LiteBIRD

A Small Satellite for the Studies of B-mode Polarization and Inflation from Cosmic Background Radiation Detection

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On behalf of the LiteBIRD working group

LiteBIRD working group

- 64 members (as of Nov. 23, 2012)
- International and interdisciplinary

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S. Oguri
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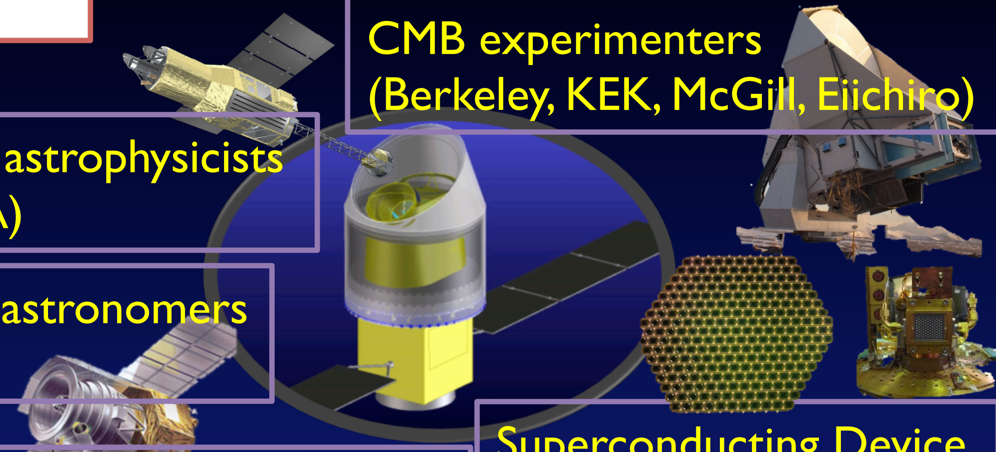


CMB experimenters (Berkeley, KEK, McGill, Eiichiro)

X-ray astrophysicists (JAXA)

Infrared astronomers (JAXA)

JAXA engineers, Mission Design Support Group, SE office

Superconducting Device (Berkeley, RIKEN, NAOJ, Okayama, KEK etc.)

LiteBIRD mission

- Check representative inflationary models
  - *requirement on the uncertainty on r*

  (stat. ⊕ **syst.** ⊕ **foreground** ⊕ **lensing**) **$\delta r < 0.001$**

No lose theorem of LiteBIRD

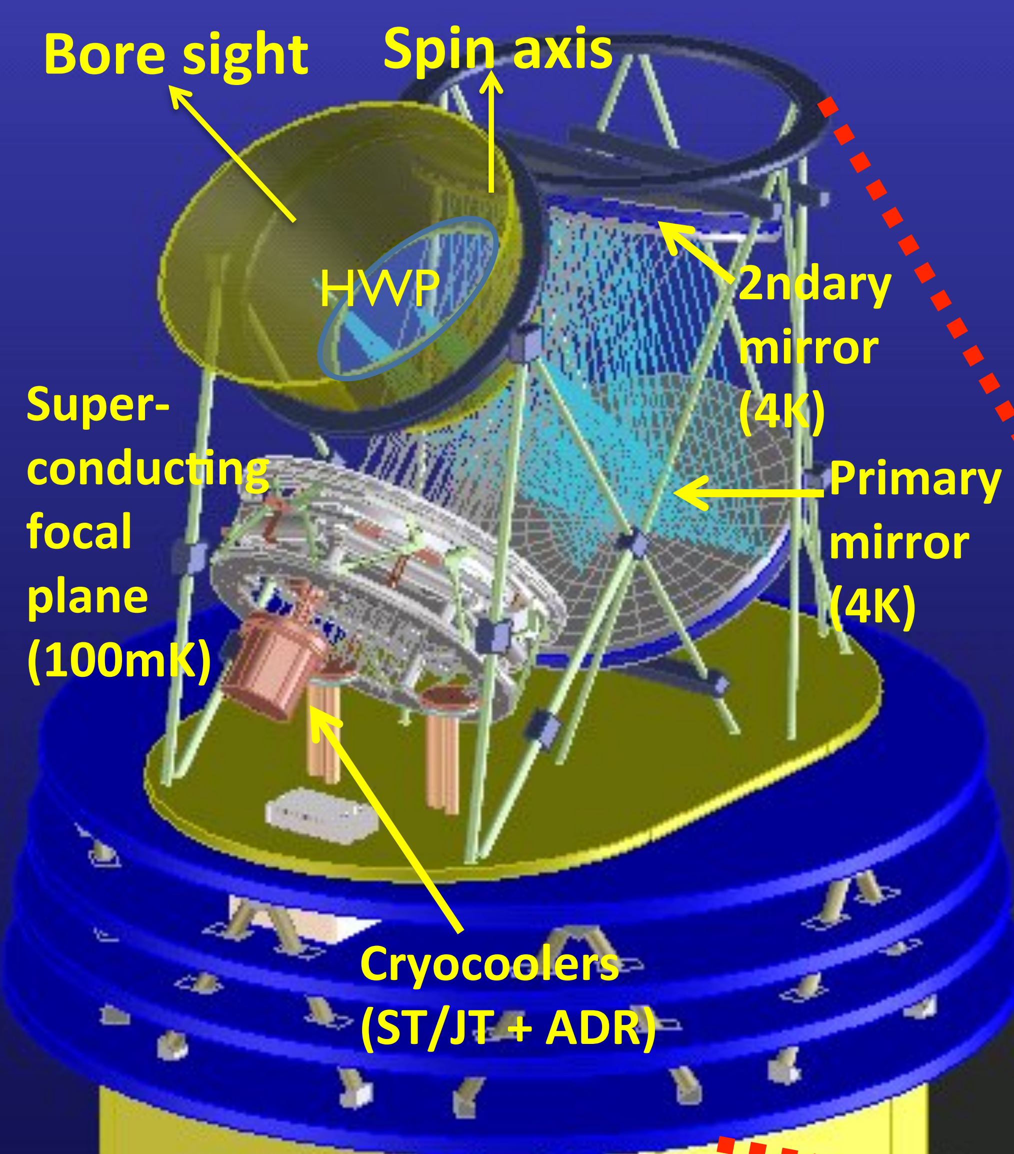
- ➢ Many inflationary models predict r>0.01 → >10sigma discovery
- ➢ Representative inflationary models (single-large-field slow-roll models) have a lower bound on r, r>0.002, from Lyth relation.

