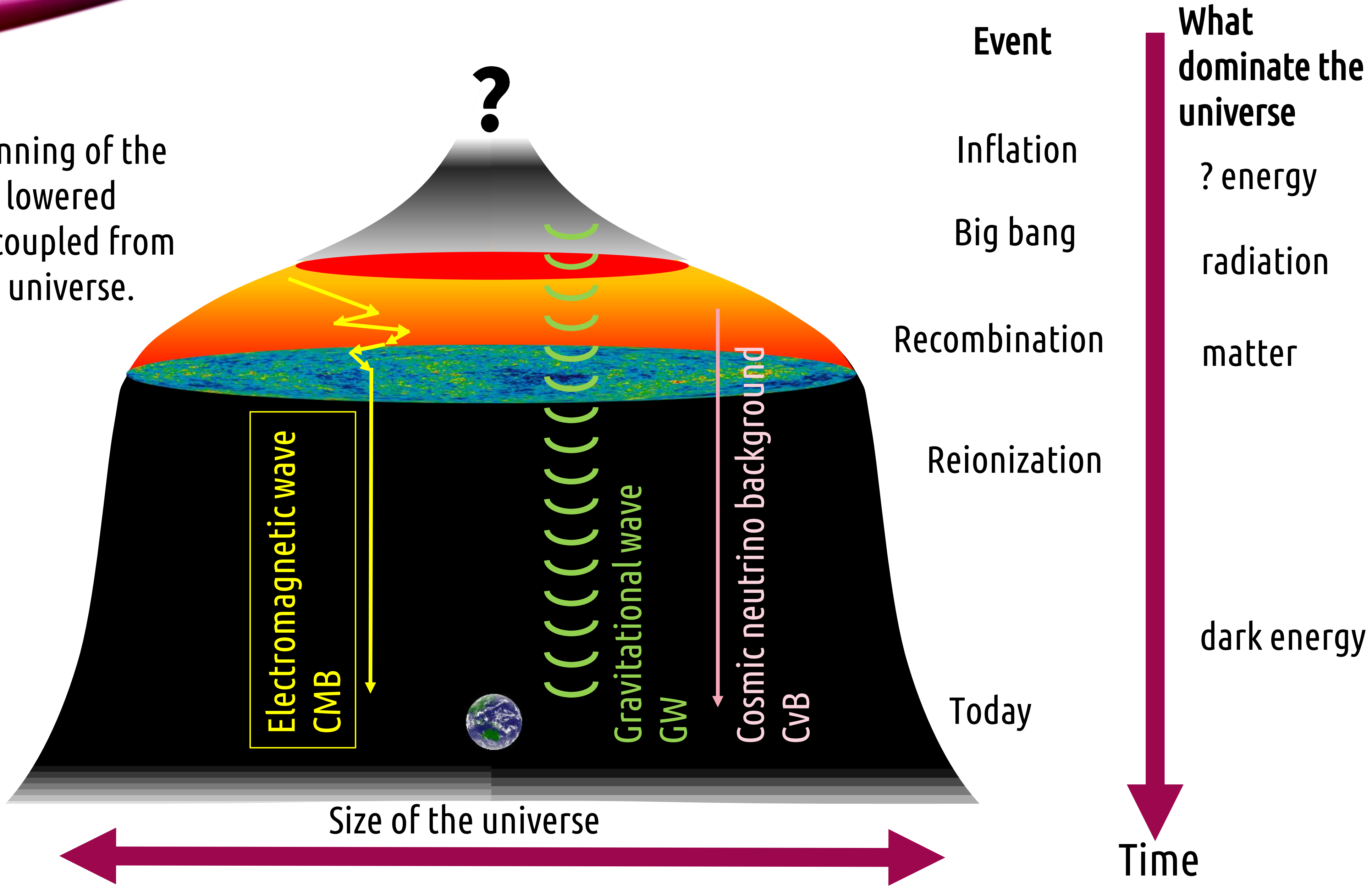
Design, deployment and commissioning of the Simons Array experiment

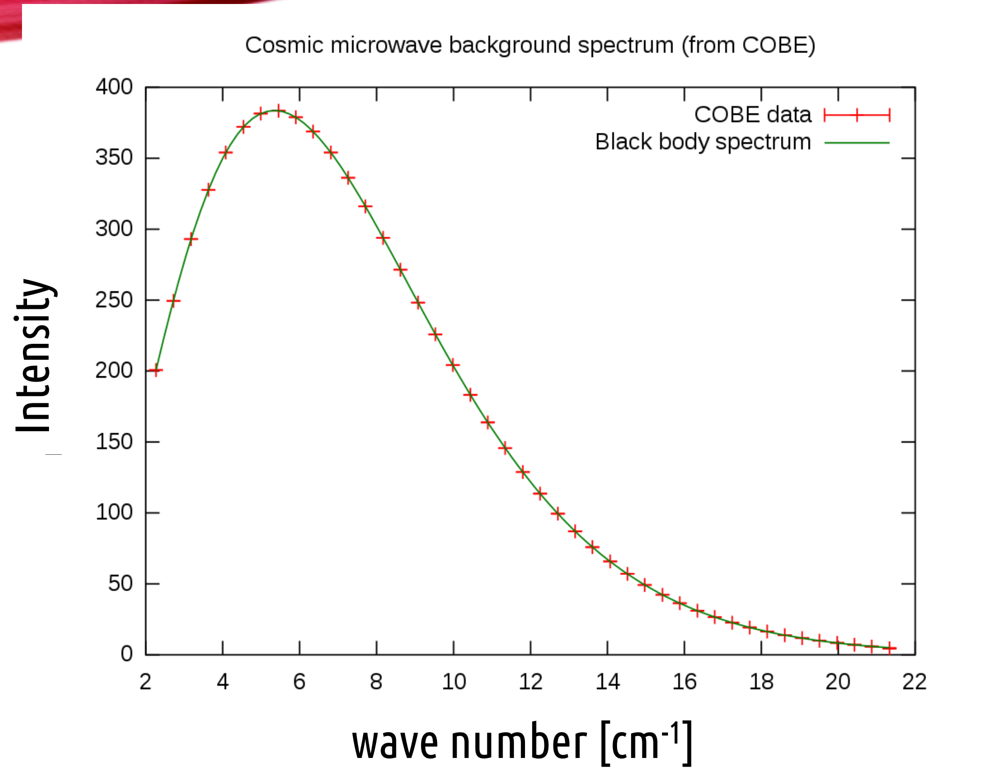
Daisuke Kaneko, from KEK IPNS

What's CMB

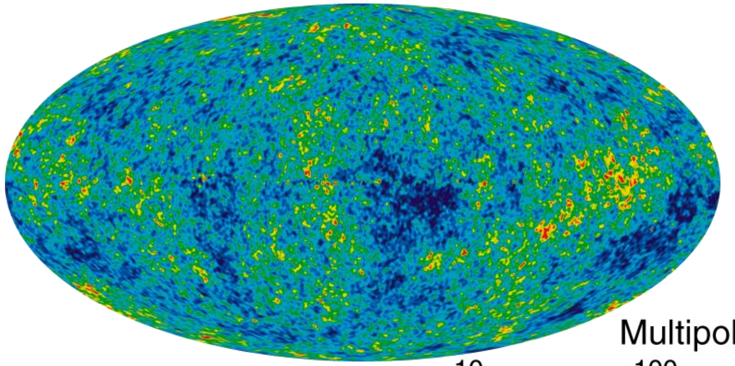
After 380k years from beginning of the universe, temperature was lowered down to 3000K, photon decoupled from matter, to freely travel the universe.



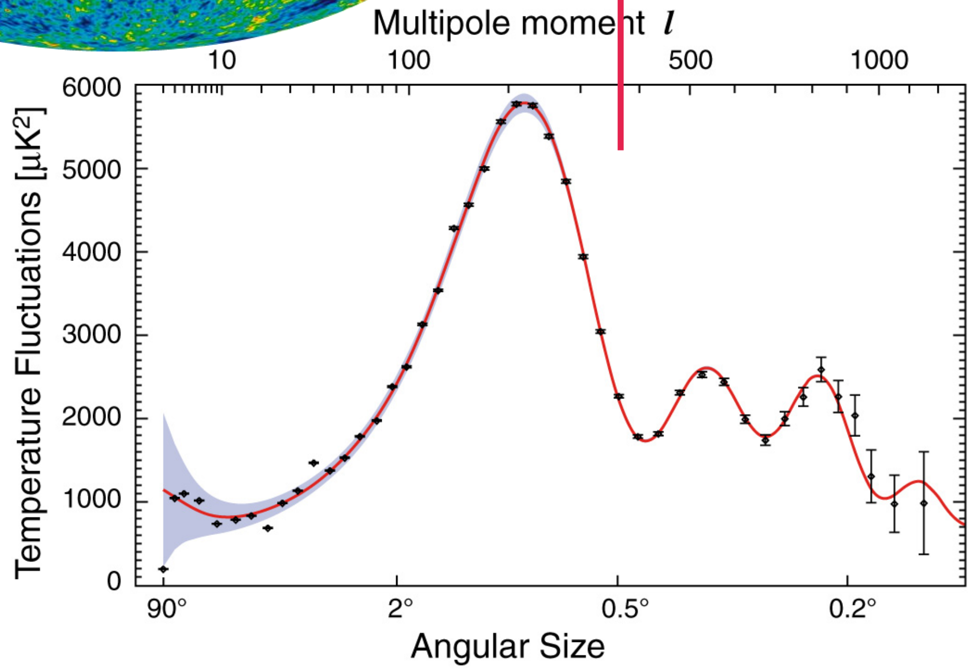
Known facts about CMB



CMB spectrum agrees extremely well with Planck's black body radiation formula.
Temperature 2.725 K
Peak is at λ ~ 2 mm, ν ~ 150 GHz.



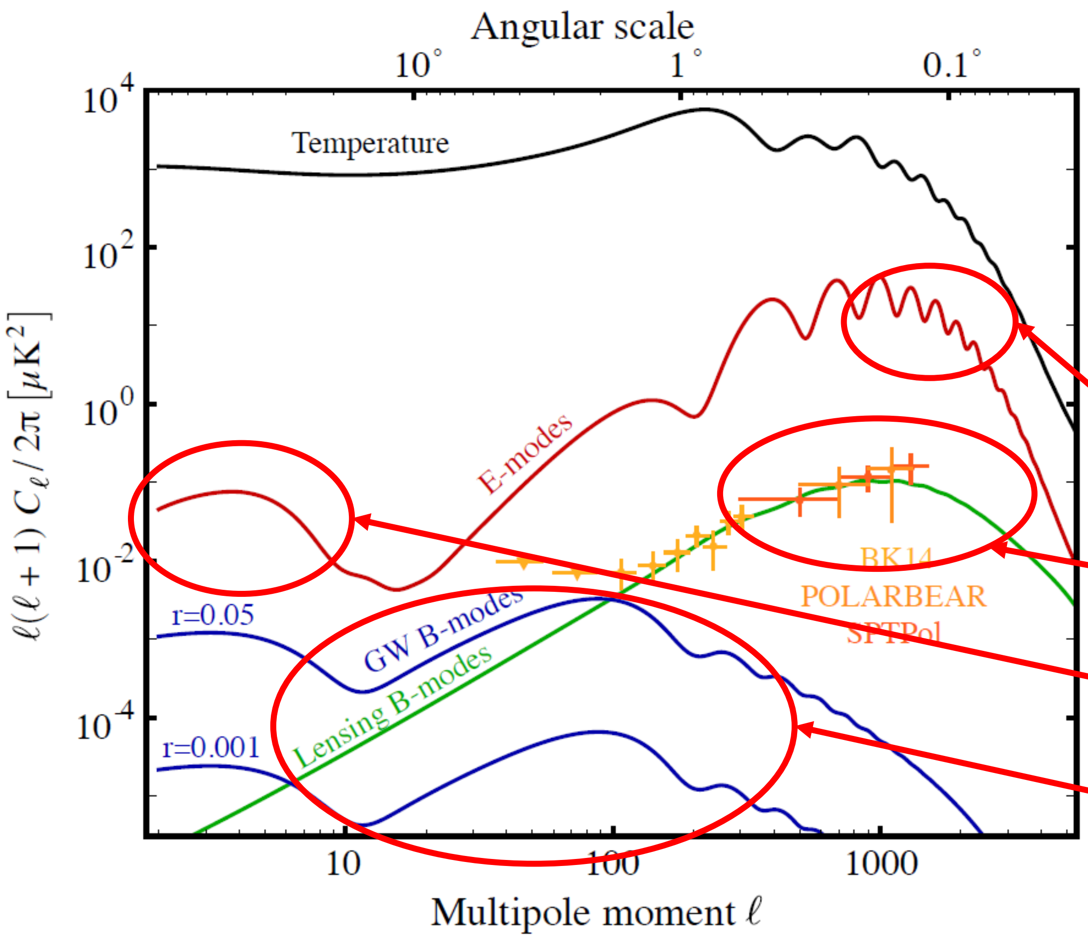
0.5°, ℓ=360
size of moon

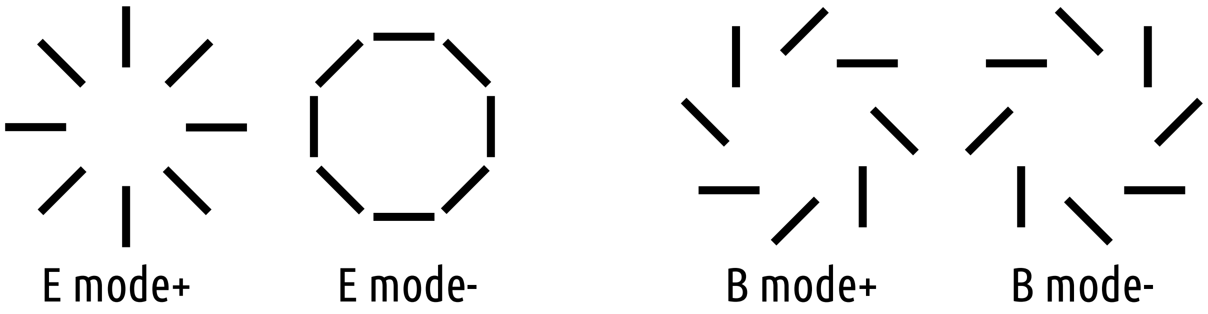


Radiation strength (temperature) has non-uniformity. It's usually indicated in power spectrum.

Why more CMB?

