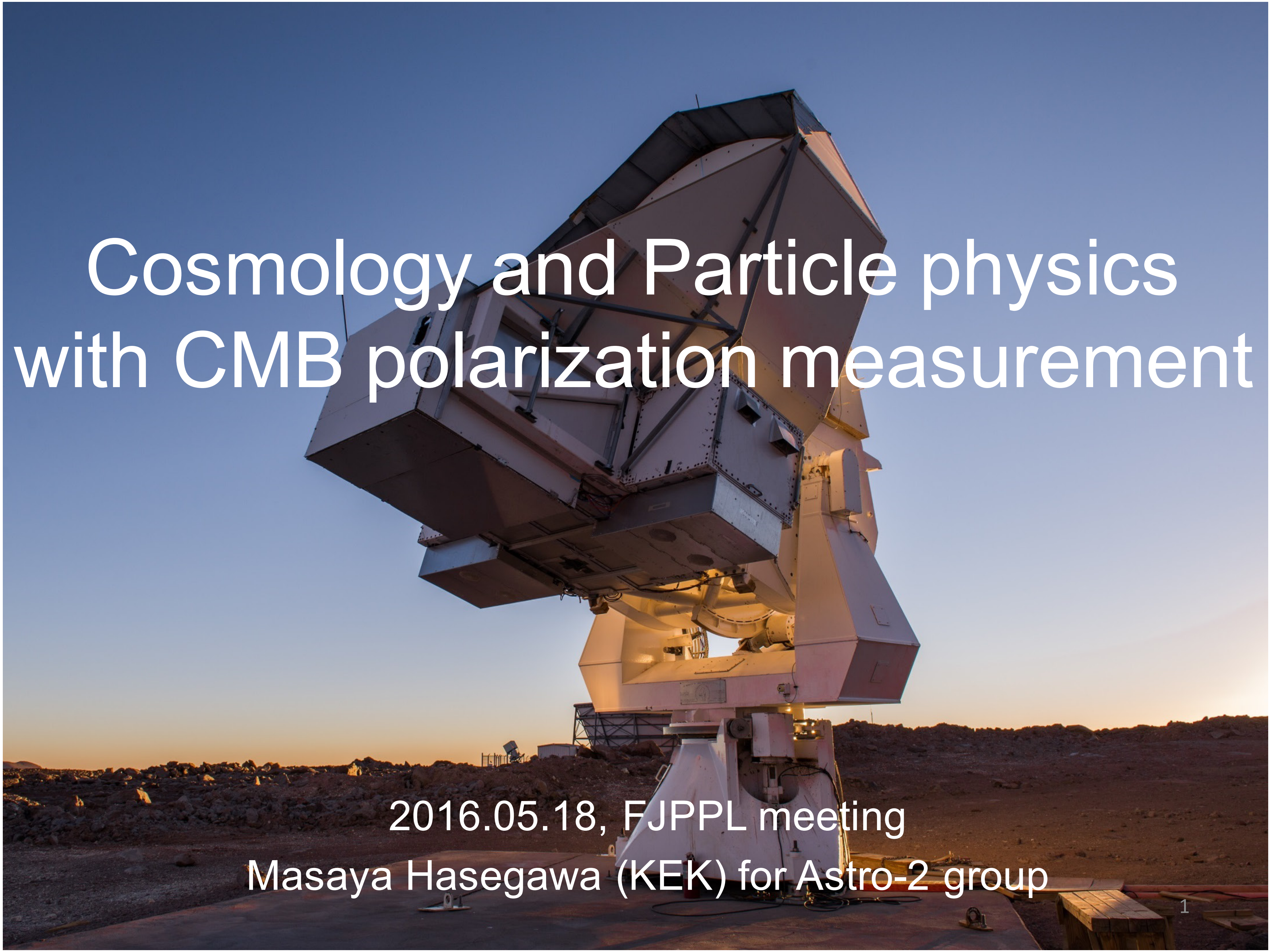


Cosmology and Particle physics with CMB polarization measurement

2016.05.18, FJPPL meeting

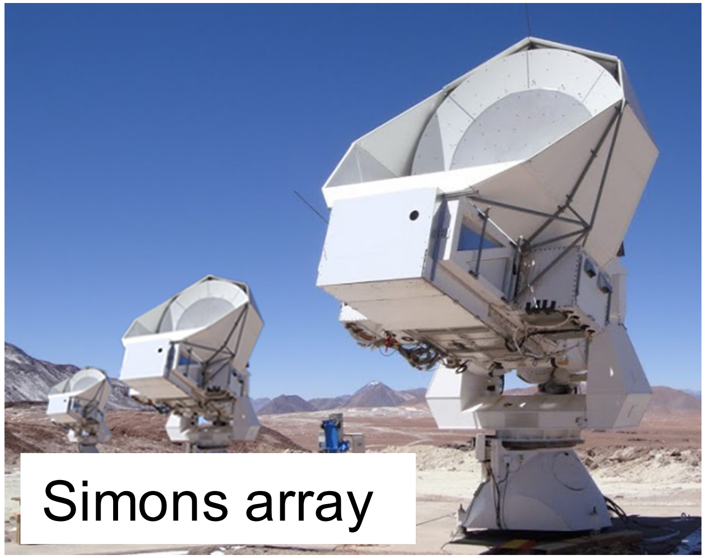
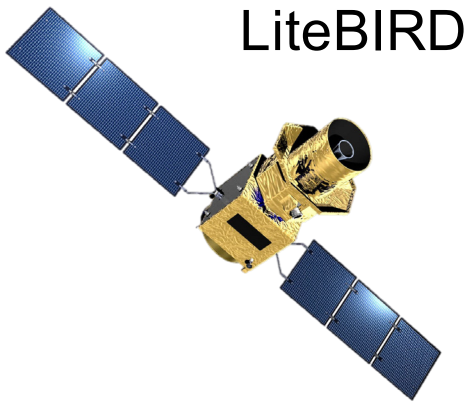
Masaya Hasegawa (KEK) for Astro-2 group

Outline

- Introduction
  - CMB polarization and its science
- POLARBEAR (main project)
- Summary

Project team (Astro 2)

PI: Stompor(APC), Hazumi(KEK)

Current	Next (in ~5 years)	Future (2020's)
		
		+ European CMB satellite

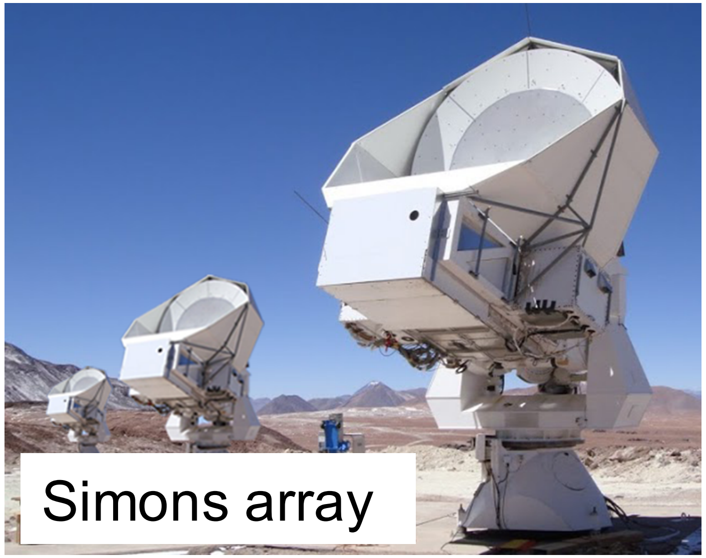
- Our team is involved to
  - (World-leading) Ground-based experiment : POLARBEAR and Simons Array (upgrade)
  - Future satellite concepts : LiteBIRD, Core++(?)

Project team (Astro 2)

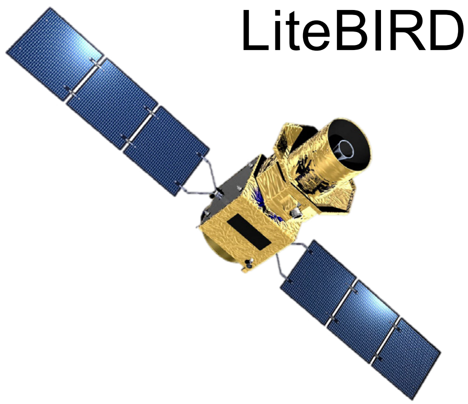
PI: Stompor(APC), Hazumi(KEK)

Current

Next (in ~5 years)



Future (2020's)



+ European CMB satellite

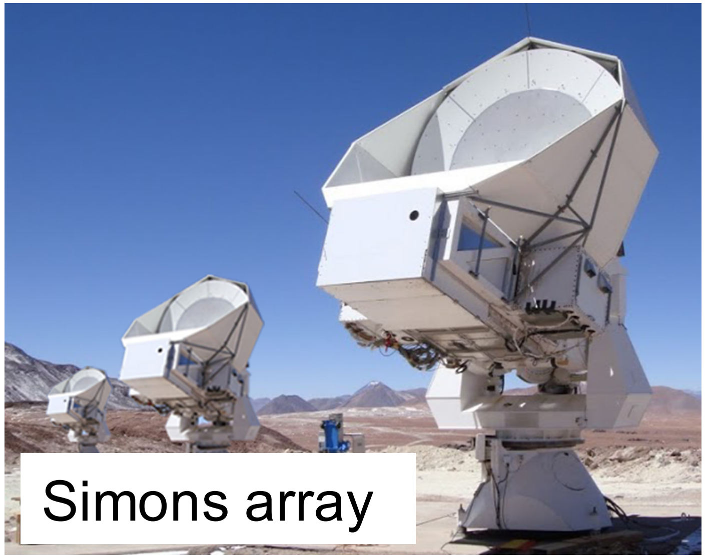
- Our goal is detection/characterization of
  - 'B-mode(odd-parity)' polarization pattern from
    - Primordial gravitational wave and
    - Gravitational lensing effect.

Project team (Astro 2)

PI: Stompor(APC), Hazumi(KEK)

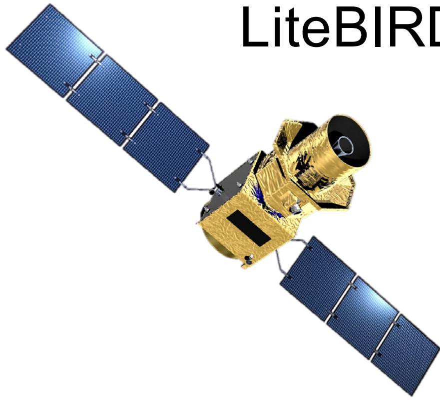
Current

Next (in ~5 years)



Future (2020's)

LiteBIRD



+ European CMB satellite

- Our goal is detection/characterization of

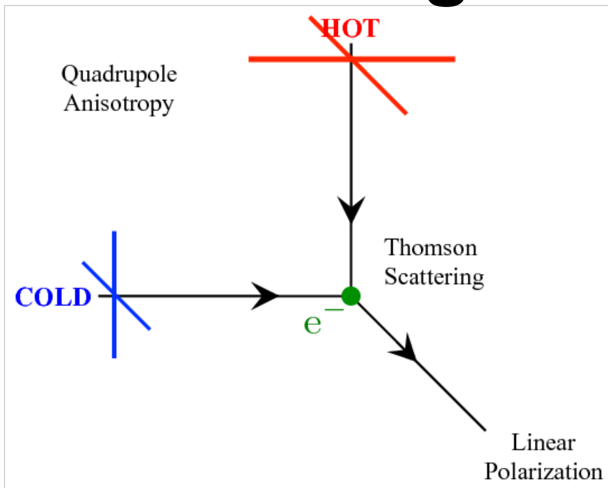
Science targets are
"Inflation" and "Neutrino masses" !

h

- Gravitational lensing effect.

