LOFAR deep fields: 3C 196

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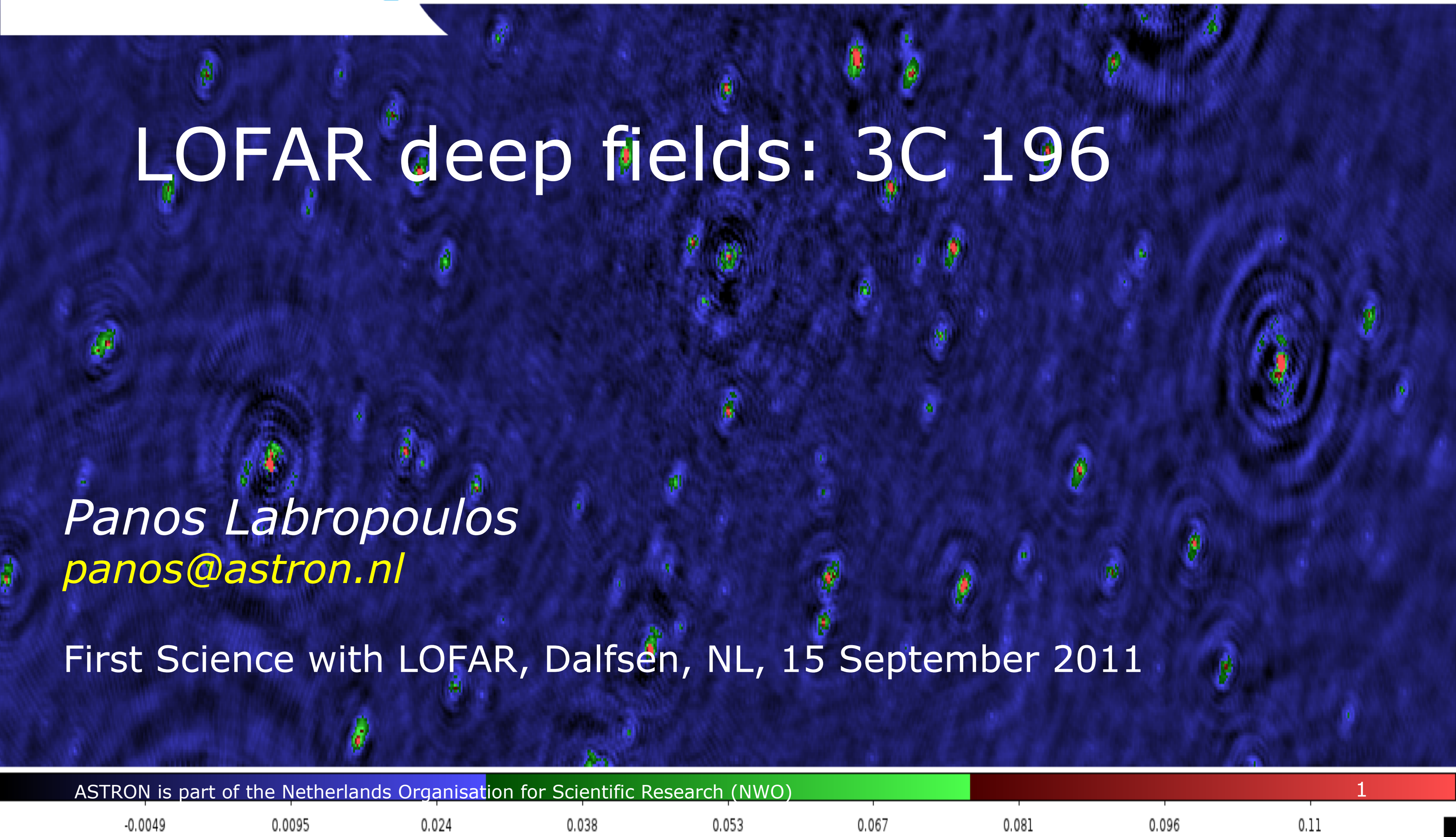
First Science with LOFAR, Dalfsen, NL, 15 September 2011



Motivation

The Epoch of Reionization (EoR) Key Science Project (KSP) on the other hand requires beating down the thermal and systematic noise (“effective noise”, S, Wijnholds) by continuously repeating the same observations on the same fields.

- Up what integration time can we reach the thermal noise?
- Does LOFAR have long term stability/systematic errors?
- What fraction of data is unusable due to RFI, ionosphere, bad calibration solutions?
- EoR strategy: day time vs night time, bright source in P.C., are foreground removal techniques adequate for sensitivities well below classical confusion?

LOFAR Early Access proposal 128: Weekly monitoring of the 3C196, J2000 NCP and a field with no bright sources (> 1 Jy)

The 3C196 and NCP fields

The fields to be picked need:

- High declination and high Galactic latitude
- Acceptable Galactic foregrounds (weak/no polarization !) and extragalactic confusion
- Enough nighttime possible

3C196	NCP
high SNR for calibration and compact source (80Jy, 6'')	3C61.1 (5 Jy) off P.C. -> dynamic range
DEC 48 (Station Beam?)	**DEC 88**
Less noise due to the Galaxy (cold halo location)	Stronger Galactic foregrounds
-	**RFI studies (0 fringe rate RFI)**
Observed with WSRT	Observed with WSRT
Winter/spring time	All year-round

(Possible) locations of EoR 'windows'

Haslam et al (1981)

408 MHz

All-sky (0.85^{o} PSF)

LOFAR windows

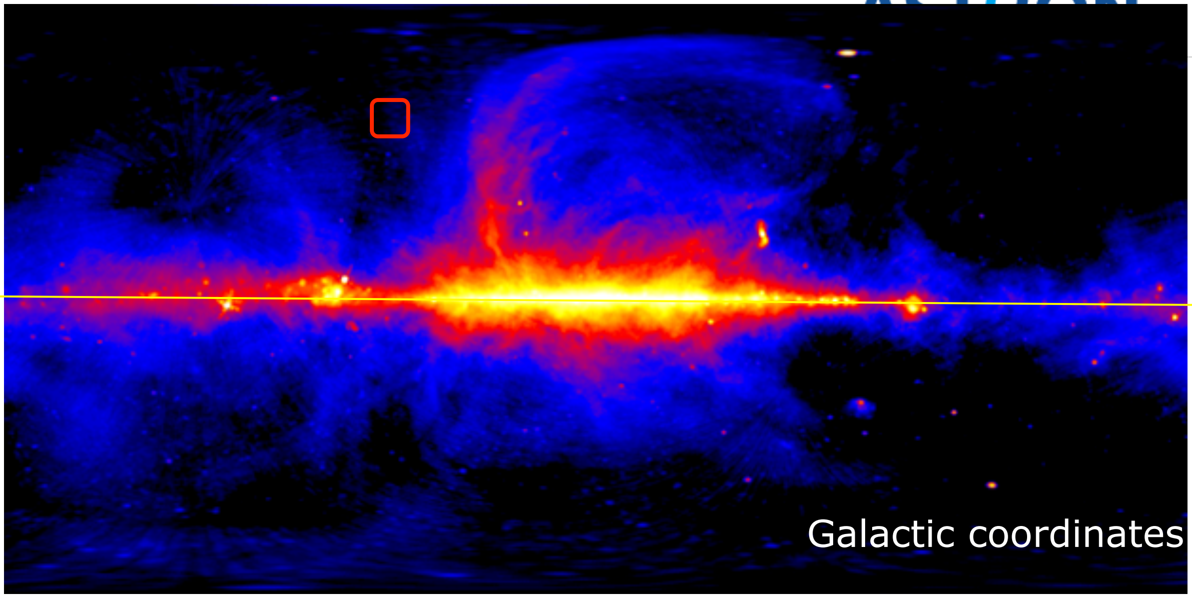
- NCP
- 3C196
- Elais N1 (?)

