# Beam holography

## LOFAR2.0 development sprint review

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LO-FASTR

# Background

## Calibration strategies for LOFAR2.0

- Aim:
  - Have (at least) **2 methods** for both **station** and **array** calibration

(previous meetings)

- *David McKenna* discussed the classical station calibration method
- *Emma van der Wateren* discussed imaging delays to assess the beamformer coherence

# Background

## Calibrate LOFAR's tied-array beams with holography

- Method described in ***Salas, Brentjens, Bordenave, Oonk & Röttgering (2020, A&A)***
  - *Determine **time delays between stations** in LOFAR core*
  - *LOFAR multibeaming allows to map voltage beam **faster** than a raster scan*

    ➡ *Simultaneous & continuous beam calibration*
- Same principles to **calibrate at station level** *(Brentjens & Bordenave 2017: https://weblectures.leidenuniv.nl/Mediasite/Play/b4f9b2beea6744138fd7ea4c540aeba51d?catalog=63487fe7-4485-43af-b2d9-de2c2ae2fb79)*

# Background

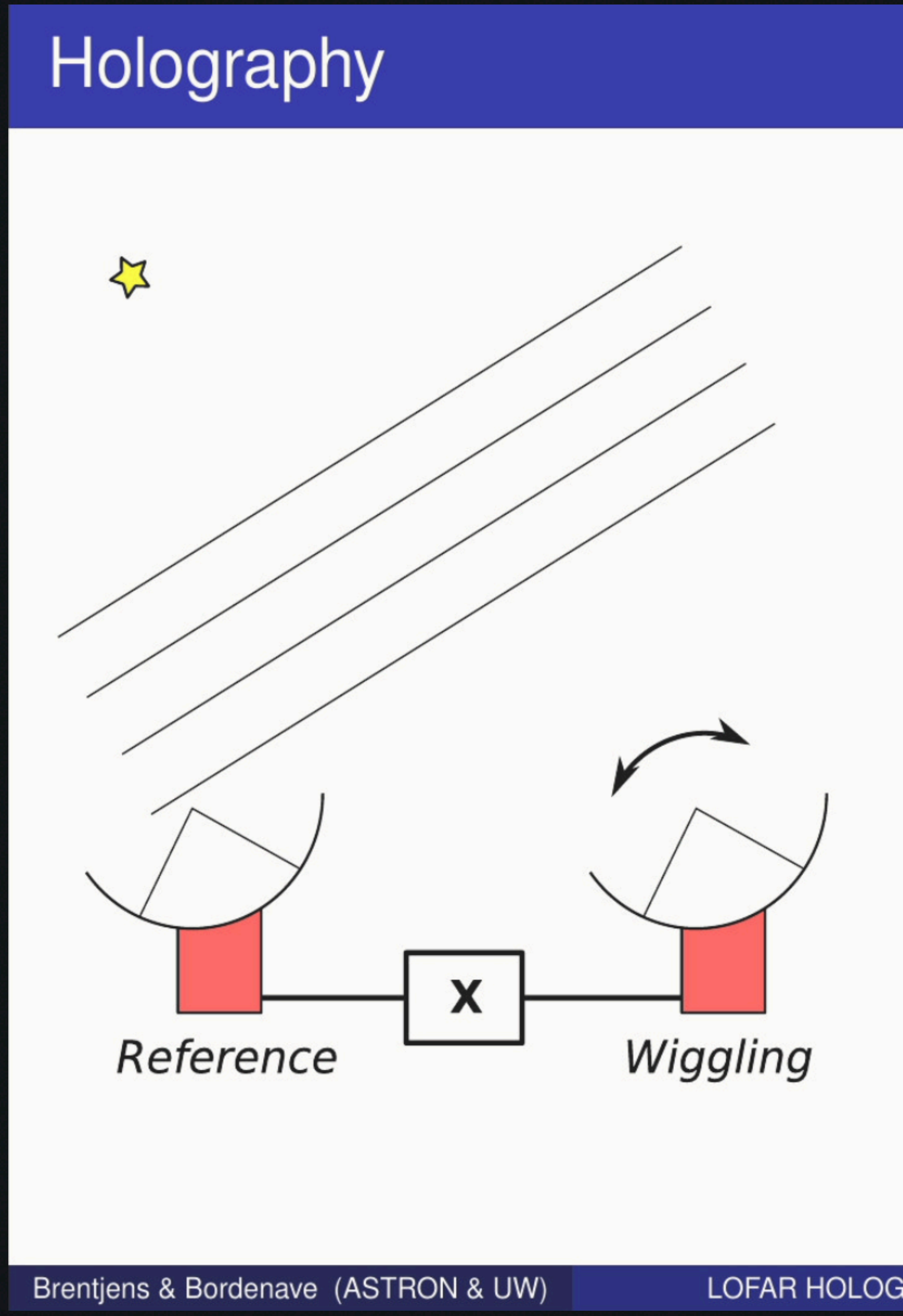
## Tied-array holography

- *Determine **time delays between stations** in LOFAR core*

➡Two station sets:

➡**Reference** station points at a bright compact source

➡**Target** stations (array under test): multibeam at and around source



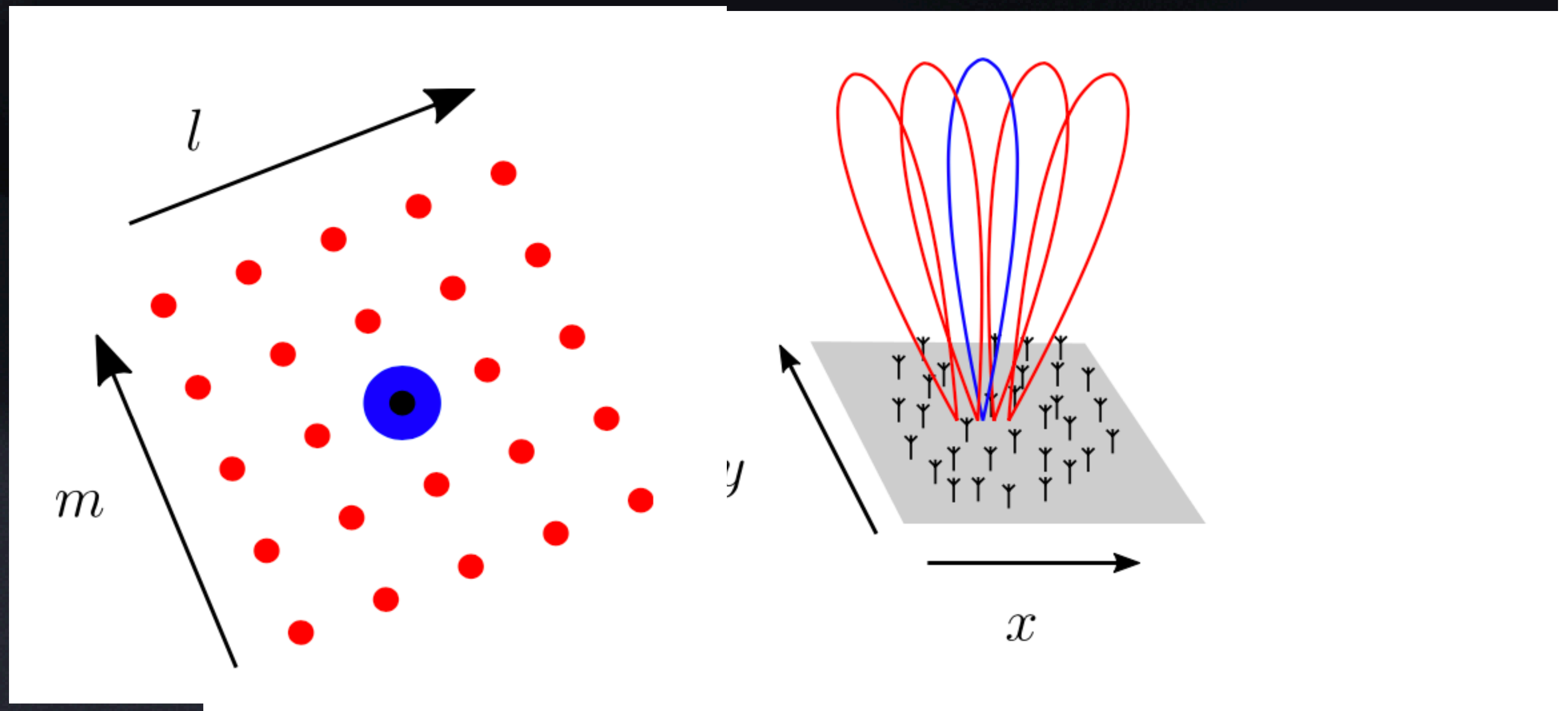




**Figure 2.** Sketch of holographic measurements for phased arrays. All beams can be formed at once in post-processing.

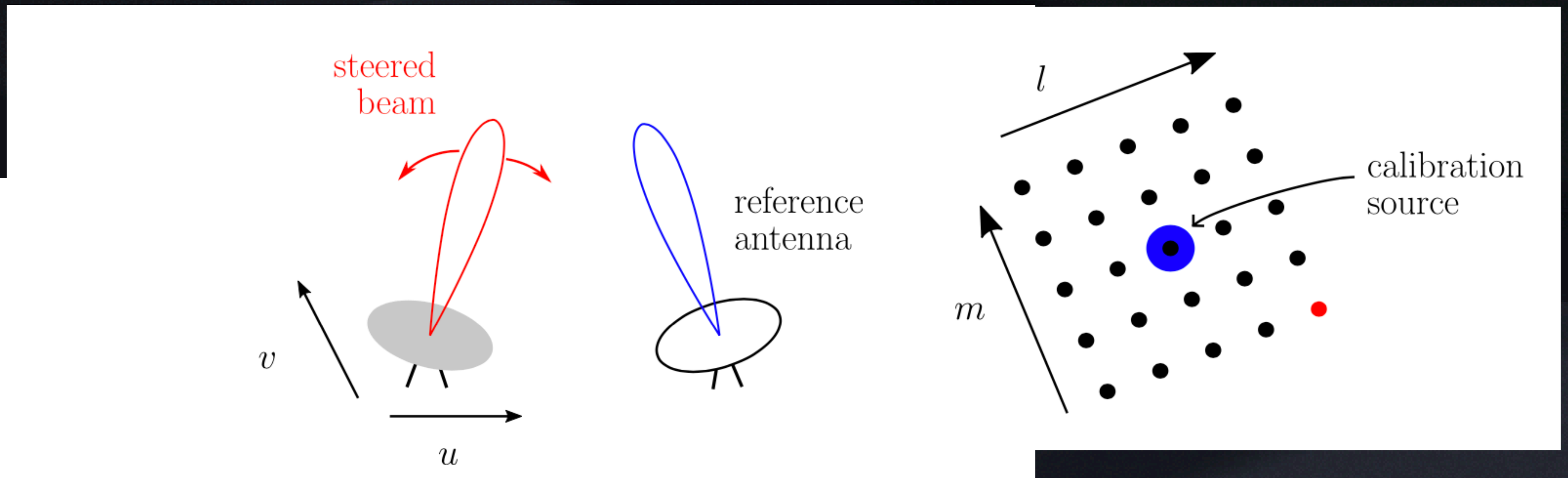



**Figure 1.** Sketch of the holographic measurement procedure for dish antennas. A separate reference antenna stays focused on the calibration source, while the AUT is adjusted to various *lm*-coordinates. The coordinate axes are drawn such that we are looking "down" on both the antennas and the sky.

