FY2018 Symposium Conference for "Cosmic Acceleration" Research Grant program

Ongoing Data Analyses at POLARBEAR and Prospects of Simons Array

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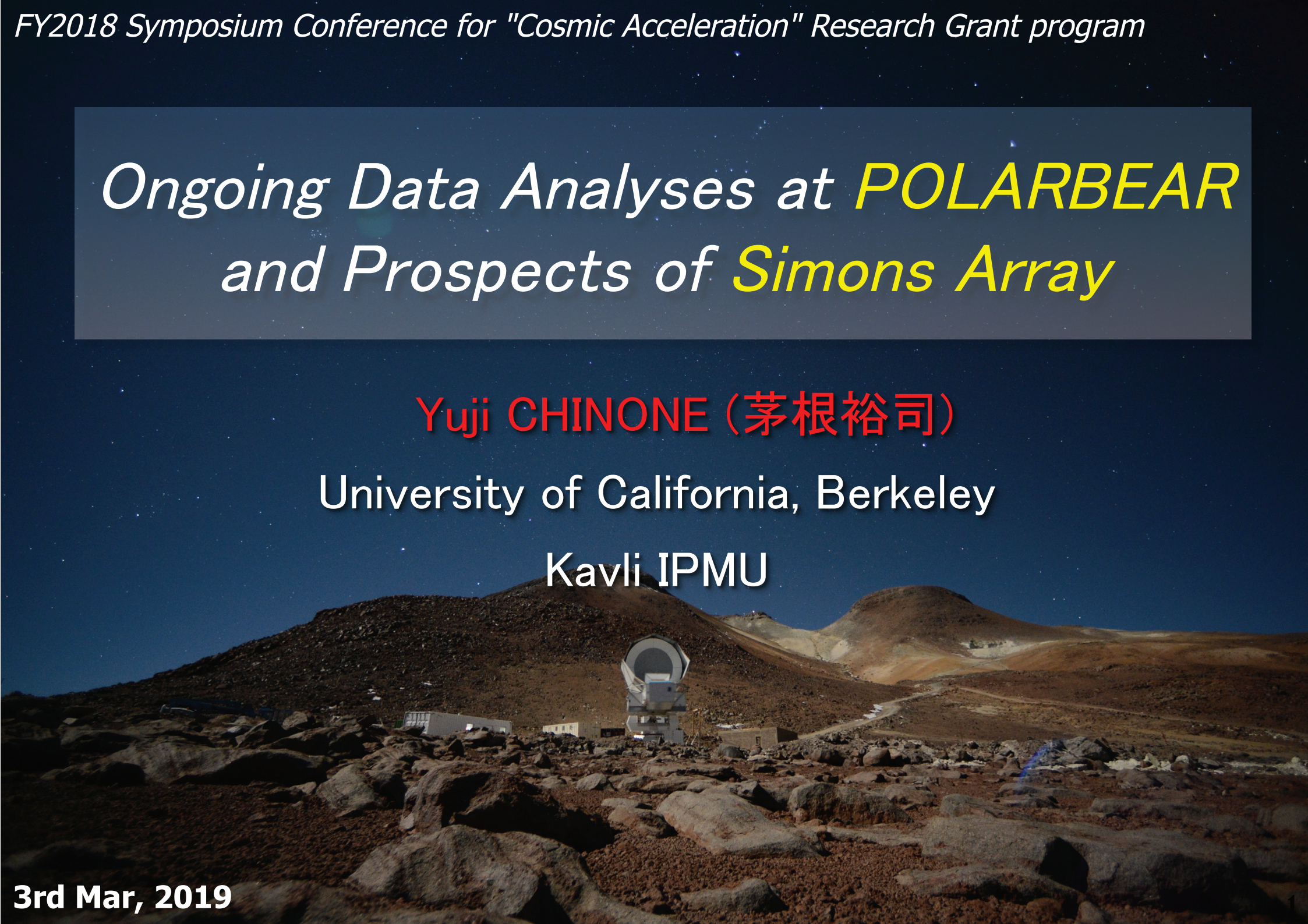
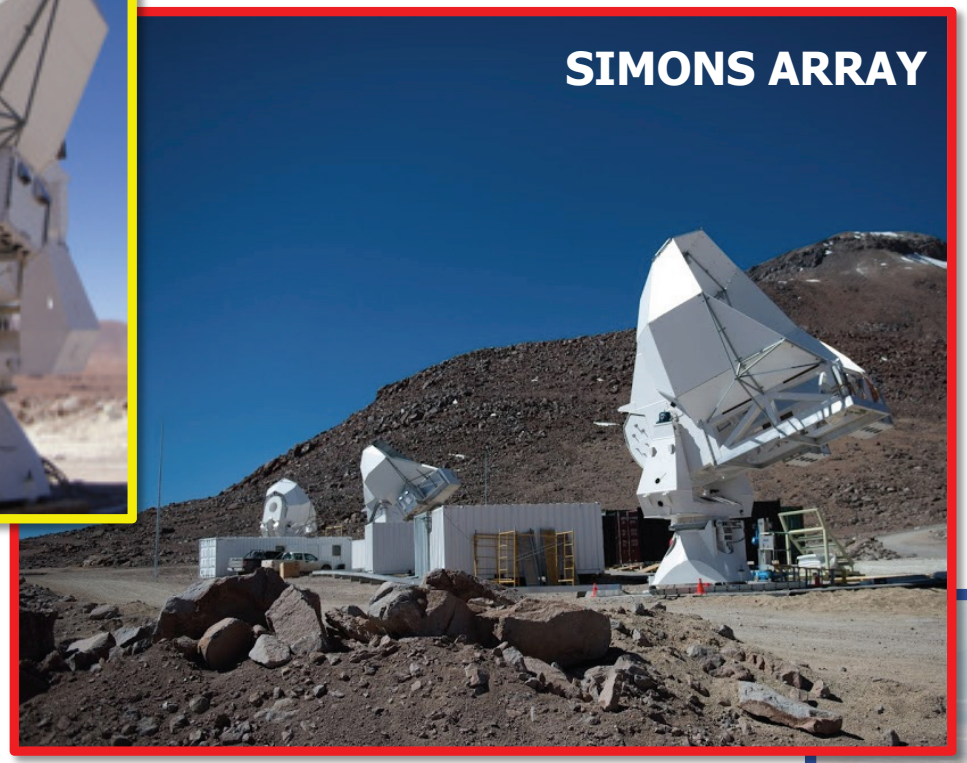
Kavli IPMU



