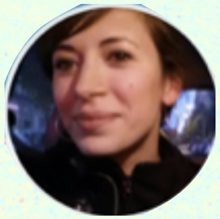
Retrieving cosmological information from small-scale CMB foregrounds: tSZ example

Marian Douspis



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

2d CMB France

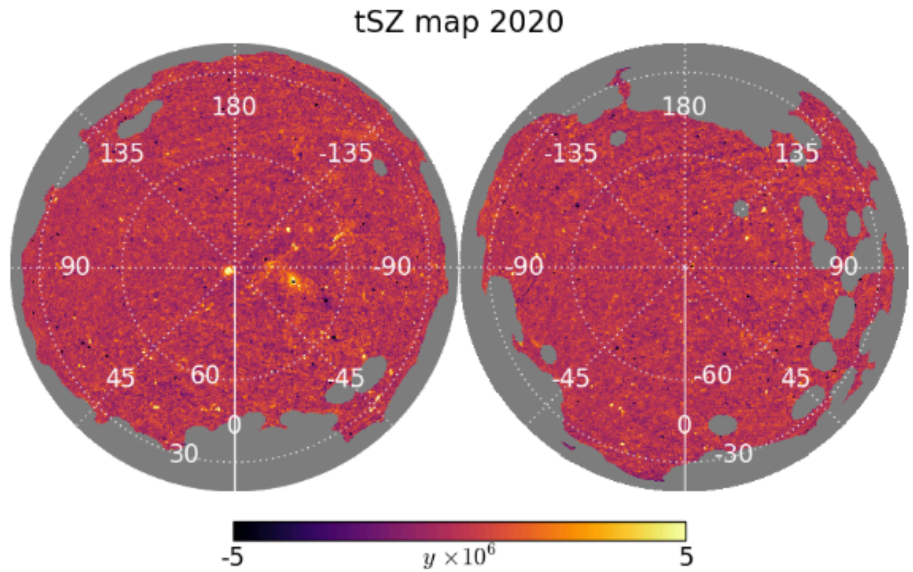
2021

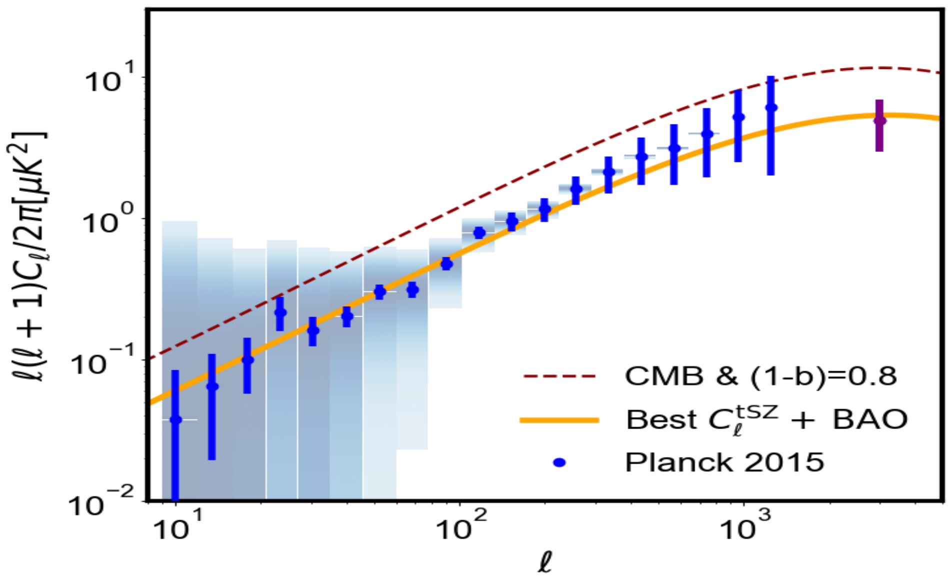
"Retrieving cosmological information from small-scale CMB foregrounds
I. The thermal Sunyaev Zel'dovich effect",
Douspis, Salvati, Gorce, Aghanim, submitted to A&A, arXiv:2109.03272

European Research Council
Established by the European Commission

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



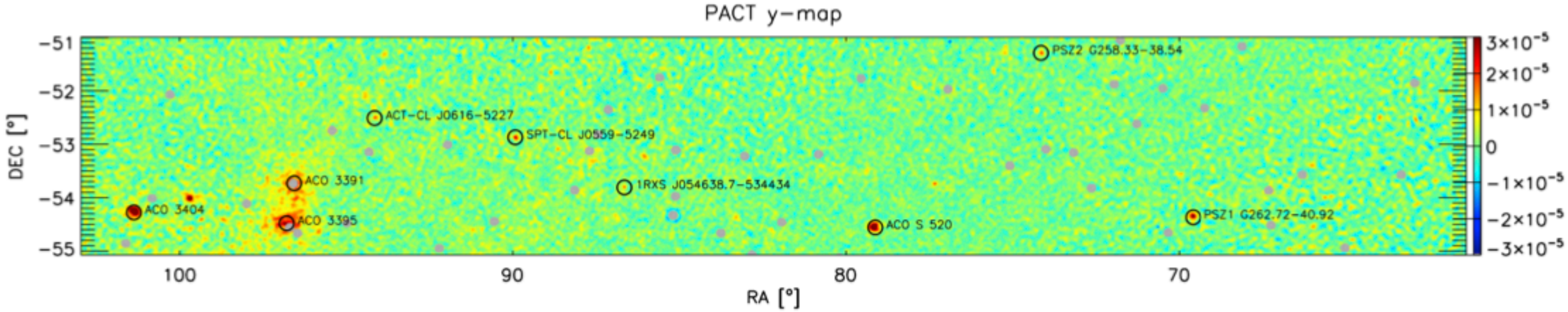


Planck *2014,* ***Planck*** *2016*
Tanimura et al. 2021
Douspis *et al.* ***Salvati*** *et al.*

