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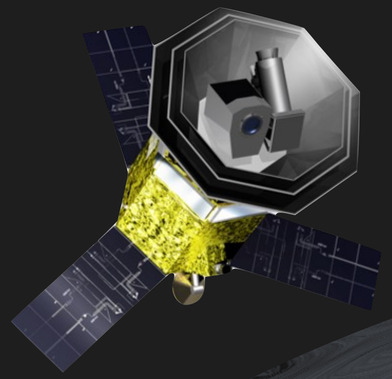
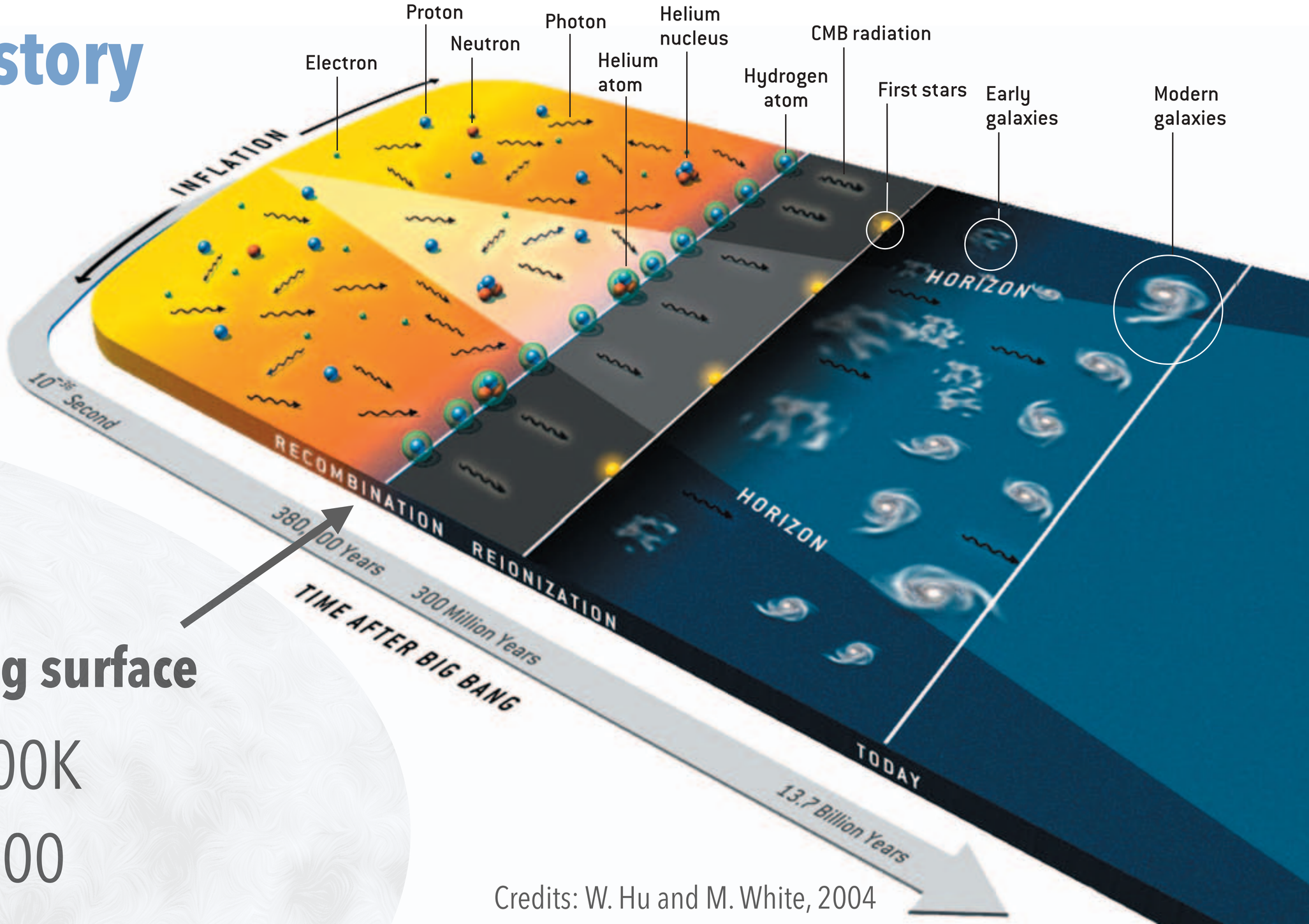
Cosmic Acceleration Workshop
Kavli IPMU, Kashiwa, Japan
February 17th, 2020



