The Cosmic Origins Explorer

Jacques Delabrouille, APC (Paris)
On behalf of the CORE collaboration

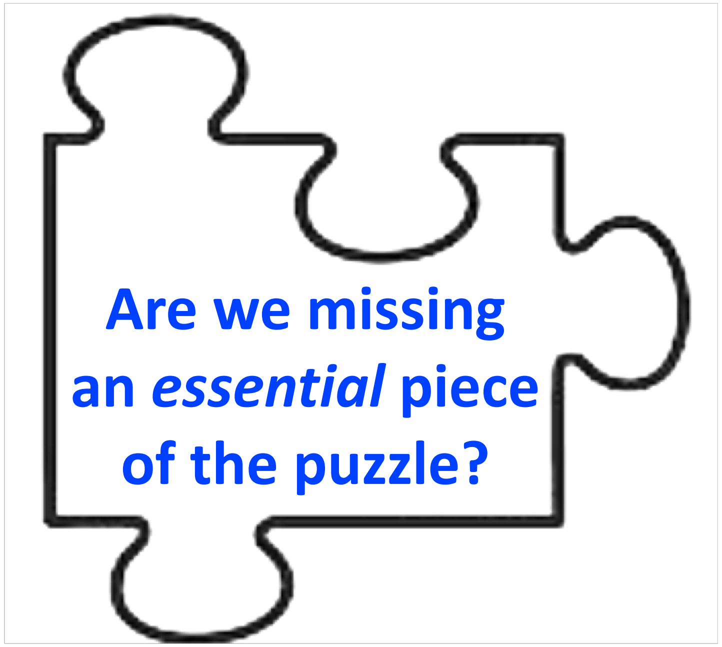
Outline

- Why the CMB again ?
- Why space ?
- CORE
- Summary

Standard paradigm

- A standard model of Cosmology has emerged: ΛCDM
- The CMB is the main observable that established the paradigm and determined its main parameters to percent accuracy
- Compatible with many cosmological observables ("concordance")
- However, major open questions remain
  - Inflation? Did it happen? At what energy scale? What drives inflation?
  - Dark matter? What is it? Does it interact? Does it decay? …?
  - Dark Energy?
  - Anomalies in the CMB? Low low multipoles, NS asymmetry?
  - Tensions (H_0, σ_8…)?
- ***Maybe in fact we do not know so much yet about our Universe...***

Also to keep in mind...

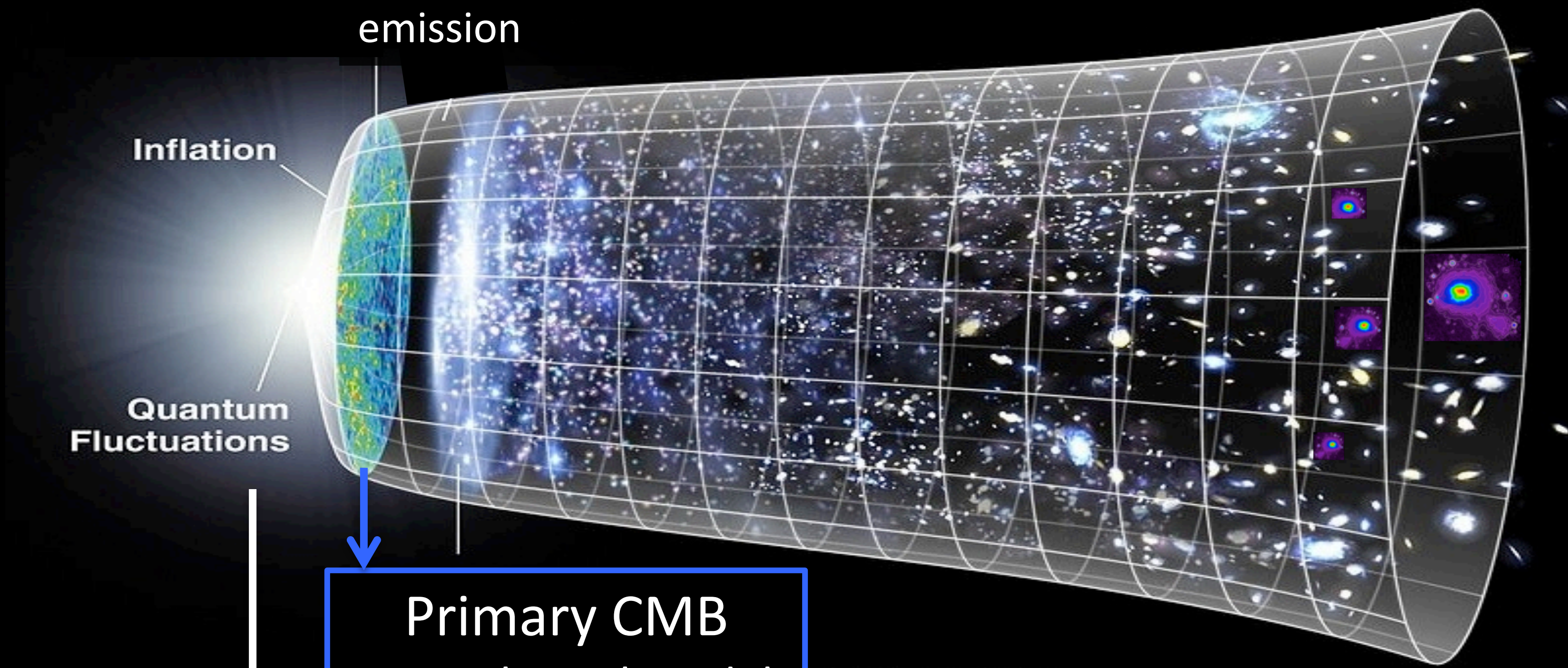


Serendipitous discoveries
(Universe expanding,
Dark matter, CMB,
Accelerated expansion)...

Srutinize the CMB

1st order : The CMB is relic radiation that was emitted 13 billion years ago, at $z \sim 1000$, and never interacted since then

CMB blackbody emission



Primary CMB
Cosmological model

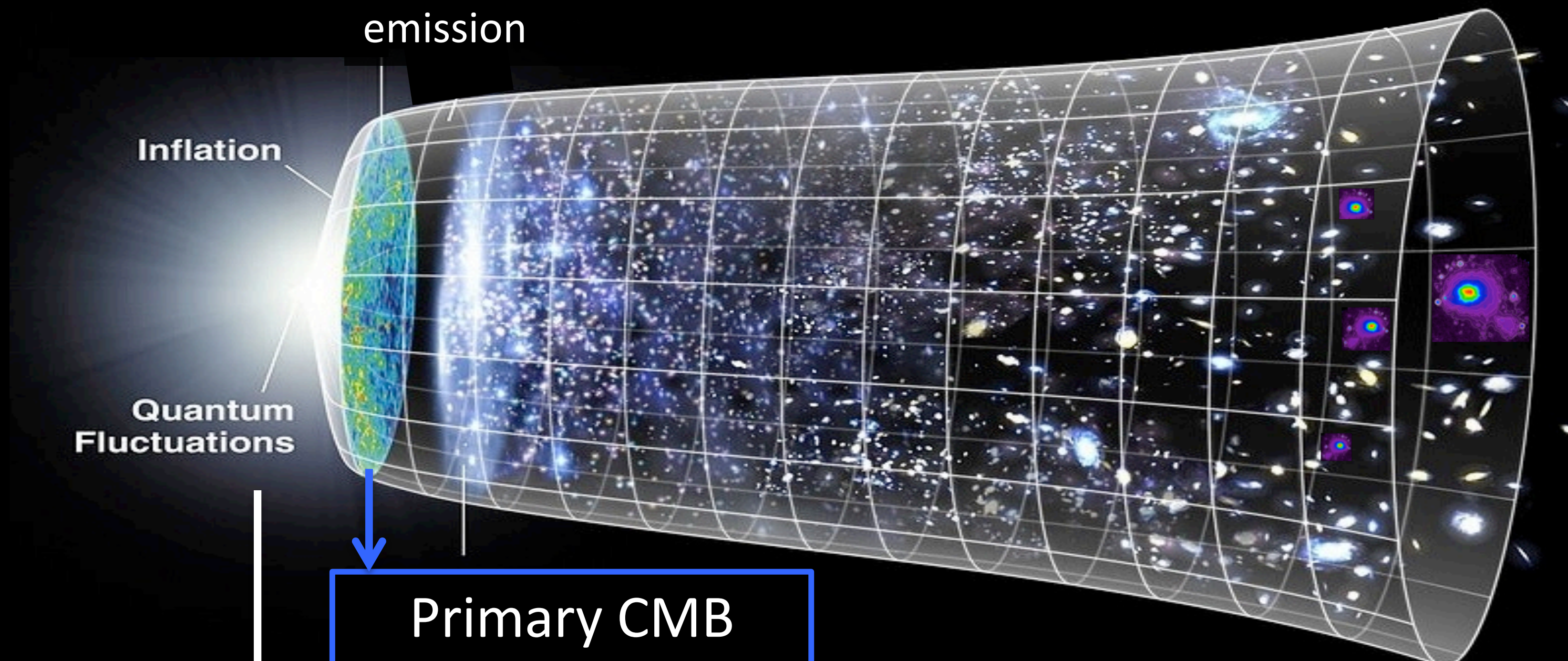
Inflation
Physics at ≈ 10^{16} GeV
$E \approx 10^{12} \times E_{LHC}$

