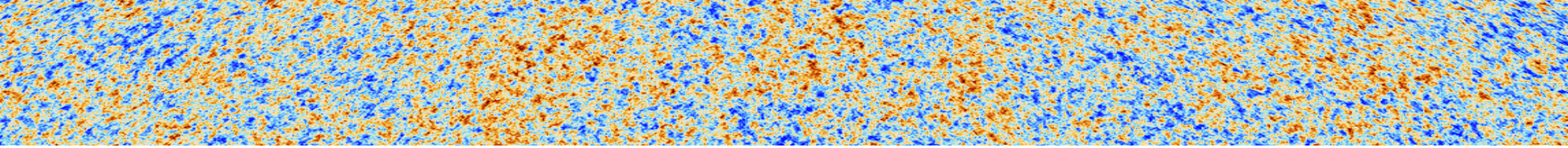


The CMB in Italy

Marco Bersanelli

Università degli Studi di Milano

on behalf of the Italian CMB community

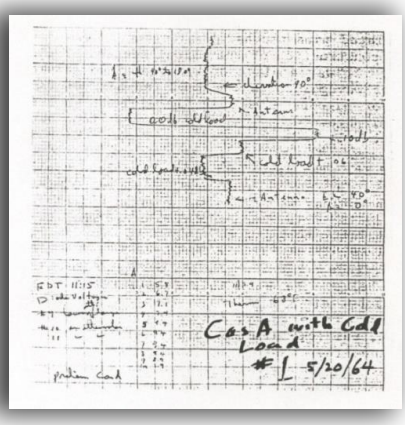
The CMB and the era of "precision Cosmology"

Special status of CMB for precision science:

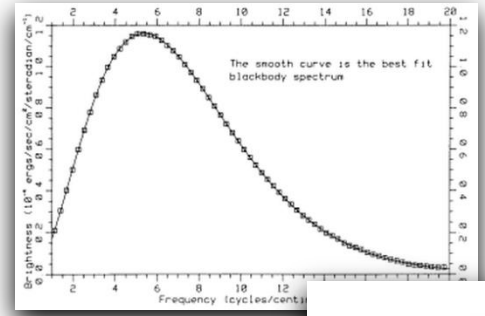
- *Simple physics: early universe was in linear regime*
- *Rapid progress in microwave and mm-wave technology*

Penzias & Wilson 1965

$T_0 = 3.5 \pm 1$ K



~30yrs

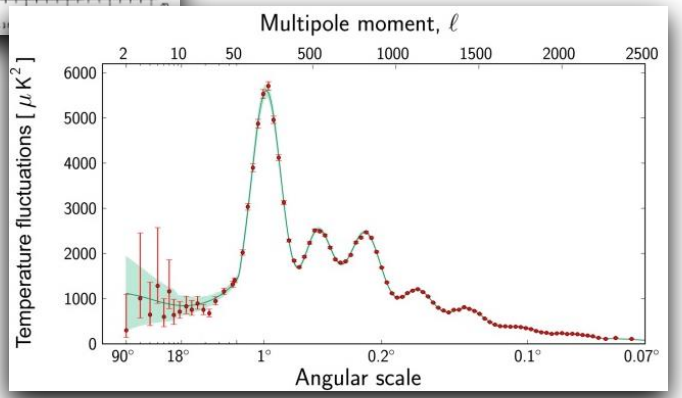


CMB frequency spectrum
COBE/FIRAS (1994)

$T_0 = 2.726 \pm 0.010$ K

~50yrs

CMB angular power spectrum Planck 2015



In 50yrs, the CMB has transformed Cosmology into a high precision, data-driven field. E.g. Curvature:

$\sigma(\Omega_K) \sim 35\%$

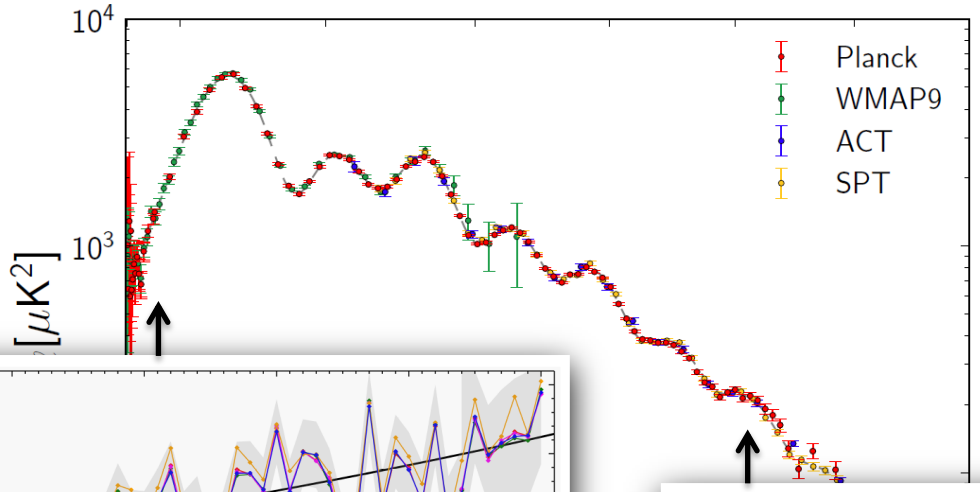
Weimberg (1972)

