Into the depth

Deepest 0.3” wide-field images with LOFAR

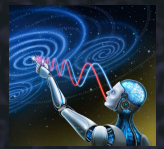
Name:
Jurjen de Jong

Collaborators:
Reinout van Weeren, Frits Sweijen, Raymond Oonk et al.

Universiteit Leiden
The Netherlands

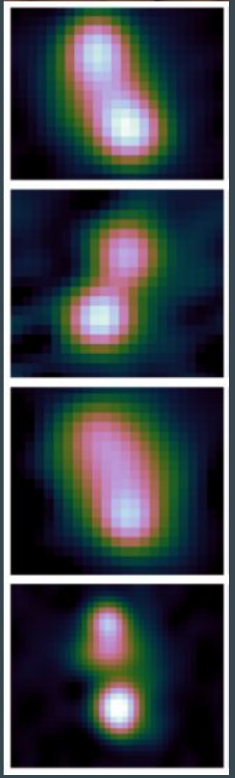
Sterrewacht Leiden

SURF

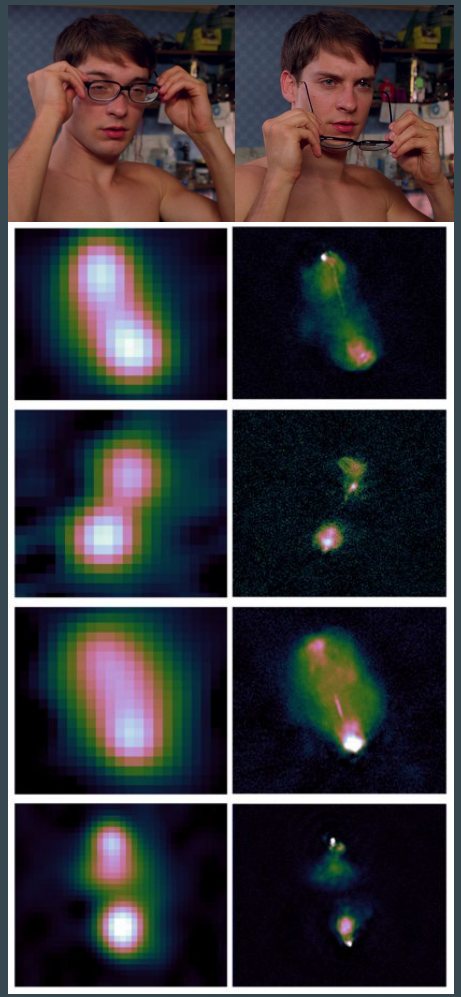


LFM 2024

LOFAR Dutch (~6”)

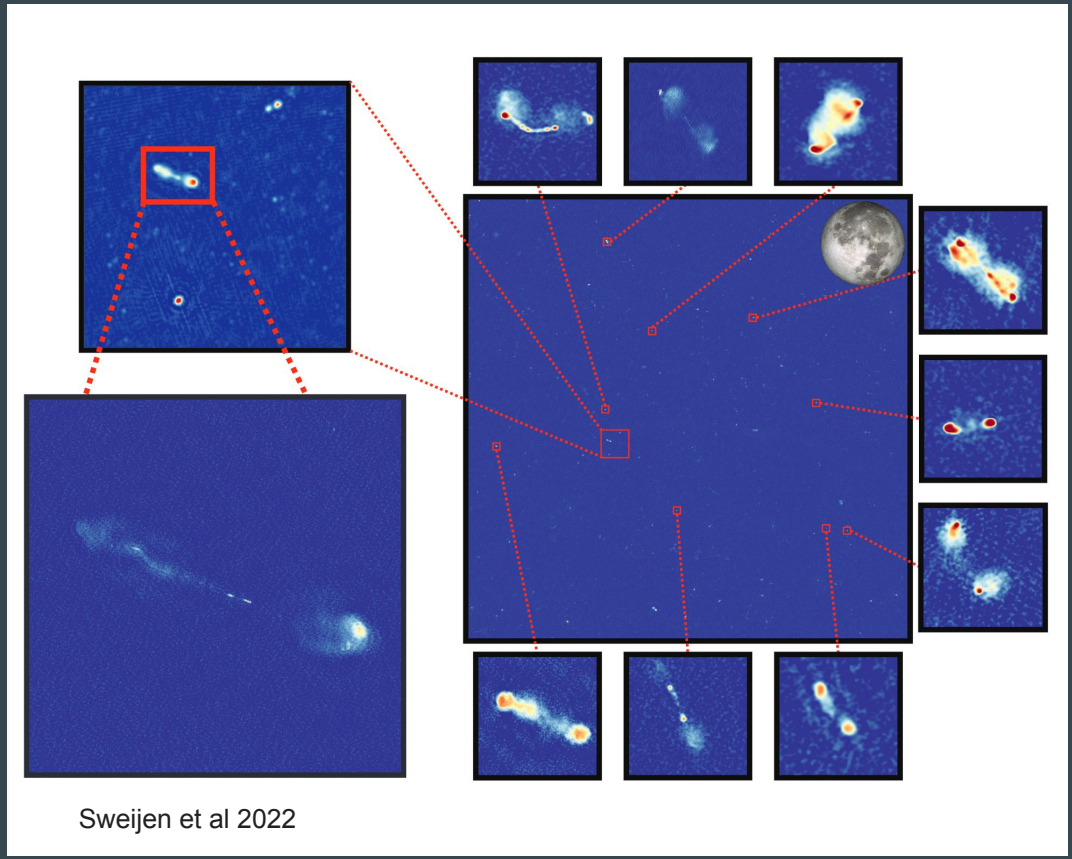


LOFAR International (~0.3”)



Lockman Hole 0.3” with 8 hours data

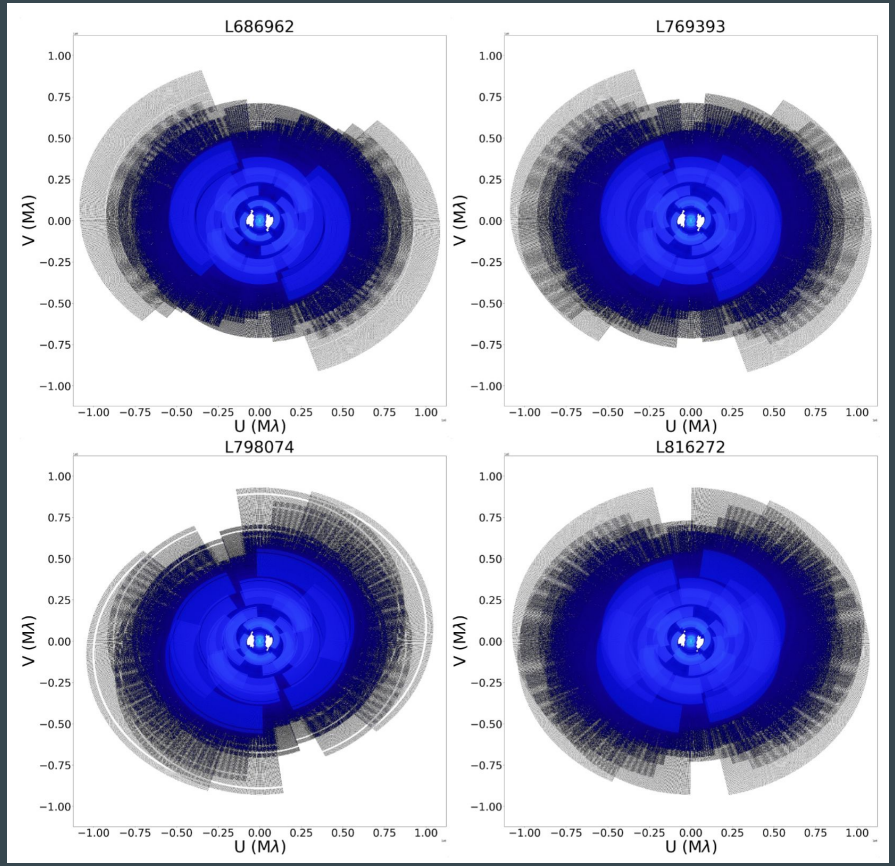
- ★ 2.5 x 2.5 degrees
- ★ ~8 billion pixels
- ★ ~2500 sources
- ★ ~30 μJy/beam