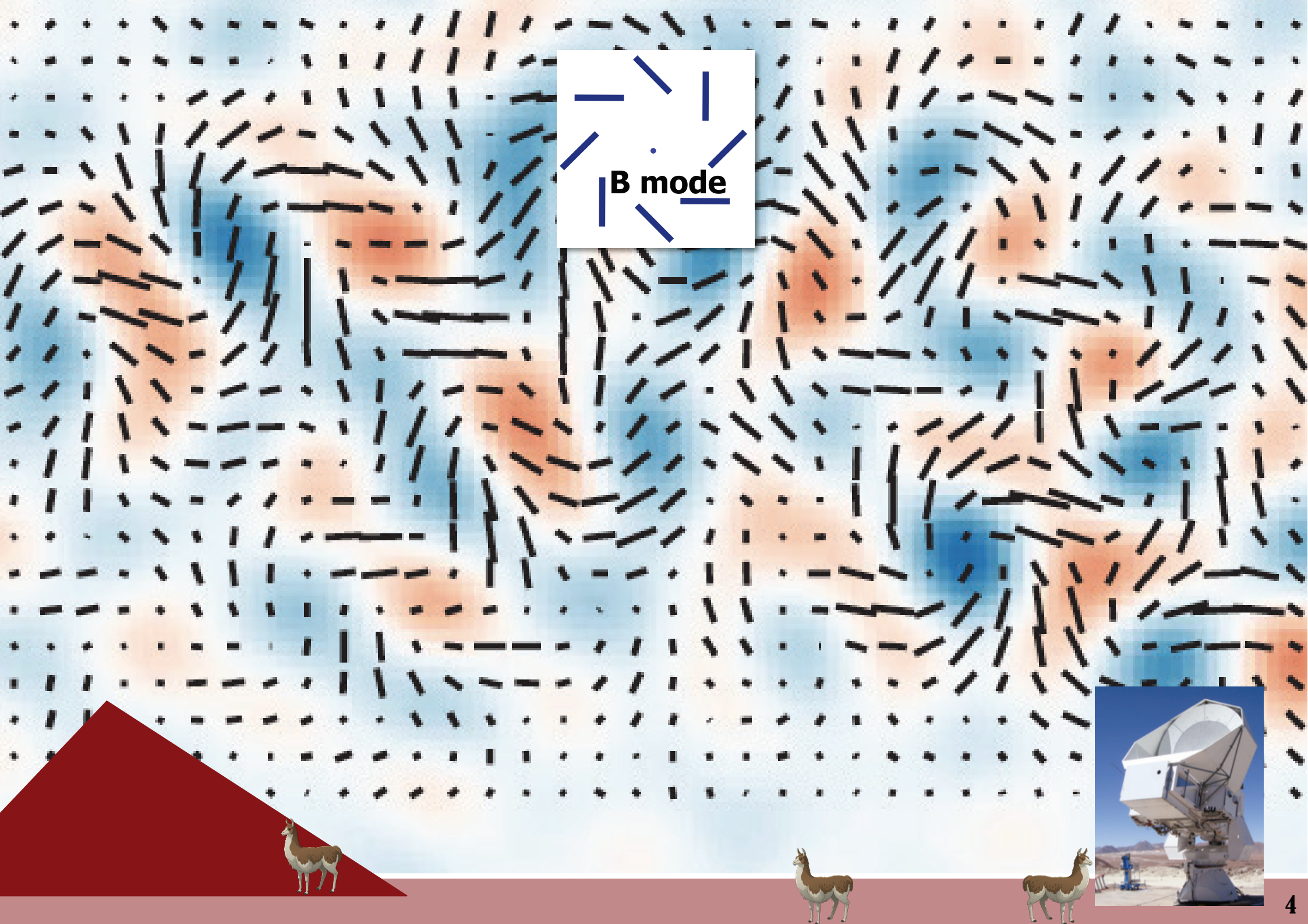
3rd Mar, 2019

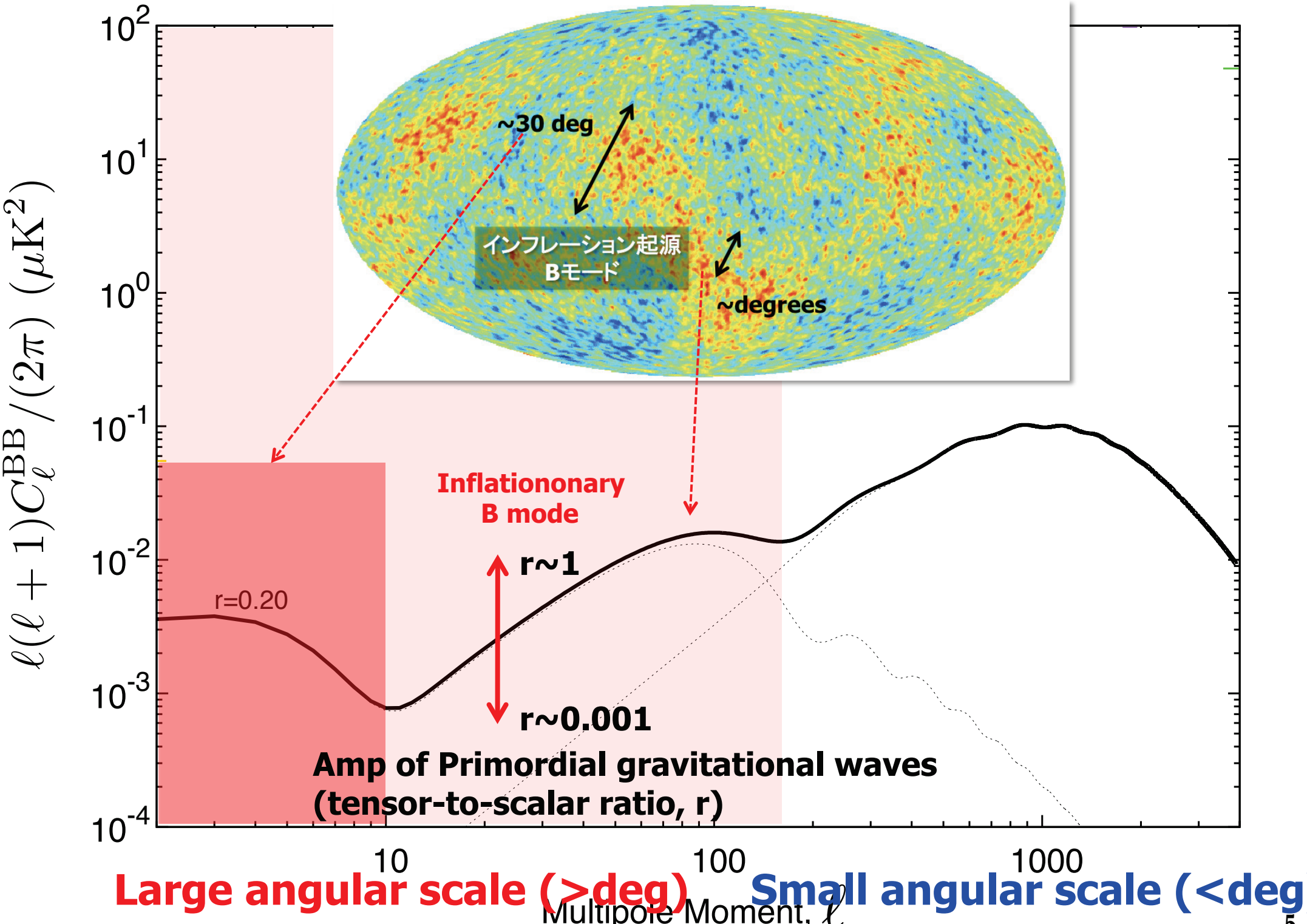
What Am I Doing @ Berkeley?

