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Intensity Mapping Foreground Cleaning with GNILC

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IAU Symposium 333

Component Separation

In radio astronomy, observations of the sky are a **mixture** of:

- cosmological signals;
- astrophysical sources;
- instrumental or local signals.

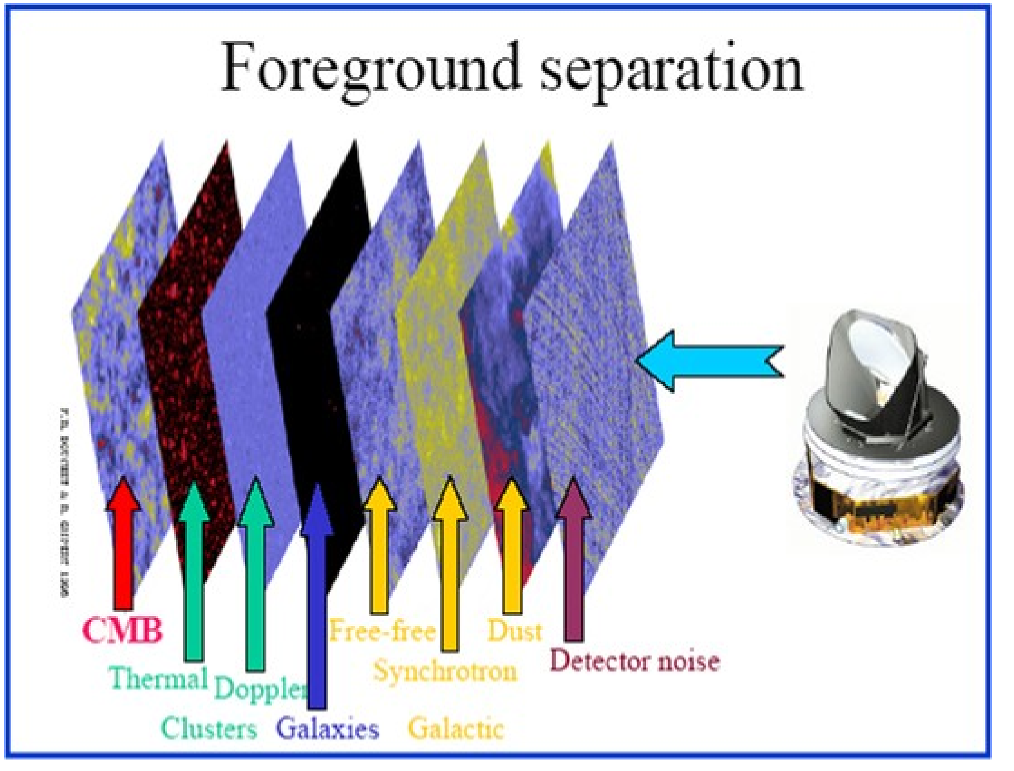
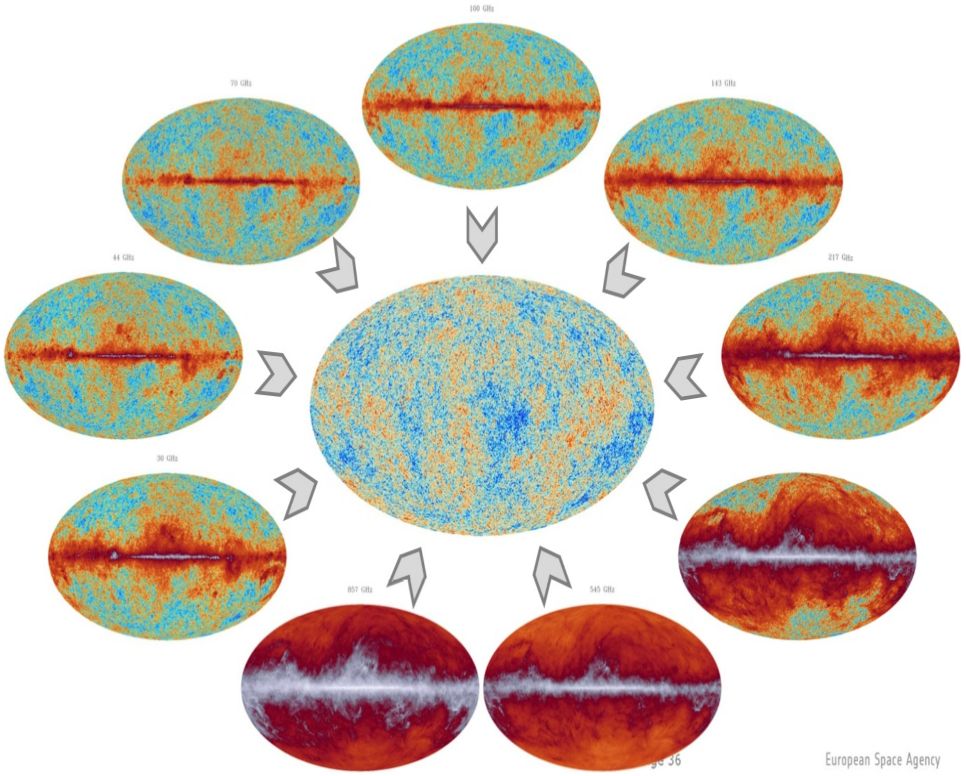


