Mapping the Cosmic Microwave Background polarization with Simons Array and LiteBIRD

Josquin Errard (APC, CNRS)

on behalf of the collaboration co-lead with **Hirokazu Ishino** (Okayama Univ.)

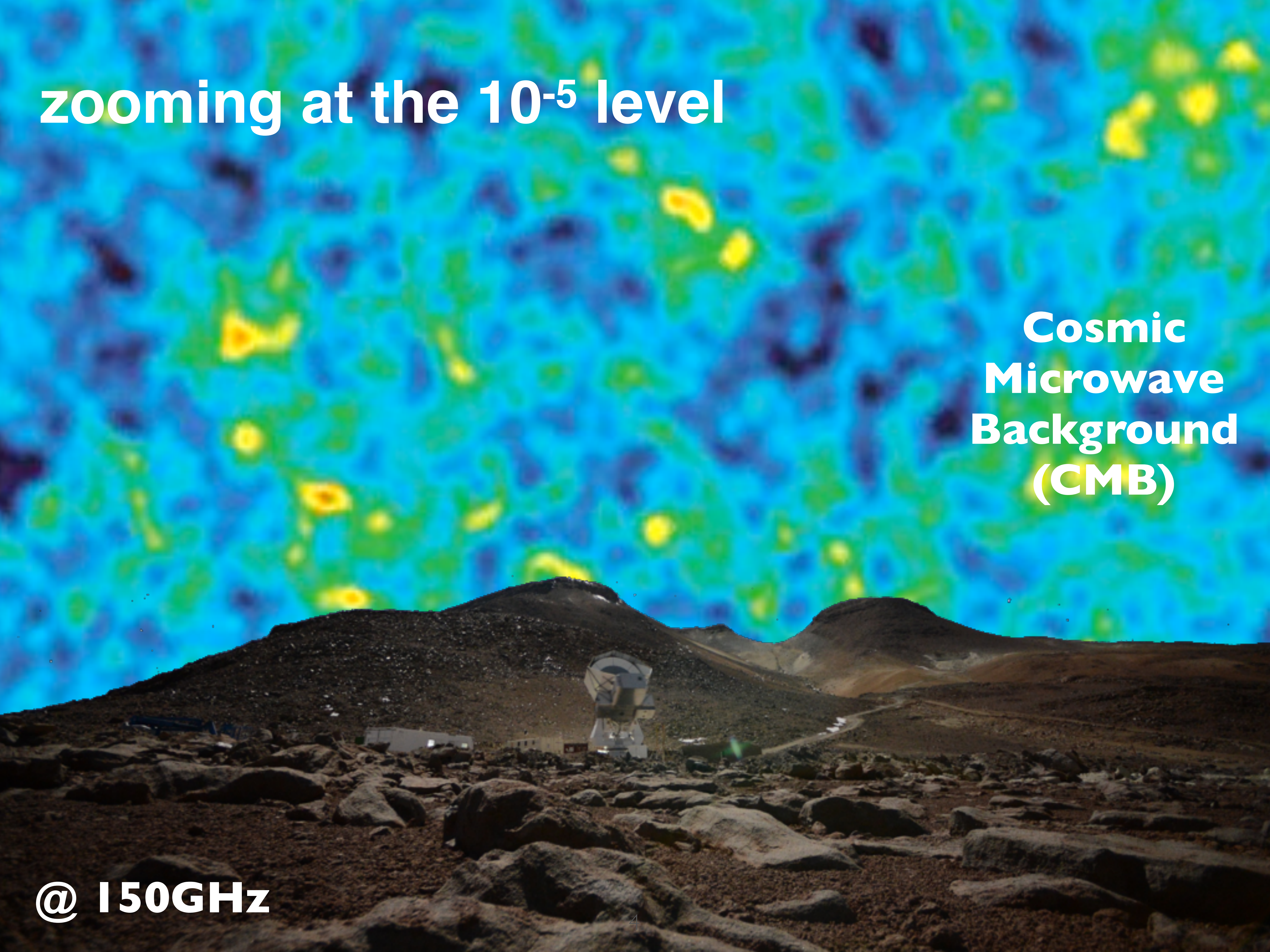
Joint workshop of the France Korea (FKPPL) and France Japan (TYL/FJPPL)

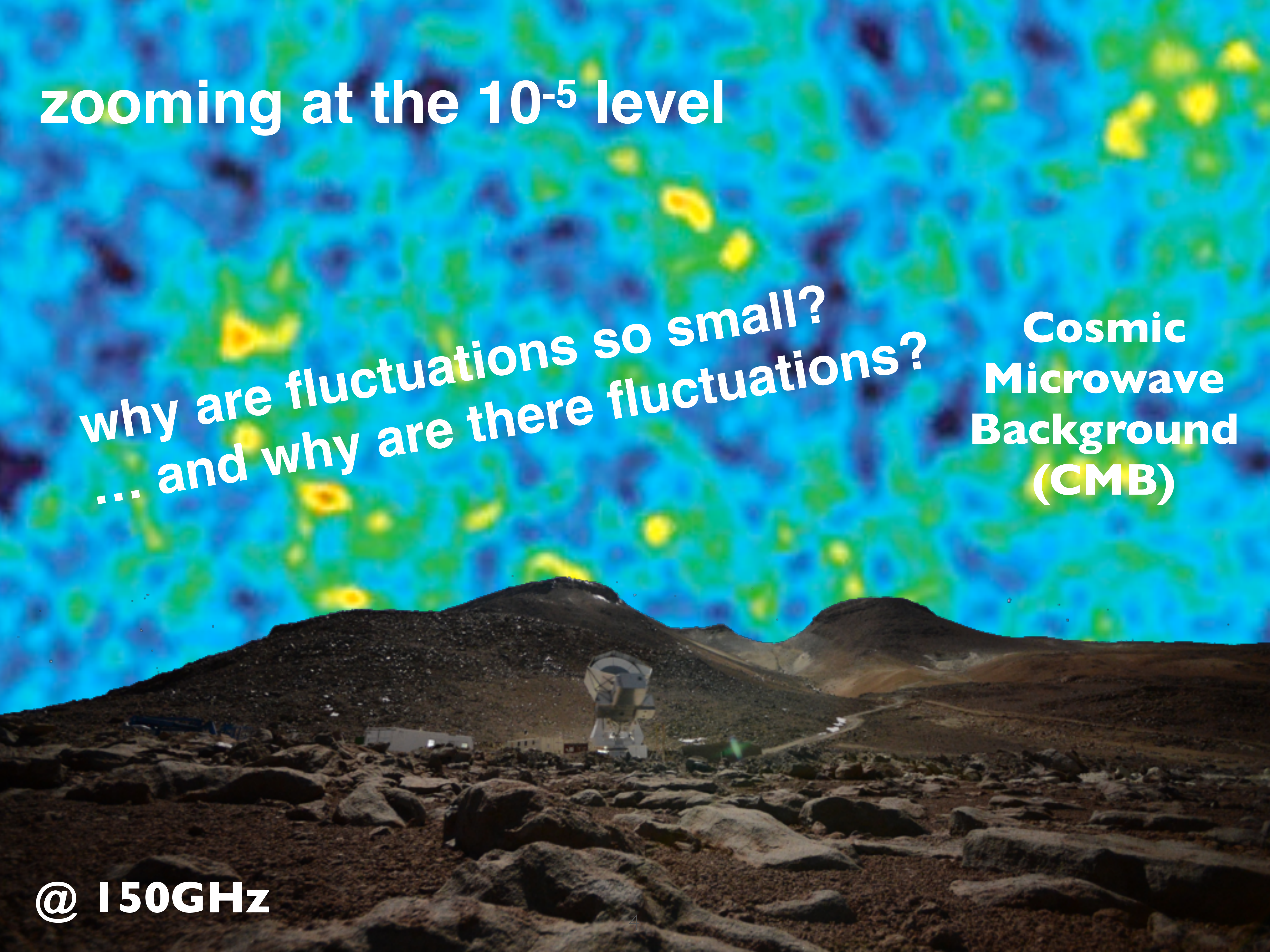
International Associated Particle Physics Laboratories

Institut Pluridisciplinaire Hubert Curien (IPHC), Strasbourg, May 2017

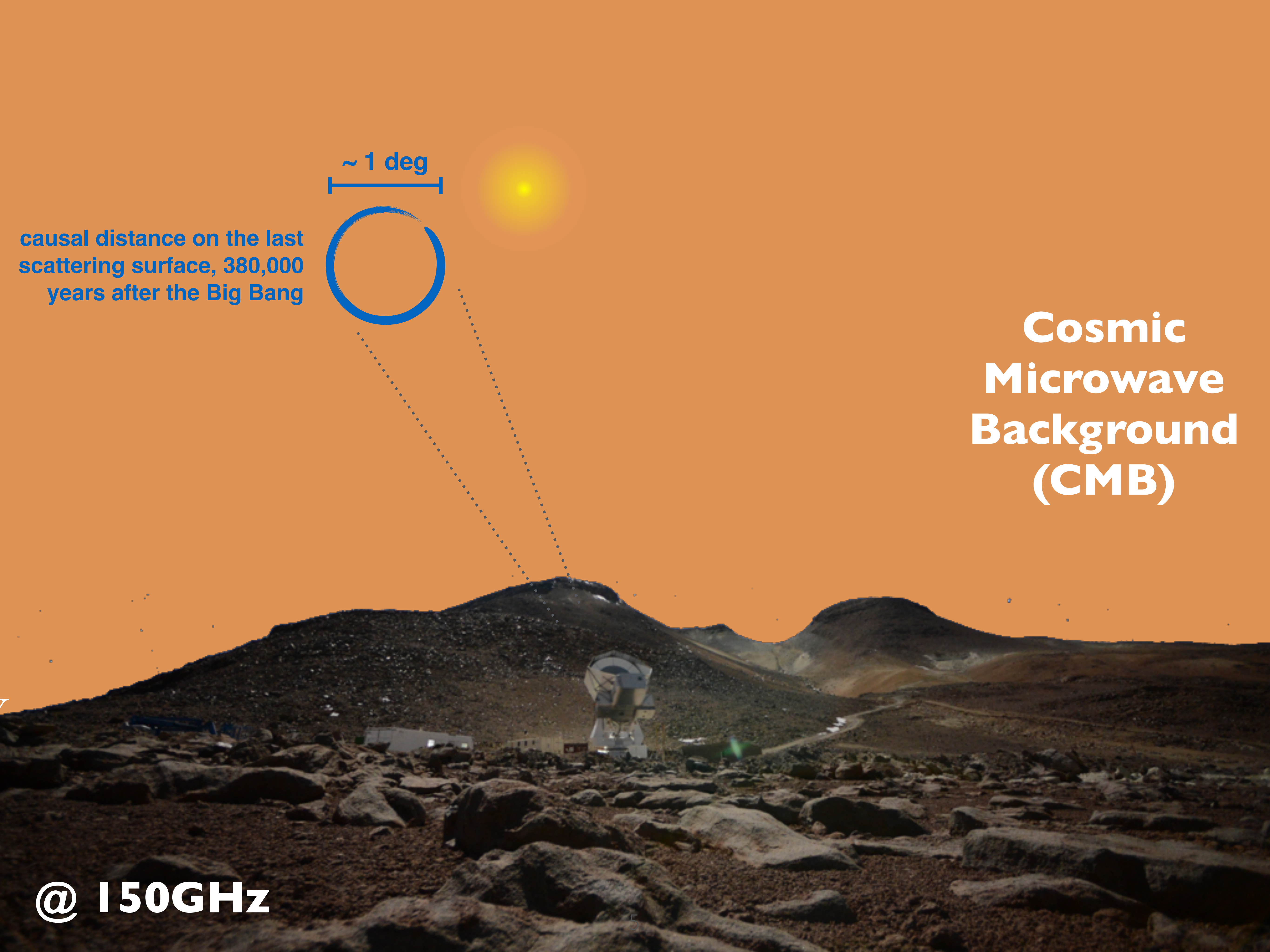

POLARBEAR telescope
5,200m, Atacama desert, Chile

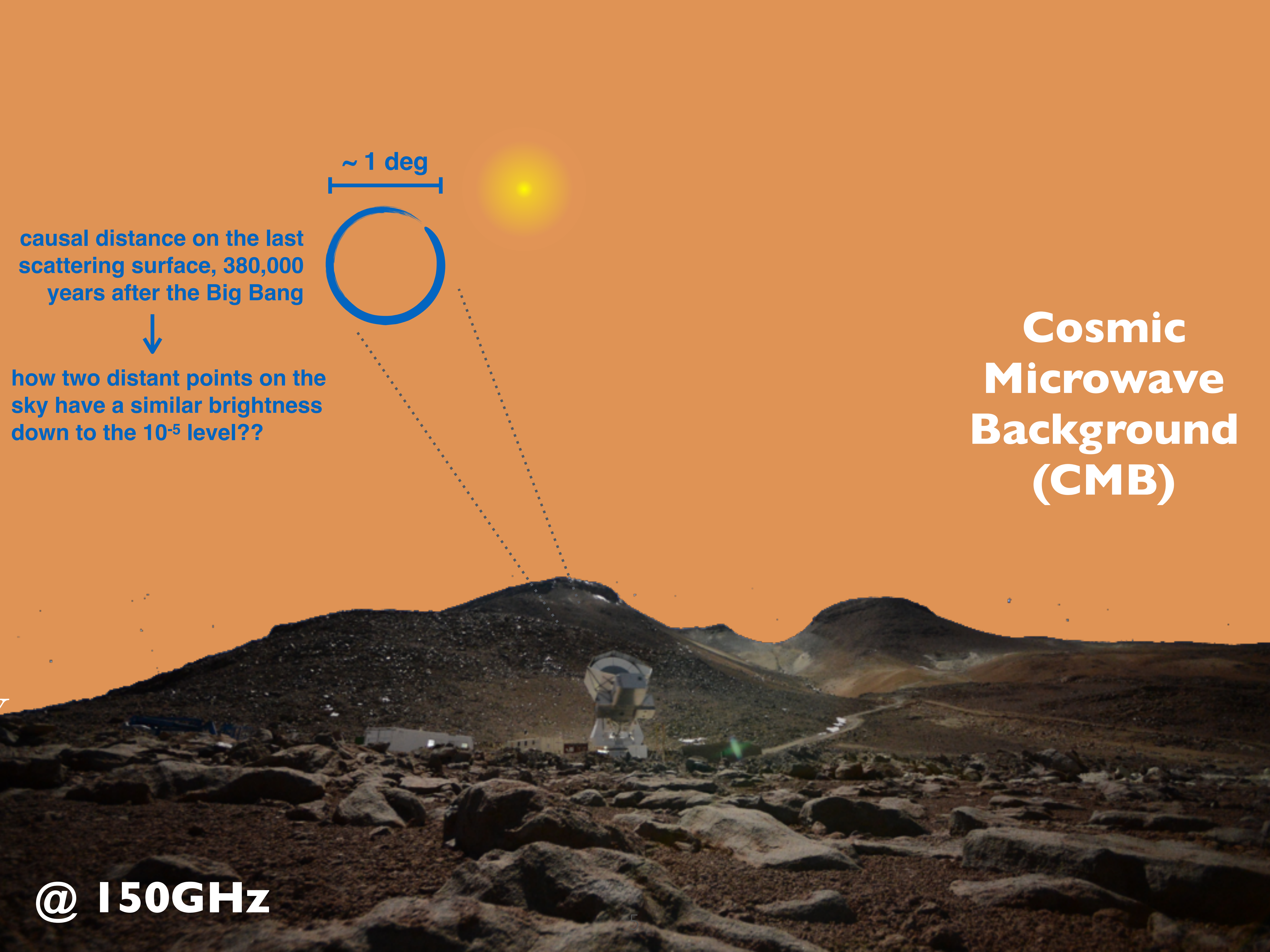

Cosmic Microwave Background (CMB)
POLARBEAR telescope
5,200m, Atacama desert, Chile
@ 150GHz


zooming at the 10^{-5} level
Cosmic Microwave Background (CMB)
@ 150GHz


zooming at the 10^{-5} level
why are fluctuations so small?
… and why are there fluctuations?
Cosmic Microwave Background (CMB)
@ 150GHz


Cosmic
Microwave
Background
(CMB)
@ 150GHz


~ 1 deg
causal distance on the last scattering surface, 380,000 years after the Big Bang
Cosmic Microwave Background (CMB)
@ 150GHz


~ 1 deg
causal distance on the last scattering surface, 380,000 years after the Big Bang
how two distant points on the sky have a similar brightness down to the 10^{-5} level??
Cosmic Microwave Background (CMB)
@ 150GHz

~ 1 deg

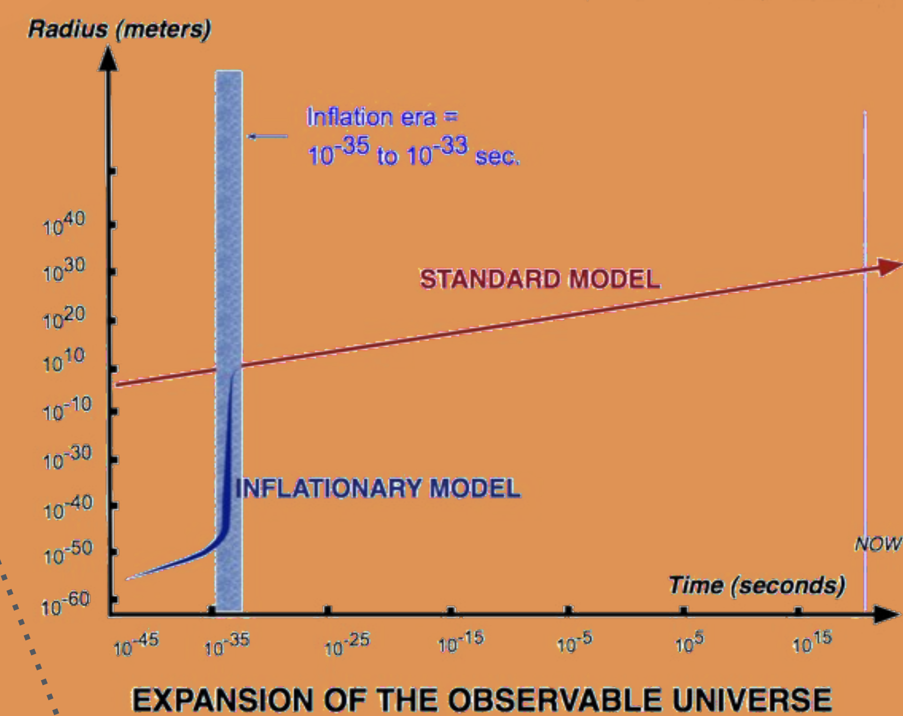
causal distance on the last scattering surface, 380,000 years after the Big Bang

↓

how two distant points on the sky have a similar brightness down to the 10^{-5} level??

