Probing the EoR with the redshifted 21cm radiation

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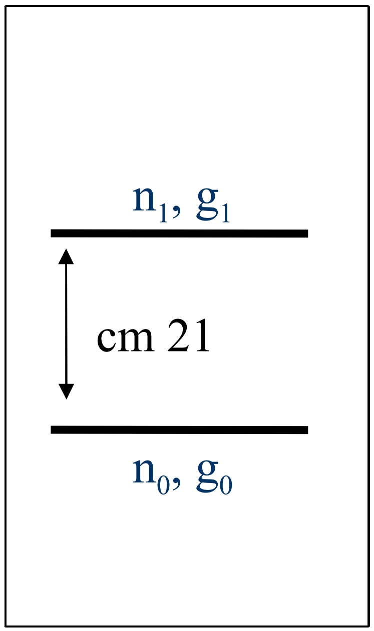
Overview

- Redshifted 21 cm observatories
  - The instruments
  - The Signal Path
- Signal and noise
- Foregrounds
- Instrument response the calibration problem
- Radio Frequency interference
- The signal extraction

The 21 cm transition



- The 21 cm hyperfine transition is a forbidden transition between the two $1^2s_{1/2}$ ground level states of hydrogen.
- The relative population of the two states is given, $n_1/n_0=g_1/g_0 \exp(-T_*/T_s)$ with T_s (the spin temp.) and $T_*=0.068$ k
- The value of the T_s is given by:

$$T_s = \frac{T_{CMB} + y_\alpha T_k + y_c T_k}{1 + y_\alpha + y_c}$$

Field 1958
Madau et al 98
Ciardi&Madau 2003

The brightness temperature: The measured quantity

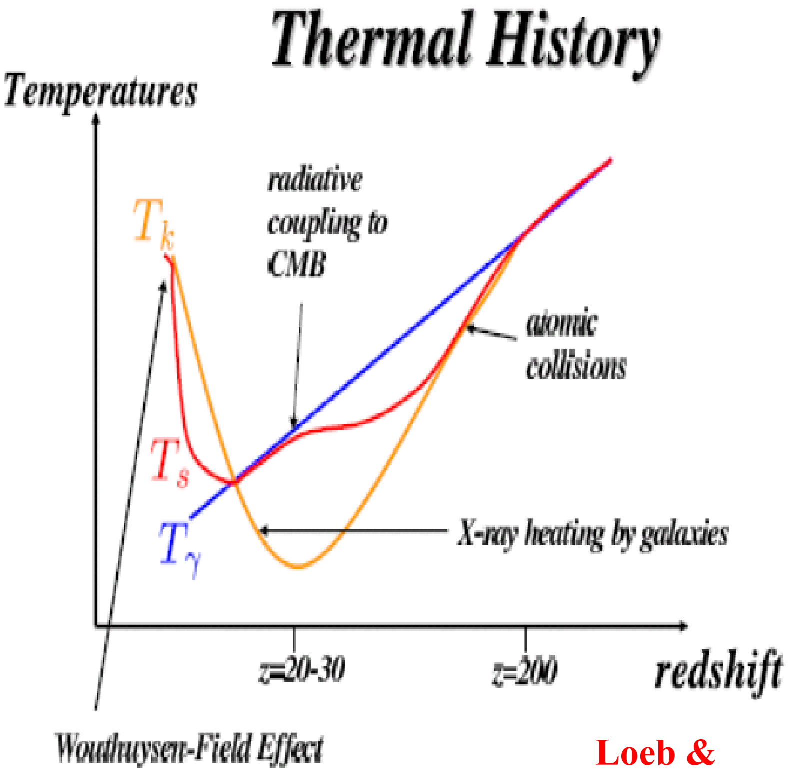
- The quantity that is measured with radio telescopes along a given line of sight and is given by:

$$\delta T_b \approx 28\mathrm{mK}\,(1+\delta)x_{HI}\,\frac{T_s - T_{CMB}}{T_s}\,\frac{\Omega_b h^2}{0.02}\left[\frac{0.24}{\Omega_m}\left(\frac{1+z}{10}\right)\right]^{\frac{1}{2}}$$

- The sources that ionize are probably the same as the ones that decouple

The Global evolution of the Spin Temperature

At z~10 T_s is tightly coupled to T_{CMB}. In order to observe the 21 cm radiation decoupling must occur.



