COrE+

The Cosmic Origins Explorer

A proposal for ESA's M4 space mission

Jacques Delabrouille

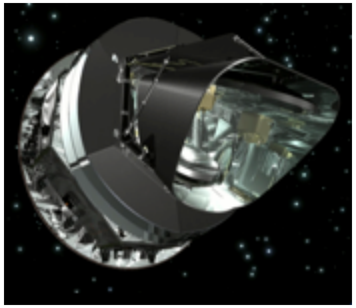
Laboratoire APC, Paris, France

On behalf of the COrE+ Collaboration

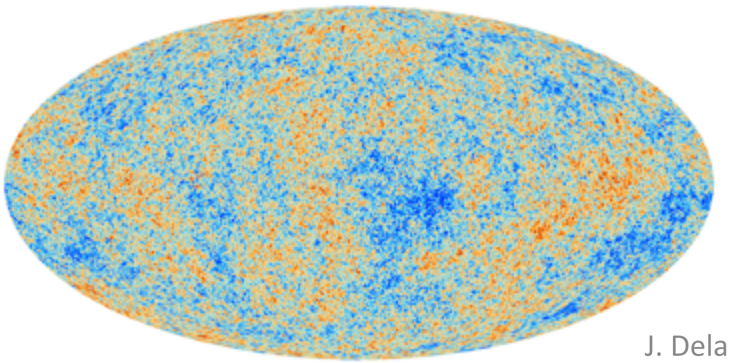
Outline

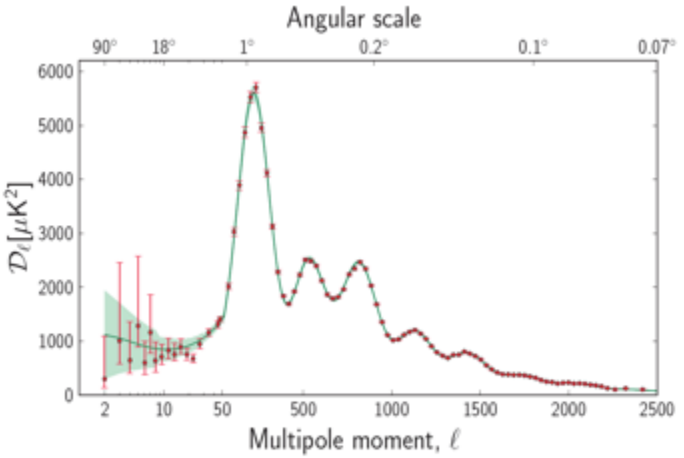
- CMB with and after Planck
- Science beyond primary CMB
- Why a space mission ?
- COrE+
- Conclusion

The Planck legacy

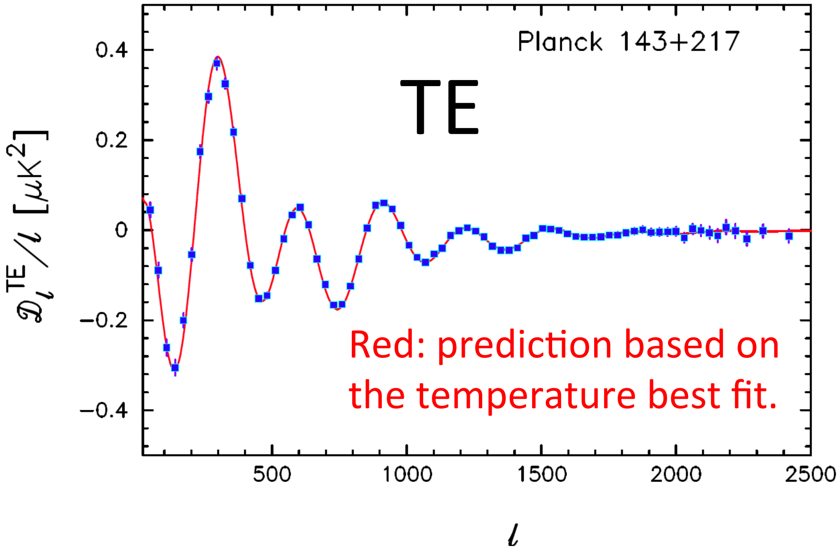


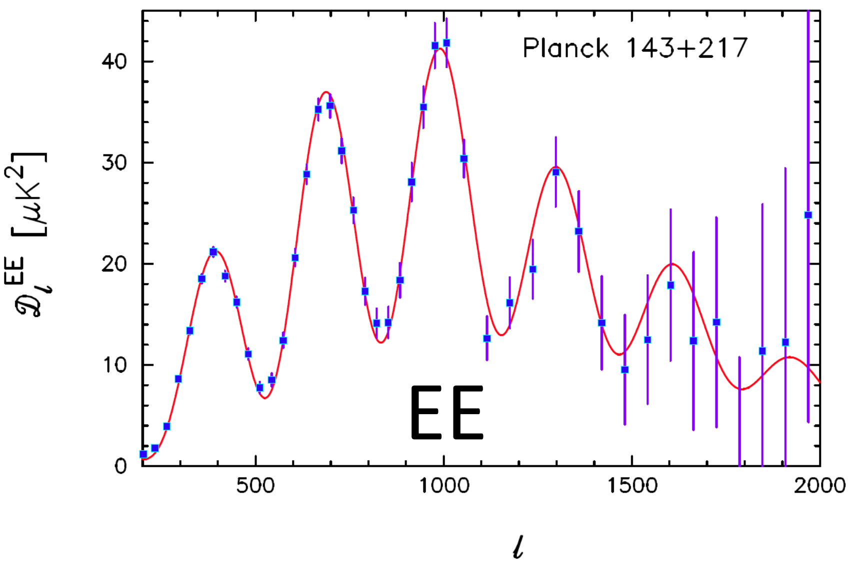
- **Planck**: a great success
  - (top and 5 out of the 10 most cited papers in physics, astronomy and archive-eprint , as given by SAO/NASA ADS, over the period Jan. 2013 – Dec. 2013).
  - near-ultimate CMB temperature anisotropies mission
  - good measurement of the power spectrum of polarization anisotropies caused by density perturbations (E-modes).
  - much science beyond the primary anisotropy C_l spectrum and parameters
    - CMB science: lensing; anomalies; primordial non-gaussianity
    - Non CMB cosmology: galaxy clusters; Cosmic Infrared Background…
    - Astrophysics: interstellar medium
    - Non-CMB science: 3/4 of the science papers, 1/2 of the citations



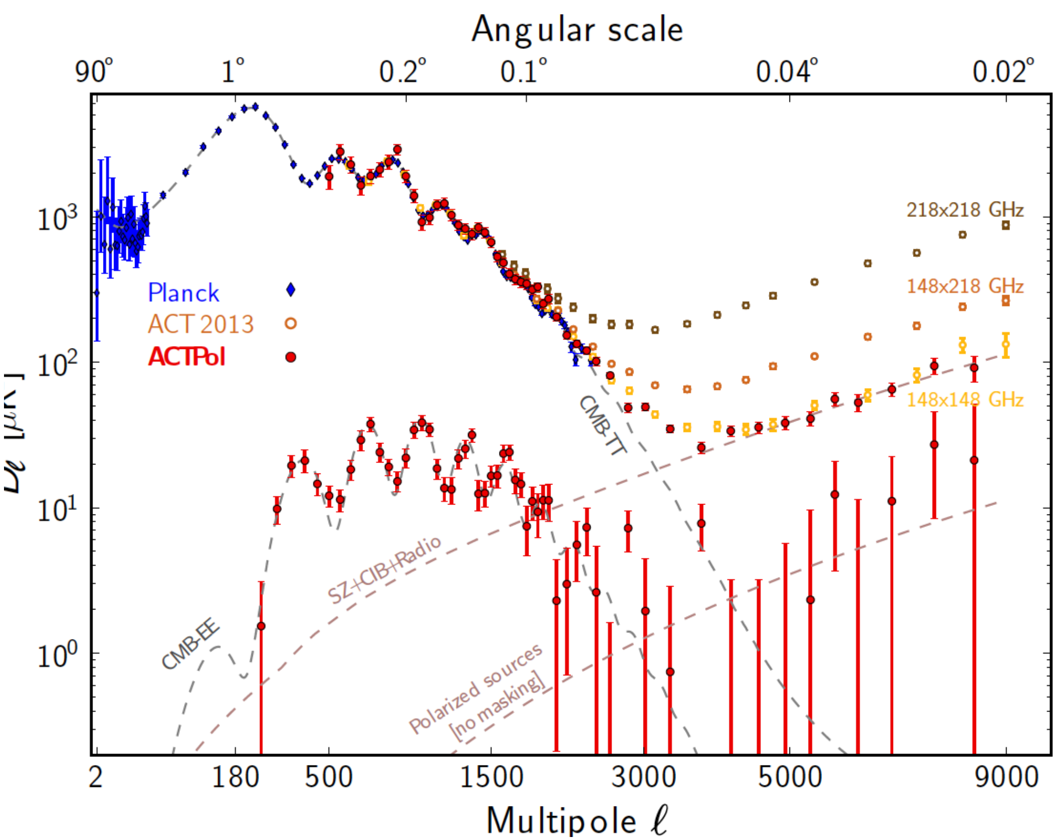


Polarisation spectrum in agreement



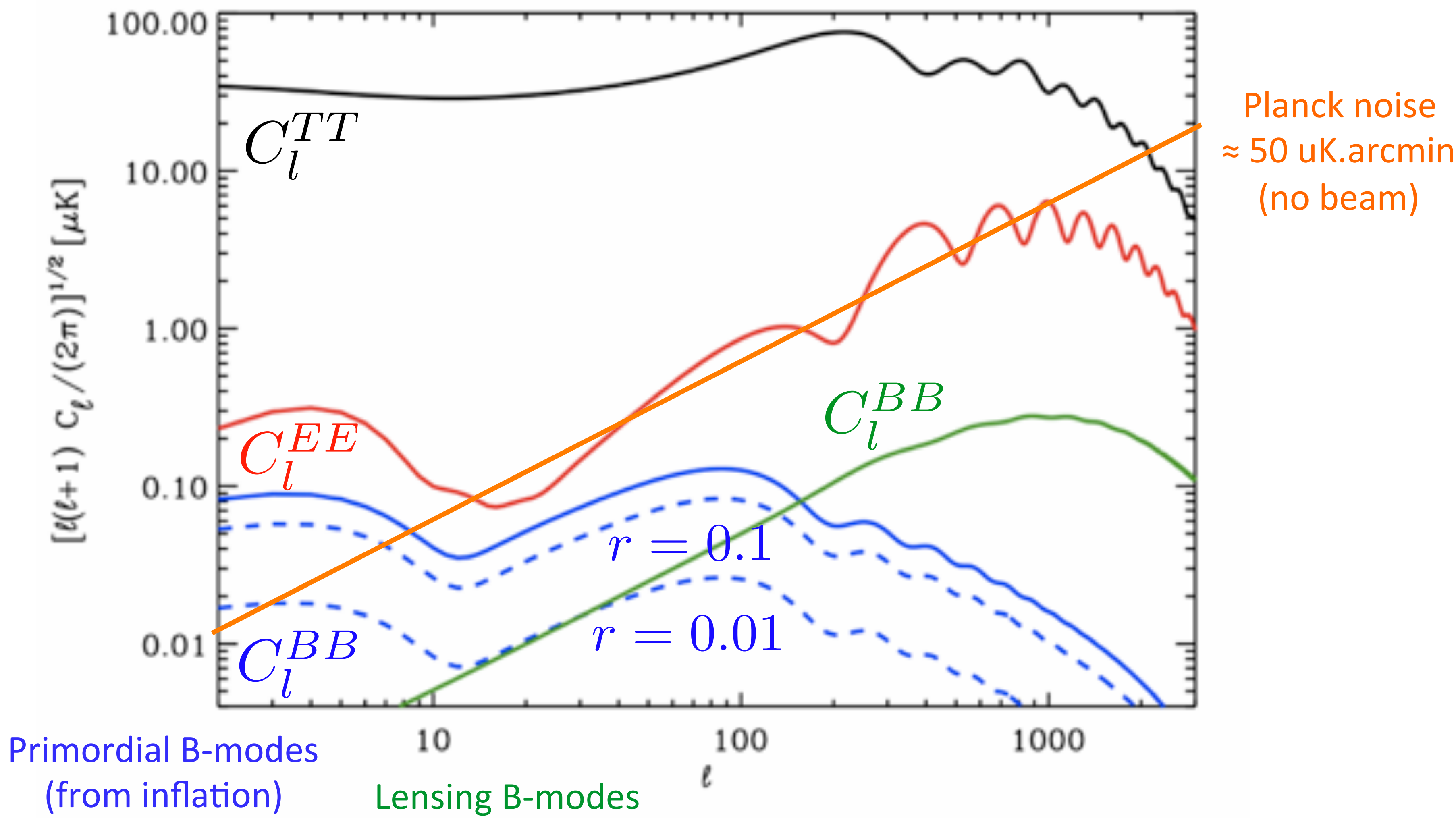


ACT collaboration, arXiv 1405.5524v1



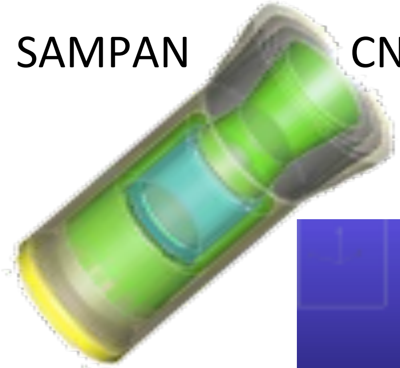
Next : Polarisation B-modes

Objective: CMB B-modes (primordial and lensing)

