Elais-N1 field: International LOFAR 1” Imaging Strategy and Results

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4. **1” imaging strategy** with International LoFAR
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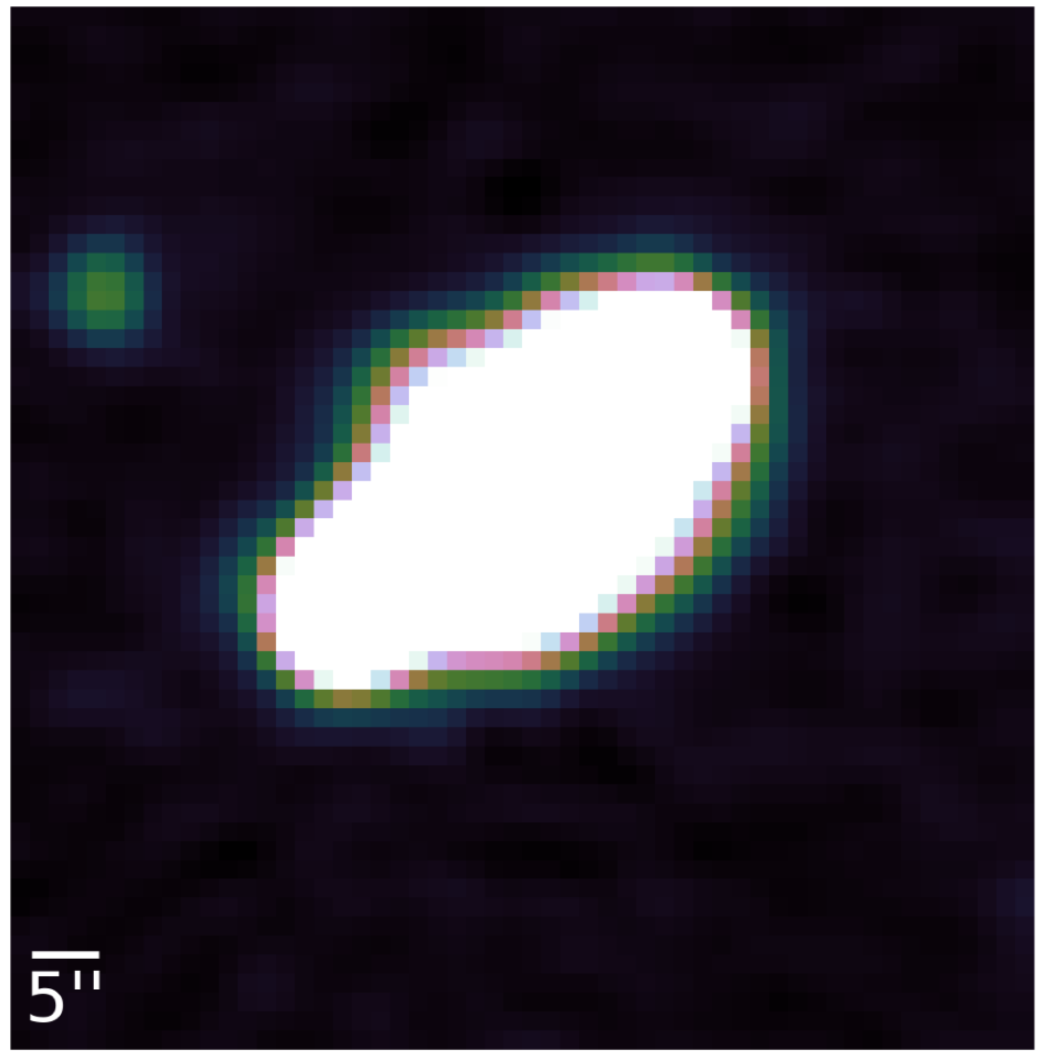
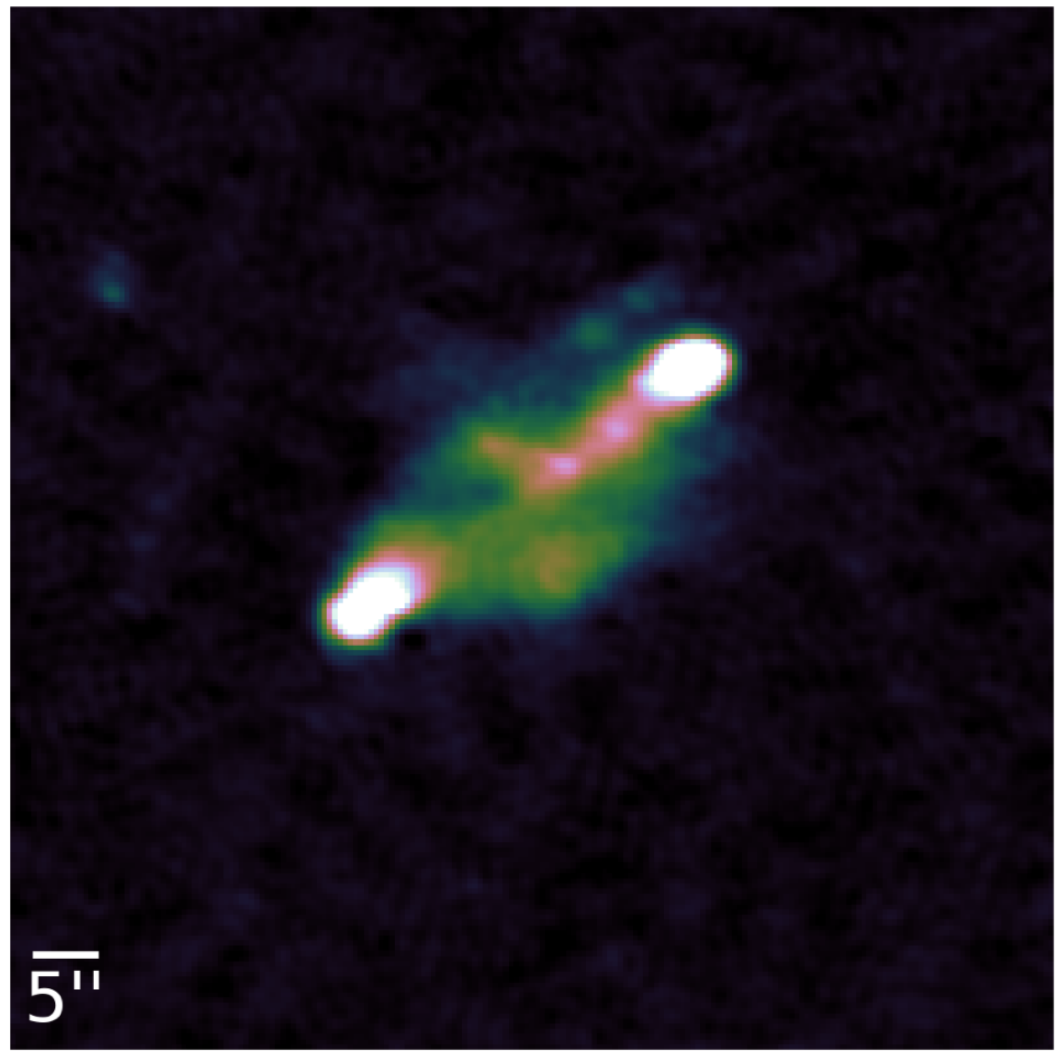
6”



1”



1.1 LOFAR

LOw **F**requency **AR**ray

1.1 LOFAR

LOw **F**requency **AR**ray

10-240 MHz

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1.1 LOFAR

LOw **F**requency **AR**ray

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1.1 LOFAR

Low Band Antenna
LBA*: 10-80 MHz

High Band Antenna
HBA*: 110-240 MHz

→ Correlator in Groningen (NL) →

Images

Spectra

Time series

*Currently, LOFAR can use only one type of antenna at the same time. Soon upgraded to simultaneously observe with both types of antennas.

1.1 LOFAR

Low Band Antenna
LBA*: 10-80 MHz

High Band Antenna
HBA*: 110-240 MHz

→ Correlator in Groningen (NL) →

HBA
144 MHz

Images

Spectra

Time series

*Currently, LOFAR can use only one type of antenna at the same time. Soon upgraded to simultaneously observe with both types of antennas.

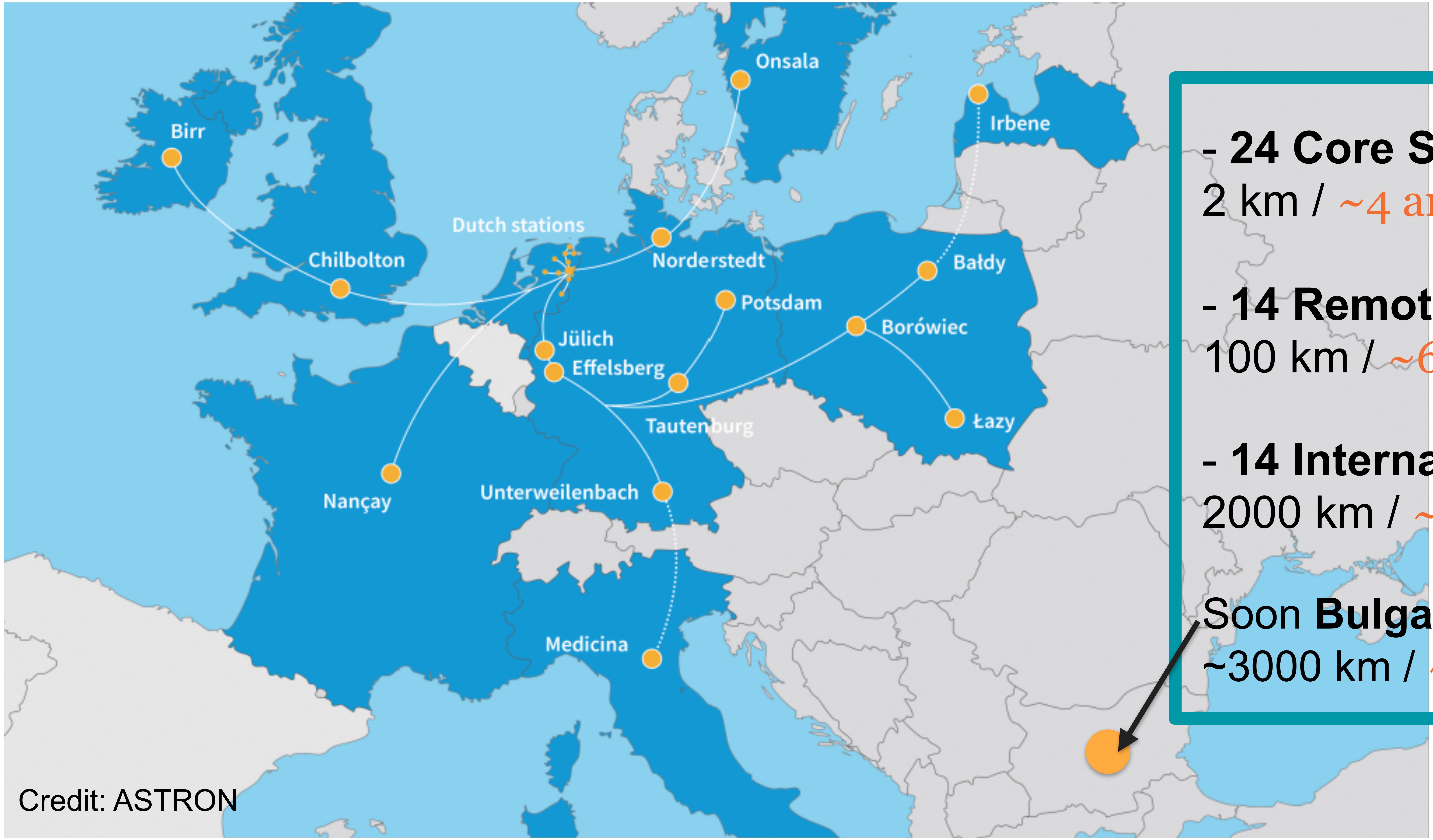
1.2 International LOFAR (ILT)

- **24 Core Stations**
2 km / ~4 arcmin (144 MHz)

- **14 Remote Stations**
100 km / ~6 arcsec (144 MHz)

- **14 International Stations**
2000 km / ~0.3 arcsec (144 MHz)

1.2 International LOFAR (ILT)



- **24 Core Stations**
2 km / ~4 arcmin (144 MHz)

- **14 Remote Stations**
100 km / ~6 arcsec (144 MHz)

- **14 International Stations**
2000 km / ~0.3 arcsec (144 MHz)

Soon **Bulgaria** to join
~3000 km / ~0.2 arcsec (144 MHz)

2. Imaging at different resolution with ILT

LOFAR Two-metre Sky Survey (LoTSS)

- 120-168MHz wide-area survey
- Aim to cover whole northern sky at **6" resolution**
- Sensitivity: ~100 μJy/beam
- DR 1: 400 deg^2 (Shimwell et al, 2022)
- DR 2: 5700 deg^2 (Shimwell et al, 2019)
- **>90% LoTSS observations with international stations**

2. Imaging at different resolution with ILT

LOFAR Two-metre Sky Survey (LoTSS)

- Image resolution: **6” resolution**
- Sensitivity: ~100 µJy/beam
- **>90% LoTSS observations with international stations**

LOFAR Deep Fields

- Fields: Elais-N1, Lockman Hole, and Boötes
- Image resolution: **6” resolution**
- Sensitivity: 19, 25 and 36 µJy/beam

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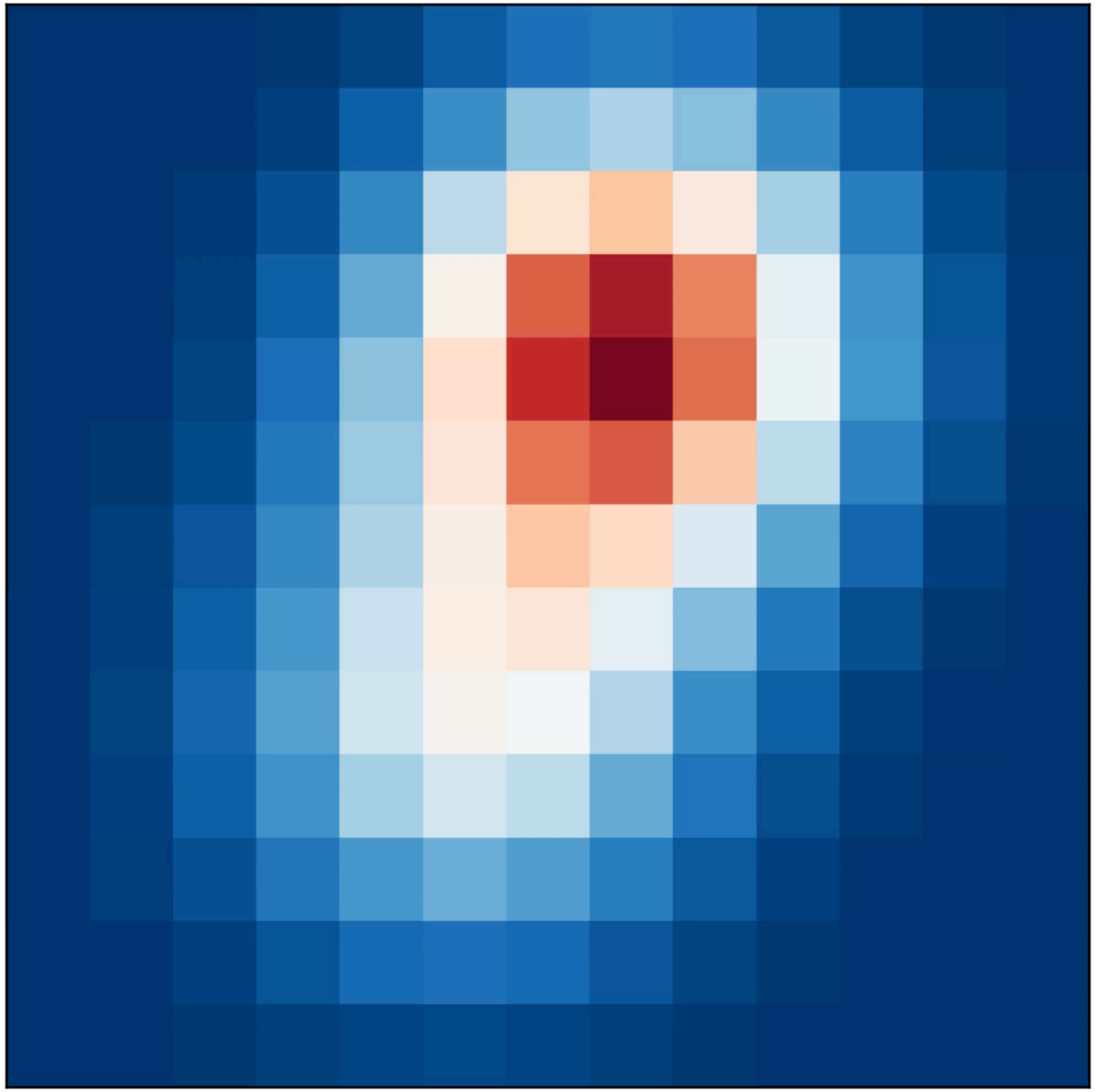
2. Imaging at different resolution with ILT

