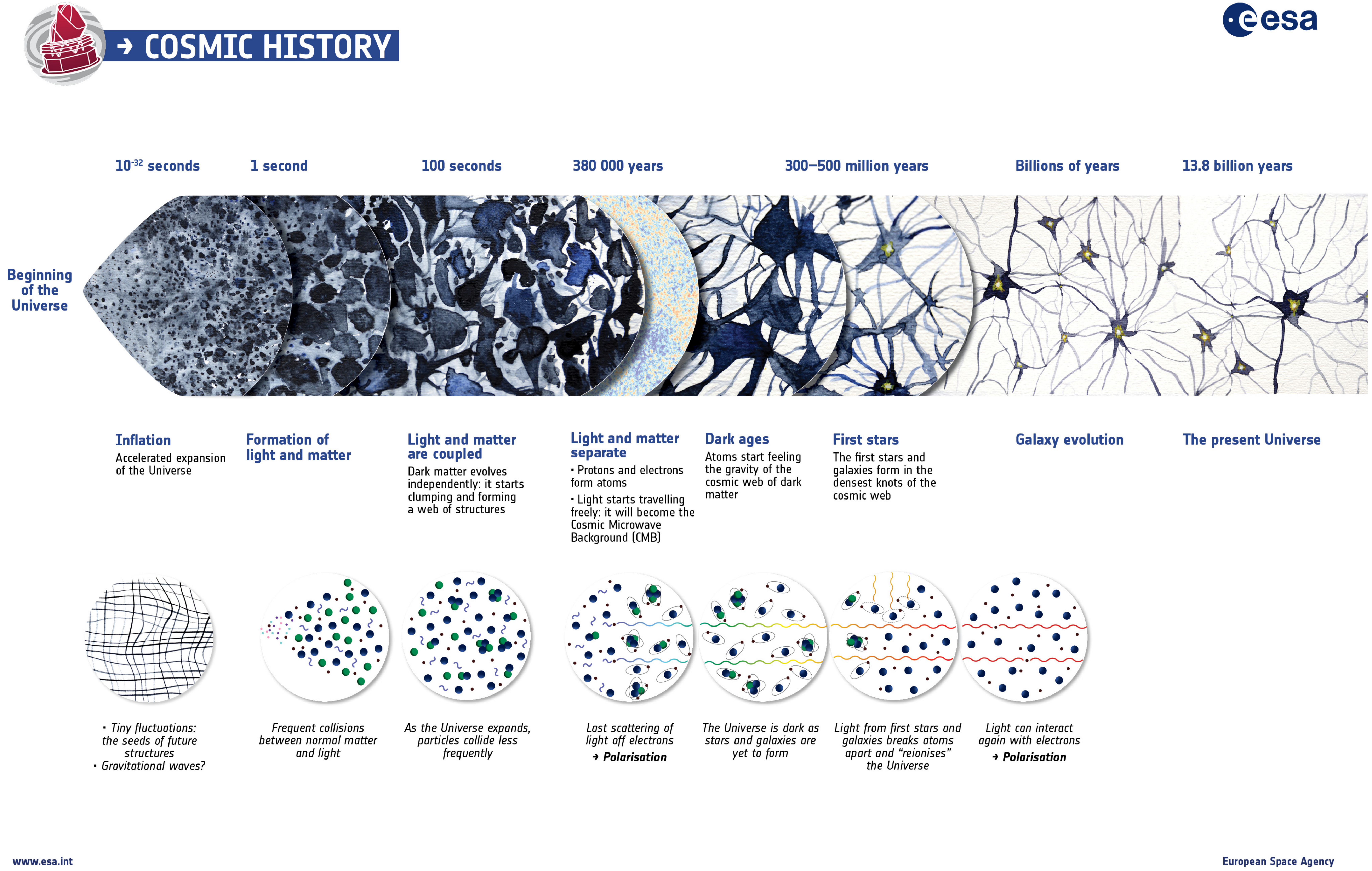
CMB Physics: Theoretical Aspects

PUMA22: Probing the Universe with Multimessenger Astrophysics

Martina Gerbino (INFN Ferrara), Sestri Levante, 27 Sep 2022

What is the CMB?



Imprints of early Universe physics and effects of late-time evolution

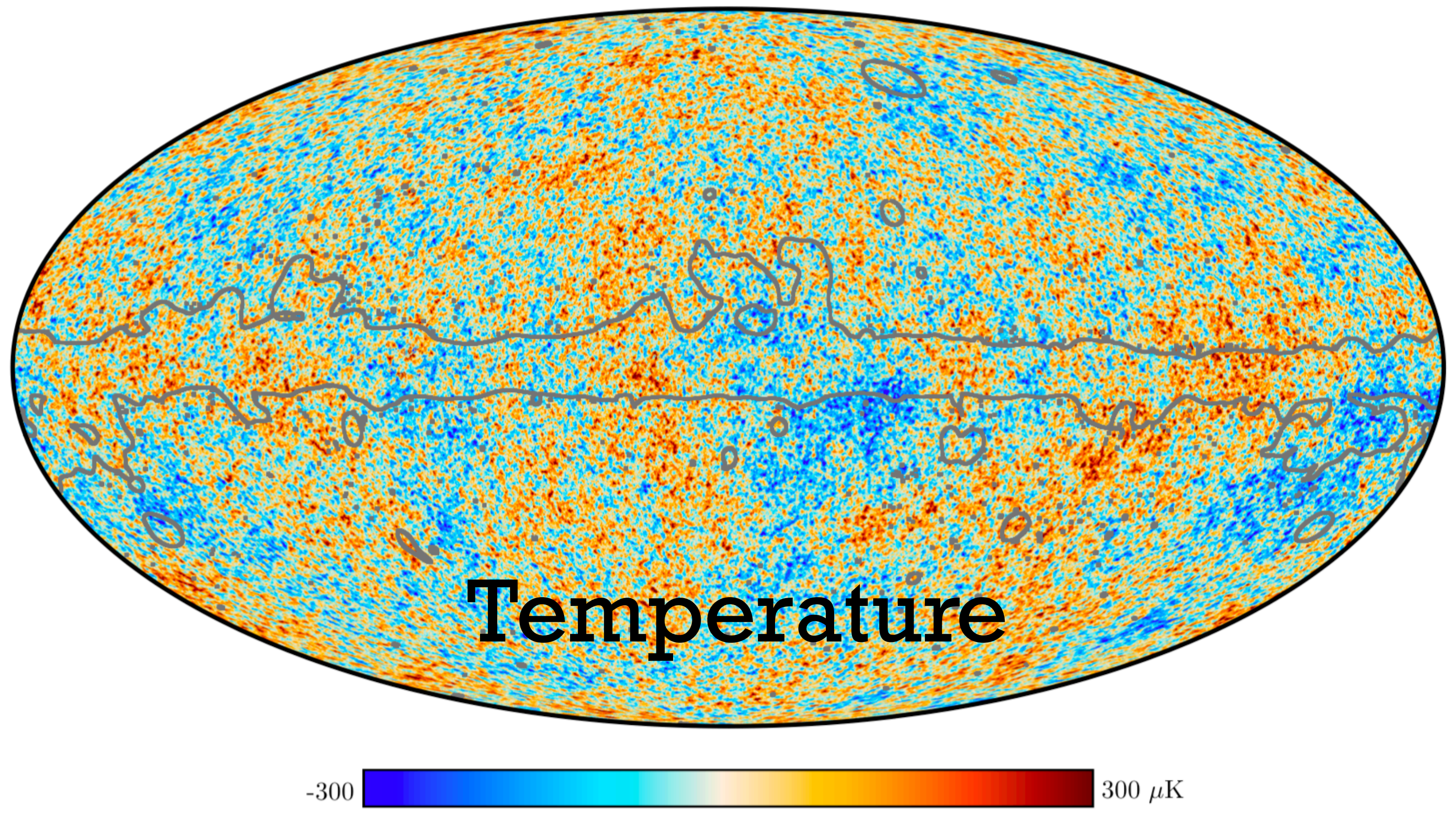
The CMB is a comprehensive cosmological probe

