Credit: M. Douspis

Cosmology with SZ galaxy clusters and consistency with primary CMB constraints in Planck

Matthieu Roman

On behalf of the Planck collaboration

Outline

- Key ingredients of cluster counts modeling
- Planck sample
- Results with cluster counts and consistency with primary CMB
- The SZ spectrum
- The future of SZ survey

Cosmological parameters estimation with cluster number counts

- Poisson statistics (Cash likelihood)
- Sampled by 2D grid or MCMC

proba to find N_{obs} clusters in a redshift bin given the expected number $N_{\theta'}$

$$\ln \mathcal{L}(\theta') = \sum_z \ln \underbrace{\mathcal{P}(N_{\rm obs}(z)|N_{\theta'}(z))}$$

$$\ln \mathcal{P}(N_{\rm obs}|N_{\theta'}) = -N_{\theta'} + N_{\rm obs} \ln N_{\theta'} - \ln (N_{\rm obs}!)$$

Key quantities to model cluster number counts

- Selection function and completeness of the sample
- Dark matter halo mass function
- Observable scaling relations

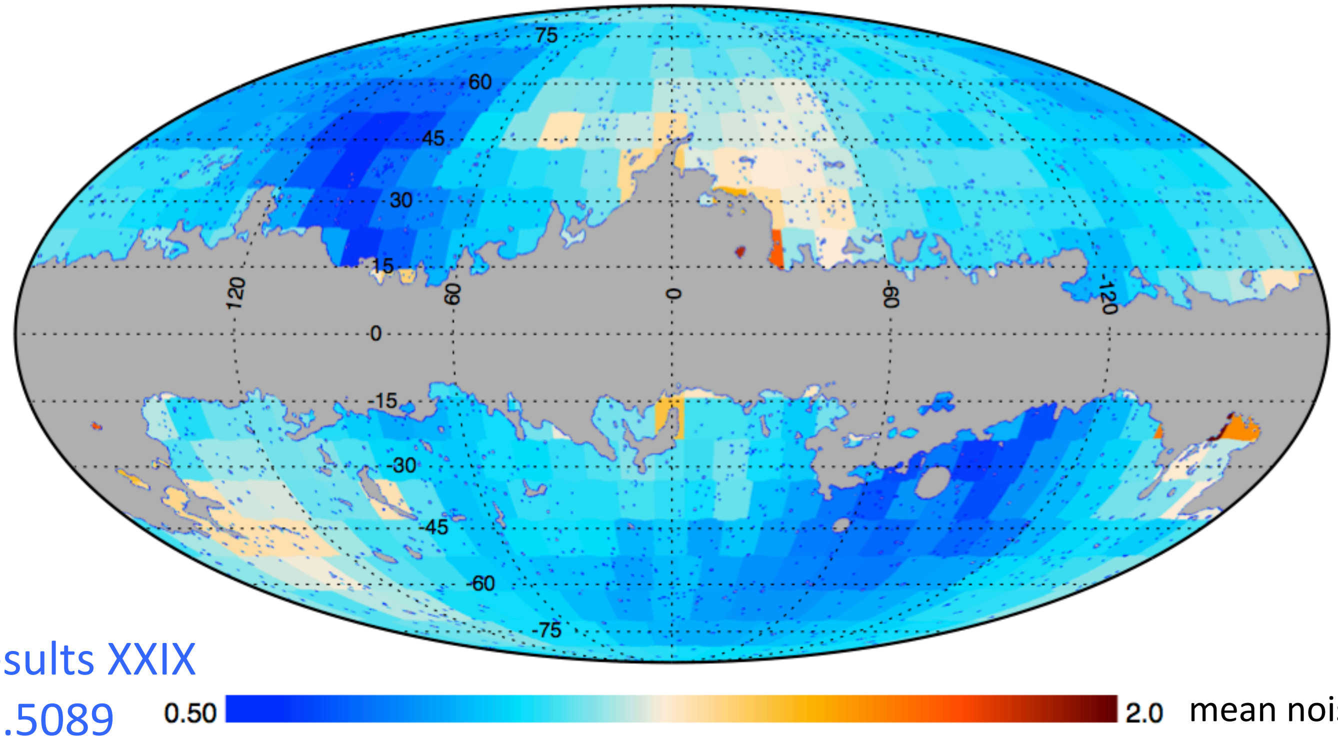
Modeling the cluster counts

$$\overbrace{\frac{dN}{dz}}^{\text{number counts}} = \int d\Omega \int \overbrace{dM_{500}}^{\text{mass in radius } R_{500} \text{ (500 times the critical density)}} \underbrace{\chi}_{\text{completeness at a given location}}(z, M_{500}, \underbrace{l, b}_{\text{galactic coordinates}}) \overbrace{\frac{dN}{dz\,dM_{500}\,d\Omega}}^{\text{mass function}}$$

Selection function and completeness

- Based on noise from match-filtered maps: assumed pressure profile of *Arnaud et al. 2010*

6 arcmin



mean noise

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arXiv 1303.5089

Selection function and completeness

- Completeness: probability to have a model cluster in the catalogue
  - zero level: simple cut in flux
  - more refined: error function (approximation)
- Good agreement with simulations (MC completeness: beam and profile effects)

$$Y > f(Y_{500}, \theta_{500}, l, b)$$

$$\boxed{y = \frac{\sigma_T}{m_e c^2} \int P_e dl}$$

$$f(Y_{500}, \theta_{500}, l, b) = \frac{1}{2}\left(1 + \mathrm{ERF}\left(\frac{Y_{500} - SNR \times \sigma_{Y_{500}}(\theta_{500}, l, b)}{\sqrt{2}\sigma_{Y_{500}}(\theta_{500}, l, b)}\right)\right)$$

Mass function

- Number distribution of clusters with mass and redshift
$$\frac{dn}{dlnM} = f(\sigma)\frac{\overline{\rho}_m}{M}\frac{dln\sigma^{-1}}{dlnM}$$
with
$$f(\sigma) = A\left[\left(\frac{\sigma}{b}\right)^{-a} + 1\right]e^{-c/\sigma^2}$$
and
$$\sigma^2 = \frac{1}{2\pi^2}\int dk\ k^2 P(k,z)|W(kR)|^2$$
- Planck: fit function from *Tinker et al.* 2008
- Alternatives: *Sheth&Tormen*, *Jenkins*, *Watson*

Scaling relations

- Link between cluster observables and mass/ redshift assuming a profile
- Y_X as a mass proxy $E(z)^{-2/3} Y_X = 10^A \left[M_{500}^{Y_X}\right]^{\alpha}$

  with $M_{500}^{Y_X} = 10^{\pm\sigma_A/\alpha} \left[M_{500}^{\mathrm{HE}}\right]^{1\pm\sigma_\alpha/\alpha}$
- Mass bias $M_{500}^{\mathrm{HE}} = (1-b) M_{500}$

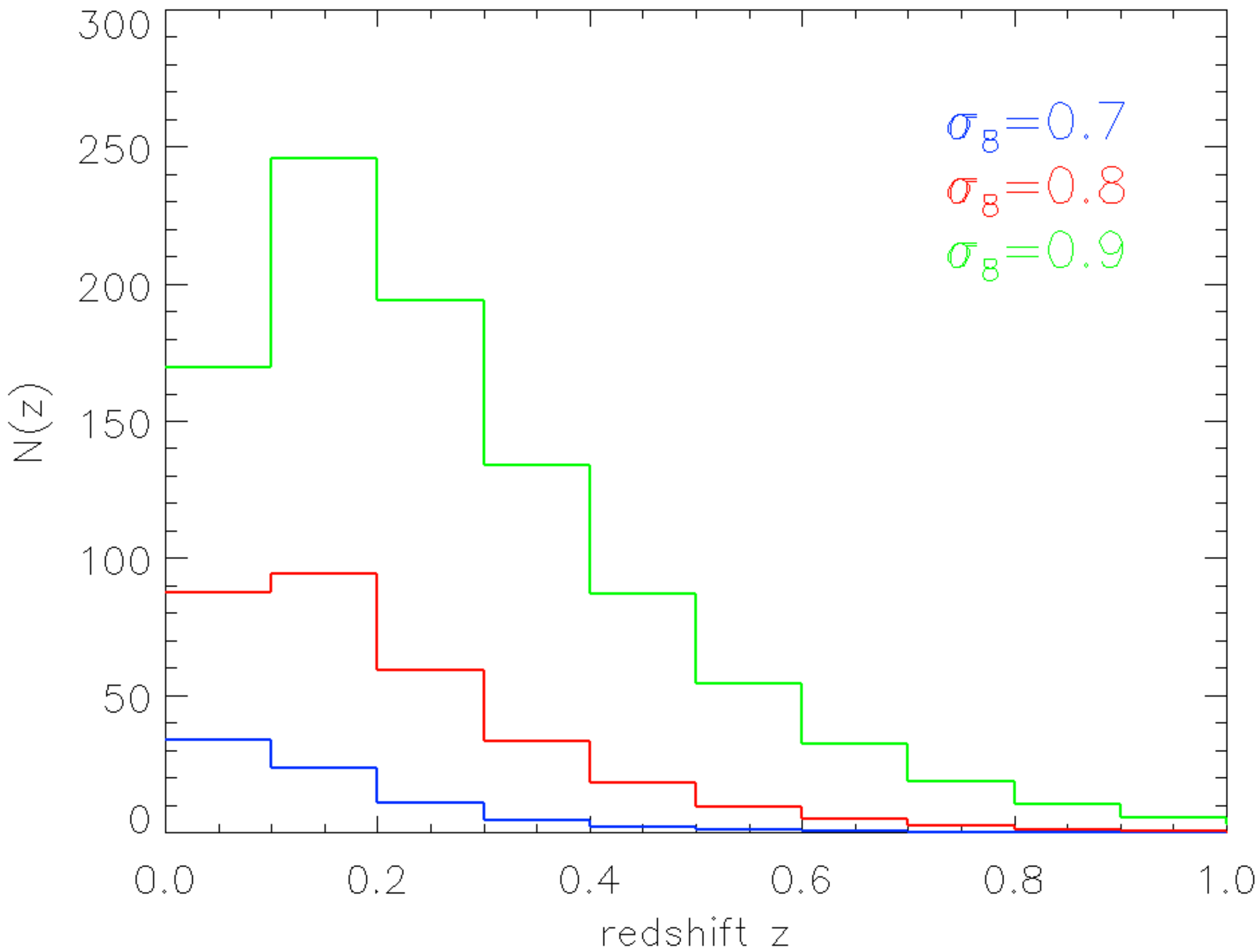
$$E(z)^{-2/3} \left[\frac{D_A(z)^2 Y_{500}}{10^{-4}\mathrm{Mpc}^2}\right] = 10^B \left[\frac{(1-b) M_{500}}{6\times 10^{14} M_\odot}\right]^{\beta}$$

$\frac{H(z)}{H_0}$

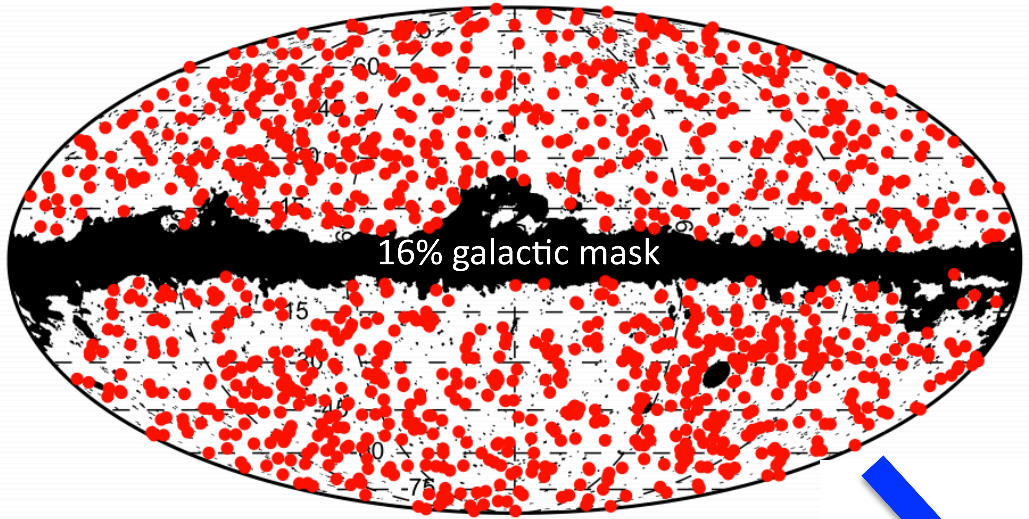
angular diameter distance

Cluster counts model

- High dependence in σ_8, Ω_m
- Here: Ω_m=0.3,h=0.7, Ω_Λ=0.7



Planck cosmological sample



Planck catalogue:
1227 detections
366 candidates
178 discoveries

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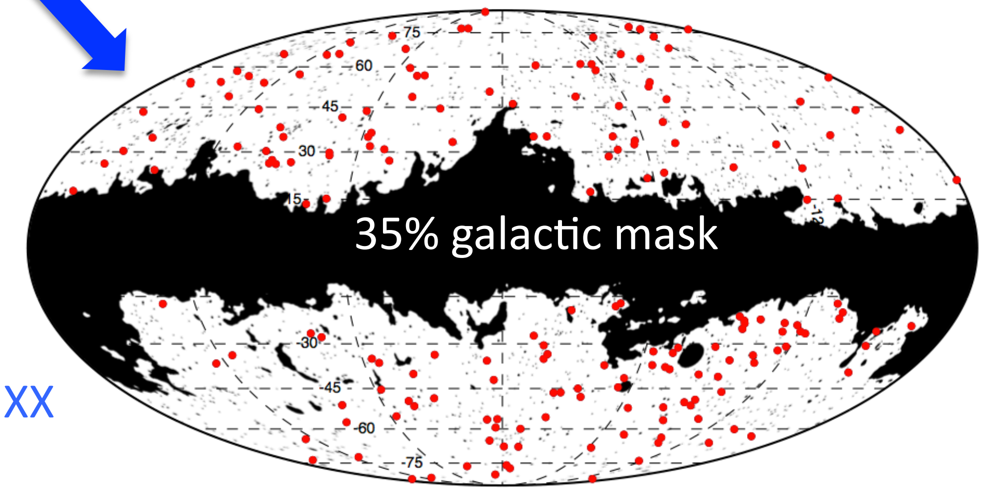

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Planck cosmological sample

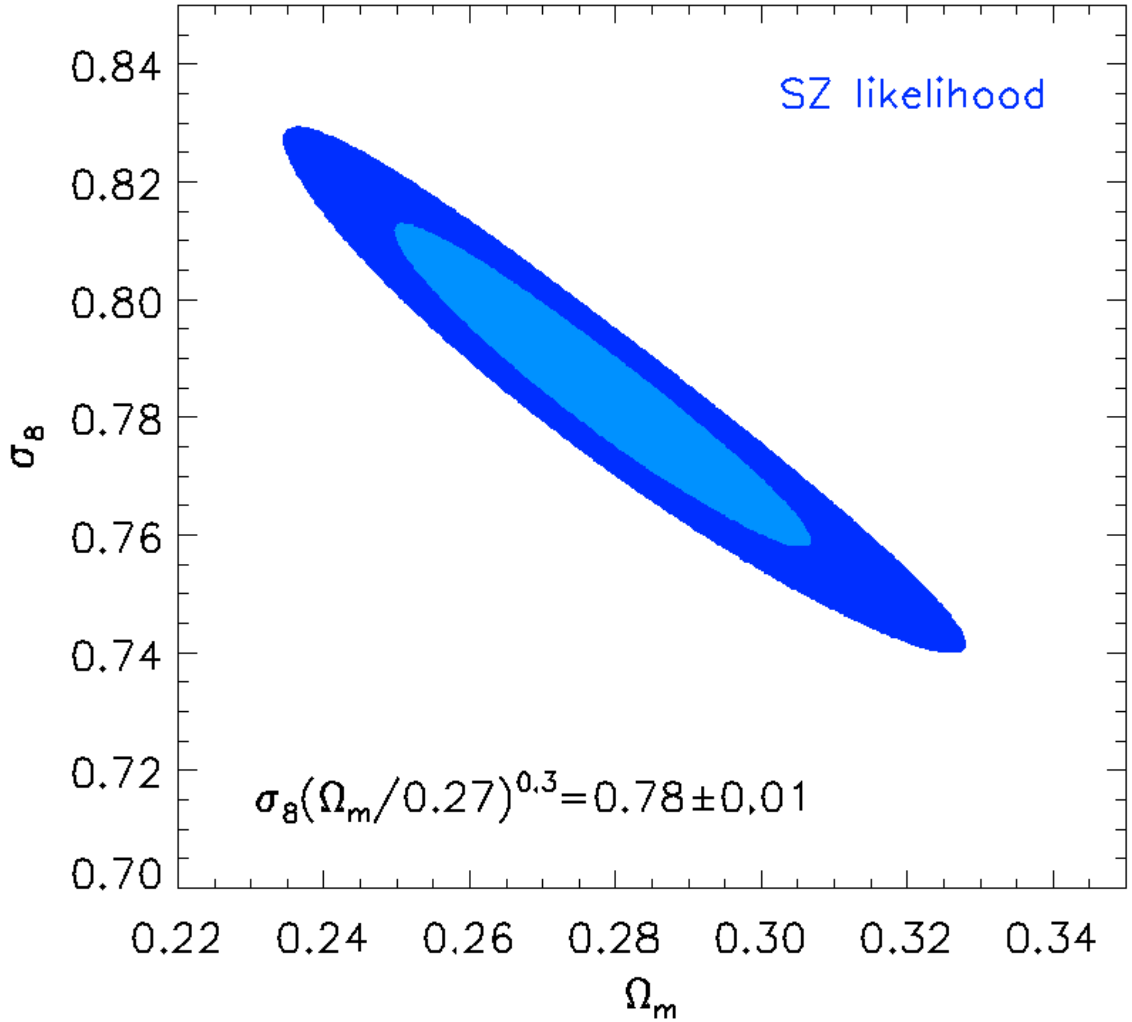
- Cut to SNR>7
- High purity
- DX9, MMF3: 189 clusters among which 188 with redshift
- Complementarity with small scales experiments (larger and more low-redshift clusters)

extracted catalog VS expected number counts

Results with Planck cosmological sample

- 3 independent number counts and likelihood codes:
  - Orsay IAS: Douspis & Aghanim *(MCMC)*
  - Manchester JBCA: Bonaldi & Battye *(MCMC)*
  - Paris APC/CEA: Roman & Melin & Delabrouille *(grid)*

Results with Planck cosmological sample: the grid code



Lots of robustness tests done

Robustness

- Observational sample (SNR, catalogue)
- Cluster modeling (mass function)
- Different likelihood and cluster model codes

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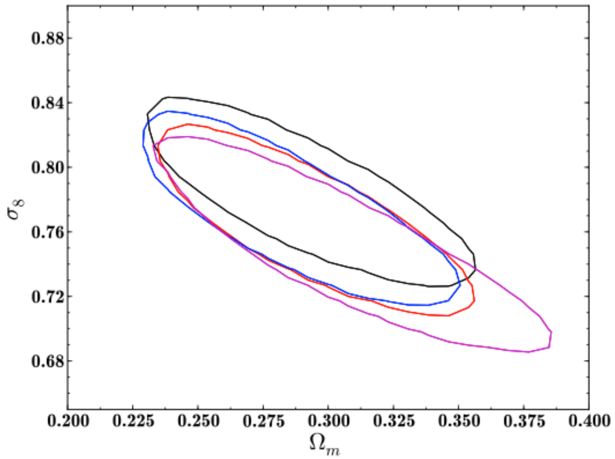


Fig. 8. 95% contours for different robustness tests: MMF3 with S/N cut at 7 in red; MMF3 with S/N cut at 8 in blue; and MMF1 with S/N cut at 7 in black; and MMF3 with S/N cut at 7 but assuming the MC completeness in purple.