1 arcmin
↓
6 arcsec
↓
1 arcsec
↓
0.3 arcsec

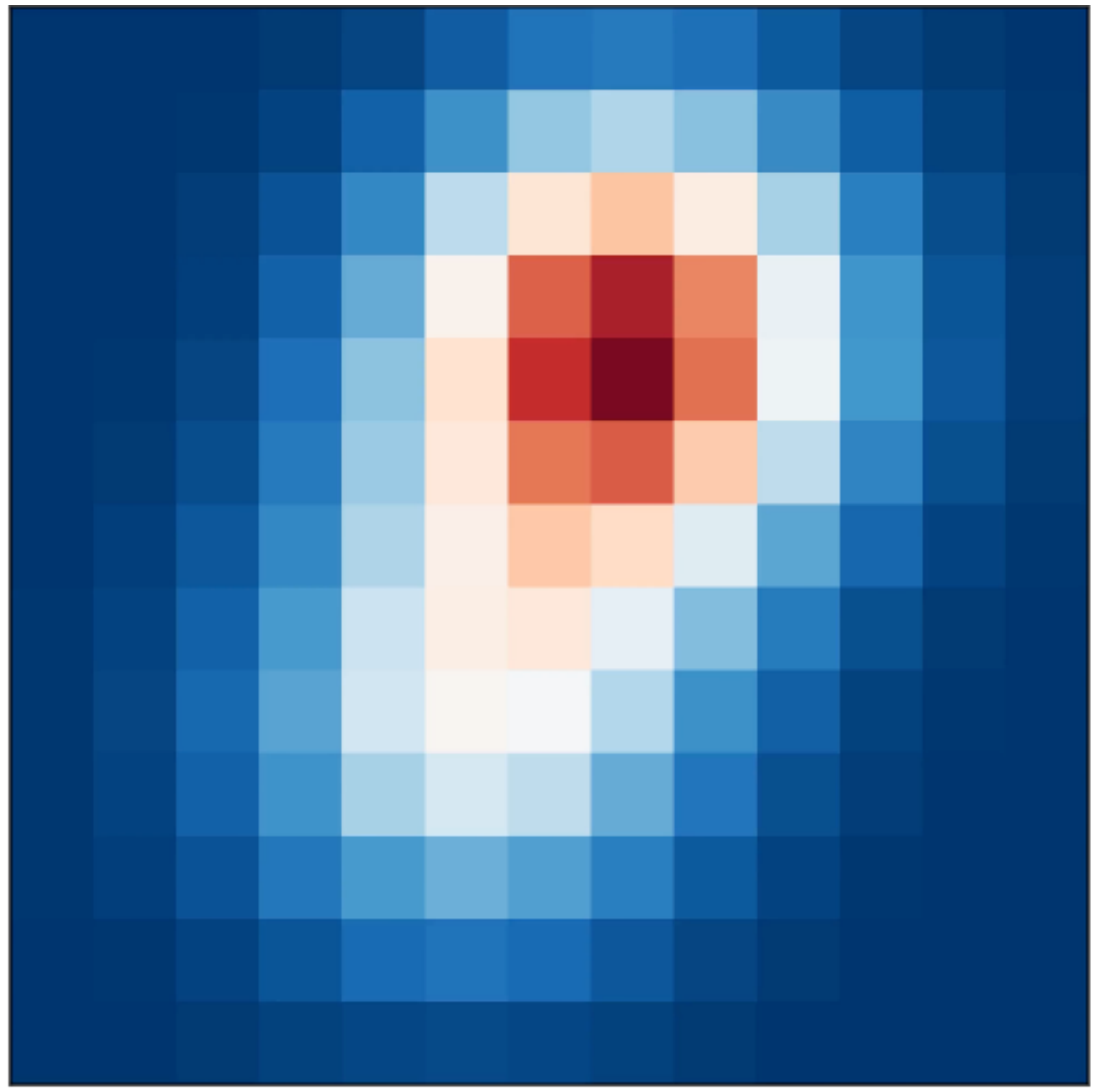
without International Stations

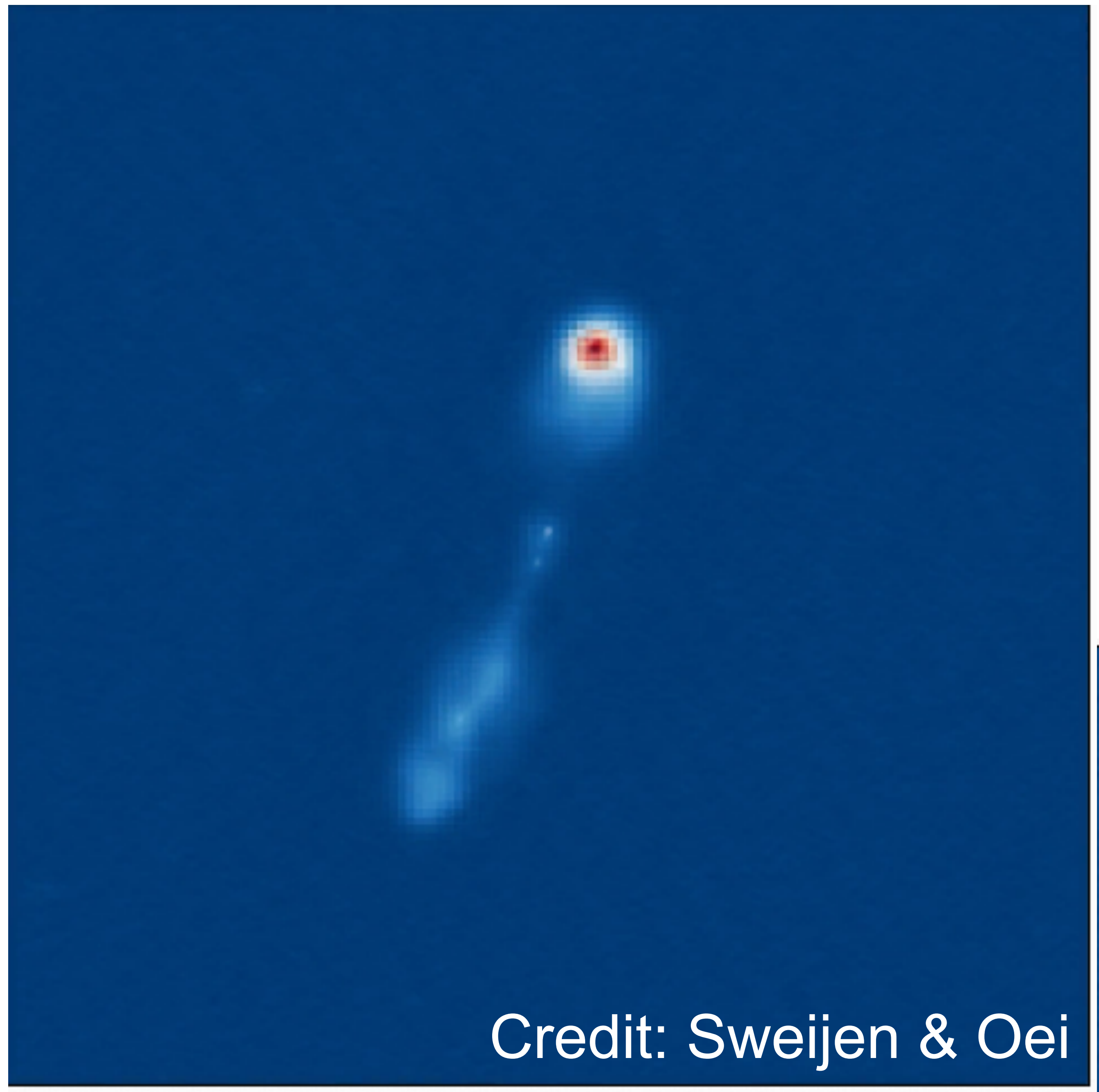
with International Stations



A selected source in the Lockmanhole | Credit: Sweijen & Oei

2. Imaging at different resolution with ILT





1'

6''

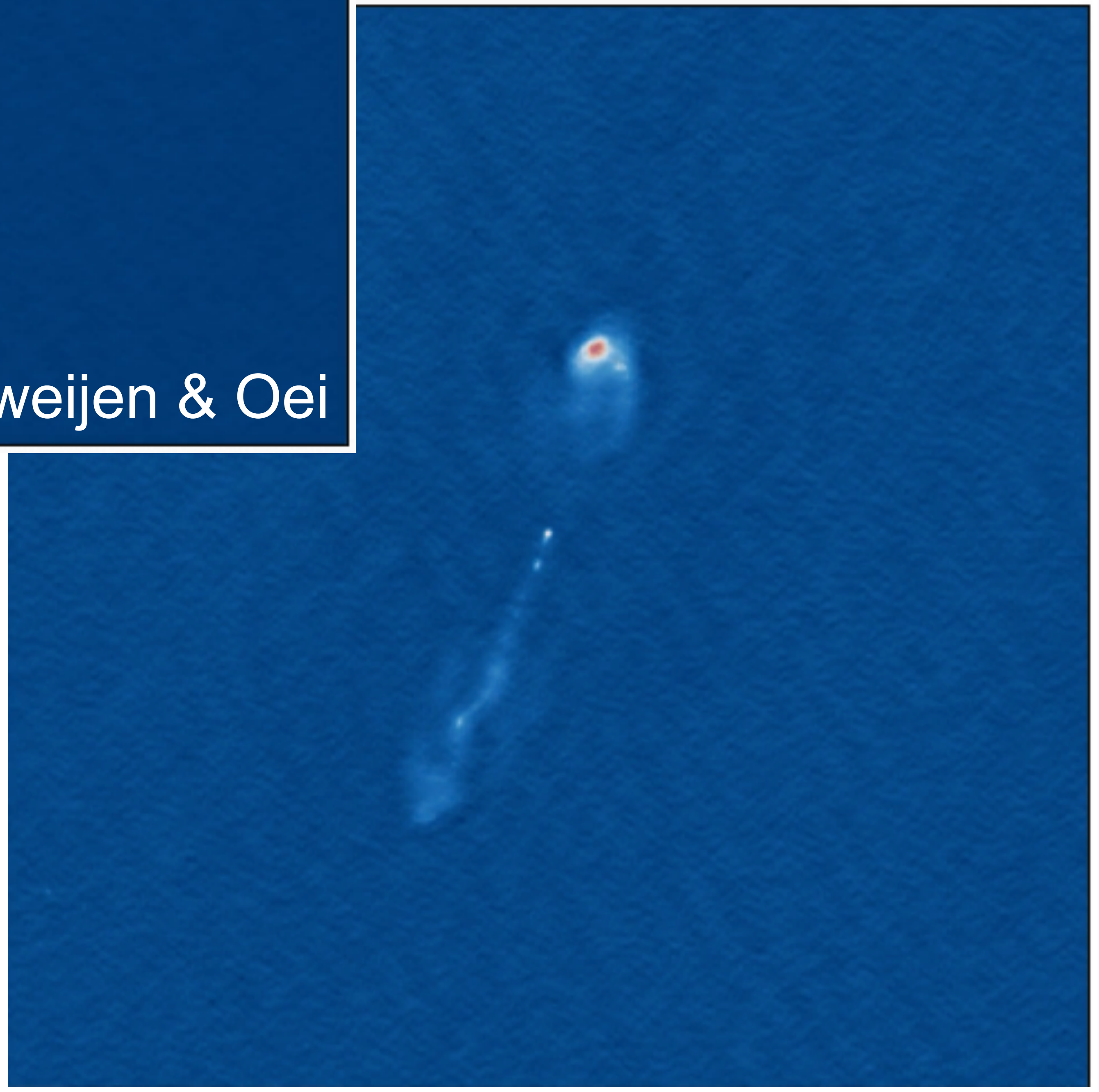
6'':

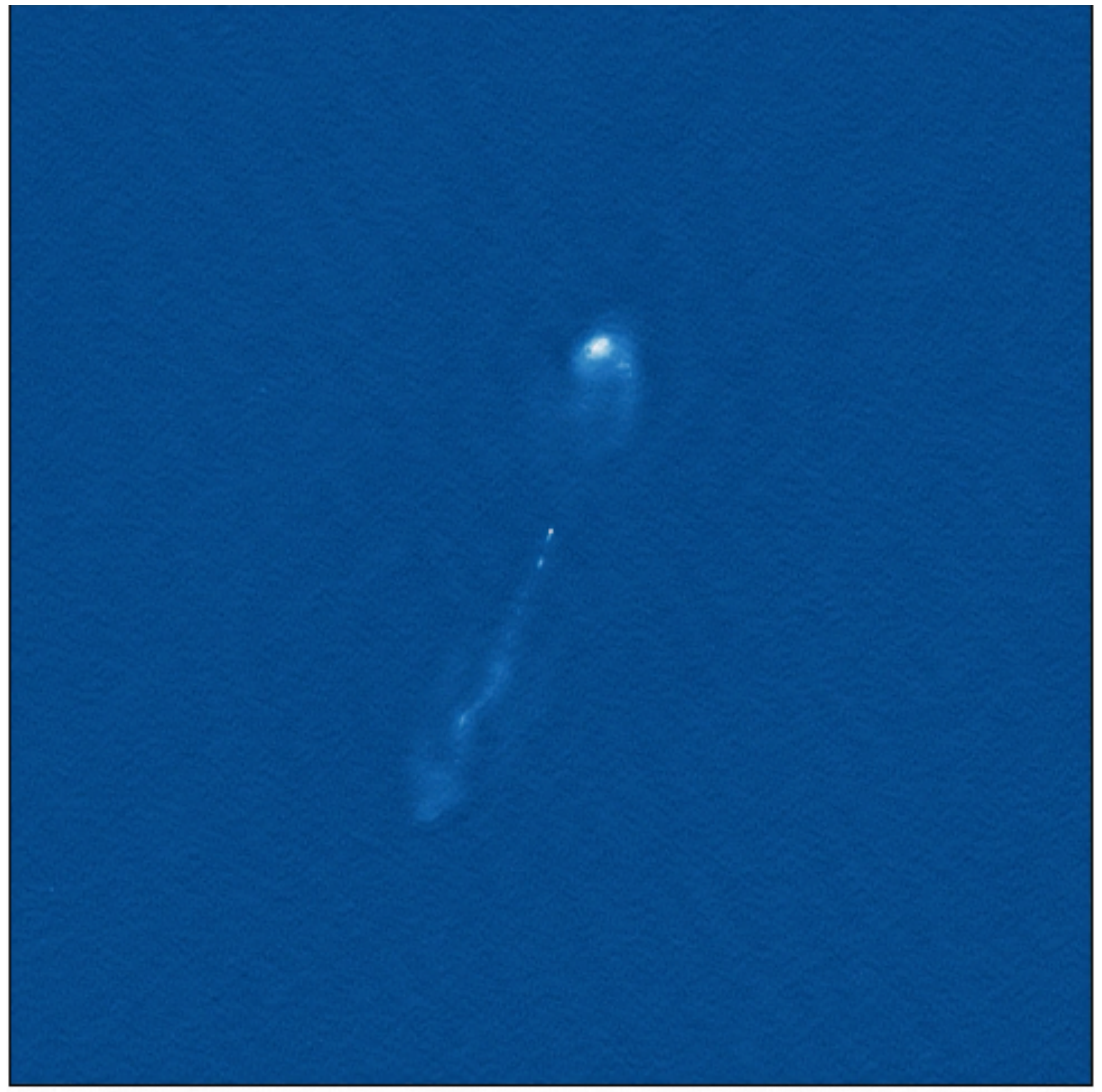
Standard imaging products of LoTSS survey DR1, DR2.

- "Mature" pipeline ✅
- Batch Processing ✅

0.3'':

The highest resolution achieved so far at 144MHz with ILT by Sweijen F., et al. (2022).



