Constraining Astrophysics with the kSZ Signal

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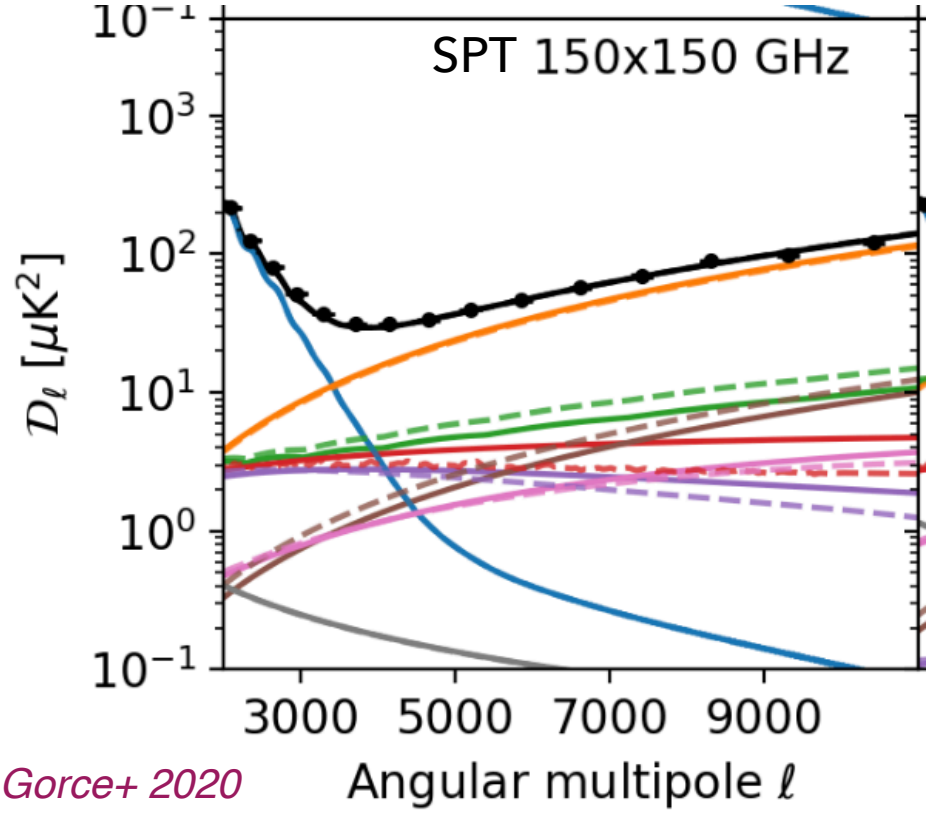
+

BATMAN collaboration

CMB ANALYSES



SPT from *Reichardt+ 2019*

kSZ

Gorce+ 2020

kSZ : one of the numerous extragalactic small scale contaminant

kSZ contains a lot of Information

$$C_\ell = \frac{8\pi^2}{(2\ell+1)^3}\frac{\sigma_T^2}{c^2}\int \frac{\bar{n}_e(z)^2}{(1+z)^2}\, F(P_{\delta\delta}(k), P_{ee}(k), b(k))\, e^{-2\tau(z)}\, \eta \frac{d\eta}{dz}\, dz,$$

Cosmology

Shaw+ (2012) [homogeneous]

- Matter power spectrum, optical depth:
  - Ω_m, n_s, A_s
  - τ

Reionization

Battaglia+ (2012)
Gorce+ (2020, 2022)
Raghunathan+ (2024)

- P_{ee}: History and topology :
  - xe(z)
  - κ, α

Astrophysics

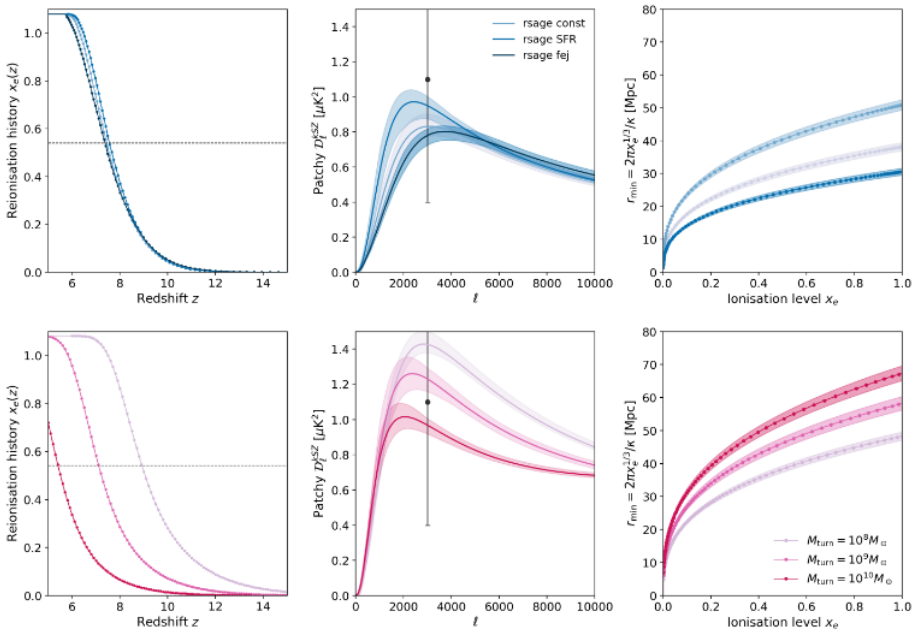
Nikolić+ (2023)

