LOFAR2.0 Telescope Commissioning

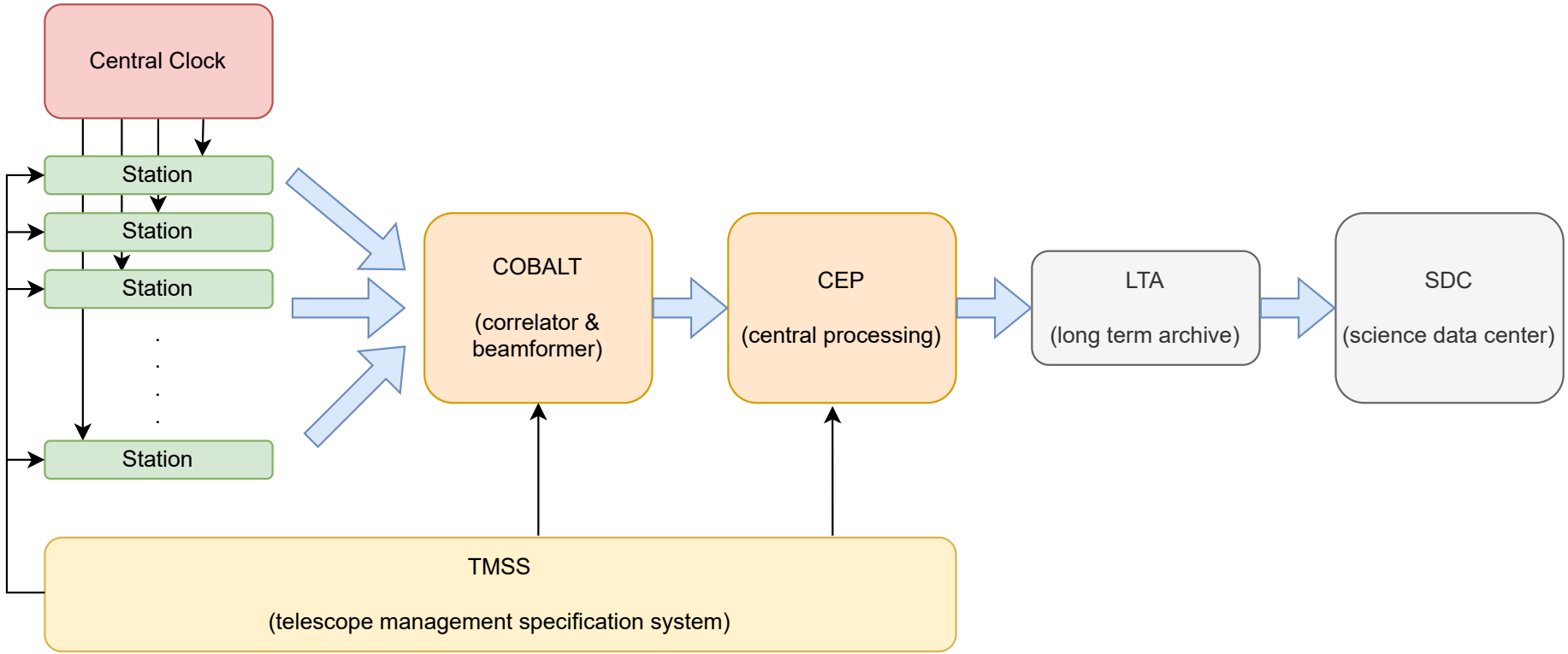
Cees Bassa

On behalf of LOFAR2.0 development and commissioning teams

2024 LOFAR Family Meeting

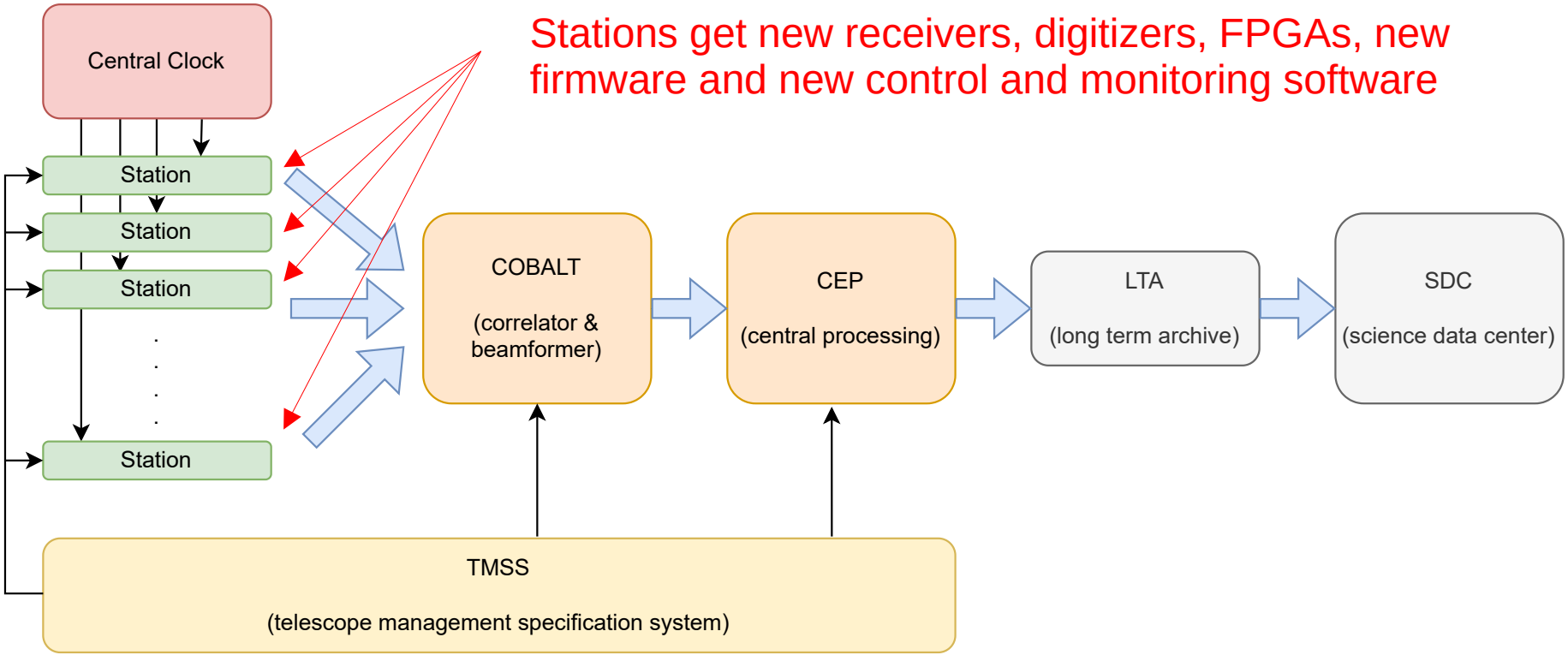
ASTRON
Netherlands Institute for Radio Astronomy

What is changing in LOFAR2.0?



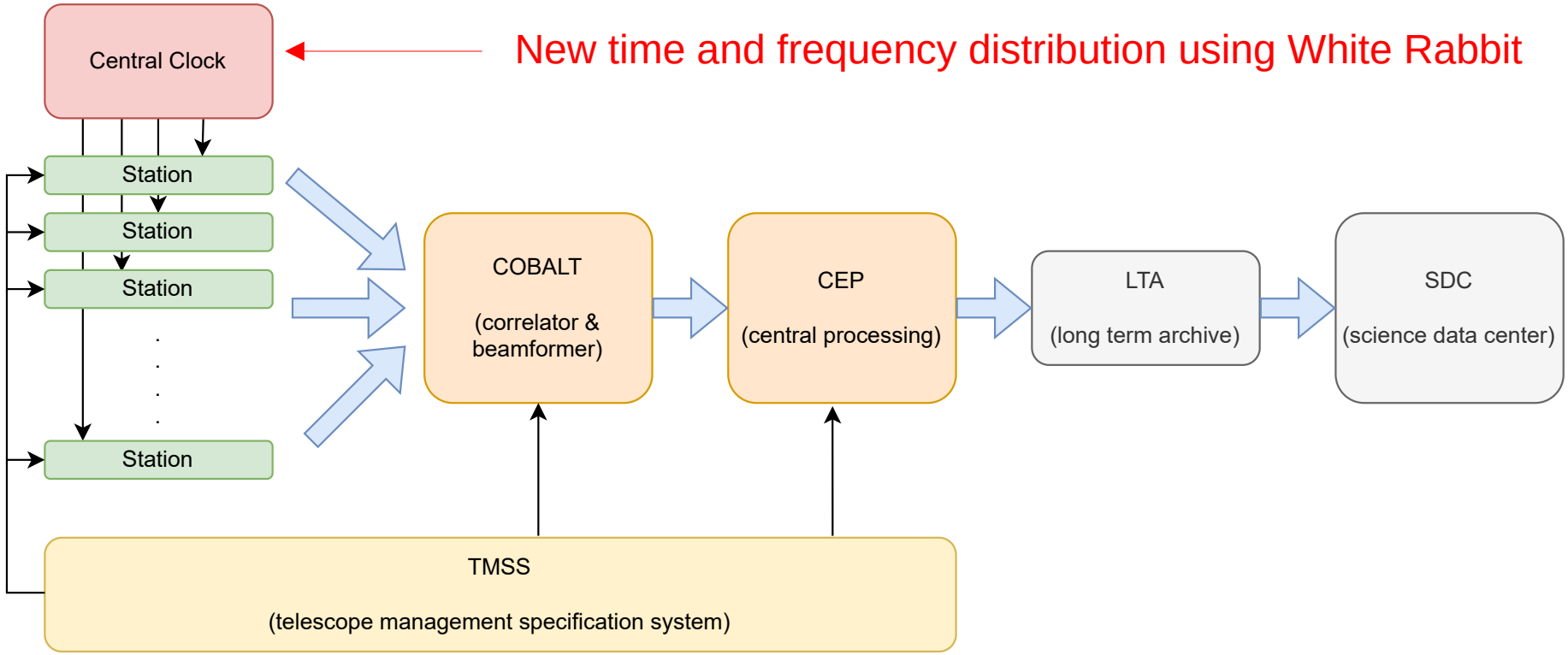
ASTRON
Netherlands Institute for Radio Astronomy

What is changing in LOFAR2.0?

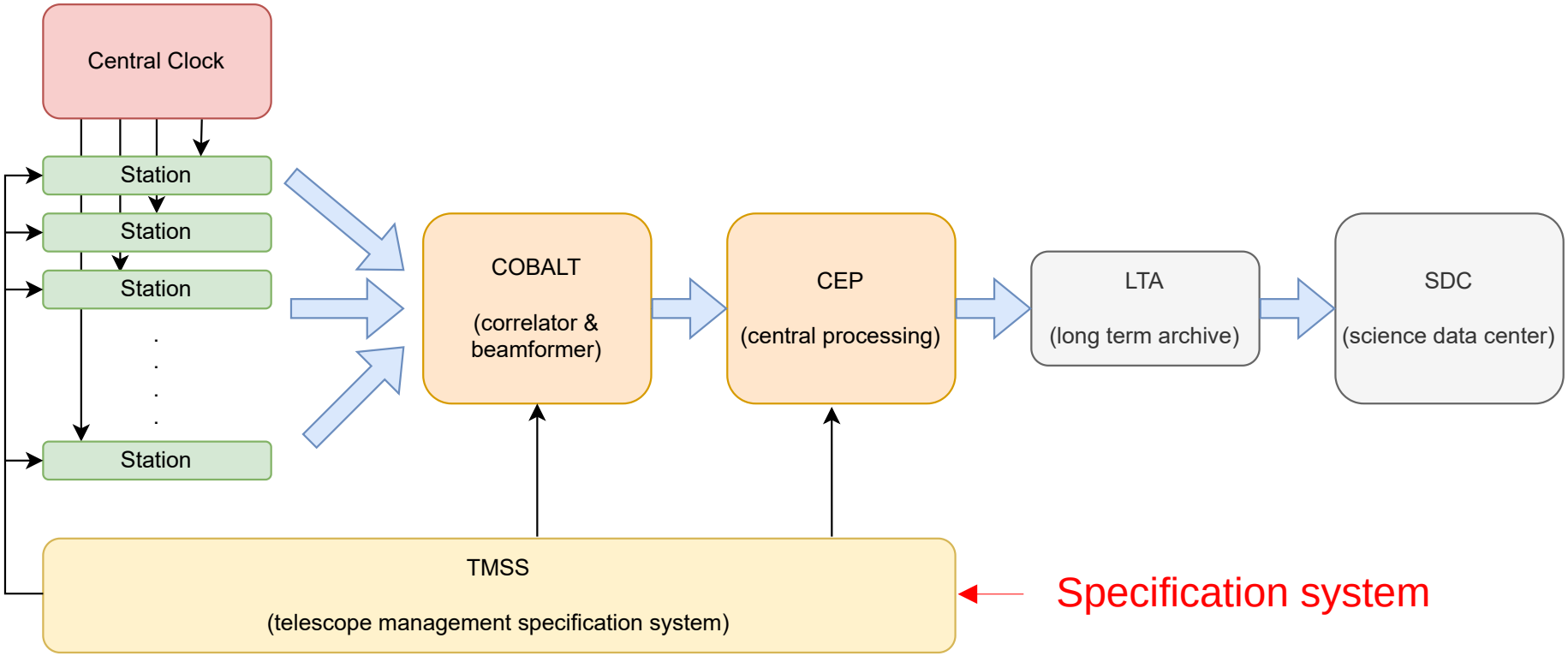


ASTRON
Netherlands Institute for Radio Astronomy

What is changing in LOFAR2.0?

