# Imaging the Extended Groth Strip with International LOFAR

## & Modelling 3C295

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Work in collaboration with: Leah Morabito, Tim Shimwell, Alex Mechev, ...

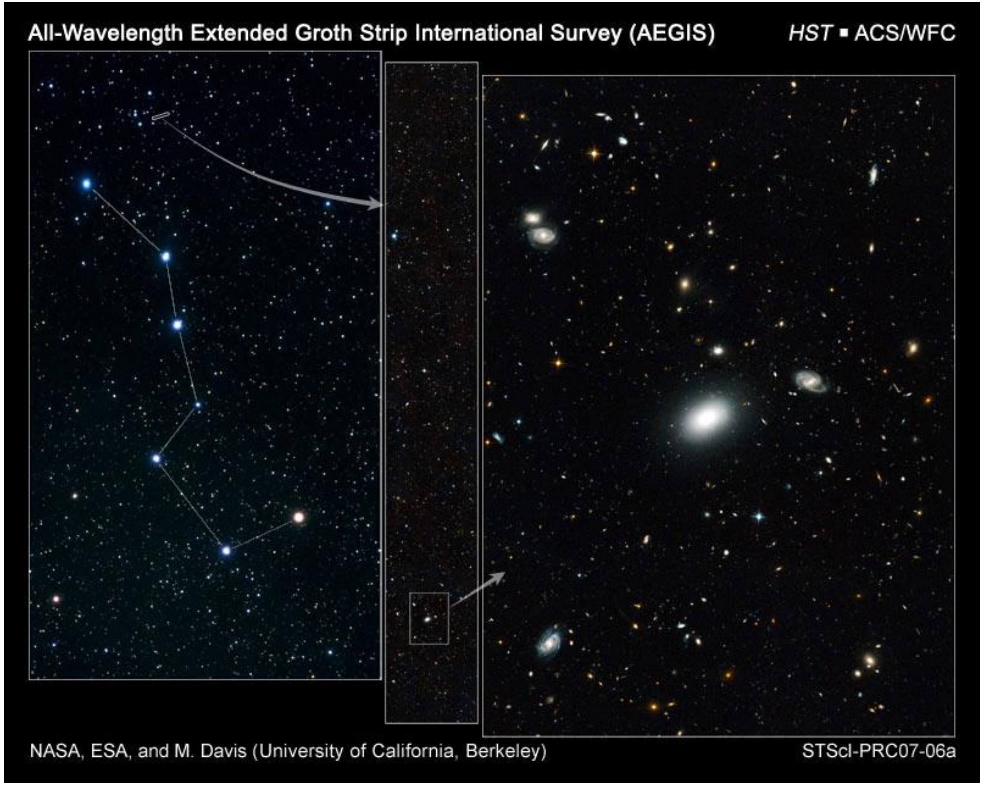
# Scientific Context: the Extended Groth Strip (EGS)

**Pros:**

- One of the “famous fields”
- Deep multi-frequency coverage
- 40h of LOFAR observation

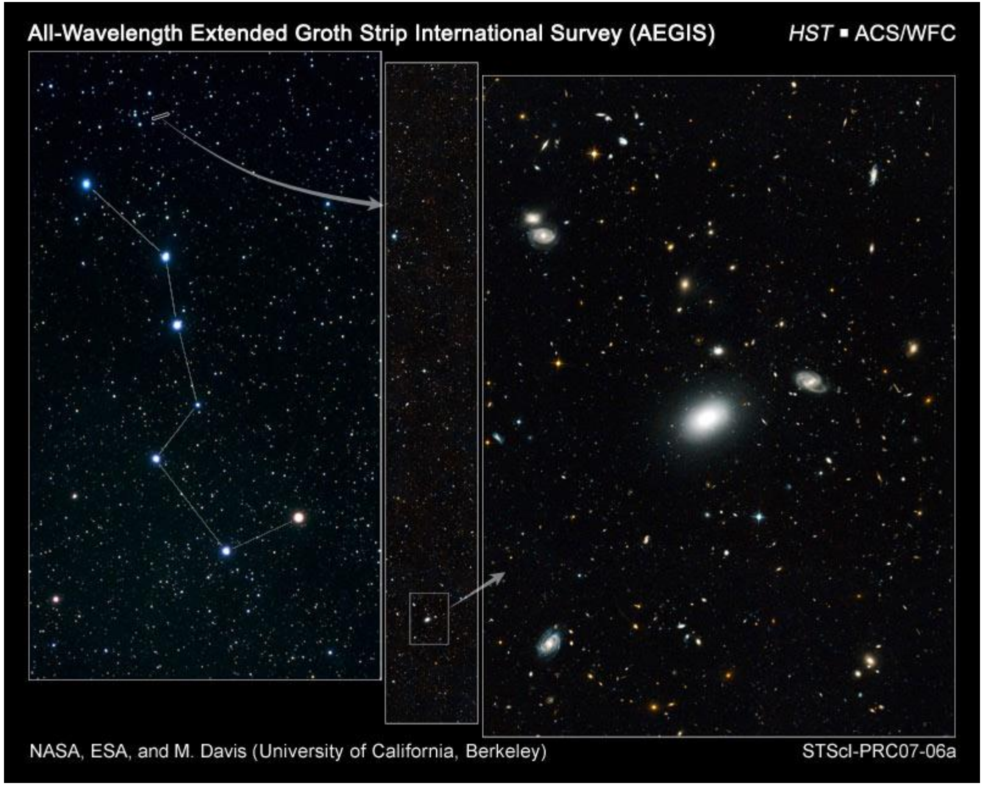
**Cons:**

- Bright, complex source (3C295) within primary beam
- Decorrelation makes calibrating the longest baselines difficult



# Scientific Context: the Extended Groth Strip (EGS)

| Telescope | Band | Resolution | Area |
|---|---|---|---|
| Chandra | X-ray | $0.5'' - 6.0''$ | $17' \times 120'$ |
| GALEX | UV | $5.5''$ | $1.25^\circ$ diameter |
| HST/ACS | Optical | $0.1''$ | $10' \times 67'$ |
| HST/NICMOS | Optical | $0.35''$ | $0.0128\ \mathrm{deg}^2$ |
| Megacam | Optical | $1.0''$ | $1\ \mathrm{deg}^2$ |
| IRAC | IR | $2.0''$ | $10' \times 120'$ |
| Spitzer | IR | $5.9'' - 19''$ | $10' \times 90'$ |
| VLA | Radio | $1.2'' - 4.2''$ | $30' \times 80'$ |

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# Project Challenges

- High-resolution model of 3C295 at this frequency not yet available
- Imaging with LOFAR international baselines complex business
- Signal loss as distance from observation phase centre increases
- Calibration quality loss as distance from calibrator increases
- Need very low noise in order to image resolved faint EGS sources

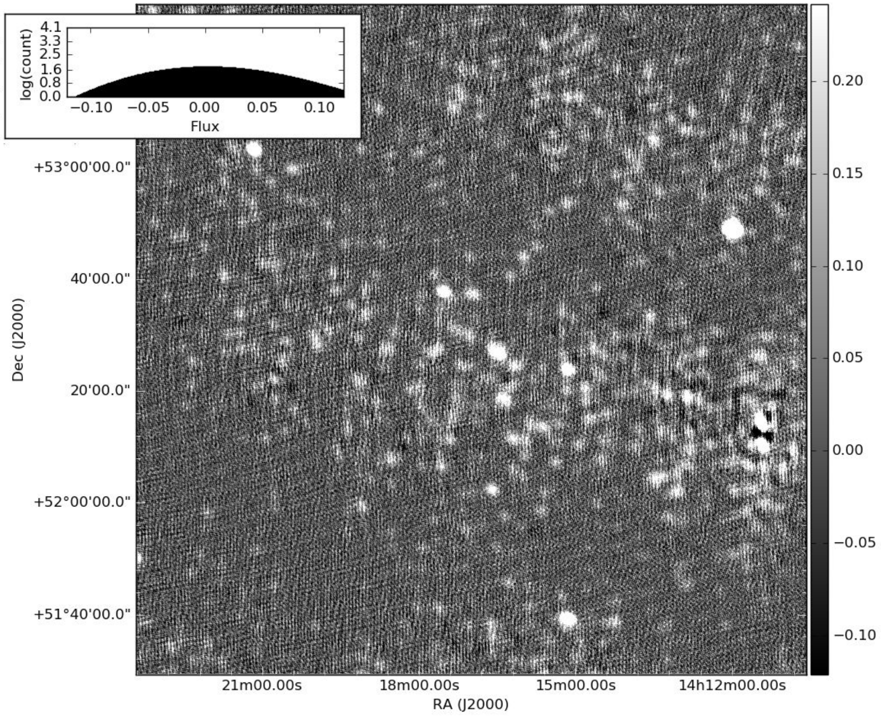
# Quality-based Weighting Schemes

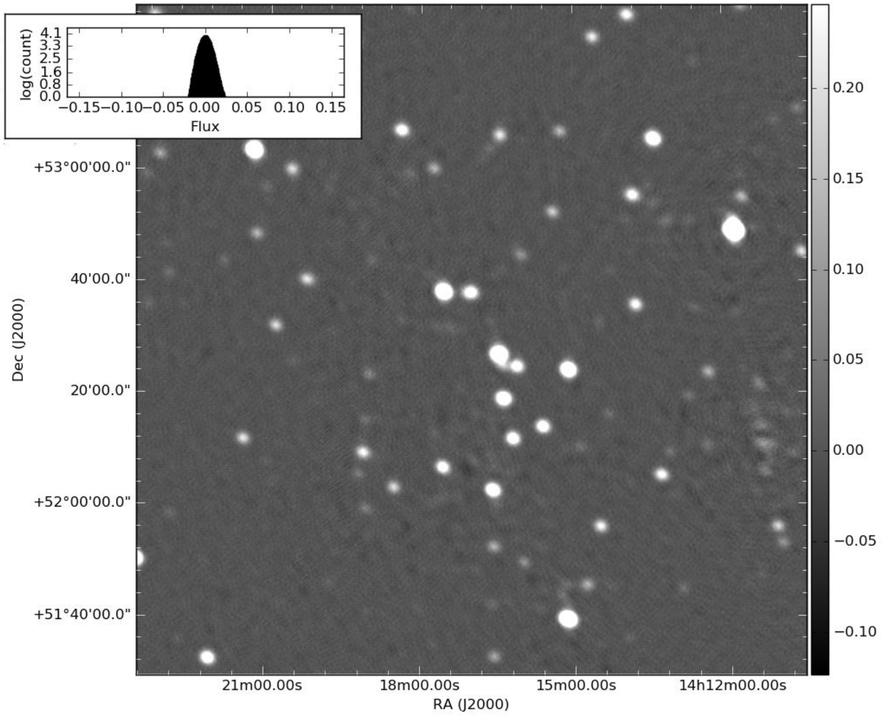
Images are improved by use of quality-based weighting schemes:

- Use relationship between residual visibility statistics and gain statistics
- Estimate variance on gain solutions
- Use these estimates to build variance on visibilities
- Weight each visibility according to inverse of its variance estimate