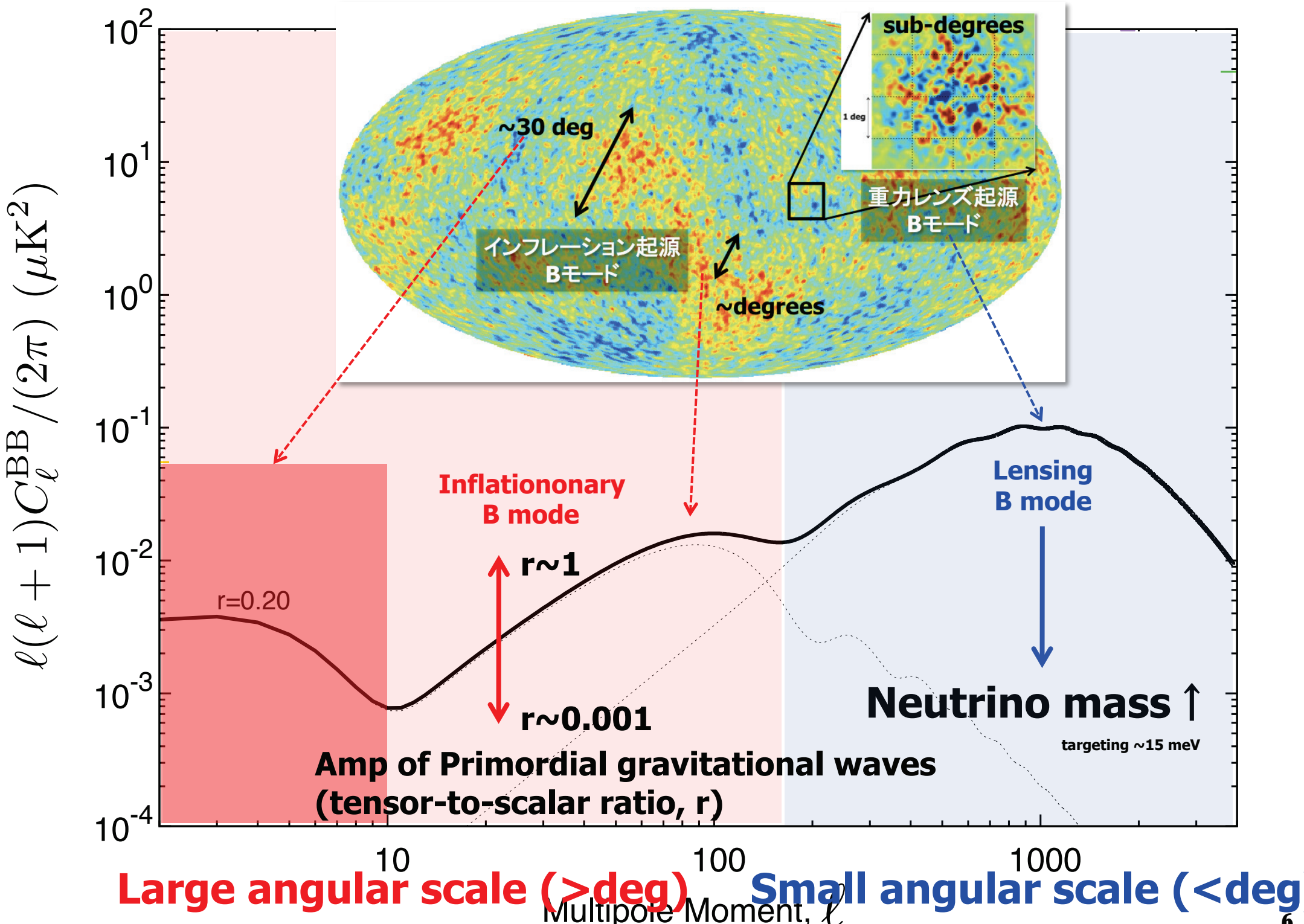


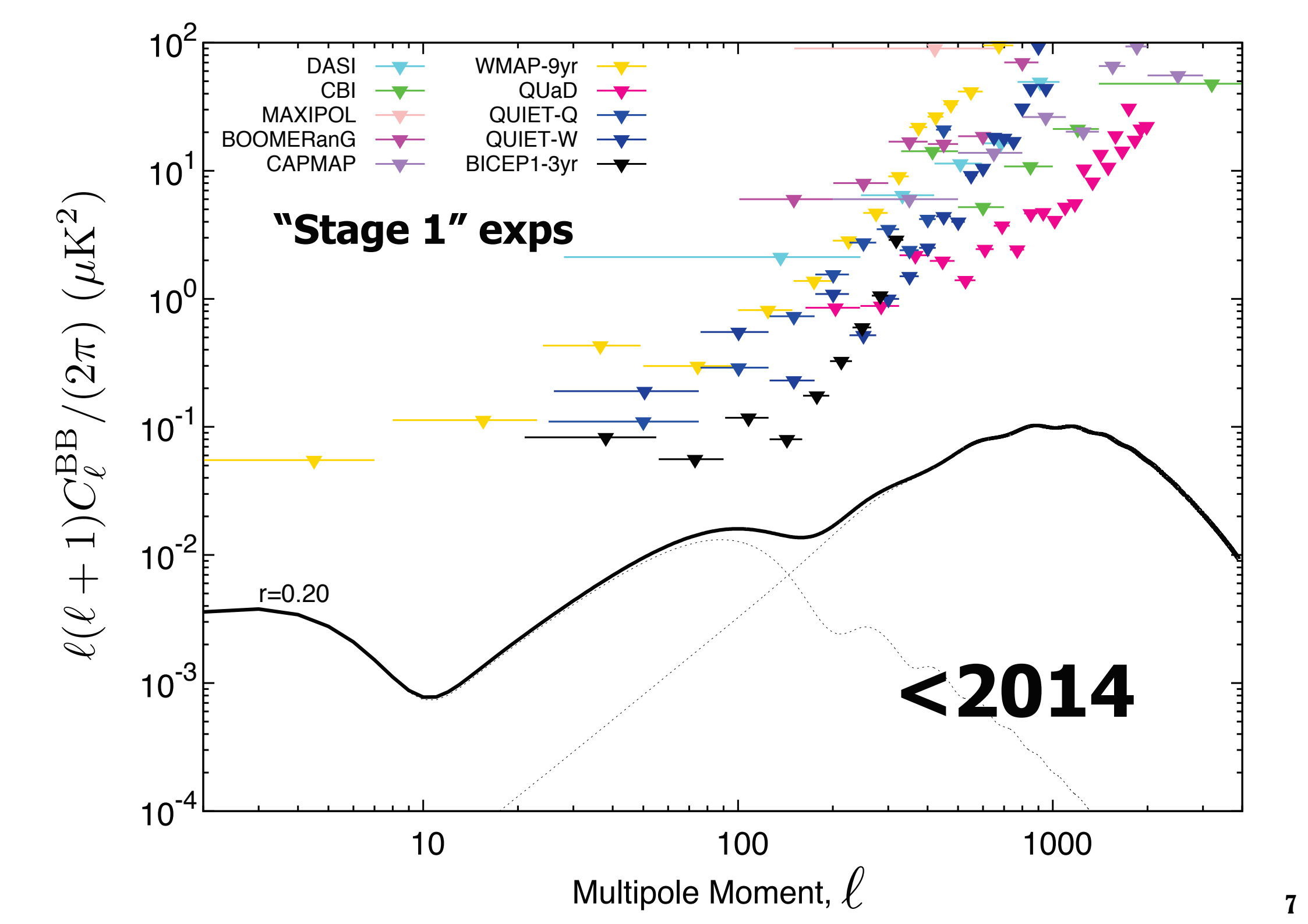
better sensitivity

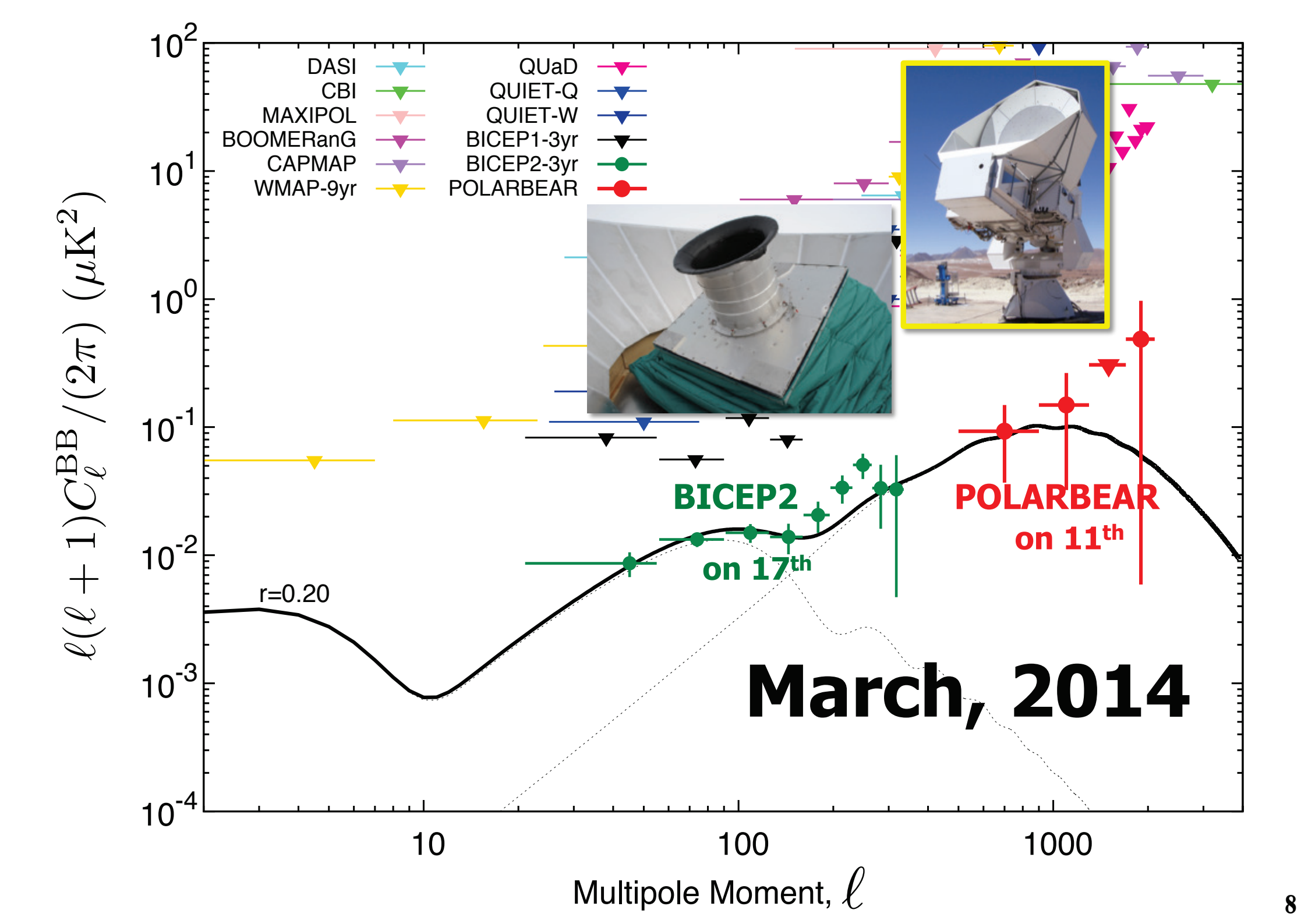
Measuring amp & angle of linear polarization on the sky

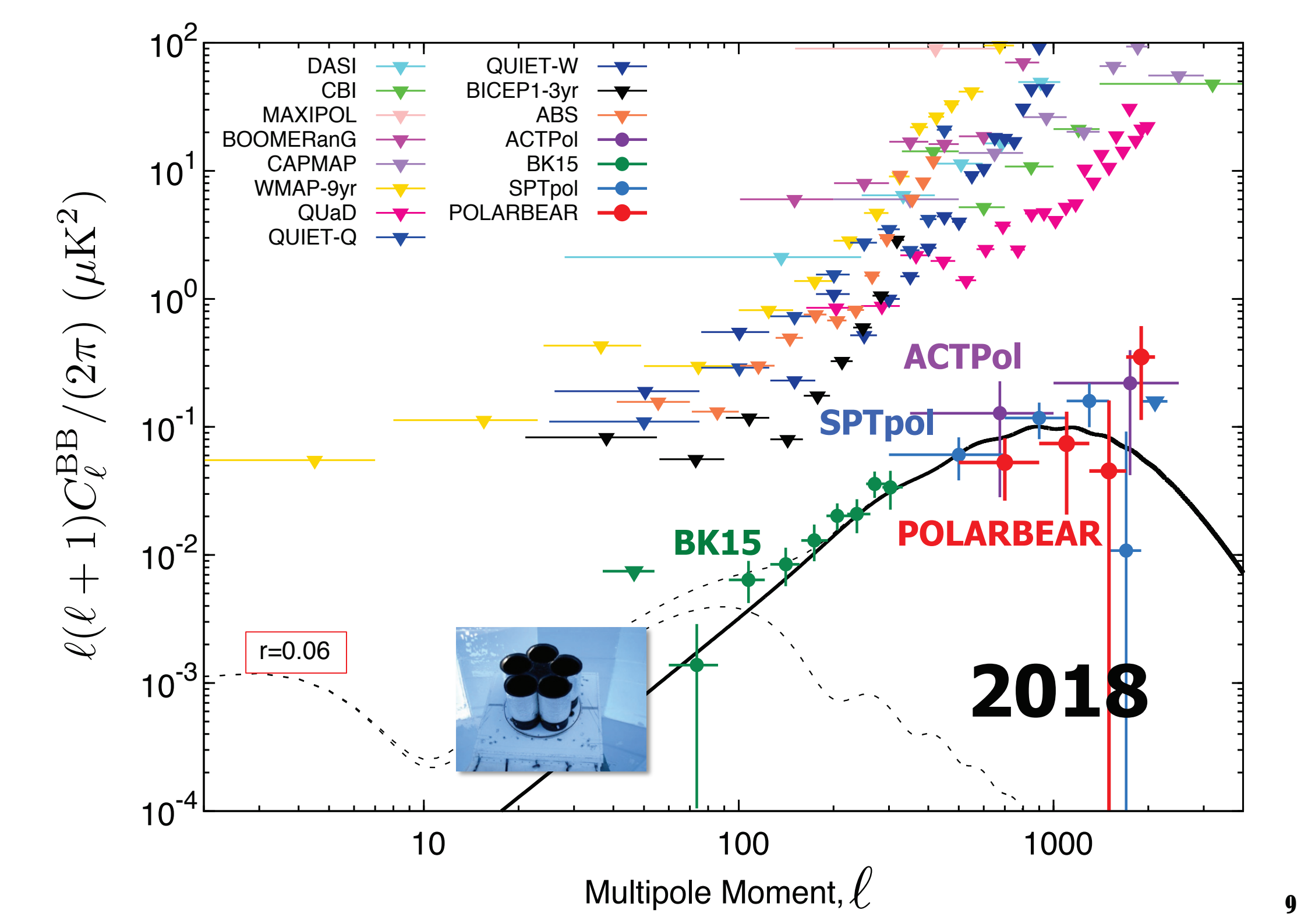

B mode


~30 deg
インフレーション起源
Bモード
~degrees
Inflationonary
B mode
r~1
r=0.20
r~0.001
Amp of Primordial gravitational waves
(tensor-to-scalar ratio, r)
$\ell(\ell+1)C_\ell^{BB}/(2\pi)\ (\mu K^2)$
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
100
1000
Multipole Moment, ℓ
Large angular scale (>deg)
Small angular scale (<deg


sub-degrees
1 deg
~30 deg
インフレーション起源
Bモード
~degrees
重力レンズ起源
Bモード
$\ell(\ell+1)C_\ell^{BB}/(2\pi)\ (\mu K^2)$
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
r=0.20
Inflationonary
B mode
r~1
r~0.001
Lensing
B mode
Neutrino mass ↑
targeting ~15 meV
Amp of Primordial gravitational waves
(tensor-to-scalar ratio, r)
10
100
1000
Multipole Moment, ℓ
Large angular scale (>deg)
Small angular scale (<deg

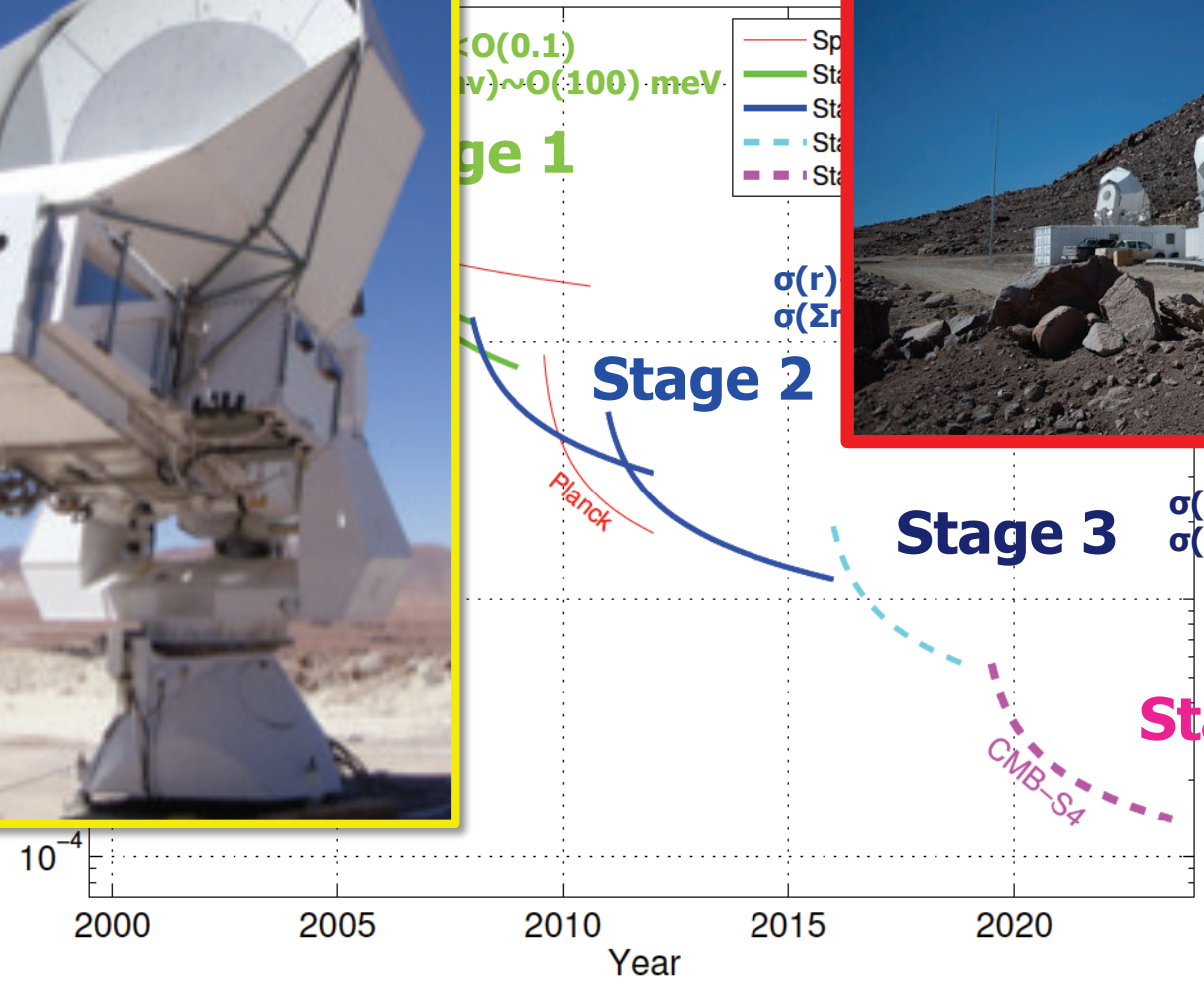

DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
"Stage 1" exps
r=0.20
<2014
$\ell(\ell+1)C_\ell^{BB}/(2\pi)$ (μK^2)
Multipole Moment, ℓ
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
100
1000


DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
BICEP2-3yr
POLARBEAR
BICEP2
on 17th
POLARBEAR
on 11th
r=0.20
March, 2014
$\ell(\ell+1)C_\ell^{BB}/(2\pi)\ (\mu K^2)$
Multipole Moment, ℓ
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
100
1000


DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
ABS
ACTPol
BK15
SPTpol
POLARBEAR
ACTPol
SPTpol
BK15
POLARBEAR
r=0.06
2018
$\ell(\ell+1)C_\ell^{BB}/(2\pi)$ (μK^2)
Multipole Moment, ℓ
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
100
1000

Stage 3:
What are prospects of Simons Array now?

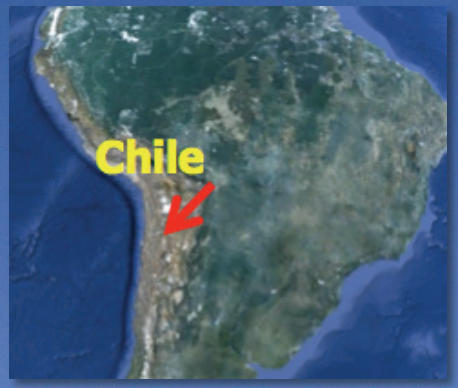
Stage 2:
What POLARBEAR has achieved? Which data analysis are ongoing?



