COrE+ : The *COsmic Origins Explorer +*

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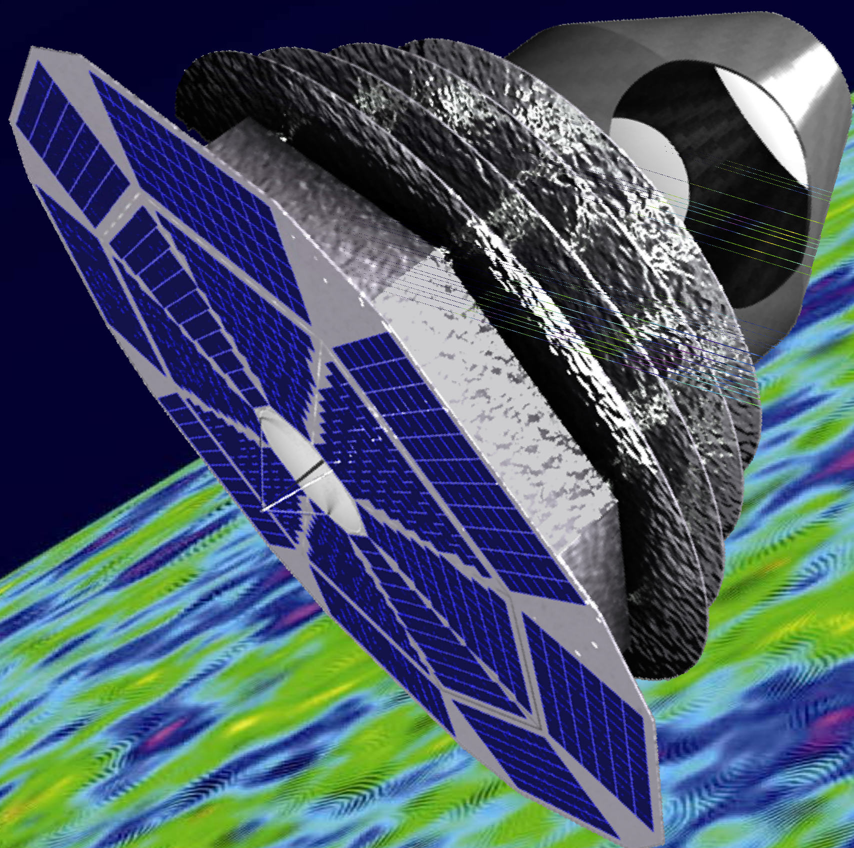
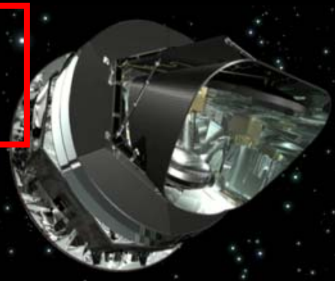
For the COrE+ collaboration



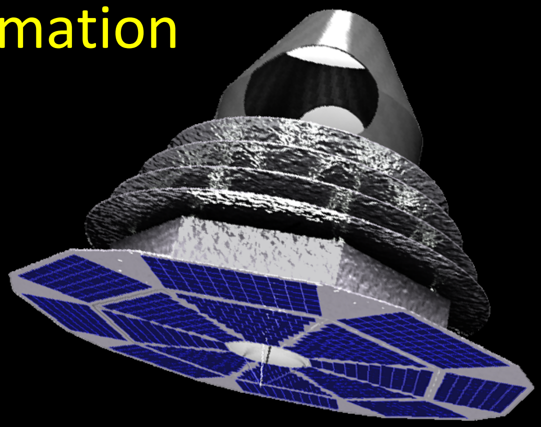
The Microwave Sky in Temperature and Polarization

Ferrara, 3 dec 2014

The Motivation

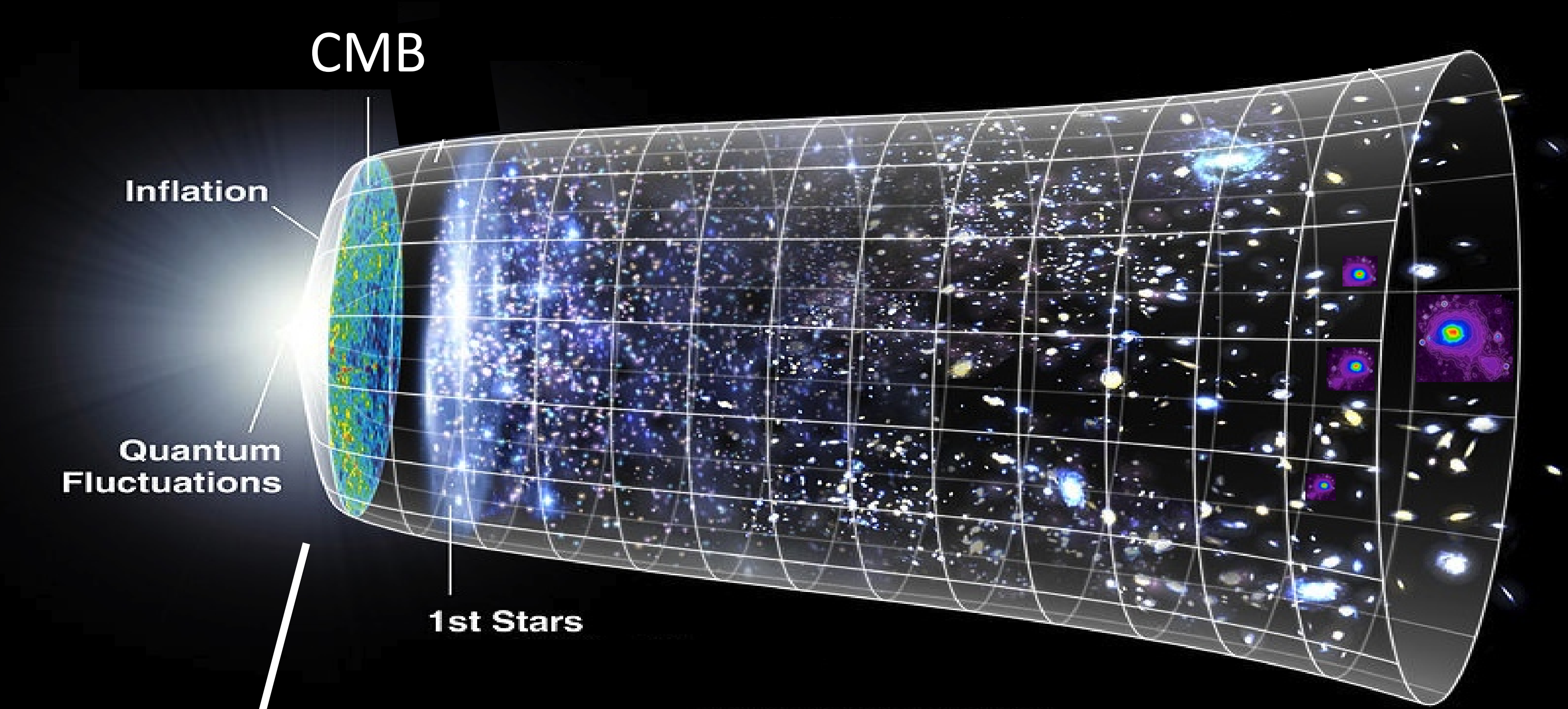


- **Planck** is the nearly-ultimate mission for the measurement of CMB temperature **anisotropy**
- **COrE+** targets at extracting ***nearly all*** the information present in CMB temperature ***and polarization*** anisotropy. This includes:
  - B-modes and inflation physics
  - Lensing potential and dark matter distribution
  - Neutrino masses & hierarchy
  - Extension of the standard model



- To do this we have to remove instrumental effects and polarized foregrounds ***at an unprecedented level of precision***.
- At a level that cannot be reached from the ground, with balloons, with small space missions.

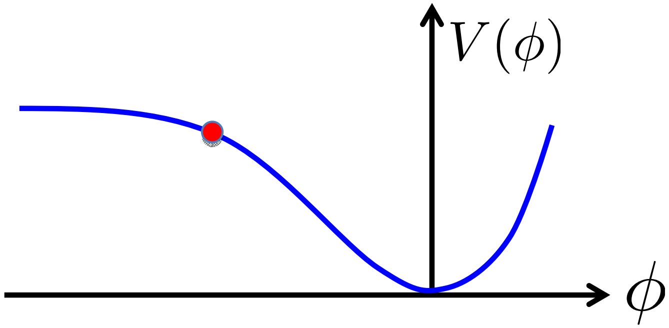
COrE+ : target 1 : primordial B-modes



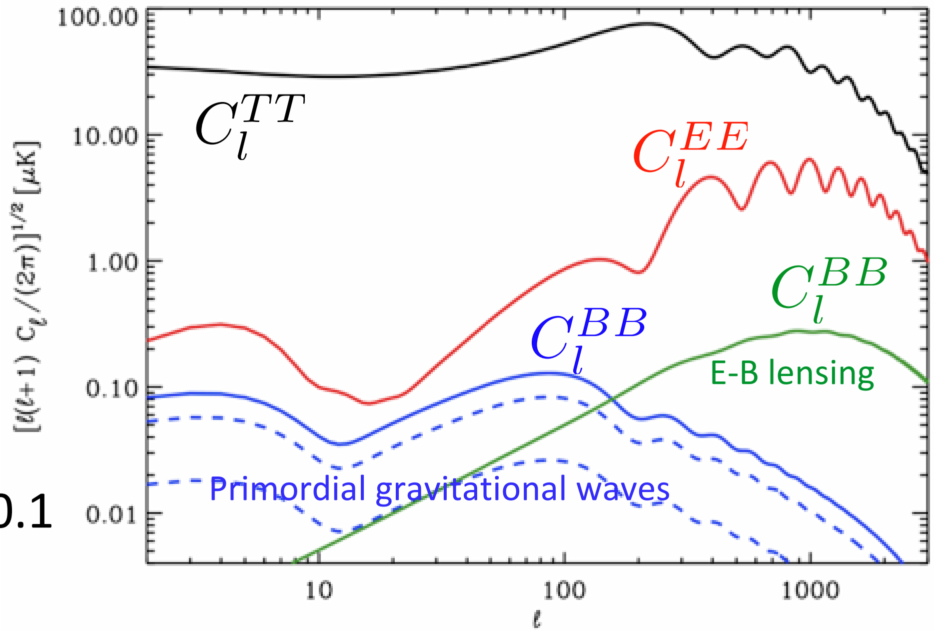
Very Early Universe
Physics at ≈ 10^{16} GeV
$E_{COrE+} > 10^{12} \times E_{LHC}$

Very early universe : physics at 10^{16} GeV

Initial Perturbations of the metric :
-scalar (density)
-tensor (gravitational waves, present in all inflation scenarios)
Depend on the potential $V(\phi)$ and its derivatives:

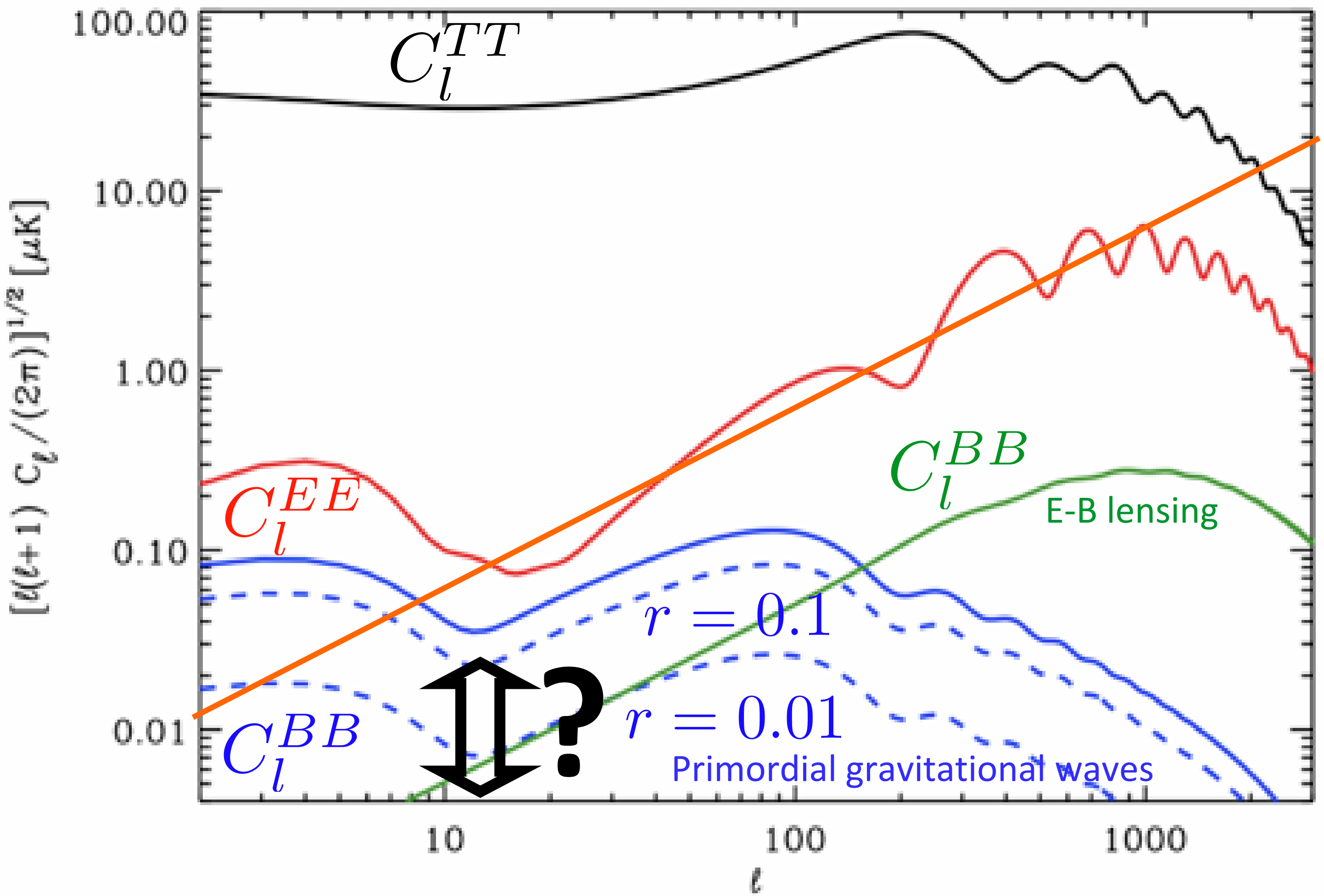


- Scalar spectral index $n_S - 1$
- running $\frac{\mathrm{d}n_S}{\mathrm{d}\ln k}$
- tensor/scalar ratio $r = T/S$
- Tensor spectral index n_T



Tensors produce B-mode polarization.
Current upper limit on *r* of the order of 0.1
Target of COrE+ : 0.001 (close to cosmic variance)

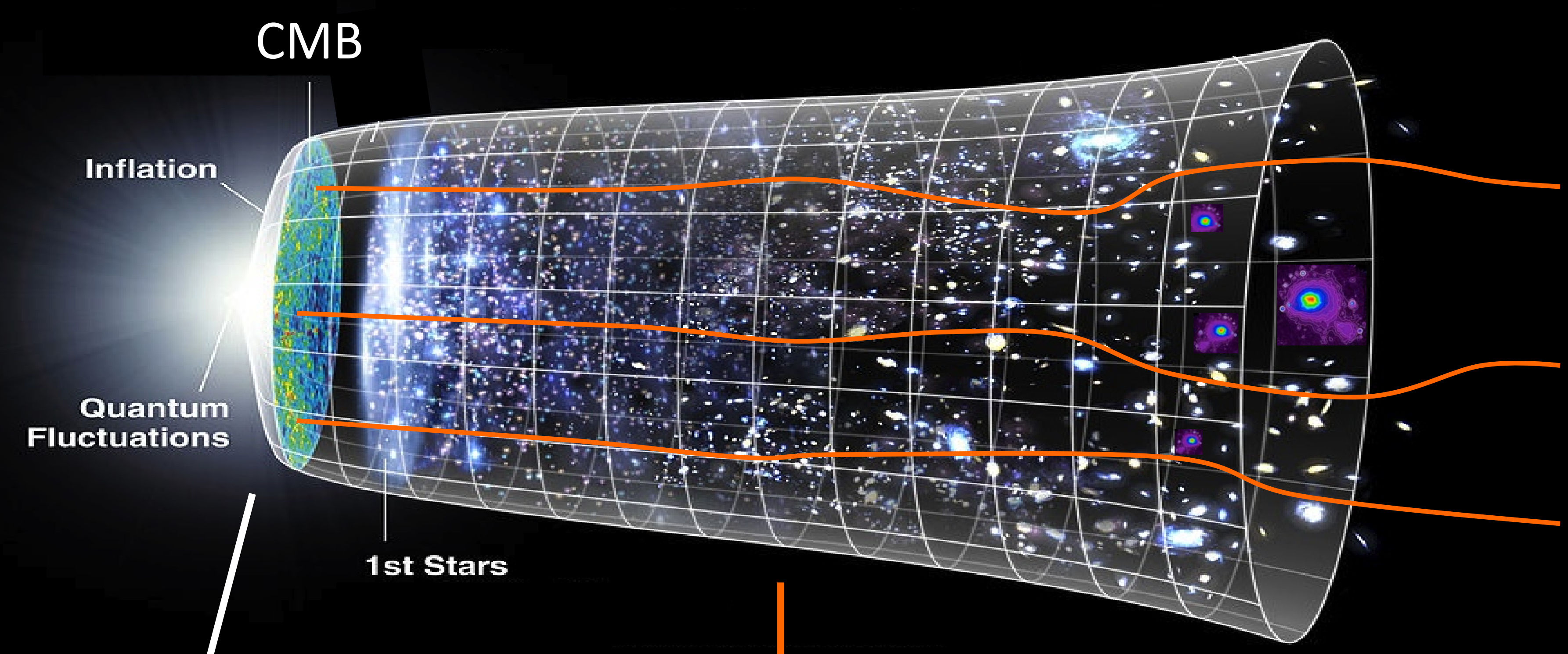
Spectra of perturbations



Noise of Planck survey ≈ 50 μK.arcmin

To reduce the noise, in BLIP conditions, we need many more detectors.
We also need exquisite control of systematic effects (expecially at large scales)