- Physics of the sources :
  - minimal halo mass, fesc…

From CMB to first galaxies

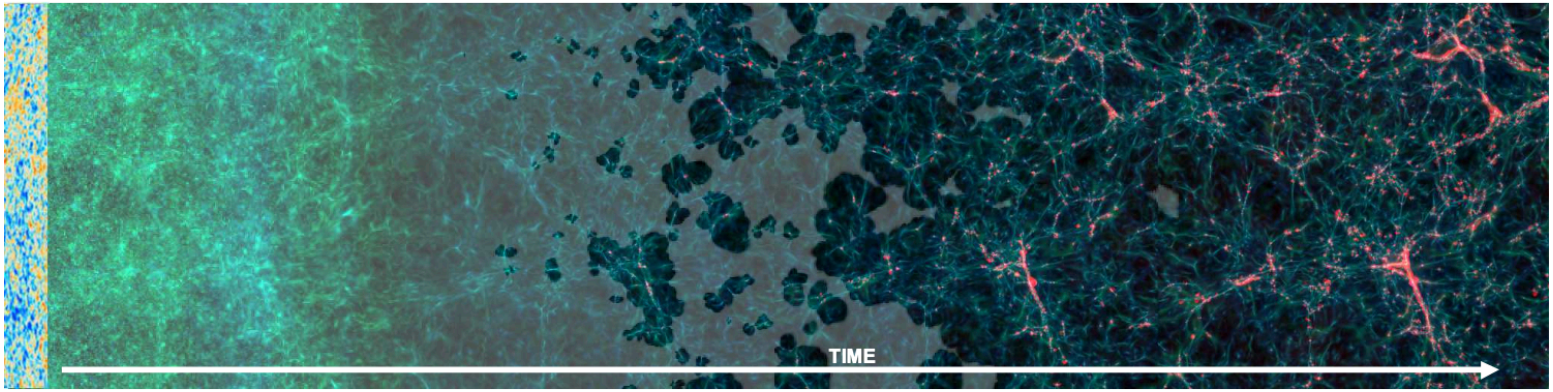
The kSZ power spectrum can be expressed in terms of the electron power spectrum (*Gorce+ 2020*)

- We can relate kSZ to the global history and topology of reionisation
  - Calibration on simulations
- **Can we relate kSZ with the properties of the sources of reionisation ?**
  - **Proof of concept**



Sources of reionisation

Visu : N. Deparis

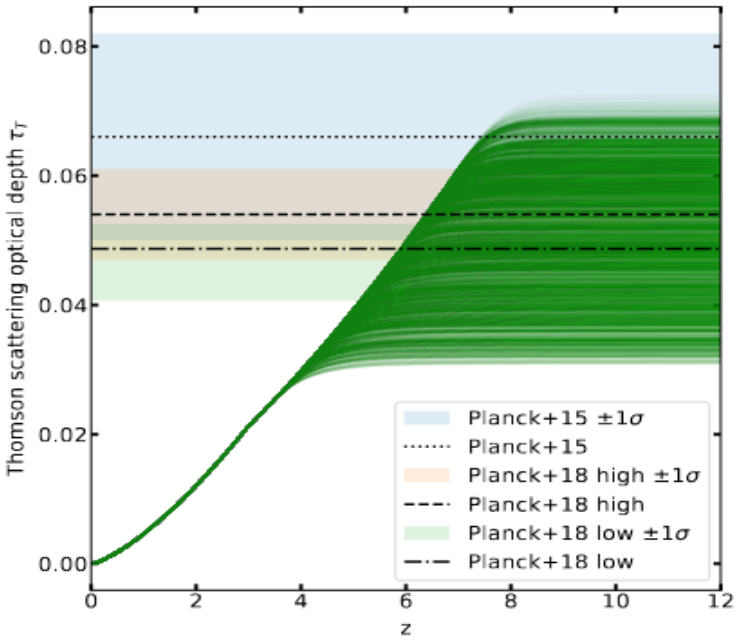


Aubert+ (2024)

First sources

- SFR: Minimal halo mass (M_{lim}) to form stars and a gas to star conversion timescale (tau)
- Photons created : Xray luminosity function (L_x) and hardness ratio (f_x)
- Ionising photons: ionising escape fraction (f_{esc})

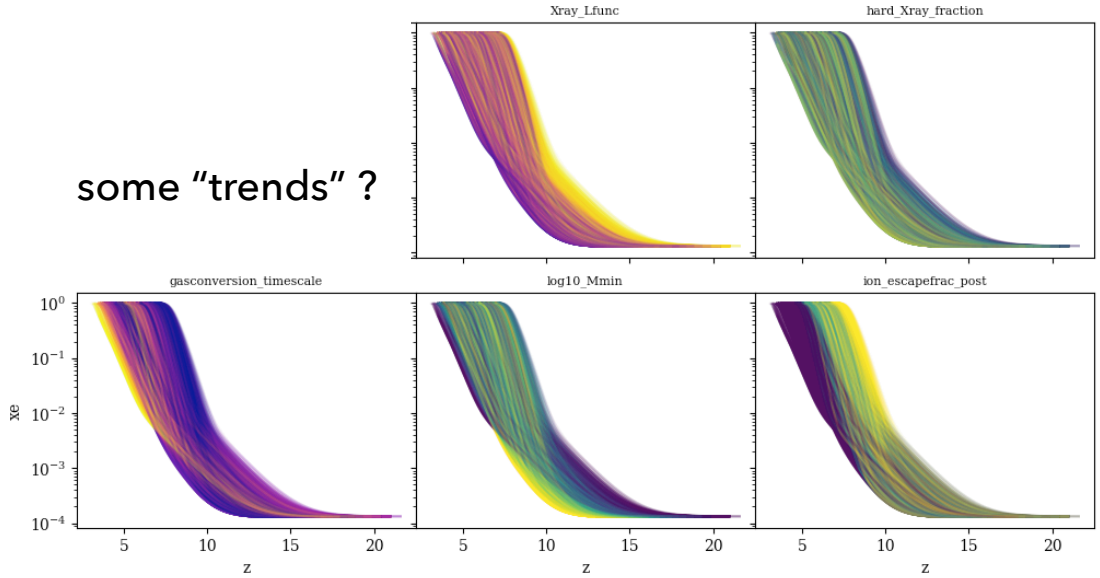
THE LORELI DATABASE



Meriot+ (2024)