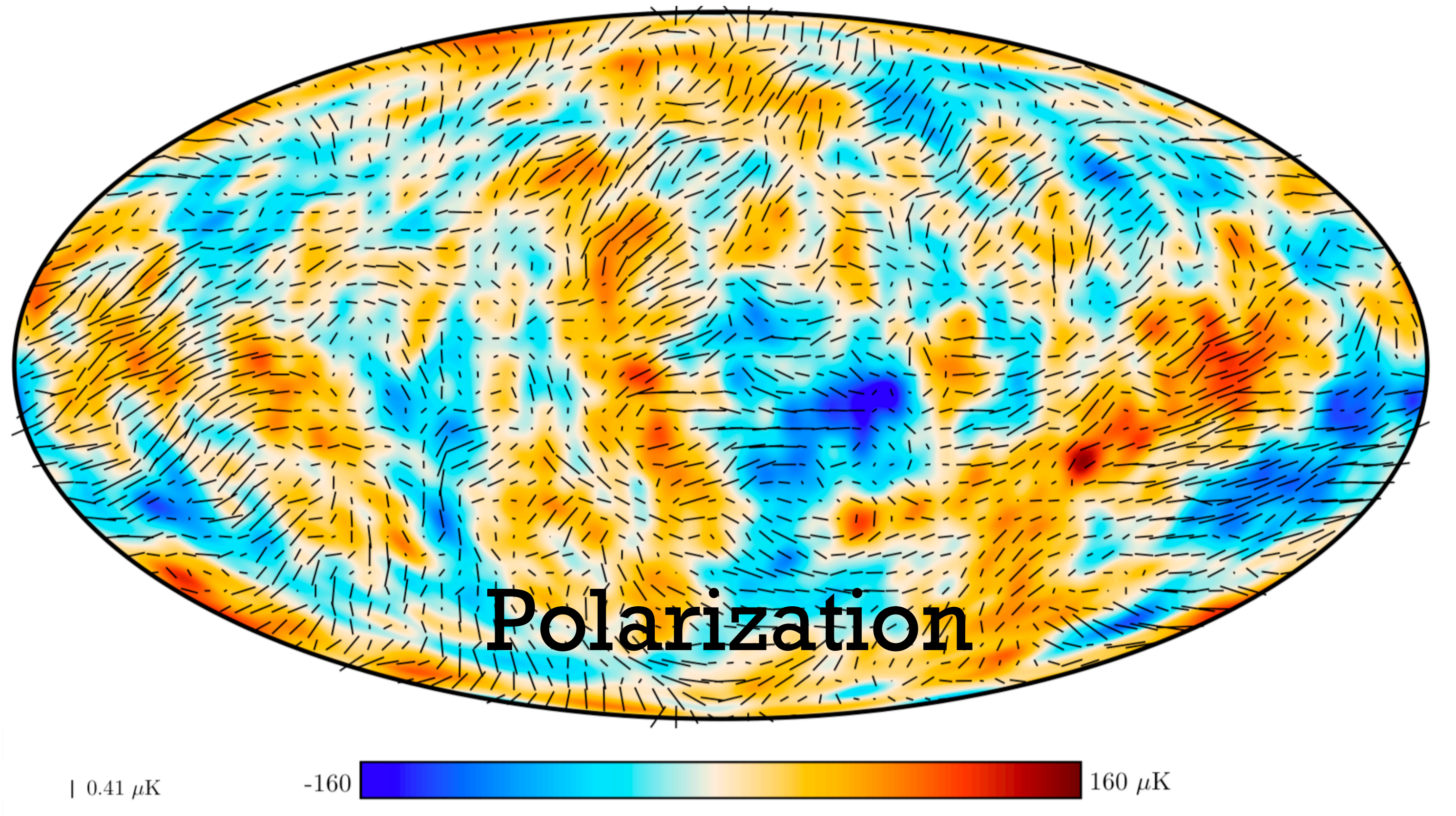
Statistics of the CMB

$$\delta^X \sim \Delta^X \delta_{\mathcal{P}}$$

Δ^X → "Deterministic" evolution

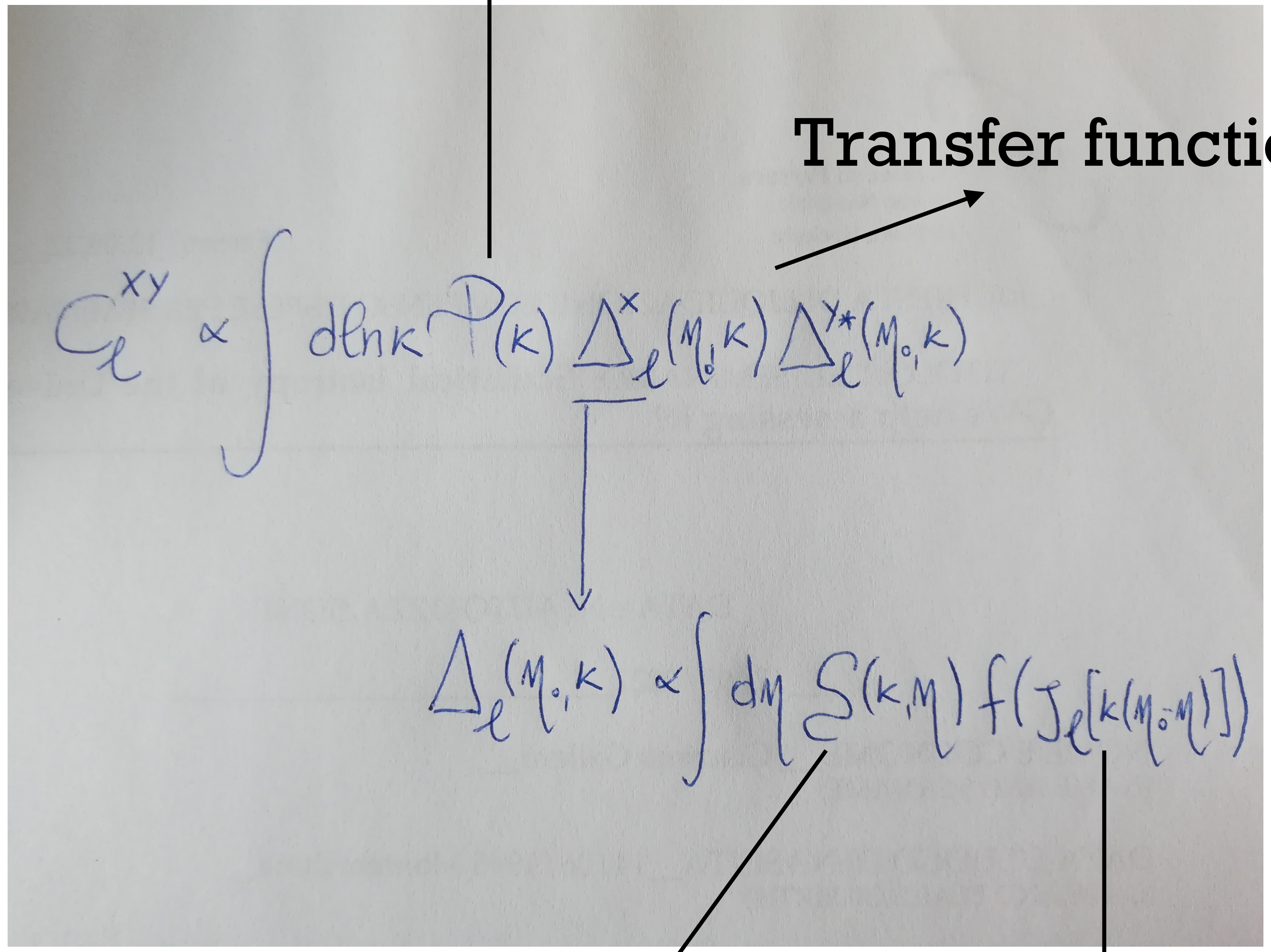
$\delta_{\mathcal{P}}$ → Stochastic primordial field