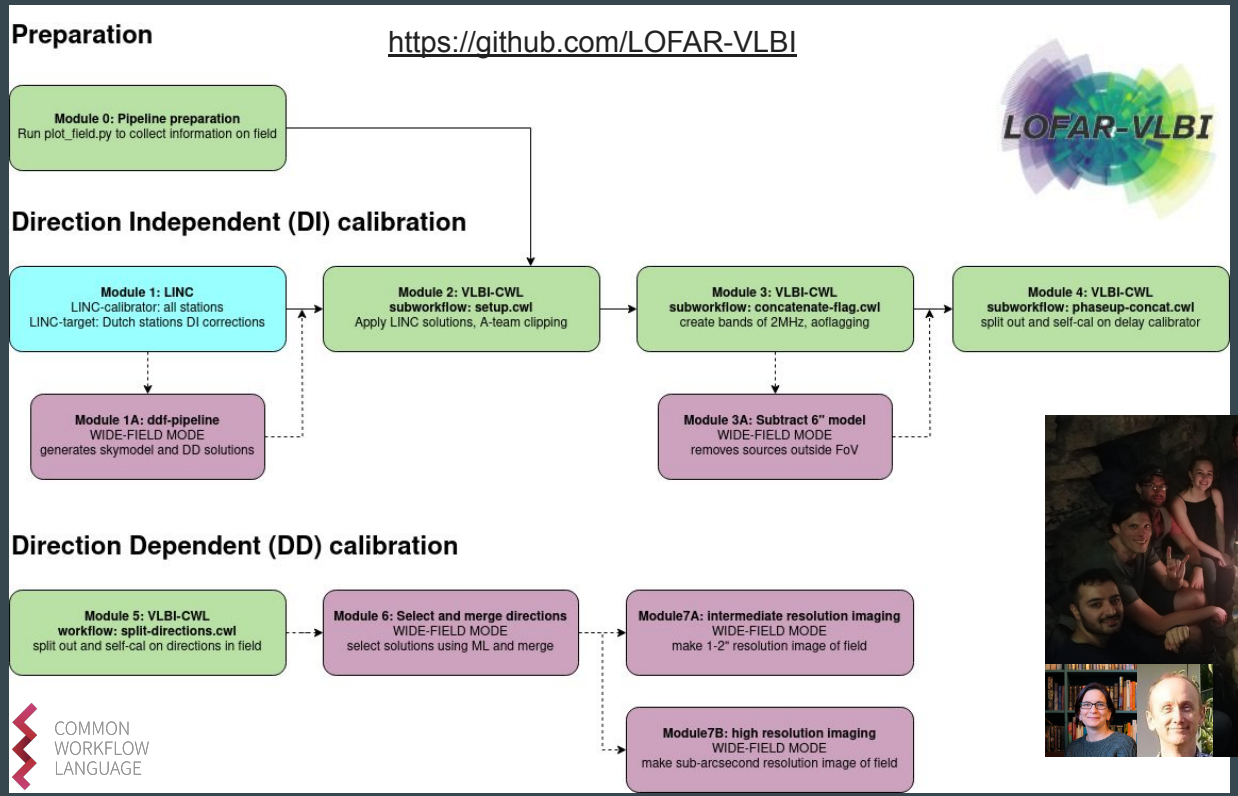
Sweijen et al 2022

ELAIS-N1 with 32 hours

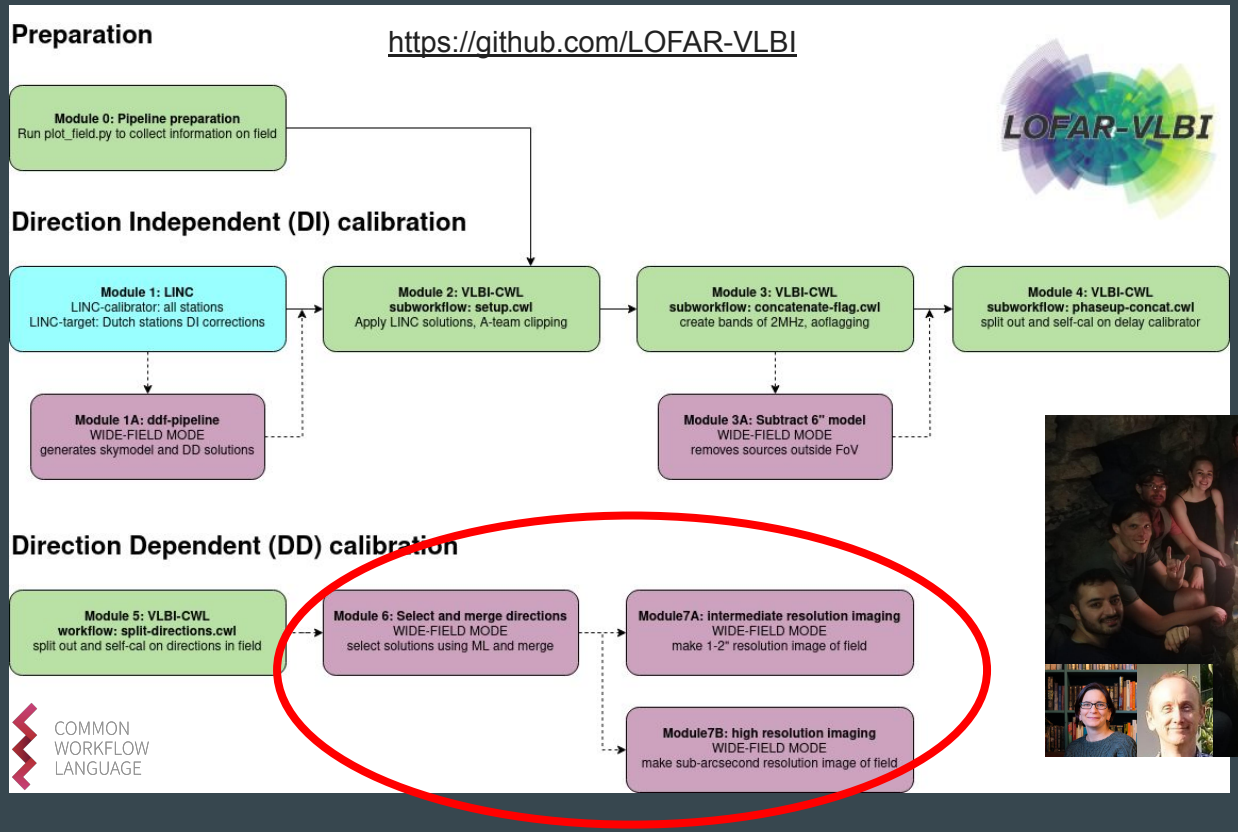
- ★ 4 observations
  - 26-11-2018
  - 24-05-2020
  - 14-11-2020
  - 13-5-2021
- ★ 2 times deeper
- ★ Large data volume: ~12 TB



Strategy


Preparation
https://github.com/LOFAR-VLBI
Module 0: Pipeline preparation
Run plot_field.py to collect information on field
LOFAR-VLBI
Direction Independent (DI) calibration
Module 1: LINC
LINC-calibrator: all stations
LINC-target: Dutch stations DI corrections
Module 2: VLBI-CWL
subworkflow: setup.cwl
Apply LINC solutions, A-team clipping
Module 3: VLBI-CWL
subworkflow: concatenate-flag.cwl
create bands of 2MHz, aoflagging
Module 4: VLBI-CWL
subworkflow: phaseup-concat.cwl
split out and self-cal on delay calibrator
Module 1A: ddf-pipeline
WIDE-FIELD MODE
generates skymodel and DD solutions
Module 3A: Subtract 6" model
WIDE-FIELD MODE
removes sources outside FoV
Direction Dependent (DD) calibration
Module 5: VLBI-CWL
workflow: split-directions.cwl
split out and self-cal on directions in field
Module 6: Select and merge directions
WIDE-FIELD MODE
select solutions using ML and merge
Module7A: intermediate resolution imaging
WIDE-FIELD MODE
make 1-2" resolution image of field
Module7B: high resolution imaging
WIDE-FIELD MODE
make sub-arcsecond resolution image of field
COMMON
WORKFLOW
LANGUAGE

Strategy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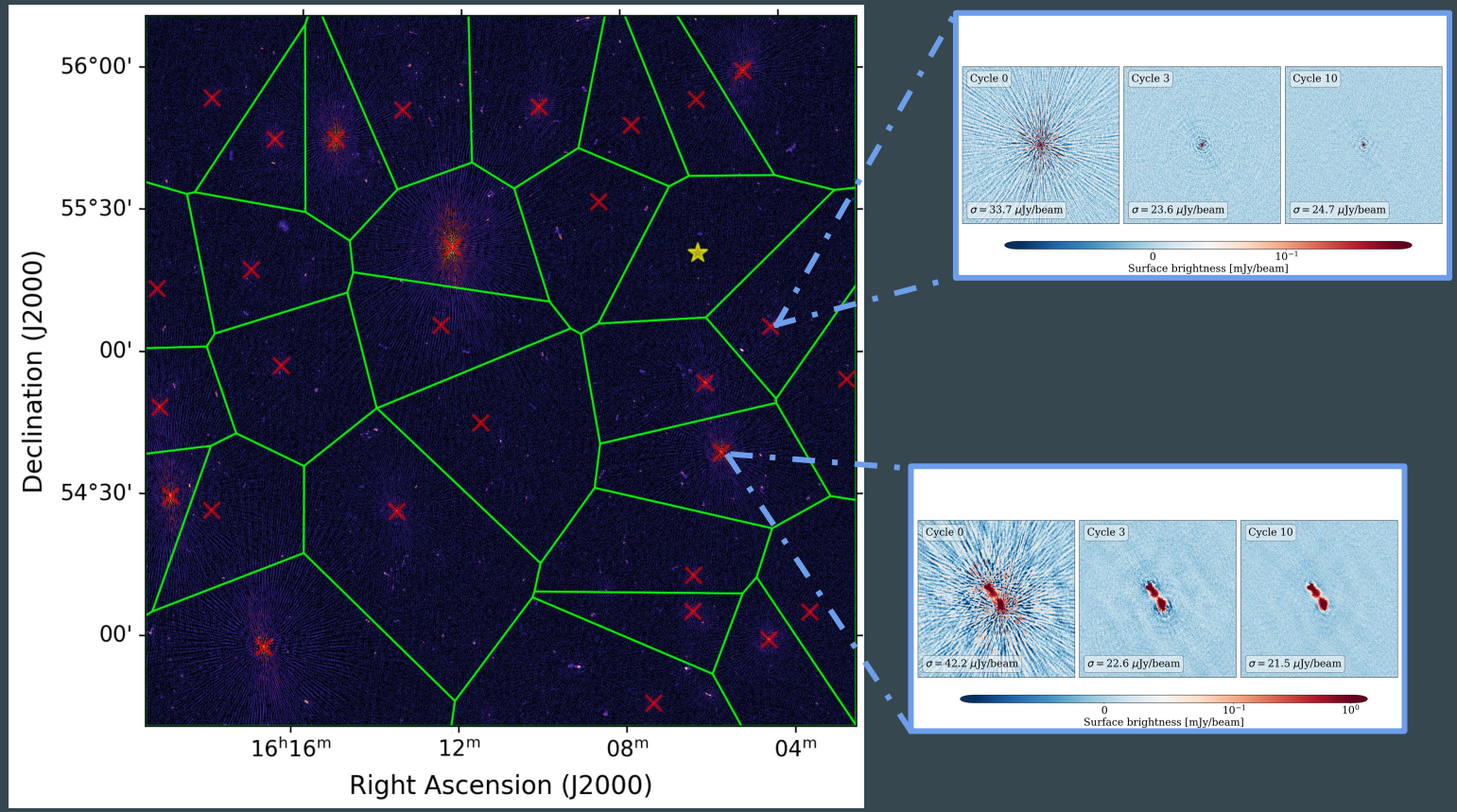
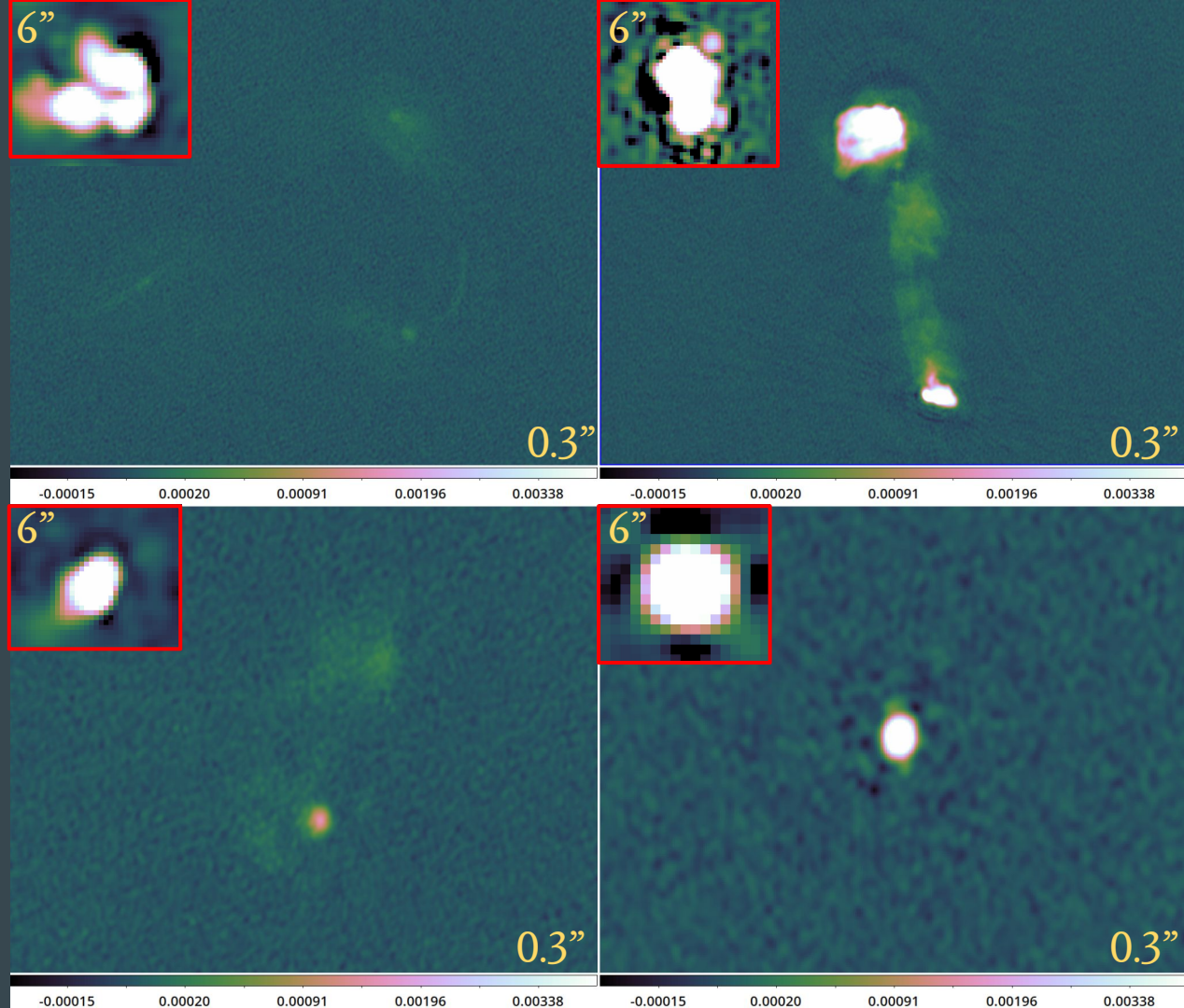
Facets and direction-dependent calibration



