Towards precision SZ cluster cosmology: from *Planck* to SO

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Outline of the talk

1. Improvements in cluster SZ detection methods.
2. Application to *Planck* data.
3. Cluster number count likelihood code.

Towards precision SZ cluster cosmology

- Number of clusters as a function of mass and redshift is a powerful cosmological probe (Ω_m, σ_8, w).

- Thermal Sunyaev-Zeldovich (tSZ) effect allows for cluster detection with CMB data to high redshift.

- These catalogues can be in turn used for cosmology (cnc), with the cluster tSZ signal as a mass proxy.

    - *Planck*: ~ 400 (SNR >6)
    - SPT-SZ/SPTpol: ~ 500
    - ACT: ~ 4000

    - SPT-3G > 10000
    - SO: ~ 20000
    - CMB-S4: ~10^5

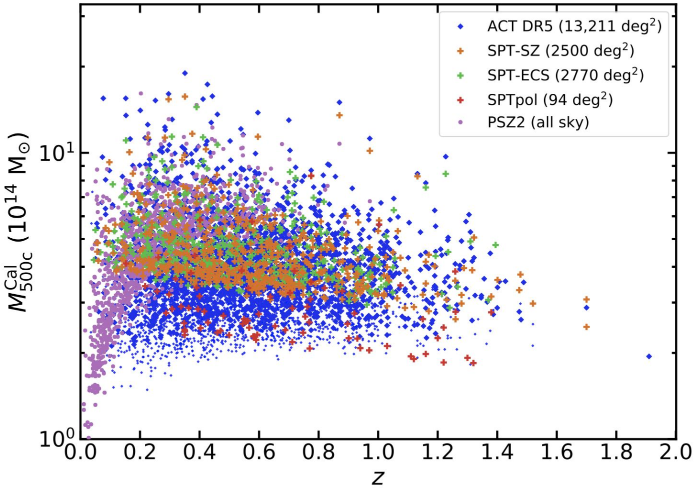


Figure credit: Hilton+ 2021

Cluster detection and characterisation need to be understood to unprecedented level if the statistical power of clusters from upcoming experiments such as SO is to be realised: cluster selection and tSZ-mass relation.

SZiFi: the Sunyaev-Zeldovich iterative Finder

- Goal: study systematics in cluster detection, tackle them if necessary, apply to *Planck* and SO.

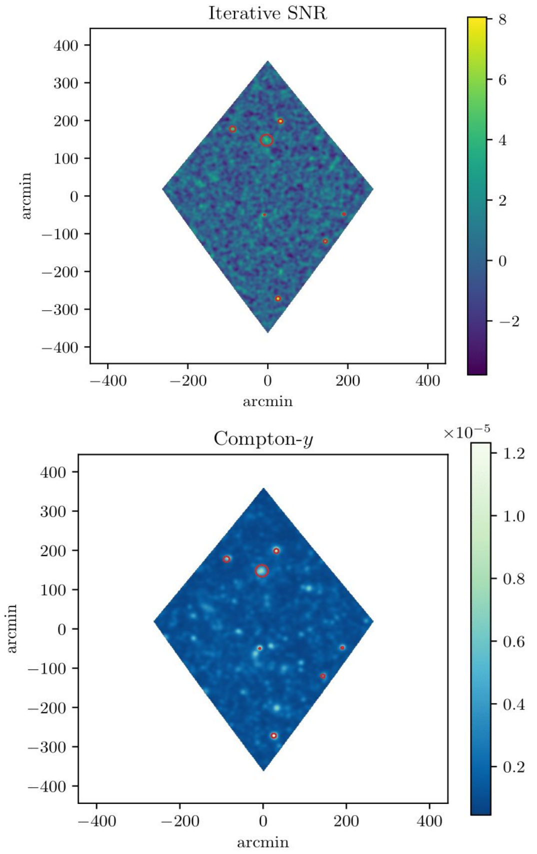
- New implementation of multifrequency matched filter (MMF) cluster-finding approach (used in *Planck*, ACT and SPT).

- Works on flat-sky tiles and searches for clusters across angular scale (θ_{500}) and sky location using an MMF, making use of both spectral and spatial information (tSZ SED and cluster Compton-y profile).

- Main cluster observable: detection SNR (q) (mass proxy), but also Compton-y and cluster angular size (θ_{500}).

- Key novel features:

    - Iterative noise covariance estimation.
    - Foreground deprojection.

