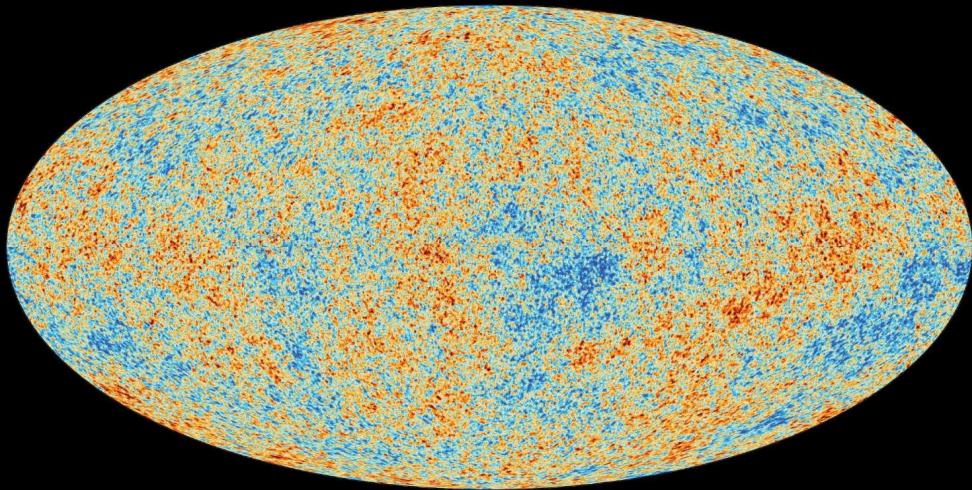


Napoli, 27-28 Marzo 2019 – Auditorium Nazionale dell’INAF “Ernesto Capocci”

Giornate INAF 2019

Cosmic Microwave Background



Marco Bersanelli

*Dipartimento di Fisica, Università degli Studi di Milano
IASF Milano, INAF
INFN Sezione Milano*



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Marco Bersanelli – CMB



The XXI Century CMB

A unique scientific intersection

Cosmology

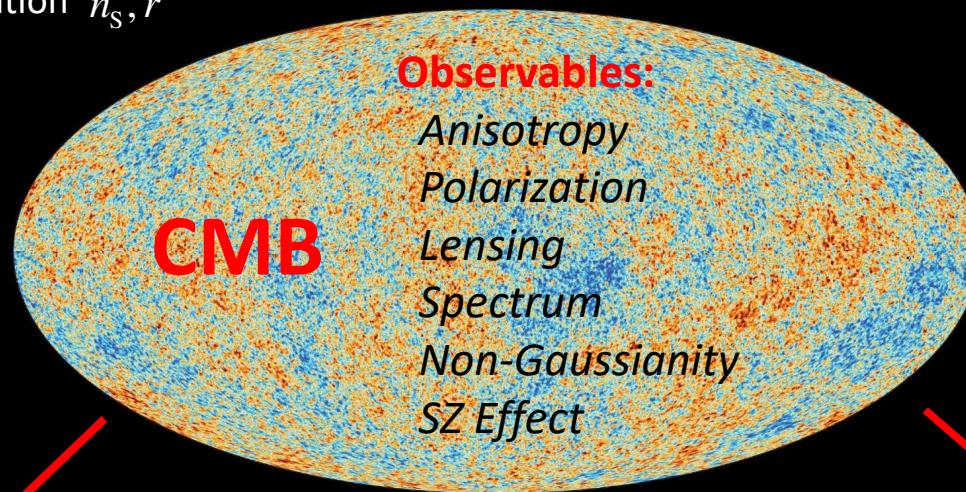
Expansion rate H_0
Density parameters $\Omega_m, \Omega_\Lambda, \Omega_b$
Curvature Ω_k
Topology
Inflation n_s, r
[...]

Astrophysics

Re-ionization epoch τ
Clusters of galaxies (SZ)
Extragalactic sources
Galactic magnetic fields
(synchrotron)
Star formation
(interstellar dust)
Solar system
[...]

Observables:

Anisotropy
Polarization
Lensing
Spectrum
Non-Gaussianity
SZ Effect



*Correlation with
data from galaxy
surveys
(e.g. Euclid)*

*Synergy with DM &
neutrino detection
experiments*

Fundamental Physics

Neutrinos $\sum m_\nu, N_{\text{eff}}$
Dark matter
Dark energy
Nuclear physics (BBN)
Gravitational waves
[...]

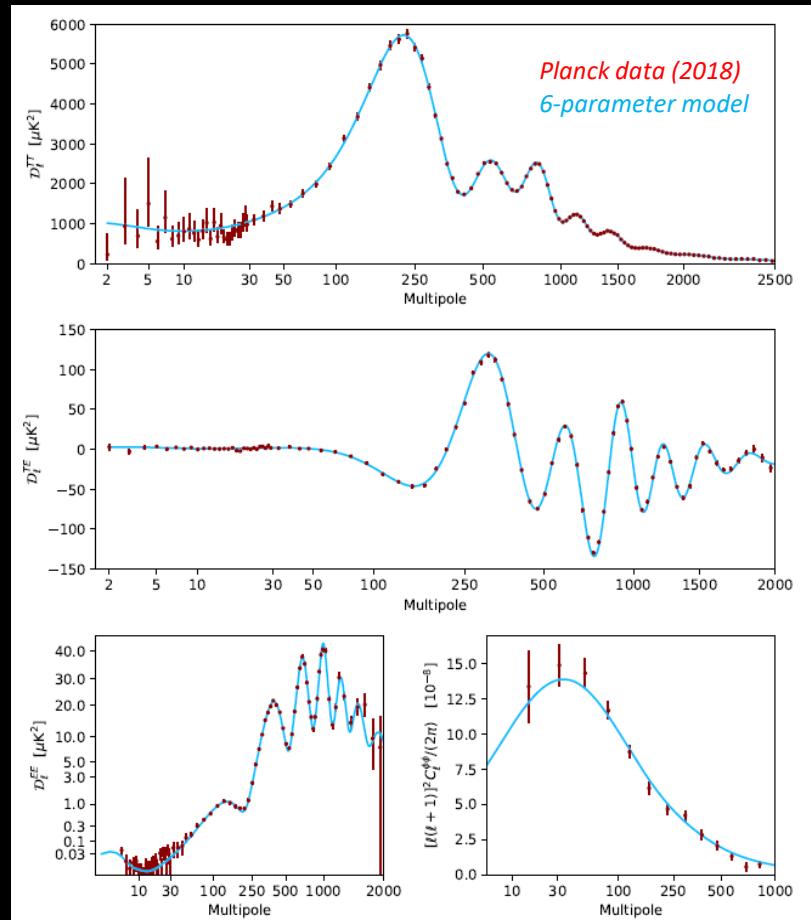
These science topics intersect a large part of the INAF Strategic Vision 2019



