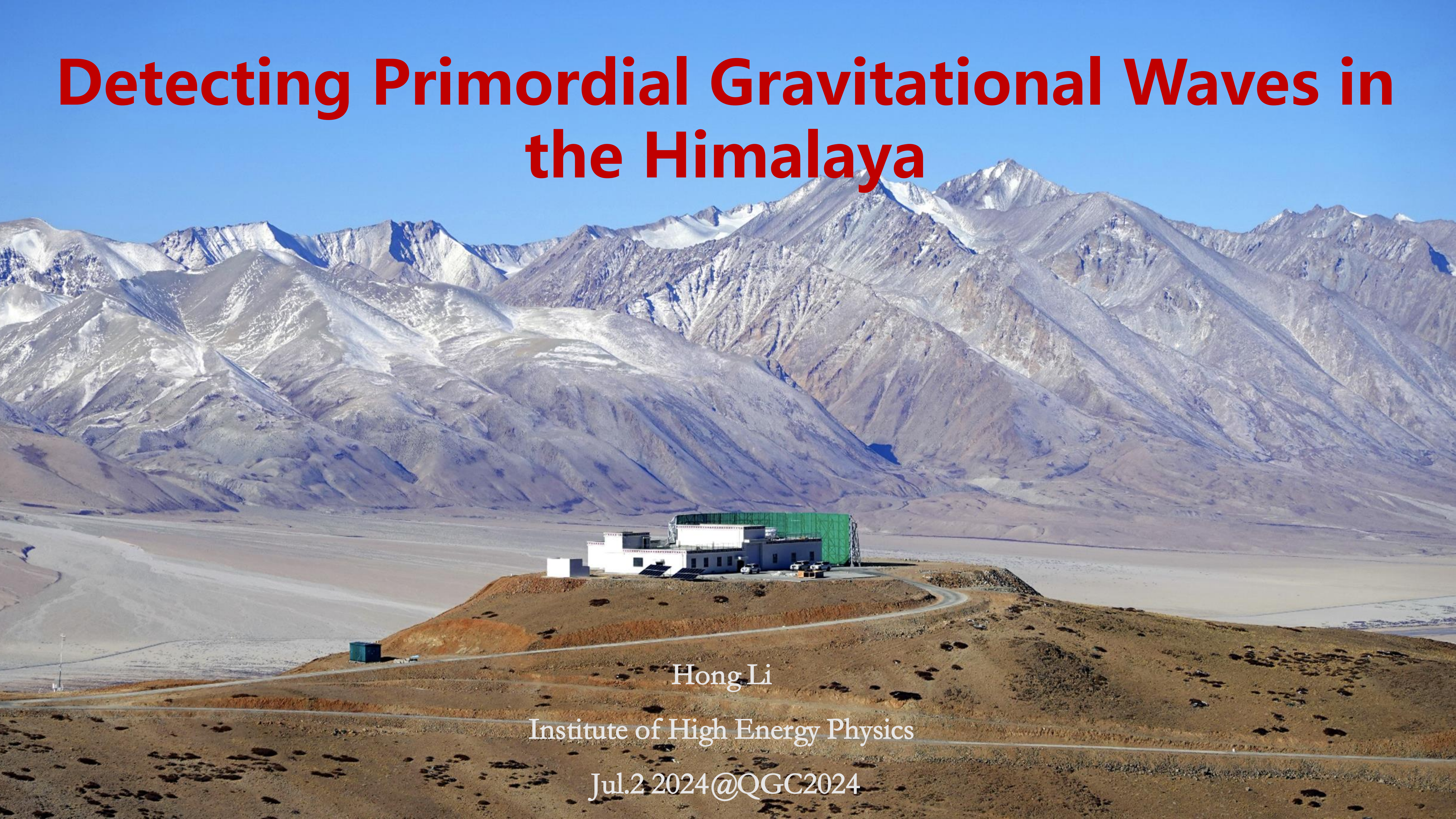
Detecting Primordial Gravitational Waves in the Himalaya



Hong Li

Institute of High Energy Physics

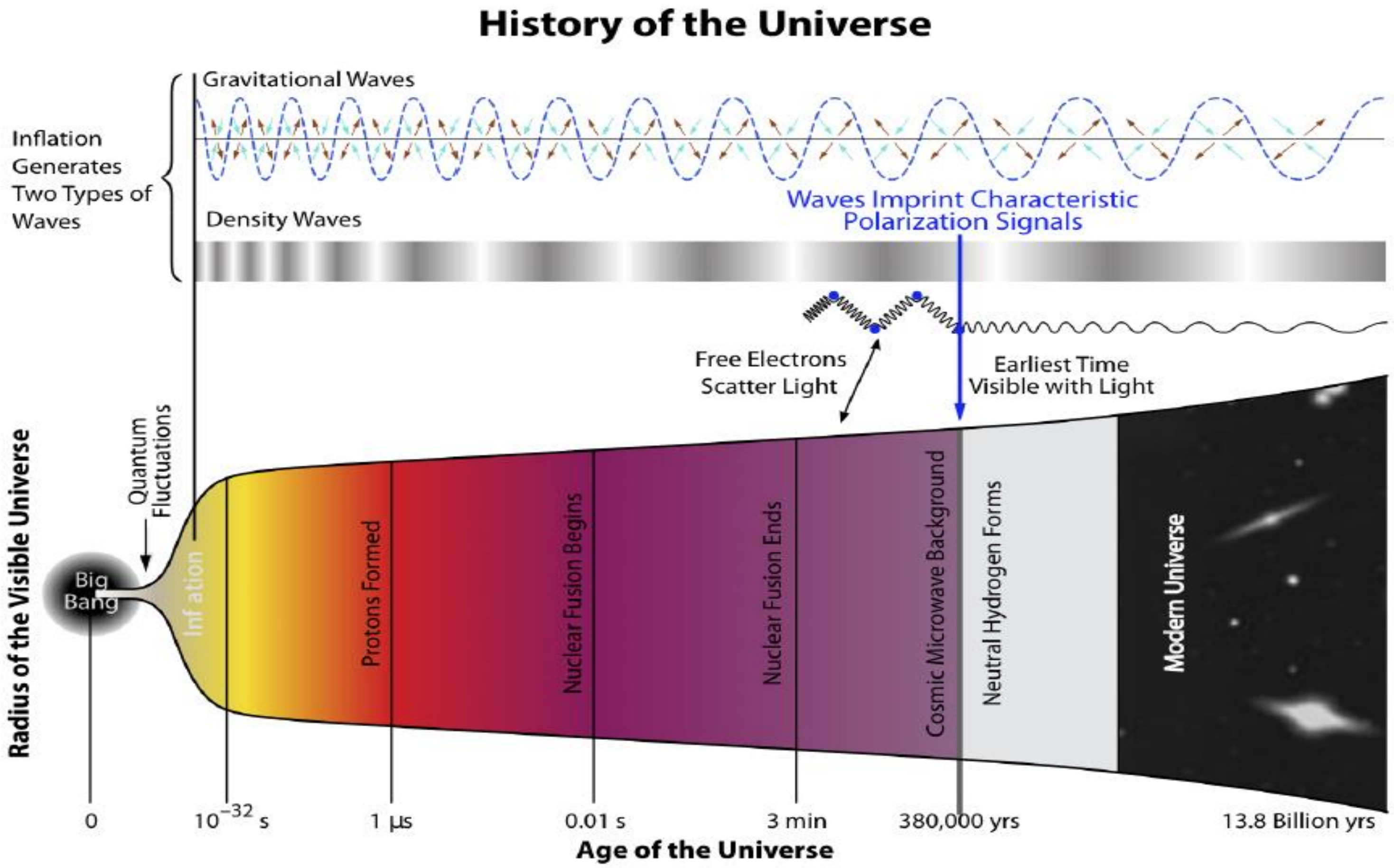
Jul.2 2024@QGC2024

Outline

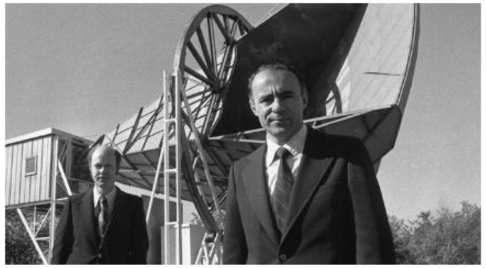
- Primordial gravitational wave and CMB observation
- Good CMB sites in Ali
- AliCPT experiment

The detection of primordial gravitational waves

- Primordial gravitational wave is an important prediction of the inflationary model.
- CMB B-mode provides a way for the detection of primordial gravitational wave.

