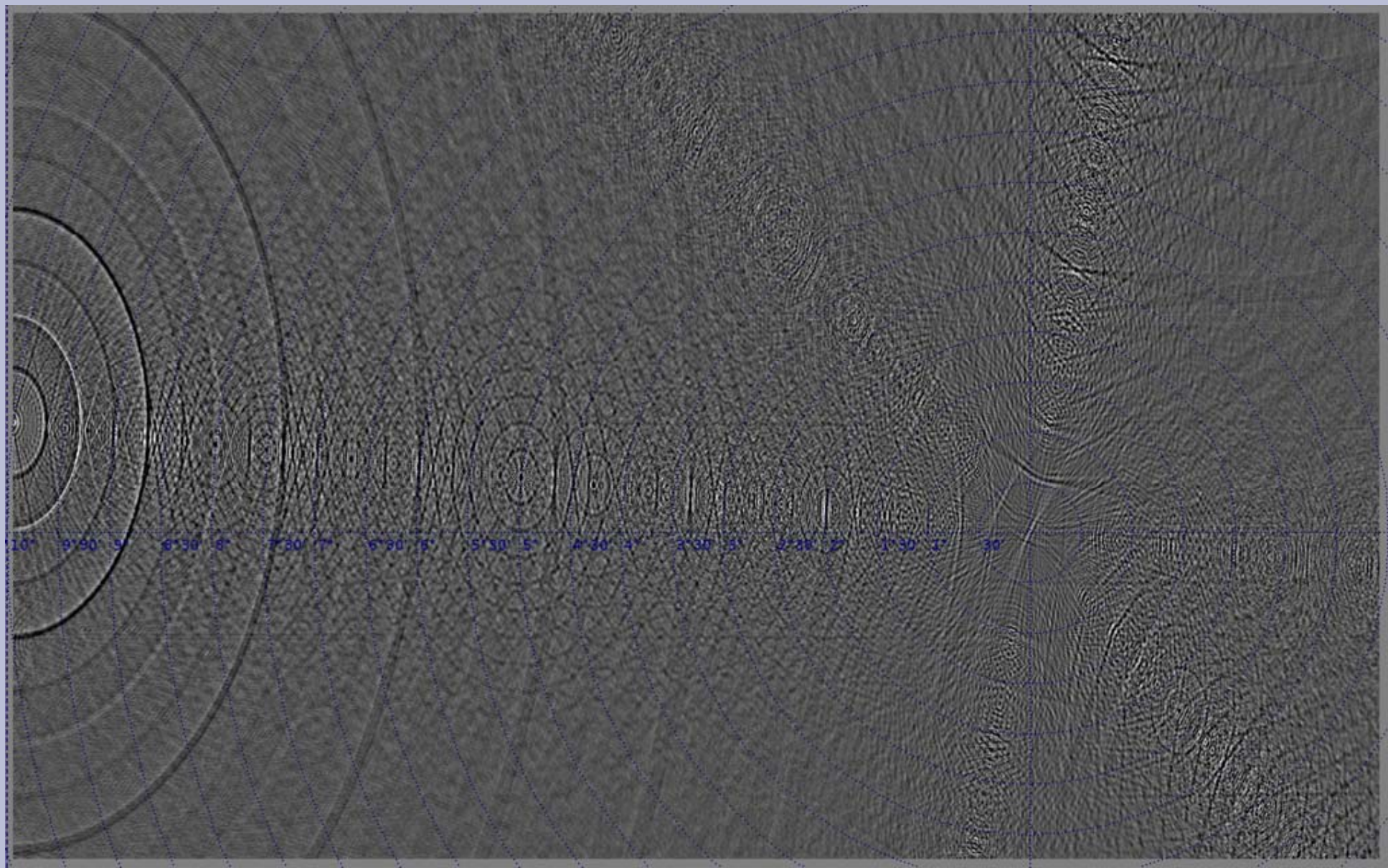
- MS1: Simulated 1 Jy source at phase centre
- MS2: added three 1 mJy sources at various distances from centre (from 10' to 20°)
- Did selfcal **on MS2** using a sky model composed of only the 1 Jy source
  - Selfcal solutions are thus slightly “contaminated” by the three off-axis sources
- Applied these solutions **to MS1**, and subtracted central source
- Result is “distilled artifacts”: flux from the central source that has been scattered by applying contaminated selfcal solutions

Ghastly Properties

- On a line from contaminator to dominator
  - ...and extend beyond both
- Perfect circles
- Sit at (some) natural harmonics
  - 1/2, 1/5, 4/5, 3/7, 4/7
  - ...but not e.g. 2/5 or 2/7!!
- Decrease in intensity with more baselines and more channels (for WSRT)
- Full of surprises...