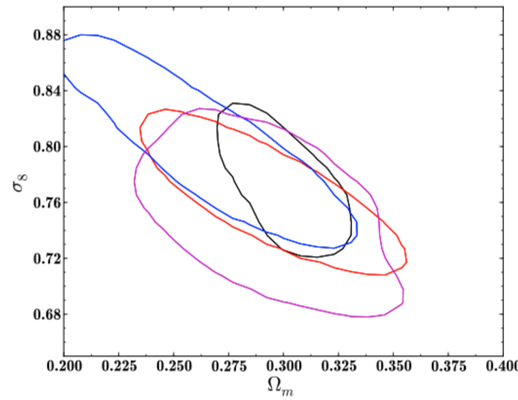
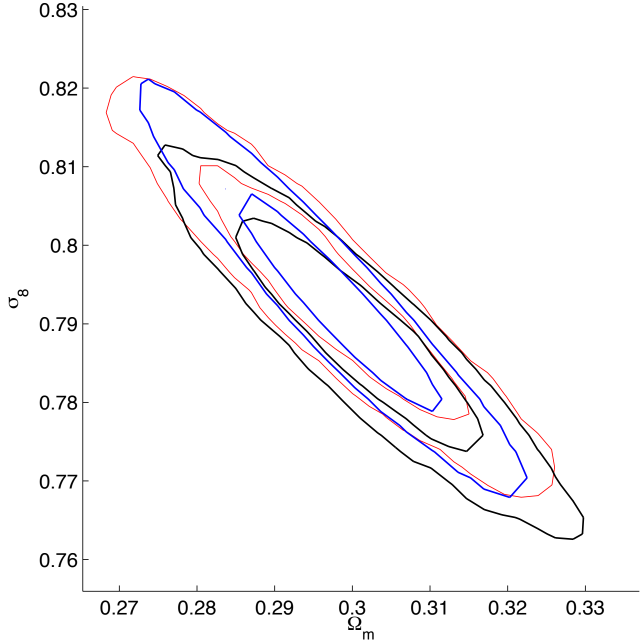


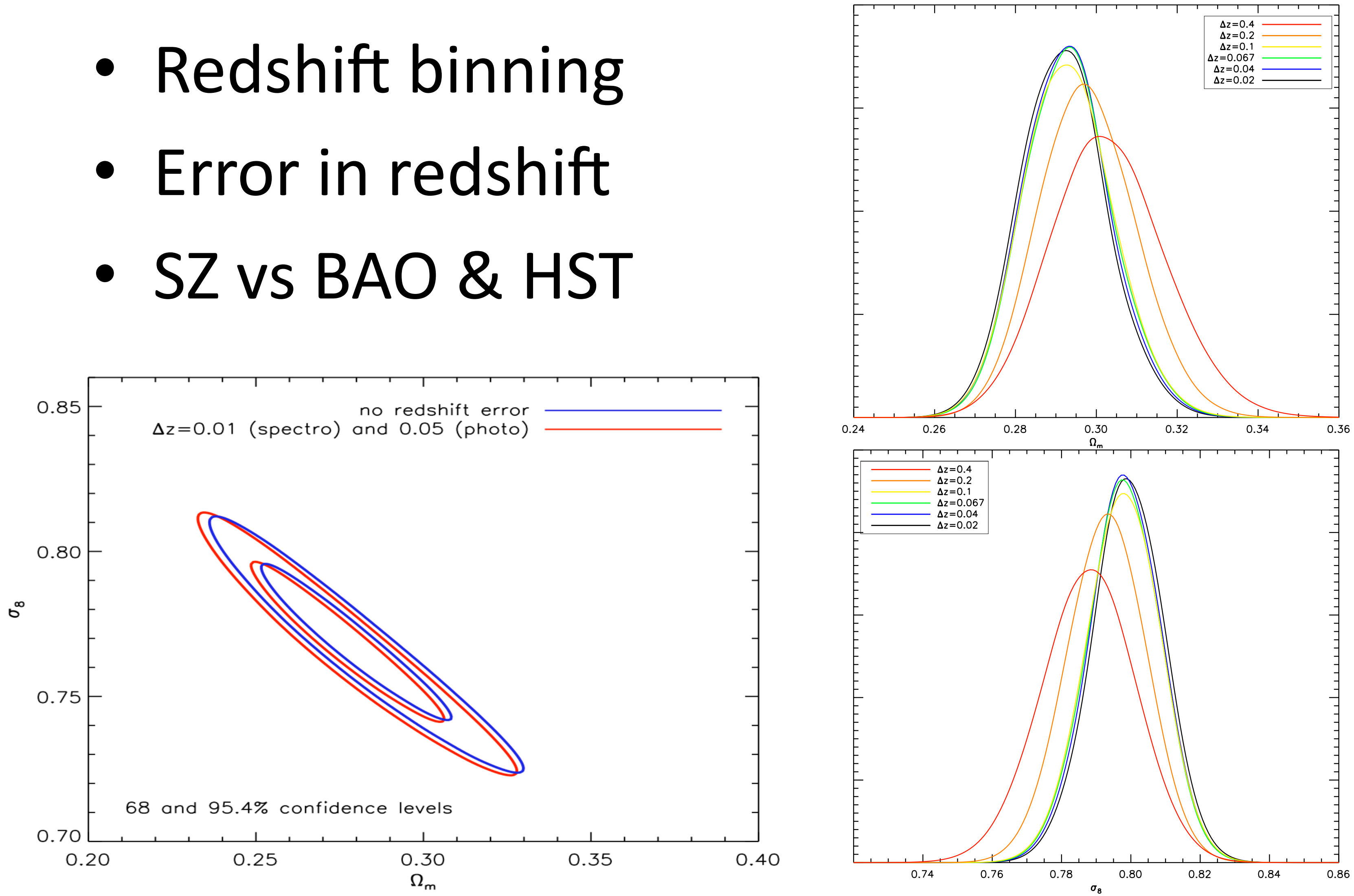
Fig. 9. Comparison of the outcome using the mass functions of Watson et al. (black) and Tinker et al. (red). Allowing the bias to vary in the range [0.7, 1.0] enlarges the constraints perpendicular to the σ_8–Ω_m degeneracy line due to the degeneracy of the number of clusters with the mass bias (purple). When relaxing the constraints on the evolution of the scaling law with redshift (blue), the contours move along the degeneracy line. Contours are 95% confidence levels here.

A. Bonaldi



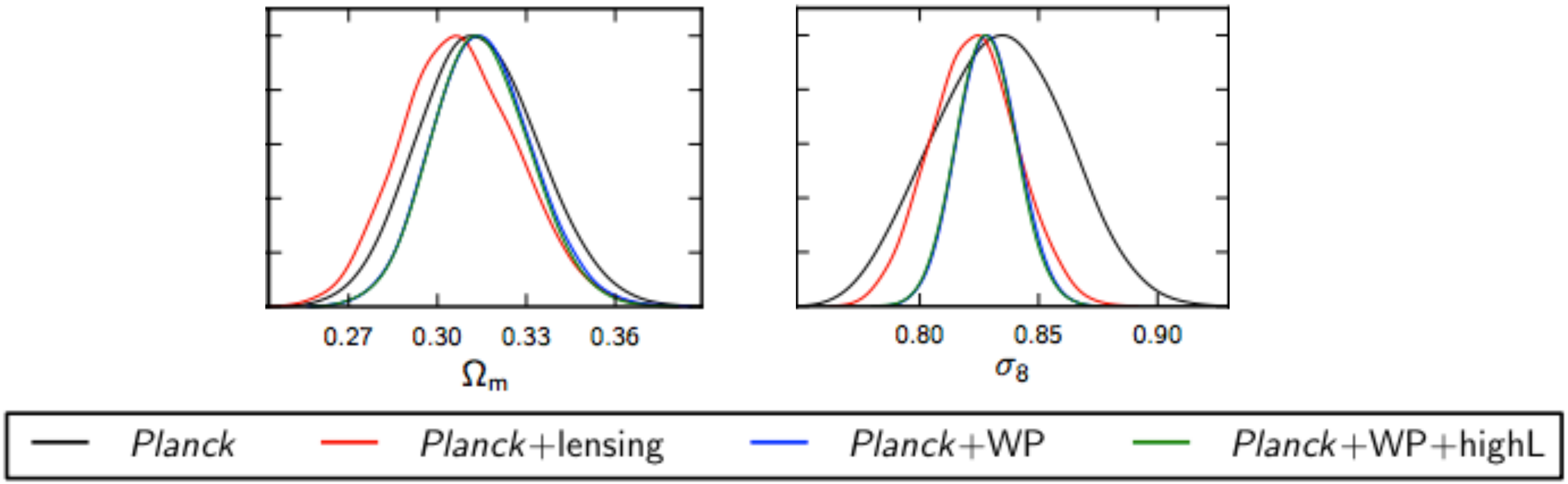
Robustness

- Redshift binning
- Error in redshift
- SZ vs BAO & HST



Consistency with primary CMB

- Constraints with CMB on the base ΛCDM model:
  - Ω_m derived from cdm parameter and measurement of H_0
  - σ_8 via A_s, the spectrum normalisation



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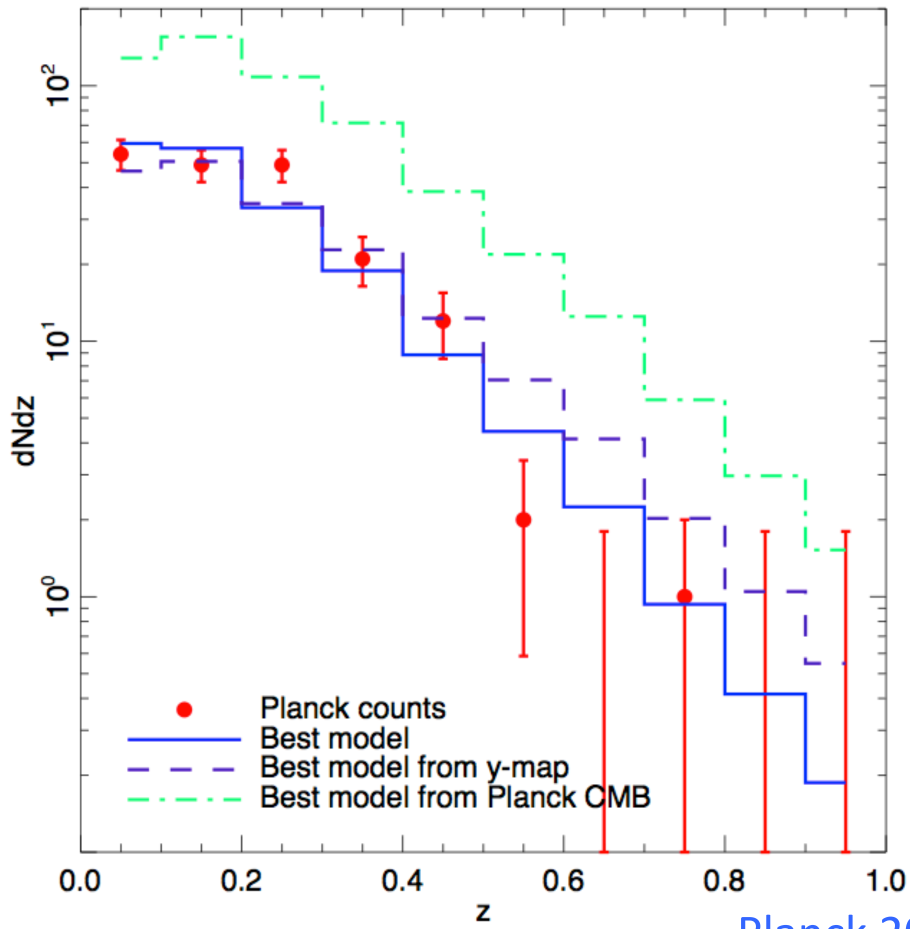
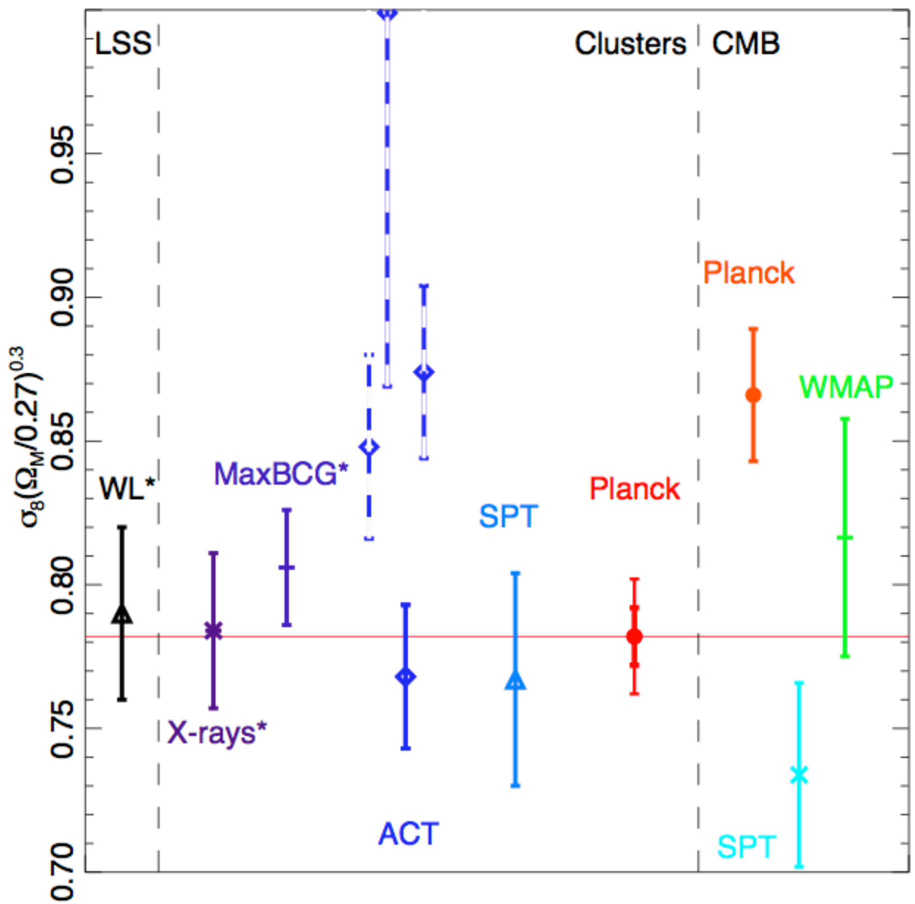
Consistency with primary CMB: impact on cluster counts





