GNILC: extracting the 21 cm signal in the presence of bright foregrounds.

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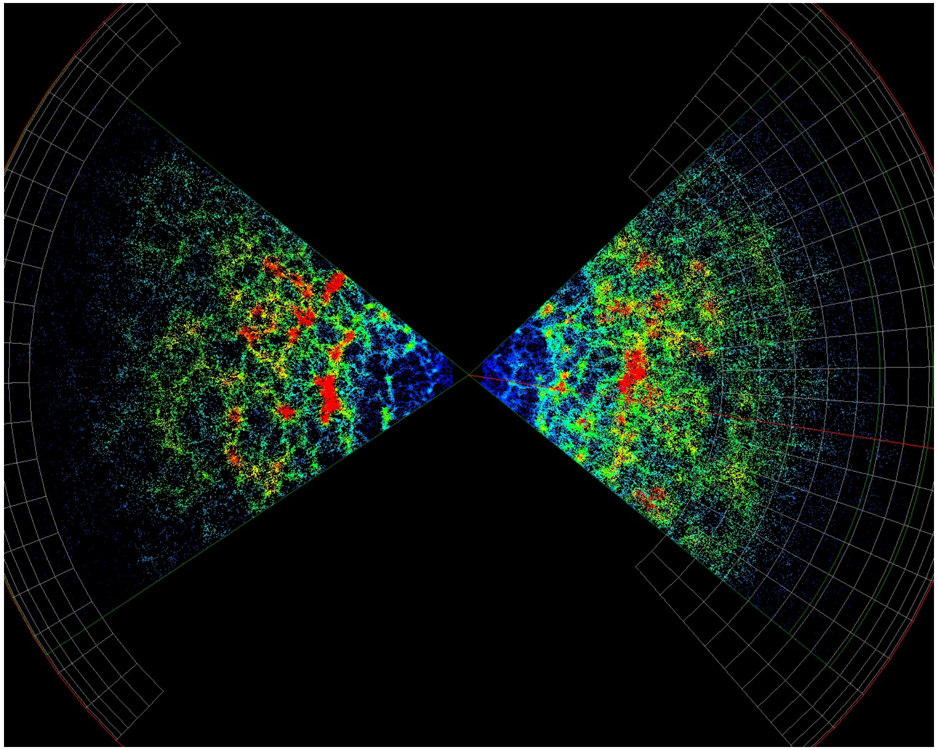
In collaboration with M. Remazeilles and C. Dickinson
(MNRAS, 2016, 456 (3), 2749-2765)

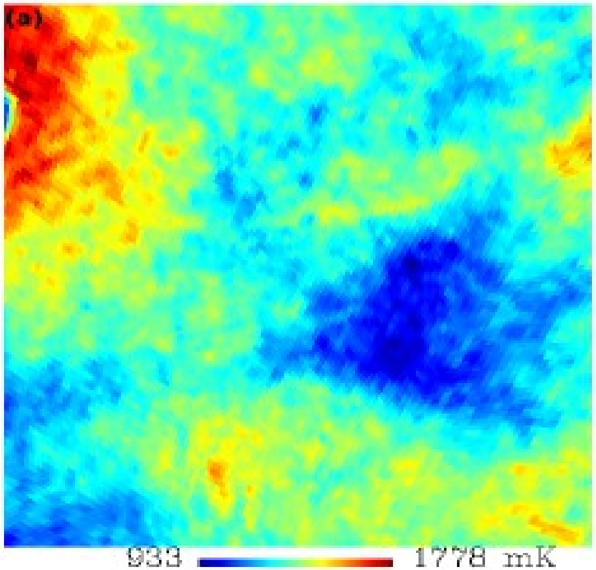
JBCA – University of Manchester **50th Rencontres de Moriond**

HI Intensity Mapping

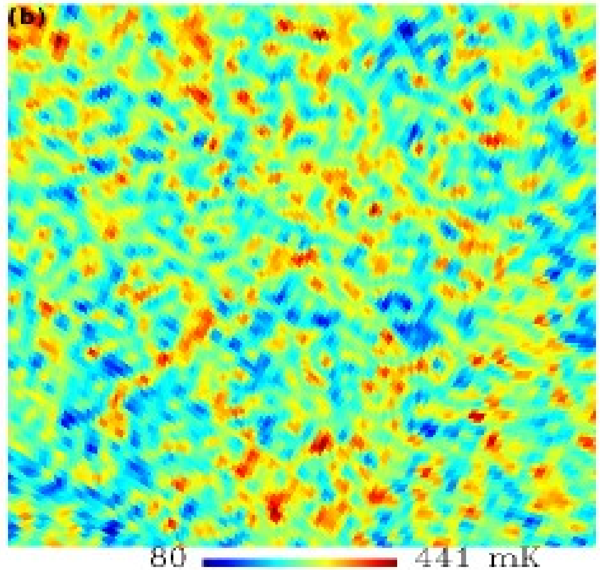
- HI IM: **fluctuations** in the intensity of the **21 cm** spectral line of **neutral hydrogen** emitted by a number of **unresolved objects**.
- HI IM advantage: a **large sky volume** in a relatively short observing time.