Kiefner et al. 2021

Kiefner et al. 2021

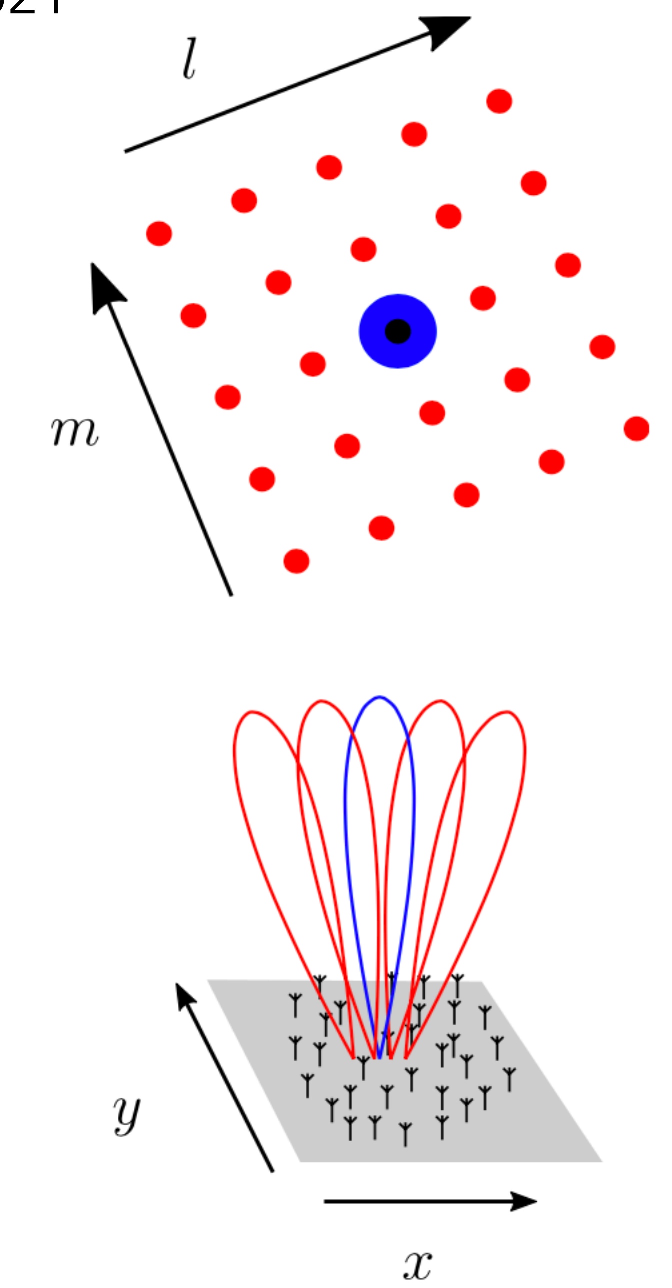
