


Ali CMB Project

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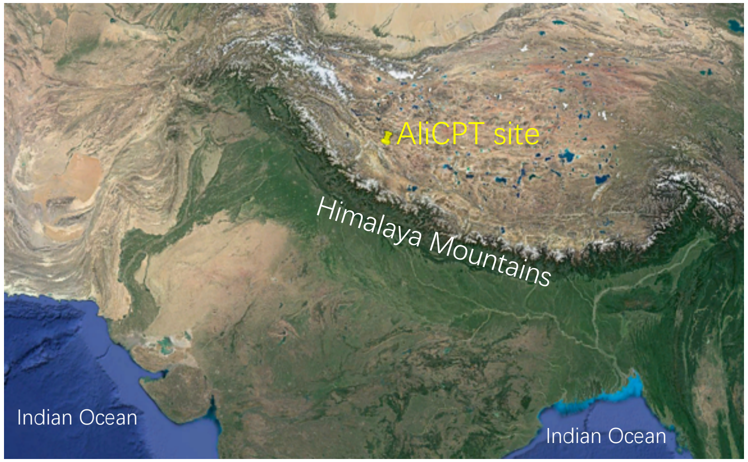
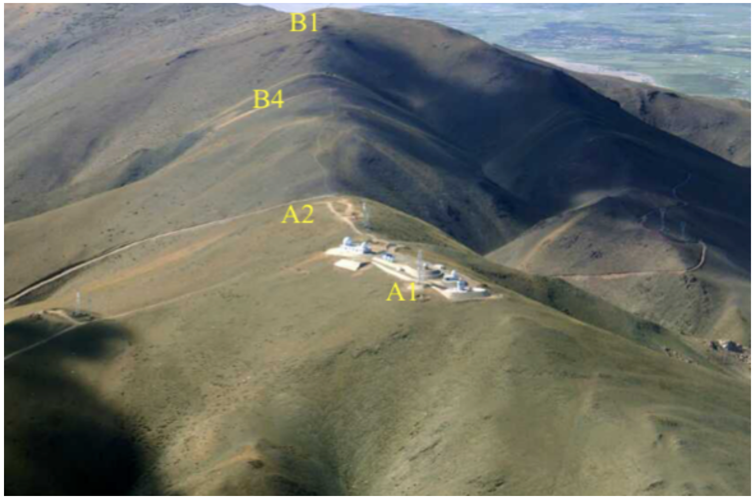
Where is the AliCPT (Ali CMB Polarization Telescope)

Located on a hilltop B1 ($\mathbf{32^{\circ}18'38''}$ N, $\mathbf{80^{\circ}01'50''}$ E),
in the Ngari(Ali) Prefecture of Tibet,
at an altitude of **5250 meters**.



- The Himalayas is to its southwest and runs from northwest to southeast, separating the Ngari(Ali) prefecture from the Indian Ocean.



- AliCPT (B1, 5250m) is only about **1km** to the current well-developed A1 station (5100m) of the Ali observatory.

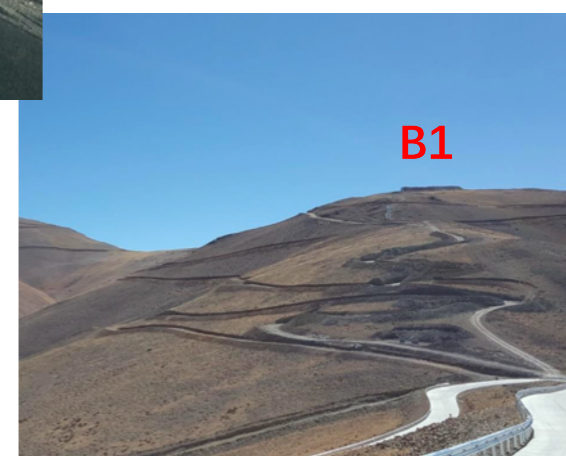
How to go to AliCPT

- Ngari Gunsa Airport is about 20 km far from the AliCPT site.
- Daily commercial flight between Ngari and Lhasa
  One flight between Ngari and Chengdu every Tuesday and Friday.

China National Highway G219

- The National Highway No. 219 is right next to the AliCPT site.

- Concrete pavement towards the B1 point has been completed this year.



Shiquanhe City

Population around 20,000,

equipped with culture, commerce and health facilities.

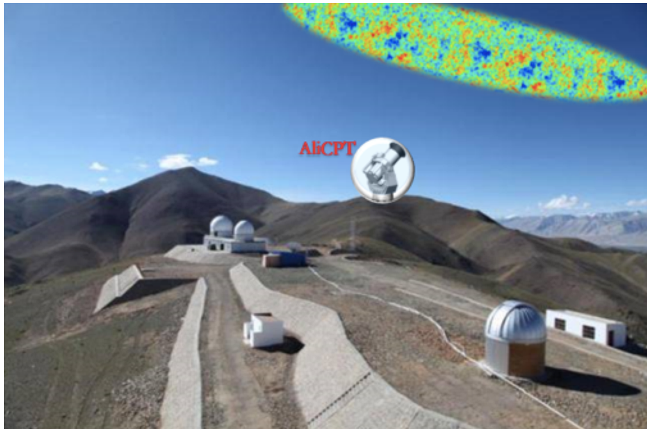
120 Emergency Center

Hotel (**with Oxygen Provided**)

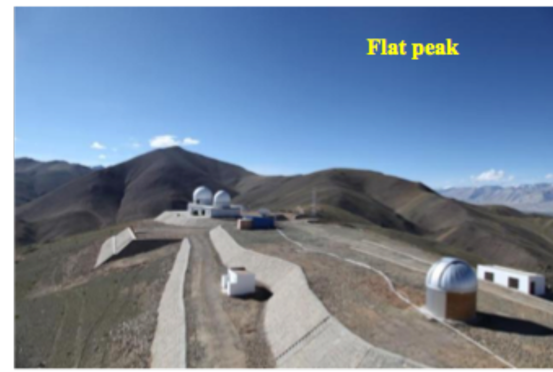
Post office

It is only 30 km far from the AliCPT site.