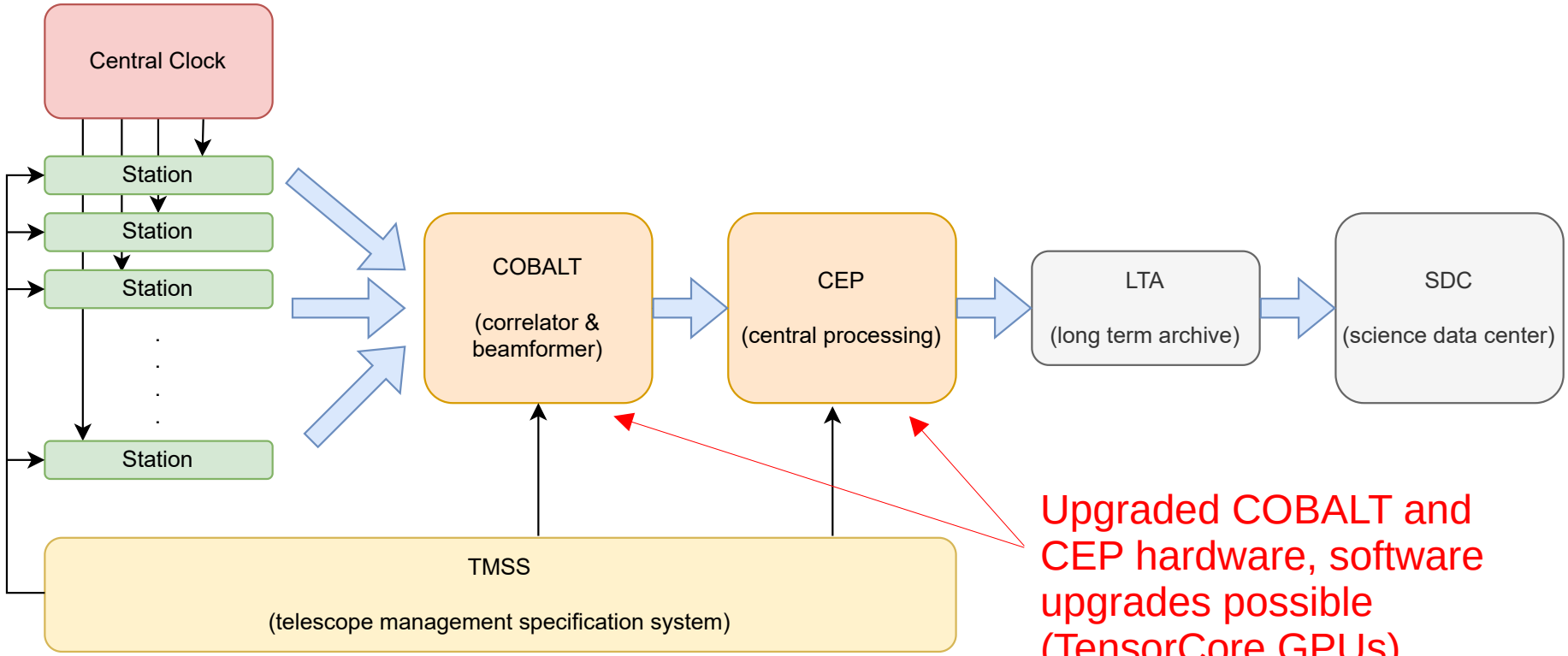


What is changing in LOFAR2.0?



ASTRON
Netherlands Institute for Radio Astronomy

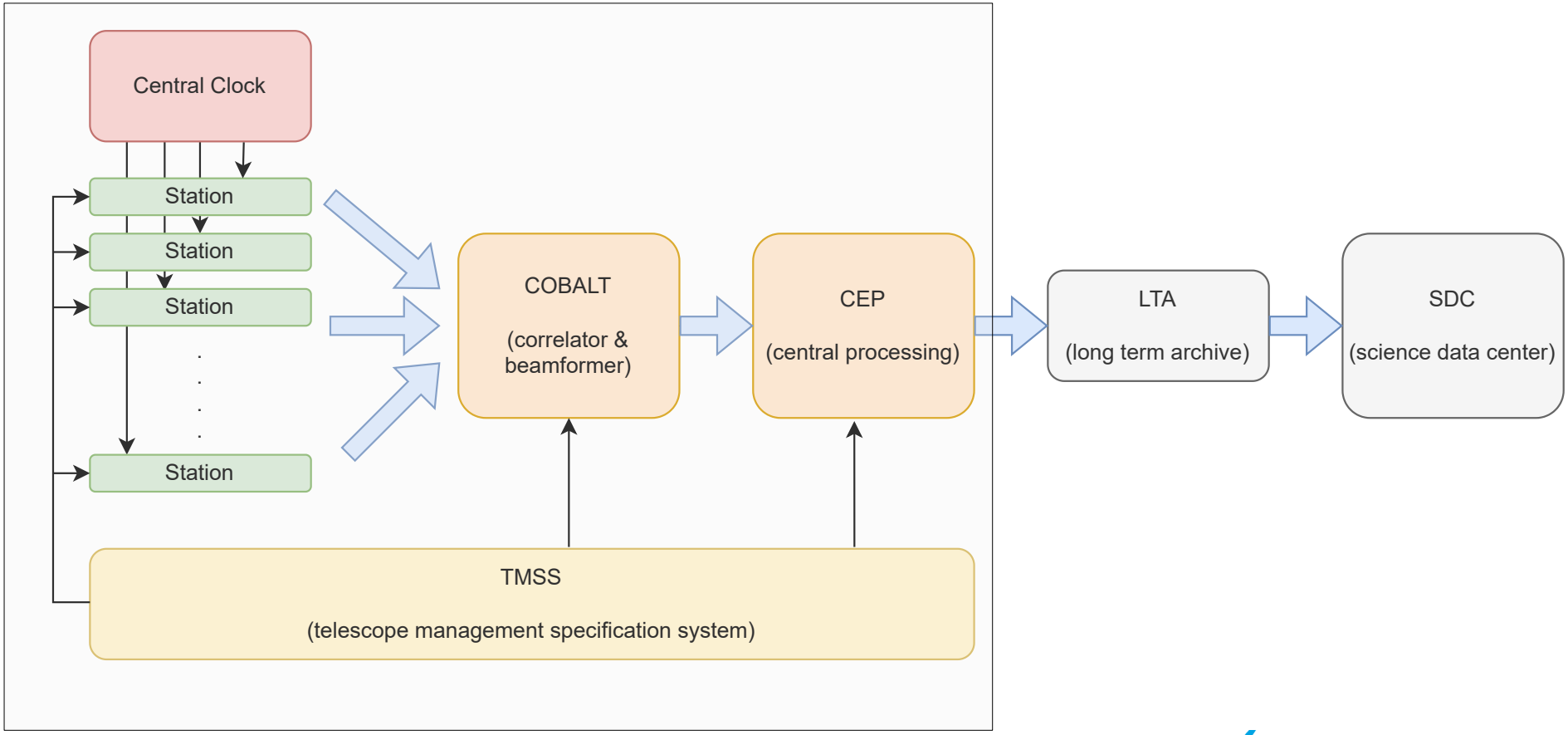
Upgrading COBALT, CEP and network



Upgraded COBALT and CEP hardware, software upgrades possible (TensorCore GPUs)

ASTRON
Netherlands Institute for Radio Astronomy

What is changing in LOFAR2.0?

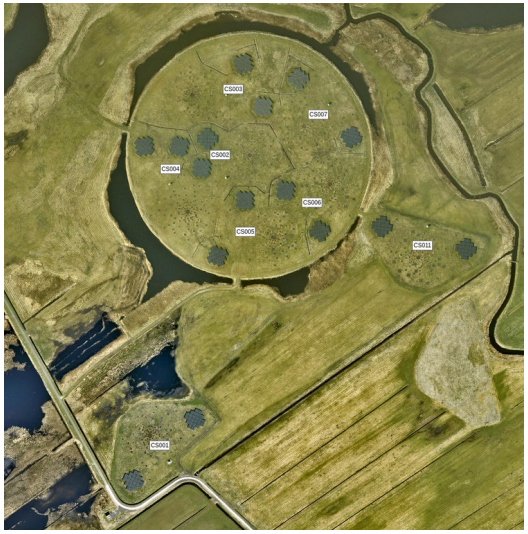


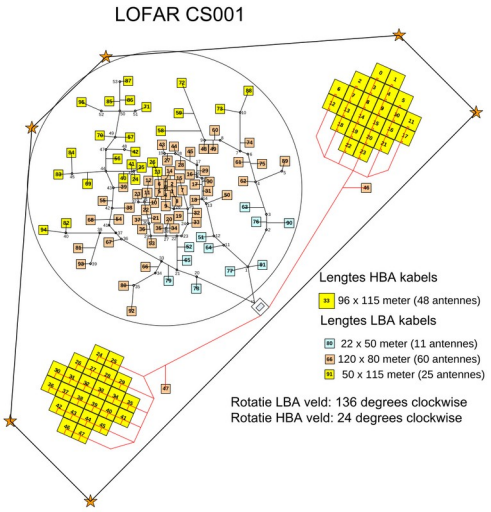
ASTRON
Netherlands Institute for Radio Astronomy

LOFAR 2.0 Test Station (CS001)

Since July 2023:

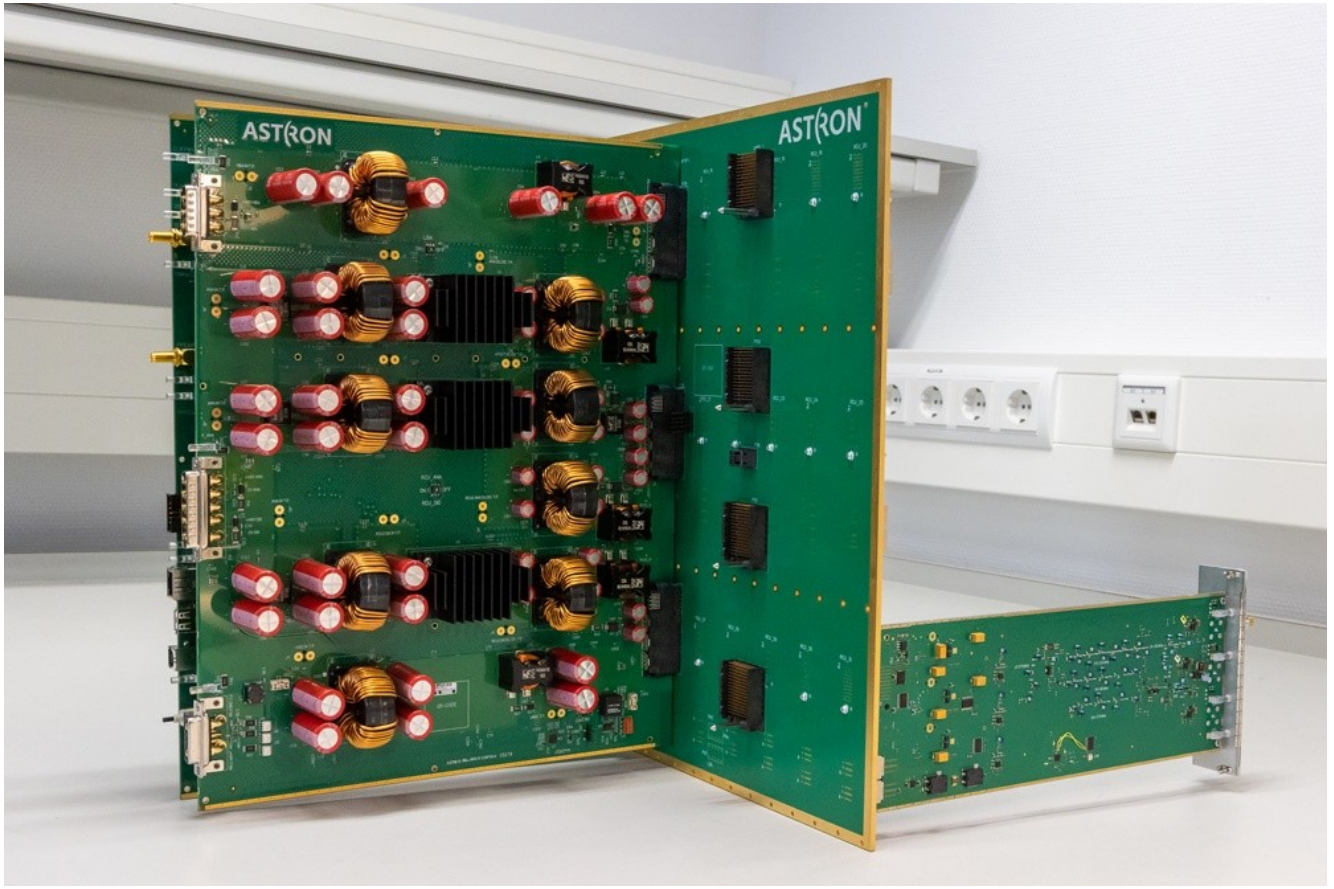
- New receiver boards (RCUs)
- New FPGA boards (UniBoard)
- New FPGA firmware
- New power supply hardware
- New clock distribution (White Rabbit)
- New monitoring and control software