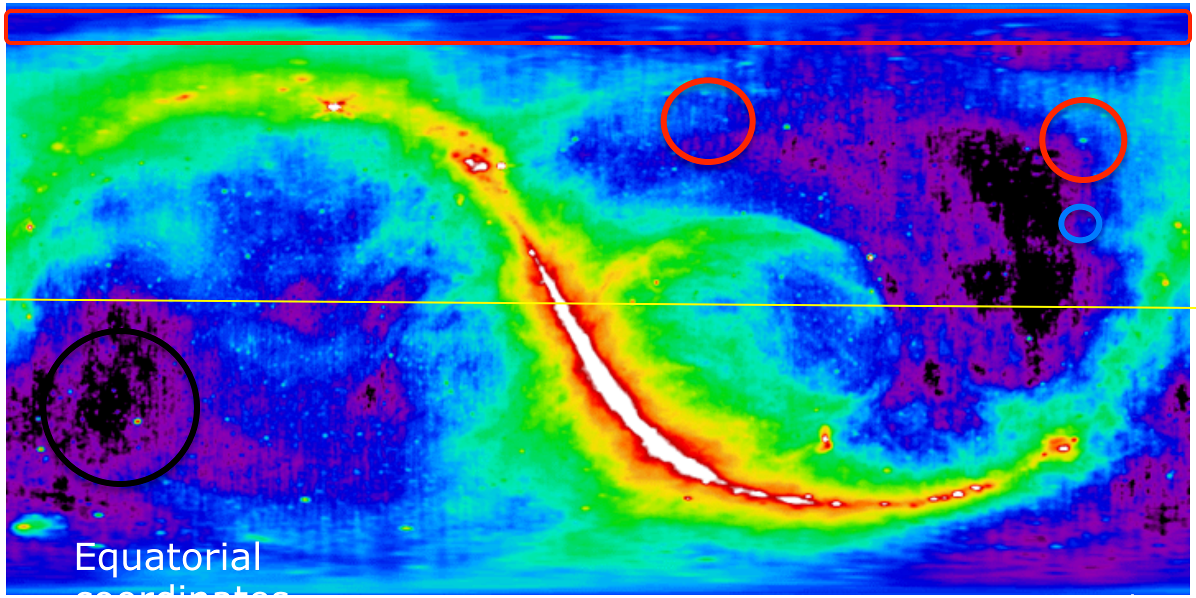
+ two more

GMRT field:

- PSR0823+26
-

MWA field





Observation specifications

- Phase center: 3C 196 (**76.8 Jy** at 150 MHz, α=0.64), NCP

3C196: R.A. = 08:13:36.00, δ= **+48.13.02.00** (l=171,b=33) 1 or 7 beams

NCP: R.A. = 04:00:00.00, δ= **+88.00.00.00** (l=124,b=25)

- Frequency range: **115-163 MHz**
- 248 sub-bands (0.183MHz) – 64 3.2 kHz ch.
- 15 x 12.2 kHz channels after compression
- **2 sec** avg. time, **6 hours** of synthesis
- **~8 arcsec** resolution
- In the future: 1s, 0.8 kHz, 24x 2CS + ~ 10x1 RS

17-19 double core stations (CS)	(each 2x24 tiles)	baselines	~	0.05 – 3 km
6-7 single remote stations (RS)	(each 48 tiles)	baselines	~	5 – 40 km
0-3 EU stations	(each 96 tiles)	baselines	~	250 – 1000 km

LOFAR EoR data processing steps

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Preprocessing (DPPP)

- Automated data flagging with AO flagger (Offringa et al, 2010) typically < 5% loss
- Data averaging (factor 4) → 2s, 12 kHz (flagmasks carried along)

Data transfer

- CEPII→ EoR cluster (~ 244 x 8 GB ~ 3 TB per 6h run ~ 300 TB available now)
- 80 nodes with 8 CPUs + 2 GPUs
- database management system (for data + diagnostics output)

Calibration
- using a steadily improving Local Sky Model
- BBS (Black Board Selfcal) , and
- SAGEcal (Yatawatta et al, 2010; Kazemi, Yatawatta et al, 2011)

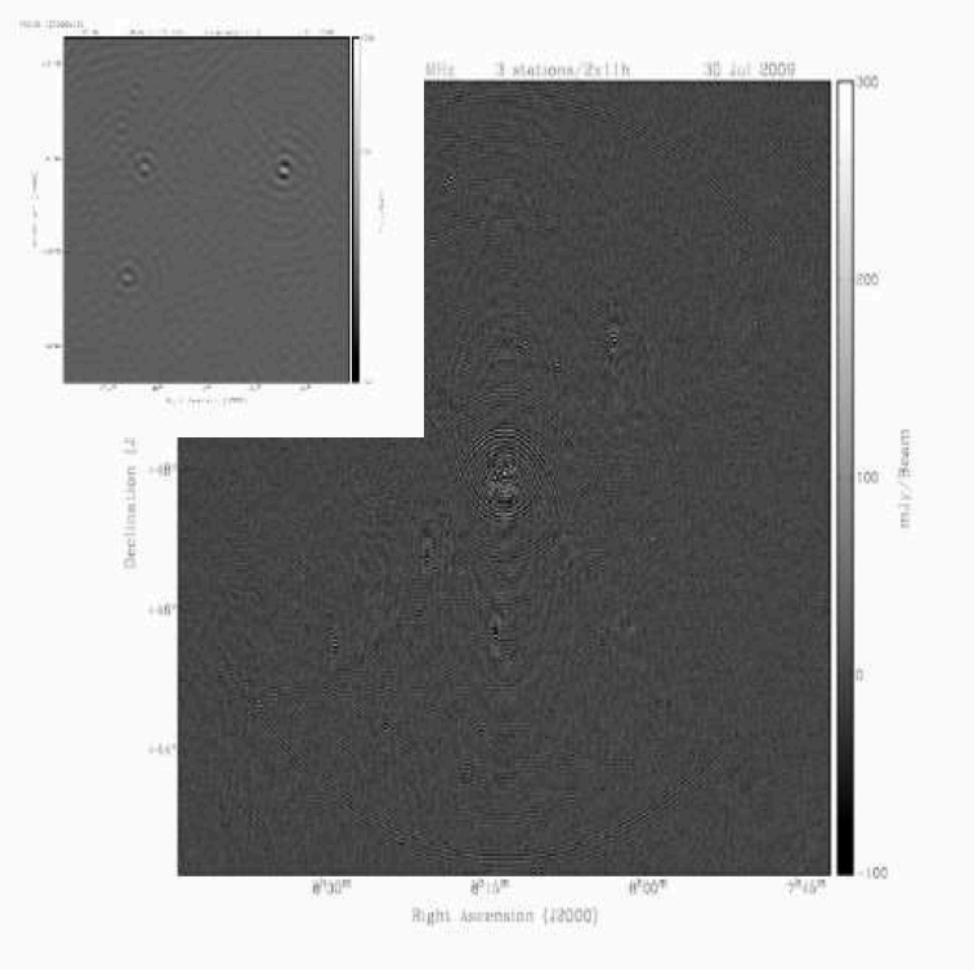
Main calibration worries/issues at this stage:
- Many stations have several/many nonfunctional tiles → unknown beam shapes (Ger's talk)
- No imager can (as yet) take time varying beams into account (working on that as well)
- Large number of unknowns to solve → SAGE-EM fit for all station Jones matrices as a function of time for many (spatially grouped) source clusters, and then subtract Works well !!
- Getting better models for bright sources