Image courtesy of F. Bouchet

Component Separation

What is it?

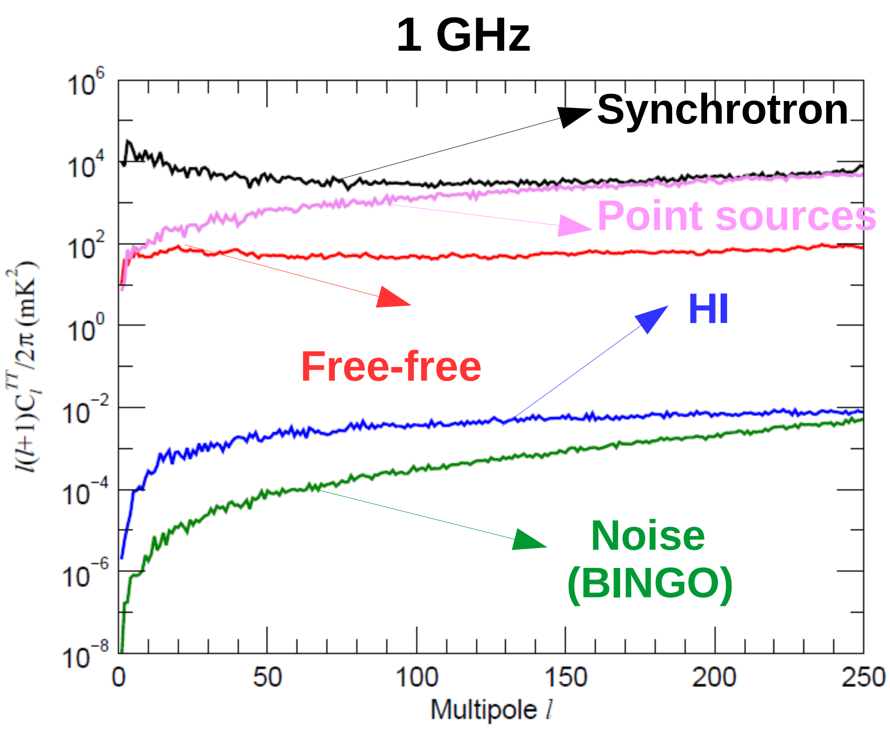
– Any attempt to **disentangle emissions** by exploiting **correlations in frequencies**, external constraints and physical models of the different sources of emission.

