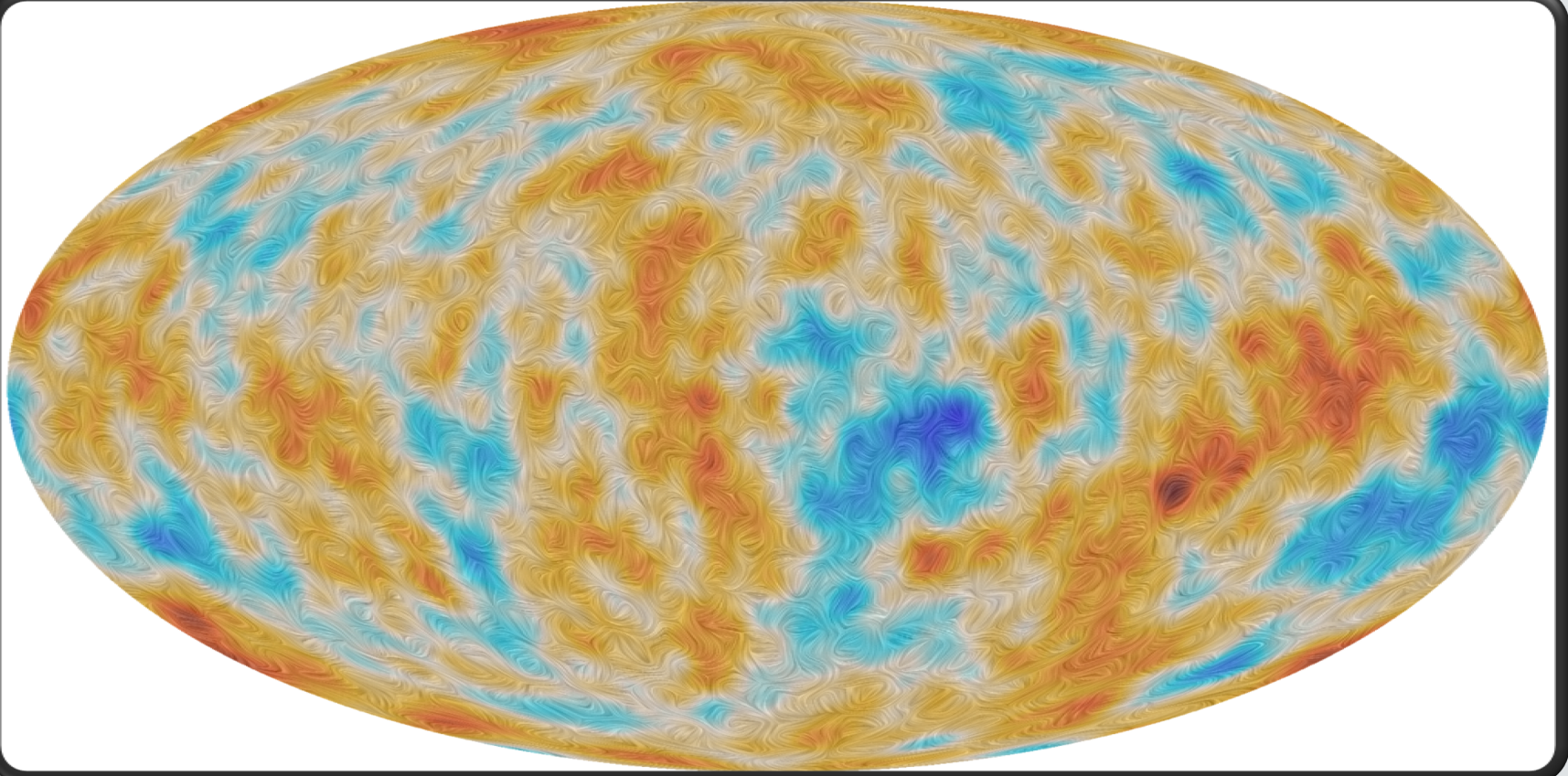




TOWARDS A NATIONAL/ EUROPEAN COORDINATION FOR CMB EXPERIMENTS

Nicola Vittorio

The 'Planck era'



