university of groningen

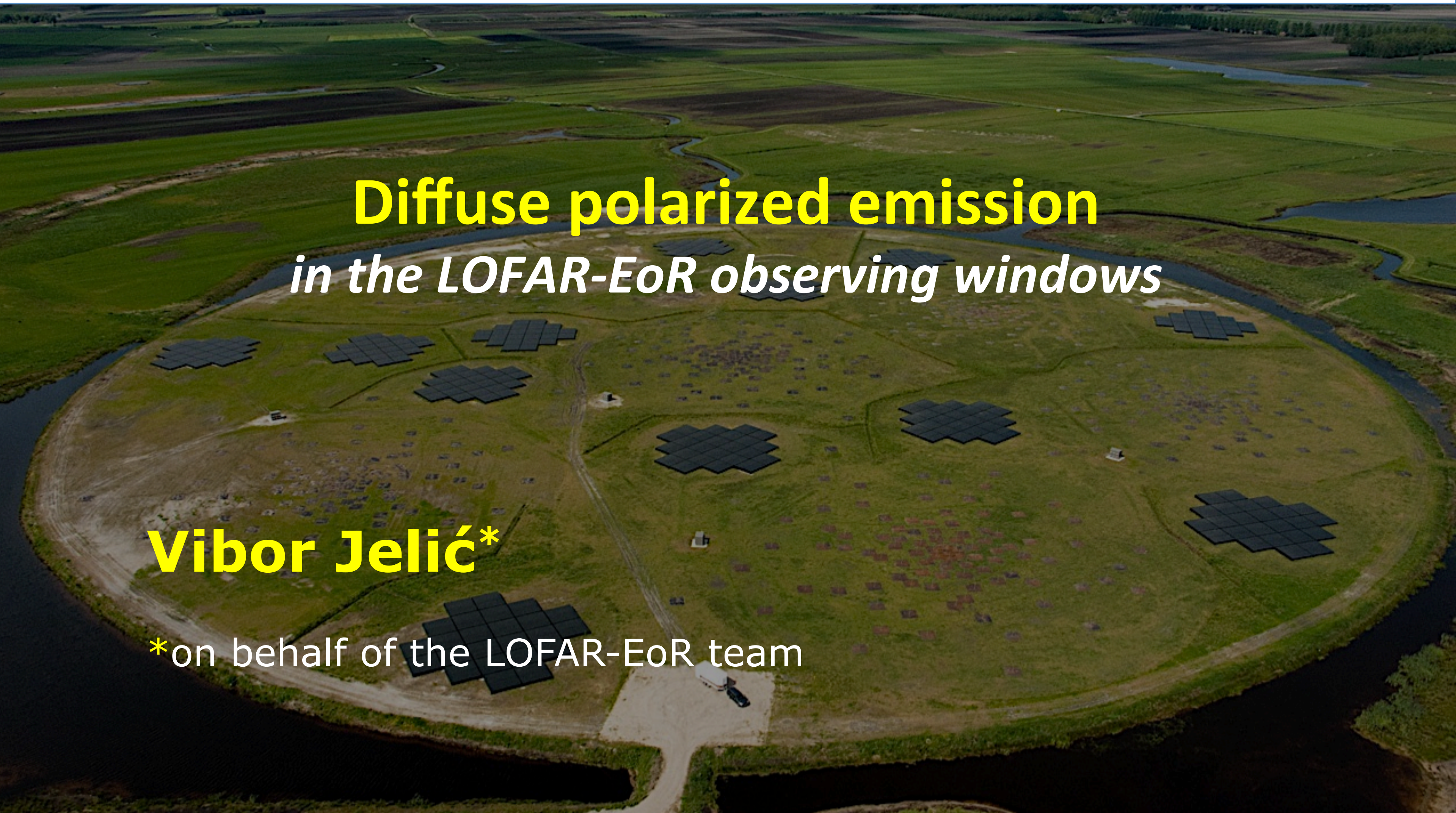
faculty of mathematics and natural sciences

kapteyn astronomical institute

LOFAR

ASTRON

Netherlands Institute for Radio Astronomy

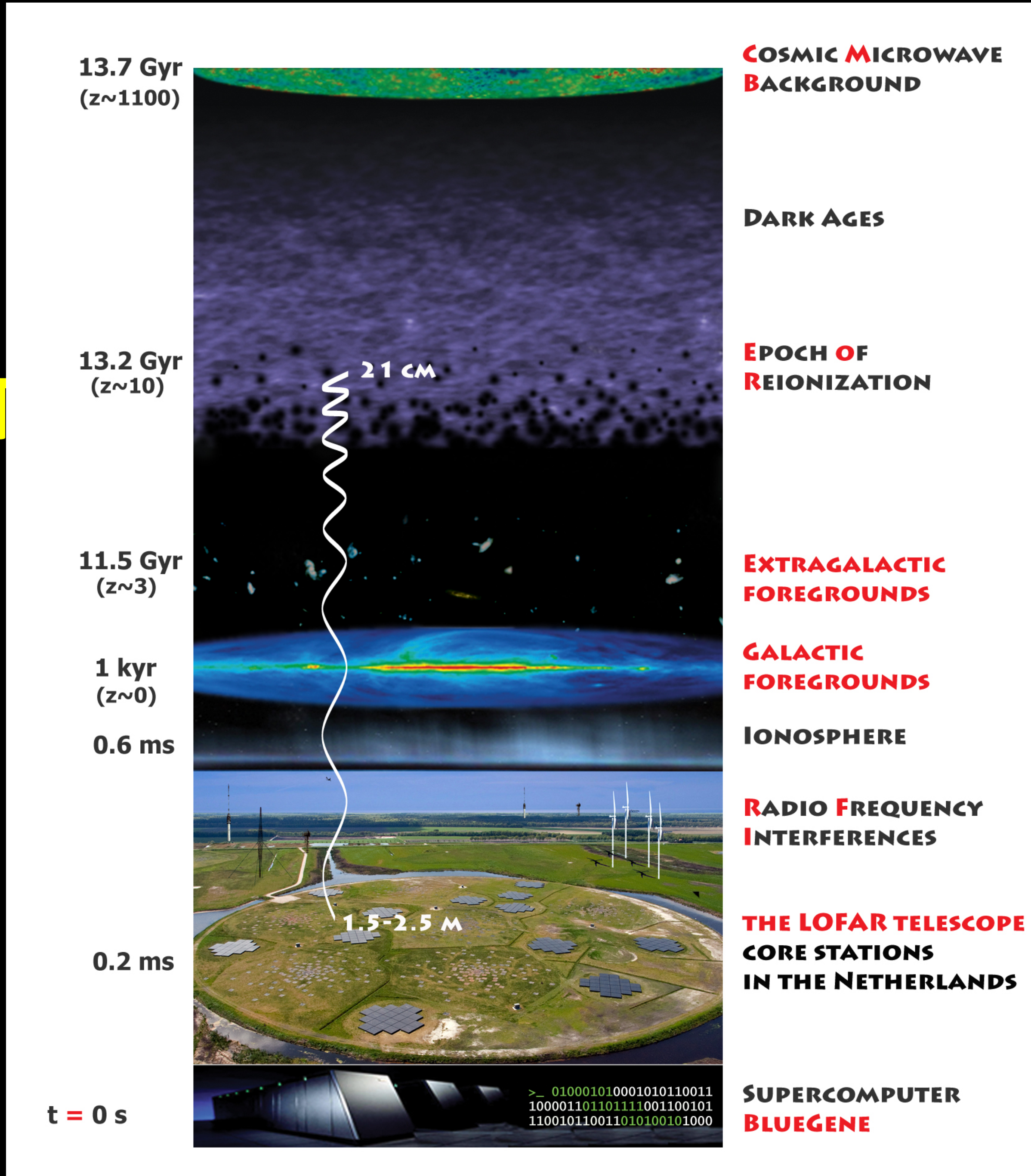


Diffuse polarized emission

in the LOFAR-EoR observing windows

Vibor Jelić*

*on behalf of the LOFAR-EoR team


13.7 Gyr
(z~1100)
Cosmic Microwave Background
Dark Ages
13.2 Gyr
(z~10)
21 cm
Epoch of Reionization
11.5 Gyr
(z~3)
Extragalactic foregrounds
1 kyr
(z~0)
Galactic foregrounds
0.6 ms
Ionosphere
Radio Frequency Interferences
1.5-2.5 m
0.2 ms
the LOFAR telescope
core stations
in the Netherlands
t = 0 s
>_ 01000101000101010110011
100001101101111001100101
110010110011010100101000
Supercomputer
BlueGene

LOFAR-EoR experiment

1. The LOFAR-EoR end-to-end simulation
2. Tested various signal extraction techniques
3. Observations with the WSRT radio telescope
4. Commissioning LOFAR observations

