

# **Angle calibration system for CMB telescope**

*– quest for neutrino hierarchy  
using CMB polarization*

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Dec. 22, 2014

Neutrino mass  
via CMB pol.

**A journey of a thousand miles**

**begins with a first step**

**千里の道も一歩から**

Today's main topic  
i.e., calibration

# Contents

- Scientific goal
  - Neutrino mass from CMB polarization
- Instrumental motivation
  - Why calibration?
- Novel cal. for polarization angle
  - Principle
  - Current status
  - prospects



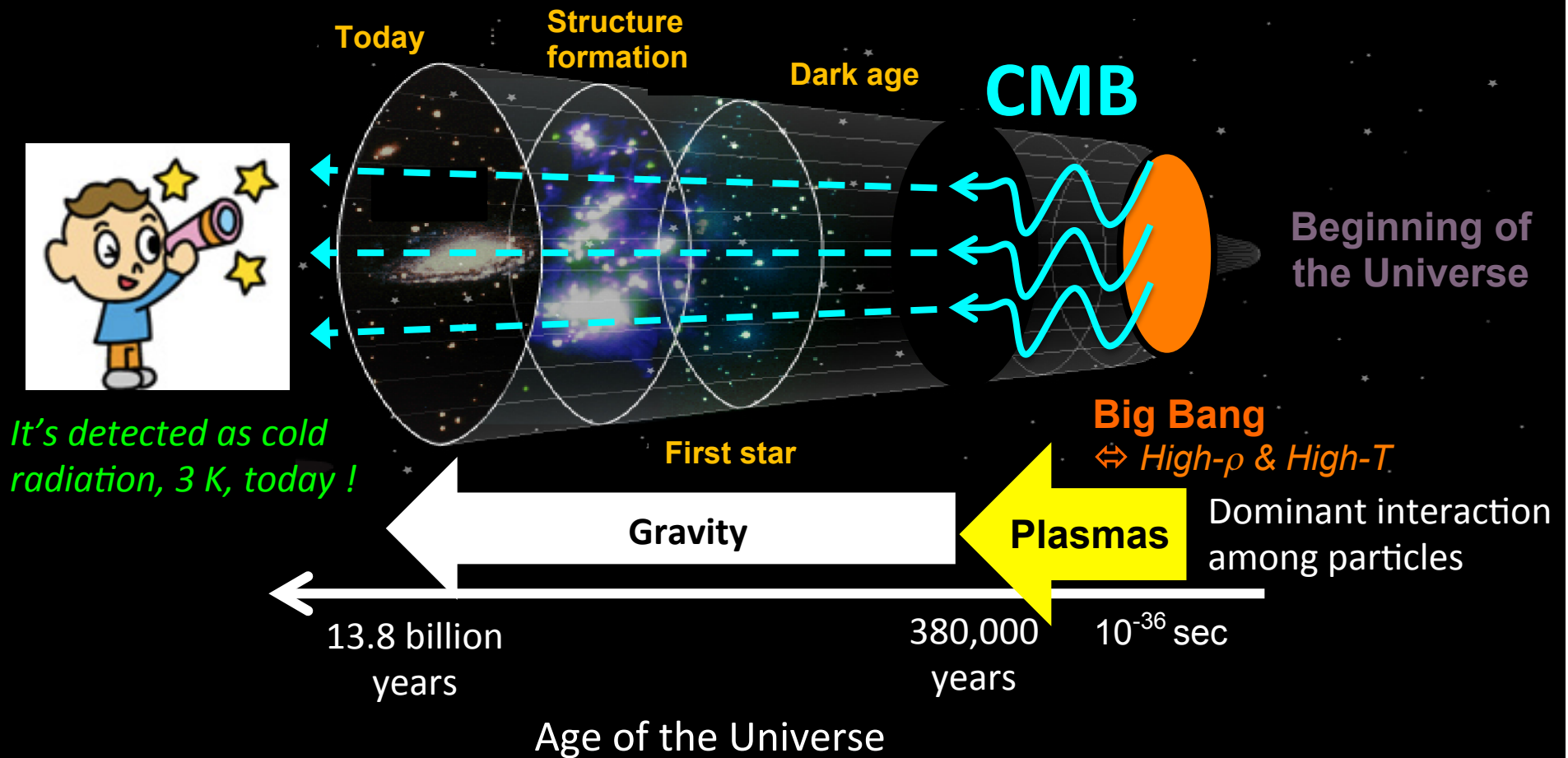
*Need a pickel for  
the first step !!*



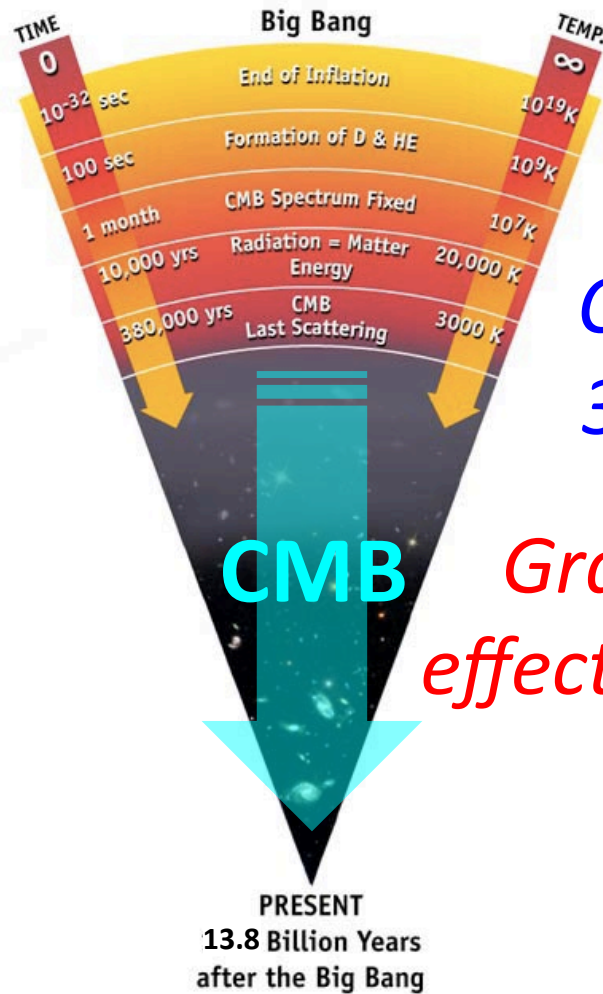
# What's CMB ?

# What's CMB ?

It's Big Bang's thermal radiation, i.e., photon !



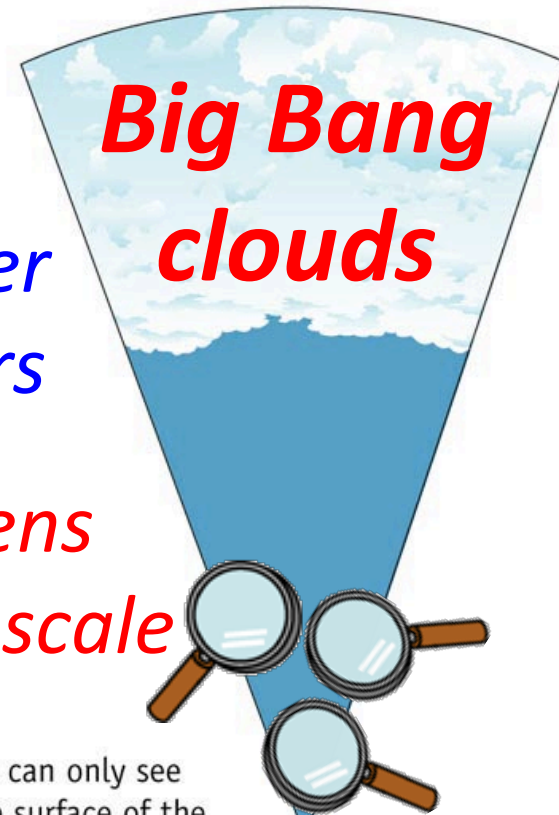
# “CMB today” is surface of “Big Bang clouds”



CMB

Clear sky after 380,000 years

Gravitational lens effects in  $O(0.1^\circ)$ -scale



We can only see the surface of the cloud where light was last scattered

The cosmic microwave background Radiation's “surface of last scatter” is analogous to the light coming through the clouds to our eye on a cloudy day.