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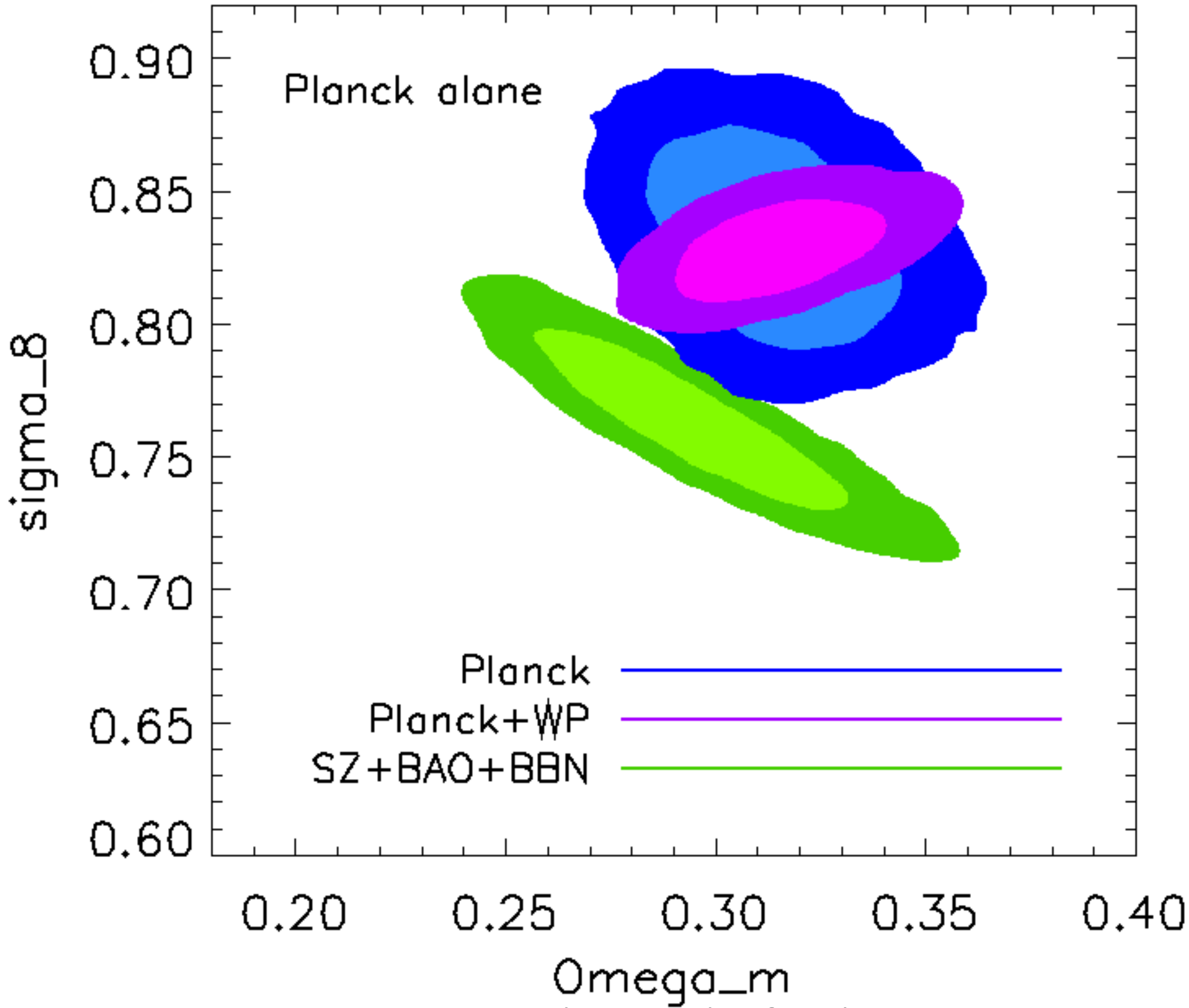
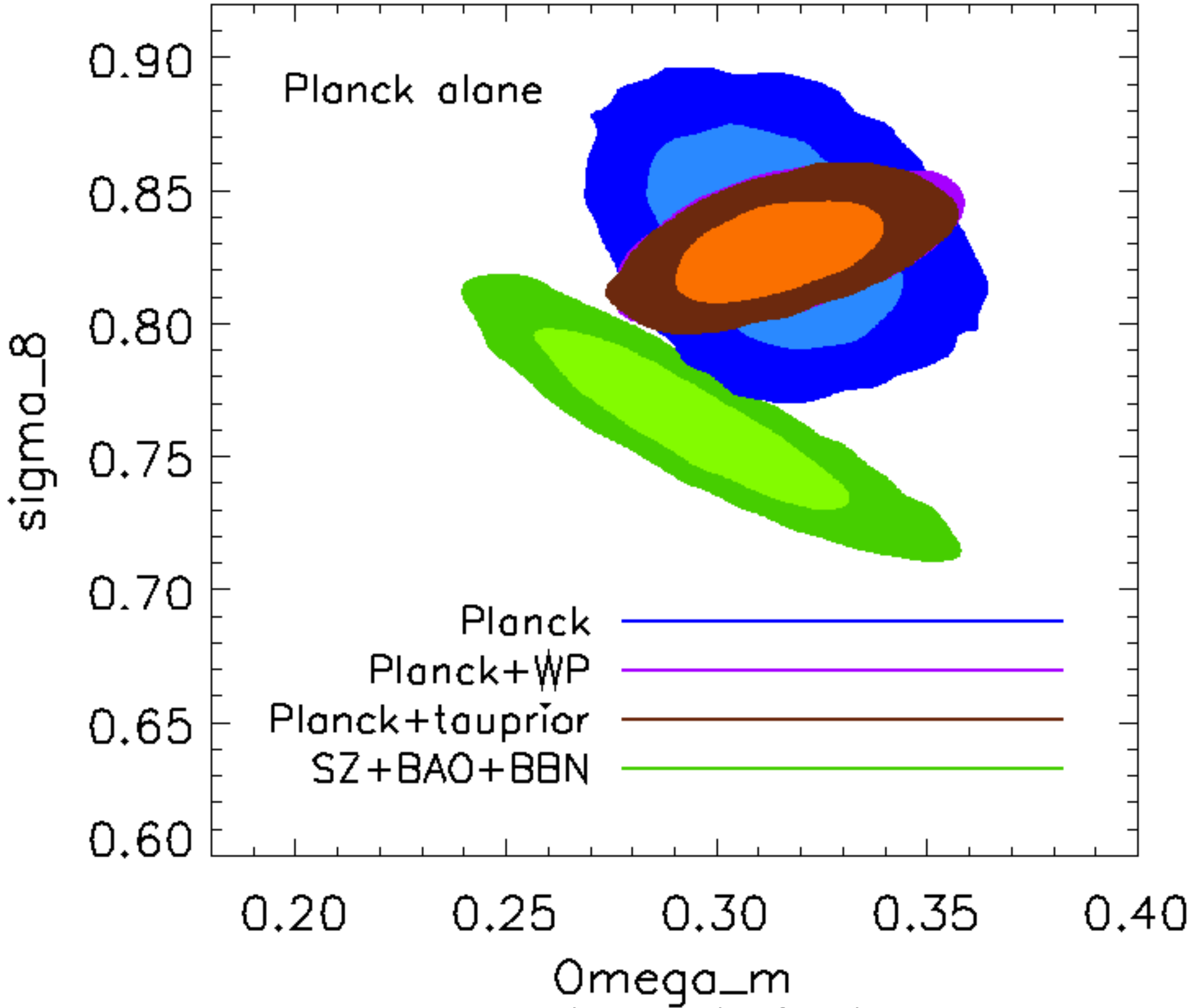
Consistency with primary CMB



Public chains can be downloaded at http://irsa.ipac.caltech.edu/data/Planck/release_1/ancillary-data/

Consistency with primary CMB



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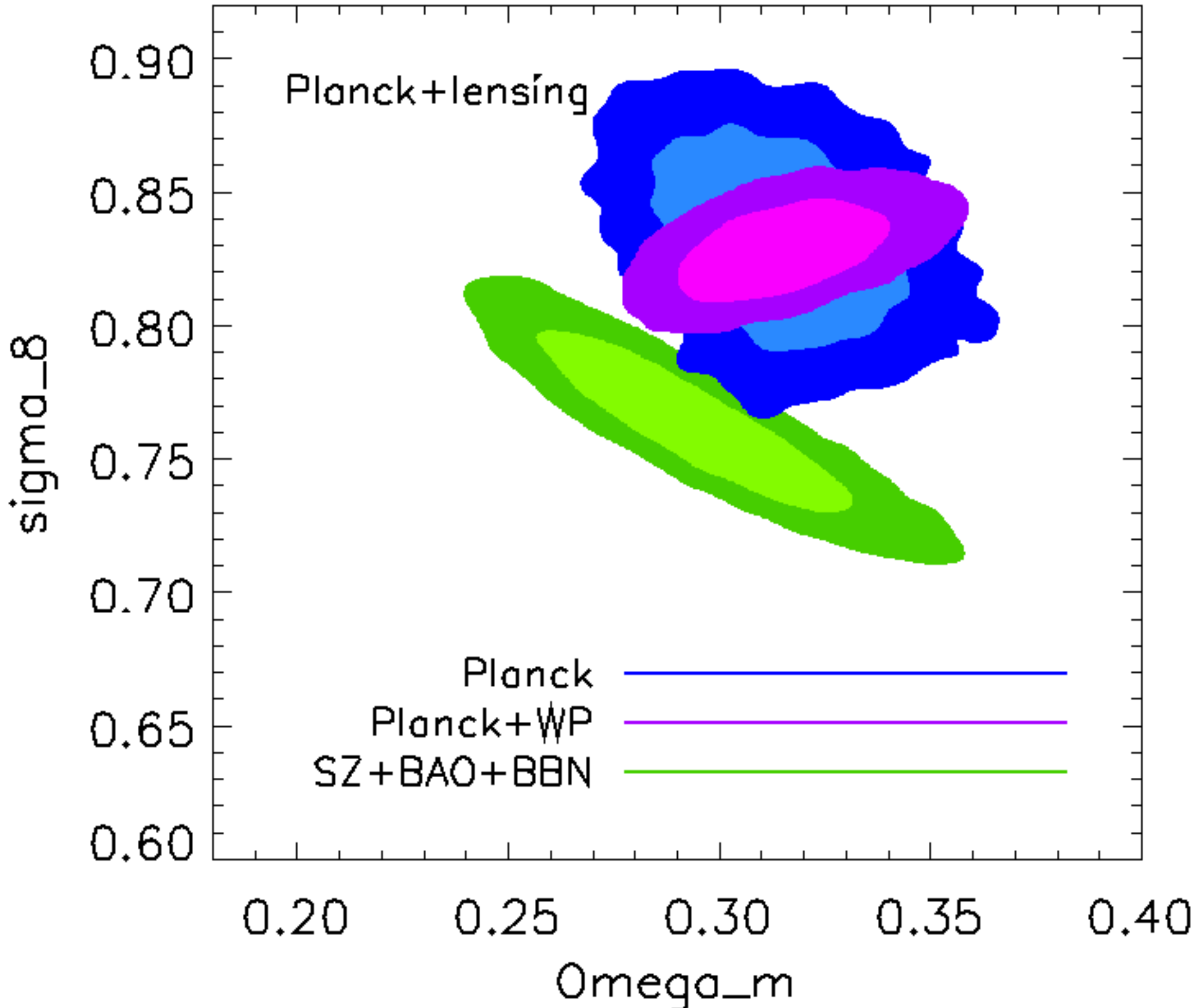
Consistency with primary CMB



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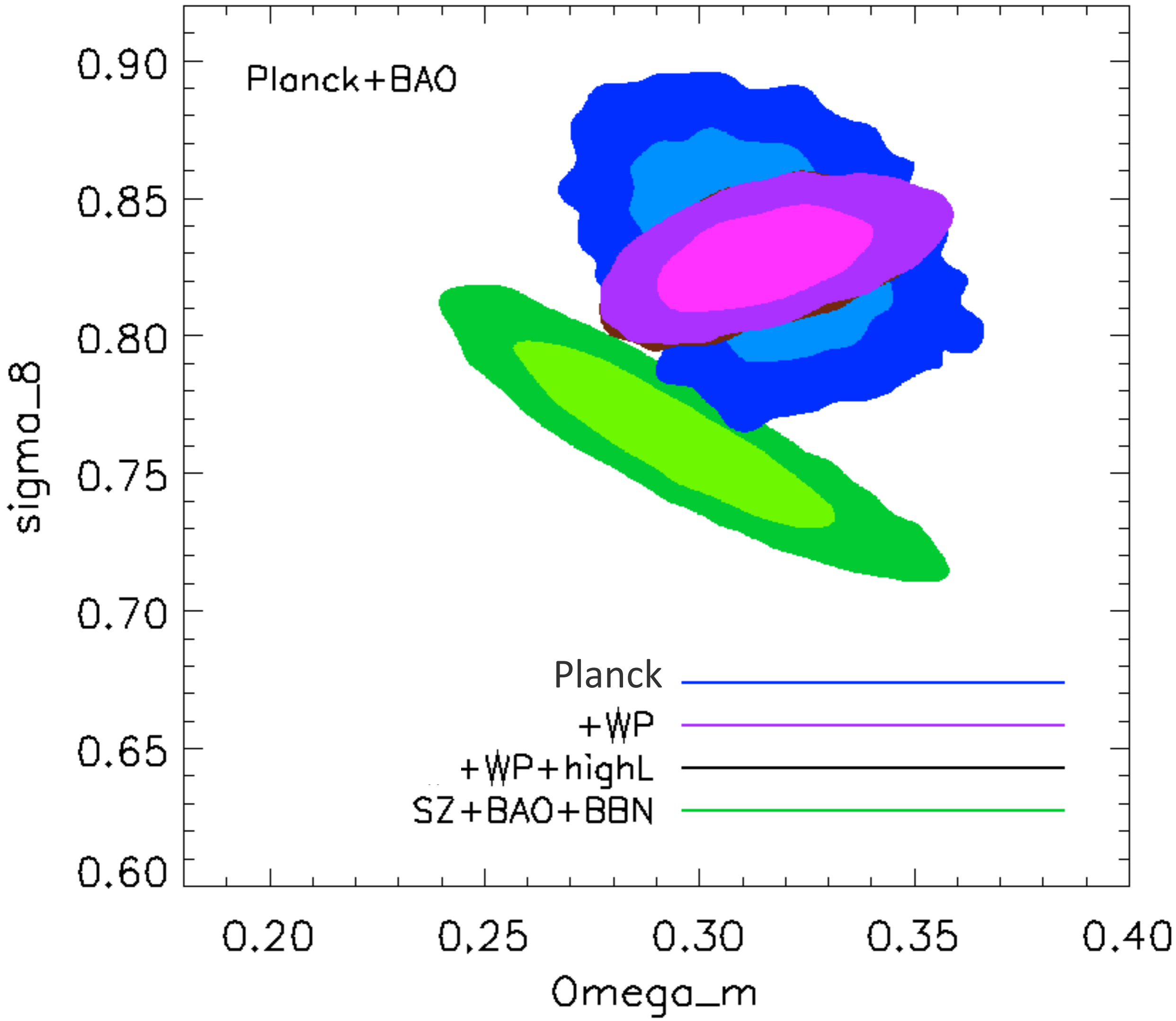

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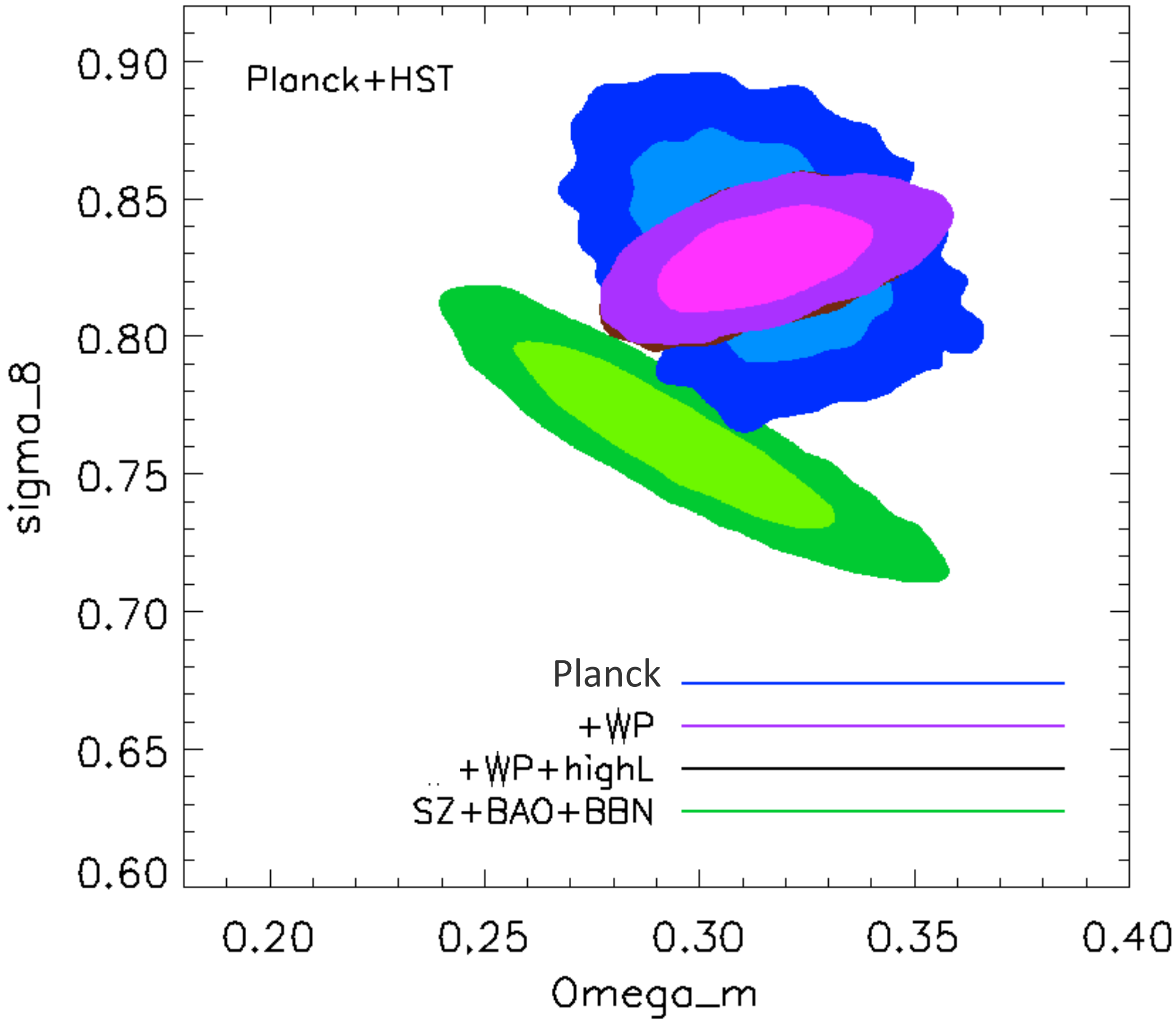


Public chains can be downloaded at http://irsa.ipac.caltech.edu/data/Planck/release_1/ancillary-data/

Solving the tension (1)

Change in the cluster physics:

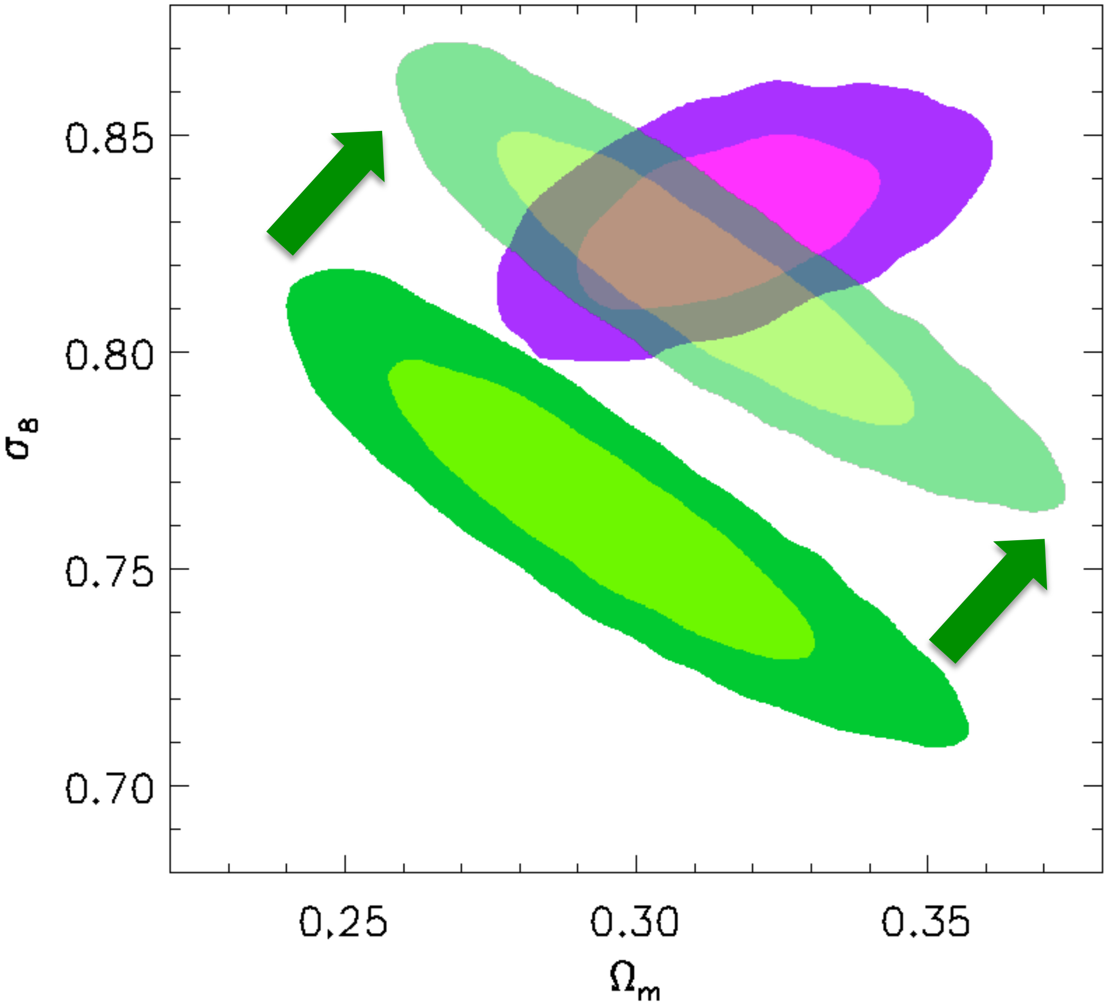
• mass bias (1-b=0.55)?