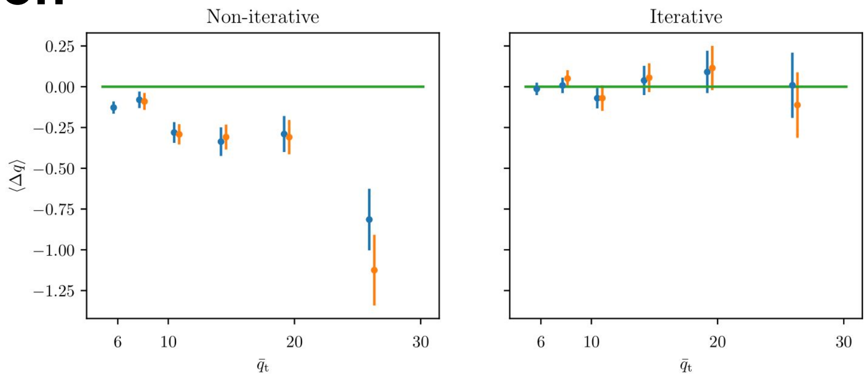


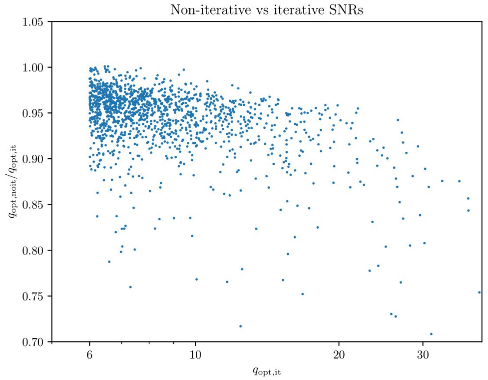
IZ, Rotti, Chluba & Battye, 2204.13780

github.com/inigozubeldia/szifi

Iterative noise covariance estimation

- Matched filter requires knowledge of the noise covariance.
- This is typically estimated from the data and taken to be the data covariance.
- However, this “noise covariance” includes the signal being searched for:
    1. Noise covariance overestimated, SNR underestimated.
    2. Covariance estimate is noisy. If the signal is present in noisy covariance: bias in the observable, which is not present (to leading order) if signal isn’t in the covariance (similar to ILC bias).
- Solution: iterative covariance estimation, masking detections (see IZ+ 2022).



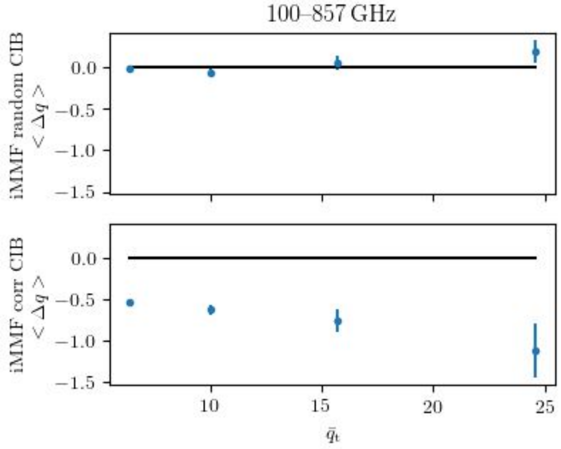


Results for *Planck*-like sample from Websky (tSZ+kSZ+CMB+CIB+noise)

Foreground deprojection: Cosmic Infrared Background (CIB)

- CIB emission spatially correlated with tSZ signal leads to bias in tSZ observable.

Results for *Planck*-like sample from Websky (tSZ+kSZ+CMB+CIB+noise)



IZ, Chluba & Battye, 2212.07410

Foreground deprojection: CIB

- Spectrally constrained iMMF: one or several foregrounds with given SEDs are nulled or deprojected.

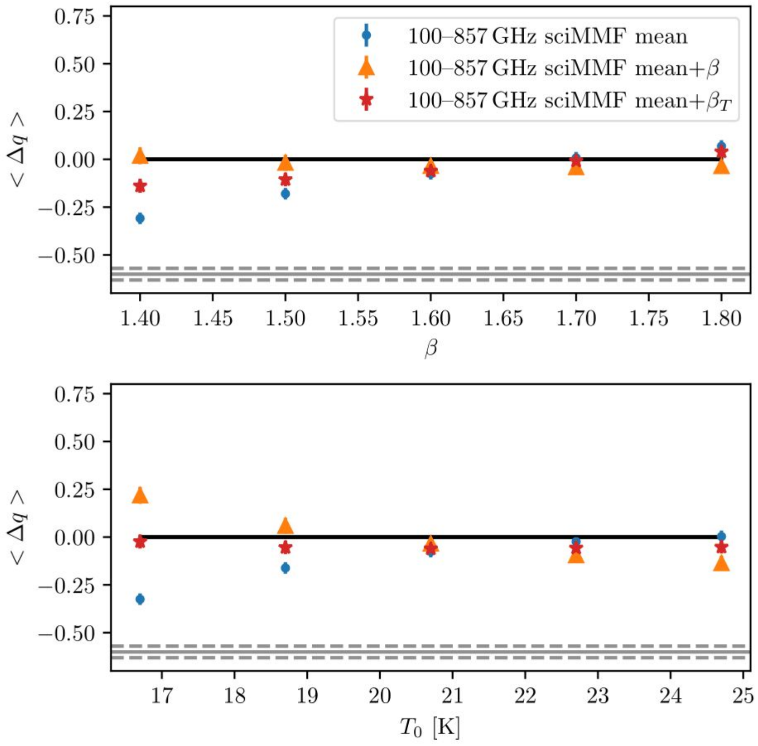
- It works perfectly if deprojection SED matches true SED. Can also deproject first-order moments with respect to SED parameters to minimise impact of assuming a wrong SED (Chluba+ 17).

$$I_\nu(z) = [\nu(1+z)]^\beta B_{\nu(1+z)}(T_0(1+z)^\alpha)$$

$$\beta_T \equiv T_0^{-1}$$

- SNR penalty:
  - *Planck*, SO: 1%, 20-30 % with one moment.
  - ACT, SPT: 30%.