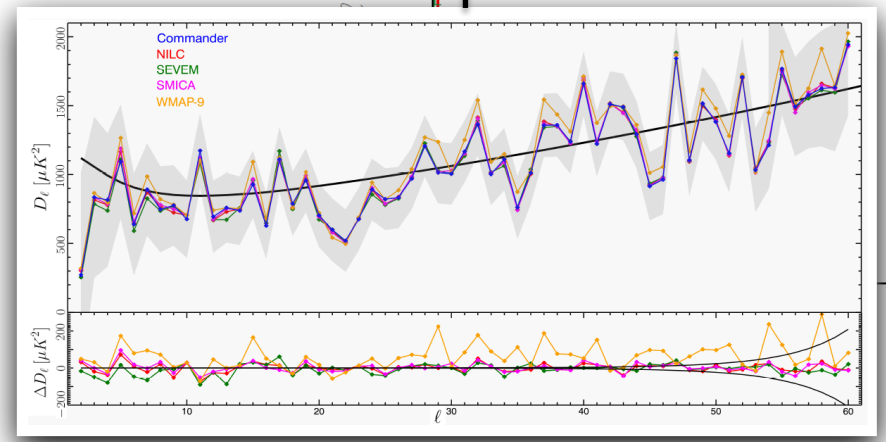
$|\Omega_K| < 0.005$ (95% c.l.)

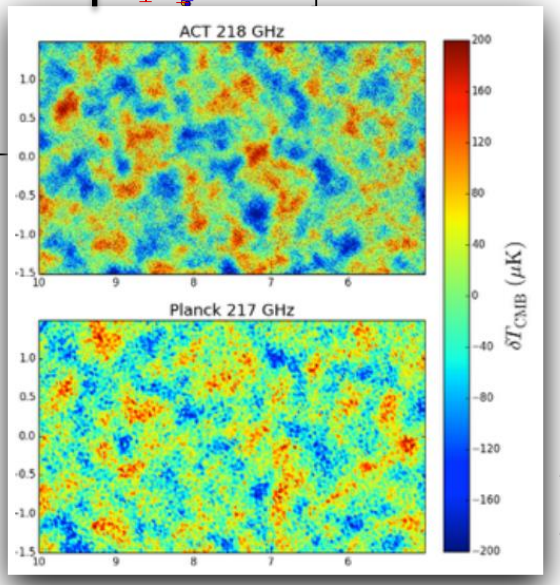
Planck Collaboration (2015)

Not just high-precision, also high-accuracy!

CMB: High precision *and* High accuracy







Planck CMB Dipole calibration <0.2%

Extend to radio (e.g. VLA) and sub-mm (e.g. Herschel)

Low multipoles:
Planck vs WMAP
~1% calibration discrepancy
Now completely solved!

High multipoles:
Planck vs ACT

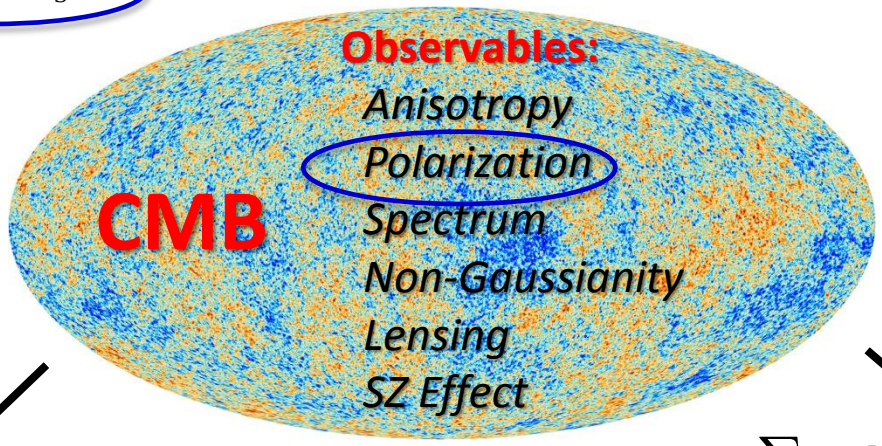
The CMB today: a unique scientific opportunity

The CMB is at a crucial intersection

Cosmology

- Expansion rate H_0
- Density parameters $\Omega_m, \Omega_\Lambda, \Omega_b$
- Curvature Ω_k
- Topology
- Inflation n_S, r
- […]

M. Liguori's talk



Astrophysics

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

P. Mazzotta, C. Burigana talks

Fundamental Physics

- Neutrinos $\sum m_\nu, N_{\rm eff}$
- Dark matter
- Dark energy
- Atomic physics
- Gravitational waves
- […]