- The ESA/Planck mission has created
 - *world-class CMB community in Europe,*
 - *unique, world-leading expertise in space-based CMB research.*



→ COSMIC HISTORY

10⁻³² seconds

1 second

100 seconds

380 000 years

300–500 million years

Billions of years

13.8 billion years

Beginning
of the
Universe



Inflation

Accelerated expansion
of the Universe

Formation of light and matter

Light and matter are coupled

Dark matter evolves
independently: it starts
clumping and forming
a web of structures

Light and matter separate

- Protons and electrons
form atoms
- Light starts travelling
freely: it will become the
Cosmic Microwave
Background (CMB)

Dark ages

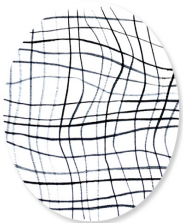
Atoms start feeling
the gravity of the
cosmic web of dark
matter

First stars

The first stars and
galaxies form in the
densest knots of the
cosmic web

Galaxy evolution

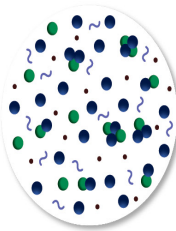
The present Universe



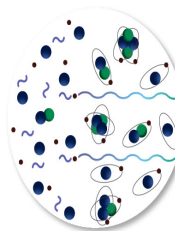
- Tiny fluctuations:
the seeds of future
structures
- Gravitational waves?



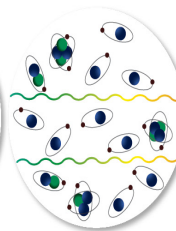
Frequent collisions
between normal matter
and light



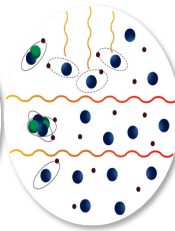
As the Universe expands,
particles collide less
frequently



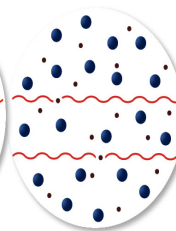
Last scattering of
light off electrons
→ **Polarisation**



The Universe is dark as
stars and galaxies are
yet to form



Light from first stars and
galaxies breaks atoms
apart and "reionises"
the Universe



Light can interact
again with electrons
→ **Polarisation**

The 'after-Planck era'

- CMB polarization and absolute CMB spectrum measurements
 - *New physics*
 - *GW produced during inflation*
 - *Neutrino physics*
 - *Lensing*
 - *Clusters of galaxies*
 - *Early star formation*
 - *Interstellar medium*
 -
- Fully exploit
 - *the expertise acquired with Planck*
- National/European coordinated effort on
 - *ground-based infrastructure*
 - *sub-orbital technology and experiments*
 - *space missions*

Cosmic Orbital and Suborbital Microwave Observations



■ At the national level

- 3 yrs *COSMOS project*
- *financed by ASI*

■ 11 nodes + ASI/SSDC

■ More than 100 people

- *Universities*
- *INAF*
- *INFN*

- Università di Roma “Tor Vergata”
- Università di Milano
- Sapienza Università di Roma
- INAF/IASF, Bologna
- INAF/OATS, Trieste
- Università di Milano-Bicocca
- Università di Genova
- INFN-Sezione di Pisa
- Università di Ferrara
- Università di Padova
- SISSA – Trieste



■ Activities

- *The “post-Planck” science case*
- *Foreground cleaning/de-lensing/systematics/data analysis tools*
 - study of available datasets (S-PASS, Planck, WMAP, ...), preparation for forthcoming studies (LSPE, QUBIC, QUIJOTE, Simons Array), design of techniques for future satellite probes (Core, LiteBird)
- *Feasibility study for forthcoming CMB experiment*
 - Ground-based (LSPE/STRIP, ...)
 - Balloon-borne (LSPE/SWIPE, ...)
 - Space missions

