

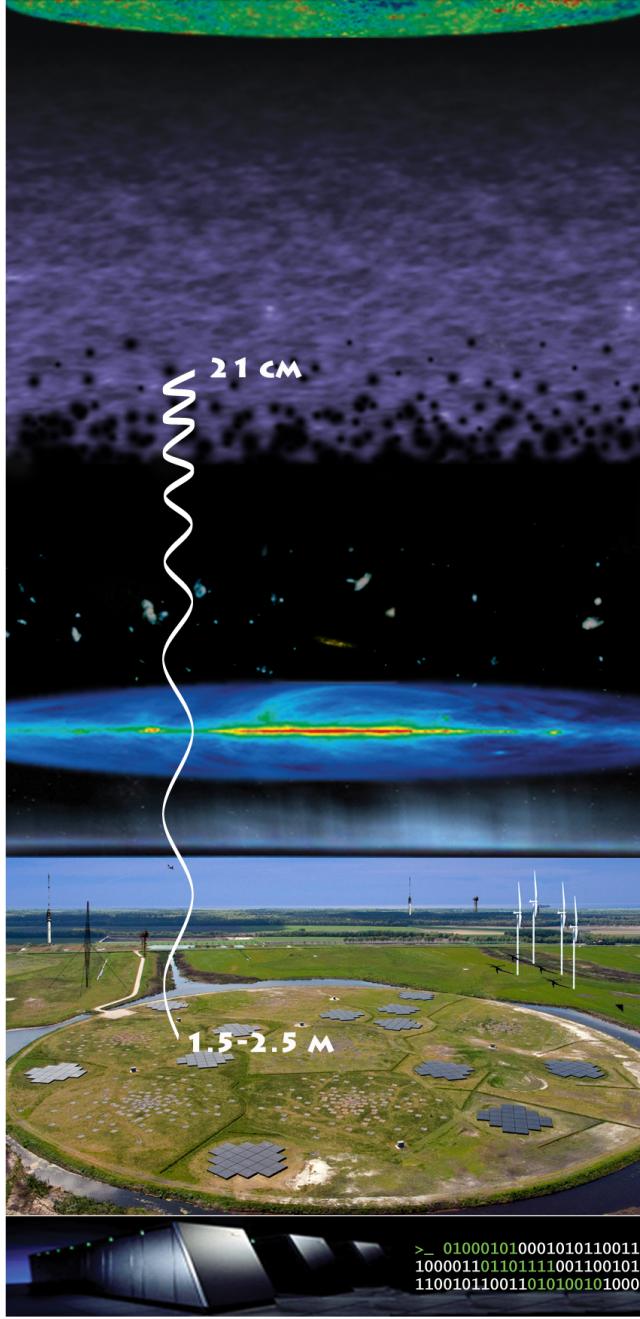
The LOFAR-EoR project: Analysis of the NCP data

Saleem Zaroubi, on behalf of the EoR team
Kapteyn Astronomical Institute
University of Groningen



$t = 0 \text{ s}$

**13.7 Gyr
($z \sim 1100$)**



**1 kyr
($z \sim 0$)**

0.6 ms

0.2 ms

**COSMIC MICROWAVE
BACKGROUND**

DARK AGES

**EPOCH OF
REIONIZATION**

**EXTRAGALACTIC
FOREGROUNDS**

**GALACTIC
FOREGROUNDS**

IONOSPHERE

**RADIO FREQUENCY
INTERFERENCES**

**THE LOFAR TELESCOPE
CORE STATIONS
IN THE NETHERLANDS**

**SUPERCOMPUTER
BLUEGENE**





The LOFAR-EoR project: Analysis of the NCP data

The LOFAR EoR members



Main Science targets

1. ‘Global’ evolution of the EoR: Variance as a function of redshift.
2. Power spectrum at various redshifts
3. High order statistics
4. Imaging!!

5. Cross-correlation with other probes
6. The 21 cm forest

How to check reliability of results

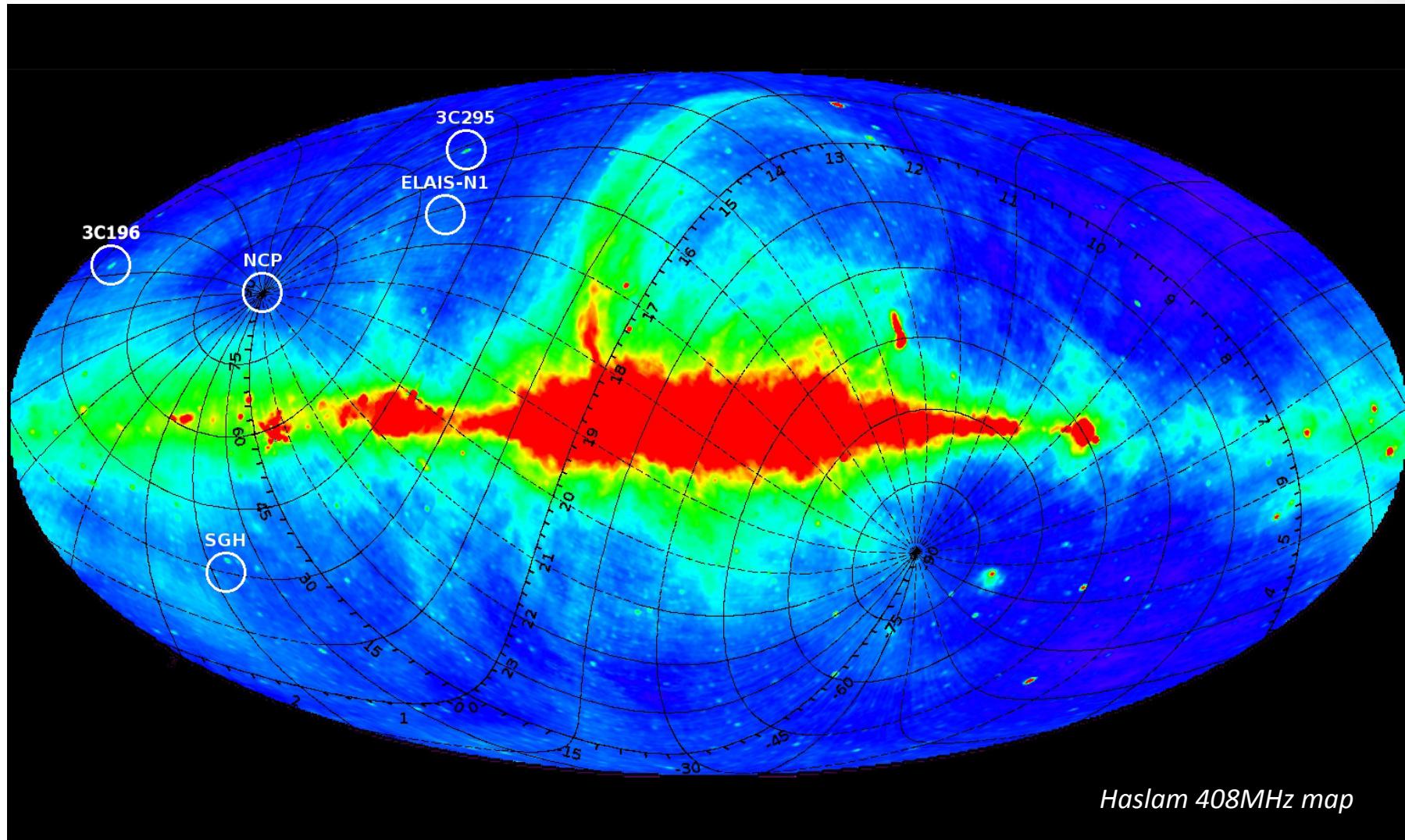
Internal consistency checks

- Avoid problematic data, e.g., high RFI, very active ionosphere, etc.
- Observing multiple fields and obtain consistent results.
- Different times
- Frequencies
- Etc.

End to end pipeline

- Test observational strategy
- Performance of calibration methods
- Test various extraction techniques.
- Realistic estimates of errors of various statistics.
- What to expect from the results.
- Etc.