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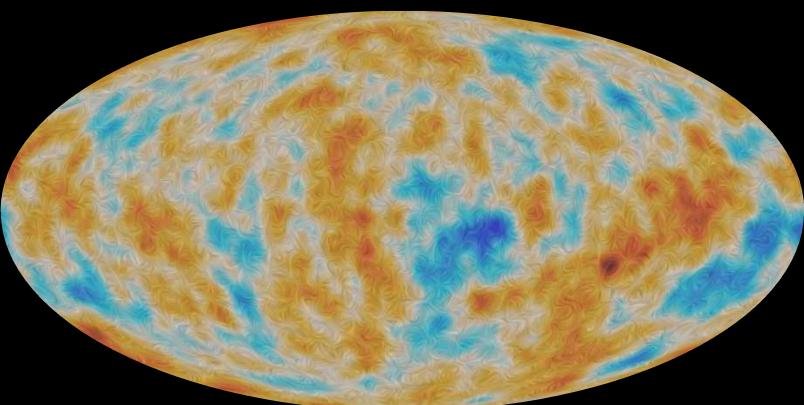
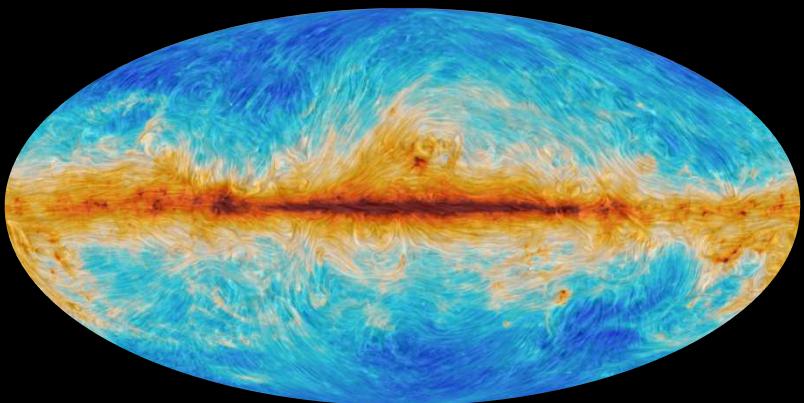
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Planck Collaboration 2018

Planck sky in polarization



Cosmological parameters at percent precision

*Next main challenge: search for B-modes in CMB polarization
as a signature of primordial gravitational waves*

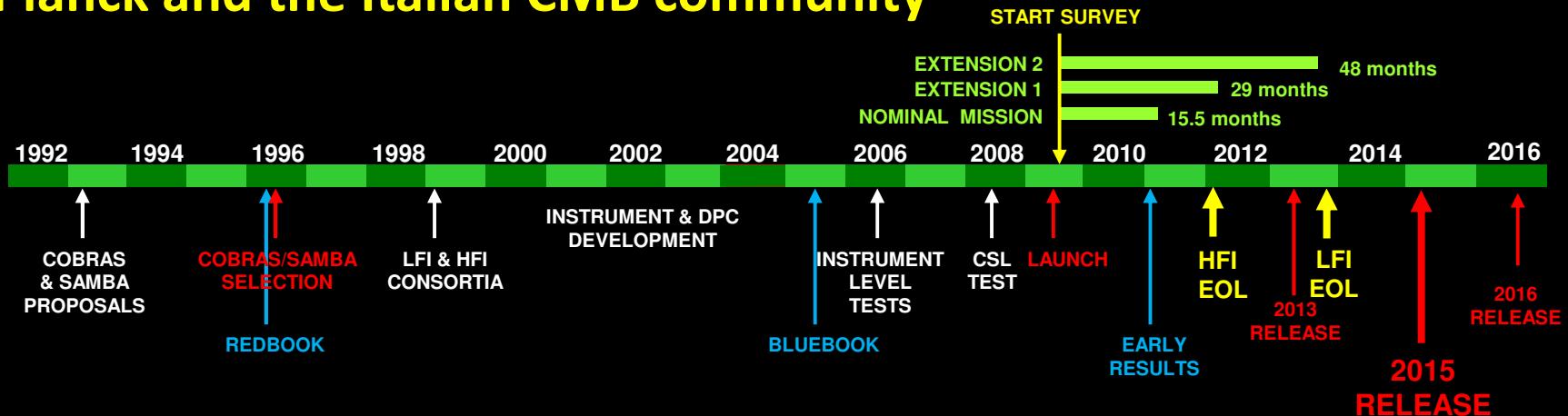


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Planck and the Italian CMB community



- Pivotal role of INAF throughout the Planck project
- Development of a large and well-organized Italian CMB community



- Expertises covering the whole range: *Hardware / Data analysis / Theory*
- New generation of top-level young scientists
- Increasing interest from new communities (e.g. INFN)



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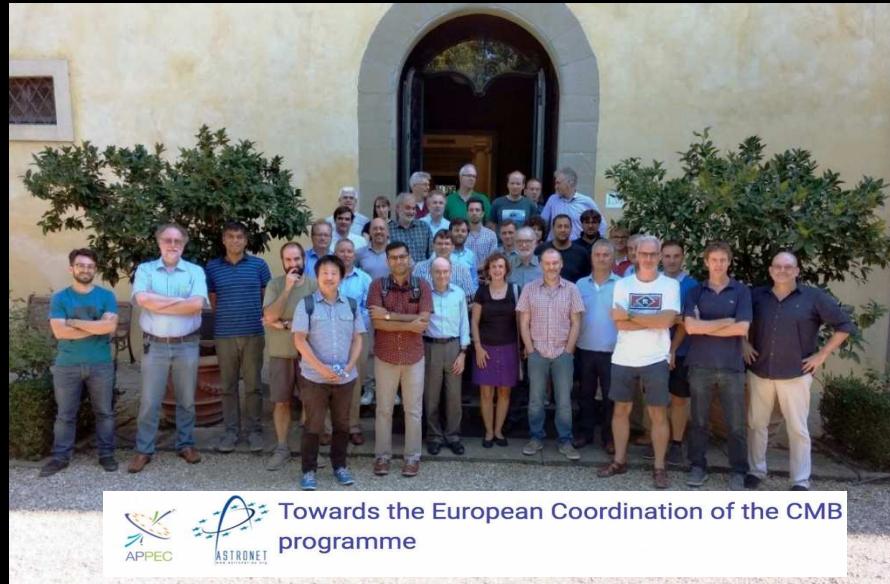
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ASI/Cosmos project 2016-2019

- ASI-funded project
- Coordination of the Italian CMB work: experiments, theory, data analysis
- 11 nodes: Universities, INAF, INFN (*Coord.: N. Vittorio*)
- Roadmap of the Italian CMB community in European and world-wide context
- 5 workshops: Theory, Data analysis, Foregrounds, Ground-based, Balloon-borne

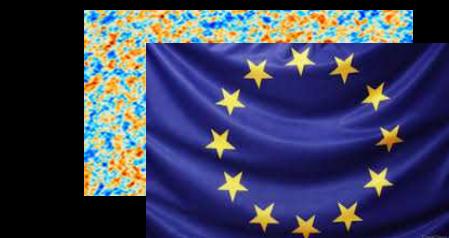


Towards the European Coordination of the CMB programme



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E-CMB
“The Florence process”
Villa Finaly
Yearly meetings since 2015

Cosmic Orbital and Suborbital Microwave ObservationS



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Osservatorio Astronomico di Roma

The Italian CMB community

Major INAF component (*see INAF Strategic Vision doc*)

- Key technology and space-experienced laboratories, System Engineering, AIV
- Data processing and data analysis



**INAF
Other Institutions**



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BOLOGNA

- INAF/INAF, Bologna
- IRA/INAF, Bologna
- INFN Sezione di Bologna

CATANIA

- INAF – Osservatorio Astrofisico di Catania

FERRARA

- Dipartimento di Fisica, Università di Ferrara

FIRENZE

- Dip. Meccanica e Tecnologie Industriali, Univ. di Firenze
- IFAC-CNR, Sesto Fiorentino (FI)
- INAF, Osservatorio Astronomico di Arcetri