Temperature non-uniformity is thoroughly searched in previous experiments, but there are more information can be derived from polarization.





high-ℓ E mode, number of light relic particle "N_{eff}"

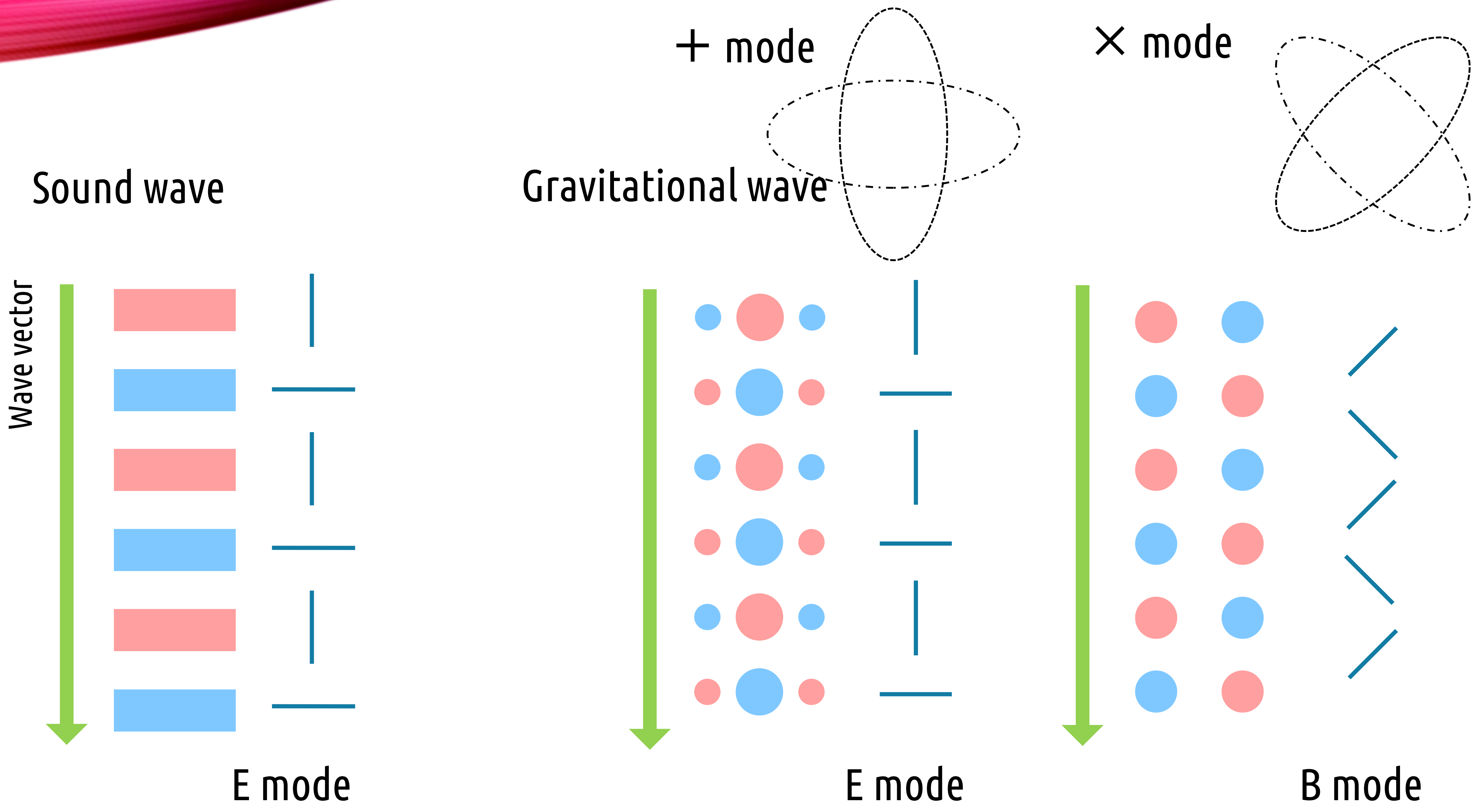
high-ℓ B mode, sum of the neutrino mass "Σm_ν"

very low-ℓ E mode, optical thickness of universe "τ"

low-ℓ B mode, tensor-scalar ratio "r"

etc. etc.

How polarization generated



B mode from inflation

Unknown mechanism

↓

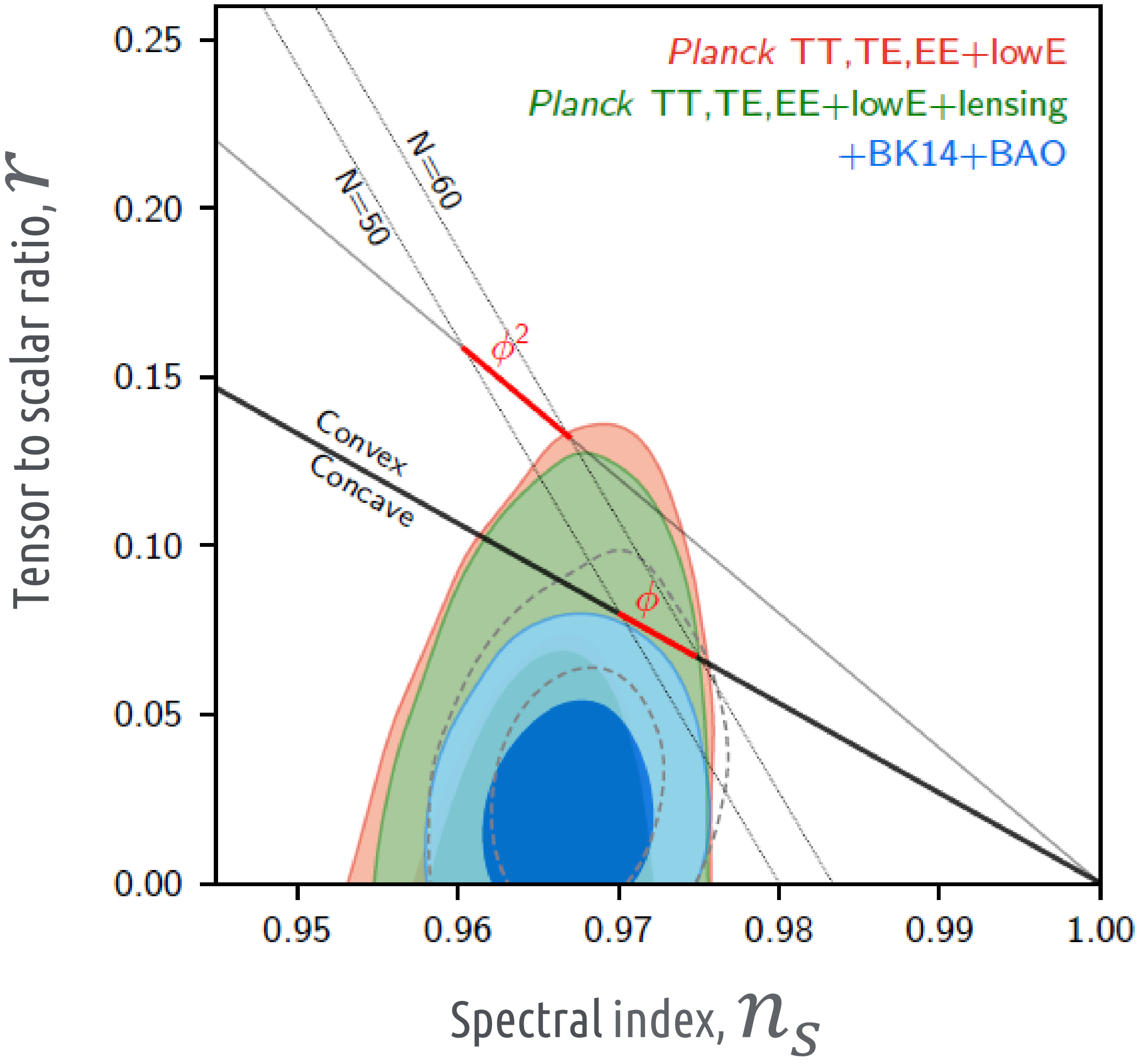
Inflation at early universe

↓

Primordial GW (tensor-scalar ratio)

↓

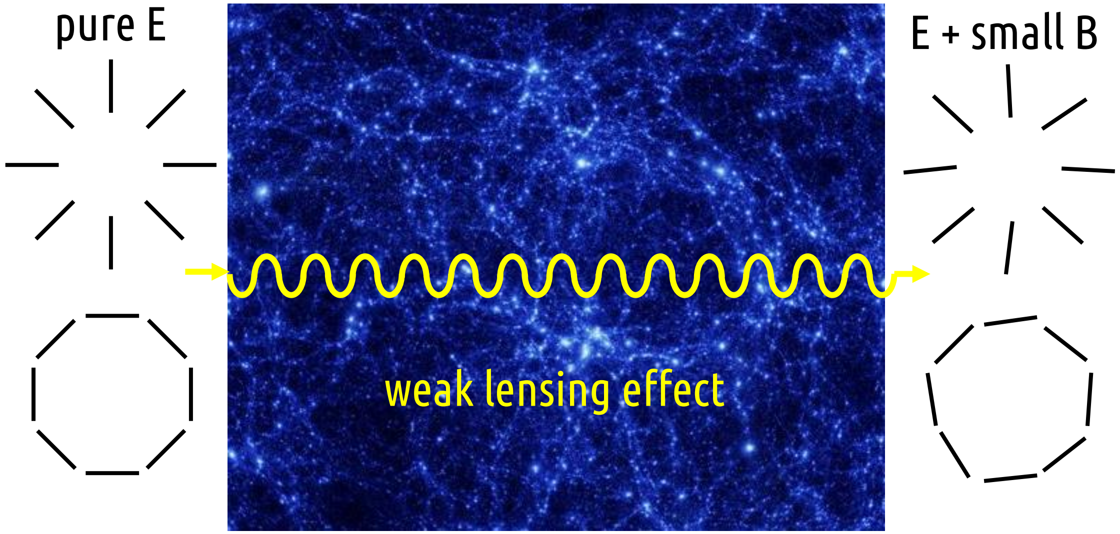
B mode polarization



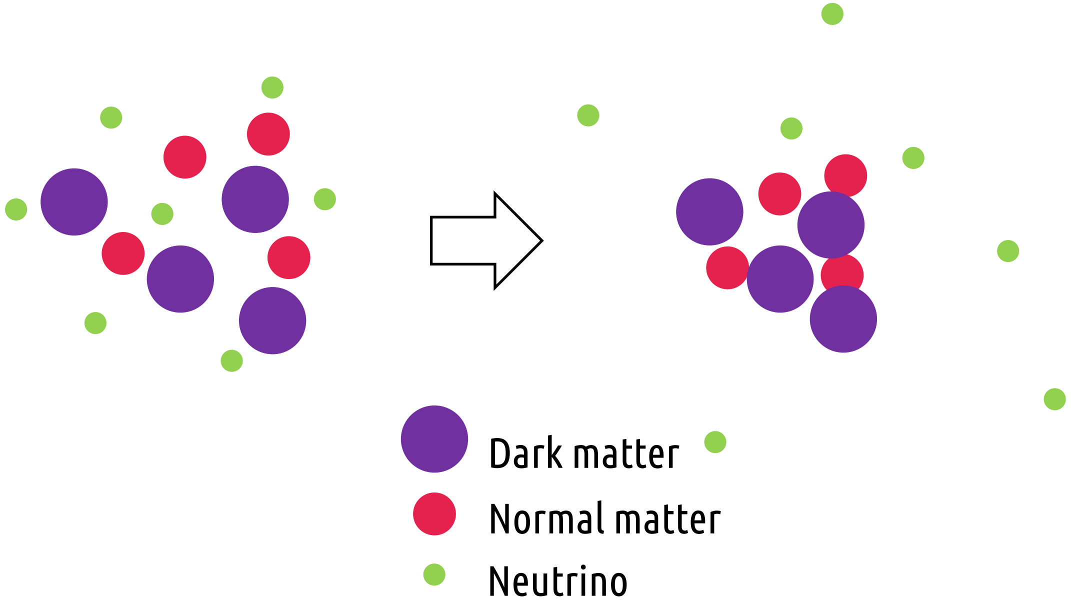
From measured amplitude of B mode, limit for the inflation model can be set.

Planck 2018 results. VI. Cosmological parameters arXiv:1807.06209 [astro-ph.CO]

