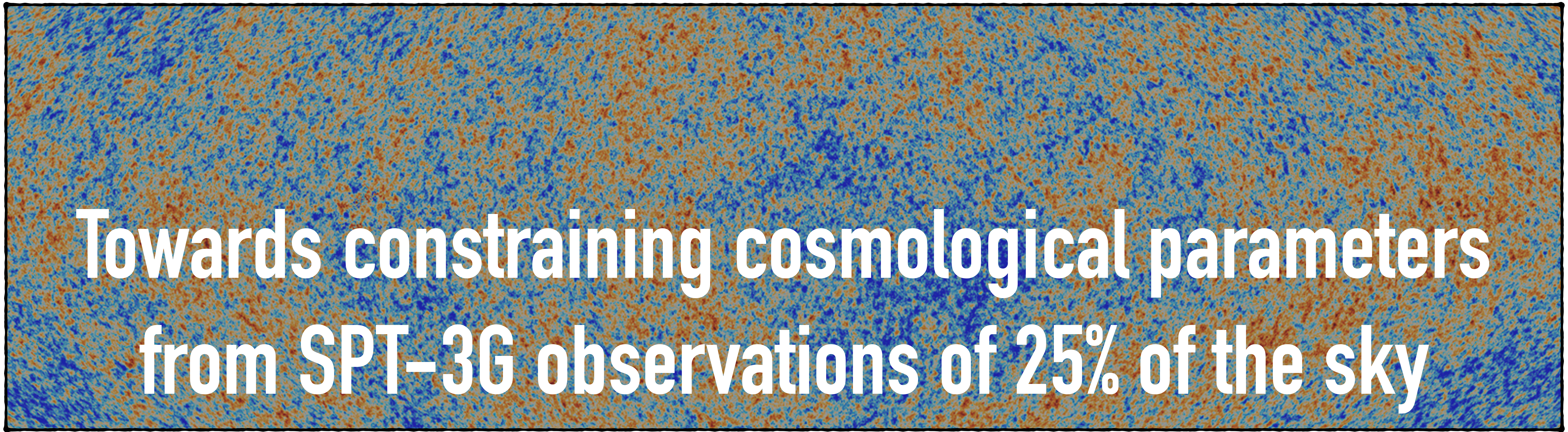


Towards constraining cosmological parameters from SPT-3G observations of 25% of the sky

Aline Vitrier - 2nd year PhD student

Supervisors : K. Benabed, S. Galli, E. Hivon

Many thanks to : L.Balkenhol, E. Camphuis, F. Guidi, A. R. Khalife

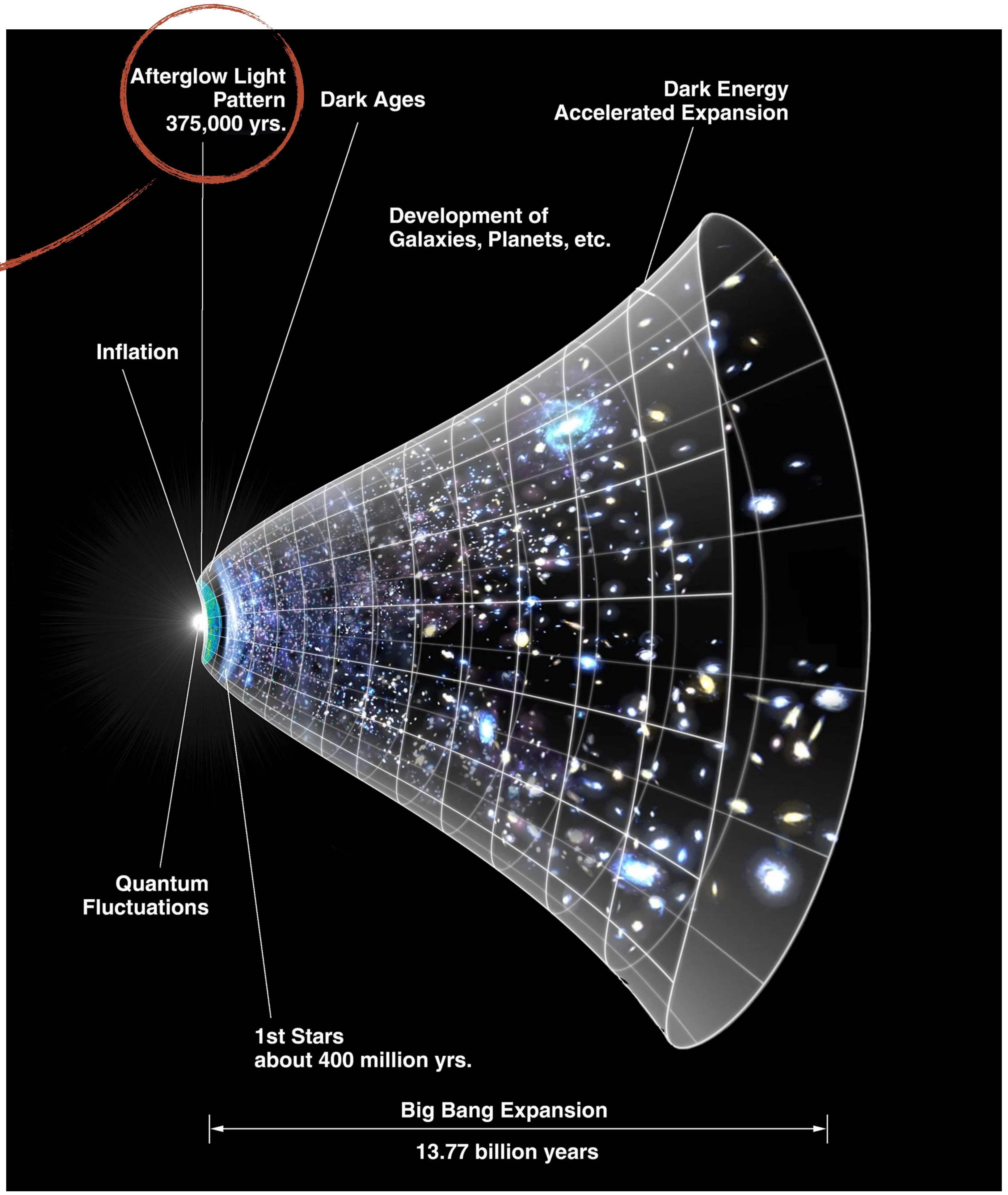
CMB-France #6 - 19/12/2024

Cosmological context

The Cosmic Microwave Background is one of the most powerful probes of the early universe.

We need telescopes and experiments to

- add complementary data to Planck's from **polarization**, from **small scales temperature**, and from **lensing**
- understand tensions such as the Hubble tension
- test the ΛCDM model and search for possible physics beyond ΛCDM.



Credit: NASA/WMAP Science Team/ Art by Dana Berry

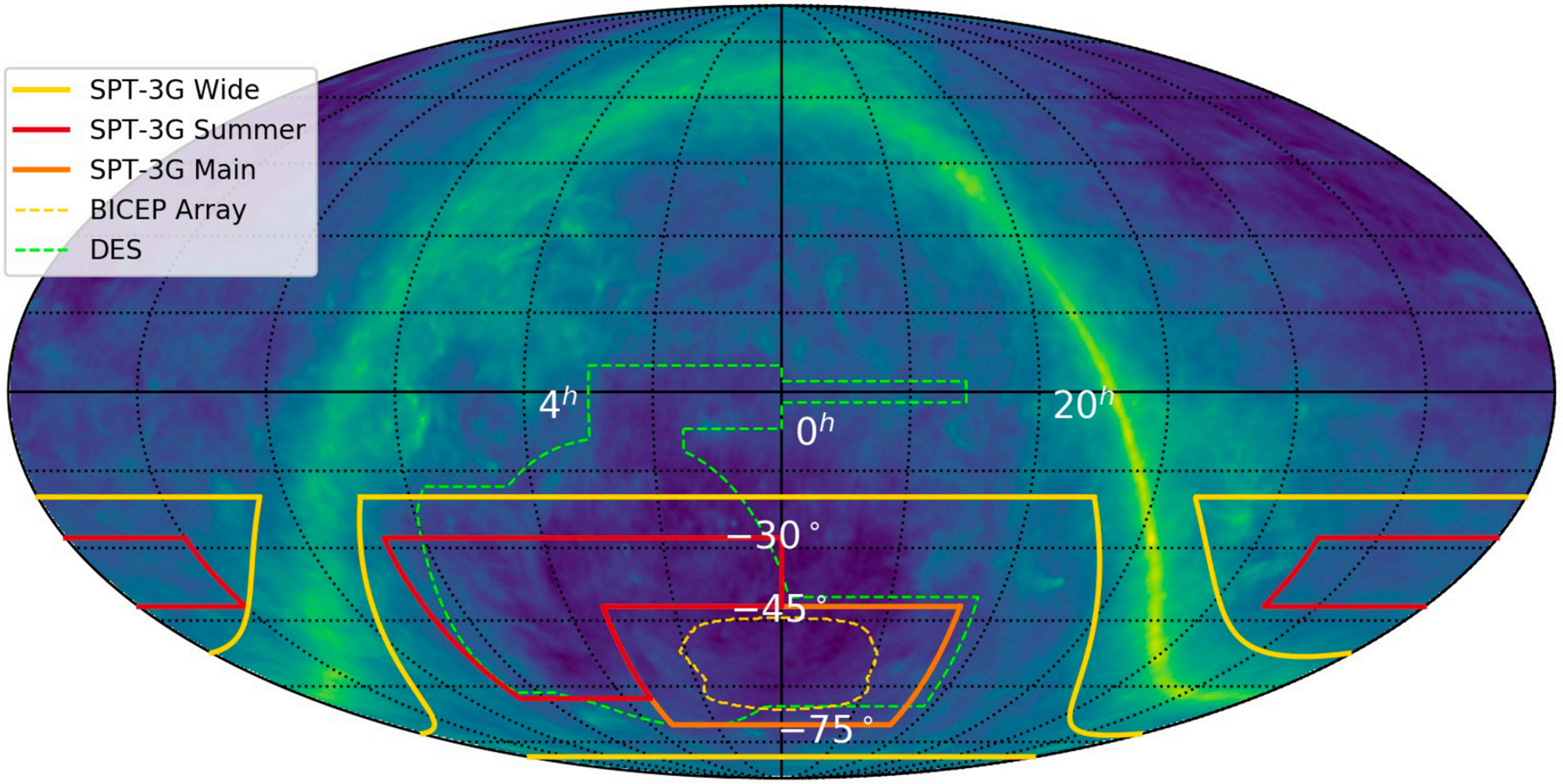
The South Pole Telescope

- 10-meter primary mirror telescope located at the South Pole
- Third generation camera **SPT-3G** since 2018
- 3 frequency bands : 95GHz, 150GHz and 220GHz

The South Pole Telescope

3 fields of observation with SPT-3G :

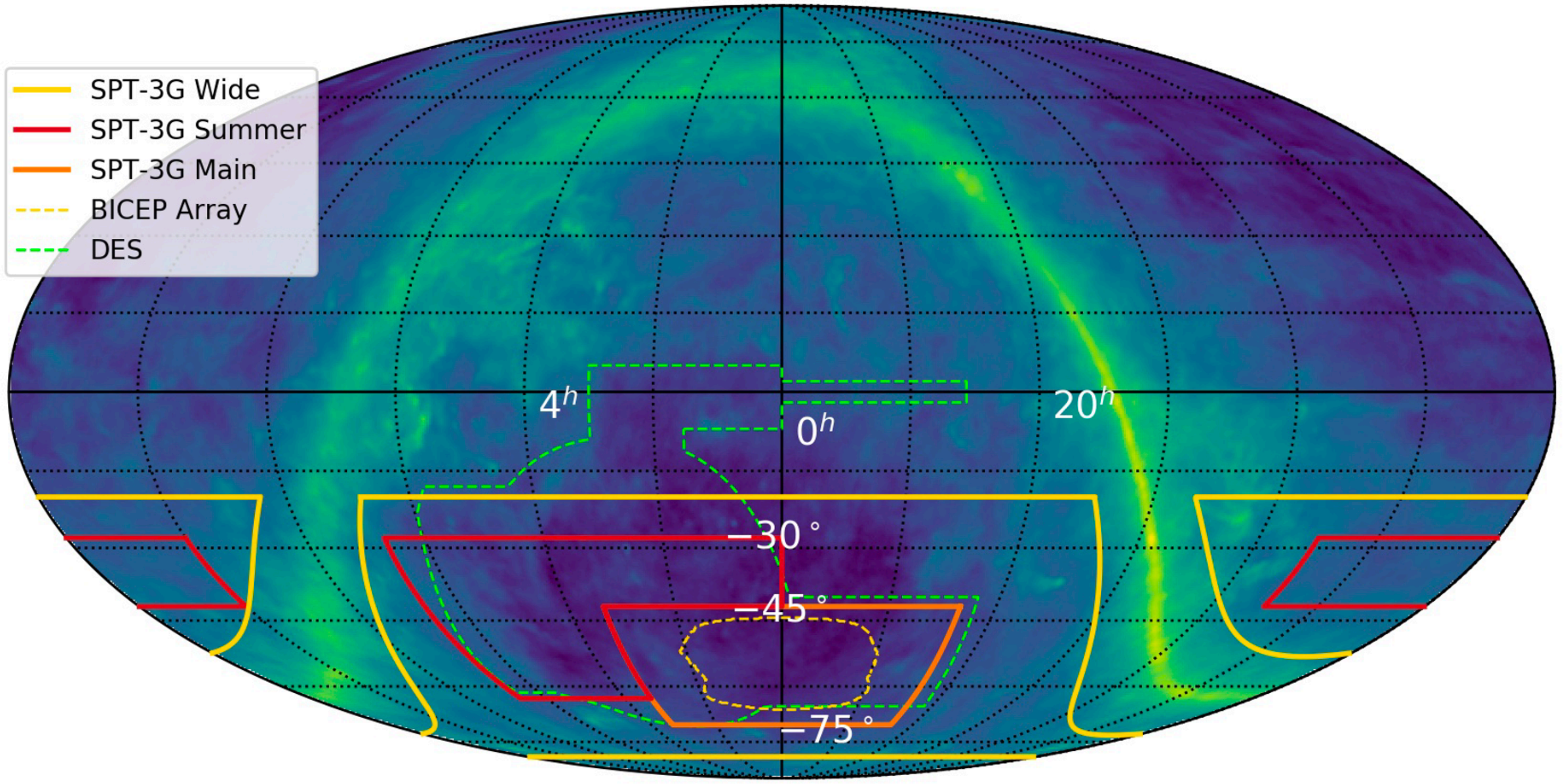
- **Winter** field (main) : 1500 deg²
  6 years of observations during austral winter



The South Pole Telescope

3 fields of observation with SPT-3G :

