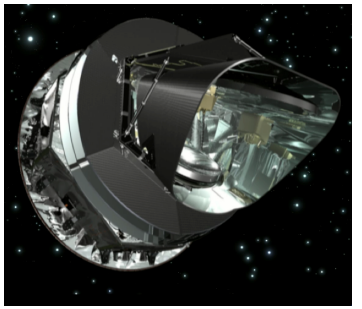
Cosmic Origins Explorer (COrE+)
An overview

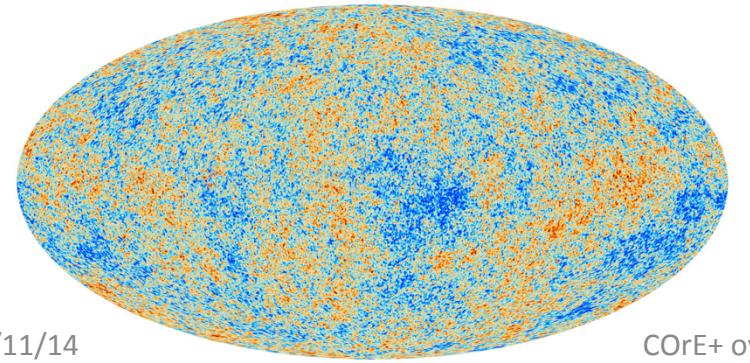
(DRAFT – 24 Nov. 2014)

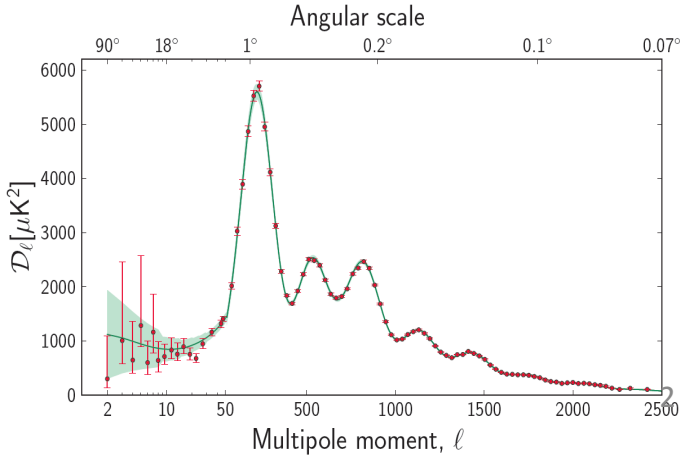
The COrE+ collaboration

The Planck legacy



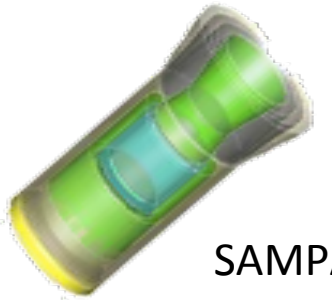
- **Planck**: a great success
  - (top and 5 out of the 10 most cited papers in physics, astronomy and archive-eprint , as given by SAO/NASA ADS, over the period Jan. 2013 – Dec. 2013).
  - near-ultimate CMB temperature anisotropies mission
  - good measurement of the power spectrum of polarization anisotropies 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



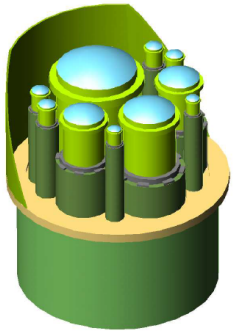


Future : A CMB polarization mission

- Several European proposals for CMB polarization between 2005 and now (and similar proposals in the US and in Japan)
  - Initially focussed mostly on inflationary B modes (SAMPAN, BPol)



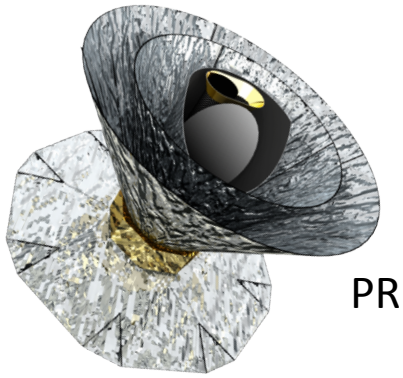
SAMPAN (CNES) ≈ 2005



BPOL (ESA) ≈ 2007

  - ***Concept evolving***: the case for polarization from space is very strong for astrophysics, cosmology, and fundamental physics (COrE, PRISM)