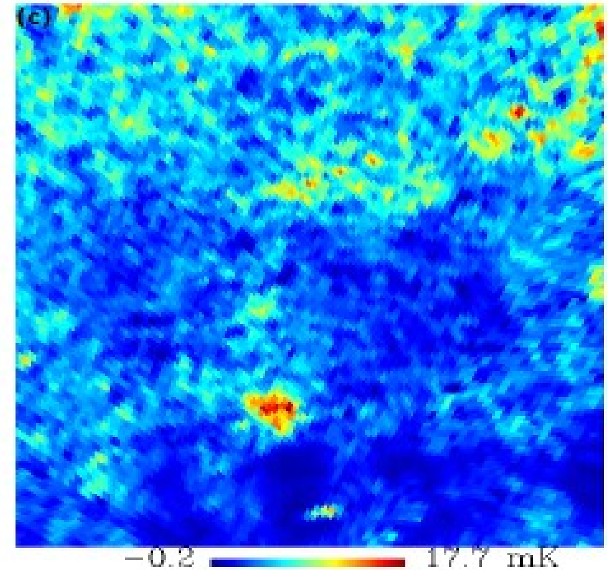
Challenges: Foregrounds



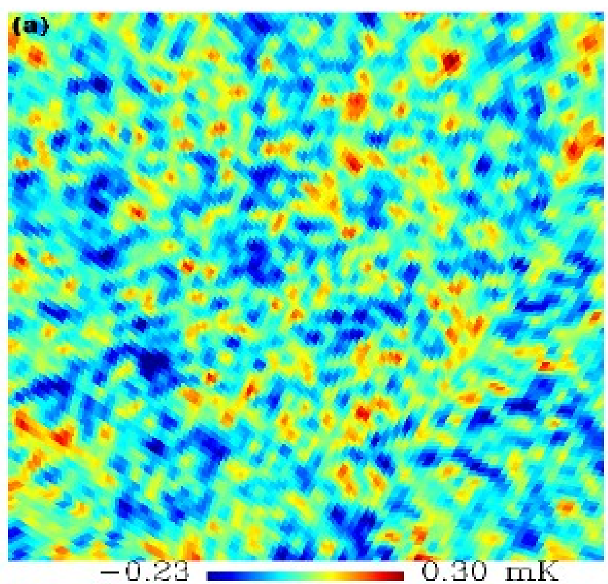
Synchrotron



Point Sources

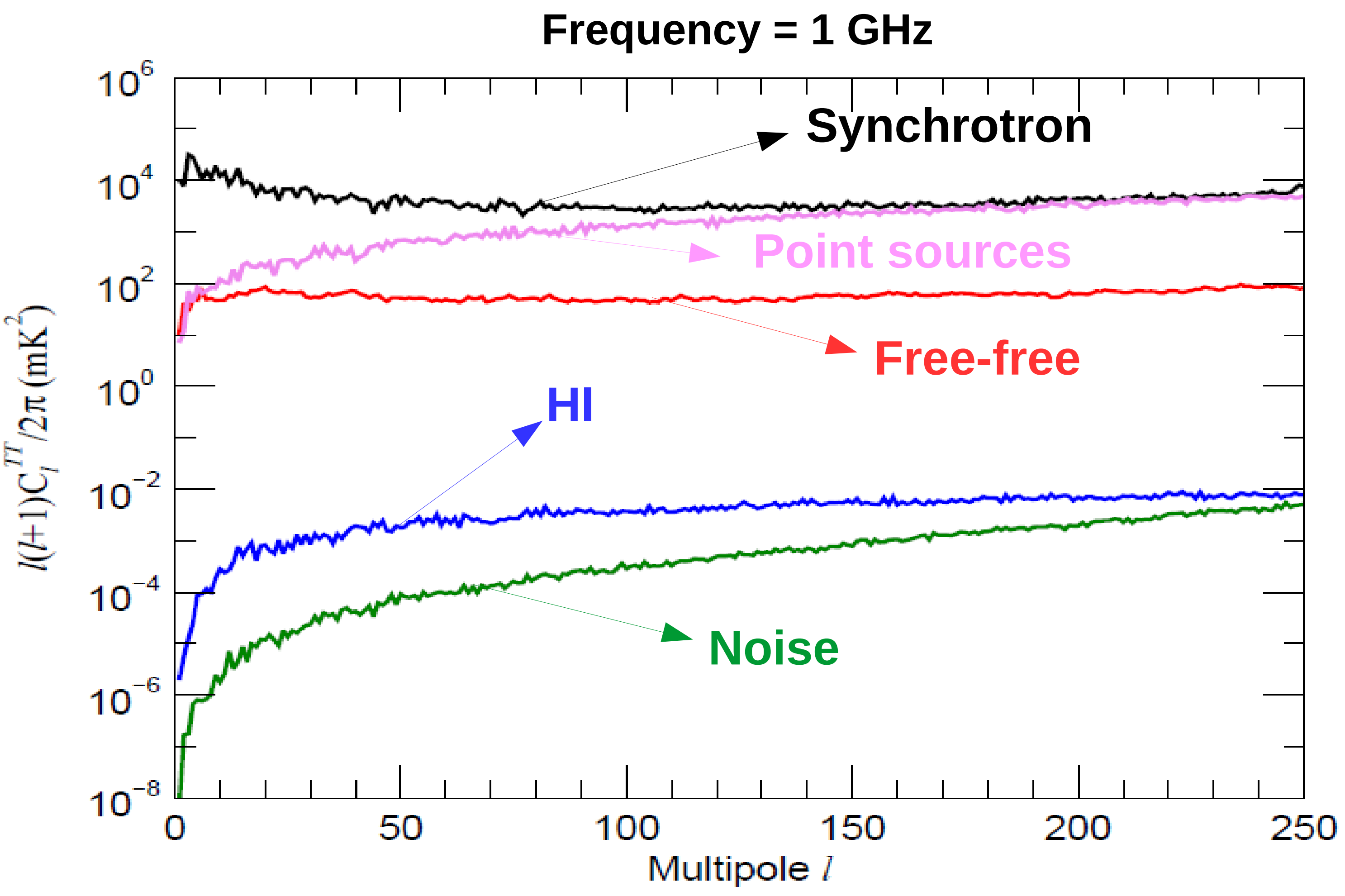


Free-free



→ **HI**

Challenges: Foregrounds

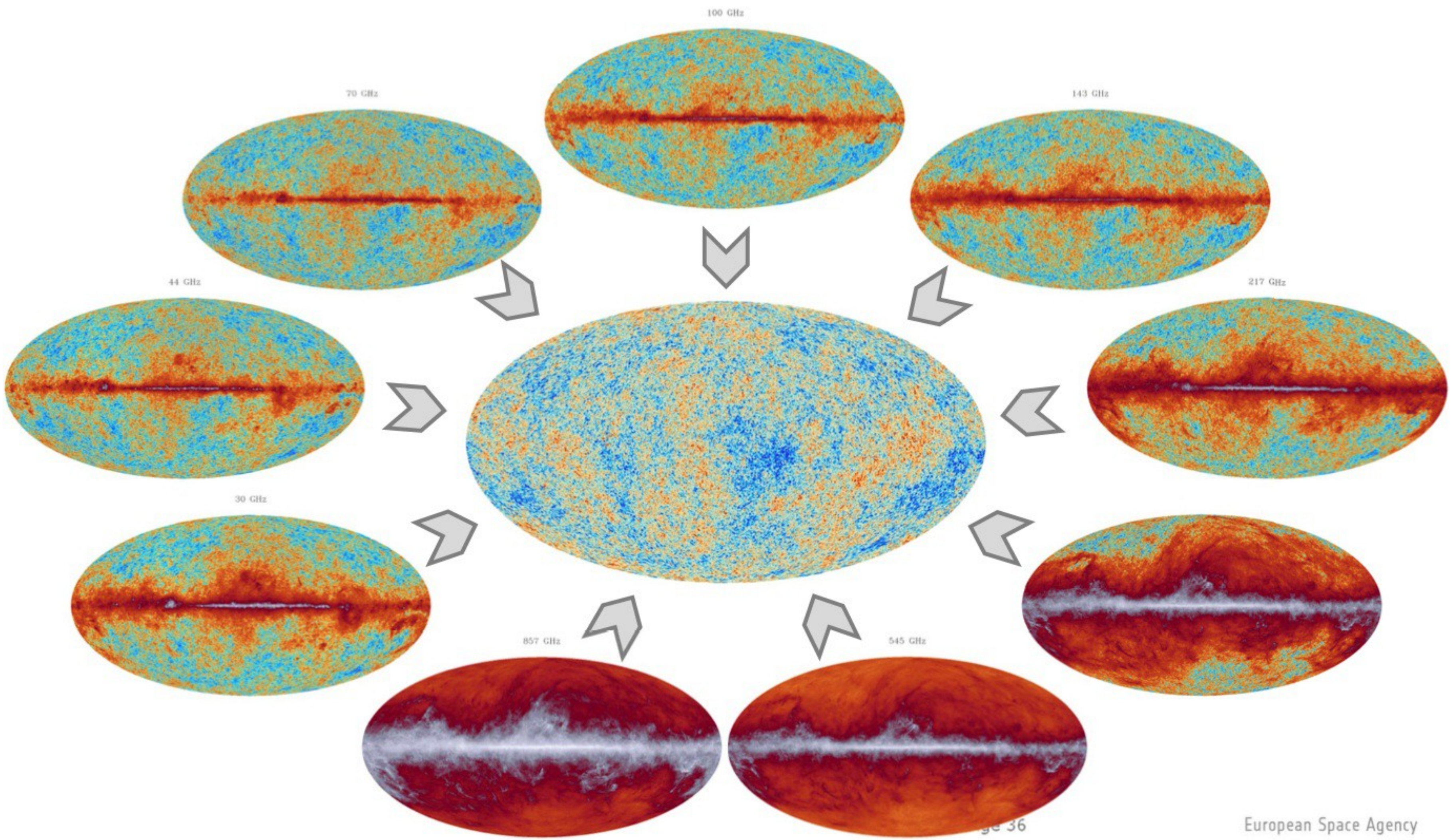


Challenges: Systematics

- Thermal noise: ~ 0.1 mK;
- 1/f noise: ~ 10 mK;
- Gain variations: frequency spectrum no longer smooth;