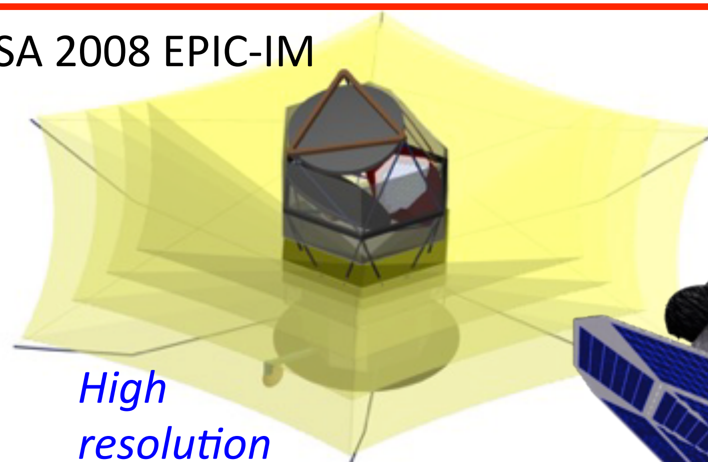


Many proposed Post-Planck CMB missions

SAMPAN CNES 2006

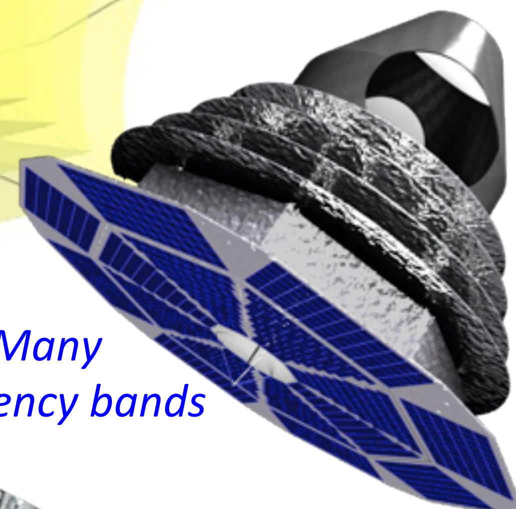


NASA 2008 EPIC-IM



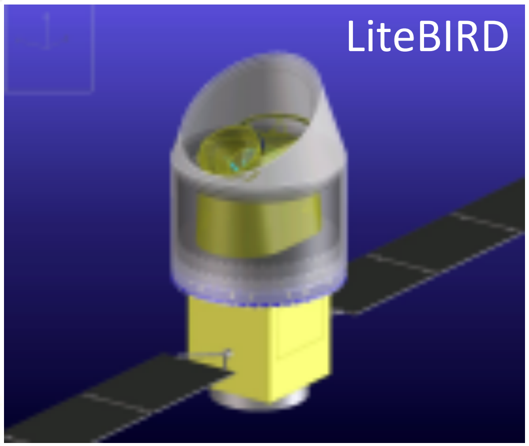
High resolution

COrE
ESA 2010

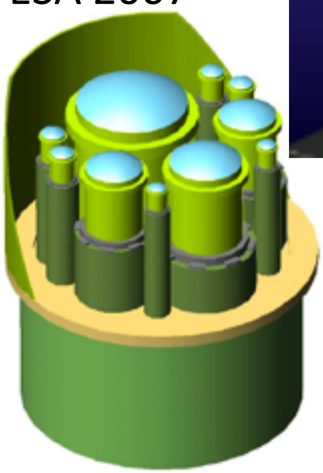


Many frequency bands

JAXA 2008

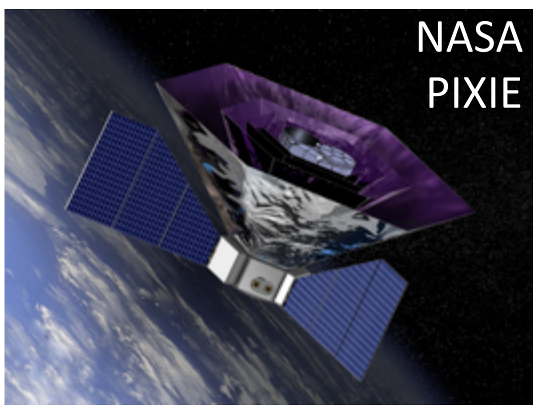


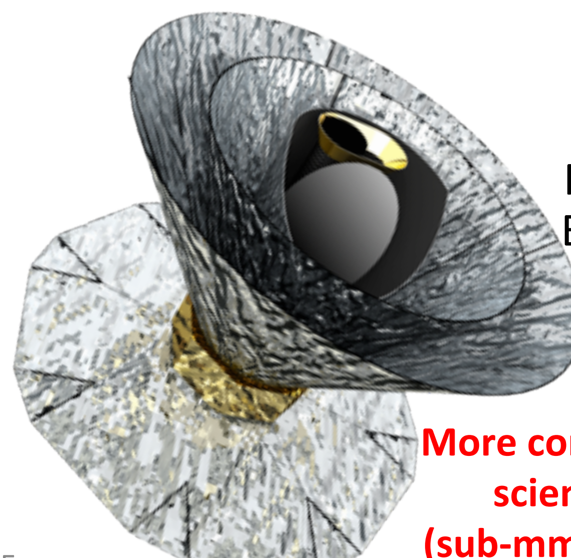
BPOL
ESA 2007



NASA

Absolute spectrophotometer





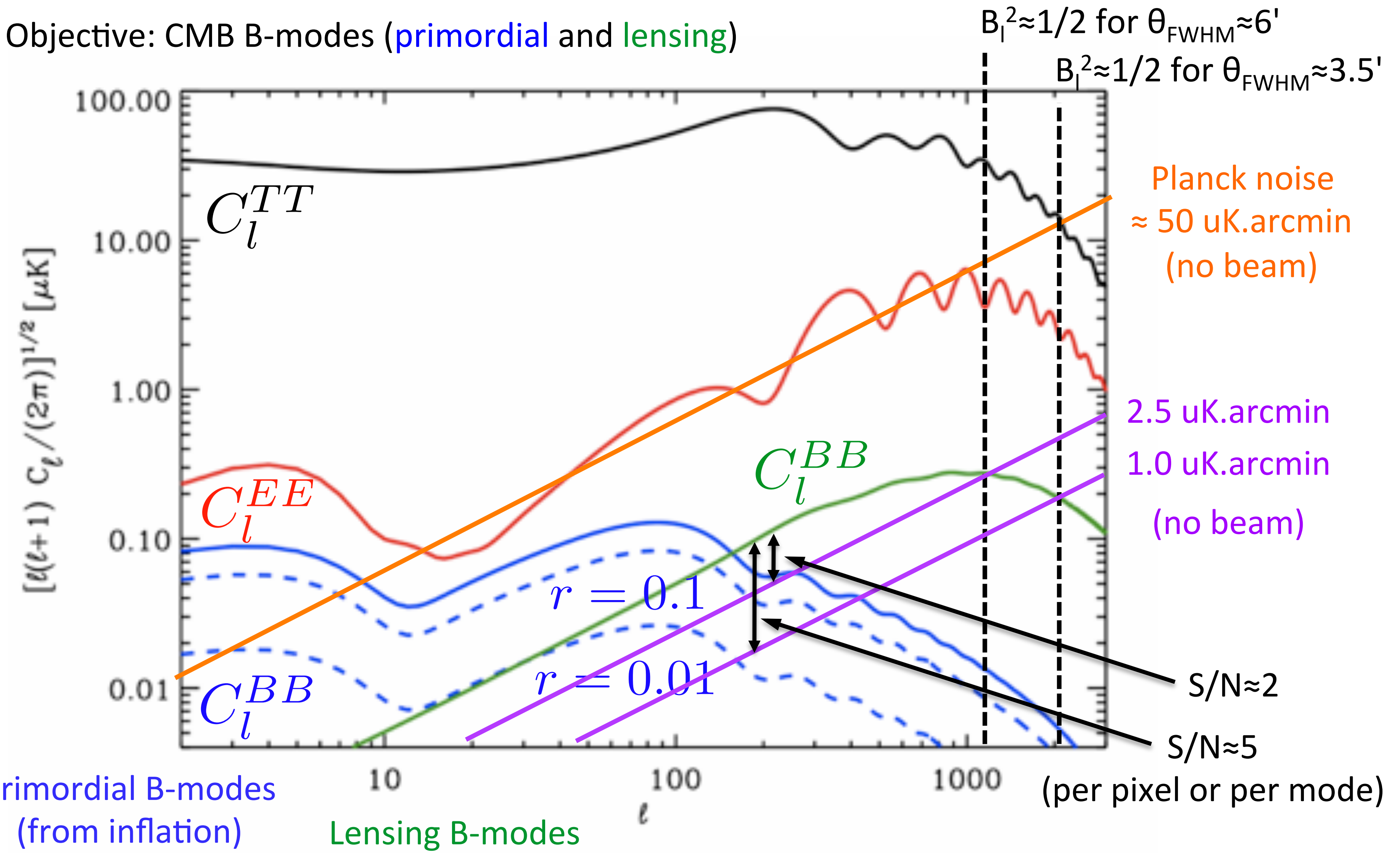
PRISM
ESA 2013

Low resolution
Limited frequency coverage
Primary CMB B-modes

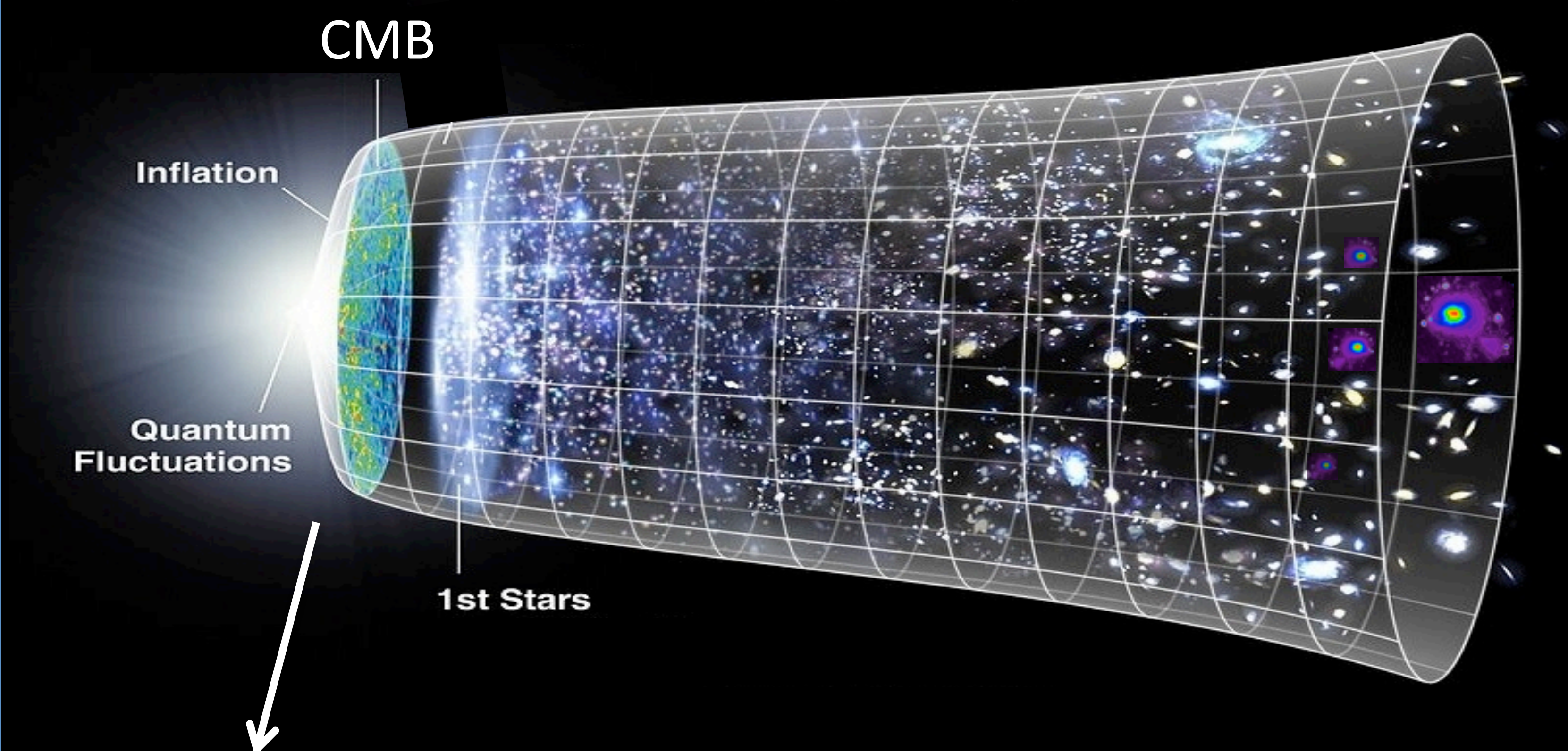
More comprehensive science cases
(sub-mm astronomy)
(astrophysical cosmology)

Next : Polarisation B-modes

Objective: CMB B-modes (primordial and lensing)



COrE+ : First goal



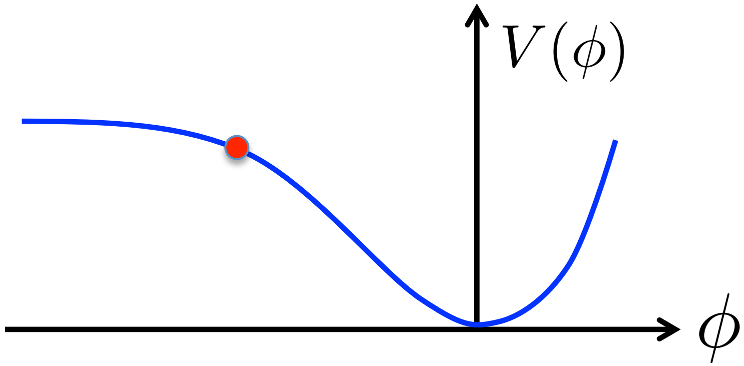
Inflation

Physics at ≈ 10^{16} GeV

$E_{COrE+} > 10^{12} \times E_{LHC}$

Inflation

Many models exist.
Single scalar field inflation in the slow roll approximation:
Inflation occurs by a scalar field slowly rolling down a potential



Inflation generates scalar (density) and tensor (gravitational-wave) perturbations with amplitudes, power spectra depending on slow roll parameters:

$$\epsilon = \frac{{M_{\rm pl}}^2 V_\phi^2}{2V^2} \qquad \eta = \frac{{M_{\rm pl}}^2 V_{\phi\phi}}{V} \qquad \xi^2 = \frac{{M_{\rm pl}}^4 V_\phi V_{\phi\phi\phi}}{V^2}$$