COrE+ : target 2 : gravitational lensing

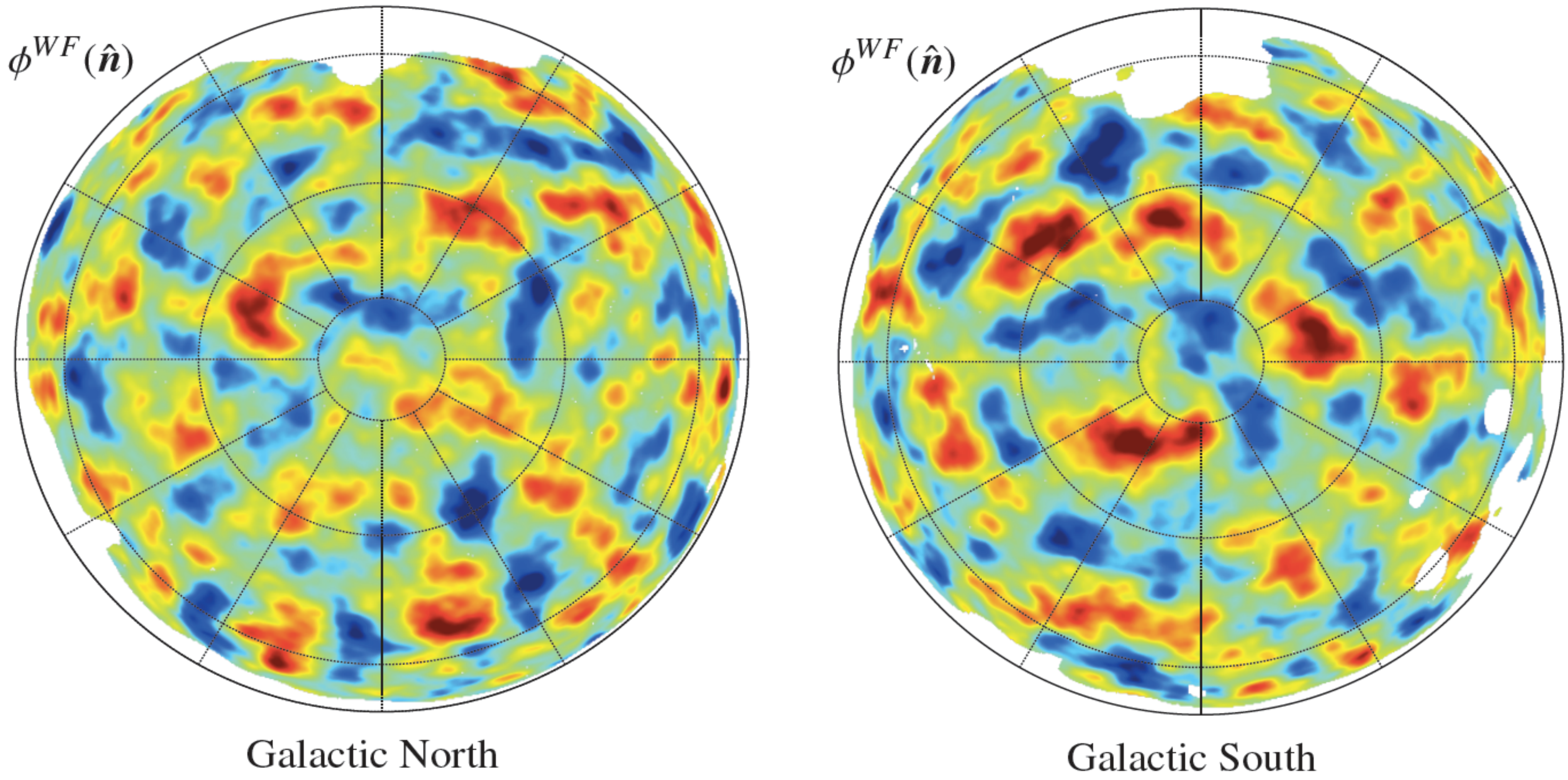


Very Early Universe
Physics at ≈ 10^{16} GeV
$E_{COrE+} > 10^{12} \times E_{LHC}$

$z \approx 1$-3
Gravitational Lensing
Mass Distribution

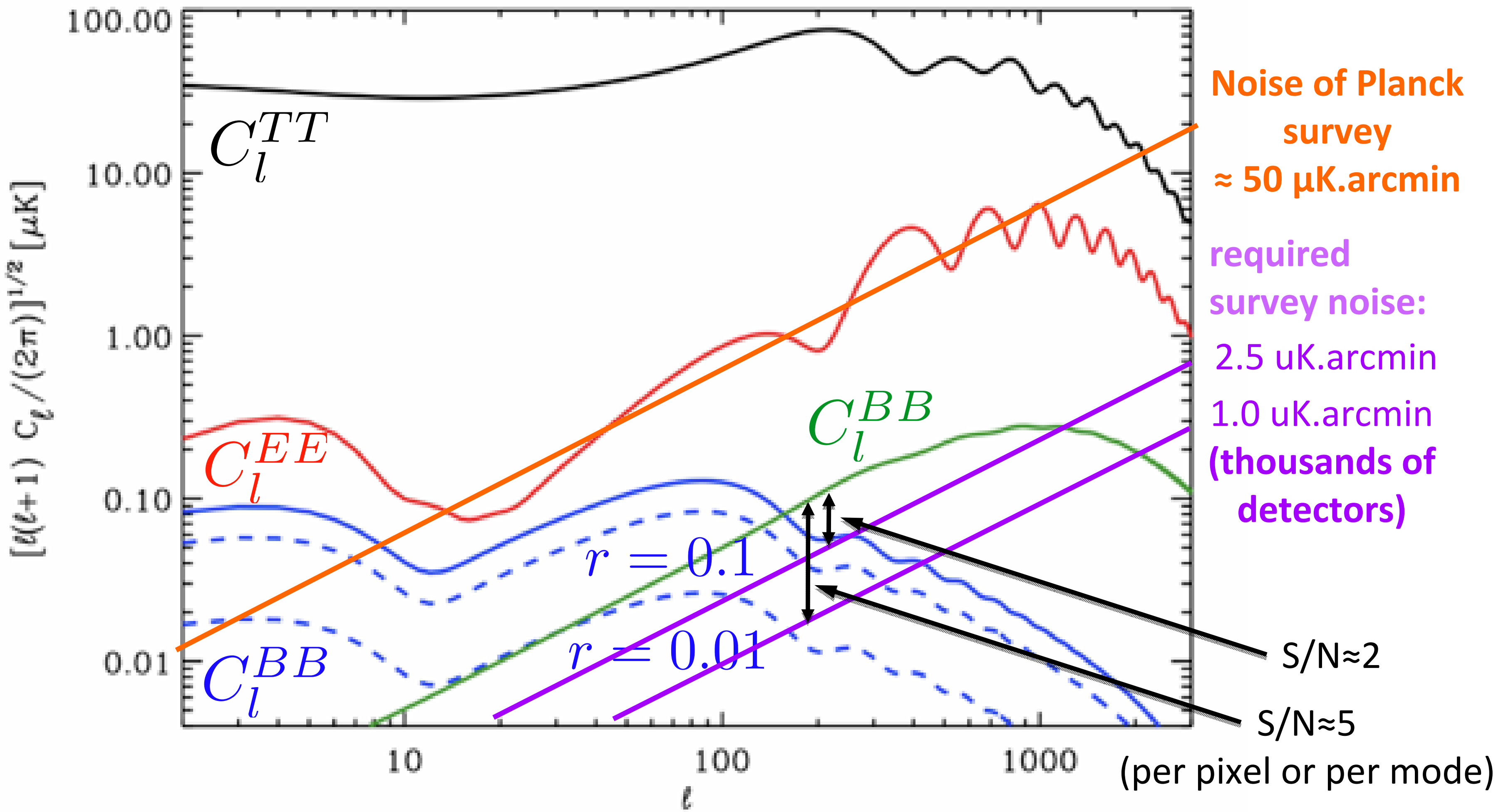
Reconstruction of the lensing potential

Planck 2013 results. XVII.

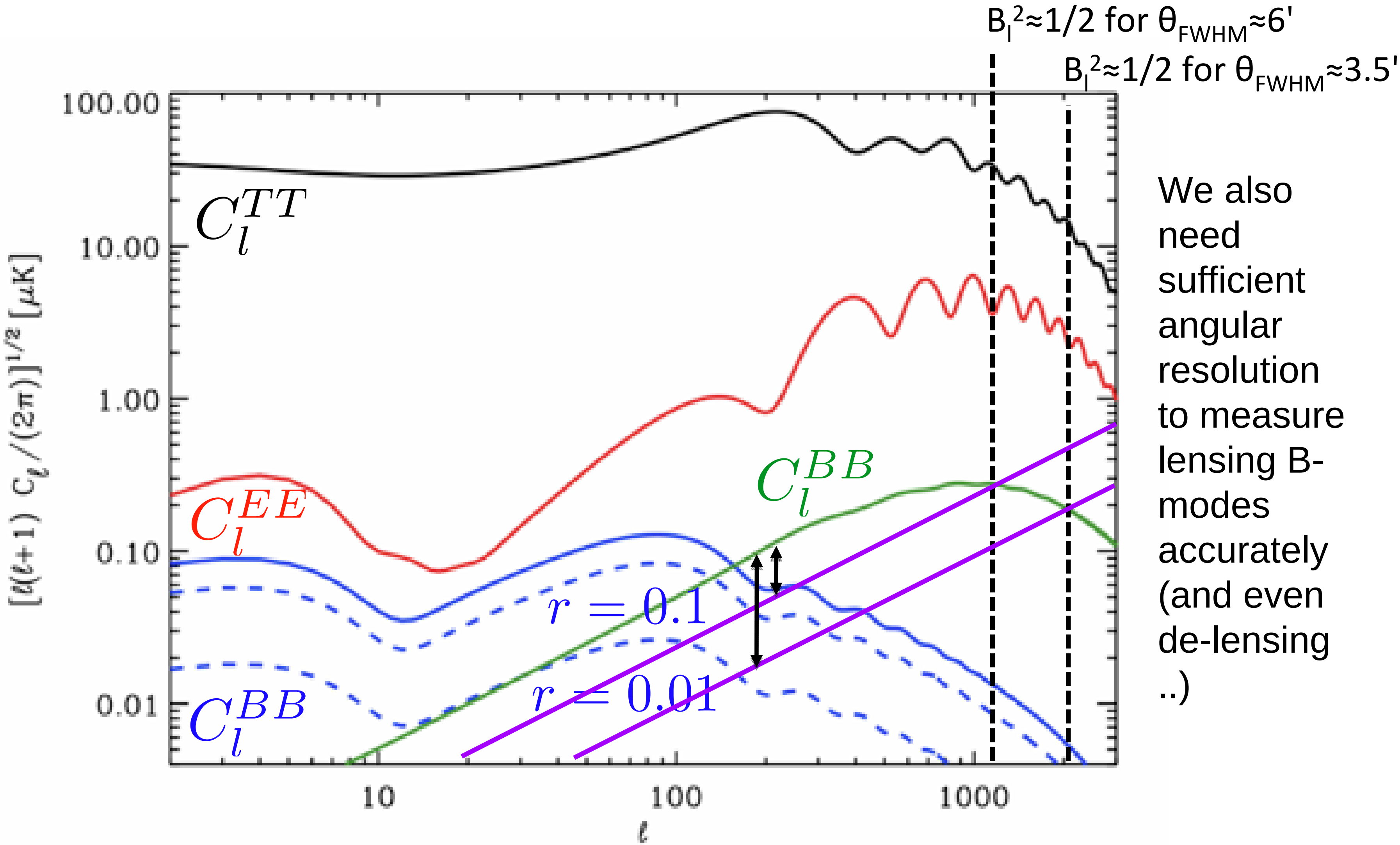


The reconstruction is noisy (S/N ≈0.6 – more noise than signal here). This can be done MUCH BETTER with lower noise, with more accurate T, E, B information

Target: primordial B-modes **and** gravitational lensing



Target: primordial B-modes **and** gravitational lensing



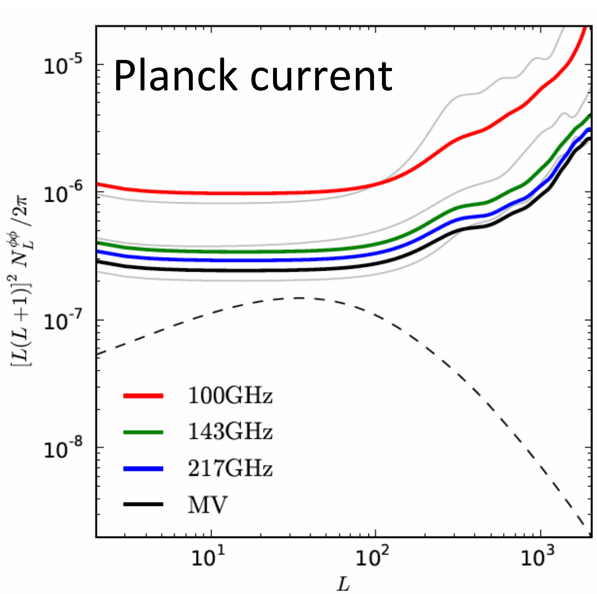
We also need sufficient angular resolution to measure lensing B-modes accurately (and even de-lensing ..)

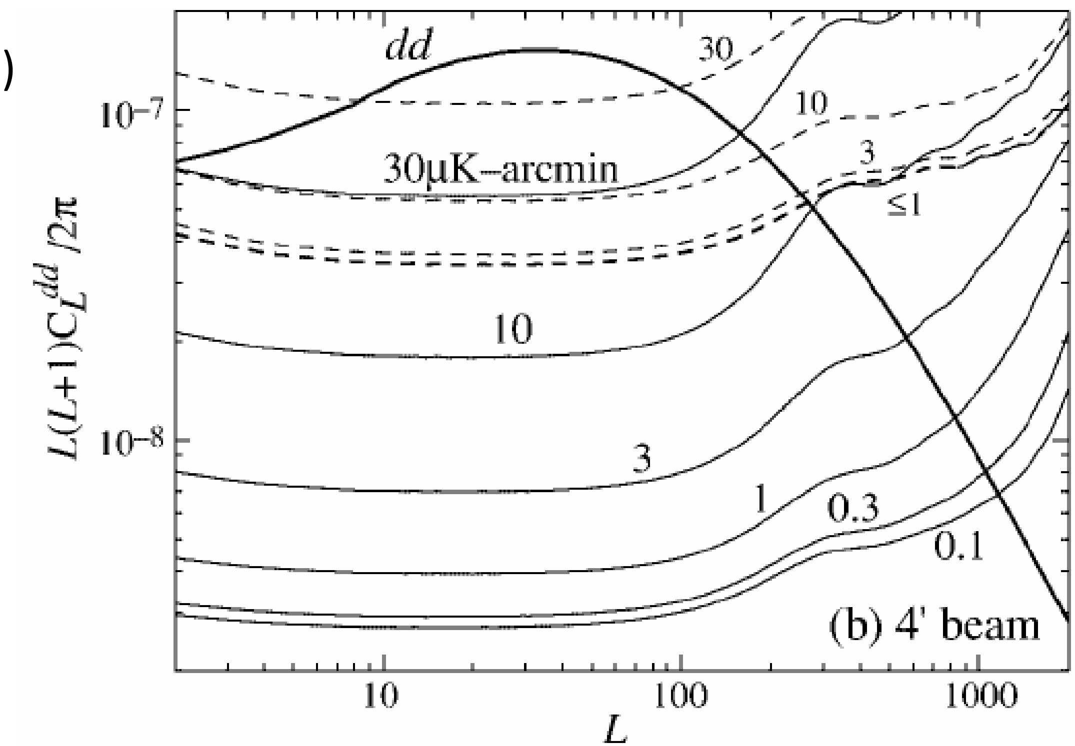
Reconstruction of the lensing potential

Impact of sensitivity

Hu & Okamoto, 2002, ApJ 574, 566

- - - - - Temperature only
——— Polarisation (E-B correlation)





Objective:

20' 15'

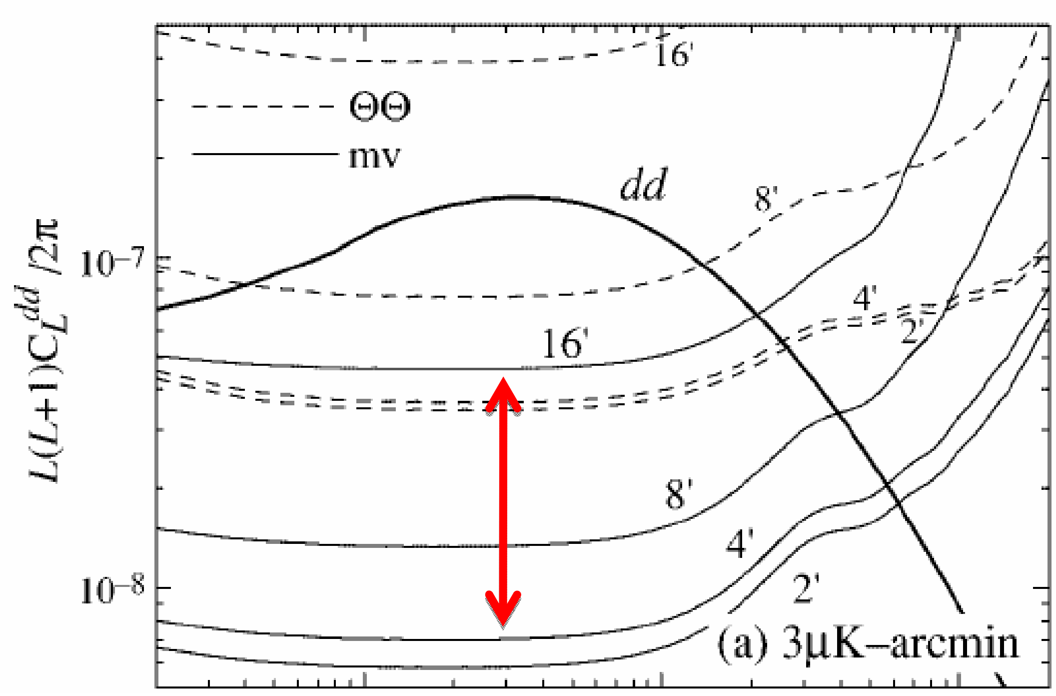
Polarization, 3 μK-arcmin sensitivity or better

Reconstruction of the lensing potential

Impact of angular resolution

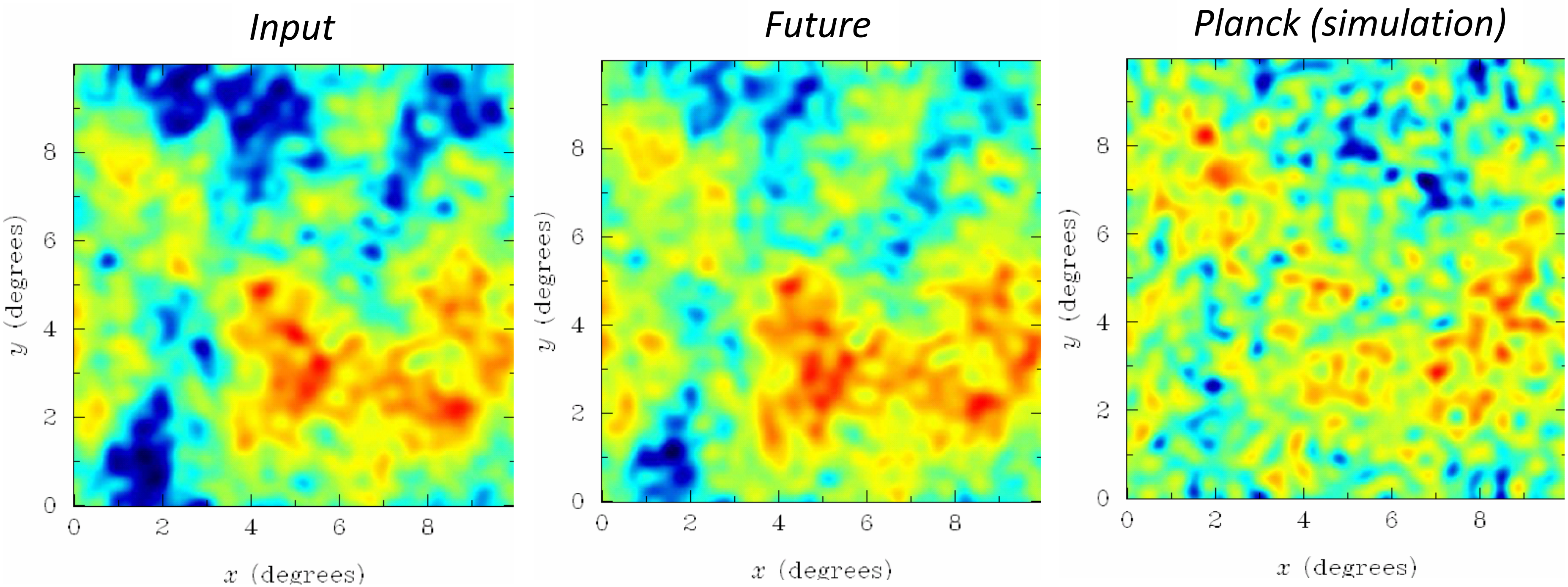
Hu & Okamoto, 2002, ApJ 574, 566

- - - - - Temperature only
——— Polarisation (E-B correlation)