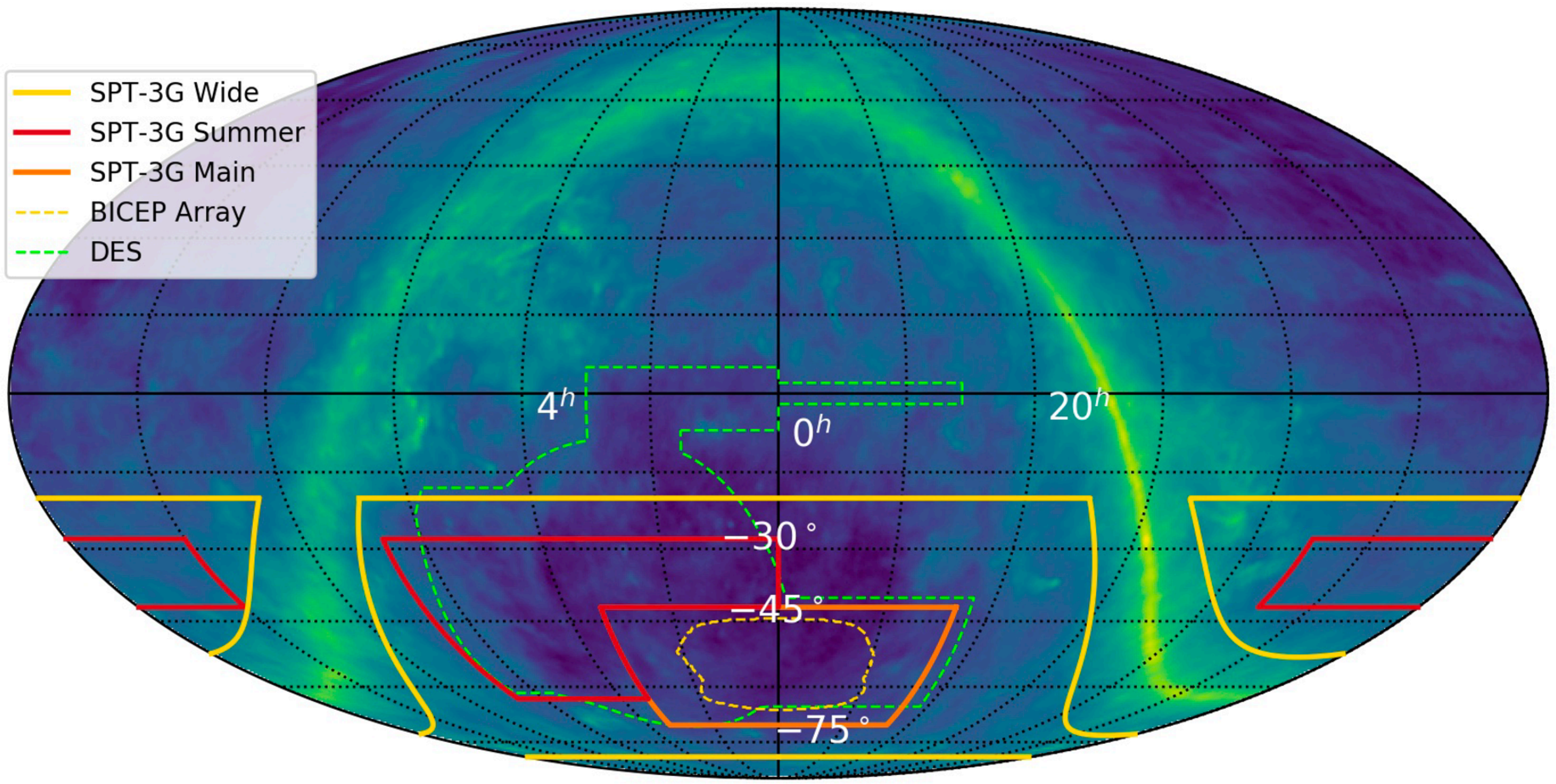
- Winter field (main) : 1500 deg^2
  6 years of observations during austral winter
- Summer field : 2600 deg^2
  4 years of observations during austral summer



The South Pole Telescope

3 fields of observation with SPT-3G :

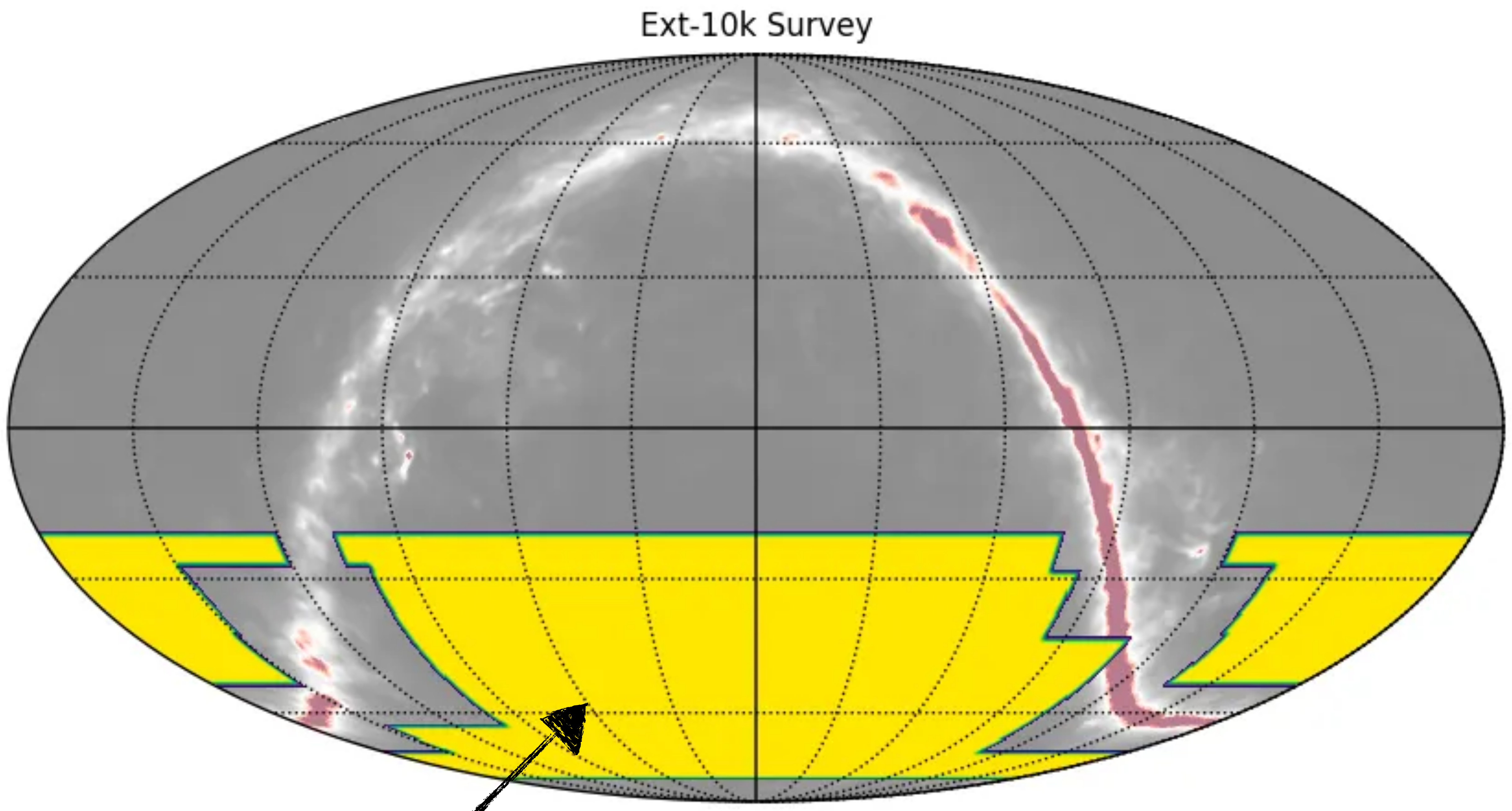
- Winter field (main) : 1500 deg²
  6 years of observations during austral winter
- Summer field : 2600 deg²
  4 years of observations during austral summer
- Wide field : 6000 deg²
  1 year of observations in 2024



The South Pole Telescope

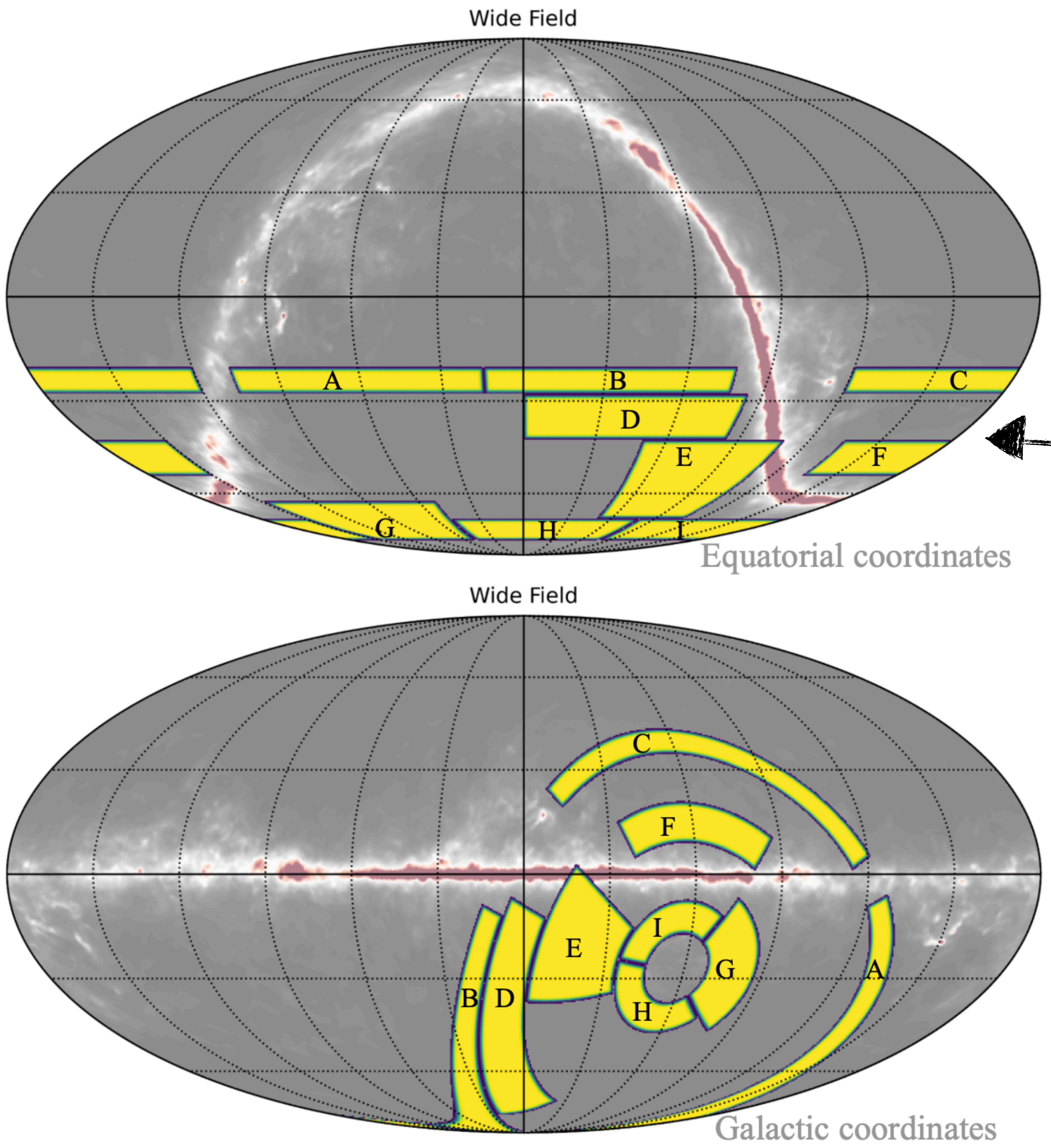
3 fields of observation with SPT-3G :

- **Winter** field (main) : 1500 deg²
  6 years of observations during austral winter
- **Summer** field : 2600 deg²
  4 years of observations during austral summer
- **Wide** field : 6000 deg²
  1 year of observations in 2024

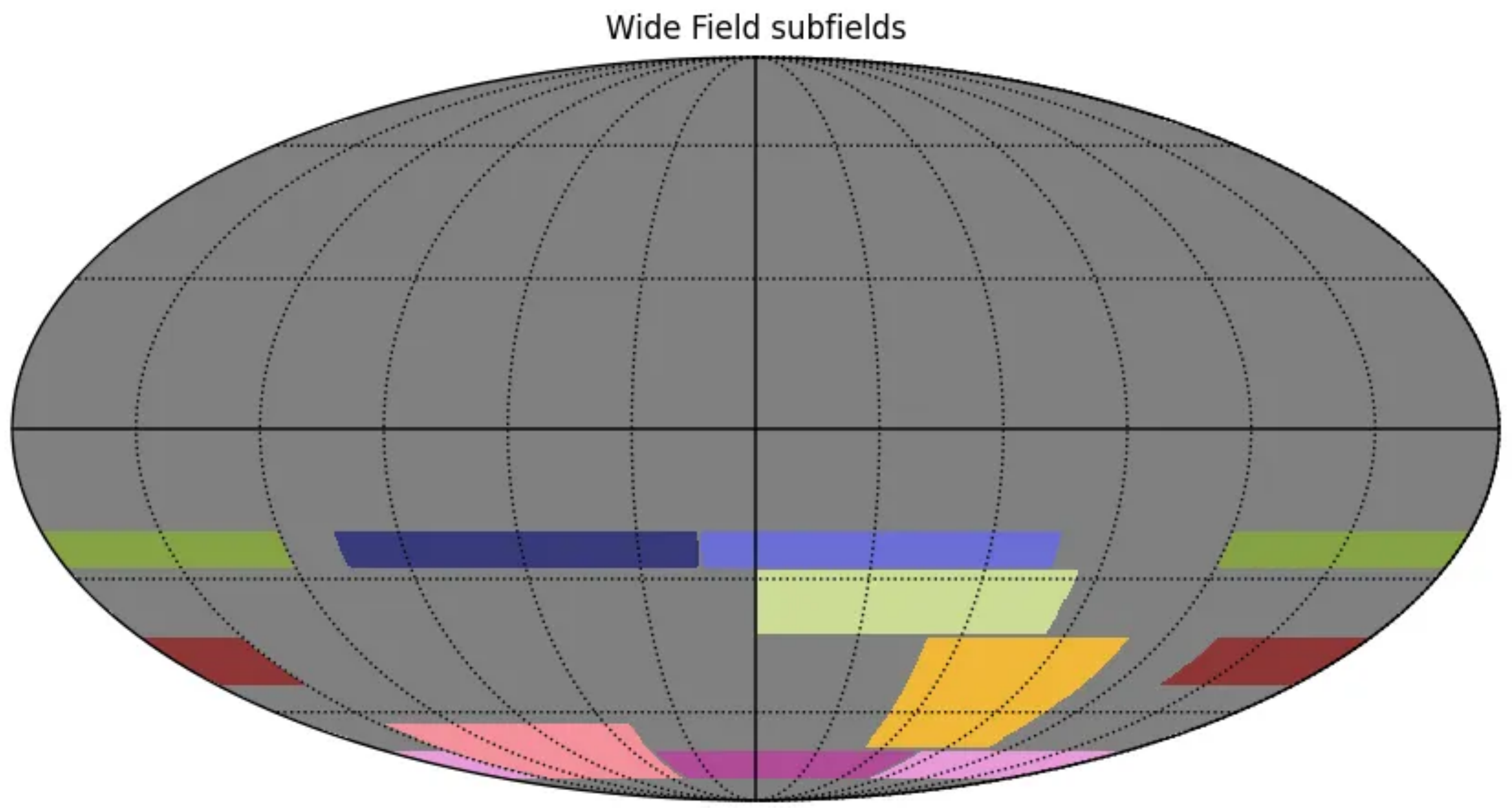


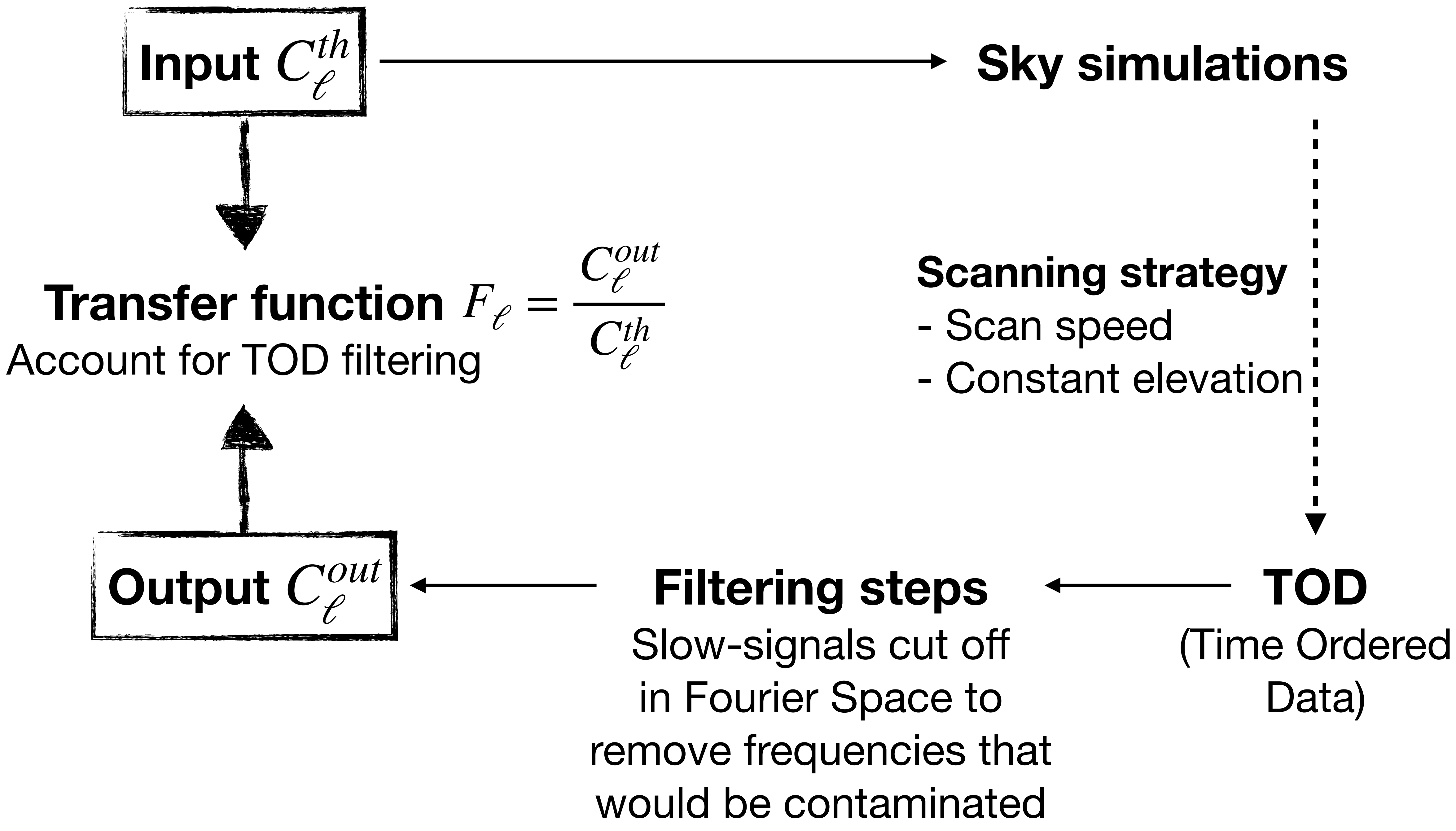
All fields combined :
SPT-3G Ext-10k : 25% of the sky