Inflation – slow roll models

scalar spectral index $$n_s - 1 = 2\eta - 6\epsilon$$

tensor spectral index $$n_t = -2\epsilon$$

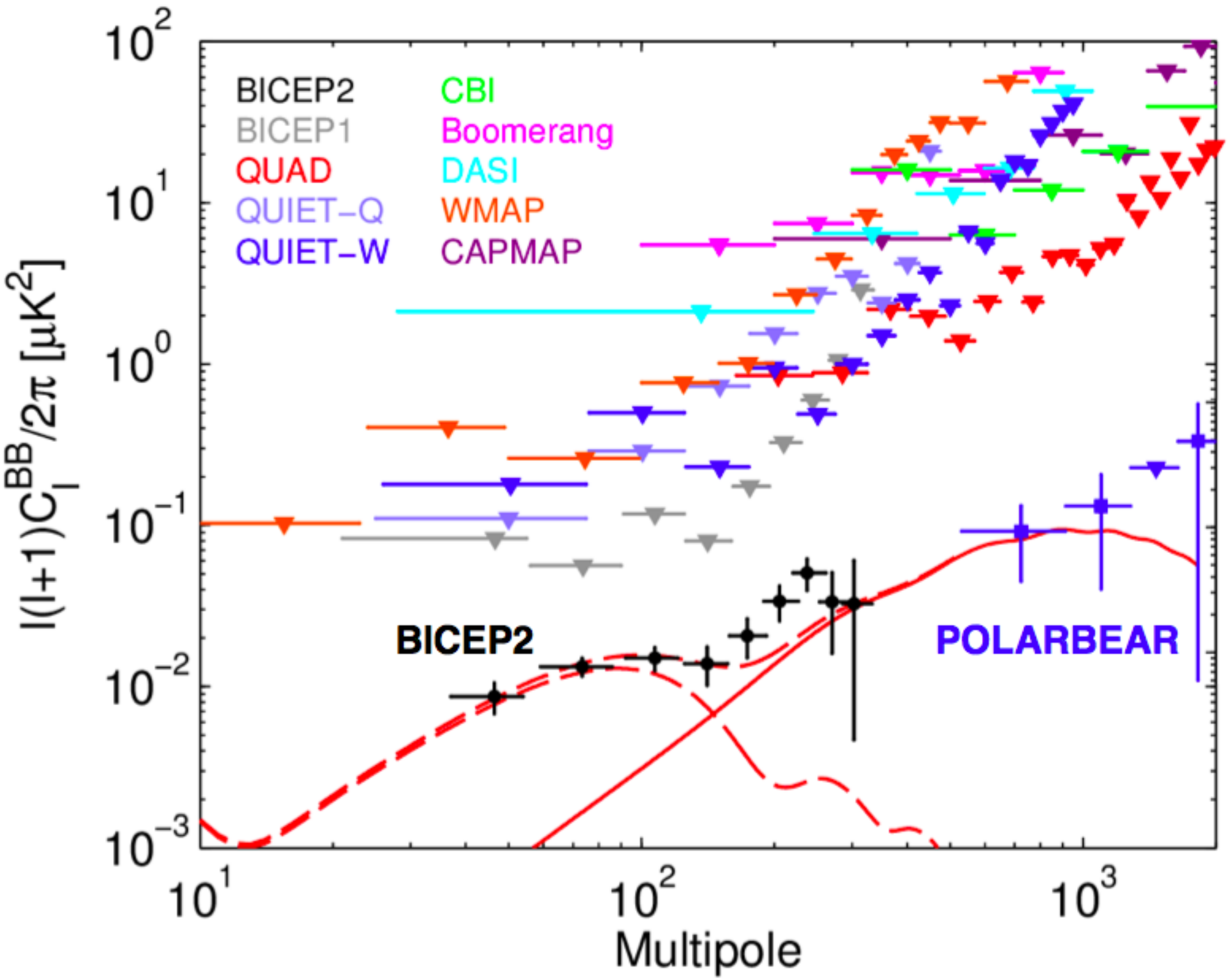
running $$\frac{\mathrm{d}n_s}{\mathrm{d}\ln k} = -16\epsilon\eta + 24\epsilon^2 + 2\xi^2$$

consistency relation $$r \simeq 16\epsilon \simeq -8n_t$$

Measuring those parameters yields constraints on the inflationary potential and hence on the physics of inflation

B-modes detected !

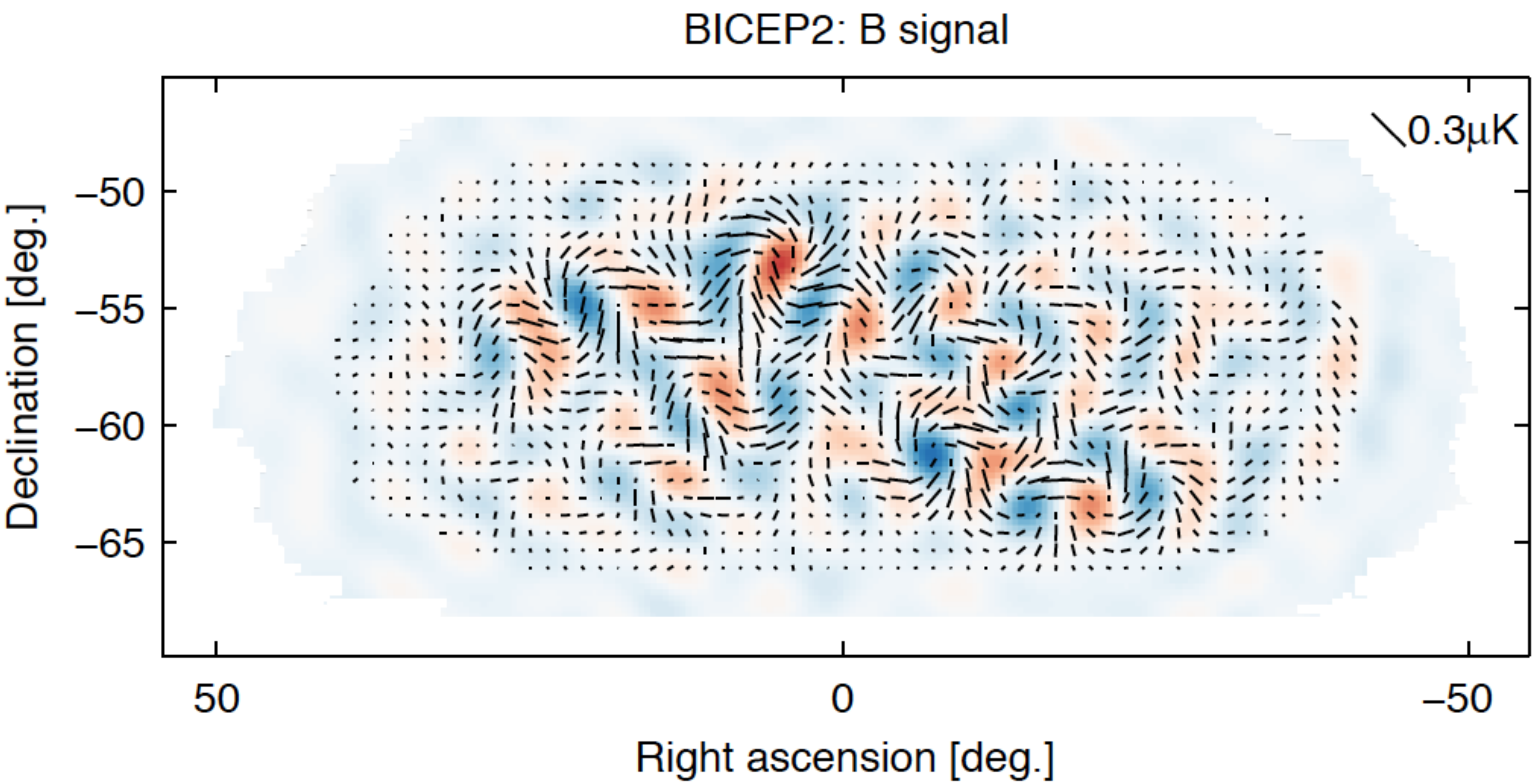
BICEP2: Ade et al., PRL 112, 24, id.241101 arXiv:1403.3985



POLARBEAR
Ade et al., ApJ 794, issue 2, Article id. 171

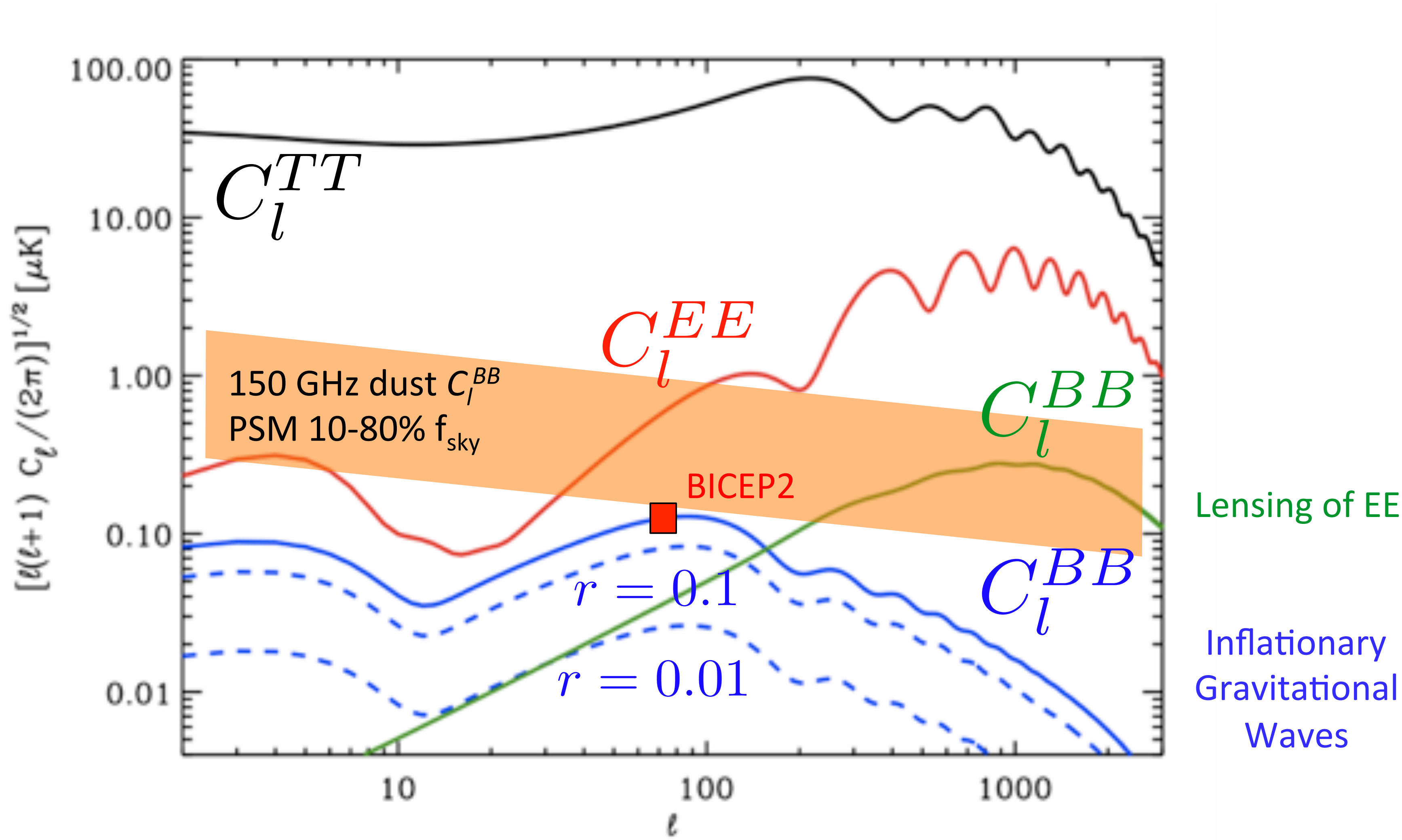
B-modes detected !