GENOVA

- INFN Sezione di Genova

MILANO

- Dipartimento di Fisica, Università degli Studi di Milano
- **INAF/INAF Milano**
- Dipartimento di Fisica, Università di Milano-Bicocca
- Istituto di Fisica del Plasma, CNR-ENEA-EURATOM, Milano

PADOVA

- Dip. di Fisica G. Galilei, Università degli Studi di Padova
- **INAF, Osservatorio Astronomico di Padova**
- INFN, Sezione di Padova

PISA

- INFN Sezione di Pisa
- CNR-ISTI, Area della Ricerca, Pisa

ROMA

- Dipartimento di Fisica, Università La Sapienza, Roma
- Dipartimento di Fisica, Università di Roma Tor Vergata
- **INAF – Osservatorio Astronomico di Roma**
- CNR, Istituto di Fotonica e Nanotecnologie, Roma
- Istituto Nazionale di Geofisica e Vulcanologia, Roma
- Agenzia Spaziale Italiana, Science Data Center, Roma

TORINO

- CNR-IEIIT/CNR, c/o Politecnico di Torino

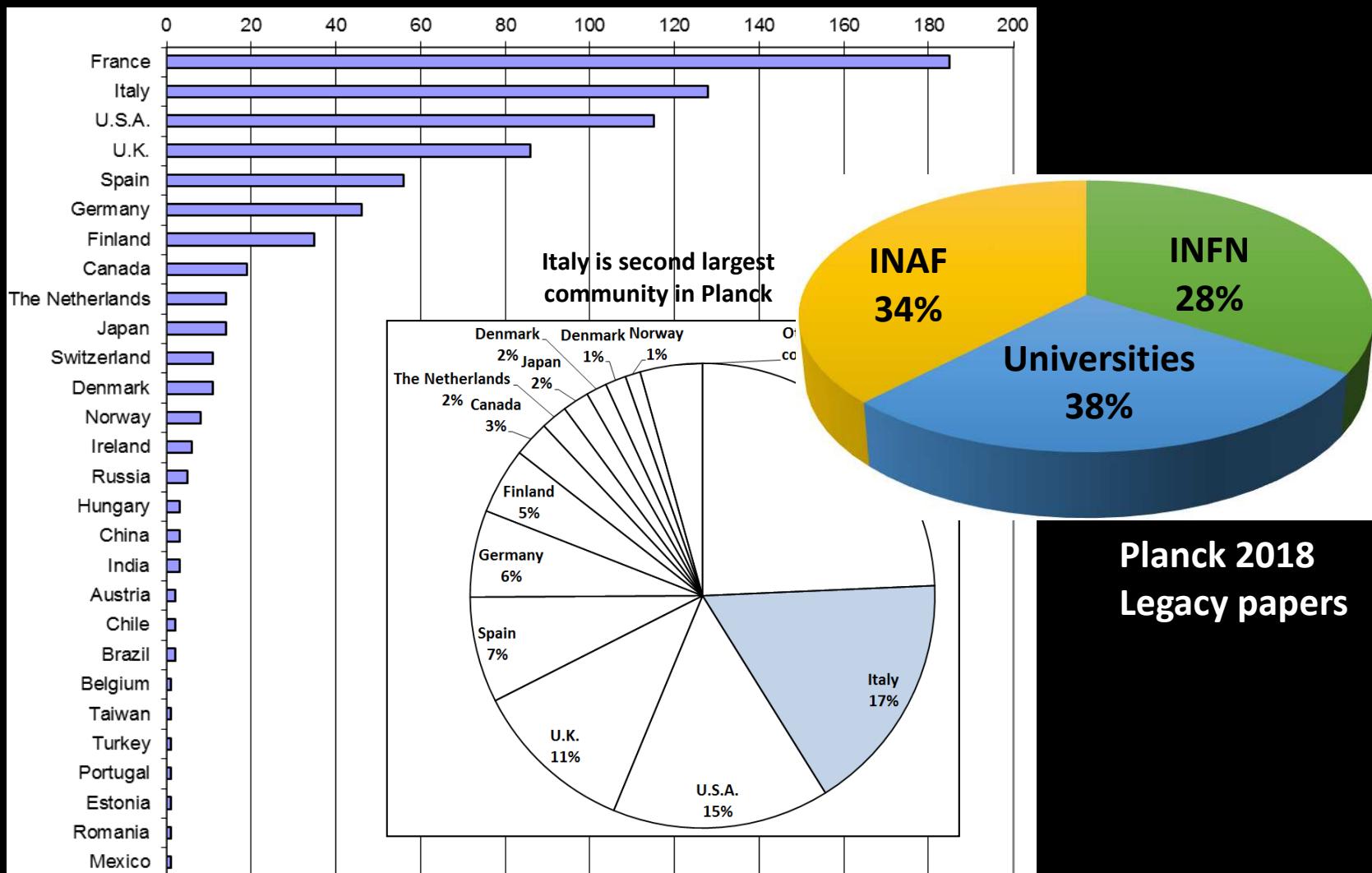
TRIESTE

- **INAF, Osservatorio Astronomico di Trieste**
- SISSA, Astrophysics Sector, Trieste
- Dipartimento di Fisica, Università degli Studi di Trieste