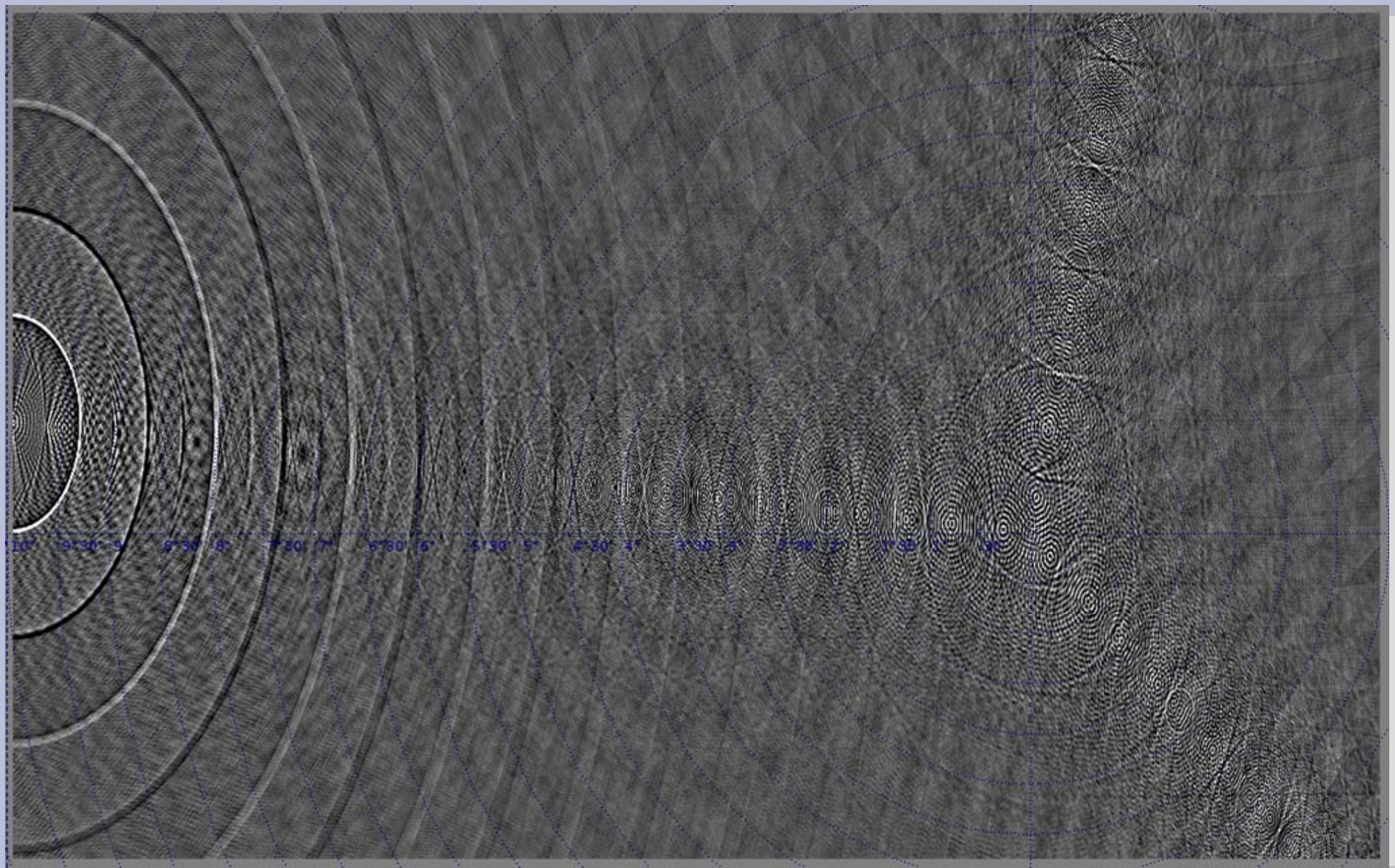
Ghastly Surprises

Going from 91 baselines (down with redundancy)...



Ghastly Surprises

...to 40 baselines



Pop Quiz 1

- What changes if we make the dominant source twice as bright?
  - 2 Jy dominator, 1 mJy contaminators

Ghastly Properties 2

- Answer: **NOTHING**

- Ghosts are proportional to contaminator flux, independent of dominator flux
- Quite faint: <μJy for a mJy contaminator
  - explains why we haven't been seeing more of them
  - a luxury problem, formerly
  - the 2004 case: a lot of Cyg A flux went unmodelled, due to frequency-dependent primary beam

