Technical challenges of long-baseline imaging

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

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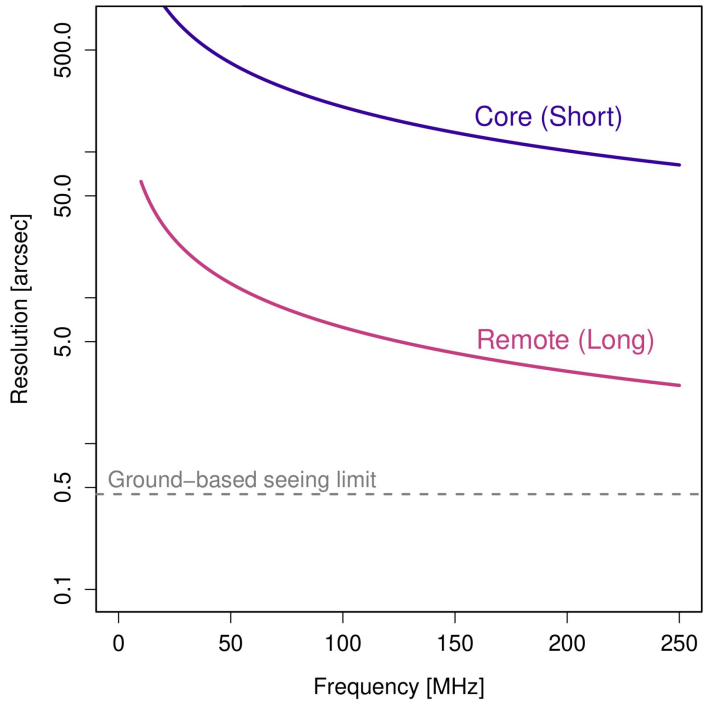
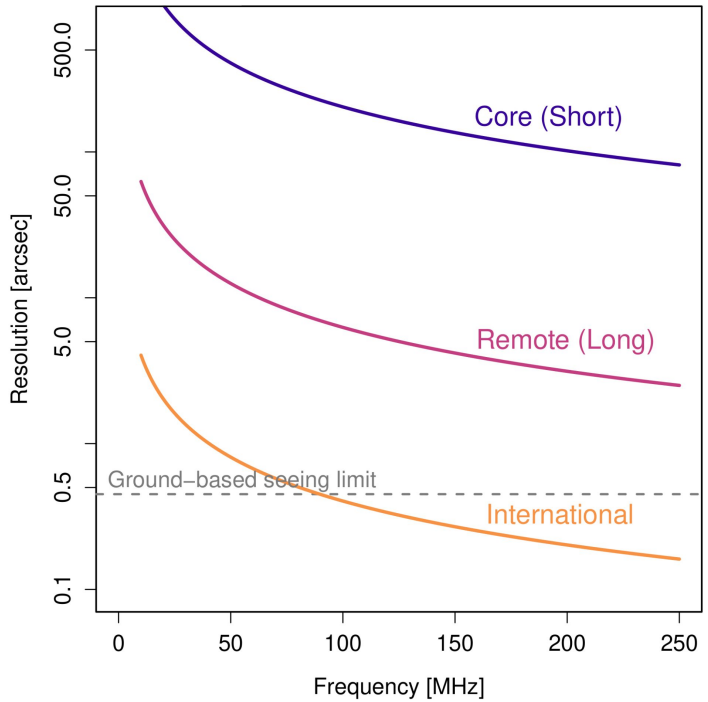
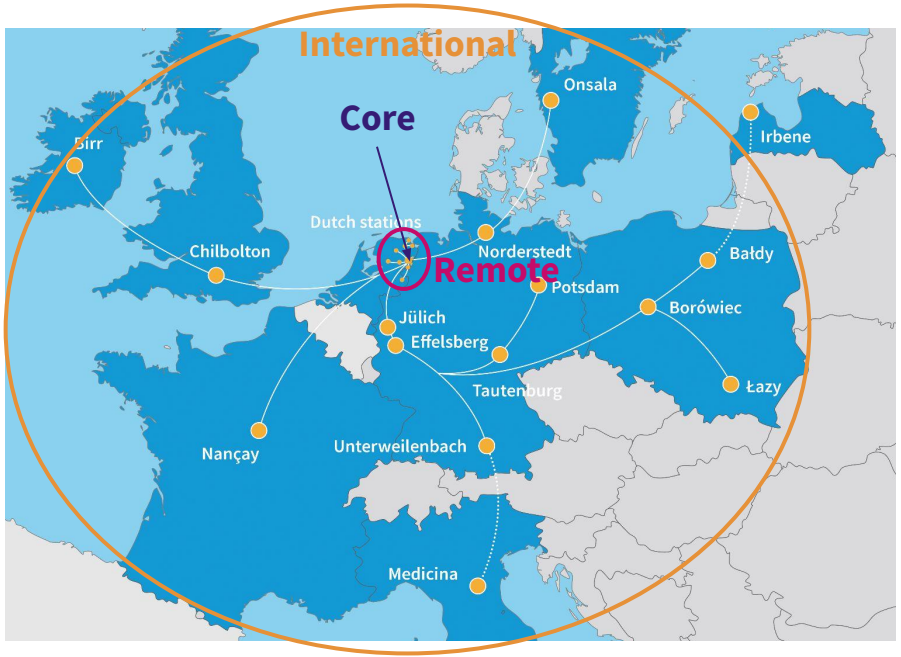
UK Research and Innovation
Durham University

