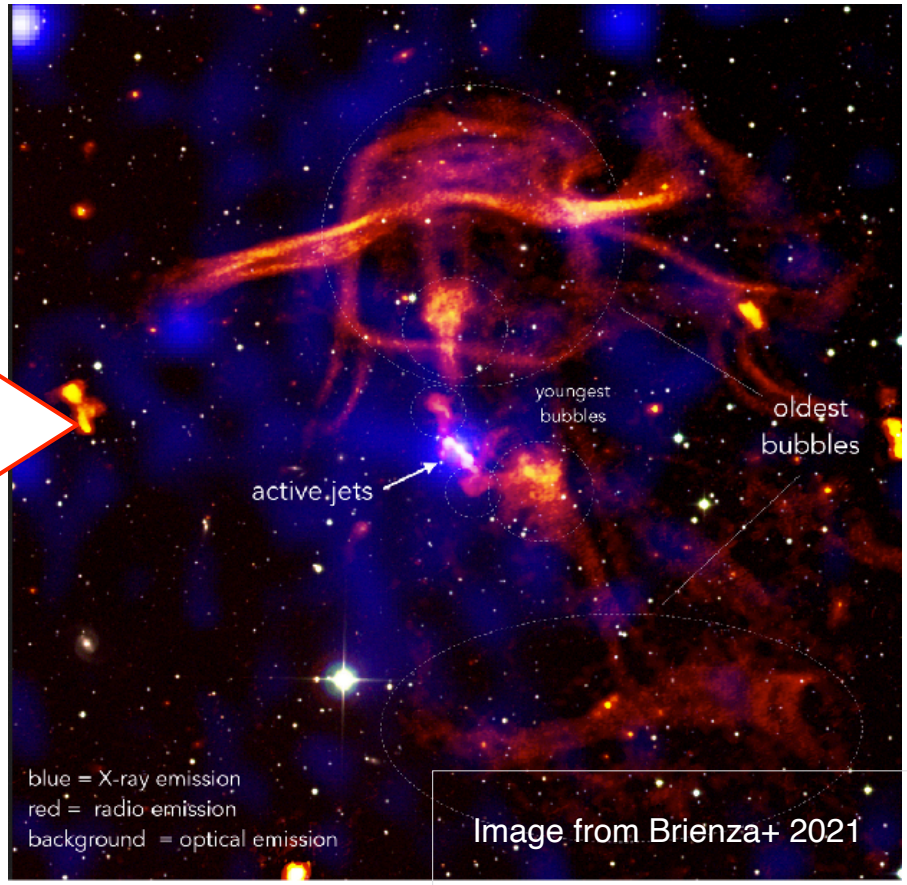
ASTRON Science Data Centre (SDC) imaging pipelines for LOFAR2.0



Timothy Shimwell (ASTRON & Leiden) on behalf of the SDC

Facilitating LOFAR2.0 large programmes

LOFAR2.0 collects data twice as fast as LOFAR. With larger LBA stations and by fully exploiting high resolution imaging capabilities we can significantly improve our view of the low-frequency sky and facilitate a lot new science.

Highly ambitious LOFAR2.0 proposals, including e.g.

V.deep observations of small fields (up to 1000's of hrs) reaching microJy noise levels