Credit:
Adapted from WMAP / NASA

Srutinize the CMB

2nd order : The CMB is a bath of photons that fills the entire universe, *and interacts with everything in there!*

CMB blackbody emission



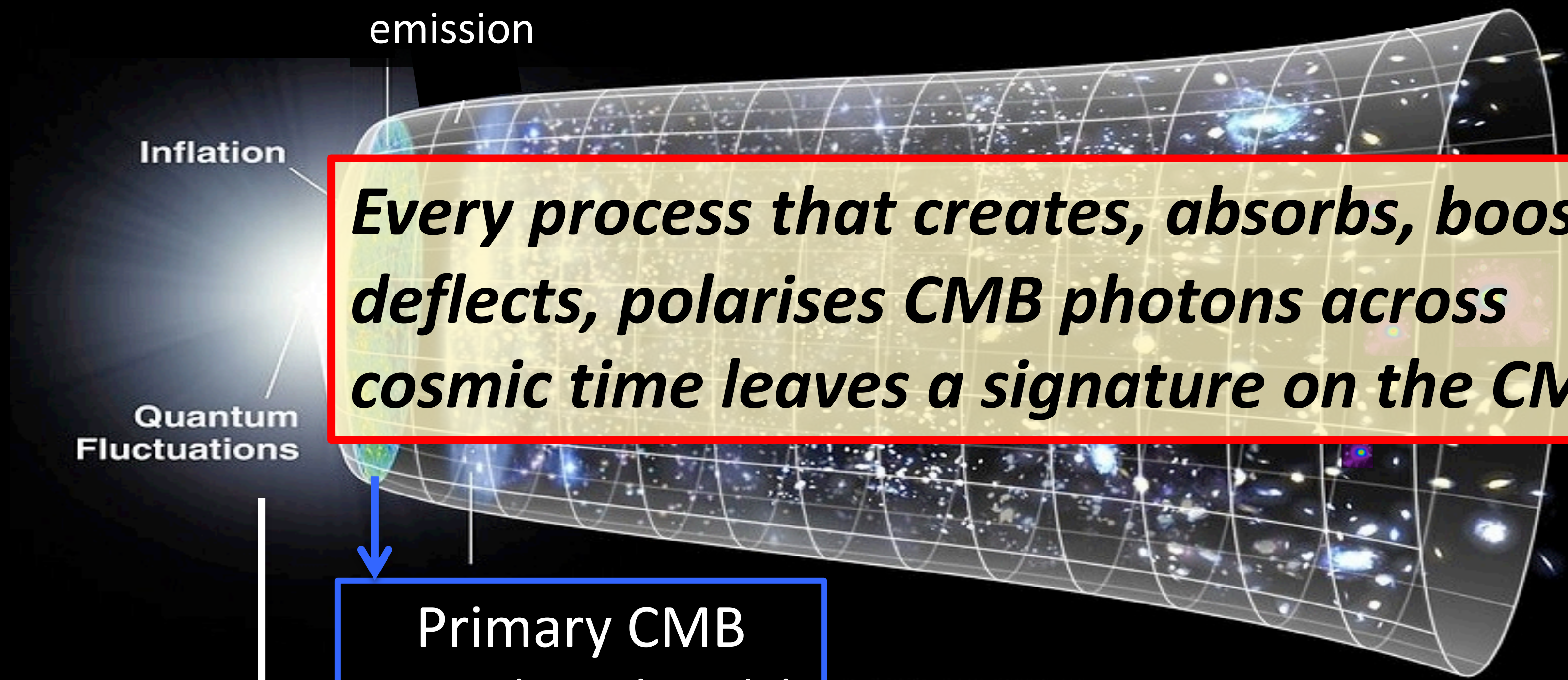
Primary CMB
Cosmological model

Inflation
Physics at $\approx 10^{16}$ GeV
$E \approx 10^{12} \times E_{LHC}$

Srutinize the CMB

2nd order : The CMB is a bath of photons that permeates the entire universe, *and interacts with everything in there!*

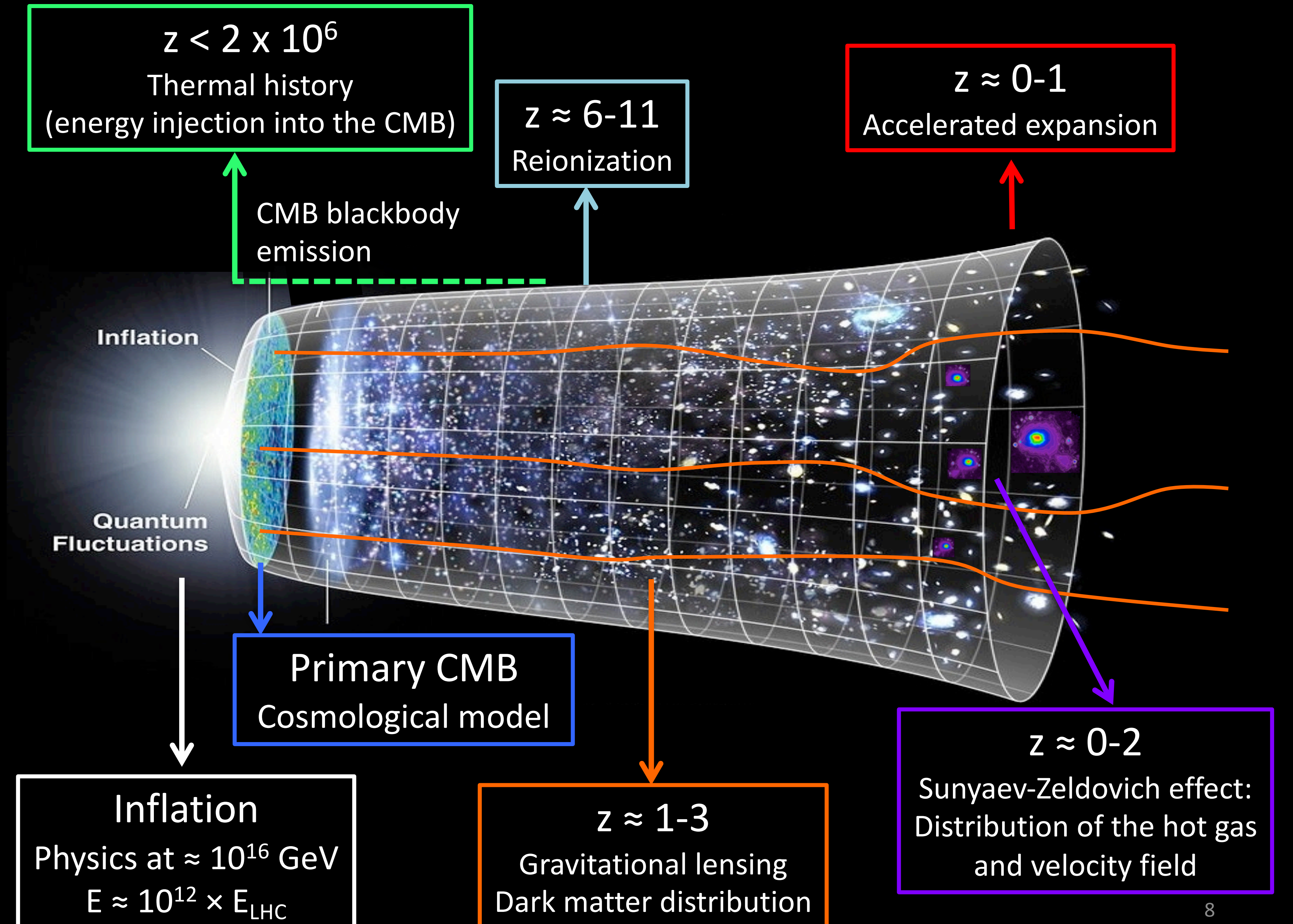
CMB blackbody emission



Every process that creates, absorbs, boosts, deflects, polarises CMB photons across cosmic time leaves a signature on the CMB

Primary CMB
Cosmological model

Inflation
Physics at ≈ 10^{16} GeV
E ≈ $10^{12} \times E_{LHC}$



z < 2 x 10^6
Thermal history
(energy injection into the CMB)
CMB blackbody emission
z ≈ 6-11
Reionization
z ≈ 0-1
Accelerated expansion
Inflation
Quantum Fluctuations
Primary CMB
Cosmological model
Inflation
Physics at ≈ 10^16 GeV
E ≈ 10^12 × E_LHC
z ≈ 1-3
Gravitational lensing
Dark matter distribution
z ≈ 0-2
Sunyaev-Zeldovich effect:
Distribution of the hot gas and velocity field