Credit: ESA Planck

Primordial perturbations
(ns, As, r, nt, …)



Source function
(tau, obh2, Neff, …)

Projection
(theta, och2, oL, …)

+ late-time effects due to interaction with LSS
(gravitational lensing)

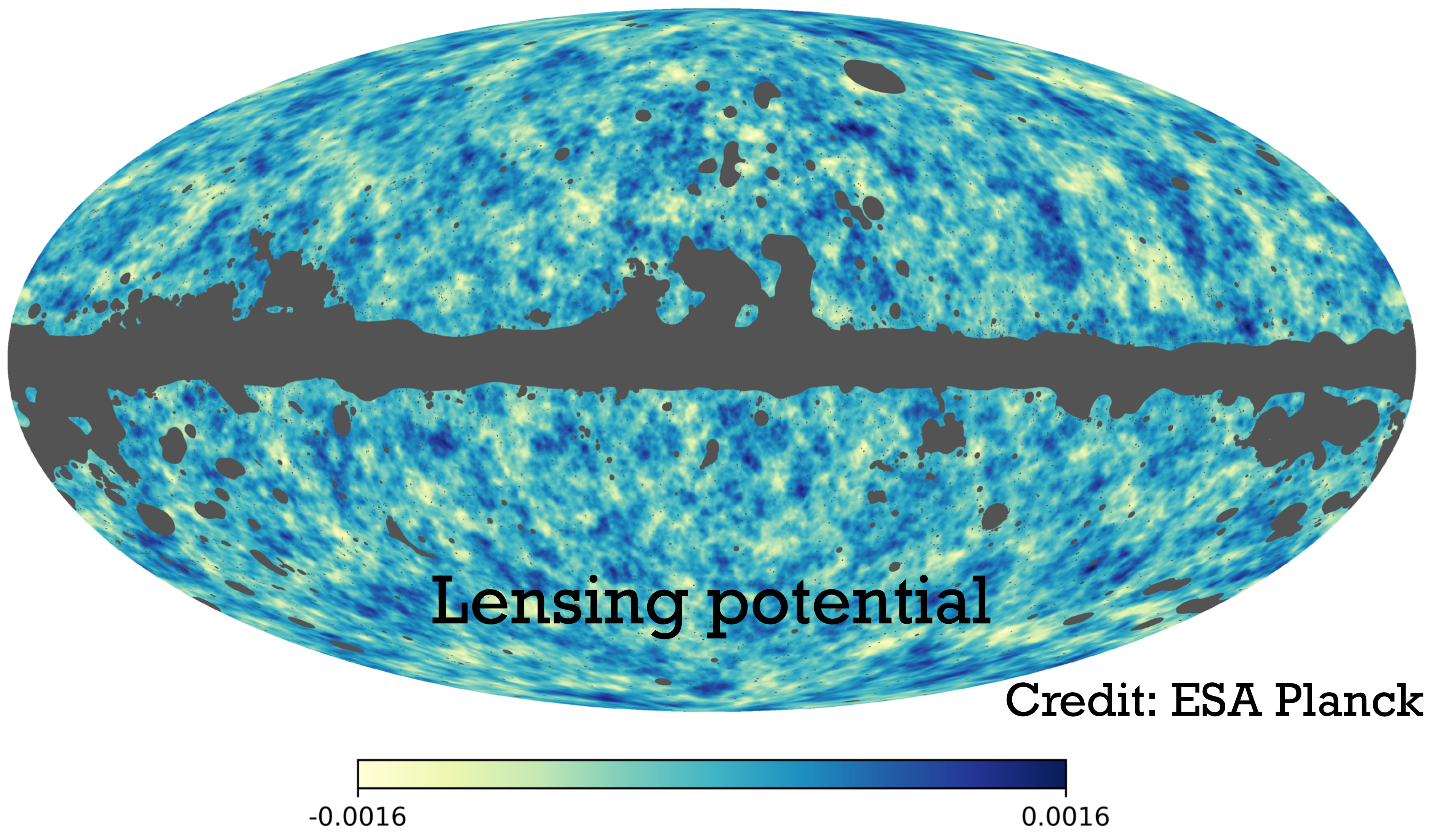
Statistics of the CMB

Evolution of the large-scale structure affects statistics of the small scales

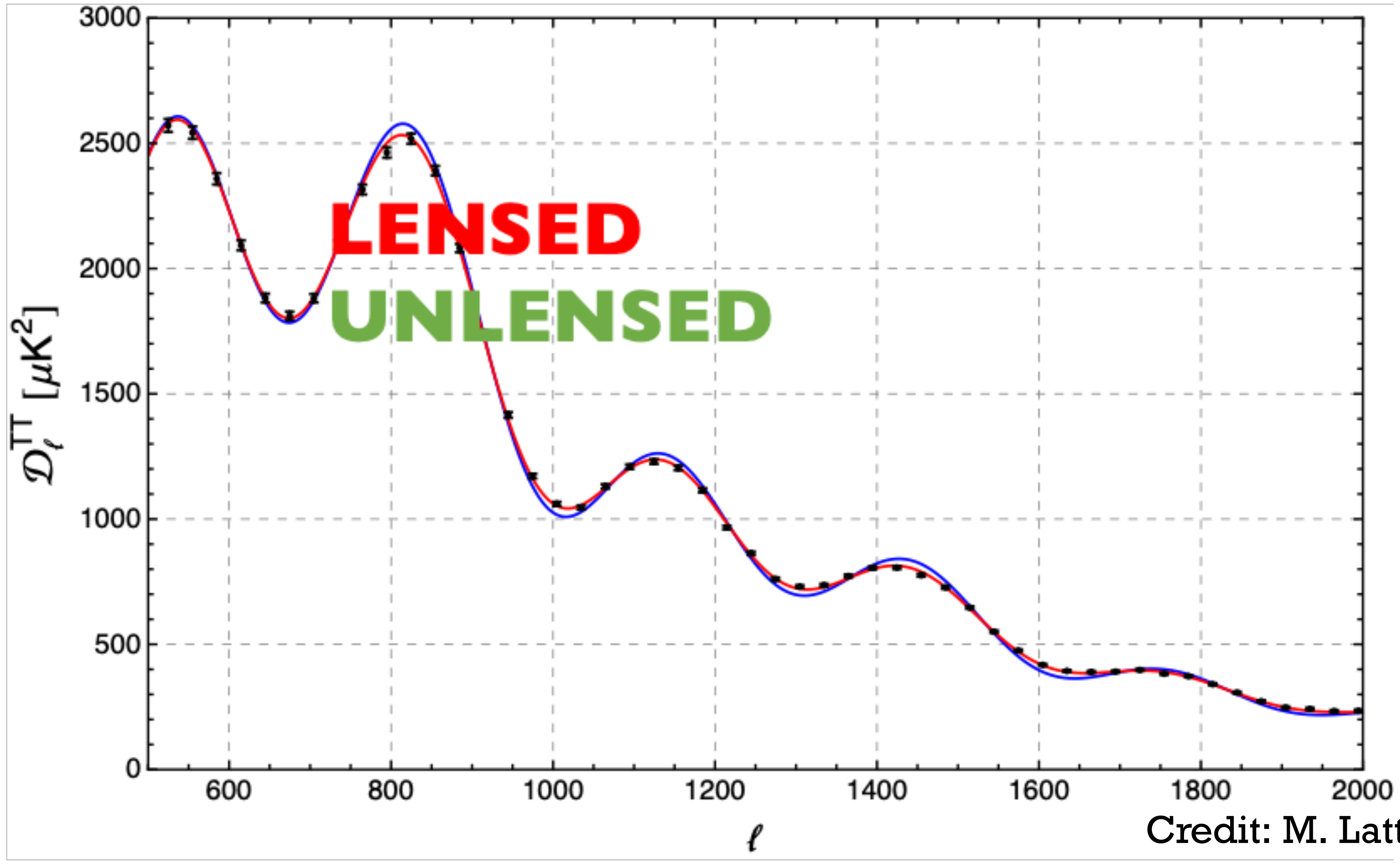
Fluctuations are “blurred”
-> acoustic peaks are smoothed