➔ **THE LOFAR-EoR OBSERVATIONS (started in Dec 2012)**

LOFAR-EoR experiment: end-to-end pipeline

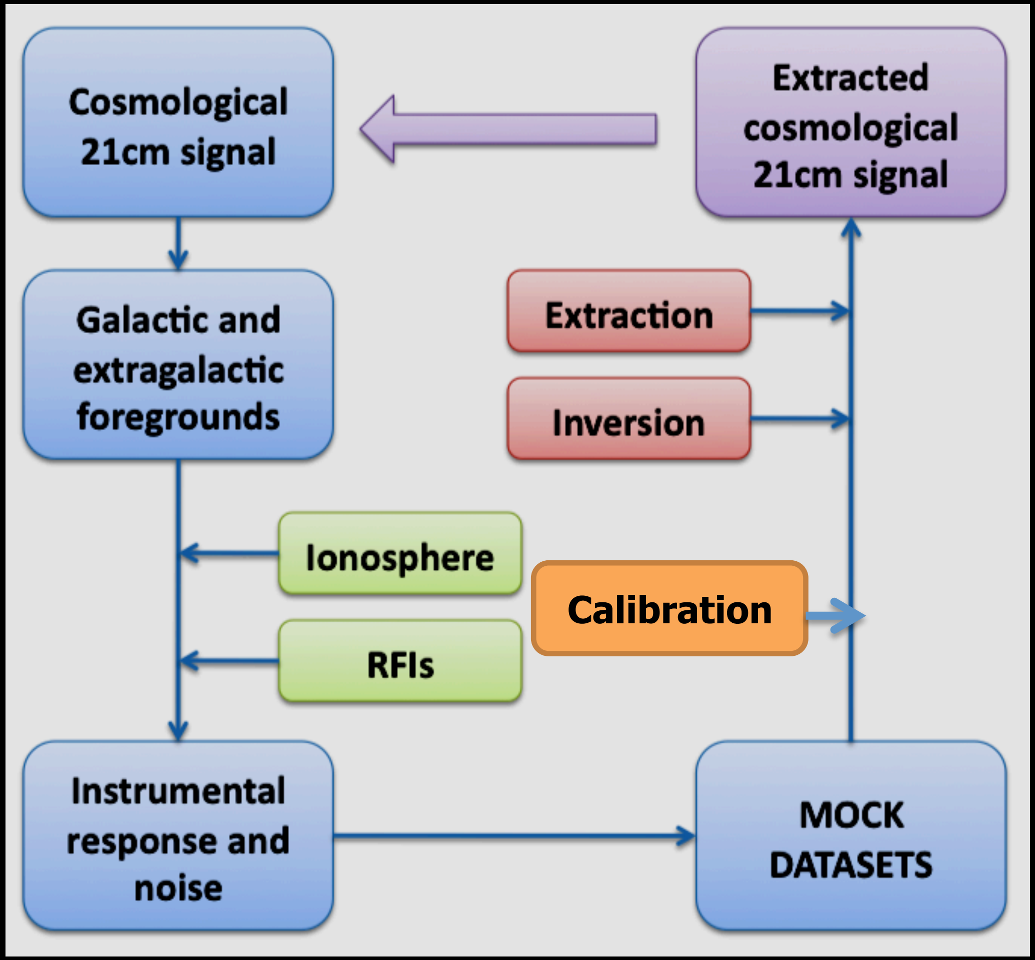
R. Thomas
PhD thesis

V. Jelić
PhD thesis

see a talk by S. Diaboo

A. Offringa
PhD thesis

P. Lambropuolos
PhD thesis



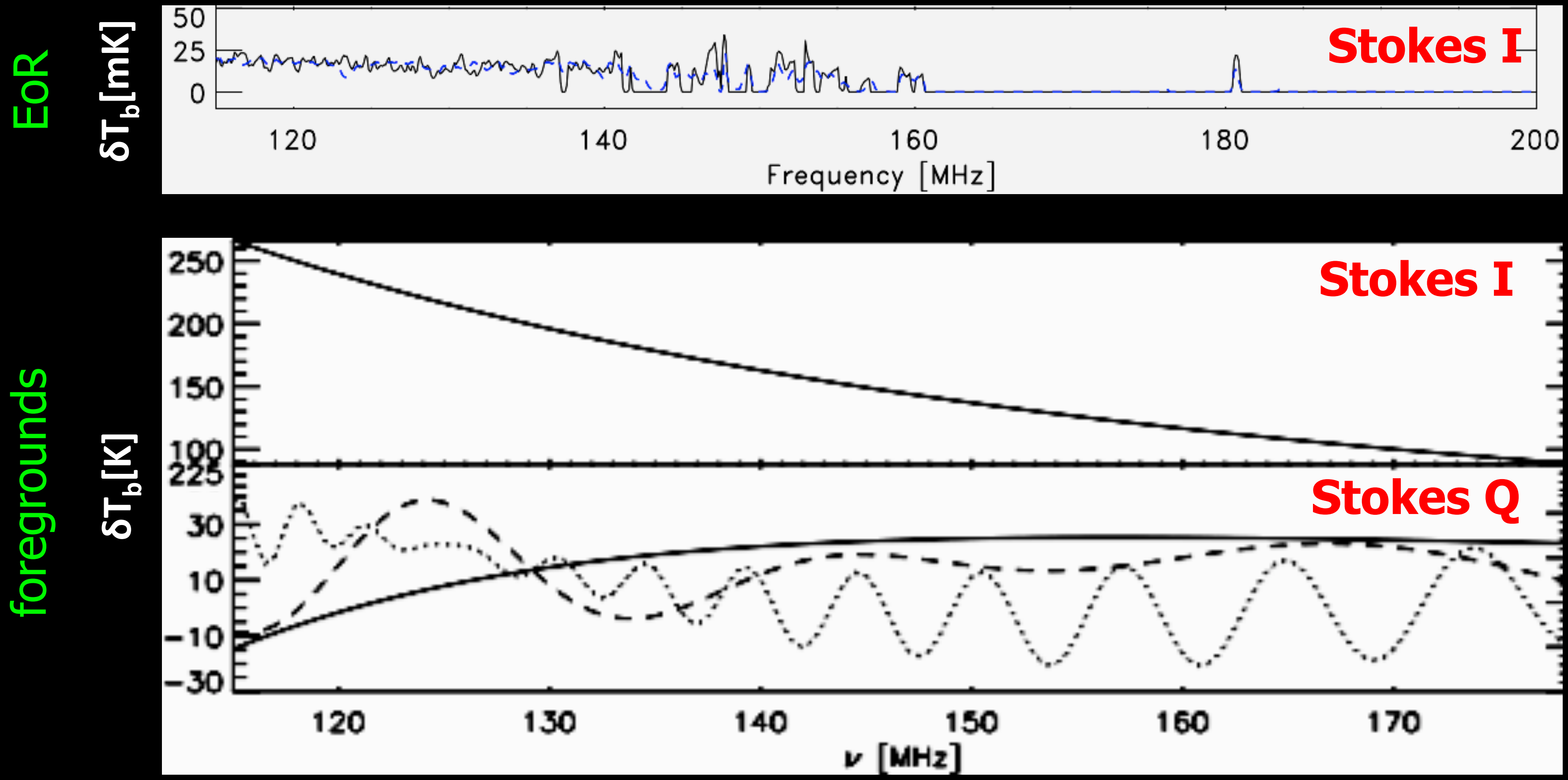
Jelic et al 2008
Harker at al 2009,2010
Chapman et al 2012,2013

see a talk by A. Gosh

Yatawatta et al 2009,2013
Kazemi at al 2011,2013

How to remove the foregrounds from the data?