- Beam effects: it can have the same magnitude of the HI signal – again structure on frequency;
- Cross polarization;
- Standing waves;
- RFI.
- And much more...

Component Separation

CMB: similar challenges – General idea: frequency information



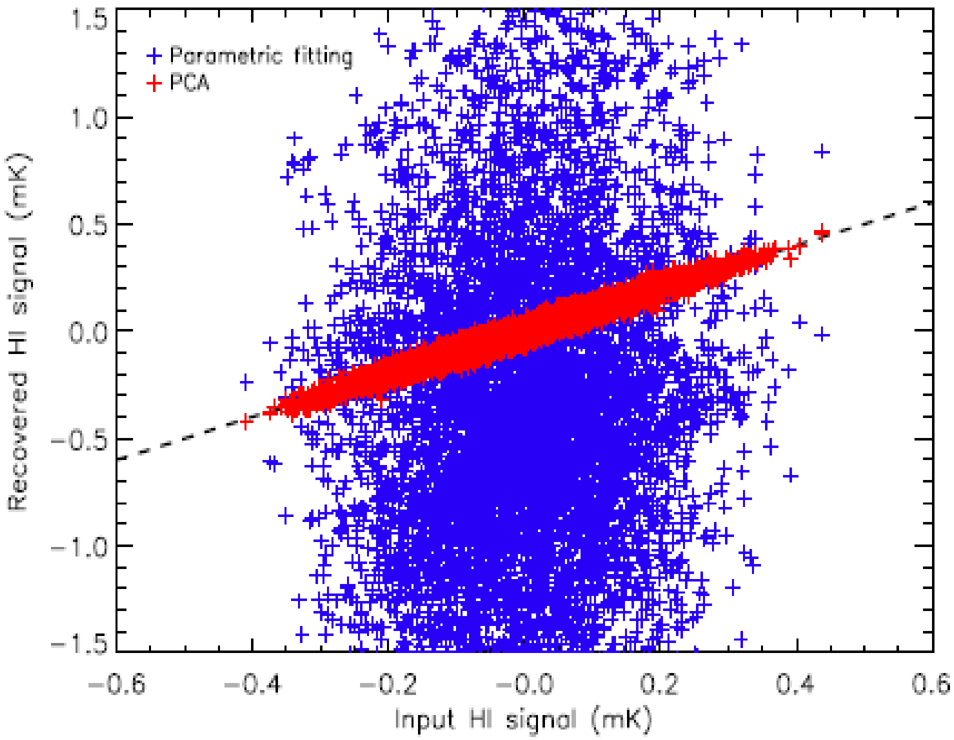
(Planck Collaboration, 2014)

Component Separation

- Data model: $d_\nu = x_\nu + n_\nu$
- Sky emission, x_ν, is a superposition of components: $x_\nu = A_{\nu c}\, s_c$
- Estimate the mixing matrix $A_{\nu c}$ and use its inverse to separate the components
- What does components mean?
  - **Degrees of freedom** that are needed to describe each signal in the data (not necessarily one emission, one component)

Component Separation

- Parametric:
  - Parametric fitting (Bigot-Sazy et al. 2015);