Cosmic Orbital and Suborbital Microwave ObservationS



- | | |
|--|--|
| <ul style="list-style-type: none"> ■ WP1-1A: MANAGEMENT ■ WP1-6X1: SUNYAEV ZEL'DOVICH SIGNAL FROM FUTURE CMB DATA ■ WP1-6X2: NEW POINT SOURCE DETECTION METHODS ■ WP2-6X1: FUTURE GROUND-BASED CMB EXPERIMENTS ■ WP2-6X2: SUPPORT TO DATA ANALYSIS FOR LSPE/STRIP ■ WP3-6X1: FUTURE BALLOON BORNE CMB EXPERIMENT ■ WP3-6X2: SUPPORT TO DATA ANALYSIS FOR LSPE/SWIPE ■ WP4-6X1: NEXT GENERATION OF CMB SPACE MISSIONS ■ WP4-6X2: HW/SW INFRASTRUCTURE FOR FUTURE | <p>CMB EXPERIMENTS</p> <ul style="list-style-type: none"> ■ WP5-6X1: RF TESTING FOR FUTURE CMB EXPERIMENTS ■ WP5-6X2: CMB CALIBRATION AND SRT ■ WP6-6X1: STRATEGIC SOLUTIONS FOR NEW CMB DETECTORS ■ WP6-6X2: READOUT ELECTRONICS FOR FUTURE CMB EXPERIMENTS ■ WP7-6X1: ASTROPARTICLE AND FUNDAMENTAL PHYSICS ■ WP8-6X1: INFLATIONARY GRAVITATIONAL WAVES ■ WP8-6X2: NON-GAUSSIANITY FROM INFLATION ■ WP9-6X1: FOREGROUND MODELING AND REMOVAL ■ WP9-6X2: CMB WEAK LENSING RECONSTRUCTION |
|--|--|



■ Training ESR: 11 three-years post-Doc positions

- *Hervé Bourdin, Tor Vergata*
- *Luca Lamagna, Sapienza*
- *Daniela Paoletti, INAF*
- *Luca Pagano, Ferrara*
- *Federico Nati, MiB*
- *Daniele Bertacca, Padova*
- *Nicoletta Krachmalnicoff
SISSA*
- *Daniele Tavagnacco, INAF*
- *Michele Biasotti, Genova*
- *Alessandro Paiella, Sapienza*
- *Cristian Franceschet, Milano*
- *Andrea Tartari, INFN Pisa*
- *Diego Molinari, Ferrara*
- *Stefano Mandelli, Milano*
- *Davide Poletti, SISSA*



■ ASI/COSMOS thematic workshops

- *Early universe (PD)*
- *Foregrounds (SISSA)*
- *Fundamental Physics (FE)*
- *Ground-based CMB experiments (MI)*
- *The challenges of Lambda CDM: low vs. high redshift (TOV)*

APPEC Recommendation

- The European Astroparticle Physics Strategy by APPEC
 - 1/9/18 @ Bruxelles.
- Recommendations for the 2017-26
 - ...
 - *“The future CMB program sets the stage for a range of opportunities to link key themes together and provides a potential stepping-stone towards further fundamental discoveries”.*



The 'Florence process'

■ 'Towards the European Coordination of the CMB programme'

- *Villa Finaly: September 2015, 2016, 2017*
- *Coordinating group*
 - Francois Bouchet & Ken Ganga
 - Eiichiro Komatsu & Joe Mohr
 - Marco Bersanelli & Carlo Baccigalupi
 - Enrique Martinez-Gonzalez & Jose-Alberto Rubiño-Martin
 - Michael Brown & Anthony Challinor
 - ...: ... & ...