CMB-S4 Science Book (arXiv:1610.02743)

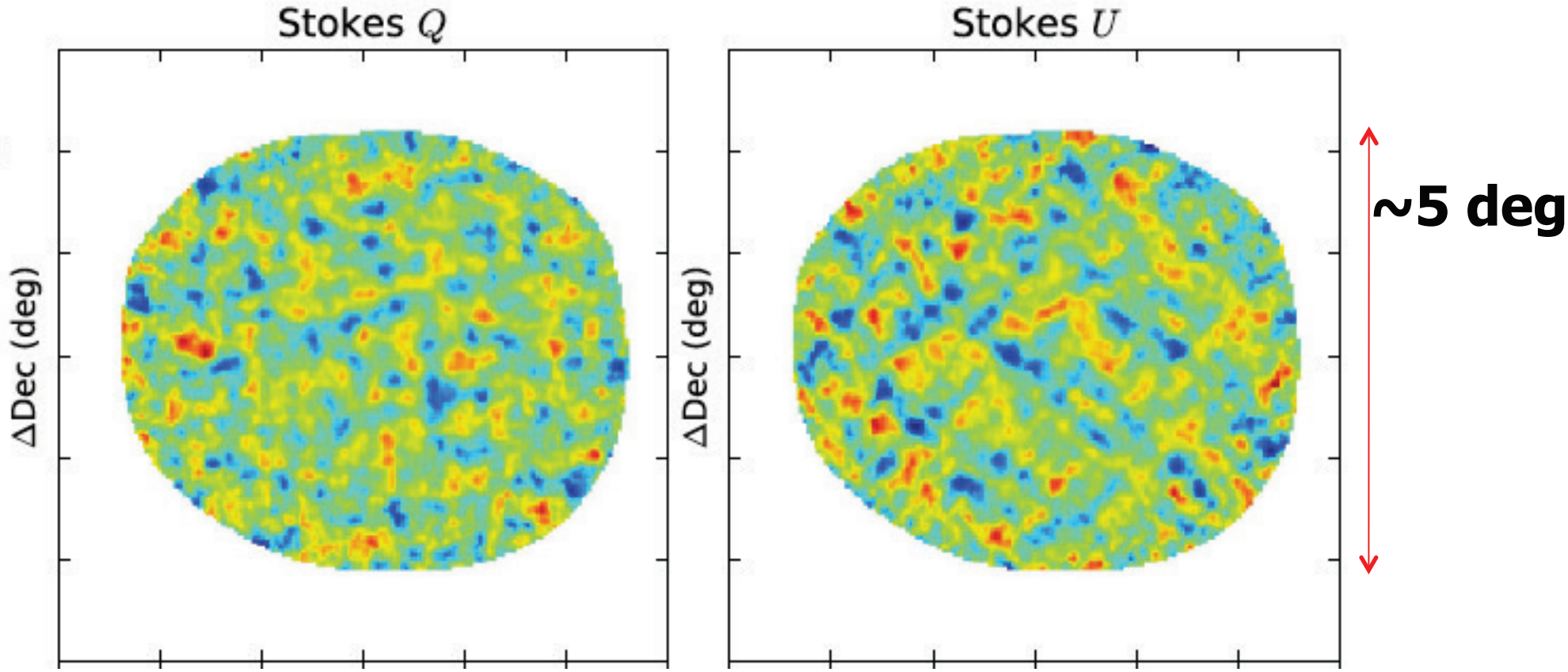
POLARBEAR since 2012 (deployed in 2011)

5,200m @ Atacama Desert, Chile



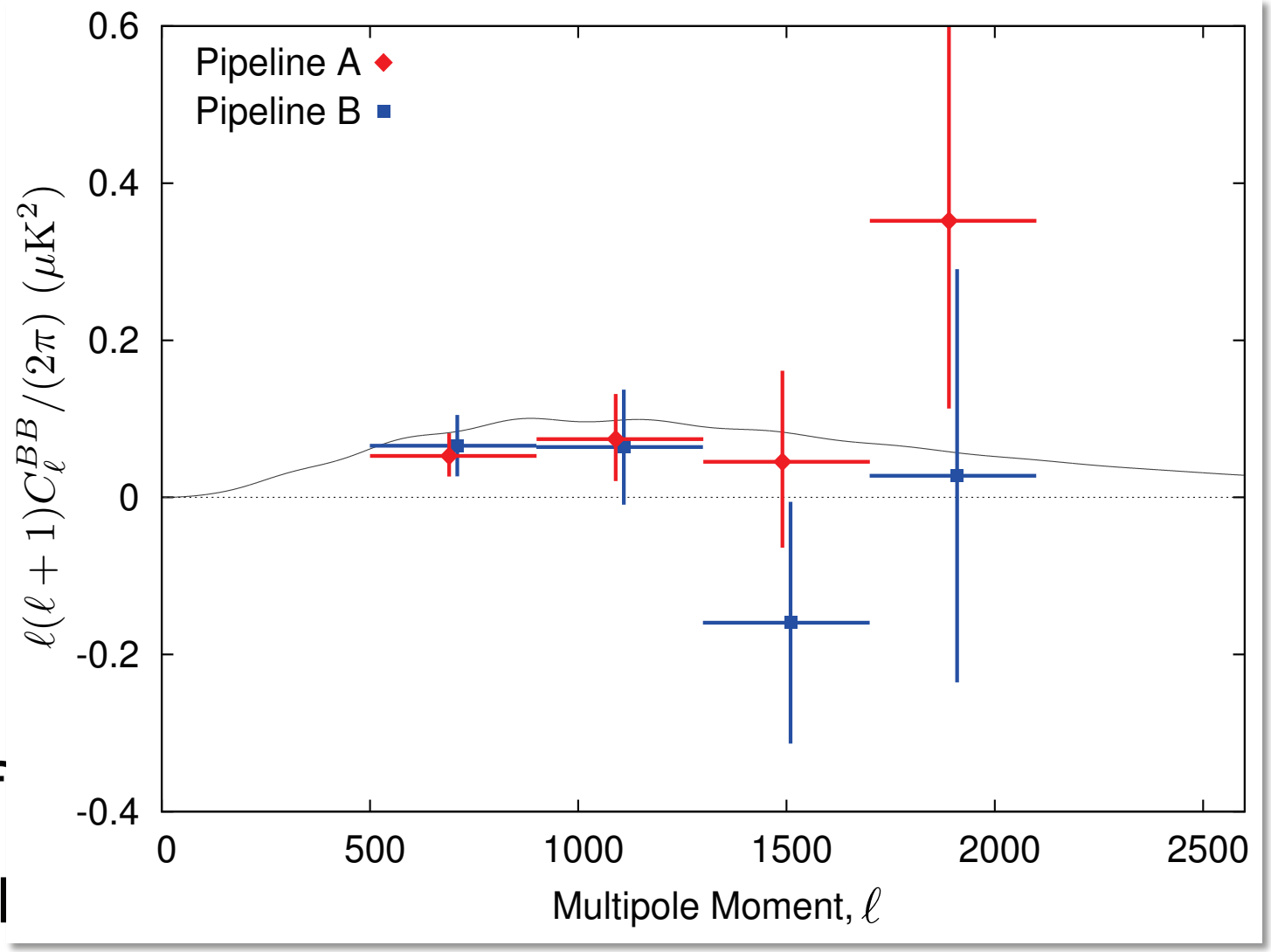
@150 GHz

Deep Survey @ Sub-Degree Scale



- One of the most "deepest" polarization maps
  - (deepest patch) ~5 μK-′ ~ lensing B-mode signal

Deep Survey @ Sub-Degree Scale



- One of
  - (deep

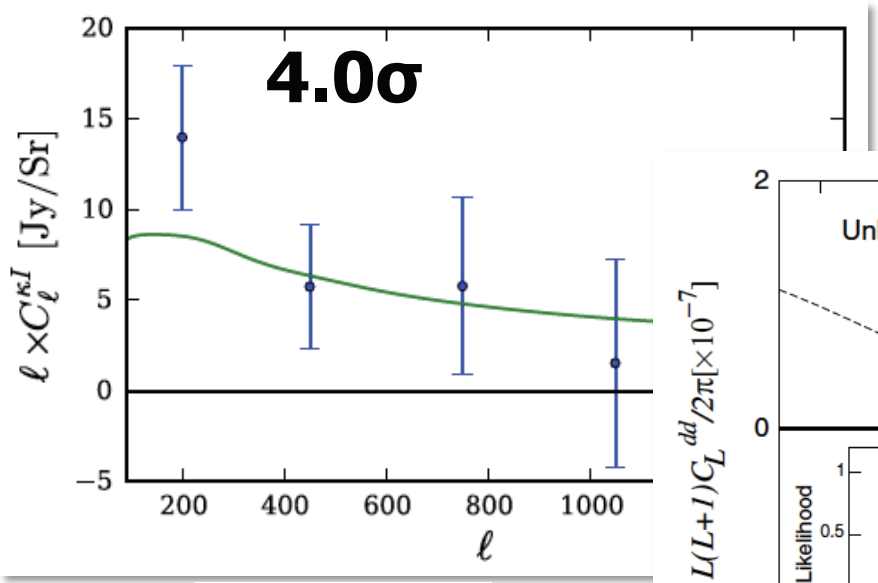
finally 3.1σ

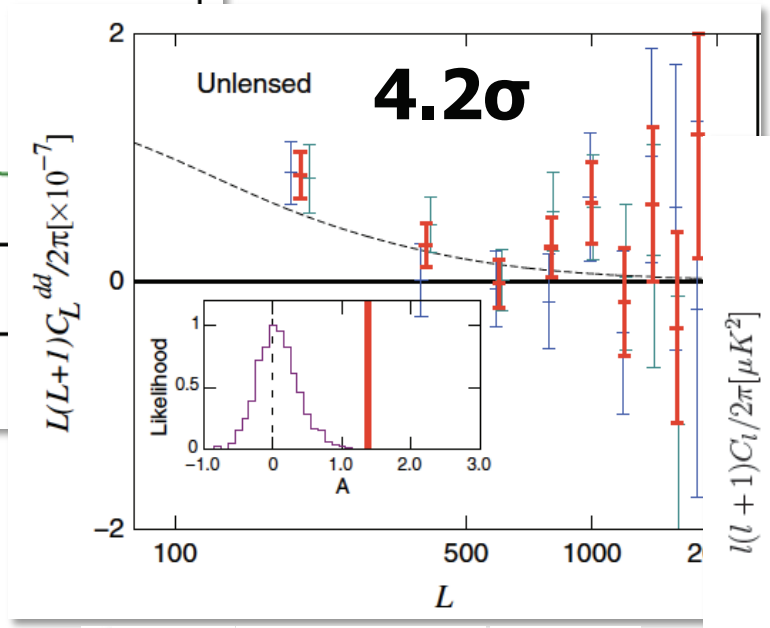
- First measurement & improvement of BB (2014 & 2017)
  - Achieved dedicated systematic control by null test & systematic simulations before unblinding (blind analysis)