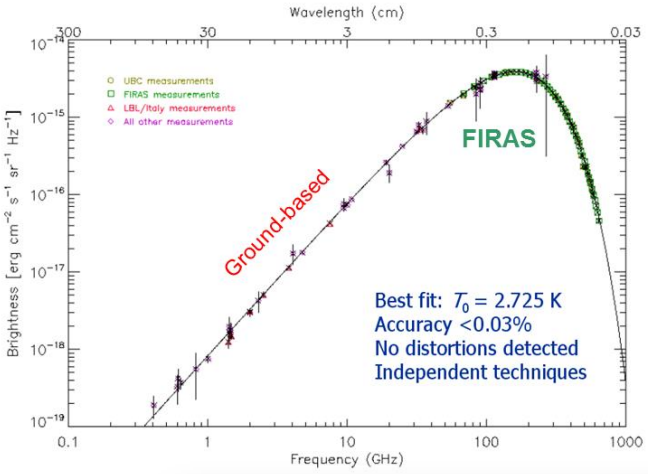
A. Melchiorri's talk

A great CMB tradition in Italy

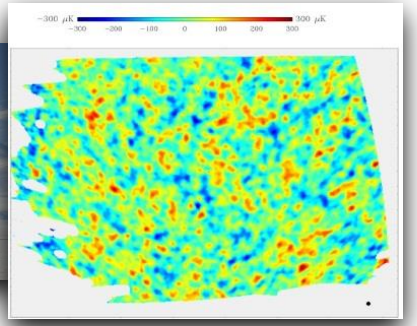
The Italian community has a long history in CMB experiments…

GROUND

Spectrum
WM+SP+TRIS
(1980-2000)



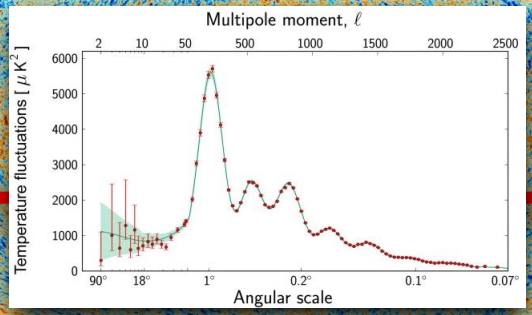
BALLOON



Boomerang
(1992-2005)

SPACE

PLANCK
(1992-2016)

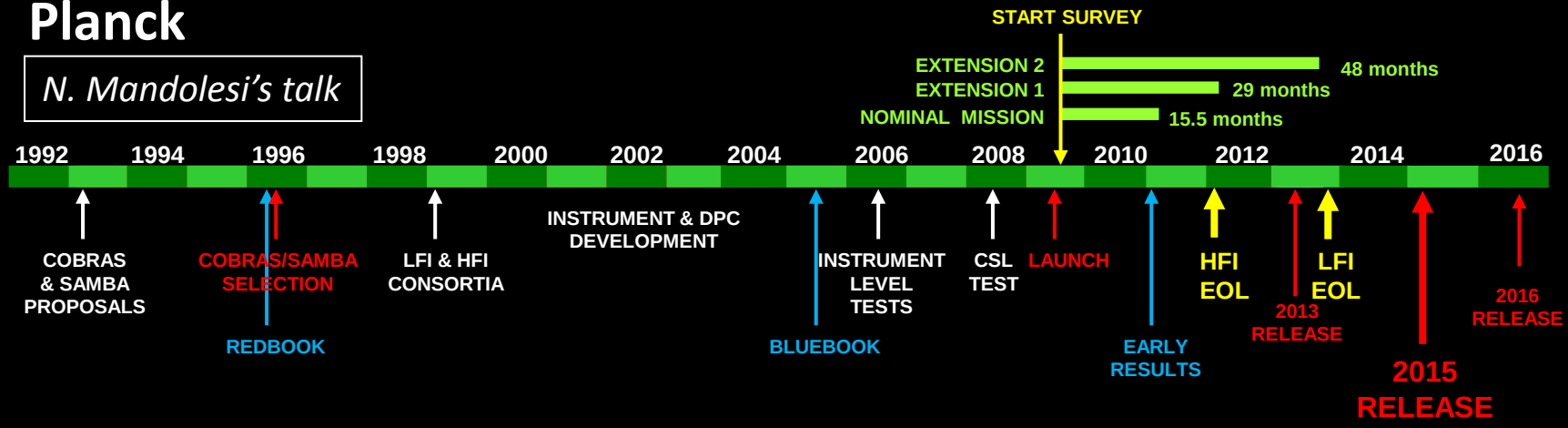


…and produced fundamental contributions to theory and data analysis

The Italian CMB Community

Planck

N. Mandolesi's talk



- Planck: development of a large and well-organized Italian CMB community
- The expertises cover the whole range: *Hardware / Data analysis / Theory*
- Top-level generaiton of young scientists
- Increasing interest from new communities (*e.g. INFN*)