Ade et al., PRL 112, 24, id.241101 arXiv:1403.3985



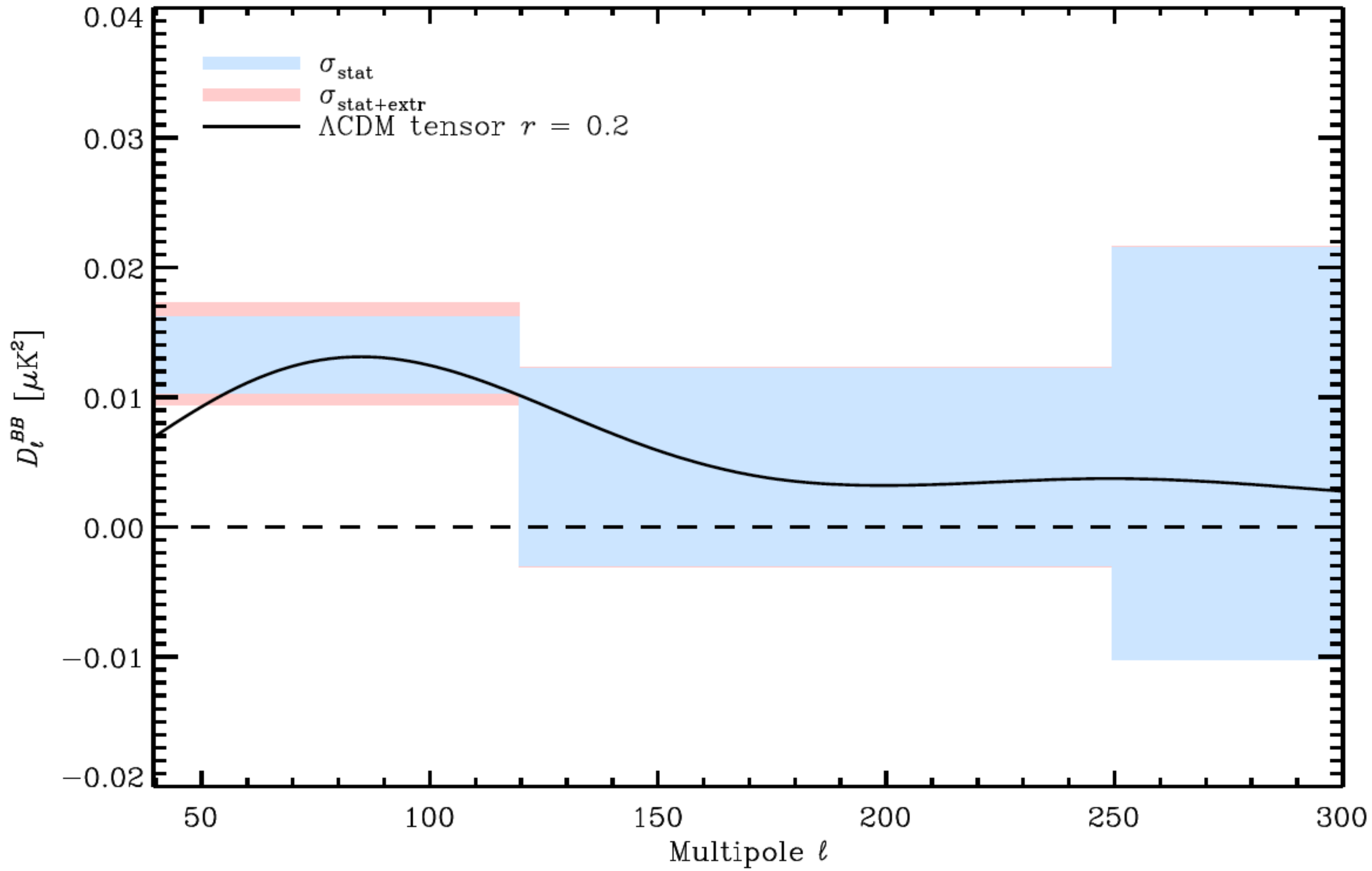
Amplitude of signal = about 0.1 uK

Dust B-mode C_l

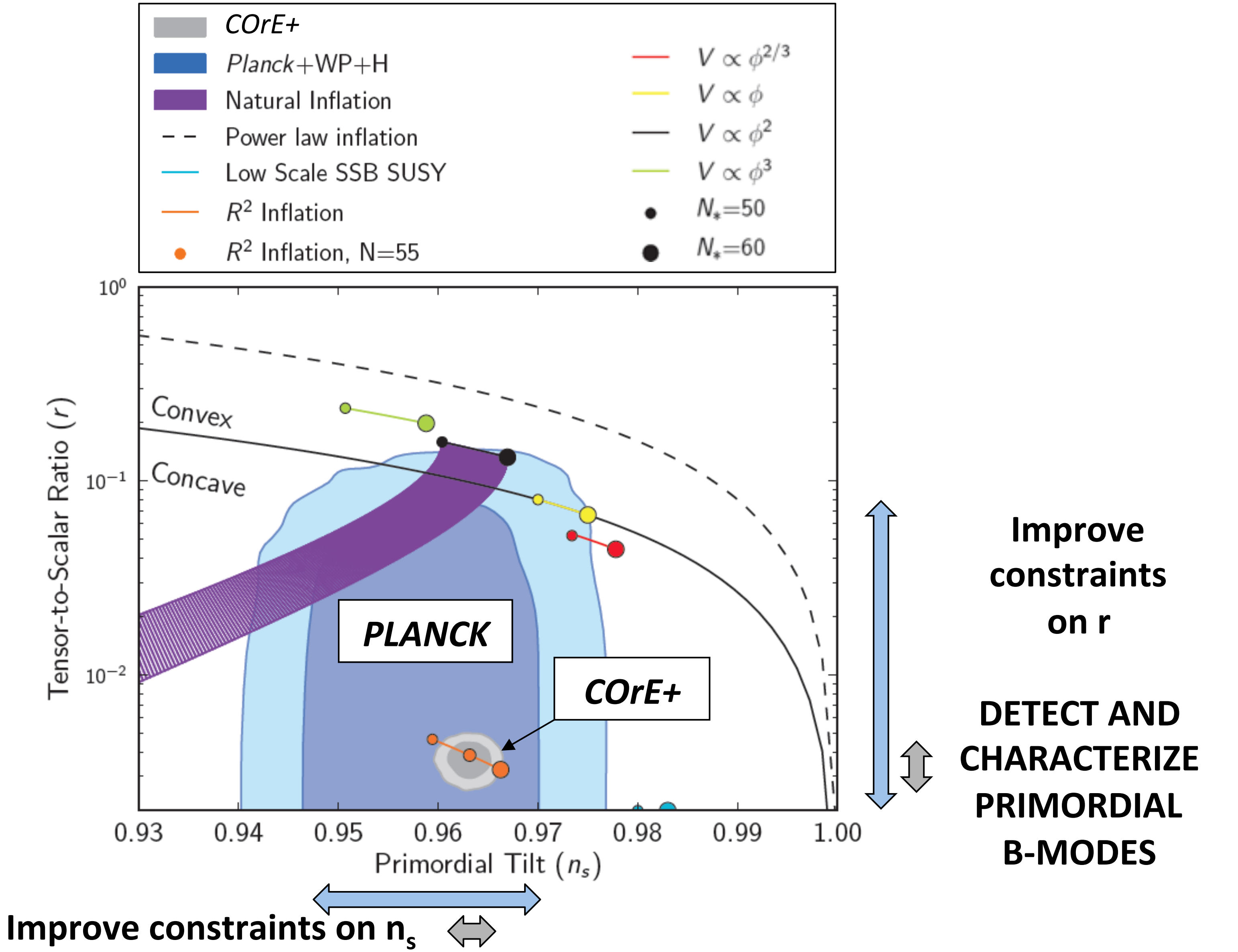


See also Flauger et al., JCAP 08, 039; Liu et al, ApJL 789, Issue 2, L29

Planck estimate of dust B-modes in BICEP2 field



CMB B-modes and inflation



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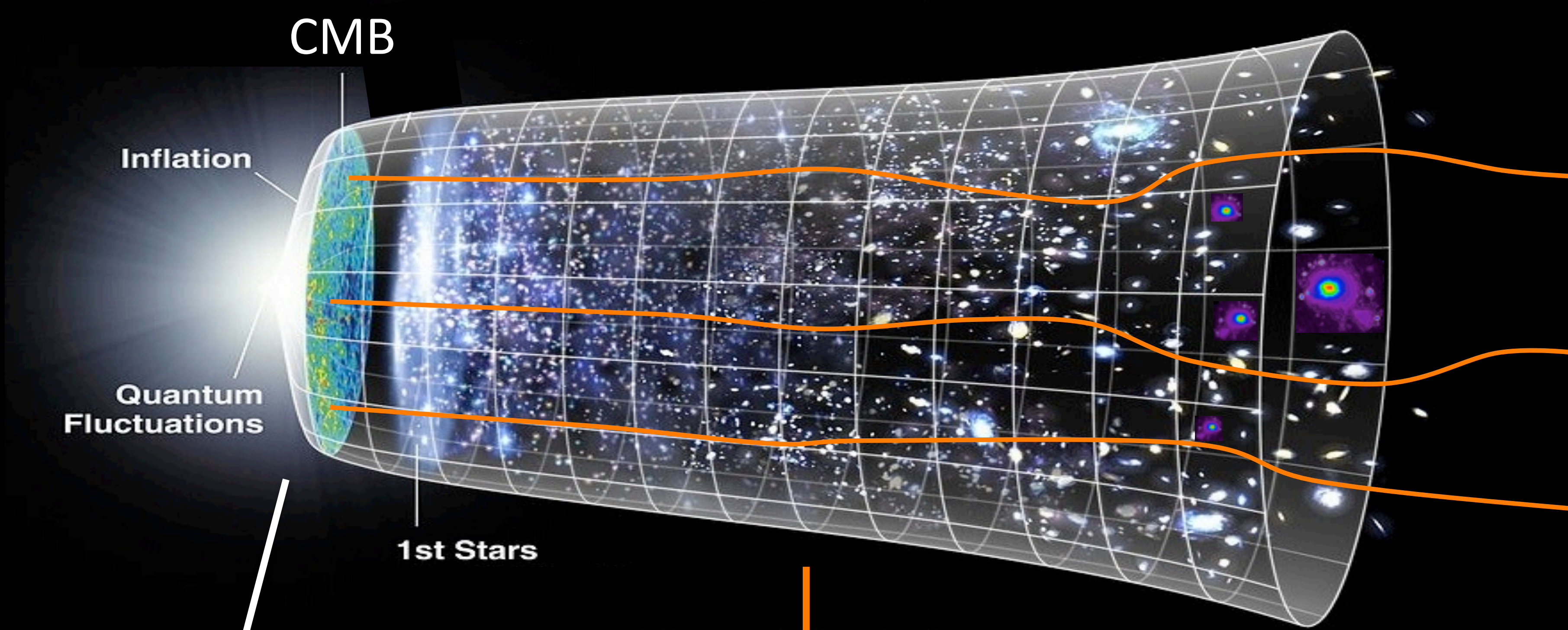
CMB lensing