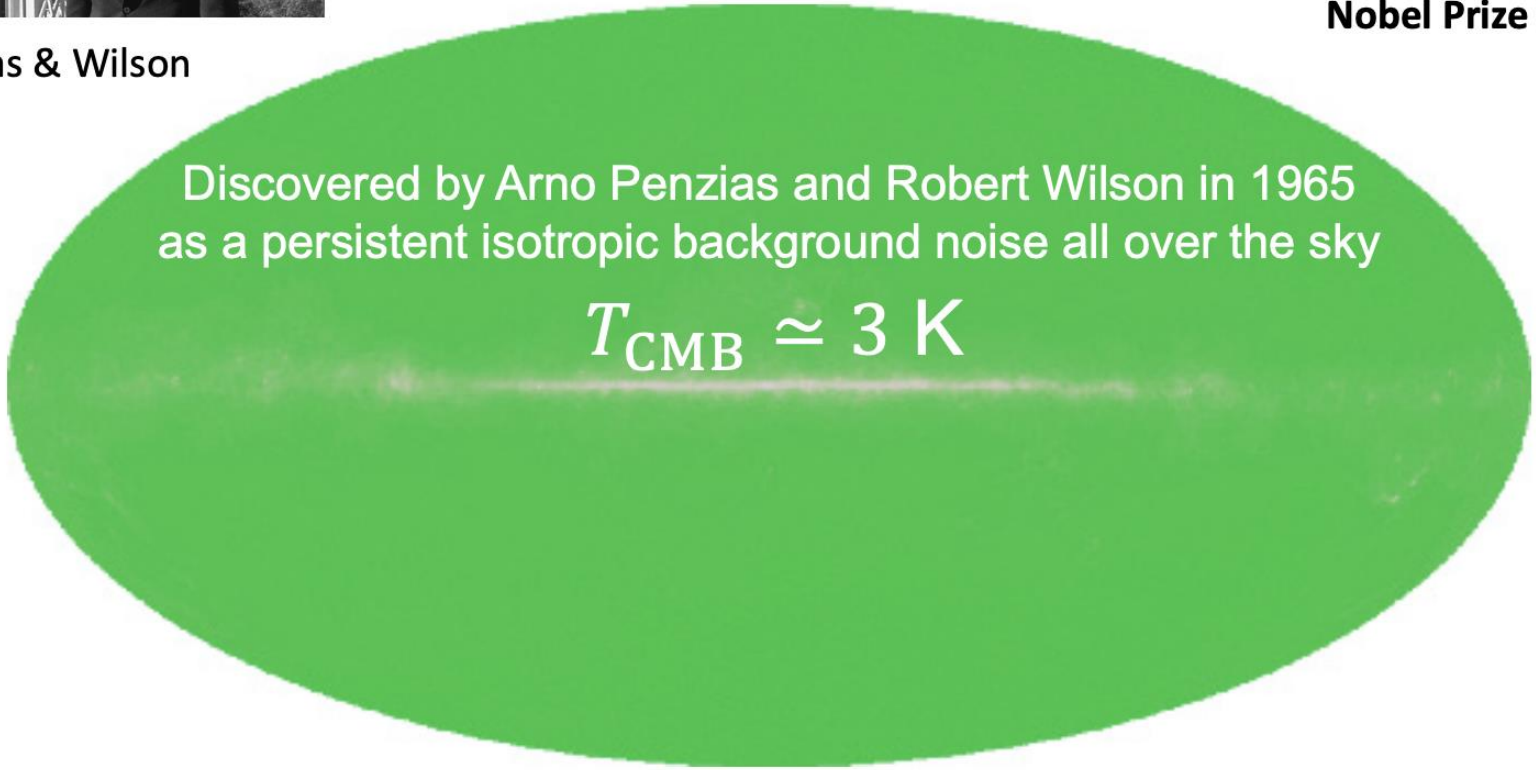


CMB: a precise probe for cosmological study



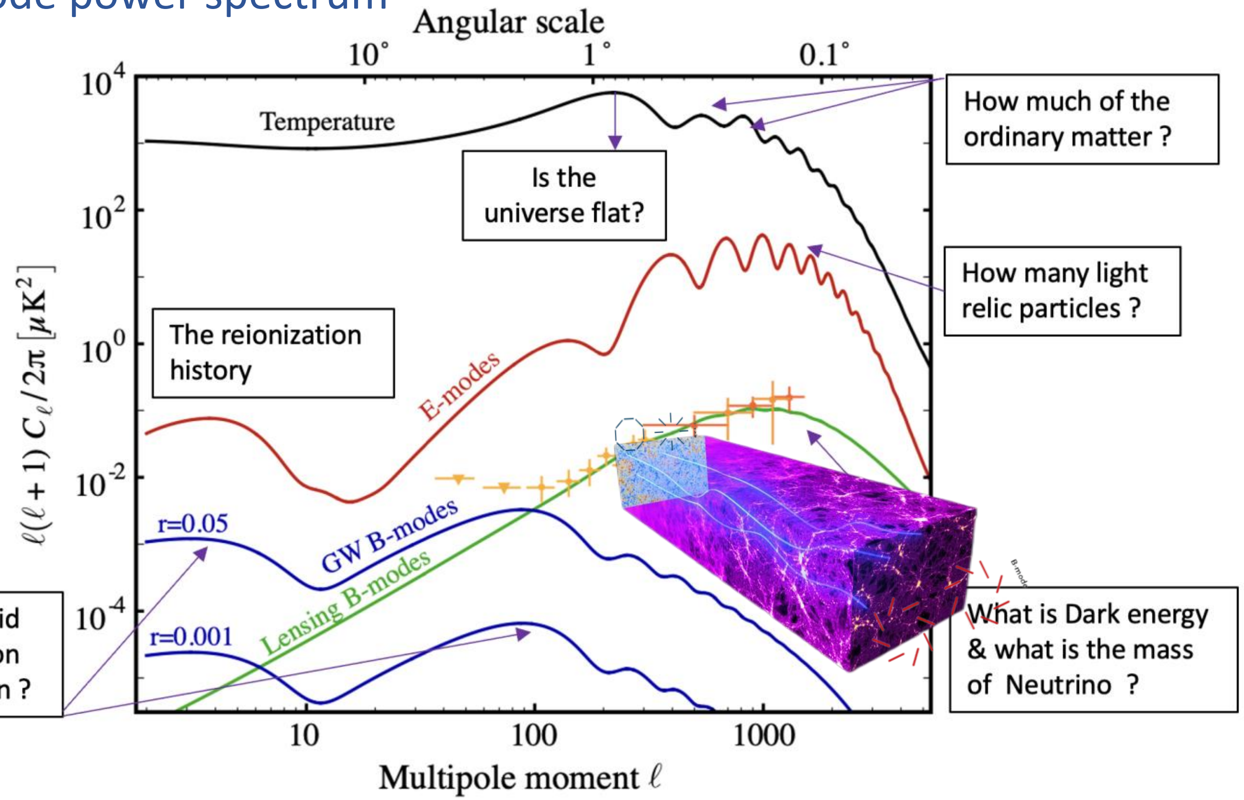
Penzias & Wilson

Nobel Prize 1978



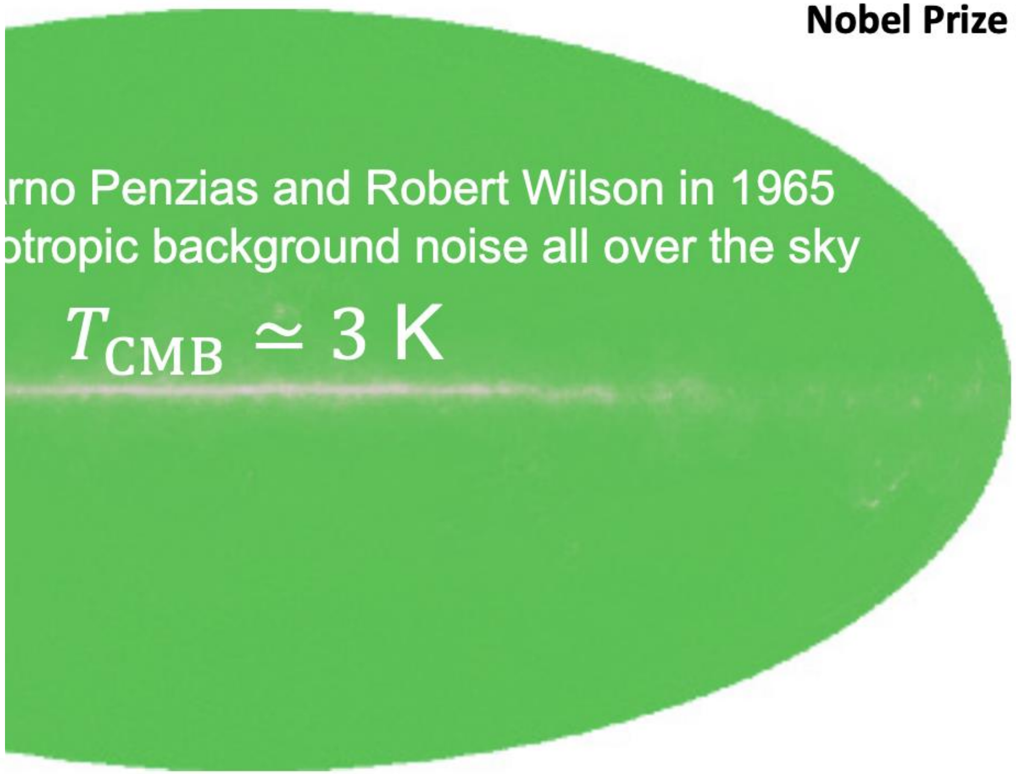
CMB: a precise probe for cosmological study