Loeb & Zaldarriaga 04

LOFAR

MWA

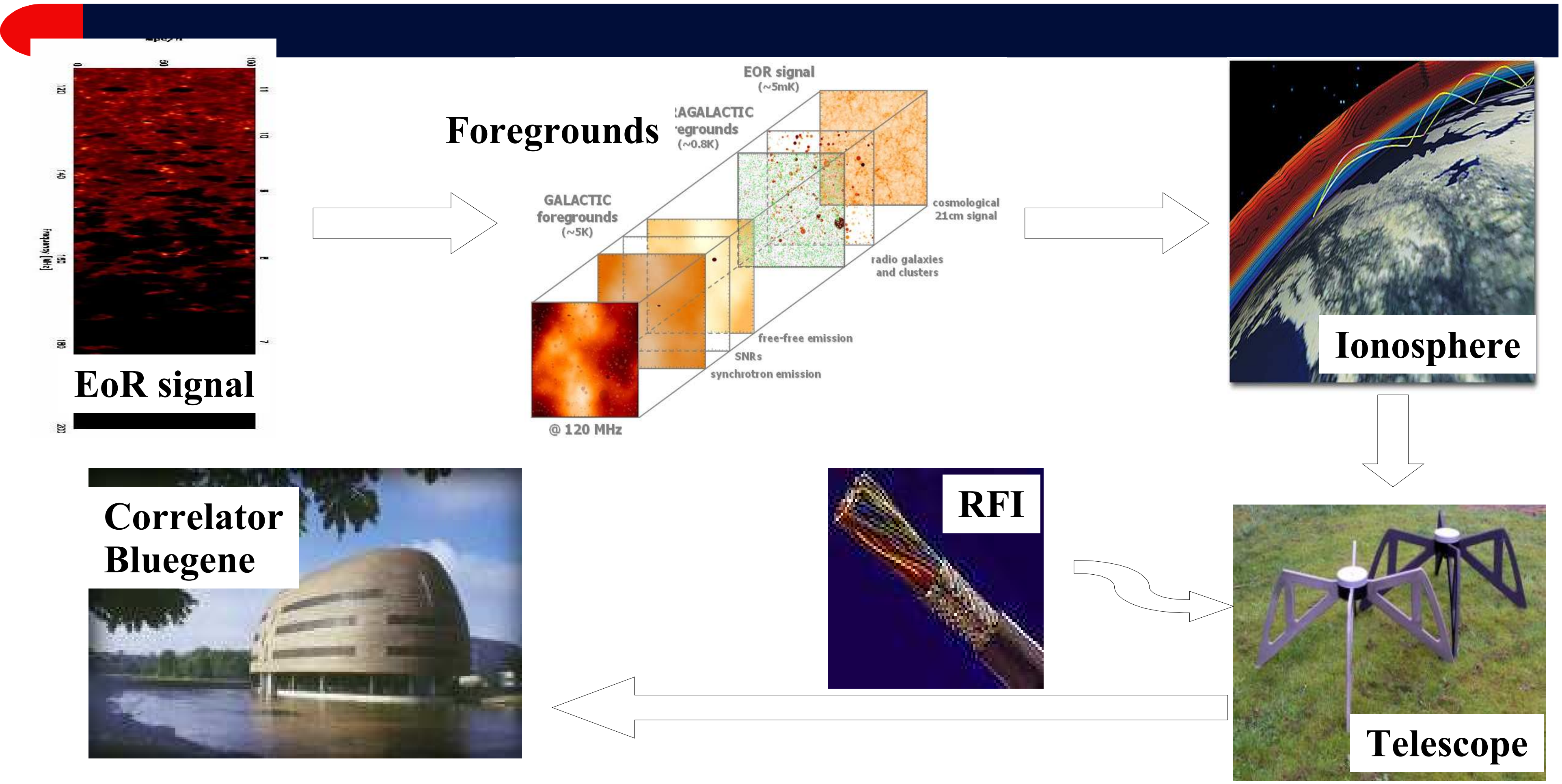
PAPER

GMRT

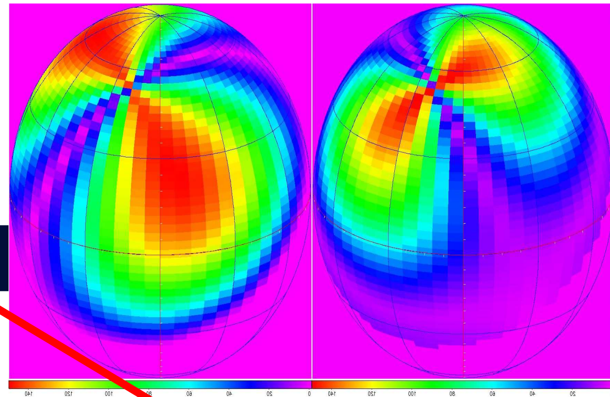
SKA

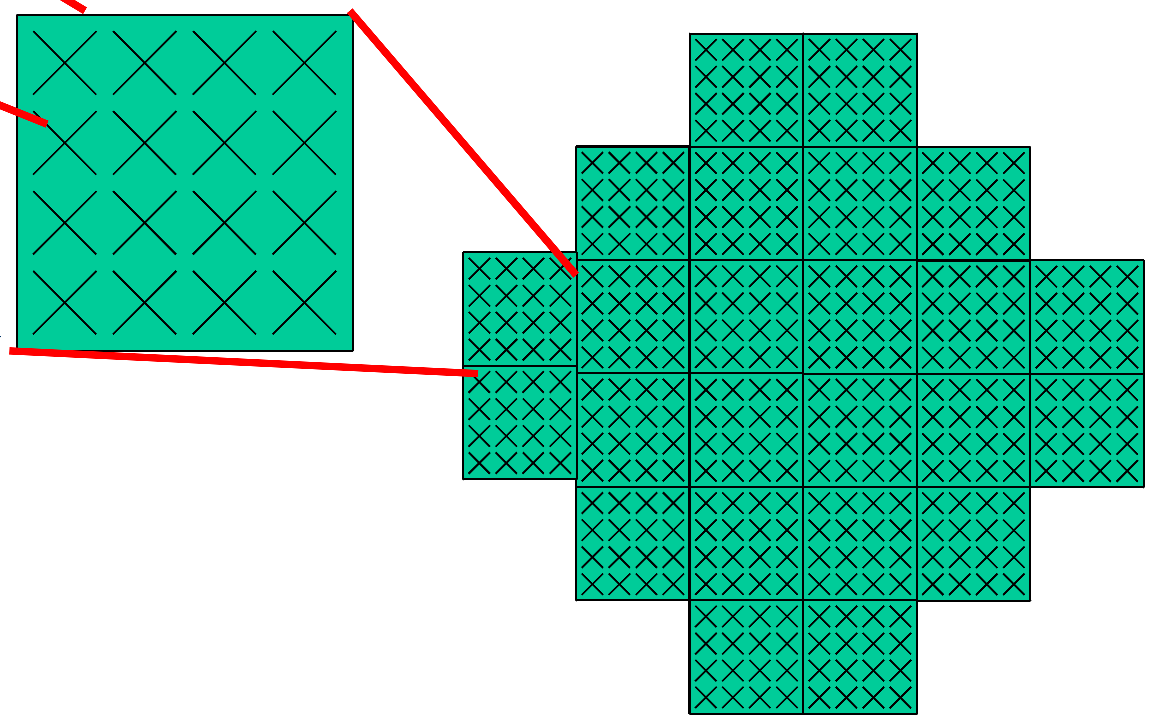
21CMA

The Observation



How to distribute the antennas?

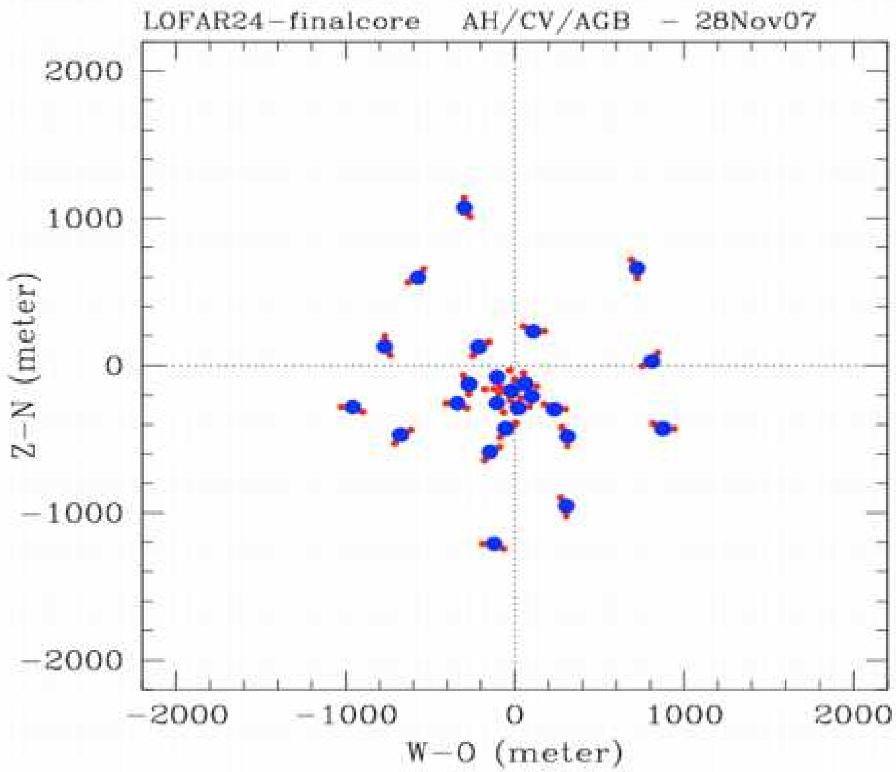




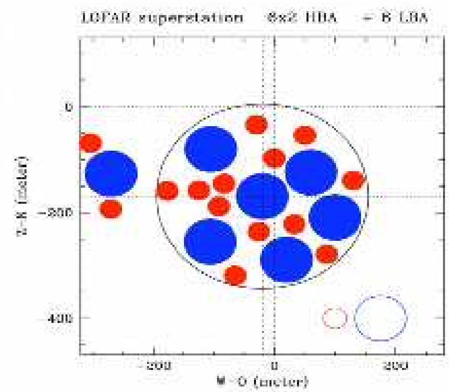
- uv coverage
- Mixing of spatial & frequency fluct.
- S/N
- Flexibility
- Calibration
- ....