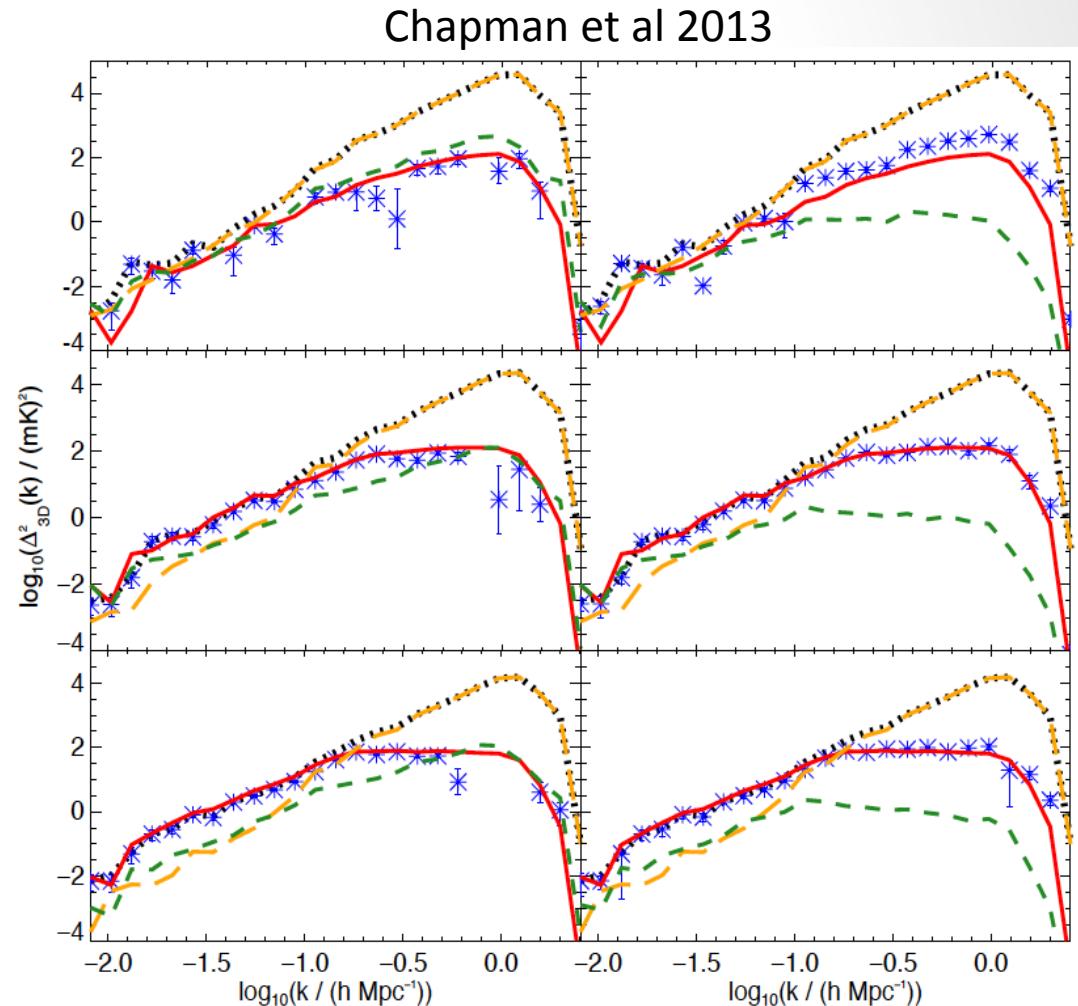
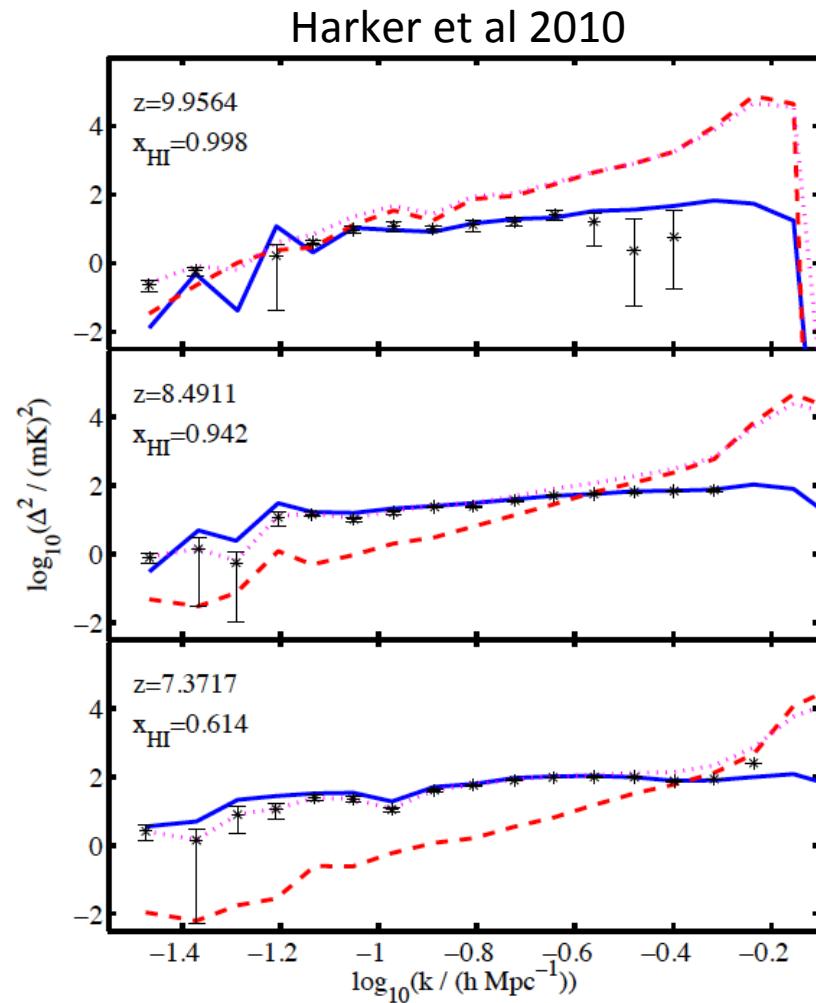
LOFAR EoR Windows



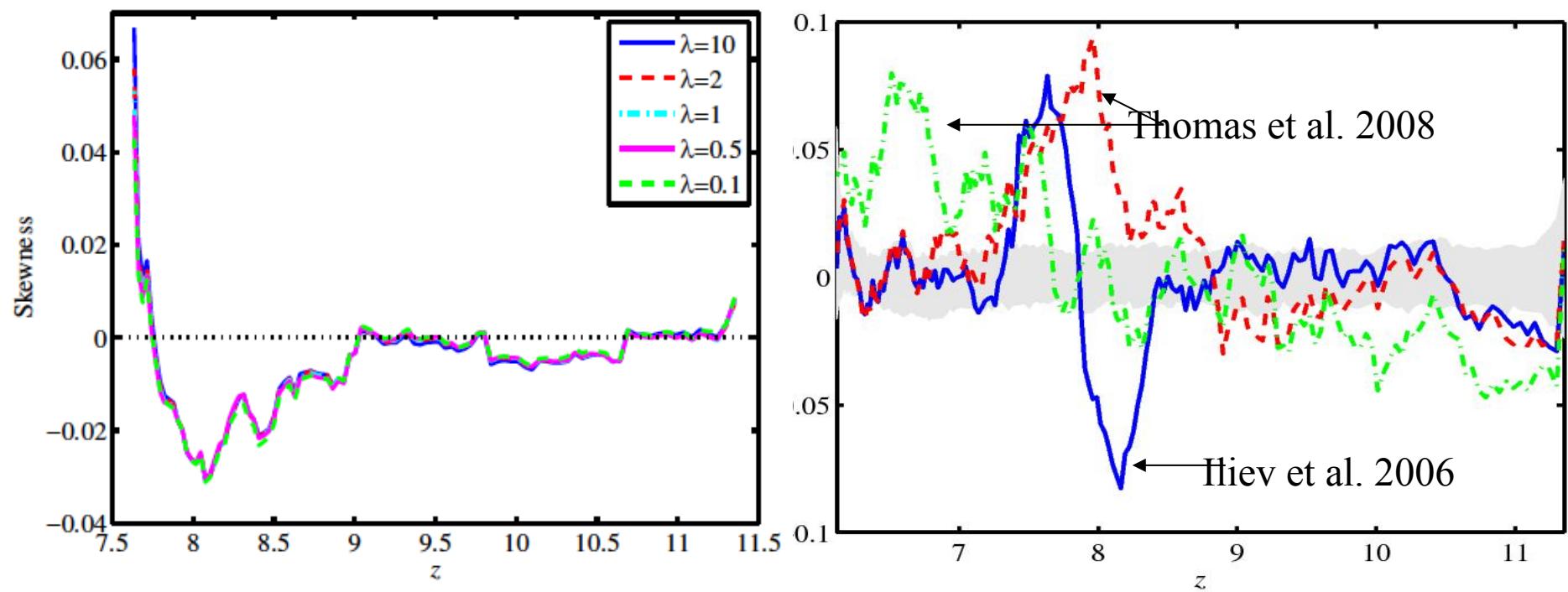
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Statistical measures of the EoR