• non-thermal pressure due to gas motions?

• derive profiles independent from X-ray ?

• account for missing clusters?

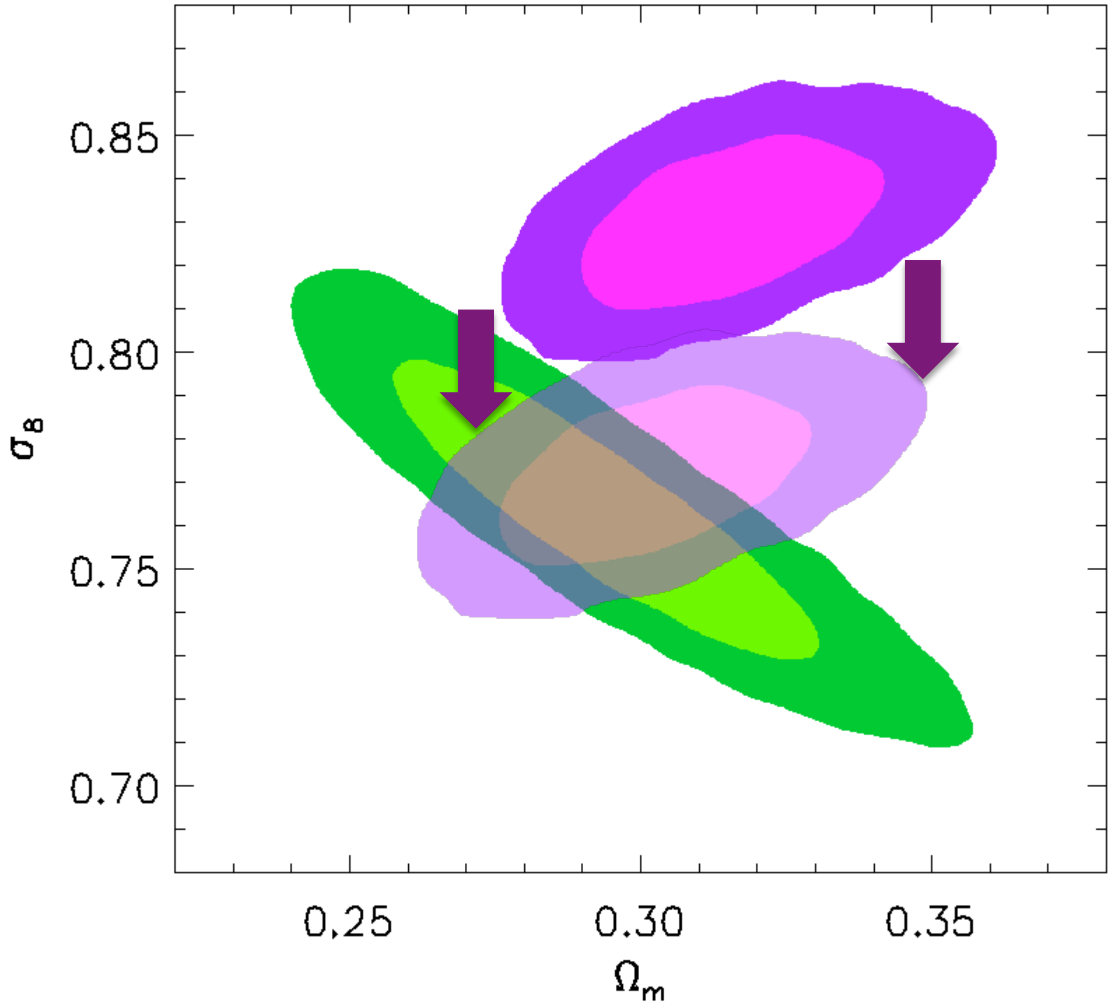
• missing baryon problem



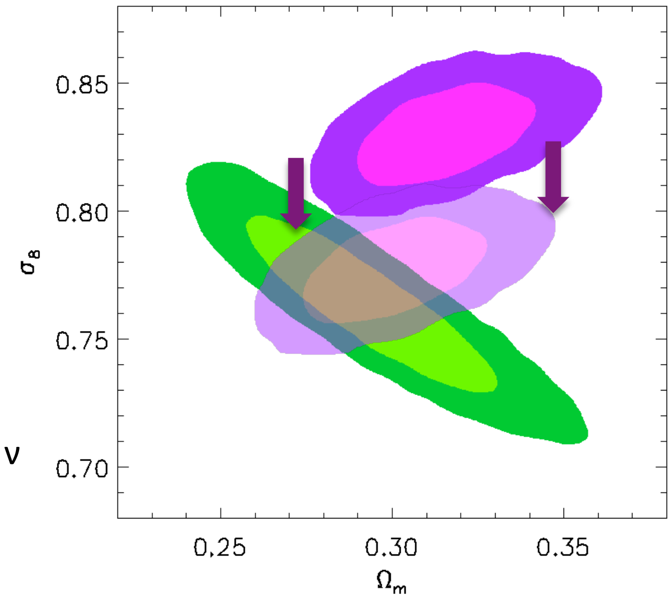
Solving the tension (2)

Parameters not seen in CMB analysis:

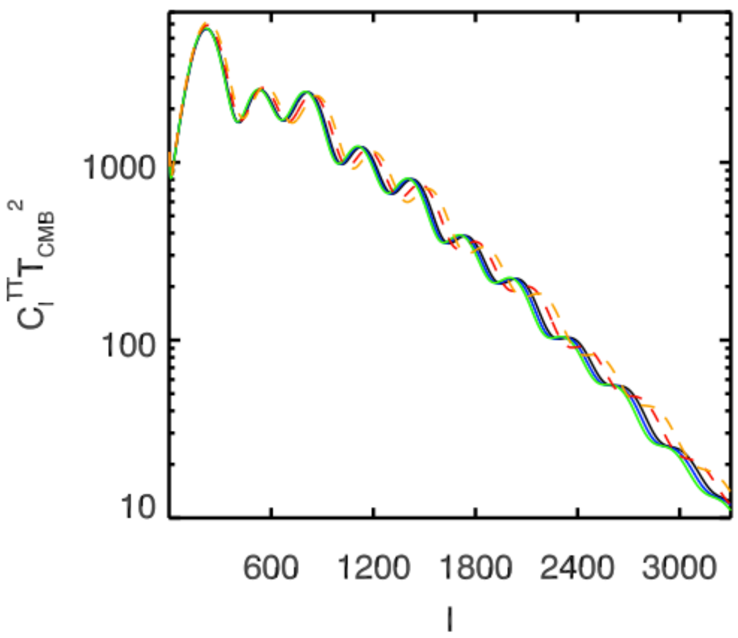
- massive neutrinos?
- running spectral index?

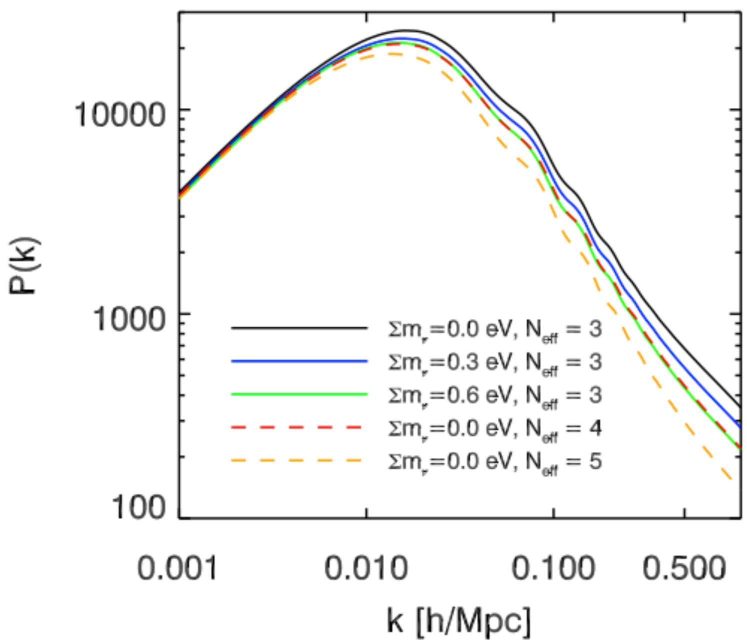


Solving the tension (2): massive neutrinos



- CMB power spectrum mostly sensitive to N_{eff}
- Matter power spectrum sensitive to both N_{eff} and Σm_ν
- Both parameters are degenerate for matter power spectrum

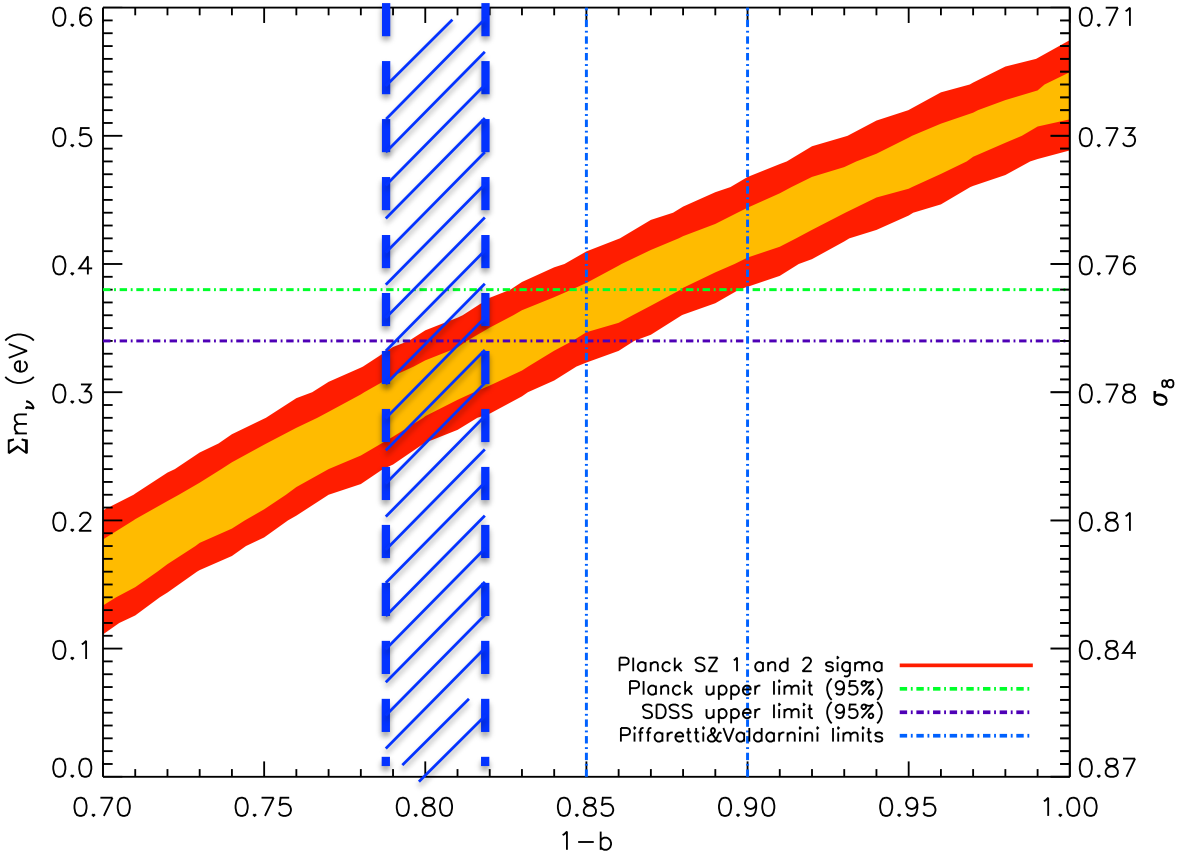


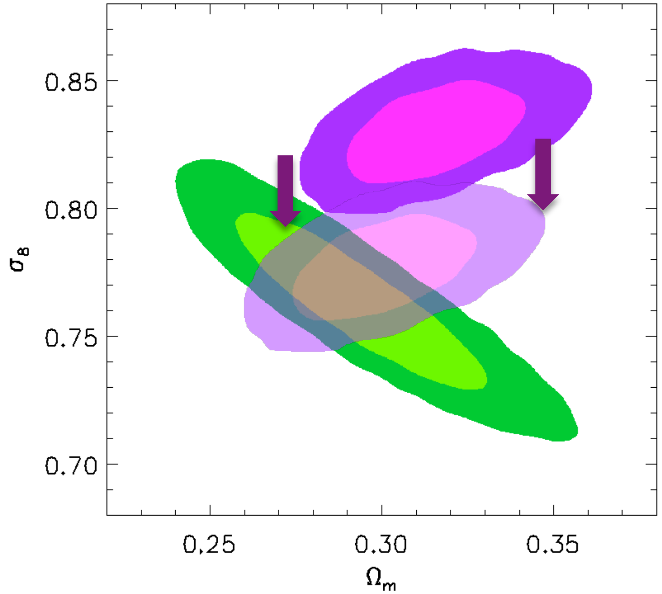


S. Riemer-Sorensen, D. Parkinson, T. Davis arXiv 1301.7102

Solving the tension (2): massive neutrinos

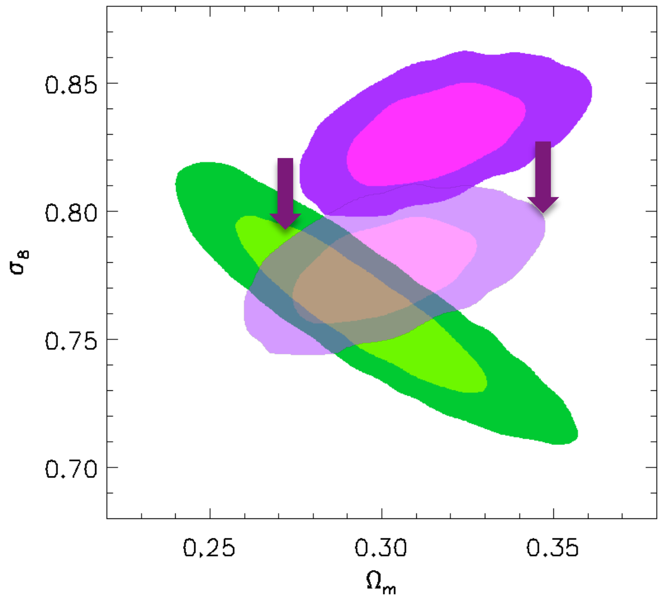
- Constraints on the total neutrino mass and the cluster mass bias





The fiducial value of the mass bias coming from numerical simulations would indicate a total neutrino mass between 0.25 and 0.35 eV

Solving the tension (2): massive neutrinos



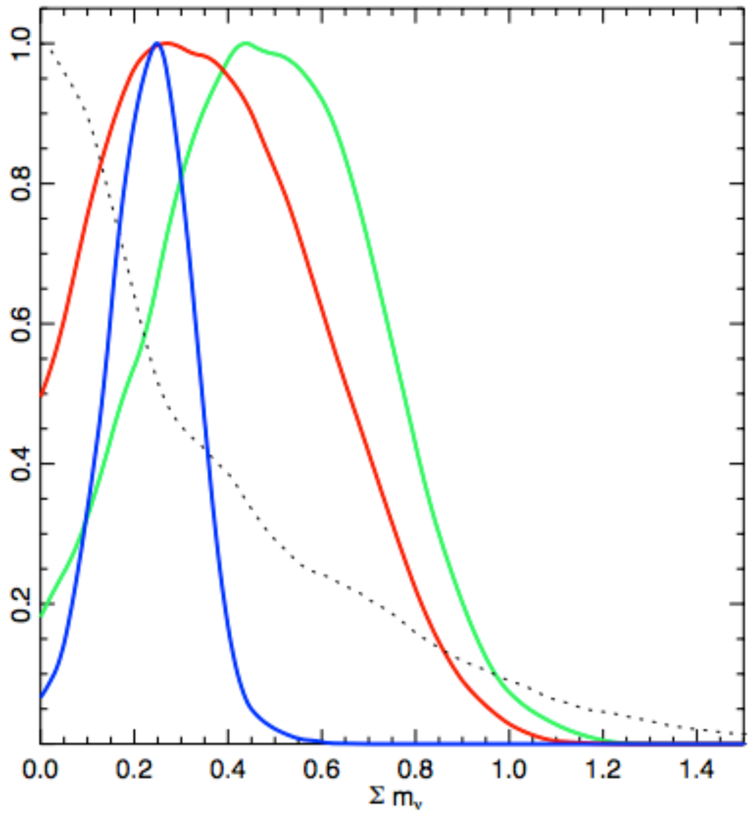


Fig. 12. Cosmological constraints when including neutrino masses $\sum m_\nu$ from: *Planck* CMB data alone (black dotted line); *Planck* CMB + SZ with $1-b$ in [0.7, 1] (red); *Planck* CMB + SZ + BAO with $1-b$ in [0.7, 1] (blue); and *Planck* CMB + SZ with $1-b = 0.8$ (green).

