



Beyond Planck: a new generation of CMB polarization experiments

Maurizio Tomasi

Congresso del Dipartimento di Fisica

June, 28th 2017

CMB cosmology group @ UniMI



Marco
Bersanelli
(P. O.)



Aniello
Mennella
(P. A.)



Davide
Maino
(P. A.)



Cristian
Franceschet
(Assegnista)



Maurizio
Tomasi
(RTD)



Jacopo
Martelli
(Assegnista)



Antonino
Troja
(P.h.D. student)

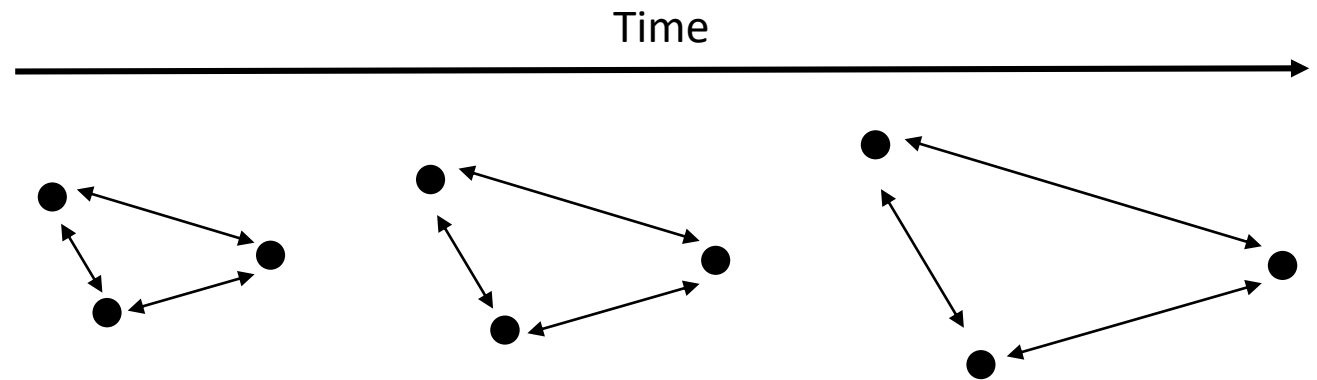


Sabrina
Realini
(Borsista)

What are B-modes?

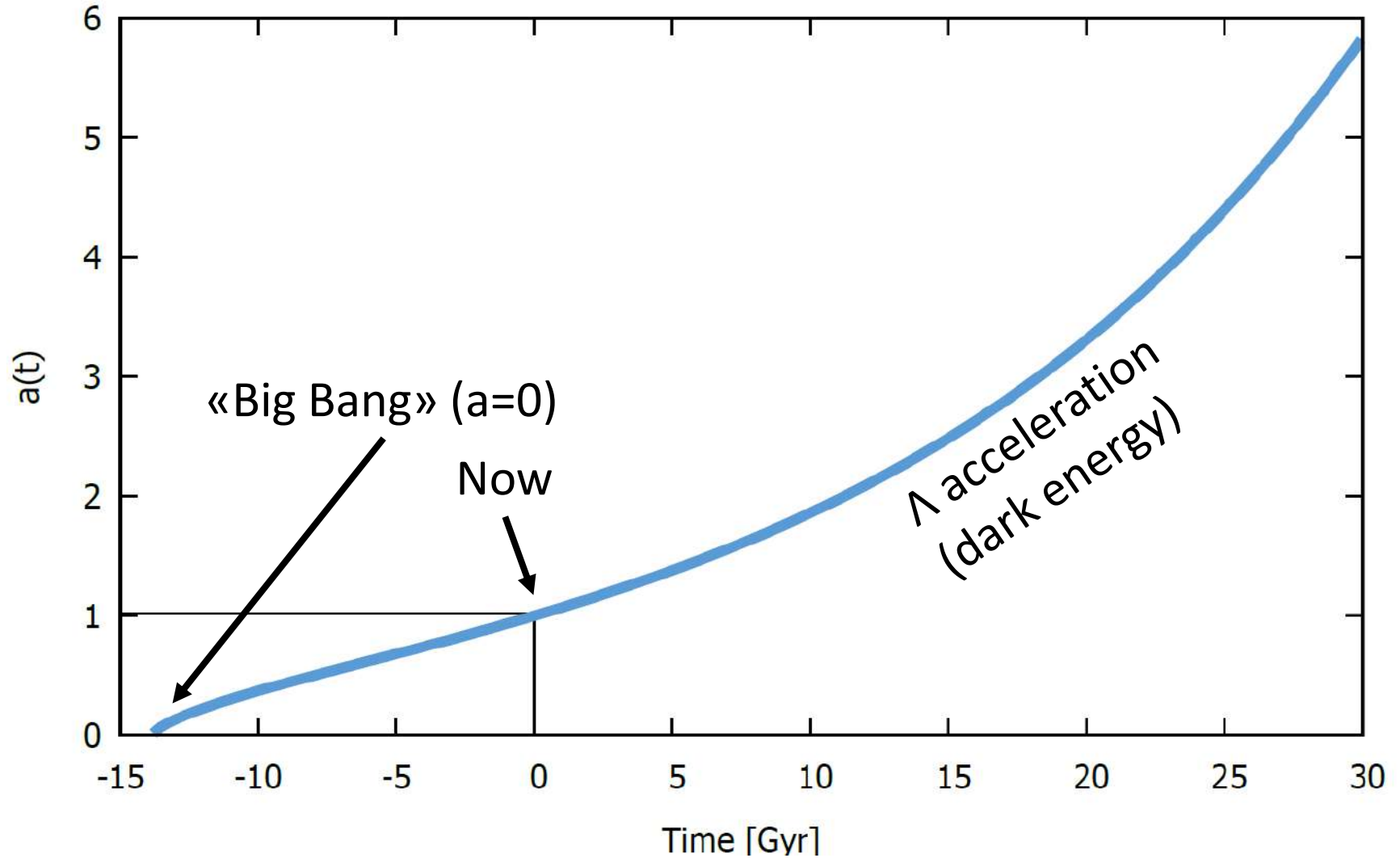
And why are they important?

Friedmann-Lemaître expansion

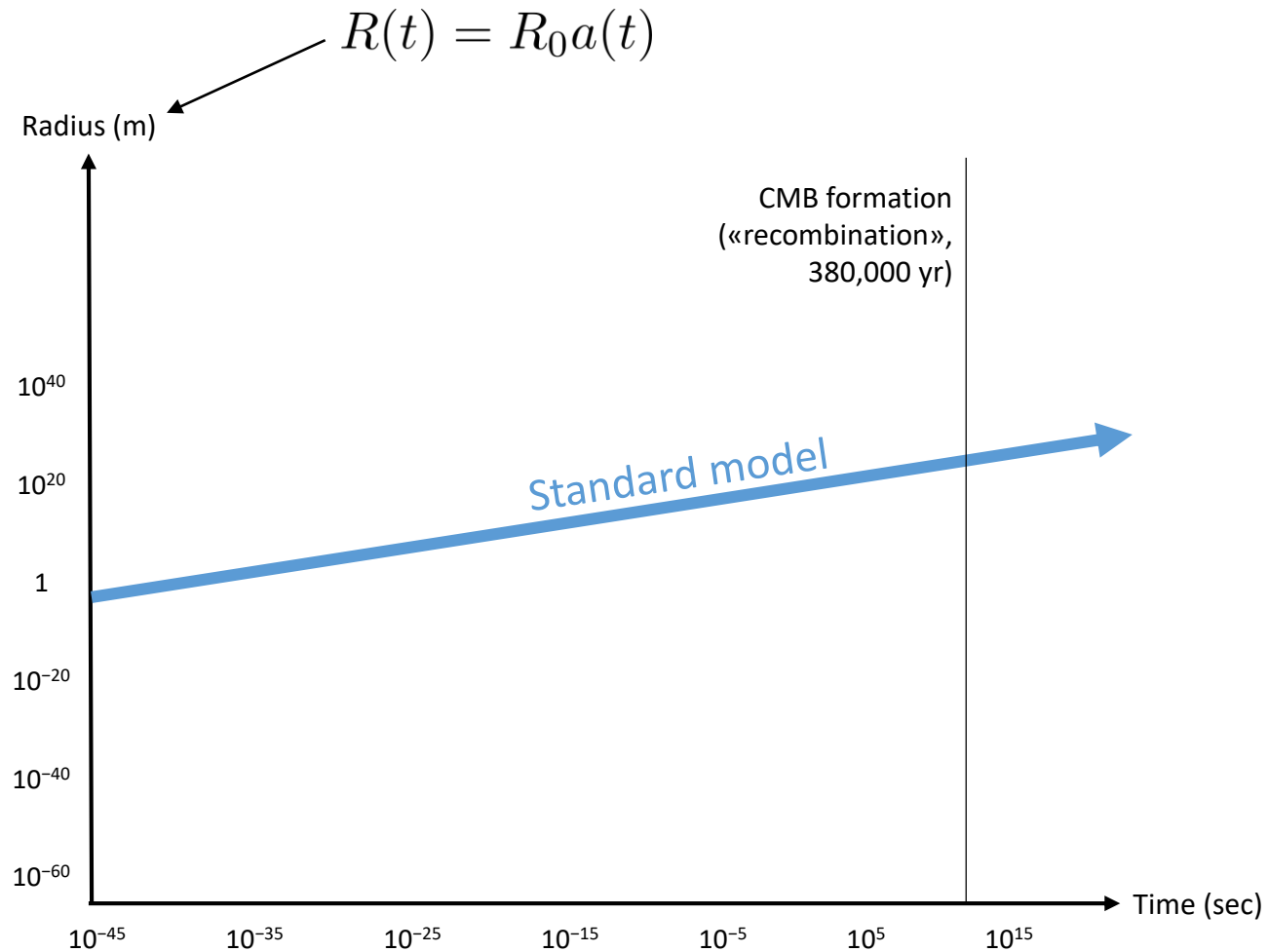


$$d(t) = a(t)R_0$$

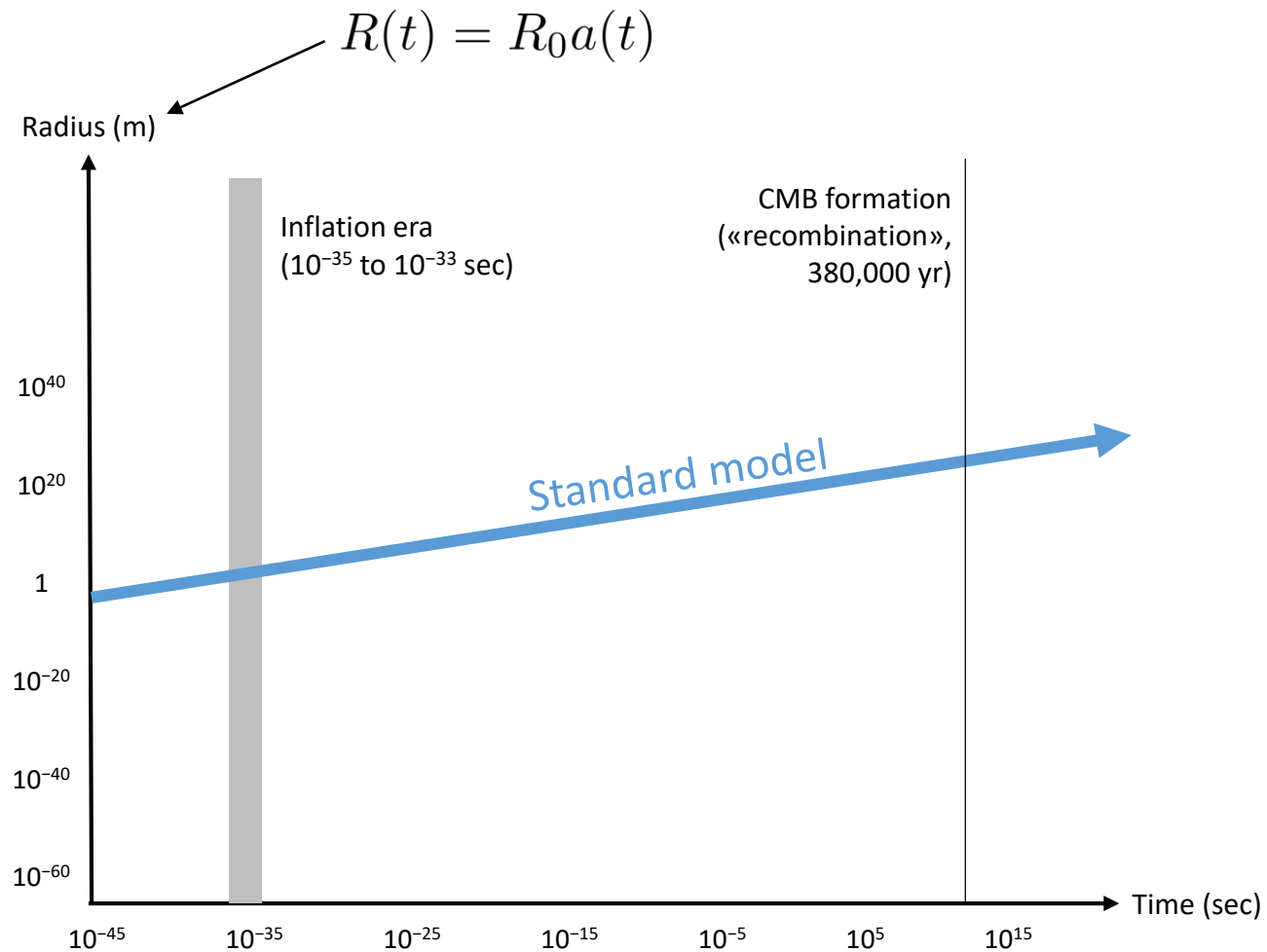
Friedmann-Lemaître expansion



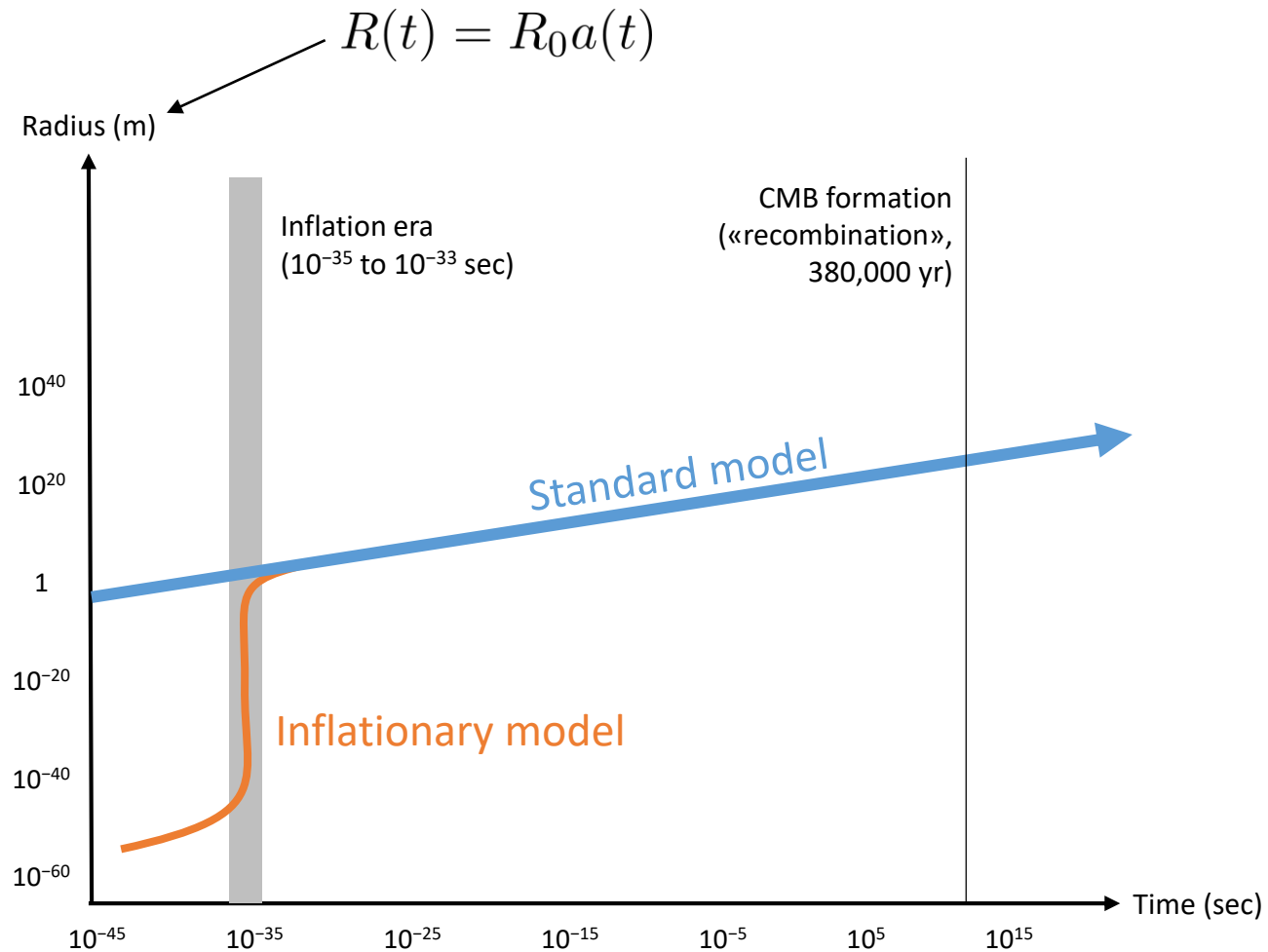
Cosmic inflation ($t \rightarrow 0$)



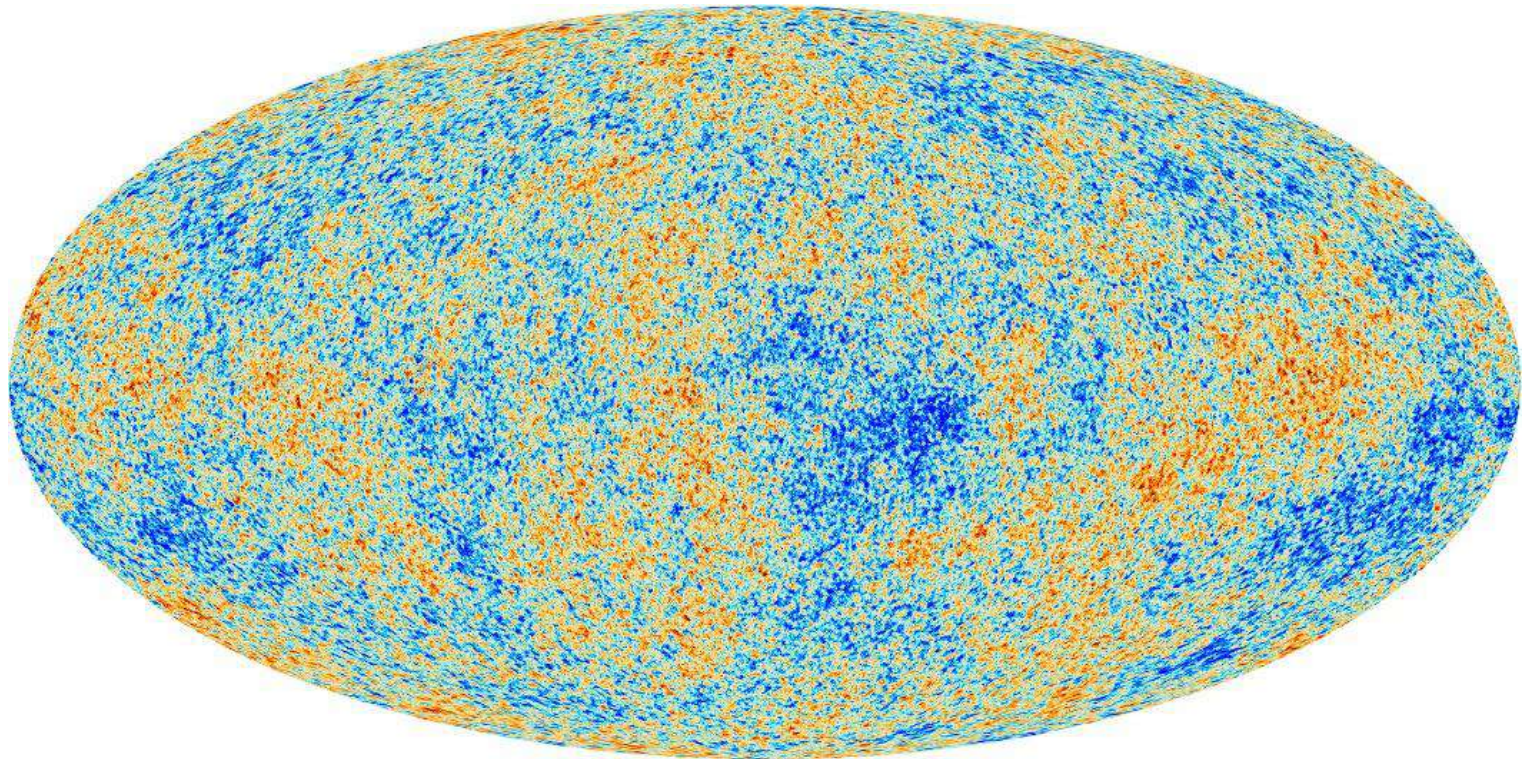
Cosmic inflation ($t \rightarrow 0$)



Cosmic inflation ($t \rightarrow 0$)

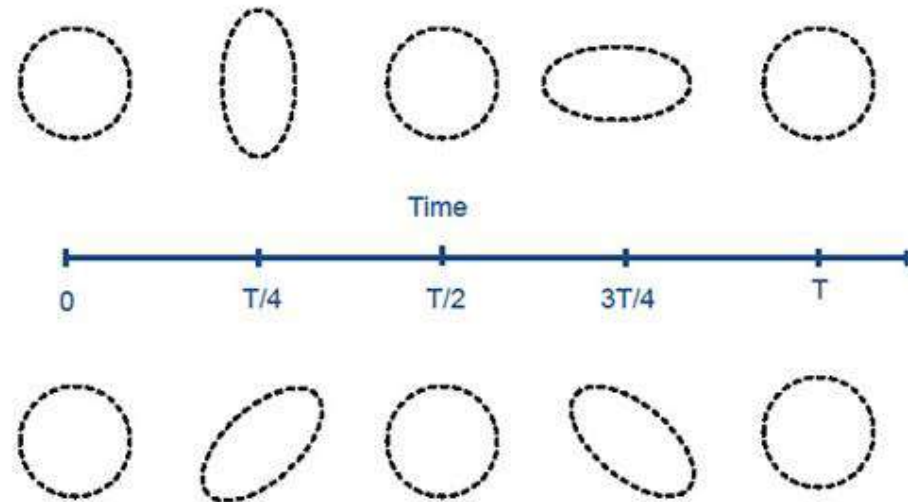


Temperature anisotropies in the CMB



- Spots with amplitude 10^{-5} K in the CMB
- Trace density fluctuations in the primordial plasma at recombination
- Pre-inflationary quantum fluctuations inflated to cosmological scales (?)

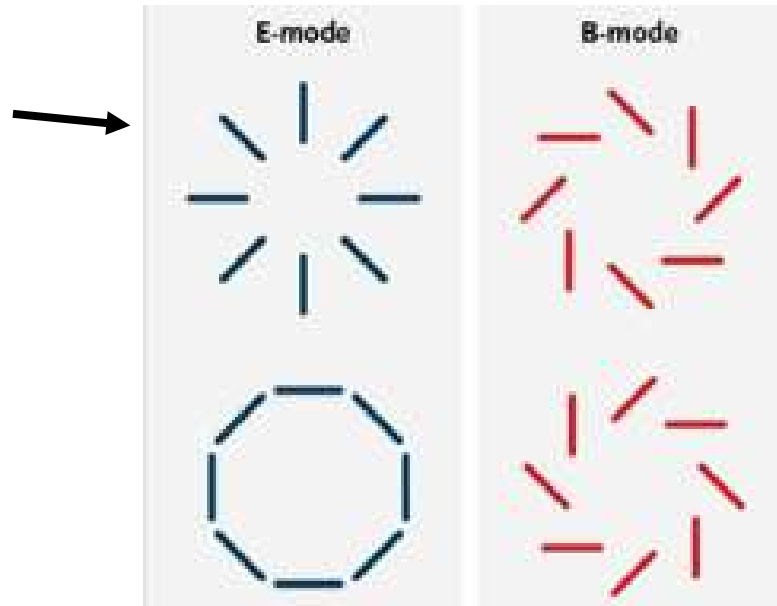
Metric fluctuations



- Primordial metric fluctuations should have produced a GW background.
- Inprint in the CMB polarization spectrum.
- Amplitude directly related to the energy scale of inflation!