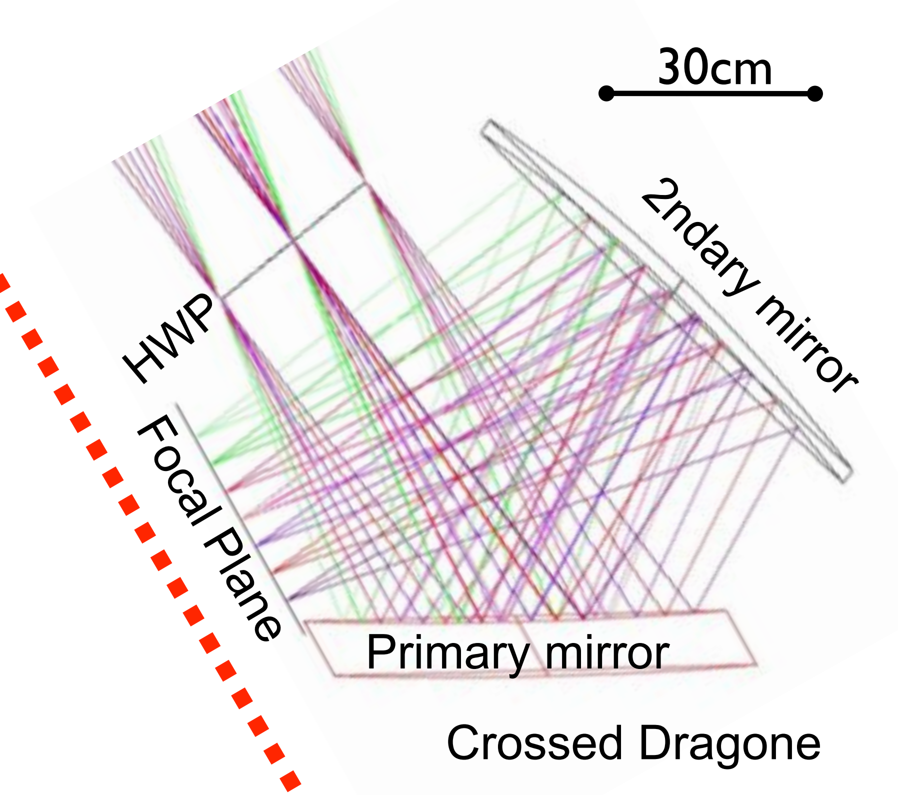
$$r = \frac{1}{N^2}\left(\frac{\Delta\phi}{m_{\rm pl}}\right)^2 \approx 2\cdot 10^{-3}\left(\frac{\Delta\phi}{m_{\rm pl}}\right)^2$$

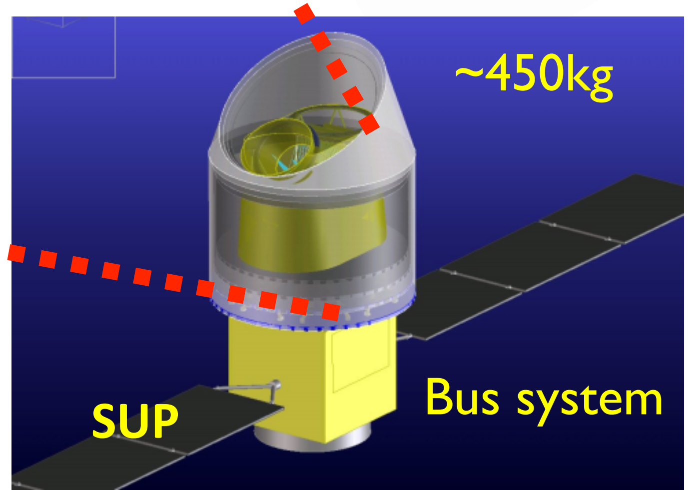
  - ➢ no gravitational wave detection at LiteBIRD → exclude representative inflationary models (i.e. r<0.002 @ 95% C.L.)
- ➢ Early indication from ground-based projects → power spectra at LiteBIRD !

Simiar to LHC Higgs case (Occam's razor)

LiteBIRD overview







- Mission Definition Review in 2013
- Target launch year: 2020 (LEO or L2)
- Launch vehicle: H2 or Epsilon
- EPIC-type scan strategy

Germany

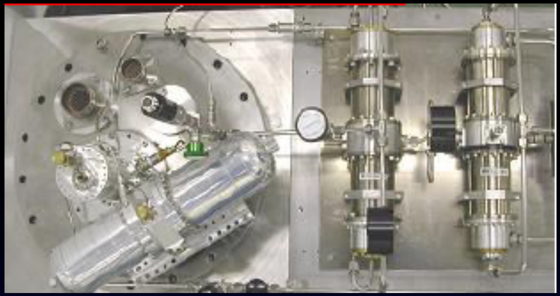
Advantages of LiteBIRD

- Not a pathfinder; small but no compromise in r sensitivity
- More launch options than a big satellite
- Less expensive
  - With LiteBIRD plus ground-based super-telescopes (e.g. O(100K) bolometers w/ arcminute angular resolution) as one package, science reach nearly as good as a large CMB polarization mission with ~1/5 total cost
- Better in terms of cooling (mirrors and baffles)
- The whole spacecraft can be tested in a large cryogenic test chamber
  - Better calibration data → less systematic uncertainties
  - Better pre-flight investigations → less chance of failure

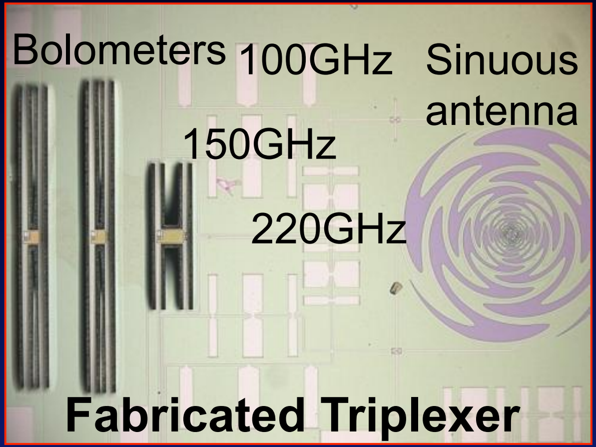
Three key technologies to make LiteBIRD light

- Small mirrors (~60cm)
- Warm launch with mechanical coolers
  - Technology alliance with SPICA for pre-cooling (ST/JT)
  - Alliance with DIOS (X-ray mission) for ADR
- Multi-chroic focal plane
  - ~2000 TES (T_{bath}=100mK, $\delta\nu/\nu$ ~ 0.3), or equivalent MKIDs
  - Technology demonstration with ground-based projects (POLARBEAR, POLARBEAR-2, GroundBIRD)