Other yMap

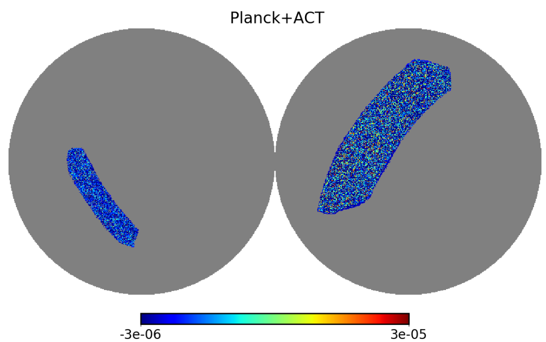
- Planck + ACT: PACT map: 1st combination of CMB experiments

Aghanim et al 2019



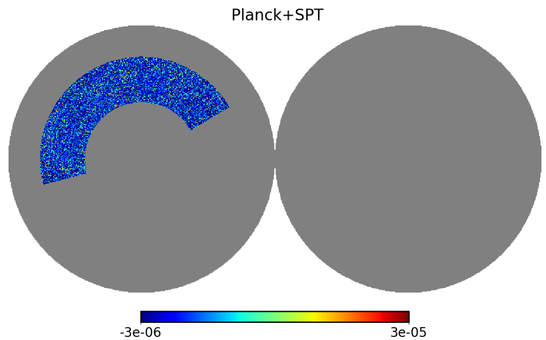
- Planck+ACT

Madhavacheril et al 2020



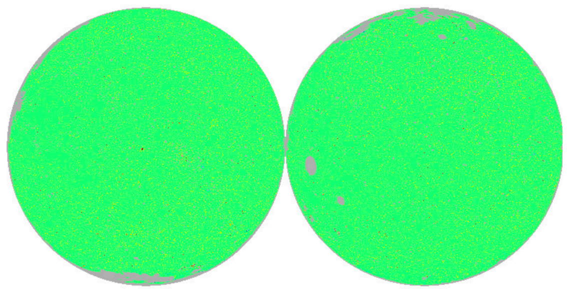
- Planck+SPT

Bleem et al 2021



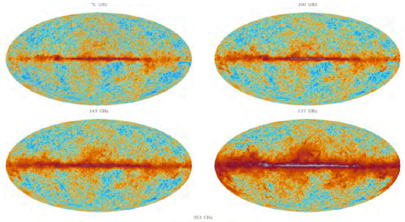
- MILCANN

Hurier, Aghanim, Douspis 2021

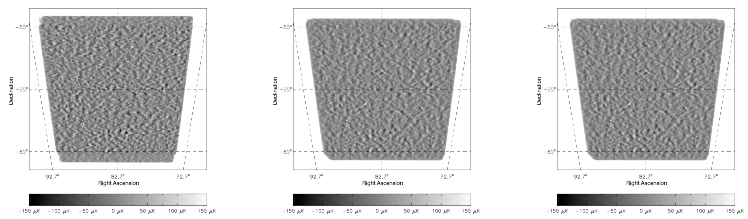


tSZ IN FREQUENCY MAPS

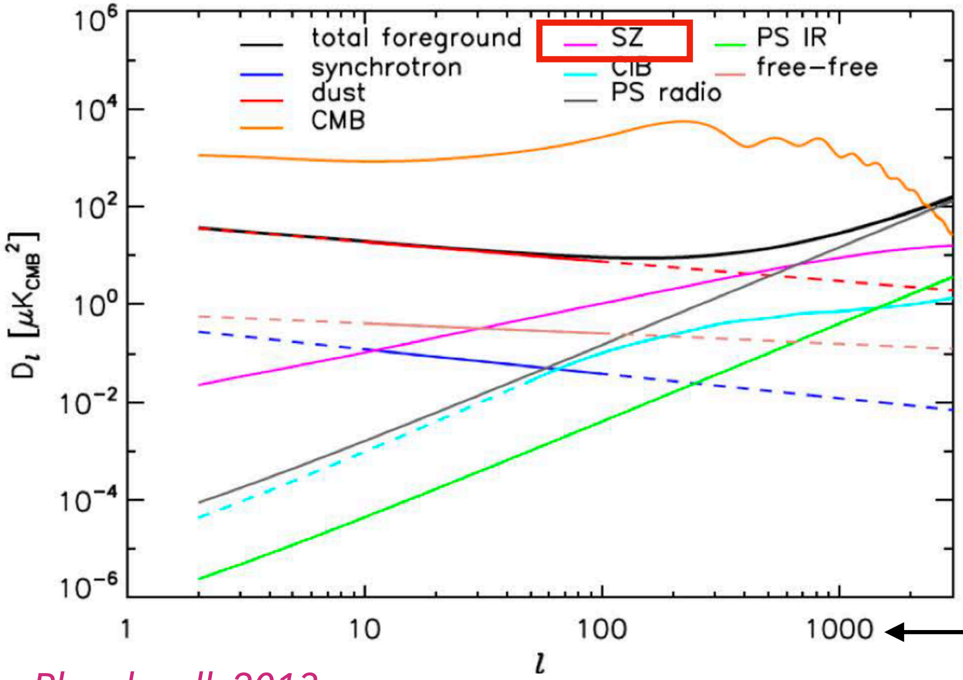
- tSZ is hidden among many other signals
- Primordial CMB becomes negligible at small scales

