

Technical challenges of long-baseline imaging

LOFAR Family Meeting, 12 - 16 June 2023, Olsztyn, Poland

Dr. Leah Morabito

UKRI Future Leaders Fellow & Assoc Prof

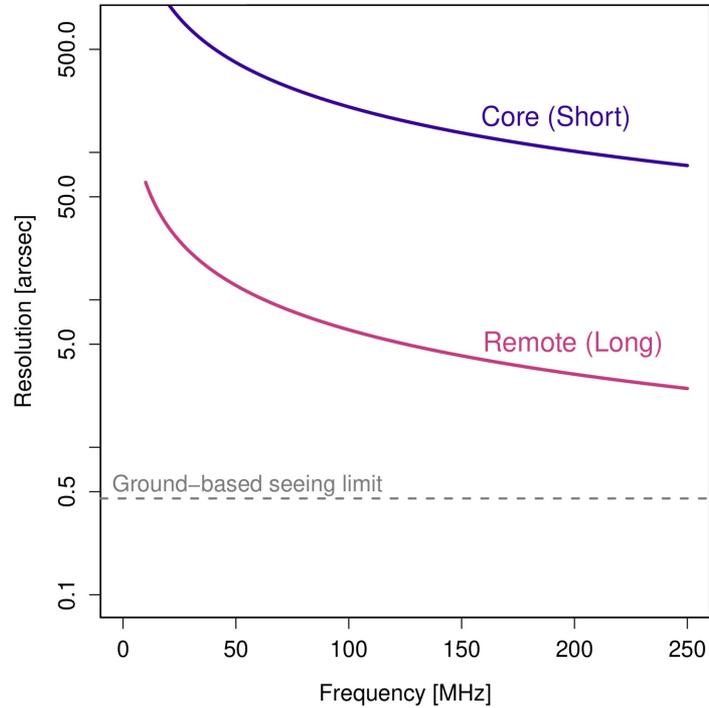


UK Research
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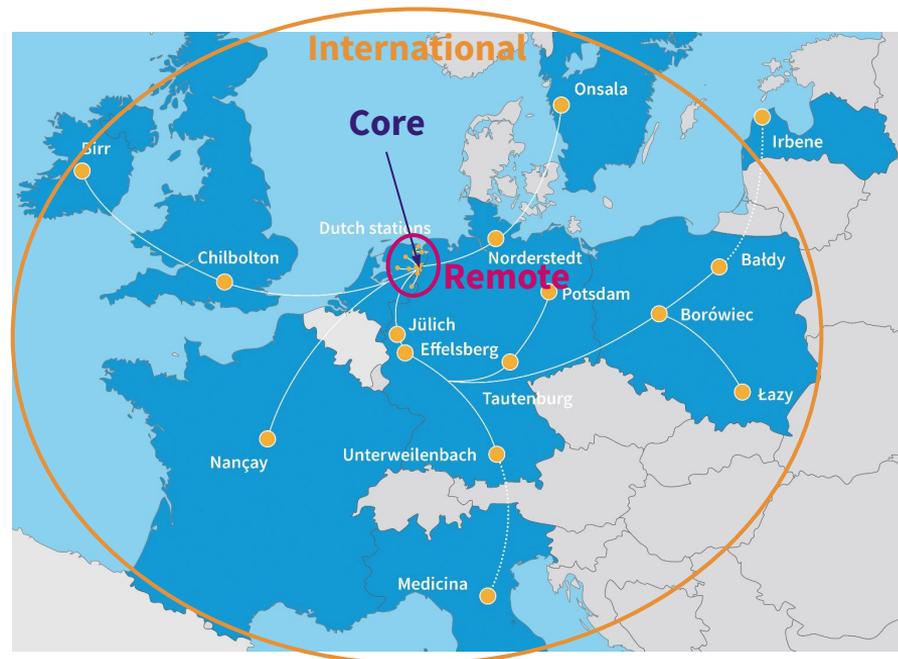
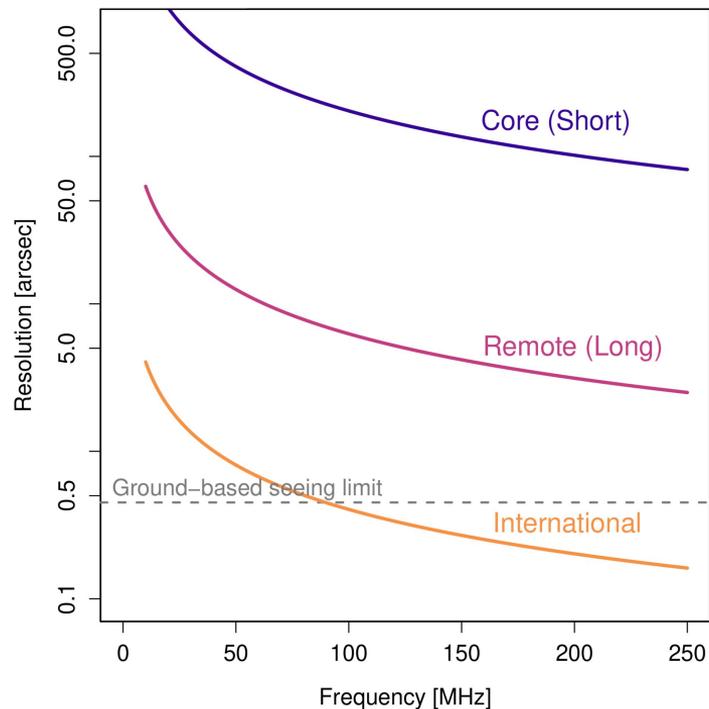