- 24 High Band Tiles
- 4x4 antenna's
- Optimized ~115-240 MHz
- 5ºx5º fields
- 3-5 arcmin resolution

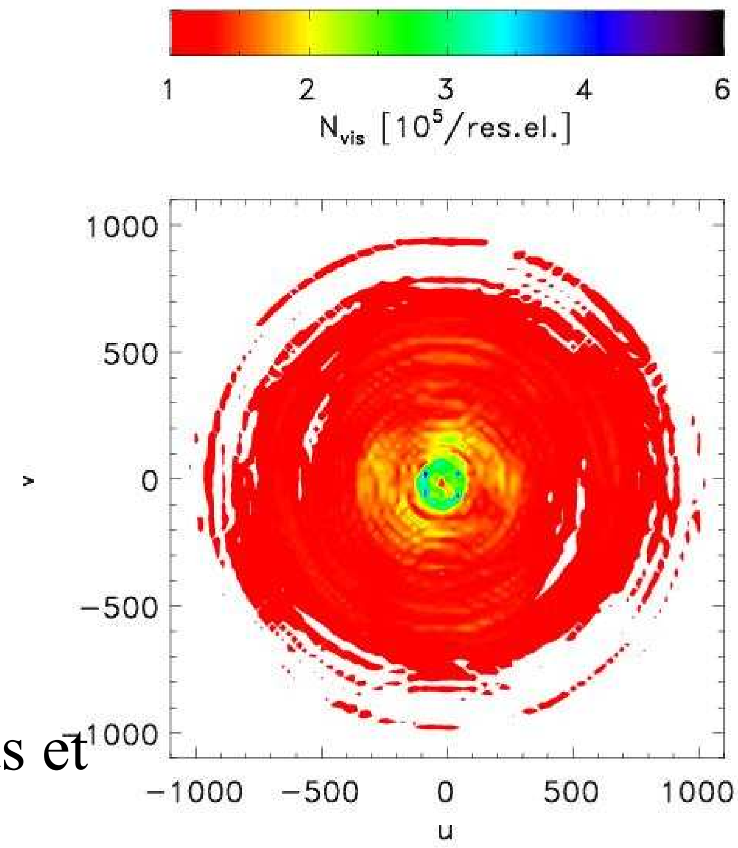
LOFAR core 24LBA and 2x24HBA



- ~ 1300 baselines
- Large data rate
- Storage of uv data
- Recalibration
- Flexibility
- Multiple beams

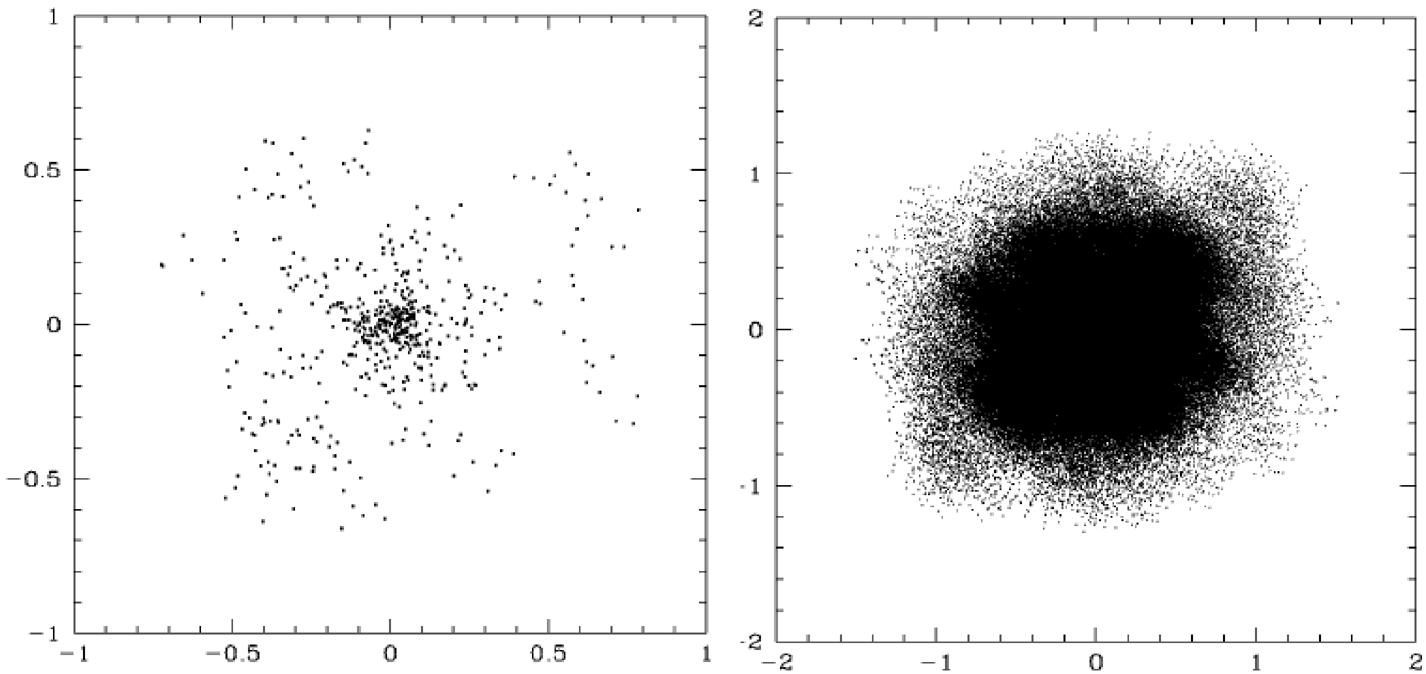


LOFAR uv coverage and beam



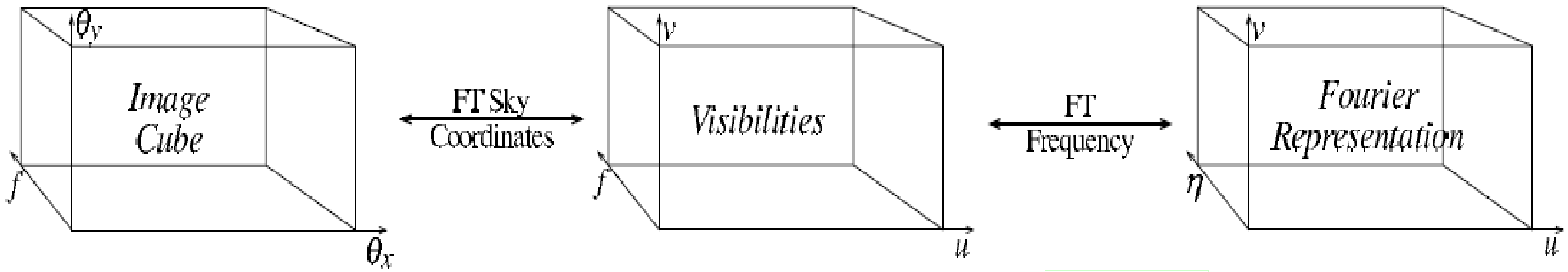
Labropulous et al, in prep.