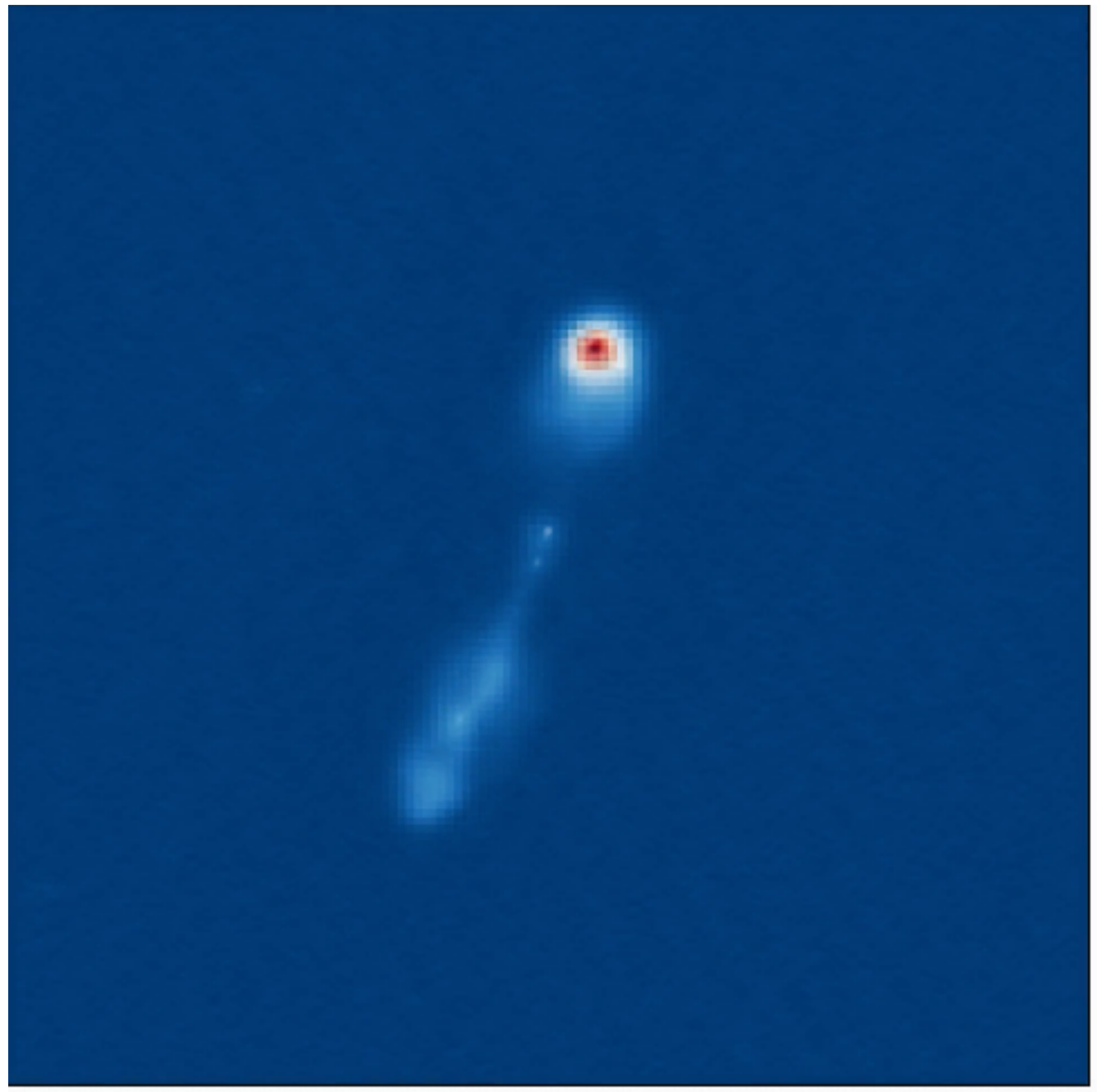


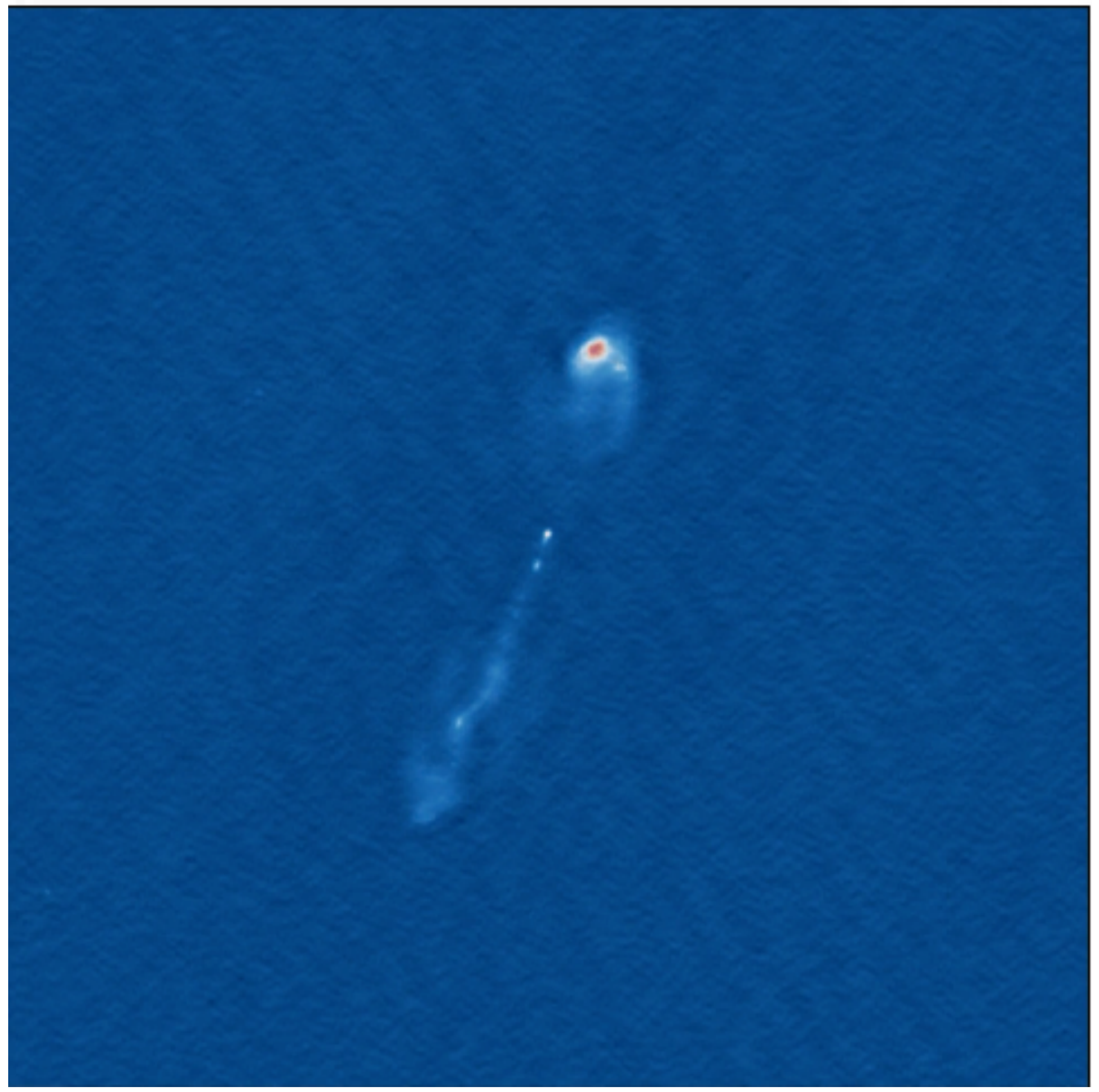
1''

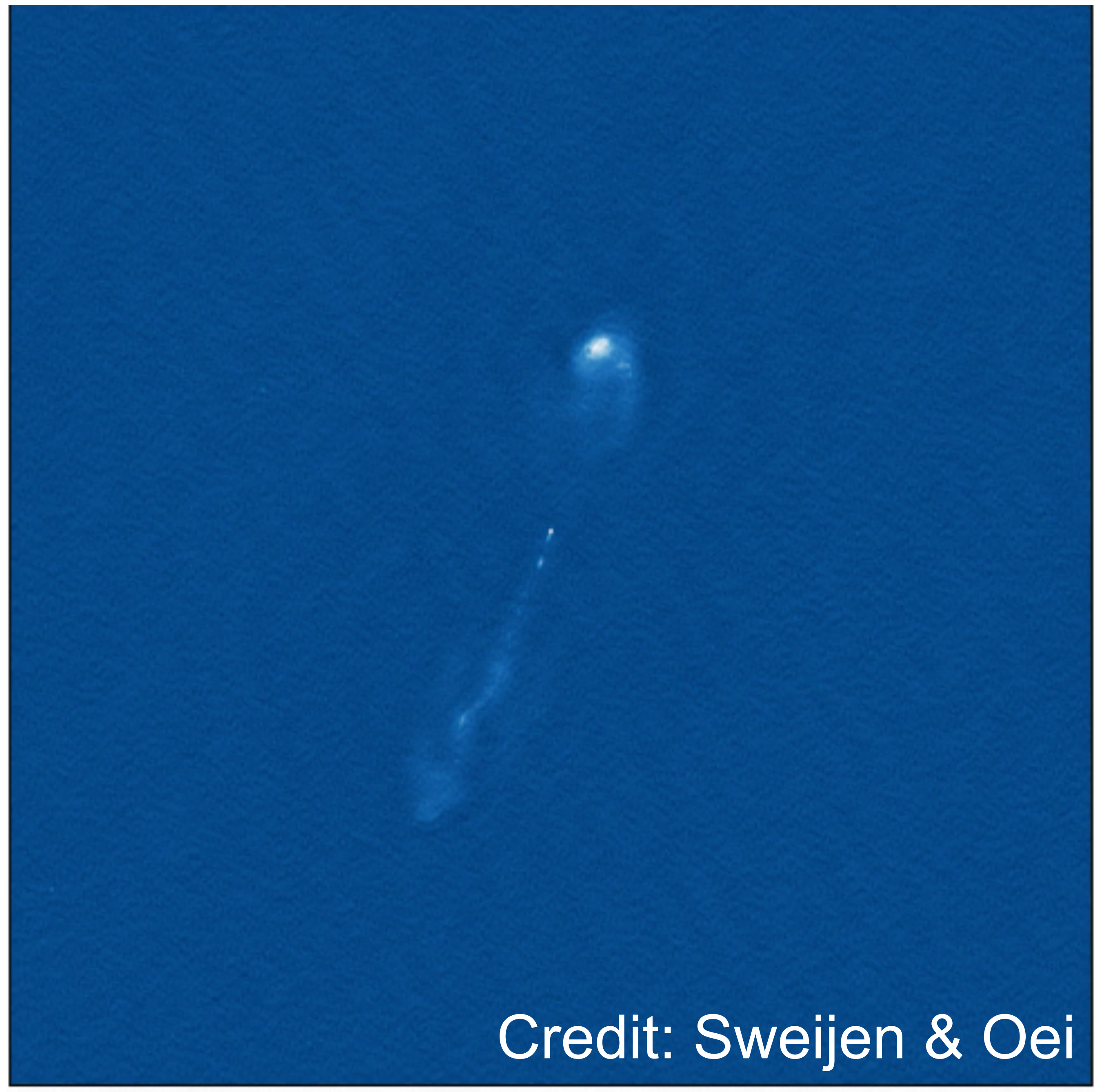
0.3''

2. Imaging at different resolution with ILT

For an 8-hour wide field LoTSS observation







6"
12k Core Hours

1"
? Core Hours

0.3"
210k-250k Core Hours

2. Imaging at different resolution with ILT

Can we have a 1” LoTSS Survey in the future?

2. Imaging at different resolution with ILT

Can we have a 1" LoTSS Survey in the future?

Can we have 1" deep fields?

3.1 Why Elais-N1 field

Elais-N1: Observation Parameters	
Observation IDs	L686960
Pointing centres	16h11m00s+54d57m00s
Integration time	8 h
Observation date	2018 Nov 26
Correlations	XX, XY, YX, YY
Frequency range	120-168 MHz
Bandwidth	48 MHz
Stations	51 total (13 International,14 remote, 24 core)

Field choice:

Elais-N1 field is one of the most well-studied fields. Apart from radio, it has also been observed at multiple wavelengths.

Aim:
Make a science-quality 1"-2" image, and see how long it takes.

3.1 Why Elais-N1 field

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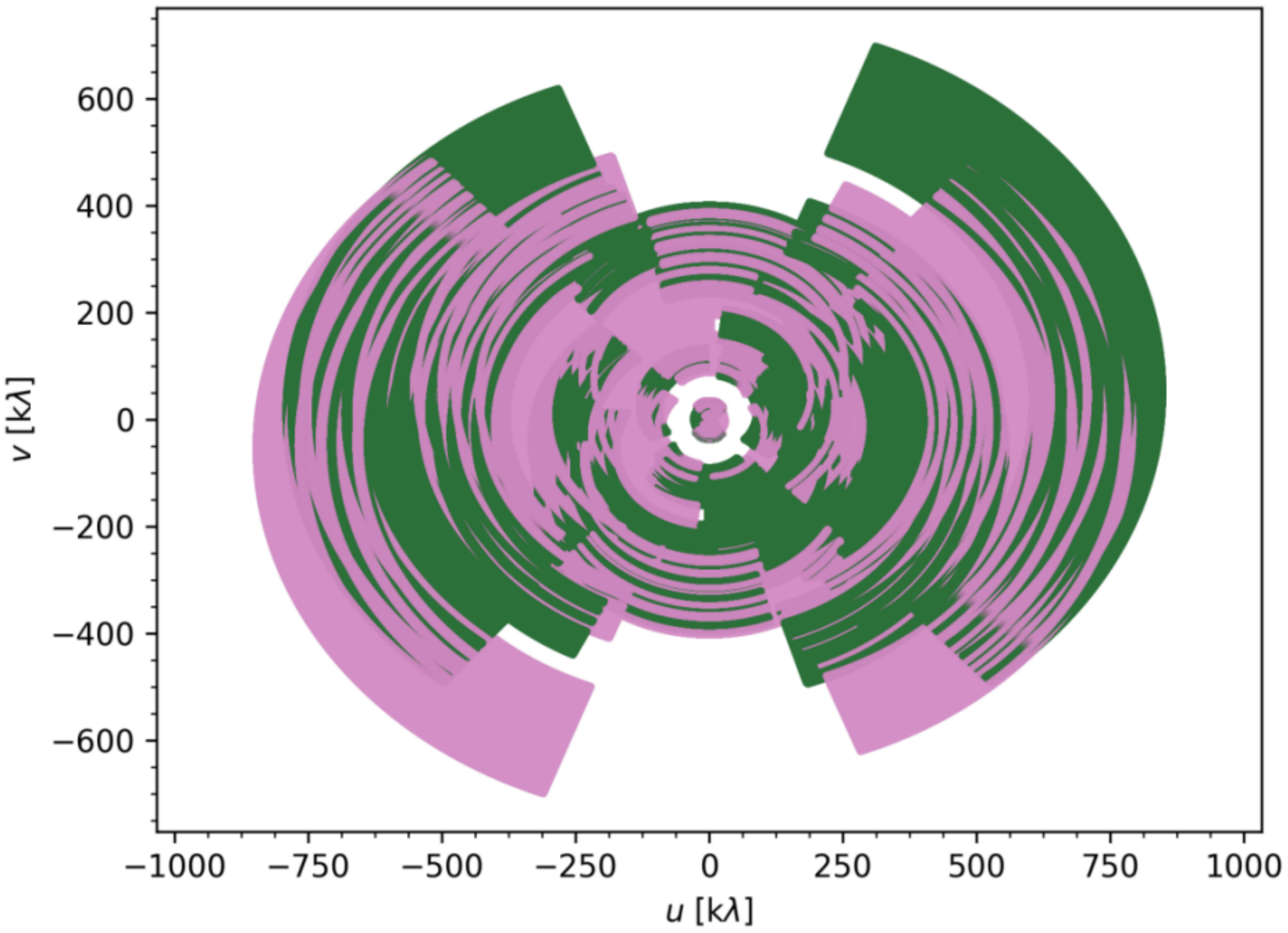

uv-coverage for this Elais-N1 field observation. The maximum baseline is 1550 km (or 662 kλ). The two colours show the symmetric uv points obtained from the conjugate visibilities.

3.2. Results: 1” Imaging of Elais-N1 field with ILT

Our image:

Haoyang Ye, Wendy Williams, Frits Sweijen, Reinout van Weeren and Jurjen de Jong

Universiteit Leiden
Sterrewacht Leiden

3.2. Results: 1” Imaging of Elais-N1 field with ILT

FoV: 2.5 x 2.5 deg^2

Image size: 25000 * 25000 pix^2

Beam size: 1.2” x 2”

Our image:

Haoyang Ye, Wendy Williams, Frits Sweijen, Reinout van Weeren and Jurjen de Jong

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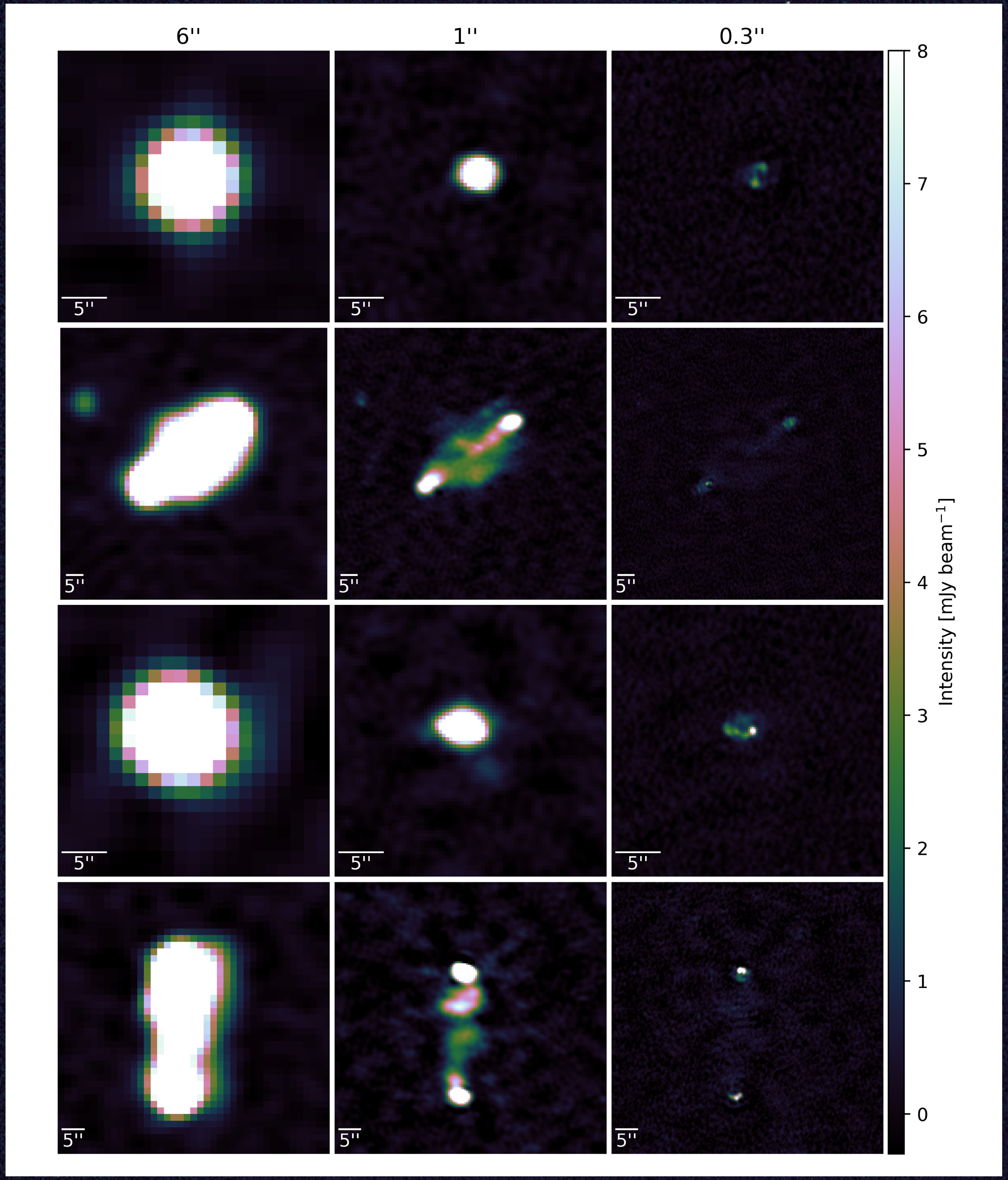
3.2. Results: 1” Imaging of Elais-N1 field with ILT



Selected sources on

Left: 6” image
Centre: 1” image
Right*: 0.3” image

* Only 25% of the data is used

Our image:

Haoyang Ye, Wendy Williams, Frits Sweijen, Reinout van Weeren and Jurjen de Jong

Universiteit Leiden
Sterrewacht Leiden

3.2. Results: 1” Imaging of Elais-N1 field with ILT

LoTSS: Continumm Image Products			
Observation	Beam Size (")	RMS (μJy/beam)	Use international baselines?
LoTSS survey	6	71	No
LoTSS Deep Fields	6	20-30	No
LoTSS - Lockman Hole (Sweijen et al. ,2022)	0.3	25	Yes
LoTSS - Elais-N1 **(This work)**	1.2	60	Yes

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3.3. Computational cost: 1” Imaging on Elais-N1

An 8-hour LoTSS observation takes at least 5-6 weeks to make the 1” image.

