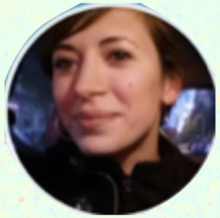
CMB @ small scales: tSZ power spectrum

Marian Douspis


Laura Salvati (IAS), Adélie Gorce (IAS→Mc Gill)


European Research Council
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"Probing the CMB small scales with Planck and SPT data", Douspis, Salvati, Gorce, A&A to be submitted.

- CMB @ small scales [focus on SZ signals]
- Standard analyses at high ell
- Alternative analysis
  - Power spectrum computation shortcut: ML
- Results on cosmological parameters
- Results on tSZ and kSZ amplitude
- Conclusion

Using tSZ signal : for Cosmology

- tSZ detected in clusters : number counts or baryon fraction as cosmological probe

*Talk: **Salvati***
Talk: Bocquet
Talk: Wicker

- Diffuse hot gas exists outside detected clusters : low mass systems, filaments

Talk: Radiconi
Talk: Lestrade
***Bonjean** et al*
***Tanimura** el al.*

  - Dedicated reconstruction of y-map

***Hurier** et al.*
***Remazeille** et al.*

  - Present in CMB frequency maps, thus in angular power spectra

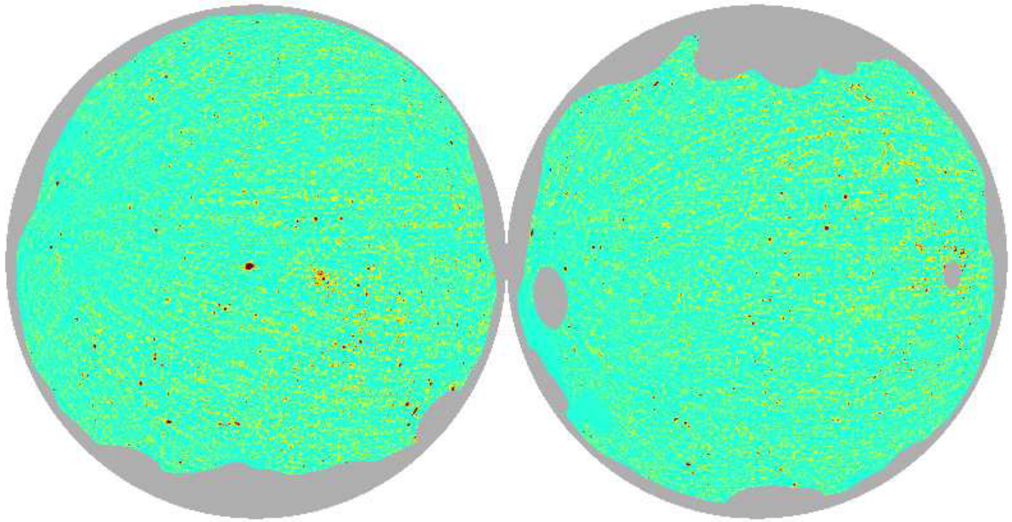
Planck collab
SPT collab
ACT collab
Taburet et al.
***Douspis** et al. in prep*

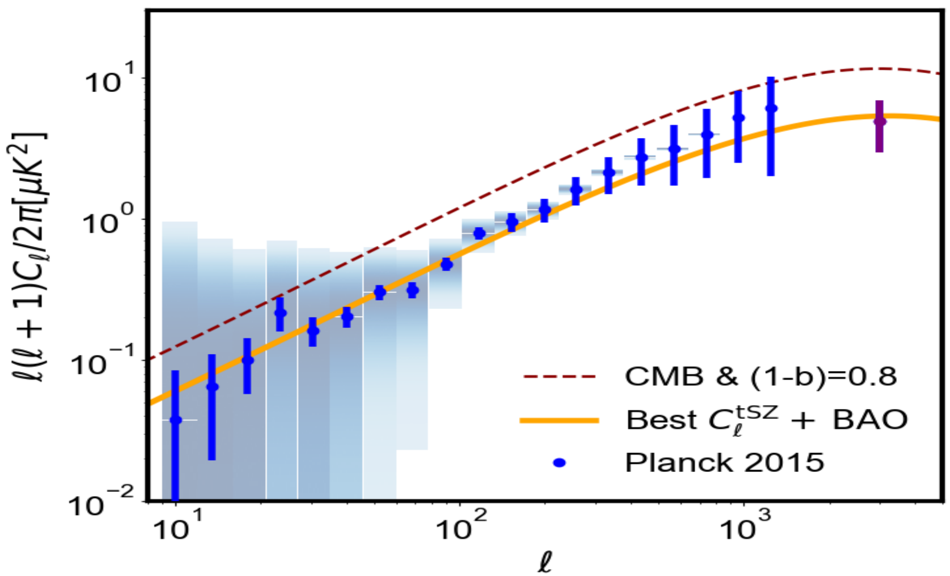
    - Power spectrum of tSZ needed

Talk: Rotti
***Taburet** et al. 2009*
***Salvati** et al.*

PLANCK YMAP

- Adapted component separation based on :
  - Constraints on emission spectra
  - Localisation in multiple domain
  - 100:857Ghz maps
- First SZ Angular power spectrum and cosmological constraints



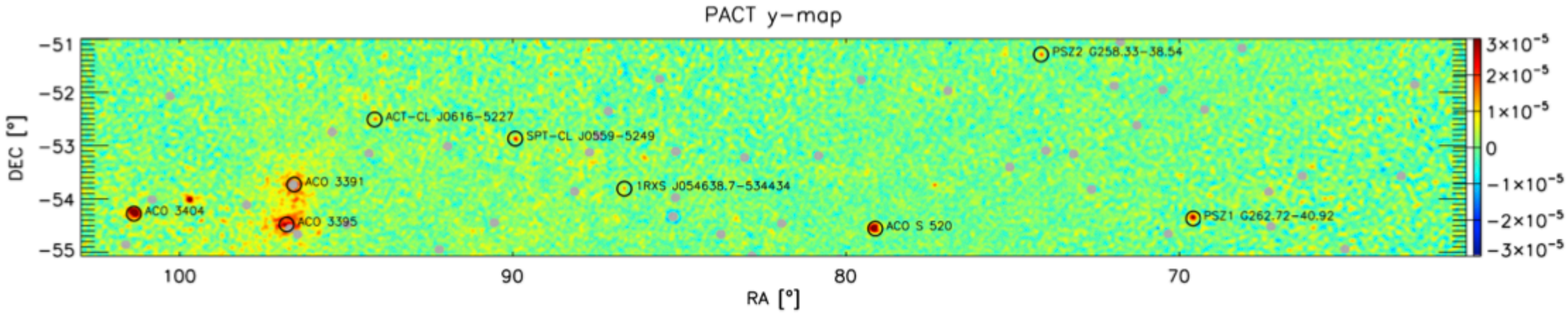


Planck *2014,* ***Planck*** *2016*
Douspis *et al.* ***Salvati*** *et al.*

OTHER YMAP

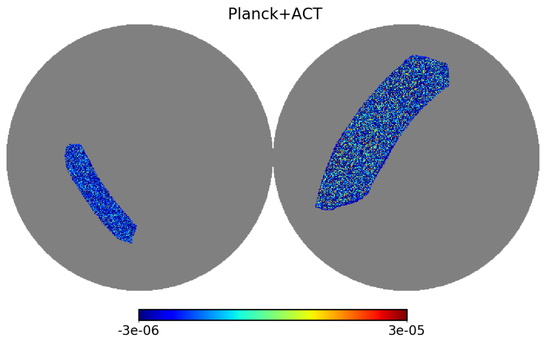
- Planck + ACT: PACT map: 1st combination of CMB experiments