Non-gaussian signal allows to reconstruct map of lensing field
(depends on total matter)

Sensitivity to late-time physics
(och2, Sumnu, oL, w, modified gravity, …)



Credit: ESA Planck



Credit: M. Lattanzi

Current measurements

CVL measurements in TT up to 2000 from Planck

Improved measurements in T and E
down to arcmin scales from ACT&SPT

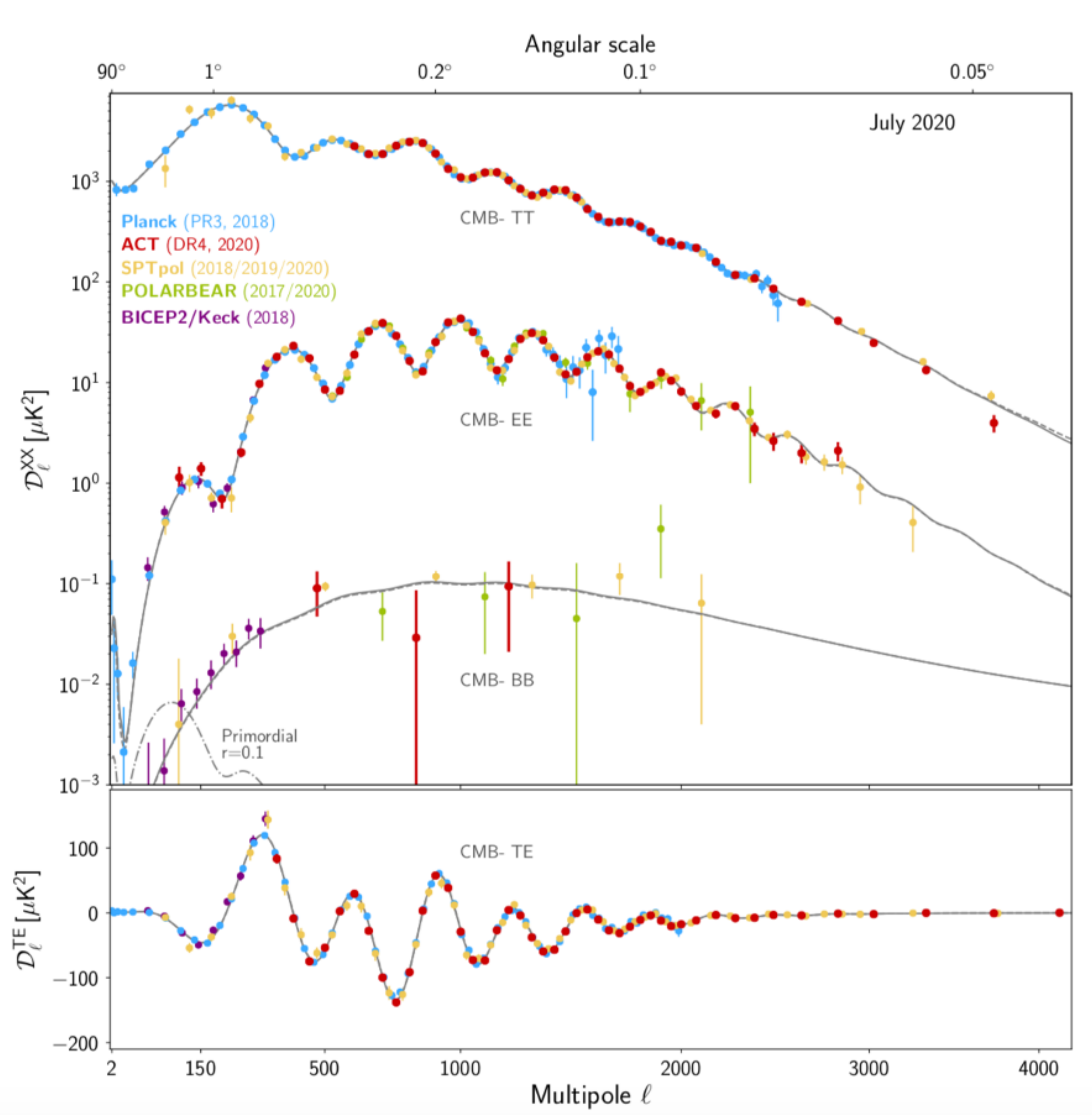
Measurements of degree and sub/degree scales in B
from BK and Polarbear

Main cosmo params (but tau) constrained
at sub/percent level

No clear evidence of deviation from LCDM

BUT

Many open questions in fundamental physics
Many bounds to (hopefully) convert to constraints
New routes to investigate
Intriguing inconsistencies between experiments
motivate next/generation surveys



ACT Coll., Aiola+,2020

Coming soon

Ground-based:
Simons Observatory (first light 2023)
CMB-S4 (start operation by 2030)
Space mission:
LiteBIRD (launch 2029)