Temperature
E-mode power spectrum
B-mode power spectrum



arxiv: 1610.02743

Nobel Prize 1978

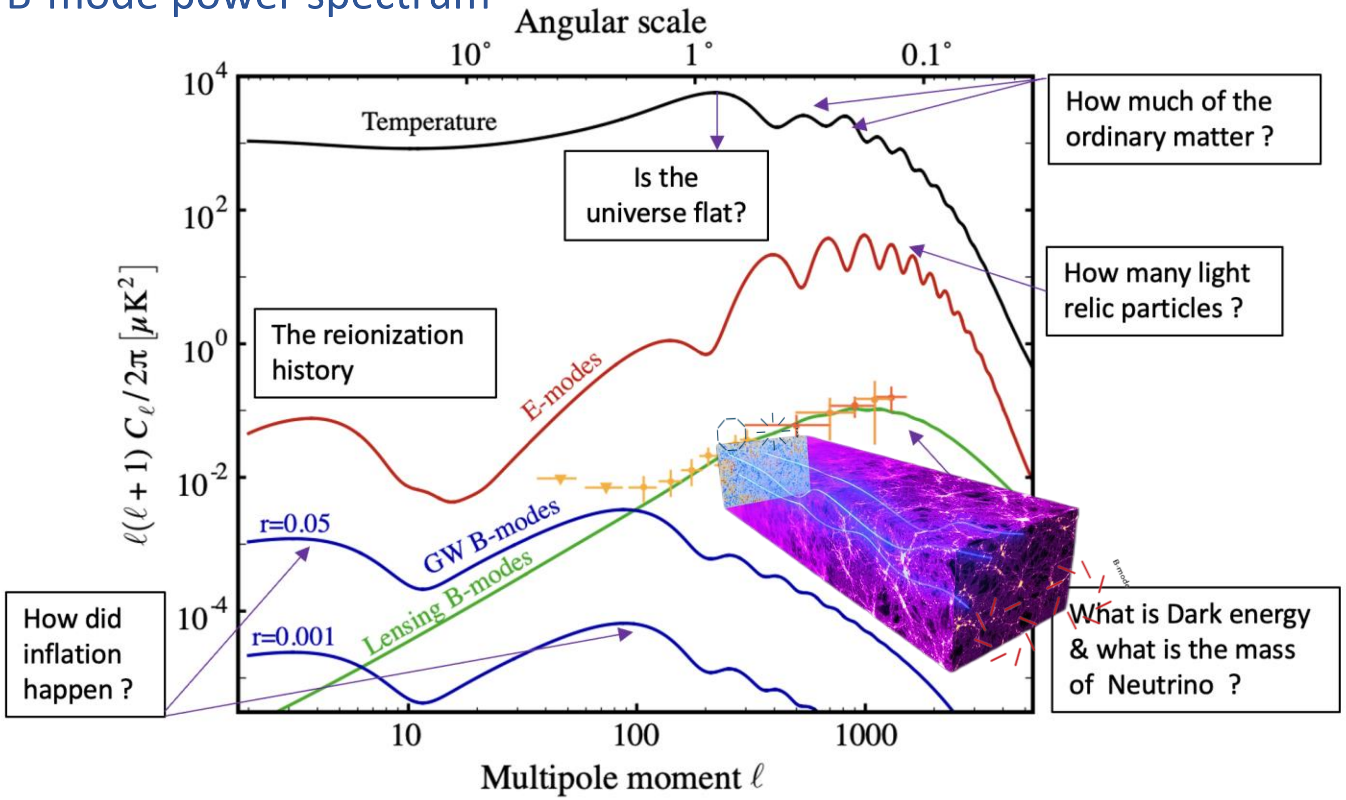


CMB: a precise probe for cosmological study

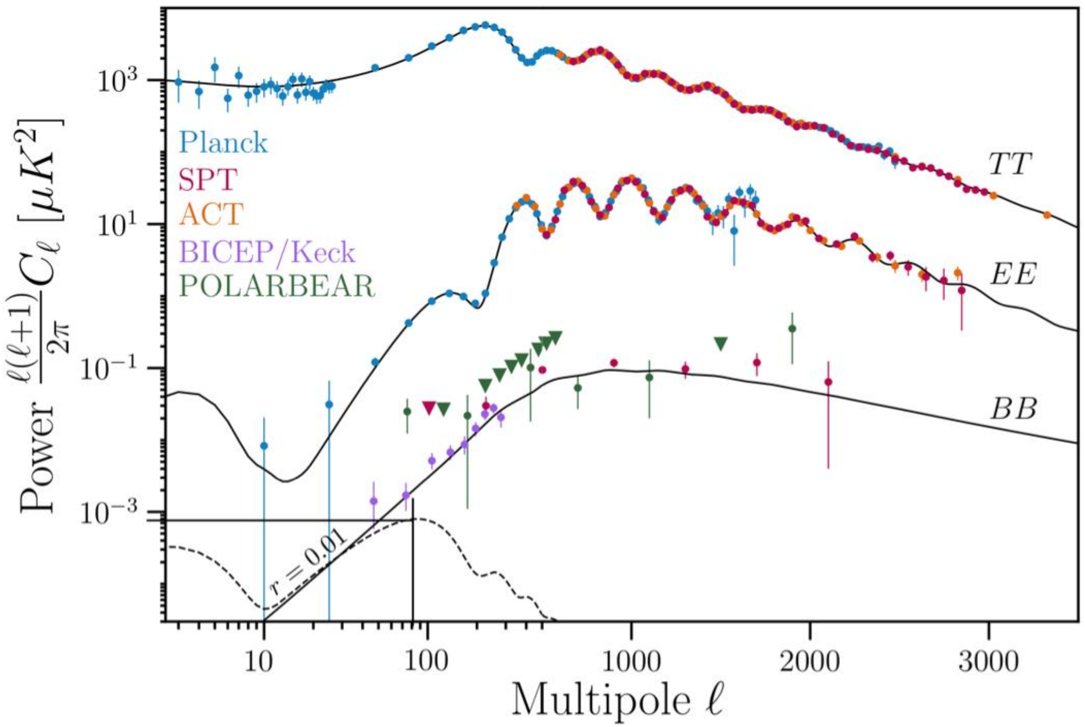
Temperature

E-mode power spectrum

B-mode power spectrum



arxiv: 1610.02743



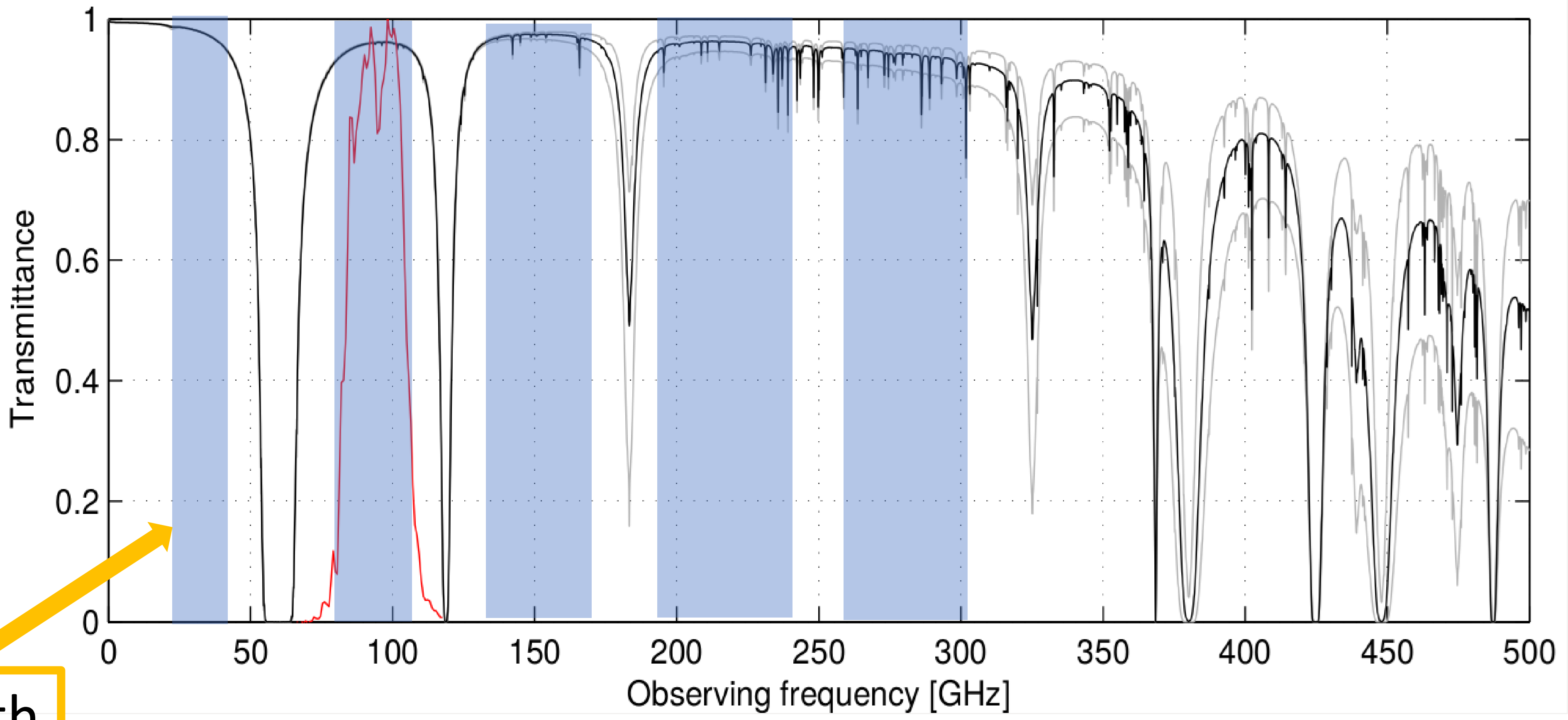
arXiv:2203.07638

Observing CMB on Earth relies on atmospheric windows

- **Requirement**: High atmospheric transmittance in microwave bands

- High altitude and dry enough :

the emission from atmosphere is sufficiently low



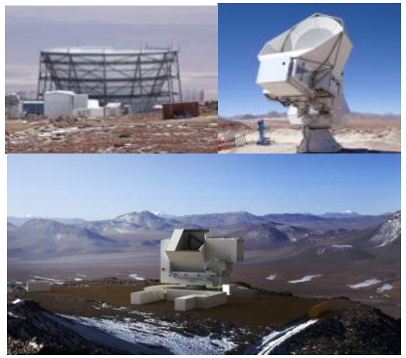
5 windows on earth

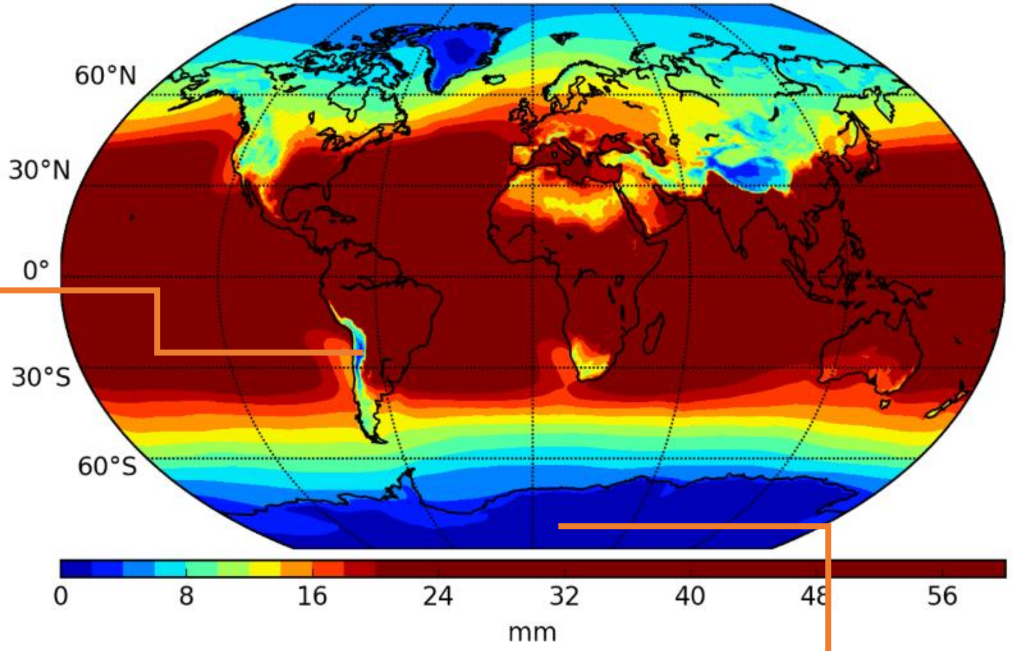
4 possible sites on earth

Need low PWV

Atacama

e.g. ACT, PolarBear,
Simons …





South pole

e.g. SPT and BICEP

H. Li *et al* **arXiv:1710.03047,**
Kuo C.-L.: arXiv:1707.08400

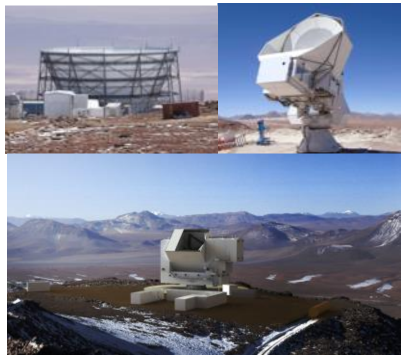
Global distribution of mean PWV (Precipitable Water Vapor)

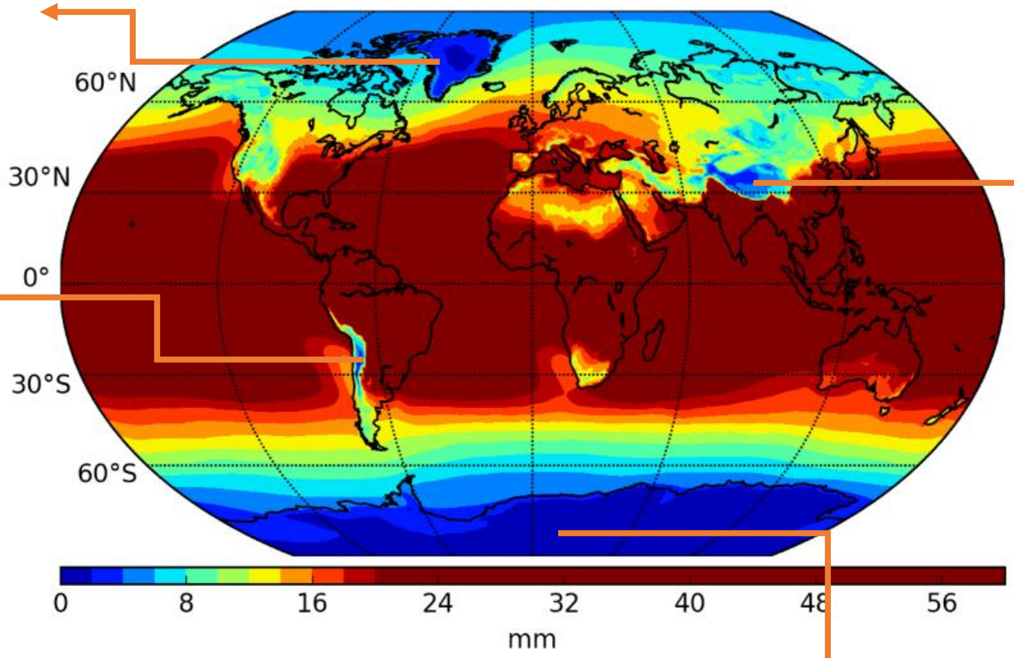
To open a new window for ground CMB observation in Northern hemisphere

