IAS
Institut d'Astrophysique Spatiale
Orsay

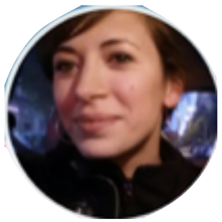
Better Accuracy and robusTness for Mass Assessment of Neutrinos

Cosmology from the Hot Gas in the Universe

Marian Douspis

Adélie Gorce (McGill), **Laura Salvati** (IAS), **Hideki Tanimura** (IPMU), **Raphaël Wicker** (IAS)

Nabila Aghanim (IAS)

ByoPiC

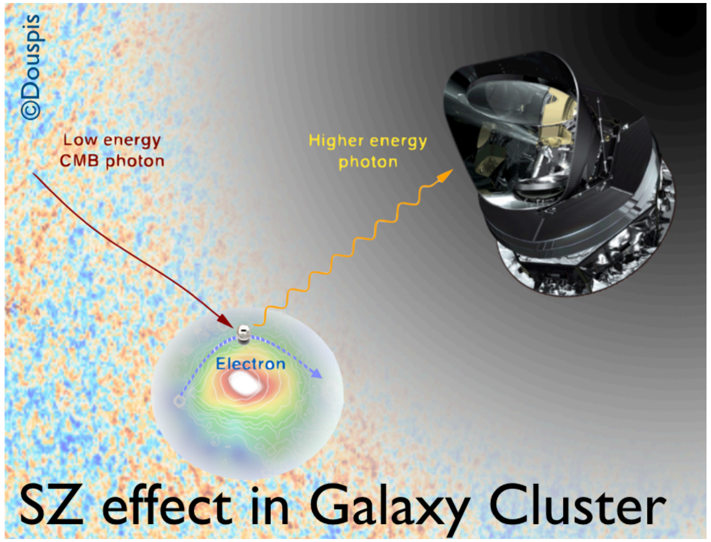
erc
European Research Council
Established by the European Commission

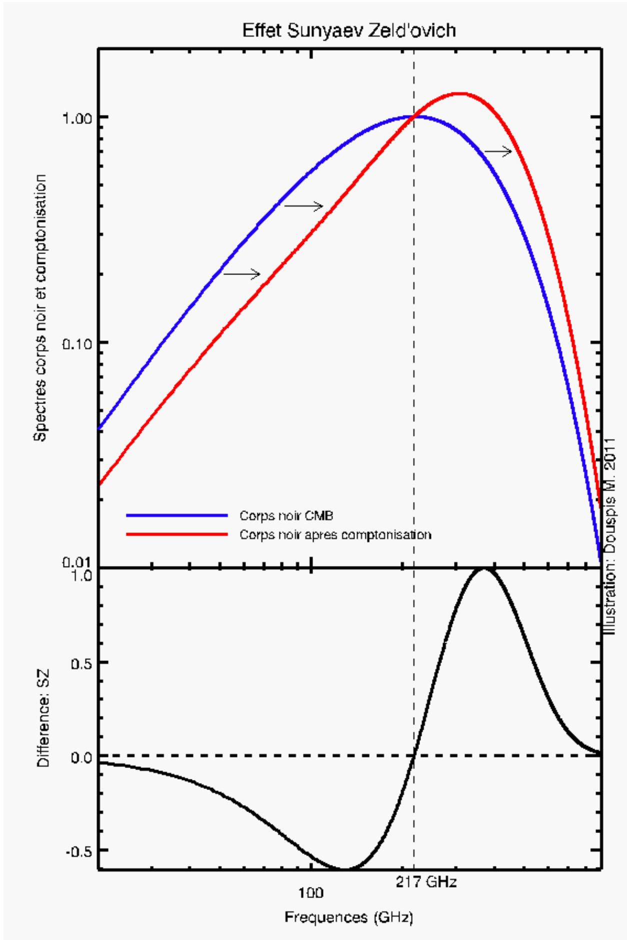
anr agence nationale de la recherche

- Hot gaz in millimeter wavelength : SZ
- SZ as cosmological probe
  - Galaxy clusters
  - ymap
  - CMB Angular Power spectrum
- Conclusion

SZ EFFECT: HOT BARYON TRACER

Inverse Compton distortion of CMB photon on ionised electrons = Sunyaev-Zeldovich effect





R. A. Sunyaev

Ya. B. Zeldovich

$$y = \int \frac{k_B T_e}{m_e c^2} n_e \sigma_T dl$$

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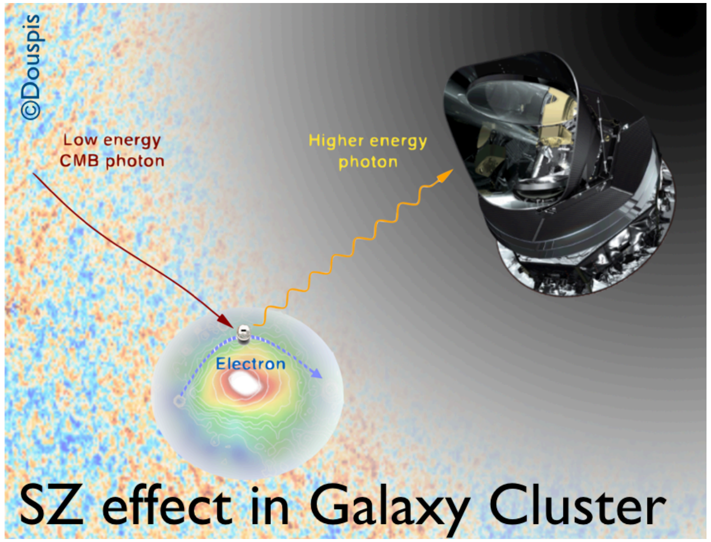

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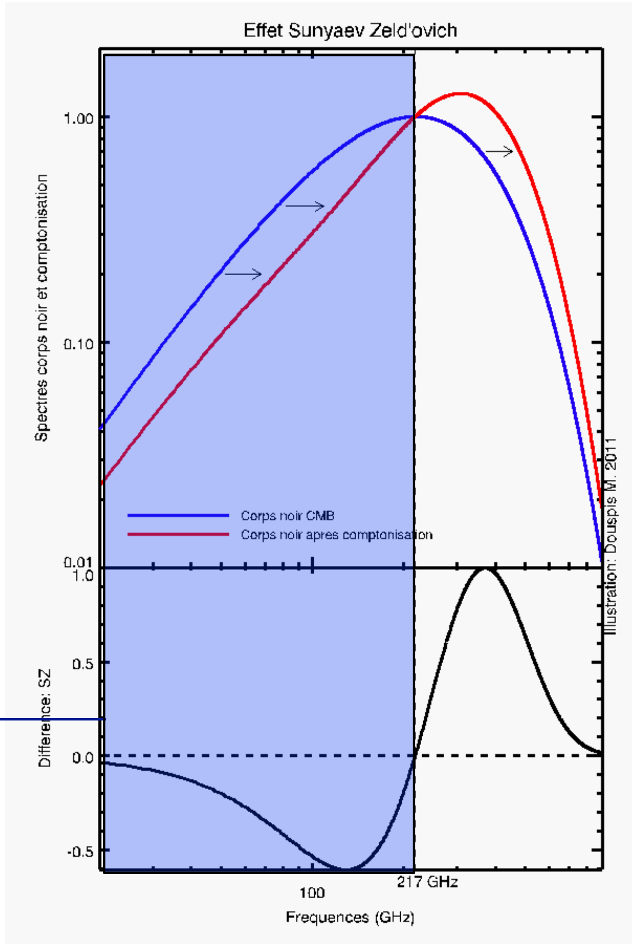

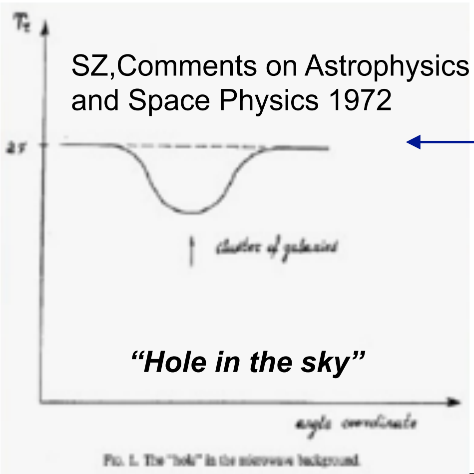

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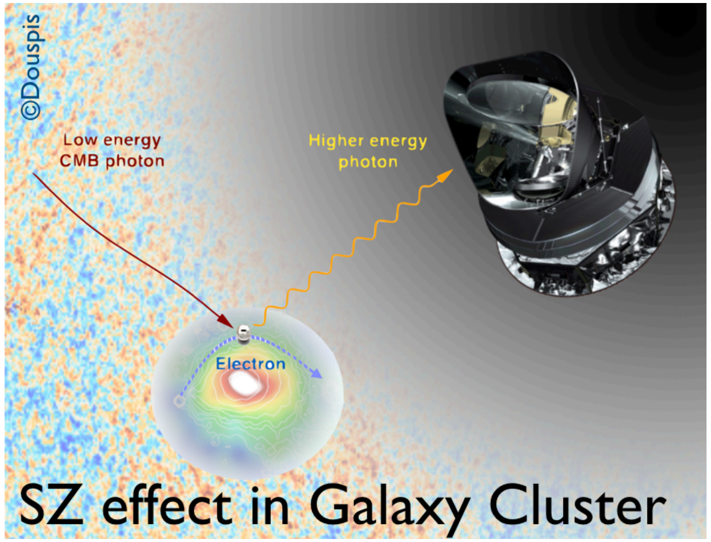