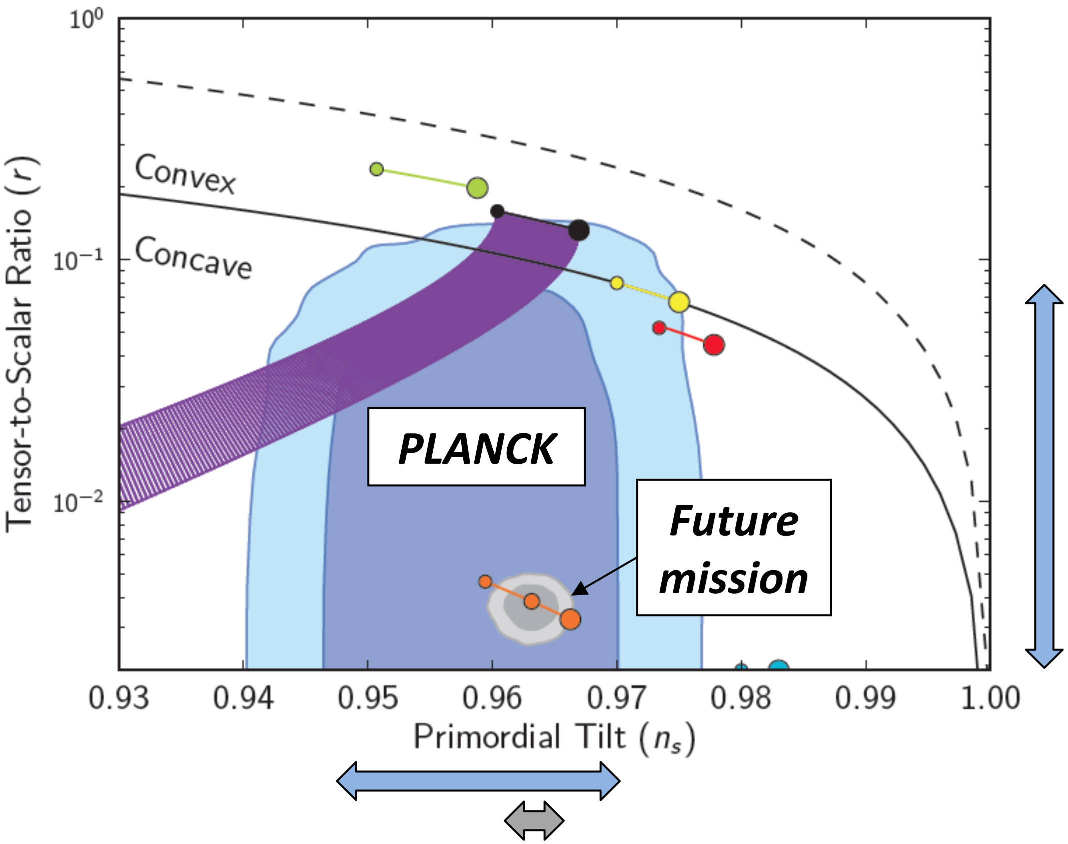
Objective: 4' resolution

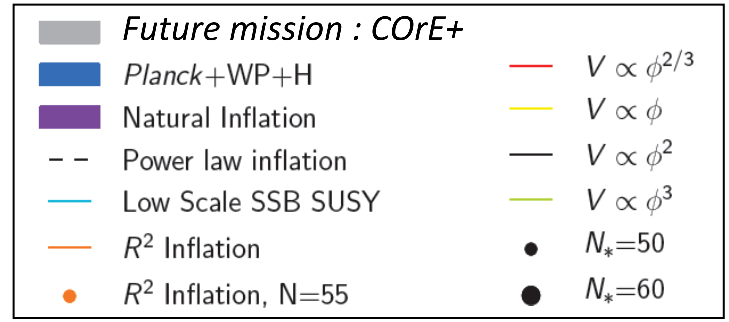
Reconstruction of the lensing potential



- High S/N reconstruction of the gravitational potential integral between z=0 and z=1000 (dominated by masses between z=1 and z=3, complementary to EUCLID)

- Correlation with other mass tracers (galaxies, clusters, quasars) to obtain a tomography of dark matter in the whole Hubble volume.





Measuring r with $\delta r < 10^{-3}$

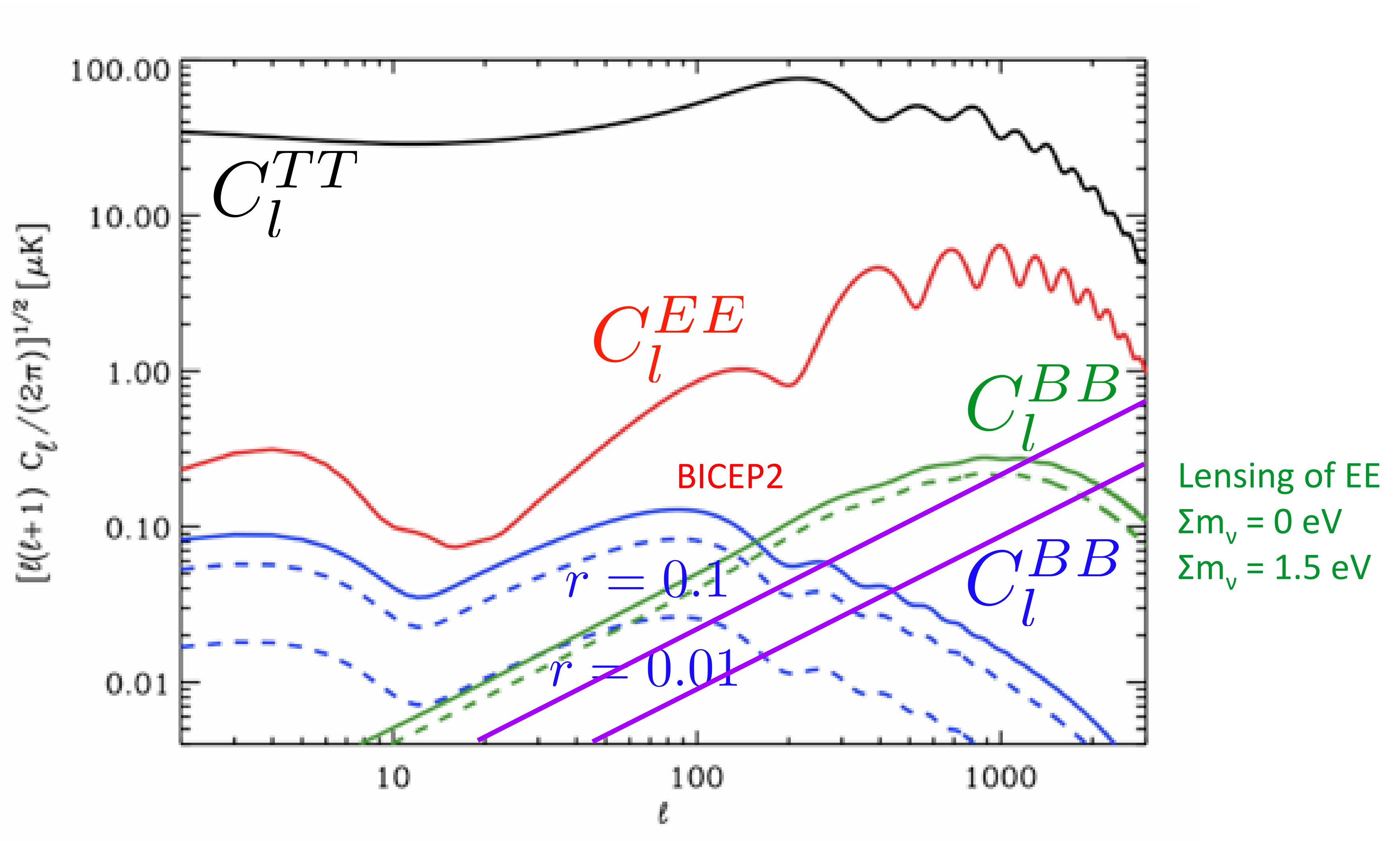
From large-scale B-modes

Improving the estimate of n_s

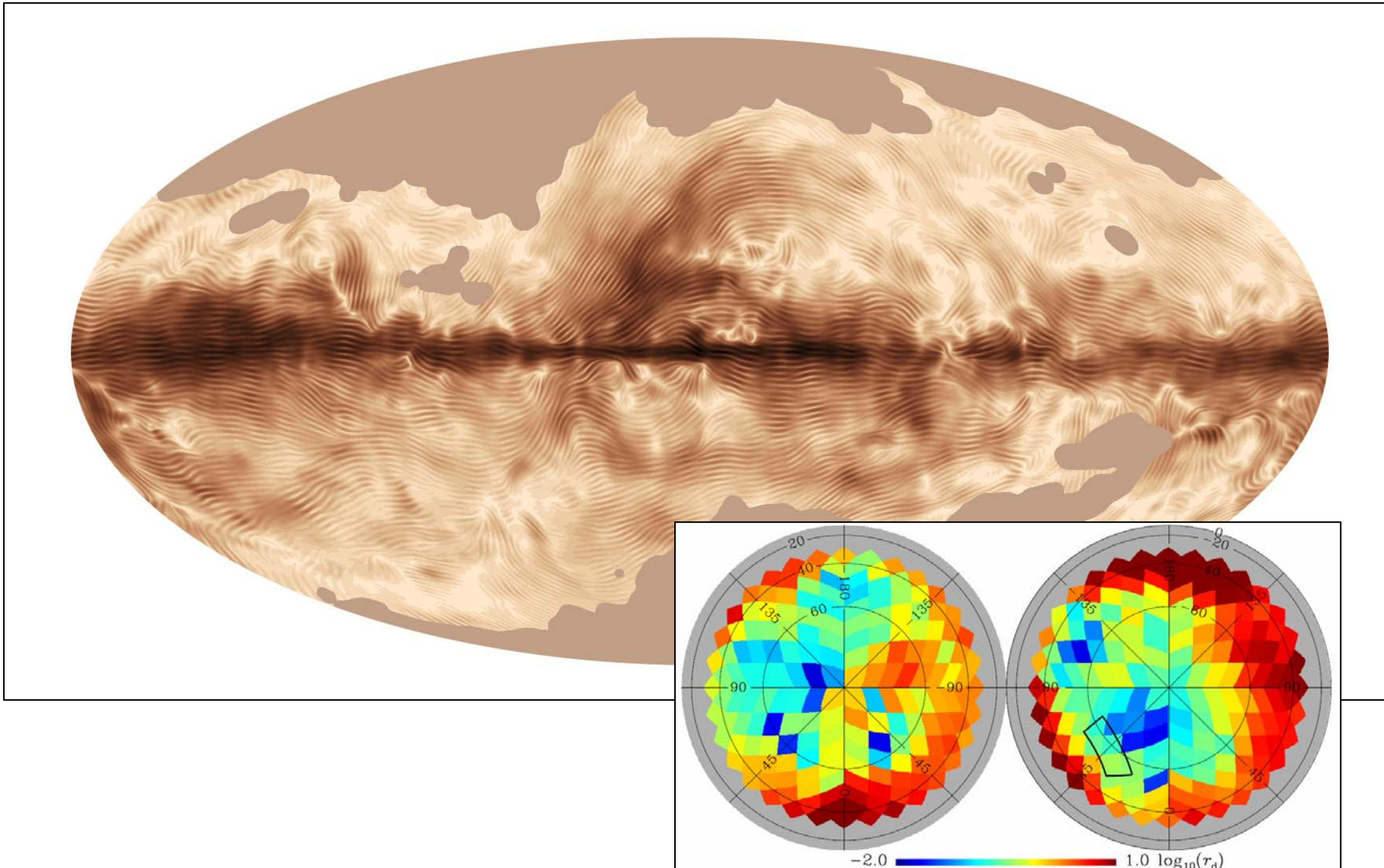
The two targets are synergic and complementary in constraining the physics of inflation

From high resolution T, E-modes, B-modes

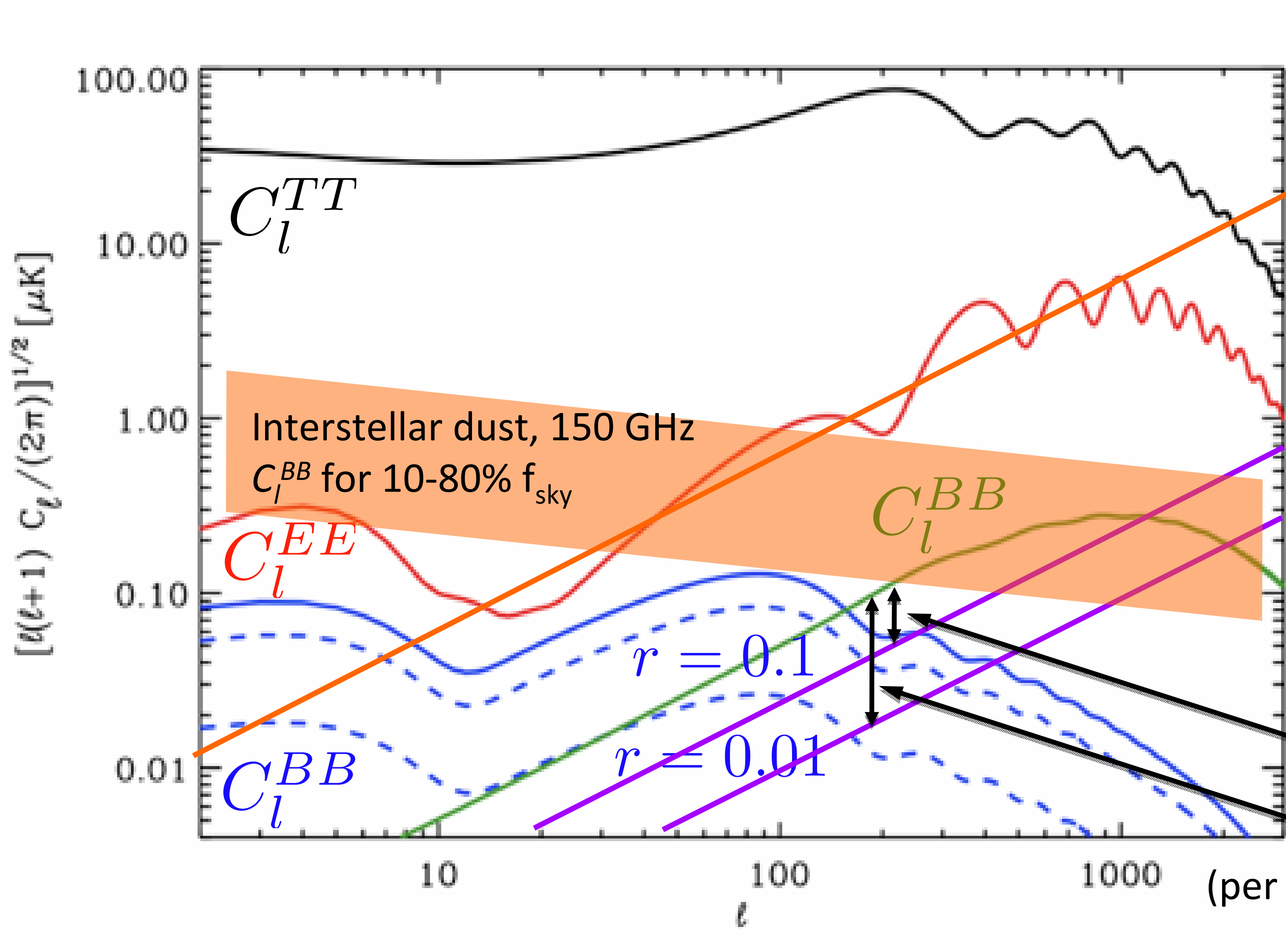
Temperature & Polarisation CMB C_l



Foregrounds are complex and polarized



Target: primordial B-modes **and** gravitational lensing



Noise of Planck survey ≈ 50 μK.arcmin

required survey noise:

2.5 uK.arcmin

1.0 uK.arcmin

after components separation : even more detectors

S/N≈2

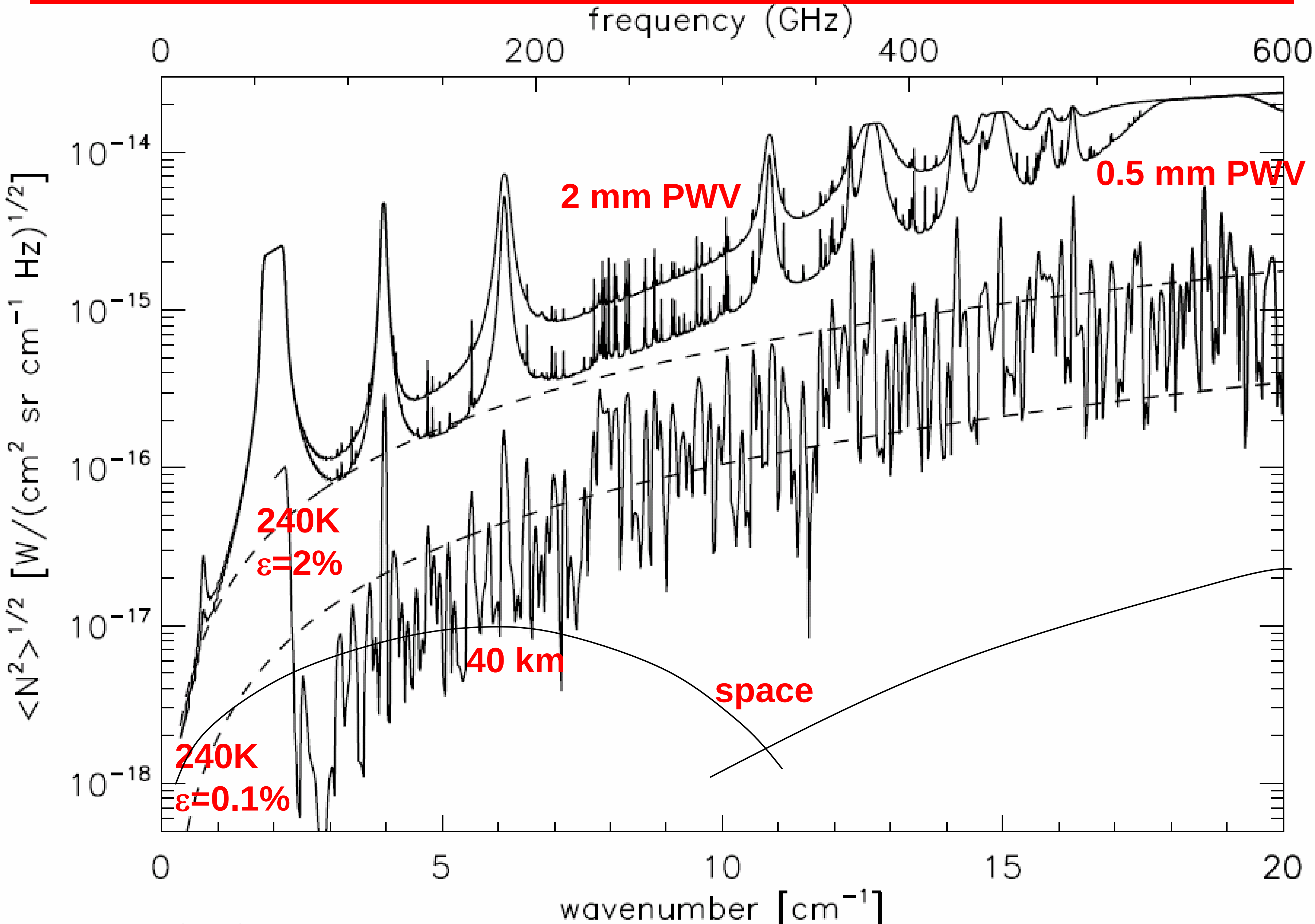
S/N≈5

(per pixel or per mode)