Greenland

Atacama

e.g. ACT, PolarBear, Simons …





Tibet

AliCPT: a small aperature telescope, with dual bands of 90/150Ghz, to probe the northern sky with high sensitivity

South pole

e.g. SPT and BICEP

H. Li *et al* **arXiv:1710.03047,**
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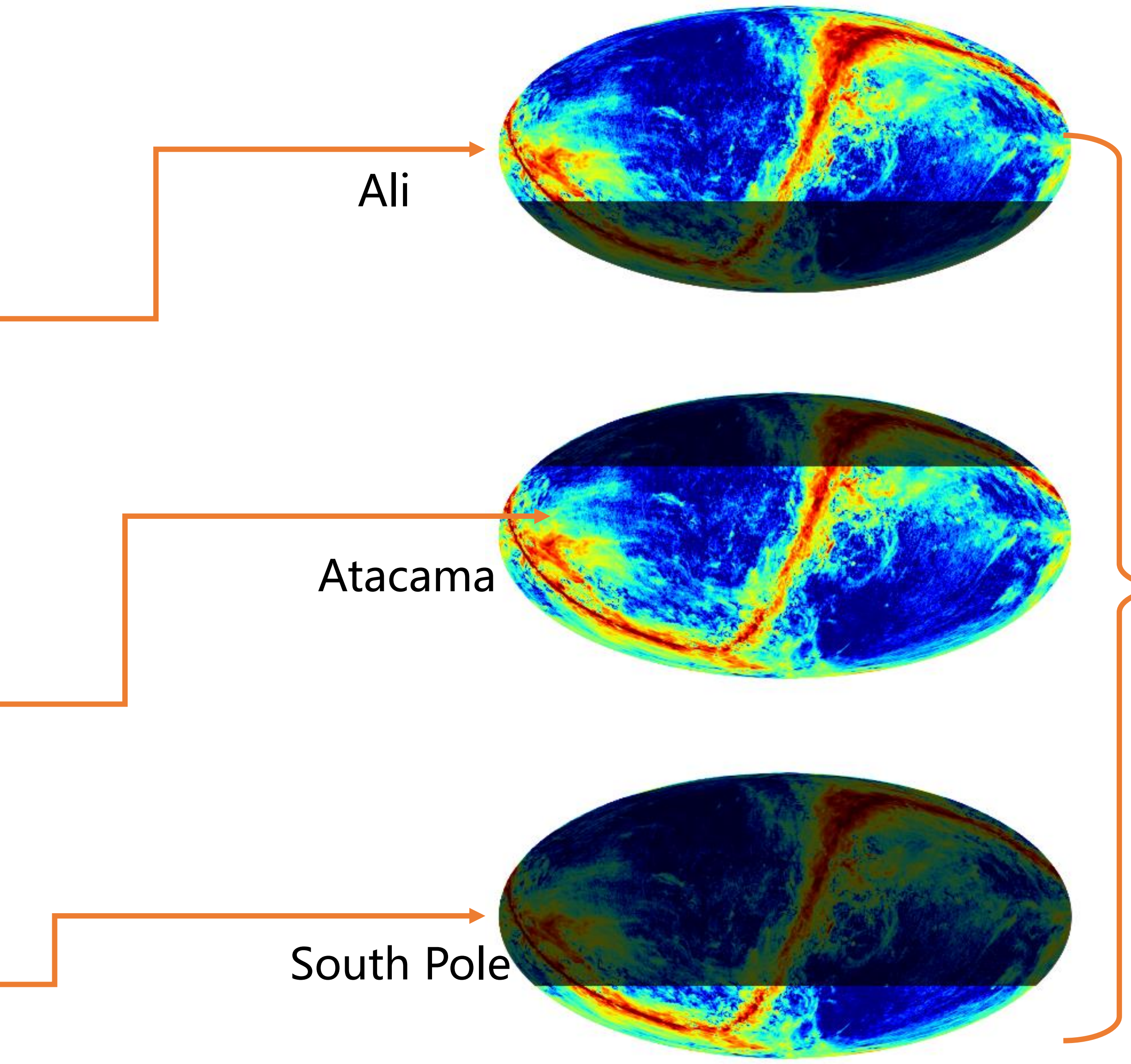
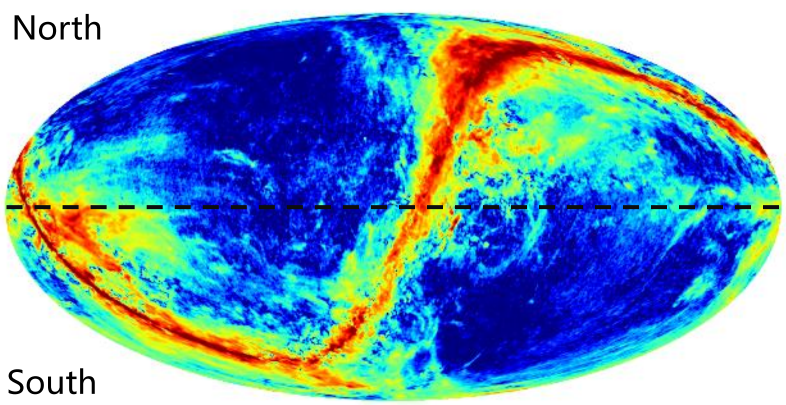
Global distribution of mean PWV (Precipitable Water Vapor)



- **AliCPT can be a complementary to telescopes in south pole and Chile**:
  - ~64% of whole sky
  - There is sky overlap
  - Good chance for cross check



- AliCPT :
  - ~10% clean patch for deep survey of r

With the three sits on earth → Full sky coverage

Site in Ali region of Tibet

Located on the hilltop B1 (32°18′38″ N, 80°01′50″ E), in the Ngari(Ali) Prefecture of Tibet, at an altitude of 5250m

The Himalayas in the southwest separates the Ali region from the Indian Ocean.

~30 km from the AliCPT site.

AliCPT-1 is only about 1.5 km from the current well-developed A1 station (5100m).

Site in Ali region of Tibet

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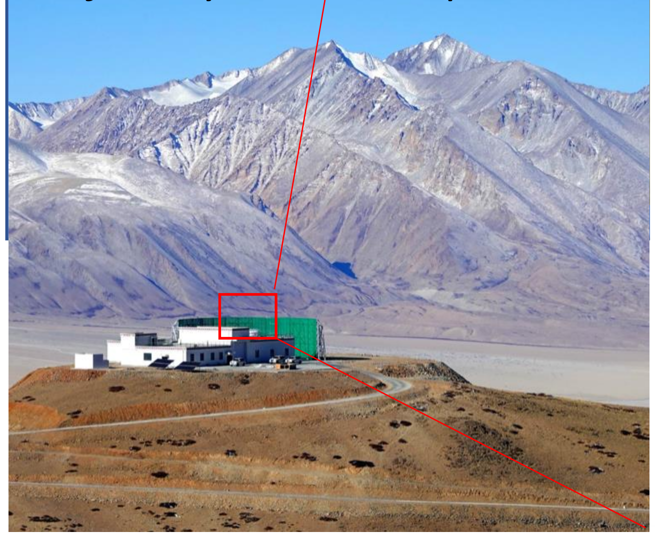
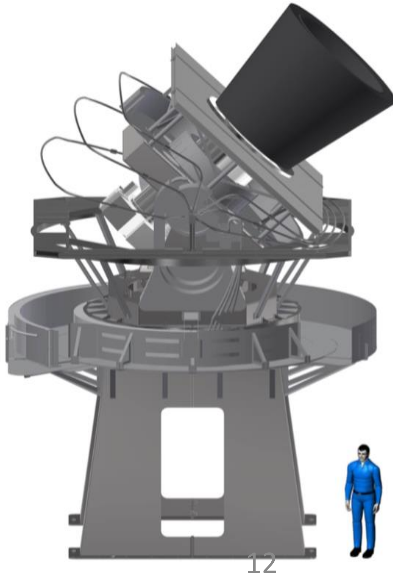
The Himalayas in the southwest separates the Ali region from the Indian Ocean.

~30 km from the AliCPT site.

AliCPT-1 is
current well
(5100m).