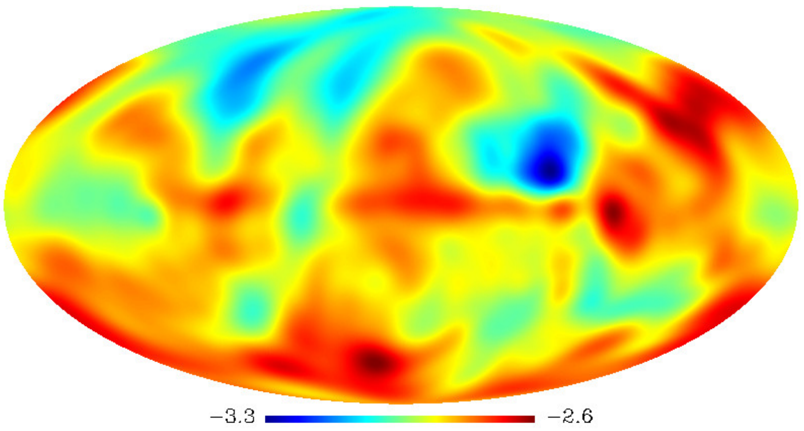


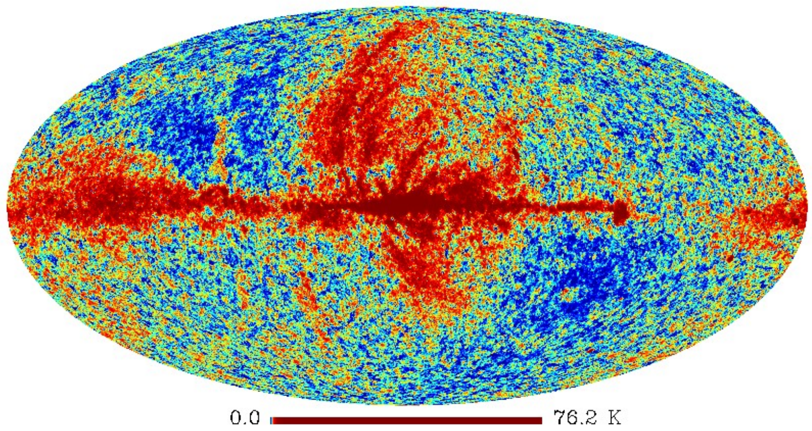
Planck Collaboration, 2014

CMB: relatively easy – same map for every frequency

Foregrounds



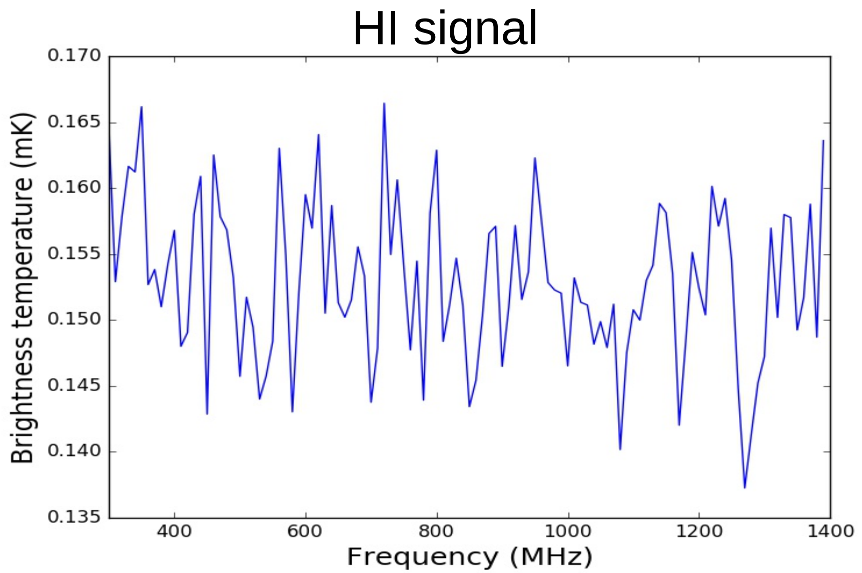


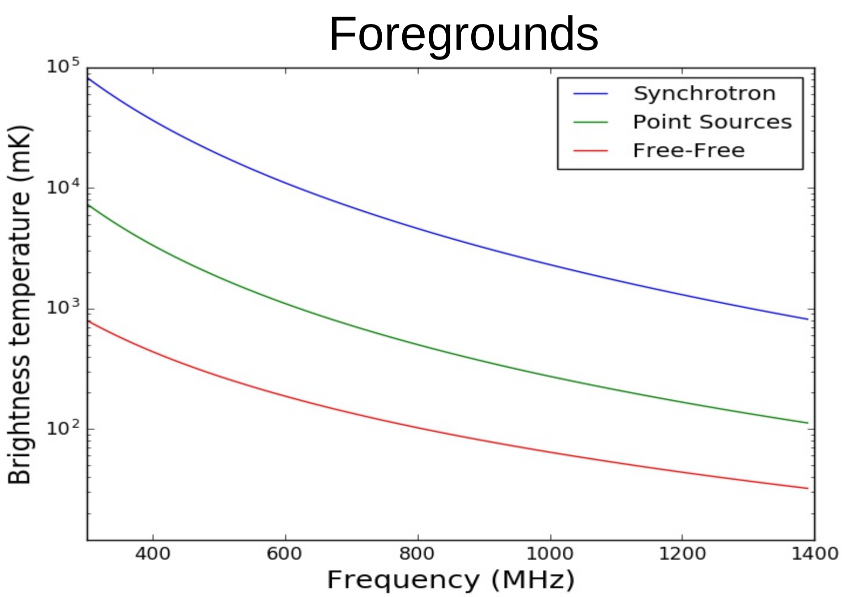


Spatially varying spectral index,
high polarization of synchrotron, etc...

Systematics

- **Examples**:
  - 1/f noise;
  - Gain variations;
  - Beam effects;
  - Cross polarization;
  - Standing waves;
  - RFI.
- **Main effect: frequency spectrum no longer smooth – extra degrees of freedom added to the problem.**





GNILC

Generalized Needlet Internal Linear Combination (GNILC)

- Developed by *Remazeilles et al. (2011)* in the CMB context.
- Adapted to be used in the 21 cm context by *Olivari et al. (2016)*.