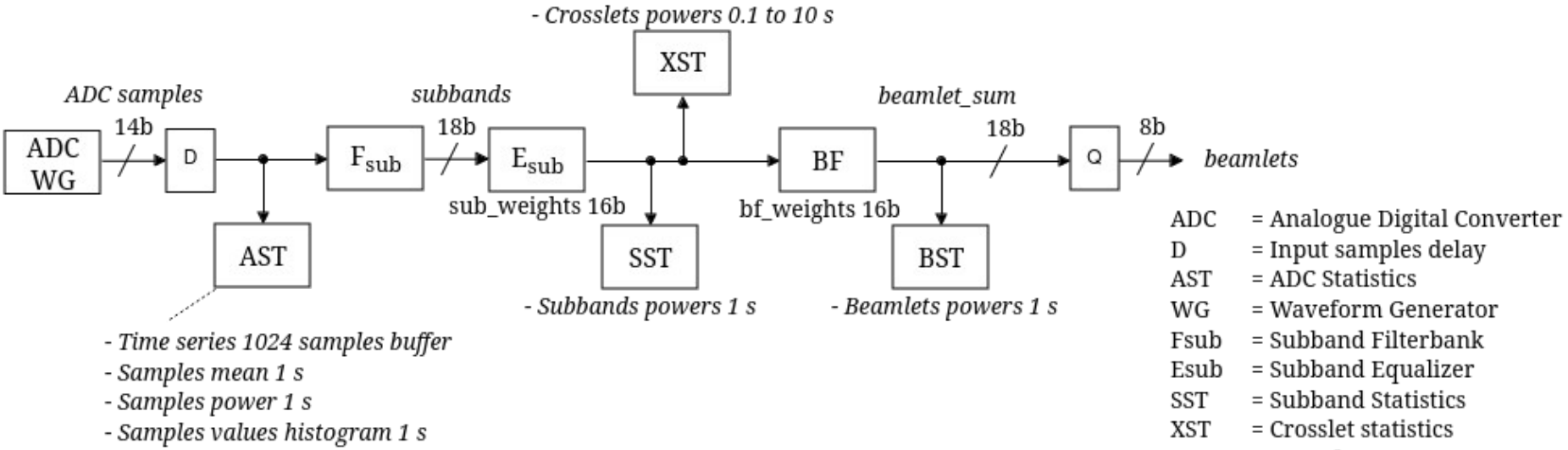
ASTRON
Netherlands Institute for Radio Astronomy

LOFAR2.0 hardware: subrack assembly



ASTRON
Netherlands Institute for Radio Astronomy

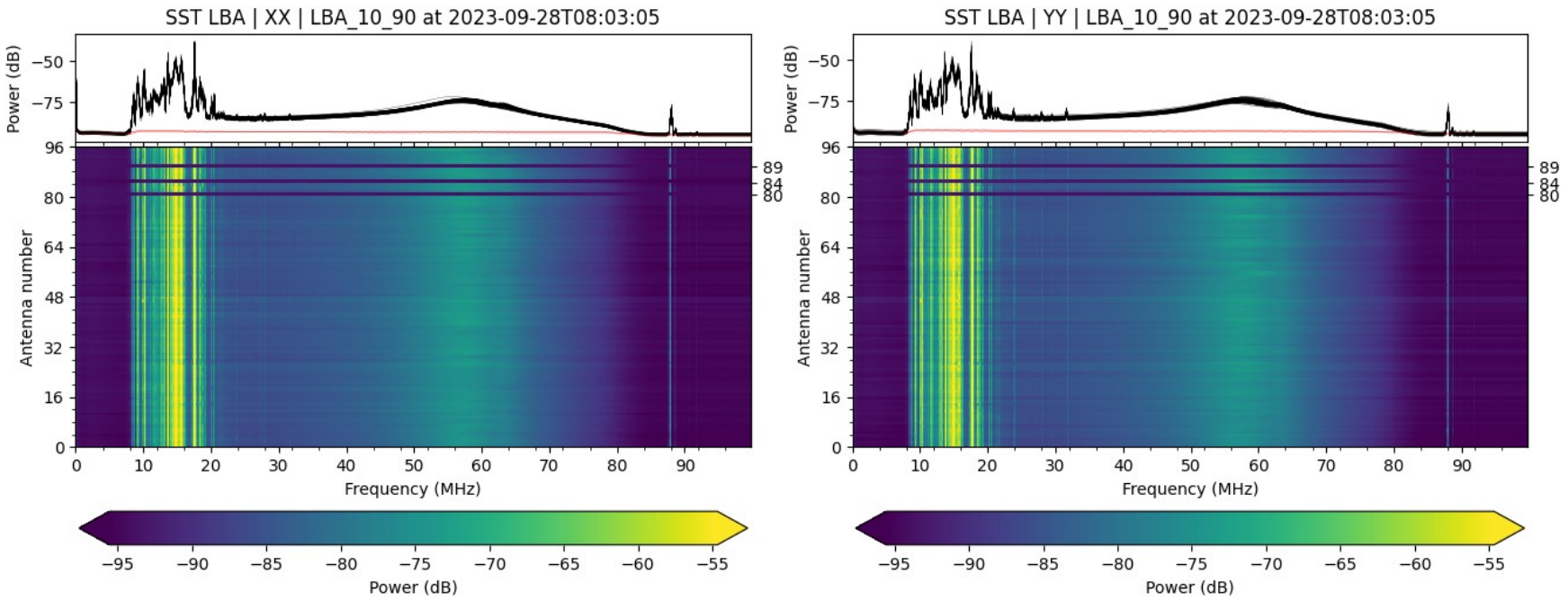
LOFAR2.0 firmware



ADC	= Analogue Digital Converter
D	= Input samples delay
AST	= ADC Statistics
WG	= Waveform Generator
Fsub	= Subband Filterbank
Esub	= Subband Equalizer
SST	= Subband Statistics
XST	= Crosslet statistics
BF	= Beamformer
BST	= Beamlet Statistics
Q	= Requantize

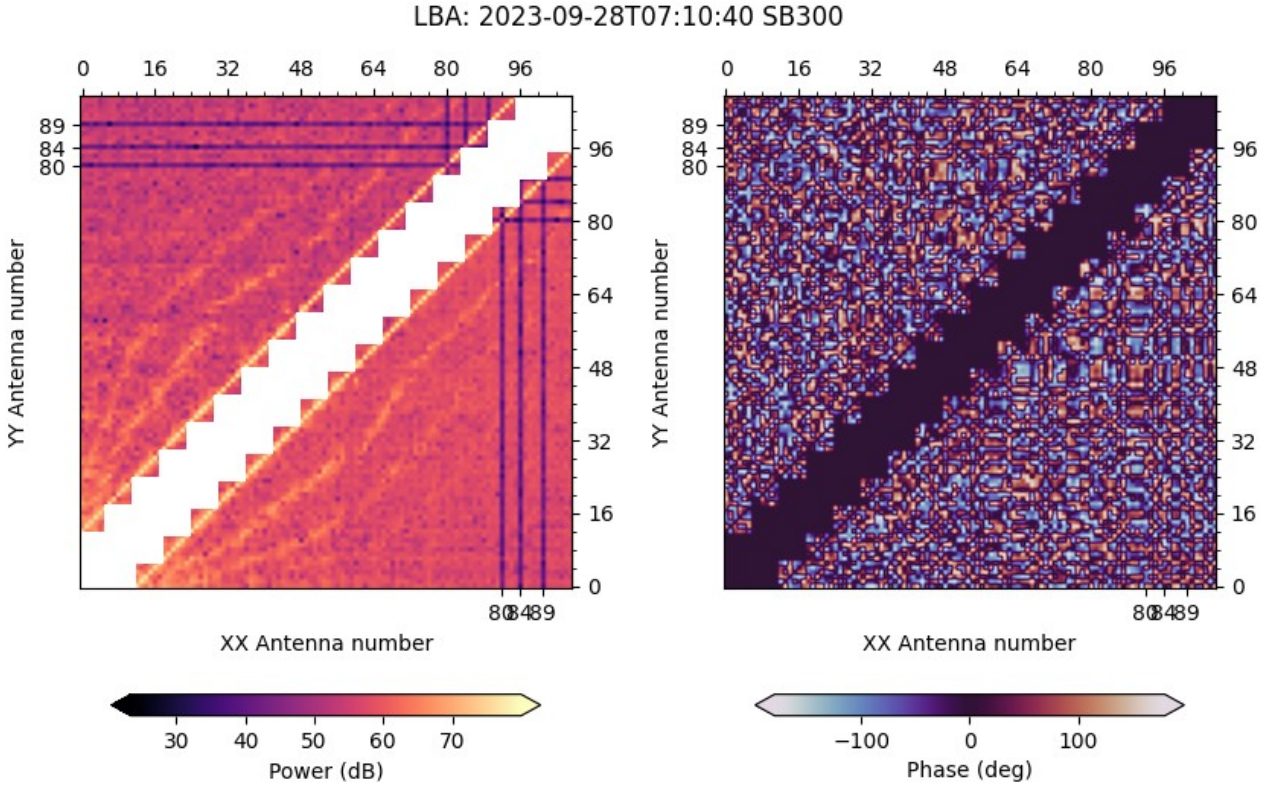
ASTRON
Netherlands Institute for Radio Astronomy

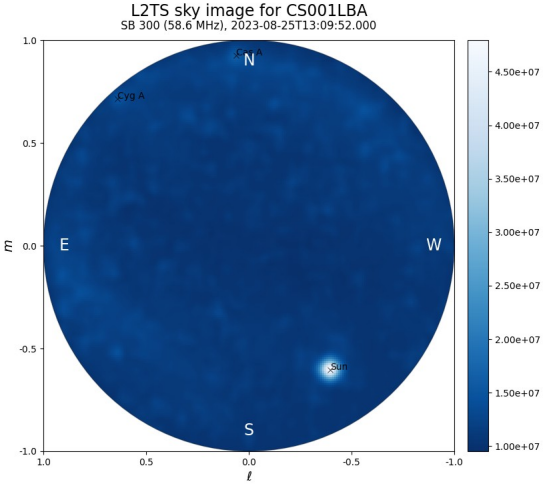
Subband statistics (SST)

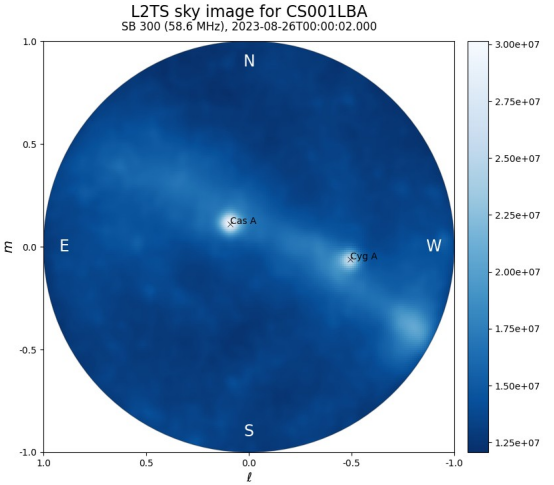


ASTRON
Netherlands Institute for Radio Astronomy

Crosslet statistics (XST)