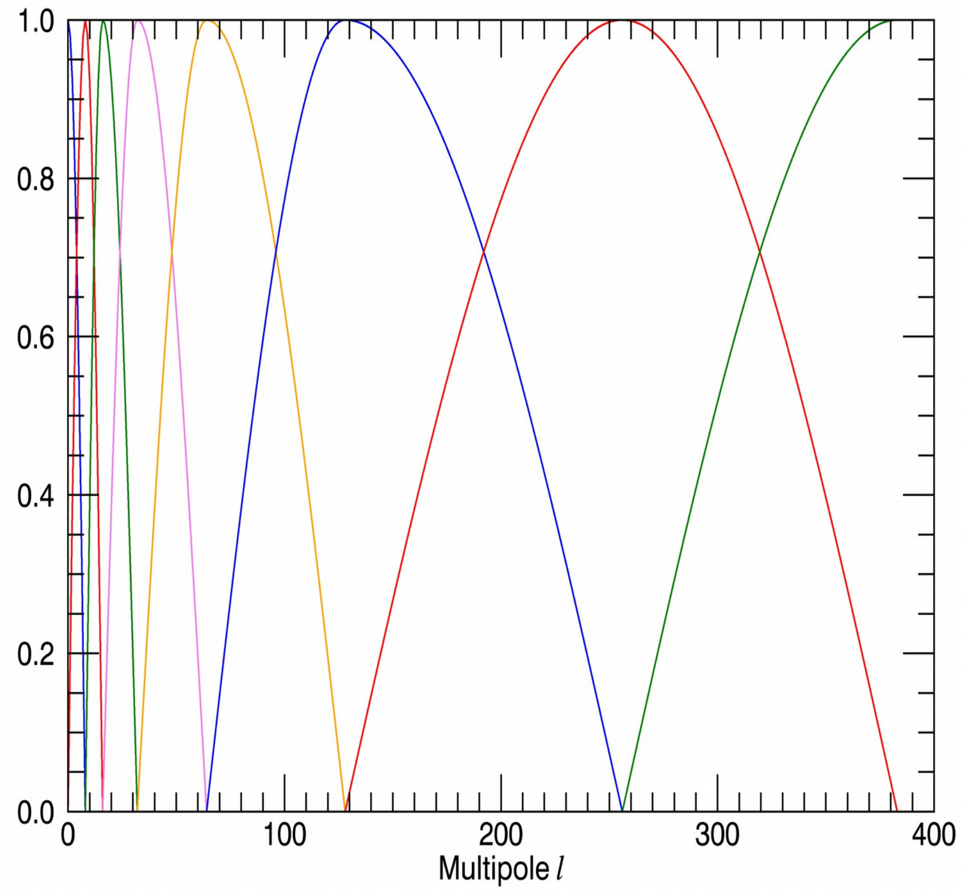
- Non-parametric:
  - PCA (Masui et al. 2013);
  - ICA (Alonso et al. 2015);
  - GMCA (Chapman et al. 2013);
  - **GNILC** (Olivari et al. 2016).

GNILC

- Generalized Needlet Internal Linear Combination (Remazeilles et al. 2011)
- Uses both *frequency* **and** *spatial* information
- ILC: weight matrix that offers **unit response** to the desired component (**HI**) while it **minimizes the total variance** of the other components

GNILC

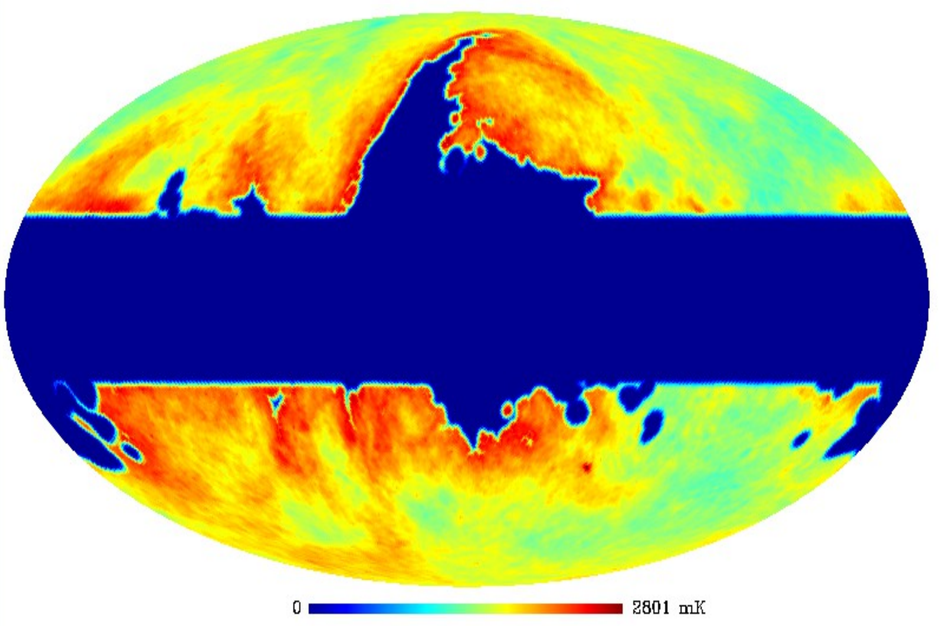
- Wavelet decomposition of the frequency maps;
- Using a prior on the HI signal: estimate the **local signal-to-noise** ratio and perform a PCA;
- PCA determines the effective **dimension of the HI subspace**;
- PCA is calculated pixel by pixel.



