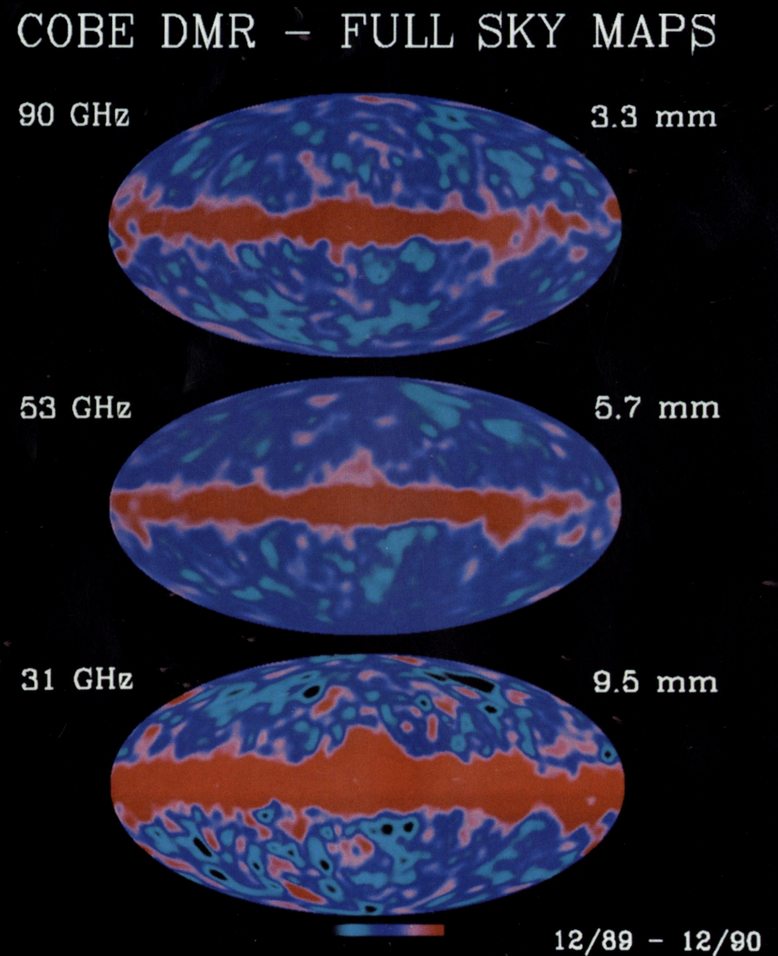
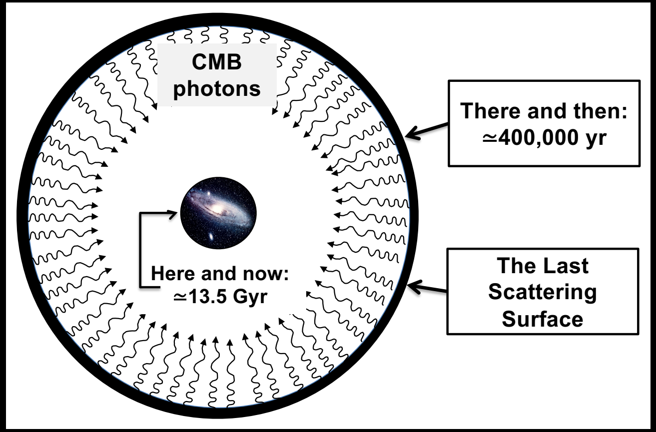
CMB@TOV
Future Perspectives

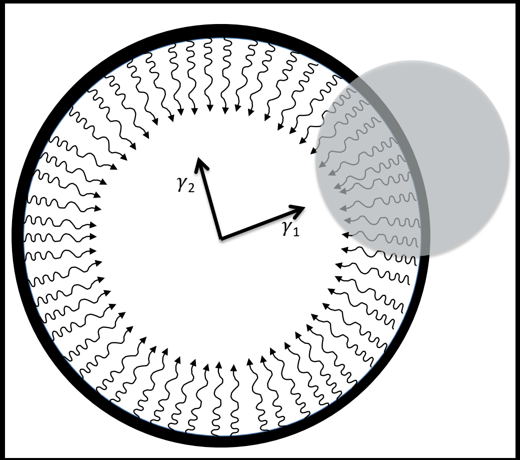
Nicola Vittorio, 11 Maggio 2022

COBE/DMR, 1992:

$$\Delta T|_{rms} = (30 \pm 5)\mu K$$

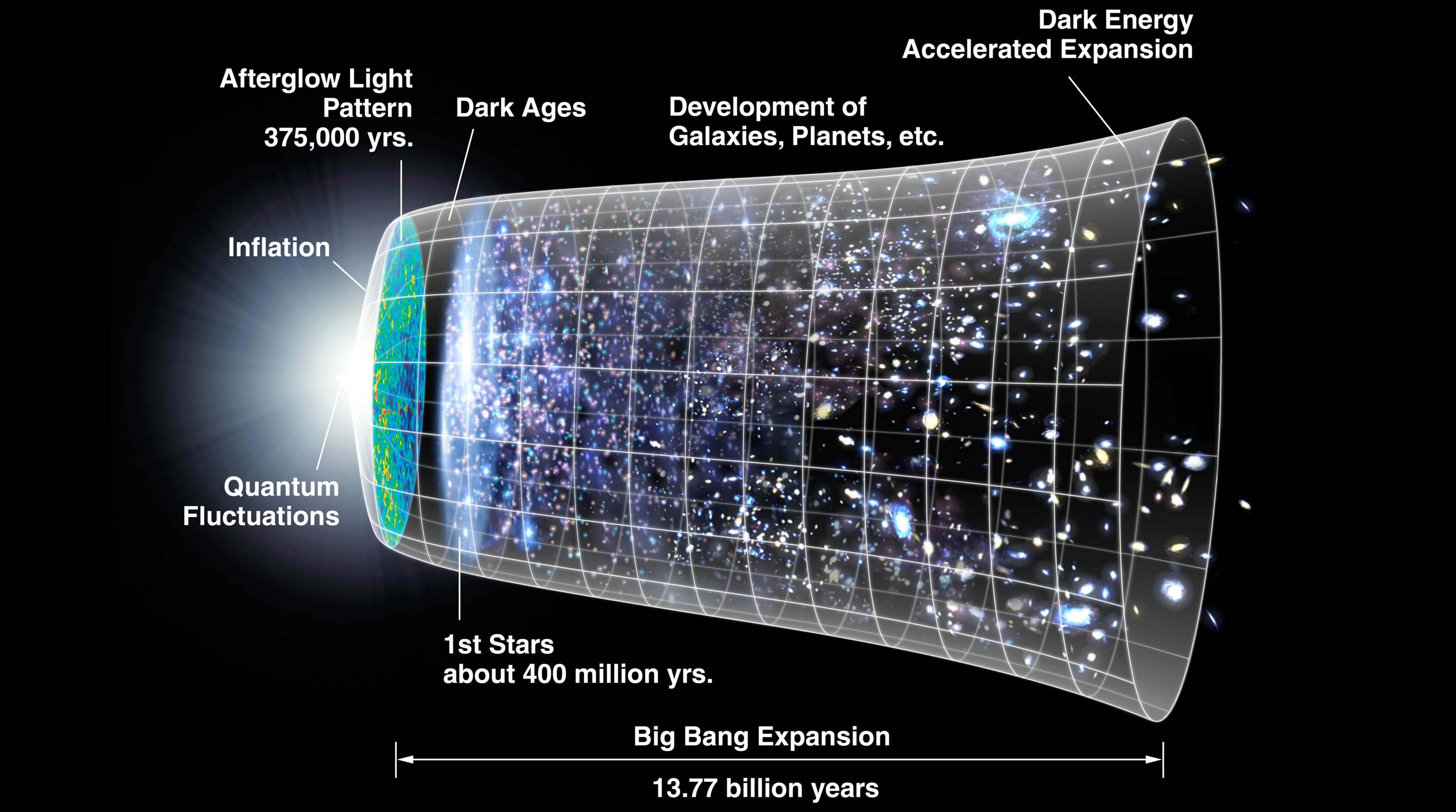






Sachs and Wolfe effect (1967)

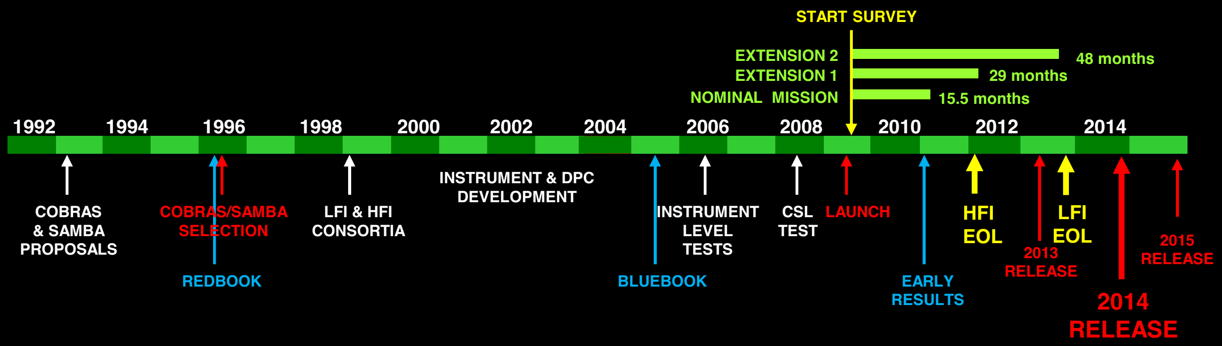
$$\frac{\delta T}{T} \simeq \frac{\delta \phi}{c^2} \simeq \frac{H_0^2}{c^2} R_0^2 \frac{\delta \rho}{\rho} \Big|_{t_0}$$



Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

COBRAS/SAMBA

The Planck Collaboration



esa

D/SCI(96)3
February 1996

COBRAS/SAMBA

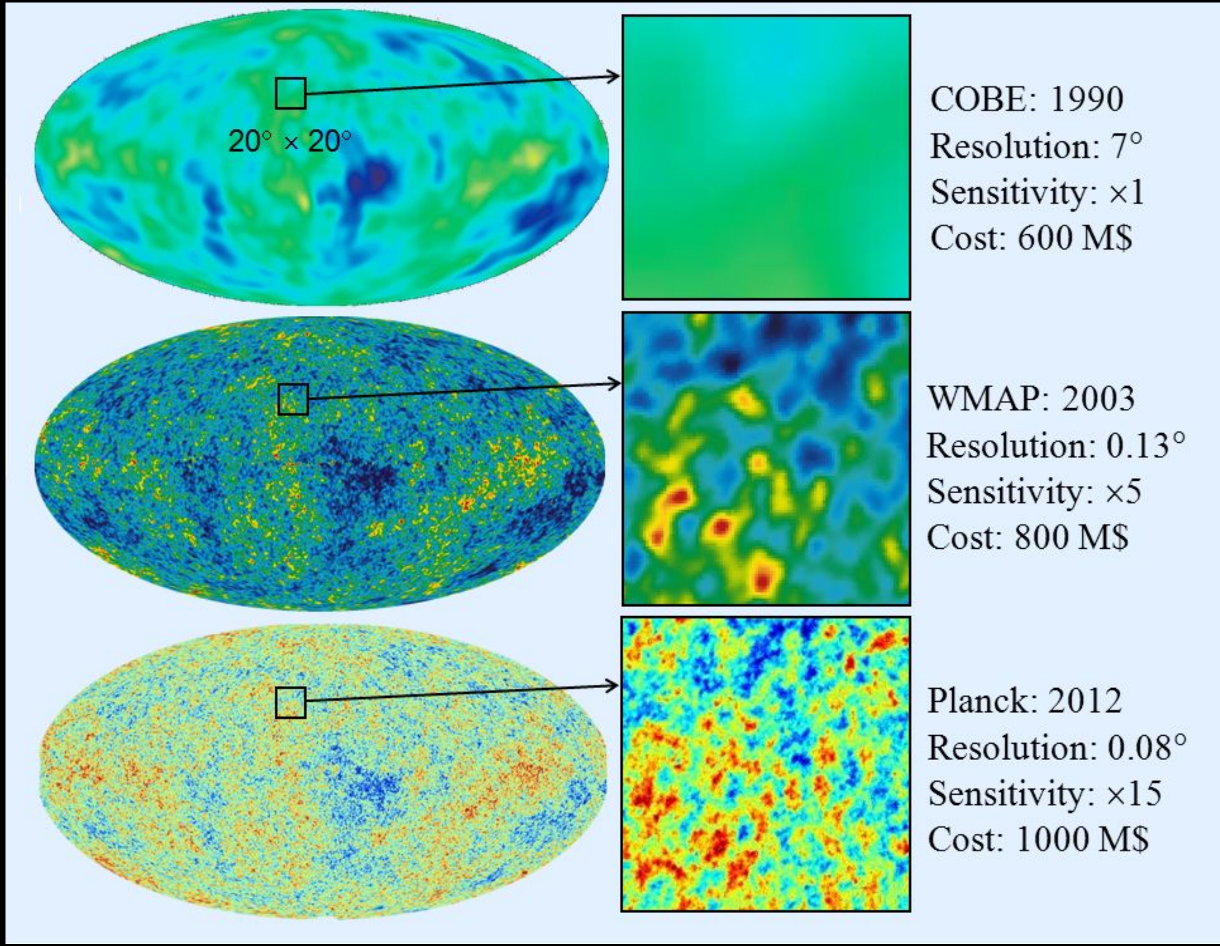
A Mission Dedicated to Imaging the Anisotropies of the Cosmic Microwave Background