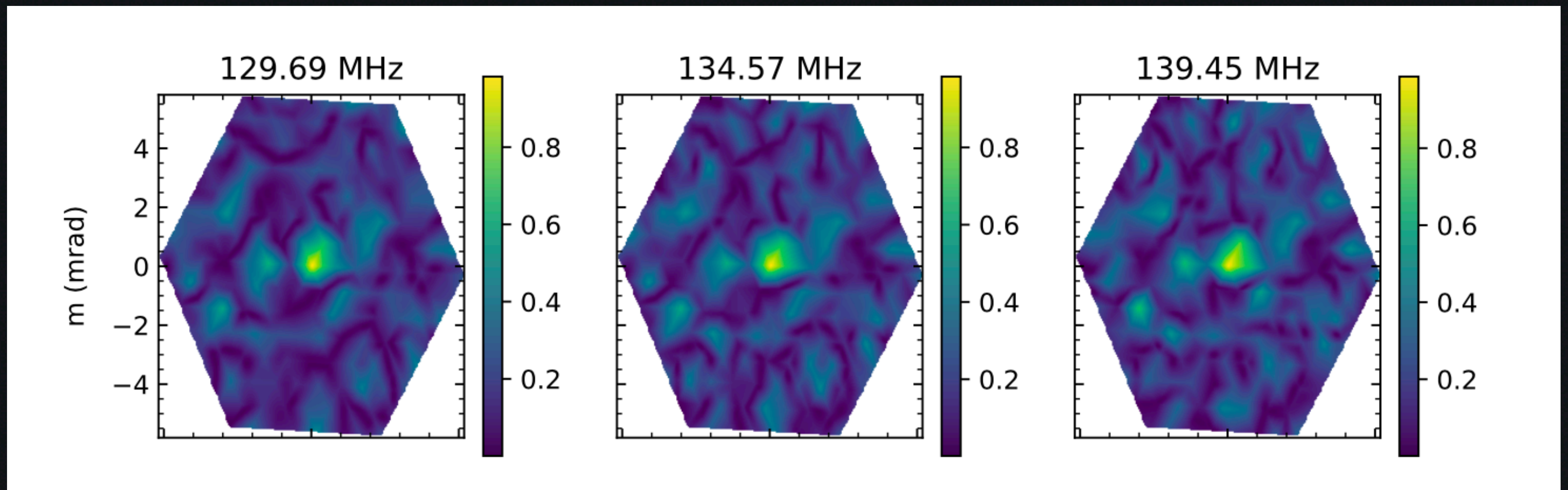
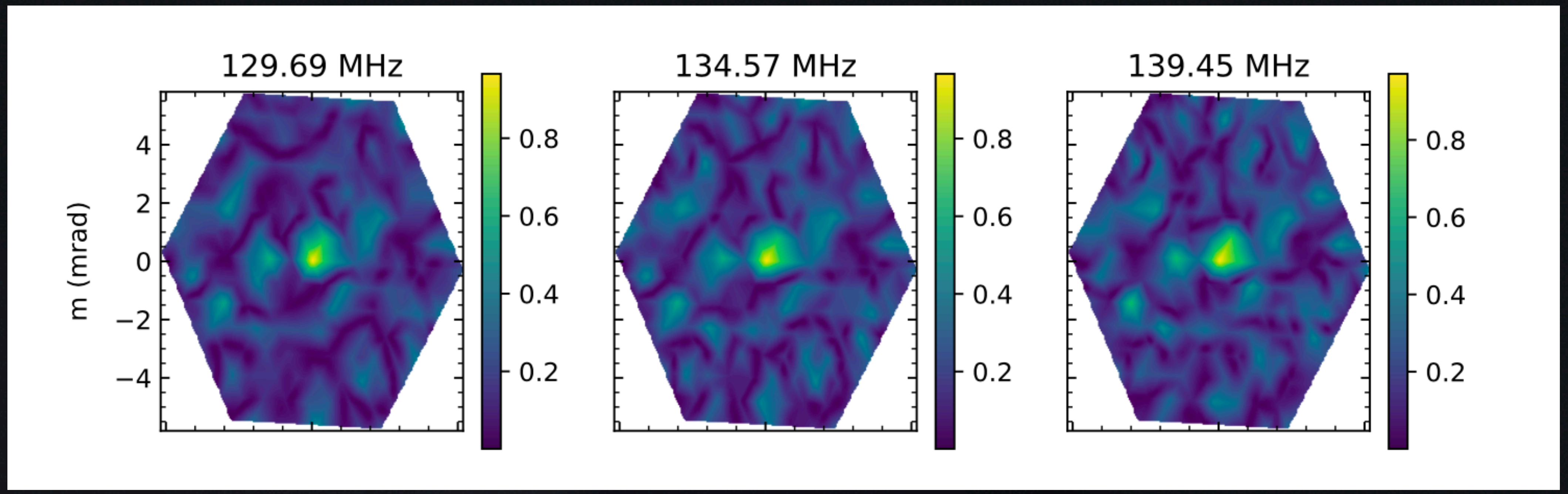