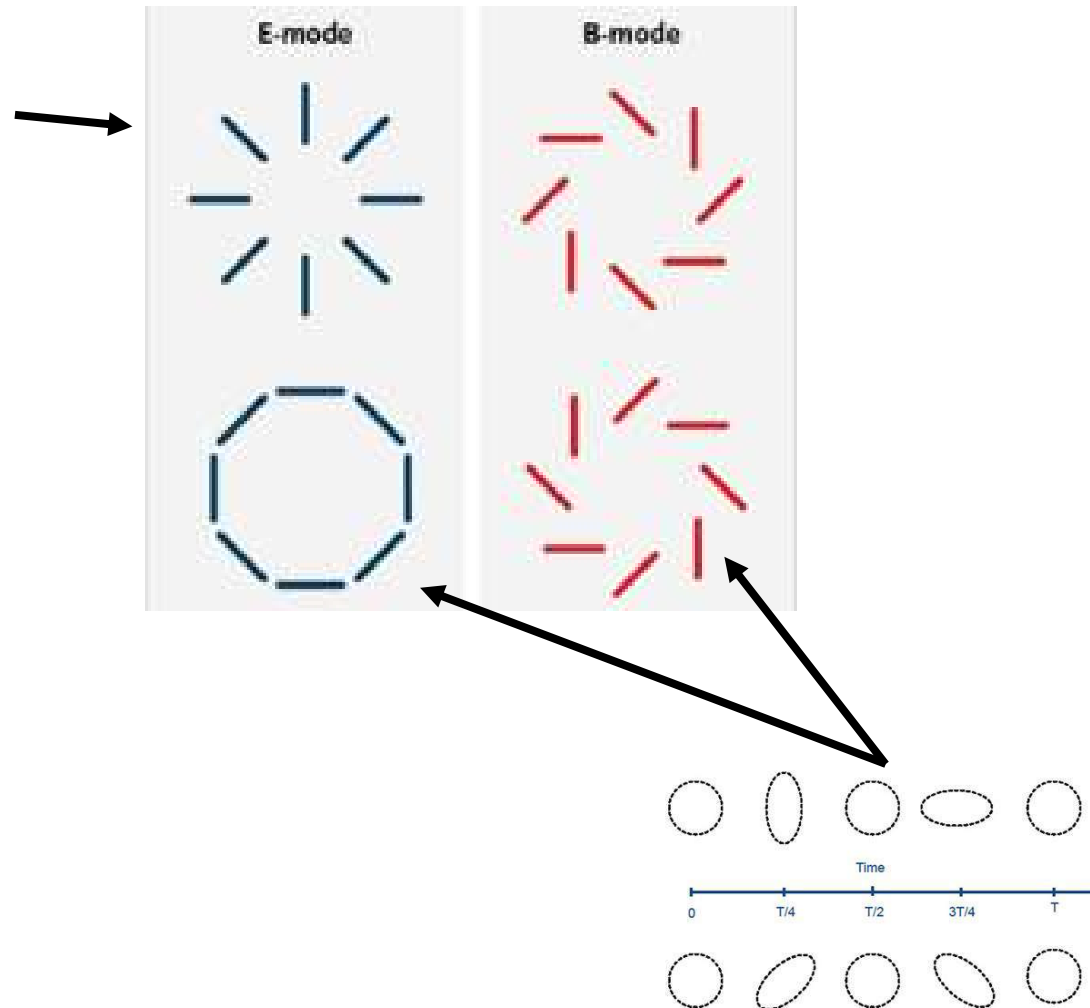
Detecting metric fluctuations in the CMB

CMB polarization pattern is decomposed into



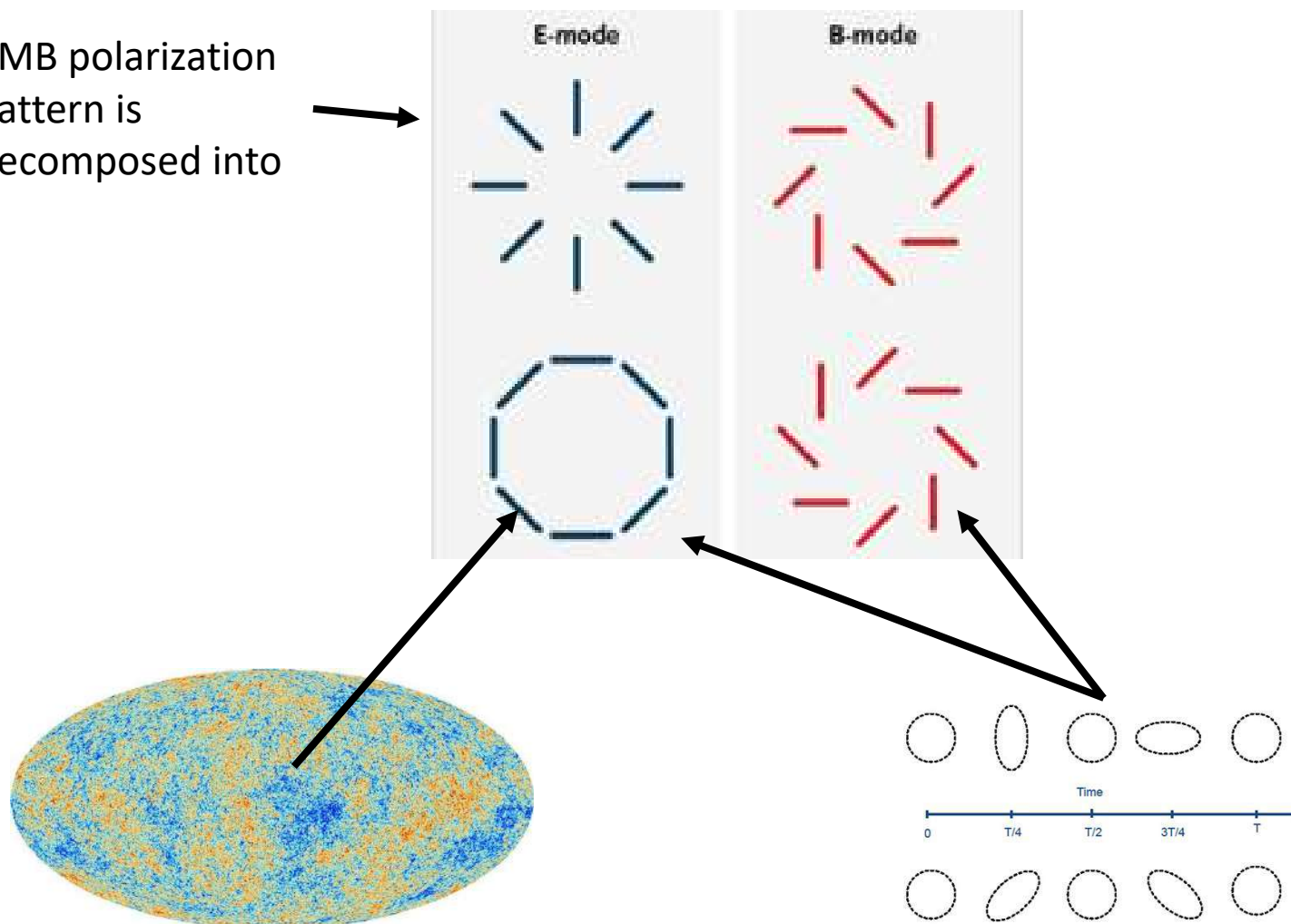
Detecting metric fluctuations in the CMB

CMB polarization pattern is decomposed into

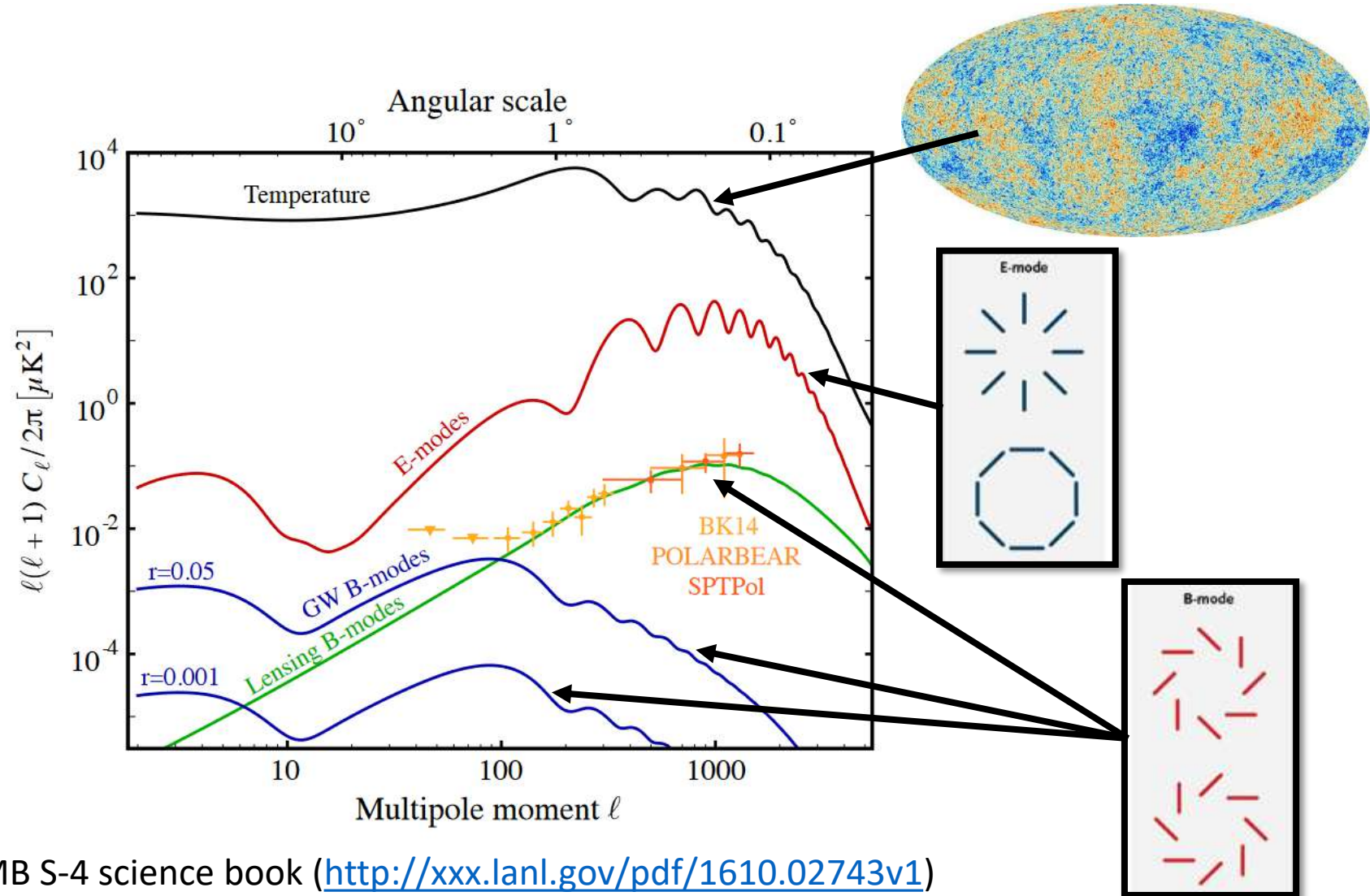


Detecting metric fluctuations in the CMB

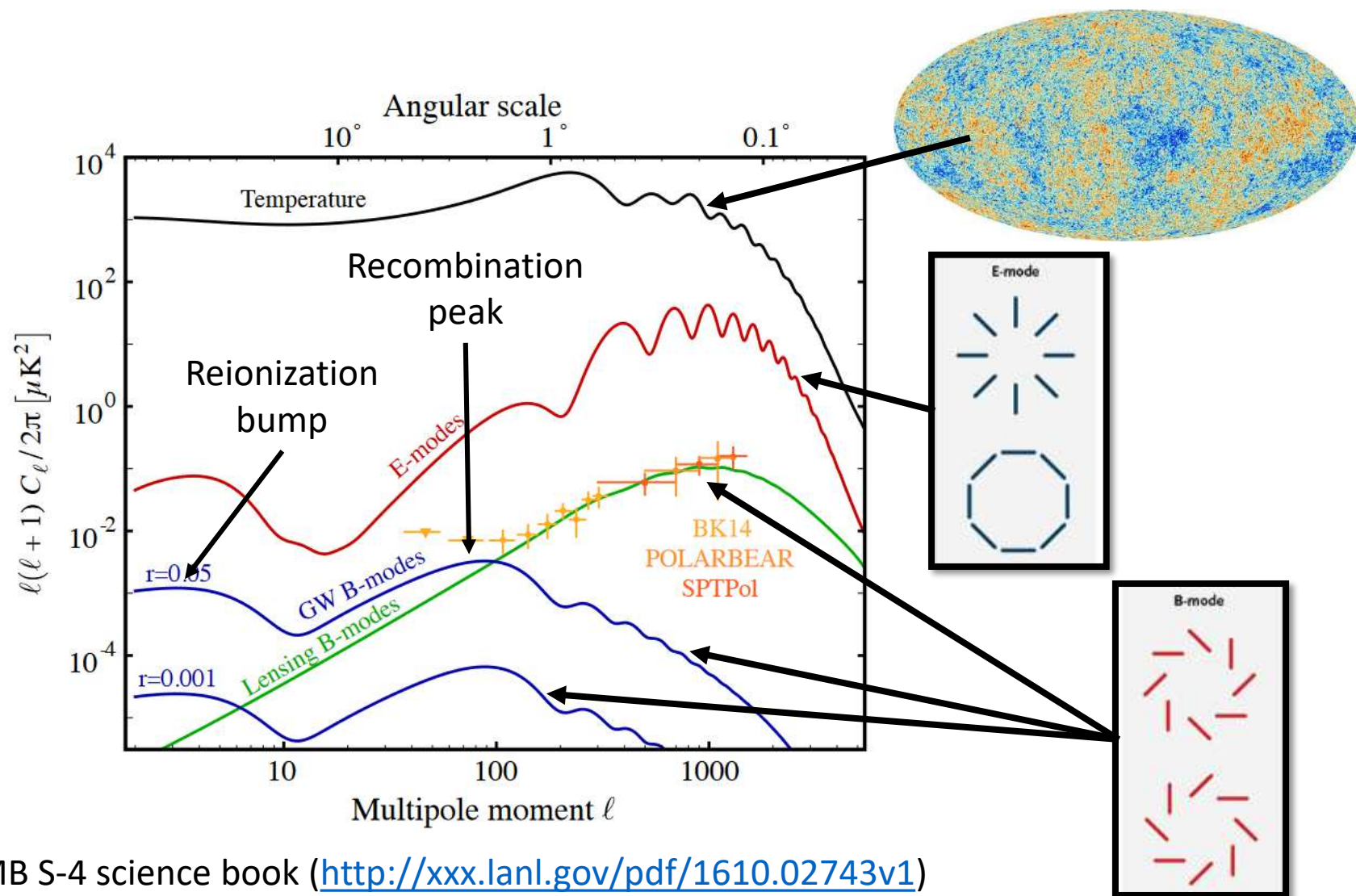
CMB polarization pattern is decomposed into



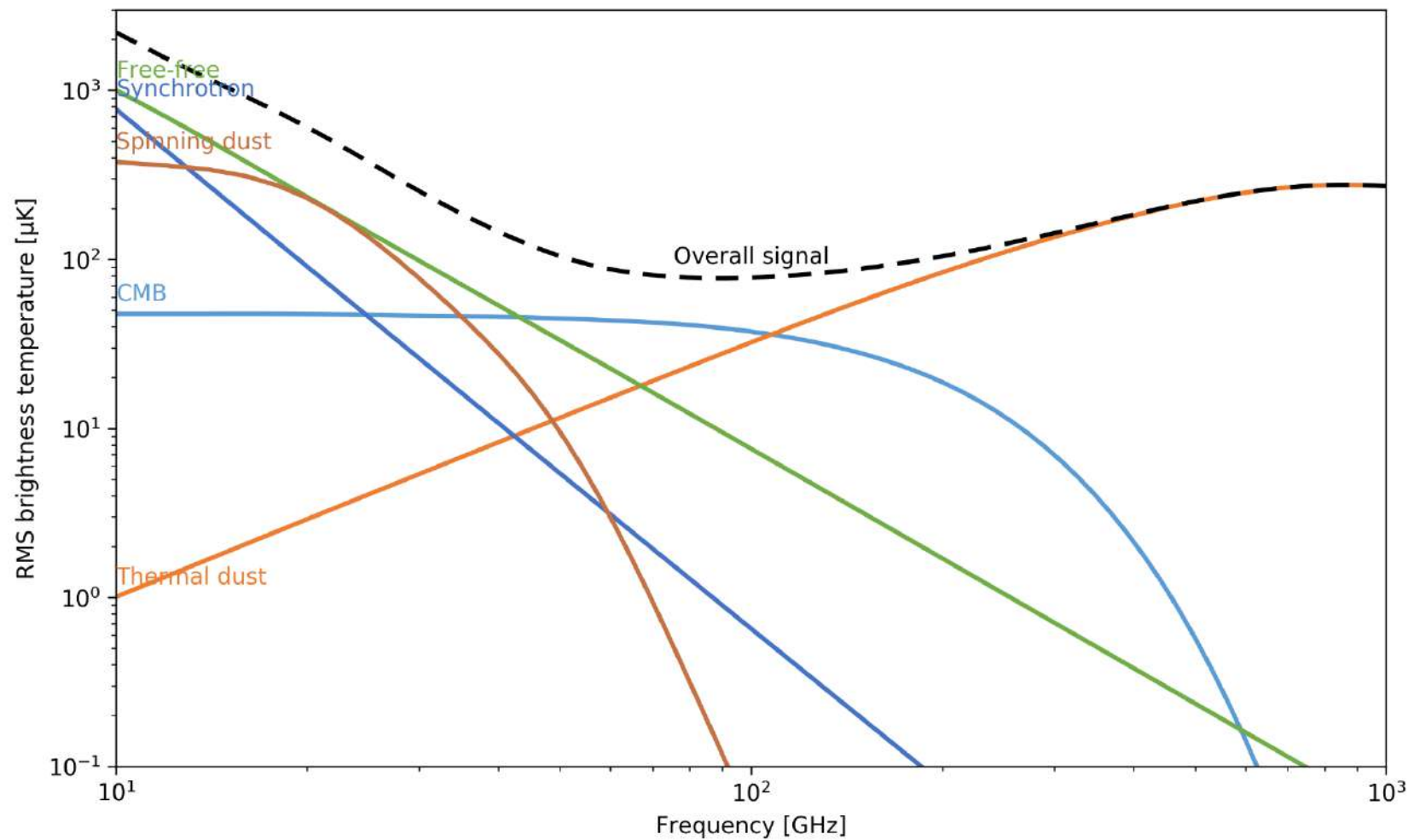
Detecting metric fluctuations in the CMB



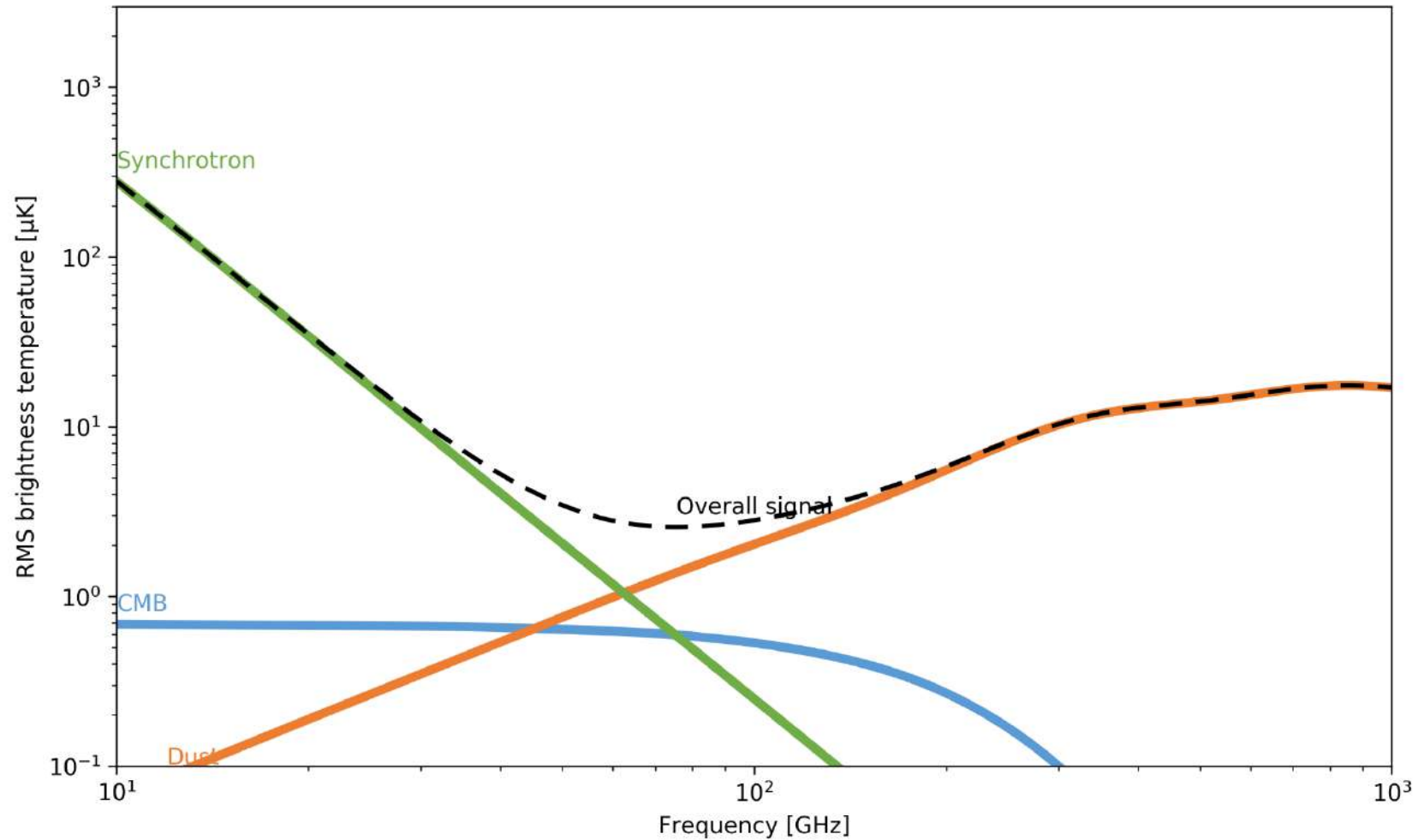
Detecting metric fluctuations in the CMB



CMB and «foregrounds» (intensity)

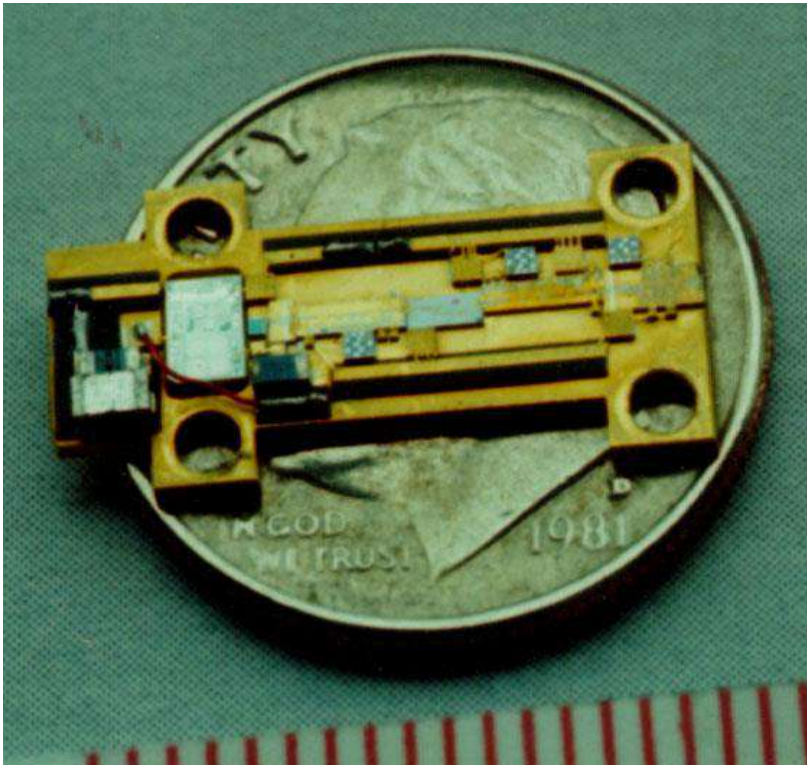


CMB and «foregrounds» (polarization)