Automatic selection

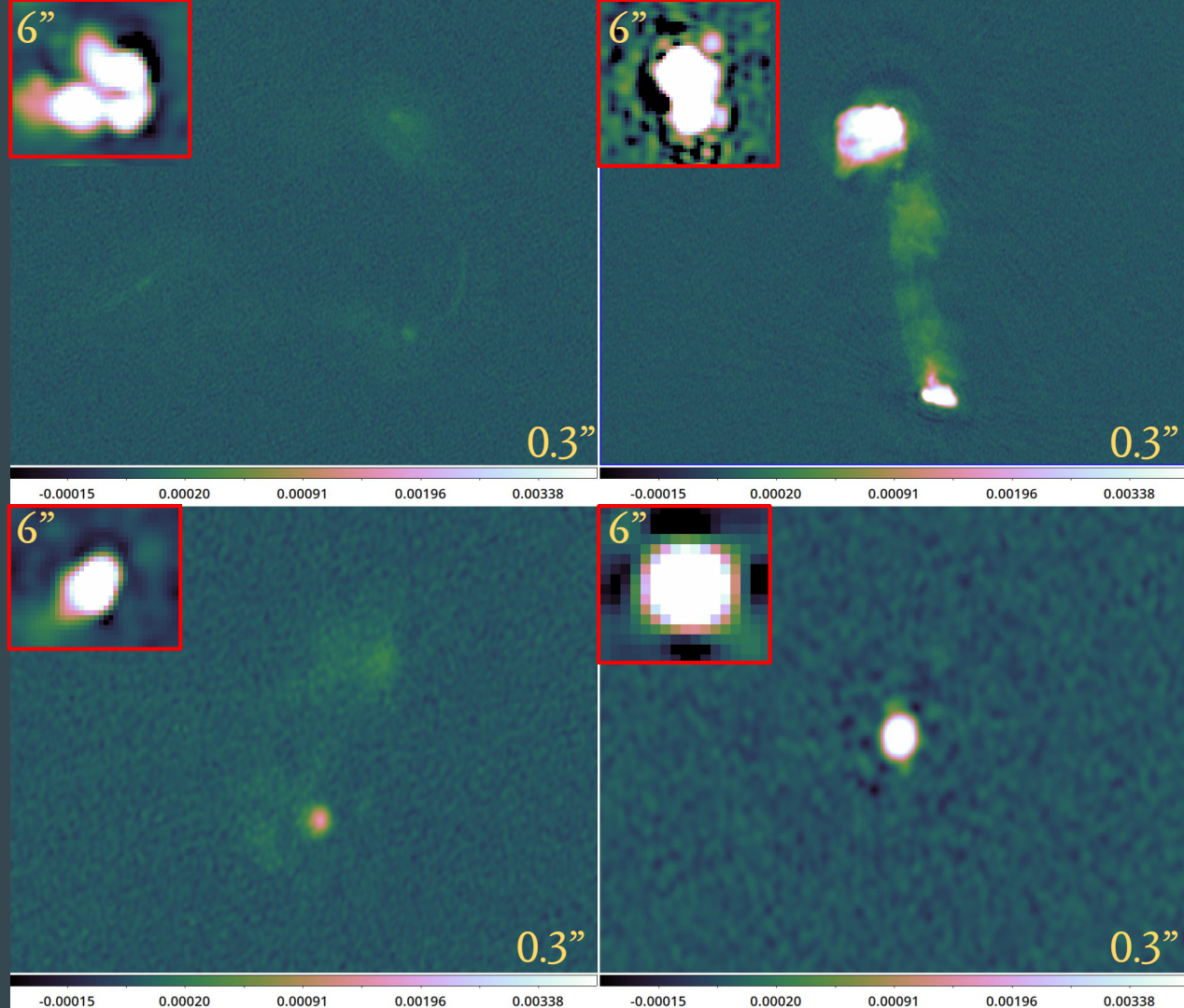
Need enough signal-to-noise at long baselines



