



BATMAN v Foregrounds: Dawn of Coherence

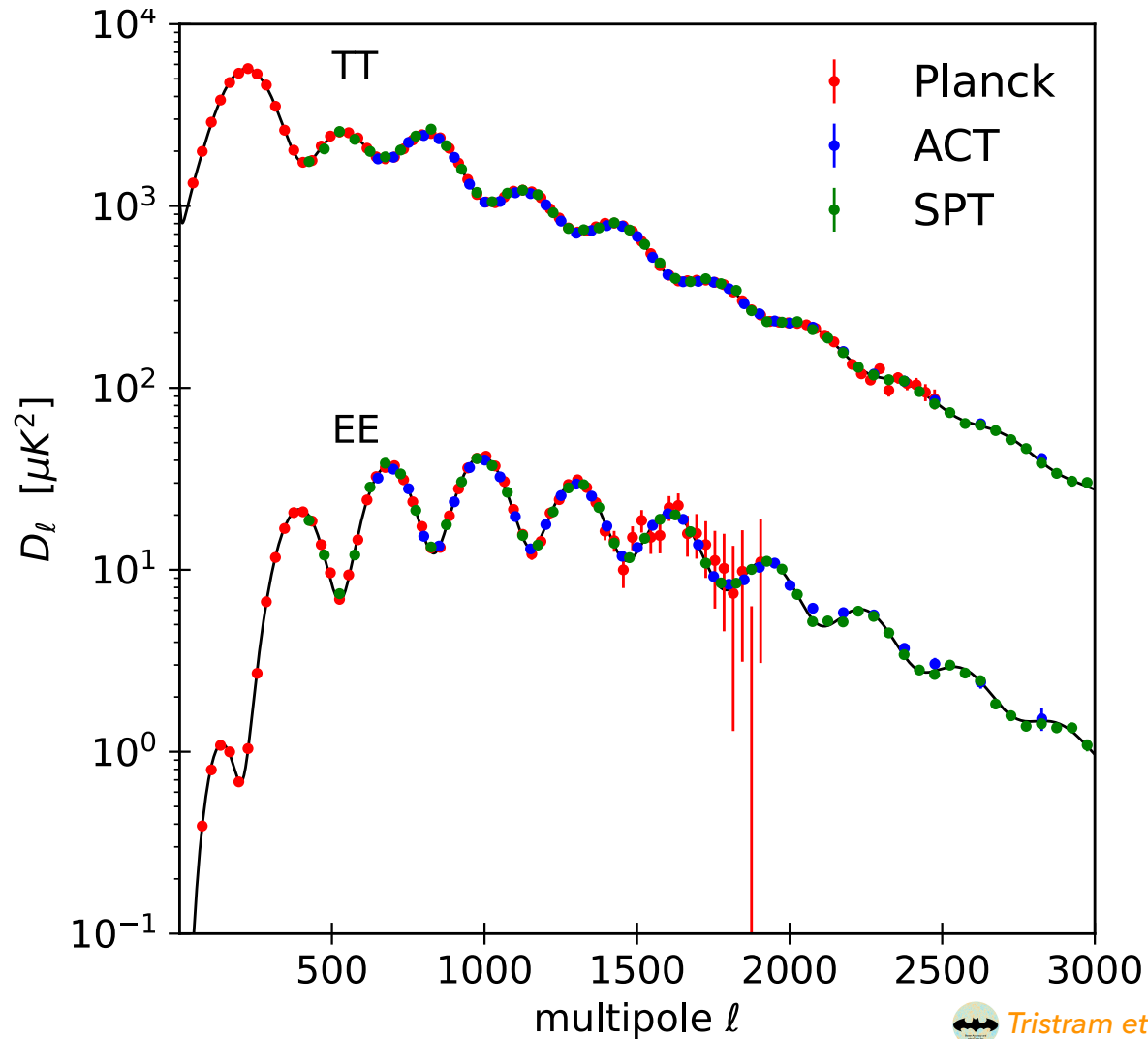
M. Douspis (IAS)

A. Gorce, S. Henrot-Versillé, L. Hergt, S. Ilić, L. McBride, M. Muñoz-Echeverría, E. Pointecouteau, L. Salvati, M. Tristram

BATMAN v FOREGROUNDS



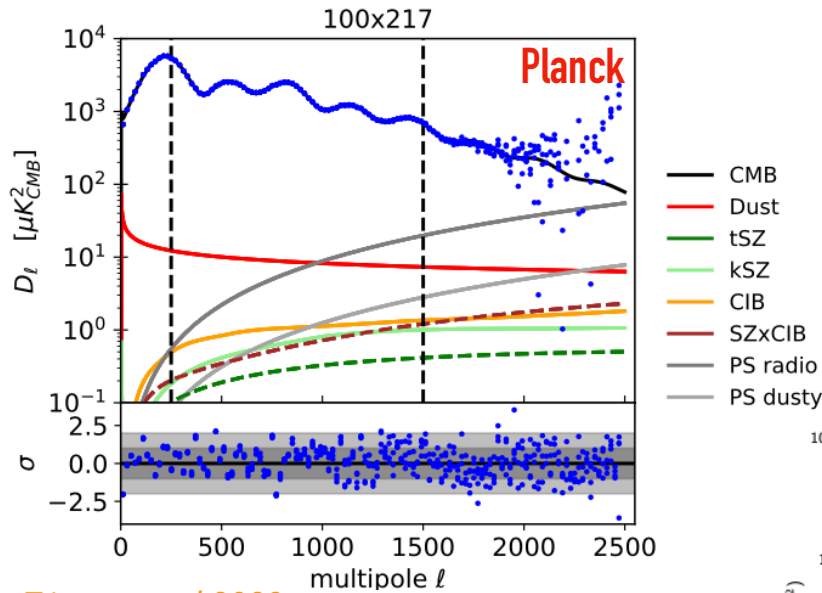
A consistent approach of current CMB dataset analyses using cosmological information from secondary anisotropies