# Gravitational lens makes rotation of polarization-axis



*IF CMB is polarized,  
we can measure the lensing power*

Is CMB polarized ?

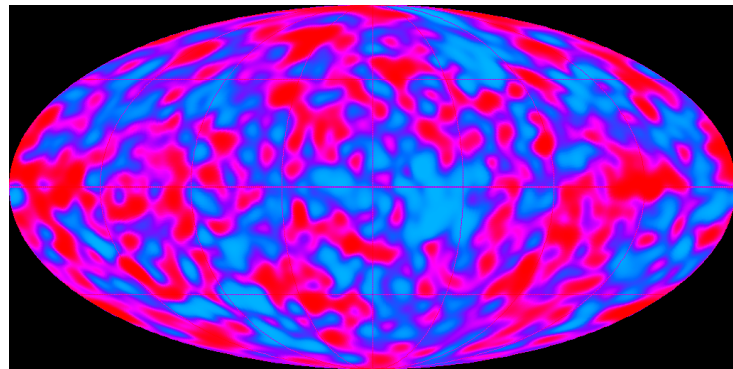
# YES, CMB is polarized



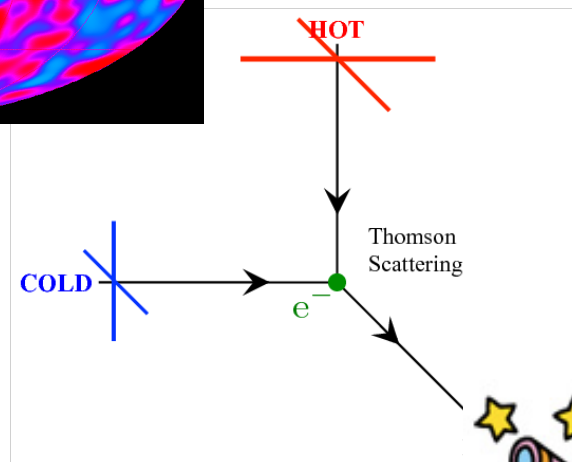
Scattering in ``clouds'' created CMB polarization !



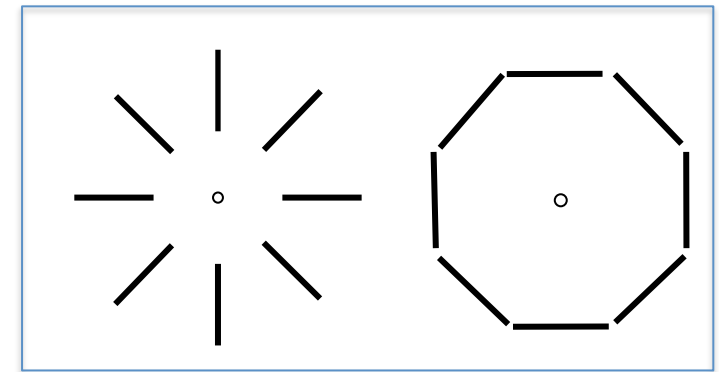
# Tiny non-uniformity of universe, 1/1,000%, made CMB polarization pattern