IZ, Chluba & Battye, 2212.07410



SED and moments at z = 0.2

Results for *Planck*-like sample from Websky (tSZ+kSZ+CMB+CIB+noise)

Application to *Planck* data

with Jens Chluba, Richard Battye and Jean-Baptiste Melin

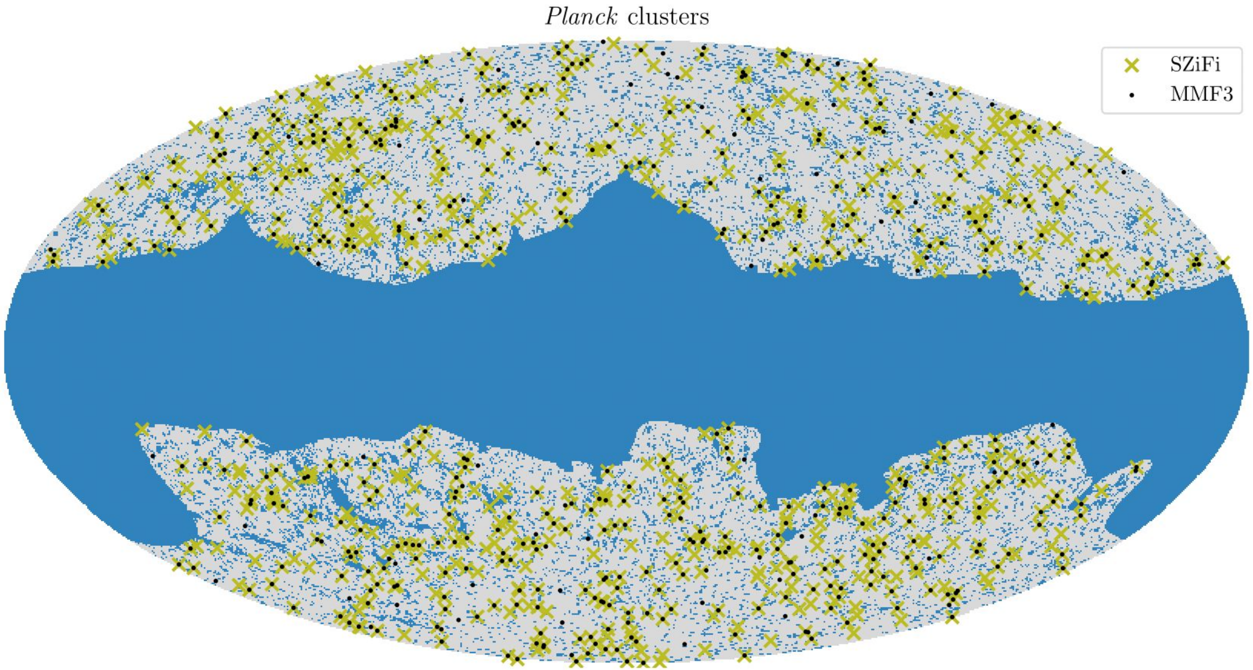
Goal: improved *Planck* cluster catalogues, cosmology

Catalogues:

- iMMF
- sciMMF:
  - Mean CIB SED
  - + moment β
  - + moment β_T

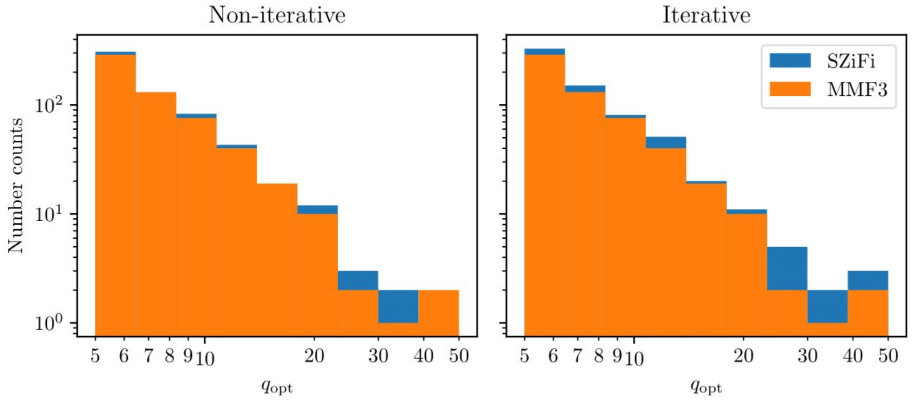
98% clusters validated at SNR > 5.
93% with z.

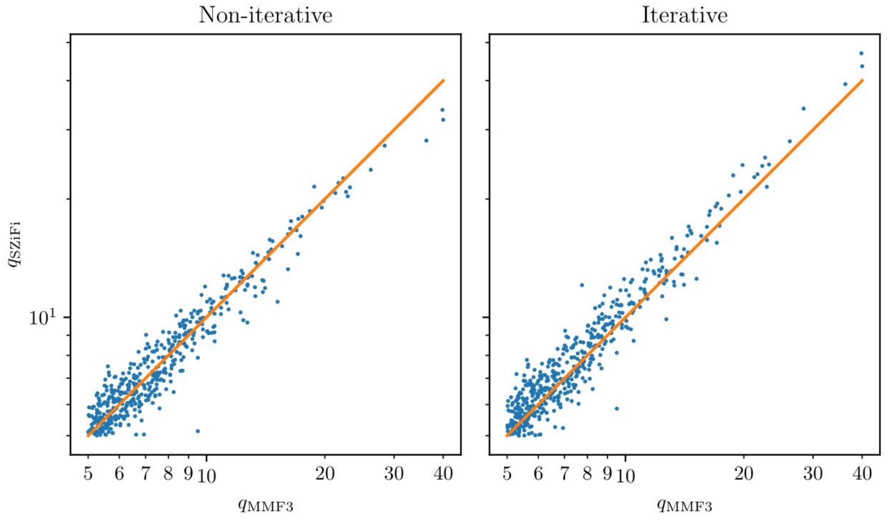
(Validation work still in progress.)