After 7 years development



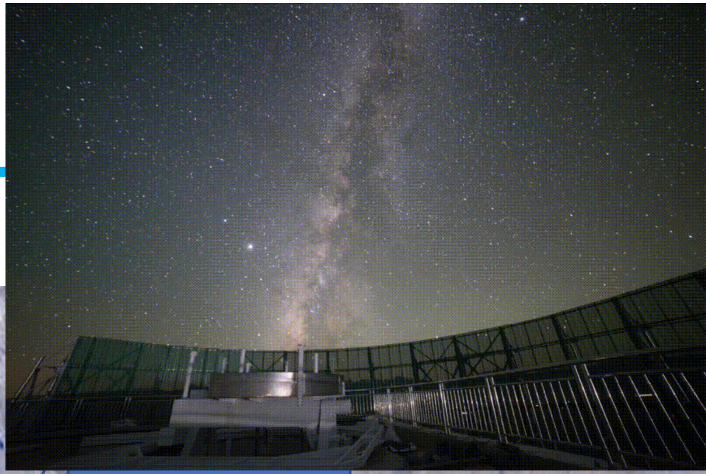
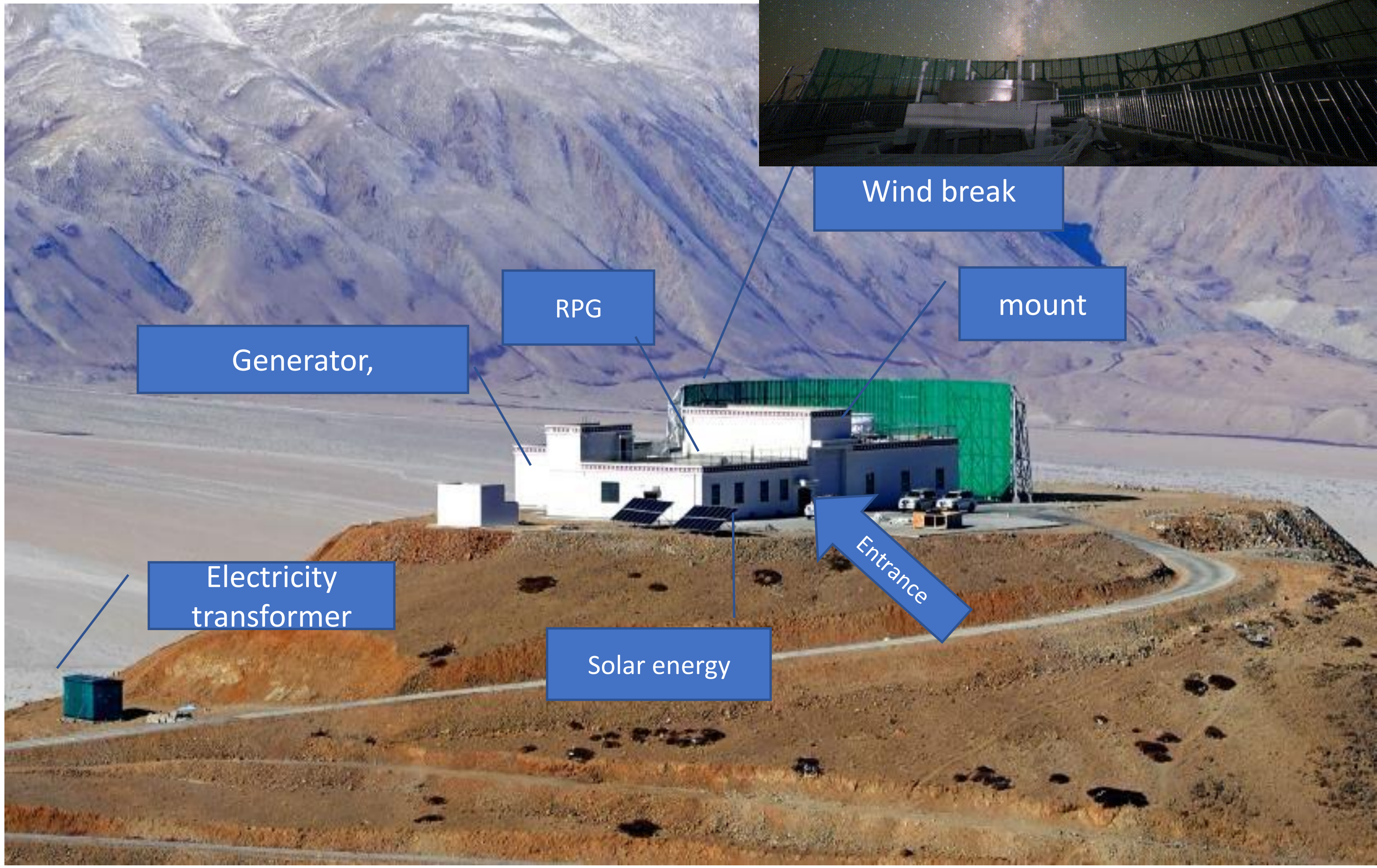


Observation station is in place

infrastructure
- Roads
- Observatory
- Wind break

Laboratory equipment
- Mount
- Star Camera
- RPG
- Near/Far filed calibration equipment
- PT/Chiller
- EMI
- Weather Stations

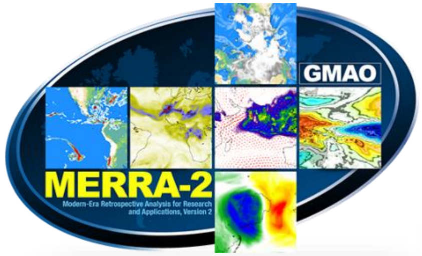
Auxiliary equipment
- Generator
- Network System
- Oxygen System
- Air condition
- Nitrogen generator
- Remote control system

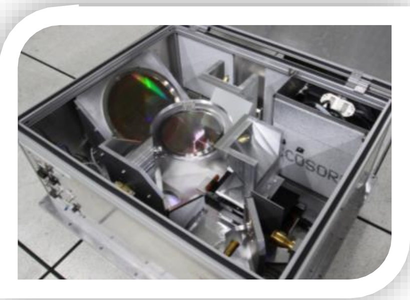
PWV measurements

Median value of PWV （unit： mm）						
data	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Observational Season**
Merra-2 (MERRA-2 2011-2017)	1.06	0.80	0.78	1.01	1.39	1.08
Balloon (2015 – 2016, 7:00, 19:00)	1.19	0.56	0.59	0.61	1.40	0.92
FTS SPT. (2017 - 2021)	-	-	-	-	-	0.90
RPG radiometer (2021)	0.72	0.64	0.87	0.81	0.98	0.78 (注：2021.11 ~ 2022.3)

- **Observational season, Oct.1 – Mar. 31, the median value of PWV ~ 1 mm， the transmittance of channels of 95 / 150 GHz are larger than 98%。**
- **Comparable with Atacama**

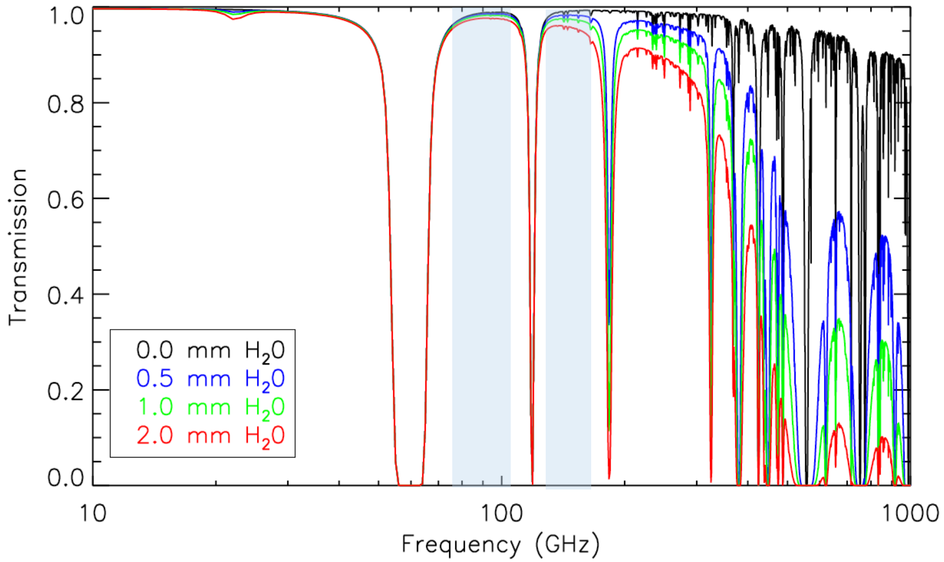


radio Sounding balloon



Fourier spectroscopy

RPG



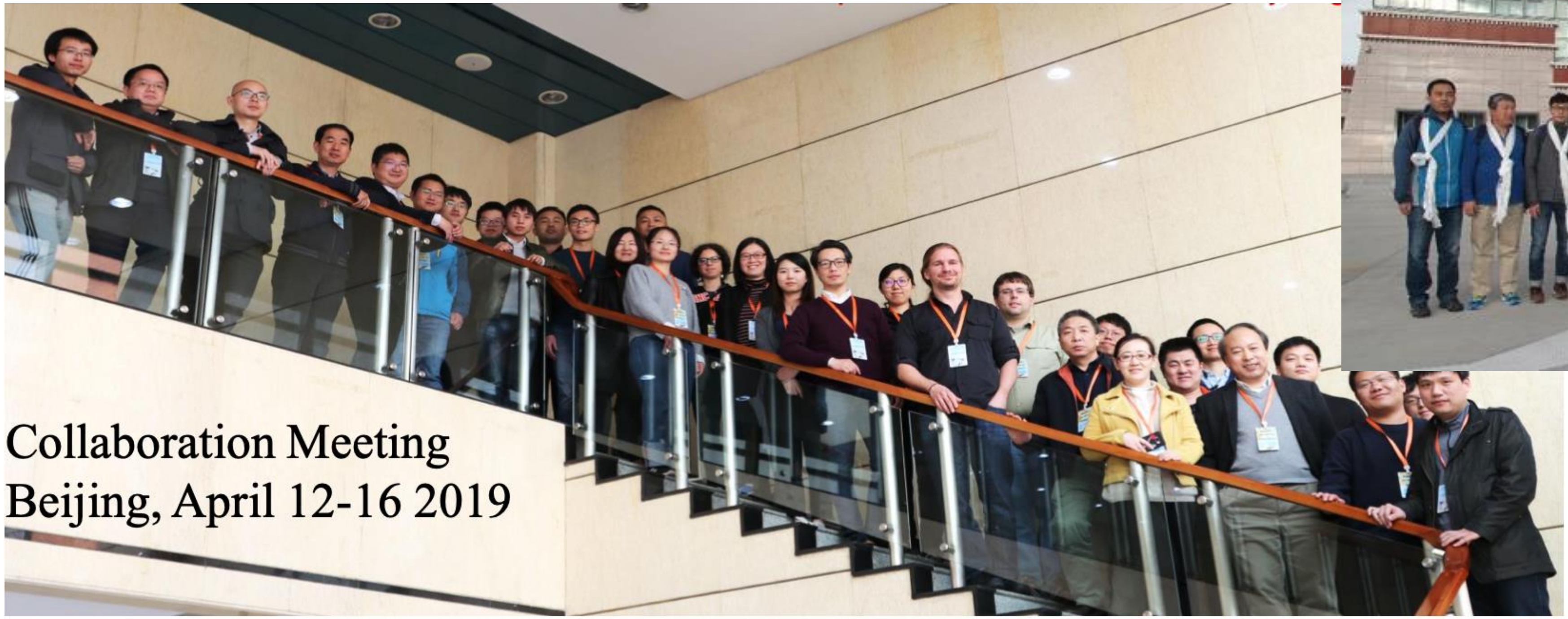
- Natl.Sci.Rev. 6 (2019) no.1
- Nat.Astron. 2 (2018) no.2

Outline

- Detecting primordial gravitational wave
- Ali has good CMB sites
- **AliCPT experiment**

AliCPT Collaboration since 2016

Institute of High Energy Physics(IHEP), Stanford University, National astronomical observatory(NAOC), NIST, ASU, CNRS/APC, SJTU, BNU, NTU, ……



Visiting Ali Site, 2019

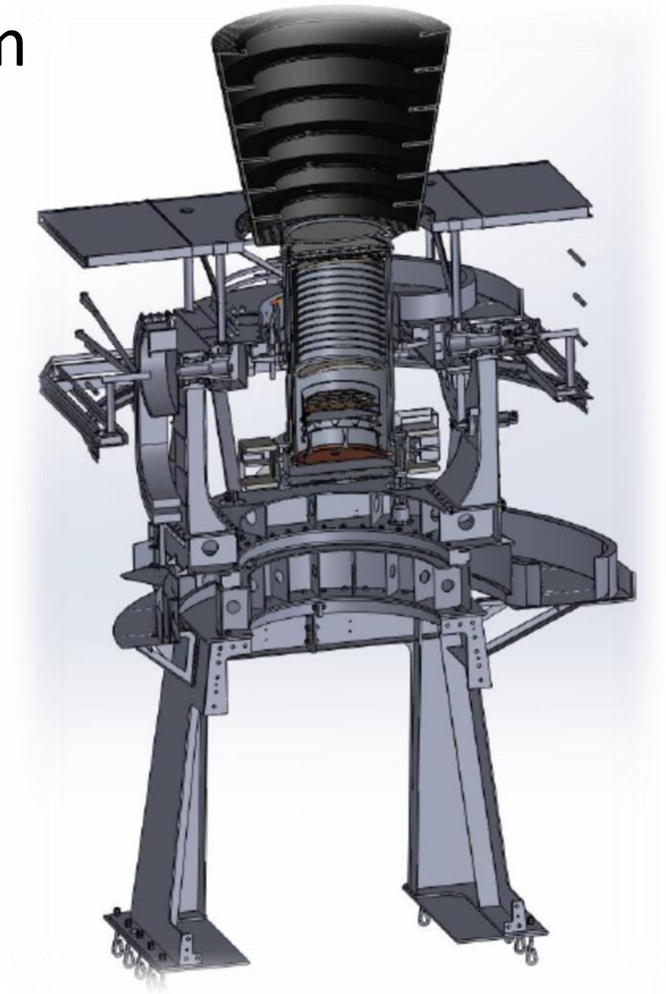
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