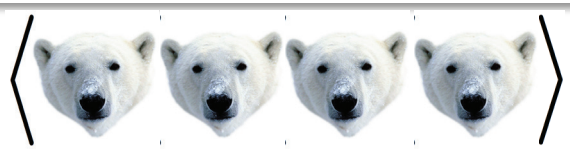
What POLARBEAR has Achieved

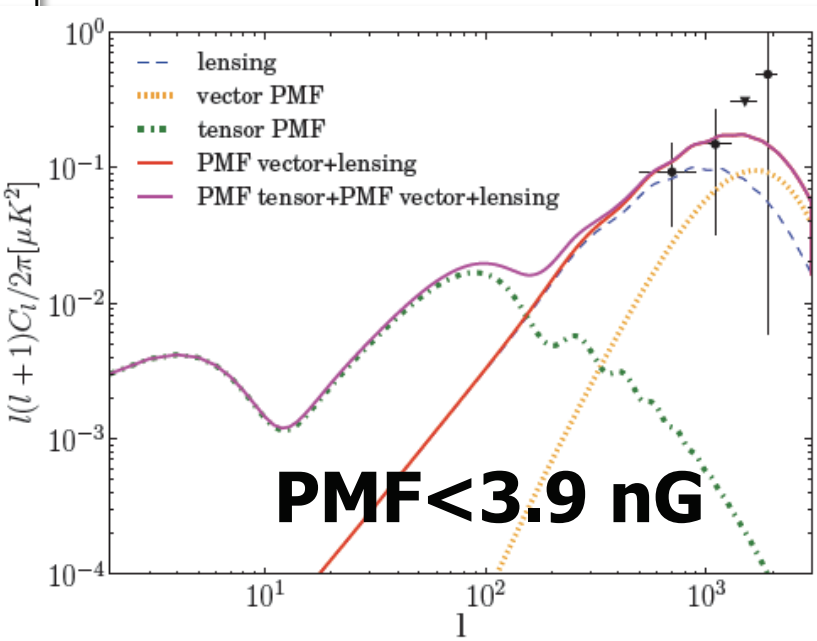
- **Detection of lensing by POLARBEAR x CIB**
- **Detection of lensing by POLARBEAR w/ 4pt**
- **Constraint on Cosmic birefringence**

  & Primordial magnetic field by POLARBEAR



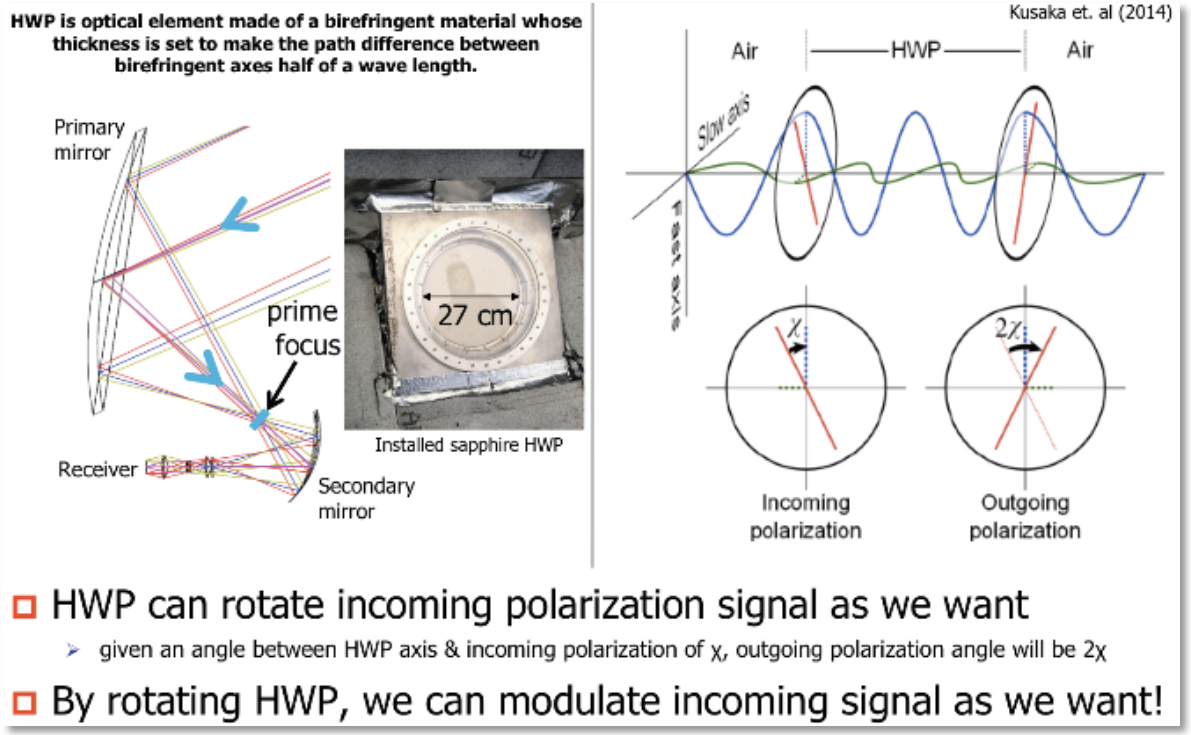






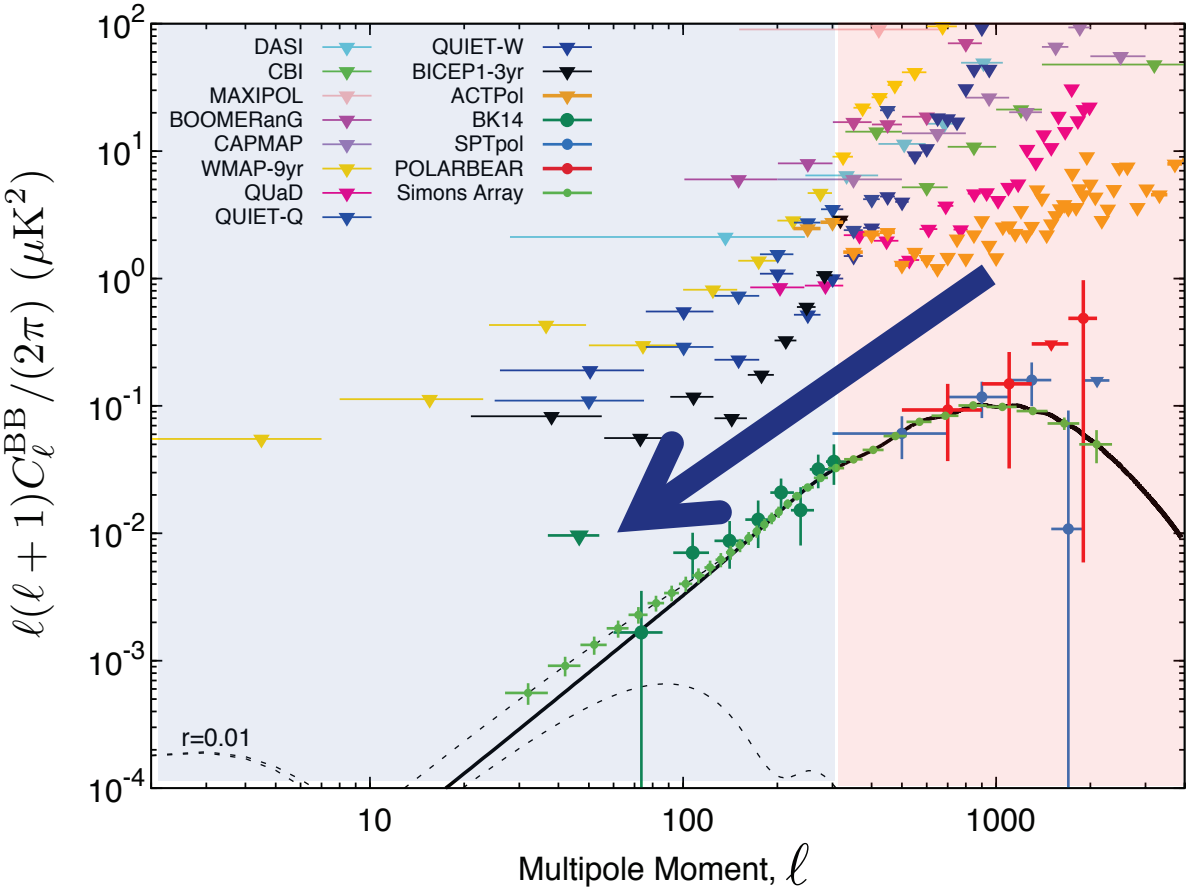
What POLARBEAR has Achieved

- **Modeling atmosphere for CMB by POLARBEAR**
- **Development of "Unbiased" making of CMB polarization for B-mode studies w/ POLARBEAR**
- **Performance of a continuously rotating half-wave plate (HWP) on the POLARBEAR telescope**



HWP is the most important technology in future projects as well as LiteBIRD for inflationary B mode

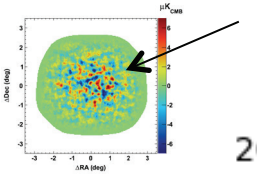
Data Analysis I'm Working On



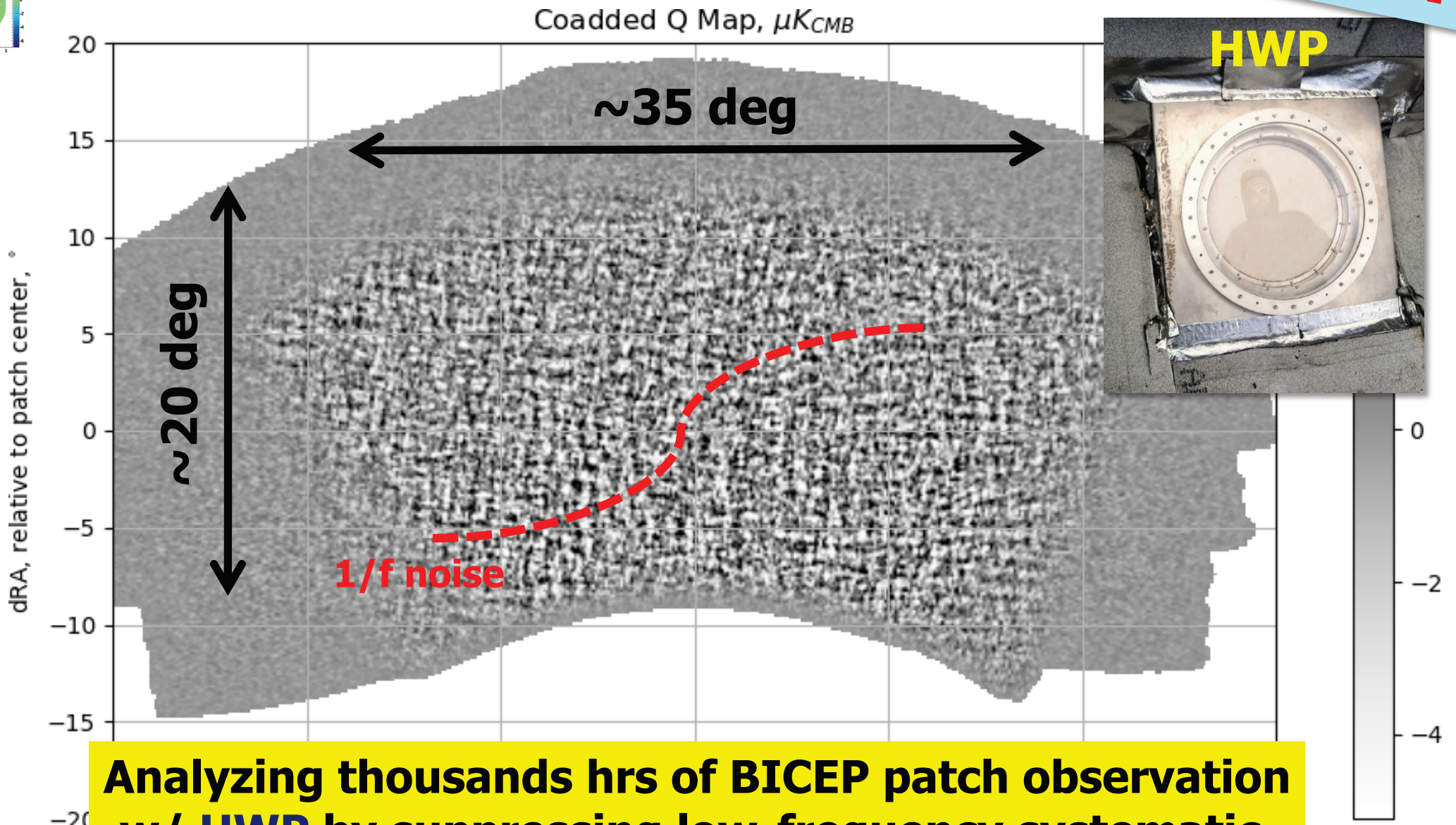
- POLARBEAR successfully measured B modes @ high ell (small angular scales)
  - have validated HWP instrument
- How about low ell (large angular scales) for inflationary B modes?
  - **→Observed BICEP patch w/ HWP**