↓

inflation mechanism!
the Universe experiences an exponential expansion in the first fraction of a second after the Big Bang



Cosmic Microwave Background (CMB)

@ 150GHz

For most single field slow-roll inflation scenarios (Lyth relation):

$$r \approx 0.002 \left(\frac{60}{N}\right)^2 \left(\frac{\Delta\phi}{m_{\mathrm{Pl}}}\right)^2$$

e-folding

reduced Planck mass

~ 1 deg

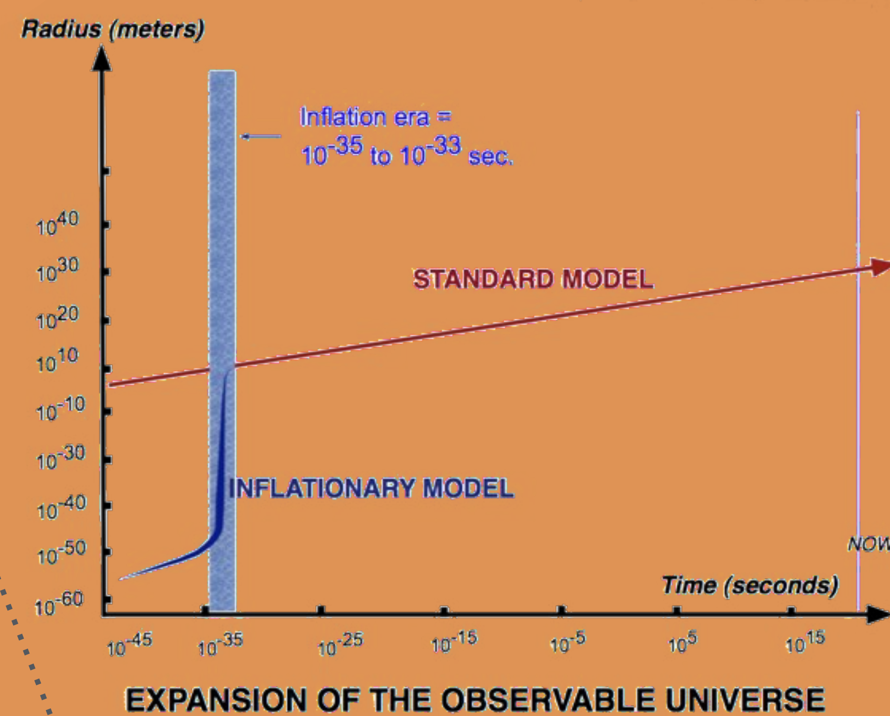
causal distance on the last scattering surface, 380,000 years after the Big Bang

↓

how two distant points on the sky have a similar brightness down to the 10^{-5} level??

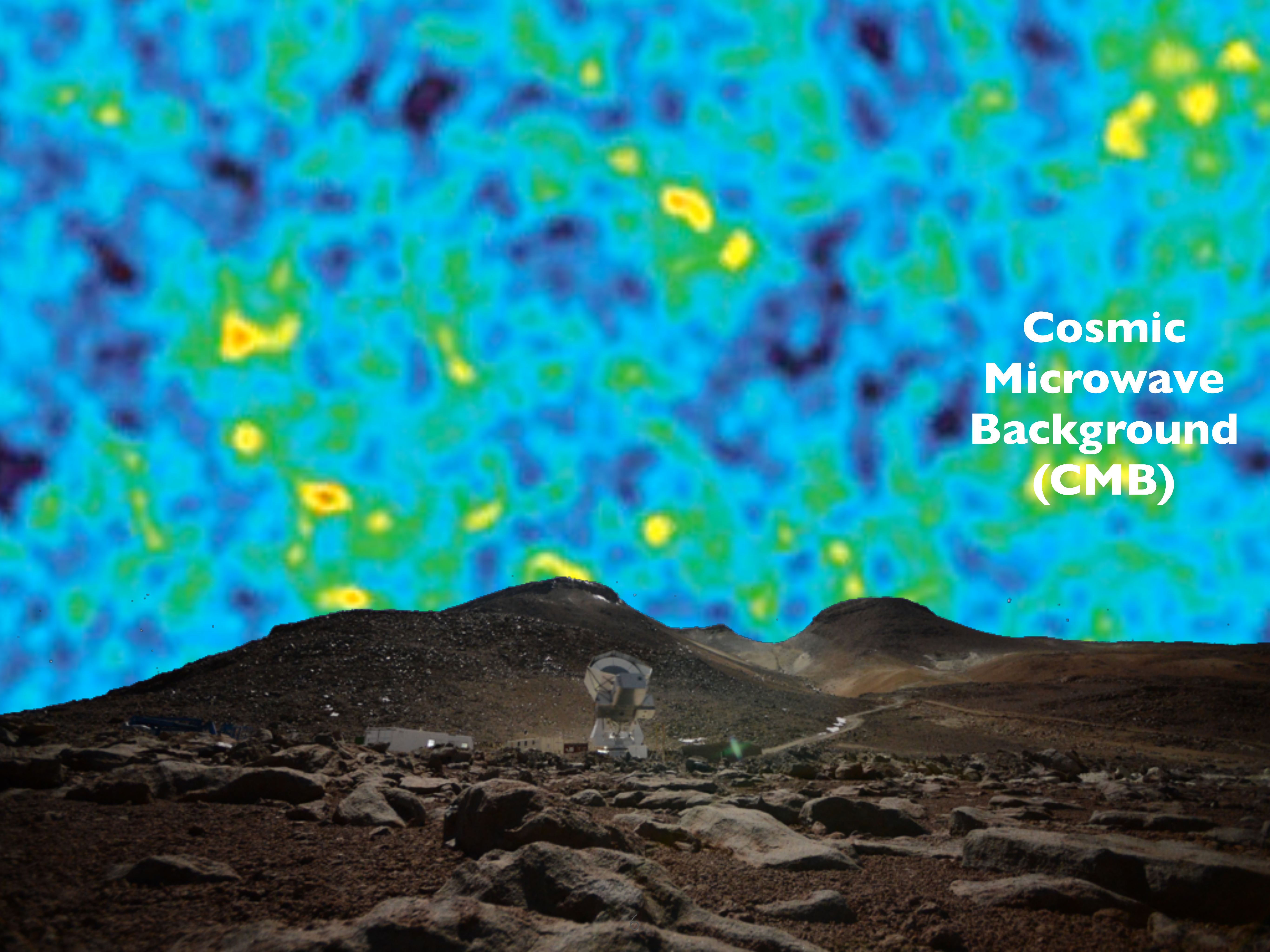
↓

inflation mechanism!
the Universe experiences an exponential expansion in the first fraction of a second after the Big Bang



Cosmic Microwave Background (CMB)

@ 150GHz


Cosmic
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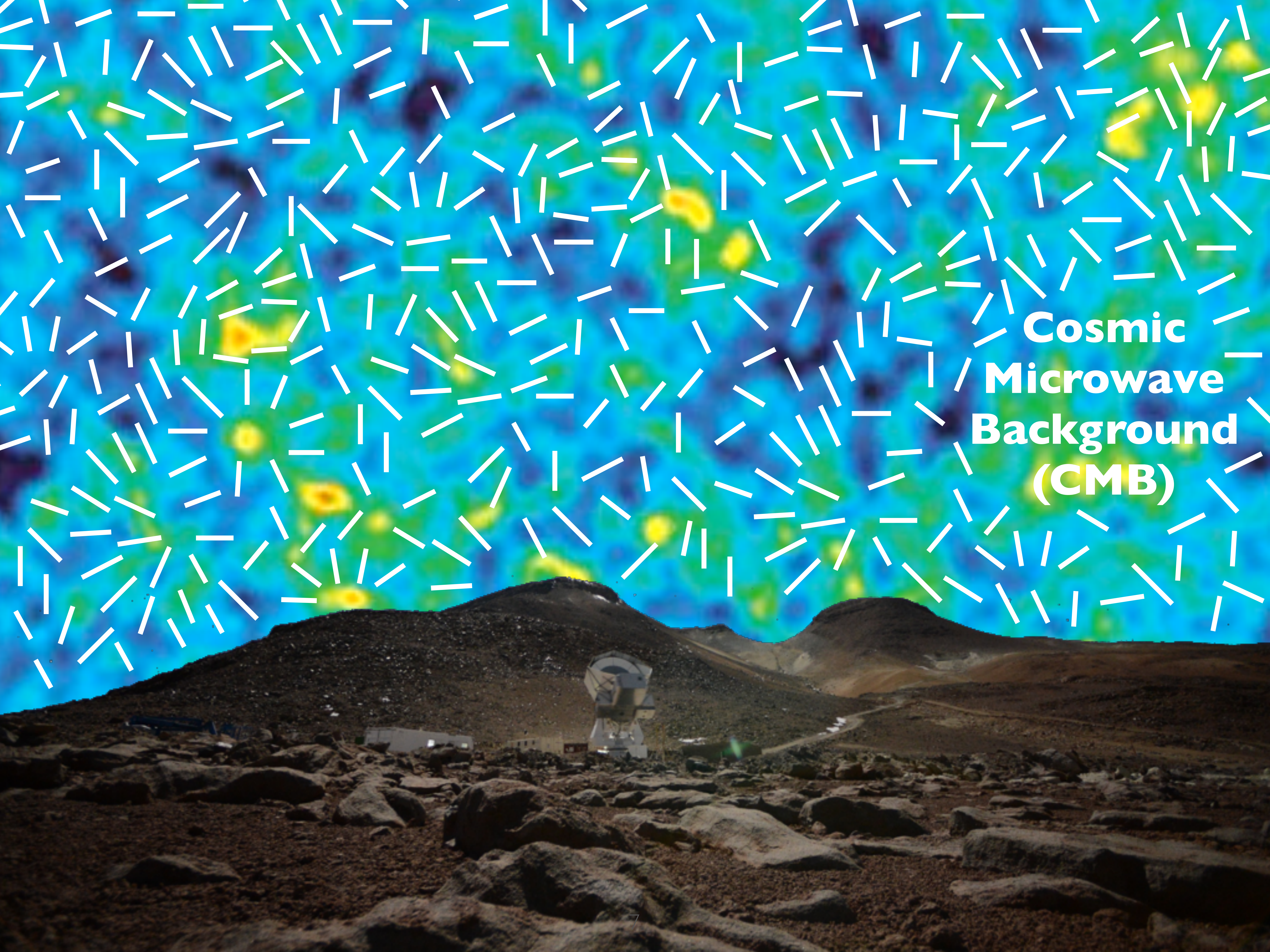
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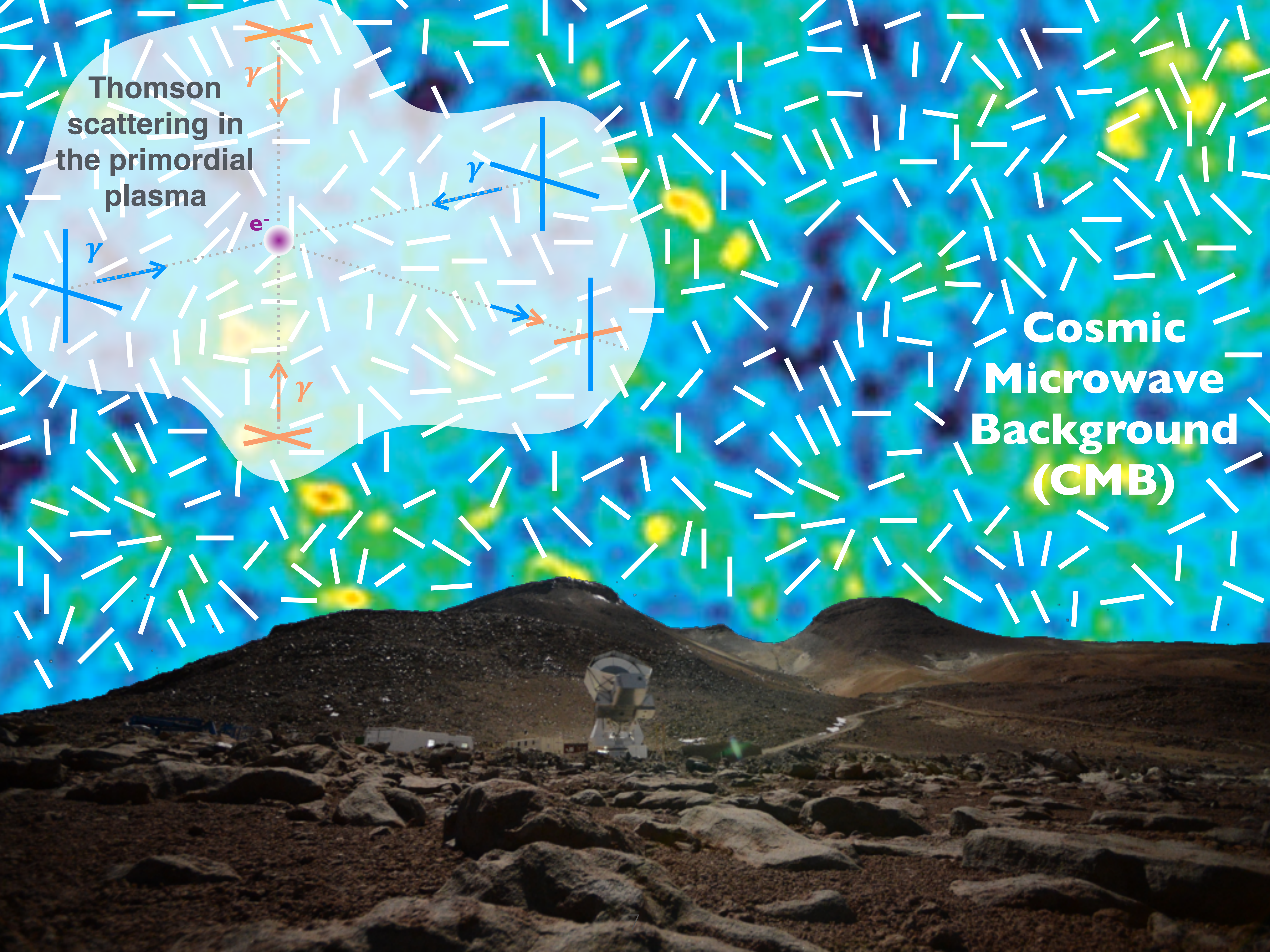
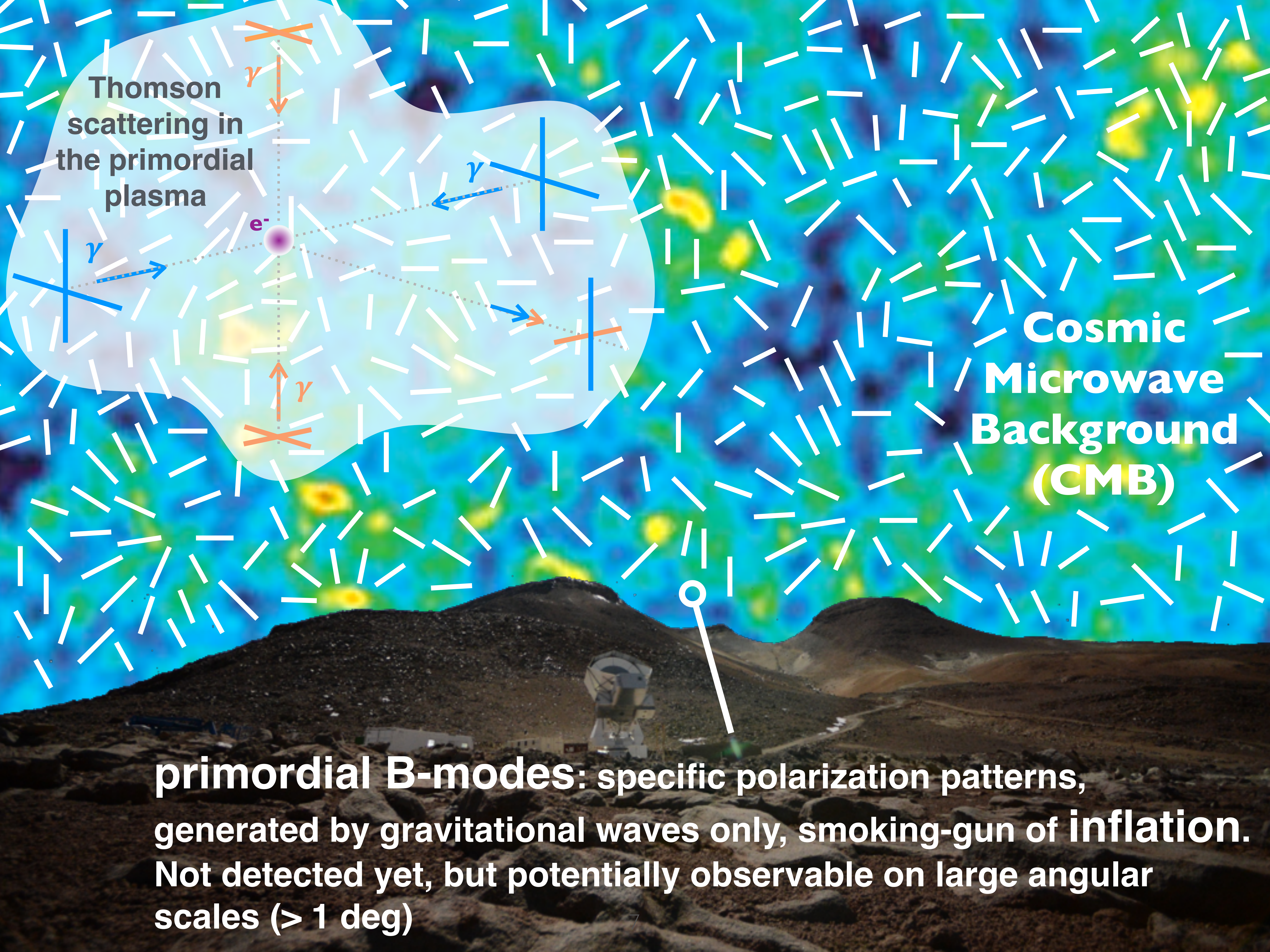
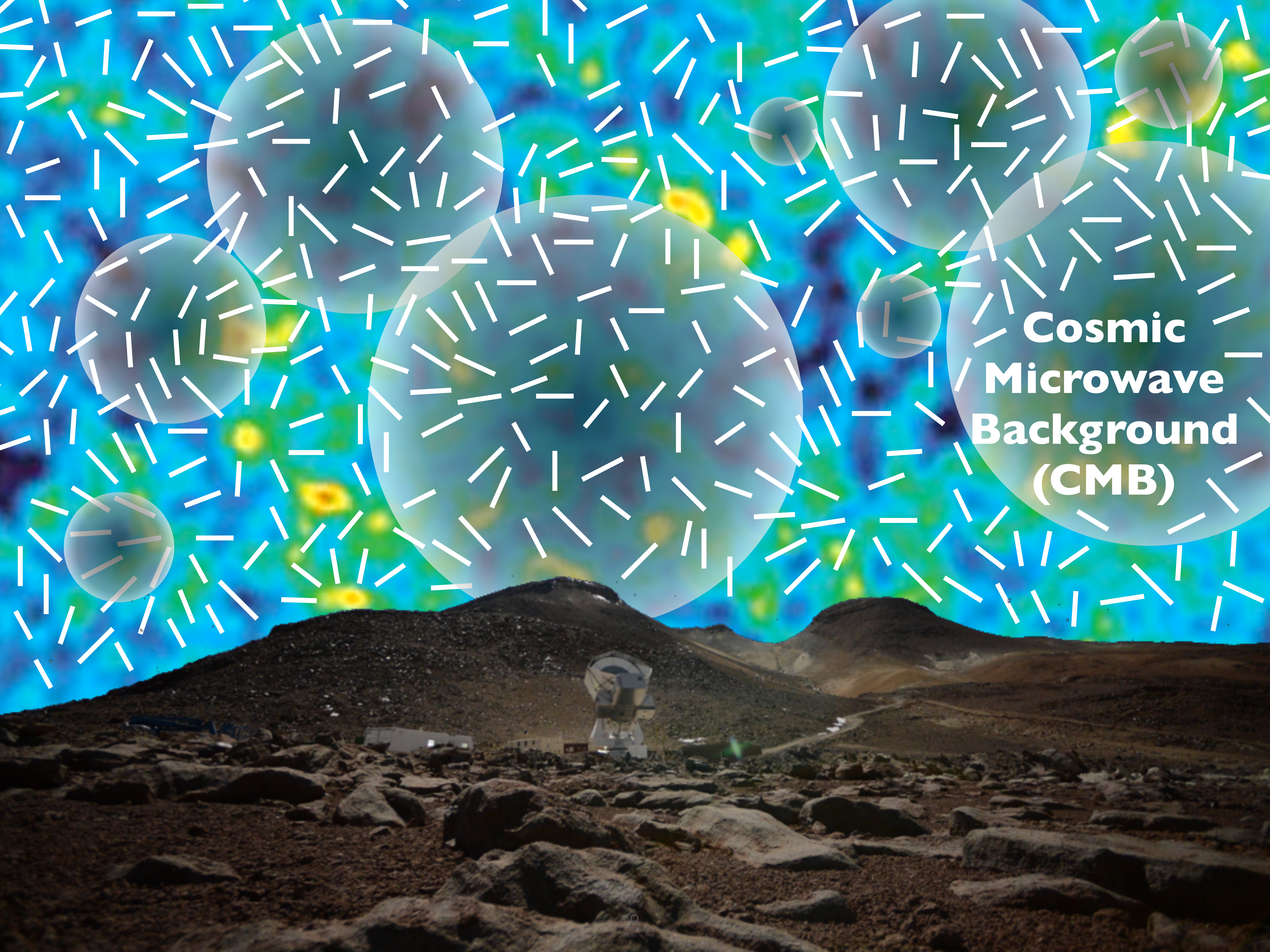