Current status and future challenges for CMB experiments

Cosmic History



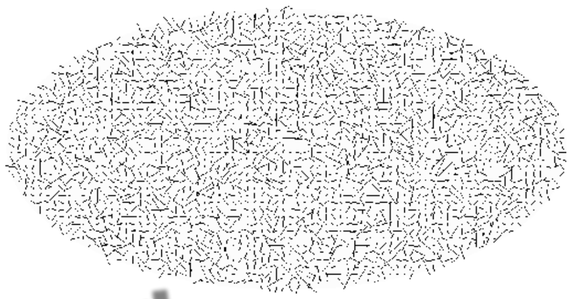
Last scattering surface

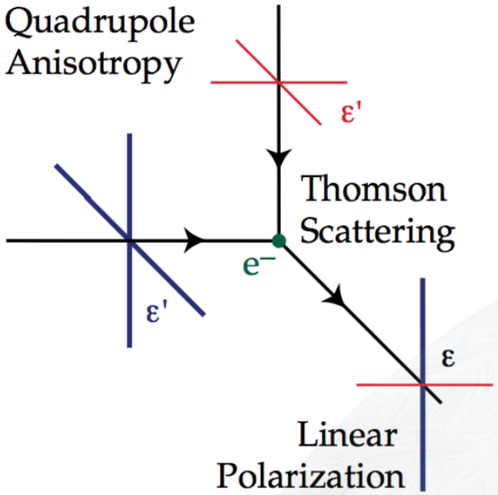
T ~ 3000K

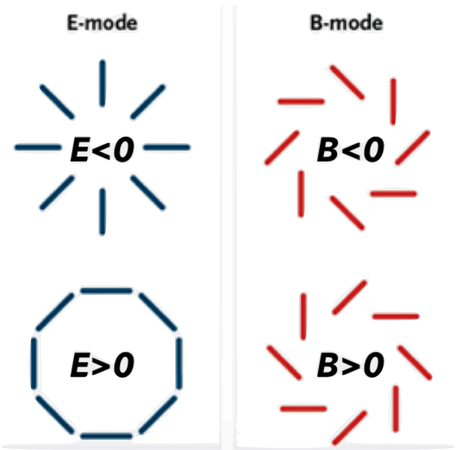
z ~ 1100

Credits: W. Hu and M. White, 2004

CMB polarization



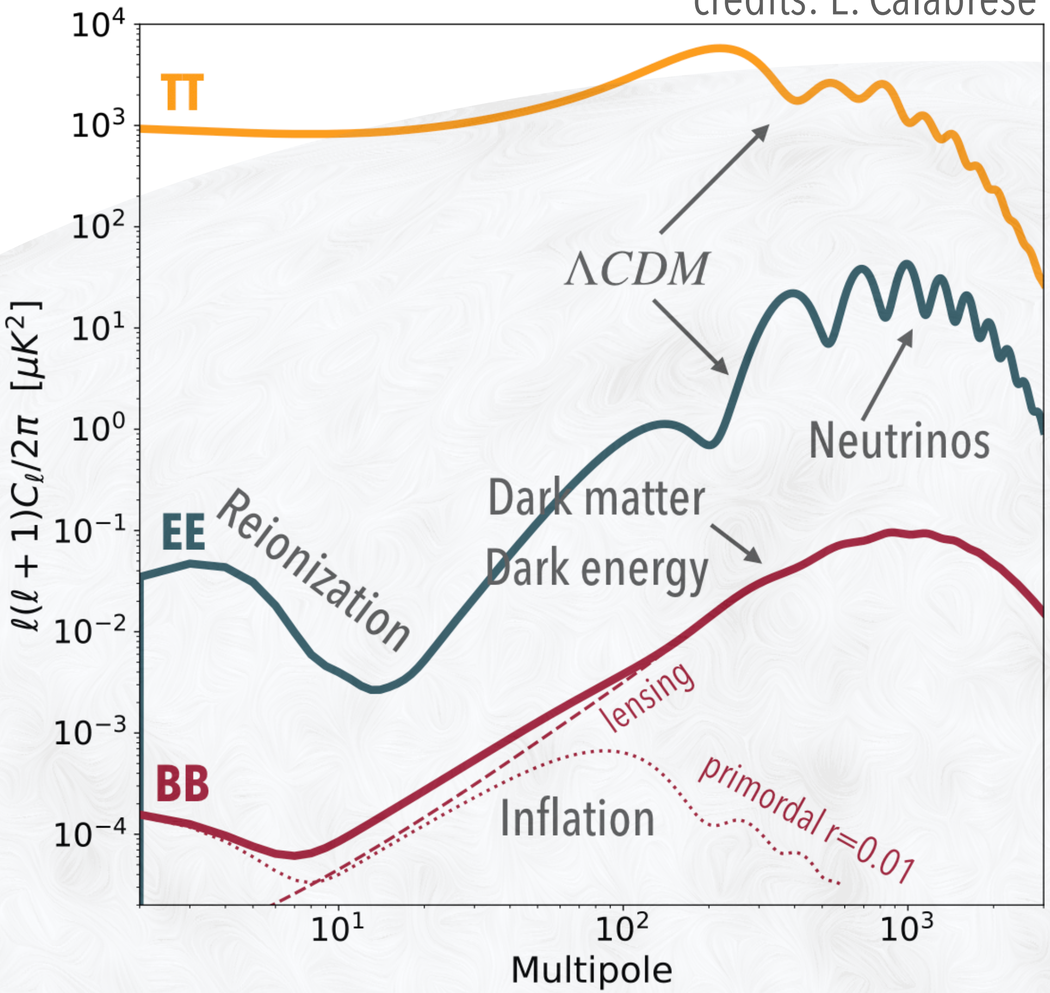




➡ Scalar perturbations: E-modes

➡ **Tensor perturbations** (GW): E and **B-modes**

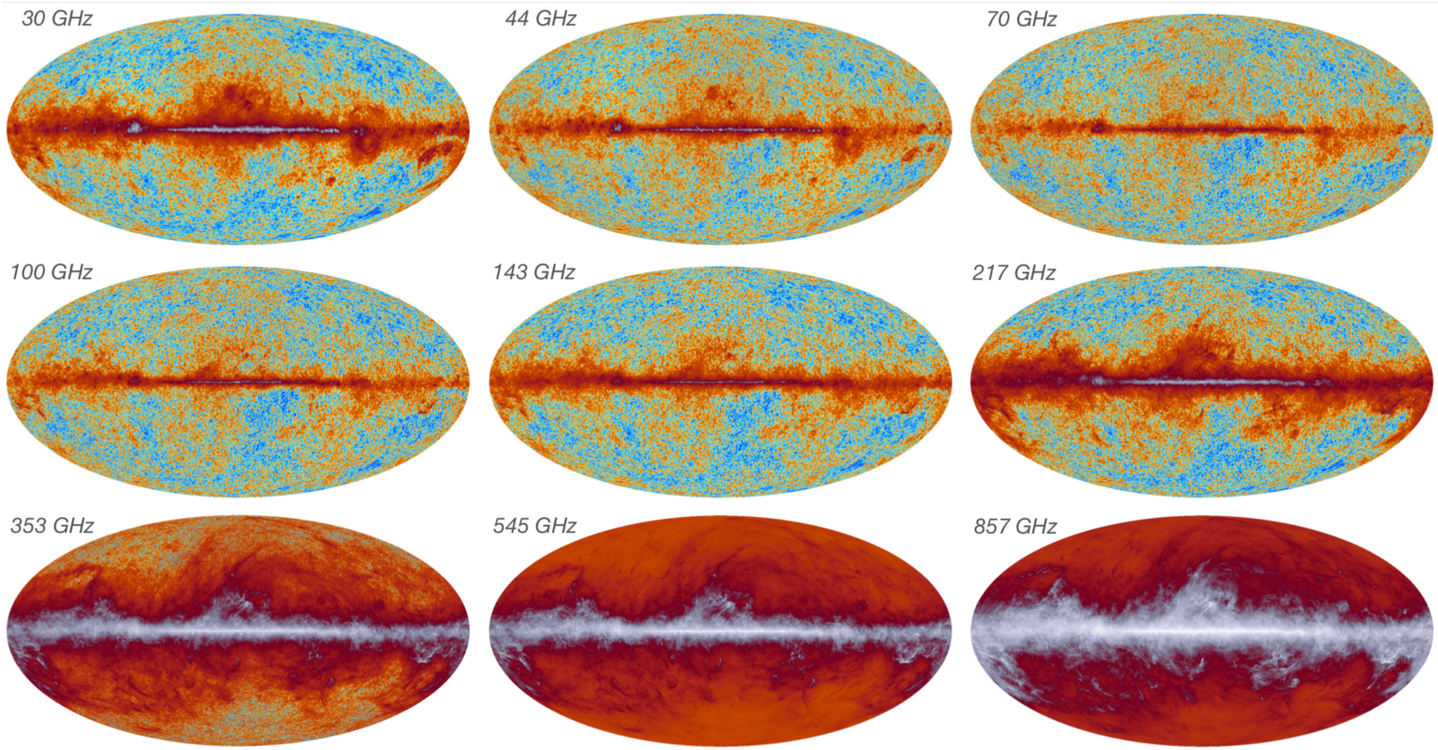
credits: E. Calabrese



Planck satellite

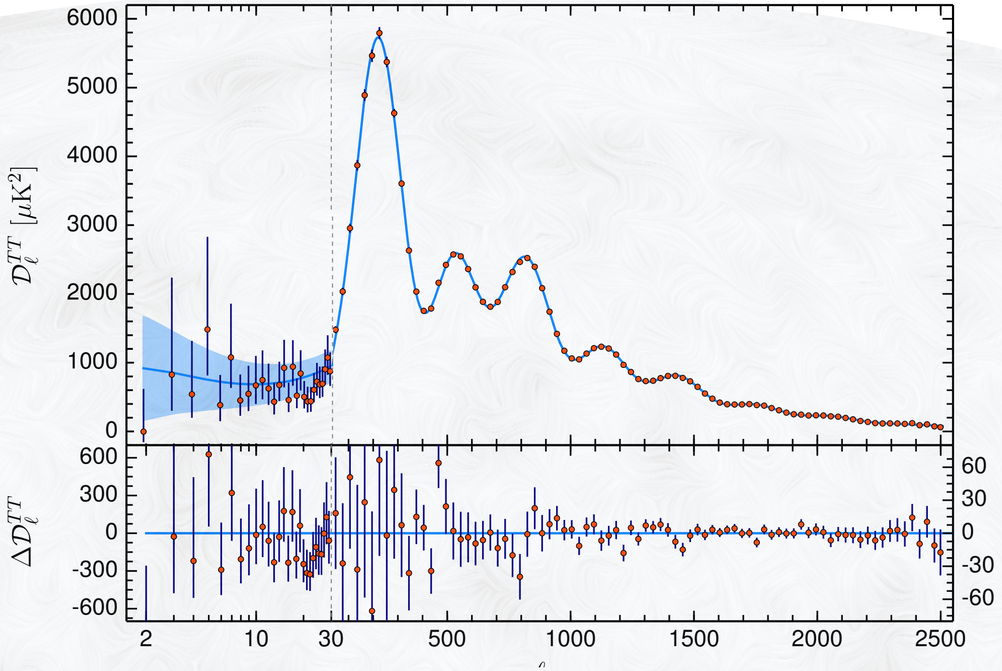
Credits: Planck Collaboration & ESA

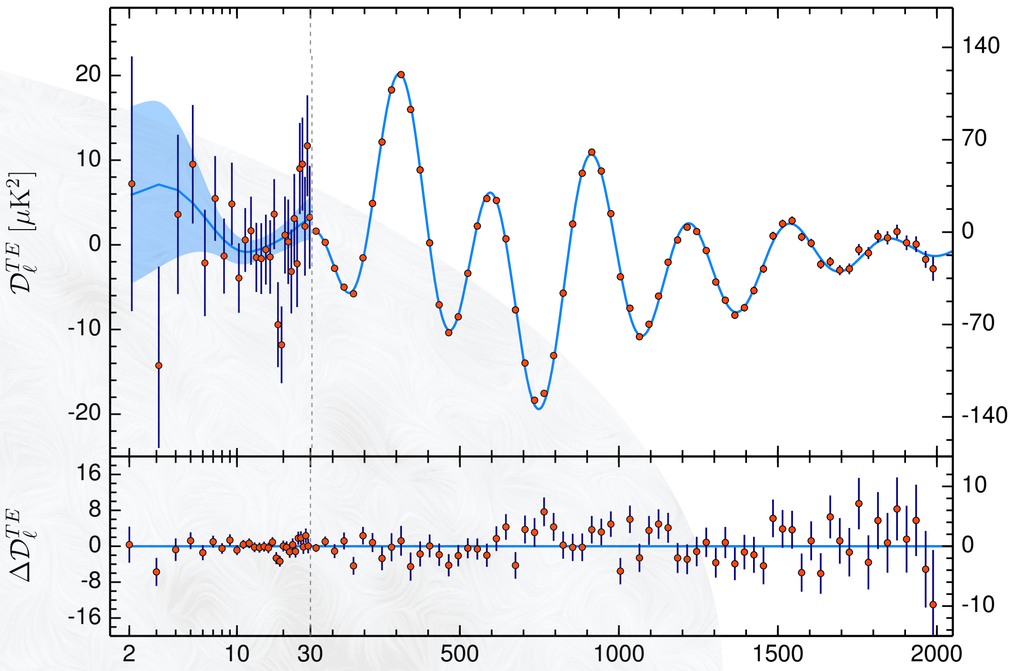
- 3rd CMB satellite, in operation from **2009 to 2013**
- **Two instruments** (on the same focal plane) with different detector teconlogies (radiometers at low freqs vs. bolometers ath high freqs)
- 9 frequencies (**30-897 GHz**), 7 polarized
- **3 data release:**
  - ★ **2013:** HFI and LFI total intensity data from 15.5 months
  - ★ **2015:** HFI temperature and small scale polarization (29 months) + LFI temperature and polarization (48 month)
  - ★ **2018 (Legacy):** Full datasets from HFI and LFI

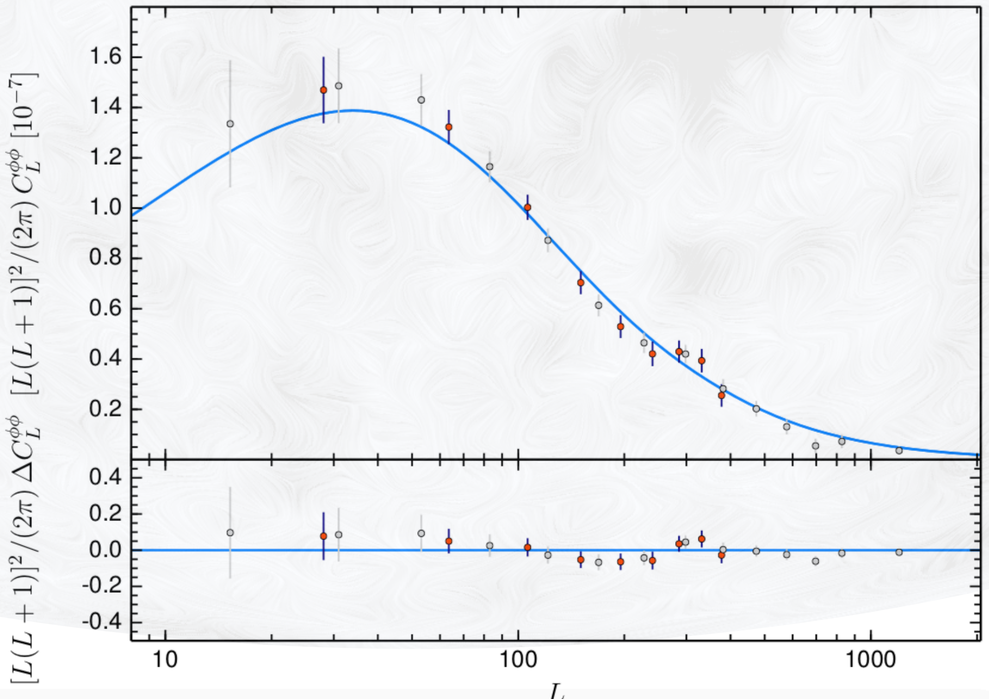


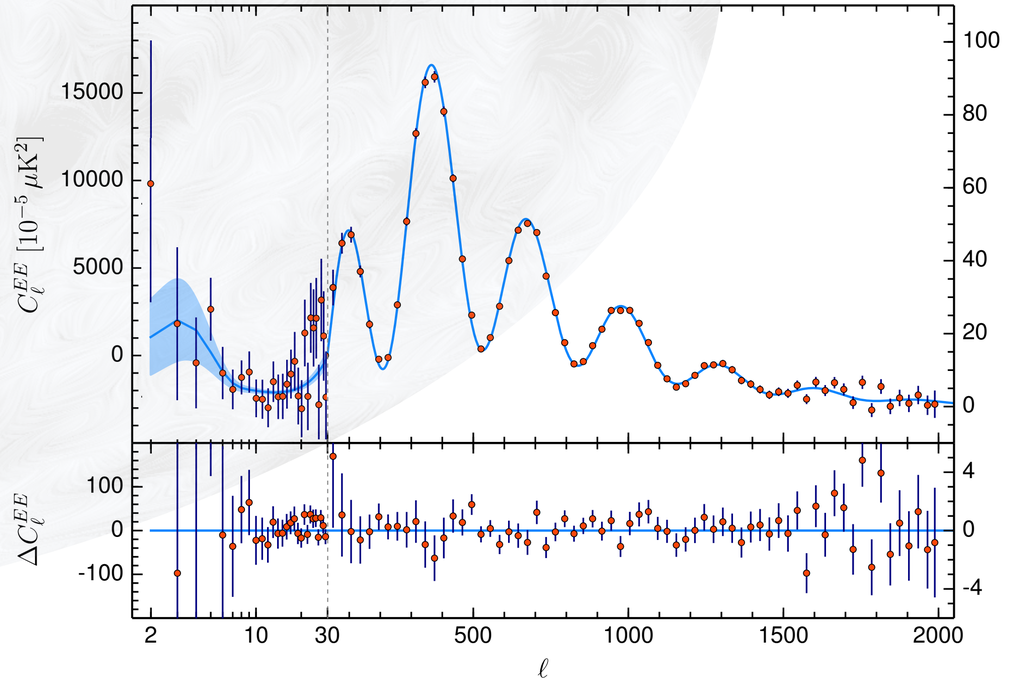
Planck legacy power spectra

Adapted from Planck Colaboration 2018, V and X









Planck ΛCDM parameters

Planck Collaboration 2018, VI

$\Omega_b h^2$	Barion density	0.002237 ± 0.00015	0.7 %
$\Omega_c h^2$	Dark-matter density	0.12 ± 0.0012	1 %
$100\,\theta$	Acoustic scale	1.04092 ± 0.00031	0.03 %
τ	Optical depth to reionization	0.0544 ± 0.0073	13 %
$\ln(10^{10} A_s)$	Scalar perturbation aplitude	3.044 ± 0.014	0.7 %
n_s	Scalar spectral index	0.9648 ± 0.0042	0.4 %