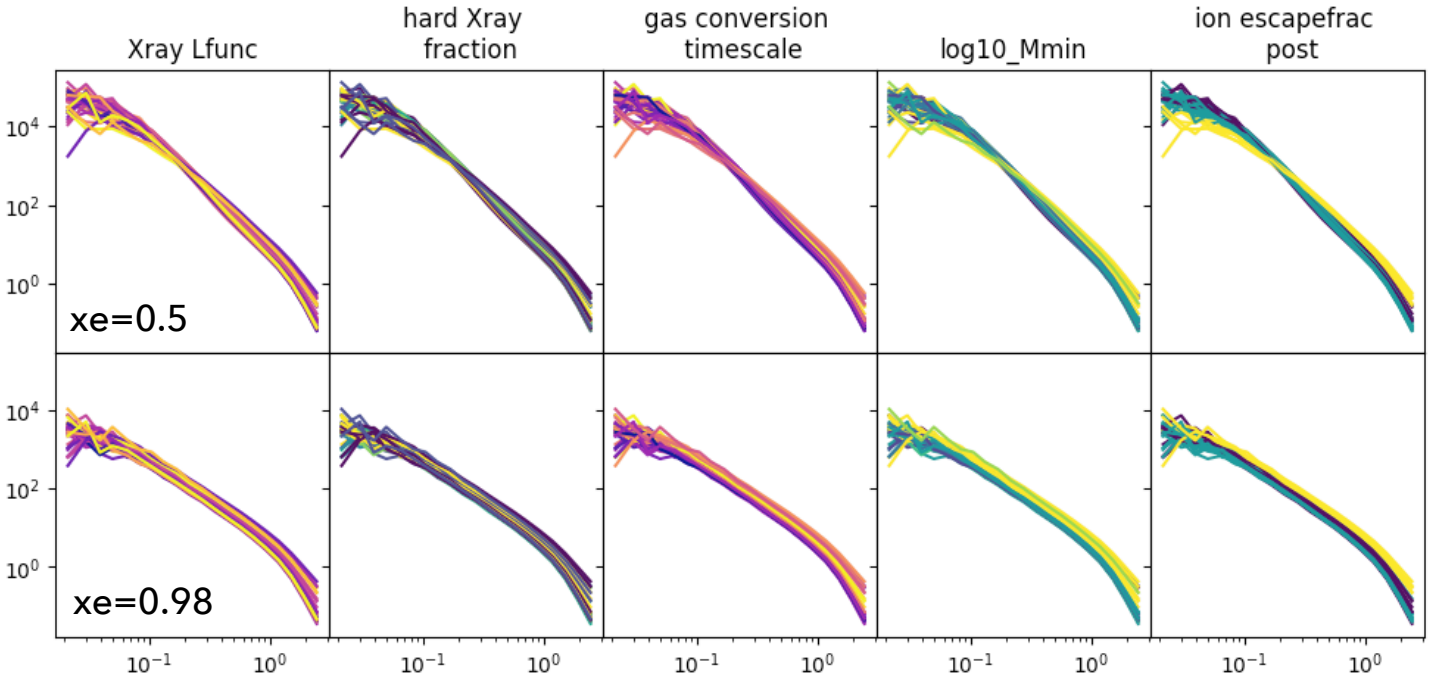
- Cosmological simulations generated using the `Licorice` code
- 3D radiative hydrodynamical simulation
- Database of ~10,000 simulations
- Function of five astrophysical parameters:

some "trends" ?



- L_X : Xray luminosity function
- f_X: hard Xray fraction
- tau: gas conversion timescale
- $\log_{10}(M_{\text{min}})$: minimum halo mass
- f_{esc} : ionising escape fraction

SIMULATED ELECTRON POWER SPECTRA



some "trends" ?

- Use these P_{ee} to construct the kSZ APS and use them as training set for an emulator
  - $P_{ee}(z,k) \rightarrow$ Interpolation (xe, k) $\rightarrow Cl_{kSZ}$