**HOT, COLD**



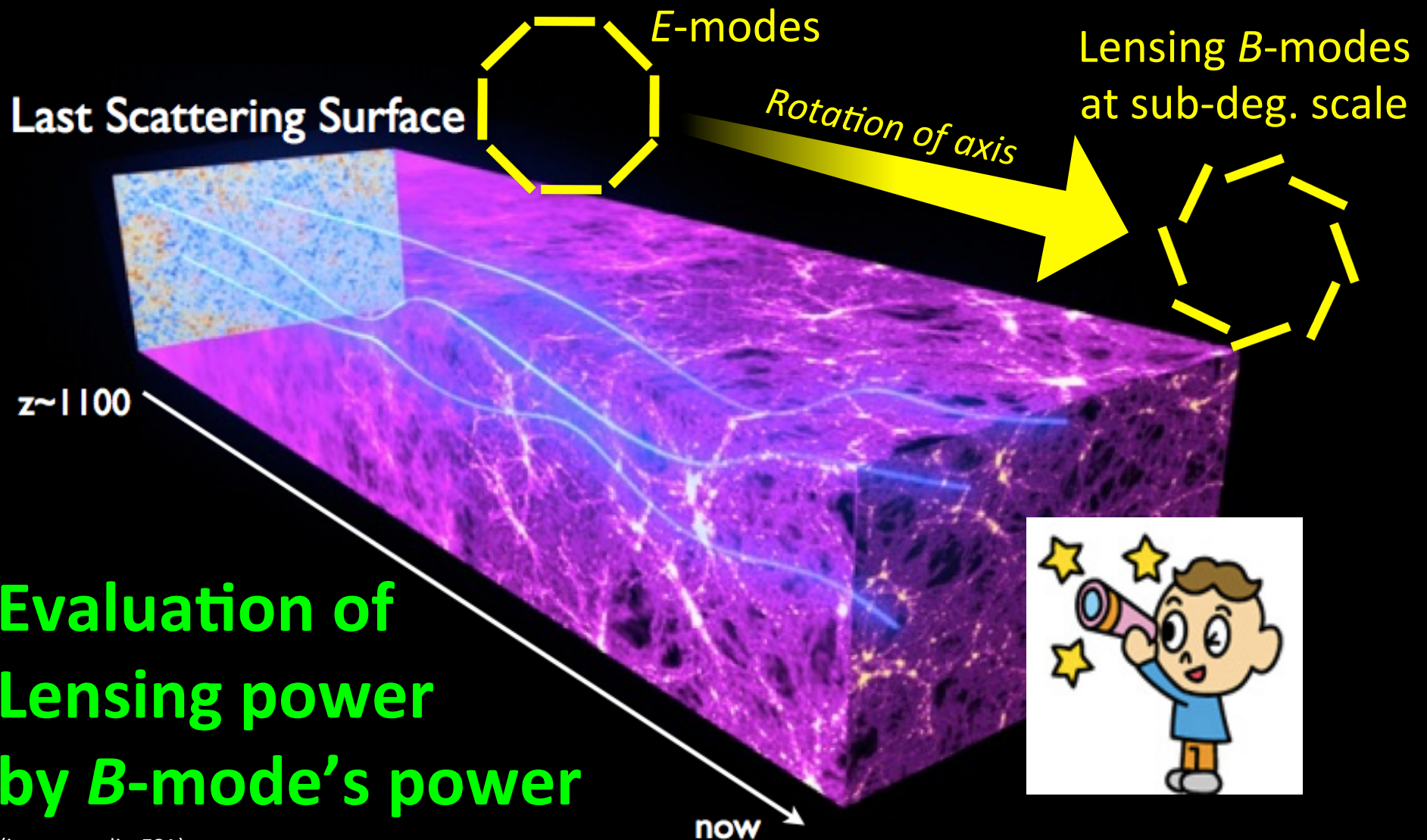
**E-modes**



*Symmetric  
polarization  
pattern !*

***E-modes are alias of non-uniformity  
(No information for gravitational lens yet)***

# Weak lensing makes asymmetric patterns in CMB polarization

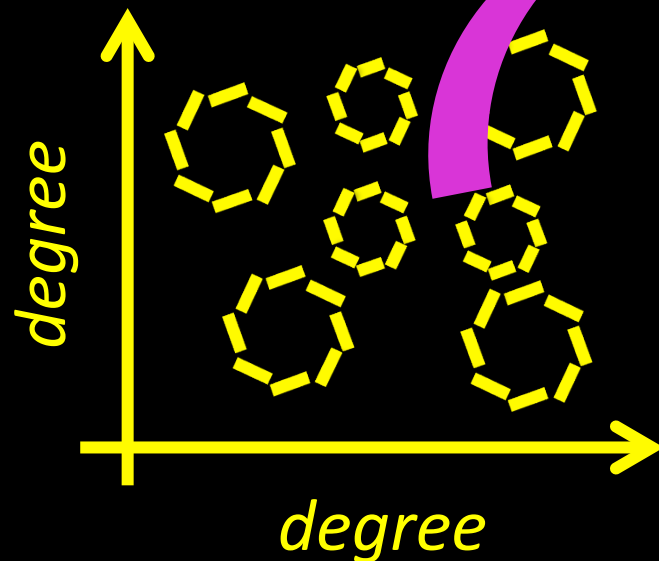


# “Voice print” analysis

Human voice is characterized in Fourier space

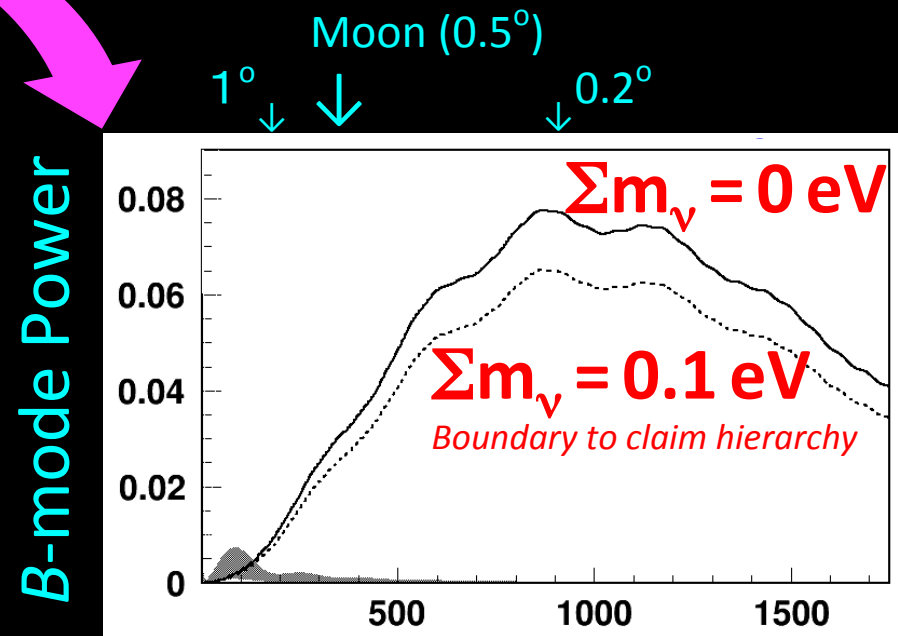


# Power of lens is also characterized in Fourier space of CMB patterns



**Pattern image map**  
*(Here, it's not realistic simulation at all)*

## Voice print spectrum



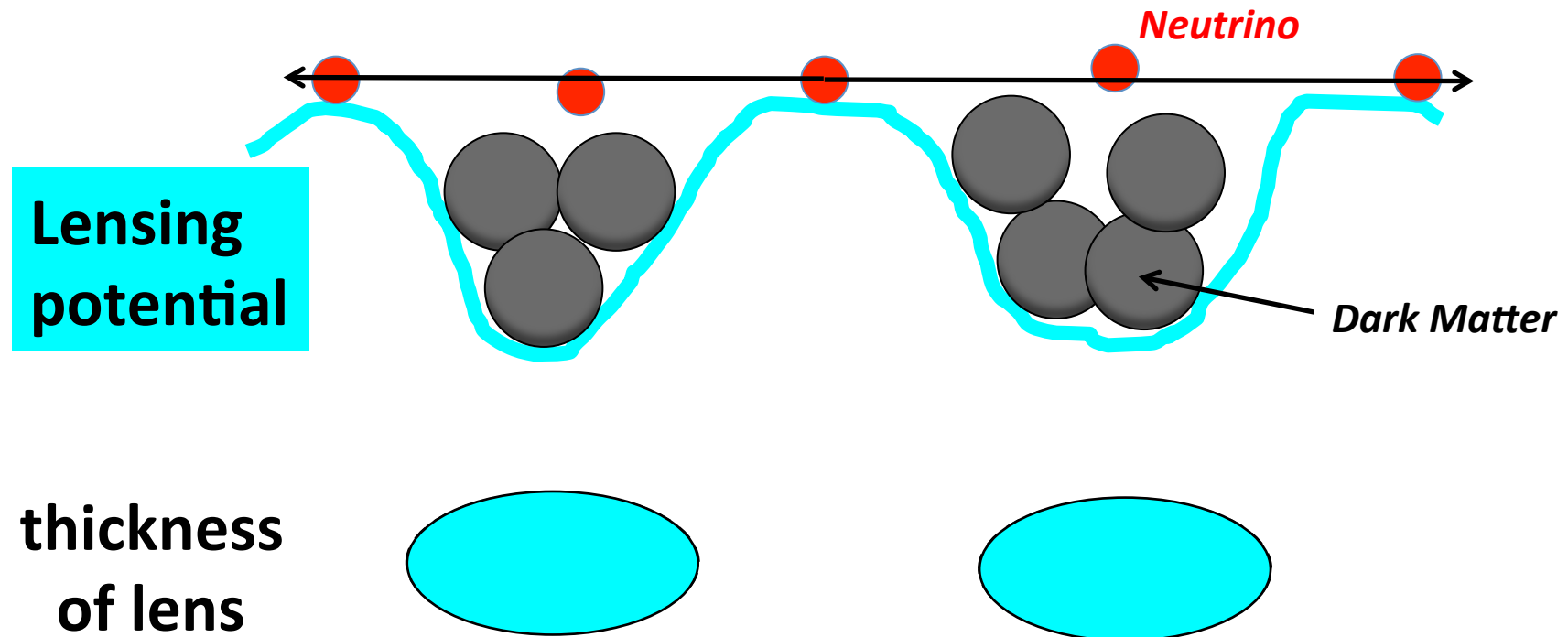
**Multipole /**  
 $= 180^\circ / [\text{pattern-scale}]$

# More neutrino mass $\rightarrow$ Less lensing

Neutrino is high-speed particle (even though it is massive)

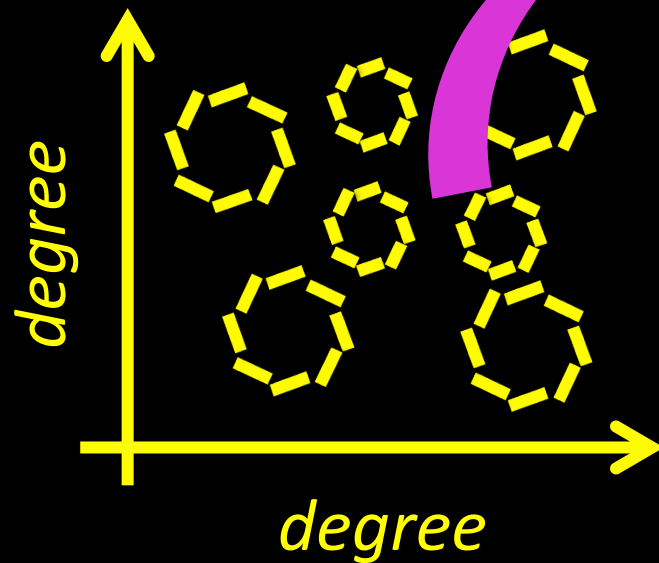
$\rightarrow$  No localization in the scale of galaxy clusters