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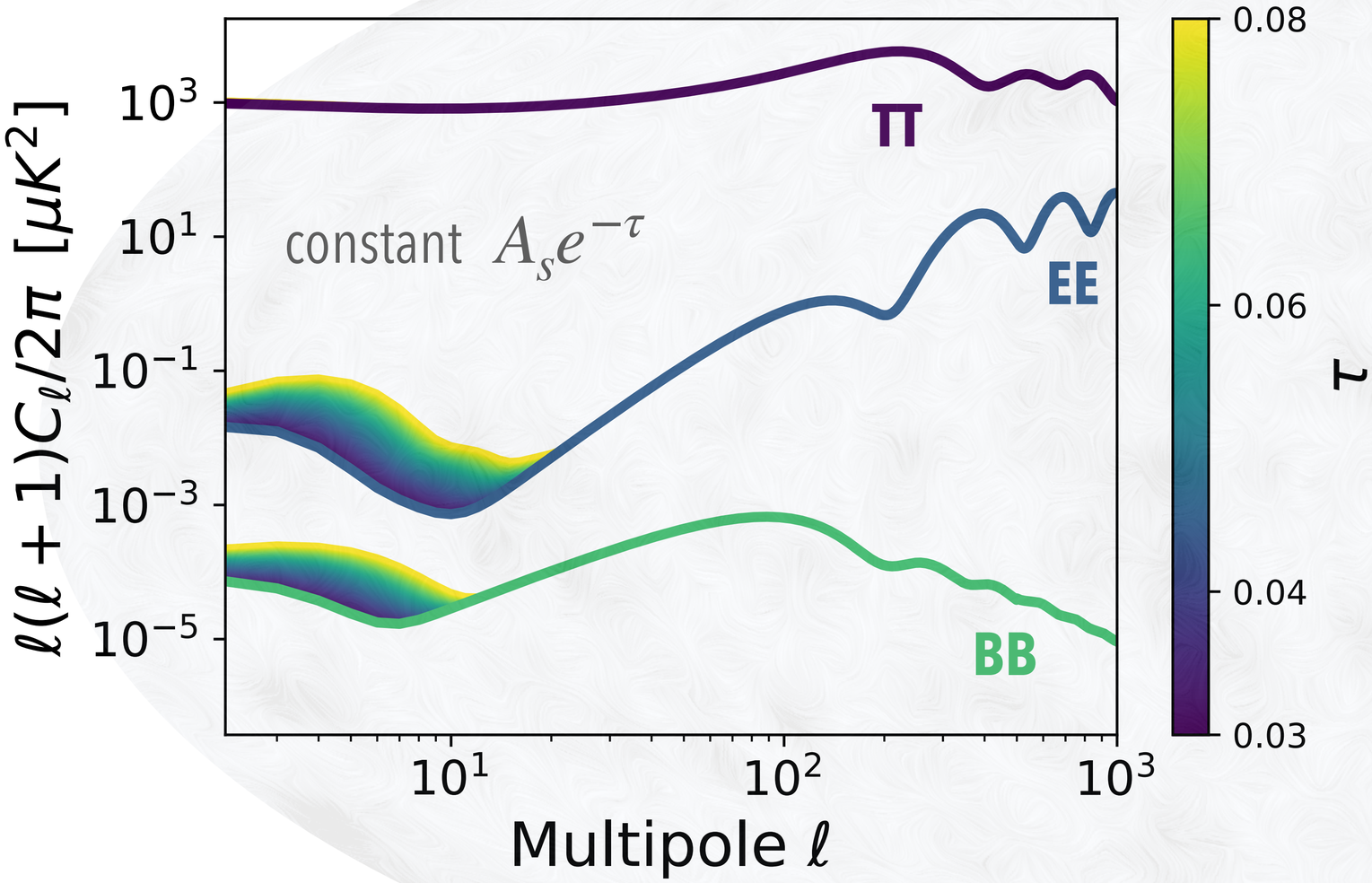
Optical depth to reionization

$$\tau = \int n_e(t)\sigma_T\, dt$$

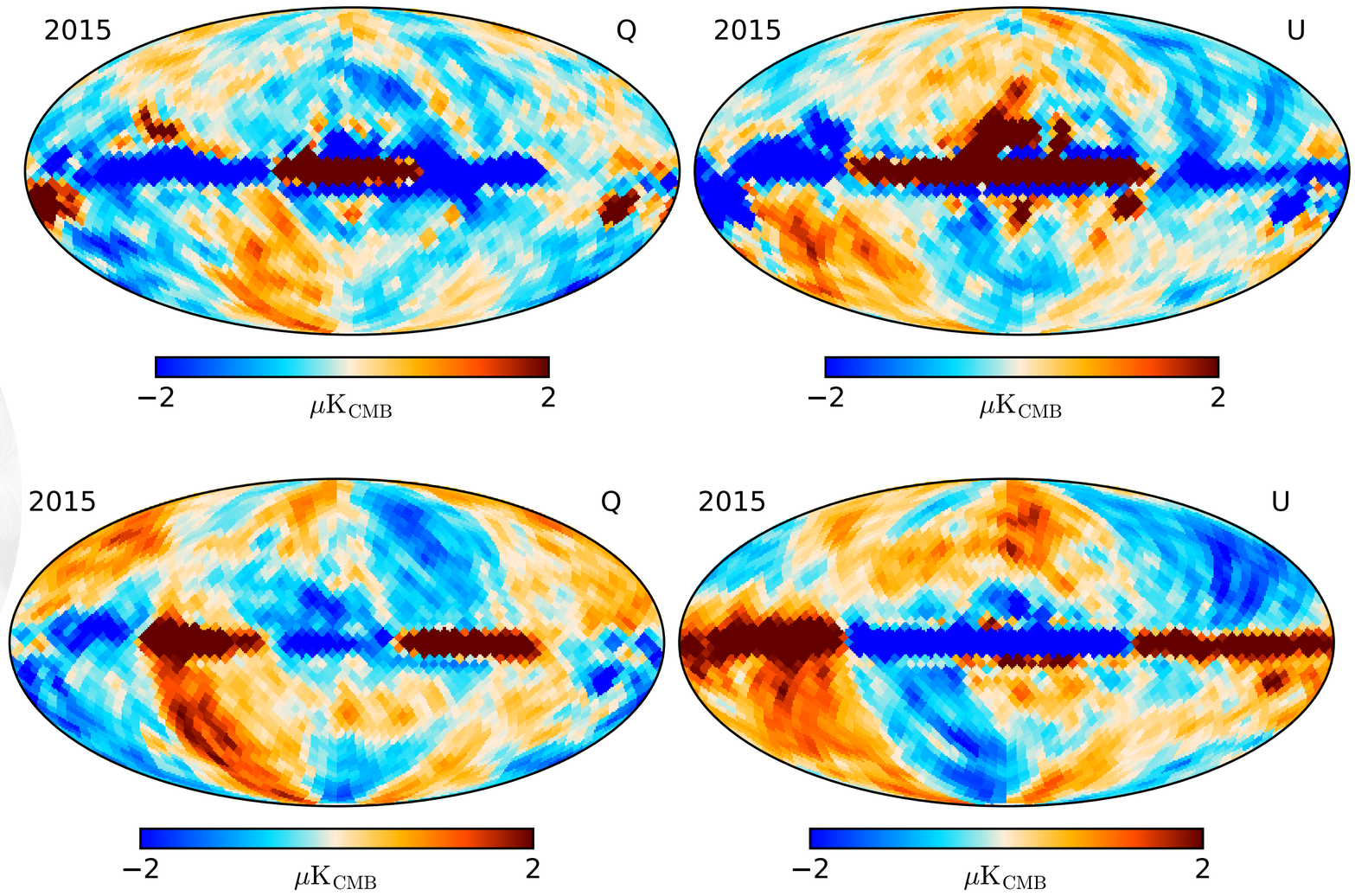
- In **total intensity** the effect is to dump the fluctuations inside the horizon - **degerate with As**
- Bump at **low-ell in polarization**
- Measure at low-ell is making difficult by **systematics and foreground!**

$$\sigma(\tau)_{CV} \simeq 0.002$$



Planck large scale maps (2015)

- Foreground cleaned **2015** polarization large scales maps (unpublished)
- High dipole residual due to $I \rightarrow P$ **leakage**



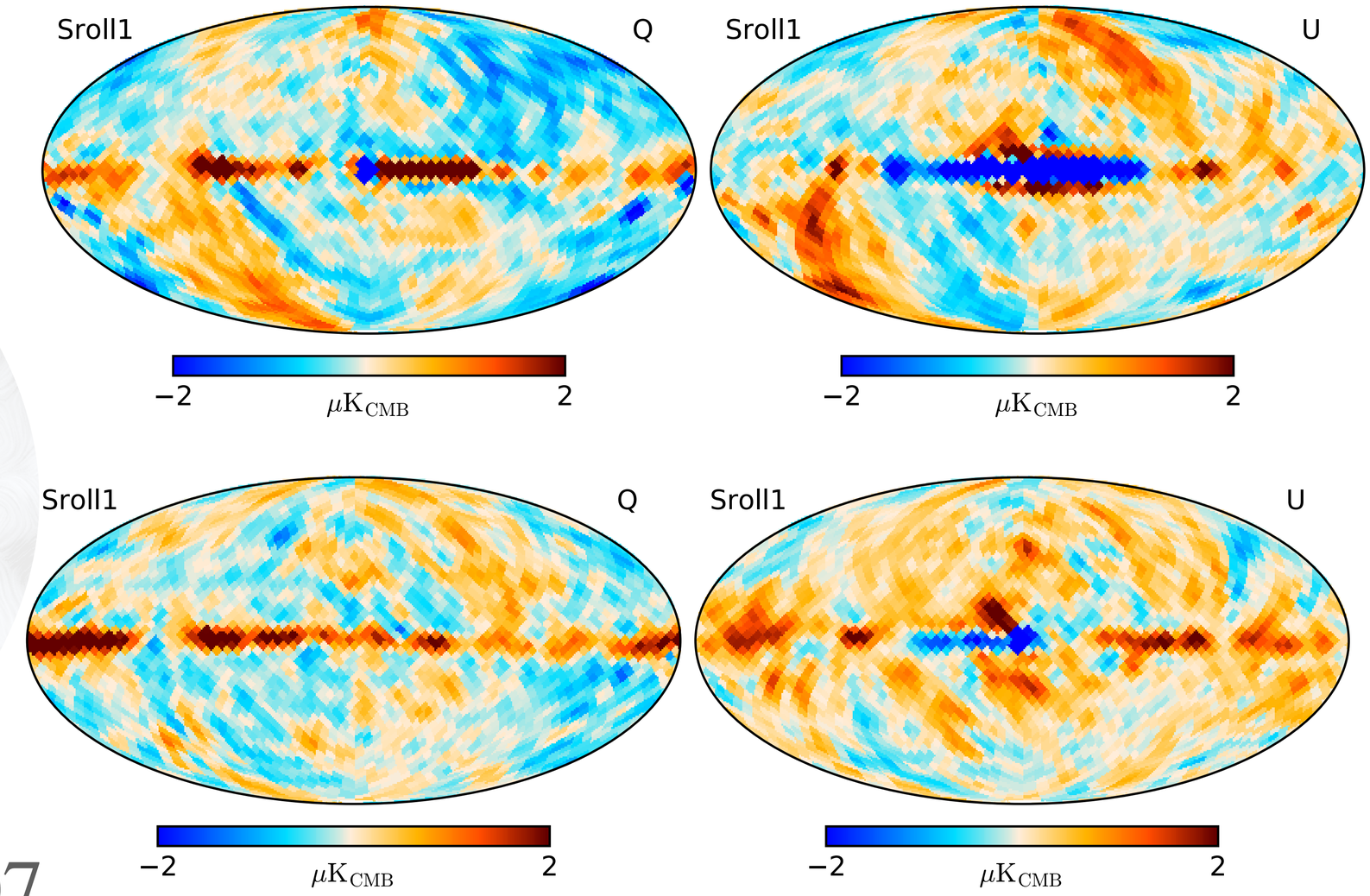
$$d(t) = K\left[\mathrm{I}(\hat{n}) + \cos\left(2\alpha(t)\right)\mathrm{Q}(\hat{n}) + \sin\left(2\alpha(t)\right)\mathrm{U}(\hat{n})\right] + n(t)$$

credits: Planck Collaboration and L. Pagano

Planck large scale maps (2018)