Aghanim et al 2019



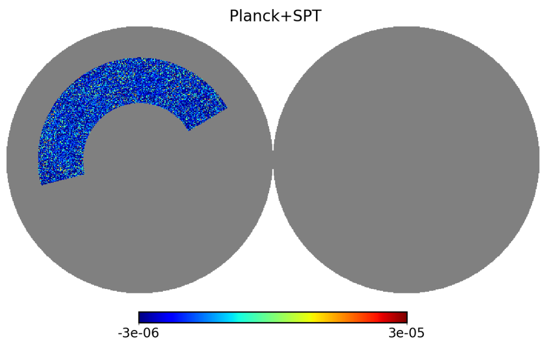
- Planck+ACT

Madhavacheril et al 2020



- Planck+SPT

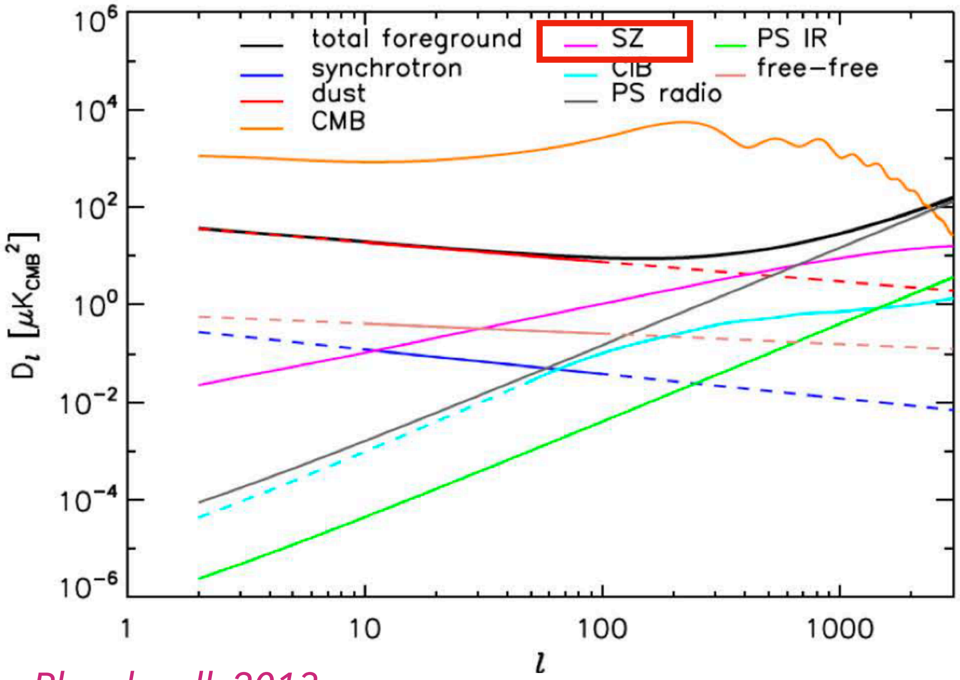
Bleem et al 2021



tSZ IN FREQUENCY MAPS (SMALL SCALES)

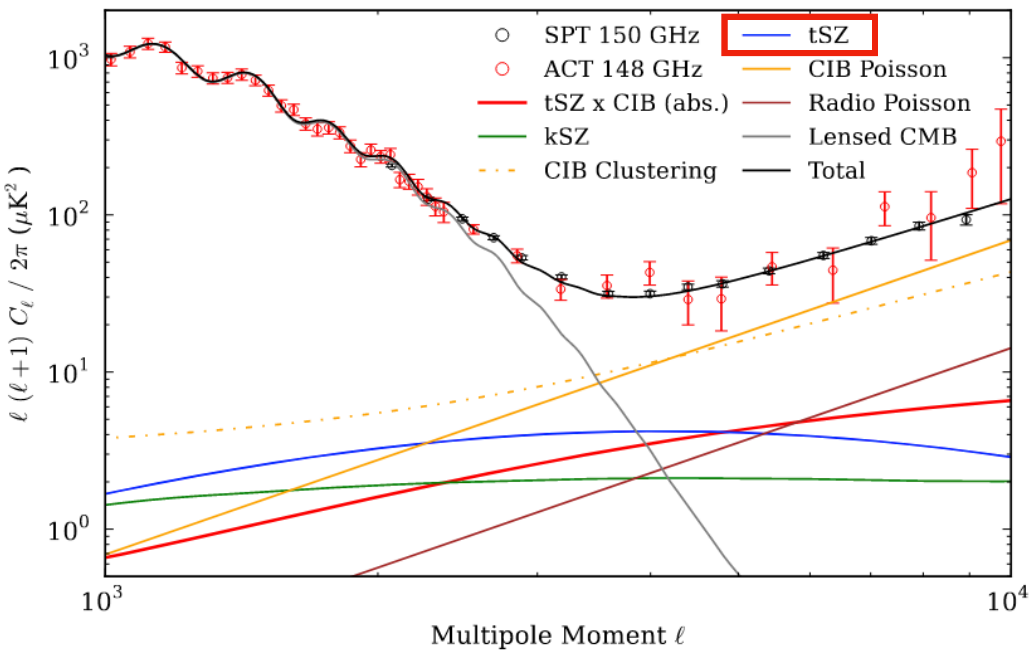
- Primordial CMB becomes negligible
- tSZ is hidden among many other signals

Planck/Large scales



Planck coll. 2013

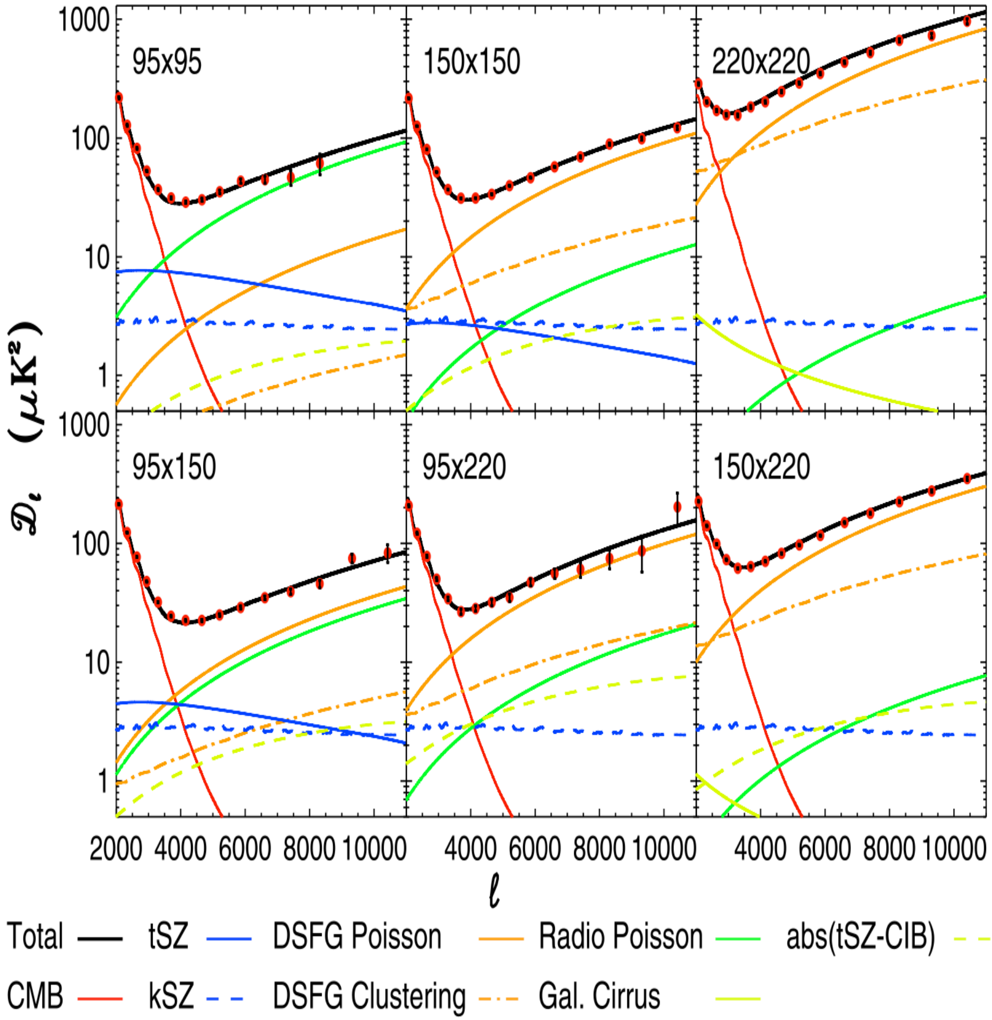
SPT/small scales



Addison et al. 2012

Focus on SPT High ell Analysis

- SPT-SZ +SPTpol data
- 3 frequencies: 95, 150, 220
- 6 cross-spectra
- 8 components
- ell in [2000:11000]