Thomson scattering in the primordial plasma
e⁻
γ
γ
γ
γ
Cosmic Microwave Background (CMB)



Thomson scattering in the primordial plasma
e-
γ
γ
γ
γ
Cosmic Microwave Background (CMB)
primordial B-modes: specific polarization patterns, generated by gravitational waves only, smoking-gun of inflation.
Not detected yet, but potentially observable on large angular scales (> 1 deg)


Cosmic
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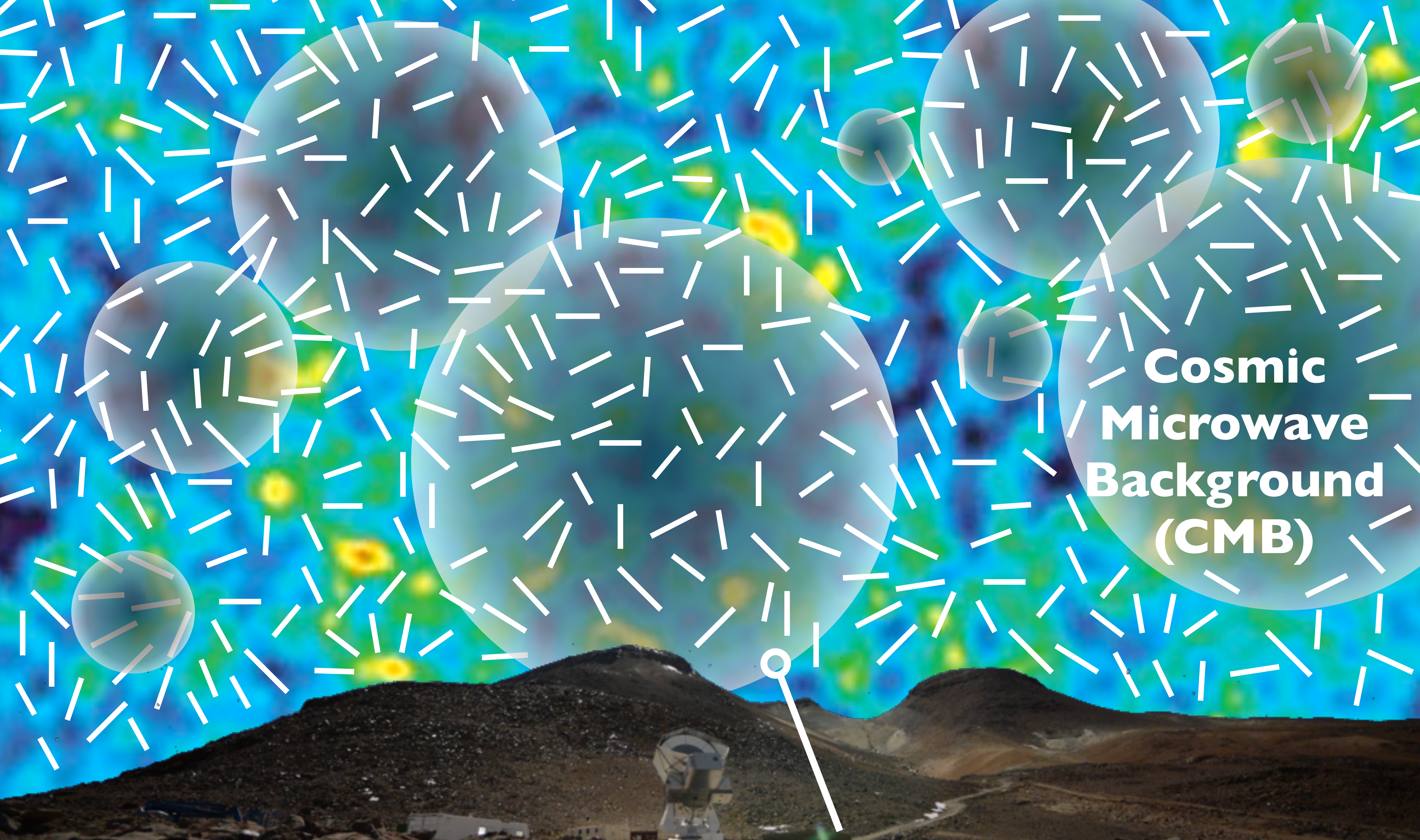
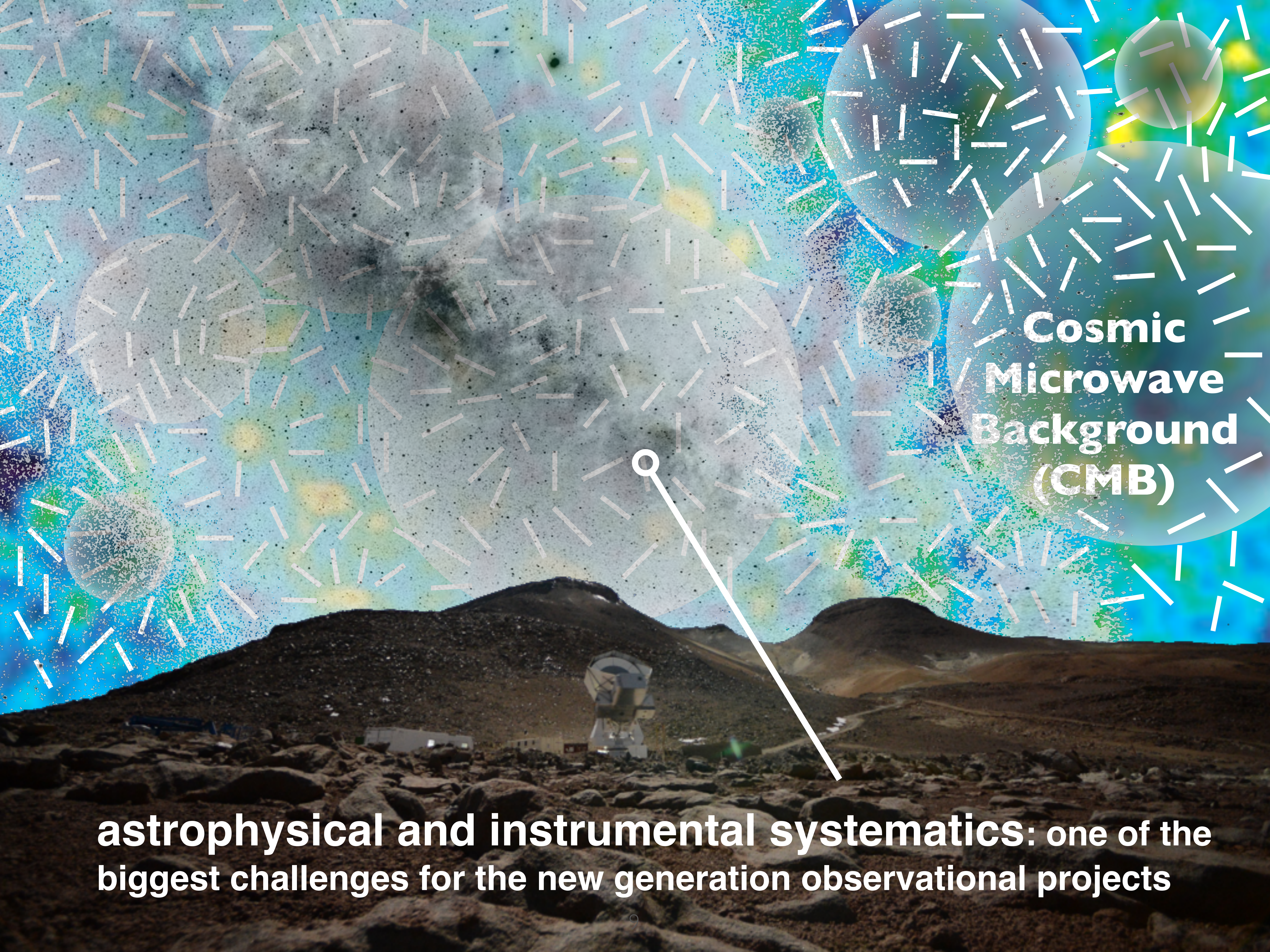


gravitational lensing: re-mapping of small angular scale CMB signal, in total intensity and polarization. The observation of this effect allows the characterization of large scale structures properties, their formation and evolution → **dark energy, total neutrino mass**


Cosmic Microwave Background (CMB)
astrophysical and instrumental systematics: one of the biggest challenges for the new generation observational projects

POLARBEAR-I

main results

- continuous observations of the CMB polarization since 2012
- first direct measurement of sub-degree B-modes (2014)
- first reconstruction of lensing potential with CMB polarization only (2014)
- new measurement of B-modes on small angular scales (2017)
- characterization of large angular scales since 2015 using rotating half-wave plate

Evidence for B-Mode Polarization of the CMB from Cross-correlating Gravitational Lensing with the Cosmic Infrared Background
The POLARBEAR collaboration
Phys. Rev. Lett. 112, 131302 (**2014**)

Measurement of the Cosmic Microwave Background Polarization Lensing Power Spectrum with the POLARBEAR Experiment
The POLARBEAR collaboration
Phys. Rev. Lett. 113, 021301 (**2014**)

A Measurement of the Cosmic Microwave Background B-Mode Polarization Power Spectrum at Sub-degree Scales with POLARBEAR
The POLARBEAR Collaboration
The Astrophysical Journal, Volume 794, 171 (**2014**)

POLARBEAR Constraints on Cosmic Birefringence and Primordial Magnetic Fields
The Polarbear collaboration
Physical Review D, Volume 92, Issue 12, id.123509 (**2015**)

A Measurement of the Cosmic Microwave Background B-Mode Polarization Power Spectrum at Sub-Degree Scales from 2 years of POLARBEAR Data
The POLARBEAR Collaboration (**2017**)
arXiv:1705.02907