Science with CMB B-mode

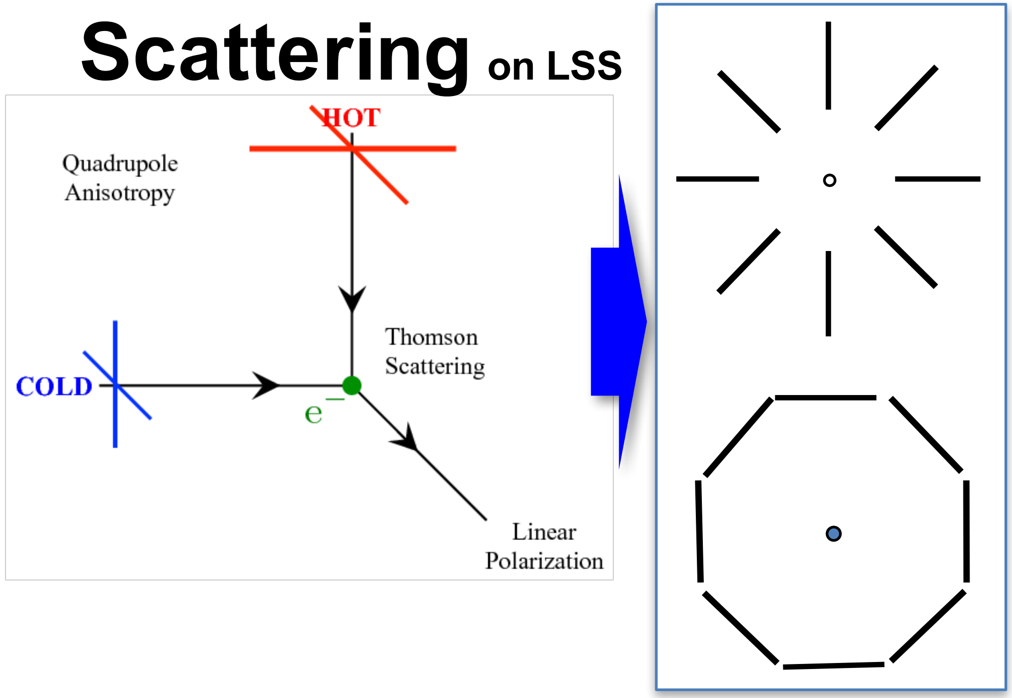
Thomson Scattering on LSS



Science with CMB B-mode

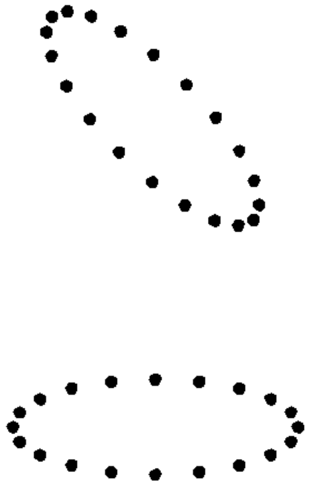
Thomson Scattering on LSS

_E_-mode

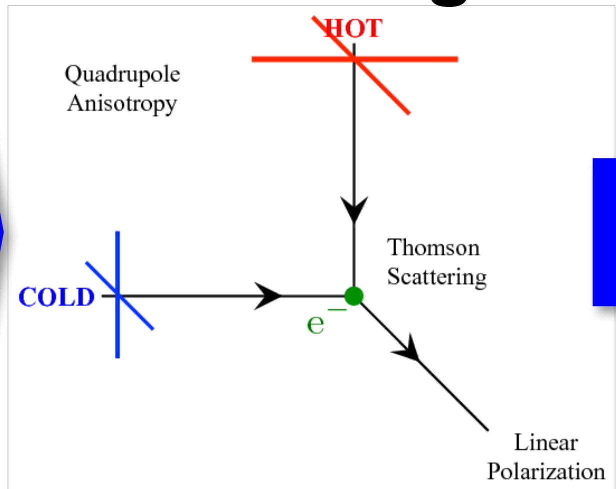


Science with CMB B-mode

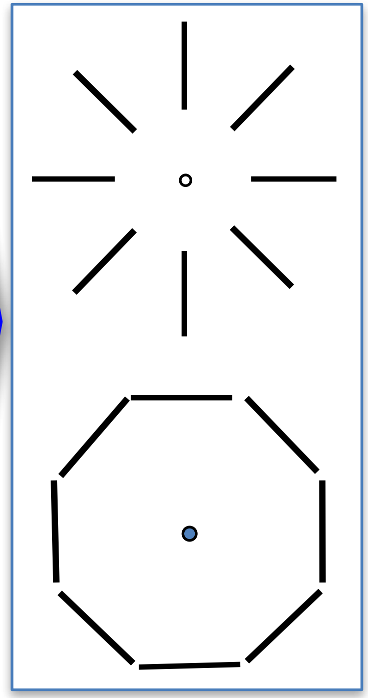
Gravitational Wave



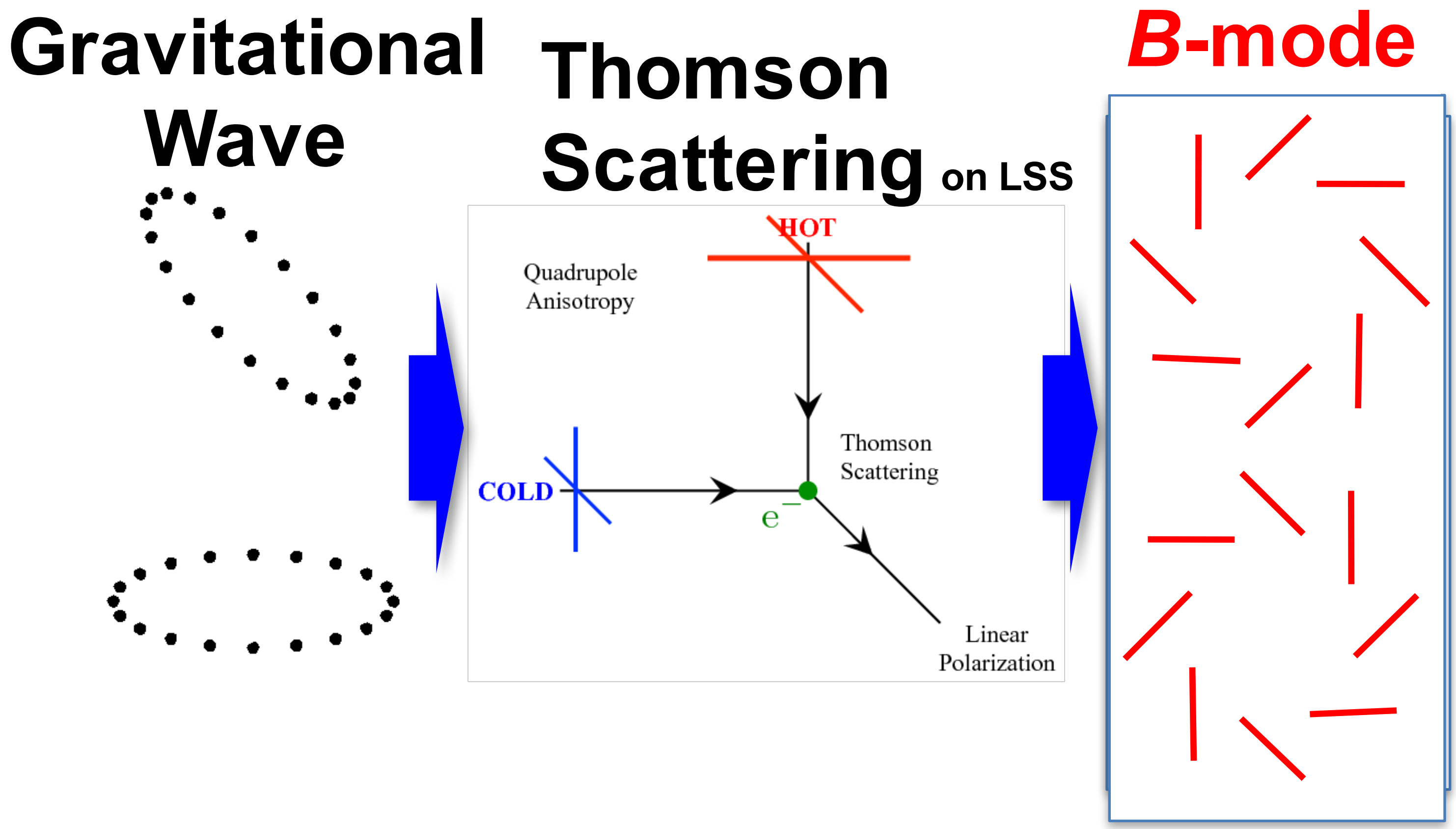
Thomson Scattering on LSS



***E*-mode**

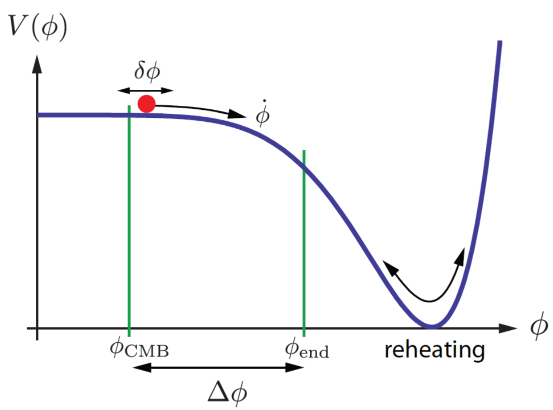


Science with CMB B-mode

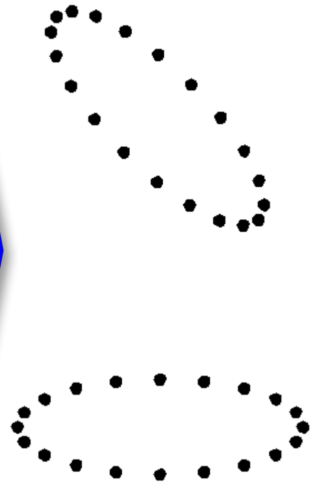


Science with CMB B-mode

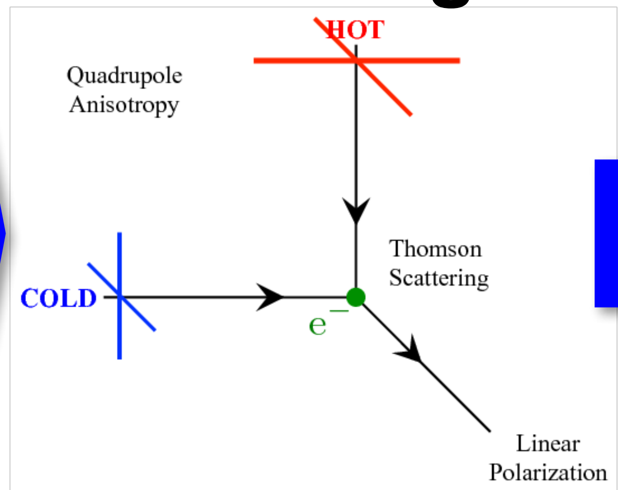
Inflation



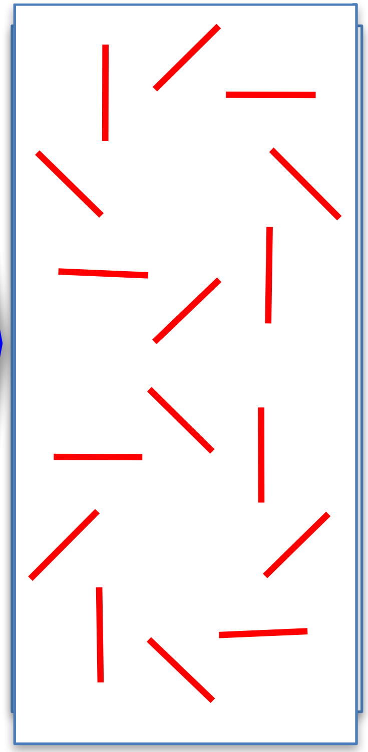
Gravitational Wave



Thomson Scattering on LSS



B-mode



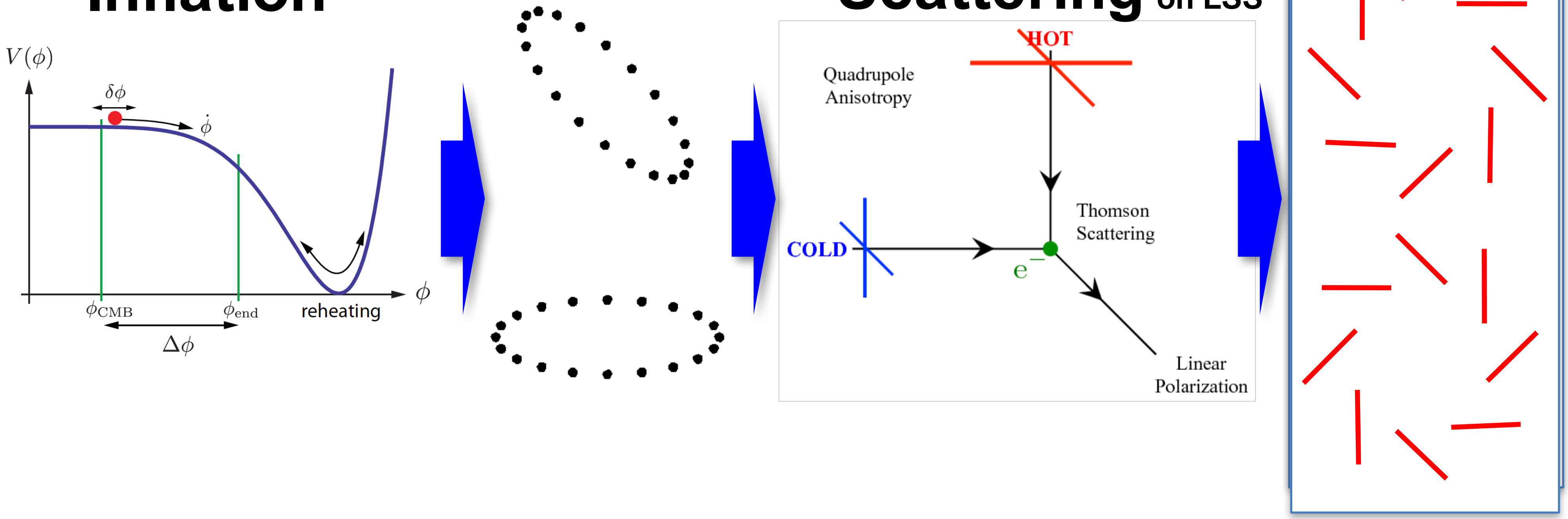
Science with CMB B-mode

Inflation

Gravitational Wave

Thomson Scattering on LSS

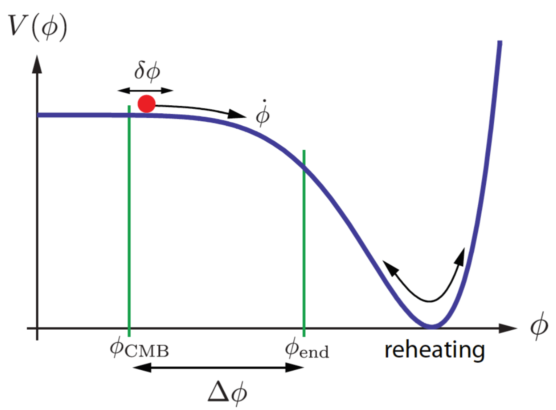
B-mode



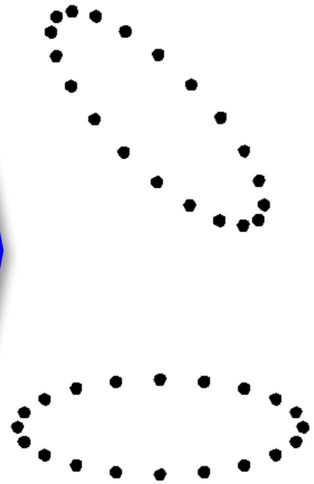
B-mode is a smoking gun signature of inflationary universe!

Science with CMB B-mode

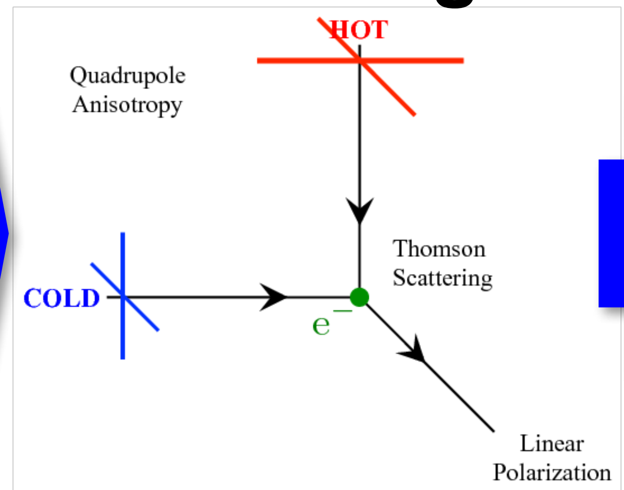
Inflation



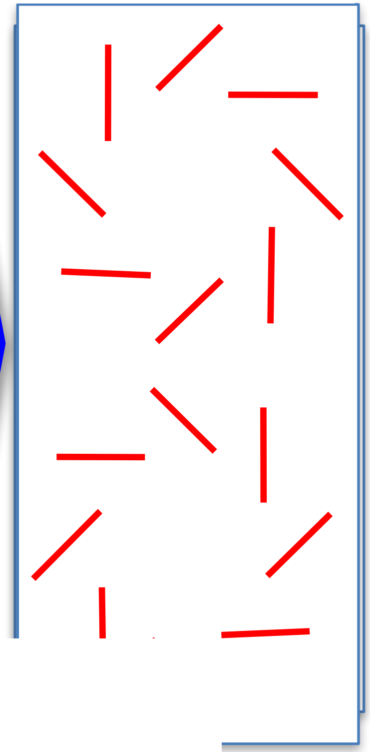
Gravitational Wave



Thomson Scattering on LSS



B-mode

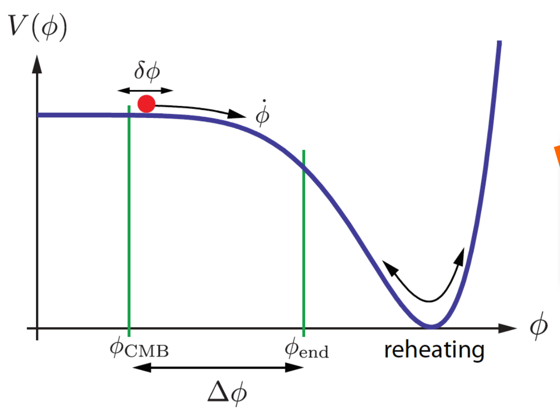


B-mode power is proportional to tensor-to-scalar ratio, r

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

Science with CMB B-mode

Inflation **Gravitational Wa...** **Thomson** ***B*-mode**



10^{12} x LHC (13TeV)

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

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

B-mode power is proportional to tensor-to-scalar ratio, r

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

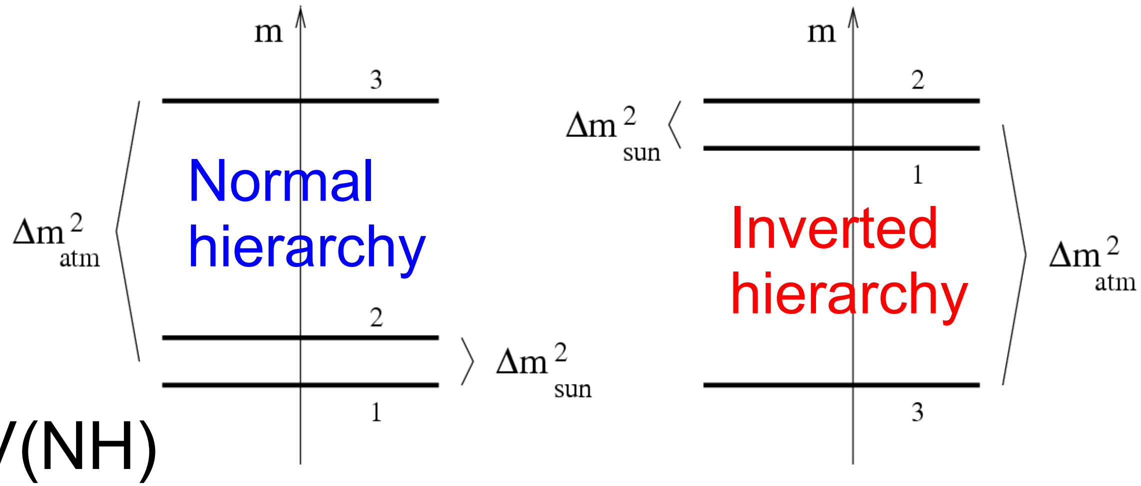
Neutrino Mass

<u>Neutrino Oscillation</u>

$\Delta m^2_{atm} \sim 10^{-3}\,\mathrm{eV}^2$

$\Delta m^2_{sol} \sim 10^{-5}\,\mathrm{eV}^2$

$\rightarrow \Sigma m_\nu > 0.10$ (IH) or 0.05eV(NH)



- Oscillation experiments confirmed "non-zero neutrino masses", but its absolute scale is still unknown.
- The region of interest is sub-eV region.

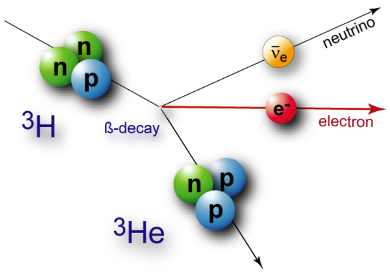
$$0.05\ \mathrm{eV} < \Sigma\, m_\nu < \sim 1.3\ \mathrm{eV}$$

Neutrinos are relativistic at LSS.

Neutrino Mass

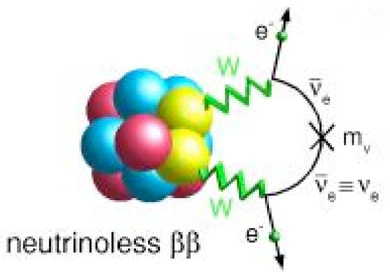
Probes to sub-eV Neutrino Mass

(Particle physics)
Single Beta Decay



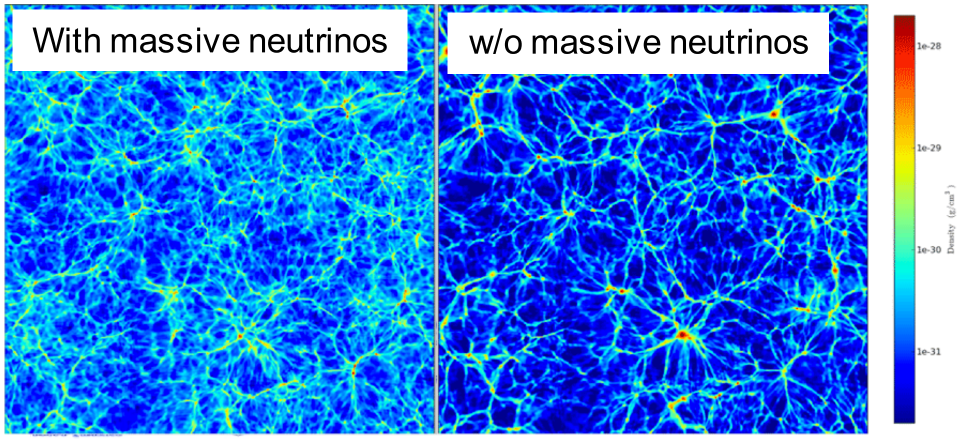
- Effective Mass
- KATRIN will reach 200meV sensitivity in ~5 years.