**https://arxiv.org/abs/1711.00421**

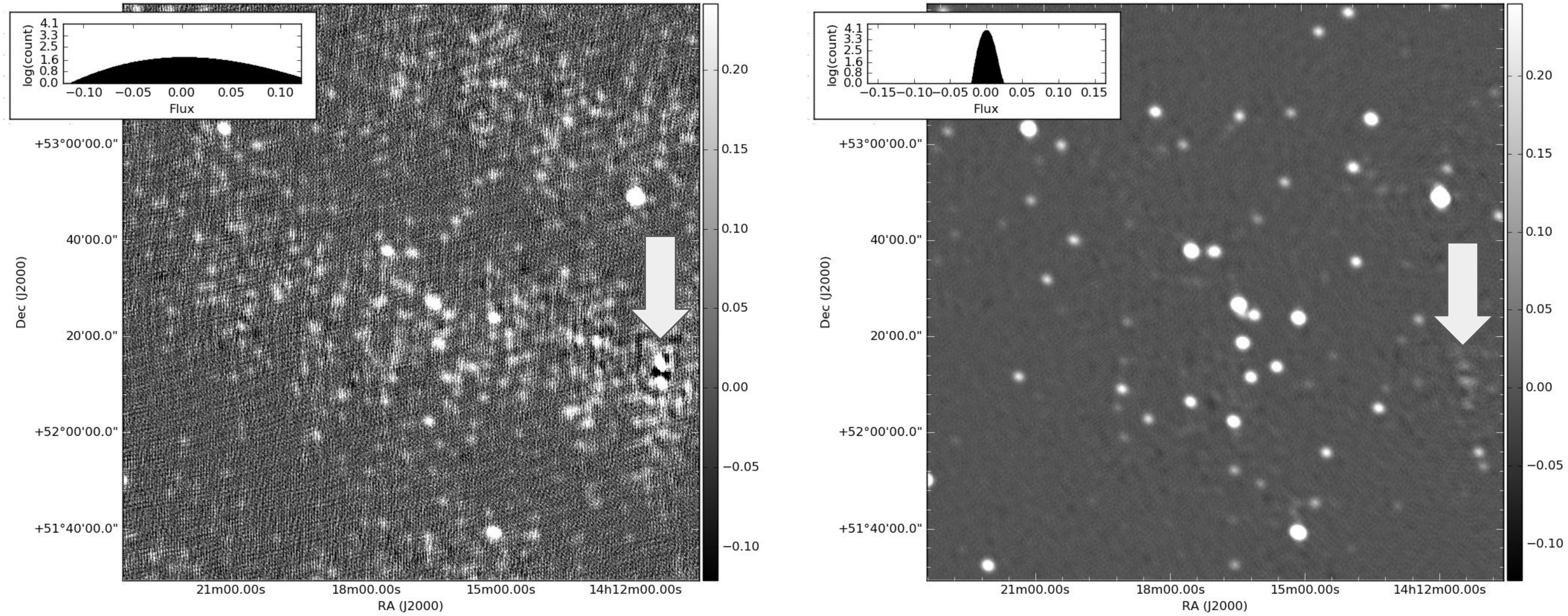
# Quality-based Weighting Schemes




Low-res image of EGS phase centre

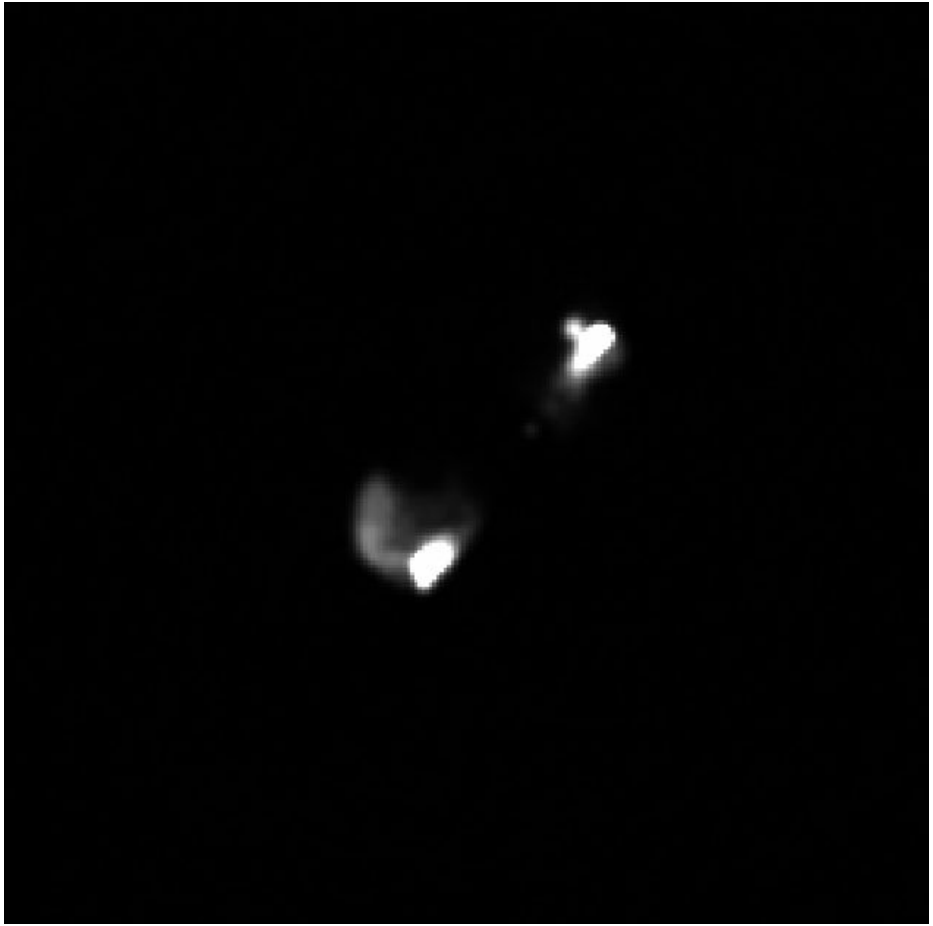
# Quality-based Weighting Schemes




Low-res image of EGS phase centre

# High-res model of 3C295

- Position:
  RA=14h11m20.5s,
  Dec=52d12m10s
- Left: VLA image, 8.7 GHz
- Resolution: 0.3’x0.3’
- Hotspots & Diffuse emission...

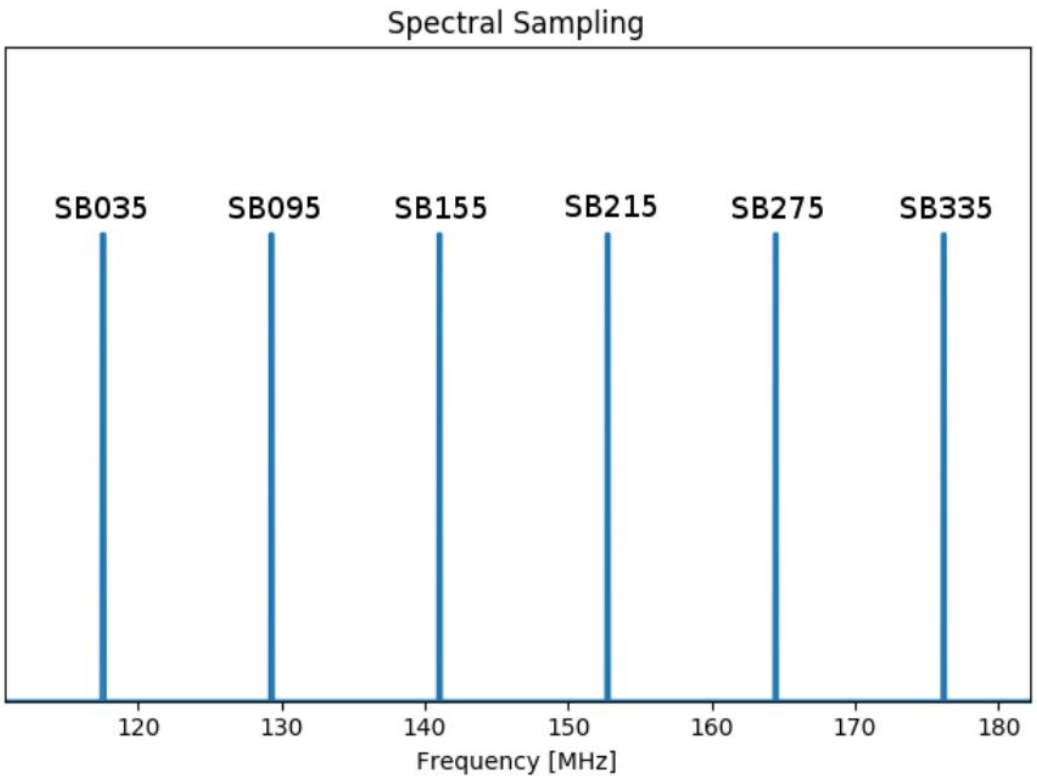


# High-res model of 3C295

Strategy:

- Starting from 2-point model extracted from VLA image, calibrate 6 subbands
- Self-calibrate & perform tests
- Move on to batches of 10 subbands around previous 6
- Self-calibrate once & perform tests
- Move on to full bandwidth
- ...
- Success, fame, funding, stern nods of approval etc.

# High-res model of 3C295



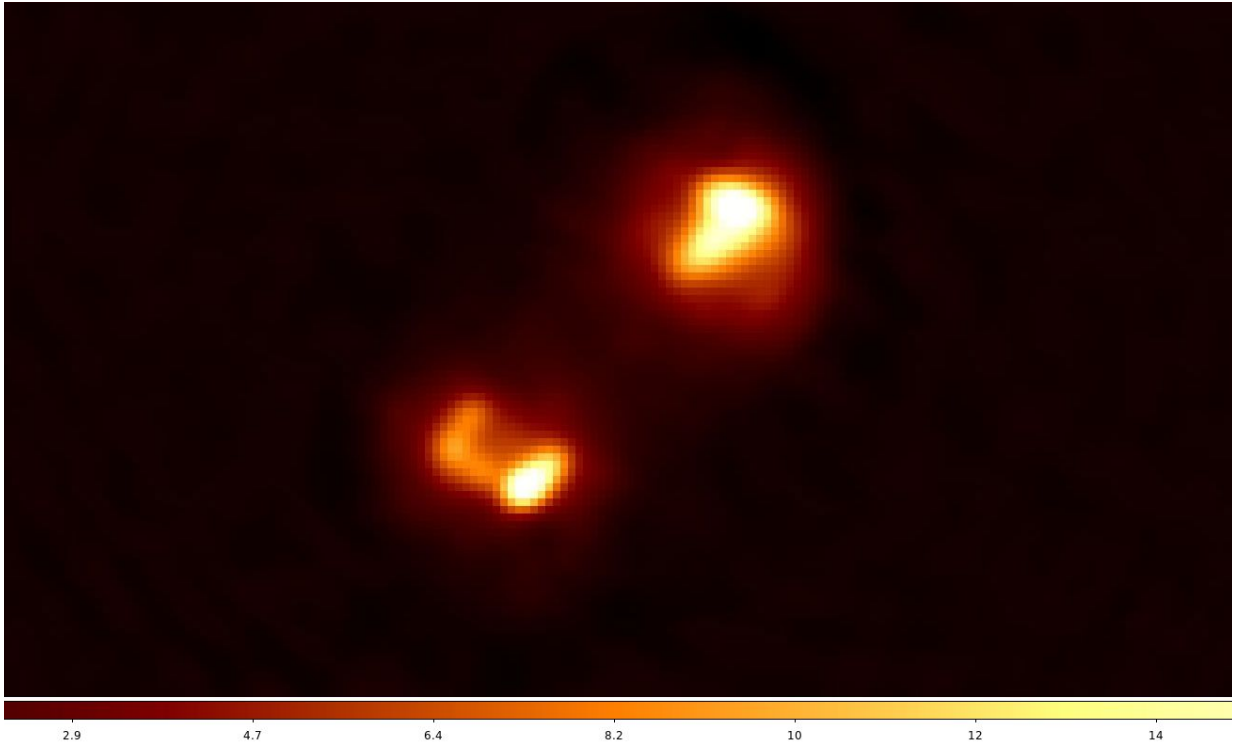

| Subband | $\nu_{\rm min} - \nu_{\rm max}$ |
|---|---|
| SB035 | 117.45-117.69 |
| SB095 | 129.21-129.41 |
| SB155 | 140.93-141.12 |
| SB215 | 152.65-152.84 |
| SB275 | 164.37-164.56 |
| SB335 | 176.08-176.28 |