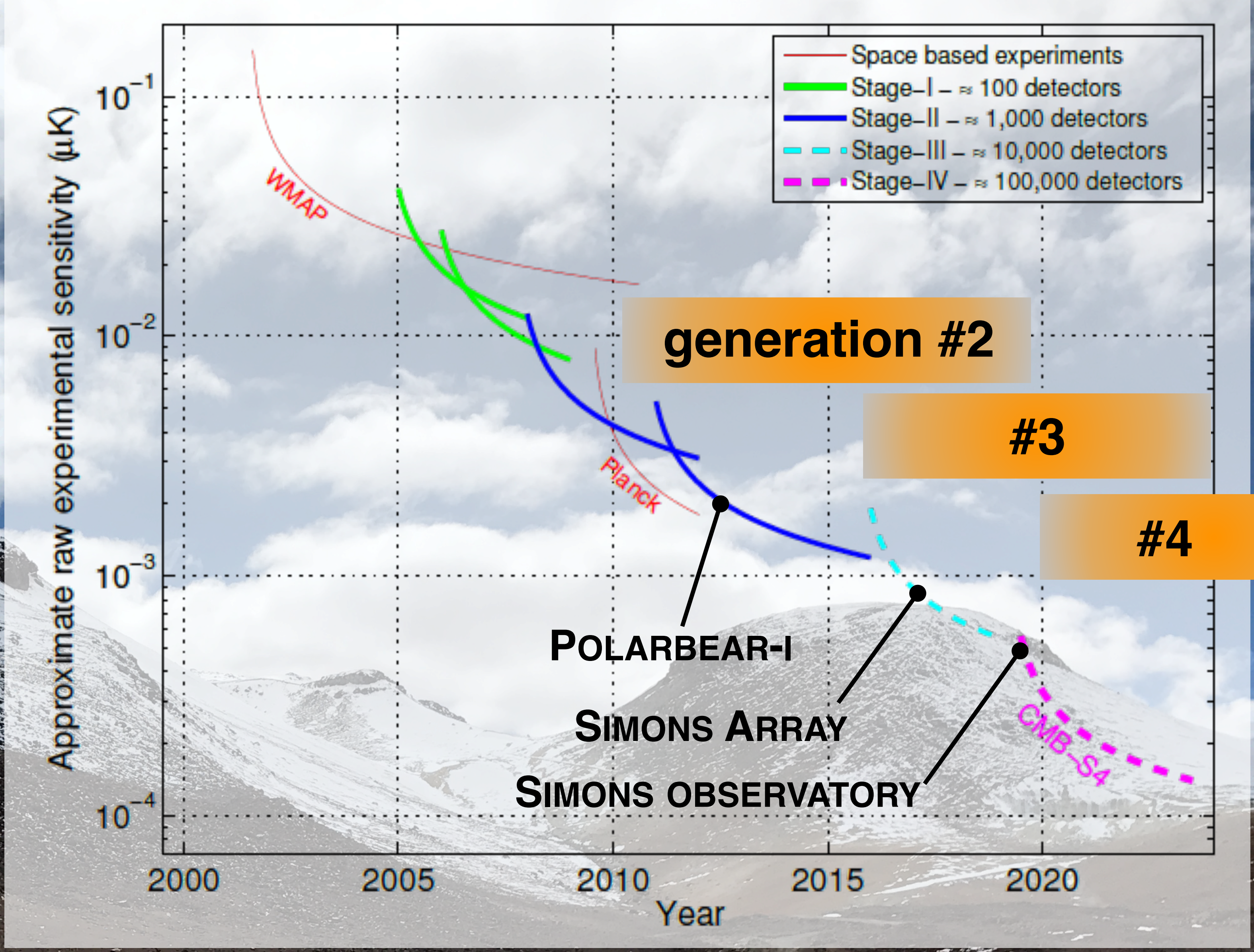
supported by FJPPL grant 2013-2016

Simons Array

➤ starting Fall 2017

Simons Array

➤ **starting Fall 2017**

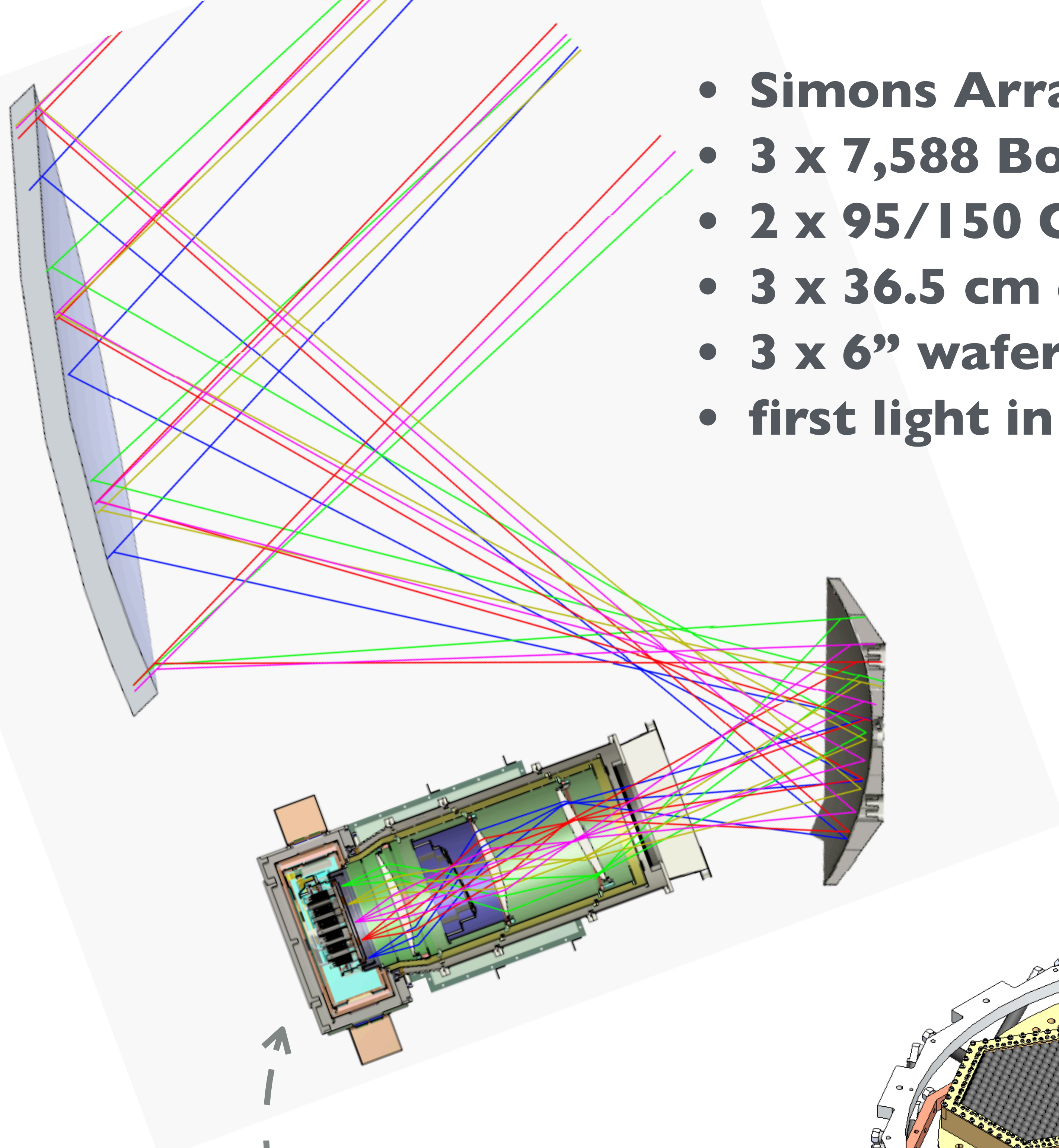


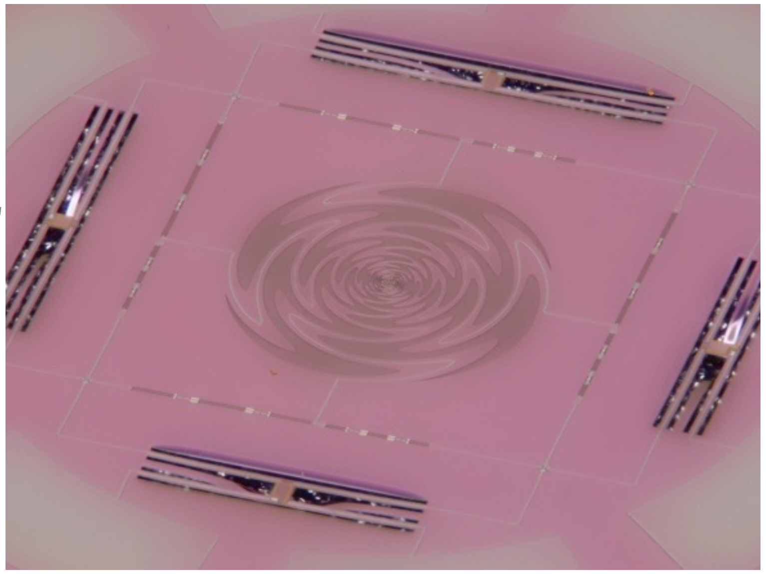
95+150GHz **220+270GHz** **95+150GHz**

constraints on inflation: σ(r=0.1) = 0.006

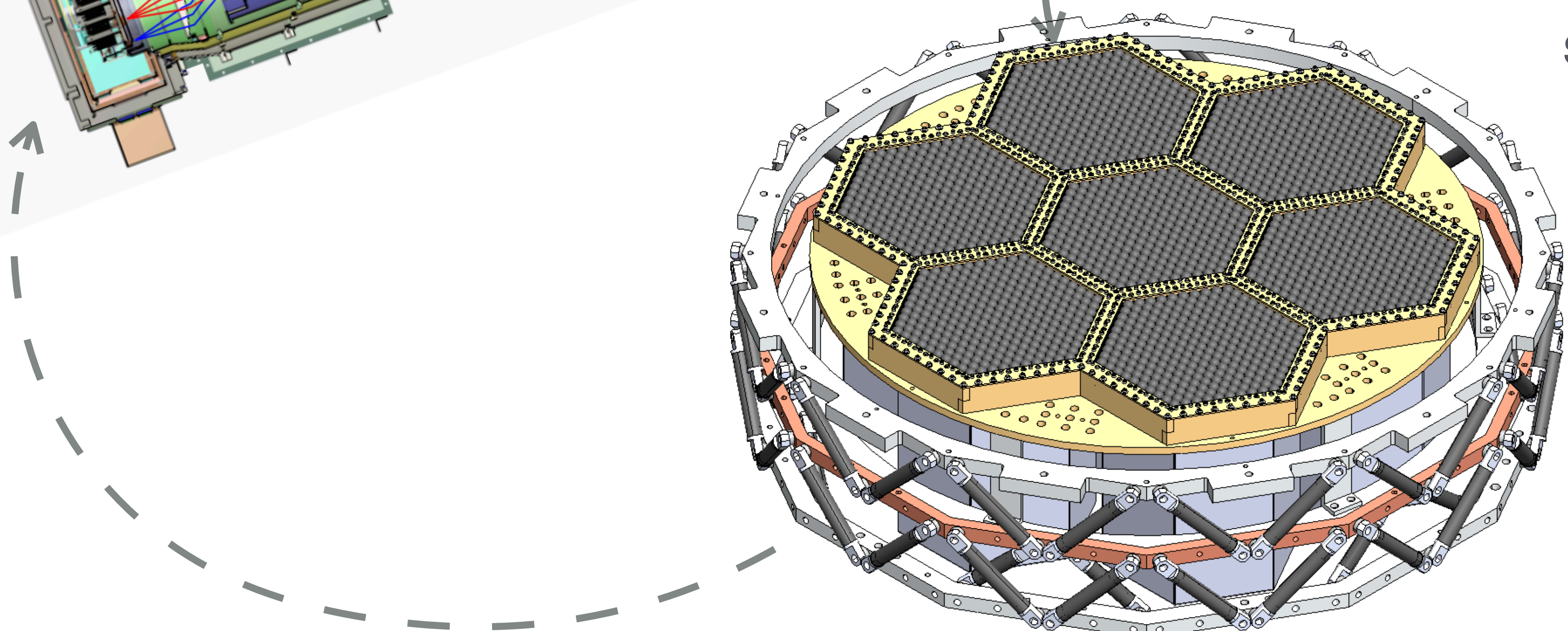
constraints on neutrino mass: σ(Σm$_\nu$) < 60 meV with DESI

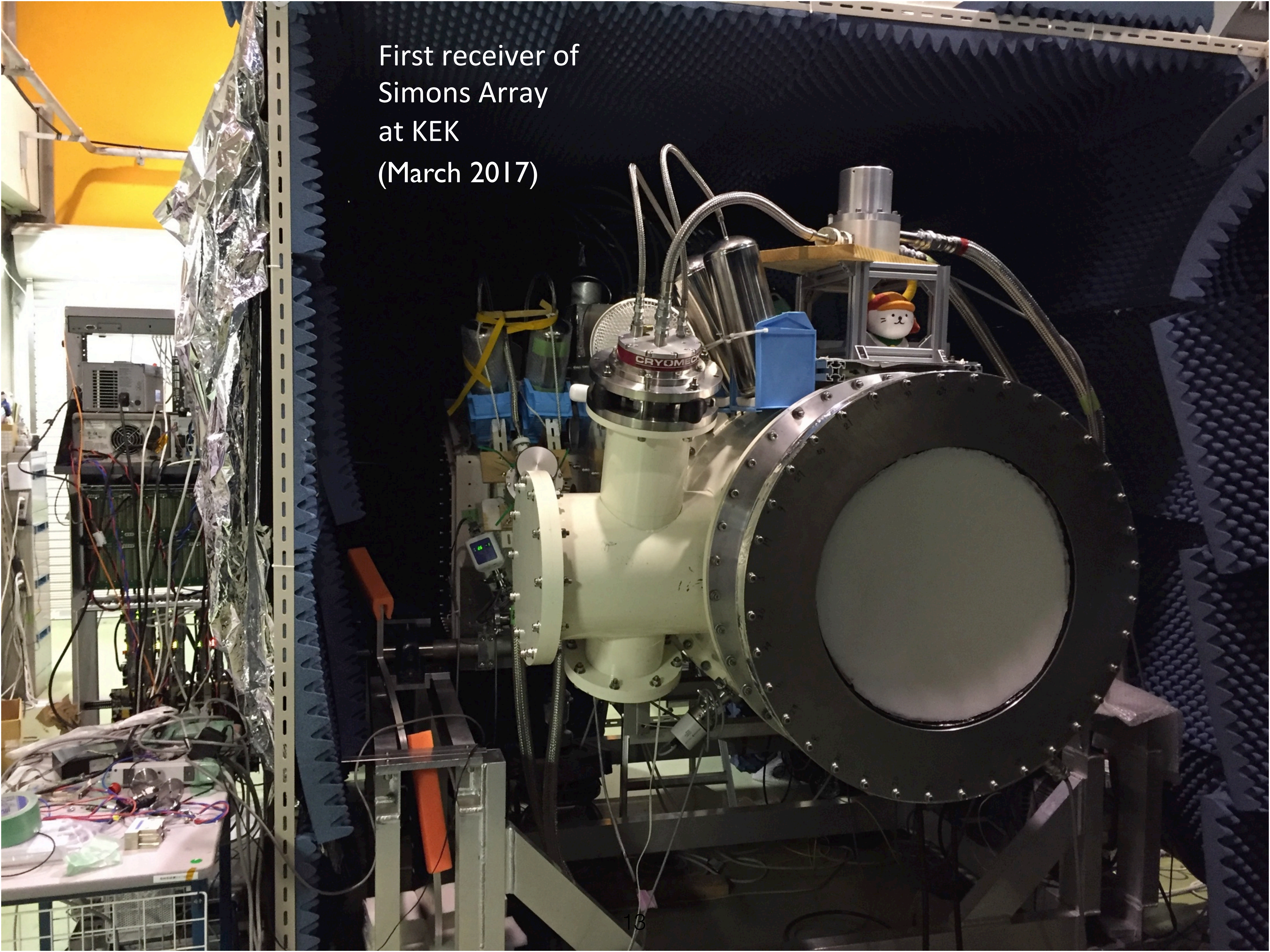
- Simons Array = 3 new-generation telescopes
- 3 x 7,588 Bolometers
- 2 x 95/150 GHz + 1 x 220/270GHz
- 3 x 36.5 cm diameter cryostats
- 3 x 6” wafers
- first light in the Fall 2017!

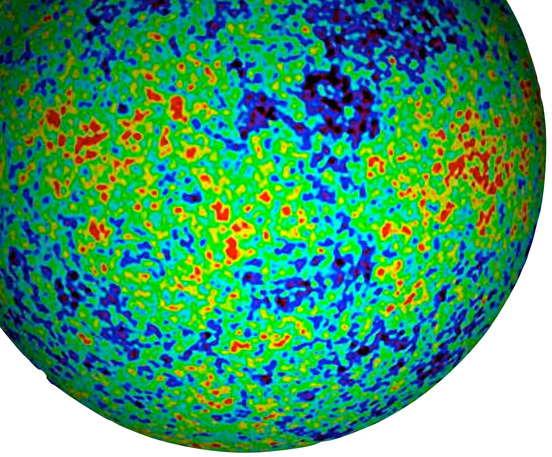




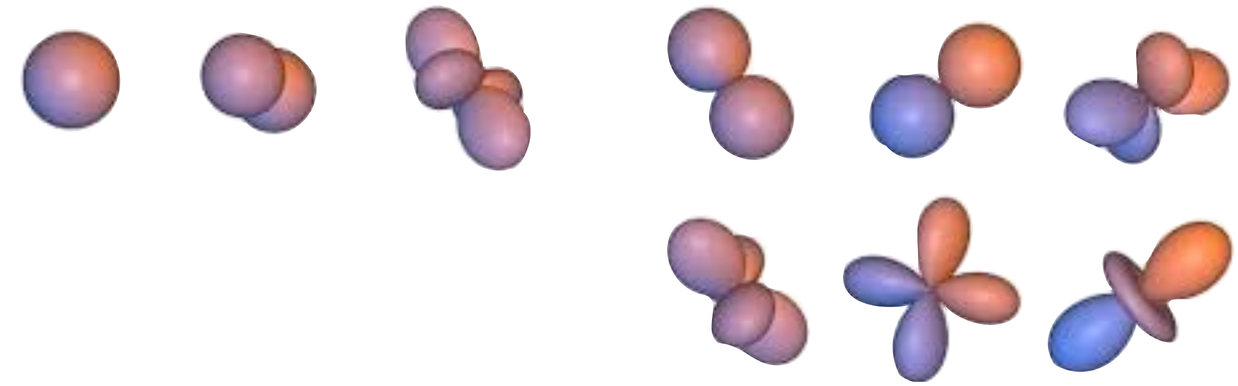
sinuous antenna

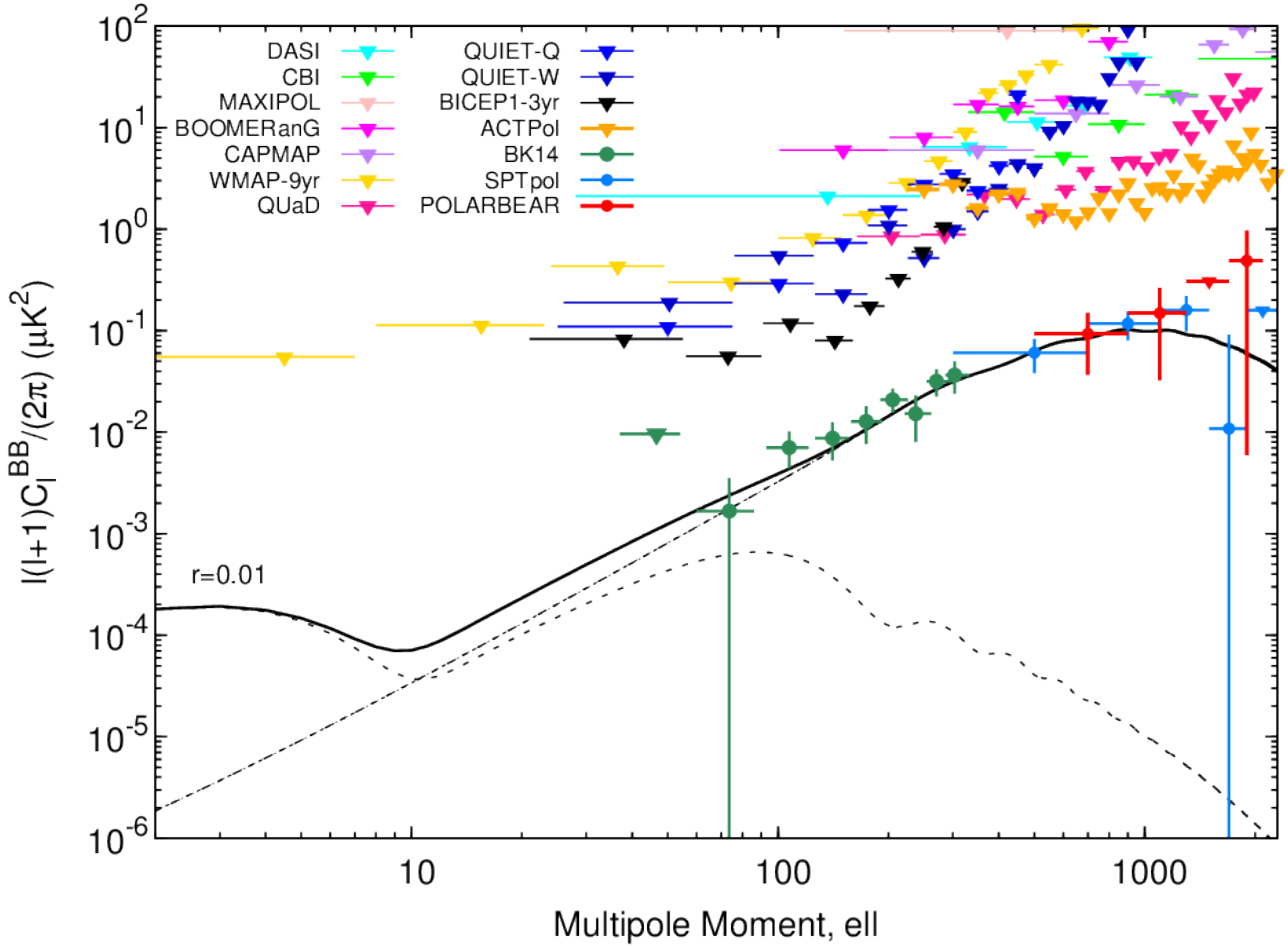


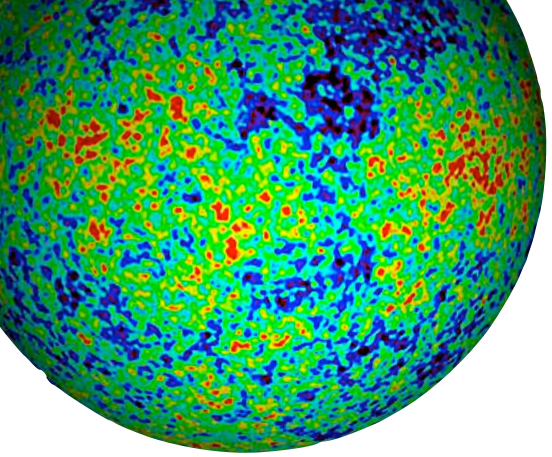

First receiver of
Simons Array
at KEK
(March 2017)
CRYOMECH



$$= \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m}^{T} Y_{\ell}^{m}(\theta, \phi)$$







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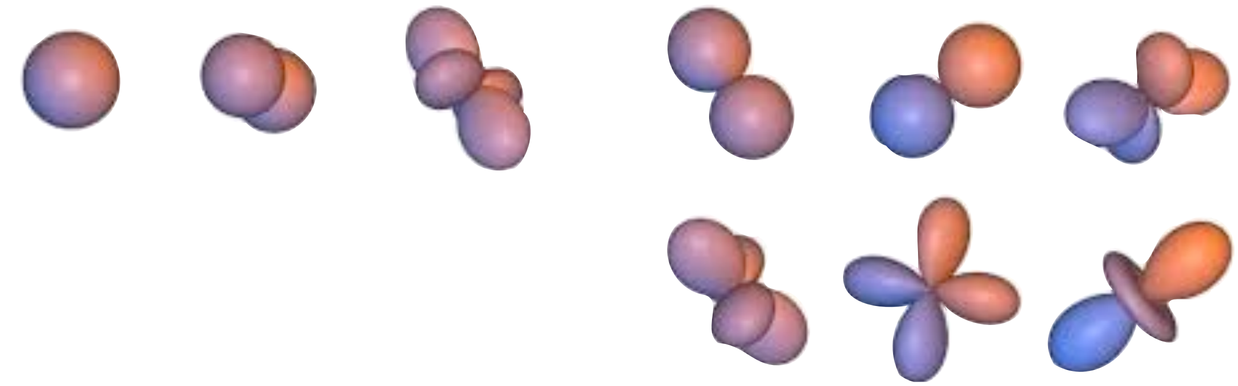
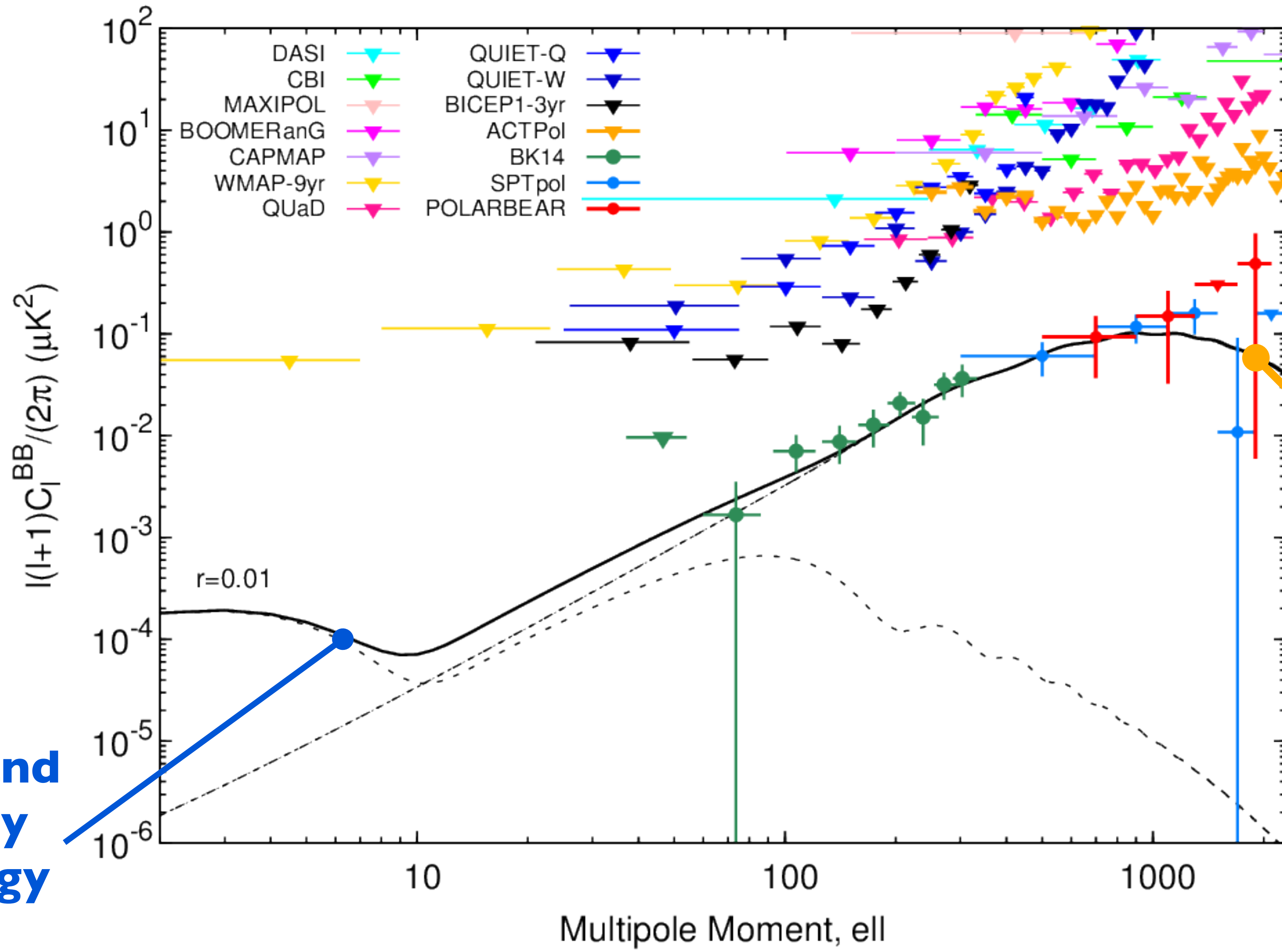
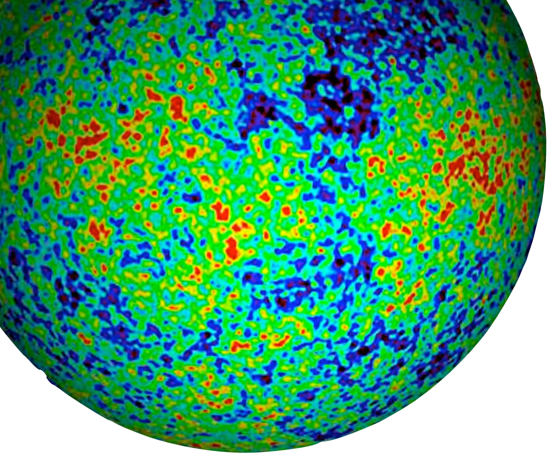




