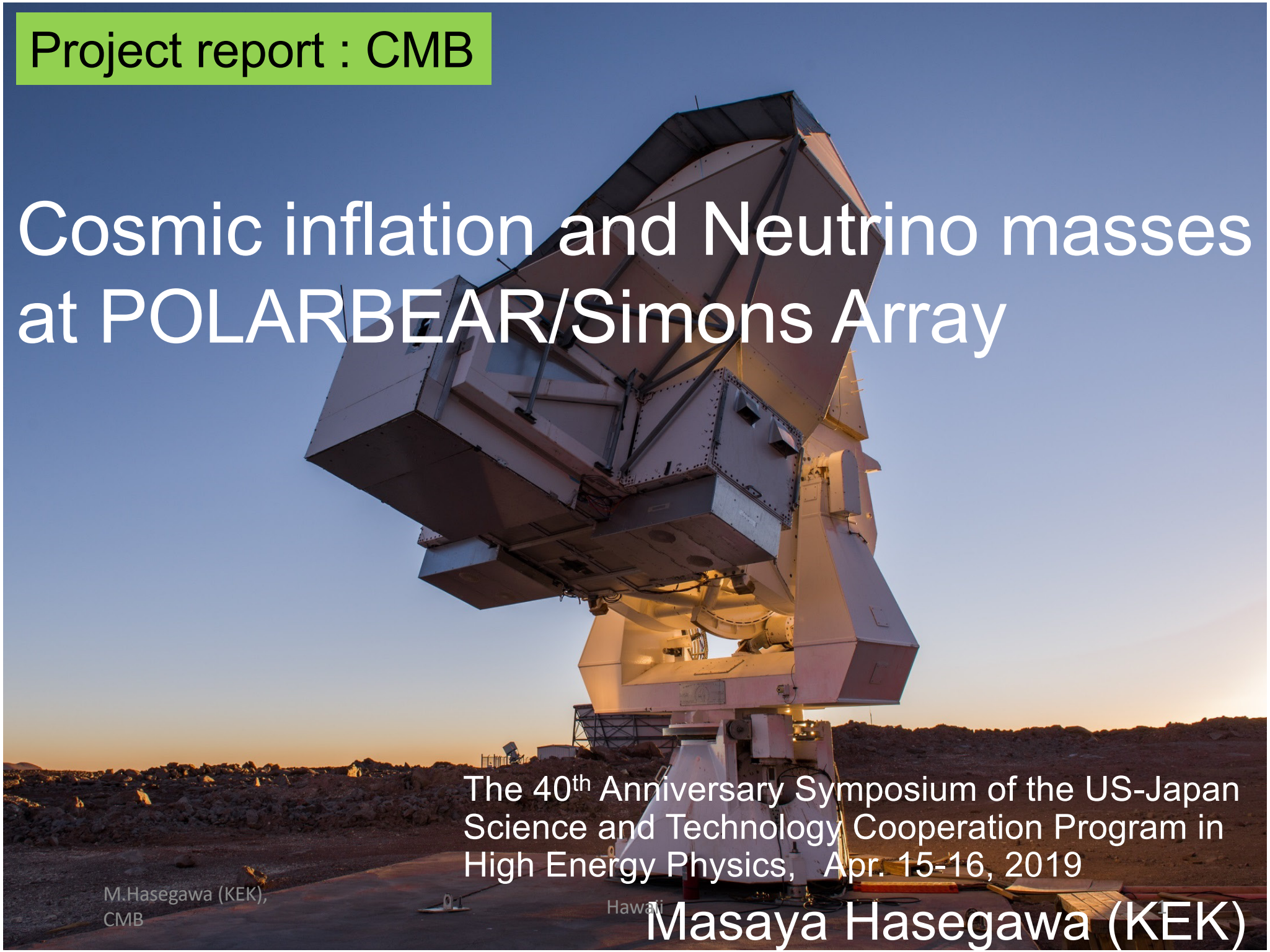
Project report : CMB

Cosmic inflation and Neutrino masses at POLARBEAR/Simons Array



The 40th Anniversary Symposium of the US-Japan Science and Technology Cooperation Program in High Energy Physics, Apr. 15-16, 2019

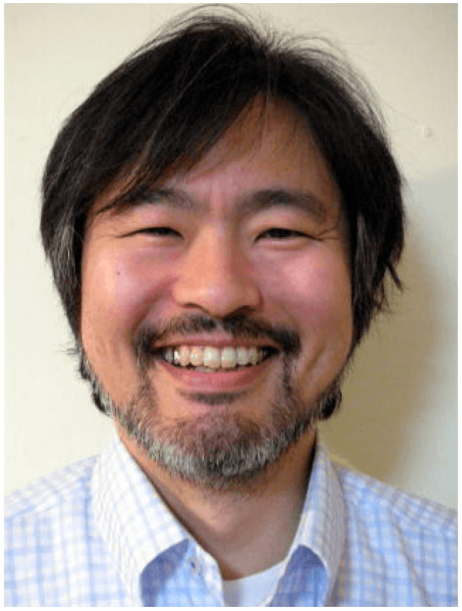
Hawaii

Masaya Hasegawa (KEK)

Supports from US-JP cooperation program

Completed programs (PI: Masashi Hazumi)

- 2008 – 2009: QUIET (+ R&D for SCD)
- **2012 – 2016: POLARBEAR/Simons Array**
  - **POLARBEAR-2 : New CMB polarization receiver**



Posters in this workshop
1. Sayuri Takatori: Calibration tool
2. Daiki Tanabe: Temperature monitor for precision measurement of CMB polarization at POLARBEAR-2

Outline

- Introduction
  - CMB polarization and its science
- POLARBEAR/Simons Array
- Summary

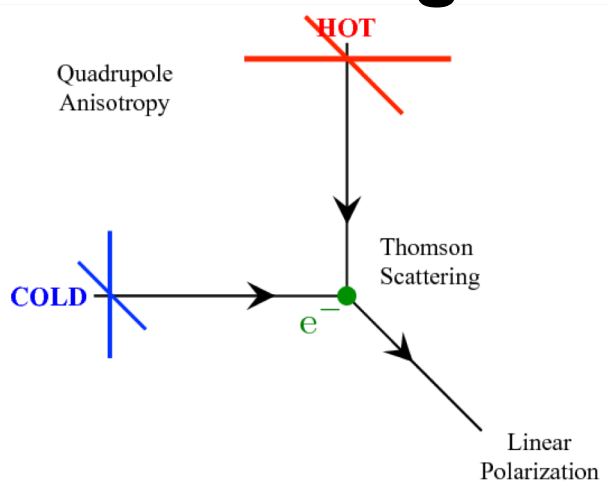
What's POLARBEAR ?

- CMB Polarization Experiment in Chile.
- Measuring the *B*-modes in CMB polarization
  - Inflationary gravitational waves
  - Gravitational lensing: Neutrino masses

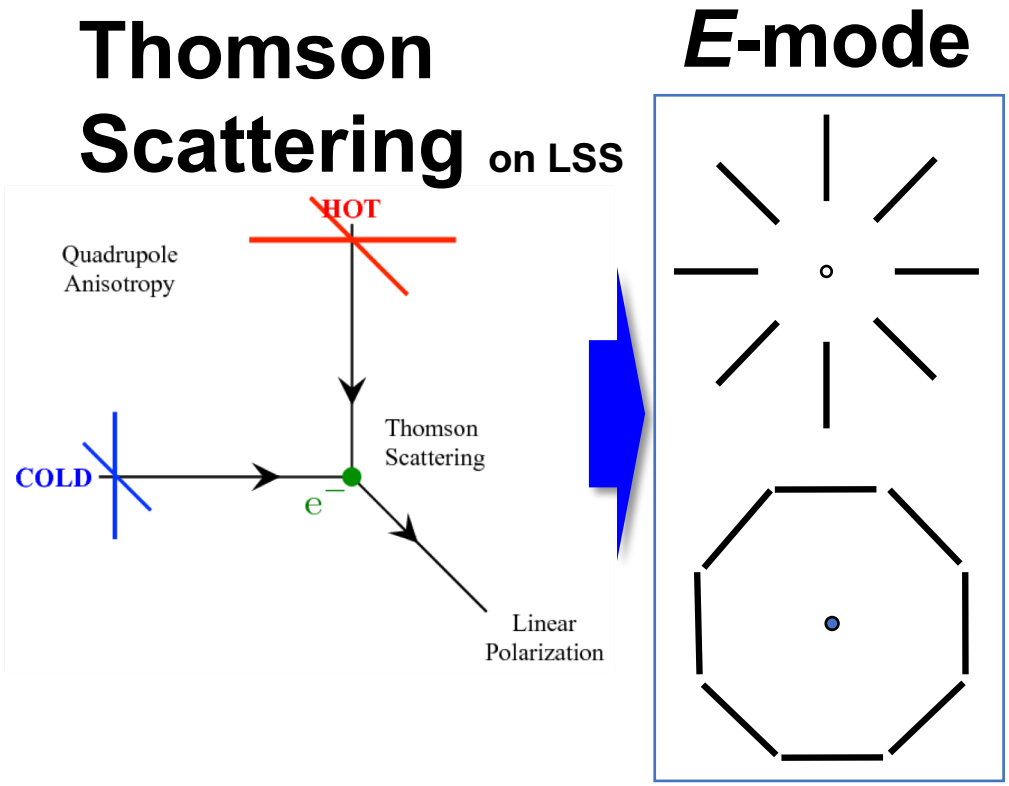
Shed light on fundamental problems in cosmology and particle physics !