AliCPT -1

- A degree scale CMB polarimeter, with aperture of 72cm

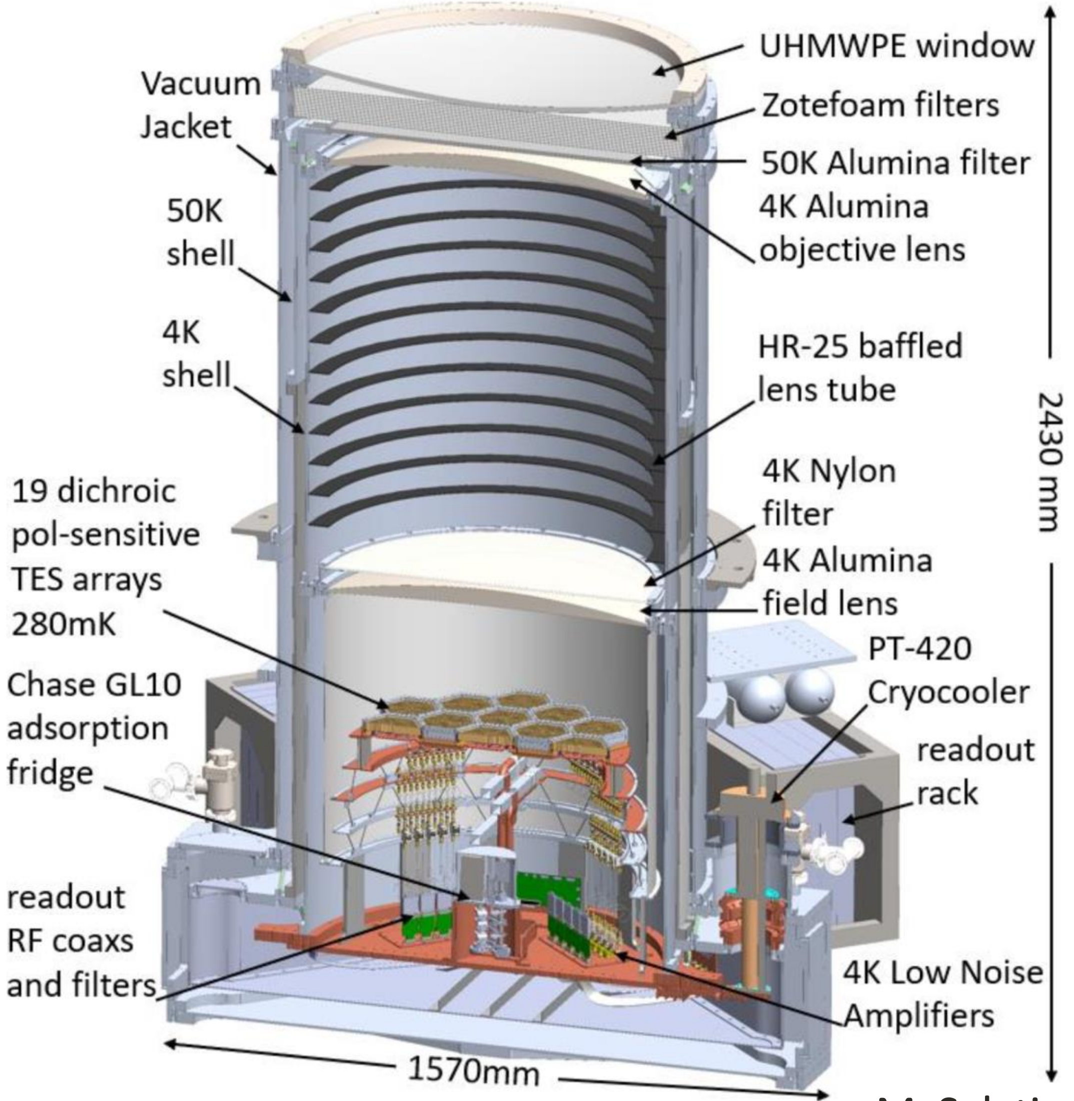
Frequencies	90GHz	150GHz
Center Frequency (GHz)	91.4	145
Bandwidth (GHz)	38	40
Optical TES count	16,188	16,188
P_{sat} (pW)	7.0	12.0
NEP Phonons (aW/$\sqrt{Hz}$)	19	25
NEP Photons (aW/$\sqrt{Hz}$)	33	46
NEP Total (aW/$\sqrt{Hz}$)	38	53
Resolution (FWHM)	19’	11’
NET CMB ($\mu K\sqrt{s}$)	274	348

Maria Salatino ,et al. IEEE Transactions on Applied Superconductivity



receiver & mount

Cryostat receiver: under testing



Cold optical section

- Windows
- Infrared blocking filters
- lenses

Camera section

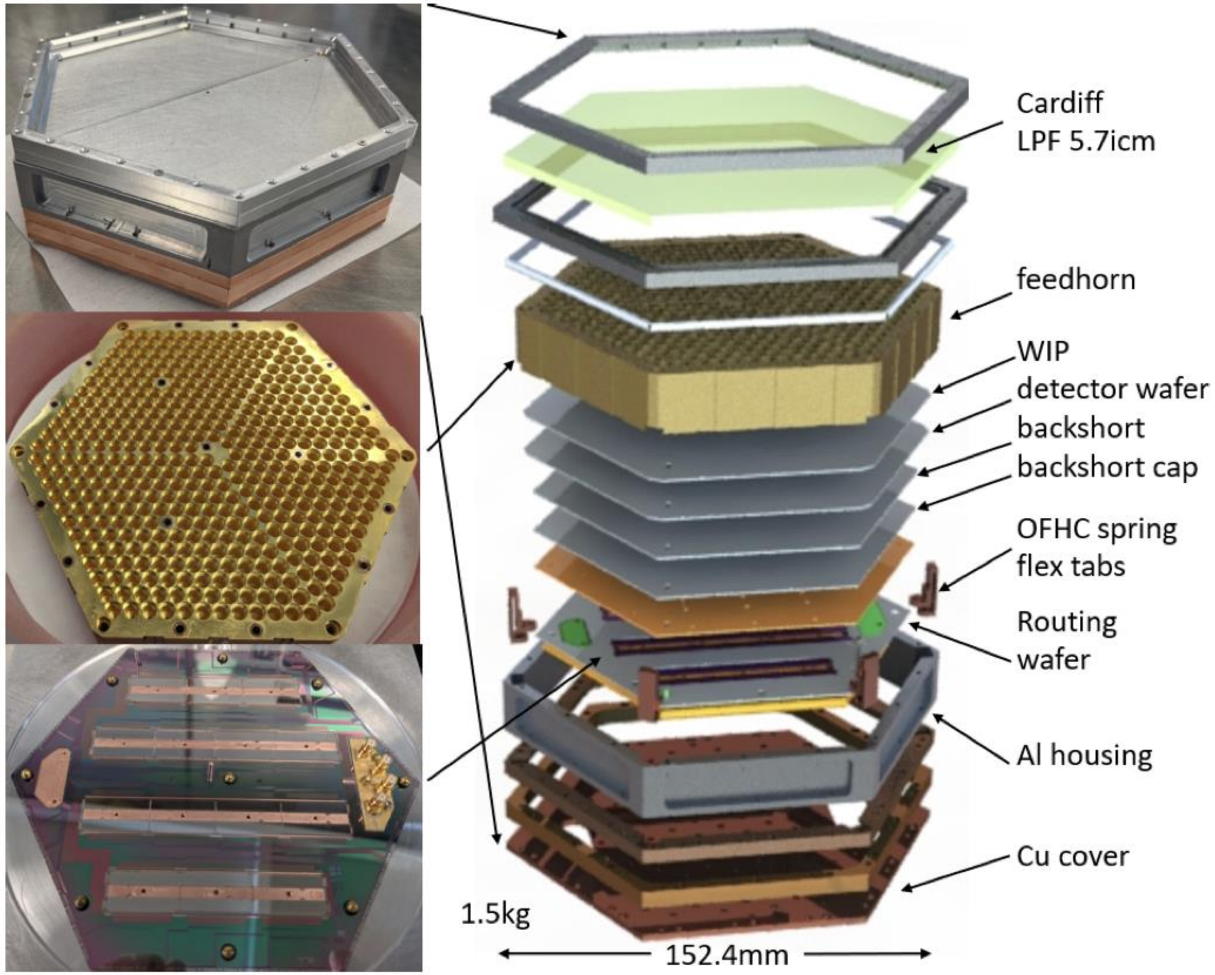
- detector arrays
- focal plane
- RF readout chains
- Cryogenics PT-420

