Cosmic inflation and Neutrino masses at POLARBEAR and Simons Array

TAUP 2017, Jul. 24, 2017
Masaya Hasegawa (KEK)
on behalf of POLARBEAR/
Simons Array collaboration
Outline

• POLARBEAR
  - Motivation: Inflation and $\nu$ masses
  - Instruments and observation
  - Recent results

• Status and Prospects
  - POLARBEAR2 and Simons Array
POLARBEAR Collaboration

8 countries, 20 institutes, ~100 people

M.Hasegawa (KEK), POLARBEAR

TAUP2017, Sudbury
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!
CMB polarization

• Polarization field can be decomposed into $E$ and $B$-mode

• Typical size of polarization pattern
  ~2deg. (inflation $B$-mode)
  ~0.2deg. (lensing $B$-mode)

\[ \text{Size of polarization pattern} = \frac{180}{\theta} \]

Polarization power $\mu K^2$

![Predicted Polarization Power Spectrum](image)
Science with CMB B-mode

Inflation

Gravitational Wave

Thomson

B-mode

$10^{12} \times \text{LHC} \ (13\text{TeV})$

$10^5 \times \text{GZK cut-off} \ (10^{20}\text{eV})$

$\rightarrow \text{CMB B-mode is a potential window to the truly-unexplored ultra-high energy phenomenon}$

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

- Small angular scale $B$-mode is the signature of lensing
- Probe of physics affecting structure growth at $\sim 1 < z < 3$. 
Application: Neutrino mass

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

Non-zero neutrino mass

Zero neutrino mass

arXiv:1006.0689
**Application: Neutrino mass**

- Signature of "finite neutrino mass" is suppression of structure growth.
- Detectable in coming CMB pol. experiments.

- \( \Delta (C_L) / C_L \) for \( \Sigma m_\nu = 0, 50, 100, 150 \) meV.

- \( \Sigma m_\nu = 0 \text{eV} \):
- \( \Sigma m_\nu = 0.15 \text{eV} \):
- ~2% change is guaranteed by oscillation exp. (\( \Sigma m_\nu > \sim 58 \text{meV} \)).

- \( \Sigma m_\nu \):
  - \( \Sigma m_\nu = 0 \text{eV} \)
  - \( \Sigma m_\nu = 0.15 \text{eV} \)

---

M. Hasegawa (KEK), POLARBEAR

arXiv:1309.5383 (Snowmass 2013)

CMB lensing potential

\( \Delta (C_L) / C_L \) for \( \Sigma m_\nu = 0, 50, 100, 150 \) meV.

\( \Sigma m_\nu = 0 \text{eV} \):
- \( \Sigma m_\nu = 0.15 \text{eV} \):
- ~2% change is guaranteed by oscillation exp. (\( \Sigma m_\nu > \sim 58 \text{meV} \)).

- \( \Sigma m_\nu \):
  - \( \Sigma m_\nu = 0 \text{eV} \)
  - \( \Sigma m_\nu = 0.15 \text{eV} \)
POLARBEAR Optics

- Primary mirror (3.5m)
- Secondary mirror (not seen)
- Guard ring

CMB

Focal plane (250mK)
- Off-axis Gregorian-Dragone
- 2.5m primary
  \[ \rightarrow \text{FWHM} = 3.5' \text{ achieved} \]

Angular resolution to measure the lensing B-modes.
POLARBEAR-1 Focal Plane

91 pixels (182 bolometers) per wafer under AR-coated lenslet.

637 pixels
(91 pixels/wafer x 7 wafers)
1274 TES bolometers

Array sensitivity: \(23 \mu K \sqrt{s}\)

- 2 TES bolometers/pixel with dual-polarization double-slot dipole antenna
- Array sensitivity: \(23 \mu K \sqrt{s}\)
• We started observation in May 2012, and have collected more than 10000 hours data.
• Released lensing $B$-mode results using small patch data ($1^{st}$ + $2^{nd}$ season data)

First & Second season data for new lensing $B$-mode analysis (arXiv:1705.02907)

Note: Calibration run is included.

Three fields, 24.5 deg$^2$ total sky area
Map depth: $\sim$5$\mu$K-arcmin (deepest patch)
The cosmological polarized signal (E-mode) is visible in the map domain.
New $C_l^{BB}$ results \(1^{st}+2^{nd} \text{ season data}\)

- Improved measurement of lensing B-mode spectrum
  - Null hypothesis of “B-mode” is rejected more than 3 sigma.
  - Lensing amplitude is consistent with $\Lambda$CDM expectation.

\[
A_L = 0.60^{+0.26}_{-0.24}(\text{stat.})^{+0.00}_{-0.04}(\text{inst.}) \pm 0.14(\text{FG}) \pm 0.04(\text{multi})
\]
Current status of B-mode measurement

Lensing B-mode is now firmly confirmed by POLARBEAR and the following experiments.

POLARBEAR successfully laid the groundwork for future $\Sigma m_\nu$ measurement!

Figure by Y. Chinone (UCB)

Lensig B-mode is now firmly confirmed by POLARBEAR and the following experiments.
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

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

x18 leap with multi-chroic pixels
1st receiver assembly at KEK

Lab. testing with full equipment is on-going.
Simons Array (projected) sensitivity

- Polarized dust at 95 GHz: $p=15\%, f_{\text{sky}}=65\%$
- Polarized synchrotron at 95 GHz: $p=15\%, f_{\text{sky}}=65\%$
- Polarized dust at 95 GHz: $p=15\%, f_{\text{sky}}=5\%$
- Polarized synchrotron at 95 GHz: $p=15\%, f_{\text{sky}}=5\%$

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

Inflation
- $\sigma(r=0.1) = 6 \times 10^{-3}$
  (4x10^{-3} (stat))

Neutrino mass
- $\sigma(\Sigma m_\nu) = 40$ meV
  (19 meV (stat))

w/ DESI BAO

Simons Array can 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 is being prepared.

Stay Tuned!
Acknowledgement

In Japan, this work was supported by JSPS Core-to-core Program, A. Advanced Research Networks.