SPT-3G WIDE FIELD



- Observations finished last September
- 14% of the sky
- Divided in 9 subfields (A, B, C, …)
- Declination from -20° to -80°
- Target noise levels : 13/11.5/42 μK-arcmin at 90/150/220 GHz (Planck noise : 78/33/47 μK-arcmin at 100/143/217 GHz)





9 TRANSFER FUNCTIONS ?

- The scan goes back and forth from left to right at a constant elevation → induced correlated noise in the scan direction (mostly atmospheric noise)

- Atmosphere varies slowly → high pass filtering to remove low frequencies in Fourier space → **transfer function is a result of filtering**

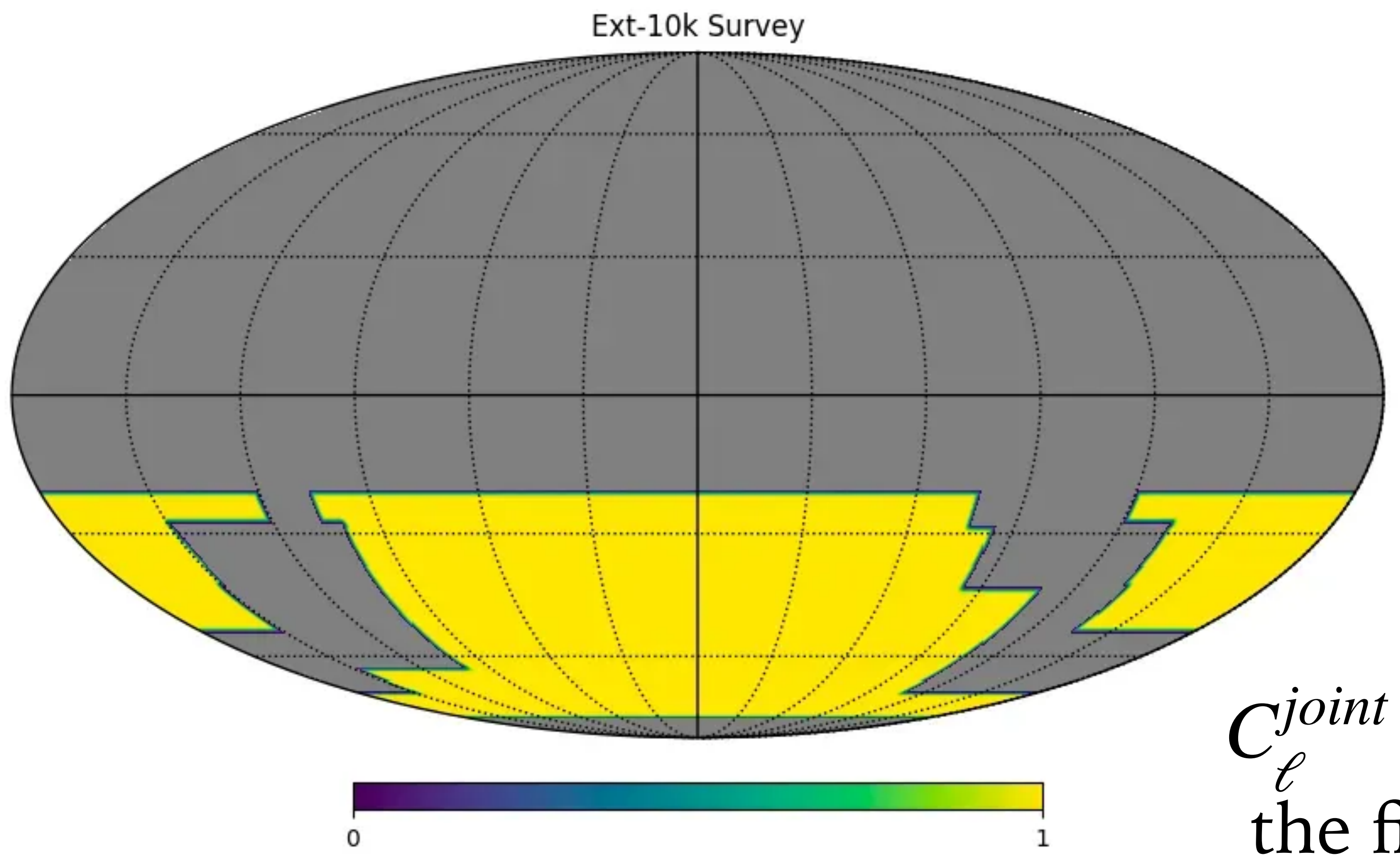
- We might have different TOD filtering for the different subfields → **different transfer functions**

Conclusion : analyzing the fields individually allows to take into account the specificity of each subfields

DO WE LOSE CONSTRAINING POWER ON COSMOLOGICAL PARAMETERS BY ANALYZING THE FIELDS INDEPENDENTLY OF EACH OTHER ?

We consider 2 different cases for the Ext-10k survey analysis

1. Best case scenario



C_ℓ^{joint} is calculated for the field as a whole.
No summation.

Ext10k_joint

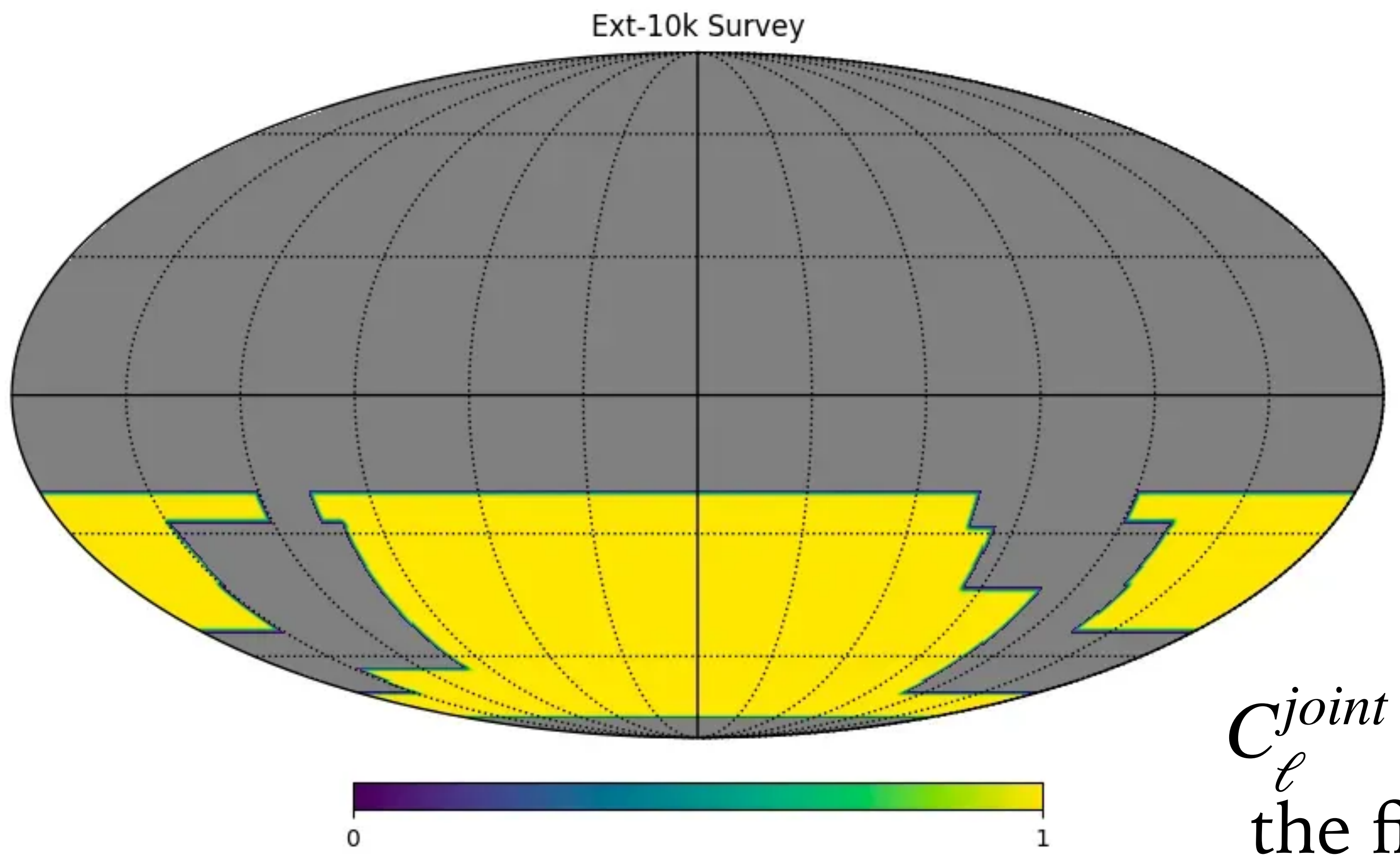
$f_{sky} = 0.2322$

1 mask used in the analysis

→ What we would do if we could analyse all the field jointly

We consider 2 different cases for the Ext-10k survey analysis

1. Best case scenario



C_ℓ^{joint} is calculated for the field as a whole. No summation.

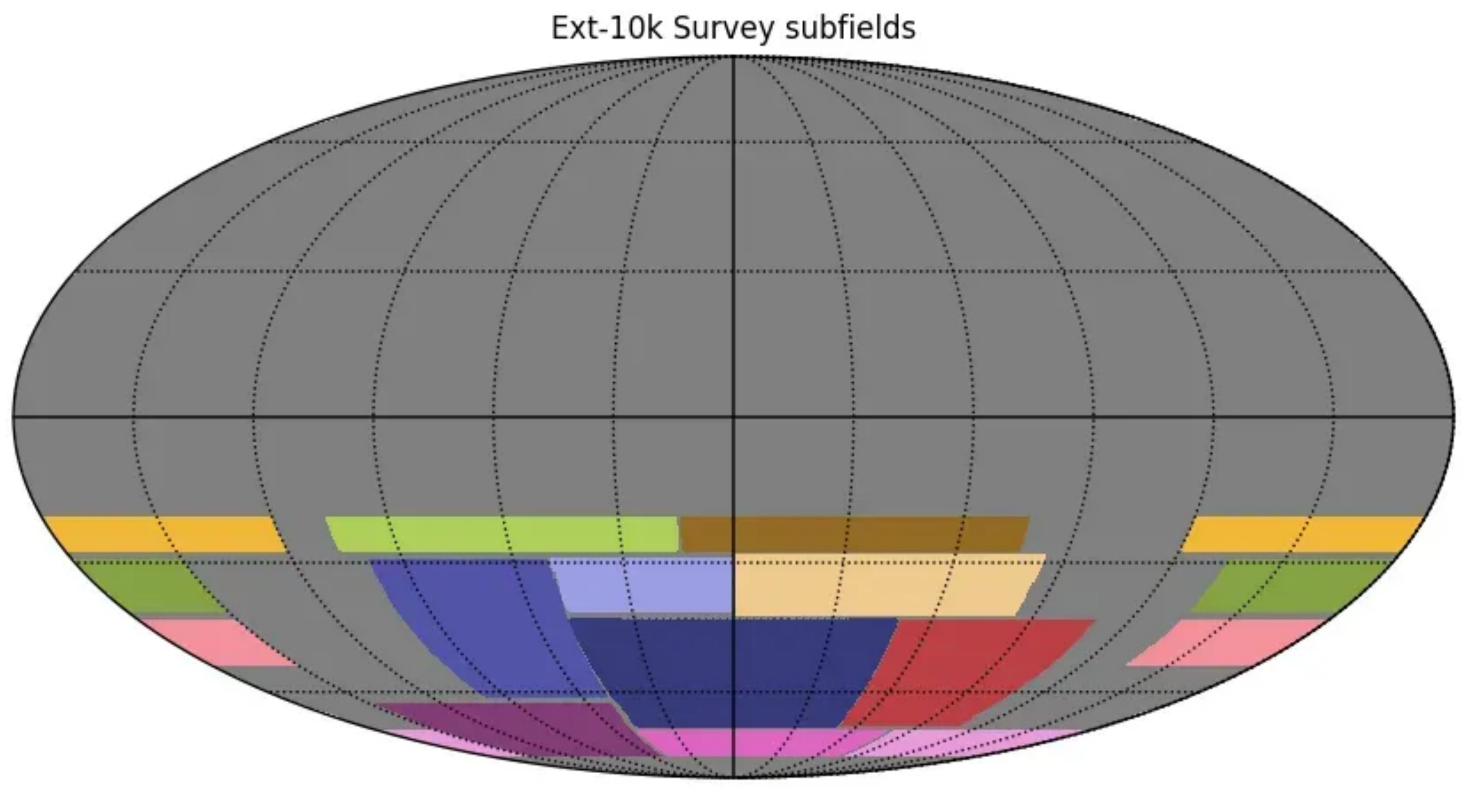
Ext10k_joint

$f_{sky} = 0.2322$

1 mask used in the analysis

→ What we would do if we could analyse all the field jointly

2. Coaddition



$$Cov(C_\ell^{coadd}, C_\ell^{coadd}) = \sum_i w_i^2 Cov(C_\ell^i, C_\ell^i)$$

$i \in$ {**wide A, B, C, D, E, F, G, H, I**} ∪ {**summer a, b,c**} ∪ {**winter**}