(Particle and Nuclear Physics)
0-ν Double Beta Decay



- Majorama Mass
- Sensitivity below 100 meV in 5 years (KamLAND…)

(Cosmology and Astrophysics)
Large Scale Structure

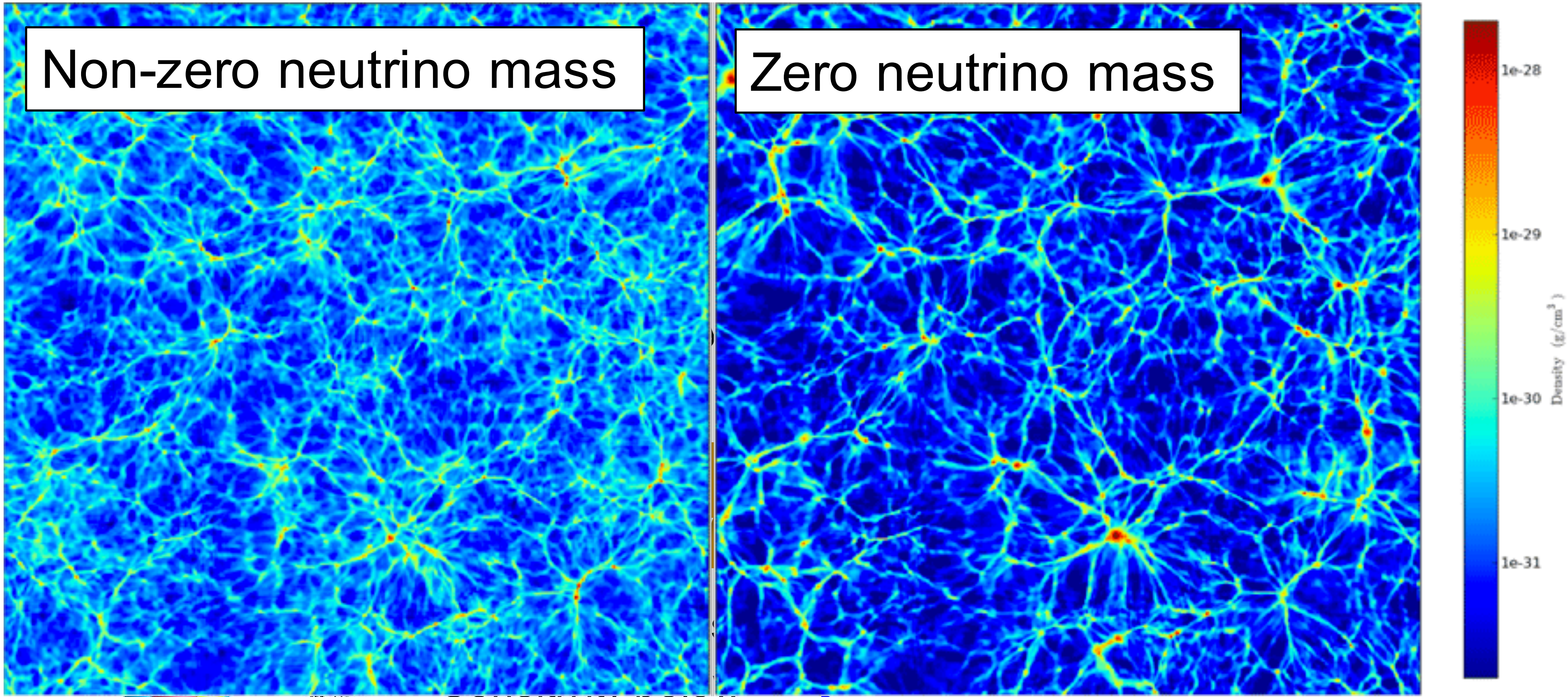


- Sum of ν Masses
- Sensitivity below "oscillation limit" in ~5 years.

Probe Σm_ν is complementary to that from particle physics.

Neutrino Mass

Probes to sub-eV Neutrino Mass

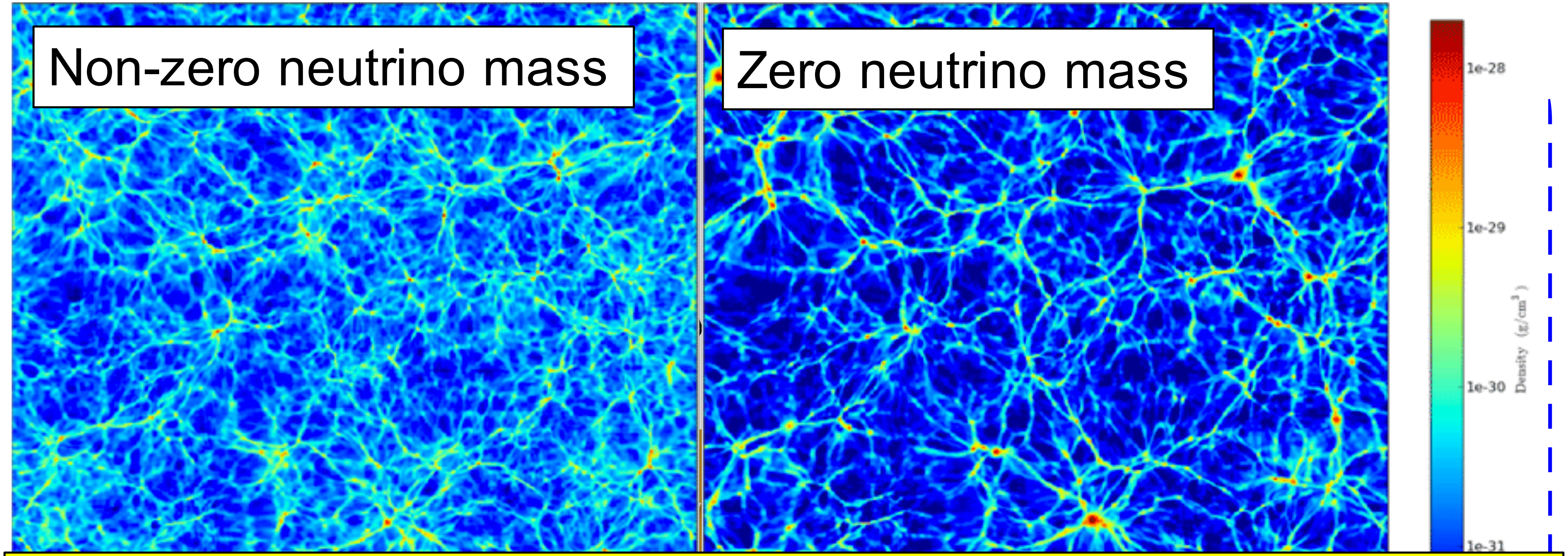


100 meV in 5 years
(KamLAND…)

Probe Σm_ν is complementary to that from particle physics.

Neutrino Mass

Probes to sub-eV Neutrino Mass

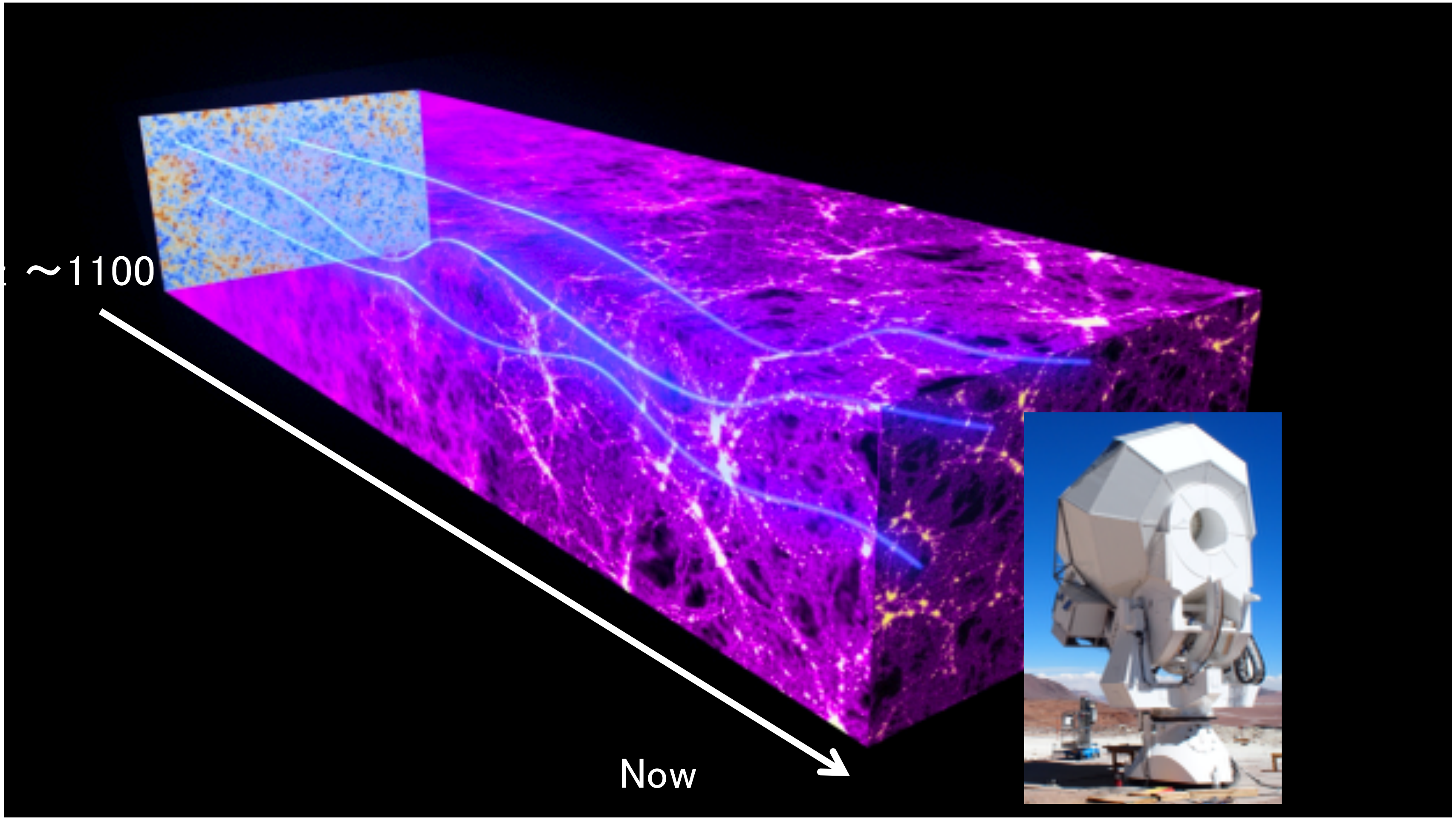


Signature of "finite neutrino mass" is decreasing of matter density.

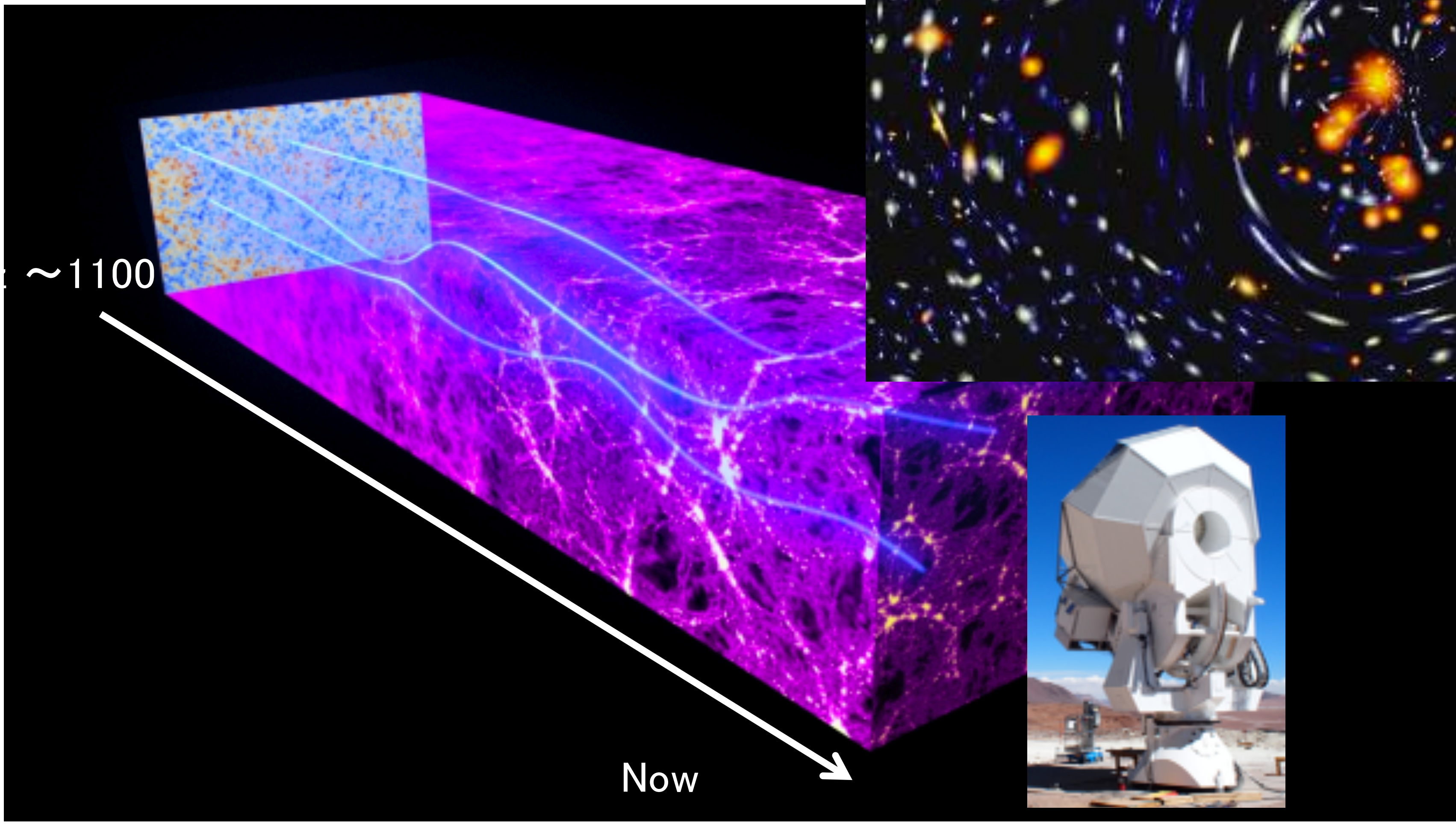
(KamLAND...)

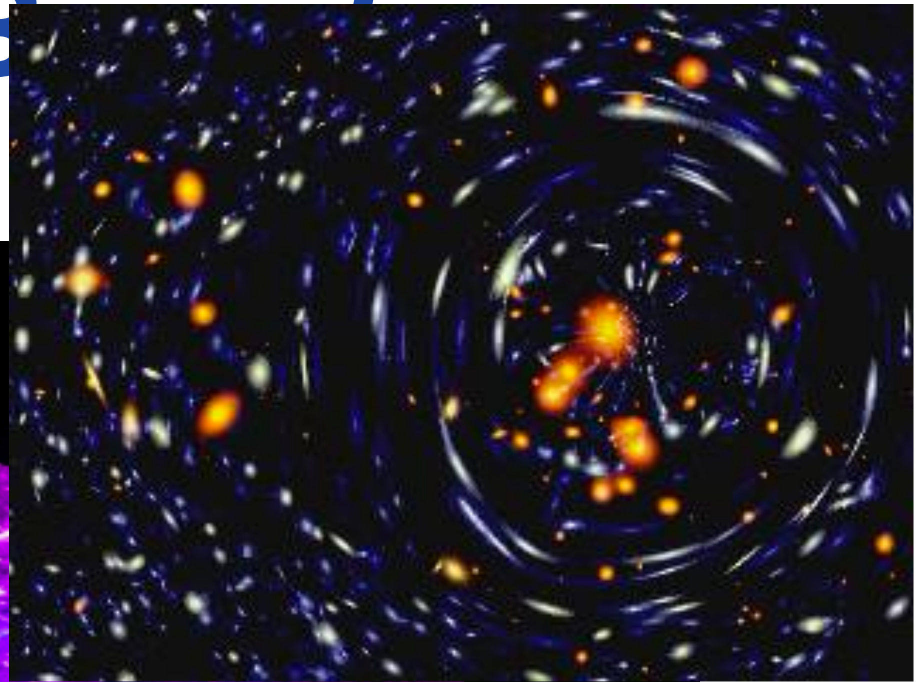
from particle physics.