System stability

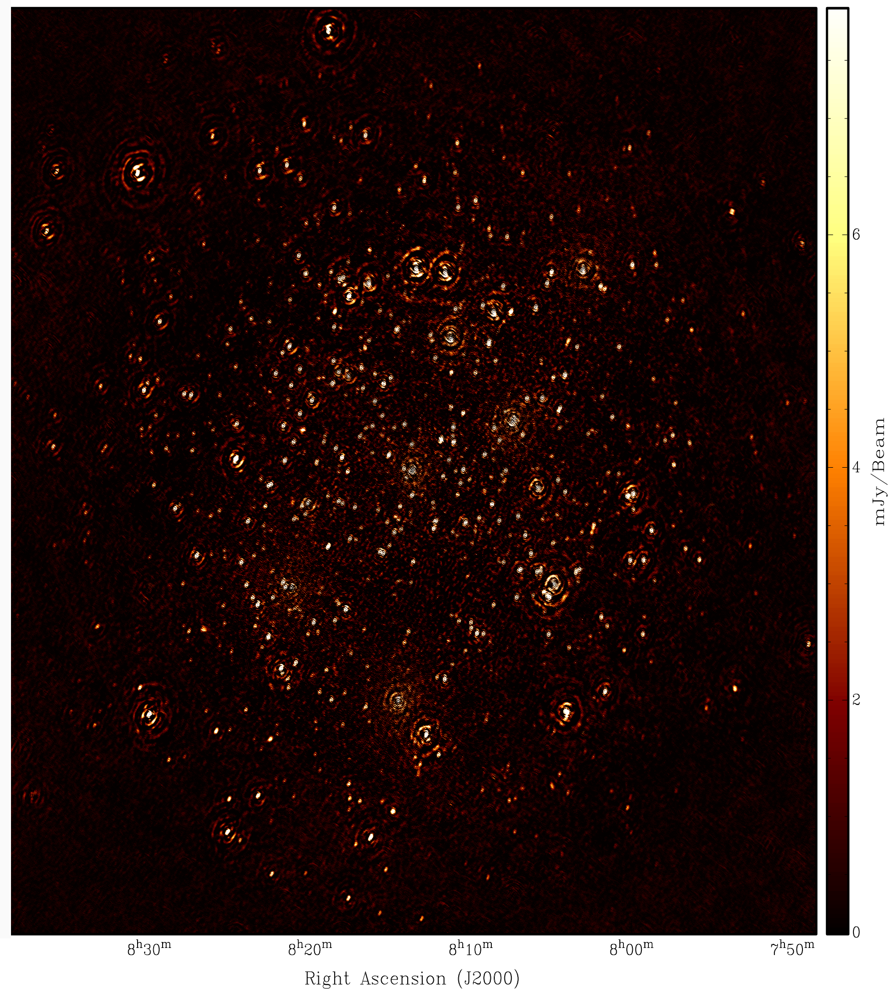
Assume sky is mostly unpolarized and use XY,YX correlations to measure noise

7 Jan 2011	L22667	SB100	S/N = 18.6
28 Jan 2011	L23092	SB100	S/N = 17.0
11 Mar 2011	L23927	SB100	(S/N > 14.8)
19 Mar 2011	L24380	SB101	S/N = 24.1
1 Apr 2011	L24837	SB100	S/N = 28.3
15 Apr 2011	L25489	SB100	S/N = 20.0
29 Apr 2011	L24801	SB100	S/N = 27.7

Progress in thee last 2 years



S. Yatawatta (2009)
3 stations, DR 1000:1



LOFAR (2011)
47 stations, DR 250000:1

But several things changed…

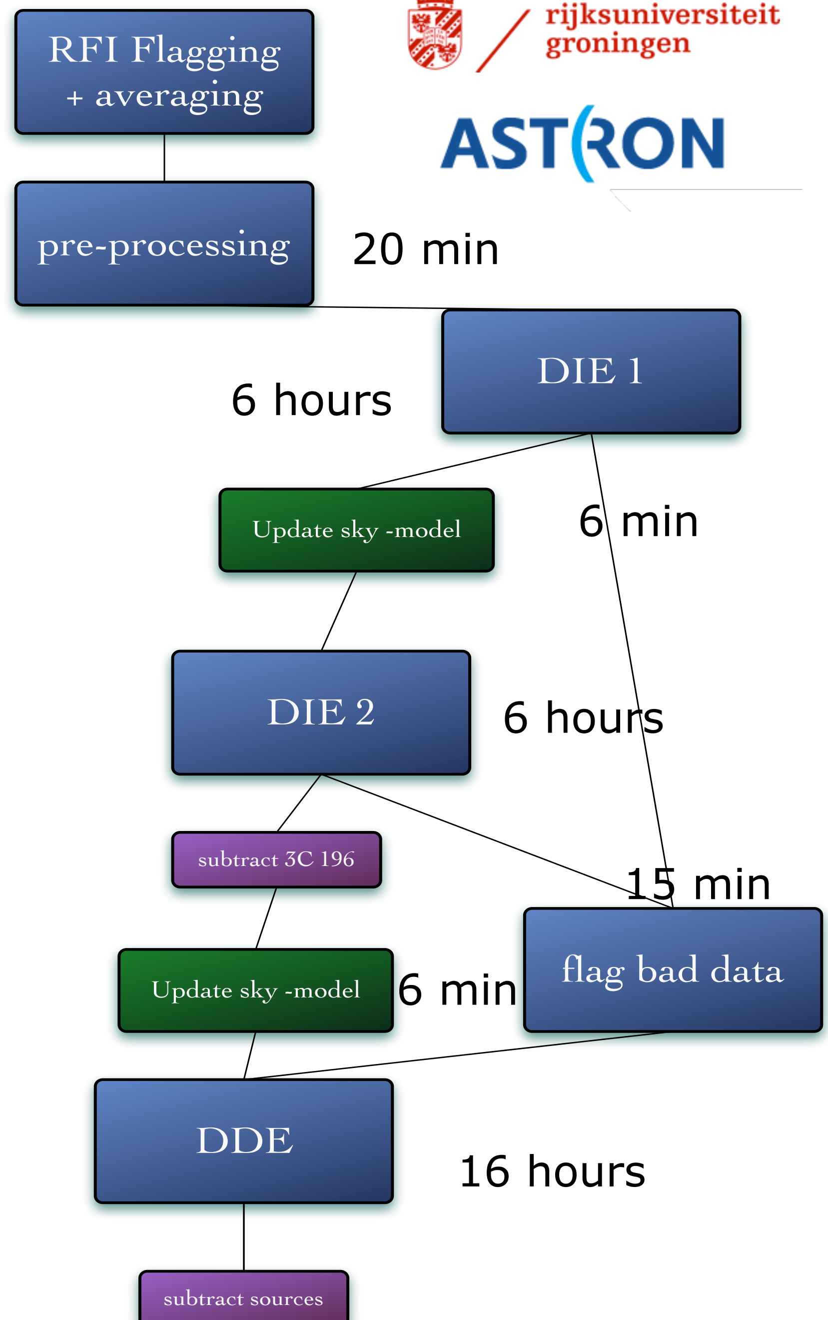
Increase in number of stations (collecting area)

Increase in baseline length (resolution)

More computing power (ability to implement and use more complicated calibration schemes)

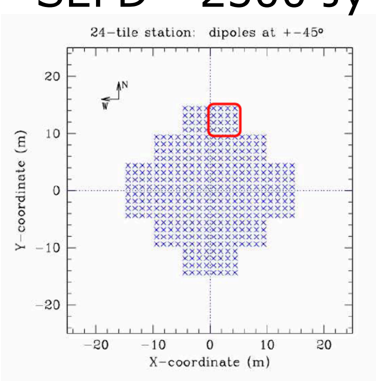
Increased familiarity with data

Processing Pipeline

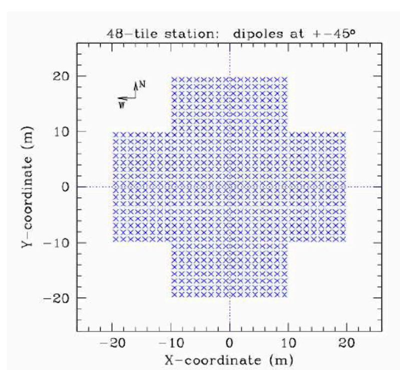


- Need a **good sky model** to begin with. (difference between 5 and 15 mJy rms noise/sbb)
- Beam attenuation complicates the sky model construction.
- Using all baseline combinations, ST-ST,ST-CS,ST-RS, CS-CS, CS-RS, RS-RS -> D(ifferent beam sizes/flux scales/noise)
- Flux scale sensitive to initial sky model and use of station beam.
- 70 model component