$$C_\ell^{coadd} = \sum_i w_i C_\ell^i$$

$$w_i = \frac{f_{sky}^i}{\sum_j f_{sky}^j}$$

Ext10k_coadd

$f_{sky} = 0.2215$

13 masks used in the analysis

→ Allows to understand the impact of a coadded analysis

Fisher forecasting and parameters covariance matrix

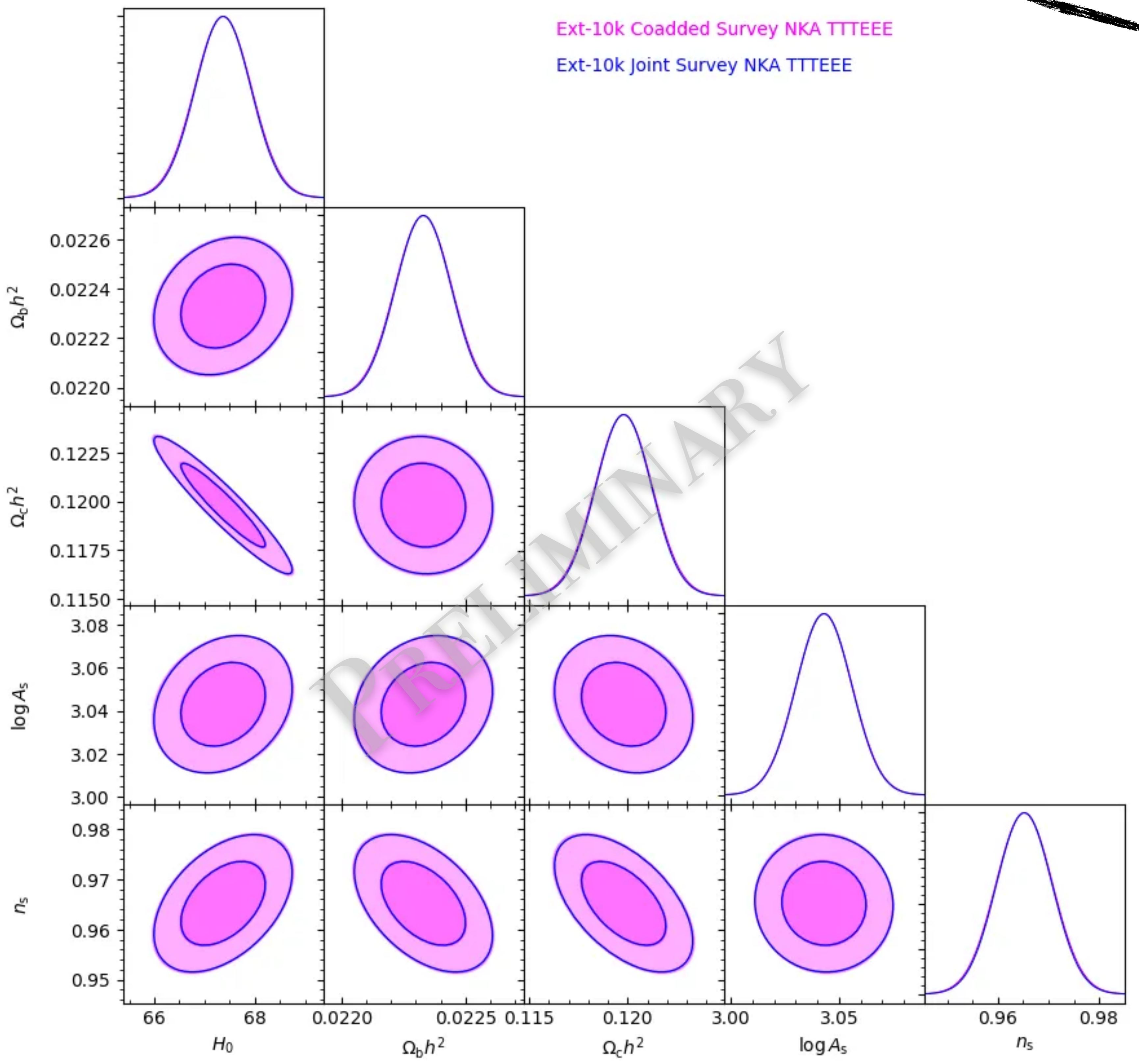
By comparing **Ext10k_coadd** with **Ext10k_joint**, we observe less than a 5% relative difference in the cosmological parameters variance between the 2 analysis.

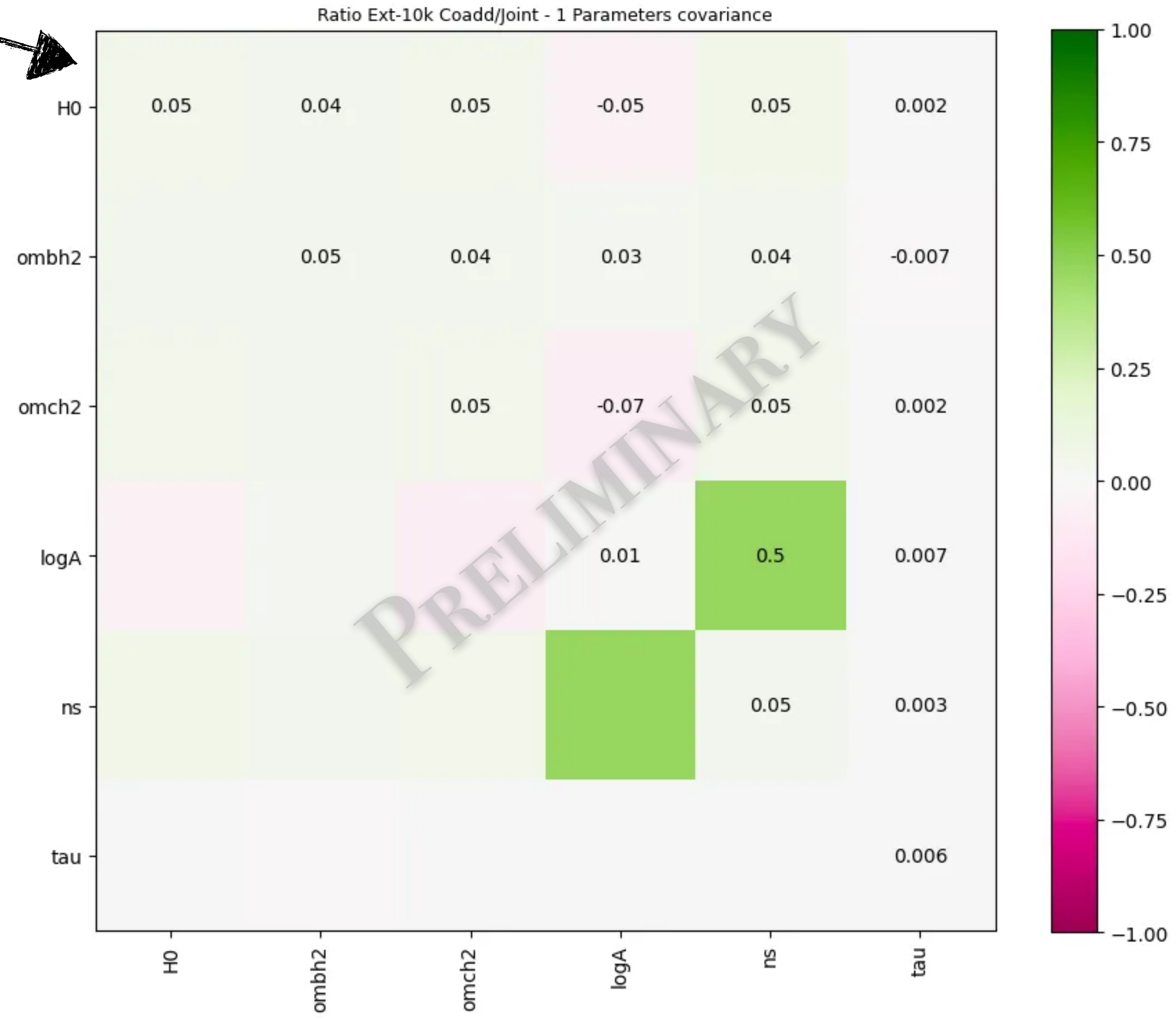
candl

Balkenhol et al., 2024

NKA
covariance matrices

Camphuis et al., 2022





Fisher forecasting and parameters covariance matrix

By comparing **Ext10k_coadd** with **Ext10k_joint**, we observe less than a 5% relative difference in the cosmological parameters variance between the 2 analysis.

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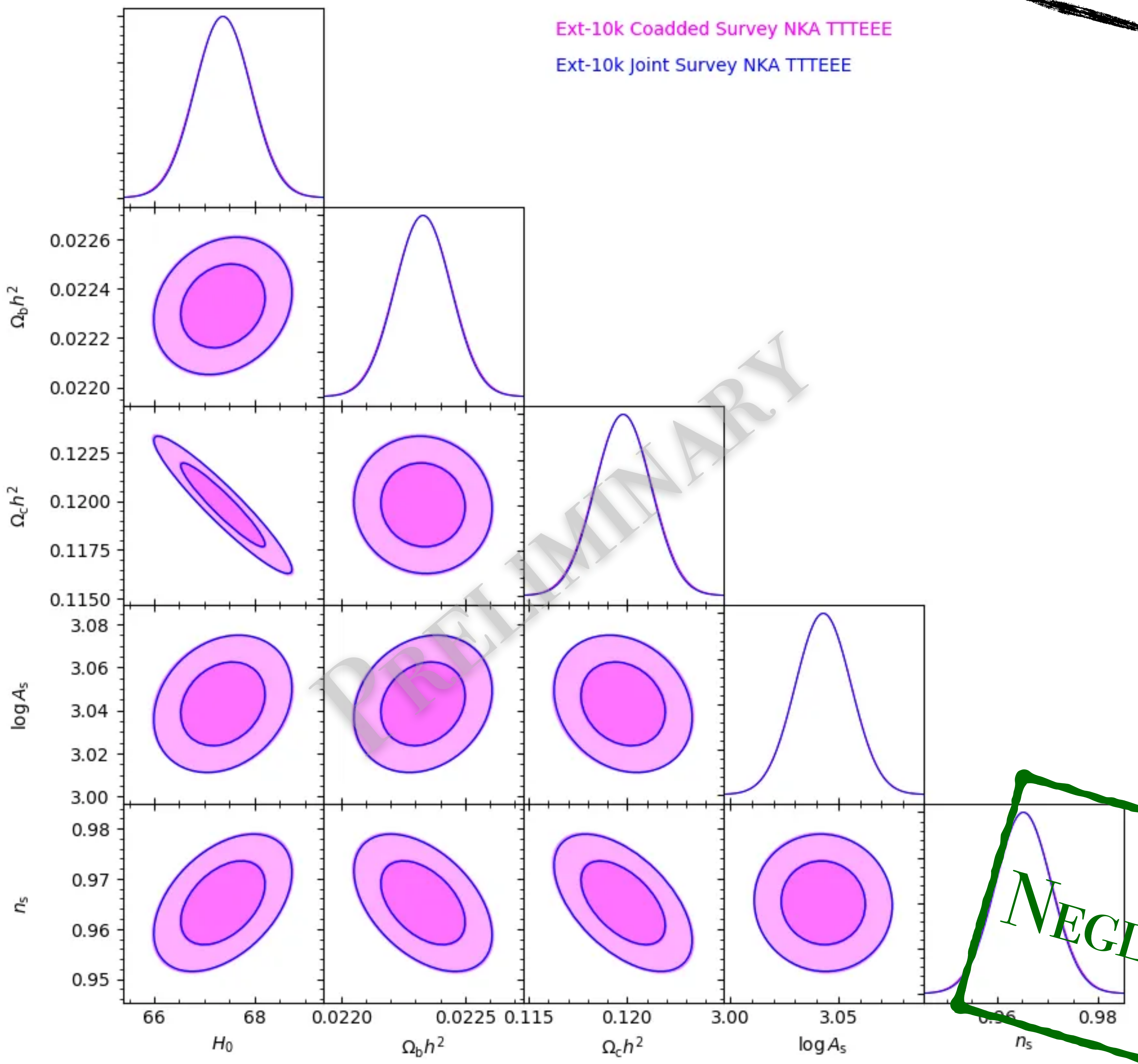
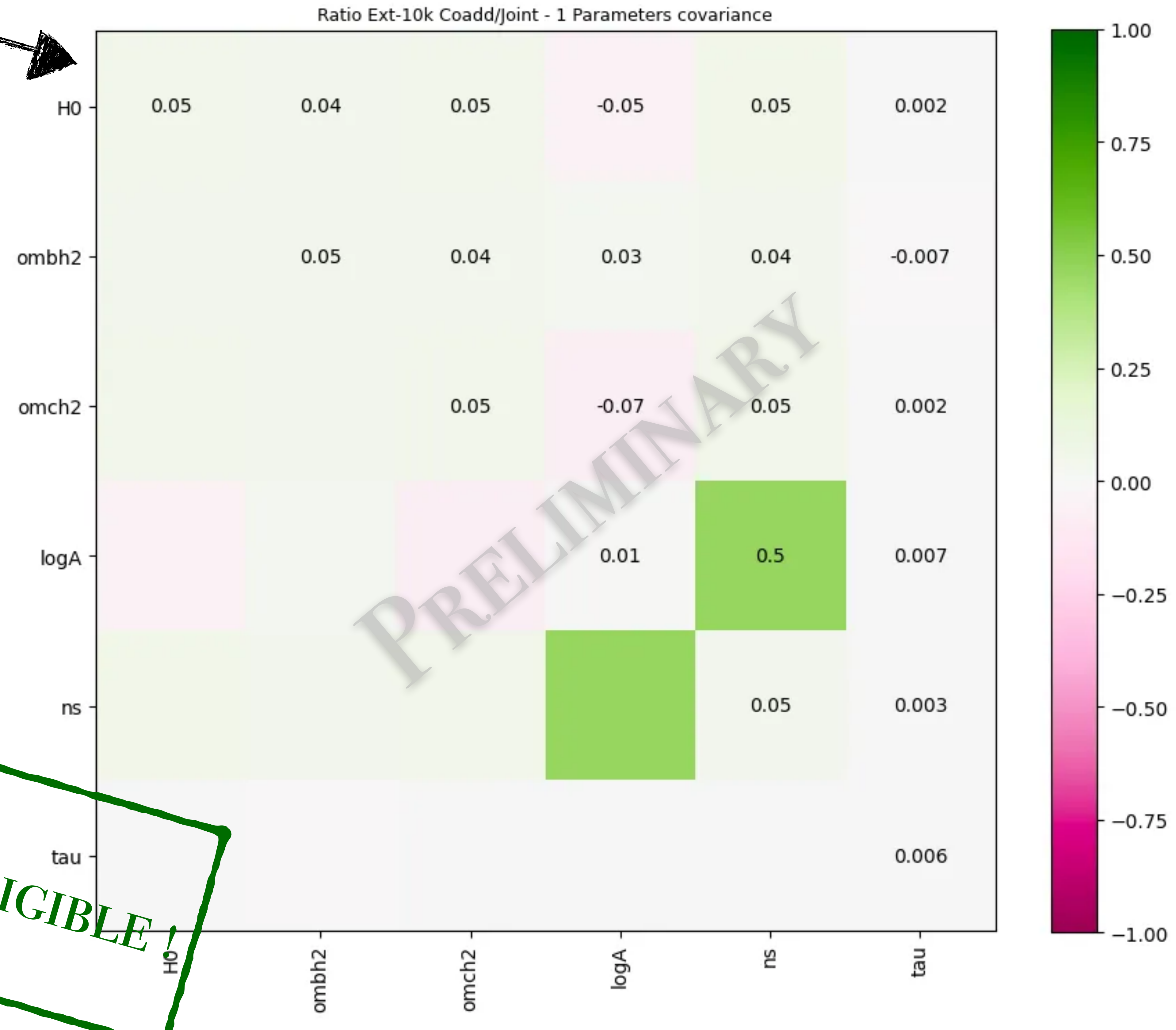
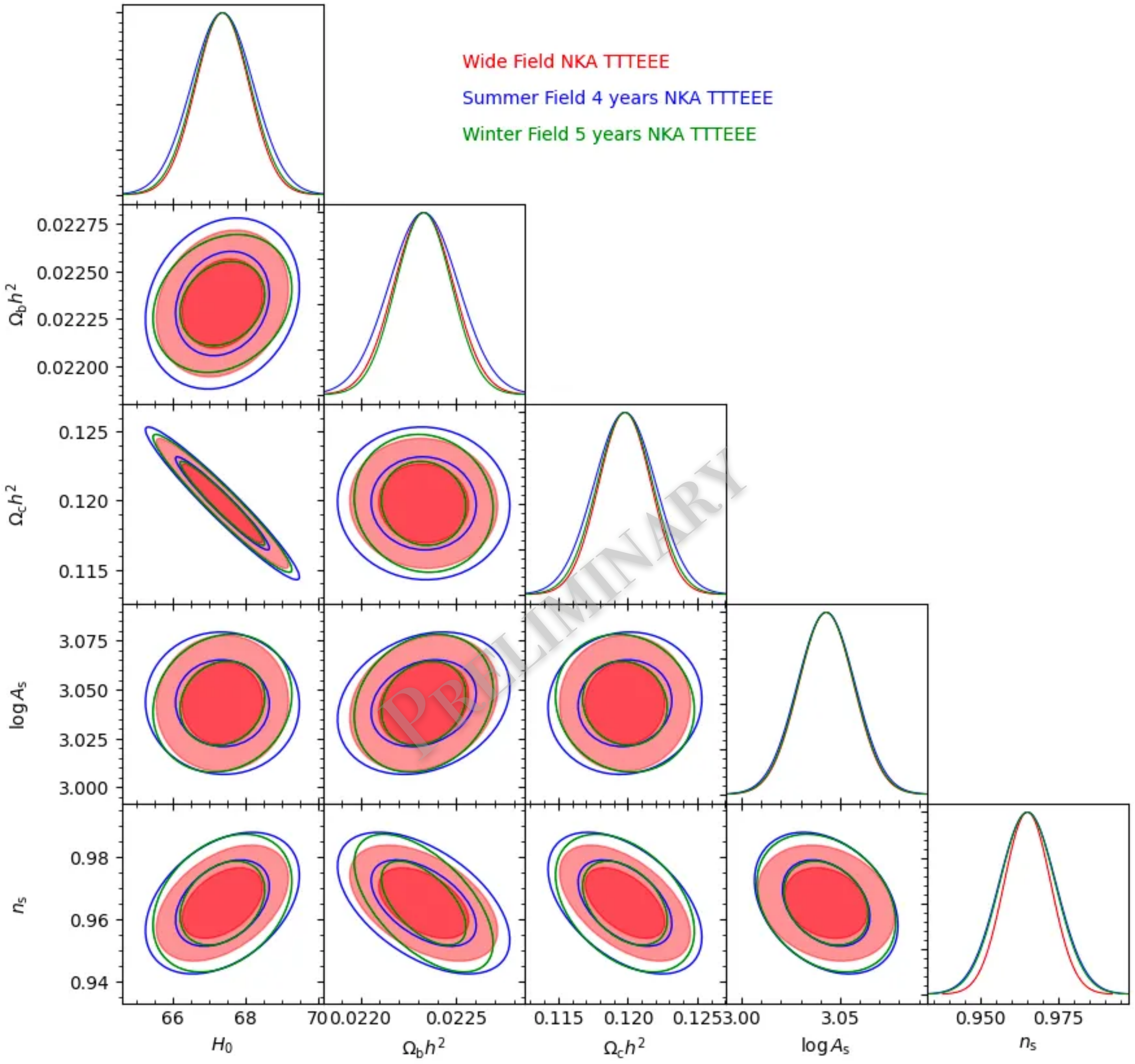