GNILC versatility:

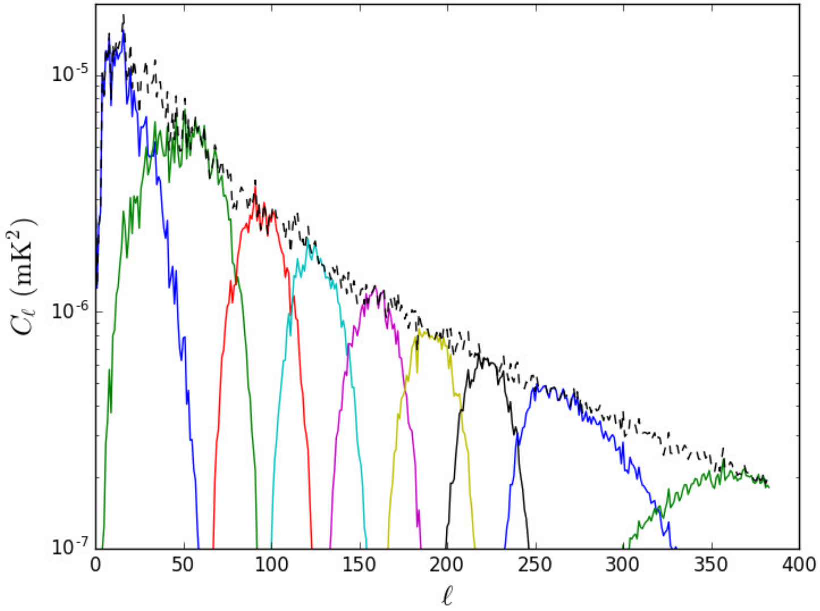
- *Planck* real data: CMB vs CIB vs Thermal Dust (Planck Collaboration XLVIII, 2016);
- Simulation: HI IM;
- Simulation: CO IM;
- Potential: CMB B-modes, EoR, etc.

GNILC: Rationale

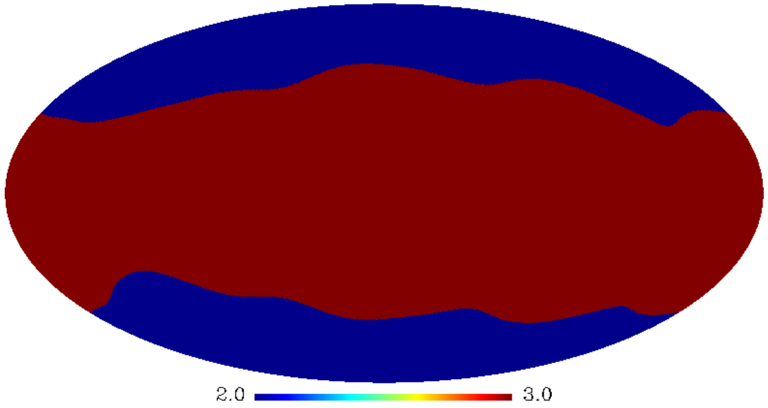
- First, using the **local ratio** between the **wanted signal** and the **total signal,** a **PCA** of the observed data is be done.
  - This gives us the **effective dimension (in frequency space) of the wanted signal subspace**.
  - The choice of this dimension is done with the help of the **Akaike Information Criterion**.
- Second, a multimensional ILC filter is performed **within the wanted signal subspace**.
  - This makes, by construction, the **foreground residual to be sub-dominant to the wanted signal** in the final maps**.**

GNILC: Rationale

Number of principal components: estimated **locally both in space and in angular scale** by using a wavelet (needlet) decomposition.



One for each wavelet



IM at Low Redshifts

- HI IM: BINGO experiment
  - Single-dish;
  - Site: Brazil;
  - Main goal: to detect BAO and HI PS in the radio.
- CO IM: COMAP experiment
  - Single-dish;
  - Site: USA;
  - Main goal: to study spatial distribution of the star formation in the Universe.