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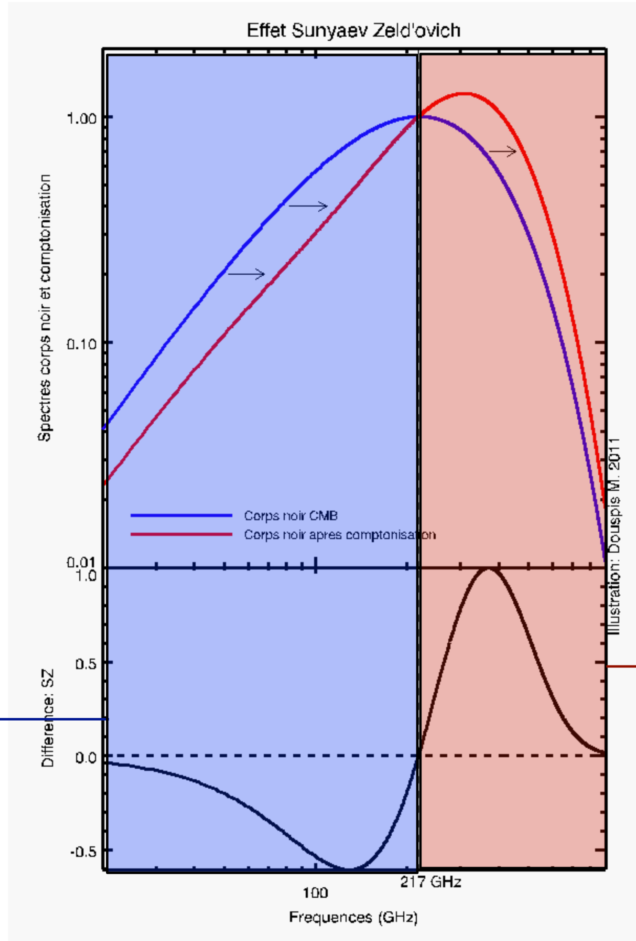

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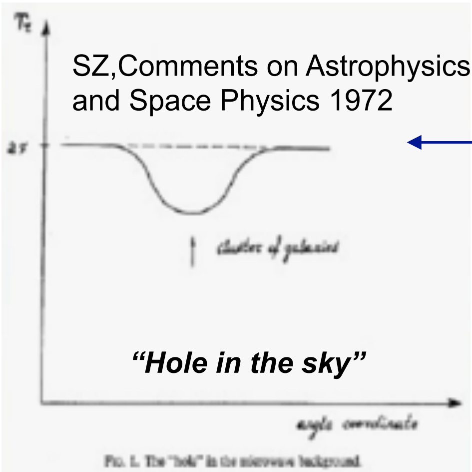

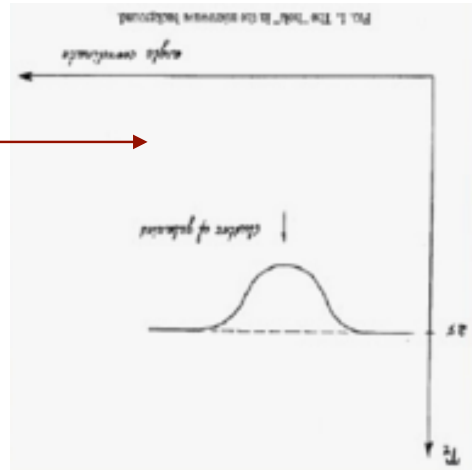

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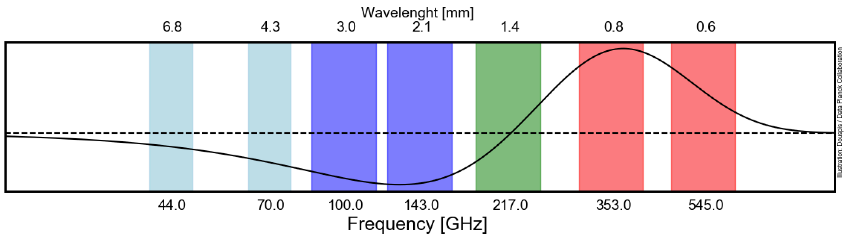
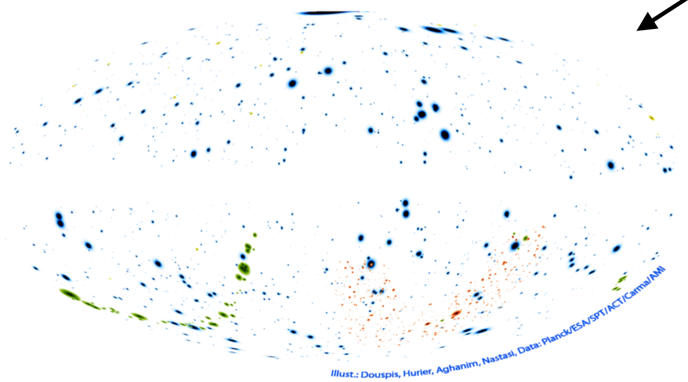
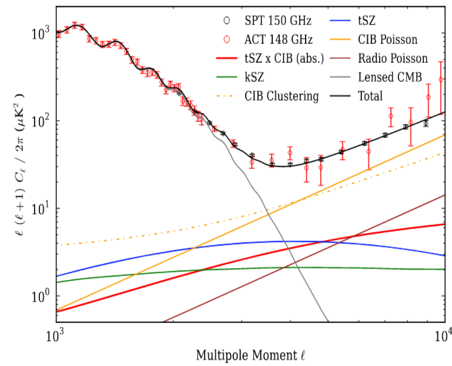