Extraction of the EoR signal: SIMULATIONS

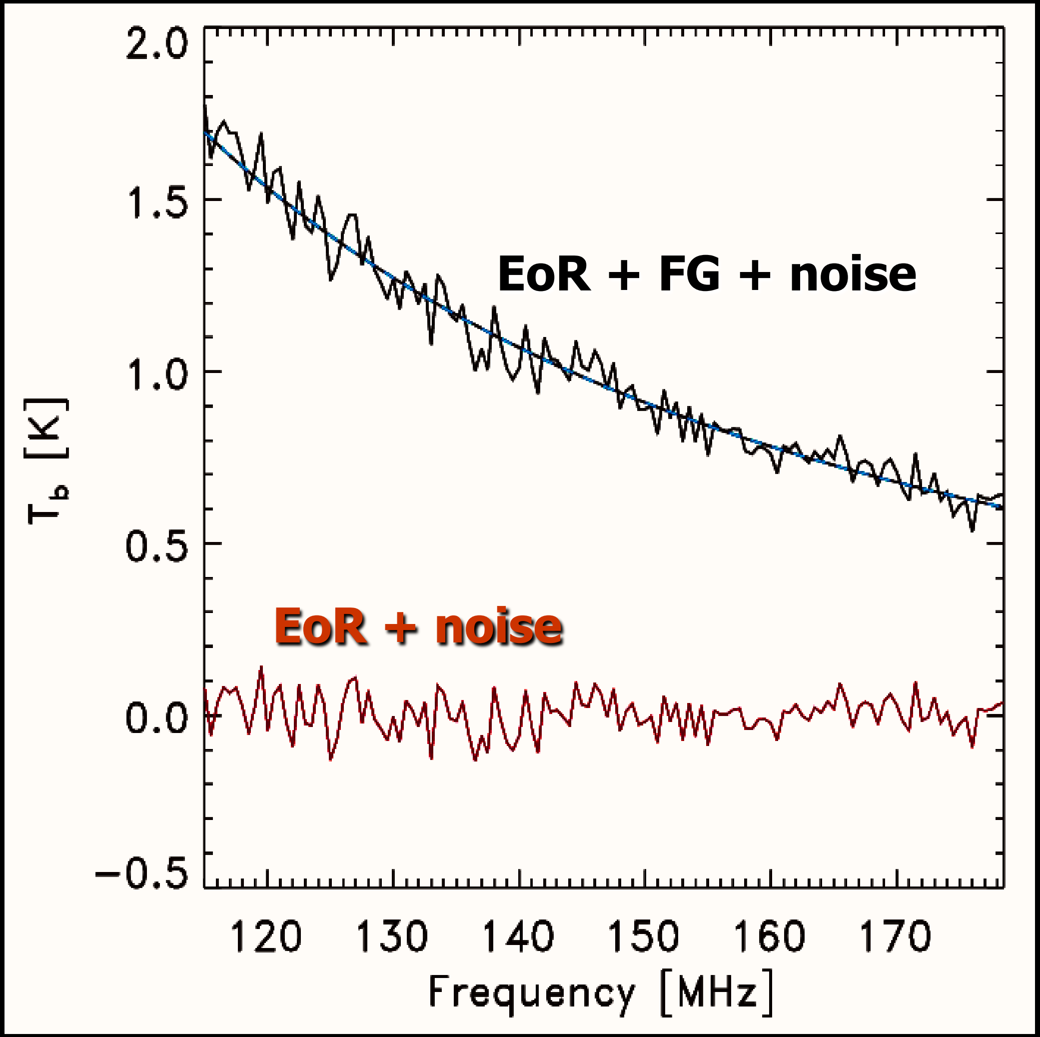


- extraction is based on smoothness of the foregrounds in total intensity

Extraction of the EoR signal: SIMULATIONS

@150 MHz, 3arcmin

T_{EoR} ~ 5 mK
T_{FG} ~ 2 K
T_{noise} ~ 78 mK



Parametric fitting
(polynomial fitting)
Jelic et al. 2008

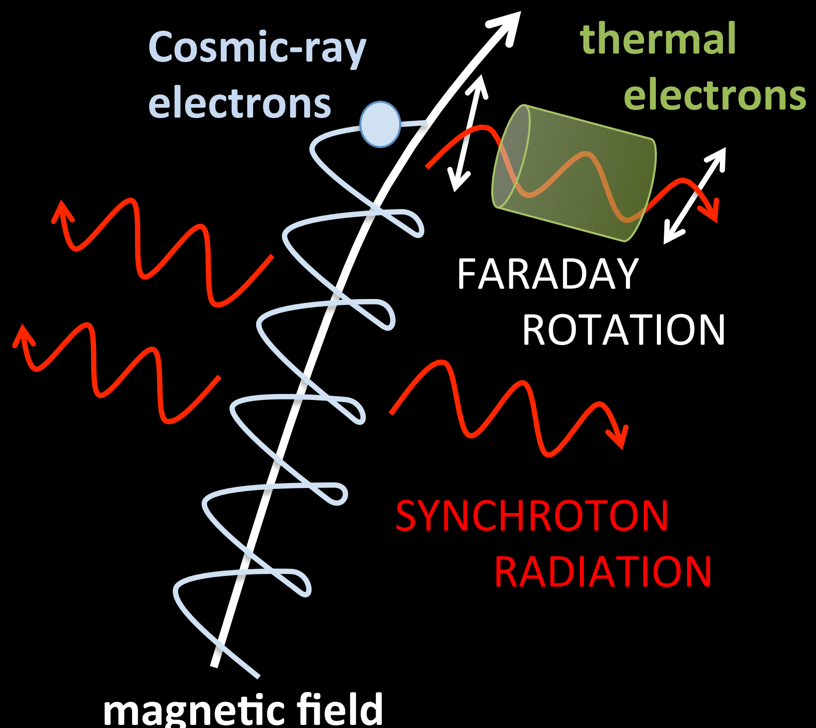
Non-parametric fitting
(Wp smoothing, ICA,..)
Harker et al. 2009
Chapman et al. 2012,2013

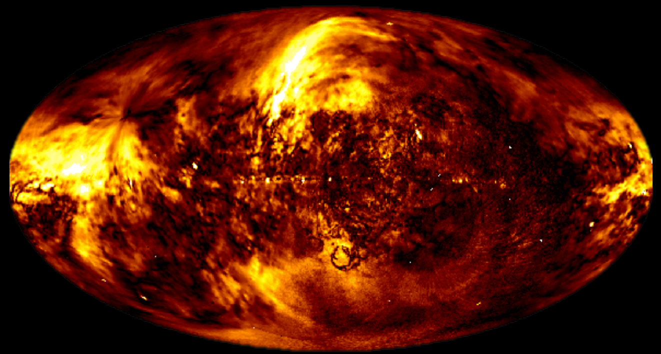
Statistical detection of the cosmological 21cm signal