SEFD ~2500 Jy

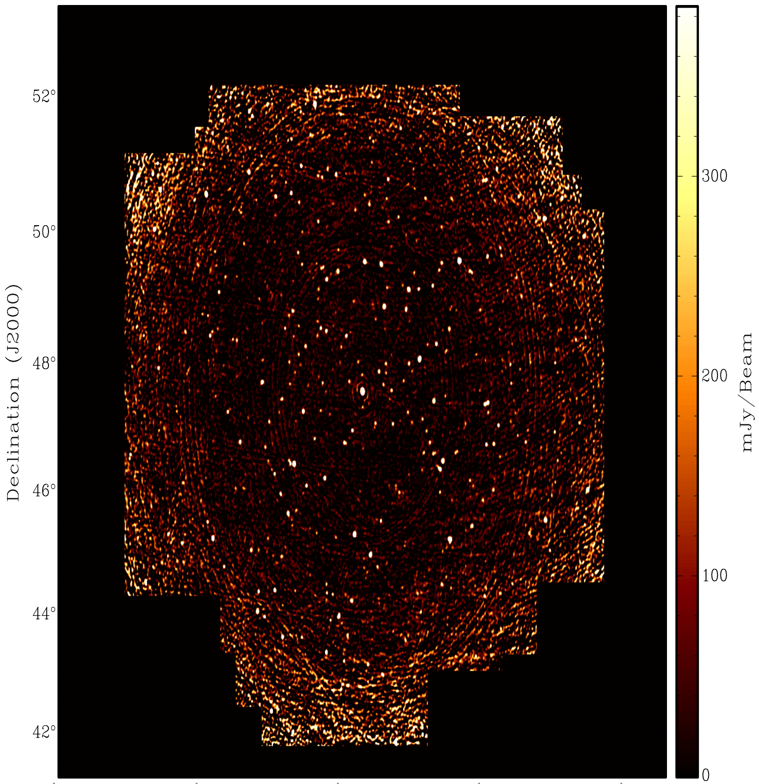


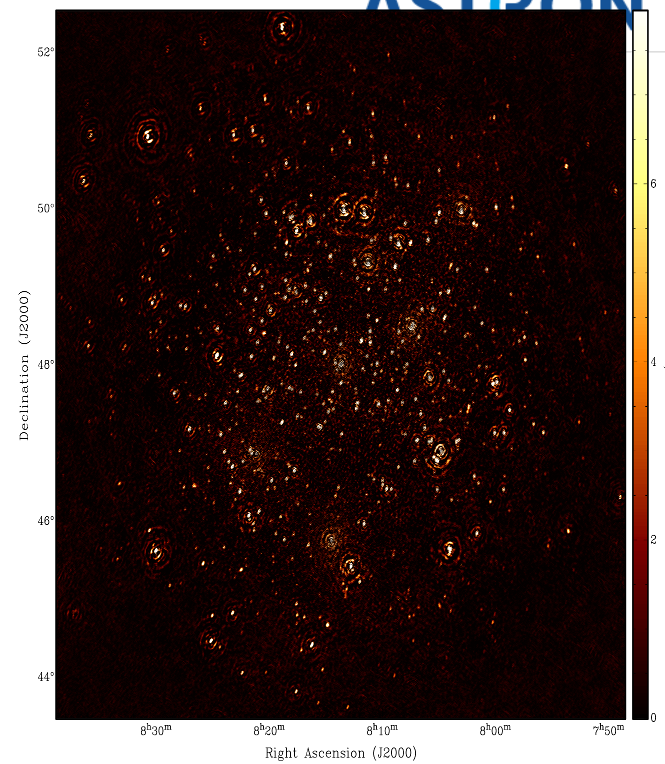
SEFD ~1250 Jy



Total: 38 hours (was 60)

3C196: WSRT versus LOFAR 115-163 MHz





LOFAR **6h** thermal noise ~ 0.1 mJy
image noise ~ 0.3-0.7 mJy

CS +RS, ~ 30 km ! 244 subbands

DR ~ 83 Jy/0.5 mJy ~ 200,000:1 average

(300.000:1 edges, 180.000:1 close to brightest sources)

Labropoulos et al., in prep.

WSRT **72 h** thermal noise 0.6 mJy
confusion noise 3 mJy

Gianni Bernardi et al (2010)

Results

A fair amount on previously undetected sources

15% of the sources have very steep spectral indices

A variable source detected

Most sources are double/triple

Seems that there are preferred orientations

Not the final say

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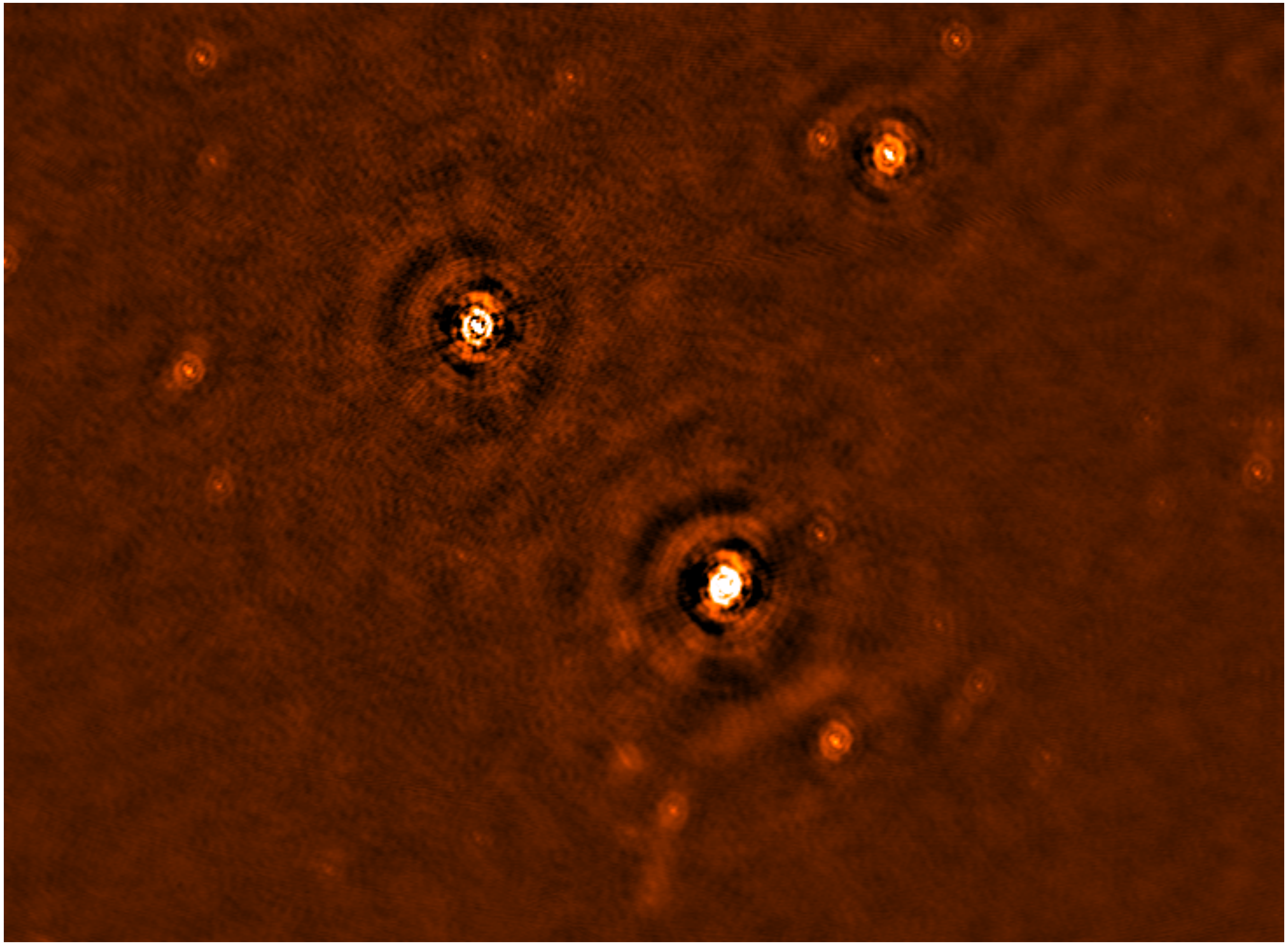
Need for expensive direction-dependent calibration



Closing the Major loop

-- Accurate sky models are really crucial in order to reach the theoretical sensitivity

-- Need longer baselines in order to properly model sources even if one needs to remove them from low resolution images

-- Sarod's **buildsky** model fits models to sources taking into account the PSF and noise.

