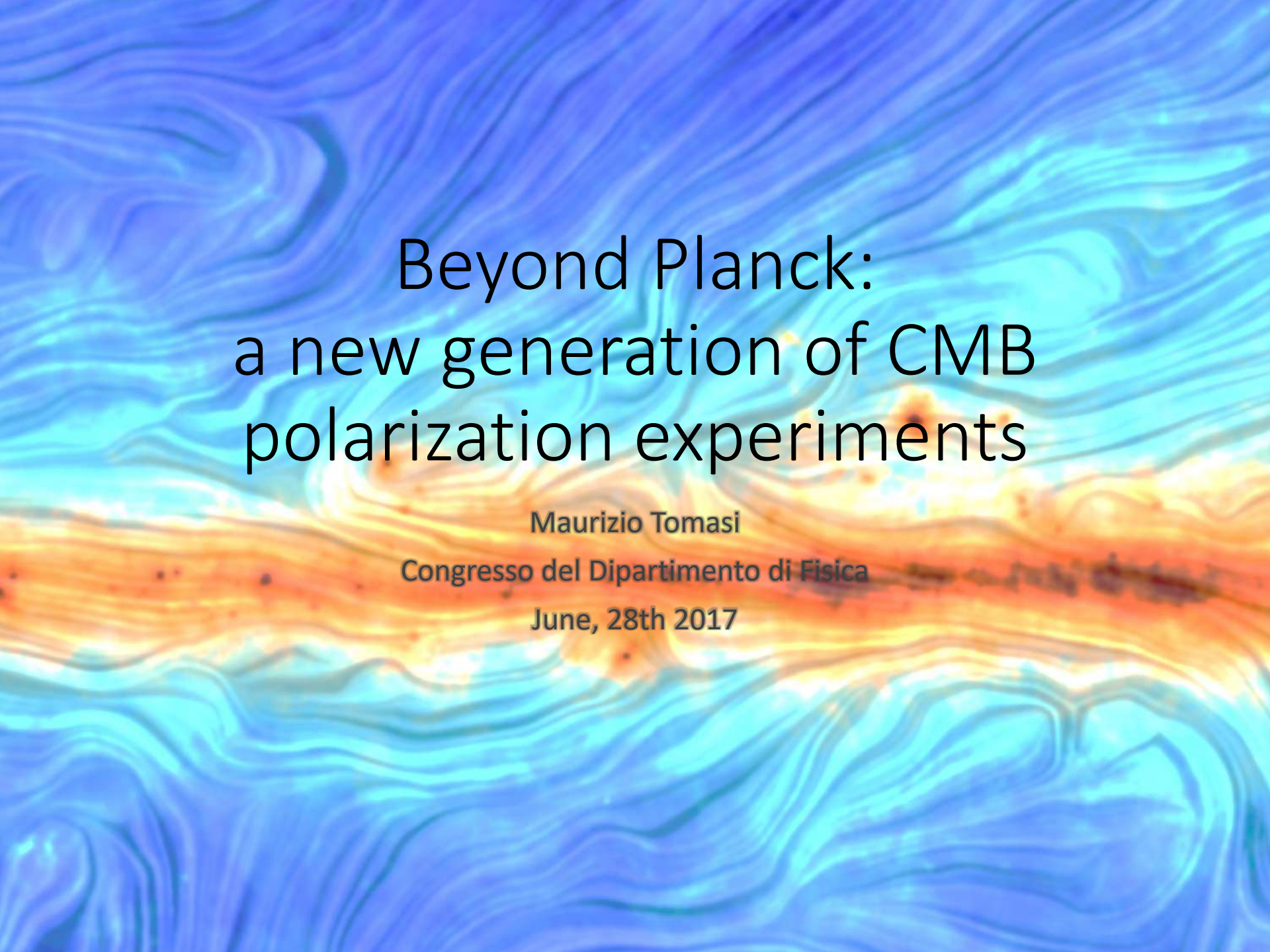

Beyond Planck: a new generation of CMB polarization experiments

Maurizio Tomasi

Congresso del Dipartimento di Fisica

June, 28th 2017

CMB cosmology group @ UniMI

Marco Bersanelli (P. O.)

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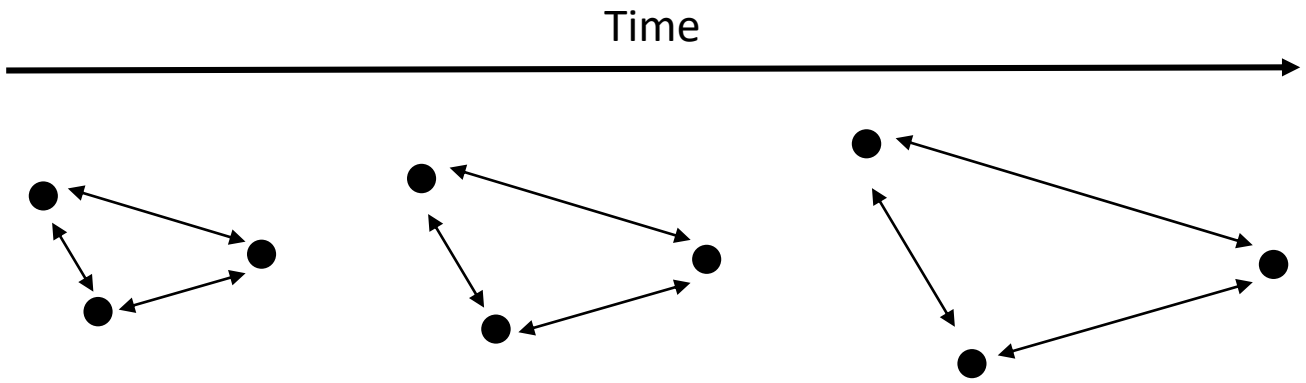
Antonino Troja (P.h.D. student)

Sabrina Realini (Borsista)

What are B-modes?

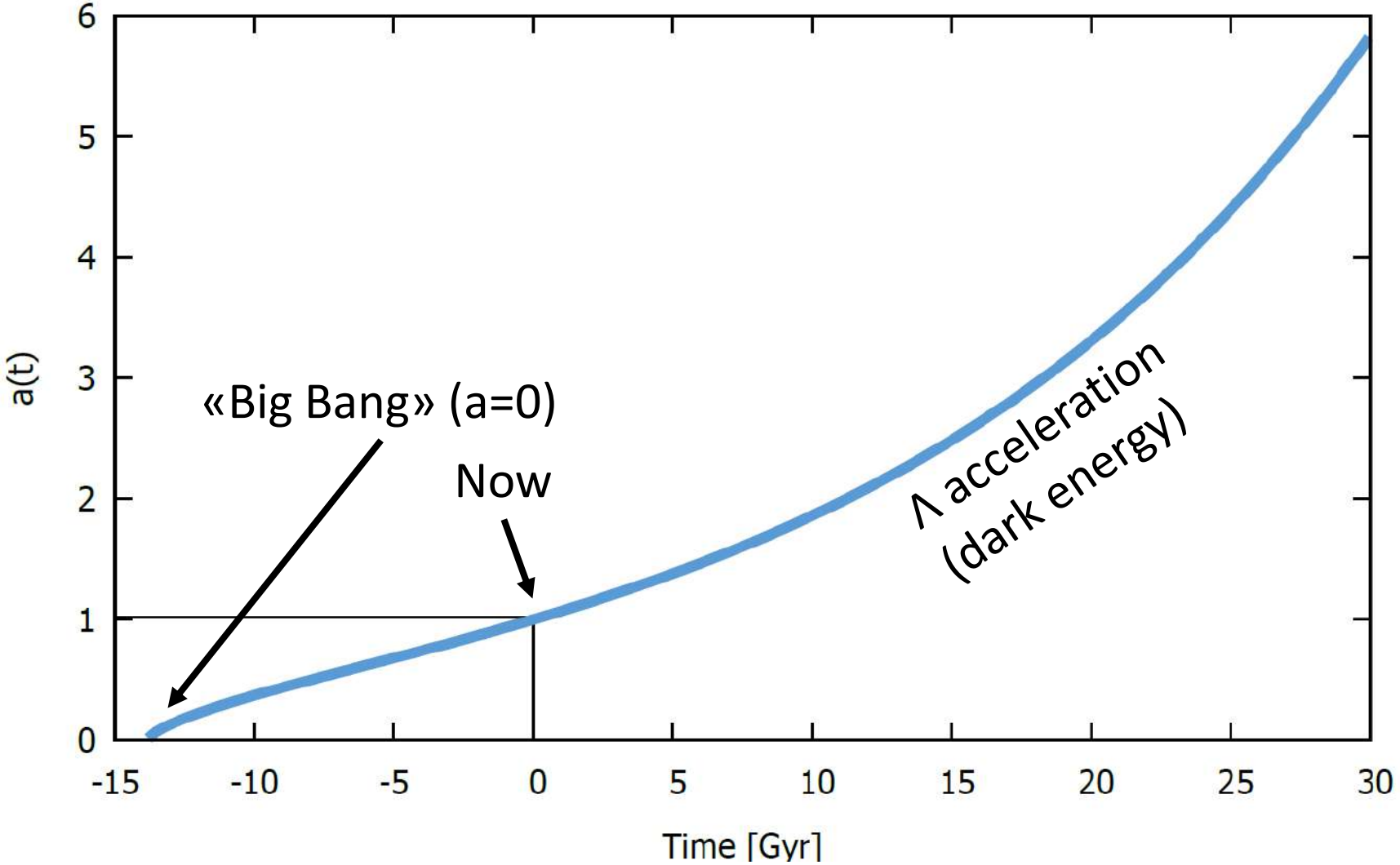
And why are they important?

Friedmann-Lemaître expansion

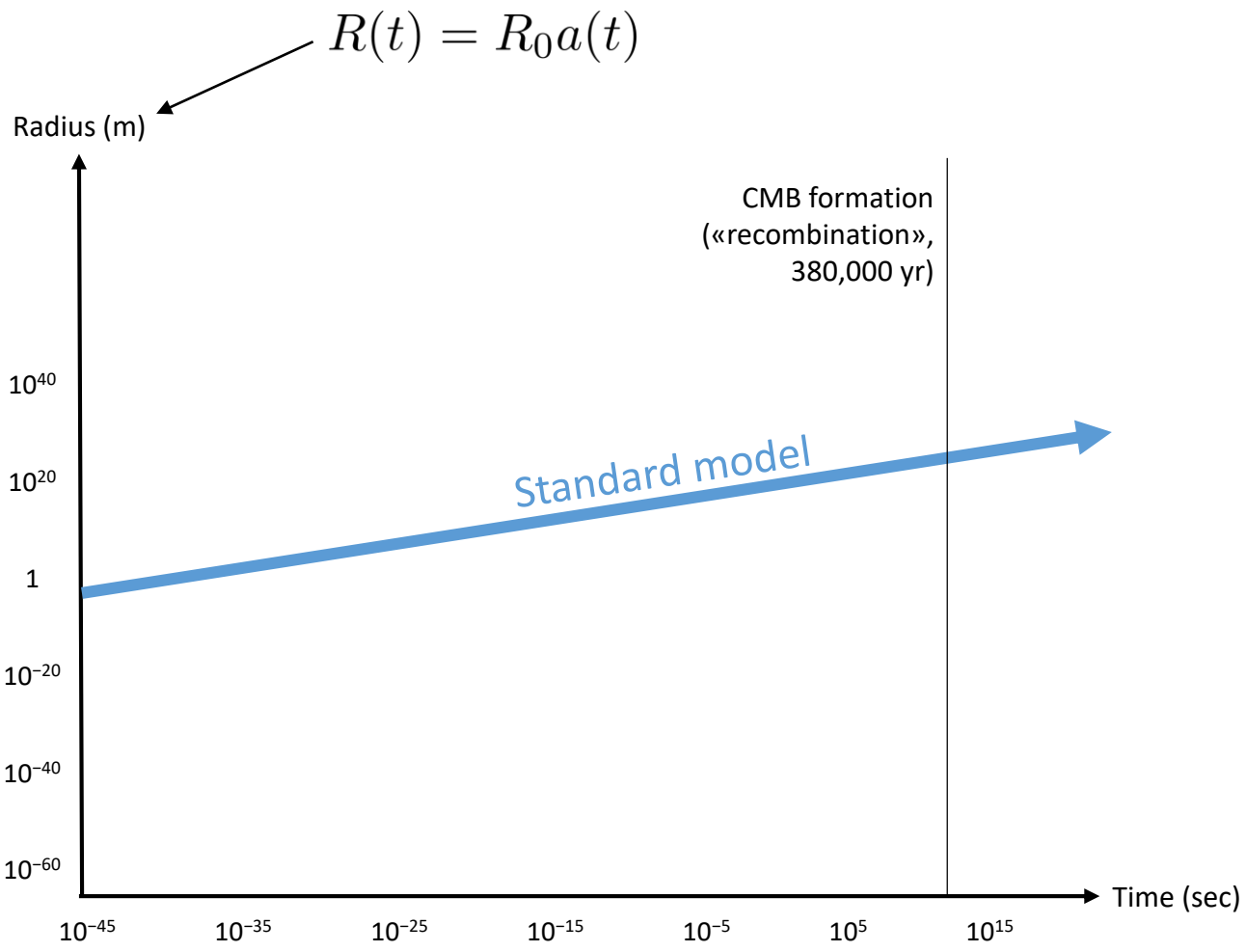


$$d(t) = a(t) R_0$$

Friedmann-Lemaître expansion



Cosmic inflation (t→0)



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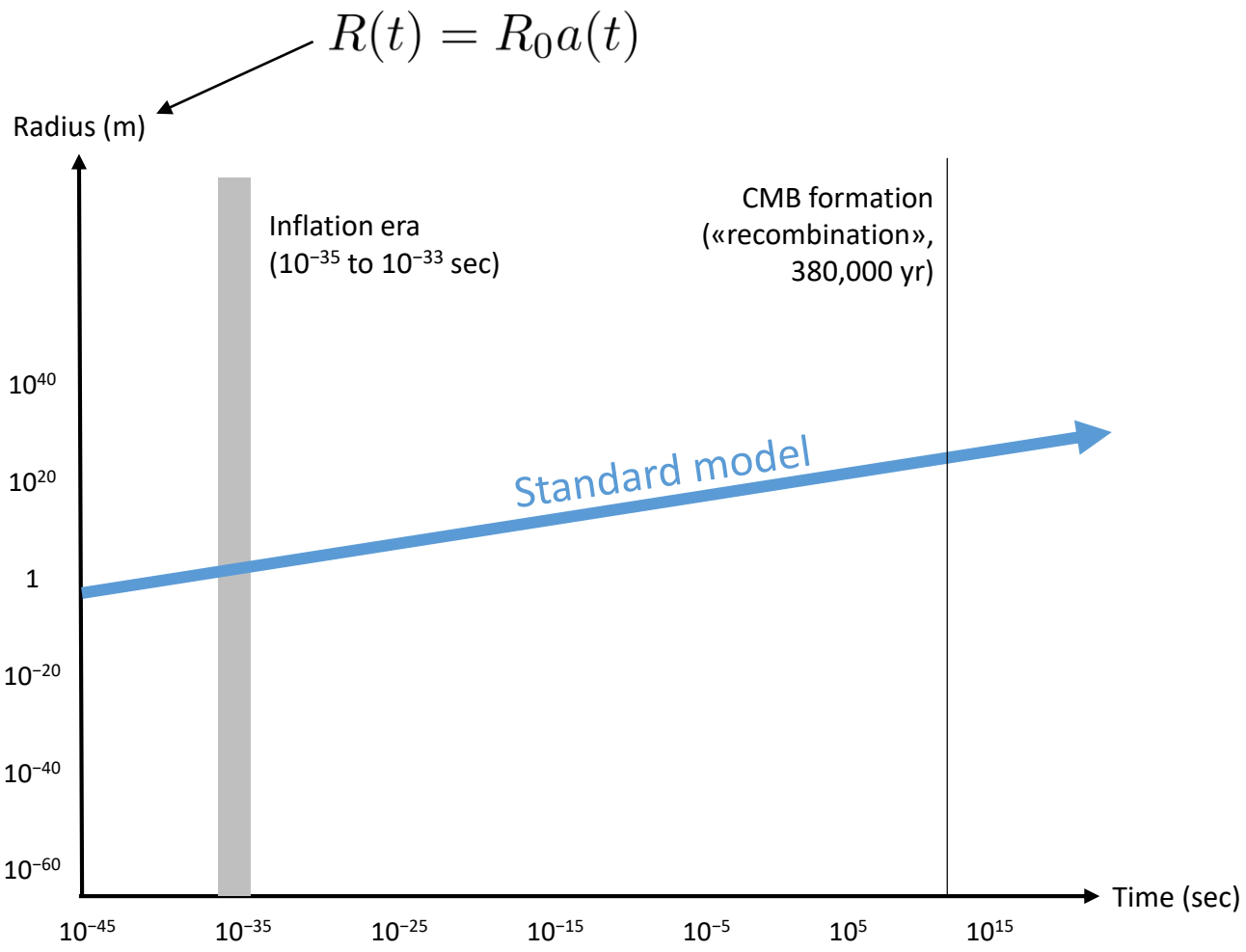
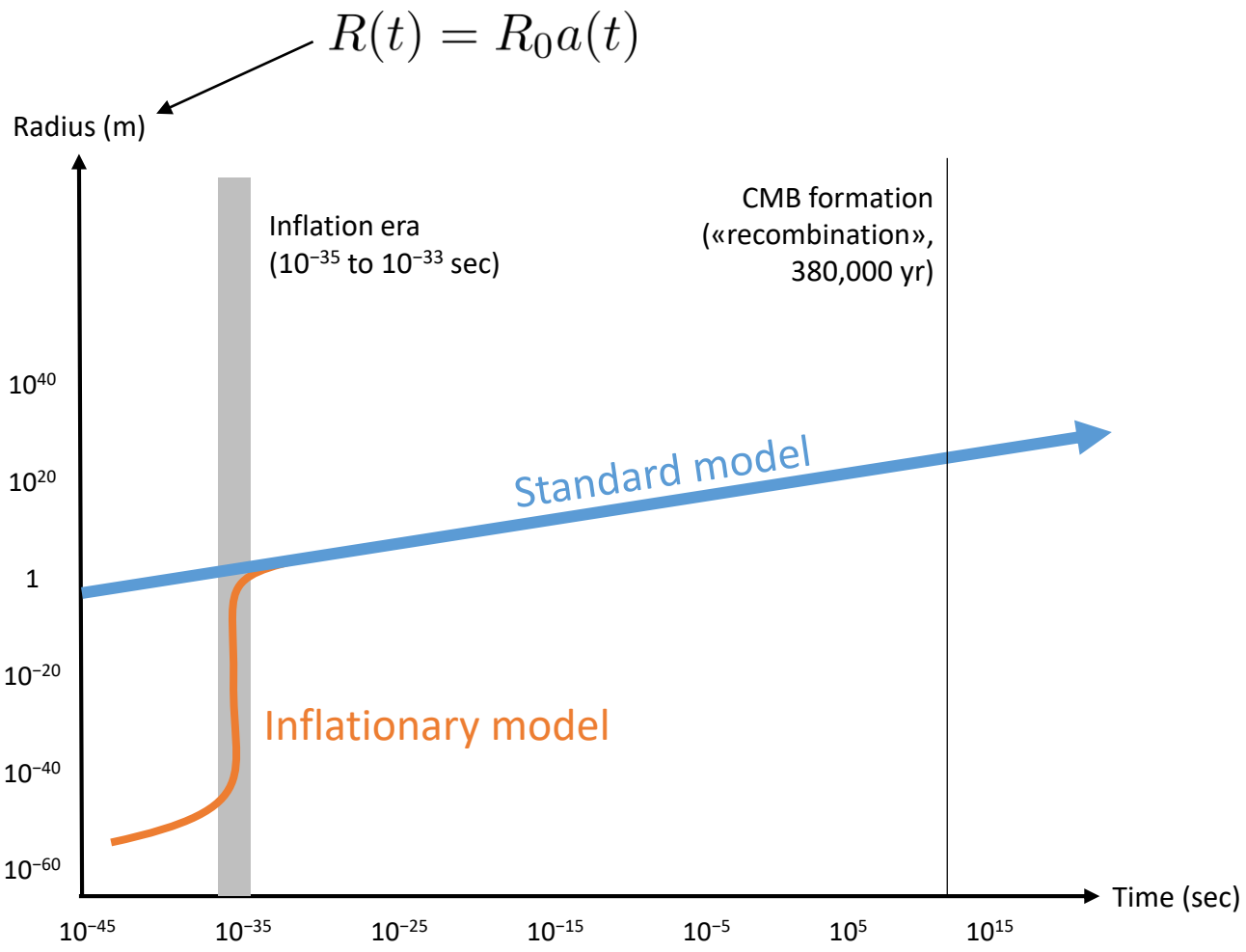
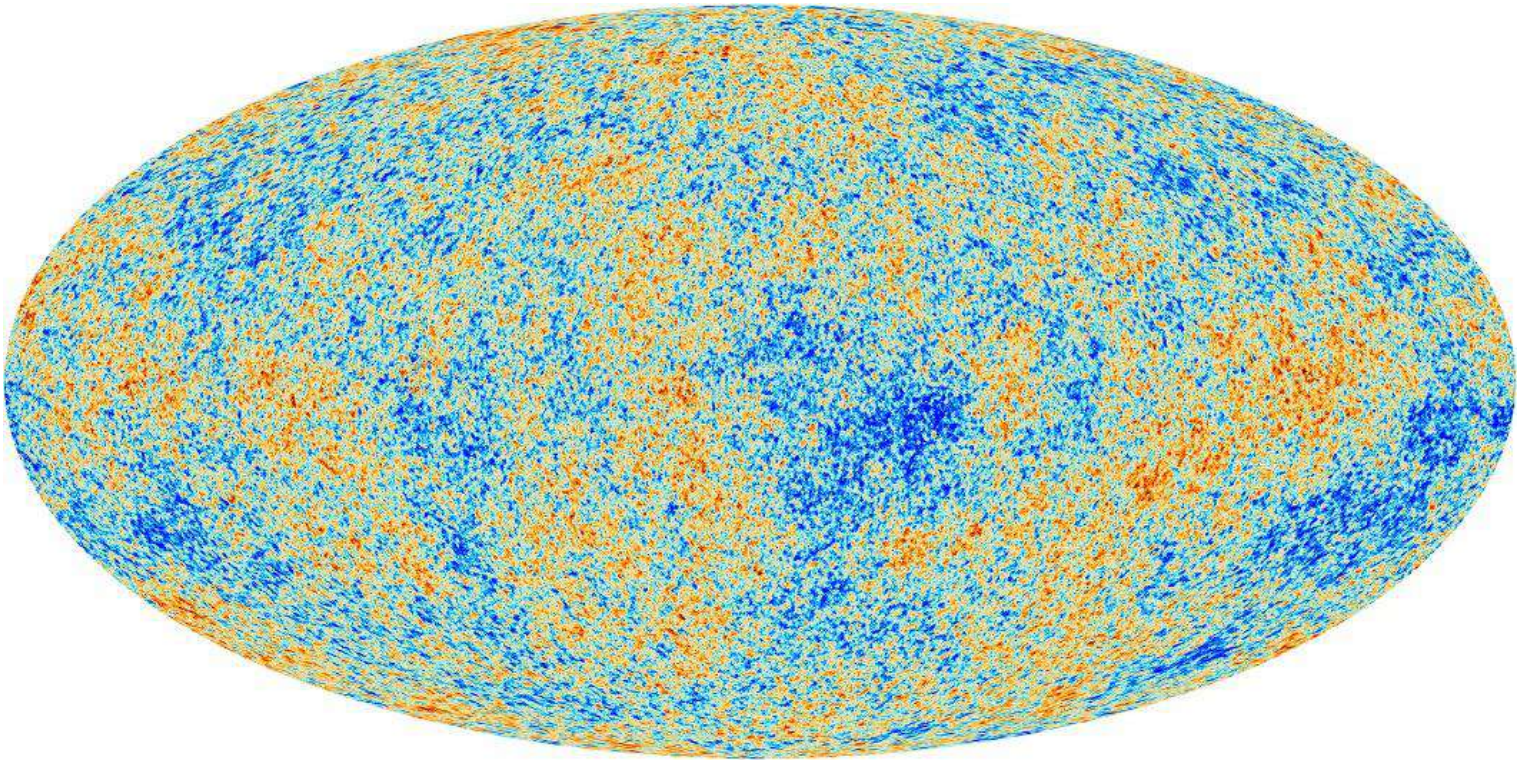


Cosmic inflation (t→0)

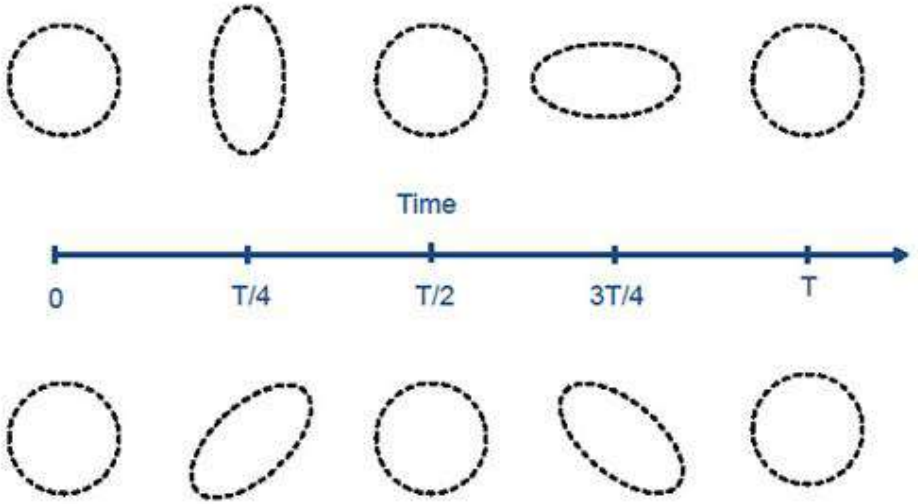


Temperature anisotropies in the CMB



- 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 (?)