Prototype crossed Mizuguchi-Dragone mirror



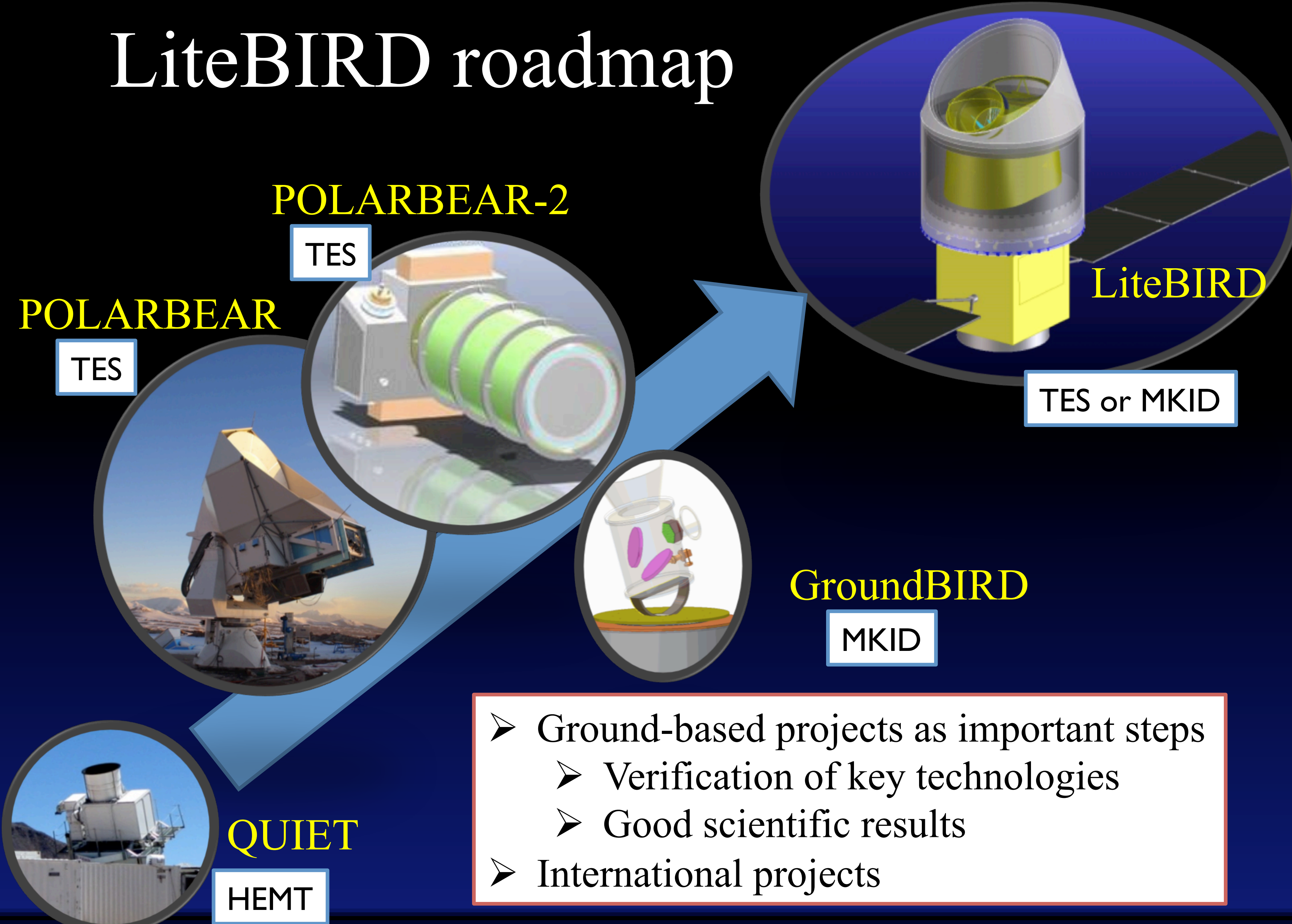
2ST/JT BBM



Filter

UC Berkeley TES option

LiteBIRD roadmap



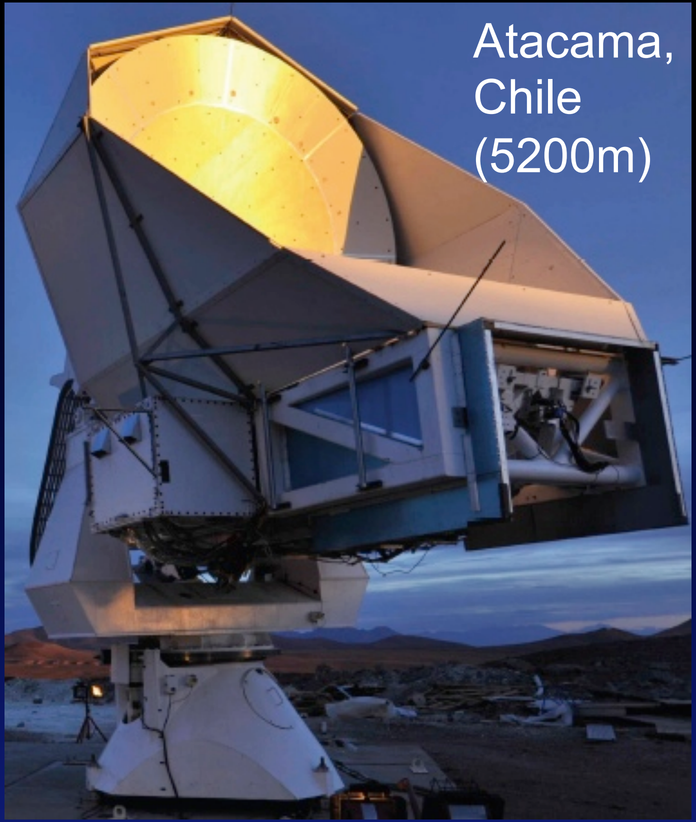
- Ground-based projects as important steps
  - Verification of key technologies
  - Good scientific results
- International projects

POLARBEAR

PI: Adrian Lee (Berkeley), APC, Berkeley, Cardiff, Colorado, Dalhousie, Imperial C., KEK, LBNL, McGill, UCSD

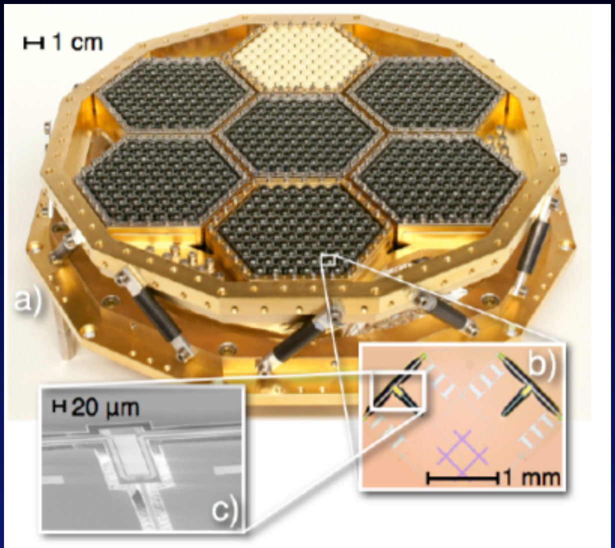
- Observing since Jan. 2012
- 150GHz (1274 TES bolometers)
- Beam (FWHM): 3.5arcmin
- Array NET: 19μK$\sqrt{s}$ (during observation)