Wavelets decomposition: one channel, several wavelet maps (local in multipoles)

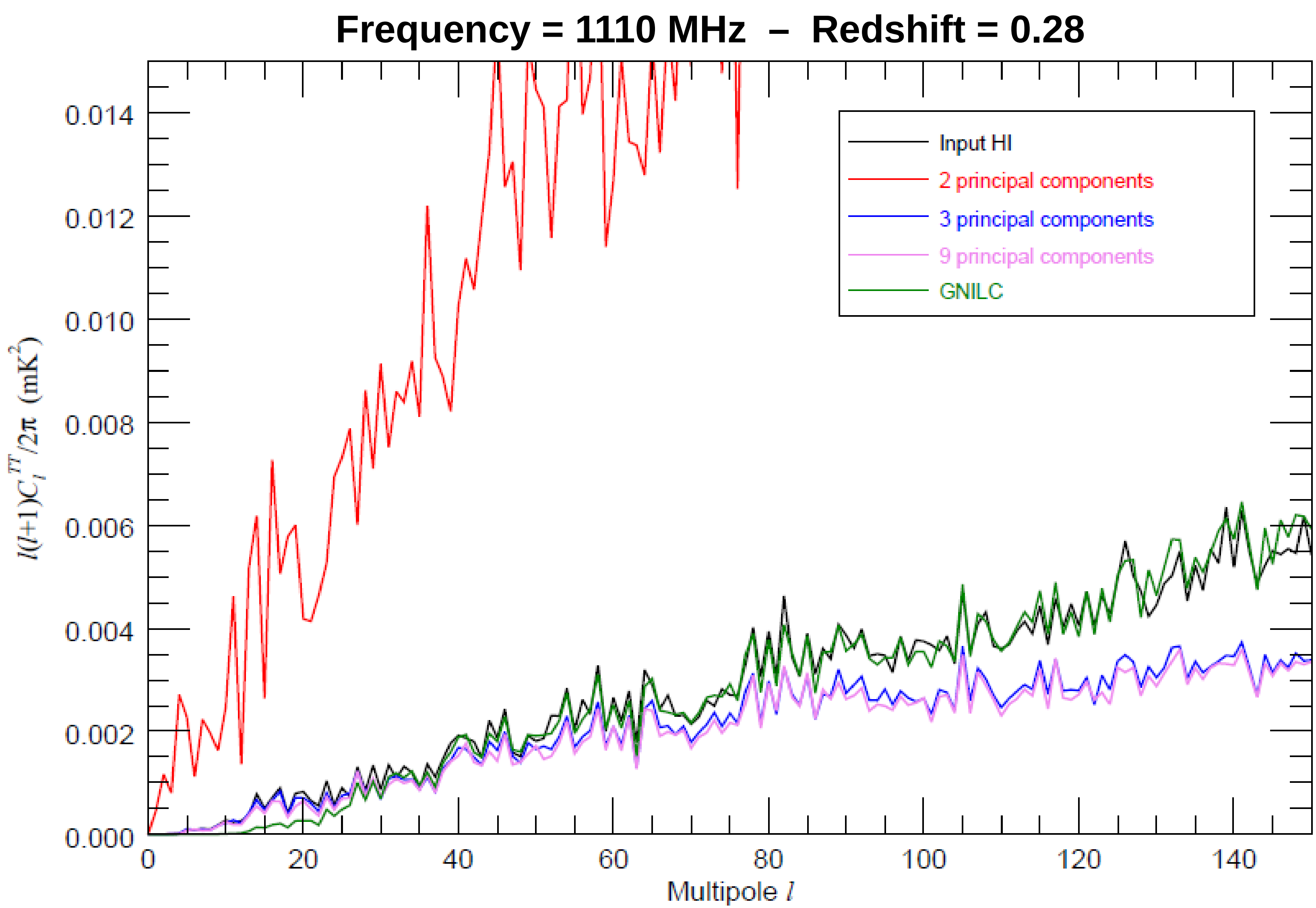
Simulation

- BINGO-like experiment: 960–1260 MHz;
- HI IM at low redshifts
- 40 channels;
- HI + **synchrotron** (variable spectral index) + **free-free** + **point sources** (Poisson and clustering) + thermal noise (0.05 mK per pixel).