The International LOFAR Telescope

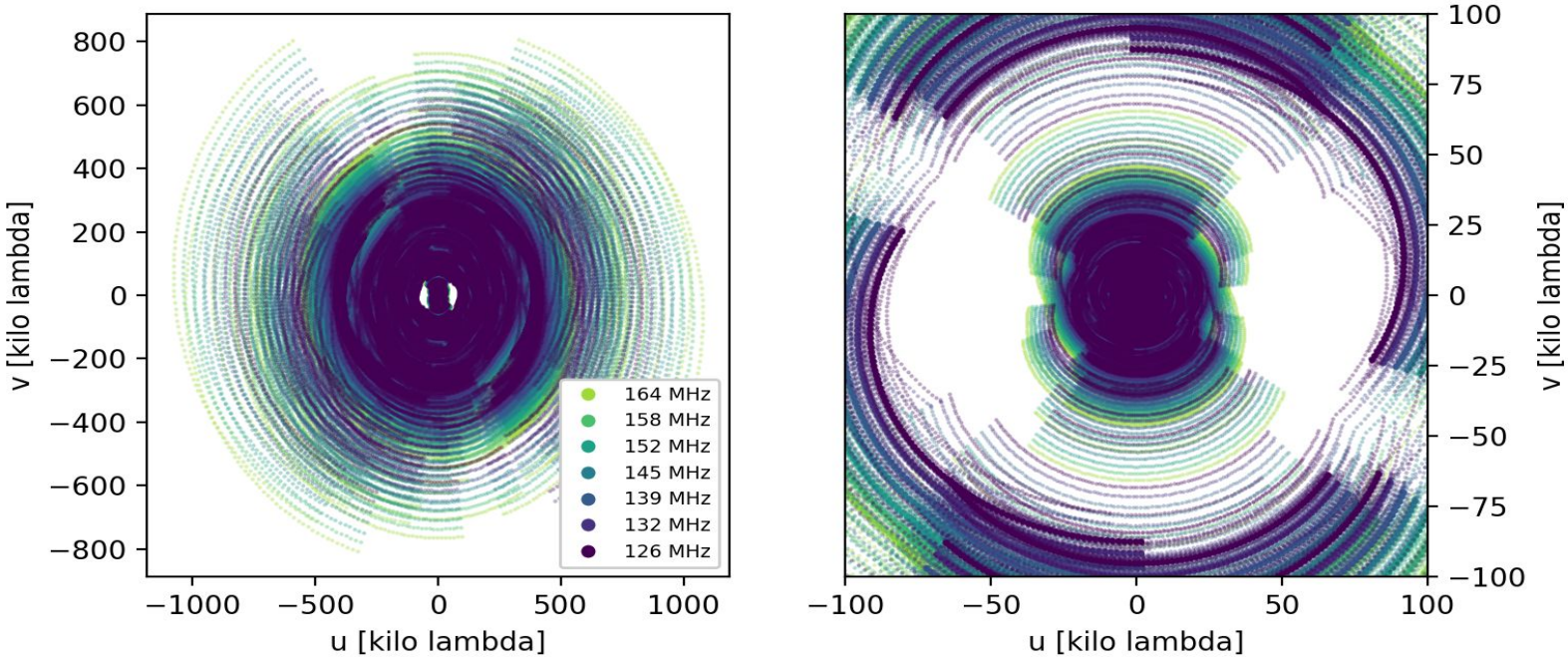


The International LOFAR Telescope





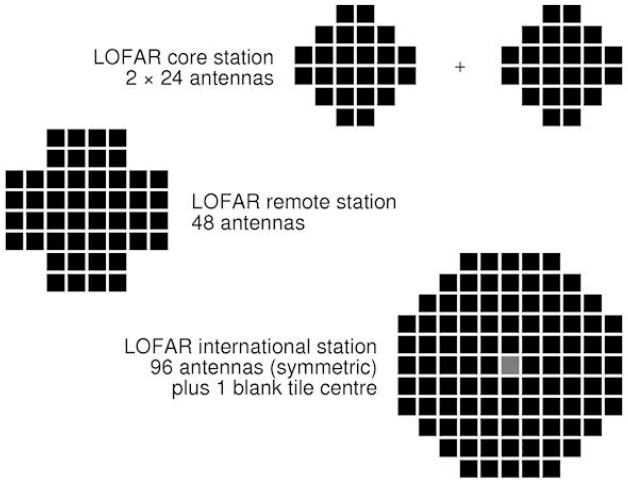
VLBI with LOFAR - *u-v* coverage



VLBI with LOFAR - Field of View (FoV)

Limited by:

- Station beam of international stations



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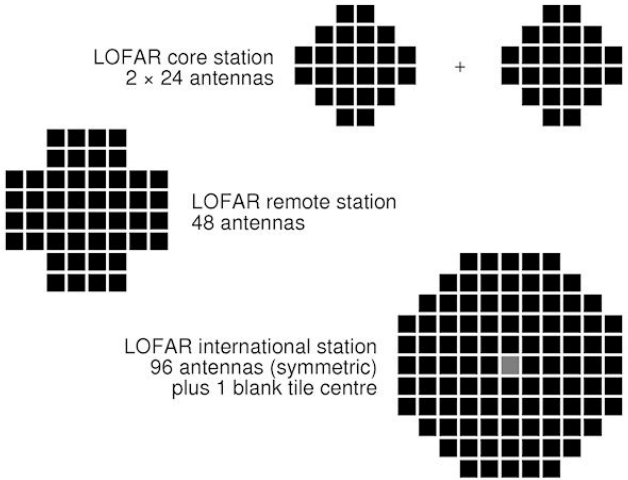
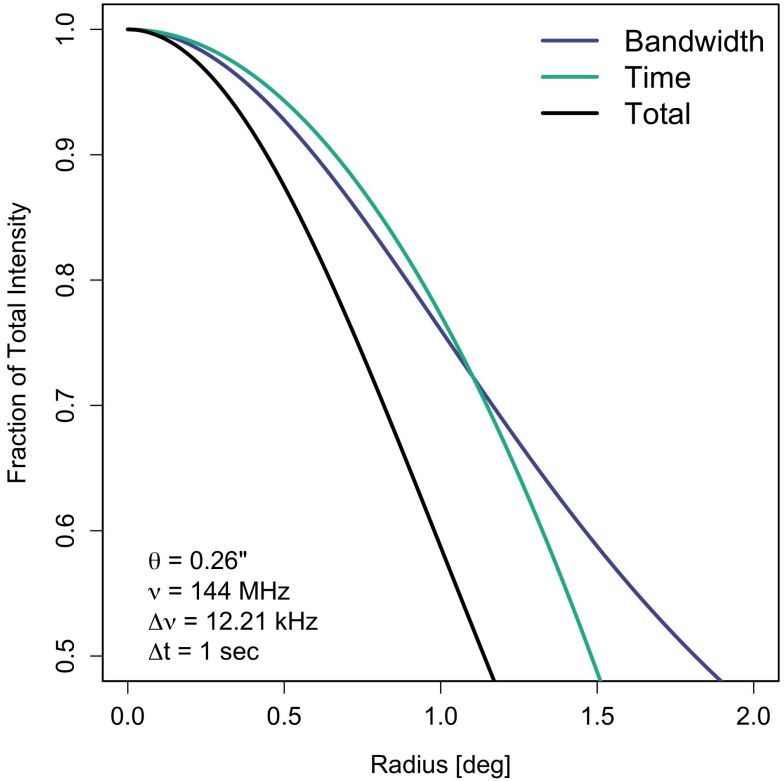
- Smearing (bandwidth and time)





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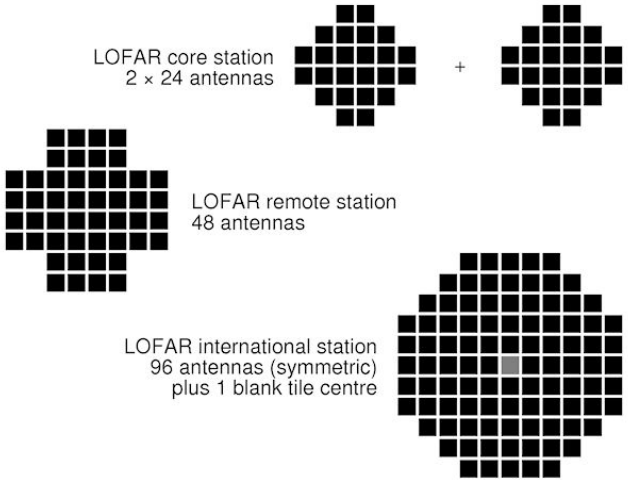