$\rightarrow$  No contribution for gravitational lens



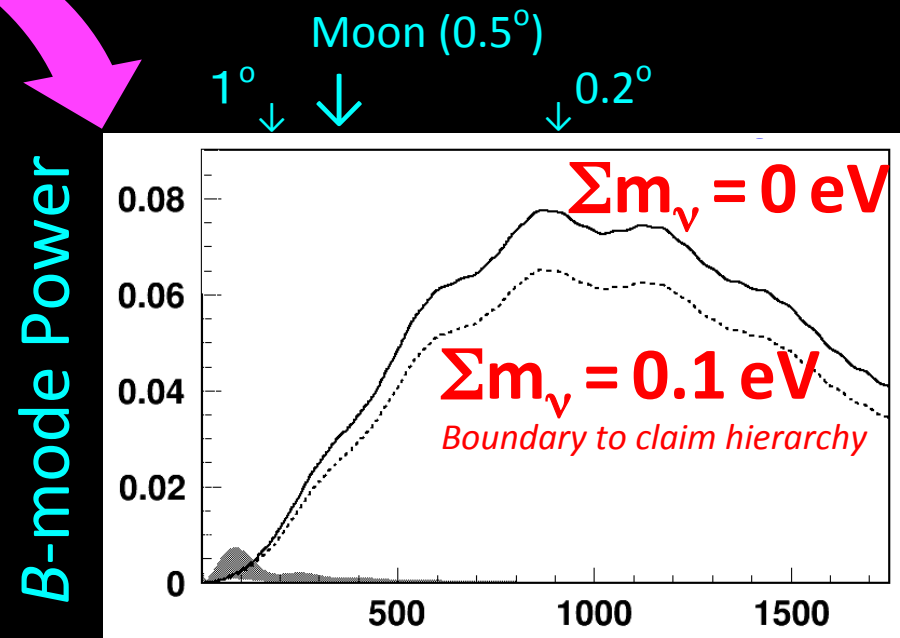
*Thickness of lens becomes smaller if neutrino has larger mass*

# Lensing B-mode's power constrains $\Sigma\nu$



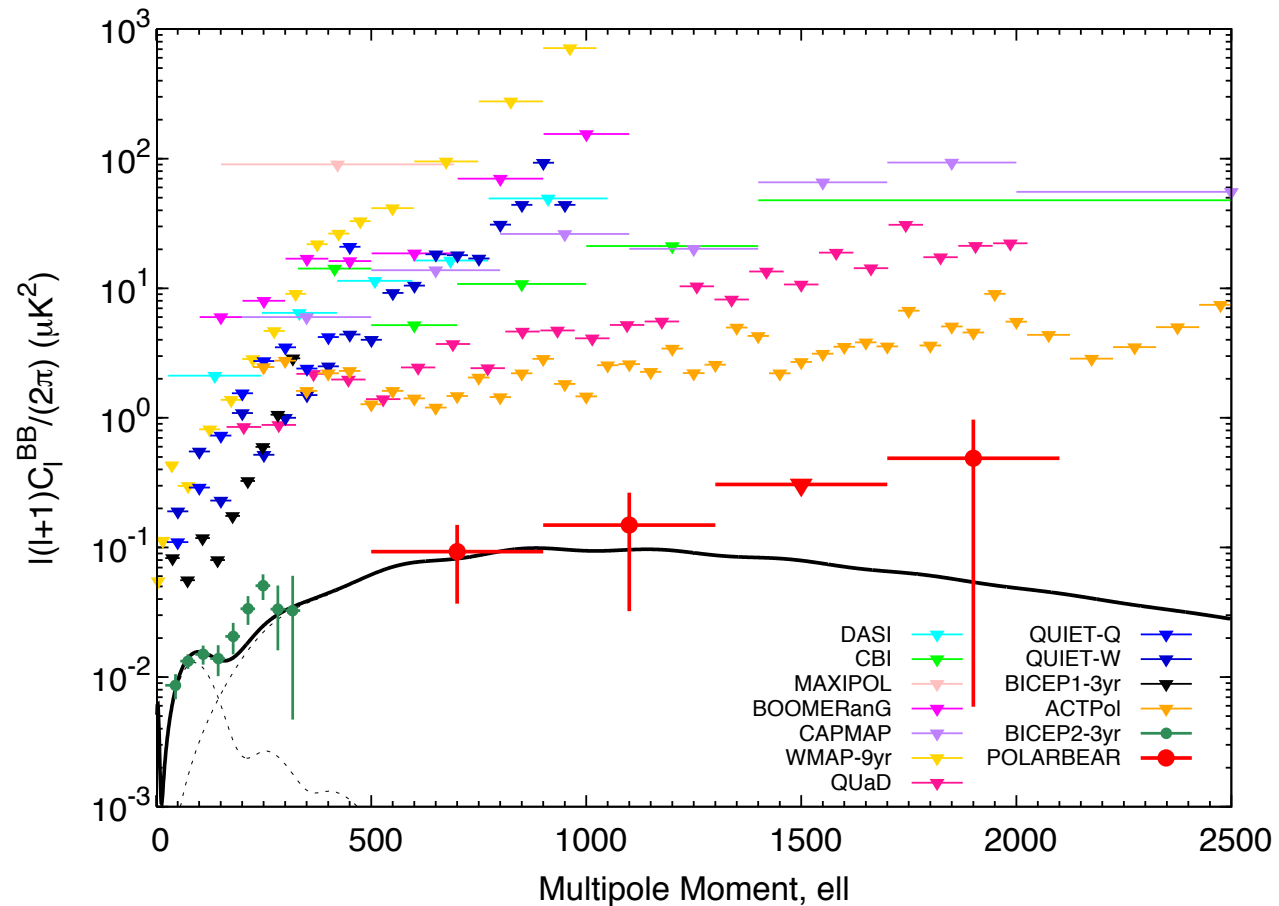
Pattern image map  
*(Here, it's not realistic simulation at all)*

## Voice print spectrum



Multipole /  
=  $180^\circ / [\text{pattern-scale}]$

# CMB B-mode observation, Today



Credit  
Y. Chinone

**We just stand at the start-line,  
i.e., just start to see non-zero power**

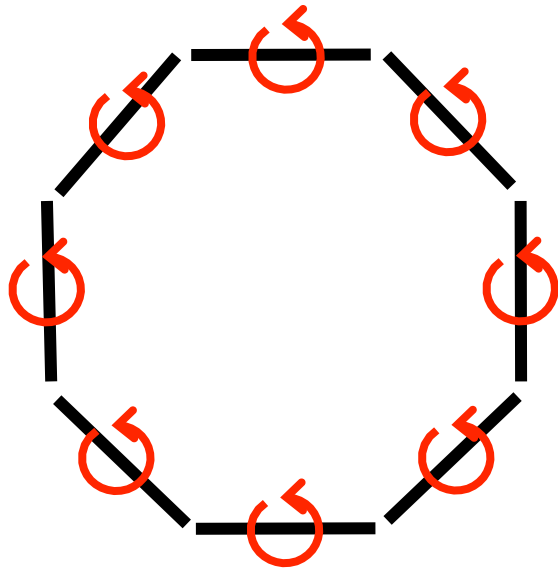
**Prior to accumulation of statistics,  
instrumental precision should be good !**



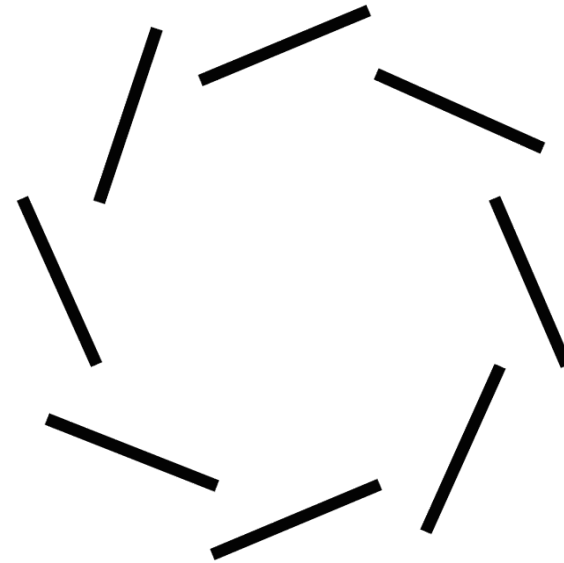
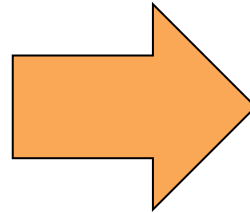


Why do we need pickel ?