Polarization and small scales
Key areas for improvements

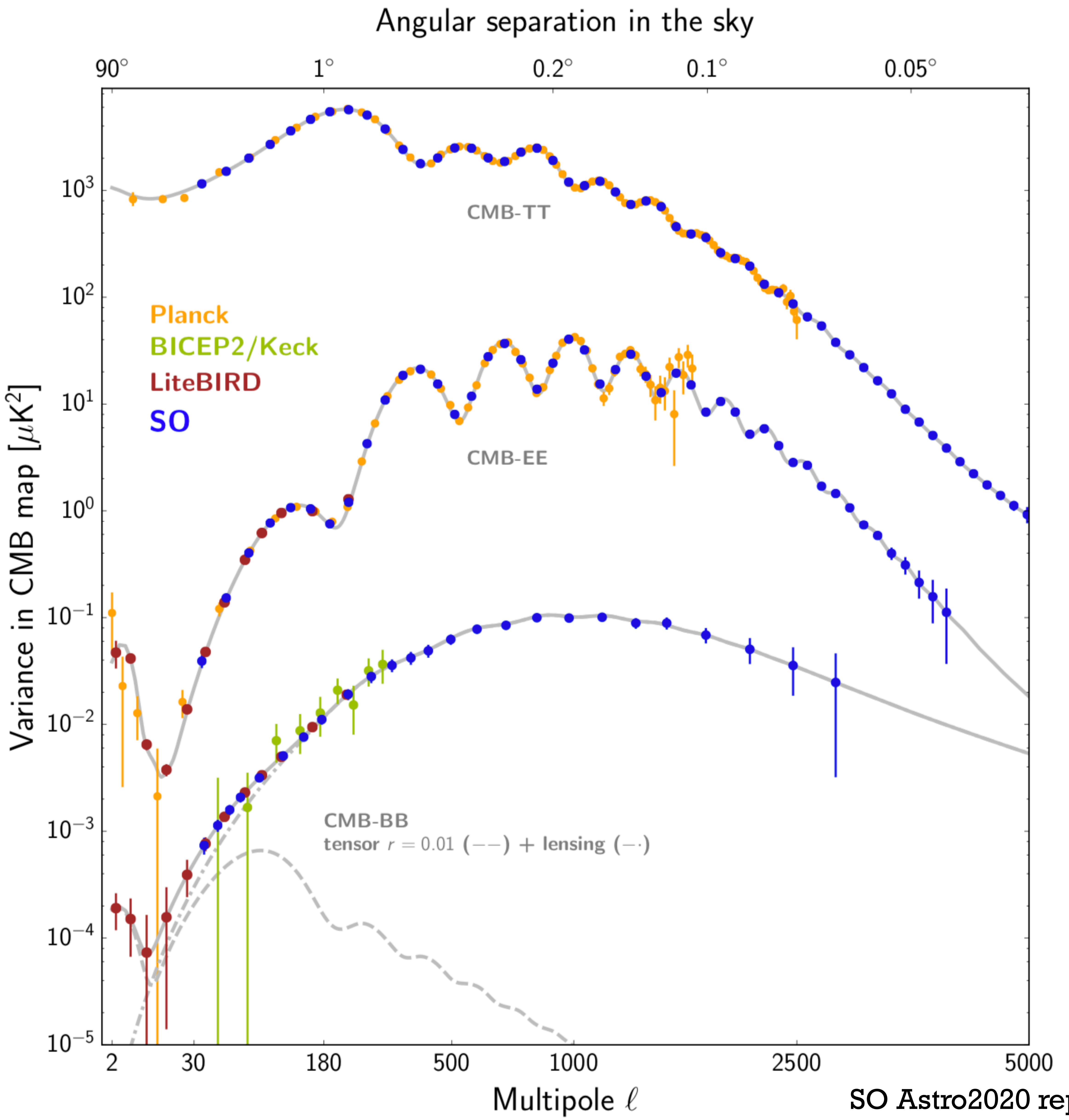
Wide range of science targets:

Early universe physics

Composition of the thermal plasma

Late/time evolution

Astrophysics



SO Astro2020 report

Polarization and Neff

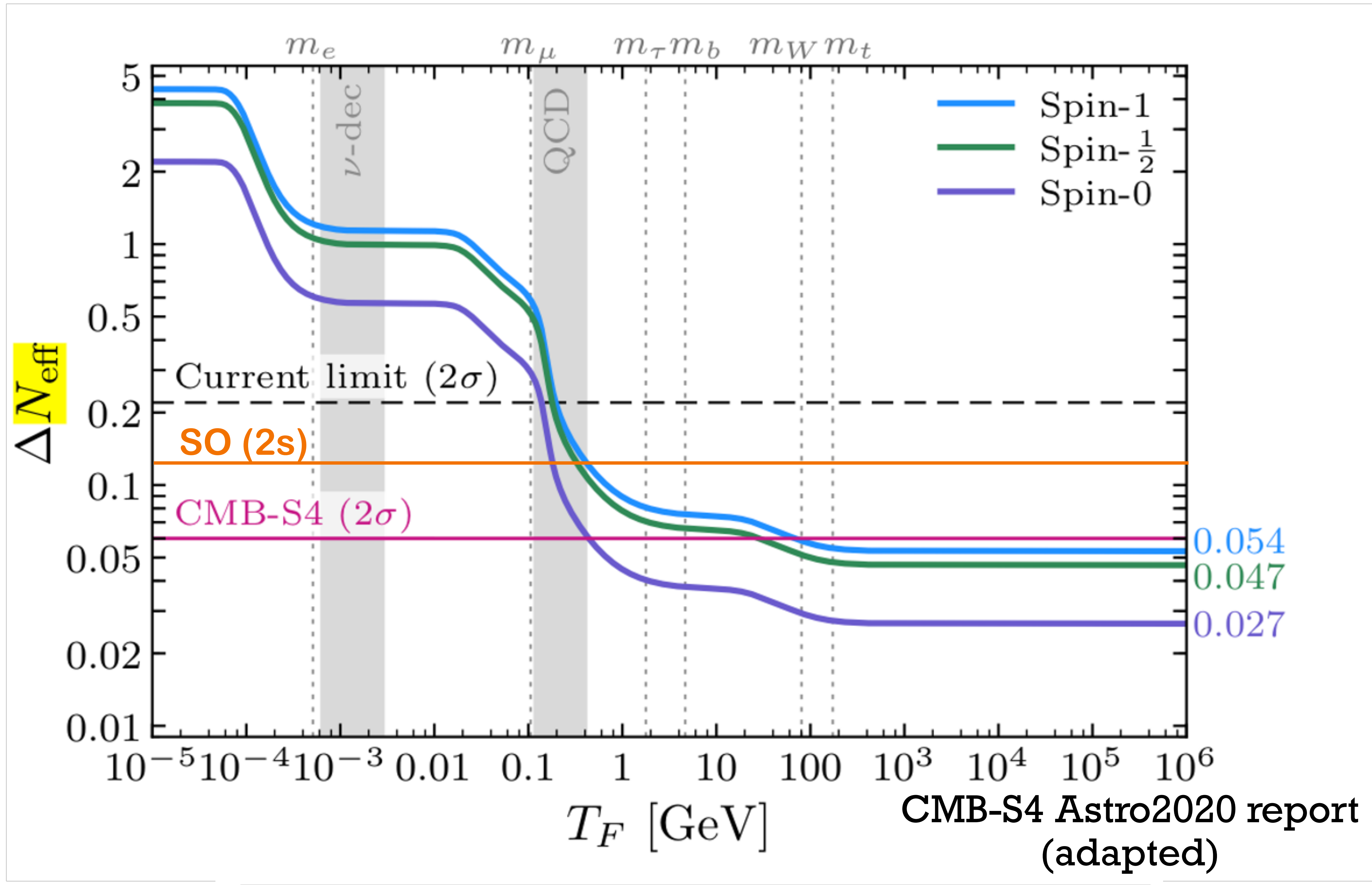
Polarization can help better constrain parameters