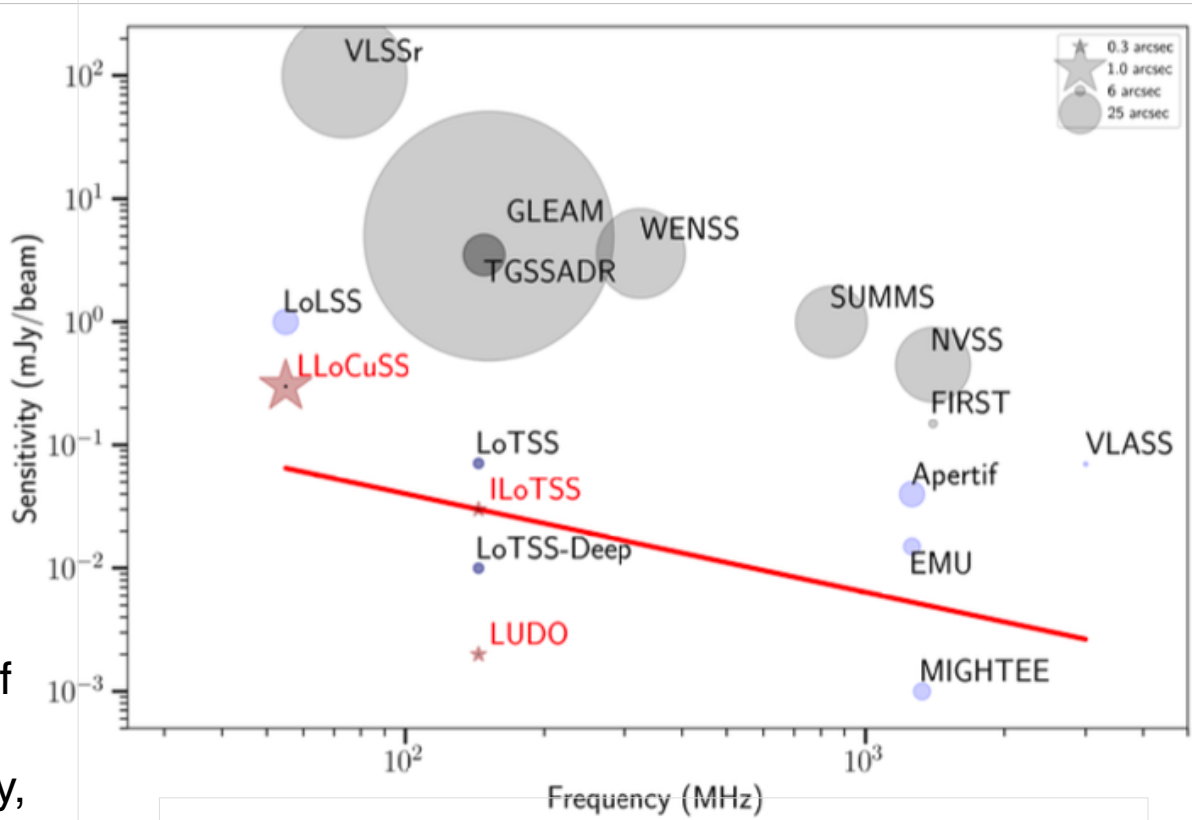
V.wide area v. high resolution imaging

V.wide area v. low resolution imaging

Very precise imaging

V. complex field imaging (e.g. galactic, low-dec)

Often in polarisation and facilitating studies of time dependency of signals. With improvements also desirable on image fidelity, flux density accuracy (overall and in-band), leakage etc.



Some LOFAR2.0 imaging ambitions (red)

Facilitating LOFAR2.0 large programmes

Estimates are:

- Over 100PB of pre-processed (e.g. flagged, averaged) data gathered (not foreseen to store for long term)
- Over a billion cpu hrs required to produce science products (stored long term).
- Likely needs several 10,000s of cpu running constantly

Intention is:

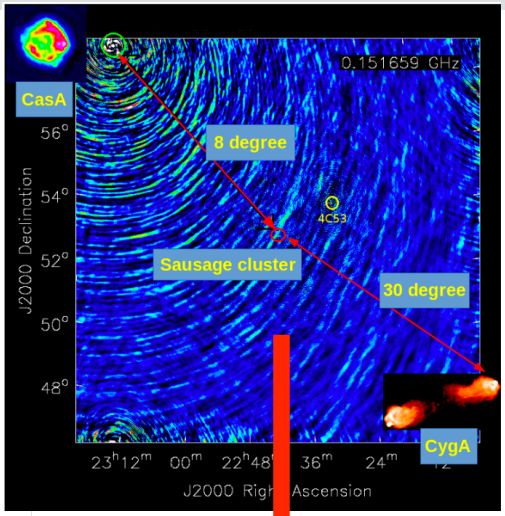
- Not keep pre-processed data too long (presently ~18 months).
- Allow fast science and easy exploitation of LOFAR2 data (from both large programmes and also fraction of time allocated through cycle calls) by producing science-ready products through the SDC.