Inflation

Physics at ≈ 10^{16} GeV

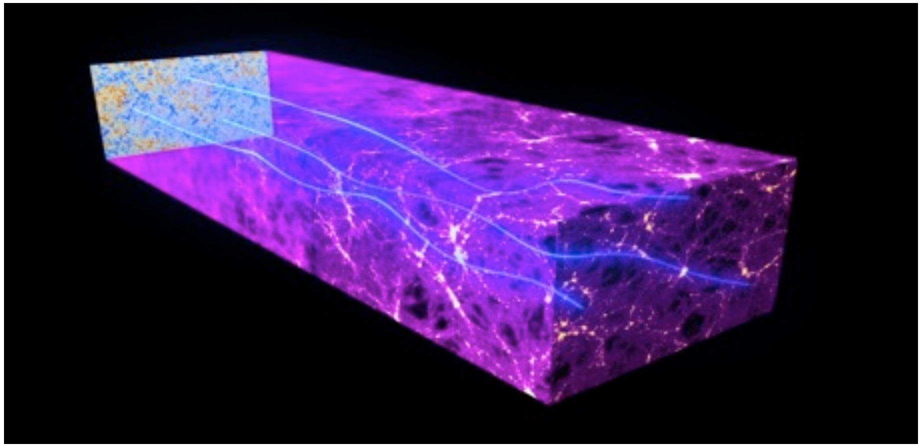
$E_{COrE+} > 10^{12} \times E_{LHC}$

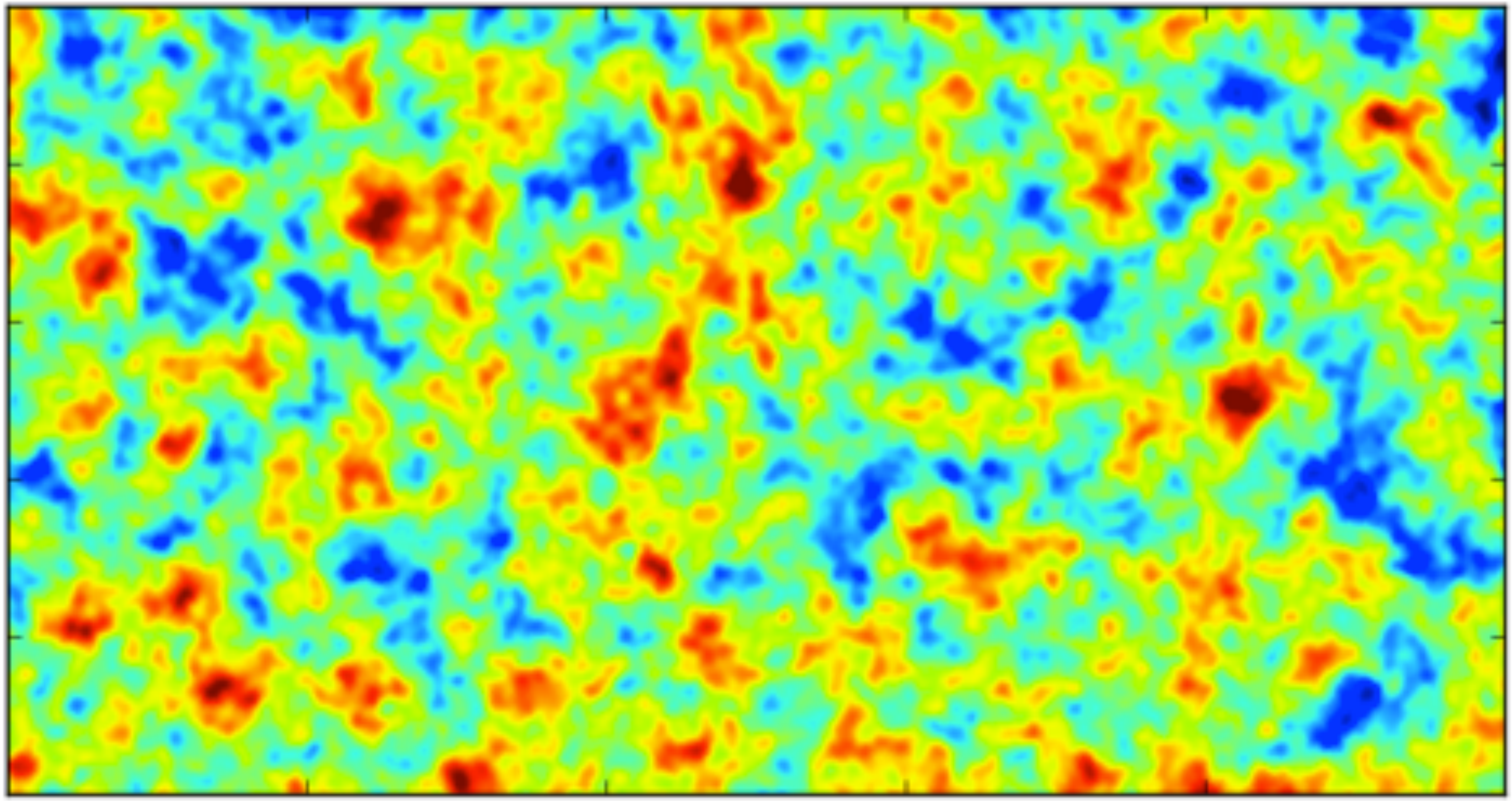
$z \approx 1\text{-}3$

Gravitational lensing

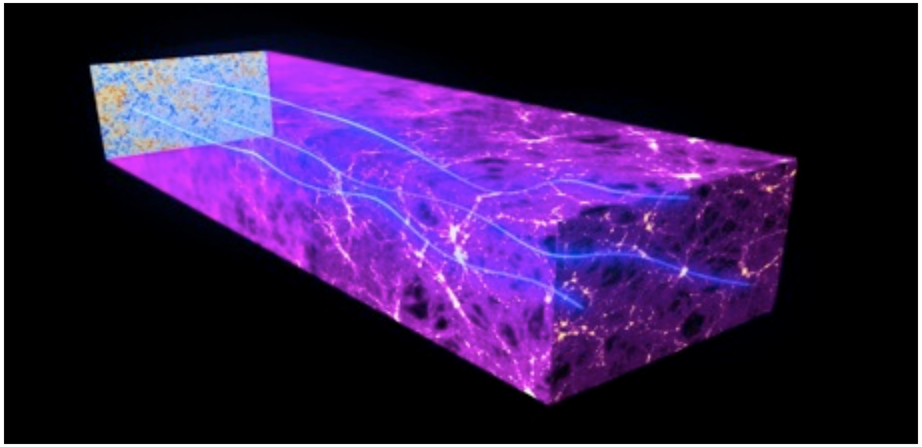
Dark matter distribution

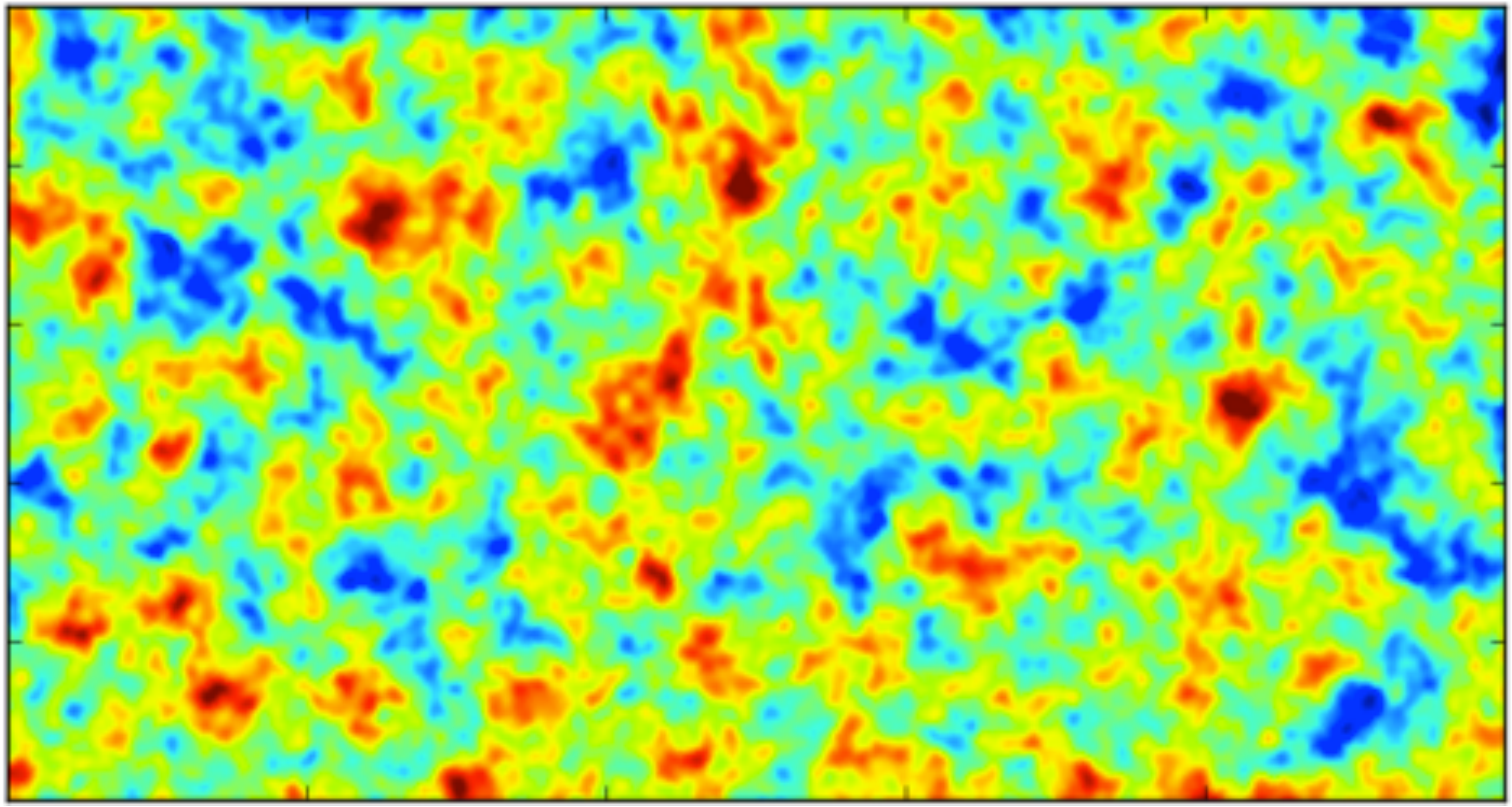
Lensing



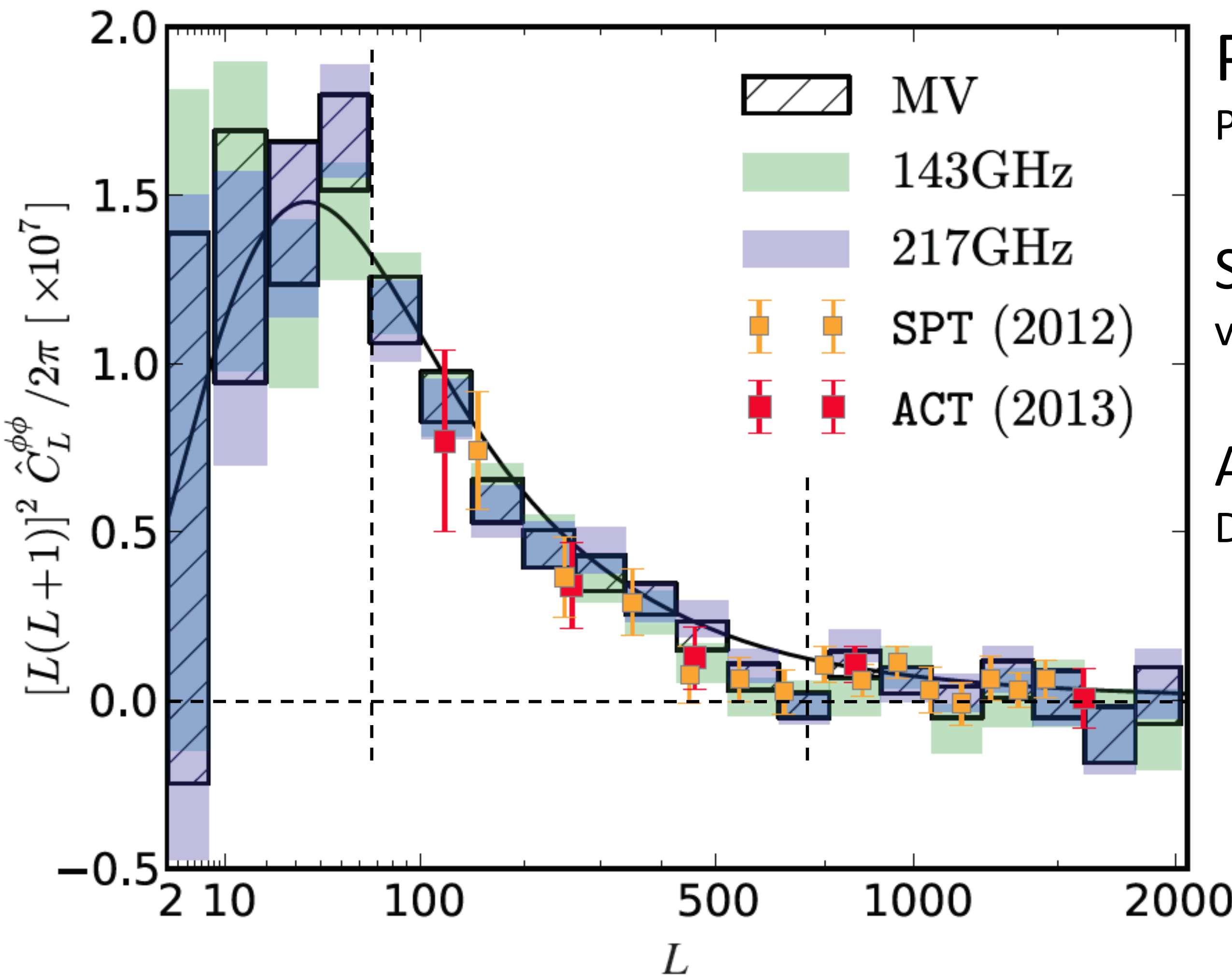


Lensing





Lensing potential power spectrum



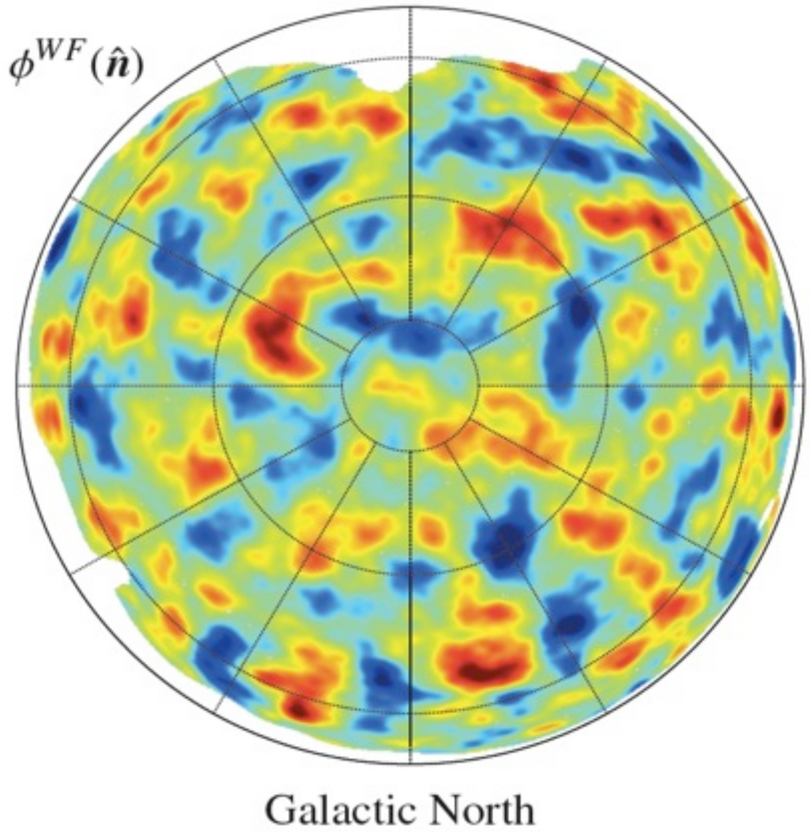
Planck
Planck 2013 results. XVII.

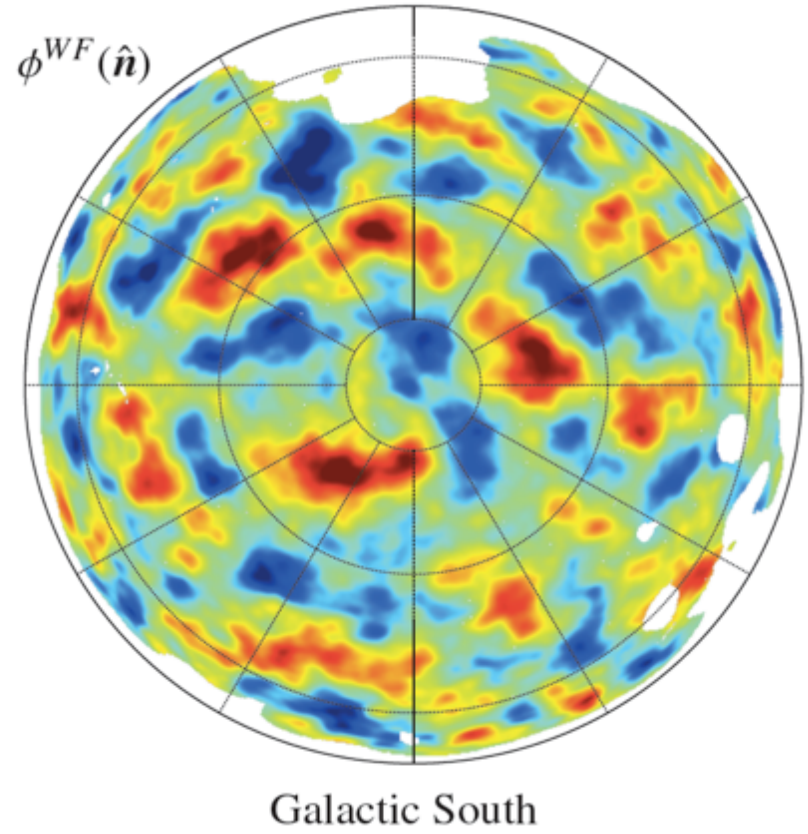
SPT
van Engelen et al 2012

ACT
Das et al 2013

Reconstruction of the lensing potential

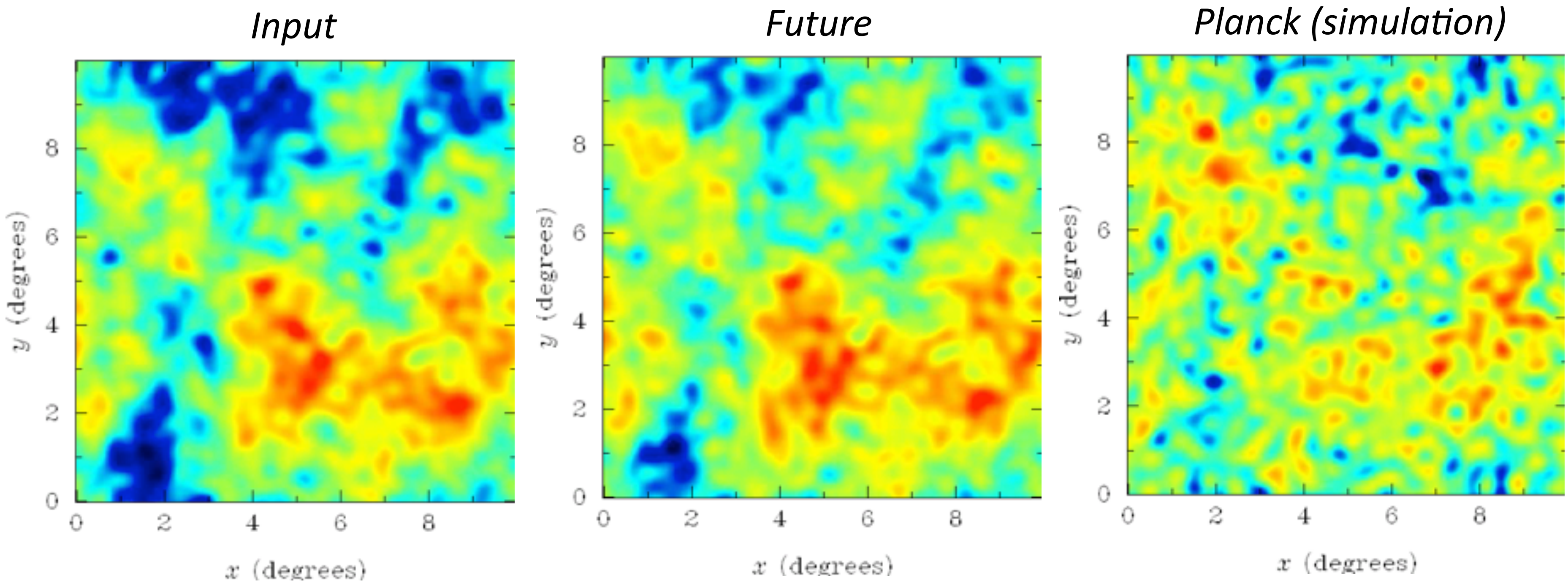
Planck 2013 results. XVII.