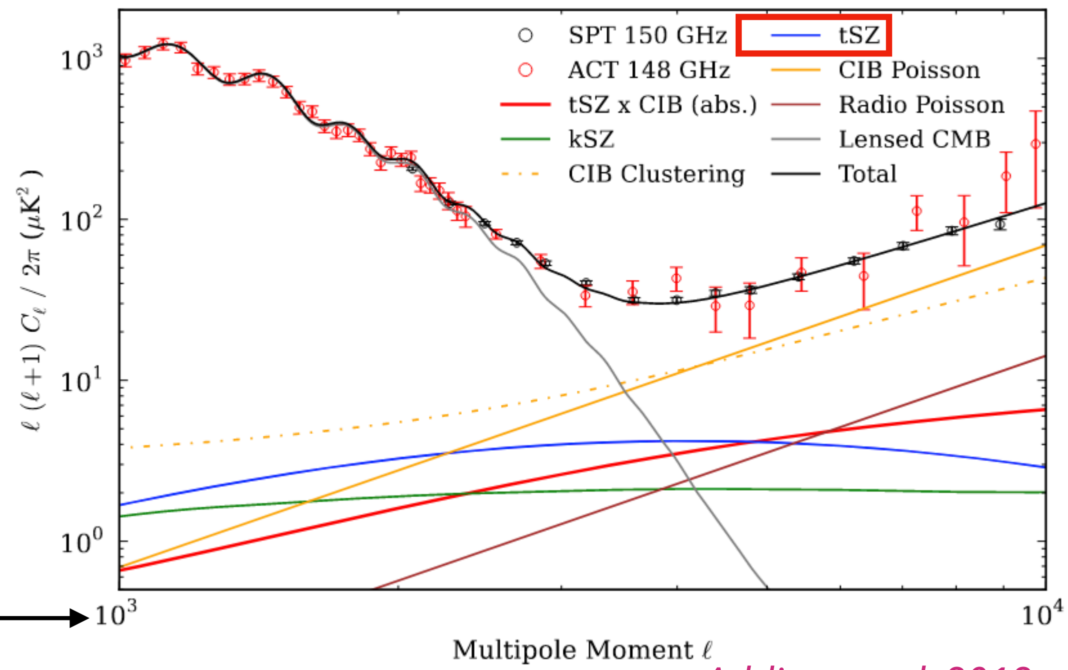


Planck/Large scales



SPT/small scales





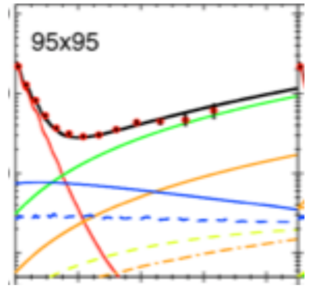
Planck coll. 2013

Addison et al. 2012

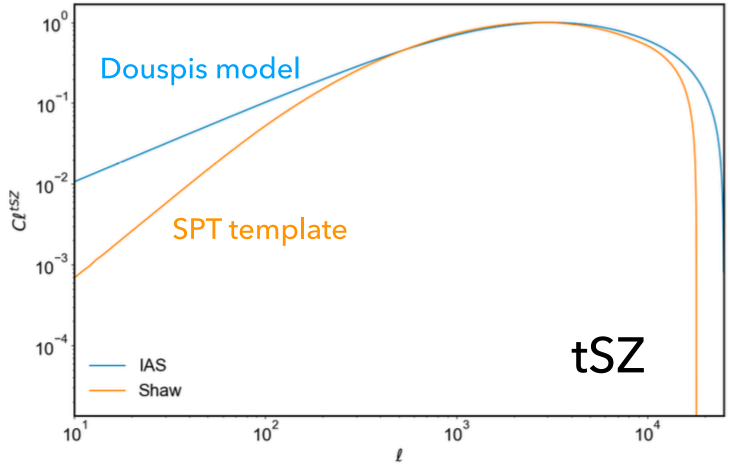
Focus on SPT High ell Analysis

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

For all 6 cross spectra simultaneously



SPT analysis uses templates for tSZ and kSZ

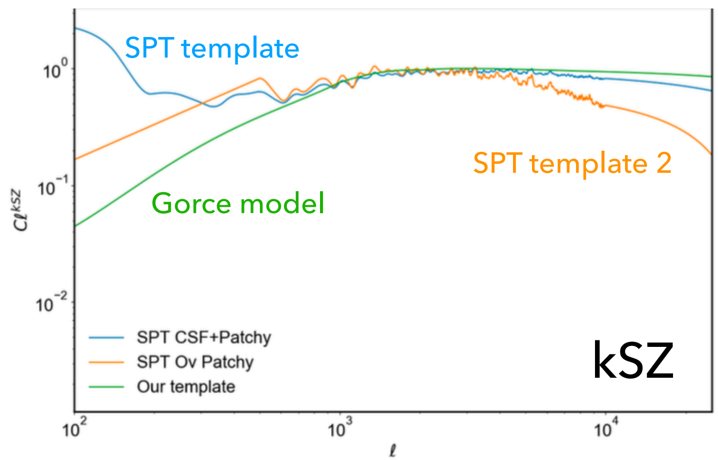


$$C_\ell^{tSZ} = A^{tSZ} \times C_\ell^{template}$$

Sims with cosmo1

$$C_\ell^{kSZ} = A^{kSZ} \times C_\ell^{template}$$

Sims with cosmo2



- Not coherent analysis
- Depends on assumed template
- No cosmological information

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.

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
Mesinger
Zahn
Planck 2016

Puget
Lagache
Knox
Maniyar

GOAL

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

Replace in SPT analysis

Reionisation

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

Cosmology

By

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

And for Planck

$$C_\ell^{\mathbf{obs}} \equiv C_\ell^{\mathbf{tSZ}}(\Theta, \Sigma) + A_{CIB} C_\ell^{CIB} + A_{IR} C_\ell^{IR} + A_{Rad} C_\ell^{Rad} + A_N C_\ell^N$$