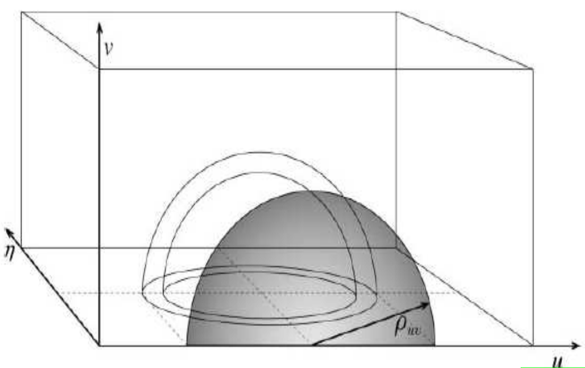
MWA layout and UV coverage



~ 125000 baselines, staggeringdata rate, image storage, real time calib.

Sensitivity & S/N





# of cells in an annulus

System Temp.

$$[C_{i,j}]_{rms} \approx 2N^{-1/2}\left(\frac{2k_B T_{sys}}{\epsilon d A d\eta}\right)^2 \frac{1}{B\bar{n}t}$$

efficiency

Station area

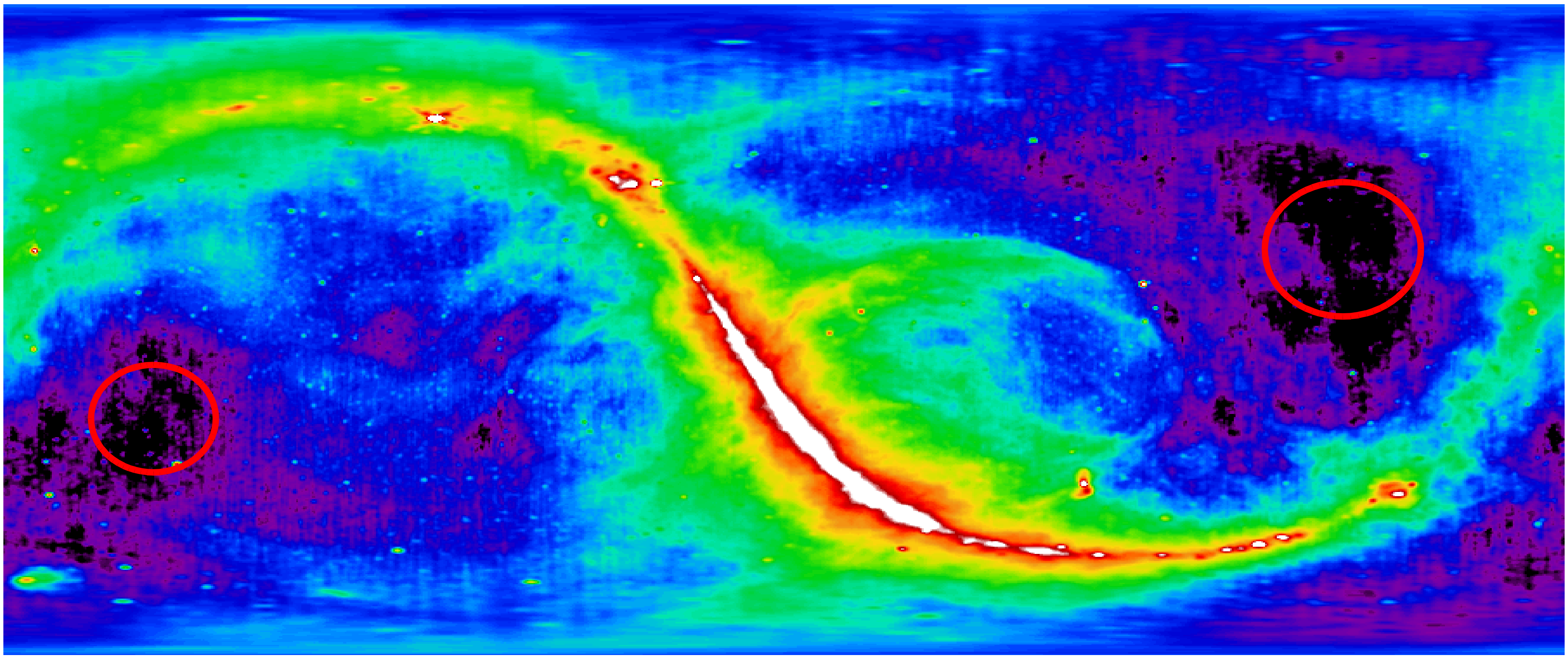
Integration time

B =Bandwidth
d η=inv. Bandwidth
n= mean # of baselines

Morales 2005

$$T_{sys} = T_{sky} + T_{Receiver}$$

At 150 MHz T_{sky} ~200K



Radio sky in 408 MHz continuum

Haslam et al, 1982

Foregrounds

Galactic foreground

- **SYNCHROTRON EMISSION (~70%)**
  - **SOURCES:** electrons trapped in the magnetic fields of discrete galactic supernovae remnants and diffuse emission from interaction of cosmic-ray electrons with galactic magnetic field
  - **DIFFUSE SYNCHROTRON EMISSION**

    ⇨ **Spectrum is close to a featureless power law with a smooth variation in spectral index.**

    ⇨ **average spectral index (100 MHz) b=-2.55, with position dispersion s(b)~0.1 (Shaver et al. 1999)**
  - **SUPERNOVAE REMENANTS**
- **Free-Free emission (1%)**

Exrtagalactic foreground

- **Radio galaxies (AGNs, starburst etc.)**

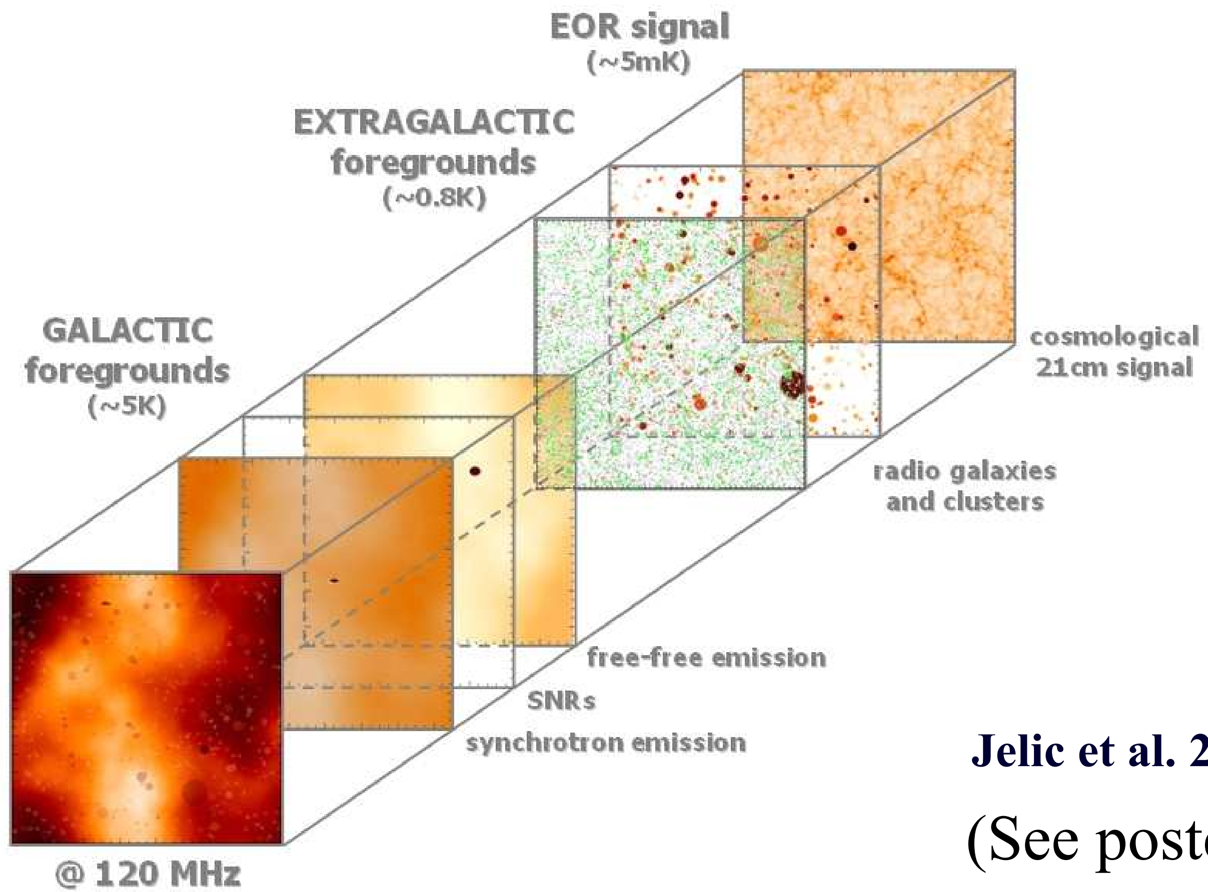
  — **based on radio sky simulations by Jackson et al. 2005**