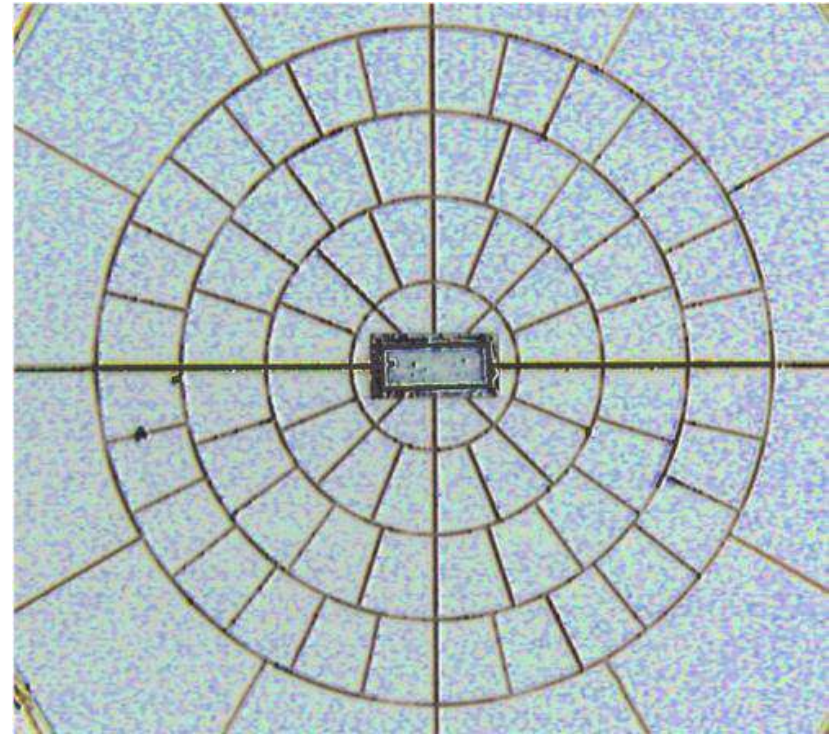


Detectors in the 10–1000 GHz range

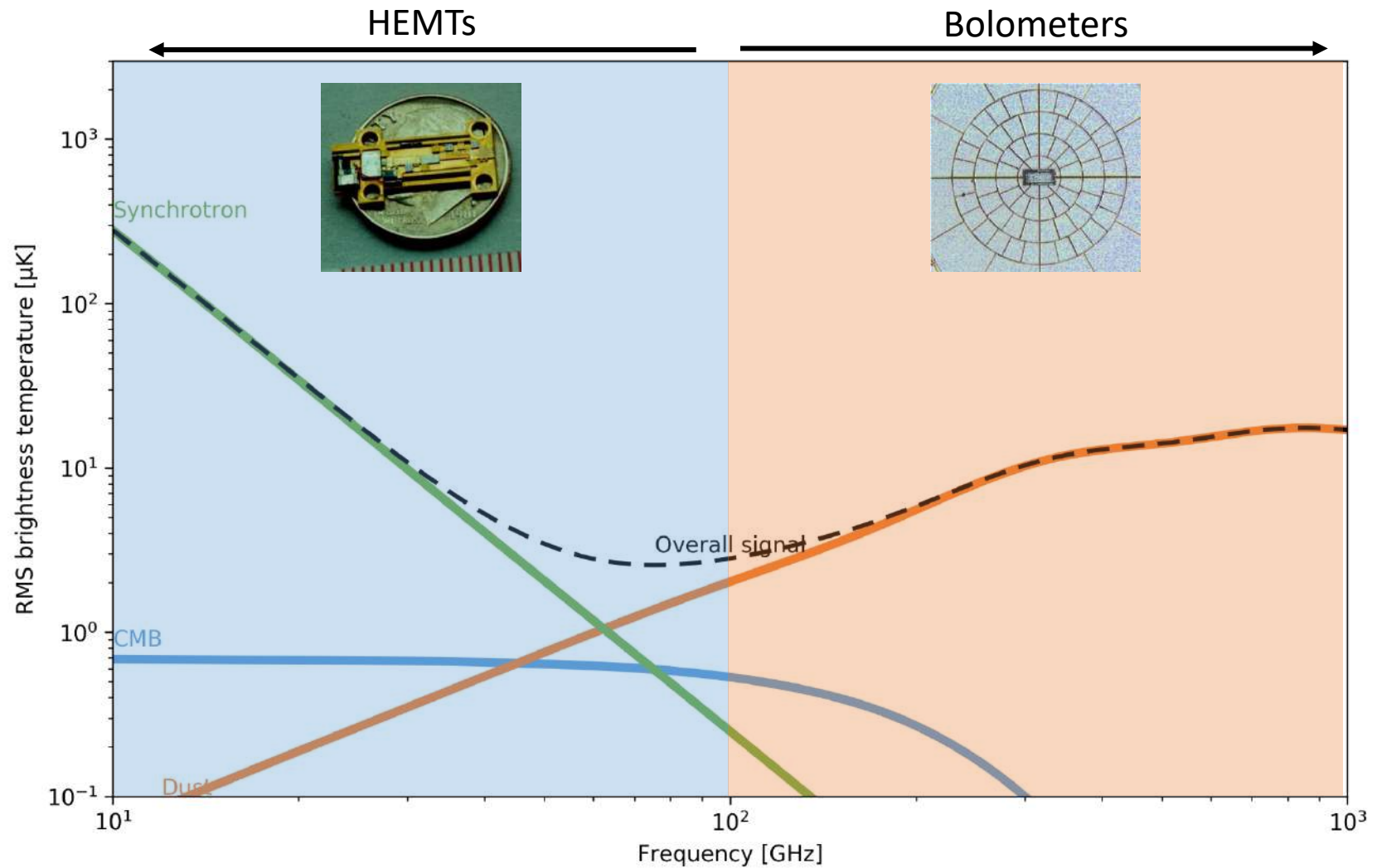
High Electron Mobility Transistors (HEMTs)



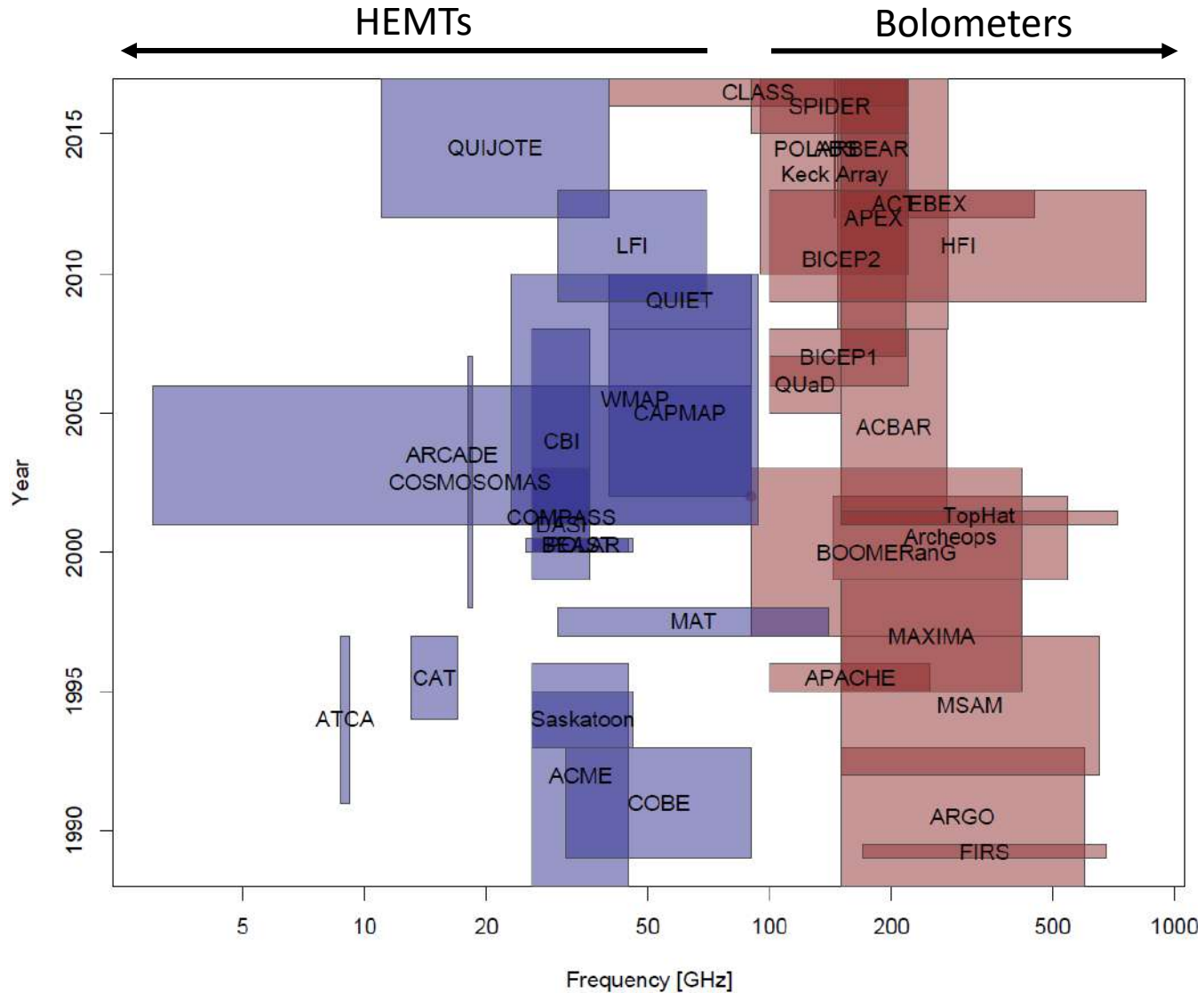
Transition Edge Sensor (TES) bolometer



Detectors in the 10–1000 GHz range

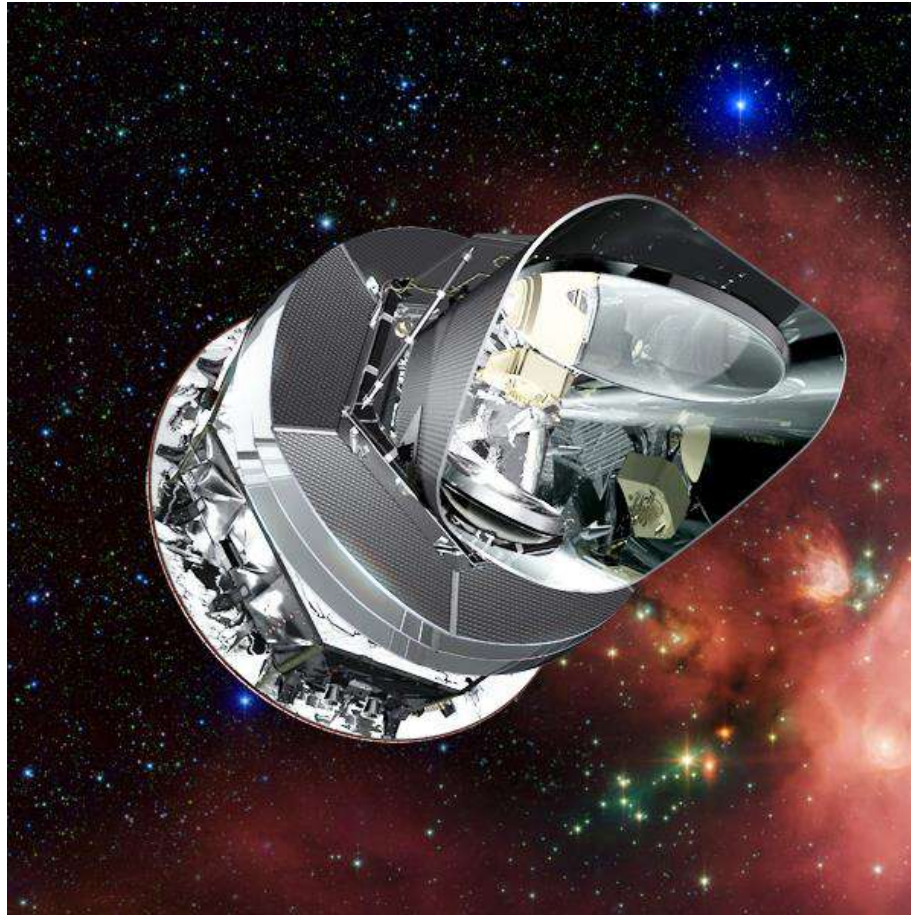


Past CMB experiments

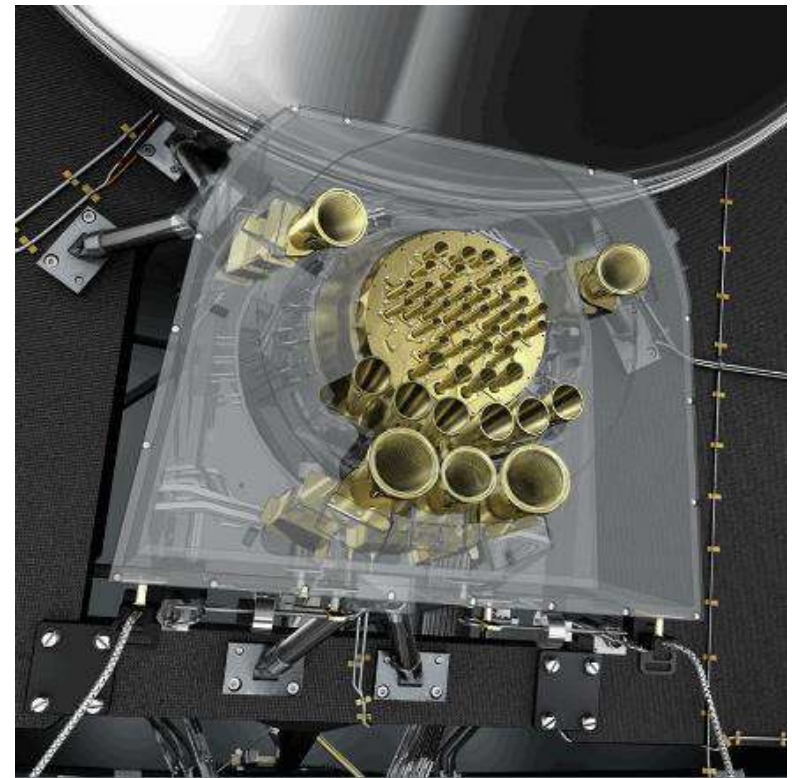


The breakthrough of Planck

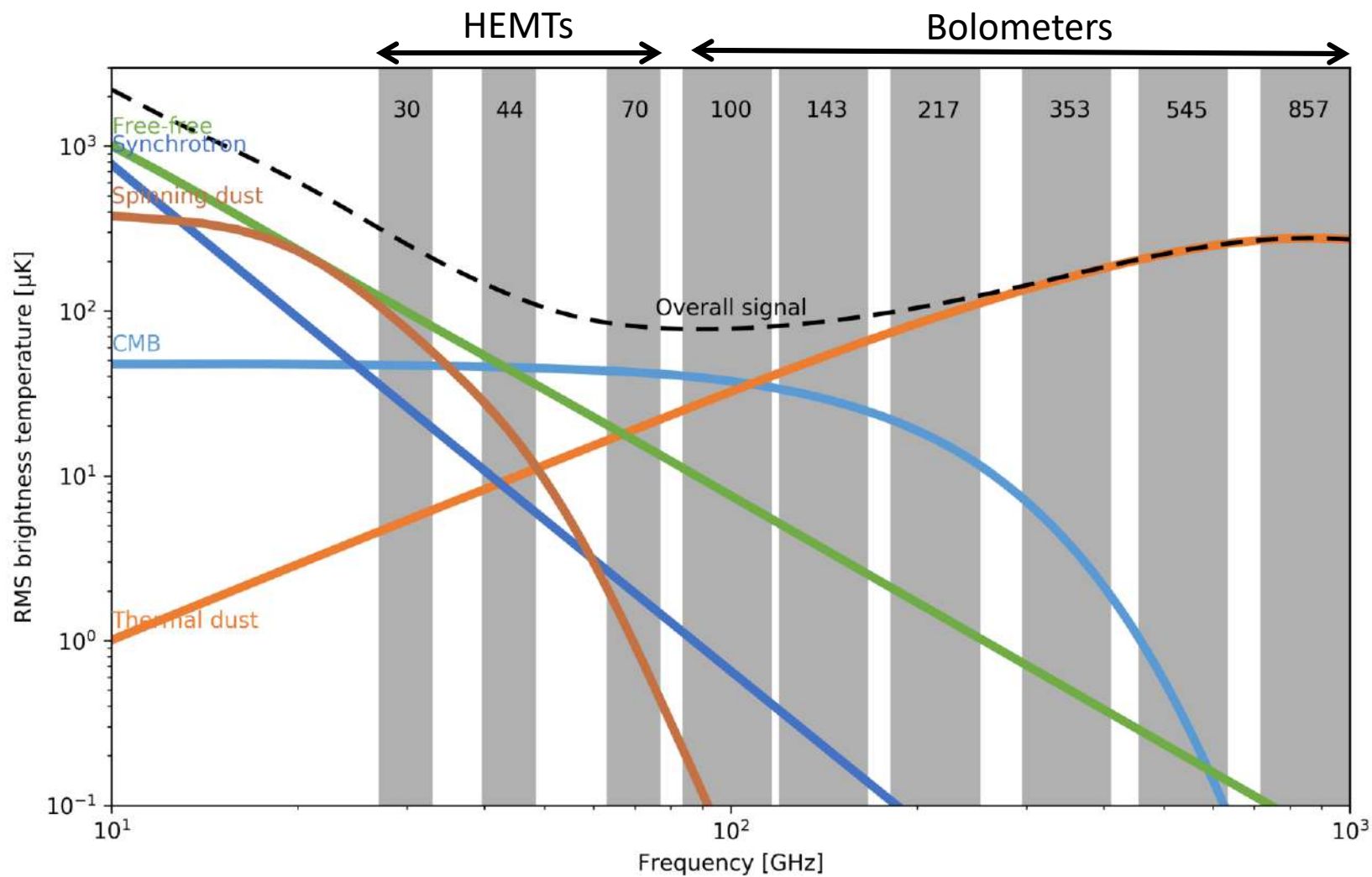
Planck (2009–2013, ESA)