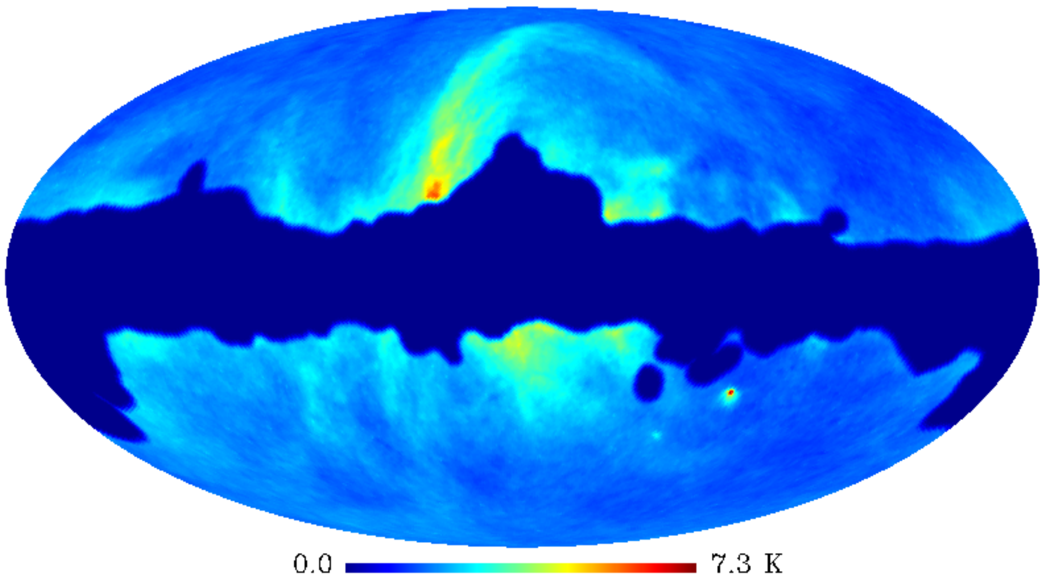
BINGO Simulation

Fictitious (almost) full-sky BINGO experiment:

- To not be strongly dependent on BINGO specifications;
- 960-1260 MHz;
- HI IM at low redshifts: 0.13-0.48.

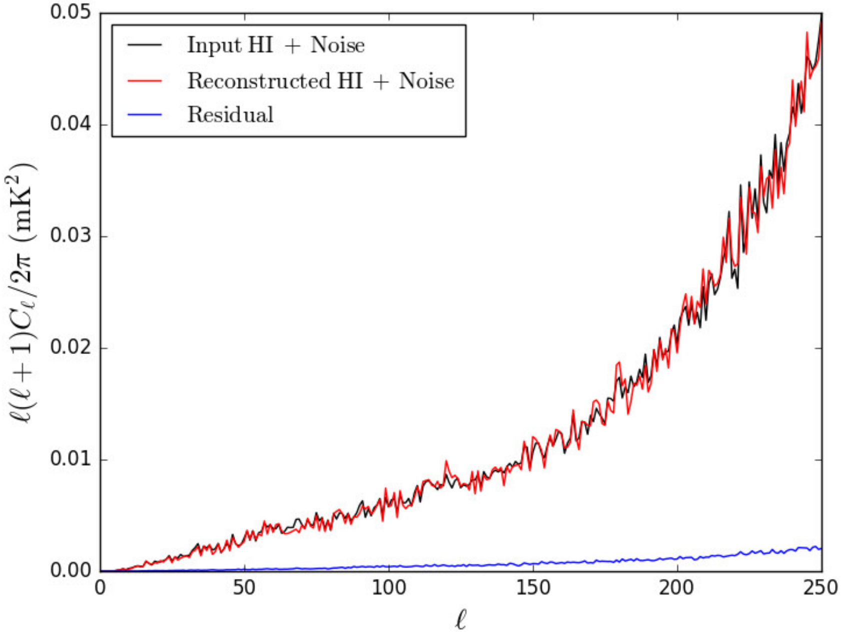
Foregrounds:

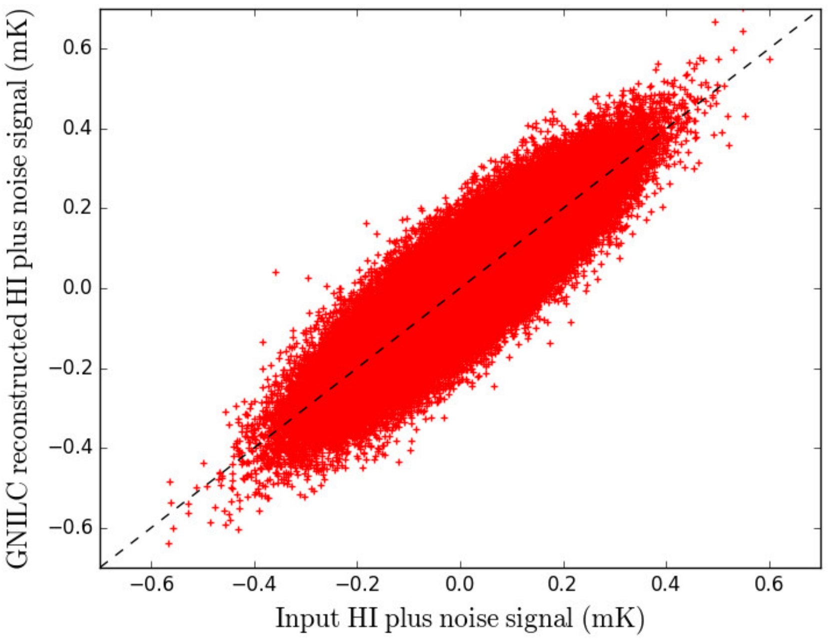
- **Galactic synchrotron and free-free;**
- **Extragalactic point sources.**