Where C_l^{XX} are residuals

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. , …]*

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

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.]*

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

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

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

Profile

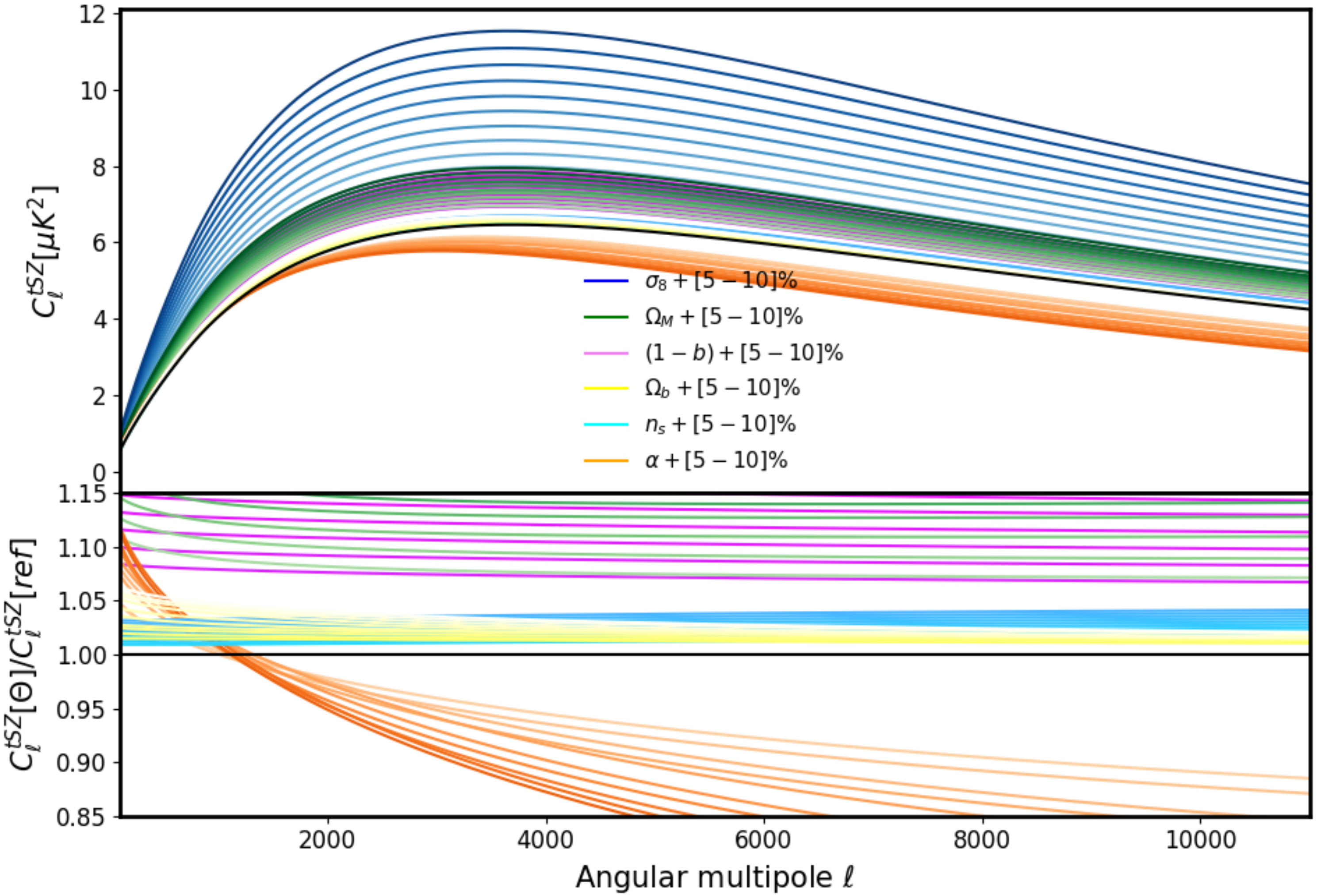
Describes the spatial distribution of the hot gas. Assume Universal pressure profile, the GNFW *[Nagai et al., Arnaud et al. , Planck 2014]*

Cosmology Θ

SZ power spectrum as geometrical and growth probe

tSZ AND COSMOLOGY

- tSZ effect contains cosmological information



tSZ POWER SPECTRUM

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

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

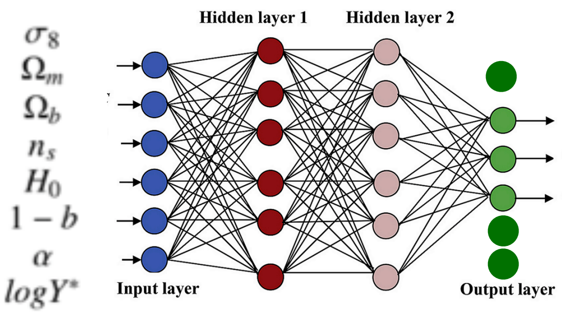
Alternative → Random forest

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 15000 models (test on 20%)
- RF Score of 96%