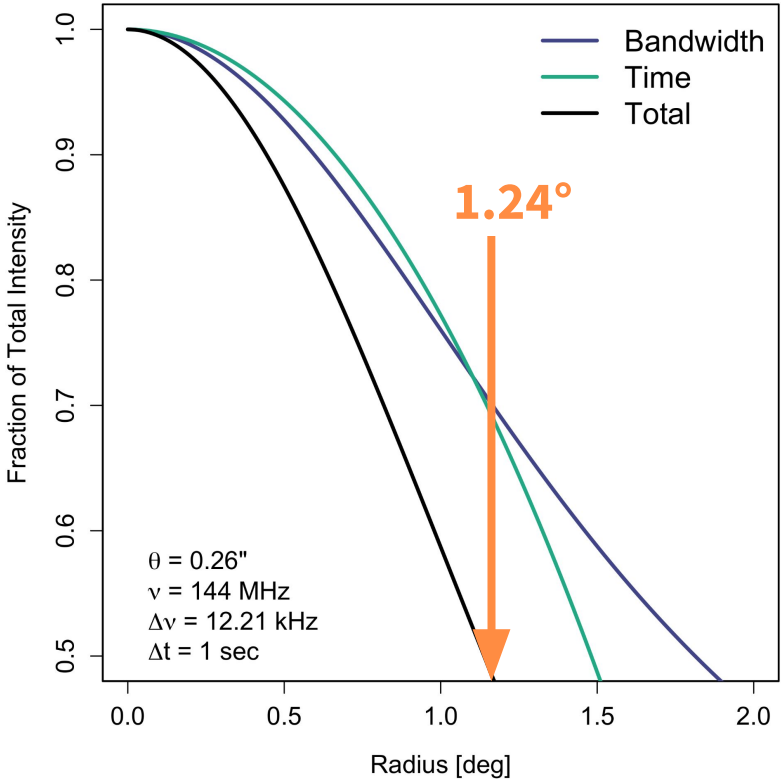

Data calibration challenges

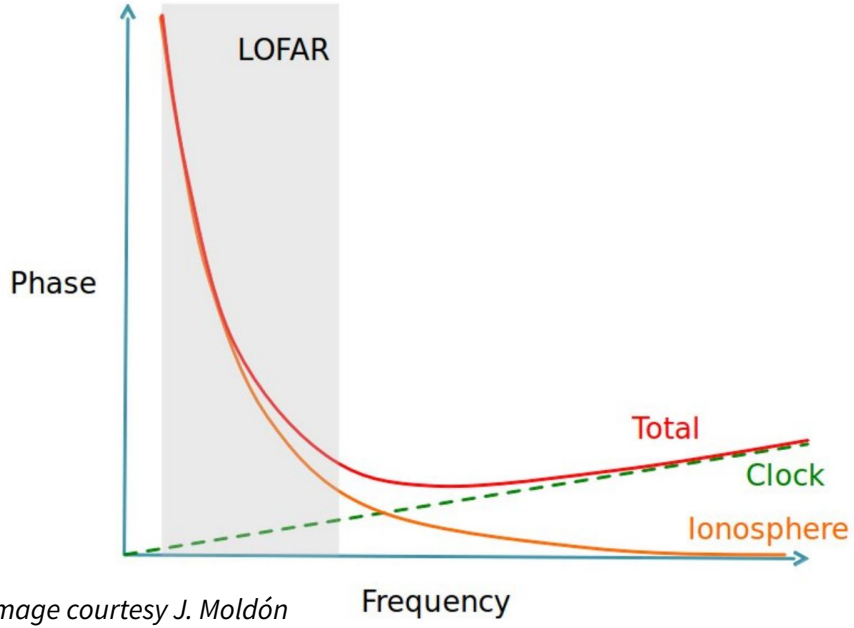

Image courtesy J. Moldón

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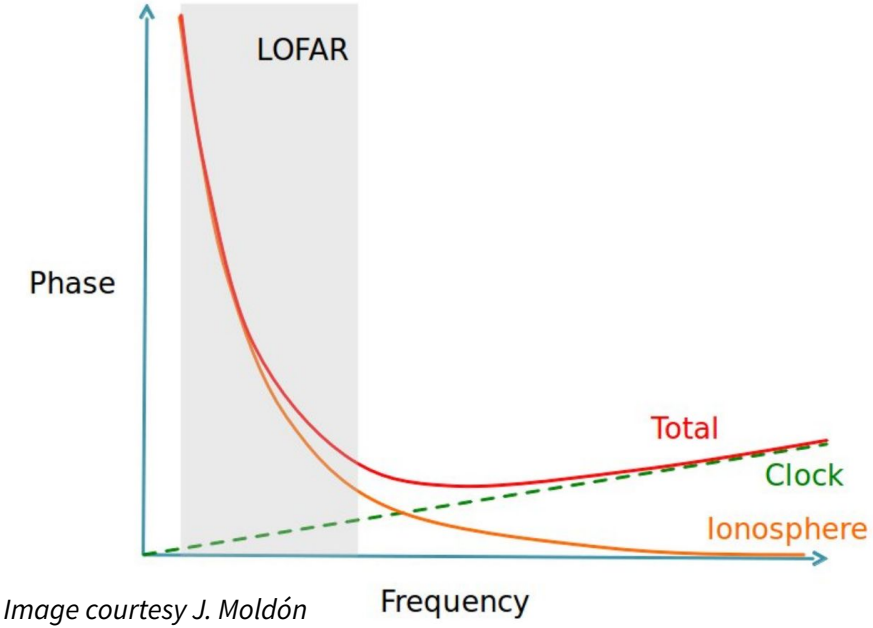

Image courtesy J. Moldón

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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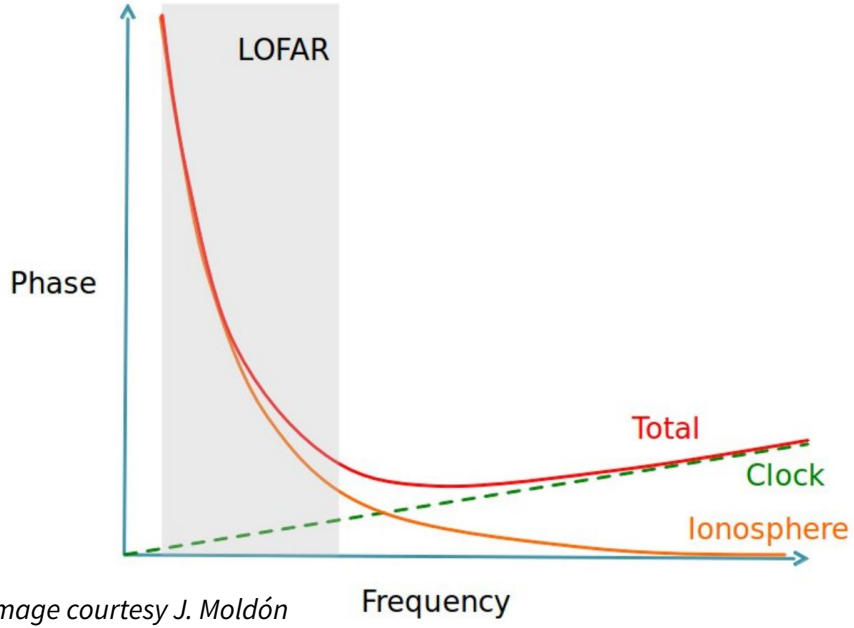