Planck CMB+SZ+BAO
(free bias)

$$\sum m_\nu = 0.22 \pm 0.09 \text{ eV}$$

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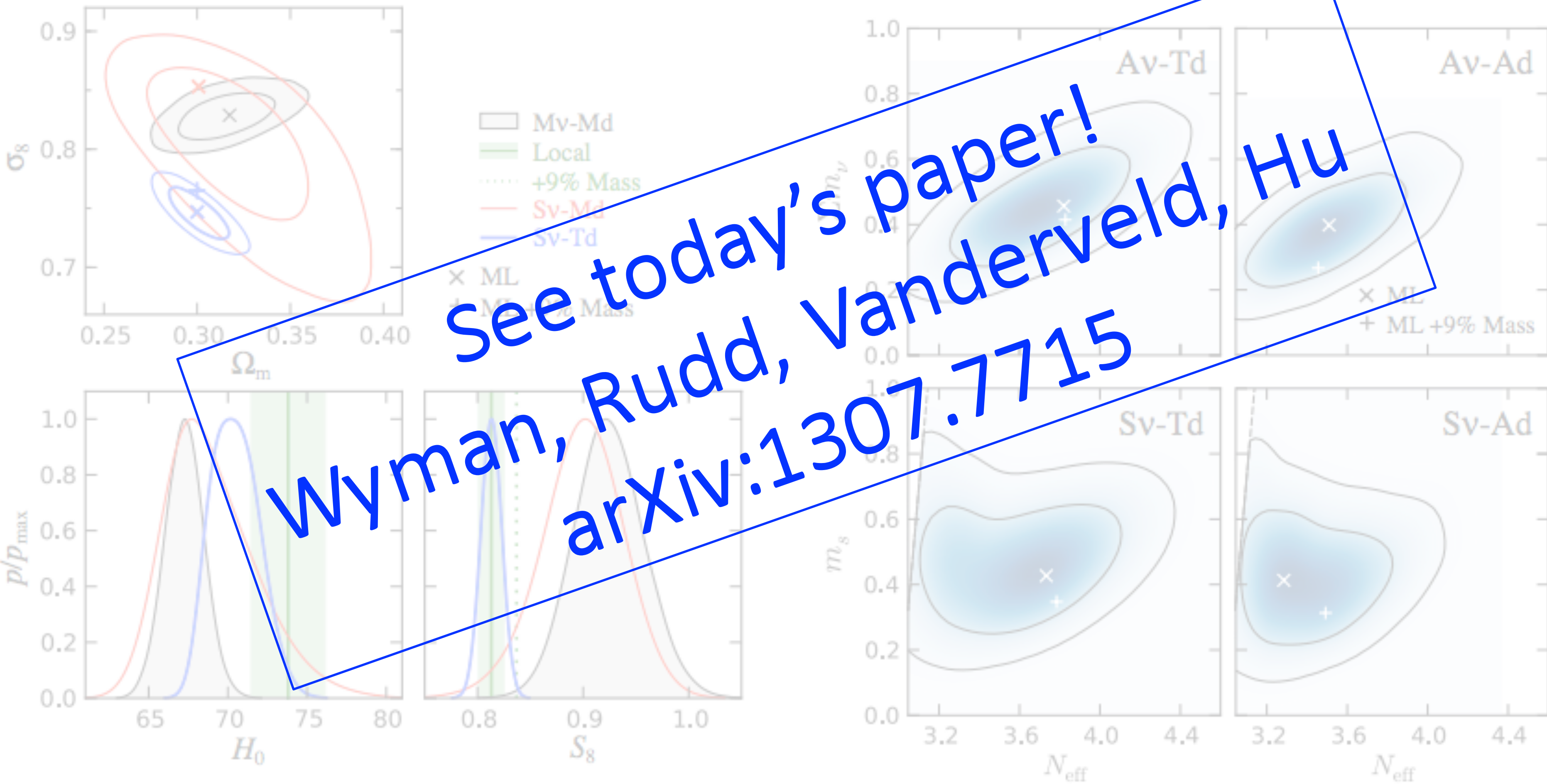
arXiv 1303.5080

Solving the tension (2): massive neutrinos

See today's paper!
Wyman, Rudd, Vanderveld, Hu
arXiv:1307.7715



Other cosmological probe: SZ spectrum

$$y(\mathbf{n}) = \int dl \; n_e \frac{k_B T_e}{m_e c^2} \sigma_T$$

$$\overbrace{C_\ell^{tSZ}}^{\text{1 halo term: intra halo correlation}} = \int_0^{z_{\max}} dz \underbrace{\frac{dV_c}{dz d\Omega}}_{\text{comoving volume}} \int_{M_{\min}}^{M_{\max}} dM \overbrace{\frac{dn(z,M)}{dM}}^{\text{mass function}} \underbrace{|\tilde{y}_\ell(z,M)|^2}_{\text{Fourier transform of radial pressure profile}}$$

+ inter halo correlation term..

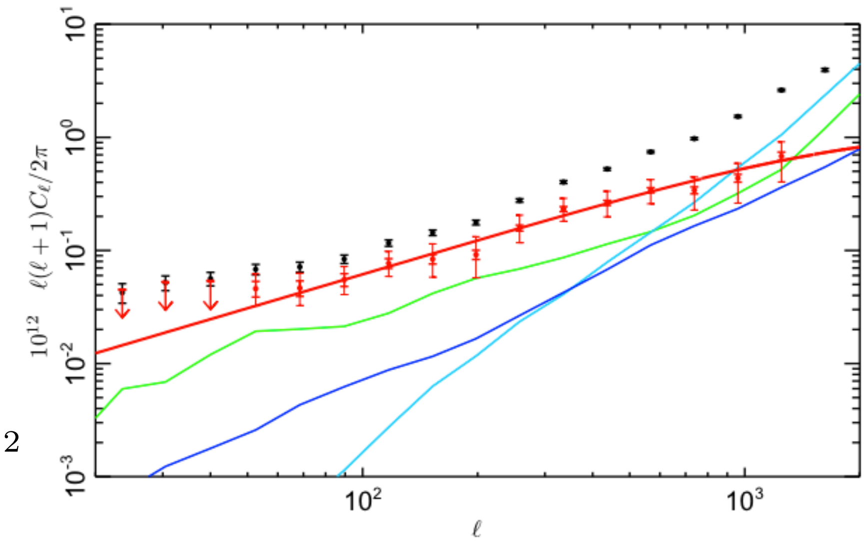


Fig. 7. NILC F/L cross power spectrum before (black points) and after (red points) foreground correction, compared to the power spectra of the physically motivated foreground models. Specifically we show: clustered CIB (green line); infrared sources (cyan line); and radio sources (blue line). The statistical (thick line) and total (statistical plus foreground, thin line), uncertainties are also shown. We also show the best-fit tSZ power spectrum model presented in Sect.7.1 as a solid red line.

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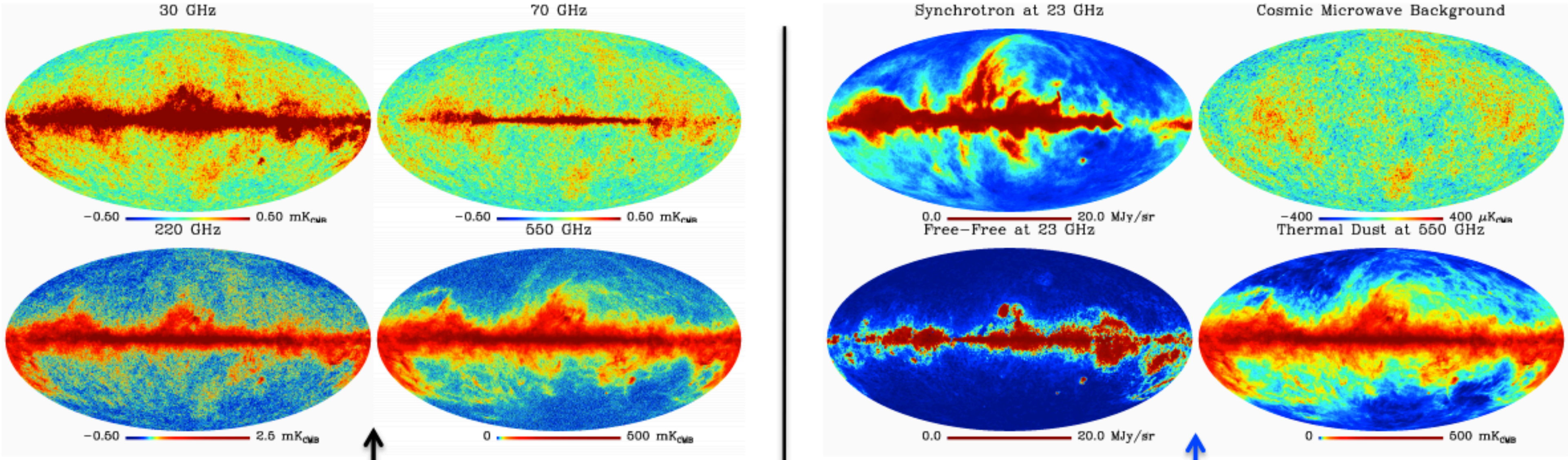
arXiv 1303.5081

SMICA: independent component analysis



$$\boldsymbol{x}(p) = \mathrm{A}\,\boldsymbol{s}(p)$$

$$\widehat{\boldsymbol{s}}(p) = \mathrm{A}^{-1}\,\boldsymbol{x}(p)$$

Estimation of A

SMICA: independent component analysis

$$x(p) = A(p)\, s(p) + n(p)$$

Different scaling laws, different maps at different resolutions

Correlated components

Observations are noisy

- NOT independent components
- Partial knowledge of A for some components
- Minimisation likelihood with conjugate gradient

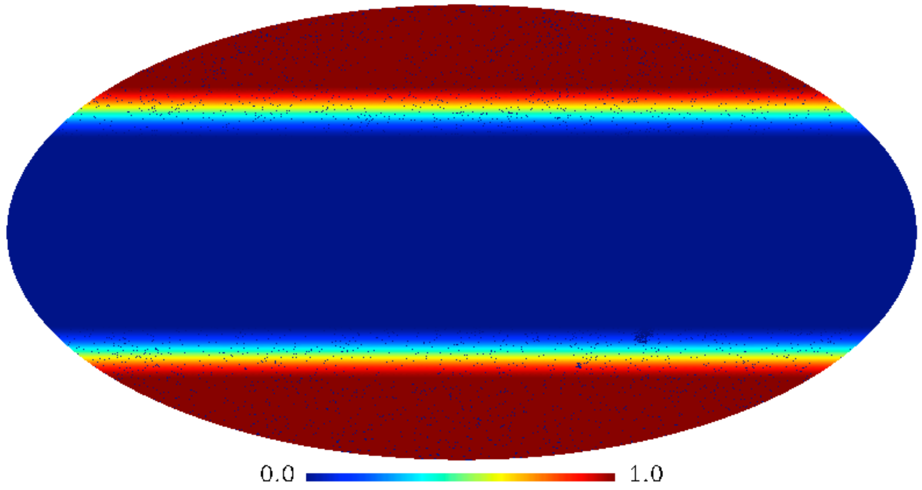
$$\mathbf{R}_x = \mathbf{A}\mathbf{R}_s\mathbf{A}^{\mathrm{T}} + \mathbf{R}_n$$

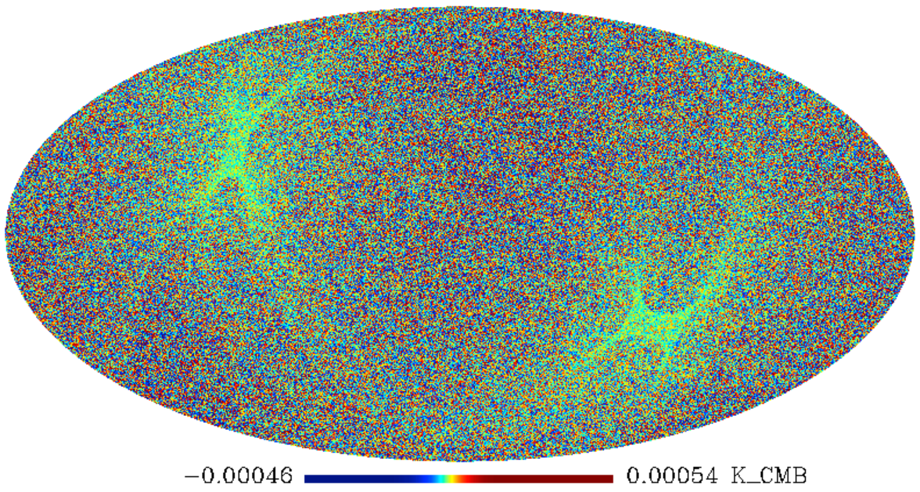
$$\mathbf{R}_{s,q} = \underbrace{\mathbf{R}_q^{\mathrm{cmb}} + \mathbf{R}_q^{\mathrm{sz}}}_{\text{coherent emissions}} + \underbrace{\mathbf{R}_q^{\mathrm{gal}}}_{n\text{ dim component}} \qquad \underbrace{\mathbf{R}_n}_{\text{diagonal}}$$

Goal: finding $c_{sz}(l)$ in a given multipole bin

Validation on simulation: pipeline

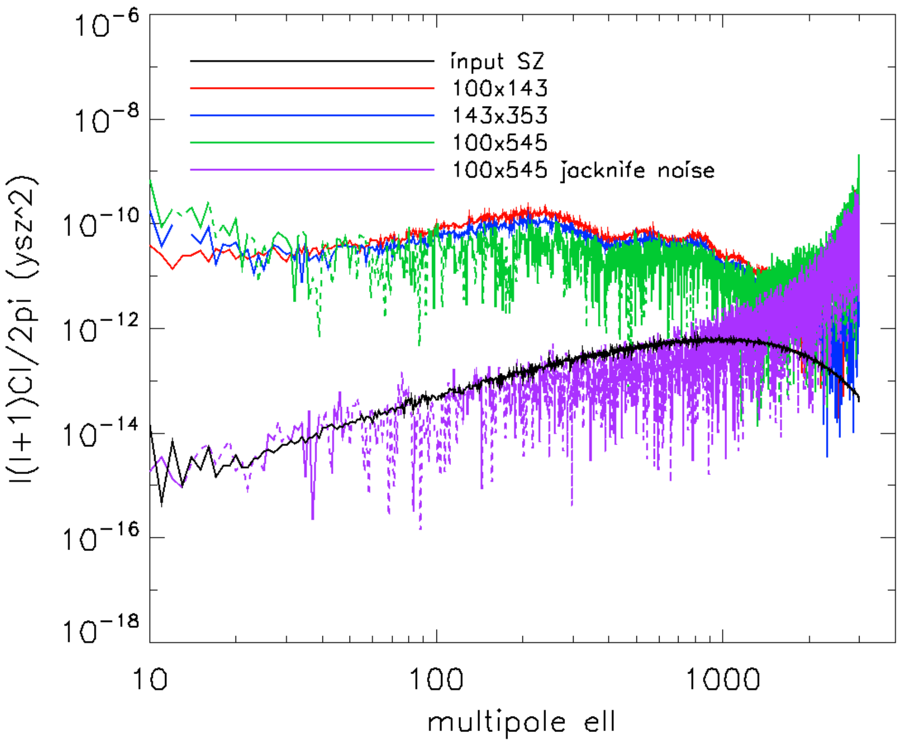
- Simulations from the *Planck Sky Model*, the reference software for sky emission and its observation by instruments
- Content of simulation maps: lensed non-gaussian CMB + point sources (radio and IR) + synchrotron + free-free + CO + thermal and spinning dust + tSZ + kSZ
- Point sources + galactic mask covering 70% of the sky
- Jacknife correlated noise
- 32 bins in ell, from 100 to 2500
- 5 arcmin resolution