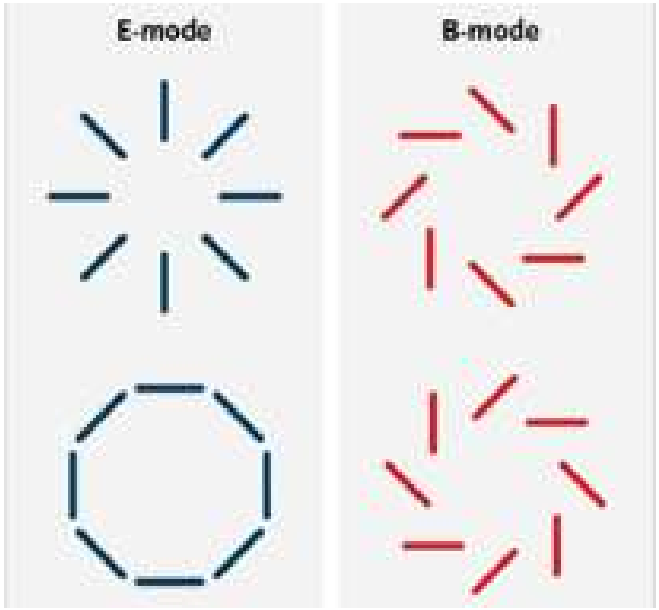
Metric fluctuations



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

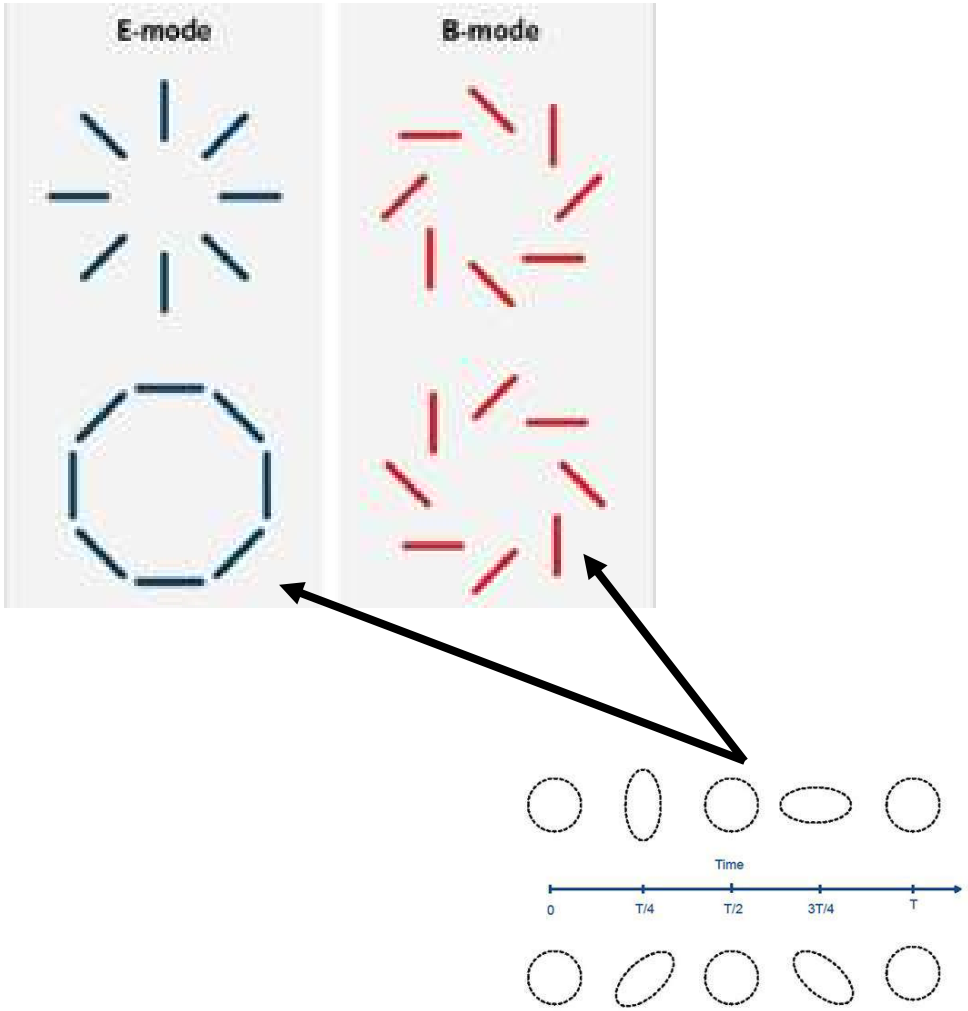
Detecting metric fluctuations in the CMB

CMB polarization pattern is decomposed into



Detecting metric fluctuations in the CMB

CMB polarization pattern is decomposed into



Detecting metric fluctuations in the CMB

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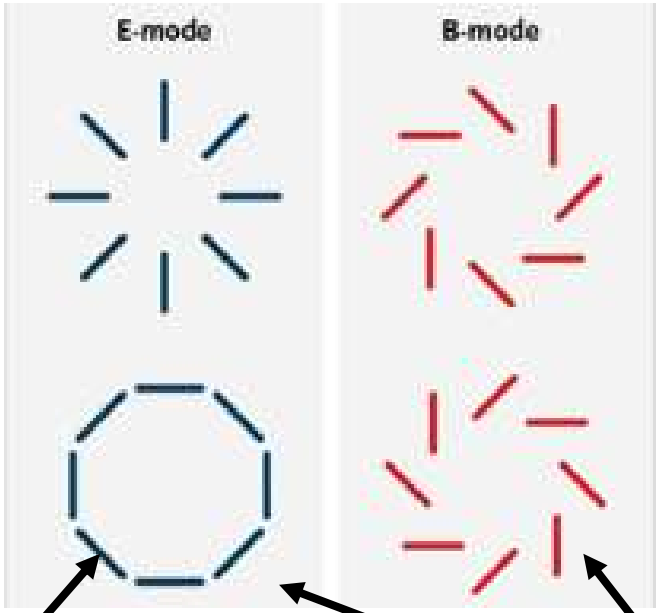
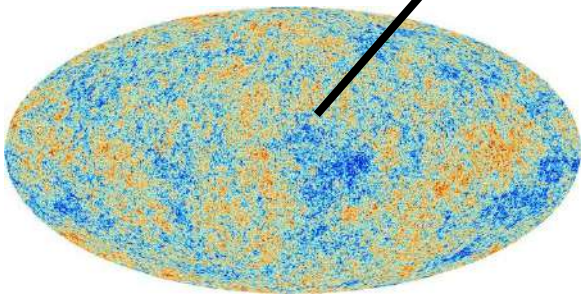
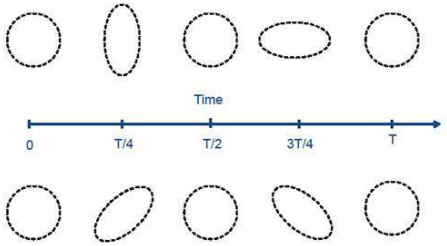
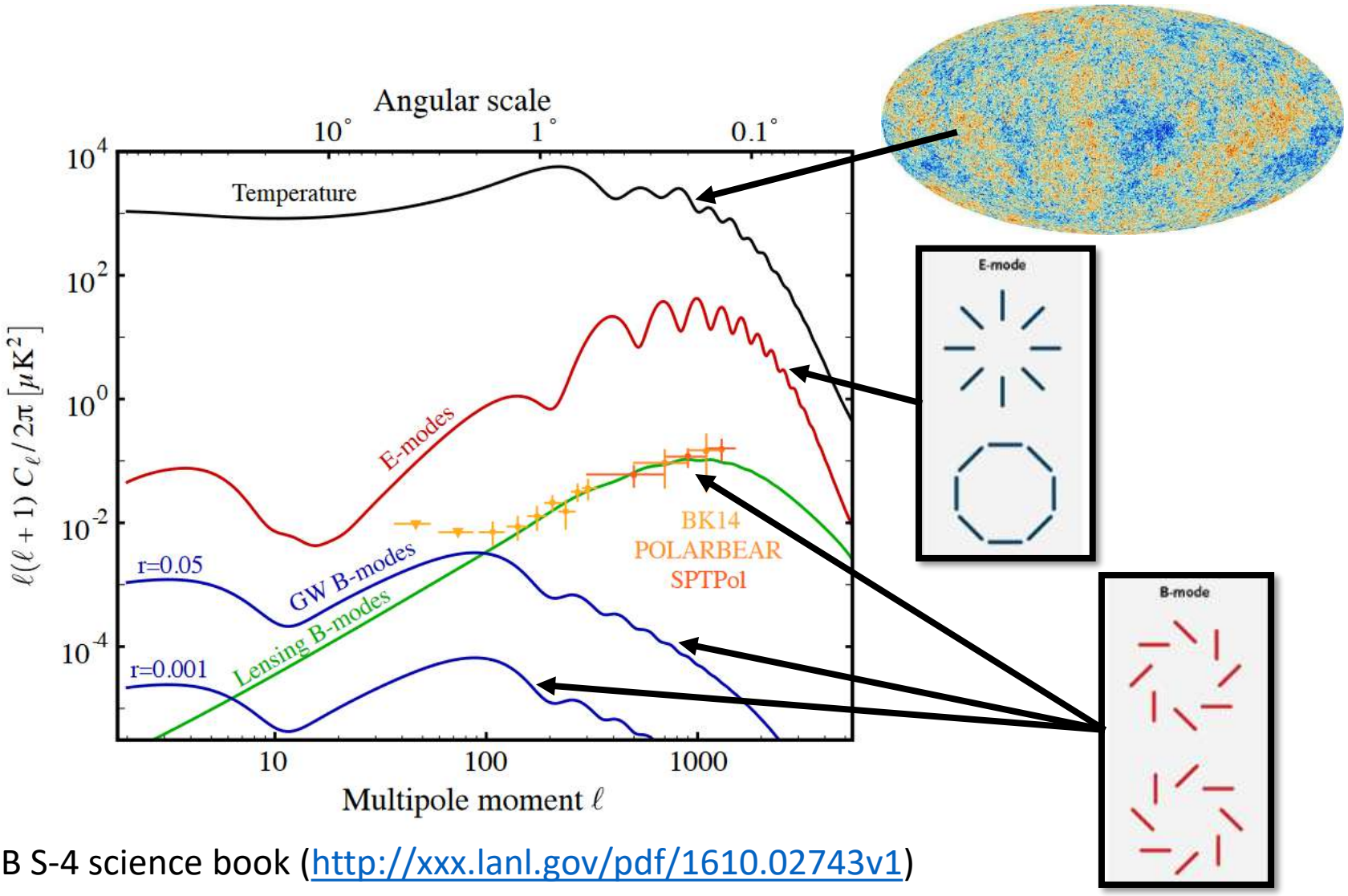




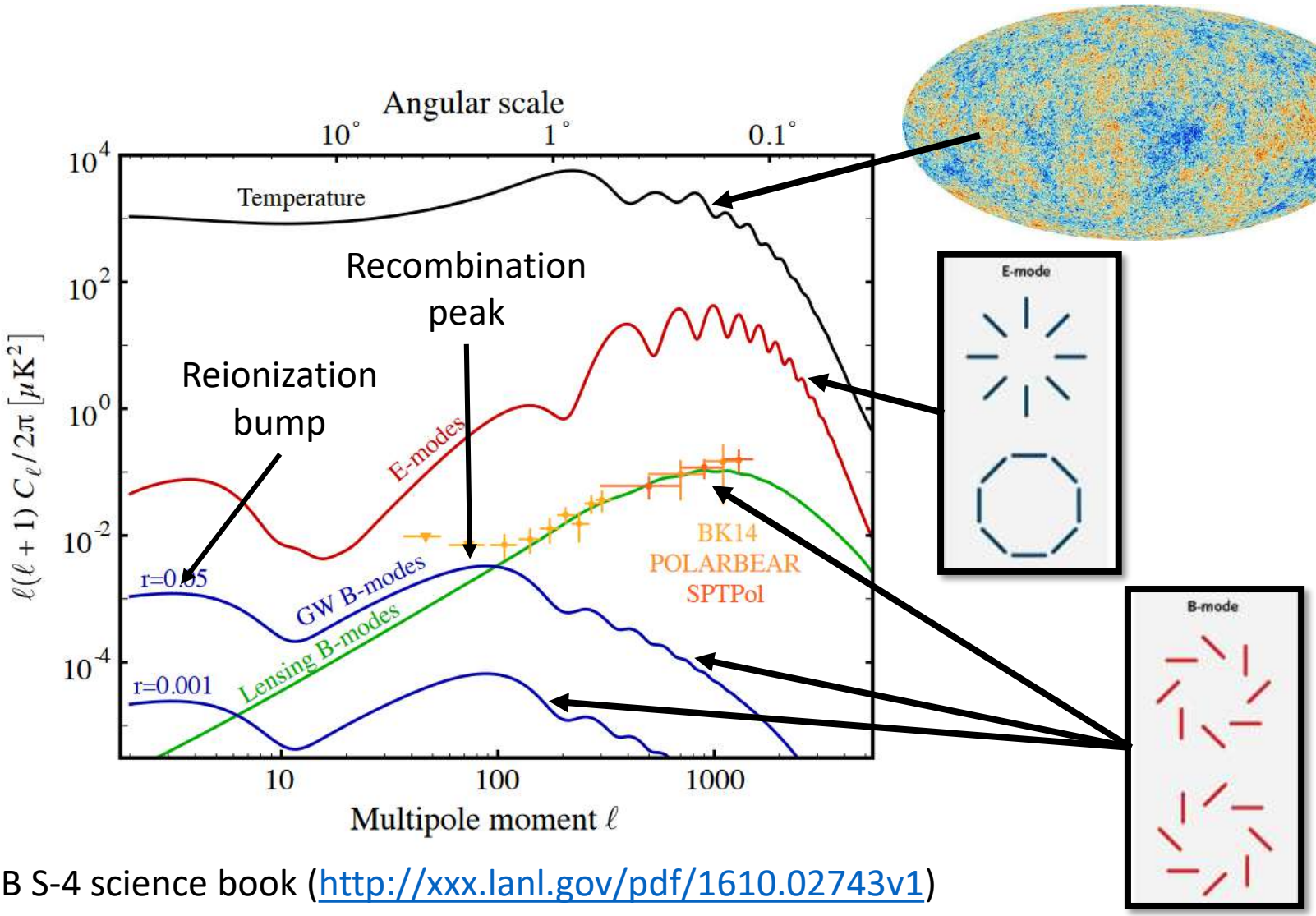


Detecting metric fluctuations in the CMB



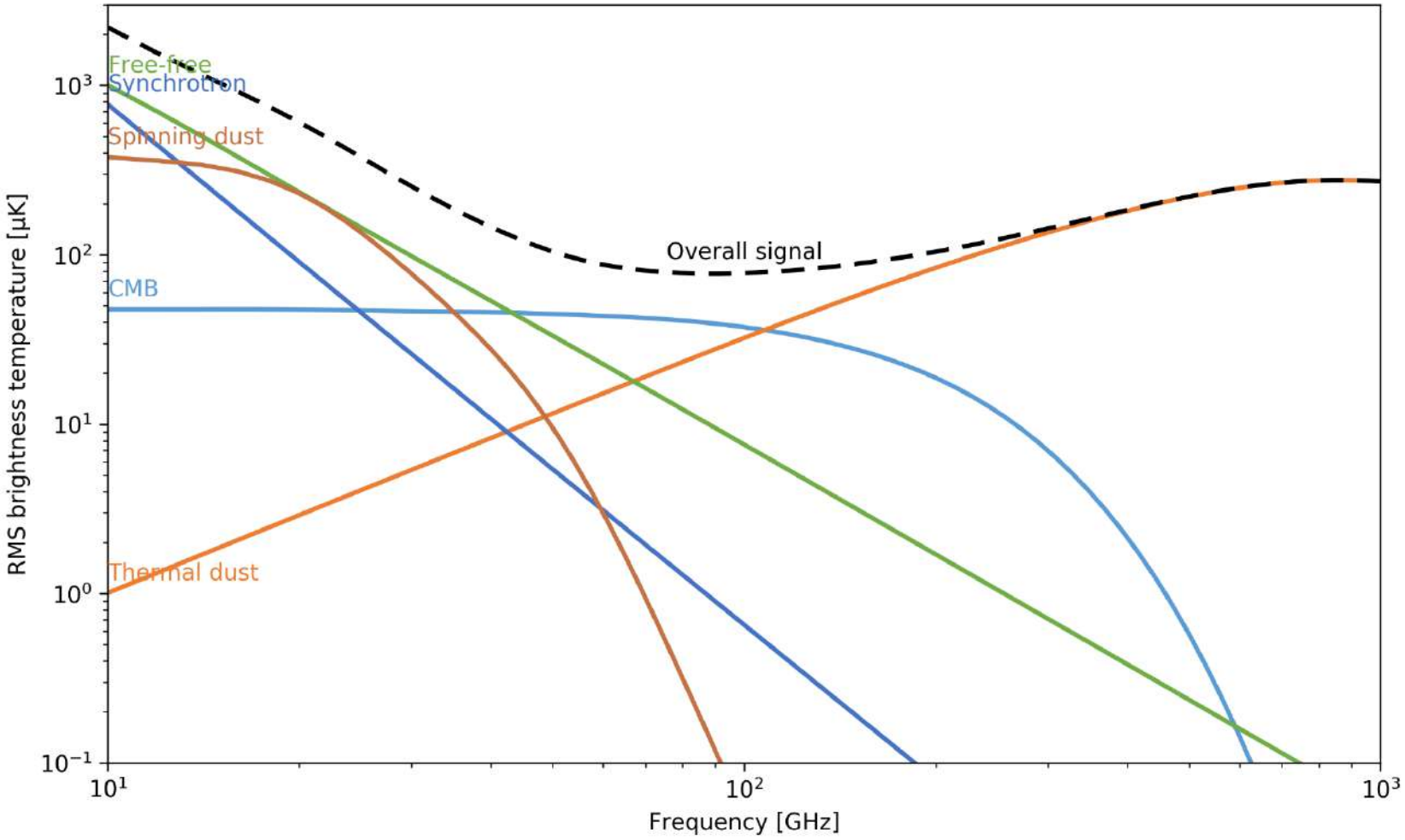
CMB S-4 science book (http://xxx.lanl.gov/pdf/1610.02743v1)

Detecting metric fluctuations in the CMB

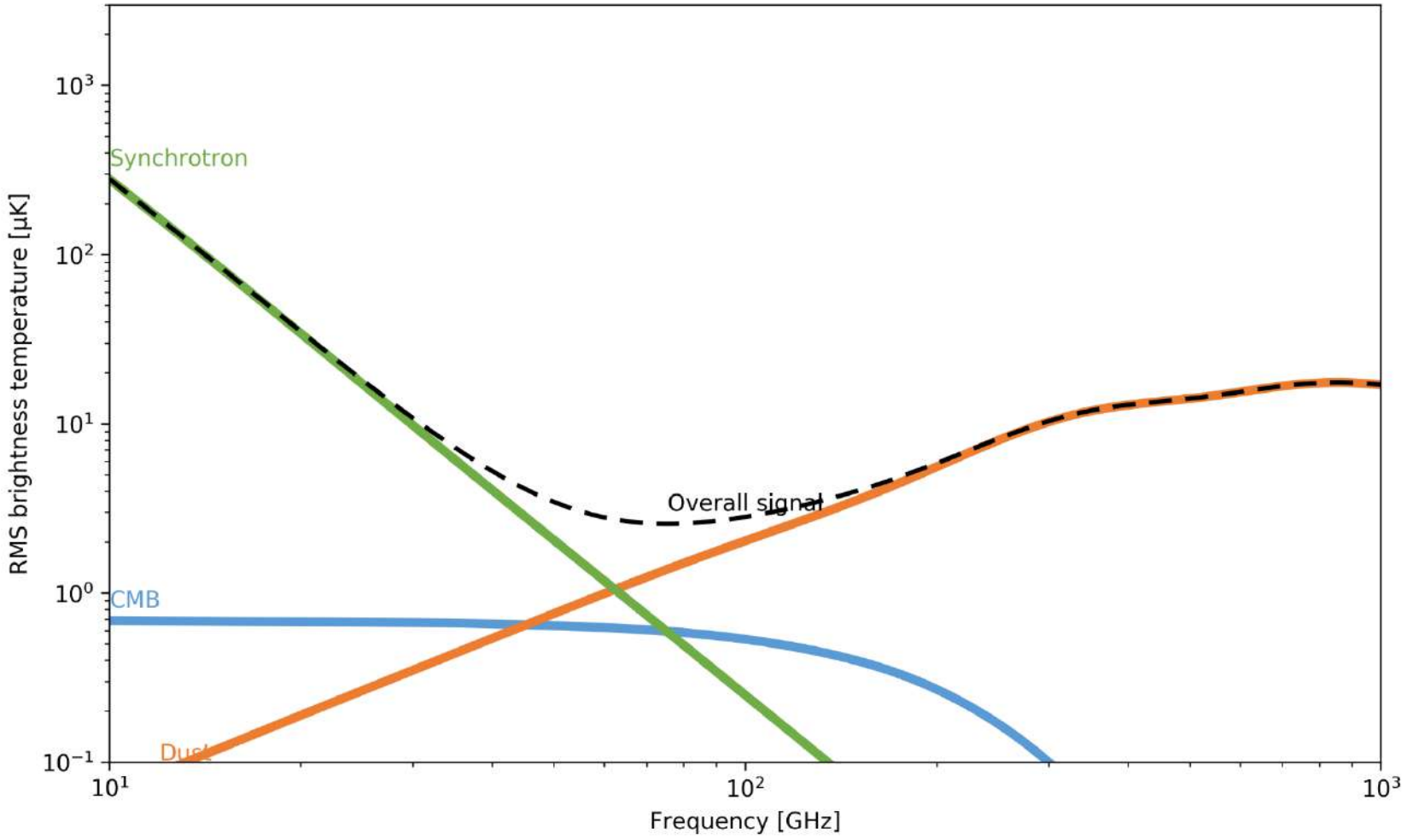


CMB S-4 science book (http://xxx.lanl.gov/pdf/1610.02743v1)

CMB and «foregrounds» (intensity)

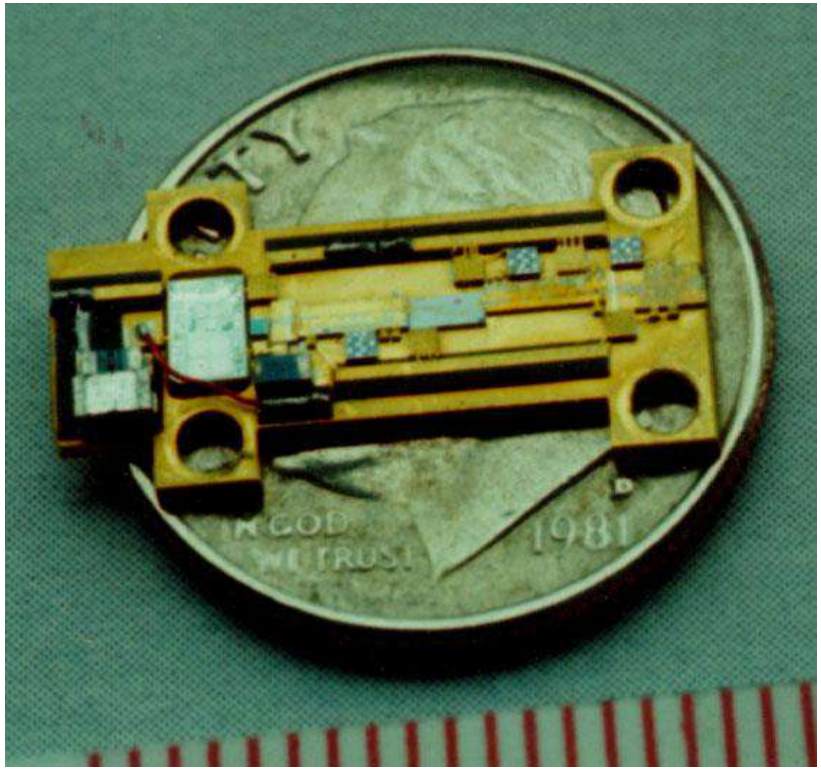


CMB and «foregrounds» (polarization)