M. Salatino, et al. arXiv:2101.09608

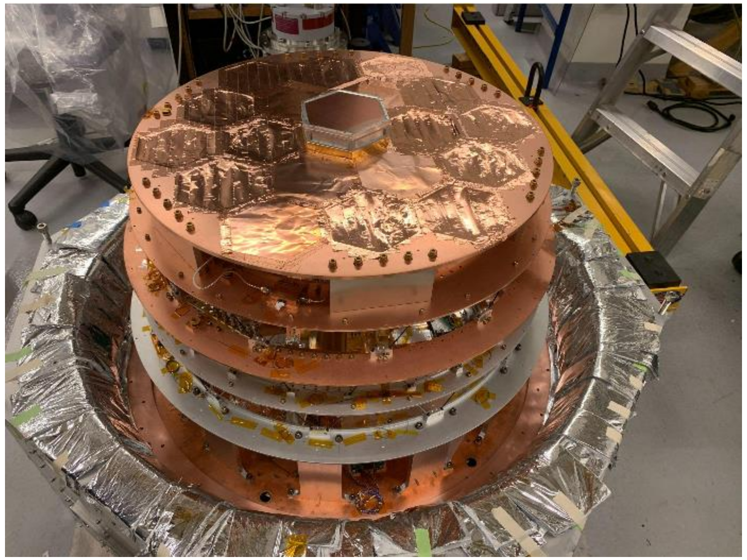
solidworks design of receiver

Detector

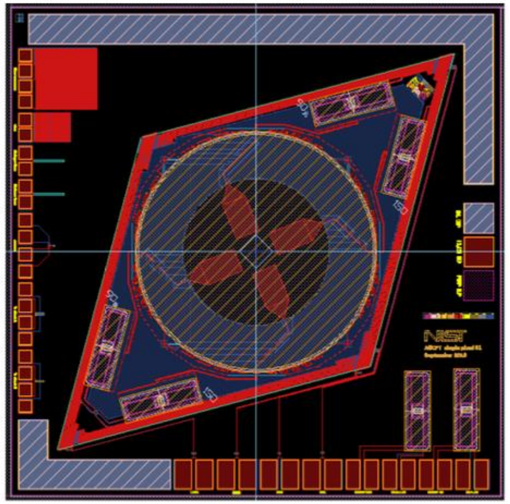
➢ **6-inch detector array**

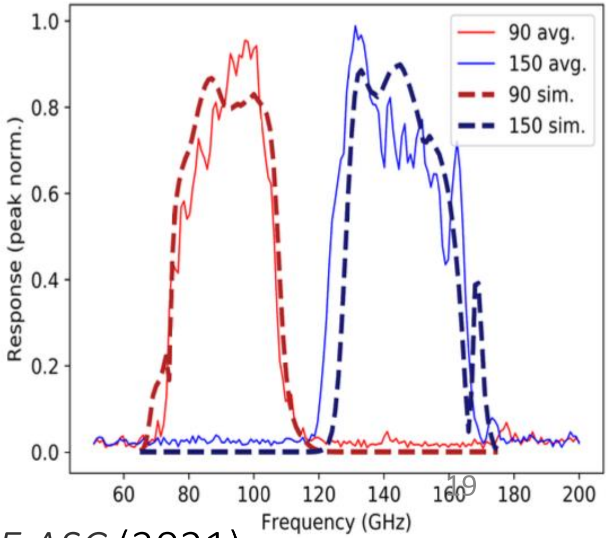


M. Salatino, et al. arXiv:2101.09608



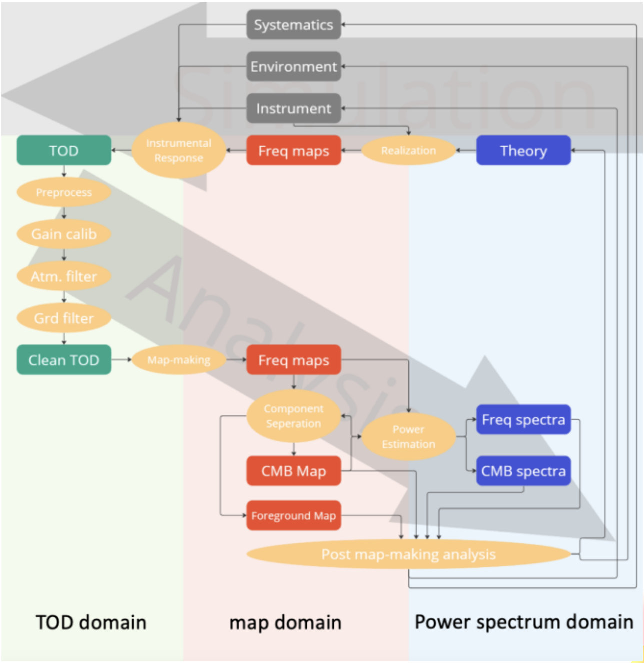
Focal plane unit

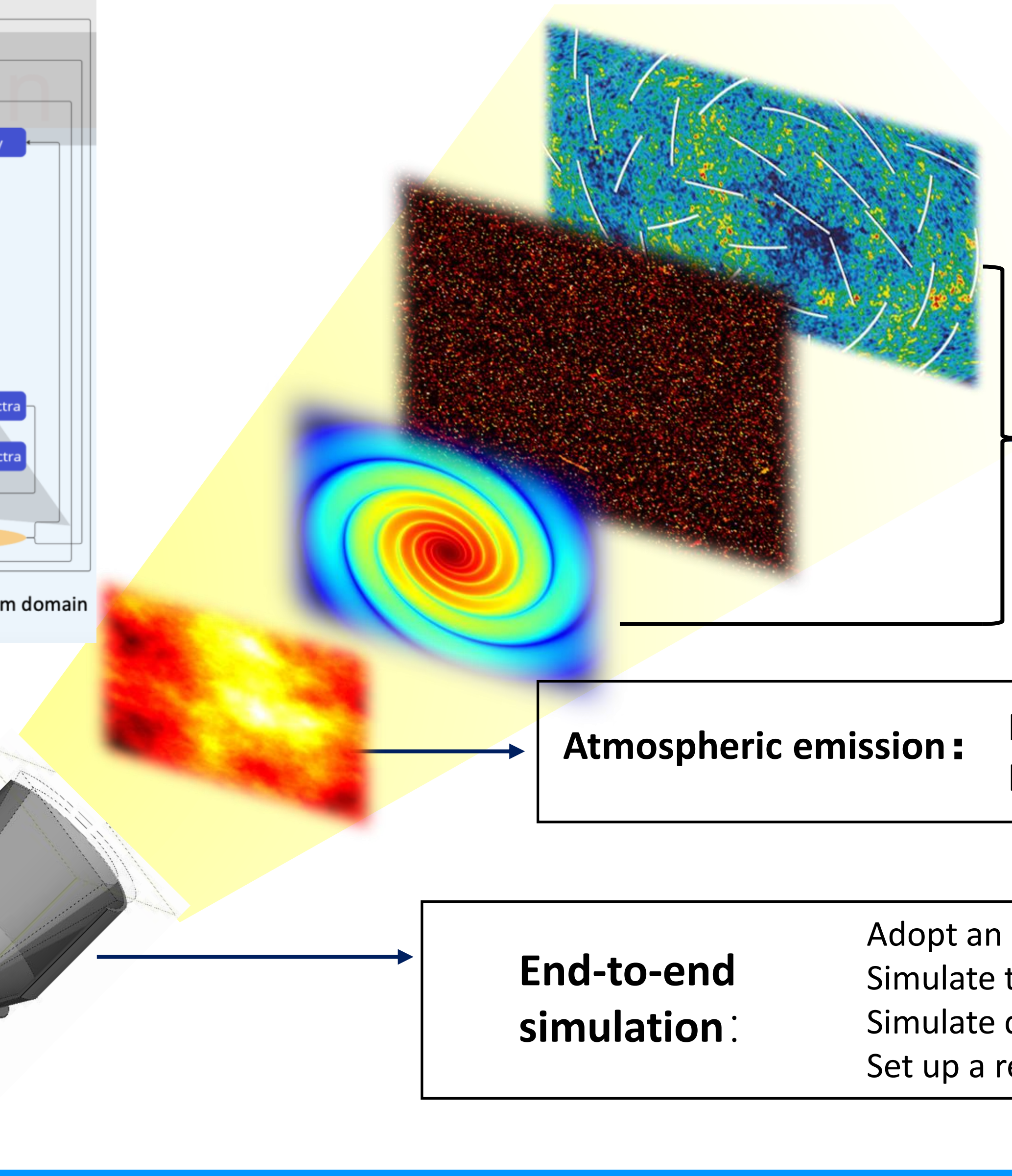




M. Salatino, et al. *IEEE ASC* (2021)

Sensitivity with end-to-end simulation and data analysis





Observed Maps in different channels：

- Lensed CMB
- Galactic emission
  (Planck Sky Model)：
  Thermal dust; Synchrotron,
  CO, Free-Free, AME …
- Point sources

Atmospheric emission： Merra-2 meteorological satellite measurements；
RPG measurement in Ali.

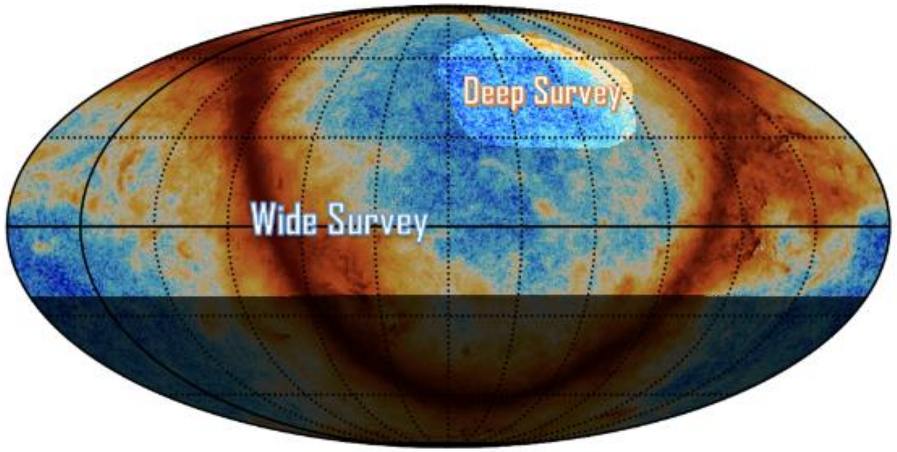
End-to-end simulation：

Adopt an optimized scanning strategy at Ali site;
Simulate telescope pointing in real time;
Simulate detector response: bandpass function, beamplot;
Set up a realistic noise model based on PWV measurements.

Simulation: noise level

◻ Noise model for single detector :

- Optical loading: $P_{load} = 2\eta k T_{RJ} \Delta v + P_{internal}$
- Total noise: $NEP = \sqrt{NEP_{photon}^2 + NEP_{phonon}^2}$
  - Photon noise: $NEP_{photon} = \sqrt{2hvP_{load} + \frac{2{P_{load}}^2}{v(\Delta v/v)}}$
  - Phonon noise: $NEP_{phonon} = \sqrt{4k_B G T^2 F}, \quad G = G_0 \left(\frac{T}{T_0}\right)^n$

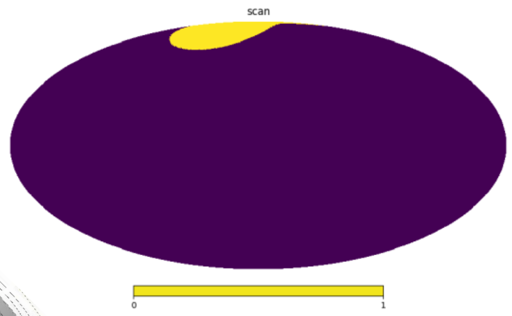


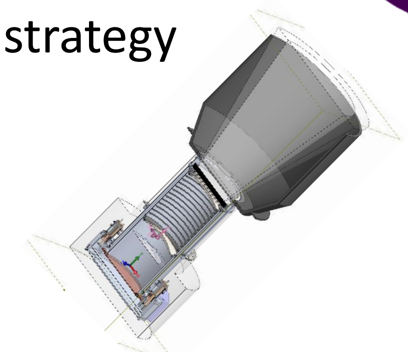
RA~[125，260]，DEC～[30，70]

Deep Survey: focus on clean patch when it is reachable by CES
Wide Survey: CES with full AZ scale