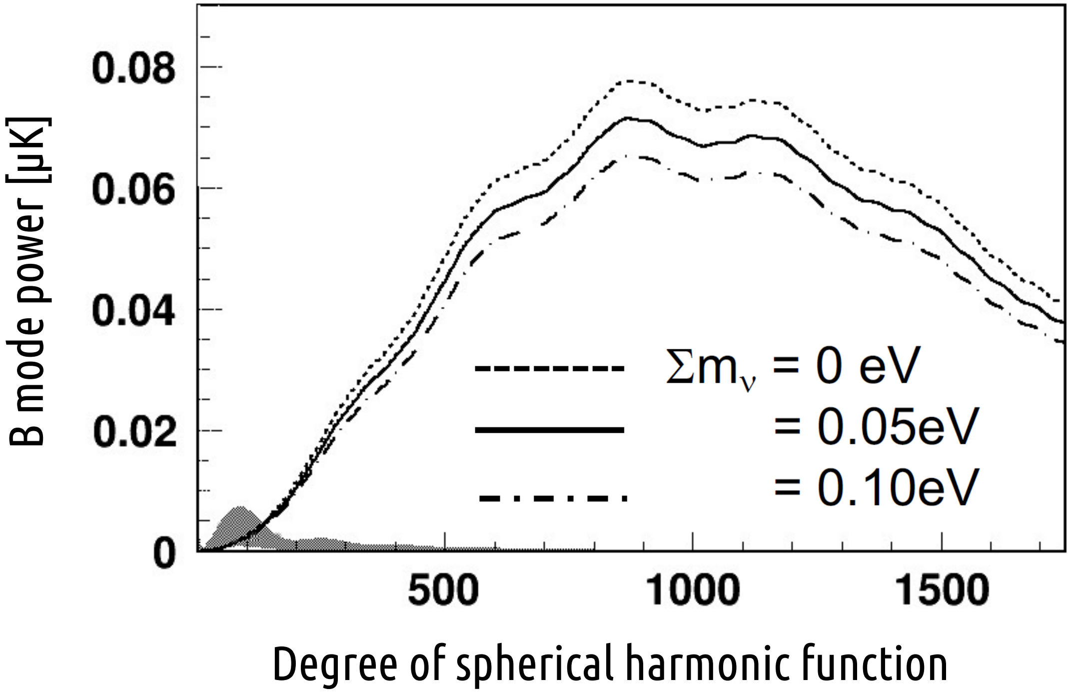
CMB observation and neutrino mass



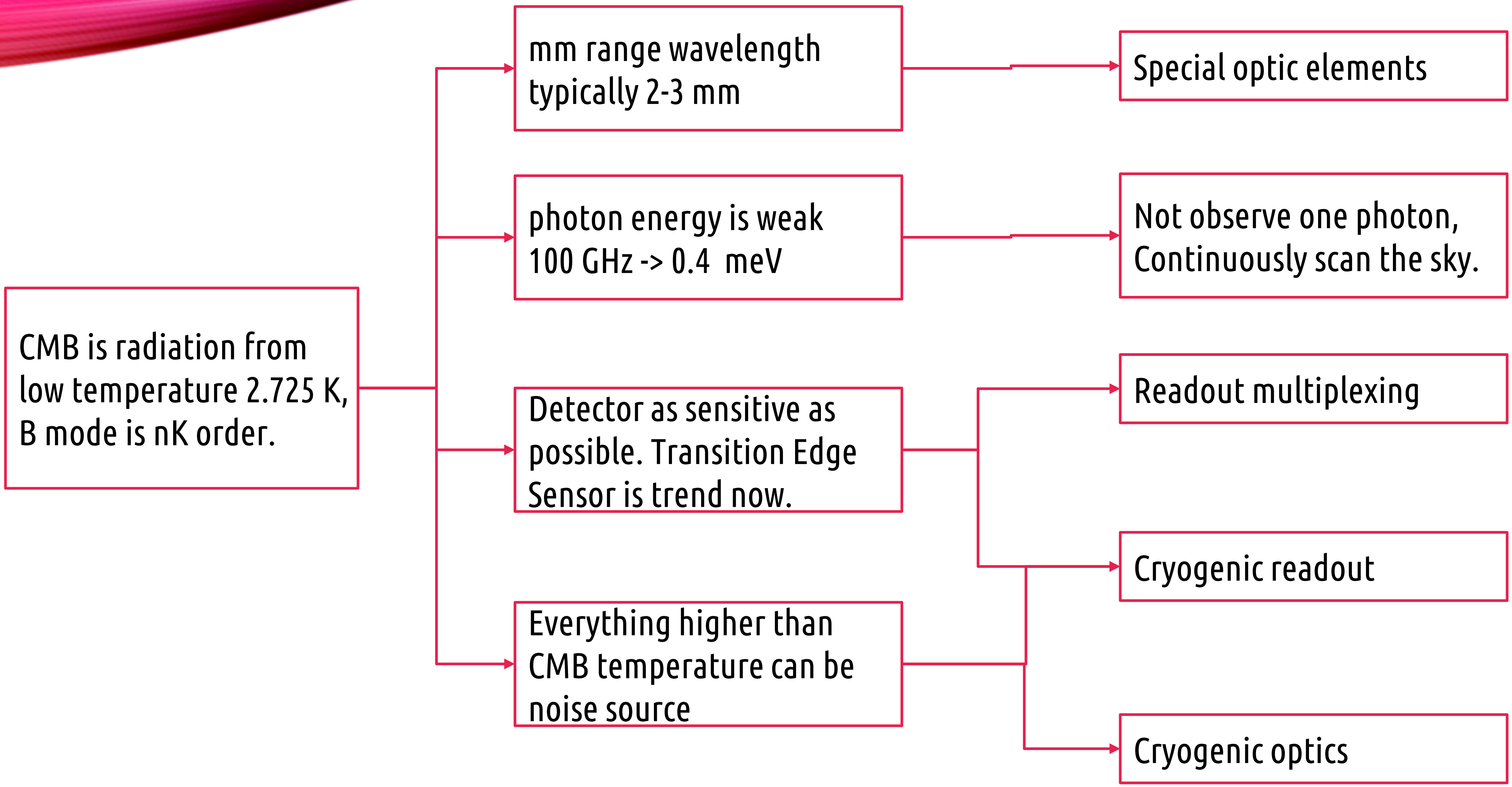
Dark matter and normal matter concentrate to form largescale structure, but neutrino don’t in small scale.



Sum of the neutrino mass can be measured as the height of B mode peak.



How CMB could be measured



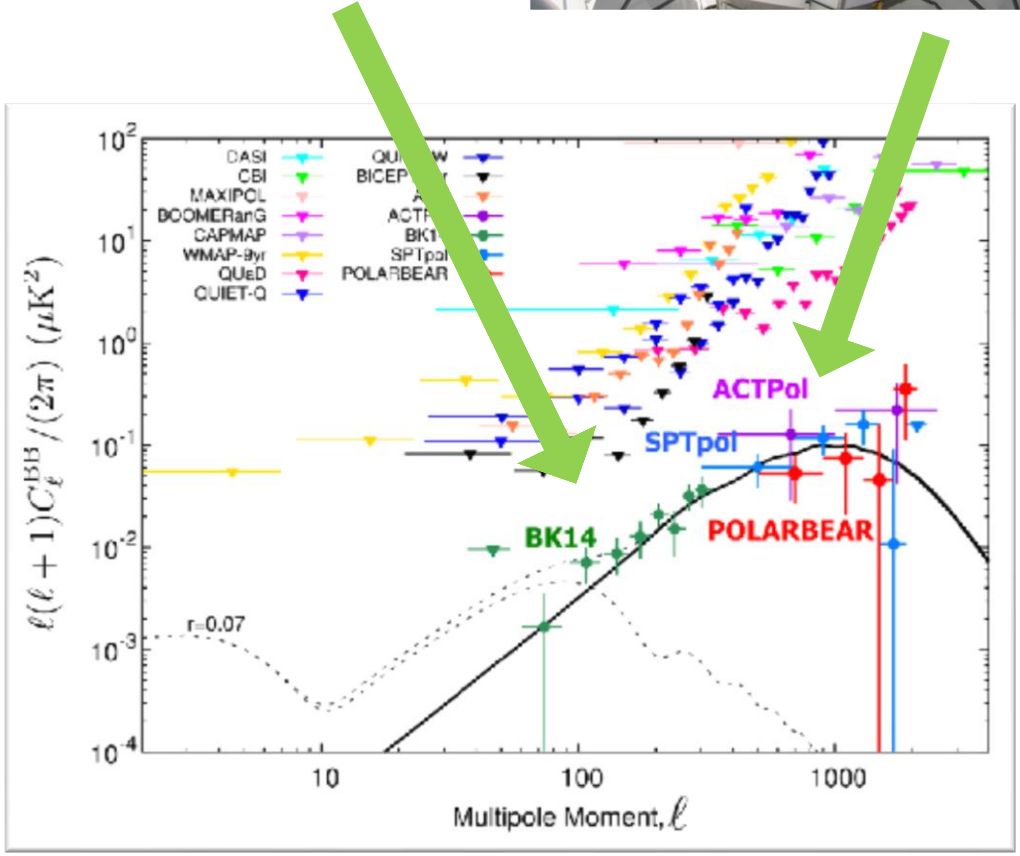
telescope size and observation band

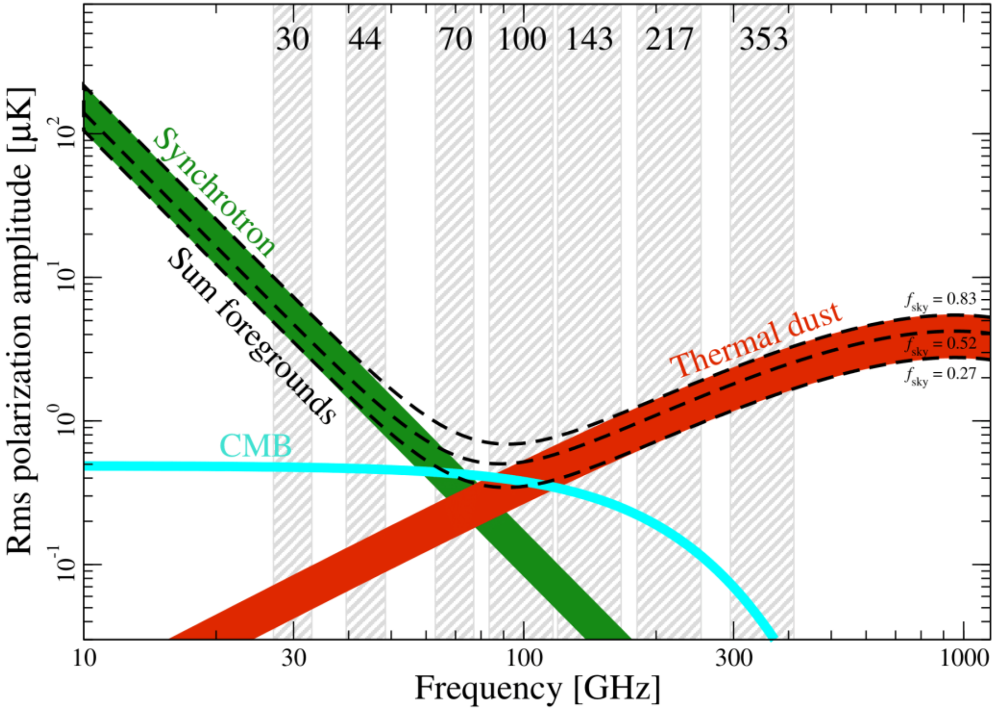
Telescope Size

Large telescope has better angular resolution, but fluctuation at larger scale is worse. Small telescope is opposite.

Band (frequency)

2 major polarized “foregrounds”, Thermal dust at high frequency, and Synchrotron radiation at low frequency.





POLARBEAR / Simons Array's strategy

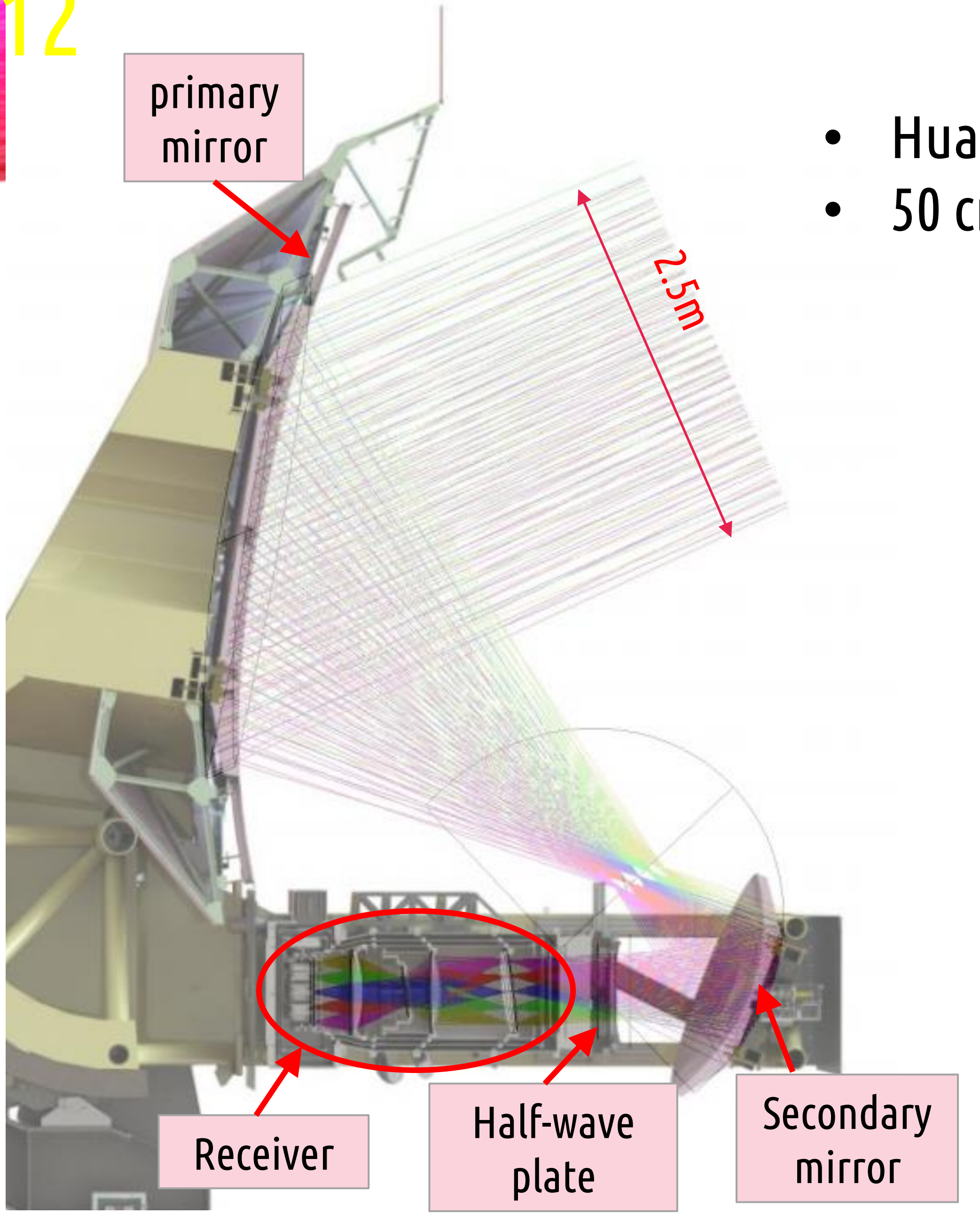
- Location
  - Chile, Atacama desert
    - Larger sky, better accessibility than Antarctica, but Inferior at sky condition
- Optics
  - 2.5 m telescope, adopt half-wave plate (HWP)
    - Unique middle-sized telescope among CMB experiments
    - HWP modulates polarization to reduce 1/f noise at low frequency
- Observation band
  - 150 GHz (PB) $\longrightarrow$ 90, 150 (PB-2a,b) + 220, 270 GHz (PB-2c)

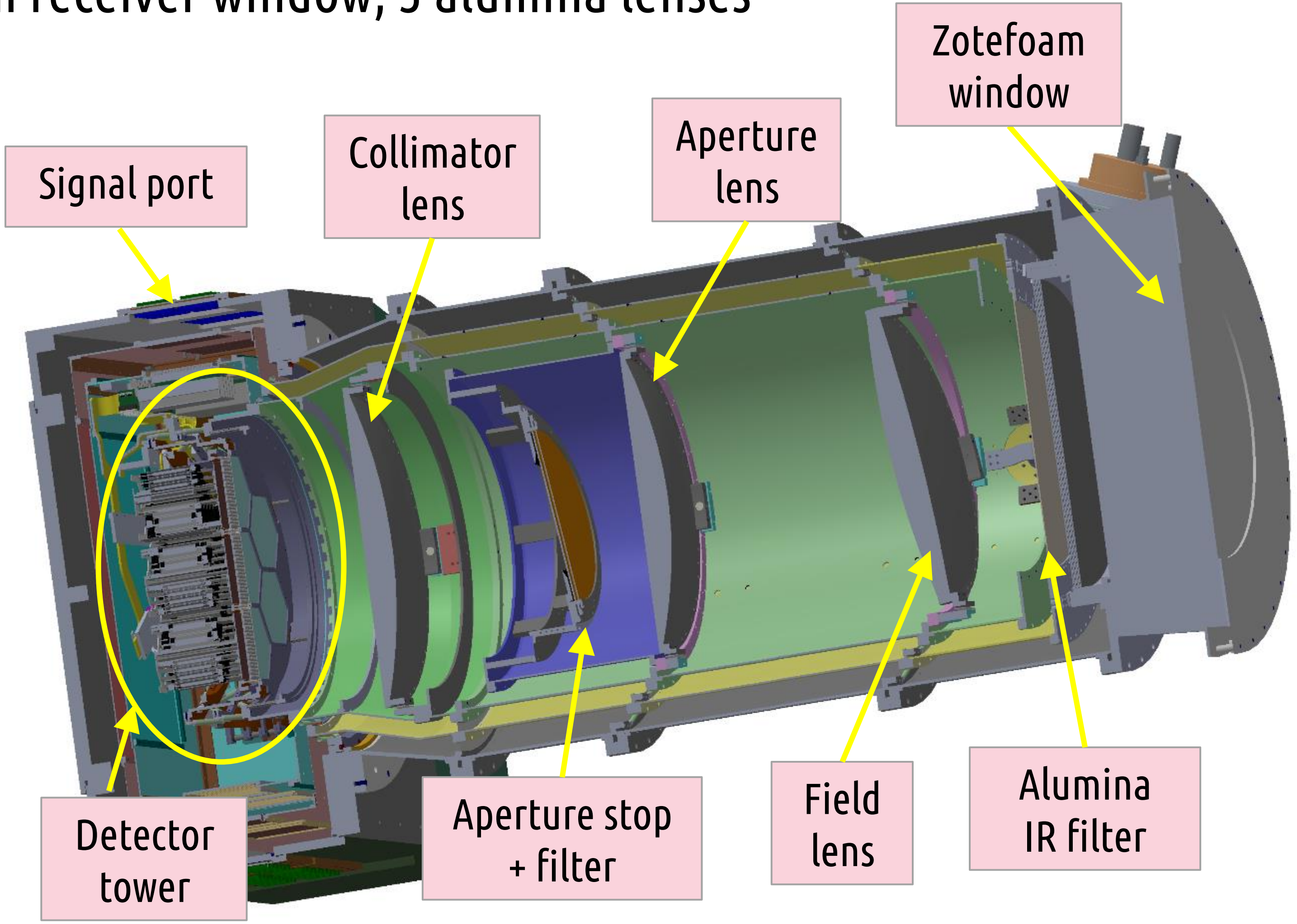
Basics of PB-2/Simons Array

- Chile, Atacama, Chajnantor plateau
- >100 recearchers from US, Japan, etc. 8 contries
- predecessor: PB-1 observed from 2012 to 2016
- 3 telescopes equipped with POLARBEAR-2(PB-2) receivers, number of TES are 20 times more
- Aiming at (1σ error)
  - tensor to scalar ratio r：0.006 (at r = 0.1)
  - neutrino mass sum Σmν：40meV (conbine with DESI experiment)