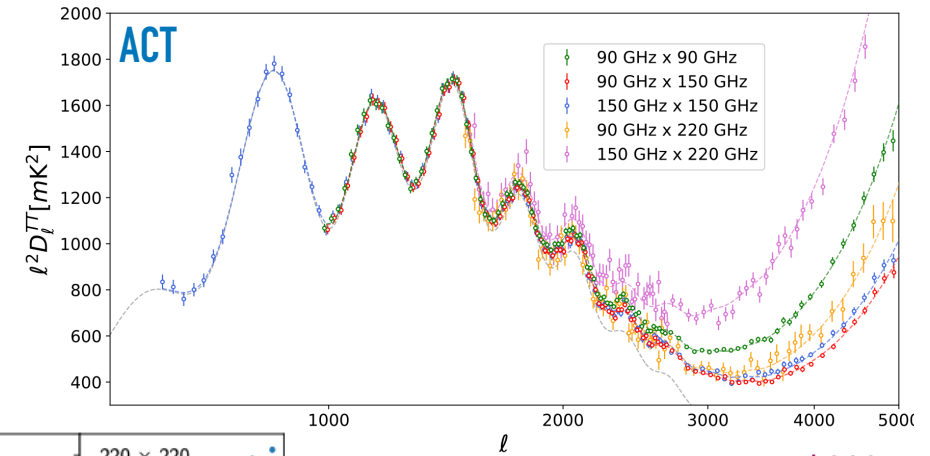
 *Tristram et al 2025*

BATMAN v FOREGROUNDS

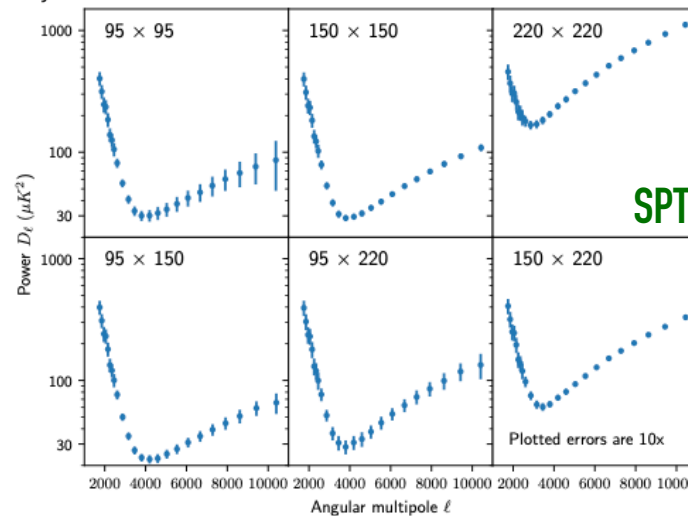
A consistent approach of current CMB dataset analyses using cosmological information from secondary anisotropies



Tristram et al 2023



Louis et al 2025



Chaubal et al 2026

CMB primary and secondary anisotropies contain cosmological information

BATMAN v FOREGROUNDS



A consistent approach of **current CMB dataset analyses** using **cosmological information from secondary anisotropies**

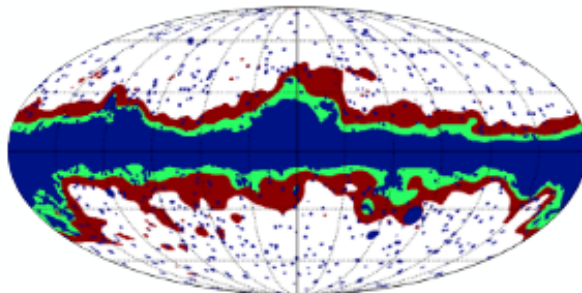
- Step 1 :
 - Construct common likelihood Planck + ACT + SPT
 - Tristram et al. 2026
- Step 2 :
 - Model coherently primary and secondary anisotropy spectra
 - Ilic et al. 2025, Muñoz-Echeverría et al. 2025, McBride et al. 2026, Douspis et al. 2026
- Step 3 :
 - Combine primary and secondary anisotropies for coherent analyses

Planck ACT SPT are complementary datasets

- different resolution (multipole range)
- different sensitivity (noise level)
- different sky-fraction (cosmic variance)
- close but different frequencies
- different systematics