# High-res model of 3C295

First test: make image with VLA pybdsm extraction

6 subbands spread across total bandwidth

Diffuse emission + bright hotspots

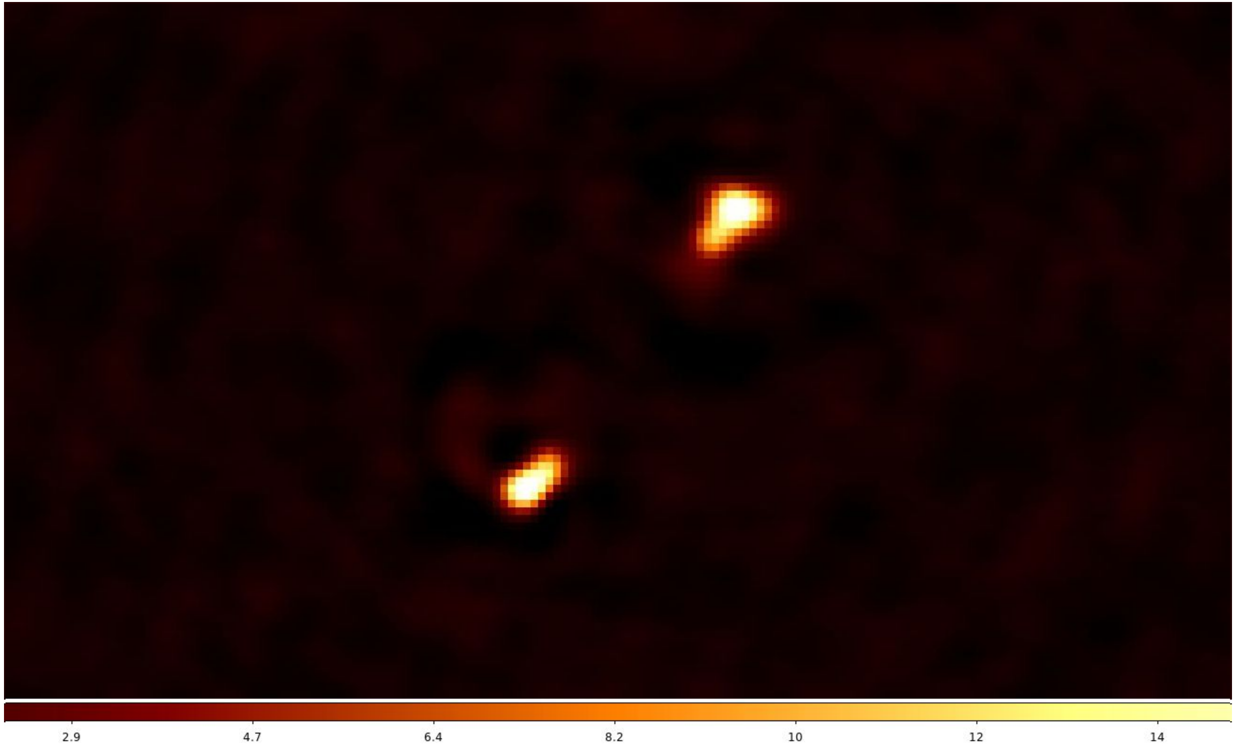


# High-res model of 3C295

Take only 2 brightest spots from VLA pybdsm model, calibrate with that

Same subbands, parameters, etc

Recover hotspots, but suppress diffuse emission (also noisier background)

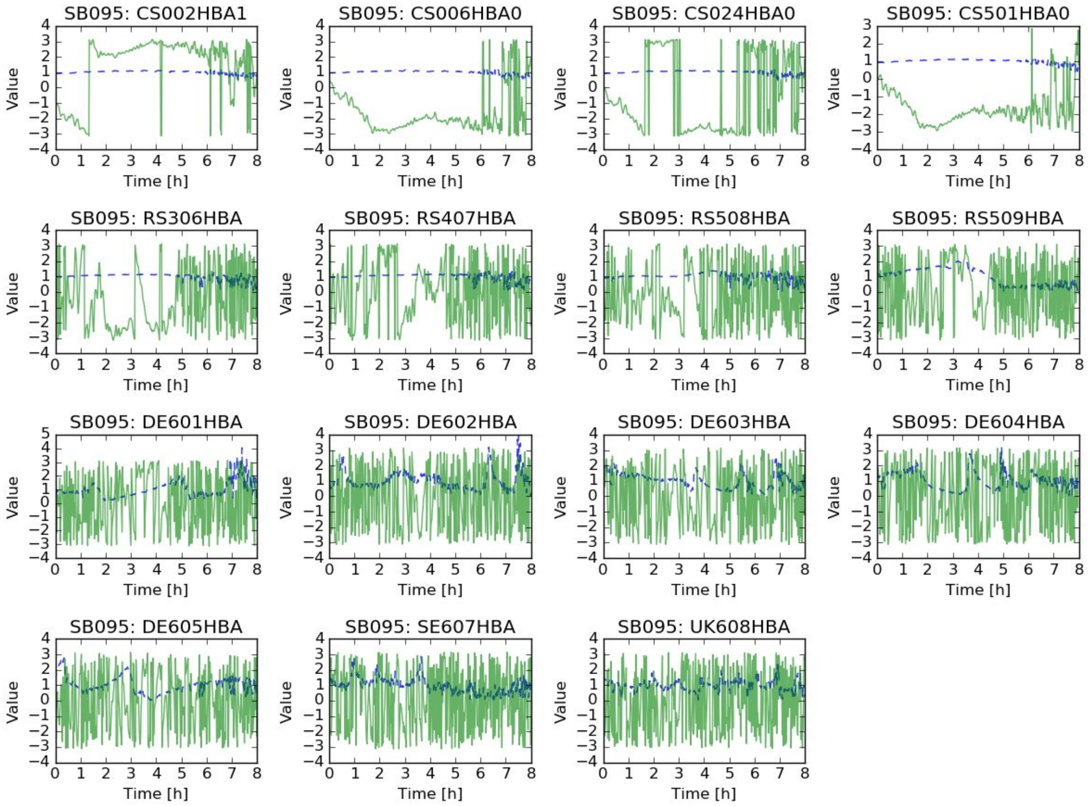


# High-res model of 3C295

True gain curves expected to be flat, smooth

As calibration model improves, gains ought to become smoother + flatter

Right: gain curves for some stations for SB095 at start of calibration w/ 2-point model



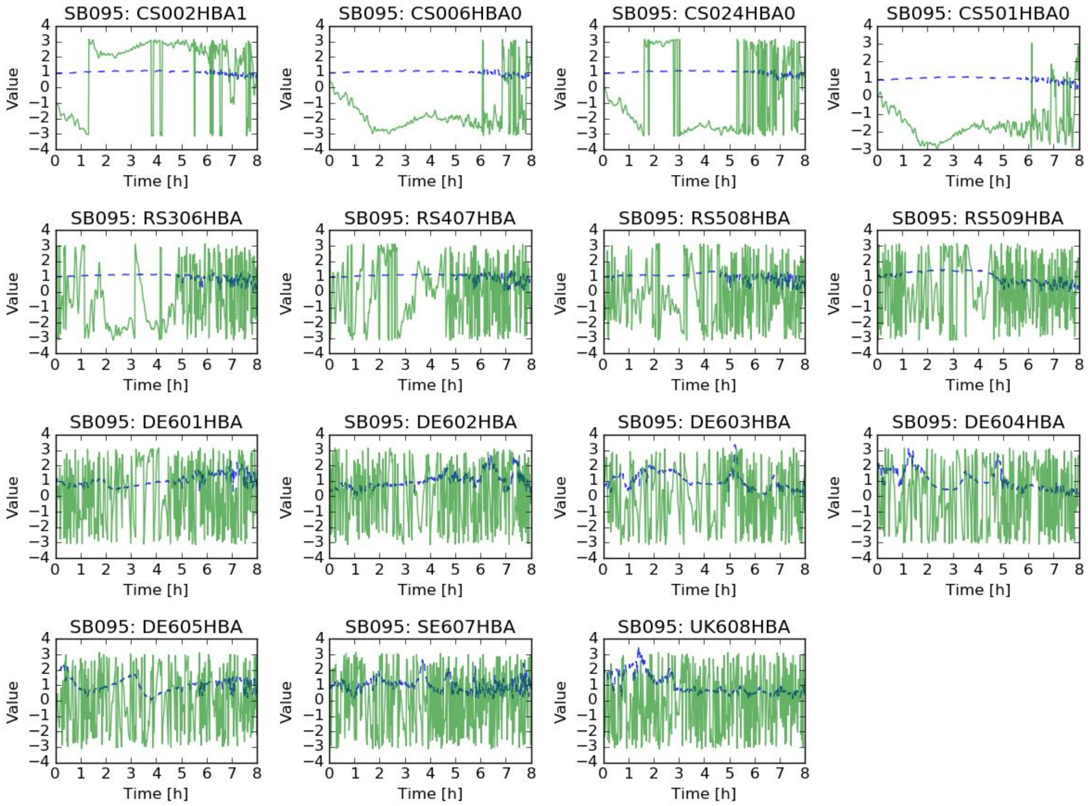
# High-res model of 3C295

True gain curves expected to be flat, smooth

As calibration model improves, gains ought to become smoother + flatter

Right: gain curves for some stations for SB095 at start of calibration w/ 2-point model

Promising, but some ways still to go...



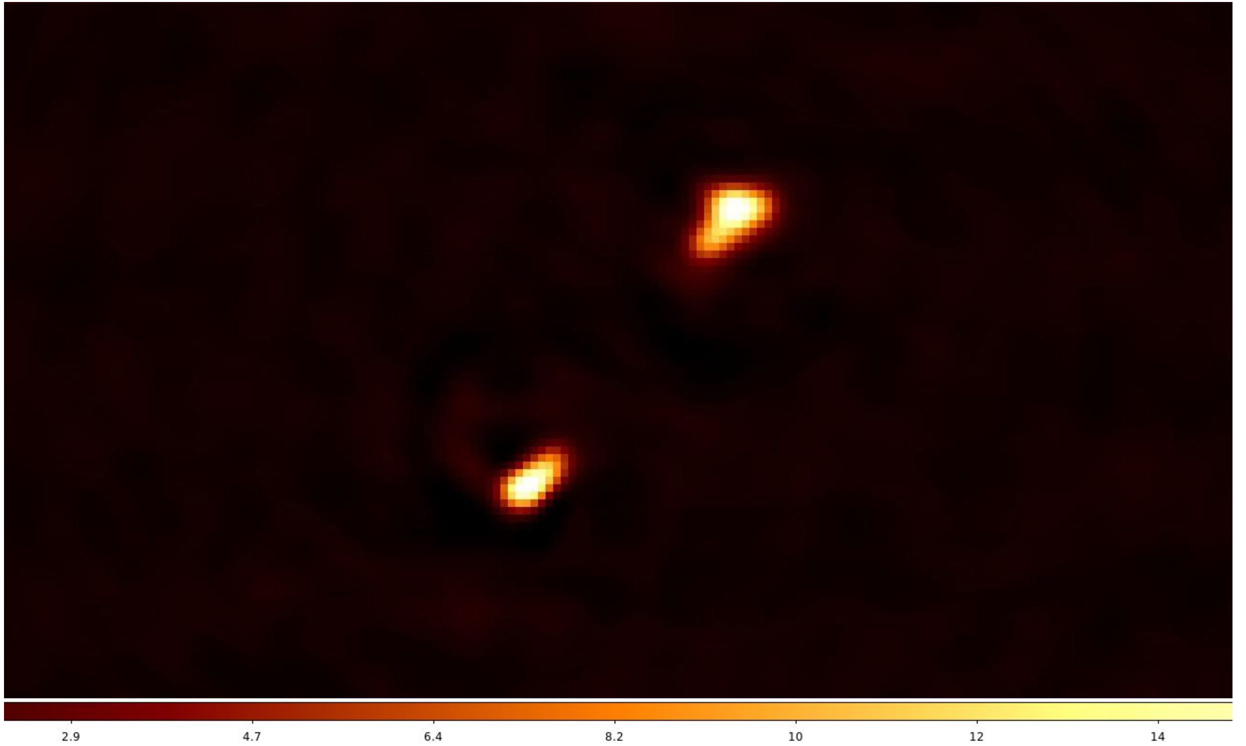
# High-res model of 3C295

Take only 2 brightest spots from VLA pybdsm model, calibrate with that

60sb, same parameters

Reduce noise by factor ~3!