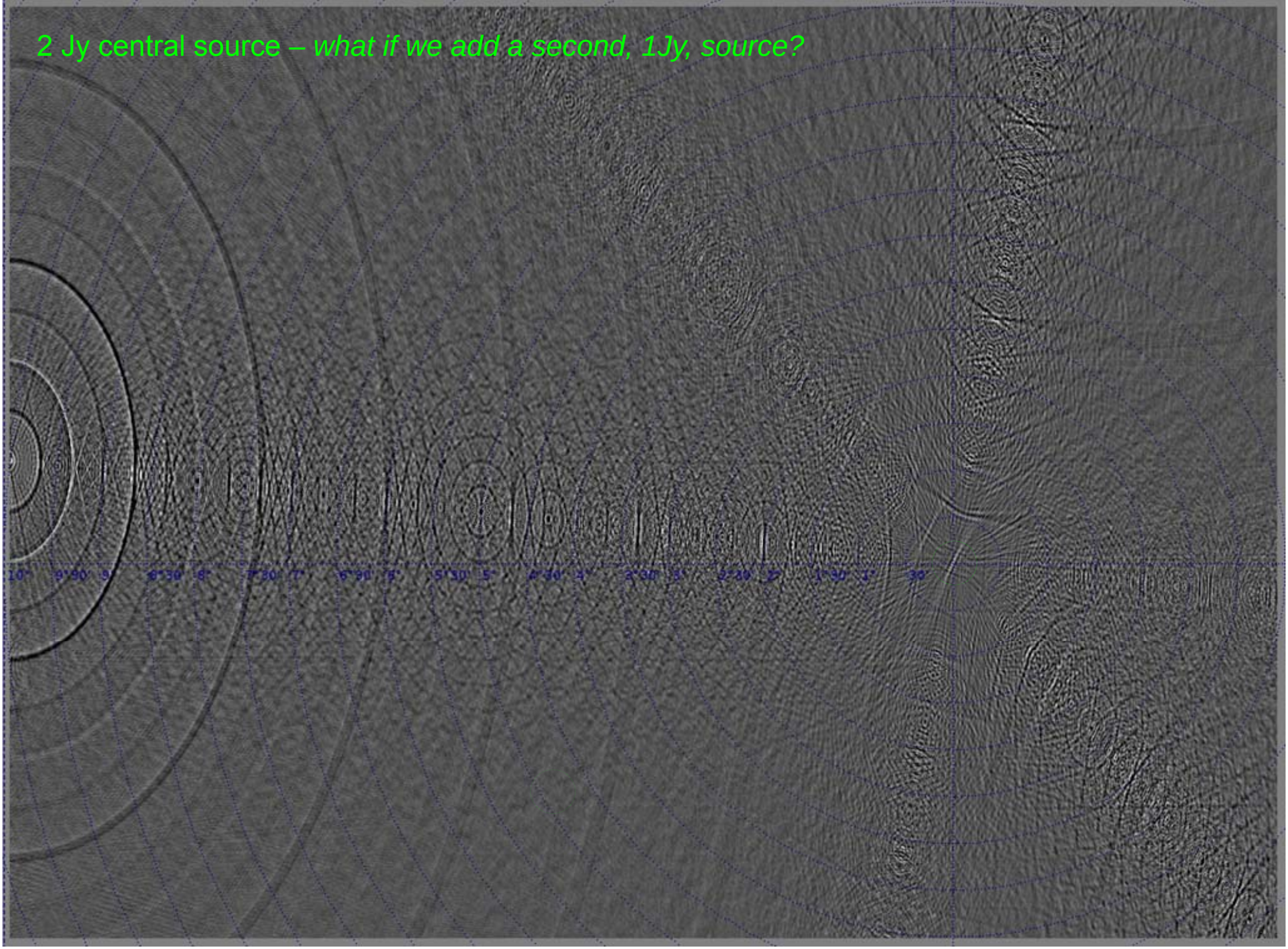
Ghastly Mysteries

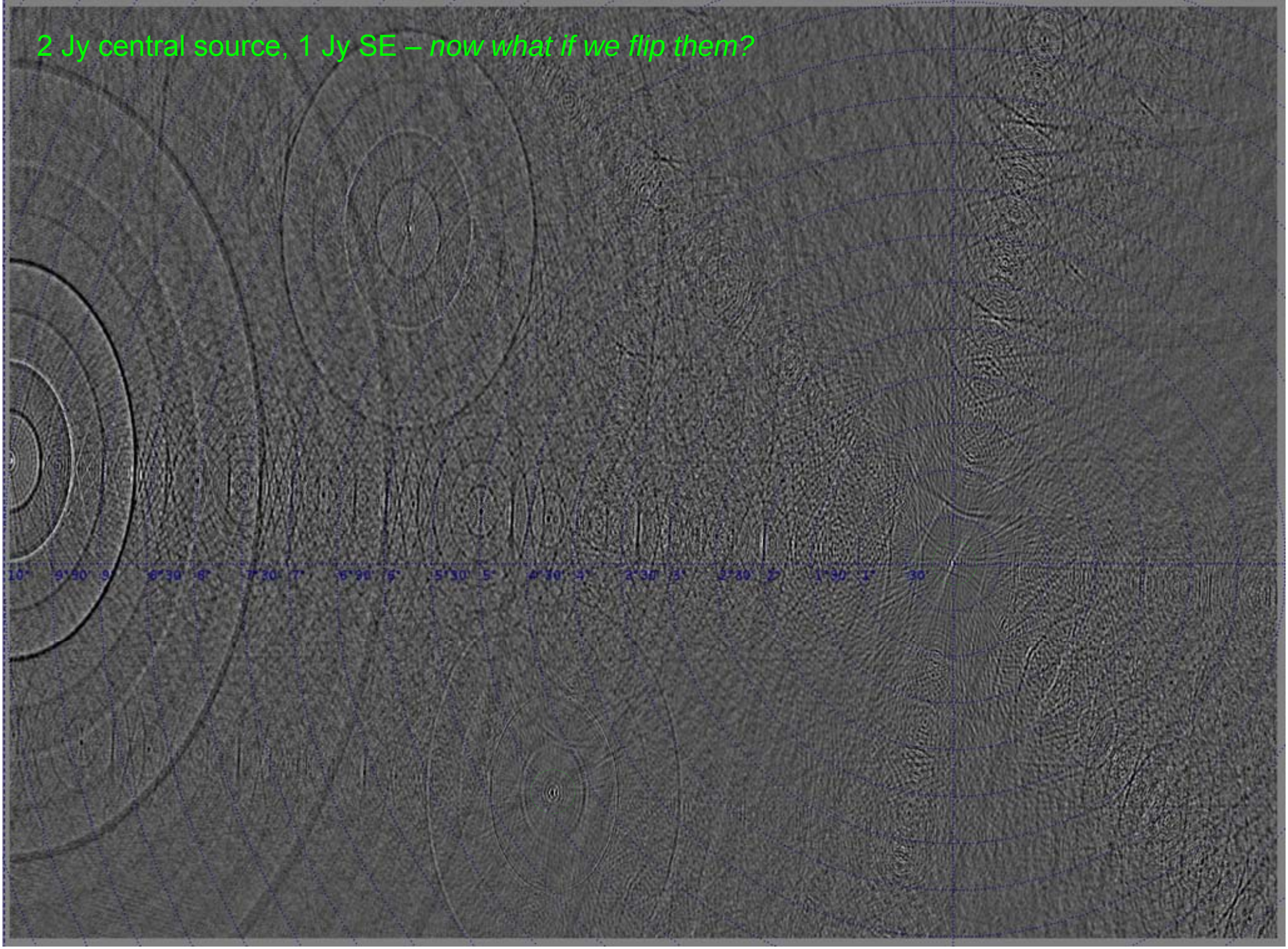
- Why are they on a line?
- Why the natural harmonics?
  - Error modes correspond to ratios phase gradients?
- Why the perfect circles?
  - source needs to be sufficiently far for perfect circles to form up

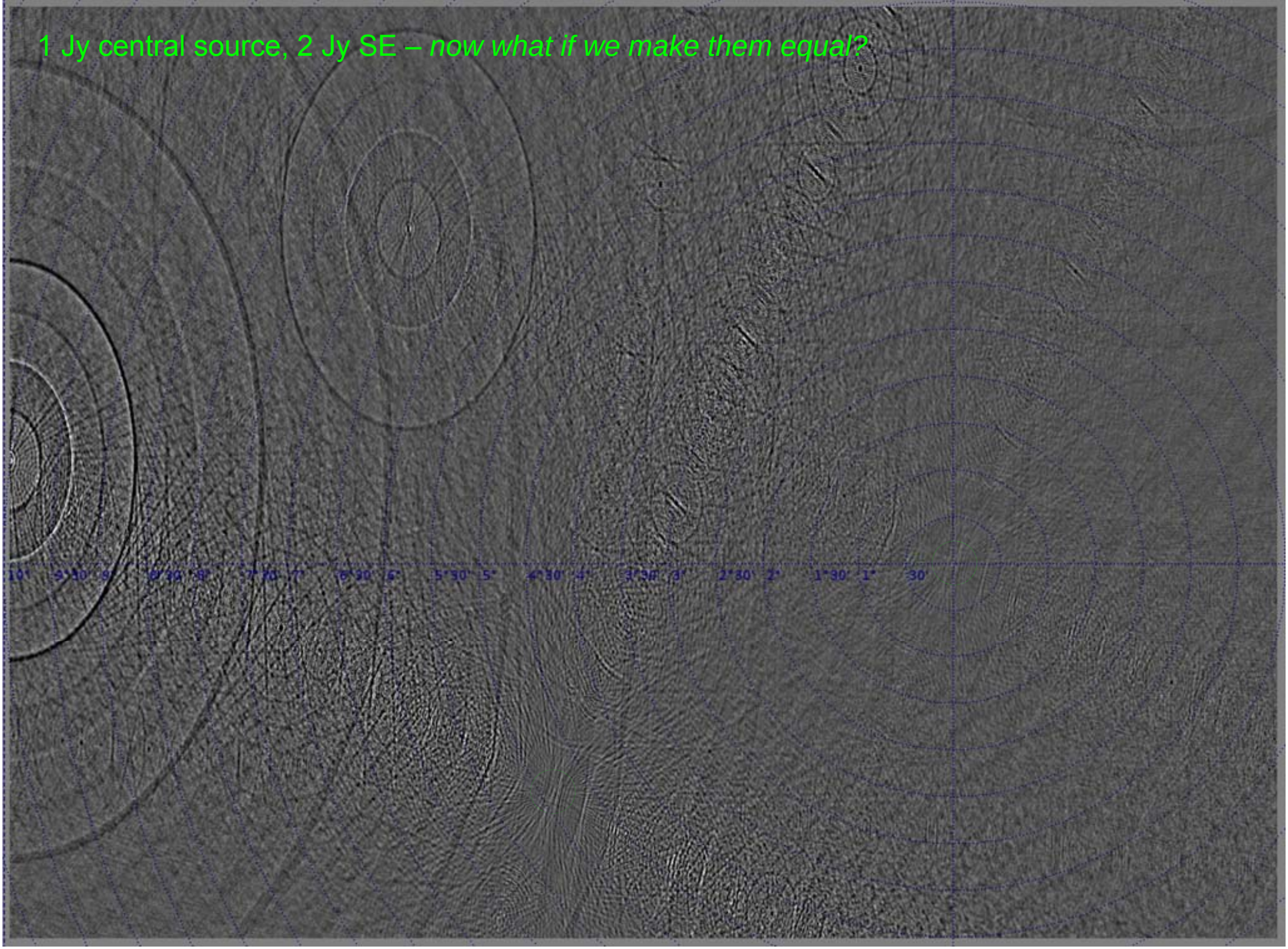
- Don't fully understand them, but we can simulate them into submission...