Lensing B-mode

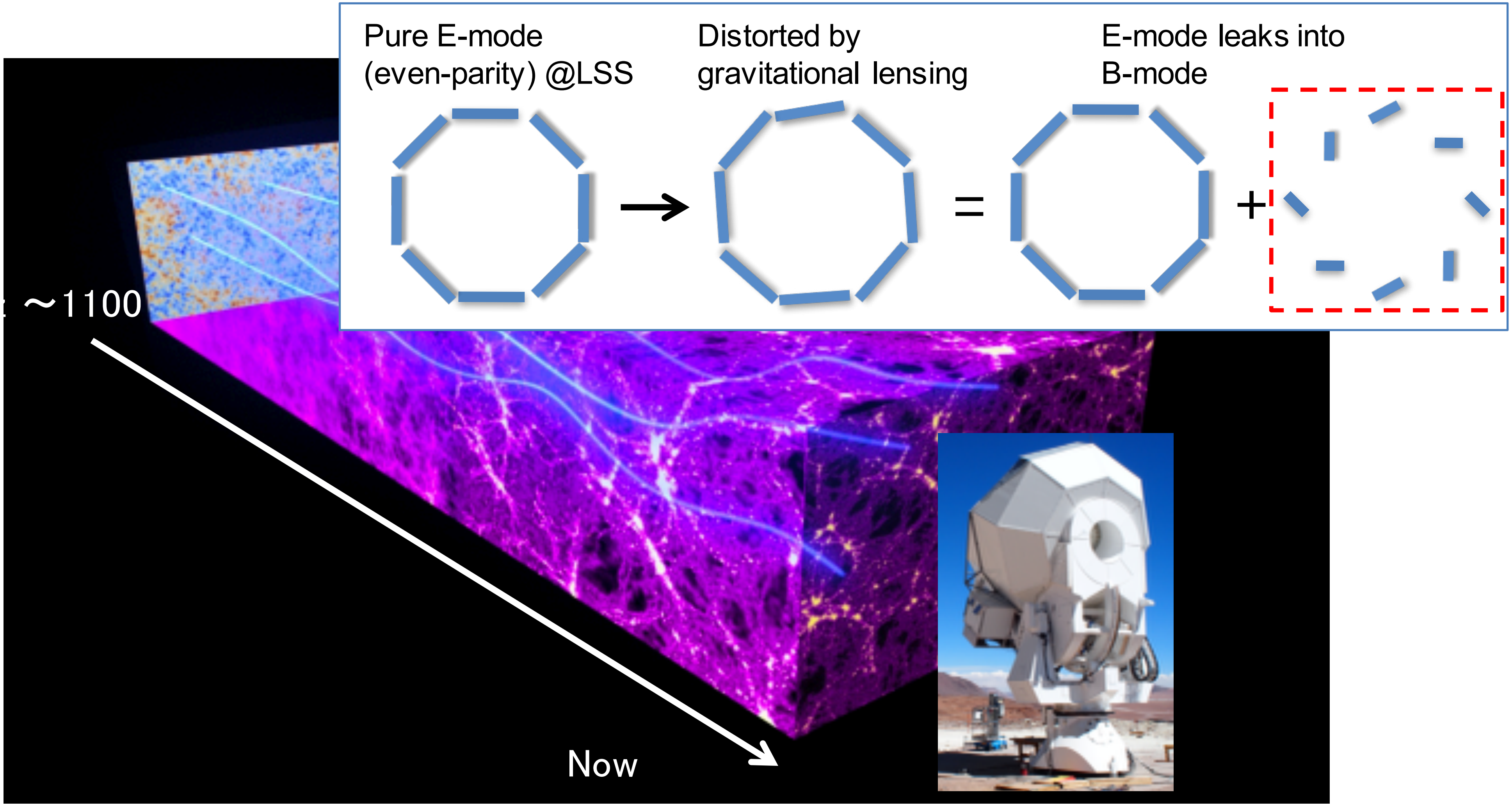


Lensing B

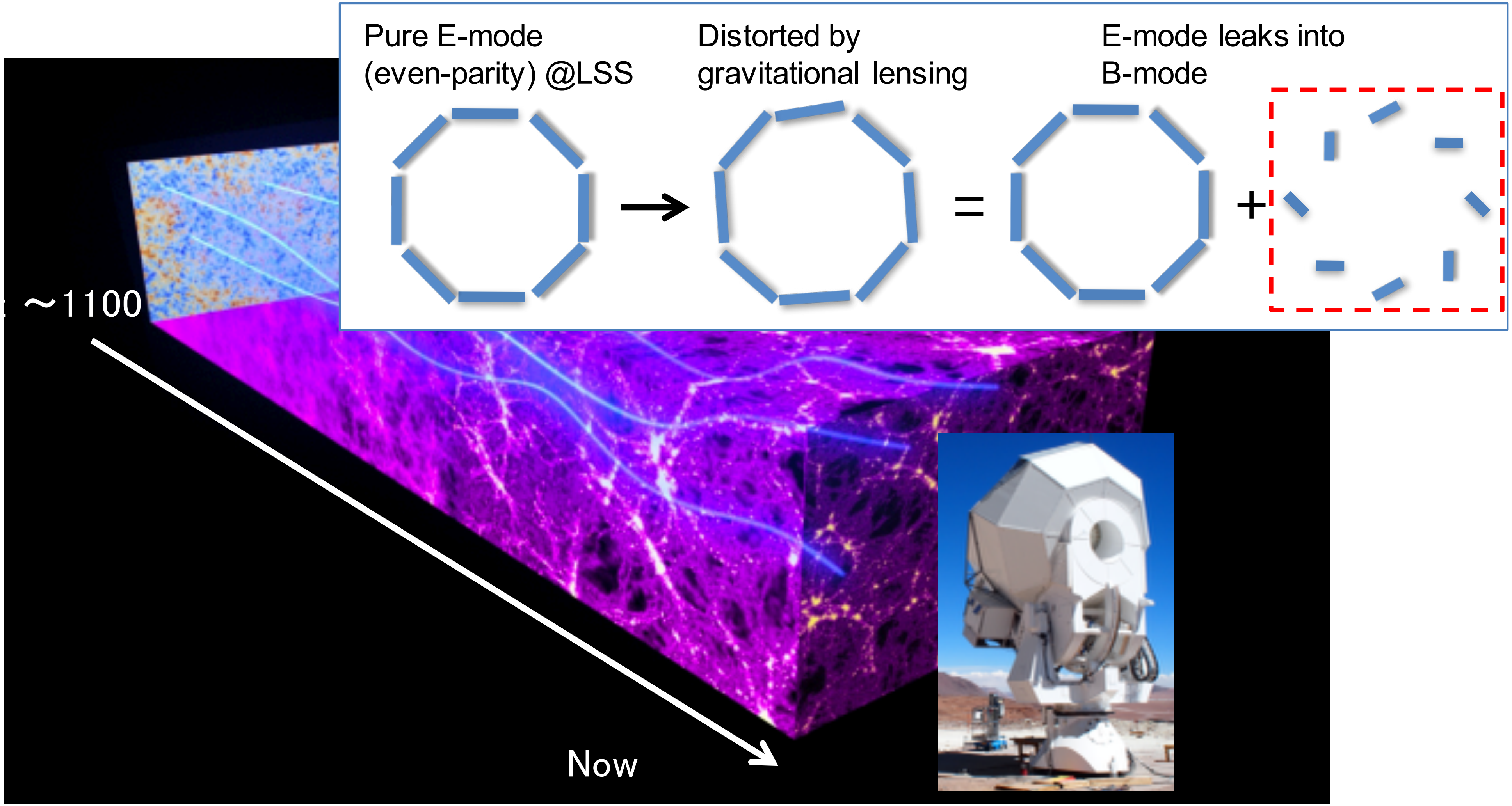




Lensing B-mode

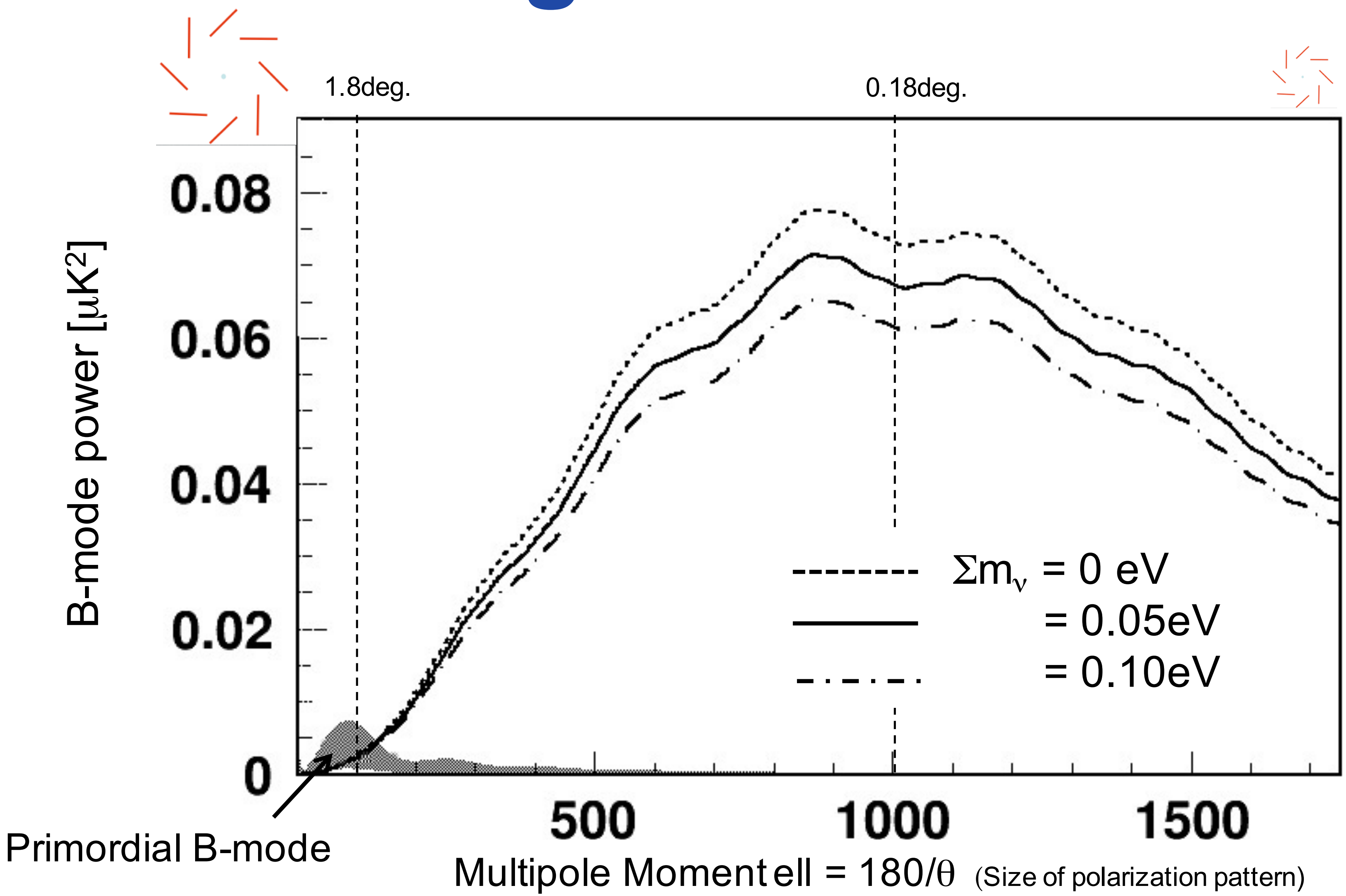


Lensing B-mode

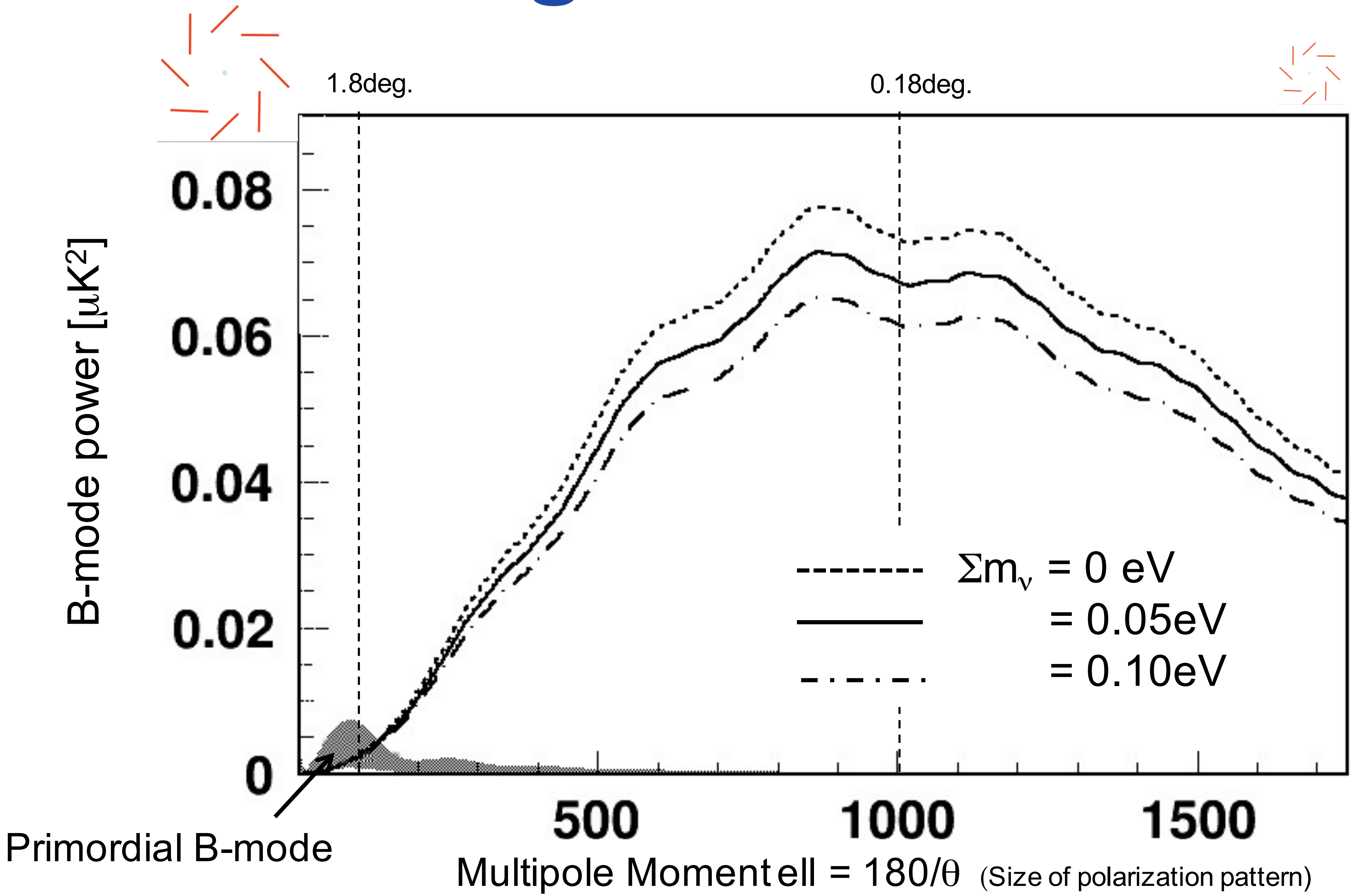


B-mode is the signature of lensing, and good tracer of LSS.

Lensing B-mode Power

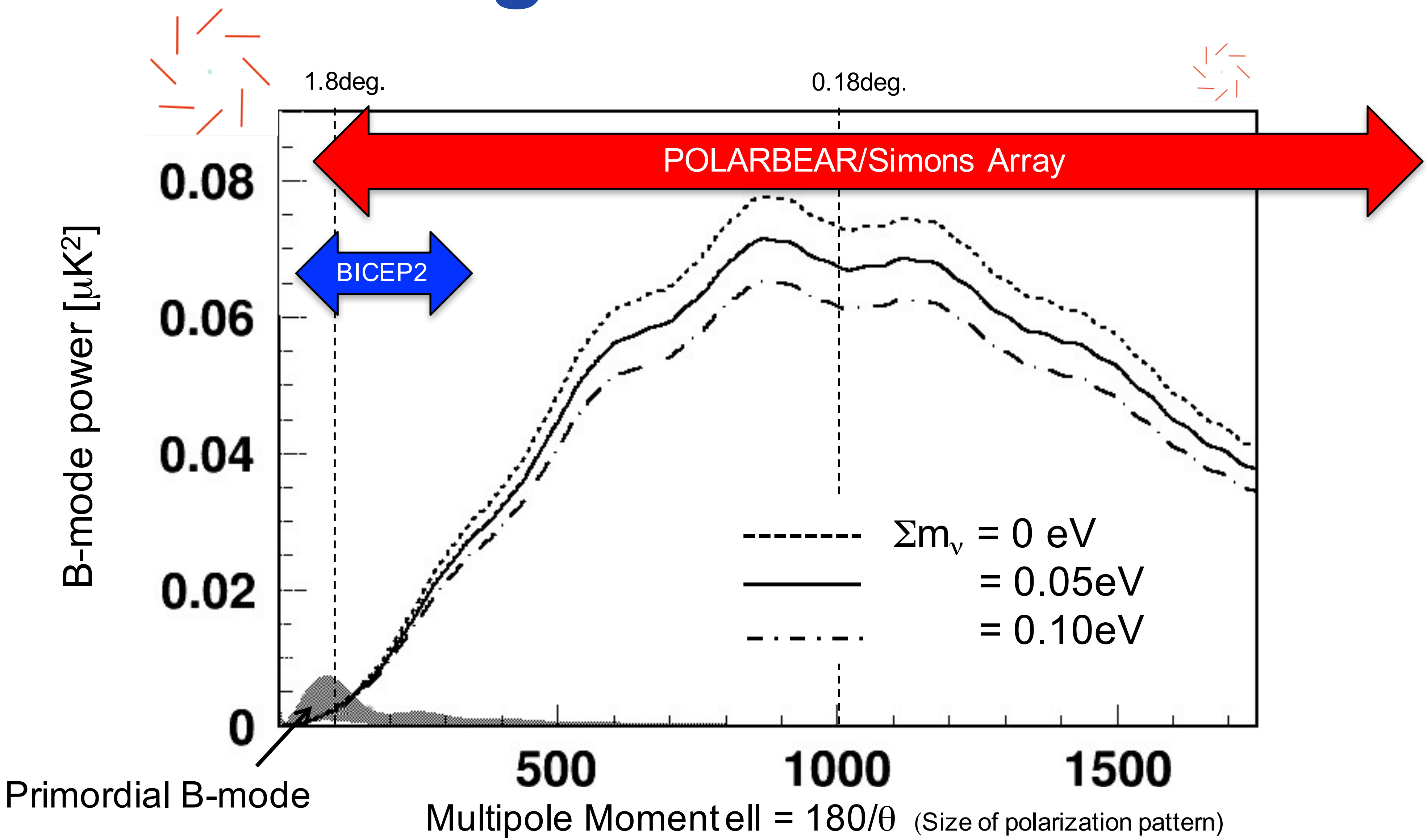


Lensing B-mode Power



The lensing B-mode amplitude is sensitive to Σm_ν.