(~12,000 CH)
LoTSS pipeline

LOFAR-VLBI
(~7,000 CH)

(~10,000 CH)
Subtraction

DD calibration
(~10,000 CH)

(~10,000 CH)
1” Imaging

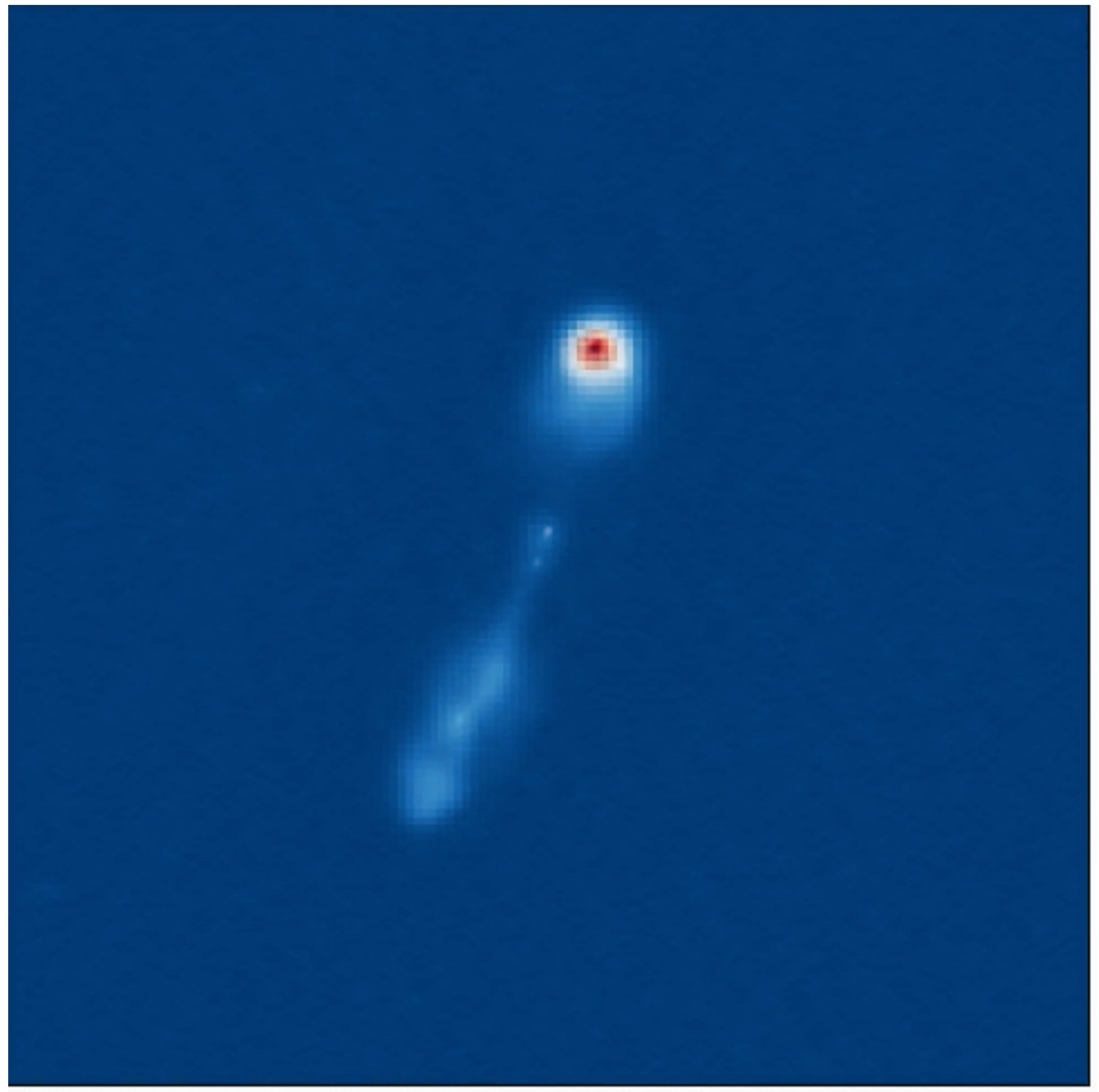
All together ~ 9 weeks @ 32 cores
(only use a single node)

We have larger cores :P

If we don’t count our trial-and-fail time:
5-6 weeks.

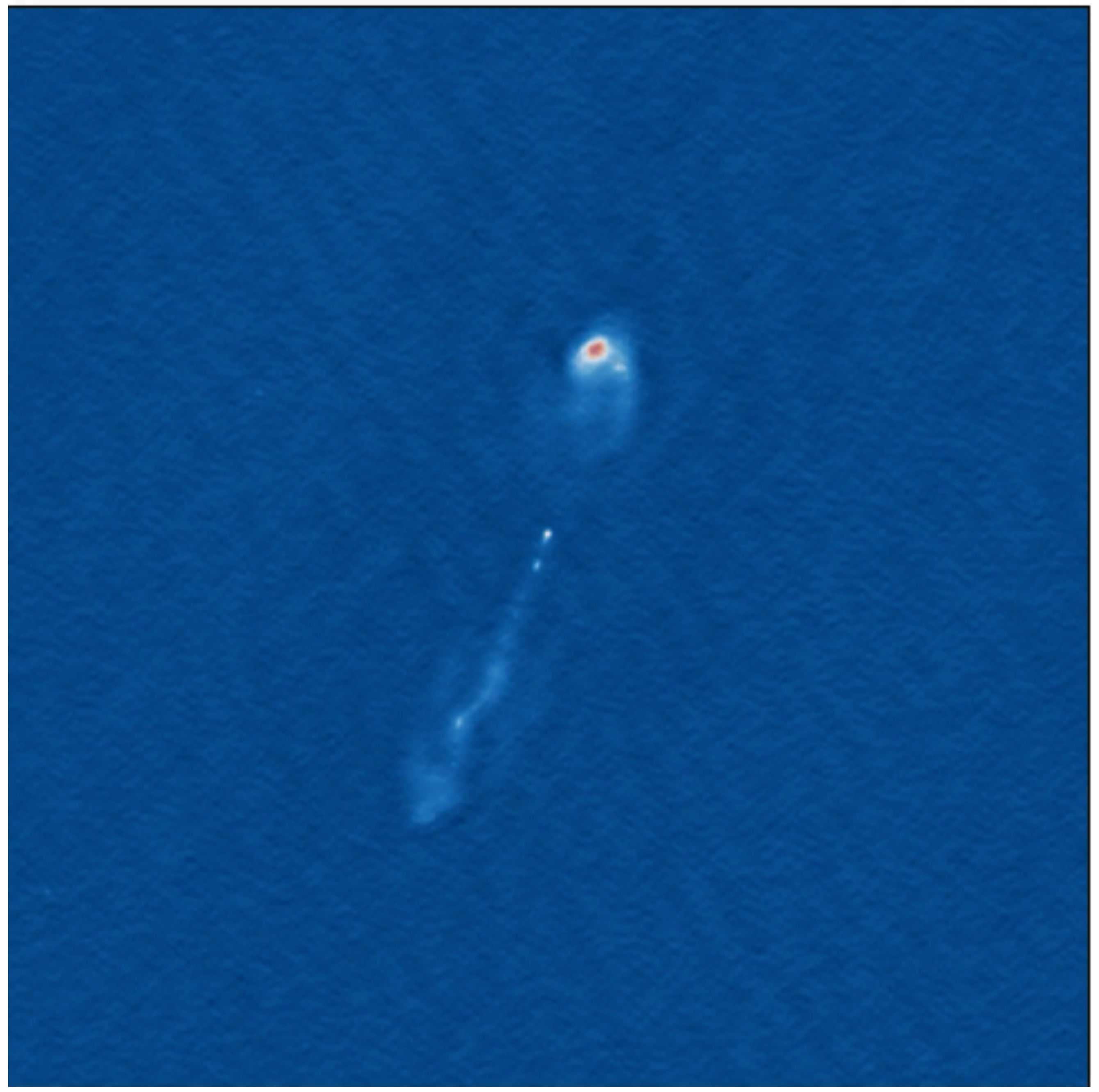
3.3. Computational cost: 1” Imaging with ILT

For an 8-hour wide field LoTSS observation



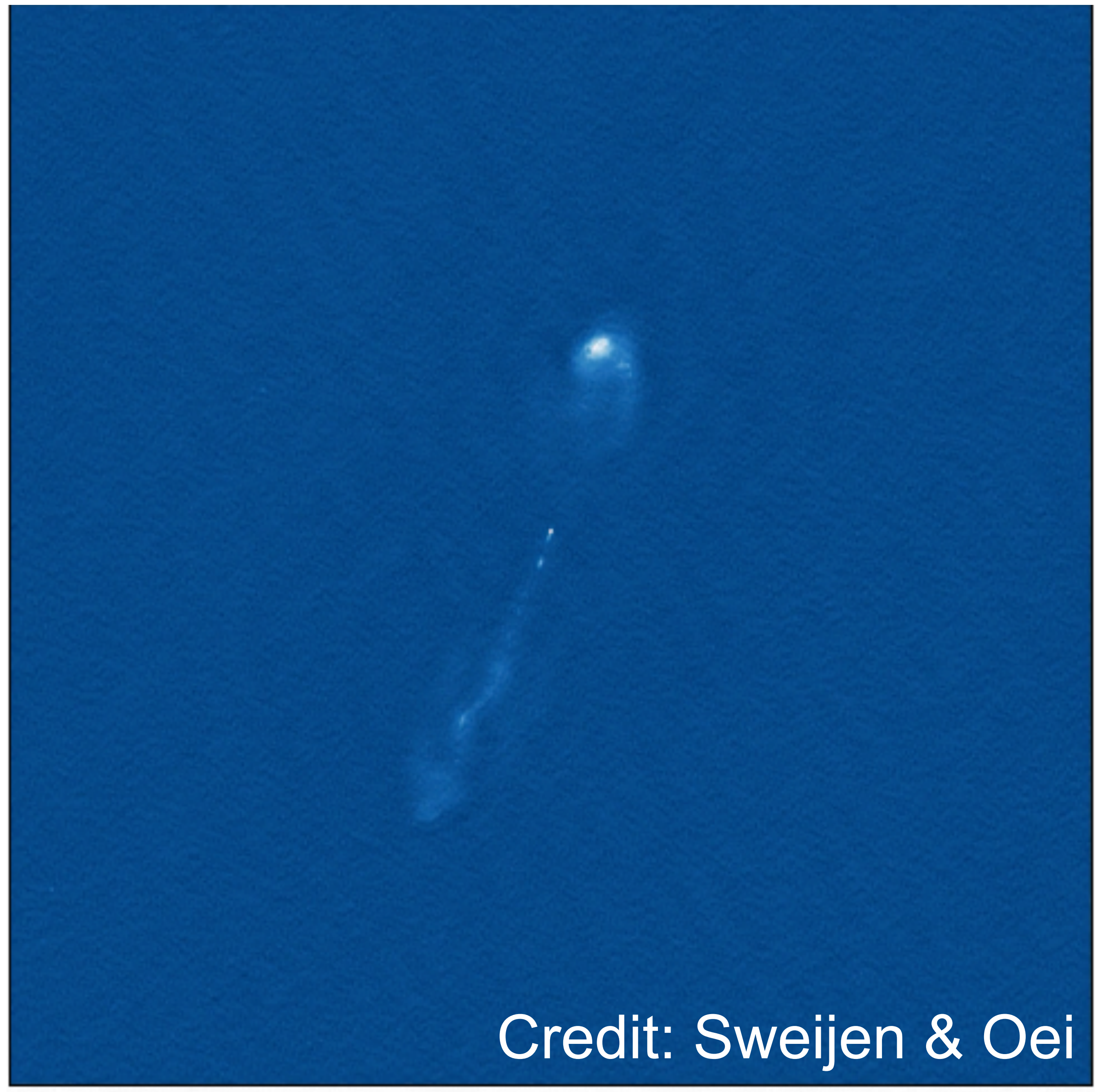
6”

12k Core Hours



1”

49k Core Hours
= 12k + 37k



0.3”

210k-250k Core Hours

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3. Elais-N1 field: 1” imaging results

Can we have a 1” LoTSS Survey in the future?

Can we have 1” deep fields?

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Can we have a 1” LoTSS Survey in the future?

Can we have 1” deep fields?

Possible :D

4. 1” imaging strategy with International LoFAR

Challenges:

1. Direction Dependent Calibration

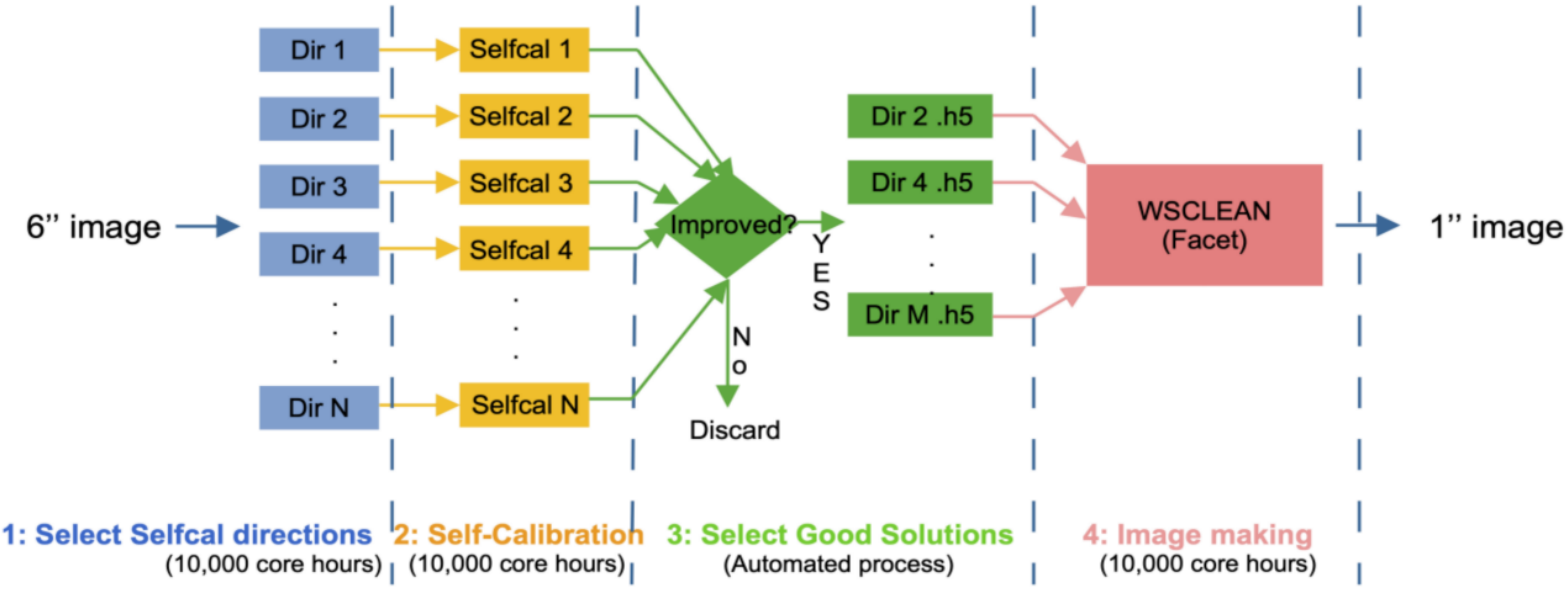
Ionosphere blurring for Low Frequency Observation

—> 1) select *enough* calibrators in the field

2) select *good* calibrators in the field

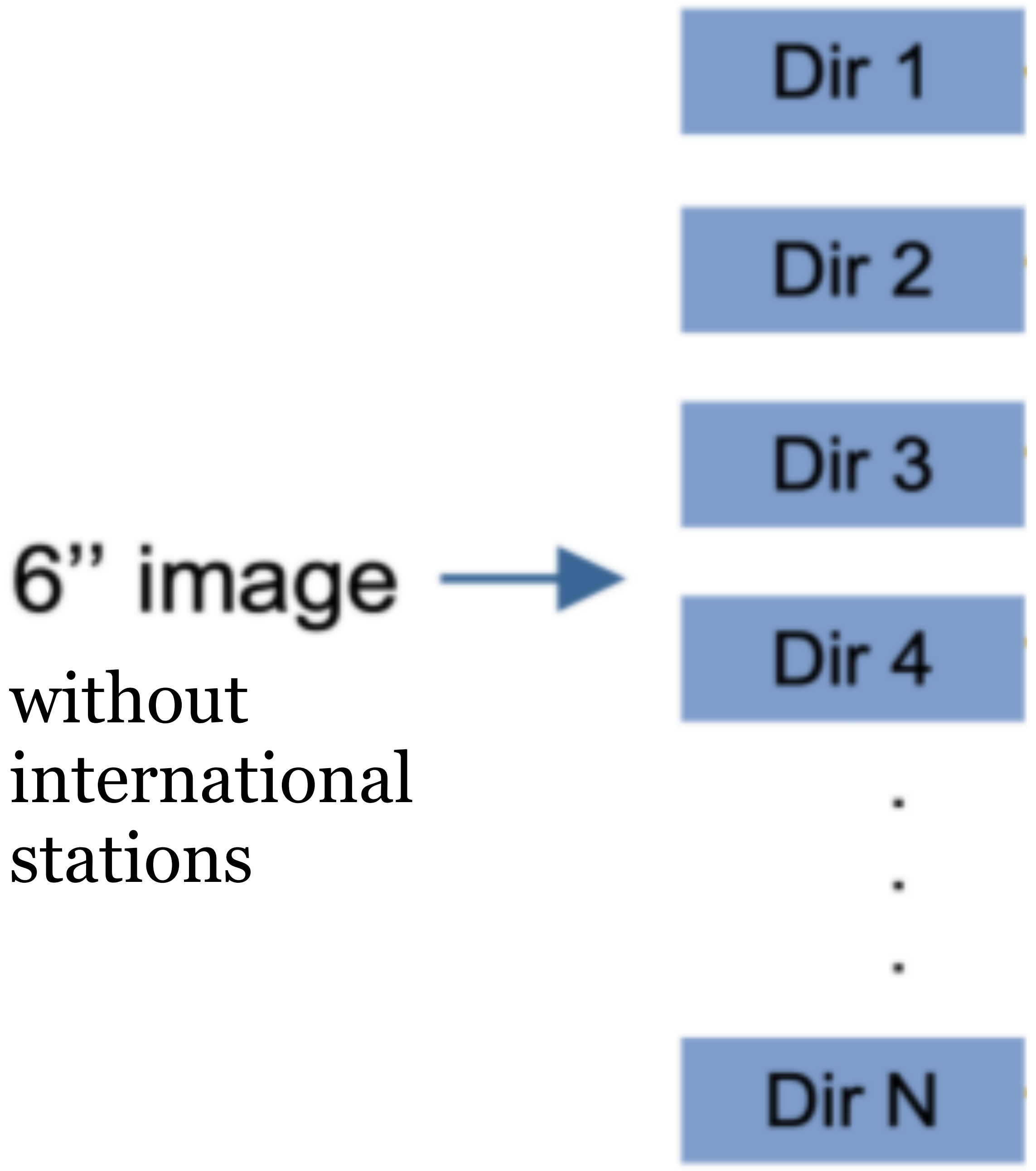
2. **Computational challenge** for producing big images (e.g. 25000^2)