Planck PR4

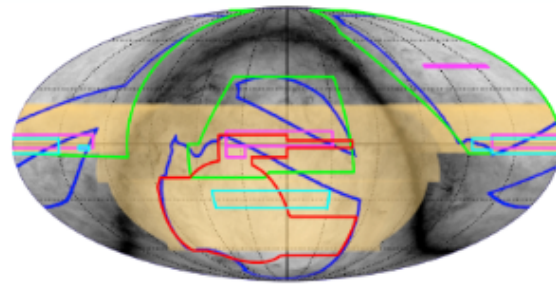
Tristram et al 24



- Full sky
- 100, 143, 217 GHz
- Galactic masks (80%, 70%, 60%)
- beam ~5arcmin

ACT-DR6

Louis et al 25

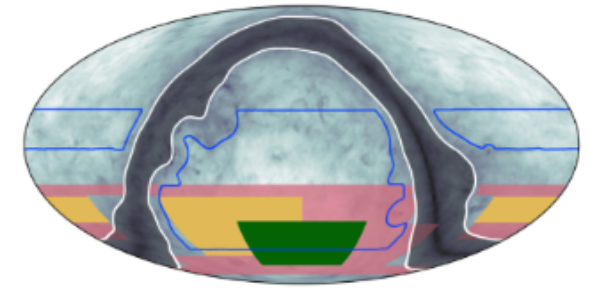


ACTDR6 EUCLID HSC SDSS/DESI DES KIDS

- 25% of sky
- 100, 143, 217 GHz
- Galactic masks
- beam ~1.5 arcmin

SPT3G-D1

Camphuis et al 25



SPT-3G Main (this work) SPT-3G Summer SPT-3G Wide
Planck galactic mask ACT DR6

- 3.8% of sky
- 100, 143, 217 GHz
- Galactic masks
- beam ~1 arcmin

Previous analyses

- uncorrelated datasets
- data model associated with each dataset
- BUT:
 - the foreground model should be consistent
 - unresolved extra-galactic foregrounds should be common
 - priors on systematics can be homogenised

$$\mathcal{L} = \mathcal{L}_{PLK} \times \mathcal{L}_{ACT} \times \mathcal{L}_{SPT}$$

➔ Likelihood framework that can consistently include P+S+A data

➔ ℓ -cuts to minimize correlations

➔ Foregrounds:

➔ TT

➔ Galactic dust, (synchrotron*)

➔ CIB (clustered),

➔ tSZ, kSZ, tSZxCIB,

➔ radio sources, CIB sources,

➔ TE, EE:

➔ Galactic dust, (synchrotron*)

➔ (PS†)

$$C_{\ell}^{\nu\nu'} = A^2 c_{\nu} c_{\nu'} \left(C_{\ell}^{CMB} + \sum_{fg} A_{fg} a_{fg}(\nu) a_{fg}(\nu') C_{\ell}^{fg} \right)$$

ν : dataset at a given frequency

A: dataset calibration (prior on absolute Planck calibration 1 ± 0.0025)

c: inter-calibration between frequency maps

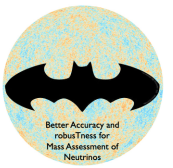
$a(\nu)$: foreground SED (model)



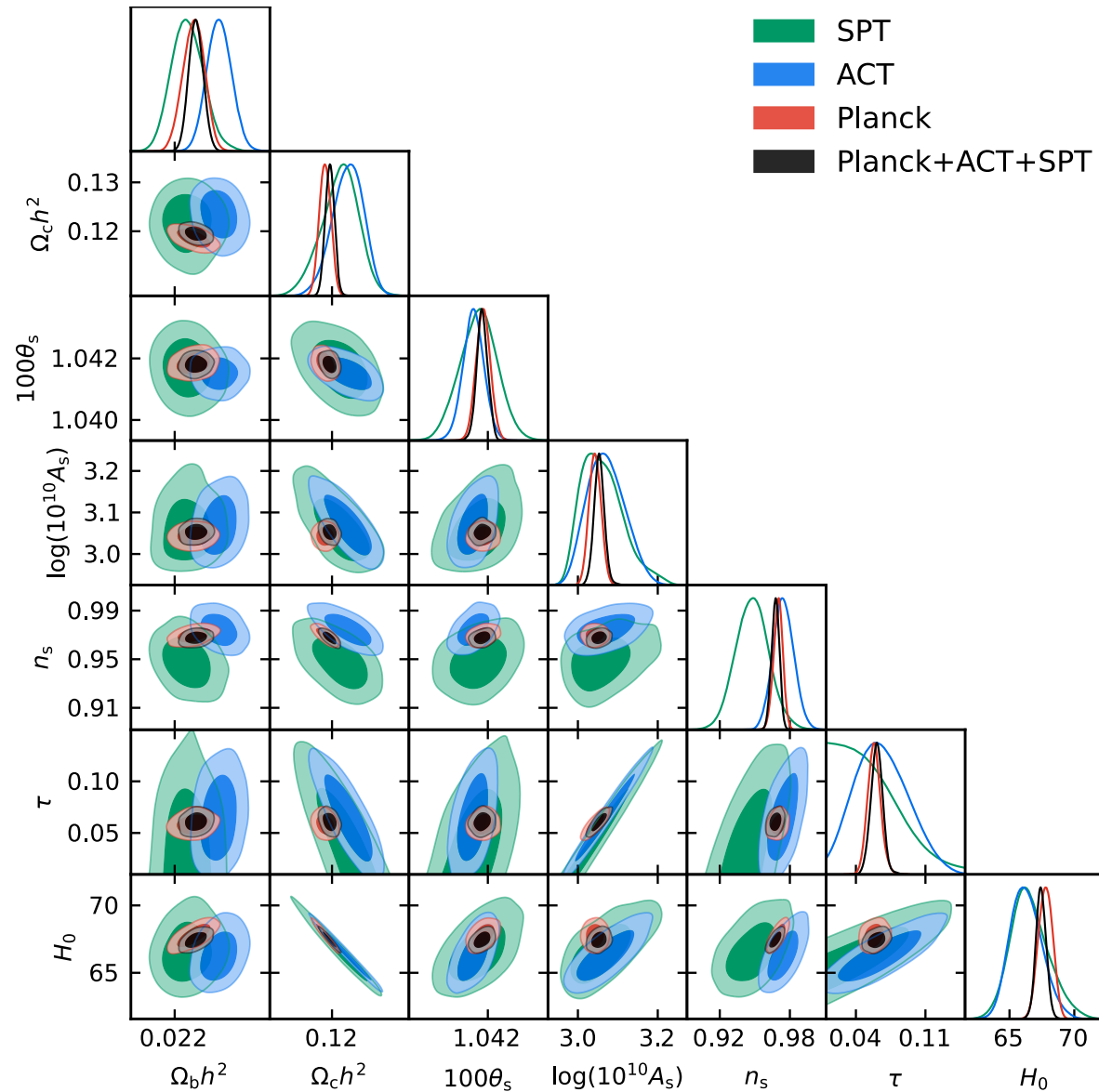
* negligible

† very small at current sensitivity Tucci et al. (2011)