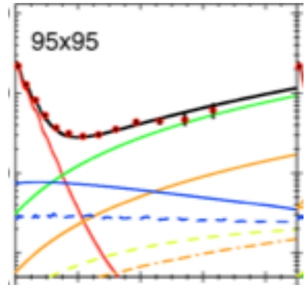


Reichardt et al. 2020

Focus on SPT High ell Analysis

$$C_\ell^{obs} = C_\ell^{CMB} + C_\ell^{tSZ} + C_\ell^{kSZ} + \ldots.$$

For all 6 cross spectra simultaneously

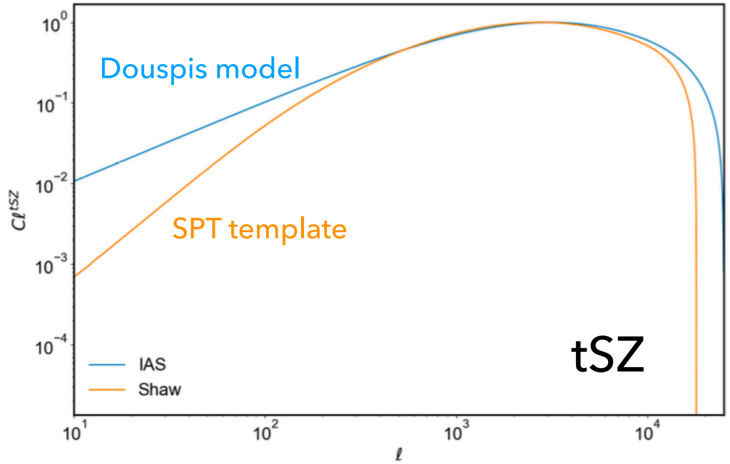


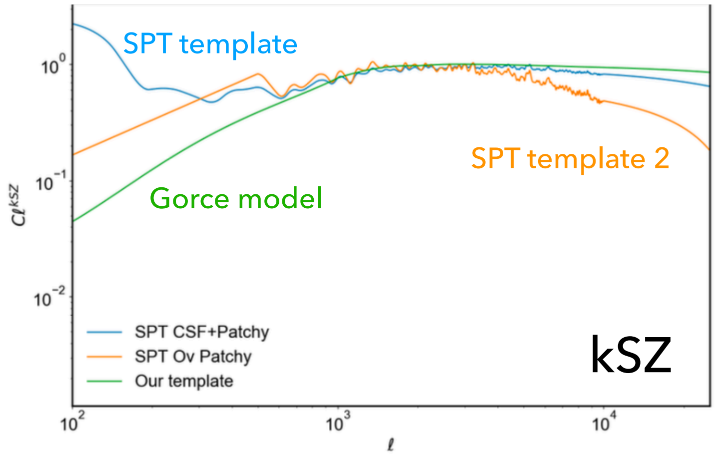
SPT analysis uses templates for tSZ and kSZ

$$C_\ell^{tSZ} = A^{tSZ} \times C_\ell^{template}$$ ← Sims with cosmo1

$$C_\ell^{kSZ} = A^{kSZ} \times C_\ell^{template}$$ ← Sims with cosmo2

- Not coherent analysis
- Depends on assumed template



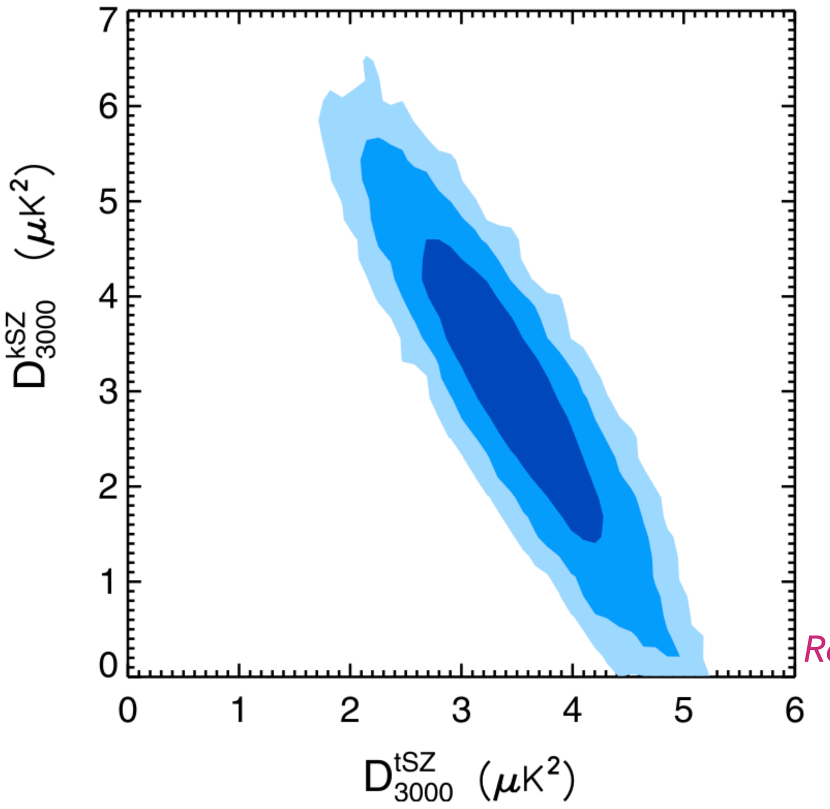


SPT constraints on SZ effects

SZ Constraints

tSZ Template	kSZ Template	$D_{3000}^{\rm tSZ}$ (μK^2)	$D_{3000}^{\rm kSZ}$ (μK^2)	ξ
Shaw	CSF+patchy	3.42 ± 0.54	3.0 ± 1.0	0.076 ± 0.040
Shaw	CSF	3.39 ± 0.58	3.1 ± 1.3	0.077 ± 0.047
Shaw	Patchy	3.45 ± 0.56	3.5 ± 1.2	0.086 ± 0.050
Battaglia	CSF+patchy	3.74 ± 0.54	2.4 ± 1.0	0.051 ± 0.033
Bhattacharya	CSF+patchy	3.46 ± 0.54	3.0 ± 1.0	0.071 ± 0.036
Sehgal	CSF+patchy	3.59 ± 0.54	2.8 ± 1.0	0.064 ± 0.039
Shaw w. Bispectrum	CSF+patchy	3.53 ± 0.48	2.8 ± 0.9	0.069 ± 0.036

Cosmology fixed to Planck 2018



Reichardt et al. 2020

But

- tSZ spectrum contains cosmological information and baryonic information in clusters
- kSZ contains mainly information on reionisation
- CIB contains cosmological information and SFR evolution information
- …

Hu & Seljak
Taburet et al.
Planck 2013
Bolliet et al.
Salvati et al.

Sunyaev & Zel'dovich
Mc Quin et al.
Mesinger et al.
Zahn et al.
Planck 2016
Gorce et al. 2020

Puget et al.
Lagache et al.
Knox et al.
Maniya et al.