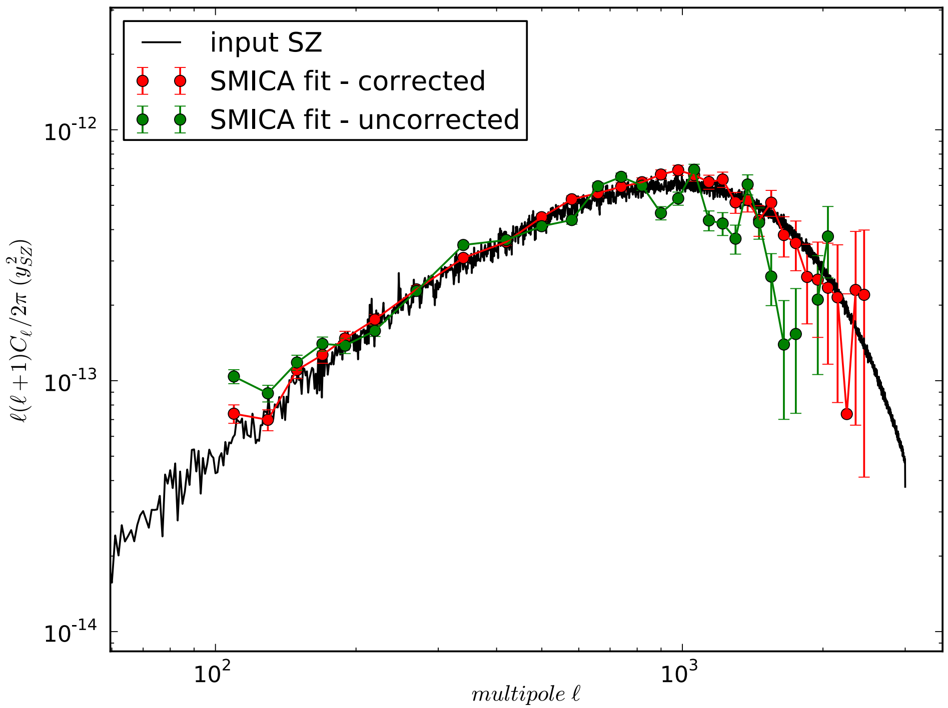




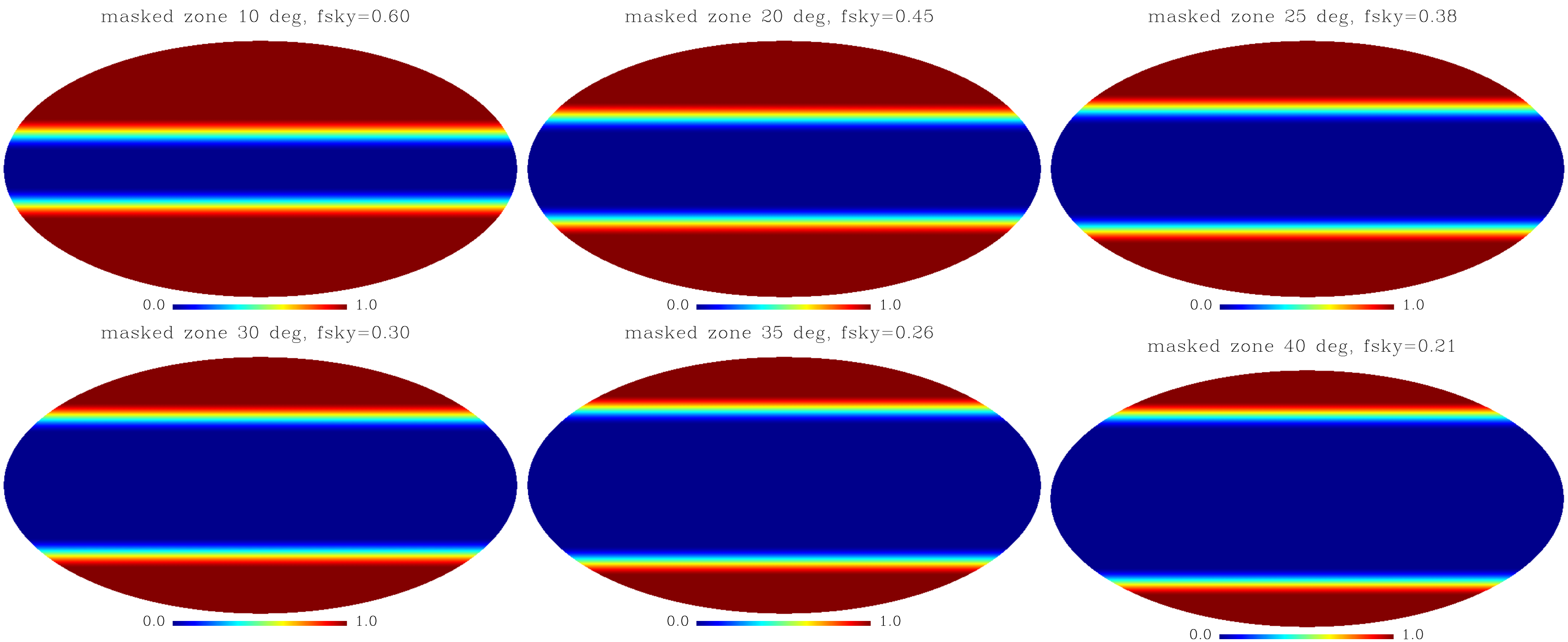
Validation on simulation: correlated jacknife noise

- Channel-to-channel correlation of the noise at the level of the input SZ power spectrum and above after l=1000
- Non-diagonal terms in the noise correlation matrix are subtracted from the data

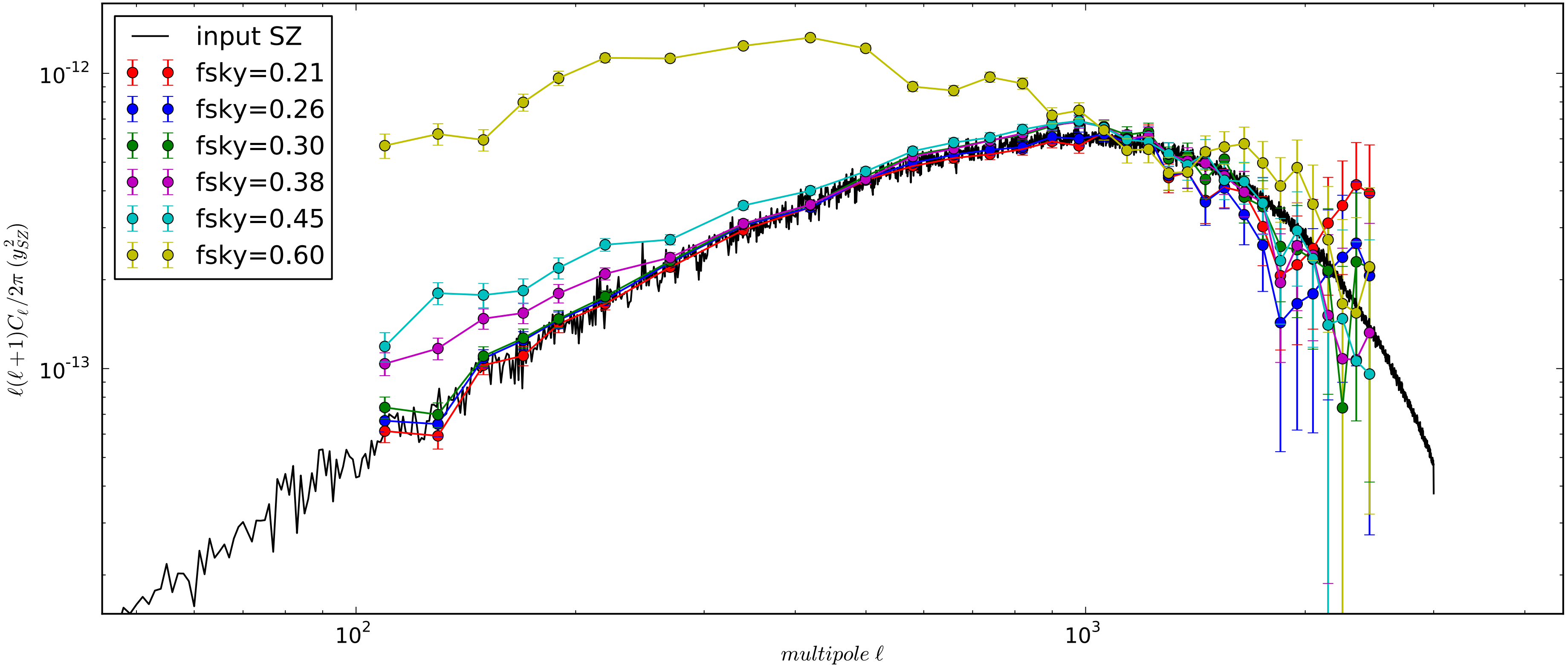




Validation on simulation: changing the galactic mask

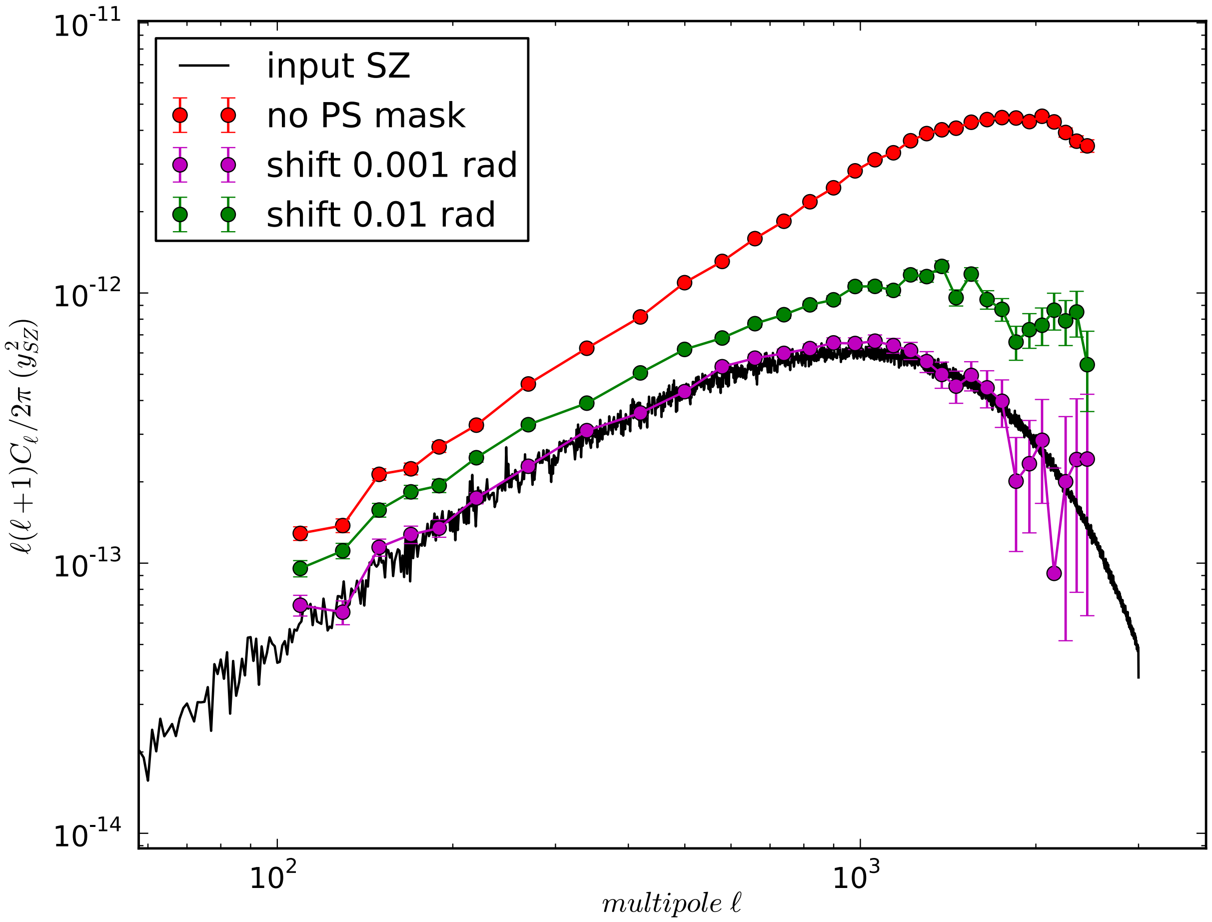


Validation on simulation: changing the galactic mask

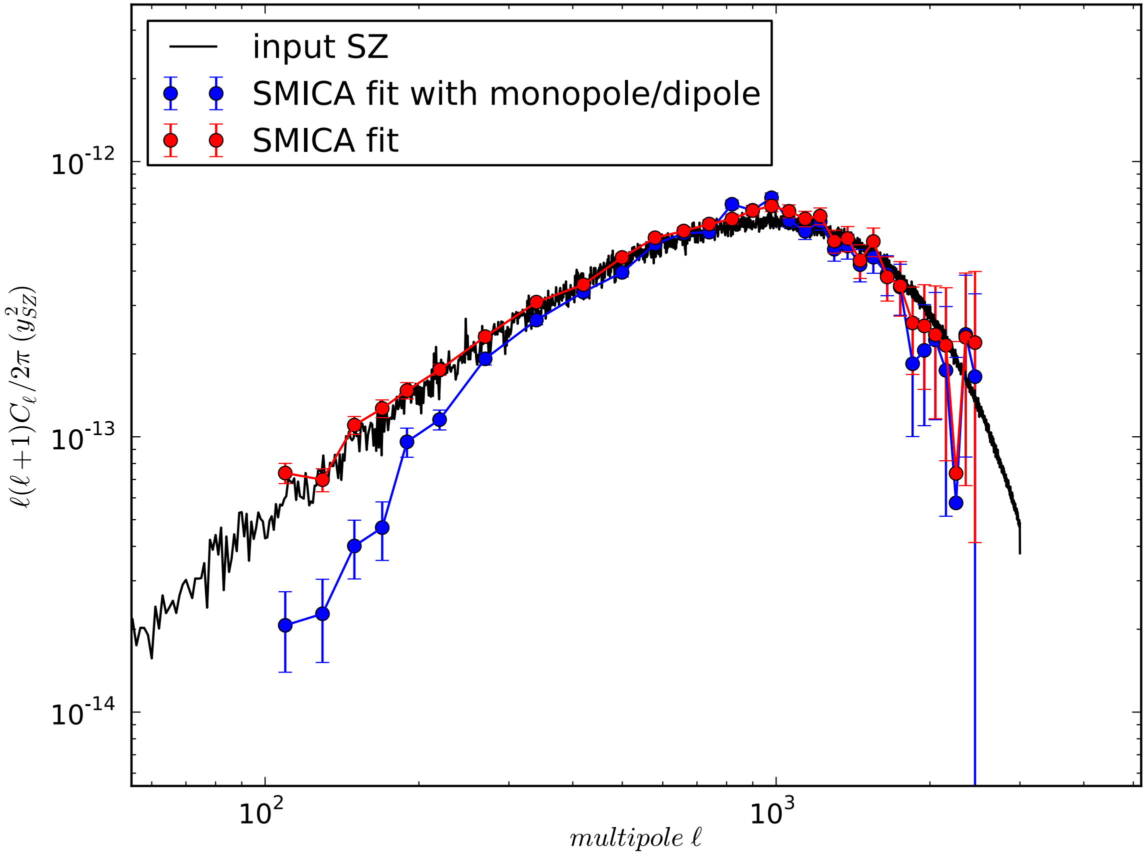


Validation on simulation: point sources contamination

- The position of the point sources are randomly drawn around their central value
- For an error comparable to the size of the mask holes, SMICA recovers correctly the input spectrum
- A non-realistic error case shows a lot of contamination and the importance of an accurate point sources masking



Validation on simulation: adding monopole/dipole contributions



- The monopole and dipole contributions are estimated on the released Planck maps and added to the simulation
- It affects the accuracy of the SZ spectrum fit at large scales
- Important to be removed on data

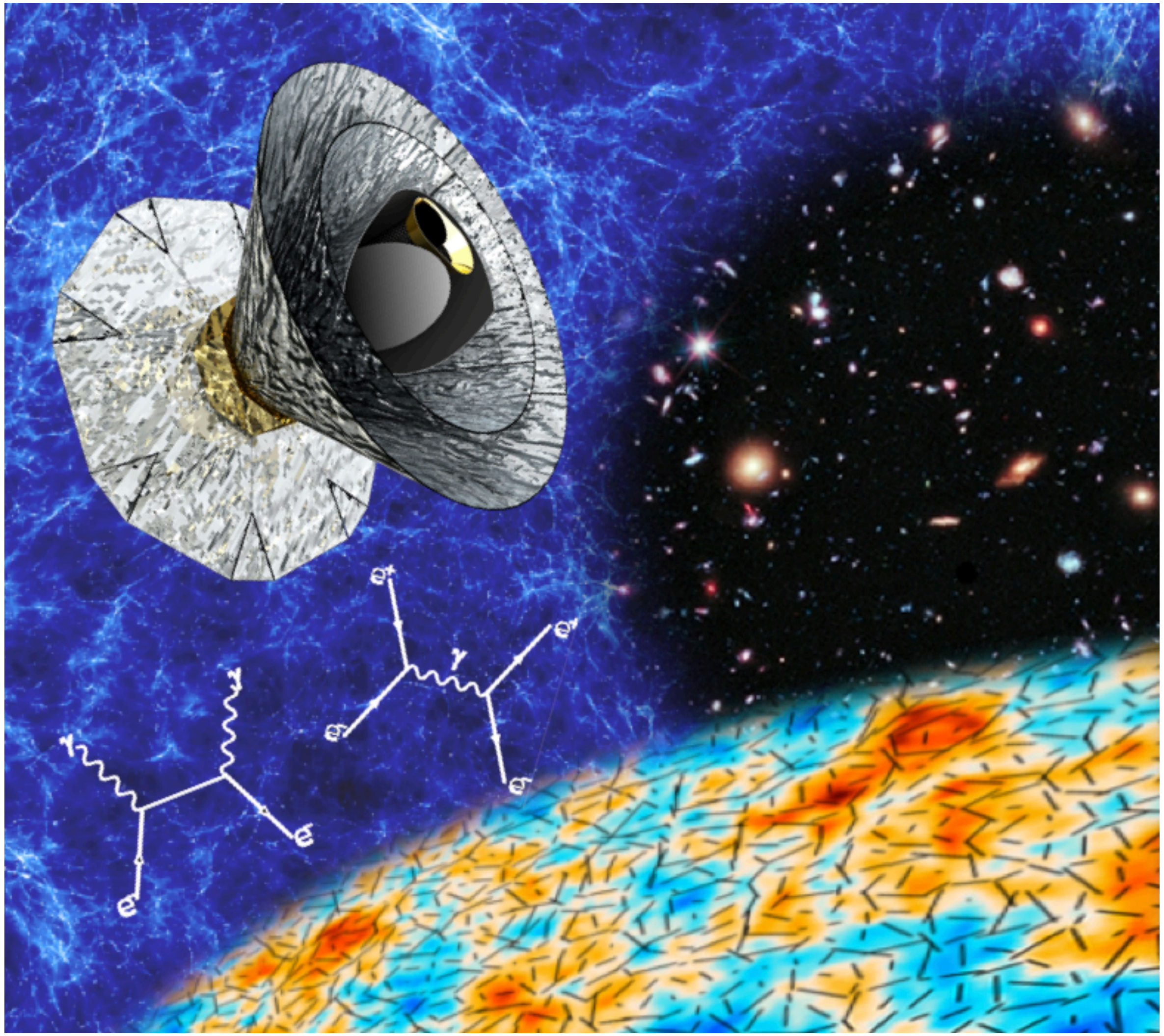
Validation on simulation

- The tests show that the method is stable concerning the fit settings:
  - number of iterations
  - error in the mixing vectors
  - dimension of the galactic component
  - …
- It is reliable from the point of view of point sources and galactic contamination
- It needs non-conservative galactic masks and accurate point sources pre-processing
- It shows the importance of the monopole and dipole contributions
- Results on public released data agree well with the published power spectrum level