A European 'Whitepaper'

■ Table of contents – TBC

- Introduction
- The State of the Art Today
- The Scientific Landscape for the Coming Years
- Mid- and long-Term Roadmap



■ Important questions to be asked

- *What contribution should Europe be making to US S3/S4 plans?*
- *How to invest on the synergy building up at Tenerife between Spain and Italy, with UK participation and, possibly Japan involvement?*

Ground-based CMB polarization

- The CMB field is advancing rapidly!
- “Stage 3” experiments have $\sim 10,000$ detectors
- CMB-S4 Science Book ([arXiv://1610.02743](https://arxiv.org/abs/1610.02743))

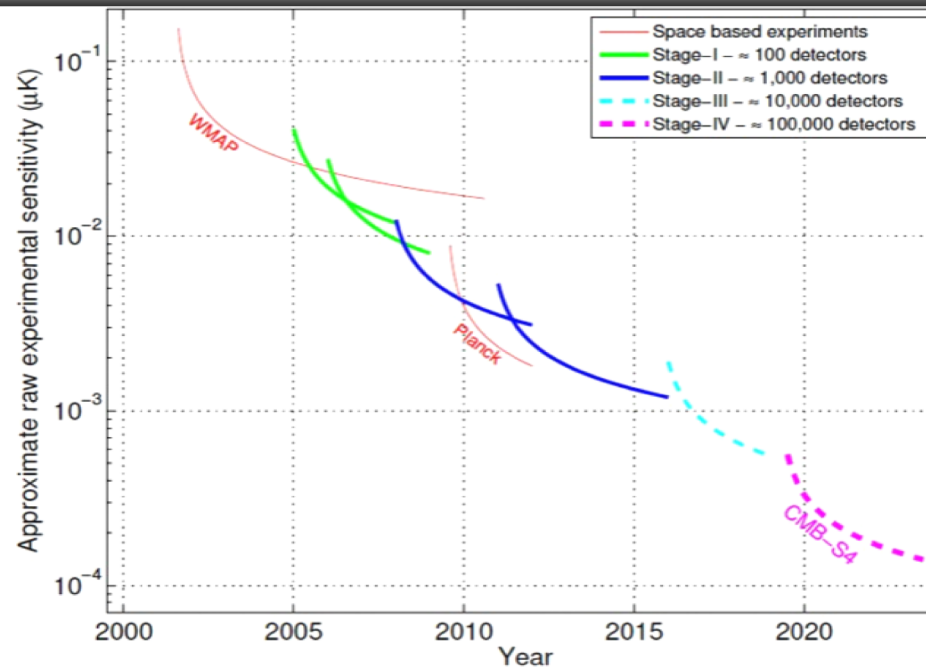
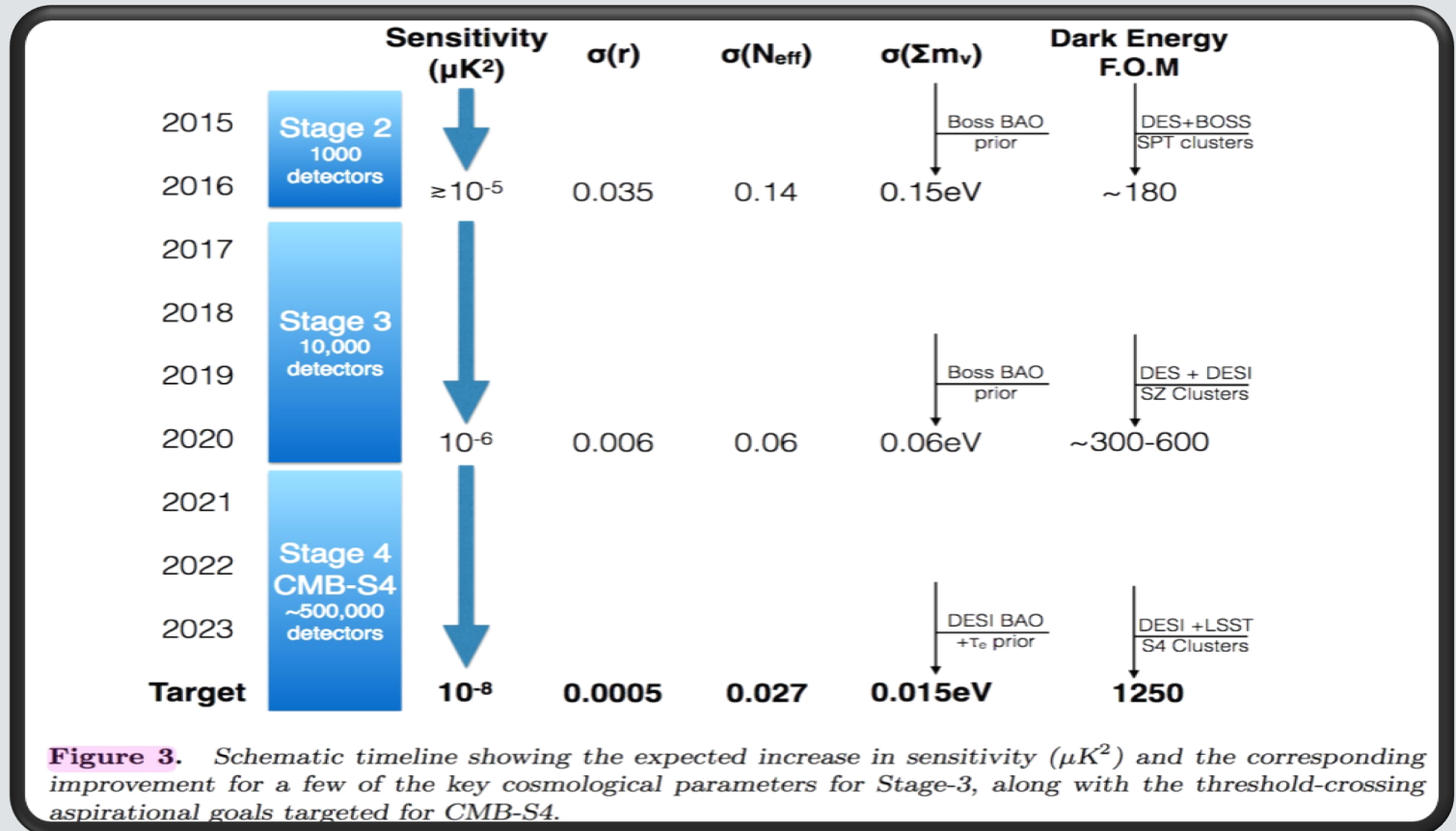