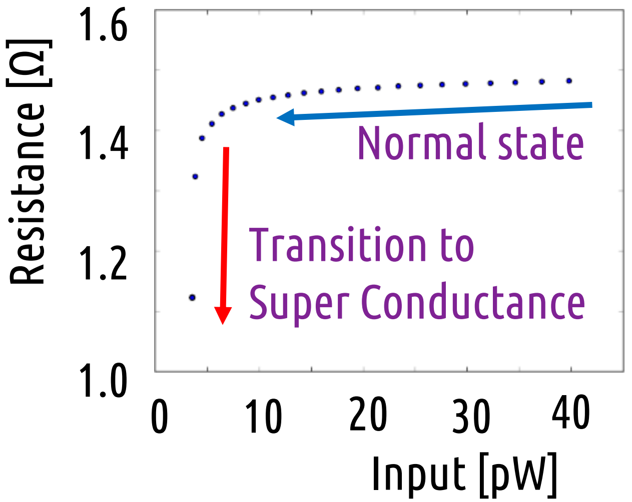
Optics of PB-2

- Huan Tran Telescope: 2.5 m off-axis Dragone system
- 50 cm receiver window, 3 alumina lenses

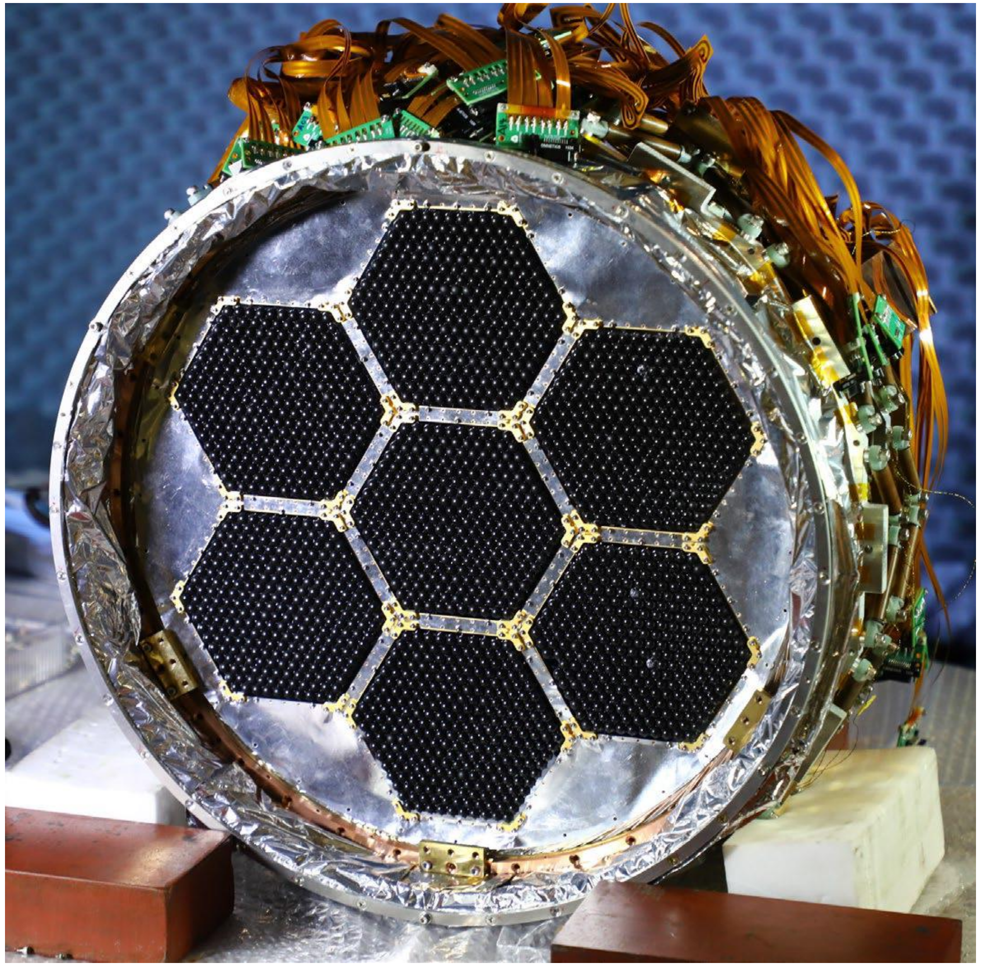




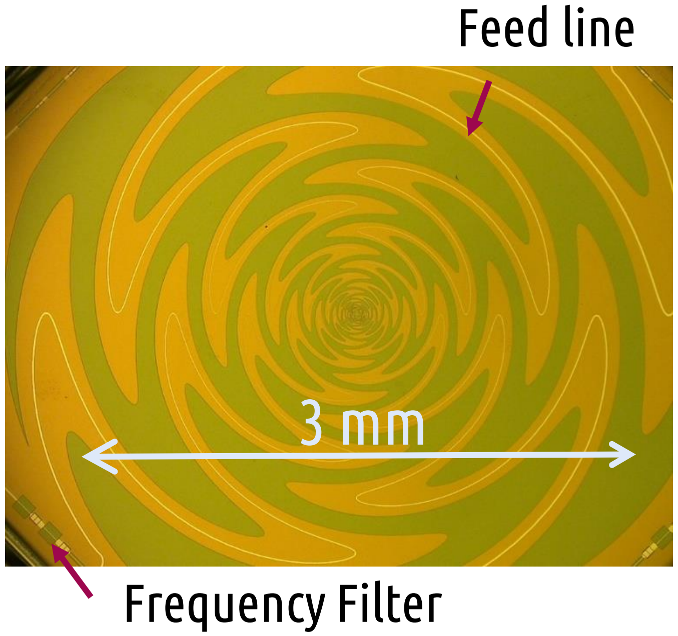
Sensor of SA

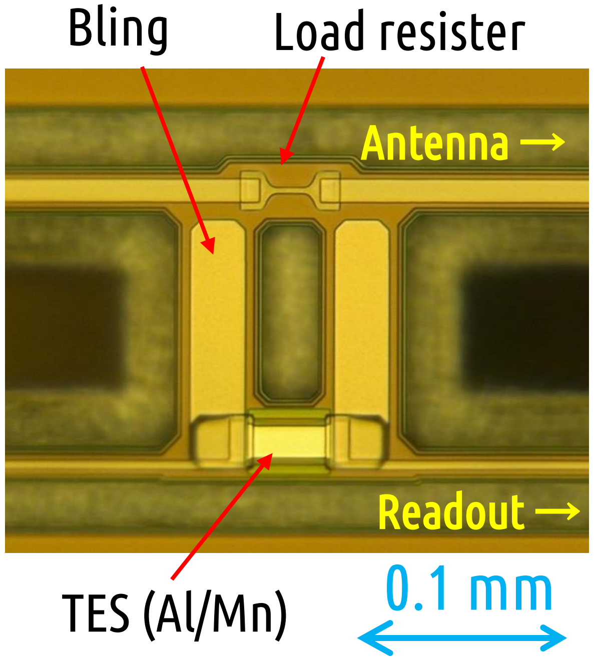


- Transition Edge Sensor
- Wide-band sinuous antenna



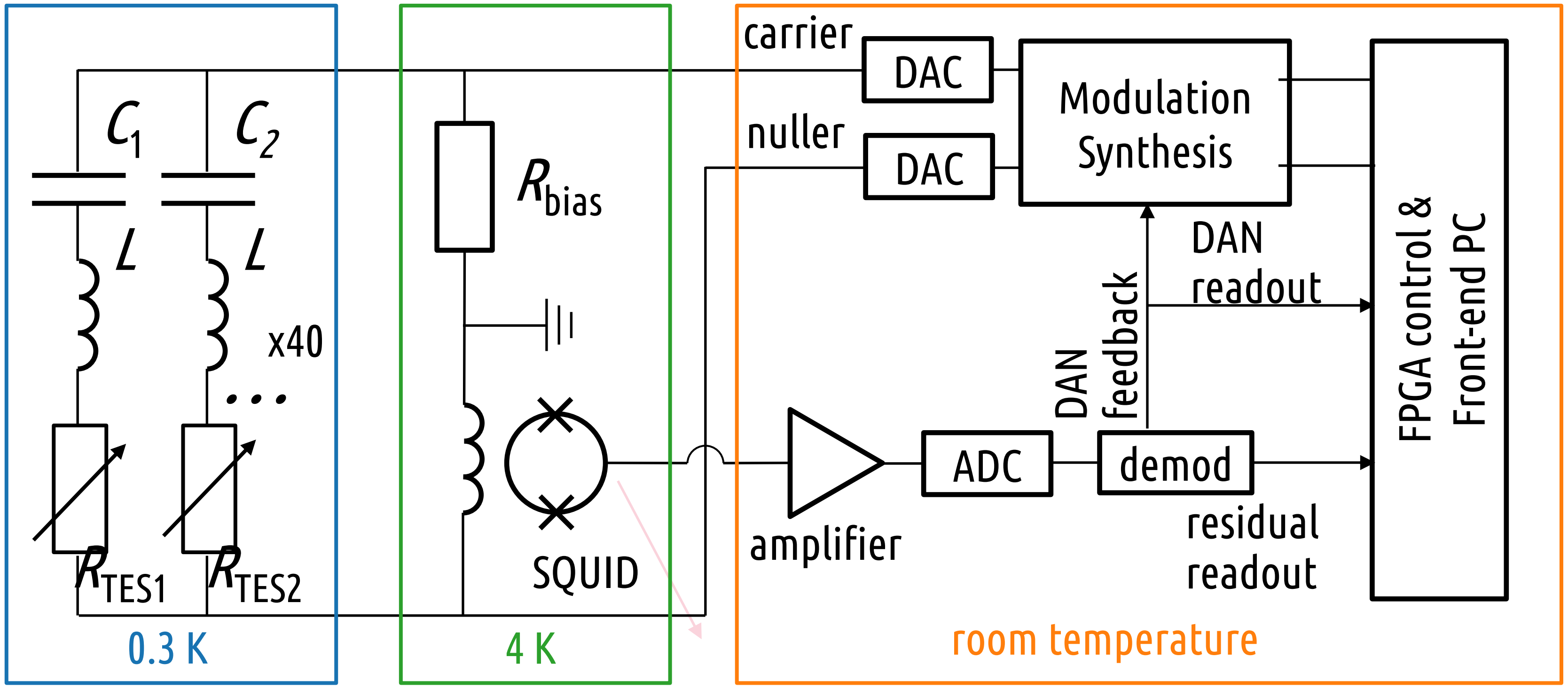
PB-2a detector structure

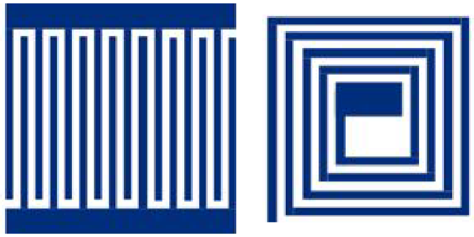


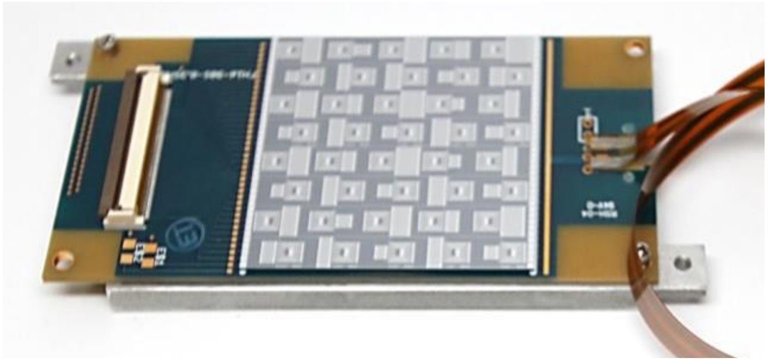


Readout of SA

SA adopts frequency multiplexing, 40 channels are read with one SQUID



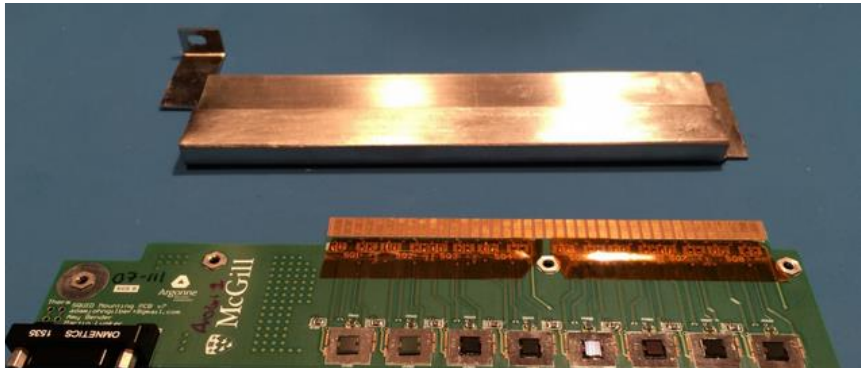




LC circuit :

Inductance and capacitance are implemented as super-conducting micro stripe.