Polarized Radiation Imaging and Spectroscopy Mission

The future: PRISM

- L-class mission to answer the 2013 ESA call for L2 and L3 missions
- Absolute emission and polarisation in the far IR to the mm range with unprecedented resolution (from a few arcsec to a few arcmin) and sensitivity



Polarized Radiation Imaging and Spectroscopy Mission

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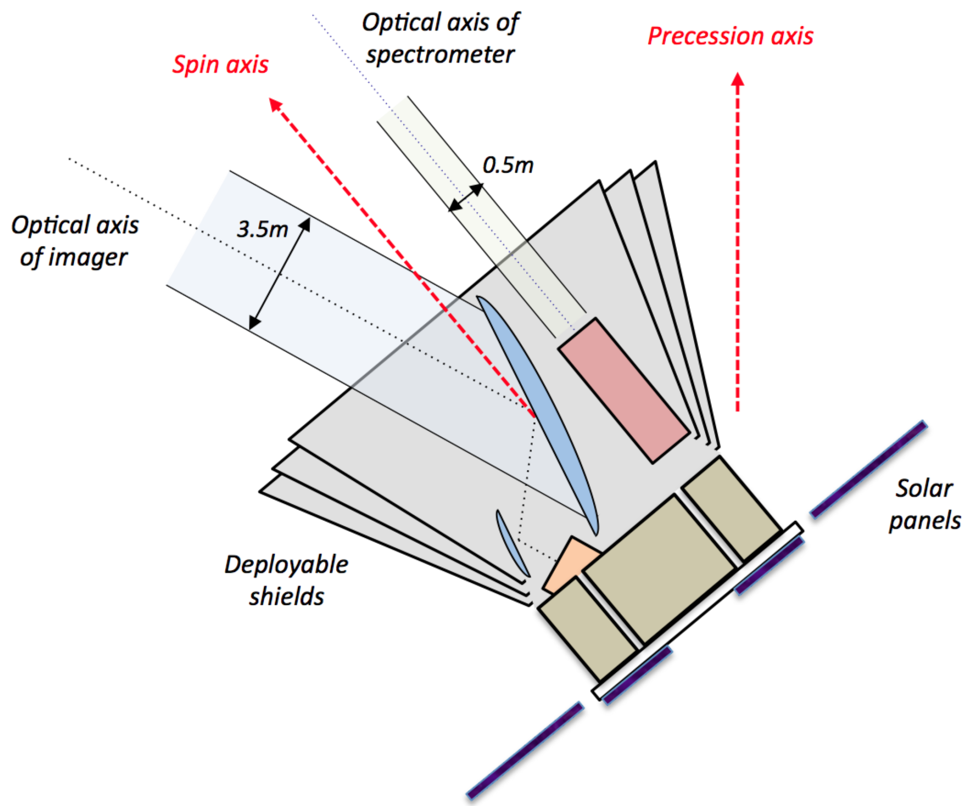
ν_0	range	$\Delta\nu/\nu$	n_{det}	$\theta_{\rm fwhm}$	σ_I per det 1 arcmin		$\sigma_{(Q,U)}$ per det 1 arcmin		main molec. & atomic lines
GHz	GHz				μK_{RJ}	μK_{CMB}	μK_{RJ}	μK_{CMB}	
30	26-34	.25	50	17'	61.9	63.4	87.6	89.7	
36	31-41	.25	100	14'	57.8	59.7	81.7	84.5	
43	38-48	.25	100	12'	53.9	56.5	76.2	79.9	
51	45-59	.25	150	10'	50.2	53.7	71.0	75.9	
62	54-70	.25	150	8.2'	46.1	50.8	65.2	71.9	
75	65-85	.25	150	6.8'	42.0	48.5	59.4	68.6	
90	78-100	.25	200	5.7'	38.0	46.7	53.8	66.0	HCN & HCO^+ at 89 GHz
105	95-120	.25	250	4.8'	34.5	45.6	48.8	64.4	CO at 110-115 GHz
135	120-150	.25	300	3.8'	28.6	44.9	40.4	63.4	
160	135-175	.25	350	3.2'	24.4	45.5	34.5	64.3	
185	165-210	.25	350	2.8'	20.8	47.1	29.4	66.6	HCN & HCO^+ at 177 GHz
200	180-220	.20	350	2.5'	18.9	48.5	26.7	68.6	
220	195-250	.25	350	2.3'	16.5	50.9	23.4	71.9	CO at 220-230 GHz
265	235-300	.25	350	1.9'	12.2	58.5	17.3	82.8	HCN & HCO^+ at 266 GHz
300	270-330	.20	350	1.7'	9.6	67.1	13.6	94.9	
320	280-360	.25	350	1.6'	8.4	73.2	11.8	103	CO, HCN & HCO^+
395	360-435	.20	350	1.3'	4.9	107	7.0	151	
460	405-520	.25	350	1.1'	3.1	156	4.4	221	CO, HCN & HCO^+
555	485-625	.25	300	55"	1.6	297	2.3	420	C-I, HCN, HCO^+, H_2O, CO
660	580-750	.25	300	46"	0.85	700	1.2	990	CO, HCN & HCO^+
					nK_{RJ}	kJy/sr	nK_{RJ}	kJy/sr	
800	700-900	.25	200	38"	483	9.5	683	13.4	
960	840-1080	.25	200	32"	390	11.0	552	15.6	
1150	1000-1300	.25	200	27"	361	14.6	510	20.7	
1380	1200-1550	.25	200	22"	331	19.4	468	27.4	N-II at 1461 GHz
1660	1470-1860	.25	200	18"	290	24.5	410	34.7	
1990	1740-2240	.25	200	15"	241	29.3	341	41.5	C-II at 1900 GHz
2400	2100-2700	.25	200	13"	188	33.3	266	47.1	N-II at 2460 GHz
2850	2500-3200	.25	200	11"	146	36.4	206	51.4	
3450	3000-3900	.25	200	8.8"	113	41.4	160	58.5	O-III at 3393 GHz
4100	3600-4600	.25	200	7.4"	98	50.8	139	71.8	
5000	4350-5550	.25	200	6.1"	91	70.1	129	99.1	O-I at 4765 GHz
6000	5200-6800	.25	200	5.1"	87	96.7	124	136	O-III at 5786 GHz

PRISM collaboration
arXiv 1306.2259

Polarized Radiation Imaging and Spectroscopy Mission

The future: PRISM

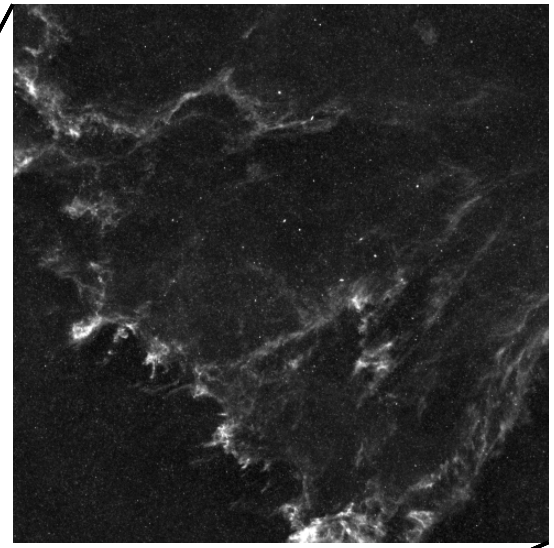
- 30 GHz – 6 THz range
- Two instruments:
  - a polarimetric imager with 30 broad and 300 narrow bands (3.5m telescope cooled to 4K)
  - an absolute spectrometer cooled to 2.7K with high and low resolution observing modes
- Platform orbiting around L2
- Companion satellite for telemetry and in-flight calibration

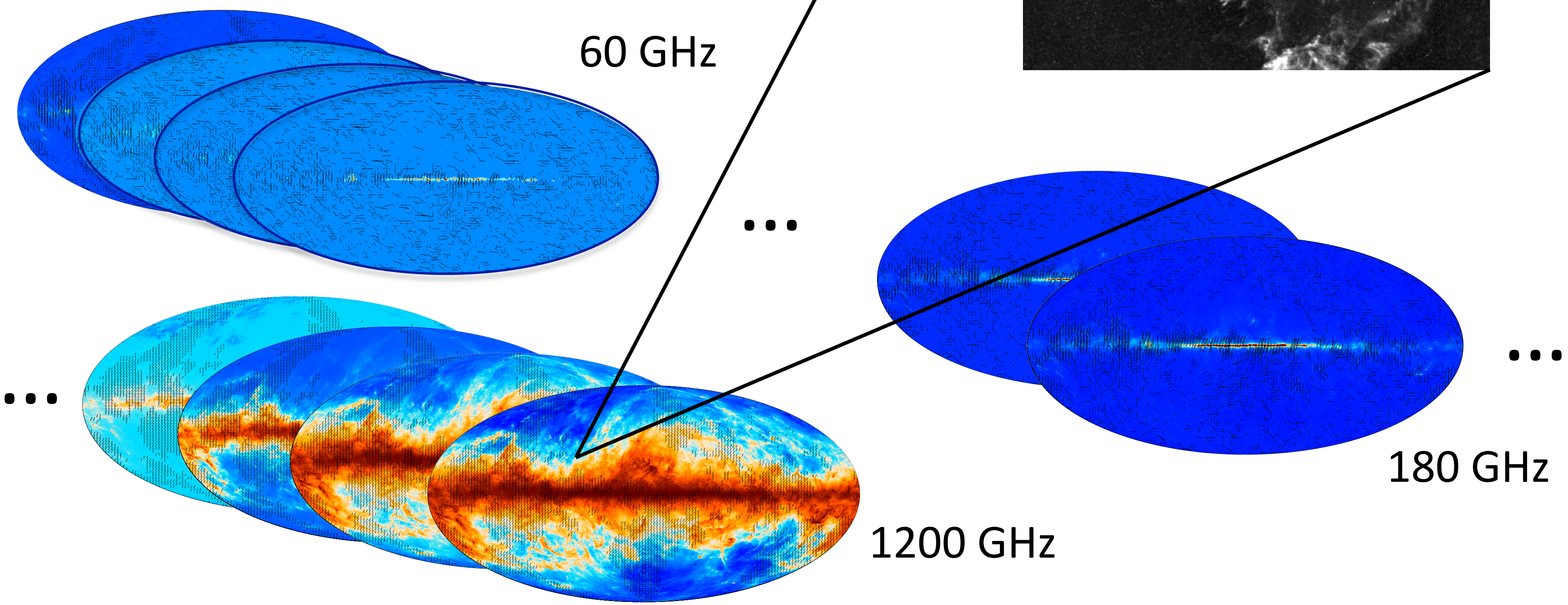


Polarized Radiation Imaging and Spectroscopy Mission

The future: PRISM

- Legacy
  - hundreds of intensity and polarisation maps
  - full spectro-polarimetric survey of the complete sky from 50 µm to 1 cm



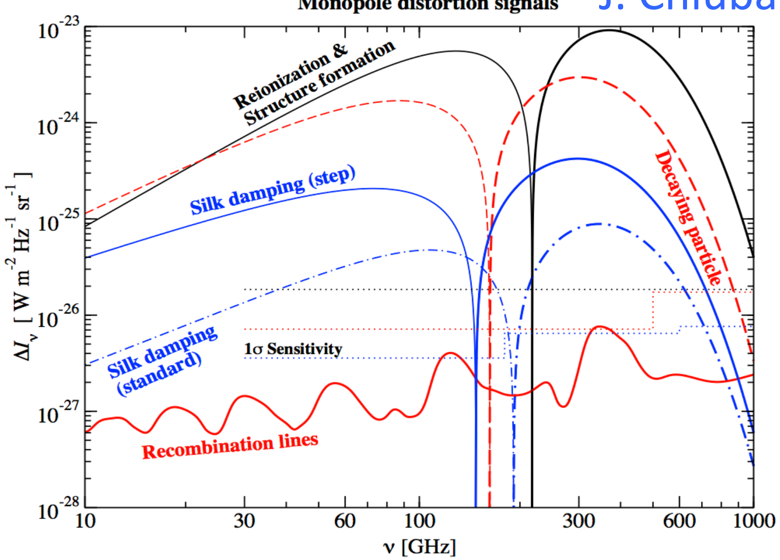


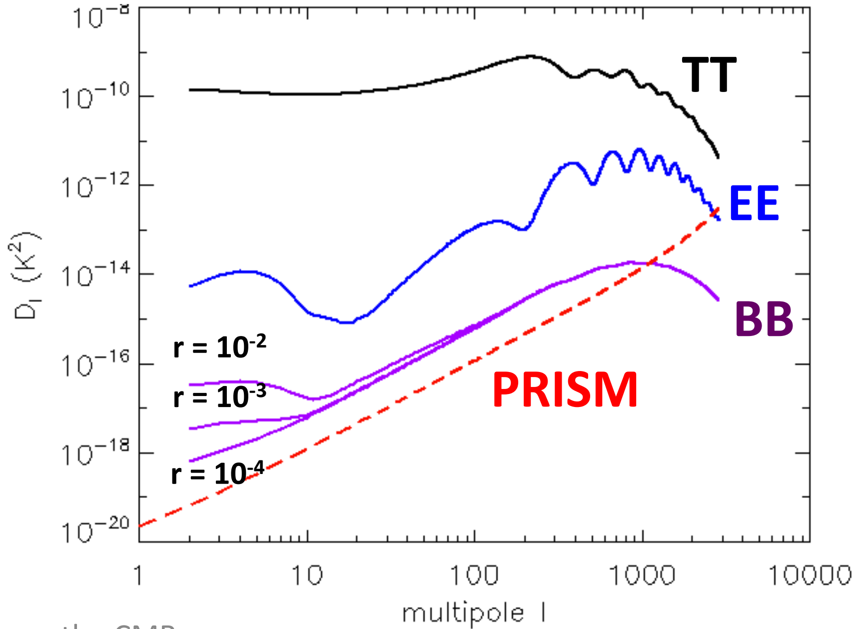
Polarized Radiation Imaging and Spectroscopy Mission

The future: PRISM

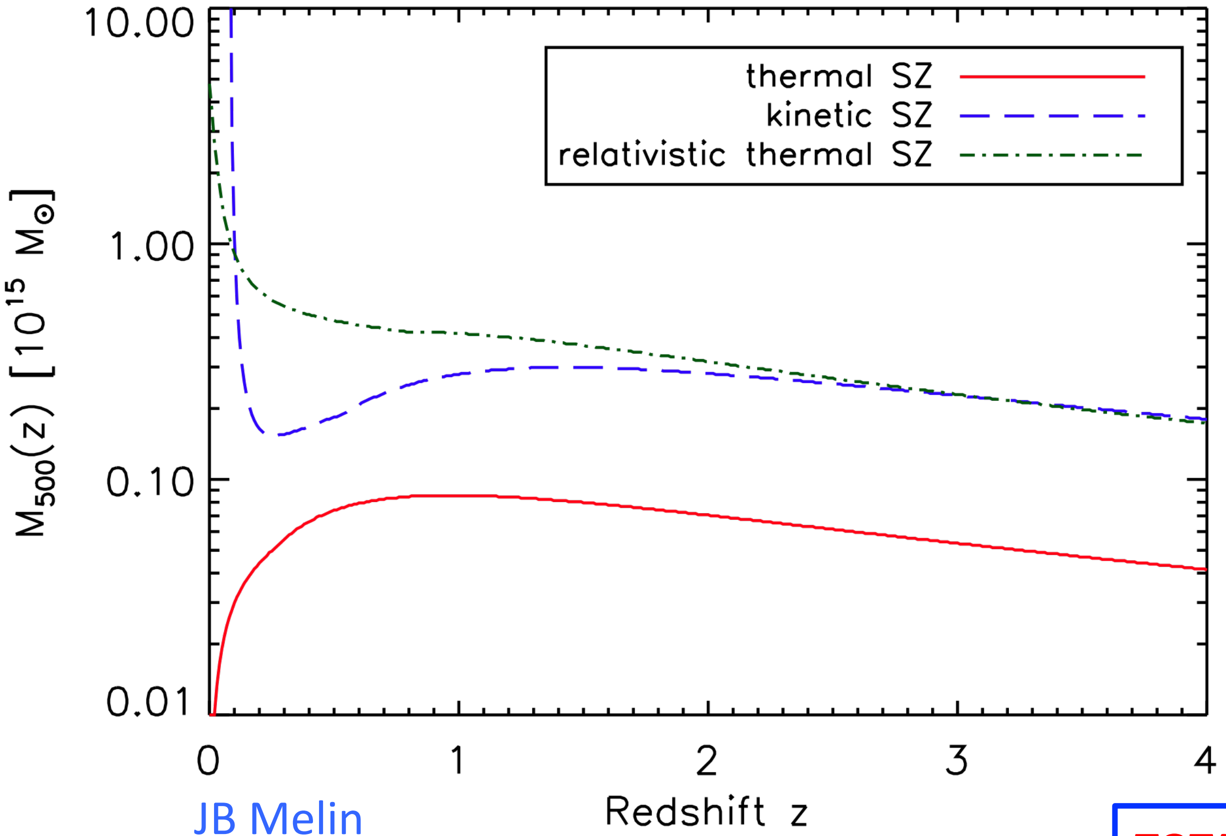
- Science case
  - Galactic ISM: role of magnetic field in star formation, composition and evolution of interstellar dust
  - CMB spectral distortions: mapping of y-distortions from hot clusters to re-ionized gas, early μ-distortions caused by decaying/annihilating dark matter
  - Inflation: detection of B-modes near the ideal instrument limit, CMB lensing, high measurements of bi-spectra and tri-spectra
  - CIB and LSS: details of star formation, cross-correlations of lensing and far-infrared emission
  - Galaxy clusters