Lensing B-mode Power

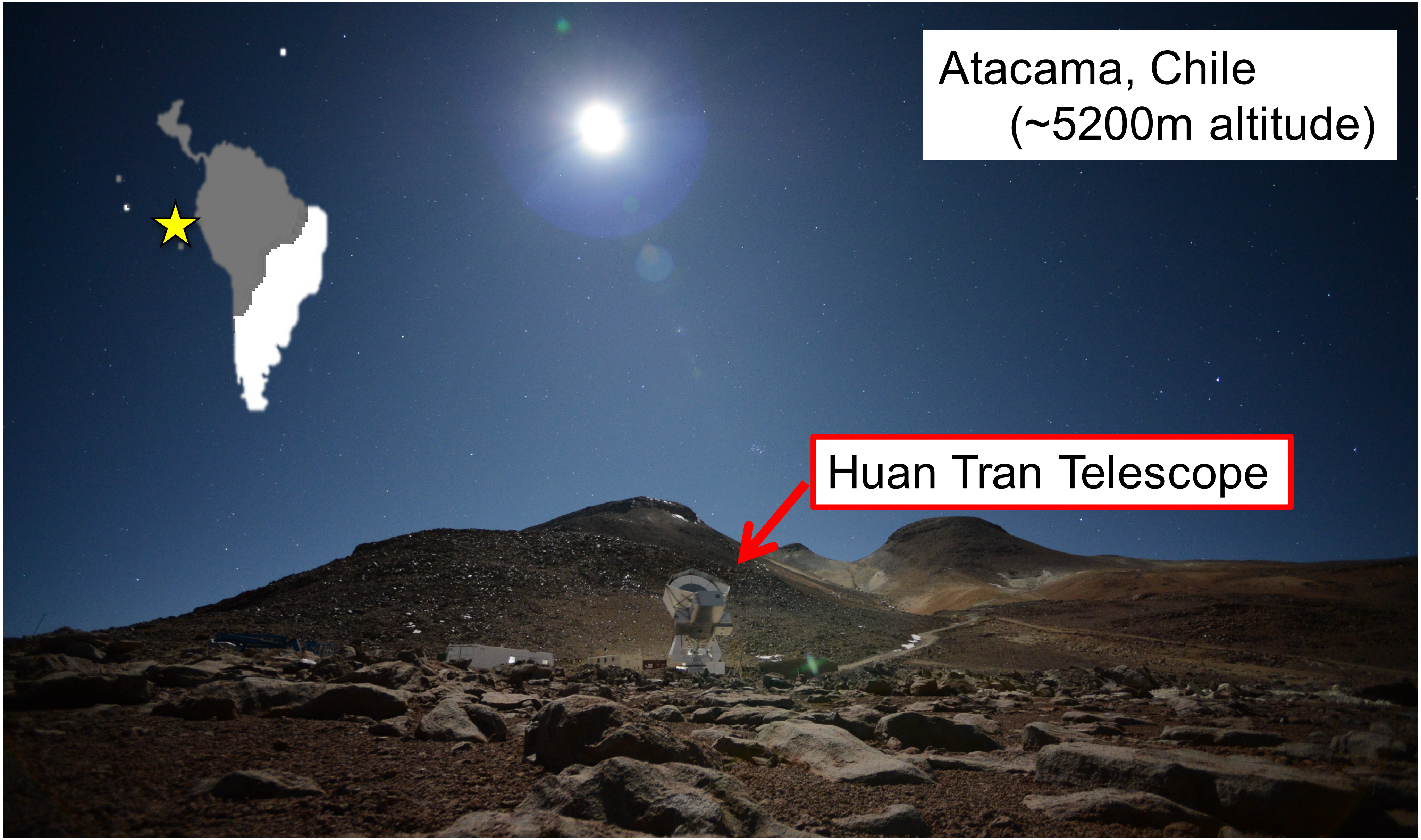


The lensing B-mode amplitude is sensitive to Σm_ν.

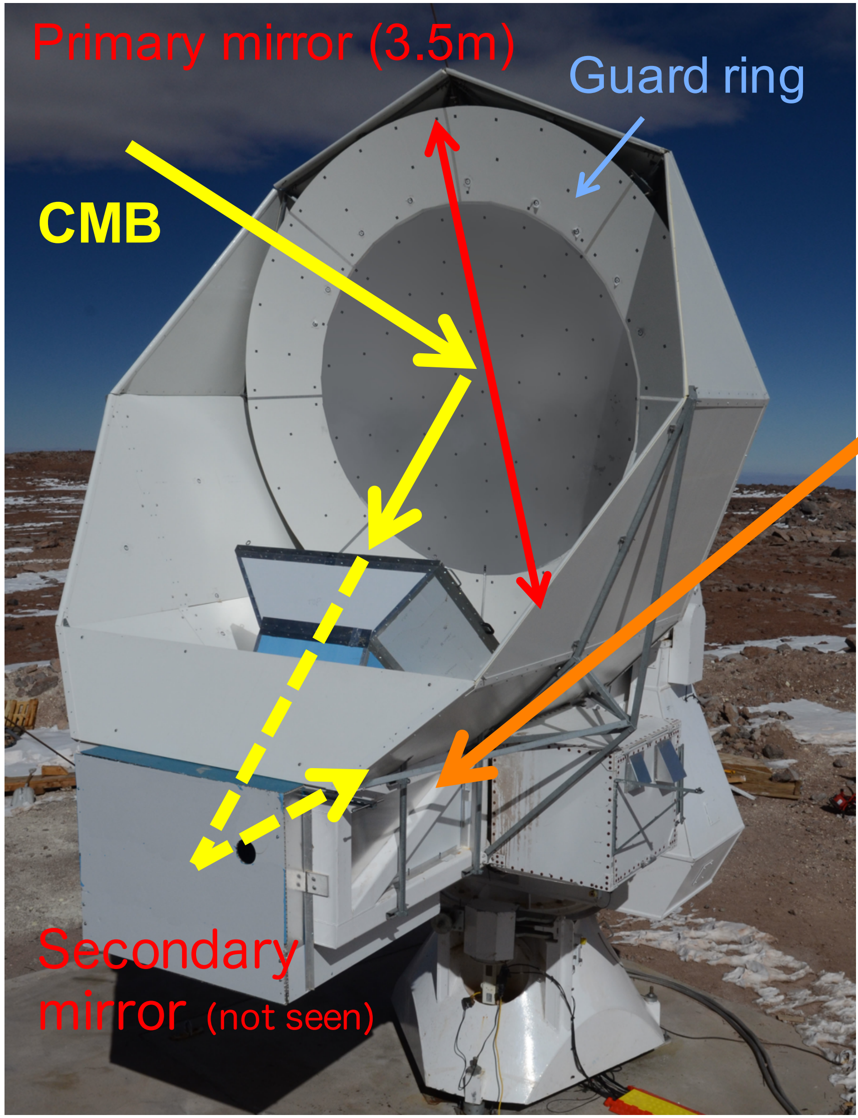
Outline

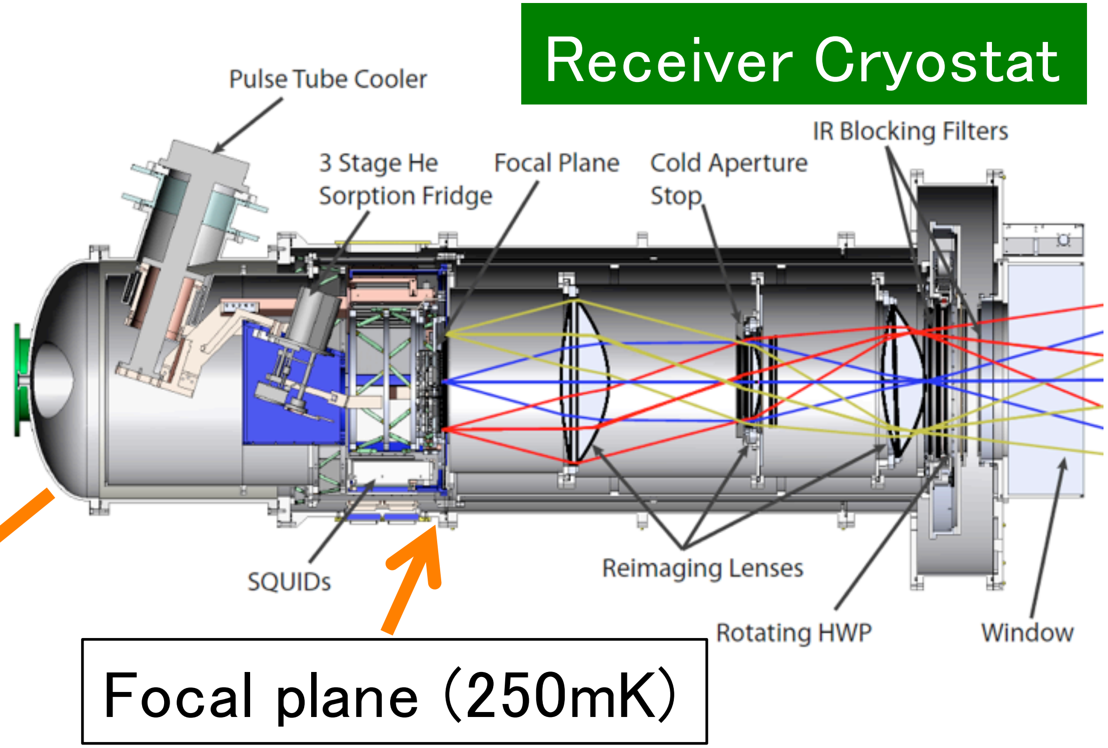
- Introduction
  - CMB polarization and its science
- POLARBEAR (main project)
- Summary

POLARBEAR Site



Huan Tran Telescope (HTT)

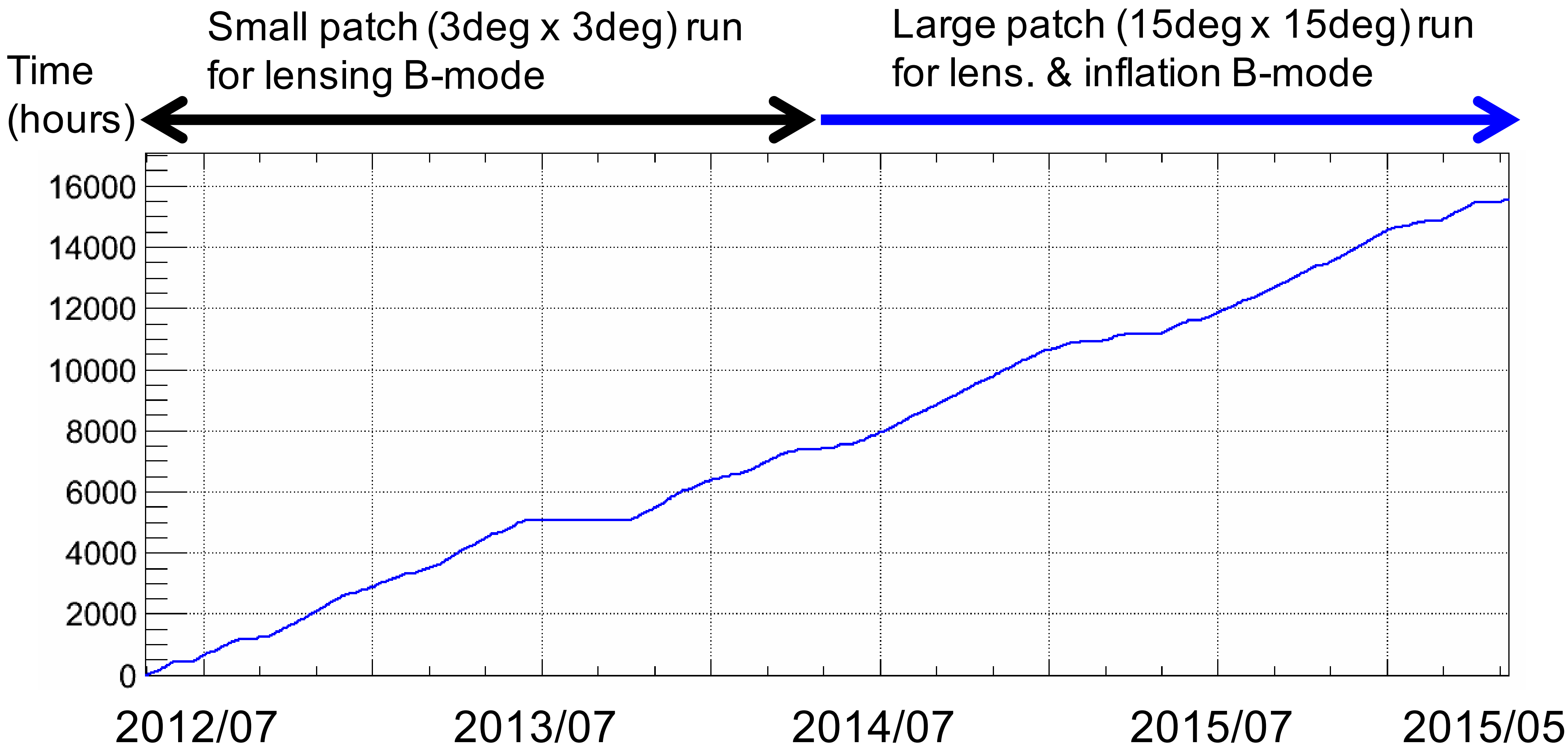




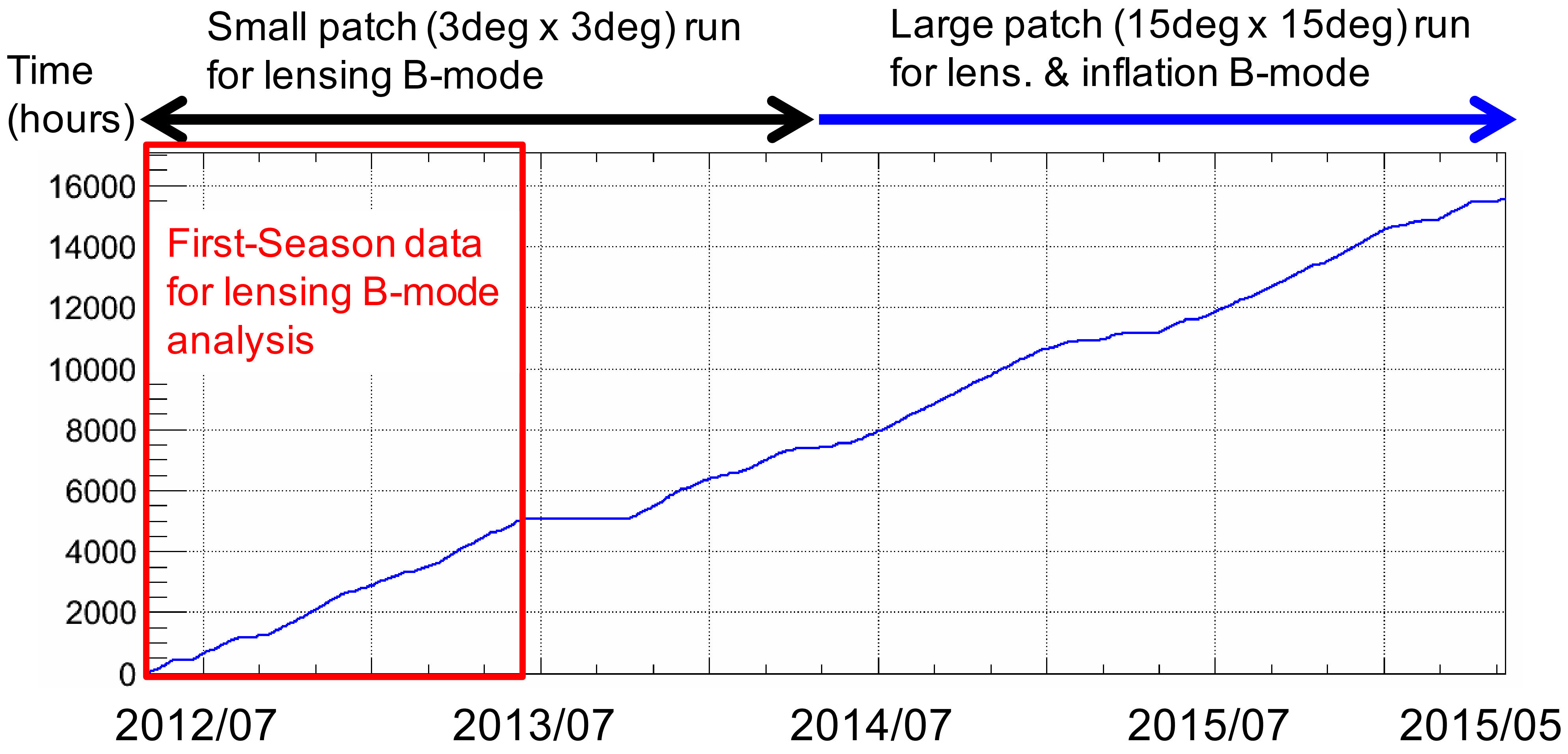
- Off-axis Gregorian-Dragone
- 2.5m primary precision machined mirror → FWHM = 3.5' achieved