The reconstruction is noisy (S/N ≈0.6 – more noise than signal here)

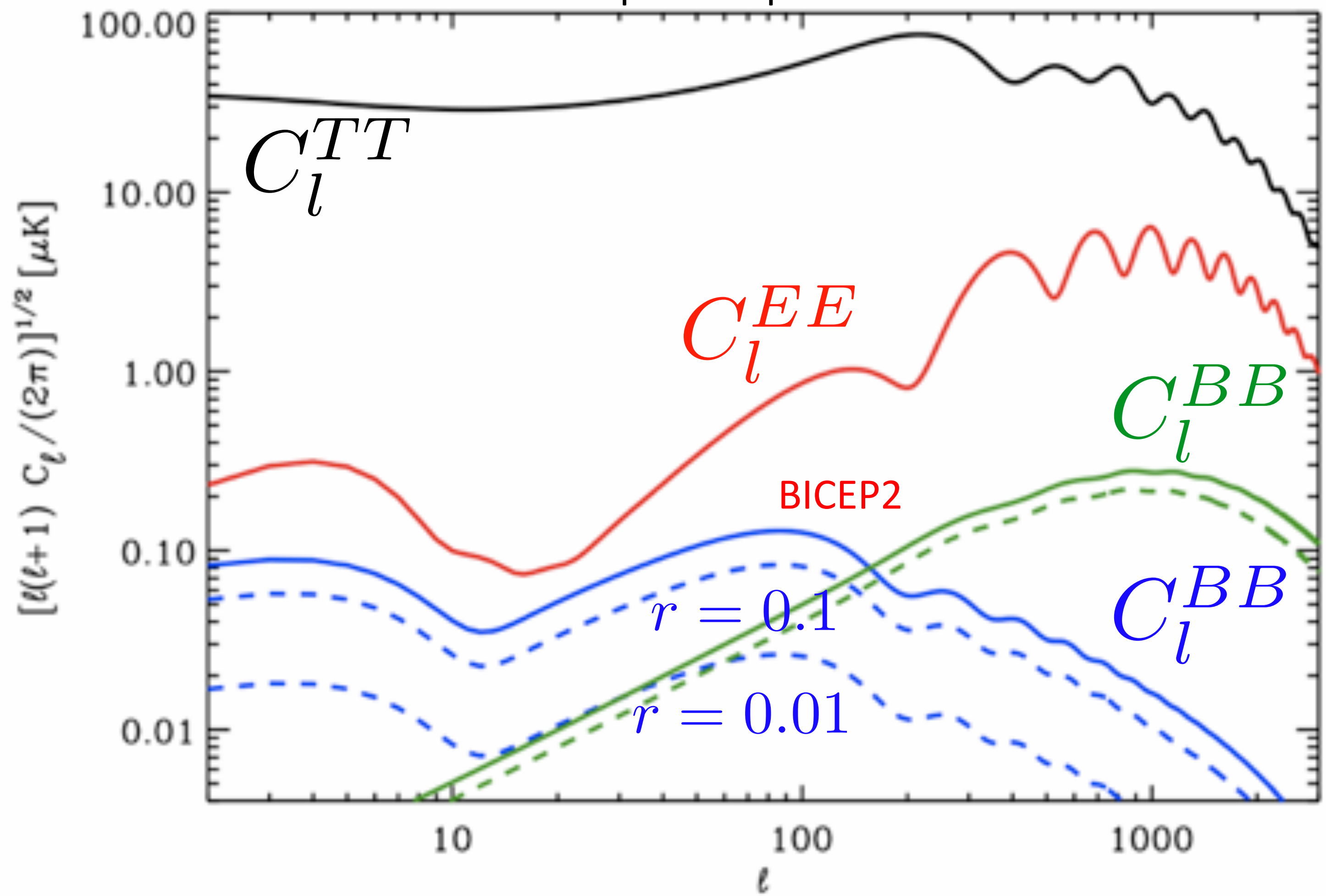
Reconstruction of the lensing potential



- Polarization: 3 observables for 3 unknown (temperature 1 for 2)
- High-fidelity reconstruction of the LOS integral of the gravitational potential all the way to recombination.
- Connected to a map of projected mass.
- Complementary to Euclid, which is limited to redshifts < 1.5.

Temperature & Polarisation CMB C_l

plot adapted from J. Carlstrom's P5 talk

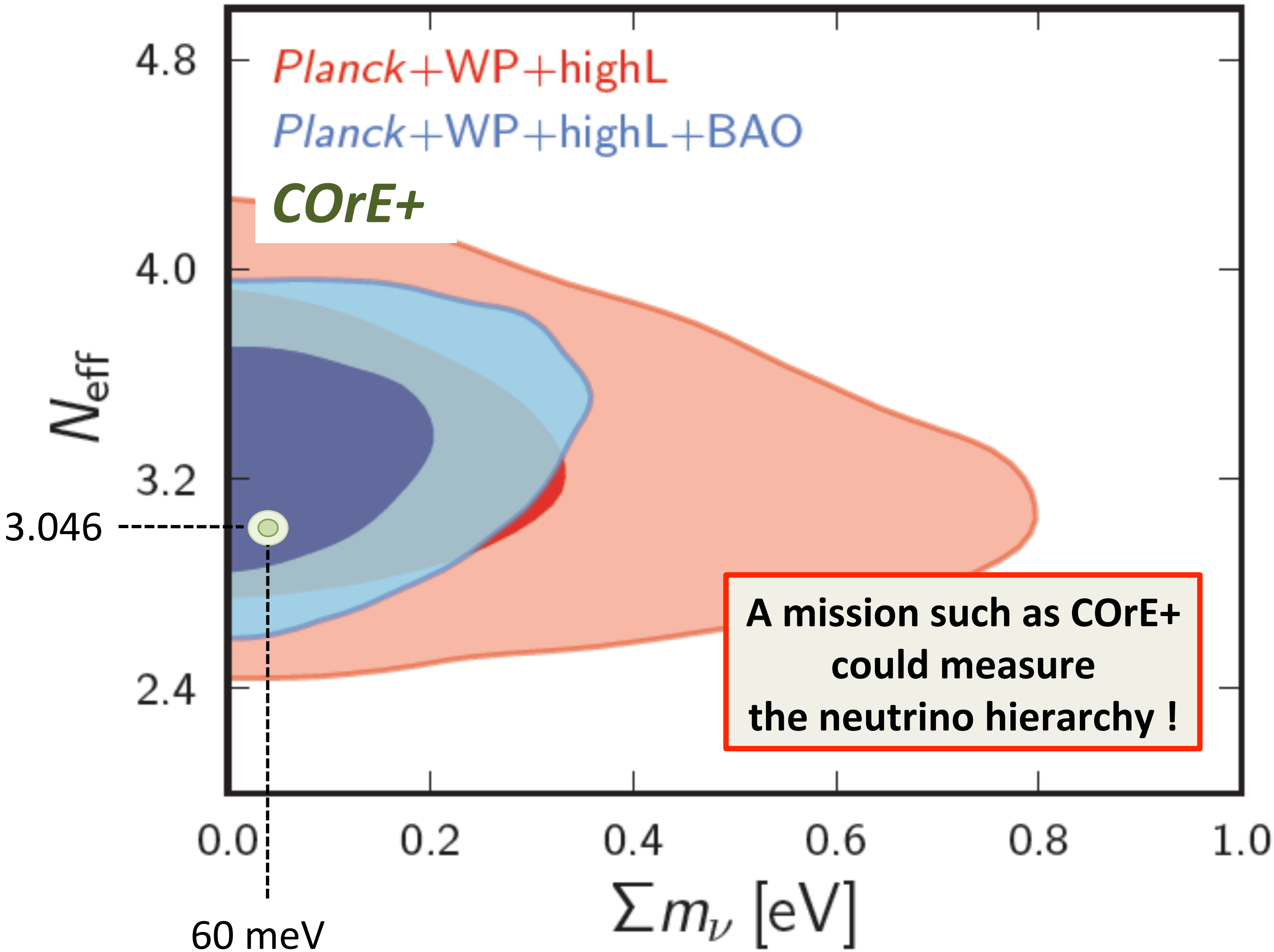


Lensing of EE

$\Sigma m_\nu = 0$ eV

$\Sigma m_\nu = 1.5$ eV

Constraining the neutrino sector



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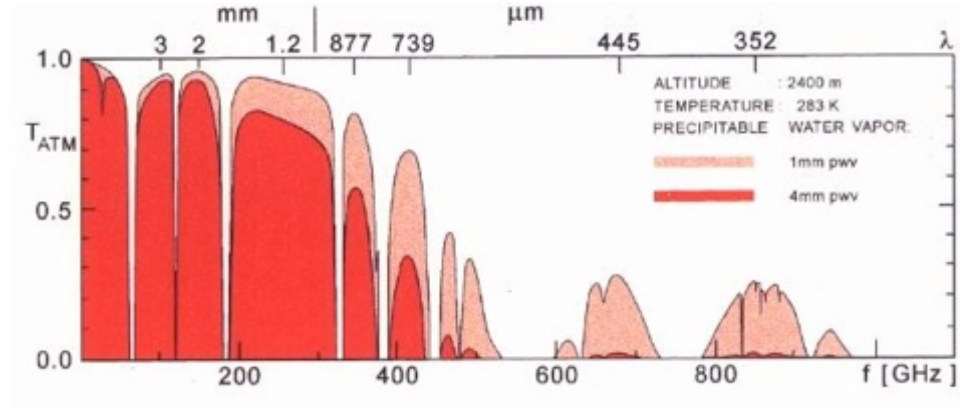
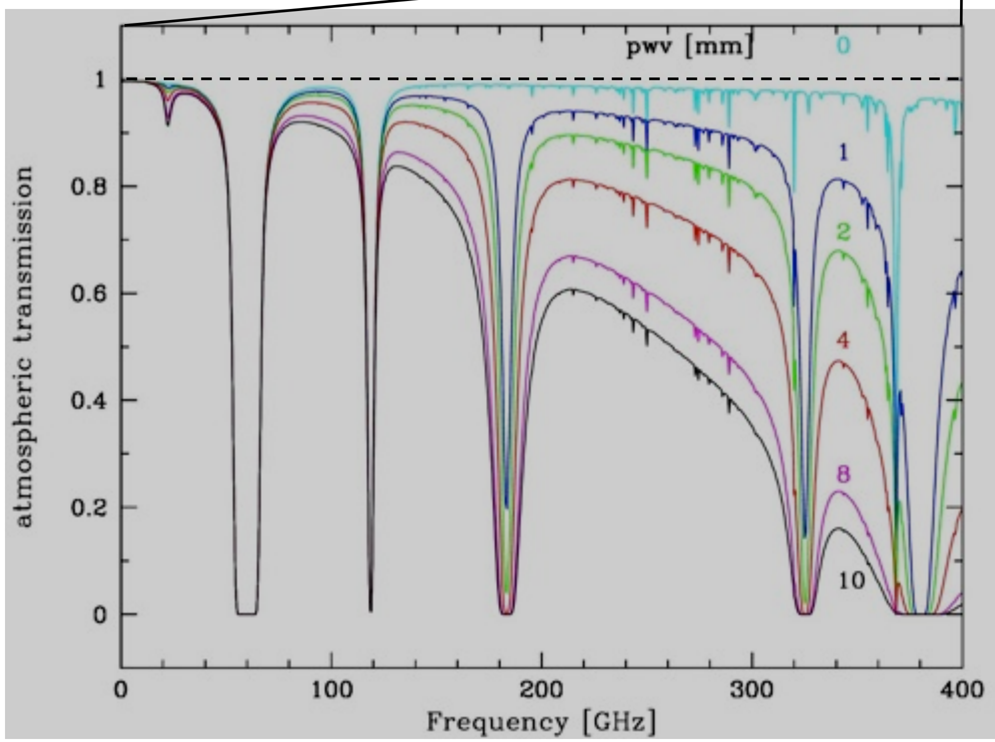
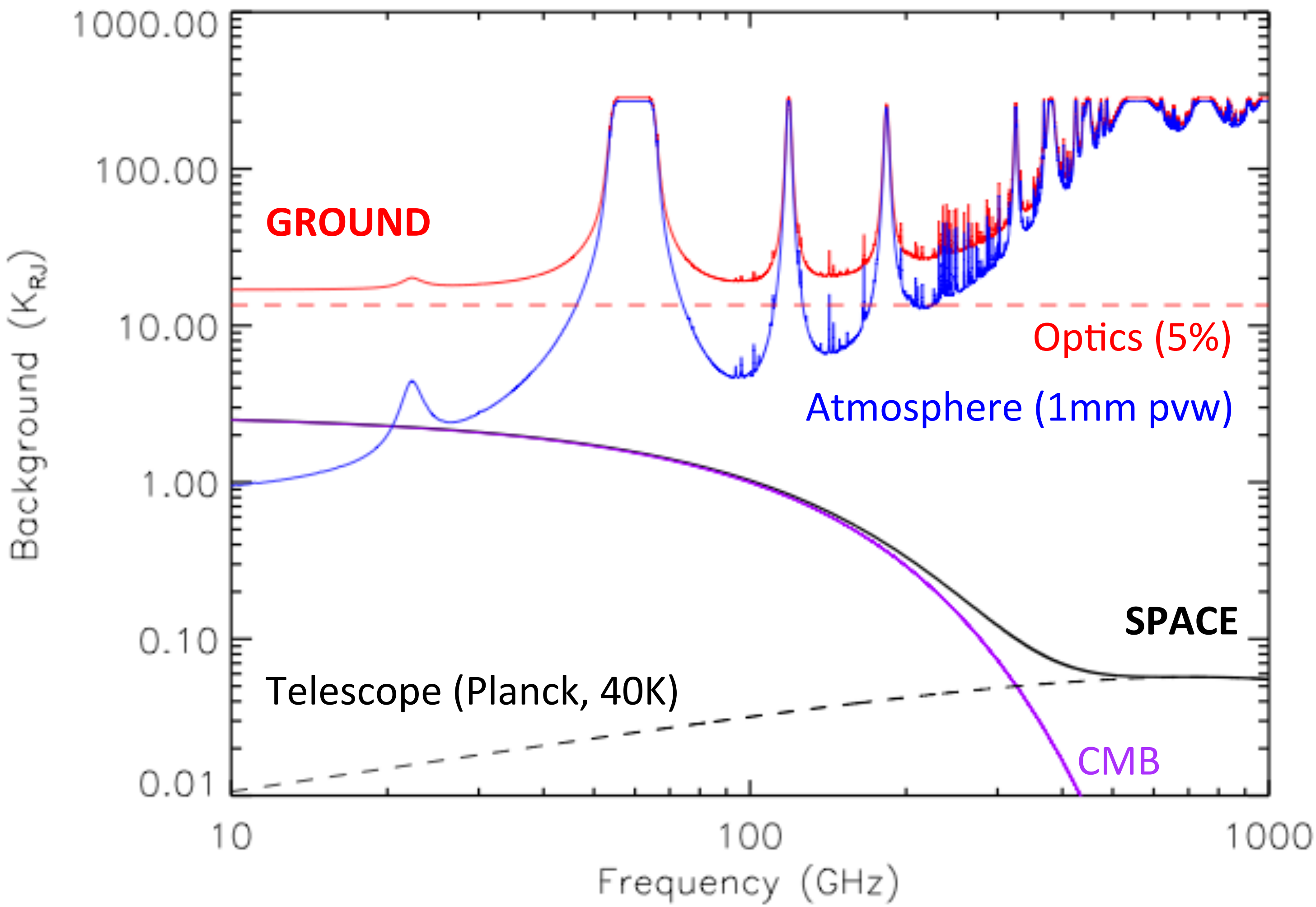
Atmosphere !