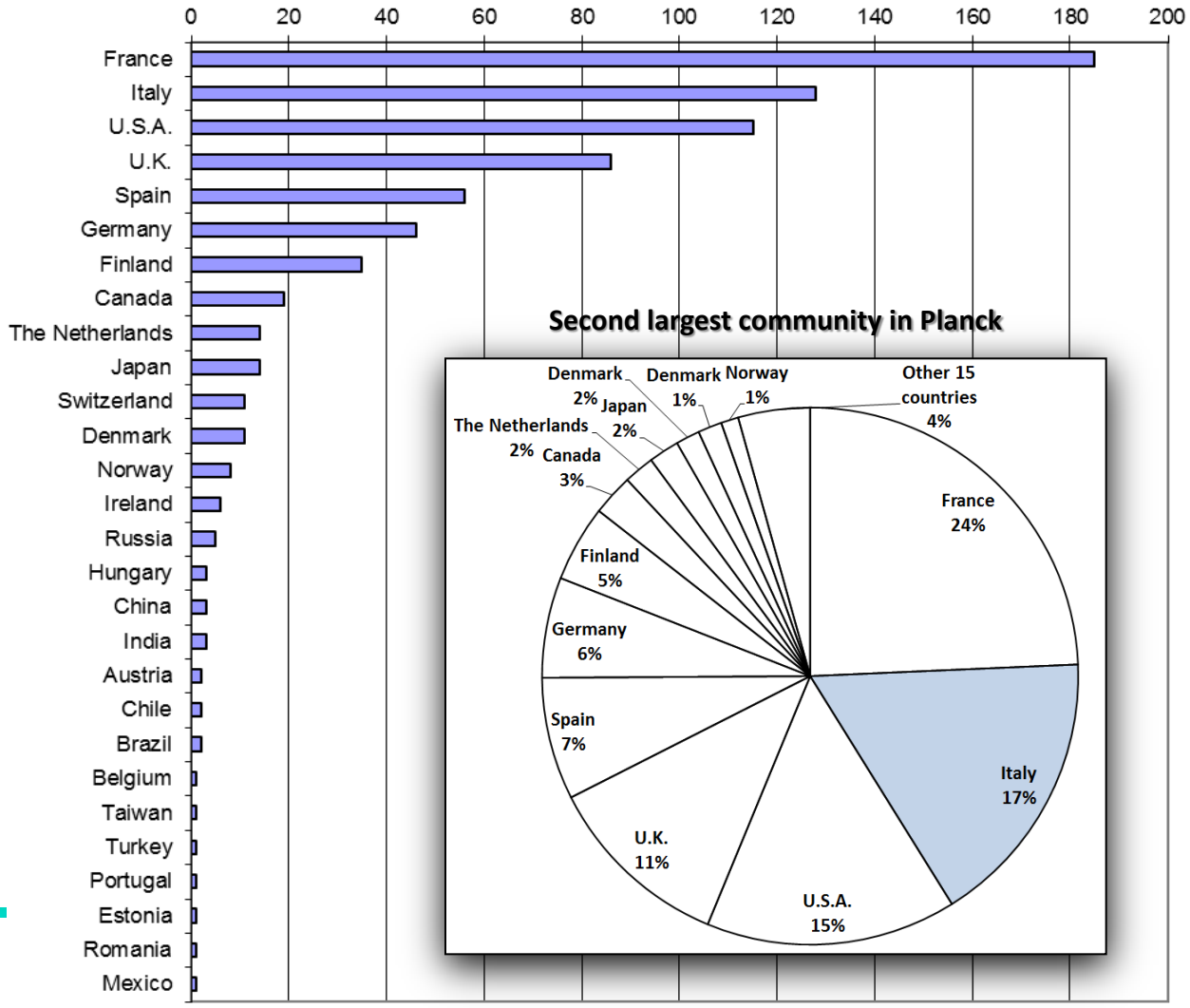
(A large fraction of the Planck CORE TEAMS are Italians)

italiana

HFI PLANCK
a look back to the birth of Universe

The Italian CMB Community

Planck – Number of authors who have co-authored at least one out of 85 submitted post-launch papers (2015)



Second largest community in Planck

The Italian CMB community

BOLOGNA
- INAF/IASF, 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/IASF 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
- SISSA, Astrophysics Sector, Trieste
- Dipartimento di Fisica, Università degli Studi di Trieste
- INAF, Osservatorio Astronomico di Trieste

All presentations given today are given on behalf of the whole Italian CMB community

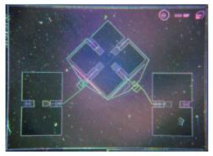
Technology developments

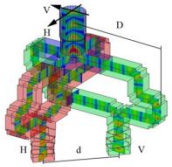
Intensive mm-wave Technology activity in Italy
ASI-funded mm-wave technology project (2010-2014)

CMB science has highly benefitted from *(and triggered new)* strategic technology in the microwaves and mm-waves

Talks by
A. Mennella,
G. Castellano,
G. Morgante,
F. Gatti

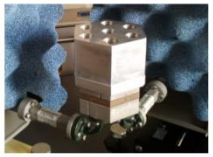
1. Passive components


Planar OMT (Q band)