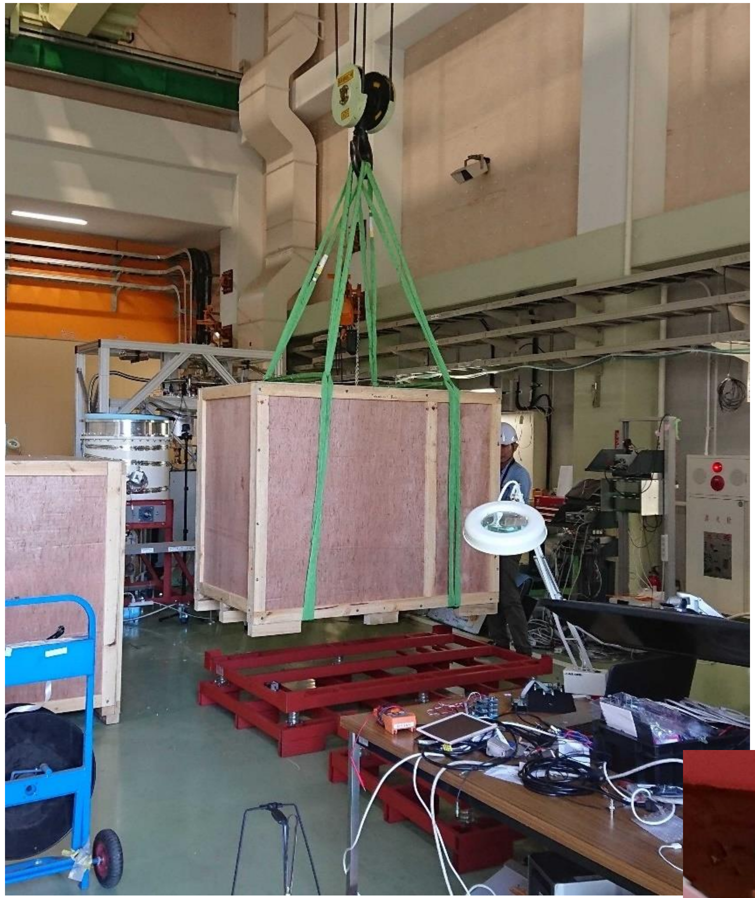
LC resonance frequency 1-4 MHz



SQUID circuit board at 4K stage

transportation to Chile

Receiver prepared for packing



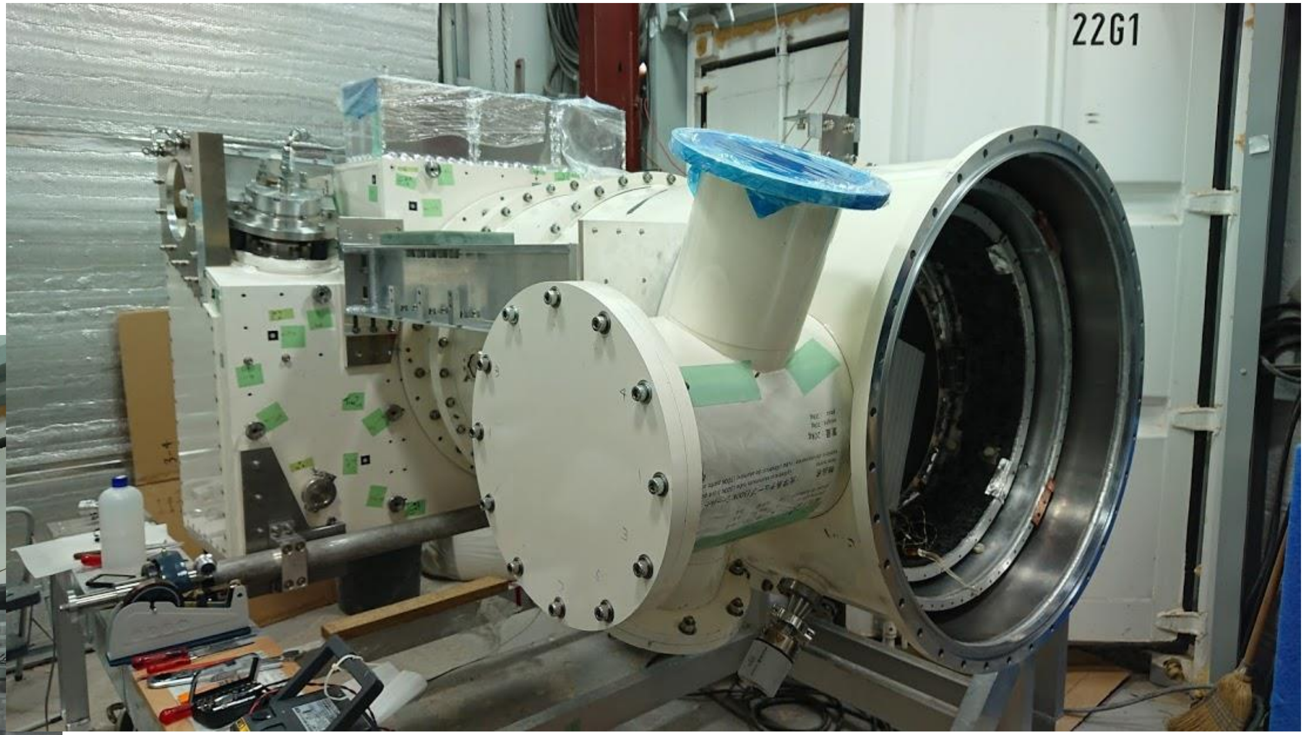
Packed in wooden box

Disassembled optics tube

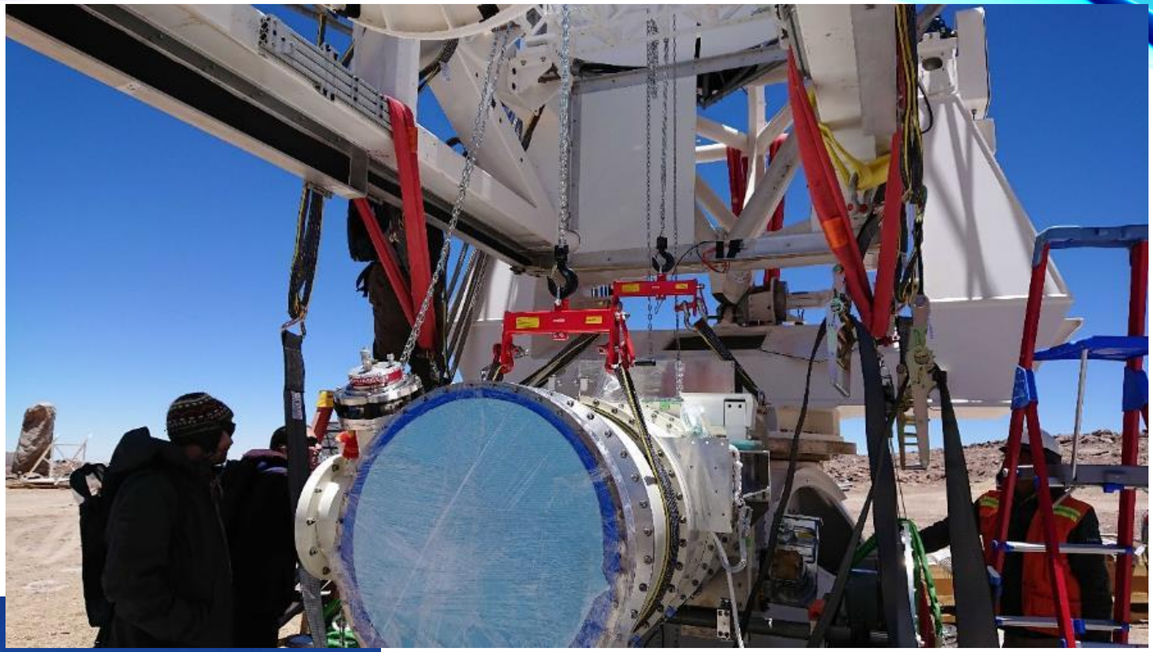
Special palette with
dumping spring

Assembly at the site

Assembly work was performed at high bay building.
It finished in 3 weeks as expected.

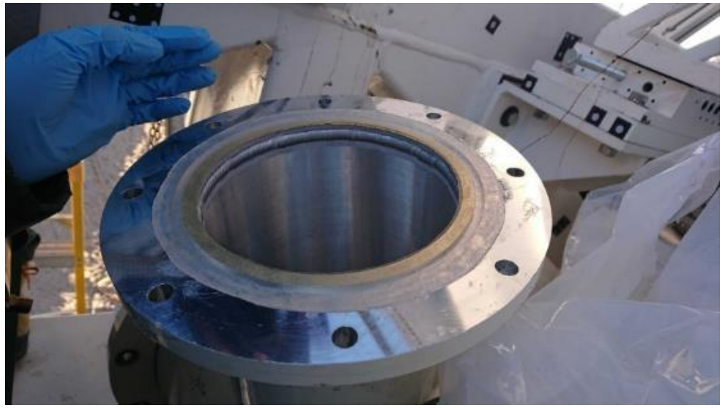


Lifting receiver by hand.
It took a half day



Temporary hoist system
mounted on telescope

Truck was hired for
receiver transport

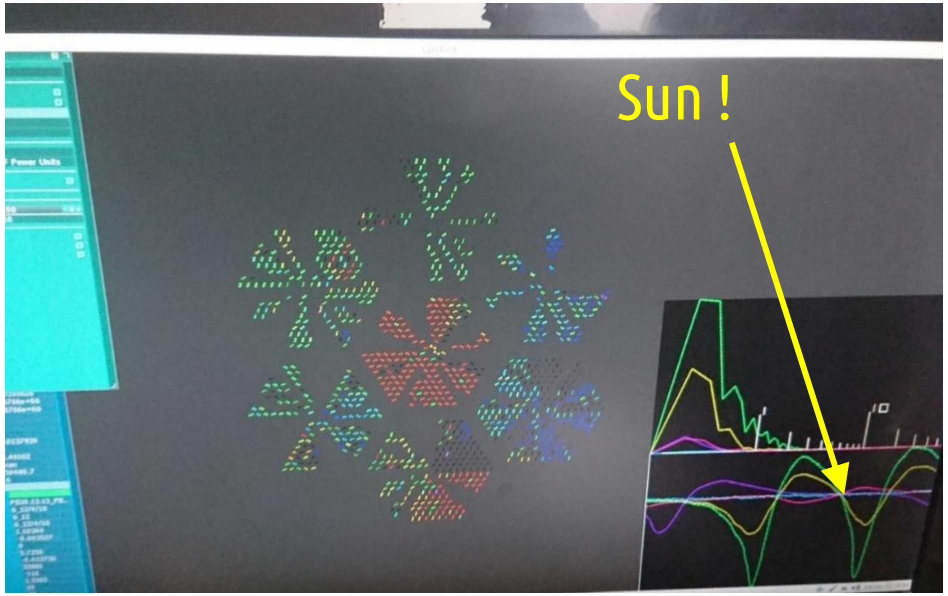


Refrigerator’s gasket replace on
telescope, hardest work in my stay.

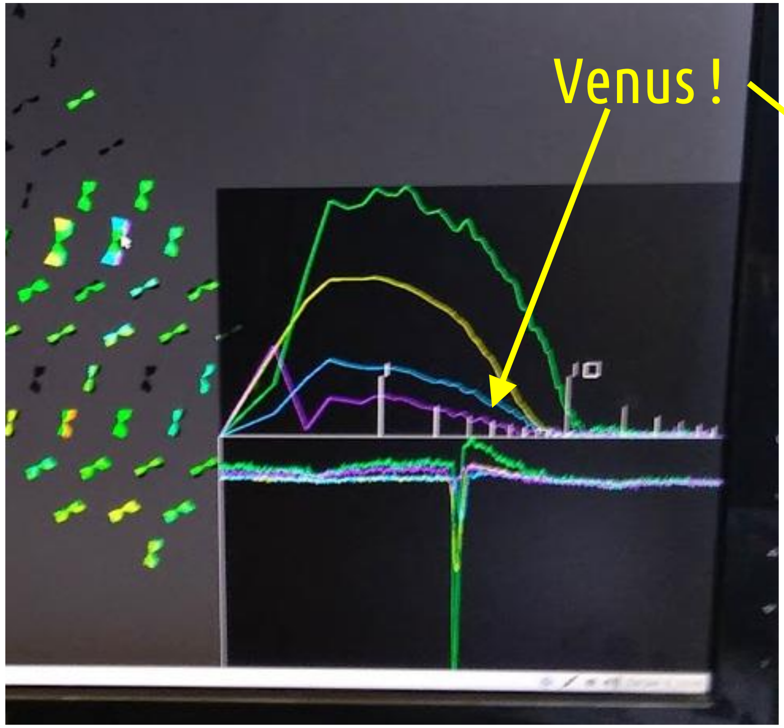
First observations

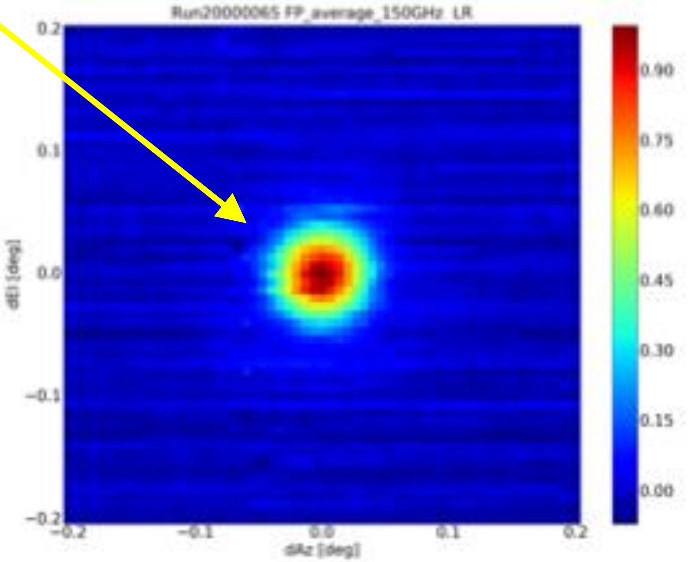
In the end of year 2019, all receiver cooling, telescope control and readout electronics got ready. First light was achieved in beginning of year 2019.