Application to *Planck* data

Standard MMF (no deprojection)



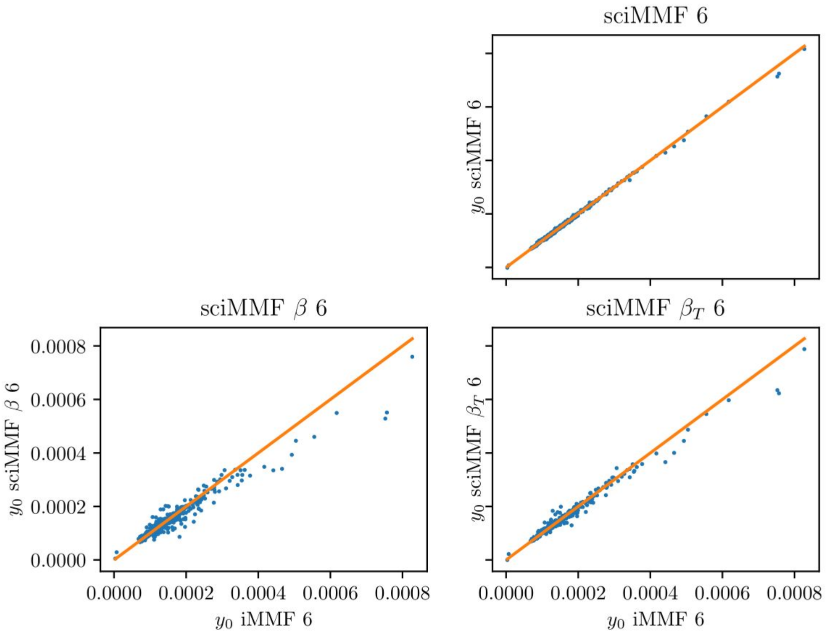


Application to *Planck* data

sciMMF: CIB deprojection

Modified blackbody at z=0.2 with β = 1.75, T_0 = 24.4 K

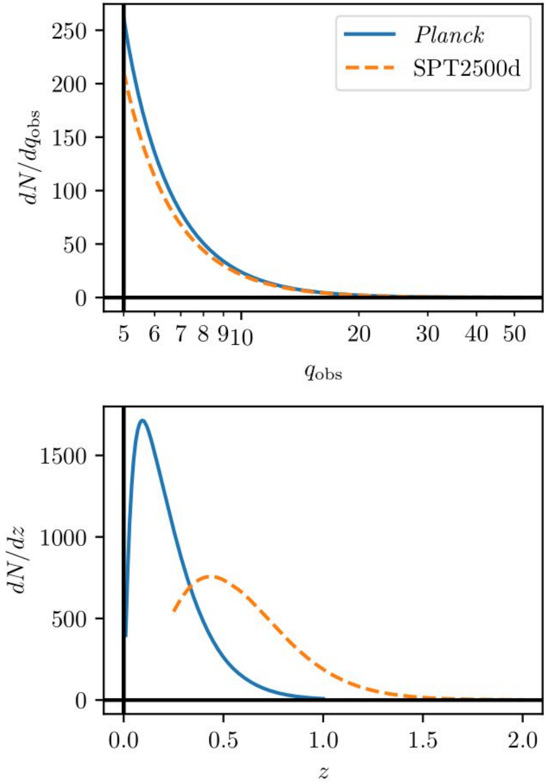
$$I_\nu(z) = [\nu(1+z)]^\beta B_{\nu(1+z)}(T_0(1+z)^\alpha)$$



Likelihood: cnc

Easy-to-use cluster number count code, general and flexible:

- Unbinned, binned, and extreme value likelihoods.
- Arbitrary number of mass proxies, with the possibility of each cluster in the sample having different combinations of them.
- Links mass to mass proxies with model with arbitrary number of layers, each layer allowing for correlated scatter.
- Redshift measurement uncertainties.
- Unconfirmed detections.
- Written in Python, interfaced with Cobaya.
- Pretty fast (*Planck* cnc likelihood in 1s on a laptop) and accurate (biases less than 0.2 sigma).
- Publicly available soon!



with Boris Bolliet

Summary

- tSZ cluster counts have huge constraining potential, but we need to understand modelling to unprecedented level.