- Scientific goals
  - >10σ detection of lensing B-mode
  - 2σ detection of r = 0.025



Atacama, Chile (5200m)

TES focal plane technology will fully be tested on ground, crucial step for LiteBIRD



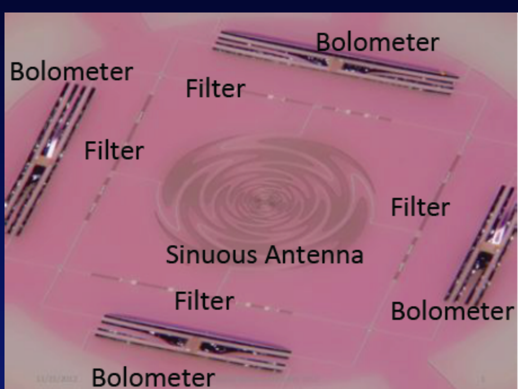
POLARBEAR-2

PI: Masashi Hazumi (KEK) and Adrian Lee (Berkeley)
APC, Berkeley, Cardiff, Colorado, Dalhousie, KEK, LBNL, McGill, Tsukuba, UCSD

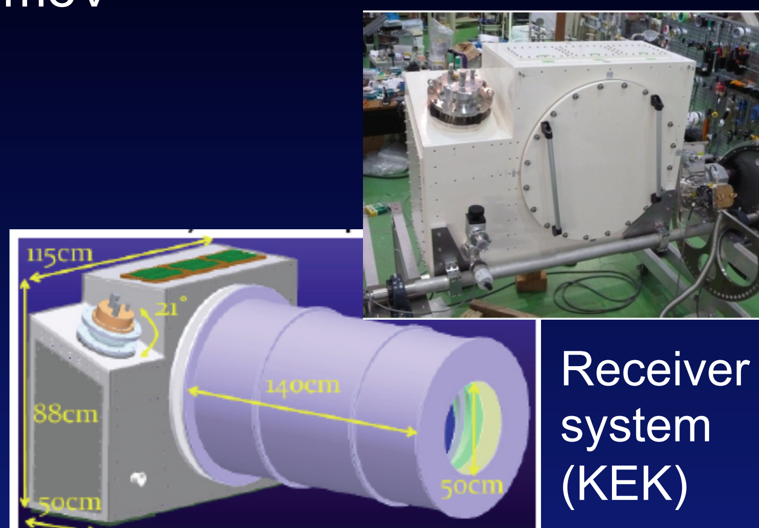
- Receiver upgrade of POLARBEAR
- Two frequencies (95, 150
- GHz) in one pixel
- Deployment in 2014

- Scientific goals
  - 2σ detection at r=0.01
  - 1σ at Σmν = 40meV

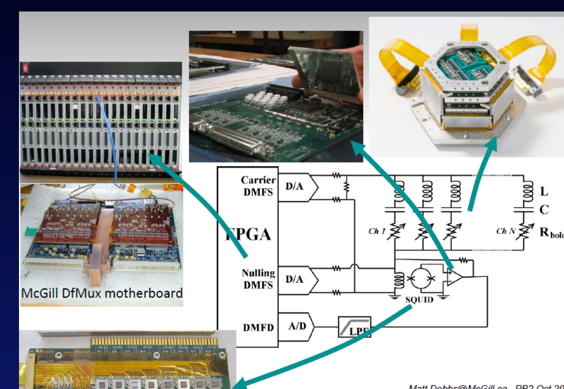
	Specifications
Frequencies	95 GHz and 150 GHz (option: 220 GHz)
Number of Pixels	1897 (7588 bolometers)
NET bolometer	500/500 μK√s (95/150 GHz)
NET array	8.1/8.1 μK√s (95/150 GHz) 5.7 μK√s (95 & 150 GHz combination)
Detector Temperature	300 mK (100 mK in 2nd phase)
Field of View	4 °



TES (Berkeley)



Receiver system (KEK)



Low power, high MUX readout (McGill)

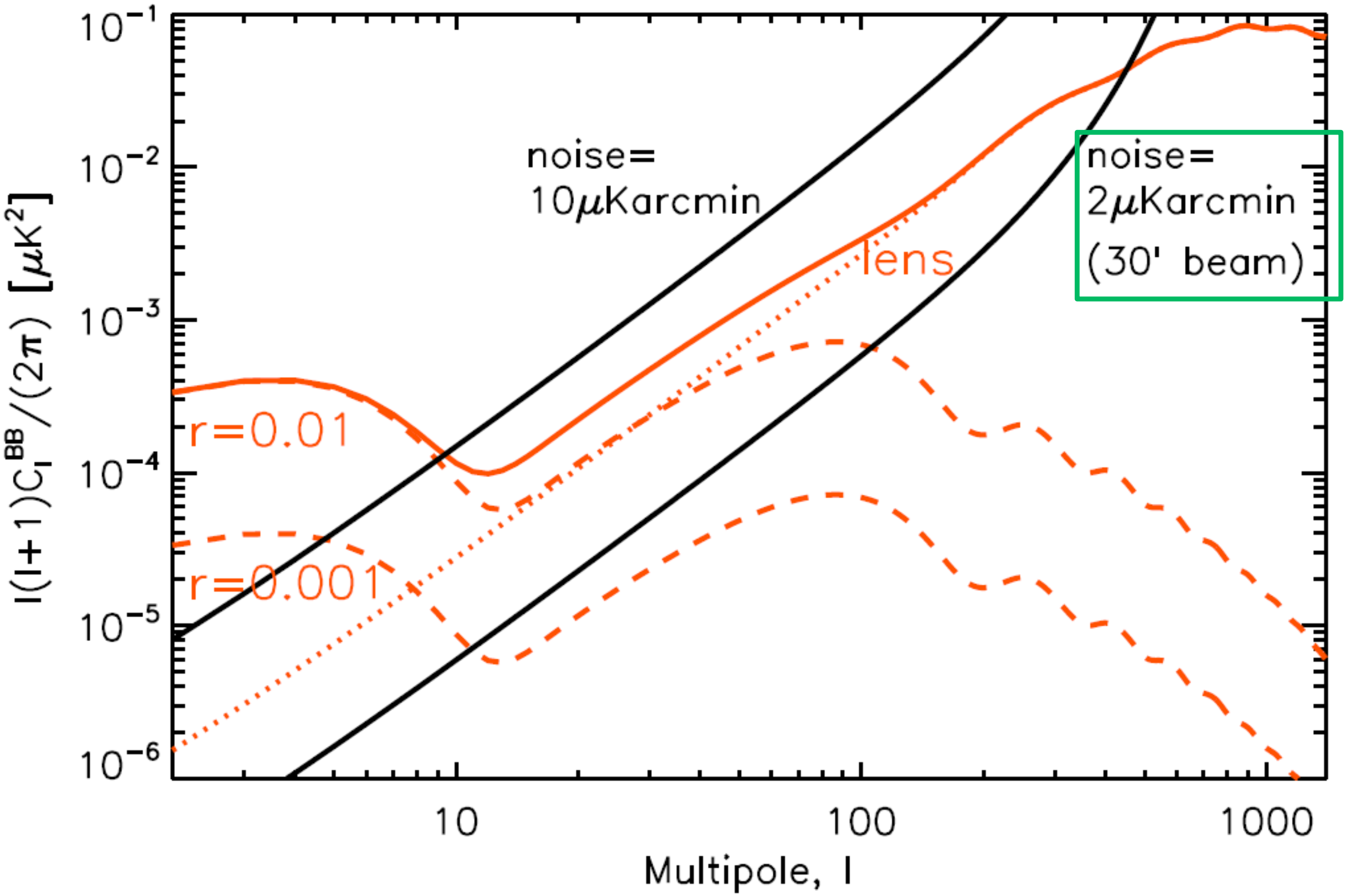
System parameters relevant for this workshop