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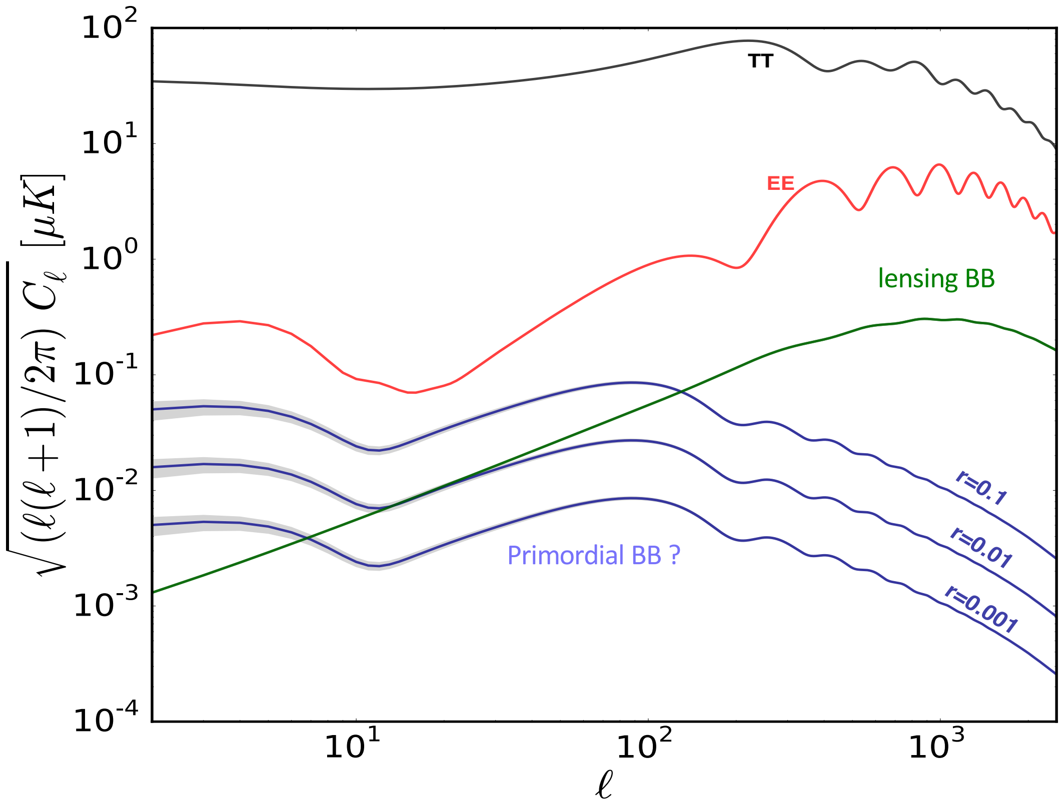
B-mode observational challenge



The level of primordial B-modes is unknown (chance of no detection)

Primordial B-modes ?

- To firmly confirm that any detection of large scale *very faint B-modes* is indeed the signature of *primordial inflationary gravity waves*, we must demonstrate

- That the frequency dependence is compatible with CMB
  - need enough frequency channels

- That the signal is stationary over the sky
  - need several large independent patches, e.g. north and south

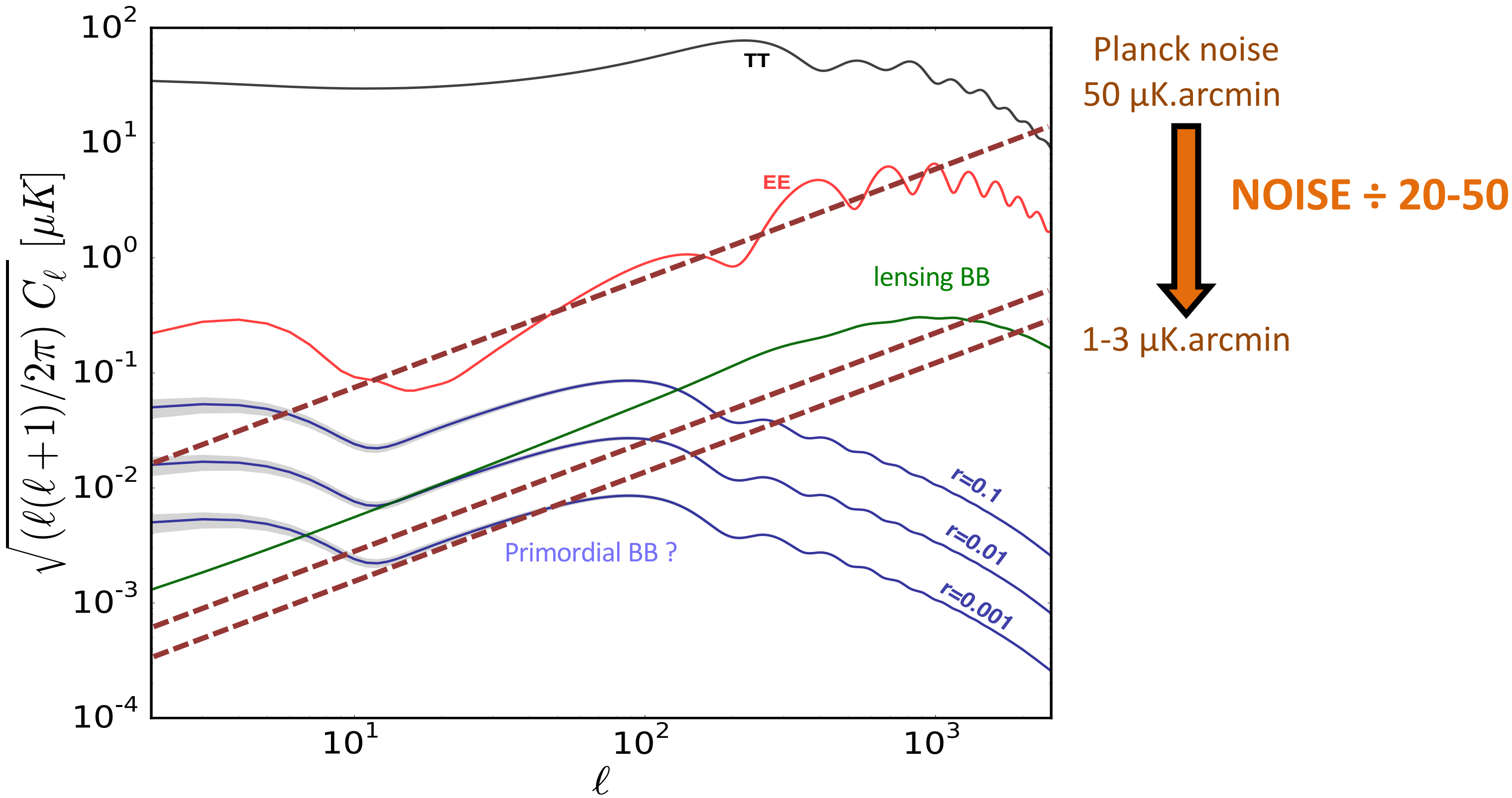
- That the signal is compatible with Gaussian
  - need enough sensitivity to check at a significant level

- That the signal is near scale-invariant
  - need the full range of harmonic modes

- That we are not seeing instrumental systematics
  - ability to detect the signal on various data cuts

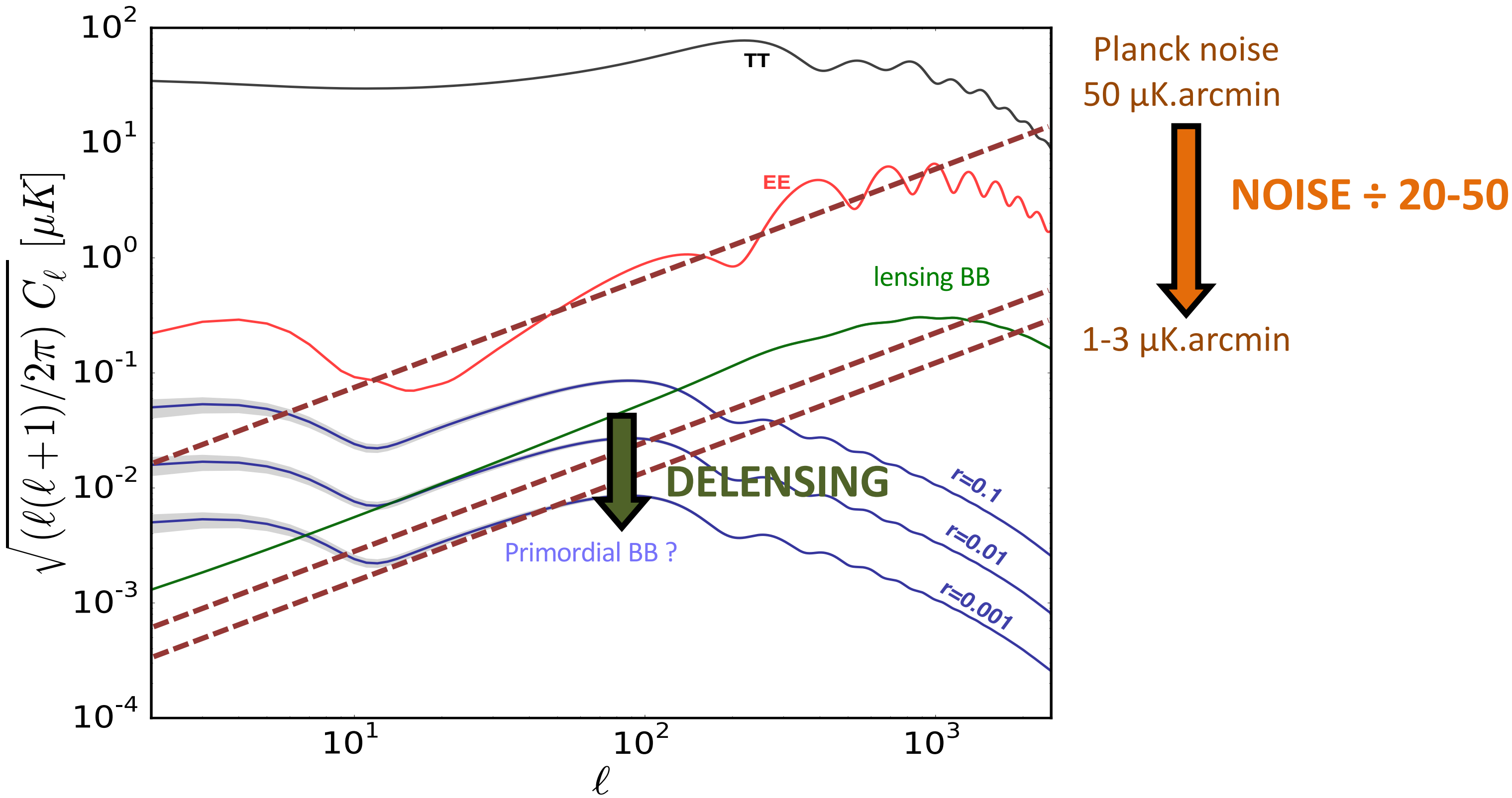
We need a sensitive space mission!