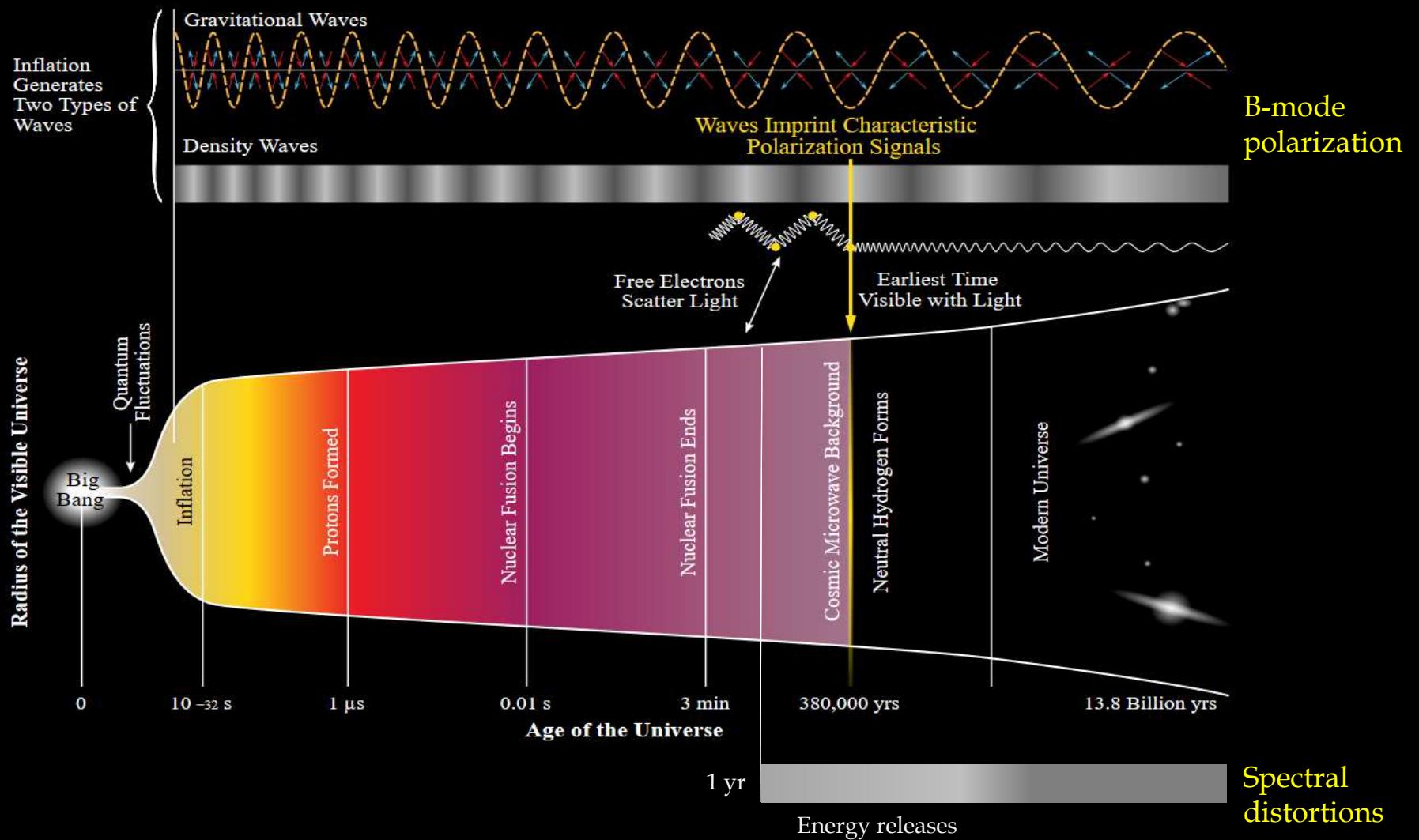


The Italian CMB community

Publication share in Planck mission papers



History of the Universe



Current limit on tensor-scalar ratio: $r < 0.06$ (Planck+Bicep/KEK array)

(See Stefano Borgani's talk)



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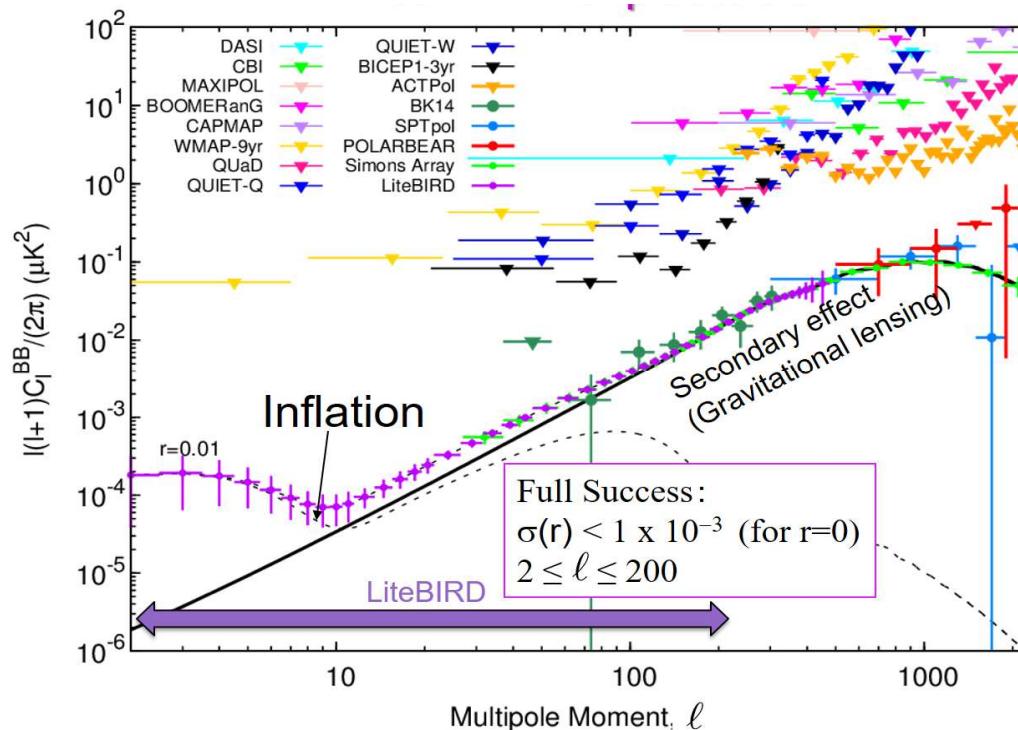
LiteBIRD

JAXA mission, strong European and USA participation



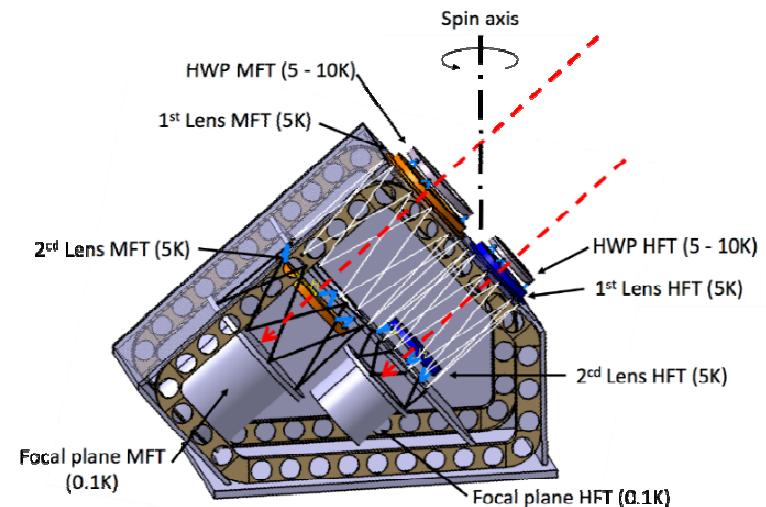
- Objective: B-modes, $r \sim 10^{-3}$
- Sensitivity: < 3uK arcmin, deg resolution
- Lissajous orbit in L2, full-sky, 3 years
- Frequency range: 40-400 GHz
- Detectors: 3500 TES, 100mK HWP
- Launch in 2027

Final down selection by June 2019 (LiteBIRD vs OKEANOS)



Medium-High Frequency Telescope

- 100-400Hz range
- European contribution to the mission
- Italy a key partner of the collaboration