4. 1” imaging strategy with International LoFAR



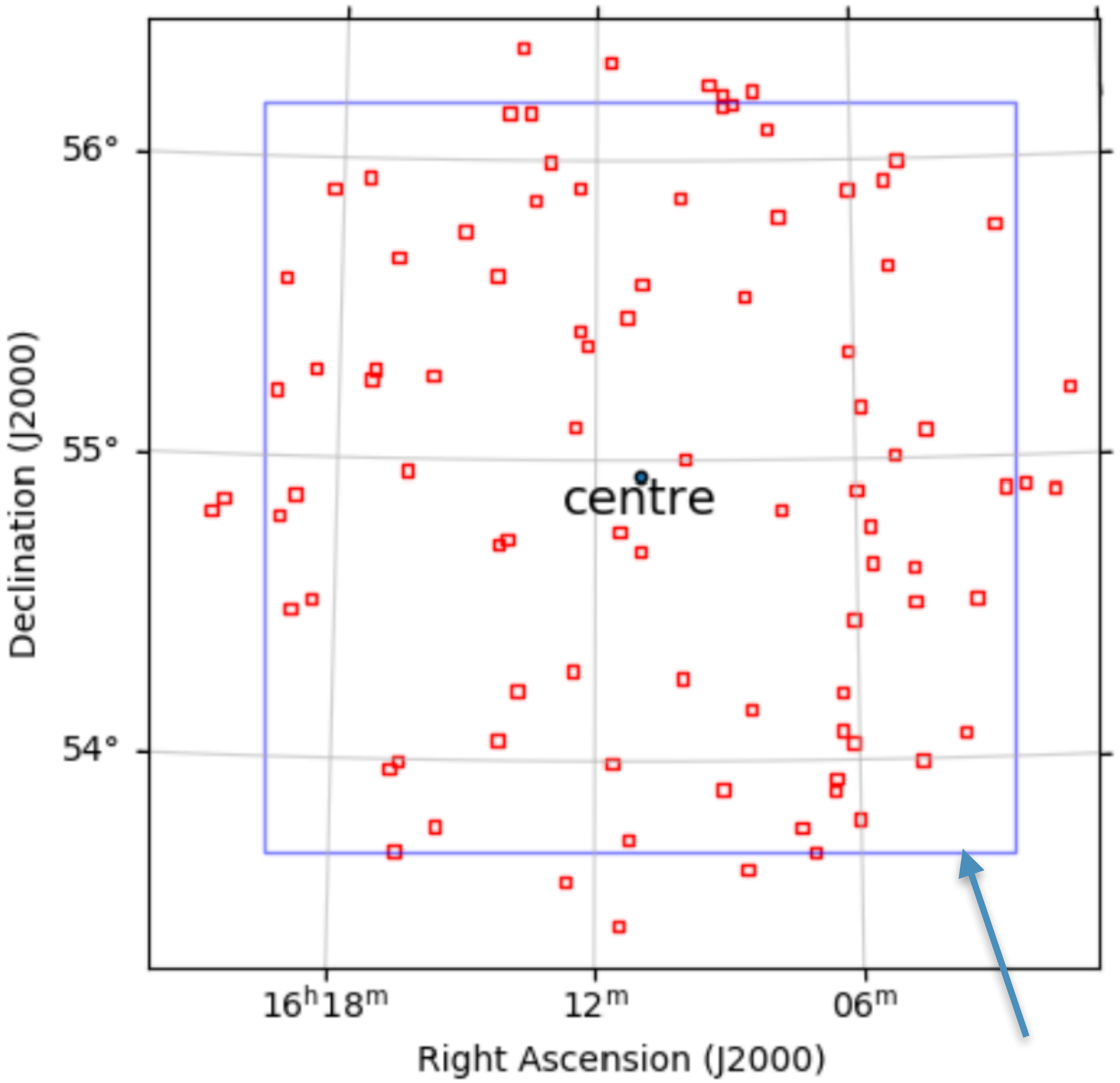
4. 1" imaging strategy with International LoFAR

Challenge 1: 1) select *enough* calibrators in the field



without international stations

1: Select Selfcal directions
(10,000 core hours)



Total flux > Threshold?

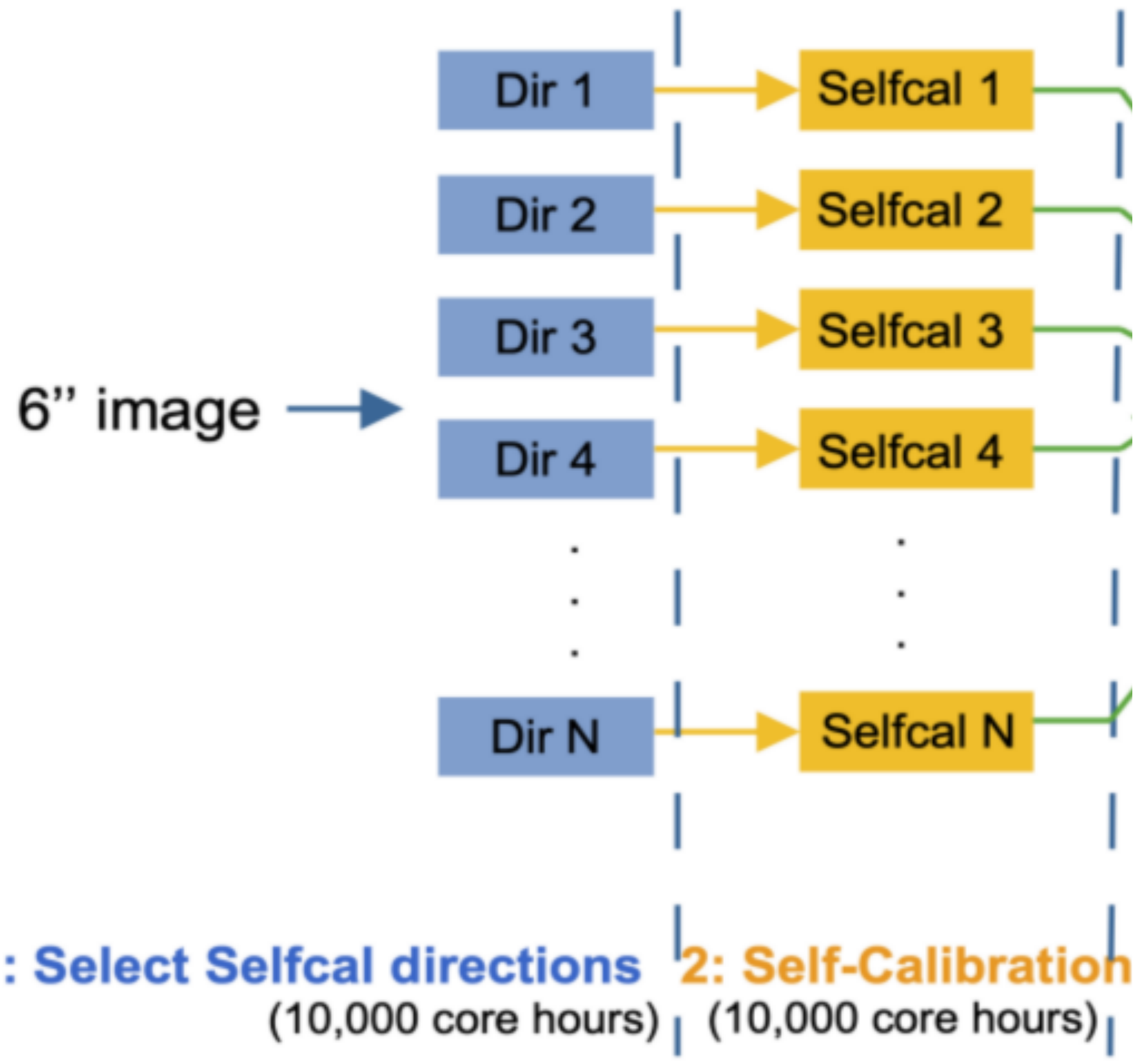
Subtract the data from this region (gridding+degridding)

.ms files

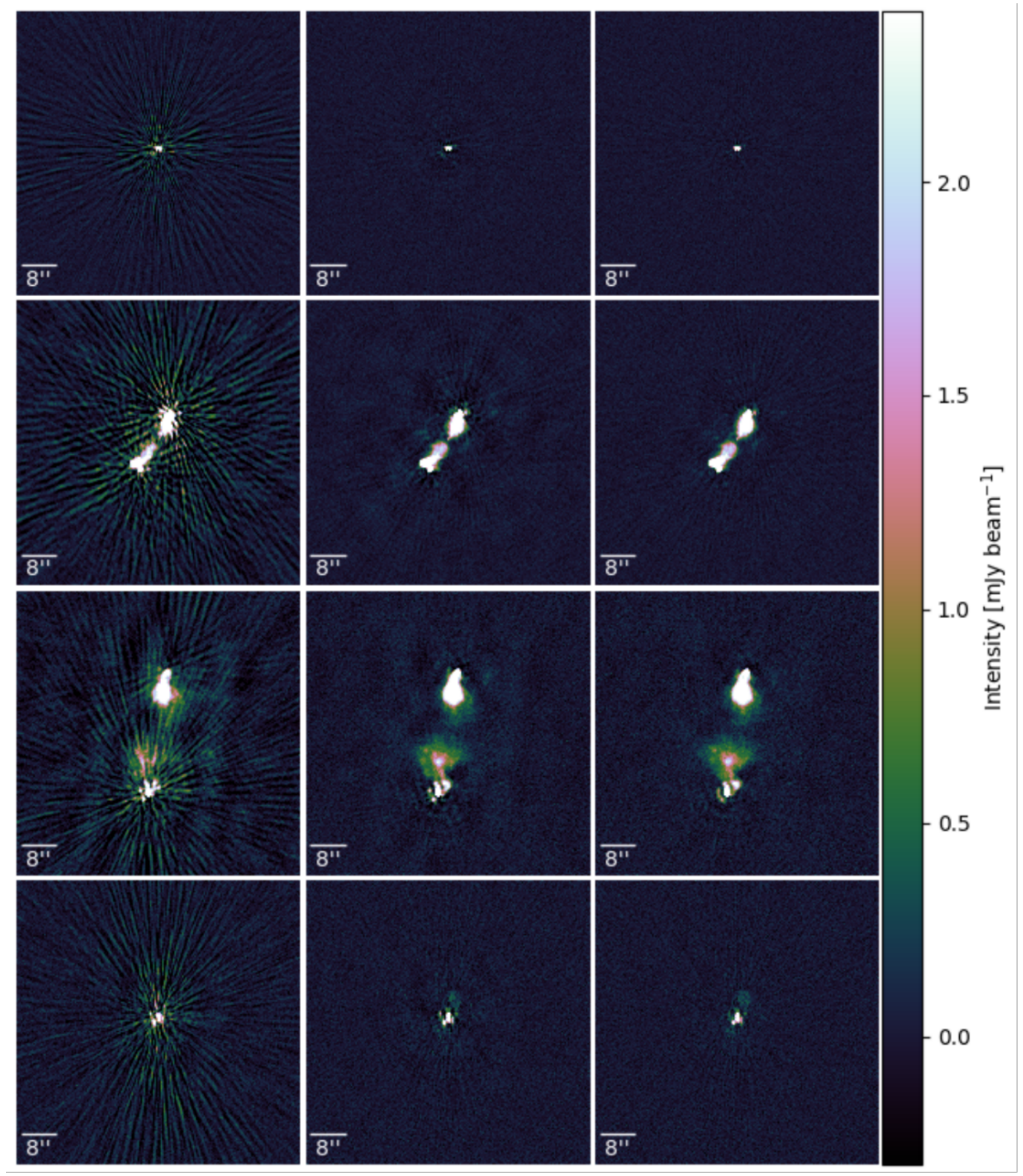
Image size chosen within 1*FWHM for maximum sensitivity

4. 1” imaging strategy with International LoFAR

Challenge 1: 1) select *enough* calibrators in the field

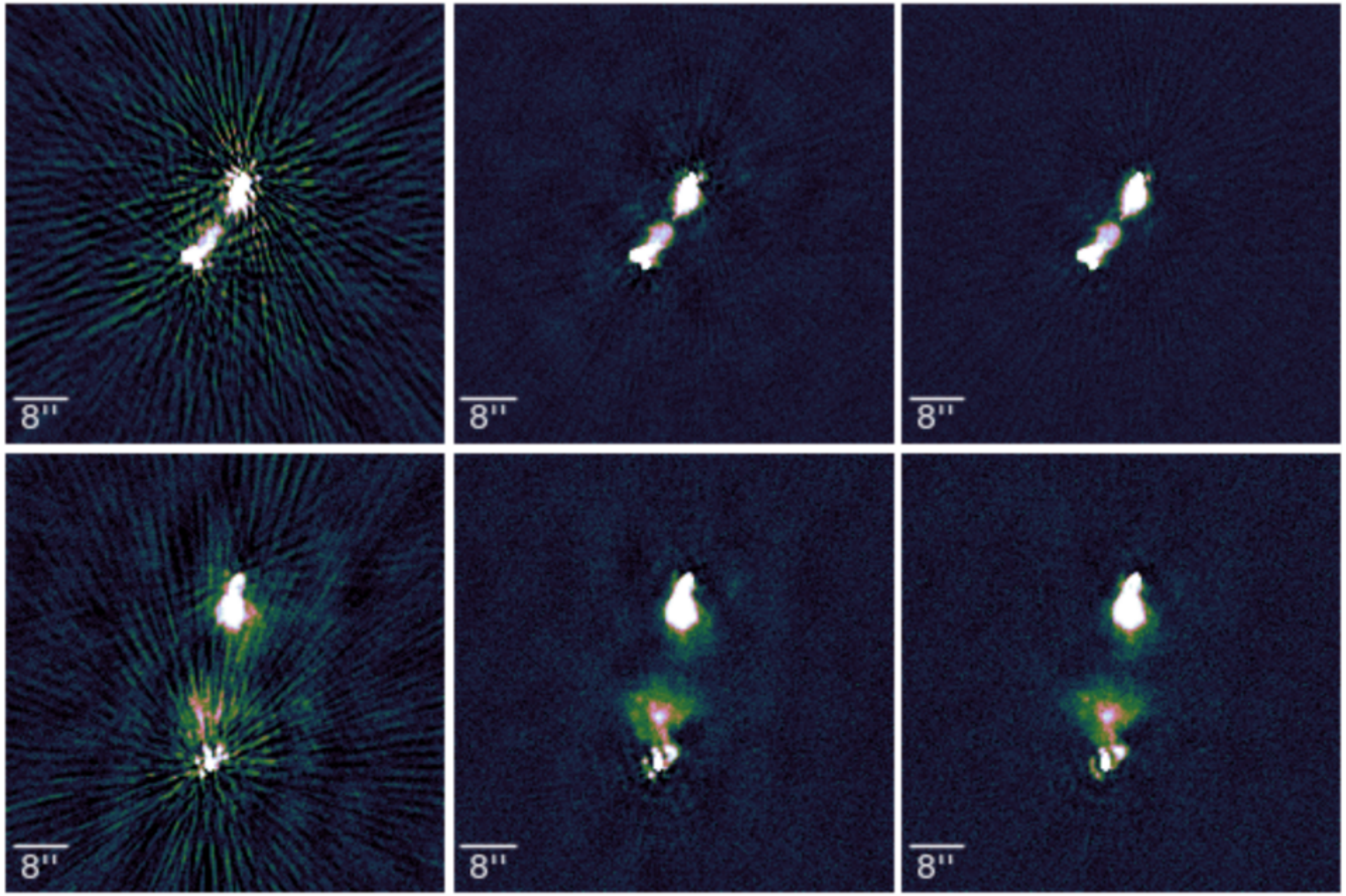


Direction-independent self-calibration:
Cycle 0, 2 and 4 (left to right)