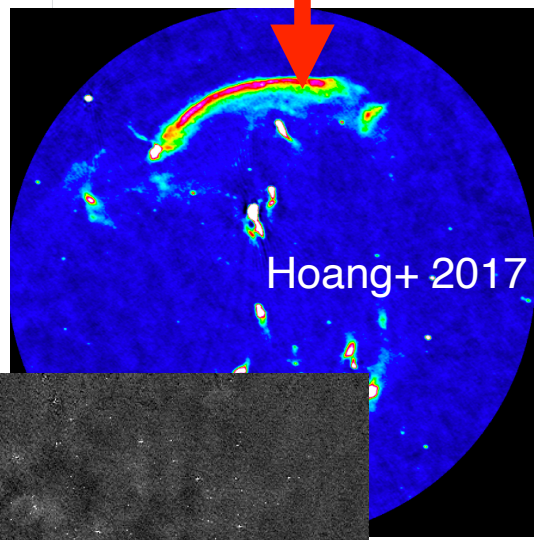
Facilitating LOFAR2.0 large programmes

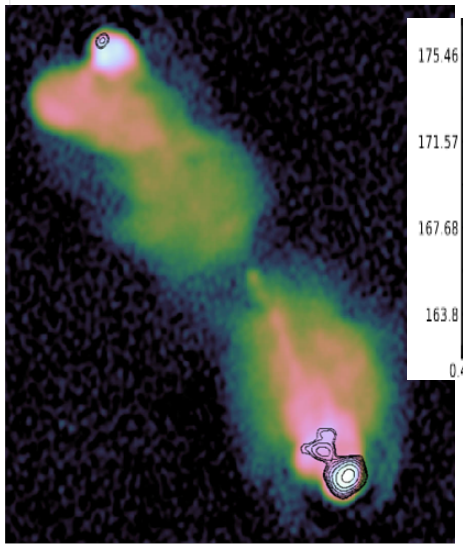
Thankfully incredible LOFAR developments mean we are not starting from scratch:

E.g. current state of art in HBA-imaging:

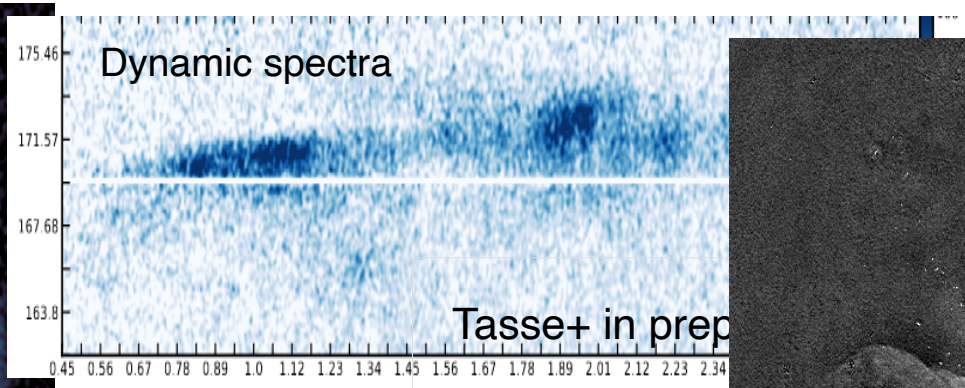
- Dealing with regions near a-team sources
- Imaging with most complex regions of northern hemisphere galaxy
- Excellent polarisation leakage levels (<0.2%)
- Detailed exploitation of time dependence
- Full field VLBI imaging and also VLBI polarisation
- Demonstrated ability for processing to keep up with observing rate for NL-only resolution imaging (~6,000 cpu hrs for 8hr obs).