J. Chluba





The ultimate SZ survey



JB Melin

5σ detections

$M_{500} = 4\times10^{13} M_\odot$ at z=4

TOTAL clusters detected: ≈ 10^6

TOTAL peculiar velocities: ≈ a few 10^5

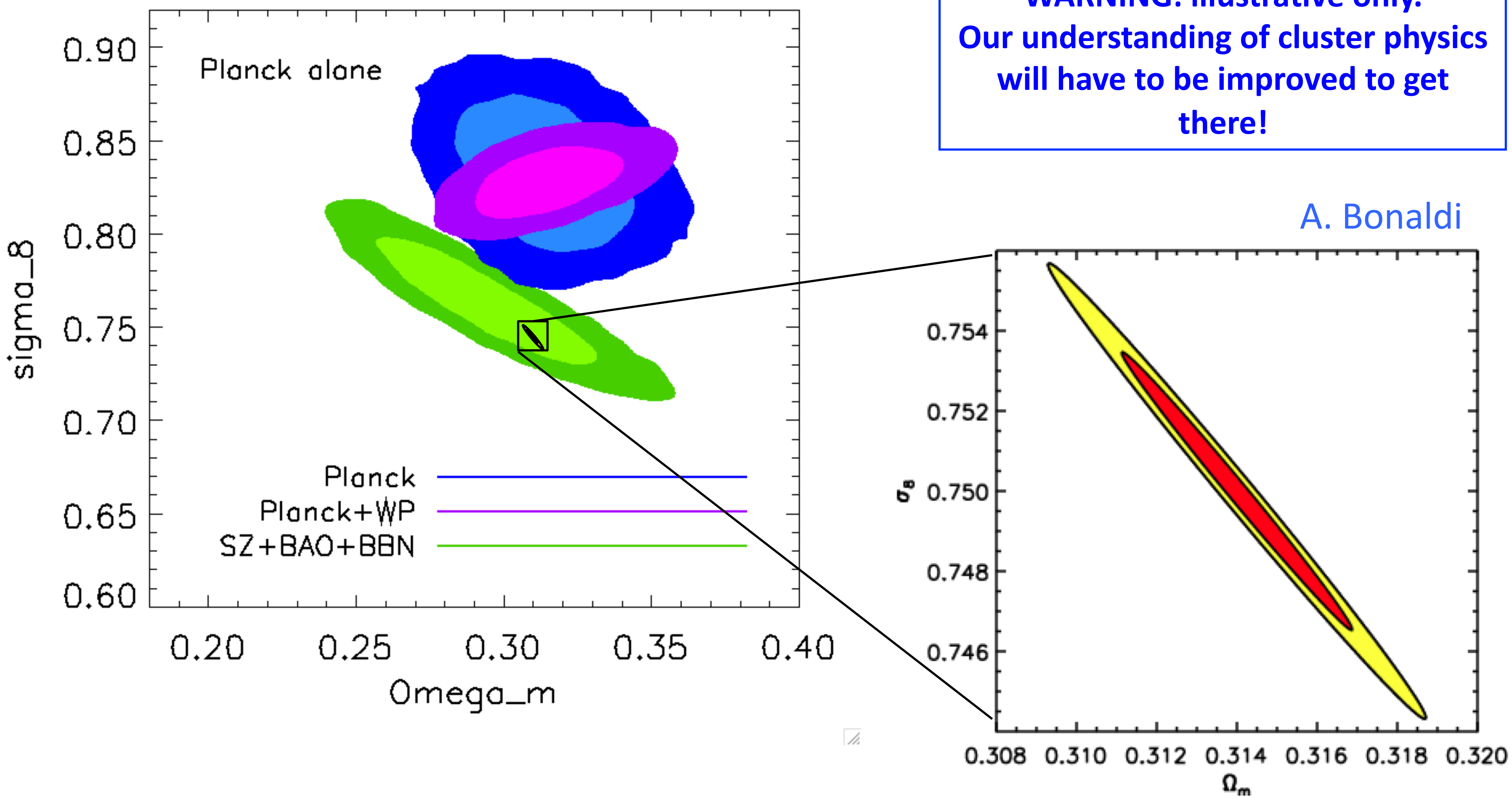
TOTAL relativistic SZ: ≈ a few 10^4

The ultimate SZ survey

Polarized Radiation Imaging and Spectroscopy Mission

**WARNING: illustrative only.
Our understanding of cluster physics will have to be improved to get there!**

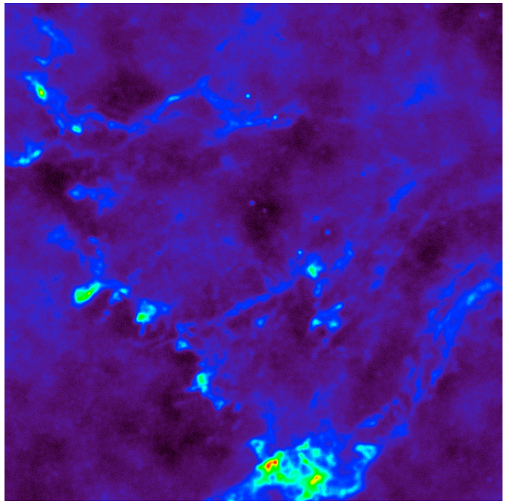
A. Bonaldi



Polarized Radiation Imaging and Spectroscopy Mission

Preliminary!

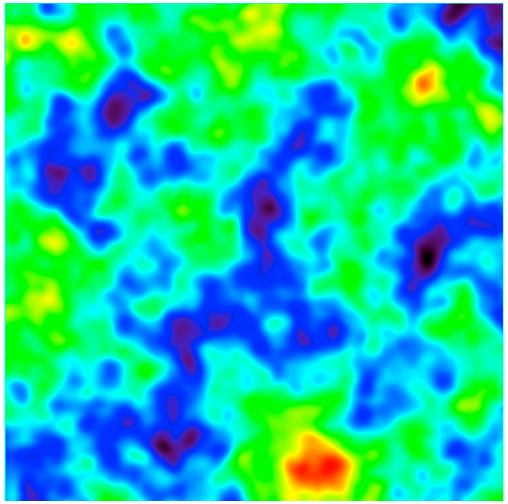
The ultimate SZ survey



Total

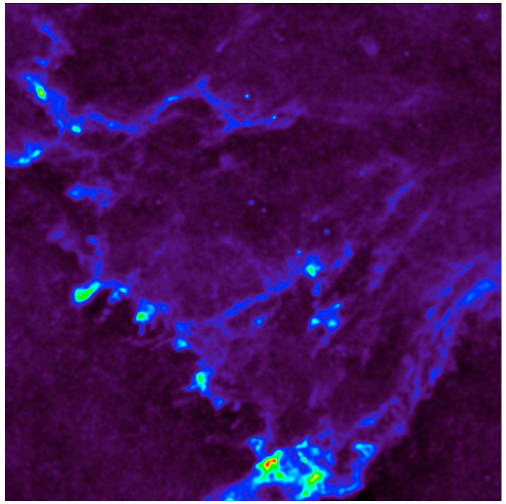
=

CMB



+

Dust

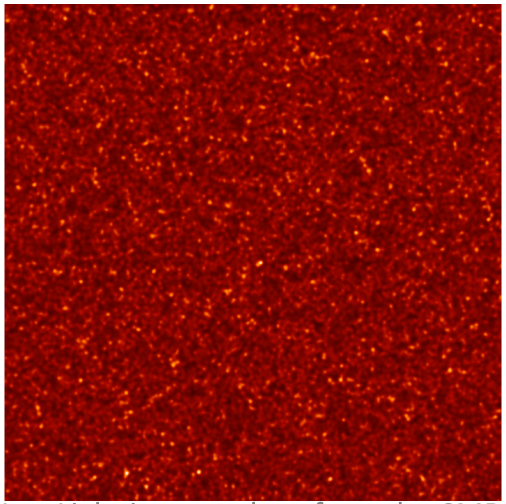


+

320 GHz, 1.6 arcmin resolution, 6 arcsec pixels, 12°x12° patches

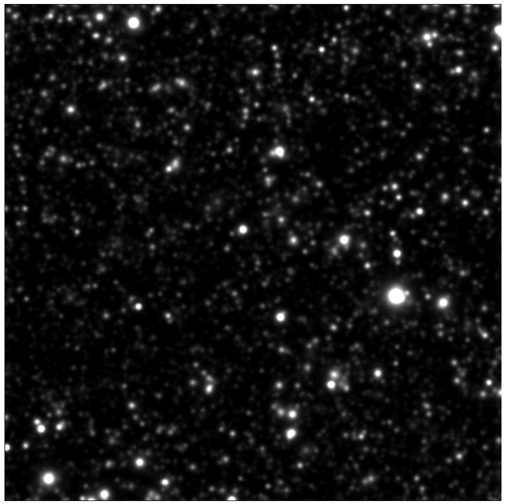
+

CIB



+

SZ clusters



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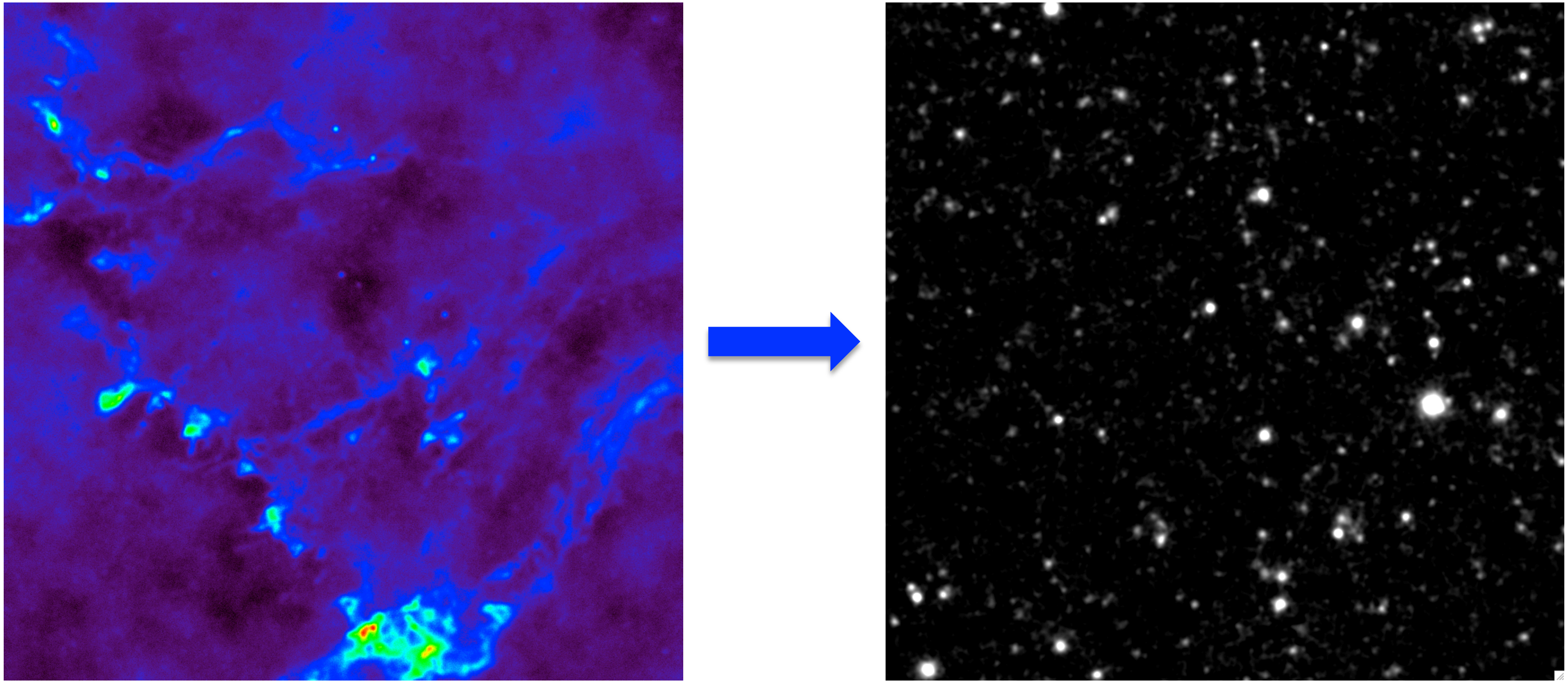
Preliminary!

The ultimate SZ survey



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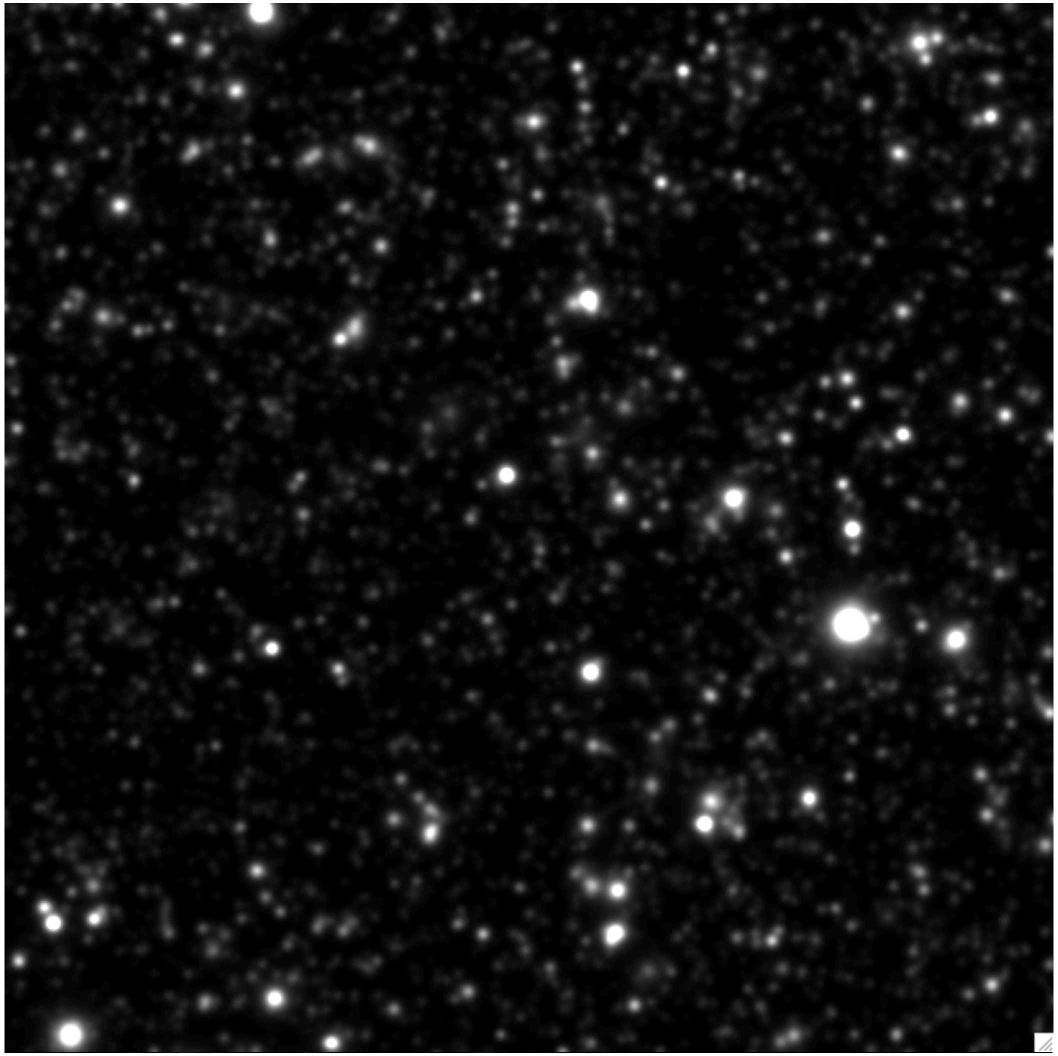
The ultimate SZ survey

Input tSZ map
at 1.6 arcmin



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The ultimate SZ survey

Output ILC map

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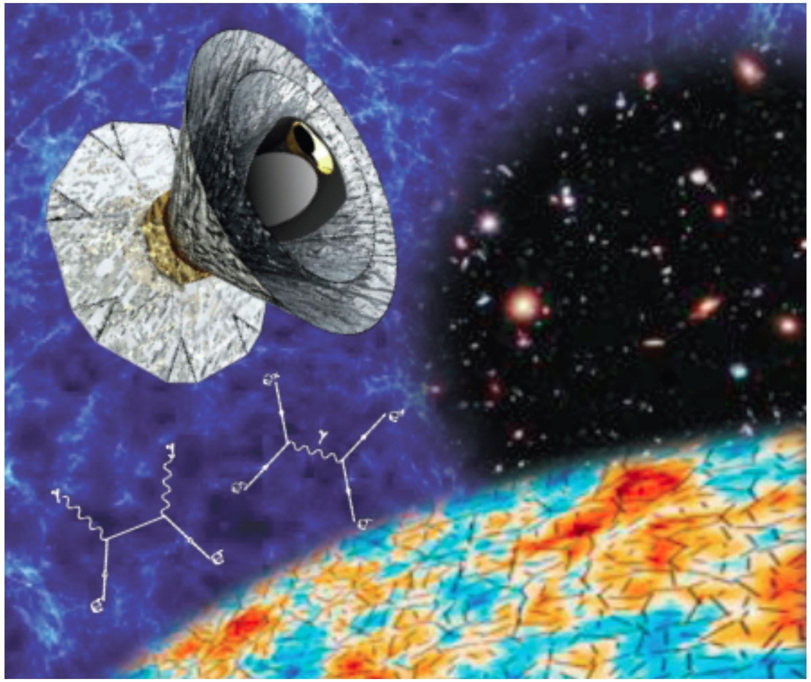
We need your support!

If you have not done so yet, please support this science case by signing in on the website

http://www.prism-mission.org



Credit: G. Castex

Thank you !