Probing the nature of dark energy and structure growth with 21cm intensity mapping

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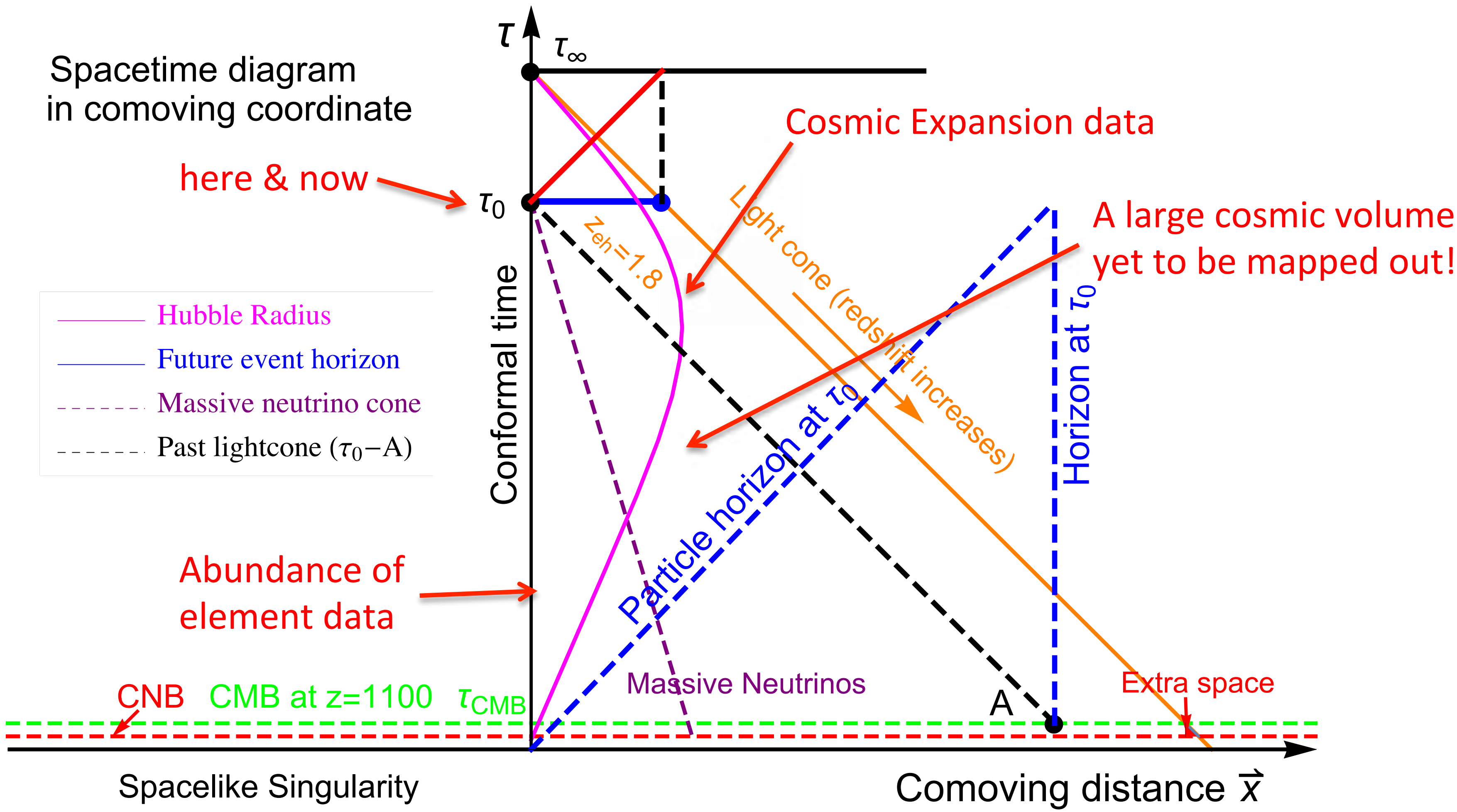
with C. Dickinson, M.-A. Bigot-Sazy, Lucas C. Olivari, R. Battye et al.

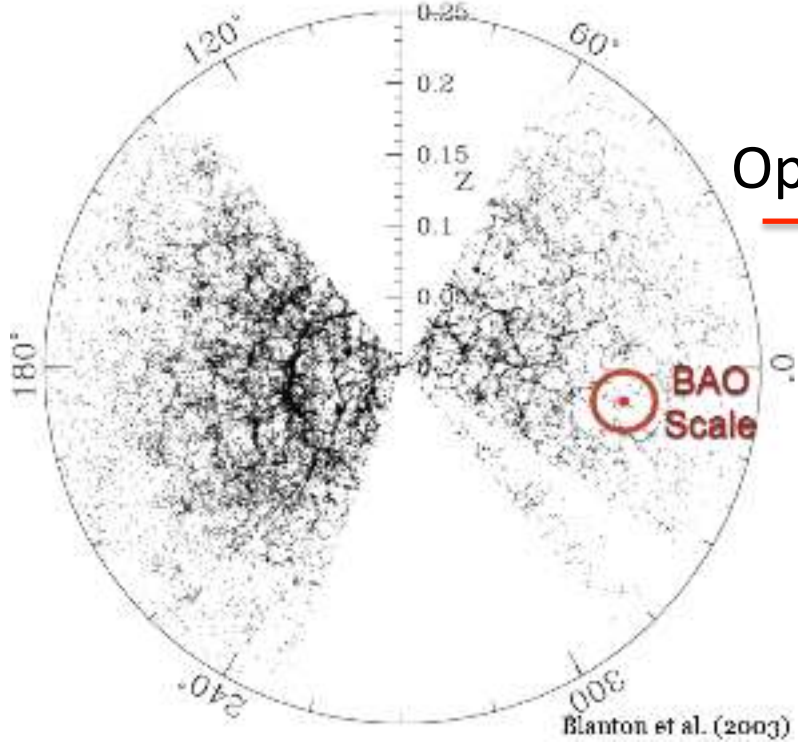
99 per cent of the Cosmology is to measure: (information ascending)