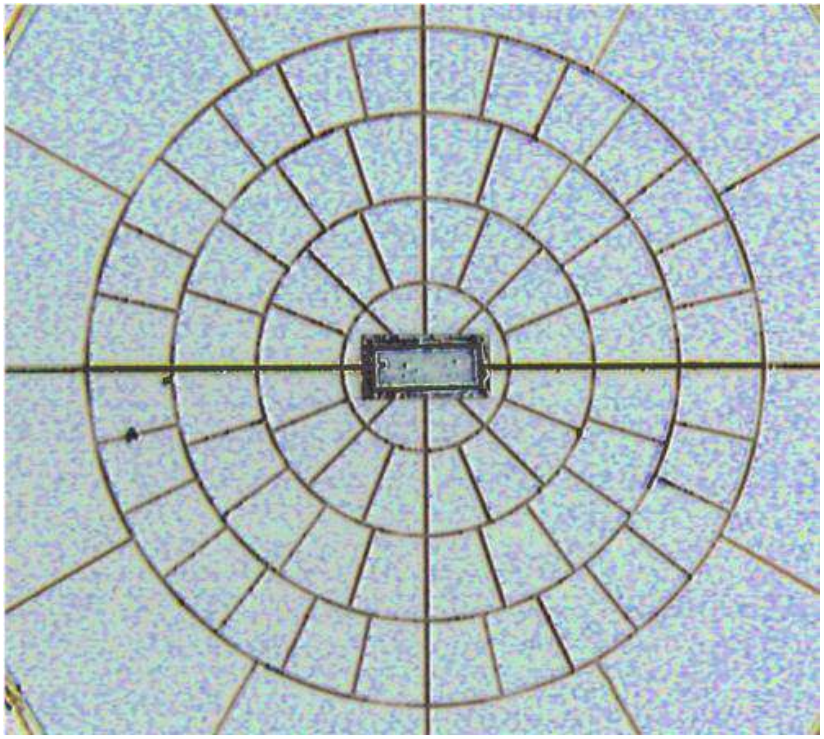


Detectors in the 10–1000 GHz range

High Electron Mobility Transistors (HEMTs)



Transition Edge Sensor (TES) bolometer



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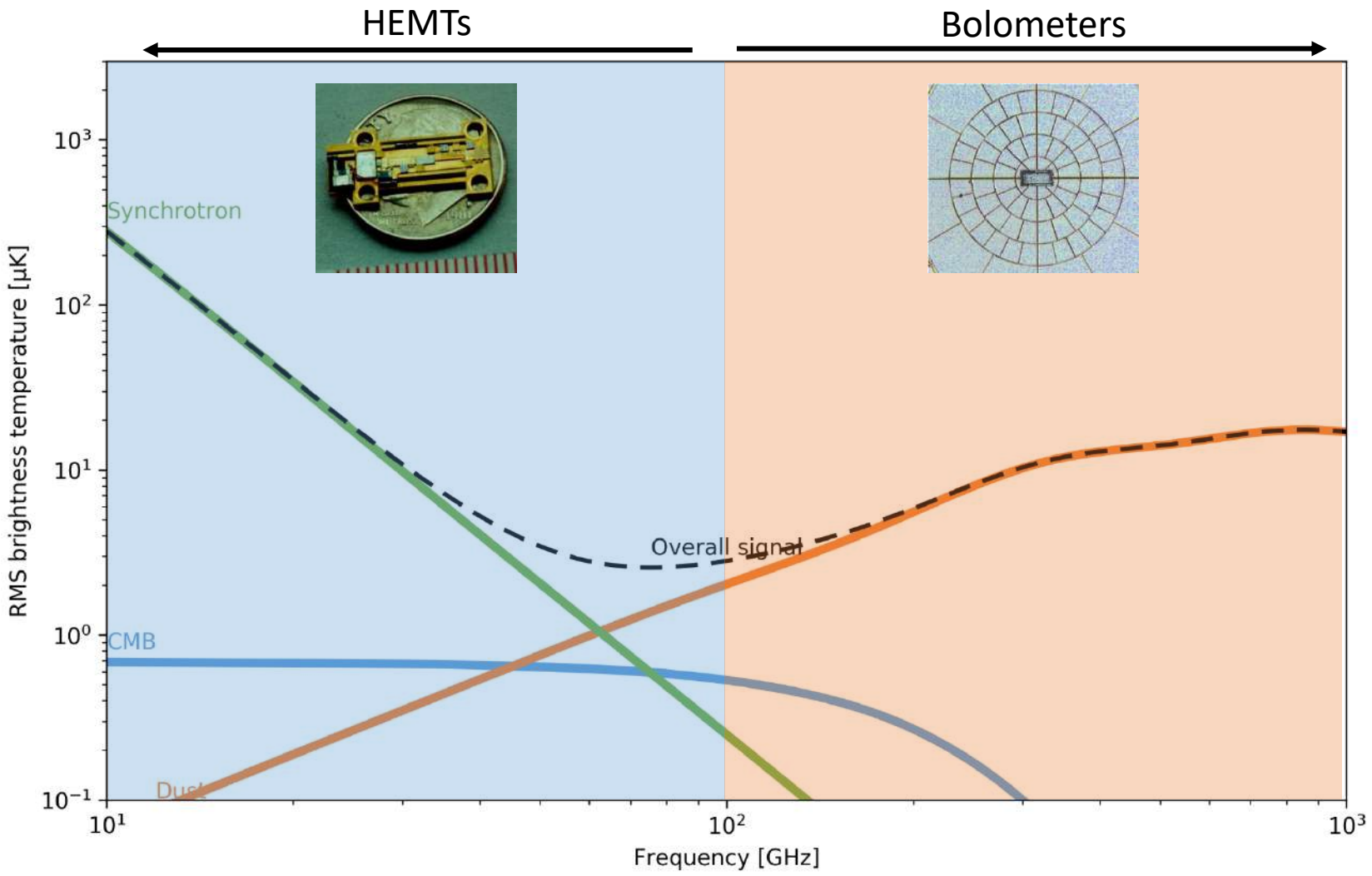
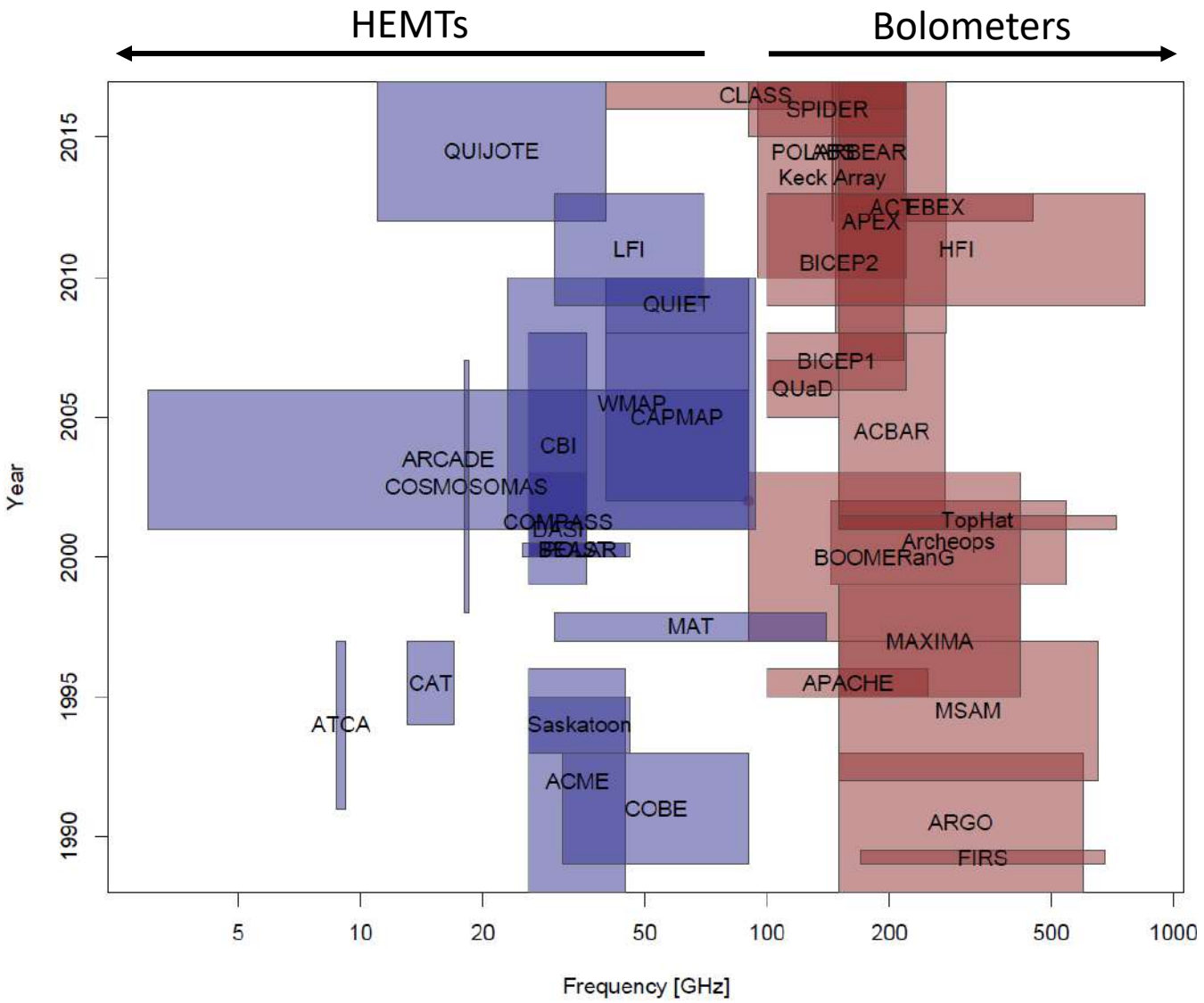
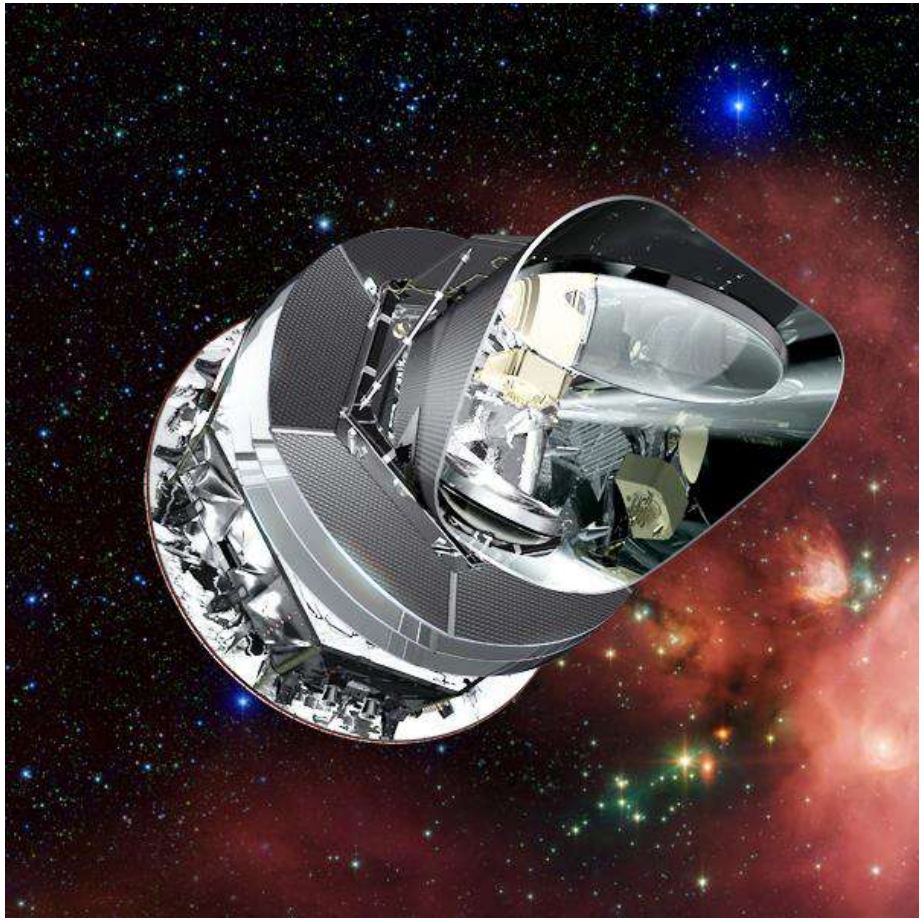


Past CMB experiments

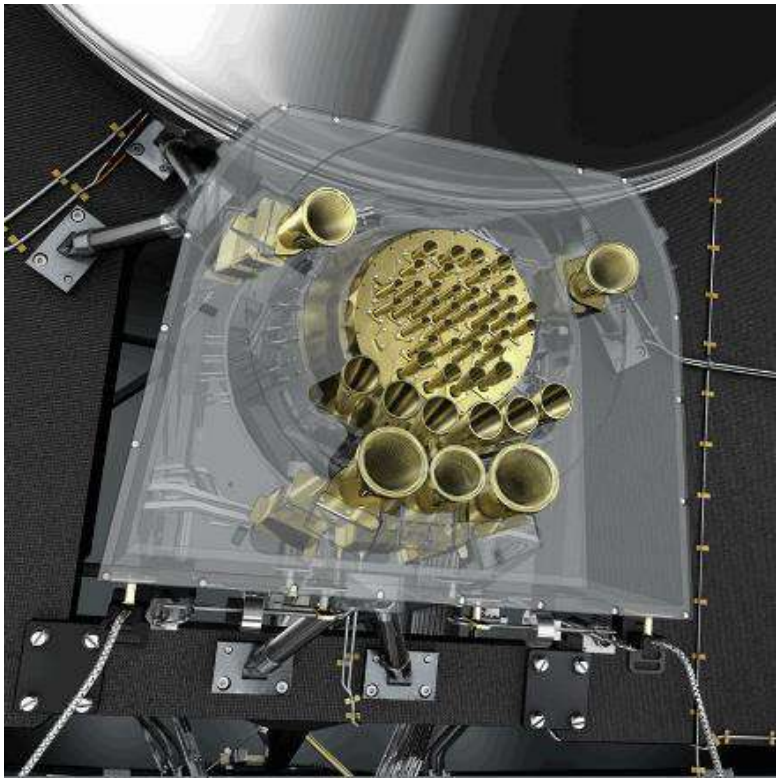


The breakthrough of Planck

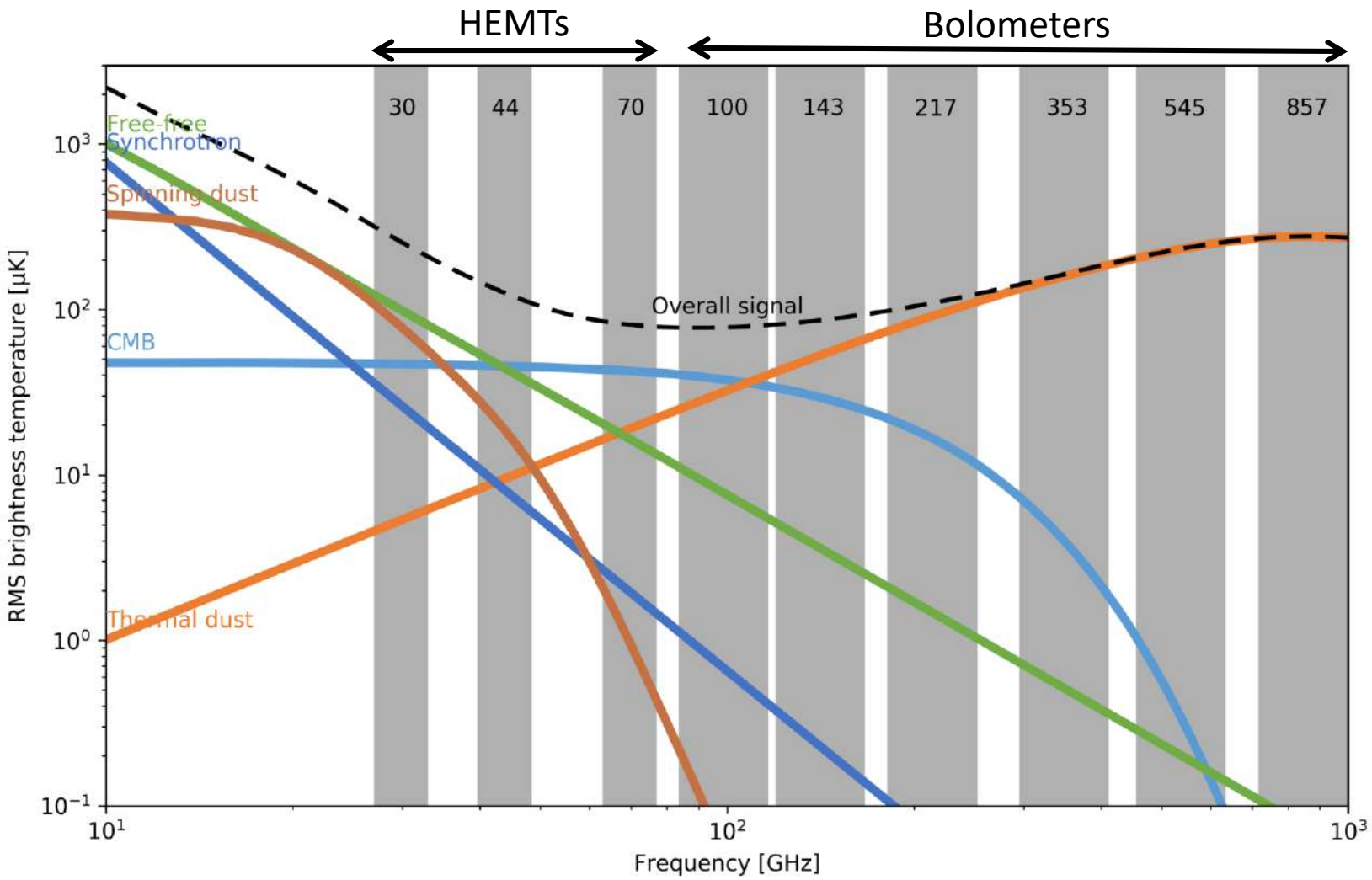
Planck (2009–2013, ESA)