4. 1'' imaging strategy with International LoFAR

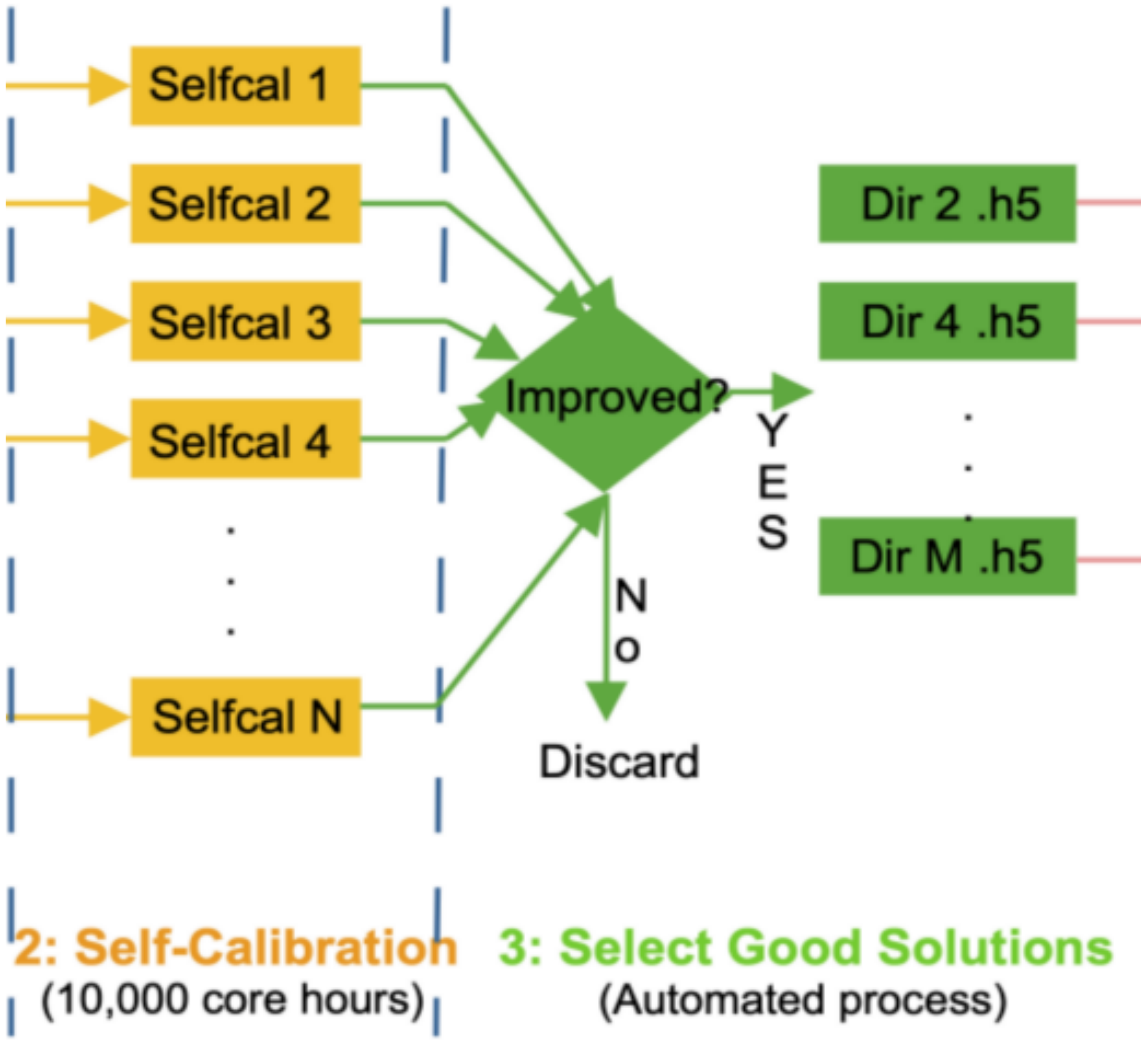
Direction-independent self-calibration:
Cycle 0, 2 and 4 (left to right)



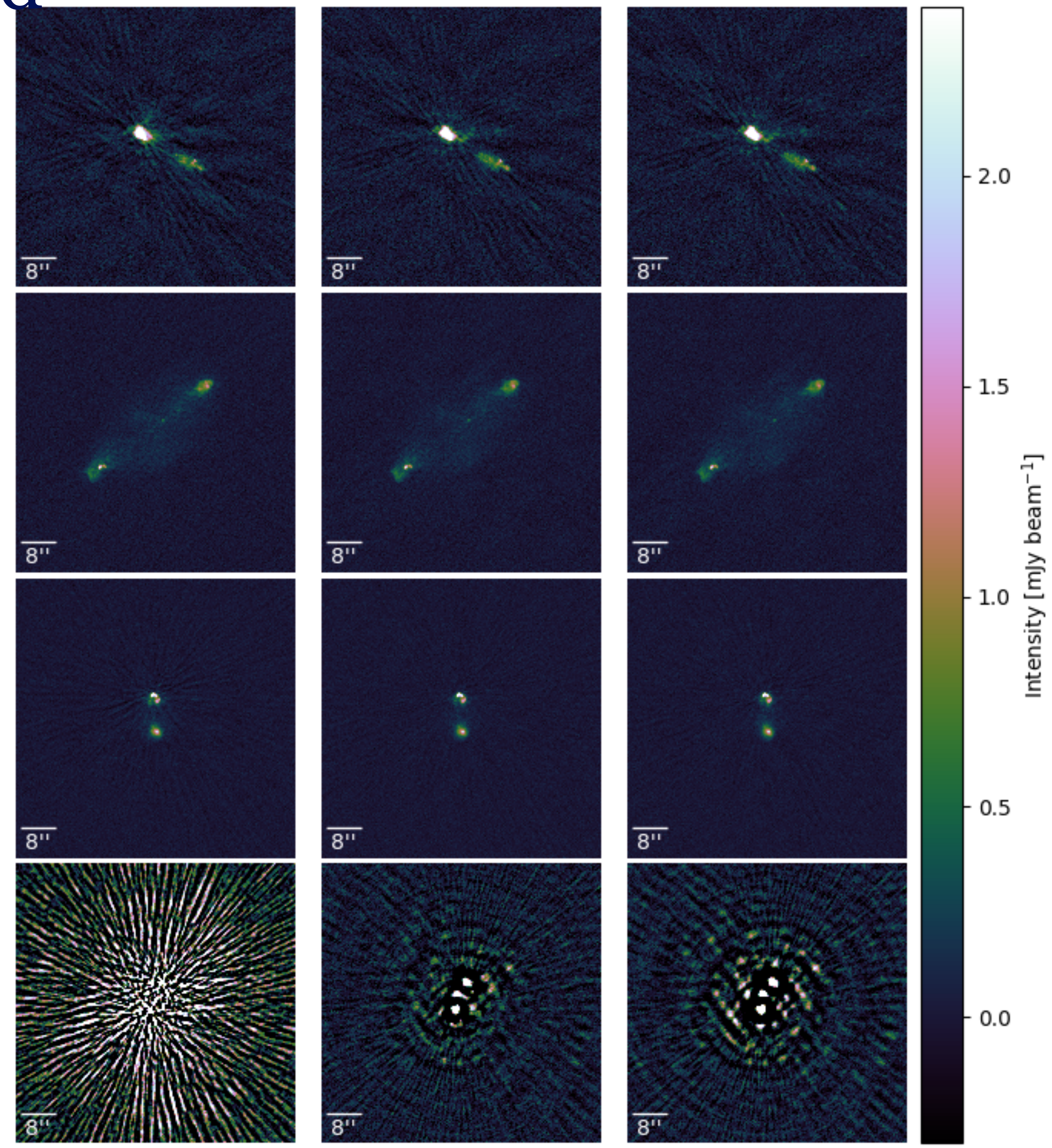
The self-calibration performs well, so it would work well for the nearby region during direction-independent self-calibration.

4. 1" imaging strategy with International LoFAR

Challenge 1: 2) select *good* calibrators in the field

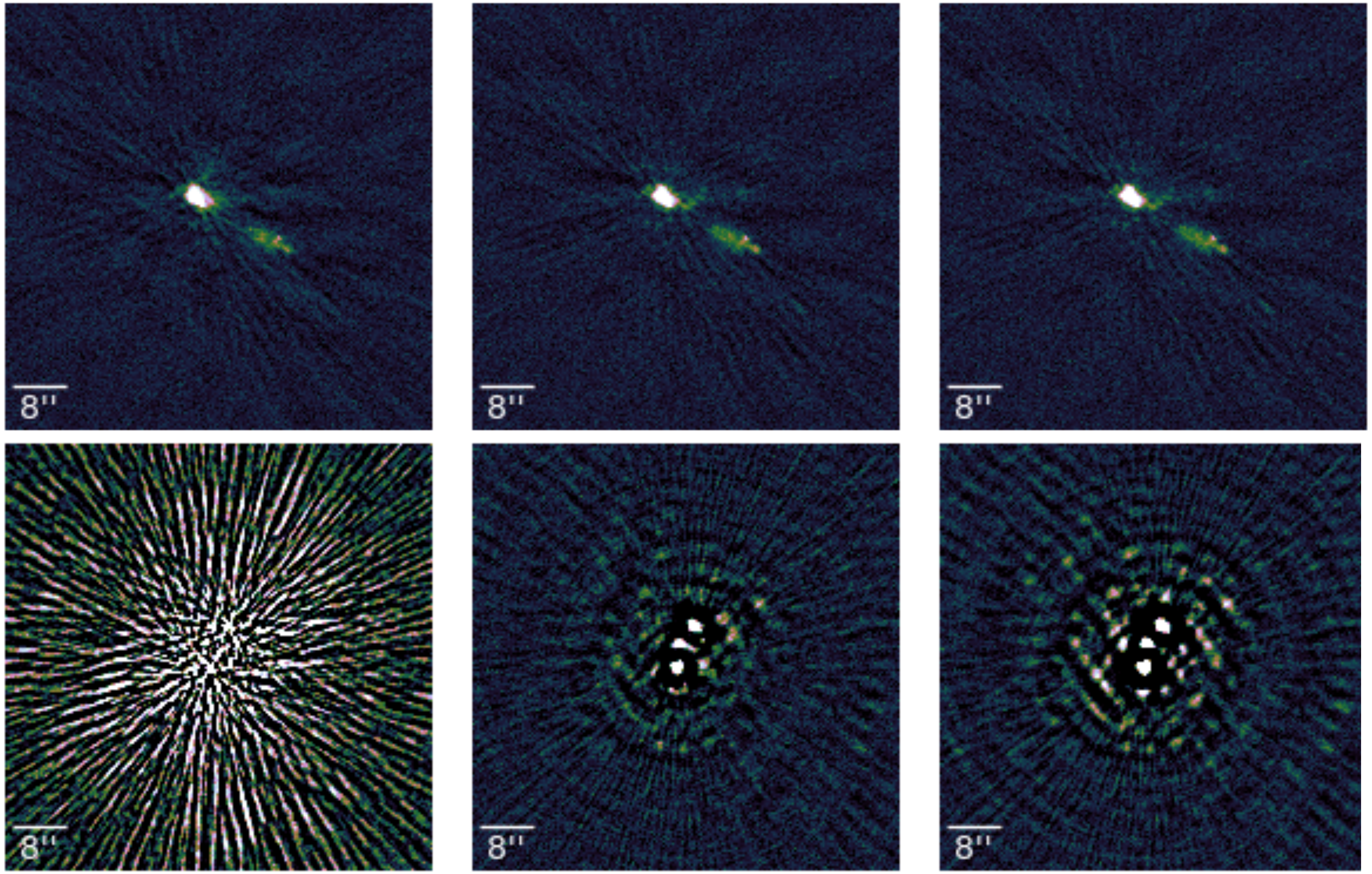


Direction-independent self-calibration:
Cycle 0, 4 and 8 (left to right)



4. 1” imaging strategy with International LoFAR

Direction-independent self-calibration:
Cycle 0, 4 and 8 (left to right)



The self-calibration doesn’t perform well, so it would not be a good calibrator for direction-independent self-cal.

Reason: not enough signal on long baselines, as the source become resolved in higher resolution.

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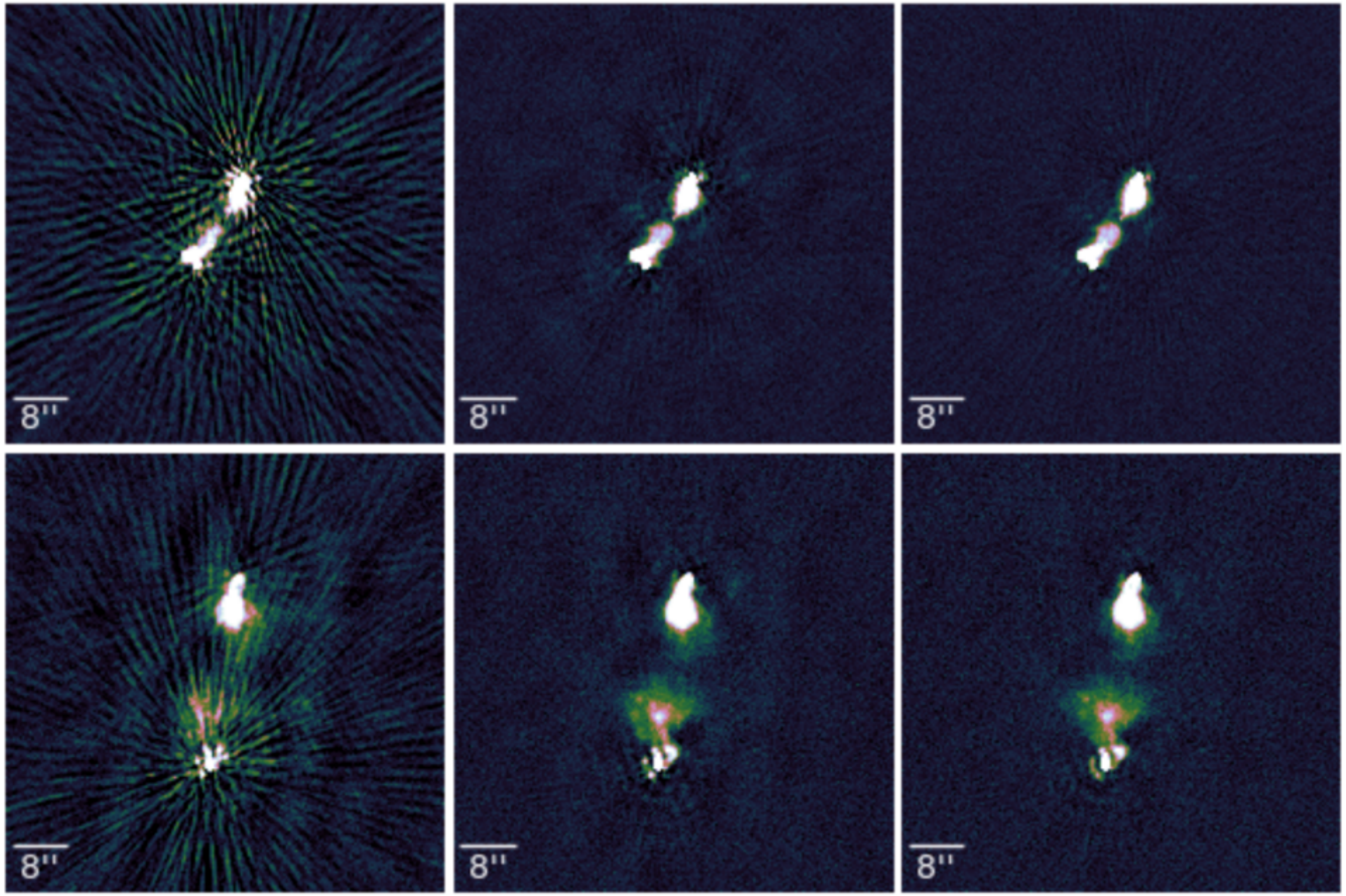
4. 1” imaging strategy with International LoFAR

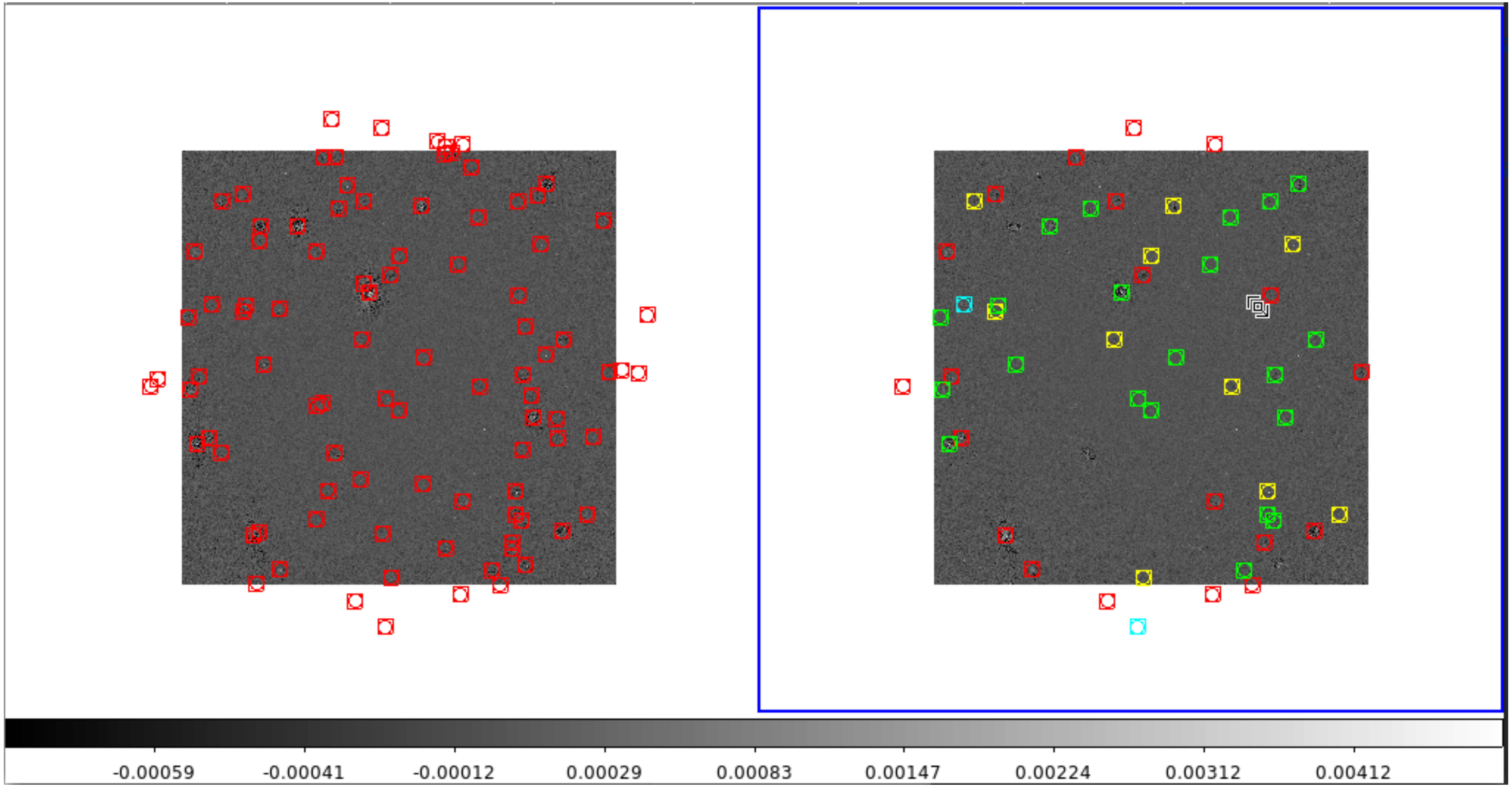
Direction-independent self-calibration:
Cycle 0, 2 and 4 (left to right)



The self-calibration performs well, so it would work well for the nearby region during direction-independent self-calibration.