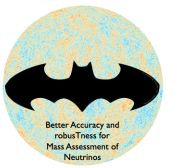
PLANCK+SPT+ACT



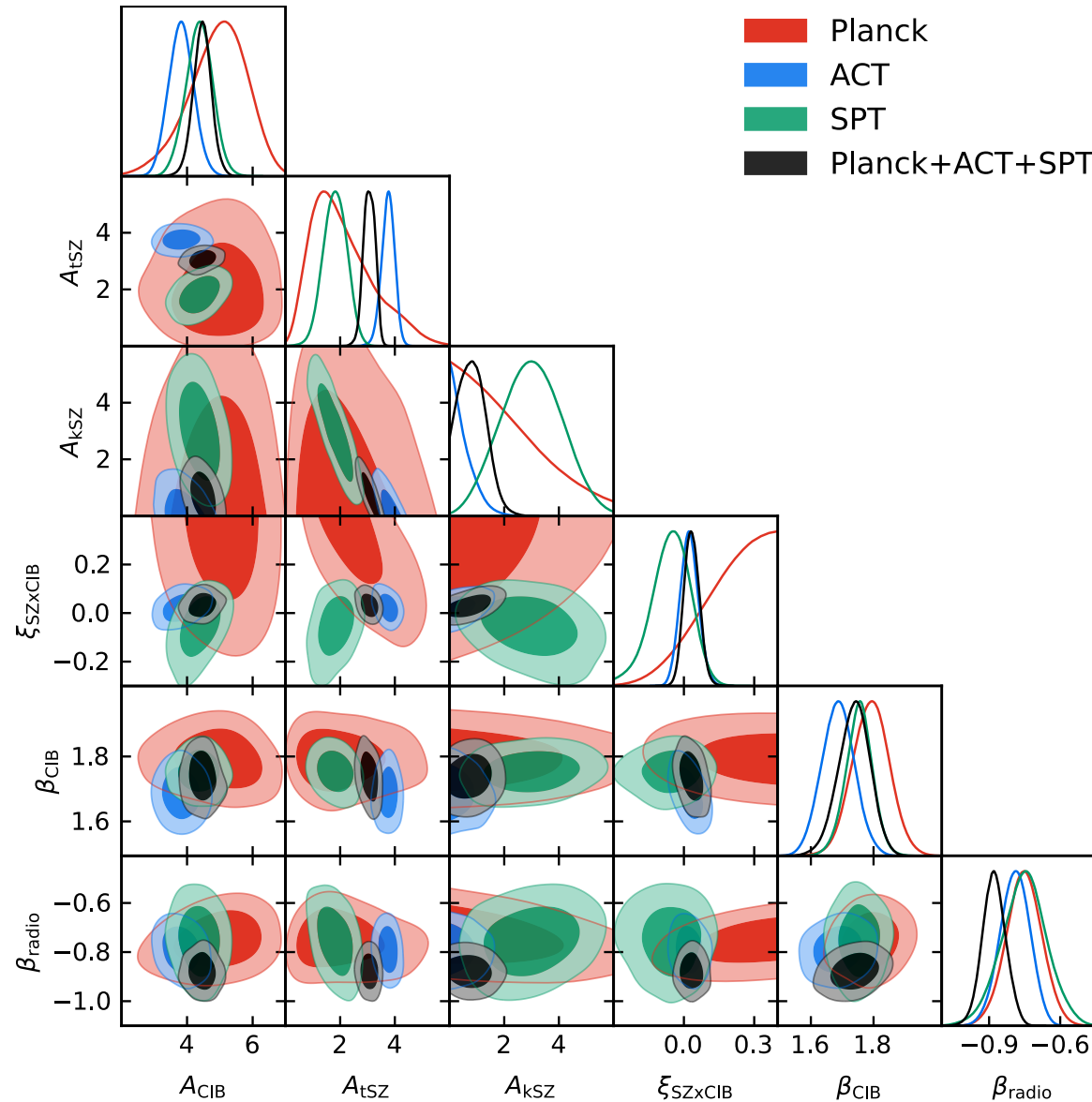
Cosmological parameters LCDM



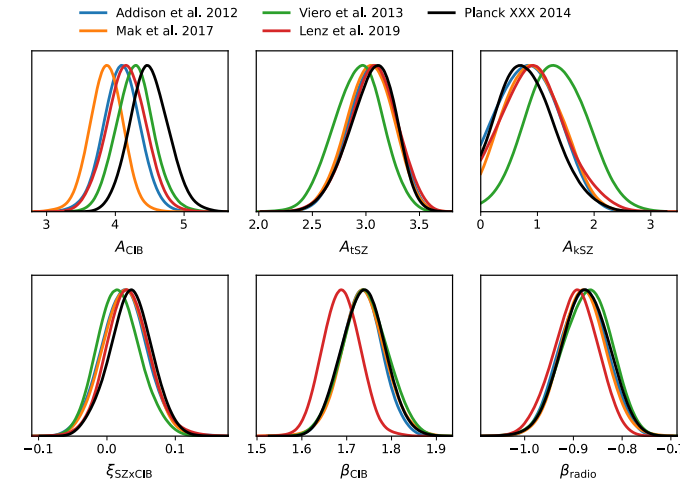
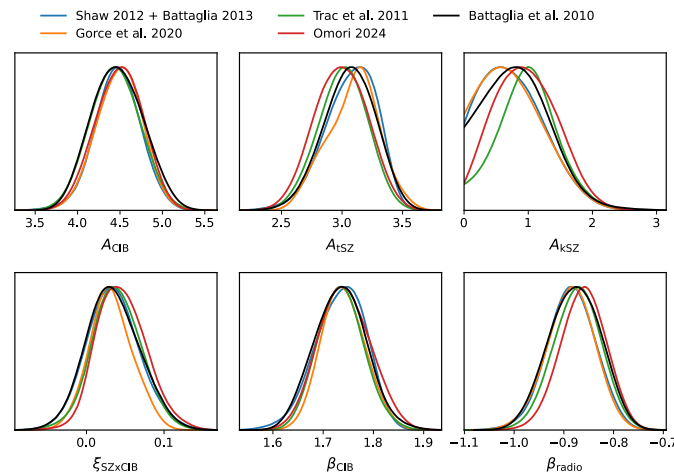