◻ Scan strategy：

- Constant elevation scan(CES): EL = 65 deg
- Sidereal fixed strategy

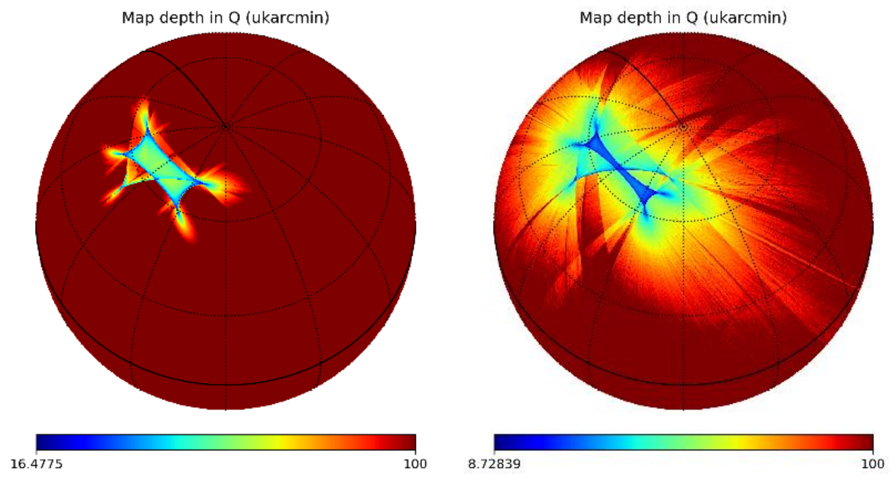




◻ Noise level of the clean patch

- For deep survey in 10% northern sky:
  - ～14 uK.arcmin for 4 module.year
  - ～6 uK.arcmin for 19 module.year
  - ～2.8 uK.arcmin for 19*5 module.year, which is close to the target noise level of CMB-S4

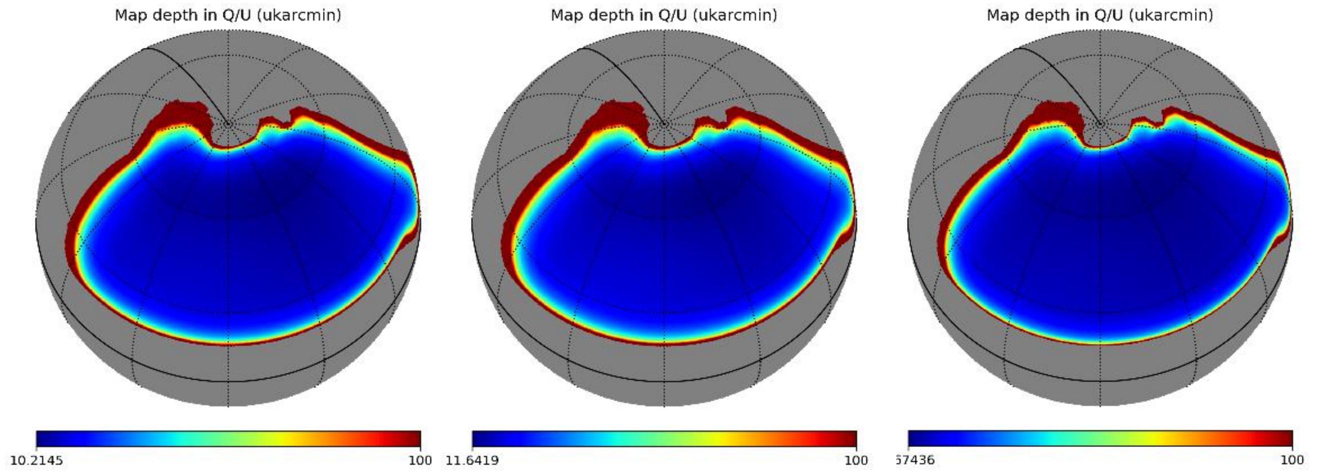
Simulation: sensitivity



PLANCK 100 GHz & 143 GHz

Pol ~50 uK arcmin in total

Planck data, http://pla.esac.esa.int/pla/#maps

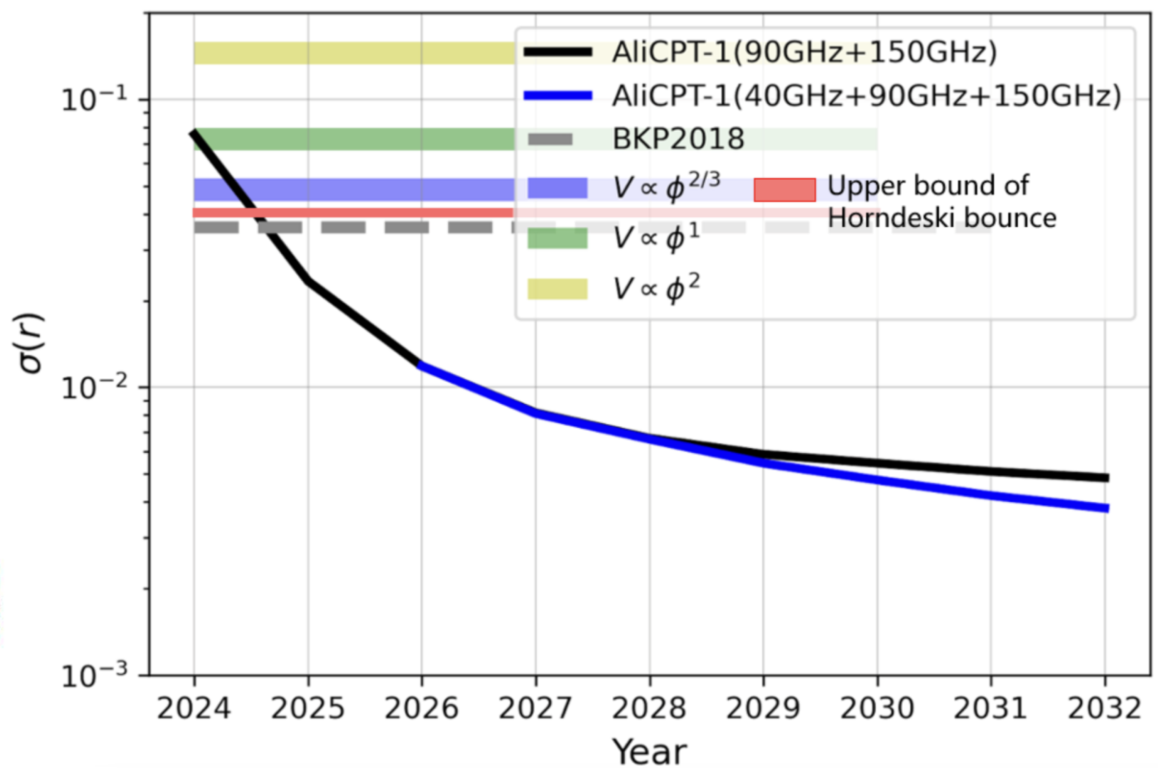


AliCPT 90 GHz & 150 GHz & Total

4 modules 1 season, median map-depth 14 uK arcmin

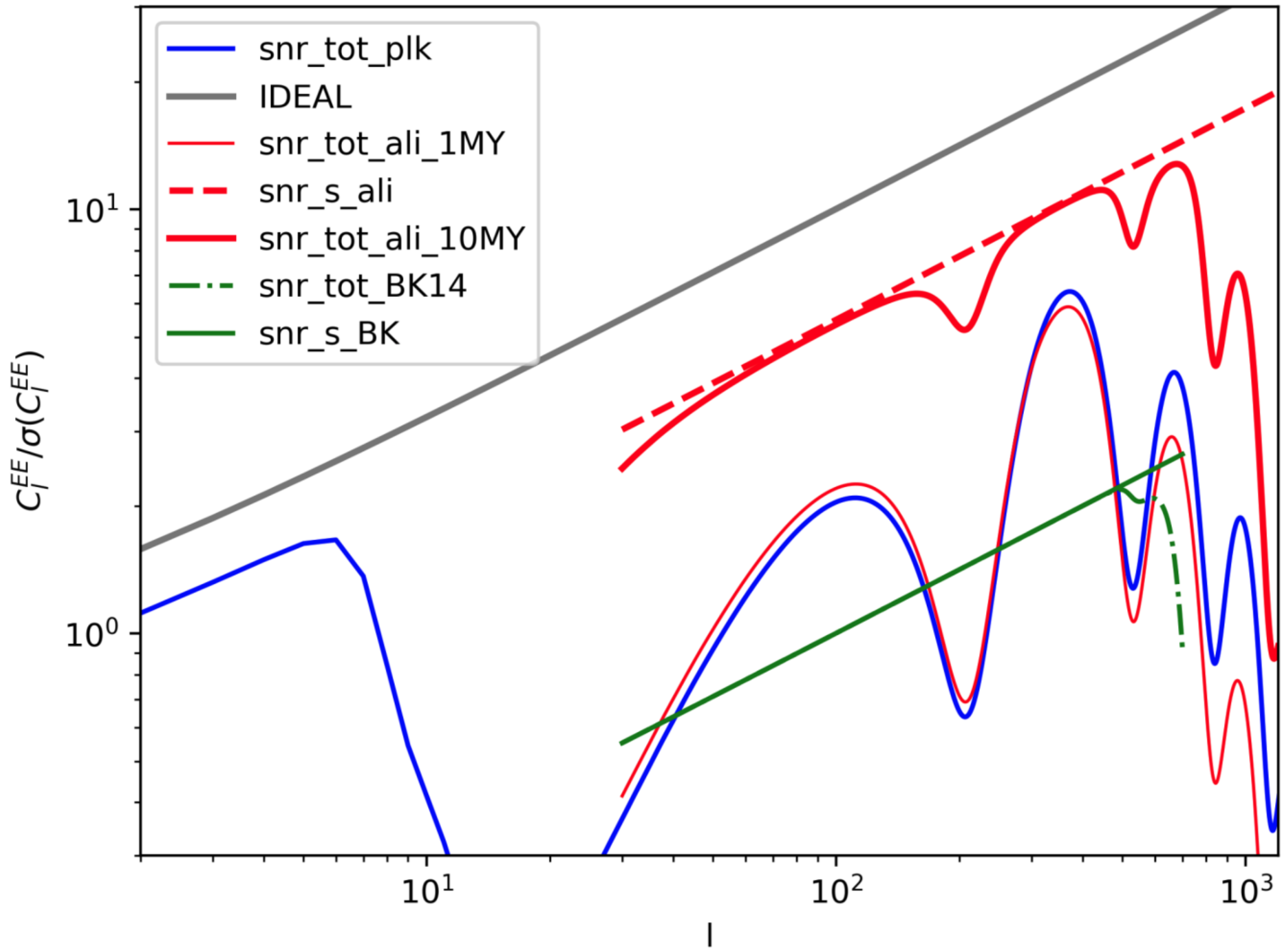
AliCPT-1 Simulated maps

■ B-mode



Simulation: ***raw*** sensitivity

Measurement of E modes



Multipole scale of AliCPT: (30～1000)

- 1 module year, AliCPT will observe the EE angular power spectrum with sensitivity comparable to that of Planck. ;
- 10 Module year, AliCPT will be better than Planck ;
- Precise measurement of early dark energy, adiabaticity of primordial fluctuations …

summary

- AliCPT will open new window in northern sky for PGWs.
- AliCPT is expected to be deployed soon, with the goal of achieving precise measurements of CMB polarization.
- Collaborations are welcome to delve into CMB science.

Thanks for your attention!