**Figure 2.** Sketch of holographic measurements for phased arrays. All beams can be formed at once in post-processing.

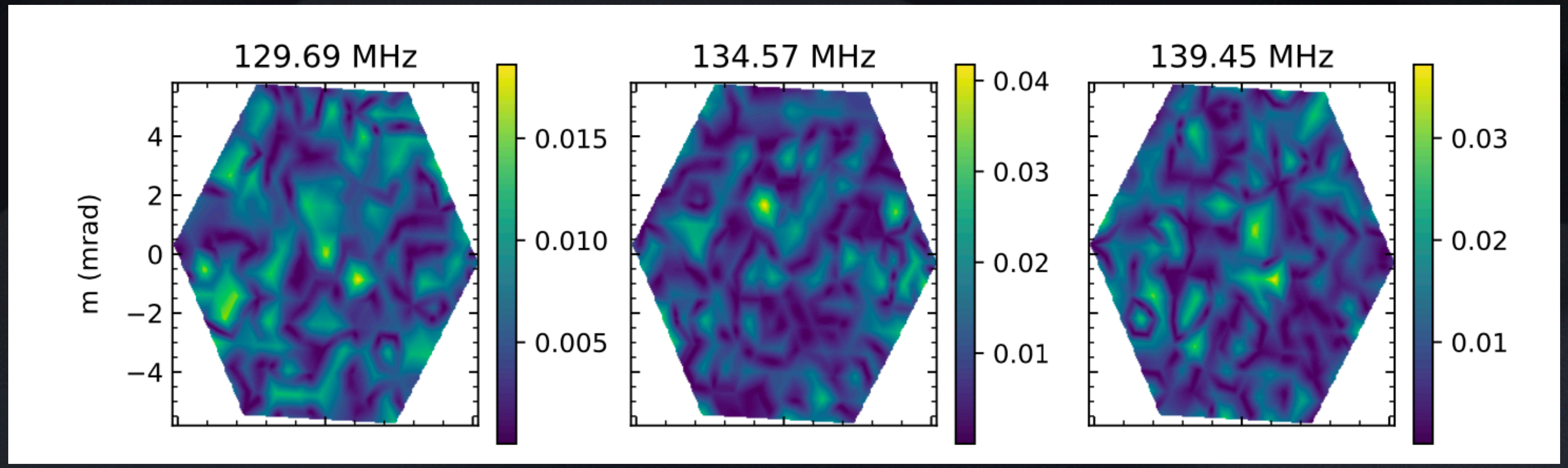
Observed beam




Model beam




Residual



Kiefner et al. 2021

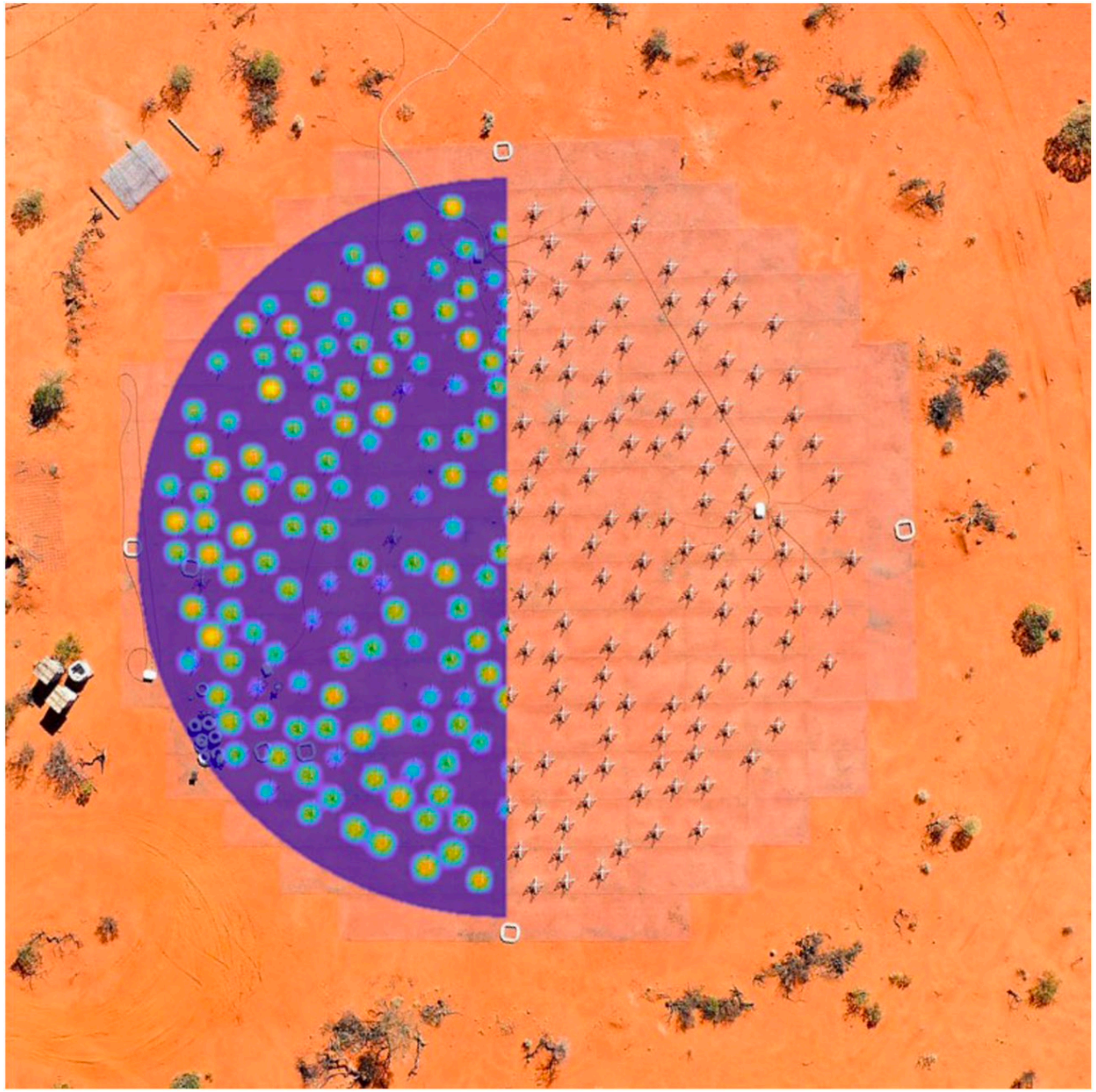


**Figure 10.** Overlay of an aperture image with an aerial drone photo of the EDA-2. The aperture image is partially transparent, and antenna dipoles can be seen in the locations of the peaks in the aperture as expected.

Salas et al.

# Background

## Tied-array holography

- Aims here:
  - Make code user-friendly (eventually for LOFAR2.0 operators)
  - Make code modular (simplify updates in method / new test / modes)
  - Make code faster? (e.g. A. Gopinath's fast imaging to search for FRBs)

# Update

## Tied-array holography

- ***holog*** (P. Salas) (which relies lightly on ***taholog*** by M. Brentjens)

1. Converted from Python 2 to 3, and containerized to singularity
    - Tested to reproduce results w/ Salas et al. original observations (L697741)
2. Refactored code for **modular** runs
    - **Profiled** the code per step to evaluate bottlenecks
        - For a 60 second observation:
            - Single-threaded mode: ~**12 hours** ; Multi-threaded w/ 16 cores ~**2 hours 20 min**

# Update

## Tied-array holography

- After refactoring

atomic

```
method:serial, cuda, to_disk:True
0:00:11.279658

method:serial, cuda, to_disk:False
0:00:07.362257

method:serial, numpy, to_disk:True
0:00:16.752776

method:serial, numpy, to_disk:False
0:00:17.500211

method:serial, pyfftw, to_disk:True
0:00:36.808636

method:serial, pyfftw, to_disk:False