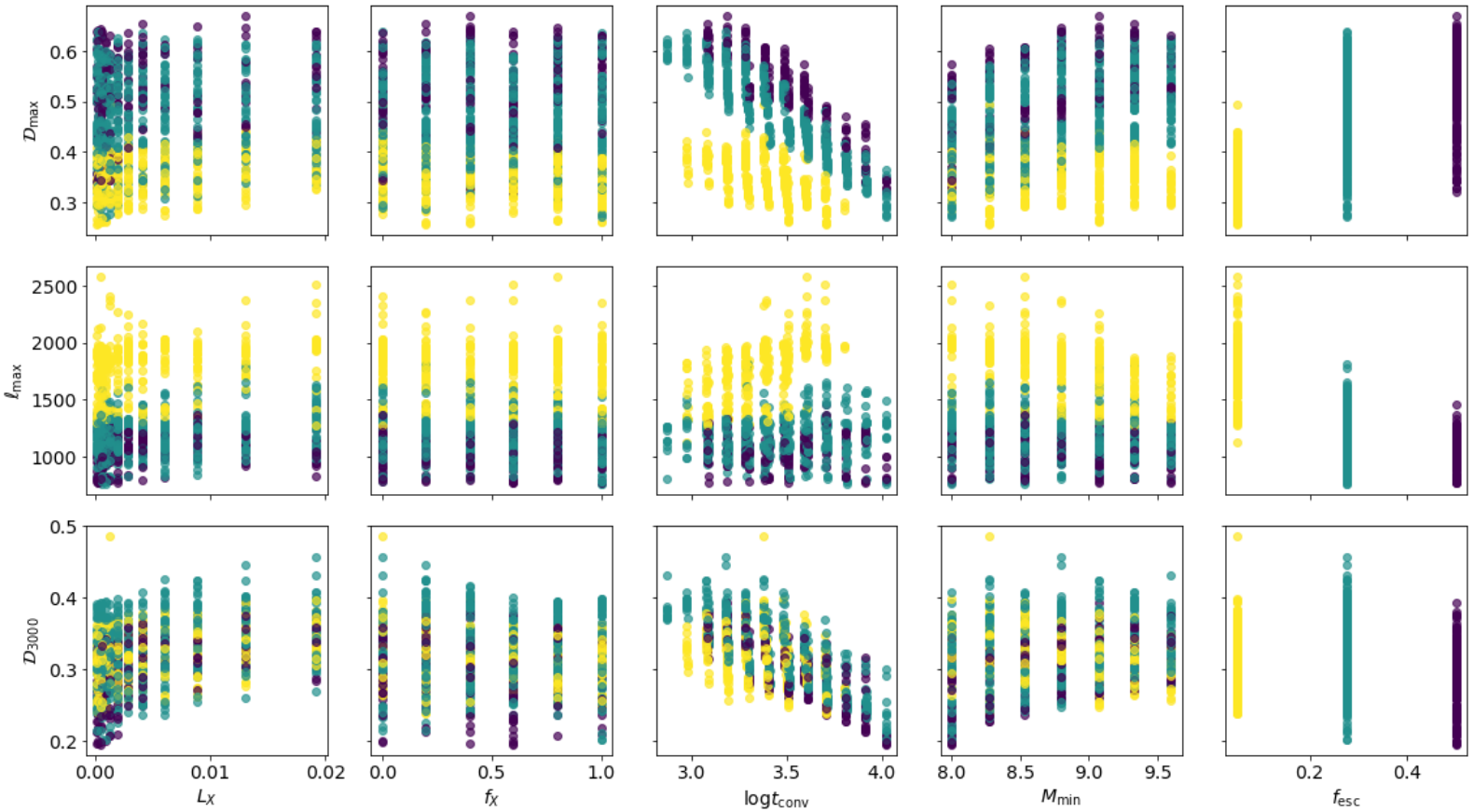
SPECTRA DEPENDENCIES

- How kSZ APS vary with parameters

Max

l_{Max}

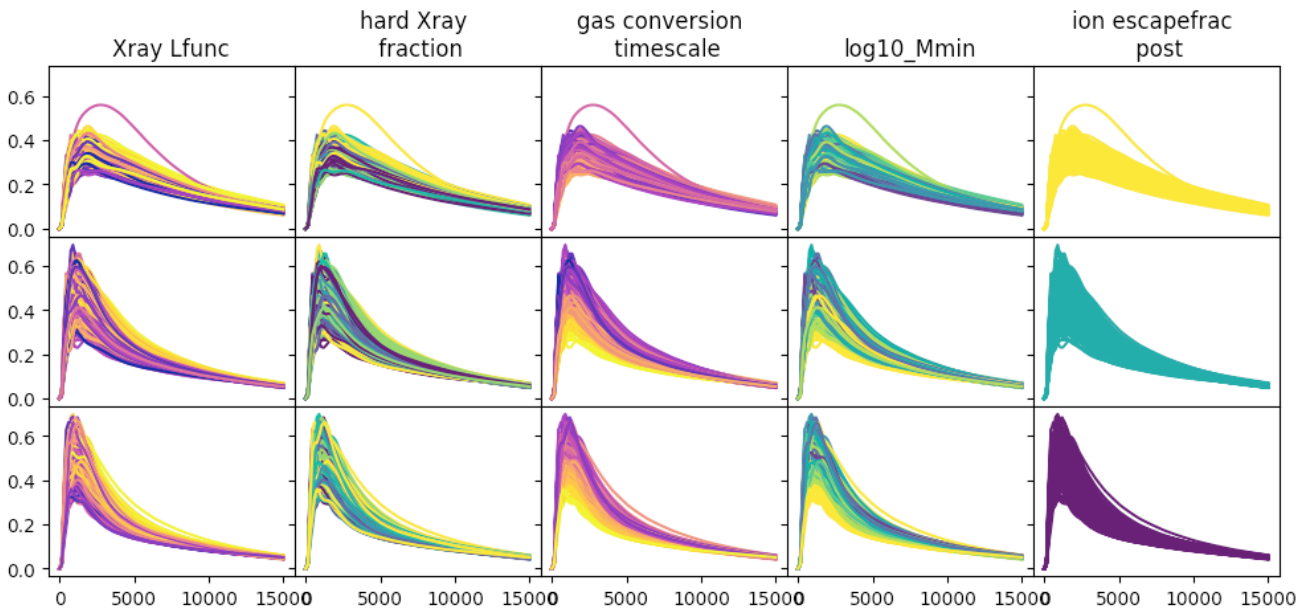
D3000



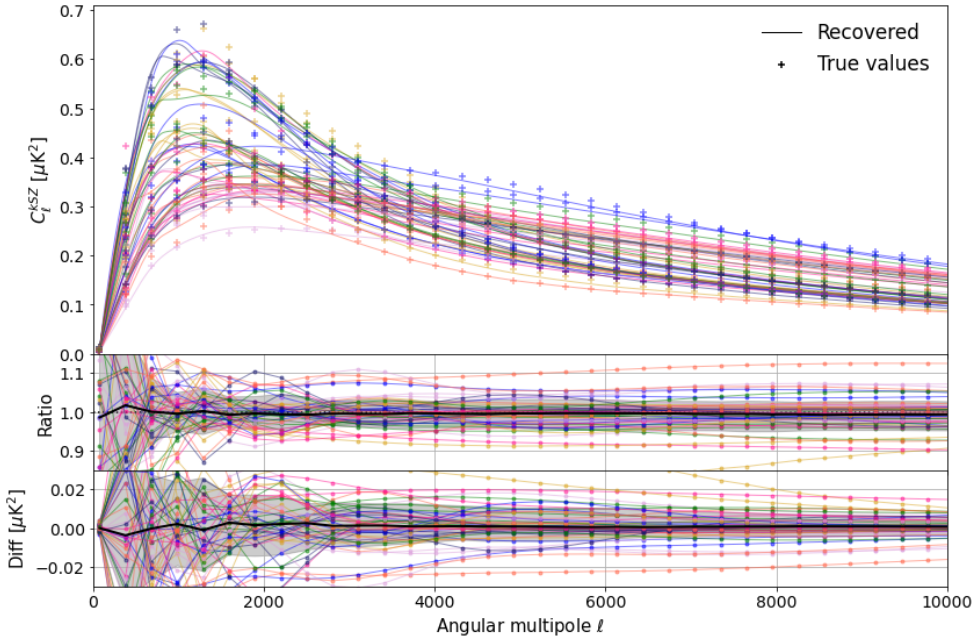
some "trends" ?