Data Analysis I'm Working On

Stay Tuned!



ref: 5x5 deg² for deep survey



Analyzing thousands hrs of BICEP patch observation w/ HWP by suppressing low-frequency systematic, so-called atmospheric "1/f noise"

Data Analysis I'm Working On

- Tomography by cross-correlation BTW CMB & optical lensing must be interesting
  - more important w/ near future projects, e.g. SA/SO/S4 & LSST
- Detecting cross-correlation BTW PB x HSC by using polarization channel must be important because polarization will dominate the sensitivity

PB deep survey has achieved ~5 μK-' in pol as deep as wide survey w/ future project, e.g. SA/SO

observes LSS via CMB B mode (=weak lensing)

X

observes LSS via shear (=weak lensing)

deepest shear map & can be seen precursor for future project, e.g. LSST

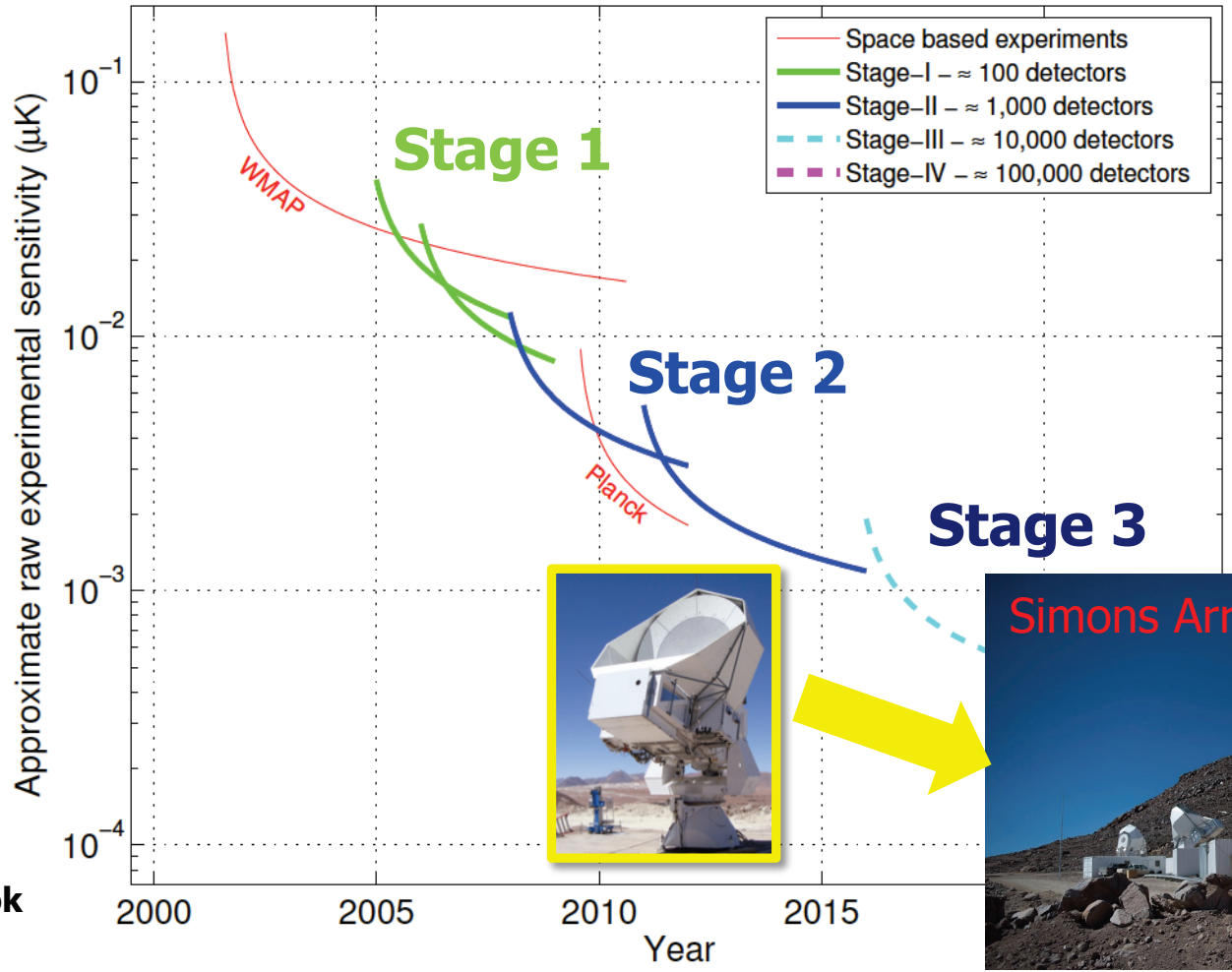
Demonstration w/ PB and HSC must be useful!

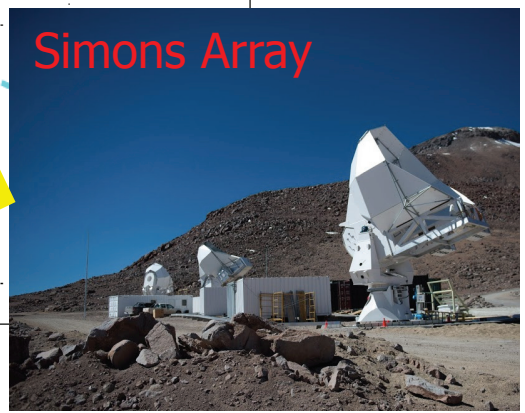
POLARBEAR has successfully achieved fist BB; Interesting analysis are still going
That means we have successfully moved on to Stage 2 from Stage 1

What's Next?

Move on to Stage 3 by decreasing CMB noise

Simons Array!





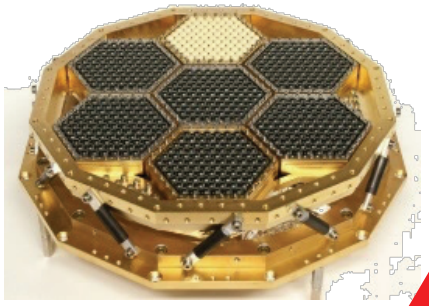
x~20 sensitivity

CMB-S4 Science Book (arXiv:1610.02743)

Simons Array

190mm

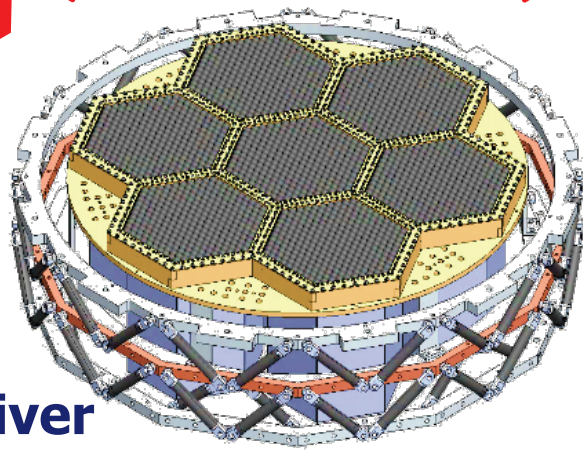
POLARBEAR receiver



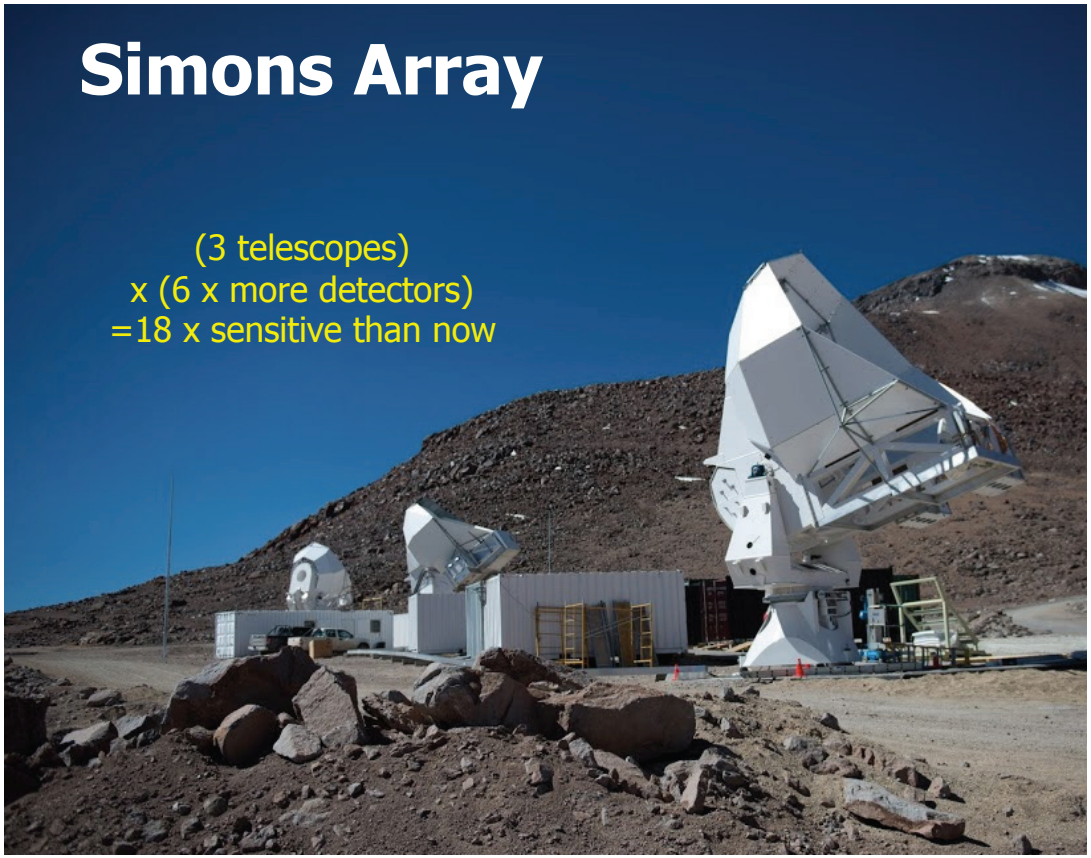
x6 more detectors

365mm

dual freq.