(1) Abundance of the light elements

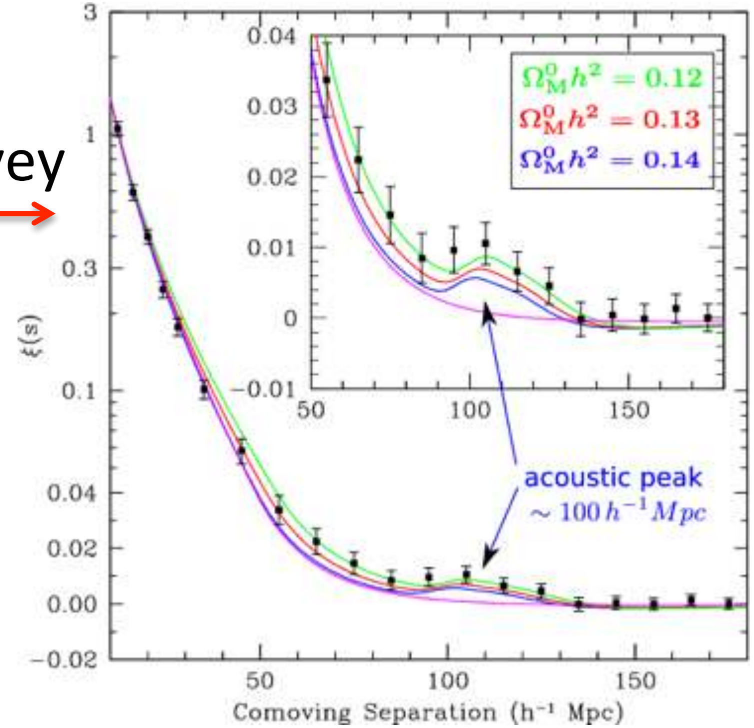
(2) Cosmic Expansion

(3) Growth of perturbations

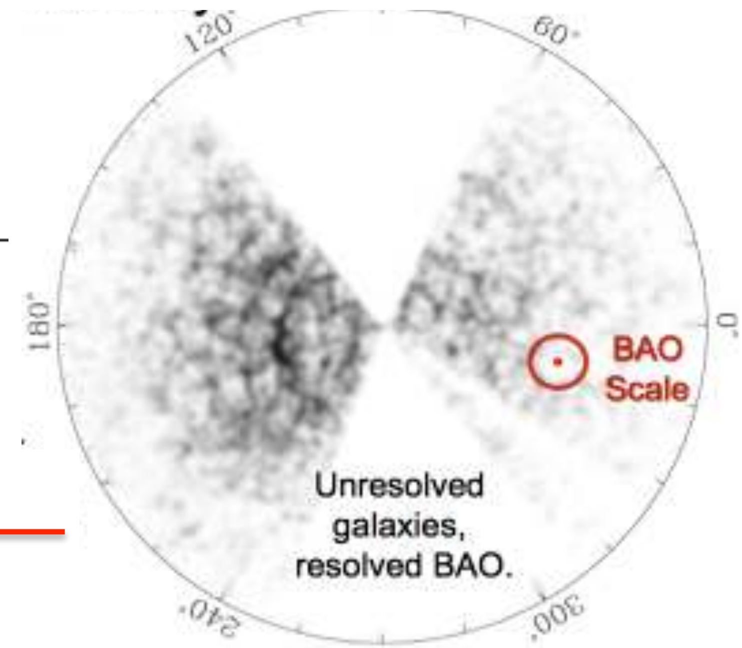




Optical survey



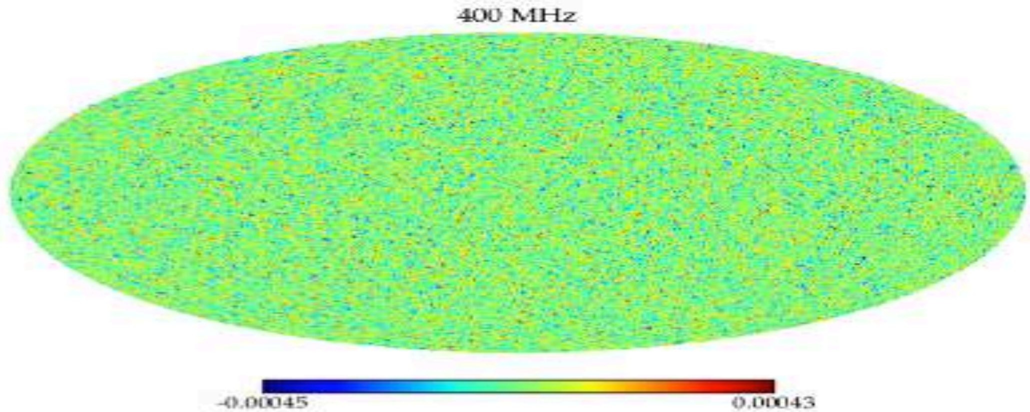
21-cm HI	BINGO (SD)	undetermined	planning	Radio: 960–1260 MHz
	CHIME (IF)	Canada	construction	Radio: 406, 473, 710, 789 MHz
	Tianlai (IF)	China	construction	Radio: 400–1420 MHz