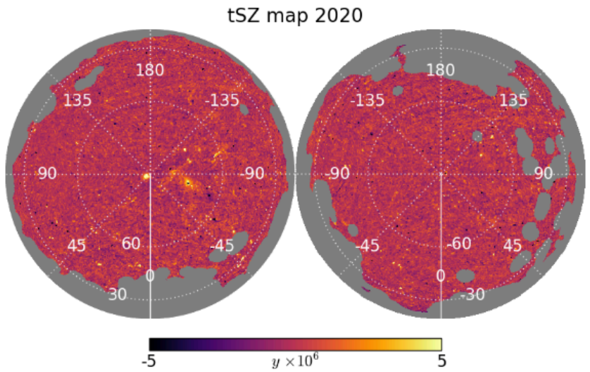
Galaxy Clusters



CMB spectrum contaminant

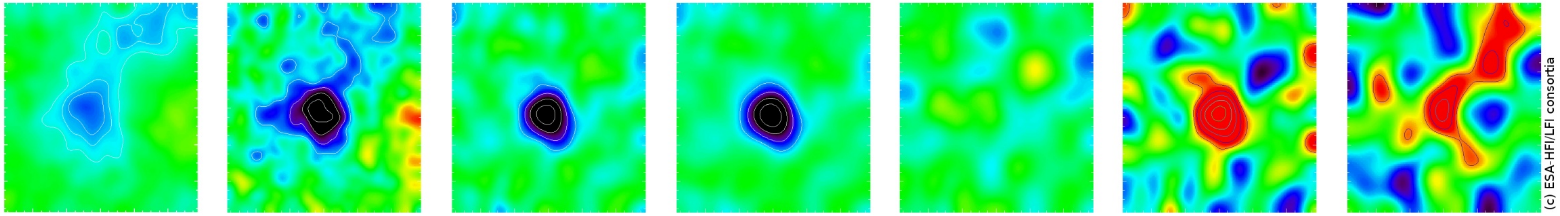


Diffuse SZ map

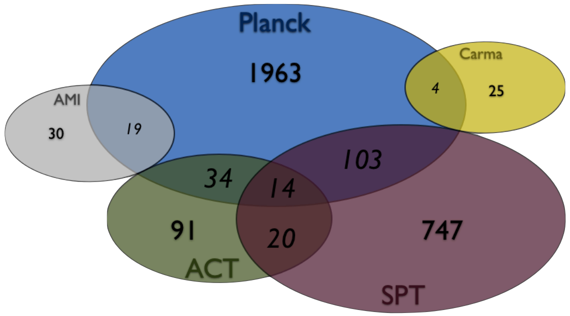


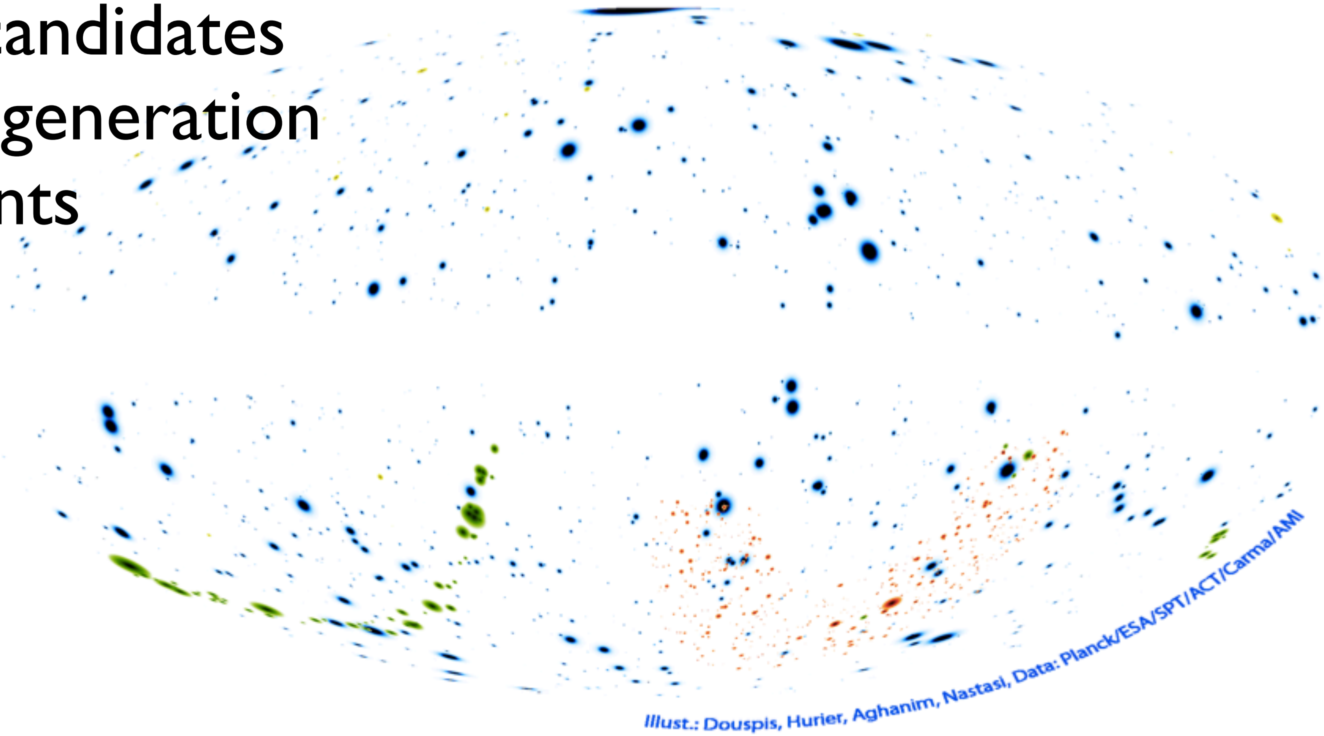
SZ Galaxy Clusters

Planck



2690 clusters and candidates
Increasing with new generation of experiments





SZ metacatalogue available at szcluster-db.ias.u-psud.fr, Douspis et al.

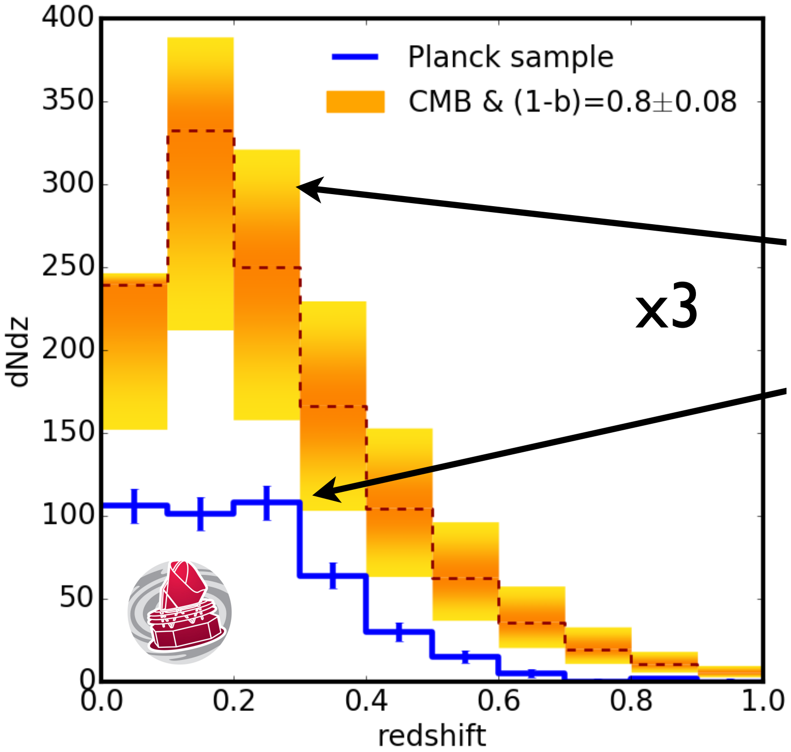
Cluster Number Counts

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

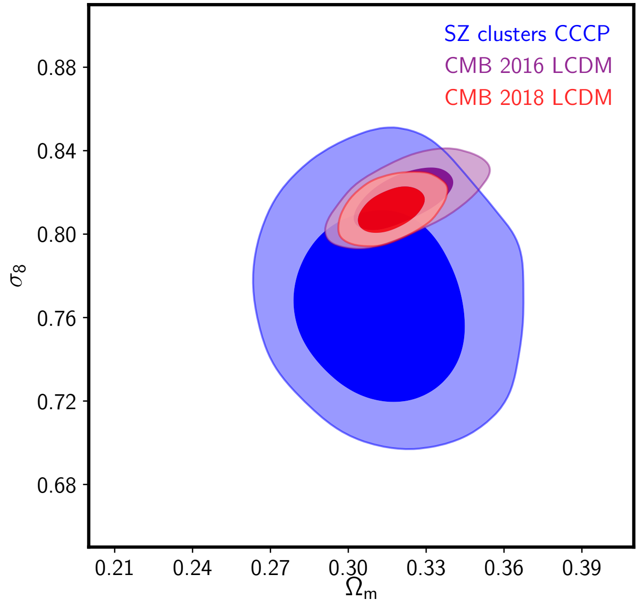
Select a well characterized sample:

- High purity
- Measured completeness
- Measured redshifts

➡ 400+ clusters



2019

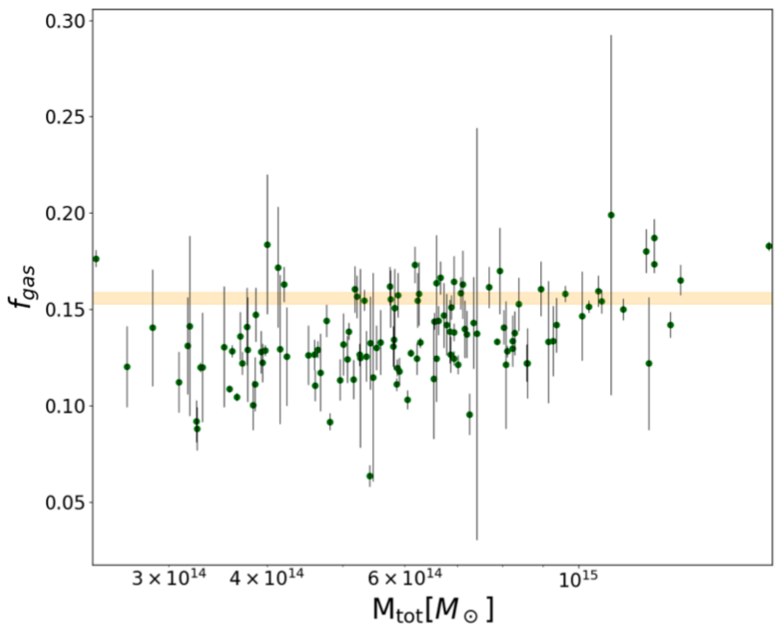


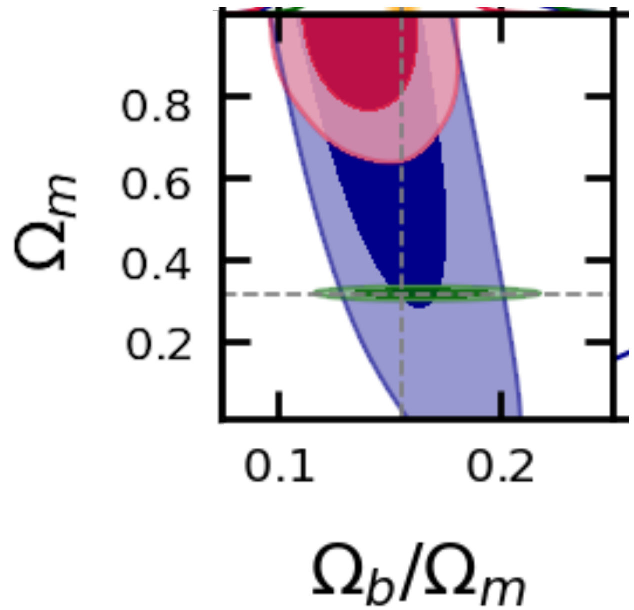
$$dN \propto \sigma_8^9\ \Omega_m^3\ (1-b)^{3.6} \qquad (1-b) = M_{obs}/M_{true}$$