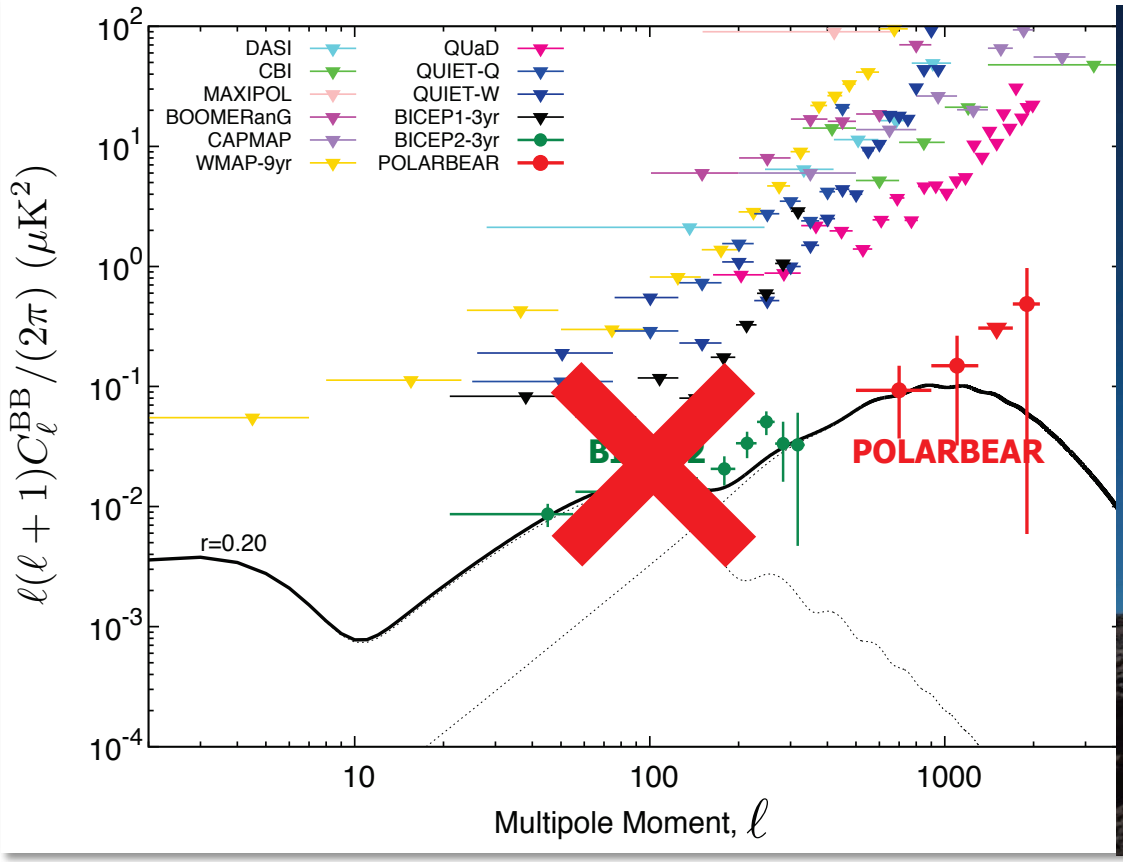


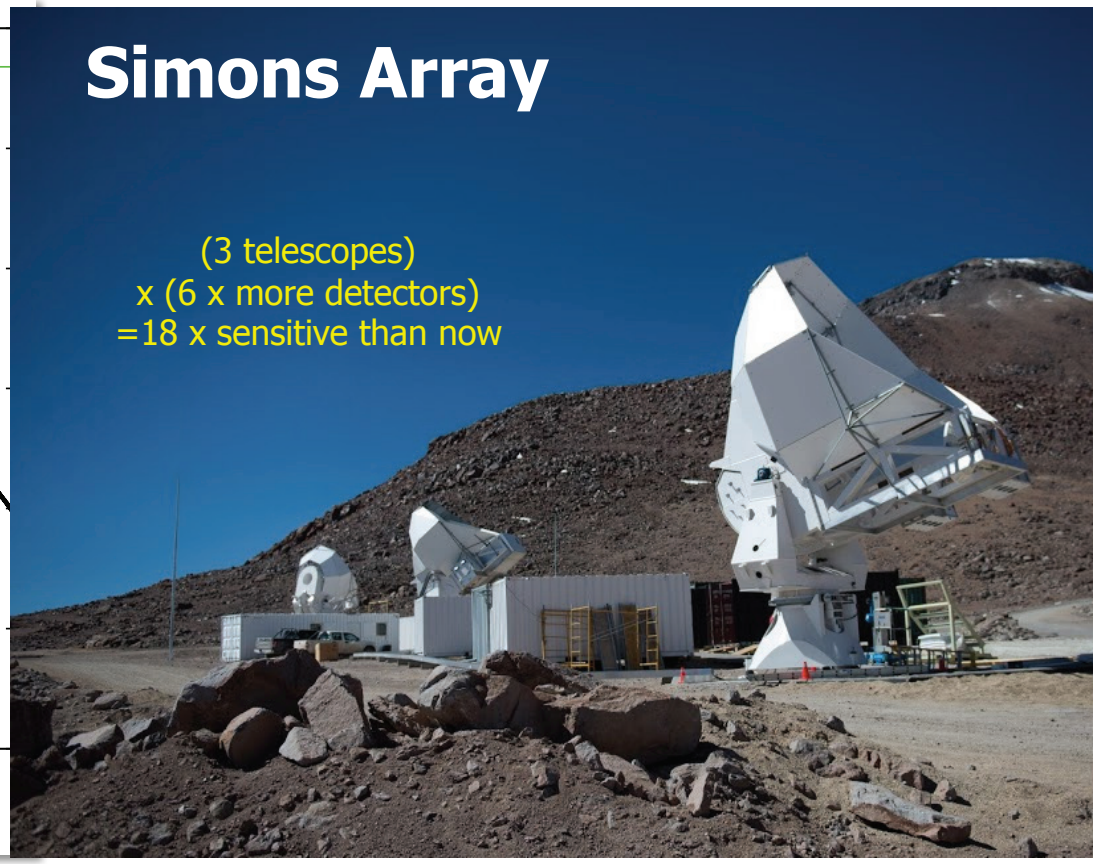
SA receiver



- 7,588 bolometers per receiver, factor of **6** increase from POLARBEAR
- **Three telescopes** (two new telescopes + one current one)
- **→ (3 telescopes) x (6 x more detectors) = 18 x sensitive than now**

Simons Array





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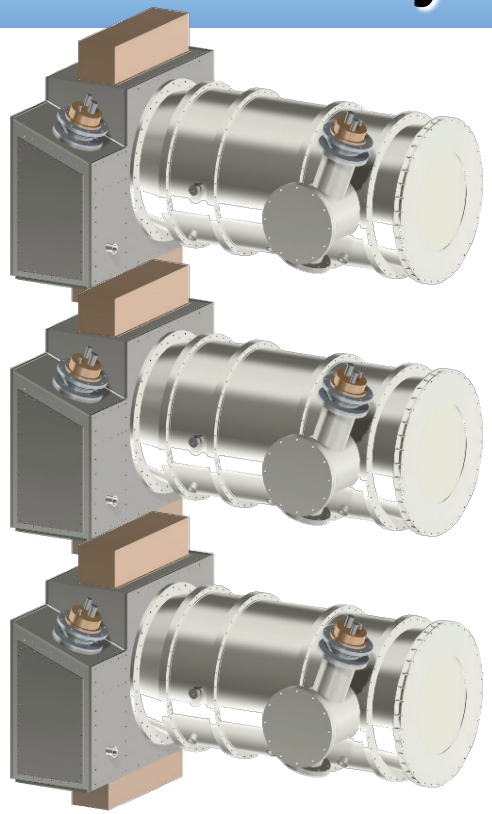
Simons Array



@KEK

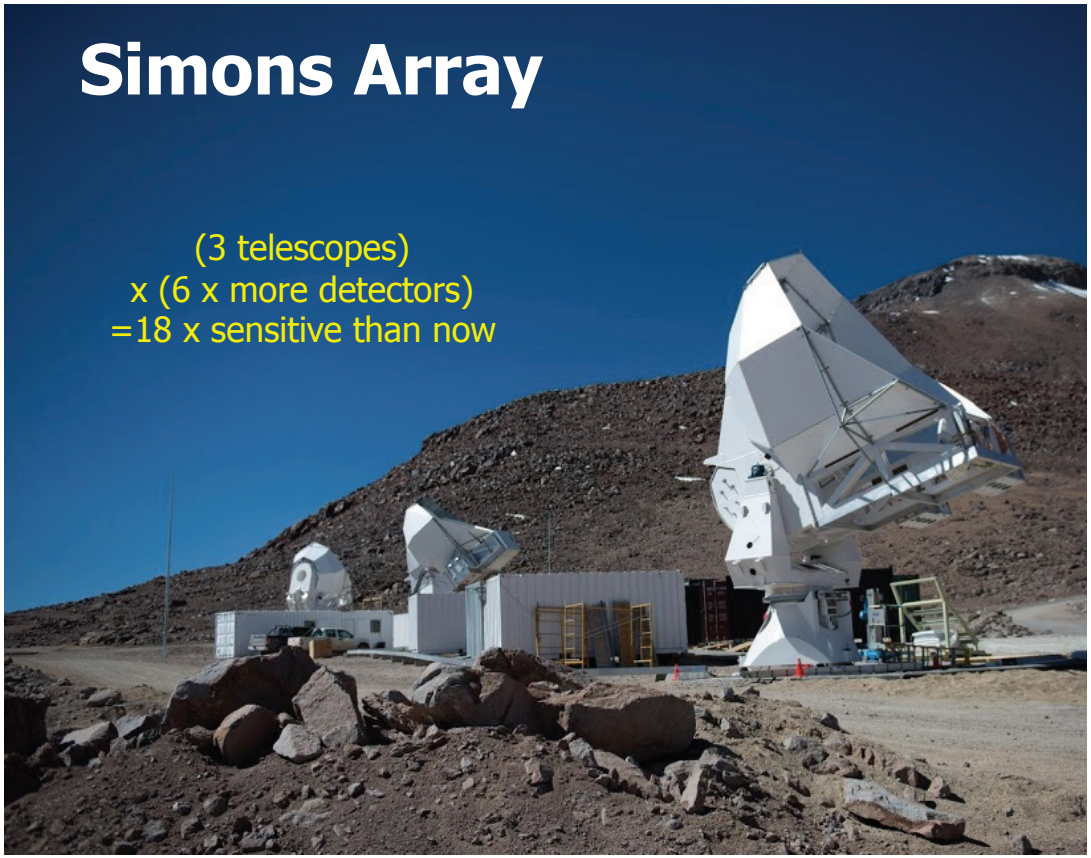
@UCB
& UCSD

POLARBEAR-2A
95/150 GHz

POLARBEAR-2B
95/150 GHz

POLARBEAR-2C
220/270 GHz

POLARBEAR-2 Receiver Frequency Plan

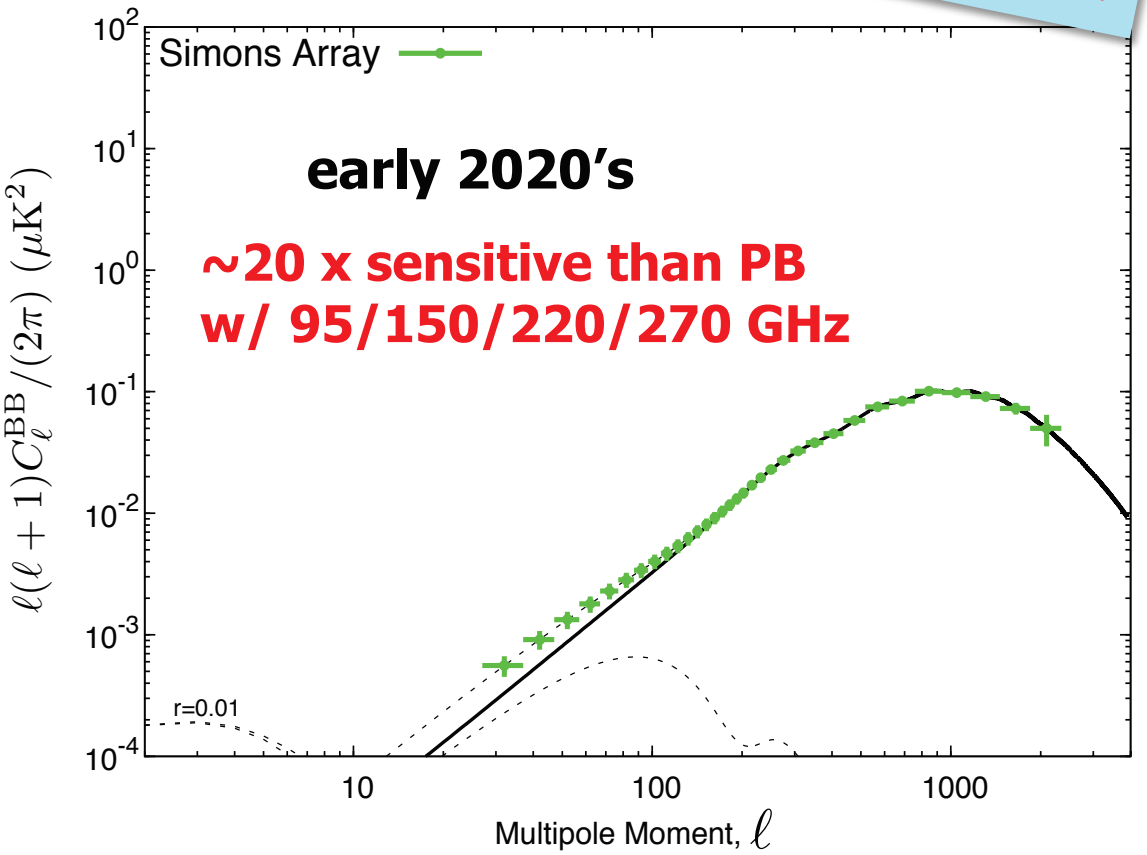


- 7,588 bolometers per receiver, factor of **6** increase from POLARBEAR
- **Three telescopes** (two new telescopes + one current one)
- **→ (3 telescopes) x (6 x more detectors) = 18 x sensitive than now**
- Expand frequency coverage for FG removal (**95/150/220/270 GHz**)