Sky model: examples

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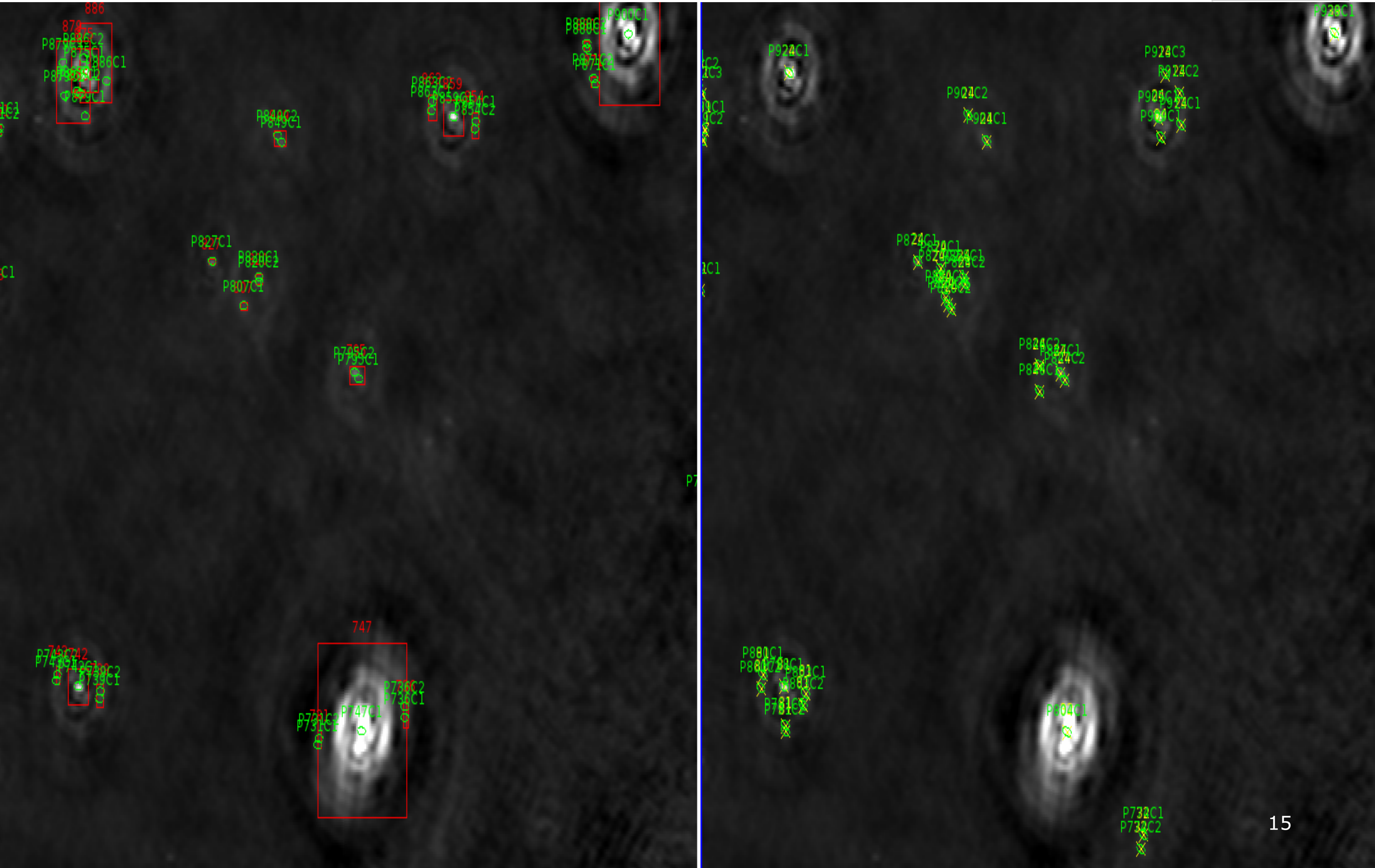

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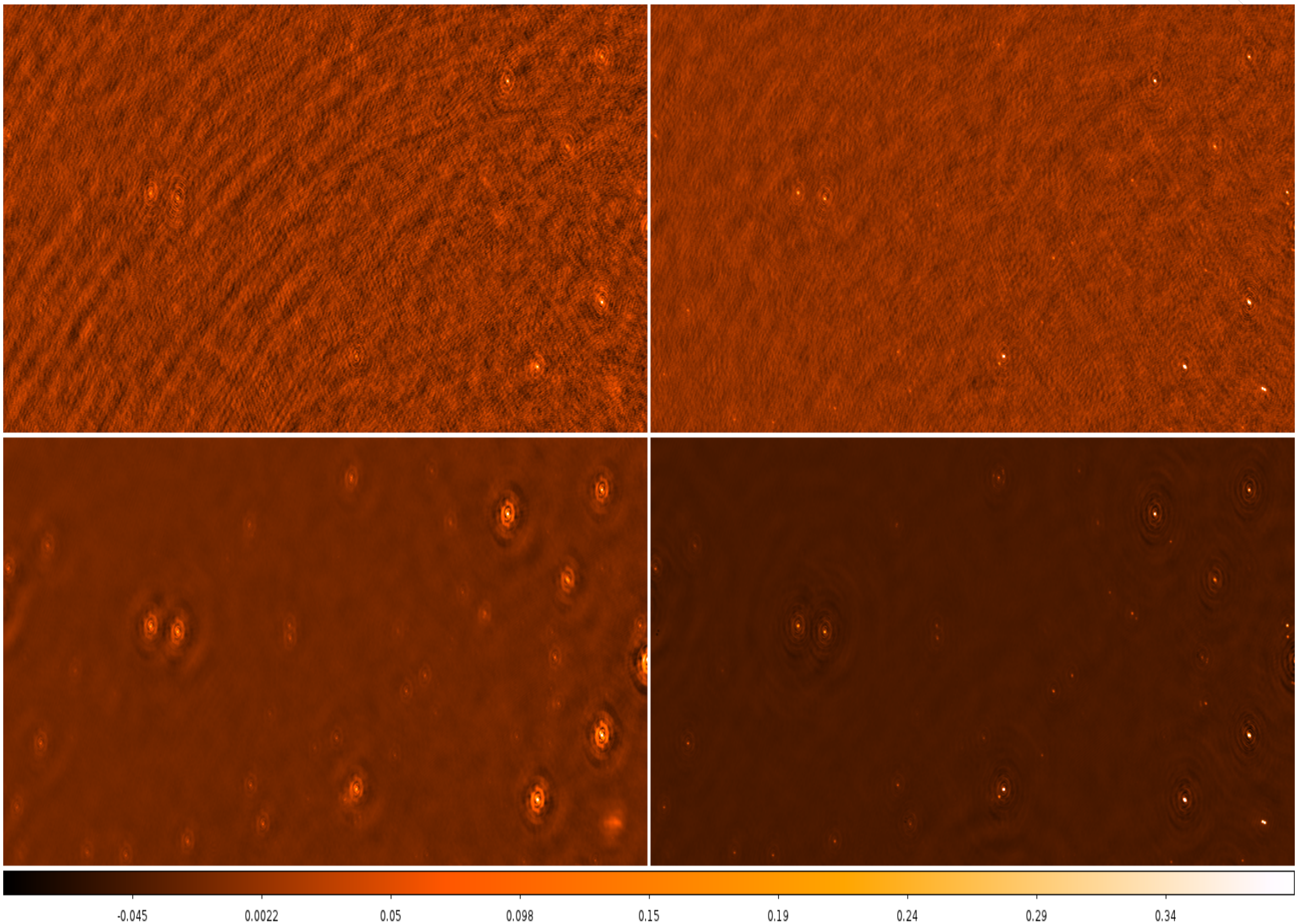
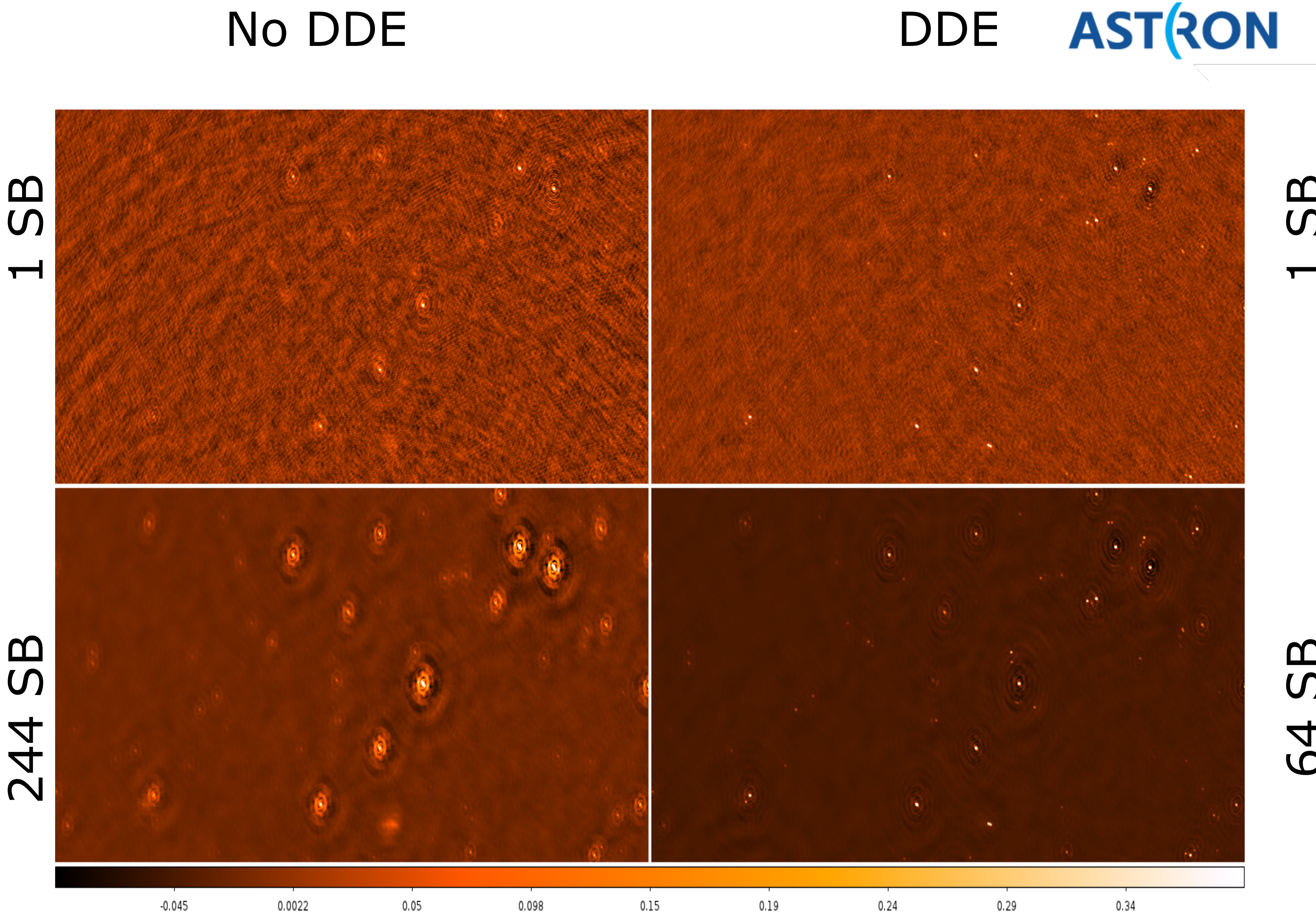
No DDE | DDE