Sharper acoustic peaks in polarisation
Improved sensitivity to Neff

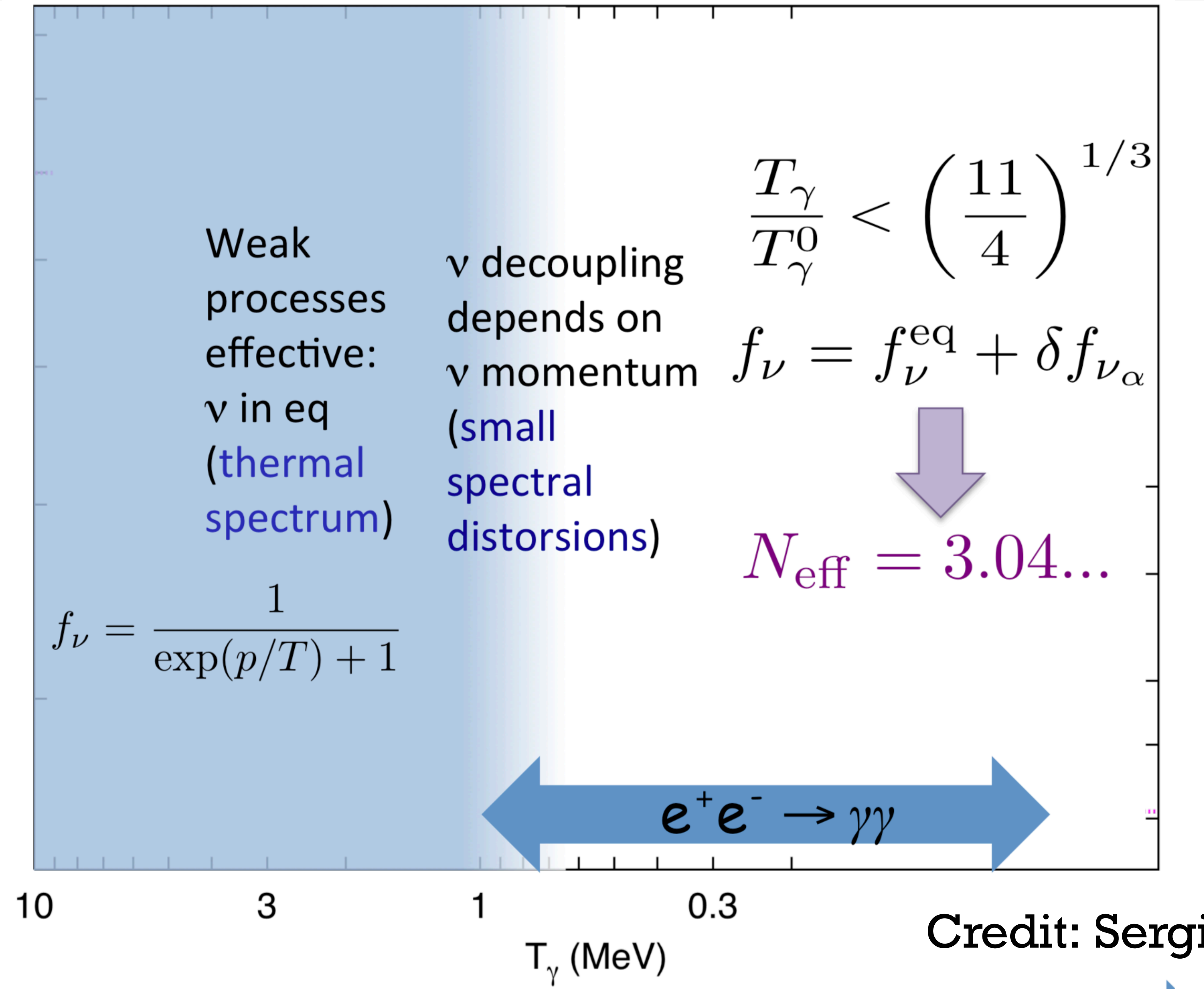
Neff as a proxy for BSM properties of light relics

BSM neutrino properties
Additional (thermal) relics -> axion properties!
Non-standard thermal evolution

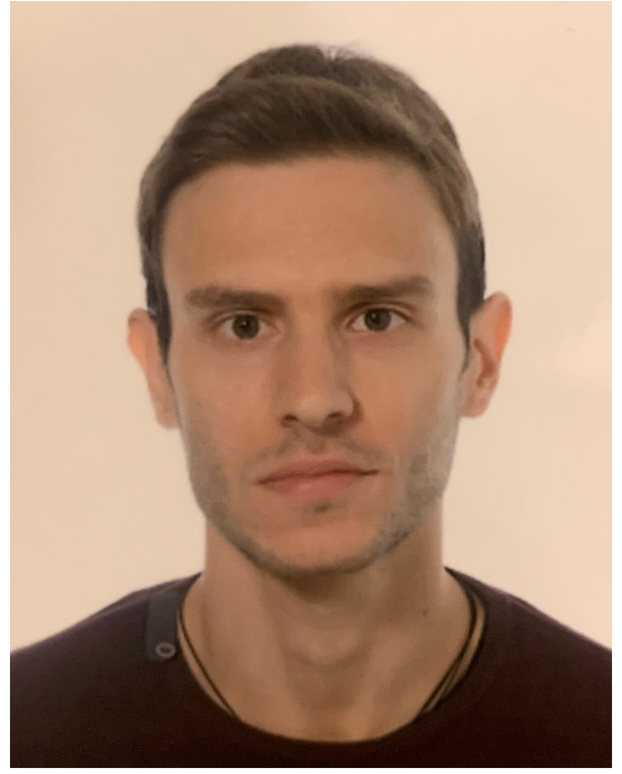
see Maria A. and Luca C. talks!



CMB-S4 Astro2020 report (adapted)



Credit: Sergio Pastor



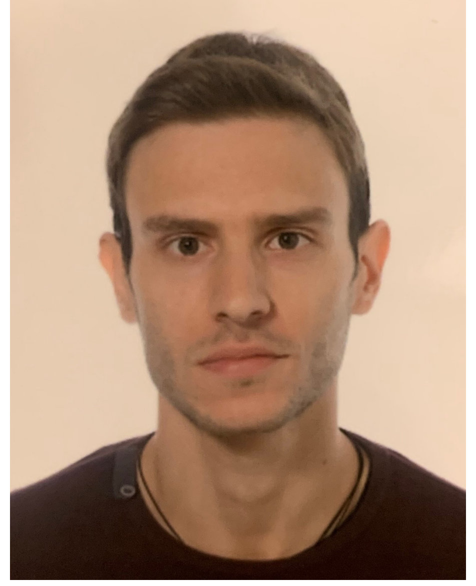
Polarization and early Universe

Polarization can probe physics not visible in T

Deviations from standard EM
(birefringence-like)