Durham
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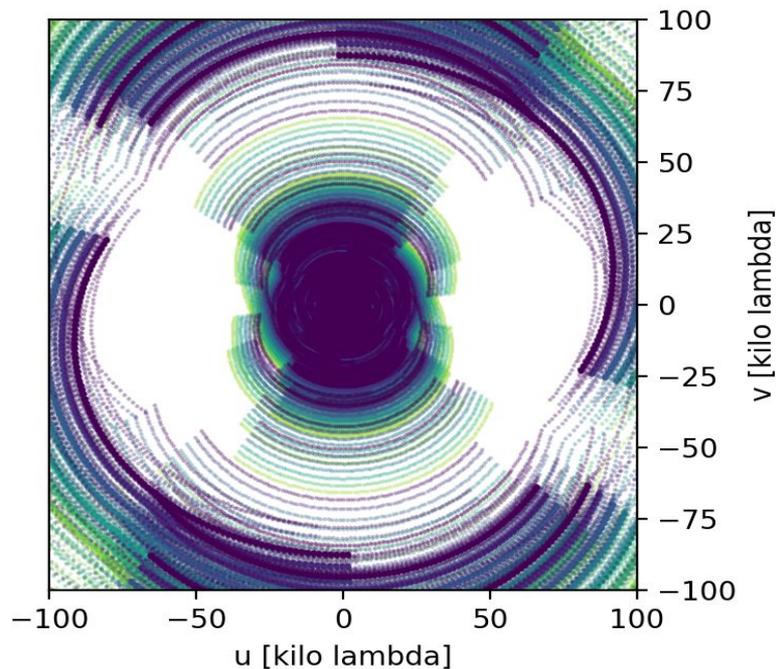
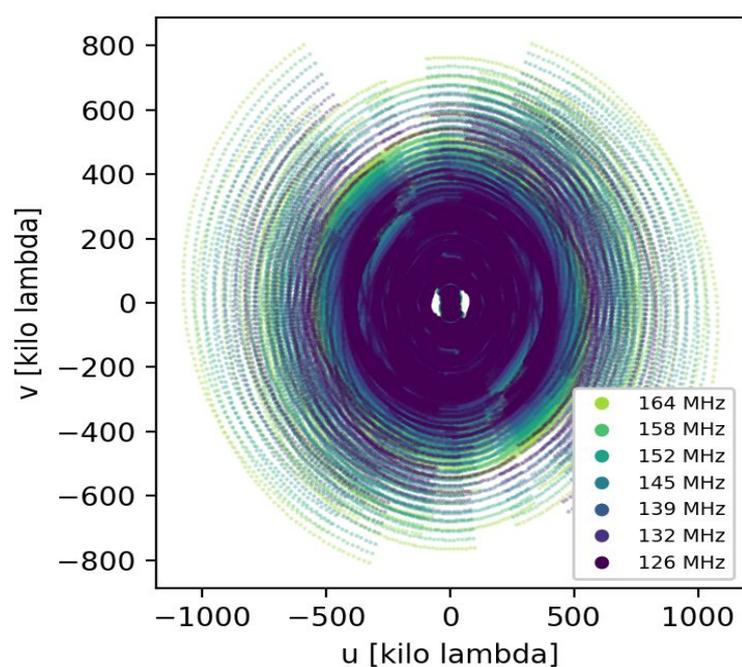
The International LOFAR Telescope



The International LOFAR Telescope



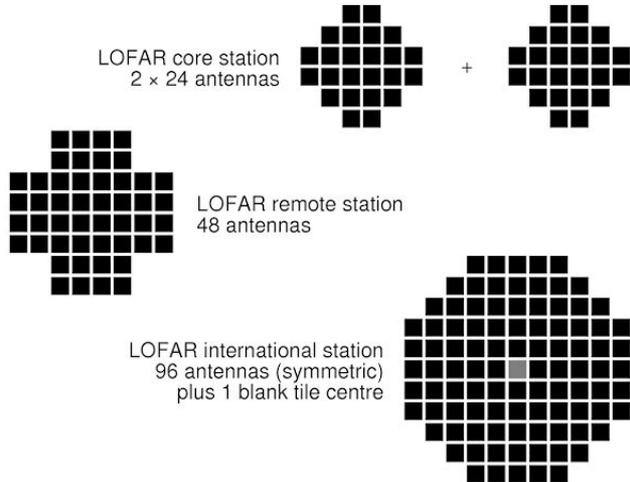
VLBI with LOFAR - u - v coverage



VLBI with LOFAR - Field of View (FoV)

Limited by:

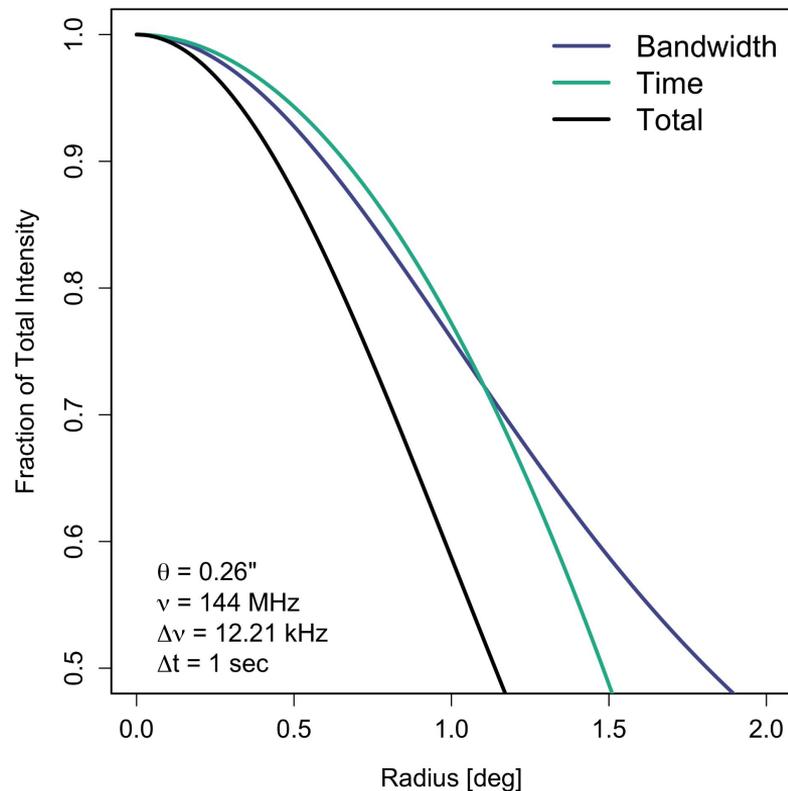
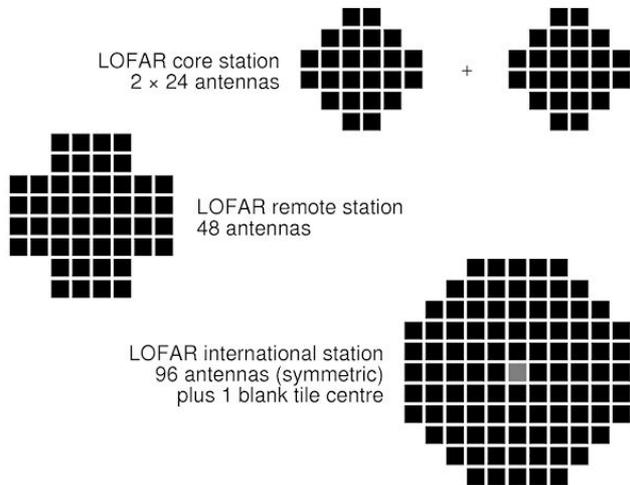
- Station beam of international stations



VLBI with LOFAR - Field of View (FoV)

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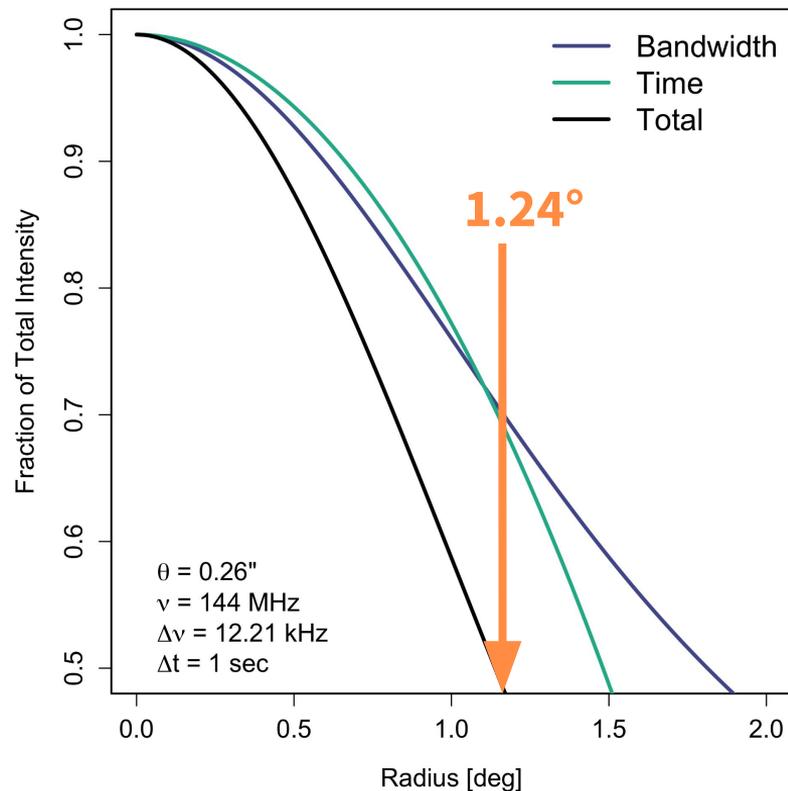
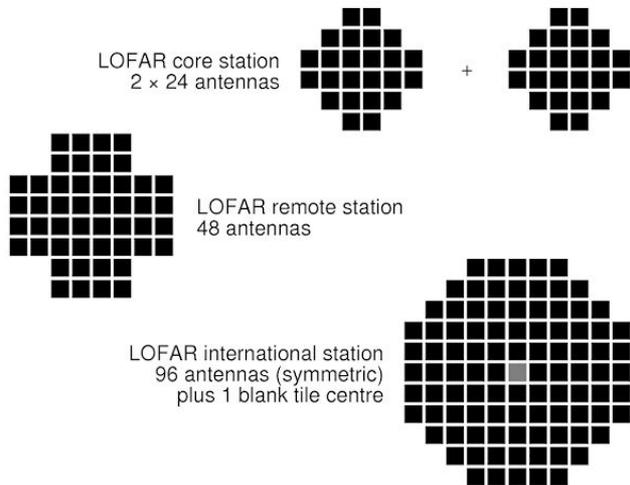
- Station beam of international station
- Smearing (bandwidth and time)