Automatic selection

Need enough signal-to-noise at long baselines

Solution:
Phase noise measure with RR-LL polarisation



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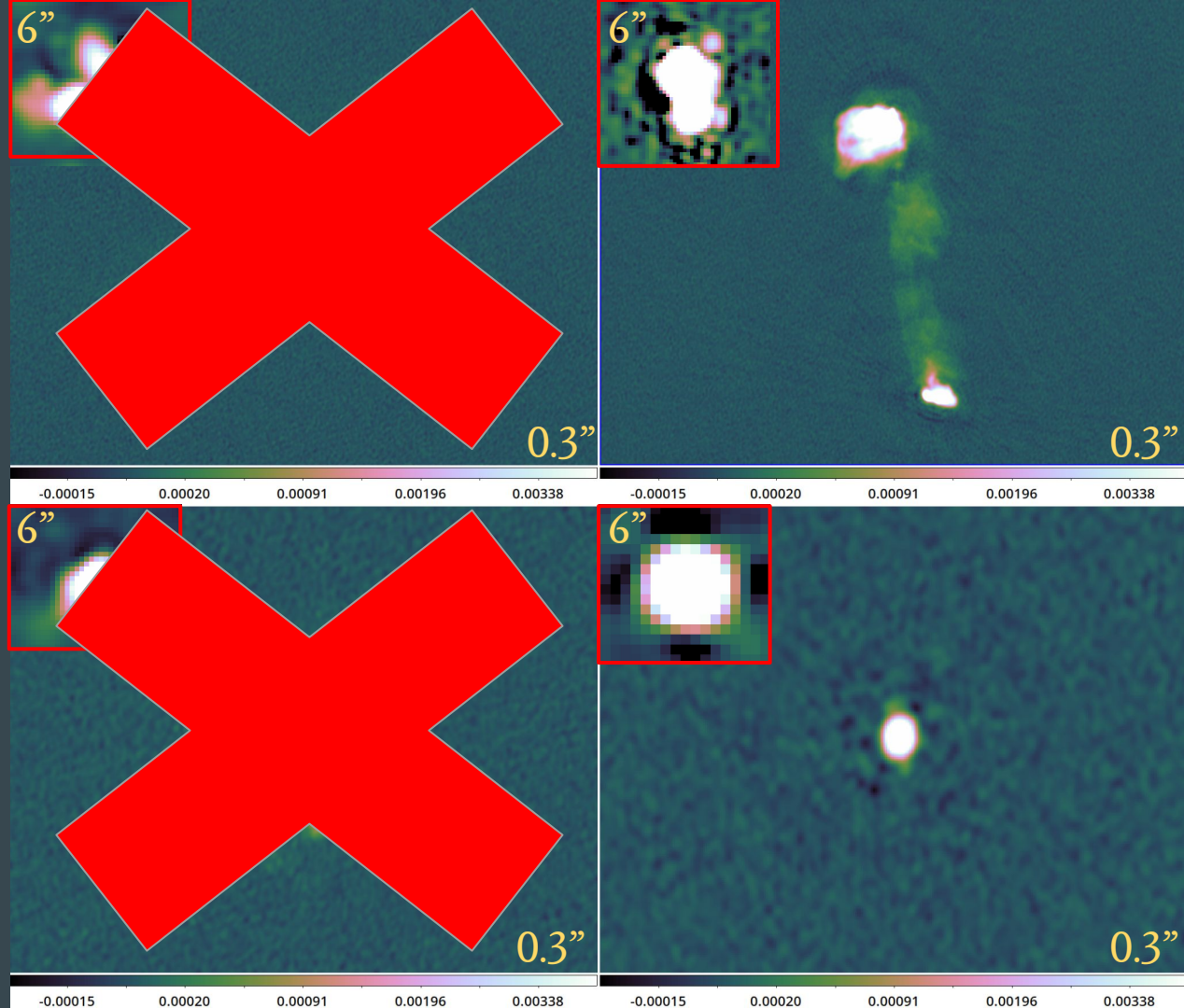
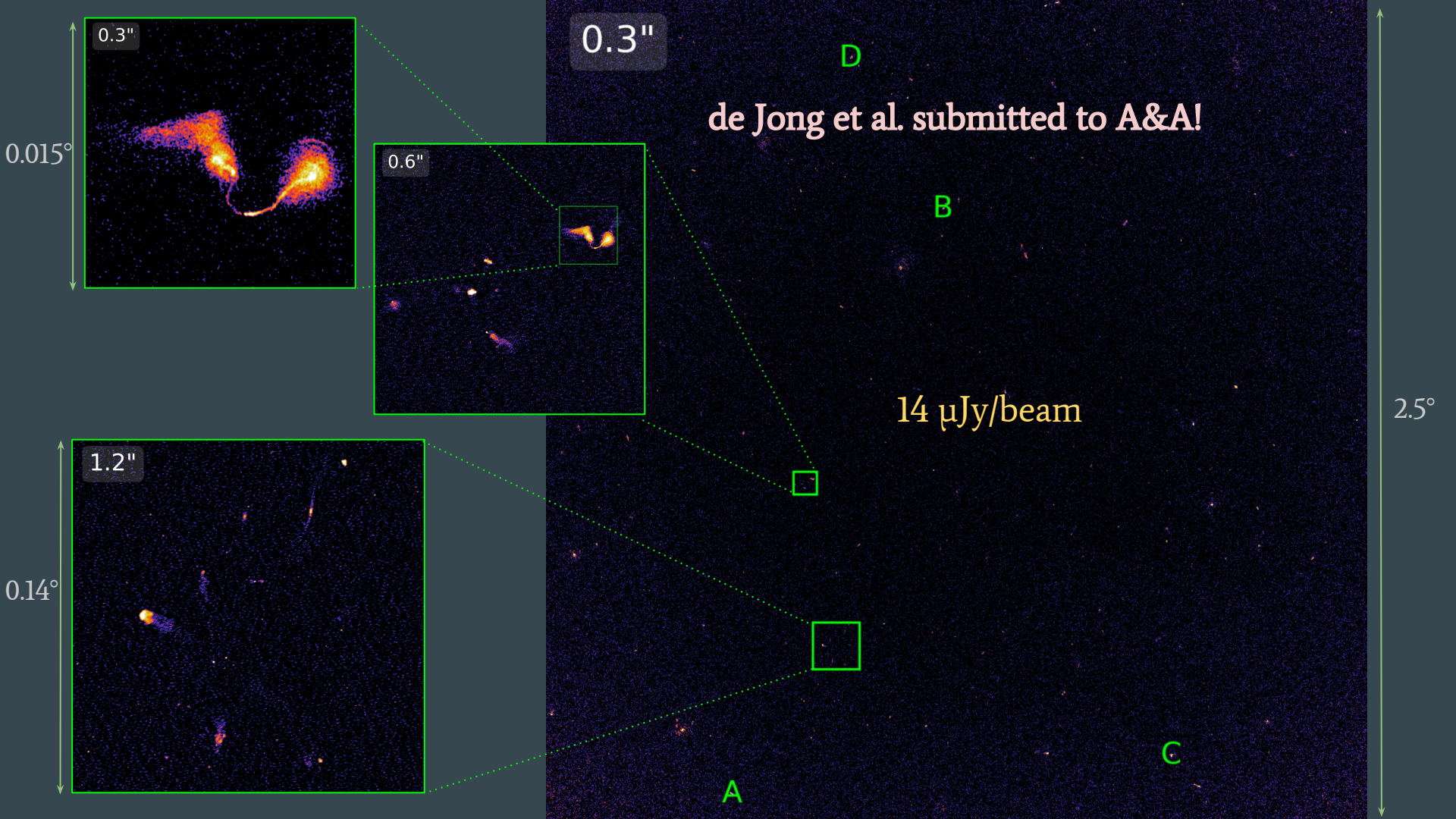
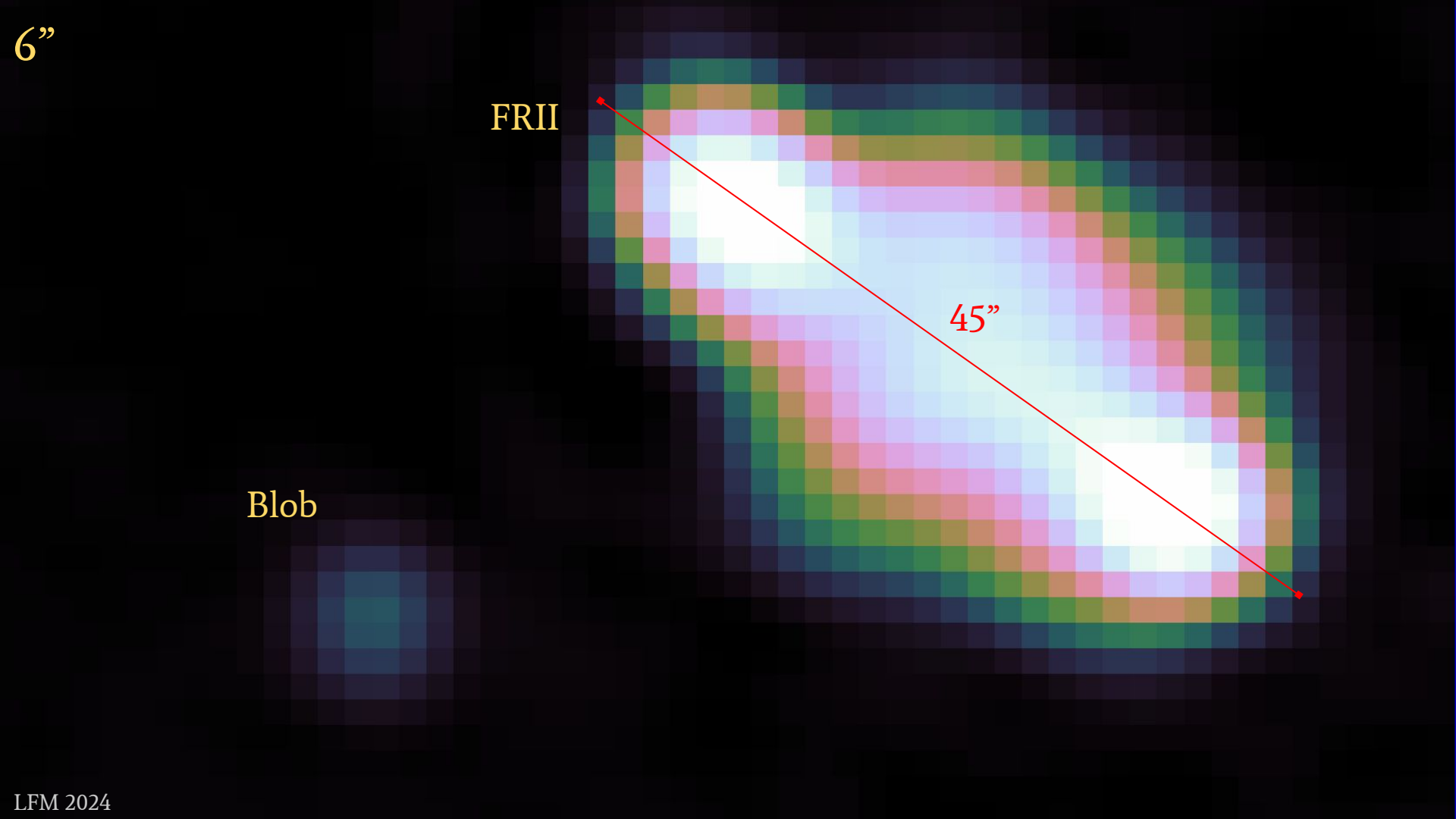
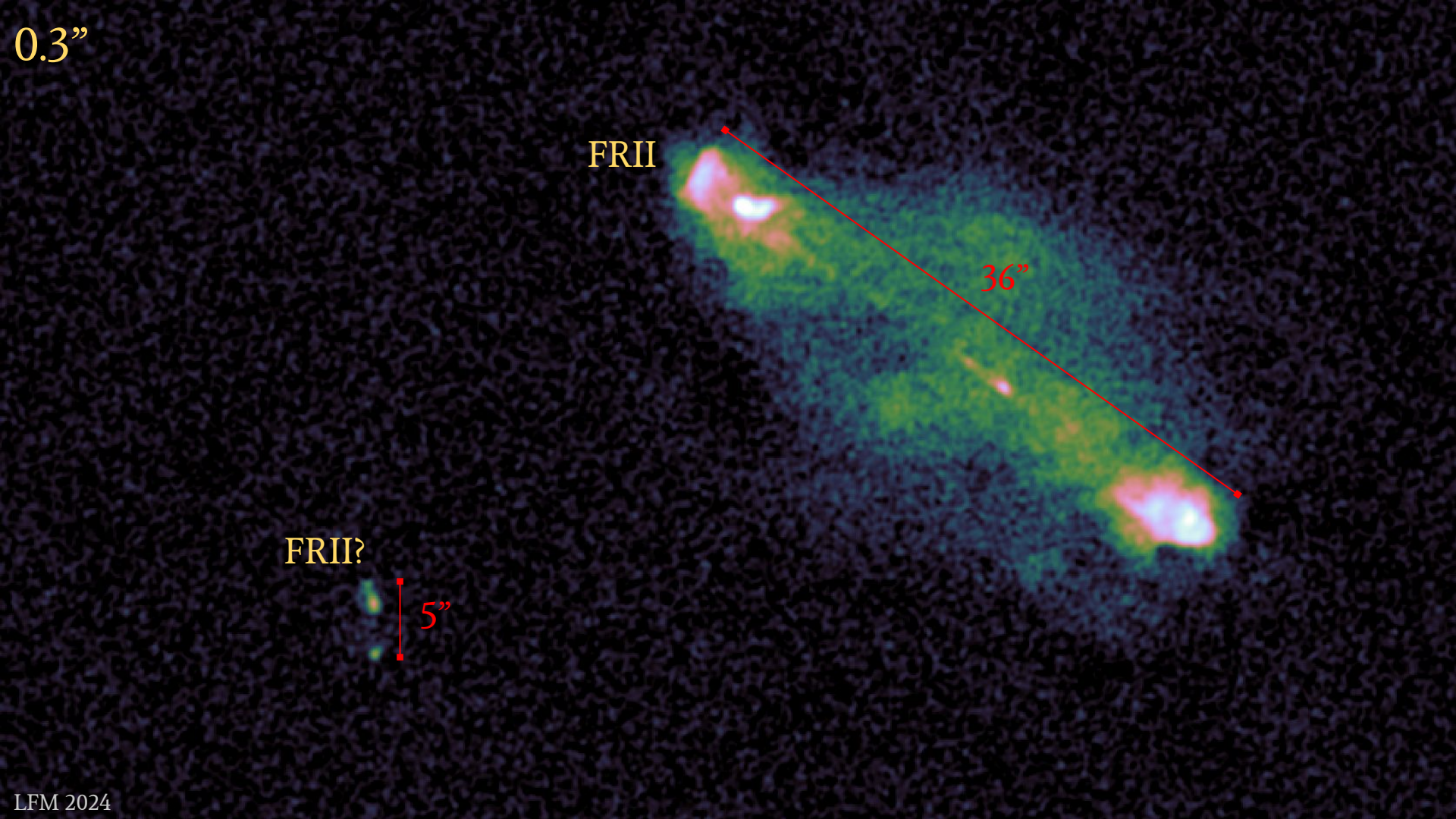
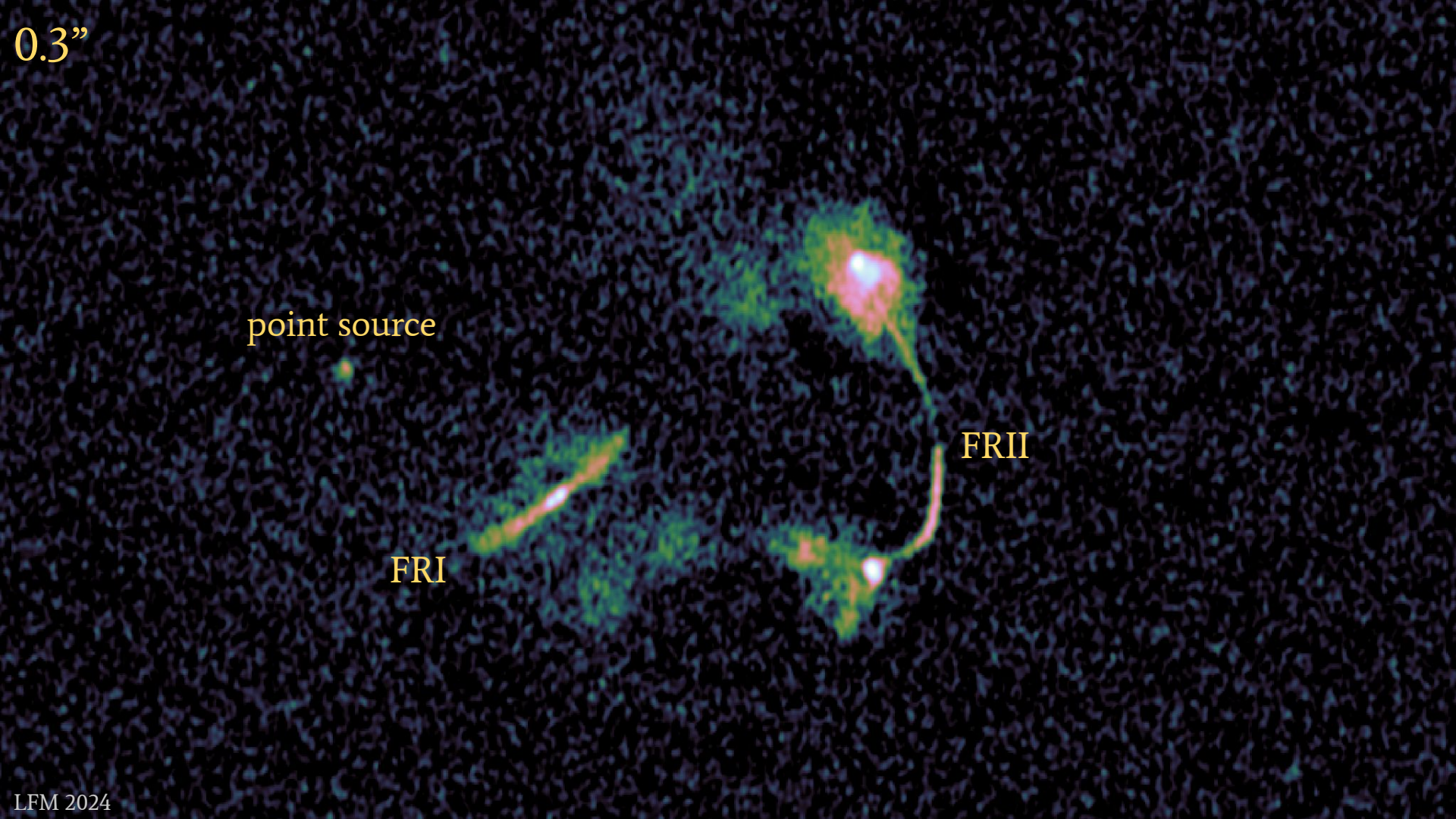