Emulating kSZ spectra (first try)

- Training set
  - ⚠ ~1000 models
    - 10000 soon
  - 5 params
  - l in [2,15000]

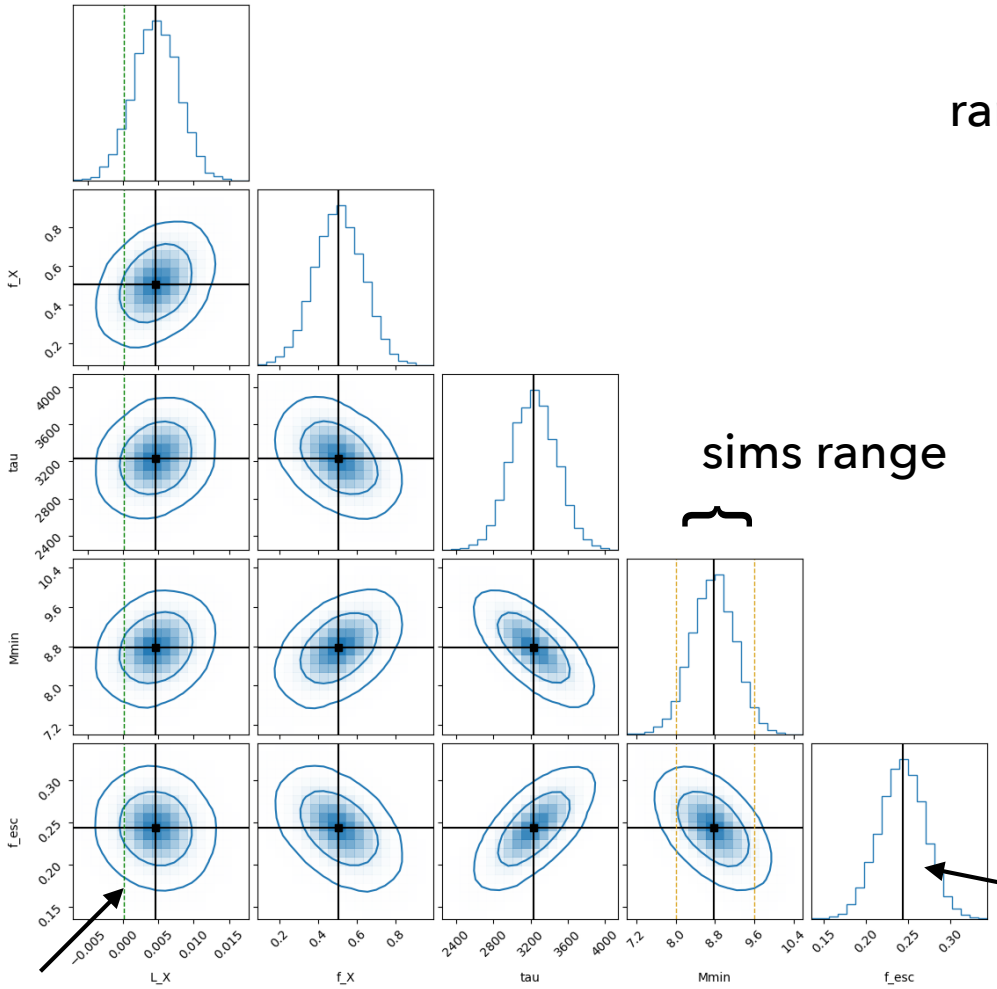


- Emulator
  - based on RF as in Douspis+22
  - score = 0.9
  - uncertainty ~10%



Fisher Forecasts and limitations

- mock data set: CMB-HD like
  - fsky=0.5, FWHM=0.5’ , Noise =2.7 muK^{2}·arcmin



⚠

ranges larger than training set
Fisher is Fisher
moving to MCMC

sims range

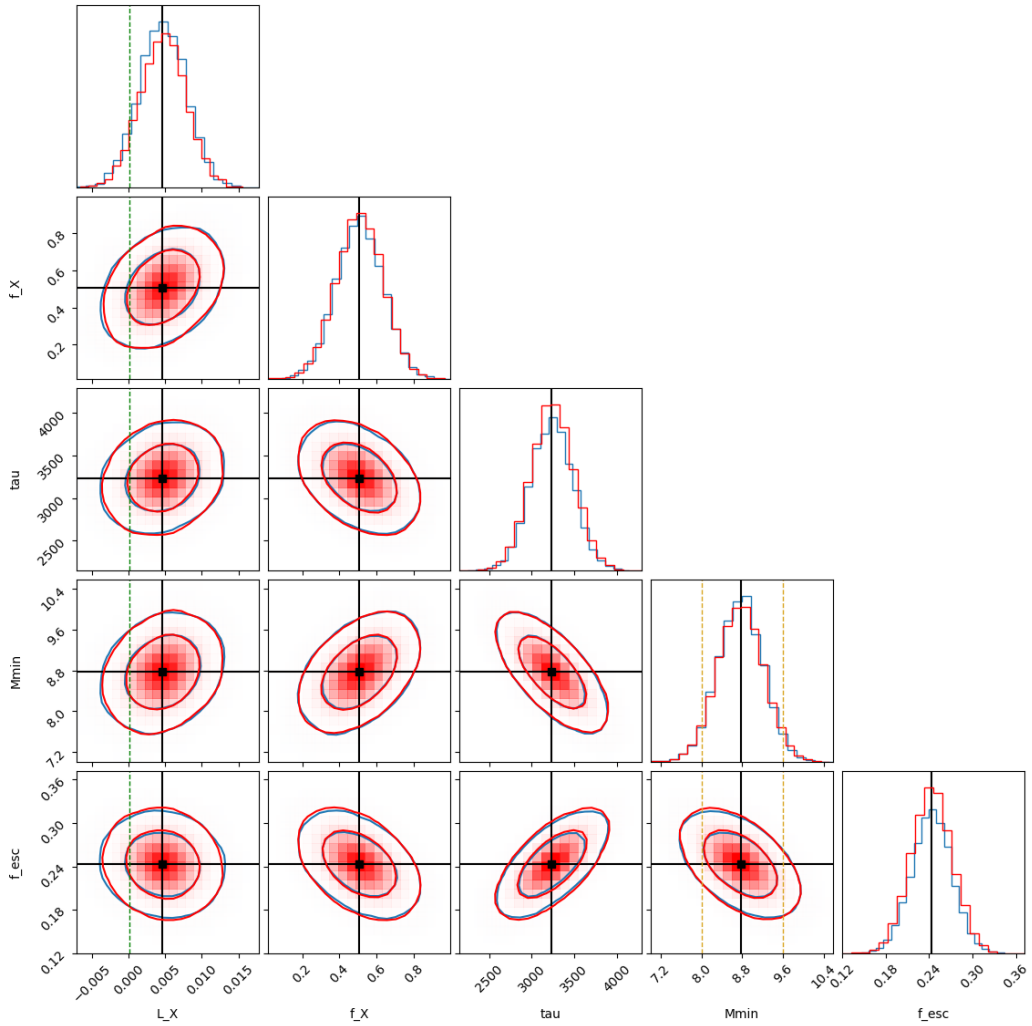
Gaussian by definition

Compatible with 0

Preliminary

FORECASTS

- mock data set: CMB-HD like
  - fsky=0.5, FWHM=0.5’ , Noise =2.7 muK^2·arcmin + Emul error