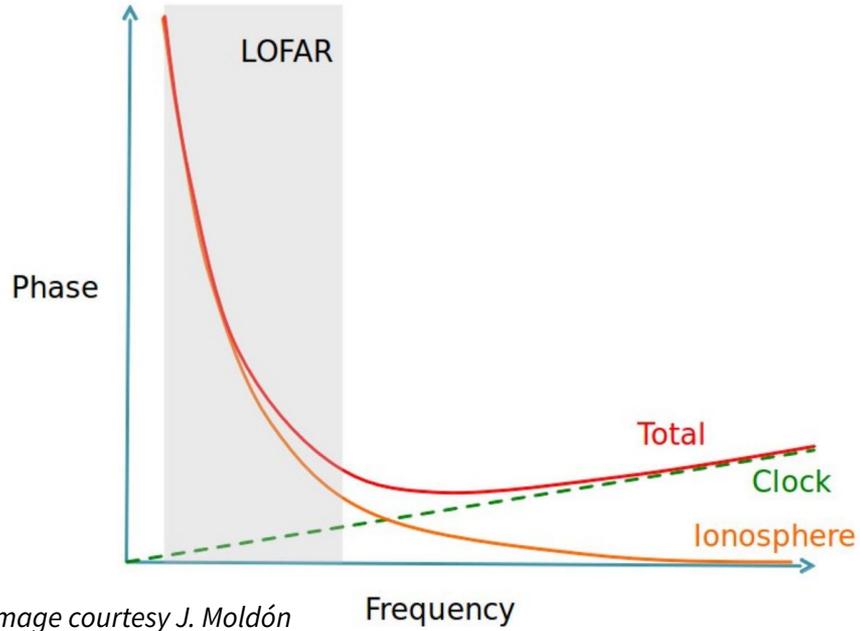
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Data calibration challenges



Data calibration challenges

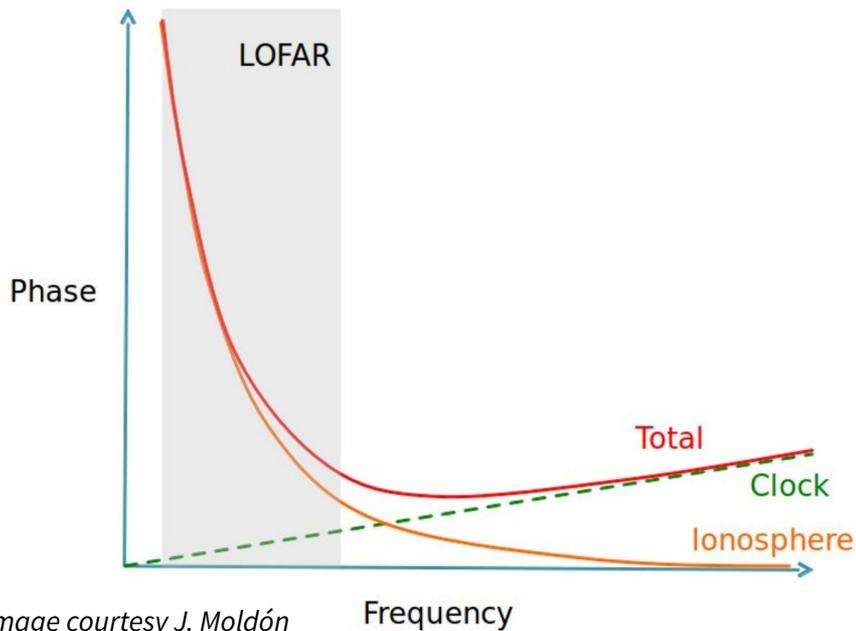
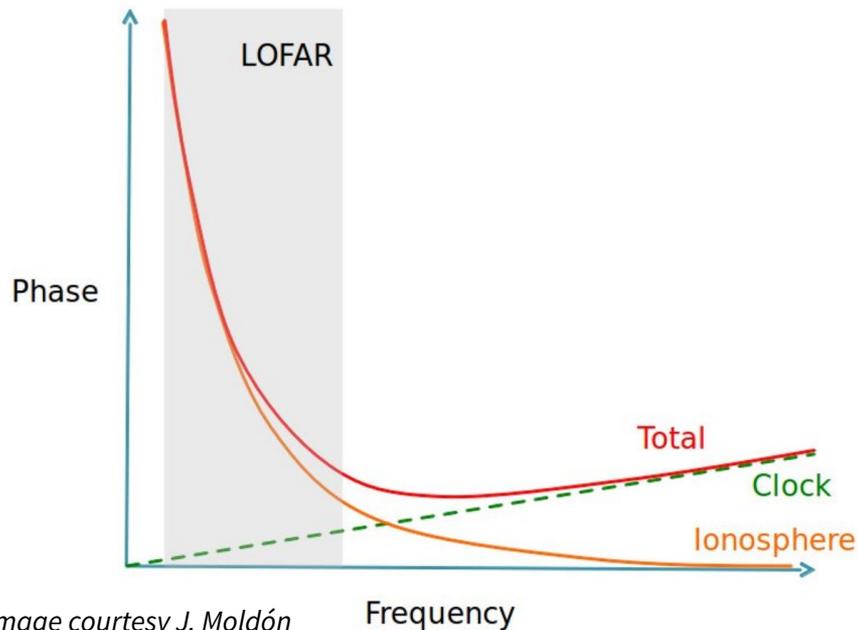


Image courtesy J. Moldón

Clock values are easily solved for on standard flux calibrators

Phase errors are dominated by **dispersive delays from the ionosphere**, which is a *direction-dependent* effect