  — **3 TYPES OF SOURCES: FRI, FRII (Fanaroff & Riley 1972) & star forming (SF) galaxies**

- **Galaxy Clusters**

  — **The Hubble Volume Simulation Cluster Catalogue (Virgo Consortium, 2002)**
  —**DMH Mass – Xray correlation (Jenkins et al., 2001)**
  — **X ray – radio luminosity correlation (Enßlin & Röttgering, 2002). 30% with radio properties.**
  — **Redshift, virial radius ⇒ angular size**
  — **Spectral index distribution from Cohen et al. 2004**

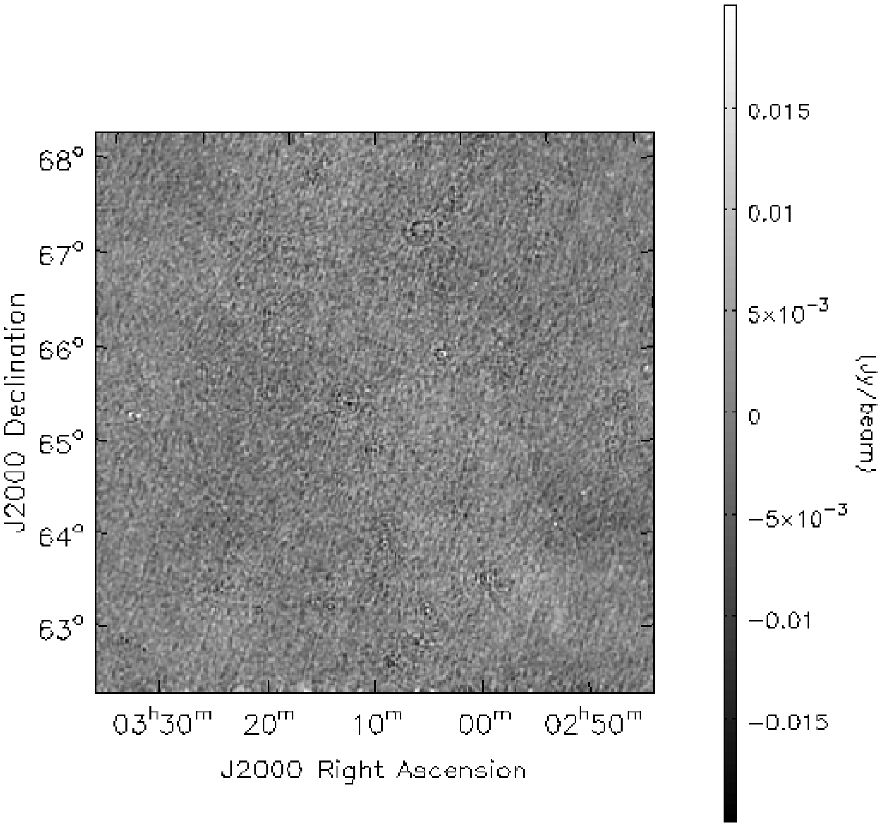
The signal + Foregrounds



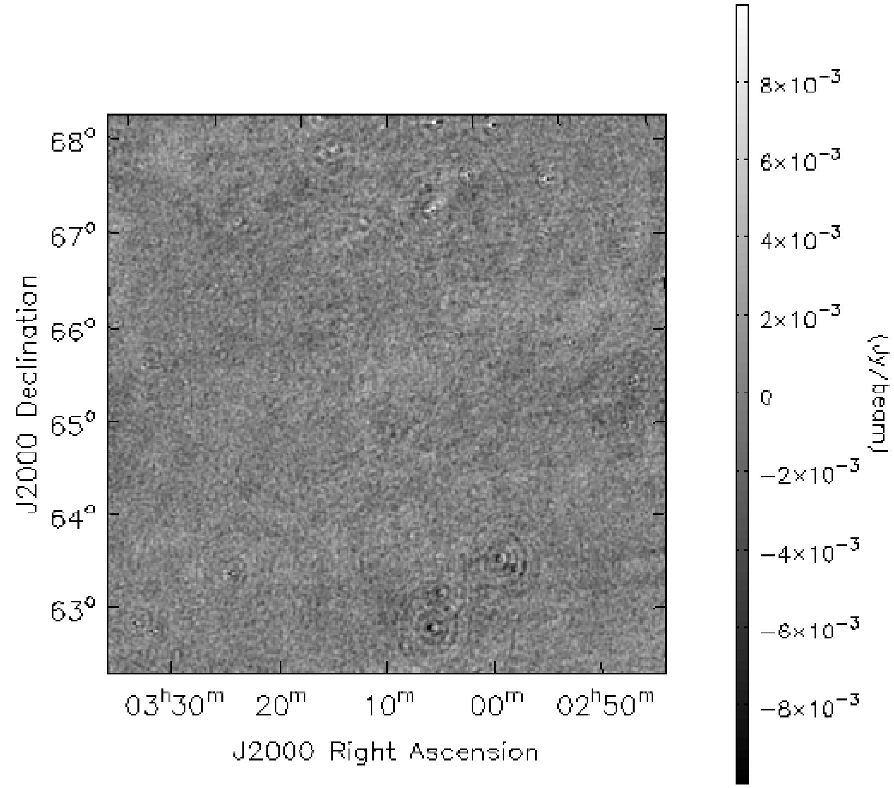
Jelic et al. 2008

(See poster)

Stokes I

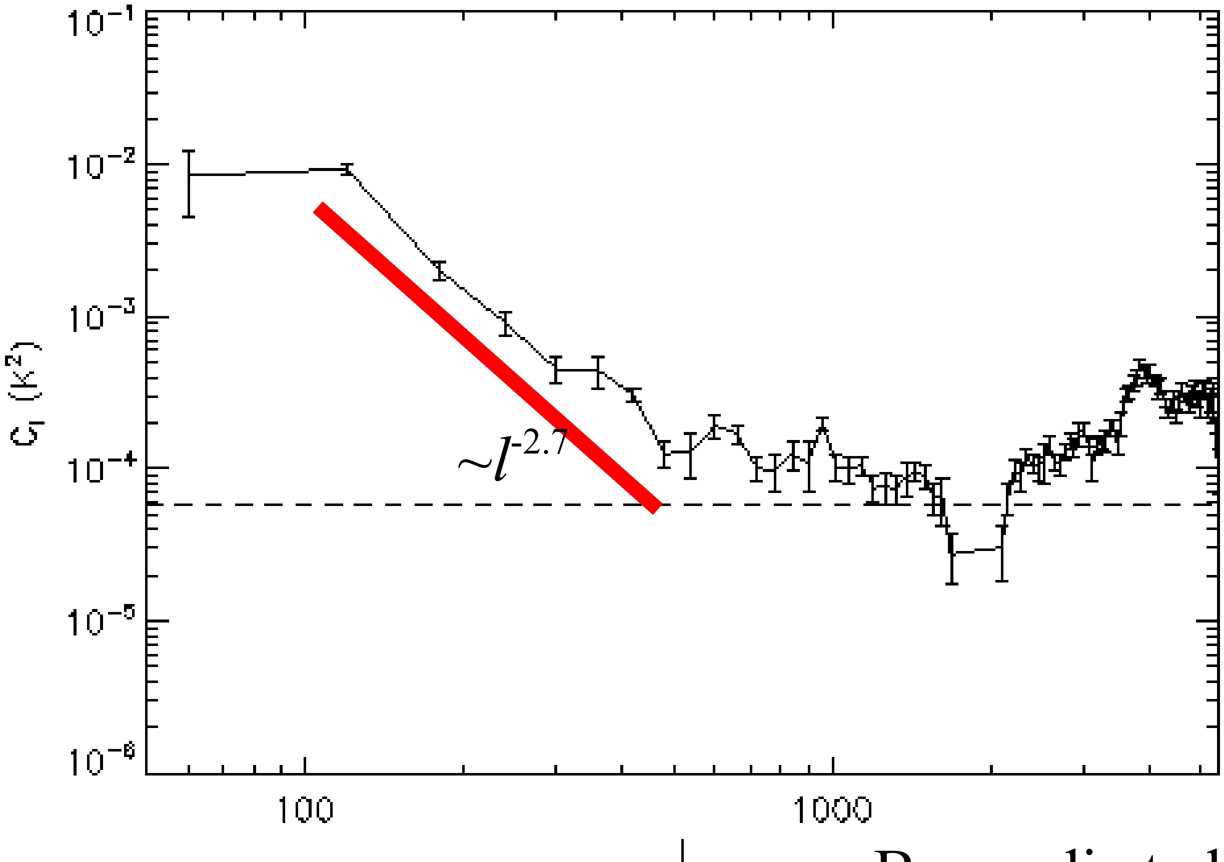


Stokes V



Bernardi et al, in perp.