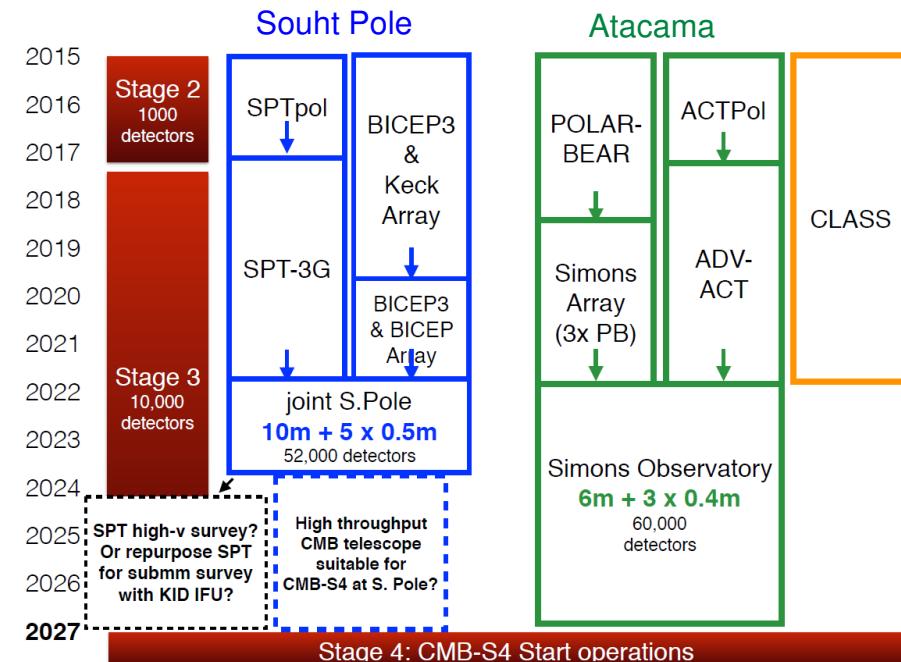
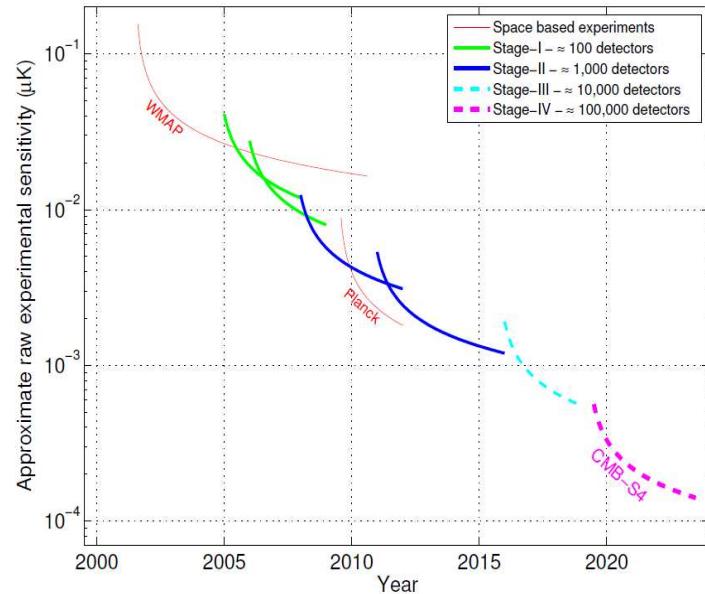


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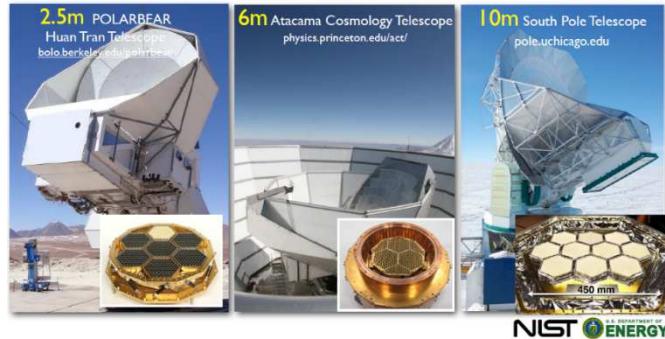


Ground-based CMB: international context

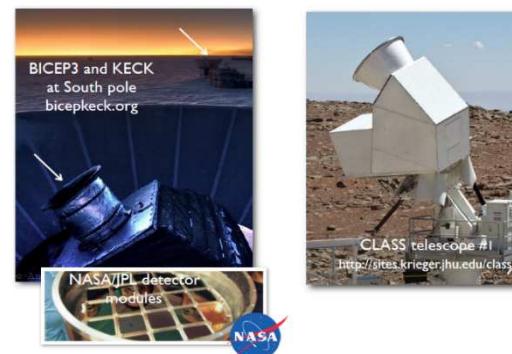


Major US-led effort on ground based CMB polarization in Southern Hemisphere

High resolution CMB experiments



Small aperture (big beam) CMB telescopes



Italian participation in
Simons Observatory,
PolarBear, US-S4



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Cosmic Orbital and Suborbital Microwave Observations



European perspective in sub-orbital experiments

B-mode polarization: highly competitive scenario set by US-S4 program

Technology development	Experiment
KIDS development (e.g. KISS) and TES	QUIJOTE
Coherent technology, horn/OMT arrays	C-BASS
Telescopes, optics, HWP	LSPE
Cryogenics, calibration facilities	QUBIC
	NextBASS
	QUIJOTE-South
	«STRIP-2»
	Contribution to Simons Observatory
	6-m class telescope at South Pole
	«ELFS»
	Full-sky low frequency survey
Major role of Italy/INAF (F. Villa's talk)	Large arrays with KIDs

Bottom-up
Top-down

Florence, E-CMB workshop, September 2018

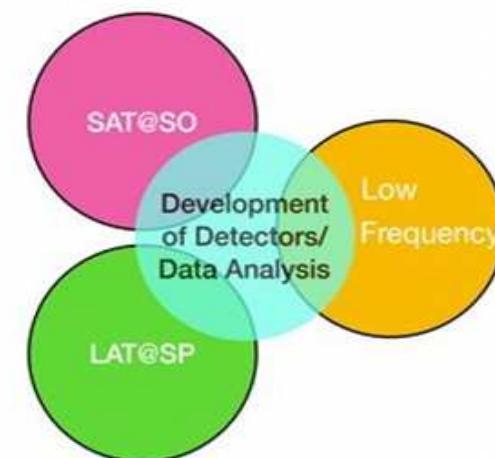


Short Term

On-going
H/W in development

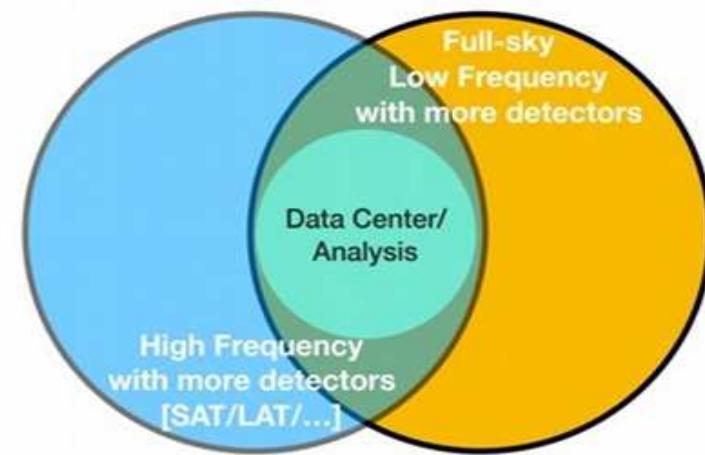
Mid Term

Chile
Pole
Tenerife+



Long Term (by 2027)

High v
Low v



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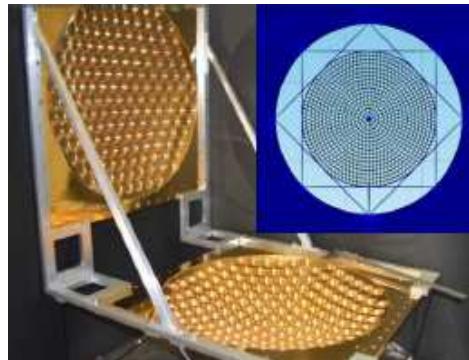
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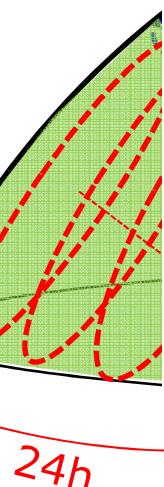
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Laboratori Nazionali di Frascati