Why angle calibration is important ?



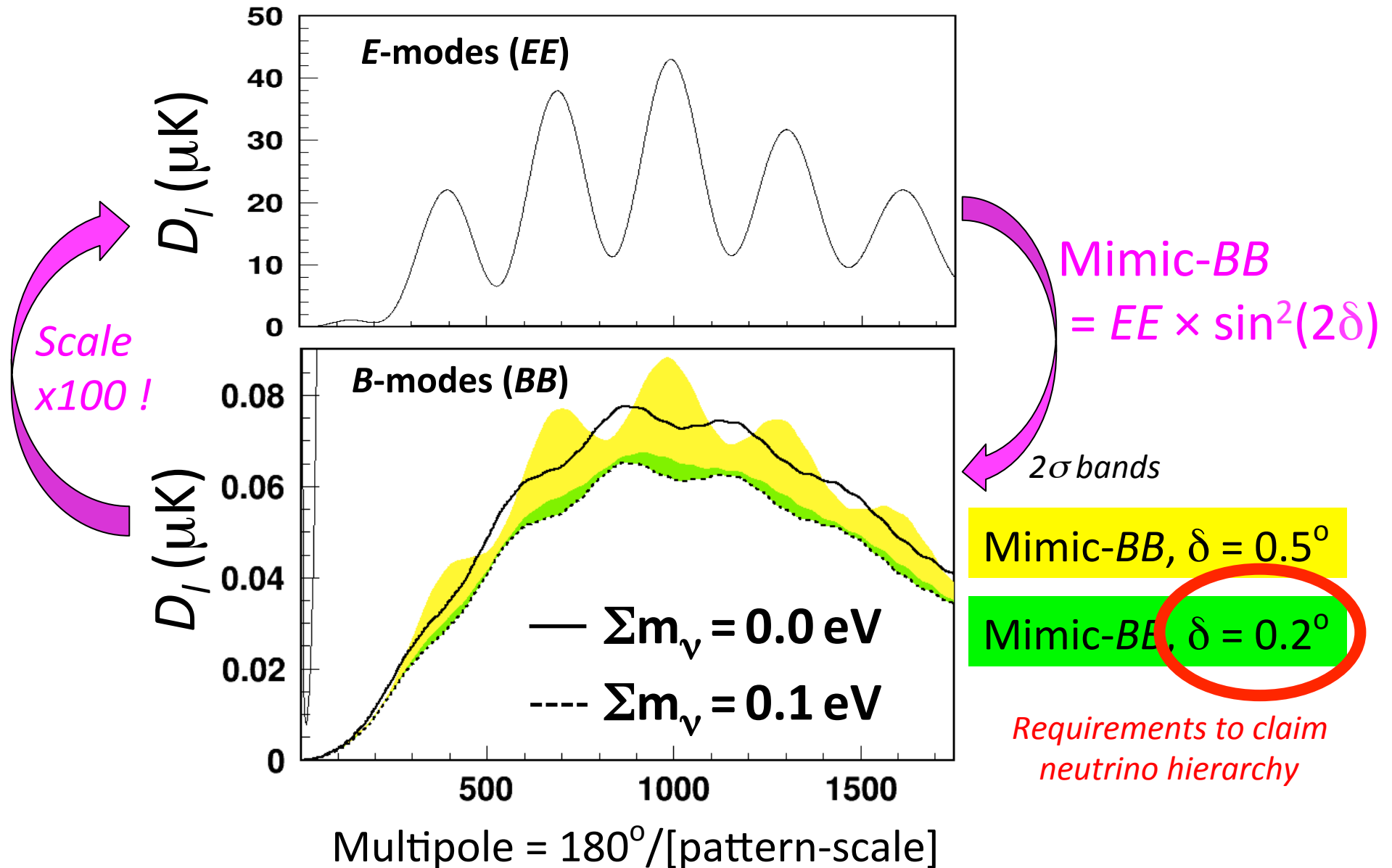
*E*-mode pattern



*B*-mode pattern

Rotation of polarization axis makes  
“mimic *B*-modes” from *E*-modes

# Requirements of angle calibration

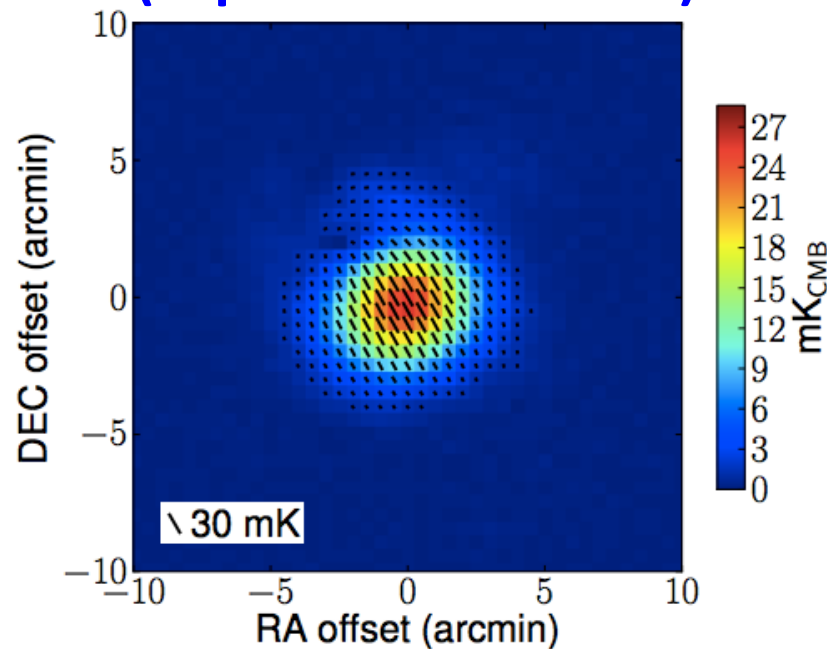


# Angle calibrations to the present

## Astronomical candle

### Taurus A

(supernova remnant)



Limitation by catalog precision

Not blackbody signal

$$\delta \approx 0.5^\circ$$

*ApJ* 794:171 (2014), *A&A*, 514, A70 (2010).