Large scale structures Σm_ν, w, N_{eff}, ...

inflation and its energy high energy physics



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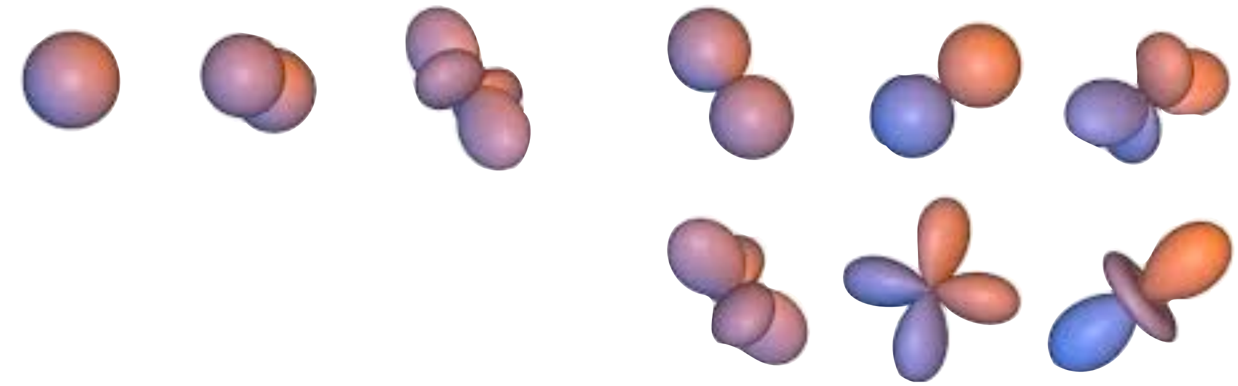
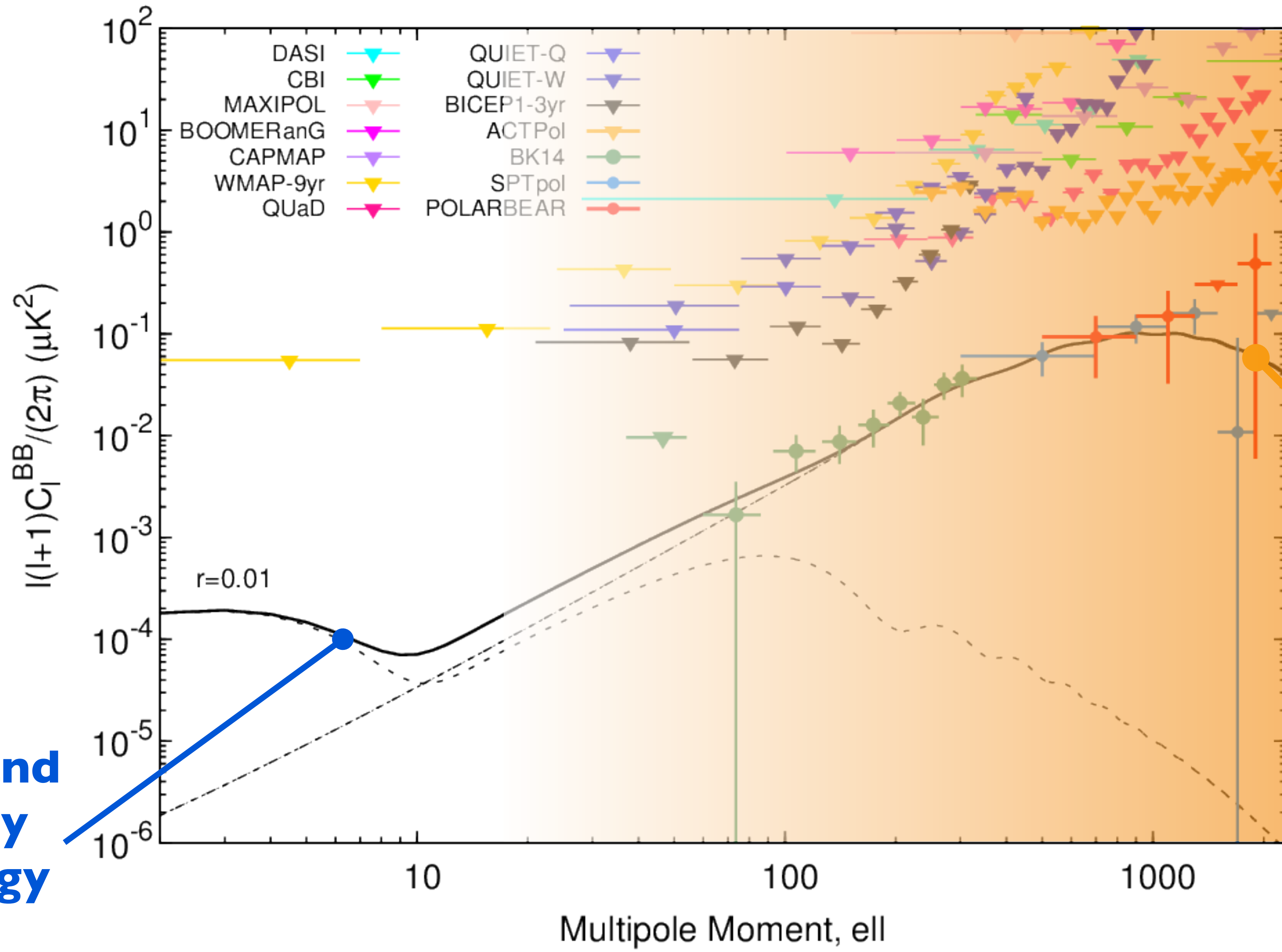
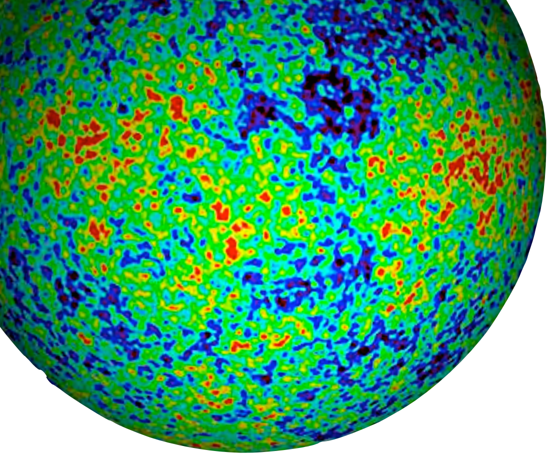


ground-based observations



inflation and its energy high energy physics

Large scale structures Σm_ν, w, N_{eff}, ...



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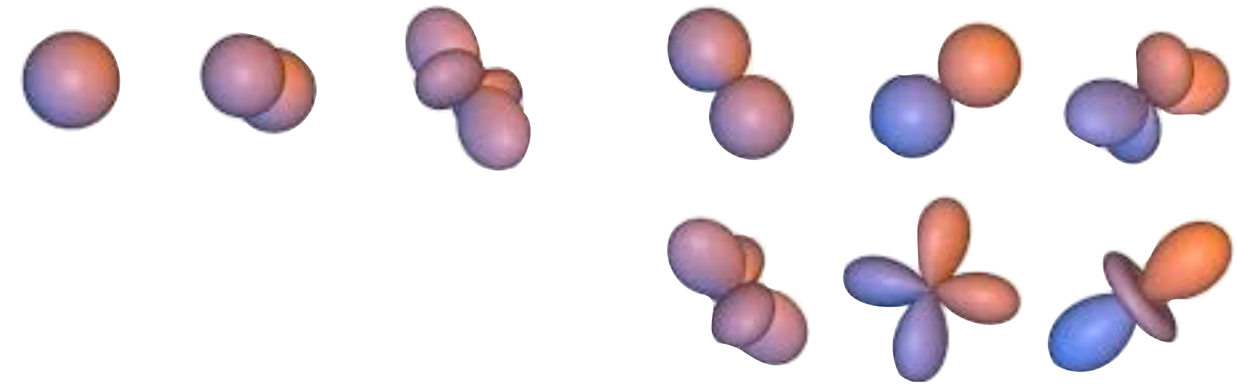
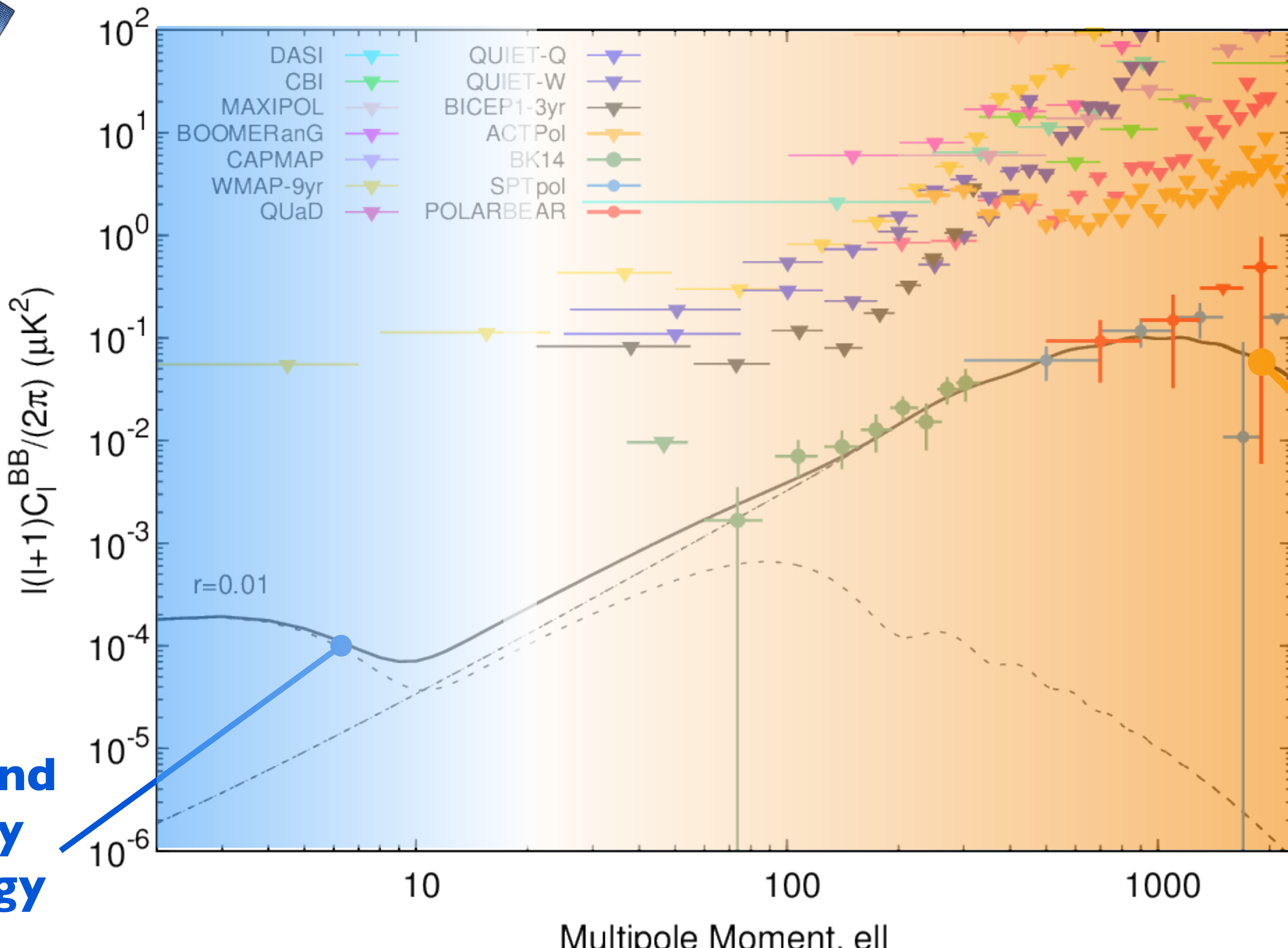


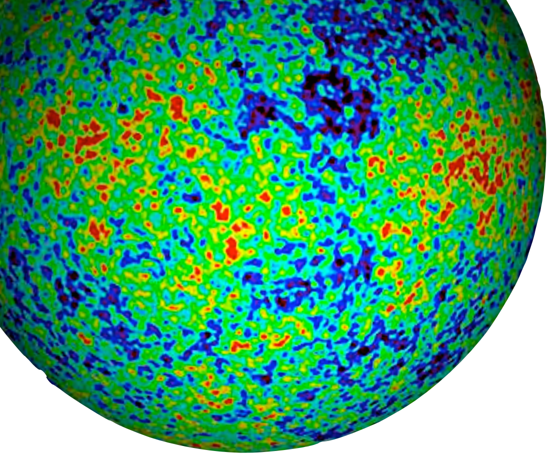
space **ground-based observations**



Large scale structures Σm_ν, w, N_{eff}, ...

inflation and its energy high energy physics

σ(r=0) < 0.001



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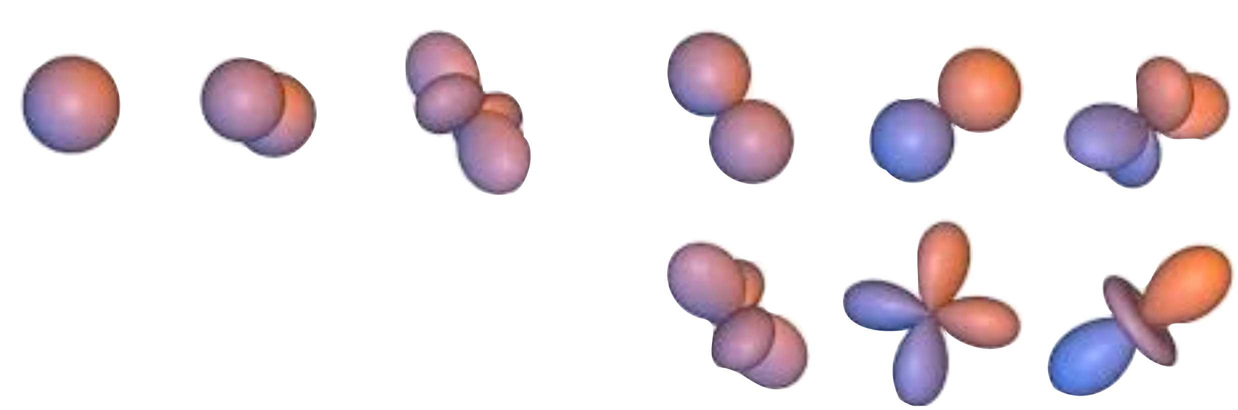
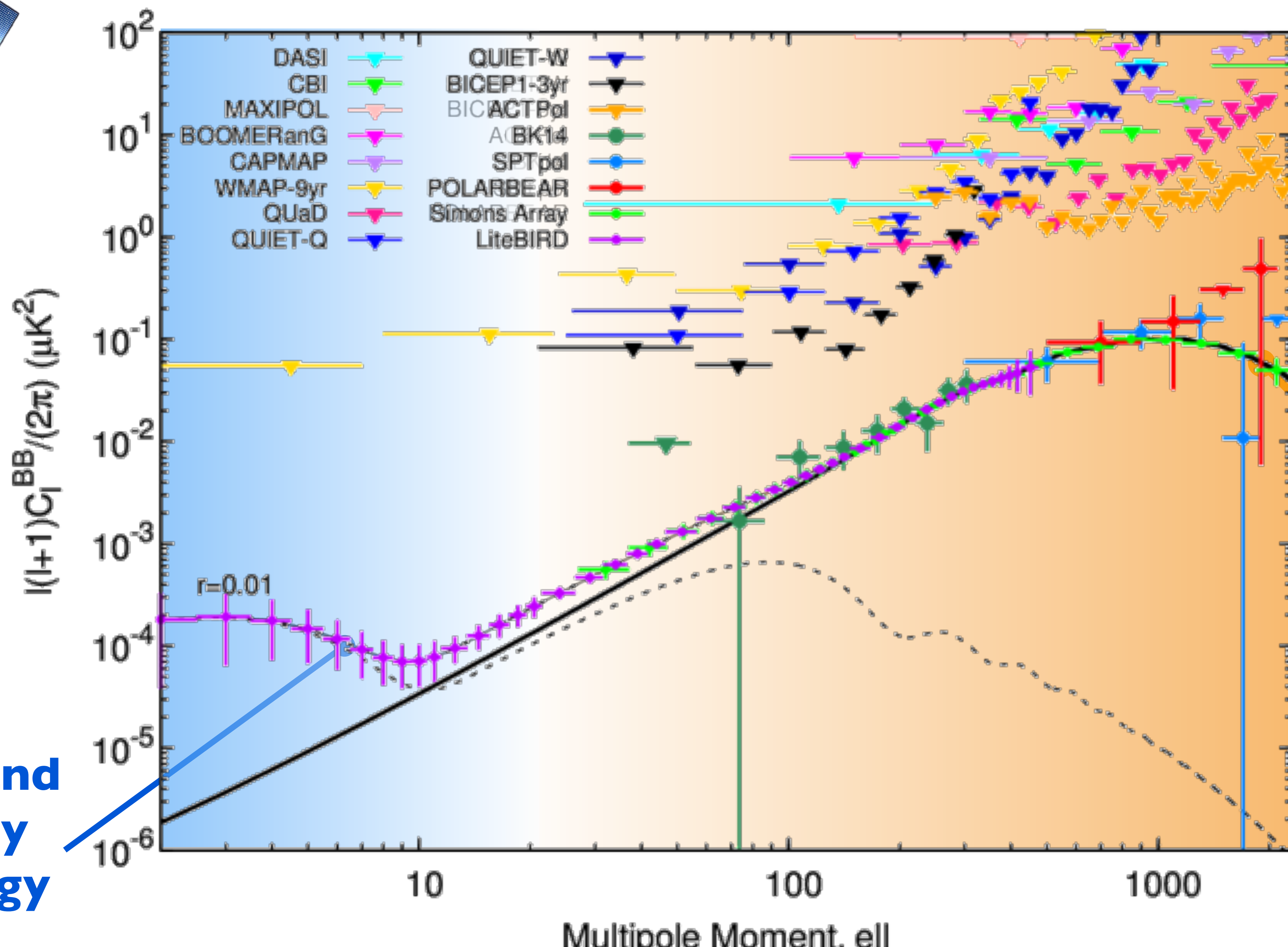


space **ground-based observations**



Large scale structures Σm_ν, w, N_{eff}, ...