- Systematic effects reduced thanks to the inclusion of time variation in the timestream calibration

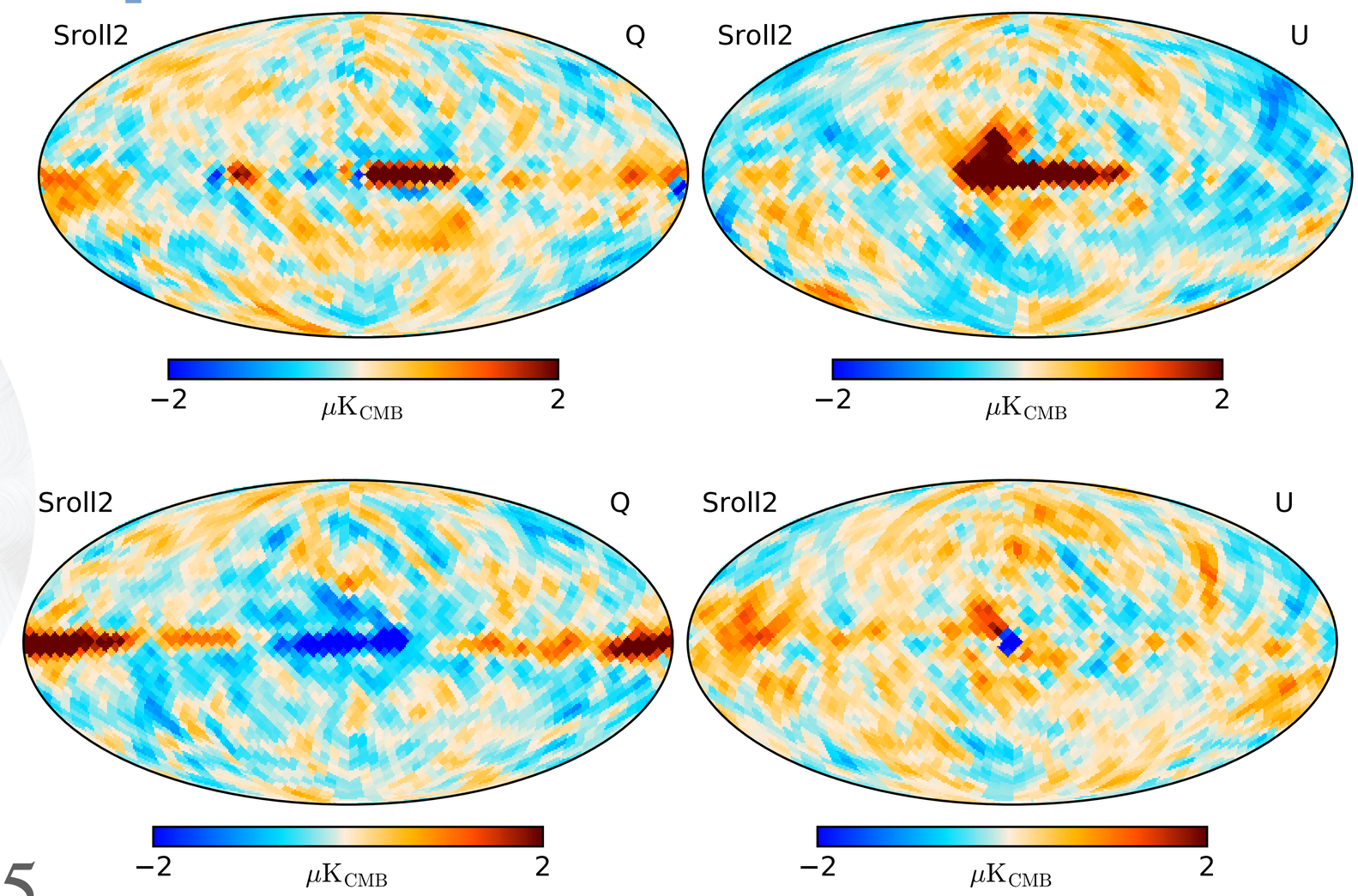
$$\tau = 0.0544^{+0.007}_{-0.008}$$



credits: Planck collaboration and L. Pagano

SRoll2 large scale maps (2019)

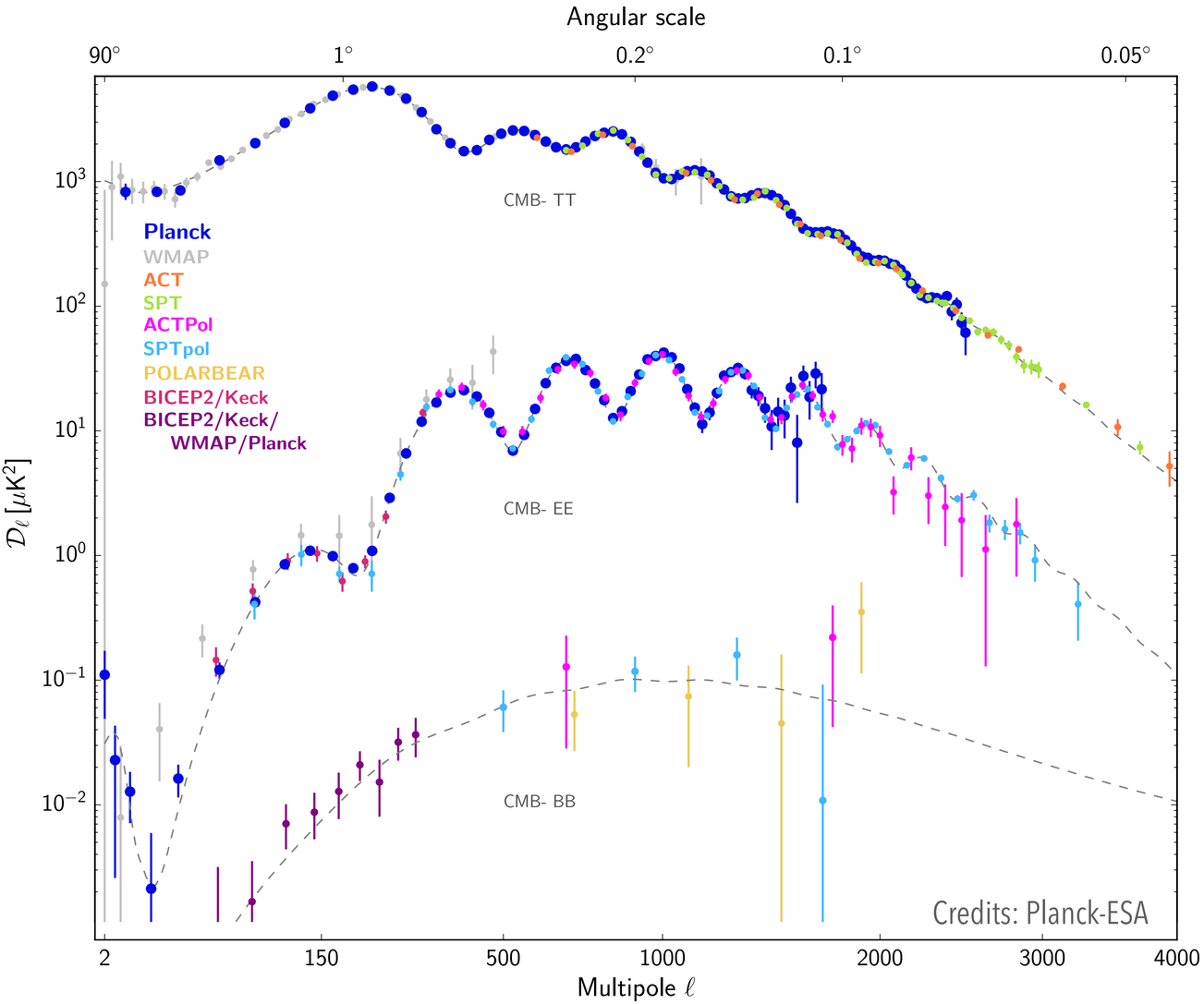
- Better modeling of ADC non-linearity in the map-making
- Better foreground modeling



$$\tau = 0.0566^{+0.005}_{-0.006}$$

Pagano et al. 2019

Current and future CMB observations



Current constraint on **r** :

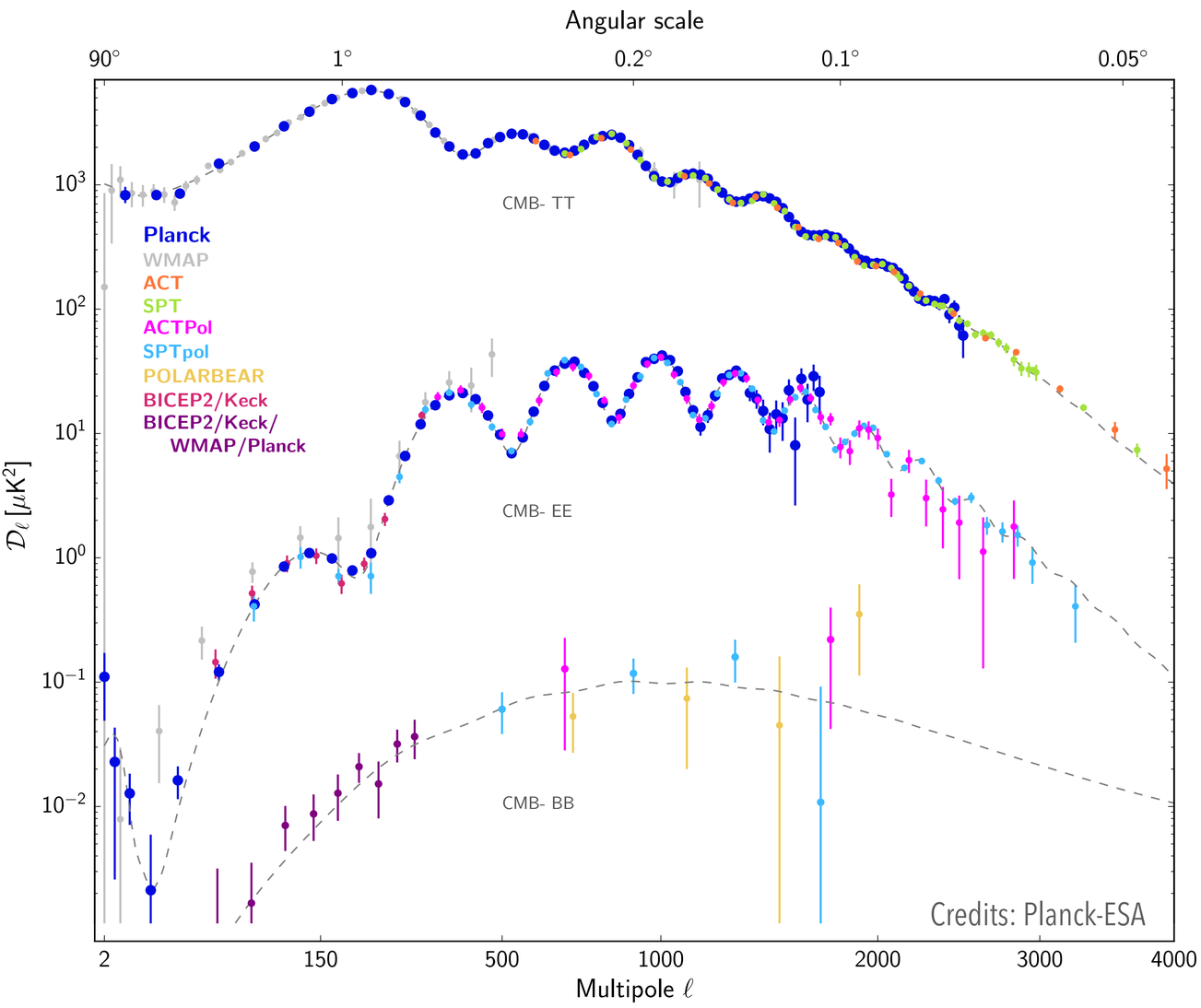
(**amplitude of primordial B-modes**)