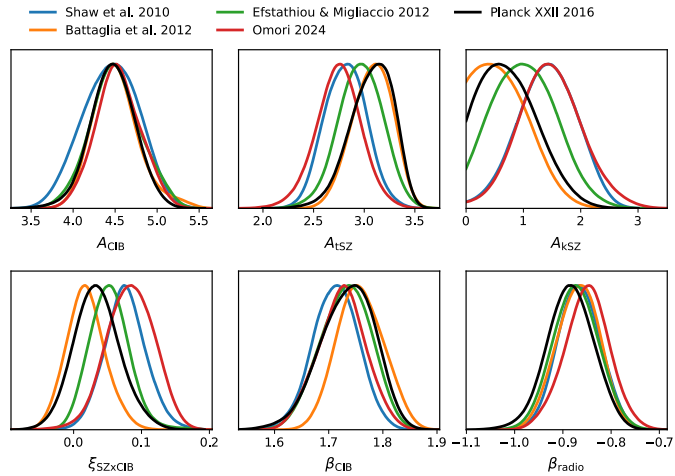
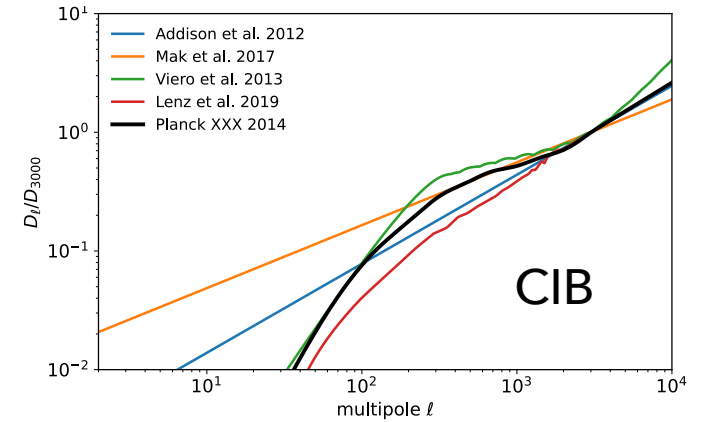
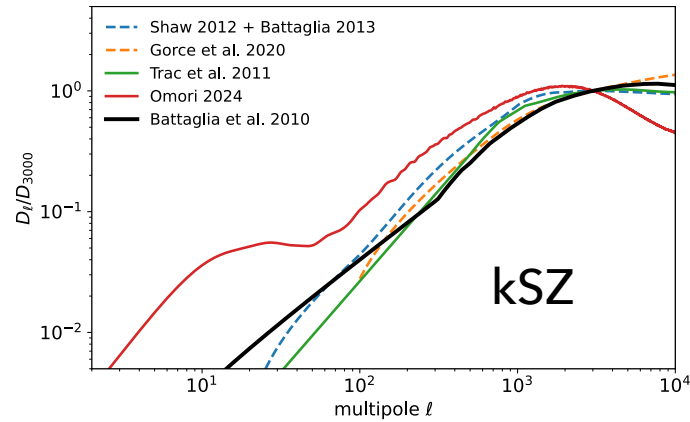
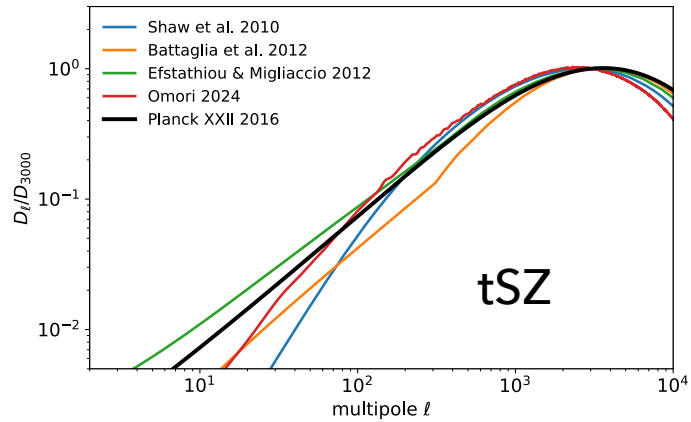
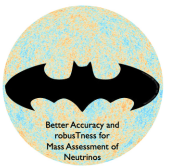
PLANCK+SPT+ACT