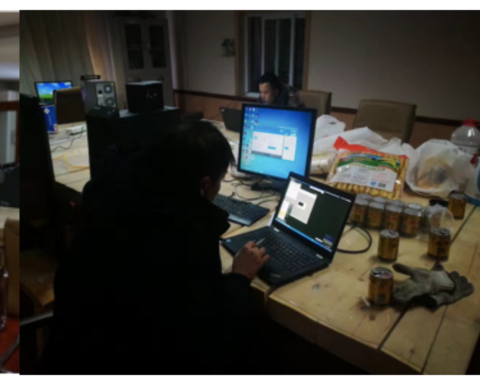
A1 station



Developed about 10 years
150m lower than B1 (AliCPT)
About 1km away from B1

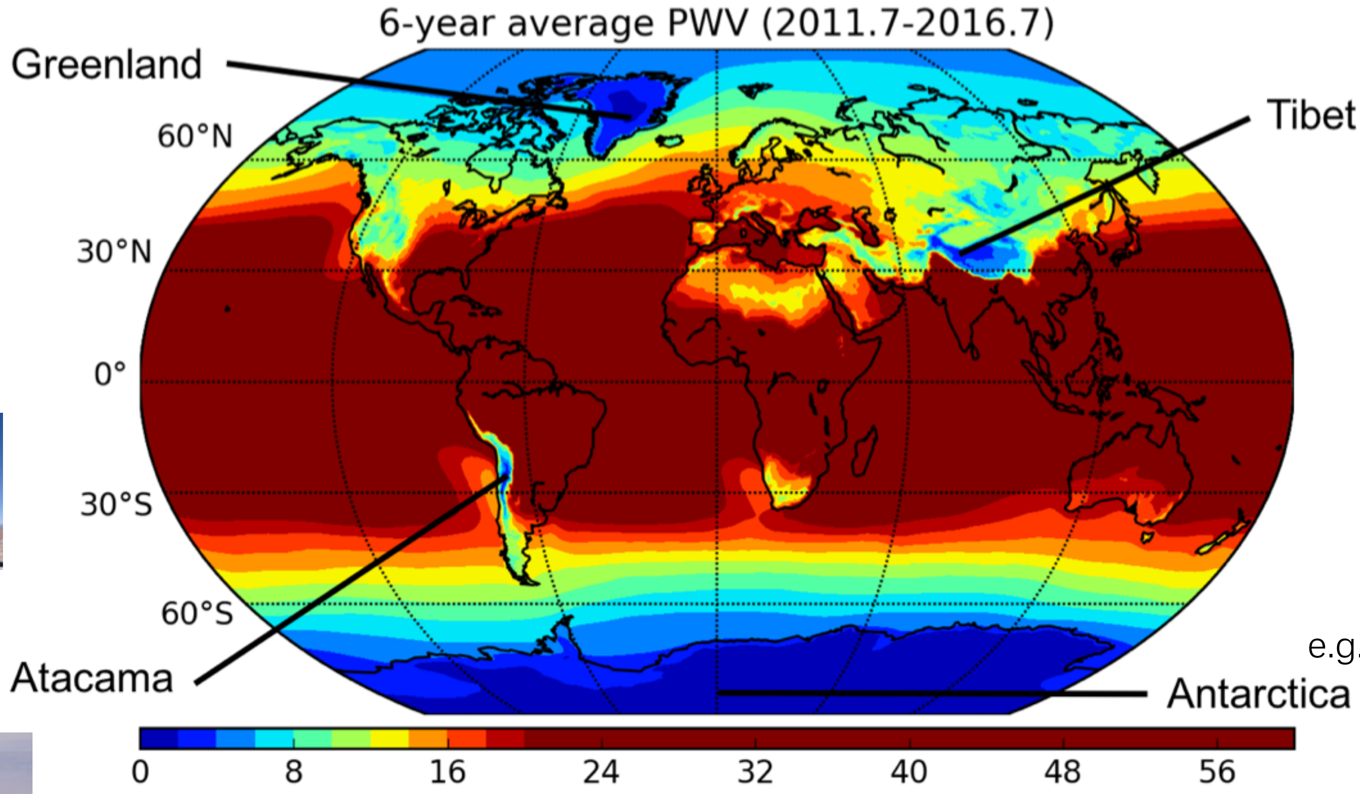


- Some optical telescopes are running now.



- City grid electric power and the network connection have been set up.

Ali: open up a new window for CMB polarization observations in the northern hemisphere



POLARBEAR

ACTpol

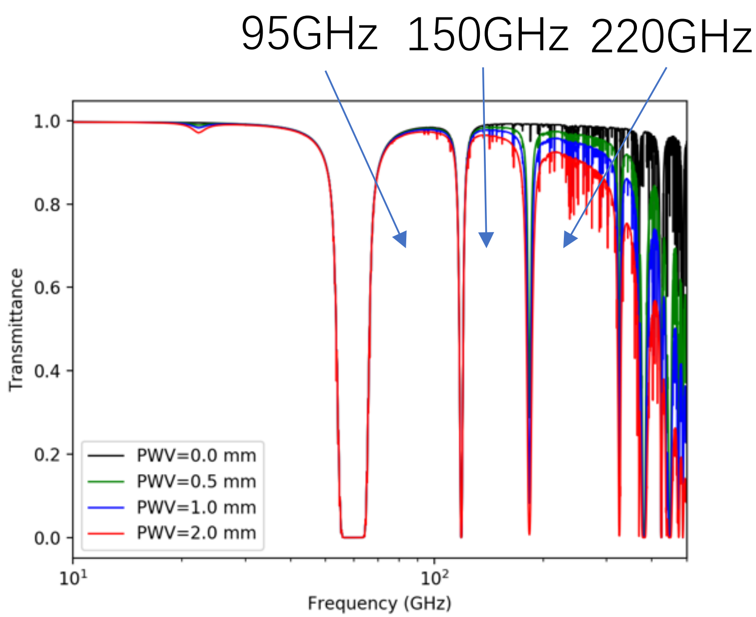
e.g. SPT and BICEP

H. Li *et al* arXiv:1710.03047

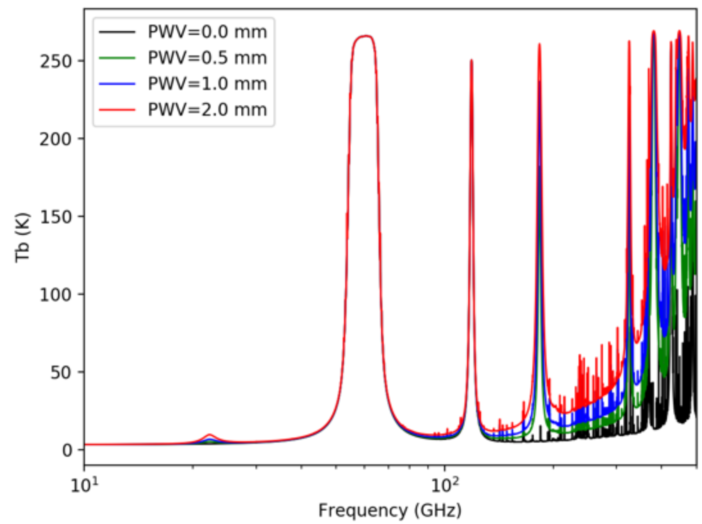
Global distribution of mean PWV (precipitable water vapor)

Importance of PWV to Ground-based CMB Experiments

Precipitable Water Vapor (PWV) characterizes the amount of water vapor, which is defined as the overall depth of water in a column of the atmosphere above ground.



Transmittance for AliCPT



Emission for AliCPT

PWV:
- Absorb CMB photons, reduce transmittance;
- Emission at microwave bands,
  - increase photon shot noise;
  - increase optical loading on detectors.

PWV is a big concern for ground-based CMB experiments.

Datasets for the calculation of PWV

Y.Li, Y.Liu, S.Li, H.Li and X.Zhang, ArXiv:1709.09053

- Datasets：
  - MERRA-2 Reanalysis data (NASA)：
    - Spatial Resolution: 0.625lon*0.5lat*72layers
    - Time Resolution: 3hours
    - Data：Relative humidity, Temperature, Pressure, Altitude....
  - Radiosonde data from Ali local weather station：
    - Send the balloon twice a day：07:00 & 19:00
    - Data ：Dew-point temperature, Temperature, Pressure....