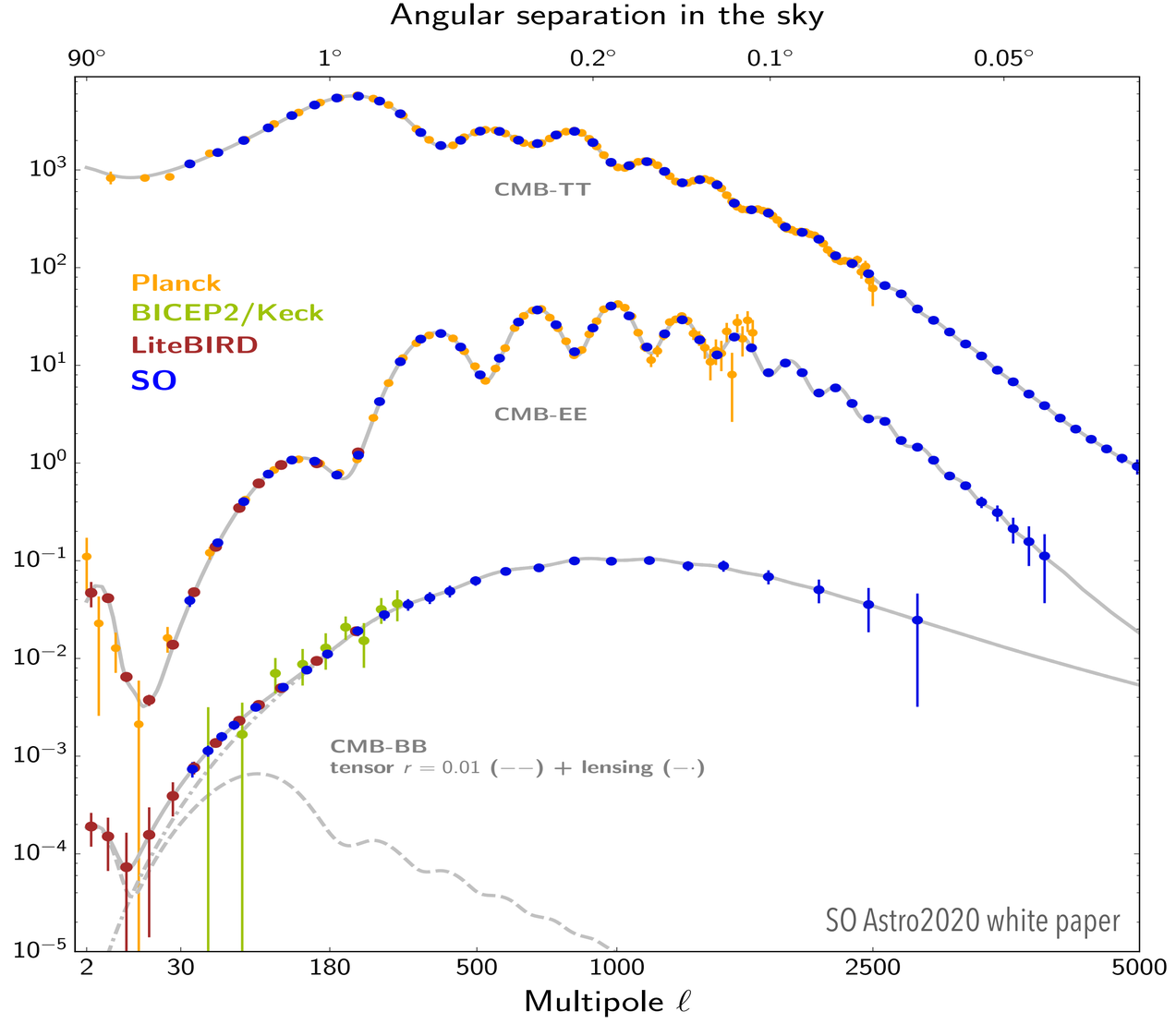
$$r < 0.06 \quad (95\,\%\ \text{C.L.})$$

from BICEP2/Keck + WMAP/Planck

Bicep2/Keck array collaboration 2018

Current and future CMB observations





Current and future CMB observations

➡ From ground:

Simons Observatory (2022)

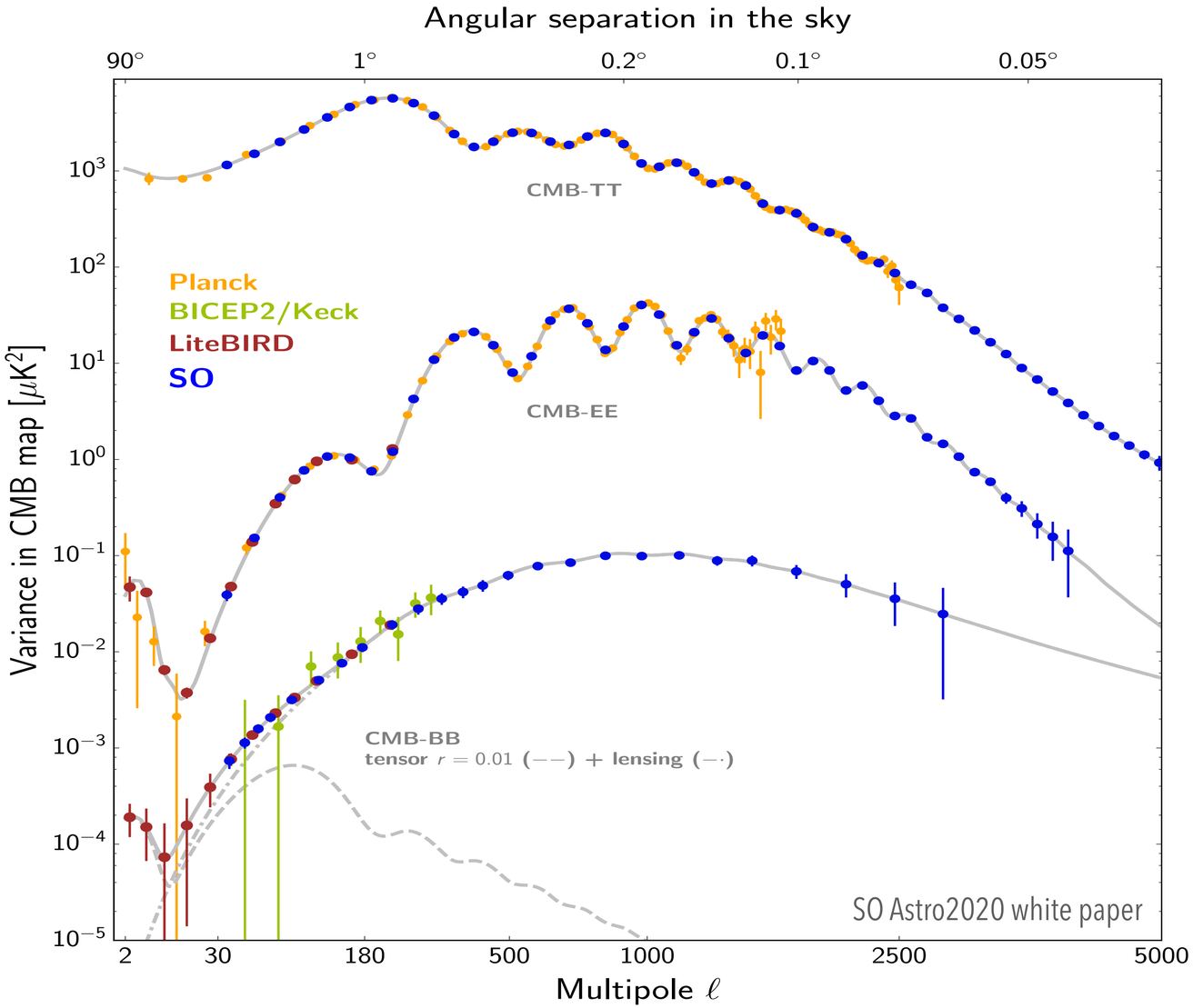
- ✳ 3 SAT (0.5m), 1 LAT (6m)
- ✳ frequency coverage: 27-280 (6 bands)
- ✳ sky coverage: 10-40%
- ✳ $\ell \gtrsim 30$
- ✳ baseline on r: $\sigma(r) \simeq 0.003$

➡ From space:

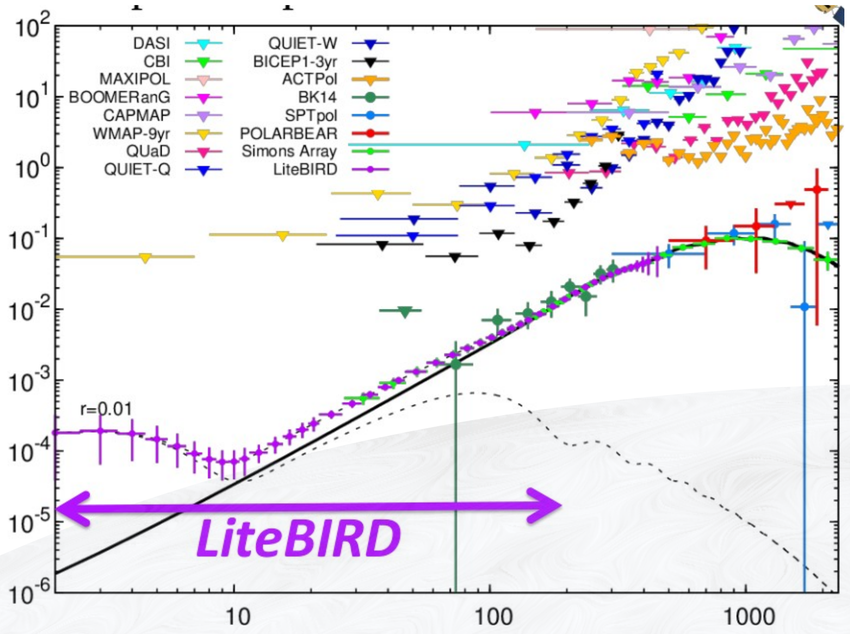
LiteBIRD (2027)

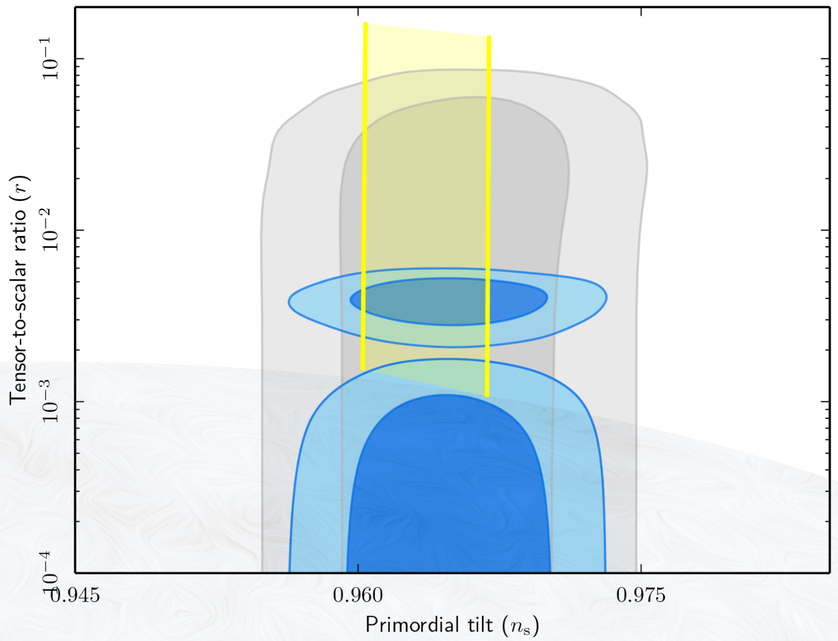
- ✳ full sky coverage
- ✳ $\ell \lesssim 200$
- ✳ 15 frequency bands 40-400
- ✳ forecast on r: $\sigma(r) \simeq 0.6 \times 10^{-3}$