Science with CMB B-mode

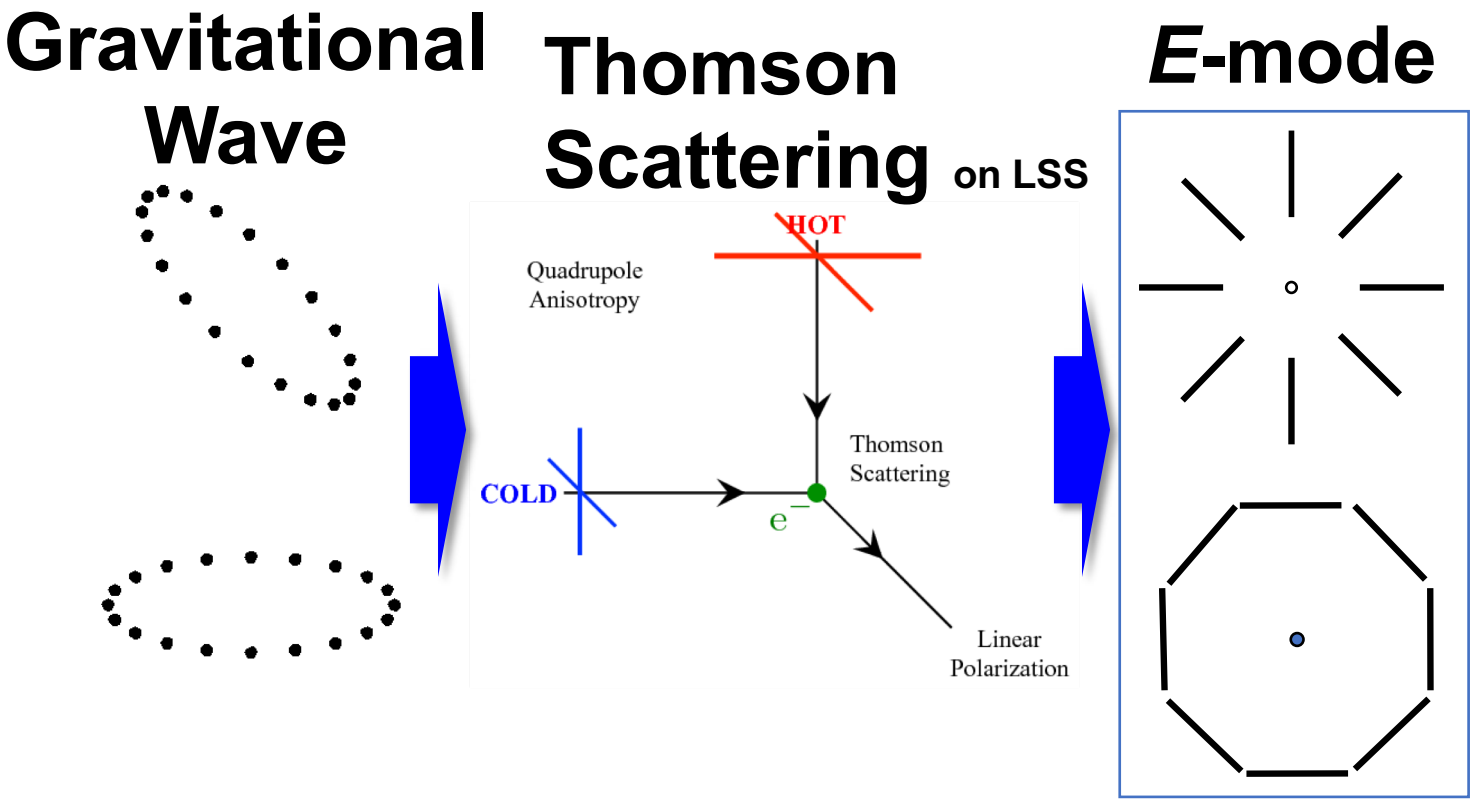
Thomson Scattering on LSS



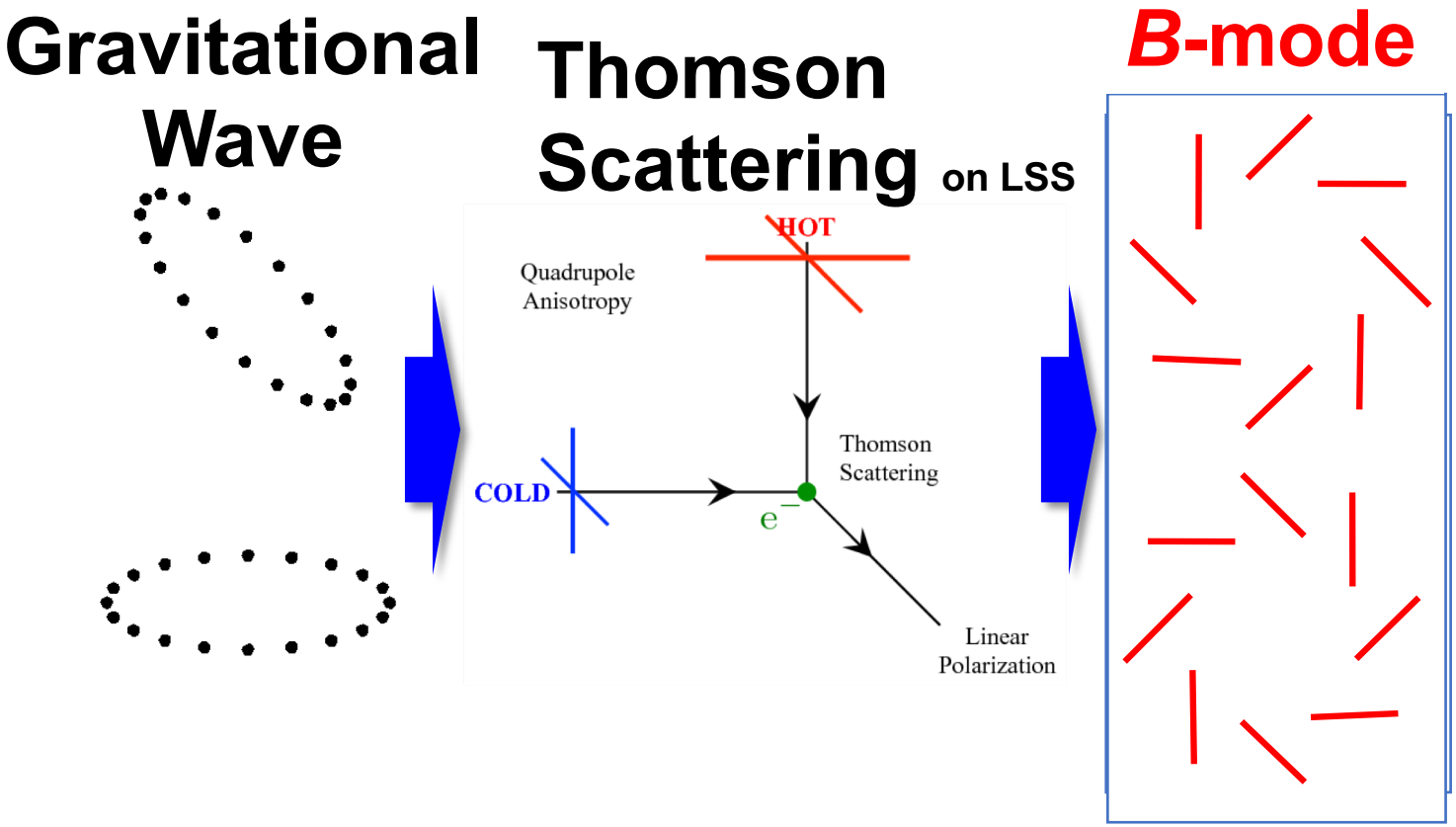
Science with CMB B-mode



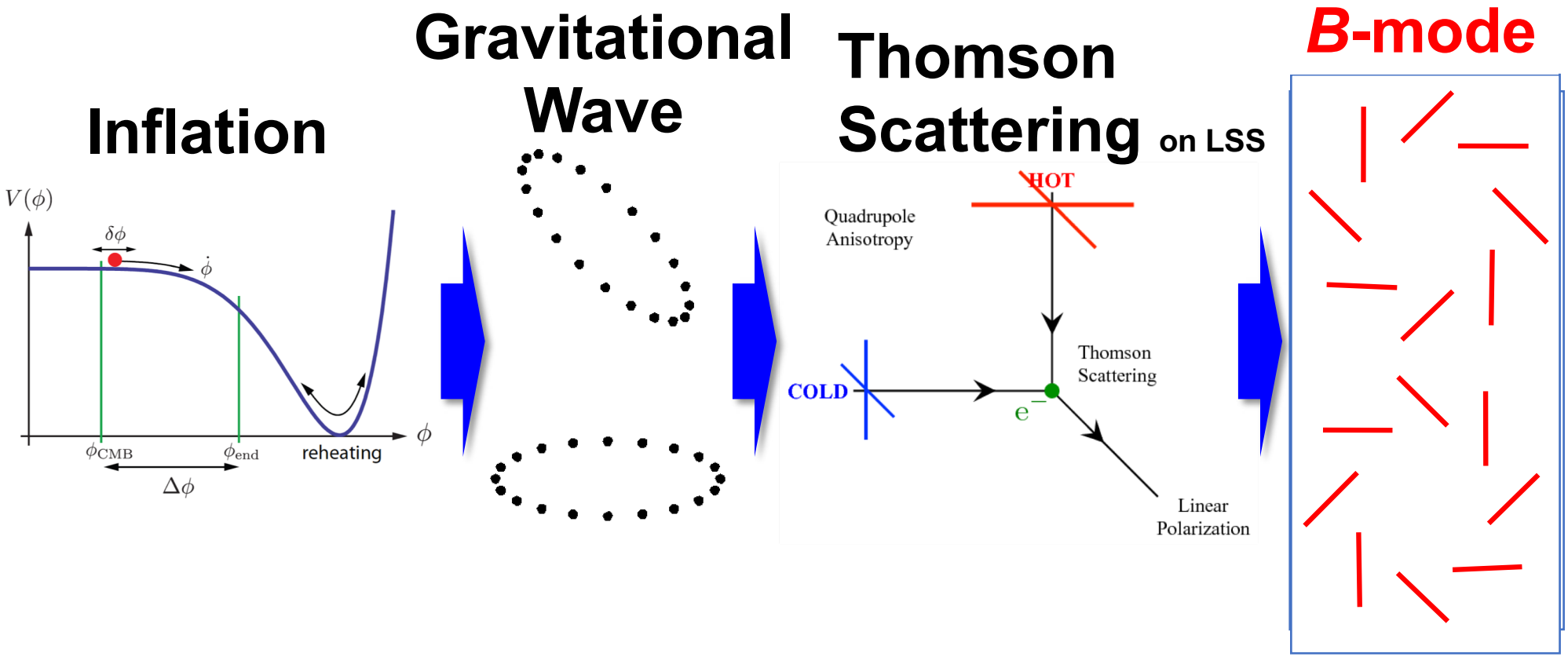
Science with CMB B-mode



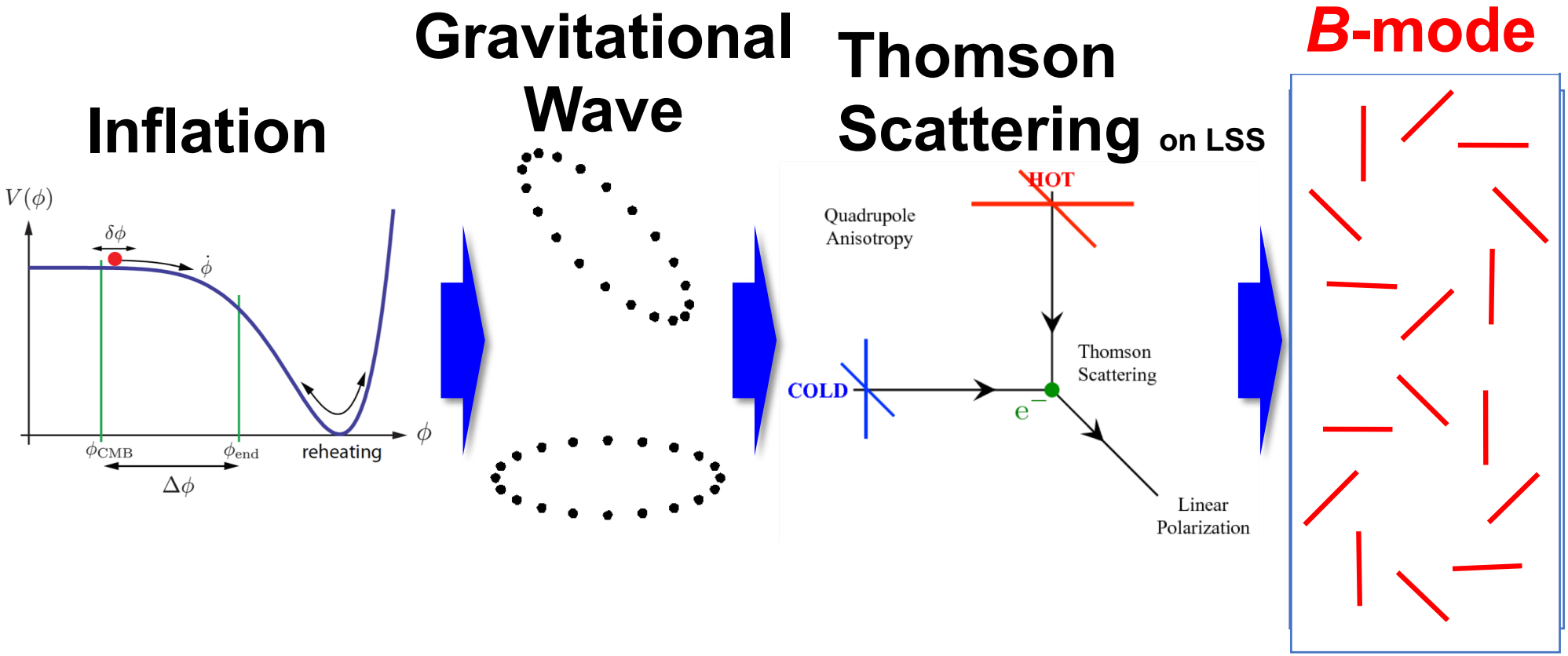
Science with CMB B-mode



Science with CMB B-mode



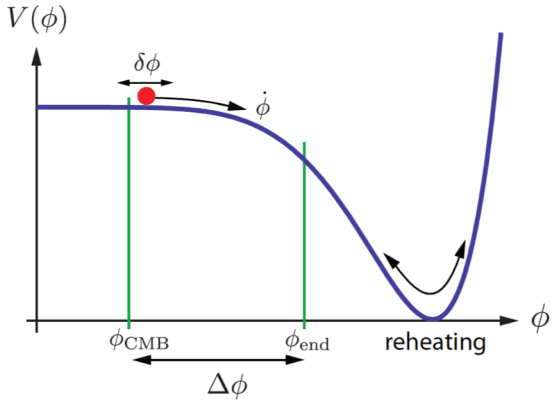
Science with CMB B-mode



B-mode is a smoking gun signature of inflationary universe!

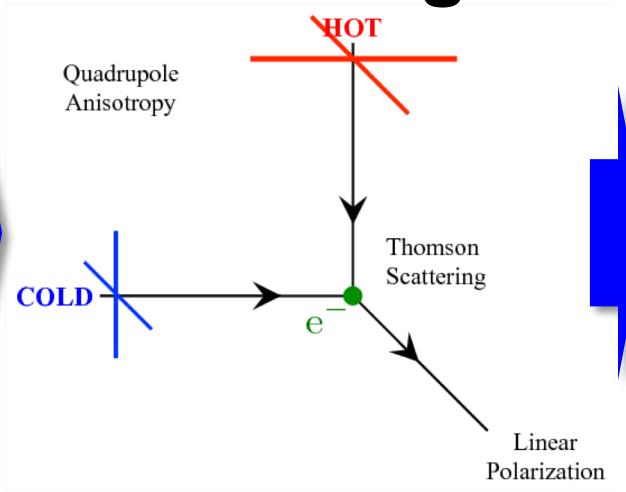
Science with CMB B-mode

Inflation

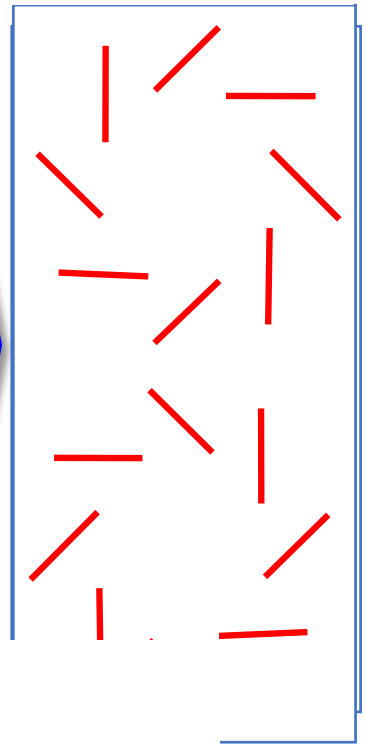


Gravitational Wave

Thomson Scattering on LSS



***B*-mode**

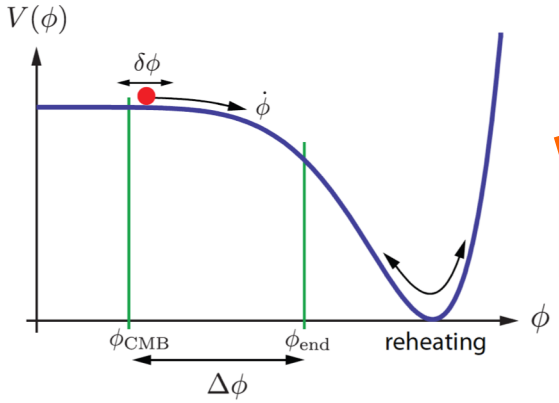


B-mode power is characterized with tensor-to-scalar ratio, r

$$V^{1/4} = 1.06 \times 10^{16} \times \left(\frac{r}{0.01}\right)^{1/4} \text{GeV}$$

Science with CMB B-mode

Inflation



Gravitational W

Thomson

***B*-mode**

10^{12} x LHC (13TeV)

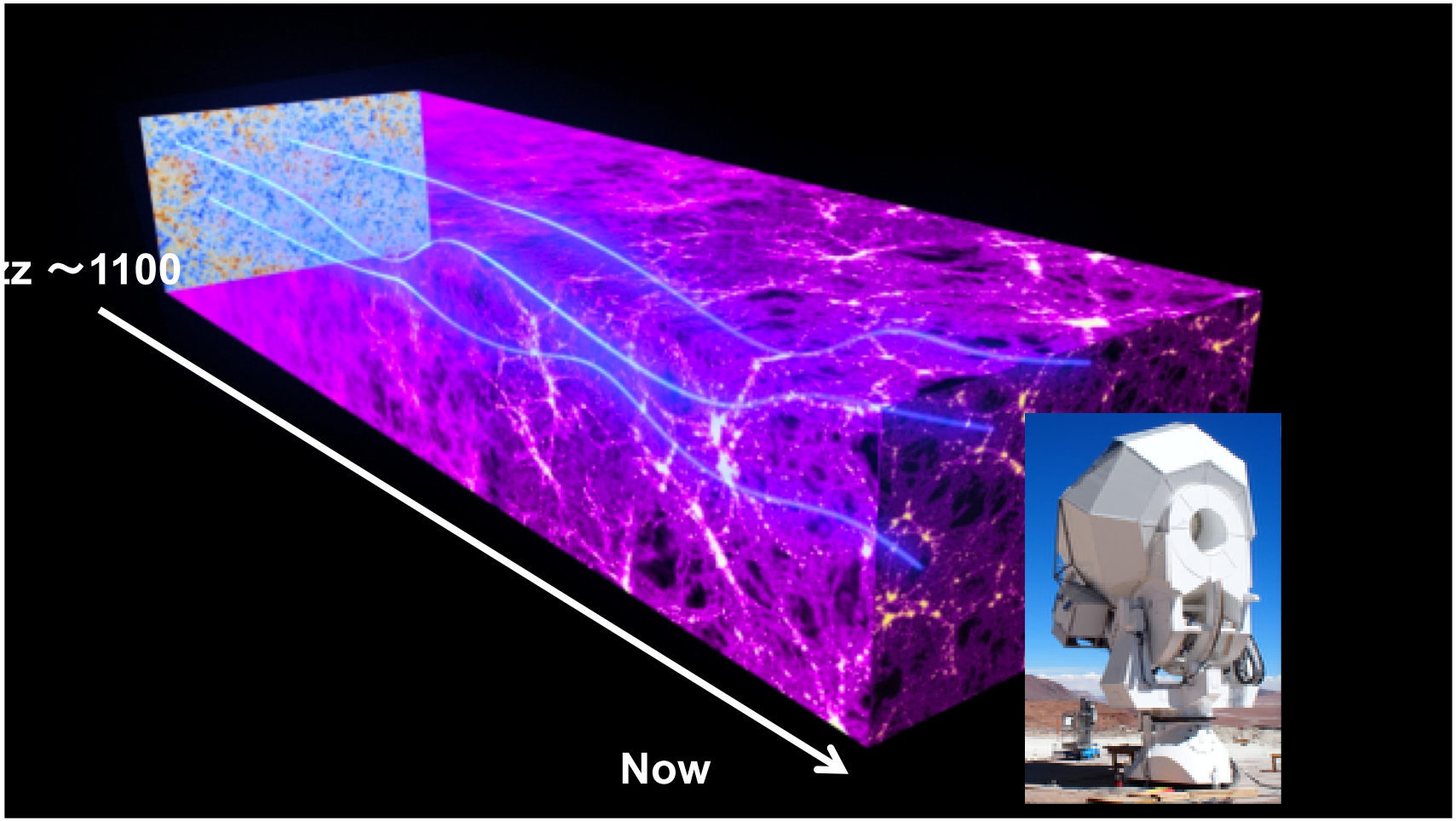
10^{5} x GZK cut-off (10^{20}eV)