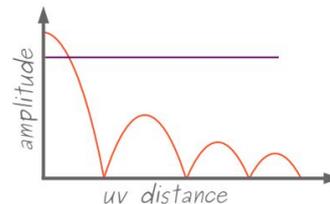
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Requires full bandwidth **or** enough signal/noise that you can solve for phases in small Δt , $\Delta \nu$



Data calibration challenges

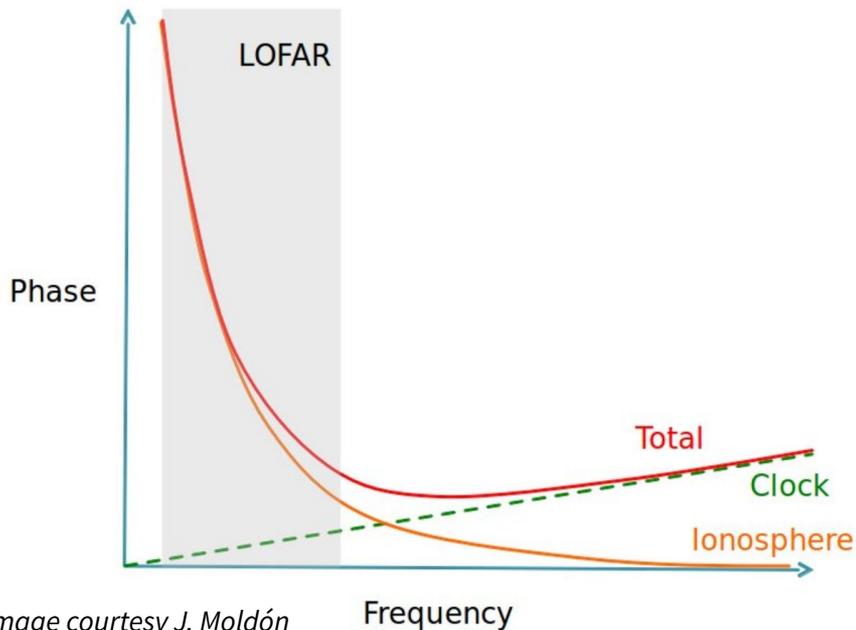


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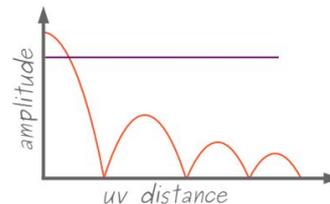


Requires full bandwidth **or** enough signal/noise that you can solve for phases in small Δt , $\Delta \nu$

point source



resolved source



Need a suitable in-field calibrator

Data calibration challenges

- Calibrators: need 'Goldilocks' calibrators for resolution / frequency
- Data volume: datasets are 4-20TB per observation
- Clocks: remote and international stations on individual clocks
- Ionosphere: requires directional dependent calibration
- Source characteristics: low-frequency absorption, source structure

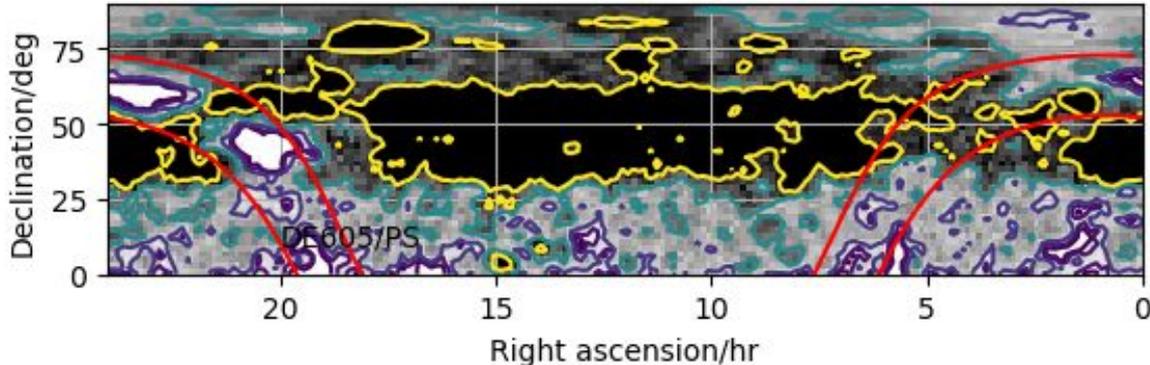
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Long Baseline Calibrator Survey (LBCS)

Covers entire Northern sky for HBA (Jackson et al, 2022, 2016)

- Multi-beaming with 3 MHz, 3 min observations of calibrator candidates
- ~30,000 sources in final catalogue, about 1 good calibrator per square deg.