0.3"
0.015°
0.6"
1.2"
0.14°
0.3"
D
de Jong et al. submitted to A&A!
B
14 μJy/beam
2.5°
C
A


6”
FRII
45”
Blob


0.3”
FRII
36”
FRII?
5”
LFM 2024

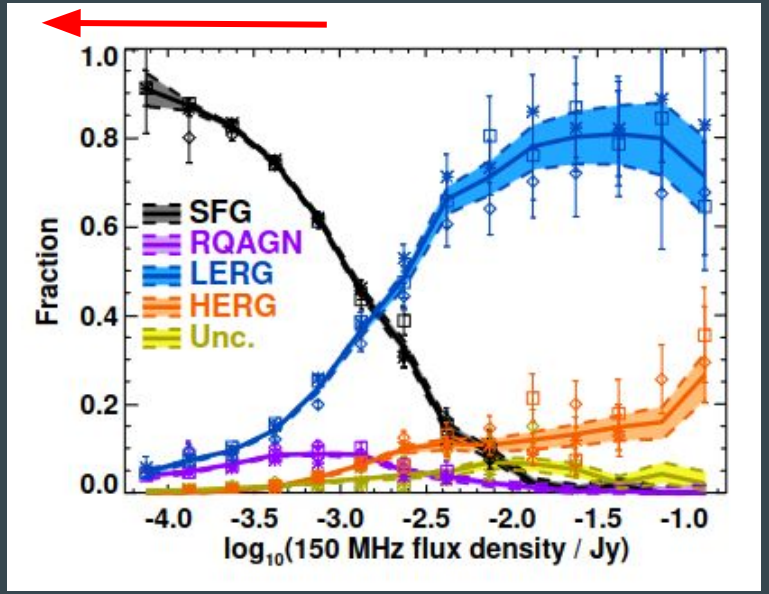
6”


0.3”
point source
FRII
FRI
LFM 2024

WHAT SHOULD WE DO NEXT?
WE NEED TO GO DEEPER....

500-hrs ELAIS-N1

- ★ 6” → 13 μJy/beam (Shimwell et al. in prep)
- ★ **0.3” → 4 μJy/beam**
- ★ **~150,000 sources** within 2.5x2.5 deg (compared to 2,500 with 8hr data)
- ★ Star-forming galaxies early universe
  Low-surface brightness emission
  Lenses? And more...

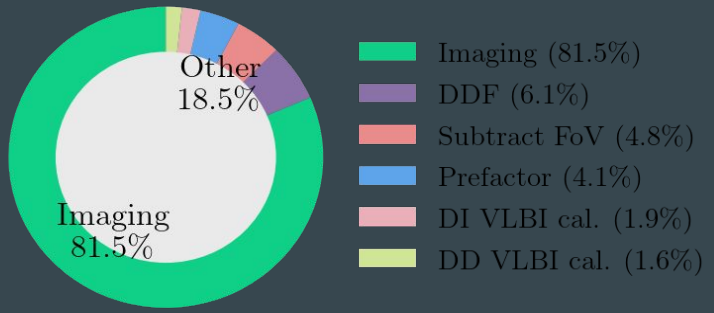


Best et al. (2023)

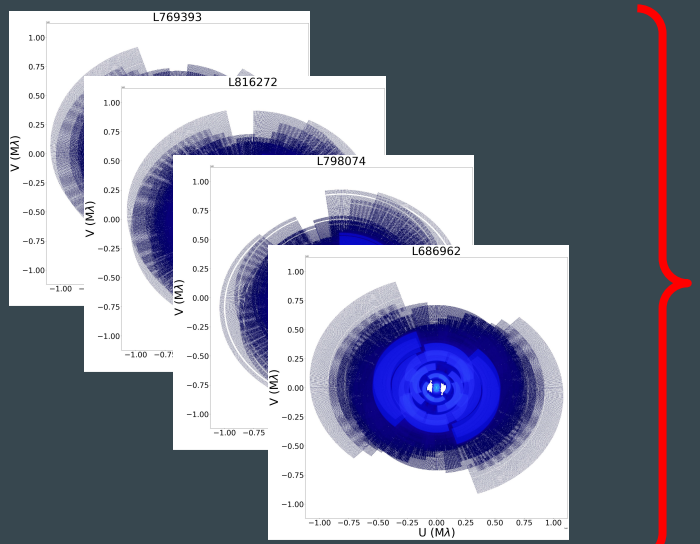
Computing costs VLBI wide-field imaging

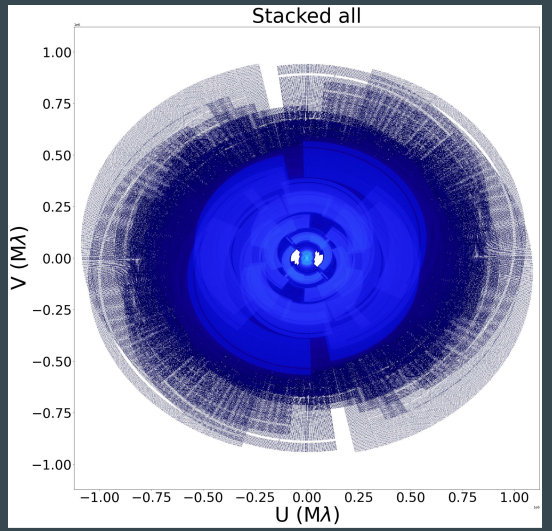
★ Very expensive:
~250,000 CPU hours for 8h data (Sweijen et al. 2022)
~680,000 CPU hours for 32h data (de Jong et al. subm.)