→ CMB B-mode is a potential window to the truly-unexplored ultra-high energy phenomenon

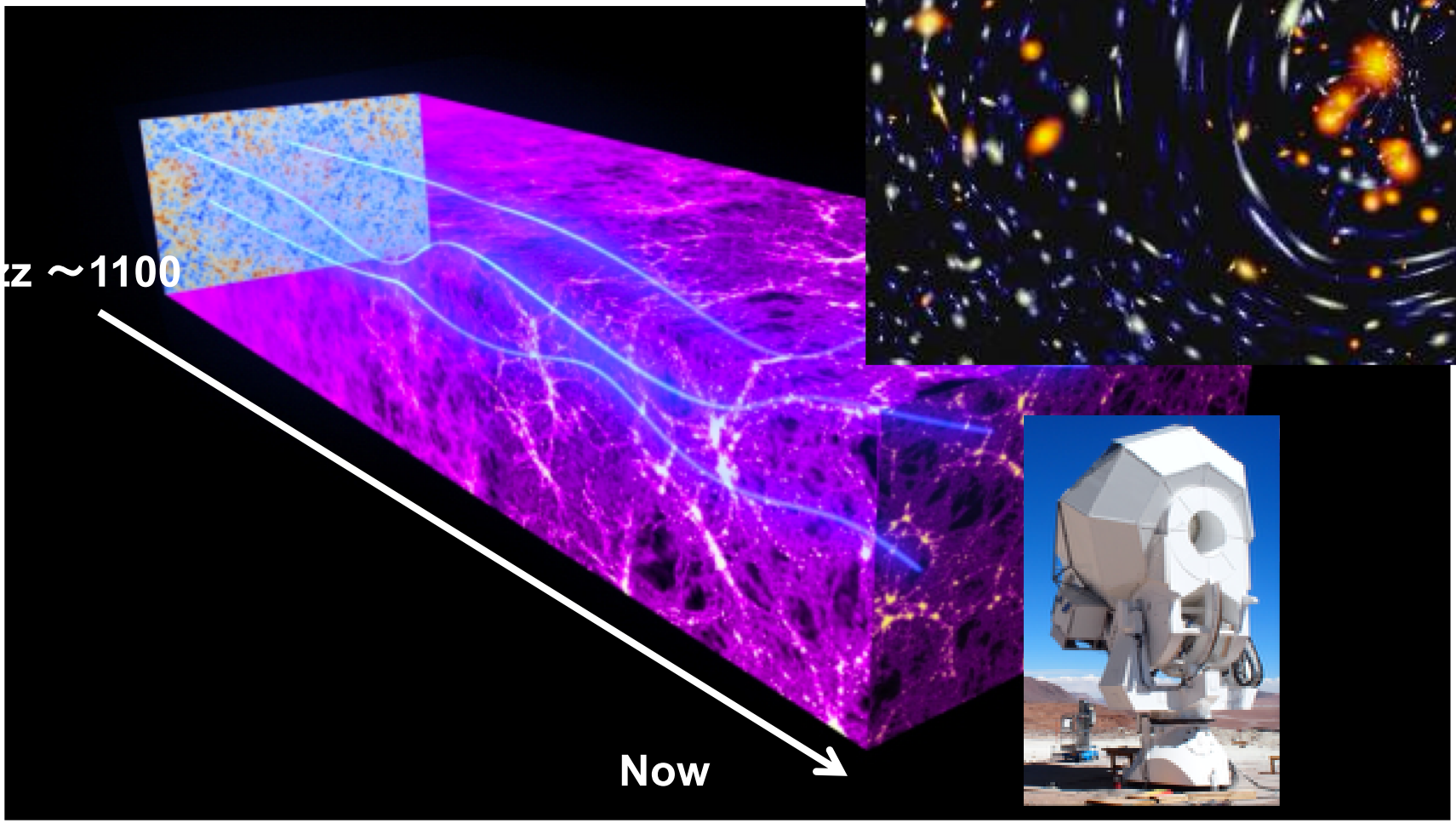
B-mode power is characterized with tensor-to-scalar ratio, r

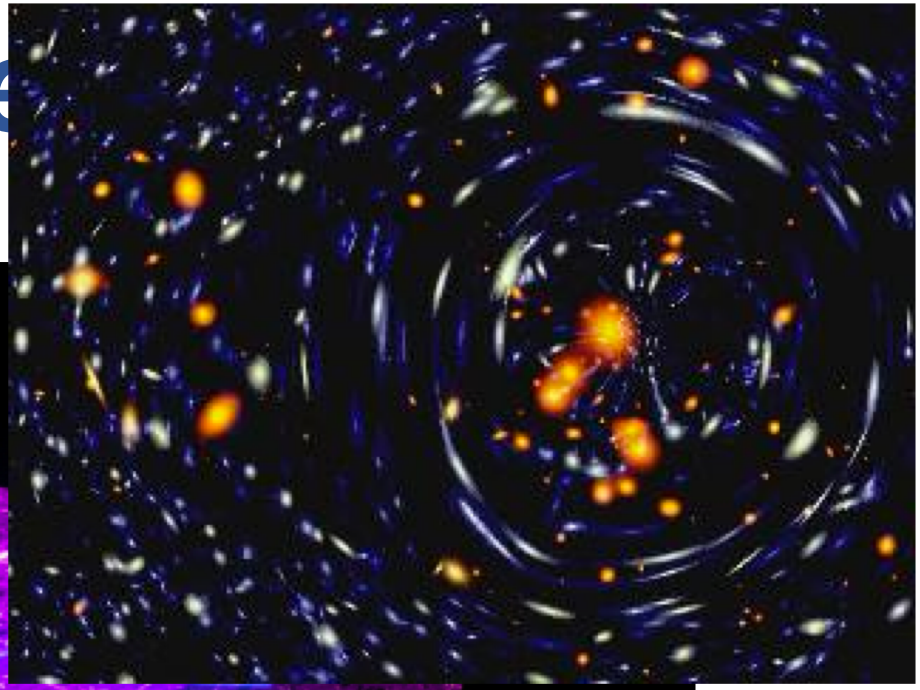
$$V^{1/4} = 1.06 \times 10^{16} \times \left(\frac{r}{0.01}\right)^{1/4} \text{GeV}$$