Good enough angular resolution to measure the lensing B-mode signal

Observation



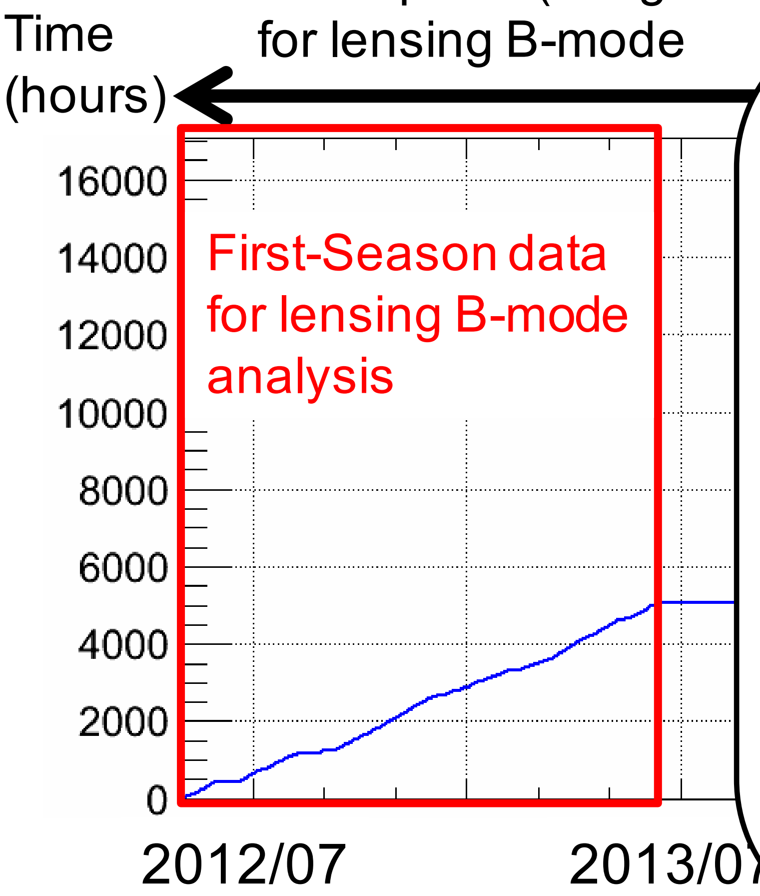
Observation



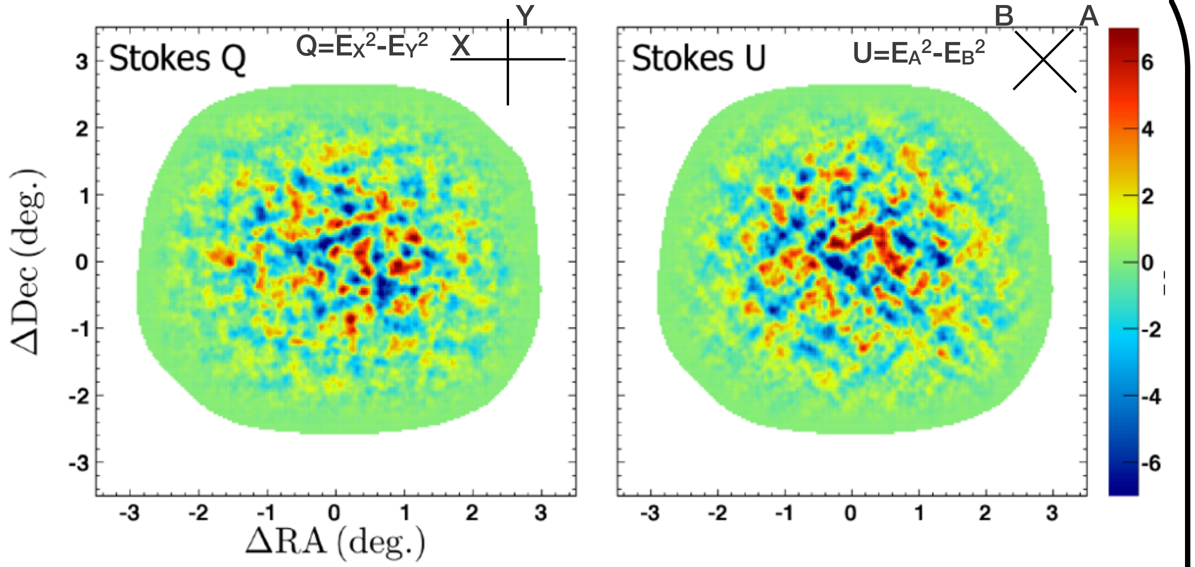
Observation

Small patch (3deg x 3deg) run
for lensing B-mode

Large patch (15deg x 15deg) run



First season polarization data



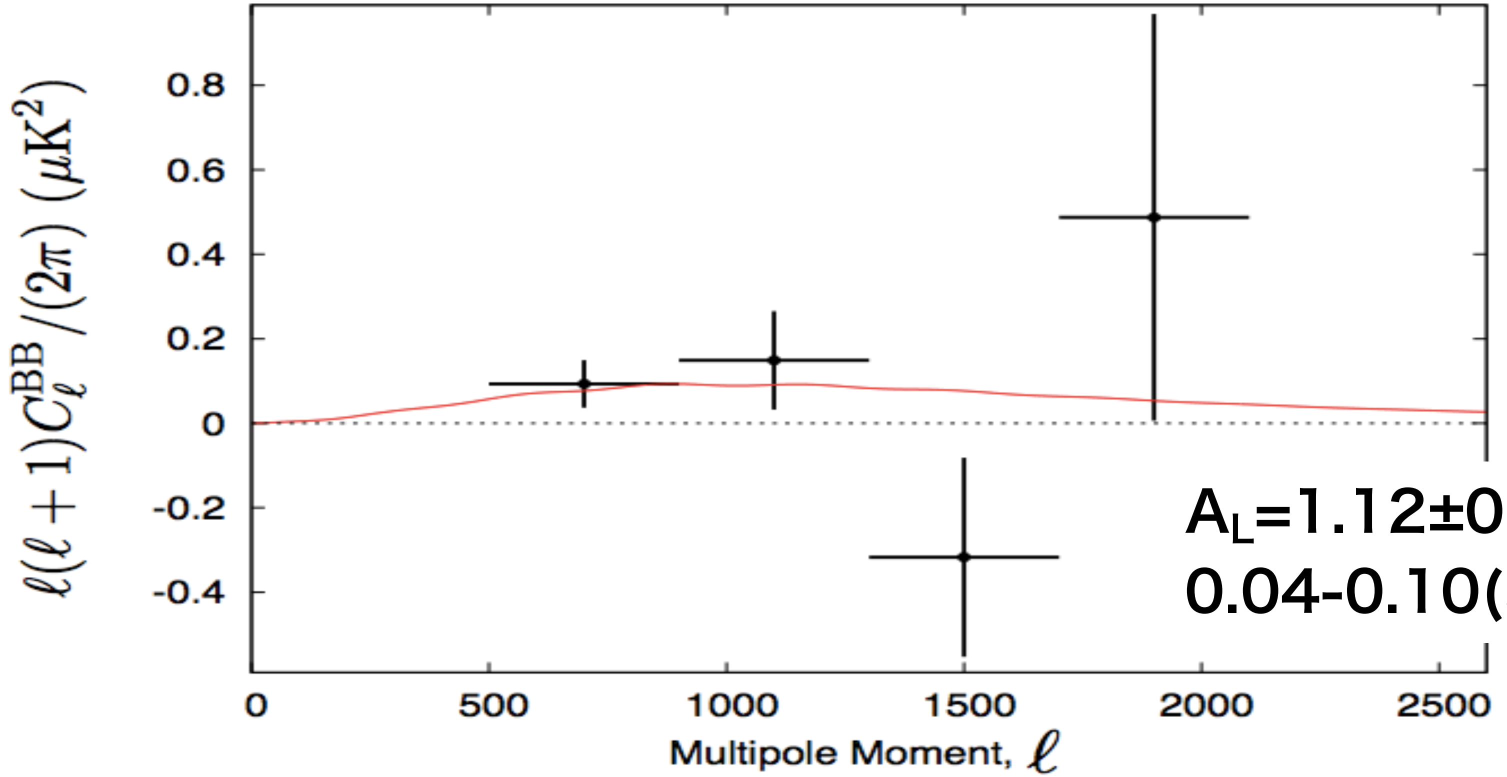
- Three fields, 24.5 deg^2 total sky area
- Map depth : 5.5 μK-arcmin

The cosmological polarized signal is visible in the map domain.

Observation

BB Power Spectrum

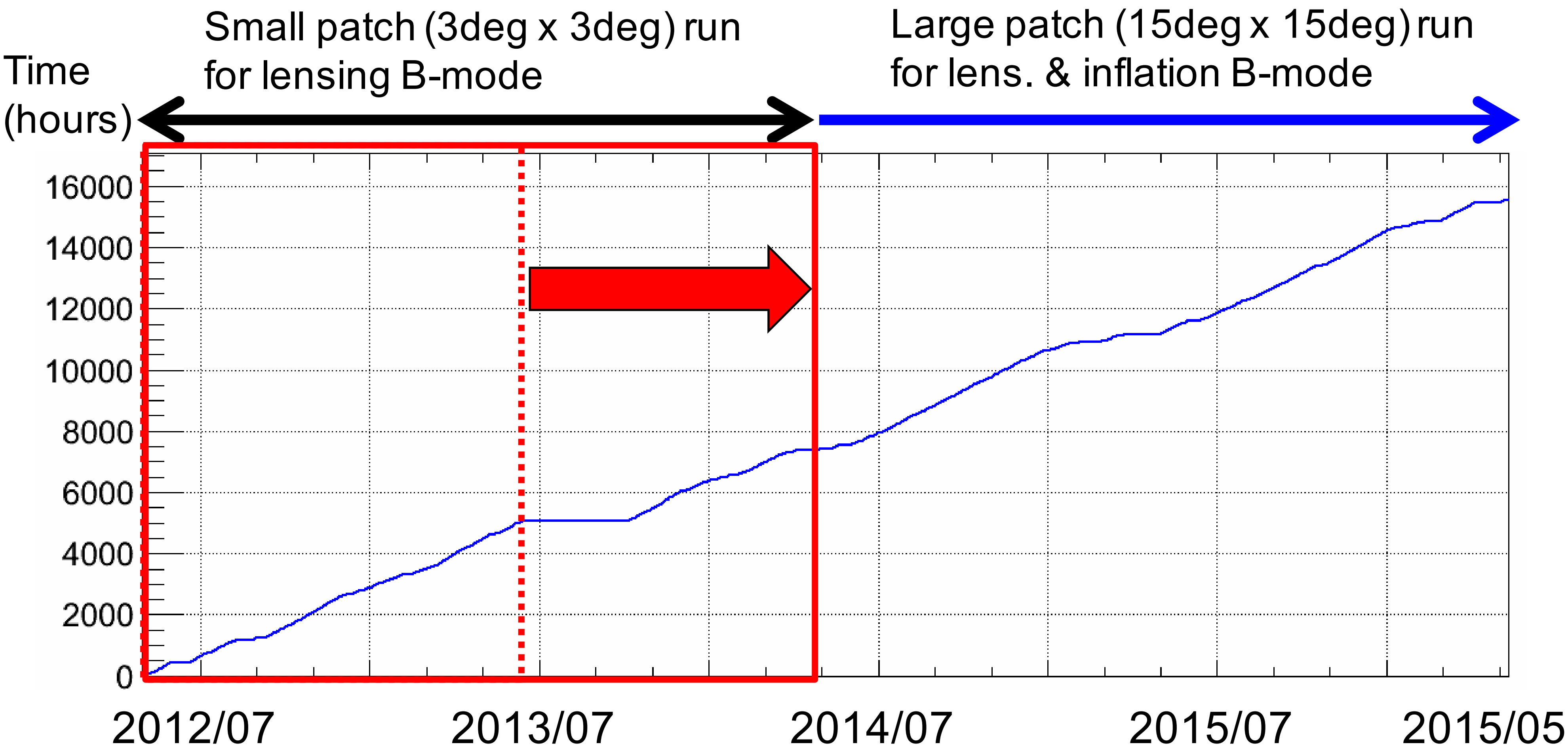
Astrophys. J. 794, 171 (2014)



A_L=1.12±0.61(stat.)+0.04-0.10(sys.)

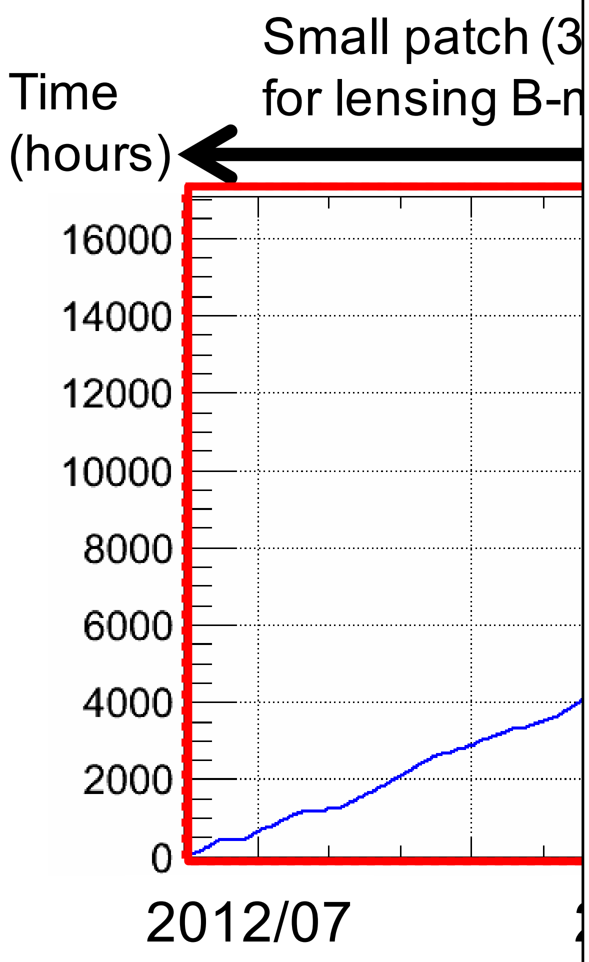
- First measurement of lensing-B mode spectrum.
  - 97.2% rejection of “no lensing B-mode”
  - Amplitude is consistent with ΛCDM expectation

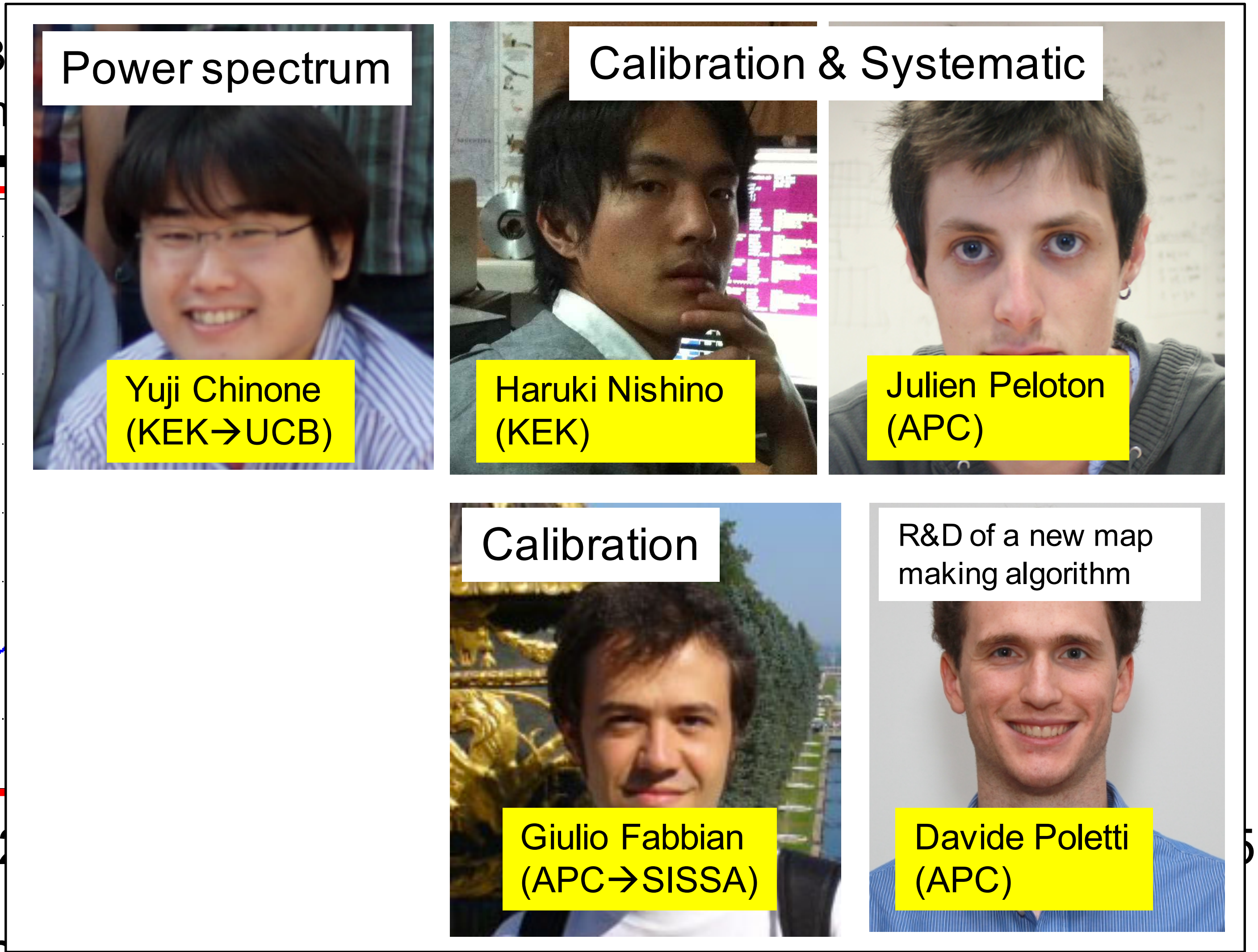
Observation



- 2nd year data analysis is on-going for tighter constraints on lensing B-mode power. (France-Japan young members lead the analysis.)