Q.Ye,M.Su,H.Li,X.Zhang, ArXiv:1512.01099
Chao-lin Kuo, ArXiv:1707.08400

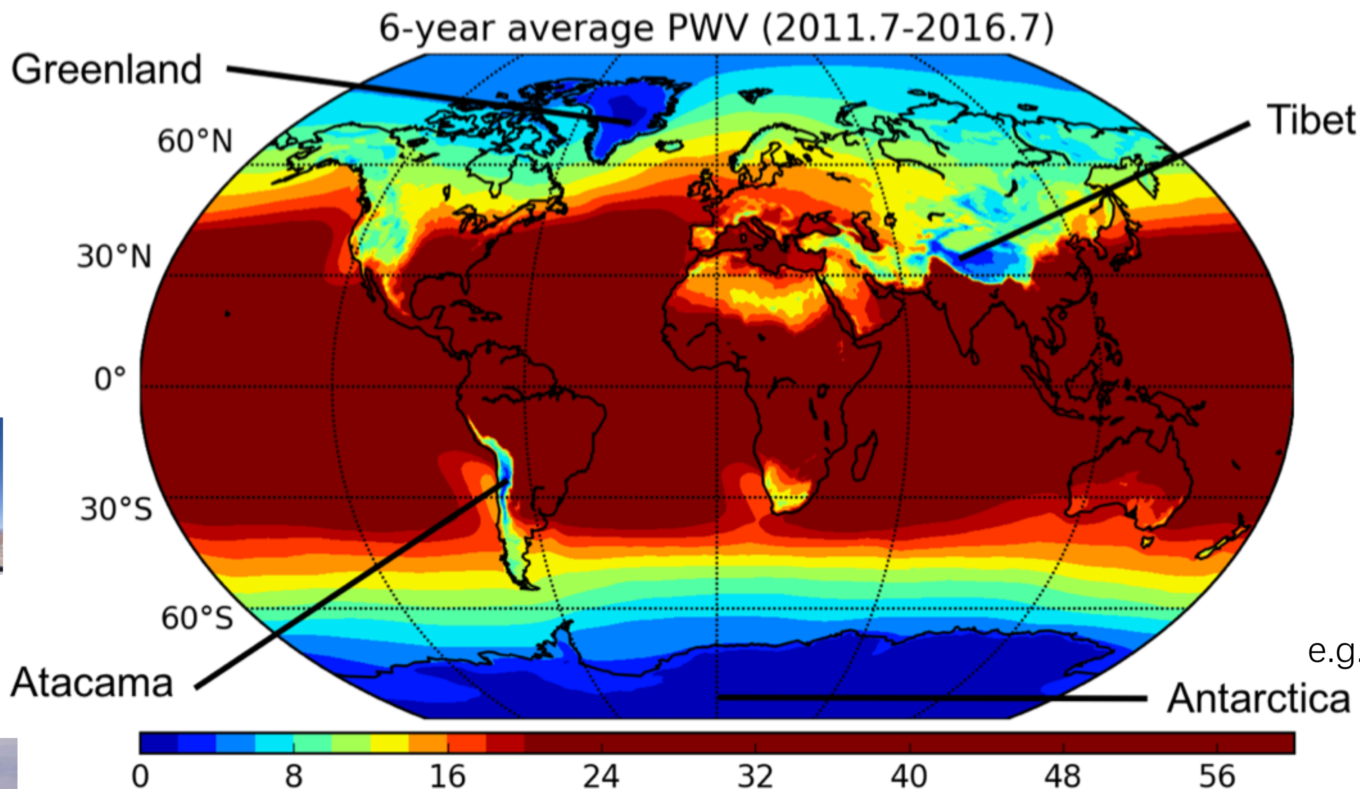
Radiosonde

Formula:

$$PWV = \int \rho_\nu dh = \int q_\nu \rho dh = -1/g \int q_\nu dp \approx -1/g \sum_i q_\nu^i \triangle p_i$$

Result 1

Ali is one of the major sites with lowest PWV



POLARBEAR

ACTpol

e.g. SPT and BICEP

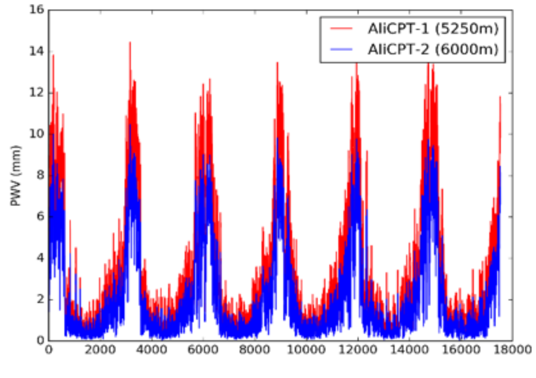
[H. Li *et al* arXiv:1710.03047](https://arxiv.org/abs/1710.03047)

Global distribution of mean PWV (precipitable water vapor) calculated with NASA's MERRA-2 reanalysis data between 2011.7 and 2016.7.

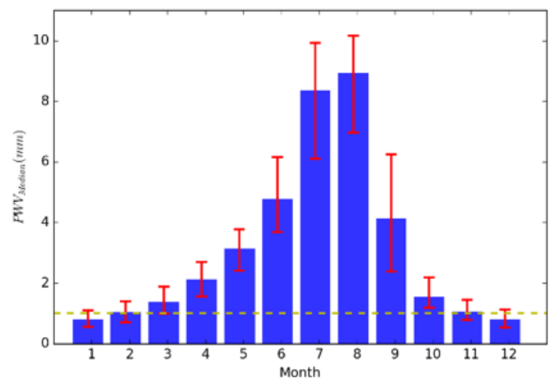
Result 2

PWV for AliCPT

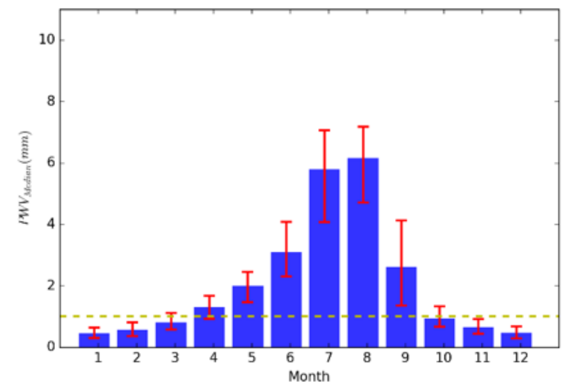
(1mm/5250m, 0.6mm/6000m)



PWV distribution (MERRA-2)



Monthly distribution (5250m,MERRA-2)



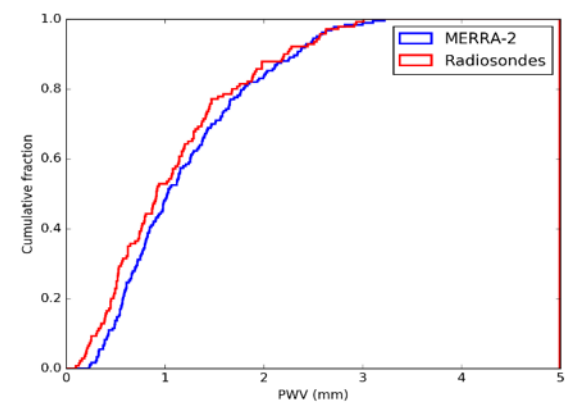
Monthly distribution (6000m,MERRA-2)