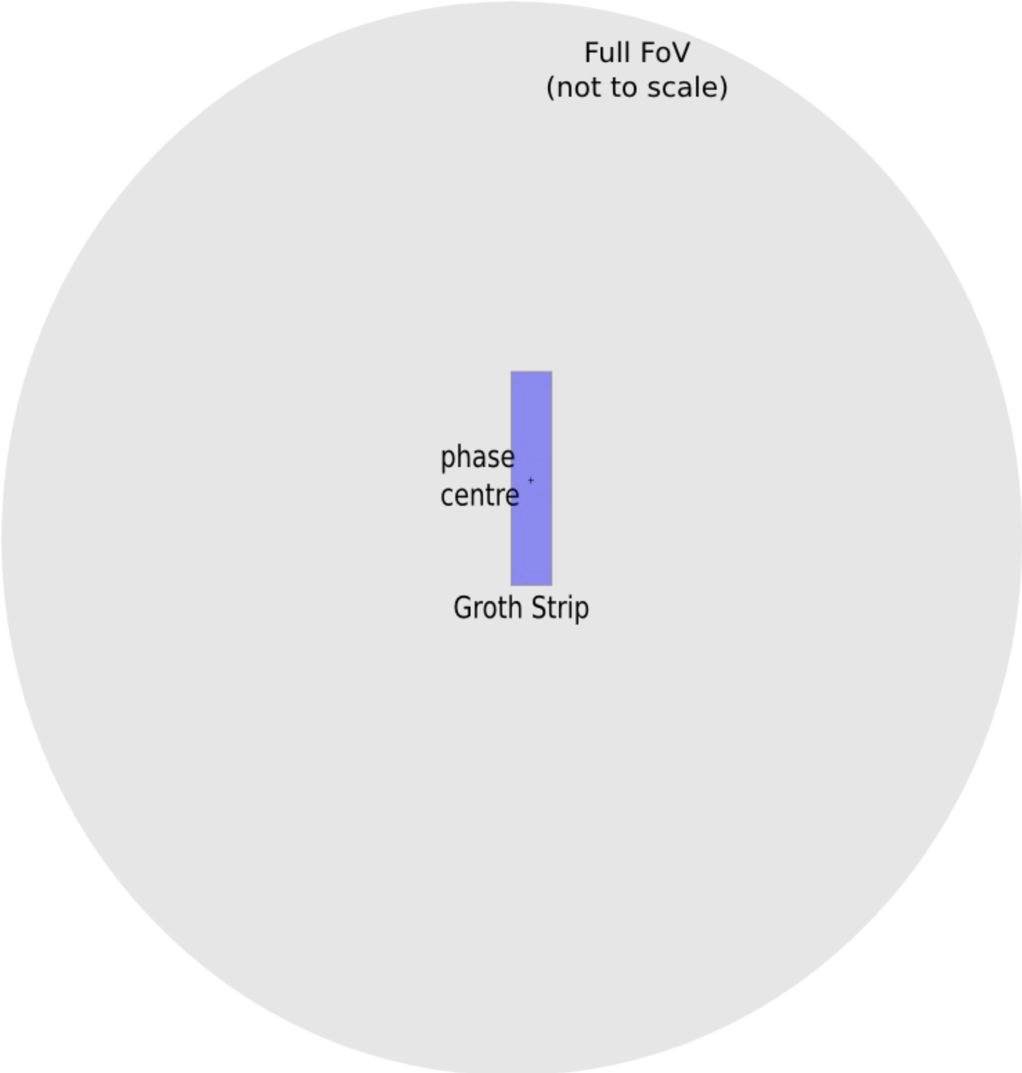
Model not complete and much work remains - but it’s too tempting not to look around in the field...



# Decorrelation & DDEs

Two effects give rise to direction-dependent errors in the image-plane, with different origins:

- Decorrelation
- Direction-Dependent Effects (ionosphere, diff. gains, etc…)



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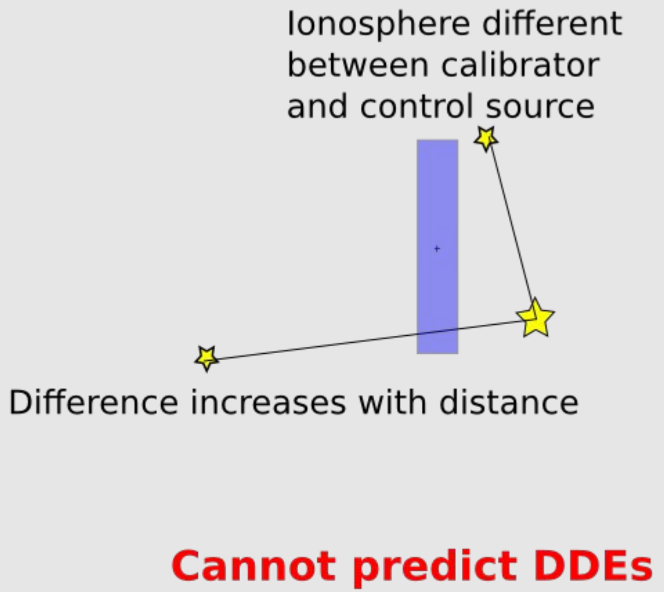

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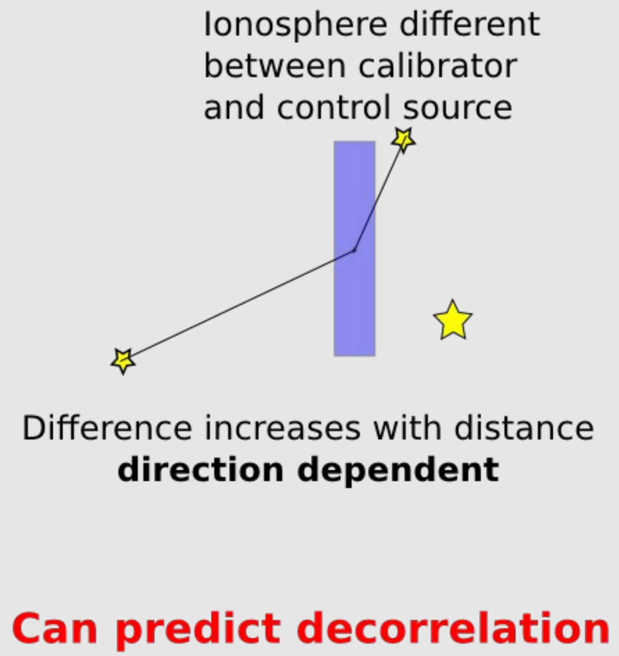
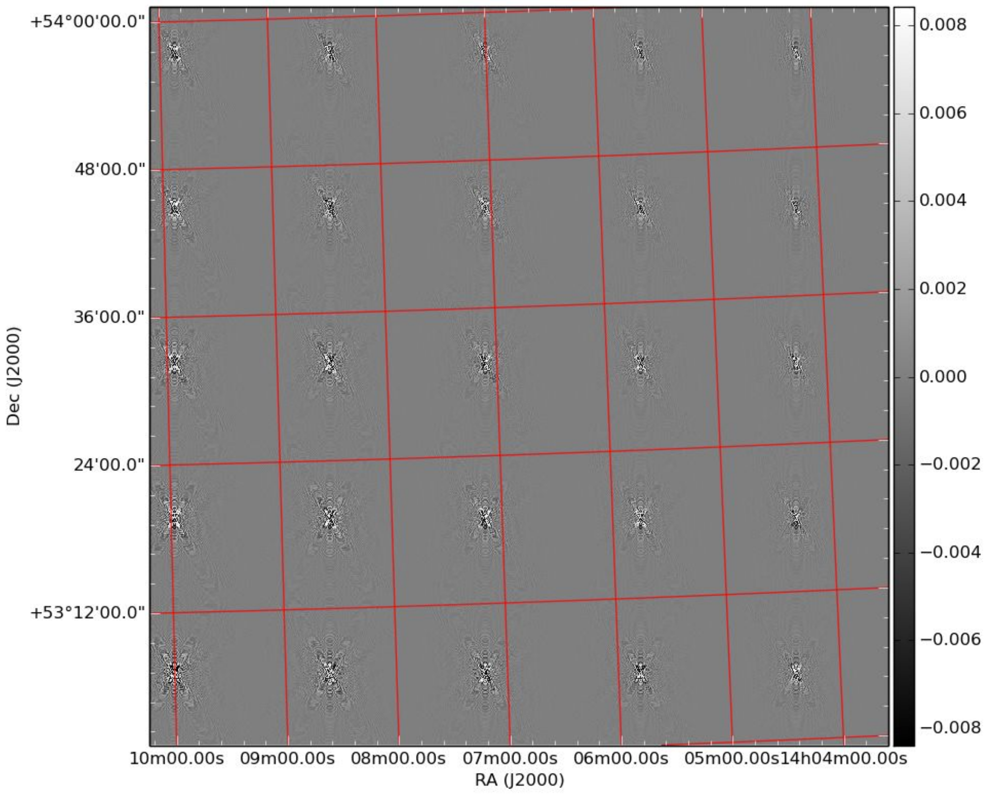


# Decorrelation - the Direction-Dependent PSF

PSF shape changes as function of direction

Change is not large but significant nevertheless - not accounting for it means deconvolution will introduce artefacts in the field!

DDF allows proper accounting of this effect for wide-field images



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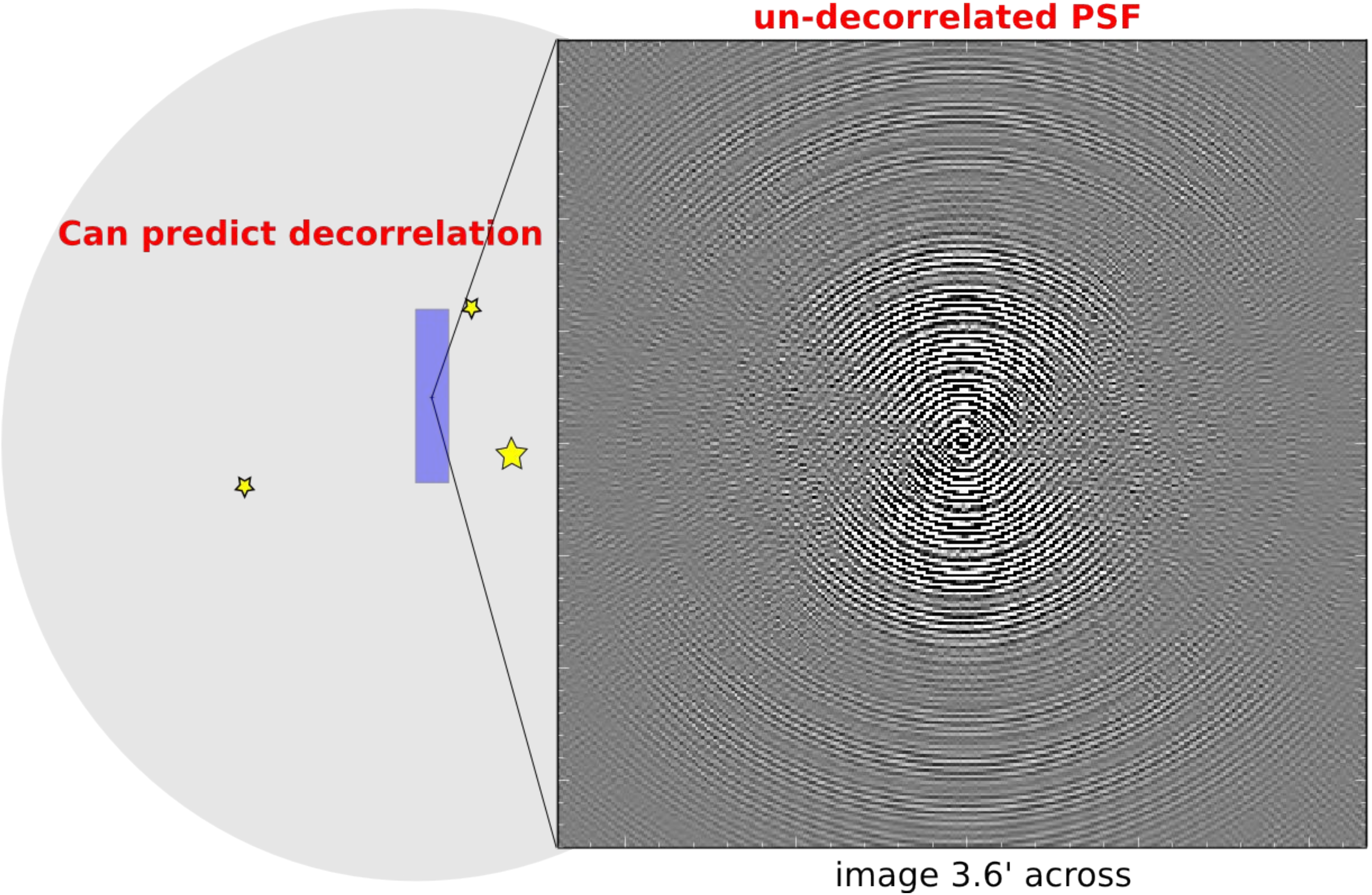