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Planck 2016

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Lagache
Knox
Maniyar

GOAL

We need :

- Consistent ingredients and analyses
- Exploit the full cosmological information in the signal

Replace in SPT analysis

Reionisation

$$C_\ell^{obs} = C_\ell^{CMB}(\Theta, xe = tanh) + A^{tSZ} C_\ell^{temp-t} + A^{kSZ} C_\ell^{temp-k} + \ldots.$$

Cosmology

By

$$C_\ell^{obs} = C_\ell^{CMB}(\Theta, xe = asym) + C_\ell^{tSZ}(\Theta) + C_\ell^{kSZ}(\Theta, xe = asym) + \ldots.$$

And for Planck

$$C_\ell^{obs} = C_\ell^{tSZ}(\Theta)$$

Because we extracted a tSZ map thus tSZ spectrum

Planck coll. 2014, 2016

tSZ power spectrum from Halo Model

$$Cls[\Theta] \equiv \iiint dMdz \, dV \, \chi(obs) \, S(obs - M) \, \frac{dN}{dMdz} \, p(M,z)$$

Scaling Relation

Needed to relate the observable (flux, size) to the mass and redshift. Given by comparison HM with simulations or WL measurements *[Planck 2013., Nagai et al. , …]*

$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,Y_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = Y^*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1\text{-}b)\,M_{500}}{6\cdot10^{14}M_\odot}\right]^{\alpha}$$

Mass function

Number of halos in bins of mass and redshift. From numerical simulations, known 10% scatter between teams *[Tinker et al., Watson et al. , Despali et al.]*

$$\frac{dN(M_{500},z)}{dM_{500}} = f(\sigma)\frac{\rho_m(z=0)}{M_{500}}\frac{d\ln\sigma^{-1}}{dM_{500}}$$

$$f(\sigma) = A\left[1+\left(\frac{\sigma}{b}\right)^{-a}\right]\exp\left(-\frac{c}{\sigma^2}\right)$$

$$\sigma \; needs \int P(k)$$

Cosmology Θ

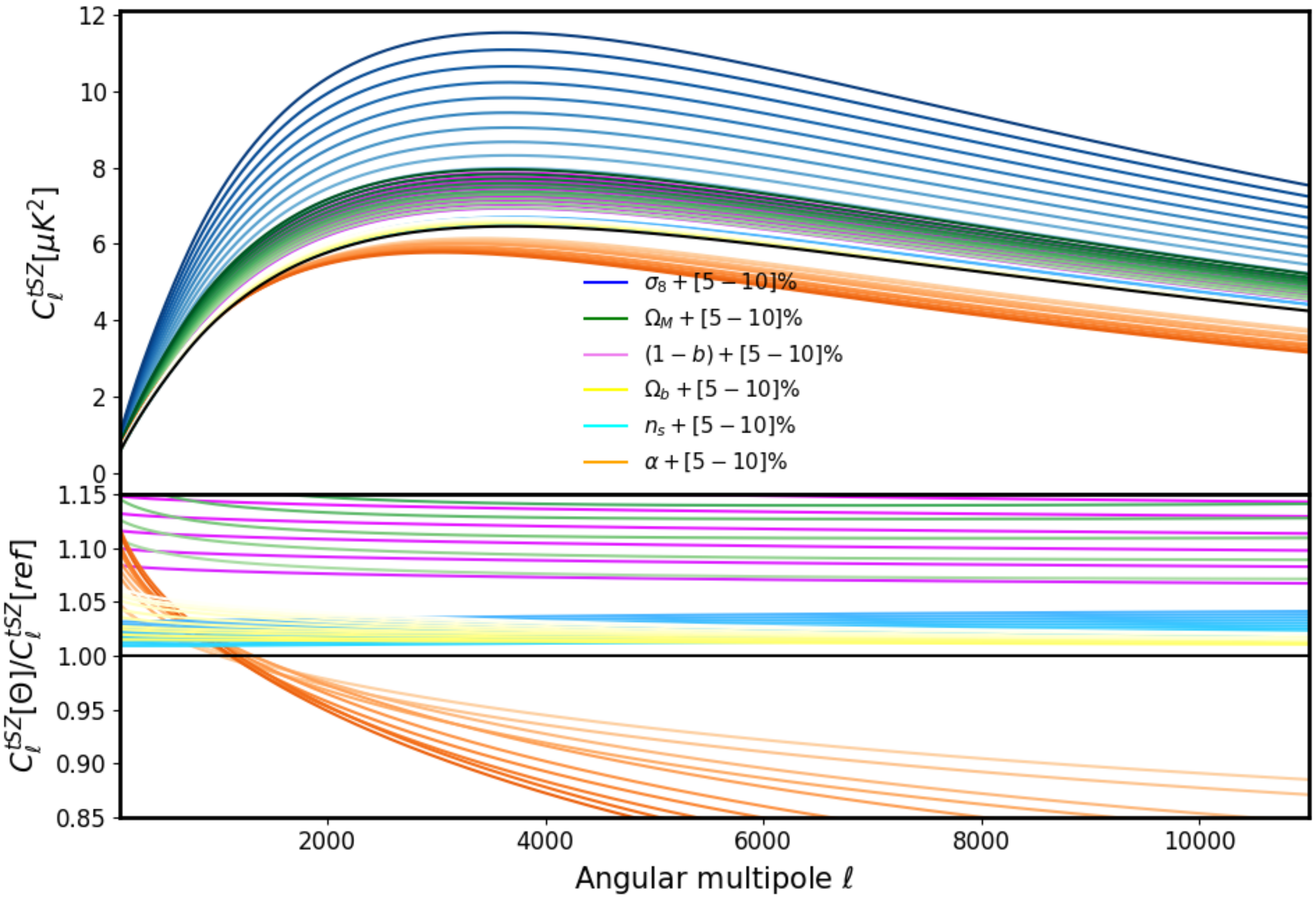
SZ power spectrum as geometrical and growth probe

Profile

Describes the spatial distribution of the hot gas. Assume Universal pressure profile, the GNFW *[Nagai et al., Arnaud et al. , Planck 2014]*

tSZ AND COSMOLOGY

- tSZ effect contains cosmological information



tSZ POWER SPECTRUM

$$Cls[\Theta] \equiv \iiint dMdz \;\; dV \;\; \chi(obs) \;\; S(obs - M) \;\; \frac{dN}{dMdz} \;\; p(M,z)$$

Cls depends on 6 cosmological parameters and
4 (up to 8) cluster physics parameters
Amplitude and shape depend on params

In practice we need to compute:
Redshifts from z=0 and z=3
Masses from 1e13 to 1e16

To cover large scales (Planck l=60 ~3deg/sky)
to small scales (SPT l=12000 ~1arcmin)

Heavy and slow to compute, and slows to
converge in MCMC

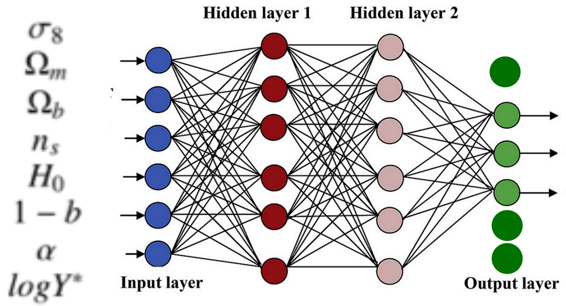
Alternative → Random forest

MACHINE LEARNING

- Training Random forest with random values of 8 params on 10 l-values of the Cls (l=10 to l=11000) [scikit-learn]
- Training 6000 models (test on 2000)
- RF Score of 95%

Approx

RF training



C_{10}

C_{100}

C_{800}

...