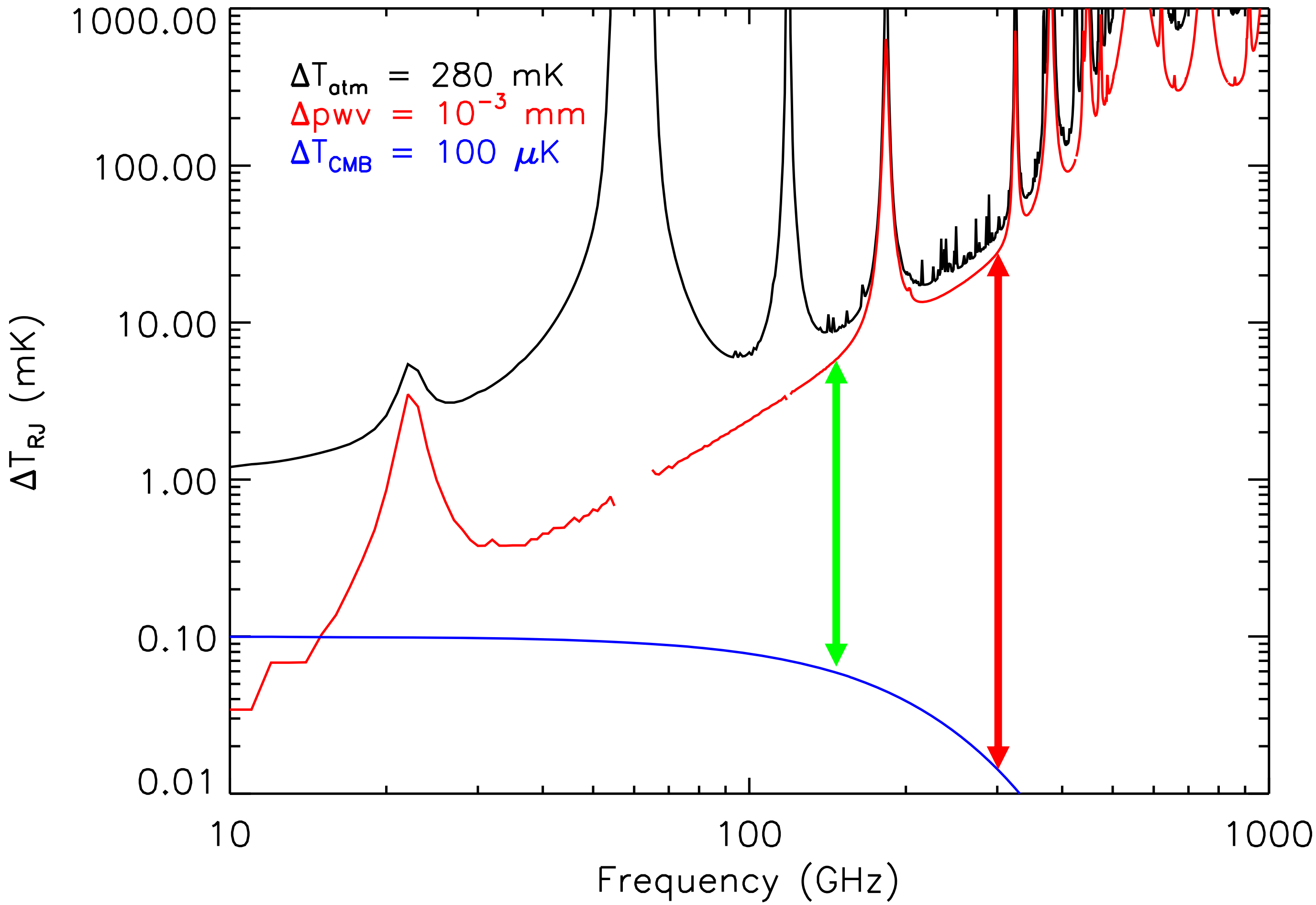
We **do need** a space-based survey

- Given the importance of polarized forgrounds, the required survey sensitivity has to be reached after the foregrounds separation process.
- To achieve this, we need
  - wide frequency coverage (70 to 600 GHz minimum)
  - a sufficient number of independent bands (order or 15)
  - absence of atmospheric fluctuations
- … i.e. we need a space based survey

Atmospheric fluctuations : quantum

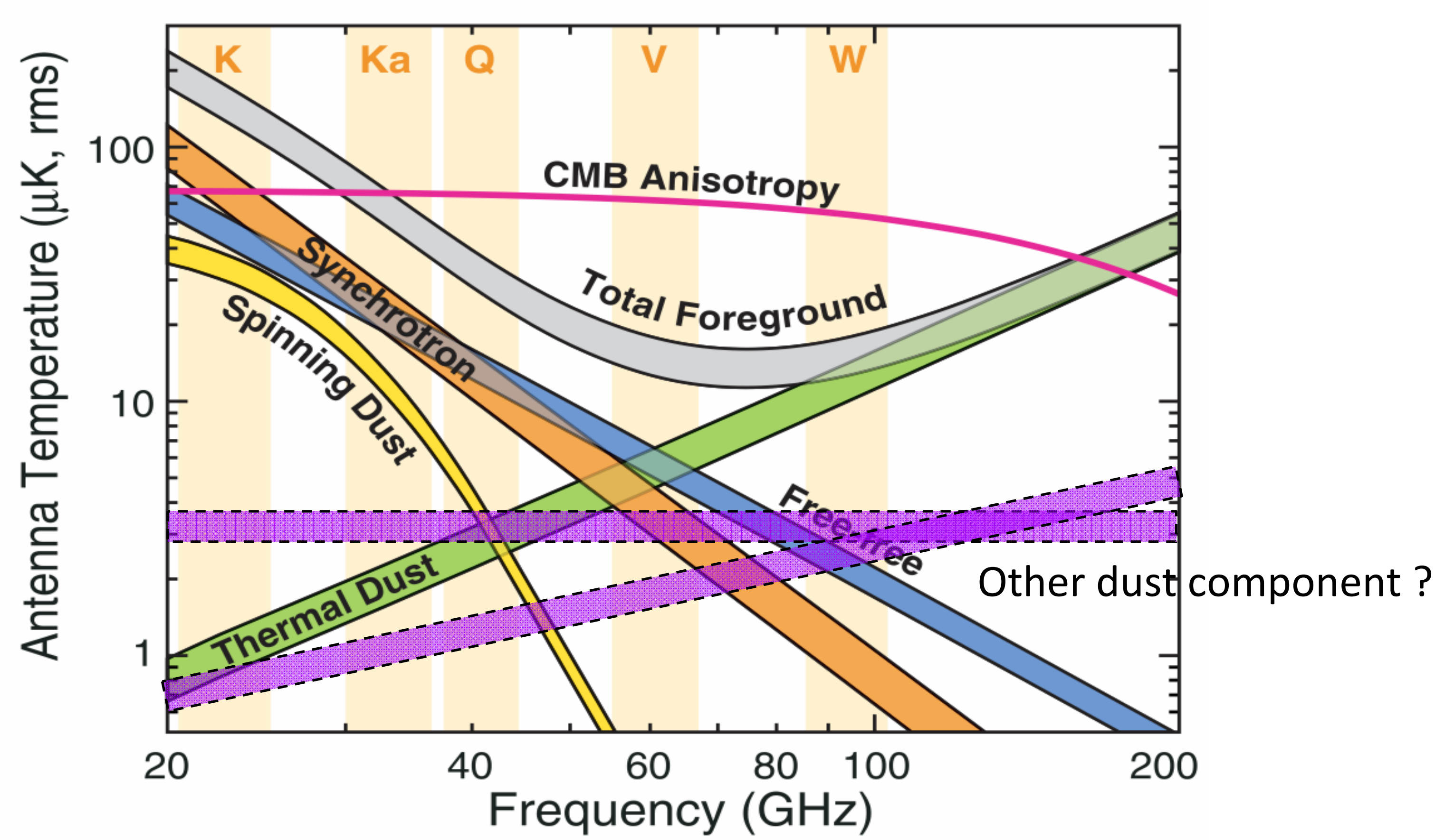


Atmospheric fluctuations : Turbulence



Extremely difficult to measure CMB fluctuations from the ground at f > 300 GHz, even in the best sites

Foreground complexity



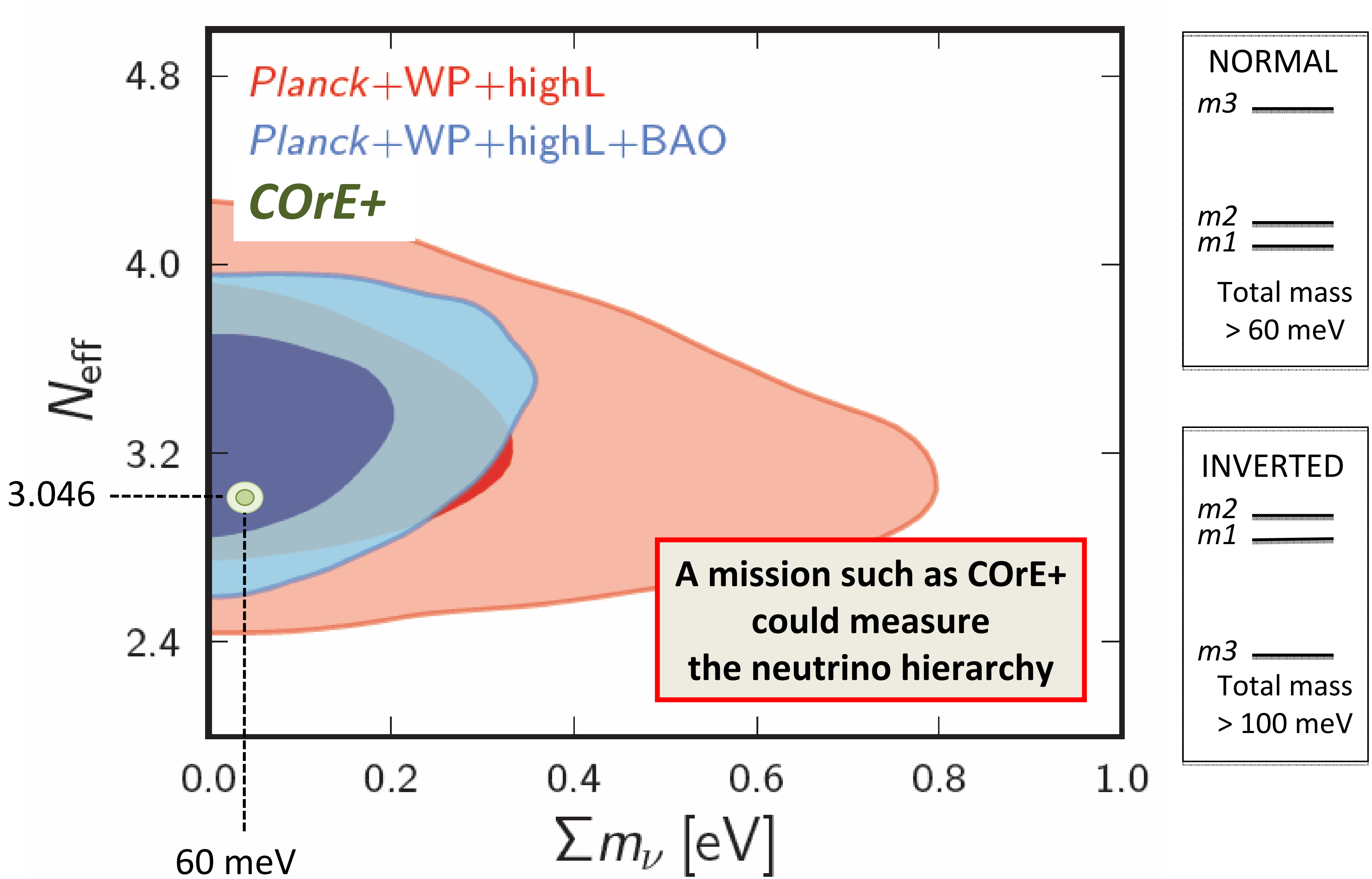
Bennett et al., ApJSS 208, 20 (2013)

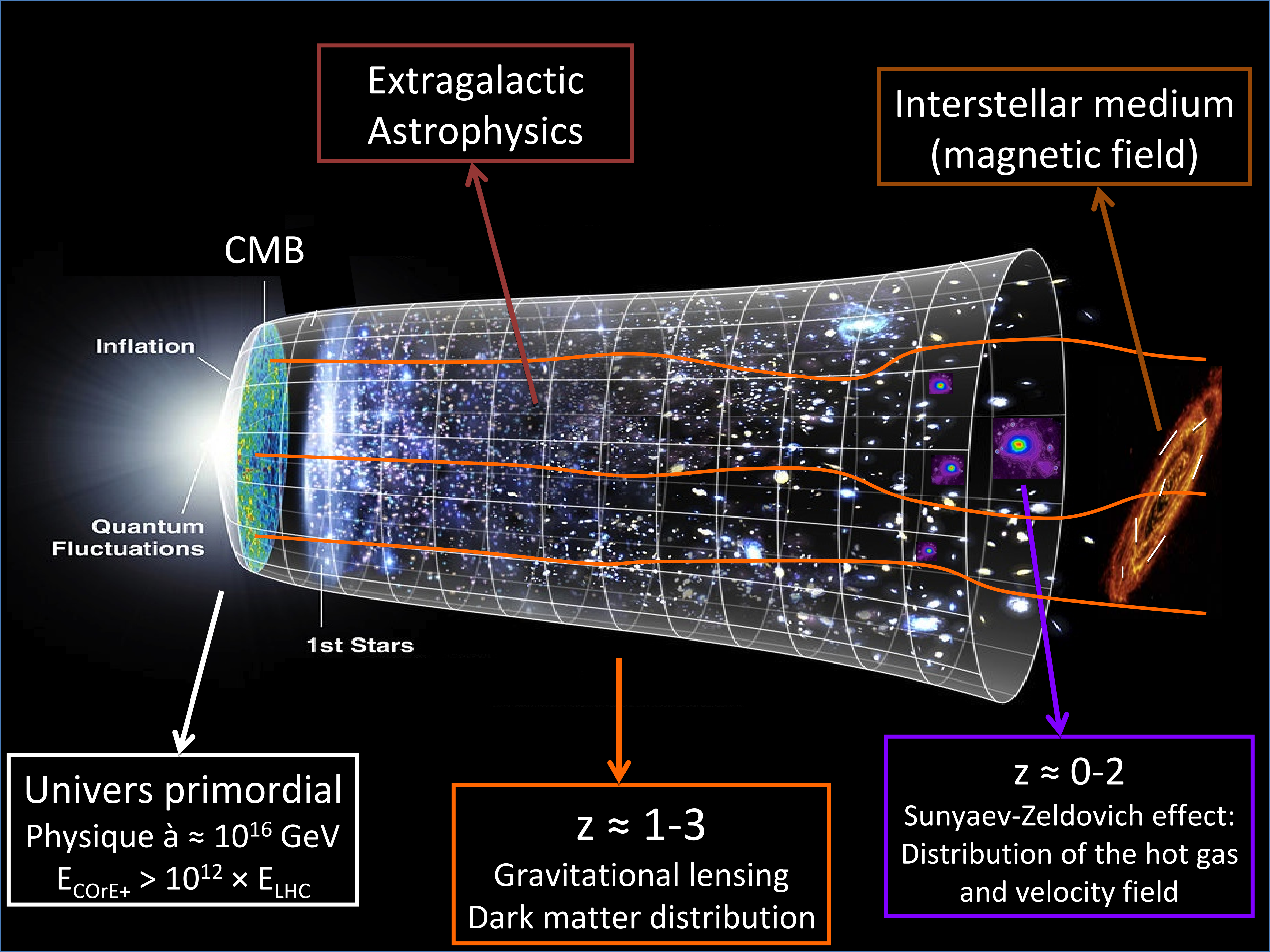
We need more bands than components

Count components (or parameters)	I	P
CMB	1	1
Thermal SZ	2	0
2-component thermal dust	6	6
2-component synchrotron	4-6	4-6
Free-free	1-2	0 ?
Spinning dust	a few	?
CIB	many	0 ?
Zodiacal light	1-3	0 ?
Radio source background	a few	a few
Surprises	?	?
TOTAL	**15-20 +**	**11-13 +**

In cleaner regions of the sky, less parameters are needed, but this depends on the sensitivity of the survey.