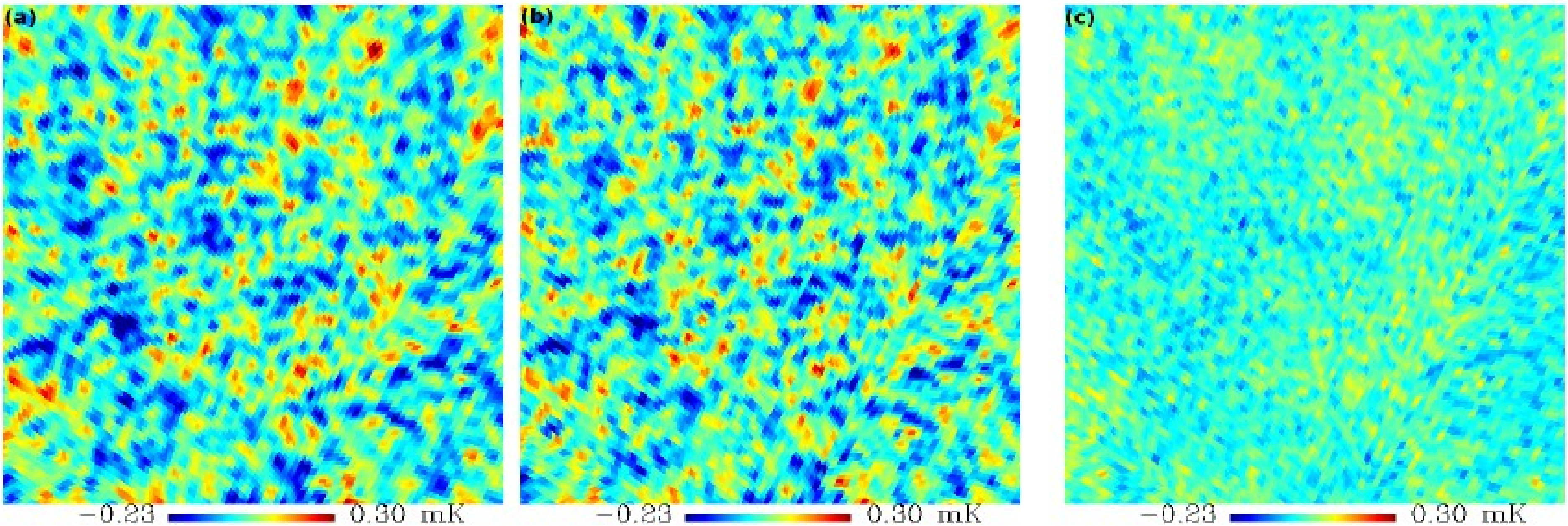


Observed sky with a Galactic mask at 1 GHz

GNILC: Results



GNILC: Results



Input HI **GNILC HI** **Residuals: rms 0.04 mK**

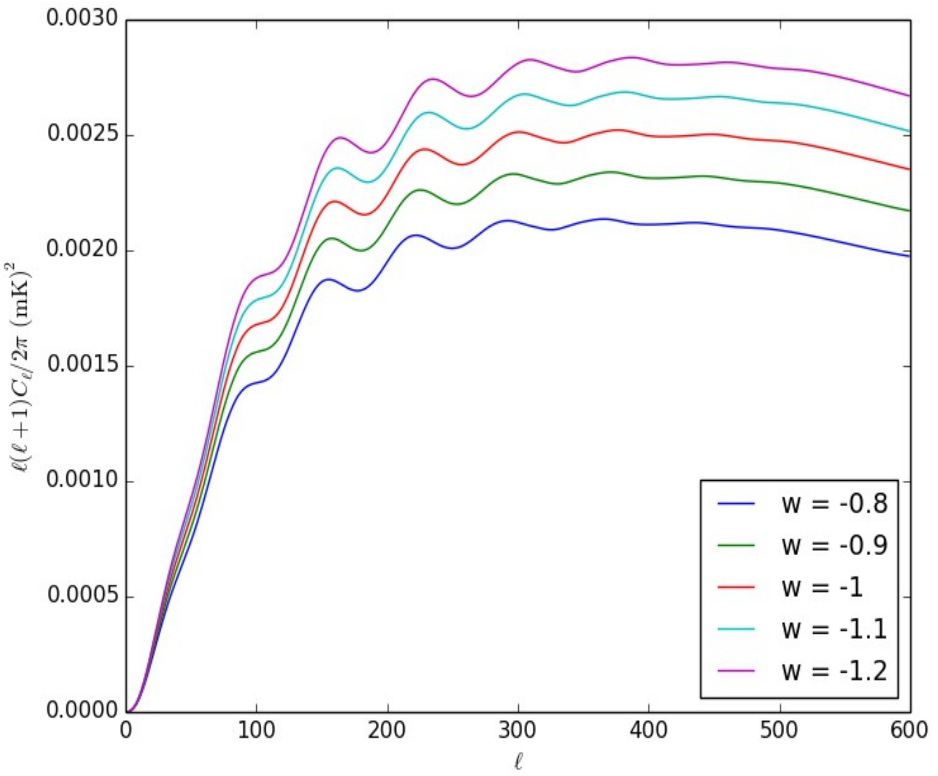
Cosmology

- CMB-like likelihood for HI IM (Verde et al. 2003):

$$\ln \mathcal{L}_i = -\frac{1}{2}\sum_{\ell}(2\ell+1)\left[\ln\left(\frac{C_\ell^{\rm th}+\mathcal{N}_\ell}{C_\ell^{\rm rec}}\right)+\frac{C_\ell^{\rm rec}}{C_\ell^{\rm th}+\mathcal{N}_\ell}-1\right]$$

$$\ln \mathcal{L} = \sum_i \ln \mathcal{L}_i$$

Information beyond BAOs – **full shape of the power spectrum**.