- SZiFi:

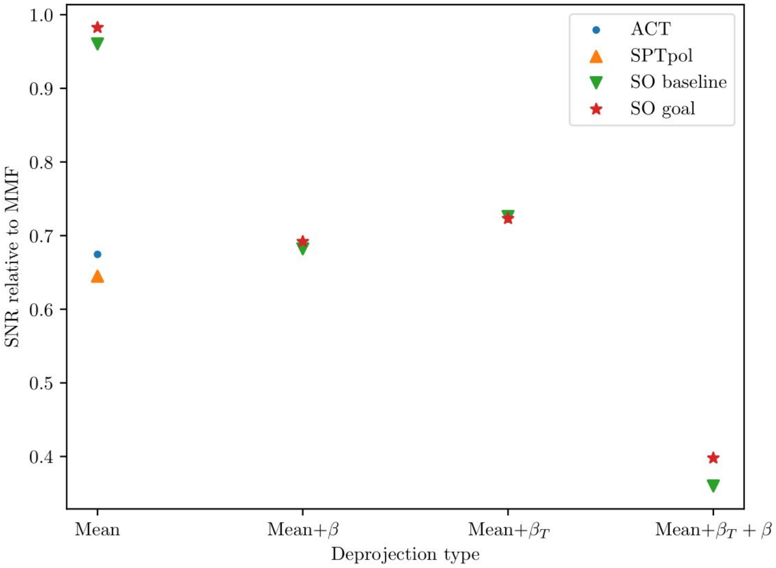
    - Iterative noise estimation: removes covariance bias, boosts SNR.
    - Spectrally constrained MMF: suppresses CIB bias.

- cnc: New fast and flexible cluster number count code.

- Other potential issues to be investigated:

    - Relativistic SZ.
    - Blending.
    - Point sources.
    - Mass calibration: how to best combine with lensing data.