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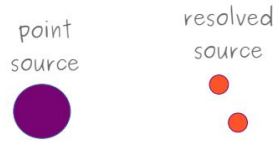
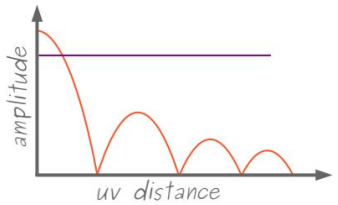
Requires full bandwidth ***or*** enough signal/noise that you can solve for phases in small Δt, $\Delta \nu$





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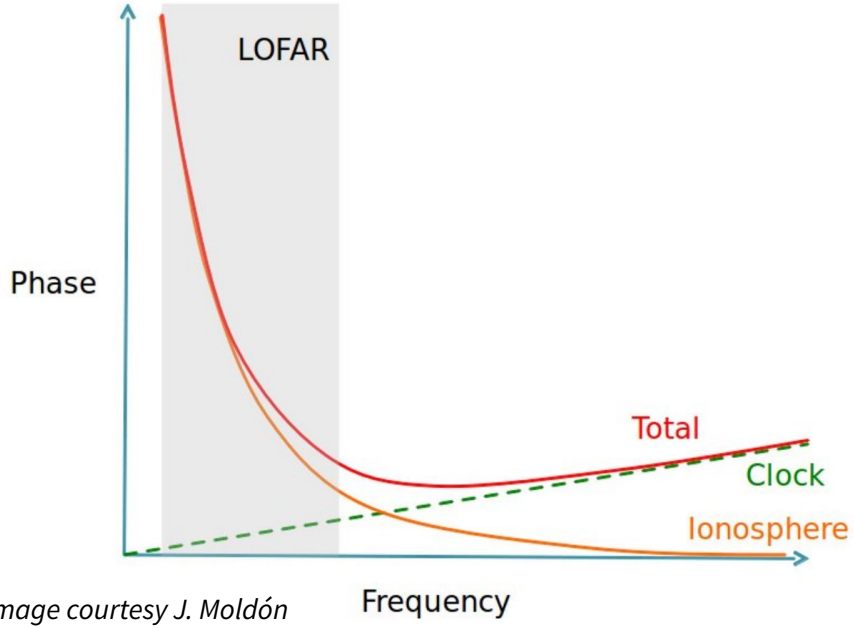

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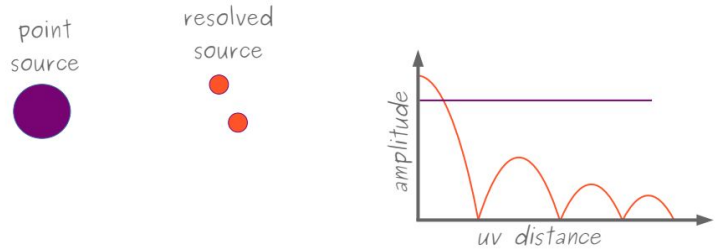

Need a suitable in-field calibrator

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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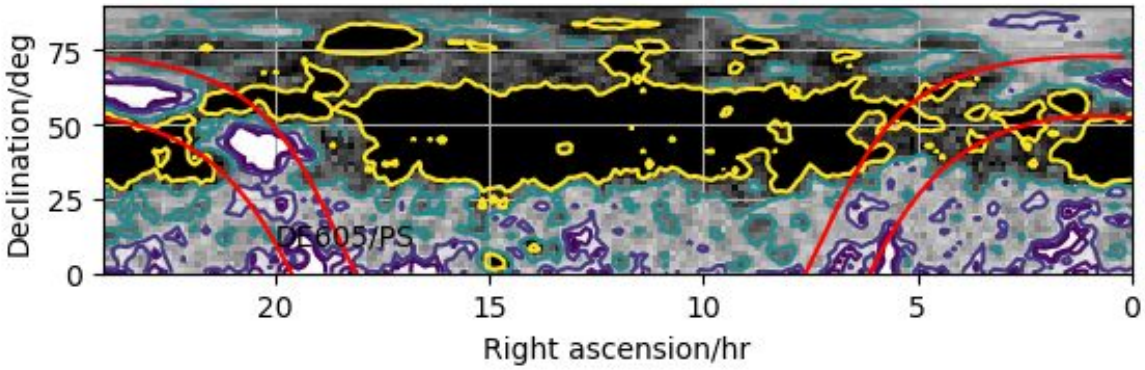
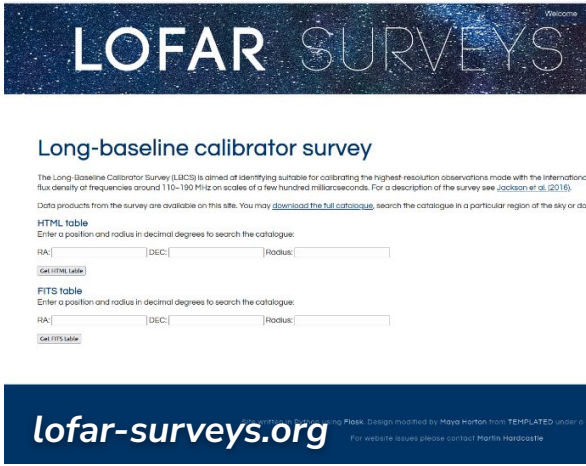
Long Baseline Calibrator Survey (LBCS)

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.