Waveguide OMT (Q band)


Cluster OMT + Feed Array in Q-band

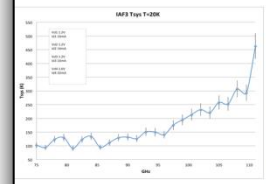

Feed+OMT array under test

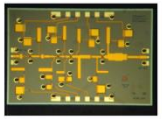
Return Loss (banda 20%)	< -30 dB
Isolamento (banda 20%)	< -45 dB
Cross-Pol	< -30 dB
Lobi laterali	

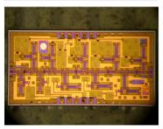
2. Coherent detectors and optics

European Technology for Cryogenic LNAs

From OMMIC and IAF

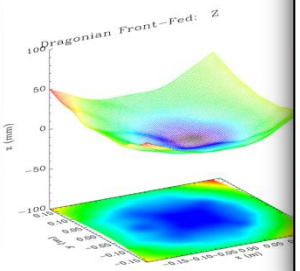






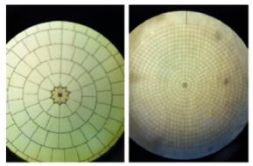

Prototype of polarized calibrator

Optimized optical systems

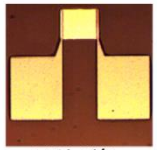


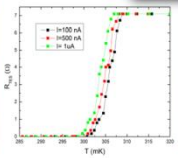
GRASP-optimized Cross-Dragone optics

3. Bolometric detectors


Spider Web Bolometer


Aluminum KIDs

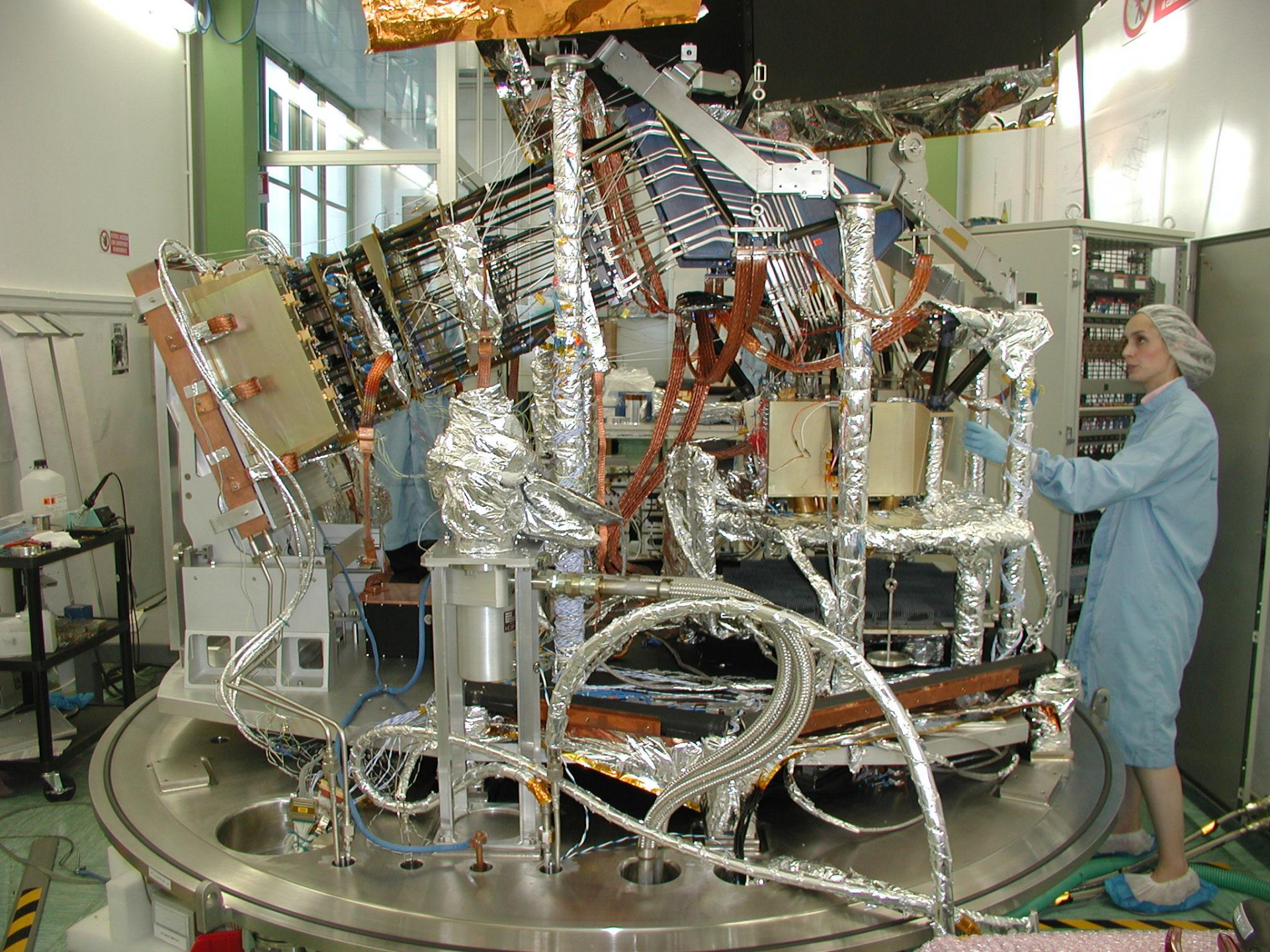

TES in Ti/Au (100 x 100 μm)