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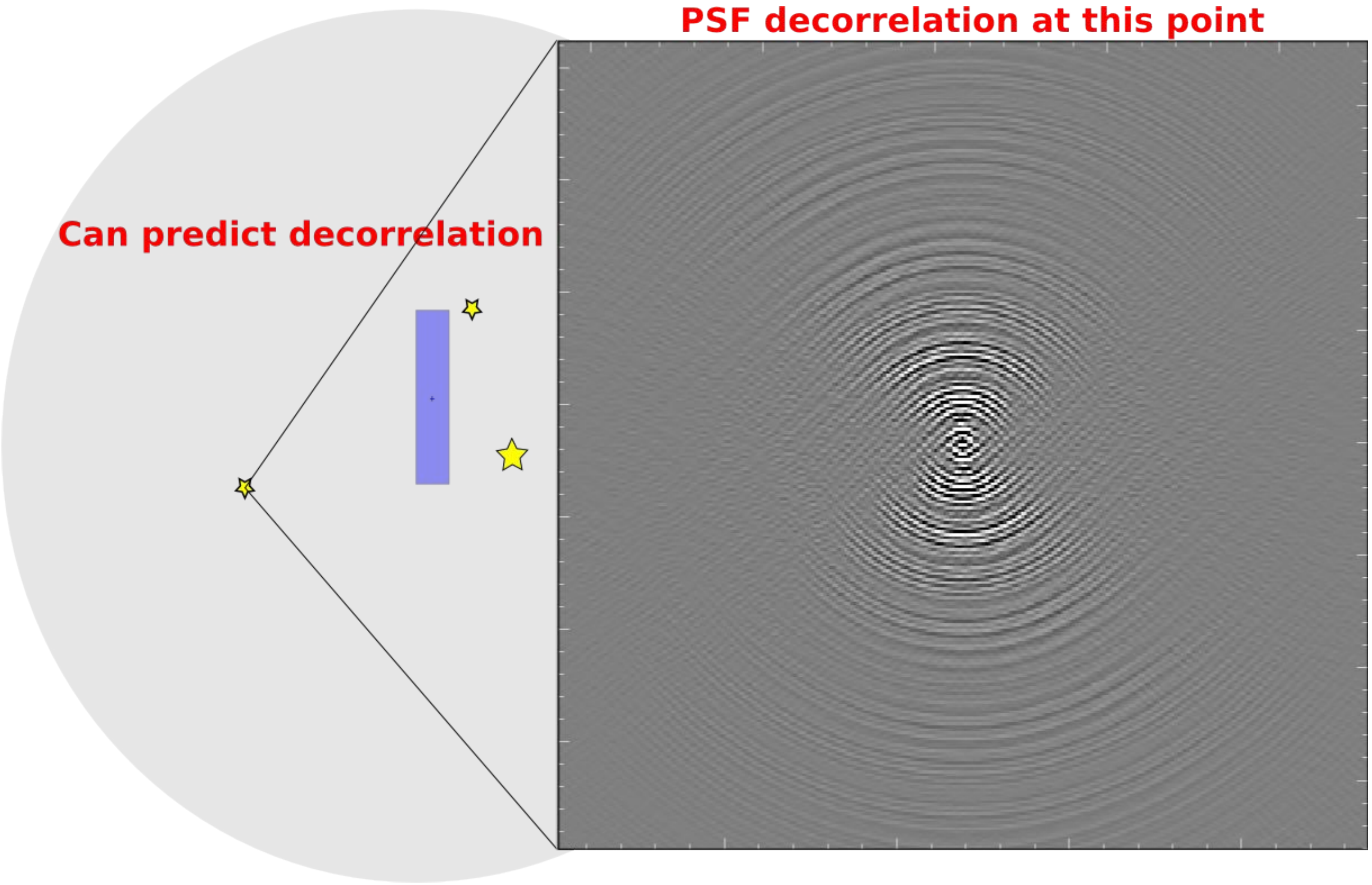

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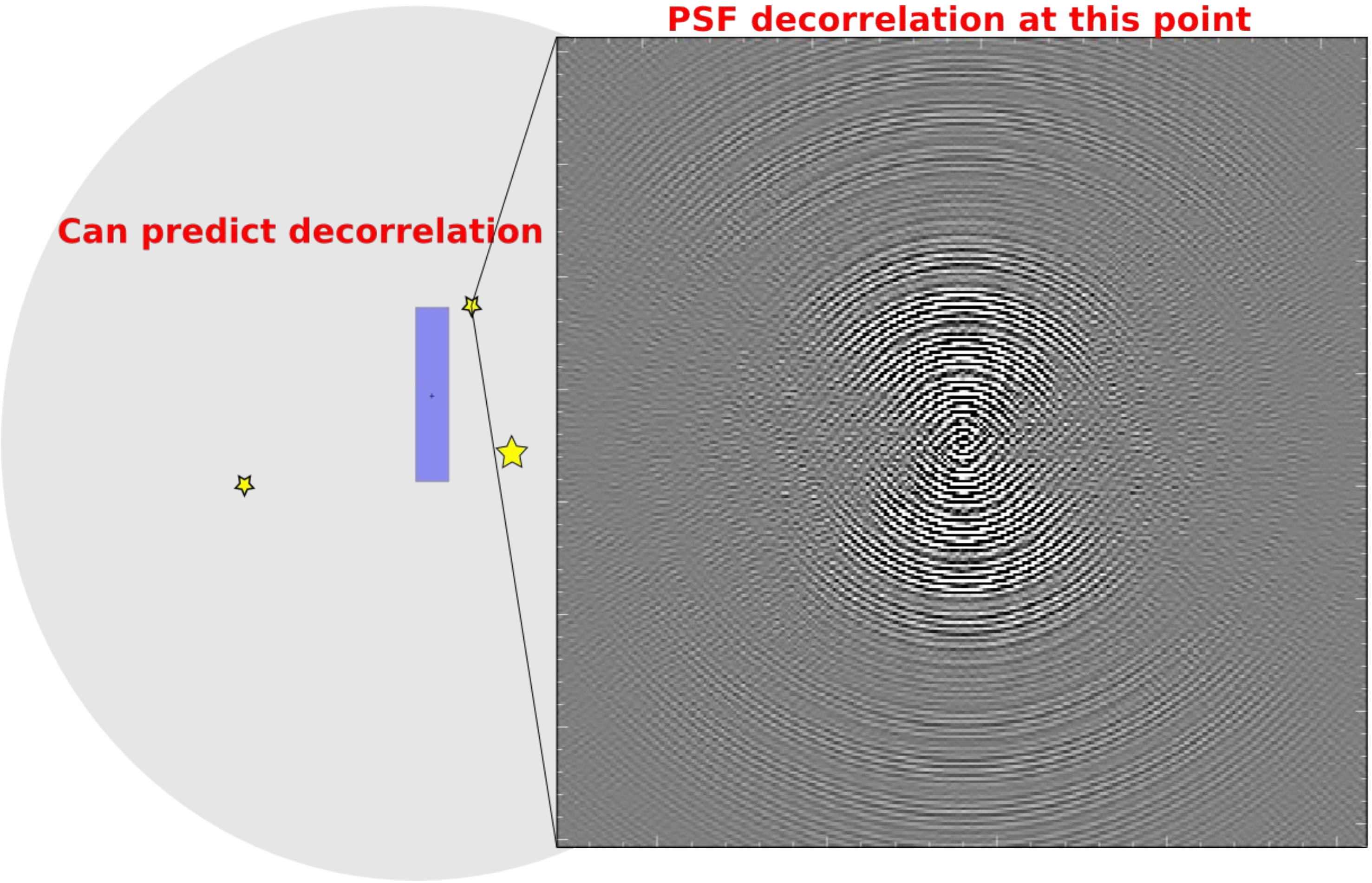


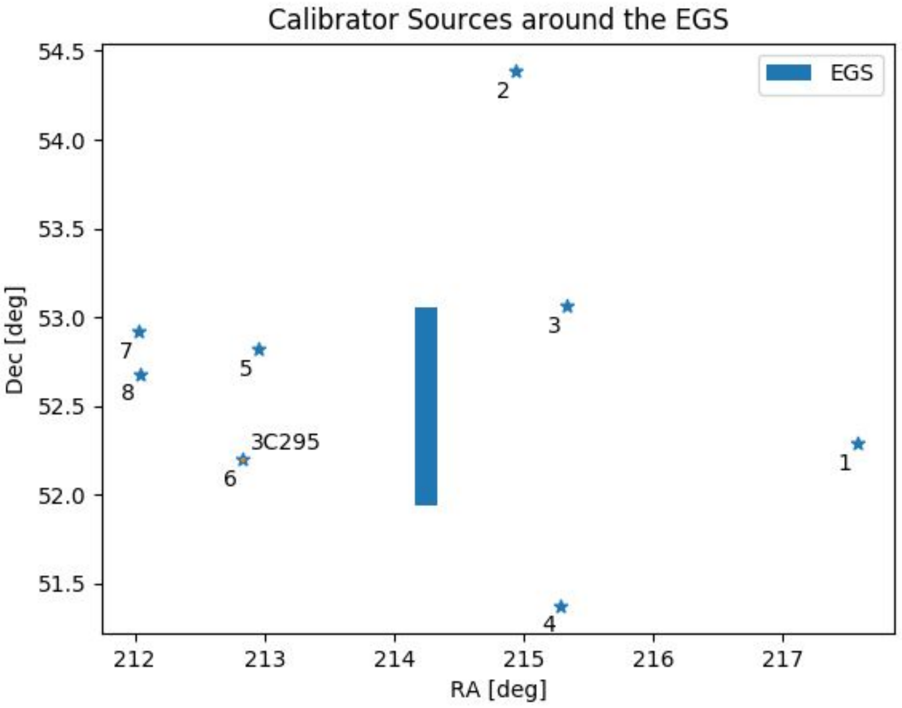
# Testing Impact of Decorrelation on EGS field

**Pros:**

- One of the “famous fields”
- Deep multi-frequency coverage
- 40h of LOFAR observation
- Surrounded by set of LBCS calibrators

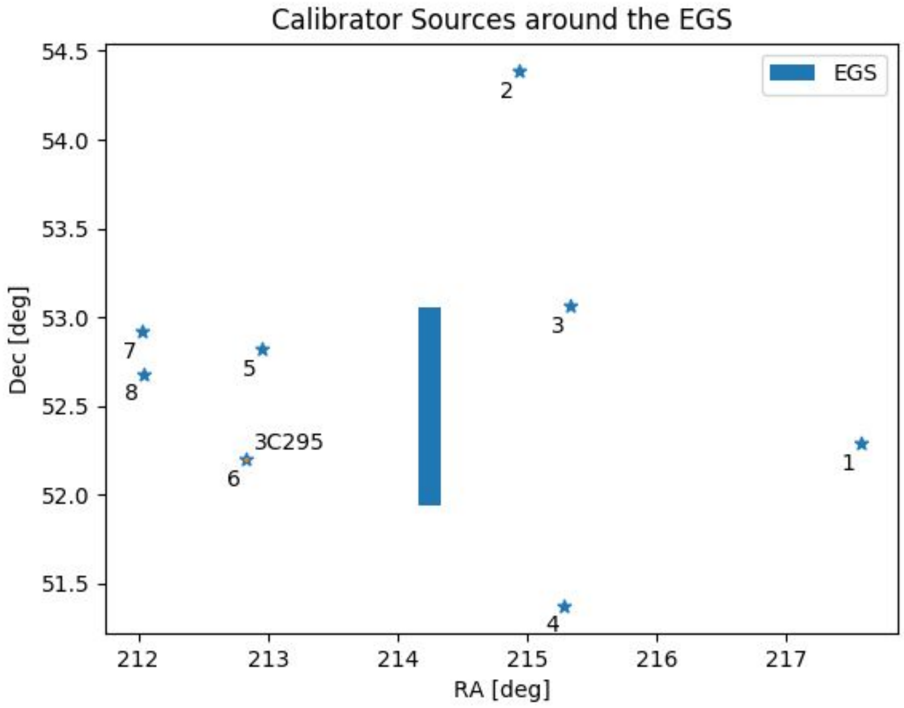
**Cons:**

- Bright, complex source (3C295) within primary beam
- No LBCS calibrator in field itself