- 30arcmin FWHM beam at 150GHz
- 1.8μKarcmin (all combined) w/ 2 effective years
- 6 bands centered at 60, 78, 100, 140, 190, 280 GHz
- 30% bandwidth

Focal plane requirement

Noise level: goal = 2μK･arcmin
(requirement: < 3μK･arcmin)

To be well below "lensing floor"



Focal plane sensitivity

Integration time = 2 effective years

T_{mirror} = 4 K

No dark bolo is included in the count.

Band [GHz]	Pixel size [mm]	Pixel#/ wafer	Bolo#/ wafer	Sensitivity per wafer [uKarcmin]	# of wafer (total # of bolo on FP)	Sensitivity per band [uKarcmin]
60	18	19	38	29	8	10.3
78	18	19	38	18	8	6.4
100	18	19	38	13	8	4.6
Sub total			**114**		**(912)**	**3.5**
140	12	37	74	8.8	5	4.0
190	12	37	74	7.0	5	3.1
280	12	37	74	9.2	5	4.1
Sub total			**222**		**(1110)**	**2.1**
All					**(2022)**	**1.8**

We limit the total number of detectors as ~2000. The MUX factor of 64 (2W/SQUID) will keep the readout power below 70W.

LiteBIRD focal plane design

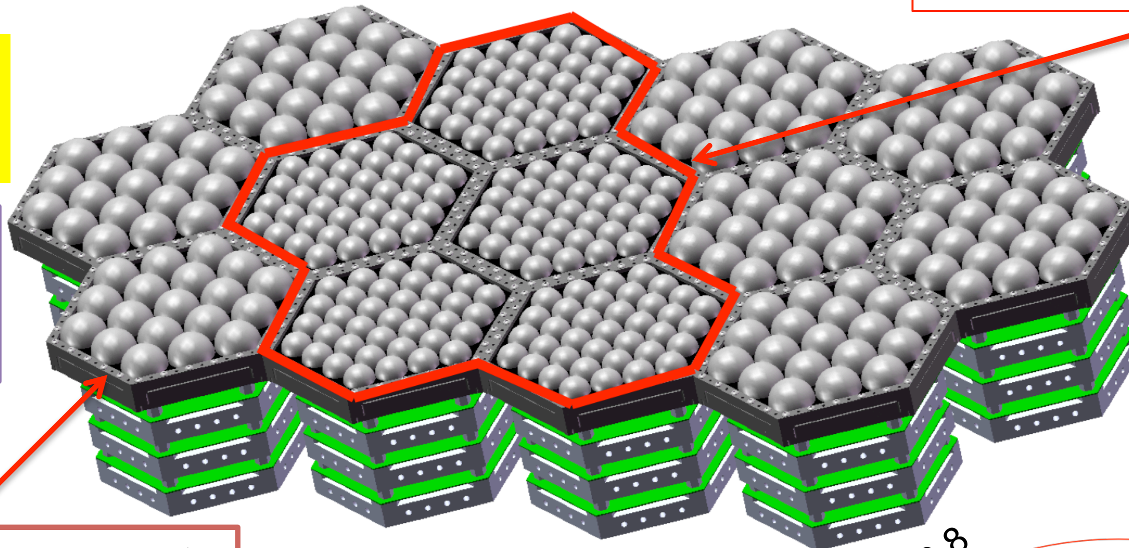
tri-chroic (140/190/280GHz)