REPORT ON THE PHASE A STUDY

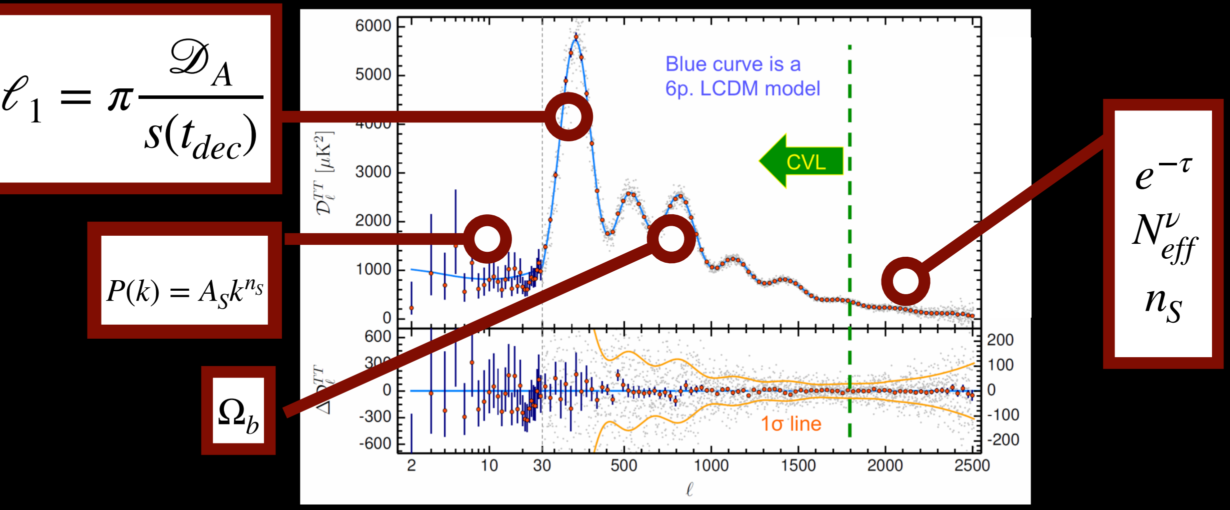
M. Bersanelli, F.R. Bouchet, G. Efstathiou, M. Griffin, J.M. Lamarre, N. Mandolesi, H.U. Norgaard-Nielsen, O. Pace, J. Polny, J.L. Puget, J. Tauber, N. Vittorio, S. Volonté

3 CMB Space Missions

- **Increasing sensitivity**
- **Increasing angular resolution**
- **Increasing control of**
  - *Systematic*
  - *Foreground*
- **Better parameter estimation**



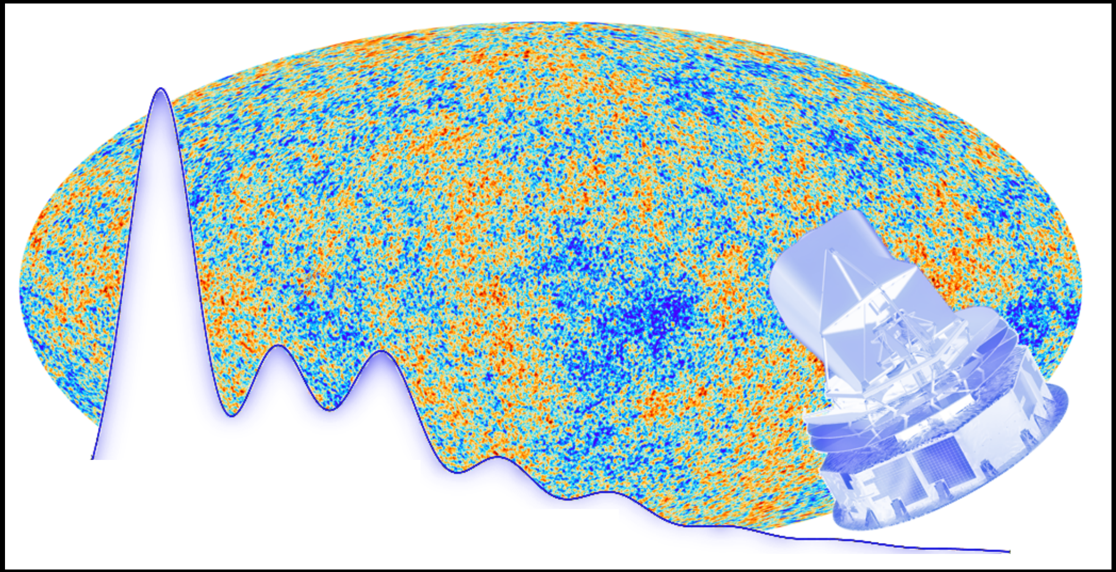
Planck 2018 TT power spectrum



	Mean	Stdev	Rel. err.
Baryon density	0.02237	0.00015	0.7%
DM density	0.1200	0.0012	1%
Acoustic horizon	1.04092	0.00031	0.03%
Optical depth	0.0544	0.0073	13%
Primordial amplitude	3.044	0.014	0.7%
Primordial spectral index	0.9649	0.0042	0.4%

Precision vs. accuracy?