Foreground deprojection: CIB

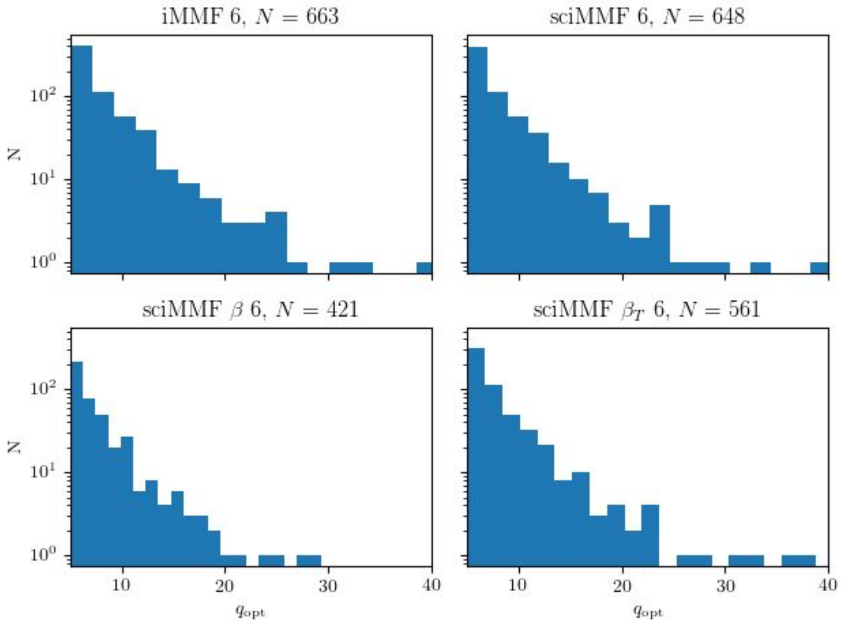


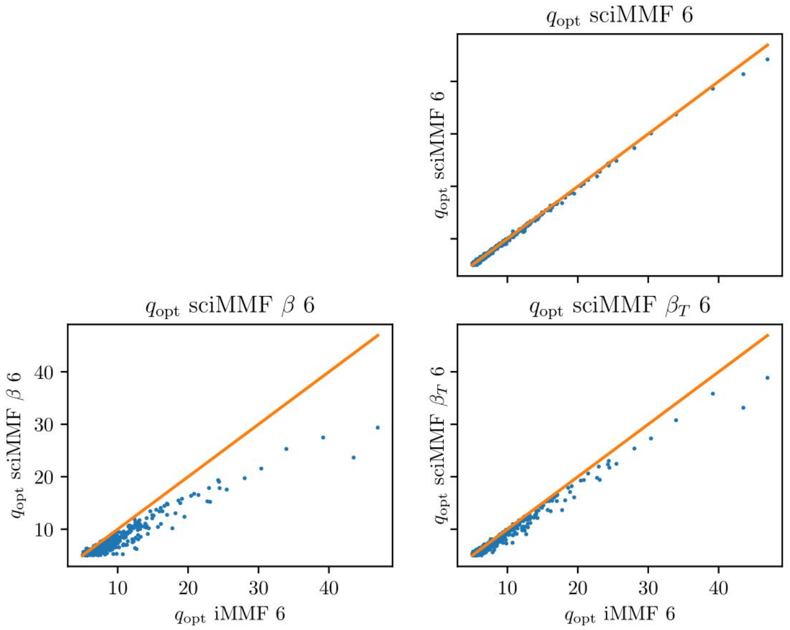
SNR penalty due to CIB deprojection

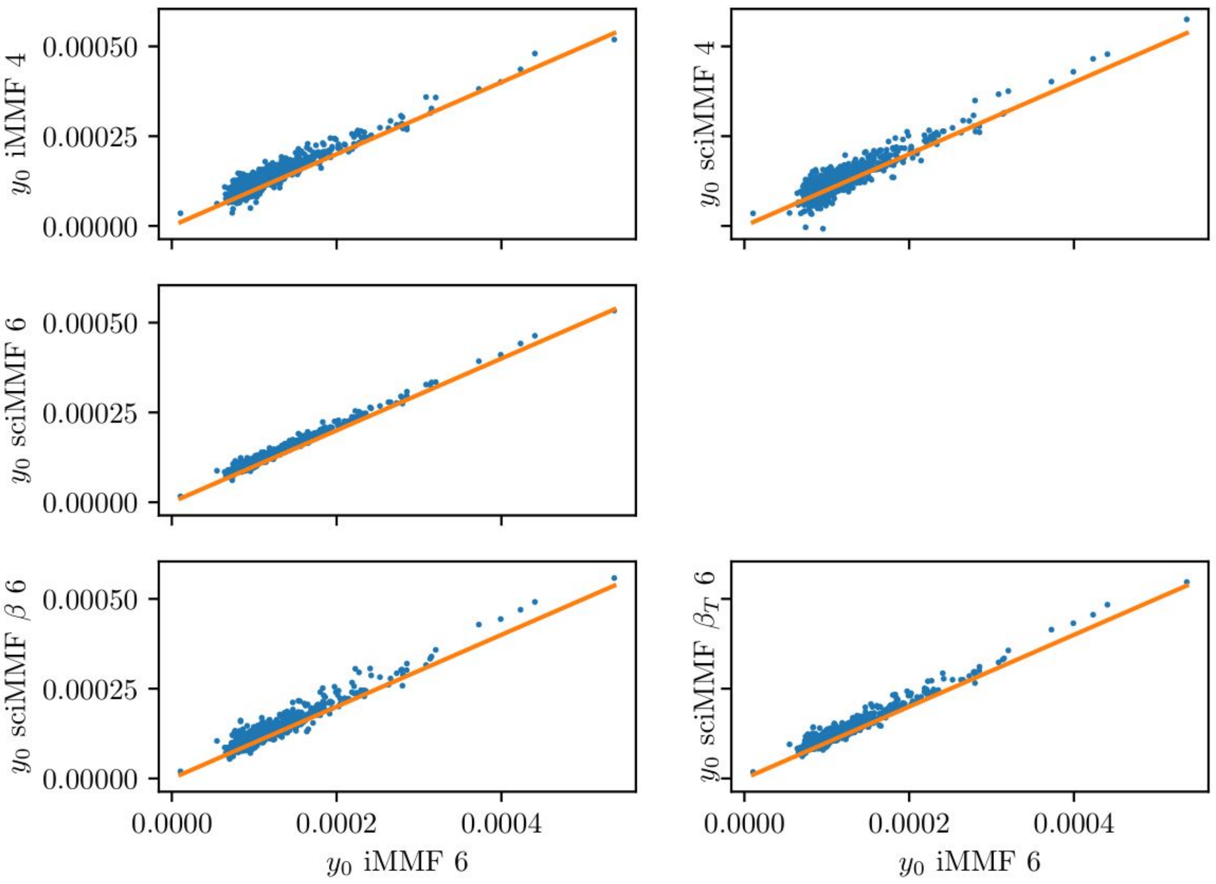
Application to *Planck* data

sciMMF

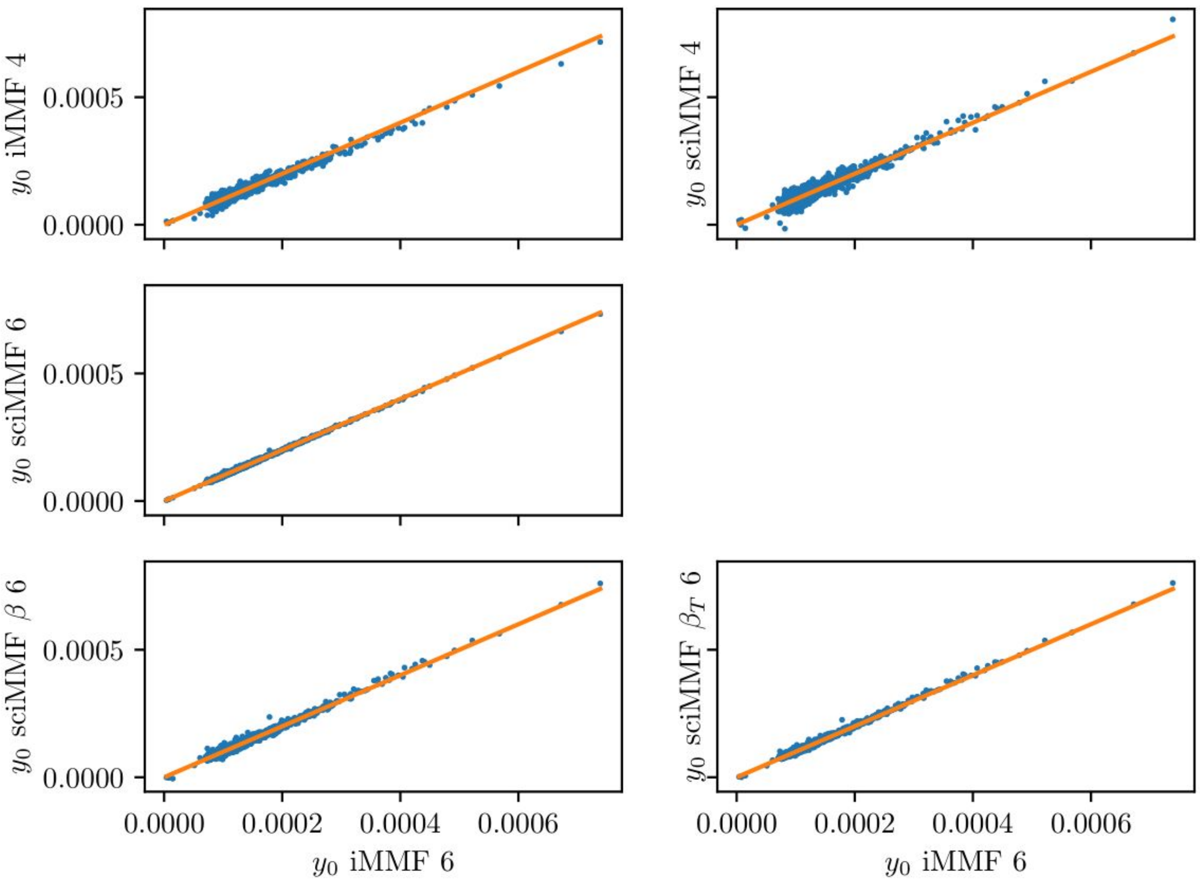
β = 1.75, T_0 = 24.4 K







0.00050
0.00025
0.00000
y_0 iMMF 4
y_0 sciMMF 4
y_0 sciMMF 6