COrE (ESA) ≈ 2010



PRISM (ESA) ≈ 2013

COrE+, the near-ultimate CMB polarization measurement

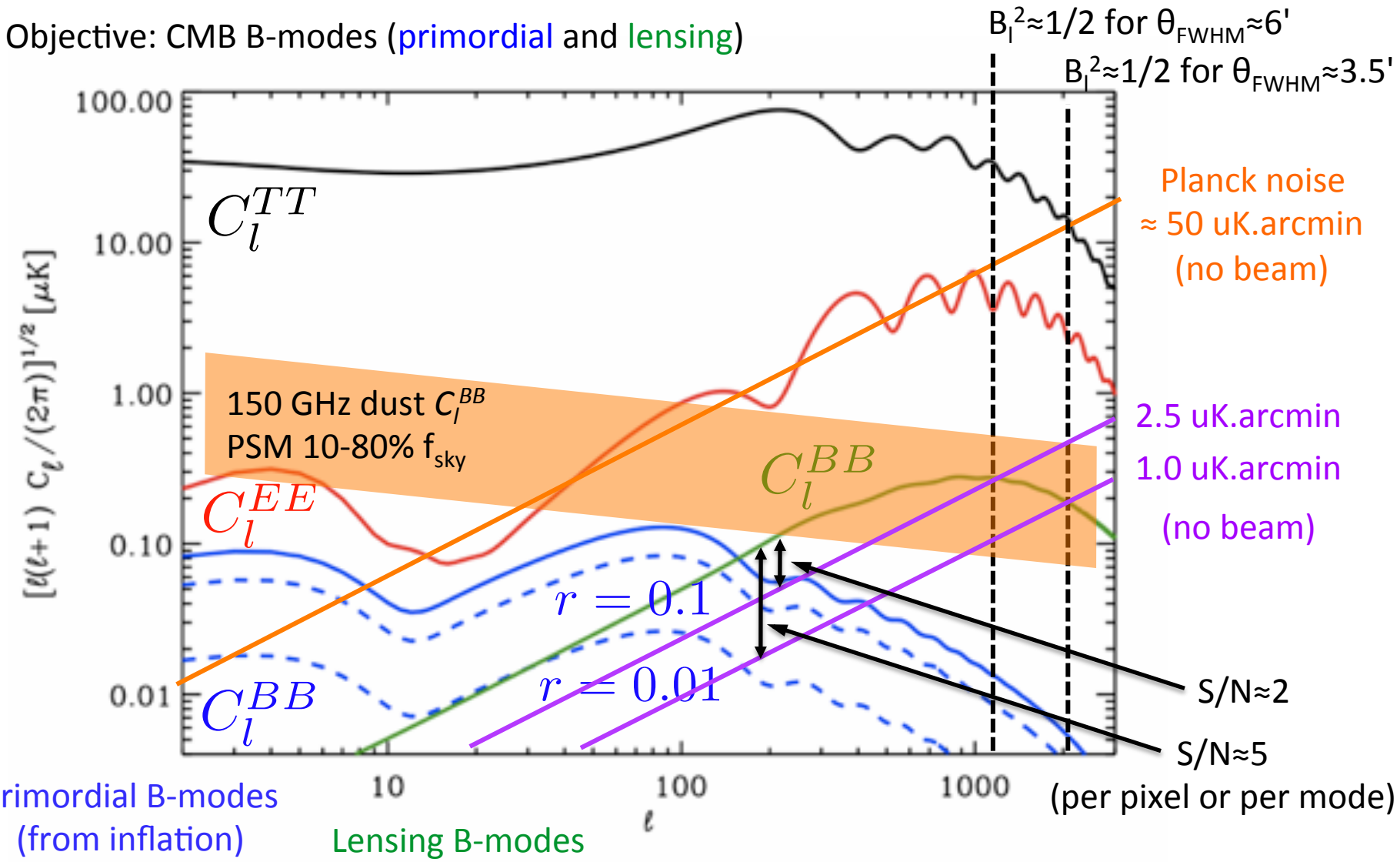
- Strong interest and support in European countries for such a future CMB mission, e.g.
  - CMB polarization top in France prospective plan for space science;
  - PRISM evaluation: " The SSC was fully convinced of the great importance of the core CMB science and encourages the CMB community to consider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

- 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.