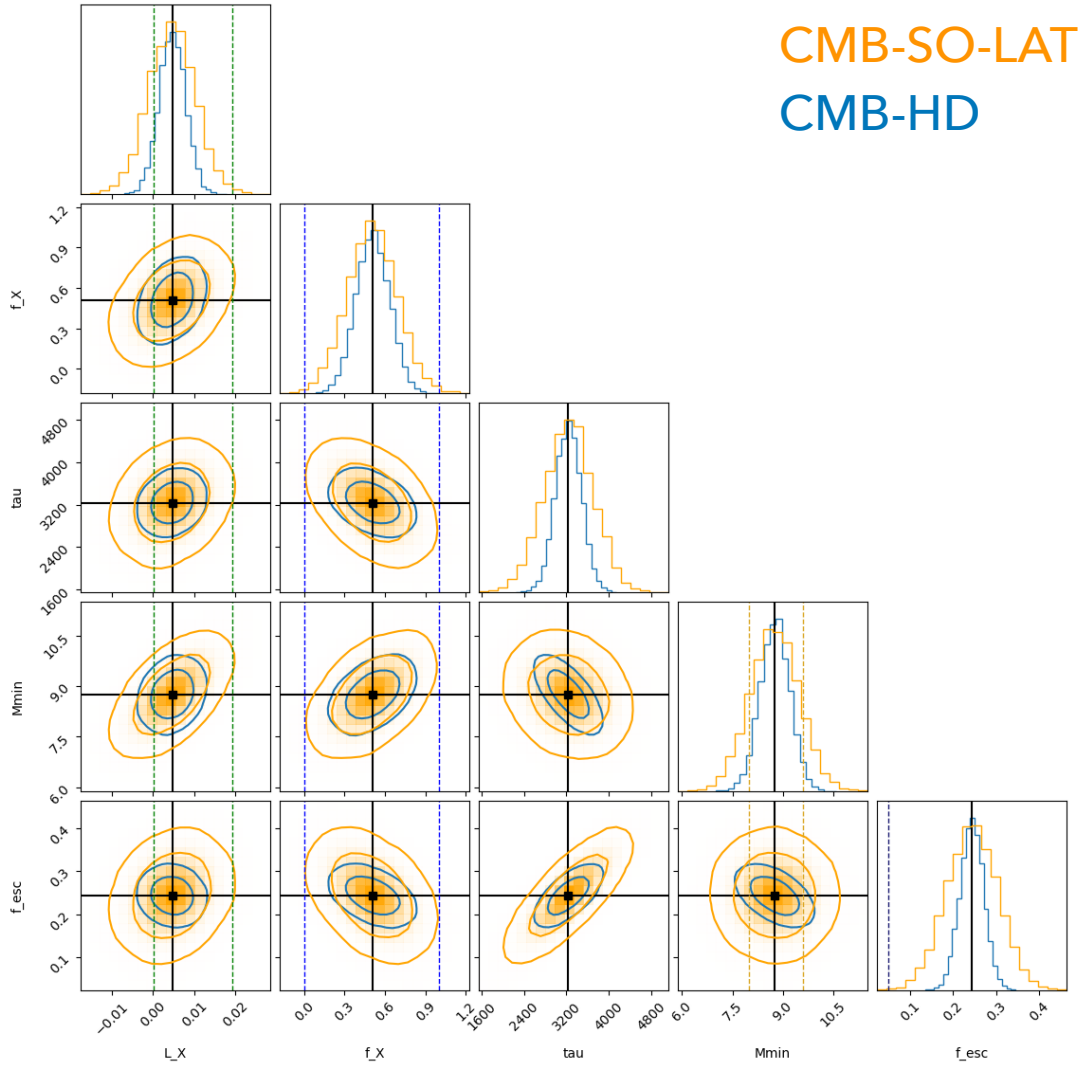


- Emulator error sub-dominant

Preliminary

Forecasts

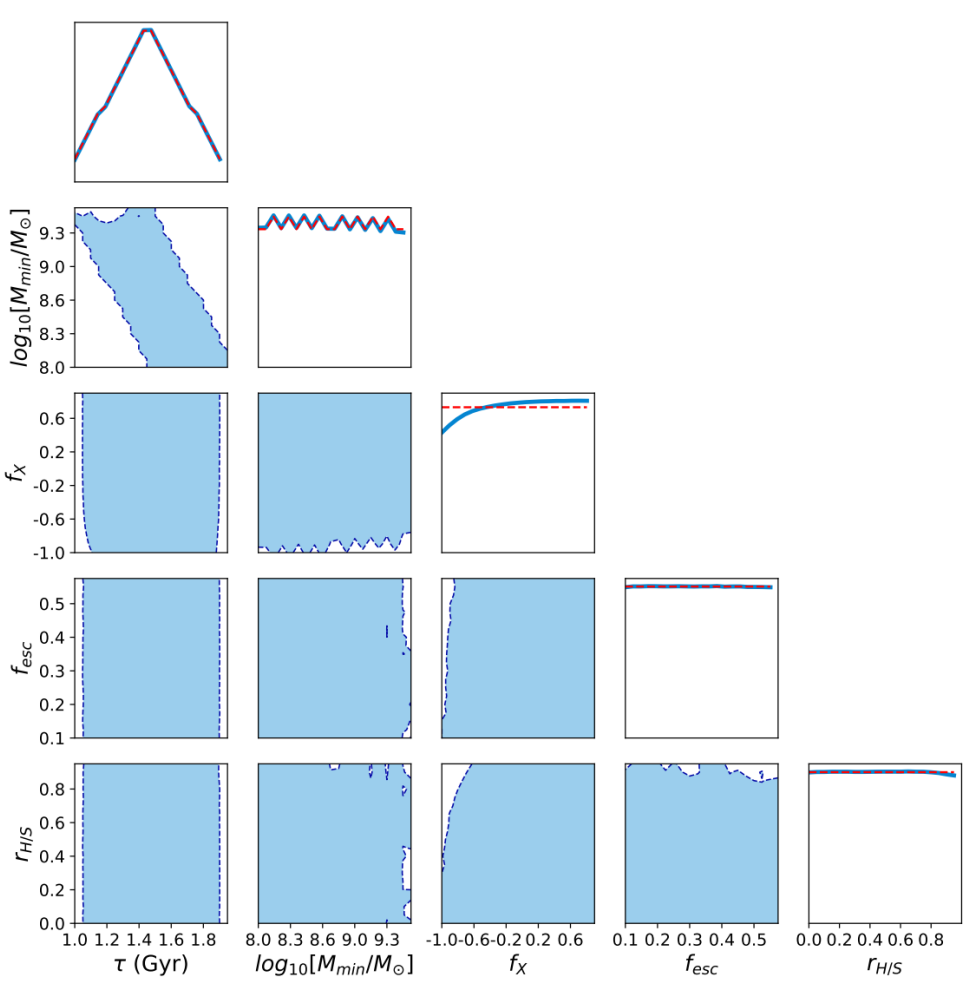