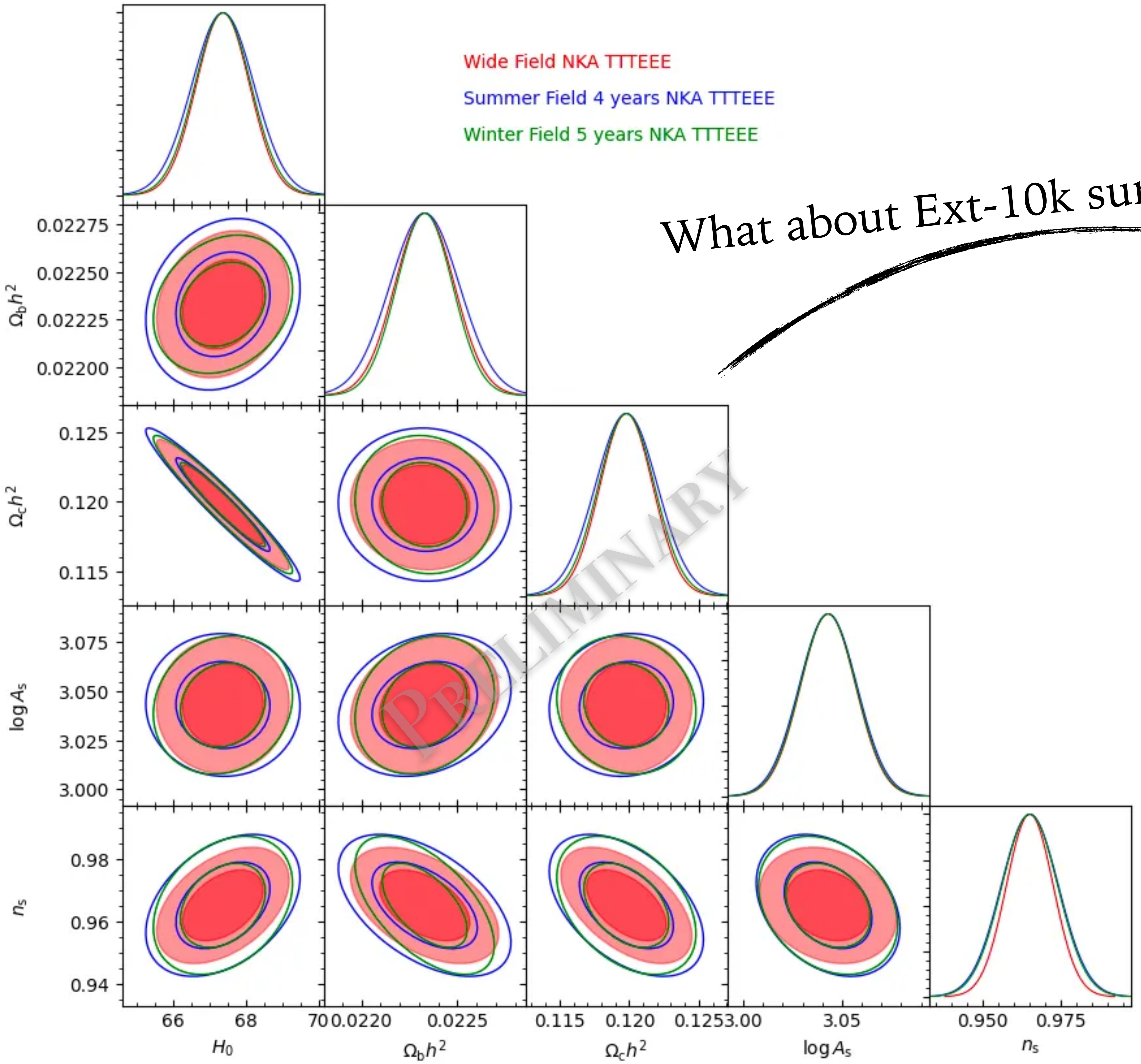


The subdivision of the fields in the analysis leads to less than a 3% increase of error bars.

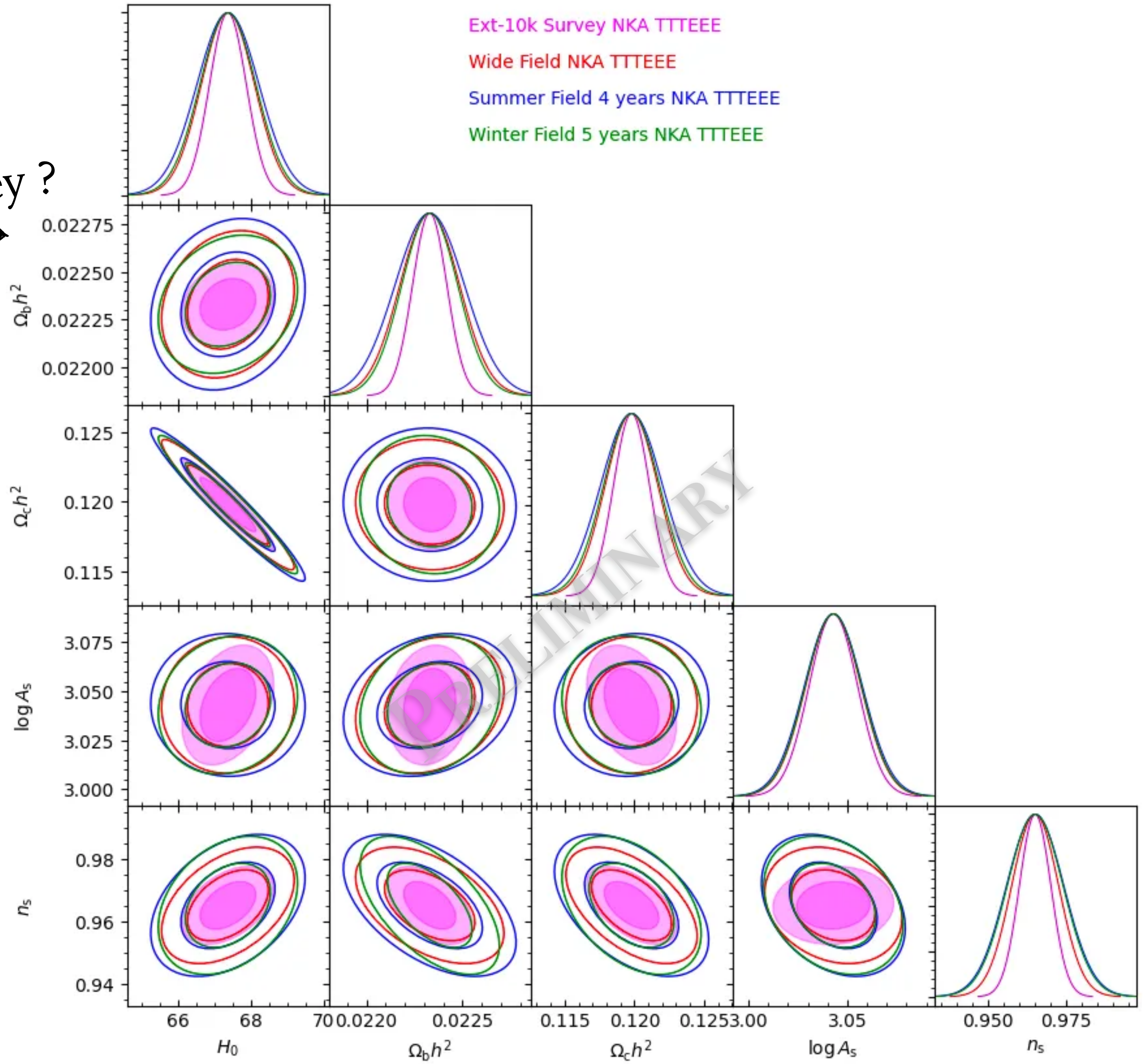
Expected improvements on cosmological parameters



Expected improvements on cosmological parameters



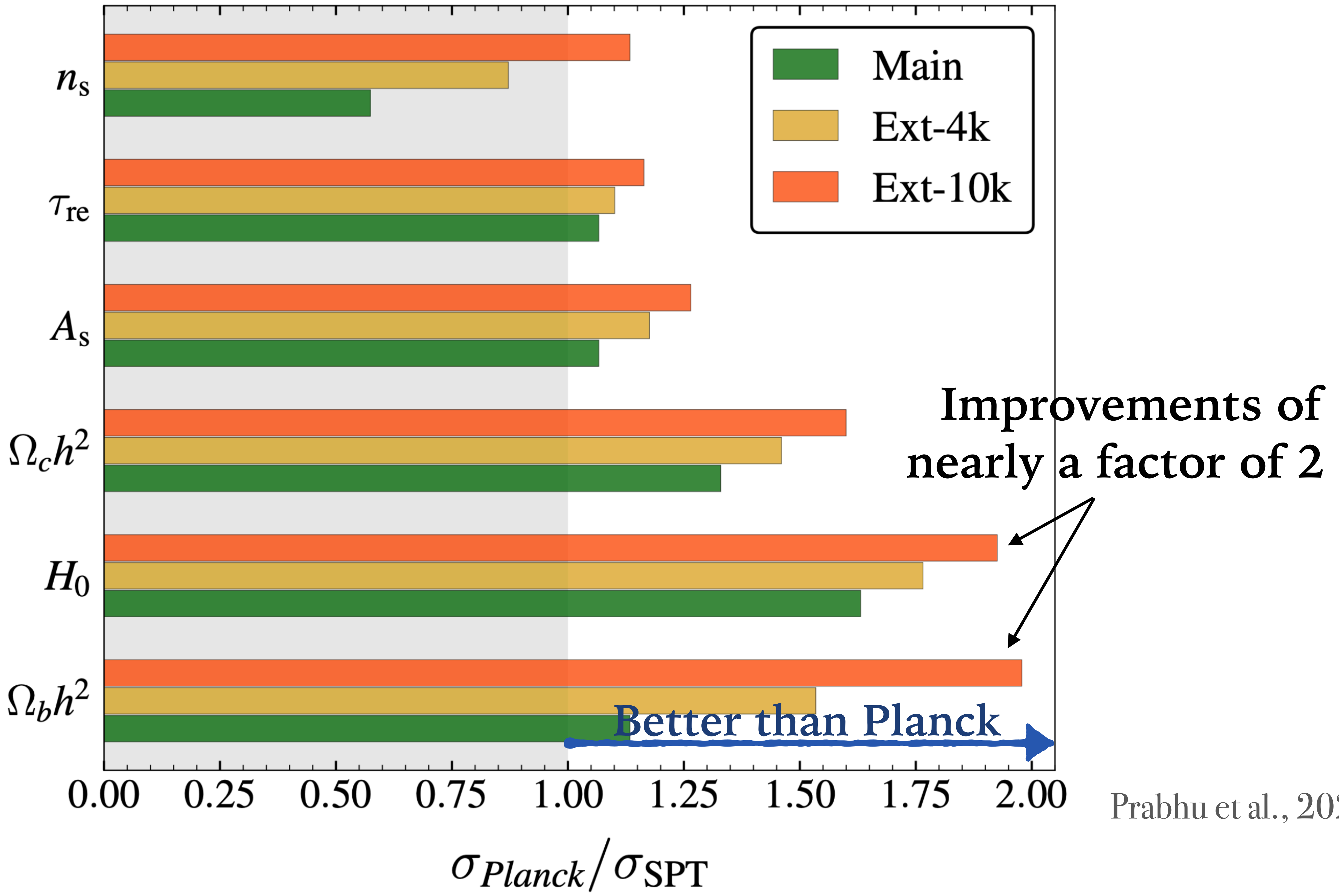
What about Ext-10k survey ?



Expected improvements on cosmological parameters

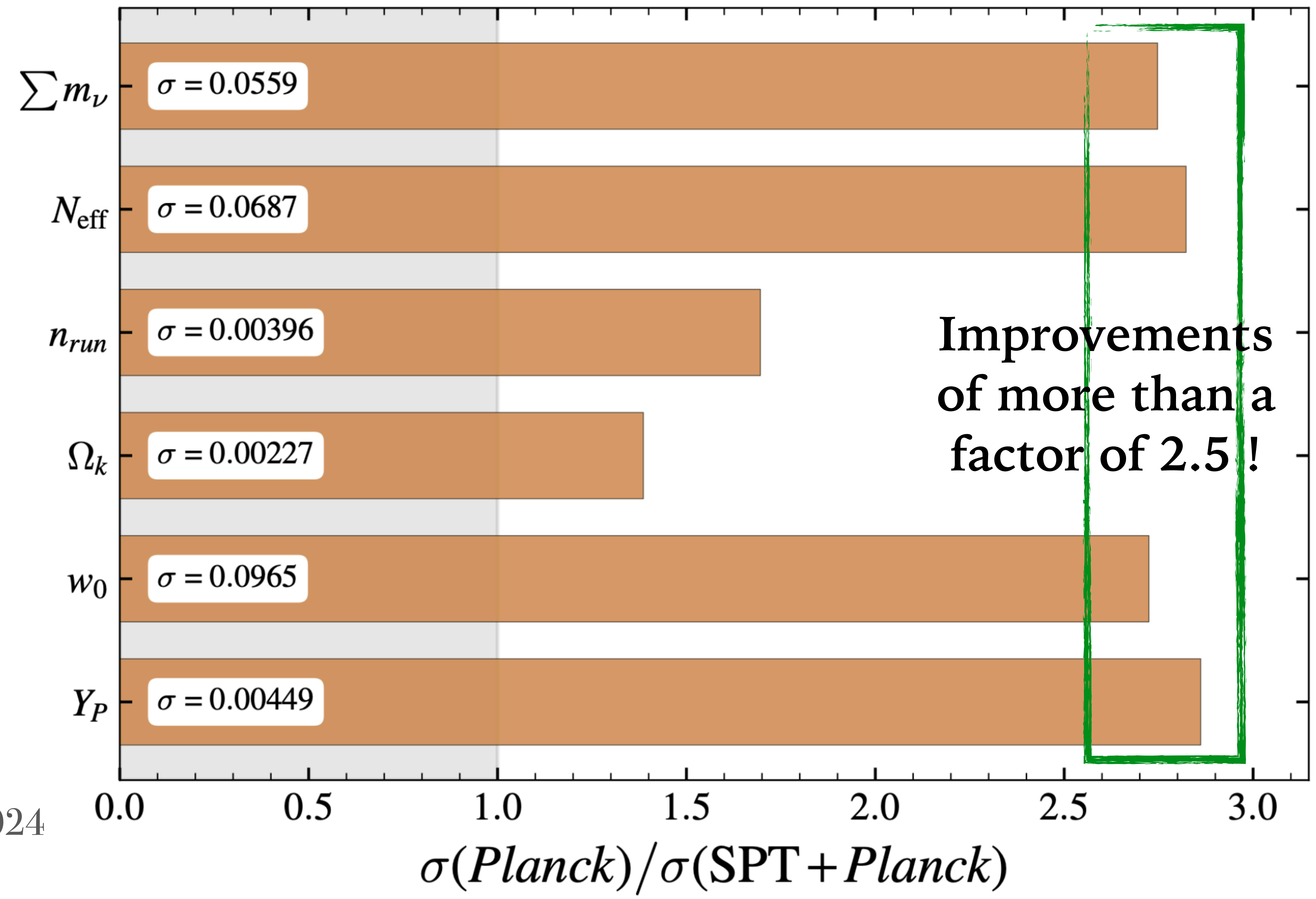
FORECASTS FROM SPT-3G EXT-10K SURVEY

- Constraints on ΛCDM parameters



Prabhu et al., 2024

- Constraints on single-parameter extensions to ΛCDM



Expected improvements on cosmological parameters

WHAT WILL BE MY CONTRIBUTION ?