Long-baseline calibrator survey

The Long Baseline Calibrator Survey (LBCS) is aimed at identifying suitable for calibrating the highest resolution observations made with the International flux density of frequencies around 110–190 MHz on scales of a few hundred milliseconds. For a description of the survey see Jackson et al. (2016). Data products from the survey are available on this site. You may [download the full catalogue](#), search the catalogue in a particular region of the sky or do

HTML table

Enter a position and radius in decimal degrees to search the catalogue:

RA: DEC: Radius:

[Get HTML table](#)

FITS table

Enter a position and radius in decimal degrees to search the catalogue:

RA: DEC: Radius:

[Get FITS table](#)

lofar-surveys.org

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- Commissioning project to extend to LBA (PI: Jackson)

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Developing a calibration strategy

LoTSS processing

Full array – instrumental effects
Dutch array – phases

de Gasperin et al. 2019

LOFAR-VLBI pipeline

Dispersive delay
Phase calibration

Techniques

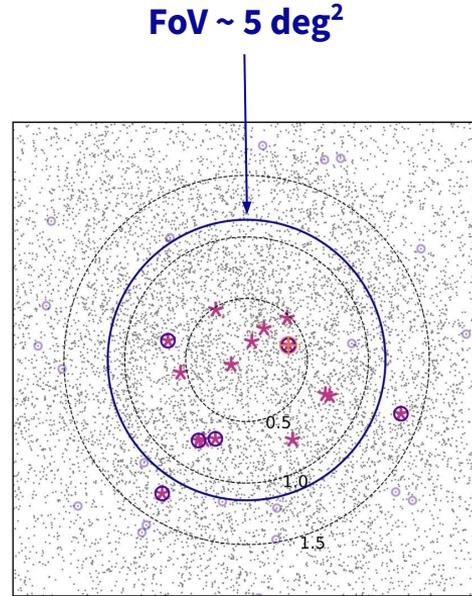
- Combine core stations
- Phase-shift & average to reduce FOV
- *now uses facetselfcal!*

Morabito et al. 2022

***Calibration uses LOFAR-native tools
but borrowing from VLBI techniques***

Demonstration: P205+55

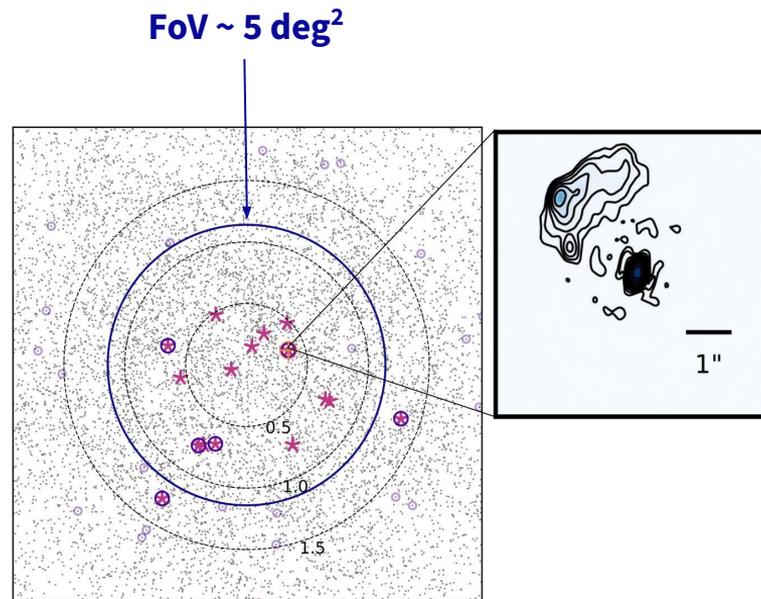
Field of view limited to 1.25° radius (by smearing and station beams)



Demonstration: P205+55

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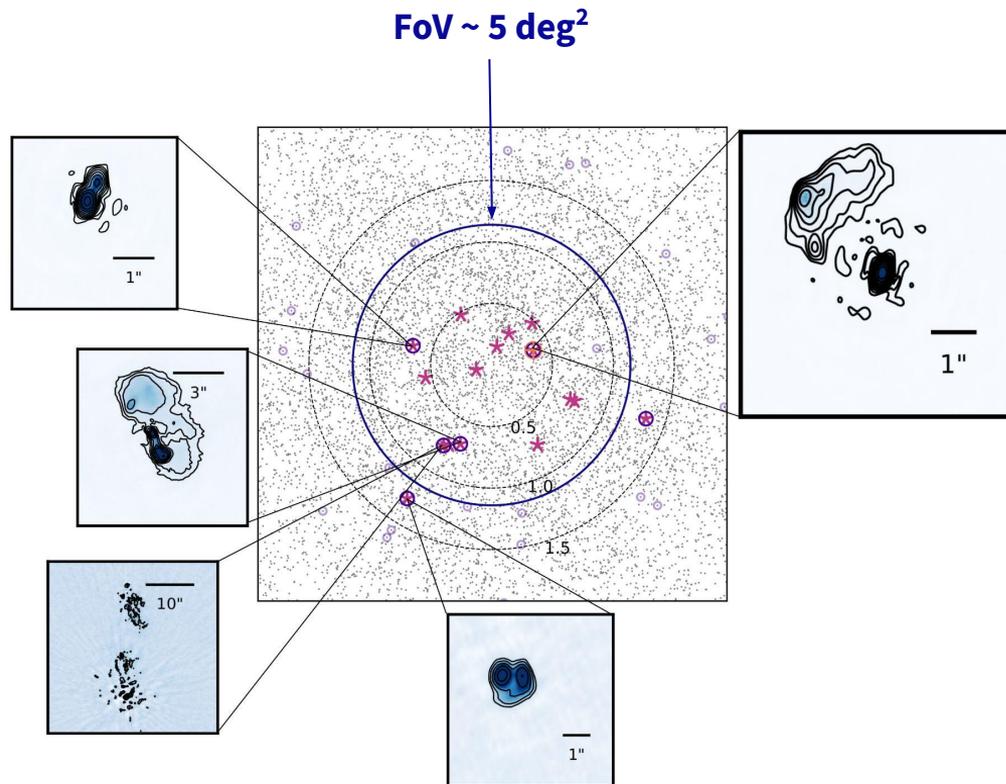
1. Find dispersive delays on best LBCS in-field calibrator