Scientific requirements

Objective: CMB B-modes (primordial and lensing)



Sensitivity and case for a space mission

SENSITIVITY

- In space, the noise level in CMB channels is about ≈ 50 μK.$s^{1/2}$.
- Full-sky observations: 1.5 × 10^8 arcminutes on the sky
- For a 3-year mission (10^8 seconds), about 5000 CMB detectors are required to reach 1 μK.arcmin sensitivity (about 2500 for 1.5 μK.arcmin).

WHY SPACE?

- ***Superior instrument sensitivity***: even in the atmospheric windows at 150 and 220 GHz, 100 to 1000 ground-based detectors are required to reach the raw sensitivity of one single spaceborne detector (assuming close to 100% observing efficiency).
- ***Measurements Over the Full Sky:*** Properly characterizing the inflationary signal requires sensitivity on the largest angular scales. A satellite provides full, cross-linked, sky maps, a feature that is difficult to achieve with sub-orbital platforms.
- ***Broad Frequency Band Coverage:*** Planck demonstrated that high fidelity characterization of the properties of galactic dust is an imperative for measurements of CMB B-mode polarization. Operating above all atmospheric emission sources, a satellite has unimpeded view of the Galaxy and the Universe over the broadest range of frequency bands.

COMPLEMENTARITY

- Ground-based instruments can observe with large telescopes. This can be used to extend the COrE+ angular resolution to 1-2’ in atmospheric windows (≈90, ≈160 and ≈220 GHz) and match the angular resolution of the space mission at higher frequencies, for superior CMB lensing and extragalactic science.

COrE+ options

- **COrE+ light concept** *(baseline for a purely European mission)*
  - CMB B-modes + lensing science for cosmology and fundamental physics.
  - ≈6' resolution at 200 GHz, ≈1m aperture telescope;
  - ≈2.5 μK. arcmin CMB polarization sensitivity after foreground subtraction;
  - Many bands (at least ≈15) for component separation covering at least ≈100-600 GHz;
  - budget: ≈550 M€ (450 M€ ESA + 100 M€ European countries)