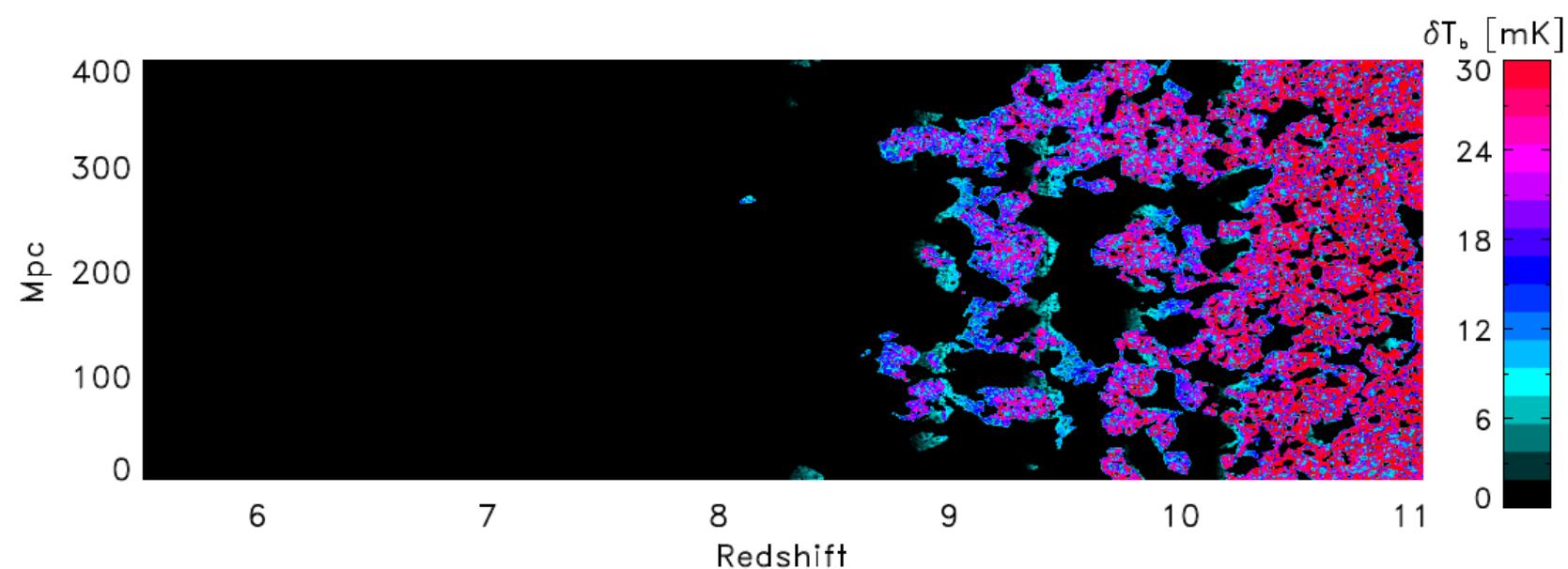
Power Spectrum Measurements



Extraction through skewness

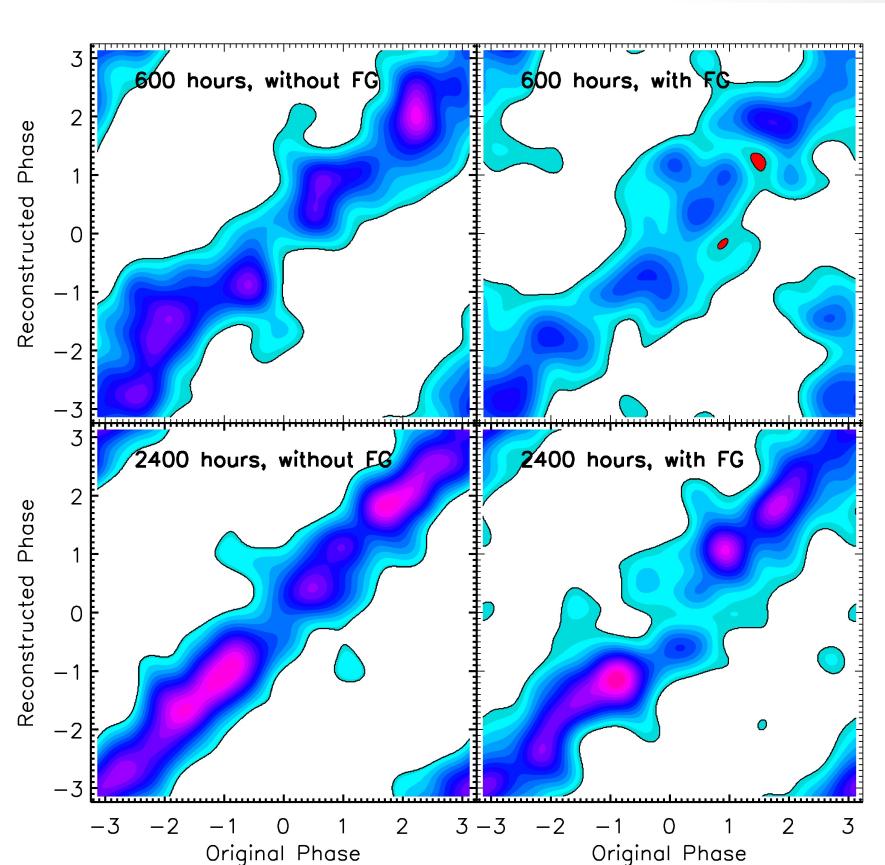
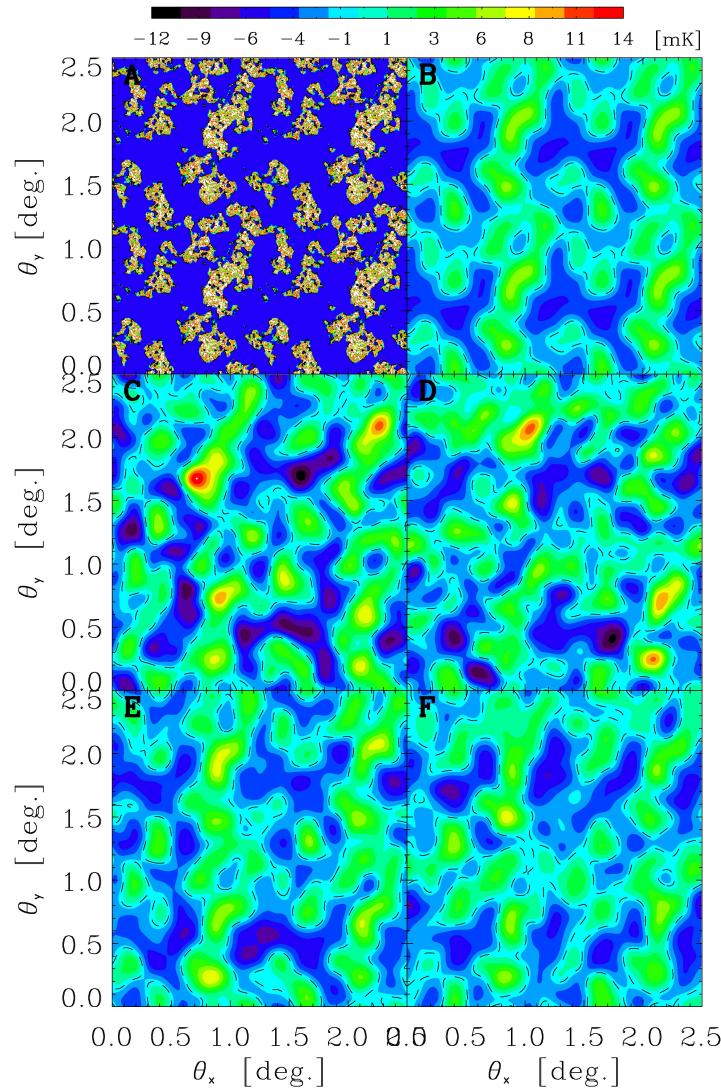