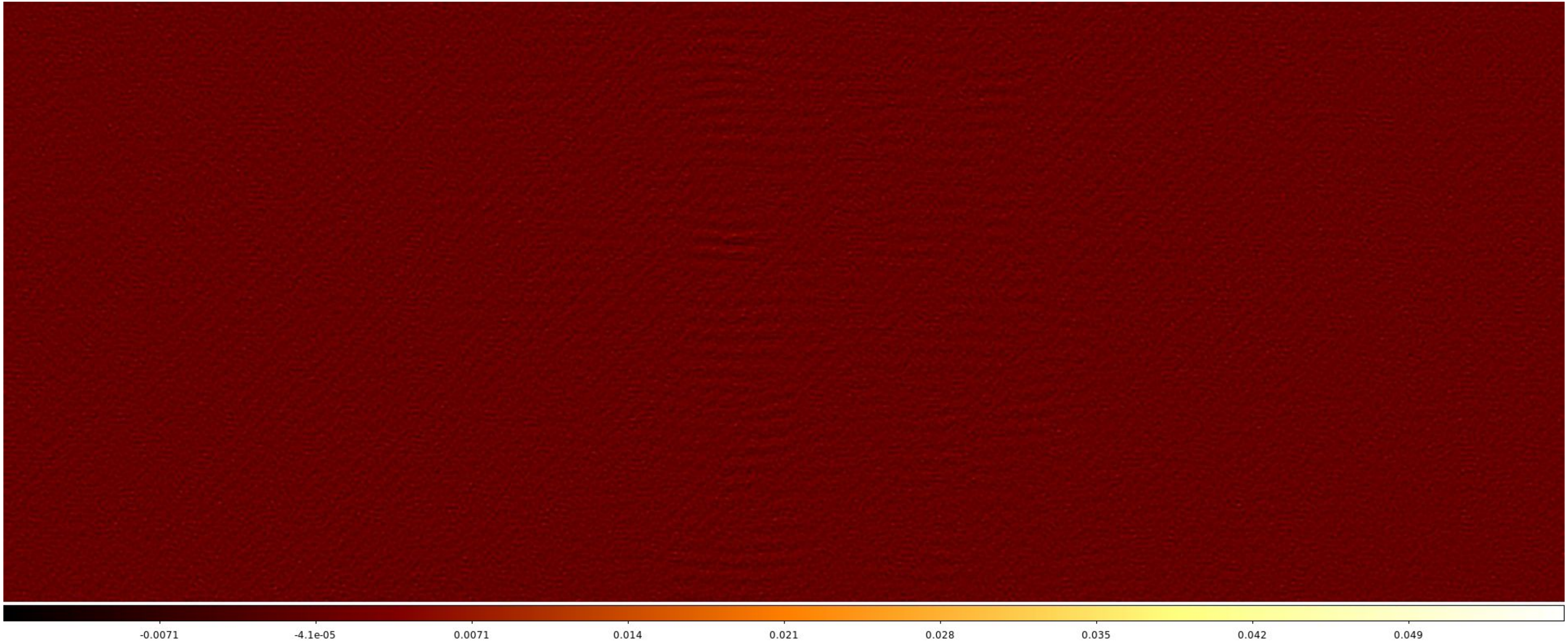
# Testing Impact of Decorrelation on EGS field

| | Dist. from EGS [deg.] | Dist. from 3C295 [deg.] |
|---|---|---|
| 1 | 2.041 | 2.904 |
| 2 | 1.928 | 2.517 |
| 3 | 0.864 | 1.743 |
| 4 | 1.294 | 1.728 |
| 5 | 0.844 | 0.619 |
| 6 | 0.915 | 0.000 |
| 7 | 1.409 | 0.869 |
| 8 | 1.354 | 0.680 |



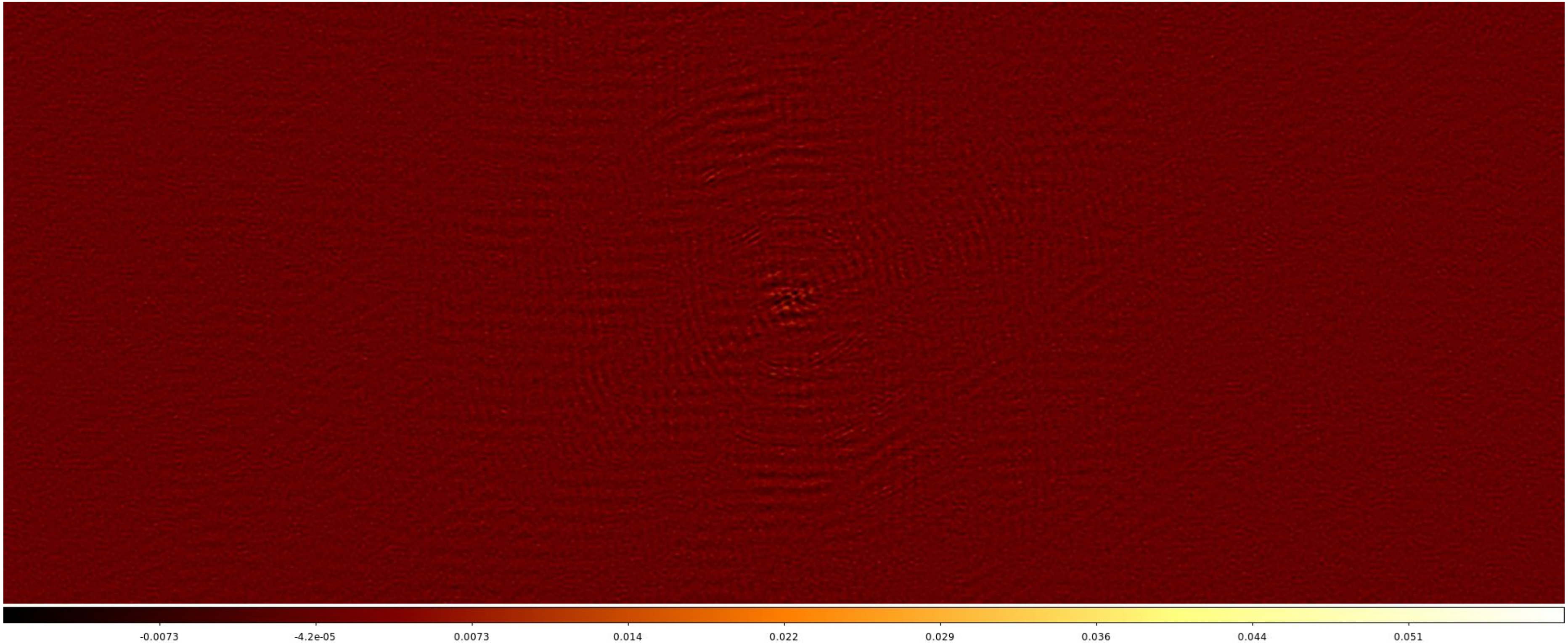

Above: list of LBCS calibrators (cf. https://arxiv.org/abs/1608.02133 ) near EGS. Positions shown to the right, without WCS projection - distances are not as they appear here.

# Testing decorrelation: LBCS 1



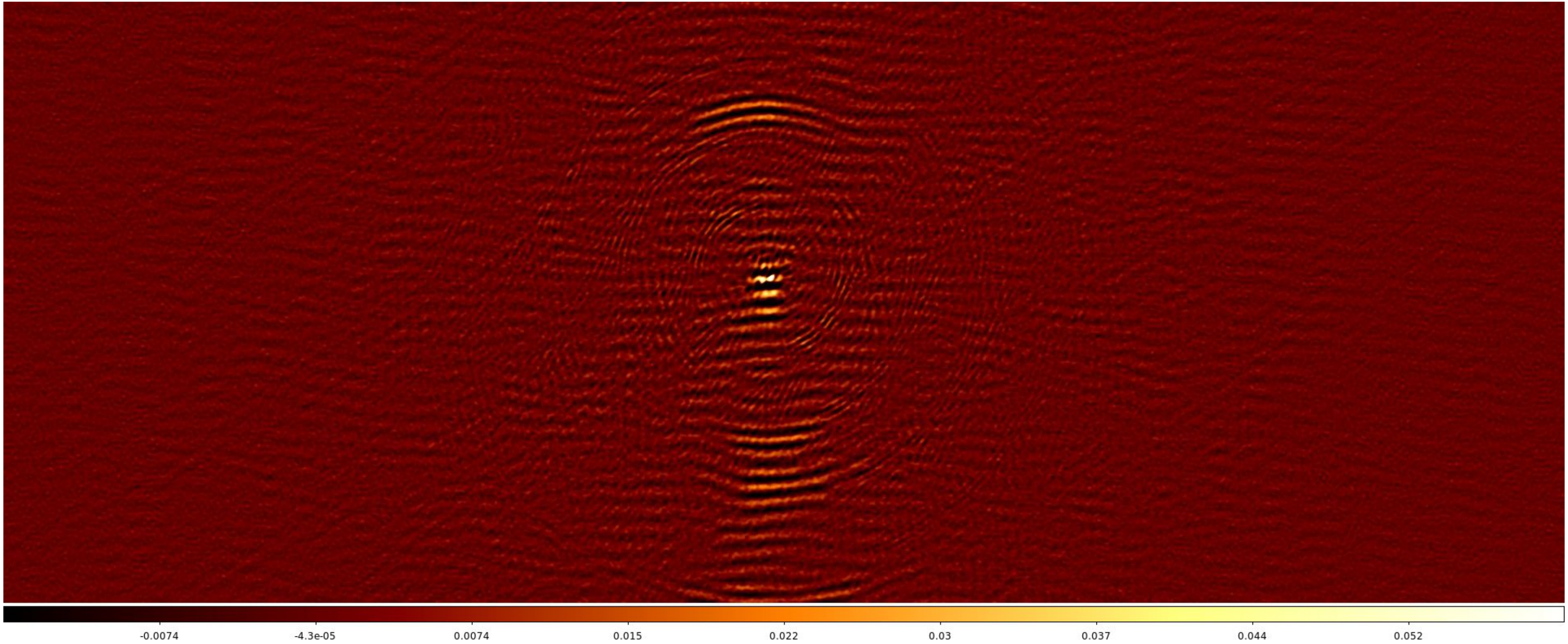

~2.9 degrees away from EGS; signal lost, pixel size 0.1’’