- Strong seasonal variation.
- Oct. to Mar: The median value of PWV is

  Radiosonde: 0.92mm/0.56mm

  MERRA-2: 1.07mm/0.62mm → Observing season

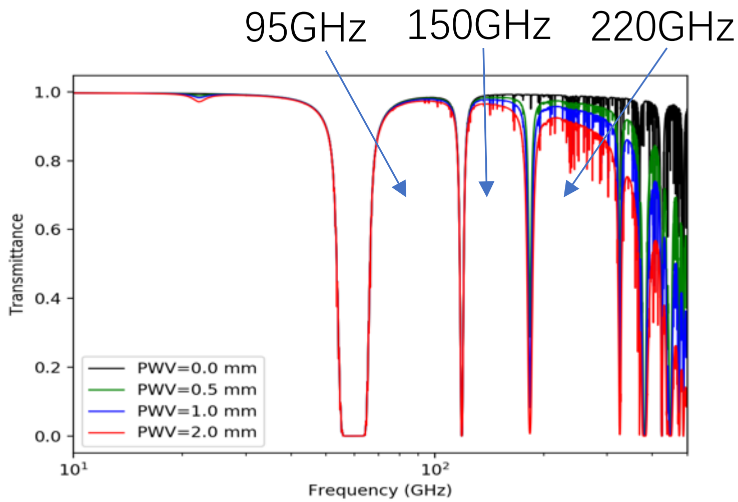
- Results derived from satellite and radiosonde are consistent.



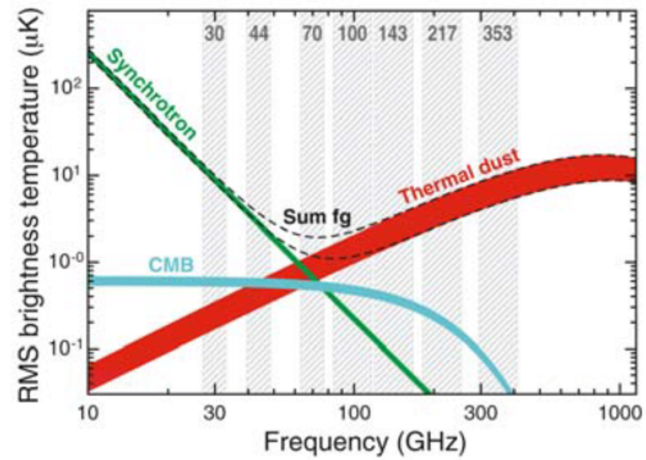
Comparison between MERRA-2 and radiosonde (Oct.-Mar)