UC Berkeley TES option

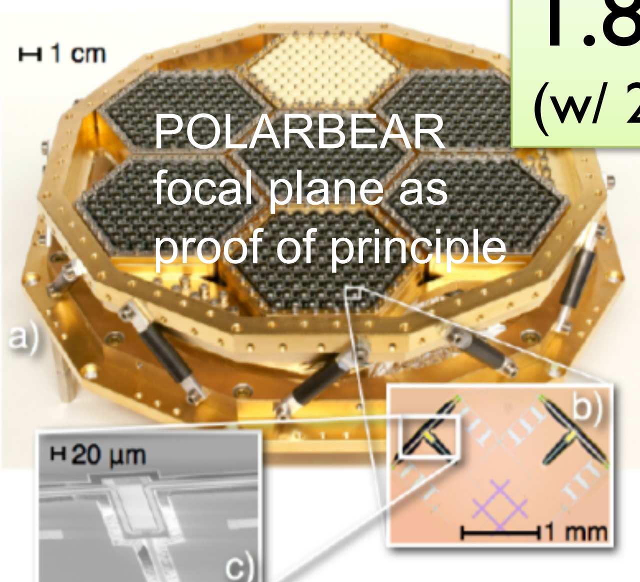
2022 TES bolometers

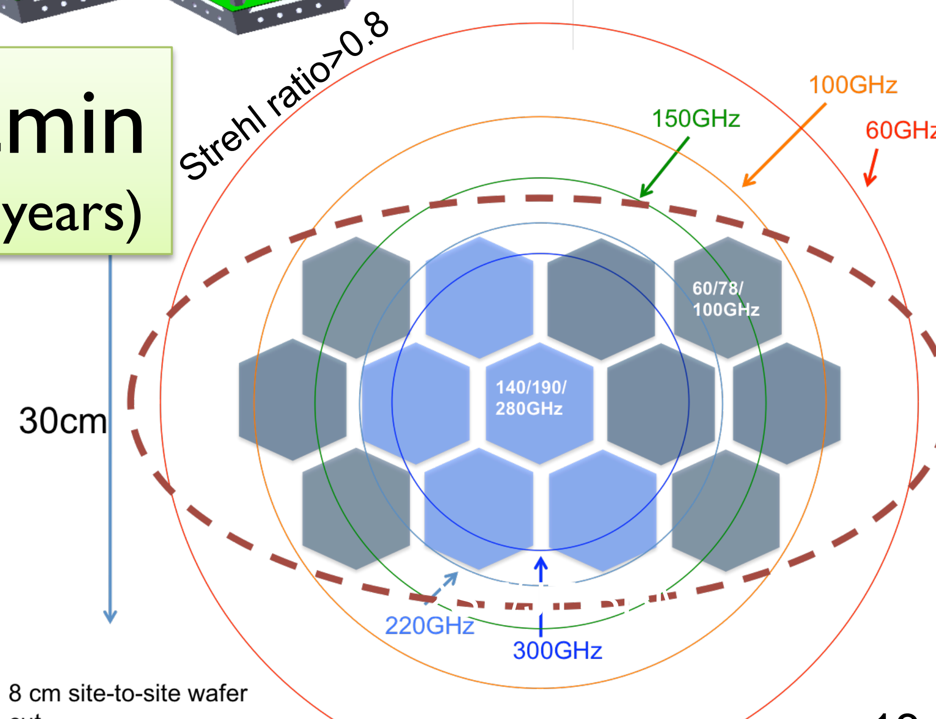
T_{bath} = 100mK

tri-chroic (60/78/100GHz)



1.8μKarcmin
(w/ 2 effective years)





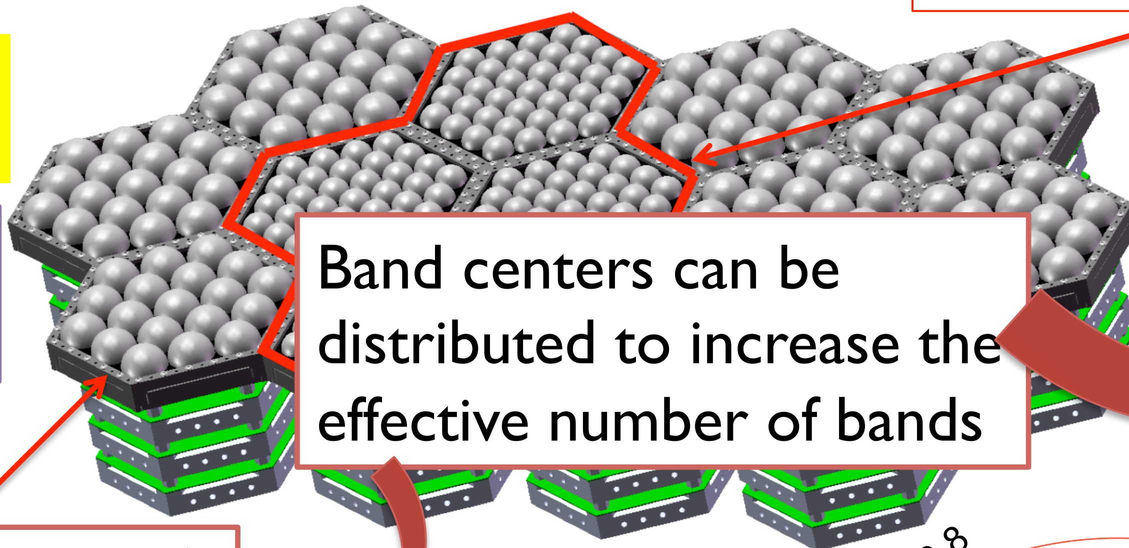
LiteBIRD focal plane design

UC Berkeley TES option

2022 TES bolometers

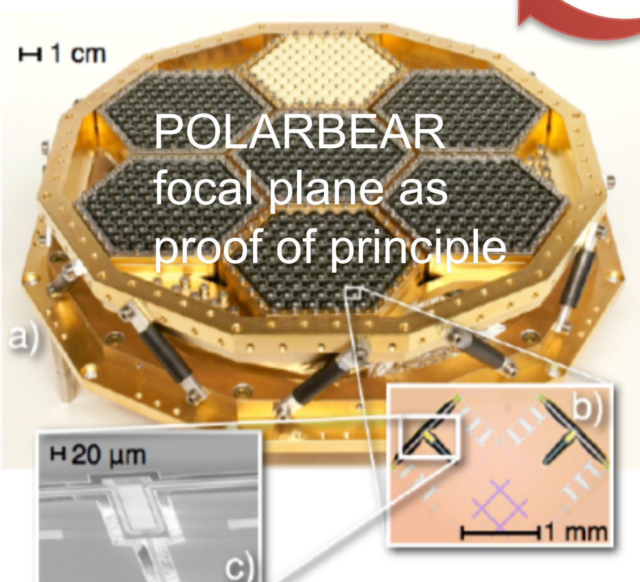
T_{bath} = 100mK

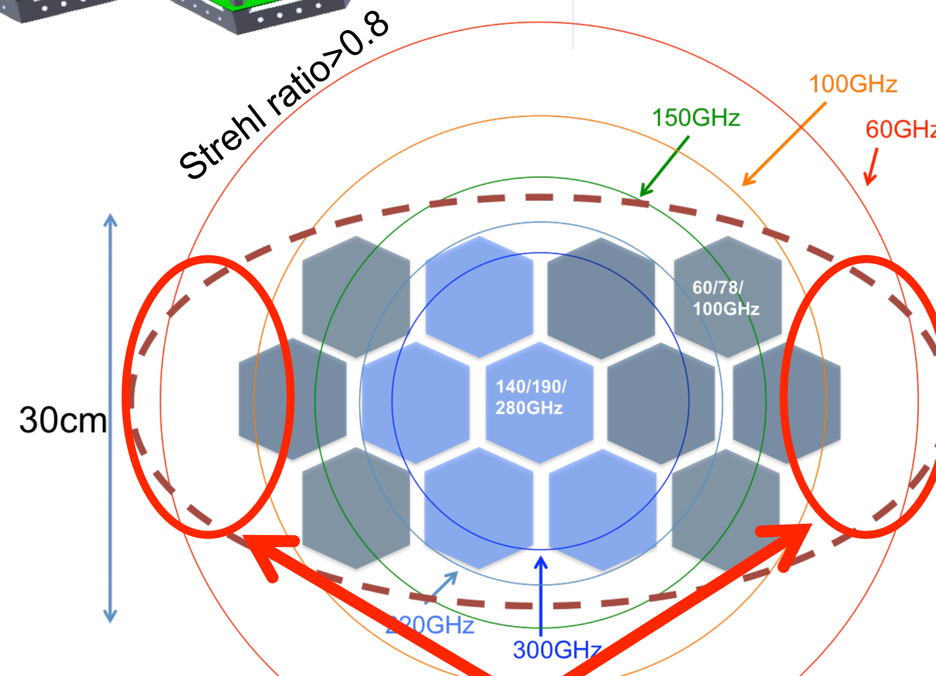
tri-chroic (140/190/280GHz)