# Testing decorrelation: LBCS 2



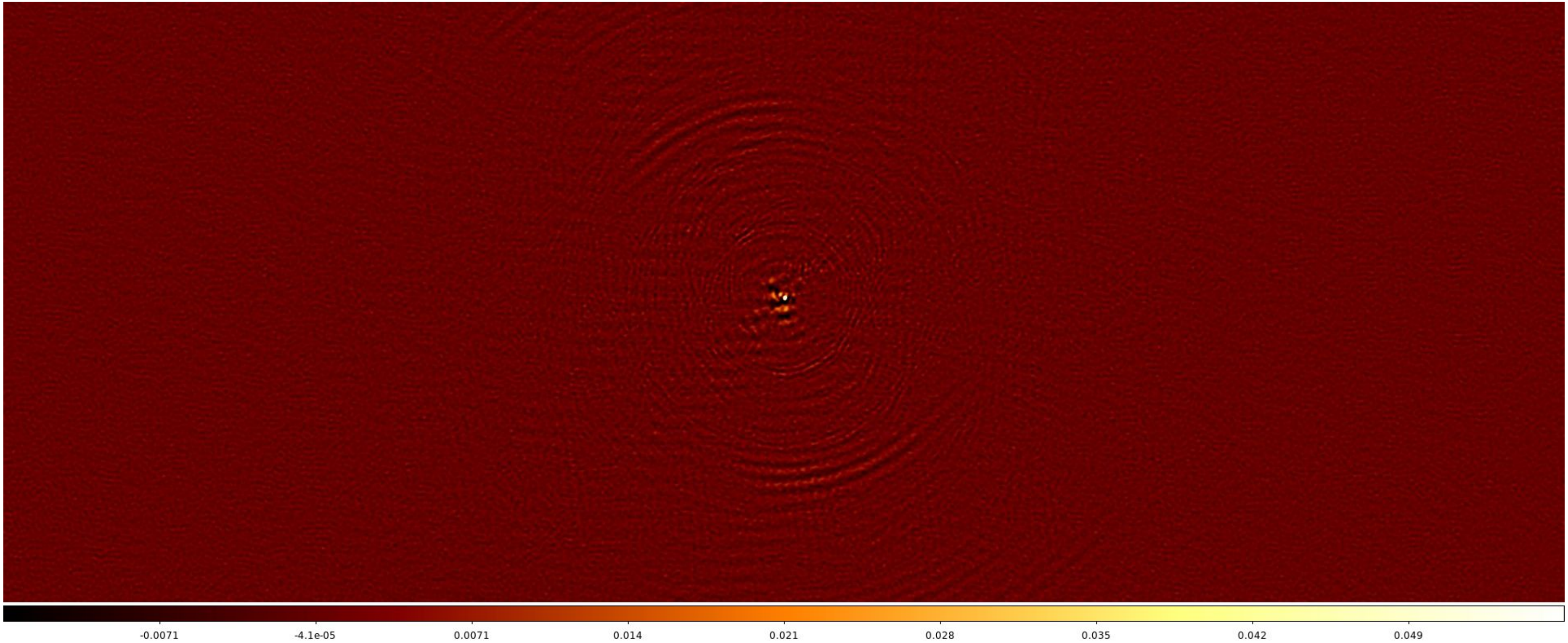

~2.5 degrees away from EGS; signal lost, pixel size 0.1’’

# Testing decorrelation: LBCS 4



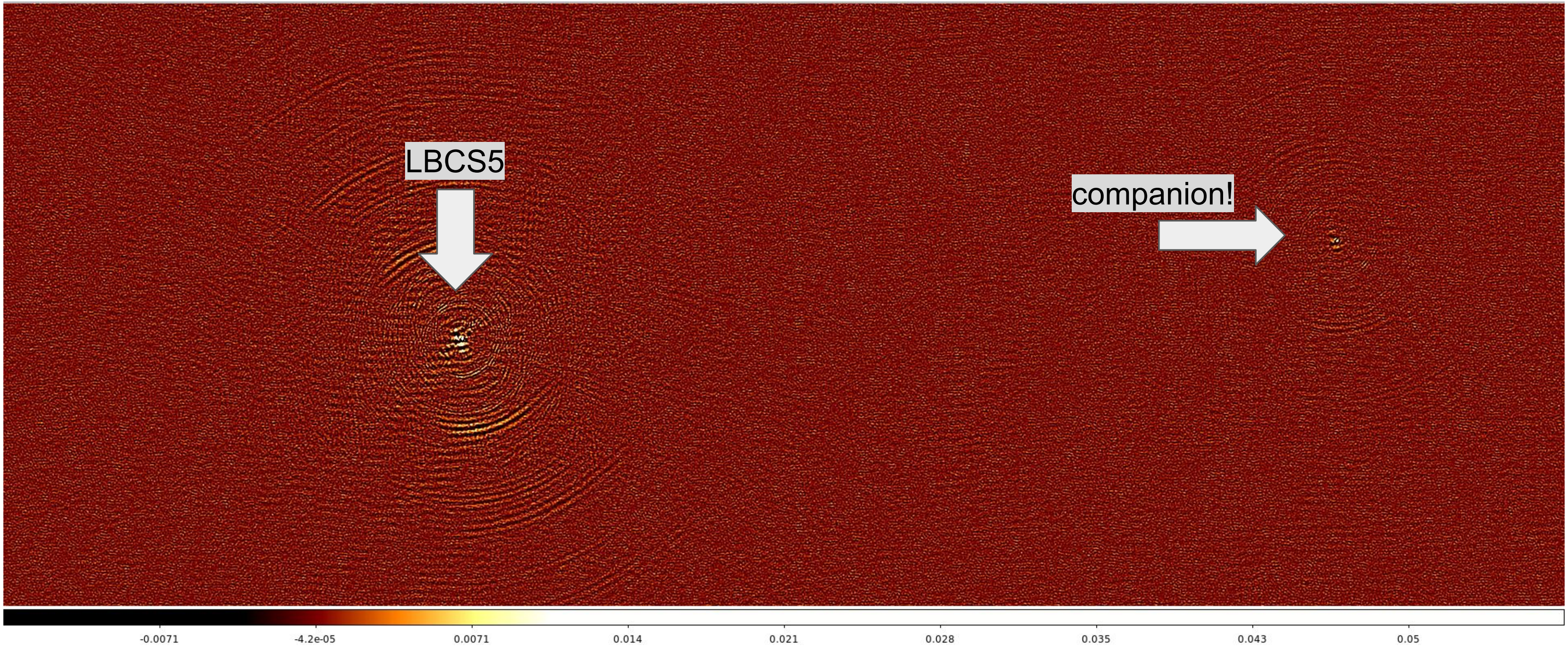

1.7 degrees away from EGS. Peak/noise ratio: ~100, pixel size 0.1’’

# Testing decorrelation: LBCS 5



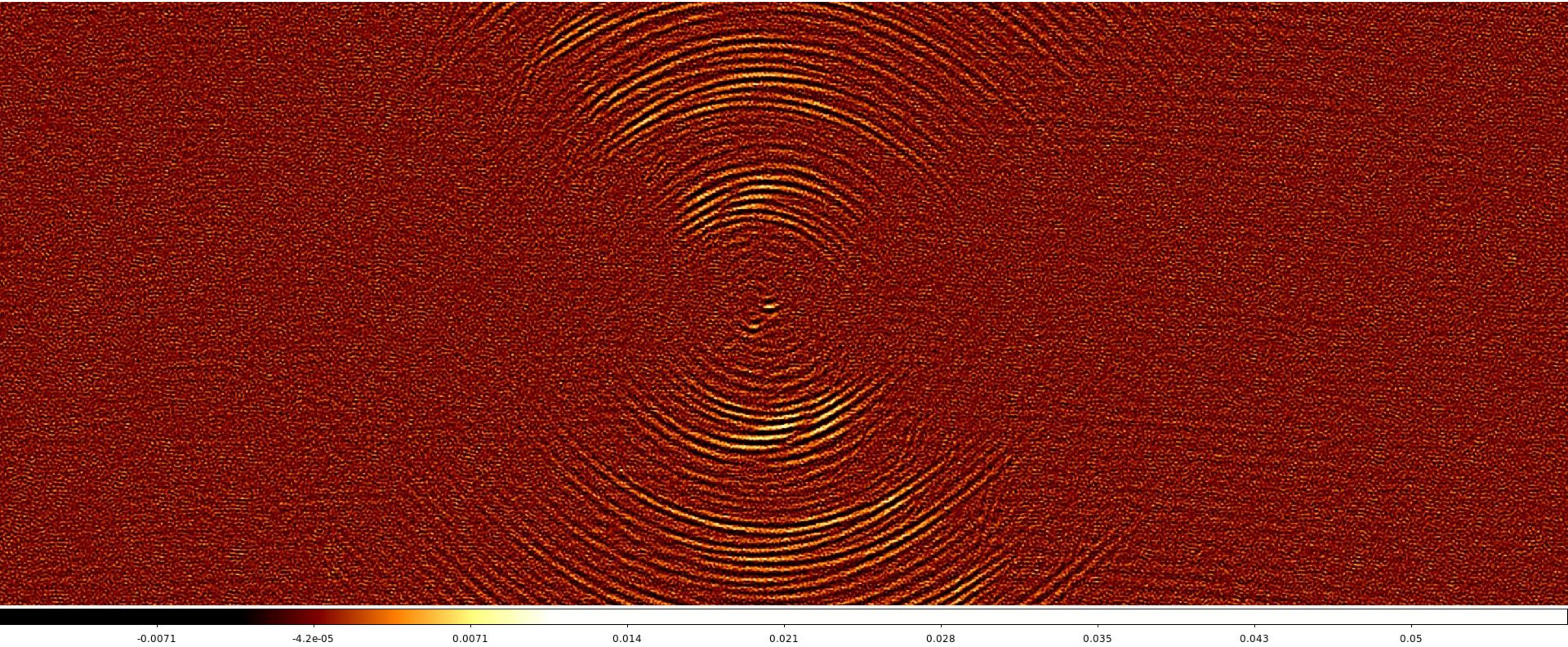

.619 degrees away from EGS. Peak/noise ratio: ~100, pixel size 0.1’’

# Testing decorrelation: LBCS 5



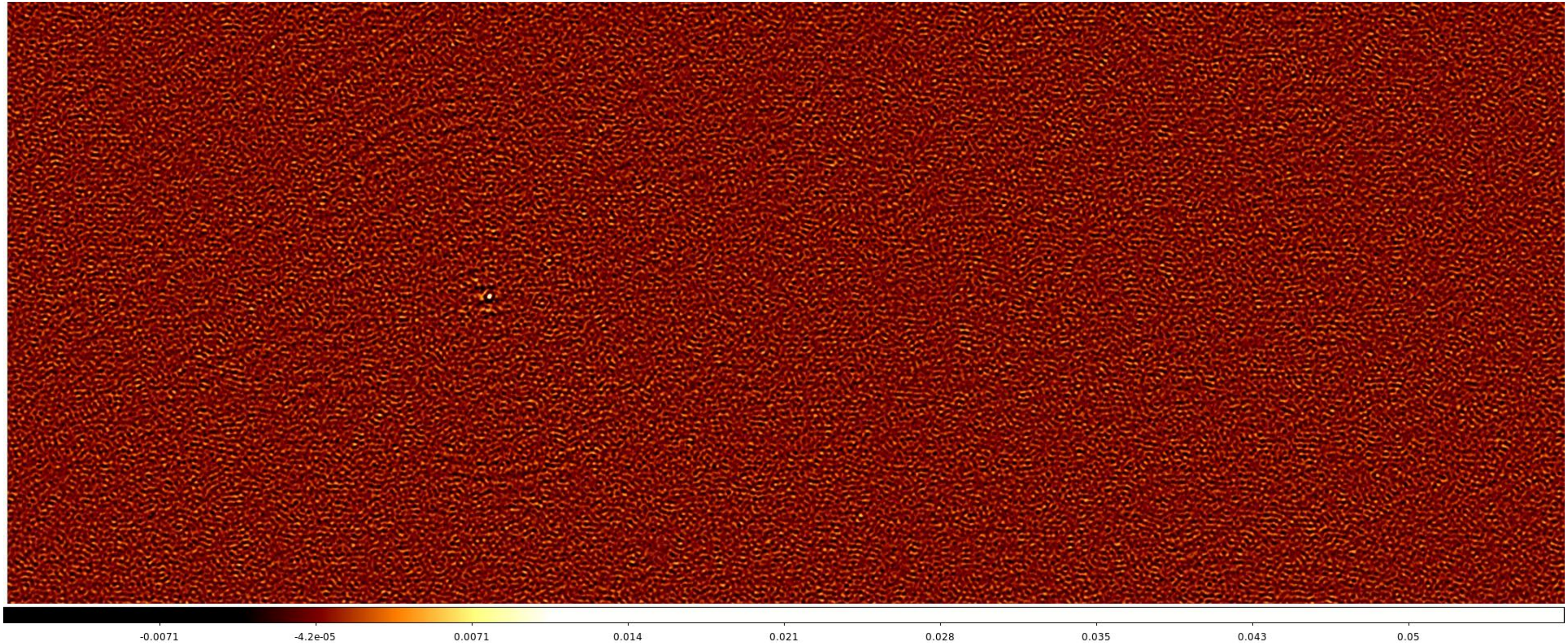

Same image, different contrast. Peak/noise ratio: ~100, pixel size 0.1’’