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SWIPE



Balloon borne
(Launch 2020)

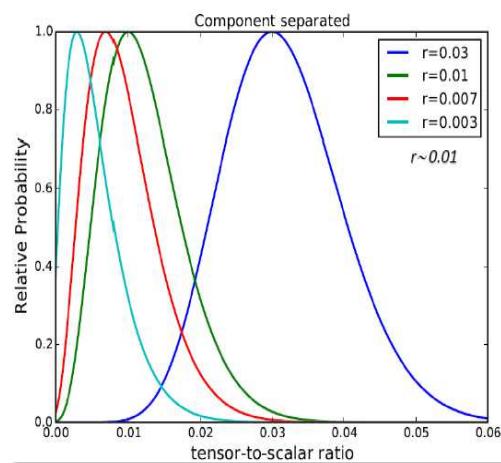
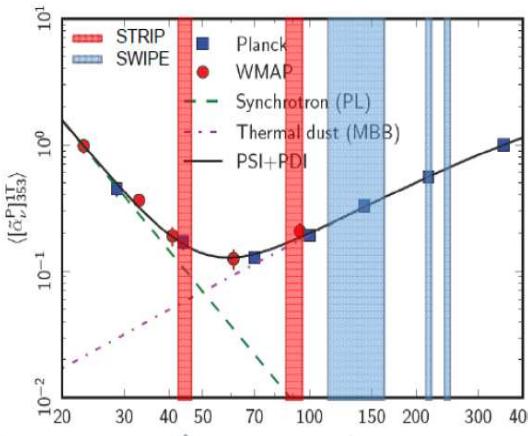


*Avoid Sun in beam
~1 yr observations*

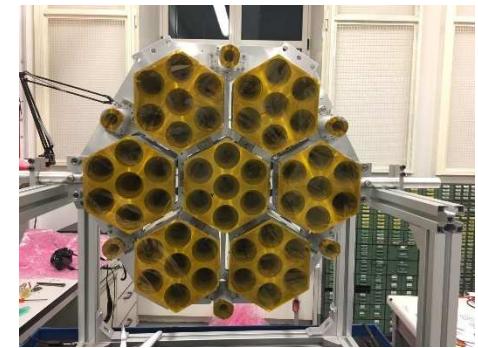
LSPE

Large Scale Polarization Experiment

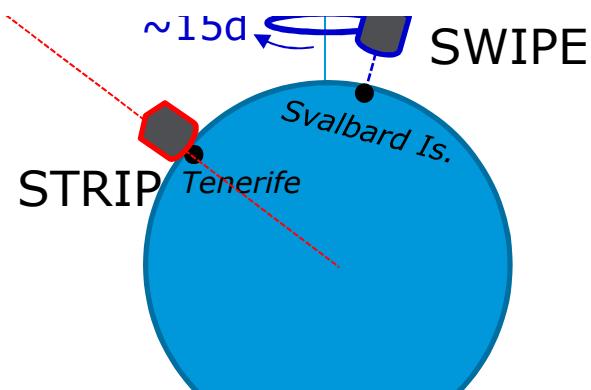
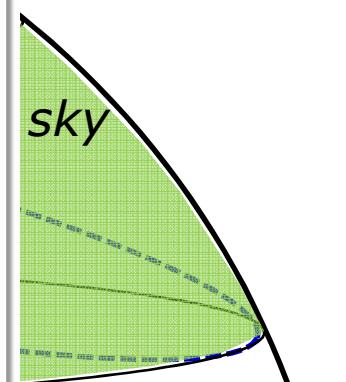
North Pole



STRIP



Ground-based
(Deploy 2020)

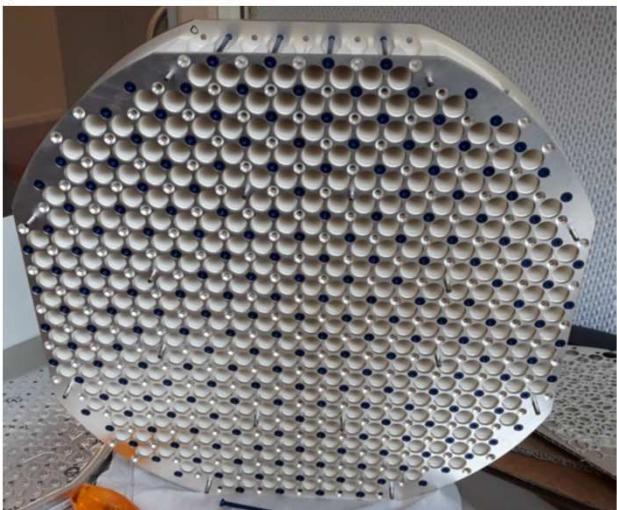


QUBIC

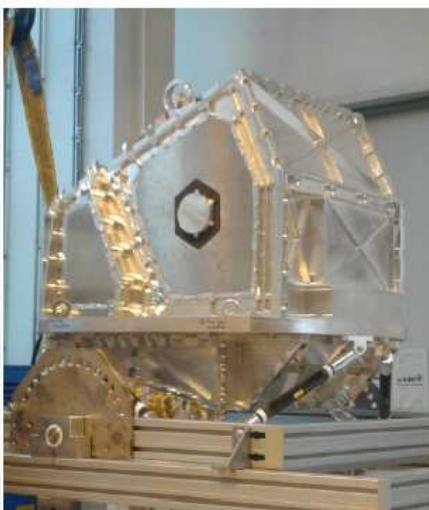
Bolometric interferometry



Cryogenic section of the
detection chain



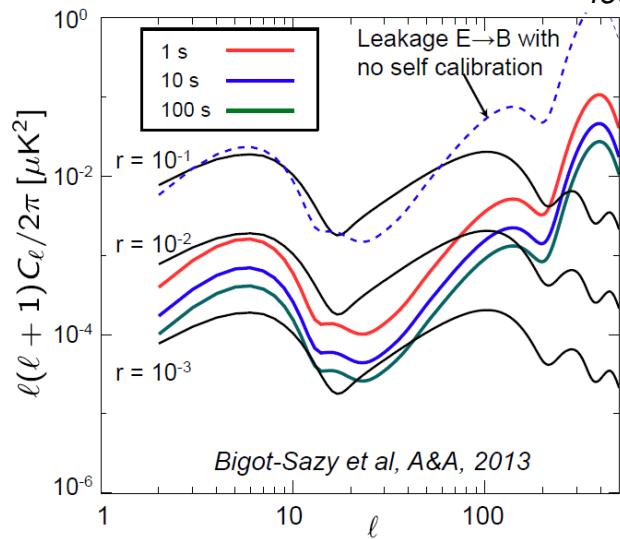
400 element back-to-back corrugated
feed-horn array