- 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

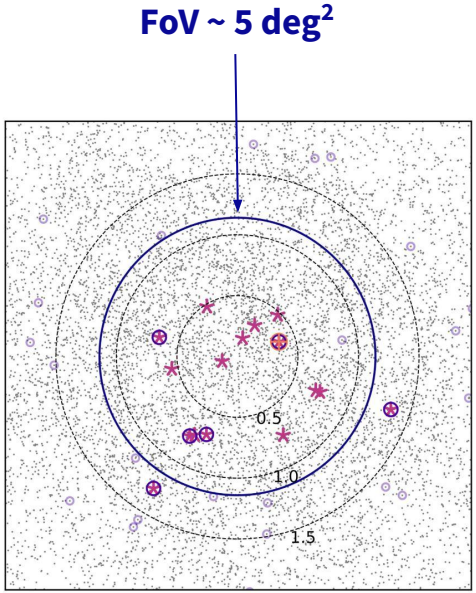
Techniques
- Combine core stations
- Phase-shift & average to reduce FOV
- *now uses facetselfcal!*

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)*



Full demonstration: Morabito et al. (2022)

Demonstration: P205+55

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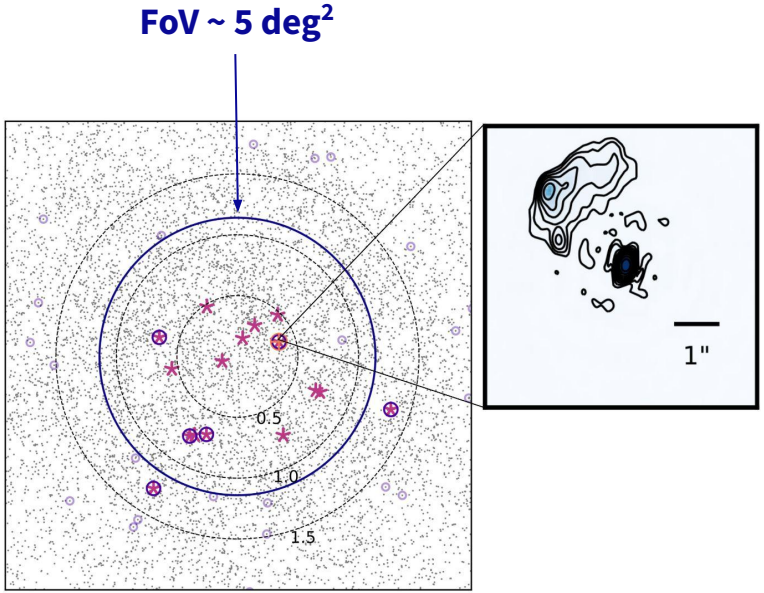
1. Find dispersive delays on best LBCS in-field calibrator



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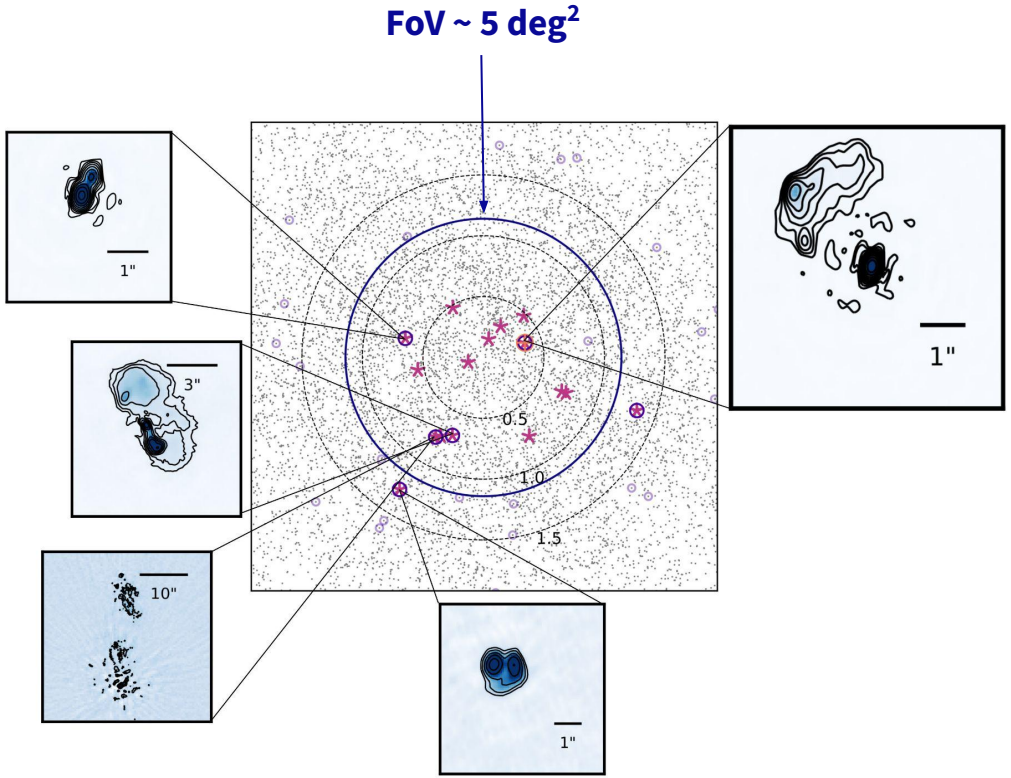
Field of view limited to 1.25° radius *(by smearing and station beams)*