Approx

RF training



C_{10}

C_{100}

C_{800}

…

C_{1100}

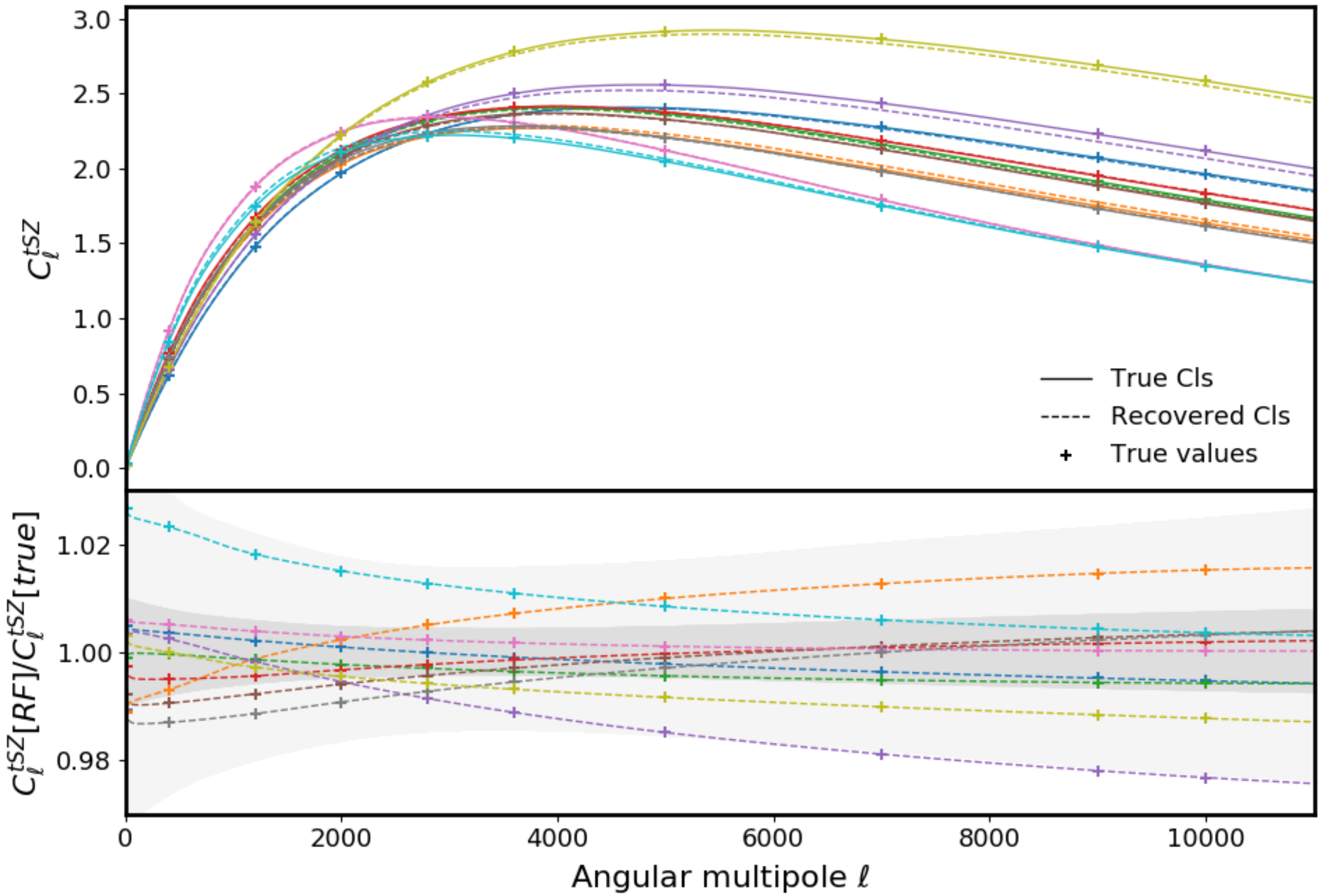
Interpolation →

Cls at all ells

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

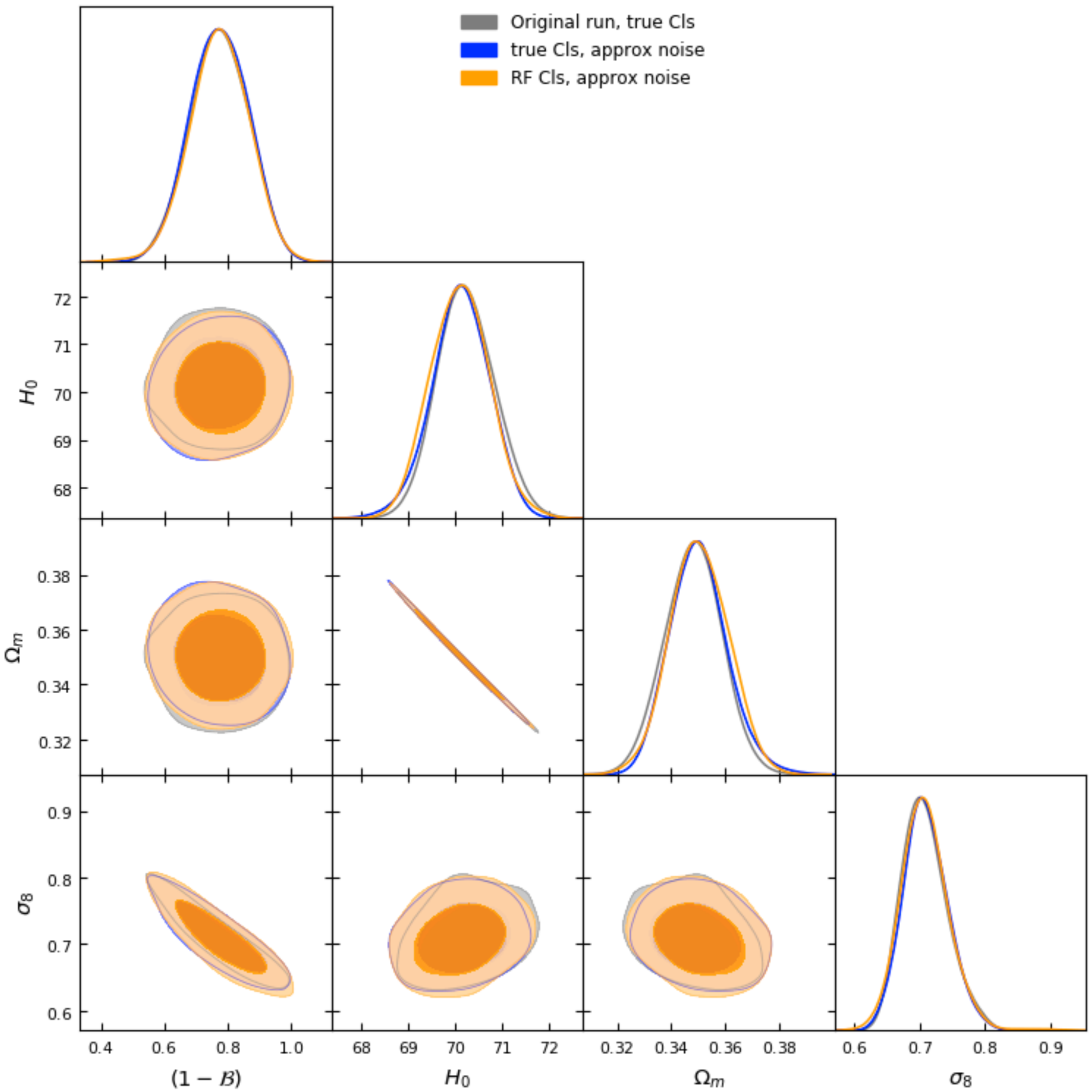


100 times faster to compute

±2% while obs errors are ~20%

RF SZ Cosmo