GNILC: BINGO

Result for the middle channel of the band





GNILC: BINGO

Relative, N_{GNILC}, and **absolute**, $N_{GNILC,\, abs}$, **normalized difference** between the input power spectra and the reconstructed power spectra of the HI plus noise signal **averaged through frequency and multipole**.

- **Baseline**: N_{GNILC} = –4.0% and $N_{GNILC,\, abs}$ = 7.0%
- **No Galactic mask**: N_{GNILC} = –3.4% and $N_{GNILC,\, abs}$ = 10.1%
- **Standing waves**: N_{GNILC} = –6.7% and $N_{GNILC,\, abs}$ = 8.6%
- **Bandpass calibration error**: N_{GNILC} = –6.6% and $N_{GNILC,\, abs}$ = 8.6%
- **Polarization leakage** (1%): N_{GNILC} = –4.8% and $N_{GNILC,\, abs}$ = 8.1%

Main problem: systematics!

Effects on the Cosmological Parameters

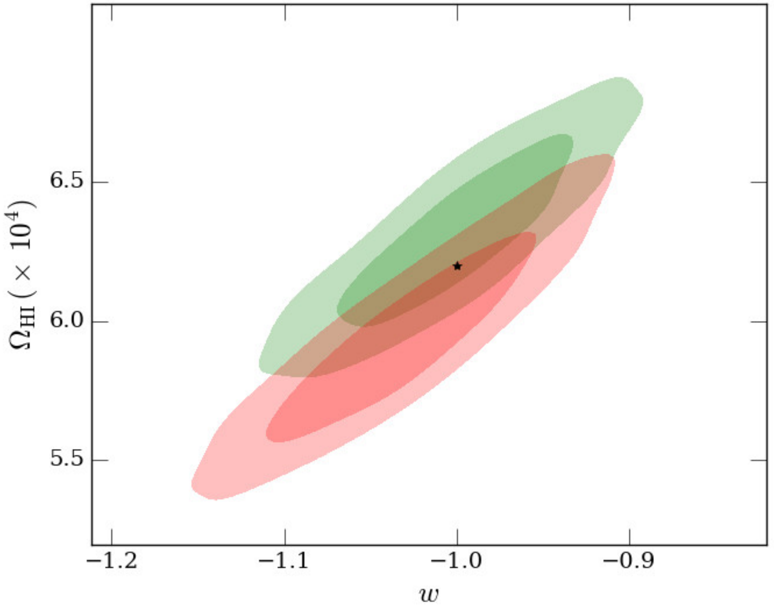
Parameter bias σ: difference between the *Planck* + BINGO mean parameter value and the baseline value divided by the respective standard deviation.

BINGO real sky coverage (~3000 deg^2) – correct cosmic variance

Likelihood: no 'foreground' uncertainty – only shot noise, thermal noise and cosmic variance

Parameters:

- **Ω_b:** σ = 0.00
- **Ω_c:** σ = 0.23
- **h**: σ = 0.82
- **τ:** σ = –0.50
- **n_s**: σ = –0.77
- **A_s**: σ = –0.45
- ***w***: σ = –0.60
- **Ω_{HI}**: σ = –1.56