y_0 sciMMF β 6
y_0 sciMMF β_T 6
0.0000
0.0002
0.0004
y_0 iMMF 6



y_0 iMMF 4
0.0005
0.0000
y_0 sciMMF 4
y_0 sciMMF 6
0.0005
0.0000
y_0 sciMMF β 6
0.0005
0.0000
y_0 sciMMF β_T 6
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0.0006
y_0 iMMF 6
0.0000
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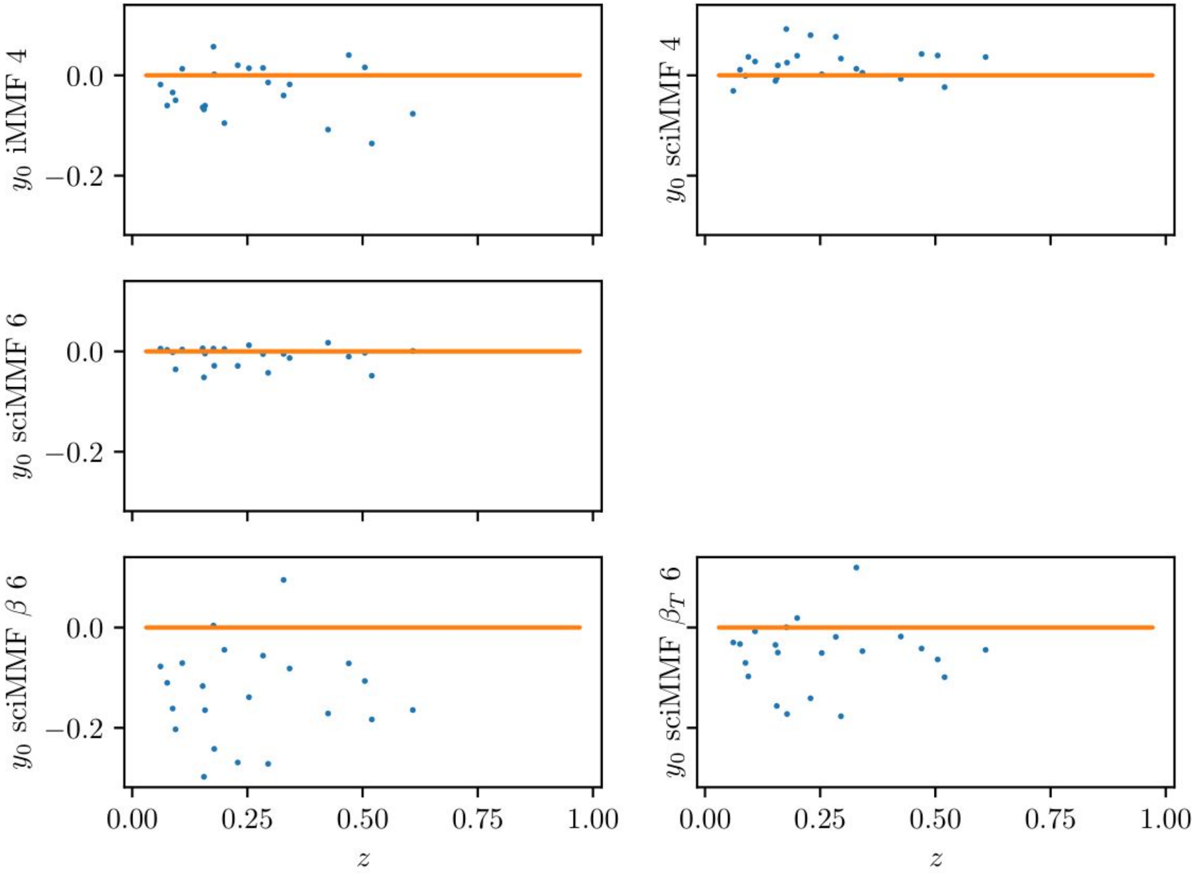
y_0 iMMF 6