- Reproducing constraints from true Cls

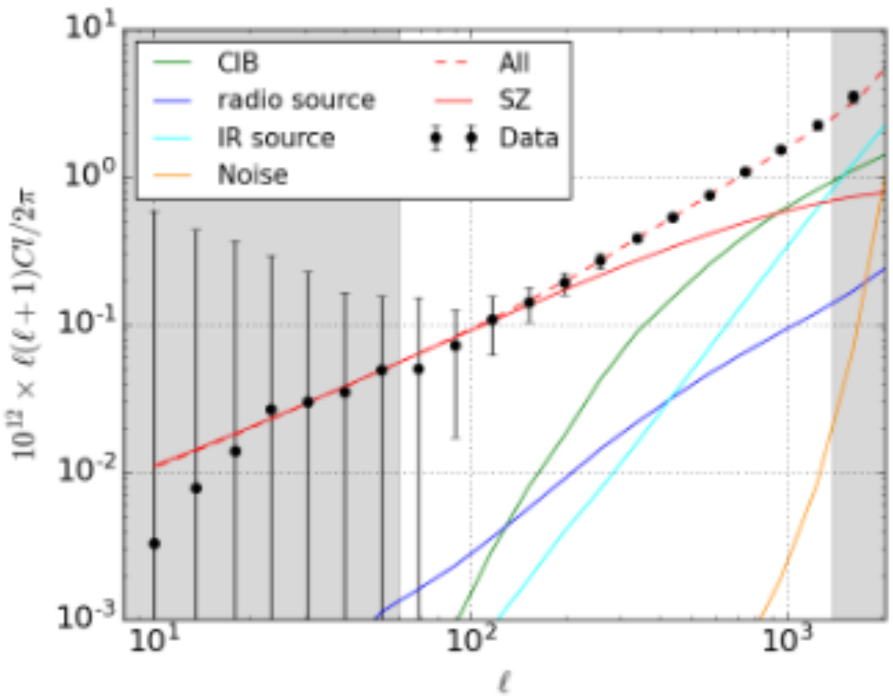


More than 10 times faster to run chains

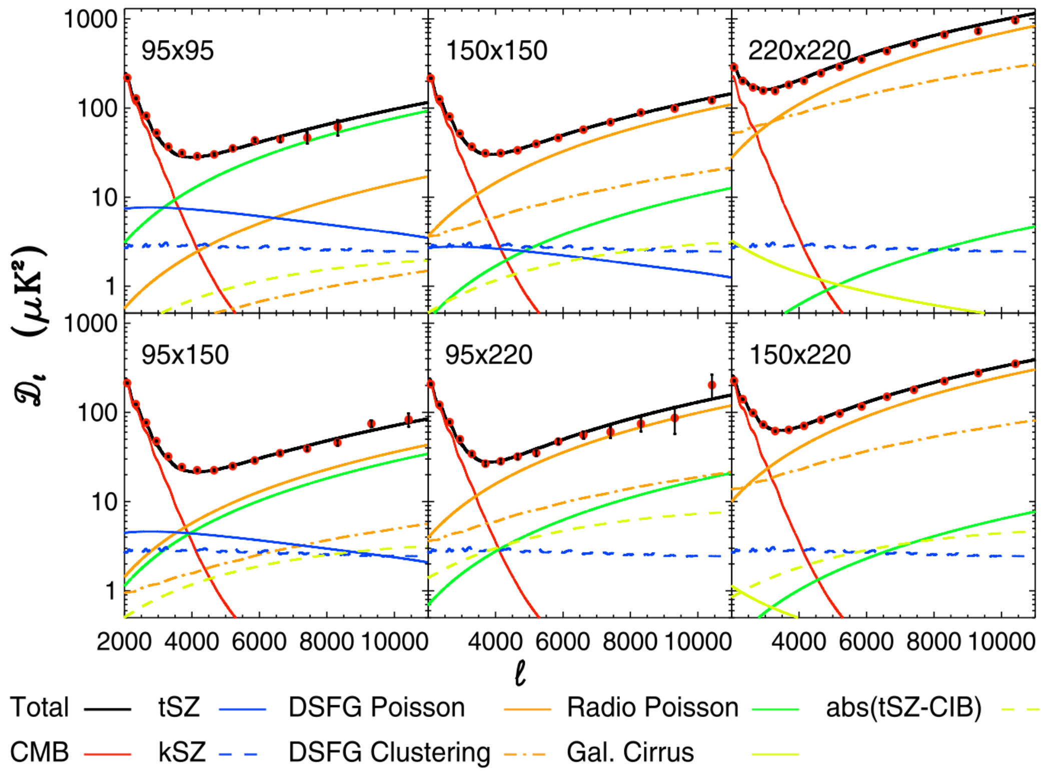
Douspis et al. 2021

NEW ANALYSIS OF SPT AND SPT+PLANCK

- tSZ spectrum from Planck y-map 2021
- 5 components
- ell in [60:1400]