- **LCDM extension**
  - *Running spectral index:* $dn_S/d\ln k$
  - *Primordial non Gaussianity:* f_{NL}
  - *Non adiabatic (isocurvature) primordial perturbations*
  - *Dark energy equation of state,* $p = w(z)\rho$
  - *Spatial curvature* $\Omega_k = 1 - \Omega_0 - \Omega_\Lambda$
  - *Neutrino total masses:* $\sum_{1}^{N_{eff}} m_\nu$
  - *Effective number of relativistic species* N_{eff}



InDark (INFN/CNS IV)
From 2014

- **8 Sezioni INFN partecipanti:**
  - ➡ *Bologna, Ferrara, Lab. Naz. del Gran Sasso, Padova, Roma II, Roma III, Torino, Trieste*
  - ➡ *Coordinatore locale @ Tor Vergata: prof. Marina Migliaccio (dal 2020)*

- **2 years INFN Fellowship @ TOV (48 applications for 1 fellowship)**
  - ➡ *Adrià Gomez-Valent (From September 2021)*
  - ➡ *Dark Energy and Modified Gravity Models in the light of Low-Redshift Observation*

Accordo ASI/INFN per lo Space Science Data Center

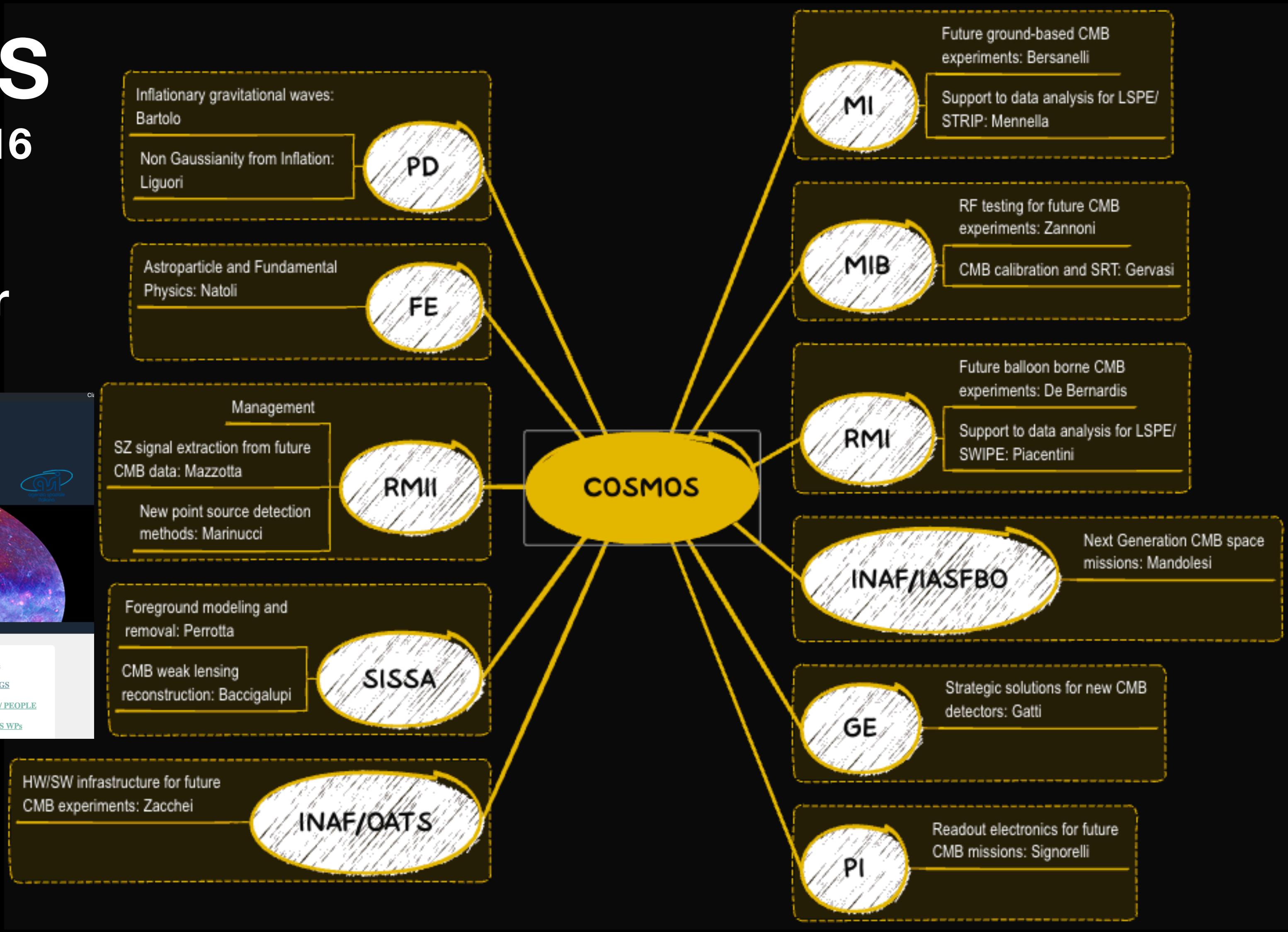
- **Accordo 2014-2017, esteso al 2021**
  - ➡ *Cosmic rays, Gamma Astronomy, Cosmology,*
  - ➡ *WP CMB : Responsible*
    - *prof. Paolo Natoli (2016-2017)*
    - *prof.Marina Migliaccio (2017-2021)*