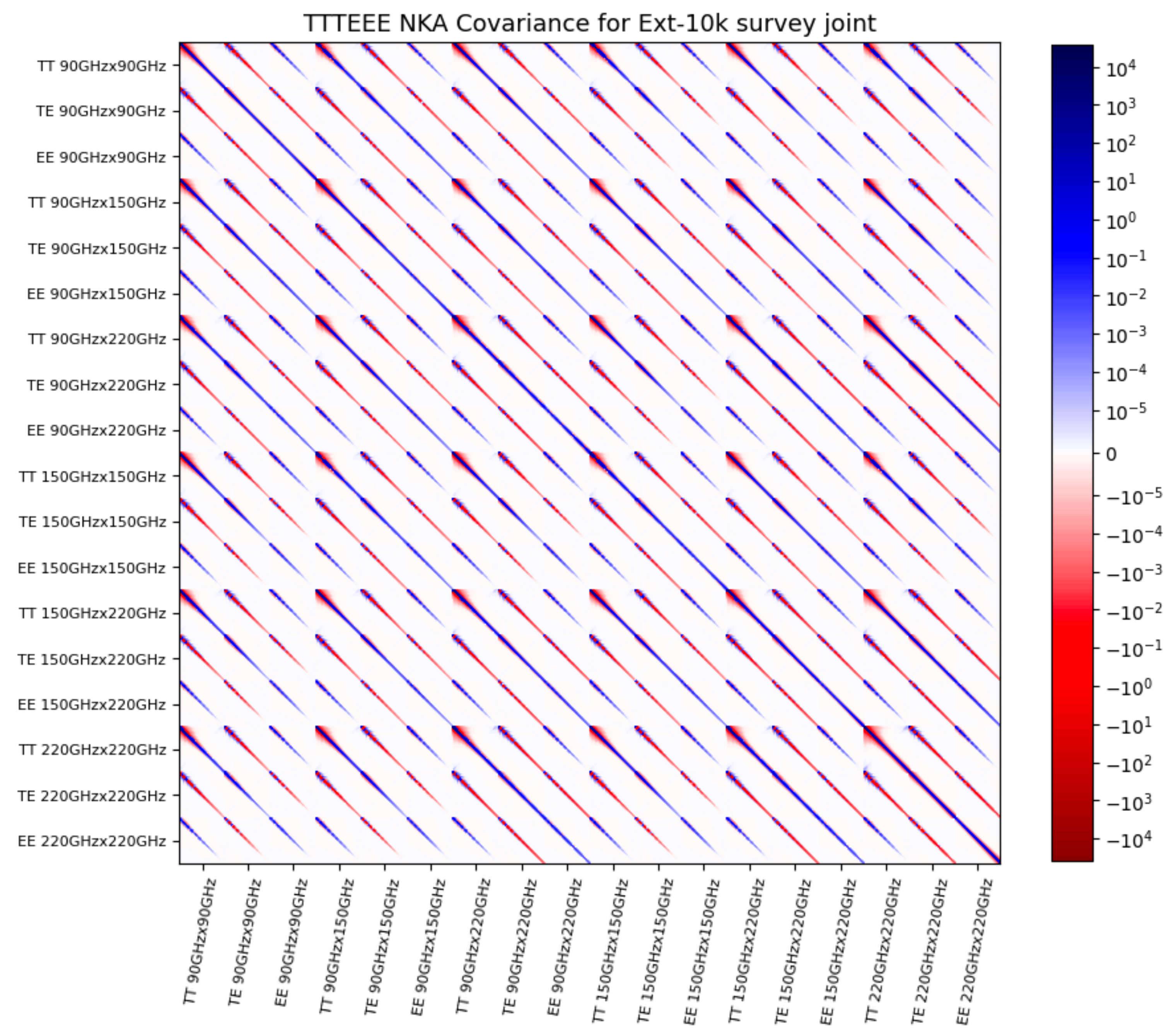
- Lead the different steps of the Wide field analysis to achieve these improvements.
- Build the Wide field likelihood using the expertise of the Winter and the Summer analysis.

$$\ln L(\theta) = -\frac{1}{2}\left(\hat{\mathrm{C}} - \mathrm{C}(\theta)\right)^T \Sigma^{-1}\left(\hat{\mathrm{C}} - \mathrm{C}(\theta)\right)$$

- ☐ Calibration
- ☐ Transfer function
- ☐ Point sources
- ☐ Foregrounds

What I am currently working on

Covariance matrix



Conclusion

- SPT-3G Wide is a new field of observation covering 14% of the sky.
- We do not lose constraining power by analyzing the subfields independently of each other
- SPT-3G Ext-10k forecasts show tighter constraints on all ΛCDM parameters than the ones from Planck.
- Constraints on H_0 should be improved by almost a factor of 2 !

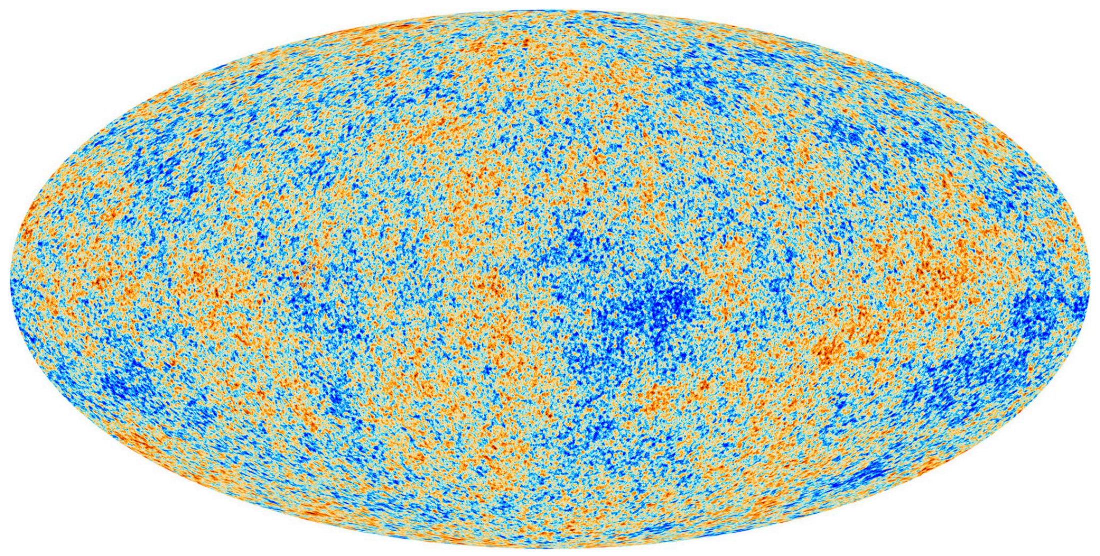
Credit: Keith Vanderlinde

BACK-UP SLIDES

Impact of a masked sky on the power spectrum analysis

- On the full sky

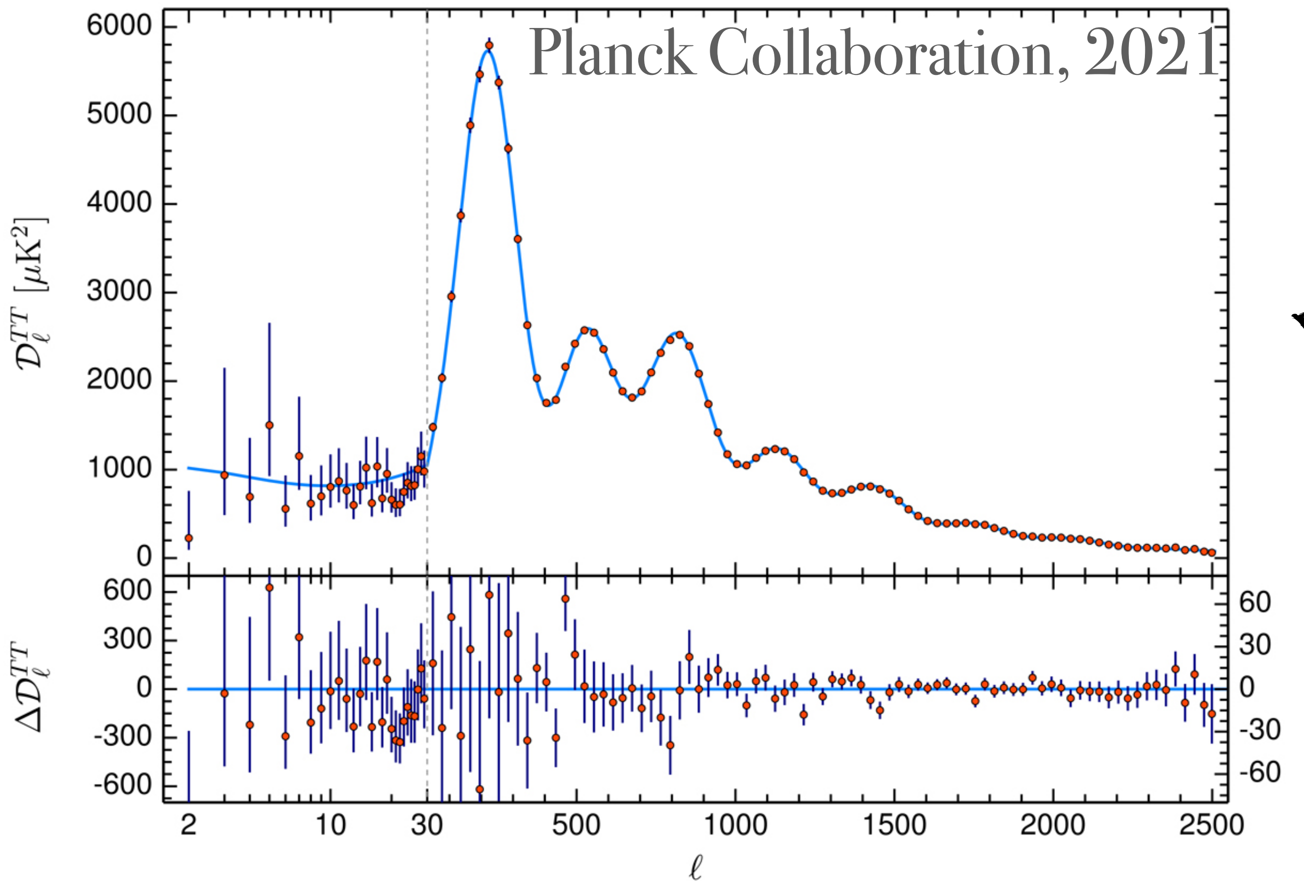
$$\Theta(\hat{n}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\hat{n})$$



Credit: ESA and Planck Collaboration

$$a_{\ell m} = \int d\hat{n}\, \Theta(\hat{n}) Y^*_{\ell m}(\hat{n})$$

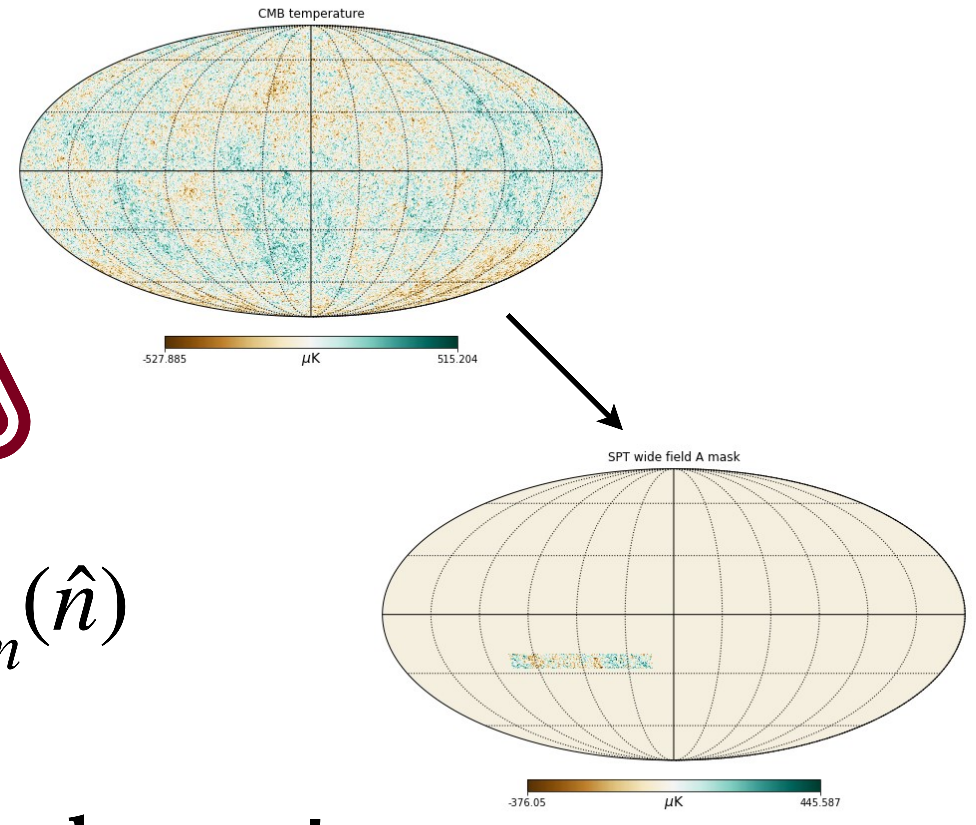
$$\hat{C}_\ell = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} a_{\ell m} a^*_{\ell m}$$



Cosmological parameters

$$\ln L(\theta) = -\frac{1}{2}\left(\hat{\mathrm{C}} - \mathrm{C}(\theta)\right)^T \Sigma^{-1} \left(\hat{\mathrm{C}} - \mathrm{C}(\theta)\right)$$

- When using a mask W



$$\Theta(\hat{n}) \longrightarrow \Theta(\hat{n}) W(\hat{n})$$

$$a_{\ell m} \longrightarrow \tilde{a}_{\ell m} = \int d\hat{n}\, \Theta(\hat{n}) W(\hat{n}) Y^*_{\ell m}(\hat{n})$$

$$\hat{C}_\ell \longrightarrow \tilde{C}_\ell$$

What we want to know !

and $\langle \tilde{C}_\ell \rangle = \sum_{\ell'} M_{\ell \ell'} C^{th}_{\ell'}$ Hivon et al., 2002

Problem : The inversion of the matrix M is impossible.
Solution : The Polspice program goes to real space and introduces a function $f(\Delta\theta)$ which avoids ringing in the multipole space.