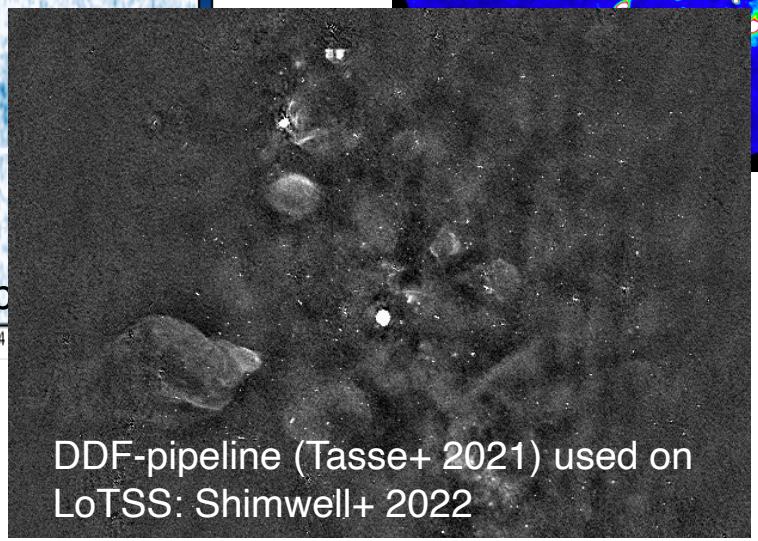






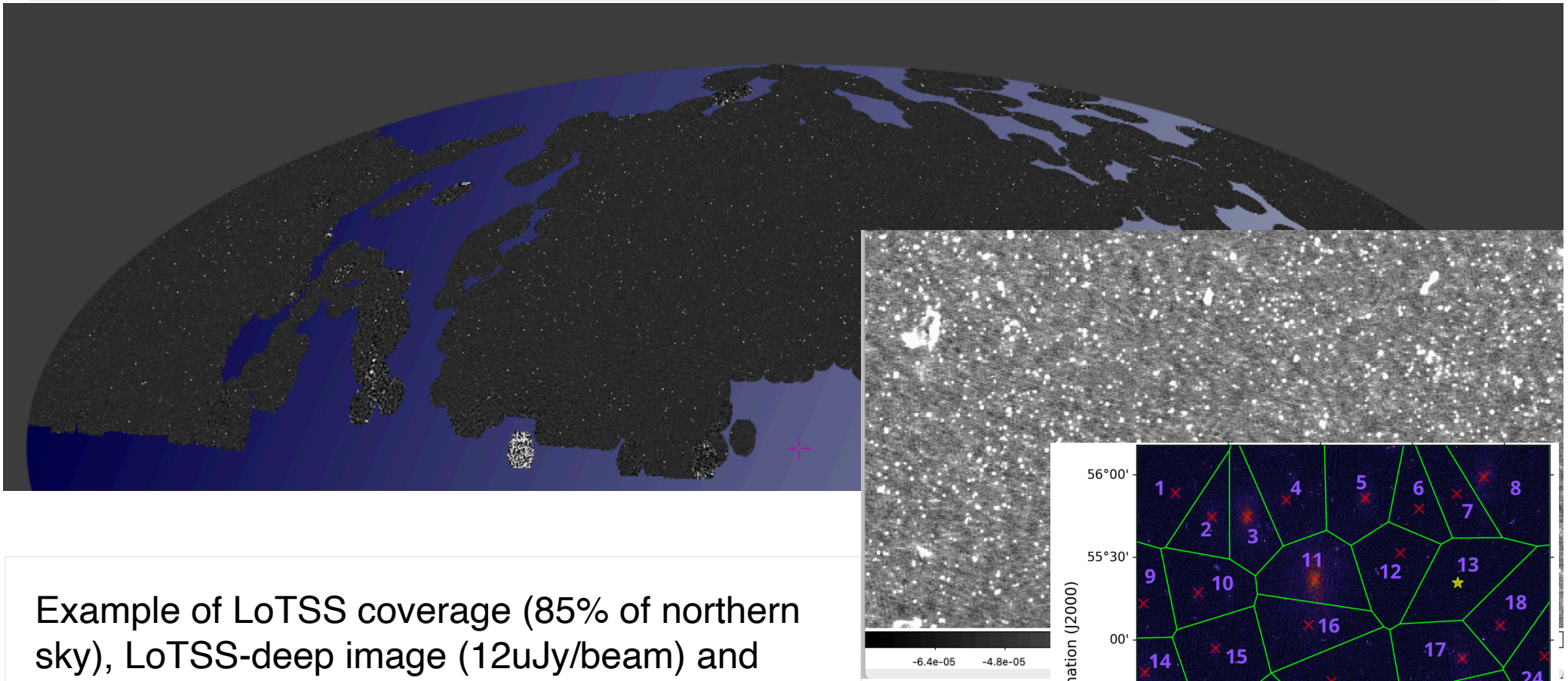
van Weeren et al., in prep.