Resistance vs Temperature


Complete bolometric system
Cavity coupling optimization
Interface with electronics

Industry involvement

- CMB H/W development
- Commercial applications

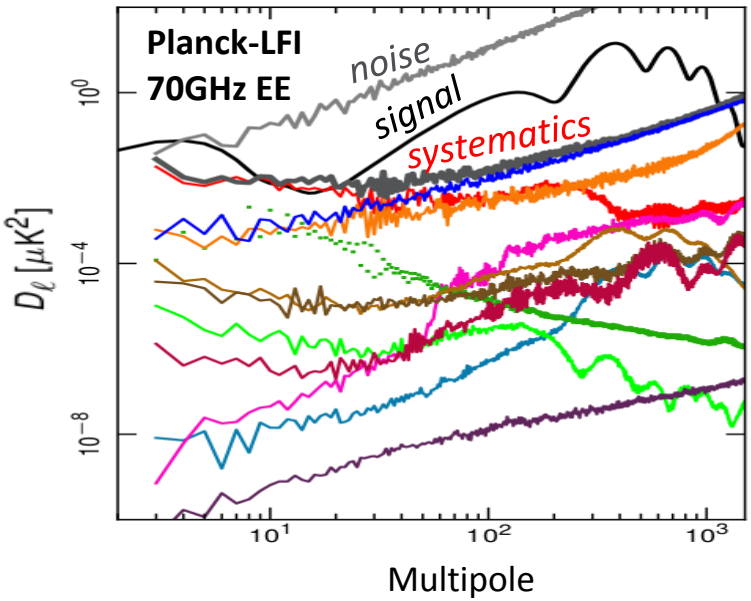


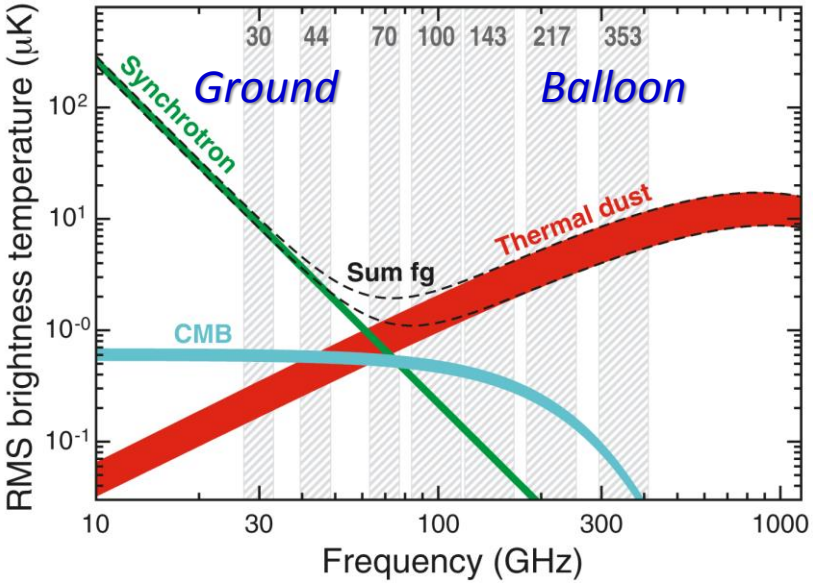
CMB polarization: Observational challenges

- WMAP and Planck were (*almost*!) noise-limited
- For Planck, this would not be the case if the sensitivity was a factor 5-10 better

Major new challenges

control *systematics* and *foregrounds* at nK level





Ground and *balloon* experiments are key preparatory/complementary stages

Ultimately *space observations* are mandatory

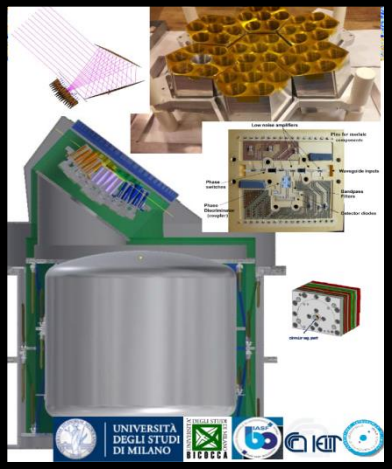
On-going ASI-funded sub-orbital experiments