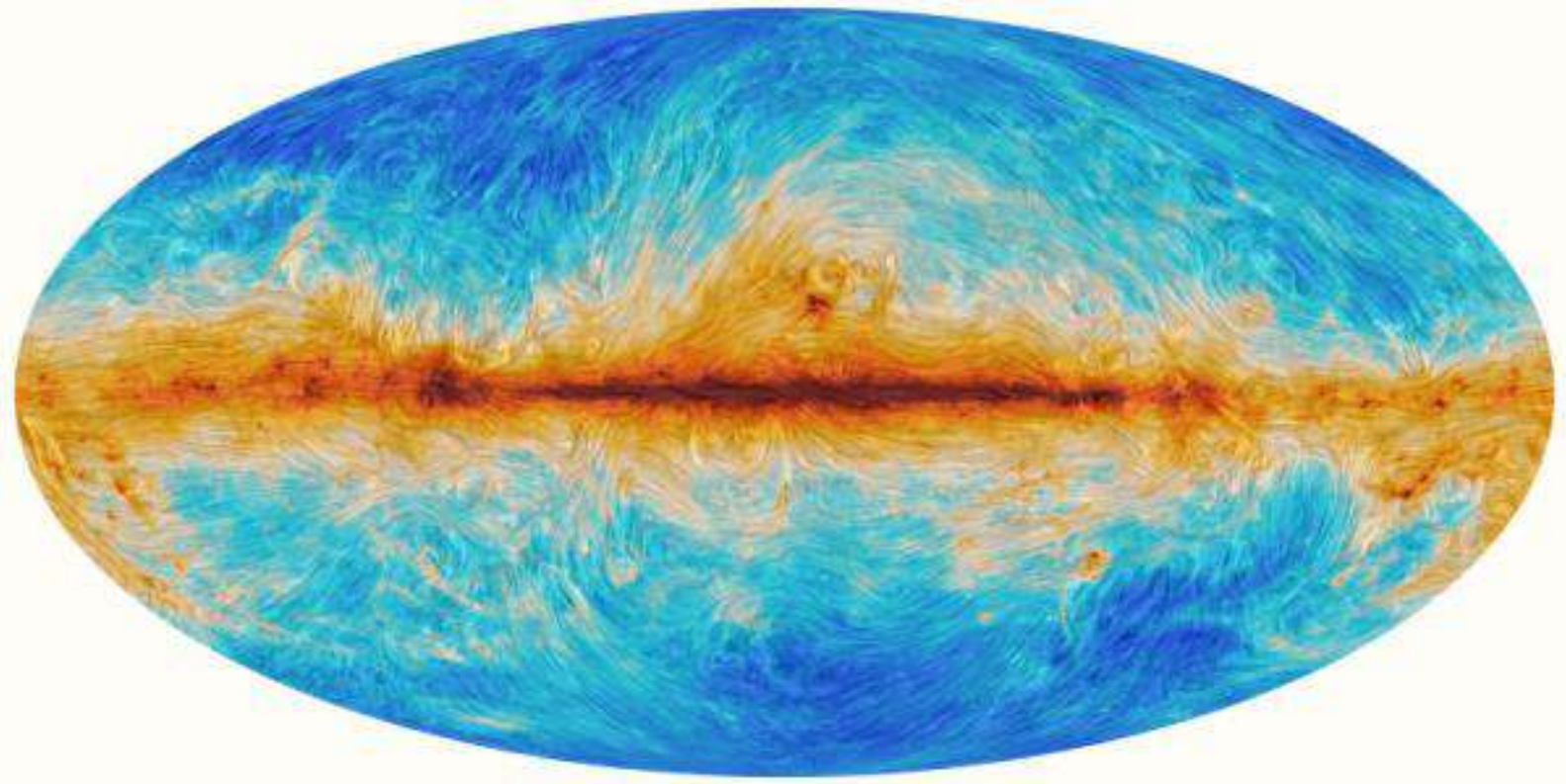
11+36 horns, 22+52 detectors



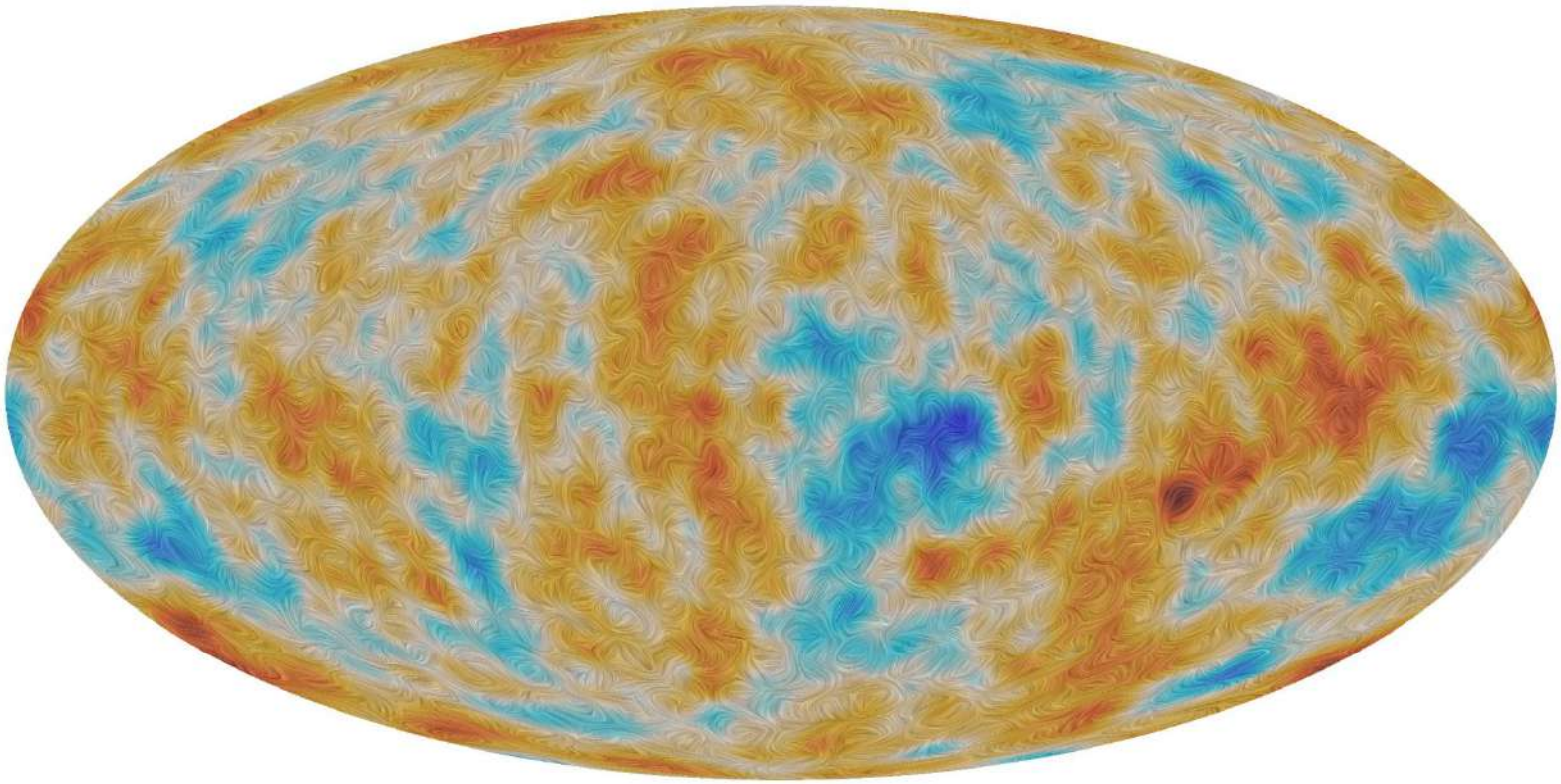
Planck frequency coverage



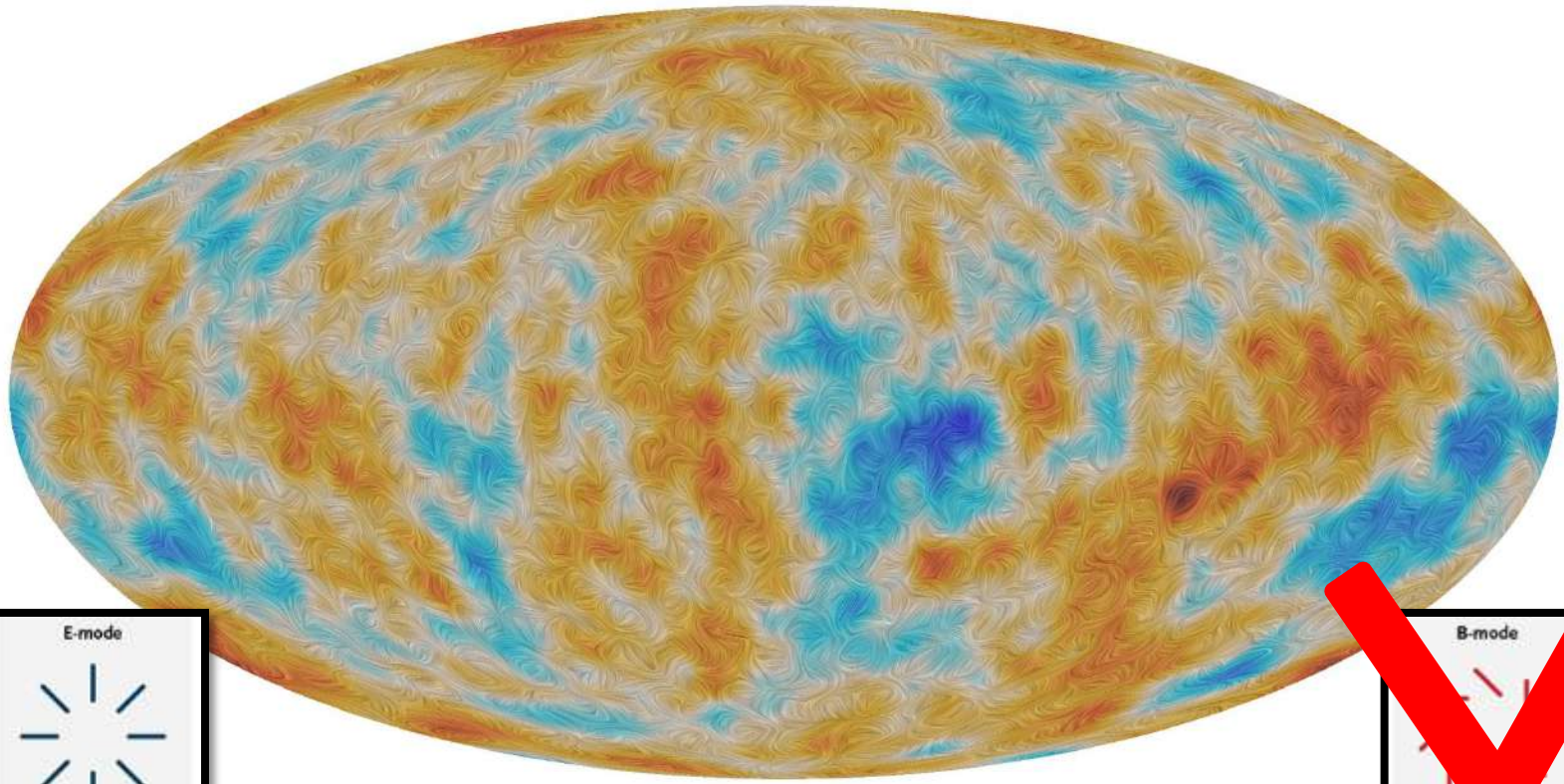
Planck polarization maps

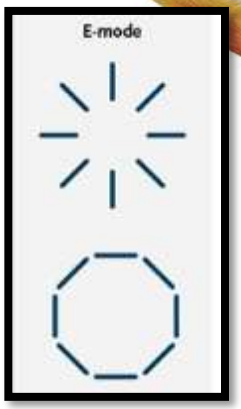


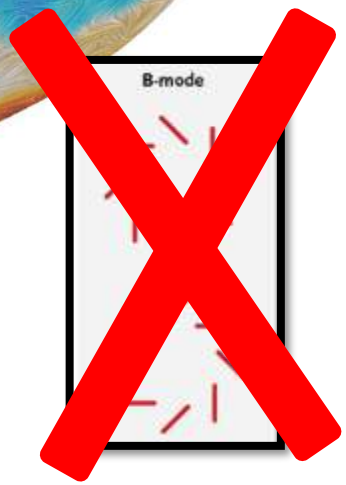
Planck polarization maps



Planck polarization maps







Future experiments

What do we need to detect B-modes?

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

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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

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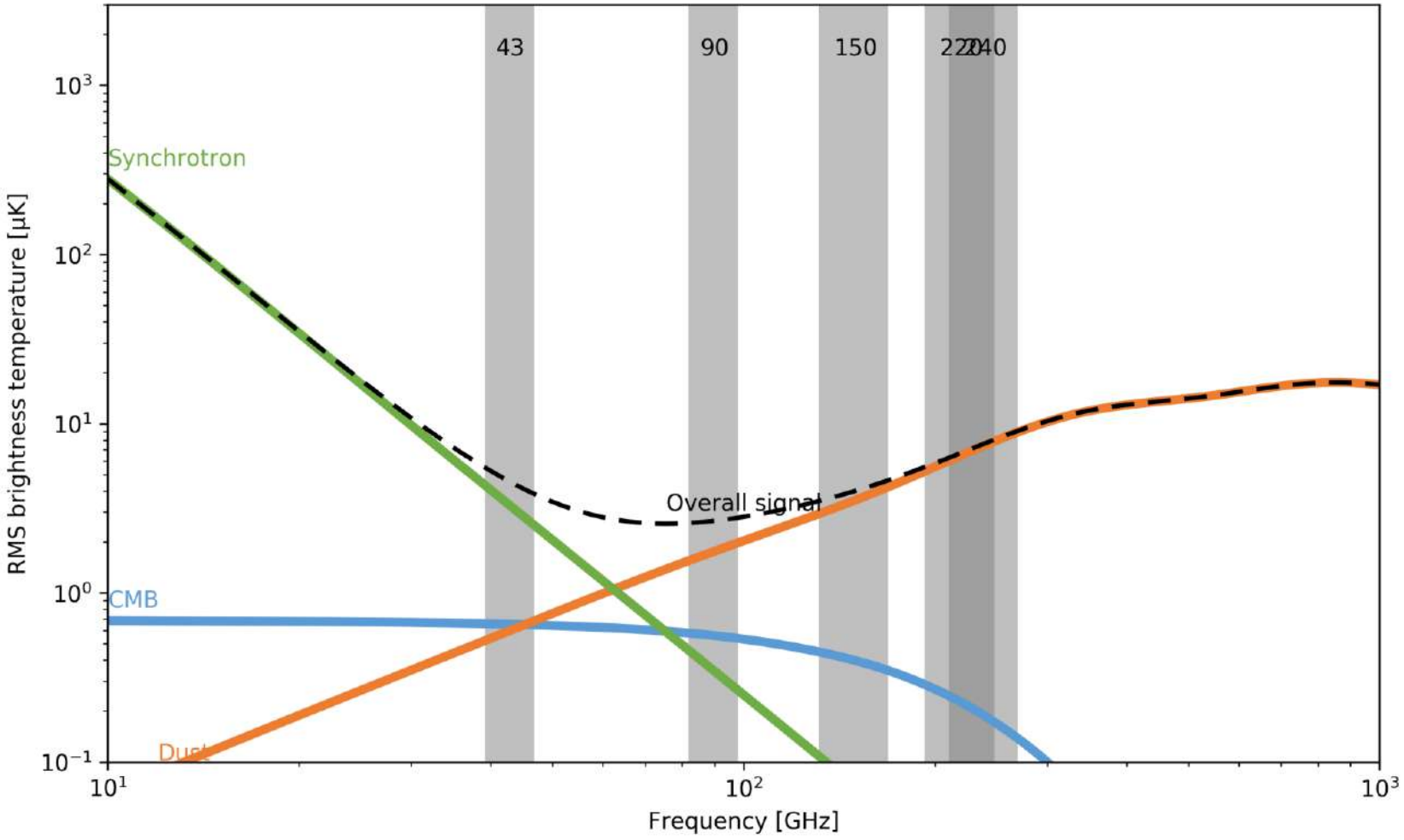
The Large Scale Polarization Explorer (LSPE)

LSPE at a glance

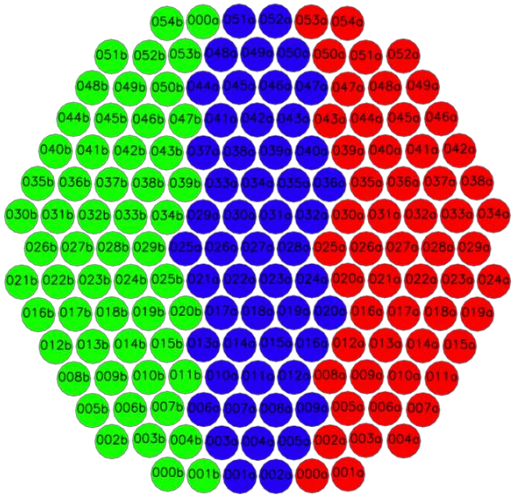
- ASI (Agenzia Spaziale Italiana) project
- Measure large-scale polarization at 40–240 GHz
- Two instruments:
  - SWIPE (balloon borne bolometers): 150, 220, 240 GHz, PI: Paolo De Bernardis (Sapienza)
  - STRIP (ground-based HEMTs): 40 and 90 GHz, PI: Marco Bersanelli (UniMI)

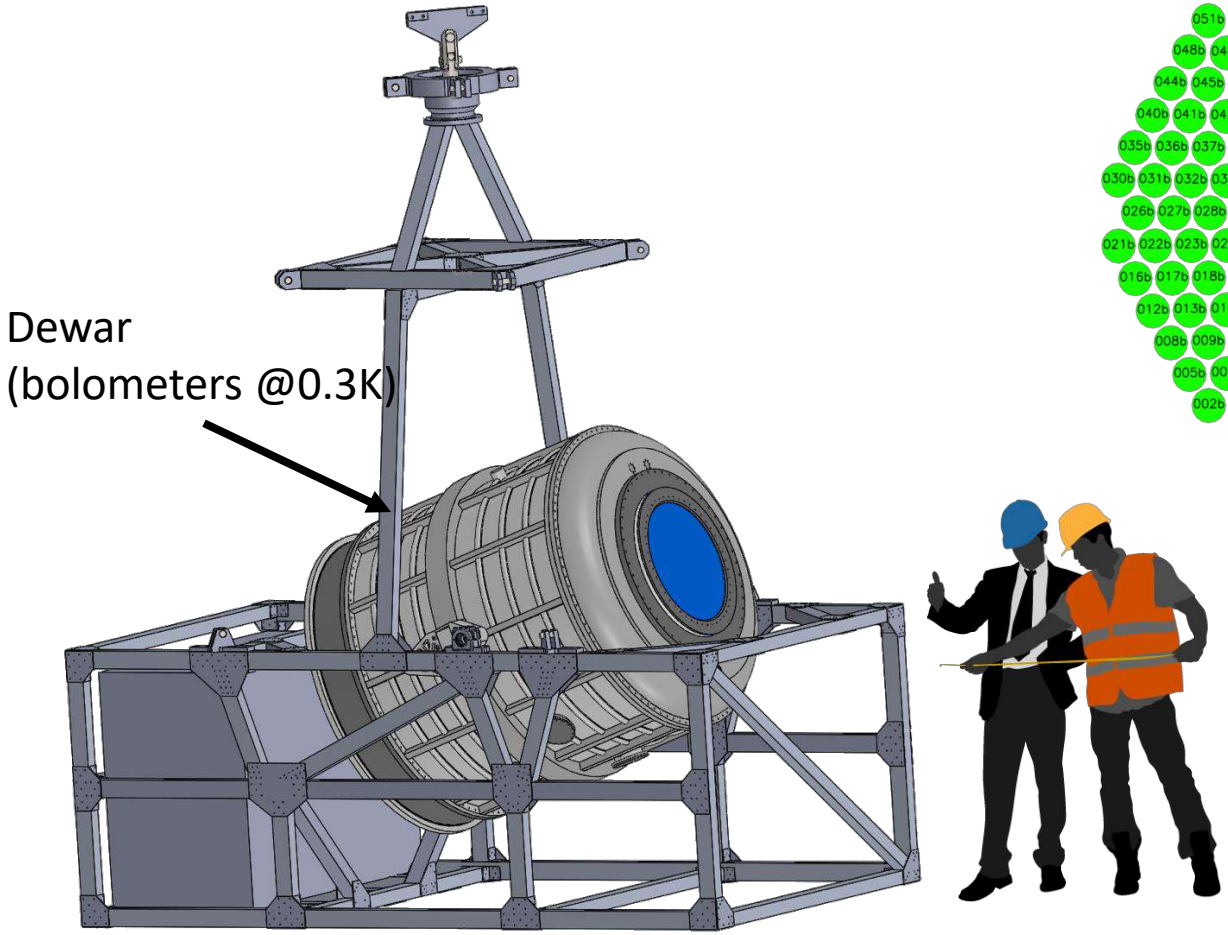
LSPE frequency coverage



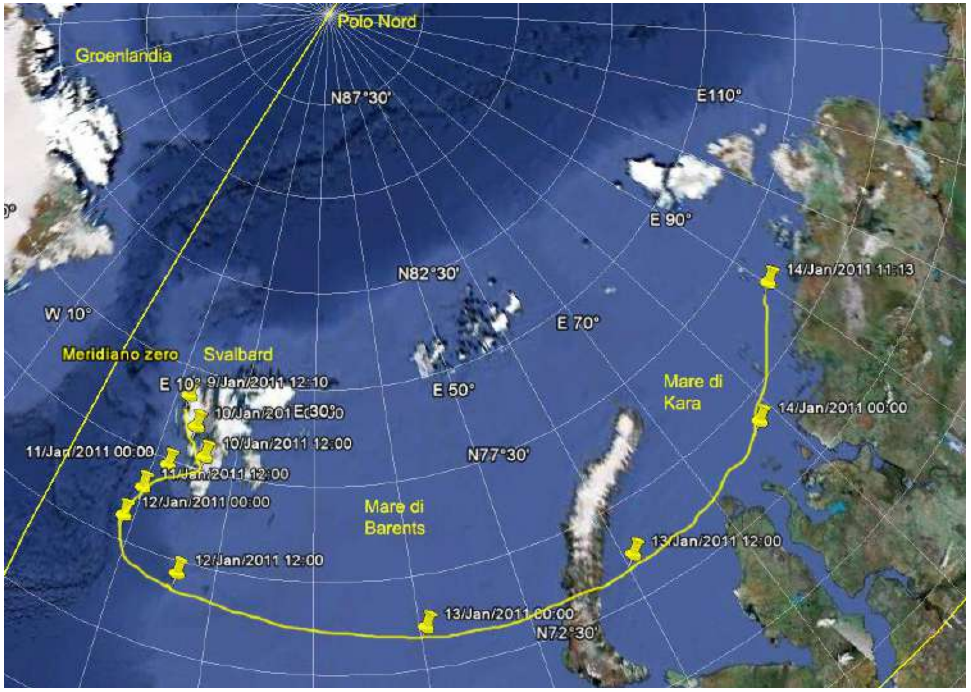
SWIPE: the balloon-borne high frequency instrument

330 TES detectors





SWIPE: the balloon-borne high frequency instrument

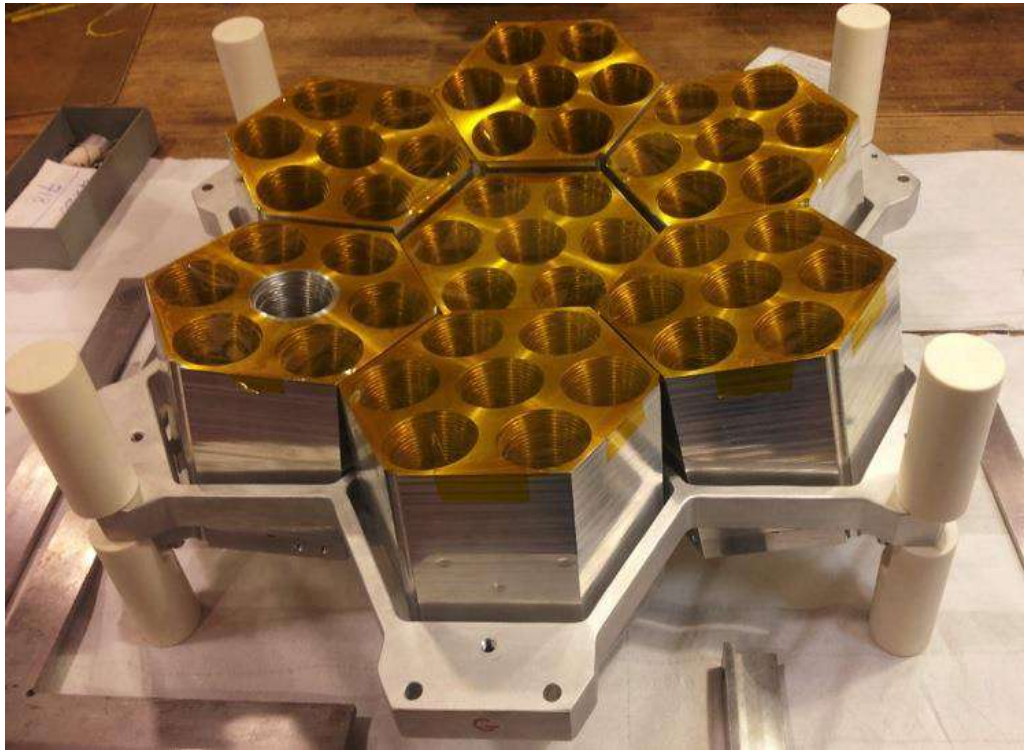


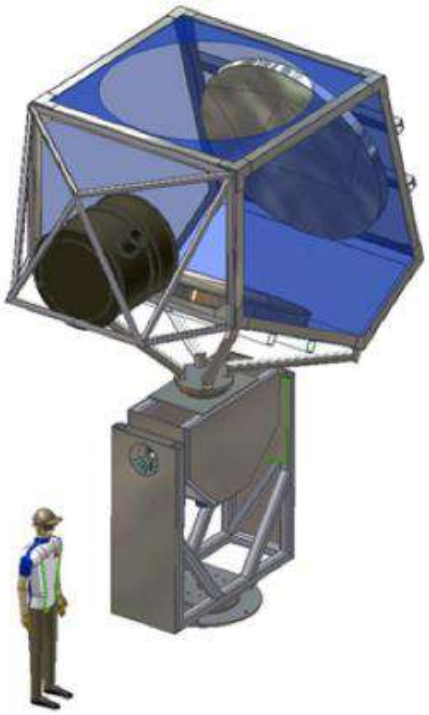
- Estimated launch date: December 2018 (Svalbard Islands)
- 15 days of flight during Artic night

STRIP: the ground-based low frequency instrument

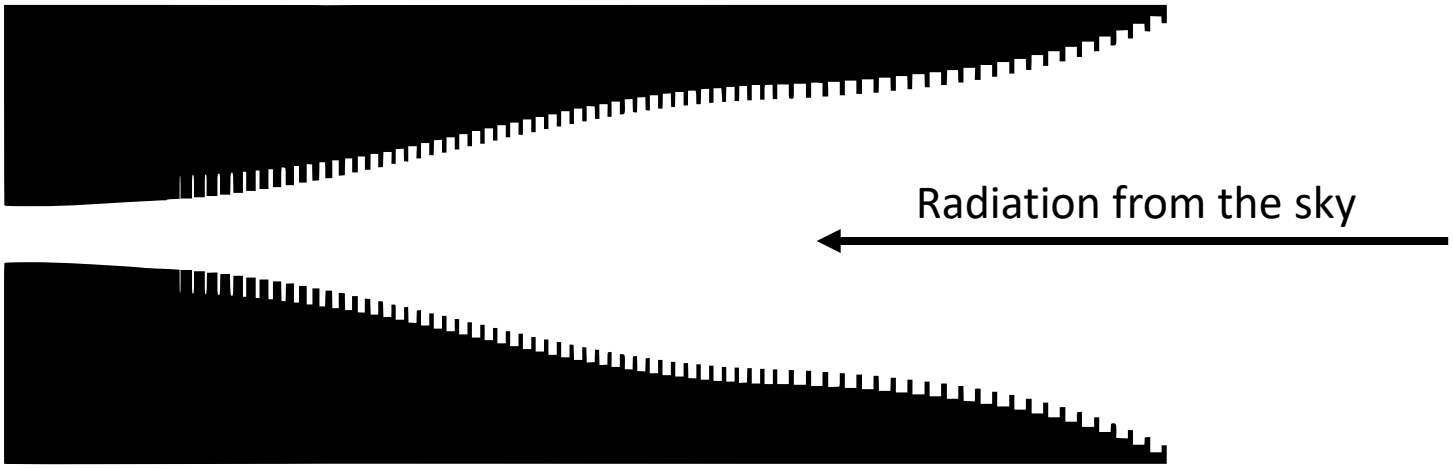
Teide Observatory, Tenerife (Canary islands)