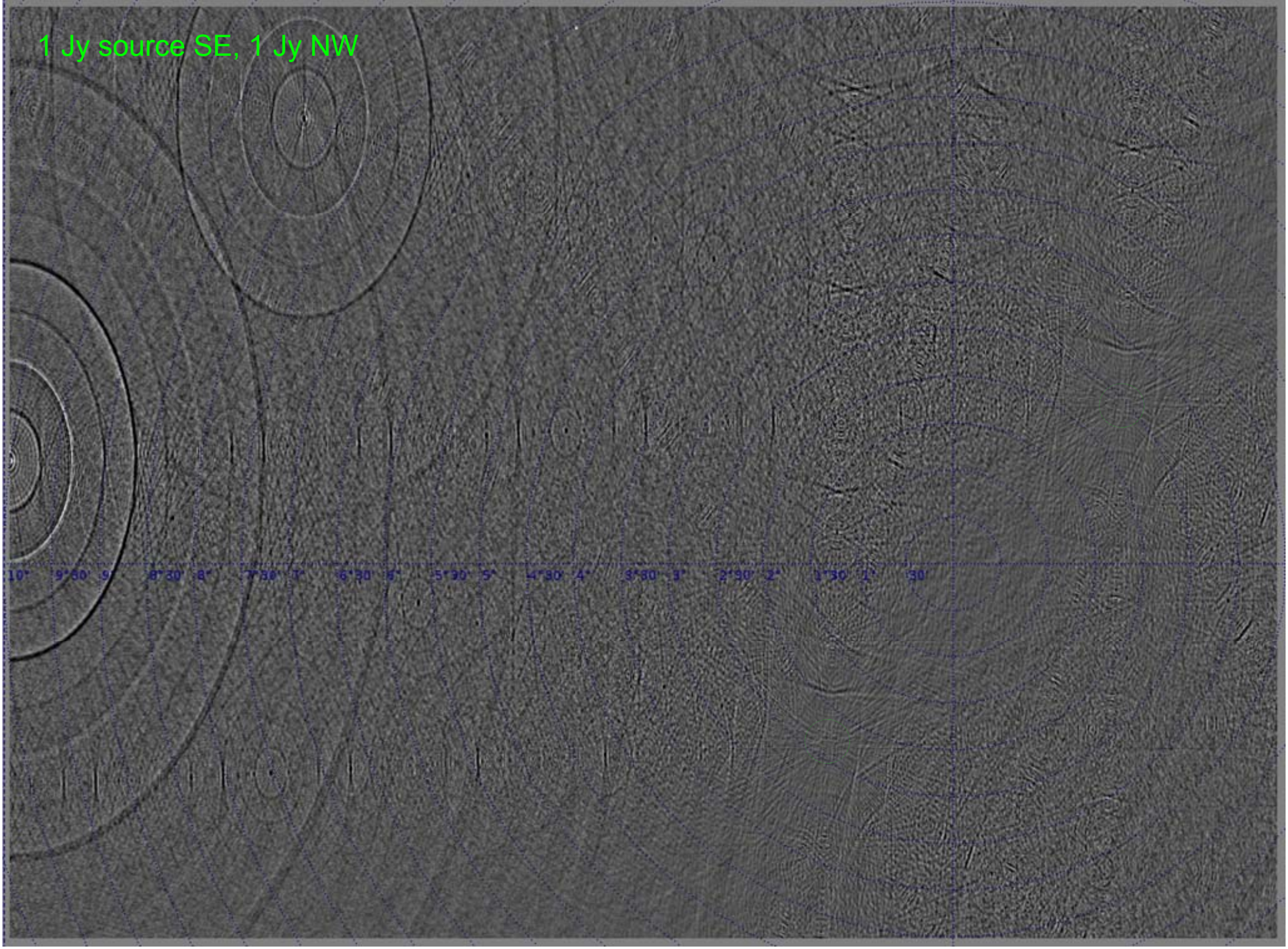
Pop Quiz 2

- Ghosts don't change if we increase the dominator flux
- ...but what happens if we put that extra flux somewhere else, i.e. add a weaker source off-center?
  - 2 Jy source at center
  - 1 Jy off-center