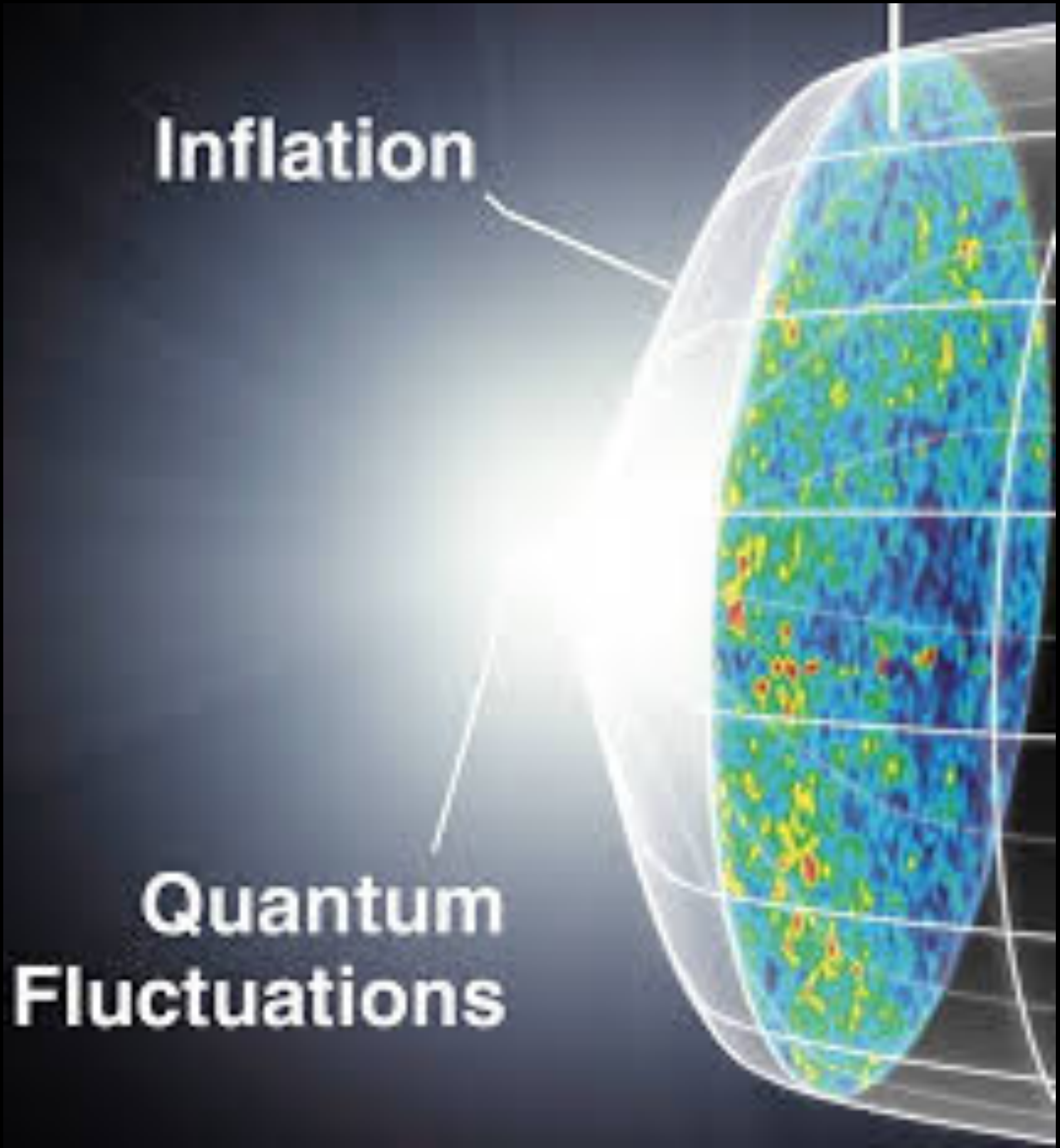
- **Accordo 2022-2025**
  - ➡ *KO Metting February 2022*
  - ➡ *Cosmic rays, Gamma Astronomy, Cosmology, Space Weather, Multimessenger Astronomy and GW, IT & AI*
  - ➡ *WP Cosmology (Responsible Prof. Marina Migliaccio)*
    - *CMB (Planck Legacy, LSPE, LiteBIRD) + cross-correlation with LSS (Euclid).*

ASI/COSMOS

KO Meeting - 21/12/2016

- **Agreement with Tor Vergata**

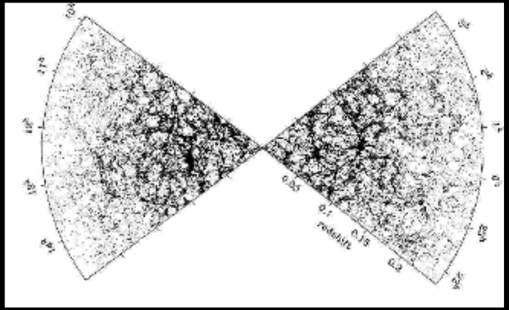



Inflation
Quantum
Fluctuations

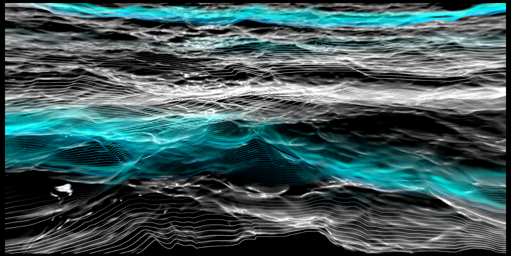
Gauge-independent cosmological perturbations

- **The metric of a perturbed, spatially flat FLRW universe**

$$ds^2 = a^2(t)\left\{ \left[1 + 2\Phi(x^k)\right] c^2 d\mathscr{T}^2 - \left(\delta_{ij}\left[1 - 2\Phi(x^k)\right] - h_{ij}^{TT}(x^\mu)\right) dx^i dx^j \right\}$$



- **Field equations:**
  - ➡ *Scalar modes:* $\nabla^2\Phi = \frac{8\pi G}{c^4}\epsilon \quad \Rightarrow$ *Large Scale Structure formation and evolution*
  - ➡ *Tensor modes:* $\Box\, h_{ij}^{(TT)} = 0 \quad \Rightarrow$ *Stochastic background of primordial GW*

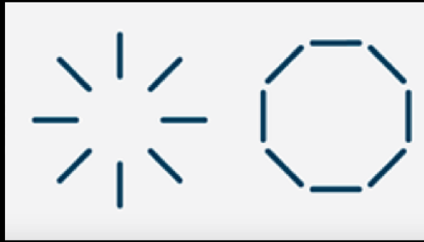


Polarization of the CMB

- **In terms of the Stokes parameters,**

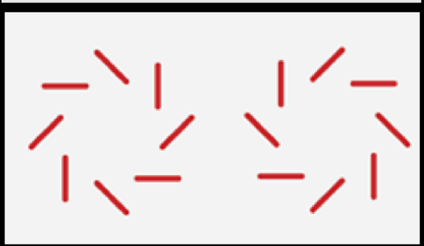
$$I = \frac{31}{16\pi}\sigma_T\left[\frac{8}{3}\sqrt{\pi}a'_{00} + \frac{4}{3}\sqrt{\frac{\pi}{5}}a'_{20}\right] \qquad Q + iU = \frac{3}{4\pi}\sigma_T\sqrt{\frac{2\pi}{15}}a'_{22}$$