see a talk by A. Patil
see a talk by S. Zaroubi

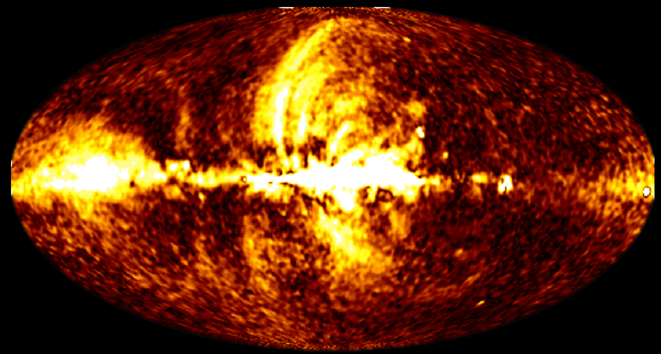
Diffuse polarized emission

Galactic polarized emission



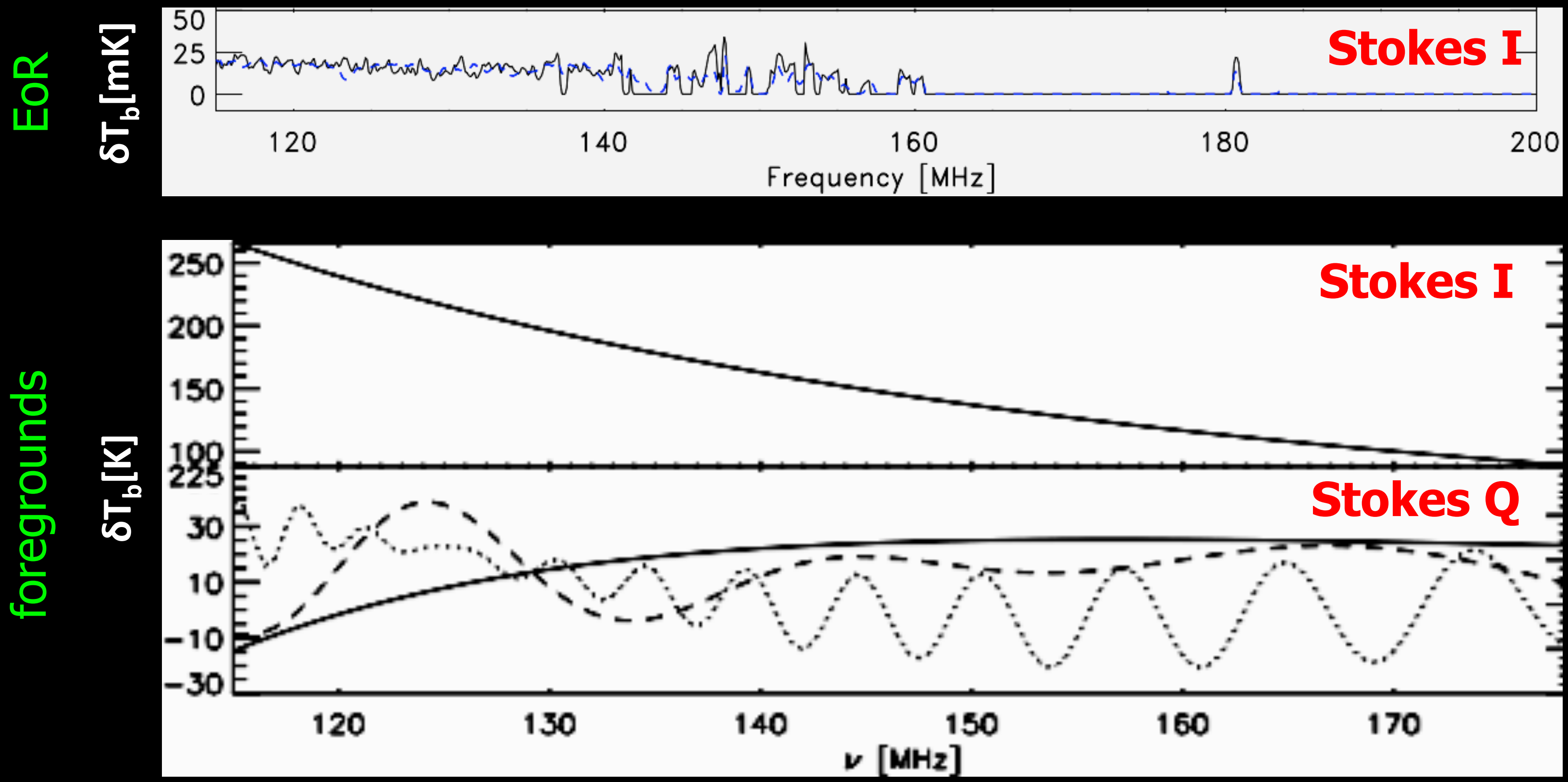


Polarized intensity WMAP @ 1.4GHz



Polarized intensity map @ 22GHz

Problem of the polarized foregrounds



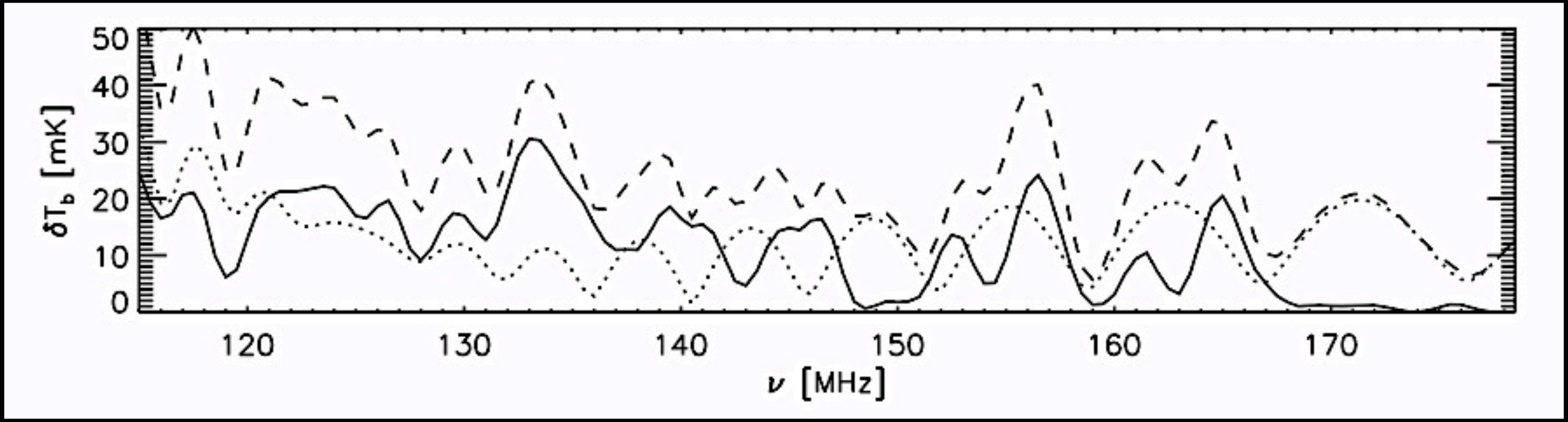
- the leaked polarized emission can mimic the cosmological signal: **extraction much more difficult**

Problem of the polarized foregrounds

EoR ~ 5 mK

FG ~ 2 K

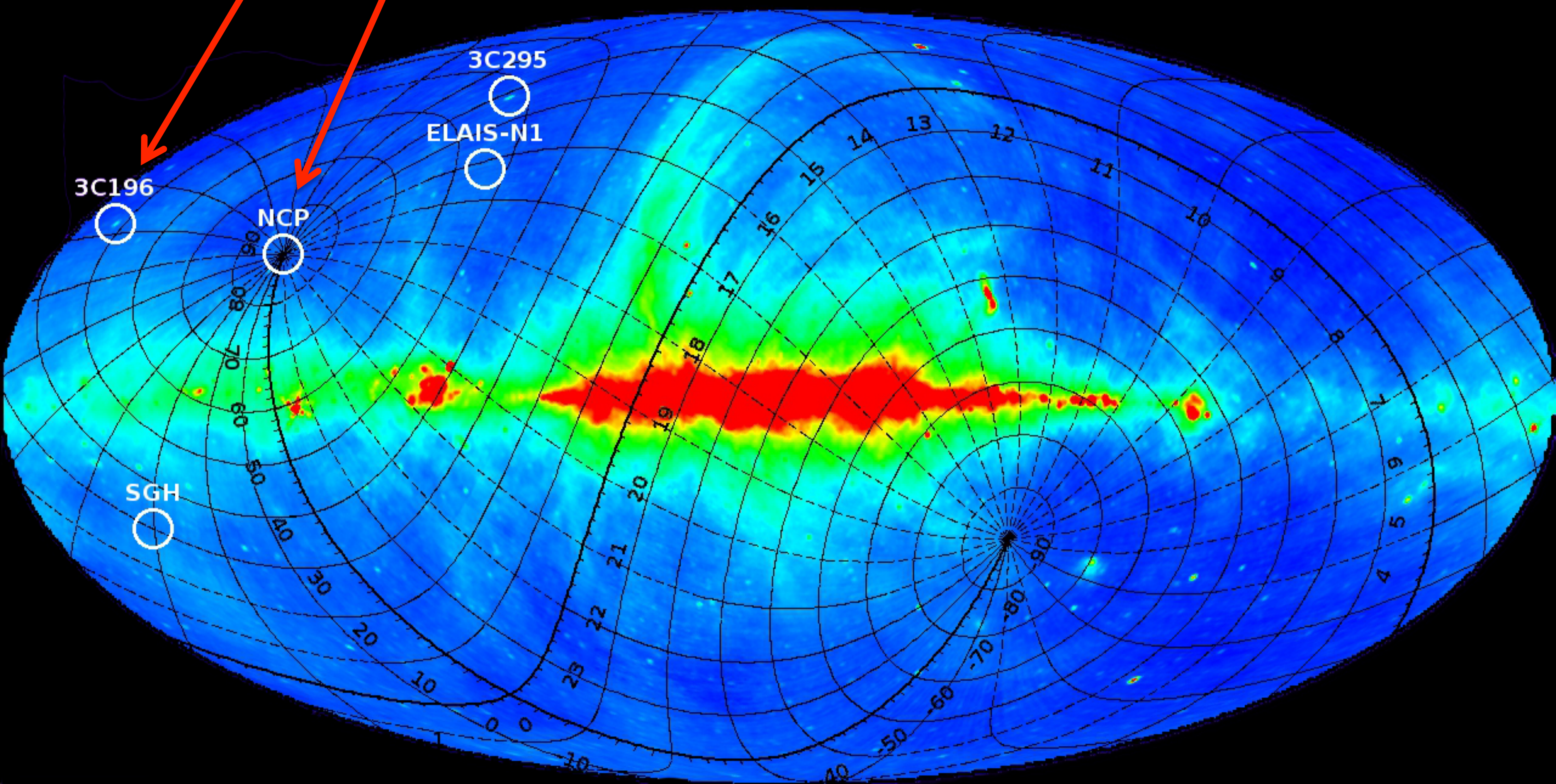
residual leakage ~ 1.5 %



Jelic et al. 2010
Geil et al. 2011

see a talk by V. Pandey

see a talk by S. Yatawatta



Haslam 408MHz map

LOFAR-EoR experiment: Elais N1 field

- **North Celestial Pole** (*Yatwatta et al.*)
- **3C196 field** (*Pandey et al.*)
- **ELAIS-N1 field** (*Jelic et al.*)
- **3C295 field** (*Daiboo & Gosh et al.*)

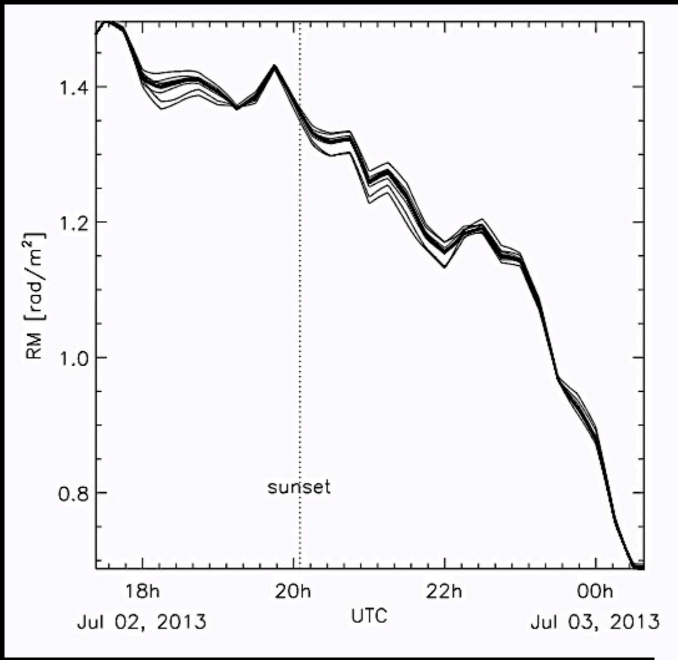
- direction independent calibration using BBS
- direction dependent calibration using SageCal
- Ionospheric Faraday rotation correction
- correction for direction and time dependent LOFAR beam (AWimager)