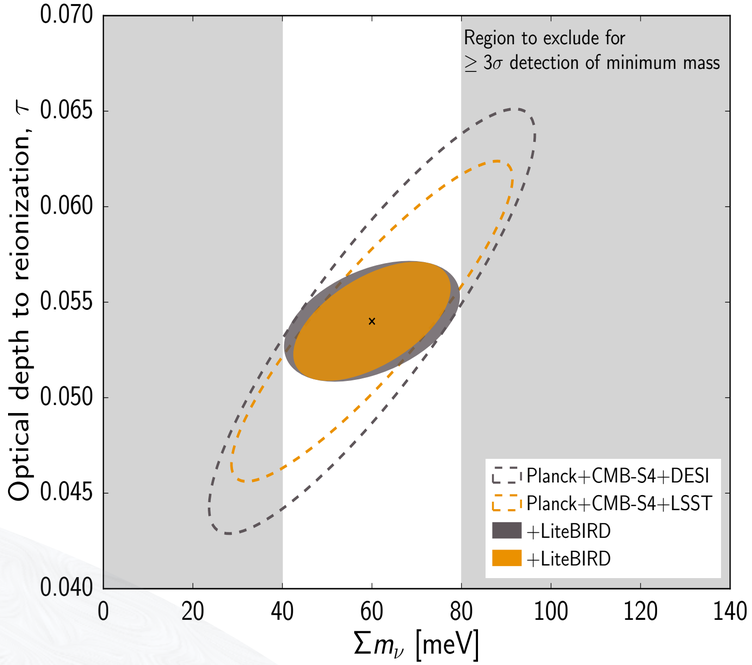
New cool LB logo I cannot show yet



Snapshot on LiteBIRD

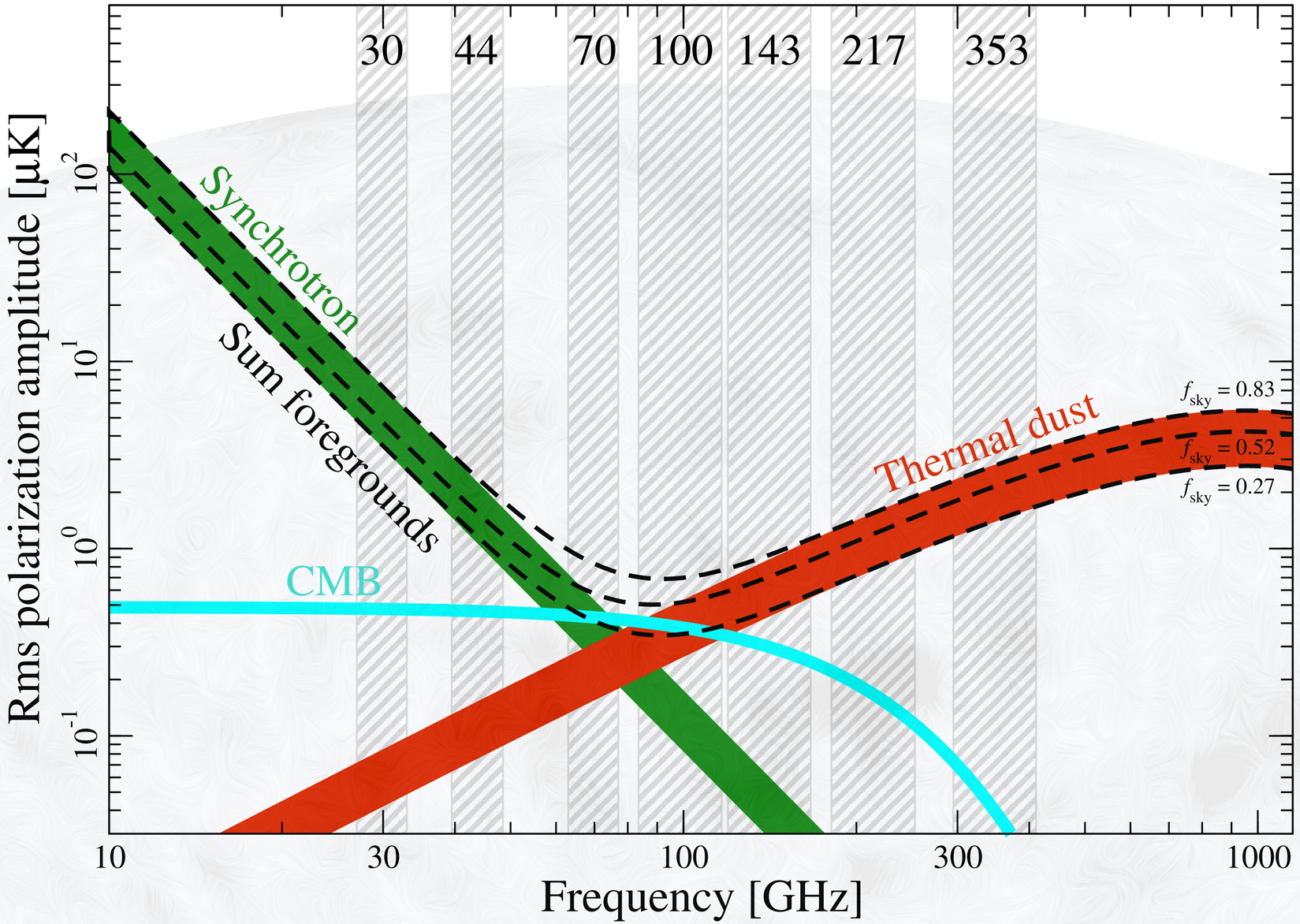




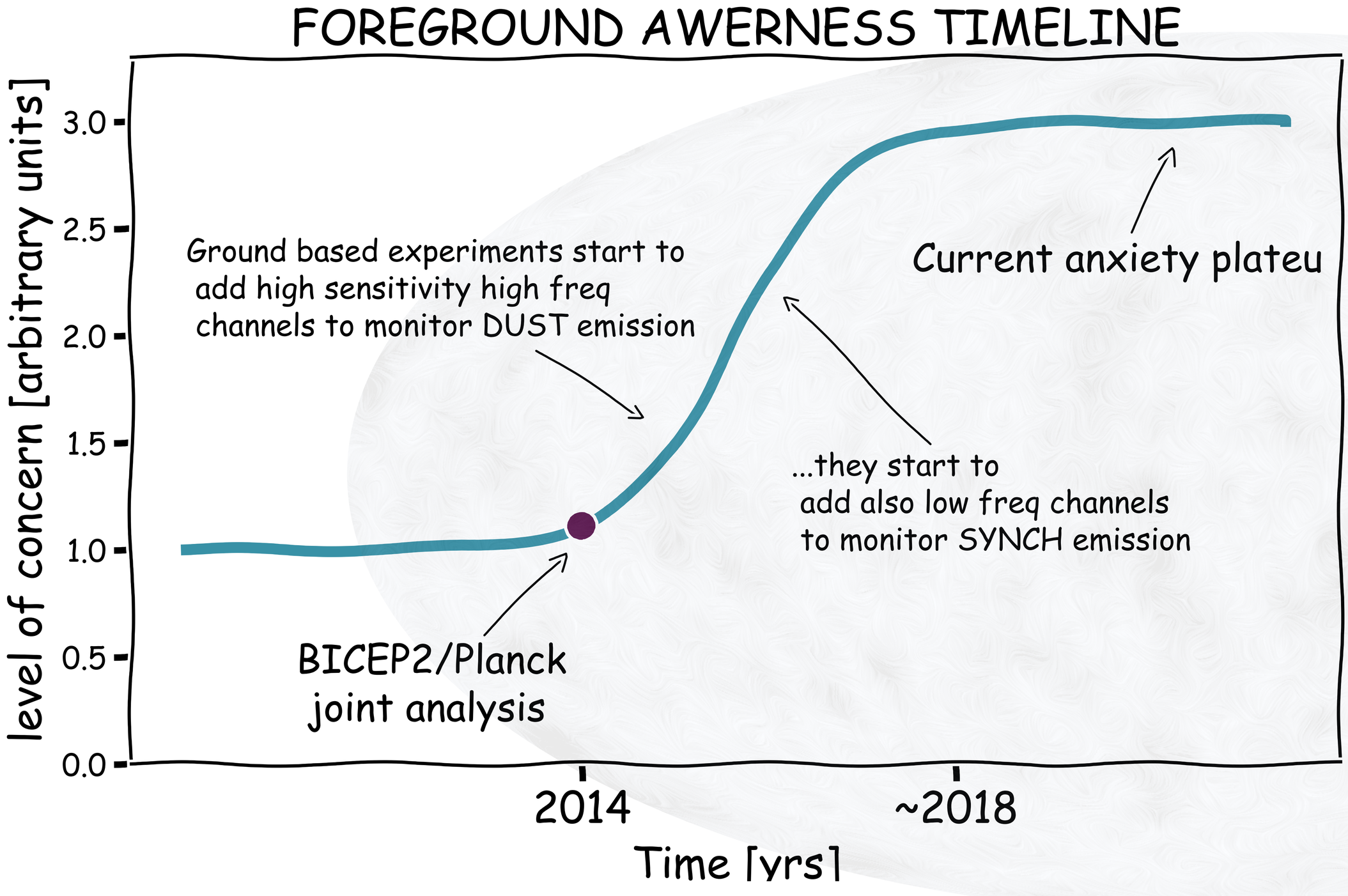


- LB will be **the only experiment having access to the very large scale**s, fundamental for a relihable reconstruction of the primordial B-mode spectrum
- With upper limit $r < 0.001$ **Starobinsky-like inflation would be ruled out**
- **Cosmic variace limited measurment of τ**, allowing tight constraint on $\sum m_\nu$