- **Q and U are combined in**
  - ➡ *E field (even under parity)*



$\Leftarrow$ *Scalar modes*

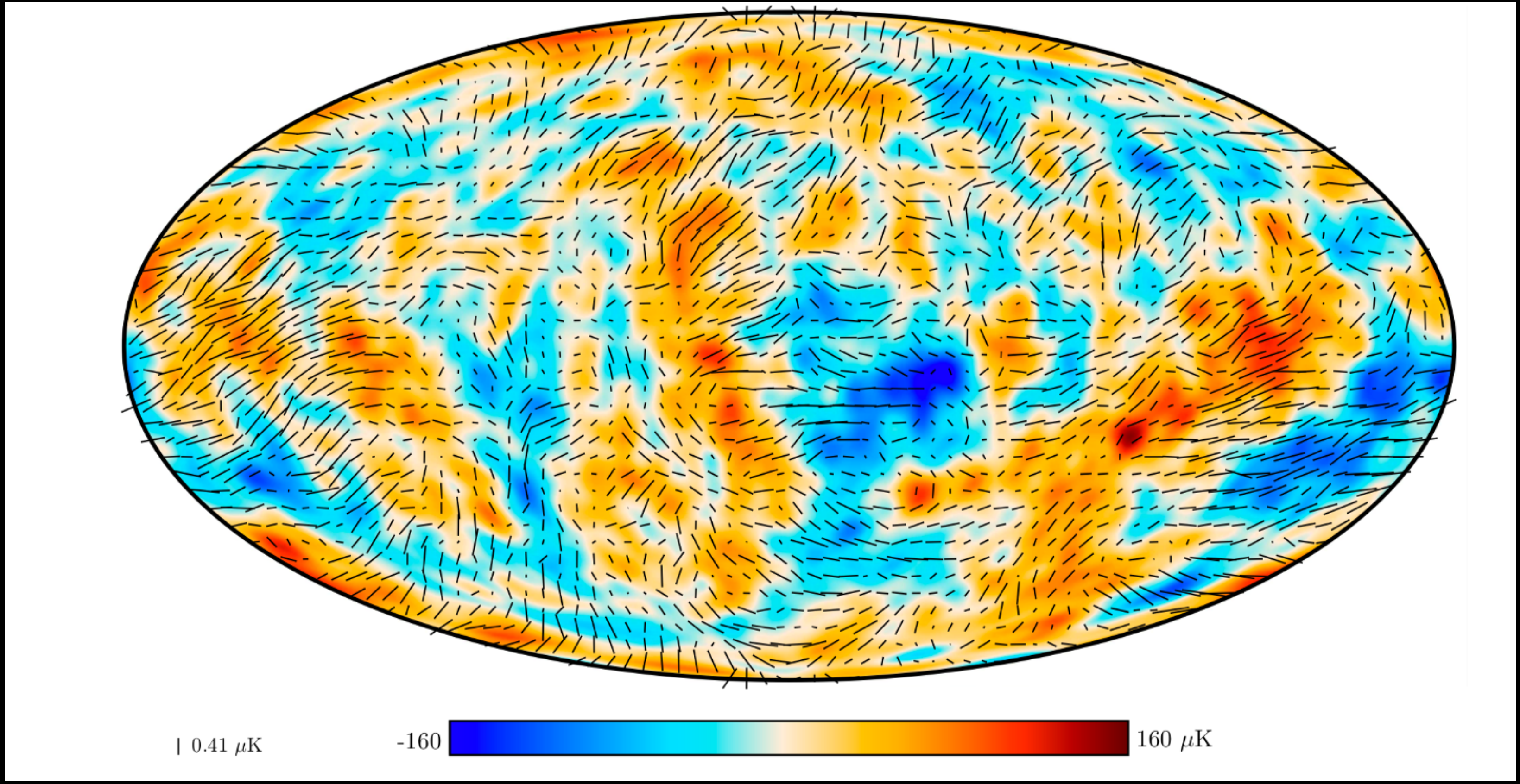
  - ➡ *B field (odd under parity)*



$\Leftarrow$ *Tensor modes* $\Leftrightarrow$ *GW from inflation*

PLANCK 2018

CMB E-modes



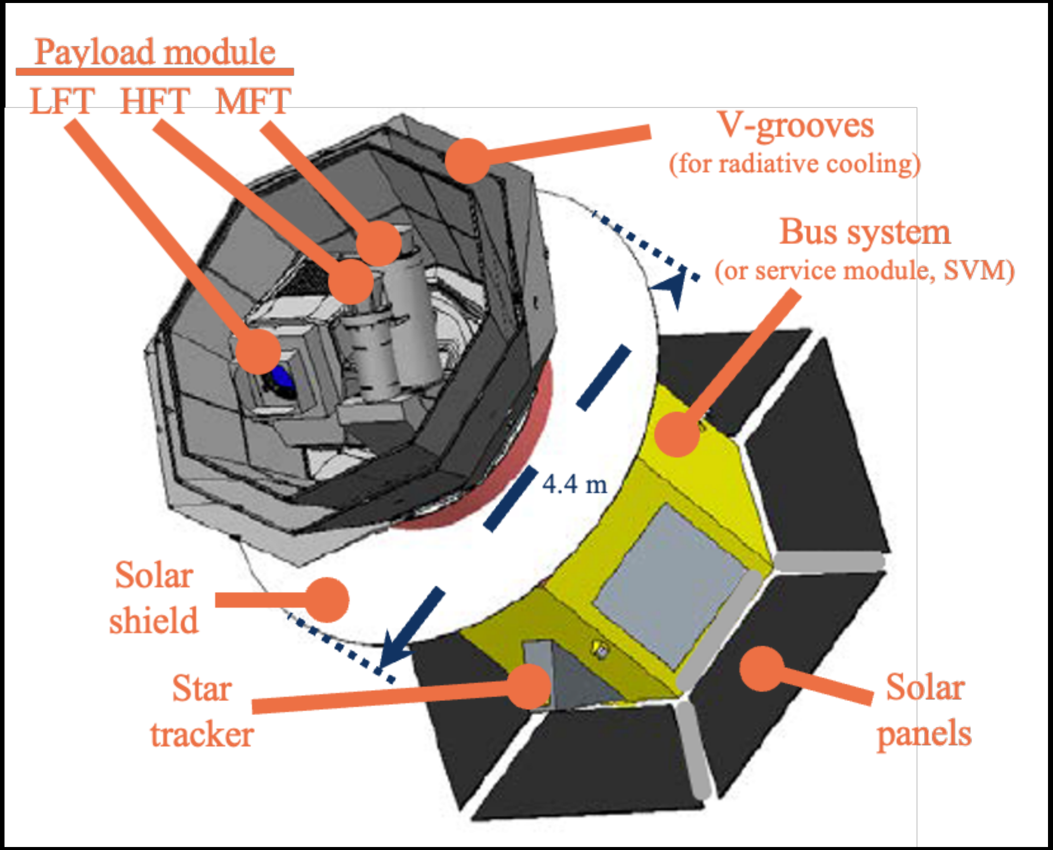
LiteBIRD

Lite(Light) B-mode Inflation Radiation Detection

- **Post-Planck space mission for CMB polarization**
  - *Selected by JAXA as strategic L-class mission (05/2019)*
  - *With participation from US and Europe*
- **Expected launch**
  - *in late 2029*
  - *JAXA's H3 rocket*
- **All-sky 3-year survey**
  - *from Sun-Earth Lagrangian point L2*