0:00:30.844438
```

block

still needs
global custom cuda
kernel

```
method:multiprocessing, cuda, to_disk:True
0:01:54.367784

method:multiprocessing, cuda, to_disk:False
0:01:54.501390

method:multiprocessing, numpy, to_disk:True
0:01:52.948554

method:multiprocessing, numpy, to_disk:False
0:01:52.819608

method:multiprocessing, pyfftw, to_disk:True
0:01:48.968451

method:multiprocessing, pyfftw, to_disk:False
0:01:49.682640
```

# Update

## Tied-array holography

```
# FFT
time python main.py --parallel --no-use_gpu --no-use_pyfftw --to_disk --verbose
--target_id 'L2036952' --reference_ids 'L2036944' --input_dir ‘/path_to/taholog/' --output_dir '/path_to/output/'
--steps  'to_freq'  >> ../taholog_L2036952_parallel_no-use_gpu_to_disk.out 2>&1

real    24m1.301s
user    60m5.783s
sys     176m4.354s


# Correlation
Singularity> time python main.py --parallel --no-use_numba --no-use_gpu --no-use_pyfftw --to_disk --verbose
--target_id 'L2036952' --reference_ids 'L2036944' --input_dir '/path_to/taholog/' --output_dir '/path_to/output/'
--steps  'xcorr' 'plot_beam' >> ../taholog_L20369
52_xcorr_till_end.out 2>&1

real    36m36.055s
user    294m41.879s
sys     135m31.484s

# MAKE PLOT
Singularity> time python main.py --parallel --no-use_numba --no-use_gpu --no-use_pyfftw --to_disk --verbose
--target_id 'L2036952' --reference_ids 'L2036944' --input_dir '/path_to/taholog/' --output_dir '/path_to/output/'
--steps 'gencal' 'applycal' 'clip' 'average_t' 'to_uvhol' 'average_uvhol' 'solve_uvhol' 'order_sols' 'plot_report' >> ../taholog_L2036952_till_end.out 2>&1

real    2m17.000s
user    8m30.428s
sys     1m24.203s
```