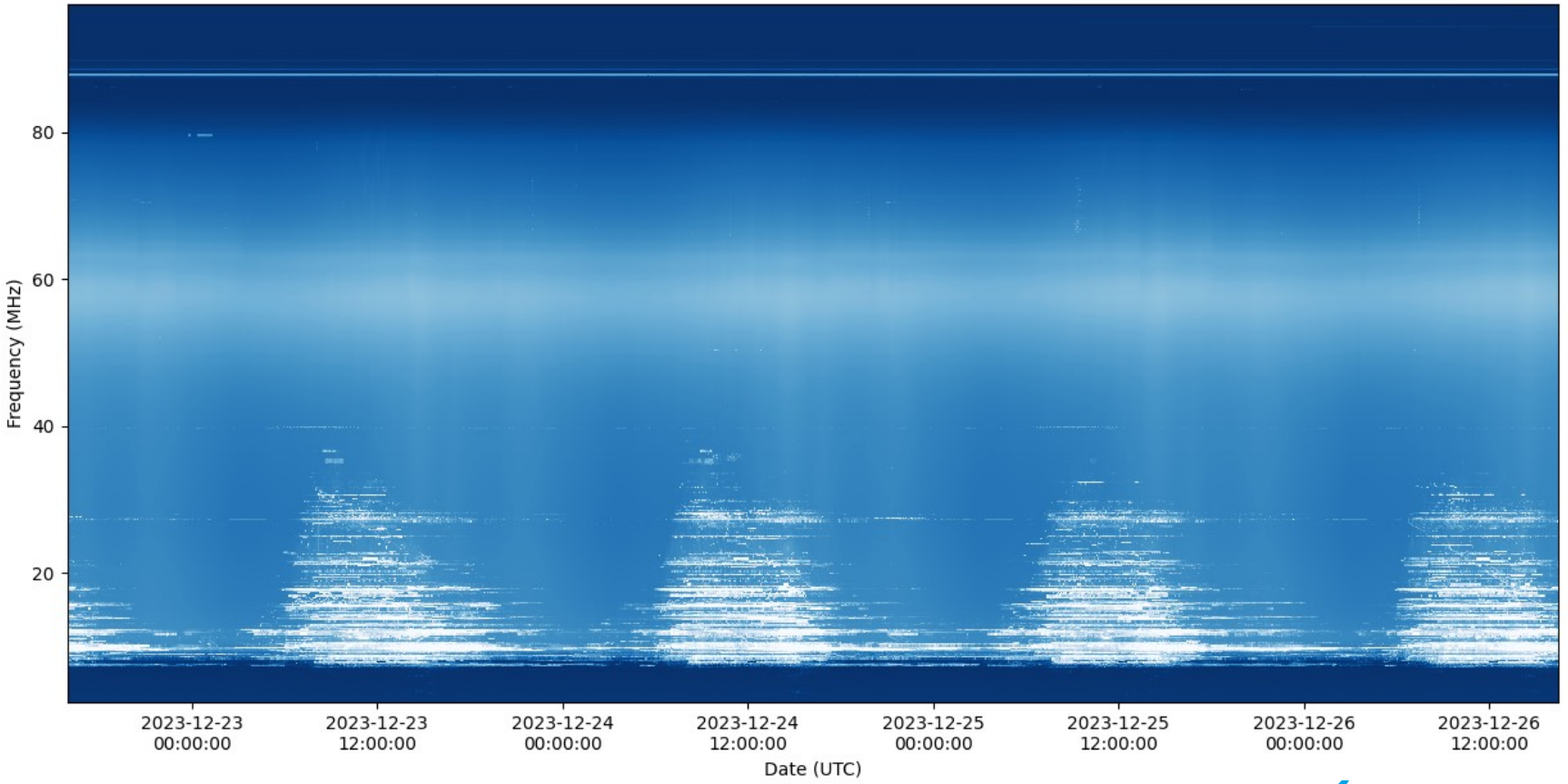






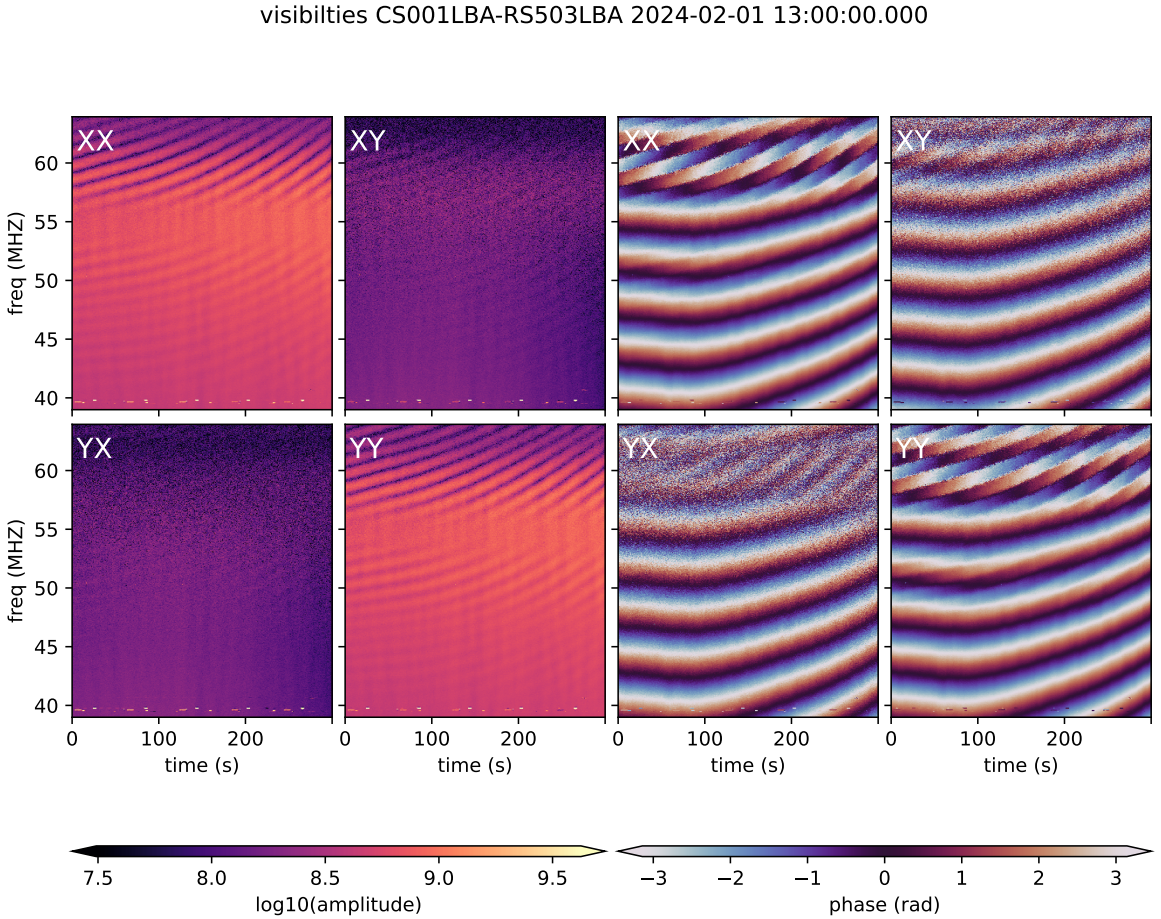
ASTRON
Netherlands Institute for Radio Astronomy

Beamlet statistics (BST)



ASTRON
Netherlands Institute for Radio Astronomy

Station data to COBALT



Netherlands Institute for Radio Astronomy

Commissioning; what needs to happen, how can you help?

ASTRON
Netherlands Institute for Radio Astronomy

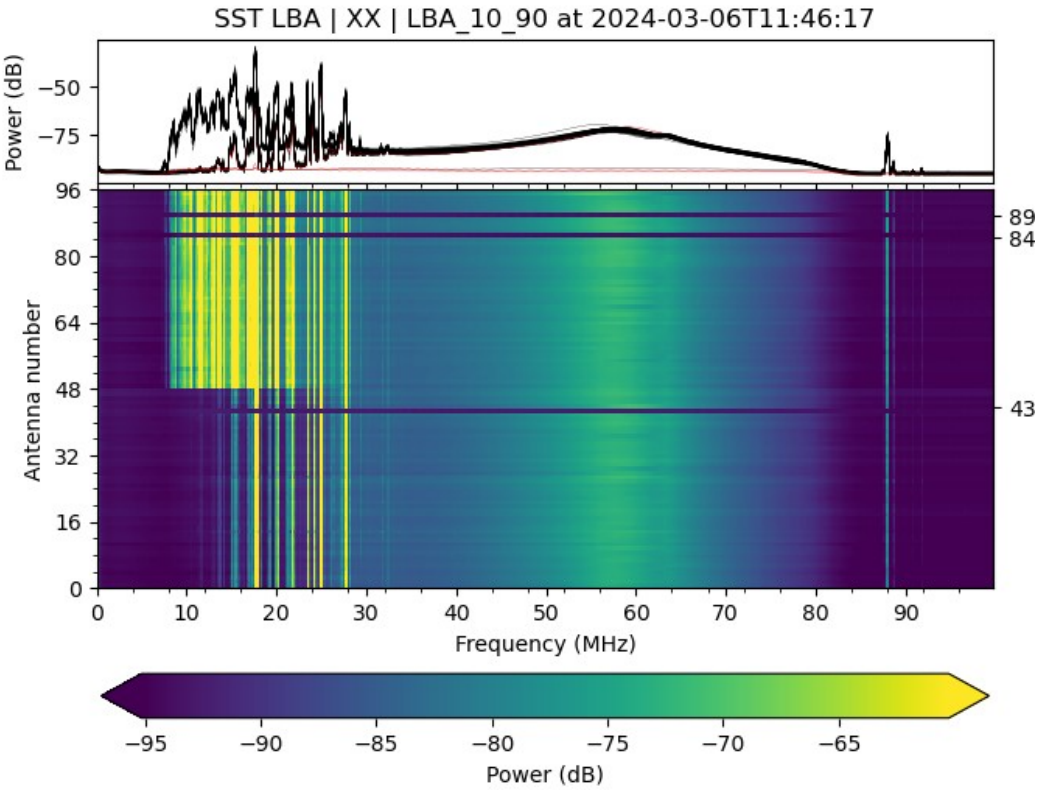
Functionality testing

Validate control of station settings:

- Filters
- Subbands
- Pointing
- Antenna selection
- Broken antennas
- Delays
- Attennuation

Testing new functionality:

- Station control software
- Station firmware



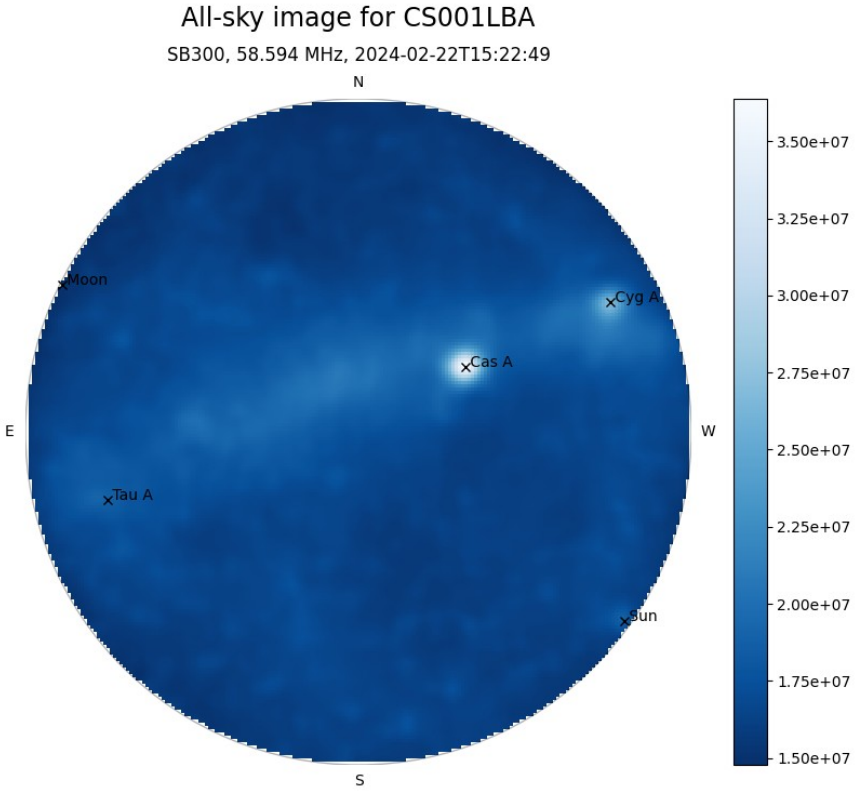
ASTRON
Netherlands Institute for Radio Astronomy

Station calibration

Delays between antennas/tiles

1. Station visibilities against sky models
- Create sky models
- Use antenna/tile beam patterns
- Investigate impact of ionosphere
- Investigate accuracy
- Full Jones calibration?

2. Station holography
- Shown to work for HBA tiles
- Investigate/implement holography for LBA
- Enable station specification in TMSS



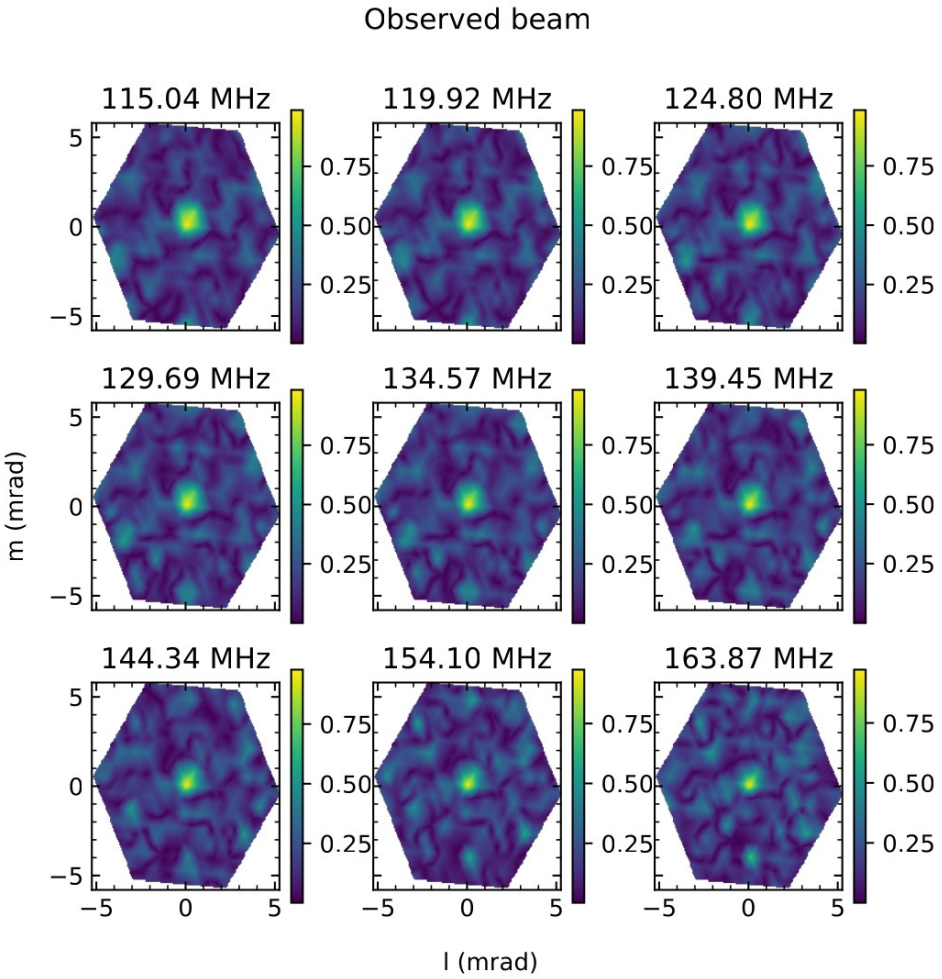
ASTRON
Netherlands Institute for Radio Astronomy

Array calibration

Delays between stations

1. Clock/TEC separation
- Works for HBA imaging observation
- Extend to LBA
- Investigate core beamformer coherency

2. Tied-array holography
- Shown to work for LBA and HBA
- Test and improve algorithm
- Design TMSS strategy, make operational