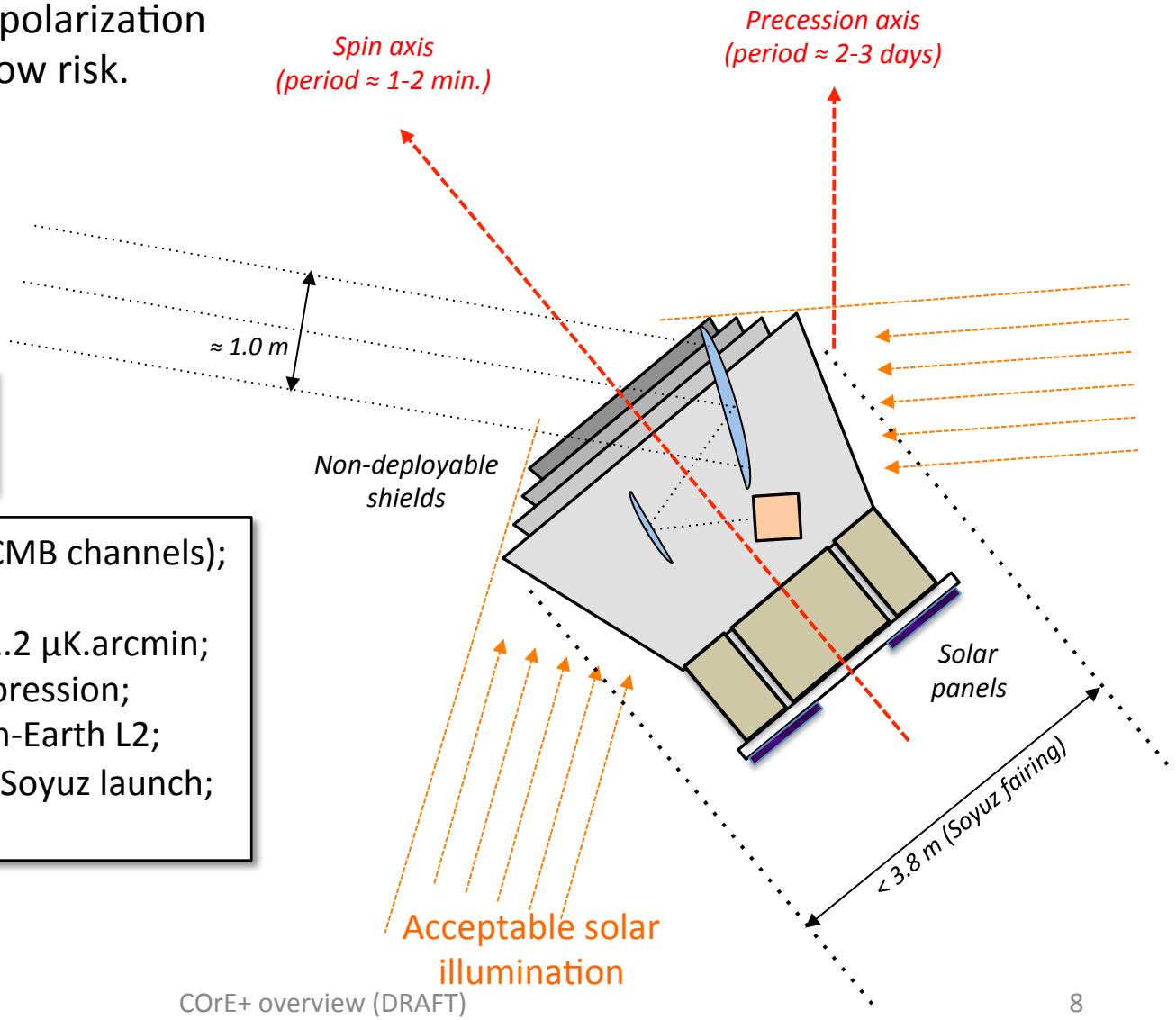
- **COrE+ extended concept** *(baseline with international partners)*
  - Near-ultimate CMB polarization space mission;
  - Extensive astrophysical cosmology (clusters) and extragalactic astrophysics; superior ISM science (with full sky resolution bridging with Herschel in small fields, at highest frequencies);
  - ≈3' to 4' resolution at 200 GHz, ≈1.5 (baseline) to 2m aperture telescope;
  - ≈1.5 μK.arcmin CMB polarization sensitivity after foreground subtraction;
  - Extended frequency coverage ≈60-1200 GHz;
  - budget: ≈700 M€ (450 M€ ESA + 250 M€ European and non-European countries).

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;
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+ light (possible configuration)

Core CMB cience mission						
Freq	**beam**	**N_{det}**	**per arcmin² 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**	**-**