Facilitating LOFAR2.0 large programmes

Using these techniques huge areas of the sky have been mapped and very deep observations already conducted. Built up fantastic models of these regions that can be utilised to aid LOFAR2.0 calibration.



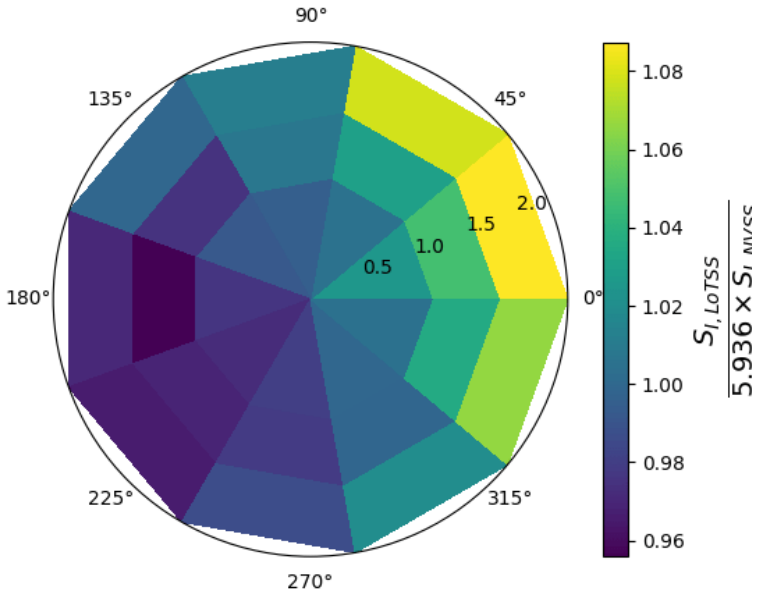
Example of LoTSS coverage (85% of northern sky), LoTSS-deep image (12uJy/beam) and wide-field LoTSS-deep with VLBI (see e.g de Jong+ 2024, Sweijen+ 2023, Morabito+ 2022). All catalogued, models existing etc.

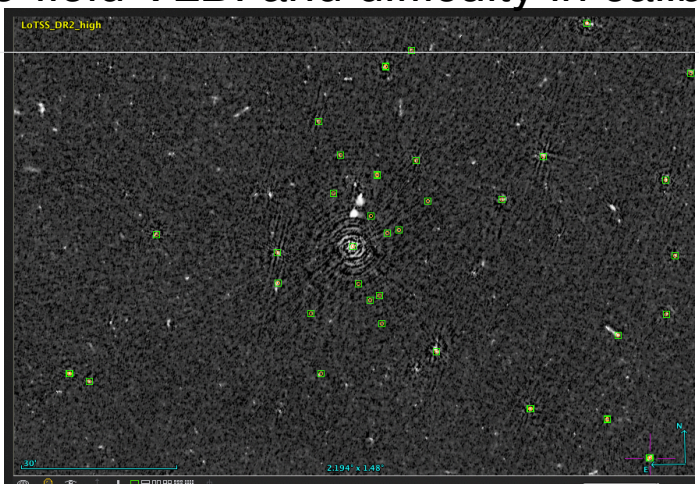
Facilitating LOFAR2.0 large programmes

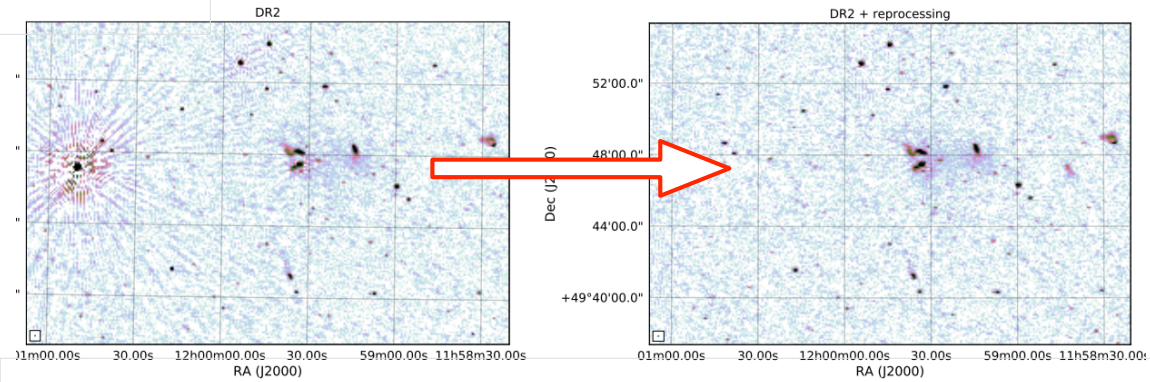
We also know how to turn these kinds of products into papers (over 500 LOFAR publications) and we also know what some issues hindering some science cases