Imaging the EoR with LOFAR



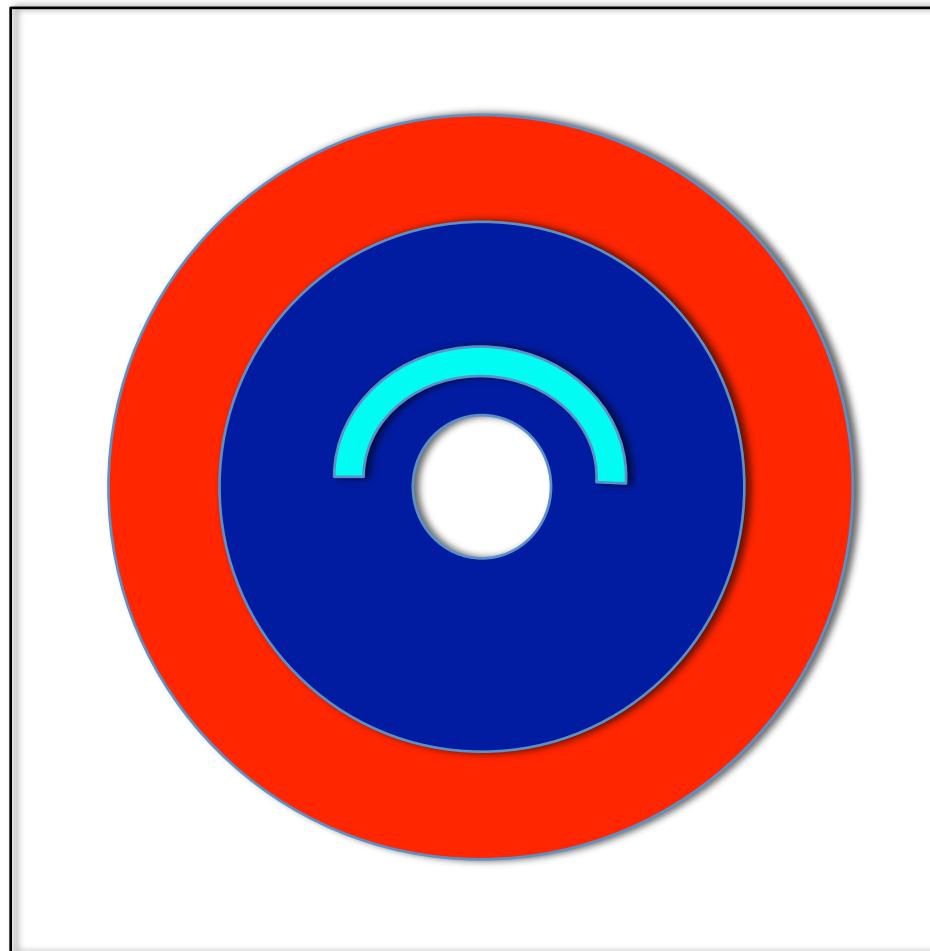
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Imaging of the EoR with LOFAR

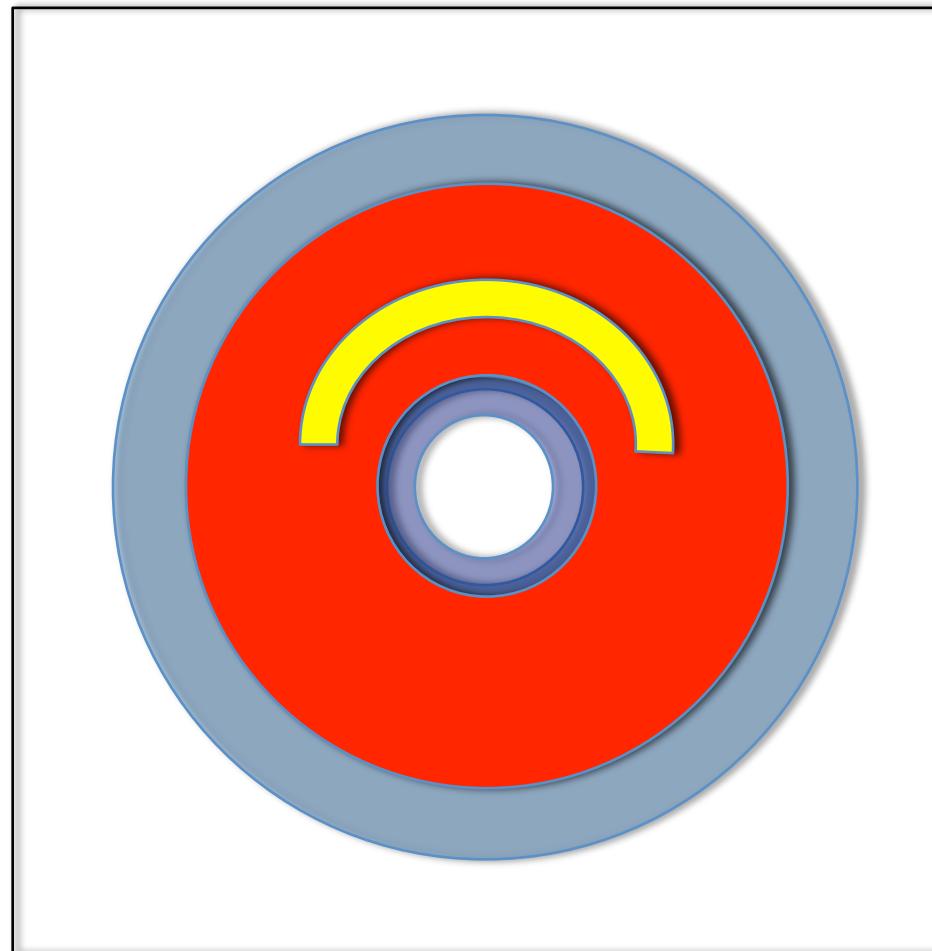


The LOFAR EoR project: Analysis of the NCP data

Schematic of UV plane



Schematic of UV plane



The foregrounds and the Signal Extraction!

The LOFAR-EoR project: Analysis of the NCP data

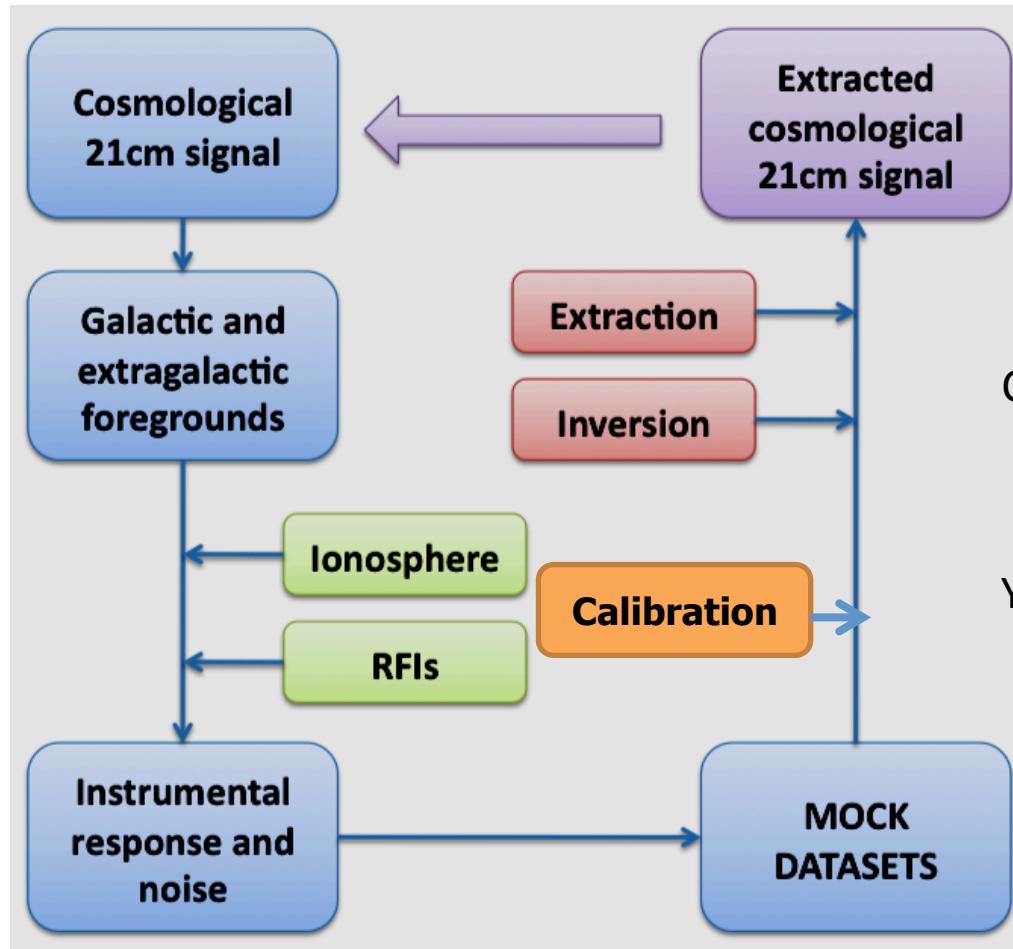
The LOFAR-EoR Project: end-to-end pipeline