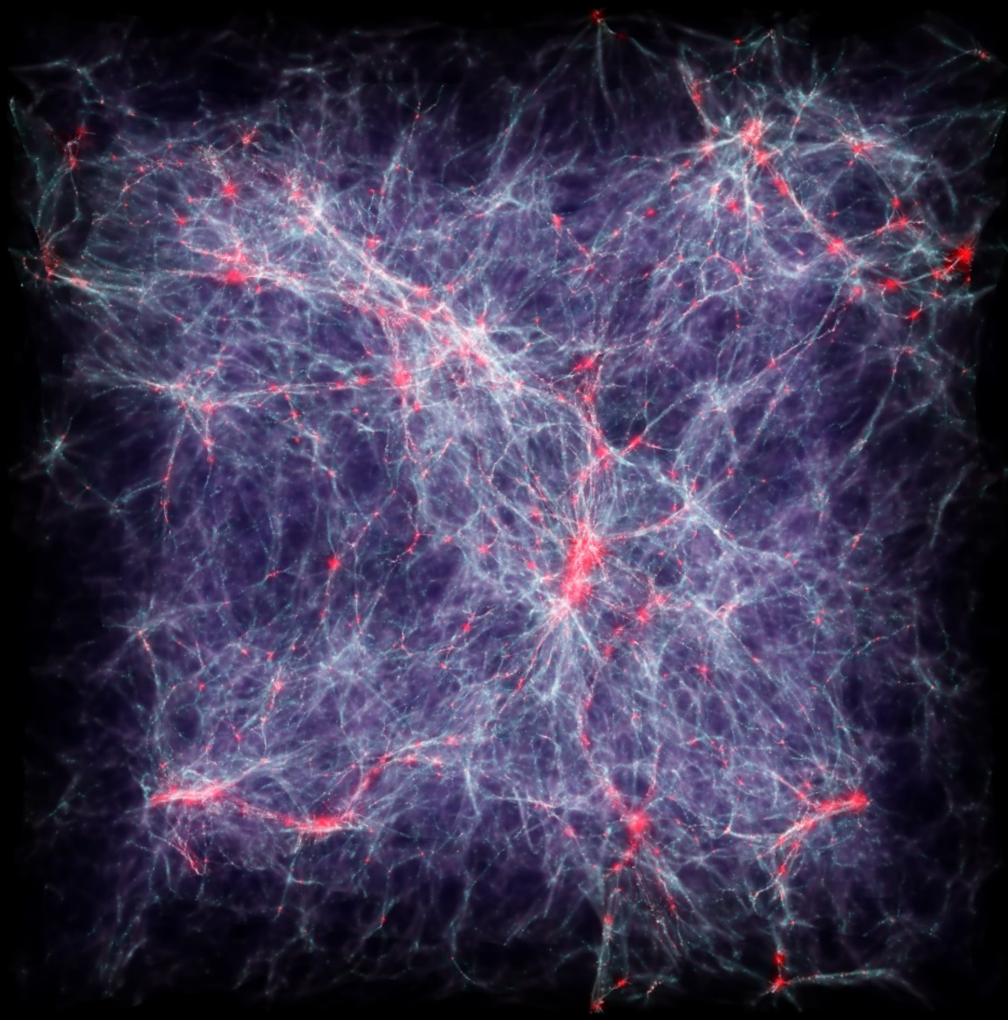
Constraining the neutrino sector




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



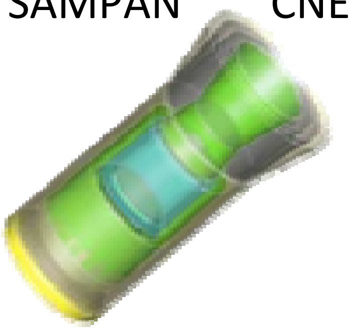
SZ in clusters: COrE+ has the same resolution of 10-m class ground based telescopes, on the positive peak of the SZ spectrum, and very effective components separation capabilities

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

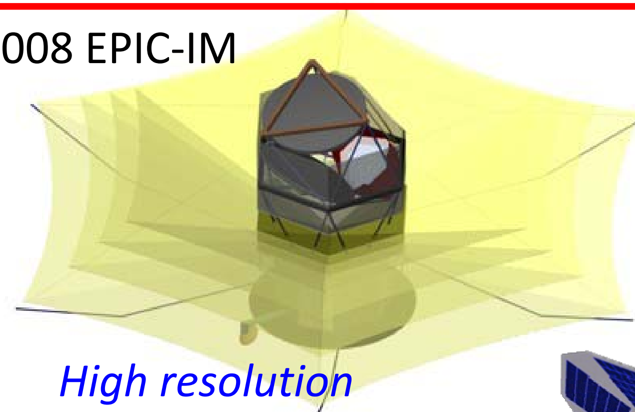
$T \approx 10^4$ K  $T \approx 10^7$ K

post-Planck mission proposals

SAMPAN CNES 2006



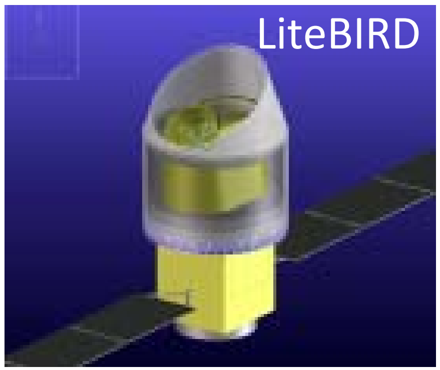
NASA 2008 EPIC-IM



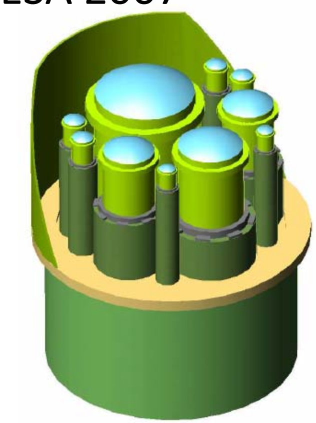
High resolution

COrE
ESA 2010

JAXA 2008

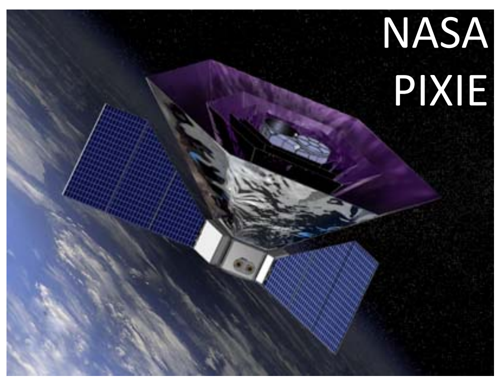


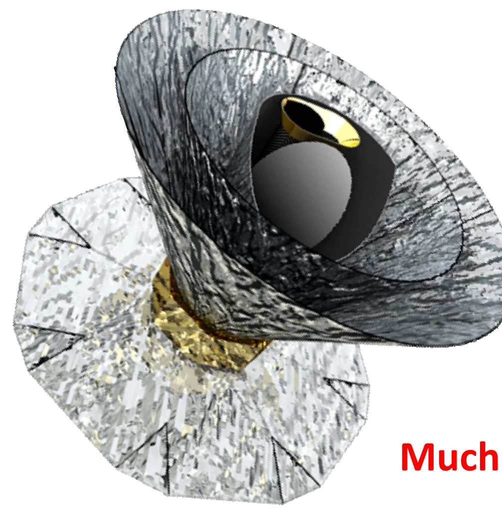
BPOL
ESA 2007



Number of frequency bands

Absolute Spectrophotometer





PRISM
ESA 2013

Low Resolution
Limited frequency coverage
Only primordial B-modes

→

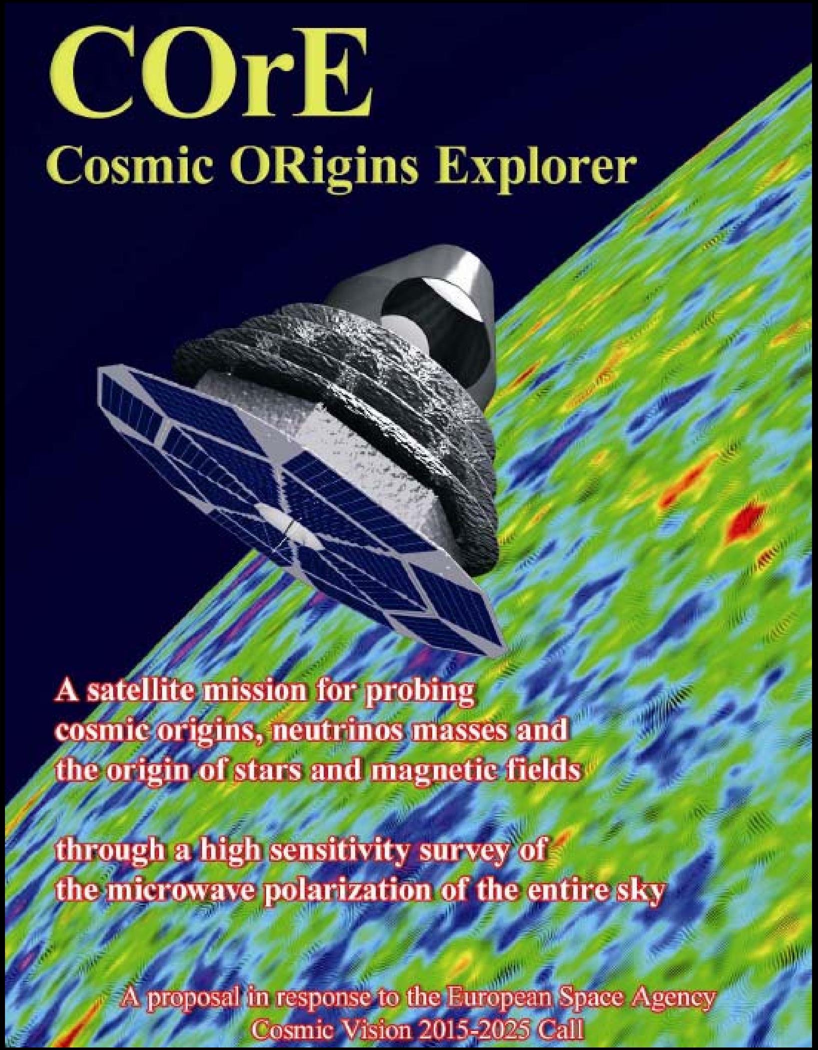
Much richer scientific program
(sub-mm astronomy)
(extra-galactic science)

ESA call for M4

- Mission in 2025
- Similar to previous M calls, BUT
  - Cost for ESA < 450 M€ (Δ=-150 M€)
  - TRL 5-6 in 2018 (start of implementation): in practice, rely on available technologies already at the time of the proposal
  - State clearly the share of responsibilities between ESA and the national agencies funded consortia (who provides what, who pays for what)
  - Requires a somewhat more defined letter of endorsement from the national agencies.
- Sept. 16th 2014, 12:00 CEST : letter of intent
- Jan. 15th 2015, 12:00 CEST : full proposal

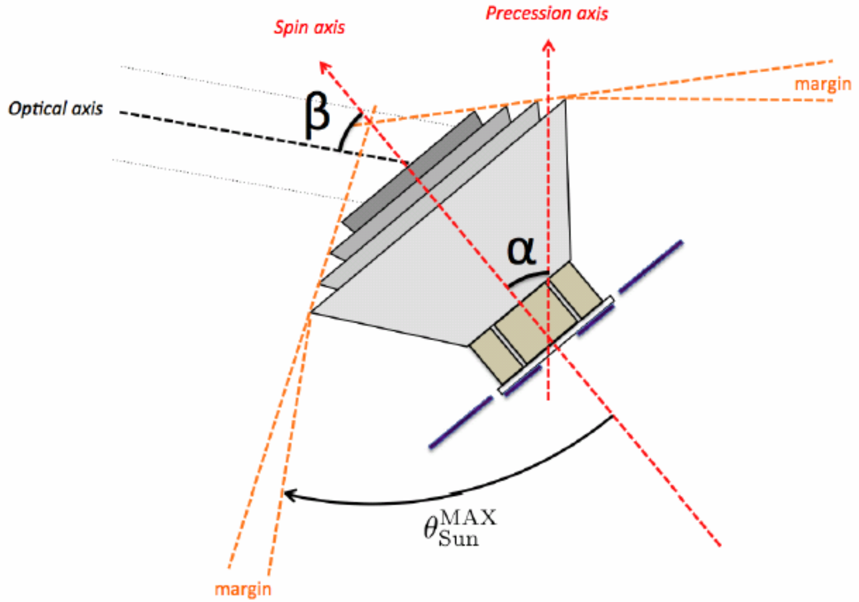
Which polarization mission for M4 ?

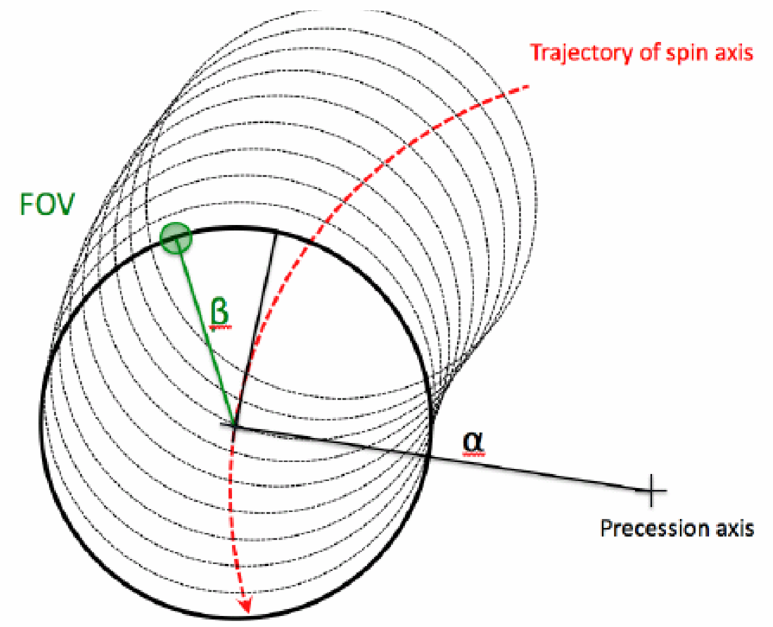
- Sensitivity between 1.5 and 2.5 μK.arcmin ≈ 6000-2000 detectors
- Angular resolution for CMB between 4' and 6‘ (1m-1.5m class telescope)
- Enough frequency channels (15) for an efficient extraction of the CMB from the foregrounds
- Simplified, optimized CORE 2010 (see www.core-mission.org)
- Similar to Planck, with many more polarization sensitive detectors, and optimized scanning strategy



No Pol modulator option ?

- The modulation of polarized signals can be obtained using a sky scan strategy more elaborated than the Planck one (similar to WMAP).
- Big advatage:
  - no moving parts in the instrument
- Possible disadvantages:
  - Requires more energy (or gas mass) for the ACS
  - Ellipticity of beams generates T-P leakage
  - Reduced thermal stability (sun aspect modulated)





No Pol modulator option ?

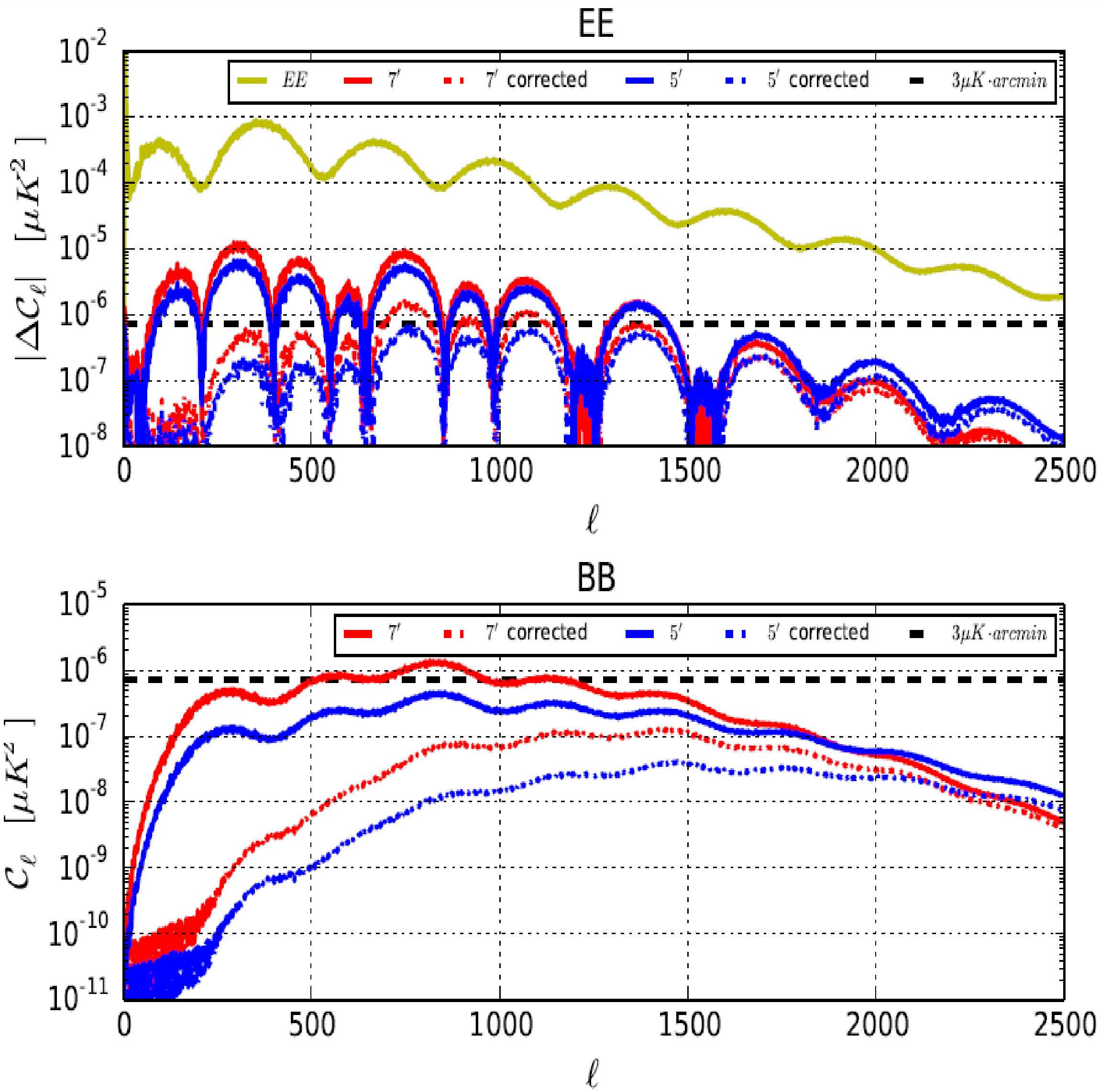
- Optimization of scan parameters (Desert, Ponthieu, Delabrouille et al.)
- Scan parameters affect sky coverage (total and per precession), angle coverage, redundancy
- Are constrained by the data sampling and data rate, the number of cycles in case of a gimbaled antenna, the energy(mass) required to control the scan, sun and earth directions and illumination of solar panels, etc …
- Good tradeoffs :

- Light version: $\alpha \simeq$ 45-50°, $\beta \simeq$ 40-45°, $T_{\rm spin} \simeq 30\,$seconds, $T_{\rm prec} \simeq 48\,$hours.
- Extended version: $\alpha \simeq$ 60-70°, $\beta \simeq$ 20-30°, $T_{\rm spin} \simeq 30\,$seconds, $T_{\rm prec} \simeq 60\,$hours.

- Thermal simulation: on-going

No Pol modulator option ?