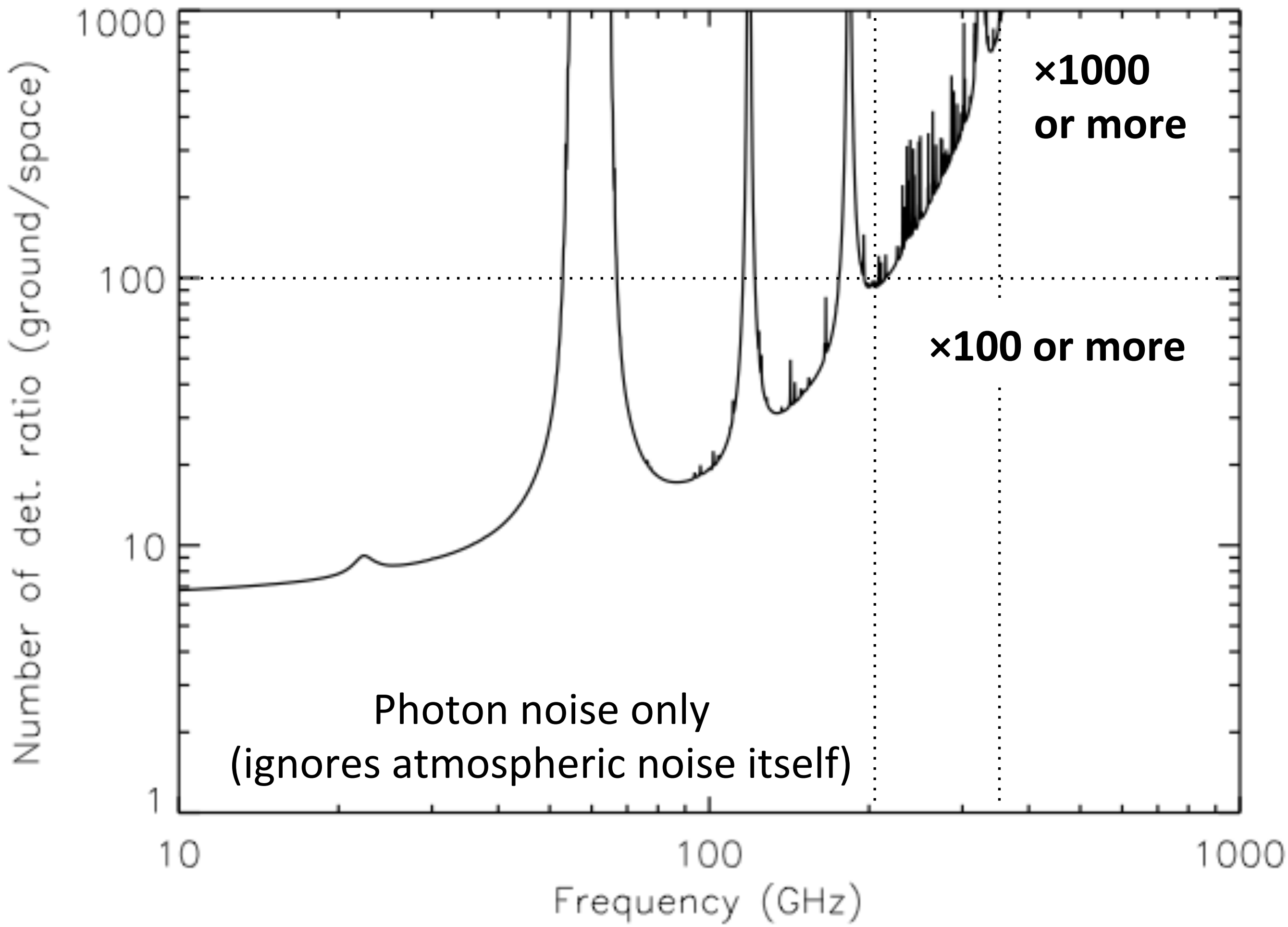
transmission and emission



Comparison of the sky background

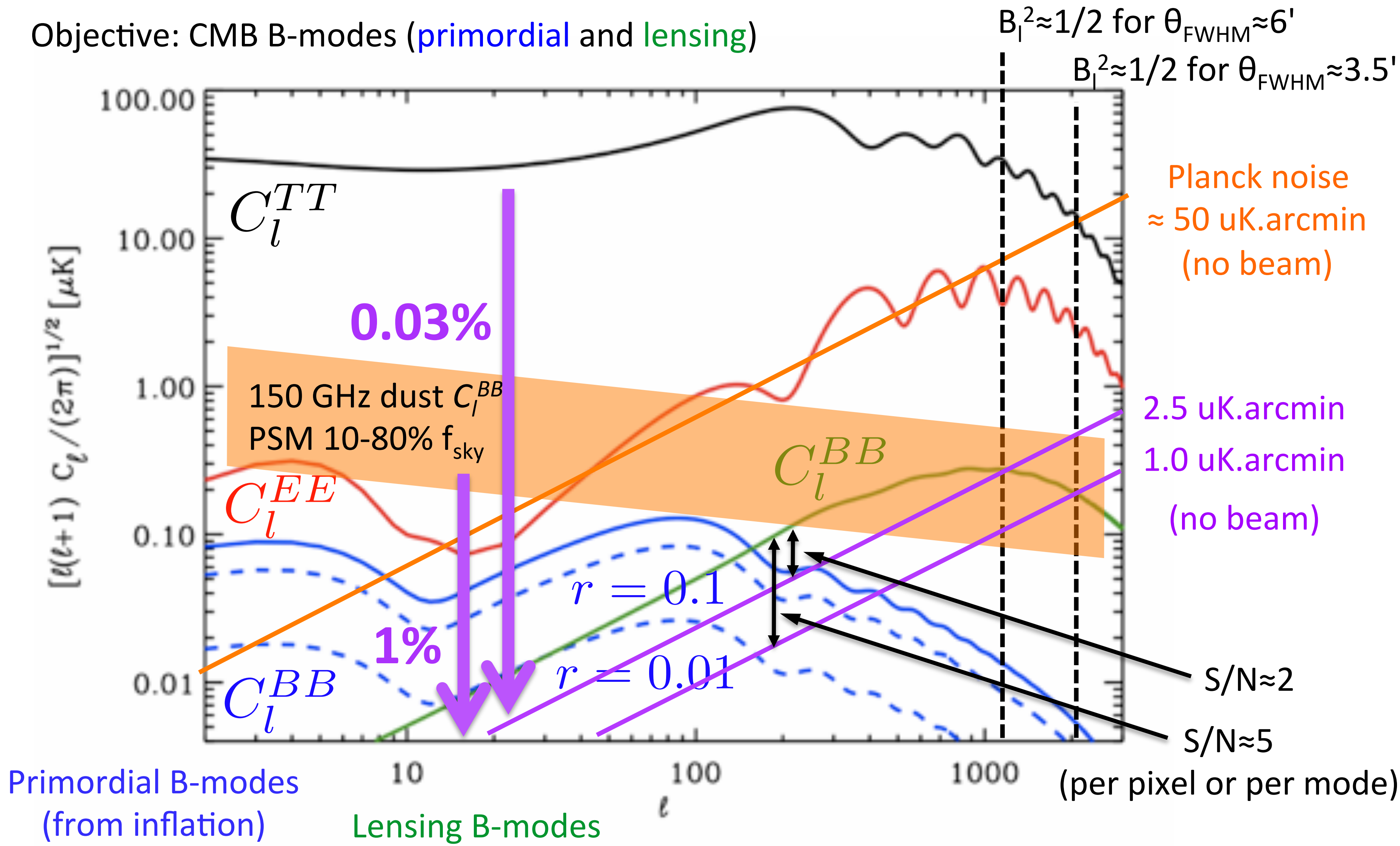


Sensitivity comparison

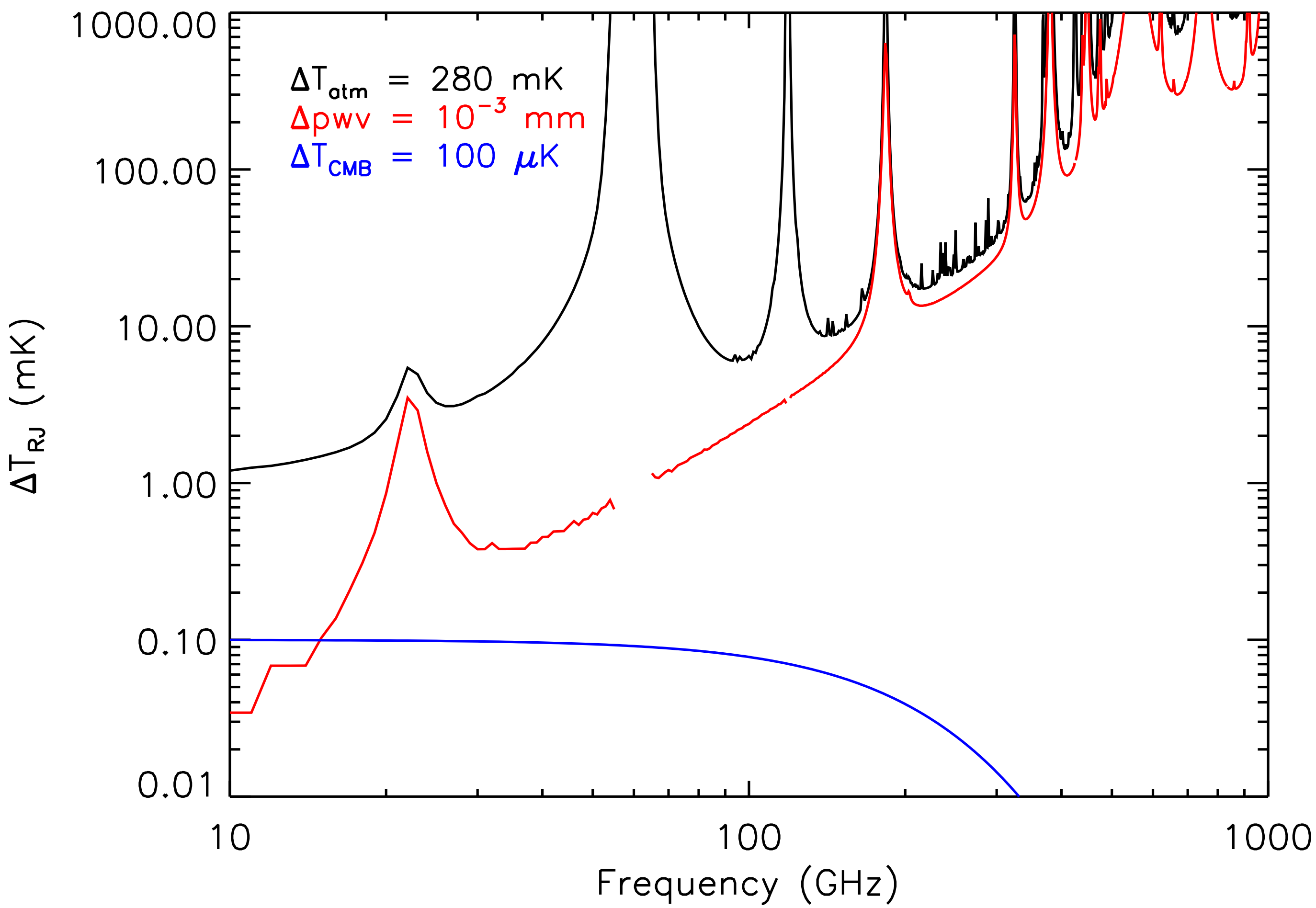


Reject foreground contamination

Objective: CMB B-modes (primordial and lensing)



Atmospheric emission



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COrE+ and ESA M4 call

- ESA M4 call for a medium mission.
  - Budget 450 M€ (ESA) + National contributions for the science payload (including international contributions, e.g. from NASA);
  - Call issued August 19th, 2014; Proposal due January 15th, 2015;
  - If pre-selected, definition phase from 2015 to 2018.
  - Selection in 2018; Launch in 2025.

- Primary objectives:
  - primordial B-modes,
  - N_{eff}, Σm_ν, Y_{He}, all extensions to the standard model of cosmology impacting CMB maps or spectra.