Planck 2014, 2016
Salvati, Douspis, Aghanim (2018)

Cluster Gas Fraction

$$f_{gas}^{obs} = \frac{M_{gas}}{M_{hydro}} = K\frac{\Upsilon(M,z)}{B(M,z)}A(z)\left(\frac{\Omega_b}{\Omega_m}\right)\left(\frac{D_A^{ref}(z)}{D_A(z)}\right)^{3/2} - f_\star$$



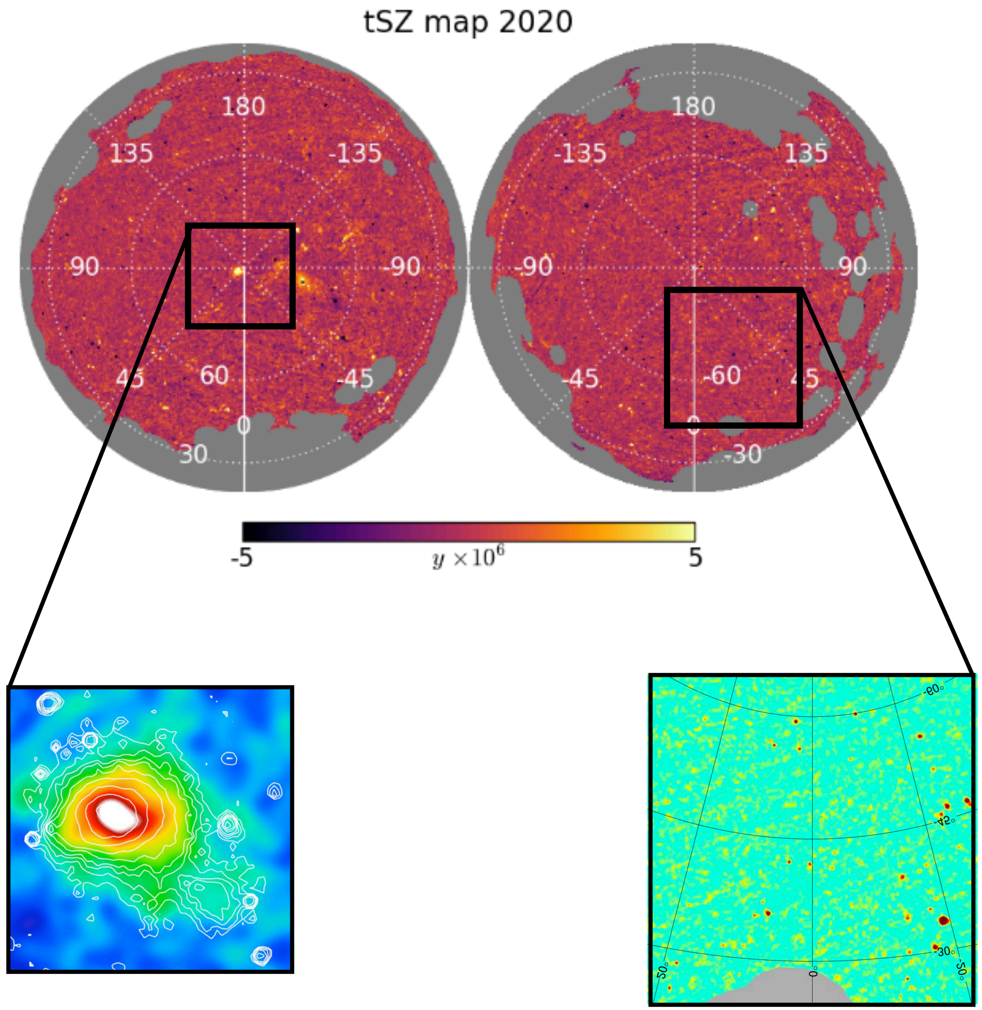


ESZ sample observed in Xray (XMM)

➡ *Talk Friday by Raphaël Wicker*

Hot Gas Map

- Adapted component separation based on :
  - Constraints on emission spectra
  - Localisation in multiple domain
  - 100:857Ghz maps
- Planck: 
  - First map with hot/warm gas on more than 50% of the sky
  - First SZ Angular power spectrum and cosmological constraints

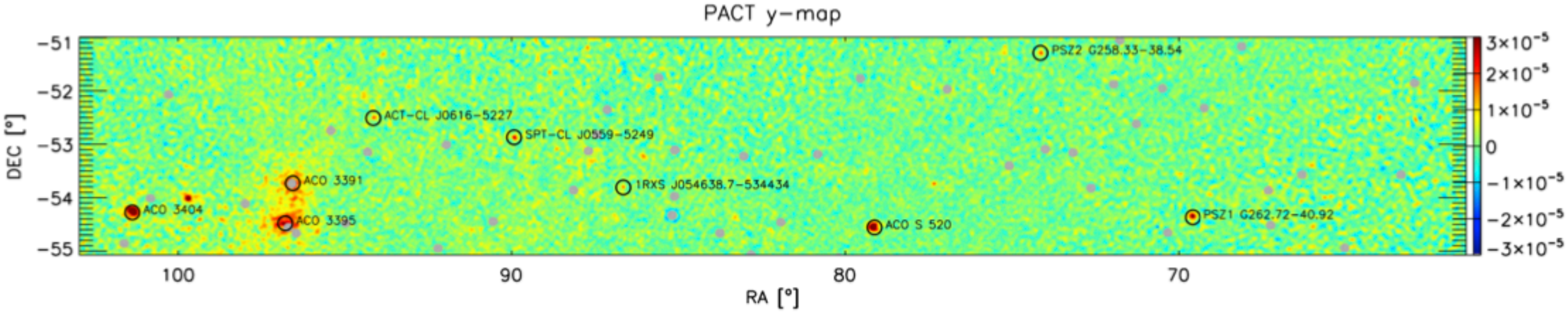


Planck *2014,* ***Planck*** *2016*
Tanimura et al. 2021
Douspis *et al.* ***Salvati*** *et al.*

Other SZ Maps

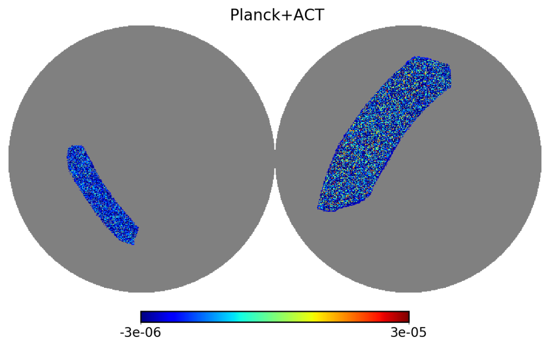
- Planck + ACT: PACT map: 1st combination of CMB experiments