# Testing decorrelation: LBCS 5



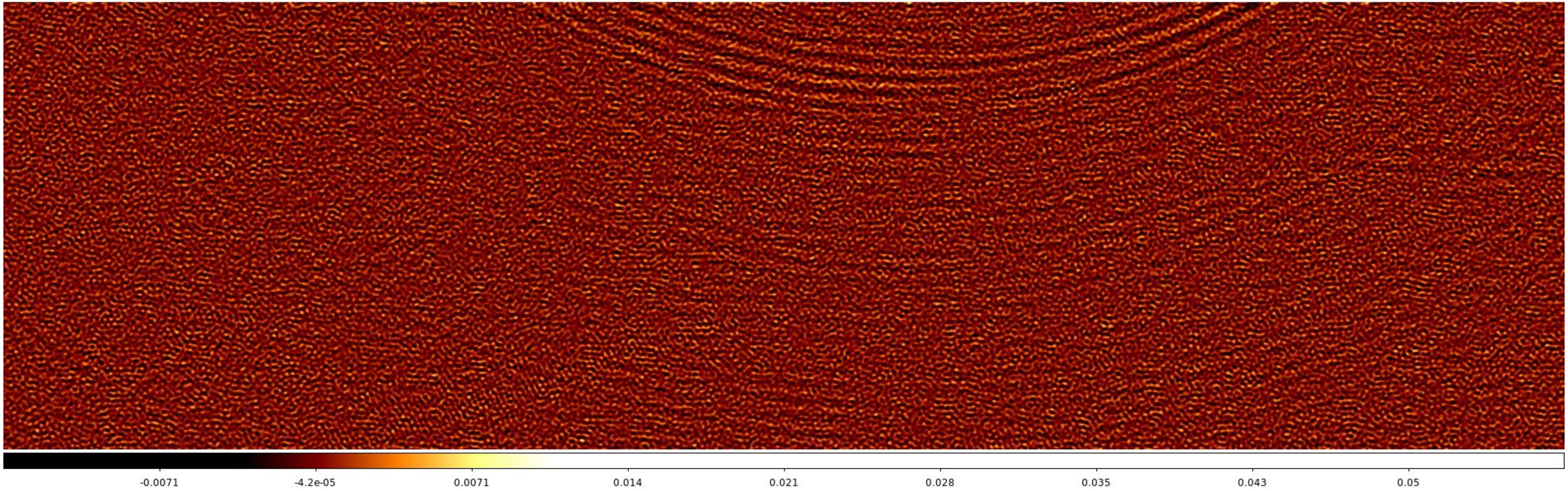

Other sources in the field...

# Testing decorrelation: LBCS 5



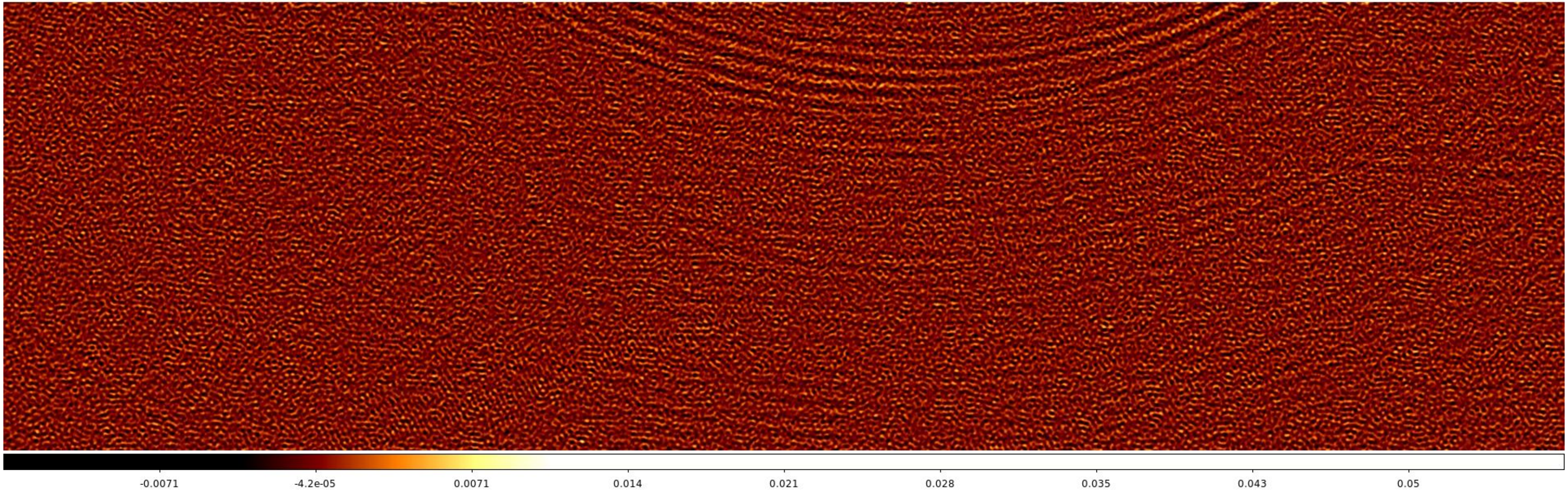

Other sources in the field...

# Testing decorrelation: LBCS 5



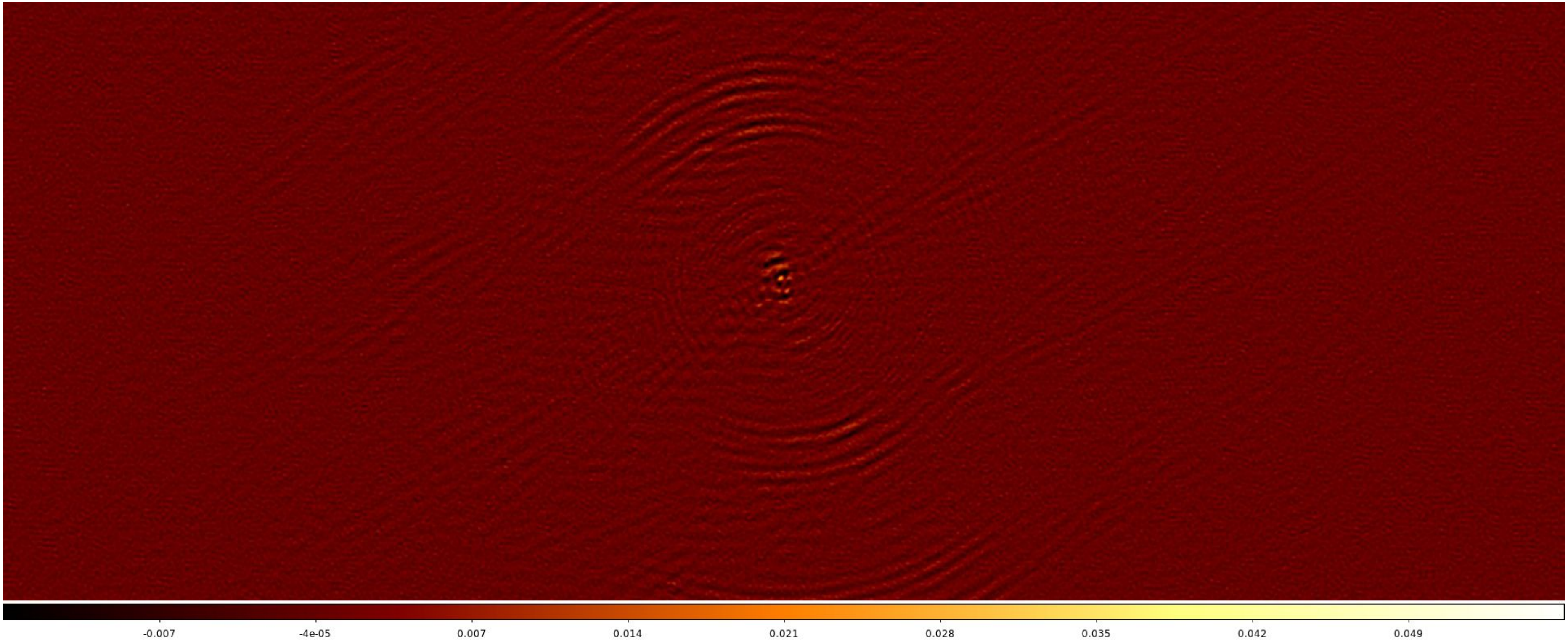

And outside the field...

# Testing decorrelation: LBCS 5



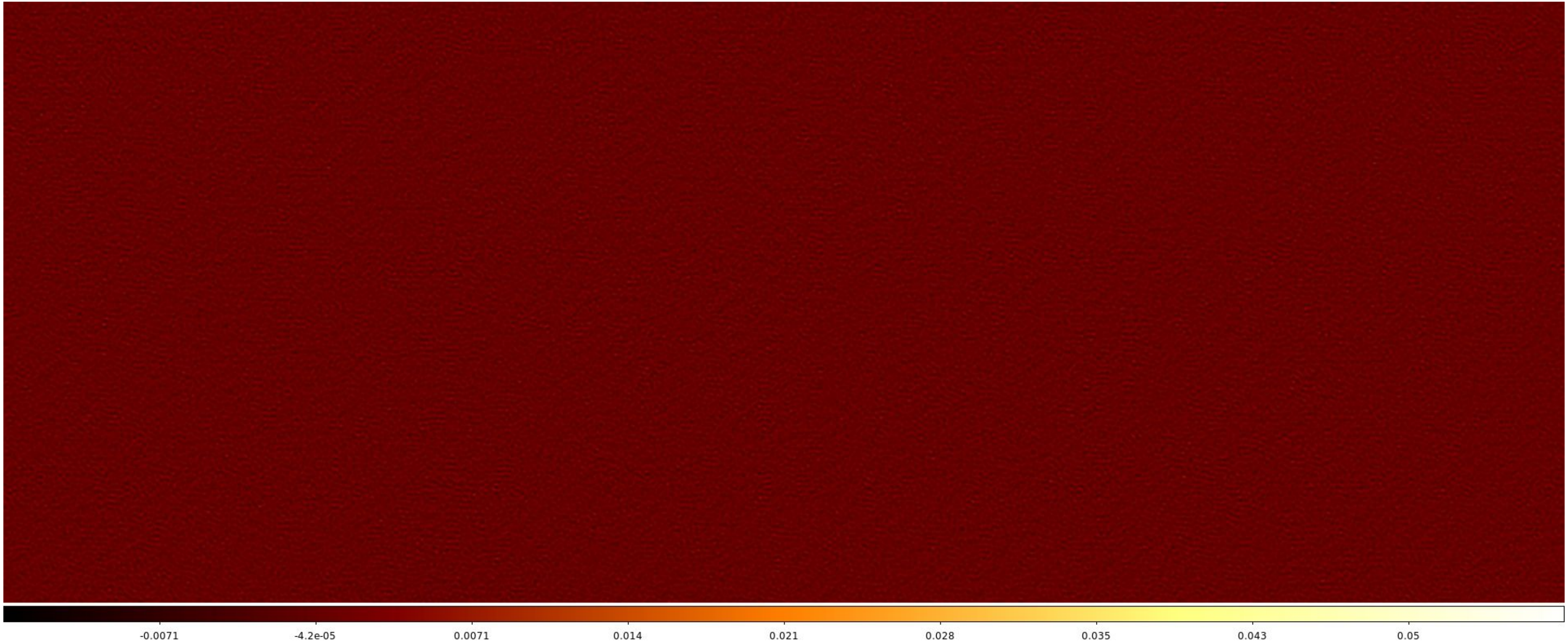

And outside the field...

# Testing decorrelation: LBCS 7




Dirty image; .869deg from 3c295, signal still present

# Testing decorrelation: LBCS 8




Dirty image; .68deg from 3c295, presumably resolved...

# Conclusion

Positive:

- Starting from 2-point model leads to recovery of 3C295 physical emission
- Signal still present on LBCS sources a degree away from calibration centre in spite of tentative & incomplete model of 3C295
- Fainter sources rising above the noise in some of the field, even with uniform weighting & 1/6 of the data
- All done through pipeline: easily & reliably repeatable

Negatives:

- DDE impact LBCS sources...direction-dependent calibration likely required
- Long ways to go until satisfactory model 3C295 acquired

# Conclusion

Future work:

- First and foremost: improve model of 3C295 with more data, better constraints on gain solutions...
- Apply clock/tec solver on calibration solutions for better constraints
- Expect true underlying gain amplitudes to be smooth; amplitude smoothing could point closer to underlying gains
- Direction-dependent calibration potentially necessary; due to low signal-to-noise in the EGS, solving for directional gains could require fringe fitting