	BAOBAB (IF)	USA	construction	Radio: 600–900 MHz
	HIRAS	South Africa	planning	Radio: 400–800 MHz
	SKA (SD and IF)	Australia & South Africa	planning	Radio: 50 MHz–14 GHz

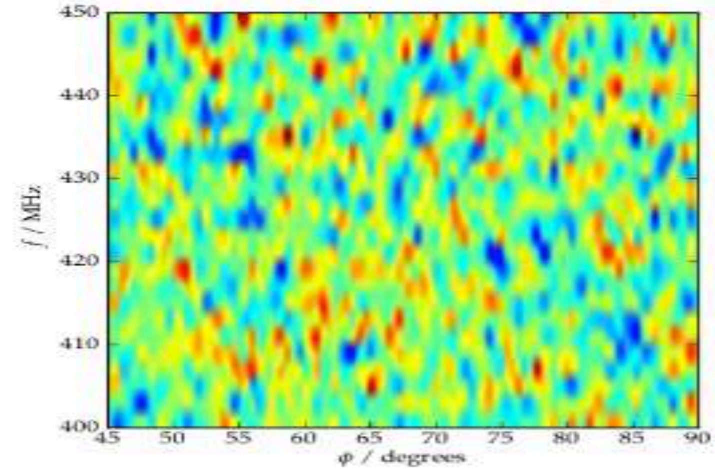


HI Intensity Mapping

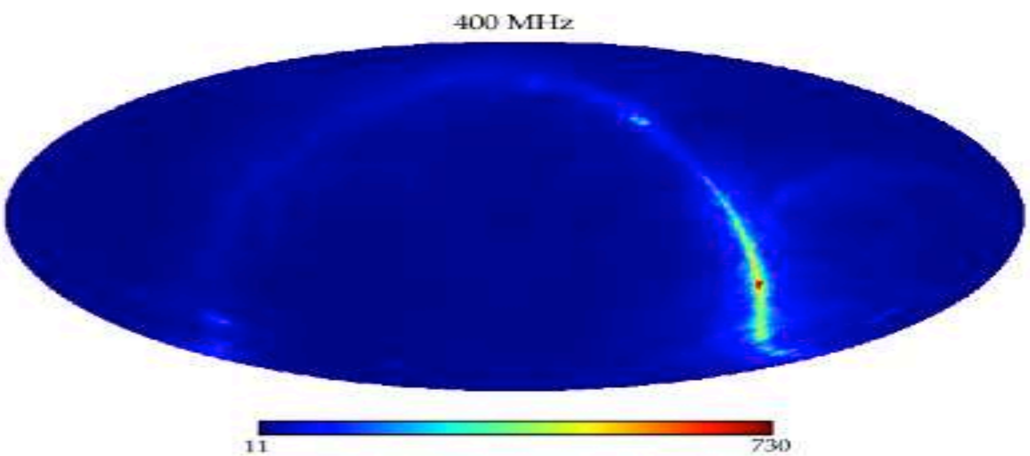
Amplitude 1 mK, lots of spectral structure

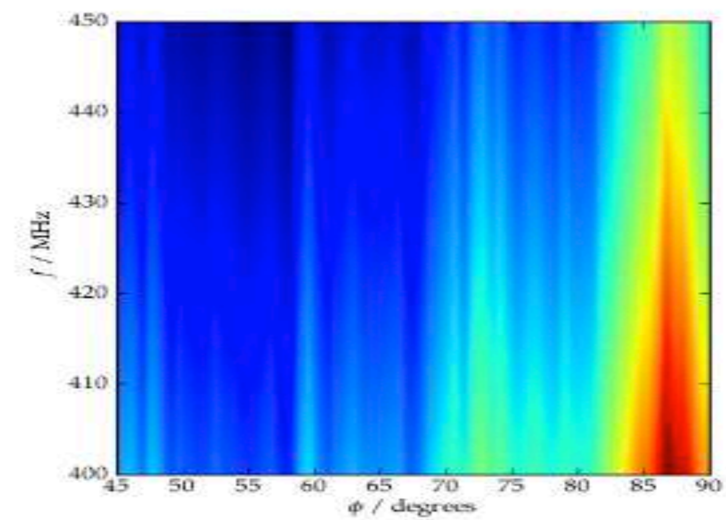
Shaw et al.