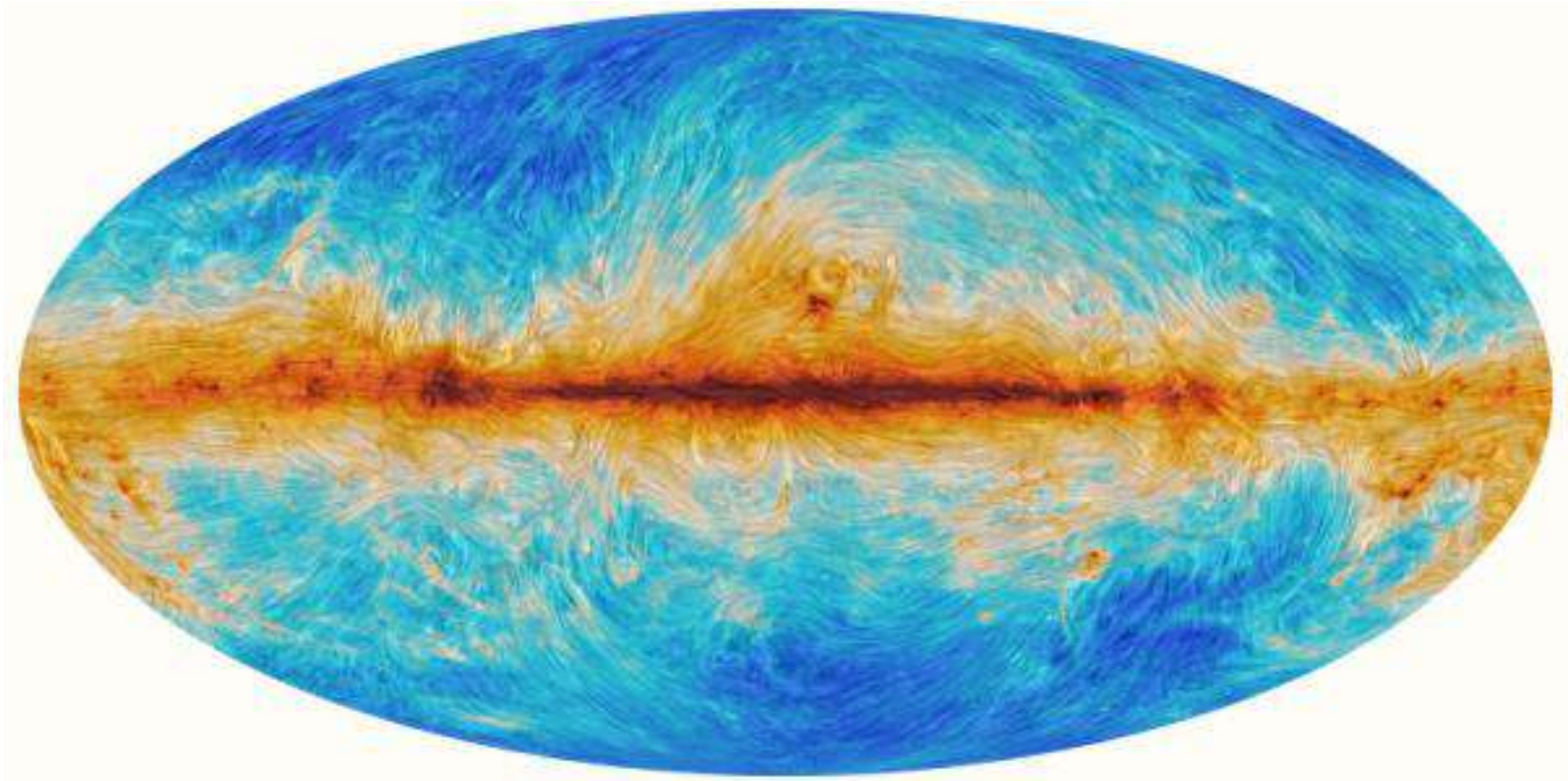
11+36 horns, 22+52 detectors



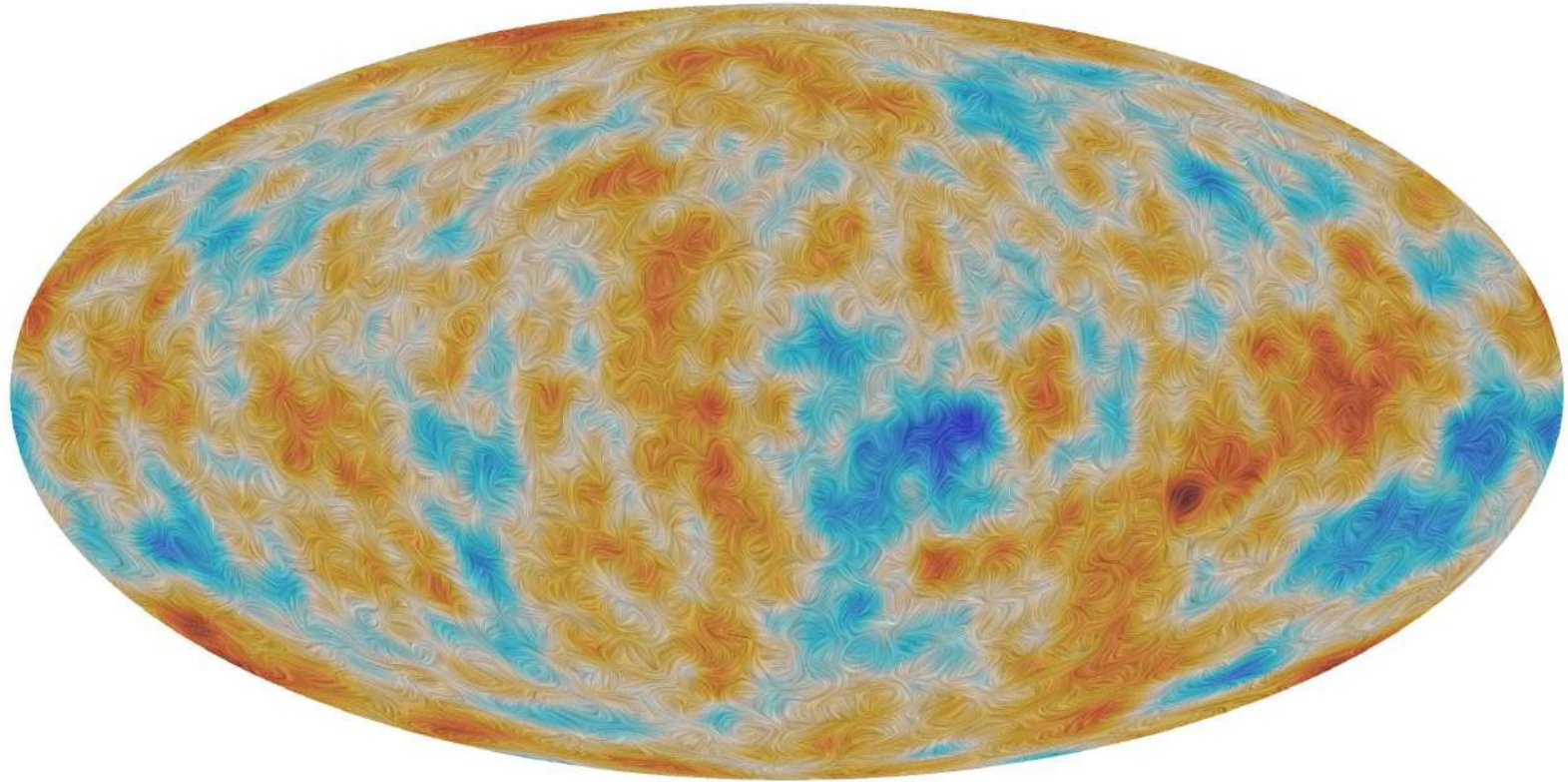
Planck frequency coverage



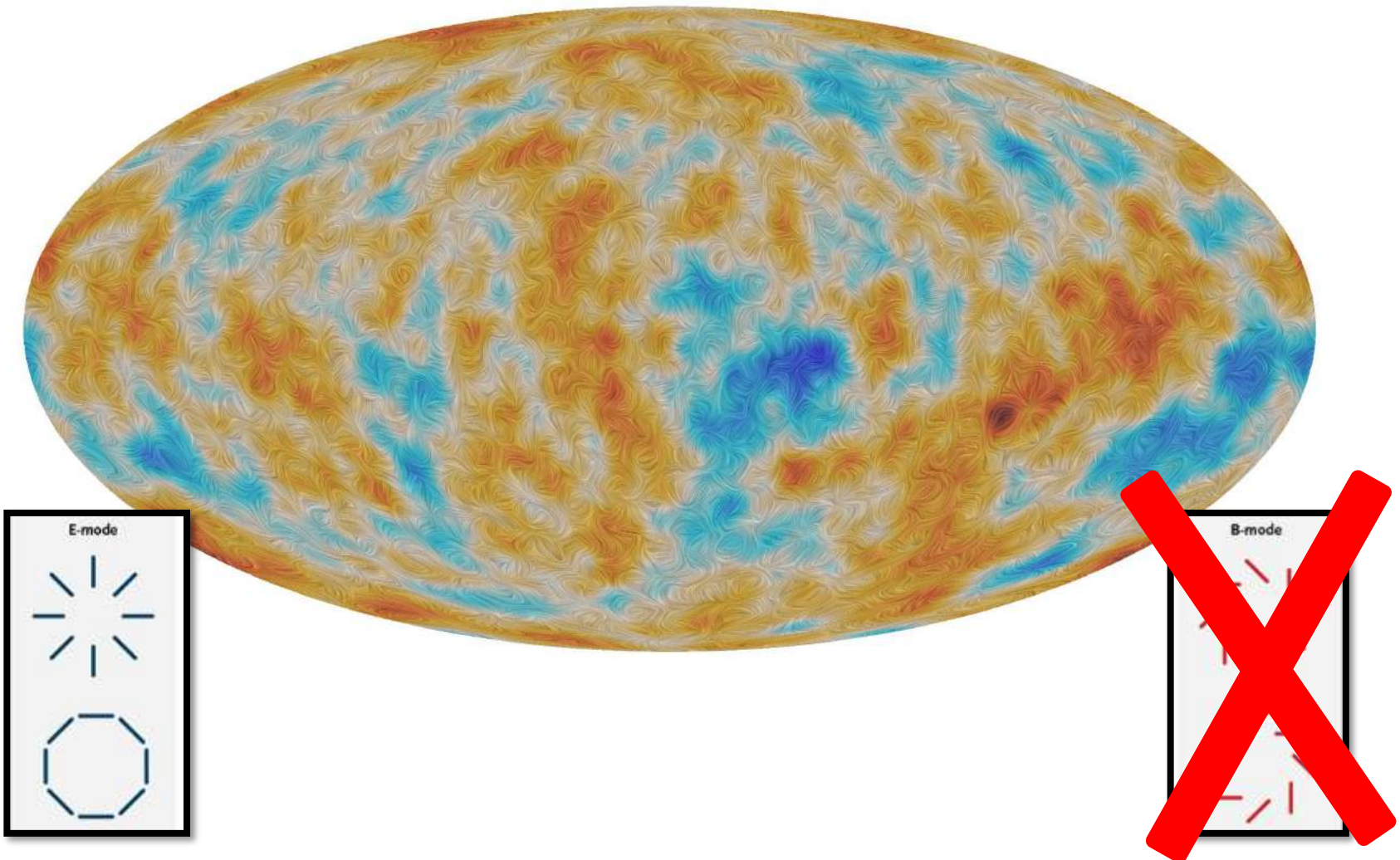
Planck polarization maps



Planck polarization maps



Planck polarization maps



Future experiments

What do we need to detect B-modes?

- Signal is weak ($\lesssim 1 \mu\text{K}$)
 - many detectors (up to 10^5), good control of systematics
- Polarized foregrounds not well known
 - broad frequency coverage

What do we need to detect B-modes?

- Signal is weak ($\lesssim 1 \mu\text{K}$)
 - many detectors (up to 10^5), good control of systematics
- Polarized foregrounds not well known
 - broad frequency coverage

Promising paths:

- New kinds of broadband detectors with very small size (KIDs)
- Large arrays of feed horns (platelet horns, see e.g. LSPE & QUBIC)
- New designs to properly control systematics (QUBIC)

Hunting B-modes: a lot of competition!

Name	Years	Frequency range	Technology
ACTPol	2014-	90, 146, 875	Bolometers
POLARBEAR	2012-	150	TES bolometers
Simons Array	Future	90, 150, 220, 280	TES Bolometers
CLASS	2016-	38, 95, 147, 217	TES bolometers
ABS	2011-	145	Bolometers
SPTpol	2012-	95, 150	TES bolometers
BICEP2	2014-	95	TES bolometers
KECK	2010-	35, 270	TES bolometers
QUIJOTE	2012-	11, 13, 17, 19, 30	HEMT
LSPE	Future	40, 90, 150, 220, 240	HEMT, TES bolometers
GroundBIRD	Future	145, 220	MKIDs
QUBIC	Future	97, 150, 230	Bolometric interferometer
C-BASS	2015-	5	HEMT
B-Machine COFE	2002-	10, 40	HEMT

Hunting B-modes: a lot of competition!

Name	Years	Frequency range	Technology
ACTPol	2014-	90, 146, 875	Bolometers
POLARBEAR	2012-	150	TES bolometers
Simons Array	Future	90, 150, 220, 280	TES Bolometers
CLASS	2016-	38, 95, 147, 217	TES bolometers
ABS	2011-	145	Bolometers
SPTpol	2012-	95, 150	TES bolometers
BICEP2	2014-	95	TES bolometers
KECK	2010-	35, 270	TES bolometers
QUIJOTE	2012-	11, 13, 17, 19, 30	HEMT
LSPE	Future	40, 90, 150, 220, 240	HEMT, TES bolometers
GroundBIRD	Future	145, 220	MKIDs
QUBIC	Future	97, 150, 230	Bolometric interferometer
C-BASS	2015-	5	HEMT
B-Machine COFE	2002-	10, 40	HEMT

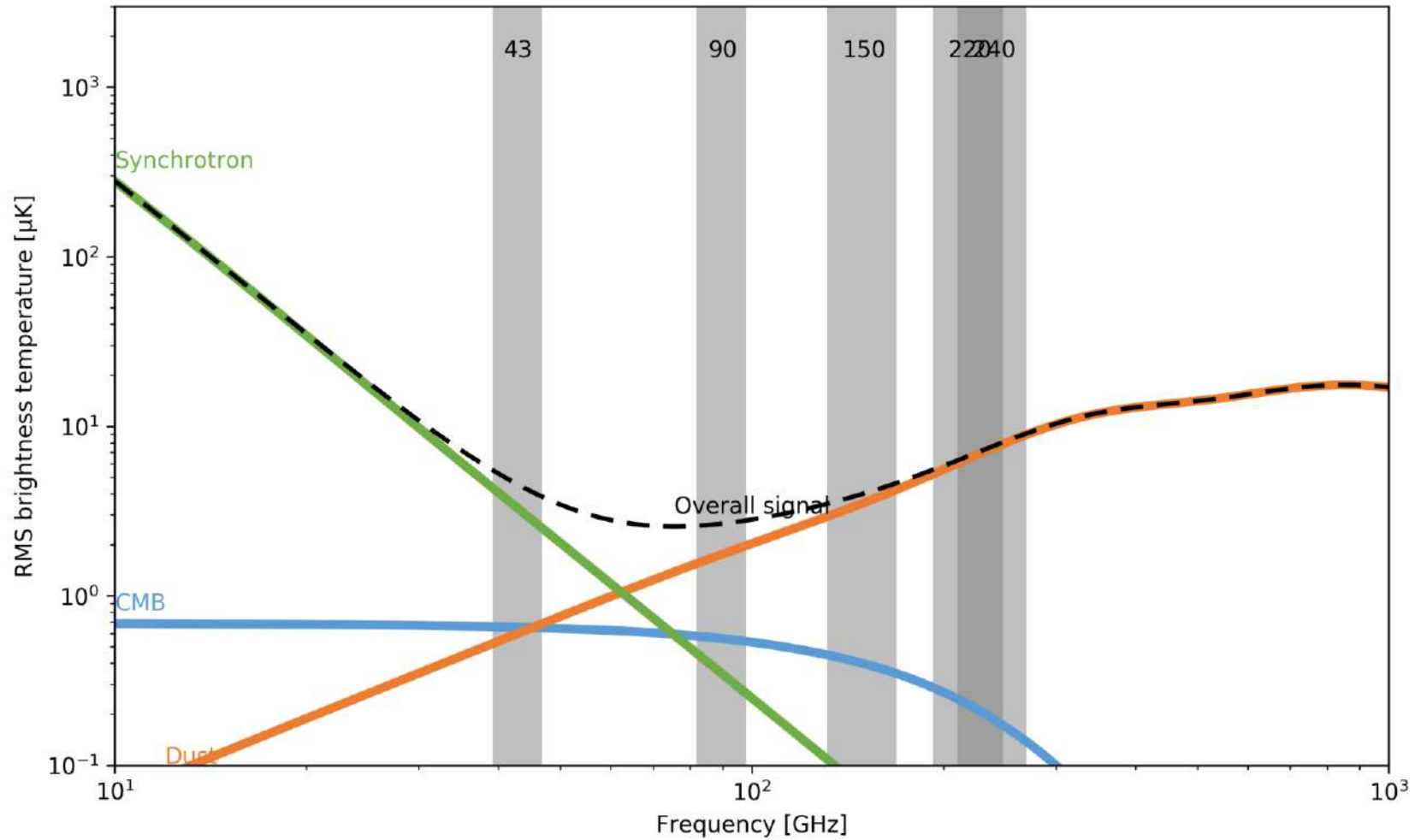
The Large Scale Polarization Explorer (LSPE)

LSPE at a glance

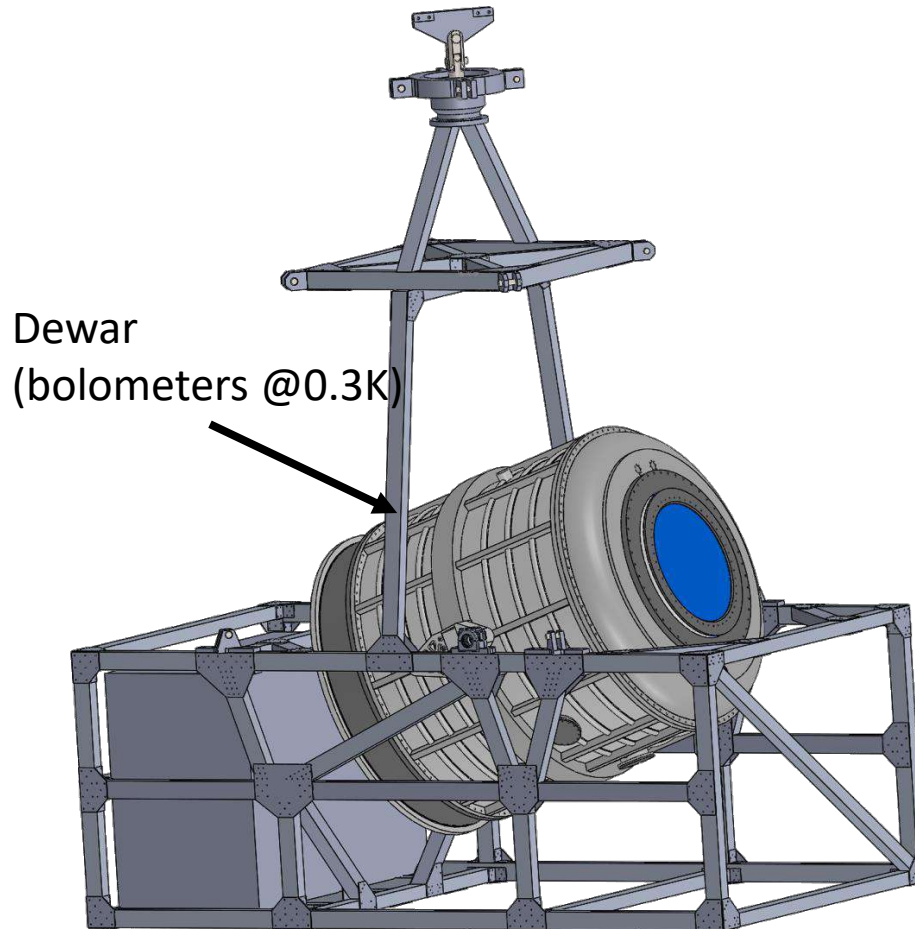
- ASI (Agenzia Spaziale Italiana) project
- Measure large-scale polarization at 40–240 GHz
- Two instruments:
 - SWIPE (balloon borne bolometers): 150, 220, 240 GHz, PI: Paolo De Bernardis (Sapienza)
 - STRIP (ground-based HEMTs): 40 and 90 GHz, PI: Marco Bersanelli (UniMI)



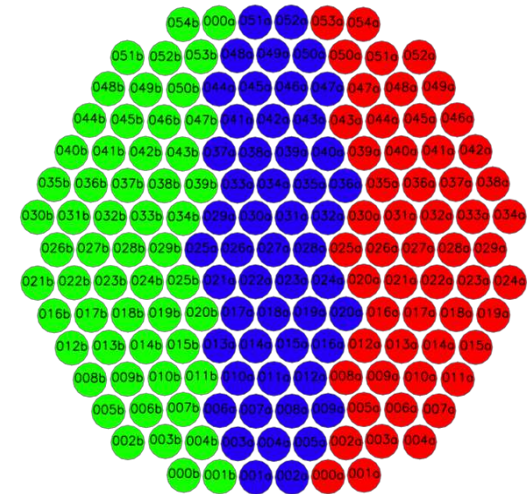
LSPE frequency coverage



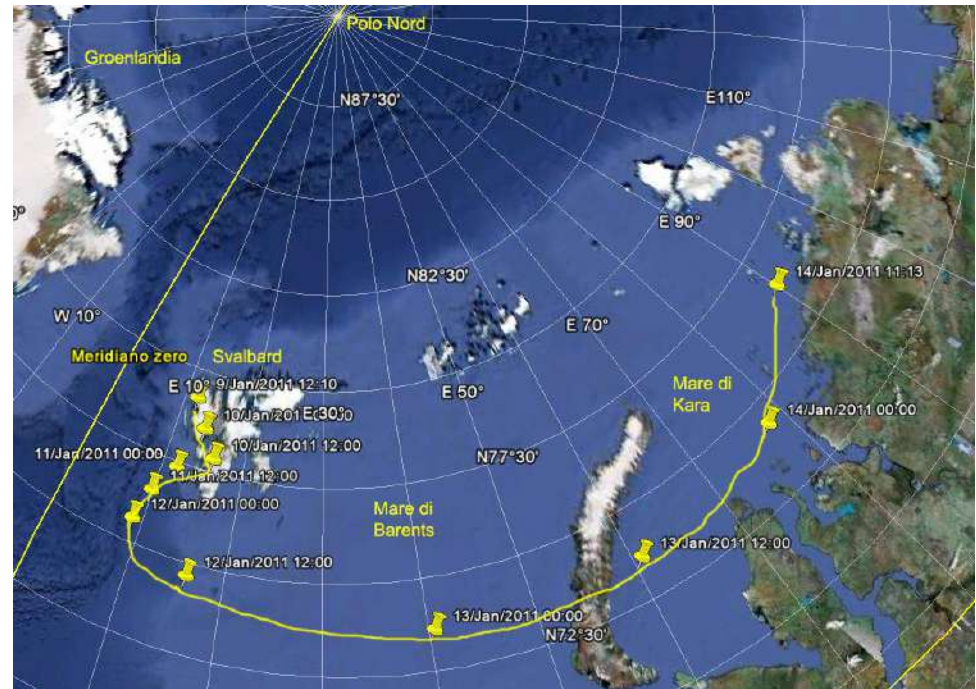
SWIPE: the balloon-borne high frequency instrument



330 TES detectors



SWIPE: the balloon-borne high frequency instrument



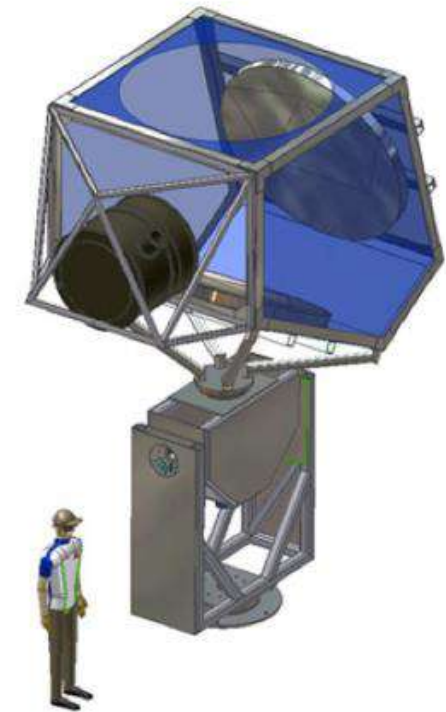
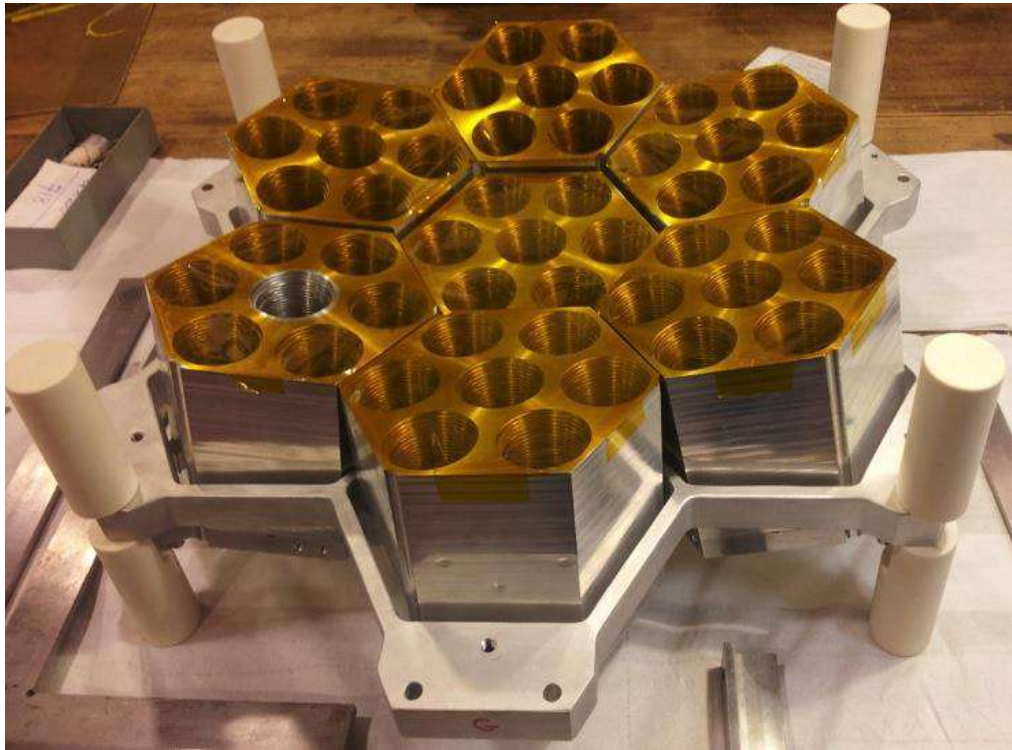
- Estimated launch date: December 2018 (Svalbard Islands)
- 15 days of flight during Arctic night

STRIP: the ground-based low frequency instrument

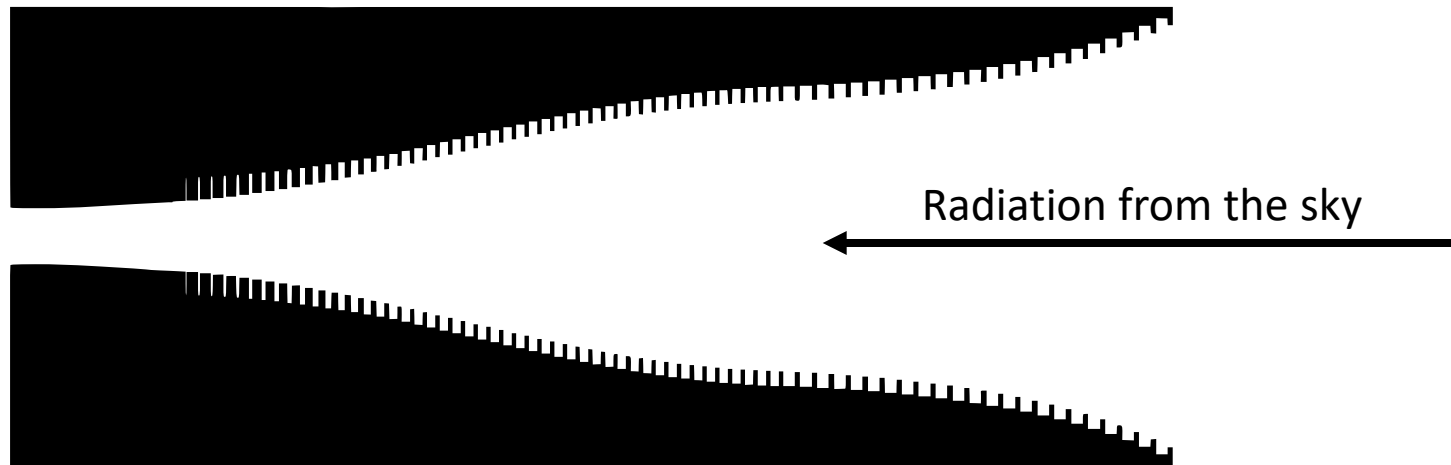


Teide Observatory, Tenerife (Canary islands)