LiteBIRD spacecraft overview

- **3 telescopes**
  - *LFT (low frequency telescope)*
  - *MFT (middle frequency telescope)*
  - *HFT (high frequency telescope)*
- **MFT and HFT are European Instruments**
- **Large frequency coverage**
  - *40–402 GHz, 15 bands*
  - *70–18 arcmin angular resolution*
  - *Final combined sensitivity: 2.2 μK·arcmin*



LiteBIRD

Lite(Light) B-mode Inflation Radiation Detection

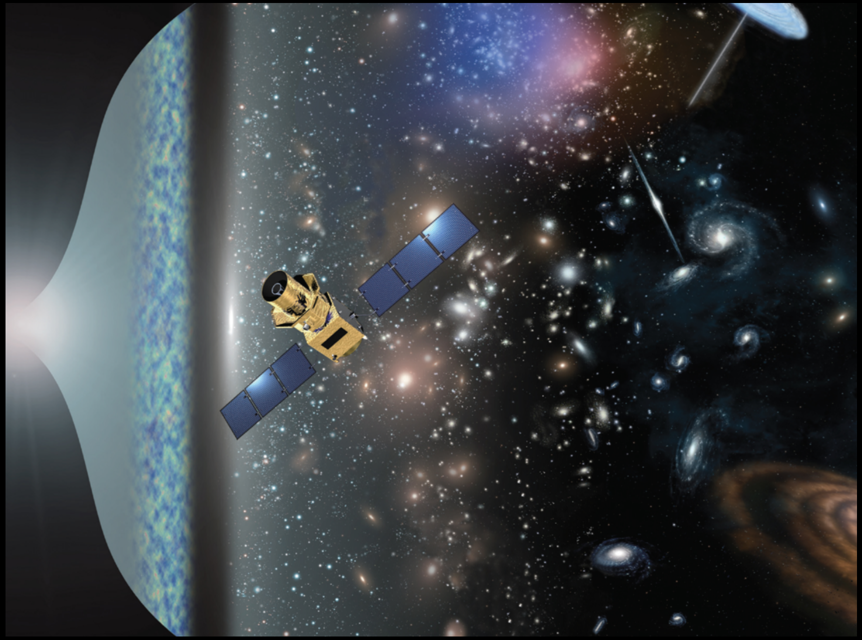
- **Science outcome**
  - *Detection of CMB B-mode from primordial gravitational waves*

$$r = \frac{A_T}{A_S} \quad @ \quad k = 0.05\, Mpc^{-1}$$

  - *Direct evidence for inflation*
  - *Knowledge on the inflation energy scale*

$$V^{1/4} \simeq 10^{16} \left(\frac{r}{0.01}\right)^{1/4} GeV$$

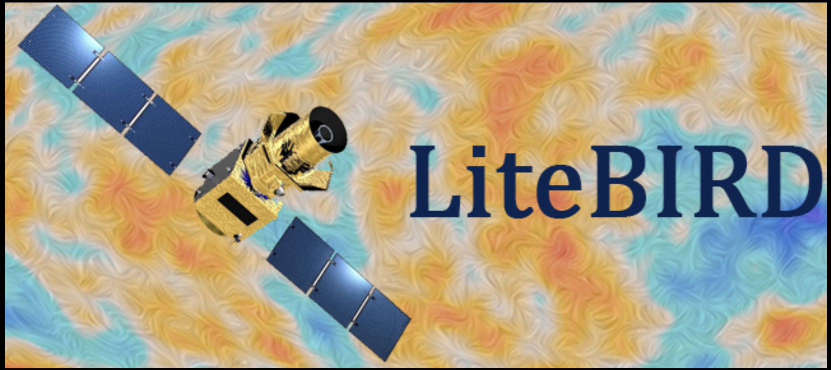
  - *First evidence for quantum fluctuation of space-time*