Sun scan on 2018 December 30



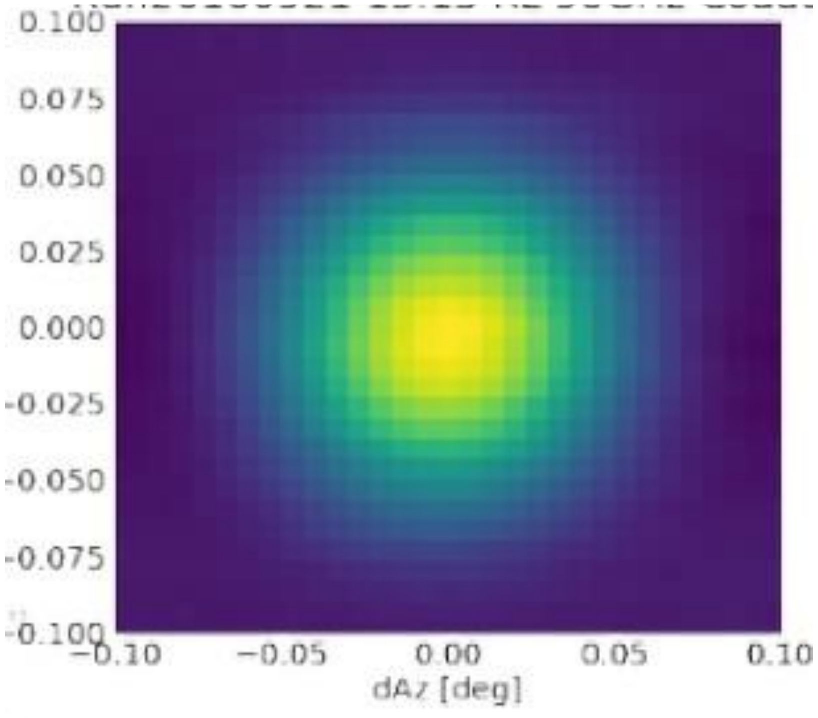
Venus scan on 2019 January 5





Planet observation

Jupiter observation 90 GHz TESs averaged

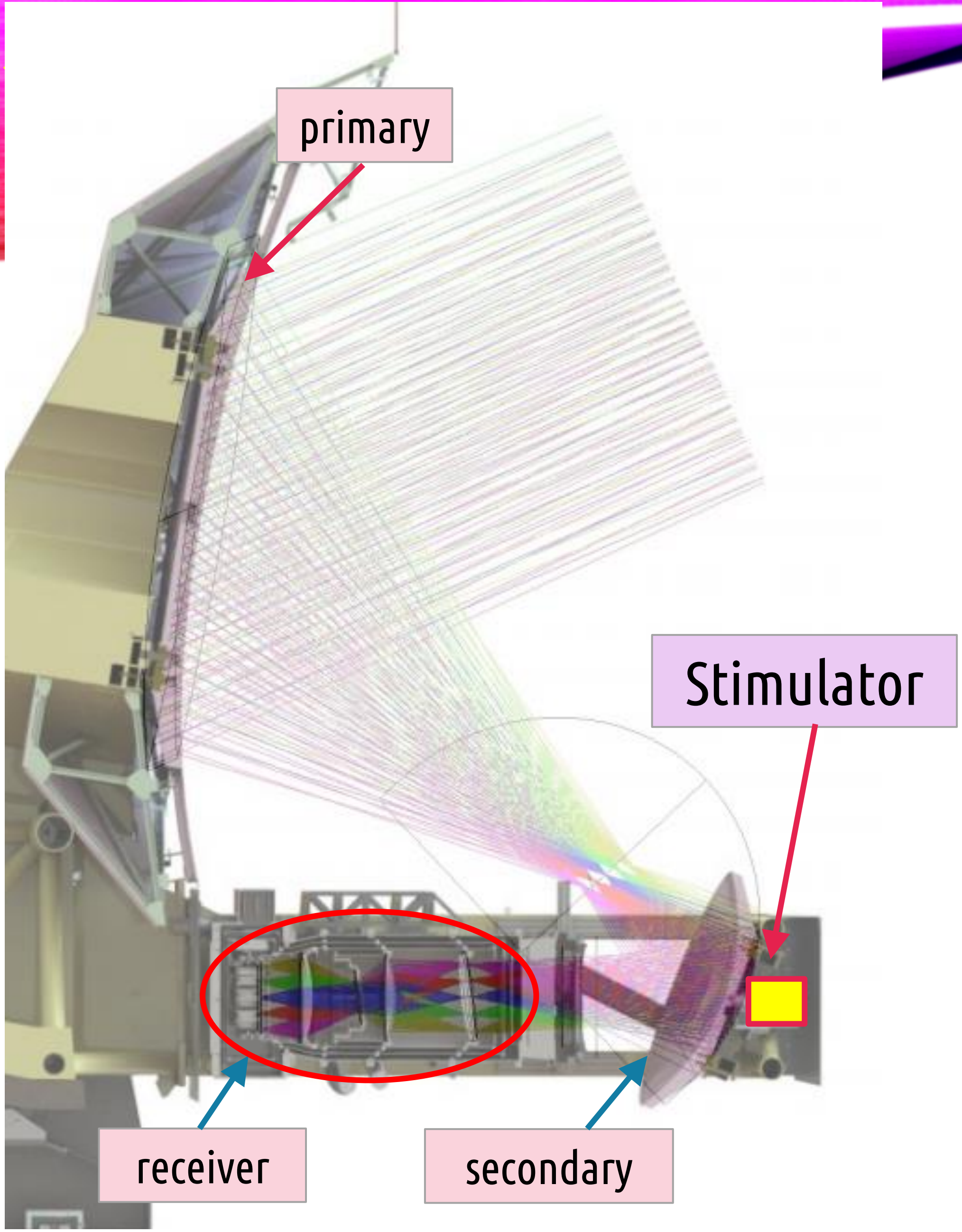


Telescope focusing performance is checked with planet observation.

After several alignment work of receiver, similar resolution as design was obtained.

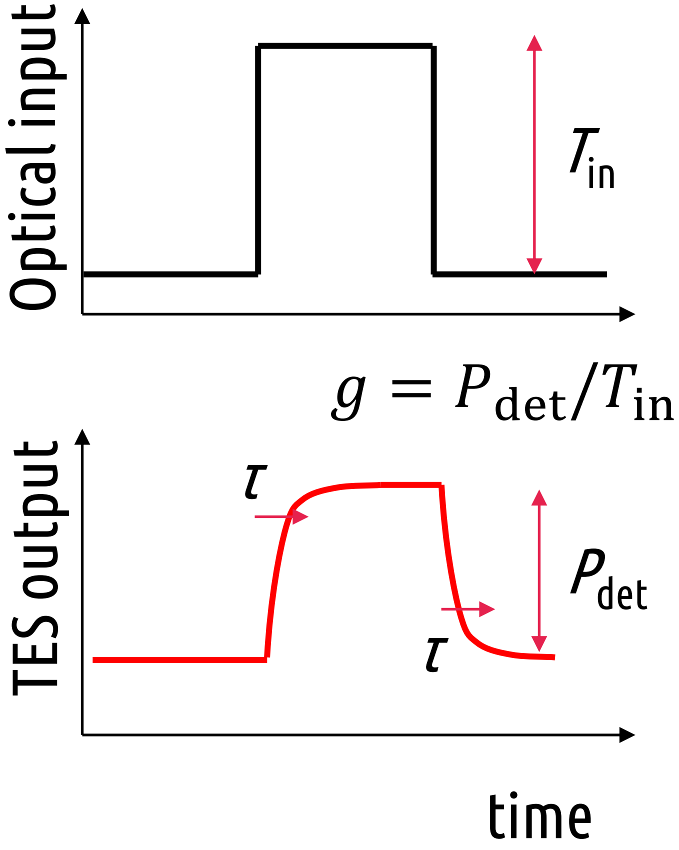
Expected beam width (FWHM)
3.5 arcmin (150 GHz)
5.2 arcmin (90 GHz)

Calibration source: Stimulator

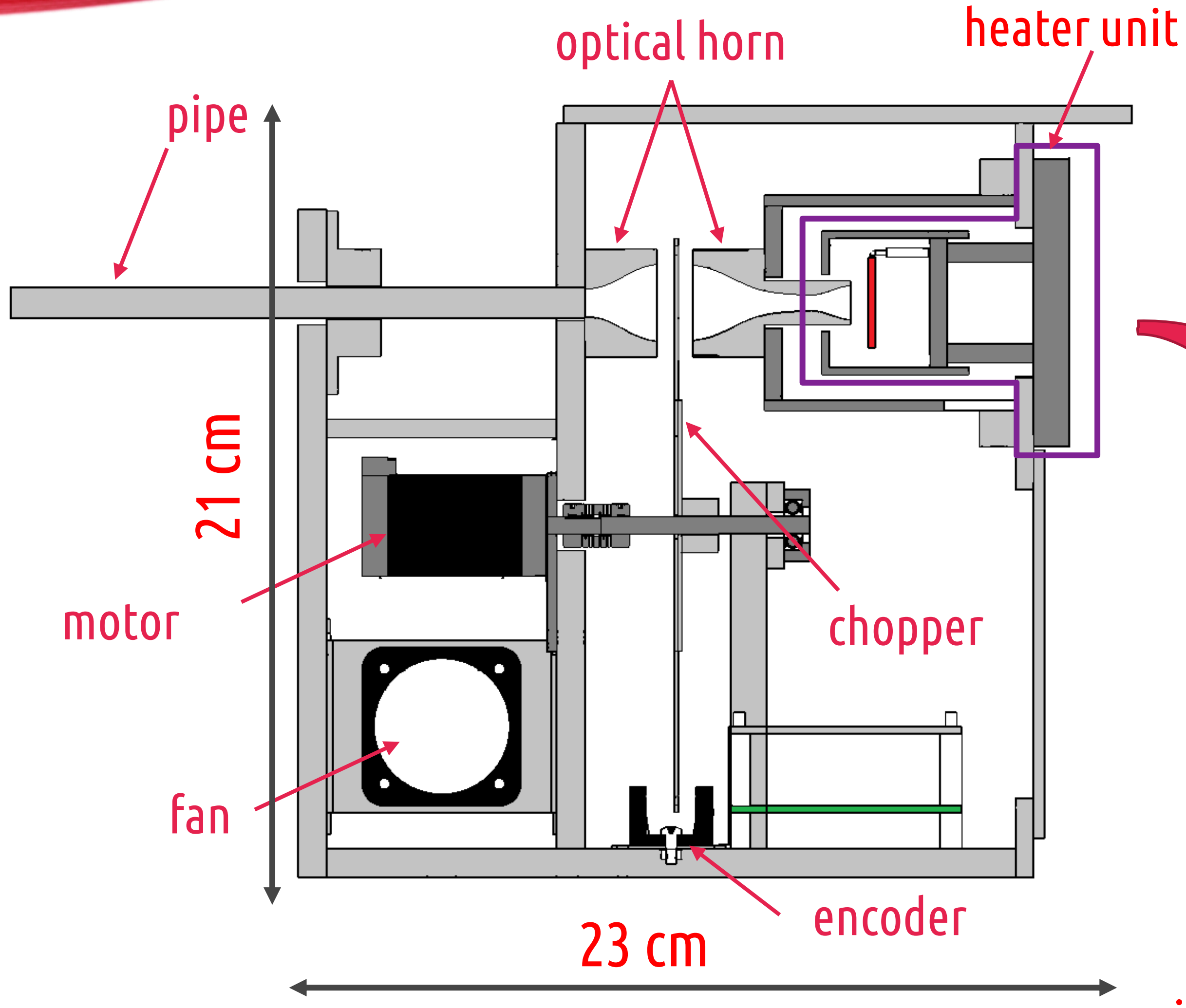


Role

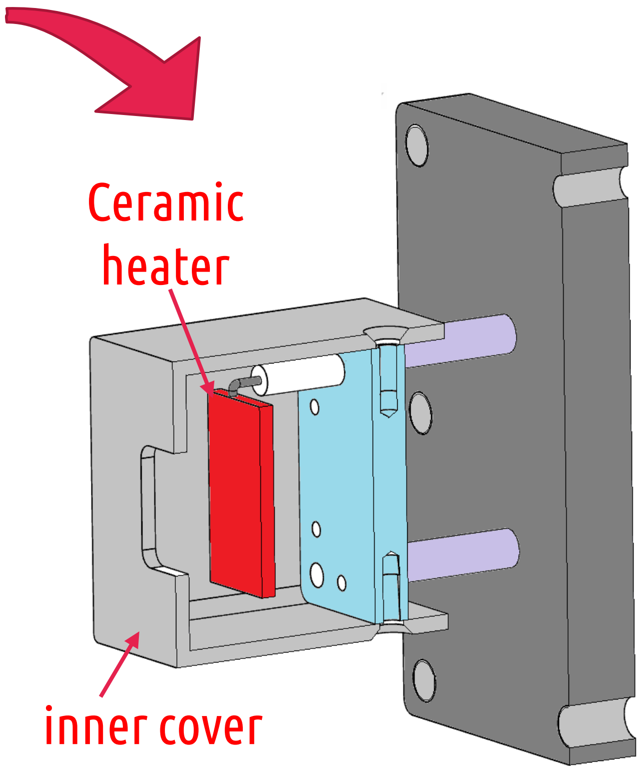
- Evaluation of detector
  - Response magnitude gain (g)
  - Response delay time constant (τ)
- Use as a reference with constant intensity