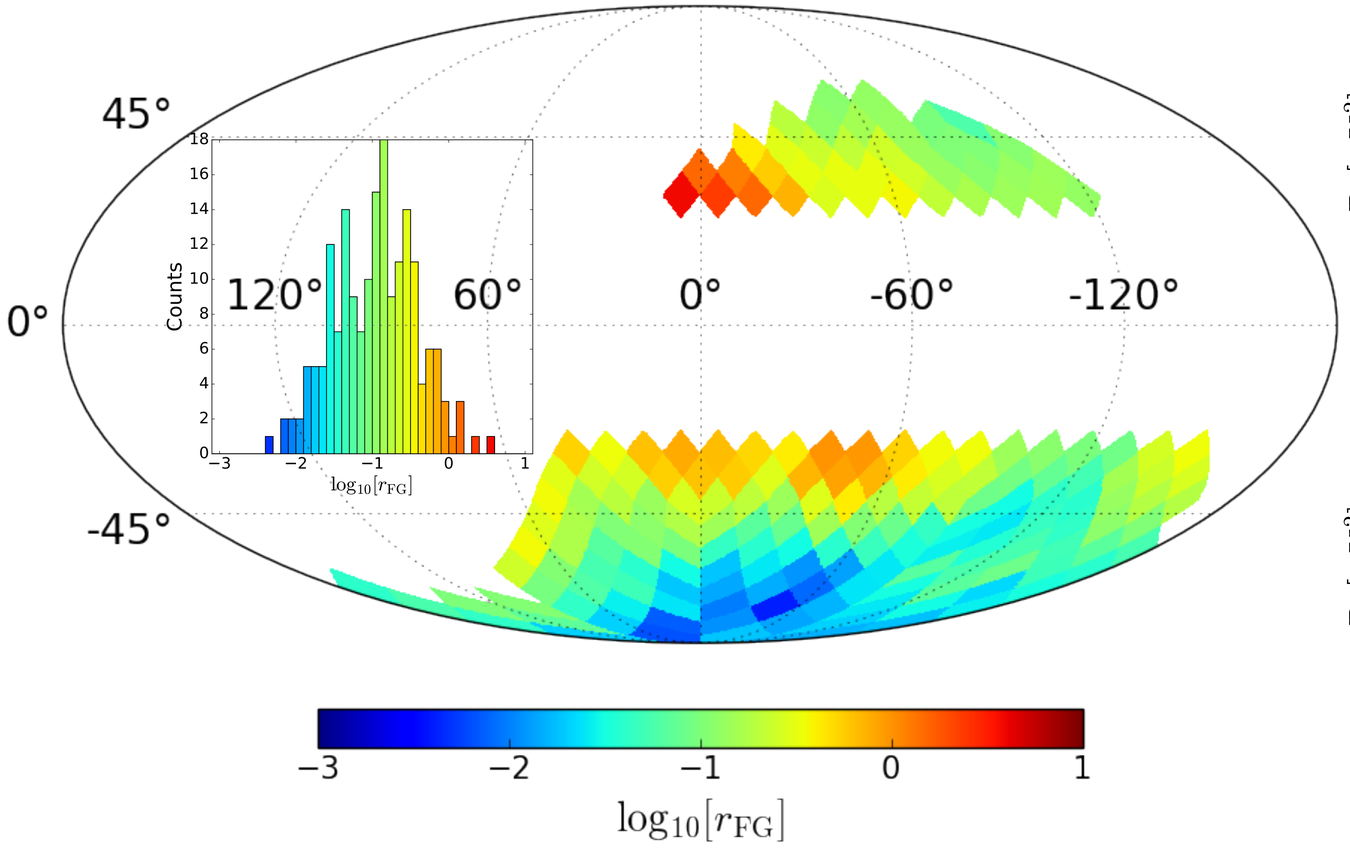
CMB Polarized Foregrounds

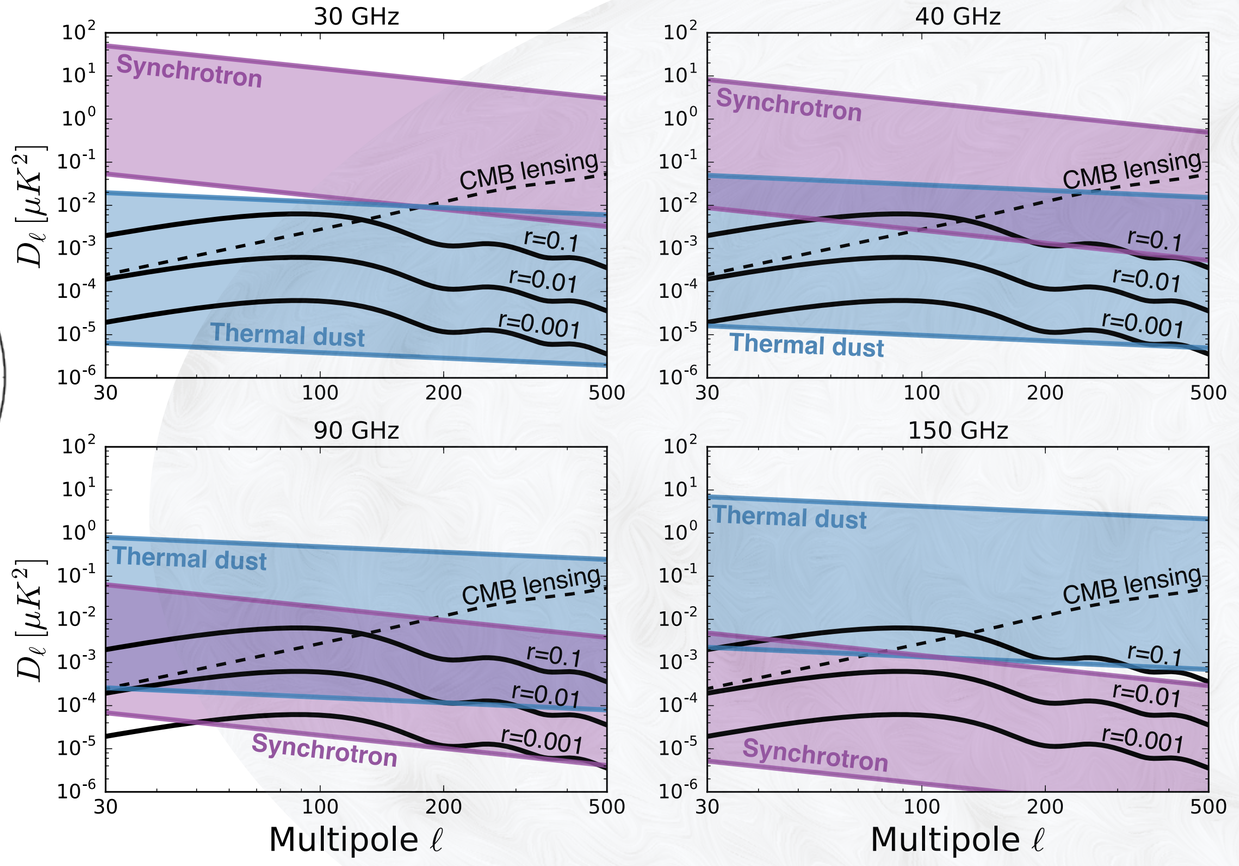


Planck Collaboration X, 2015


FOREGROUND AWERNESS TIMELINE
level of concern [arbitrary units]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ground based experiments start to add high sensitivity high freq channels to monitor DUST emission
Current anxiety plateu
...they start to add also low freq channels to monitor SYNCH emission
BICEP2/Planck joint analysis
2014
~2018
Time [yrs]