Lensing B-mode

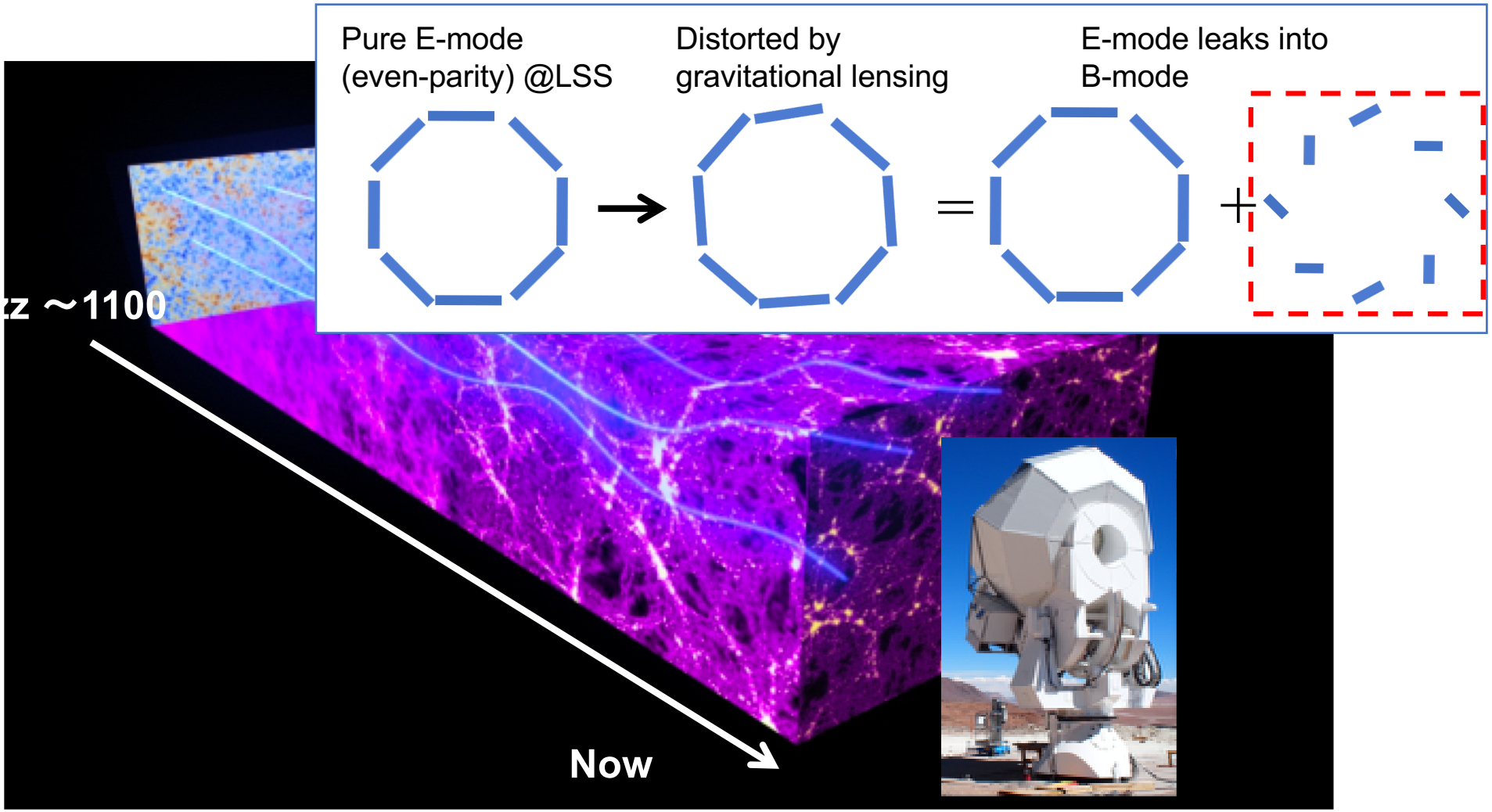


Lensing B-mode

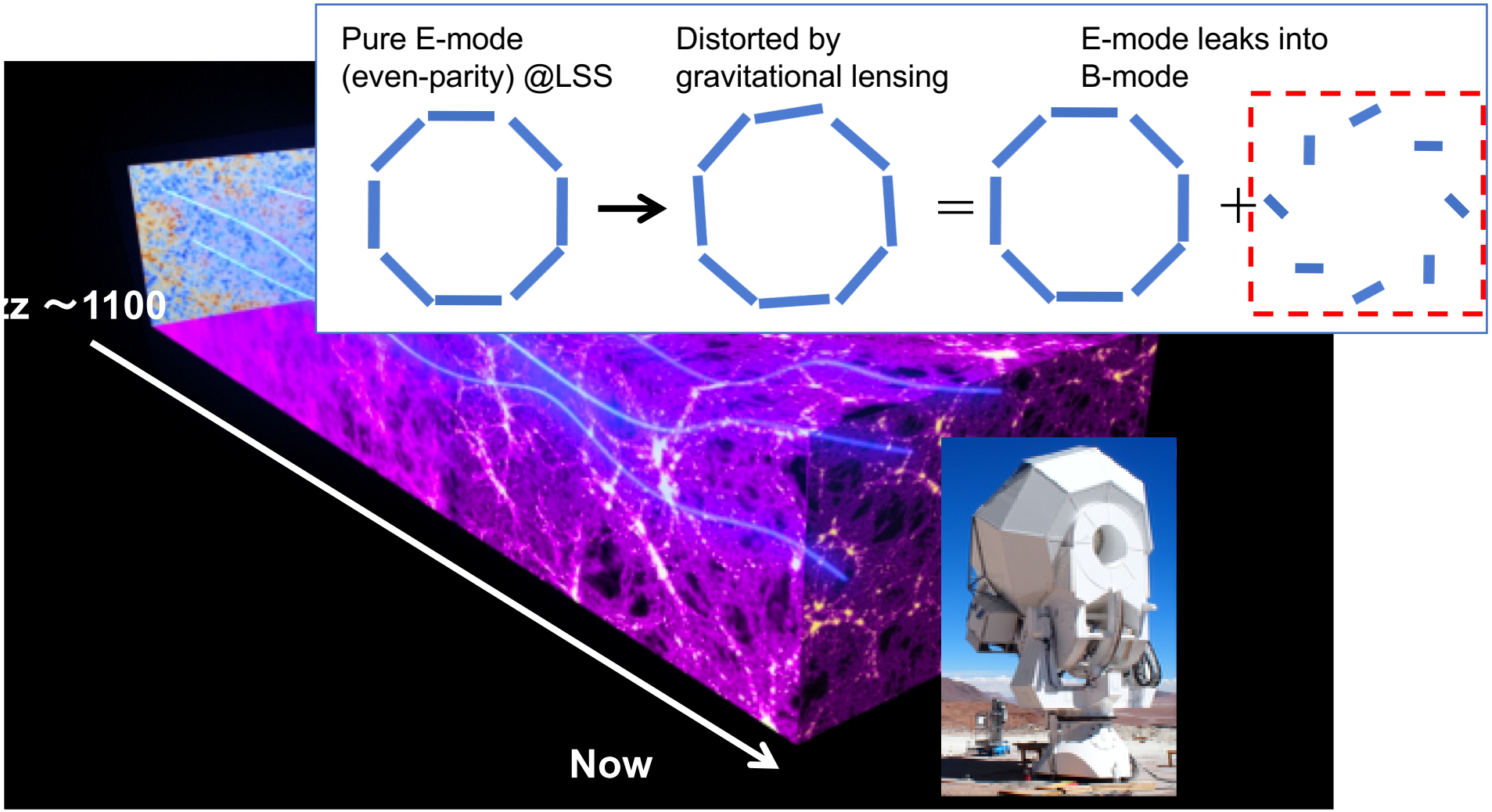




Lensing B-mode

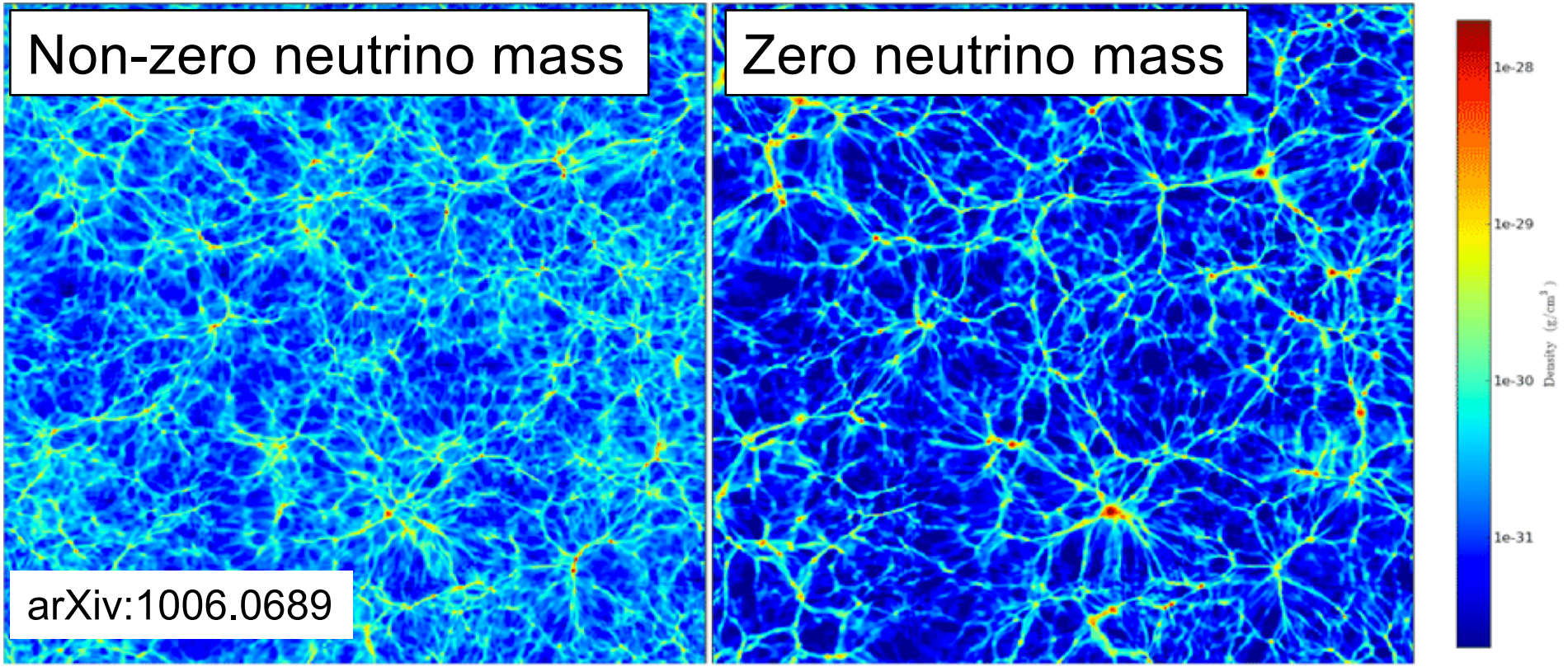


Lensing B-mode



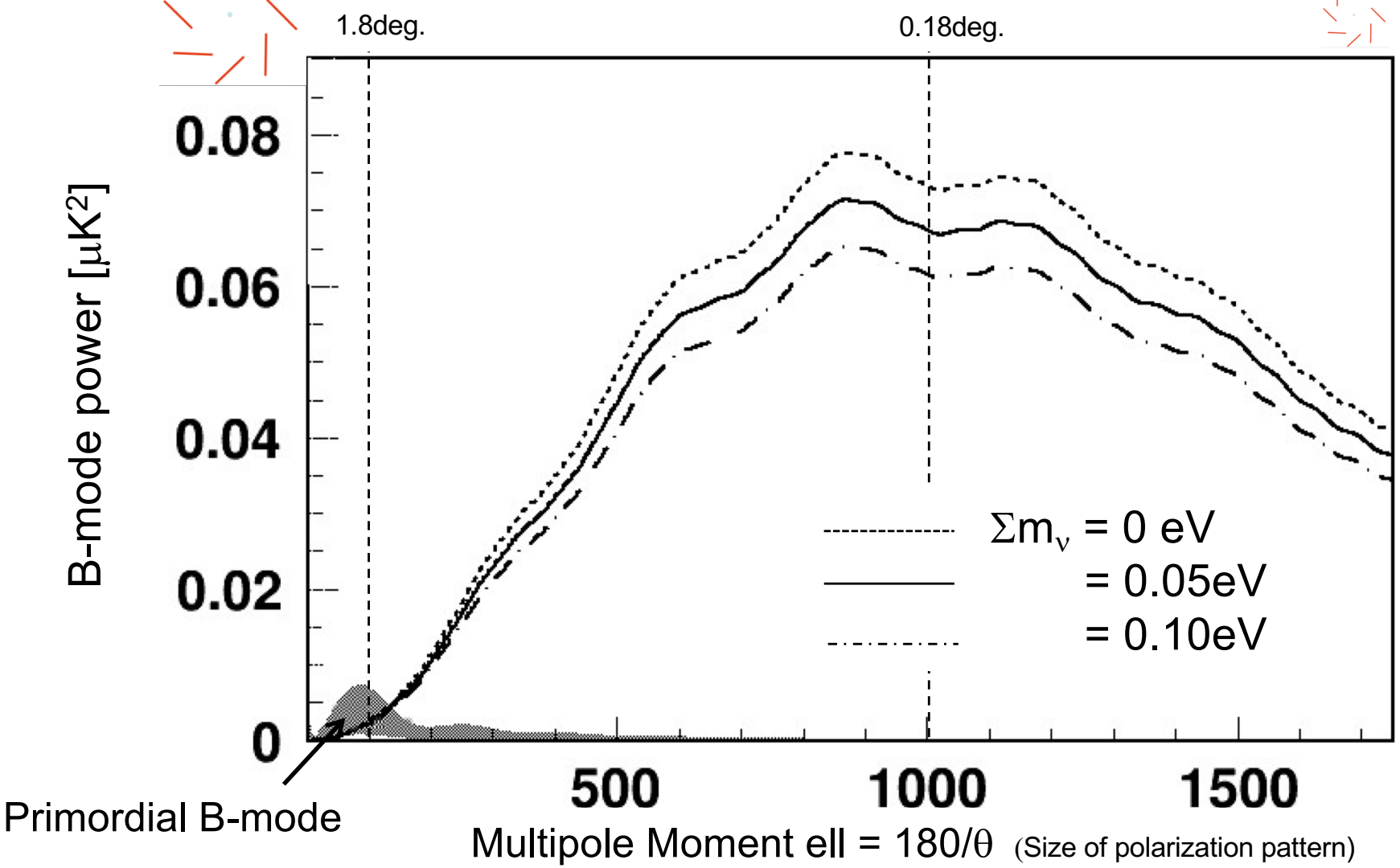
- Small angular scale *B*-mode is the signature of lensing
- Probe of physics affecting structure growth at ~1<z<3.

Application: Neutrino mass



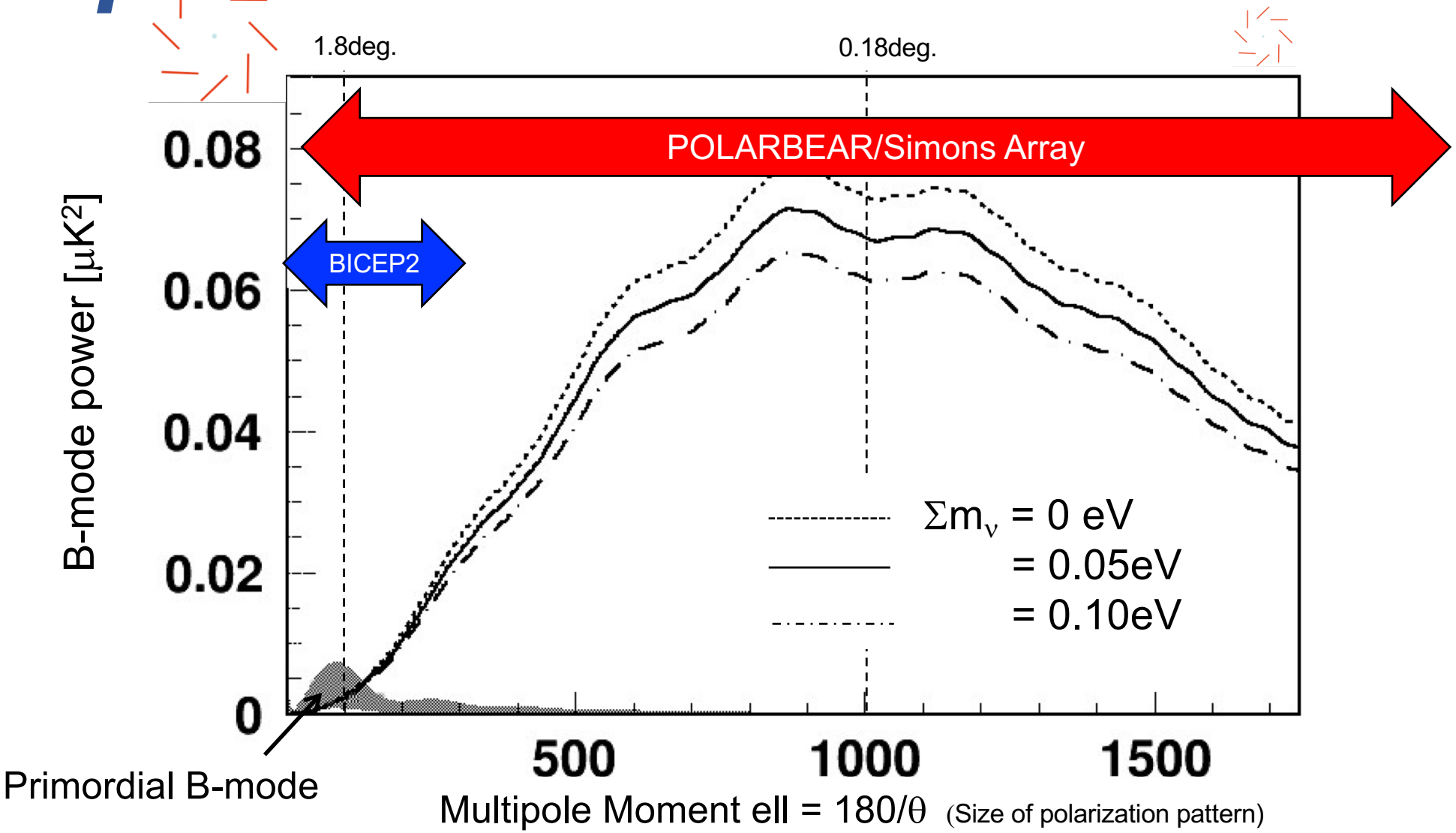
- Signature of “finite neutrino mass” is suppression of structure growth.

Application: Neutrino mass



The lensing B-mode amplitude is sensitive to Σm_ν.

Application: Neutrino mass



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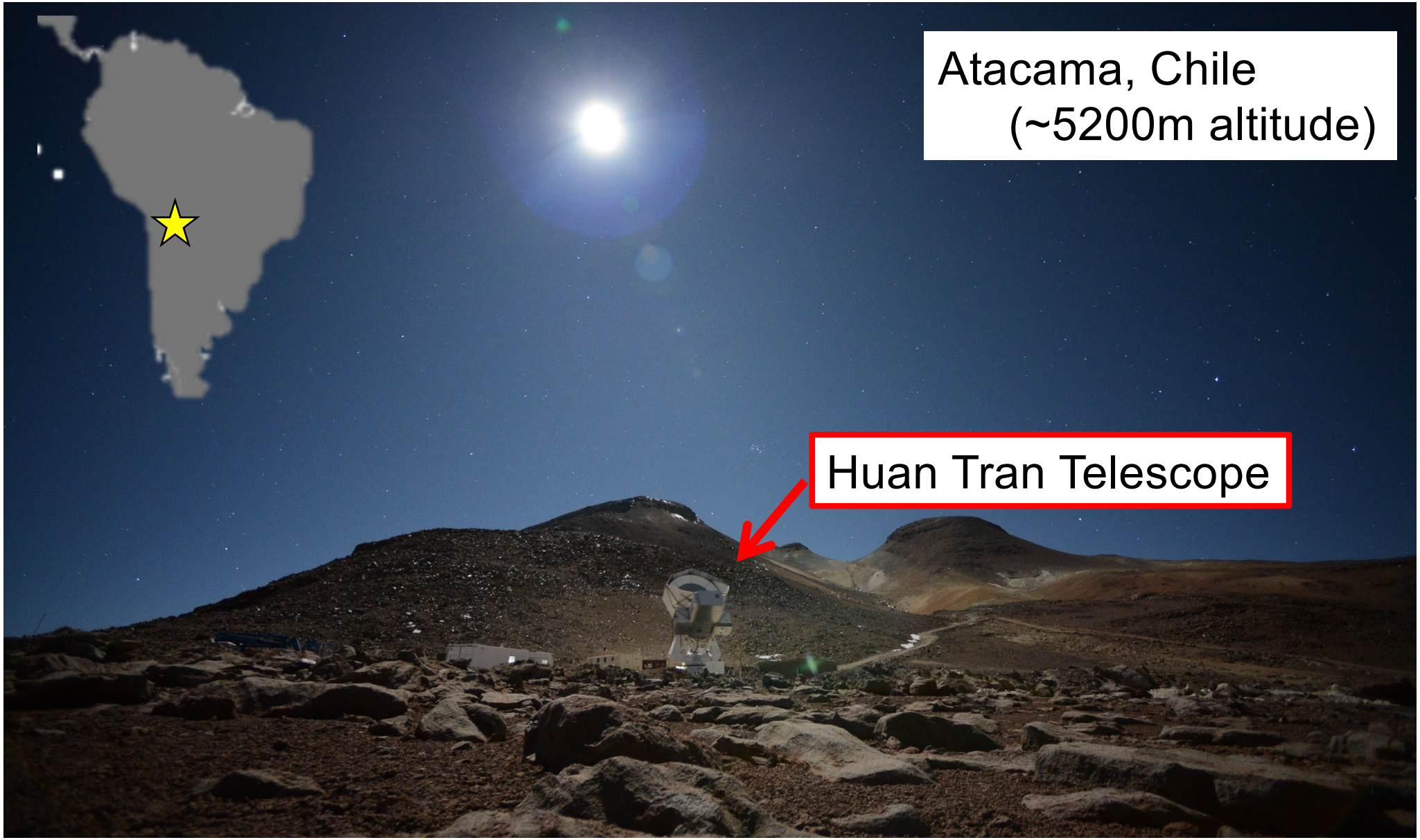
POLARBEAR Collaboration