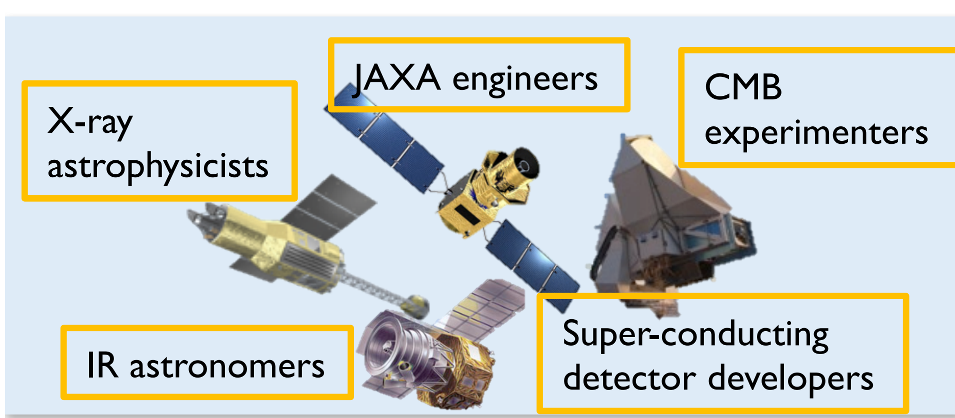
inflation and its energy high energy physics

σ(r=0) < 0.001

M. Hazumi (PI)

A. T. Lee (US PI)

LiteBIRD working group



JAXA
T. Dotani
H. Fuke
H. Imada
I. Kawano
H. Matsuhara
T. Matsumura
K. Mitsuda
T. Nishibori
K. Nishijo
A. Noda
A. Okamoto
S. Sakai
Y. Sato
K. Shinozaki
H. Sugita
Y. Takei
S. Utsunomiya
T. Wada
R. Yamamoto
N. Yamasaki
T. Yoshida
K. Yotsumoto

Osaka U.
S. Kuromiya
M. Nakajima
S. Takakura
K. Takano

Osaka Pref. U.
M. Inoue
K. Kimura
H. Ogawa
N. Okada

Okayama U.
T. Funaki
N. Hidehira
H. Ishino
A. Kibayashi
Y. Kida
K. Komatsu
S. Uozumi
Y. Yamada

NIFS
S. Takada

Kavli IPMU
K. Hattori
N. Katayama
Y. Sakurai
H. Sugai

KEK
M. Hazumi (PI)
M. Hasegawa
N. Kimura
K. Kohri
M. Maki
Y. Minami
T. Nagasaki
R. Nagata
H. Nishino
S. Oguri
T. Okamura
N. Sato
J. Suzuki
T. Suzuki
O. Tajima
T. Tomaru
M. Yoshida

Kansei Gakuin U.
S. Matsuura

Kitazato U.
T. Kawasaki

Konan U.
I. Ohta

NAOJ
A. Dominjon
T. Hasebe
J. Inatani
K. Karatsu
S. Kashima
T. Noguchi
Y. Sekimoto
M. Sekine

Saitama U.
M. Naruse

NICT
Y. Uzawa

SOKENDAI
Y. Akiba
Y. Inoue
H. Ishitsuka
Y. Segawa
S. Takatori
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S. Matsuoka
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U. Tokyo
S. Sekiguchi
T. Shimizu
S. Shu
N. Tomita

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Nagoya U.
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Yokohama Natl. U.
T. Fujino
F. Irie
H. Kanai
S. Nakamura
T. Yamashita

RIKEN
S. Mima
C. Otani

APC Paris
J. Errard
R. Stompor

Cardiff U.
G. Pisano

CEA
L. Duband
J.M. Duval

CU Boulder
N. Halverson

McGill U.
M. Dobbs

MPA
E. Komatsu

NIST
G. Hilton
J. Hubmayr

Stanford U.
S. Cho
K. Irwin
S. Kernasovskiy
C.-L. Kuo
D. Li
T. Namikawa
K. L. Thompson

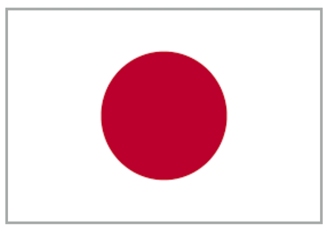
UC Berkeley / LBNL
D. Barron
J. Borrill
Y. Chinone
Cukierman
D. Curtis
T. de Haan
L. Hayes
J. Fisher
N. Goeckner-wald
C. Hill
O. Jeong
R. Keskitalo
T. Kisner
A. Kusaka
A. Lee(US PI)
E. Linder
D. Meilhan
P. Richards
E. Taylor
U. Seljak
B. Sherwin
A. Suzuki
P. Turin
B. Westbrook
M. Willer
N. Whitehorn

UC San Diego
K. Arnold
T. Elleot
B. Keating
G. Rebeiz

139 members, international and interdisciplinary

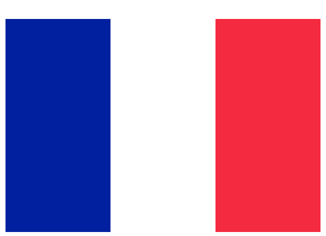
Status of LiteBIRD

- A candidate of **JAXA's next strategic large missions**, aiming to launch in mid of 2020's. Conceptual design phase-A1 started in Sep. 2016.



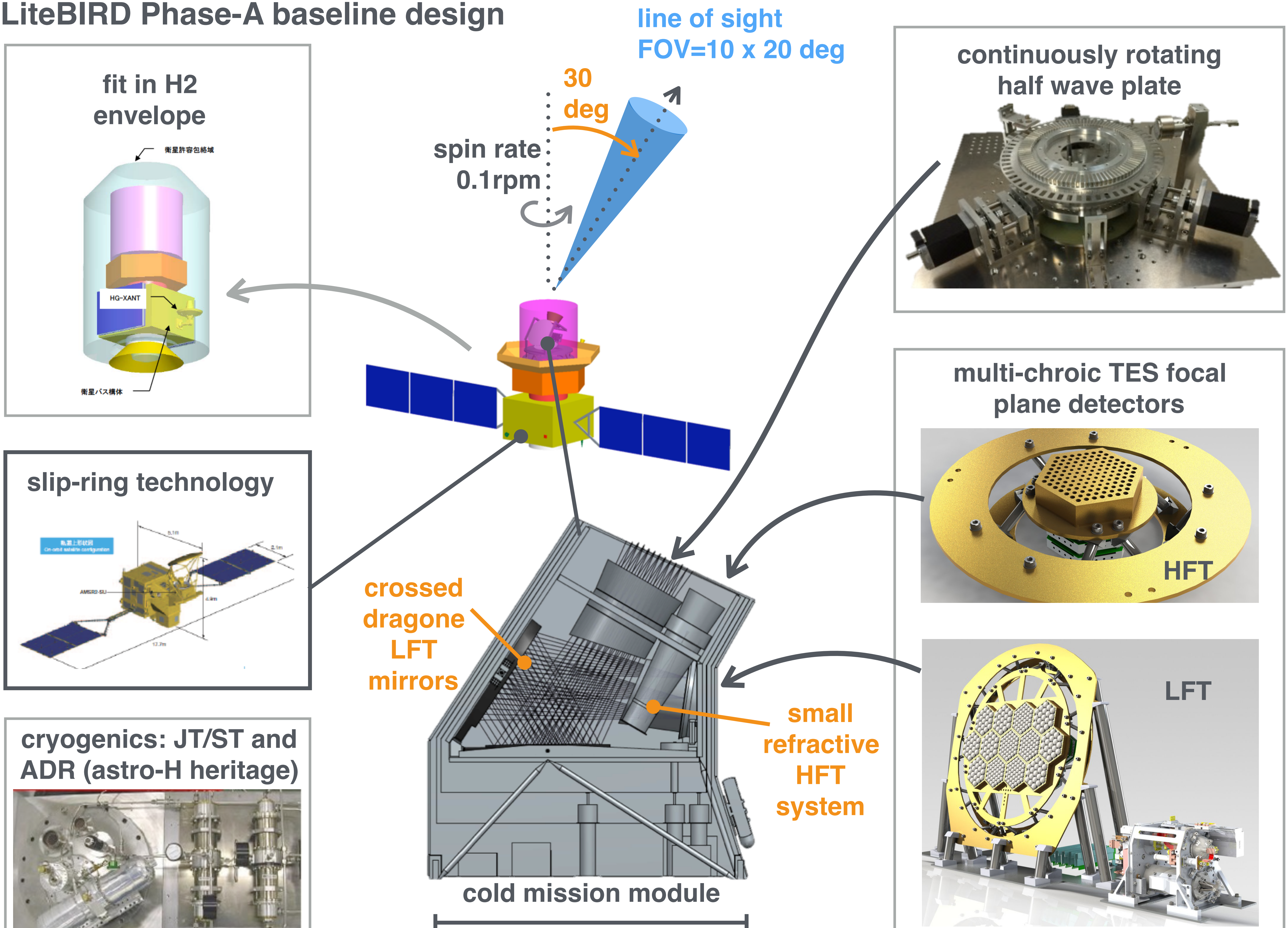
- LiteBIRD selected as **one of the top-priority projects in Master Plan 2014 and 2017 by Science Council of Japan**, and one of the ten new projects in **MEXT Roadmap 2014 for Large-scale Research Projects**.

- NASA supports the US team to work on the technical development of the detectors.

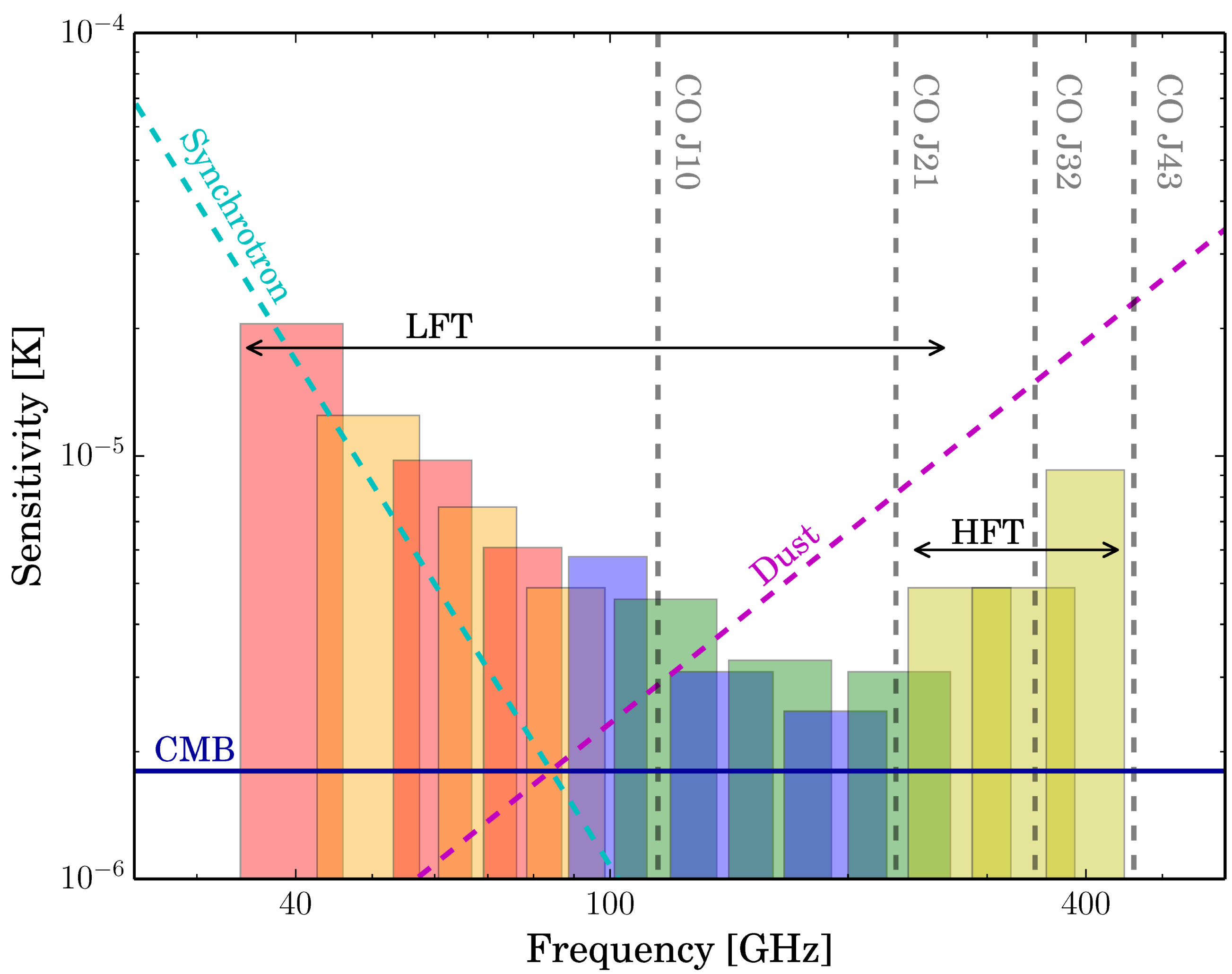


- 30 researchers / 8 institutes from France are interested in the project and are actively writing a proposal to French space agency. It will aim at contributing to the project through several technological challenges.

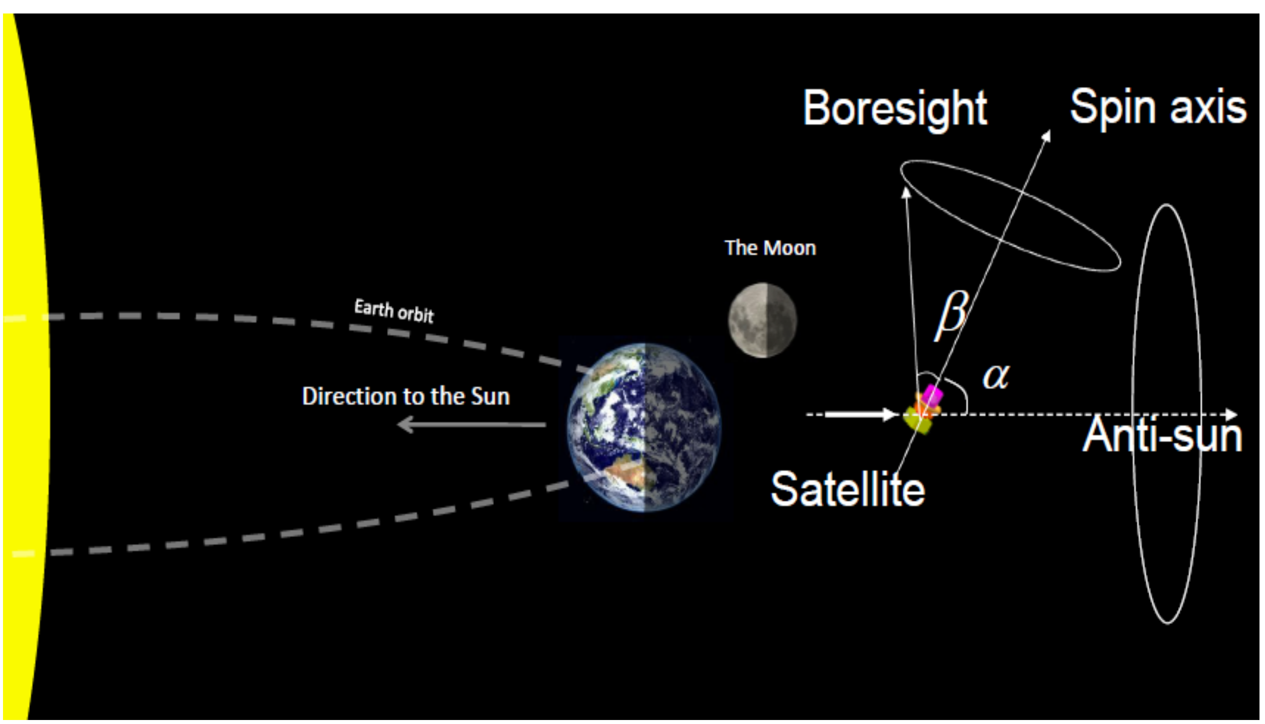
LiteBIRD Phase-A baseline design

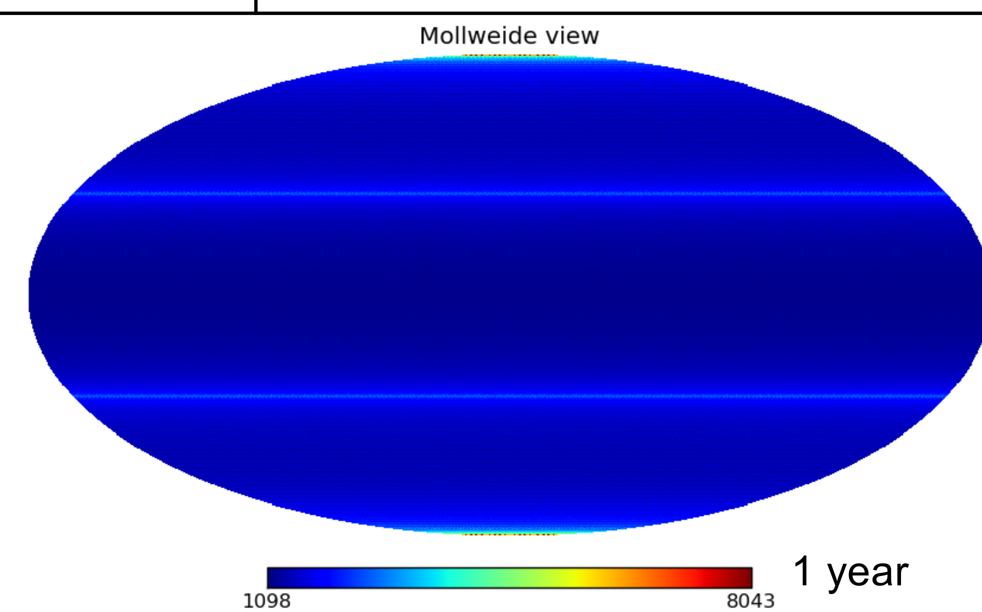


constraints on inflation: σ(r) < 10^{-3}



Main specifications (Phase-A baseline design)	
Item	**Specification**
Orbit	L2 halo orbit
Launch year (vehicle)	2025** (H3)
Observation (time)	All-sky CMB survey (3 years)
Mass	2.2 t
Power	2.5 kW
Mission instruments	• Superconducting detector arrays • Continuously-rotating half-wave plate (HWP) • Crossed-Dragone mirrors + small refractive telescope • 0.1K cooling system (ST/JT/ADR)
Frequencies (# of bands)	40 – 400 GHz (15 bands)
Data size	4 GB/day
Sensitivity	2.5 microKarcmin (3 years)
Angular resolution	0.5deg @ 100 GHz (FWHM)





FJPPL (TYL) application 2017-2018

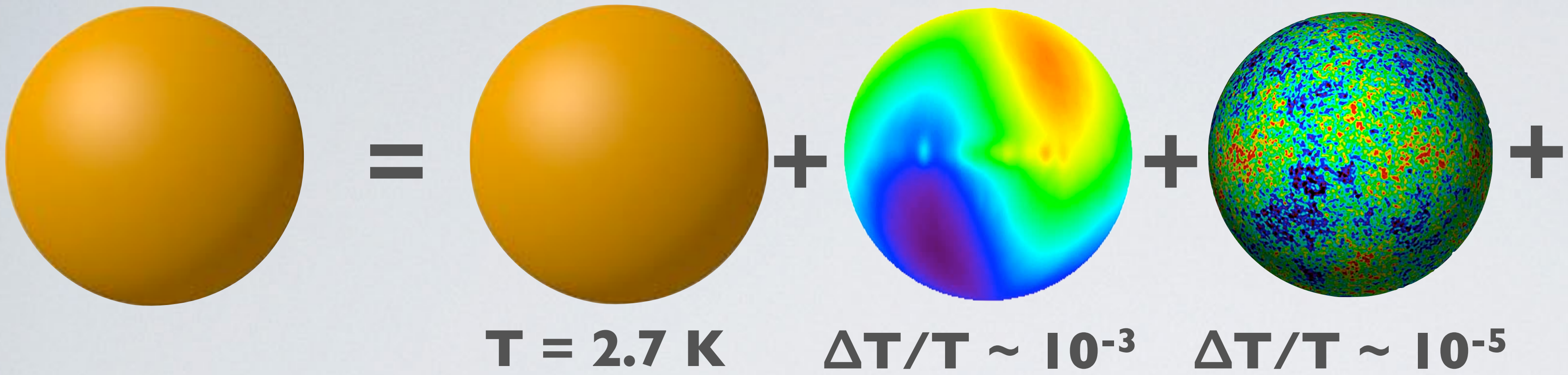
Leaders: **Hirokazu Ishino** (Okayama Univ.) and **Josquin Errard** (APC/IN2P3)