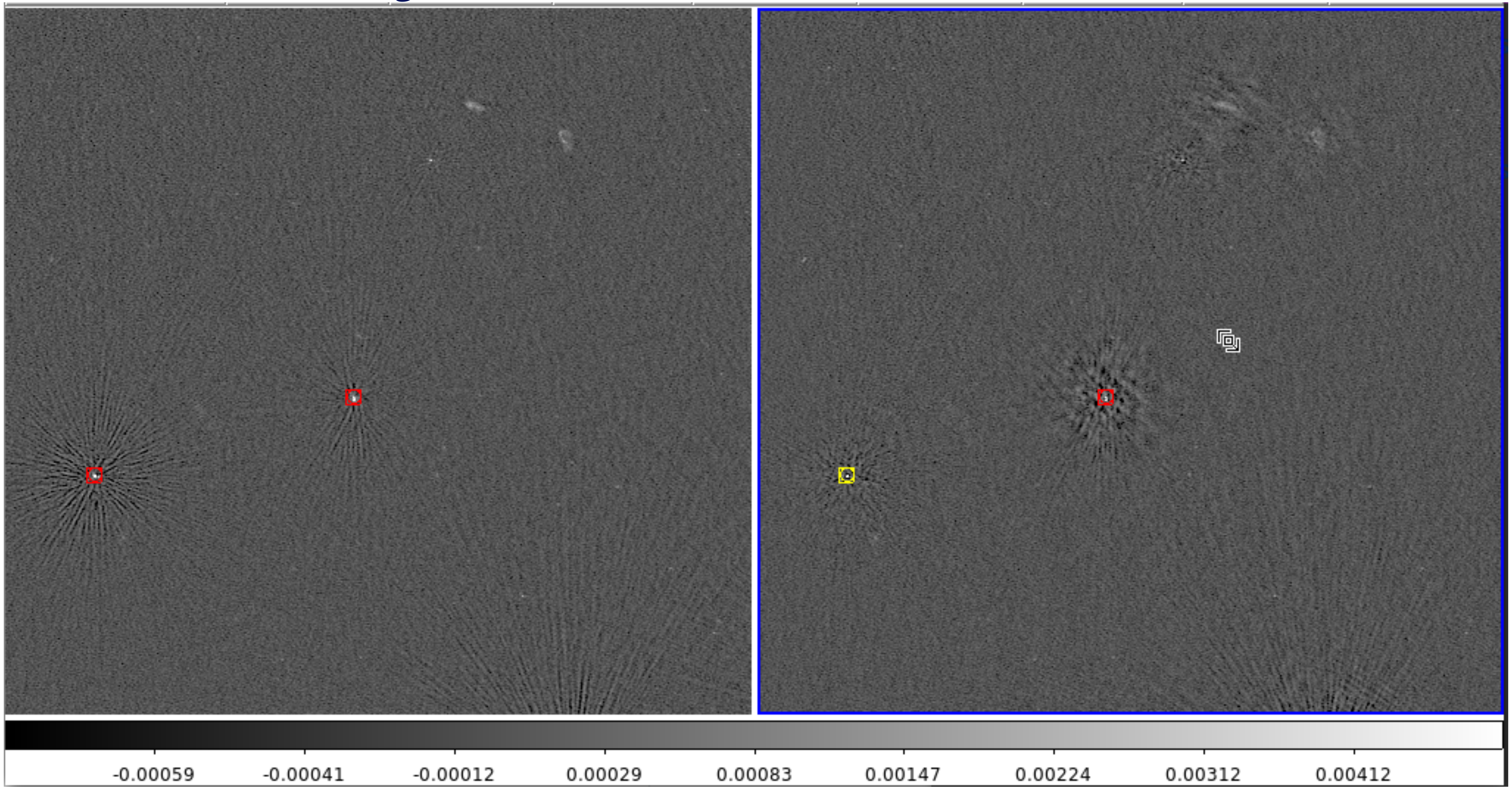
4. 1” imaging strategy with International LoFAR

What if we select *not so good* calibrators in the field



4. 1" imaging strategy with International LoFAR

What if we select *not so good* calibrators in the field



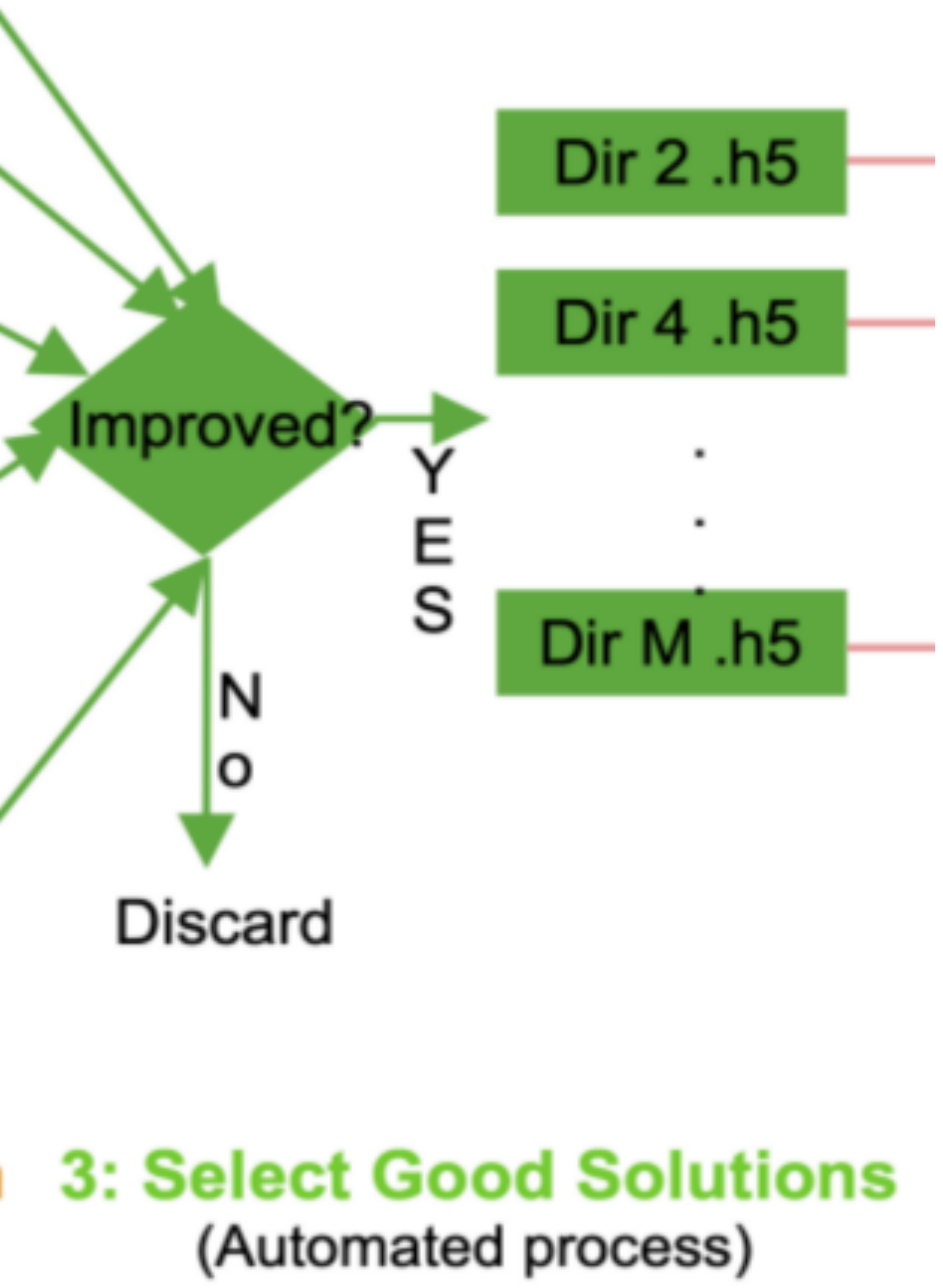
4. 1” imaging strategy with International LoFAR

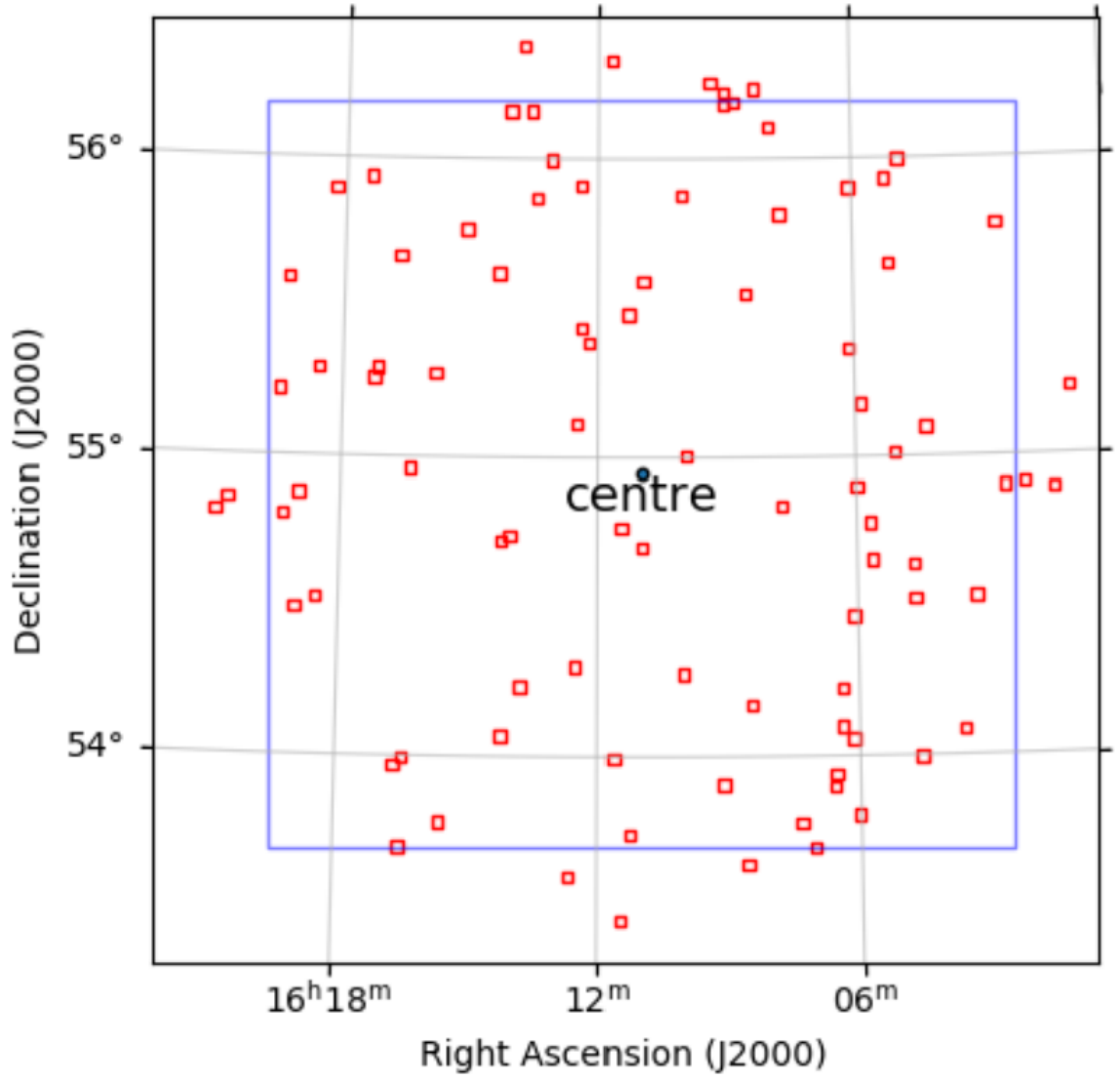
What if we select *not so good* calibrators in the field

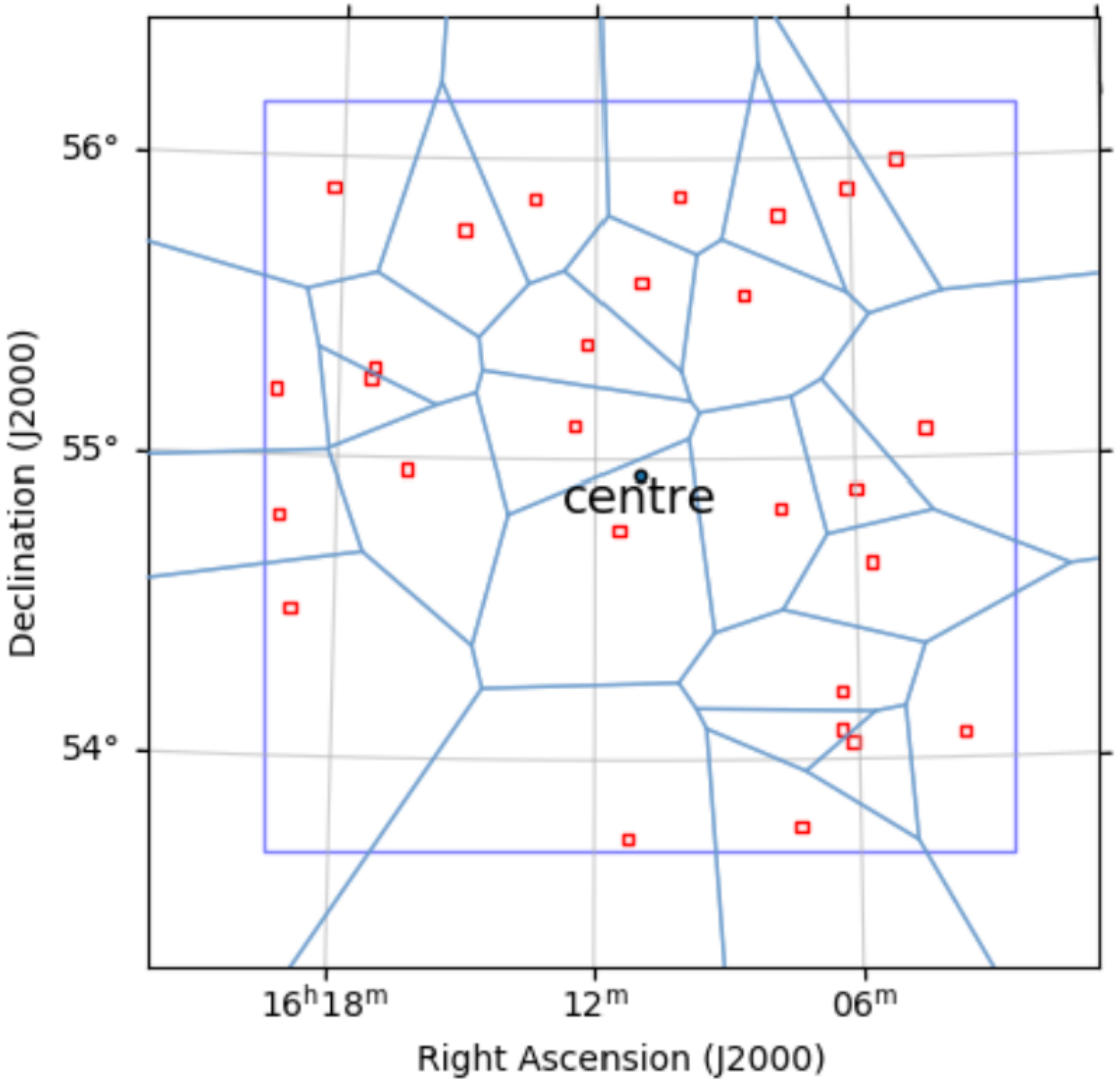
Don’t…

4. 1” imaging strategy with International LoFAR

Challenge 1: select calibrators in the field

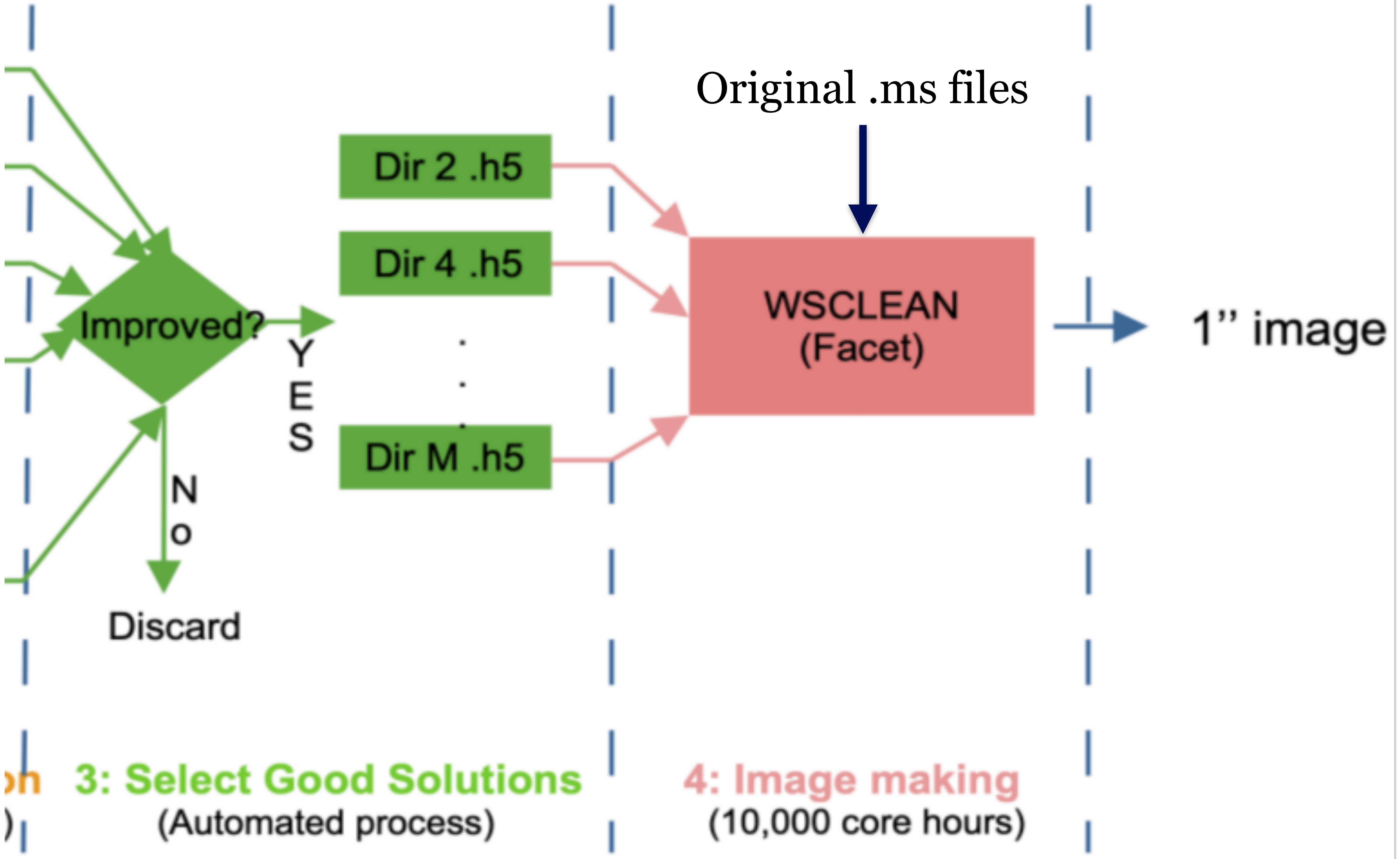






4. 1” imaging strategy with International LoFAR

Challenge 2: Make big direction-dependent-corrected image



Next Step:

WSCLEAN (facet module)
1” image (25,000^2)

WSCLEAN (facet module)
0.3” image* (75,000^2)

* different technique compared to Sweijen F., et al. (2022)

5. Next steps

- Test other fields on the existing 1" imaging automated workflow
  - **Lockman Hole**: Sweijen et al. 2022
  - **ELAIS-N1**: H. Ye / J. de Jong (Leiden)
  - **Boötes**: E. Escott (Durham)
  - **NEP** – M. Bondi (INAF)

- Experiment with 0.3" imaging with WSCLEAN
  - R. van Weeren, J. de Jong (Leiden), ASTRON, SURF

Reference

Morabito, L., et al. 2022, A&A, 658, A1
Shimwell T., et al. 2019, A&A, 622, A1
Shimwell T., et al. 2022, A&A, 659, A1
Sweijen F., et al. 2022, Nature Astronomy, 6, 350

Thank you!