Band centers can be distributed to increase the effective number of bands

tri-chroic (60/78/100GHz)





8 cm site-to-site wafer cut

More space to place <60GHz detectors

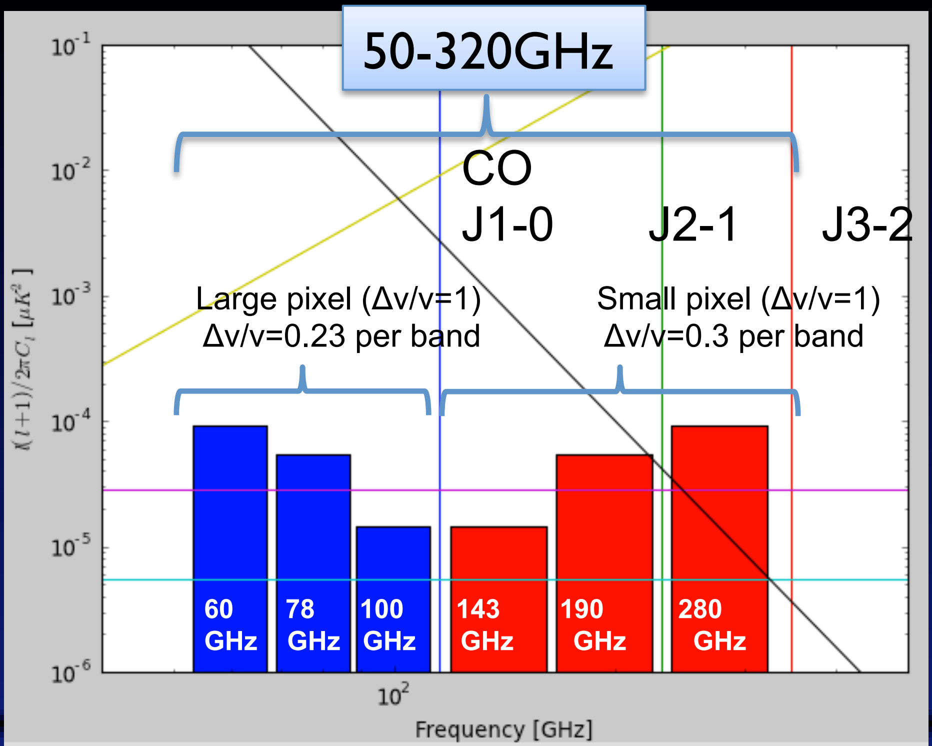
LiteBIRD band selection for multi-chroic pixels

We chose the band locations with the following reasons.

1. Katayama-Komatsu (2010) suggested the range of frequency from 50-270 GHz based on the template subtraction.
2. We want to exclude the CO lines.
3. From the practical consideration such as AR coating on a lenslet array, it is reasonable to limit the bandwidth to Δv/v~1.

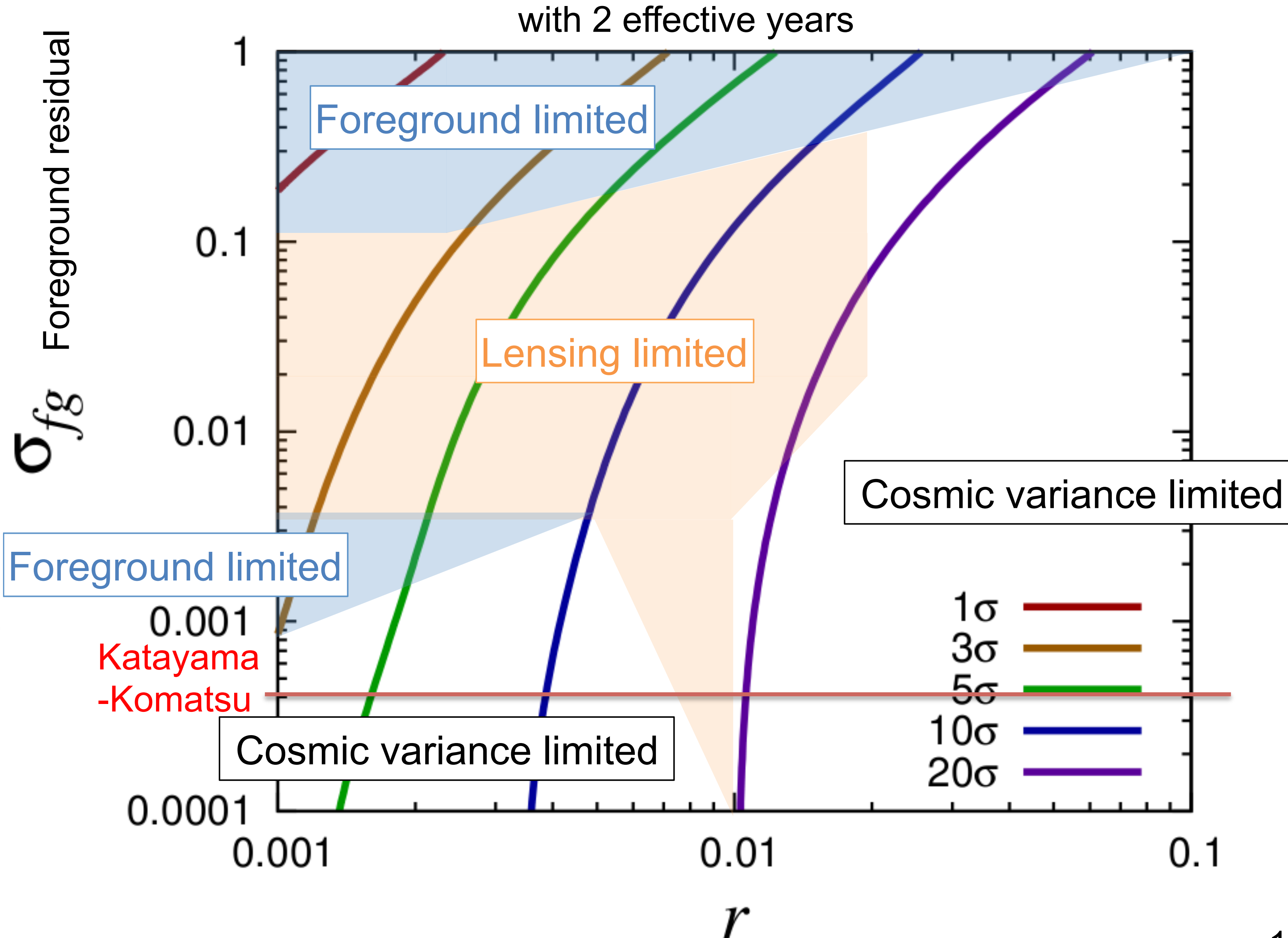
Above three constraints naturally put us to the band locations.