2 Jy central source – *what if we add a second, 1Jy, source?*


2 Jy central source, 1 Jy SE – *now what if we flip them?*

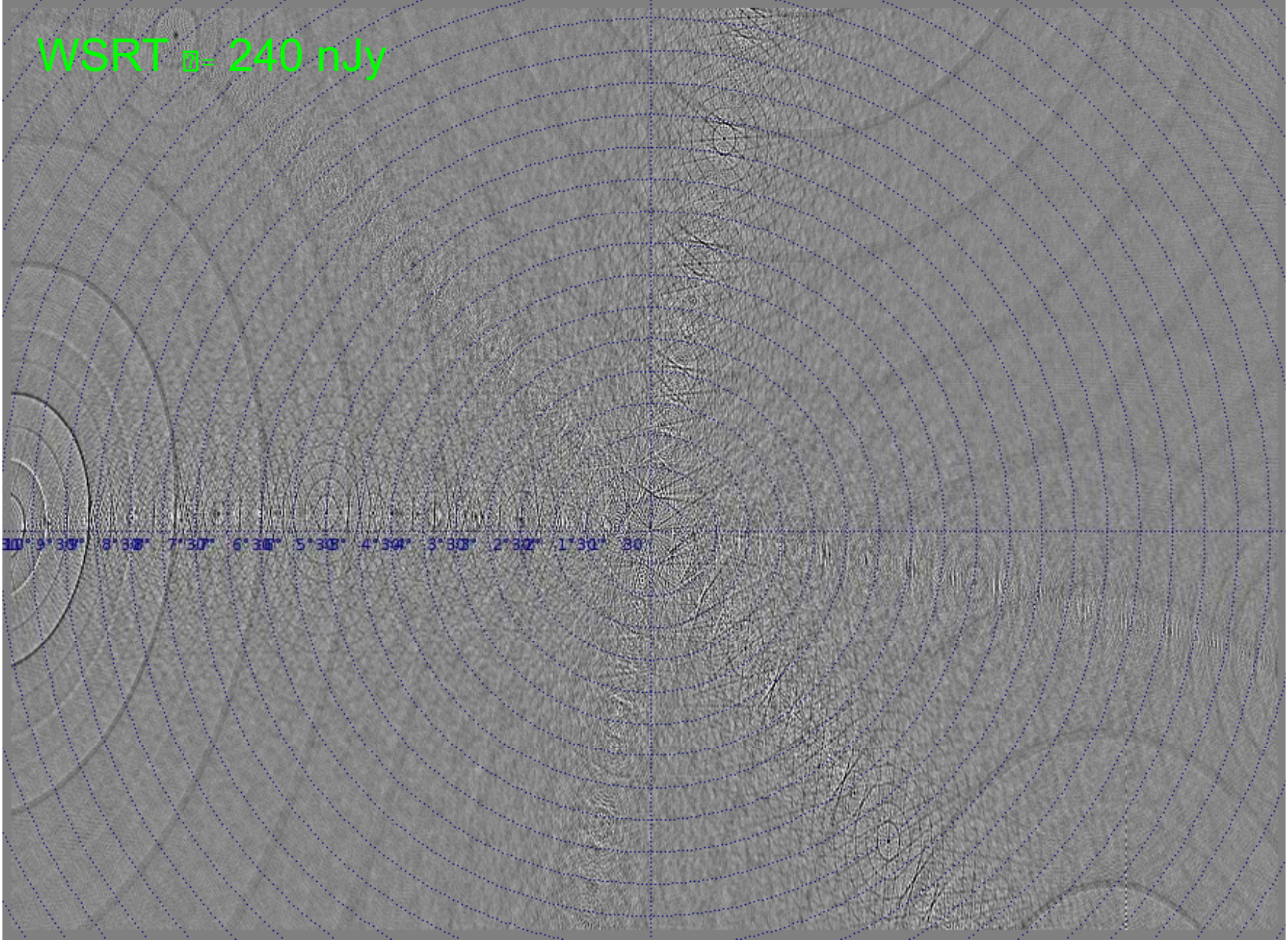

1 Jy central source, 2 Jy SE – *now what if we make them equal?*
10°
9°30'
9°
8°30'
8°
7°30'
7°
6°30'
6°
5°30'
5°
4°30'
4°
3°30'
3°
2°30'
2°
1°30'
1°
30'