★ Most expensive: imaging



Stacking UV plane





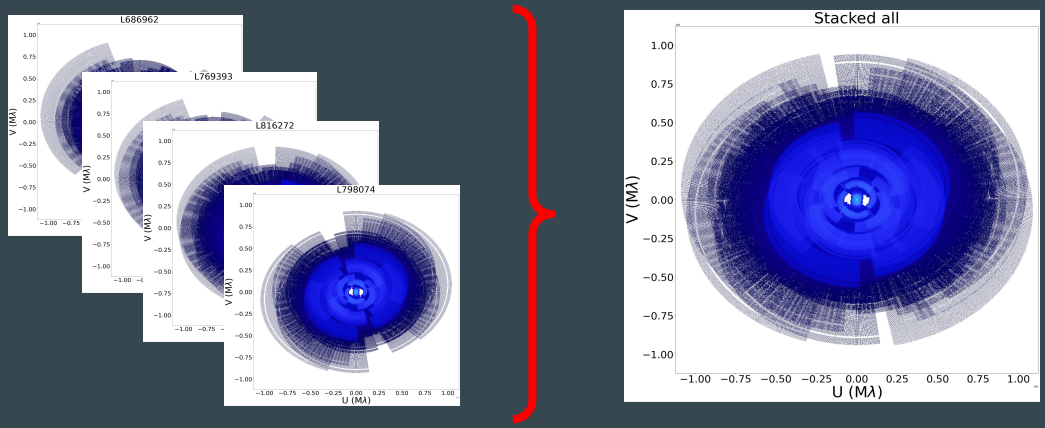
Stacking UV plane

Pros:

- ★ Reduce data volume (storage)
- ★ Faster imaging (# obs faster)
- ★ Allowing for imaging different resolutions/weightings

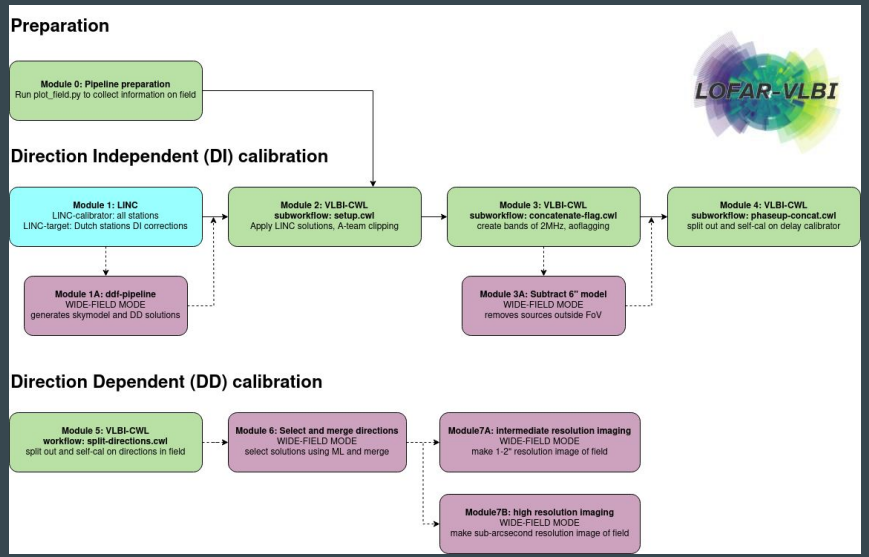
Cons:

- ★ Losing time axis information



Stacked 32h
Non-stacked 32h

HPC data processing



COMMON WORKFLOW LANGUAGE

Pipeline Workflow

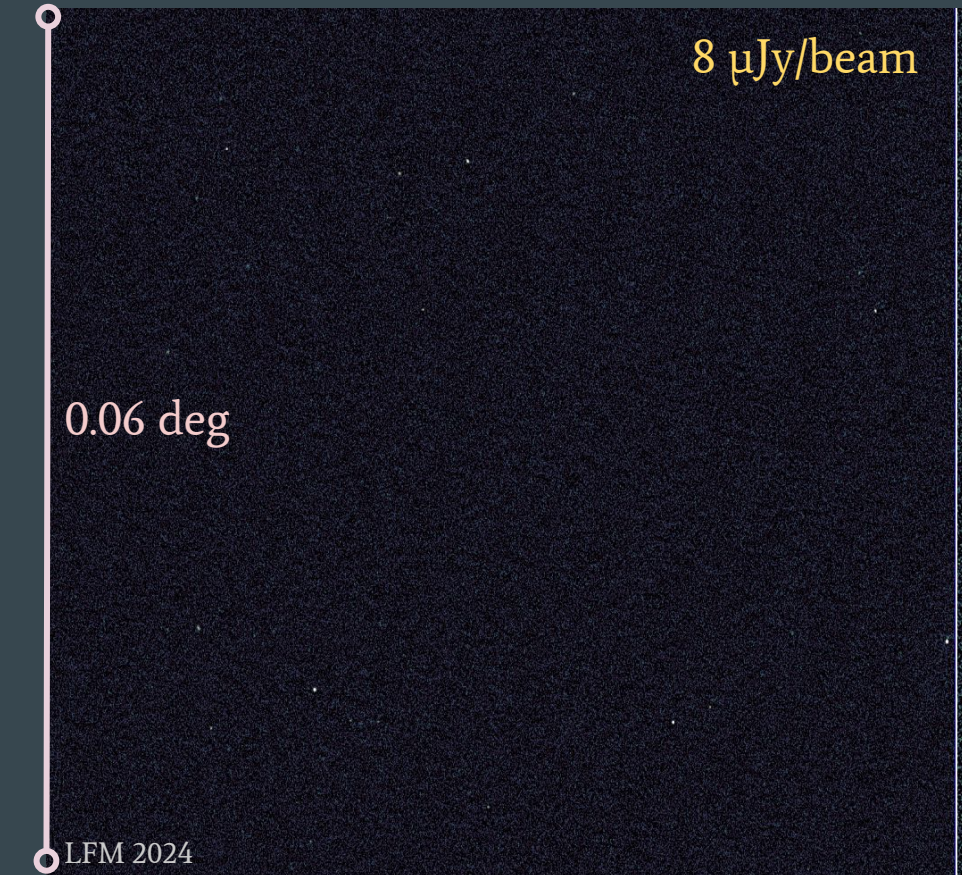
Toil

Runner

slurm workload manager

Scheduler

Current status ELAIS-N1: 128-hrs vs. 32-hrs

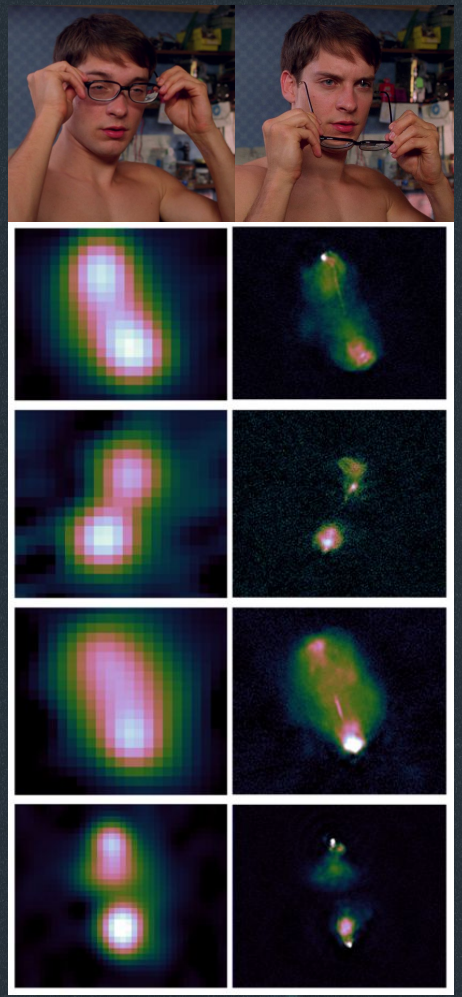


Summary

- ★ Deepest 0.3” wide-field image with LOFAR at 14 μJy/beam
- ★ First steps to automation
- ★ Paper submitted to A&A (de Jong et al. subm.)

Future prospects

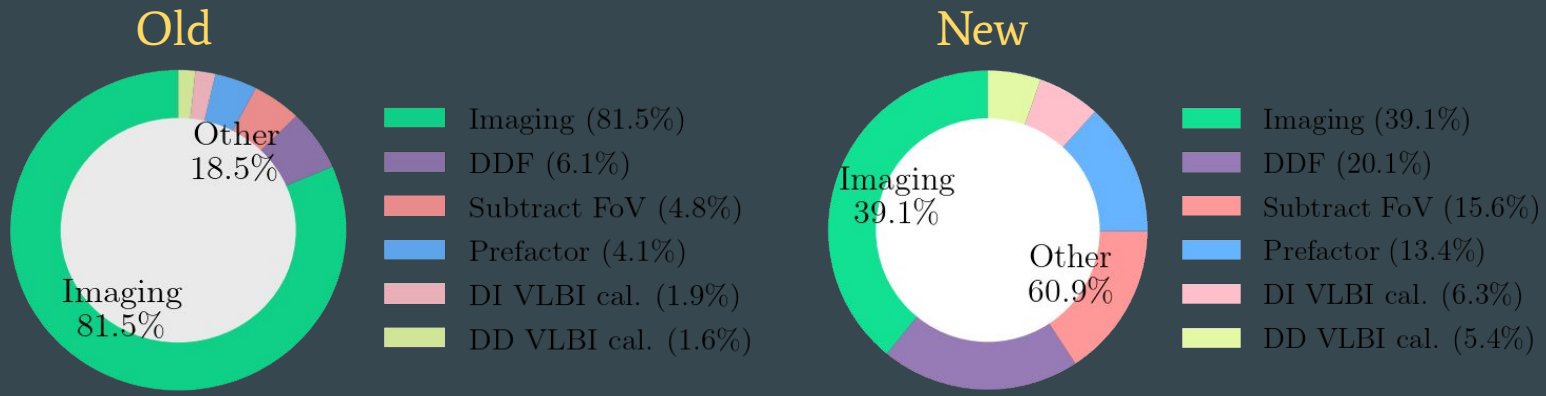
- ★ Processing improvements (software, strategy)
- ★ Fully automated wide-field VLBI pipeline
- ★ Stacking → Going to 4 μJy/beam!