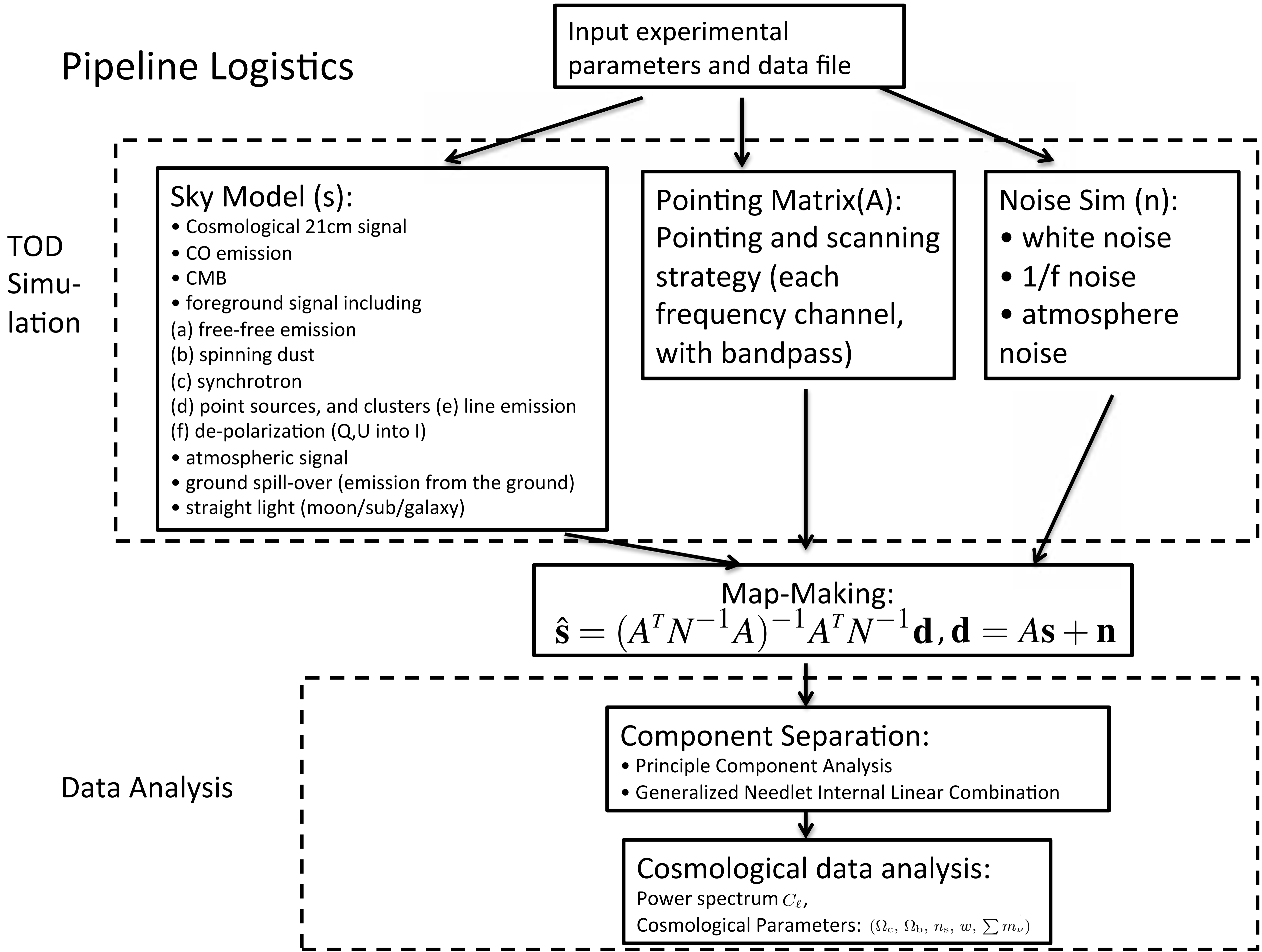




Amplitude 700 K, spectrally smooth





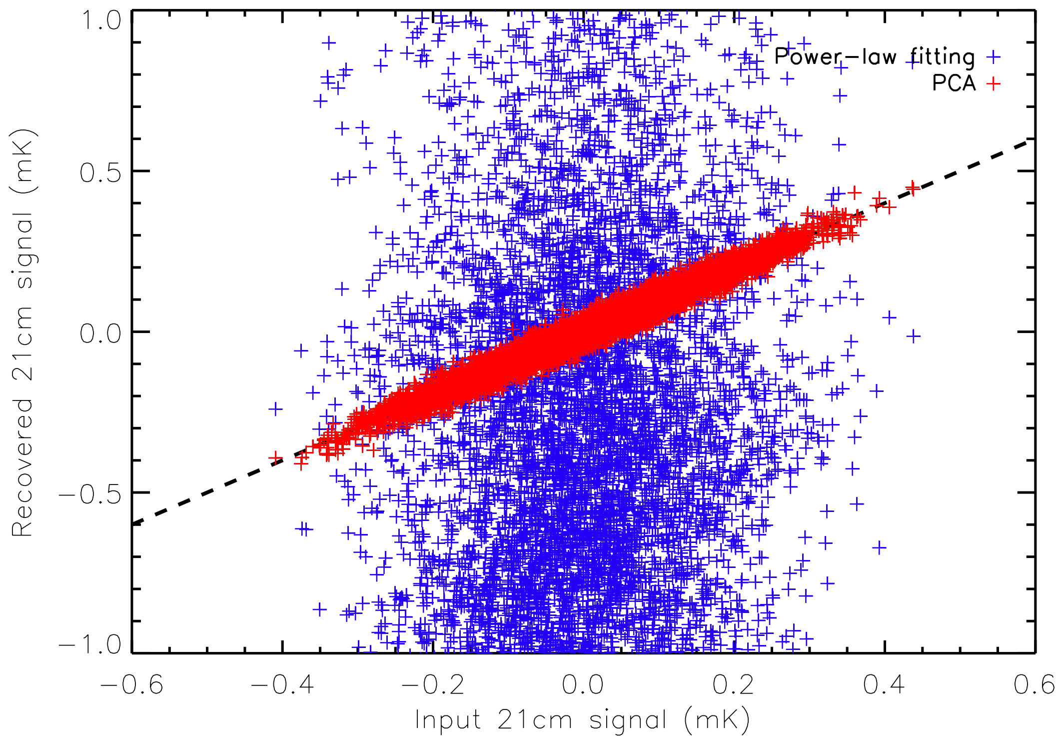

Pipeline Logistics
Input experimental parameters and data file
TOD Simulation
Sky Model (s):
• Cosmological 21cm signal
• CO emission
• CMB
• foreground signal including
(a) free-free emission
(b) spinning dust
(c) synchrotron
(d) point sources, and clusters (e) line emission
(f) de-polarization (Q,U into I)
• atmospheric signal
• ground spill-over (emission from the ground)
• straight light (moon/sub/galaxy)
Pointing Matrix(A): Pointing and scanning strategy (each frequency channel, with bandpass)
Noise Sim (n):
• white noise
• 1/f noise
• atmosphere noise
Map-Making:
$\hat{\mathbf{s}} = (A^T N^{-1} A)^{-1} A^T N^{-1} \mathbf{d}, \mathbf{d} = A\mathbf{s} + \mathbf{n}$
Data Analysis
Component Separation:
• Principle Component Analysis
• Generalized Needlet Internal Linear Combination
Cosmological data analysis:
Power spectrum C_ℓ,
Cosmological Parameters: $(\Omega_c, \Omega_b, n_s, w, \sum m_\nu)$

Component separation: PCA

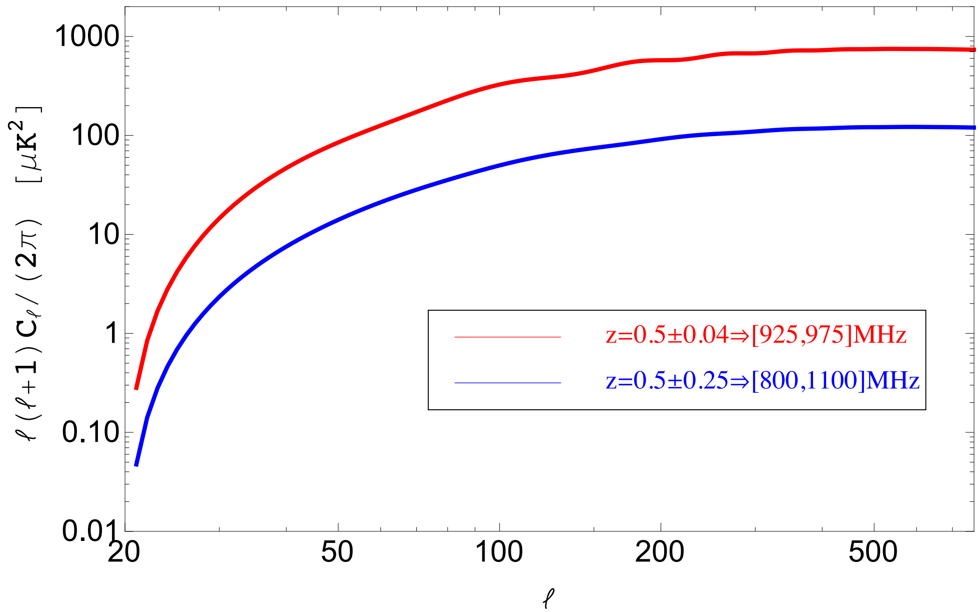
$$C_{ij} = \frac{1}{N_p} SS^T = \frac{1}{N_p} \sum_{p=1}^{N_p} T(\nu_i, \hat{n}_p) T(\nu_j, \hat{n}_p) \qquad R_{jk} = \frac{C_{jk}}{C_{jj}^{1/2} C_{kk}^{1/2}}$$

$$P^T R P = \Lambda \equiv \mathrm{diag}\{\lambda_1, \ldots, \lambda_{N_f}\} \qquad \phi = P_c^T S \qquad S_c = P_c \phi \qquad S_{\mathrm{HI}} = S - S_c$$