# Further development

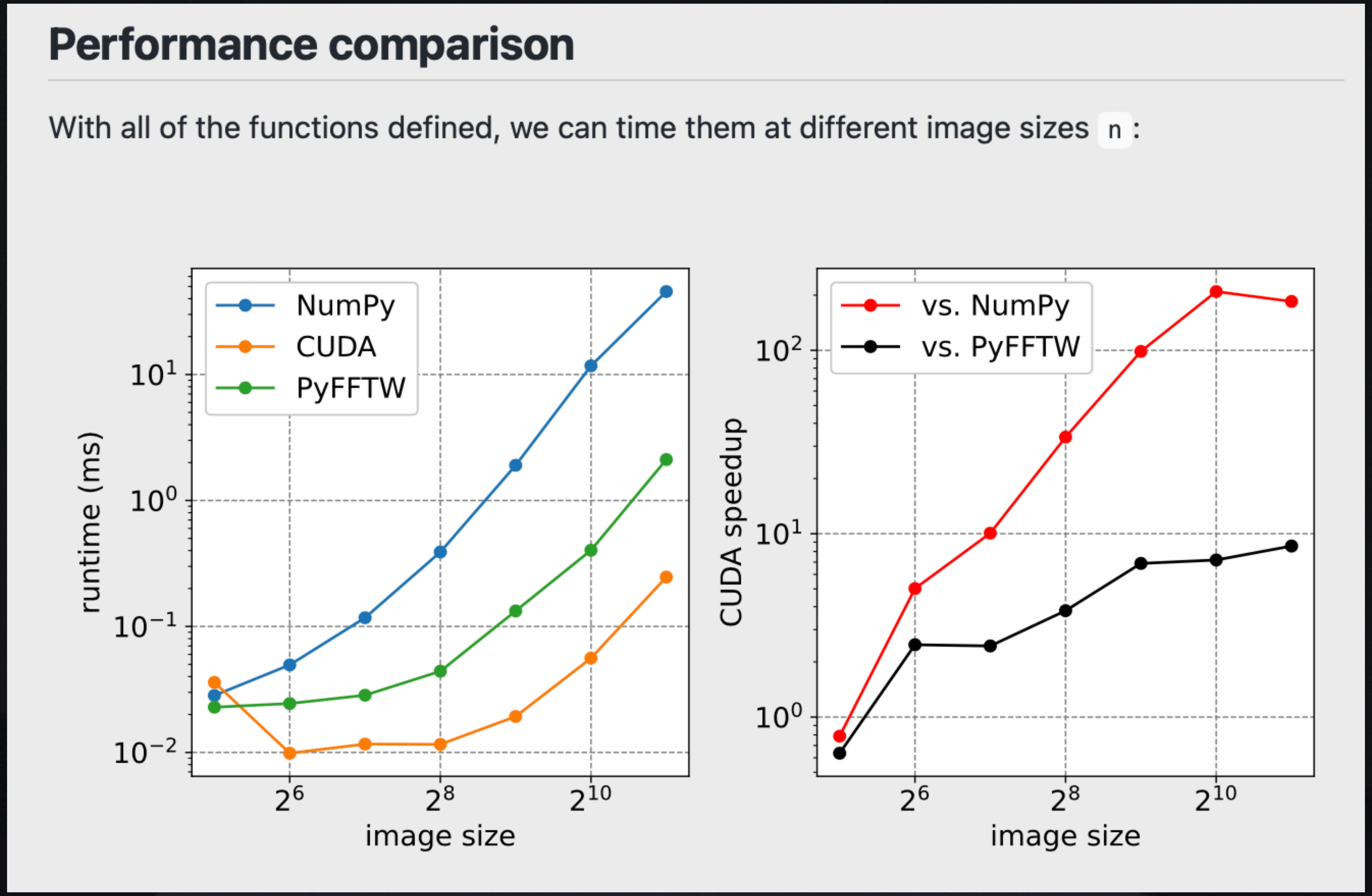
## Updated observation strategy with TMSS: *updated data structure*

- Gathered recent observation through TMSS (w/ C. Bassa) to reproduce original observation
- Now stored into a single HDF5 file as different beams. The test station was recorded by itself.
- Long term,  best to simply schedule a single observations that would include both the reference and test stations into a single file (and hence, need only to schedule a single observation, instead of two simultaneous observations).

# Current and next steps

## LOFAR2.0

- Finish fixes to new format
- Enable FFTs and correlation onto GPU
- Documentation & tests




johnaparker.com/blog/fft_2d_performance