***Aghanim** et al 2019*



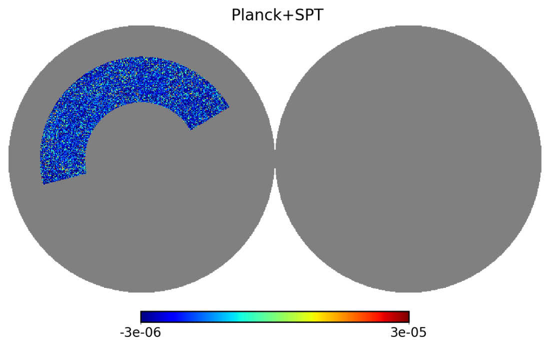
- Planck+ACT

Madhavacheril et al 2020



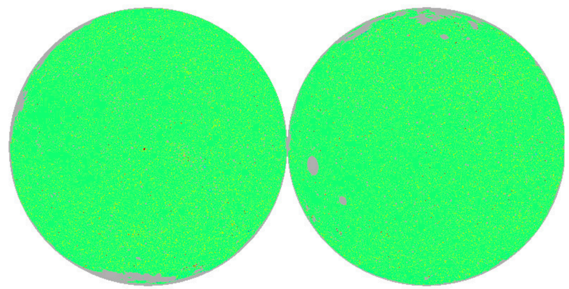
- Planck+SPT

Bleem et al 2021



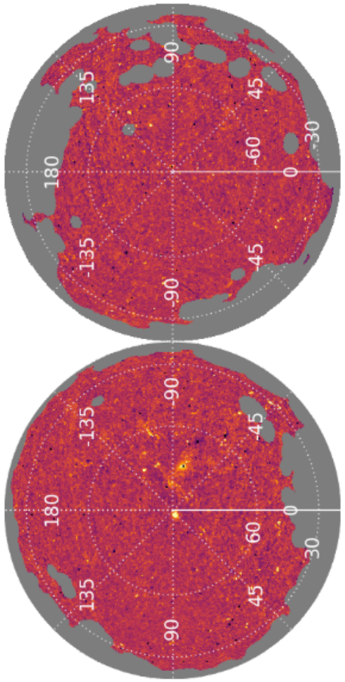
- MILCANN

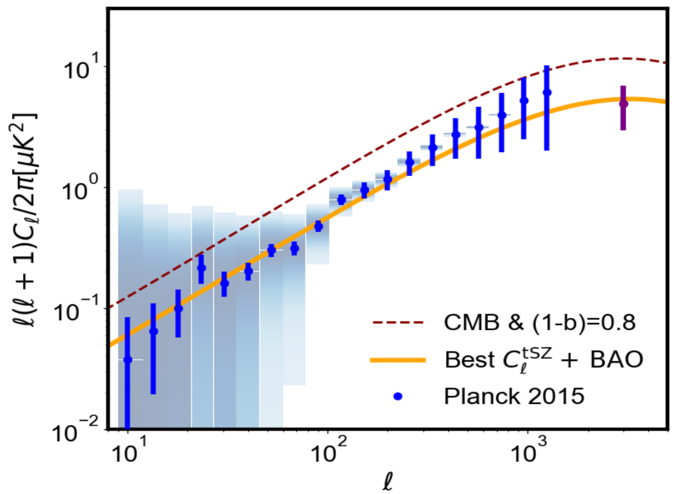
***Hurier, Aghanim, Douspis** 2021*

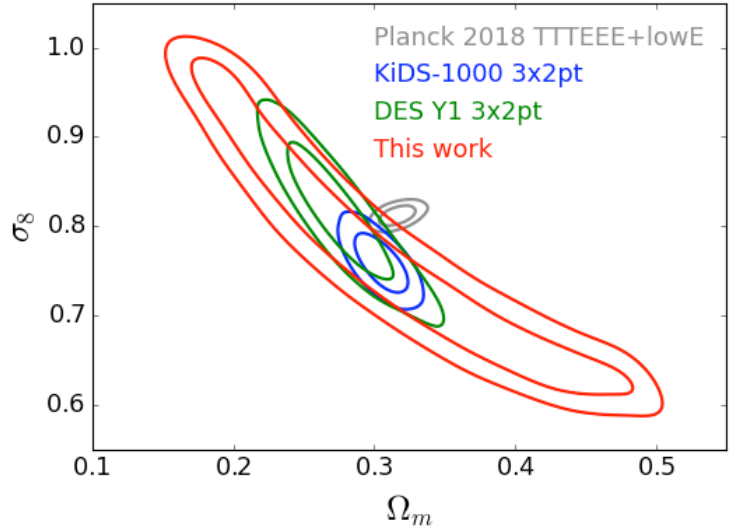


YMAP CONSTRAINTS

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



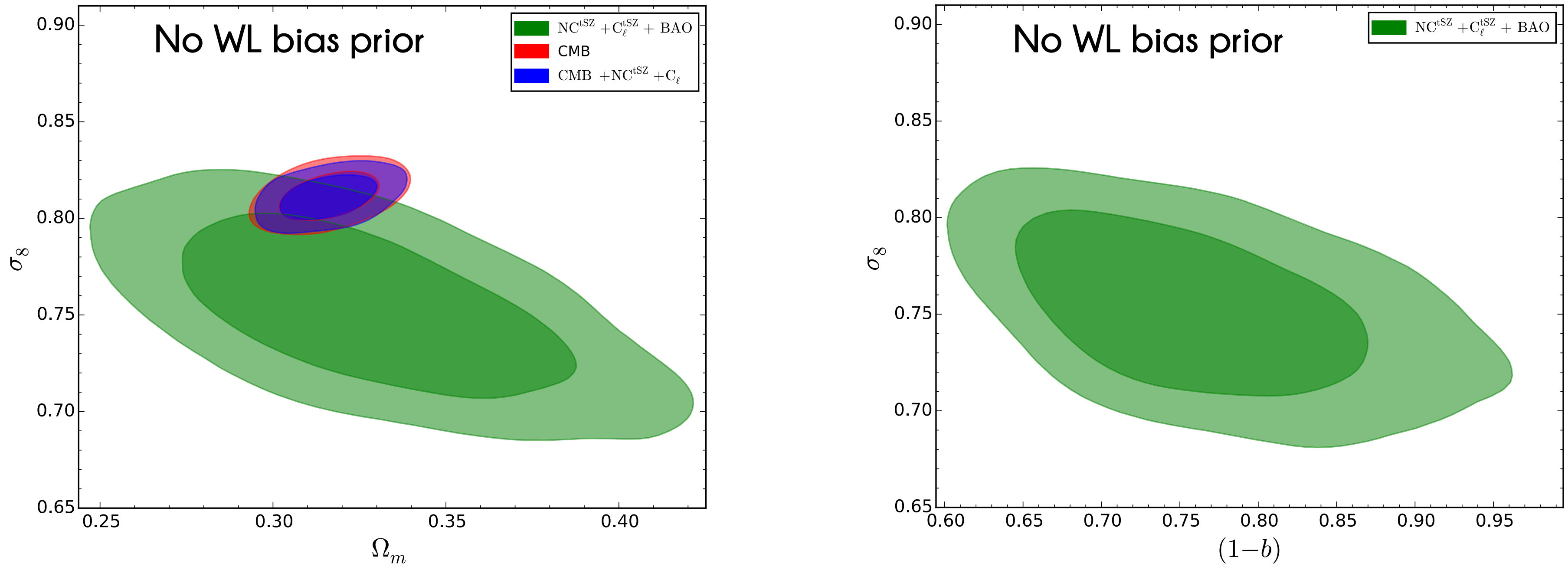




$$C_\ell \propto \sigma_8^{8.1}\ \Omega_m^{3.2}\ (1-b)^{3.2}$$

***Tanimura** et al. 2021*

Combination Number Counts + Power Spectrum



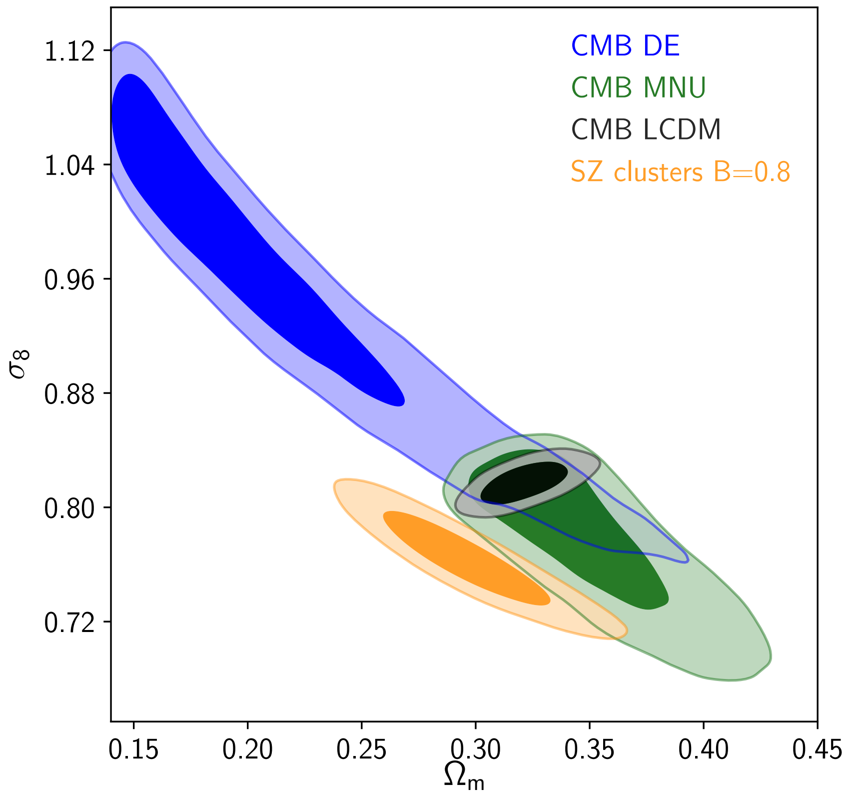
Salvati, Douspis, Aghanim (2018)