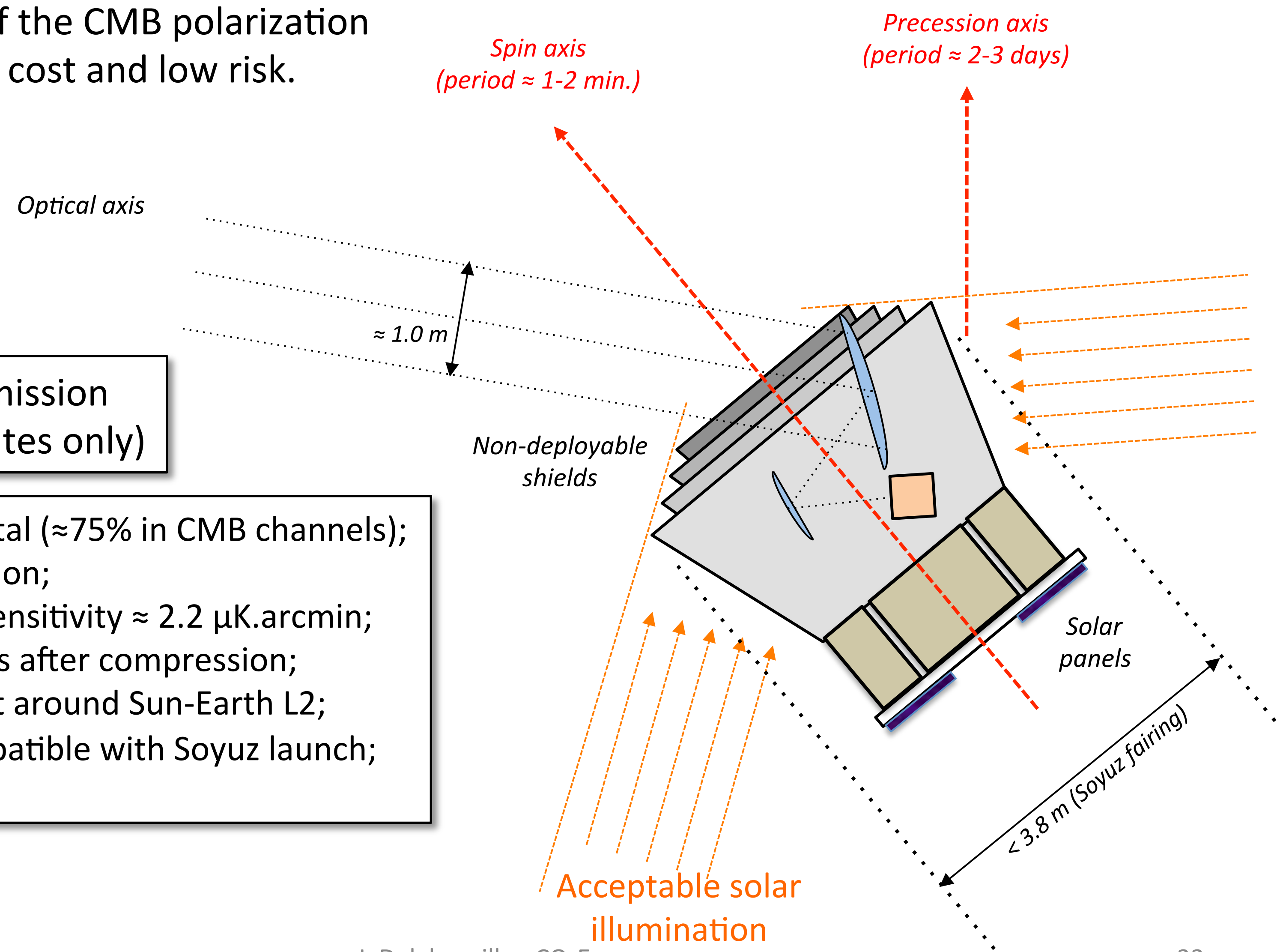
- Strong interest and support in European countries for such a future CMB mission, e.g.
  - CMB polarization top in France prospective plan for space science;
  - PRISM evaluation: " The SSC was fully convinced of the great importance of the core CMB science and encourages the CMB community to consider proposing this science for a future M-class mission."

COrE+ light

OBJECTIVE: Most of the CMB polarization science, at reduced cost and low risk.

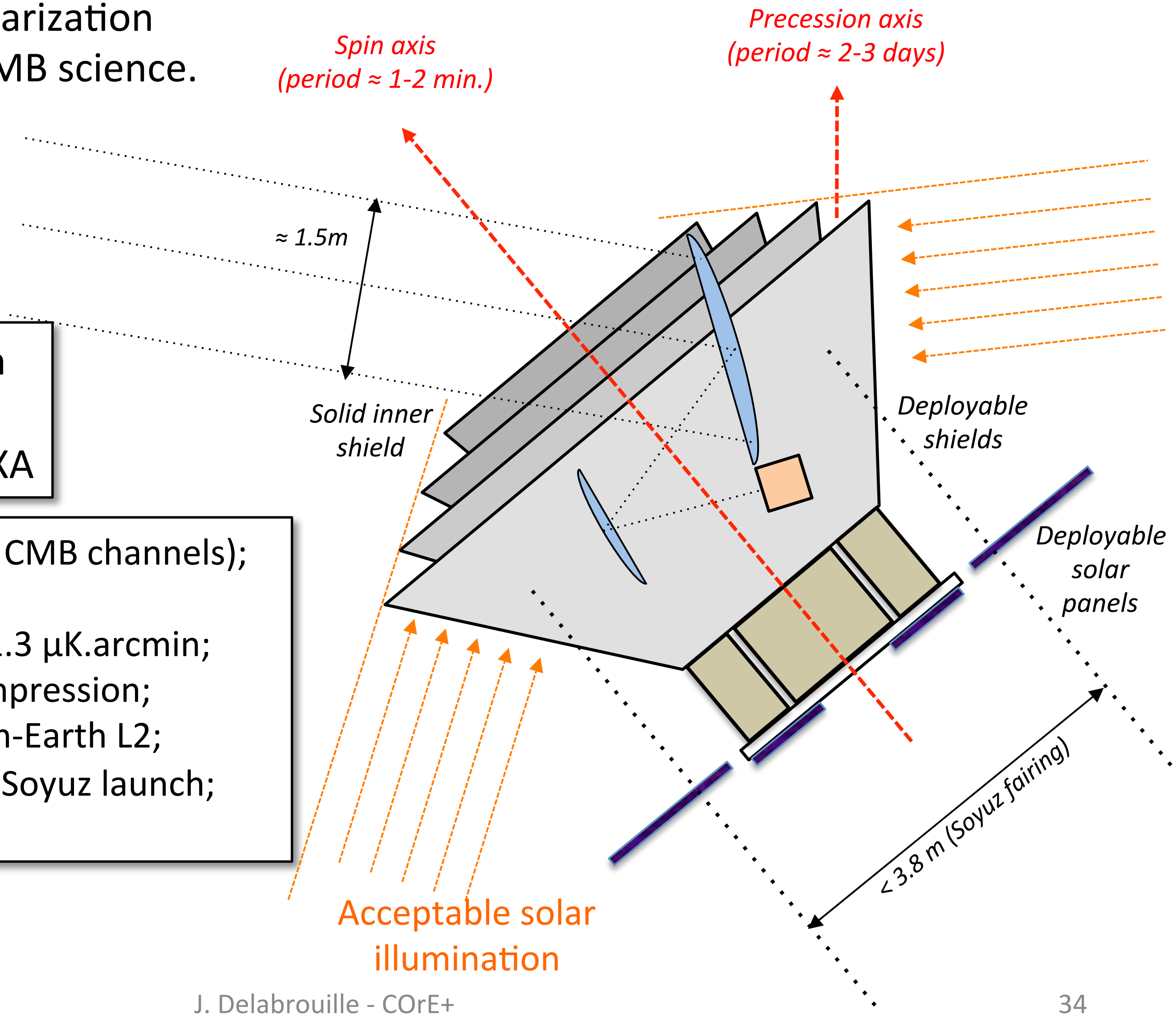
OPTION: ESA mission
(ESA member states only)

≈2000 detectors total (≈75% in CMB channels);
3 years of observation;
CMB polarization sensitivity ≈ 2.2 μK.arcmin;
Data rate ≈ 3 Mbit/s after compression;
Large lissajous orbit around Sun-Earth L2;
Mass and size compatible with Soyuz launch;
Budget 550 M€.



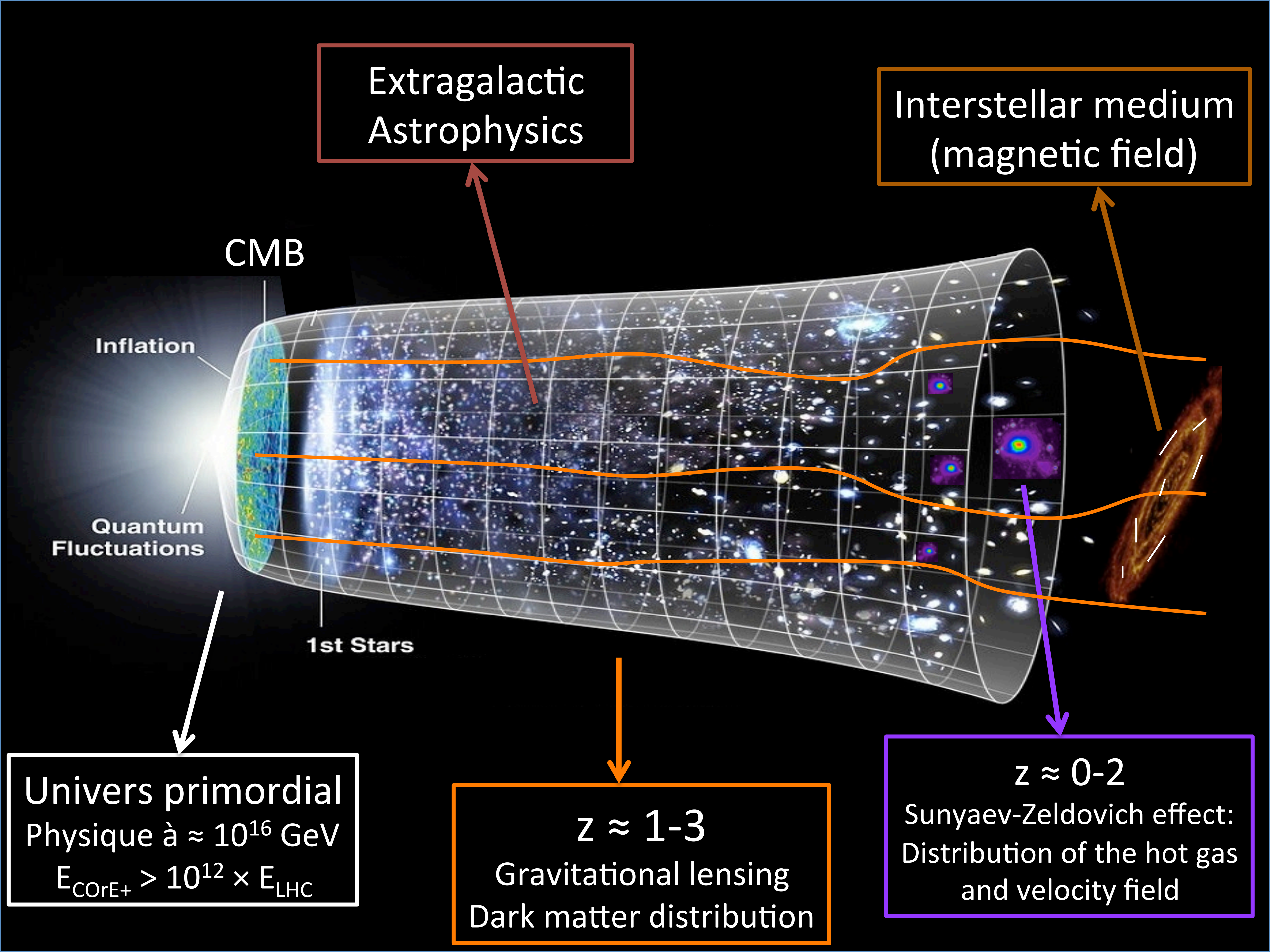
COrE+ extended

OBJECTIVE: Ultimate CMB polarization mission, and extensive non-CMB science.



OPTION: ESA mission with substantial international contribution, e.g. NASA, JAXA

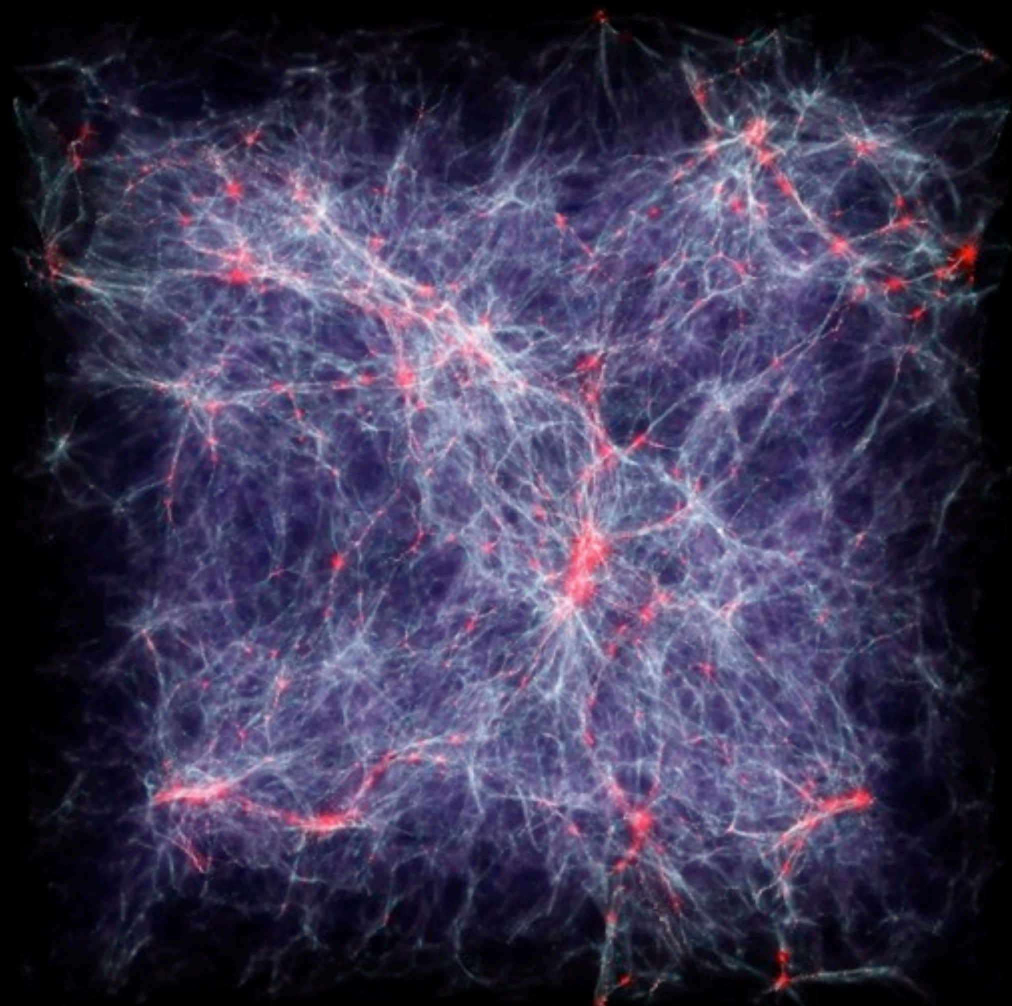
≈6000 detectors total (≈65% in CMB channels);
3 years of observation;
CMB polarization sensitivity ≈ 1.3 μK.arcmin;
Data rate ≈ 15 Mbit/s after compression;
Large lissajous orbit around Sun-Earth L2;
Mass and size compatible with Soyuz launch;
Budget 700 M€.



Extragalactic
Astrophysics
Interstellar medium
(magnetic field)
CMB
Inflation
Quantum
Fluctuations
1st Stars
Univers primordial
Physique à ≈ 10^{16} GeV
$E_{COrE+} > 10^{12} \times E_{LHC}$
z ≈ 1-3
Gravitational lensing
Dark matter distribution
z ≈ 0-2
Sunyaev-Zeldovich effect:
Distribution of the hot gas
and velocity field

Detection of the cosmic web

25 h^{-1} Mpc
Planck ΛCDM



In filaments:
$T \approx 10^5$-10^7 K
$\rho_{gas} \approx 5$-$200 \times \rho_{gas}$

$T \approx 10^4$ K  $T \approx 10^7$ K

Conclusion

Let's do it !