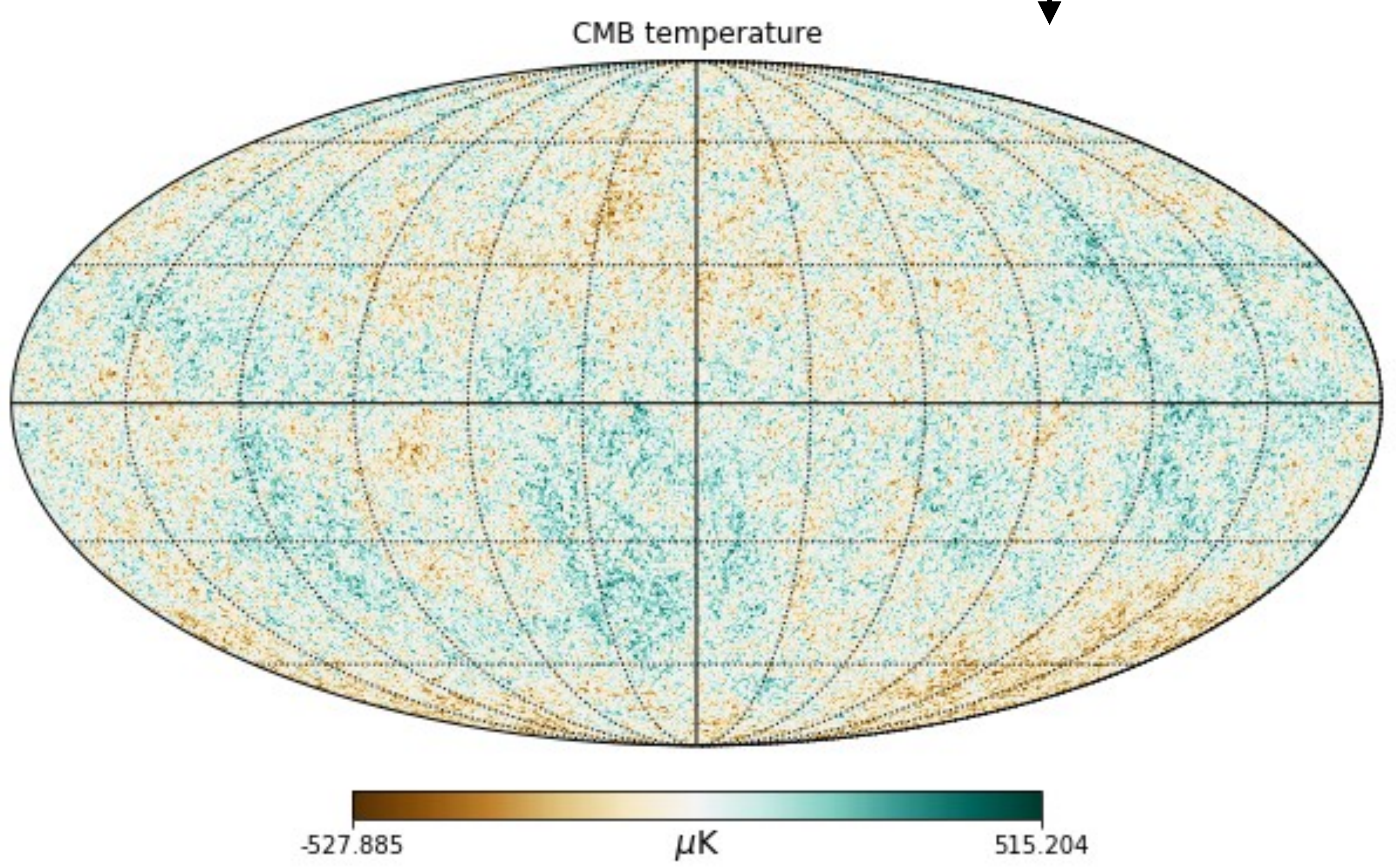
$$f(\Delta\theta) = \frac{1}{2}\left(1 + cos\left(\frac{\pi \Delta\theta}{\sigma}\right)\right)$$