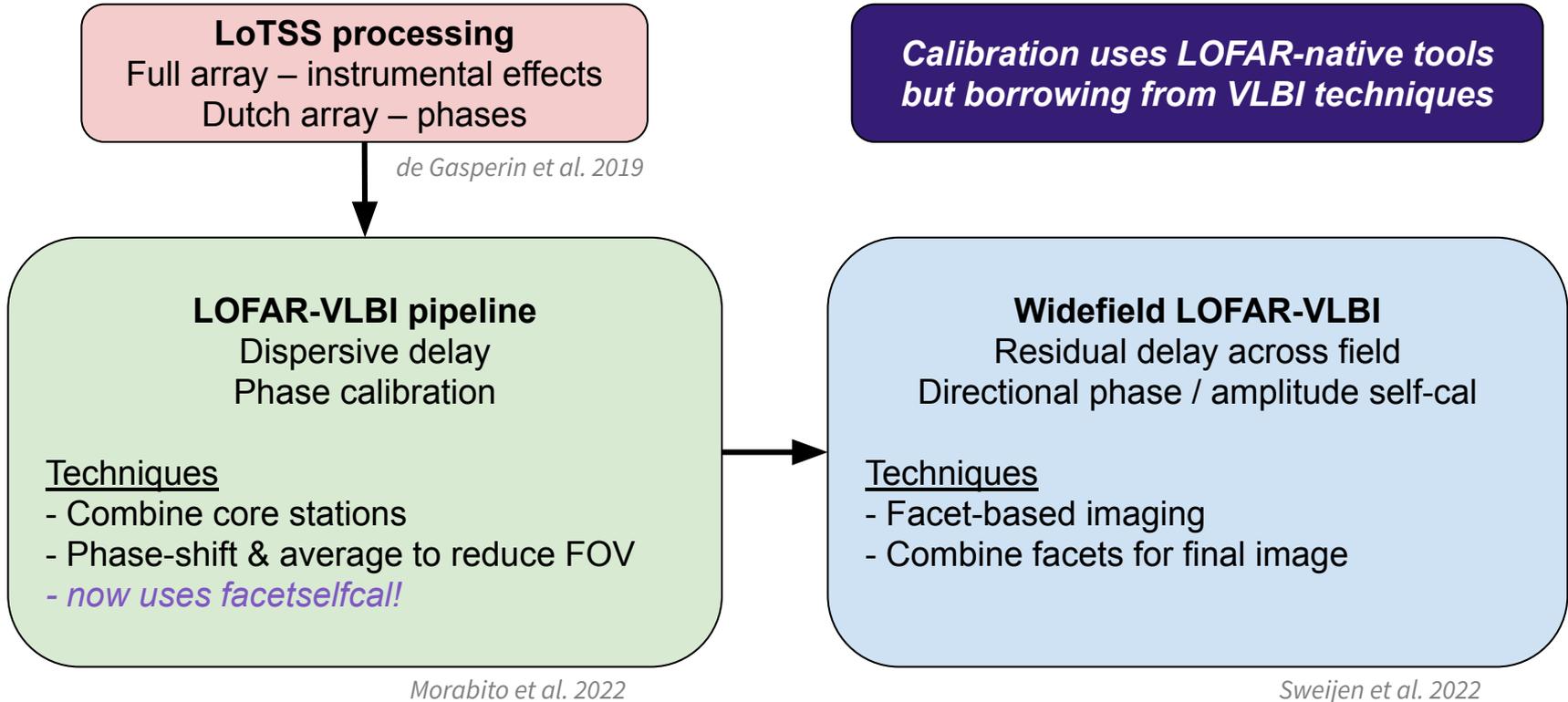
Demonstration: P205+55

Field of view limited to 1.25° radius (by smearing and station beams)

1. Find dispersive delays on best LBCS in-field calibrator
2. Apply to field / other sources
3. Self-calibrate residual errors