STRIP: the ground-based low frequency instrument

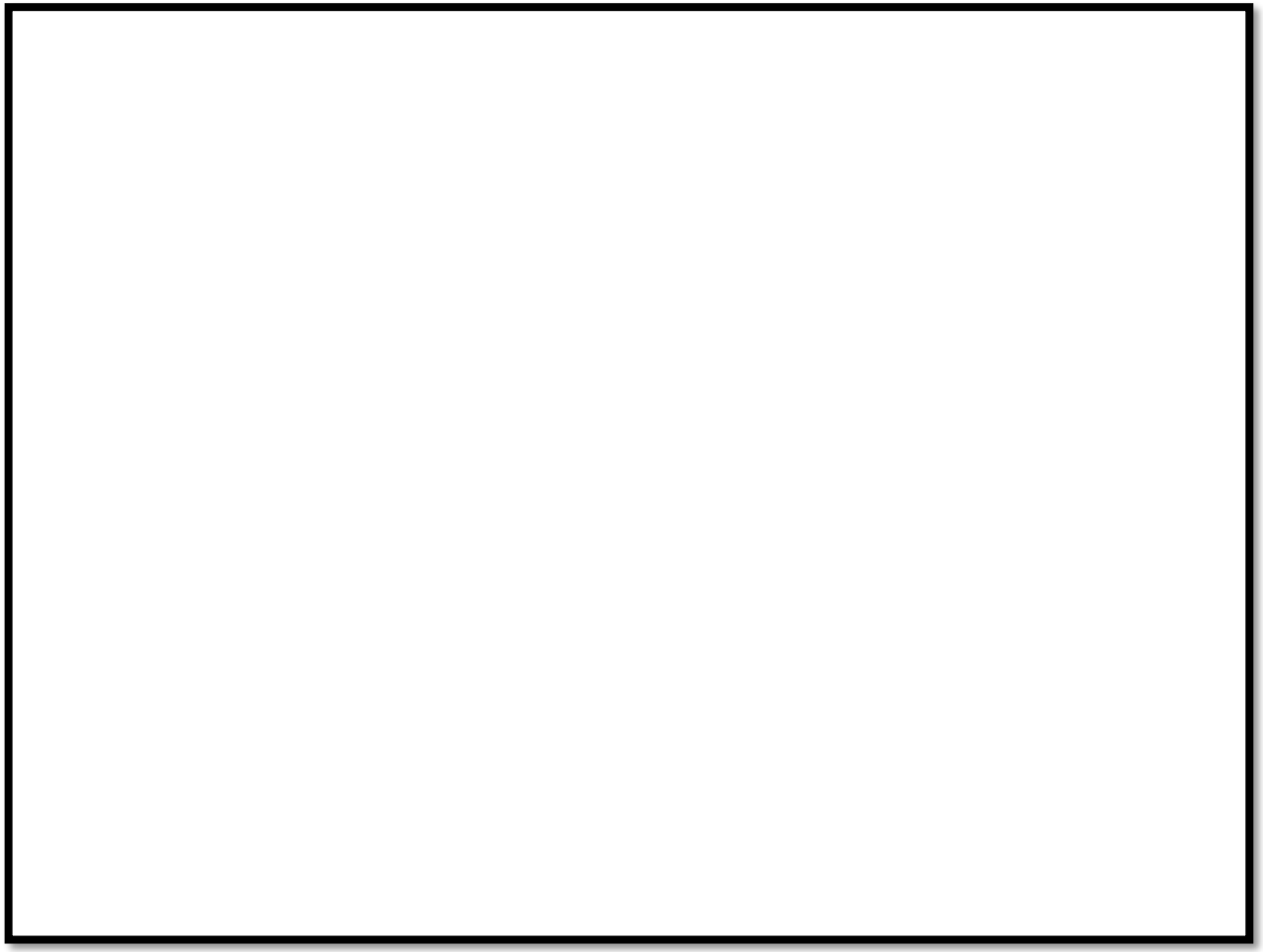




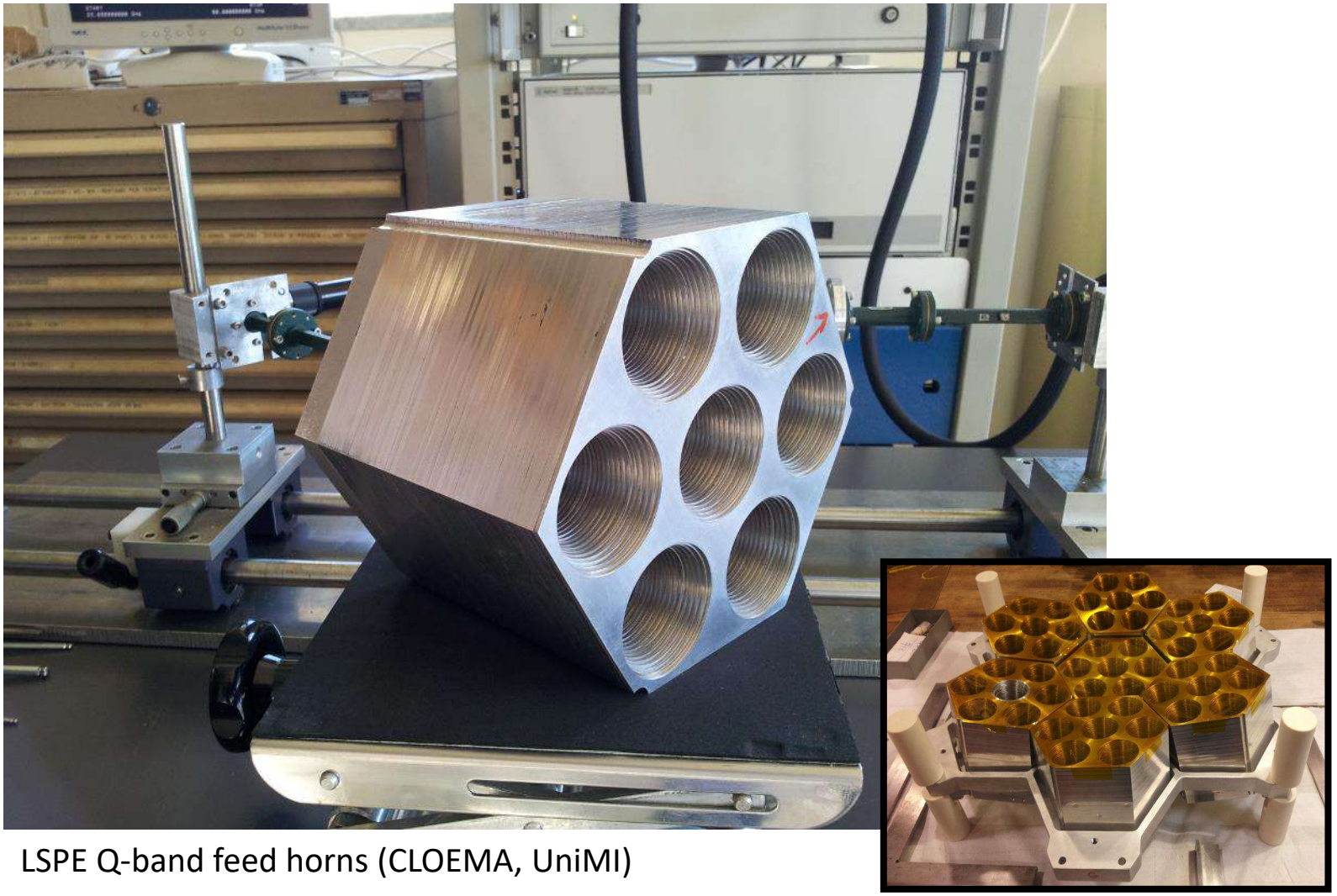
How to design a microwave horn



The platelet technique

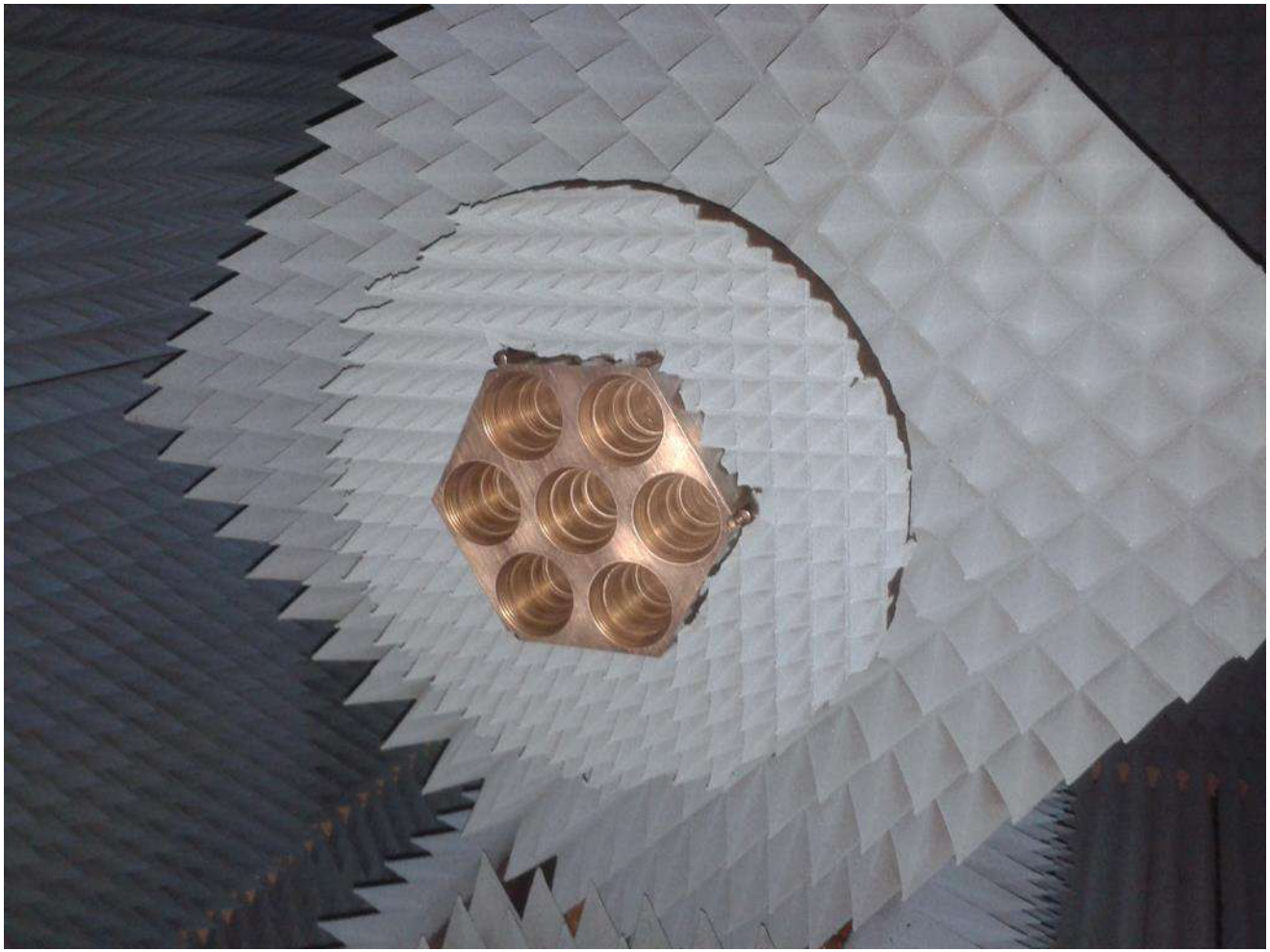


The STRIP focal plane modules



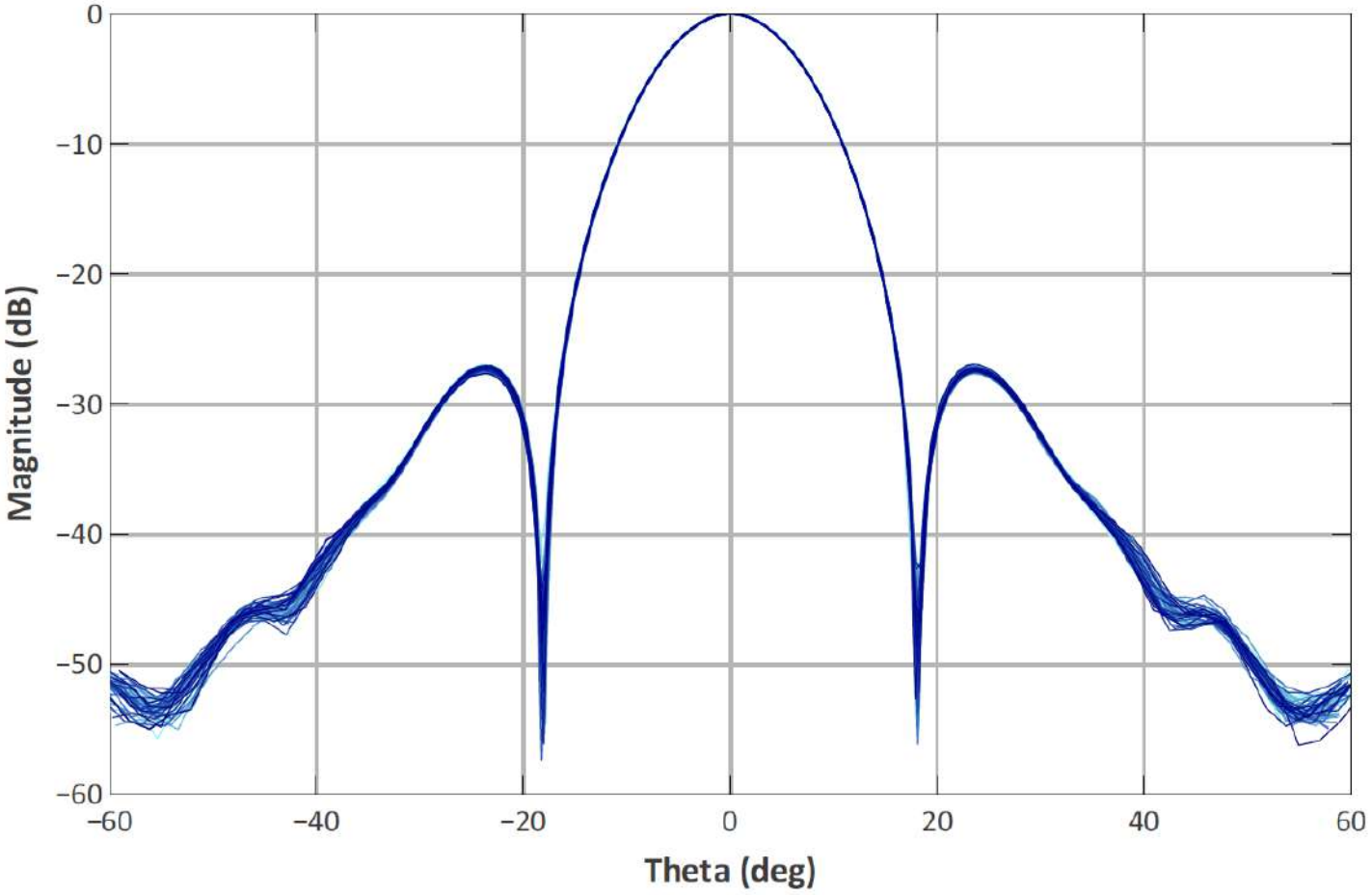
LSPE Q-band feed horns (CLOEMA, UniMI)

The STRIP focal plane modules



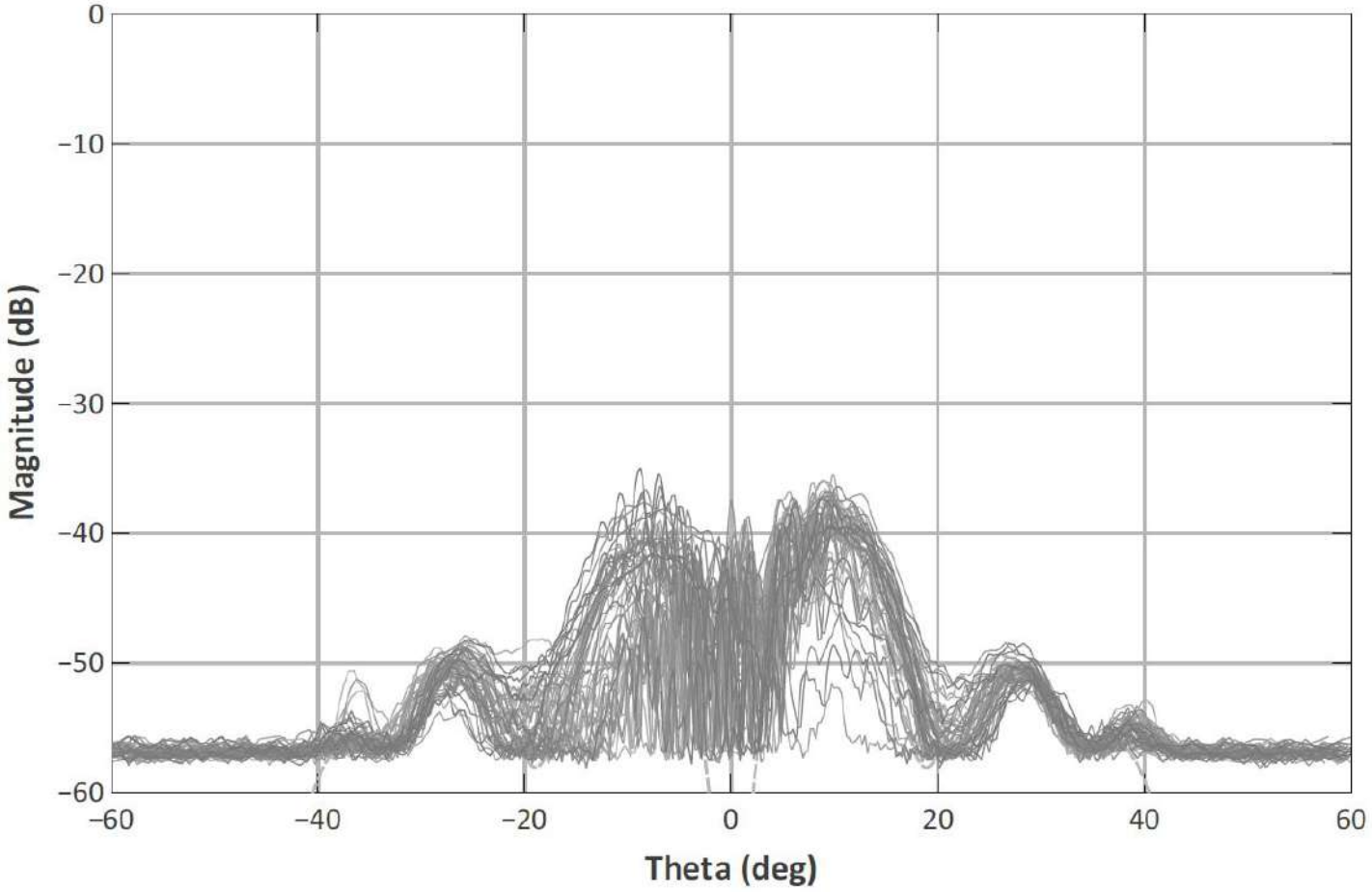
LSPE/STRIP module being tested in the anechoic chamber@UniMI

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

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

$$\frac{\ddot{a}(t)}{a(t)} = -\frac{4\pi G}{3c^2}\big(\epsilon(t) + 3P(t)\big) + \frac{\Lambda}{3}.$$

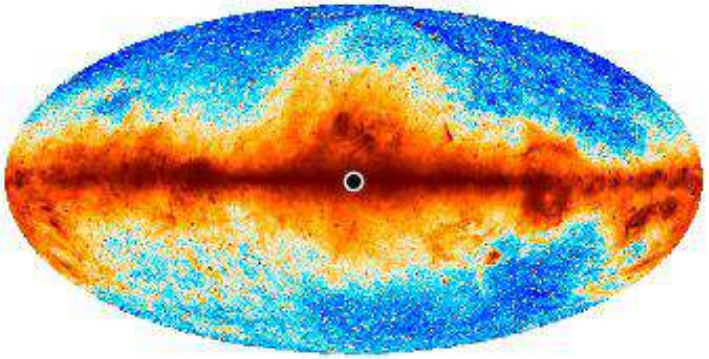
$a(t)$ Scale factor (dimensionless)

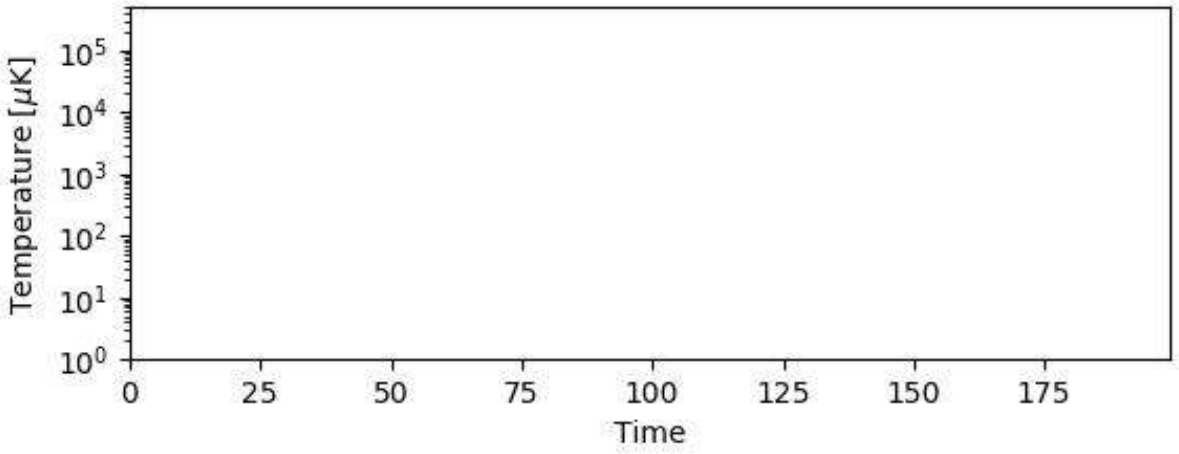
$\epsilon(t)$ Mass-energy density (energy/volume)

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

Λ Dark energy term (1/time^2)

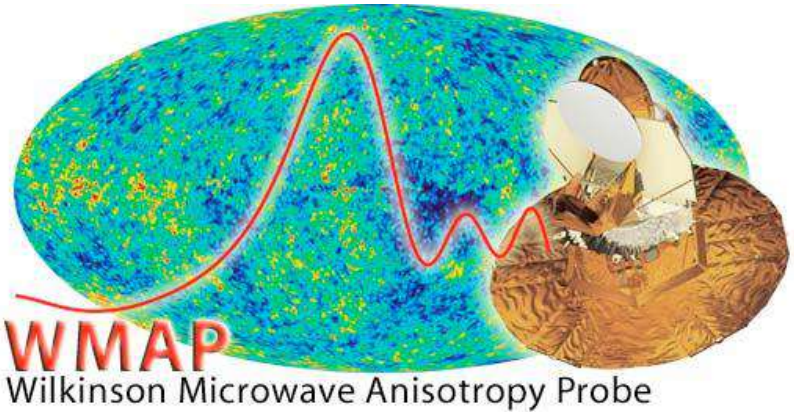
Observing the sky



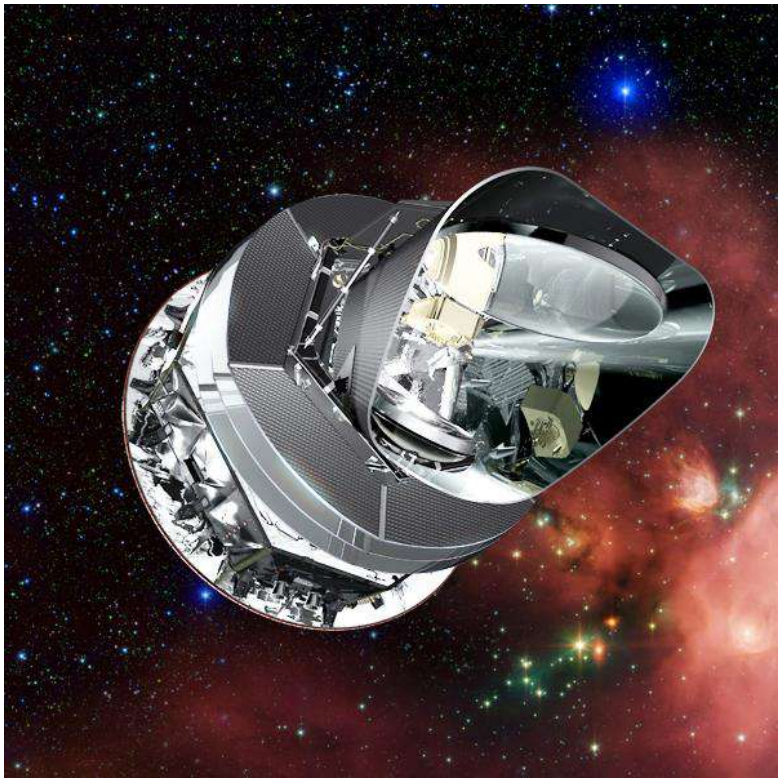


WMAP and Planck

NASA mission (2001-2010)

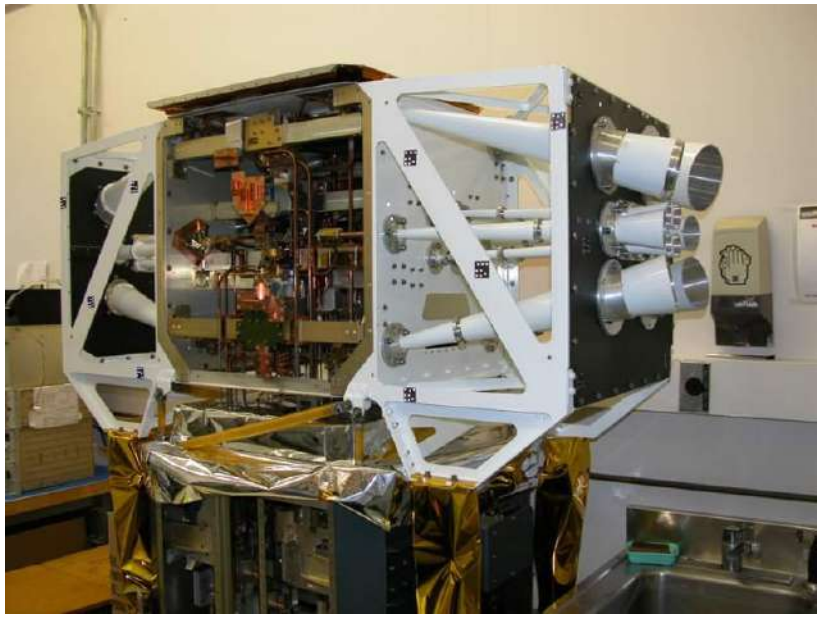


ESA mission (2009-2013)