E.g. some HBA imaging features:

- Not possible to make image products that satisfy all scientific aims.
- Calibration and imaging often need refining for detailed studies of complex objects
- Flux density scale very poor
- Spurious polarised sources (due to lack of polarised sky model)
- Poor removal of some A-team sources
- Exceptionally high computational cost of wide-field VLBI and difficulty in calibrating.



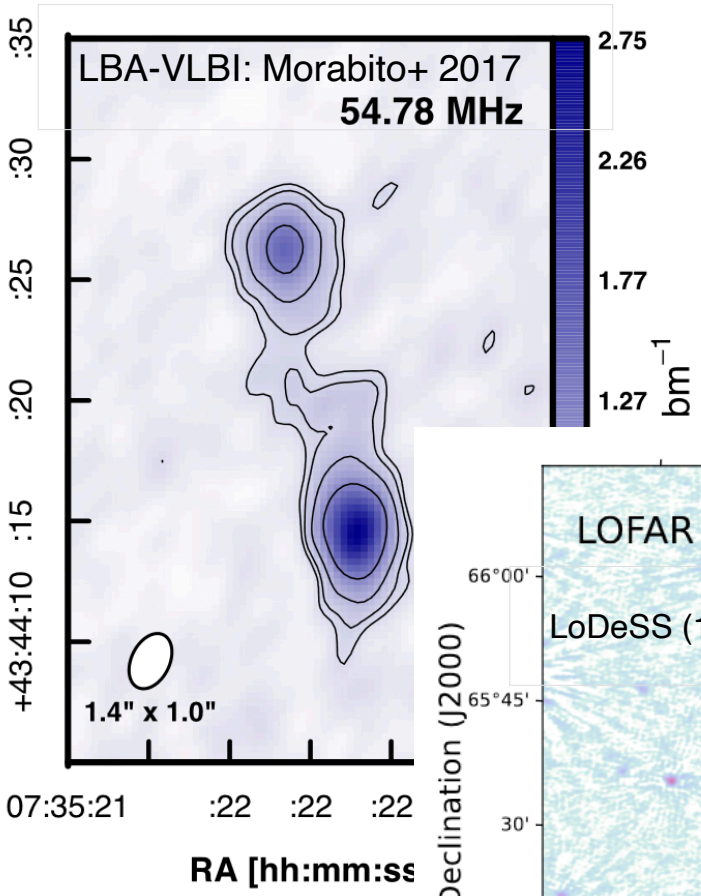


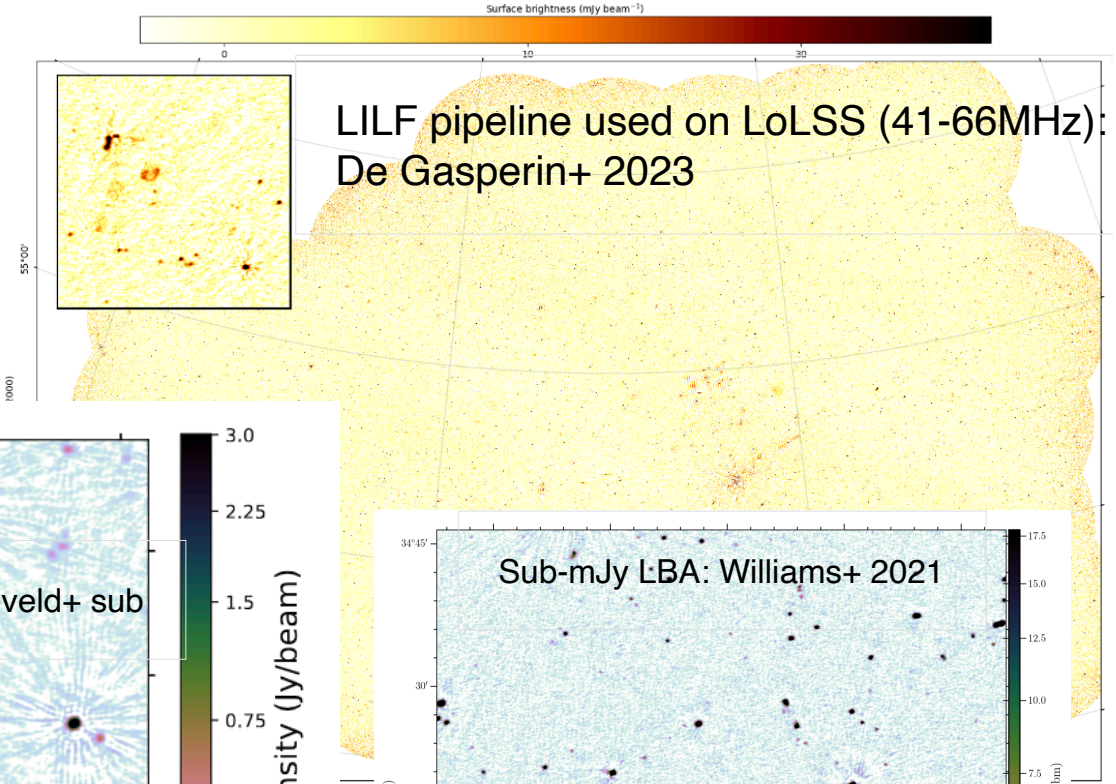


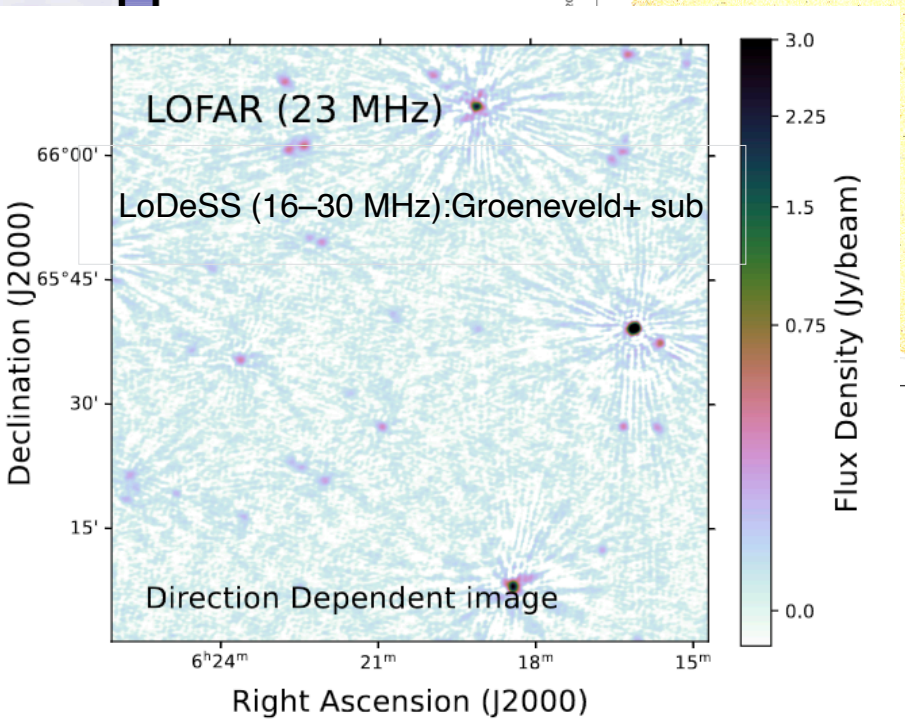
Post processing to tune calibration for a cluster (van Weeren+ 2021) - from 4TB to ~5-20GB