- Comparing CMB-SO-LAT with CMB-HD

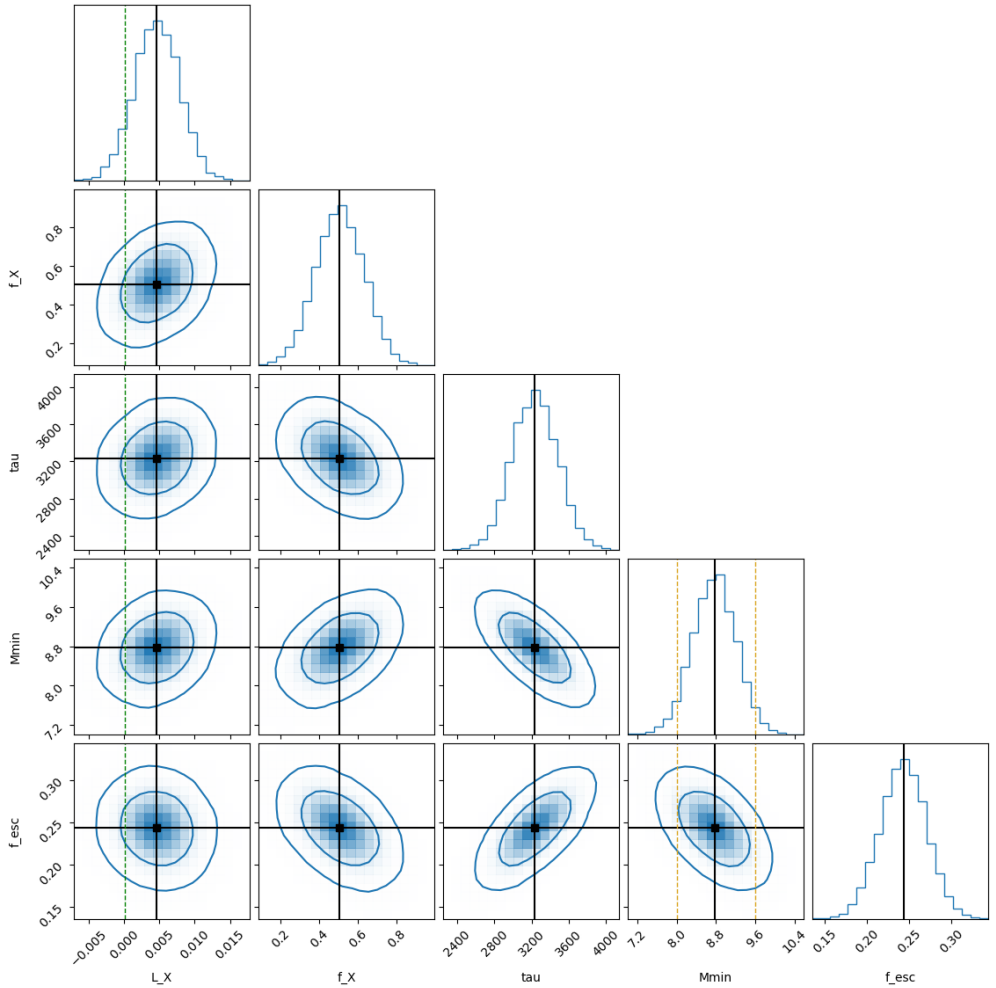


Preliminary

Is kSZ useful ?