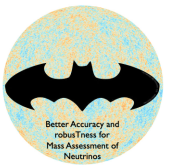
Foreground parameters LCDM



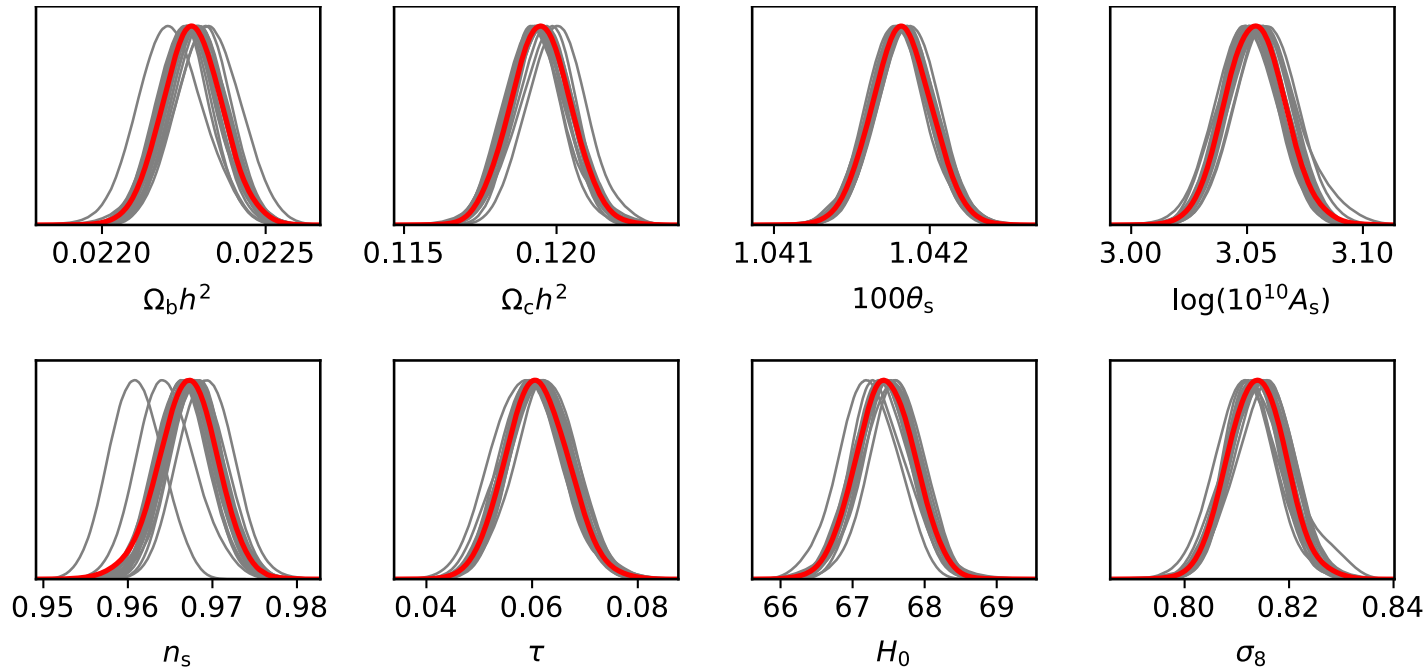
FOREGROUND VARIATION WITH TEMPLATE



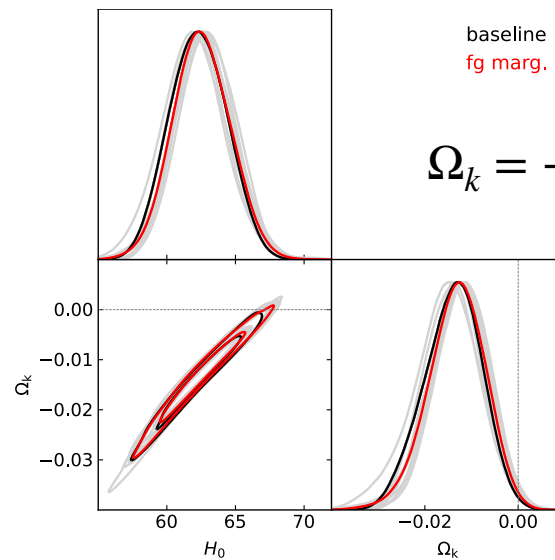
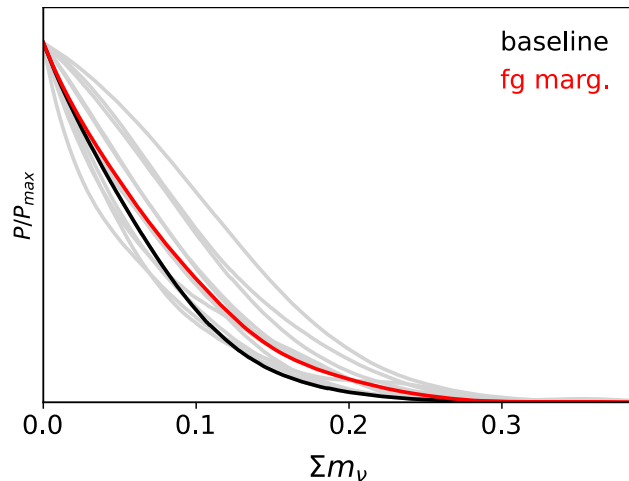
IMPACT OF FOREGROUND TEMPLATES



LCDM



Extensions



$$\Omega_k = -0.0140^{+0.0068}_{-0.0053} (stat) \pm 0.0005 (fg)$$

(Planck+SPT+ACT)

BATMAN v FOREGROUNDS



○ Step 1: Combining datasets



Tristram et al 2026

- not as simple as a product of likelihoods
- need for accurate and consistent foreground model
- marginalisation over the foreground templates provides very stable cosmological constraints for Λ CDM and basic extensions (Alens, Neff, Ω_k , $\sum m_\nu$)