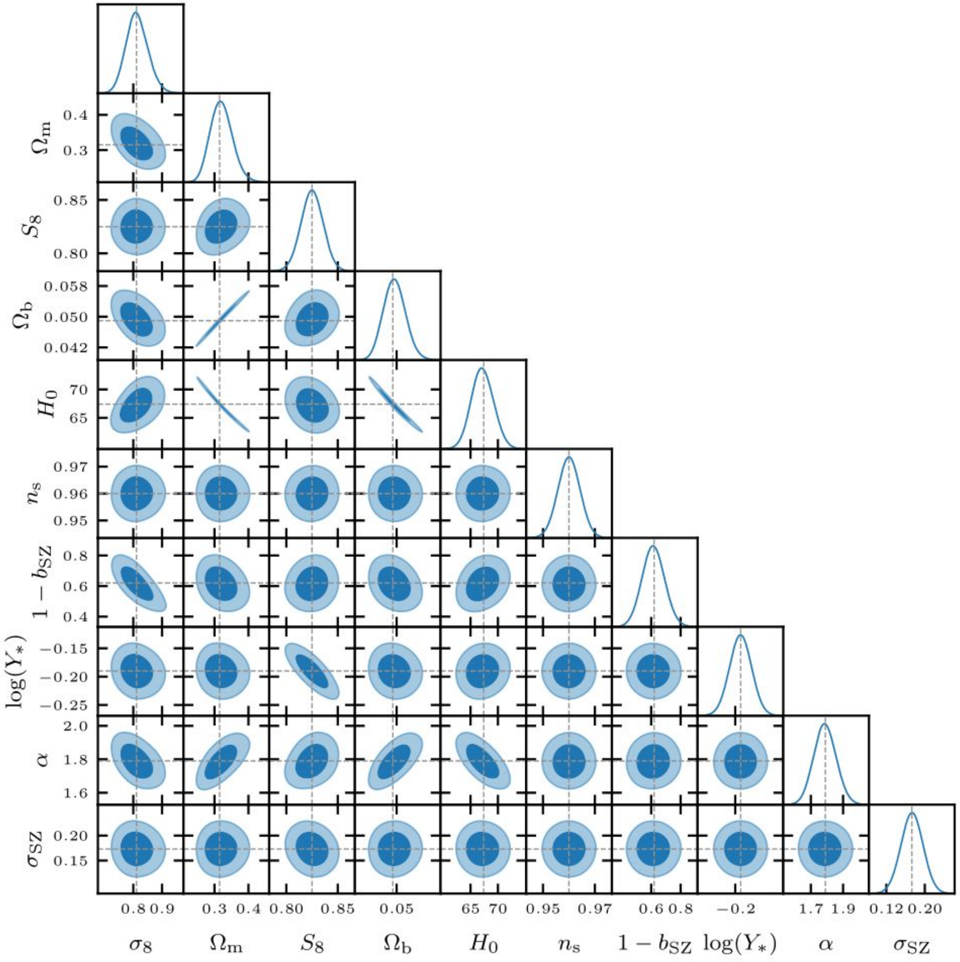


y_0 iMMF 4
y_0 sciMMF 4
y_0 sciMMF 6
y_0 sciMMF β 6
y_0 sciMMF β_T 6
0.0
−0.2
0.00
0.25
0.50
0.75
1.00
z

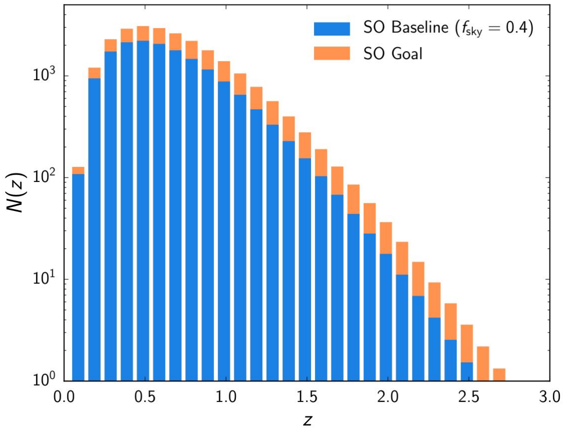
Likelihood: cnc

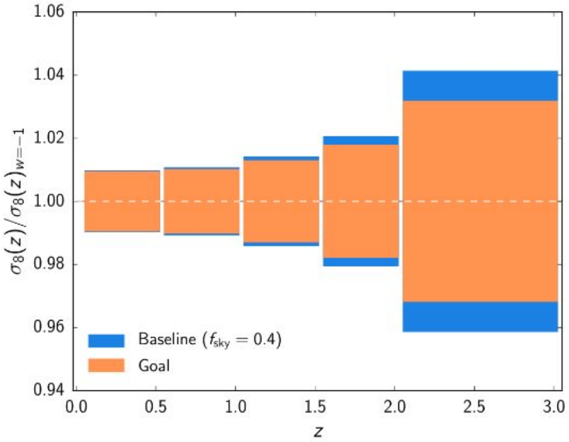
96 *Planck*-like synthetic catalogues

Biases less than 0.2σ for all parameters.



Towards precision SZ cluster cosmology





Cluster detection and characterisation need to be understood at unprecedented level if the statistical power of clusters from upcoming experiments such as SO is to be realised:

- Cluster selection.
- tSZ - mass.

$$y_0 = 10^A \left(\frac{(1-b)M}{3 \times 10^{14} h_{70}^{-1} M_\odot} \right)^\alpha E^2(z) h_{70}^{-1/2},$$

$$\bar{q} = \frac{y_0(M, z)}{\sigma_{y_0}(\theta_{500}(M, z))}$$