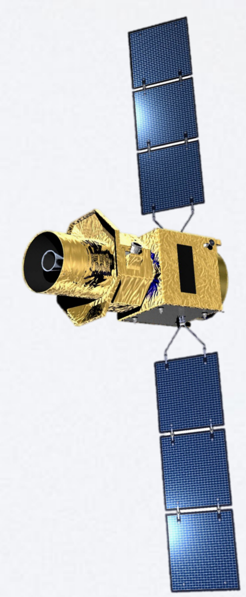
Projects objectives

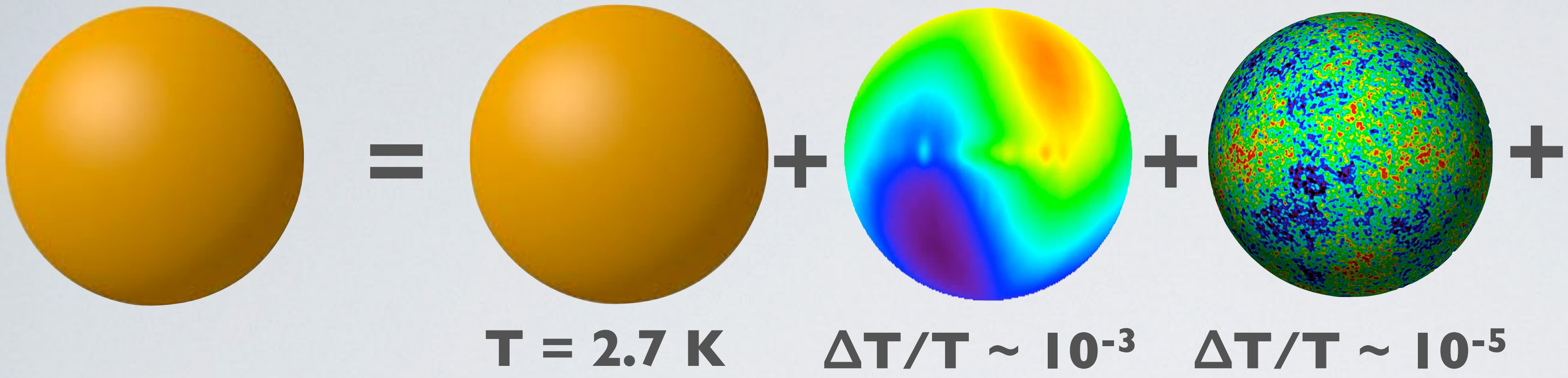
- Long term: Detect or establish an upper limit on the large scale B-mode signal, thus **constraining the amplitude of primordial gravitational waves generated during the inflationary phase**, and **characterize extremely high energy physics**
- Shorter term:
  - ⋆ Characterize **astrophysical foreground emission** with the unique frequency coverage of LiteBIRD
  - ⋆ Study gravitational lensing with small scale measurements made by the Simons Array, leading to **constraints on neutrino masses and dark energy**

- Systematics simulations
- Foregrounds and component separation analysis
- Cosmological analysis

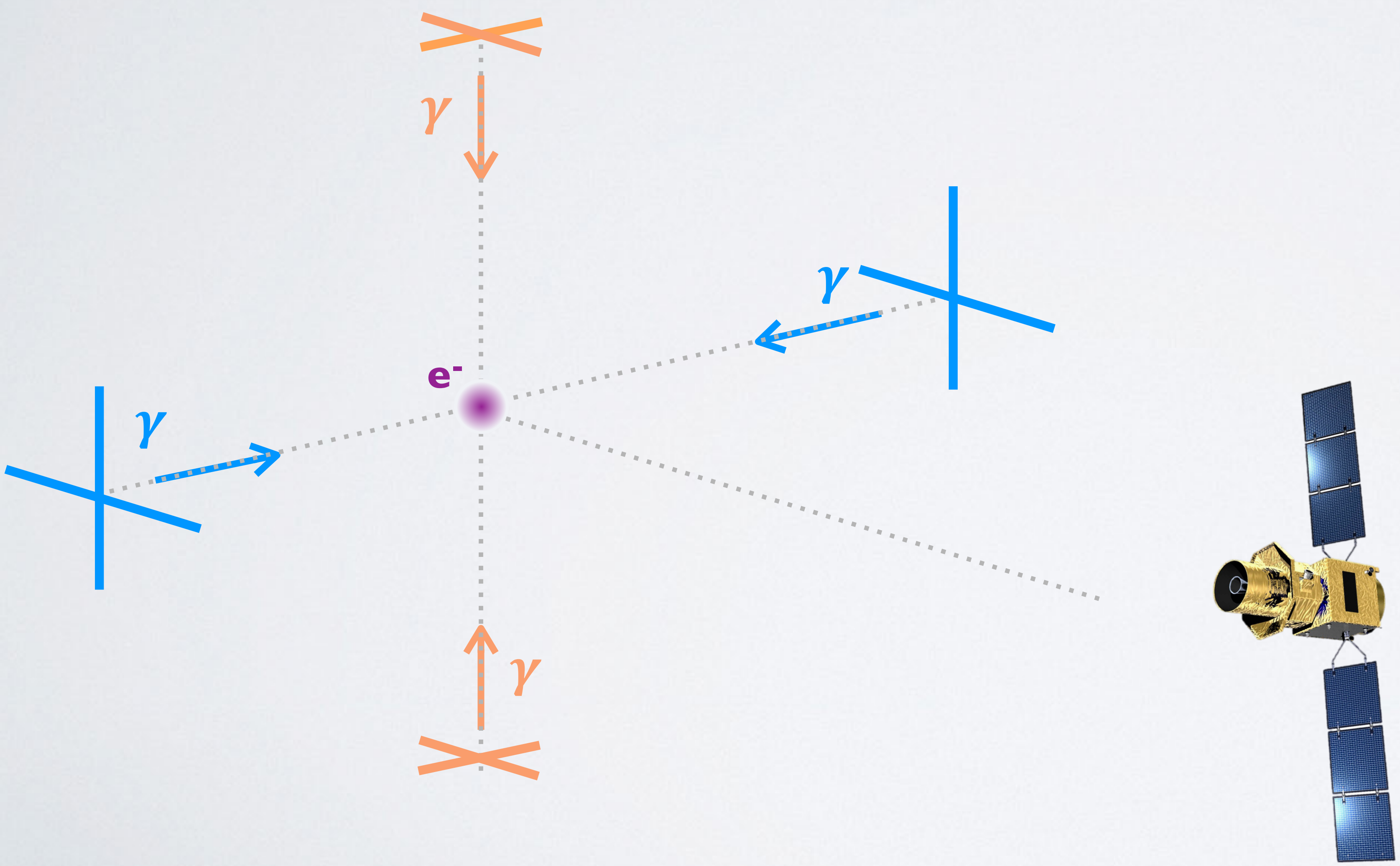
BACKUP

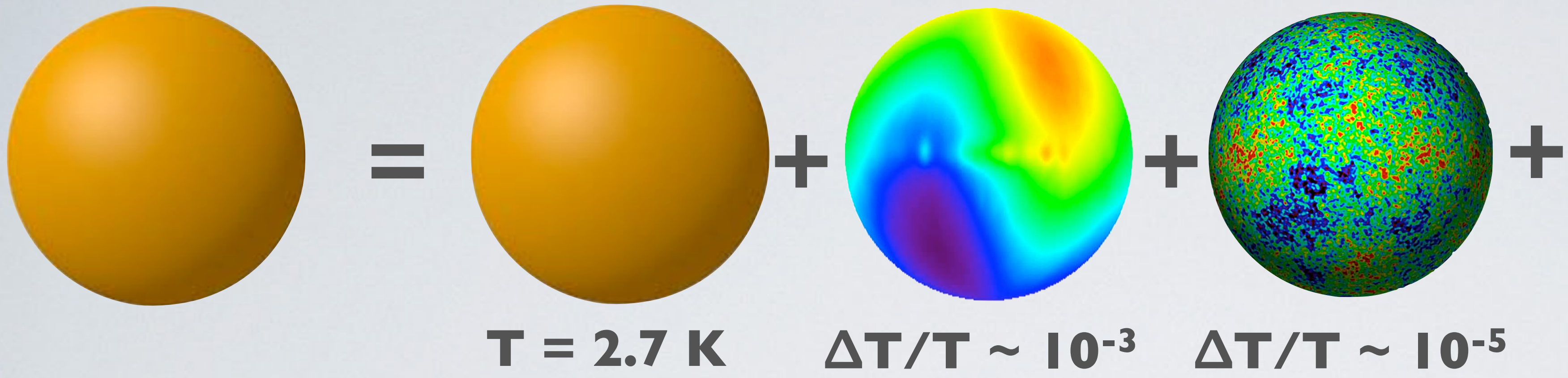

=
+
+
+
T = 2.7 K
ΔT/T ~ 10-3
ΔT/T ~ 10-5



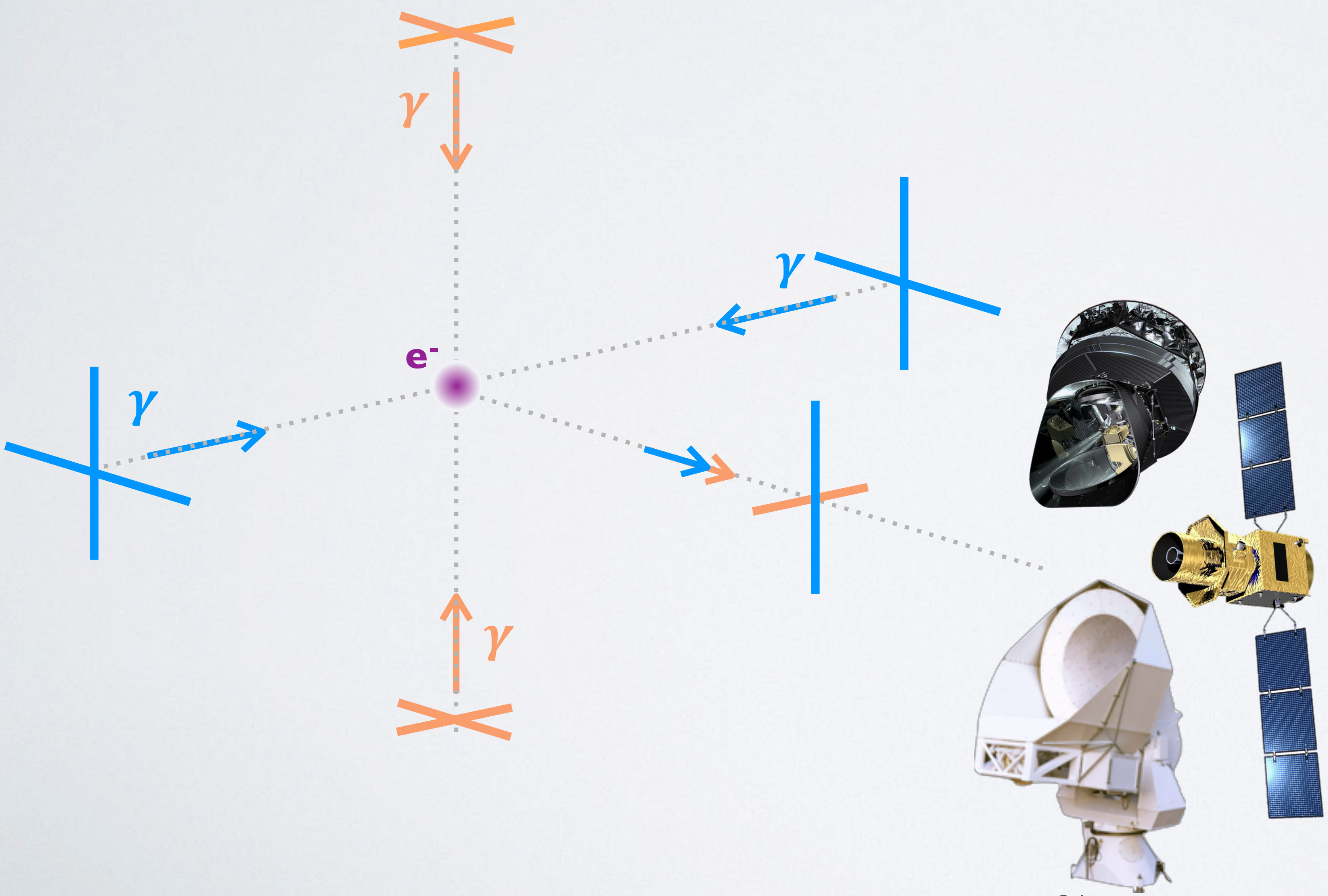


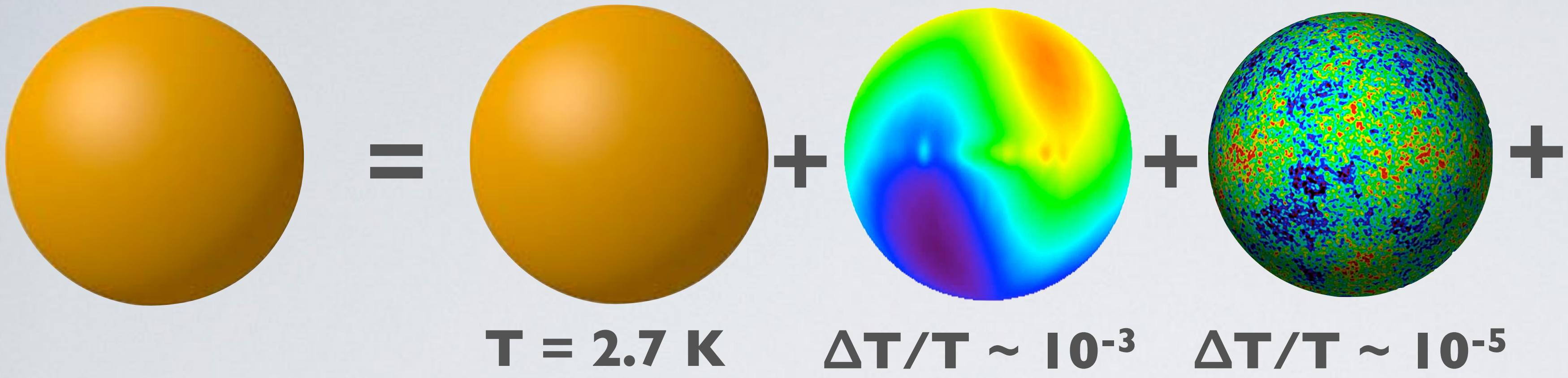
Thomson diffusion at the last scattering surface



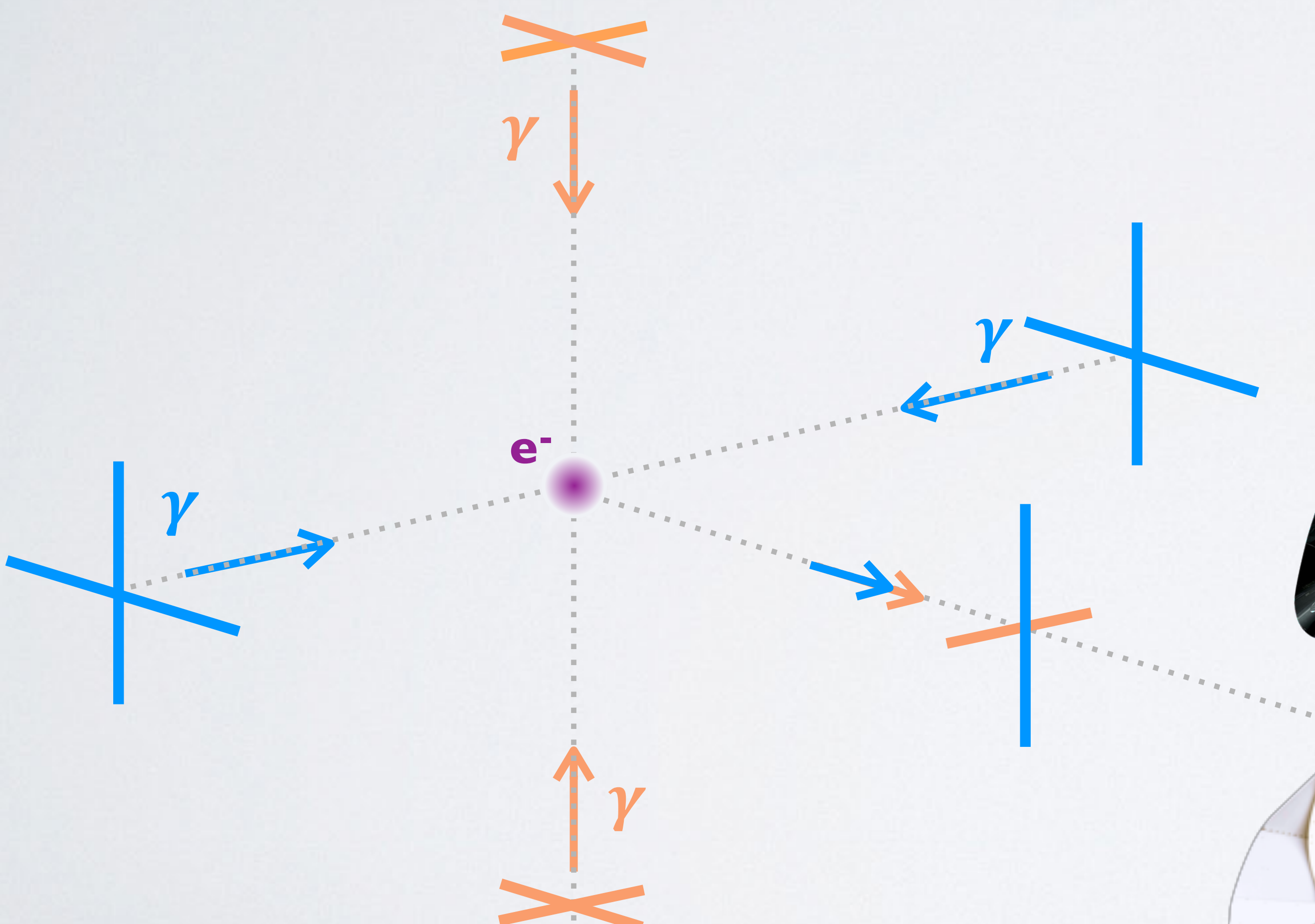


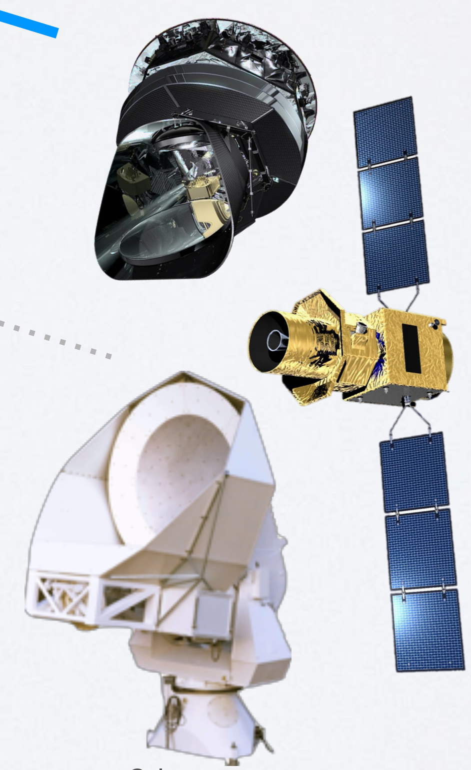
Thomson diffusion
at the last scattering
surface