Deploying Simons Array

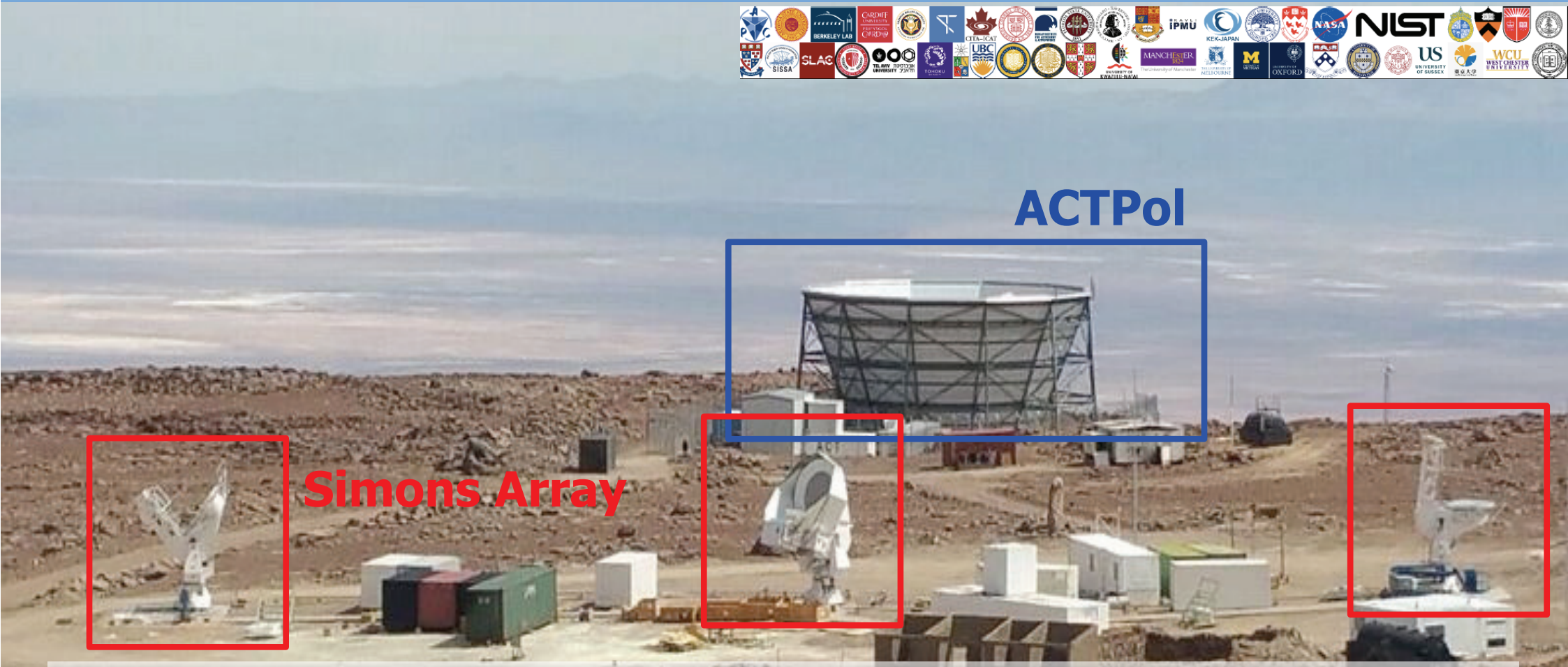
Stay Tuned!

Deploying first receiver



- **We're deploying 3 new receivers by ~2020**
- **On early 2020's, w/ ~20x sensitive than PB w/ 4 freq.**
  - **Inflation: $\sigma(r) = 6\times10^{-3}$ (4×10^{-3} stat.) w/ HWP**
  - **Neutrino masses: $\sigma(\Sigma m_\nu) = 40$ meV (19 meV stat.)** w/ BAO from DESI

Simons Array to Simons Observatory

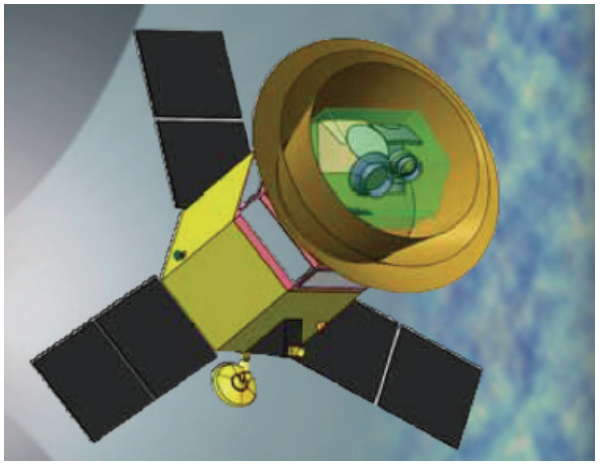


- Simons Array & ACT will be combined to "Simons Observatory" (SO)
  - The Simons Foundation is providing $40M in support for the Simons Observatory
  - Can observe ~80% of the sky from Chile
    - ✓ then can provide rich astronomical probes & lensing info
- SO is targeting to achieve **$\sigma(r)<2\times10^{-3}$**; **$\sigma(\Sigma m_\nu)\sim30$ meV**
  - developing and will start science observation in early 2020's

Collaboration & Synergy Among PB/SA/SO/LB

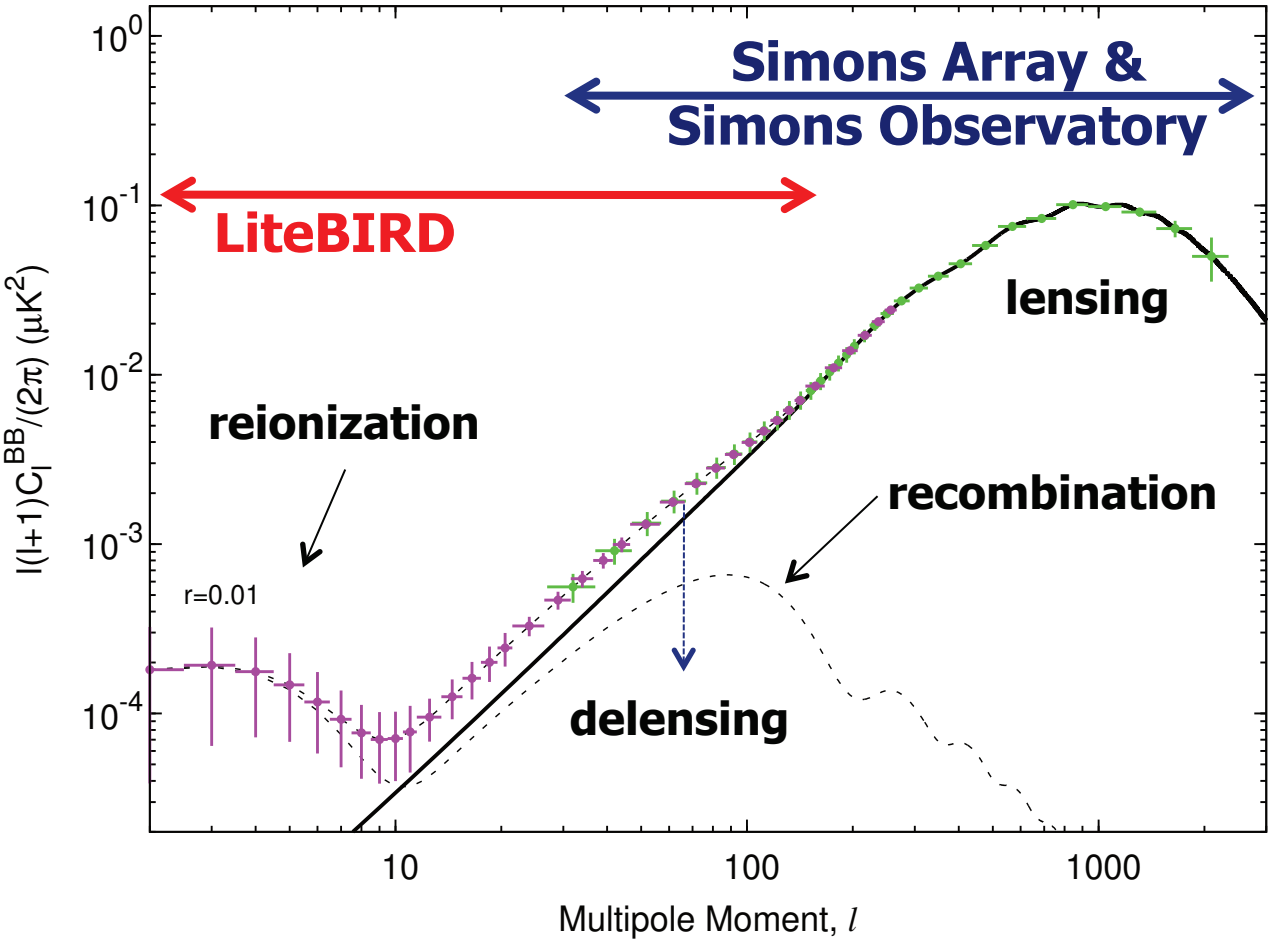
- **Need to scan full sky to measure reionization bump**
- **LiteBIRD is an only experiment can scan full sky**
  - Ground-based exps have been validating technologies that LiteBIRD requires, i.e. HWP, to achieve it
- **→ Powerful & natural synergy**

2027?~



+

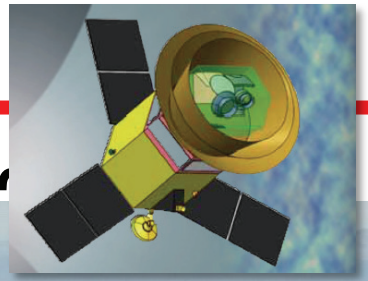
2019 & 2020's~



Summary

- POLARBEAR is a "stage 2" CMB experiment, which successfully measured B-mode lensing; Low-ell BB and PBxHSC will come!
- Upgrading POLARBEAR to Simons Array, which is a "stage 3" CMB experiment; Developing/deploying new receivers by ~2020
- Developing Simons Observatory & will start on early 2020's
- Synergy BTW advanced ground-based experiments & LiteBIRD on late 2020's must be powerful!?

late 2020's



Now

σ(r)<O(0.1)

2019~

σ(r)<0.01; σ(Σm$_\nu$)~40 meV

early 2020's

σ(r)<0.002; σ(Σm$_\nu$)~30 meV