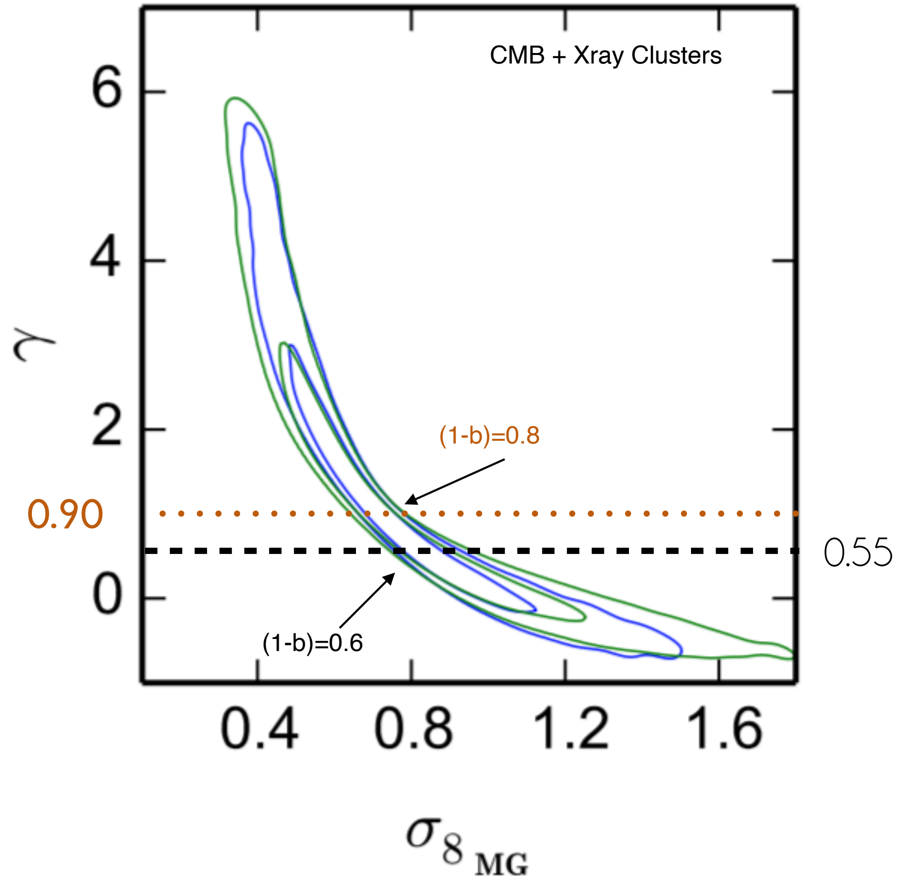
tSZ determination of the mass bias ~0.75

$\sigma_8 (\Omega_m/0.3)^{1/3} \sim 0.78 \pm 0.03$ SZ (Clusters+Cl)+BAO (1-b) ~ 0.75±0.10

$\sigma_8 (\Omega_m/0.3)^{1/3} \sim 0.84 \pm 0.02$ CMB+tSZ (1-b) ~ 0.64±0.03

Can we reduce even more with Extensions of LCDM?





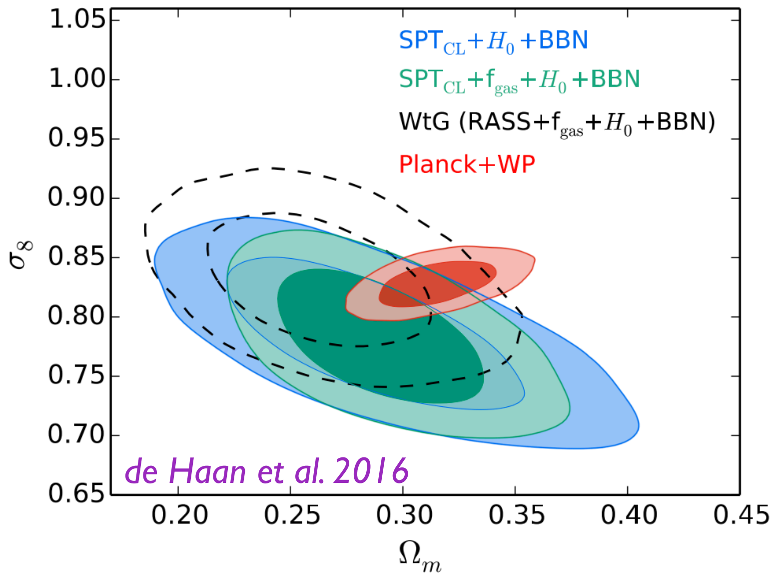
Neutrinos and wCDM do not help

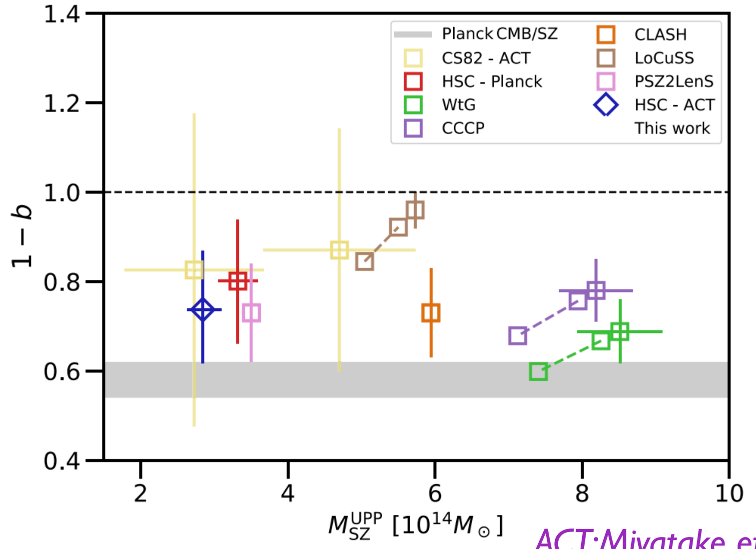
Strong Modified Gravity may help

***Salvati, Douspis, Aghanim** (2018)*

Sakr , Ilić, Blanchard (2018)

Other SZ Probes





ACT:Miyatake et al. 2019

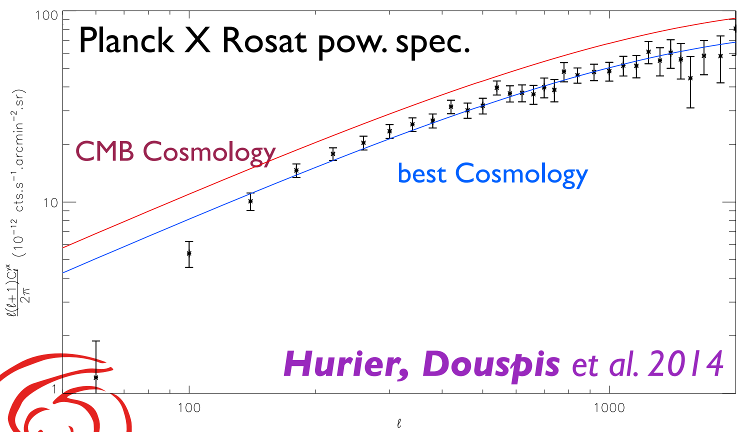
SPT contours compatible with Planck (1-b)=0.8
[same for SPT-2018]

- **1-PDF** *Planck 2014 XXI*
  - PLCK: $\sigma_8 = 0.779 \pm 0.02$
  - ACT: $\sigma_8 = 0.793 \pm 0.04$

Colin Hill, 2014

- **Bispectrum** *Hurier & Lacasa, 2017*
  - PLCK: $\sigma_8 = 0.74 \pm 0.04$
  - SPT: $\sigma_8 = 0.787 \pm 0.03$