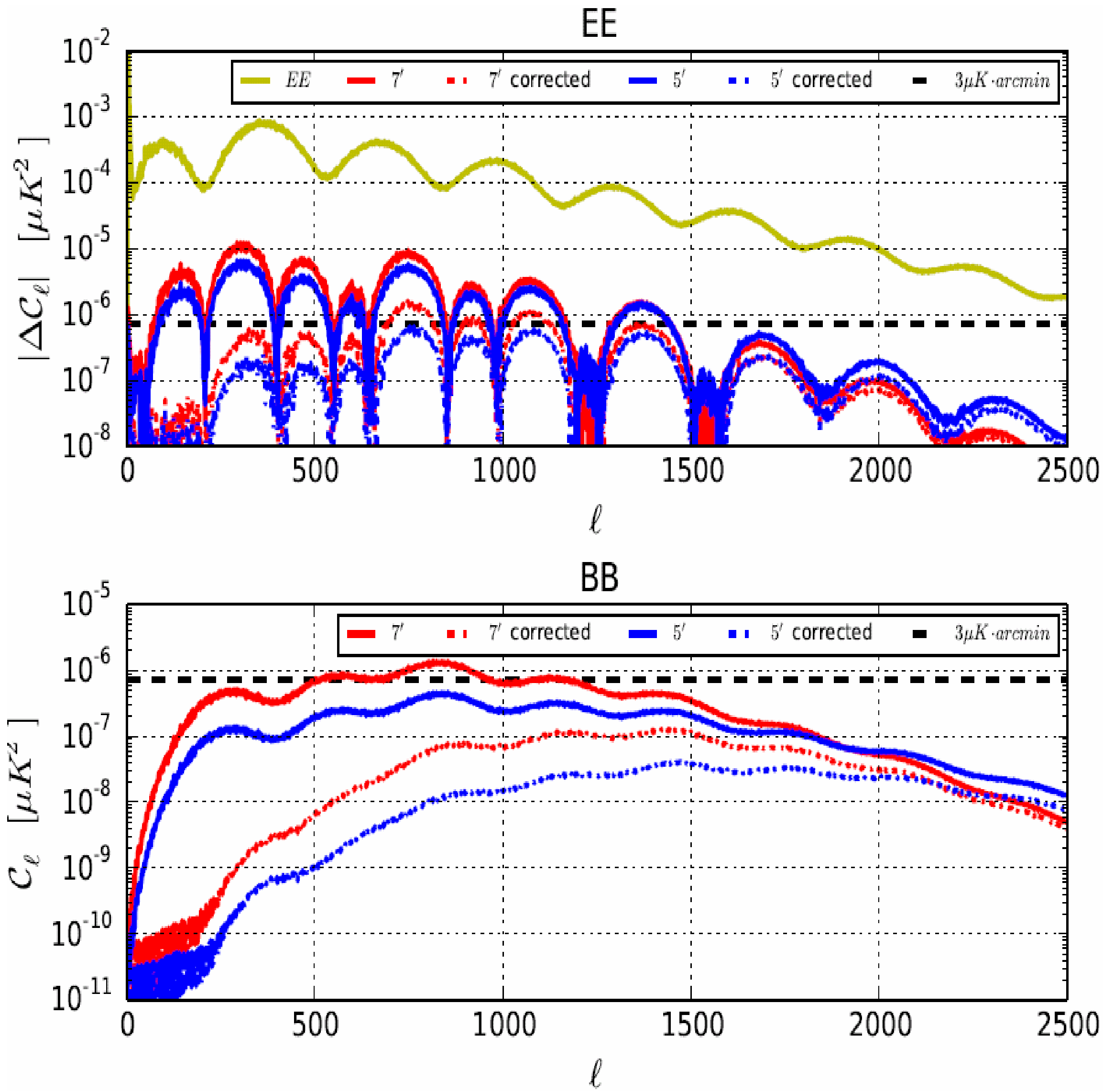
- Temperature to Polarization leakage due to elliptical beams etc. can be mitigated using appropriate scan strategy and advanced (iterative) map making
- Iterative method: J. Delabrouille
- Simulations by L. Pagano, F. Piacentini
- Works OK for small beams



Beam: Gaussian, e=0.05 - No B-modes in simulation

No Pol modulator option ?

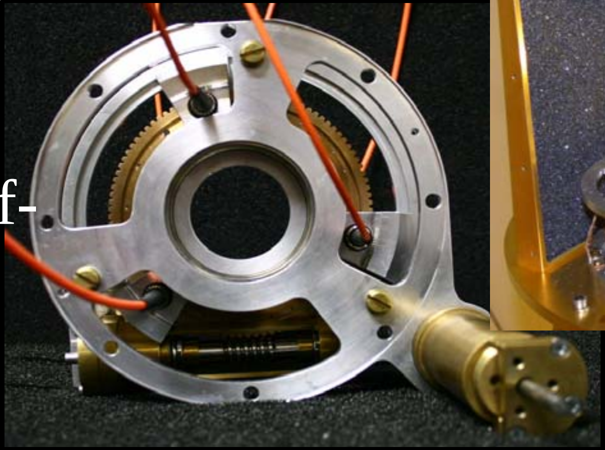
- Polarization modulator development going on in parallel
- ESA ITT

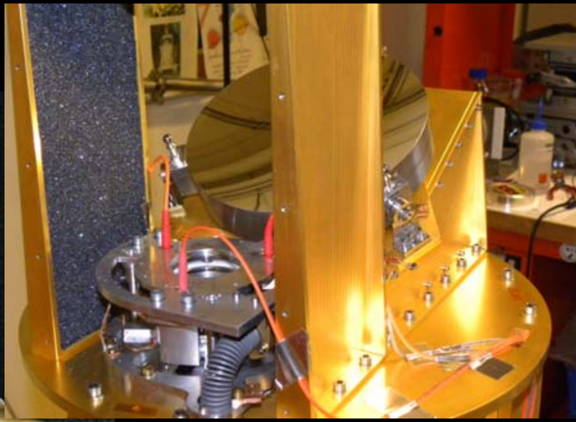


Beam: Gaussian, e=0.05 - No B-modes in simulation

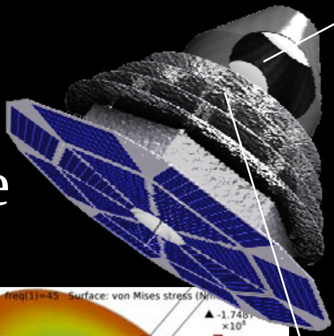
Pol modulator option ?

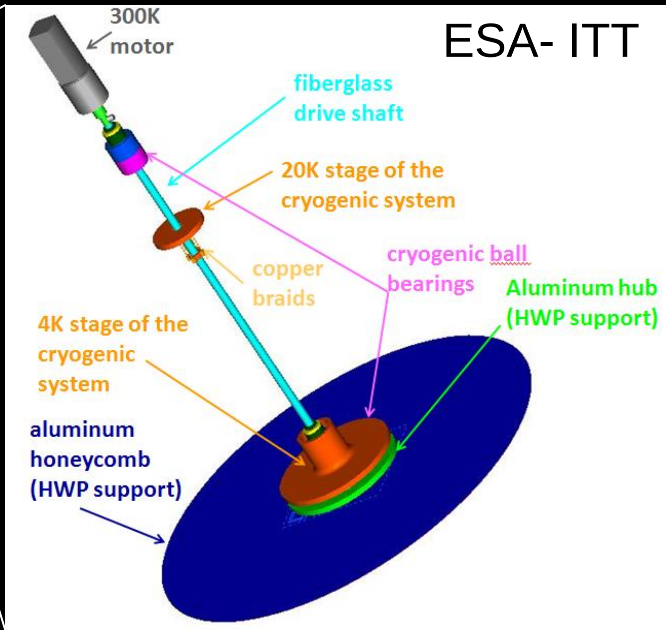
- In COrE the polarization modulator was large and was the first optical element.
- On-going study “ESA ITT AO/1-7136, Large Radii Half-Wave Plate (HWP) Development” for the reflective option
- A smaller polarization modulator (reflective or refractive) can be placed between the telescope and the focal plane.
- Option under study.

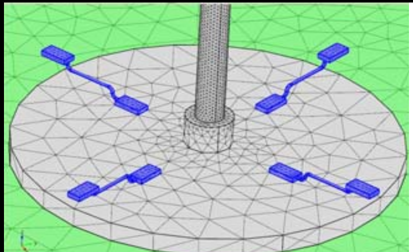


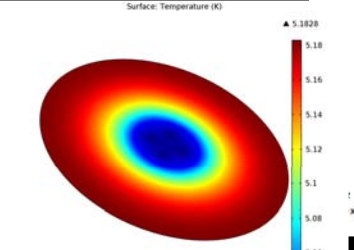


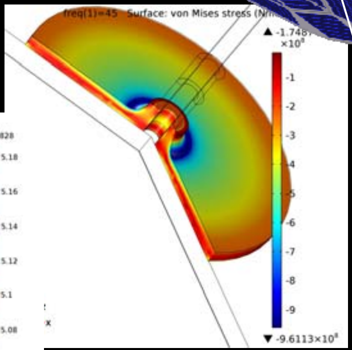
PILOT (CNES)



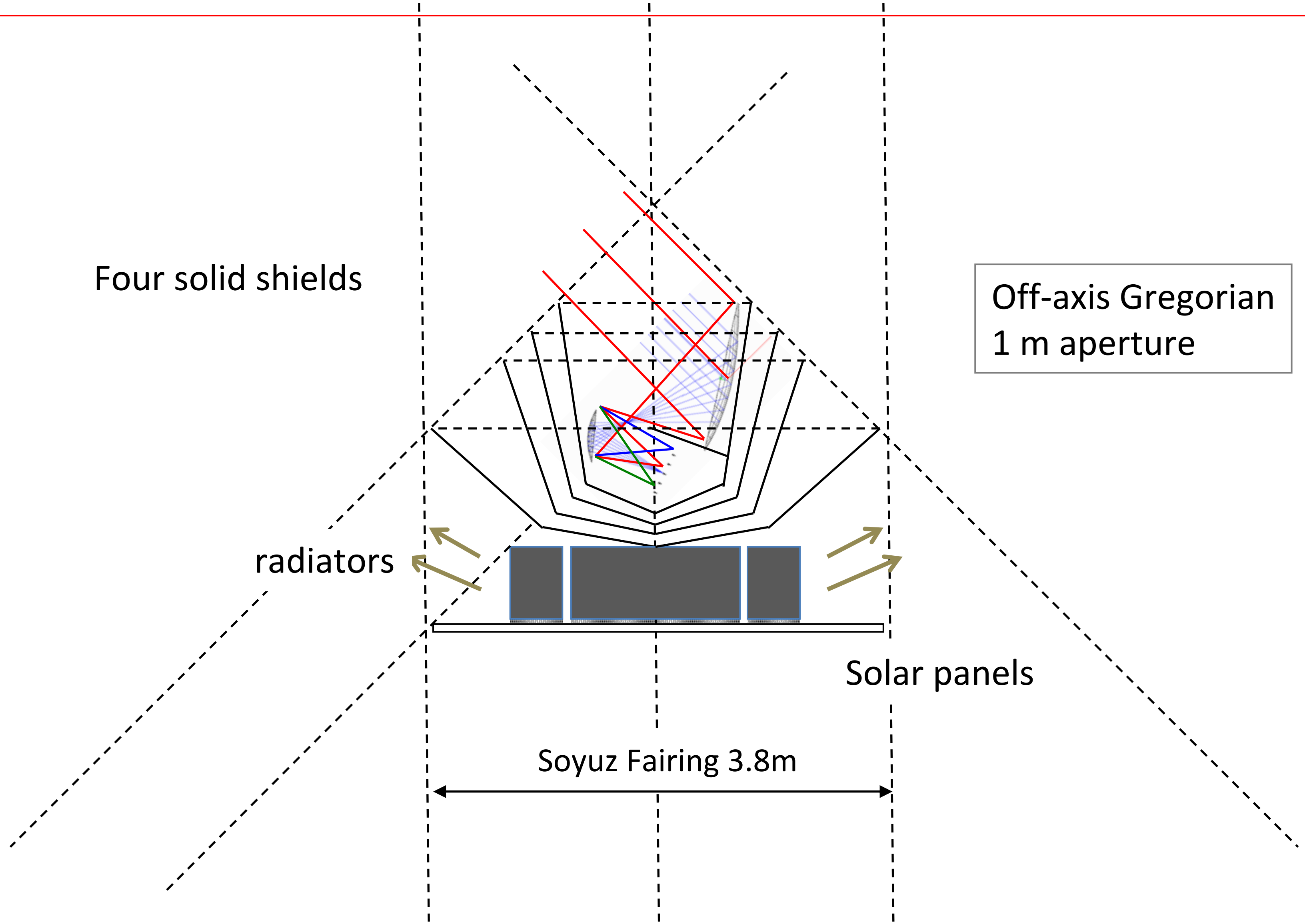




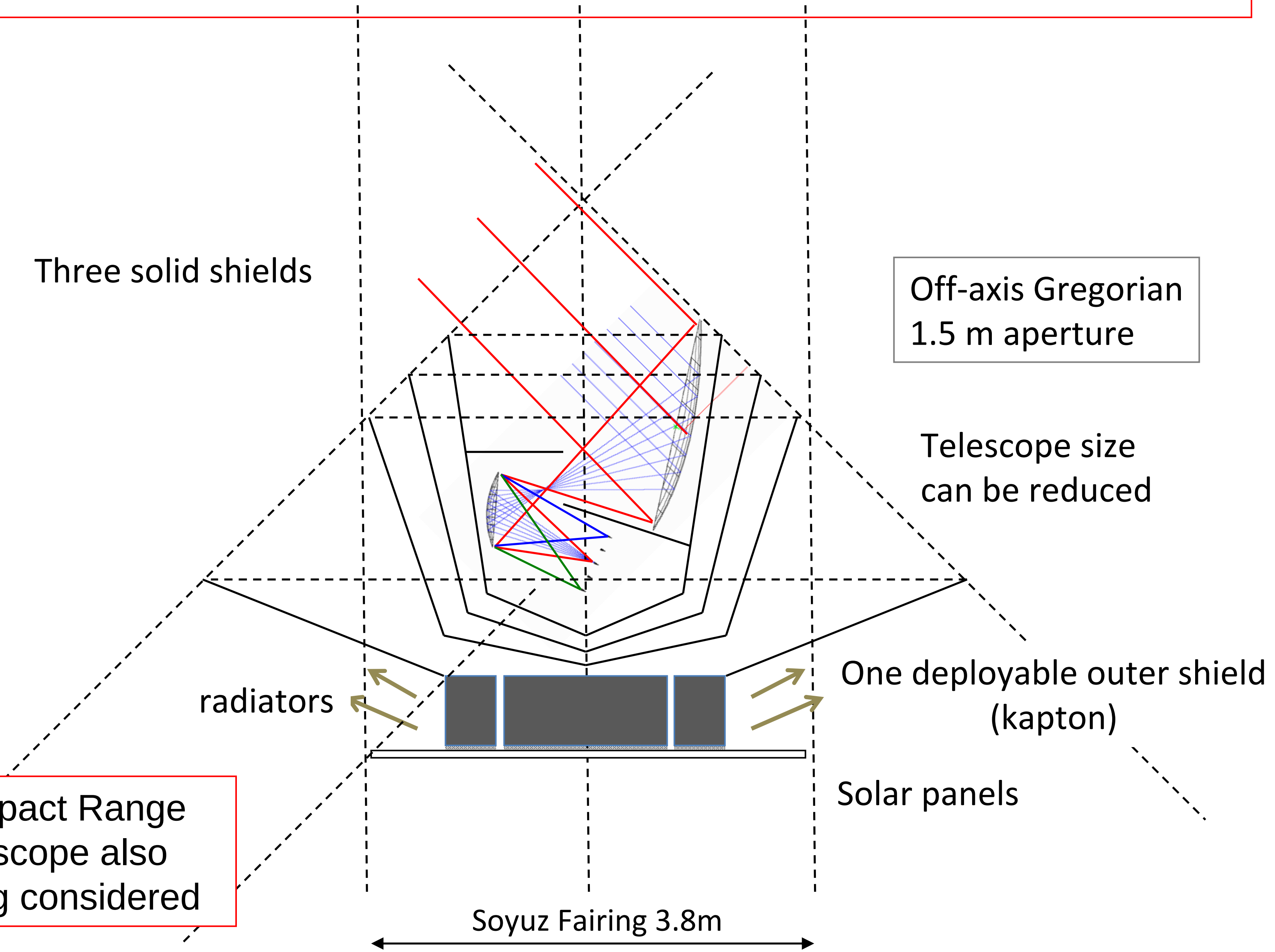




Wide Focal Plane



Wide Focal Plane



Compact Range Telescope also being considered

Cryo chain

- **OPTIONS**
  - 100 mK done for Planck, several options
  - 15-20K
    - Sorption cooler Planck:
    - 15K pulse tubes Air Liquide + CEA
    - Specific JT
  - 2-4K
    - JT He4: 4K – for closed-cycle dilution need an additional 1.7K stage
    - JT He3: 2K – RAL (TRL TBC); Japan
  - 100 mK
    - Closed cysle dilution including 1.7K stage if necessary (Sorption Univ. Twente, Netherlands)
    - ADR (CEA): Good TRL, not continuous
- **Strategy**
  - Keep several options and decide in phase A
  - Continue developments

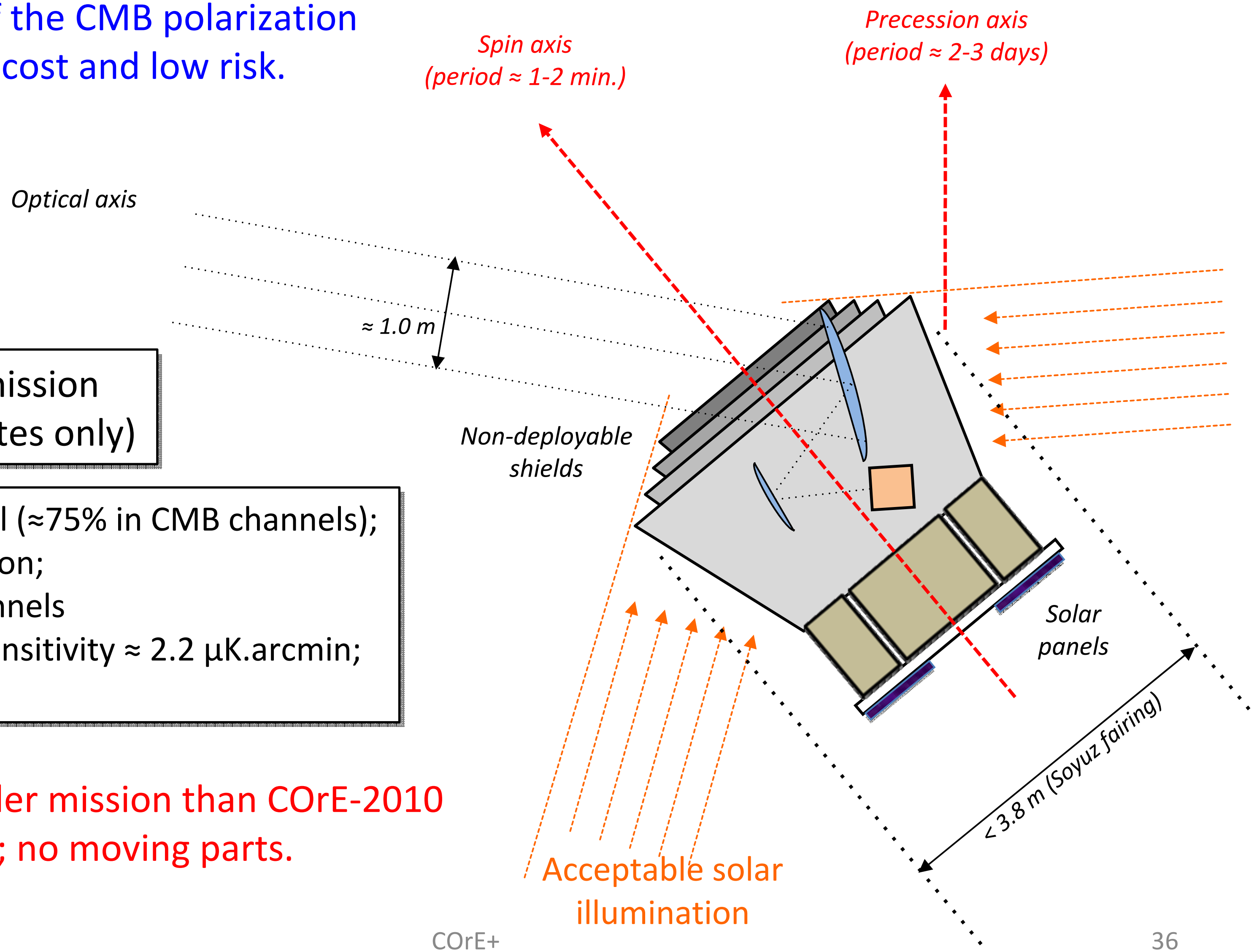
COrE+ light

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

OPTION: ESA mission
(ESA member states only)

2100 detectors total (≈75% in CMB channels);
3 years of observation;
> 15 frequency channels
CMB polarization sensitivity ≈ 2.2 μK.arcmin;
Budget 550 M€.