LSPE
CMB B-modes

Silvia Masi's talk

STRIP

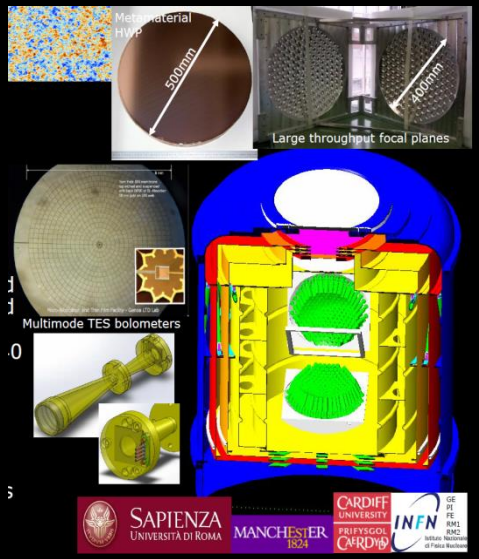
Polarimeter array
44, 90 GHz
Cooling to 20K



Ground-based option being considered

SWIPE

Bolometer array
140, 220, 240 GHz
Cooling to 0.3K



OLIMPO
SZ effect

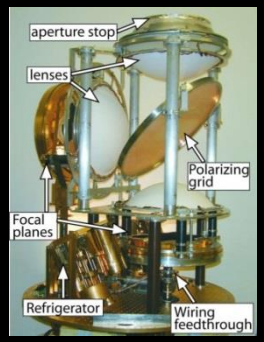
2.6m telescope
140-480 GHz
Resolution 1.8GHz

The international context is extremely competitive

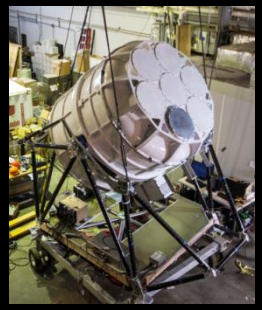
Future sub-orbital experiments:
Low resolution polarization

F. Piacentini's talk

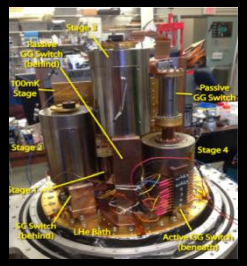
Balloon



EBEX

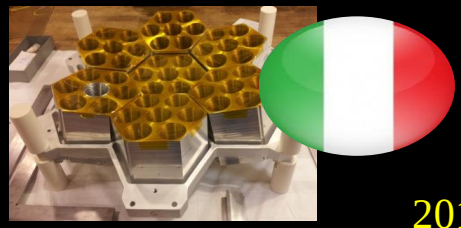


SPIDER



PIPER

LSPE



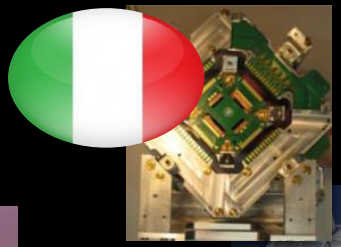
2016 2017 2018

Ground

KECK

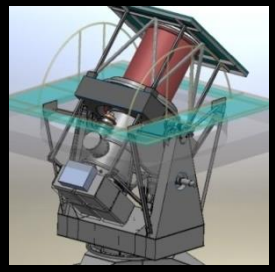
QUIJOTE

ABS



QUBIC

CLASS



BICEP3

Future sub-orbital experiments:
High resolution

F. Piacentini's talk

Balloon

OLIMPO
(T only)

2016 2017 2018

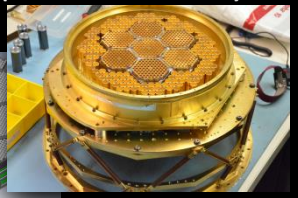
Ground

Polarbear-I
(1280 dets)

Simons Array/PB3
(~20,000 dets, 3 tel.)

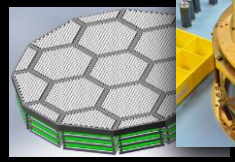
ACTPol
(3000 dets)

Advanced ACTPol
(~16,000 dets)



SPTPol
(~1000 feeds)