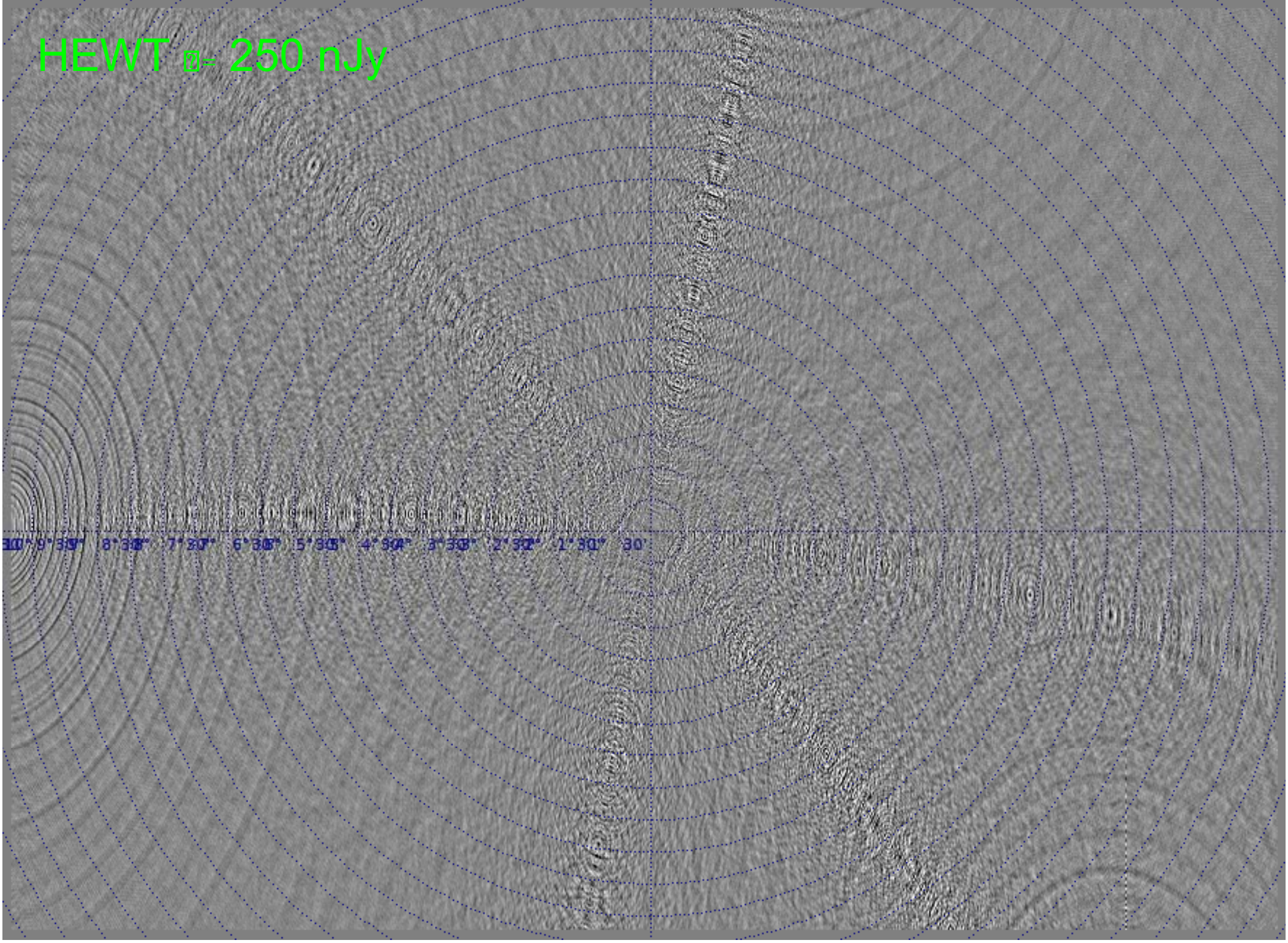

1 Jy source SE, 1 Jy NW
10°
9°30'
9°
8°30'
8°
7°30'
7°
6°30'
6°
5°30'
5°
4°30'
4°
3°30'
3°
2°30'
2°
1°30'
1°
30'

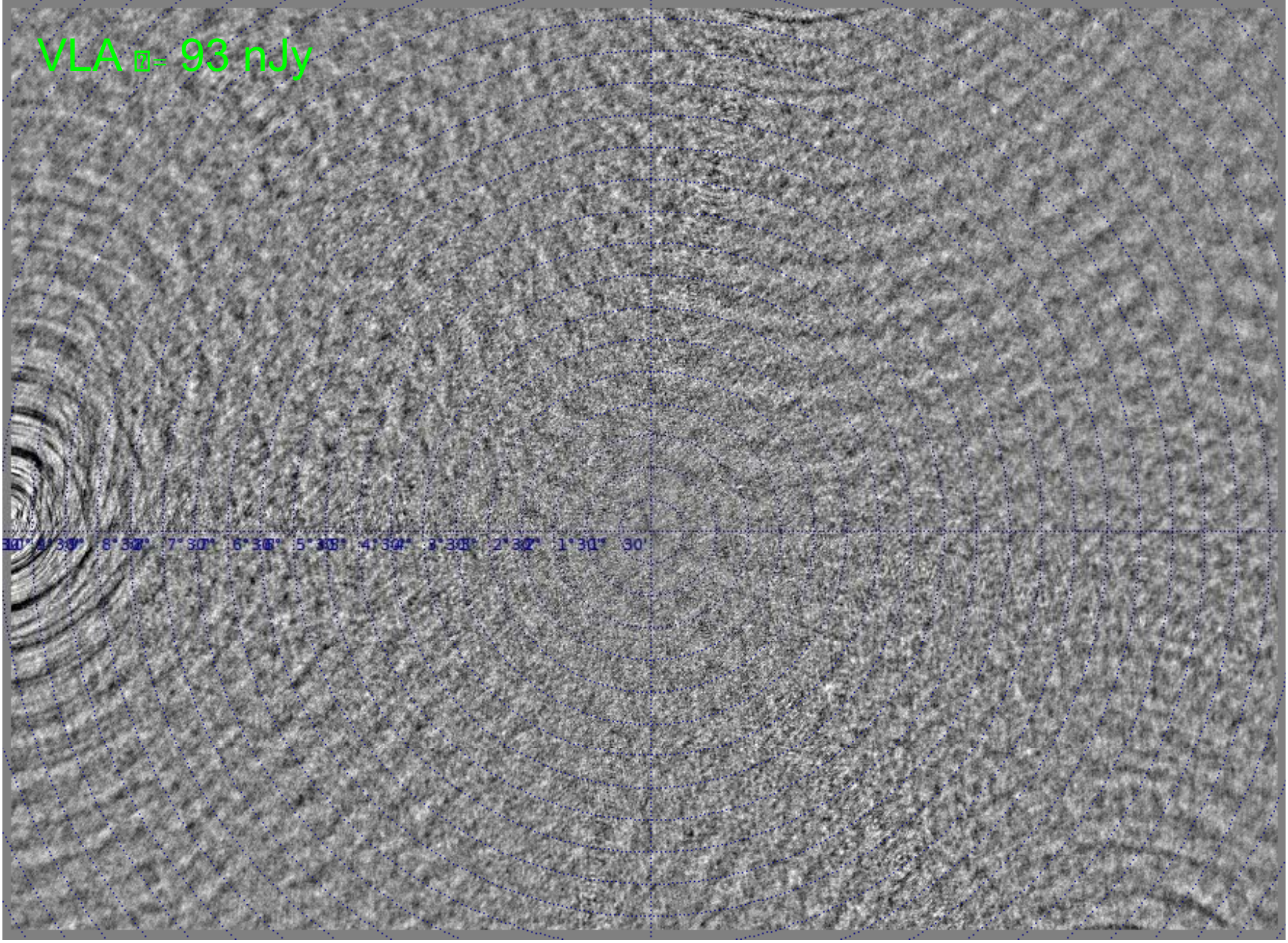
Array Configuration?

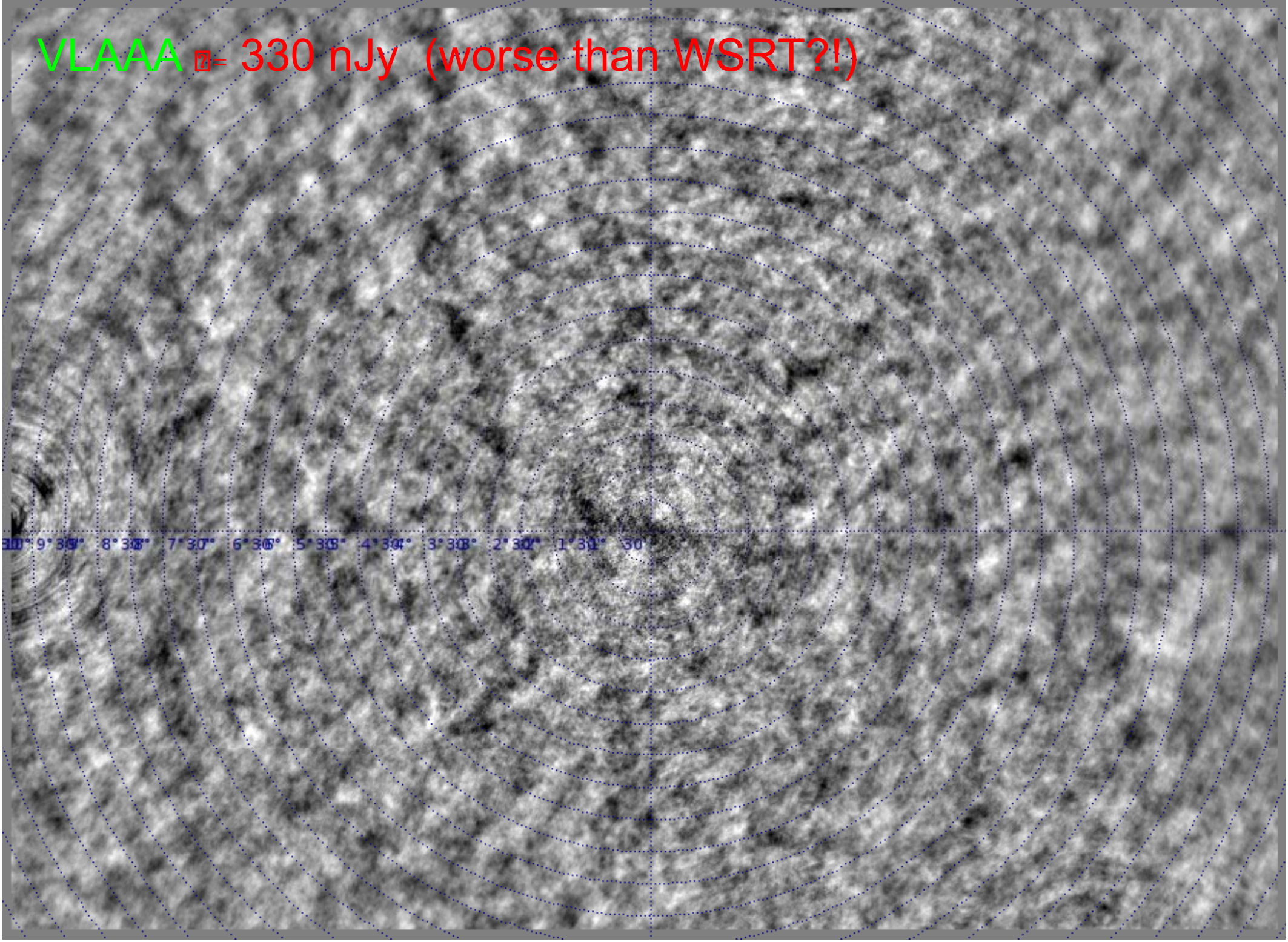
- Conjectures: ghosts related to redundancy and/or periodicity and/or E-W config
- Tested other telescopes (thanks to Ian Heywood for the layouts):