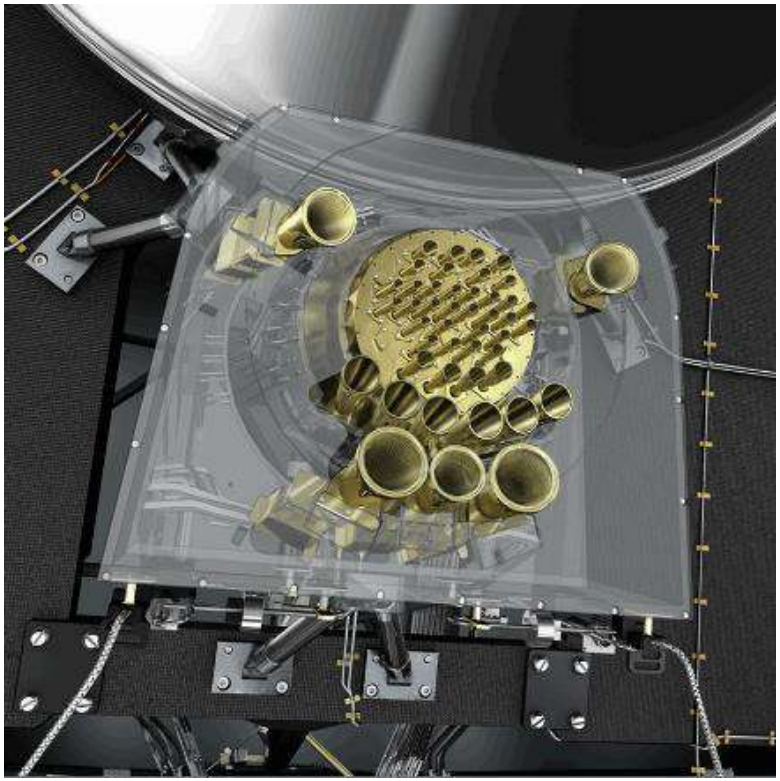


WMAP and Planck

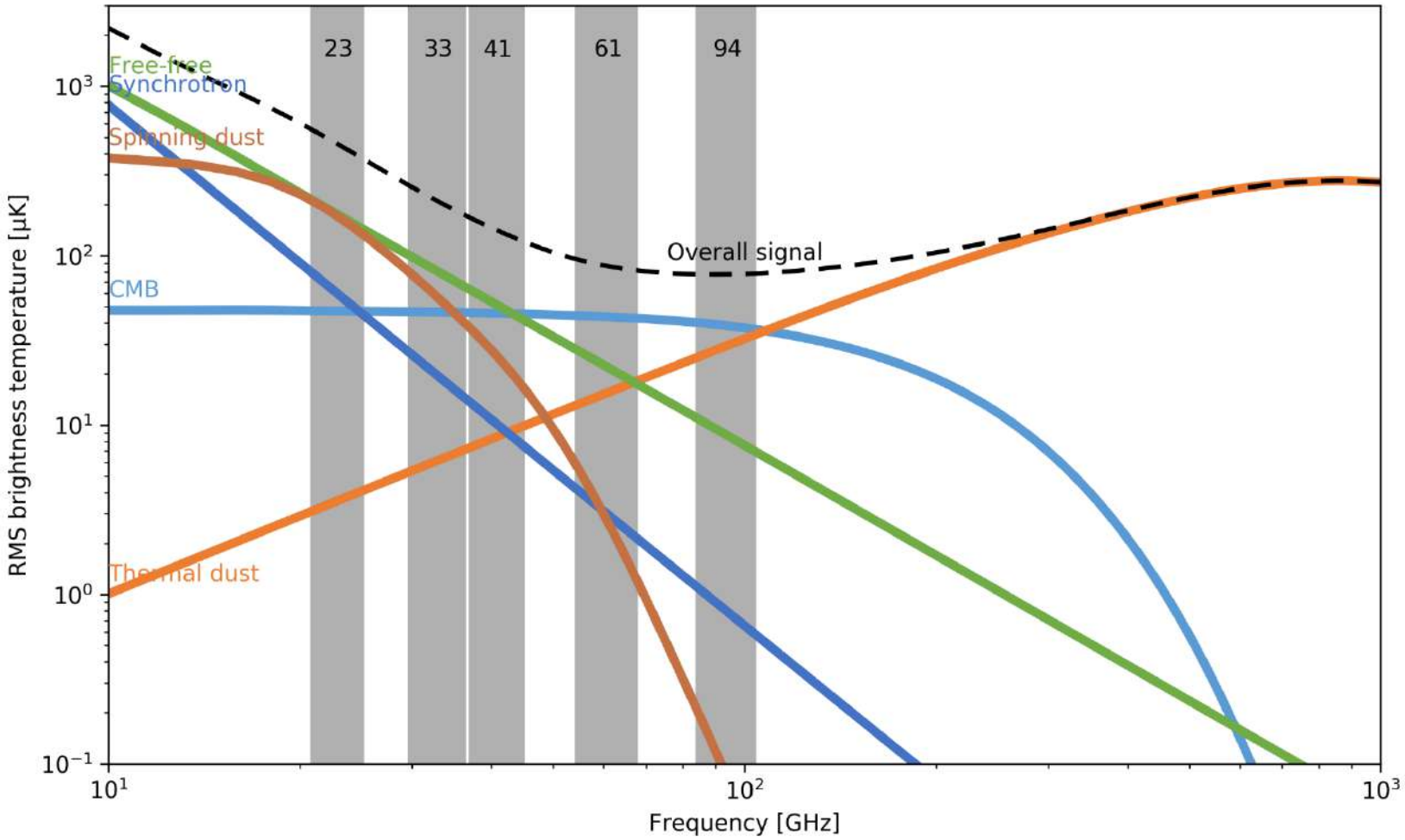
2x10 horns, 40 detectors



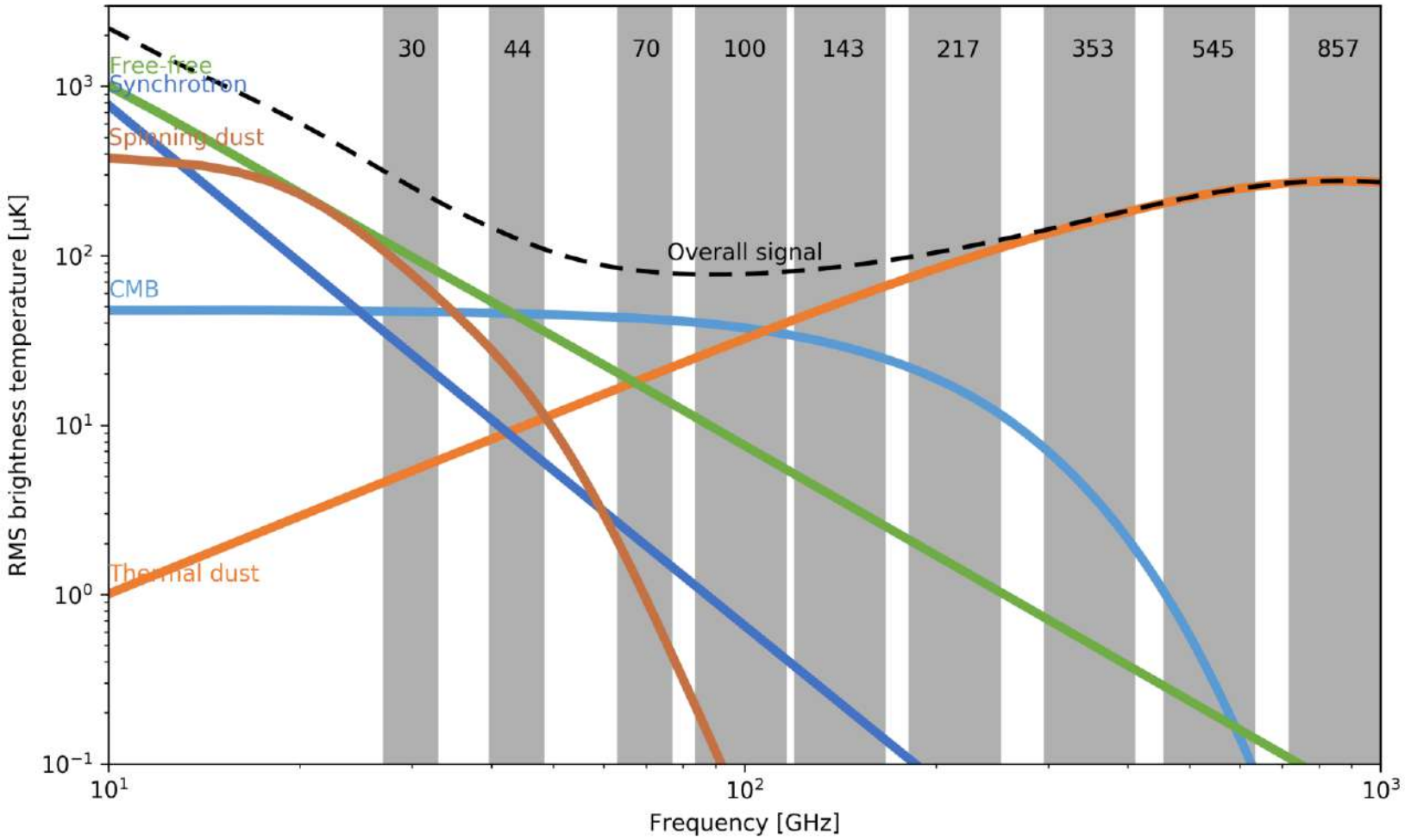
11+36 horns, 22+52 detectors



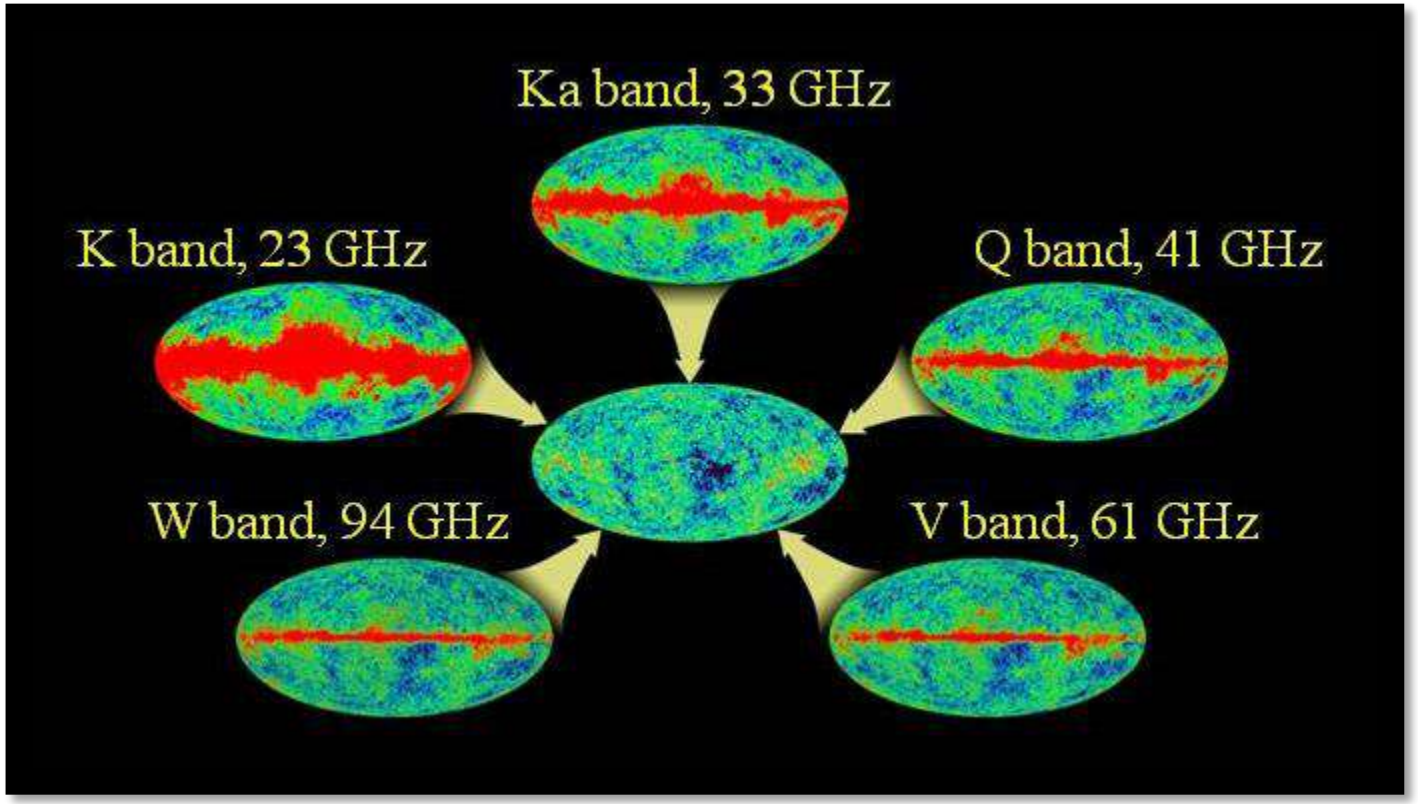
WMAP frequency coverage



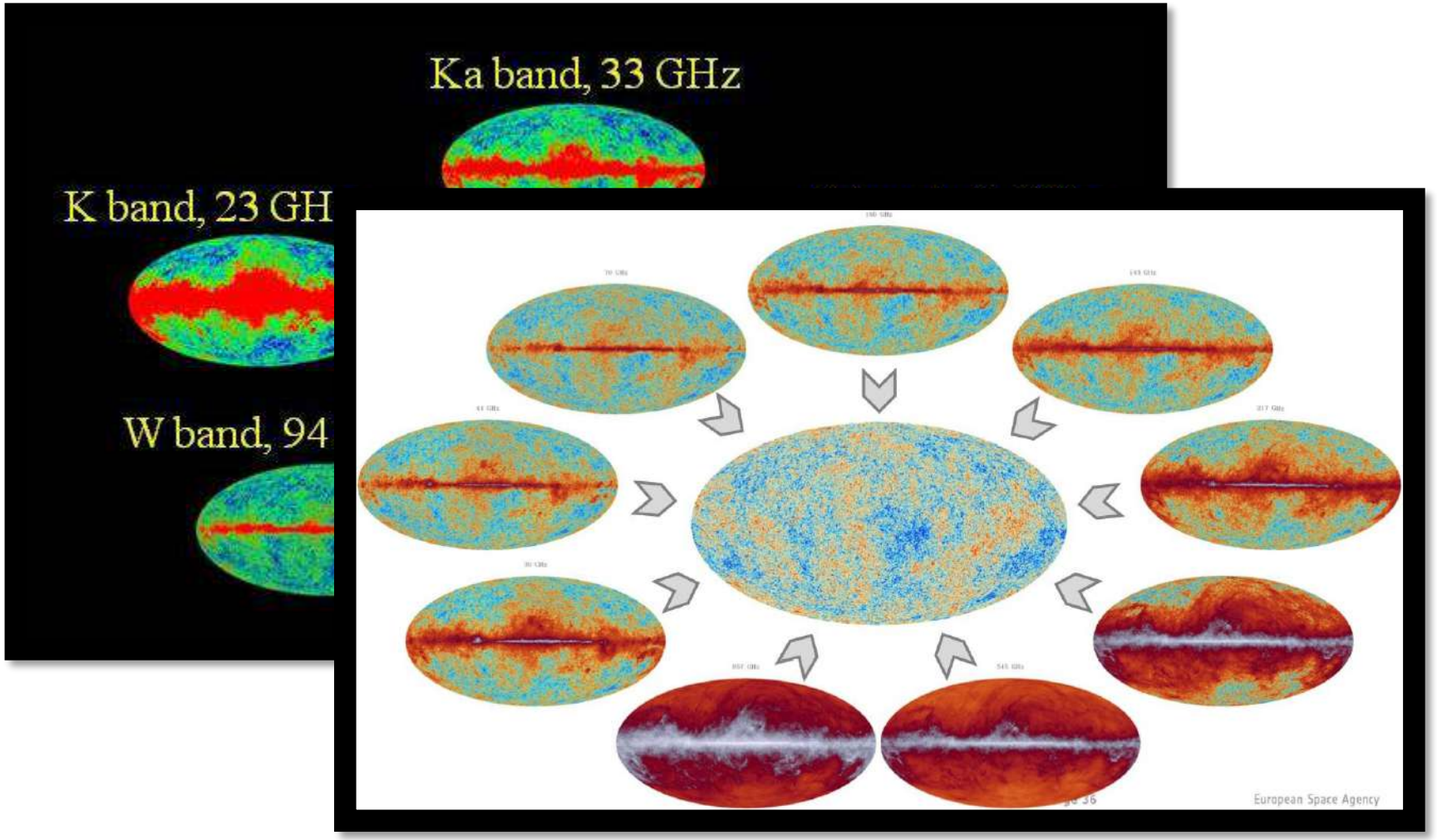
Planck frequency coverage



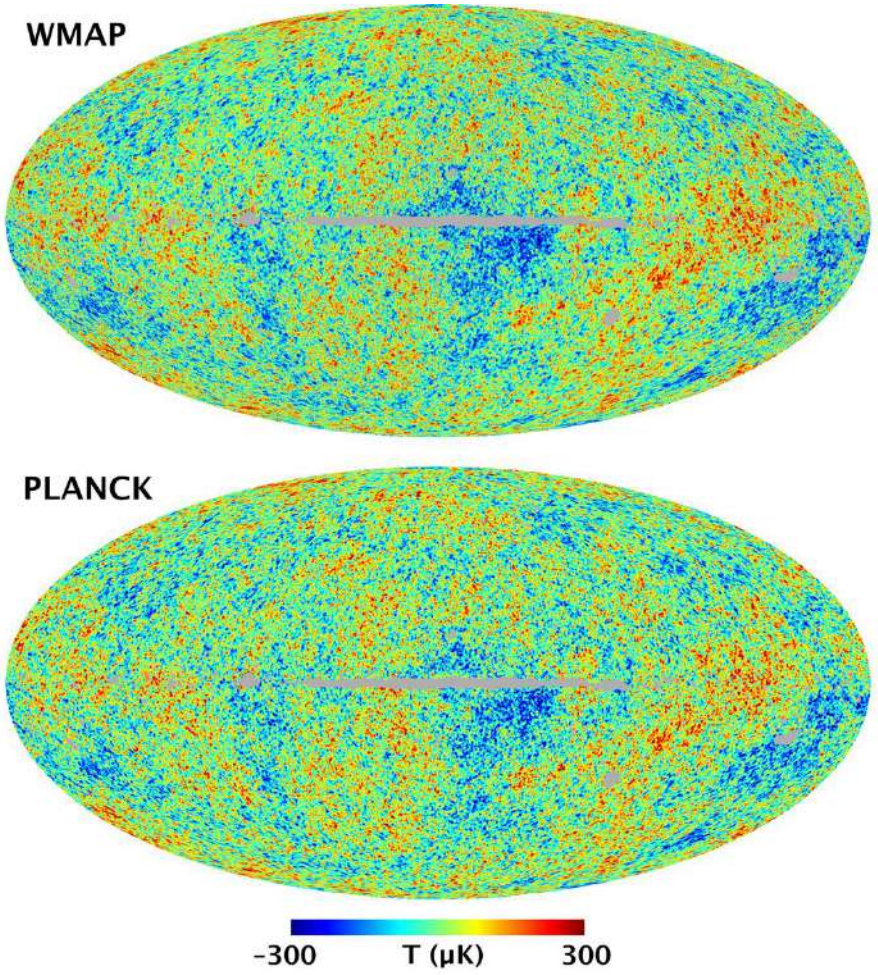
Component separation



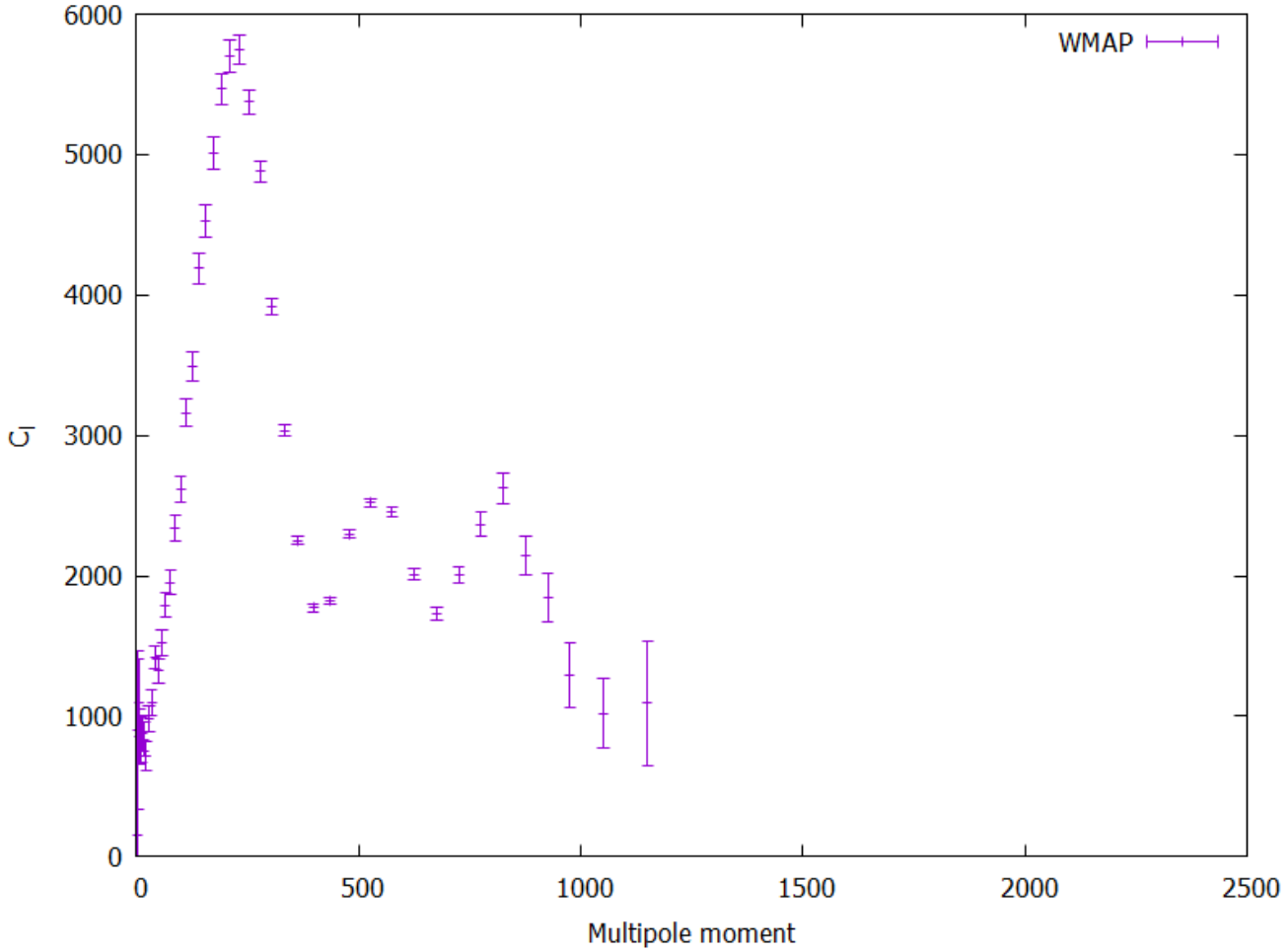
Component separation



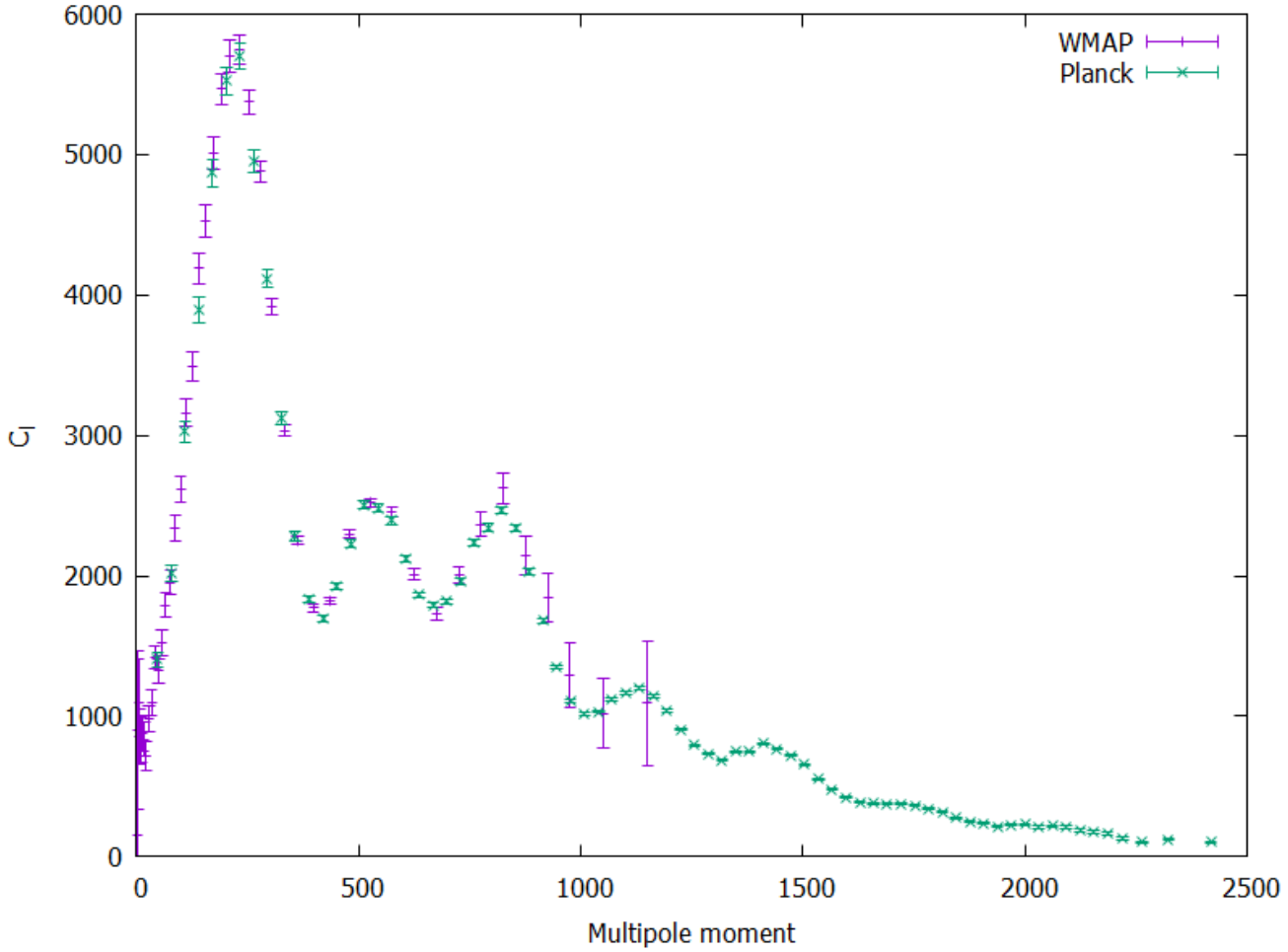
Comparison of the results



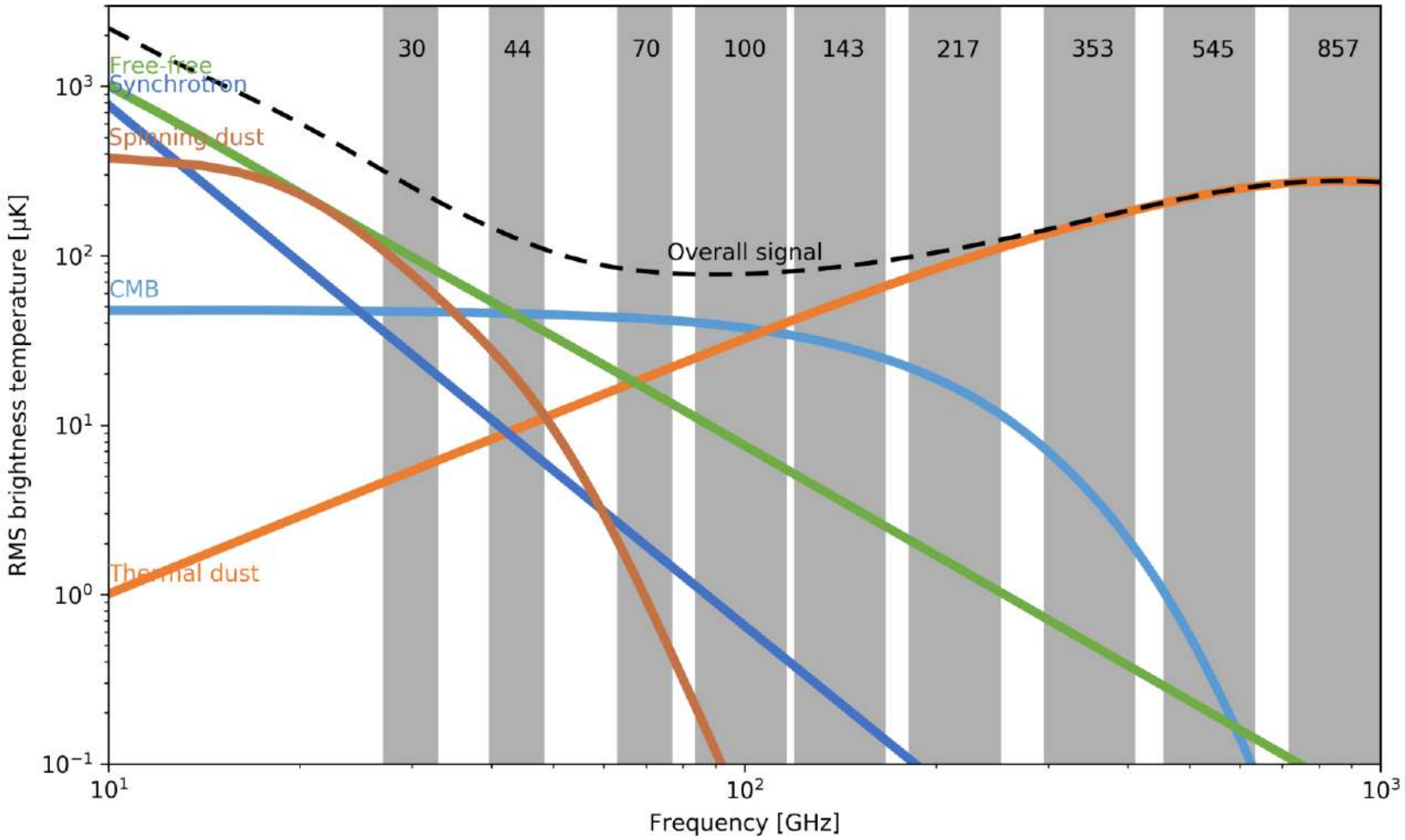