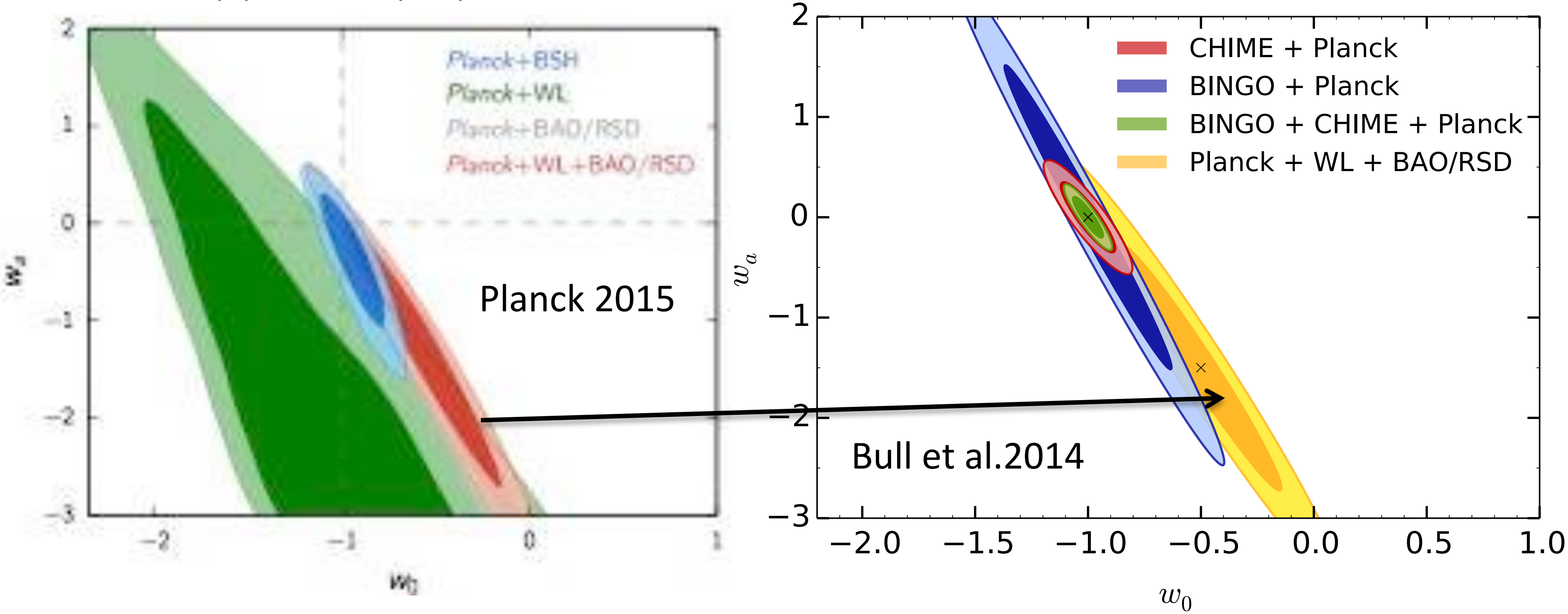
M.-A.Bigot-Sazy et al.



For Generalized Needlet Internal Linear Combination method (GNILC), see Lucas C. Olivari's poster


$\ell(\ell+1)C_\ell/(2\pi)$ [μK^2]
ℓ
z=0.5±0.04⇒[925,975]MHz
z=0.5±0.25⇒[800,1100]MHz