B-mode observational challenge



The level of primordial B-modes is unknown (chance of no detection)
Full-sky sensitivity of 2 µK.arcmin requires 1000s of detectors in space

B-mode observational challenge



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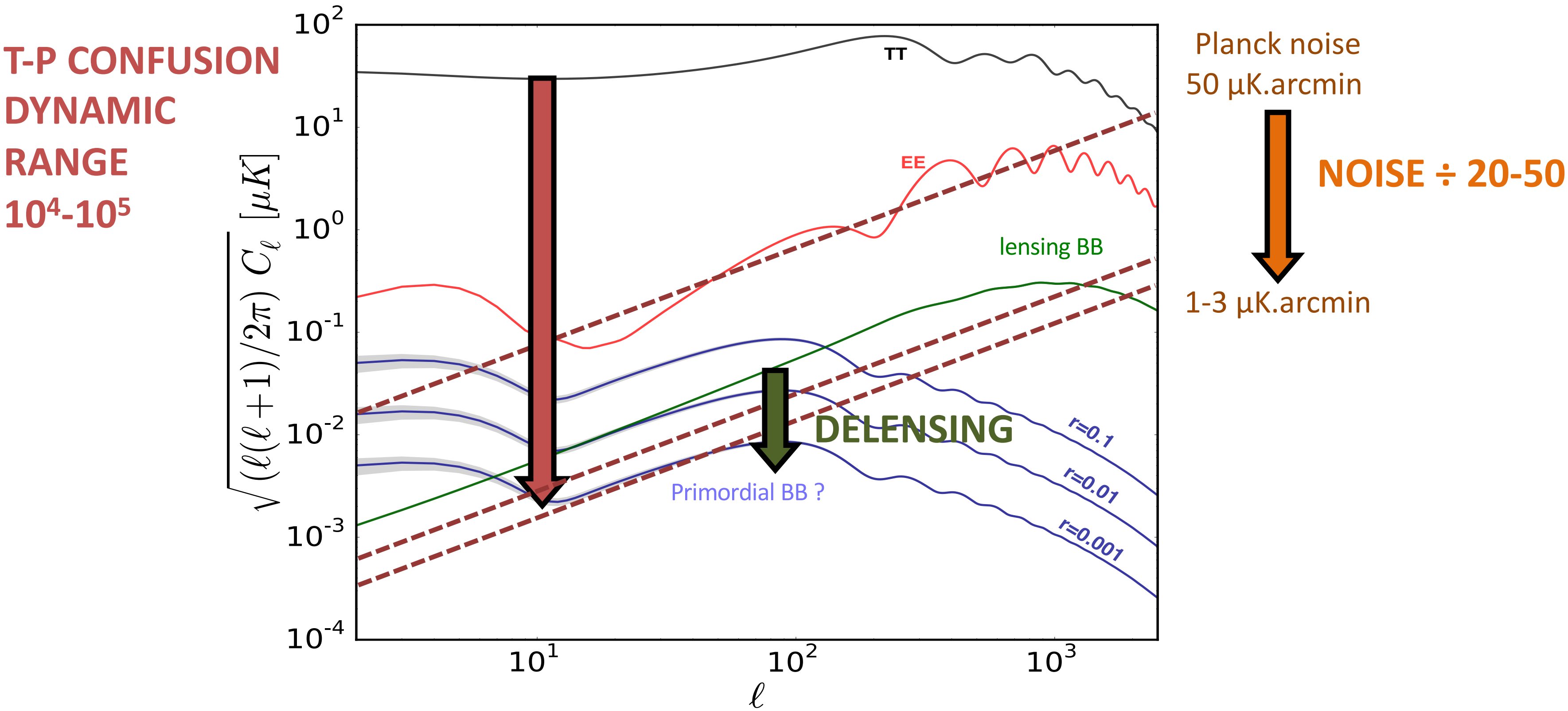
"Delensing" requires few arcmin angular resolution

B-mode observational challenge



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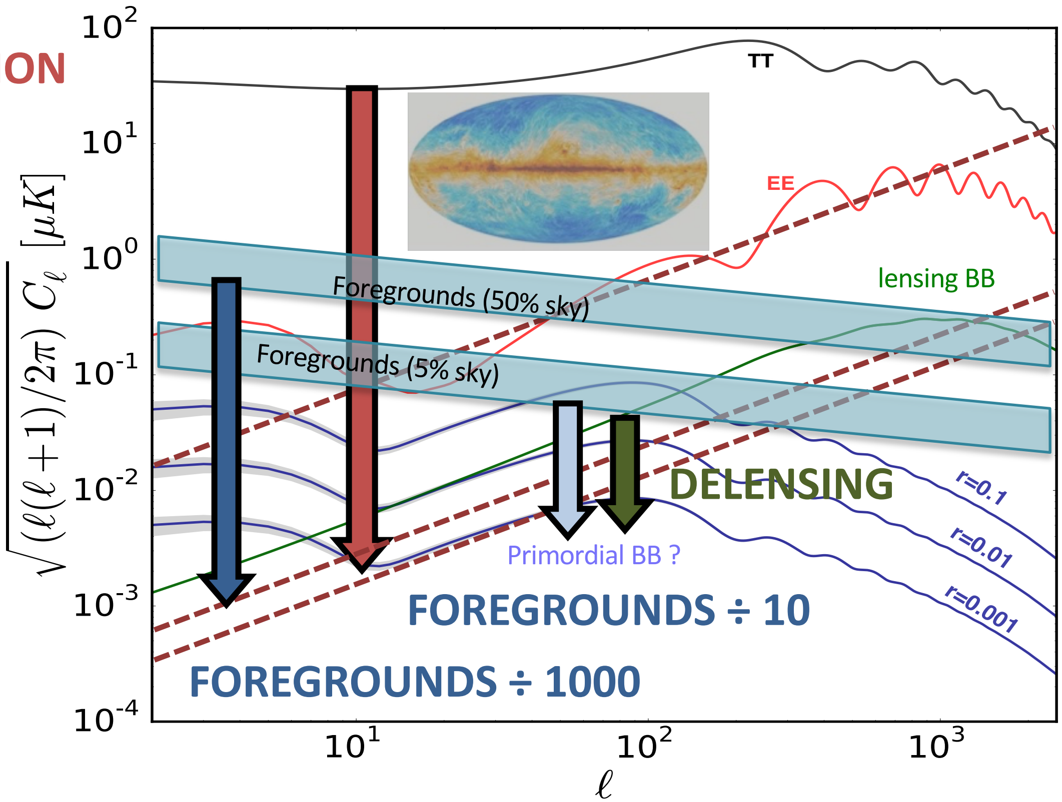
T-P confusion must be controlled at the 10^{-4}-10^{-5} level