Figure 2. Plot illustrating the evolution of the raw sensitivity of CMB experiments, which scales as the total number of bolometers. Ground-based CMB experiments are classified into Stages with Stage II experiments having $O(1000)$ detectors, Stage III experiments having $O(10,000)$ detectors, and a Stage IV experiment (such as CMB-S4) having $O(100,000)$ detectors. Figure from Snowmass CF5 Neutrino planning document.

Ground-based CMB polarization

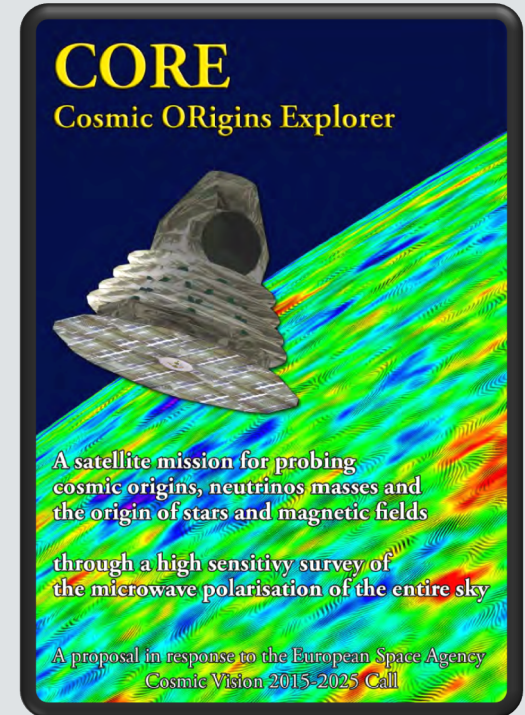
- CMB Stage 4 experiments should be able to set unprecedented limits on the neutrino sector, the dark sector, and Inflation
- CMB-S4 Science Book ([arXiv://1610.02743](https://arxiv.org/abs/1610.02743))