See also Beringue et al 2025

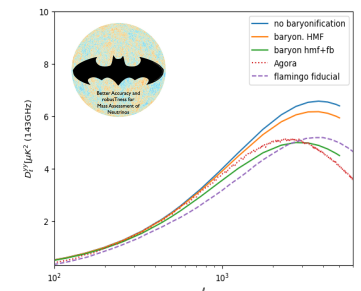
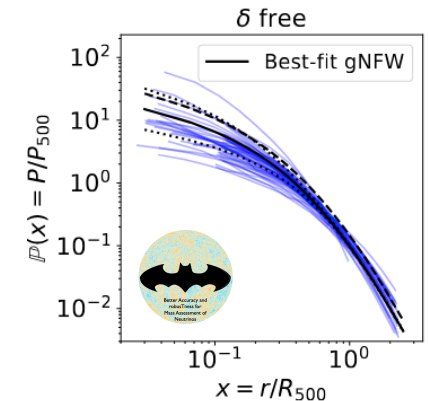
○ Step 2: cosmological and physical model of foregrounds

- Physical model of tSZ, kSZ, CIBxtSZ, CIB (cosmo+astro)
- External likelihoods

Improve tSZ modelling

- Emulator of tSZ (and kSZ) spectra depending on cosmological and astrophysical parameters
- Hot gas profile in halos
- Simultaneous reconstruction of profile and mass (*Muñoz-Echeverría et al 2025*)
- Baryonic effects
 - Effects on mass function and baryon fraction in halos (*Douspis et al. in prep.*)

szdb.osups.universite-paris-saclay.fr




CIB modelling

- Based on *Maniyar et al 2021*
- Alternative 2 population model by *Zagatti et al 2025 (Next Talk!)*

tSZxCIB modelling

- based on tSZ above and Maniyar CIB

cobaya theory
called by
likelihoods for
tSZ, CIB, tSZxCIB



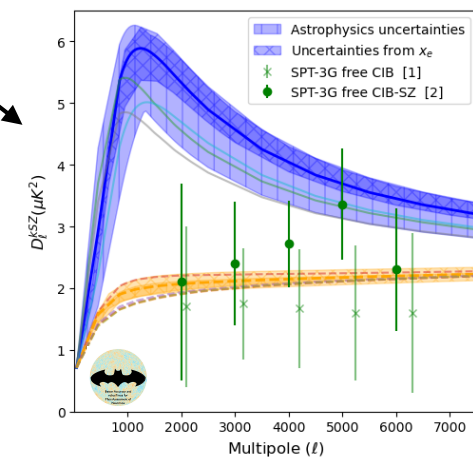
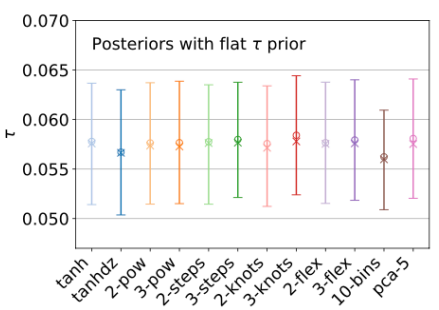
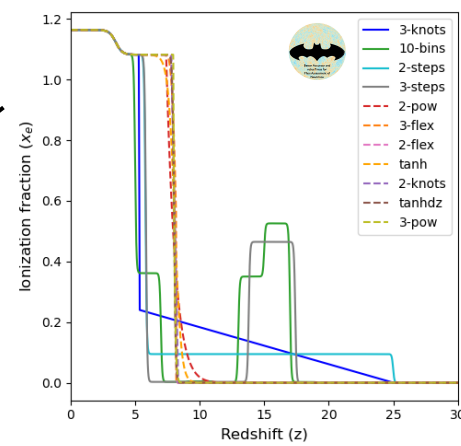
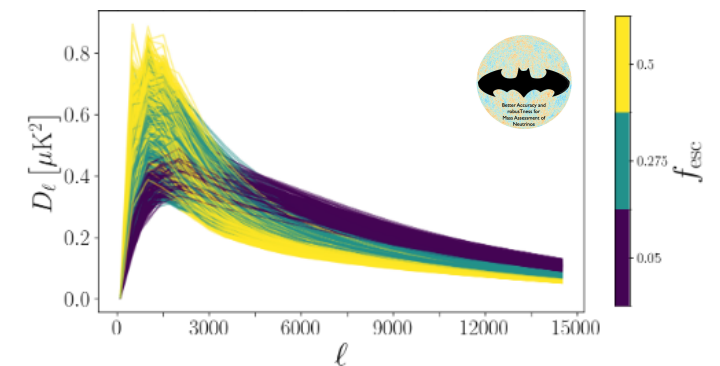
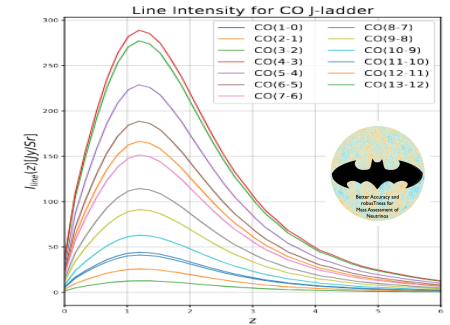
PHYSICAL MODEL

High redshift CO

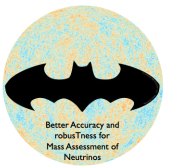
- CO 0-13 lines, modelling in progress, *Zagatti et al. in prep*

kSZ and Reionisation

- Modelling and emulator of kSZ spectra, *Gorce et al. 22*
- Simulation based emulator of kSZ, *McBride et al. 26*
- Revisit of Planck PR4 constraints, *Ilic et al 25*
- Discrimination by kSZ, *Douspis et al 26*



fgd module
calling
emulatorsB



⦿ tSZ galaxy cluster counts

- ⦿ Planck cluster: updated by *Salvati et al 18*
- ⦿ Planck + DES (WL) : *Aymerich et al. 26*