ASTRON
Netherlands Institute for Radio Astronomy

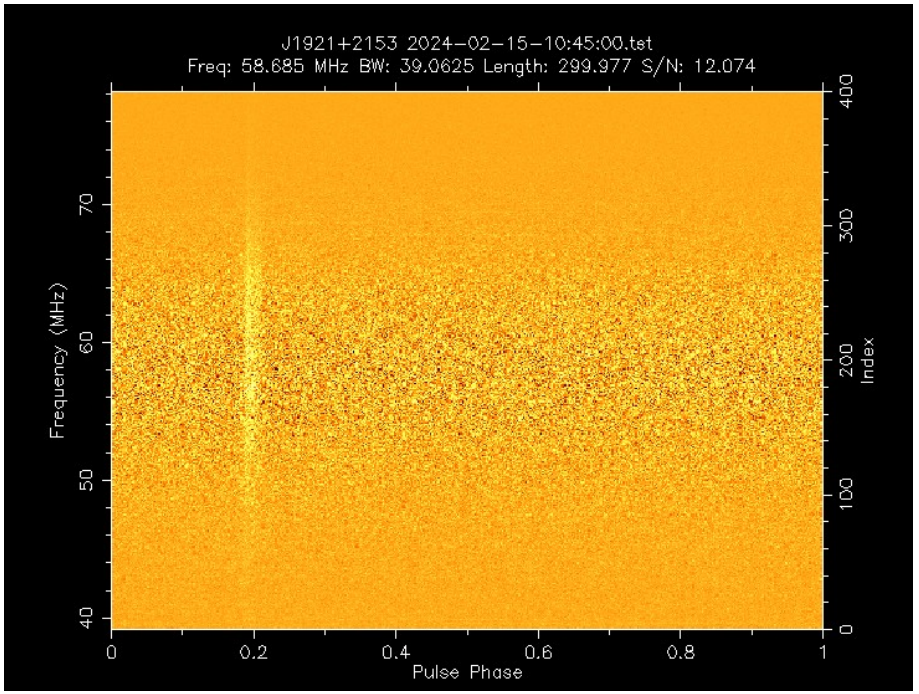
Automate station rollout with commissioning pipelines

Specify test in TMSS → observe on station → process with COBALT/CEP

Ideal situation:
- Suite of test observations in TMSS
- Observed with rollout of new station
- Results analyzed automatically

Examples:
- Functionality
- Delay Calibration
- Sensitivity

Requires:
- Analysis software (python scripts)
- Pipelines on CEP or elsewhere
- Means to start processing from TMSS



ASTRON
Netherlands Institute for Radio Astronomy

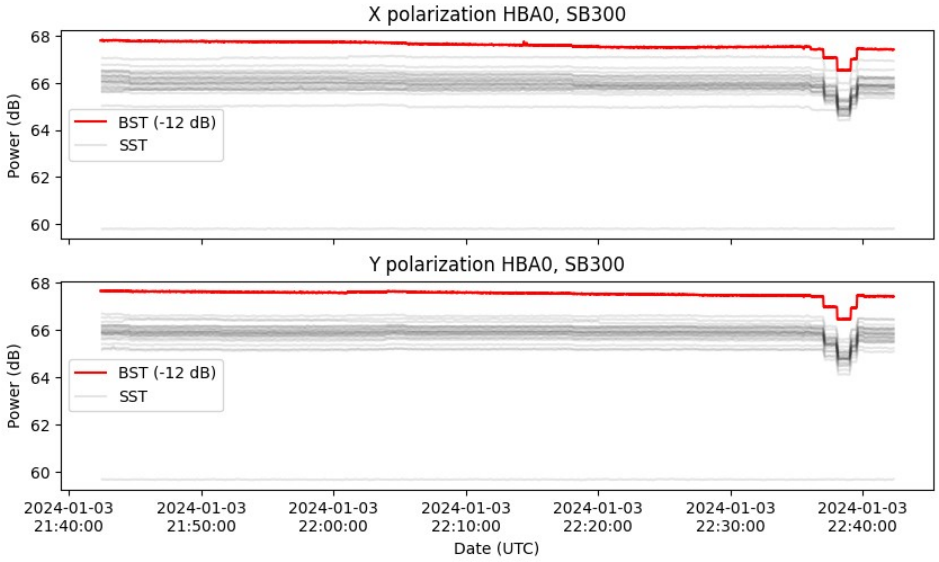
Validate station stability

- Issues in station hardware, firmware or software may be rare in a single station…

- … but would be common in the full array

Volunteers to operate single stations for long periods of time and investigate the station data for issues

Possible single station use cases:
- Solar monitoring
- Ionospheric monitoring
- Jupiter bursts?
- RFI monitoring?
- ….



ASTRON
Netherlands Institute for Radio Astronomy

Define operational use cases

Reduce HBA intermodulation products

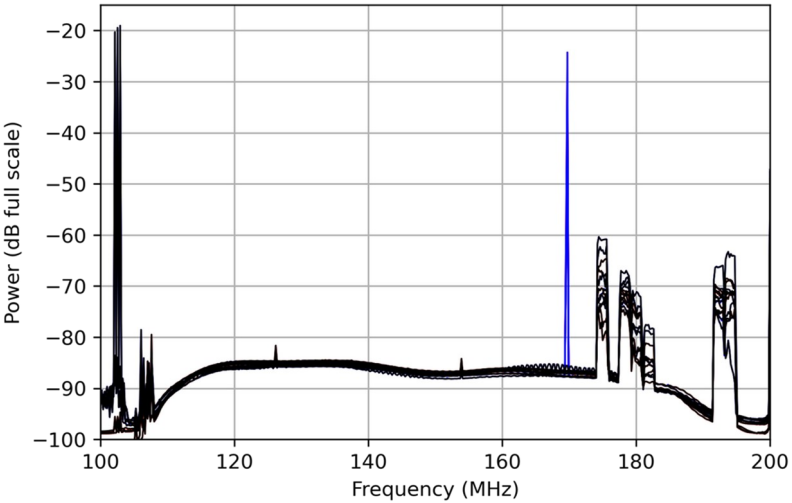
- Dithering to enforce ADC linearity
- 110 to 170MHz to filter out DAB
  How to use in large programs?

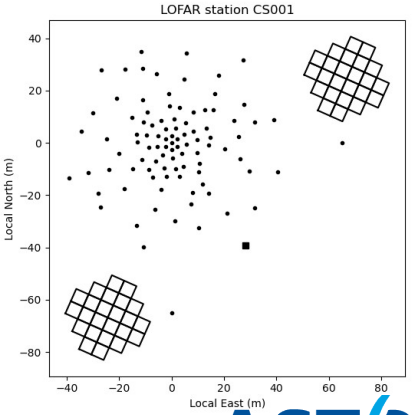
- TMSS observing strategies for large programs?

- Calibration transfer from HBA to LBA?

- Simultaneous LBA & HBA observing?

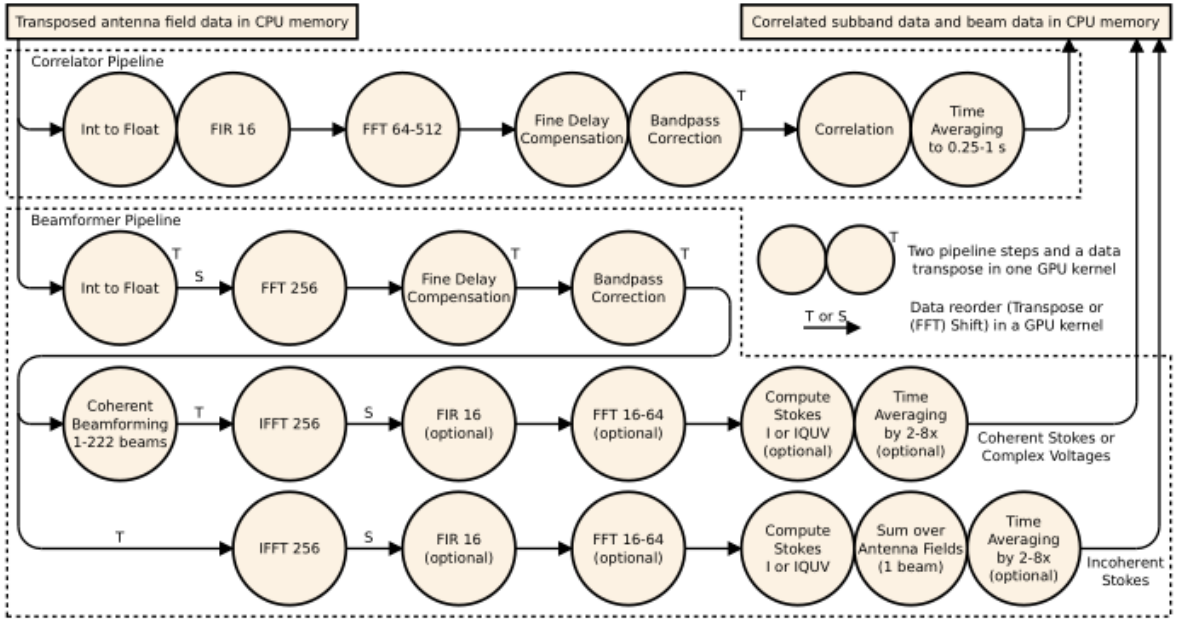
- LBA antenna selection?
  (include calibration antennas?)





ASTRON
Netherlands Institute for Radio Astronomy

Test and improve COBALT functionality



- Validate simultaneous pipelines
- Validate beam repointing
- Validate spectral fidelity

- Improve signal processing
- Mode for recording raw station data
- TensorCore beamformer design

ASTRON
Netherlands Institute for Radio Astronomy

What will change for you?

- Higher sensitivity for LBA observations with LBA_ALL
- Possibility of observing simultaneously with LBA and HBA
- More stable clocks and hence easier calibration
- Improved robustness against HBA intermodulation

- Future expansion to allow more station beams
- Improved quality control due to better monitoring

What will change for you?

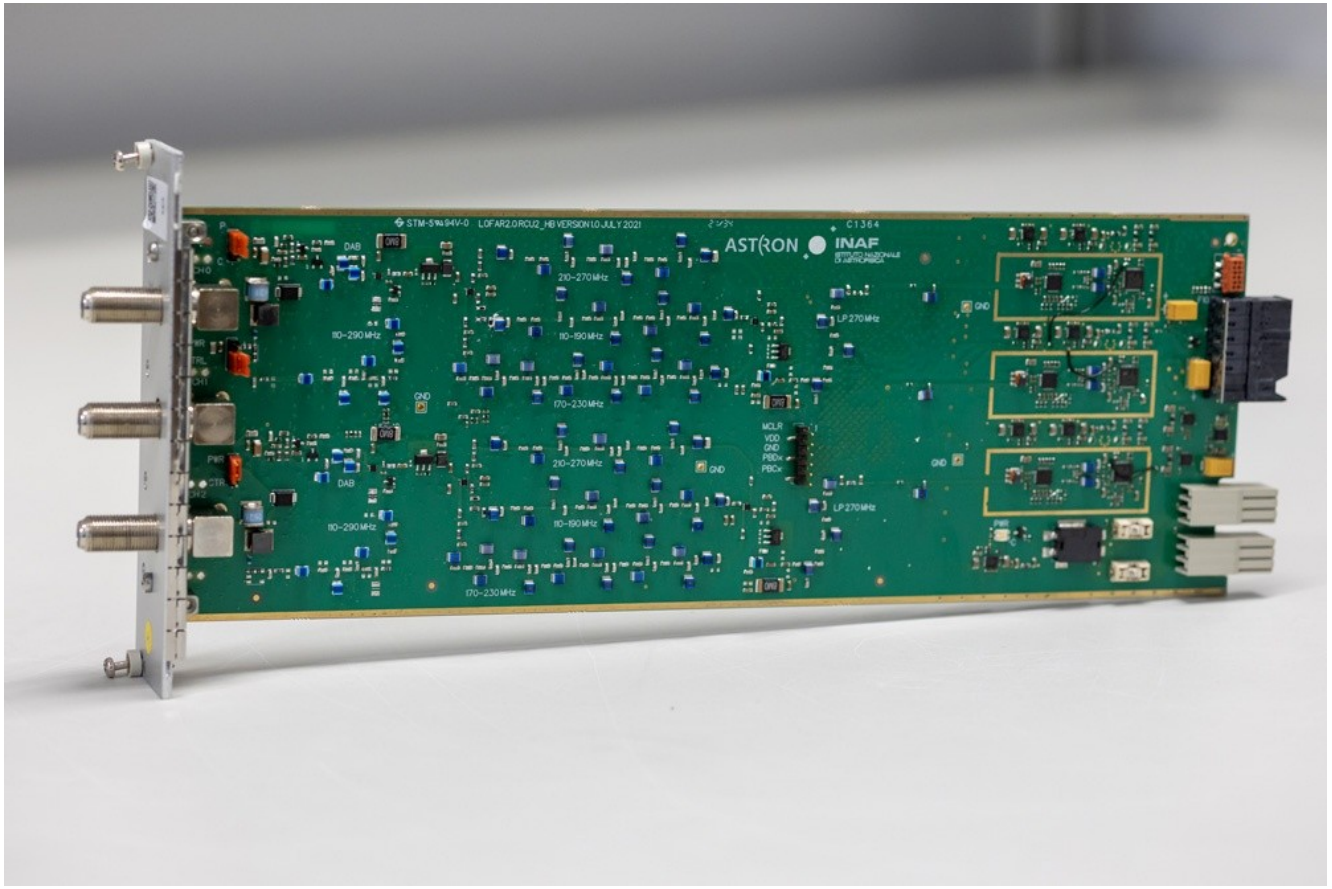
- Higher sensitivity for LBA observations with LBA_ALL
- Possibility of observing simultaneously with LBA and HBA
- More stable clocks and hence easier calibration
- Improved robustness against HBA intermodulation

- Future expansion to allow more station beams
- Improved quality control due to better monitoring

Thank you

ASTRON
Netherlands Institute for Radio Astronomy

LOFAR2.0 hardware: receiver unit (RCU)