Order-of-magnitude improvement with current data

Promising prospects with future data
including V-mode sensitivity



L. Caloni

S. Giardiello

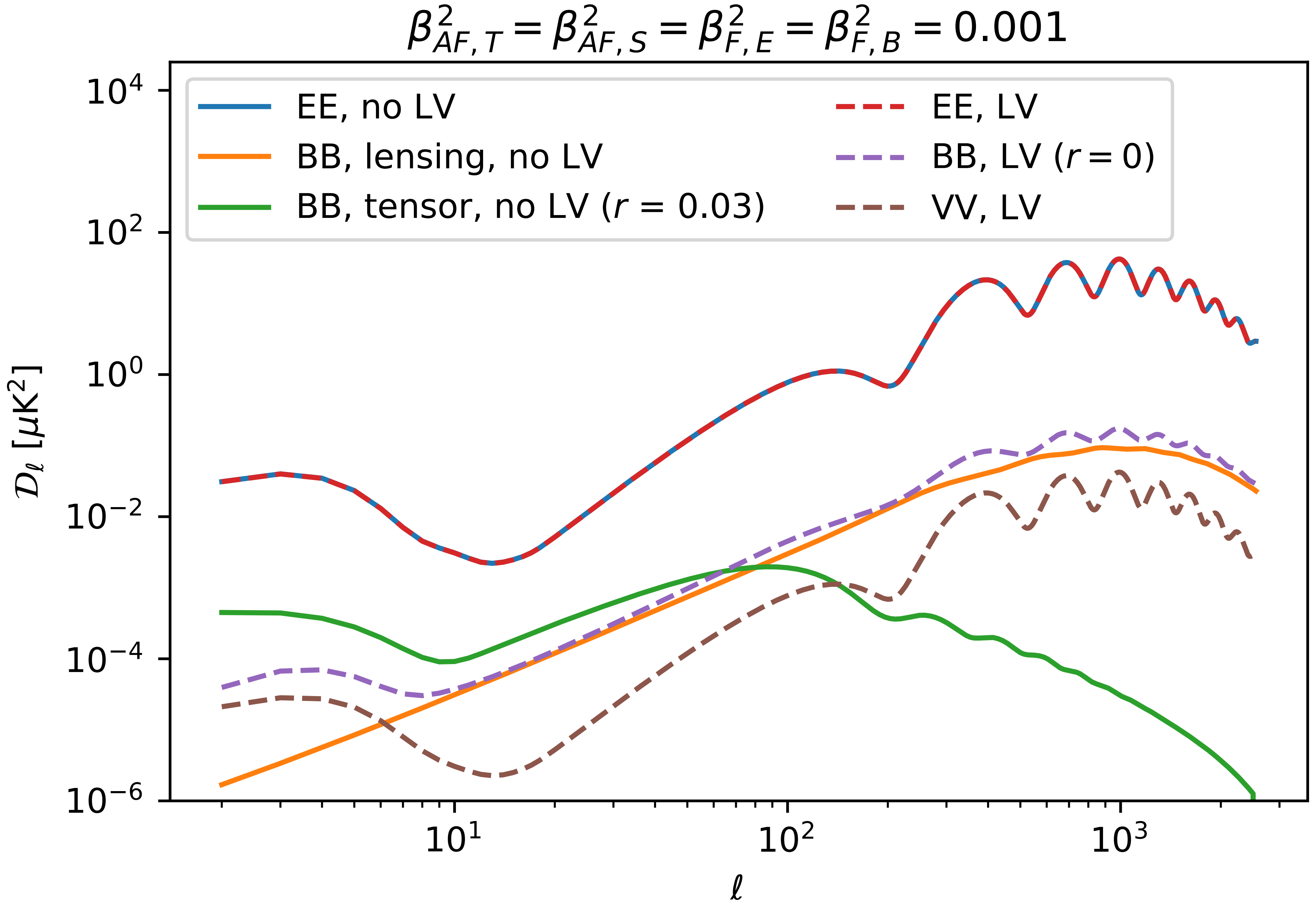
N. Raffuzzi

M. Lembo

Minimal SM extension with Lorentz-violating EM

$$\mathcal{L} = \sqrt{-g}\left[-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\varepsilon^{\alpha\beta\mu\nu}A_\beta(k_{AF})_\alpha F_{\mu\nu} - \frac{1}{4}(k_F)^{\alpha\beta\mu\nu}F_{\alpha\beta}F_{\mu\nu}\right]$$

mixes Q, U and V modes



Caloni, Giardiello+ (incl.MG), in prep.
Lembo+, PRL 2021

Small scales

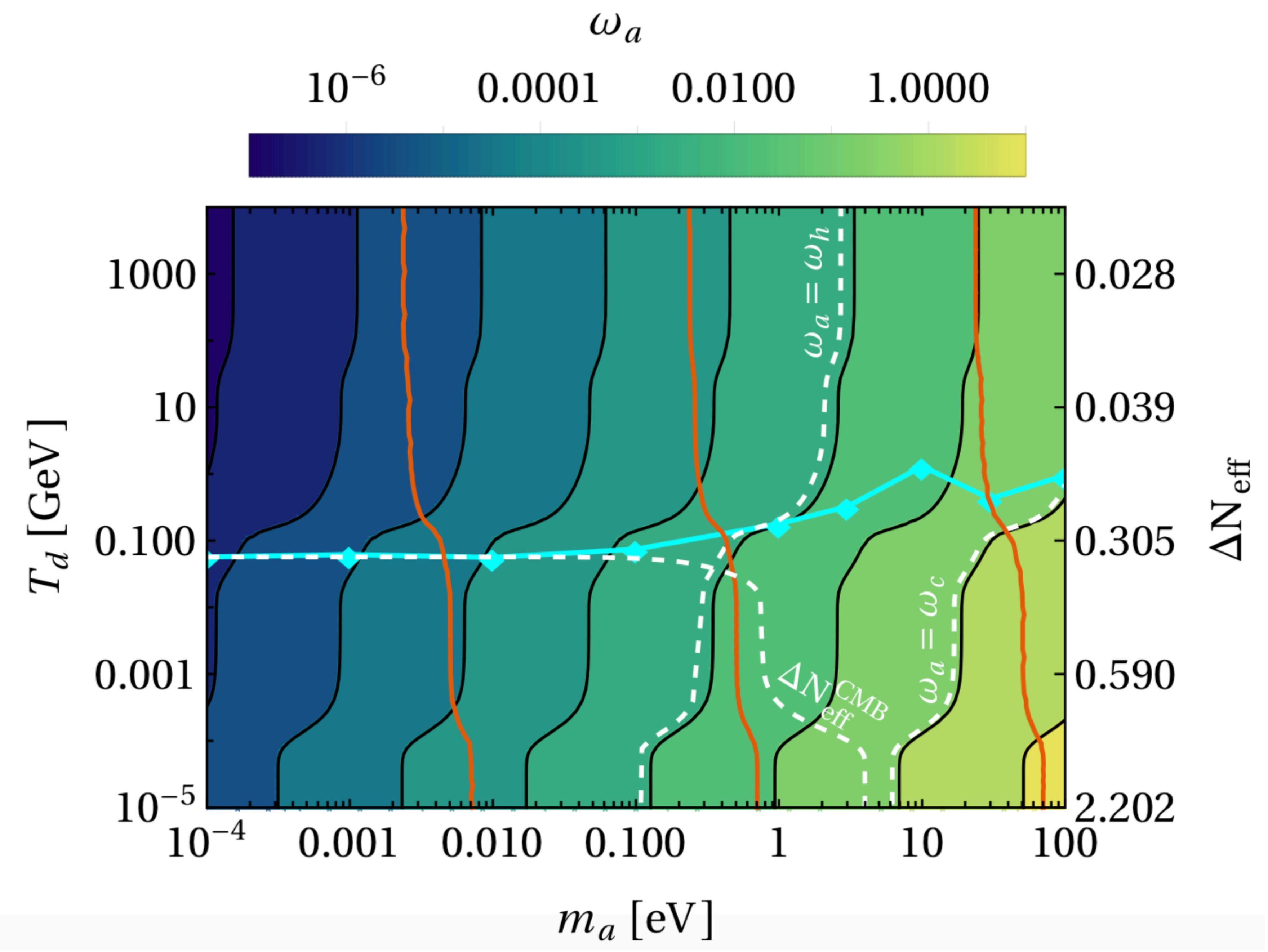
Lensing of the CMB allows reconstruction of lensing potential
SZ effect allows mapping of clusters

Key tracers of matter field from CMB observations
Cross-correlation with LSS surveys

Impact of light yet massive relics
(see talks by Maria and Luca)