The FAN region: Power spectrum of the Diffuse Foregrounds

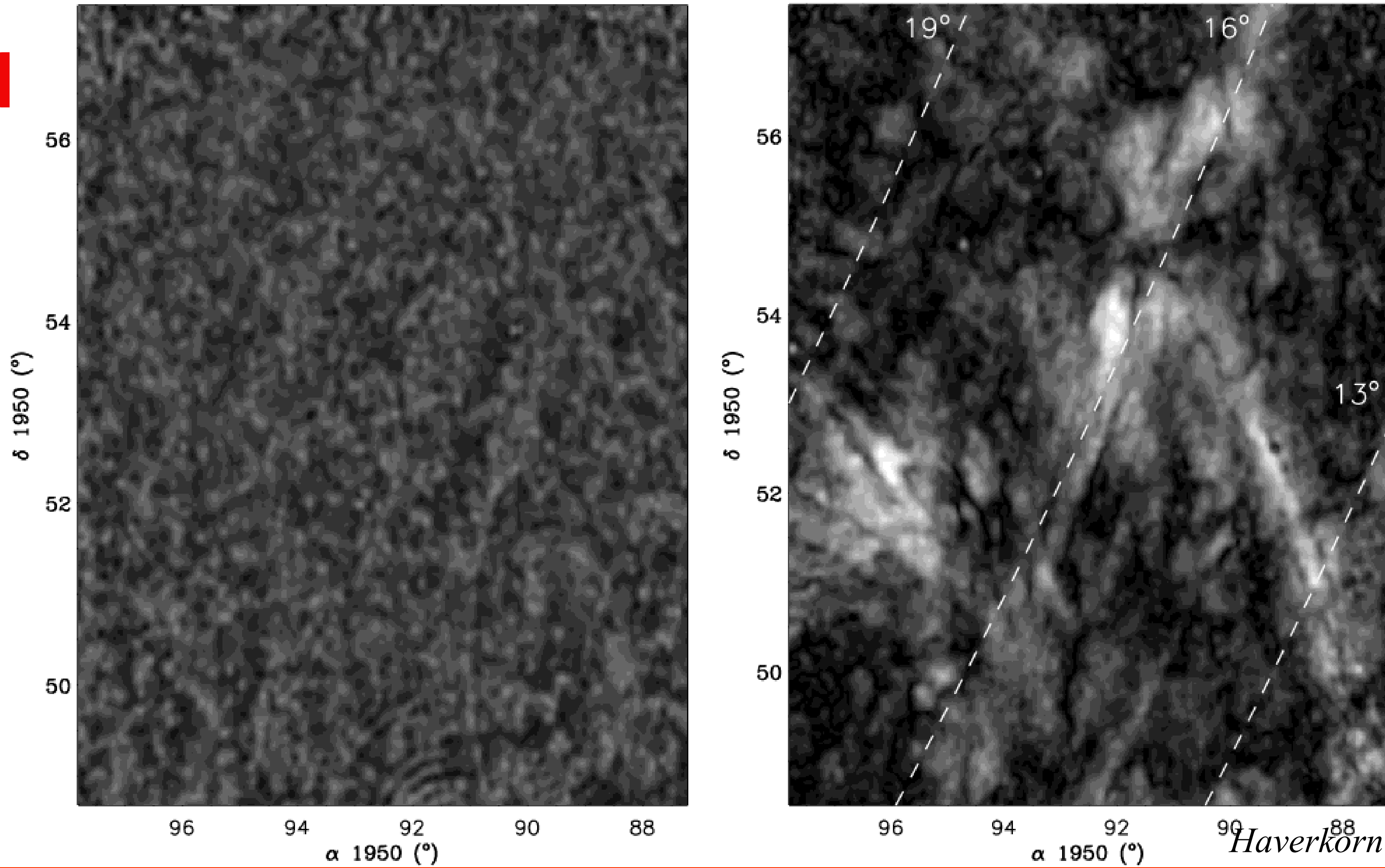


Bernardi et al, in perp.

The ‘DOGLEG area’ in Auriga

WSRT ~ 350 MHz

Total intensity ← same intensity scale → Polarised intensity

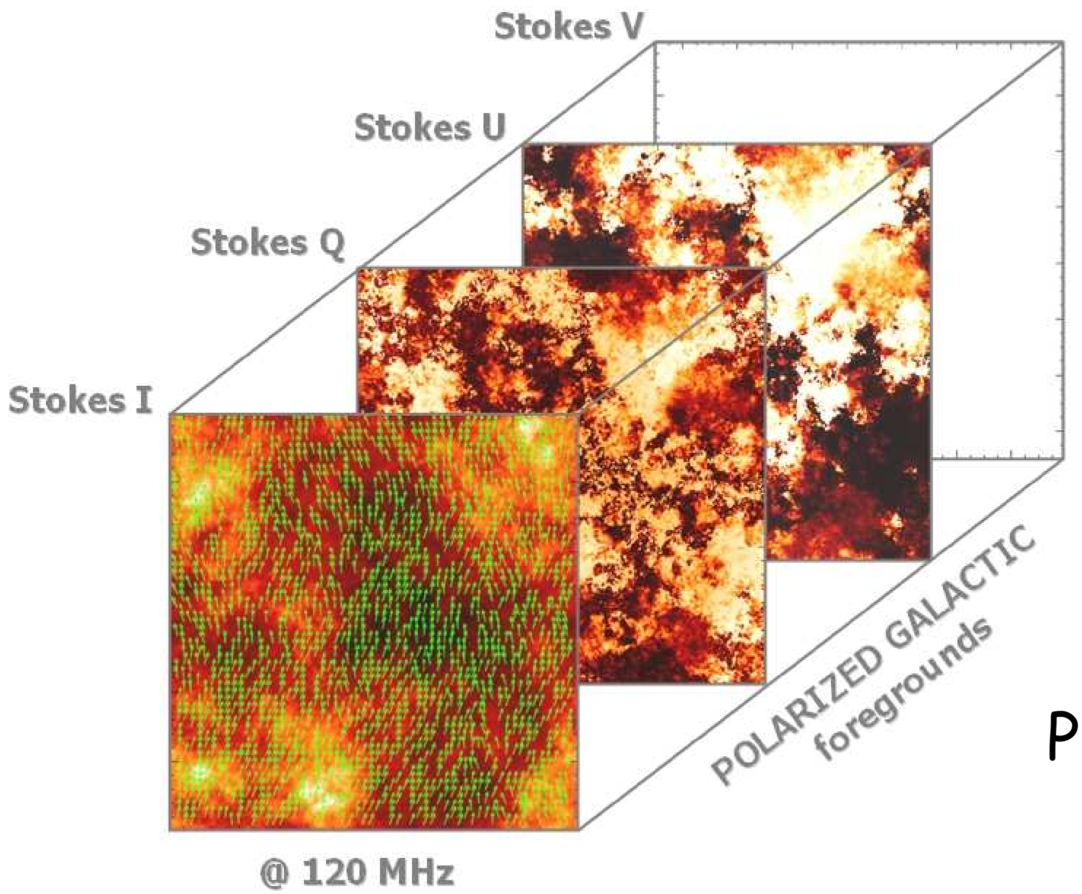


Haverkorn et al, 2003

Polarized Foregrounds are NOT smooth along the frequency direction, therefore, they should taken out with very high accurecy

Movie of the Fan region's RM cube

Polarized foreground simulations



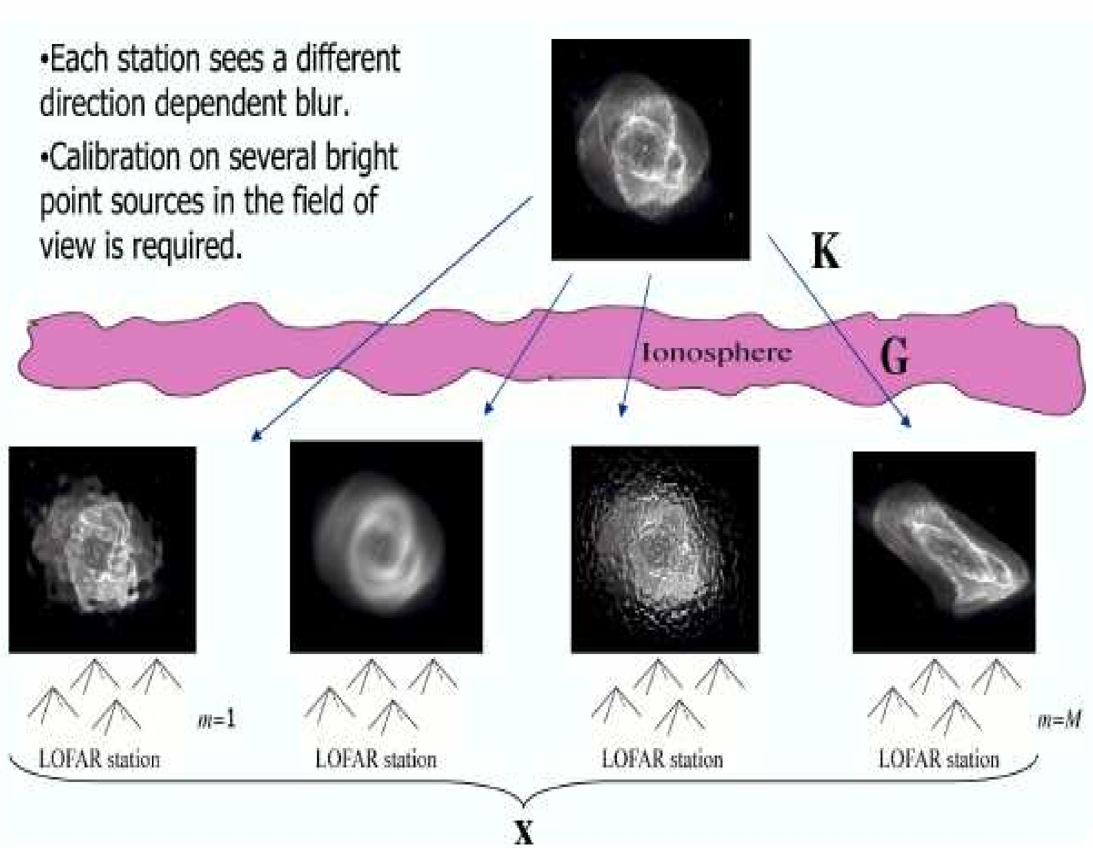
Polarized Synchrotron

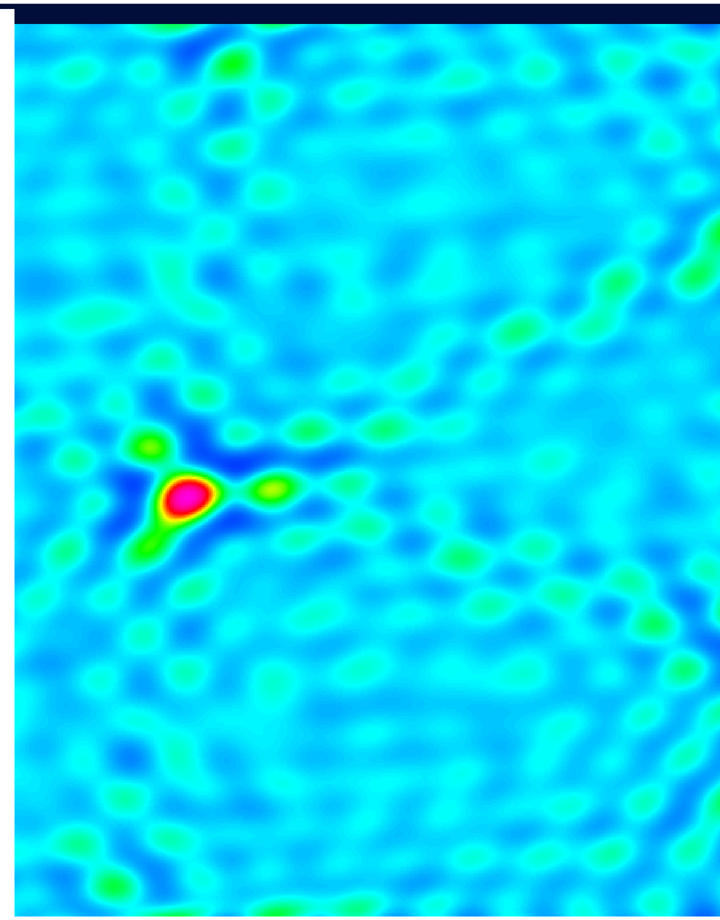
Jelic et al 2008

The Ionosphere and the calibration problem

- The measurement equation
- Global and local sky models
- Calibrate out the:
  - ionospheric distortion
  - variation of gain (e.g., cows shewing your cables)
  - antenna polarized response (THE NIGHTMARE)
  - ...
-