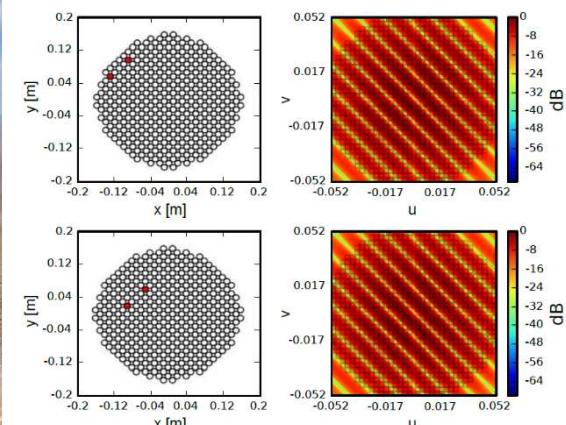
The QUBIC integrated
1K box



Integration of the 1K box
in cryostat shell

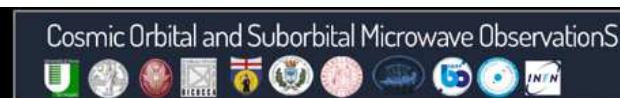


Technical Demonstrated Campaign (8x8 element array)
Test Campaign: Late Spring 2019



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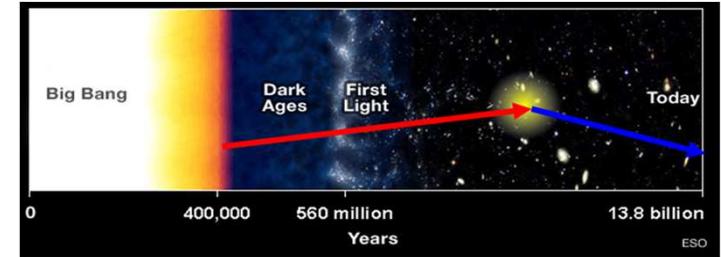


Balloon flights

Crucial for high frequency observations, spectral distortions

OLIMPO

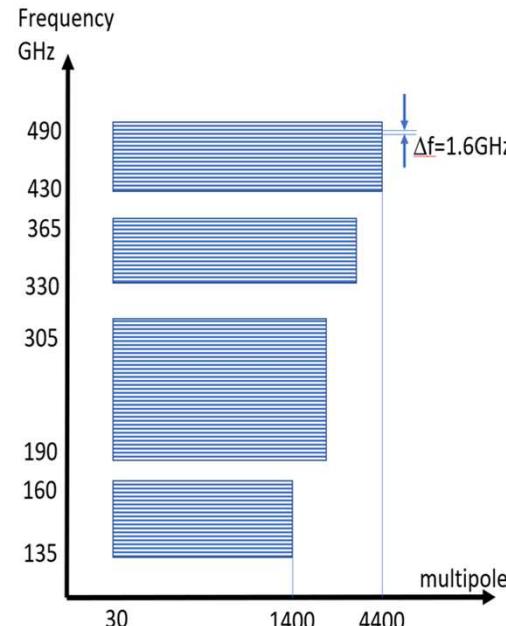
- Balloon-borne telescope for differential spectroscopy (SZ effect)
- Covers wide multipoles and frequencies space
- Dets. validated with the OLIMPO test flight of July 2018 (Paiella et al. 2018, Masi et al. 2019)



LSPE/SWIPE

- Designed for launch from Svalbard Islands
- Alternatives being considered

Long term commitment from ASI is necessary to maintain and support the long Italian tradition on balloon flights



<http://olimpo.roma1.infn.it>



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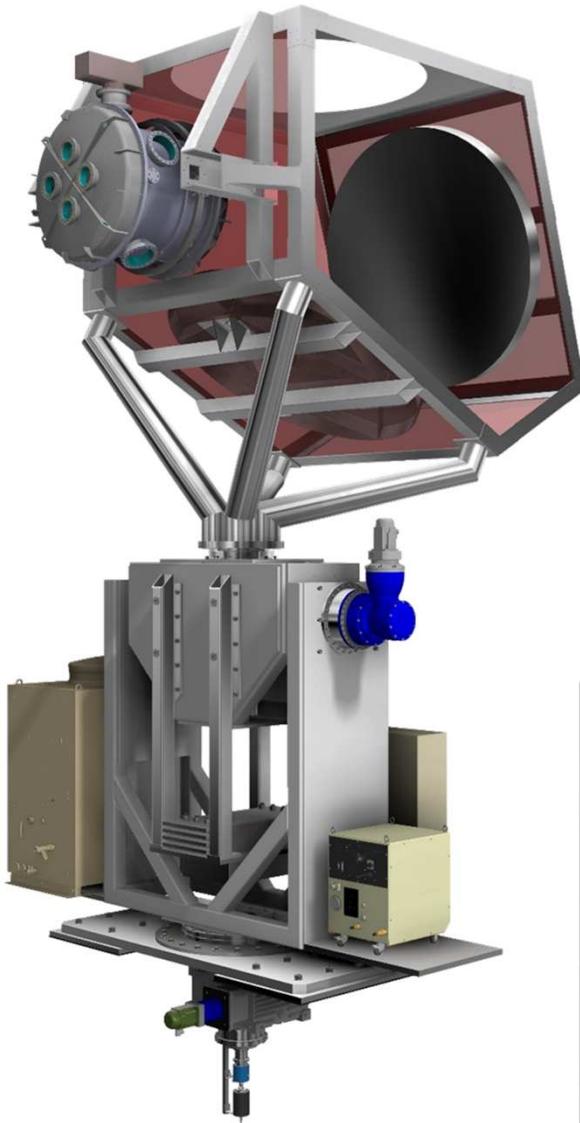
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STRIP-2

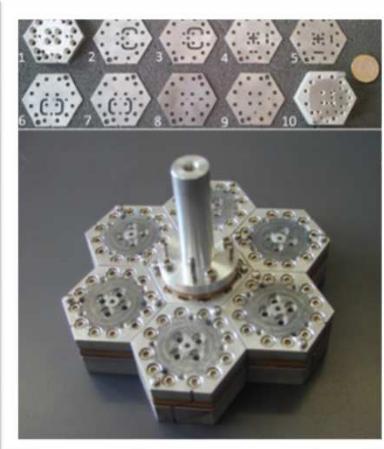
Planned extensions of existing experiments



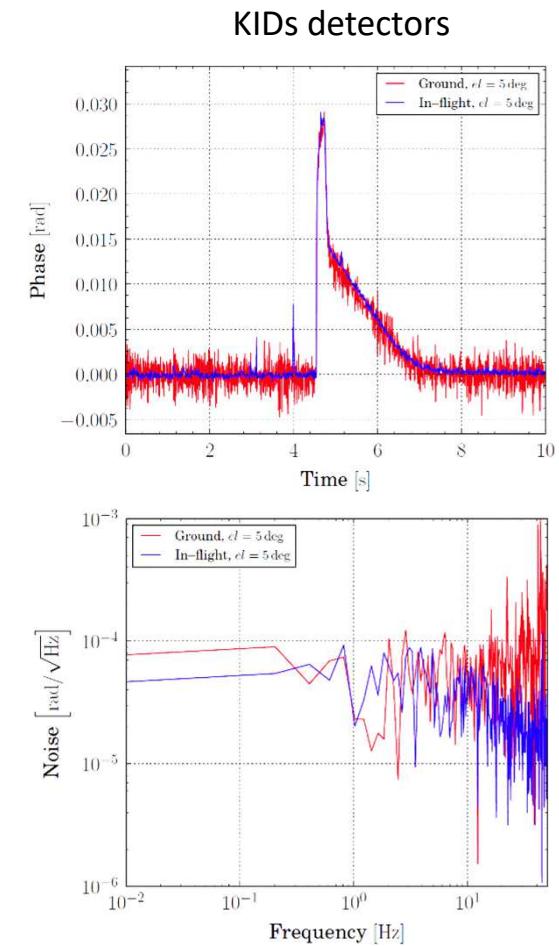
Use STRIP/Clover 1.5m telescope, Tenerife site
514-element W band array
KIDs technology