Our image:

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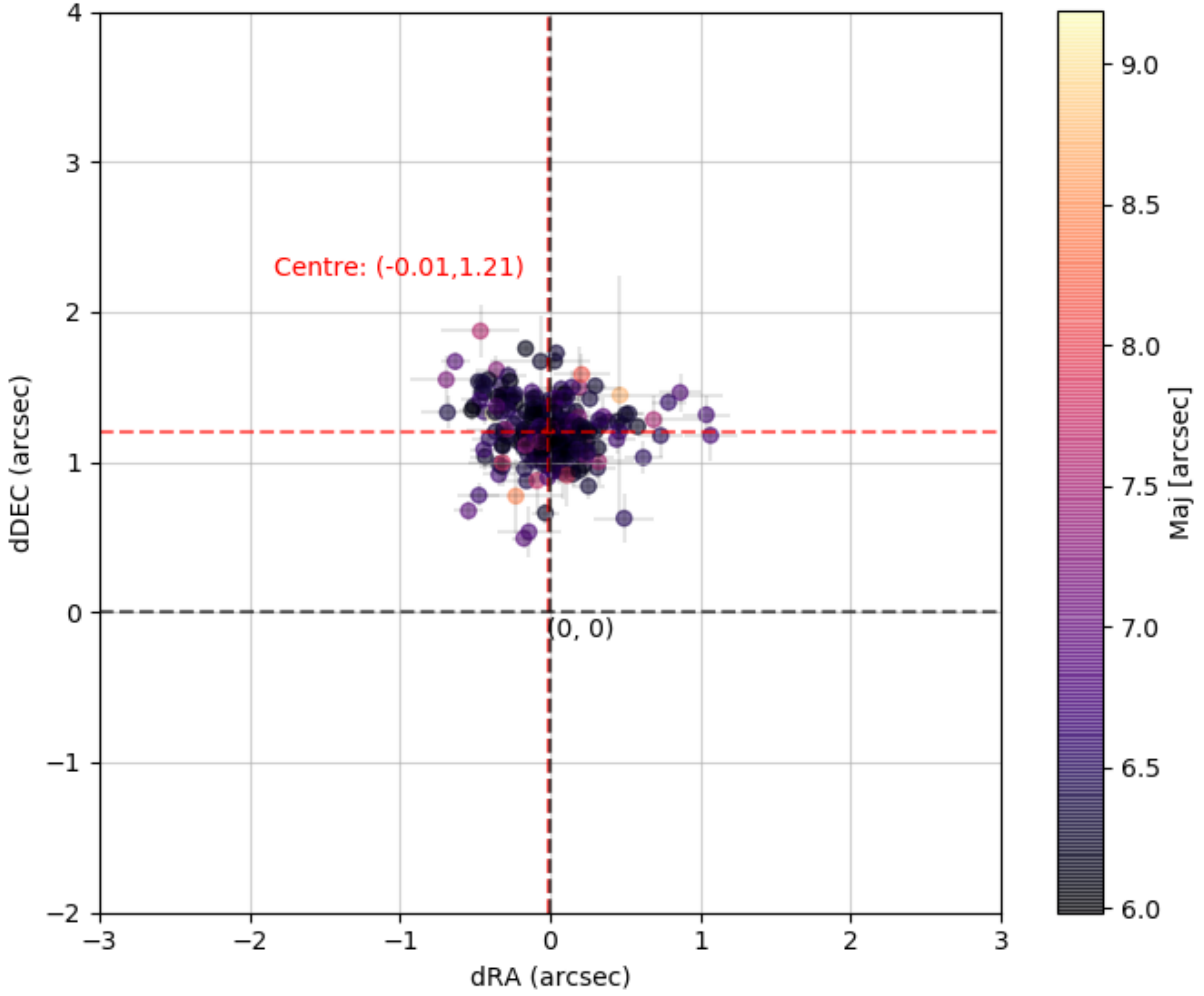
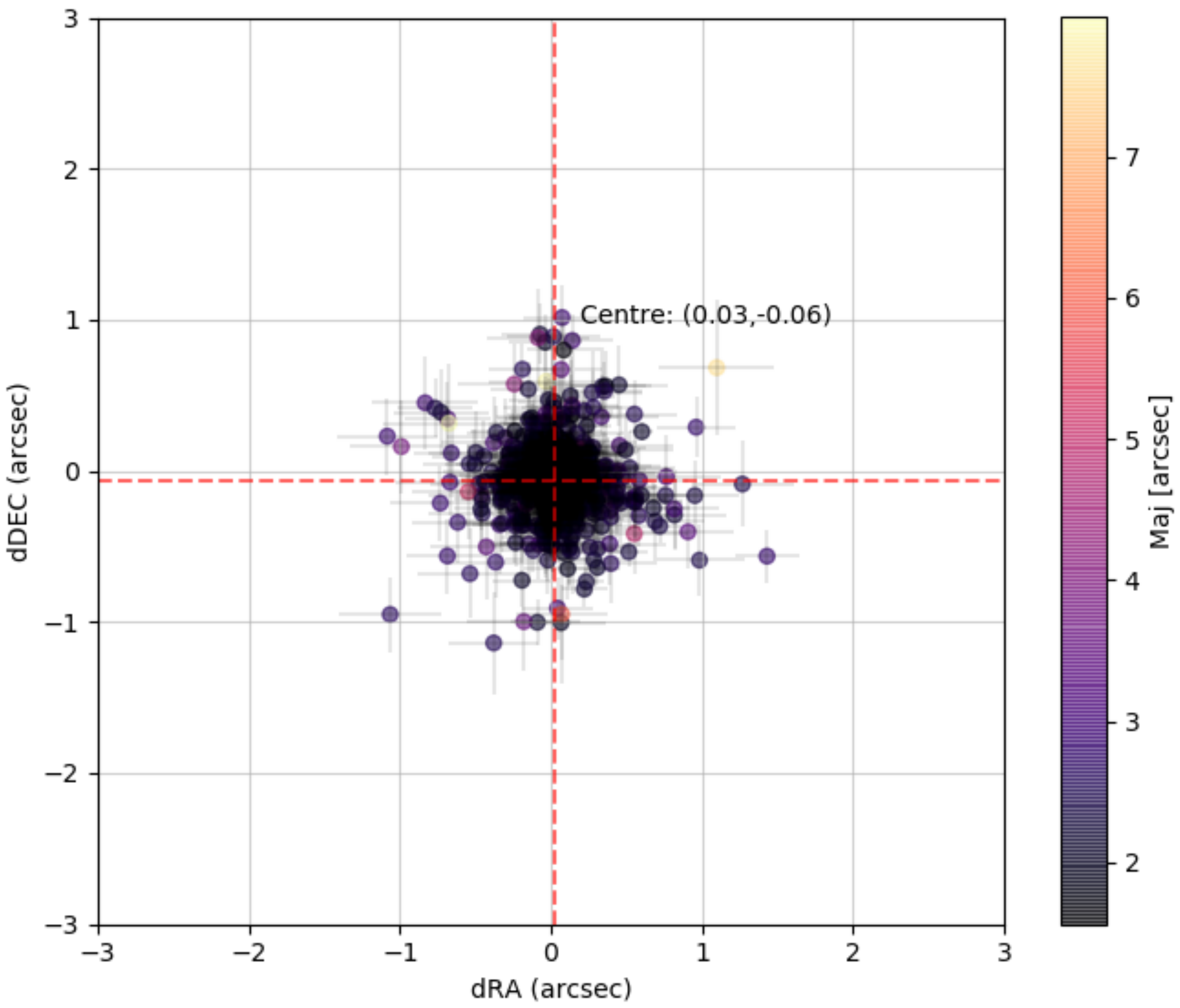
Astrometry: dRA = RA_1” - RA_6”(radio); dDEC = DEC_1” - DEC_6”

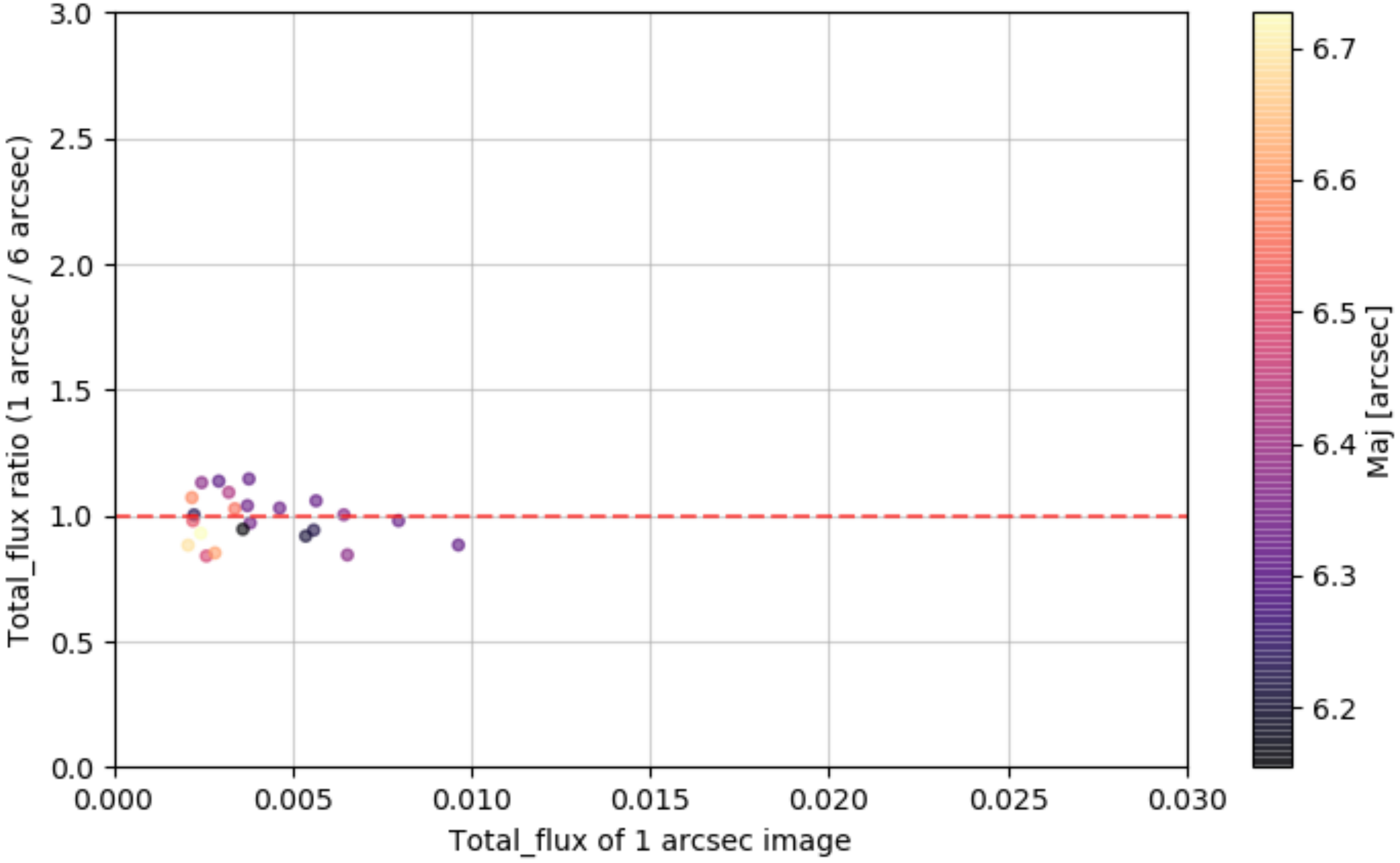


Astrometry: dRA = RA_1” - RA_optical; dDEC = DEC_1” - DEC_optical



The median astrometric offsets are within 1.2”, the pixel size of our image, while the pixel size of the optical images are 0.2”.

Flux: Total_flux_1” / Total_flux_6”



Cross-matched 1-1 compact sources

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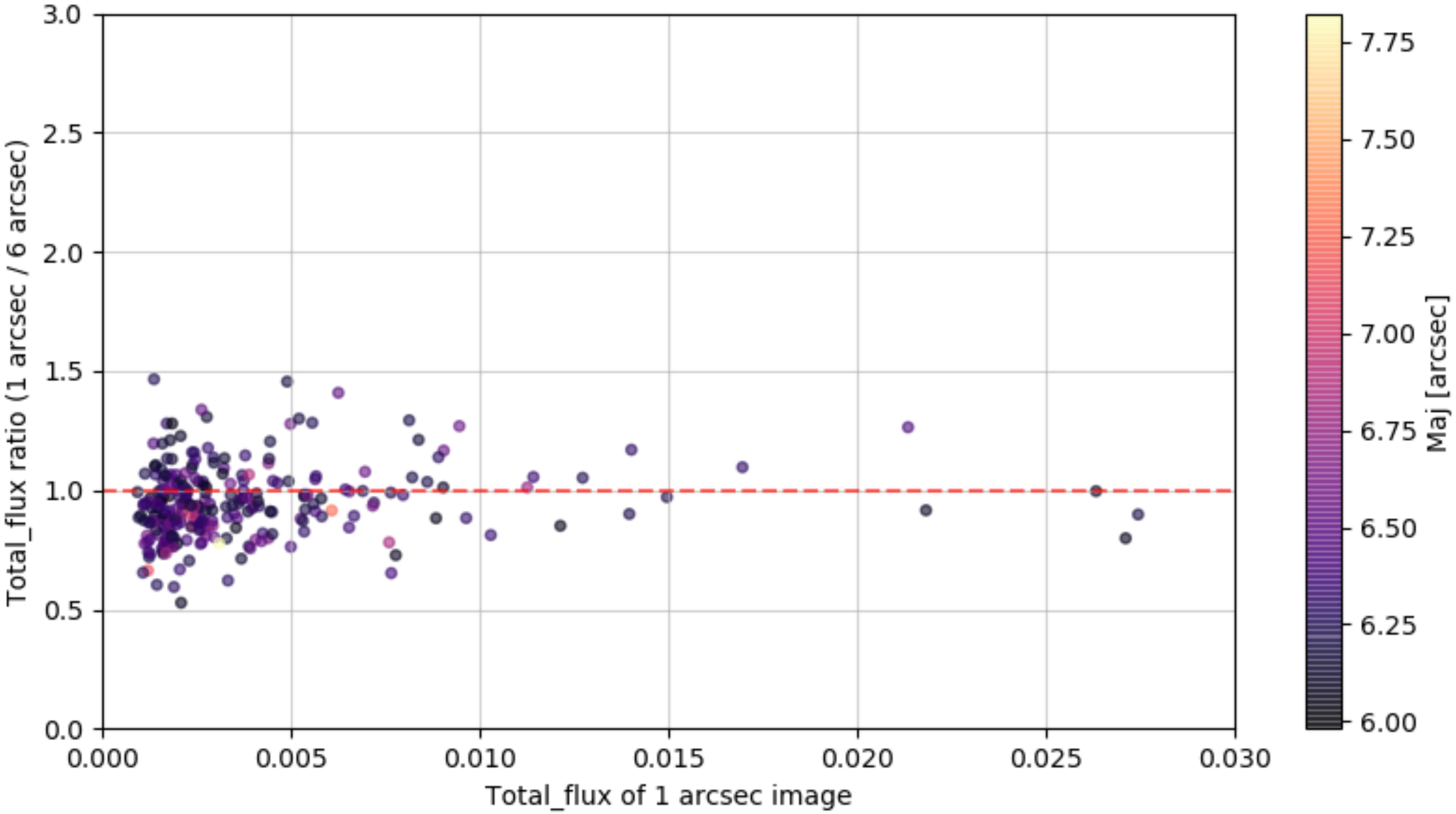
Flux: Total_flux_1” / Total_flux_6”



Cross-matched compact sources