AliCPT bands : 95GHz/150GHz

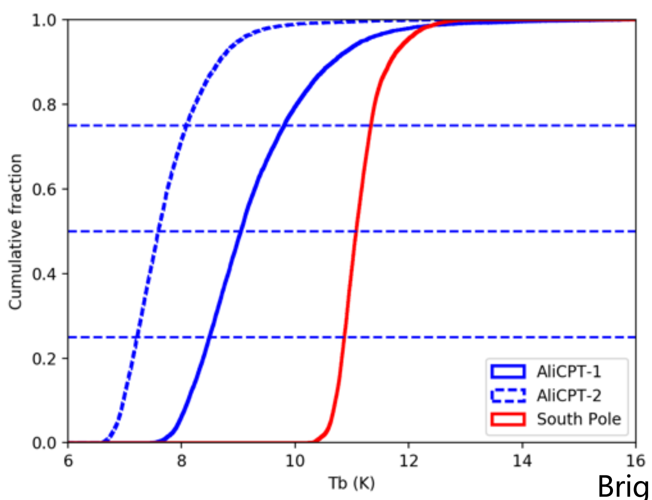
Transmittance

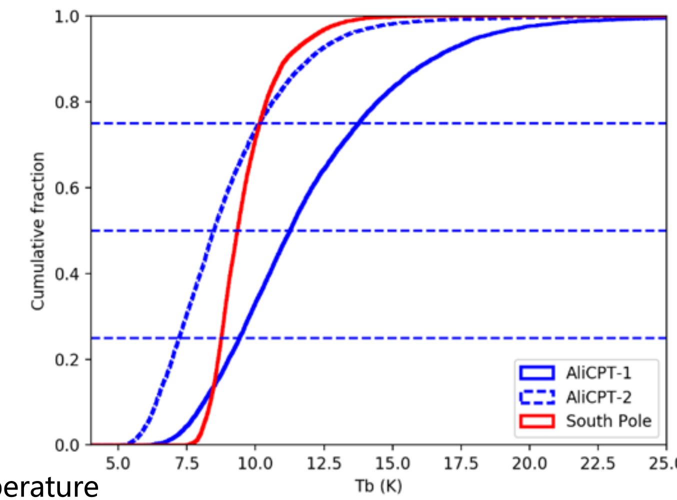


Foreground Spectrum



Intensity of atmospheric emission



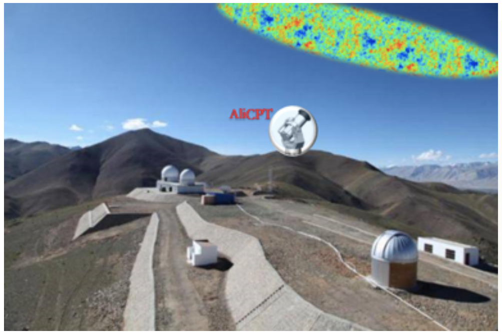


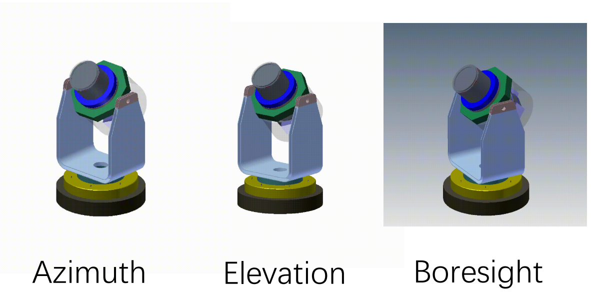
Brightness temperature

95GHz

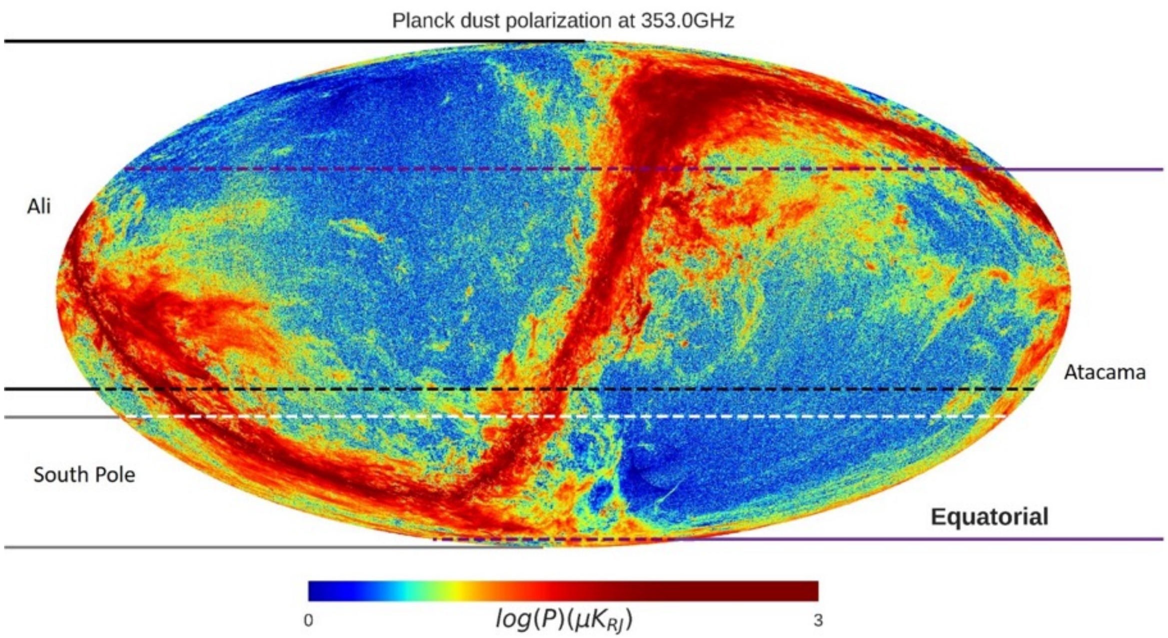
150GHz

Observable sky for AliCPT



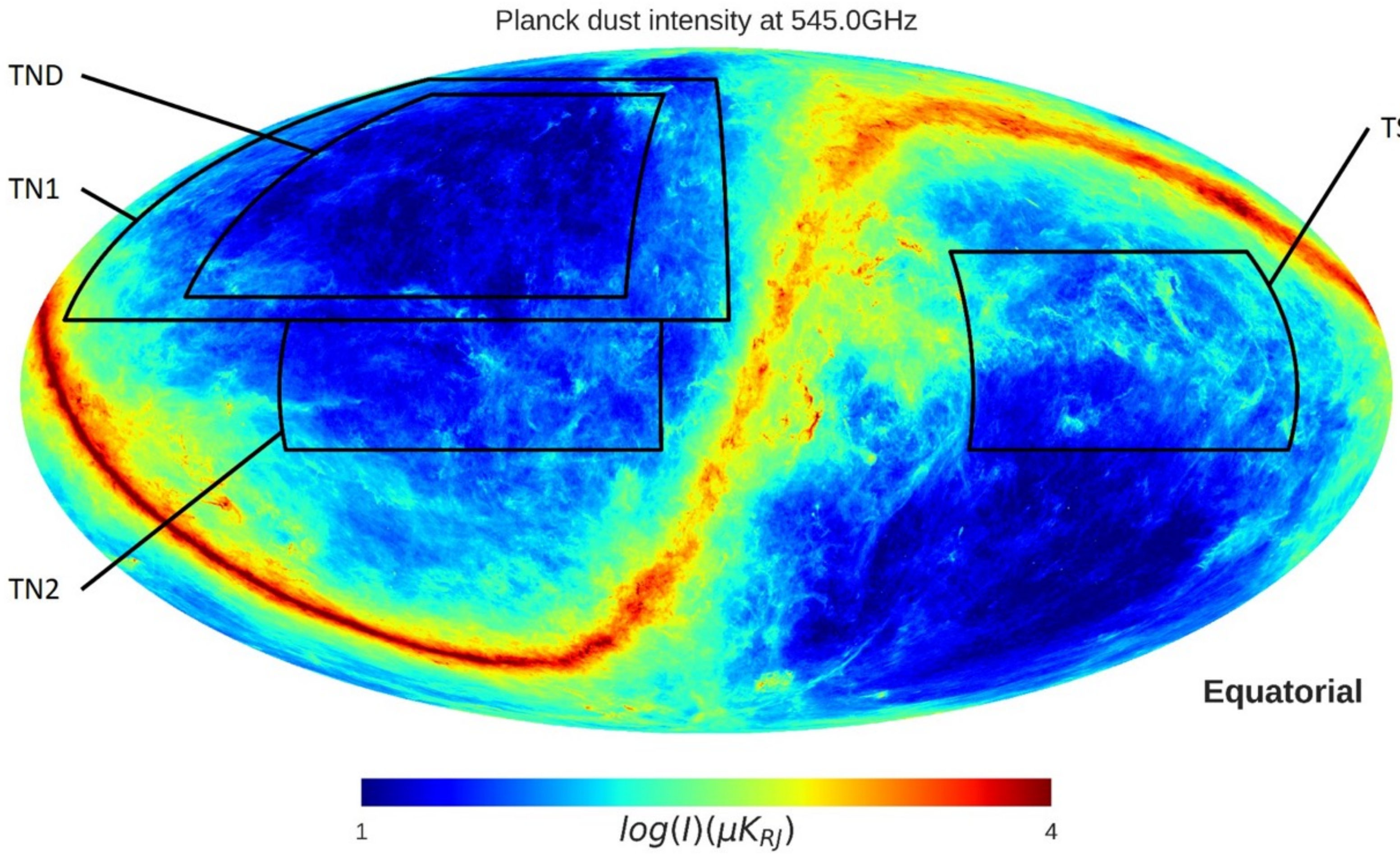


Three-axis driving mount :
FOV ~30°
Elevation : >45°



- AliCPT can cover whole northern sky and partial southern sky.
- AliCPT can cover region with the lowest foreground contamination in the north.
- Overlap between AliCPT and southern experiments can be used for cross-check.
- Complementary to missions in Antarctic and Atacama. Realize full sky coverage.

Target fields for AliCPT



AliCPT will firstly perform large sky patch scanning (TN1, TN2 and TS) then focus on a smaller patch (TND) for deeper survey.

Brief Summary on AliCPT Site Conditions and Comparison with others.

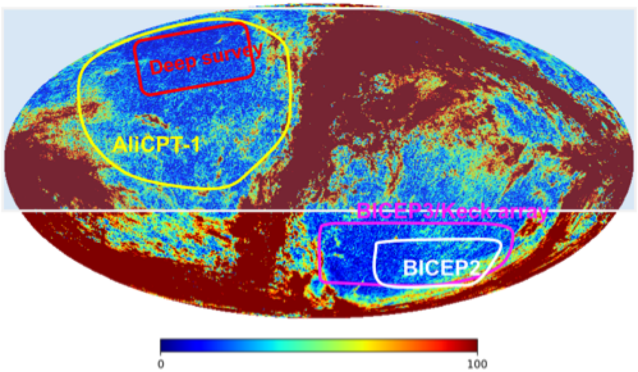


TABLE II: Profile for different sites. Labels [1] and [2] represent the PWV obtained with MERRA-2 and radiosondes.

Site	Height(m)	Time range	PWV(mm)	Sky range	Observable sky (%)
[1]AliCPT-1/AliCPT-2	5250/6000	Oct. - Mar.	1.07/0.62	whole North + Part South	70
[2]AliCPT-1/AliCPT-2	5250/6000	Oct. - Mar.	0.92/0.56	whole North + Part South	70
South Pole(BICEP3)	2835	Apr. - Sep.	0.27	Part South	20
Atacama(POLARBEAR)	5190	Apr. - Sep.	0.85	whole South + Part North	80
Dome A	4093	Apr. - Sep.	0.12	Part South	25

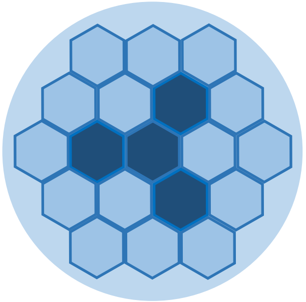
Dome A: the lowest PWV,

but the infrastructure need to be developed.

AliCPT: excellent for CMB experiment in the northern hemisphere.

complementary to CMB experiments in South Pole and Atacama.