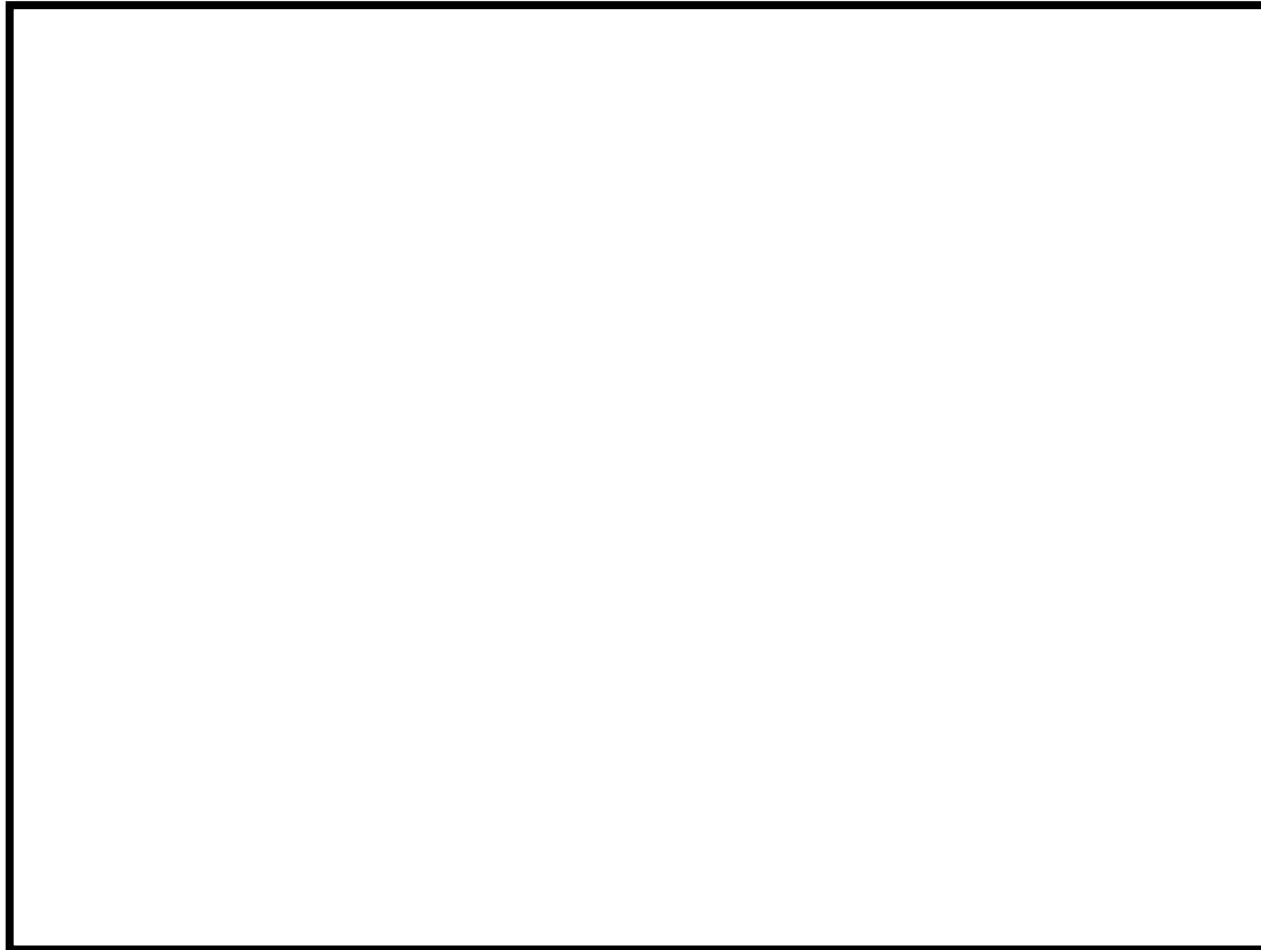
STRIP: the ground-based low frequency instrument



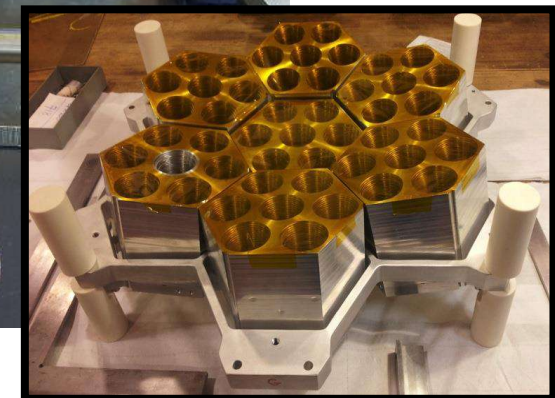
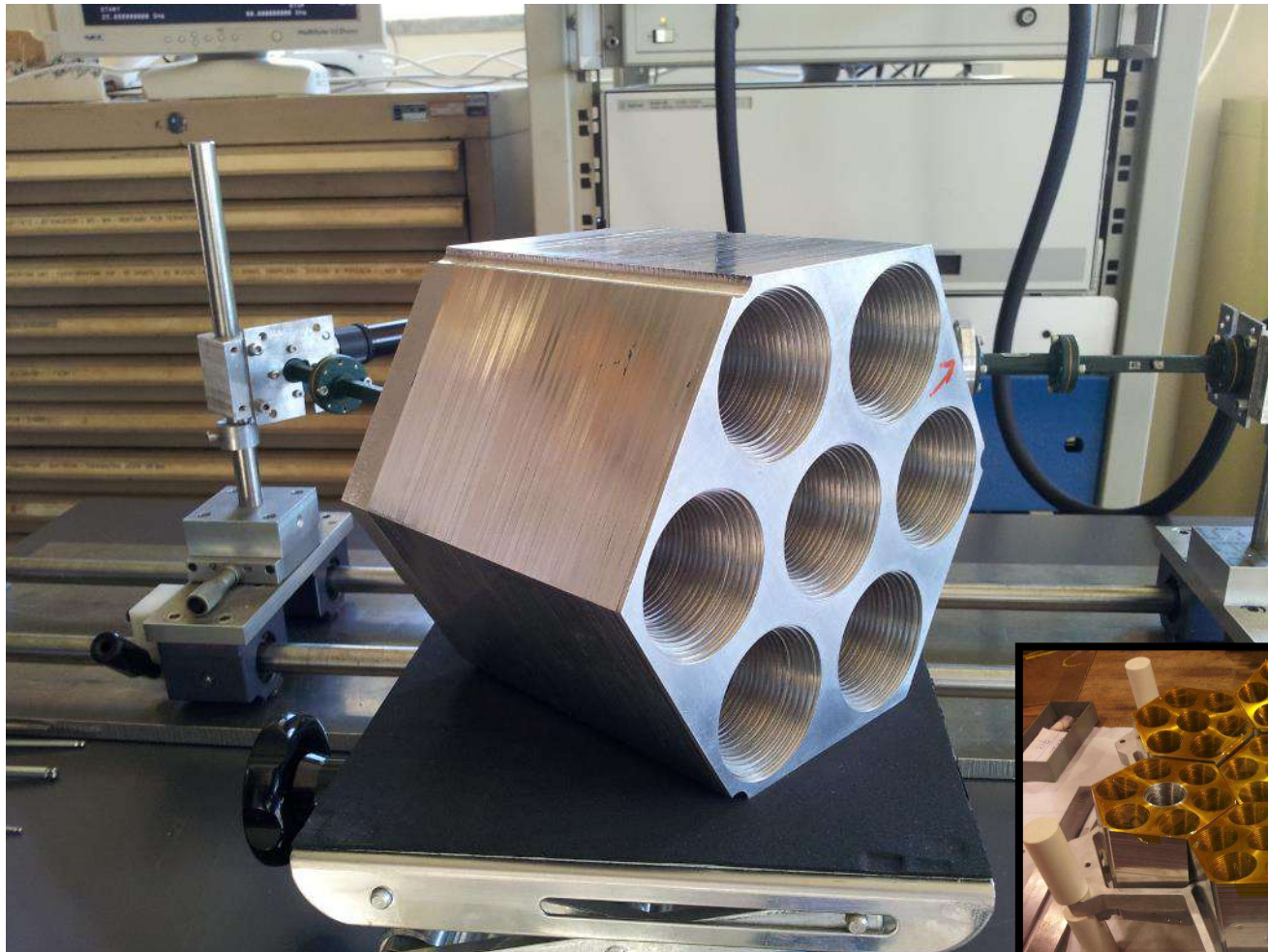
How to design a microwave horn



The platelet technique

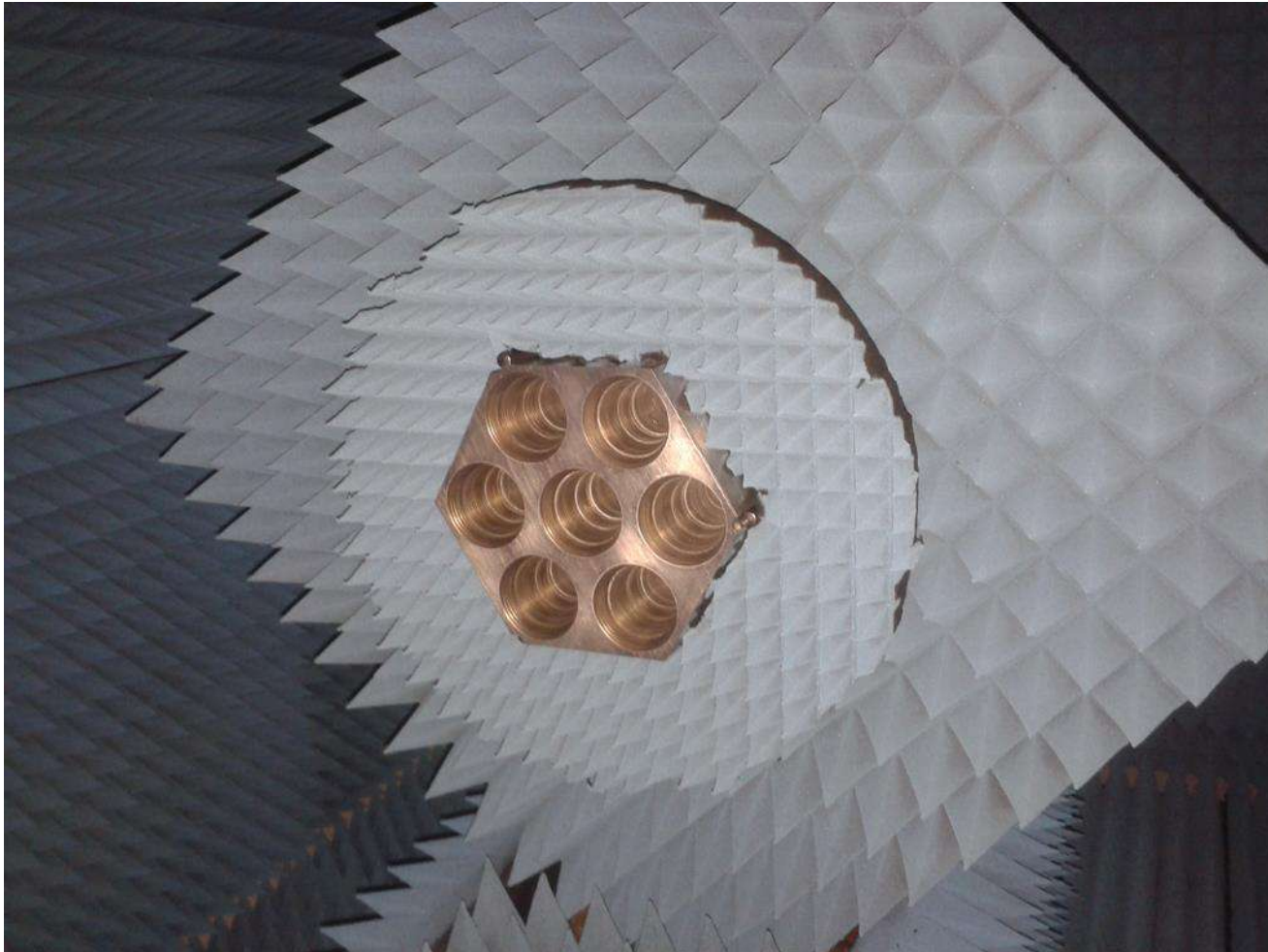


The STRIP focal plane modules



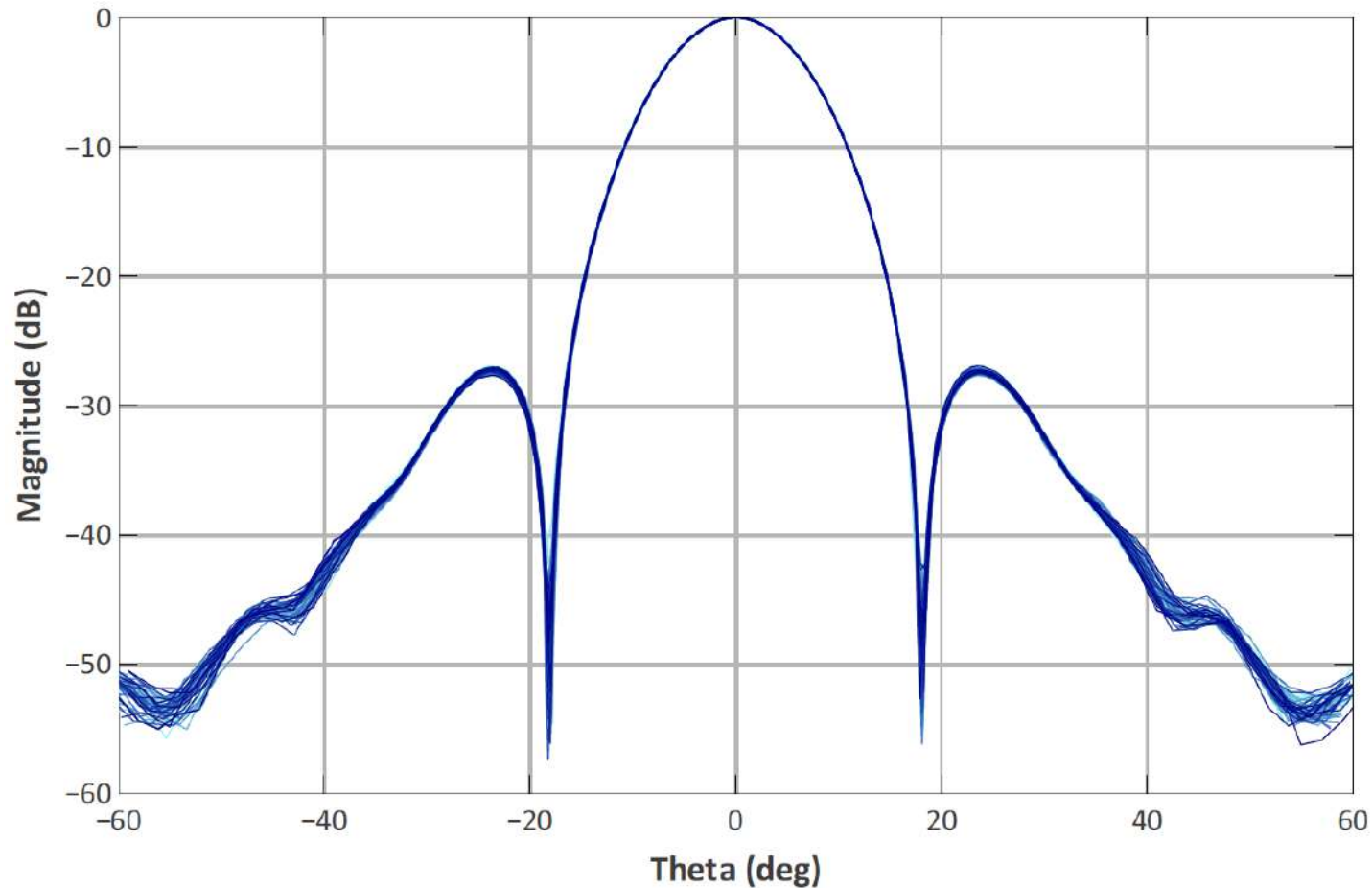
LSPE Q-band feed horns (CLOEMA, UniMI)

The STRIP focal plane modules



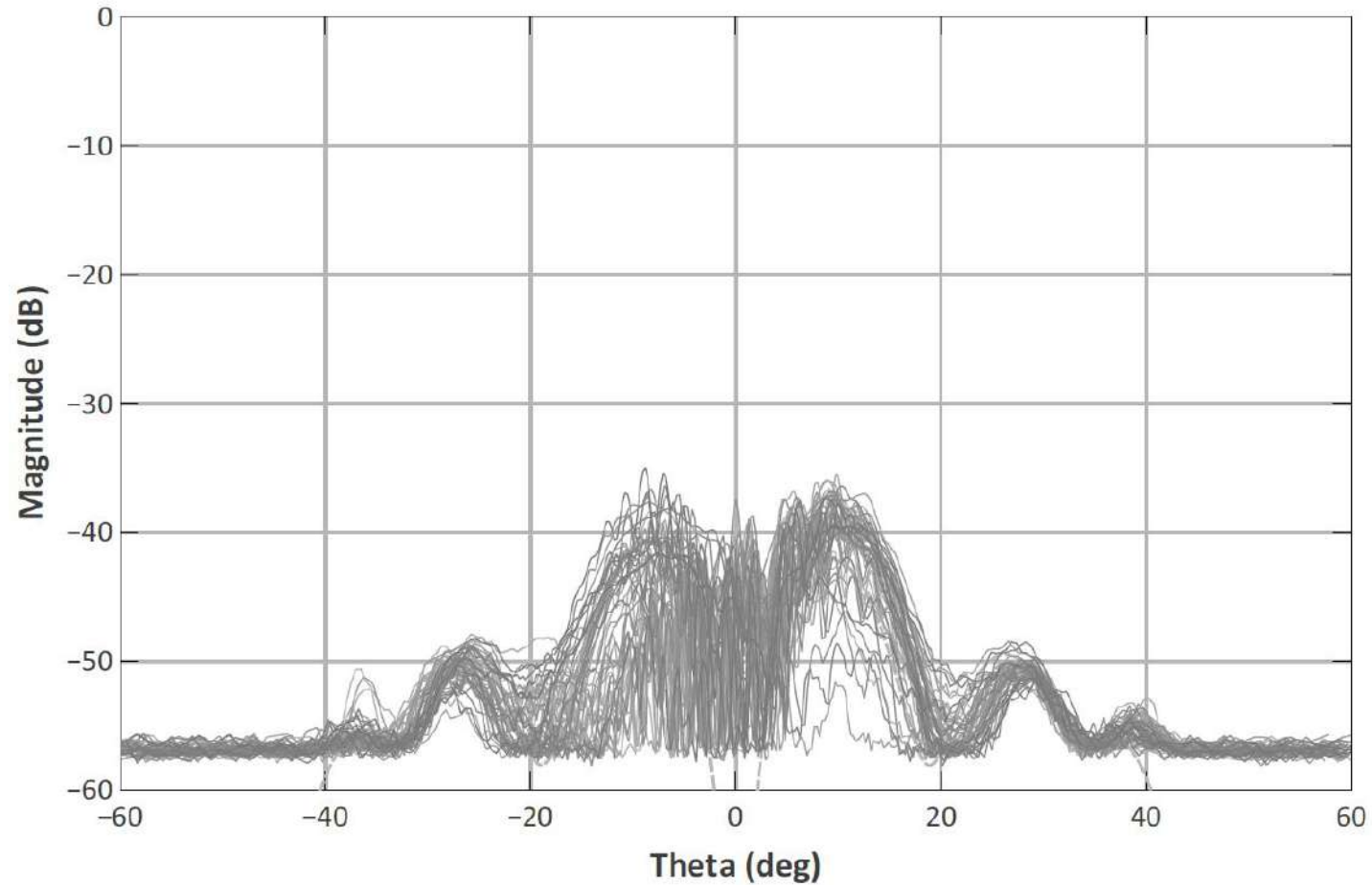
LSPE/STRIP module being tested in the anechoic chamber@UniMI

Optical performance of the 49 STRIP horns



Co-polar measurement of the 49 E-planes

Optical performance of the 49 STRIP horns



Cross-polar measurement of the 49 +45°-planes

Further reading

- WMAP papers: <https://lambda.gsfc.nasa.gov/product/map/dr5/>
- Planck papers: <https://www.cosmos.esa.int/web/planck/publications>
- CMB S-4 website: <https://cmb-s4.org/>
- LSPE website: <http://planck.roma1.infn.it/lspe/>
- QUBIC website: <http://qubic.in2p3.fr/QUBIC/Home.html>
- μ -LAB: <http://milab.fisica.unimi.it/>

Additional slides

Friedmann-Lemaître expansion

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = -\frac{kc^2}{a^2(t)} + \frac{8\pi G}{3c^2}\epsilon(t) + \frac{\Lambda}{3},$$
$$\frac{\ddot{a}(t)}{a(t)} = -\frac{4\pi G}{3c^2}(\epsilon(t) + 3P(t)) + \frac{\Lambda}{3}.$$

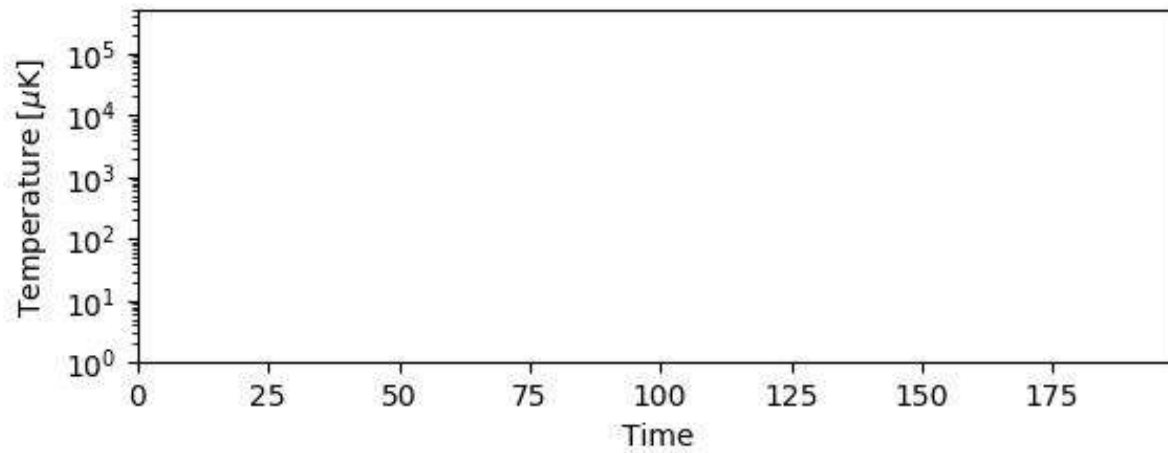
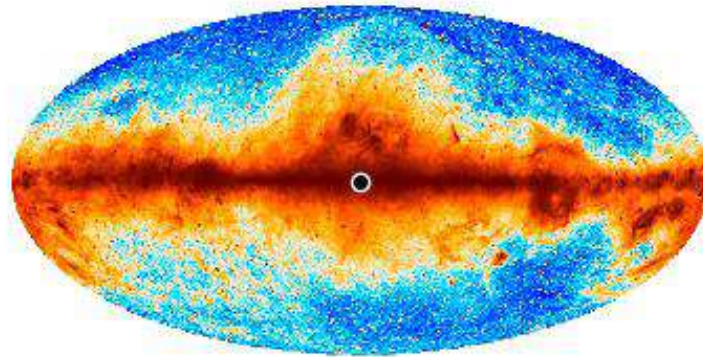
$a(t)$ Scale factor (dimensionless)

$\epsilon(t)$ Mass-energy density (energy/volume)

$P(t)$ Pressure (energy/volume)