- Comparison with 21cm (HERA upper limit PS)





Meriot+ 2024

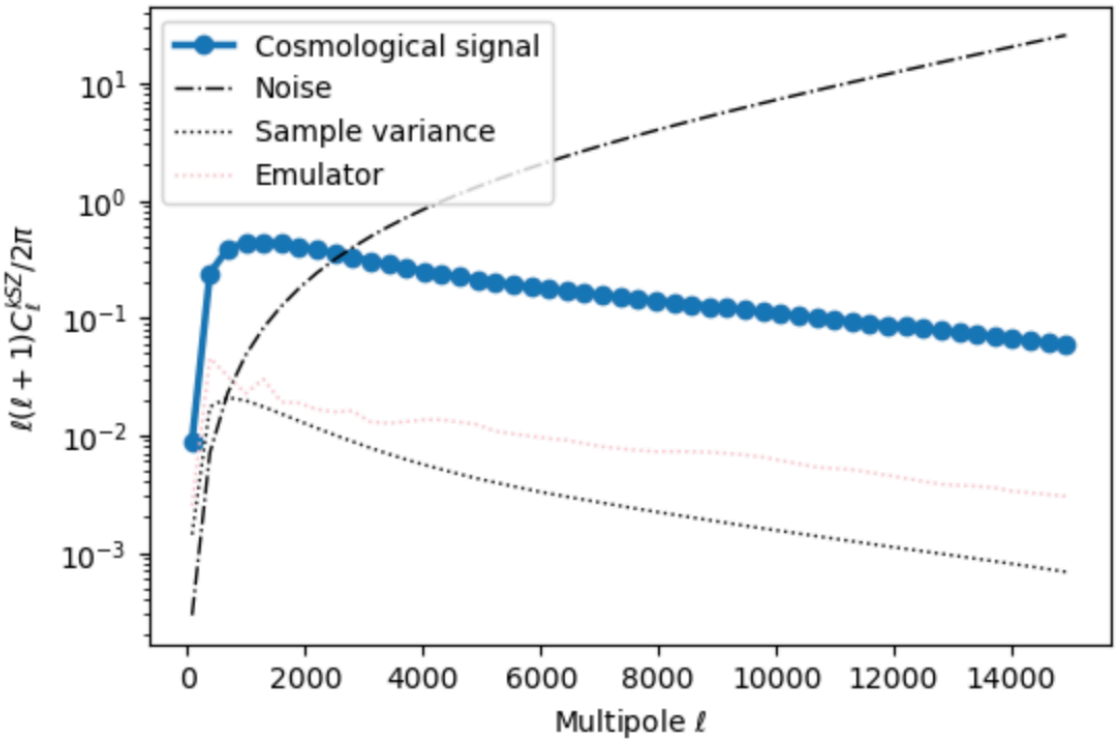
Preliminary

Conclusions

- kSZ is both a contaminant in CMB analyses and a source of information on cosmology and reionisation
- First study showed that we could reconstruct kSZ and global history of reionisation with SPT data by modelling P_{ee} power spectrum calibrated on numerical sims
- Current work aims at retrieving astrophysical properties during EoR by modelling kSZ APS as function of a few astrophysical parameters
  - First try emulator + Fisher forecast show promising constraints
  - Maybe competitive (complementary) to 21cm studies
  - Consolidation and updates soon


Better Accuracy and
robusTness for
Mass Assessment of
Neutrinos

- The parameters of the subgrid star formation model : 42 pairs of $\tau_{SF} \in [7\,Gyr, 105\,Gyr]$ and $M_{min} \in [10^8\ \mathrm{M}_\odot, 4 \times 10^9\ \mathrm{M}_\odot]$ were selected (6 τ_{SF} values for each of the 7 M_{min} values). They produce star formation rate densities within 2σ of the observational data presented in J. Bouwens et al. (2016), Oesch et al. (2018), McLeod et al. (2016).
- The escape fraction of UV radiation in particles with $\langle x_{HII} \rangle > 3\%$: $f_{esc,post} \in \{0.05, 0.275, 0.5\}$. In particles with $\langle x_{HII} \rangle < 3\%$, the escape fraction is kept at 0.003.
- The X-ray production efficiency f_X : 13 logarithmically spaced values in $[0.1, 10]$. this parameter controls the X-ray luminosities of source particles according to $L_X = 3.4 \times 10^{40} f_X \left(\frac{SFR}{1\,\mathrm{M}_\odot \mathrm{yr}^{-1}}\right) \mathrm{ergs}^{-1}$ (e.g. Furlanetto et al. (2006))
- The ratio between hard (> 2keV) and soft (< 2keV) X-ray $r_{H/S}$: 6 linearly spaced values in $[0, 1]$. $r_{H/S}$ is the ratio of energy emitted by X-ray binaries to the total energy emitted in X-rays : $r_{H/S} = \frac{f_X^{XRB}}{f_X}$.


Cosmological signal
Noise
Sample variance
Emulator
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
$\ell(\ell+1)C_\ell^{kSZ}/2\pi$
0
2000
4000
6000
8000
10000
12000
14000
Multipole ℓ