B-mode observational challenge

T-P CONFUSION DYNAMIC RANGE 10^4-10^5



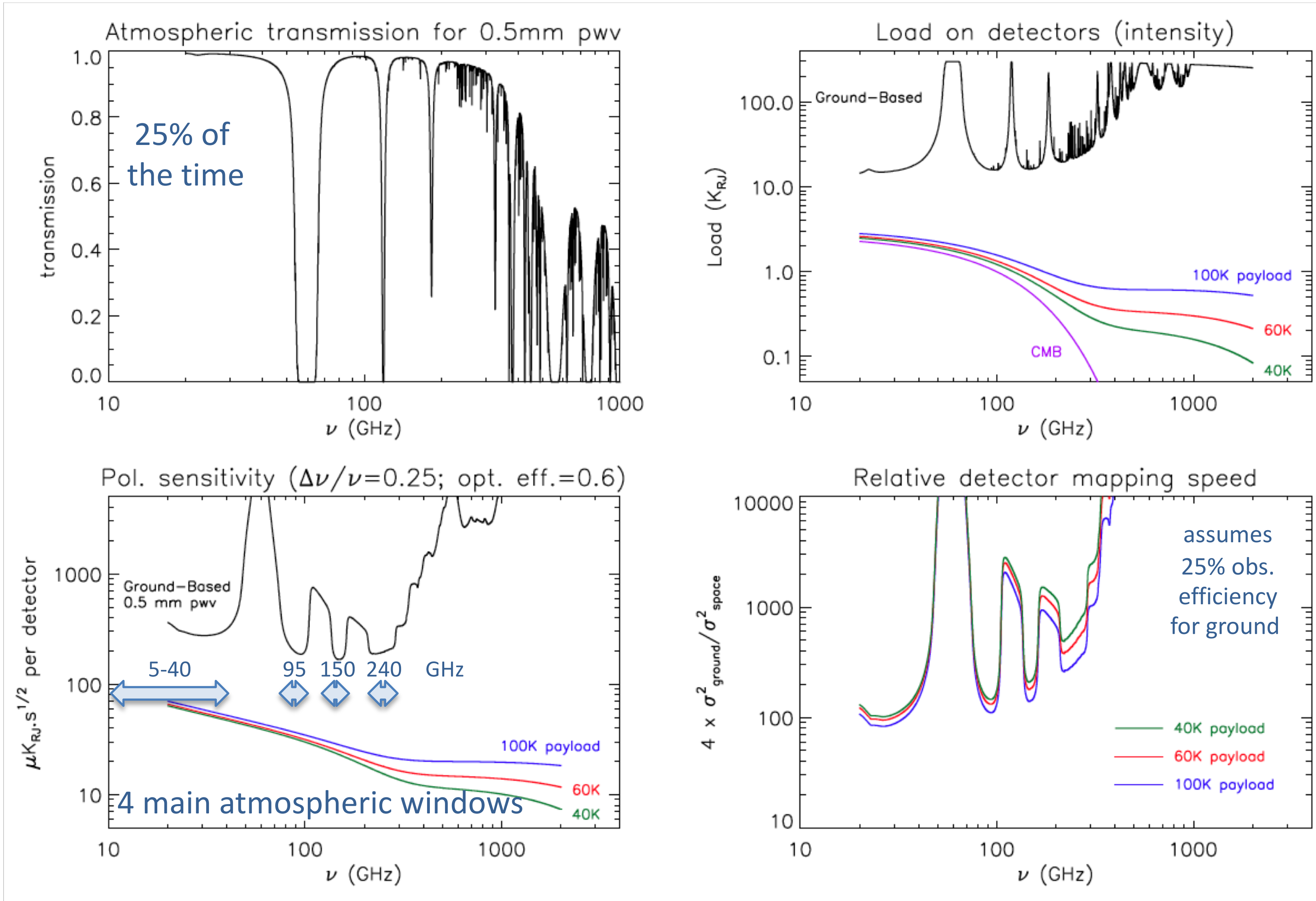
Planck noise
50 μK.arcmin

NOISE ÷ 20-50

1-3 μK.arcmin

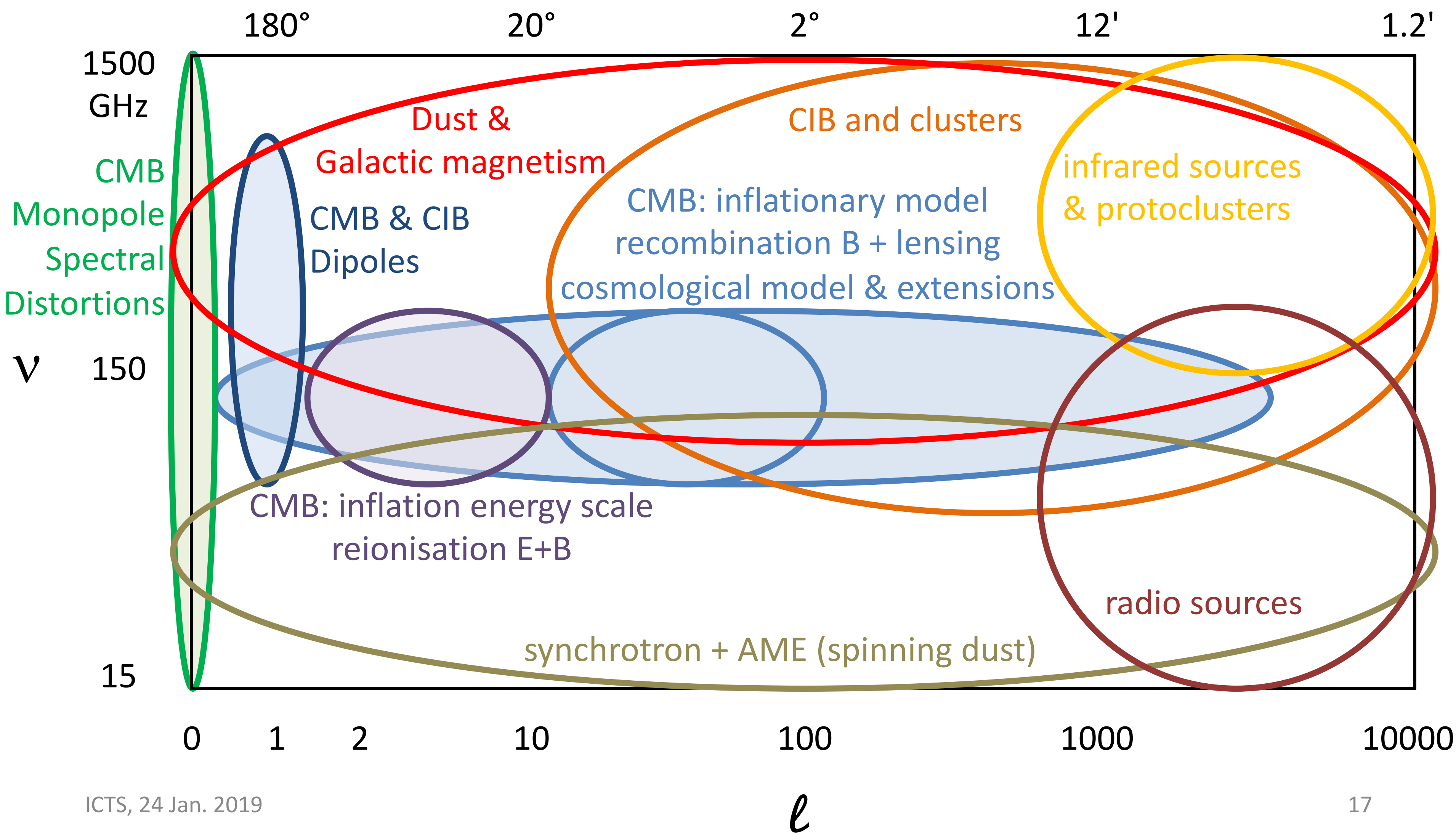
The level of primordial B-modes is unknown (chance of no detection)
Full-sky sensitivity of 2 μK.arcmin requires 1000s of detectors in space
"Delensing" requires few arcmin angular resolution
T-P confusion must be controlled at the 10^{-4}-10^{-5} level
Reducing foregrounds to 1‰ is a challenging "component separation" task