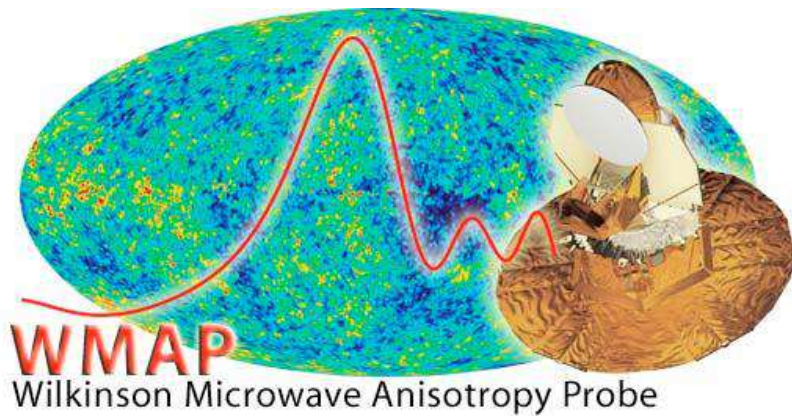
Λ Dark energy term (1/time²)

Observing the sky

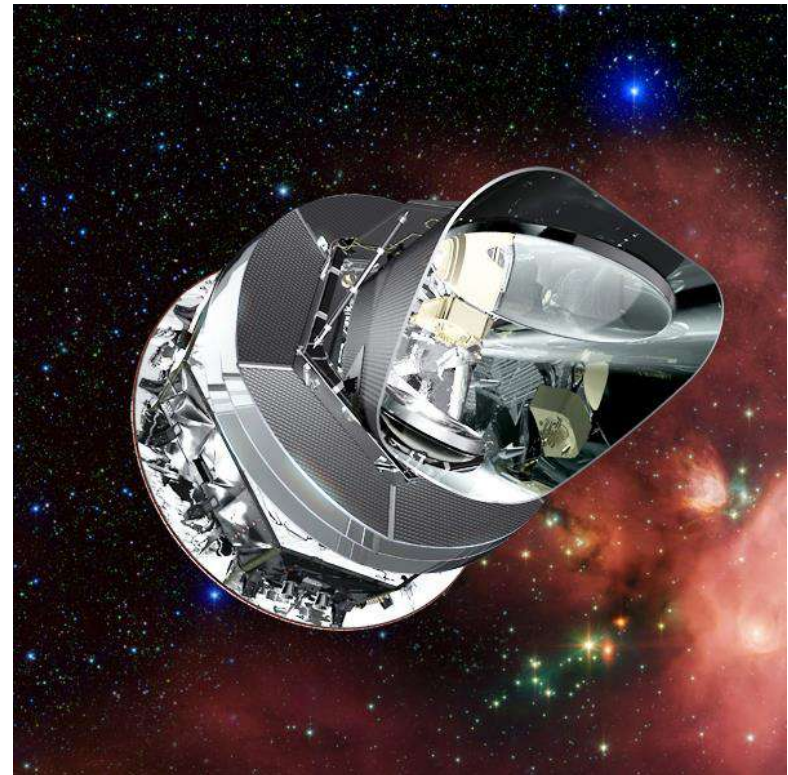


WMAP and Planck

NASA mission (2001-2010)

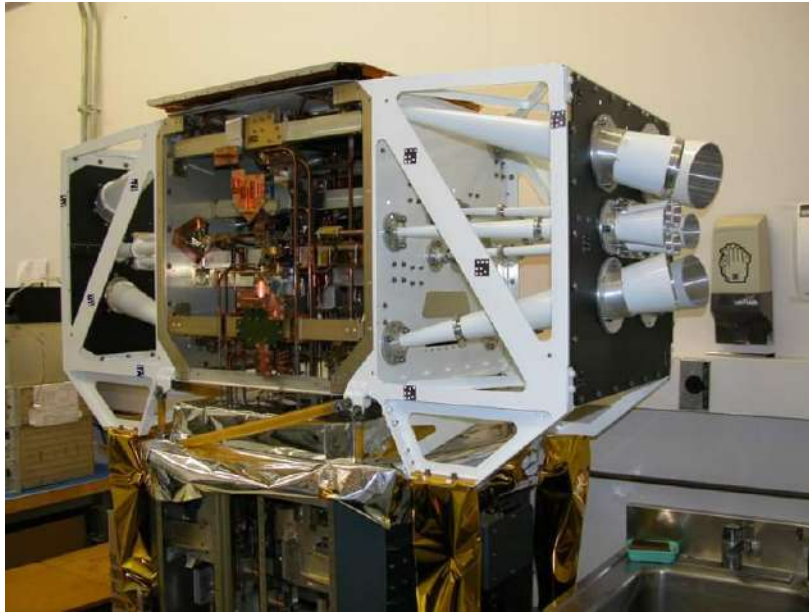


ESA mission (2009-2013)