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



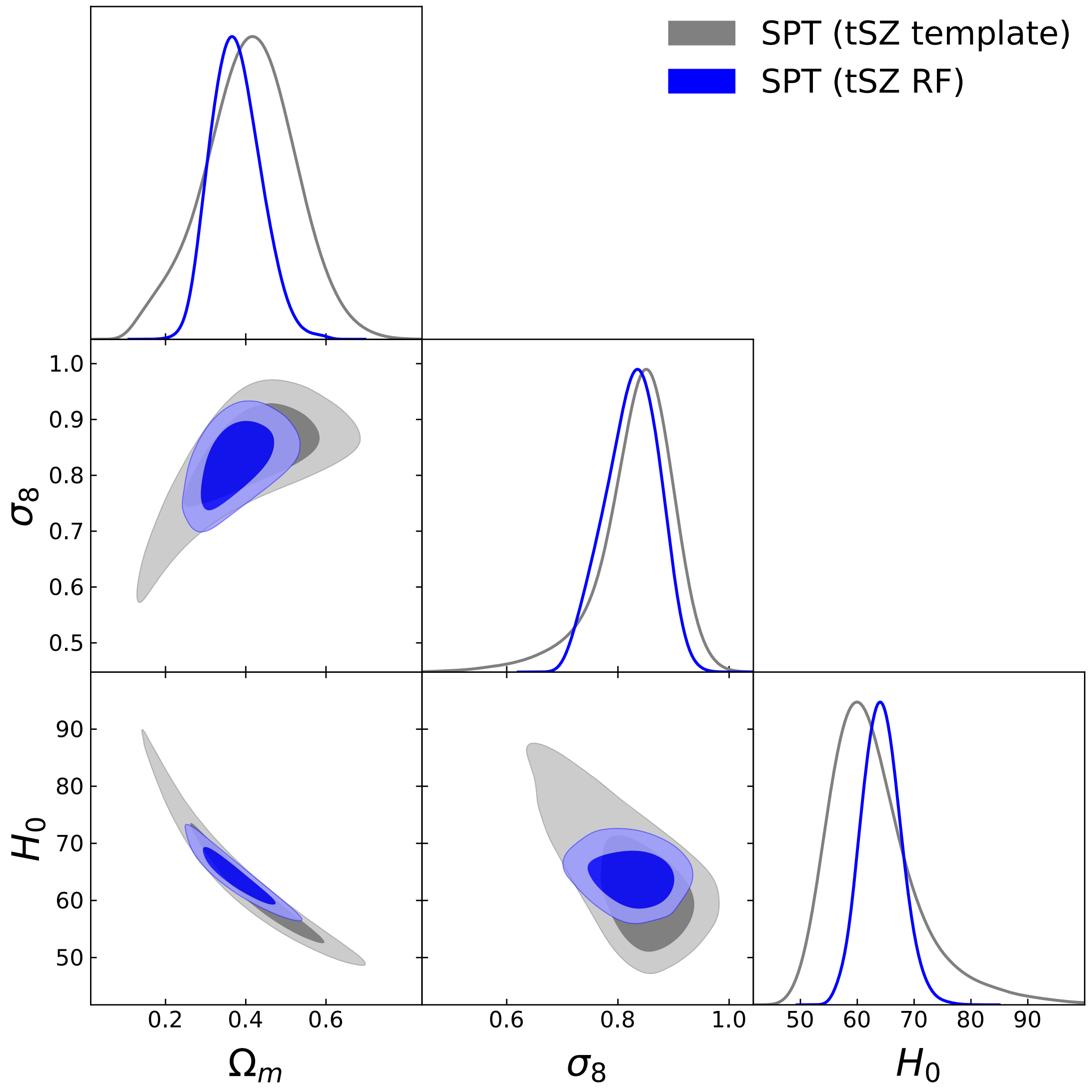
NEW ANALYSIS OF SPT

- 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 $Y*$



Compatibility of results

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

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

Douspis et al. 2021

New Analysis of SPT and SPT+Planck

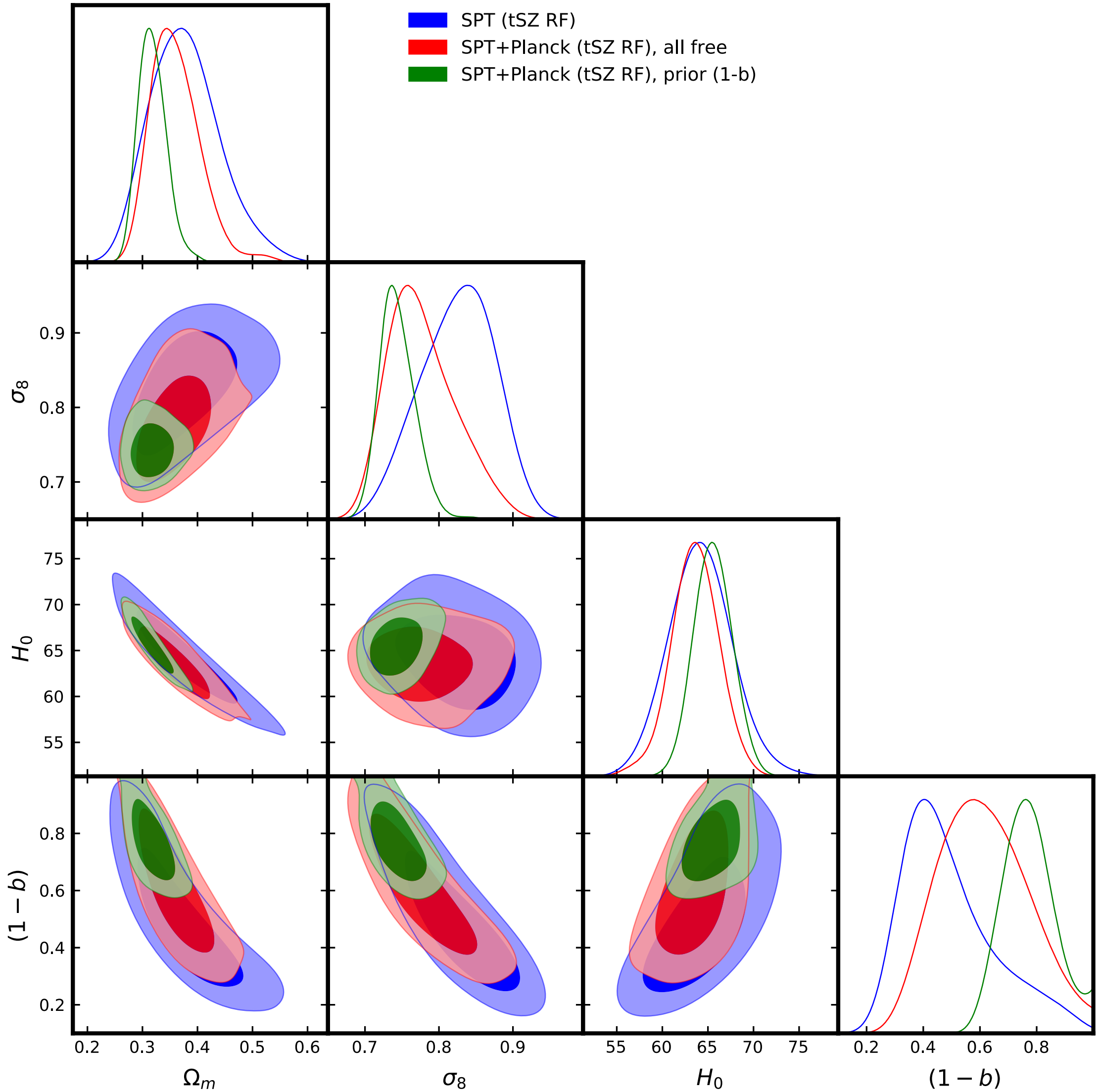
- Adding more information

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

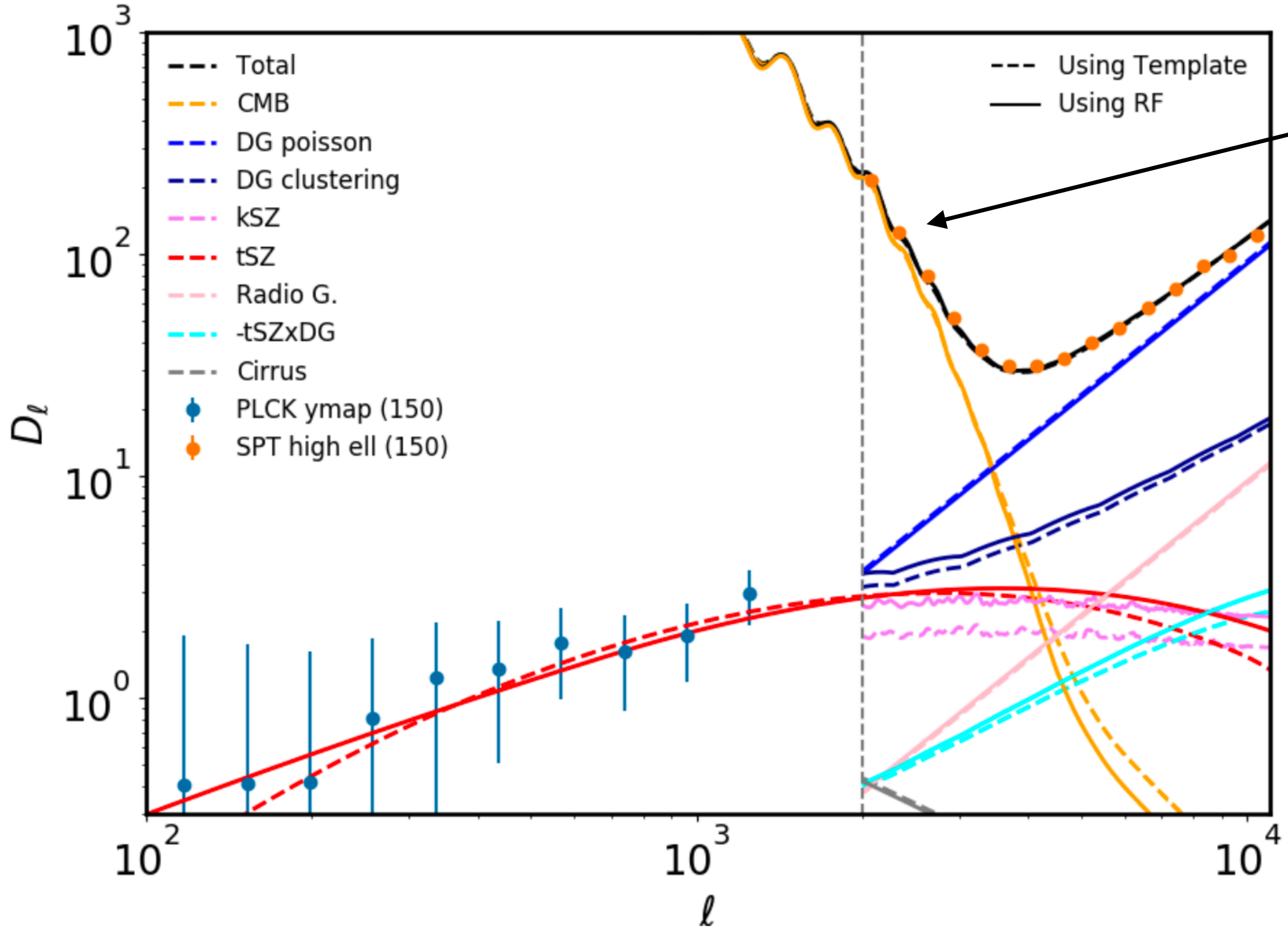
Adding Planck tSZ spectrum and prior on the mass bias reduces by factor 2 error bars

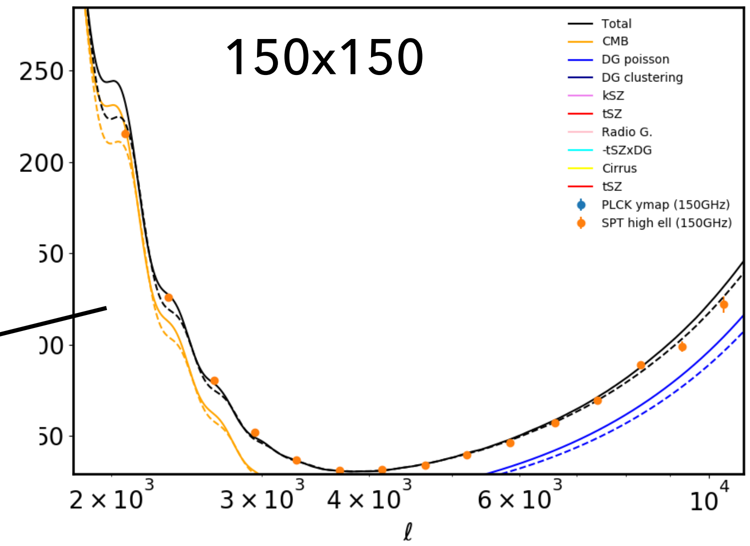
CCCP: Hoekstra et al.

***Douspis** et al. 2021*

BACK TO SPECTRA

- Best fits template vs RF(Θ)





Other 5 cross spectra to be considered

Douspis et al. 2021

Conclusions

- First attempt to bring full information of high ell components (focus only on tSZ)
- Moving from template to cosmology dependency brings consistent but stronger constraints
- First combination of Planck tSZ spectrum with SPT-High-ell
  - Slight change in preferred model
  - *When prior on bias, agreement to low value of s8*

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 for reionization (*Gorce et al. paper 2*), include CIB (*Maniyar et al.*) … for a full all-ell cosmological analysis (Paper3)