Atmosphere…



Delabrouille, de Bernardis, Bouchet et al. arXiv:1706.04516

Emissions in the (ν , ℓ) plane



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Context & Status

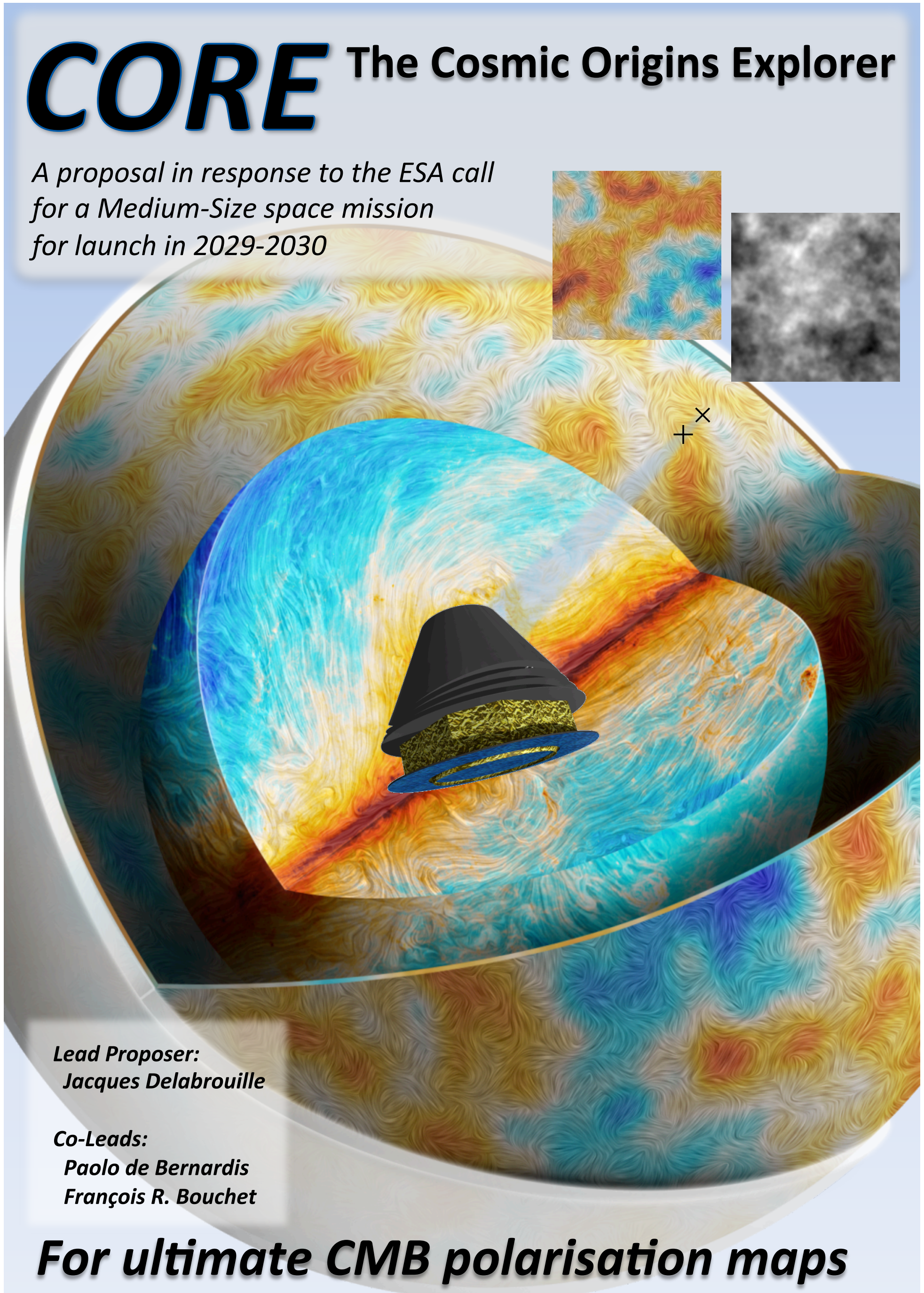
- In October 2016, the European CMB community proposed to ESA the Cosmic Origins Explorer (CORE), a next-generation space mission dedicated to CMB polarization observations.

- Building on Planck experience, CORE is designed as a "near-ultimate" CMB polarization mission (as Planck was for CMB temperature anisotropies), with also great astrophysics legacy value.

- In spite of strong support from the community and from major national space agencies in Europe, the proposed mission concept did not pass the initial technical and programmatic screening by ESA in January 2017.

- The main issue was an ESA cost estimate exceeding the M-class cost cap.

- ESA encouraged the CORE consortium to consider a joint proposal with a major international partner.



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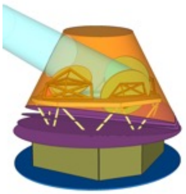
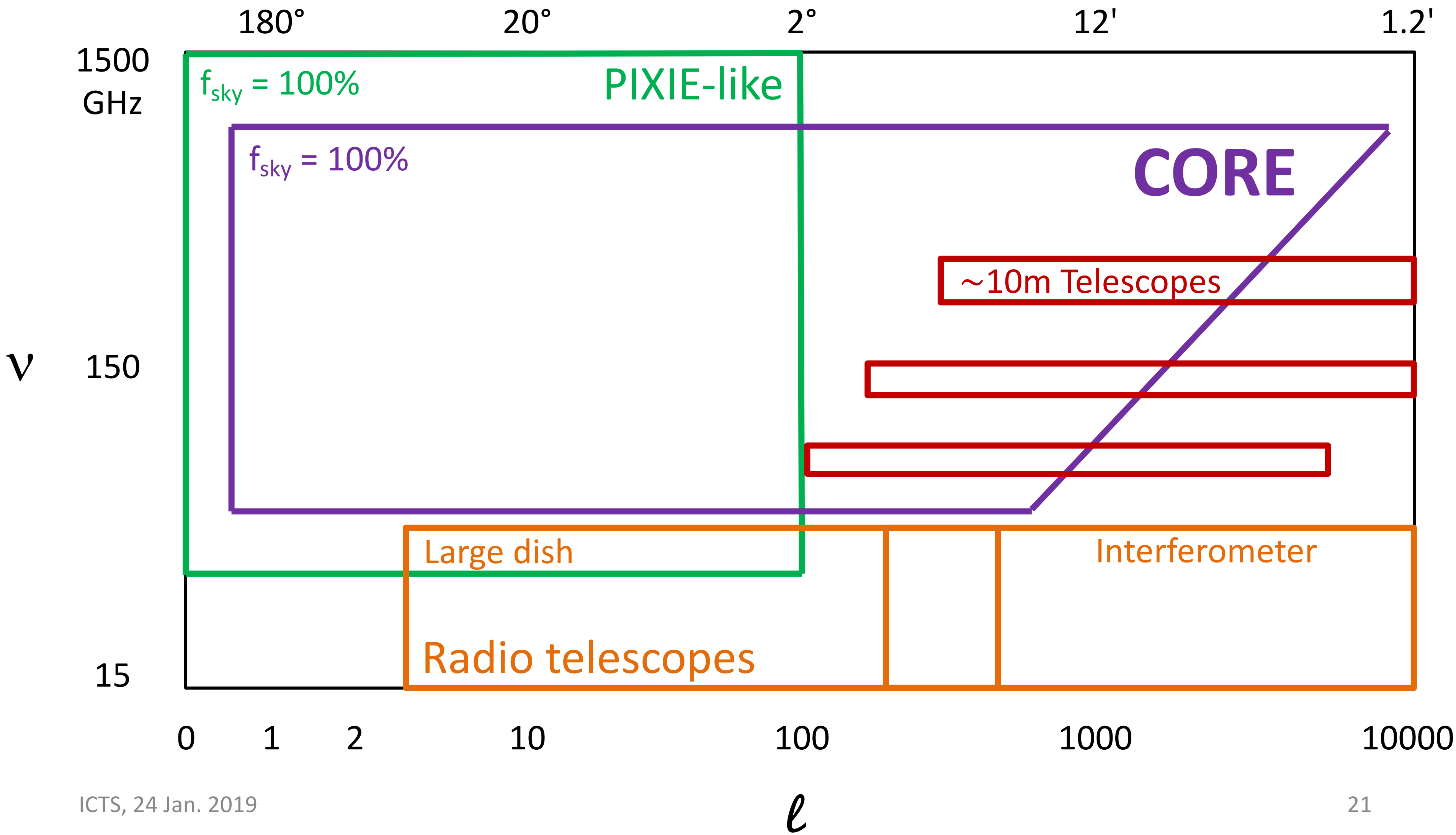
The *CORE* collaboration thanks CNES, Thales Alenia Space, and Air Liquide Advanced Technologies for advice and technical support during the preparation of this proposal. We also thank the ESA CDF team for the CMB Polarization CDF study performed in March 2016, the results of which were extensively used to define the mission concept presented in this proposal.