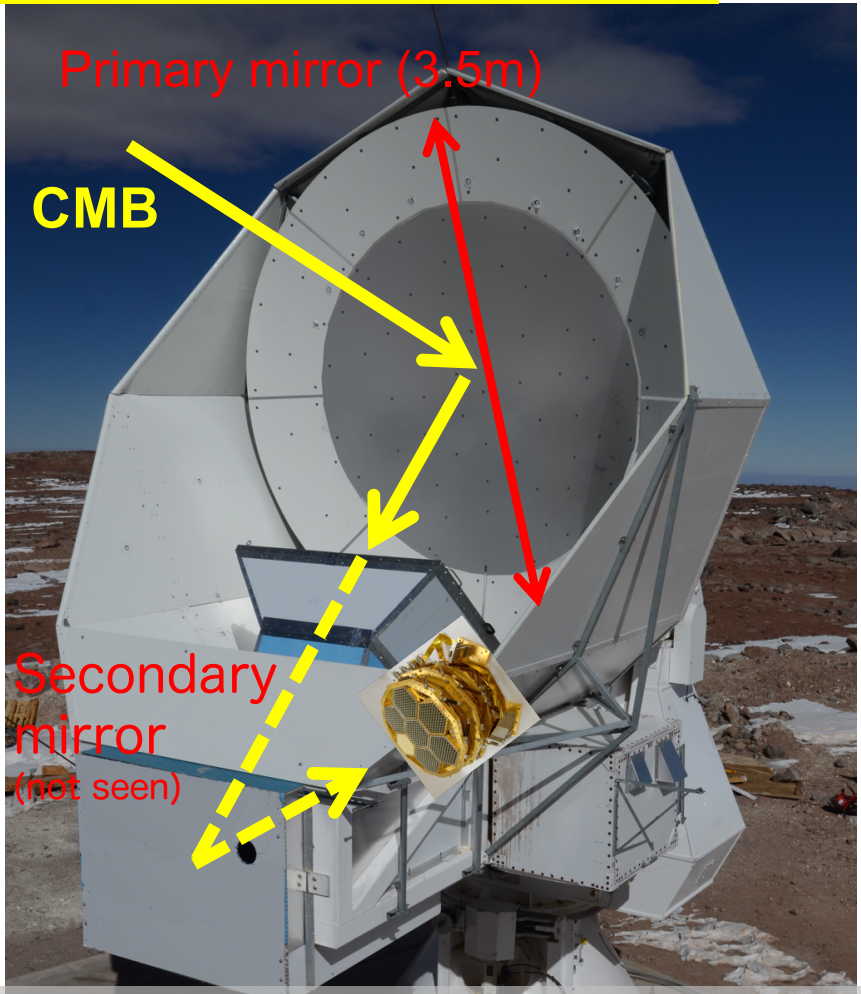
8 countries, ~100 researchers

POLARBEAR Site



POLARBEAR

Huan Tran Telescope



Offset Gregorian telescope 3.5 arcmin (0.06°) beams at 150GHz

- Observing since 2012 with 1274 TES bolometers at 150 GHz.

2012-2014: Small patch (3 x 3 deg^2)

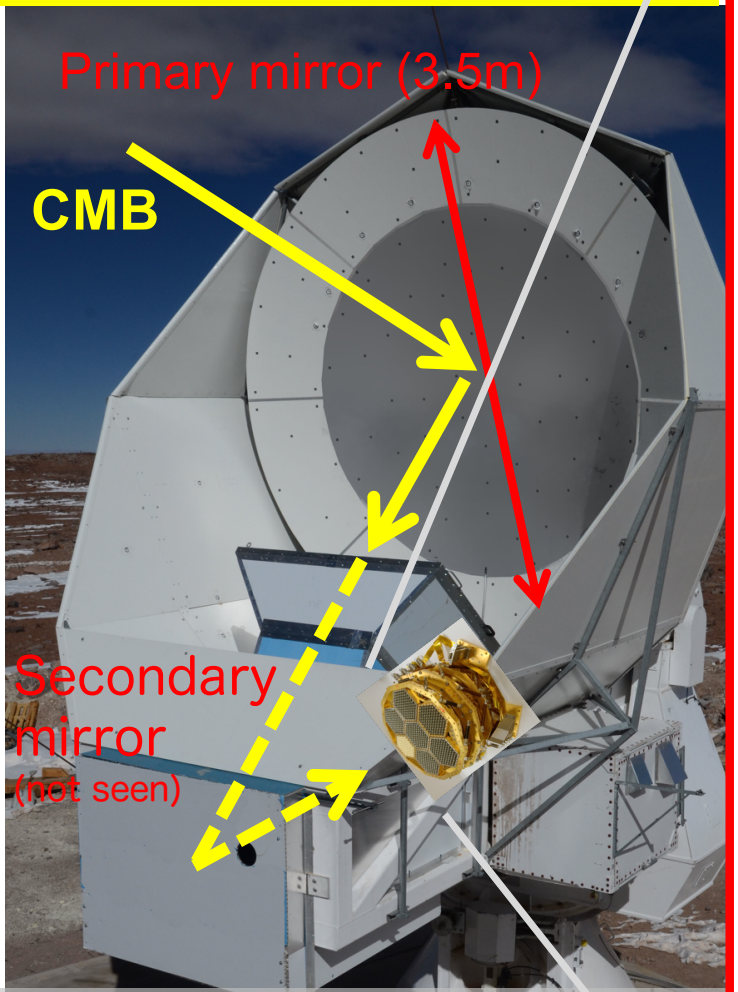
- Focus on lensing B-mode
- First measurement of lensing B-mode spectrum (ApJ 794, 2 (2014), ApJ 848(2),1-15 (2017))

2014 - :Large patch (~25 x ~30 deg^2)

- Target to inflation B-mode
- Analysis is underway.

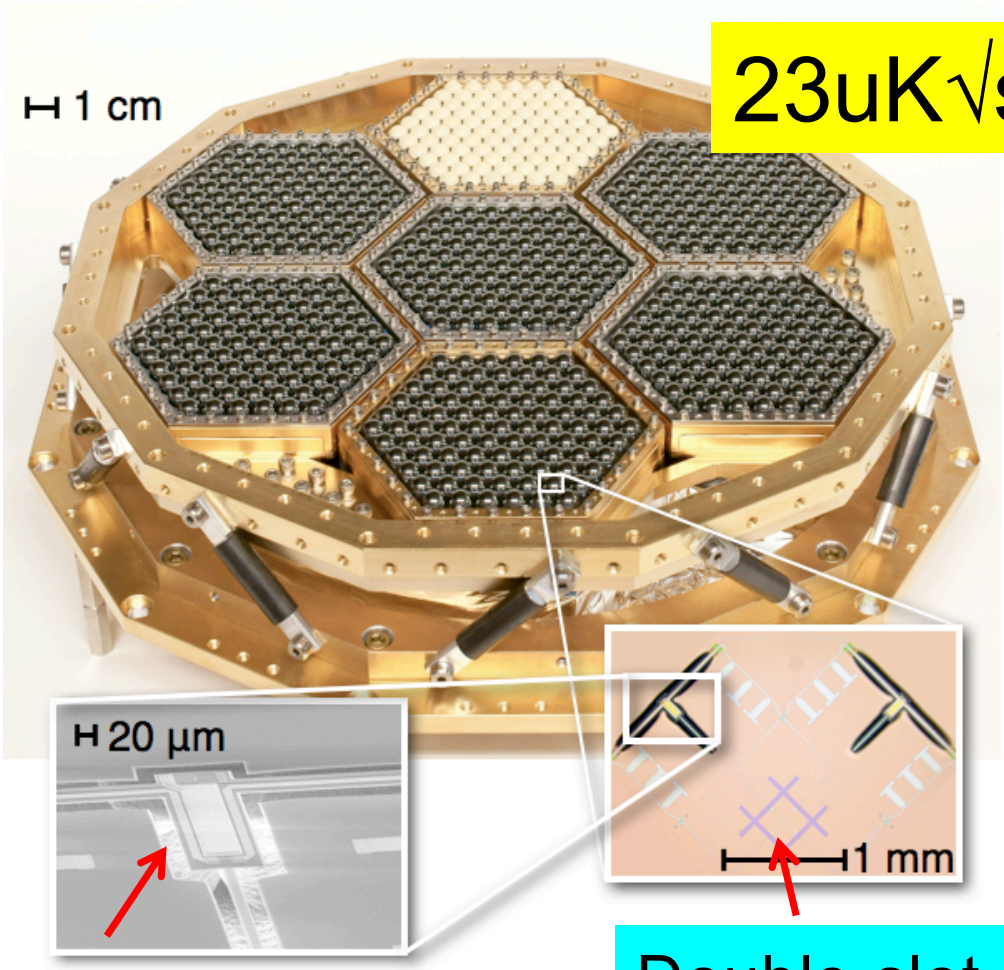
POLARBEAR

Huan Tran Telescope



Offset Gregorian telescope
arcmin (0.06°) beams at 15

POLARBEAR Focal Plane



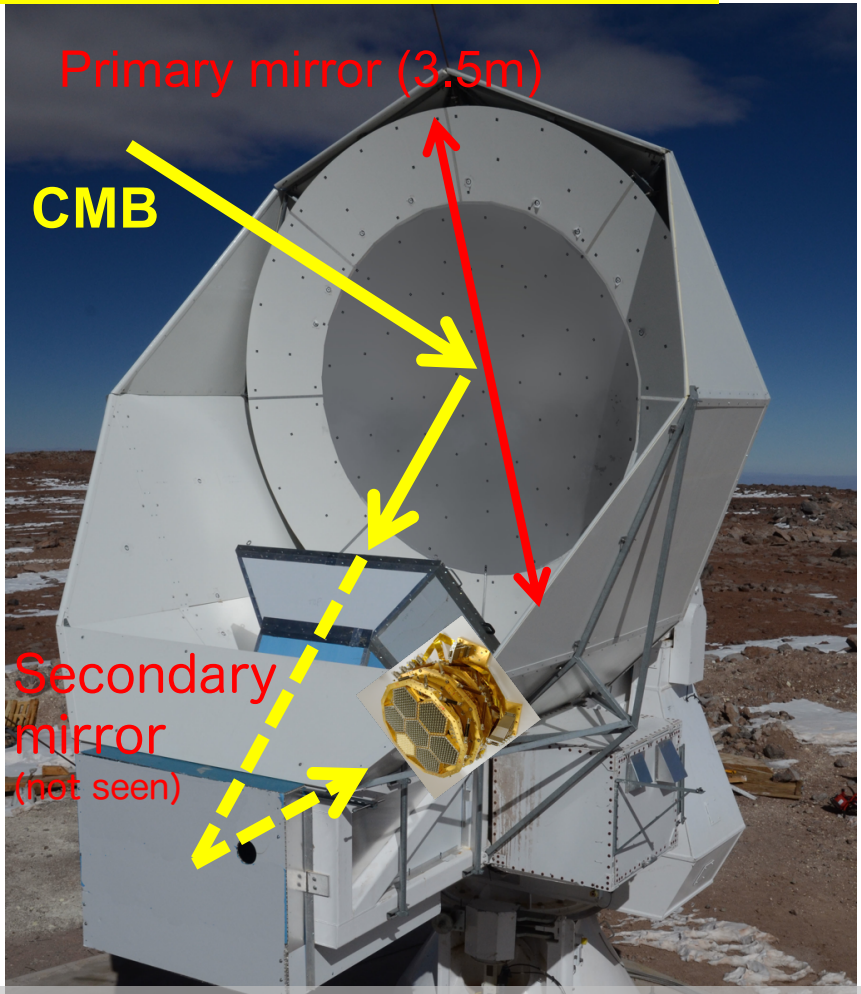
23uK√s

Superconducting Transition Edge Sensor (TES)

Double-slot dipole antenna (pol. sensitive)

POLARBEAR

Huan Tran Telescope



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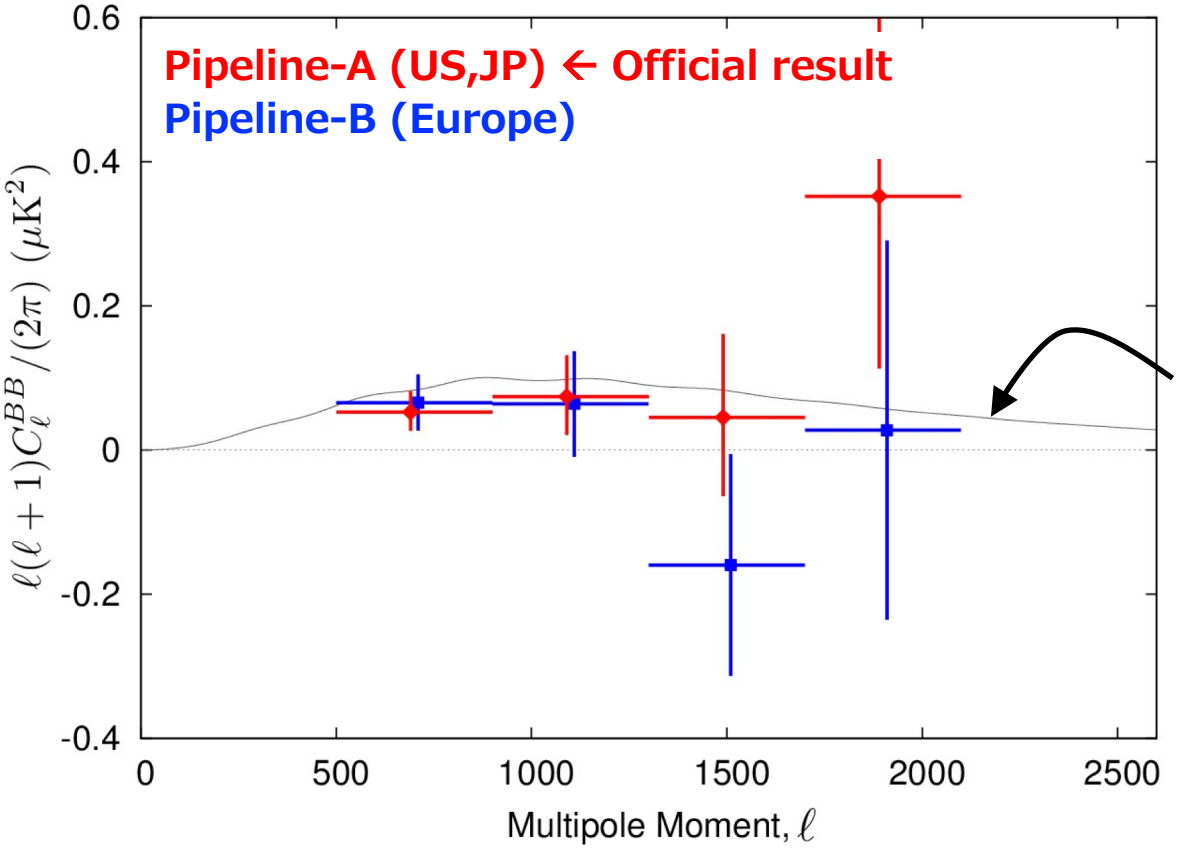
Latest lensing B-mode results
(1st+2nd season data)



APJ 848(2) 1-15, 2017

Planck2015 best-fit model prediction (A_L = 1)

arXiv:1705.02907
(submitted to ApJ)

- Improved measurement of lensing B-mode spectrum
  - Null hypothesis of "B-mode" is rejected more than 3 sigma.
  - Lensing amplitude is consistent with ΛCDM expectation.

$$A_L = 0.60^{+0.26}_{-0.24}(\mathrm{stat.})^{+0.00}_{-0.04}(\mathrm{inst.}) \pm 0.14(\mathrm{FG}) \pm 0.04(\mathrm{multi})$$