➢ LOFAR – HBA observation @ 115 – 175 MHz, 0.2 MHz

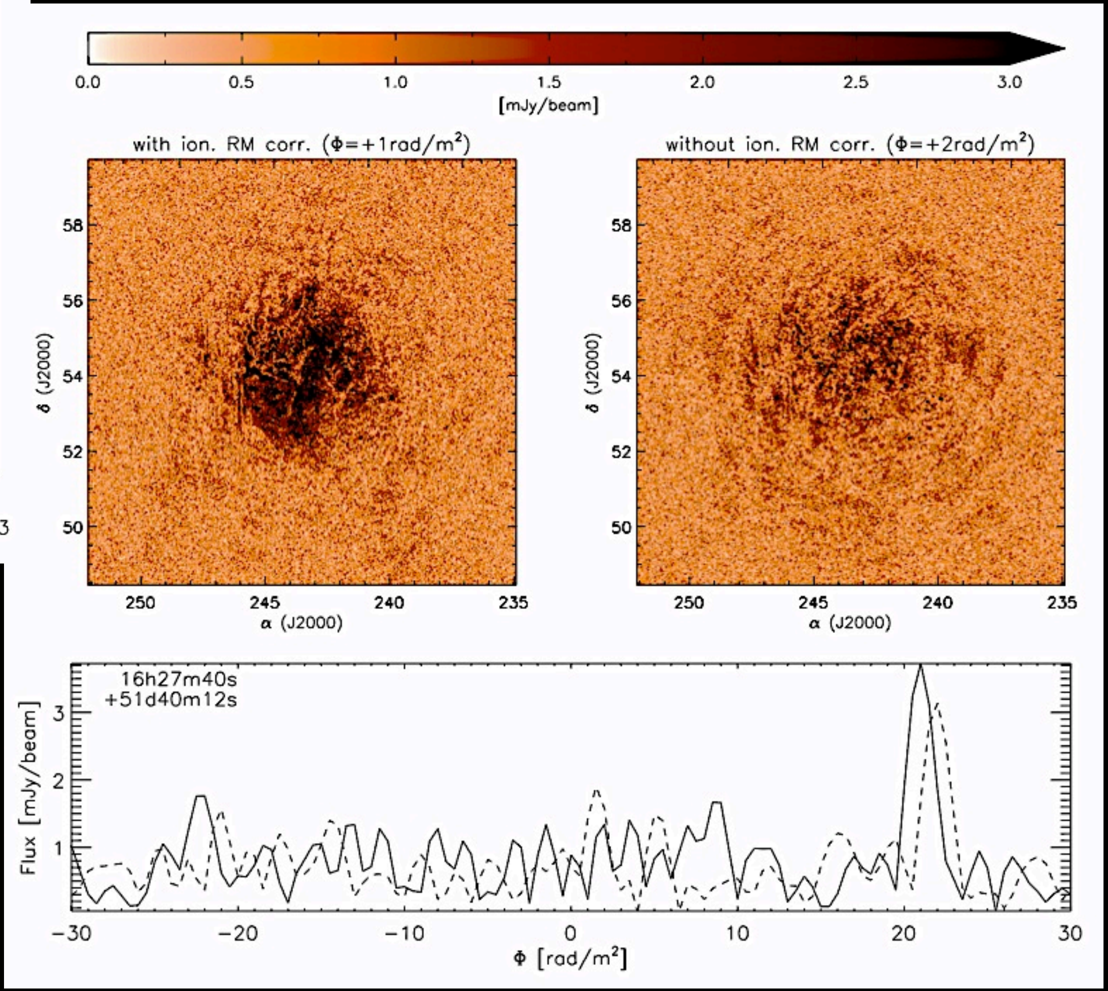
robust weighting, 40 - 1000λ, 3 arcmin

RM synthesis: $\Delta\Phi \approx 1\ \mathrm{rad/m^2}$

Elais N1 field: ionospheric RM correction

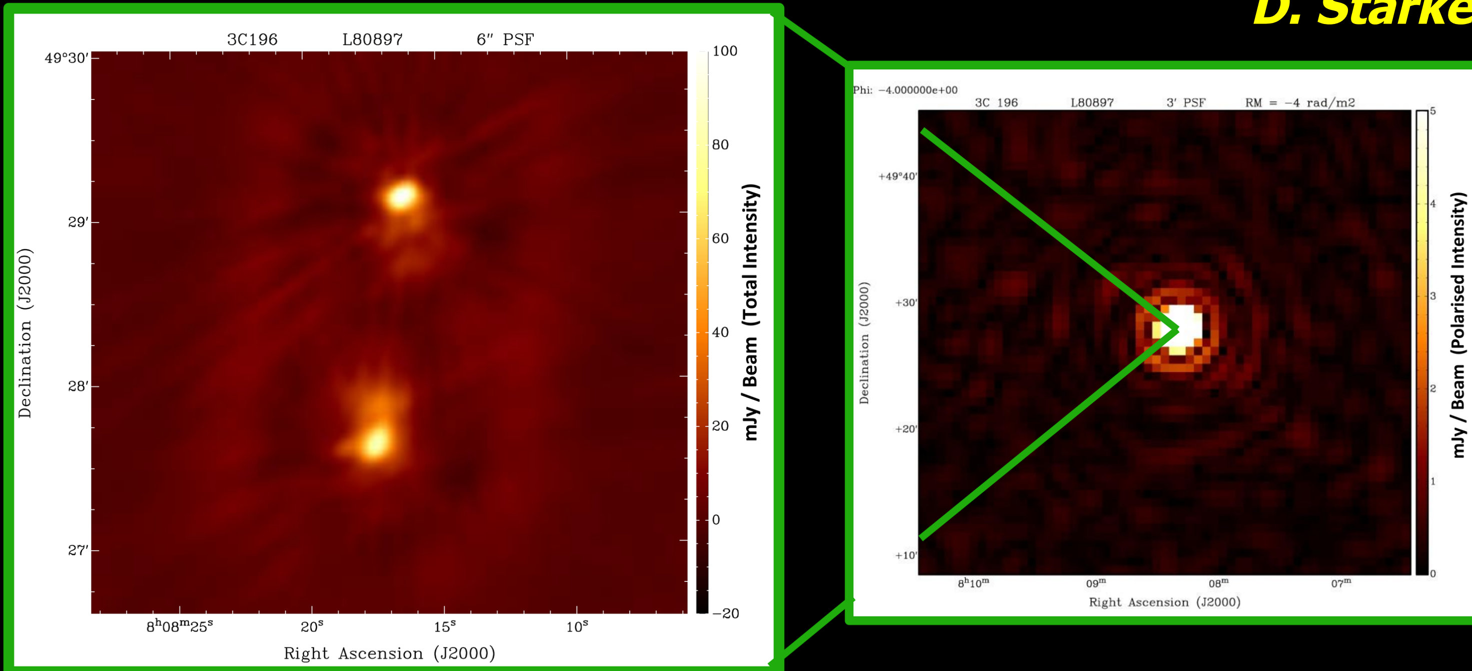


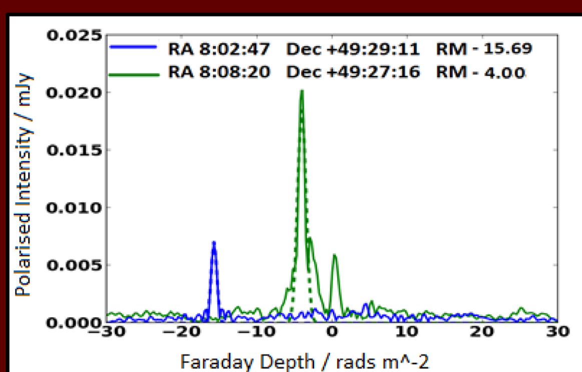