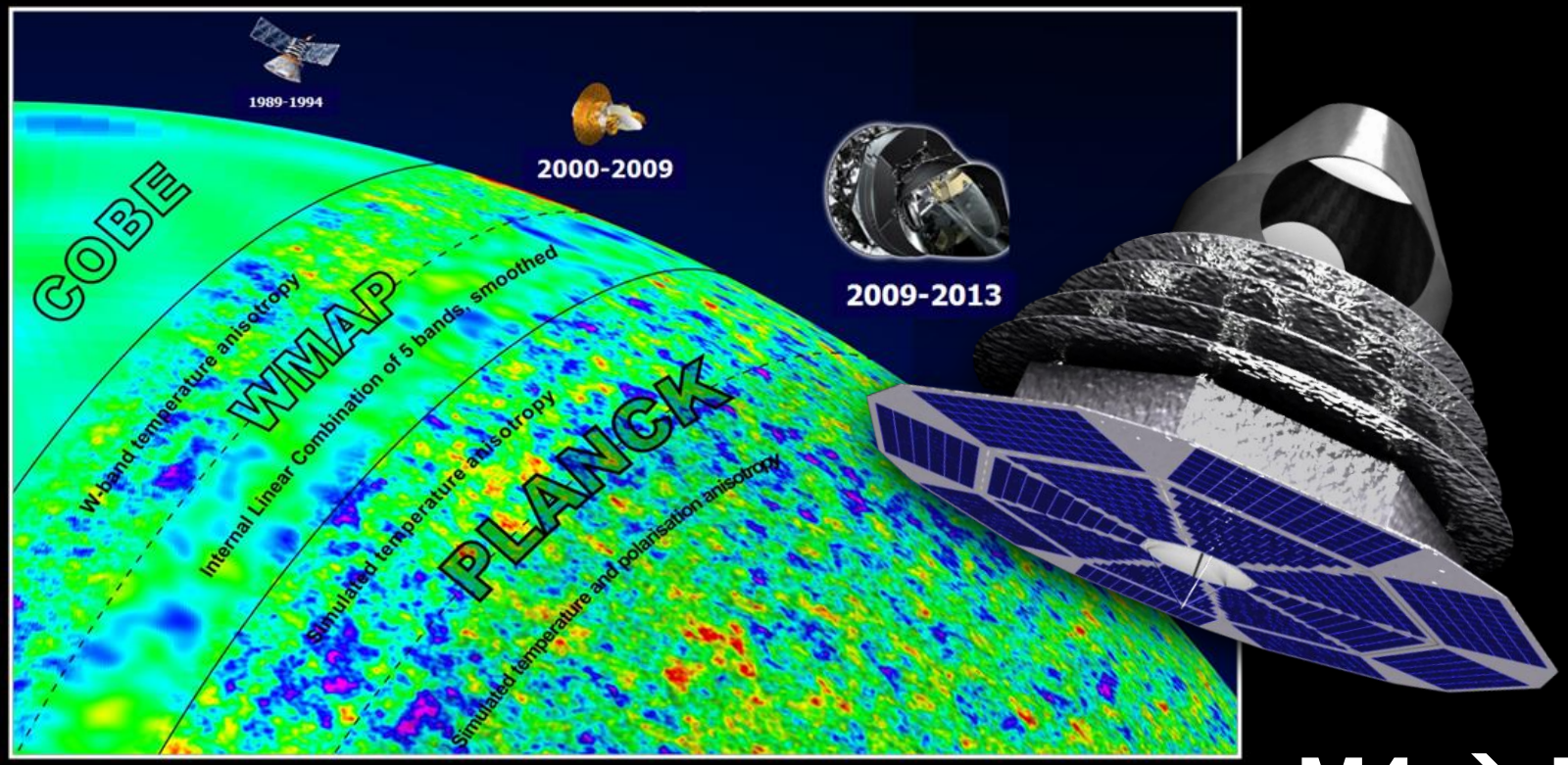
SPT 3G
(~15,000 dets)



COrE

P. De Bernardis talk

Fourth generation CMB space mission



M4 → M5

Data analysis

Future data analysis will impose new challenges

- Likelihood analysis with detailed treatment of systematics
- Large MC simulations (computational resources)
- High precision component separation (in polarization)
- Combining different data sets

Top-level expertise gained by the Italian Community

Talks by C. Baccigalupi, P. Natoli, G. Polenta

Synergy with other data sets

- Cross-correlations of CMB data with Large Scale Structure data sets (*on-going WG within Euclid Consortium*)
- JWST observations of first galaxies complemented by Re-ionization constraints from EE CMB (*Tau parameter*)
- X-ray observations with CMB SZ data provide powerful probes to the physics of clusters, as well as cosmology
- SKA, ALMA, …

CONCLUSIONS (1/2)

The scientific potential of CMB studies is far from being completed

- *Frontier of Cosmology: probing inflation with precision CMB polarization measurements*
- *Astrophysics and fundamental physics*
- *Synergy with other large data bases*

The Italian CMB community has a leading role

- *It is crucial to maintain and further develop such great heritage*
- *Human expertise requires continuity!*

The international competition is very high

- *The Italian community is ready to take the challenge*

The support and involvement of ASI is crucial

CONCLUSIONS (2/2)

We wish to propose a roadmap, to be discussed with ASI:

1. Completion of the ongoing ASI-funded missions LSPE and OLIMPO in the short term (2016-2020);

2. Strong support aimed at the acquisition of a leading role of Italy in the forthcoming CMB satellite mission of ESA/M5;

3. Strong support, in coordination with INAF and INFN, to Italian participation to ground-based CMB experiments, preparatory and complementary to space;

4. Definition of a pre-phase A study for a polarimetric stratospheric balloon in the medium timescale (2020-2025), to complement ground based Stage-IV .

Other key issues:

- *Data archiving and maintenance of CMB data (Planck, and more)*
- *Technological development, industry involvement, commercial applications*
- *High-level education: PhD, post docs, young researchers*