## Artificial candle (active signal generator)



Limitation of instruments

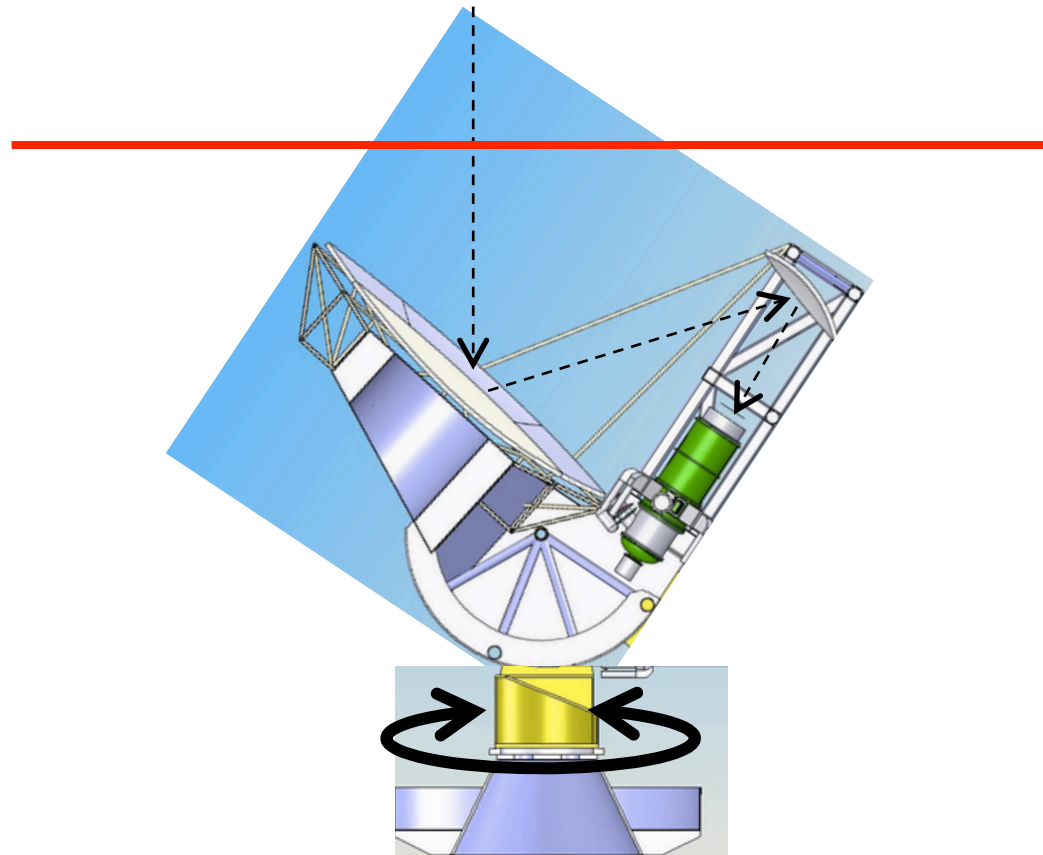
Not blackbody signal

$$\delta \approx 0.5^\circ$$

*arXiv* 1411.1042

# Novel calibration

*Just hanging a metal wire on top of telescope's field of view*



Passive (not active control) ⇔ **very stable with appropriate intensity**

No need any instrumental alignment *(will explain in latter page)*

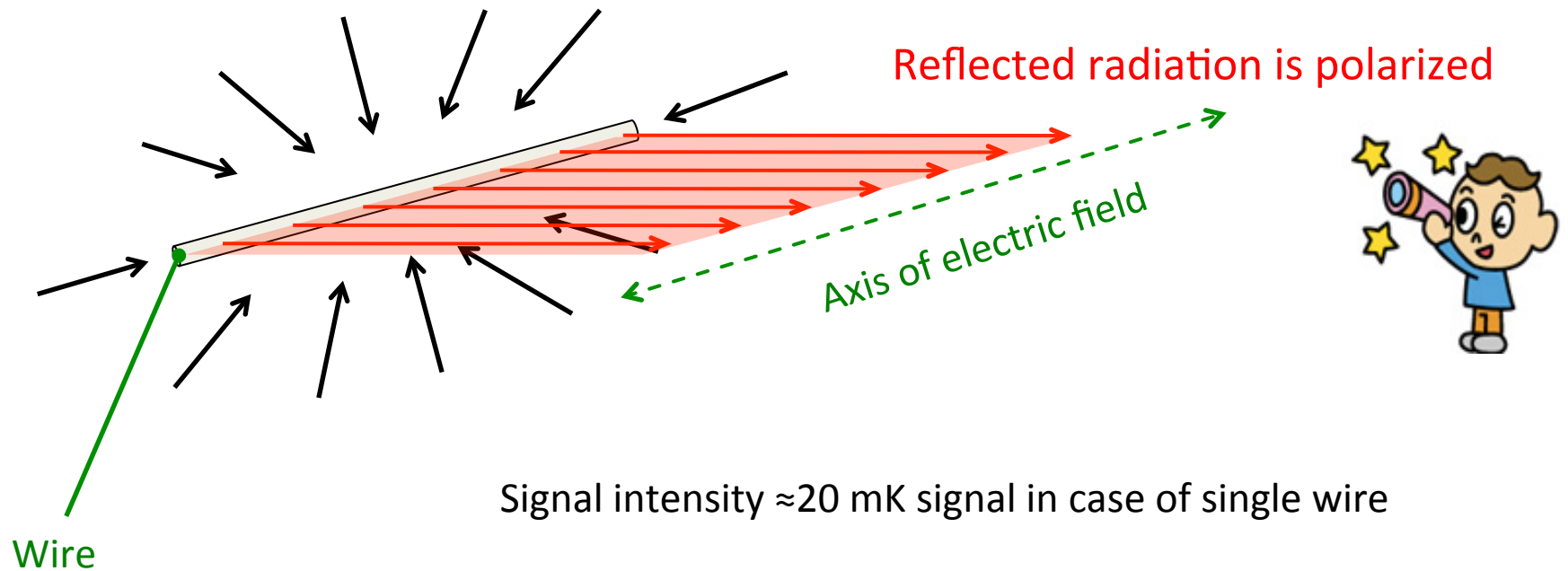
⇔ **Easy & simple, i.e., robust for systematics**

Blackbody polarization ⇔ **similar frequency properties to CMB**

# Principle

Linear polarization  $\Leftrightarrow$  Light whose direction of electric field is aligned

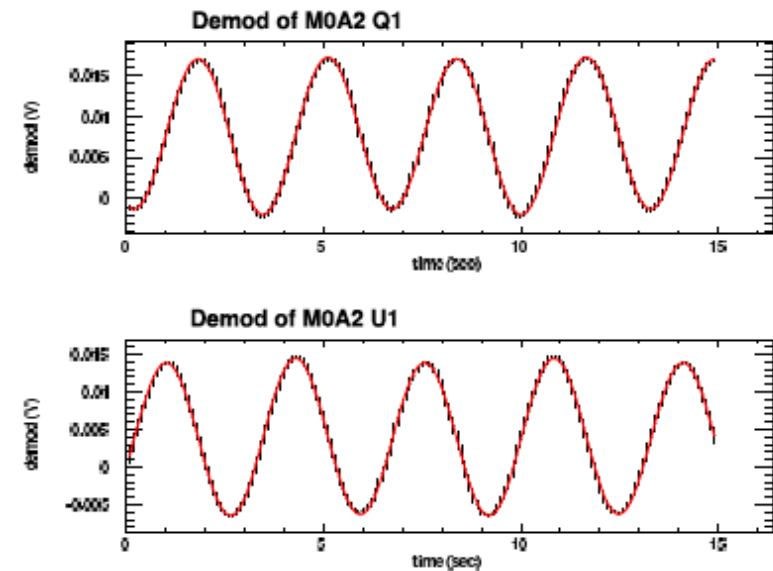
Ambient temperature radiations, mainly come from the ground (300K)



# Proof of principle in 2008



## Stokes-Q & U response for QUIET's detector



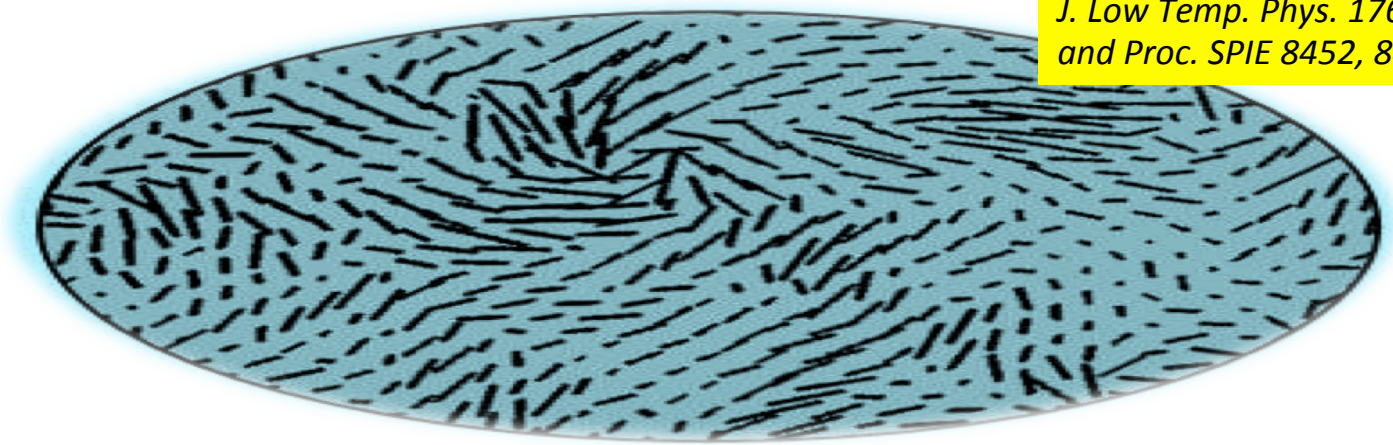
Prototype in Chicago lab., Nov. 20, 2008.