M. Mevius

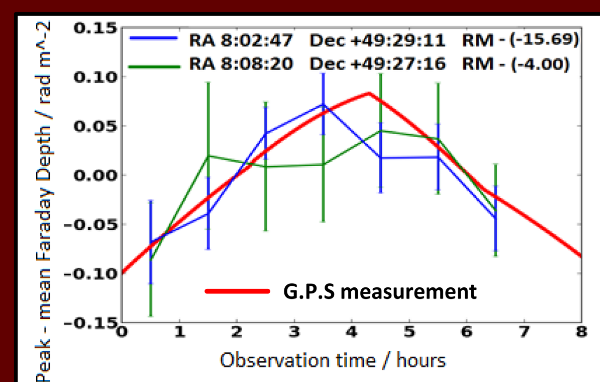


3C196 field: ionospheric RM correction

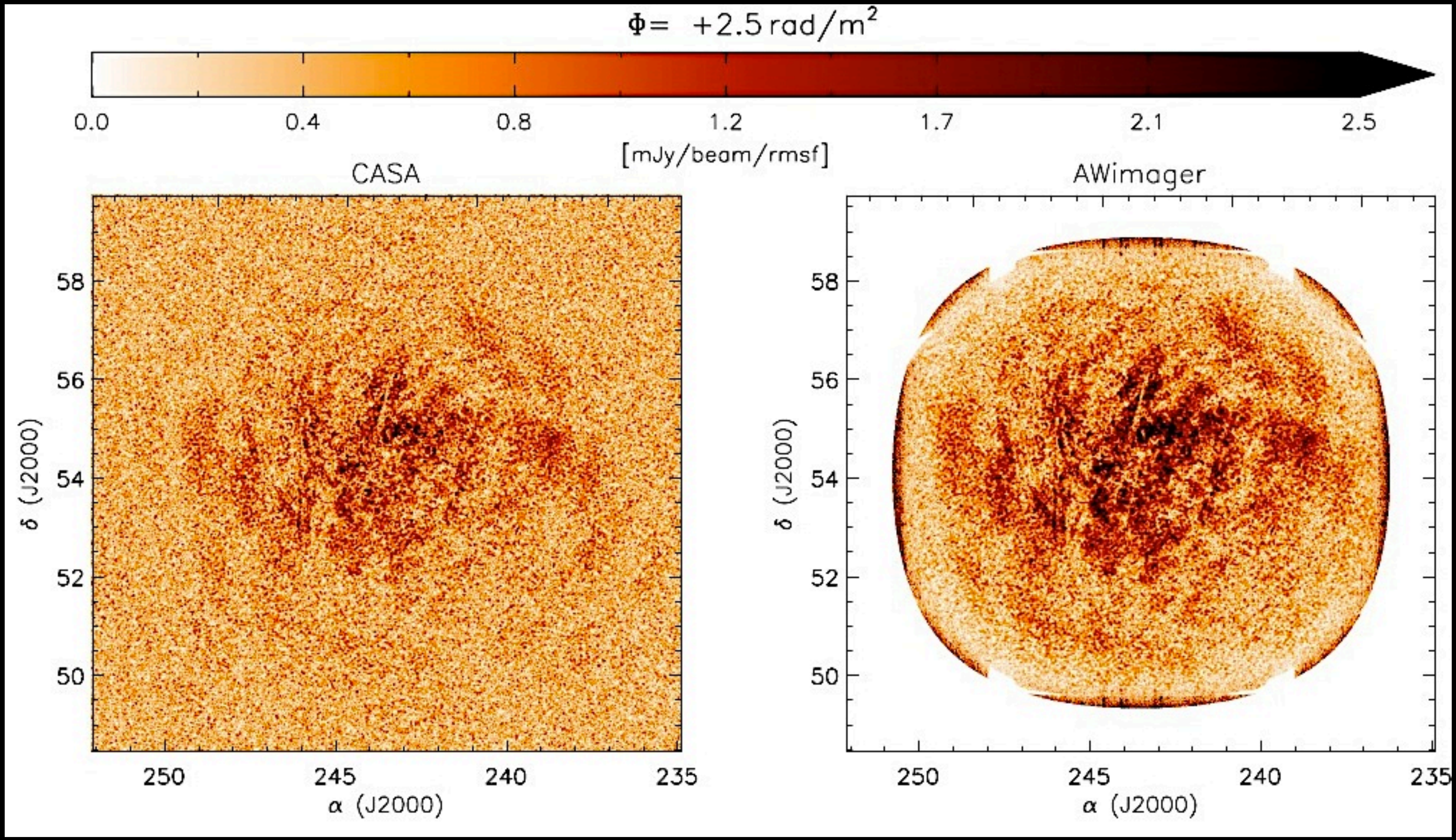
D. Starkey



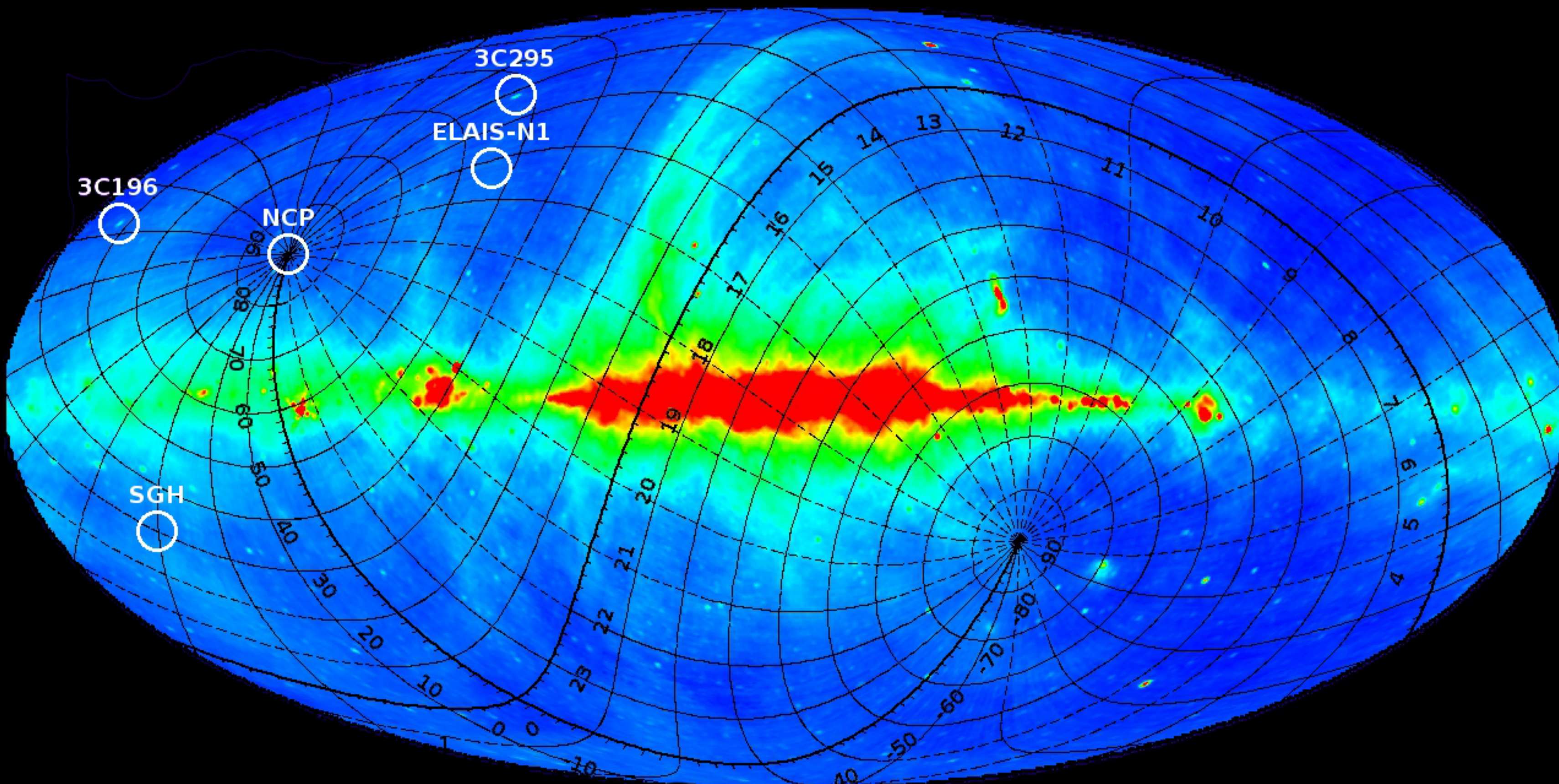




Elais N1 field: beam corrections



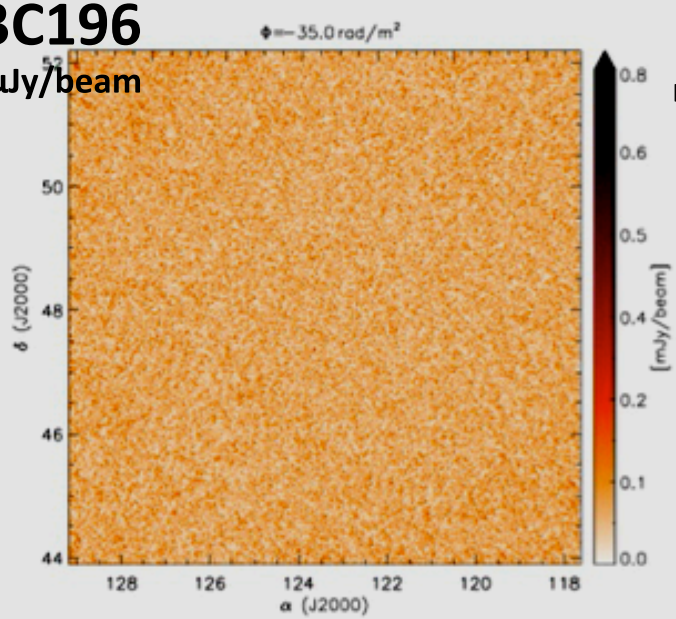
LOFAR-EoR observations: polarized emission