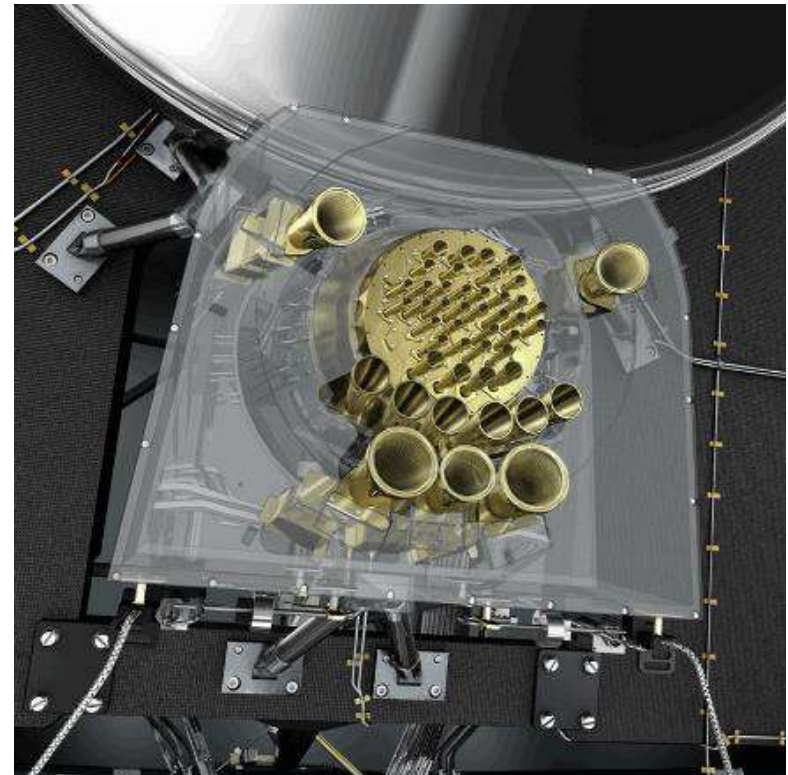


WMAP and Planck

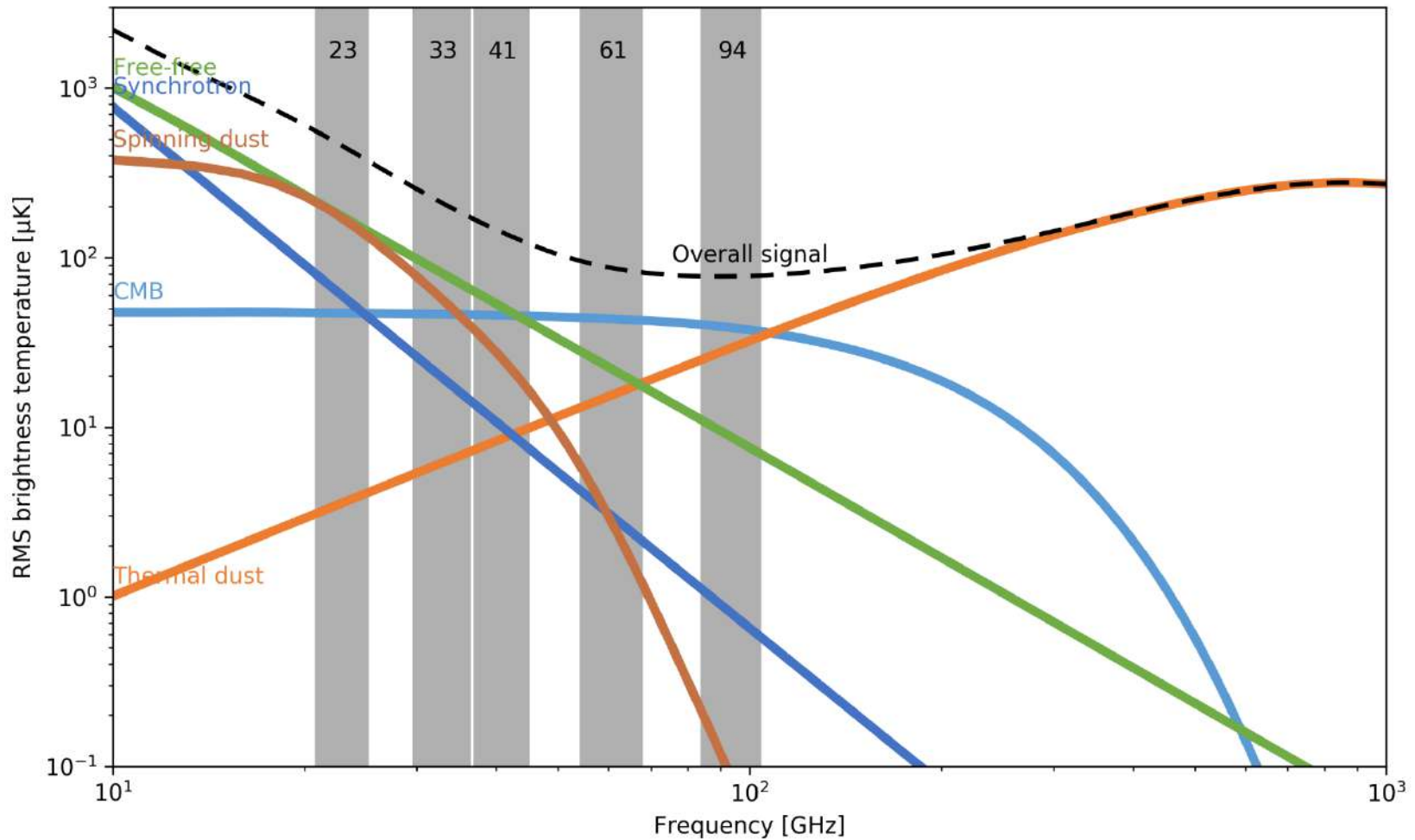
2x10 horns, 40 detectors



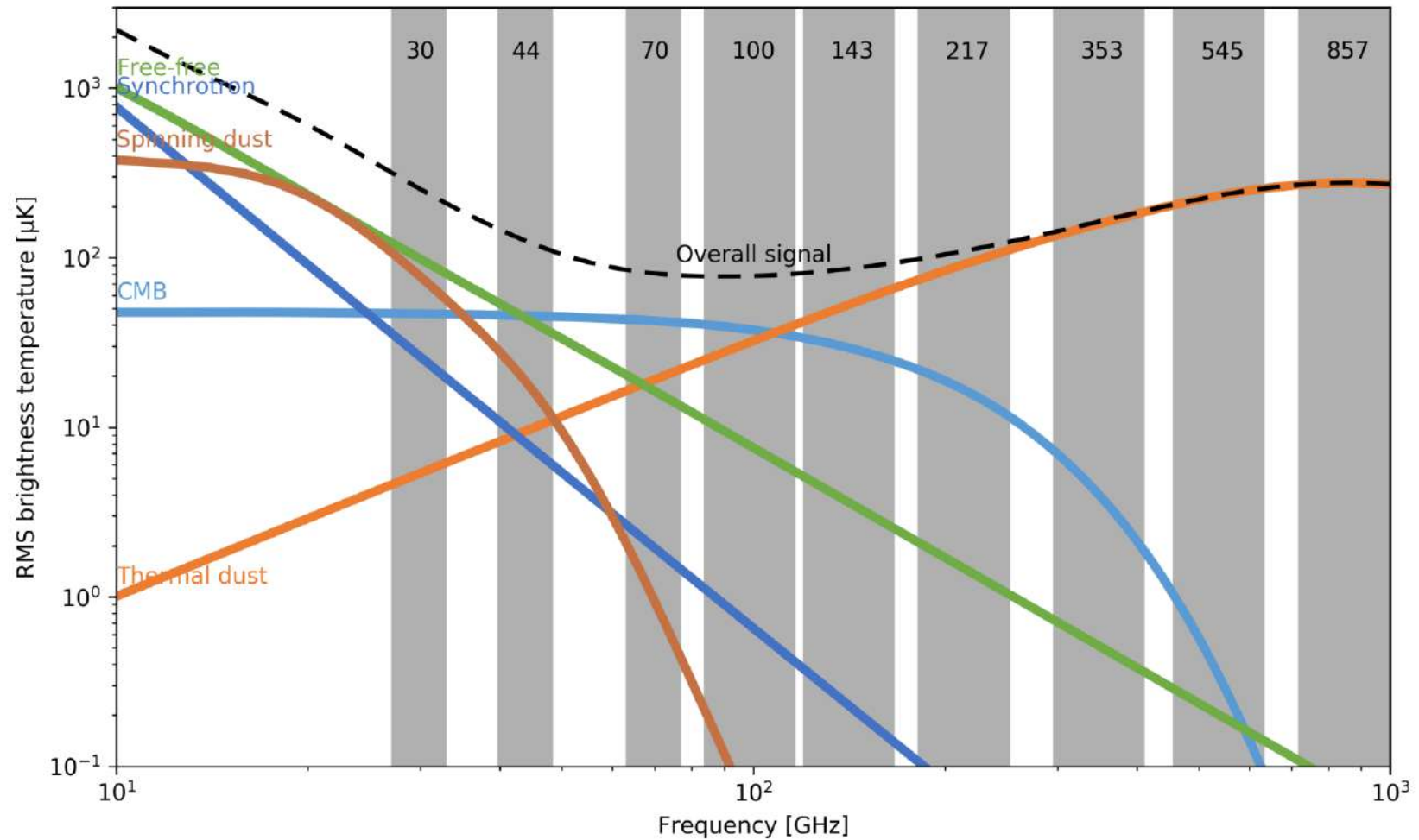
11+36 horns, 22+52 detectors



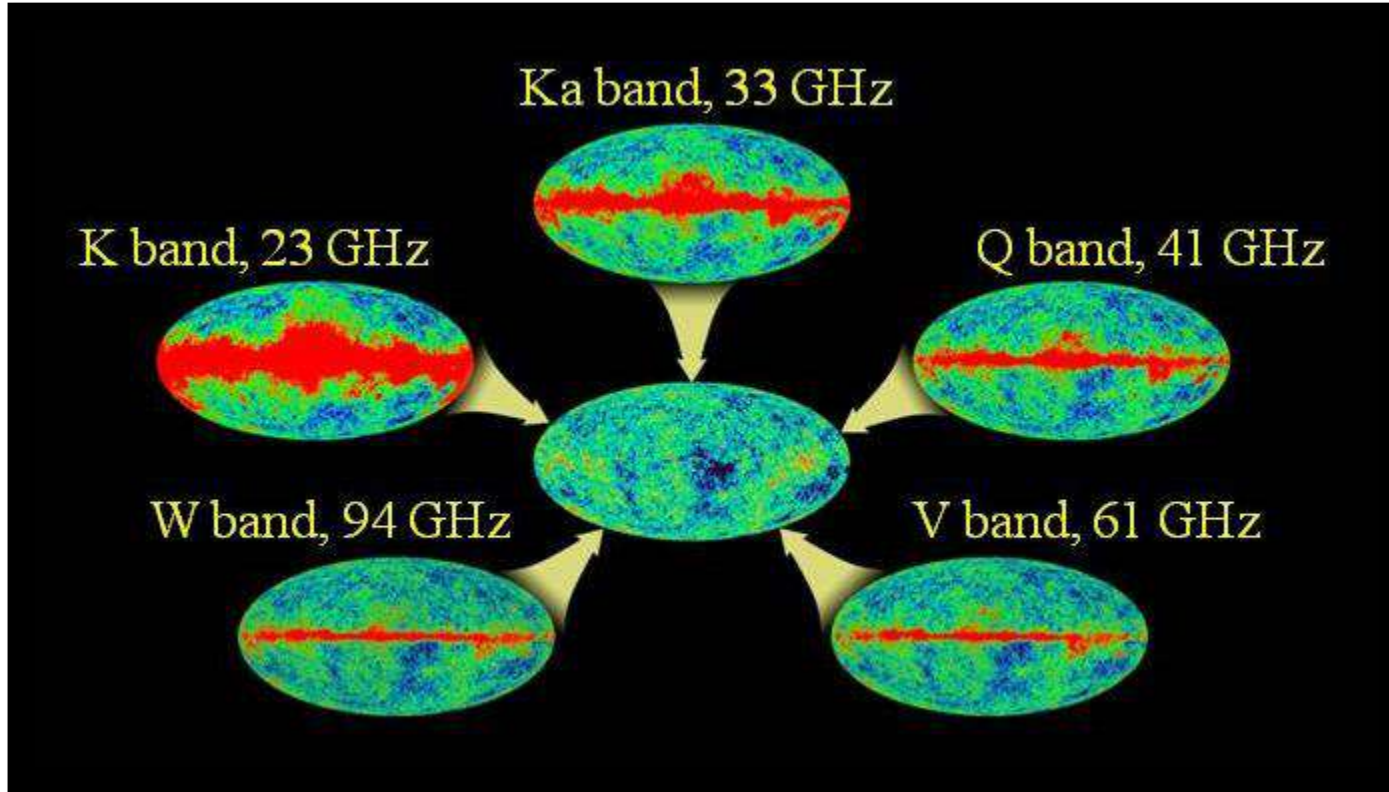
WMAP frequency coverage



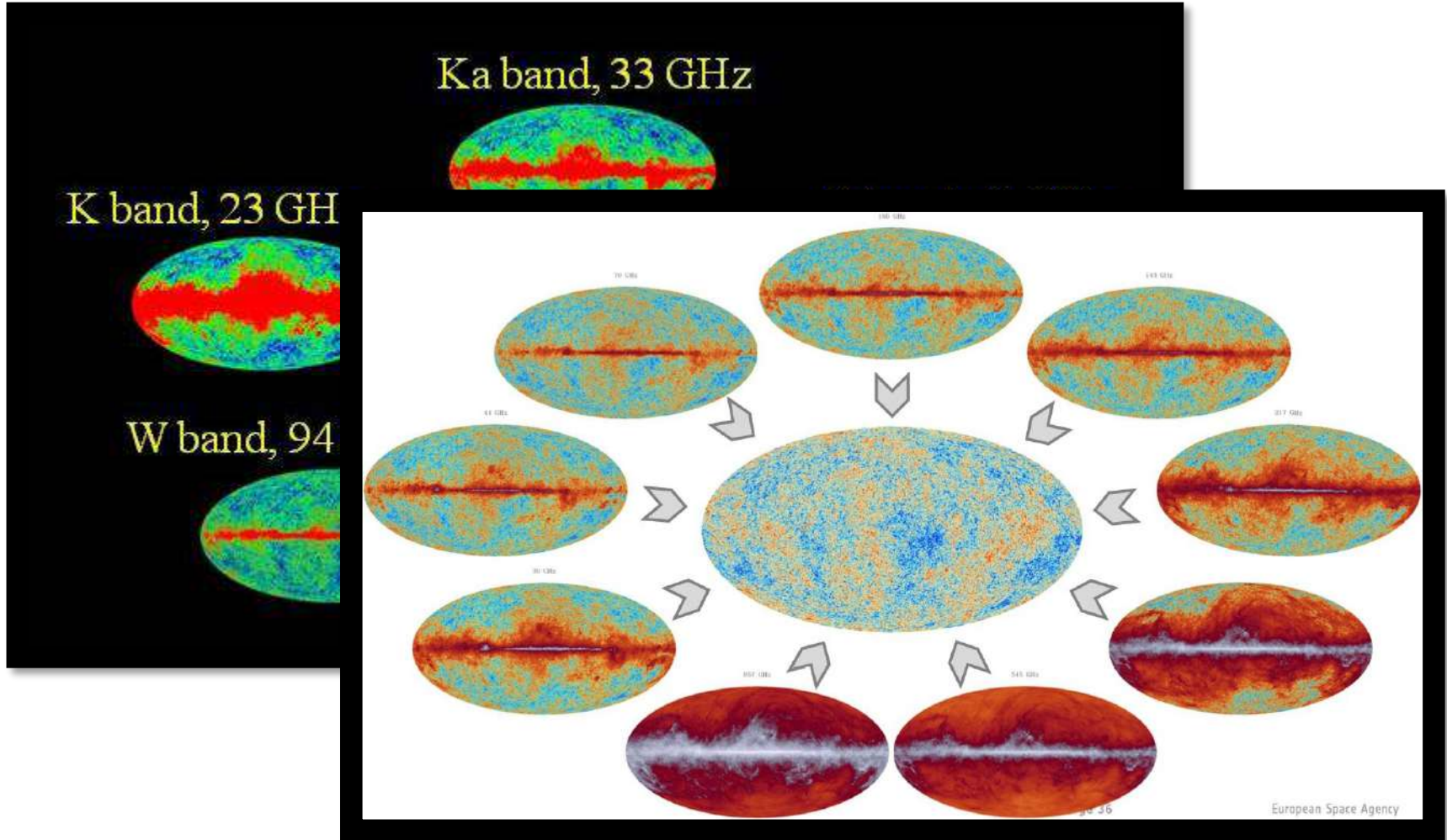
Planck frequency coverage



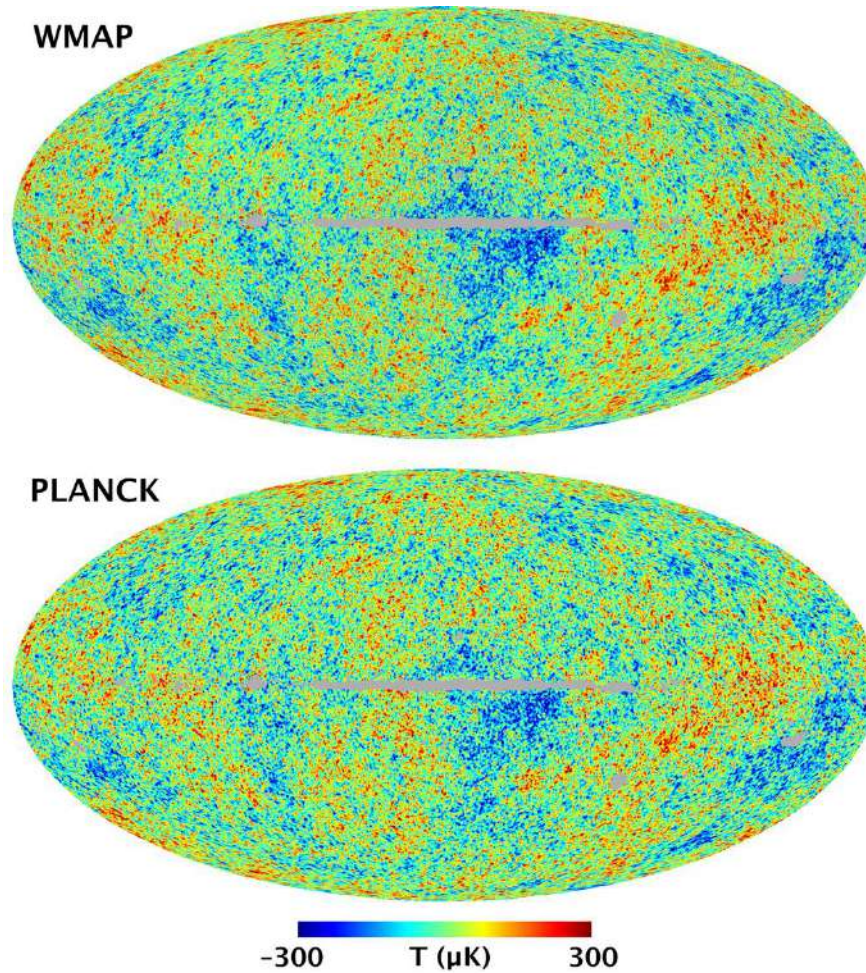
Component separation



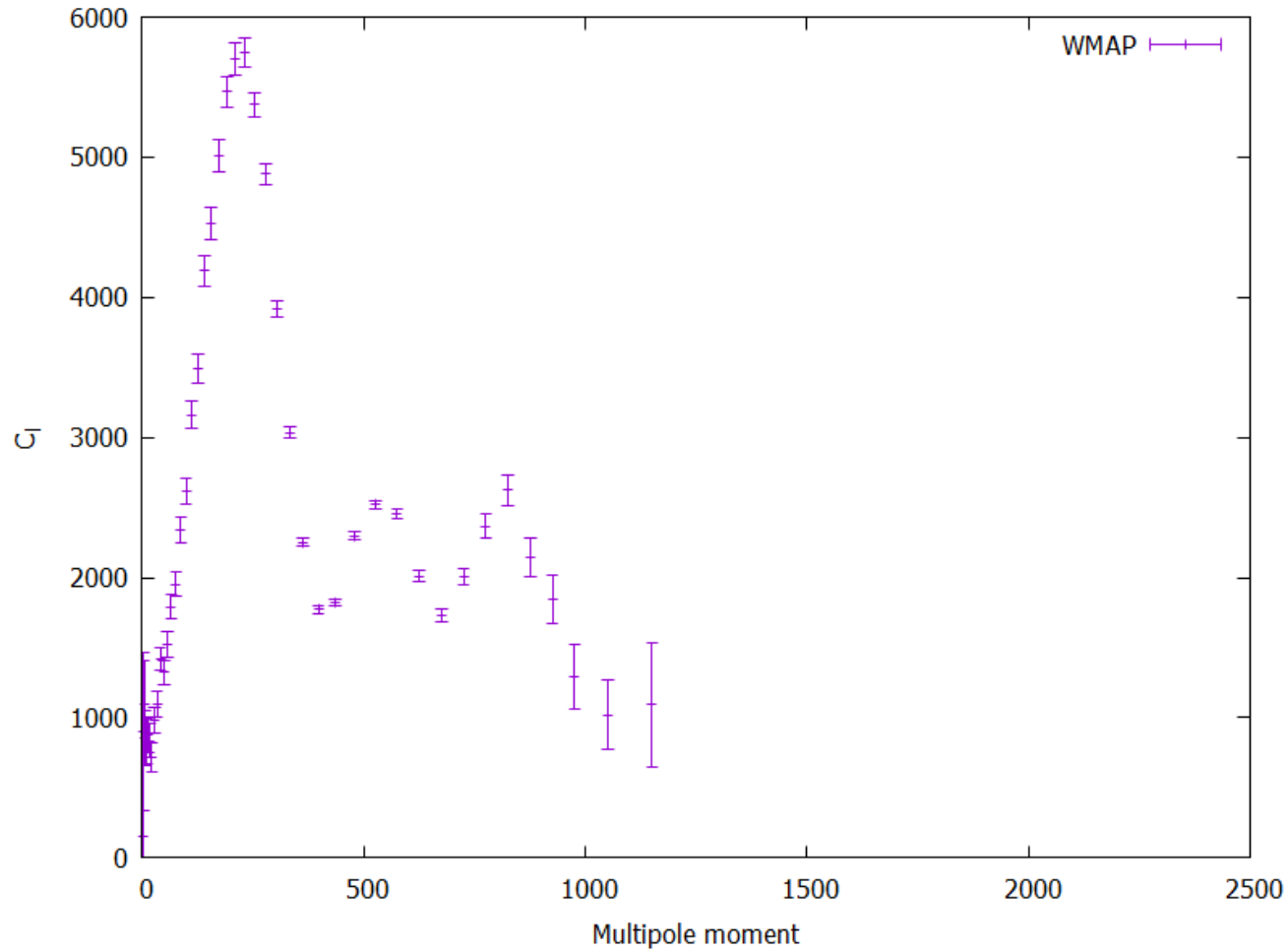
Component separation



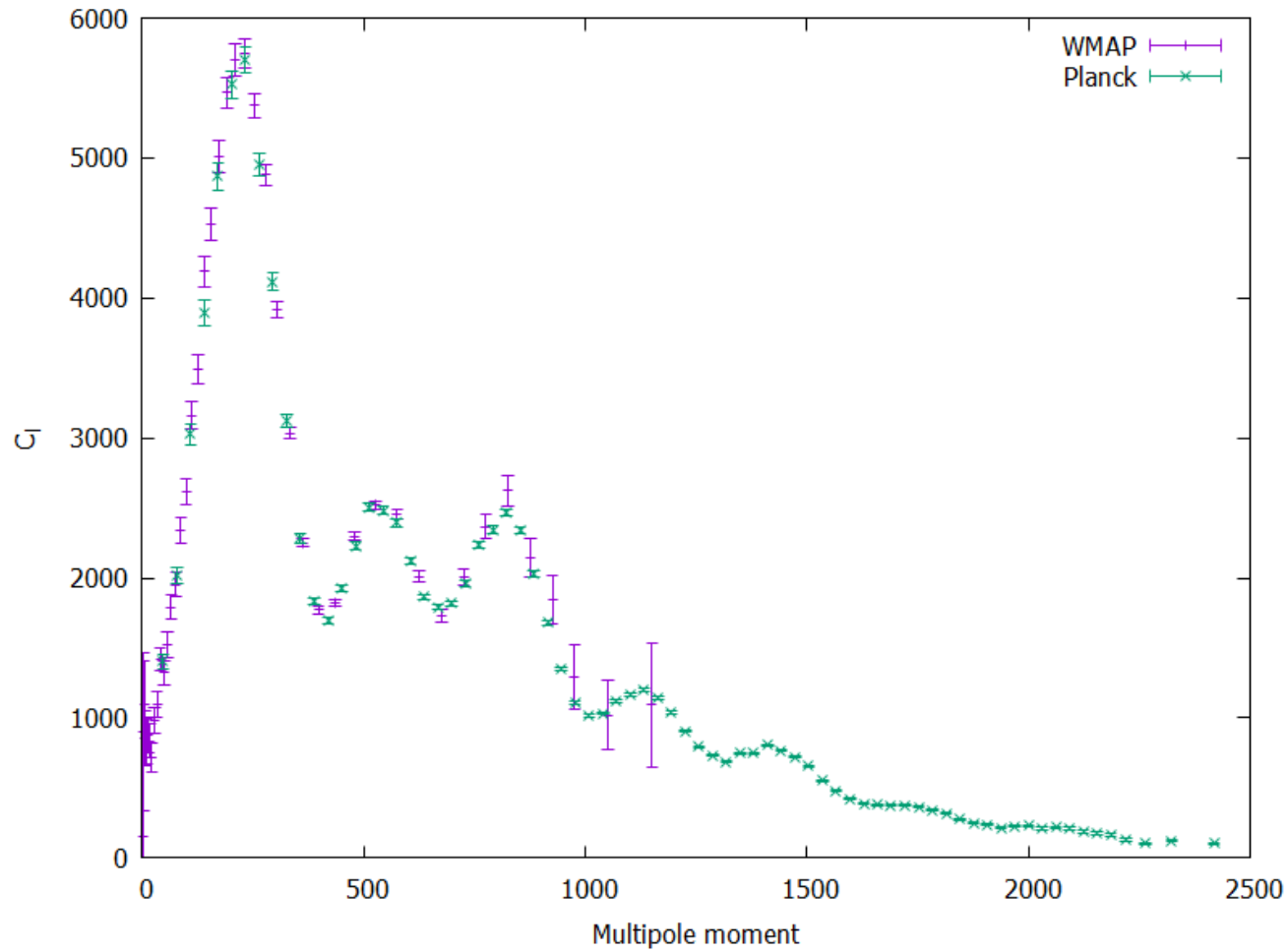
Comparison of the results



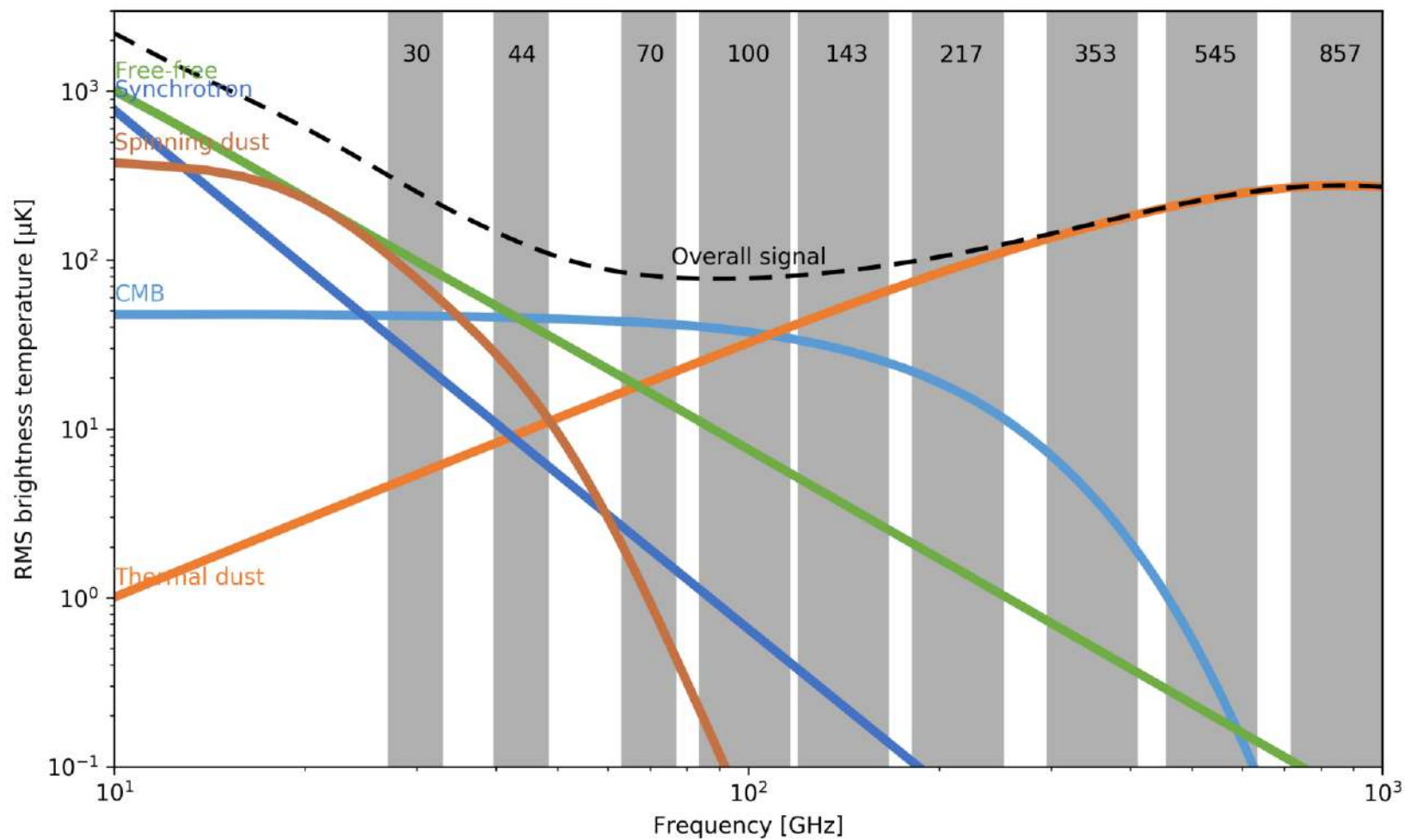
Comparison of the results



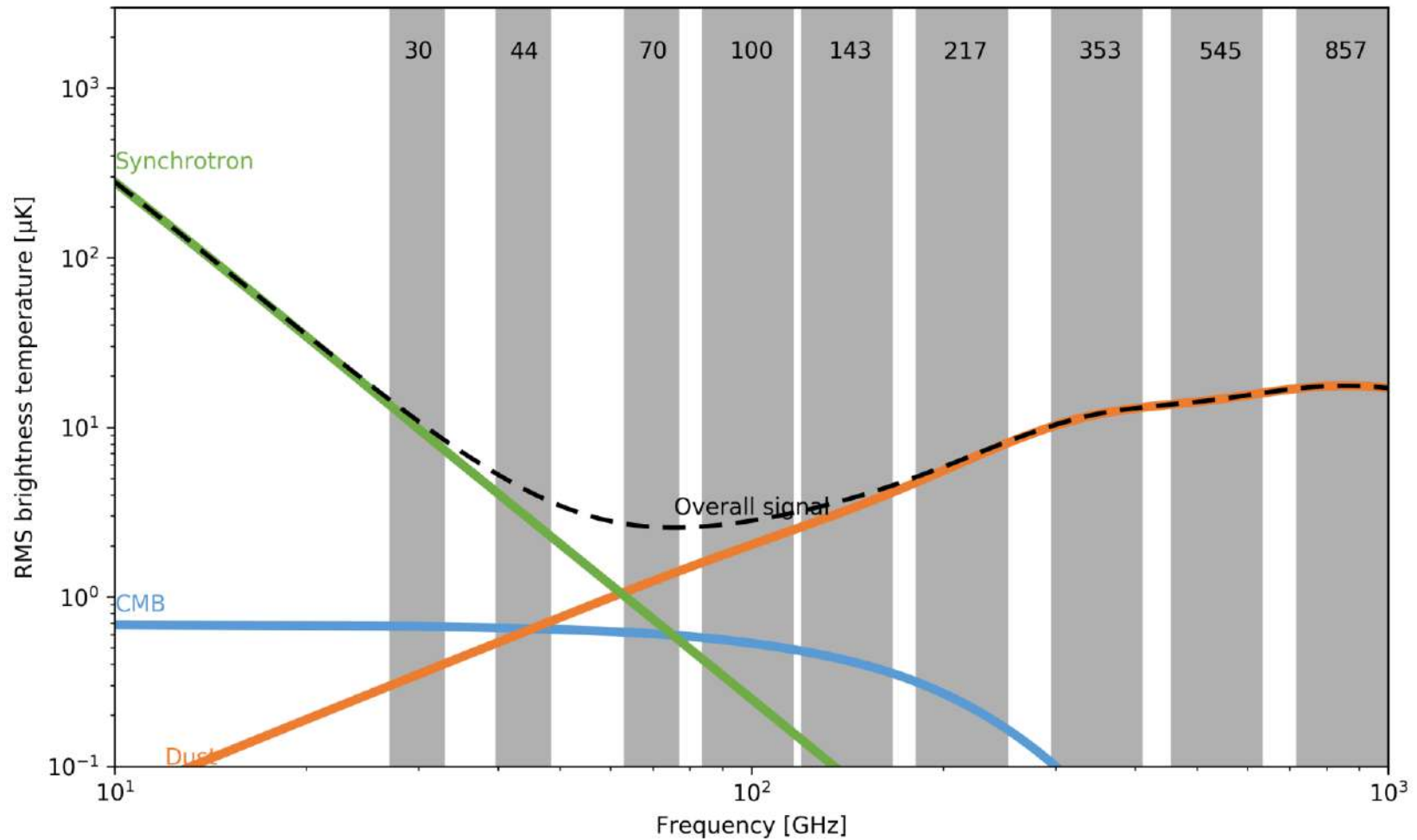
Comparison of the results



Planck frequency coverage

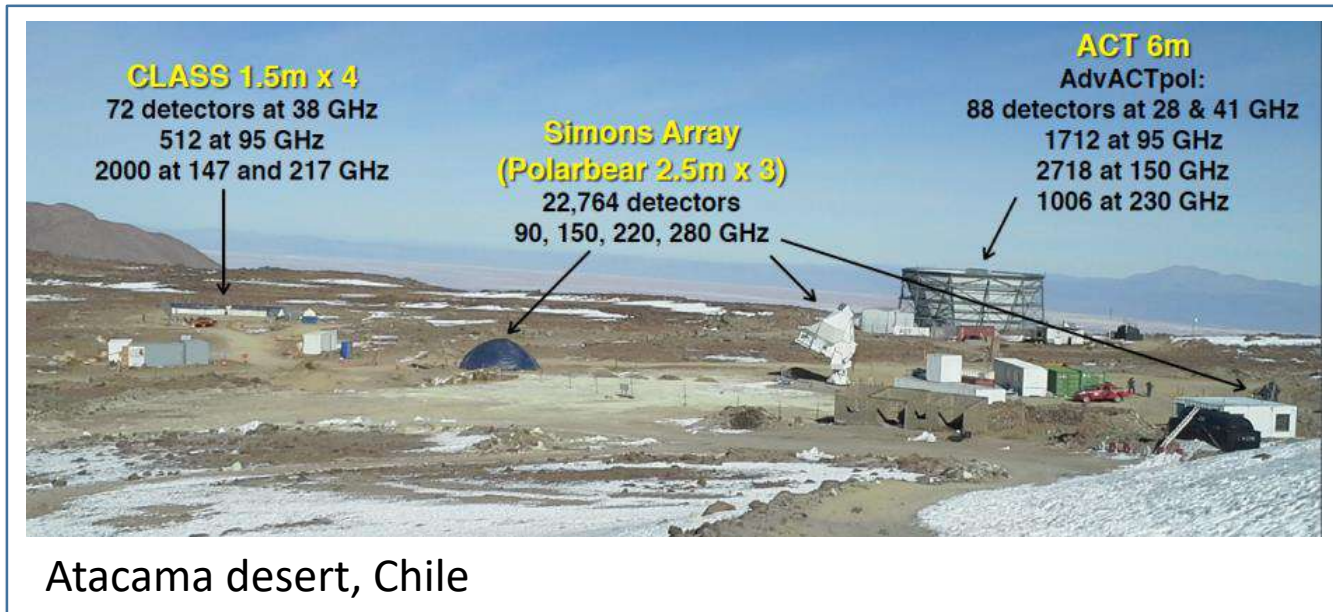


Planck frequency coverage



Hunting B-modes: a lot of competition!

Hunting B-modes: a lot of competition!



Hunting B-modes: a lot of competition!

CLASS 1.5m x 4
72 detectors at 38
512 at 95 GHz
2000 at 147 and 21

ACT 6m
AdvACTpol:

10m South Pole Telescope
SPT-3G: 16,400 detectors
95, 150, 220 GHz

BICEP3
2560 detectors
95 GHz

KECK Array
2500 detectors
150 & 220 GHz
pending:
~29,000 detectors
35, 95, 150, 220, 270 GHz

Atacama dese

Amundsen-Scott South Pole station

Hunting B-modes: a lot of competition!

CLASS 1.5m x 4
72 detectors at 38
512 at 95 GHz
2000 at 147 and 21

ACT 6m
AdvACTpol:

10m South Pole Telescope

KECK Array

QUIJOTE
11, 13, 17, 19, 30 GHz
Large scale surveys, deep fields

LSPE/SWIPE
140-220-240GHz
(Coordinated balloon flight)

LSPE/STRIP
42 + 90 GHz channels
Large scale surveys, deep fields

GroundBIRD
145 + 220 GHz channels

Atacama dese

Amundse

Teide observatory, Tenerife (Canary Islands)

The future: S4



CMB-S4
Next Generation CMB Experiment

OVERVIEW SCIENCE COLLABORATION NEWS EVENTS DOCS & TALKS CDT CMB-S4 WIKI

1 2 3 4 5 6 7 8

Current status of CMB-S4

CMB-S4: Next Generation CMB Experiment

The 'Stage-4' ground-based cosmic microwave background (CMB) experiment, CMB-S4, consisting of dedicated telescopes equipped with highly sensitive superconducting cameras operating at the South Pole, the high Chilean Atacama plateau, and possibly northern hemisphere sites, will provide a dramatic leap forward in our understanding of the fundamental nature of space and time and the evolution of the Universe. CMB-S4 will be designed to cross critical thresholds in testing inflation, determining the number and masses of the neutrinos, constraining possible new light relic particles, providing precise constraints on the nature of dark energy, and testing general relativity on large scales.

<https://cmb-s4.org/index.php>

The future: LiteBIRD

The image shows a banner for the LiteBIRD project. The banner features a central graphic of a satellite (LiteBIRD) and a timeline of the universe's expansion. The timeline is a cylinder with a grid, showing the progression from Quantum Fluctuation and Inflation to the Dark Ages, the formation of the first stars, and the development of galaxies and planets. The timeline is labeled with 'CMB B-Mode Polarization' and 'Dark Energy Accelerated Expansion'. The satellite is shown in a yellow and white color scheme. The background of the banner is a dark blue and purple gradient with a starry field. The text 'LiteBIRD' is prominently displayed in the upper right of the banner. Below the banner is a navigation menu with two columns: 'Contents' and 'News & Topics'. The 'Contents' column has two items: 'Home' and 'Science'. The 'News & Topics' column has two news items, each with a date and a link to a news article.

LiteBIRD
Lite (Light) satellite for the studies of **B**-mode polarization and **I**nflation from cosmic background **R**adiation **D**etection

Quantum Fluctuation
Inflation
Dark Ages
Development of Galaxies, Planets, etc.
CMB B-Mode Polarization
1st Stars about 400 million yrs.
Dark Energy Accelerated Expansion
LiteBIRD
POLARBEAR
Big Bang Expansion 13.7 billion years

Credit: NASA / WMAP Science Team
Source : National Aeronautics and Space Administration

Contents

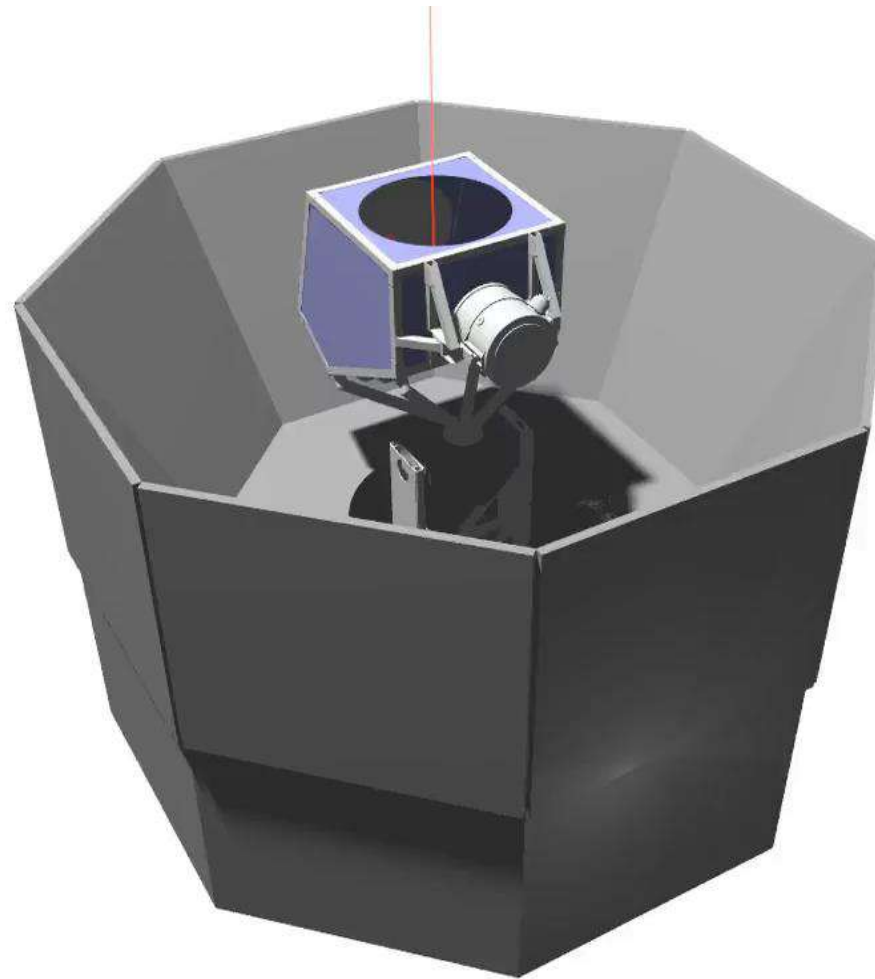
- ▶ Home
- ▶ Science

News & Topics

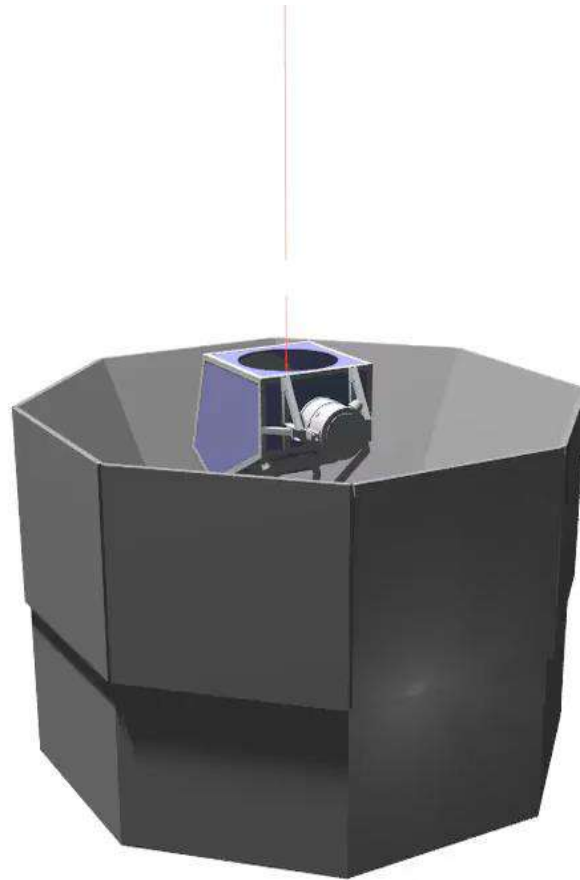
- 2017-02-08 [LiteBIRD is selected as one of 28 highest-priority large projects by the Science Council of Japan.](#)
- 2016-09-30 [LiteBIRD has started ISAS Phase-A1](#)