  - **HEWT** (Heywood East-West Telescope): a log-WSRT
  - **VLA Oranje:** VLA-C, teleported to Holland
  - **Vanilla VLAAA**: a VLA-like log-spiral of 24 antennas


WSRT σ= 240 nJy


HEWT σ= 250 nJy


VLA σ = 93 nJy
8° 30'
7° 30'
6° 30'
5° 30'
4° 30'
3° 30'
2° 30'
1° 30'
30'


VLAAA = 330 nJy (worse than WSRT?!)

Implications & Burning Issues

We will always have contamination, so:

- Possibility of coherent structures
  - can they bias blind surveys?
- Contamination adds to image noise
  - Is this a dynamic range limitation?
- “Strange” noise statistics
  - How does this affect our ability to e.g. detect the EOR?
- Non-trivial dependence on array config
  - Both in terms of overall level, and distribution
  - Does this follow from an existing Figure Of Merit?

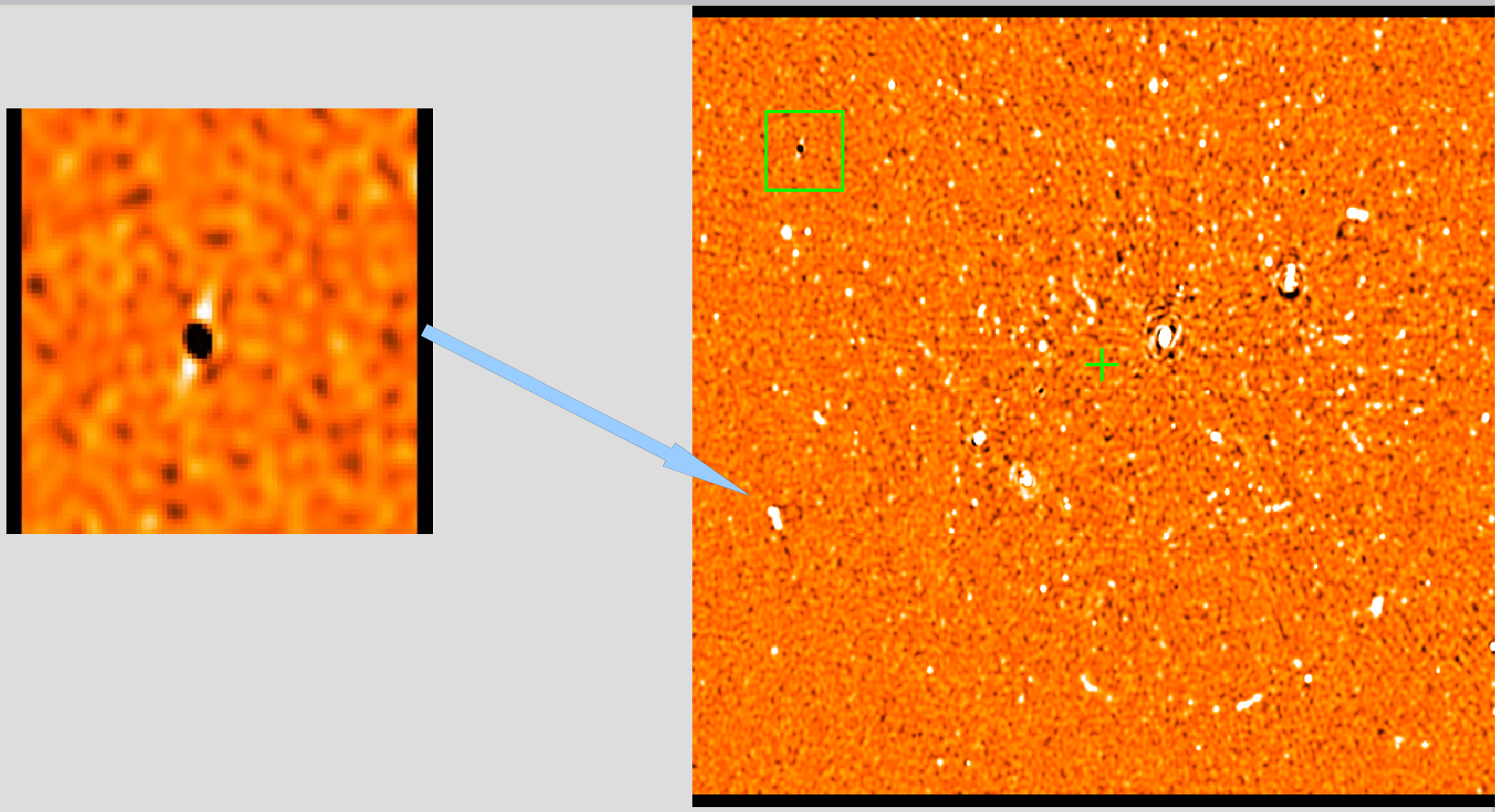
Why Do We Trust Selfcal?

- Peer pressure
- Brainwashed as a PhD student
- Stockholm syndrome

- But mostly, because it
  - Makes better maps
  - And the gain/phase solutions make physical sense

- We use priors to discriminate false results
  - So can we feed our priors into calibration?
  - Can we even trust our priors?