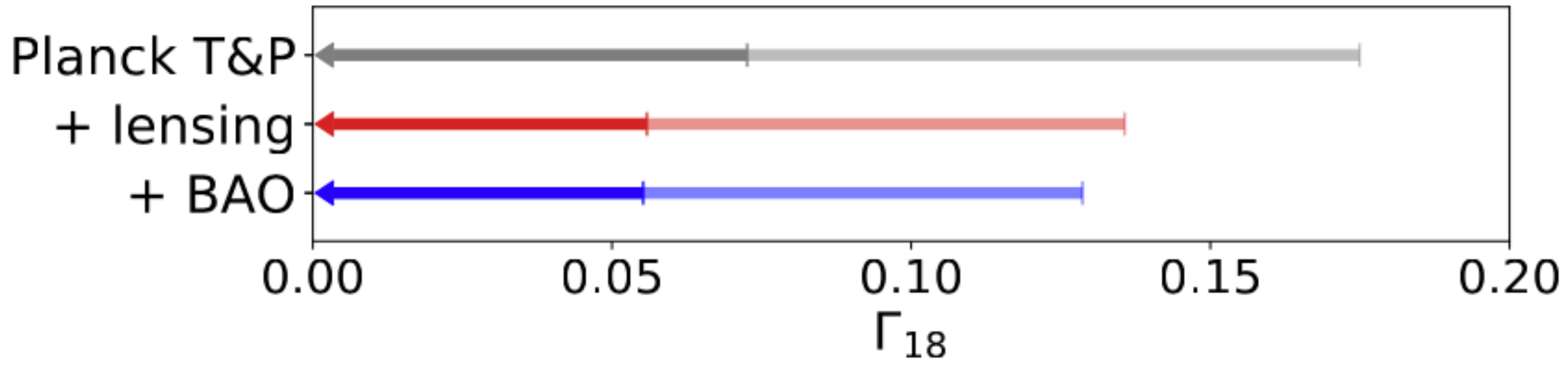
Stability of dark matter

Handle to structure evolution



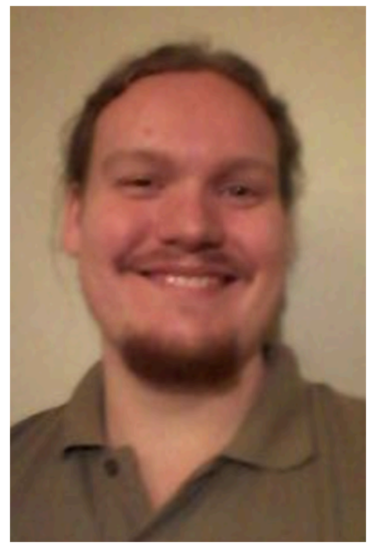
Caloni, MG, Lattanzi, Visinelli, JCAP 2022

Dataset\Parameter	$\Gamma_{18} = \Gamma_{DCDM}/10^{-18}s^{-1}$	τ_{DCDM} Gyr
Planck T&P	< 0.175	> 181
+ lensing	< 0.136	> 234
+ BAO	< 0.129	> 246



Alvi, Brinckmann, MG, Lattanzi, Pagano, arXiv:2205.05636

S. Alvi



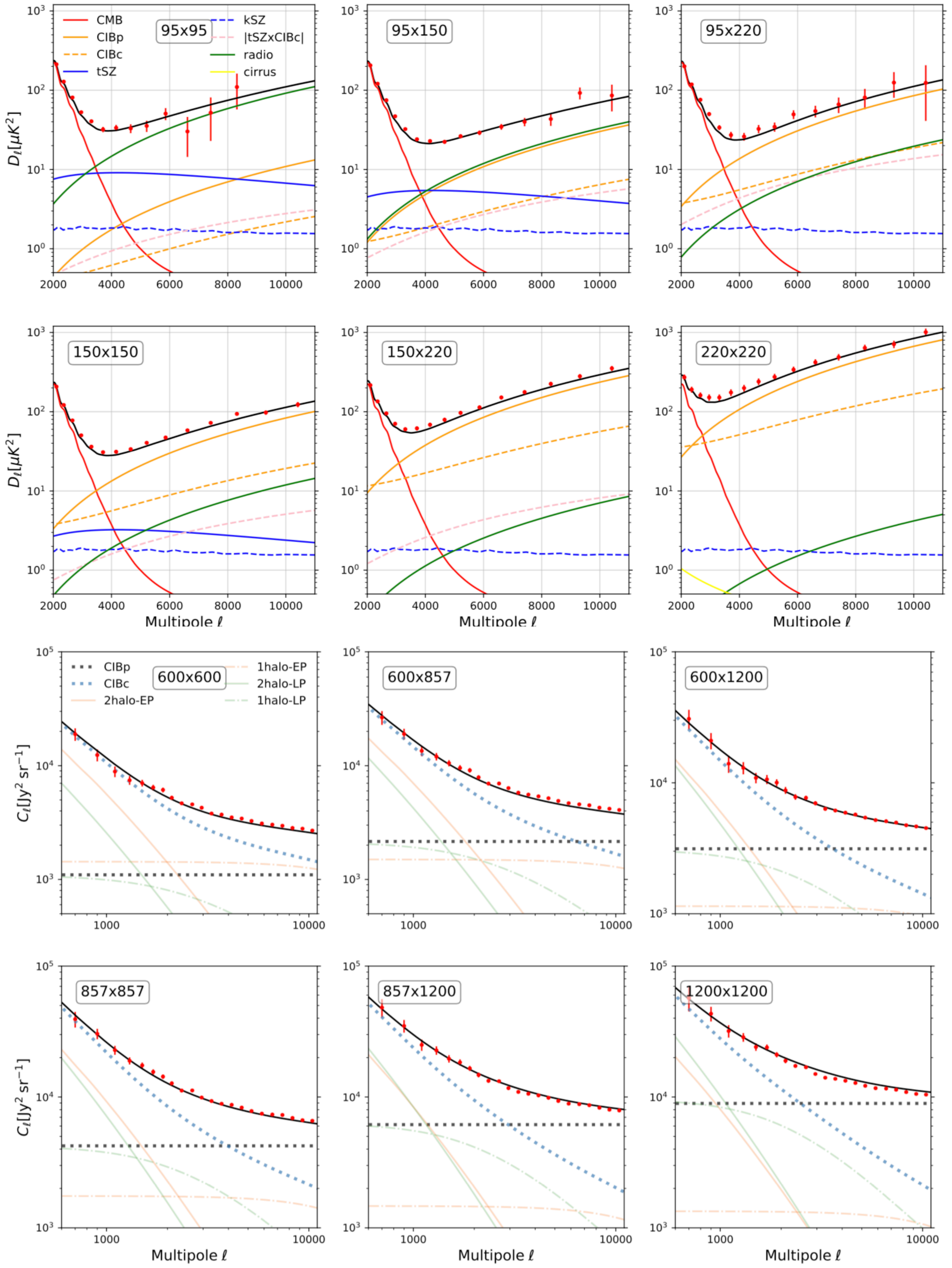
T. Brinckmann

Small scales

High-resolution, multi-frequency observations
-> enhanced sensitivity to astrophysical emissions

Foreground as astrophysical tools!

Possibility to constrain structure evolution
CIB -> dusty star-forming galaxies
tSZ, kSZ -> massive galaxy clusters



Chiocchetta PhD thesis,
advisors: L. Pagano, M. Negrello
in collab. with E. Calabrese, MG

C. Chiocchetta

Conclusions

CMB measurements are a pillar of modern, precision cosmology

Wide range of information from fundamental physics to astrophysics

Complementarity with other searches (lab, astrophysics) -> multi-probe approach

Novel exciting results expected from next-gen surveys

Challenges ahead -> theory modelling, systematic effects, combined analyses

Voyage2050: "The Senior Committee recommend that ESA should develop a Large mission capable of deploying new instrumental techniques such as gravitational wave detectors or precision microwave spectrometers to explore the early Universe"

THANKS FOR YOUR ATTENTION!