350 proposers mostly from Europe

The CORE observations range





CORE Mission concept and requirements

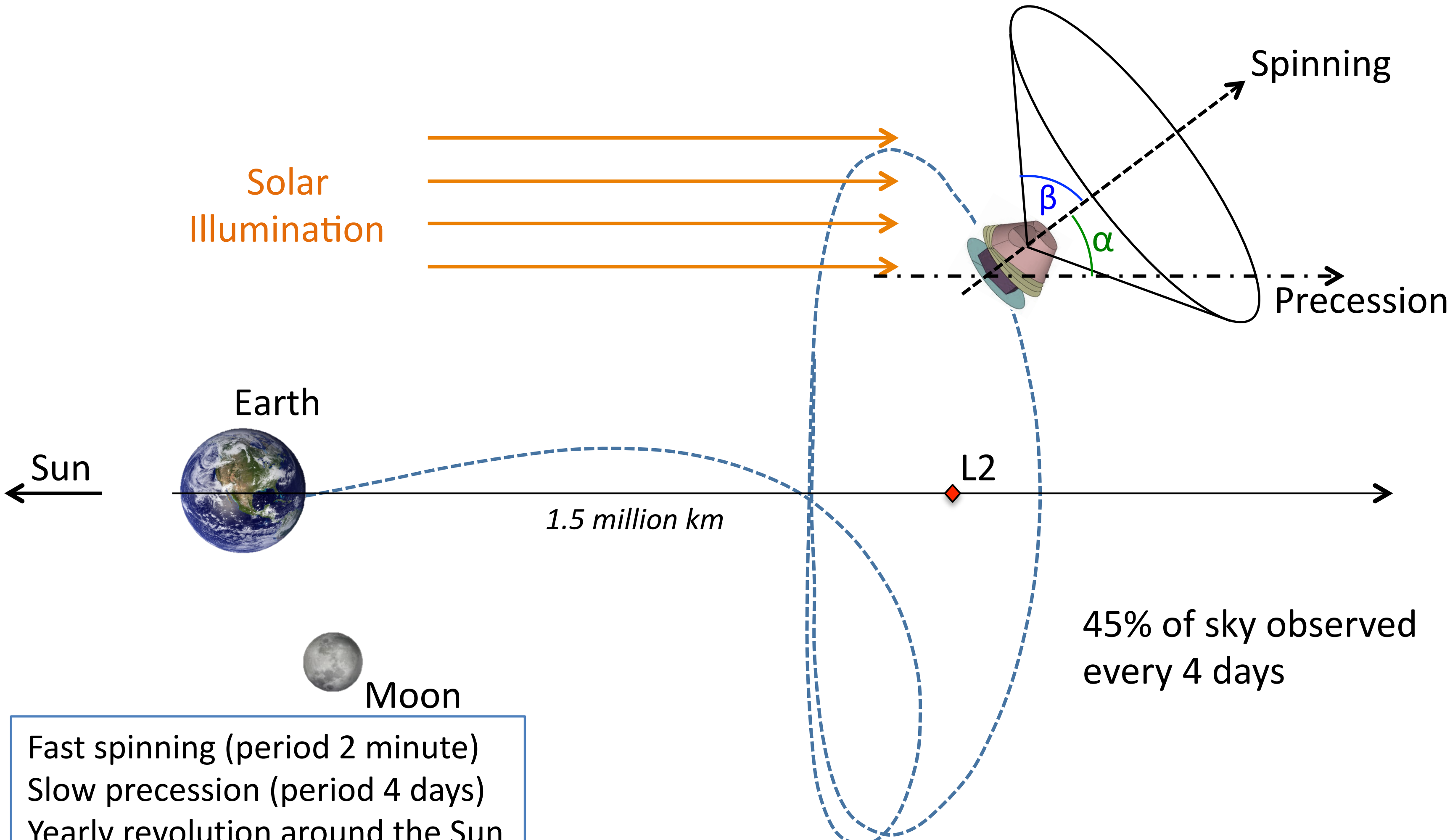
Comprehensive CMB polarisation mission, with great legacy value and discovery potential.

Performance / requirement	***Solution***
Resolve the CMB ≈ 4'-6' resolution at CMB frequencies	1.5m class telescope ≈ 6' at 135 GHz; ≈ 4' at 200 GHz
Signal dominated data (S/N >2-3 for B_{lens}) $\sigma_P \approx$ 1.5-2.5 μK.arcmin on ≈ 100% sky	2100 detectors in space at ≈ 100 mK
Exquisite control of systematic effects for polarisation measurements	L2 orbit; Redundancy and polarisation modulation by scanning strategy
Exquisite control/separation of polarised (and intensity) foregrounds	15-20 frequency bands (or more) covering ≈ 60-600 GHz (or more)

CORE channels

channel GHz	beam arcmin	N_{det}	ΔT μK.arcmin	ΔP μK.arcmin	ΔI μK_{RJ}.arcmin	ΔI kJy/sr.arcmin	$\Delta y \times 10^6$ y_{SZ}.arcmin	PS (5σ) mJy
60	17.87	48	7.5	10.6	6.81	0.75	-1.5	5.0
70	15.39	48	7.1	10	6.23	0.94	-1.5	5.4
80	13.52	48	6.8	9.6	5.76	1.13	-1.5	5.7
90	12.08	78	5.1	7.3	4.19	1.04	-1.2	4.7
100	10.92	78	5.0	7.1	3.90	1.2	-1.2	4.9
115	9.56	76	5.0	7.0	3.58	1.45	-1.3	5.2
130	8.51	124	3.9	5.5	2.55	1.32	-1.2	4.2
145	7.68	144	3.6	5.1	2.16	1.39	-1.3	4.0
160	7.01	144	3.7	5.2	1.98	1.55	-1.6	4.1
175	6.45	160	3.6	5.1	1.72	1.62	-2.1	3.9
195	5.84	192	3.5	4.9	1.41	1.65	-3.8	3.6
220	5.23	192	3.8	5.4	1.24	1.85	-	3.6
255	4.57	128	5.6	7.9	1.30	2.59	3.5	4.4
295	3.99	128	7.4	10.5	1.12	3.01	2.2	4.5
340	3.49	128	11.1	15.7	1.01	3.57	2.0	4.7
390	3.06	96	22.0	31.1	1.08	5.05	2.8	5.8
450	2.65	96	45.9	64.9	1.04	6.48	4.3	6.5
520	2.29	96	116.6	164.8	1.03	8.56	8.3	7.4
600	1.98	96	358.3	506.7	1.03	11.4	20.0	8.5
Array		2100	1.2	1.7			0.41	

Orbit and scan strategy

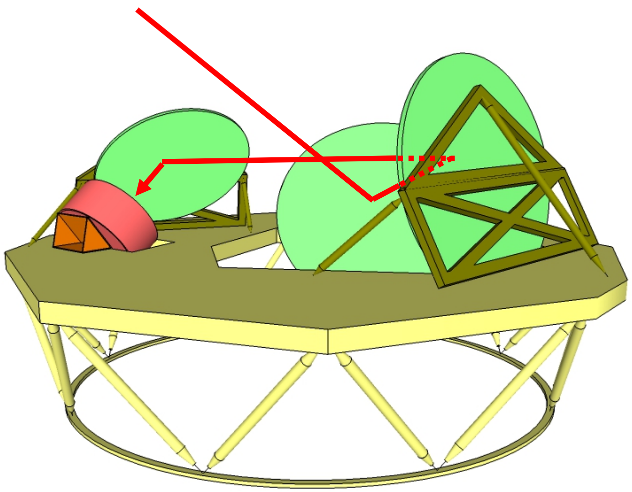


45% of sky observed every 4 days

Fast spinning (period 2 minute)
Slow precession (period 4 days)
Yearly revolution around the Sun

CORE payload, optics and shields

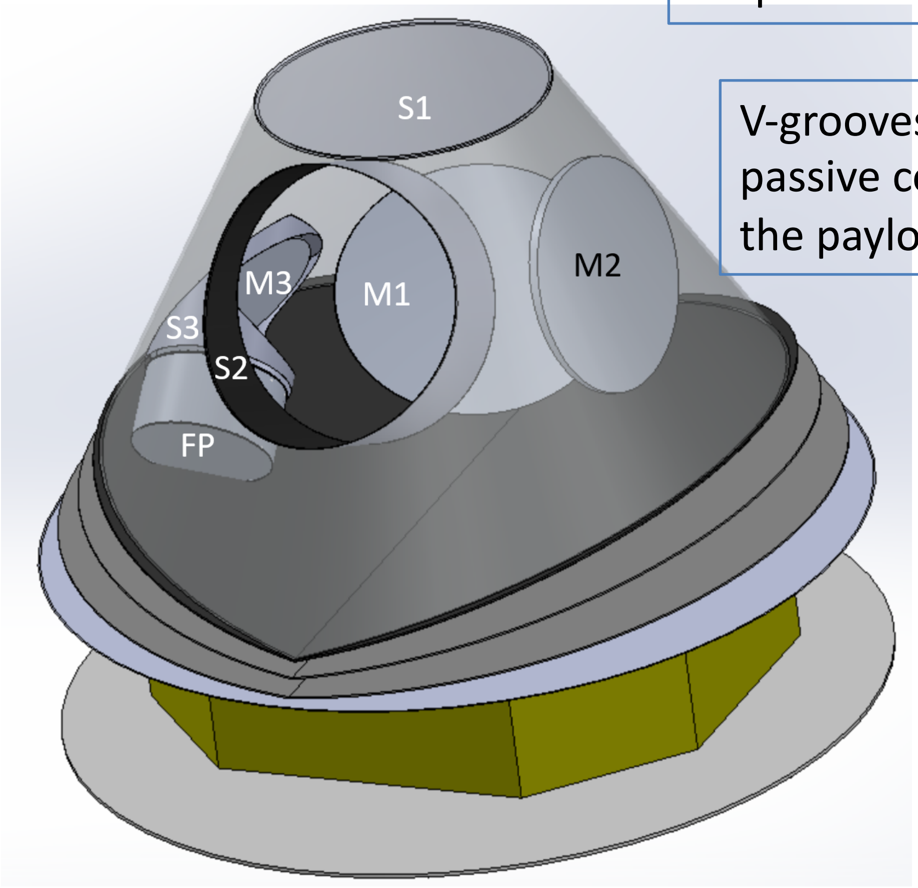
Crossed-Dragone Telescope
- Excellent polarisation properties
- Large, flat, telecentric focal plane