Haslam 408MHz map

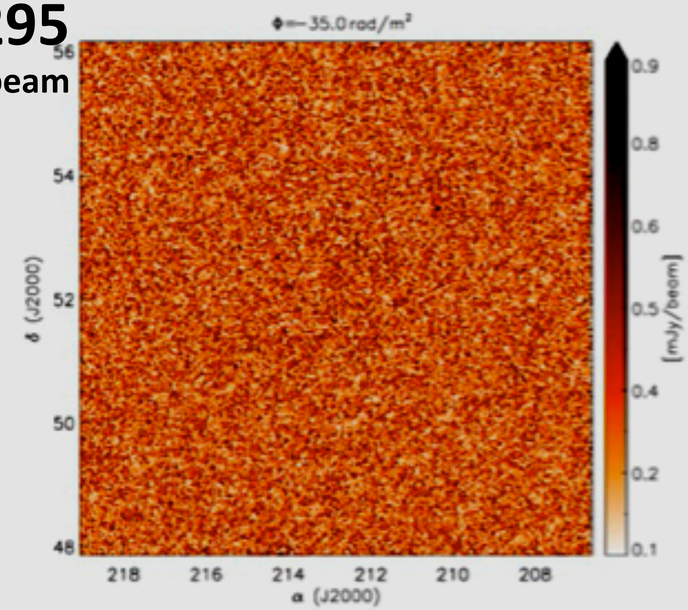
3C196

rms ≈ 45μJy/beam



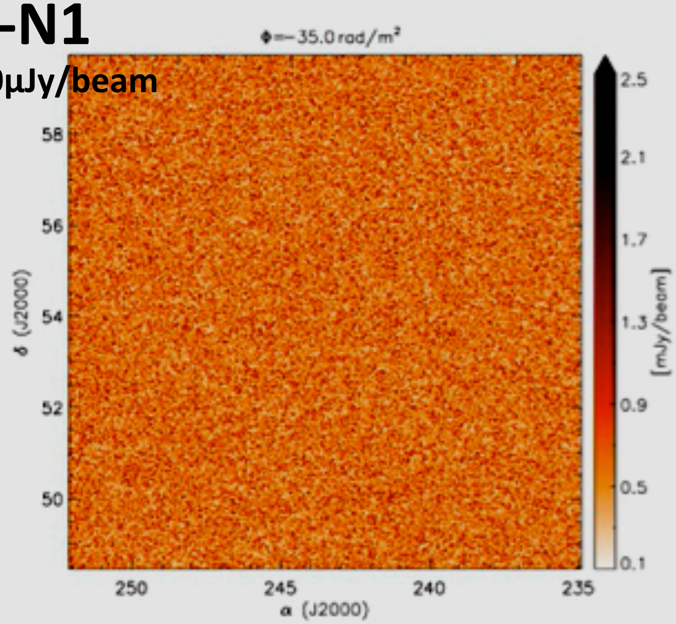
3C295

rms ≈ 160μJy/beam



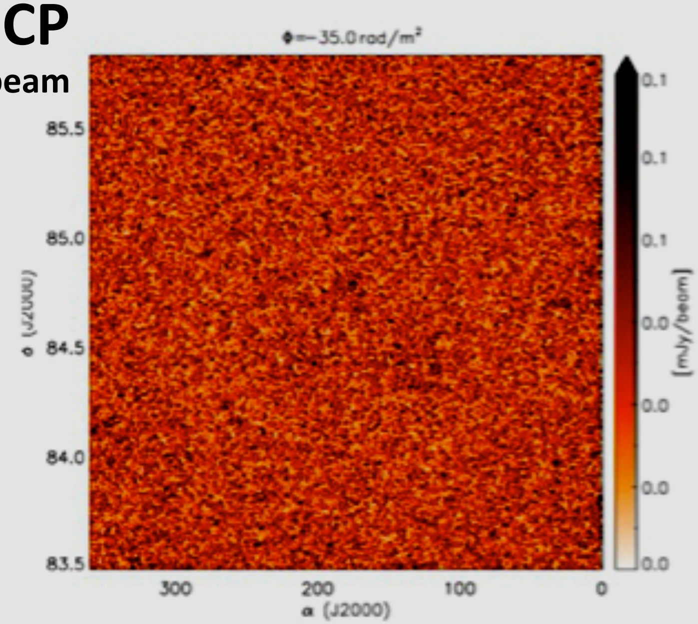
ELAIS-N1

rms ≈ 320μJy/beam

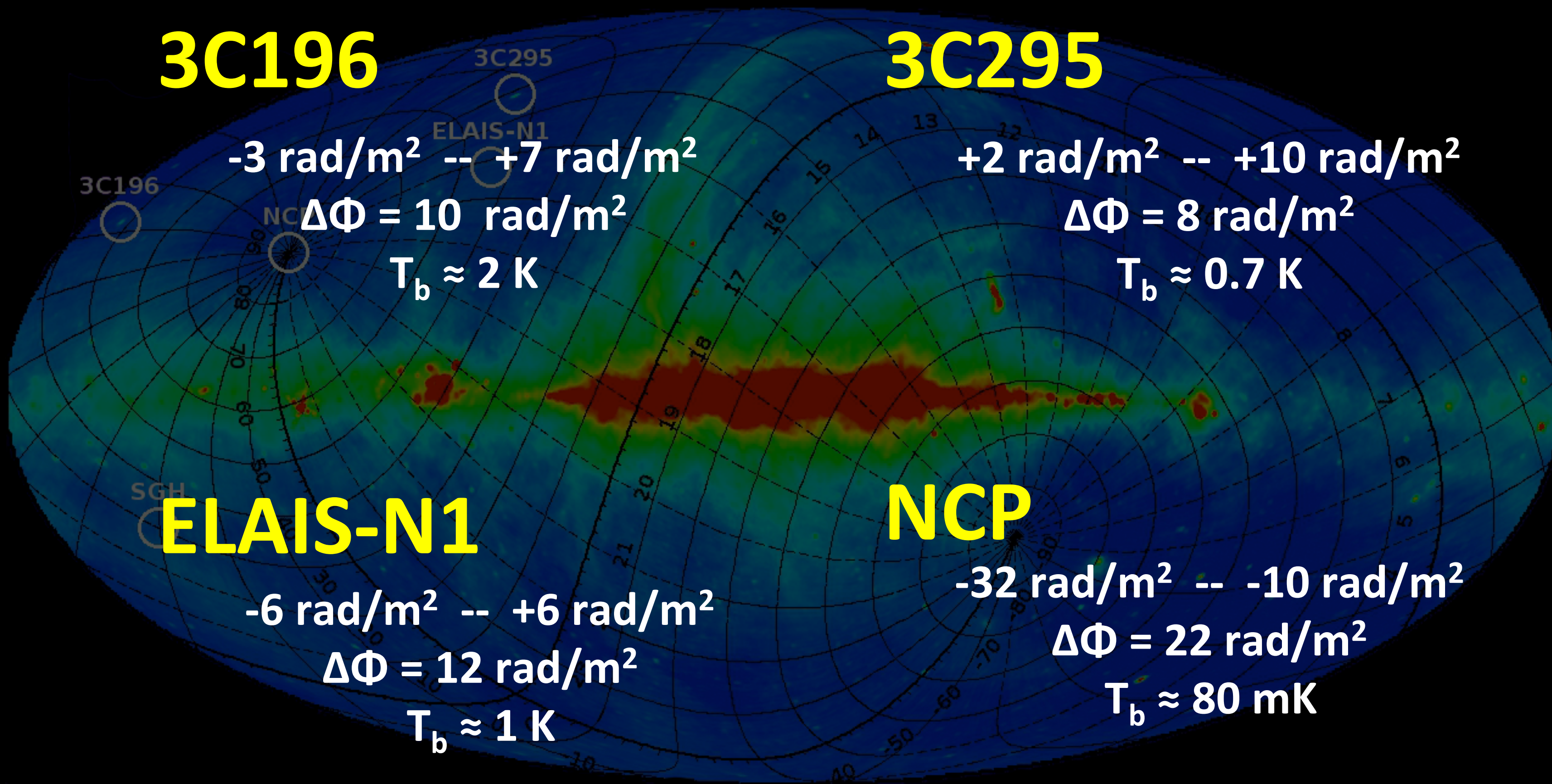


NCP

rms ≈ 15μJy/beam



LOFAR-EoR observations: polarized emission



3C196

-3 rad/m^2 -- +7 rad/m^2
$\Delta\Phi$ = 10 rad/m^2
$T_b \approx 2$ K

3C295

+2 rad/m^2 -- +10 rad/m^2
$\Delta\Phi$ = 8 rad/m^2
$T_b \approx 0.7$ K

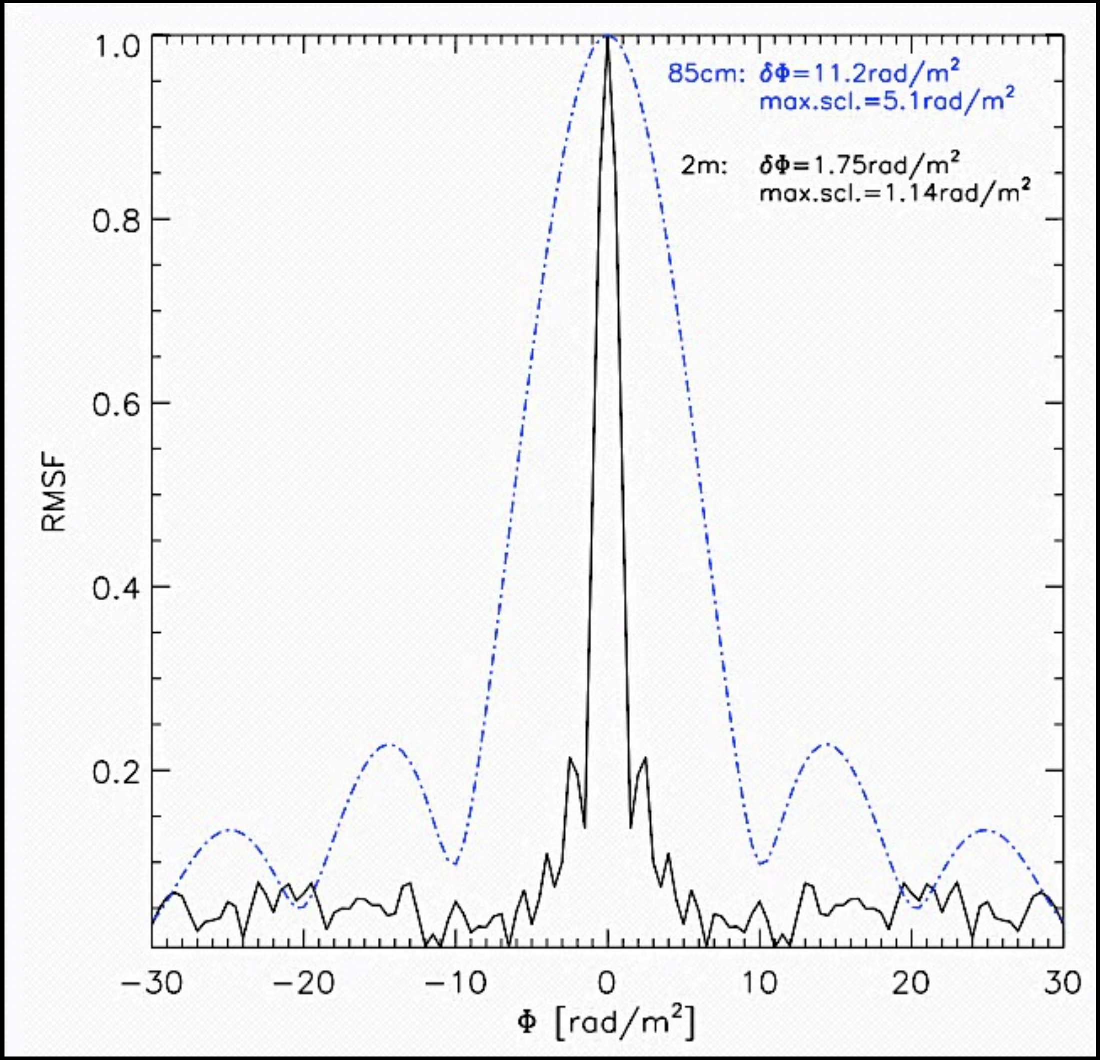
ELAIS-N1

-6 rad/m^2 -- +6 rad/m^2
$\Delta\Phi$ = 12 rad/m^2
$T_b \approx 1$ K

NCP

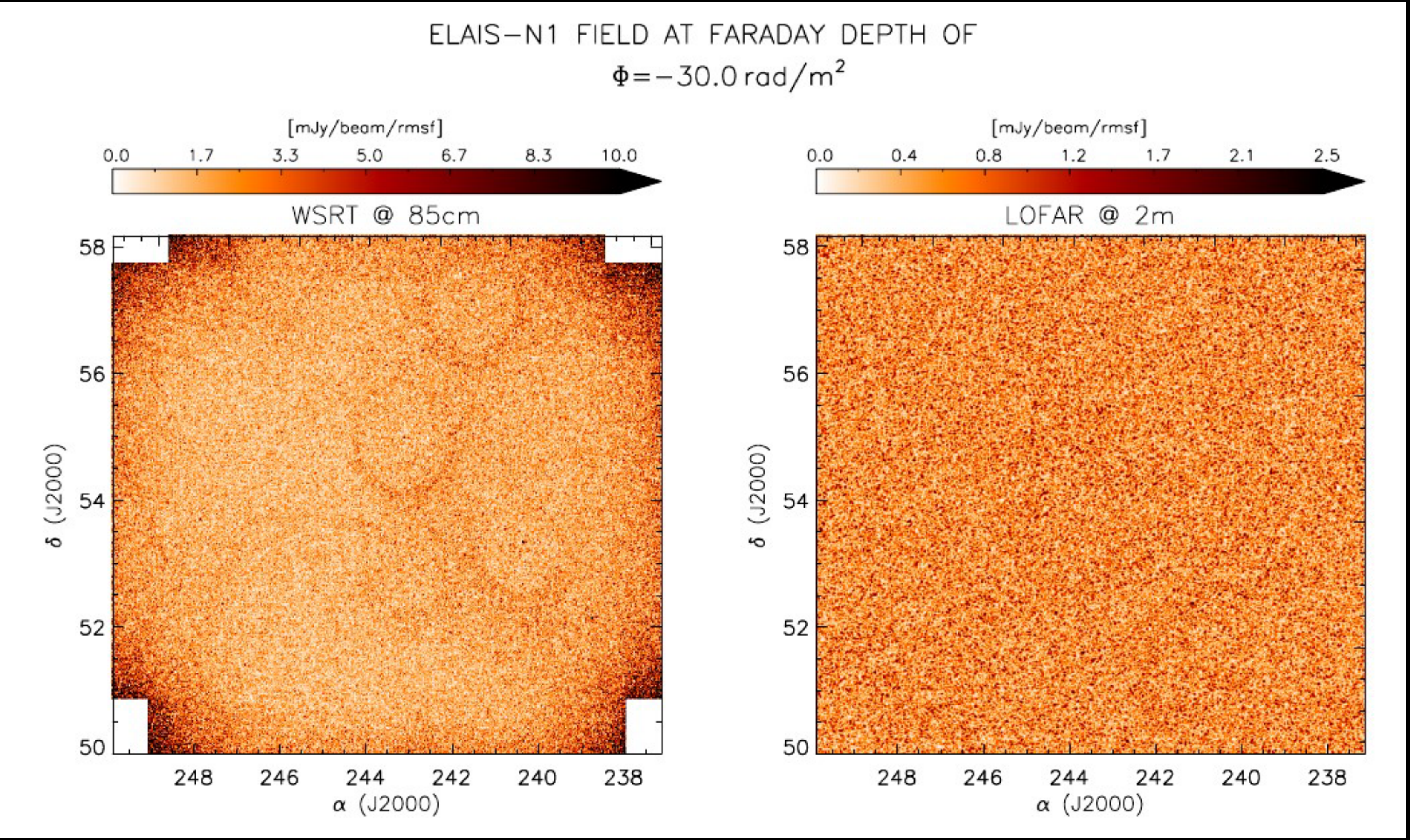
-32 rad/m^2 -- -10 rad/m^2
$\Delta\Phi$ = 22 rad/m^2
$T_b \approx 80$ mK

LOFAR-EoR observations: WSRT @ 350 MHz



315-385 MHz Follow Up

LOFAR-EoR observations: Elais N1 field



Summary & Conclusions

EoR FOREGROUNDS

- **Galactic** (synchrotron) emission dominates **on large scales** and **extragalactic** sources **on small scales**
- **extraction of the EoR signal** is based on the **smoothness of the foregrounds** in total intensity along the frequency direction

LOFAR-EoR OBERVING WINDOWS

- at high Galactic latitudes, where Galactic emission is not so bright (both in total and polarized intensity)
- **good frequency coverage,** excellent resolution in Faraday depth (~1rad/m^2)

POLARIZED DIFFUSE EMISSION

- various structures detected at different Faraday depths