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



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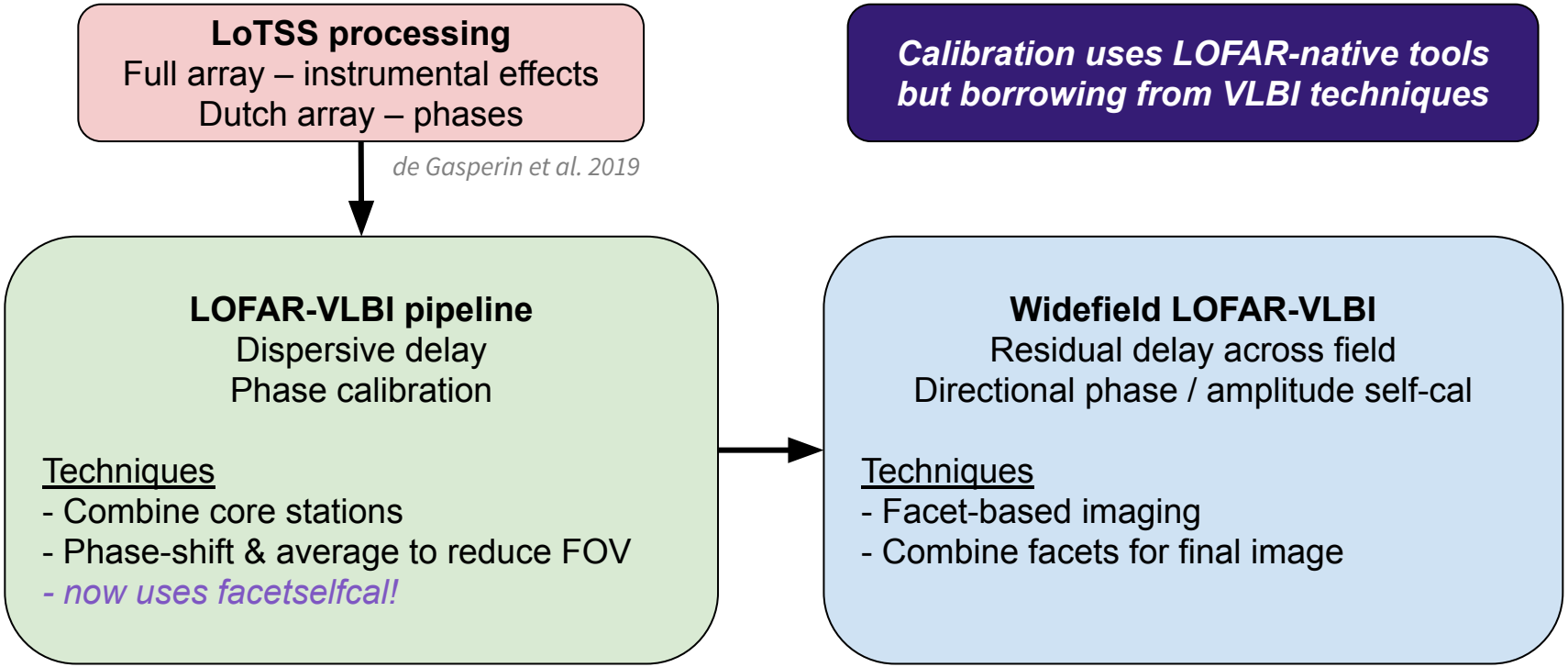
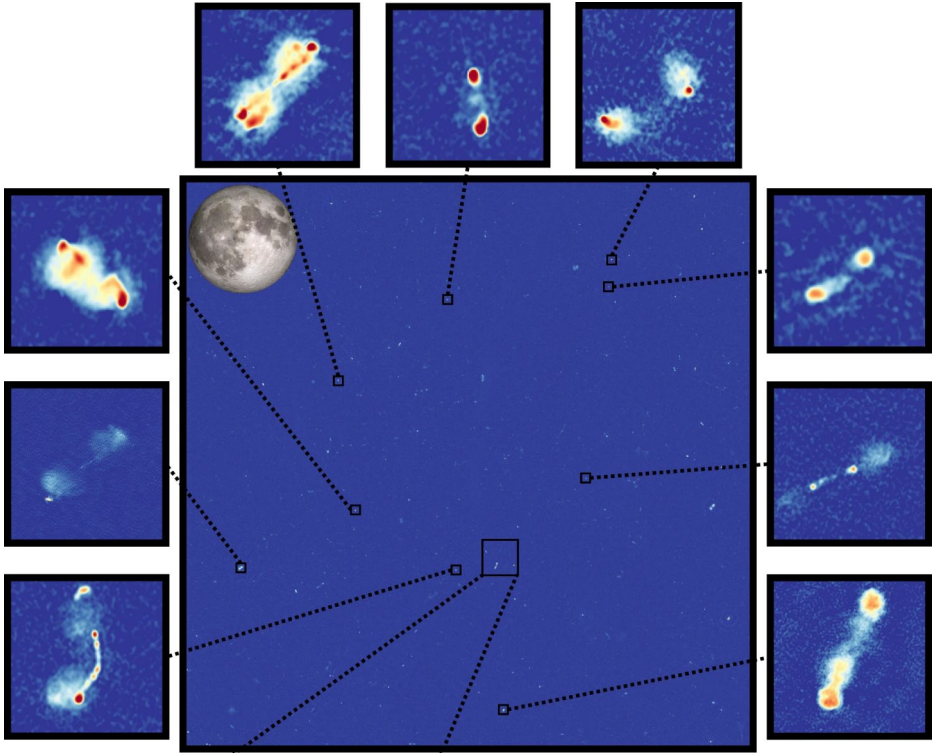
Developing a calibration strategy