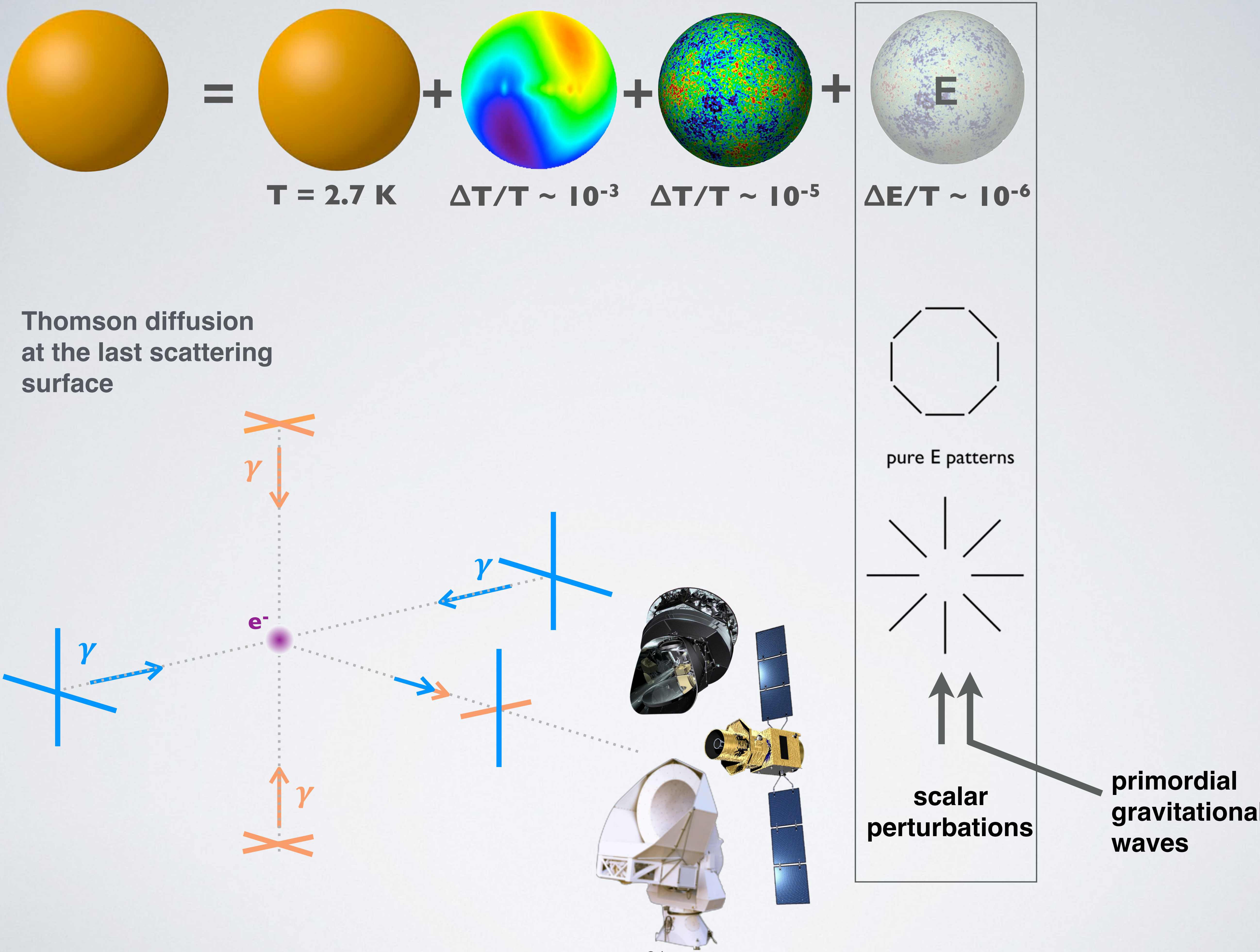
Thomson diffusion at the last scattering surface

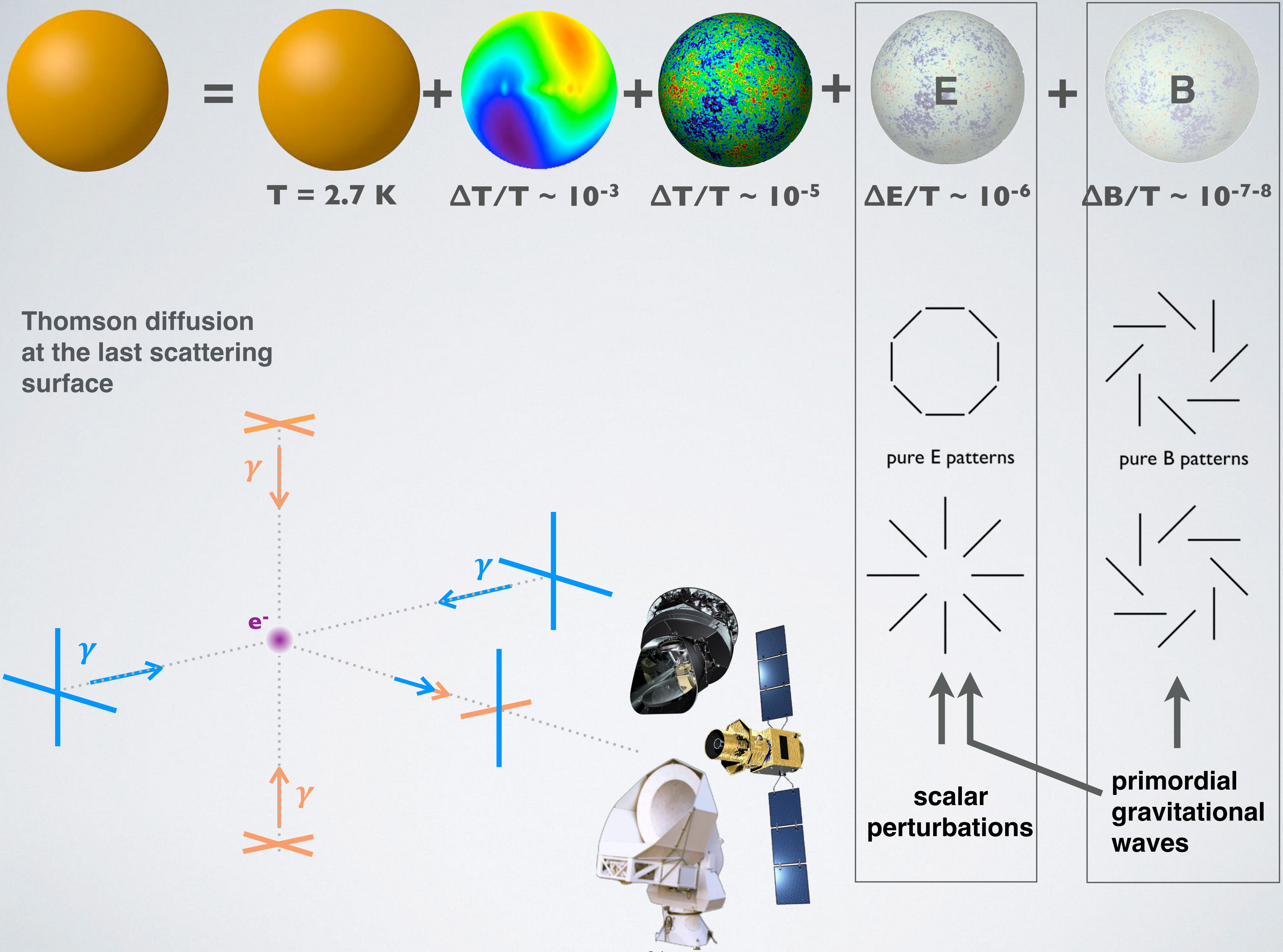




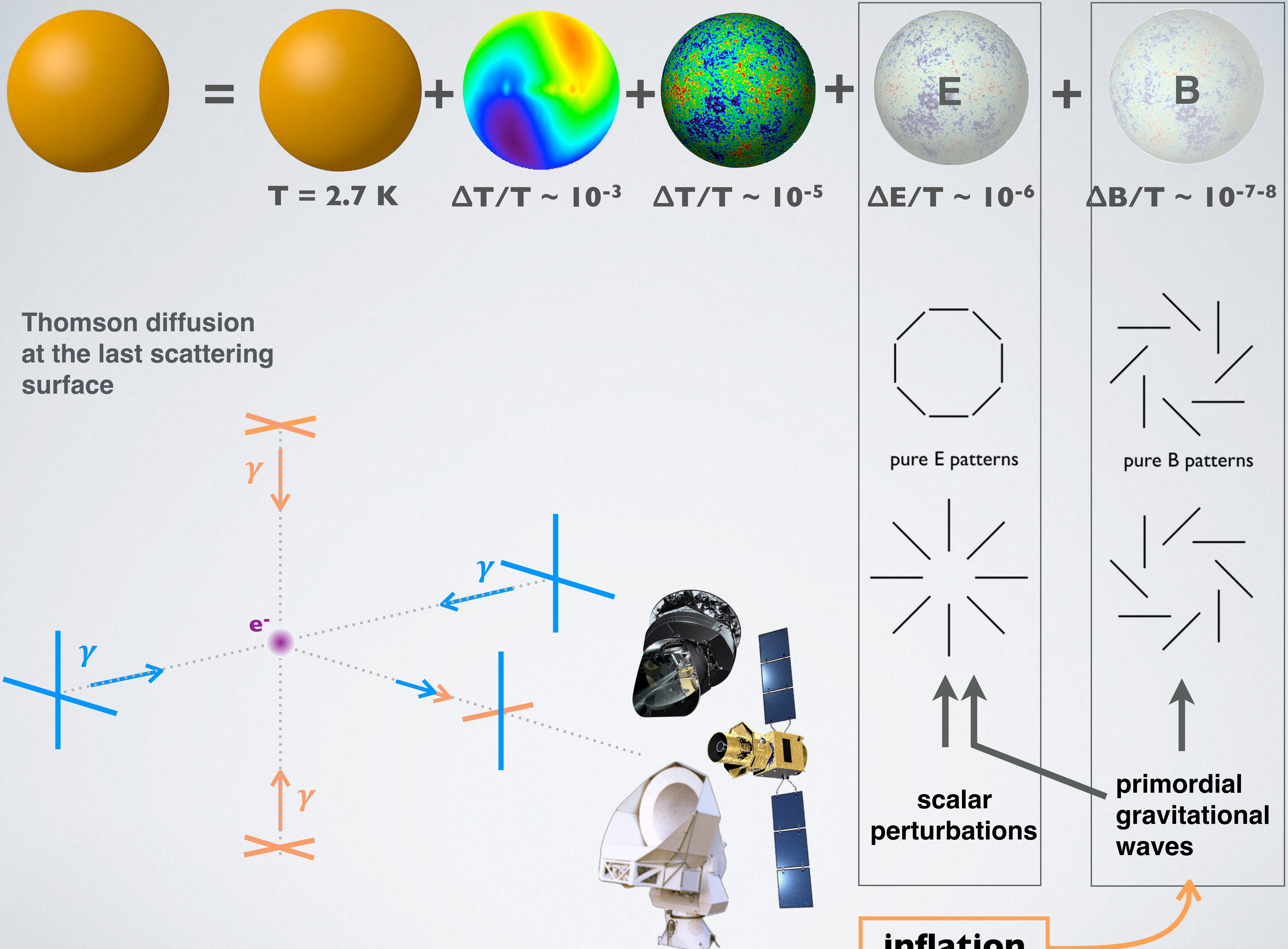
scalar perturbations

primordial gravitational waves


=
+
+
+
E
T = 2.7 K
ΔT/T ~ 10-3
ΔT/T ~ 10-5
ΔE/T ~ 10-6
Thomson diffusion at the last scattering surface
γ
γ
γ
e-
γ
pure E patterns
scalar perturbations
primordial gravitational waves



=
+
T = 2.7 K
ΔT/T ~ 10^-3
ΔT/T ~ 10^-5
E
ΔE/T ~ 10^-6
B
ΔB/T ~ 10^-7-8
Thomson diffusion at the last scattering surface
γ
e-
pure E patterns
pure B patterns
scalar perturbations
primordial gravitational waves


=
+
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ΔE/T ~ 10-6
B
ΔB/T ~ 10-7-8
Thomson diffusion
at the last scattering
surface
γ
e-
pure E patterns
pure B patterns
scalar
perturbations
primordial
gravitational
waves
inflation

Constraints from n_s:

ϕ^2 Inflation:

best-fit r	3σ bound
0.13	0.057

Monodromy ϕ:

best-fit r	3σ bound
0.087	0.038

Monodromy $\phi^{2/3}$:

best-fit r	3σ bound
0.065	0.028

R^2 Inflation:

best-fit r	3σ bound
0.003	6×10^{-4}

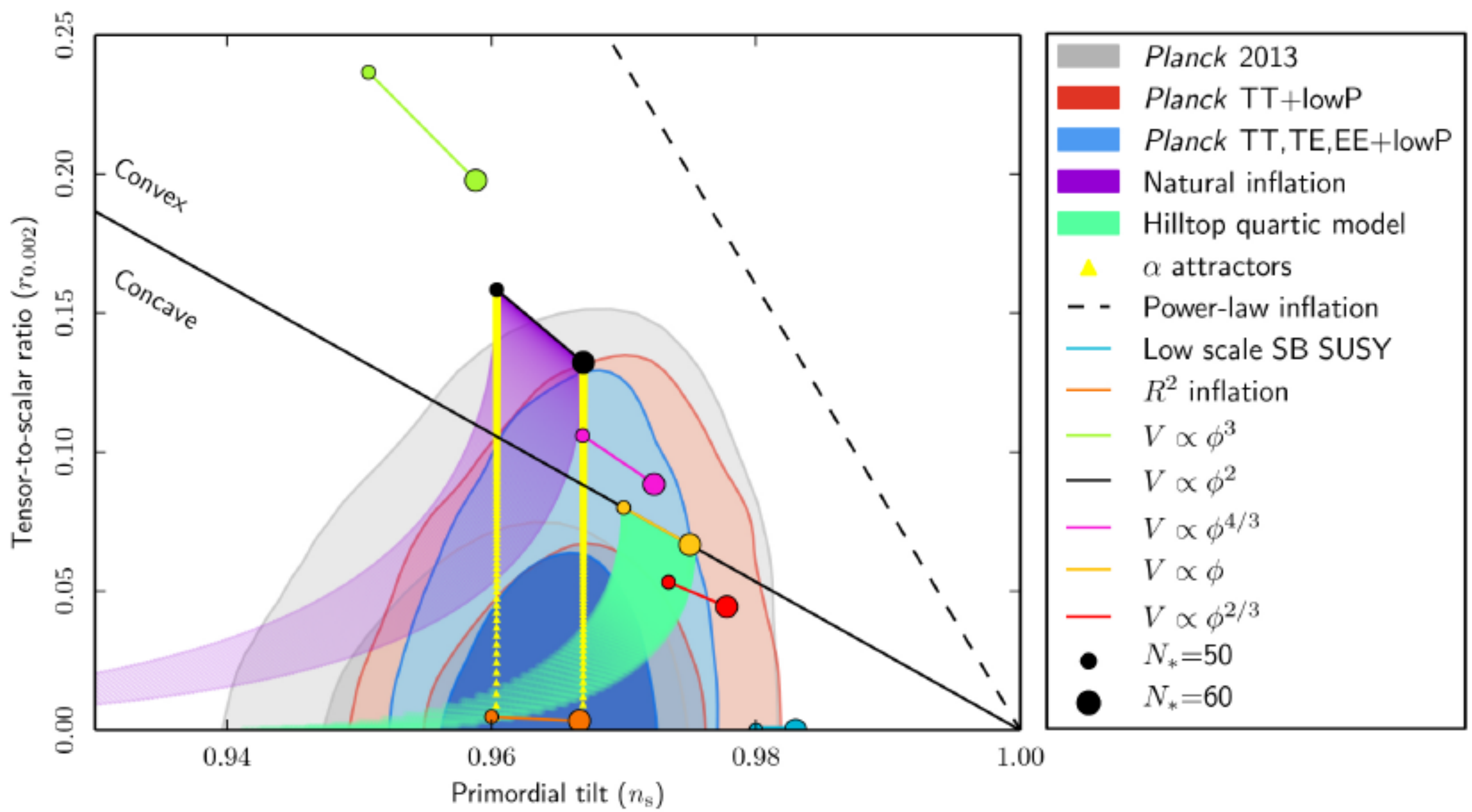
Natural Inflation:

3σ bound
0.04

Higgs-like Potential:

3σ bound
0.03

Well-motivated models



arXiv:1510.06042 by Kamionkowski and Kovetz

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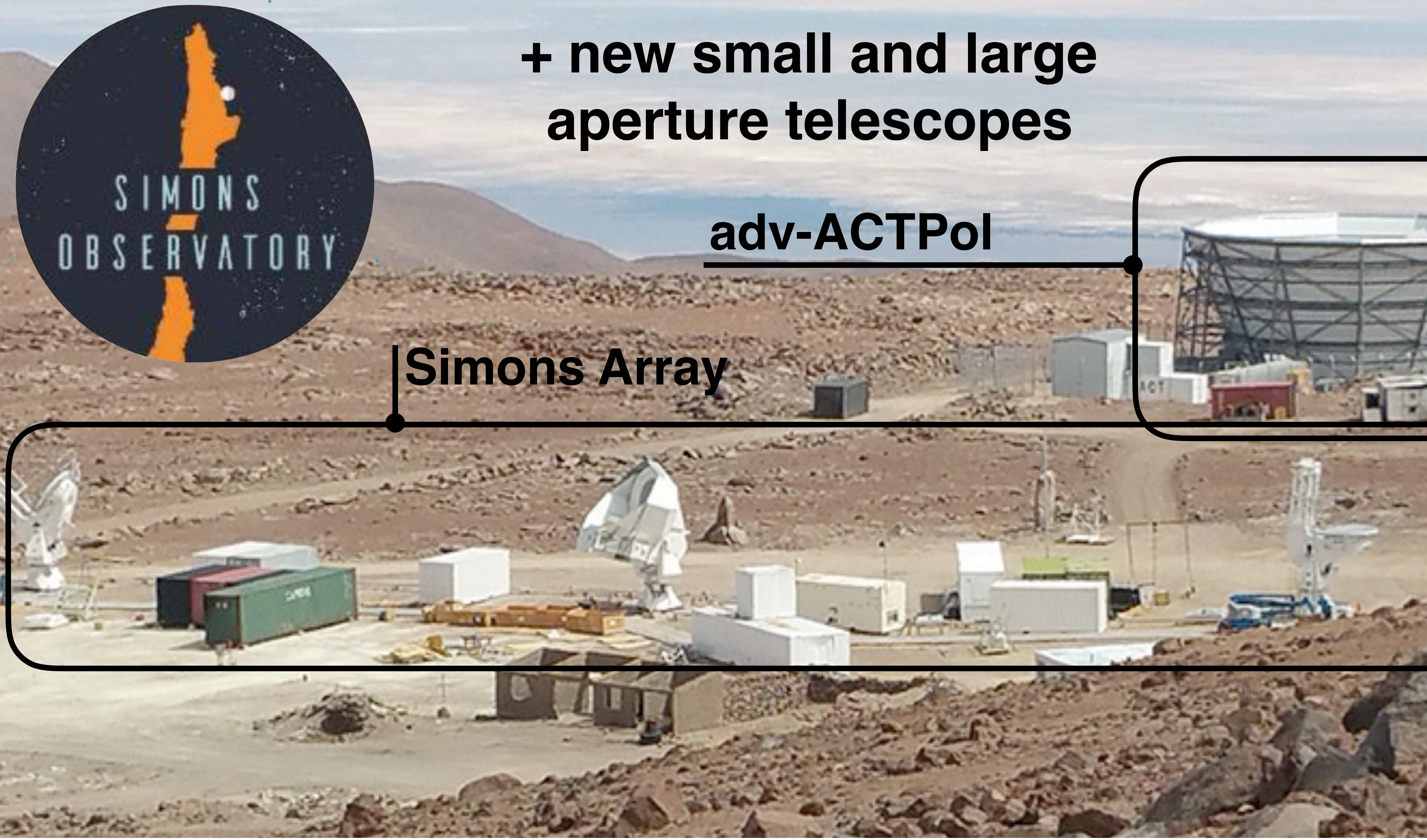
+ new small and large aperture telescopes



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