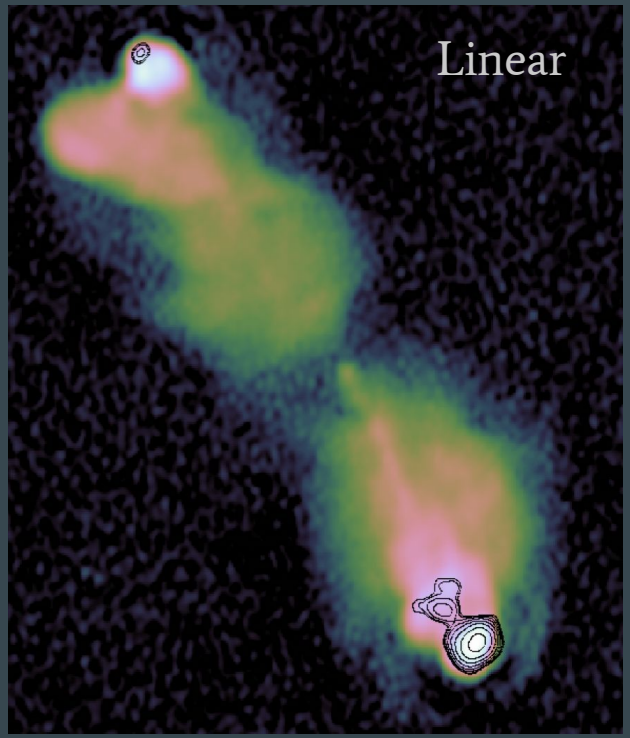
EXTRA SLIDES

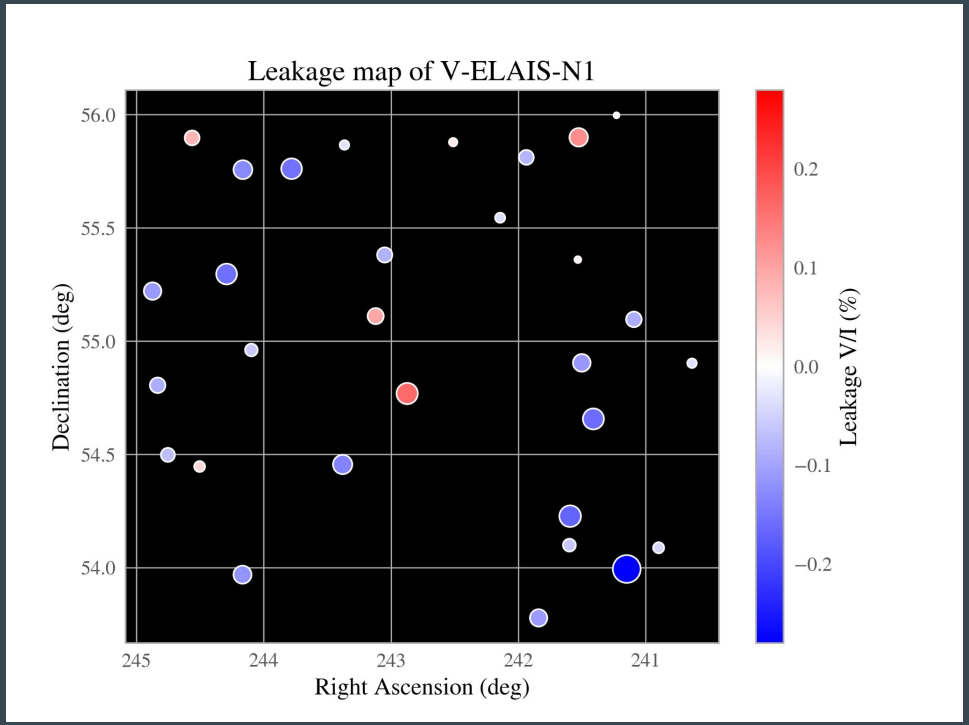
ELAIS 128h vs. 32h

Total estimated speedup of a **factor 4**

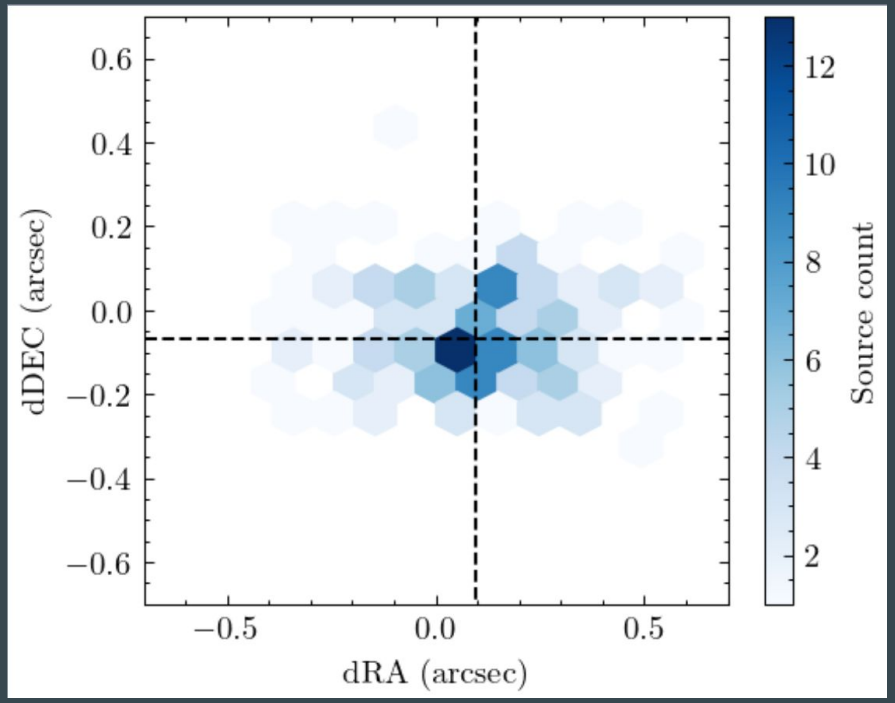


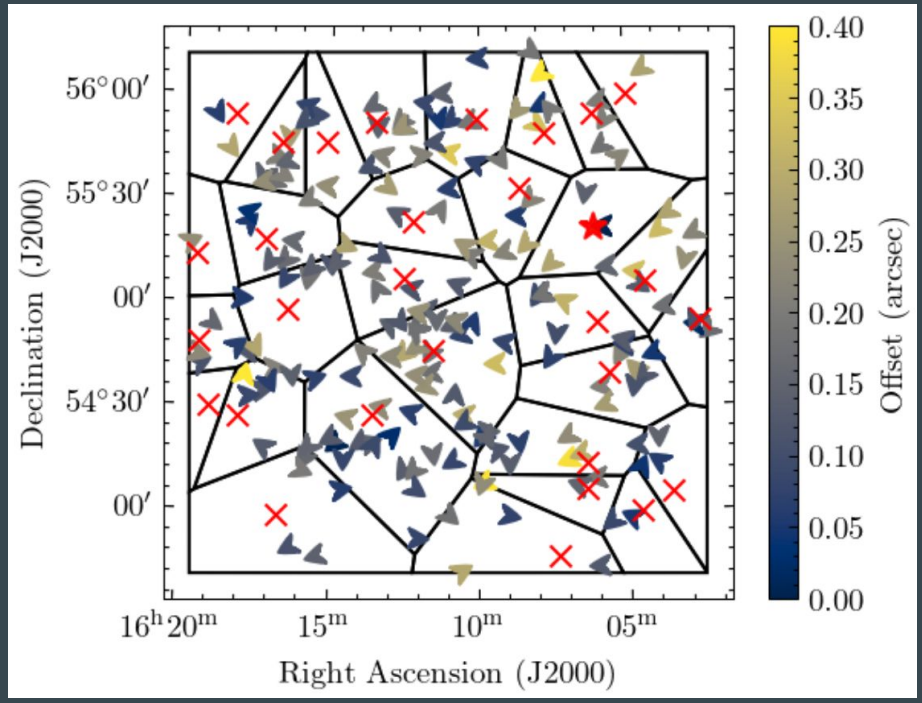
Polarisation





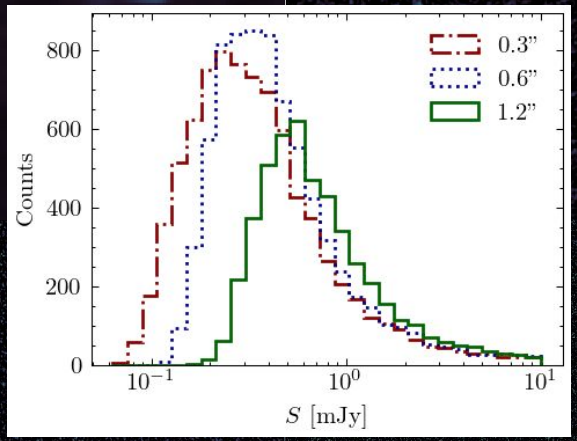
Astrometry


0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
dDEC (arcsec)
−0.5
0.0
0.5
dRA (arcsec)
12
10
8
6
4
2
Source count


56° 00′
55° 30′
00′
54° 30′
00′
Declination (J2000)
16h 20m
15m
10m
05m
Right Ascension (J2000)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Offset (arcsec)

6”

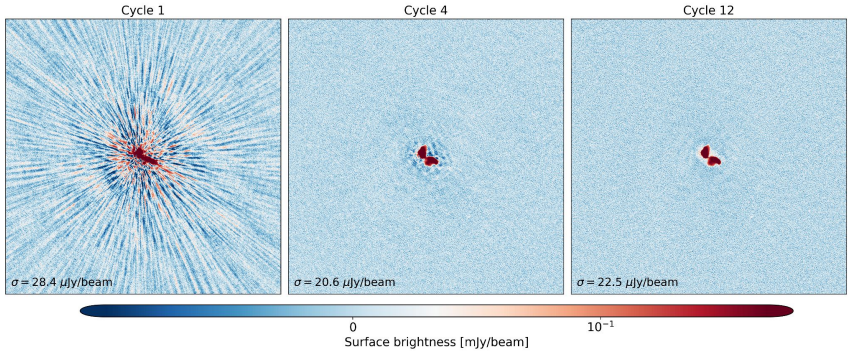
1.2”