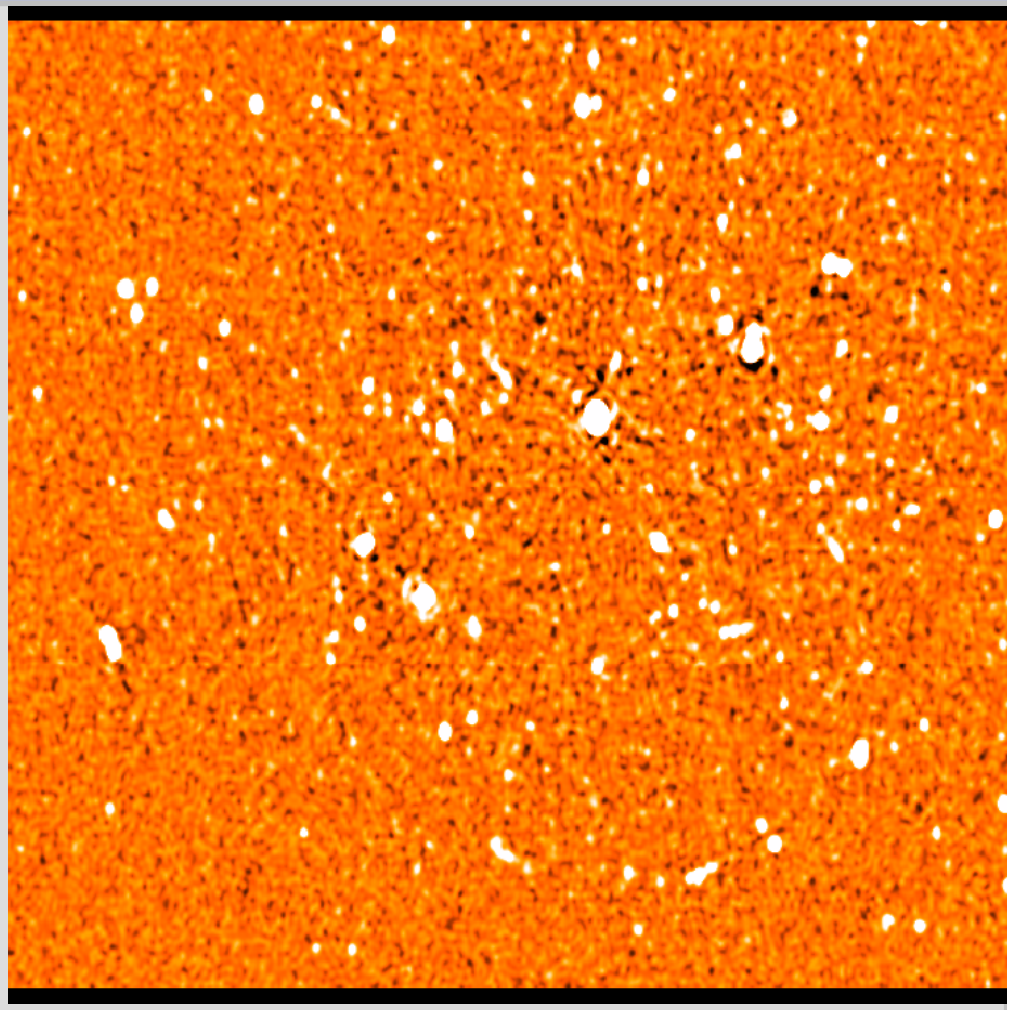
A Different Kind Of Ghost



- A residual image from one of my HDR 3C147 experiments
- Note artists' impression of an AGN...

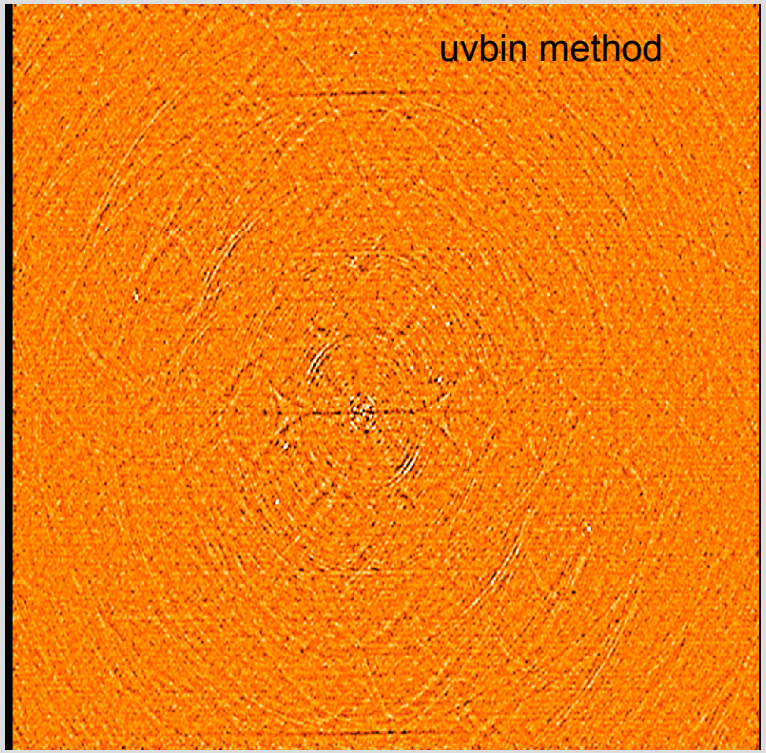
A Good Image, For Comparison

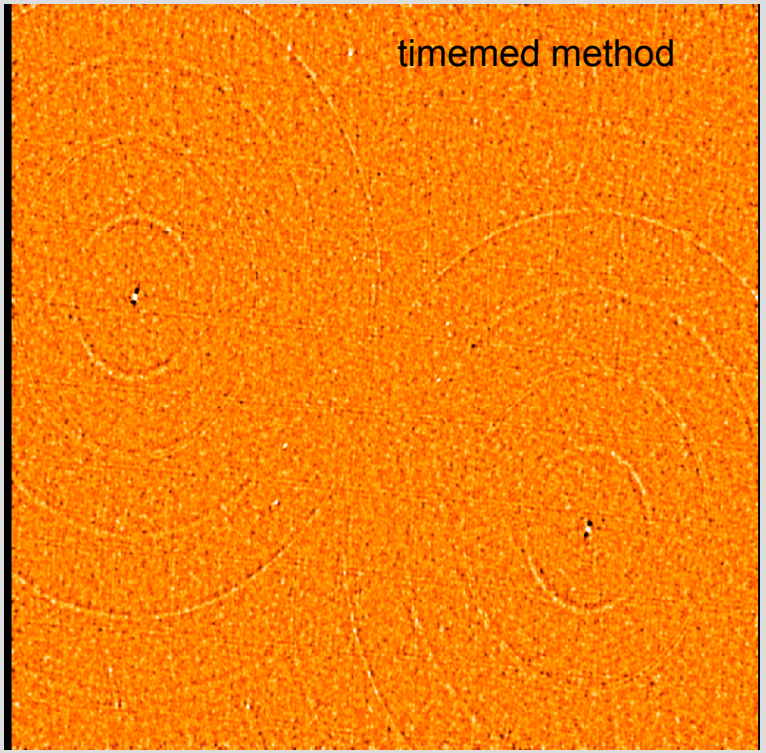
- Spot the differences
- Bright off-axis sources have negative counterparts **symmetric** w.r.t. dominant source (≠ phase centre!!!)
- Can you guess what caused it?



“Flagging Bias”

- *Amplitude-based flagging in the presence of significant flux can introduce coherent structure into the maps*
- Difference between flagged and unflagged:





Exit Poll: Does Anybody Still Understand Selfcal?

- Second Law Of Smirnov:
  You do not understand selfcal.