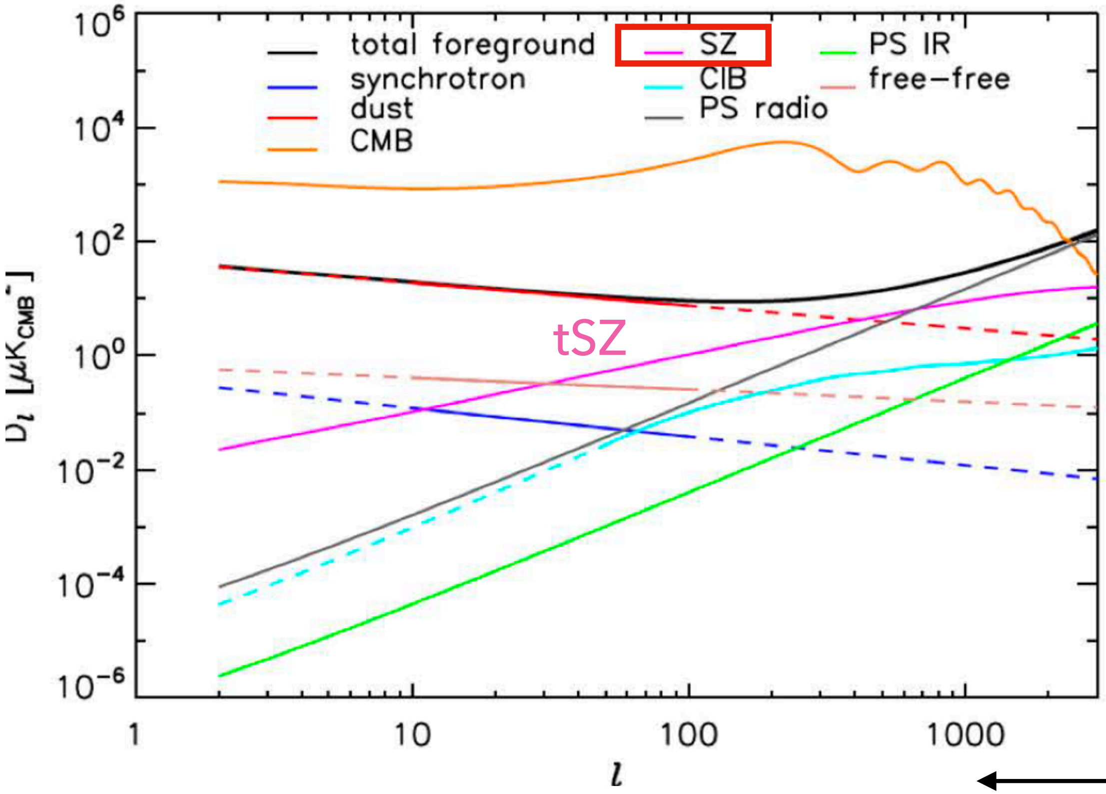
Crawford, 2014



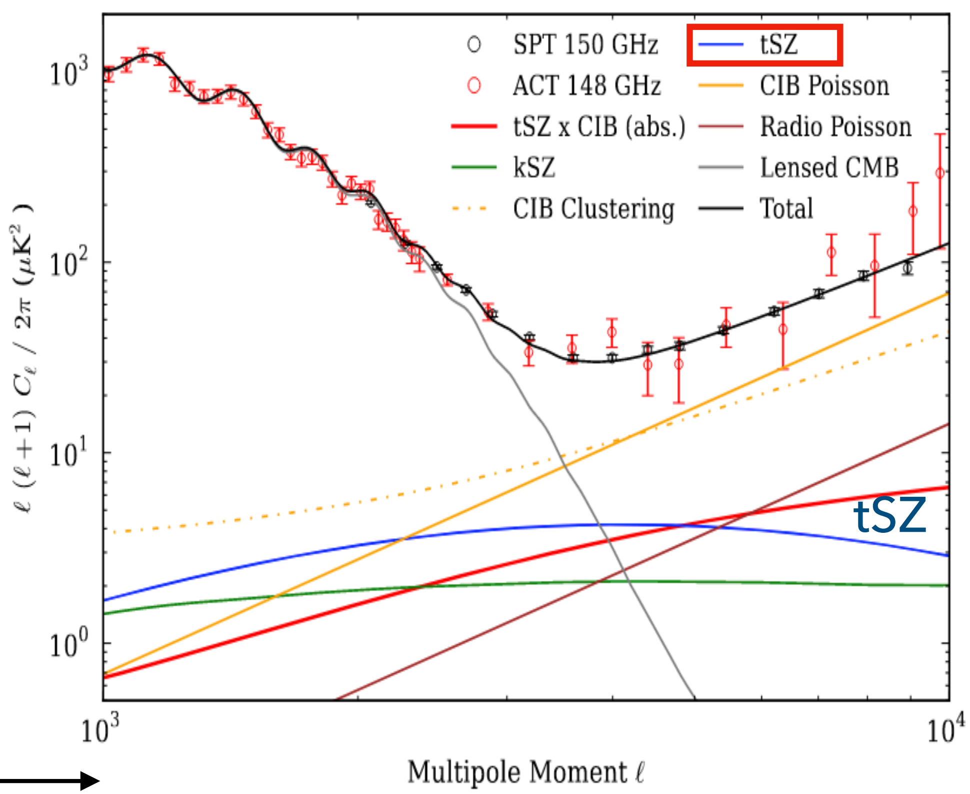
Hot gas in frequency maps

- tSZ is hidden among many other signals
- tSZ not negligible at small scales as Primordial CMB damped

Planck/Large scales



SPT/small scales



Planck coll. 2013

Addison et al. 2012

RATIONALE

- Can we exploit the full cosmological information of extragalactic components (CMB, tSZ, kSZ, …) in CMB analyses ?
- Yes by using coherent modelling and analysis !