Significantly simpler mission than COrE-2010
1/3 the detectors; no moving parts.



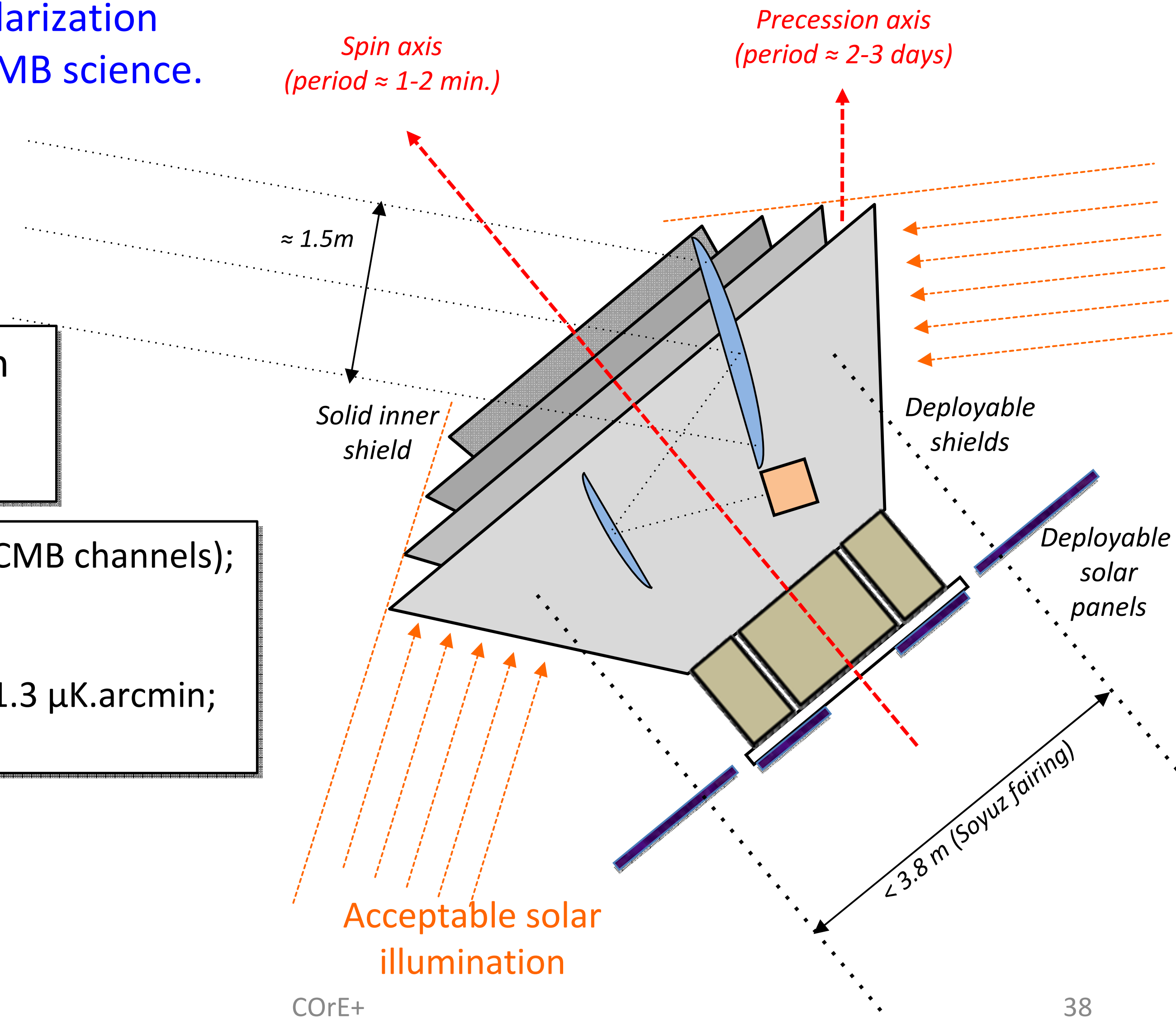
COrE+ light (possible configuration)

Core CMB cience mission						
Freq	beam	N_{det}	per arcmin^2 pixel		5σ PS or SZ	
GHz	arcmin		σ_P μK_{CMB}	σ_I kJy/sr	$5\sigma_P$ mJy	$5\sigma_I$ $10^5 \times Y_{SZ}$
60	*21.0*	*10*	*29.1*	*2.1*	*16.3*	*38.6*
70	*18.0*	*10*	*28.0*	*2.6*	*17.7*	*33.0*
80	*15.8*	*20*	*19.2*	*2.3*	*13.4*	*20.7*
90	*14.0*	*30*	*15.4*	*2.2*	*11.6*	*15.5*
100	**12.6**	**50**	**11.8**	**2.0**	**9.4**	**11.3**
115	**11.0**	**100**	**8.3**	**1.7**	**7.0**	**7.7**
130	**9.7**	**160**	**6.6**	**1.6**	**5.8**	**6.2**
145	**8.7**	**240**	**5.5**	**1.5**	**4.9**	**5.4**
160	**7.9**	**260**	**5.5**	**1.6**	**4.9**	**6.1**
175	**7.2**	**300**	**5.4**	**1.7**	**4.6**	**7.2**
195	**6.5**	**350**	**5.4**	**1.8**	**4.4**	**11.9**
220	**5.7**	**200**	**8.1**	**2.8**	**5.9**	**-**

Core CMB science mission						
Freq	beam	N_{det}	per arcmin^2 pixel		5σ PS or SZ	
GHz	arcmin		σ_P μK_{CMB}	σ_I kJy/sr	$5\sigma_P$ mJy	$5\sigma_I$ $10^5 \times Y_{SZ}$
255	**5.0**	**120**	**13.1**	**4.3**	**8.0**	**12.6**
295	**4.3**	**60**	**25.8**	**7.4**	**11.8**	**10.1**
340	**3.7**	**40**	**49.0**	**11.1**	**15.5**	**10.3**
390	**3.2**	**30**	**98.7**	**16.0**	**19.4**	**12.7**
450	**2.8**	**20**	**252.3**	**25.2**	**26.5**	**20.7**
520	**2.4**	**20**	**632.1**	**32.8**	**29.8**	**34.1**
600	**2.1**	**80**	**950.9**	**21.4**	**16.8**	**35.0**
700	-	-	-	-	-	-
800	-	-	-	-	-	-
950	-	-	-	-	-	-
1100	-	-	-	-	-	-
1250	-	-	-	-	-	-

COrE+ extended

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



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

5800 detectors total (≈65% in CMB channels);
3 years of observation;
> 18 channels
CMB polarization sensitivity ≈ 1.3 μK.arcmin;
Budget 700 M€.

COrE+ extended (possible configuration)

Extended science mission						
Freq	**beam**	**N_{det}**	**per arcmin^2 pixel**		**5σ PS or SZ**	
GHz	arcmin		σ_P μK_{CMB}	σ_I kJy/sr	$5\sigma_I$ mJy	$5\sigma_I$ $10^5 \times Y_{SZ}$
60	*14.0*	*20*	*20.5*	*1.5*	*7.7*	*18.2*
70	*12.0*	*40*	*14.0*	*1.3*	*5.9*	*11.0*
80	*10.5*	*80*	*9.6*	*1.1*	*4.5*	*6.9*
90	**9.3**	**130**	**7.4**	**1.1**	**3.7**	**5.0**
100	**8.4**	**200**	**5.9**	**1.0**	**3.1**	**3.8**
115	**7.3**	**360**	**4.4**	**0.92**	**2.5**	**2.7**
130	**6.5**	**600**	**3.4**	**0.83**	**2.0**	**2.1**
145	**5.8**	**650**	**3.4**	**0.92**	**2.0**	**2.2**
160	**5.3**	**700**	**3.4**	**1.0**	**2.0**	**2.5**
175	**4.8**	**700**	**3.5**	**1.1**	**2.0**	**3.1**
195	**4.3**	**700**	**3.8**	**1.3**	**2.1**	**5.6**
220	**3.8**	**450**	**5.4**	**1.9**	**2.6**	**-**

Extended science mission						
Freq	**beam**	**N_{det}**	**per arcmin^2 pixel**		**5σ PS or SZ**	
GHz	arcmin		σ_P μK_{CMB}	σ_I kJy/sr	$5\sigma_I$ mJy	$5\sigma_I$ $10^5 \times Y_{SZ}$
255	**3.3**	**250**	**9.1**	**3.0**	**3.7**	**5.8**
295	**2.9**	**230**	**13.2**	**3.8**	**4.0**	**3.4**
340	**2.5**	**150**	**25.3**	**5.7**	**5.3**	**3.6**
390	**2.2**	**130**	**47.4**	**7.7**	**6.2**	**4.1**
450	**1.9**	**90**	**118.9**	**11.9**	**8.3**	**6.5**
520	**1.6**	**70**	**337.9**	**17.5**	**10.6**	**12.2**
600	**1.4**	**50**	**1203**	**27.0**	**14.2**	**29.5**
700	**1.2**	**40**	**5610**	**40.2**	**18.1**	**93.0**
800	**1.1**	**160**	**12200**	**25.6**	**10.1**	**146**
950	*0.9*	*40*	-	*69.5*	*23.0*	-
1100	*0.76*	*40*	-	*89.4*	*25.6*	-
1250	*0.67*	*40*	-	*110*	*27.8*	-

Collaboration COrE+ (from LOI, still open)

- **Institutions from ESA member states:**

Nations already in Planck

  - **Italy** : Università di Ferrara; Università di Genova; Università di Milano; Università di Milano Bicocca; Università di Padova; Università di Roma La Sapienza; Università di Roma Tor Vergata; Università di Trieste; INAF-IASF Bologna; INAF - IRA; INAF - Osservatorio Astronomico di Padova; INAF - Osservatorio Astronomico di Trieste; INAF-IAPS Roma, SISSA Trieste, INFN sections Ge, Pi, Rm1, Rm2
  - **France** : APC Paris, CEA Saclay and Grenoble, IAP Paris, IAS Orsay, Institut Néel Grenoble, IPAG Grenoble, IRAP Toulouse, LAL Orsay, LPSC Grenoble, LPT Orsay.
  - **United Kingdom** : Cardiff University; University of Cambridge; University of Manchester; Rutherford Appleton Laboratory; University of Edinbourg / UK ATC; University of Oxford; Imperial college London; University College London; University of Sussex;
  - **Germany** : MPIfR Bonn; LMU Munich; MPA Garching; RWTH Aachen University.
  - **Spain**: Instituto de Astrofísica de Canarias; Instituto de Física de Cantabria (CSIC-UC); Institut de Ciències del Cosmos de la Universitat de Barcelona; Universidad de Oviedo ; Centro de Estudios de Física del Cosmos de Aragón; Universidad de Granada.
  - **Switzerland** : Departement Physik, Universität Basel; Laboratoire d'Astrophysique, EPFL; Département d'Astronomie, Université de Genève ; Département de Physique Théorique, Université de Genève.
  - **Finland** : University of Helsinki.
  - **Norway**: Institute of Theoretical Astrophysics, University of Oslo.
  - **Denmark**: Niels Bohr Institute and Discovery Center; DTU Space Research Center.
  - **Ireland**: Maynooth

New

  - **The Netherlands**: University of Groningen; Radboud University Nijmegen; University of Leiden; NIKHEF; SRON Netherlands Institute for Space Research.
  - **Poland**: CBK PAN, Warsaw; NCBJ, Warsaw; Jagiellonian University, Cracow; Silesian University, Katowice; Nicolaus Copernicus University, Torun; CFT PAN, Warsaw; Jan Kochanowski University, Kielce; CAMK PAN, Warsaw.
  - **Portugal**: Institute of Astrophysics and Space Sciences, Porto and Lisbon ; University of Evora ; Institute of Telecommunications.
  - **Austria** : TBD

- **Possible Non-european partners :**
  - **USA:** Caltech/JPL; Goddard Space Flight Center; UC Berkeley; LBNL/NERSC; Stanford University; University of Minnesota; NIST.
  - Being discussed: Japan; Brasil; Canada; India.

Collaboration COrE+, Steering Committee

Country	Representatives
• Italy:	M. Bersanelli, P. de Bernardis, C. Burigana
• France:	F. Bouchet, M. Bucher, J. Delabrouille, M. Giard
• UK:	A. Challinor, B. Maffei, G. Pisano
• Germany:	E. Komatsu, R. Sunyaev
• Spain:	E. Martinez-Gonzalez, J.-A. Rubino-Martin, L. Verde
• Poland:	A. Pollo
• The Netherlands:	R. van de Weijgaert
• Switzerland:	M. Kunz
• Portugal:	C. Martins
• Norway:	H.-K. Eriksen
• Finland:	H. Kurki-Suonio
• Ireland:	N. Trappe
• Denmark:	P. Naselsky
• Austria:	J. Alves

Role of SC :

- Communication and internal organization of different countries
- Contacts with national space agencies

Collaboration COrE+, WG structure

Working Group	Coordinators
• Mission (global coordination):	P.de Bernardis, F.Bouchet, J. Delabrouille
• Payload:	B. Maffei, M. Piat
• Calibration:	M. Bersanelli, F-X. Desert
• CMB science:	M. Bucher, A. Challinor
• Extragalactic Science:	E.Komatsu, G. de Zotti
• Interstellar medium :	F. Boulanger, C. Dickinson
• Data Processing:	C. Baccigalupi, H-K. Eriksen
• Simulations:	M. Ashdown, P. Natoli
• Spectroscopy:	J. Chluba, J-A. Rubino Martin

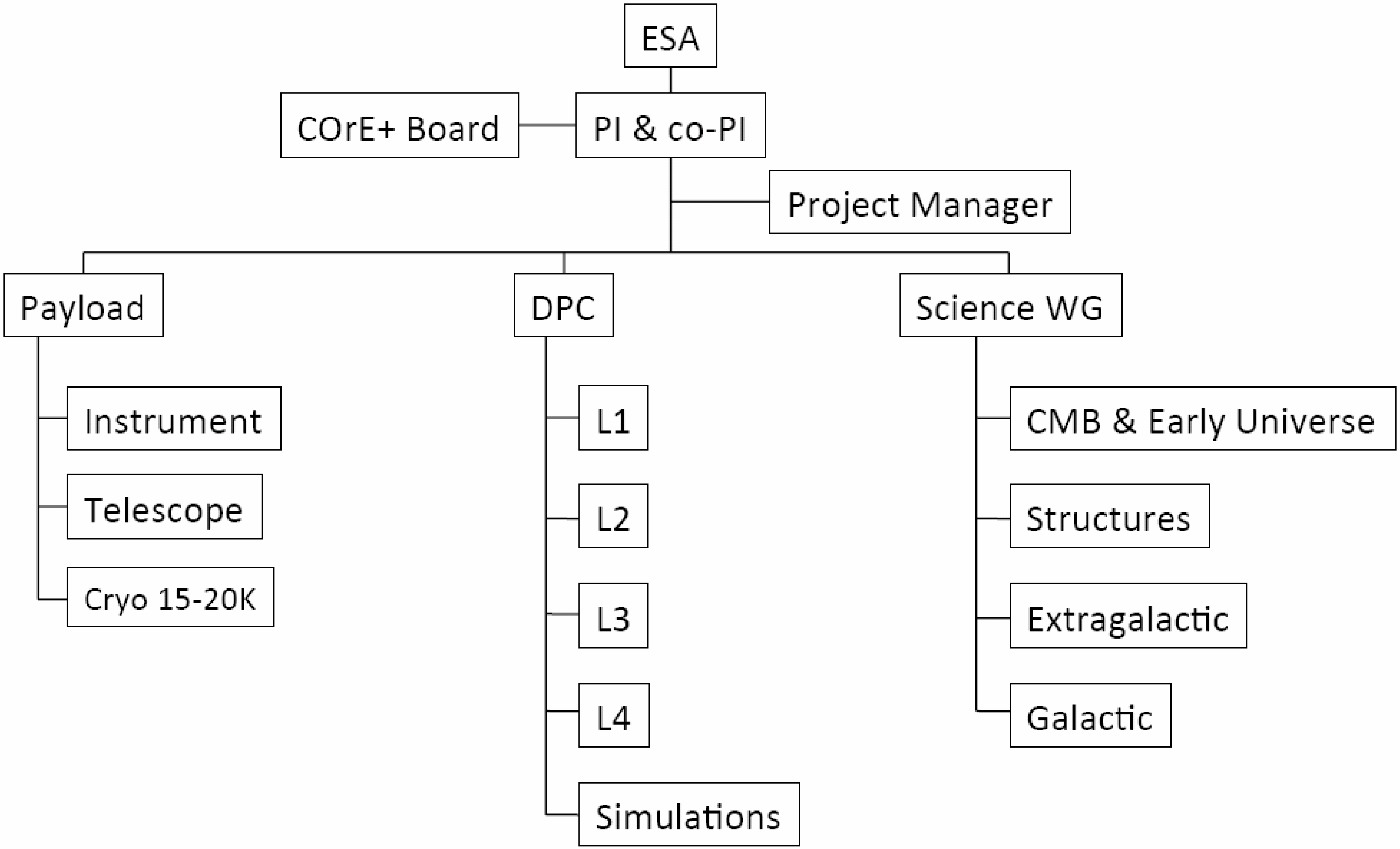
Role of current working groups :