Demonstration: Lockman Hole

- 8 hour observation
- 36 μJy/beam median noise
- Field of View - 6.6 deg2
- 2,214 sources
- ***250,000 CPU hours***



Sweijen et al. 2022

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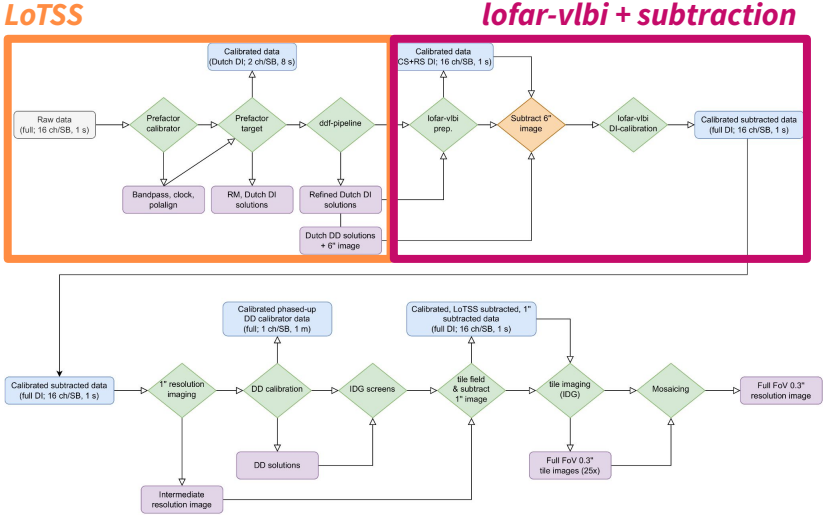

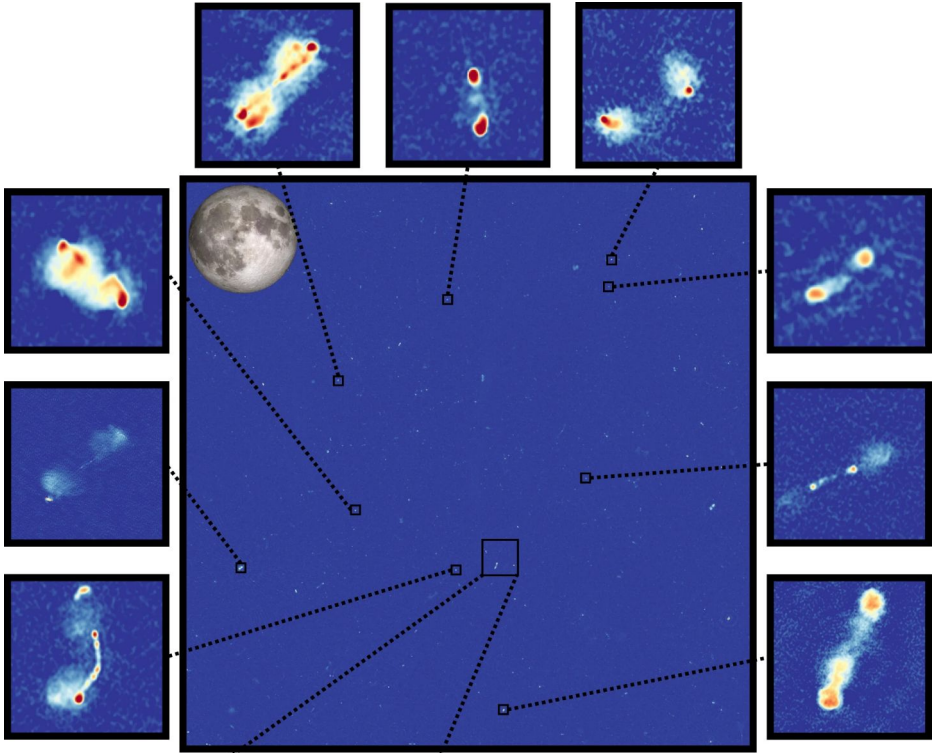

Sweijen et al. 2022

Have we solved all the problems?

- ✓ Long Baseline Calibrator Survey is complete
  - ✓ Still poor coverage below +30° 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