Olivari et al. 2017

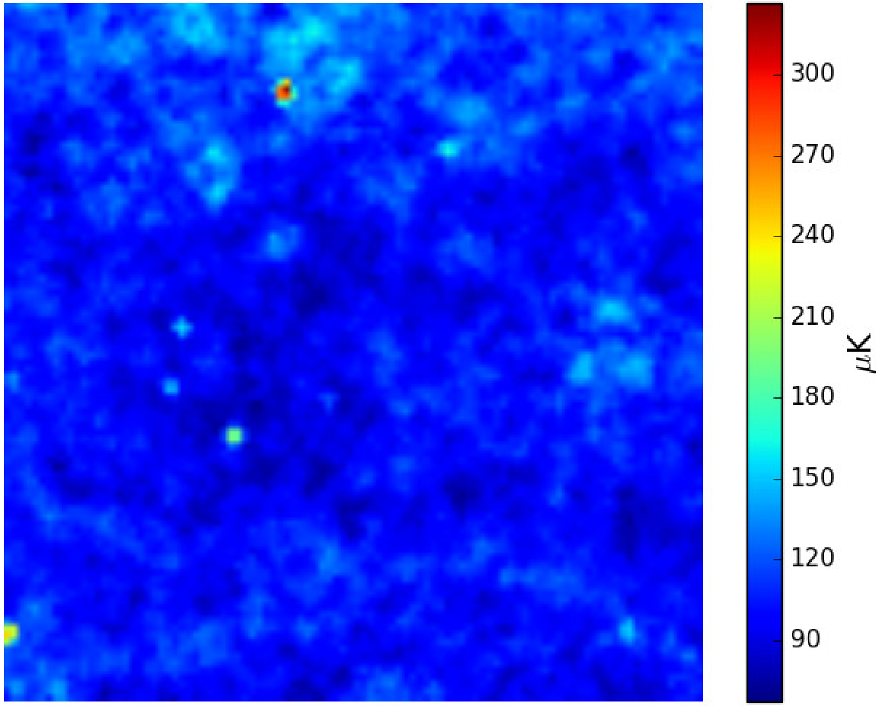
COMAP Simulation

COMAP experiment (phase-2):

- 26–34 GHz;
- CO IM at “medium” redshifts (2.4–3.5).

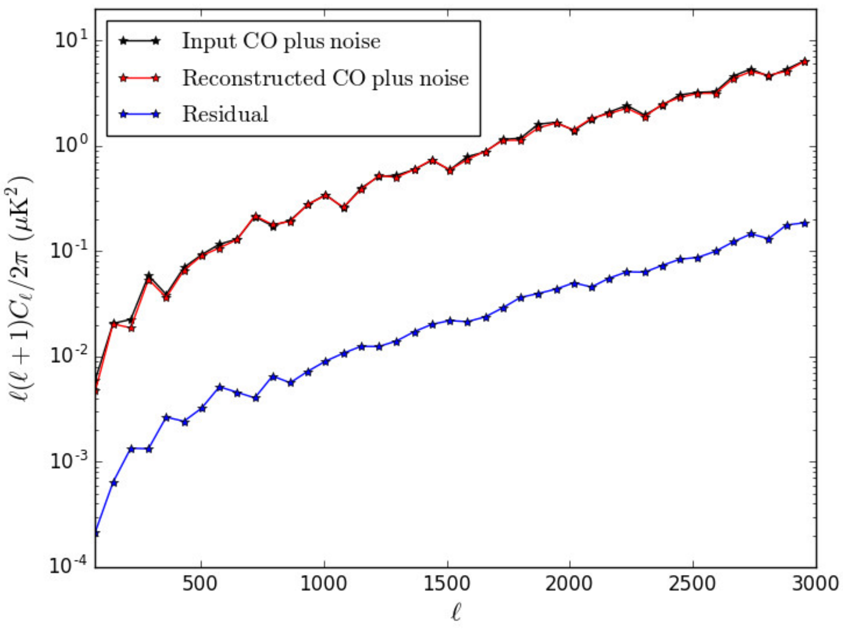
Foregrounds:

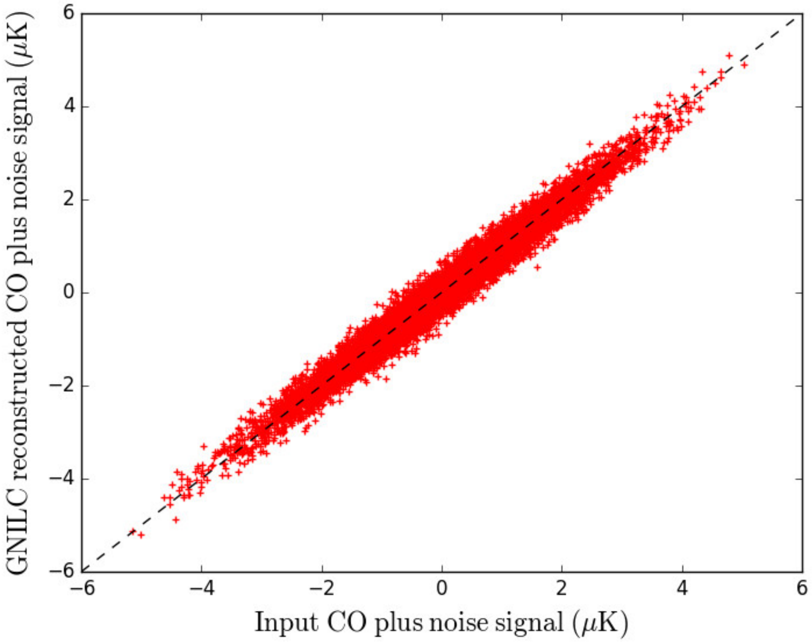
- **Galactic synchrotron, free-free and AME;**
- **Extragalactic point sources.**