<http://litebird.jp/eng/>

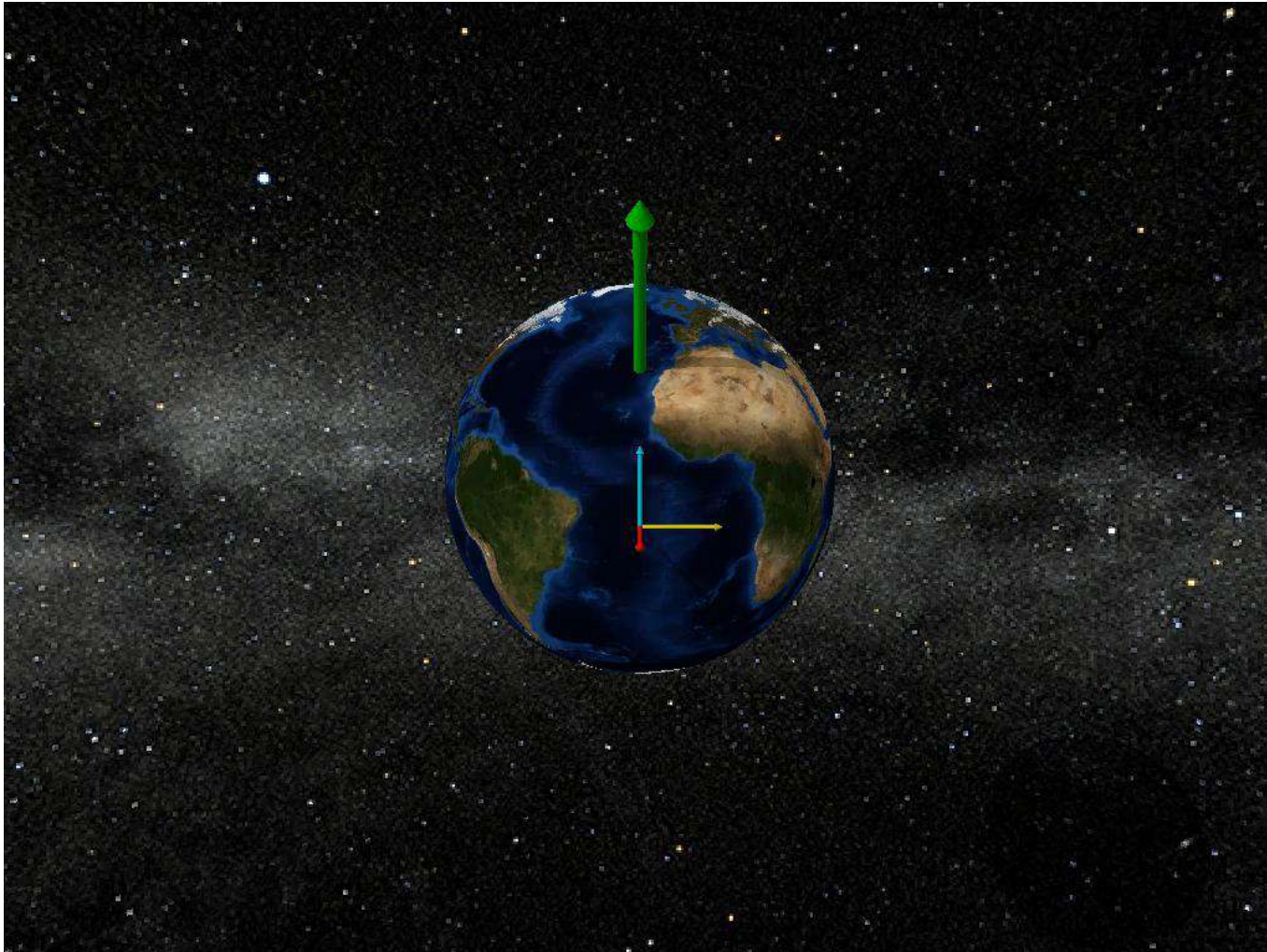
Flyby



How Strip will observe the sky

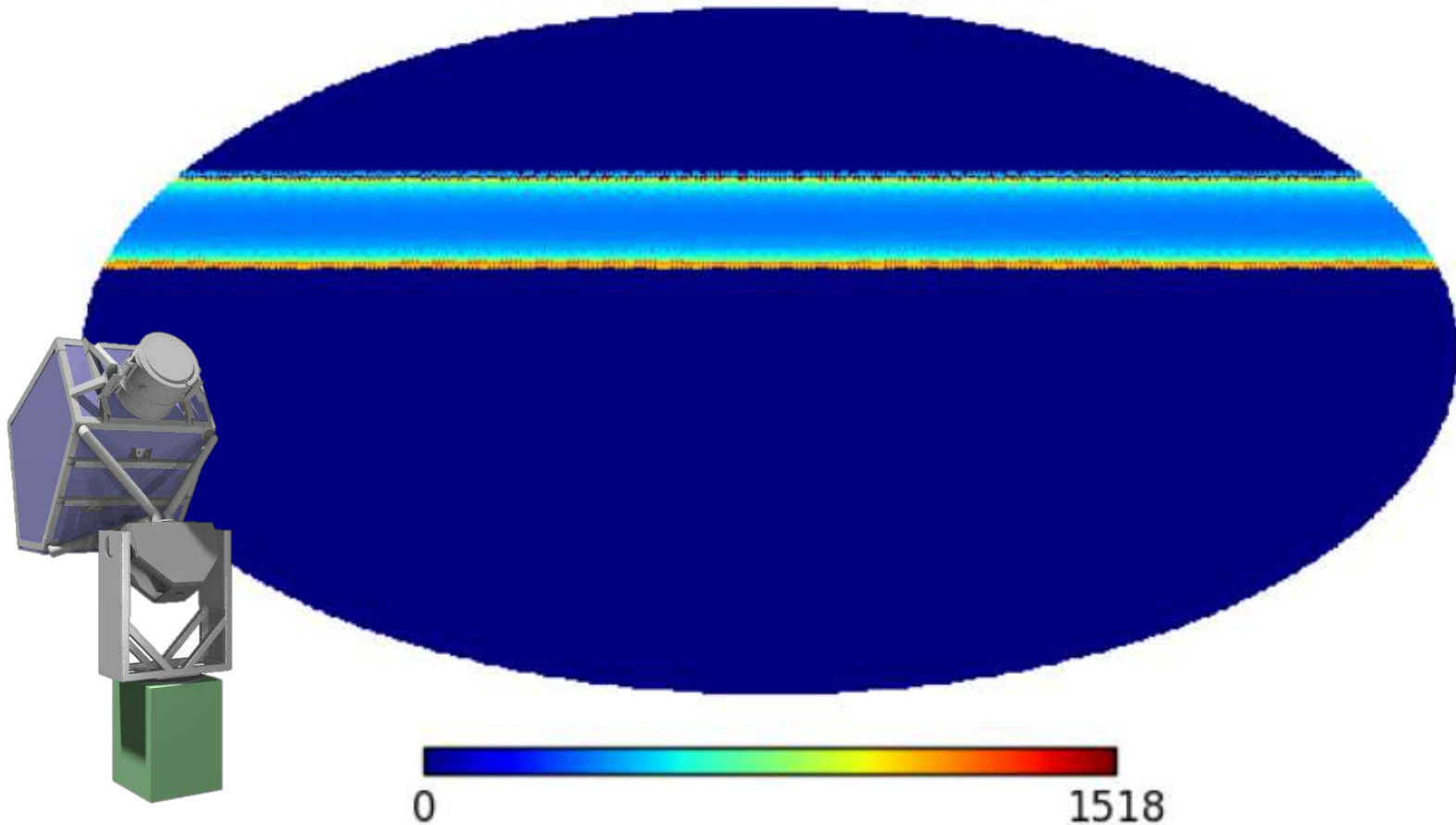


How Strip will observe the sky

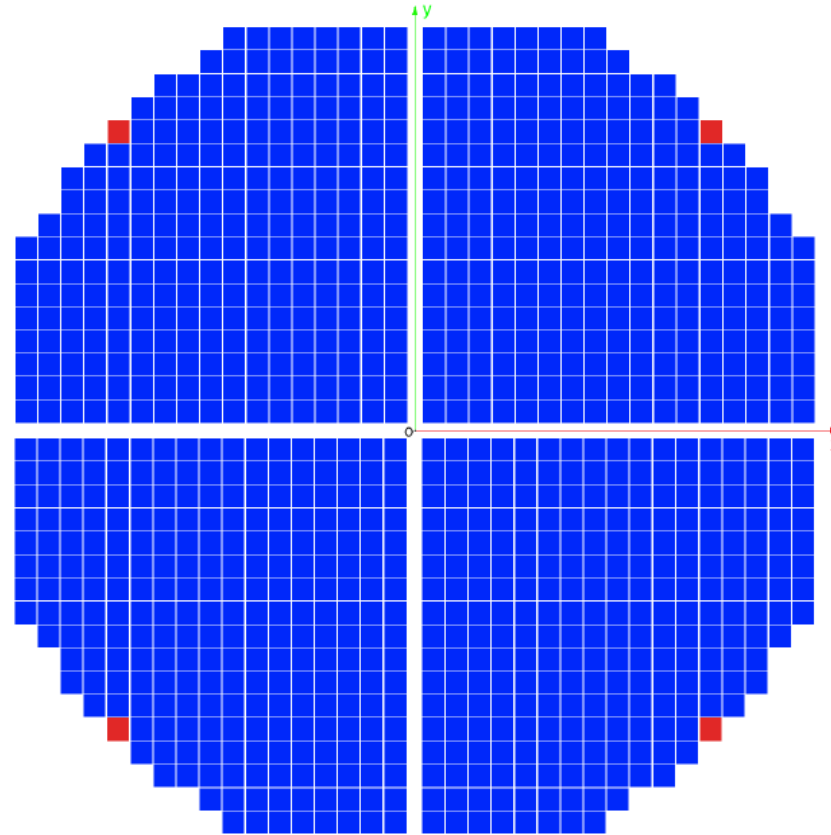


How Strip will observe the sky

Hit count (fsky=16.1%)



Placement of the 992 QUBIC detectors



QUBIC Technical Design Report 1.0 (May 2017)
(Available at <http://qubic.in2p3.fr/QUBIC/Home.html>)

QUBIC

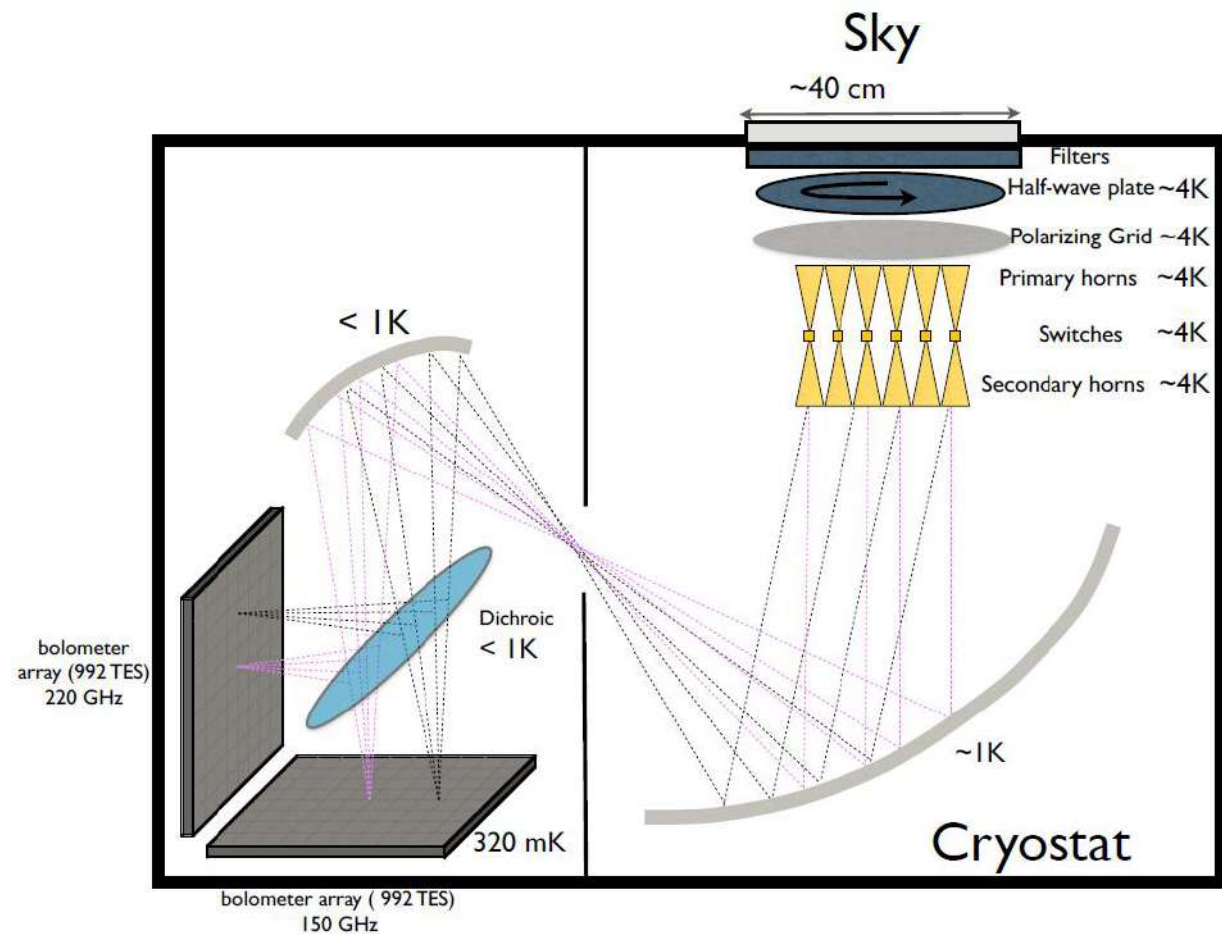


Q&U Bolometric Interferometer for Cosmology

What is QUBIC?

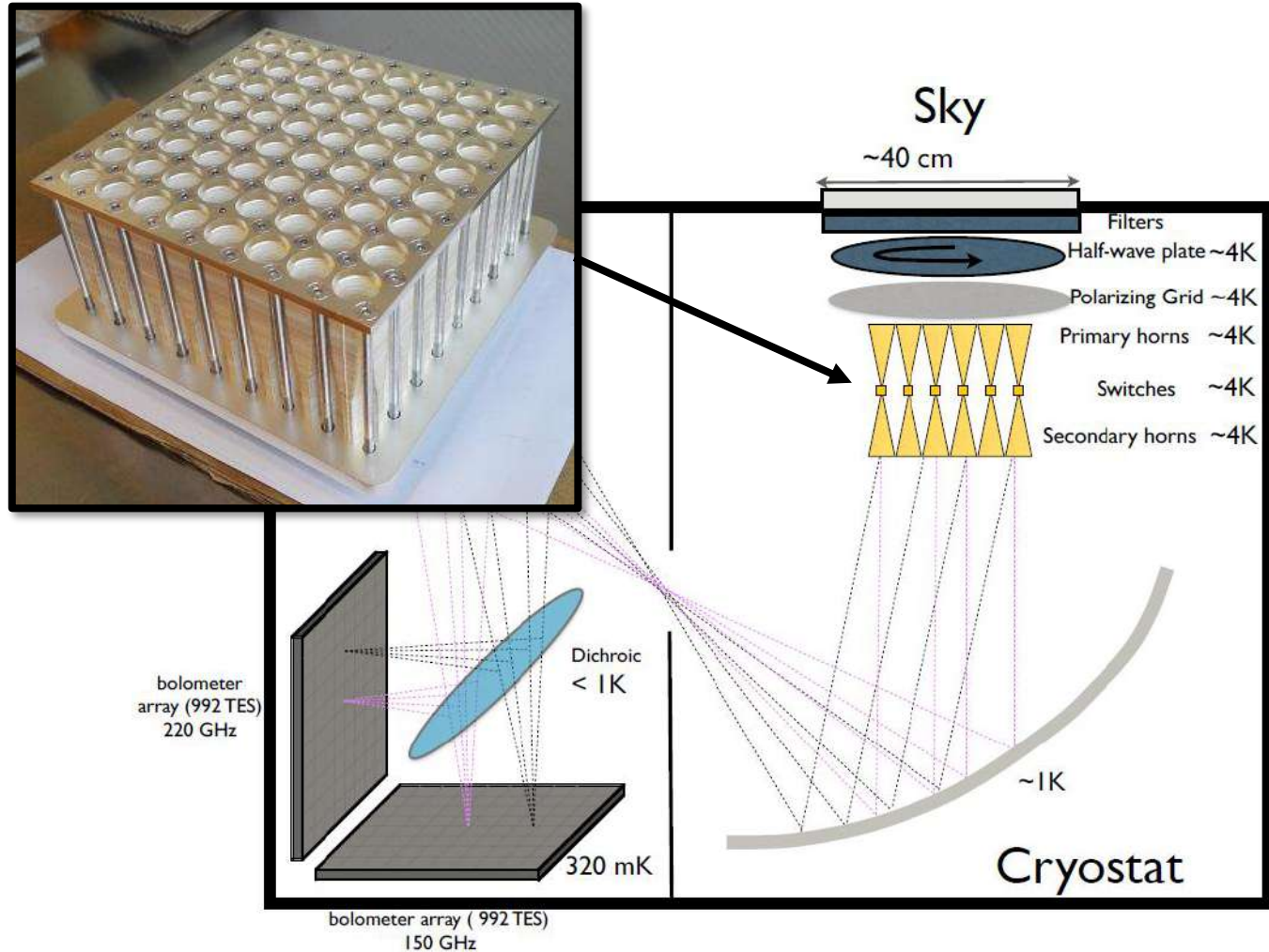
- Ground-based experiment
- *Bolometric interferometer!*
- TES bolometers @ 95, 150, 220 GHz
- First technological demonstrator under construction
- First module to be deployed to Argentina next year

The design of QUBIC



The design of QUBIC

QUBIC demonstrator (Lasertech)



How QUBIC sees the sky

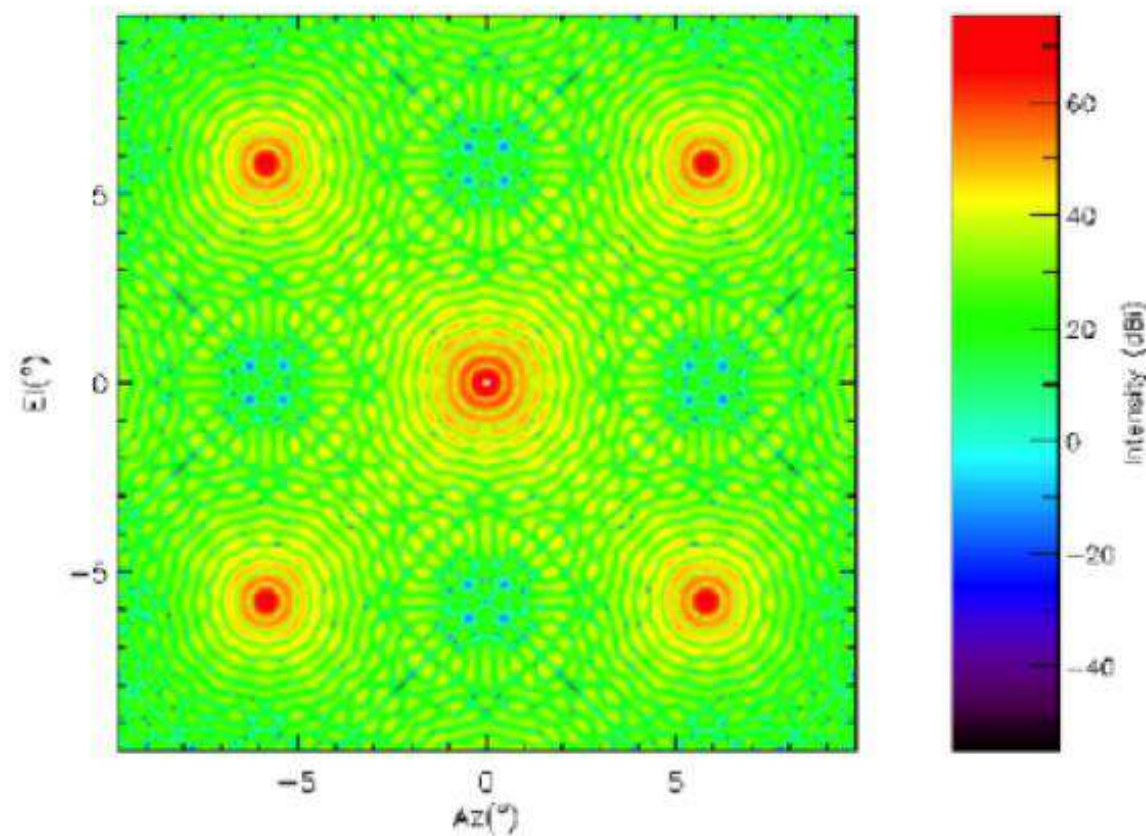
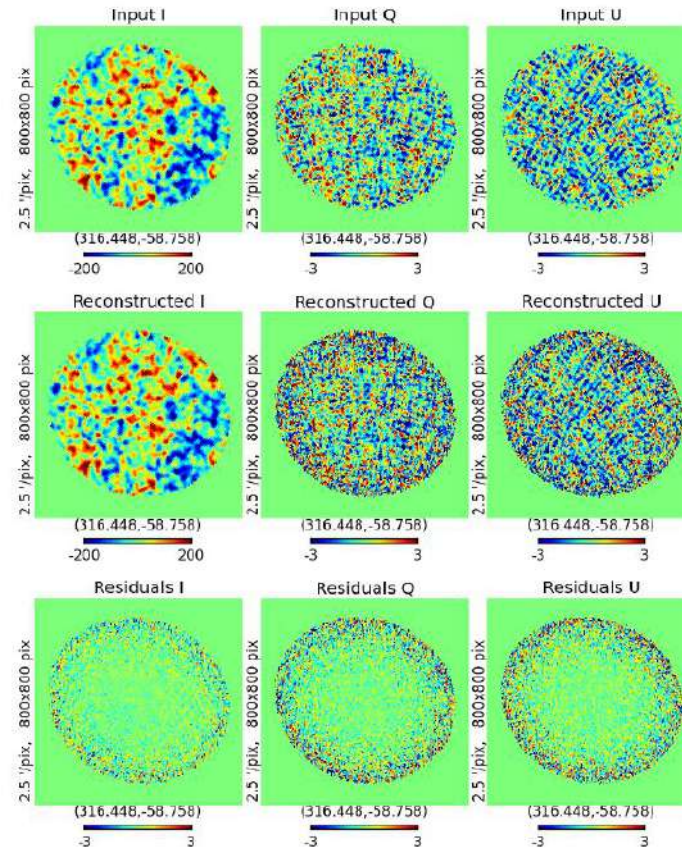


Image produced by a monochromatic point source
along the boresight of the QUBIC telescope

Reconstructing the sky



QUBIC Technical Design Report 1.0 (May 2017)
(Available at <http://qubic.in2p3.fr/QUBIC/Home.html>)

Self-calibration