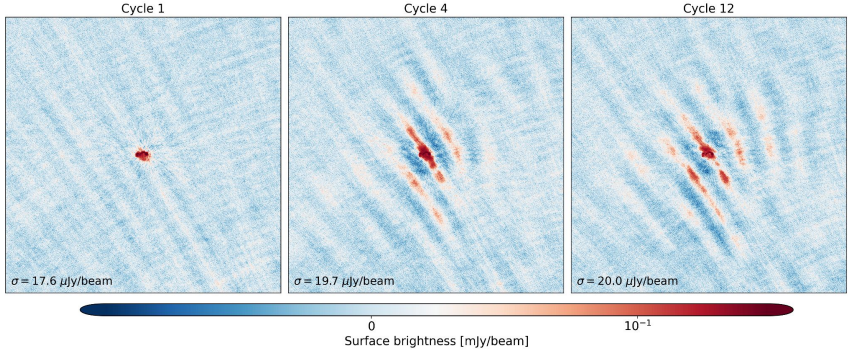


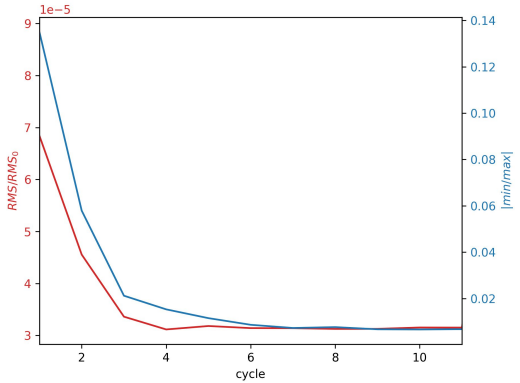
0.6”

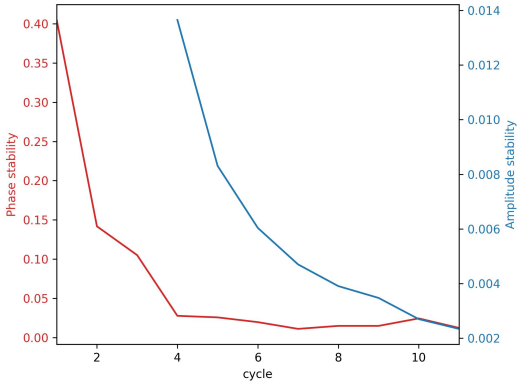
0.3”

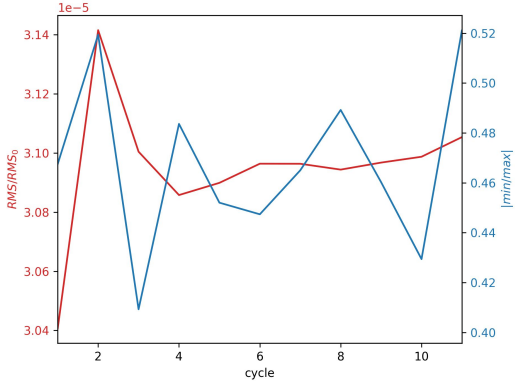
Final inspection

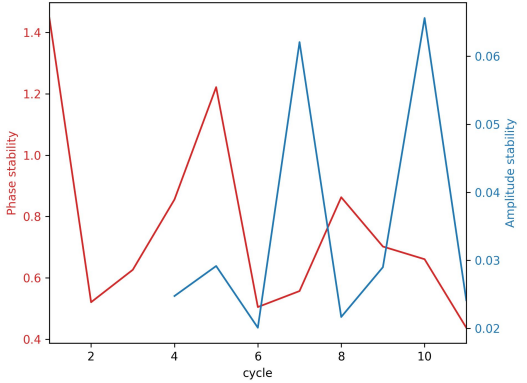




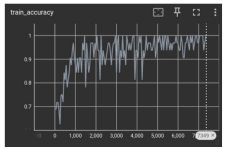
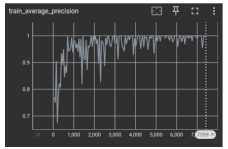
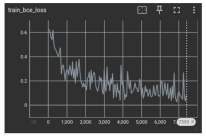
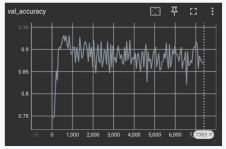
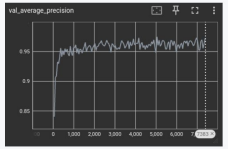
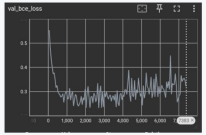


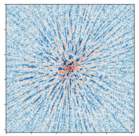
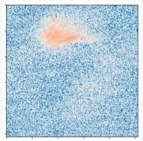
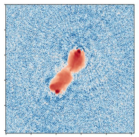


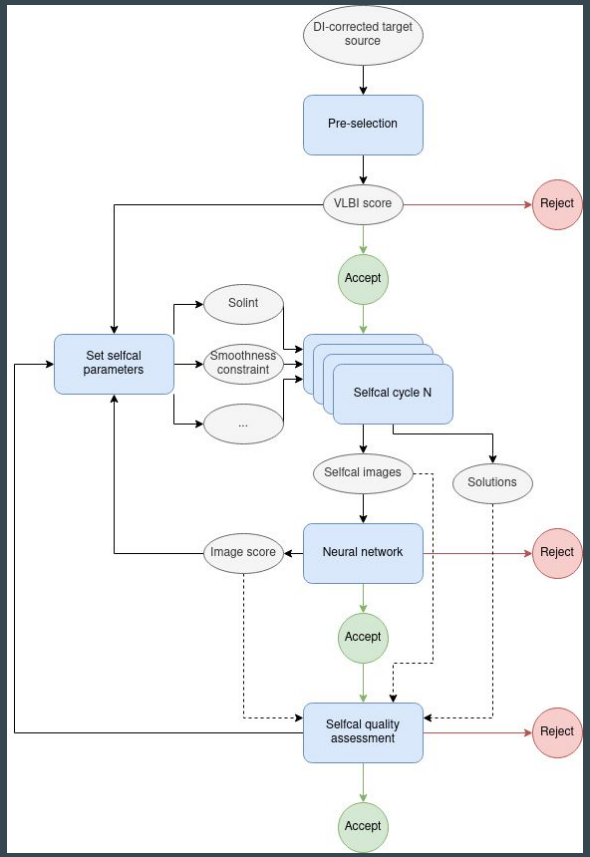




In progress: ML-based parameter tuning

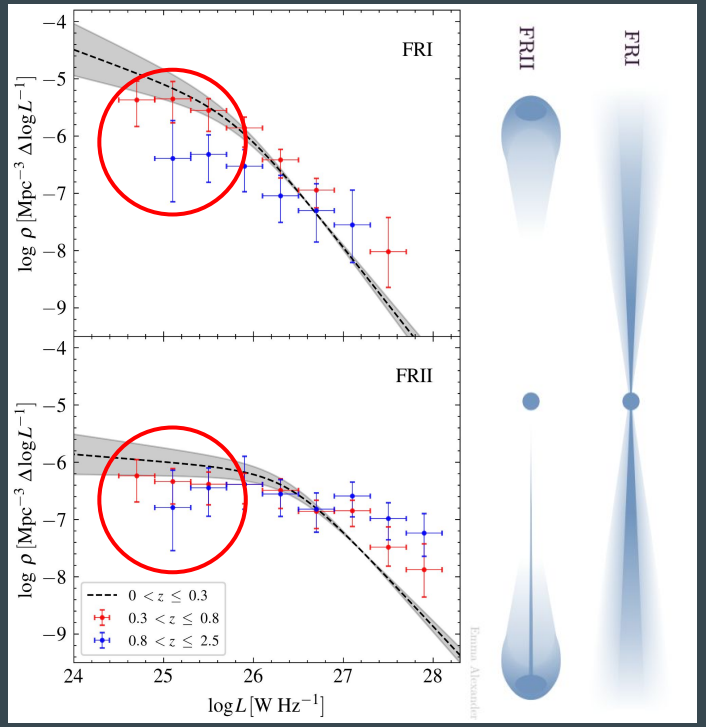
	Accuracy	Average Precision	BCE loss
Training			
Validation			

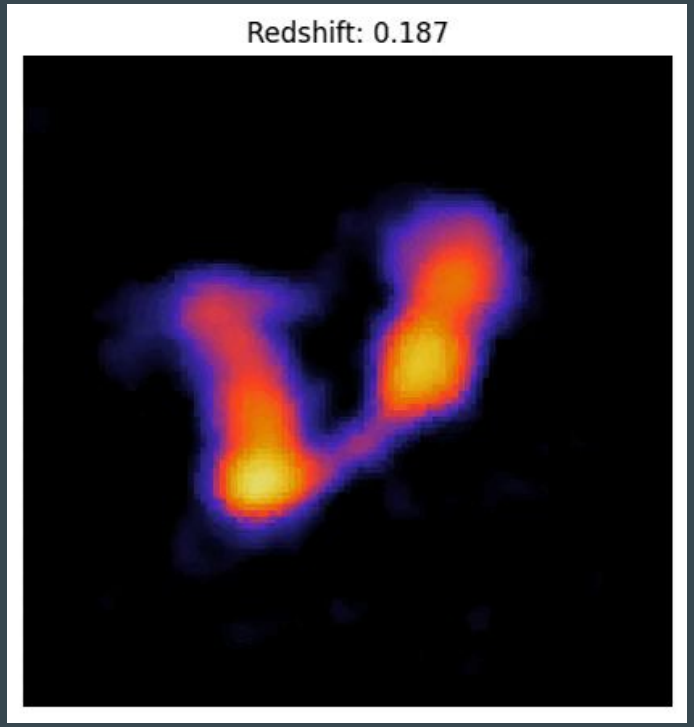
Description	Example
Bright compact source considered good enough to **continue** self-calibration	
Source considered to be too faint to calibrate on and therefore needs to **stop** self-calibration at cycle 0	
Source considered to be 'good enough' after several rounds of self-calibration and strong calibration improvements. This source can therefore **stop** self-calibration:	



FRI/FRII evolution (de Jong et al. 2024)

- ★ 6” and 144 MHz
- ★ Space density enhancements
- ★ Remaining selection biases below 40”





See: https://github.com/jurjen93/redshifting

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