planning and organization of different tasks for the proposal

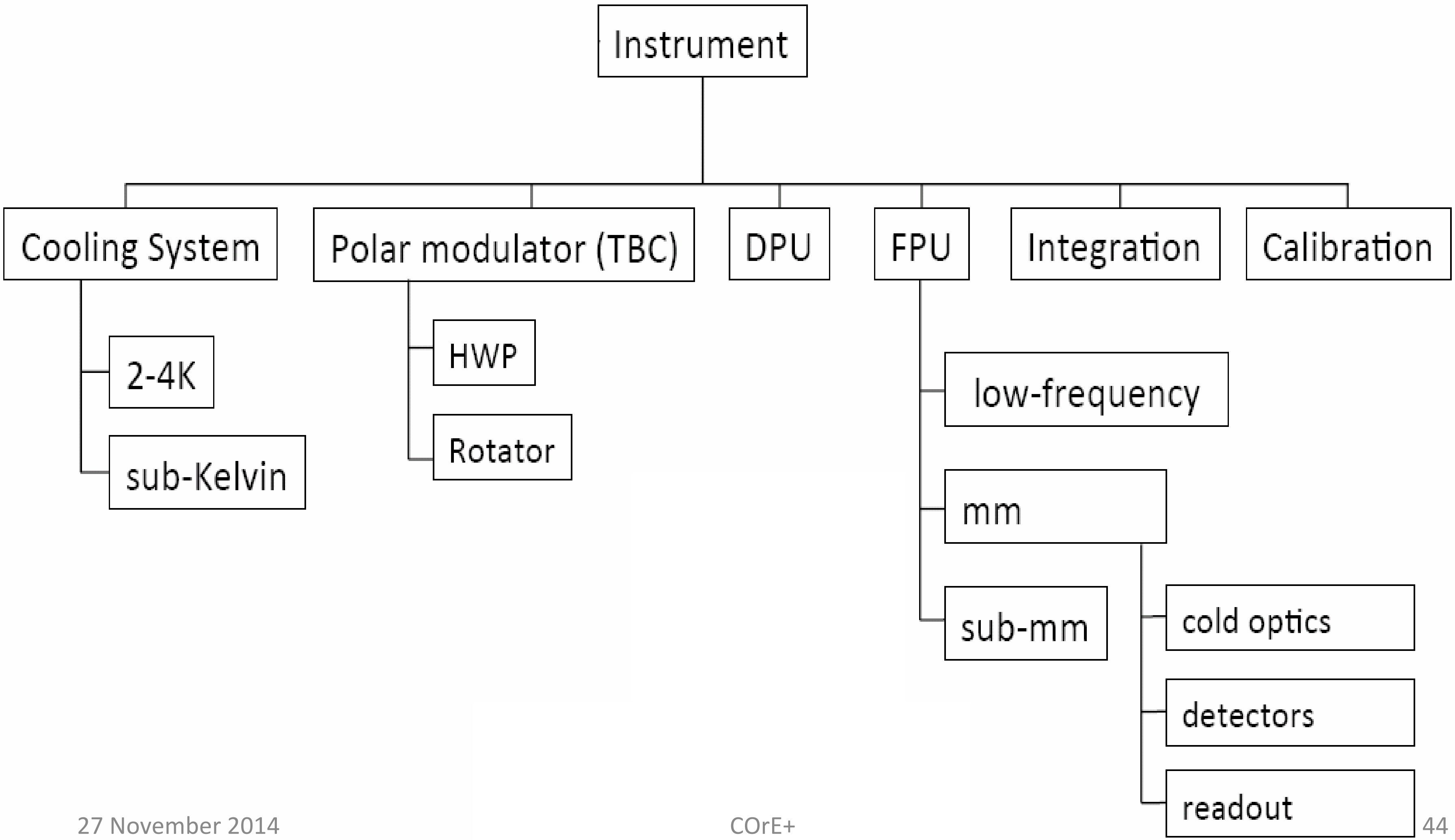
interaction with global coordinators

proposal writing coordination

COrE+ organization (preliminary)



Instrument Organization (preliminary)



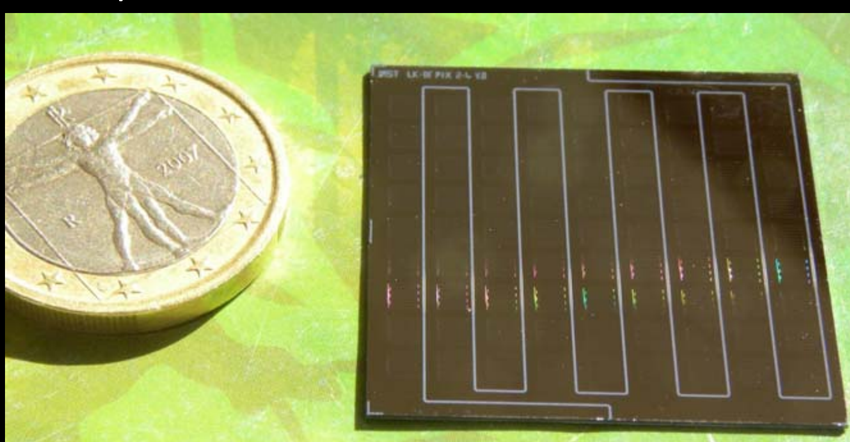
Possible Italian Contributions

- Payload
  - Part (up to 1/3 !) of the focal plane: horns-coupled low-frequency (70-150 GHz) detectors arrays (KID or TES), readout electronics, on-board processing, on-board data storage ; polarization modulator cryomechanics ; thermal design ; calibration
- Ground Segment
  - Contributions to L1..L4 + simulation; DPC
- Science
  - Large italian CMB community (heritage of BOOMERanG, Planck, OLIMPO, LSPE) fully involved

Italian Detectors for COrE+

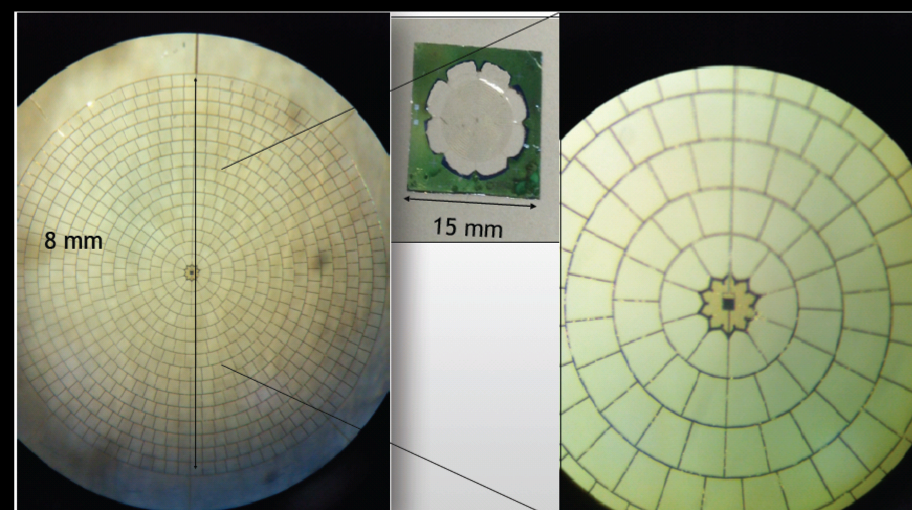
KIDs
Kinetic Inductance Detectors

- Large arrays already operated at large telescopes (IRAM, CSO)
- Italian development funded by INFN-CNS5 (RIC project, PI PdB)
- See Calvo et al. Exp.Astron. 2010 for first results
- Arrays can be produced in Italy at FBK, CNR-IFN, …
- Readout electronics also can be produced in Italy (INFN, TAS)
- Technology well advanced in Europe (camera at IRAM produced in France, camera at APEX produced in The Netherlands, UK-led European activity Space-KIDs



TESs
Transition Edge Sensors

- Large Arrays operating for CMB measurements (SPT, ACTpol, PolarBear, SPIDER, …)
- Italian development funded by ASI with the mm technology project (M.Bersanelli, PdB) and by INFN for the LSPE mission (F. Gatti, PdB)
- Detectors can be produced in Italy at INFN-Ge
- Readout electronics also can be produced in Italy (INFN, TAS)



Italian readout electronics

Frontend (cryogenic)

- Cryogenic SQUIDs for TES
  - In principle can be built in Italy (CNR-IFN) or can be procured (NIST,
  - Good usage know-how (OLIMPO)

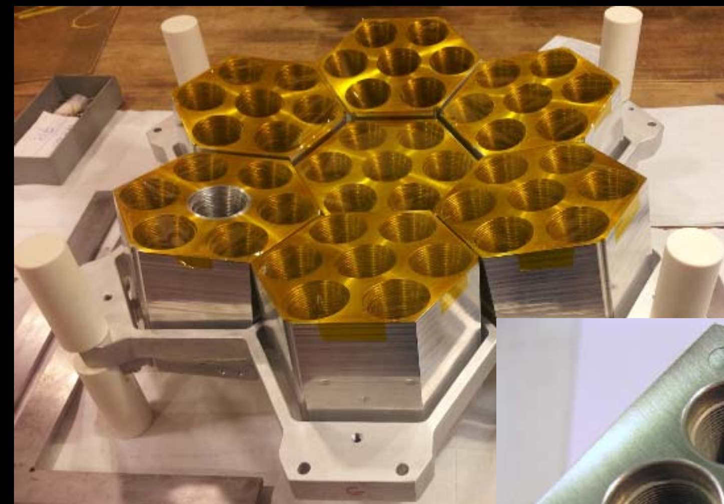
- Cryogenic HEMT amplifiers for KIDs
  - Can be procured (Caltech, …)
  - Good usage know-how (RIC, CALDER)

Backend (warm)

- Requires in both cases (TES or KID) tone generation and demodulation, with FPGA, fast ADC, fast DAC cards.
- Good heritage (mm-technology project, TASI)
- In both cases requires on-board storage and pre-processing (TAS)

Front-end Feeds & OMT for COrE+

- Extremely important for efficient rejection of telescope spillover / sidelobes
- Development in Milan, heritage Planck-LFI (Bersanelli, Mennella), ongoing activity for LSPE Q-band
- Heritage of mm-technology program of ASI (W-band): platelets
- Ongoing activity for D-band in the framework of the QUBIC project (S. Masi, D. Mennella, M. Gervasi)
- For higher frequency, experience with large throughput horns in Sapienza (PdB, Lamagna) in the framework of LSPE (mm-bands 140, 220, 240 GHz)



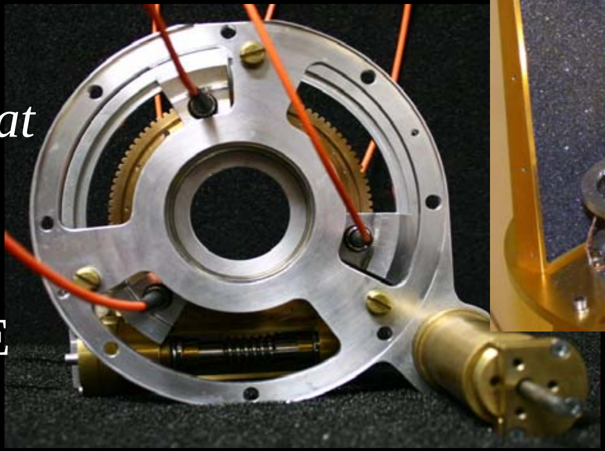
44 GHz

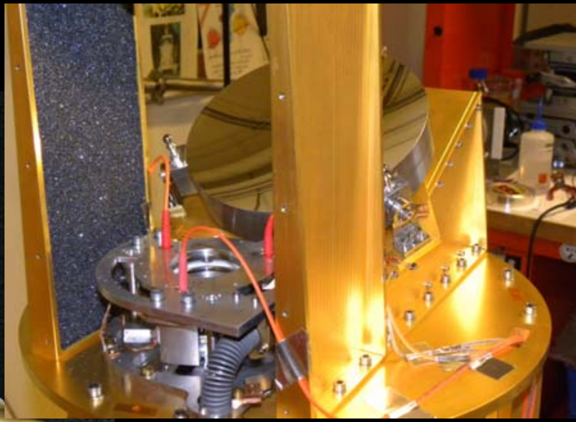
140 GHz

140, 220, 240 GHz, multimode

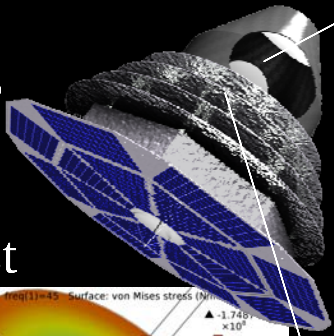
Italian Cryogenic Rotator for polarization modulator

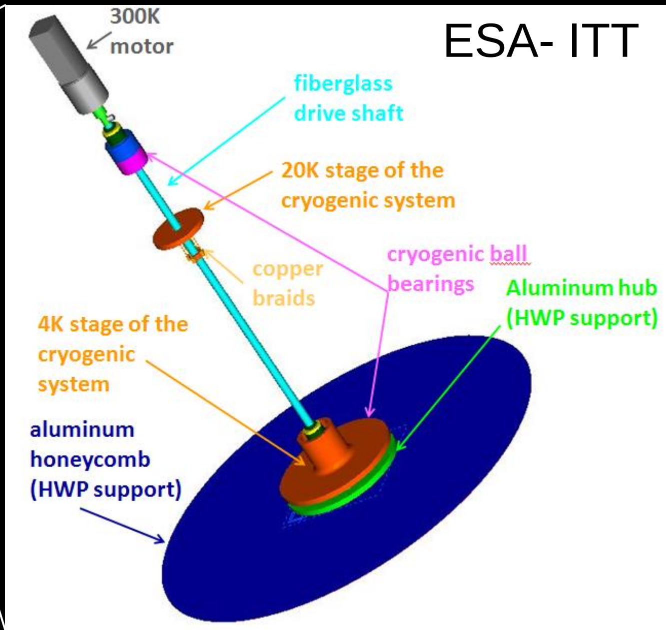
- Complete system developed in Sapienza (PdB, SM, MS) for the PILOT payload (CNES).
- See Salatino et al. *A cryogenic waveplate rotator for polarimetry at mm and submm wavelengths*, Astronomy and Astrophysics, **528**, A138, pages 1-8, (2011)
- The one being developed for LSPE is significantly larger, and will be similar to the refractive option for COrE+
- On-going study “ESA ITT AO/1-7136, Large Radii Half-Wave Plate (HWP) Development” for the reflective option
- Thermal-mechanical design and test tasks: Sapienza (PdB, SM, MS); Industrial support: KI

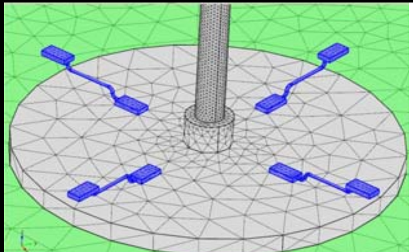


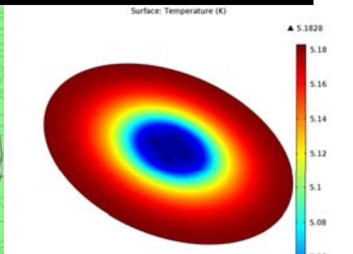


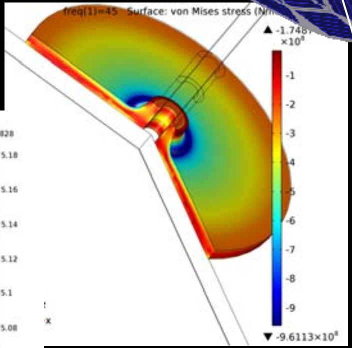
PILOT (CNES)





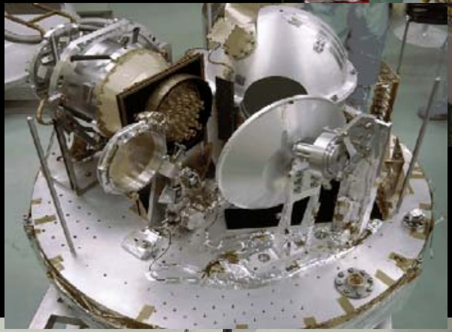


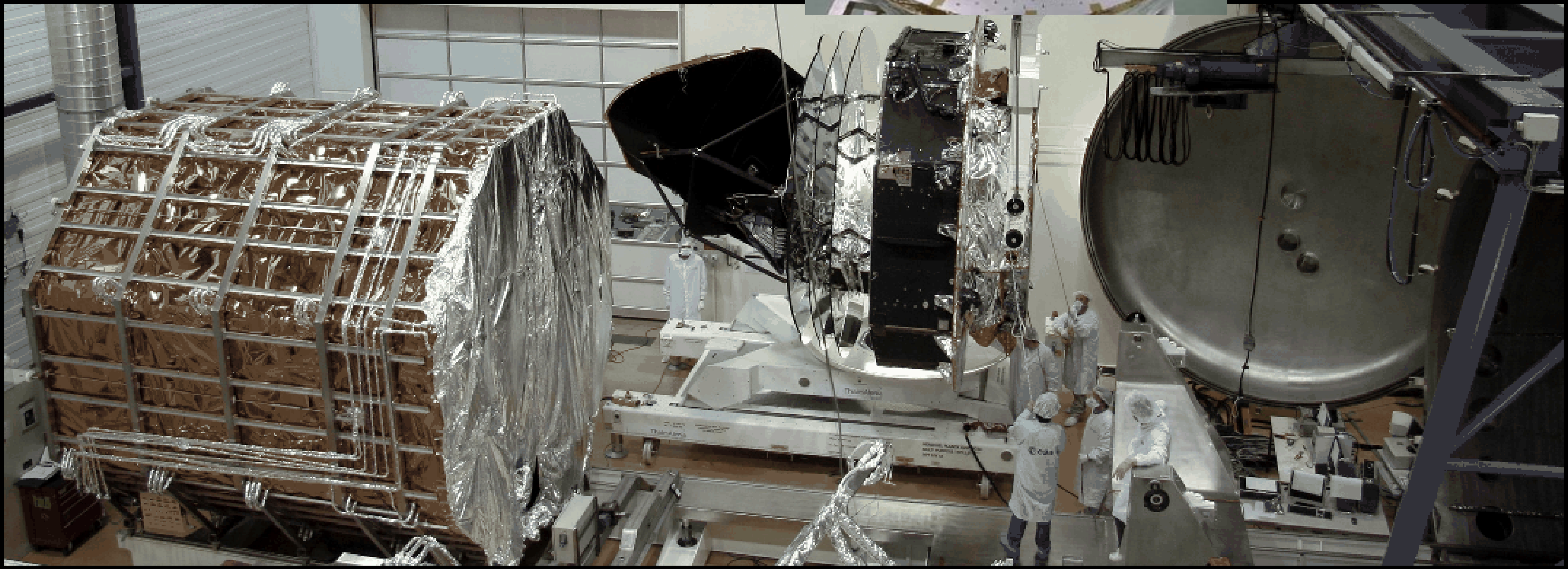




System Calibration

- Heritage of Planck
- Ground:
  - Sub-system-level: thermal, vacuum and cryo facilities (Terni, TAS, INAF-IASF-Bo, INAF-IAPS)
  - System level: definition, planning, sources, data processing and reduction
- In-flight
  - planning
  - On-board sources
  - On-sky sources selection
  - data processing and reduction





COrE+ summary

- Well identified science case
  - Primary objective : new generation mission for CMB primordial B-modes & lensing DM
  - Well defined requirements (sensitivity, resolution, …)
  - The need to remove foregrounds produces rich ancillary astrophysics science
- Mission similar to Planck, but
  - >100 times more detectors and better distributed for different frequencies
  - mission optimized for polarization measurements (observation strategy and calibration)
  - European expertise and TRL much better than for Planck in 1994
- Nice synergy between COrE+ and ground based CMB telescopes (S4) : same angular resolution at different frequencies
- Collaboration: heritage of Planck, enriched by the interst of extra-EU scientists
- Well tested European consortium, playing a key role internationally on a mission very interesting also for USA, Brazil and Japan potential partners

We need your support. In the proposal writing, but also ….
… register to support the mission at https://hangar.iasfbo.inaf.it/core/