R. Thomas
PhD thesis

V. Jelić
PhD thesis

A. Offringa
PhD thesis

P. Labropulos
PhD thesis



Jelic et al 2008

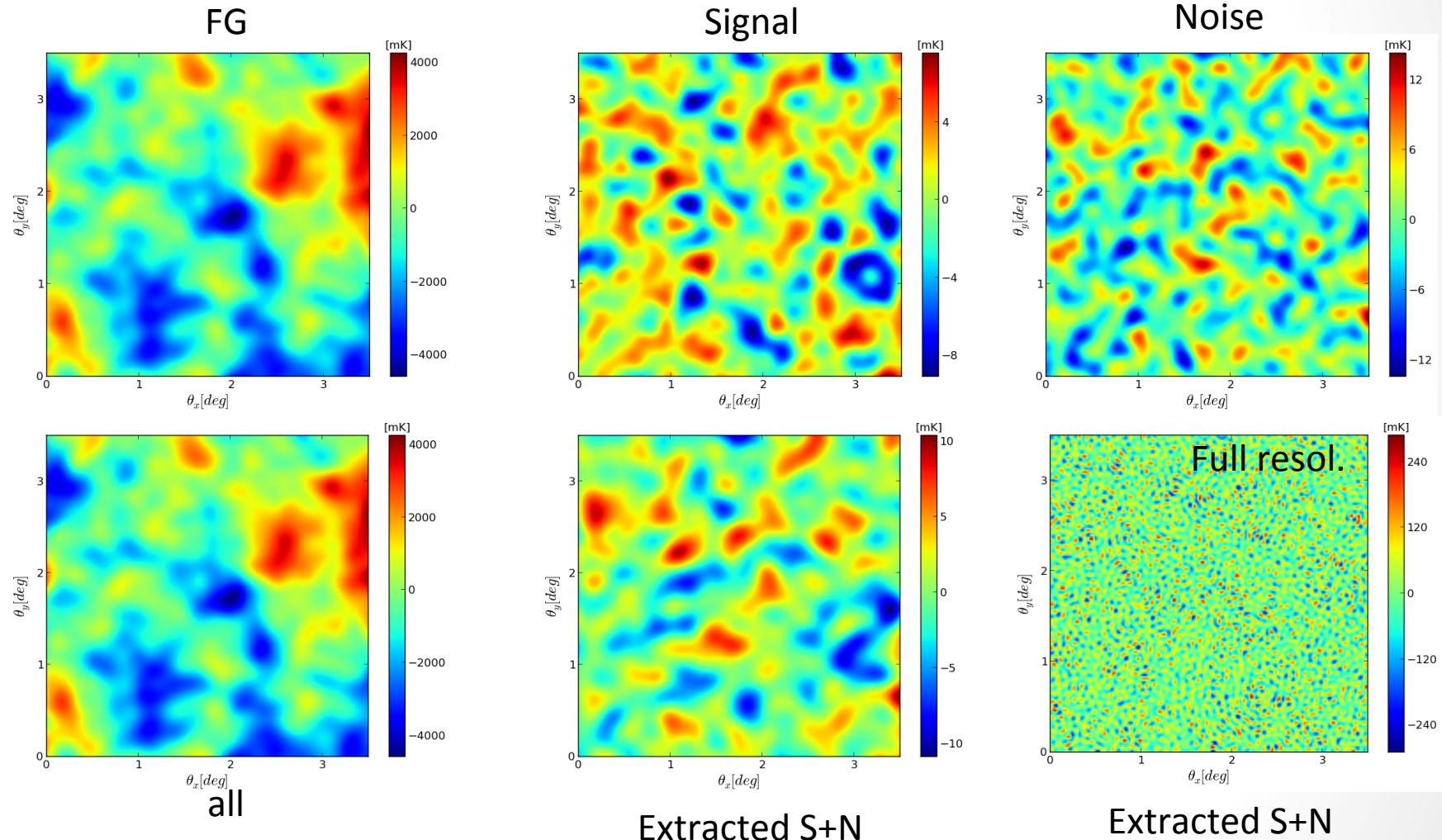
Harker et al 2009,2010

Chapman et al 2012,2013

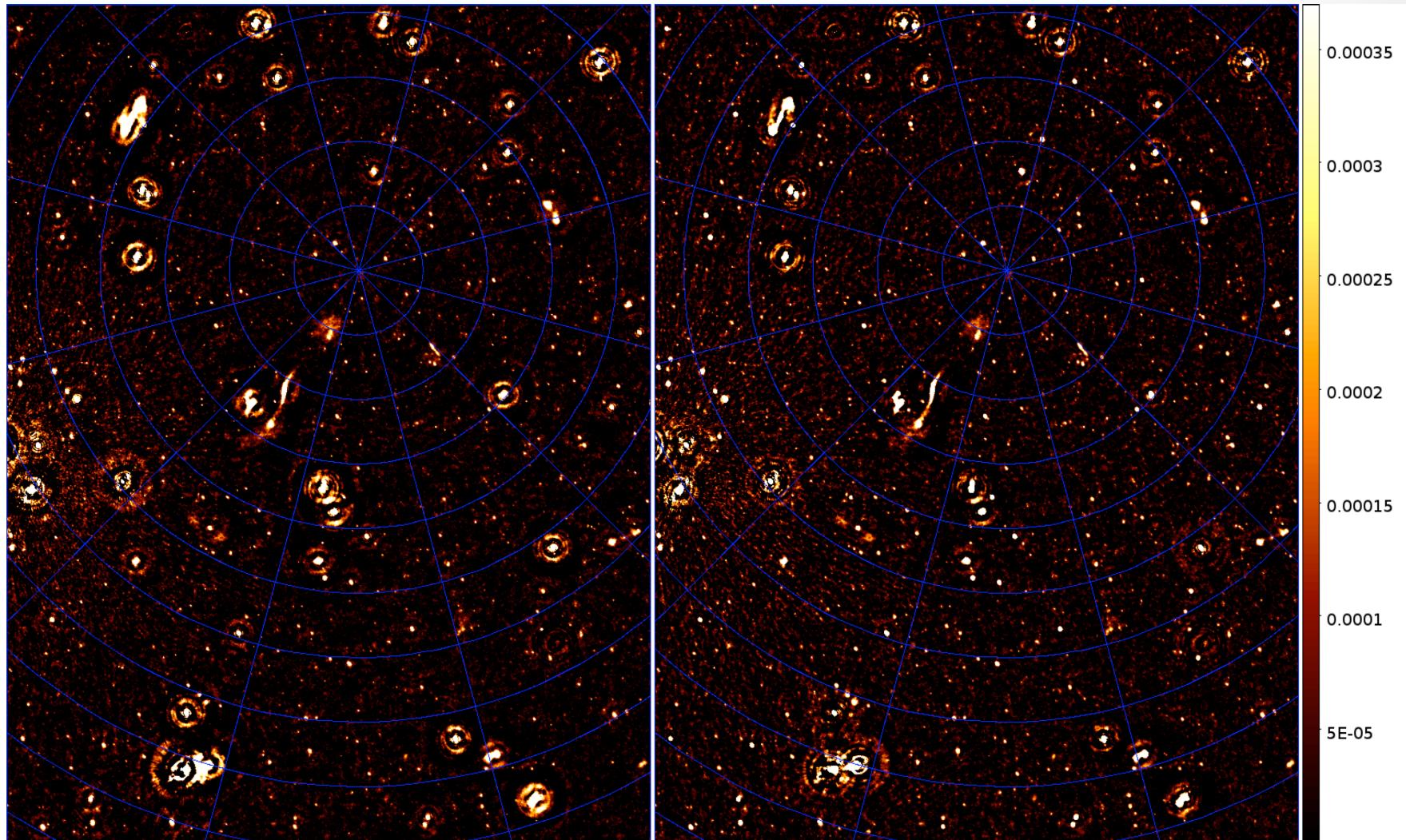
Yatawatta et al 2009,2013

Kazemi et al 2011,2013

Example of extraction @ 150MHz 5' (σ) smoothed