AliCPT Schedule and Preliminary Design



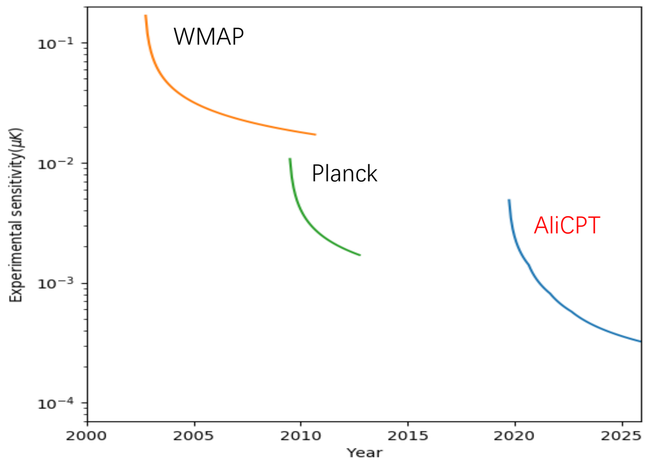
- The AliCPT project has two planned stages. Site construction began in early 2017.
- First stage: AliCPT-1, a dichroic refractor operating at 95 and 150GHz frequency bands with Transition Edge Sensor (TES) bolometers and Superconducting Quantum Interference Devices (SQUIDs) readouts. Sensors and their readouts will be packaged into highly integrated modules, and each contains 1,704 TES sensors. AliCPT-1 will include four modules and its number of detectors will reach 6,816. First light will be in 2020.
- Second stage: AliCPT-2, start in 2020 with four additional modules installed each year until 2022, and the total number of detectors will reach more than 20,000.

	AliCPT-1
Frequency	95GHz/150GHz
Optical Aperture	72cm
F-number	f/1.4
Beam width(deg)	0.3/0.2
FOV (deg)	33.2
Throughput (cm^2sr)	~1000
Number of TES	~7000
$NET_{per\text{-}detector}$ (uK_{CMB}*Sqrt(s))	350
NET_{array} (uK_{CMB}*Sqrt(s))	5.98
Readout	TDM(64:1)

AliCPT Science and Sensitivity

- High precision measurement on CMB polarization in the northern-sky.

Year	2022	2025
Map depth	2.39 uk arcmin	1.38 uk arcmin



- Science and Simulations:
  - Probing the primordial gravitational waves (PGWs) with BB spectra.
  - Measuring the rotation angle, testing CPT symmetry with TB and EB spectra.
  - Investigating the CMB polarization hemispherical asymmetry.
  - Studying the galactic foreground and searching for the cleanest region with lowest foreground for deep survey.
  - Studying the weak-lensing effect, and the cross-correlation between CMB and LSS.
  - Studying the dark energy property, neutrino masses

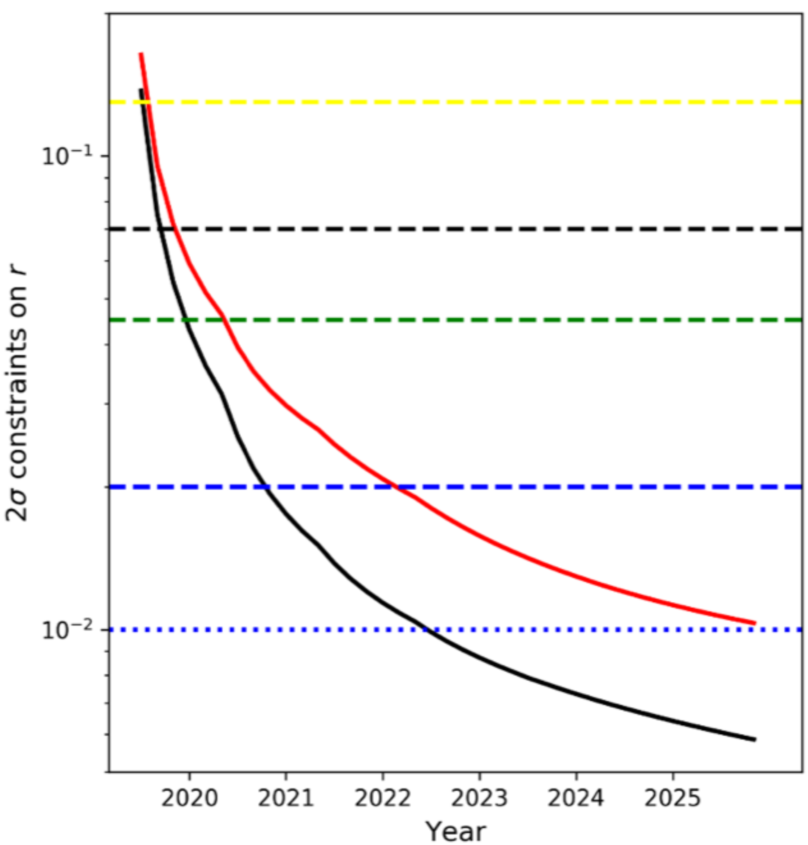
    。。。。。。

AliCPT Science 1

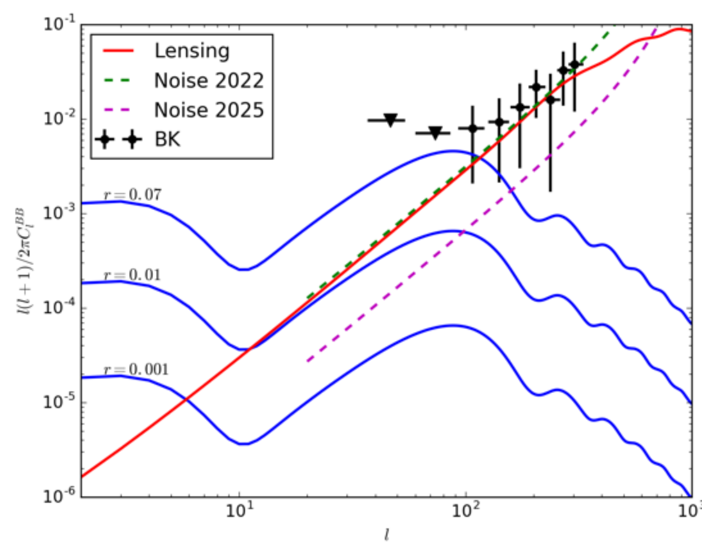
Forecast on tensor-to-scalar ratio r
testing inflation models
(preliminary results)

- Black curve: 2σ limits (1% forground)
- Red curve: 2σ limits (10% forground)

- Black dashed: current limit from BKP (Keck/BICEP2 2016)
- Yellow dashed line: ϕ^2 (Linde, A. D.,1983)
- Green dashed line: $\phi^{2/3}$ (McAllister, L., 2014)
- Alpha attractor (Kallosh, R.,2013)
  - Blue dashed: $\alpha = 5$
  - Blue dotted: $\alpha = 2$



- e-folds number is taken to be 50.