Area: 25 deg^2
Resolution: 3 arcmin

GNILC: COMAP



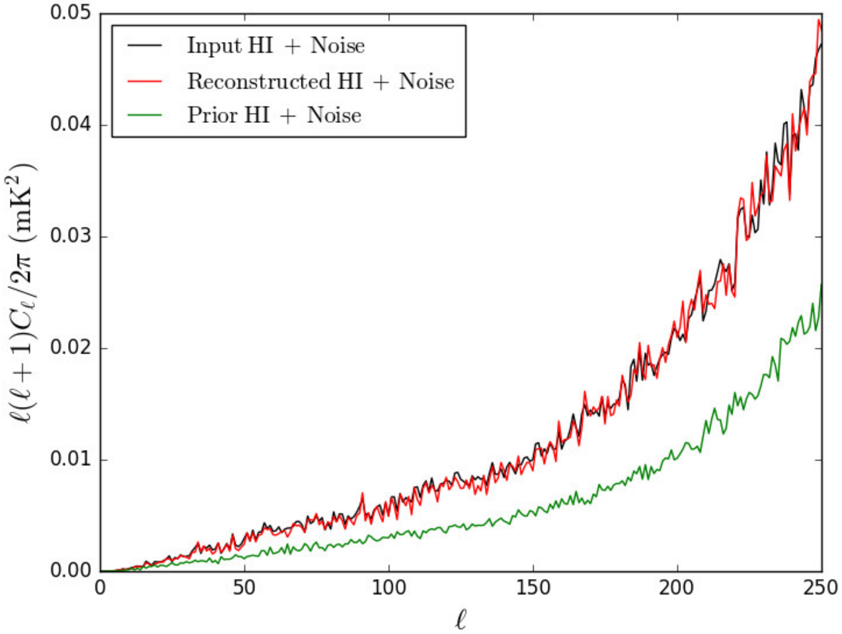


Olivari et al. (in prep)

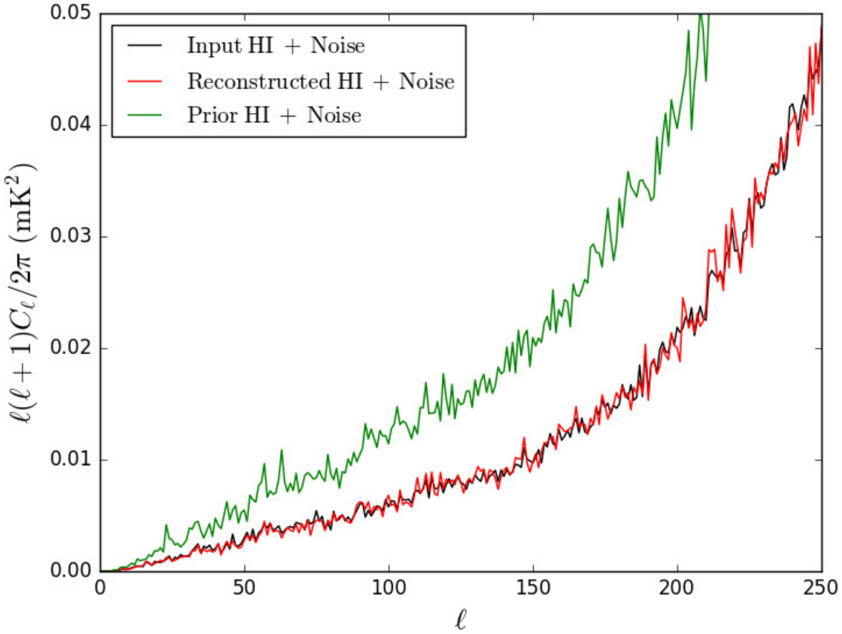
Summary

- GNILC is a versatile method: not only it can work for HI IM but also for CO IM, which is an indicative that it can also work for any type of IM, including EoR.
  - Note that it can use either spherical harmonic transform or Fourier transform, so it is useful for large and small patches of the sky.

Extra: Prior



Input HI + Noise
Reconstructed HI + Noise
Prior HI + Noise
$\ell(\ell+1)C_\ell/2\pi$ (mK^2)
ℓ
0.00
0.01
0.02
0.03
0.04
0.05
0
50
100
150
200
250



Input HI + Noise
Reconstructed HI + Noise
Prior HI + Noise
$\ell(\ell+1)C_\ell/2\pi$ (mK^2)
ℓ
0.00
0.01
0.02
0.03
0.04
0.05
0
50
100
150
200
250