Observation



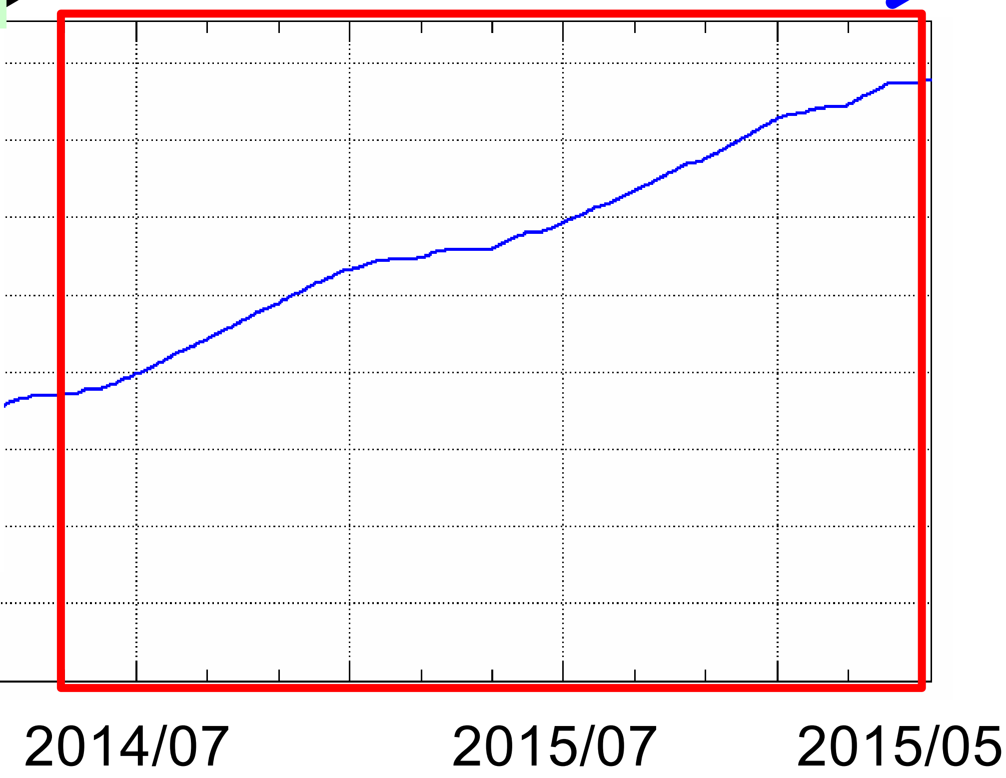


- 2nd year data analysis is on-going for tighter constraints on lensing B-mode power. (France-Japan young members lead the analysis.)

Observation

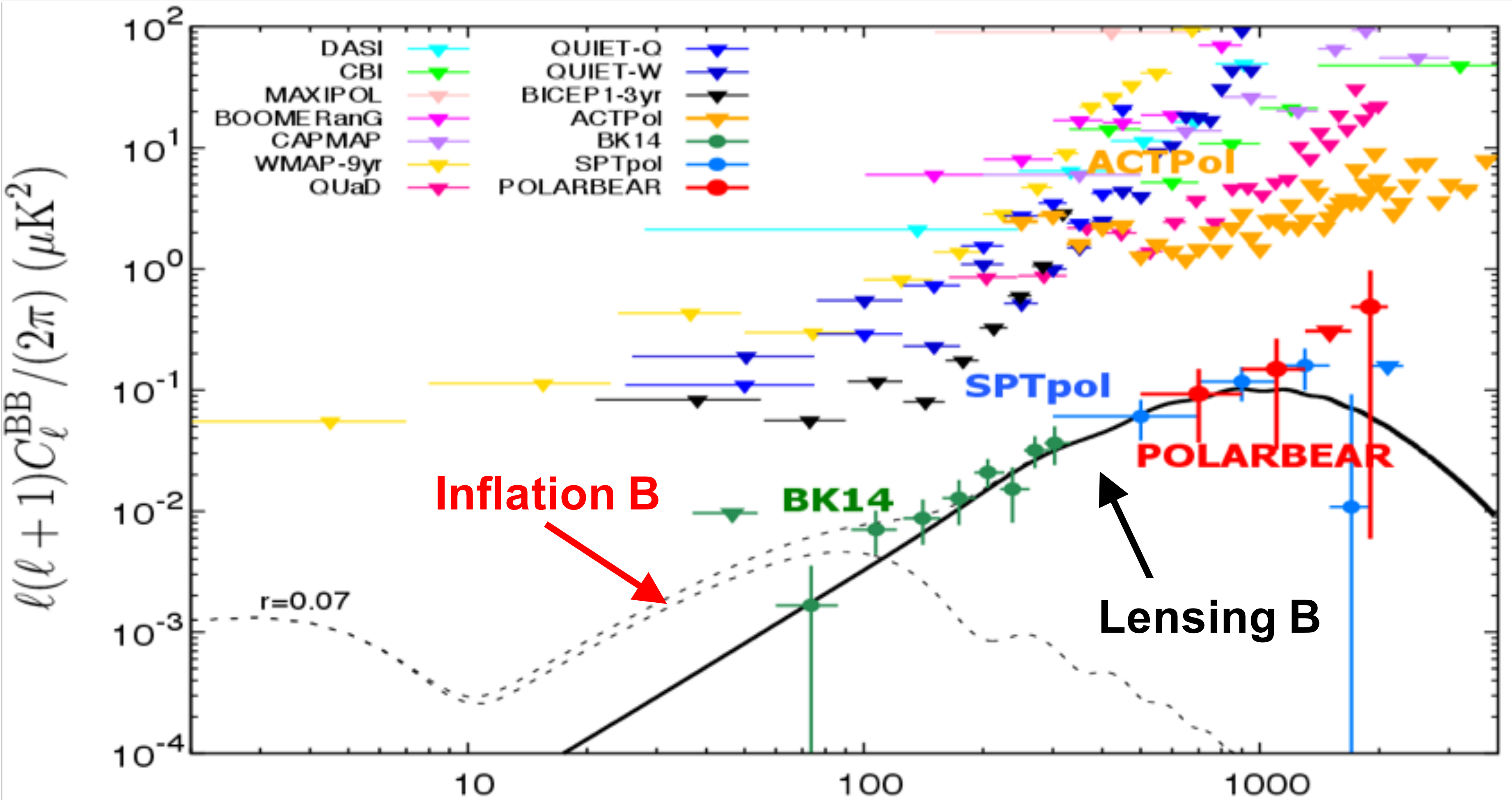
Cowboy of Chile

Large patch (15deg x 15deg) run
for lens. & inflation B-mode



- Large patch analysis is also in progress.
- Satoru Takakura and other 'astro2' members are working on
  - analysis pipeline for large patch data.

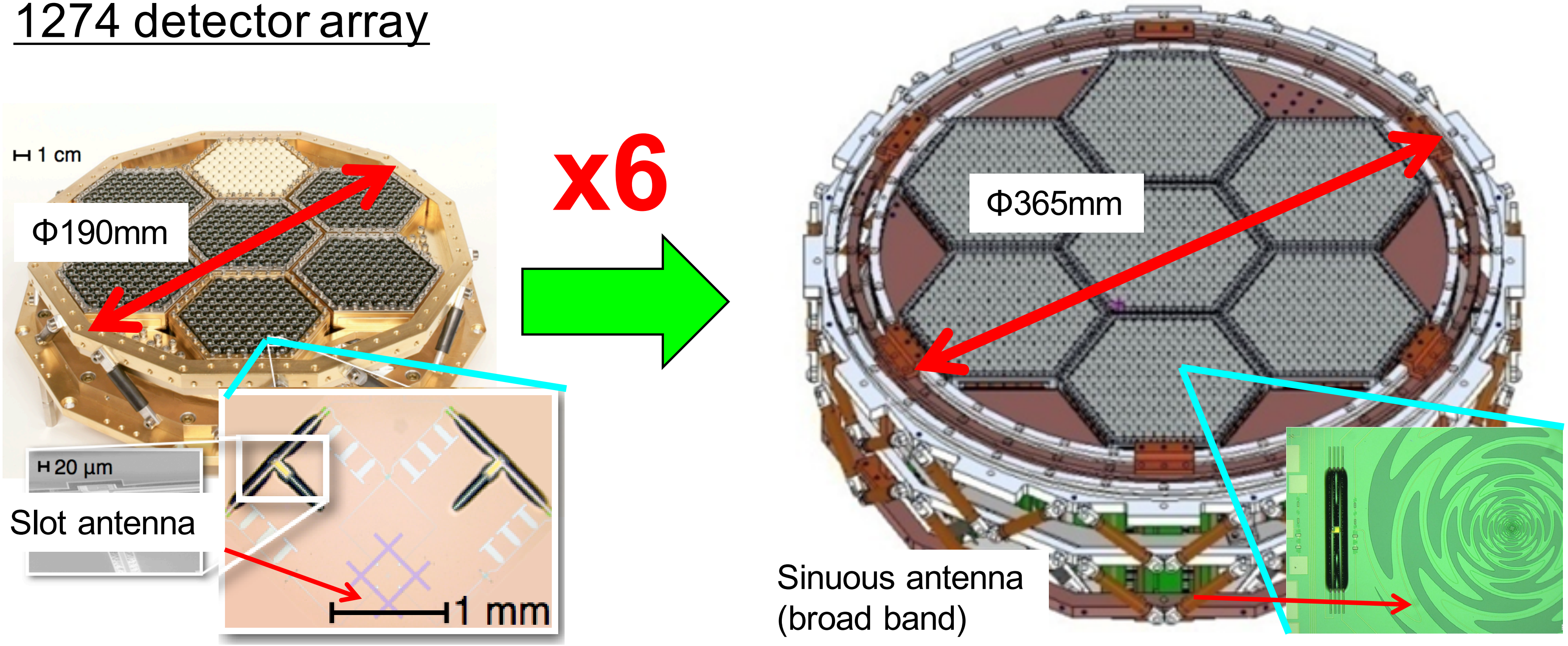
Experimental status



- Lensing B-mode has been detected by a several groups (1st detection was made by PB).
- No clear evidence is found for inflation B-mode.

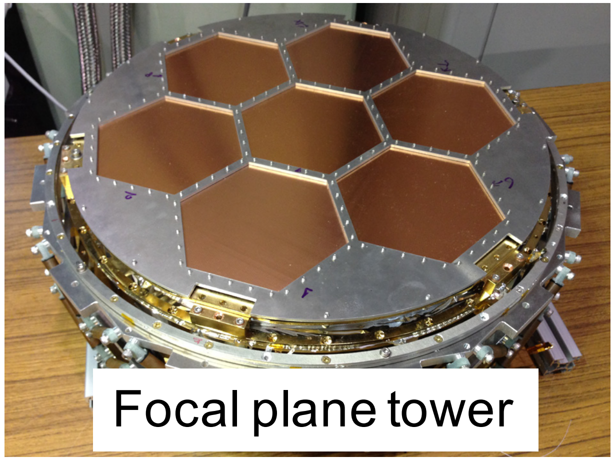
Next: POLARBEAR-2

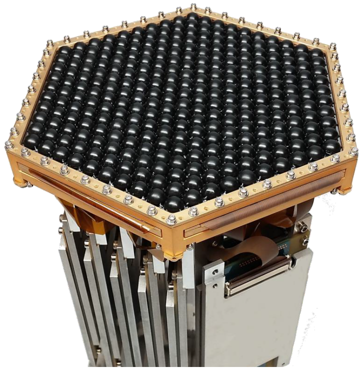
POLARBEAR-1
1274 detector array

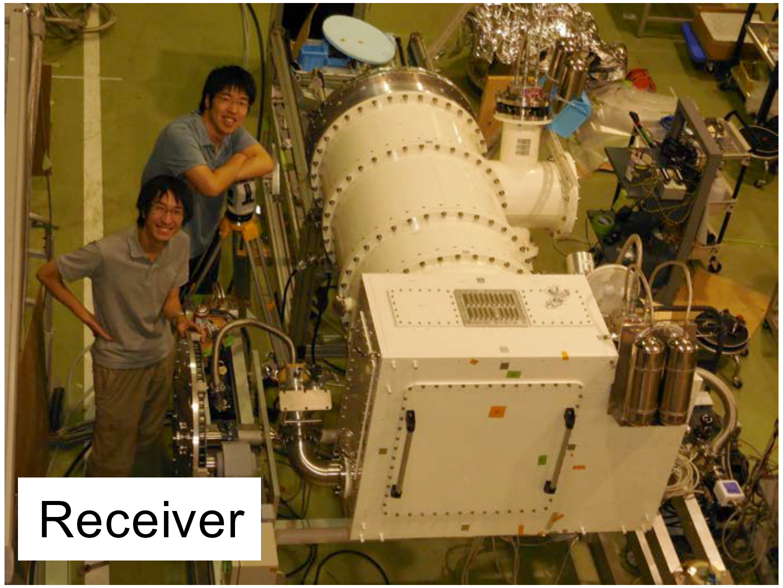


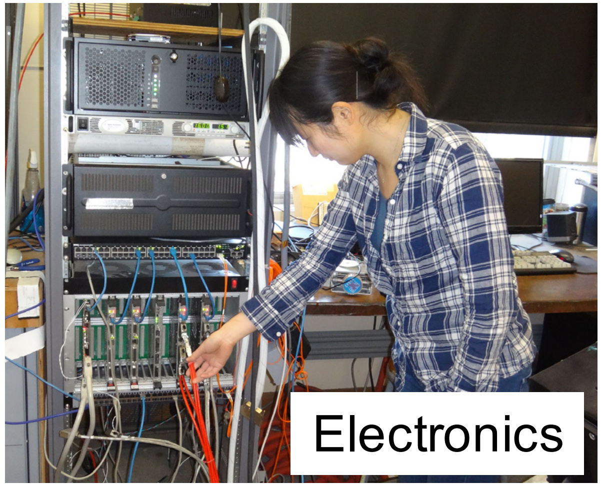
- Larger focal plane (Φ365)
    - 7588 TES bolometers (~6x increase in mapping speed)
- Multi-chroic pixels with 95/150GHz frequency coverage.

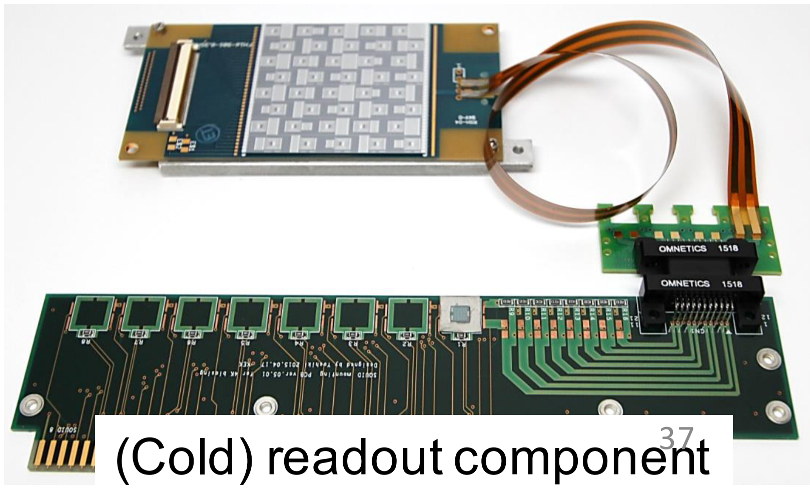
PB2 receiver assembly at KEK


Focal plane tower


Detector module


Receiver


Electronics

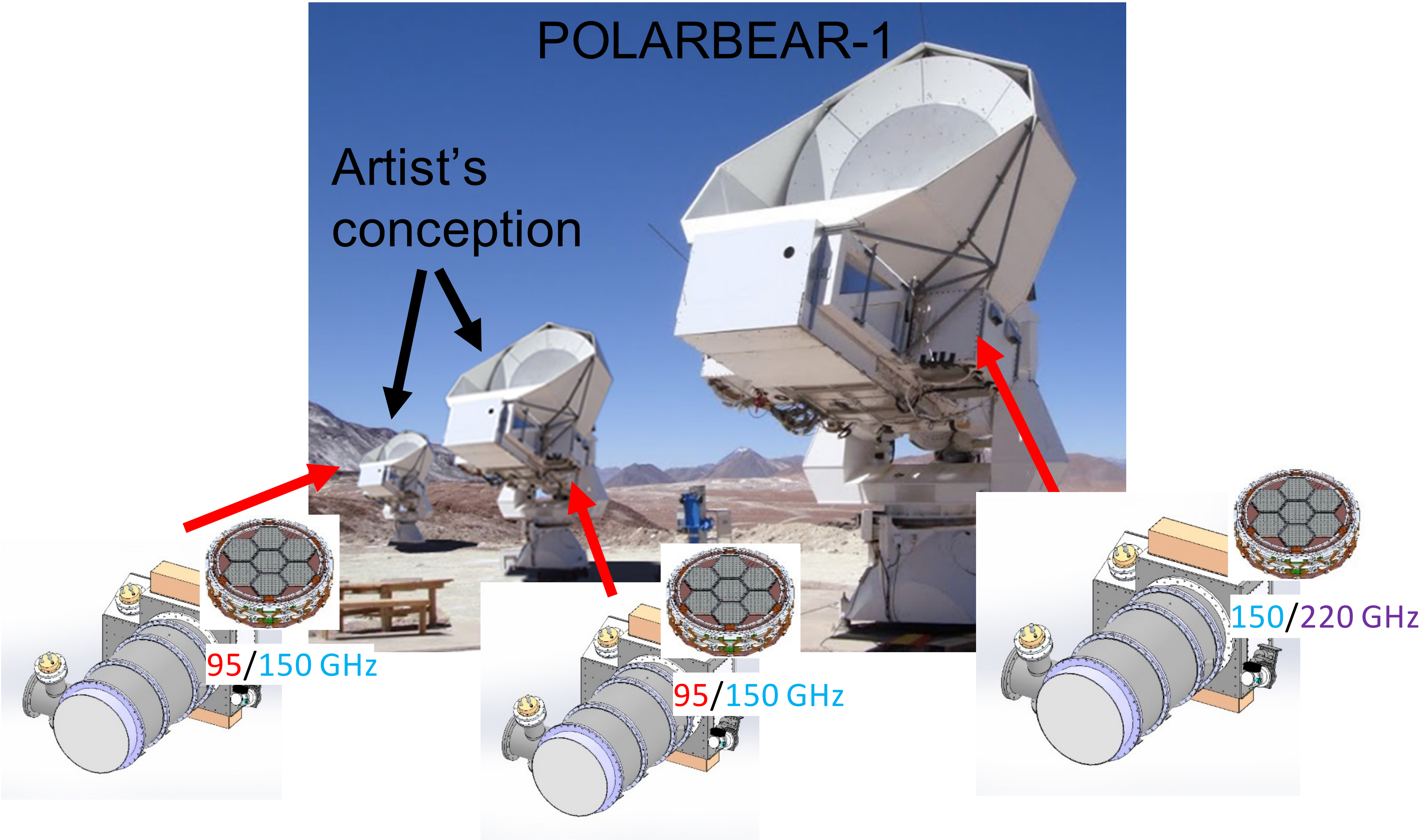

(Cold) readout component

Lab. testing with full equipment will be started soon.