ASTRON
Netherlands Institute for Radio Astronomy

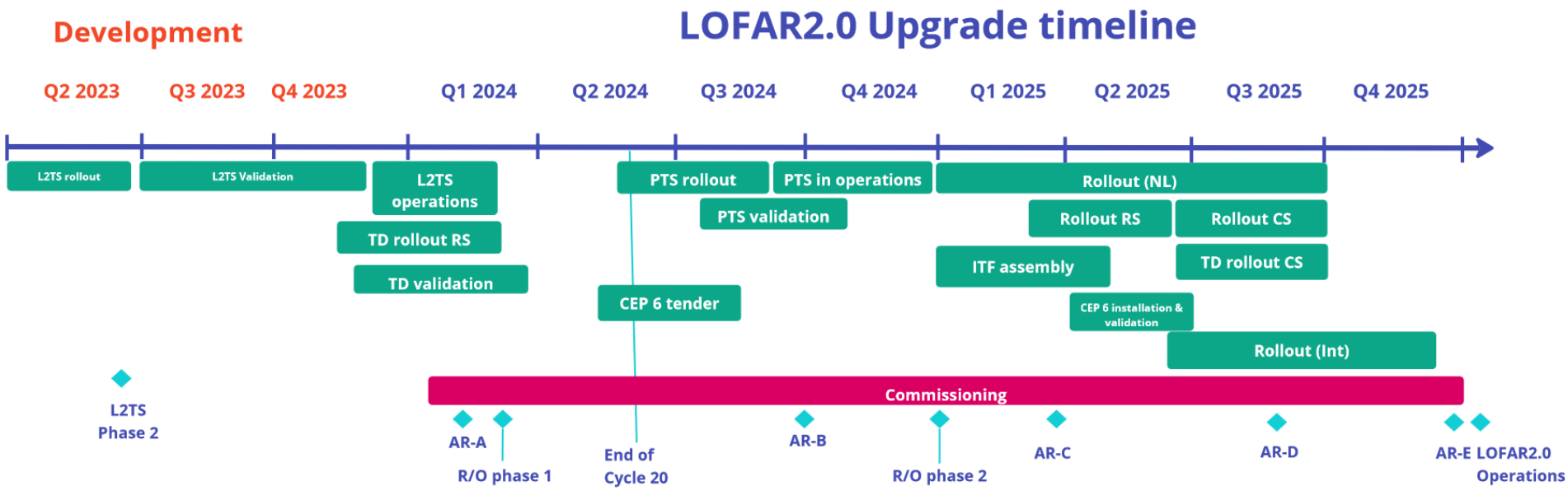
What is changing in LOFAR2.0?

Current LOFAR:
Dutch stations:
- 2x48 digital inputs
  (half LBA dipoles *or* all HBA tiles)
- Separate clocks at remote stations

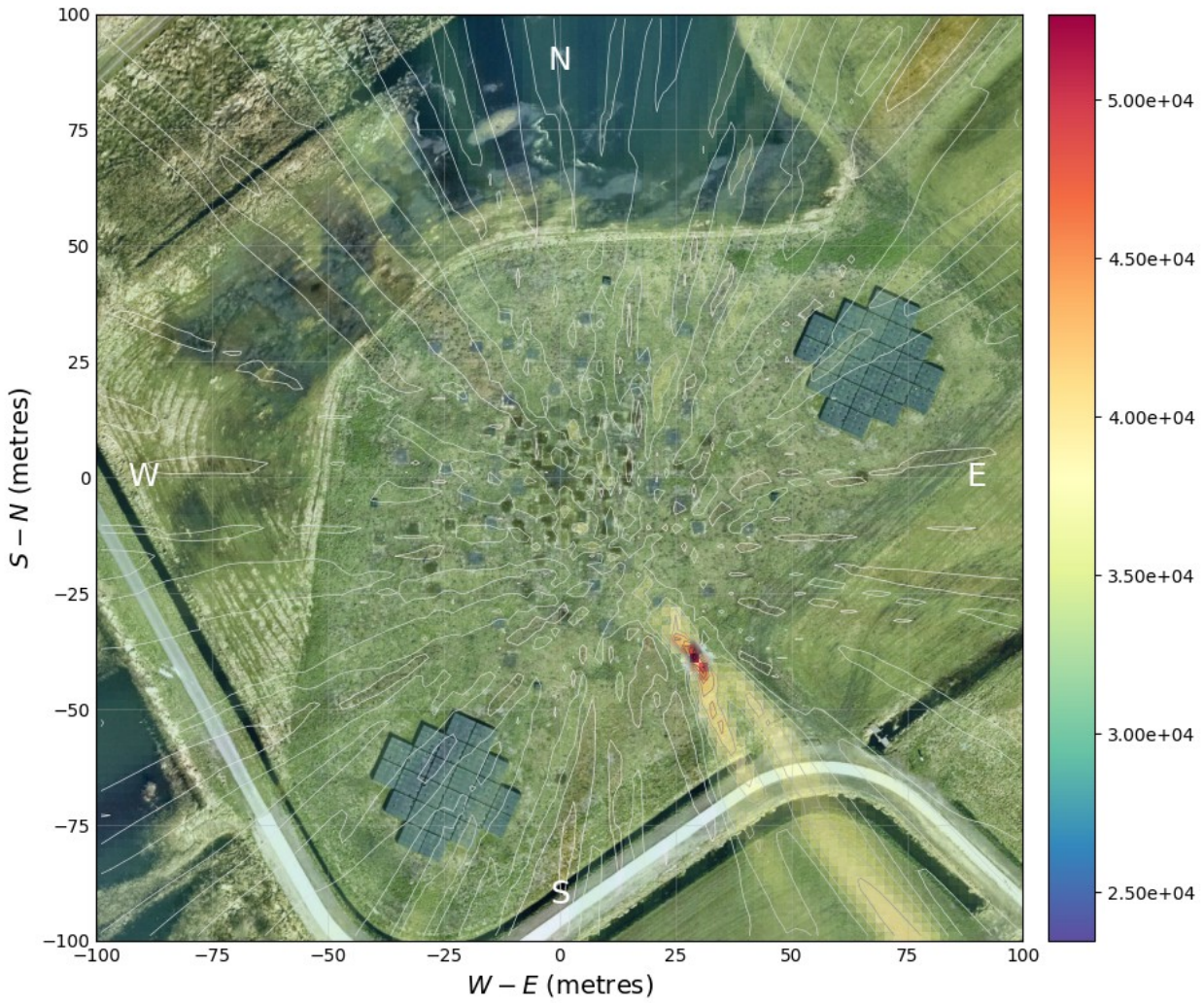
LOFAR2.0:
Dutch stations:
- 3x(2x48) digital inputs
  (all LBA dipoles and all HBA tiles)
- Single clock and frequency
  distribution system (White Rabbit)

ASTRON
Netherlands Institute for Radio Astronomy

LOFAR2.0 planning

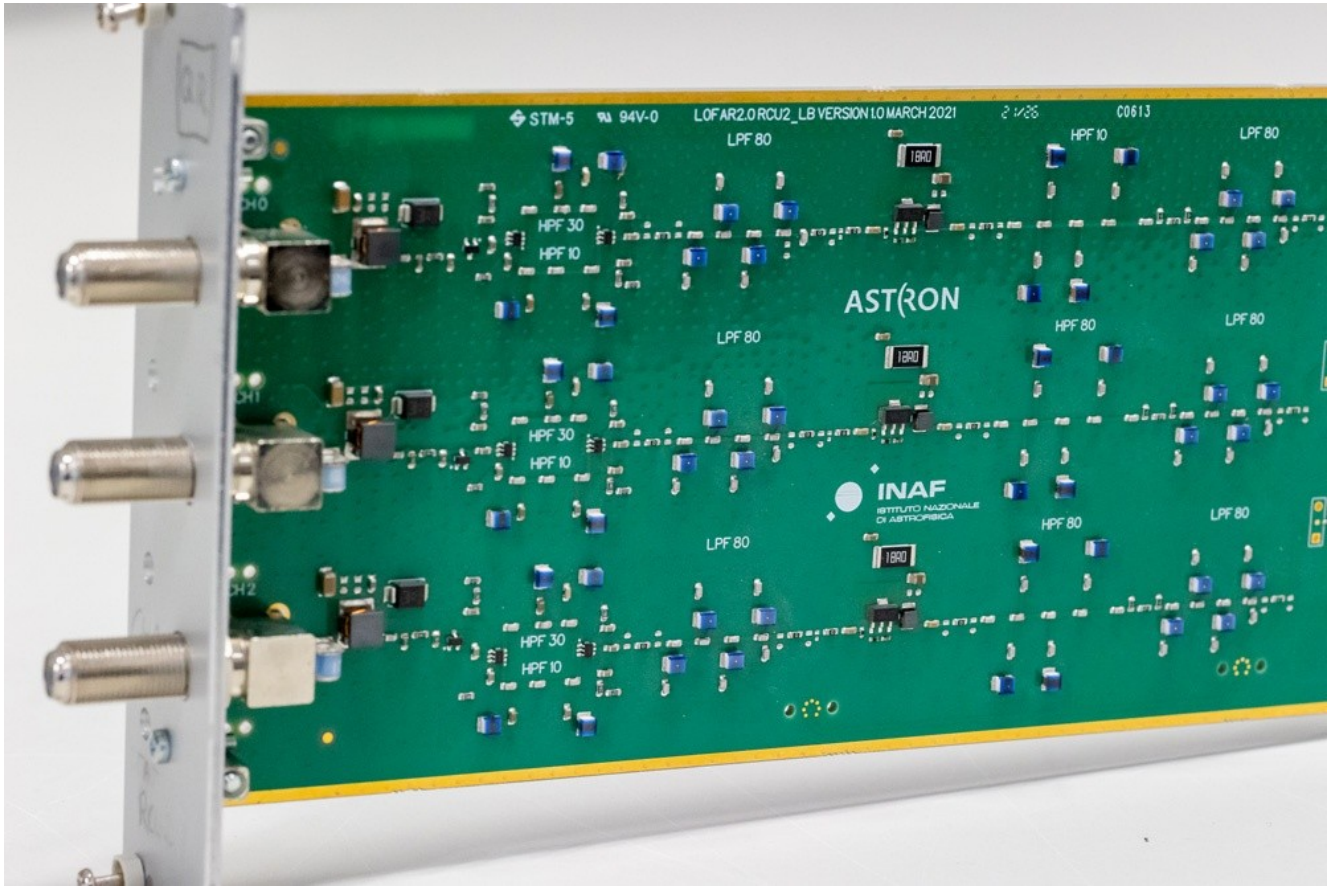


ASTRON
Netherlands Institute for Radio Astronomy



ASTRON
Netherlands Institute for Radio Astronomy

LOFAR2.0 hardware: receiver unit (RCU)