C_{1100}

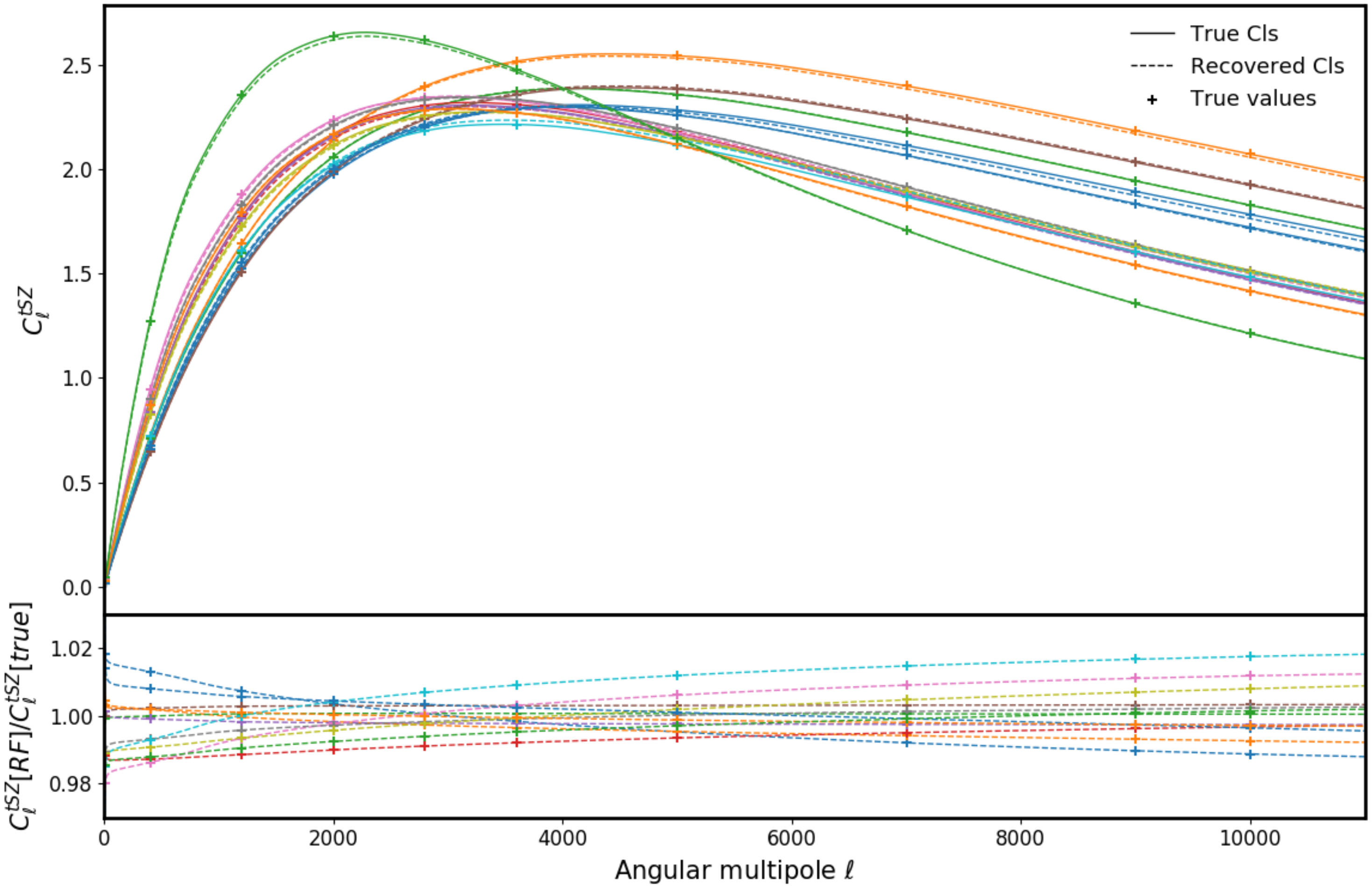
Interpolation →

All Cls

σ_8	Amplitude of fluctuations
Ω_m	Matter density
Ω_b	Baryon density
n_s	Spectral index
H_0	Hubble constant
$1-b$	Mass bias parameter
α	SR Mass exponent
$logY^*$	SR amplitude