Made by one student and me using **cable & duck tape**

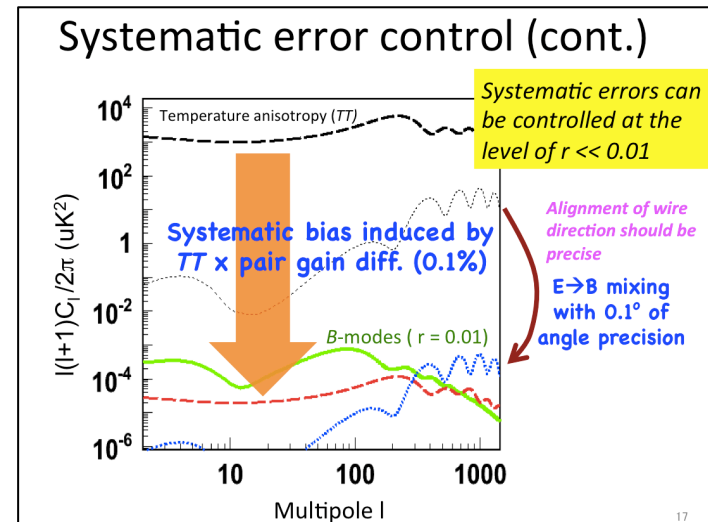
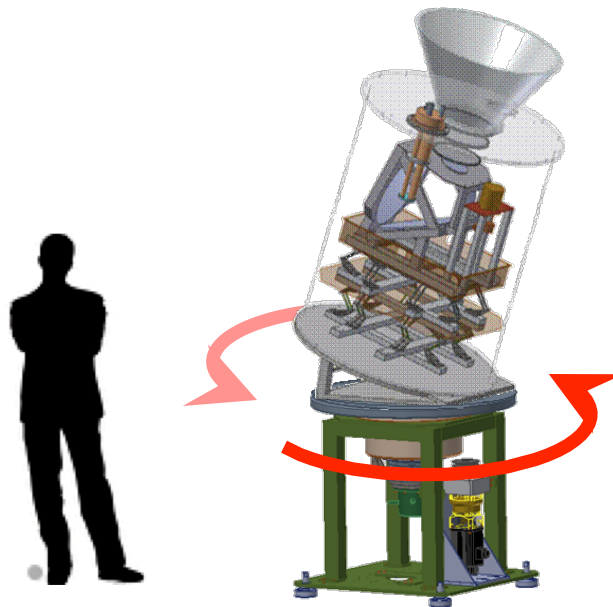
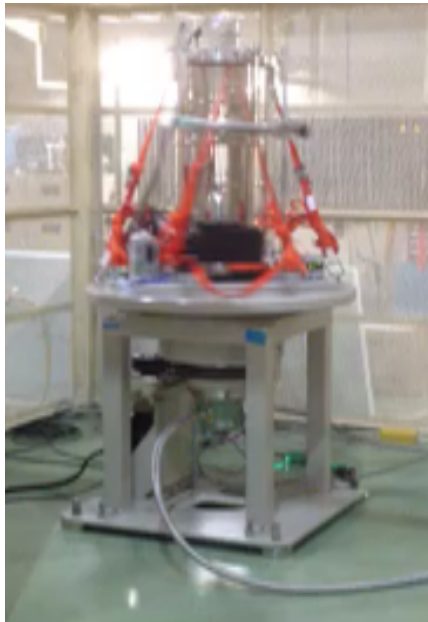
sounds super-easy !!

# Key technology for GroundBIRD !

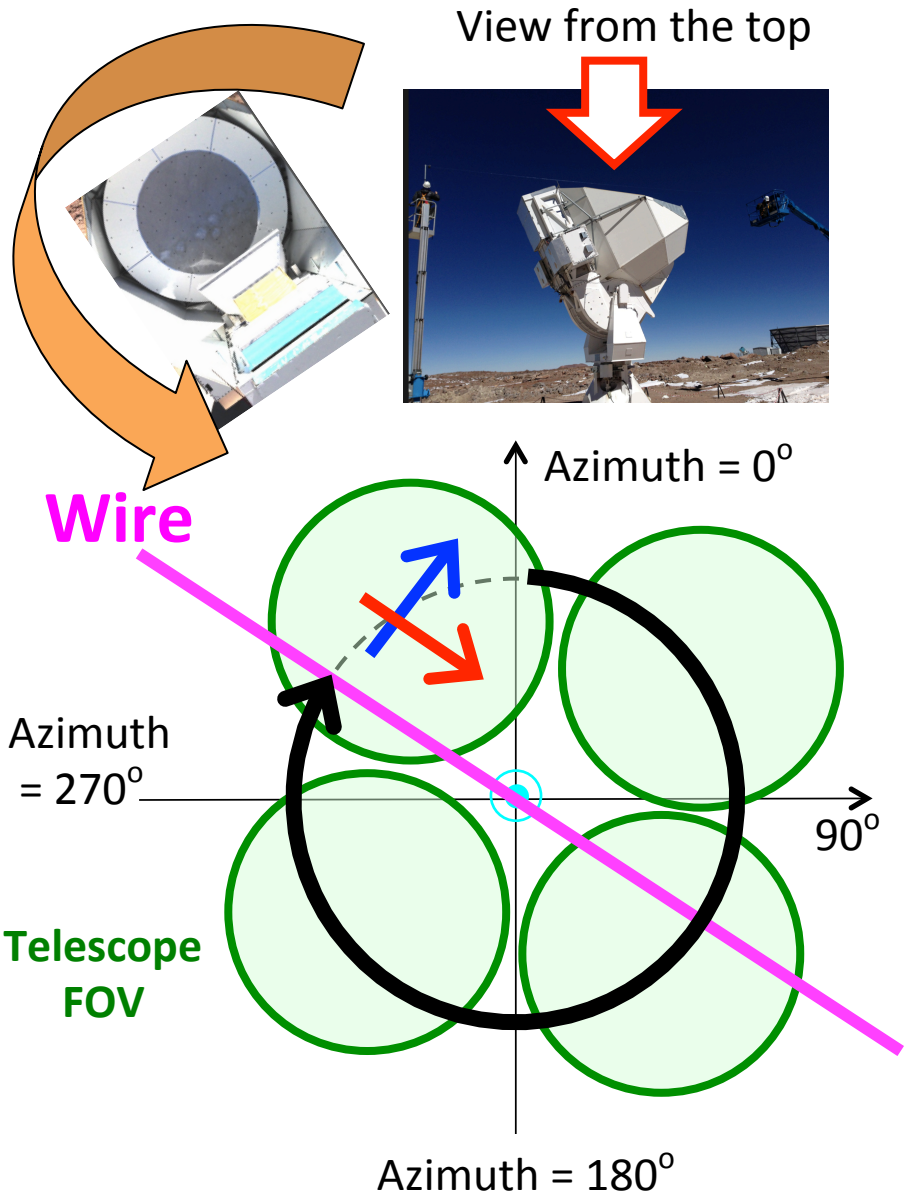
*J. Low Temp. Phys.* 176, 691 (2014),  
and *Proc. SPIE* 8452, 84521M (2012).