The ionosphere

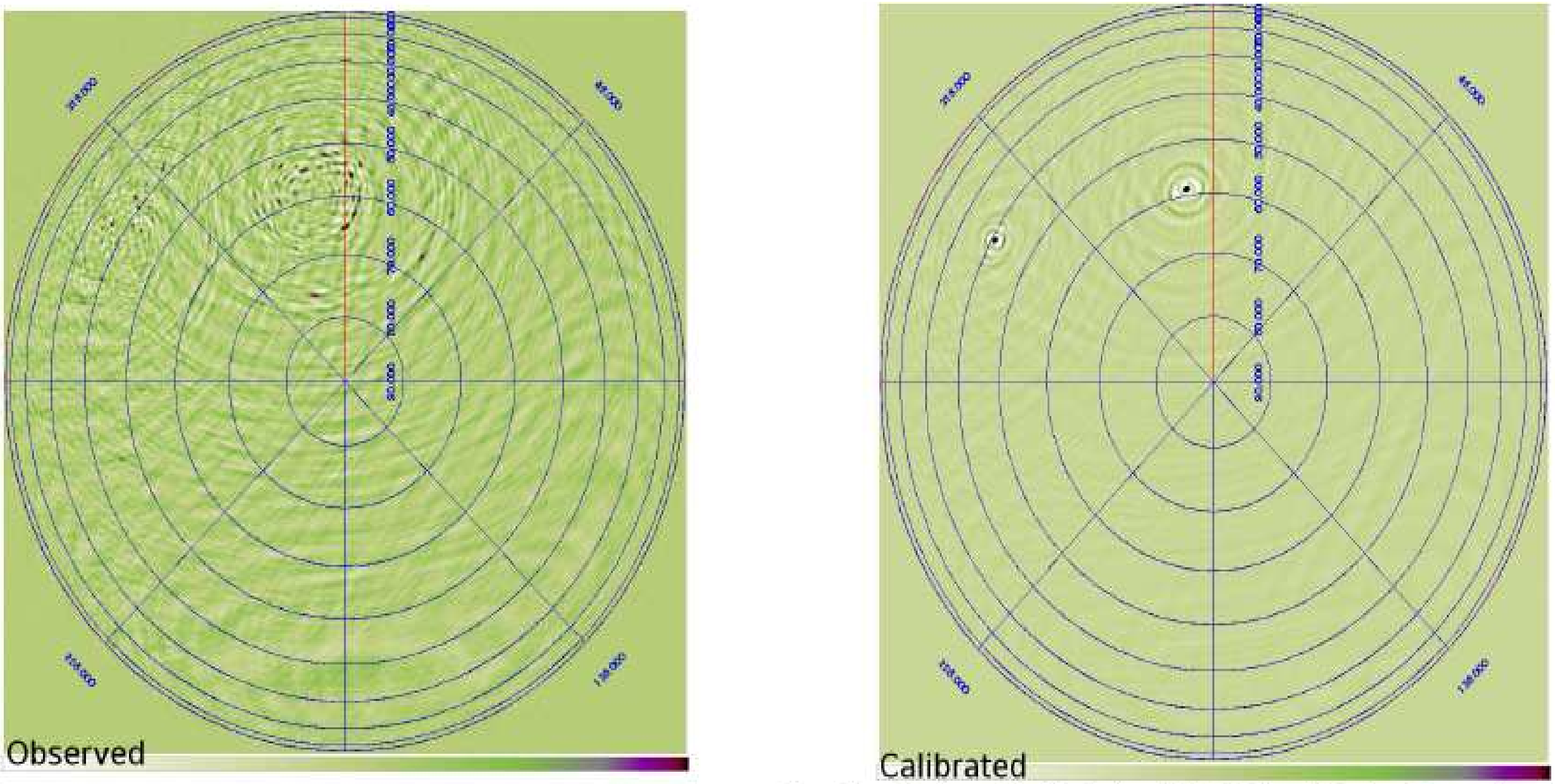




Simulations by O. Smirnov

The LOFAR calibration an example

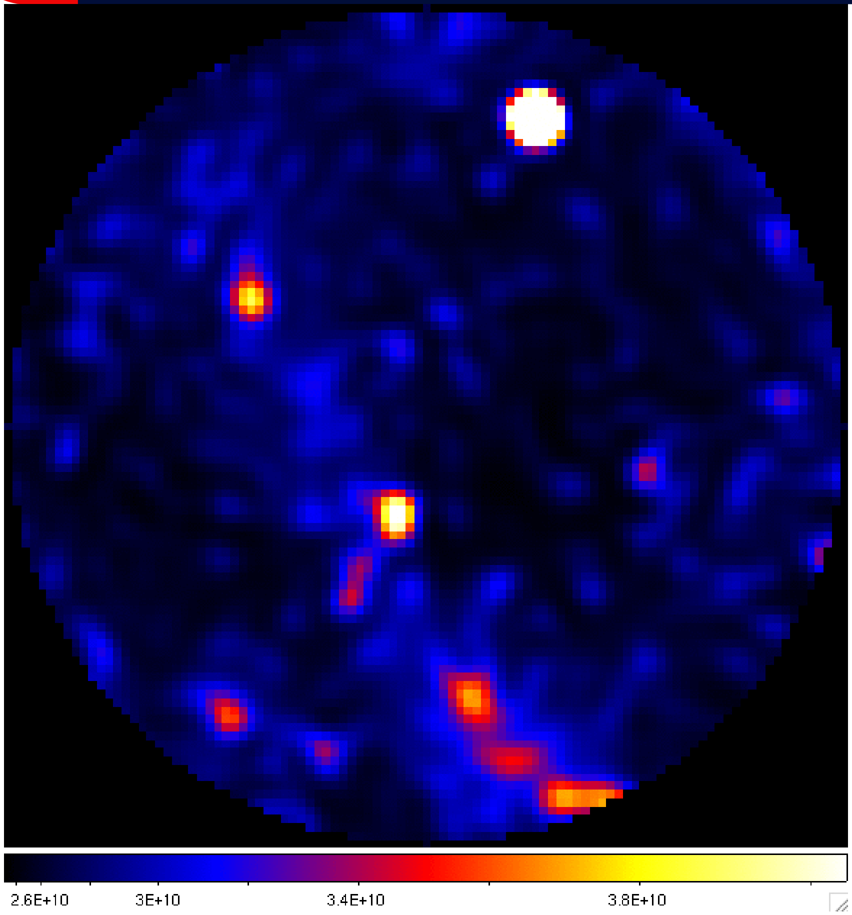
Yatawatta et al, in prep

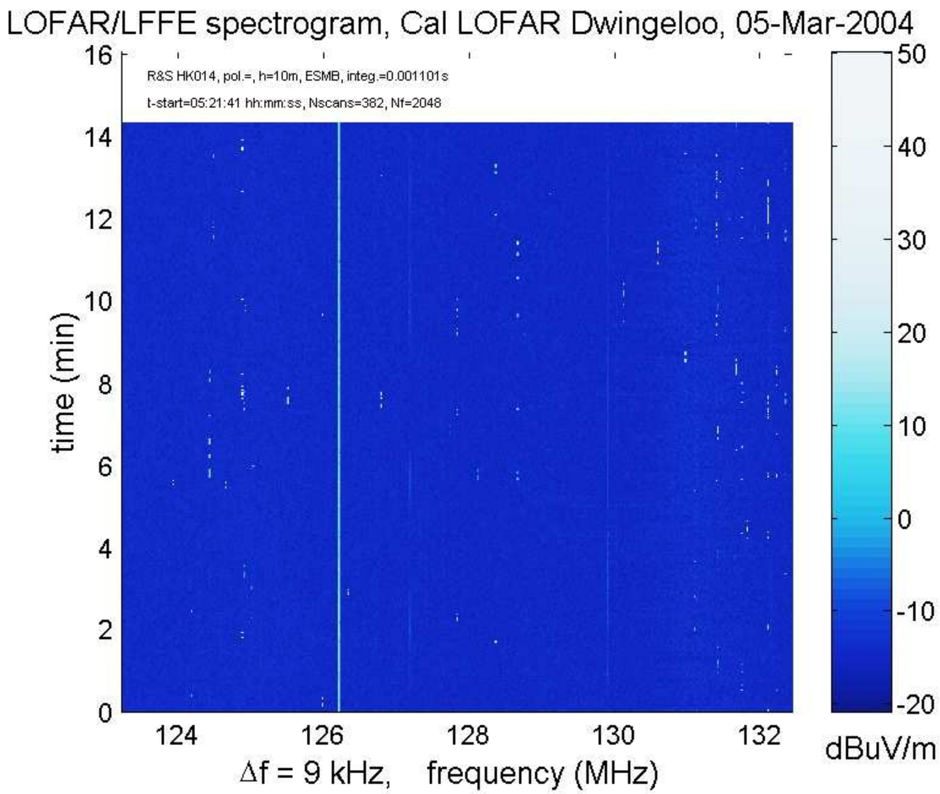


North Celestial Pole (NCP), LBA

North Celestial Pole (NCP), LBA, Cas A, Cyg A

Radio Frequency Interference



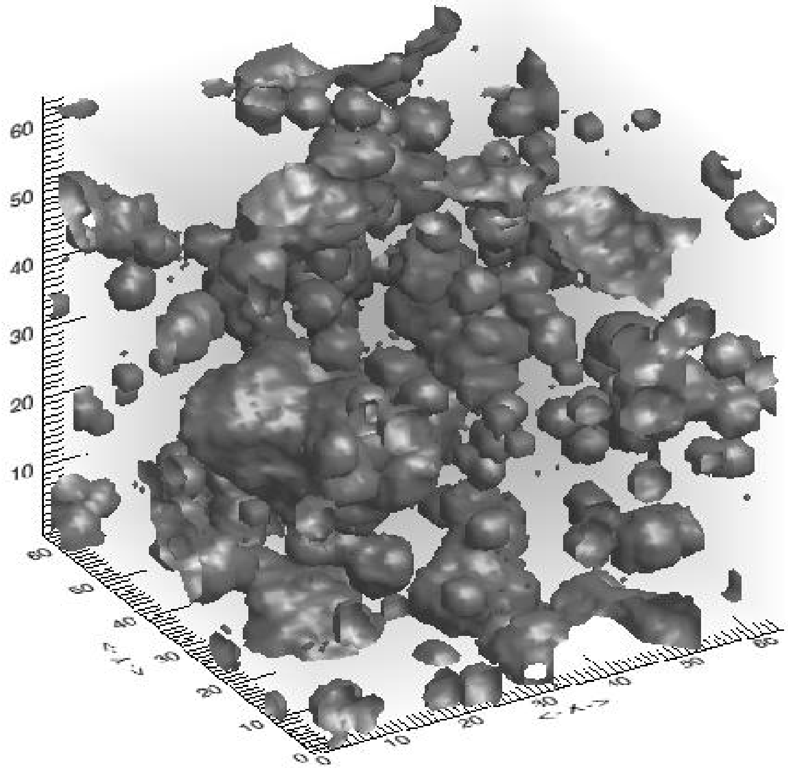


Courtesy of M. Brentjens

The extraction problem

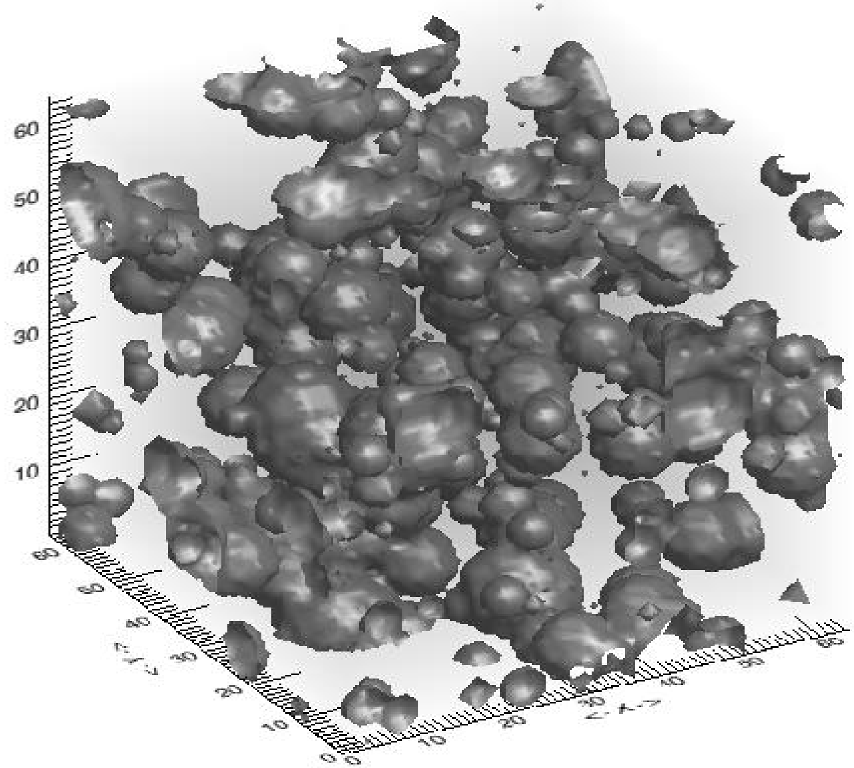
The Signal: Quick and dirty simulations

CRASH

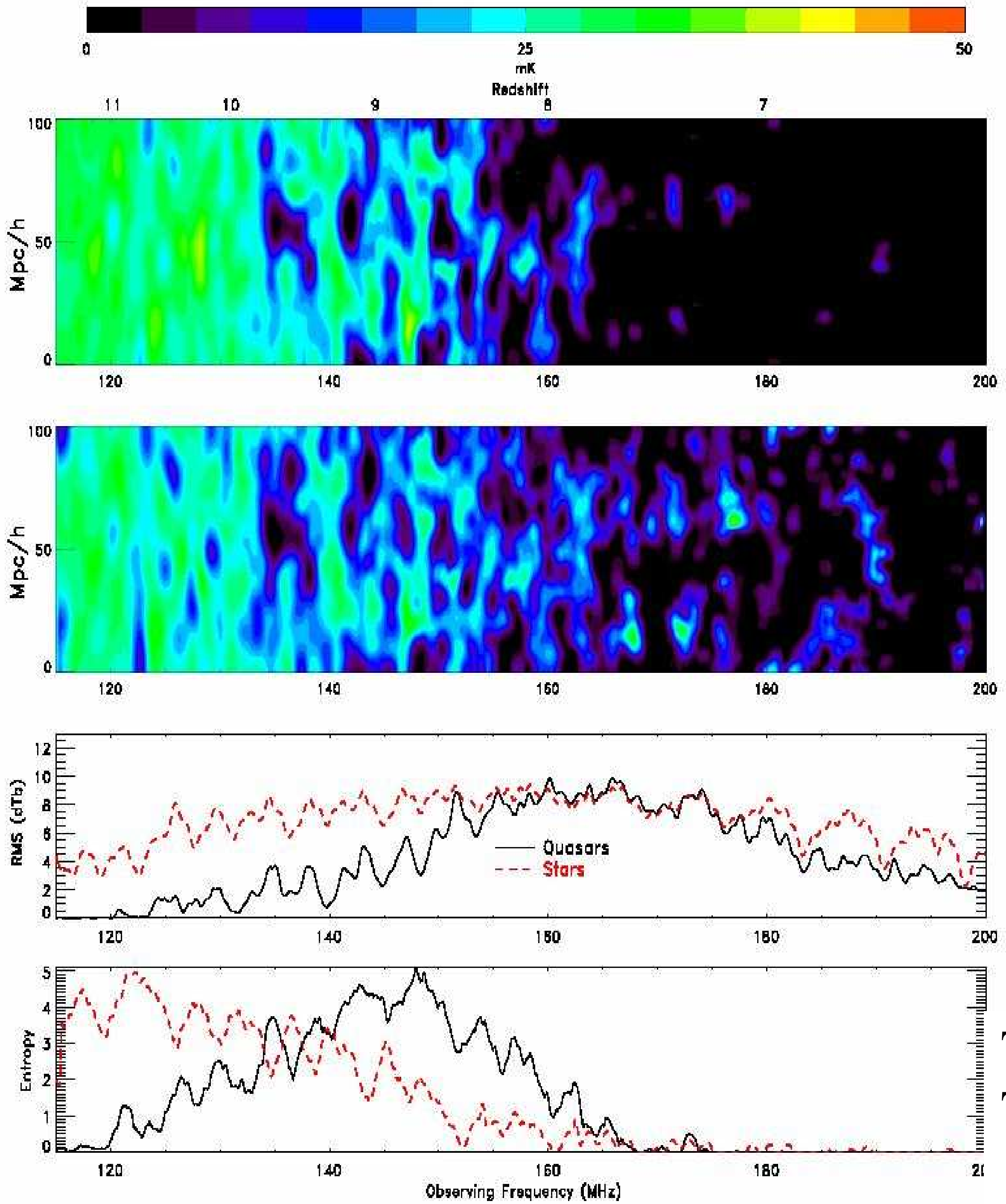


Ciardi et al. 2001, Maselli et al. 2003

BEAR



Thomas et al. 2008 (see poster)