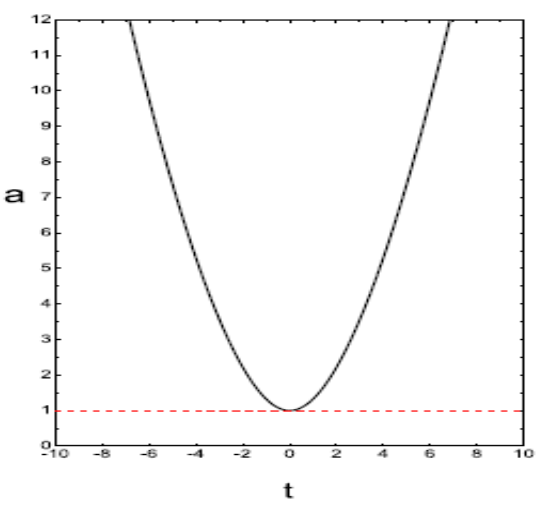
Testing bounce models:

- Ekpyrotic Model: collision of two M branes in 5D (P.Steinhardt 。。。)
  description of effective field theory in 4D is

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{16\pi G} \mathcal{R} + \frac{1}{2} (\partial\phi)^2 - V(\phi) \right)$$

===➔ singular bounce

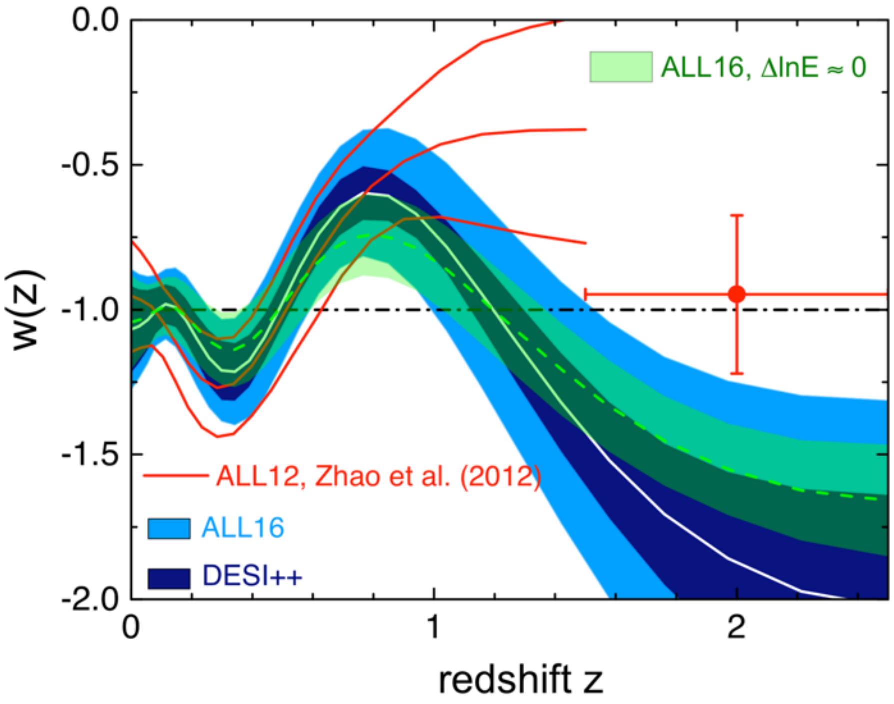
- Non-Singular Bounce with Quintom Matter (Xinmin Zhang. *et al*)



- Quintom Property:
  Equation-of-state: w across -1
- Quintom Models:
  Multi-scalar fields
  Single-scalar field
  with higher derivatives

Current Status on Quintom Dark Energy

Gongbo Zhao et.al.
Nature Astronomy, 1, 627-632, (2017)



Reconstructed evolution history of the dark energy equation of state w

3.5 sigma significance supporting for w across -1

CMB Polarization Rotation Angle

------ Cosmological CPT Violation and its test with CMB

$$\mathcal{L} \sim -\frac{1}{2} C \partial_\mu \phi K^\mu \qquad K^\mu = A_\nu \tilde{F}^{\mu\nu} = \frac{1}{2} A_\nu \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$$

Quintessential Baryo/Leptogenesis & CMB polarization

Bo Feng, Hong Li, Ming-zhe Li, Xin-min Zhang,
Phys.Lett.B620:27-32,2005.

CPT violation → $\Delta\alpha \neq 0$

$$\tan\alpha \equiv \frac{B_z}{B_y} = \tan(\frac{1}{2} C\phi + I) \quad \alpha = \frac{1}{2} C\phi + I \quad \Delta\alpha = \frac{1}{2} C \Delta\phi$$

$$\begin{cases} Q' = Q\cos 2\Delta\alpha + U \sin 2\Delta\alpha \\ U' = -Q\sin 2\Delta\alpha + U\cos 2\Delta\alpha \end{cases}$$

$$C_l'^{TT} = C_l^{TT}$$

$$C_l'^{EE} = C_l^{EE} \cdot \cos^2 2\Delta\alpha + C_l^{BB} \sin^2 2\Delta\alpha$$

$$C_l'^{BB} = C_l^{EE} \cdot \sin^2 2\Delta\alpha + C_l^{BB} \cos^2 2\Delta\alpha$$

$$C_l'^{TE} = C_l^{TE} \cdot \cos 2\Delta\alpha$$

$$C_l'^{TB} = C_l^{TE} \cdot \sin 2\Delta\alpha$$

$$C_l'^{EB} = \frac{1}{2}(C_l^{EE} - C_l^{BB}) \sin 4\Delta\alpha$$

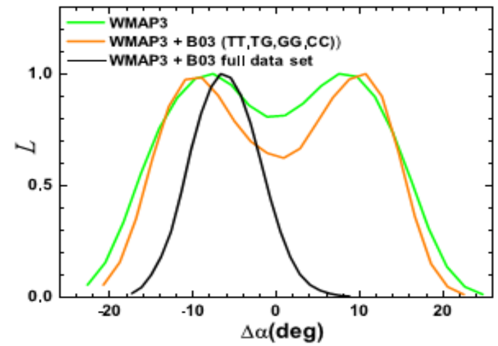


FIG. 1 (color online). One-dimensional constraints on the rotation angle $\Delta\alpha$ from WMAP data alone (green or light gray line), WMAP and the 2003 flight of BOOMERANG B03 TT, TG, GG and CC (orange or gray line), and from WMAP and the full B03 observations (TT, TG, GG, CC, TC, GC) (black line).

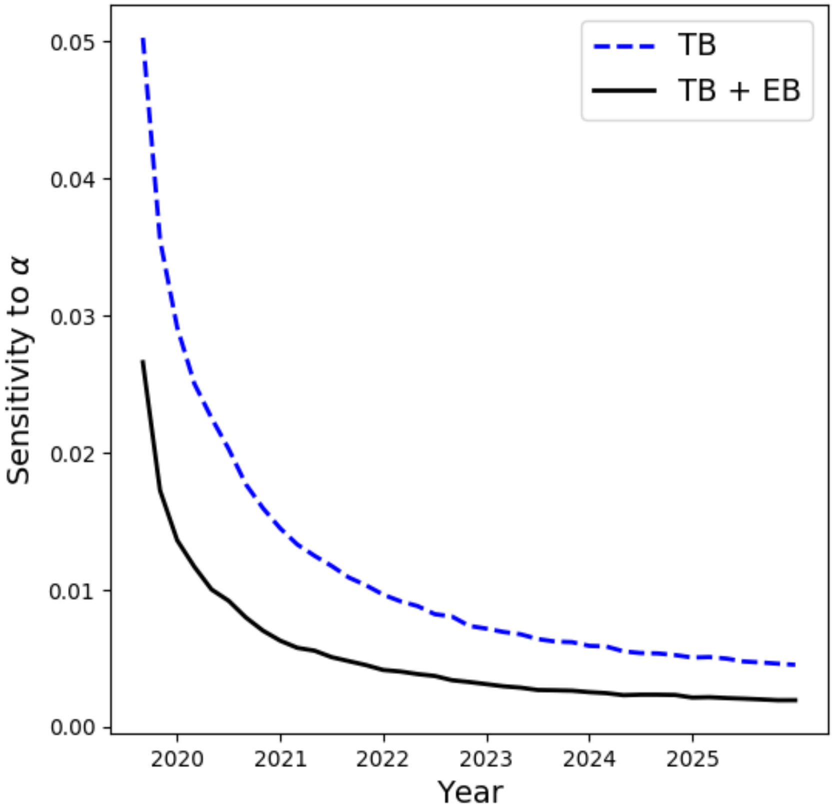
Bo Feng, Mingzhe Li , Jun-Qing Xia, Xuelei Chen and Xinmin Zhang
Phys. Rev. Lett. 96, 221302 (2006)