⦿ tSZ y-map spectra

$\Omega_m, \sigma_8, astro$

- ⦿ Planck y-map: $\ell < 1000$ *Planck, Bolliet, Tanimura*
- ⦿ Planck y-map: *Chandran et al 26* (to be implemented)
- ⦿ SPT+Herschell: $1000 < \ell < 5000$ *Raghunathan et al. 26*

⦿ Reionisation

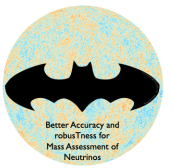
- ⦿ Compilation of direct measurement of ionisation fraction with quasars based on CoreCon compilation (*Garaldi et al 23*) (being implemented)
- ⦿ 21cm upper limits from HERA (*HERA 25*) , LOFAR (*Mertens et al 25*) and NenuFAR (*Munshi et al. 25*) (to be implemented)

$\tau, x_e(z), astro$

Cobaya
likelihoods



BATMAN v FOREGROUNDS

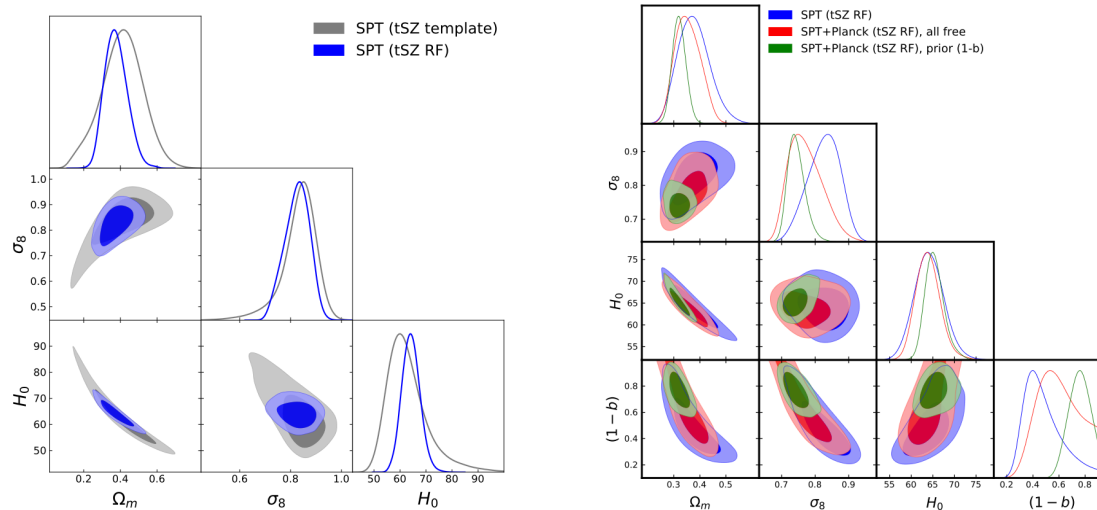


- Step 2: cosmological and physical model of foregrounds
 - Physical model of tSZ, kSZ, CIBxtSZ, CIB
 - minimal models and emulators available
 - External likelihoods
 - few likelihoods available
- Step 3: Primary/Secondary combined analysis
 - First attempts
 - Putting everything together

COHERENT PRIMARY AND SECONDARY ANALYSIS

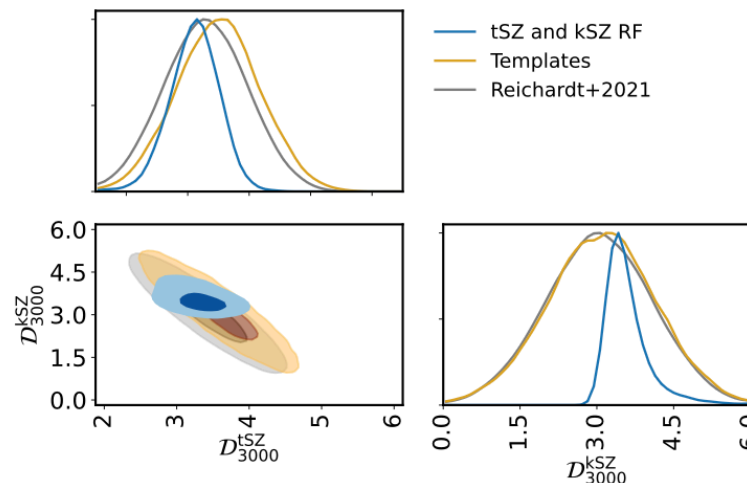


☉ CMB+tSZ : SPT data (*Douspis et al. 2022*)

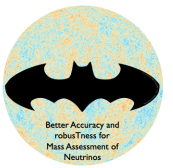


Cosmological information from tSZ, kSZ breaks degeneracies

☉ CMB+tSZ+kSZ : SPT data (*Gorce et al. 2022*)



CONCLUSIONS



- Quality of recent CMB experiments calls for precise and coherent framework
 - Consistent likelihood: common systematics and foregrounds
 - ✓ ○ done with PSA with foregrounds templates
 - Consistent modelling including cosmo and astro information
 - ⚠ ○ more and more complex astrophysics add parameters
 - Combined likelihood with external information
 - ⚠ ○ Cosmological constraints will be better if external likelihoods to complement pure CMB observations
- ➔ all this needed for upcoming observations of SO, LiteBIRD, ...