Douspis et al 2006

Replace in SPT analysis

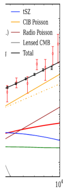
Reionisation

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

Cosmology

By

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



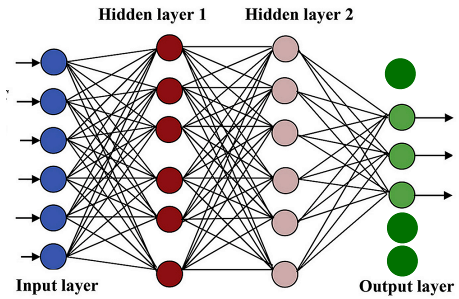
Building an SZ emulator

- 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

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 training

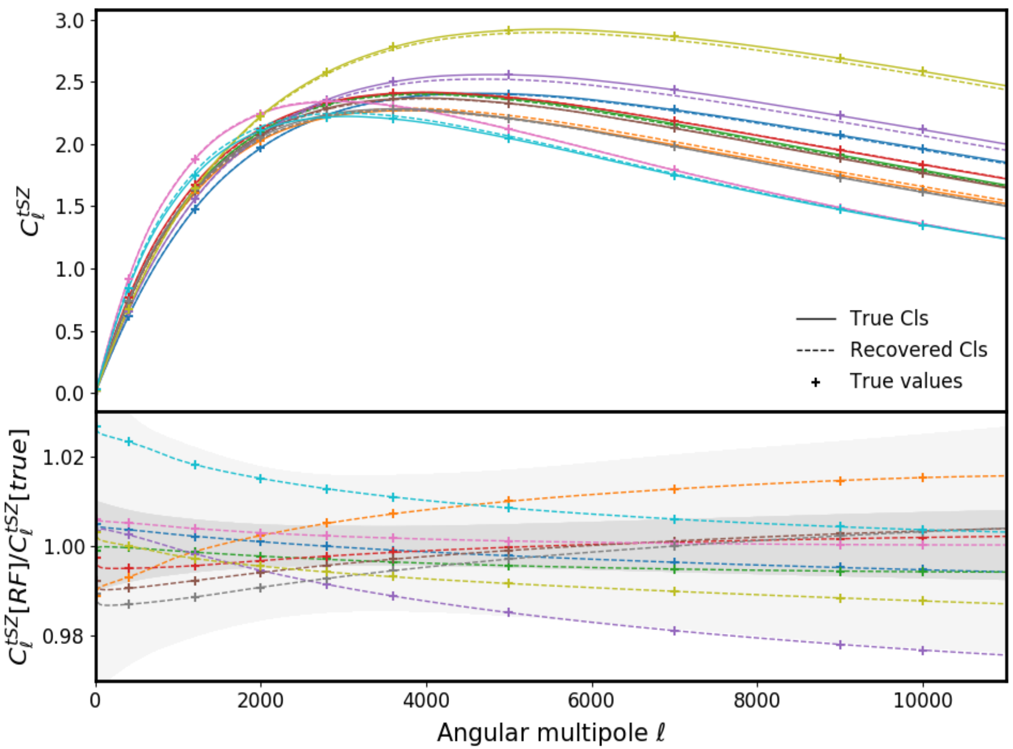


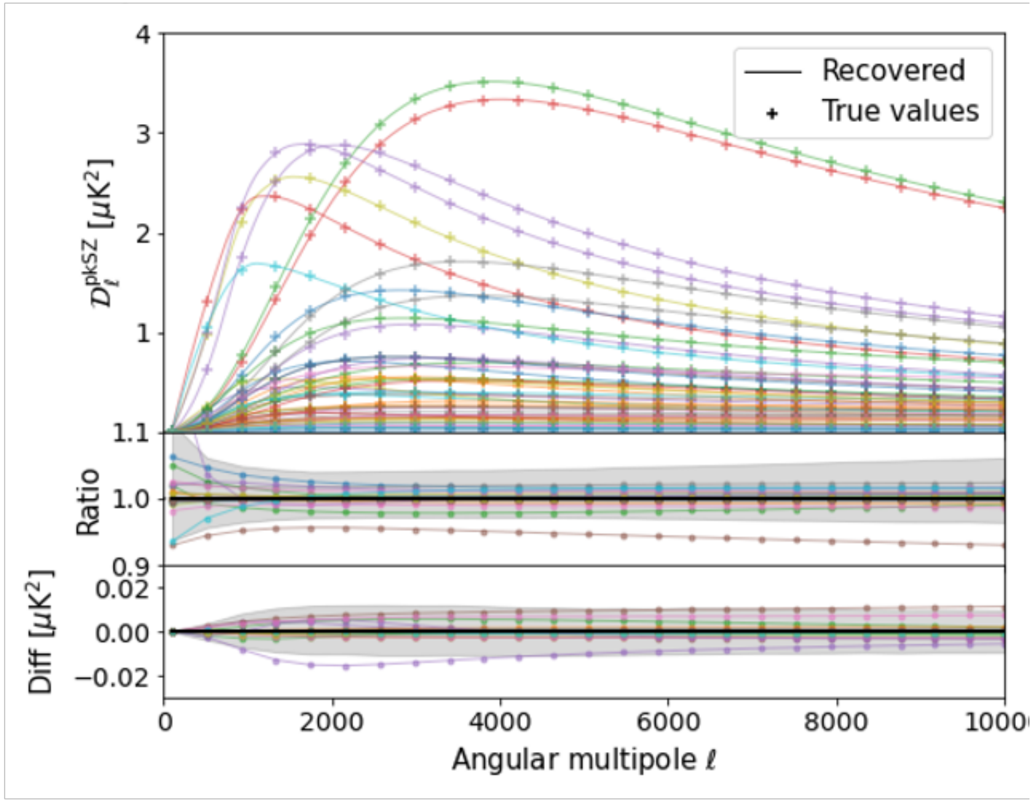
C_{10}
C_{100}
C_{800}
…
C_{1100}

Interpolation → Cls at all ells

Emulator precision

- Comparison Halo model vs RF





± 2% while observation errors are ~20%

Paper I: ***Douspis*** *et al. 2022*

Paper II: ***Gorce*** *et al. 2022*

100 times faster to compute

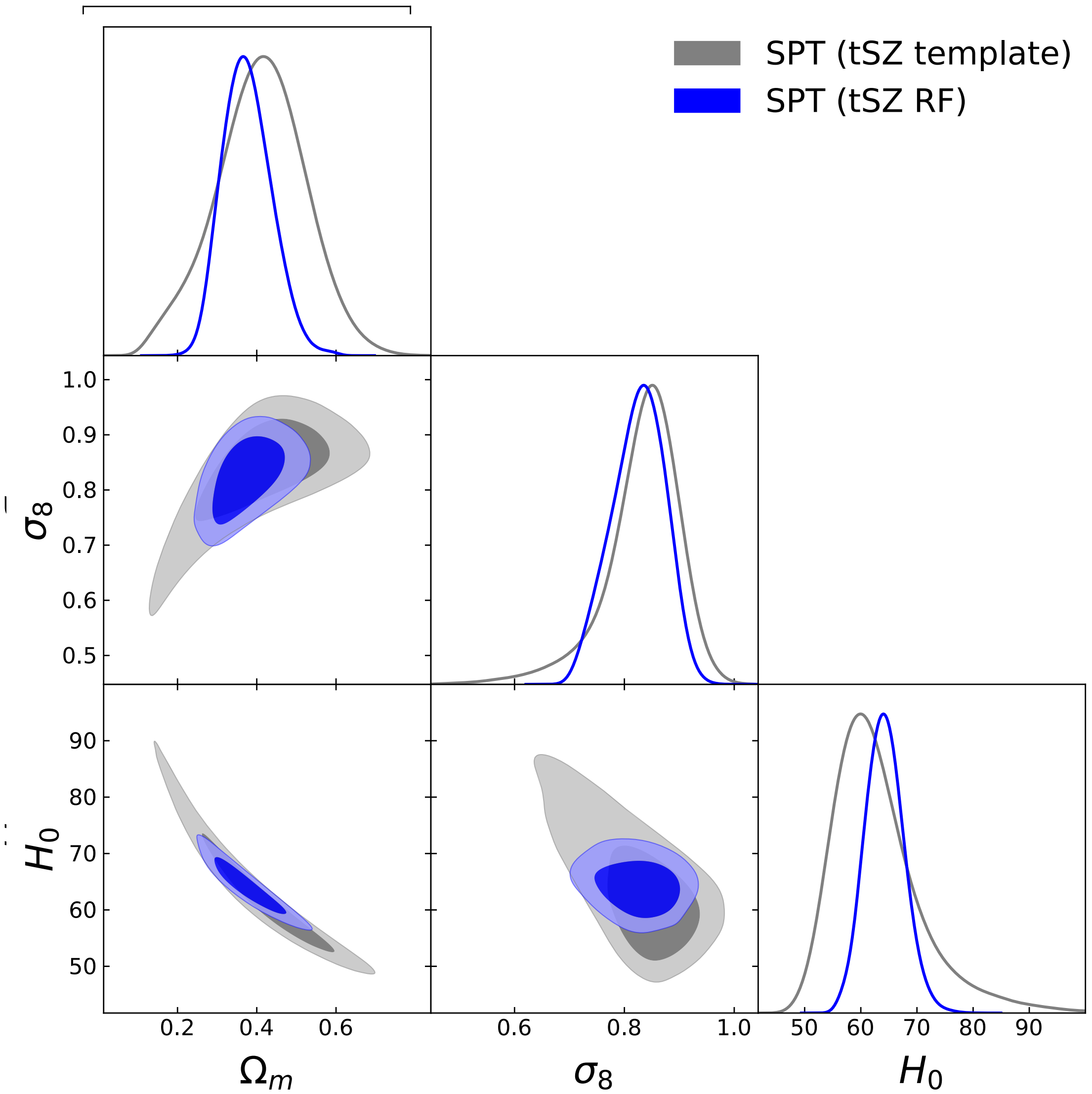
New Analysis of SPT

- 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 (Ω_M, σ_8)

Douspis et al. 2022

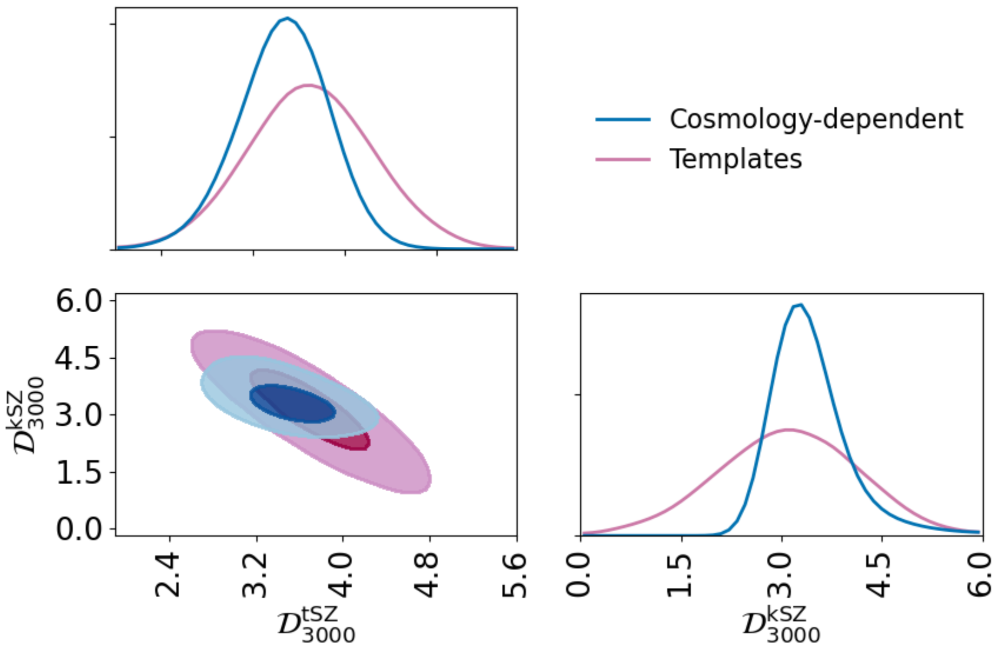
New Analysis of SPT : tSZ+kSZ

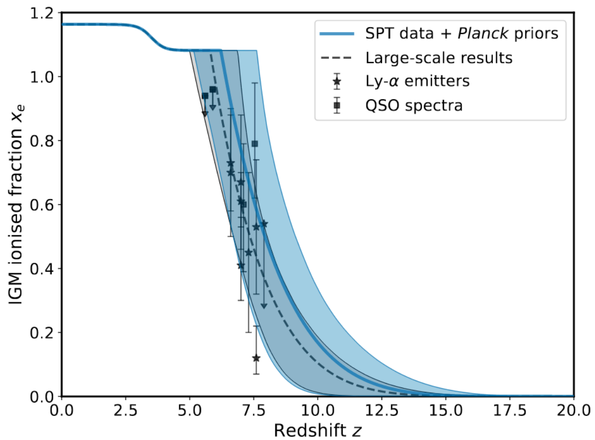
- Hot gas + reionisation

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

+ 4 reio params
+ 6 foreg
+ 4 instrum

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





Adding cosmological information breaks degeneracy of tSZ with kSZ

May bring additional information on reionisation

Gorce et al. 2022

Talk on Cosmix Dawn by Adélie Gorce thursday

Conclusions

- Hot gas traced by SZ offers multiple probes of the cosmological model, independent of CMB, SN, BAO
  - Limited by baryon physics but mitigated by combination of probes and current/ upcoming multiwavelength observations
- Thanks to coherent and novative analyses we are able to retrieve the full cosmological information in millimeter wavelengths

French ANR funding project "**BATMAN**" on

CMB constraints on neutrinos with acurrate reionisation history and gas physics

⟹ 3 postdoc positions opened now !!

http://batman-anr.ias.universite-paris-saclay.fr

https://inspirehep.net/jobs/2170877

https://inspirehep.net/jobs/2170876

https://inspirehep.net/jobs/2170871