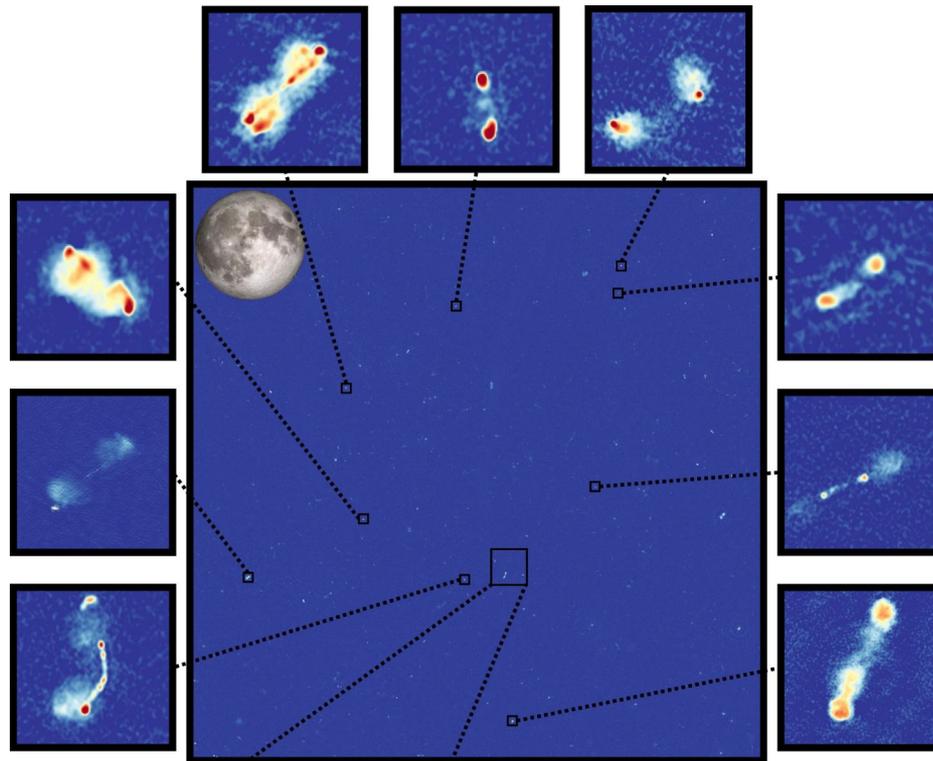


Developing a calibration strategy



Demonstration: Lockman Hole

- 8 hour observation
- $36 \mu\text{Jy}/\text{beam}$ median noise
- Field of View - 6.6 deg^2
- 2,214 sources
- **250,000 CPU hours**



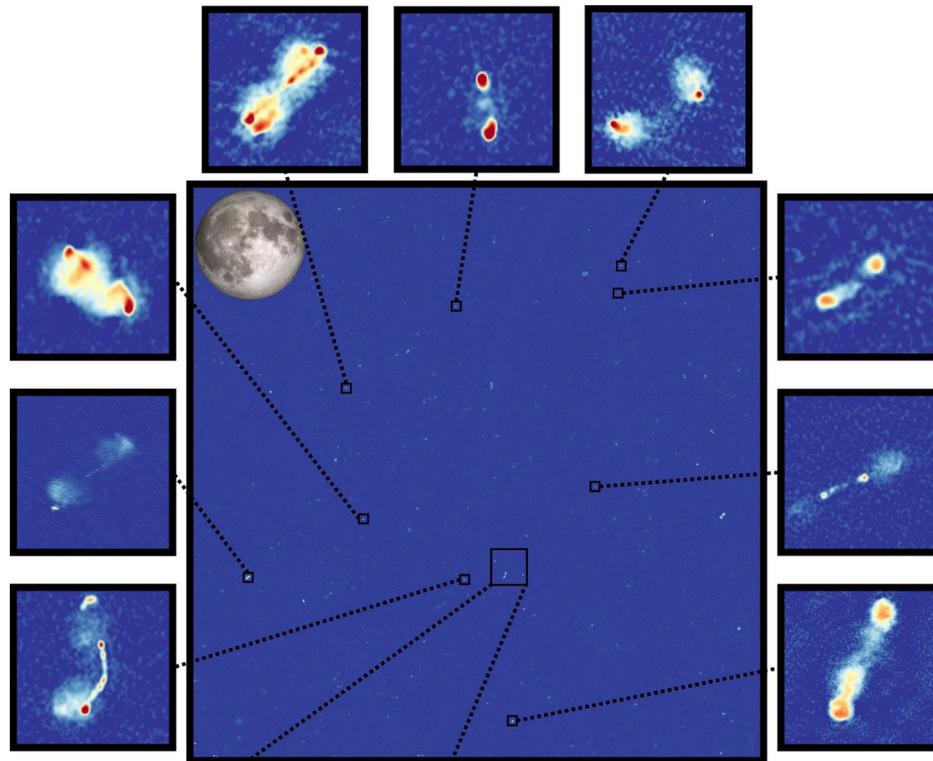
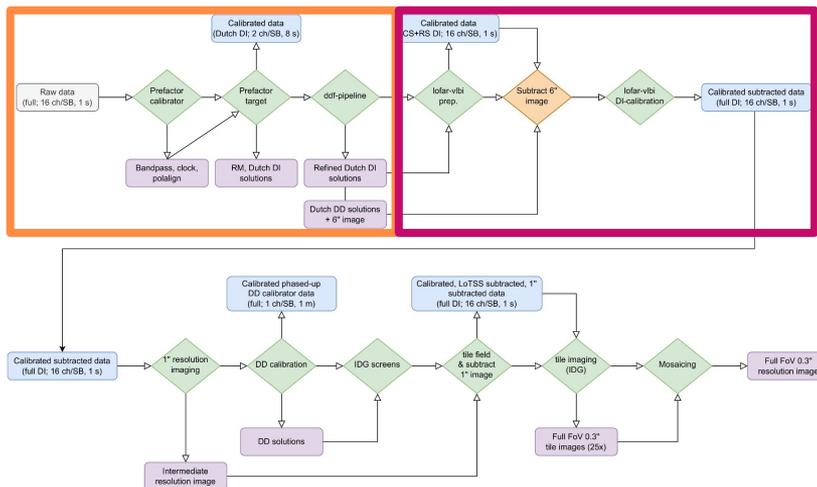
Sweijen et al. 2022

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LoTSS

lofar-vlbi + subtraction



Sweijen et al. 2022

Have we solved all the problems?

- ✓ Long Baseline Calibrator Survey is complete
 - ✓ Still poor coverage below $+30^\circ$ dec, but can use observation itself (although cumbersome)
- ✓ Pipeline for in-field calibrators / individual sources - V4.0 available
 - ✓ CWL version being tested, still need optimisation and some quality controls
 - ✓ In-field calibration for delays works, but still needs to be optimised to work in all cases
- ✓ Widefield VLBI imaging successfully demonstrated in Lockman Hole
 - ✓ Working on optimising algorithms / software to reduce computational cost

Do we need LOFAR2.0?

Yes! Increased sensitivity, and ability to extend this to LBA