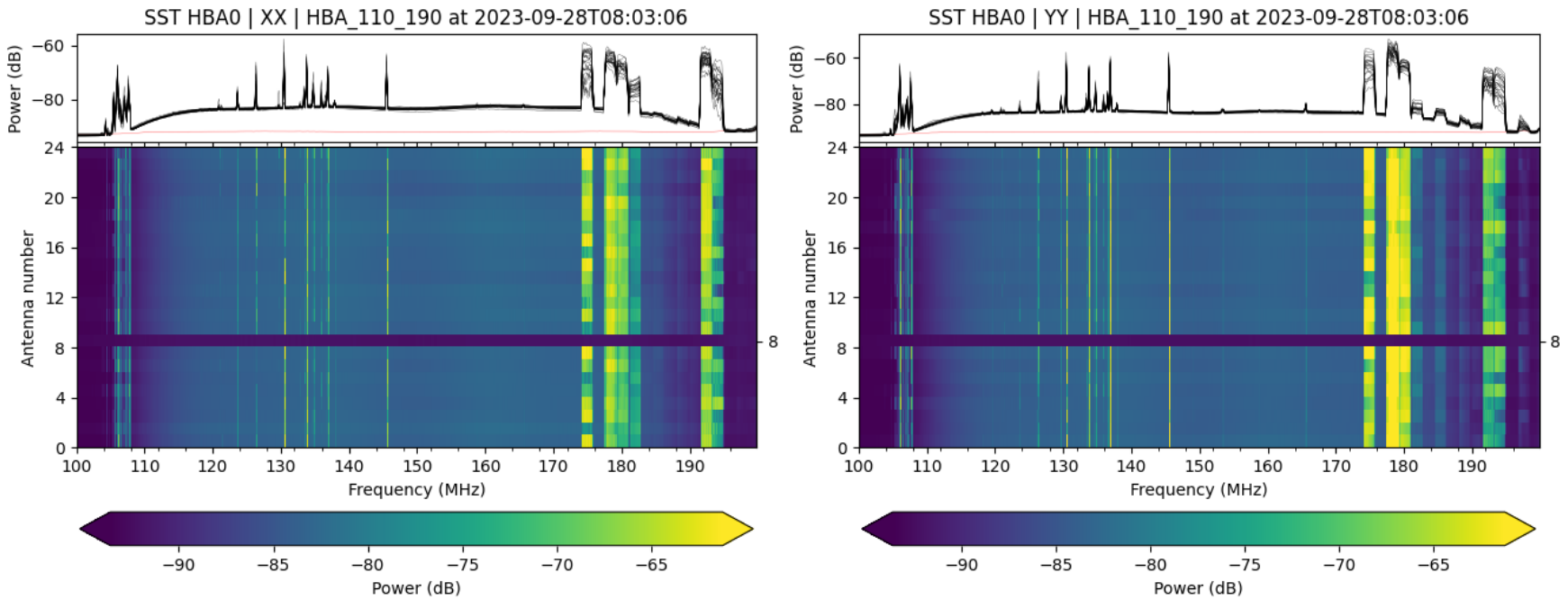


ASTRON
Netherlands Institute for Radio Astronomy

LOFAR2.0 hardware: subrack assembly

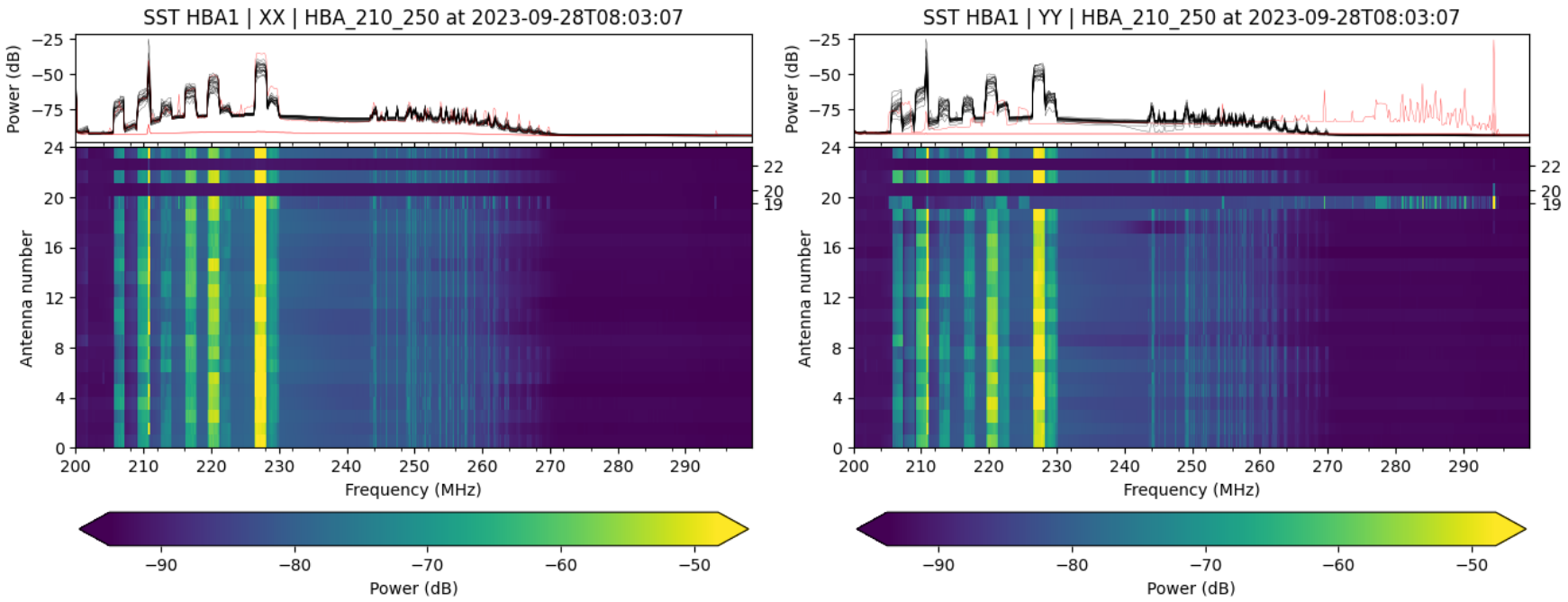
ASTRON
Netherlands Institute for Radio Astronomy

Subband statistics (SST)



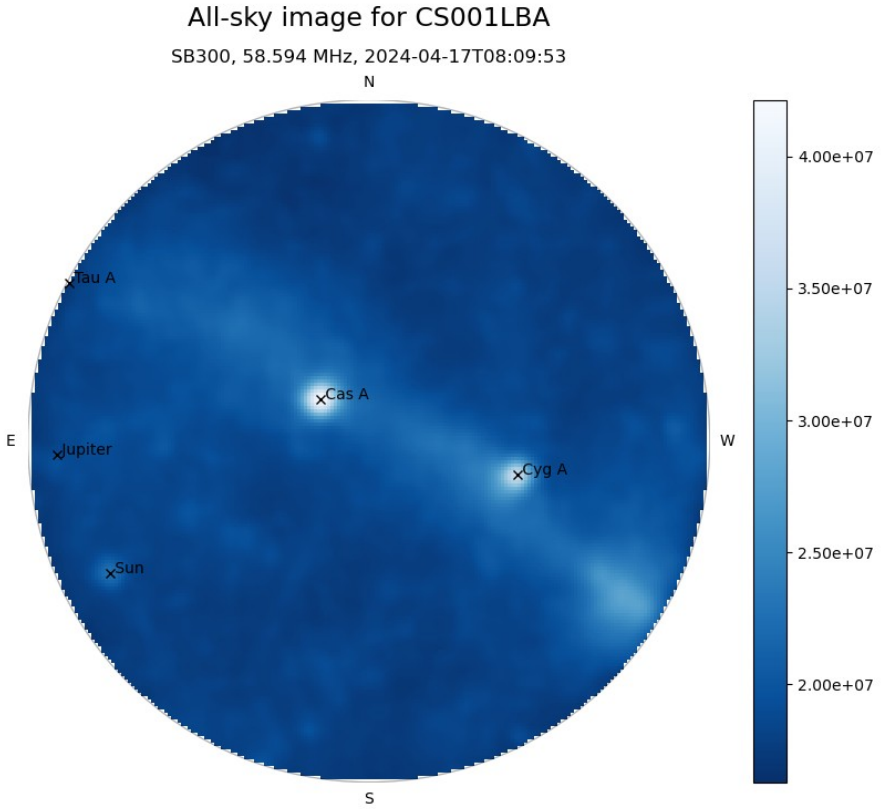
ASTRON
Netherlands Institute for Radio Astronomy

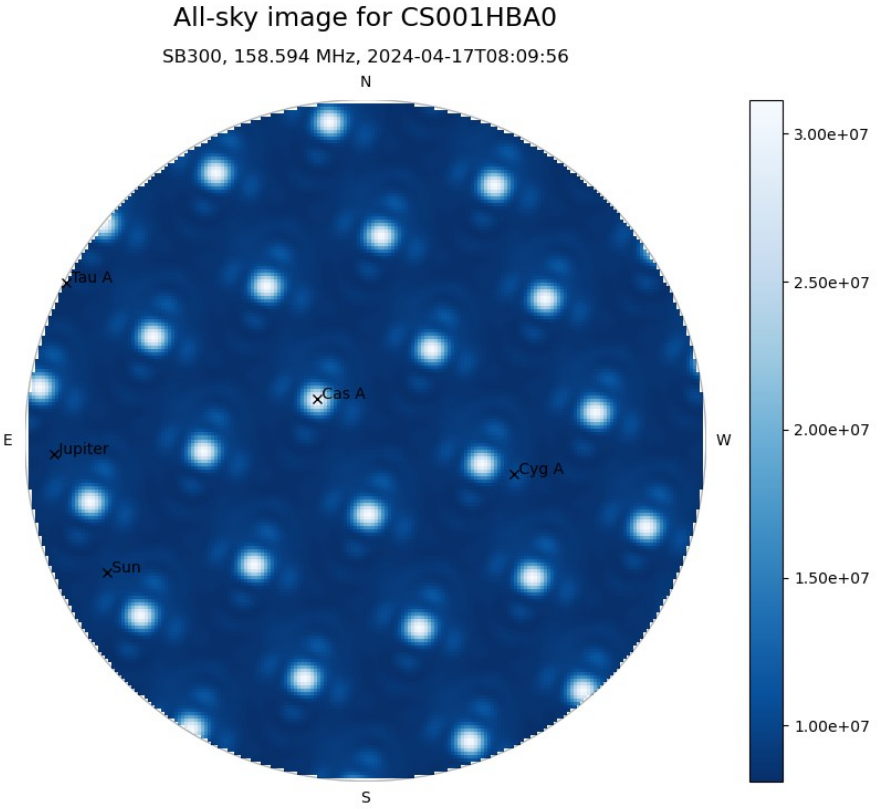
Subband statistics (SST)



ASTRON
Netherlands Institute for Radio Astronomy

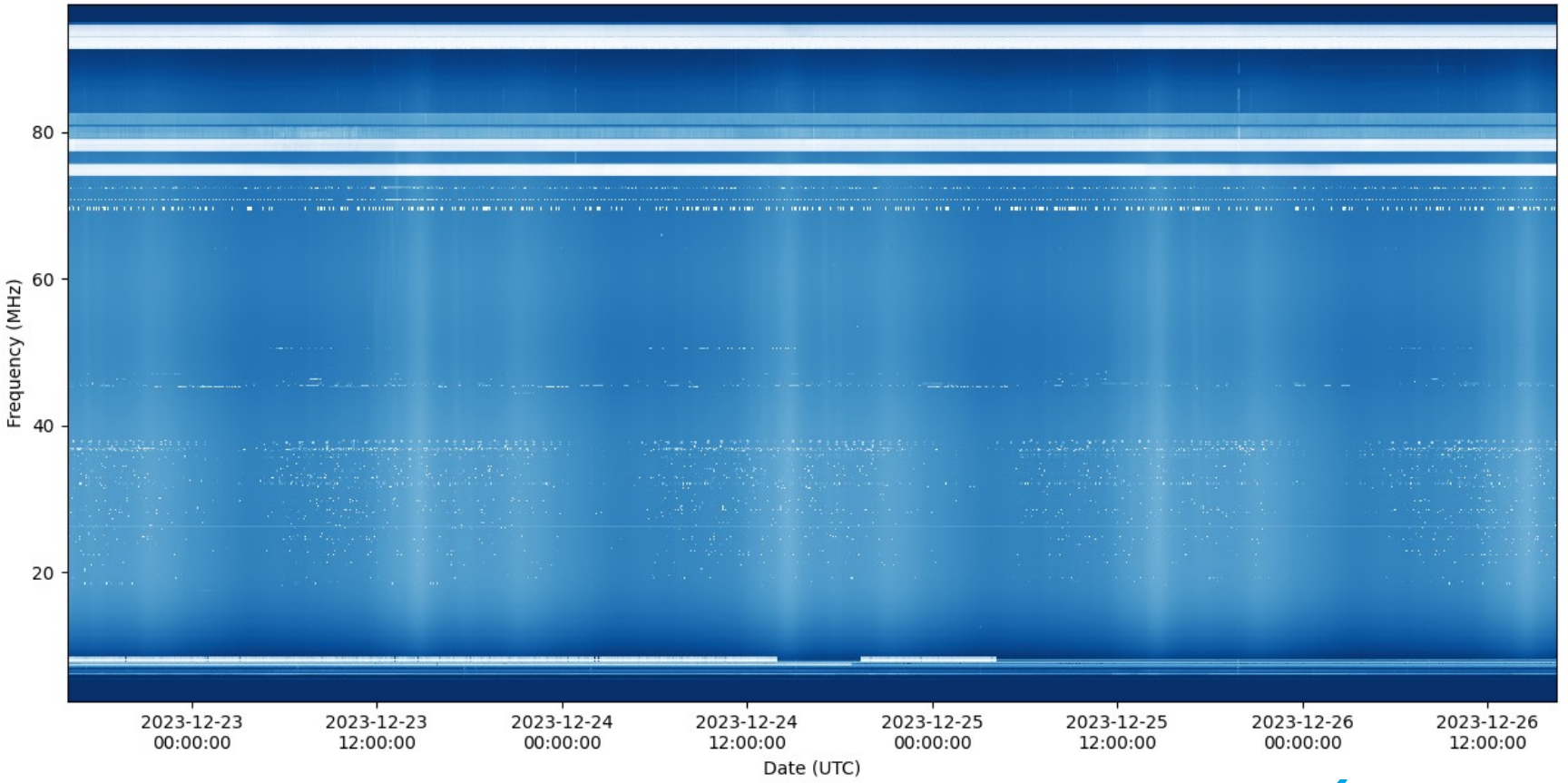
All sky images





ASTRON
Netherlands Institute for Radio Astronomy

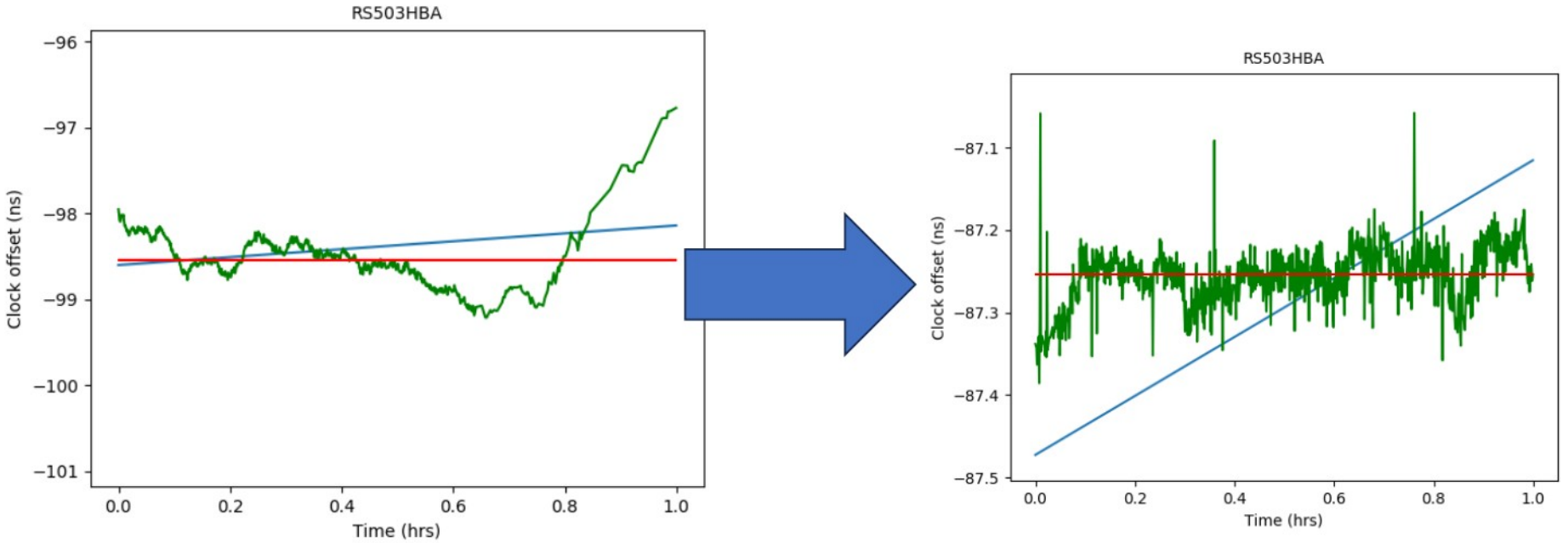
Beamlet statistics (BST)