PB-2a stimulator design

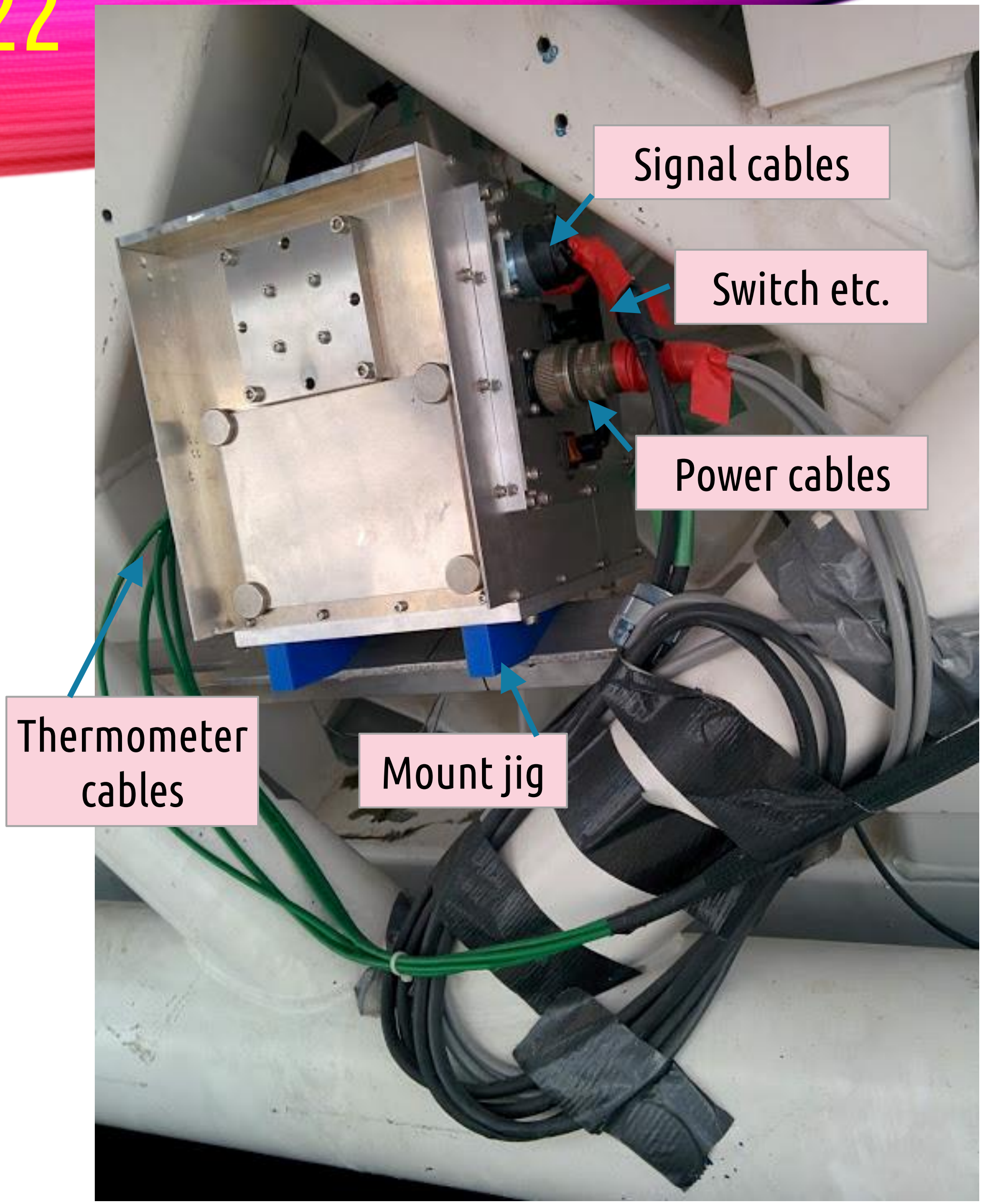


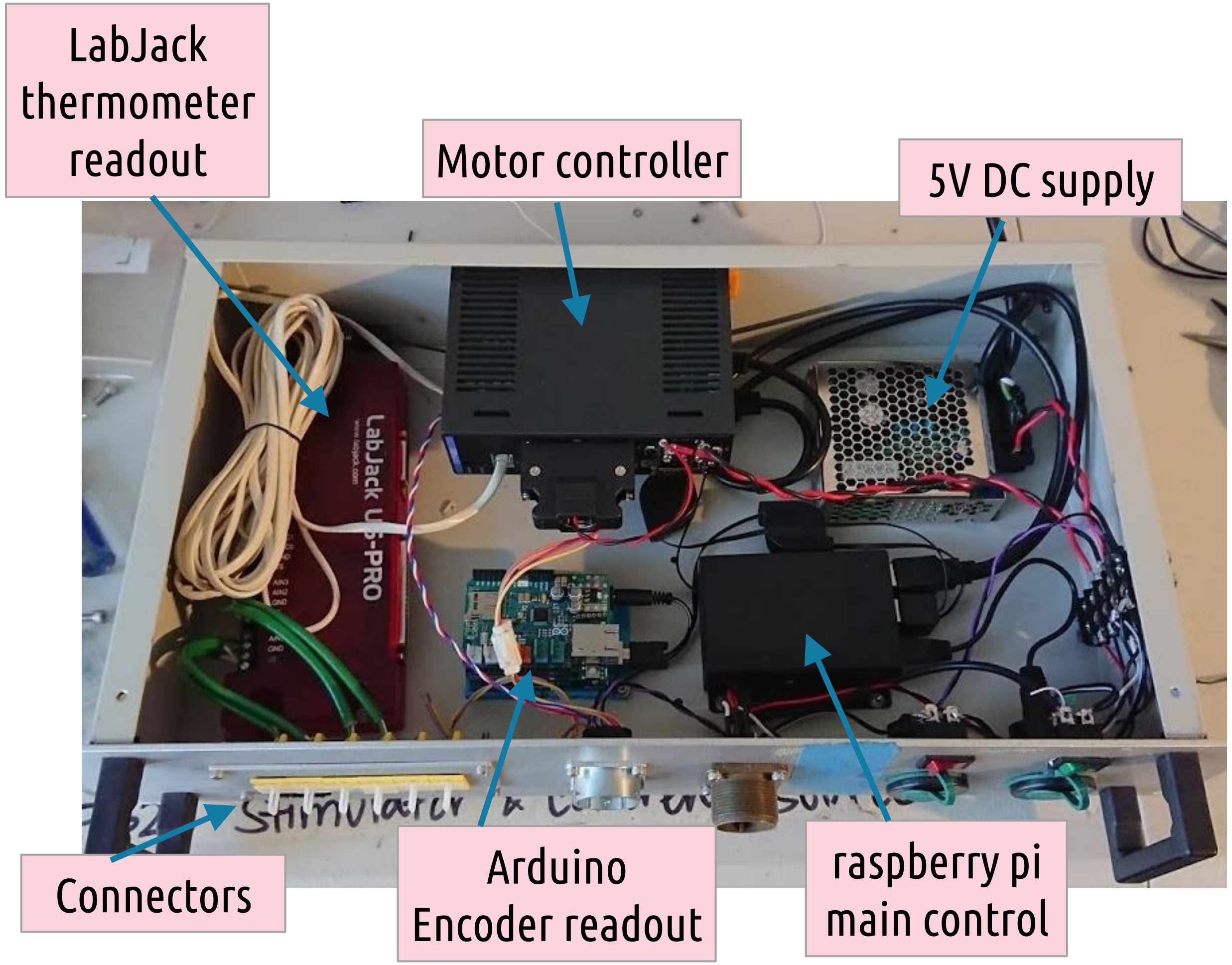
Black body radiation from ceramic heater (~700℃) is modulated with chopper and is emitted from the pipe to the receiver.



cross-section image of heater unit. Heater unit could be replaced on telescope with minimal cabling work.

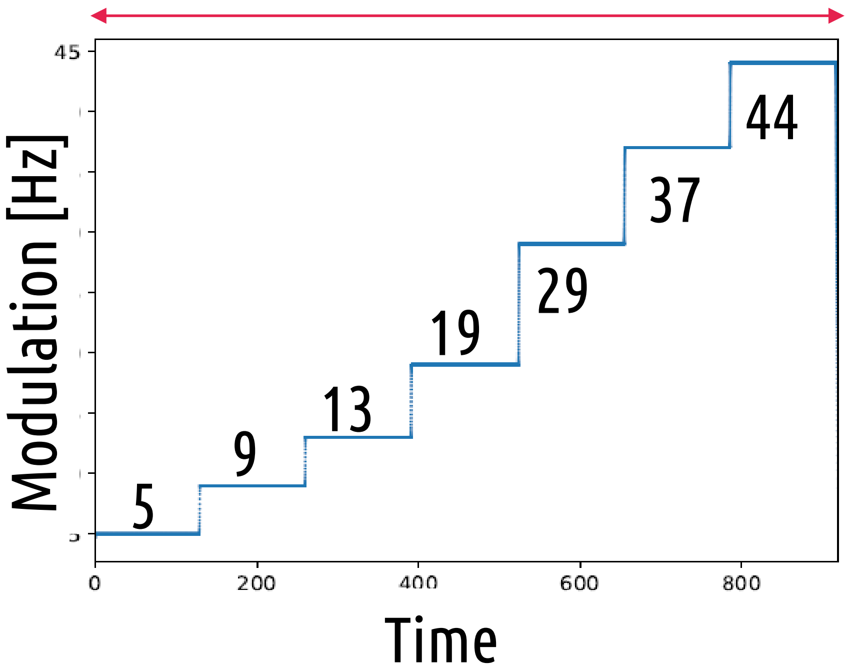
Current implementation

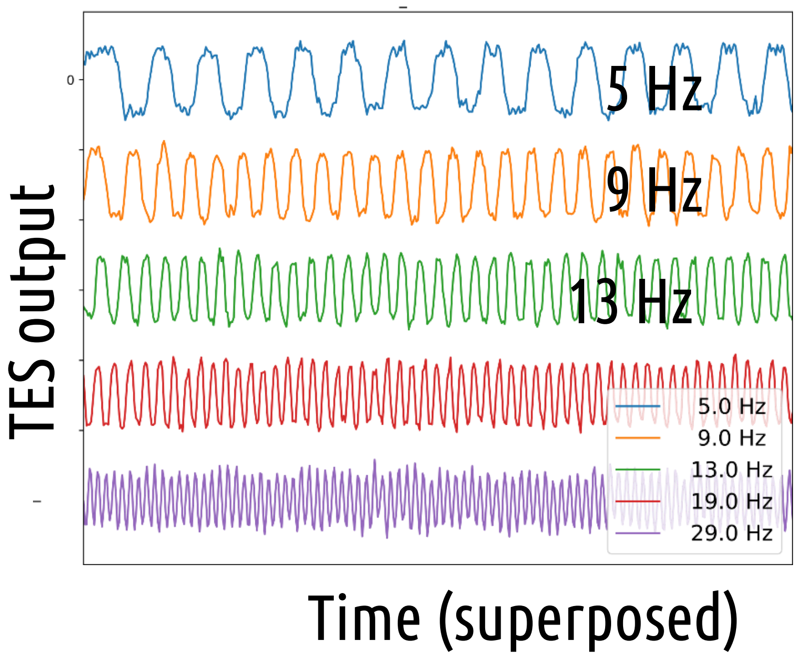


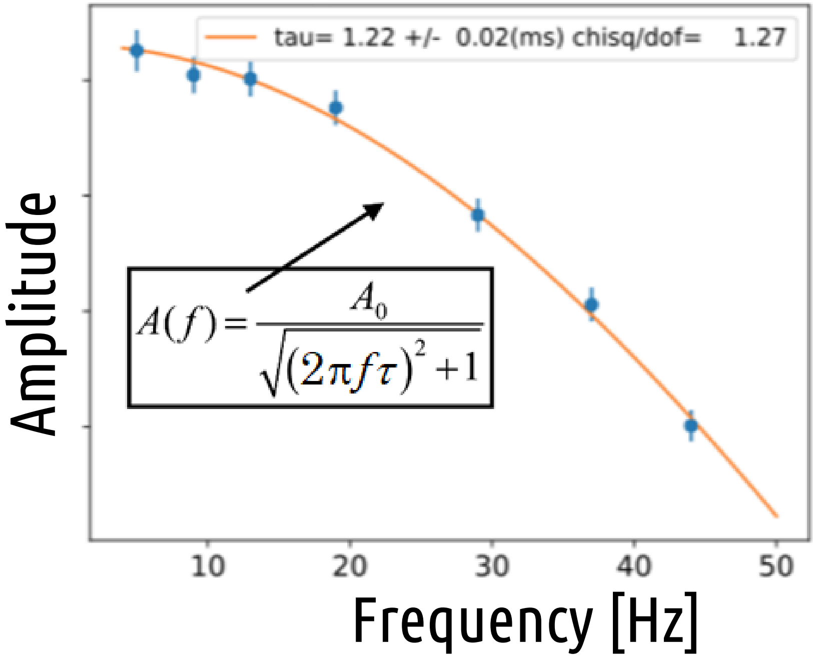


Controlling electronics are installed in a 19” box, and it is inserted in a telescope co-moving rack.

Operation principle of stimulator







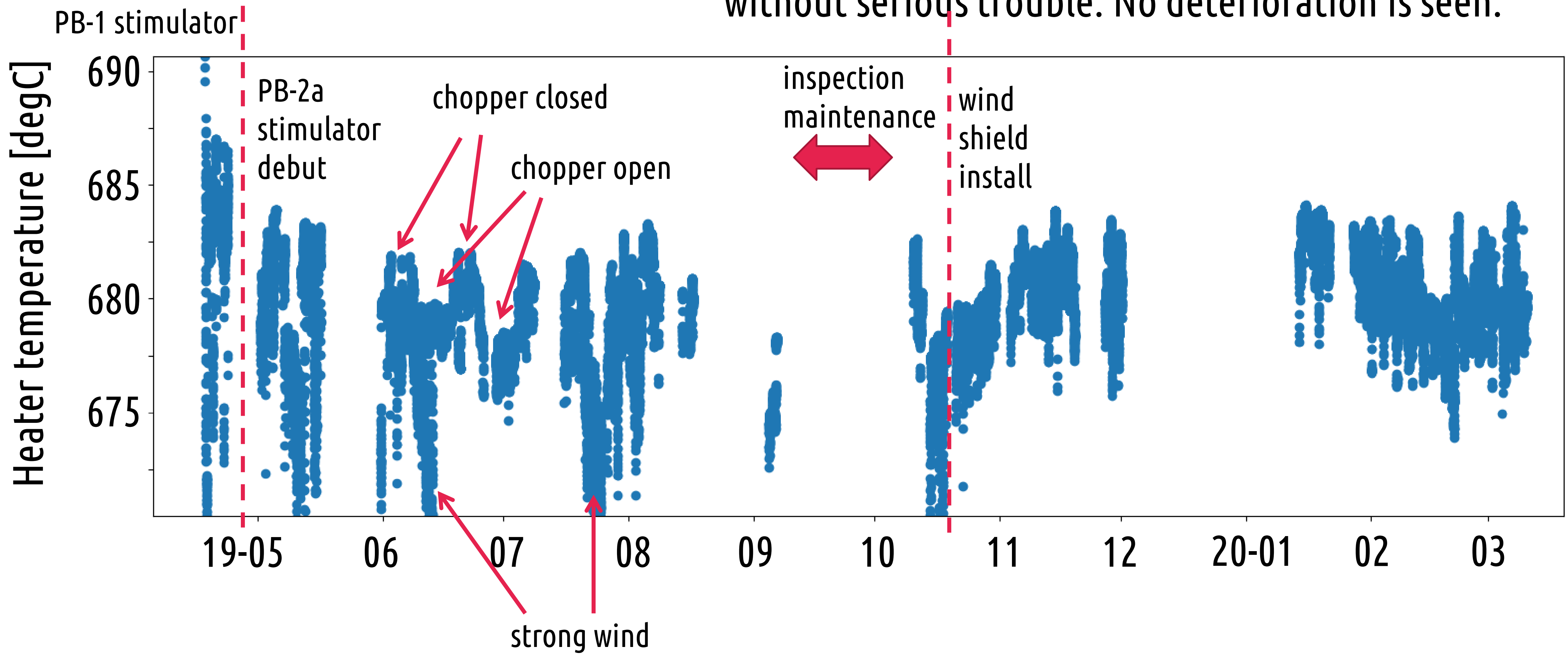
1.
Operate stimulator with various modulation frequency.

2.
Measure detector output amplitude for each frequency

3.
Fit curve to obtain gain and time constant of detector

Long-term stability

Stimulator have worked ~150 days since installation without serious trouble. No deterioration is seen.



PB-2b arrived at site

Picture when container arrived

PB-2b assembly at high bay

- PB-2b container is at site, and assembly work started
- Telescope, electric apparatus etc. are prepared in parallel.

Status of the site

- 2020 March, COVID-19 finally landed Chile. The infection spread whole country.
- We decided evacuation from the site.
- All system were shutdown, instruments were protected from weather, and all personnel evacuated.
- As of August, we start discussion how to return to the site.

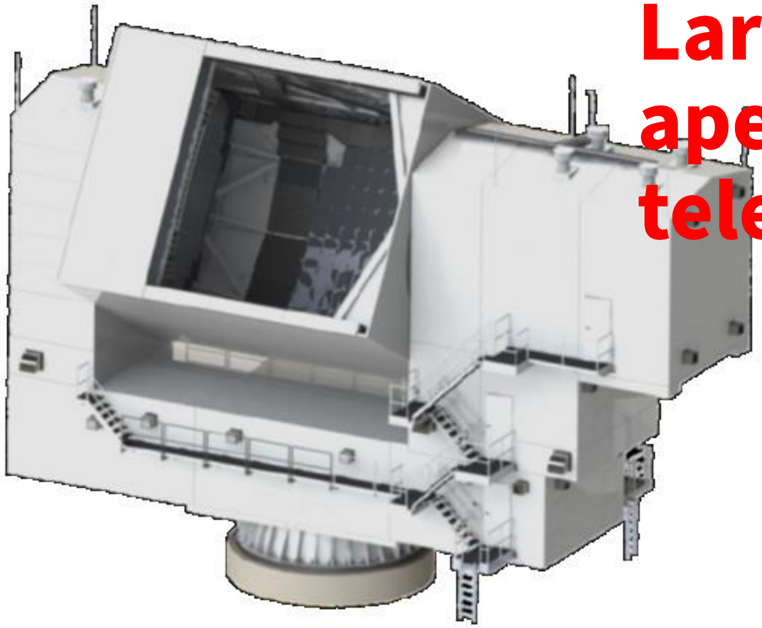
Covered telescope

Next experiment, Simons Observatory

Next experiment of Simons Array,
Simons Observatory is in preparation.