RF SZ SPECTRUM

- Prediction on 10 l-values then interpolation

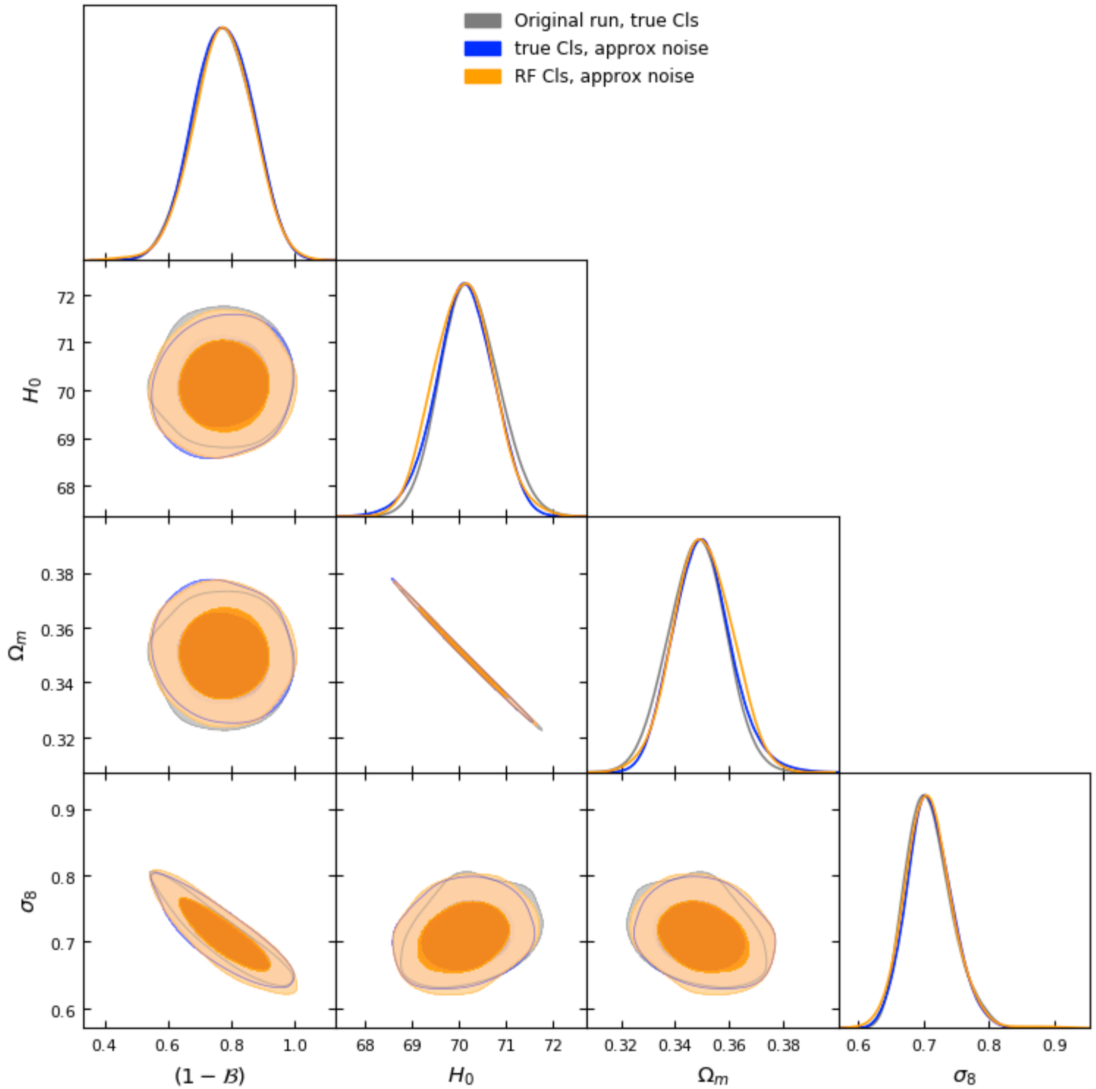


100 times faster to compute

±2% while obs errors are ~20%

RF SZ Cosmo

- Reproducing constraints from true Cls



More than 10 times faster to run chains

***Douspis** et al. in prep*

New Analysis of SPT and SPT+Planck

- 6 cross spectra from SPT
- tSZ spectrum from Planck y-map

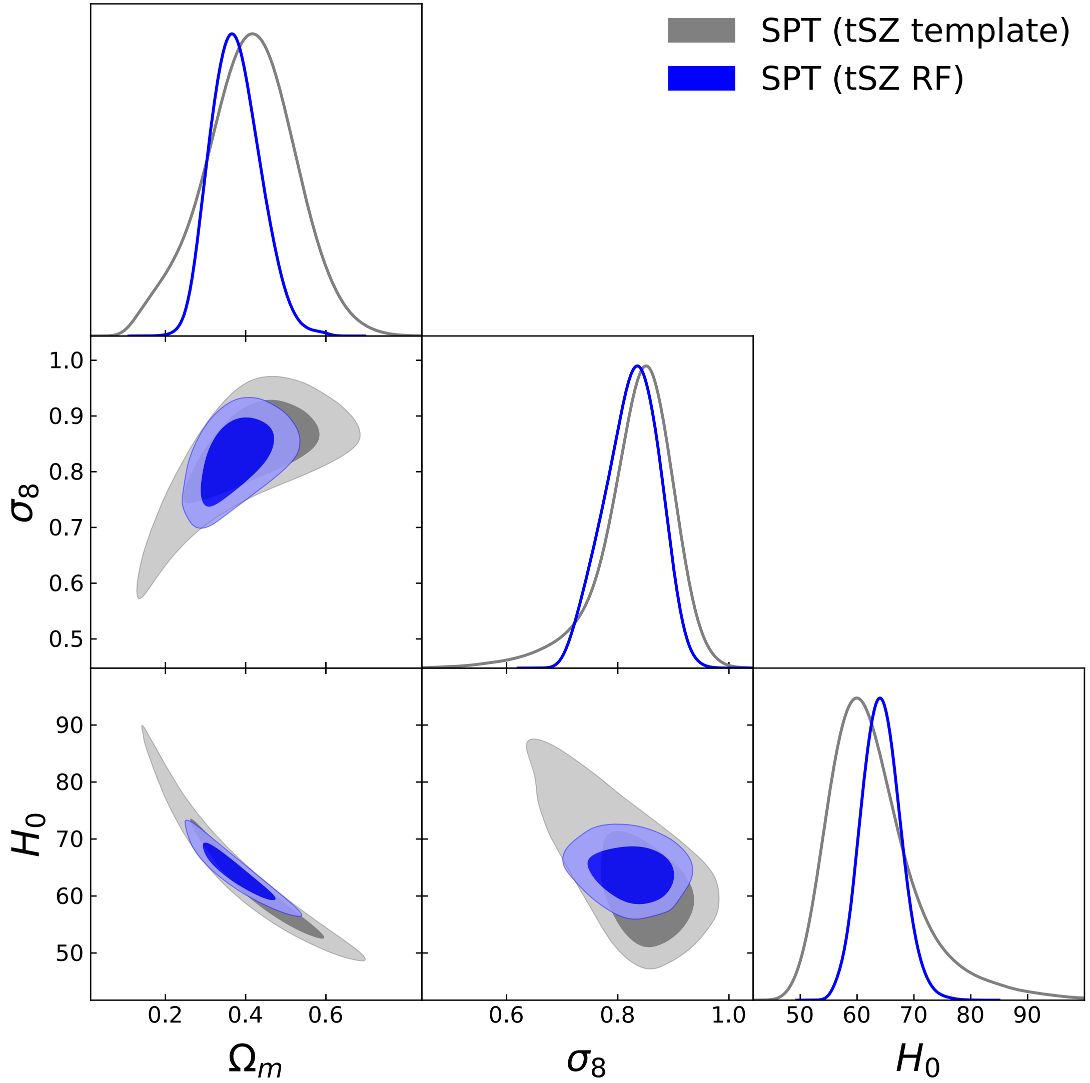
New Analysis of SPT

- Effect of cosmological information of tSZ

Ω_M
Ω_b
H_0
n_s
σ_8
A_{tSZ}
$Y*$
α
$(1-b)$

+ 6 foreg
+ 4 instrum

prior on $\Omega_b h^2$
prior on n_s
prior on α
prior on $Y*$



Stronger constraints on $(\Omega_M,\ \sigma_8)$

Better χ^2 with free cosmological parameters:

Fixed Cosmo Template	Free Cosmo Template	Free Cosmo RF(Θ)
236	216	215
dof	~dof-3	~dof-3

***Douspis** et al. in prep*

New Analysis of SPT and SPT+Planck

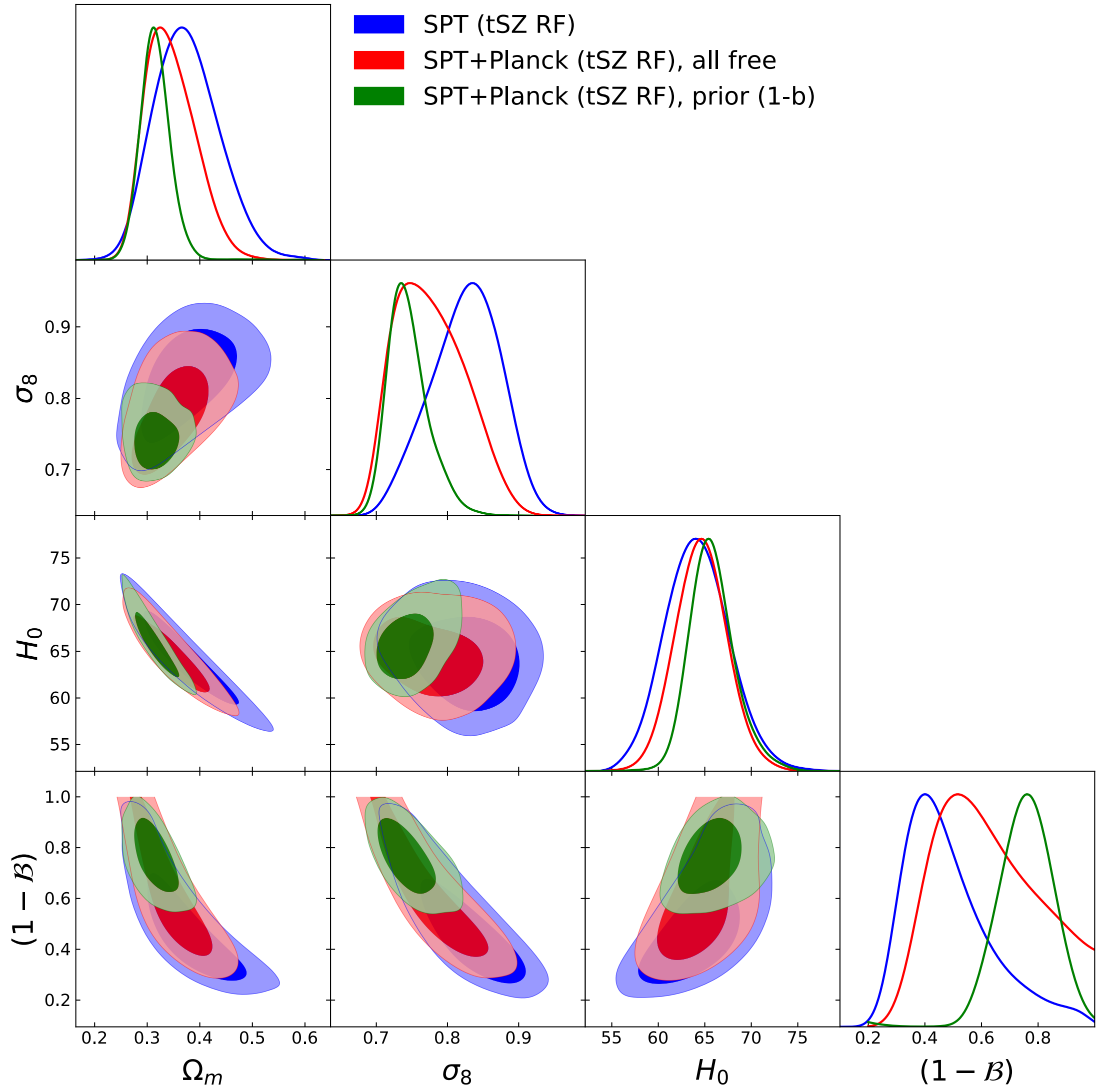
- Adding more information

Ω_M
Ω_b
H_0
n_s
σ_8

$Y*$
α
$(1-b)$

+ 6 foreg
+ 4 instrum

prior on $\Omega_b h^2$
prior on n_s
prior on α
prior on $Y*$



Adding Planck tSZ spectrum shifts parameters to more usual values of $(\Omega_M,\ \sigma_8)$
But do not improve drastically the error bars

Adding Planck tSZ spectrum and prior on the mass bias reduces by factor 2 error bars

CCCP: Hoekstra et al.