1 SB | 1 SB



244 SB | 64 SB


No DDE
DDE
1 SB
1 SB
244 SB
64 SB
-0.045
0.0022
0.05
0.098
0.15
0.19
0.24
0.29
0.34

Sky model errors: need MORE resolution

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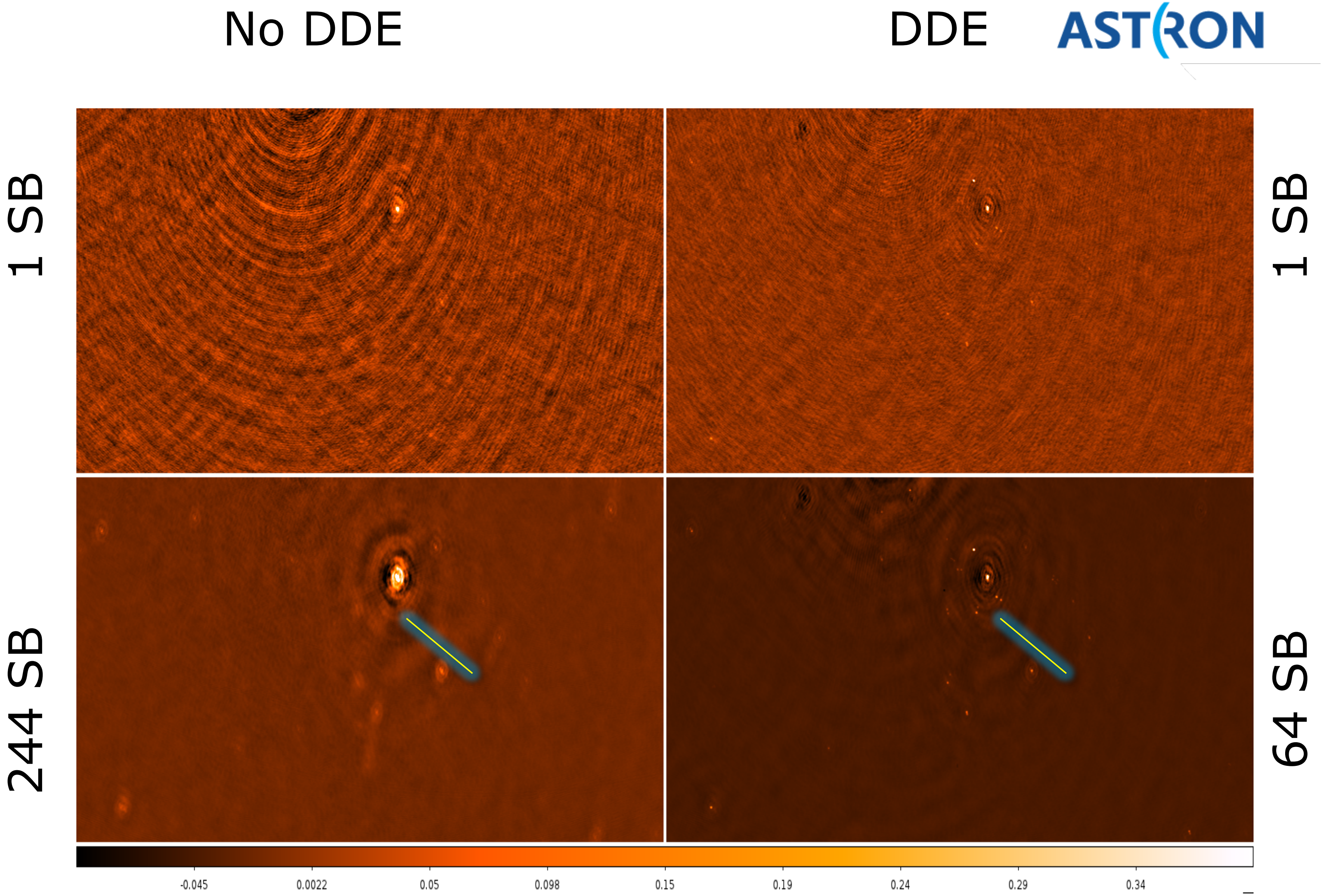
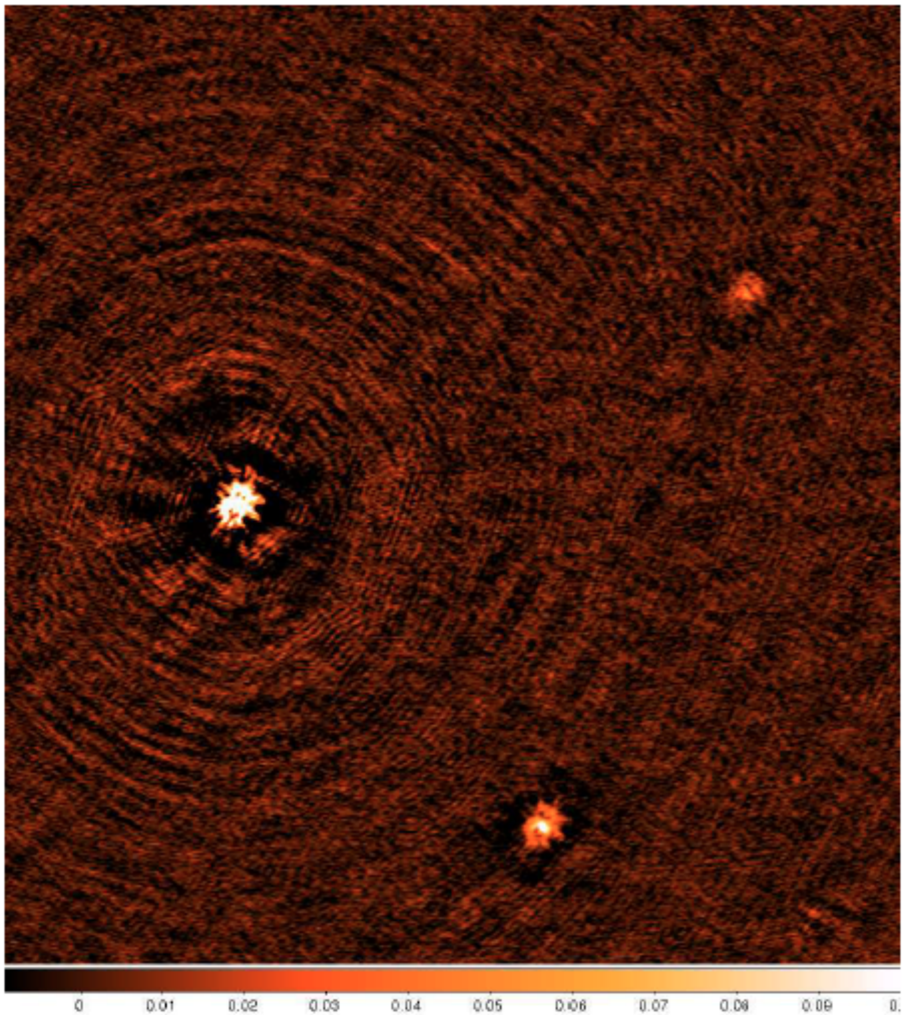
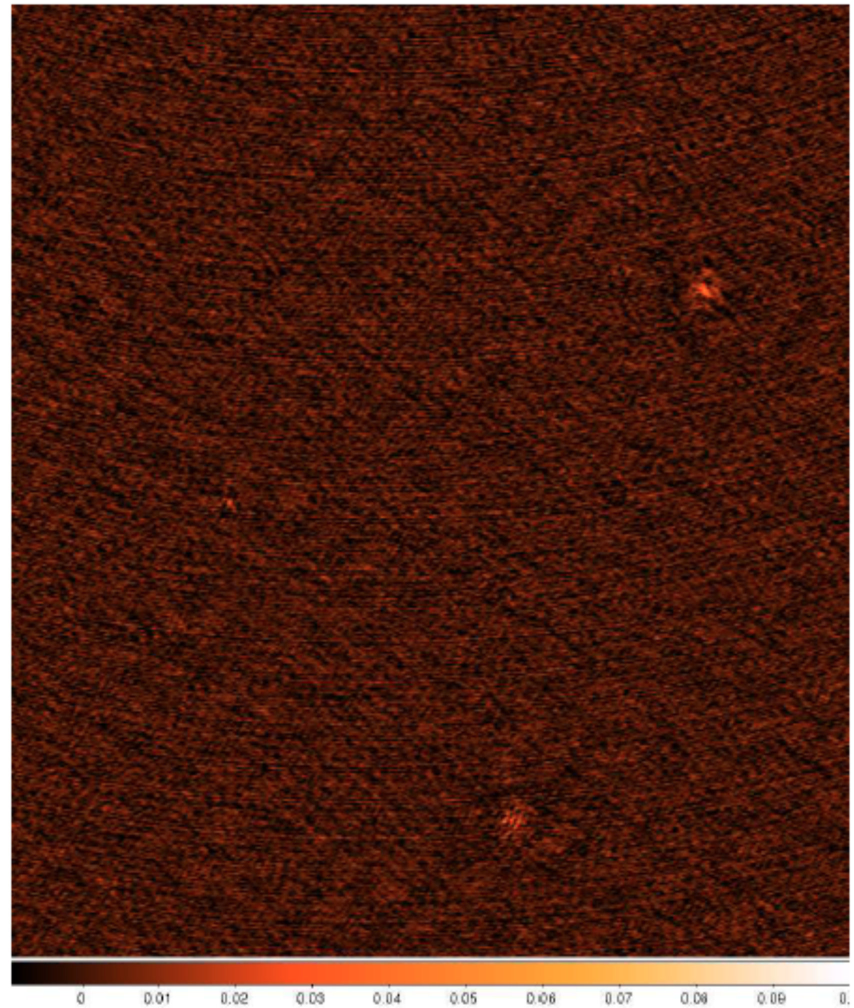
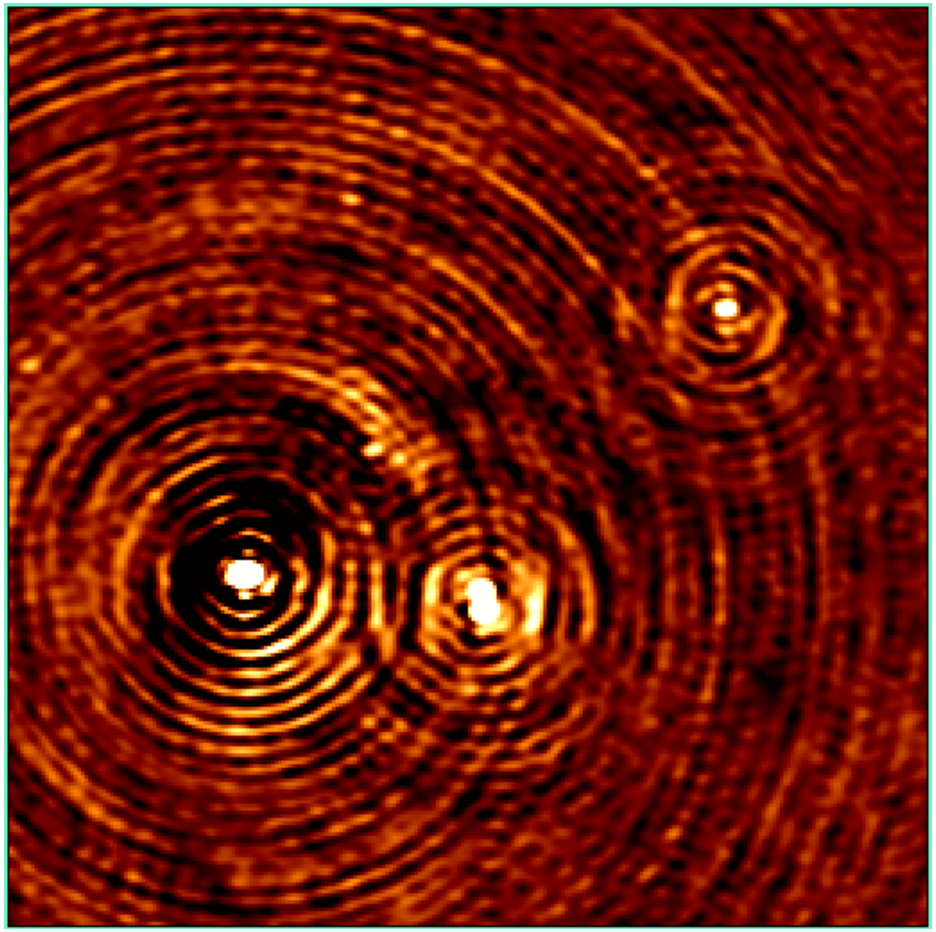