Cosmology

- 6 CDM parameters: A_S, n_s, $\Omega_b h^2$, $\Omega_c h^2$, h, τ;
- 2 extra parameters: w, $b_{HI}\Omega_{HI}$;
- BINGO-like experiment (multipole range: from 25 to 250) + Planck (13);
- Planck flat priors;
- MCMC with CosmoSIS (Zuntz et al. 2014).

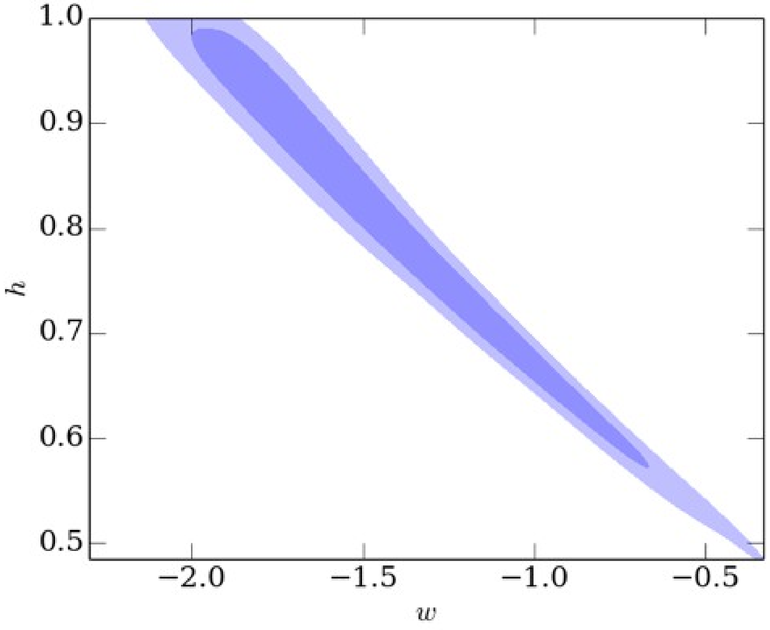
Cosmology

Parameter	Planck (13)	Planck (13) + HI IM
$\Omega_c h^2$	0.1199 ± 0.0027	0.1371 ± 0.0022
$\Omega_b h^2$	0.0212 ± 0.00022	0.0203 ± 0.00022
h	0.711 ± 0.012	0.588 ± 0.009
τ	0.088 ± 0.014	0.075 ± 0.012
10^9 As	2.181 ± 0.060	2.123 ± 0.060
n_s	0.9617 ± 0.0063	0.9039 ± 0.0047
w	**-1.44 ± 0.39**	**-0.978 ± 0.068**

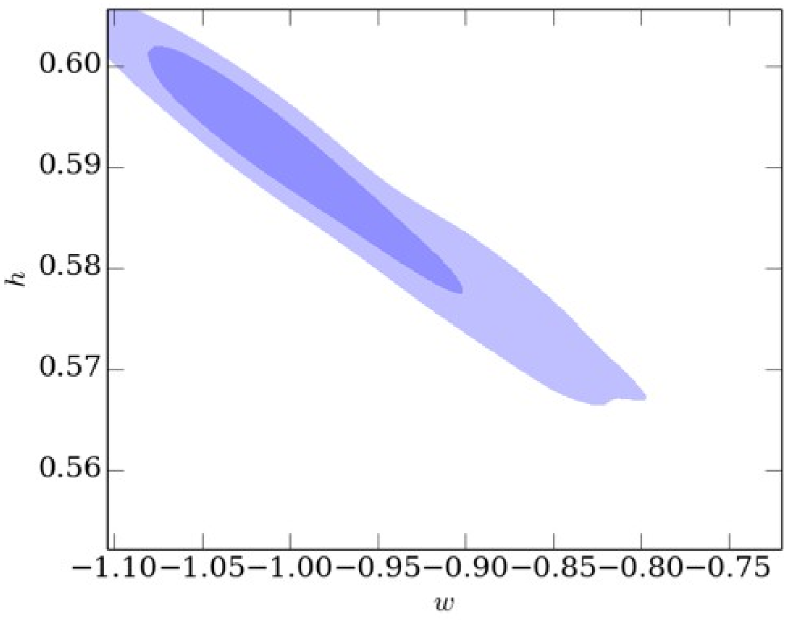
Work in progress: very preliminary results

Cosmology

Reducing the degeneracy between *w* and *h*:



Planck (13)



Planck (13) + HI IM

Conclusions

- Foregrounds and systematics: **major challenges** to reconstruct the HI signal;
- GNILC: new component separation method that uses both **spatial and frequency** information. GNILC can also be used for high redshift 21 cm cosmology (EoR) and CO IM;
- Cosmology with HI IM: can **break the degeneracy** between ***w*** and ***h***. Moreover: neutrinos, non-Gaussianity, modified gravity...