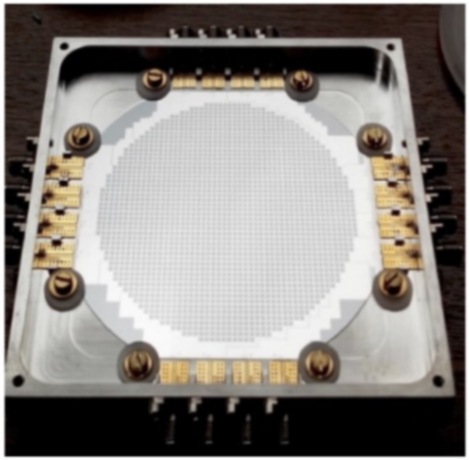
A set of shields prevents unwanted radiation to reach the detectors

Large main shield radiates to cold space for passive cooling

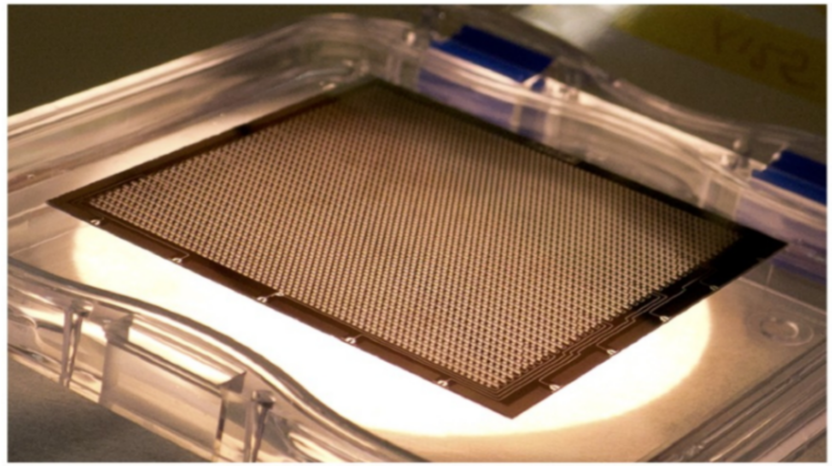
V-grooves provide passive cooling of the payload to 40K



CORE focal plane

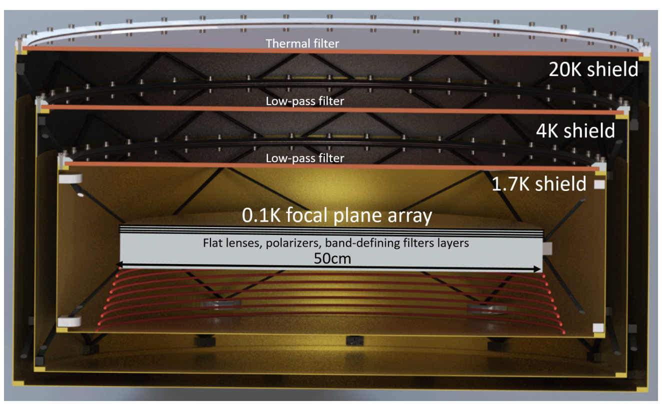


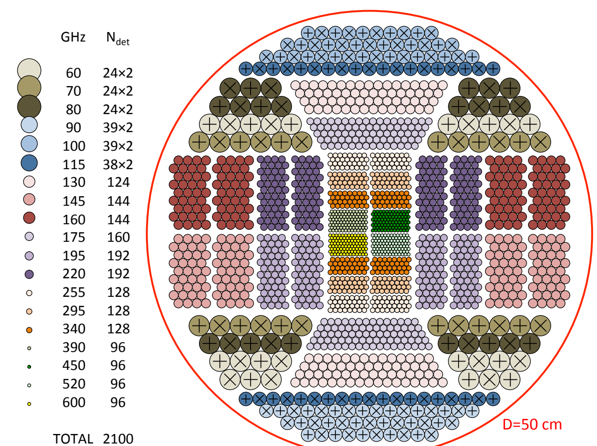
NIKA2 array 200-300 GHz
(Grenoble) -> IRAM30m



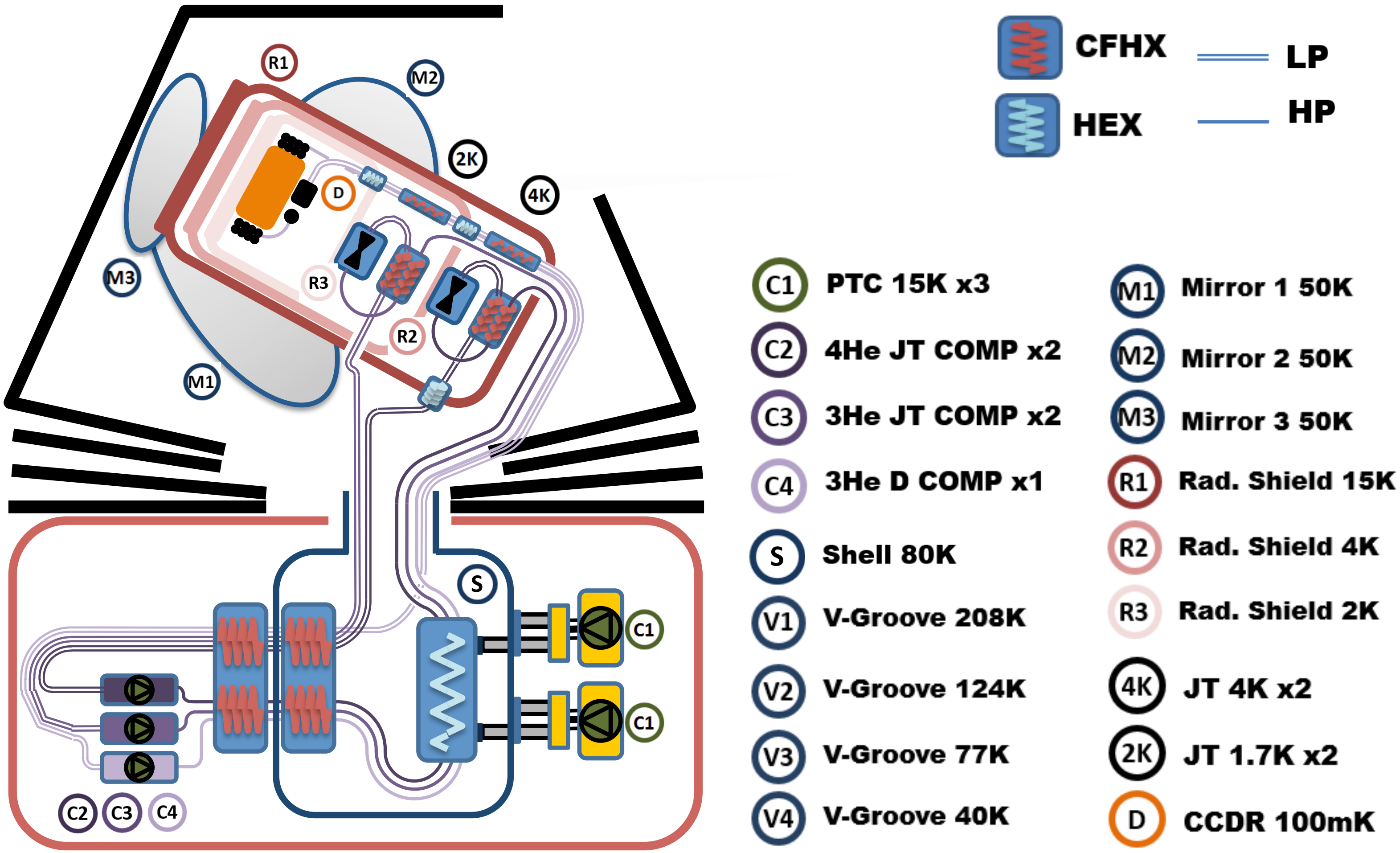
AMKID array - submm
(Groningen) -> APEX ALMA

LEKID for 150 GHz
(Rome)





CORE cooling chain concept



CORE: Some references

Space mission: "Exploring Cosmic Origins (ECO) papers" (special issue of JCAP)

DESIGN

- Mission: Delabrouille, de Bernardis, Bouchet et al. JCAP04(2018)014
- Instrument: de Bernardis, Ade, Baselmans et al. JCAP04(2018)015

SCIENCE

- Inflation: Finelli, Bucher, Achucarro et al. JCAP04(2018)016
- Parameters: Di Valentino, Brinckmann, Gerbino et al. JCAP04(2018)017
- Lensing: Challinor, Allison, Carron et al. JCAP04(2018)018
- Clusters: Melin, Bonaldi, Remazeilles et al. JCAP04(2018)019
- Sources: De Zotti, Gonzalez-Nuevo, Lopez-Caniego et al. JCAP04(2018)020
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Outline

- Why the CMB again ?
- Why space ?
- CORE
- Summary

Summary

- The CMB is the single observable that sets the stage for precision cosmology.
- Even after Planck, ***the science remains extremely rich***.
- Its comprehensive exploitation requires a sensitive space mission such as CORE.
- We plan to re-submit a proposal at the next opportunity at ESA.
- We invite international partners to participate in this process.