Feature is combination of small telescope for large-scale, and large telescope for small-scale. Total number of sensor is about 3 times more than SA.

Each component is being produced, assembly and test are being performed.



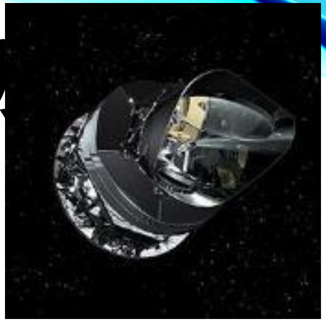
Future plan of ground experiment

NOW

	POLARBEAR	Simons Array	Simons Observatory	CMB-S4
Year	2012〜	2020〜	2021〜	Late 20s〜
Number of sensors	~ 1,000	~ 20,000	~ 60,000	~ 500,000
Expected r sensitivity		0.006	0.003	0.001

Fin.
Thanks for listening

CMB観測の



地上実験は大気(水蒸気)の影響を抑えるため
高地・乾燥した場所

衛星
〇 大気の影響がない
× 宇宙で運用は難しい

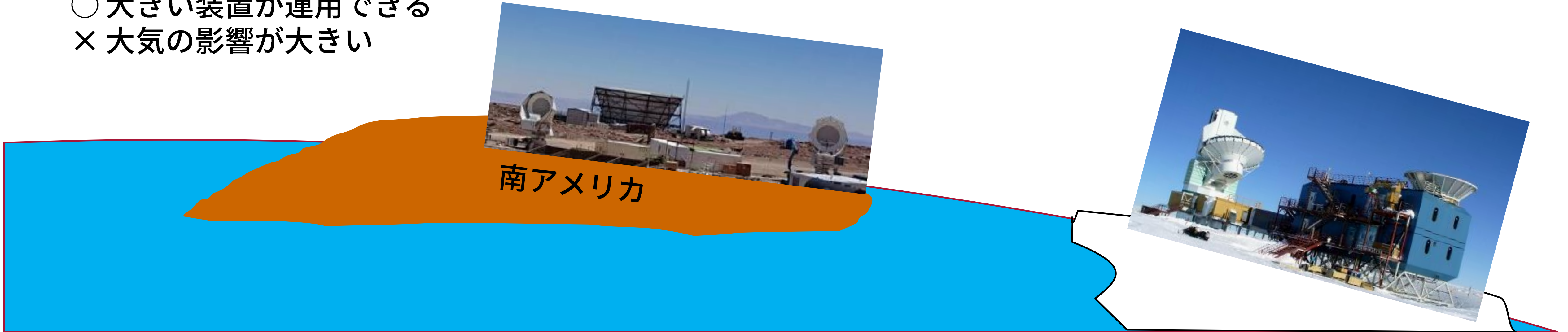
南極点
BICEP/Keck, SPT

気球
〇 大気の影響を除くには安価
× 観測期間を長くできない

南米 チリ
ACT, POLARBEAR, CLASS

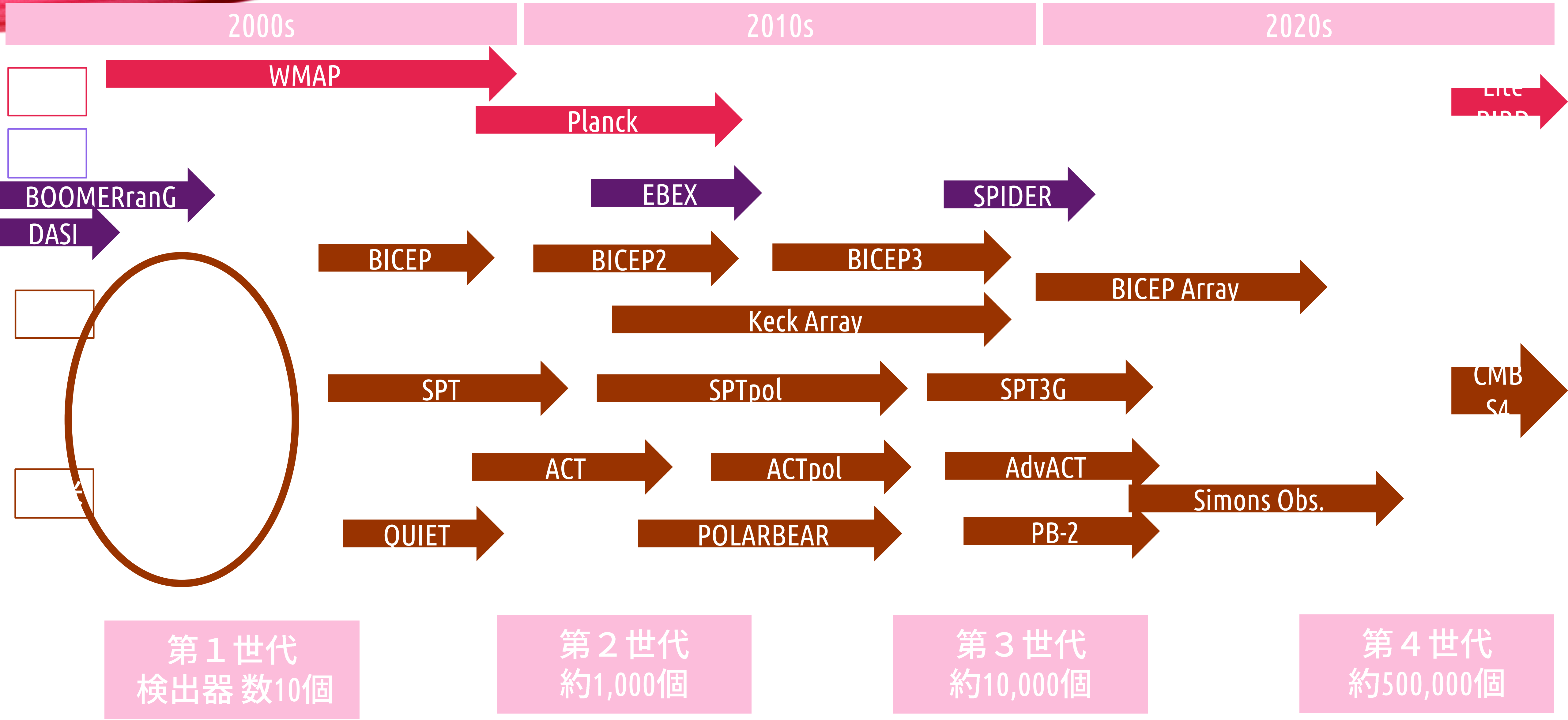
カナリア諸島
QUIJOTE, GroundBIRD (来週のトーク)

地上
〇 大きい装置が運用できる
× 大気の影響が大きい



各実験の進行状況

全部は把握できていませんがご了



POLARBEAR (PB) 実験

宇宙の謎を解き明かす国際共同実験。

アメリカ（UCバークレー・サンディエゴ）
日本 (KEK, IPMU) など、8カ国100人超が参加。

2019年7月に開かれたコラボレーションミーティング

実験地は標高5,200mで乾燥したアタカマ砂漠。

PB-1 での観測は2012年から
重力レンズBモードの検出に成功！

より高性能なPB-2型受信器3台による
Simons Array へのアップグレードが現地で進行中

チリ・アタカマの実験現場

どうやって行く？

日本から飛行機は乗り換え2回
所要時間は約2日

最寄りの大都市カラマからはバスで2時間
サンペドロ・デ・アタカマに滞在

オアシスの町サンペドロ

現地での暮らし

ホテルには猫数匹

４WDのトラックに荷物を載せ通勤

拠点のホテルは日干しレンガの建物
ベッドとシャワー室の簡素な部屋

ホテルの食事

町中には小さいお店やスーパー多数

アタカマの生き物

←リャマ
通勤中よく見る

ビスカーシャ→
ウサギに似ている
がネズミに近い種

キツネ　　　→
人に慣れていて
車に近づいてくる

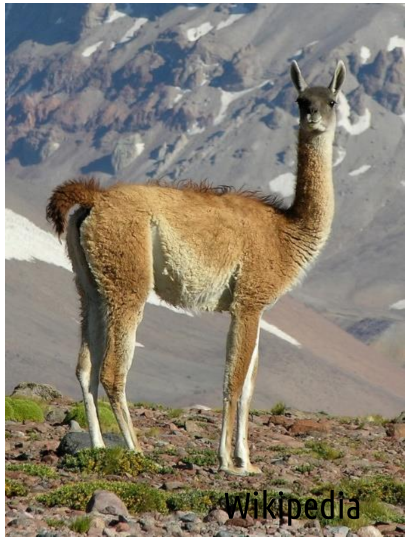
←　フラミンゴ
湖ではたくさん見
られる

南米のラクダ科を見分けよう

リャマ属

リャマ 家畜

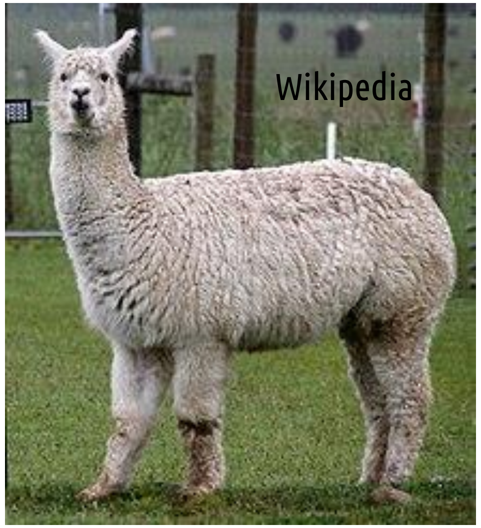
体高 1.2mくらい
体色 白、黒、茶色、灰色とその混合



グアナコ

体高 1.5mくらい
この中で一番大きい種
この写真の色のみ

ビクーニャ属



アルパカ 家畜

体高 1.0mくらい
フワフワの毛で日本でも人気に
白、黒、灰色、茶色

ビクーニャ

体高 1.4mくらい
首元の毛はとても細く高級品
茶色のみ

共通して、威嚇のために臭い唾液を吐く。肉は牛や羊に似た味で、おいしい。

James ax天文台へ向かう

サンペドロから現地に向かう幹線道路からの眺め

セロ・トコ山頂近くの高原地帯
（チャナントール高原の一部）
近くには他の天文台が多数

POLARBEARサイト

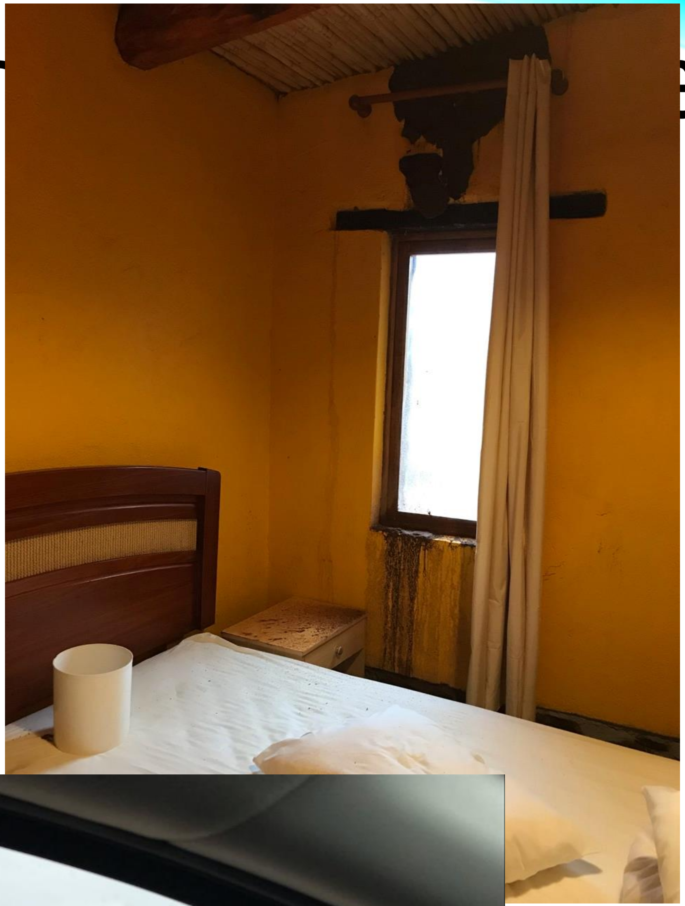
となりの実験 徒歩3分

気圧は地上の半分
酸素ボンベが必要

Bad weather

From the end of January to mid of February, there was unusually heavy rain in Atacama desert. Site crew needed to escaped to Calama, a 100km away city.

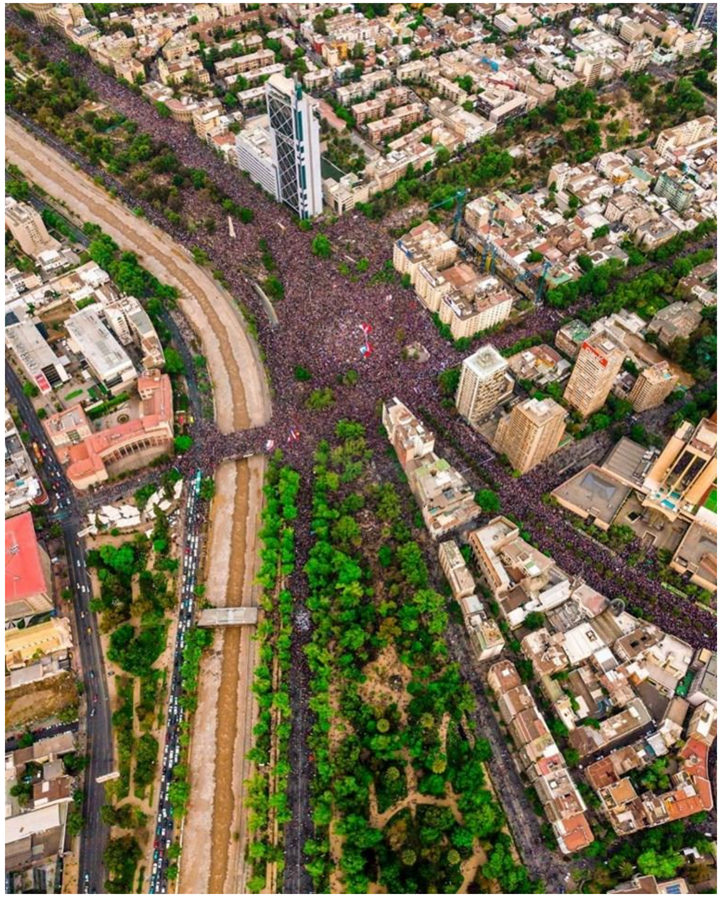
Wall of hotel room was broken

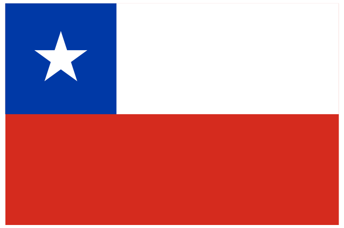


Flood in middle of desert

Road to site was damaged

地下鉄運賃の値上げ反対に端を発した活動が
チリほぼ全土を巻き込む大規模な抗議行動に。





首都サンチアゴでは100万人の
デモ行進

軍隊も緊急出動

滞在していた町でも小規模な
がら集会が、警官との乱闘も。