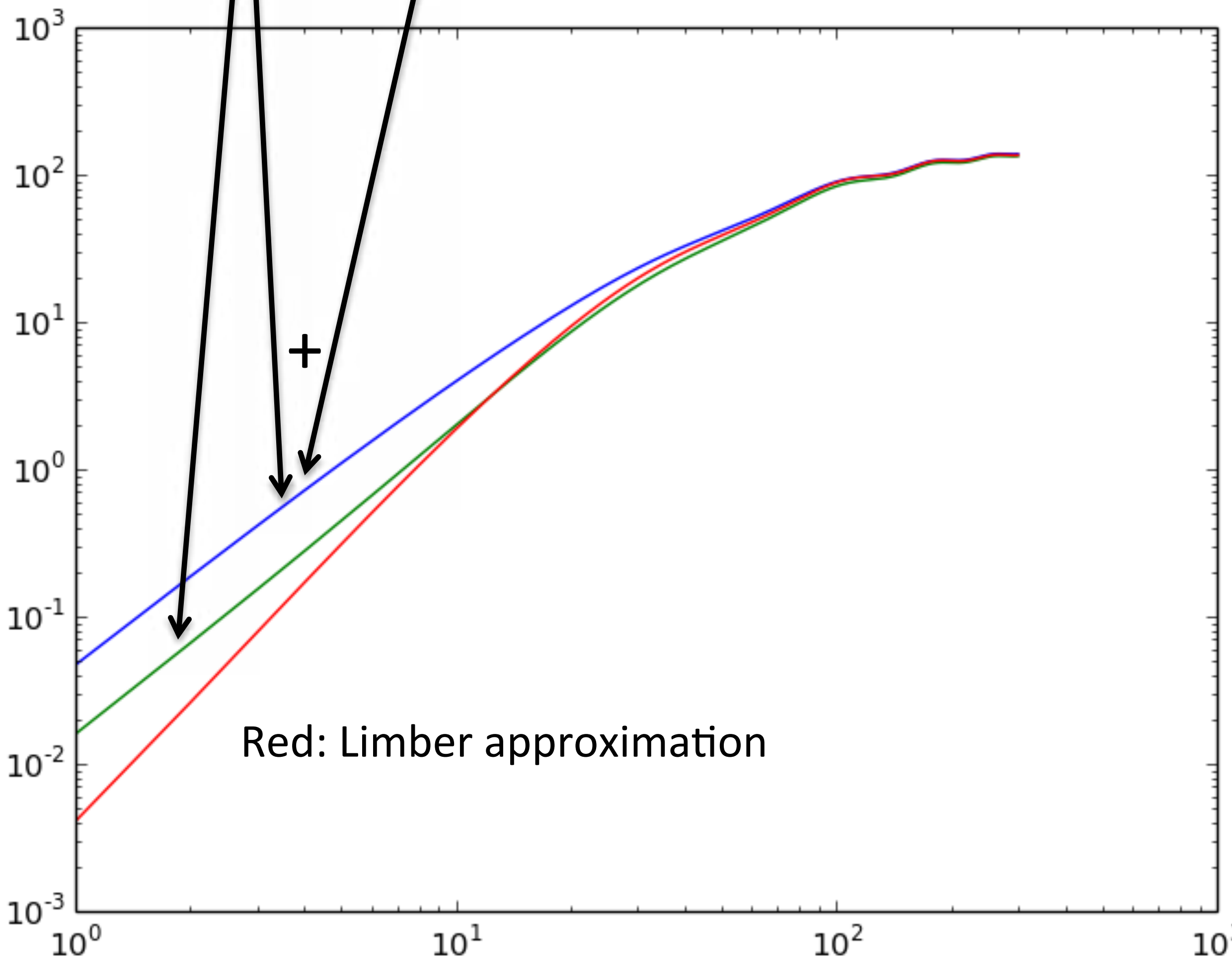
w(a)=w0+wa(1-a)


Planck+BSH
Planck+WL
Planck+BAO/RSD
Planck+WL+BAO/RSD
Planck 2015
w_a
w_0
CHIME + Planck
BINGO + Planck
BINGO + CHIME + Planck
Planck + WL + BAO/RSD
Bull et al.2014

A more detail expansion on higher-order terms

$$\Delta_{T_b,l}(\mathbf{k},z) = \delta_n\, j_l(k\chi) + \frac{kv}{\mathcal{H}} j_l''(k\chi) + \left(\frac{1}{\mathcal{H}}\dot{\Phi} + \Psi\right) j_l(k\chi)$$
$$- \left(\frac{1}{\mathcal{H}}\frac{\mathrm{d}\ln(a^3\bar{n}_{\mathrm{HI}})}{\mathrm{d}\eta} - \frac{\dot{\mathcal{H}}}{\mathcal{H}^2} - 2\right)\left[\Psi\, j_l(k\chi) + v\, j_l'(k\chi) + \int_0^{\chi}(\dot{\Psi} + \dot{\Phi}) j_l(k\chi')d\chi'\right]$$