$\Delta\theta$: angular separation in the sky

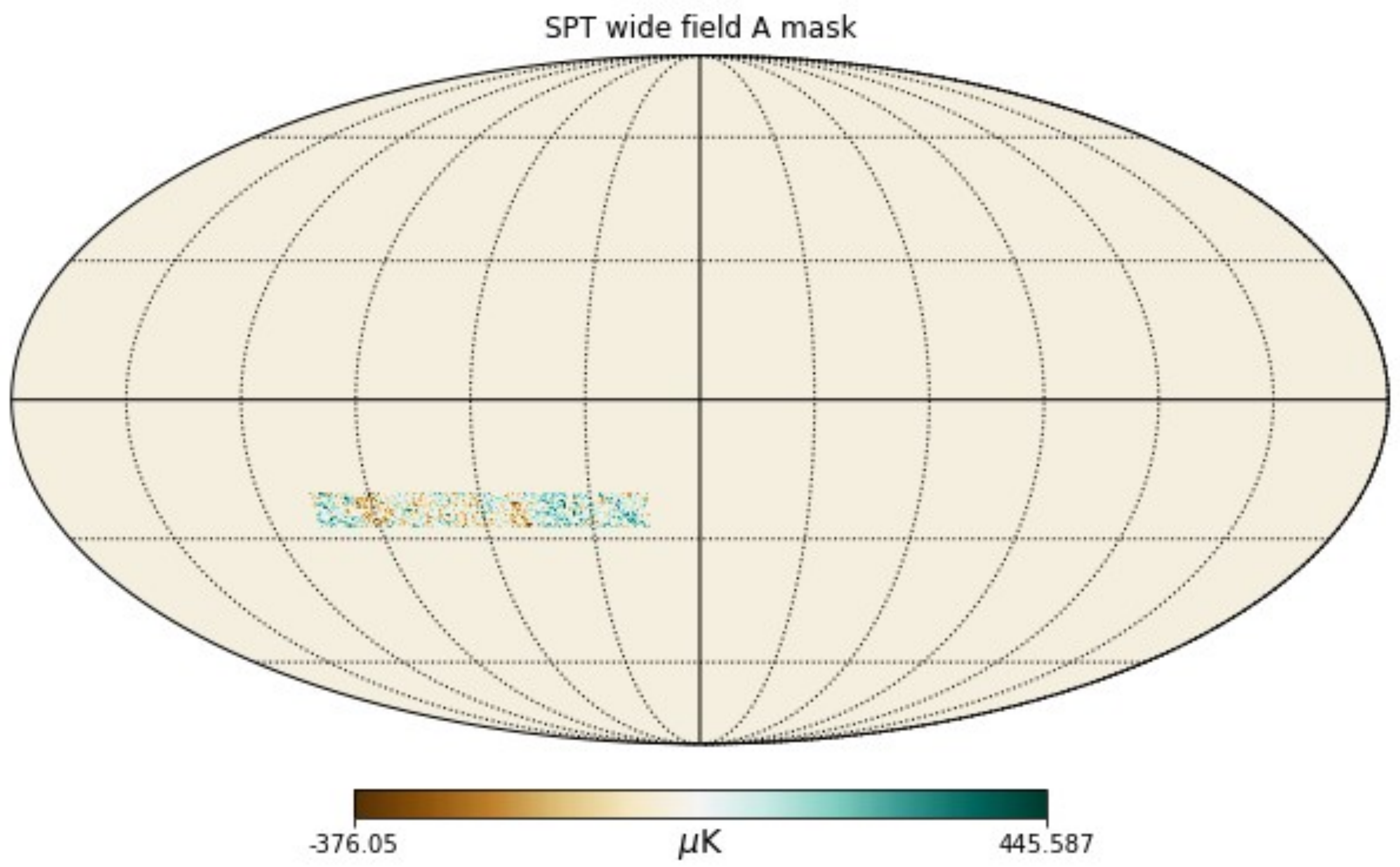
apodizesigma

Polspice apodizesigma parameter determination

hp.synfast

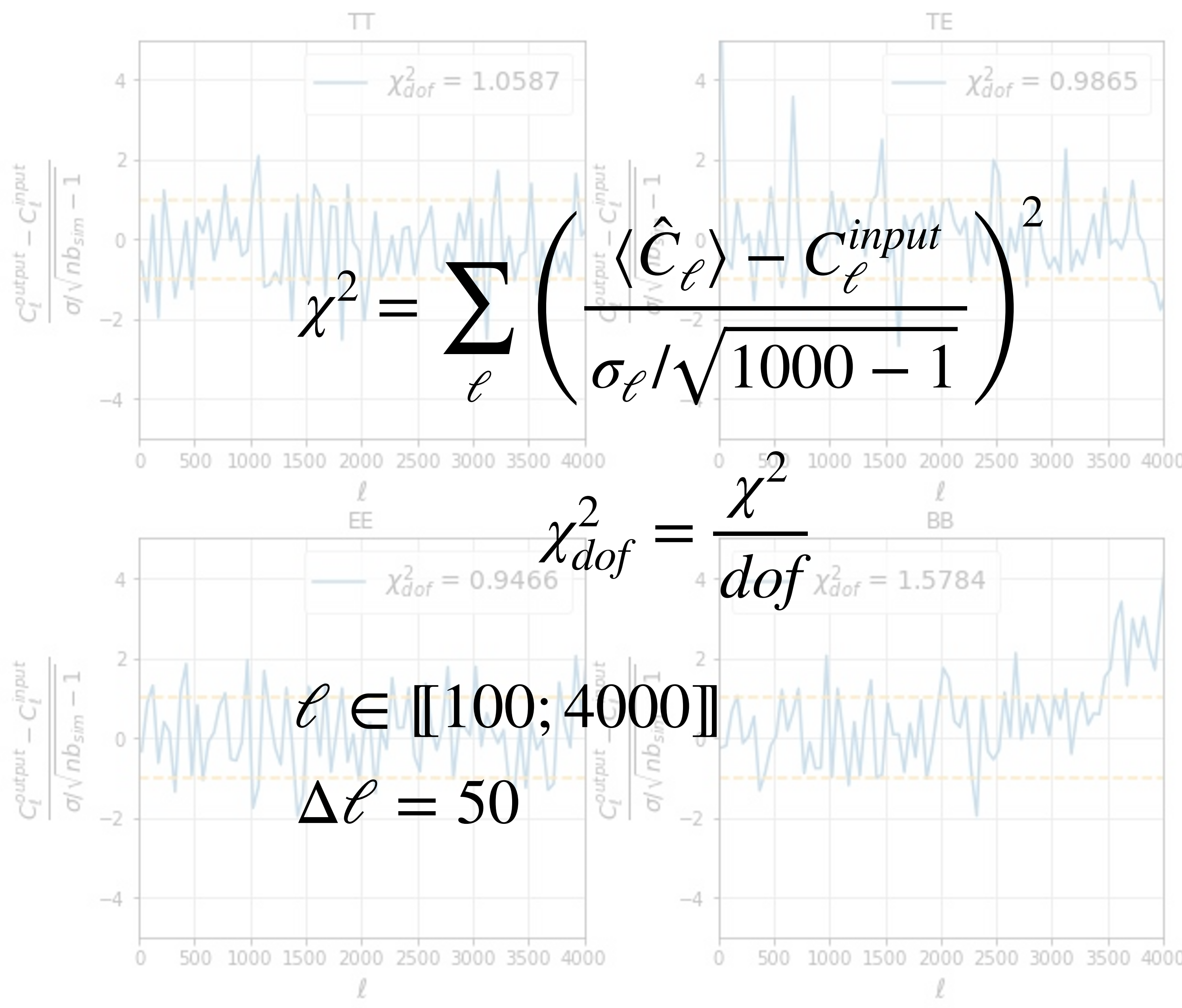


x Mask



apodizesigma $\hat{C}_\ell$

Mean and StDev of 1000 spectra

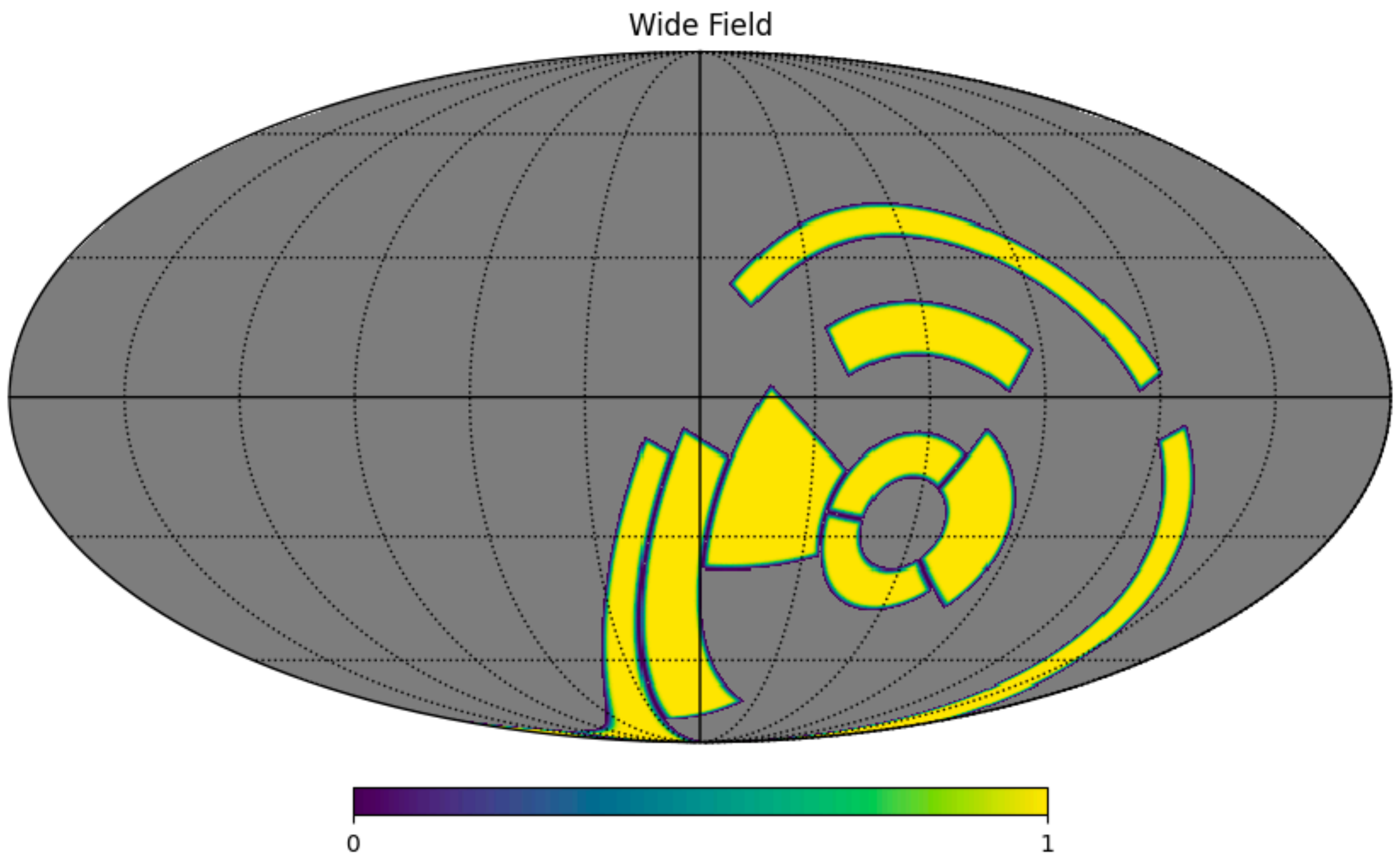


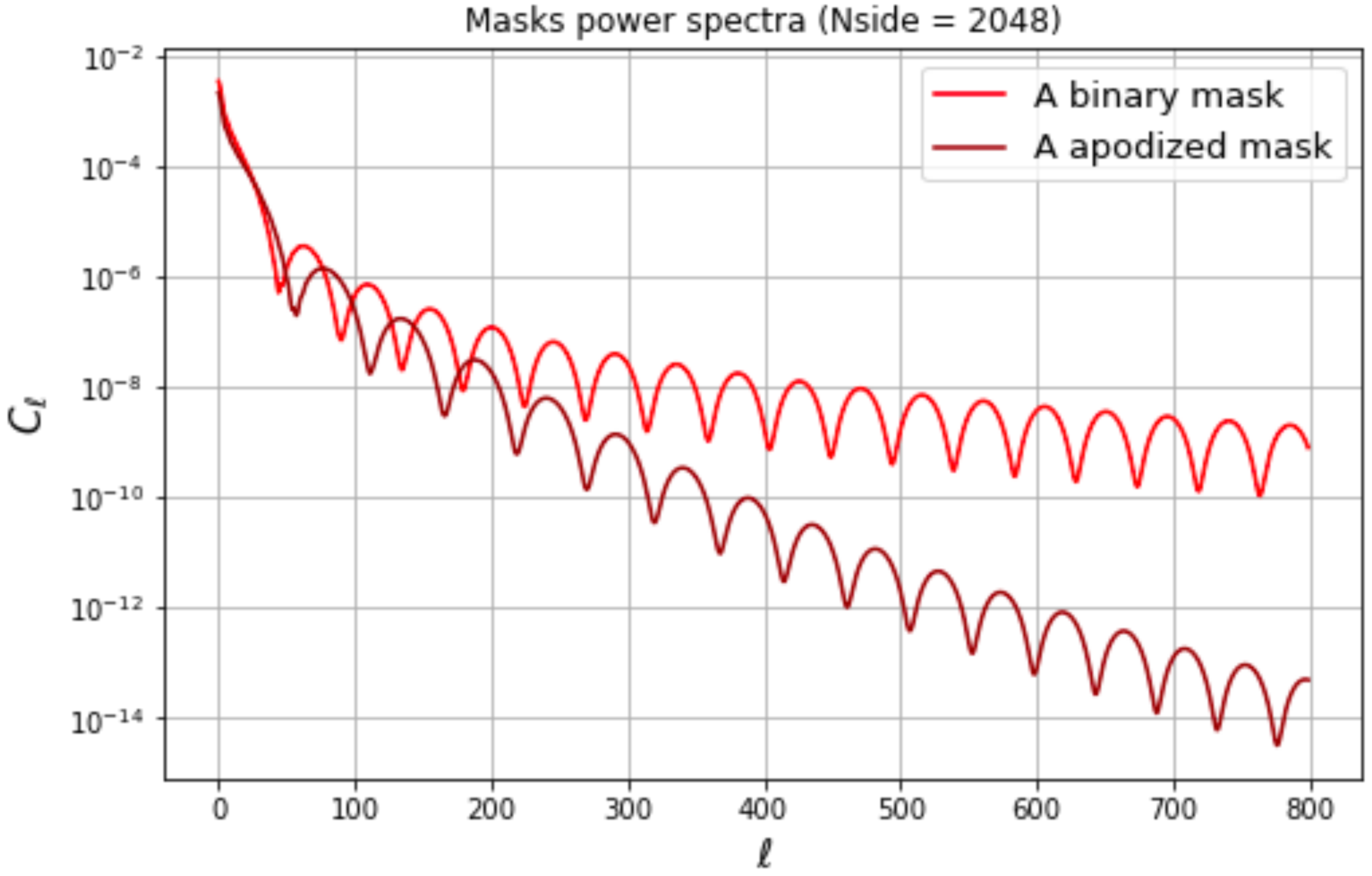
$$\chi^2 = \sum_\ell \left(\frac{\langle \hat{C}_\ell \rangle - C_\ell^{input}}{\sigma_\ell / \sqrt{1000 - 1}} \right)^2$$

$$\chi^2_{dof} = \frac{\chi^2}{dof}$$

$\ell \in [\![100; 4000]\!]$

$\Delta \ell = 50$





APODIZED MASKS

The masks have been apodized in order to

- avoid ringing in the multipole space
- reduce correlation between modes

Fisher forecasting and parameters covariance matrix : Methodology

- Fisher forecasting with candl Balkenhol et al., 2024

- To compute Fisher matrices we provide :

$$F_{\alpha\beta} = \sum_{\ell_1,\ell_2} \sum_{XY,WZ} \frac{\partial C^{XY}_{\ell_1}}{\partial p^\alpha} \left[\Sigma^{XY,WZ}_{\ell_1 \ell_2}\right]^{-1} \frac{\partial C^{WZ}_{\ell_2}}{\partial p^\beta}$$

1) A covariance matrix
   We use **NKA** (Narrow Kernel Approximation) covariance matrices Camphuis et al., 2022

2) A cosmology
   We use the Planck 2018 best fit →

```
pars = {'H0': 67.37,
        'ombh2': 0.02233,
        'omch2': 0.1198,
        'logA': 3.043,
        'ns': 0.9652,
        'tau': 0.054}
```

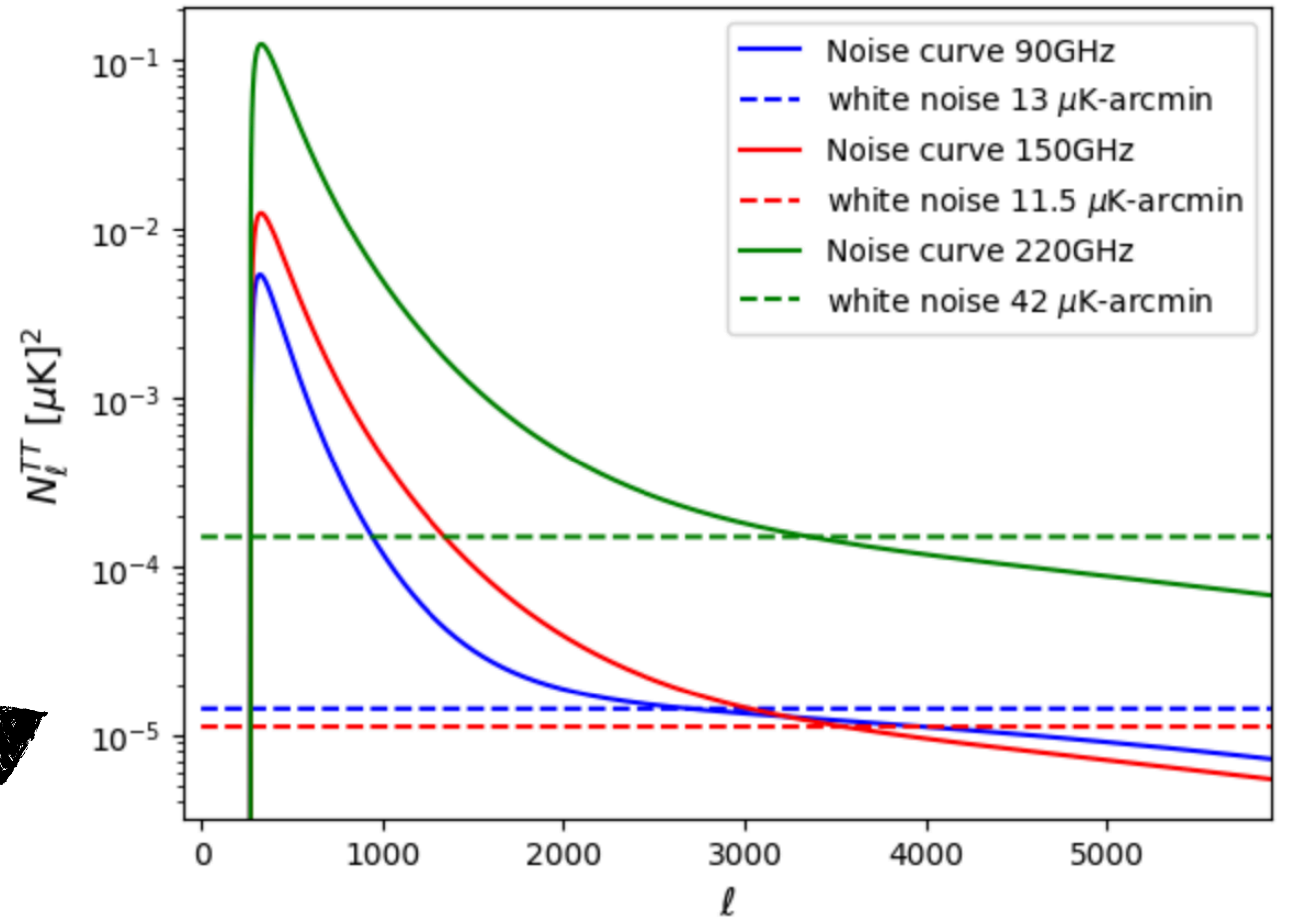
3) A foreground model
   We use the data model of SPT-3G 2018 TT/TE/EE
   Balkenhol et al., 2023

Fisher forecasting and parameters covariance matrix : Methodology

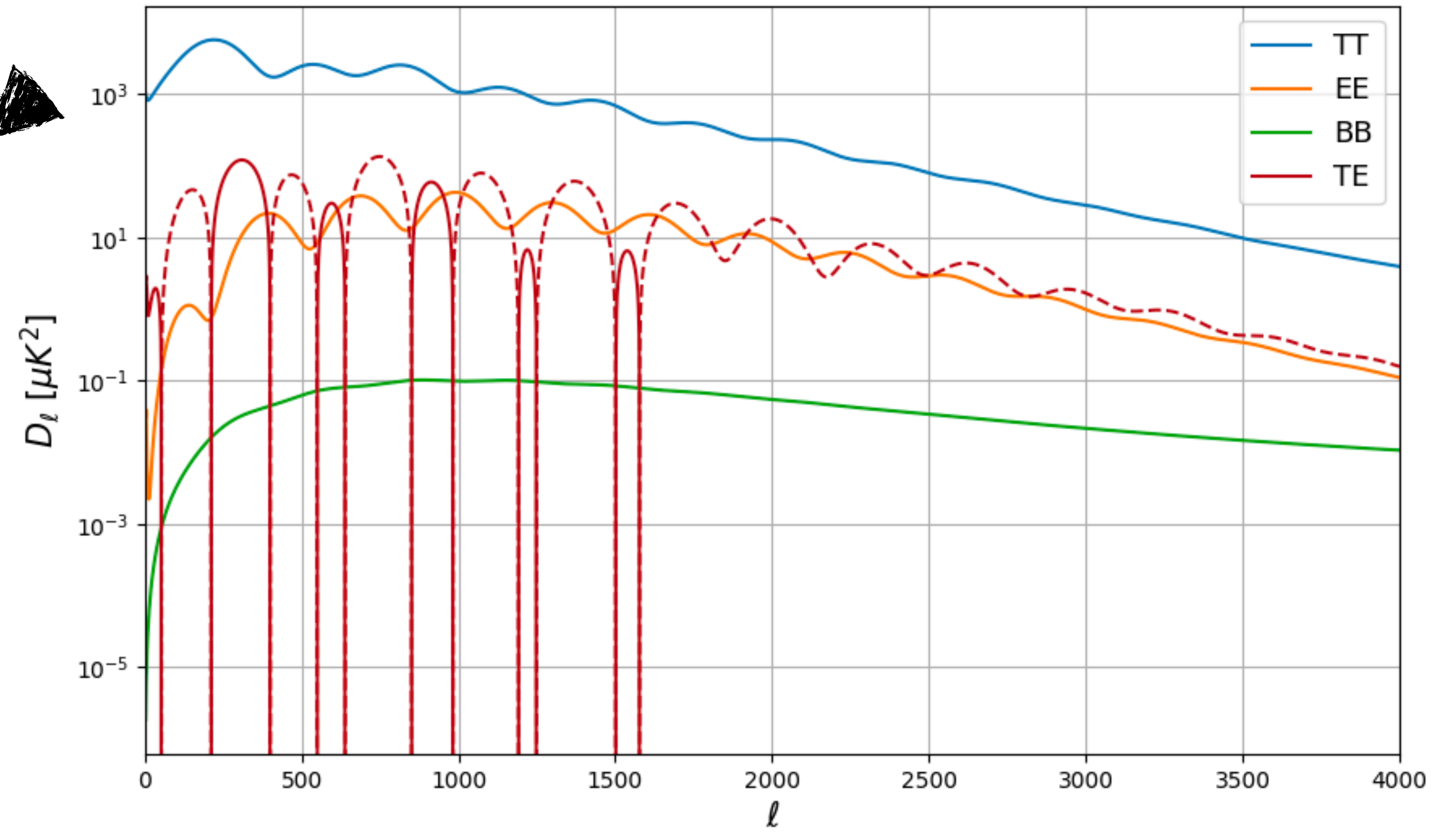
- For the NKA covariance matrix computation we need :

  1) The **mask** of the field we want to study
  We use apodized masks without point sources.

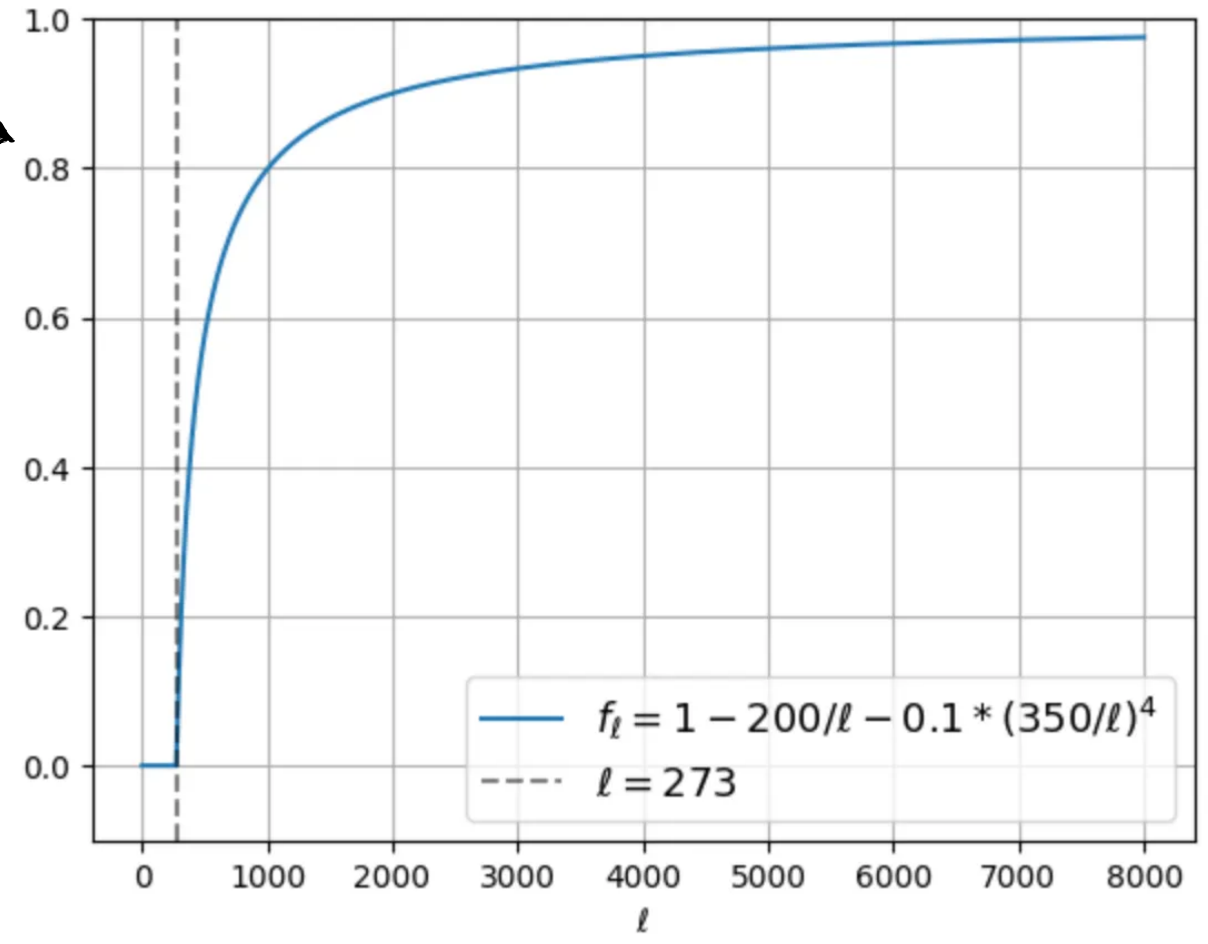
  2) Noise curves for the Wide field Prabhu et al., 2024



  3) A cosmology : theoretical power spectra
  We use the Planck 2018 best fit power spectra



- We do include a foreground model
- We include winter 2020 beams
- We apply a transfer function



- Bins : ellmin = 350, ellmax = 4000
- Binsize = 50
- Apodizesigma = 30deg for each subfield