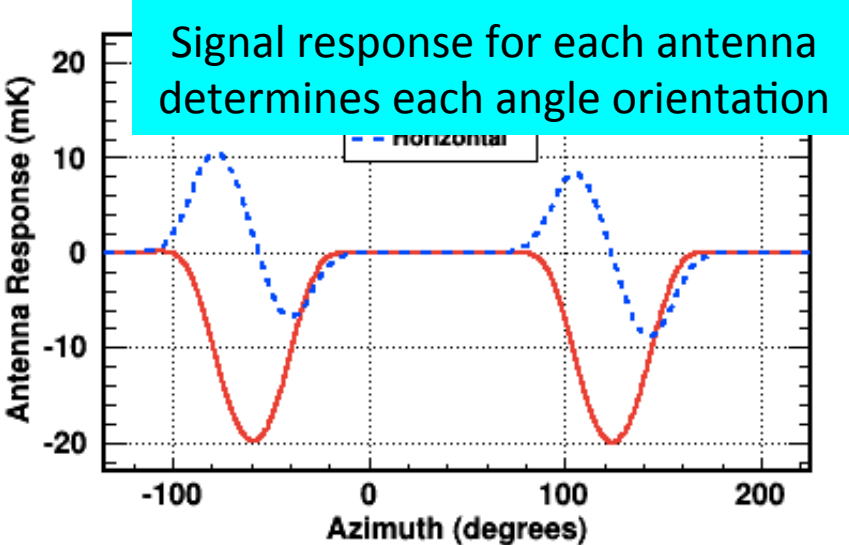
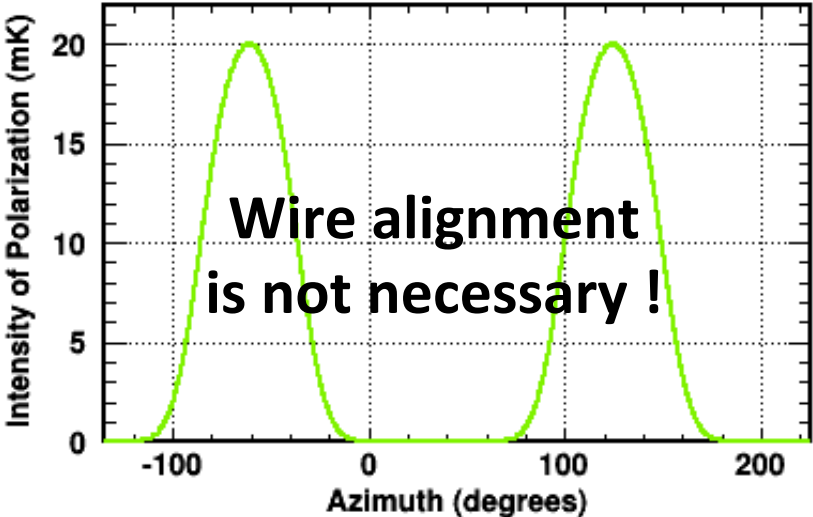
**Hanging wire  
for calibration !**



# Expected signal response



*Absolute intensity of signal is proportional to length of wire above telescope's FoV*  
→ *Determination of wire-direction*

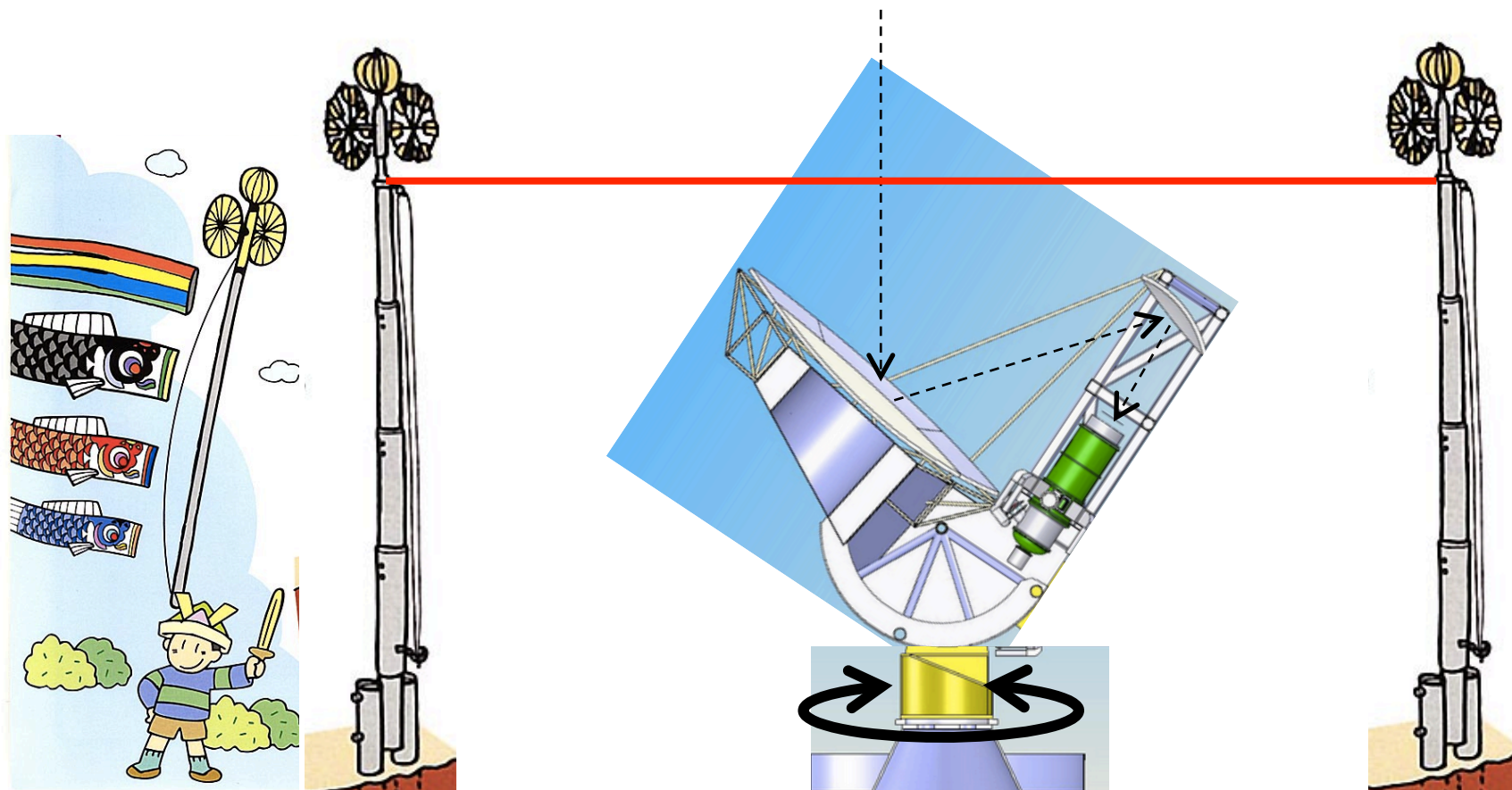




**Good achievement in 2014,  
e.g., proof of concepts**

**What's next in 2015 ?**

# Stationary calibration by using Koinobori-poles !



# Summary

- Towards constraint of  $\Sigma m_\nu$  by using CMB polarization, angle calibration is the most important
  - Requirement:  $\delta \leq 0.2^\circ$  to claim  $\Sigma m_\nu = 0.1$  eV
  - Limitation of past calibrations:  $\delta \approx 0.5^\circ$
- Novel calibration, single-wire + azimuth rotation
  - Stable, Easy & Blackbody polarization as CMB
  - Key technology for GroundBIRD experiment
  - Proof of concepts using POLARBEAR telescope in Aug.
  - *STAY TUNED*
- *Acknowledgement for Neutrino新學術*