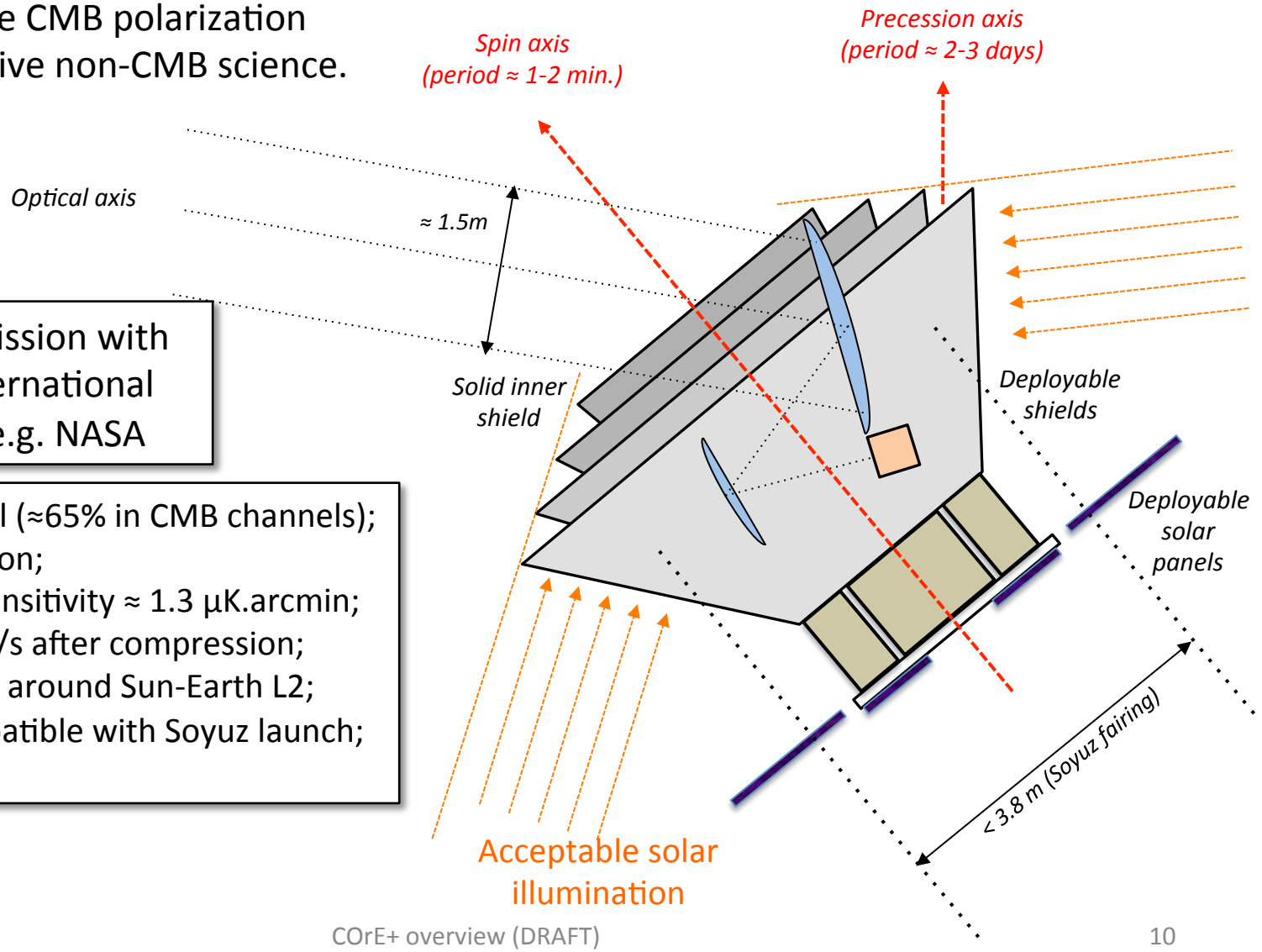
Core CMB science mission						
Freq	**beam**	**N_{det}**	**per arcmin² pixel**		**5σ PS or SZ**	
GHz	arcmin		σ_P μK_{CMB}	σ_I kJy/sr	$5\sigma_P$ mJy	$5\sigma_I$ $10^5 \times Y_{SZ}$
255	**5.0**	**120**	**13.1**	**4.3**	**8.0**	**12.6**
295	**4.3**	**60**	**25.8**	**7.4**	**11.8**	**10.1**
340	**3.7**	**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;
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€.



COrE+ extended (possible configuration)

Extended science mission						
Freq	**beam**	**N_{det}**	**per arcmin² 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 arcmin² 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*	*-*

Proposed COrE+ collaboration

- **ESA member states**
  - **France**: APC Paris, CEA Saclay and Grenoble, IAP Paris, IAS Orsay, Institut Néel Grenoble, IPAG Grenoble, IRAP Toulouse, LAL Orsay, LPSC Grenoble, LPT Orsay.
  - **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; SISSA Trieste.
  - **UK**: 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
  - **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 foreign partners**
  - **US:** Caltech/JPL; Goddard Space Flight Center; UC Berkeley; LBNL/NERSC; Stanford University; University of Minnesota; NIST.
  - Others TBD: Japan; Brasil; Canada; India.