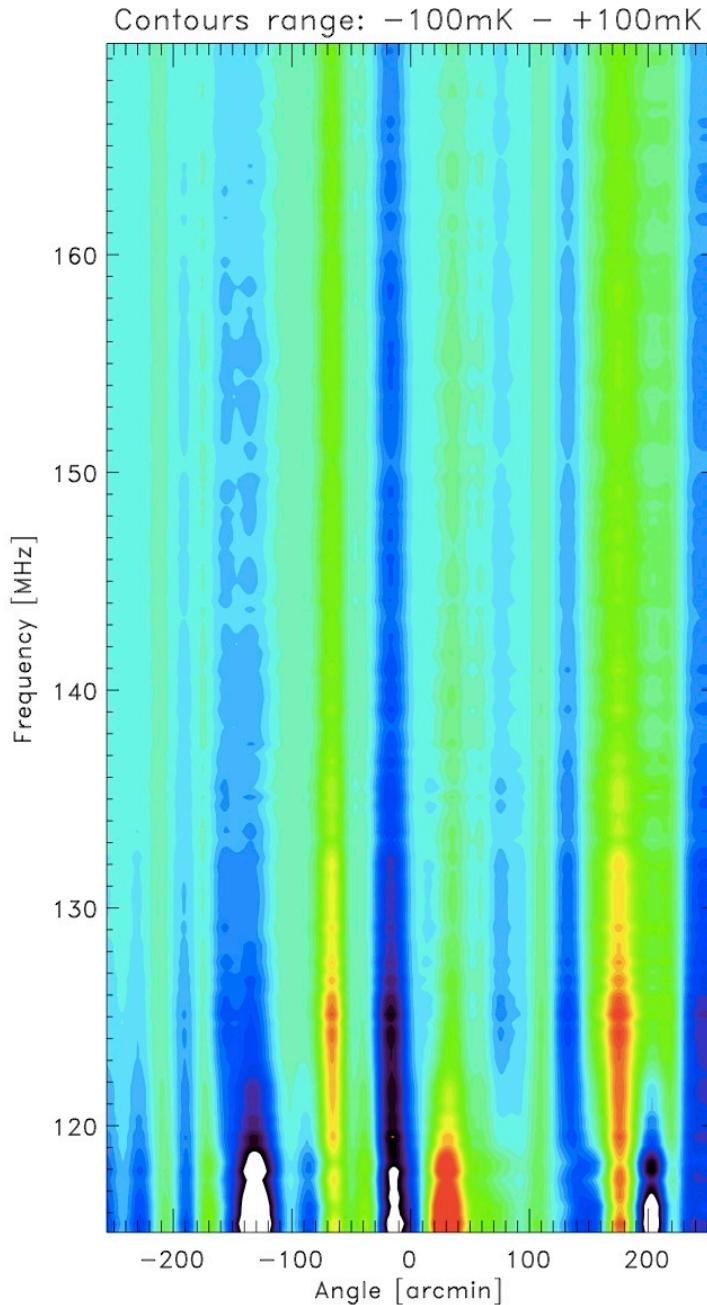
NCP data: 114 hours



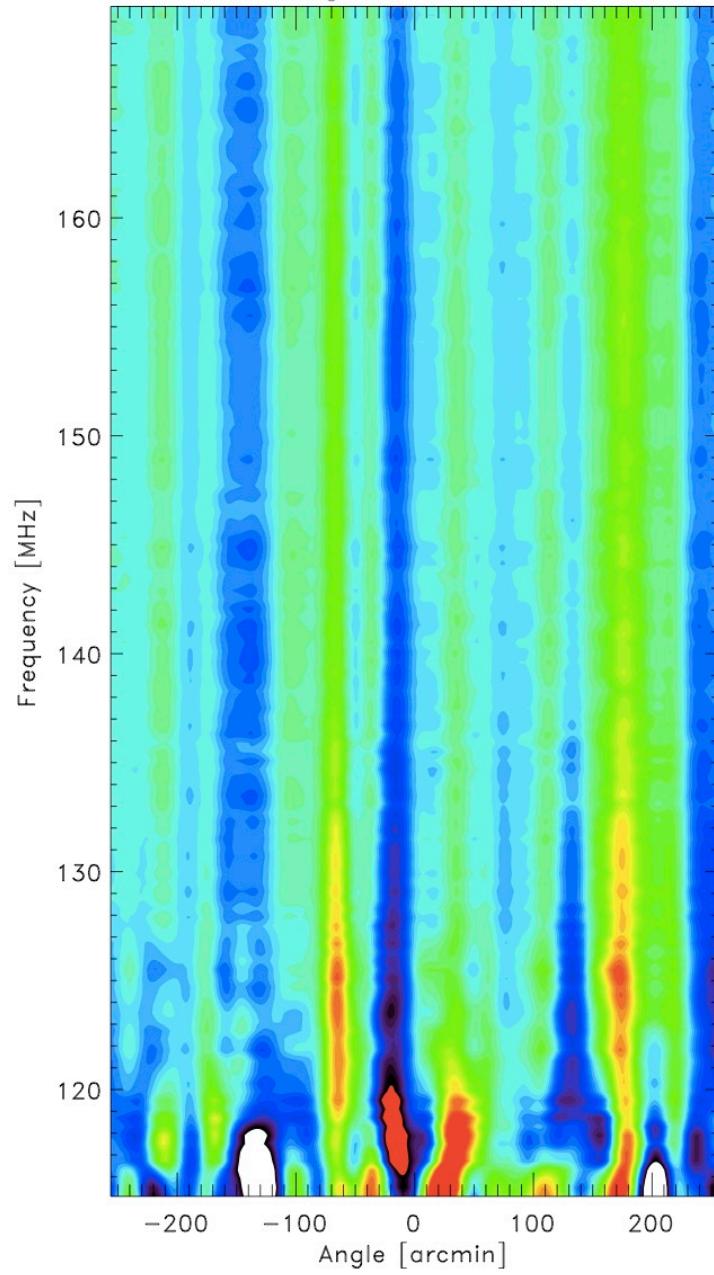
Foreground extraction

Procedure

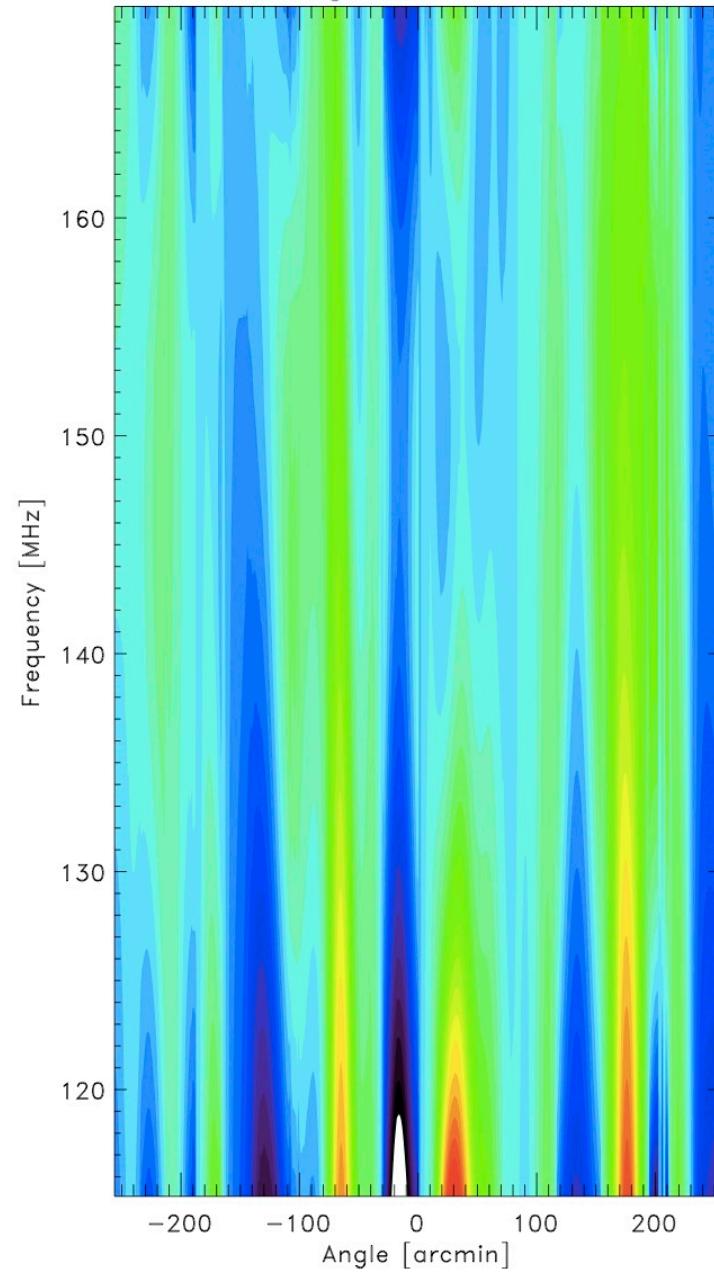
- Calibrate
- Subtract sky model
- Make the uv uniform (!)
- Smooth on 5' (σ) scale
(11.8' FWHM)
- Apply a FG extraction
method (preferably non
parametric).