Comparison of the results



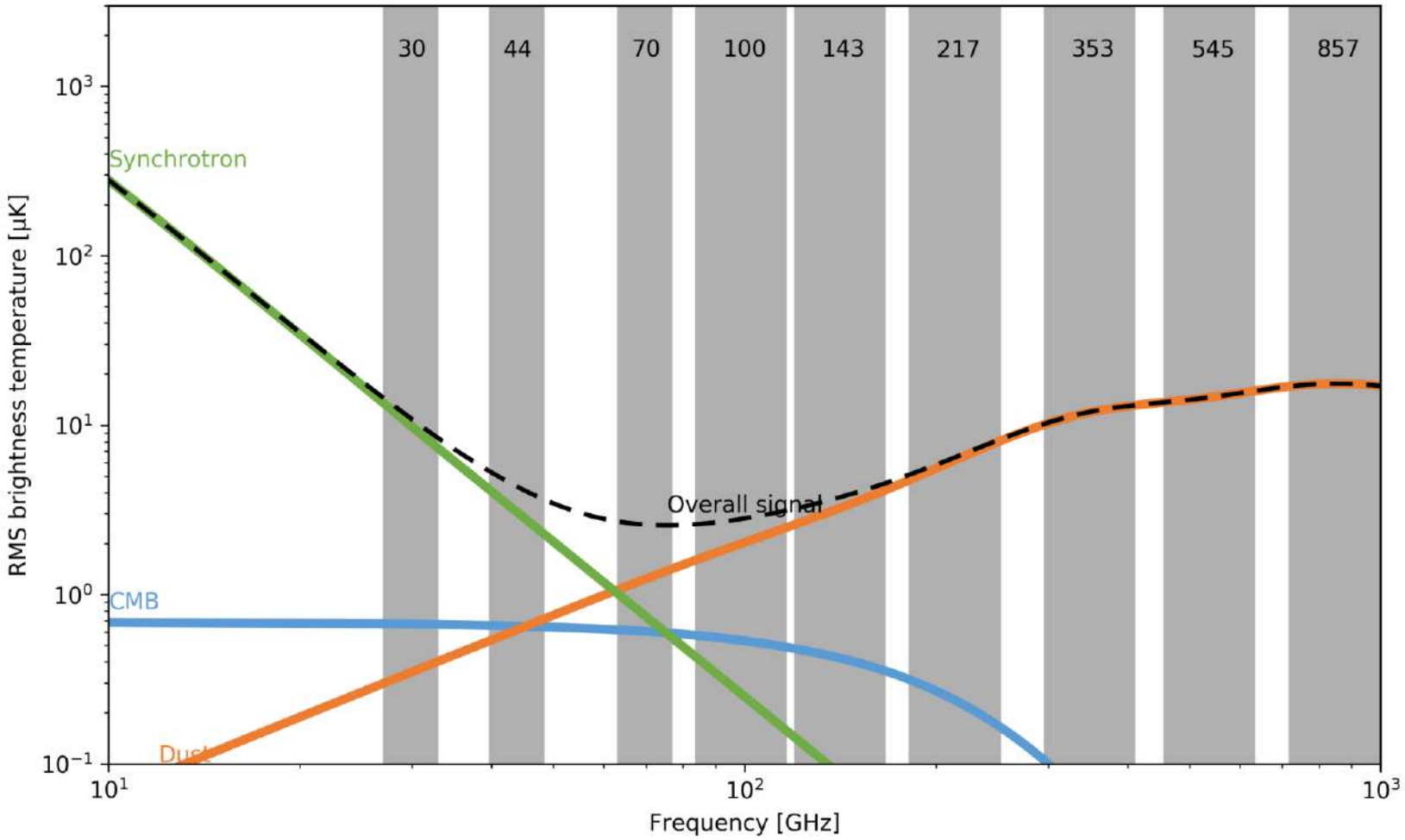
Comparison of the results



Planck frequency coverage



Planck frequency coverage



Hunting B-modes: a lot of competition!

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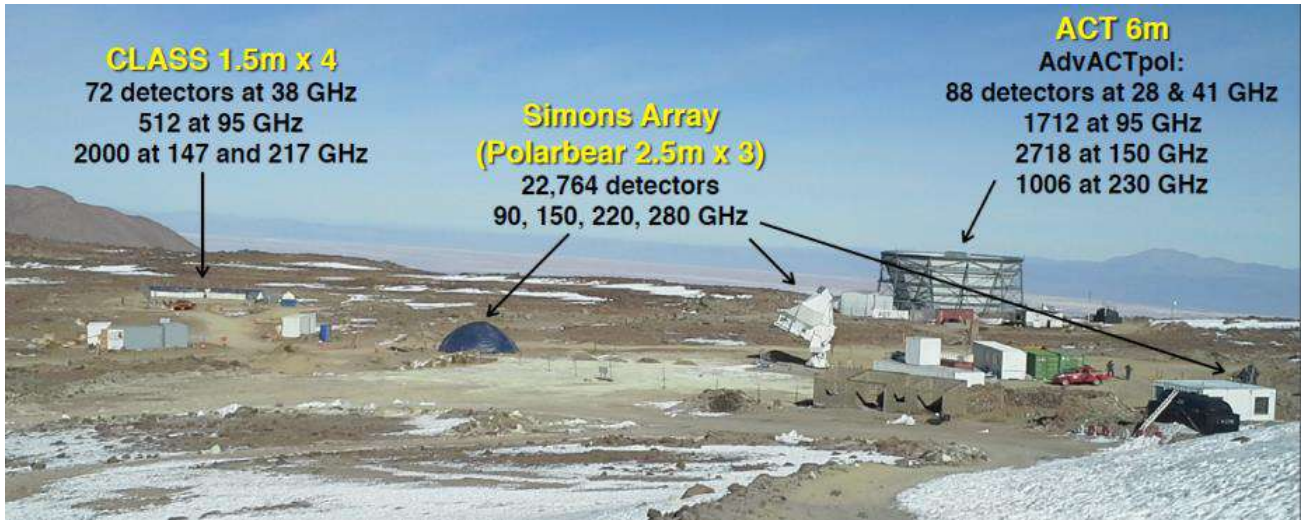
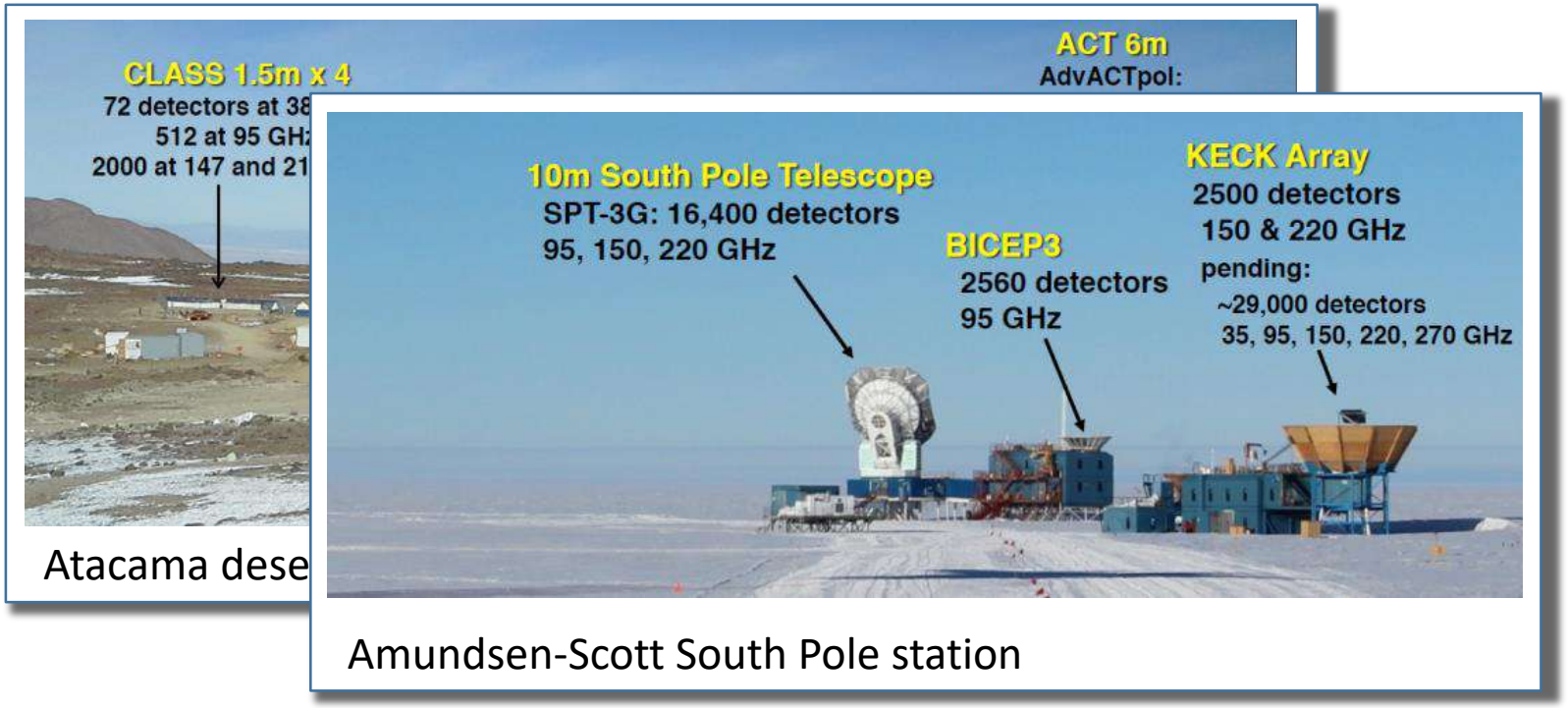


Atacama desert, Chile

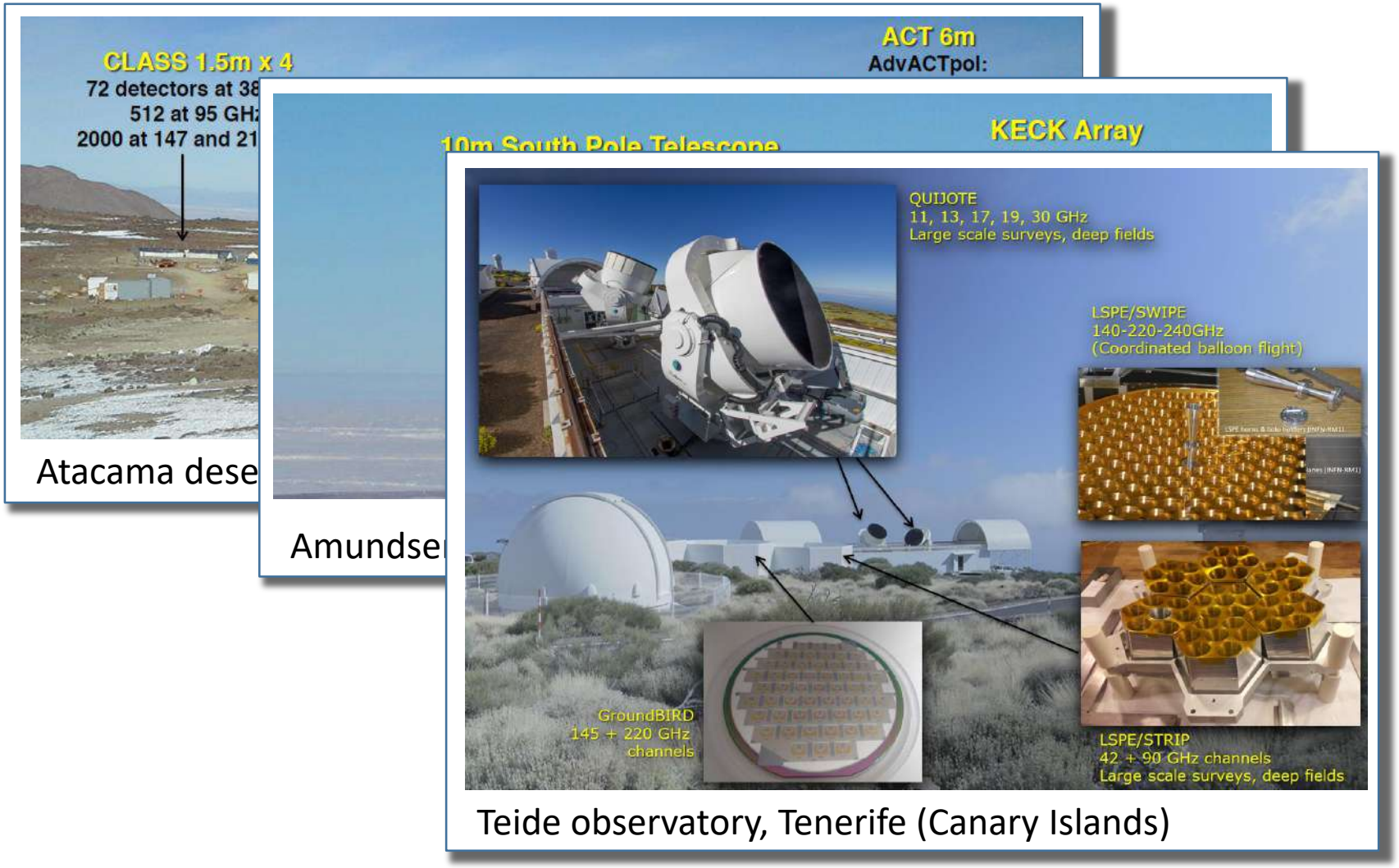
Hunting B-modes: a lot of competition!



Atacama dese

Amundsen-Scott South Pole station

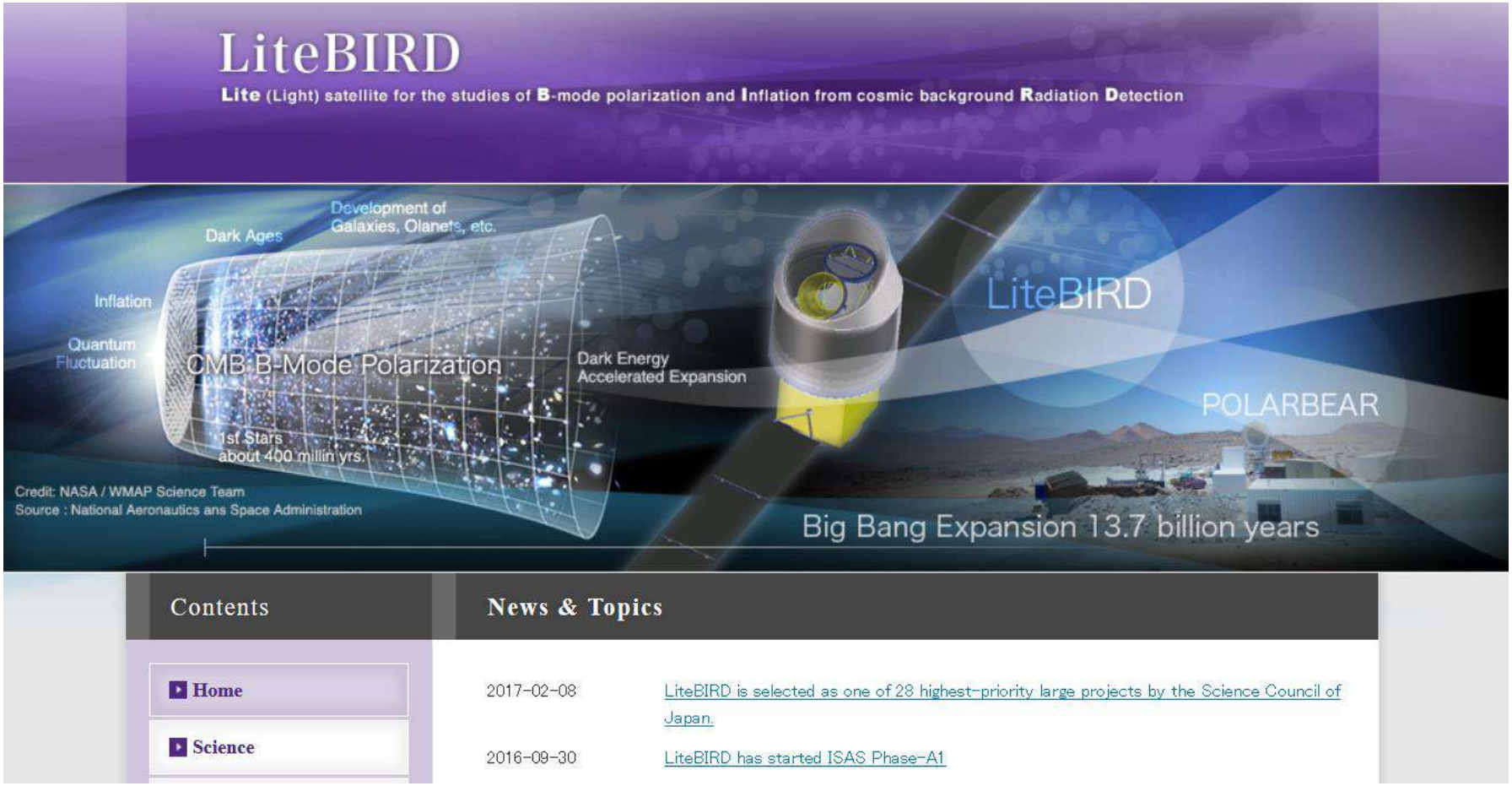
Hunting B-modes: a lot of competition!