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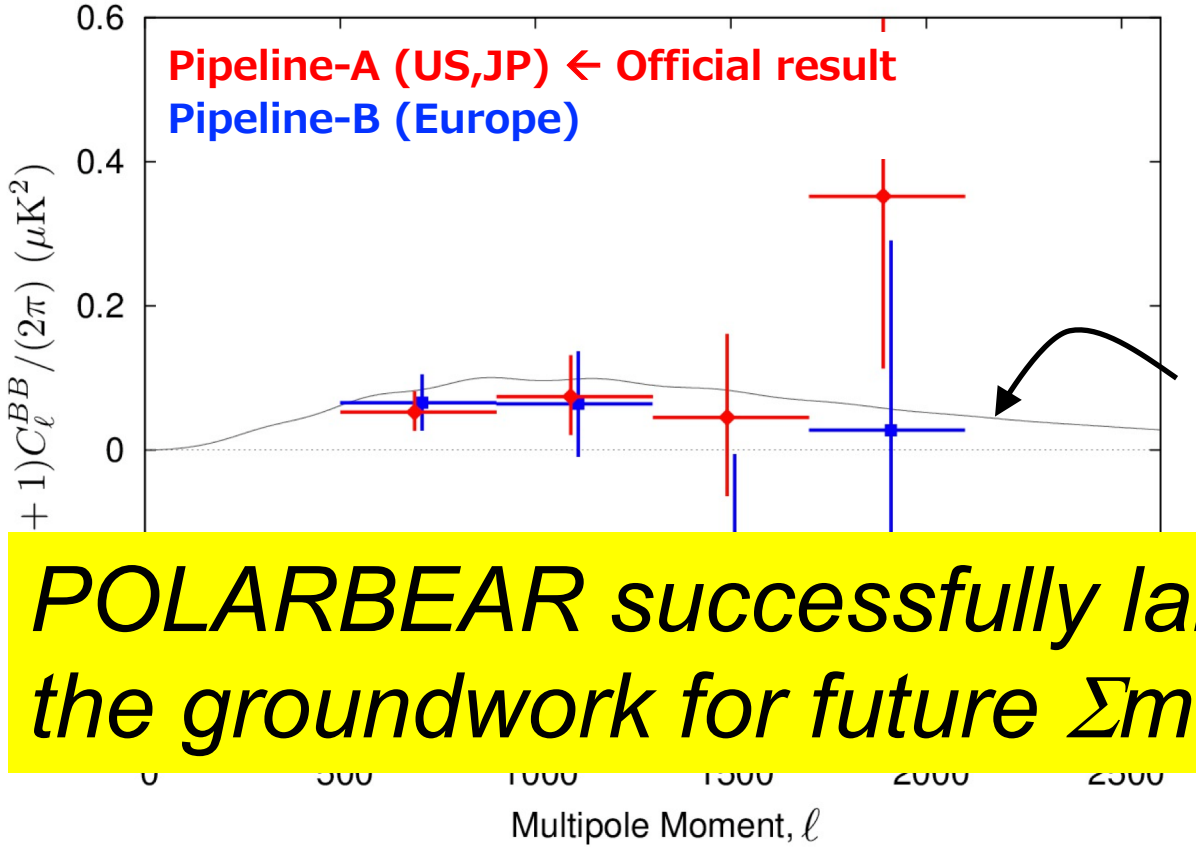
APJ 848(2) 1-15, 2017



Planck2015 best-fit model prediction (A_L = 1)

POLARBEAR successfully laid the groundwork for future Σm_ν measurement !

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  - Null hypothesis of "B-mode" is rejected more than 3 sigma.
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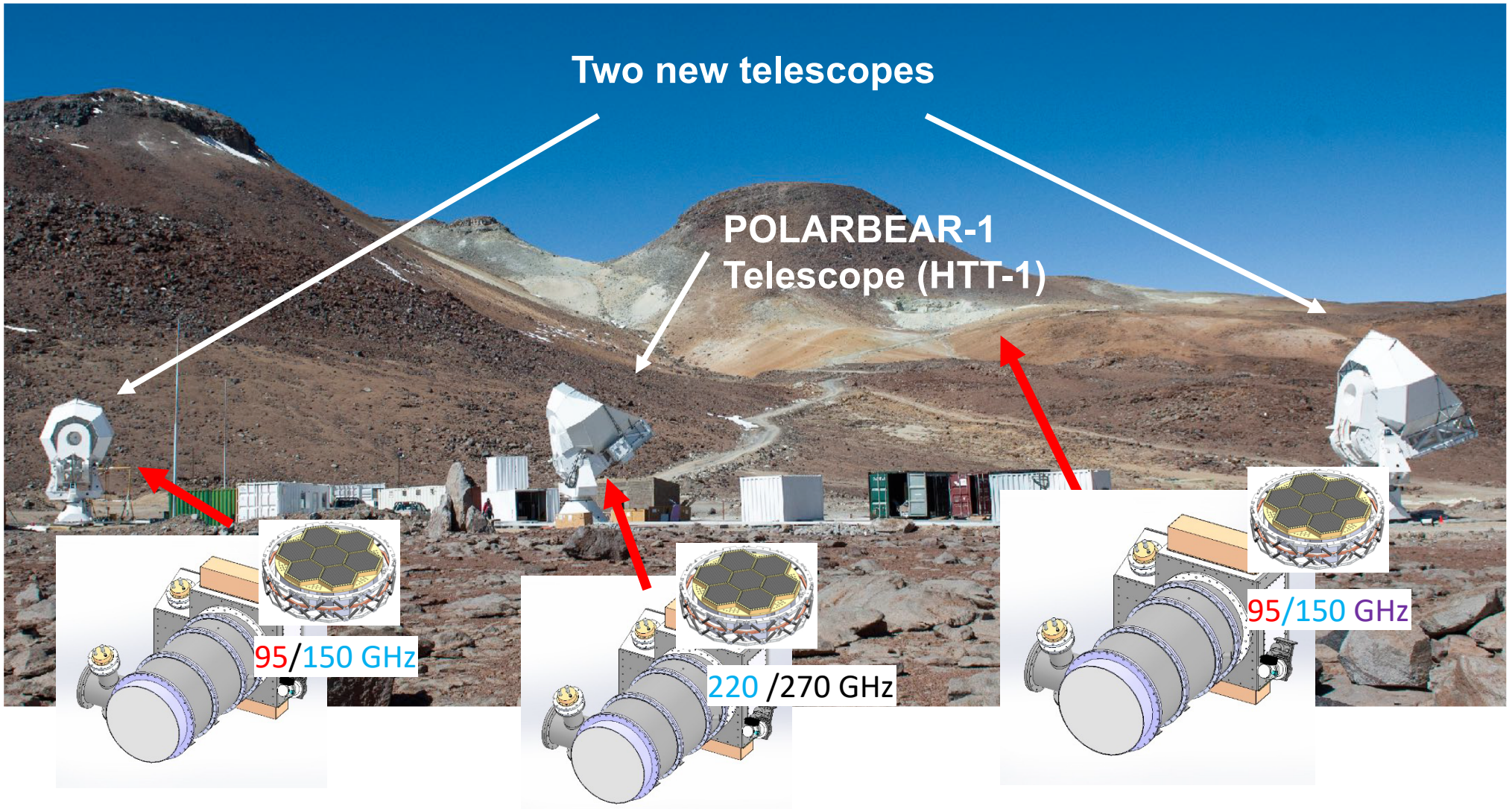
Topic	Journal	
Cross correlation of lensing deflection with Cosmic Infrared Background	PRL 112, 131302 (2014)	Editor's suggestion
Lensing deflection power spectrum	PRL 113. 021301 (2014)	Editor's suggestion
CMB B-mode auto power spectrum (1^{st} year)	ApJ 794, 2 (2014)	
Modeling of atmospheric emission	ApJ 809, 63 (2015)	
Cosmic Birefringence and Primordial Magnetic Field	PRD 92, 123509 (2015)	Editor's suggestion
Map-making algorithm	A&A 600, A60 (2017)	
Performance of continuously HWP	JCAP 05 008 (2017)	
B-mode auto power spectrum (1^{st}+2^{nd} year)	APJ 848, 2 (2017)	
Ice cloud	APJ 870, 2 (2019)	
POLARBEAR x Herschel-ATLAS	arXiv: 1903.07046	
POLARBEAR x HSC	arXiv: 1904.02116	

POLARBEAR continues timely publication of high profile results.

Next: The Simons Array

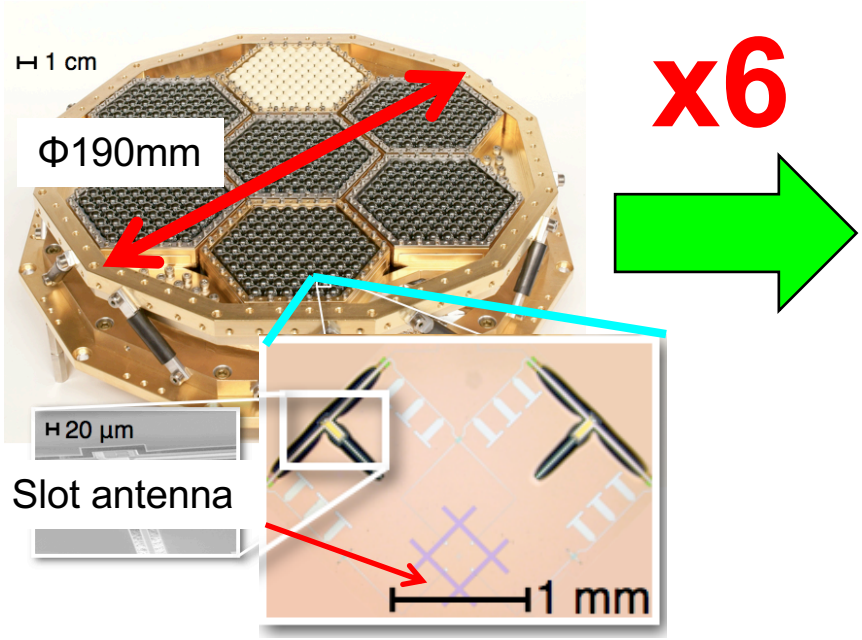
Expanding POLARBEAR to three multi-chroic telescopes



Three upgraded receivers (POLARBEAR-2 receiver), observing at 95, 150, 220, 270 GHz

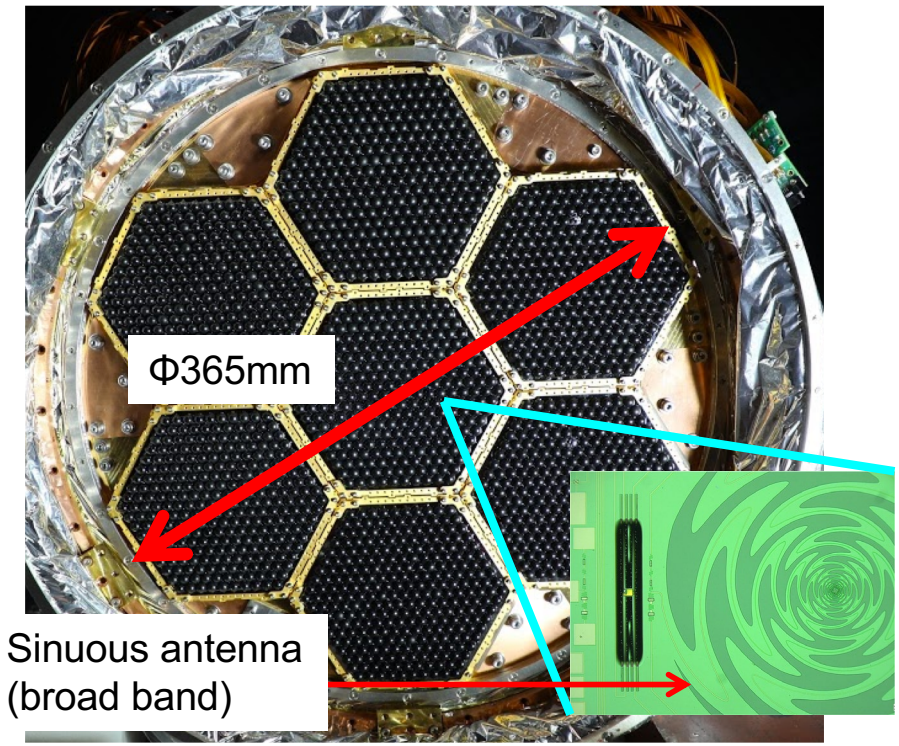
POLARBEAR to Simons Array

POLARBEAR-1
1274 detector array



x6

POLARBEAR-2 focal plane

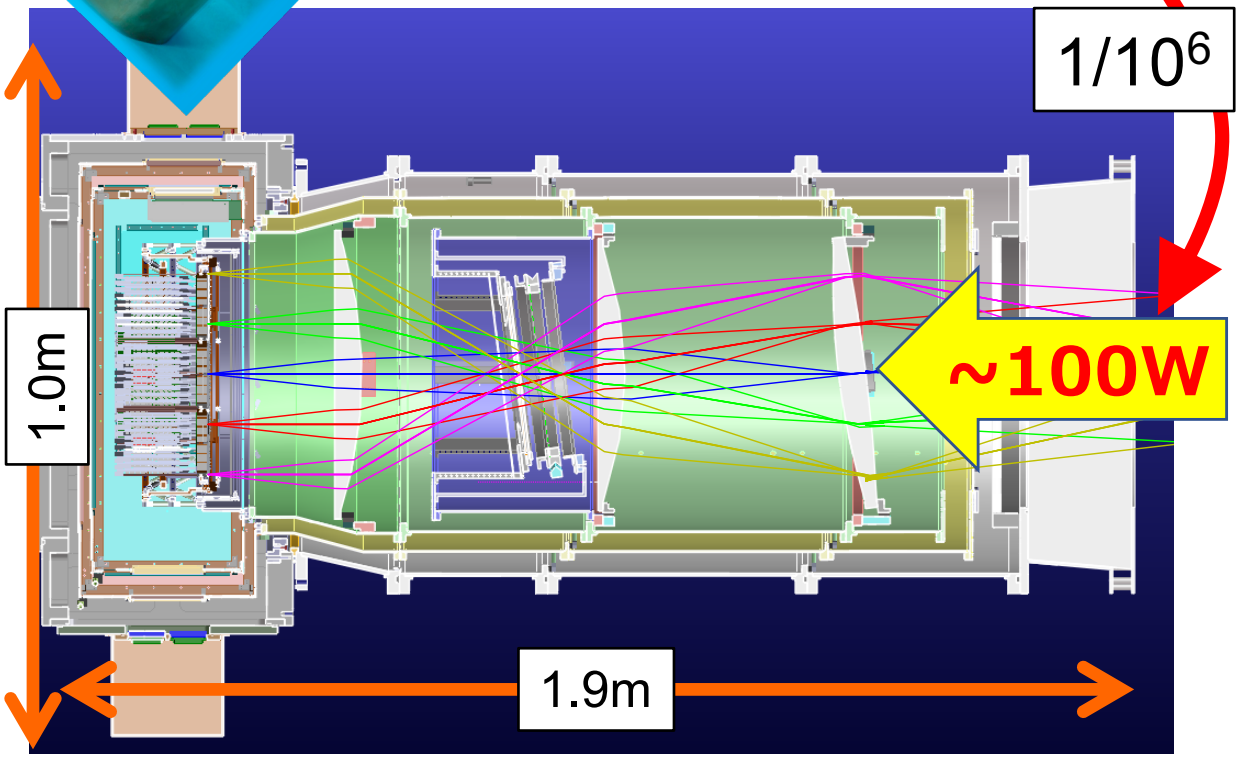


- Three larger focal plane (7588 TES / focal plane)
- Multi-chroic pixels with 95/150, 220/270GHz frequency coverage.