Contours range: -100mK – +100mK



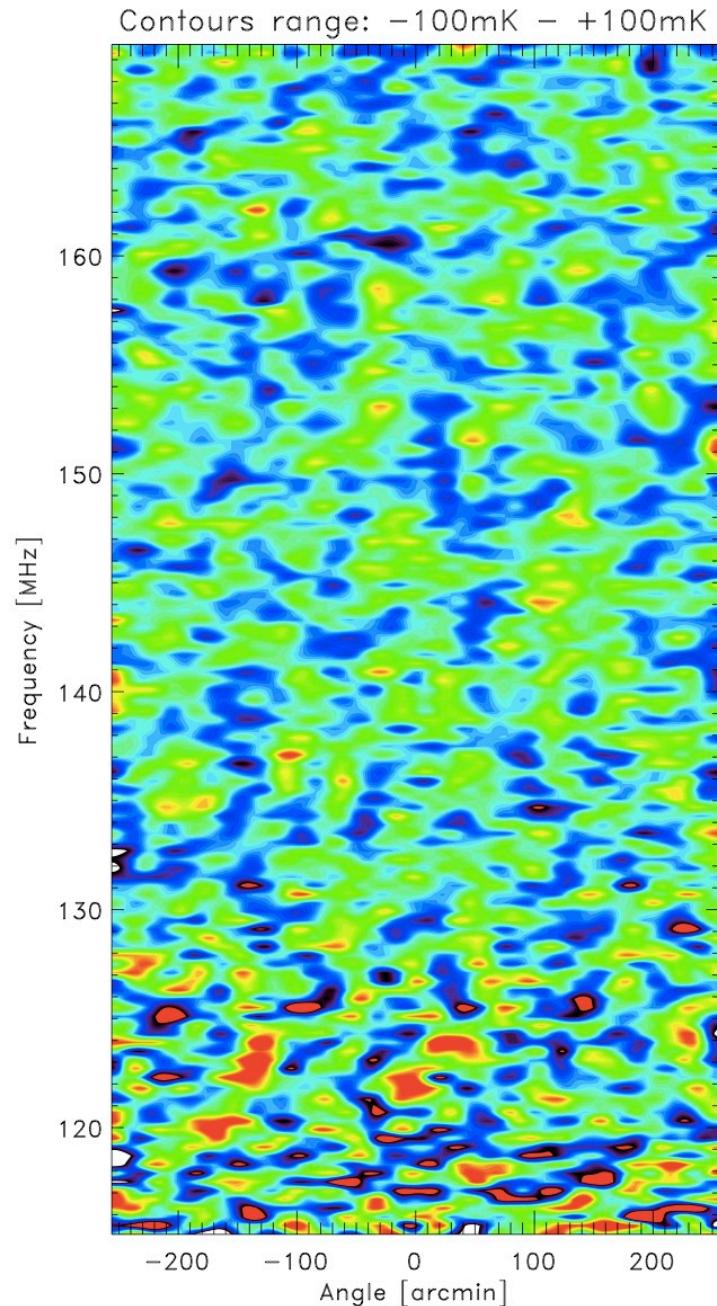
Contours range: -100mK – +100mK

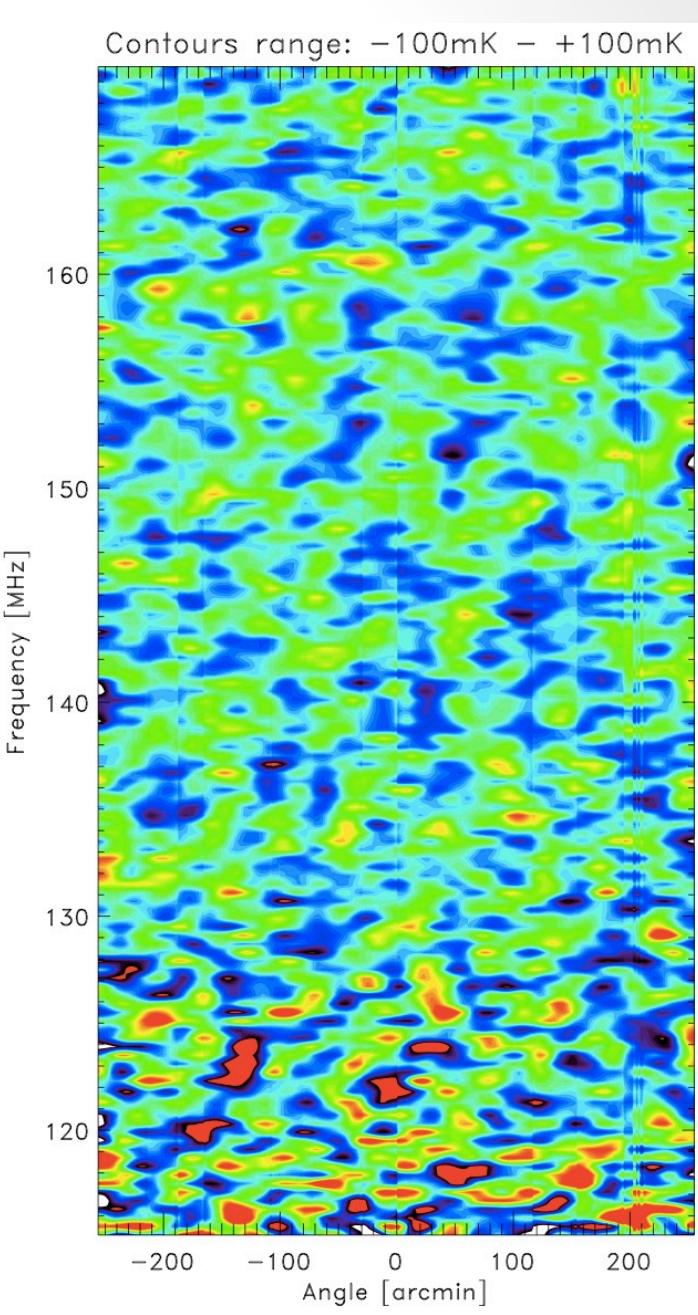
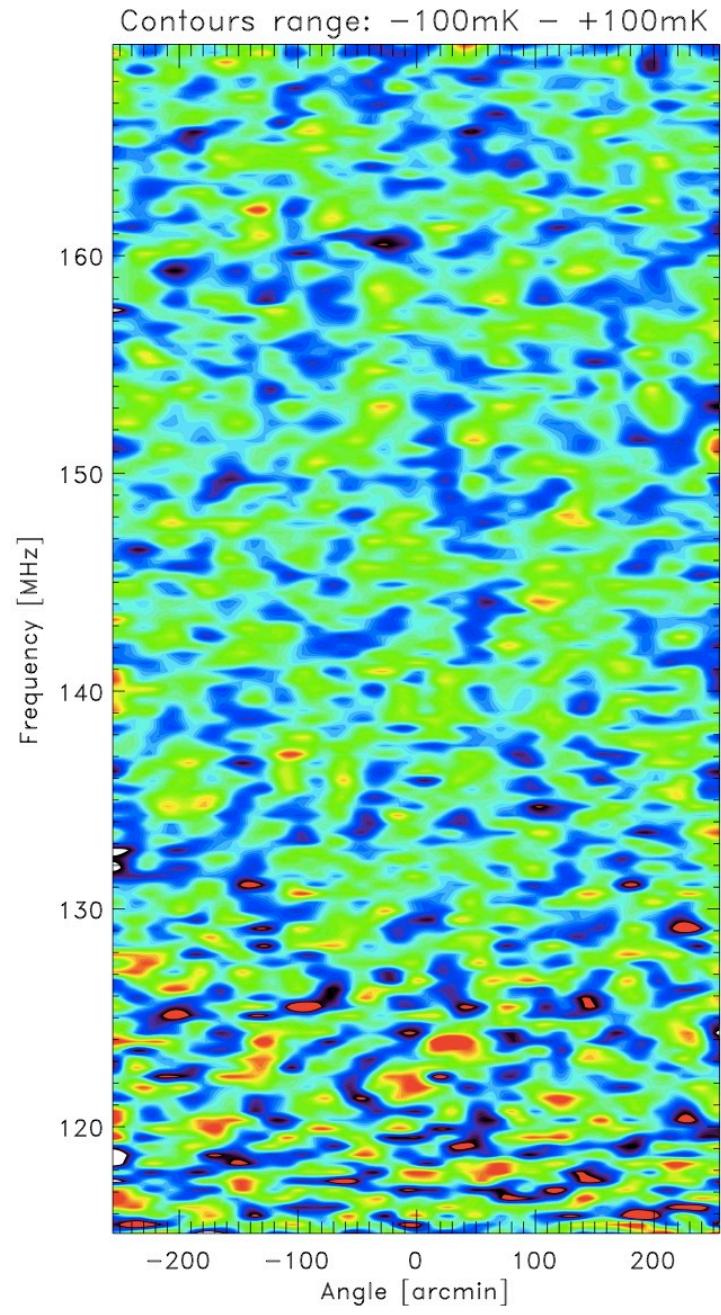