ASTRON
Netherlands Institute for Radio Astronomy

White Rabbit clock and frequency distribution

Already being rolled out to Dutch remote stations



ASTRON
Netherlands Institute for Radio Astronomy

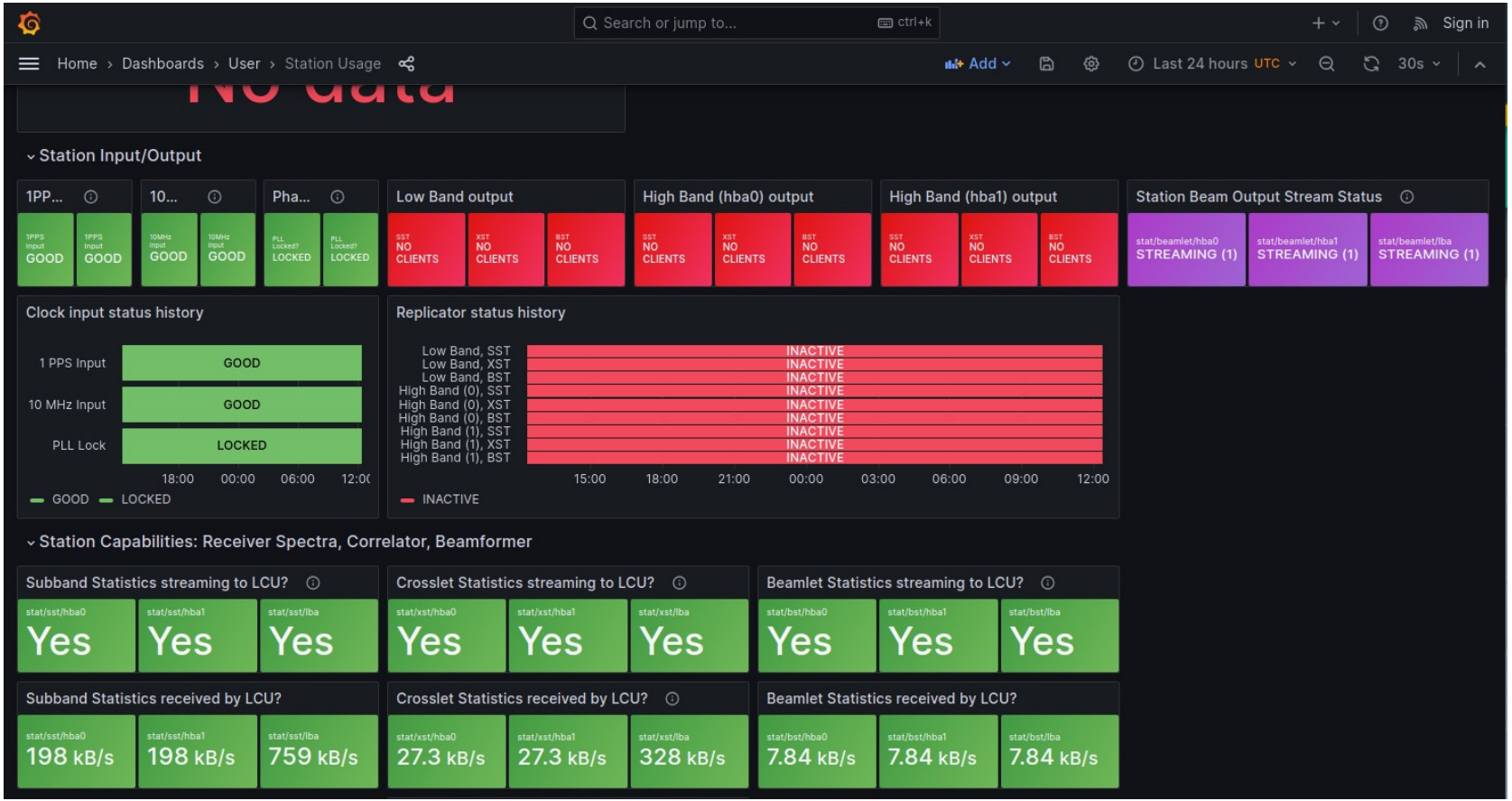
LOFAR2.0 control software

Broken Antennas

```
[26]: # Set antenna quality
# See explanation at: https://git.astron.nl/lofar2.0/tango/-/blob/master/tangostationcontrol/tangostationcontrol/devices/antennafiel
# OK = 0, SUSPICIOUS = 1, BROKEN = 2, BEYOND_REPAIR = 3

# LBA
antenna_dict_l = {0: [],
                  1: [43],
                  2: [],
                  3: [84, 89]}

# HBA0
antenna_dict_h0 = {0: [],
                   1: [],
                   2: [8],
                   3: []}

# HBA1
antenna_dict_h1 = {0: [],
                   1: [],
                   2: [19, 20, 22],
                   3: []}

# Set antenna
for antennafield, antenna_dict, field in zip([antennafield_l, antennafield_h0, antennafield_h1], [antenna_dict_l, antenna_dict_h0, a
    antenna_quality = np.zeros_like(antennafield.antenna_quality_r)
    nant = len(antenna_quality)
    for idx in range(4):
        for antenna in antenna_dict[idx]:
            antenna_quality[antenna] = idx
    print(field, np.arange(nant)[antenna_quality > 0], antenna_quality)
    antennafield.put_property({"Antenna_Quality": antenna_quality})
    antennafield.Off()
    antennafield.Initialise()
    antennafield.On()
```

```
LBA [43 84 89] [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 3 0 0 0 0 0 0]
HBA0 [8] [0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
HBA1 [19 20 22] [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 2 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

LOFAR2.0 monitoring



ASTRON
Netherlands Institute for Radio Astronomy

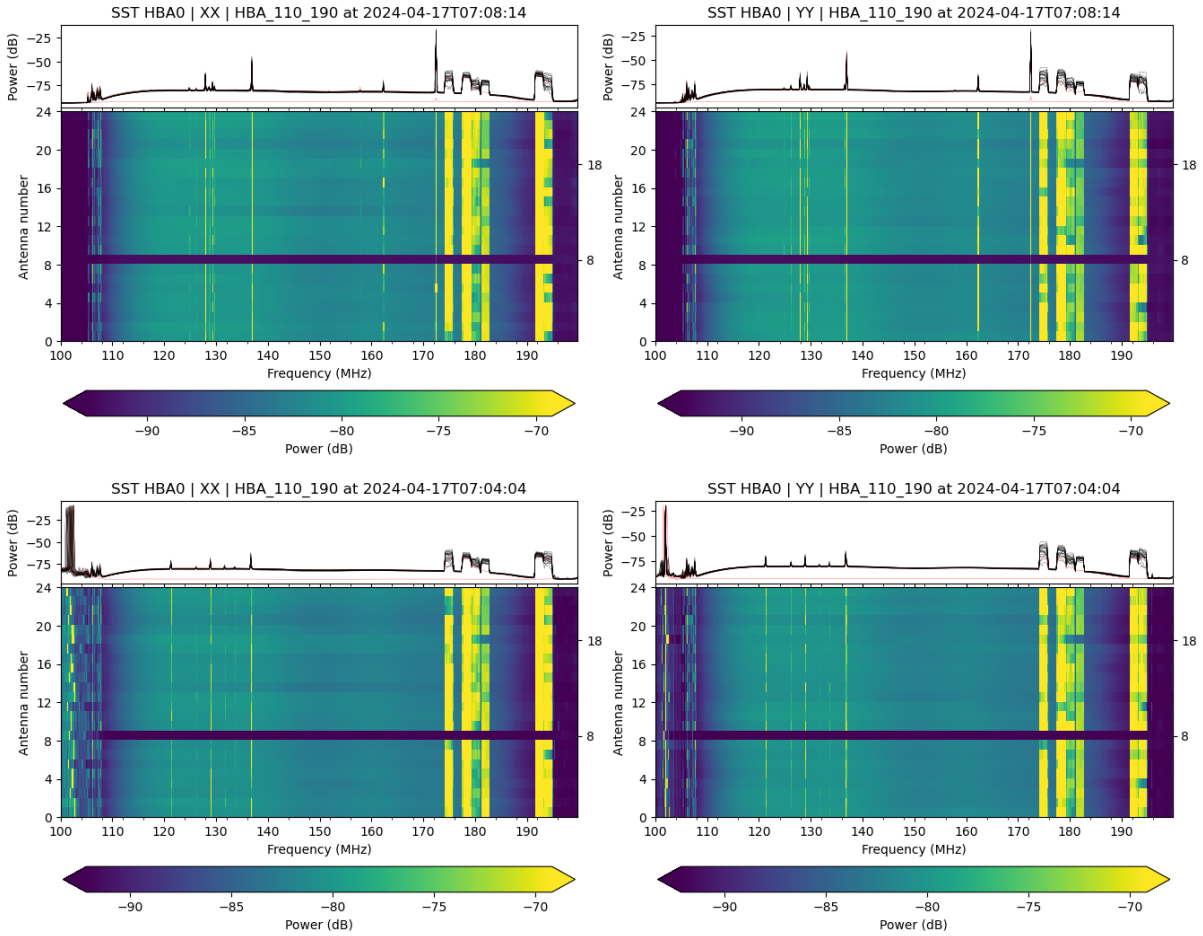
New and dropped functionality

New functionality:

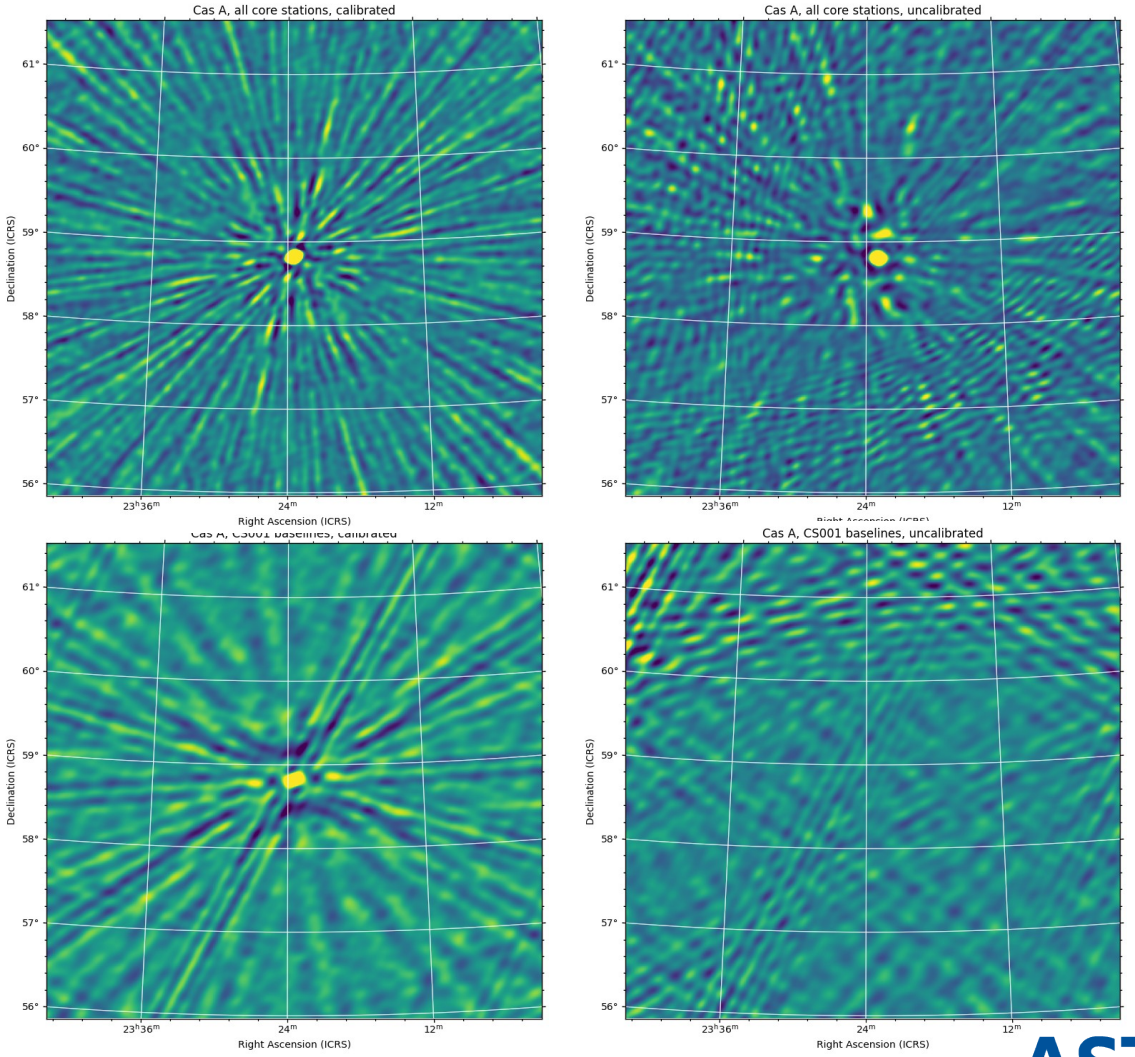
- Single clock
- LBA_ALL
- LBA and HBA simultaneous
- DAB filter
- Dithering
- Meta data for statistics
- Improved linearity

Dropped functionality:

- HBA_JOINED antenna set
- 160MHz clock
- 16bit station data



ASTRON
Netherlands Institute for Radio Astronomy



ASTRON
Netherlands Institute for Radio Astronomy