x18 leap with multi-chroic pixels

POLARBEAR-2 Large Optics

Helium Sorption cooler
(Cooling power : ~70uW @0.35K)



POLARBEAR-2 Large Optics

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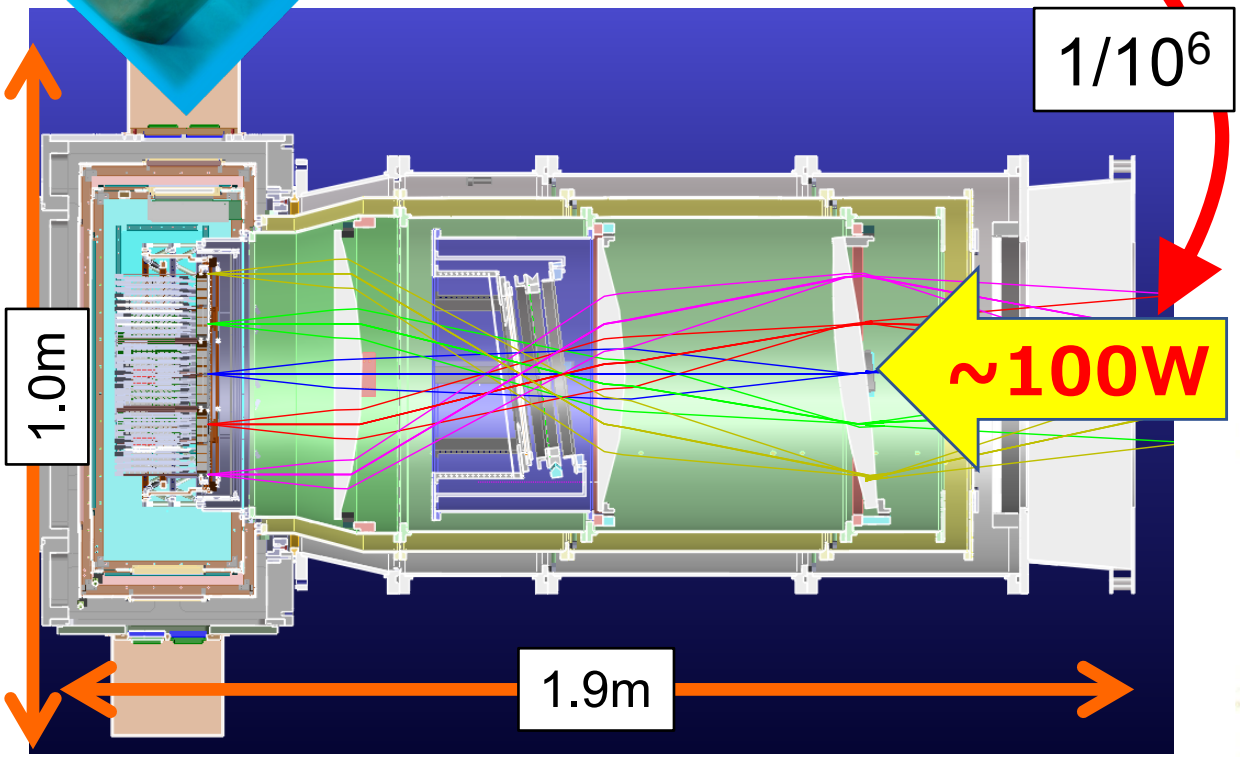
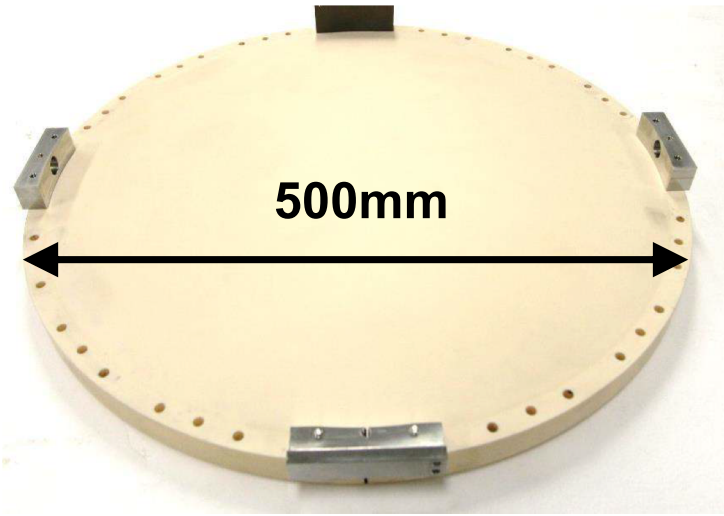


Alumina lens

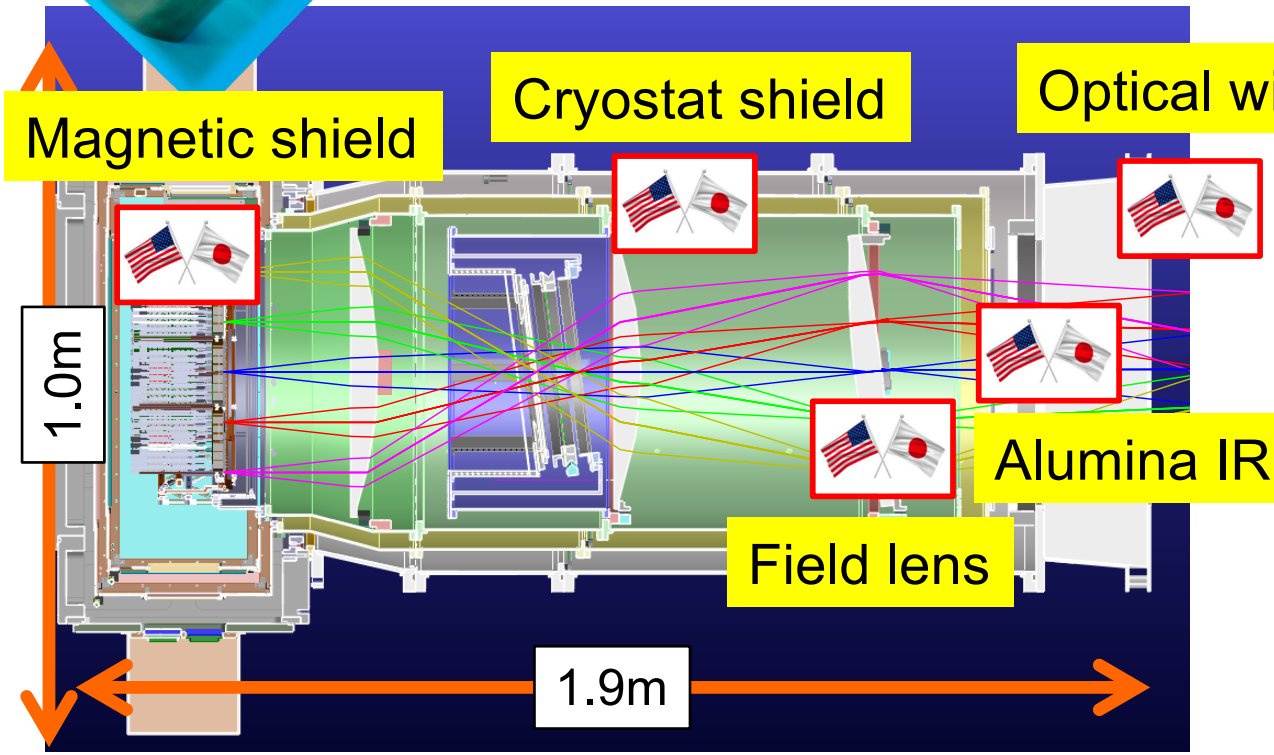


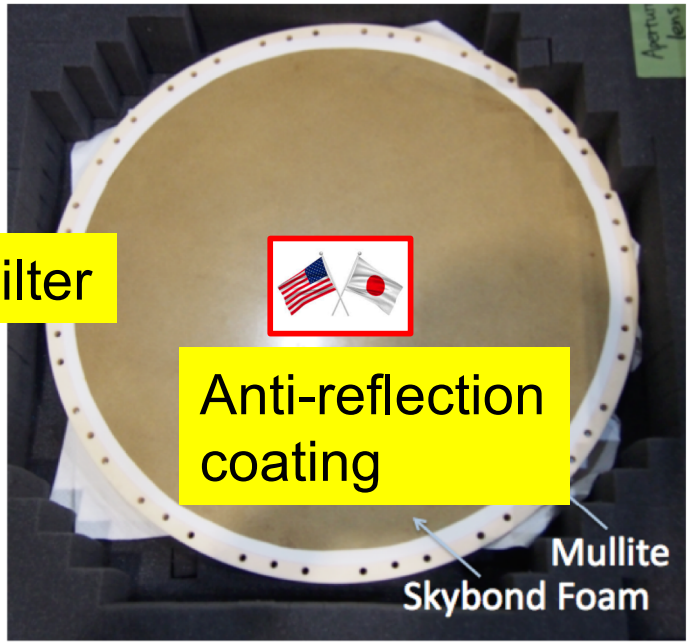
- Employ the advanced materials (Al_2O_3)
  - for large PB2 cold optics (~50cm aperture)

Applied Optics 53, 1727 (2014), Applied Optics 55, 22 (2016)

POLARBEAR-2 Large Optics

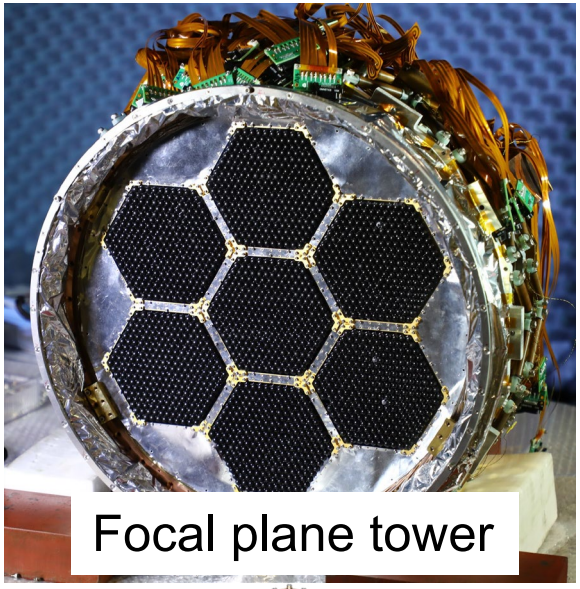
Helium Sorption cooler
(Cooling power : ~70uW @0.35K)

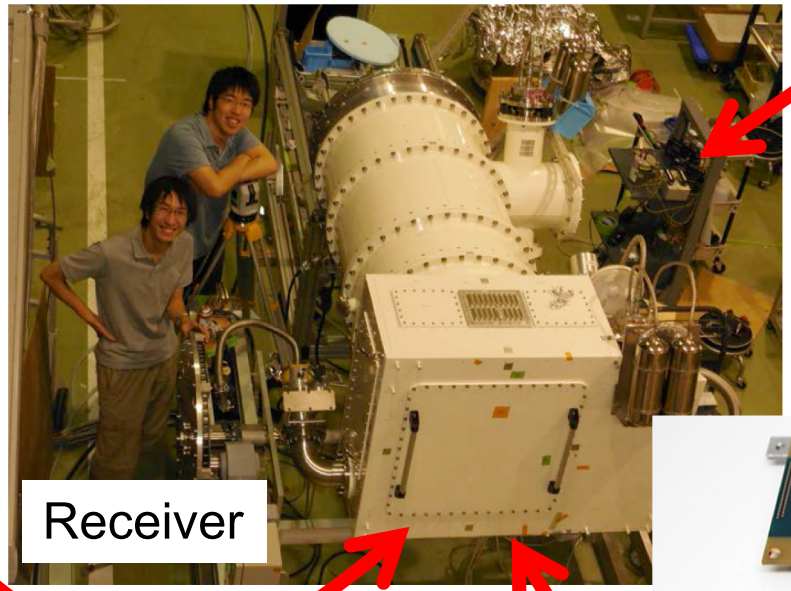


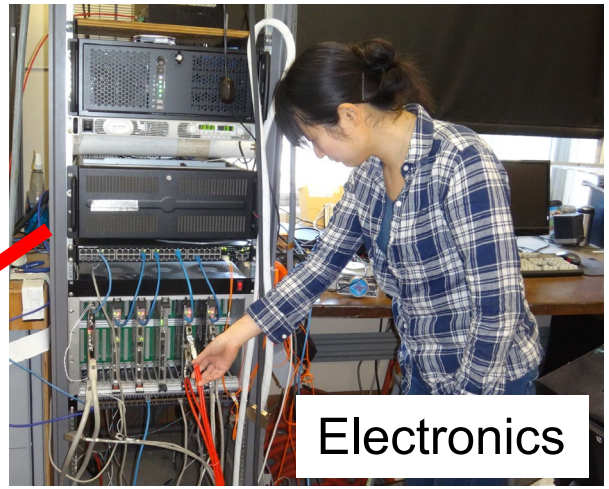


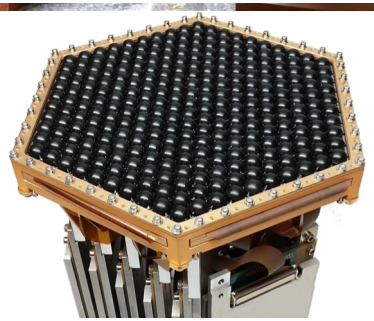
Development/fabrication of PB-2 alumina optics are strongly supported by the program.