Foreground contamination to B-modes



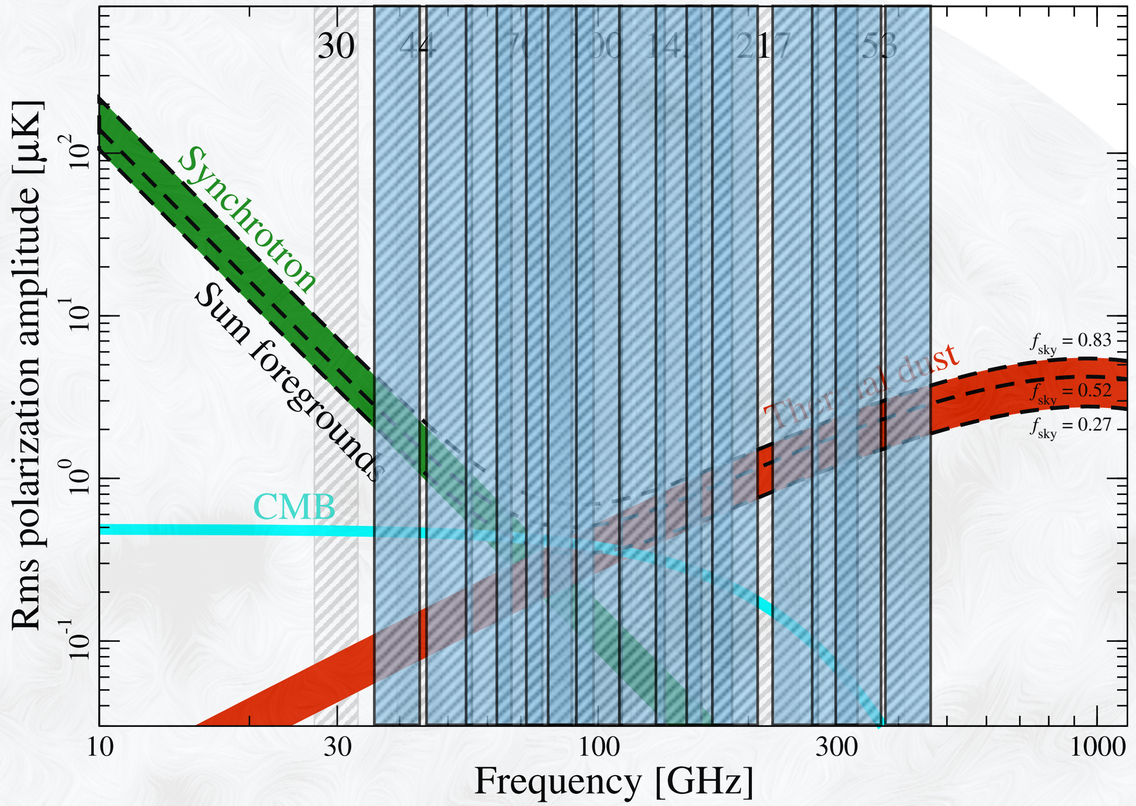


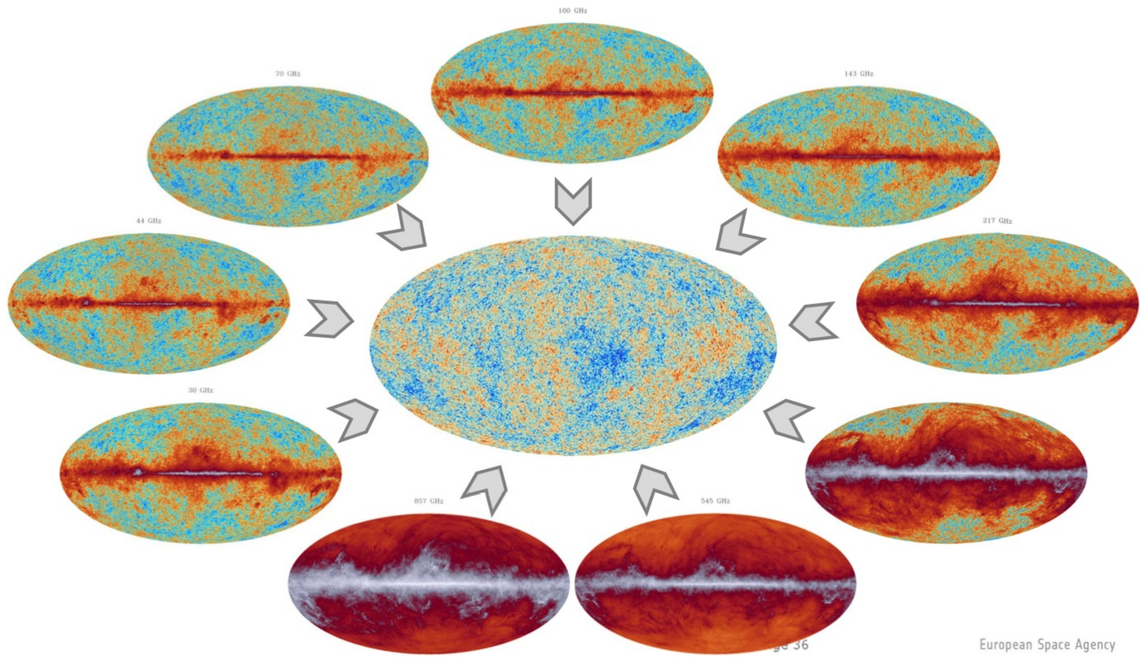
Krachmalnicoff et al. 2018

Component separation

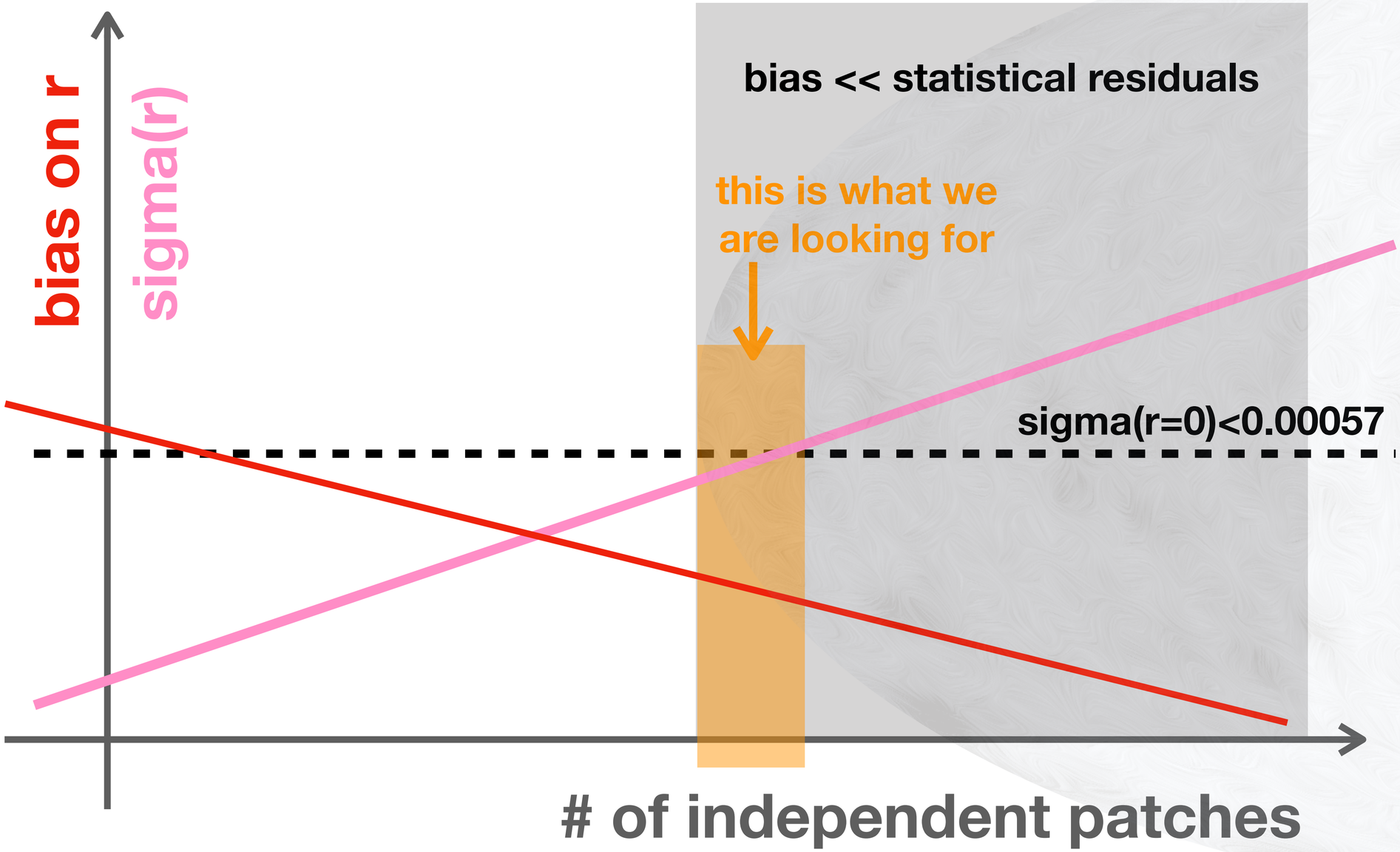
$$X = A\,S + N$$

- X: # frequencies × # pixels on map — Data
- A: # frequencies × # components — Frequency scaling **Mixing Matrix**
- S: # components × # pixels on map — Amplitudes of sky components (FGs and CMB)
- N: # frequencies × # pixels on map — Noise



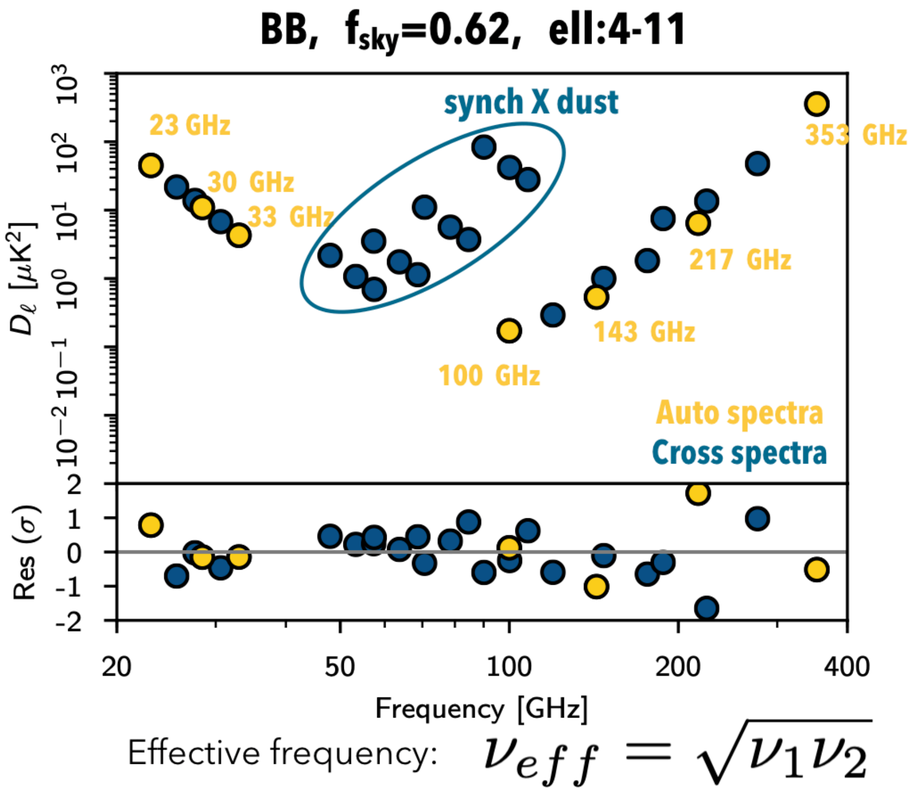


Component separation



credits: J. Errard

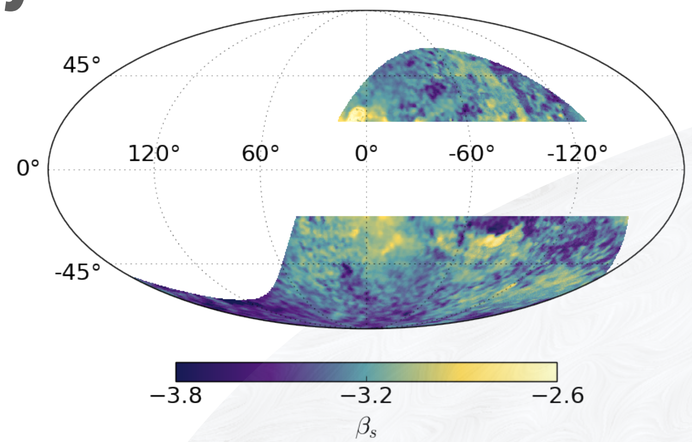
Foreground studies

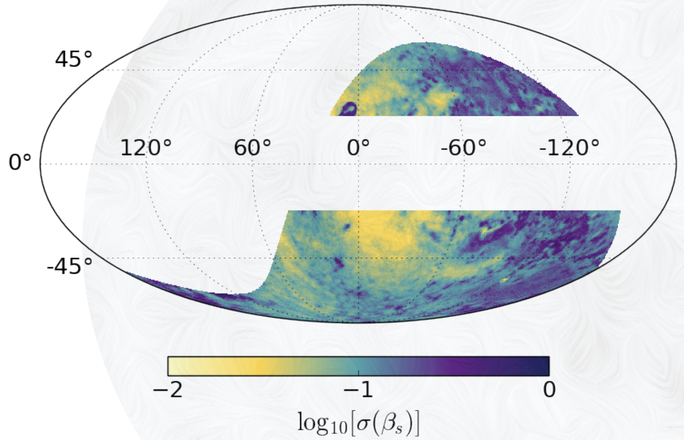


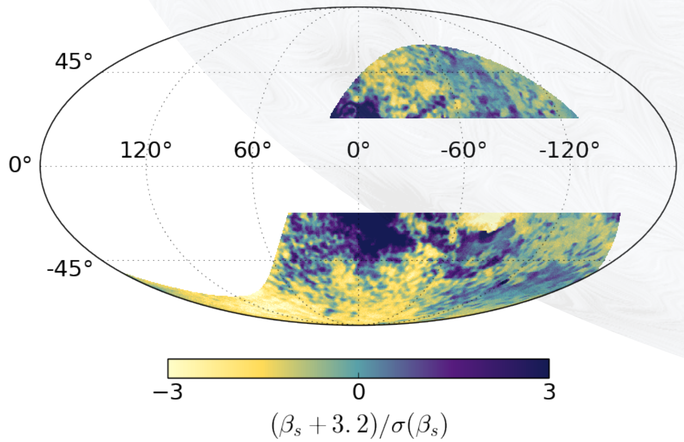
Effective frequency: $\nu_{eff} = \sqrt{\nu_1 \nu_2}$

- We need to **know foregrounds** to perform optimal and **reliable component separation**
- **Data are mostly coming from Planck and WMAP (not sensitive enough)**

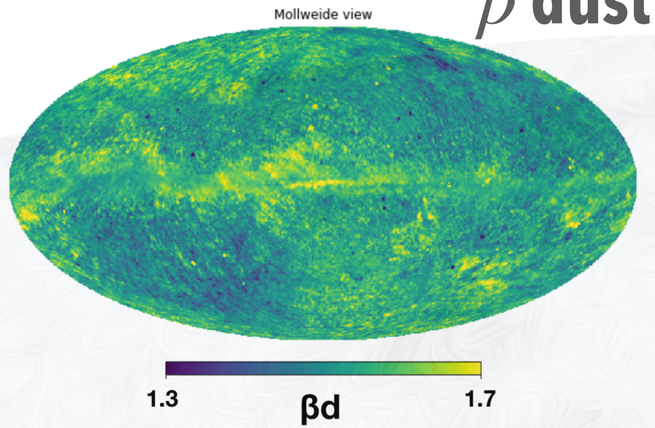
β synchrotron

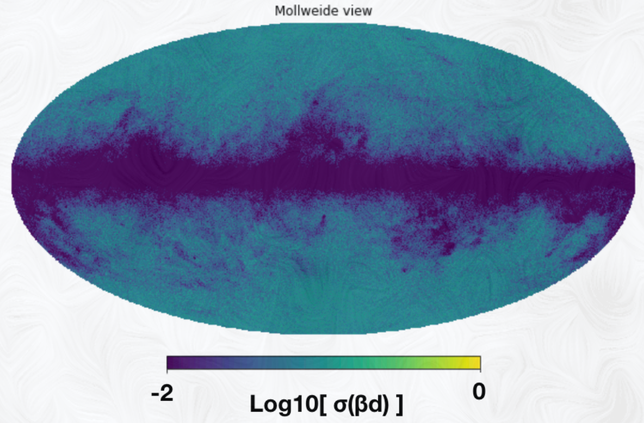


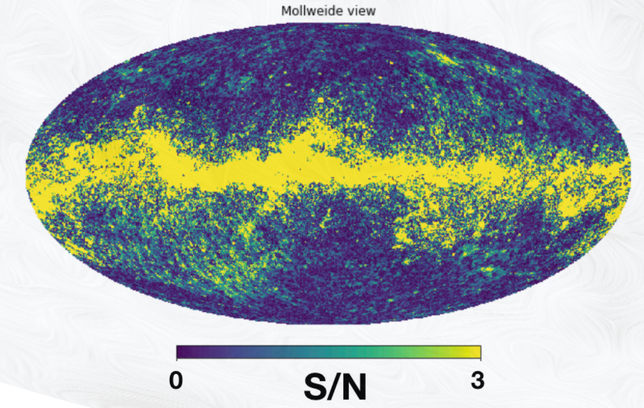




β dust







Conclusions

- **CMB** is probably the **most powerful tool** we have **to study** the history and evolution of **our Universe**
- CMB observations have already allowed to **constrain with impressive precision cosmological parameter**
- …but a lot still needs to be unvailed
- **This decade** will be **fundamental** especially to put contraints on **inflation thourgh CMB polarizations**, with **singery** of ground based and satellite experiments
- **Challanges are huge** (systematics and foregrounds) but we are ready to face them! Stay tuned!