CMB Space mission

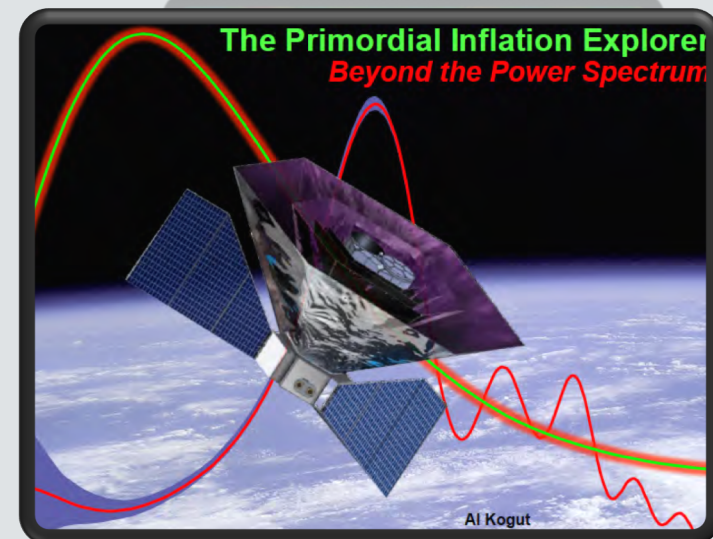
■ The ESA/Core mission proposal

- *'incompatible with the boundary conditions for the M5 Call'*



■ The NASA/PIXIE proposal

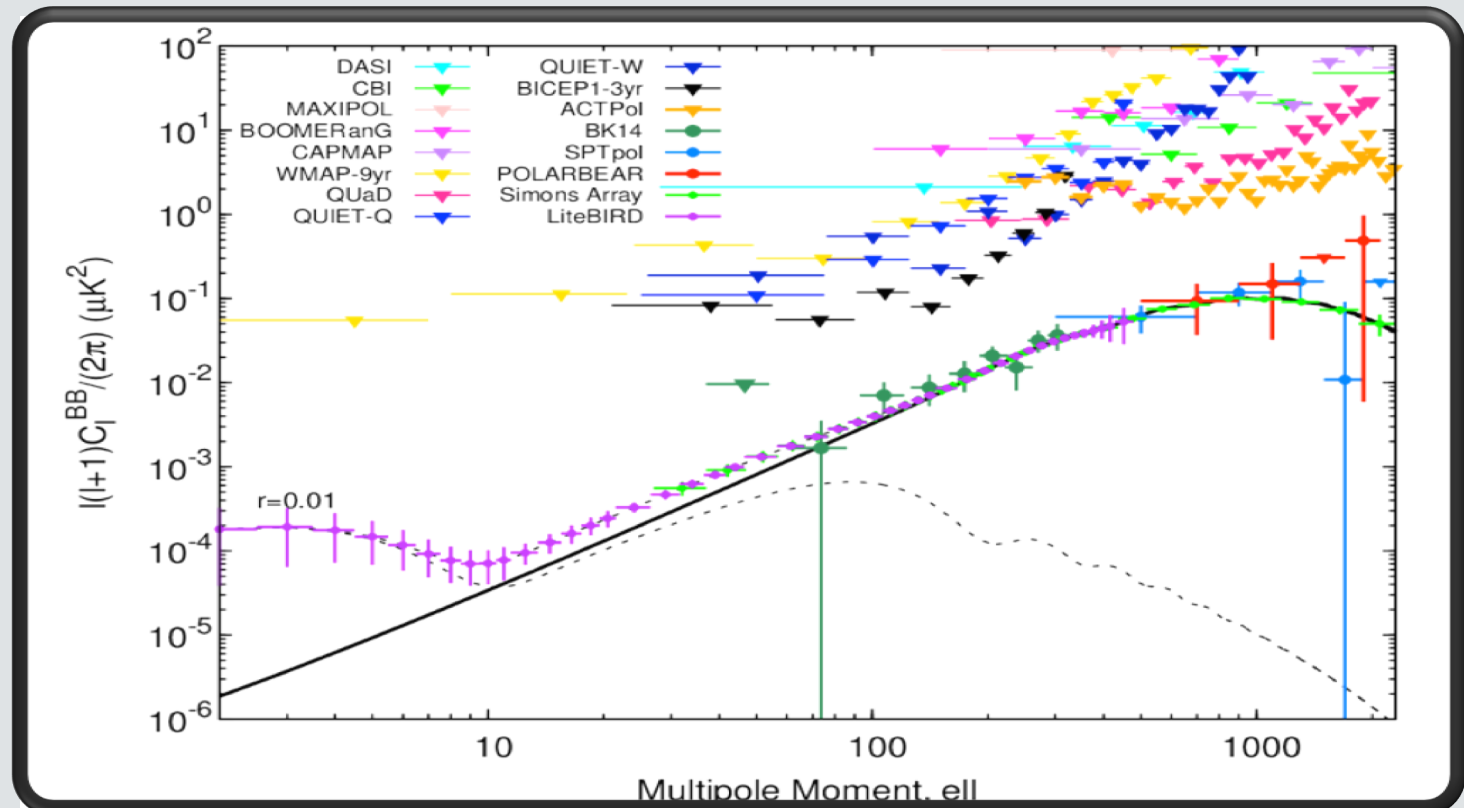
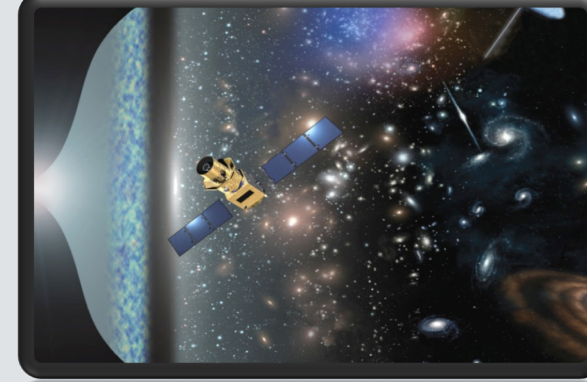
- *not selected...*
- *no other space mission to measure CMB spectral distortions*