The future: S4

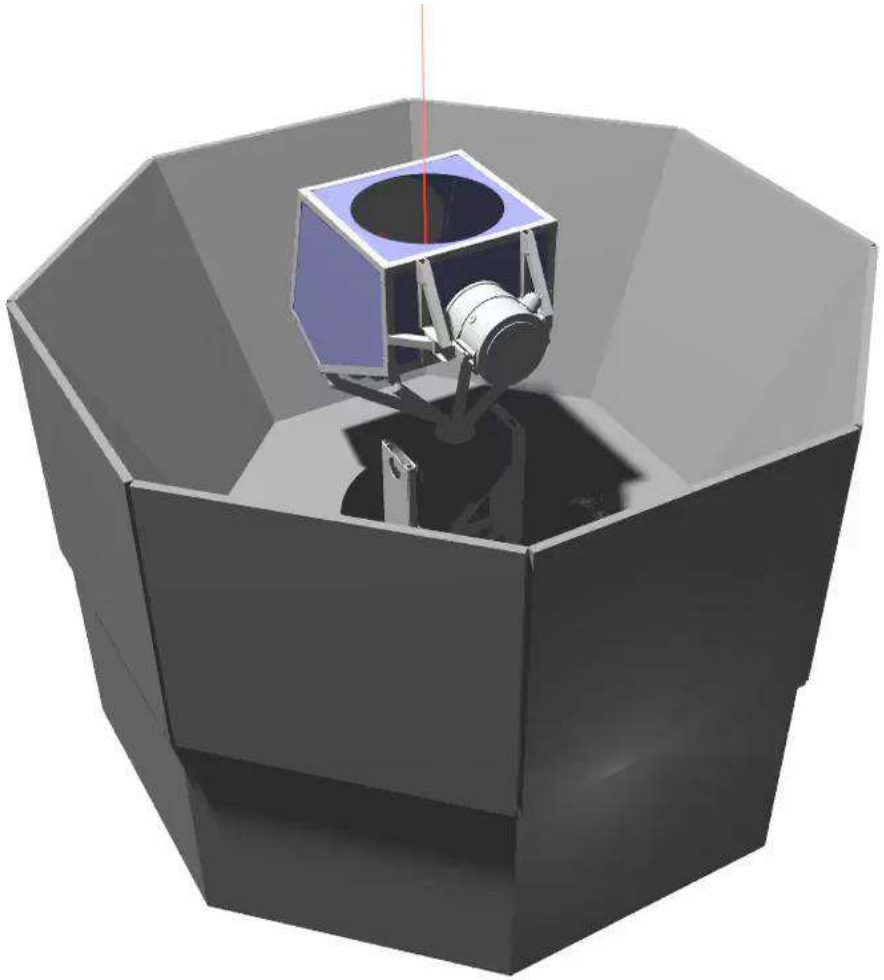
https://cmb-s4.org/index.php

The future: LiteBIRD

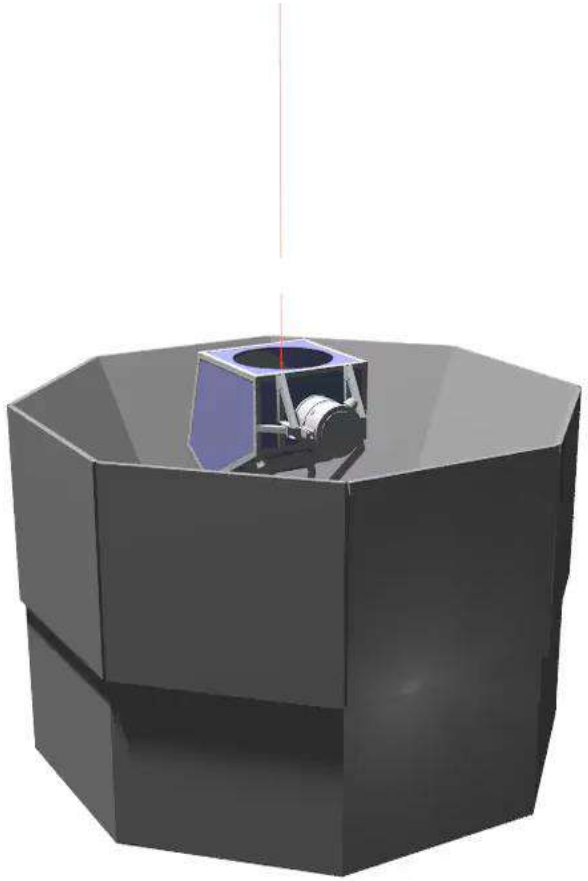


http://litebird.jp/eng/

Flyby



How Strip will observe the sky



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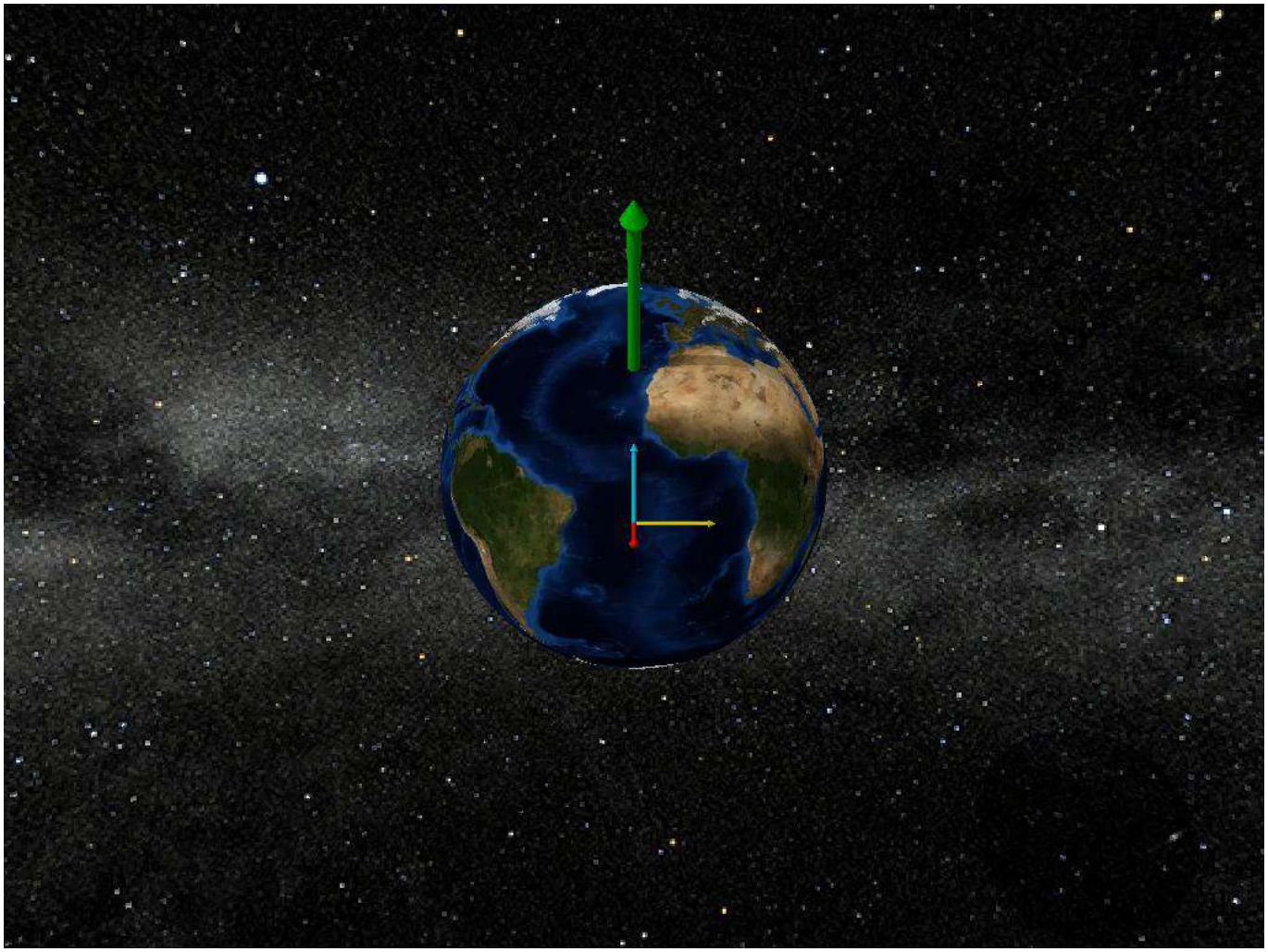
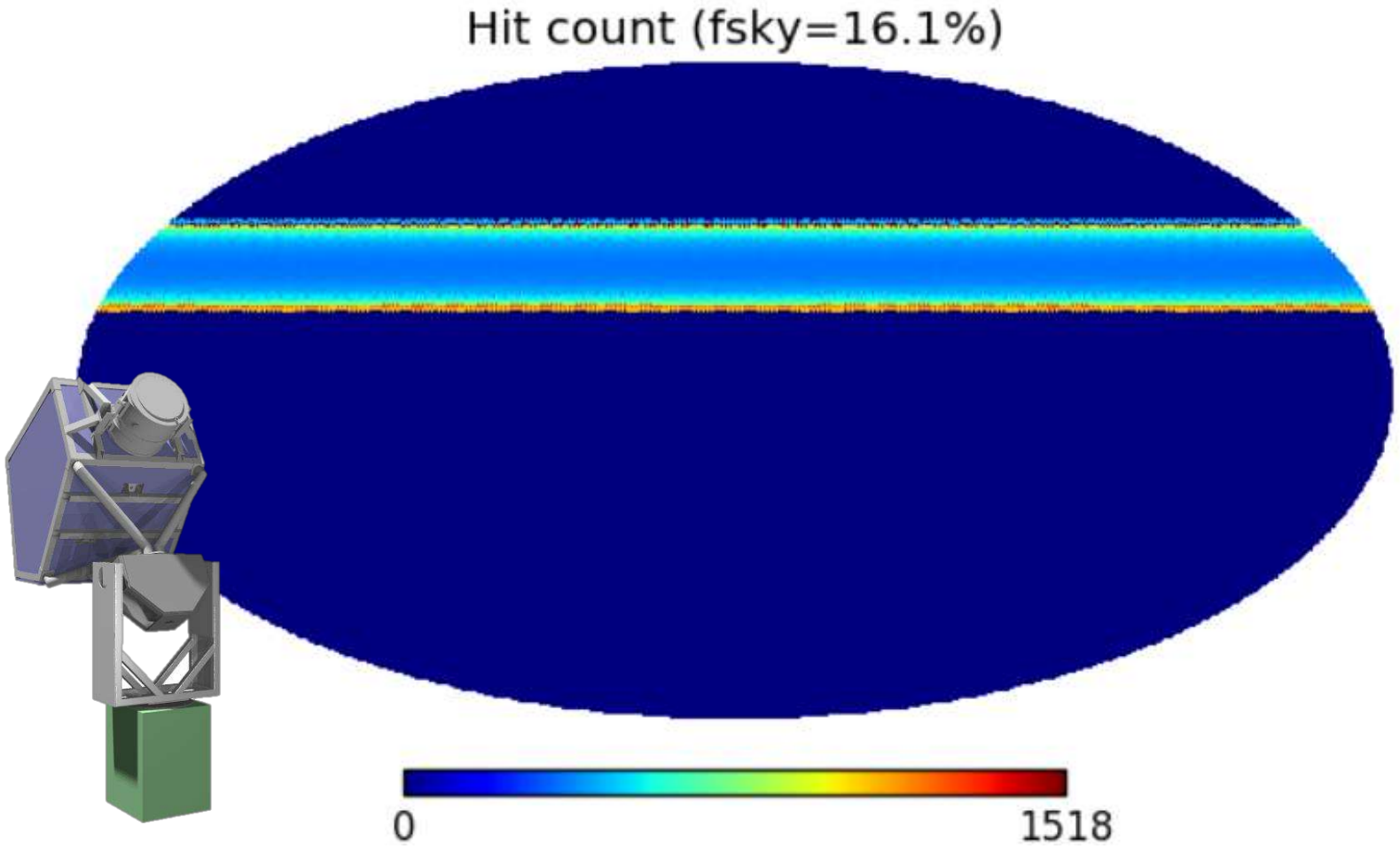
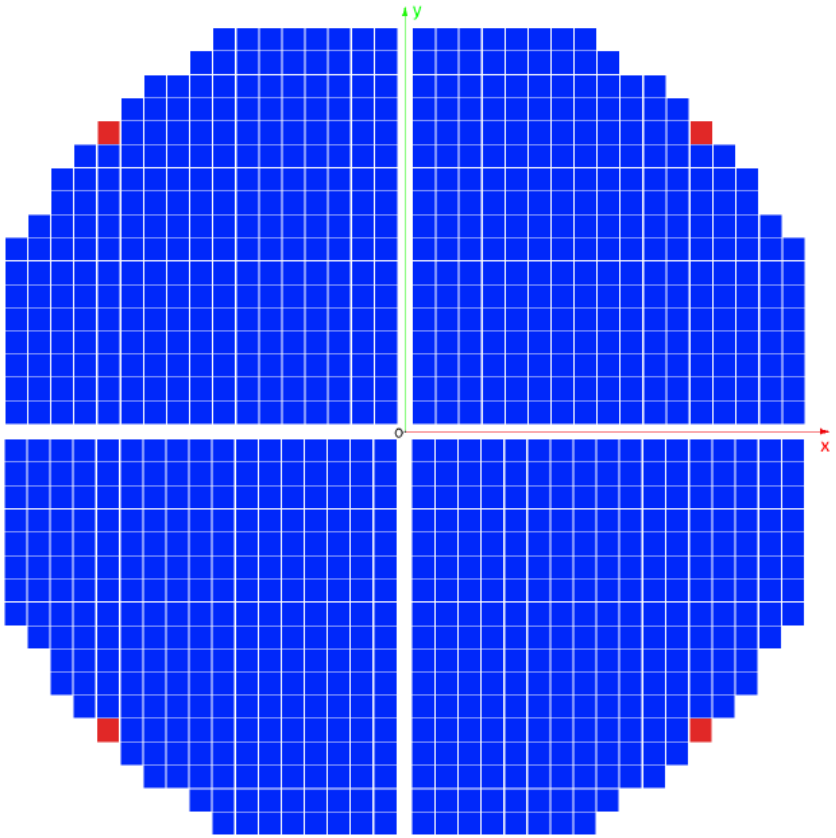


How Strip will observe the sky



Placement of the 992 QUBIC detectors



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

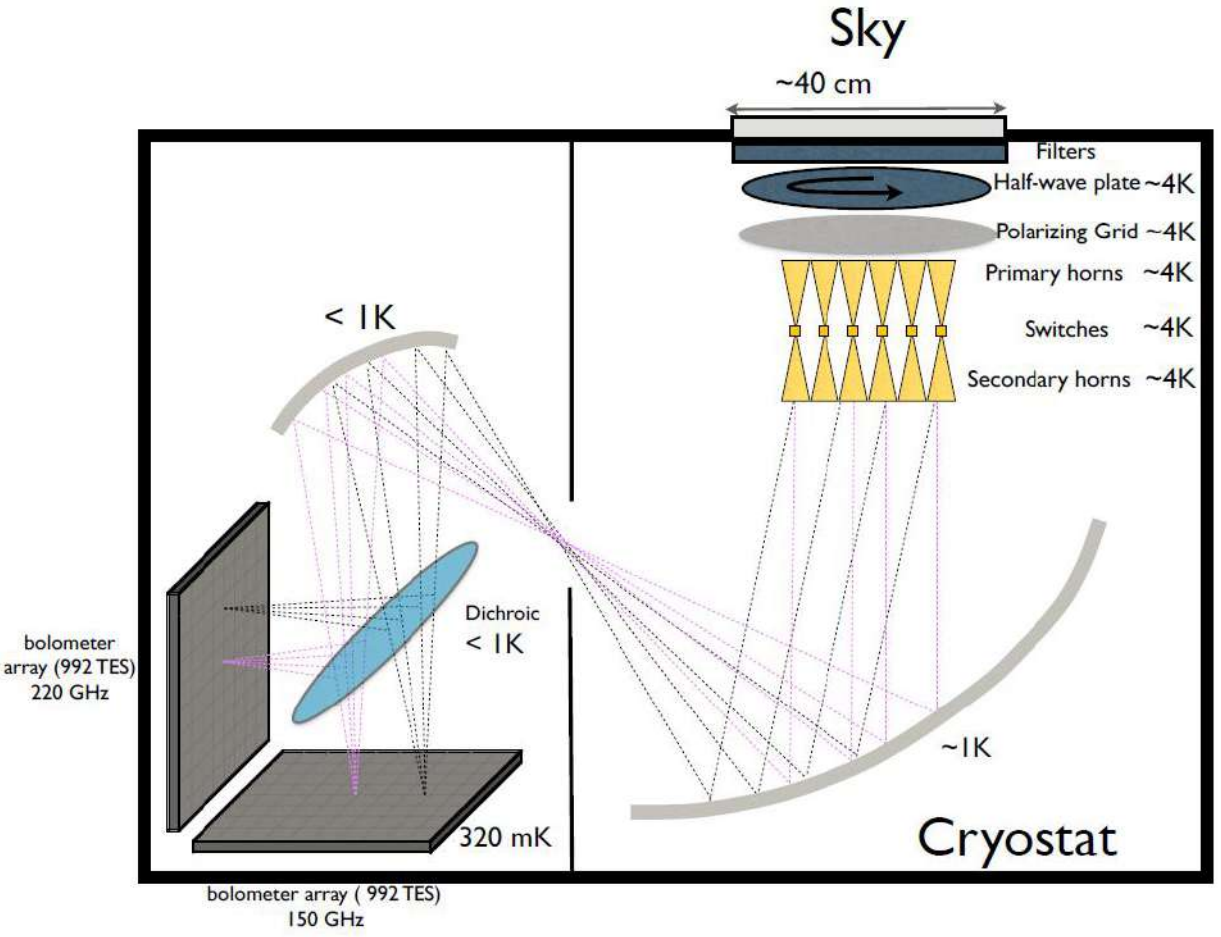
QUBIC

Q&U Bolometric Interferometer for Cosmology

What is QUBIC?

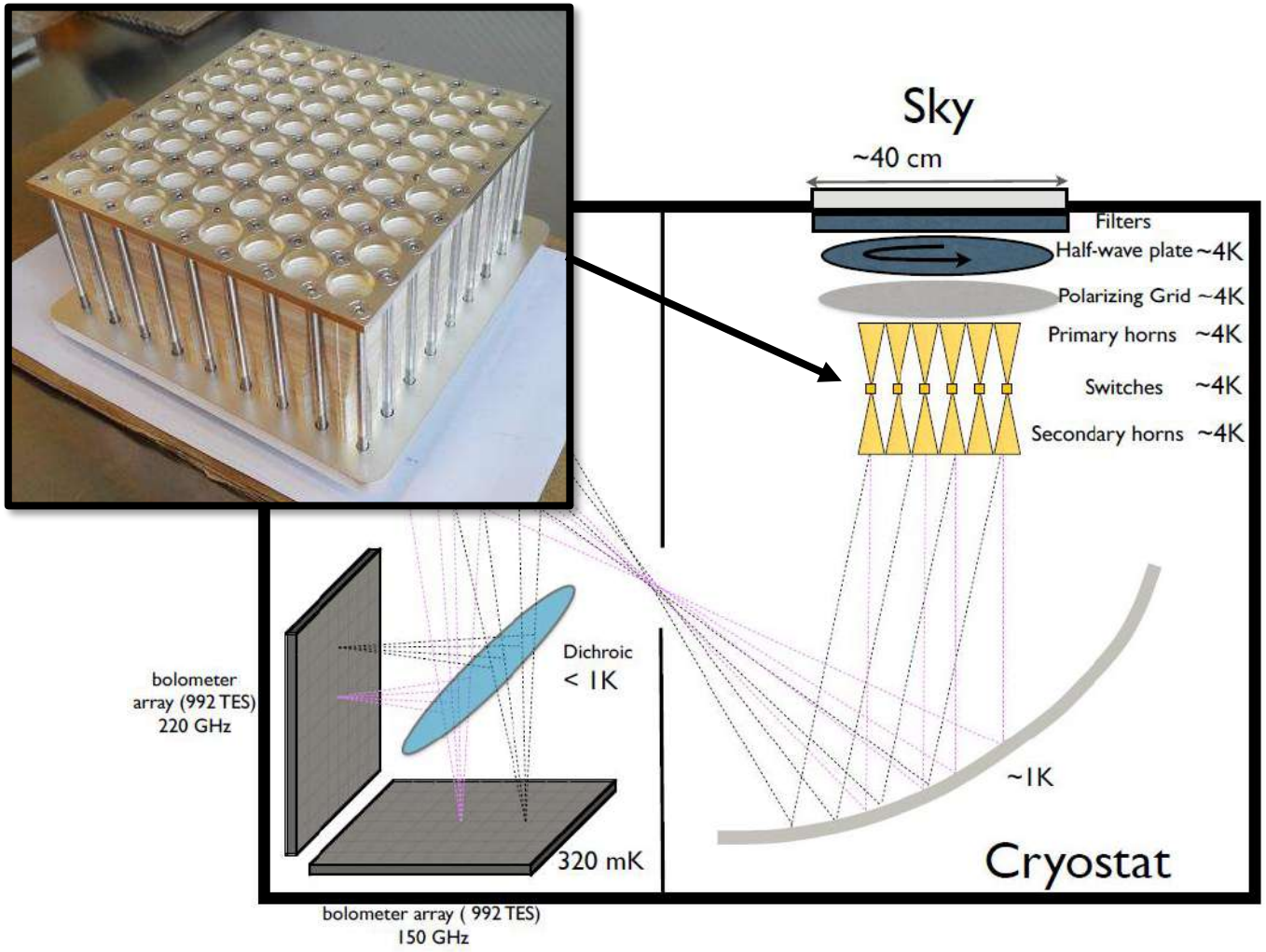
- Ground-based experiment
- *Bolometric interferometer*!
- TES bolometers @ 95, 150, 220 GHz
- First technological demonstrator under construction
- First module to be deployed to Argentina next year

The design of QUBIC



The design of QUBIC

QUBIC demonstrator (Lasertech)



How QUBIC sees the sky

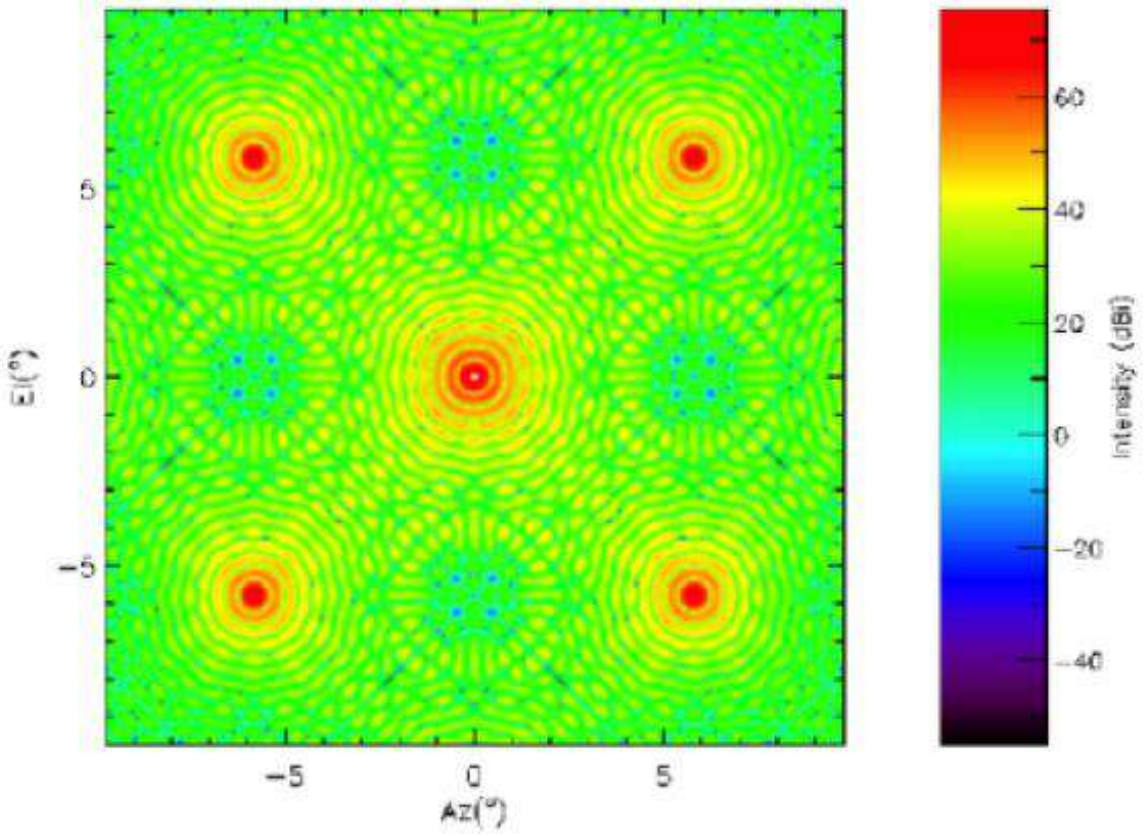
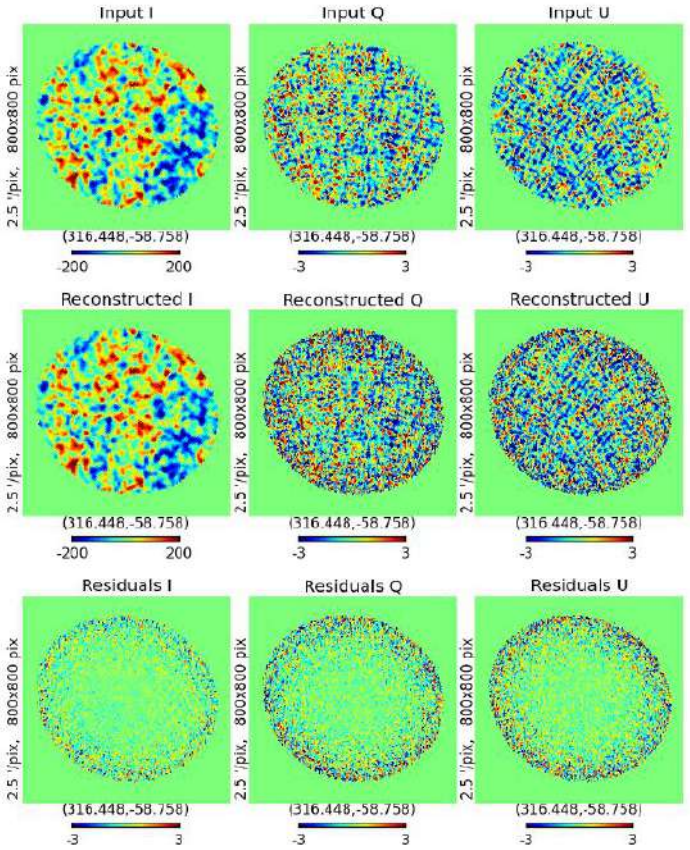


Image produced by a monochromatic point source along the boresight of the QUBIC telescope

Reconstructing the sky



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Self-calibration