Forecast on rotation angle

(preliminary results)

Current Constraints:

	Data	$\alpha + \sigma_\alpha^{stat} + \sigma_\alpha^{sys}$
1	WMAP3+BOOMERANG	$-6^\circ \pm 4^\circ$
2	WMAP3	$-2.5^\circ \pm 3.0^\circ$
3	WMAP5	$-1.7^\circ \pm 2.1^\circ$
4	WMAP7	$-1.1^\circ \pm 1.4^\circ \pm 1.5^\circ$
5	WMAP9	$-0.36^\circ \pm 1.24^\circ \pm 1.5^\circ$
6	QUaD	$-0.56^\circ \pm 0.82^\circ \pm 0.5^\circ$
7	BICEP1	$-2.6^\circ \pm 1.02^\circ$
8	BICEP1	$-2.77^\circ \pm 0.86^\circ \pm 1.3^\circ$
9	POLARBEAR	$-1.08^\circ \pm 0.20^\circ \pm 0.5^\circ$
10	ACTPol	$-0.2^\circ \pm 0.5^\circ$
11	Planck 2015	$0.35^\circ \pm 0.05^\circ \pm 0.28^\circ$



Current limit: about 1 deg
By 2022: reach 0.01 deg.

Will improve the current limit by two order of magnitude.

Spatial Dependent CMB Rotation Angle

Anisotropic rotation M.L. & Zhang, PRD (2008)

$$p_\mu = \frac{\beta}{M}\partial_\mu\phi \qquad \alpha = \frac{\beta}{M}[\phi_0 - \phi(\vec{x},\ \eta_{LSS})] \qquad \alpha = \bar{\alpha} + \delta\alpha$$

$$\tilde{C}_l^{TE} = C_l^{TE}\cos(2\bar{\alpha})(1-2\langle\delta\alpha^2\rangle)\ ,$$

$$\tilde{C}_l^{TB} = C_l^{TE}\sin(2\bar{\alpha})(1-2\langle\delta\alpha^2\rangle)\ ,$$

$$\tilde{C}_l^{EE} = [C_l^{EE}\cos^2(2\bar{\alpha}) + C_l^{BB}\sin^2(2\bar{\alpha})](1-4\langle\delta\alpha^2\rangle) + \sum_{l_1 l_2}\begin{pmatrix} l & l_1 & l_2 \\ 2 & -2 & 0 \end{pmatrix}^2 \frac{(2l_1+1)(2l_2+1)}{2\pi} C_{l_2}^{\alpha}\{[1+(-1)^{L+1}\cos(4\bar{\alpha})]C_{l_1}^{EE} + [1+(-1)^{L}\cos(4\bar{\alpha})]C_{l_1}^{BB}\}$$

$$\tilde{C}_l^{BB} = [C_l^{EE}\sin^2(2\bar{\alpha}) + C_l^{BB}\cos^2(2\bar{\alpha})](1-4\langle\delta\alpha^2\rangle) + \sum_{l_1 l_2}\begin{pmatrix} l & l_1 & l_2 \\ 2 & -2 & 0 \end{pmatrix}^2 \frac{(2l_1+1)(2l_2+1)}{2\pi} C_{l_2}^{\alpha}\{[1+(-1)^{L}\cos(4\bar{\alpha})]C_{l_1}^{EE} + [1+(-1)^{L+1}\cos(4\bar{\alpha})]C_{l_1}^{BB}\}$$

$$\tilde{C}_l^{EB} = \frac{1}{2}\sin(4\bar{\alpha})(C_l^{EE} - C_l^{BB})(1-4\langle\delta\alpha^2\rangle) + \sin(4\bar{\alpha})\sum_{l_1 l_2}\begin{pmatrix} l & l_1 & l_2 \\ 2 & -2 & 0 \end{pmatrix}^2 \frac{(2l_1+1)(2l_2+1)}{2\pi} C_{l_2}^{\alpha}(-1)^{L+1}(C_{l_1}^{EE} - C_{l_1}^{BB})$$

Kamionkowski., PRL(2008)
Gluscevic,*et al.*, PRD(2009)
Yadav, *et al.*, PRD(2009)
Keck/BICEP2. PRD (2017)
。。。。。。

Sources: Cosmic Scalar, Axion-like Cosmic String。。。

AliCPT Science 3

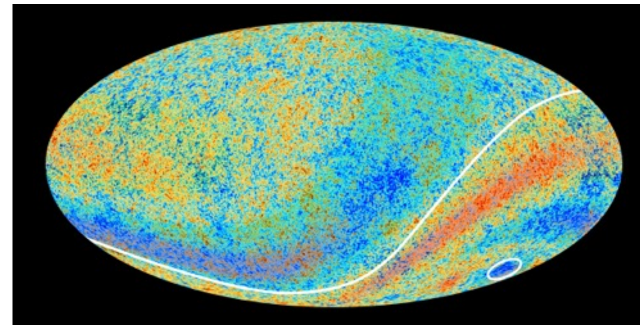
Test on Hemispherical Asymmetry in CMB Polarization

Temperature Asymmetry (WMAP, Planck):

- Average temperatures in ecliptic hemispheres:
  slightly lower in the north
  slightly higher in the south
- Dipole modulation

$$\frac{\Delta T}{T}(\hat{n}) = s(\hat{n})\left[1 + A\ \hat{n}\cdot\hat{p}\right]$$

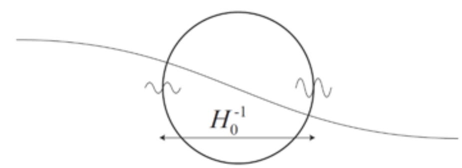
  - Systematical errors
  - Contaminations
  - Physical origins
    - Superhorizon Perturbation



Planck

Best-fit dipole:

Amplitude: A=0.072±0.022
Direction: (227,-27)deg.



A.L.Erickcek, *et al*
Phys.Rev.D78:123520,2008

Polarization Asymmetry:

- Similar asymmetry may be observed in polarization.
- Measurement on large-scale polarization map needed.
- Combining AliCPT in the north and other projects in the south,
  test the asymmetry in polarization for the first time.

Activities & Meetings

Summary and Discussions

- **Brief introduction to Ali CMB Project**
  One of the four gravitational waves projects in China
  (the others being FAST, space probes TianQin & TaiJi)

- **Led by IHEP, a worldwide collaboration with more than 15 institutes and universities**

- **Supported by the CAS, NSFC and MOST of China**

- **Lab construction started in early 2017**
  First light scheduled in 2020

Thank you all for being interested in AliCPT !