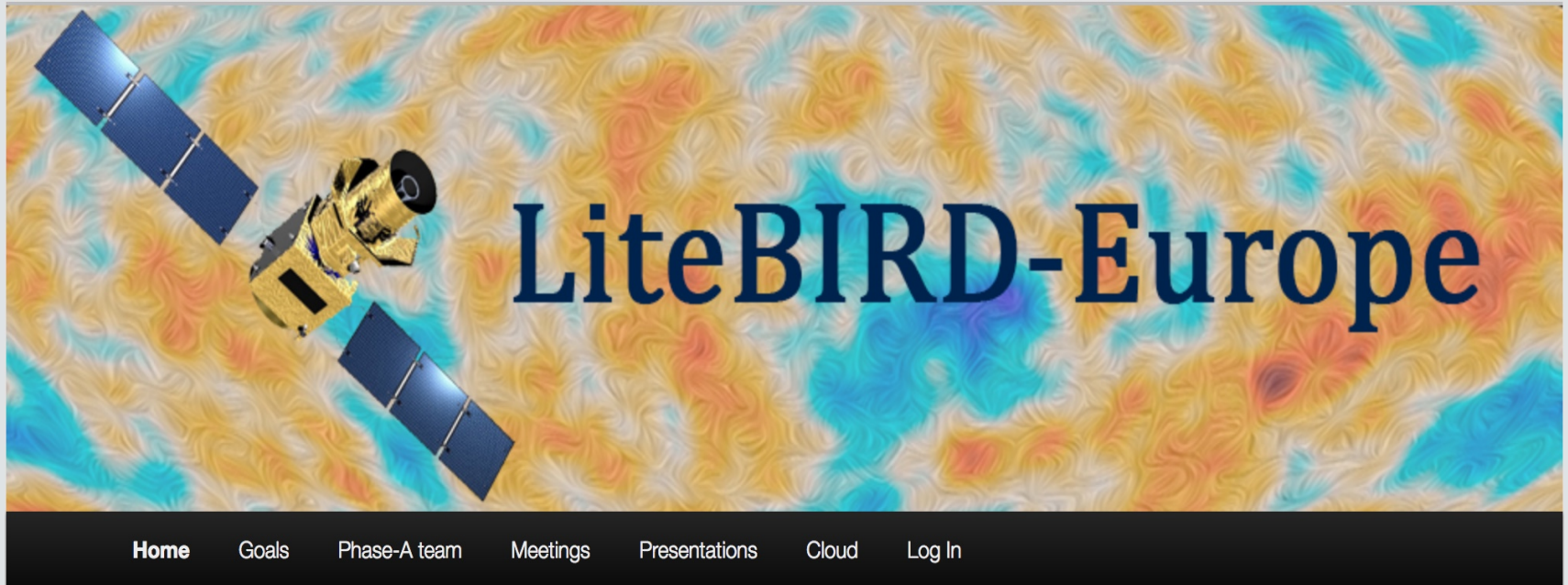


The JAXA/LiteBIRD satellite

- Lite (Light) Satellite for the Studies of B-mode Polarization and Inflation from Cosmic Background Radiation Detection

– PI: Masashi Hazumi, US PI: Adrian Lee





- <http://www.litebird-europe.eu/>
- No single EU country has the resources to provide the MHFT
- European cooperation is essential
- Important to organize a consortium
 - *to have a credible management structure to deliver the HFT*
 - *to be inserted in a Project Management Module*
- ESA and National Agencies
 - *interested in having a visible and identifiable role*

European Institutions involved in the activities



France

- APC (Paris)
- CEA-DAP (Saclay)
- CEA-SBT (Grenoble)
- ENS-LERMA (Paris)
- IAP (Paris)
- IAS (Orsay)
- Institut Néel (Grenoble)
- IPAG (Grenoble)
- IRAP (Toulouse)
- LAL (Orsay)
- LPSC (Grenoble)



Italy

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- Università di Padova
- SISSA – Trieste



UK

- Cardiff University
- University of Cambridge
- Imperial College London
- University of Manchester
- University College London
- University of Oxford
- University of Portsmouth
- University of Sussex



Germany

- Max Planck Society (MPA, MPE, MPIfR)
- Ludwig-Maximilians-Universität München
- Universität Bonn
- RWTH Aachen Universität

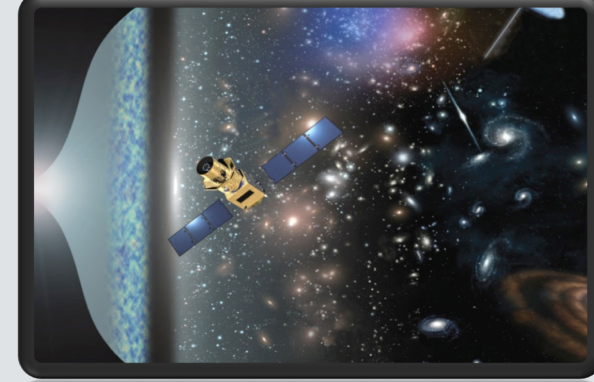


Spain

- IFCA, IDR/UPM, DICOM/UC
- ICCUB, IAC
- Universidad de Oviedo
- Universidad de Salamanca
- Universidad de Granada
- CEFCa

- The Netherlands: SRON RuG
- Norway: University of Oslo
- Sweden: University of Stockholm

The JAXA/LiteBIRD satellite



- CMB polarization all-sky survey probing $l < 200$
- Detect r with $\sigma(r=0) < 0.001$, including
 - *statistical, instrumental systematics, uncertainties due to residual foregrounds and bias, uncertainties due to lensing B-mode, cosmic variance (for $r > 0$)*
- Final selection
 - *end of June 2019*

Thank you for your attention