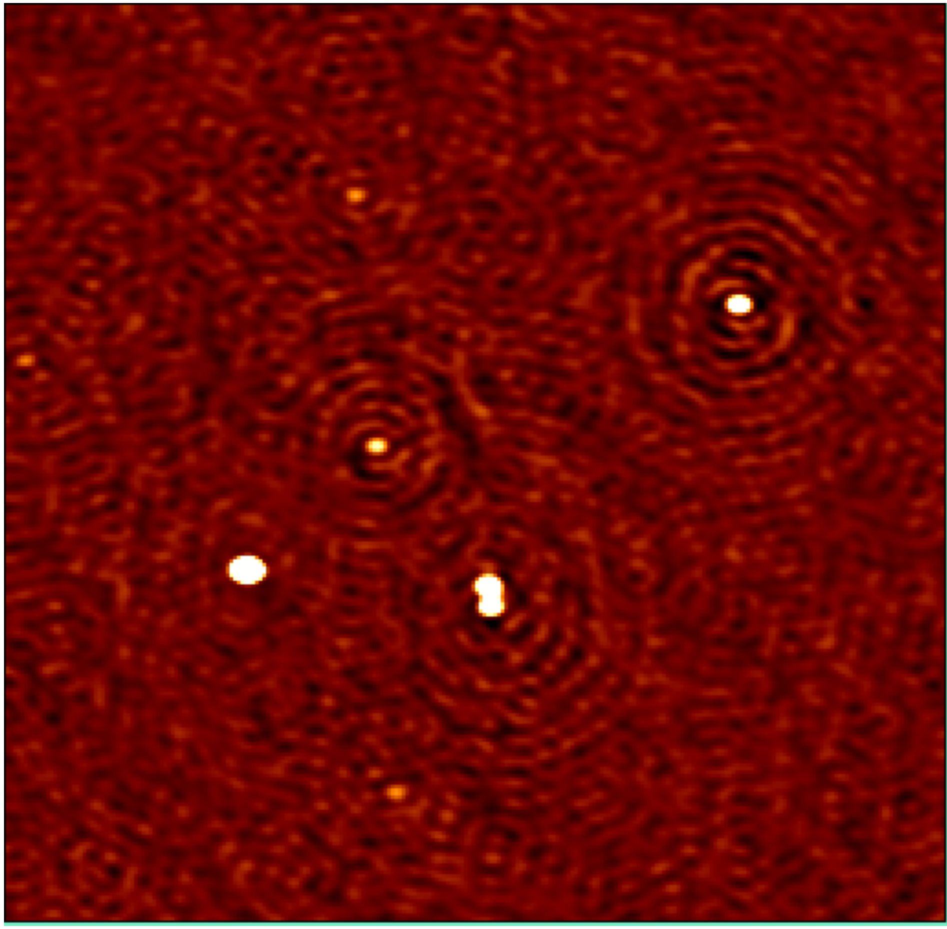
Source sub-traction from uv-data

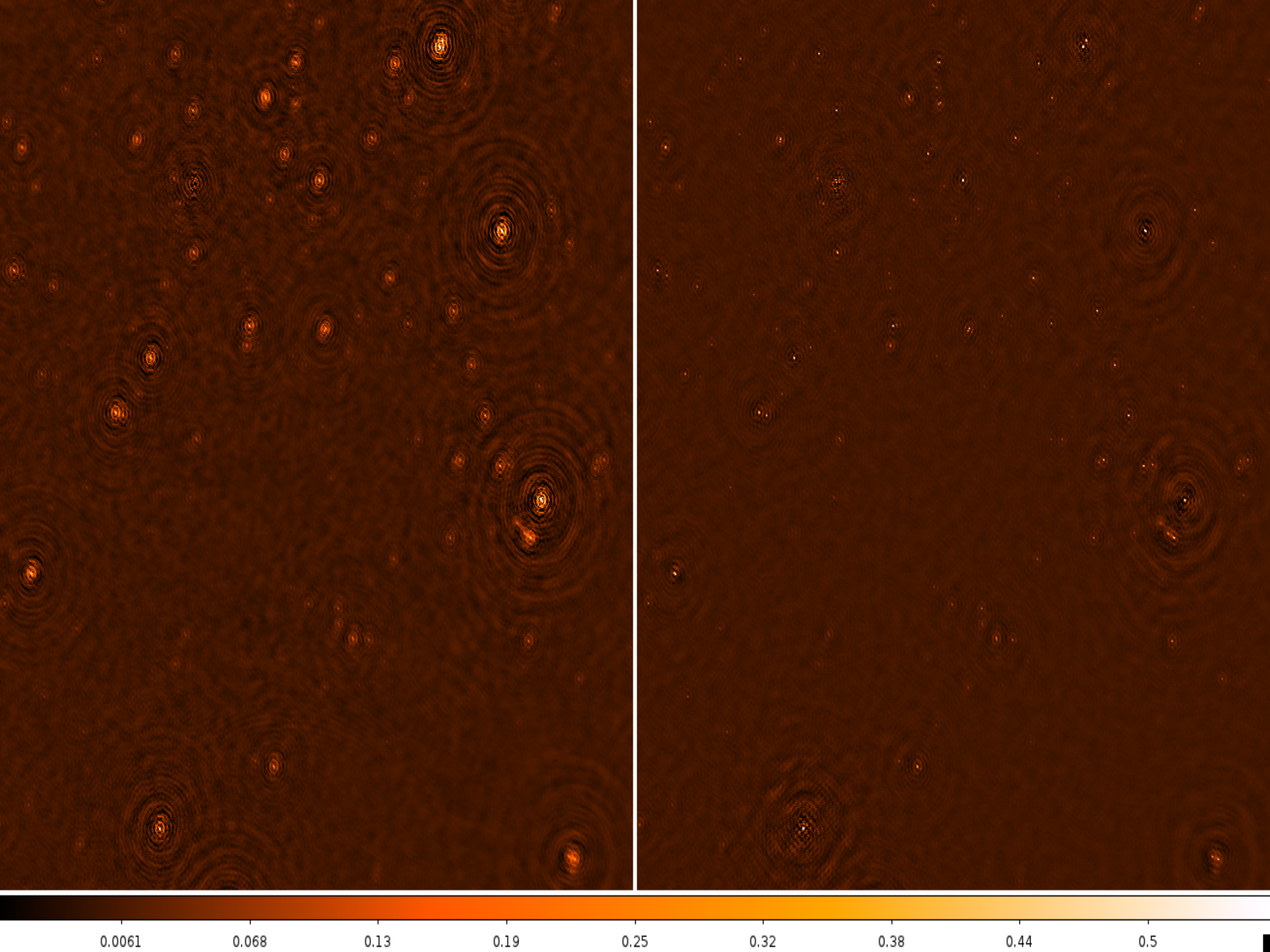




Calibration and restoration






0.0061
0.068
0.13
0.19
0.25
0.32
0.38
0.44
0.5

Computational feasibility

Solving and subtracting 1600 sources (2700 components) using 100 directions requires 14h with sagecal. (using also long baselines)

BBS requires larger unknown amount of time.

Each node can process 1 sub-band at a time -> 244 nodes or 3 times the EoR cluster to finish processing within one day.

Indicates the amount of processing required to reach the thermal noise for a given field.

Getting an accurate skymodel requires 3 or more self-cal iterations

Conclusions

- Redshifted HI from the EoR is a unique observational tool on a very important era
- Frequencies from **190 - 115 MHz (z = 6.5 – 11.5) is key window** (lucky !)
- Calibration challenges formidable; important steps in last 2 years
- Foregrounds are **probably manageable – long baselines important**

Results from LOFAR EoR experiments on NCP and 3C196:

- achieved a noise of 0.2 mJy, with, in 6h, 40 MHz in range 120-160 MHz
- DR 200,000:1 → **Now show stoppers in HDR imaging**
- still factor ~2 from thermal noise in the 3C196, also in (sub-MHz) differential imaging
- chromatic sidelobe noise ?
- **processing time still a major concern !**
- **LOFAR seems to perform close to its specifications**

Next LOFAR calibration steps:
- better and stable station beams; parametrized description
- better high resolution (1-4") models for all bright sources
- wide field ionospheric interpolation schemes (~ 50 km ground array
- ML inversion of data sets

Proper observing campaigns in the 2011/2012 season (?)

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Netherlands Institute for Radio Astronomy

LOFAR NWO

THANK YOU FOR YOUR ATTENTION !

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