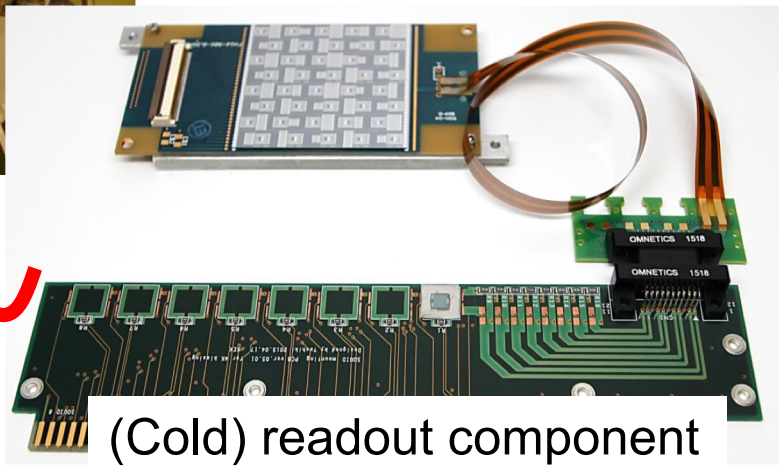
(1st) Receiver assembly at KEK


Focal plane tower


Receiver


Electronics


TES Detector module

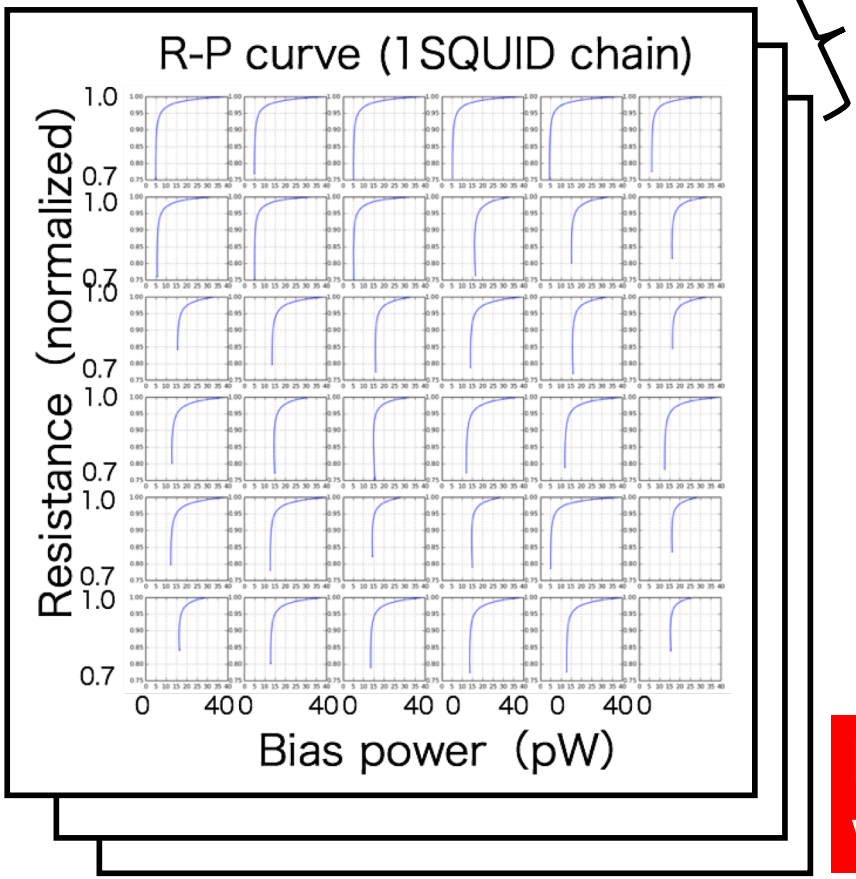


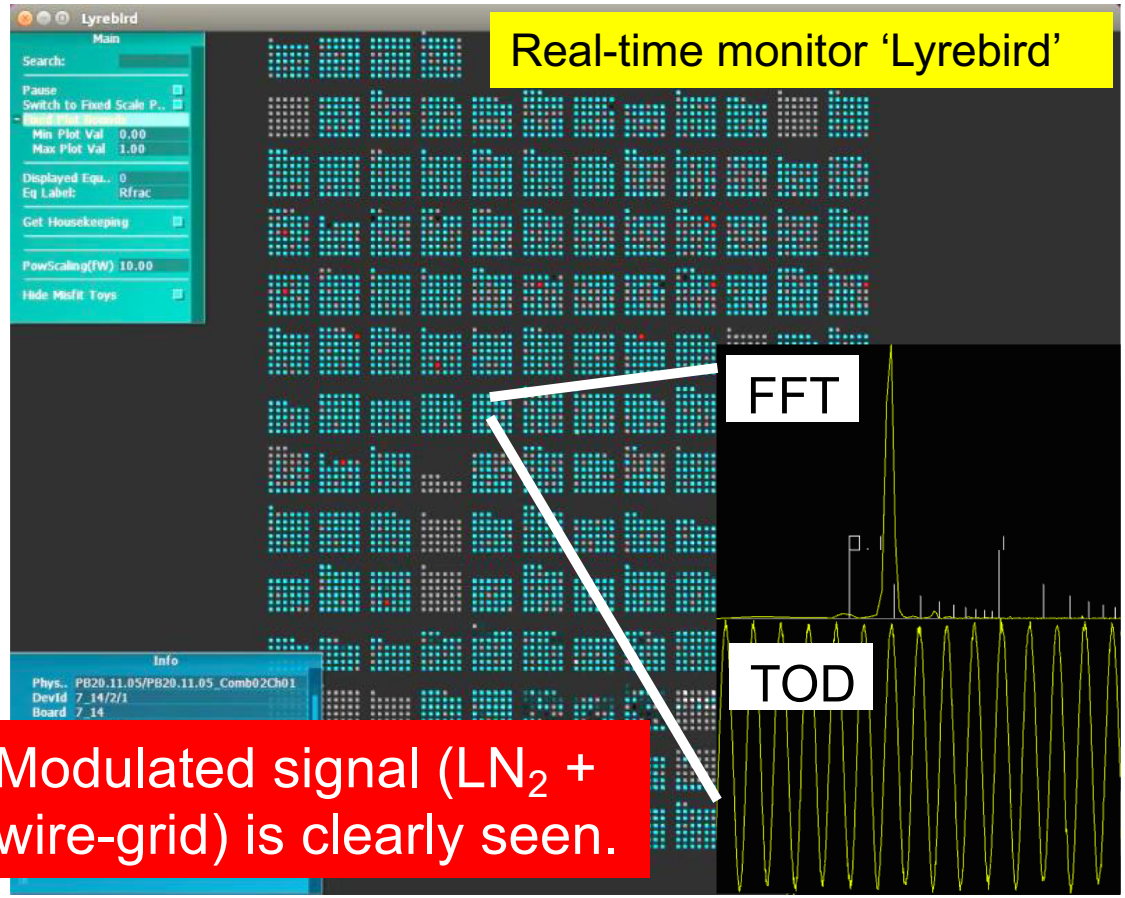
(Cold) readout component

2018: PB-2 receiver was integrated and tested at “Advanced Instrumentation Lab.” at KEK.

PB2 detector array worked !

x ~200





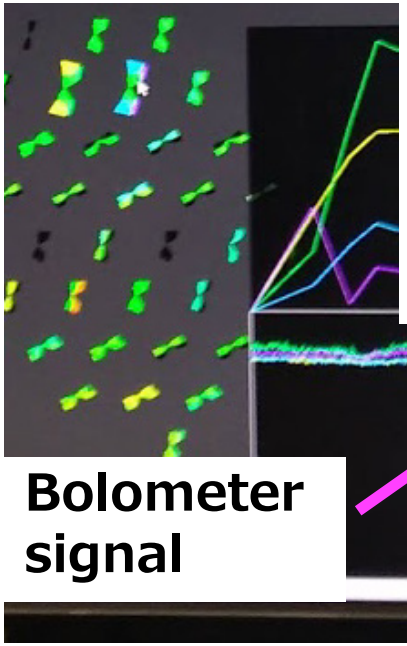
Full scale (~7588) PB2 TES bolometer array is successfully operated and readout.

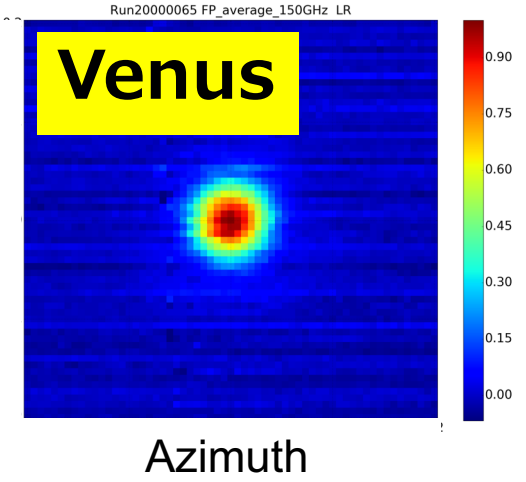
Deployment

1st receiver for Simons Array was shipped to the Atacama desert from KEK on Oct. 1&2, 2018.

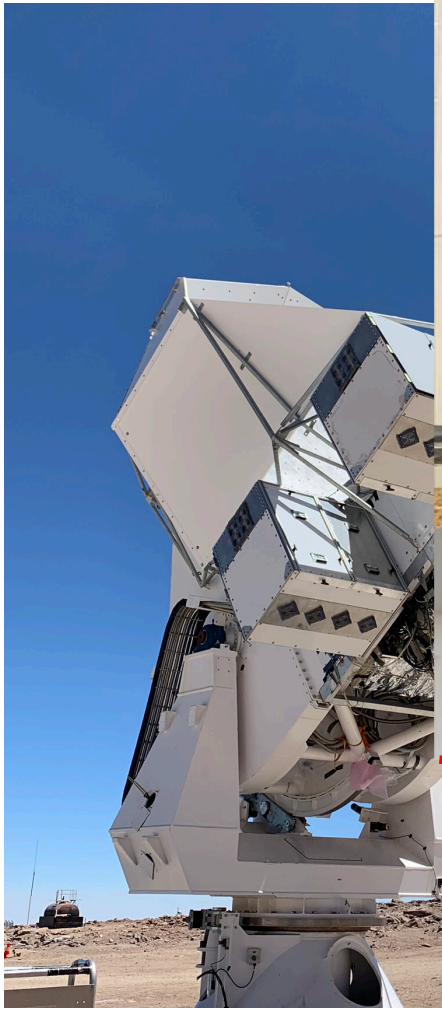
First light !

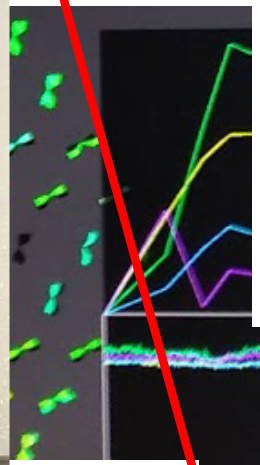
Achieved First light for PB2/SA !





First





meter
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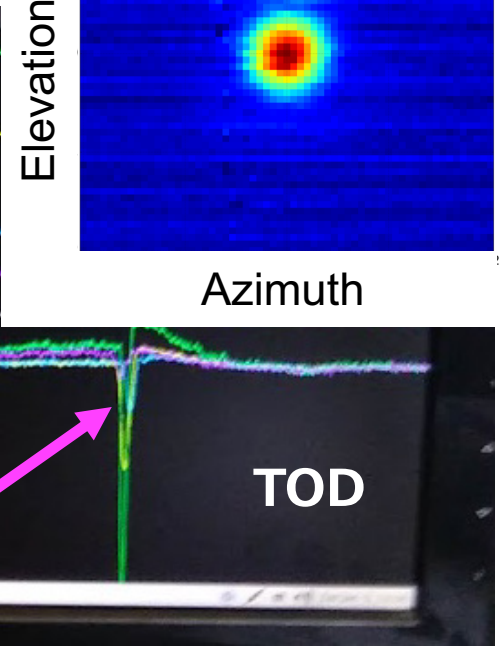
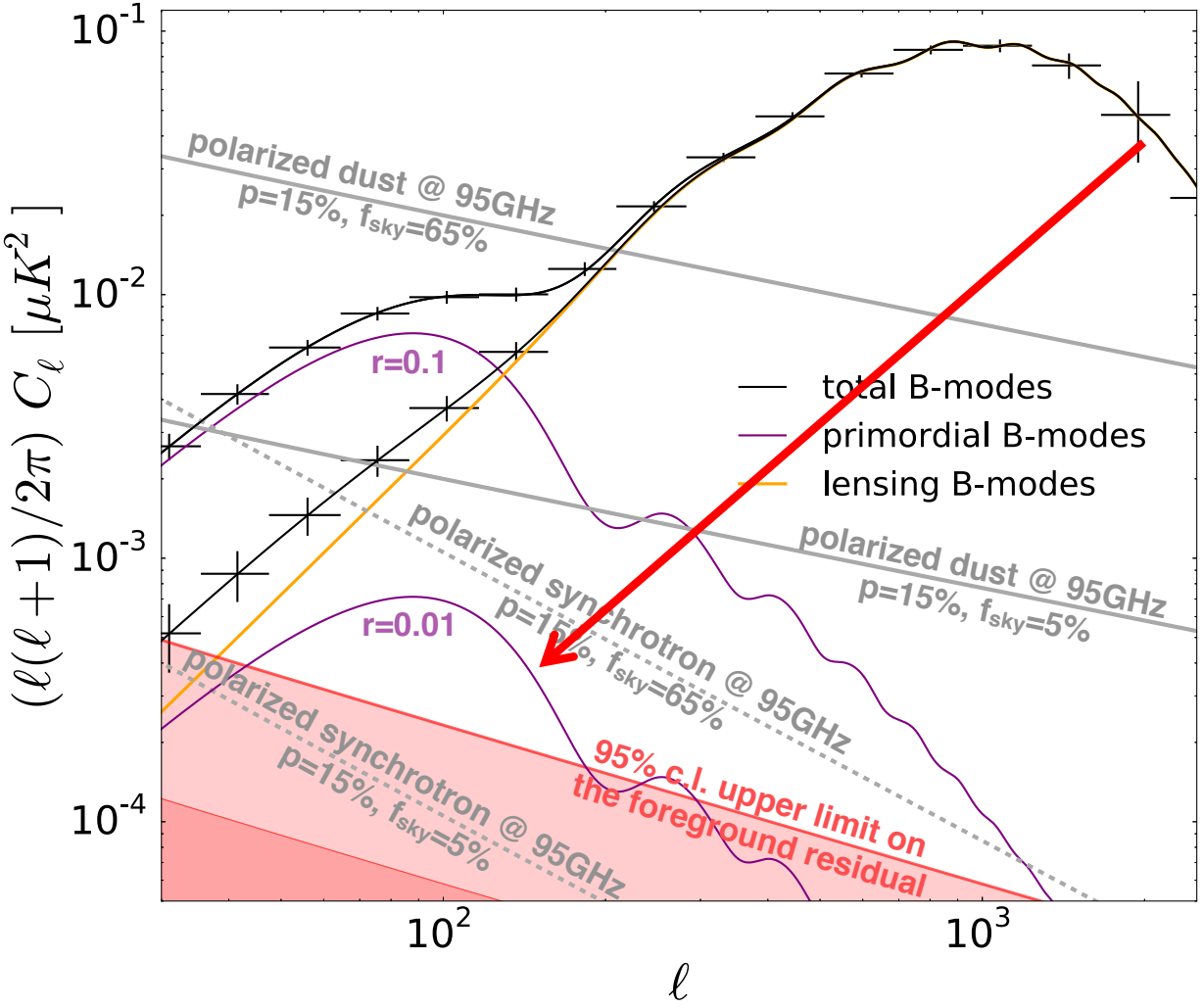


TOD

Site crew at 1st light

Achieved First light for PB2/SA !

Simons Array (projected) sensitivity



Foreground rejection with 90/150/220/270 GHz, Planck, & C-BASS data

Inflation

- $\sigma(r=0.1) = 6\times10^{-3}$

Neutrino mass

- $\sigma(\Sigma m\nu) = 40$ meV w/ DESI BAO

Simons Array will contribute to cosmology and particle physics significantly.

Summary

- POLARBEAR is a ground-based CMB polarization experiment, aiming to reveal the inflationary universe and neutrino absolute mass scale.
- POLARBEAR-1
  - Established “lensing *B*-mode” with small patch data
    - Laid the groundwork for neutrino mass measurement
  - Started large patch observation for inflationary *B*-mode
- POLARBEAR-2/Simons Array
  - Successfully deployed a new receiver “POLARBEAR-2”

Stay Tuned !