Receiver will be deployed in 2016.

The Simons Array

Expanding POLARBEAR to three multi-chroic telescopes



Three upgraded receivers, observing at 95, 150, 220 GHz

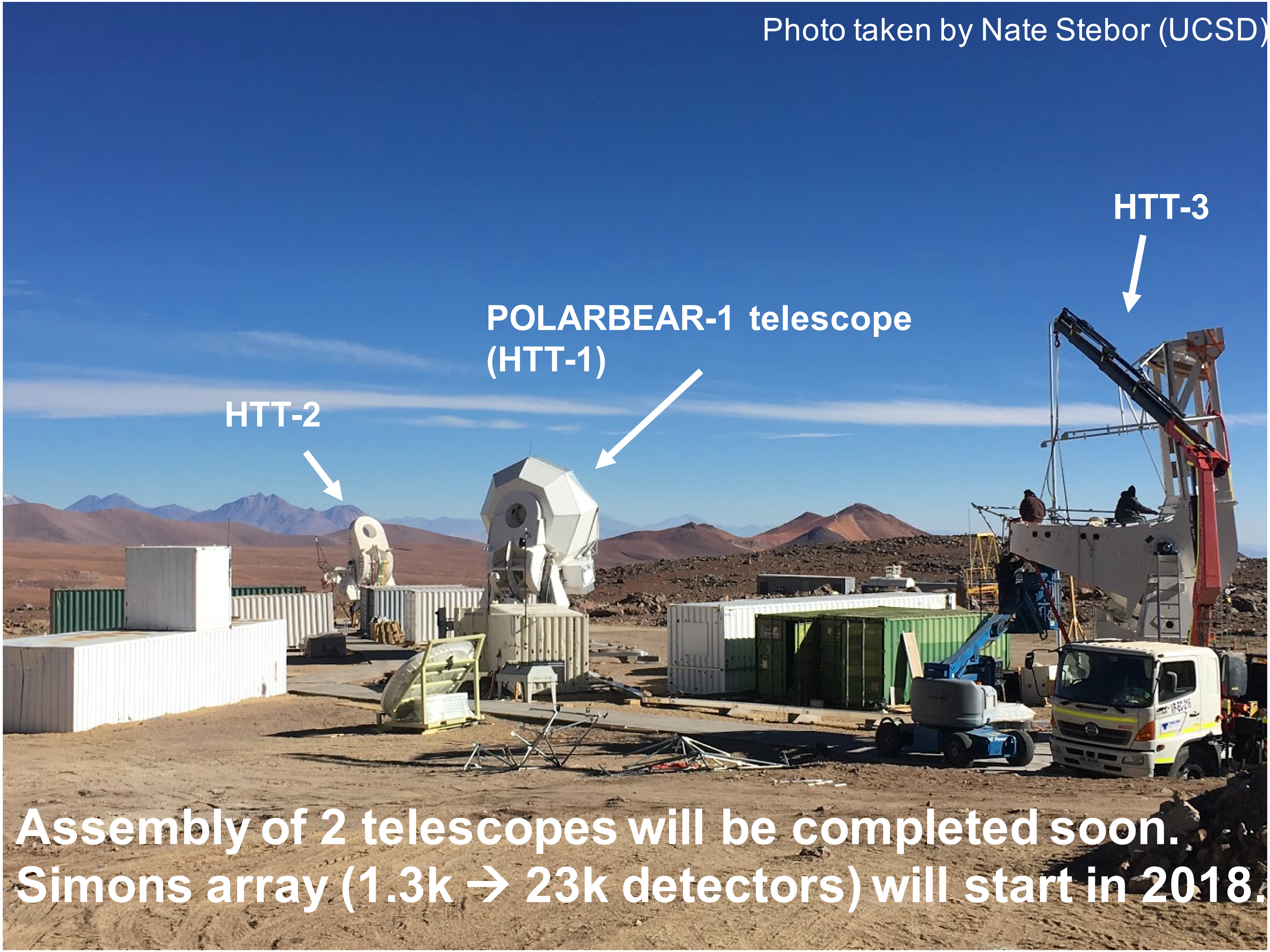
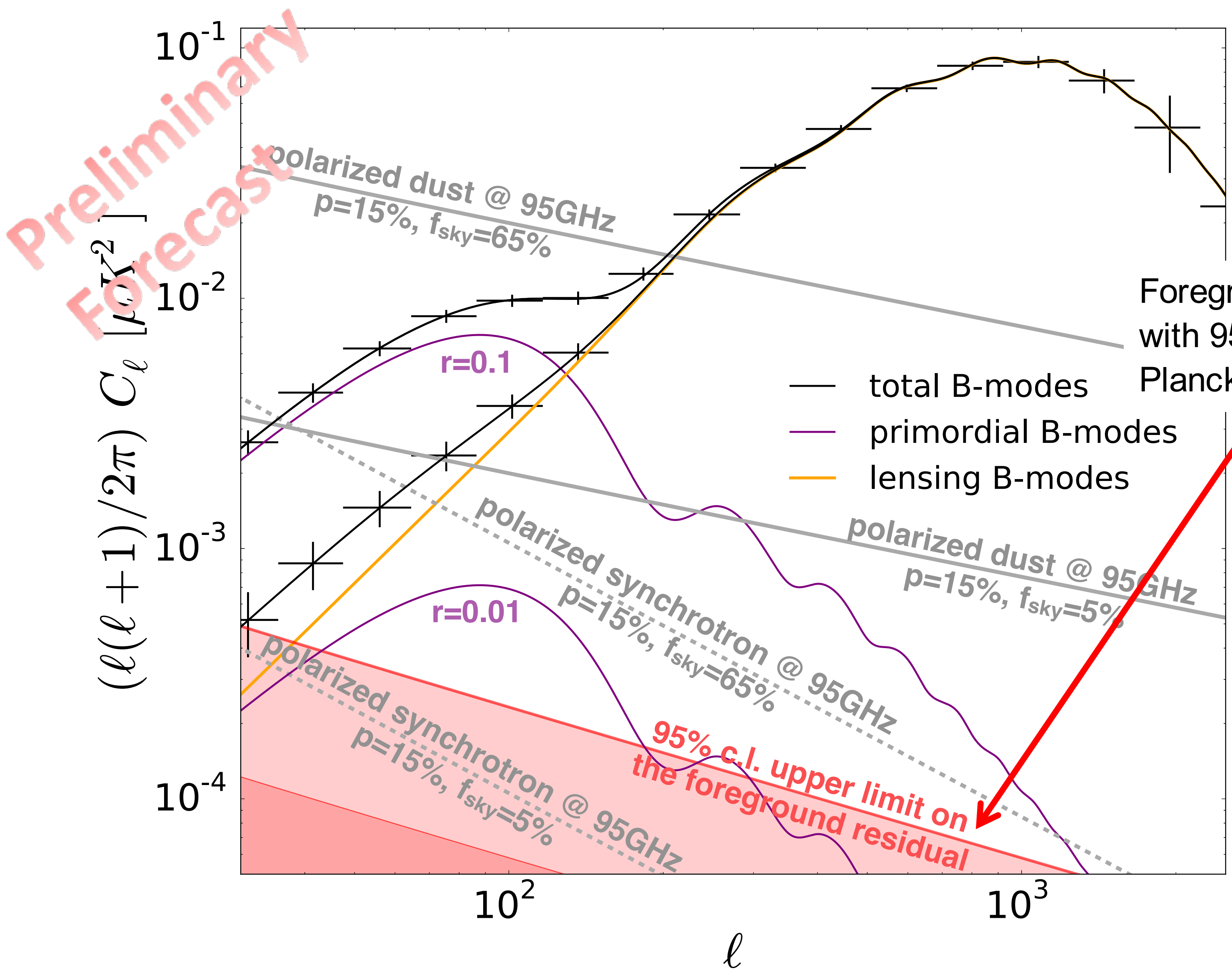


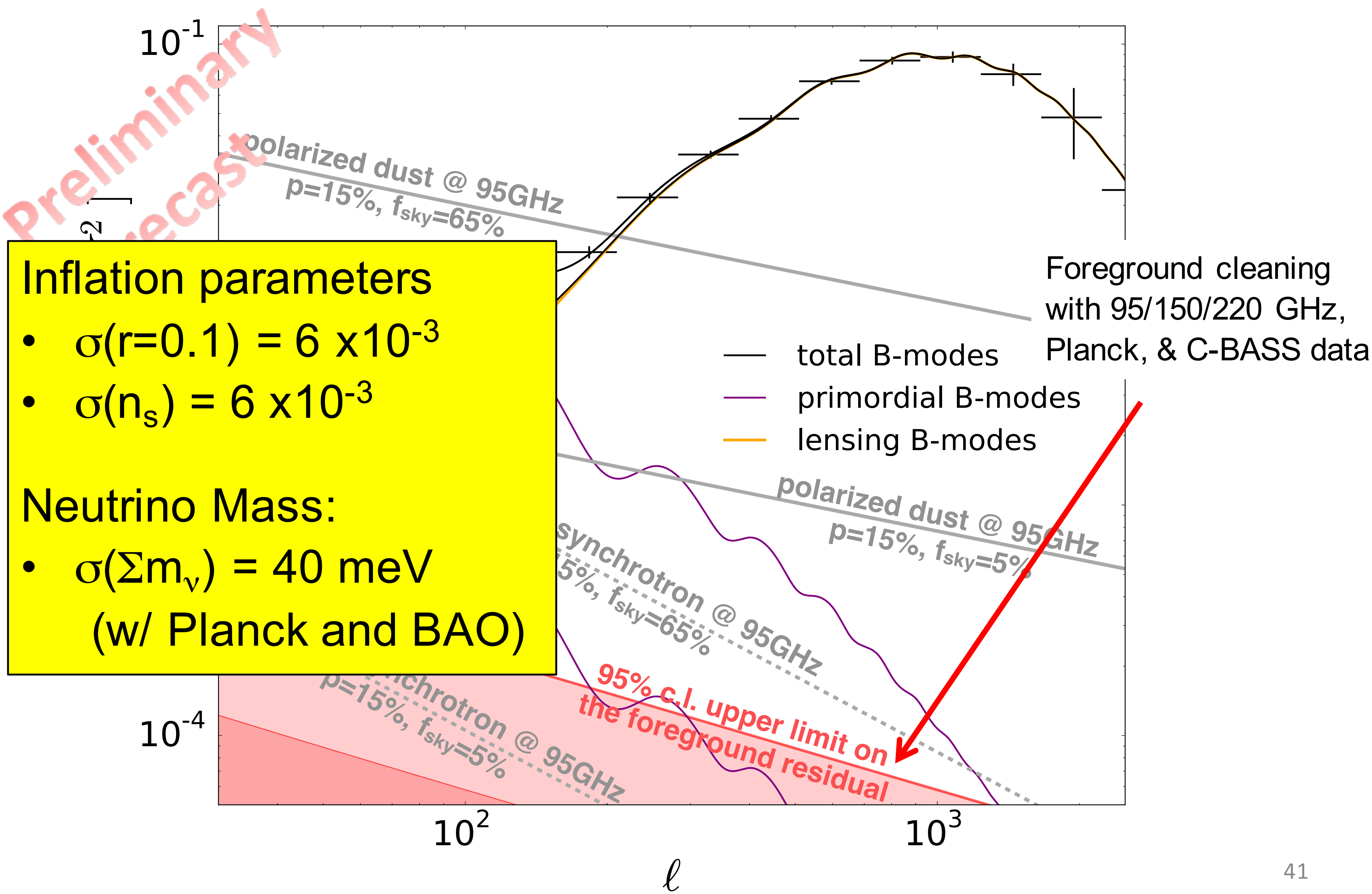
Photo taken by Nate Stebor (UCSD)
HTT-3
POLARBEAR-1 telescope
(HTT-1)
HTT-2
Assembly of 2 telescopes will be completed soon.
Simons array (1.3k → 23k detectors) will start in 2018.

Simons Array (projected) sensitivity



Foreground cleaning with 95/150/220 GHz, Planck, & C-BASS data

Simons Array (projected) sensitivity



Inflation parameters

- $\sigma(r=0.1) = 6 \times 10^{-3}$
- $\sigma(n_s) = 6 \times 10^{-3}$

Neutrino Mass:

- $\sigma(\Sigma m_\nu)$ = 40 meV
  (w/ Planck and BAO)

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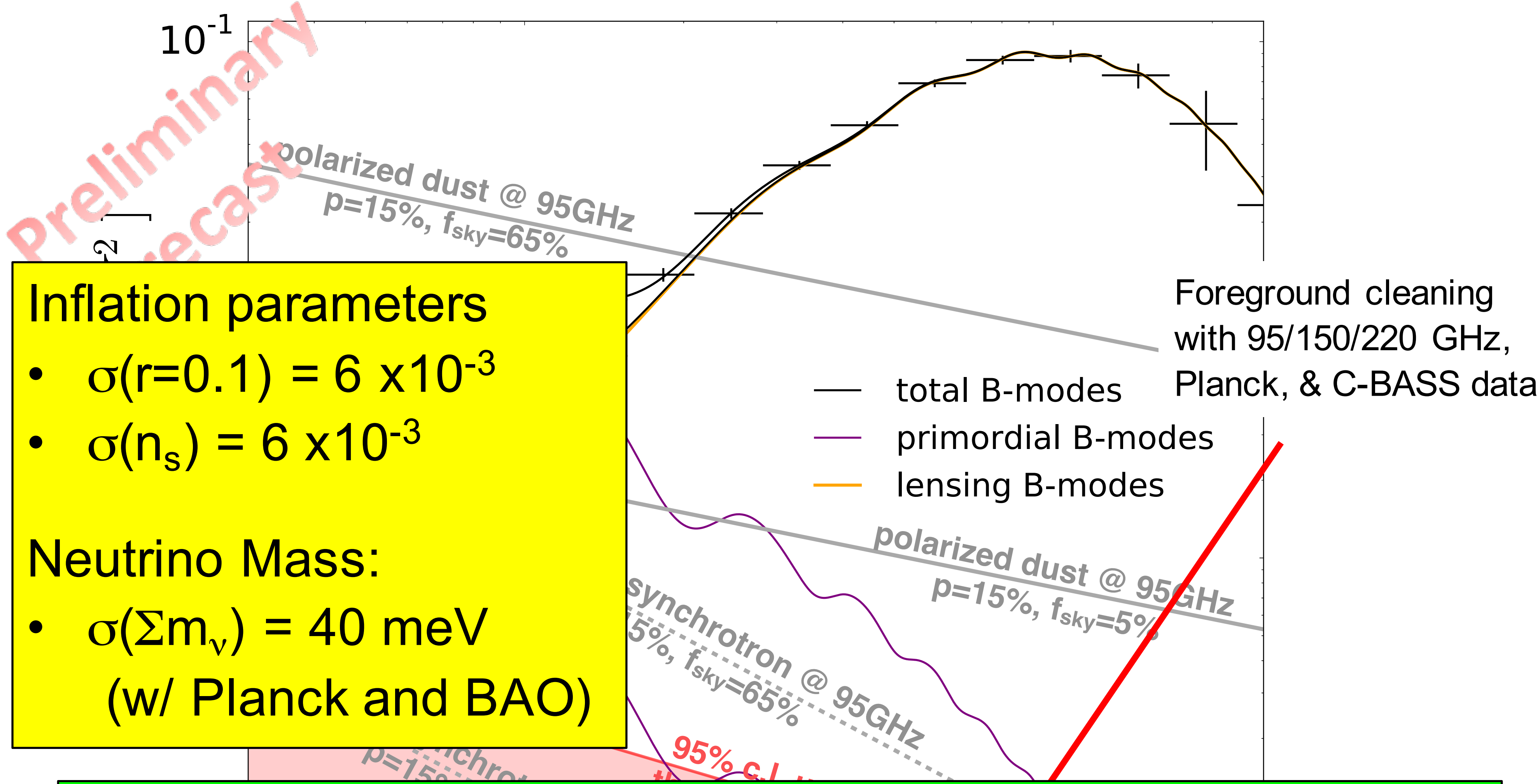

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Simons Array can contribute to cosmology and particle physics significantly.

Goals of this project 2016/2017

POLARBEAR/Simons Array

- Continue analysis of existing and forthcoming data sets
  - Finalize small patch data analysis
  - Development and implementation of techniques and methods suitable for large patch observations.

Future satellite CMB missions

- Study the impact of the systematics and foreground emission.
- Development and validation of a power spectrum estimation technique suitable for a (nearly) full-sky survey

Collaborative work in this project will get good results.

Last words

- CMB polarization measurements are at the heart of cosmology and particle physics.

- Our team are involved to POLARBEAR, Simons array, and future satellite mission.

- By 2020, the Simons Array will:
  - Constrain (or measure) inflation parameters
    - Tensor-to-scalar ratio : $\sigma(r=0.1) = 6 \times 10^{-3}$
  - Produce a map of projected gravitational potential
    - Neutrino Mass : $\sigma(\Sigma m_\nu) = 40$ meV