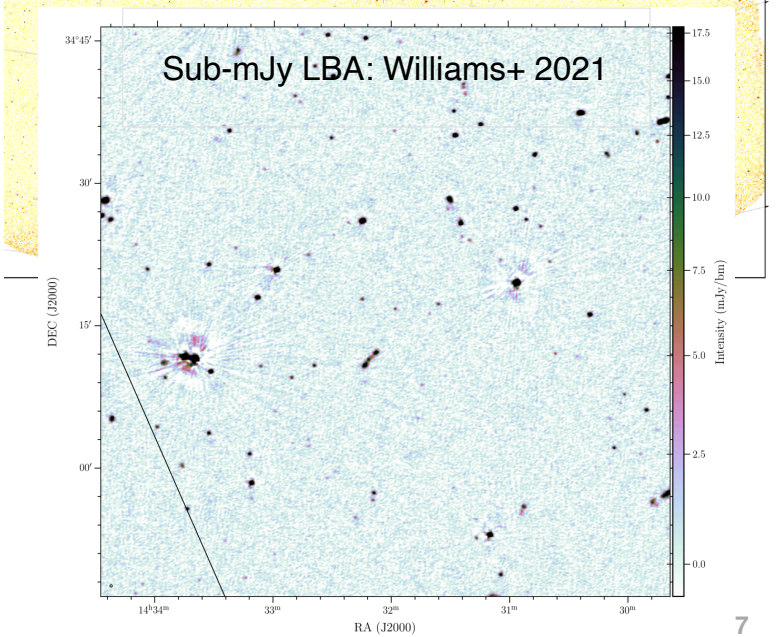
Facilitating LOFAR2.0 large programmes

Similarly excellent foundations for LBA with wide-field areas robustly mapped, deep fields explored (cpu cost feasible), VLBI and ultra-low frequencies demonstrated.









LOFAR2.0 pipeline development

Requirements for SDC LOFAR2.0 pipelines are that they run in the common workflow language (CWL) and for maintenance/development purposes utilise DP3 and WSClean for calibration and imaging.

Pipelines must also be computationally efficient, fully automated and executable on large scales.

What are these pipelines (HBA and LBA versions).

Pre-processing pipeline: Preparation of data (flagging, averaging, demix, compression)

LINC: Direction independent calibration.

RAPTHOR: Direction dependent calibration and imaging at 6” (Netherlands baselines) of data

VLBI: Full wide-field field (and/or targeted) imaging and direction dependent calibration at full ILT resolution (0.3” for HBA).

LOFAR2.0 pipeline development

Where are the SDC LOFAR2.0 imaging pipelines (HBA and LBA versions) are:

Pre-processing pipeline: Improvements in quality of demix required and possibly cpu usage. Possibility to revisit data compression factors.

LINC: HBA-strategy is state of art. Fine tuning of aspects such as self calibration, clock fitting, model selection and ensuring optimal compatibility with VLBI processing. LBA-strategy first version but strategy evolving (see de Gasperin talk).

RAPTHOR: Effective in driving development of components and framework, but RAPTHOR is not yet state of art compared to the DDF-pipeline and LILF pipelines for NL-resolution HBA and LBA imaging respectively: it is a factors of a few too slow, and for some fields produces image quality slightly below state of art. Work ongoing to make compute costs competitive and improve strategy (Offringa talk). LBA-strategy is rapidly evolving (de Gasperin talk)

VLBI: Full wide-field field (and/or targeted) imaging and direction dependent calibration at full ILT resolution (0.3” for HBA). Understandably very computationally intensive (~100,000 cpu hrs for a single wide field image) and not all steps are easy to fully automate (see Morabito talk). LBA still research question.

LOFAR2.0 pipeline development

LOFAR2.0 pipelines need improving, testing, making as computationally efficient as possible and ensuring they meet LOFAR2 requirements.

If interested in joining the efforts in developing/commissioning the LOFAR2.0 imaging (or other - e.g. solar, pulsar, transient) pipelines:

Please sign up on https://miro.com/app/board/uXjVKWueITA=/ or email myself (shimwell@astron.nl) and Marco Iacobelli (iacobelli@astron.nl).

Discussion session:

RAPTHOR: - A. Offringa

LBA: - de Gasperin

VLBI: Morabito