ISW

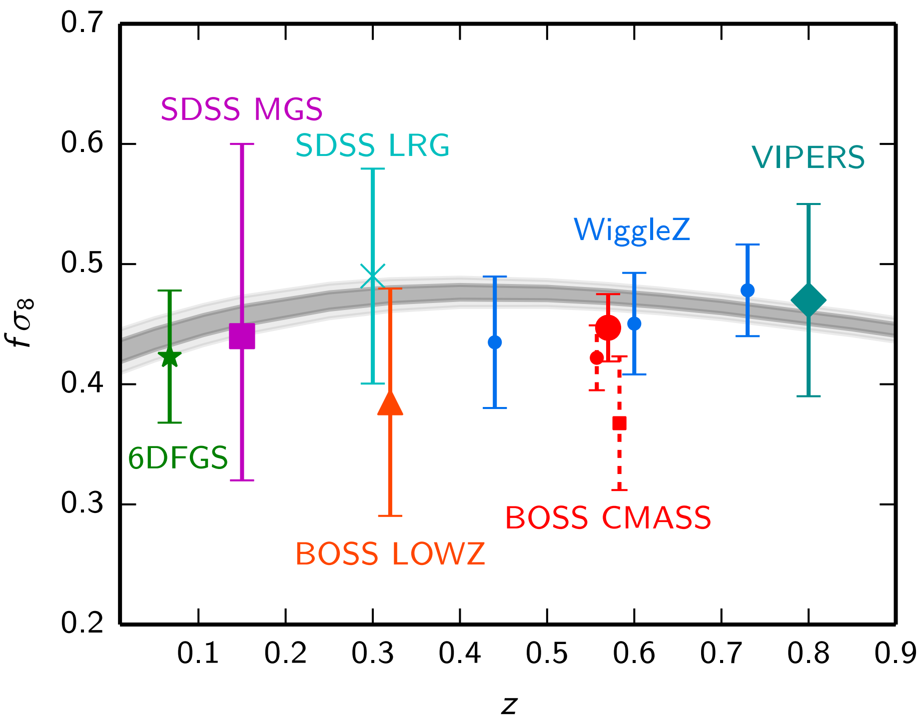


Hall et al. 2013

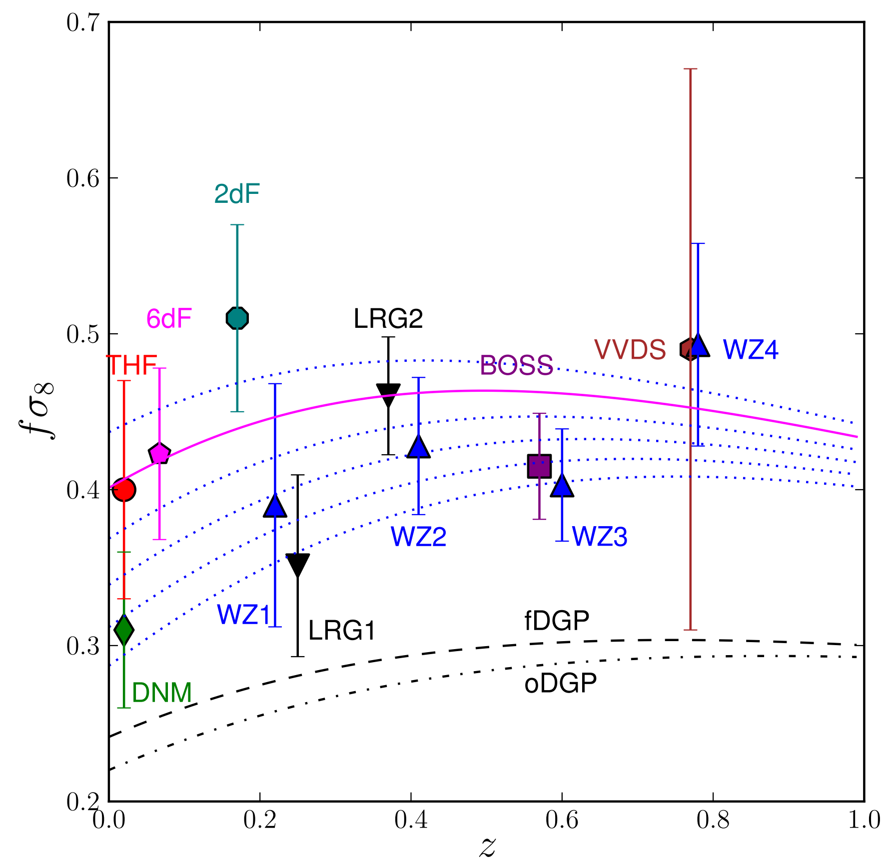
L.C.Olivari,
&Y.Z.Ma in
preparation

$$C_\ell = \frac{1}{\bar{T}^2_{\mathrm{b},\bar{z}}}\left(\frac{2}{\pi}\right)\int \mathrm{d}z\mathrm{d}z'\left(W(z)\bar{T}_\mathrm{b}(z)D(z)\right)\left(W(z')\bar{T}_\mathrm{b}(z')D(z')\right)\int \mathrm{d}k k^2 P_\mathrm{m}(k, z=0)$$
$$\times\left[b^2_{\mathrm{HI}} j_\ell(k\chi)j_\ell(k\chi') - 2b_{\mathrm{HI}}(f(z)j''_\ell(k\chi)j_\ell(k\chi')) + f(z)f(z')j''_\ell(k\chi)j''_\ell(k\chi')\right]$$

Density fluctuation | density X RSD | RSD



Planck 2015 Cosmological Parameters



Turnbull & Hudson 2012

Conclusion

- We are developing the 21cm intensity mapping pipeline which can allow us to simulate the noise and reduce the foreground emission, therefore recover the true 21-cm signal.
- The PCA analysis with realistic simulation shows that the power spectrum can be reconstructed. We are pursuing the constraints on cosmological parameters and redshift-space distortion and other smaller effects.
- A lot of sciences can be done for a single dish radio telescope(BINGO):

(1) BAO and HI power spectrum:

Matter density, RSD, anisotropic BAOs, curvature, the life history of hydrogen (Omega_HI), cross-correlation with other tracers: galaxy redshift surveys and ISW effect.

(2) Fast radio burst:

New transit sources (~10 known), very bright but last only a few millisecond: can be used to weight the intergalactic baryons and their distribution.

The CMB information has been nearly extracted out

$$\Delta C_\ell = \sqrt{\frac{2}{(2\ell+1)}} C_\ell \qquad \sqrt{\sum_{\ell=2}^{\ell_{\max}} (C_\ell/\Delta C_\ell)^2} \simeq 2 \times 10^3$$

Planck Collaboration: Cosmological parameters

O(10^3)

Parameter	*Planck* Best fit	*Planck* 68% limits	*Planck*+lensing Best fit	*Planck*+lensing 68% limits	*Planck*+WP Best fit	*Planck*+WP 68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022242	0.02217 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.11805	0.1186 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04150	1.04141 ± 0.00067	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0949	0.089 ± 0.032	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9675	0.9635 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.098	3.085 ± 0.057	3.0980	$3.089^{+0.024}_{-0.027}$