Smooth-wall feed horns
(Franceschet et al 2019)



W-band
platelet
OMT



Ref.: S. Masi, P. De Bernardis, et al., 2019



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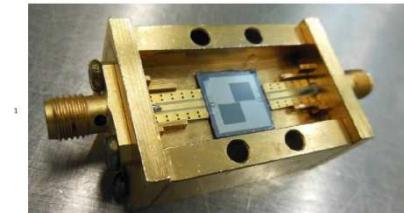
Long-Term European Low Frequency Full-sky Survey (ELFS)

Recent evidence (S-PASS, QUIJOTE, C-BASS, see Krachmalnicoff et al 2018) call for deep measurements of synchrotron at degree scale (limiting $r > 10^{-3}$ everywhere in the sky)

- Full sky Coverage
- Resolution: 10' at 30GHz
- Frequency range 5-120GHz
- Tech: 5-40GHz (HEMTs), 100GHz(KIDs)
- Technology fully available in Europe/Italy

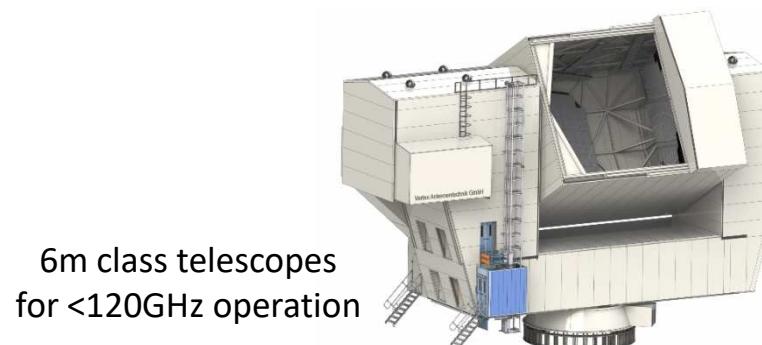
Parameter	Test Condition	Value	Unit
Gain	23-42GHz	28	dB
Noise	23-41GHz	7.9	K
IRL	23-42GHz	13	dB
ORL	23-42GHz	17	dB
P_{1dB}	23-42GHz	-10	dBm
OIP3	23-42GHz	0	dBm

0.25 K/GHz HEMTs

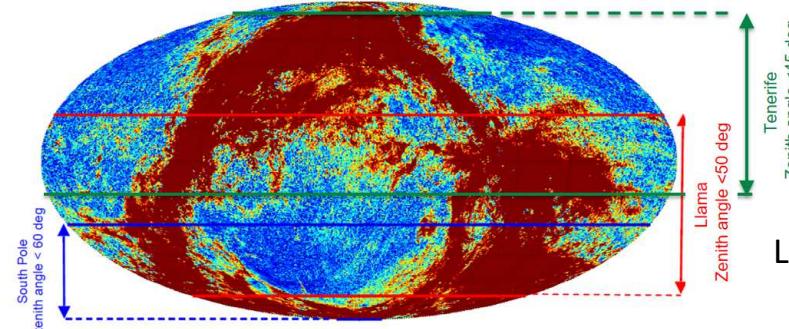


W Band KIDs

Deploy two 6-m class CMB telescopes, North and South Hemispheres (sites TBD)
Atmosphere benign (at least up to Q band) also from Northern sites



6m class telescopes
for <120GHz operation



Llama + Tenerife
combination

ELFS is **strategic, and complementary**, to major efforts already ongoing worldwide:

- European contribution to the **US CMB-S4**,
- Low frequency complement to future space mission such as **LiteBIRD**.



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SRT as a powerful CMB-related probe



Possible targets

- High-resolution polarization survey in S-band:
Northern extension of S-PASS
(Carretti et al. 2018)
- Follow up of LSPE observations
Anomalous Dust Emission regions
Transient / variable sources
- Calibration (Planets, standard sources)

Slides by A. Navarrini
(Milano COSMOS Workshop 2019)

INAF SRT Front-Ends in operation			Future SRT Front-Ends		
Dual-frequency L-P band receiver for primary focus	High-C-band monofeed receiver for BWGI focus	K-band 7-feed receiver for Gregorian focus	S-Band (3.0-4.5 GHz) 7-beam receiver for primary focus	Q-Band (33-50 GHz) 19-beam receiver for Gregorian focus	W-Band (75-116 GHz) multibeam receiver for Gregorian focus
T_{rec} (P band)=17-22 K T_{rec} (L band)=10-13 K	T_{rec} =6.5-9 K				



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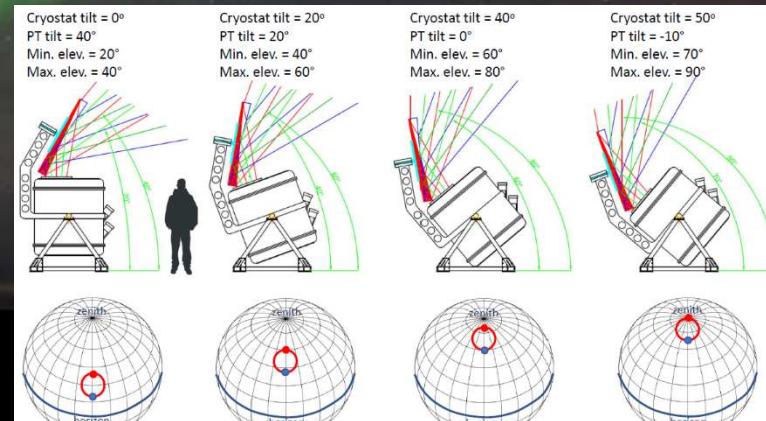
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COSMO

S.Masi et al

The **COSmic Monopole Observer** :

- An attempt to measure **spectral distortions of the absolute brightness** of the CMB from the ground (Dome-C, Antarctica)
- Uses a differential Fourier Transform Spectrometer comparing sky emission to the emission of an internal blackbody.
- Copes with atmospheric emission
 - Selecting the best site in the world for observations
 - Using fast detectors and fast modulation
- Funded by Programma Nazionale di Ricerche in Antartide
- Main limiting factor: **Atmosphere**
(Scan 2500rpm!)
- Possible follow-up:
Balloon-borne experiment



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Conclusions

- The Italian CMB community (INAF, Universities, INFN) has been at the forefront of the great advances of CMB science in the past decades.
- The COSMOS framework is key to identify a coherent roadmap and to promote synergy with our European and International partners
- New exciting scientific targets ahead: B-modes; spectral distortions; SZ effect; lensing; non-Gaussianity;

These are a key part of INAF science vision

Powerful correlations with *Euclid* mission and other surveys

- Next generation space (LiteBIRD) sub-orbital experiments (LSPE, QUBIC, COSMO, STRIP-2, ELFS) are being pursued
 - INAF structures are uniquely equipped to support CMB experiments
 - INAF support essential for future Ground-Based (non-ASI) CMB efforts
- An enthusiastic and talented new generation of CMB researchers has developed in Italy, now ready to lead the «post-Planck» era

INAF can and should continue to play a central role
in the never-ending payoff of CMB science!



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