RMS analysis

Procedure

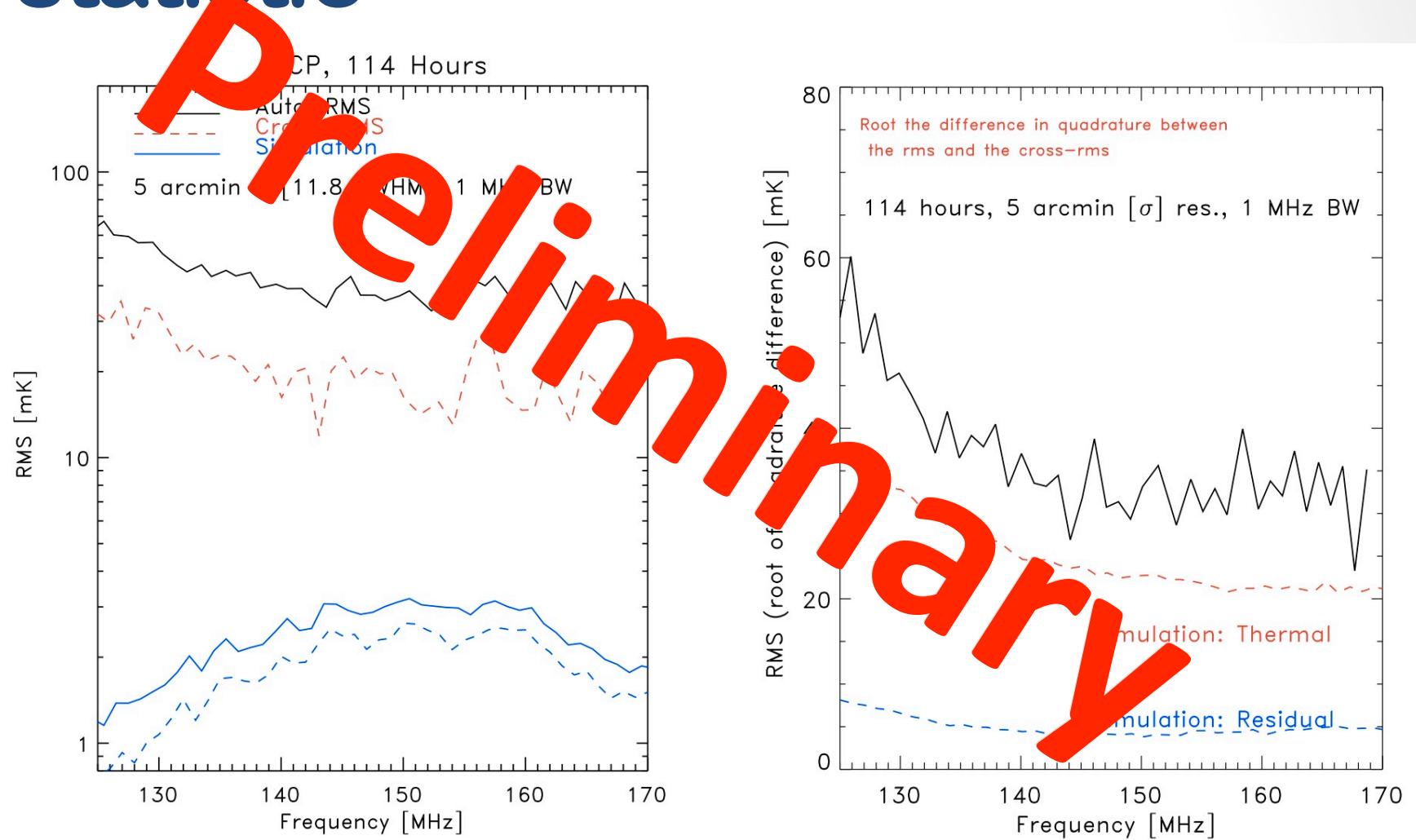
- Analyze The residual map
- RMS as a function of frequency.
- Cross-RMS as a function of frequency
- Noise, systematics

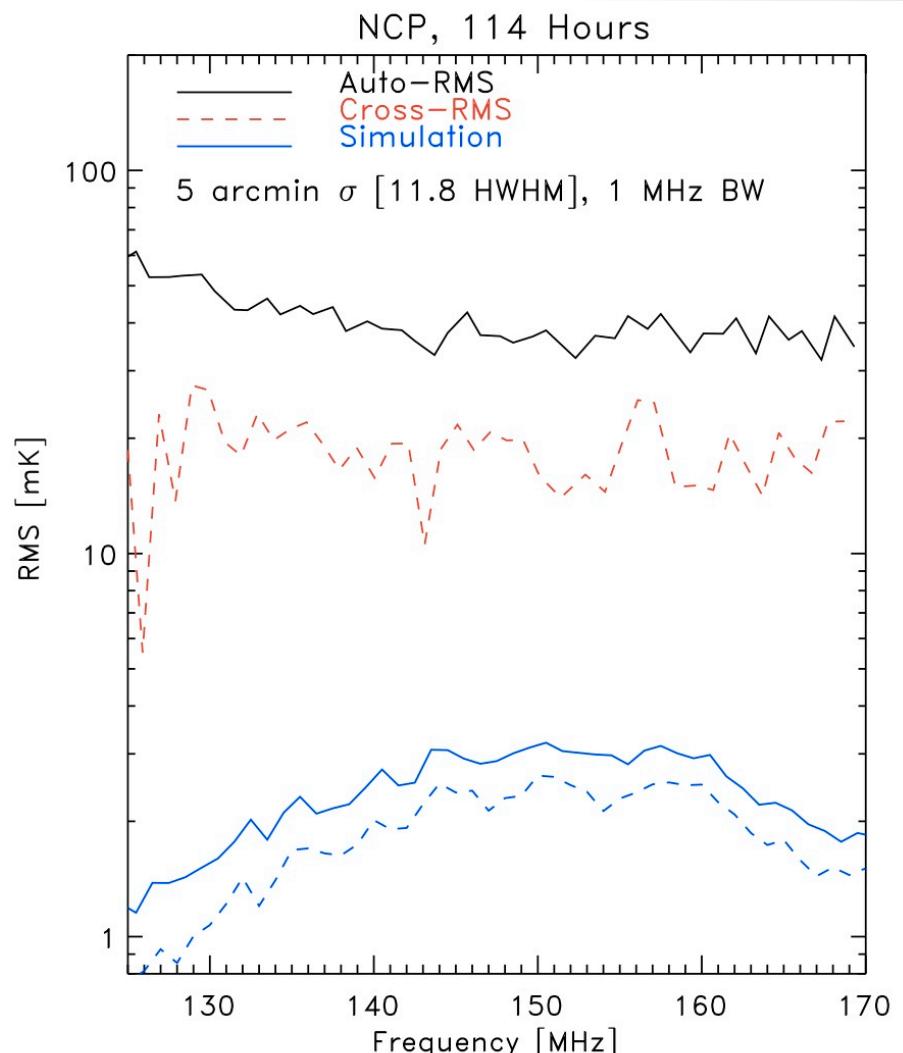
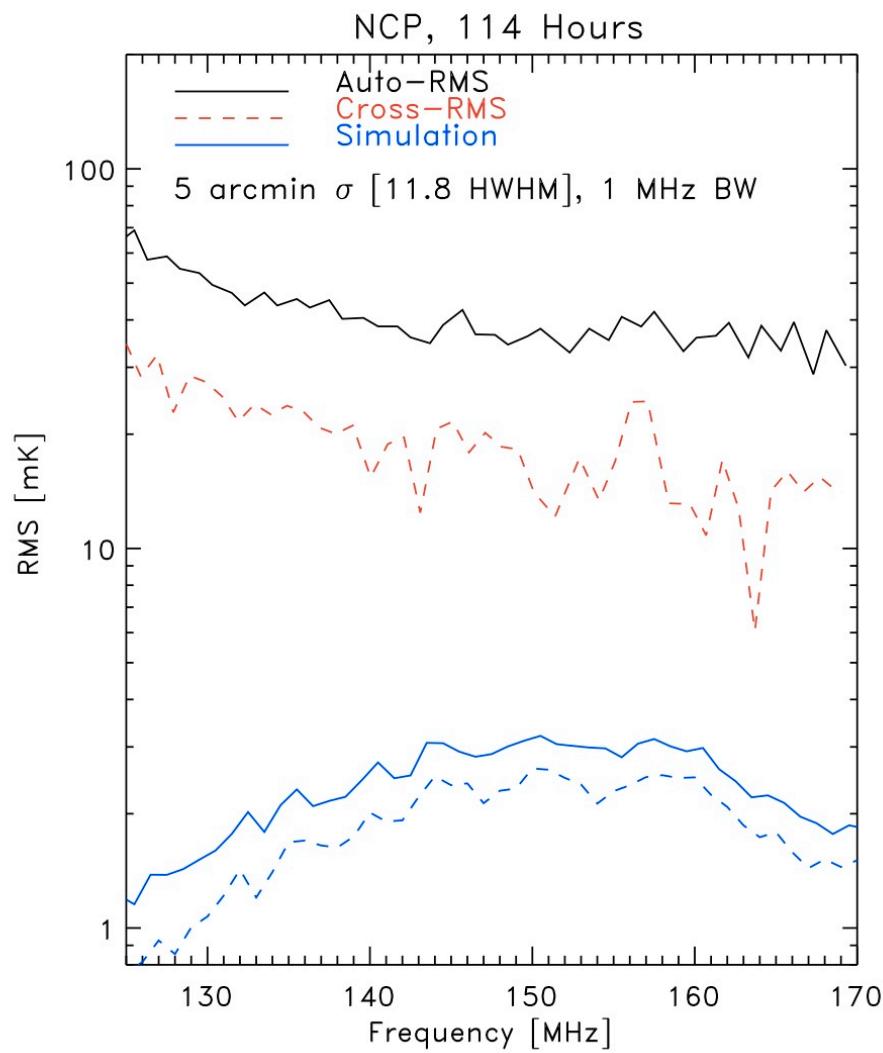




IDL movie

The rms and Cross-rms statistic





Next steps

- Understand systematics better!!!!
- Add more calibration sources (currently 11000).
- Improve the sky model.
- Calibrate on even higher frequency resolution (12 kHz)
- More data ... More data More data
- We are slowly getting there