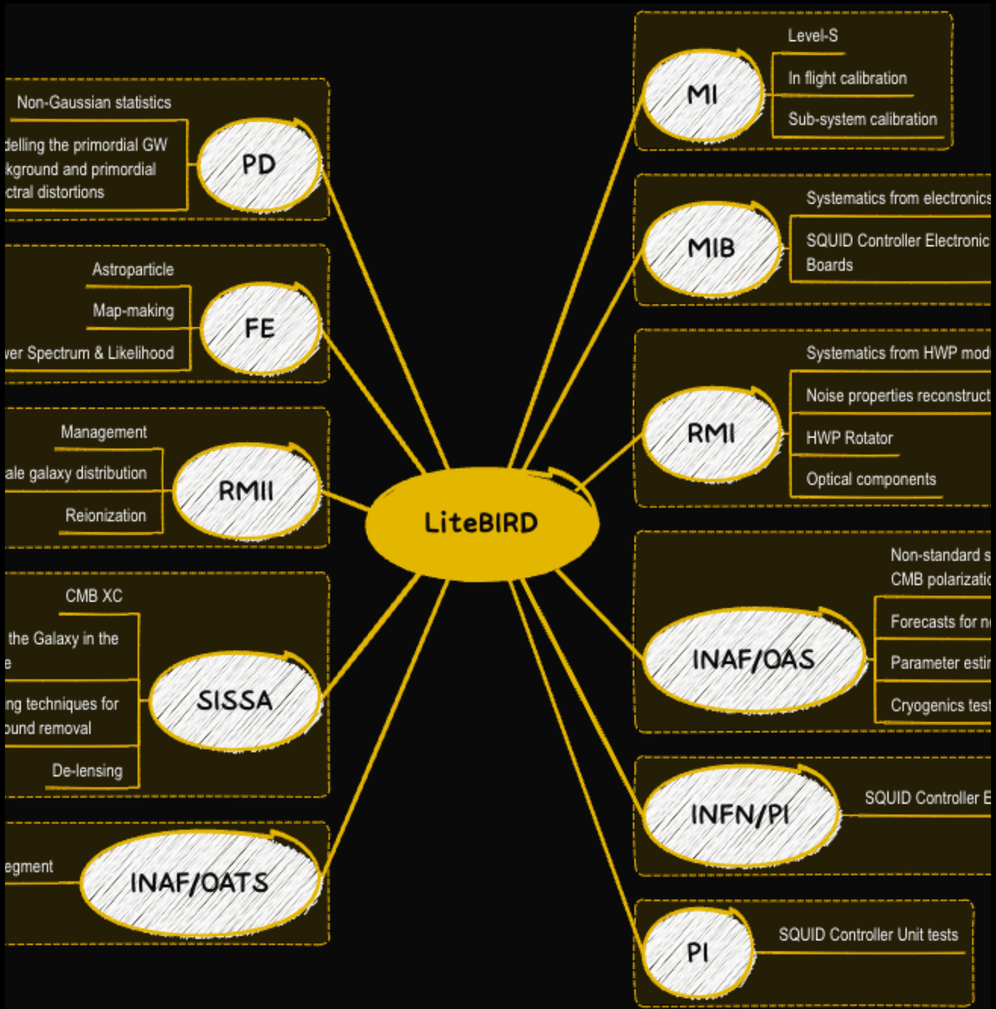


ASI/LiteBIRD

KO Meeting - 12/05/2020

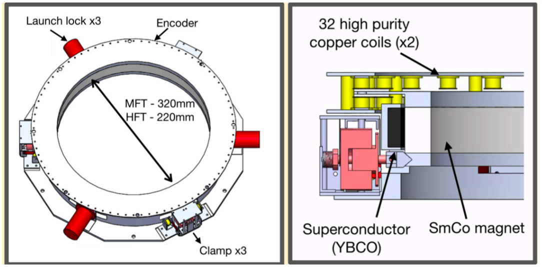
- Agreement with Tor Vergata
- Support to the Italian community for participating to the Phase A study





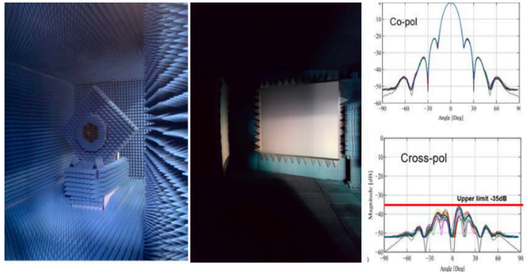
Il contributo italiano sull’HW

Rotatore di polarizzazione MHFT (Sapienza)



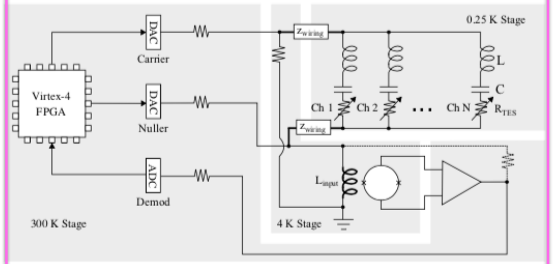
- HWP rotante a levitazione
- Componenti dell’ottica di MHFT

MHFT System-level calibrations (Milano Statale)



- Esperienza di Milano nella calibrazione di Planck

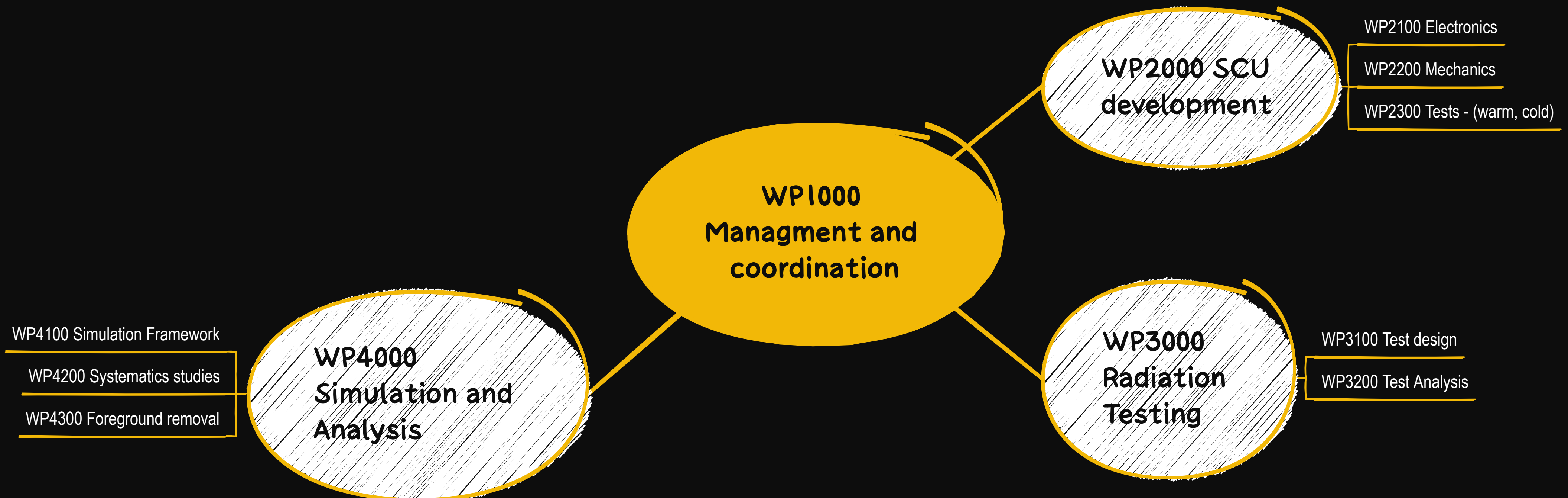
SQUID readout (INFN)



- Read-out dei bolometri criogenici

LiteBIRD (CSN II)

- **FE: P. Natoli; MI: M. Tomasi; MIB: M. Zannoni; INFN/PI: G. Signorelli (PI); RM1: L. Lamagna; RM2: M. Migliaccio; TS: N. Krachmalnicoff**



Conclusions

- **Hunting for B-modes of the CMB polarization**
  - ➡ *the forefront of the experimental research*

- **Why to go from space?**
  - ➡ *Rule of thumb: 1,000 detectors in space ⇔ 100,000 detectors on ground*
  - ➡ *No statistical/systematic uncertainty due to atmosphere, no ground pickup*
  - ➡ *The only way to access to the lowest multipoles*
  - ➡ *A wide ancillary science: neutrinos, Galactic and extragalactic astrophysics*

Conclusions

- **LiteBIRD is**
  - ➡ *approved*
  - ➡ *the only space-born CMB mission in this decade*
- **The Italian community is heavily involved**
- **The Sezione-INFN and the Physics Dept. are heavily involved**