Douspis *et al. in prep*

Comparison with Planck + SPT [ell=3000]

- Adding SPT to Planck

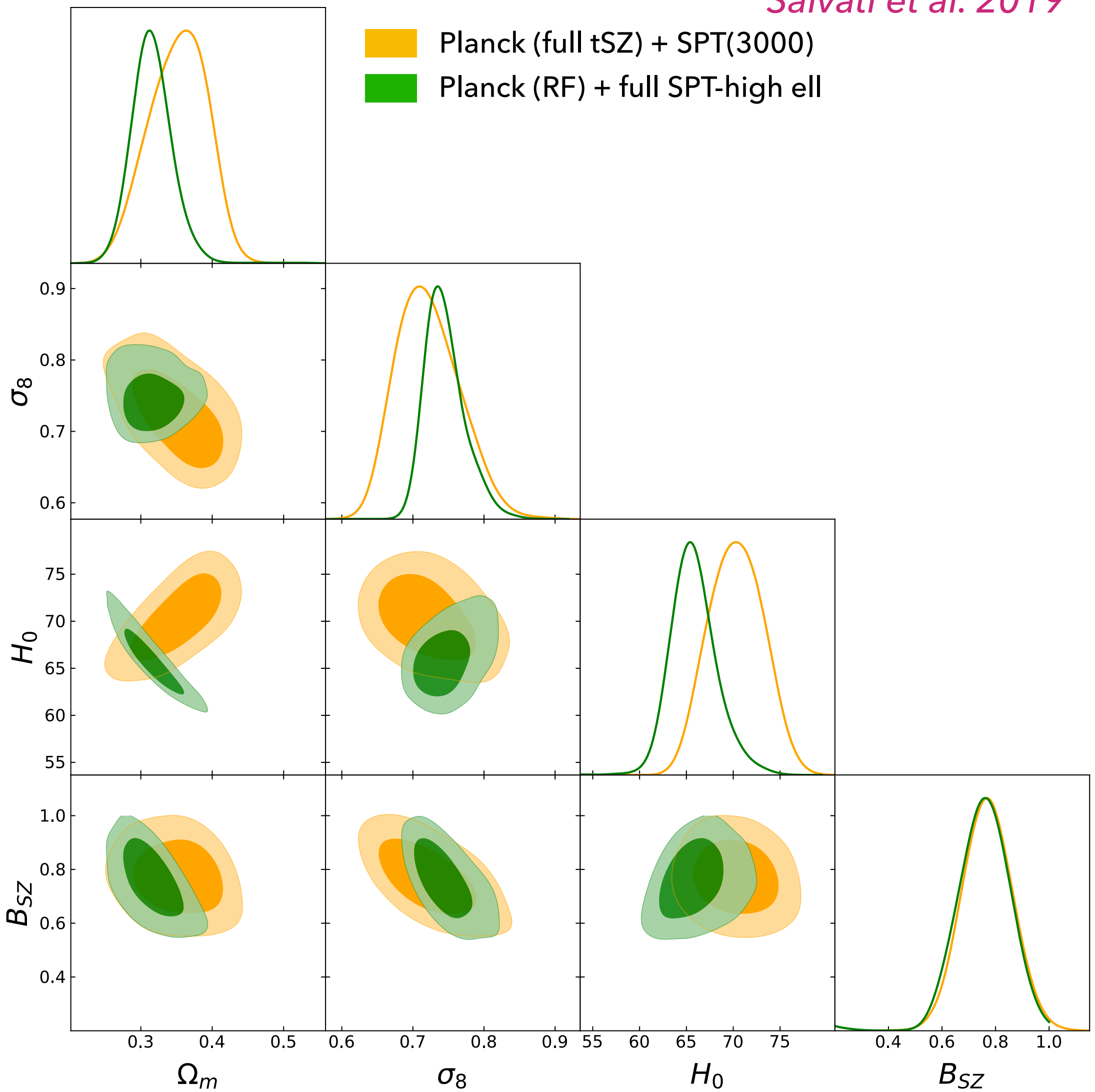
Ω_M
Ω_b
H_0
n_s
σ_8

$Y*$
α
$(1-b)$

+ 6 foreg
+ 4 instrum

prior on $\Omega_b h^2$
prior on n_s
prior on α
prior on $Y*$
prior on $(1-b)$

Salvati et al. 2019

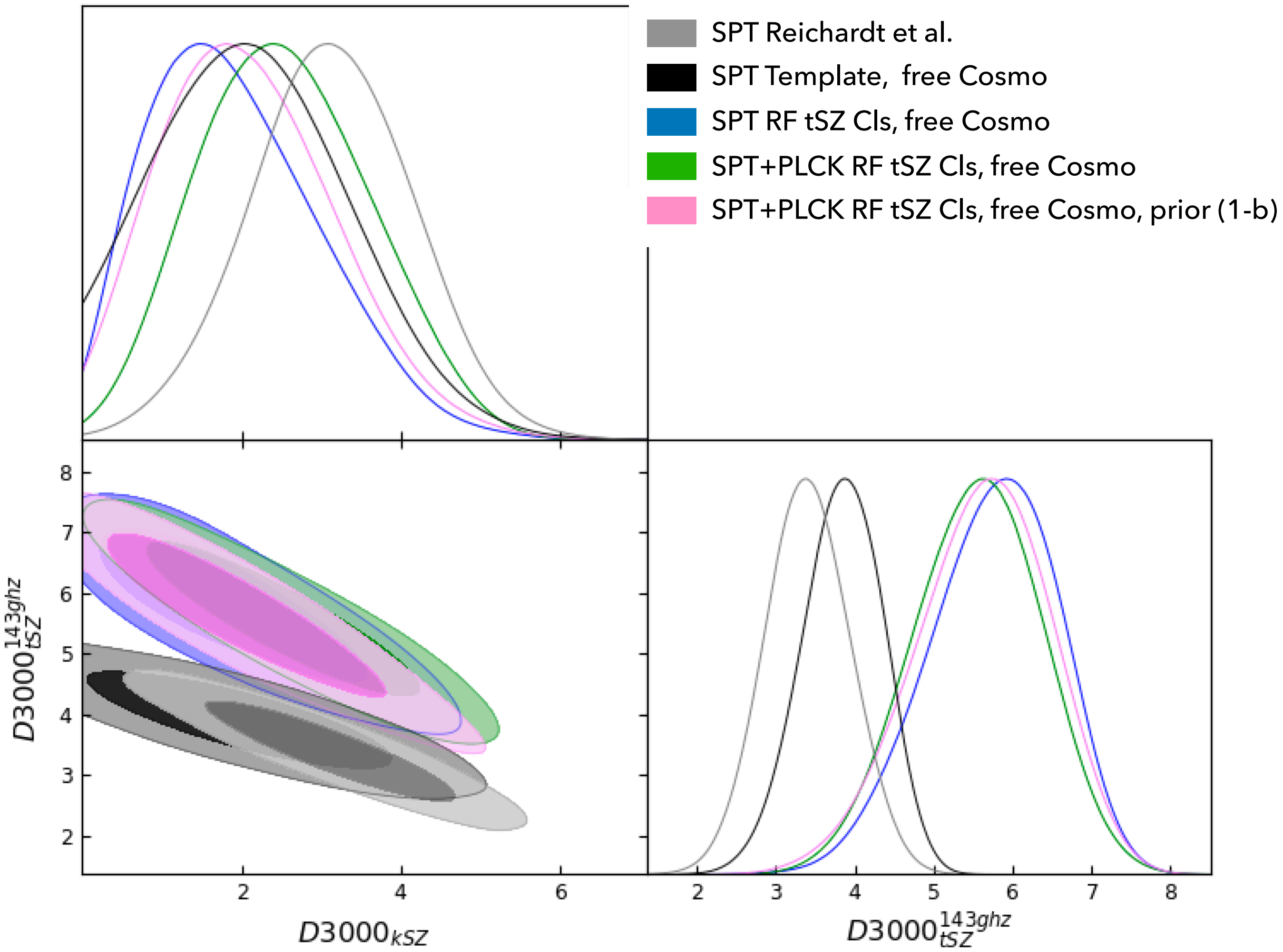


Adding SPT to Planck bring usual values of (Ω_M, σ_8)
And breaks degeneracies (because of some CMB in SPT)

***Douspis** et al. in prep*

BYOPIC

Degeneracy tSZ / kSZ



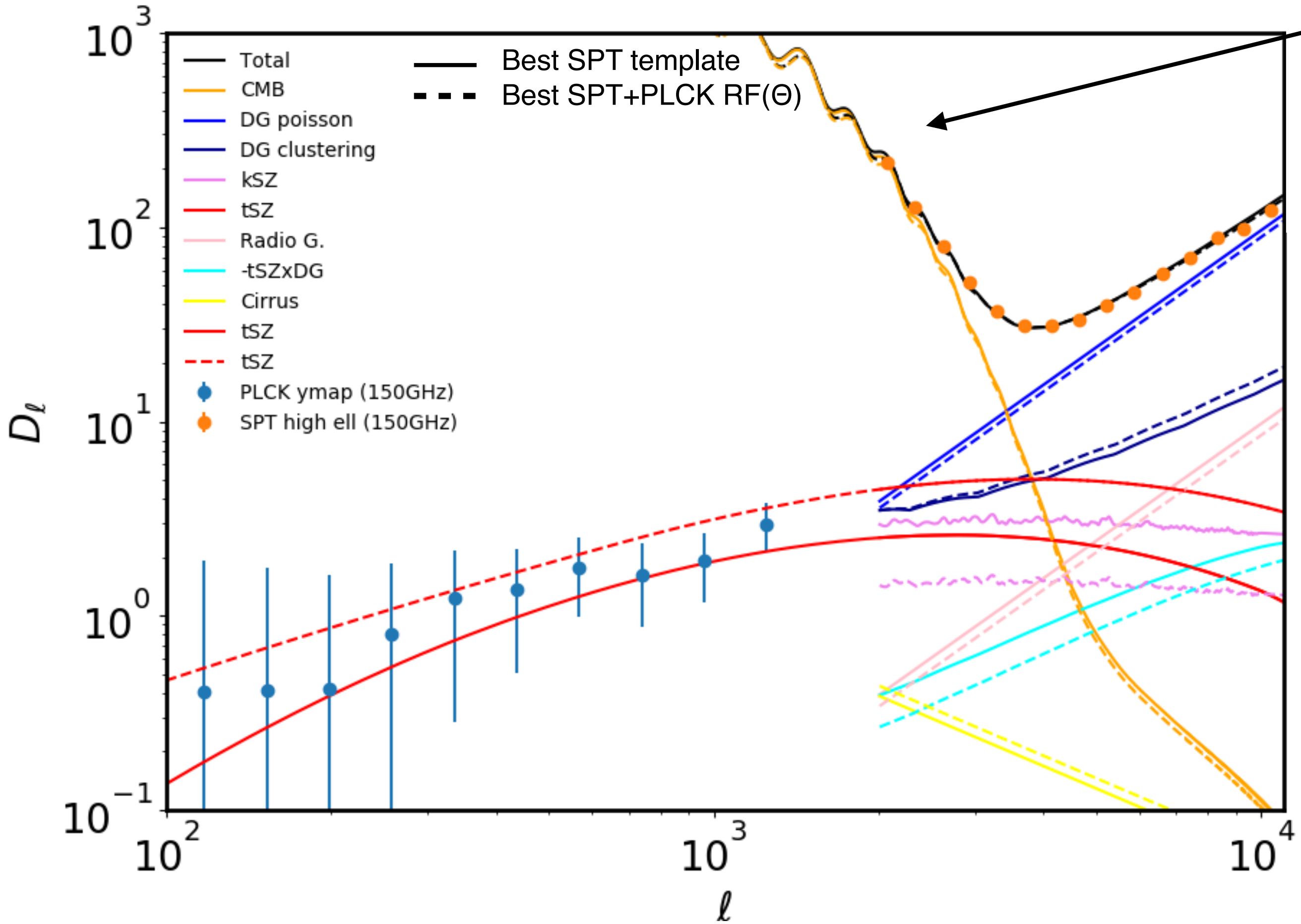
Opening cosmological parameters weakens kSZ detection
But stays between 1 and 2.5 sigmas depending of combinations

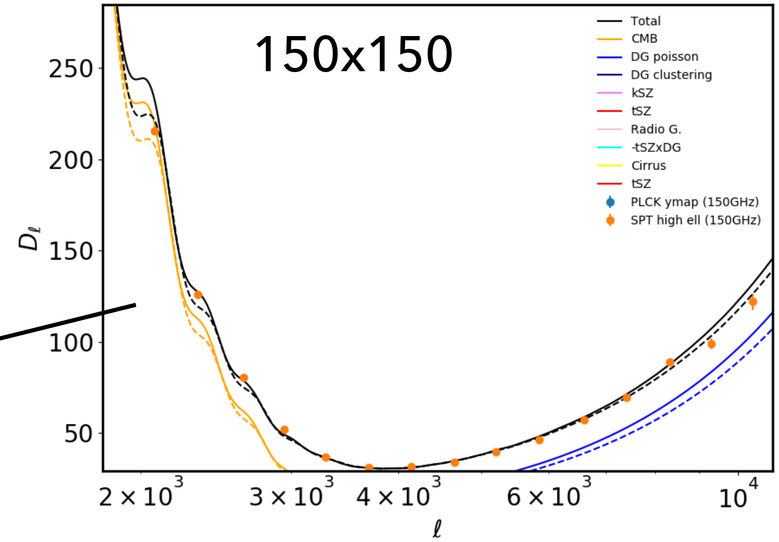
Introducing cosmological dependency of kSZ (Gorce et al.) in future work

***Douspis** et al. in prep*

Back to spectra

- Best fits template vs RF(Θ)





Other 5 cross spectra to be considered

Douspis et al. in prep

Conclusions

- First attempt to bring full information of high ell components (focus only on tSZ)
- Moving from template to cosmology dependency brings more constraints
- First combination of Planck tSZ spectrum with SPT-High-ell
  - Lower σ_8 preferred
  - Higher amplitude of tSZ spectrum
  - Less room for kSZ

Conclusions

- Inclusion in cosmoMC (f90) code instead of using template or computing halo model, by using Python sklearn Random forest output
- Computation 100 times faster and allow for many tests
- Distributing python tSZ approx for fast computation (Paper 1)
- Moving all to python and training on larger set (and more parameters) and to kSZ (*Gorce et al.*), CIB (*Maniyar et al.*) … for a full high-ell cosmological analysis (Paper2)

Thank you !