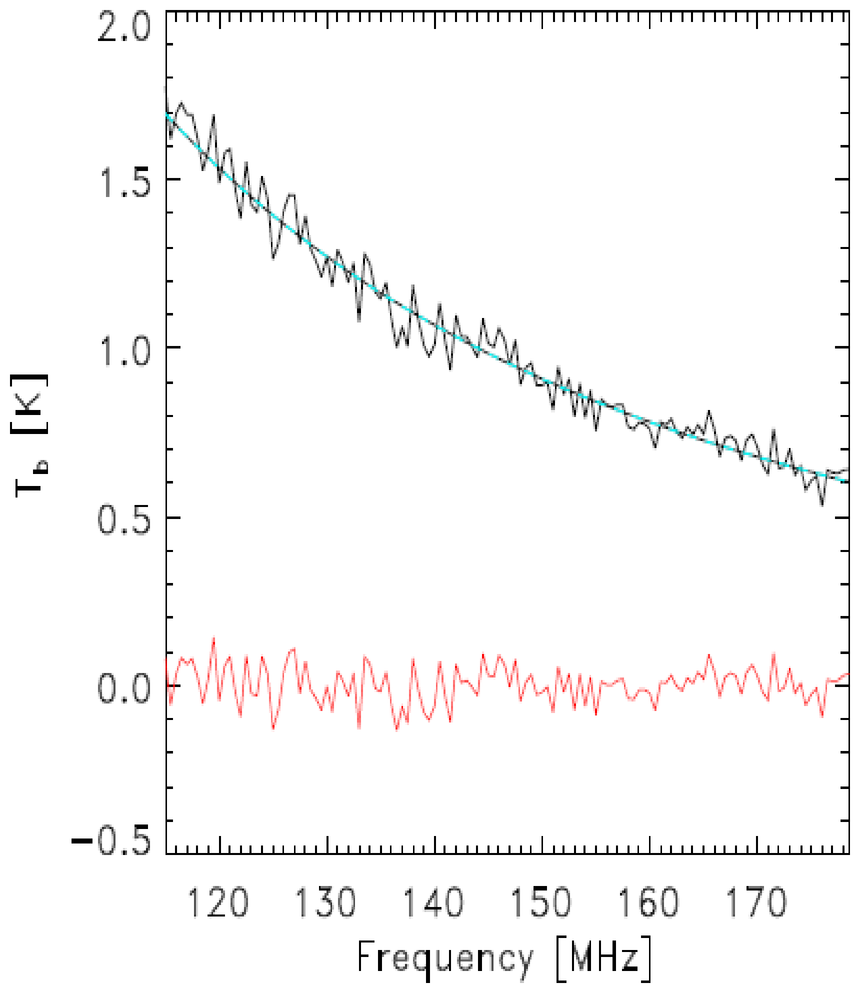


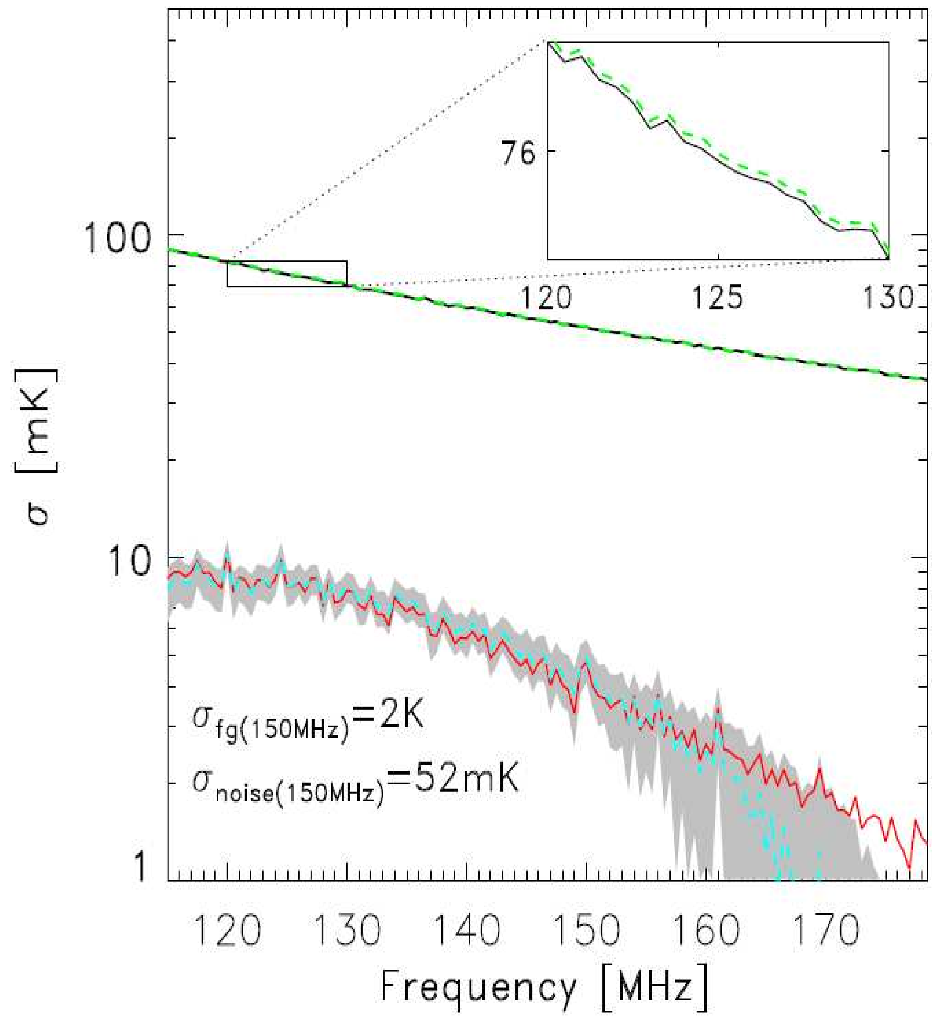
Quasars

Stars

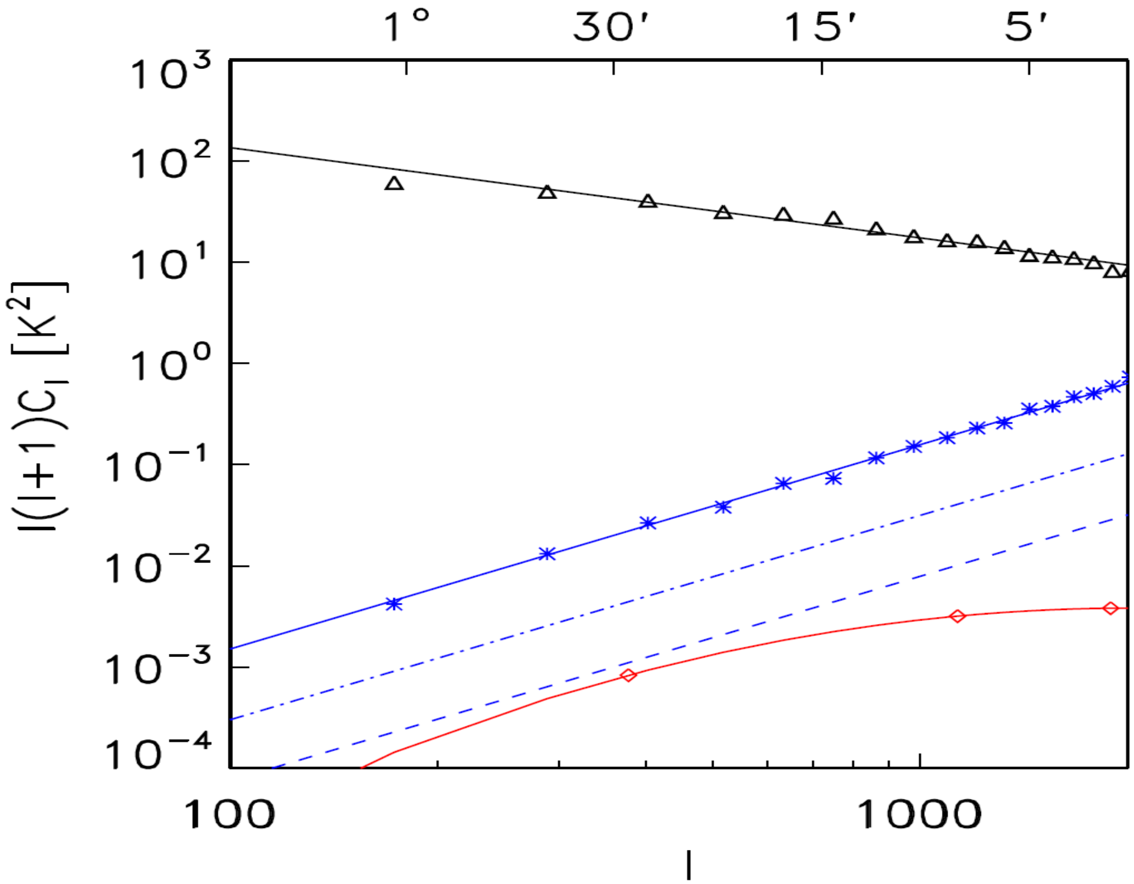
Thomas et al. 2008
Thomas & Zaroubi 2008

The extraction without Calibration errors





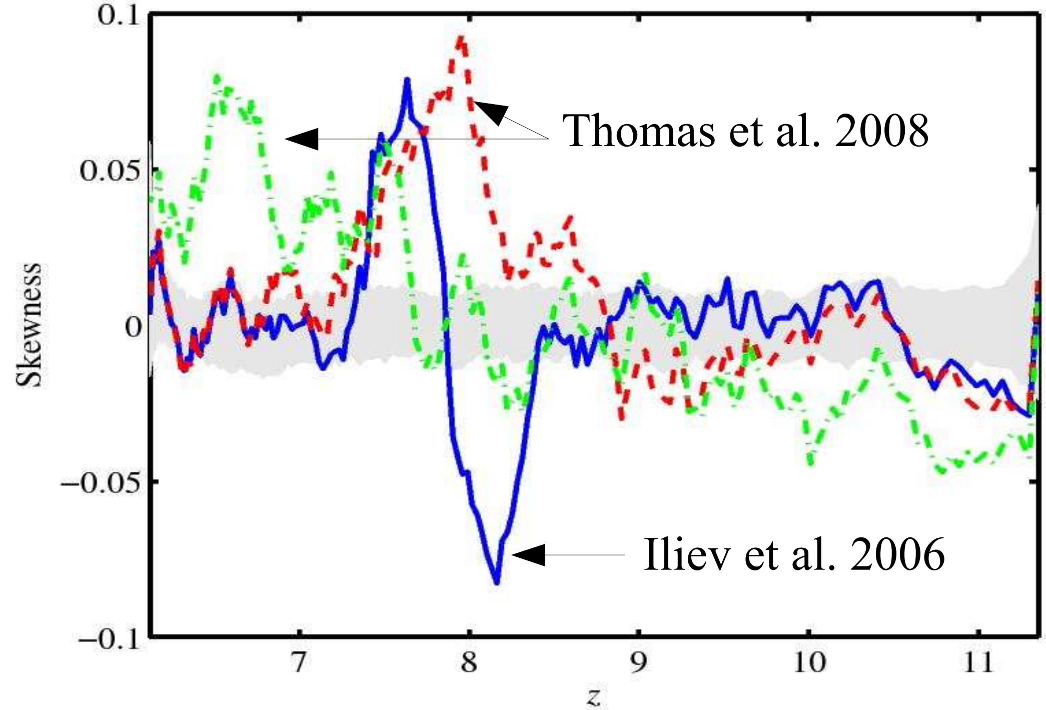
Power spectra of various contributions



Jelic at el. 2008
Santos et al.2006

Extraction through the skewness

$$\delta T_b \approx 28\mathrm{mK}\,(1+\delta)x_{HI}\frac{T_s - T_{CMB}}{T_s}\frac{\Omega_b h^2}{0.02}\left[\frac{0.24}{\Omega_m}\left(\frac{1+z}{10}\right)\right]^{\frac{1}{2}}$$



Harker et al.
in prep.
(See poster)

Summary

- High sensitivity data in the frequency range 115-190MHz will be available in the near future.
- Calibrating the data is essential in order to reach a dynamical range of 10^6. This calibration constitutes a very challenging inversion problem.
- Extracting the high z 21 cm signal requires very sophisticated component separation algorithms