- Some room for low frequencies.
- Interesting option of distributed band centers (more studies needed).



Expected sensitivity on r

$$F_\ell^{XY}(\nu) = \sum_{fg=S,D} \left[C_\ell^{fg,XY}(\nu)\, \sigma^{fg,XY} + N_\ell^{fg,XY}(\nu;\nu_{tp}) \right]$$



Some questions on foreground

1. How will the foreground removal performance be degrated by instrumental systematics
   – e.g. we may live with 1arcmin time-dependent pointing error.
2. Pathological foregrounds. What should we study ?

Answers to 1. and 2. needed for any satellite proposal for $r<0.01$

3. What foreground science can we do with 30arcmin resolution ?
   – related to data release strategy

Take-home messages to foreground folks

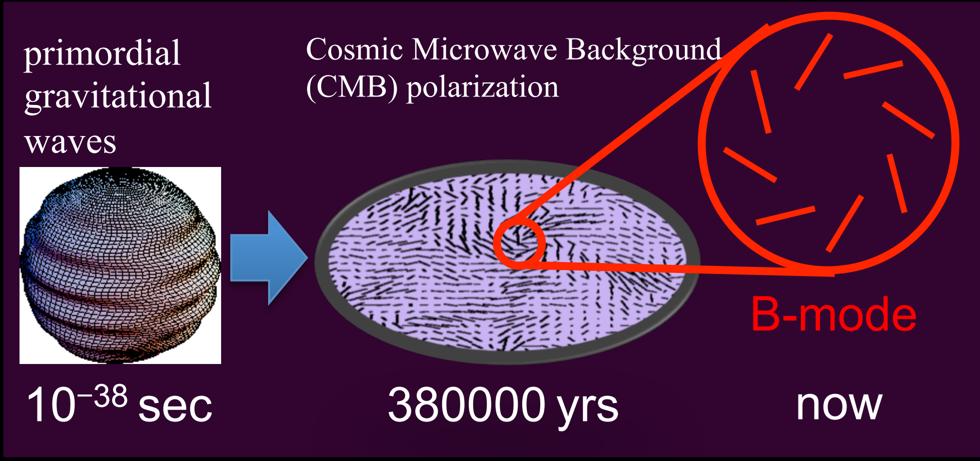
- The mission of LiteBIRD is to achieve $\delta r<0.001$. Foreground removal is one of the most critical and urgent items for the LiteBIRD mission definition review.
- LiteBIRD focal plane can accommodate many bands below 320GHz, very powerful for foreground removal.
- End-to-end foreground removal simulation will be needed where we take non-idealities of instruments into account.
- Foreground removal will be crucial at POLARBEAR-2 even if we choose magic patches. Here is another urgent and interesting work of foreground removal with less frequency bands and partial sky ahead of us.

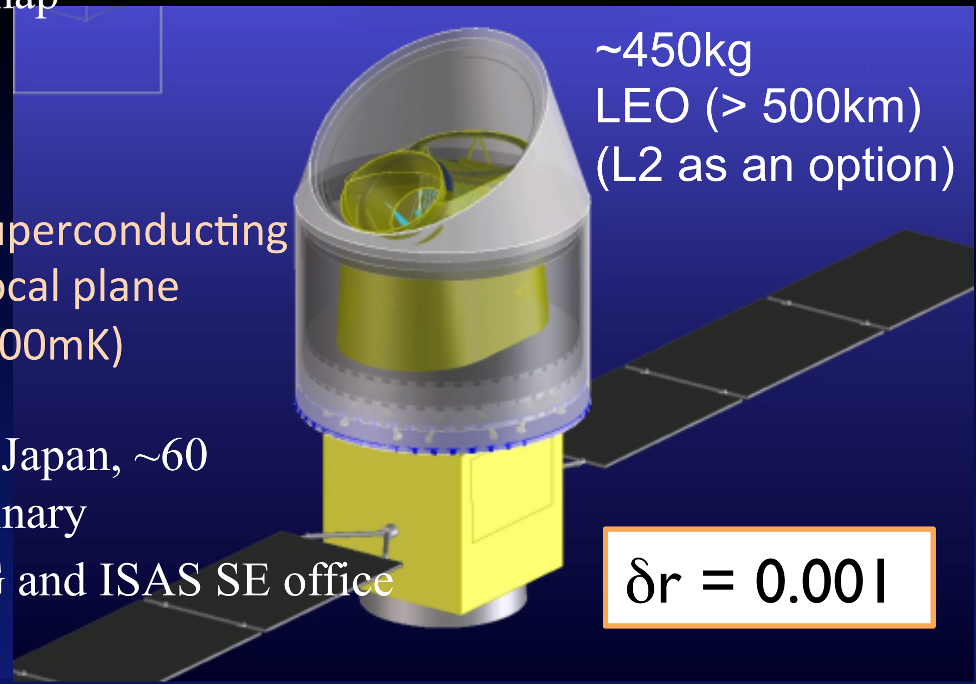
Backup Slides

LiteBIRD

Lite (Light) Satellite for the Studies of **B**-mode Polarization and **I**nflation from Cosmic Background **R**adiation **D**etection

- Scientific objectives
  - Stringent tests of cosmic inflation
  - Tests of quantum gravity theories
- Observations
  - Full-sky CMB polarization survey at a degree scale
  - Detecting primordial gravitational waves imprinted in CMB polarization map
- Strategy
  - Part of technology verification from ground-based projects
  - Synergy with ground-based super-telescopes
- Project status/plans
  - Working group authorized by SCSS in Japan, ~60 members, international and interdisciplinary
  - Technical Support from JAXA's MDSG and ISAS SE office
  - Target launch year ~2020



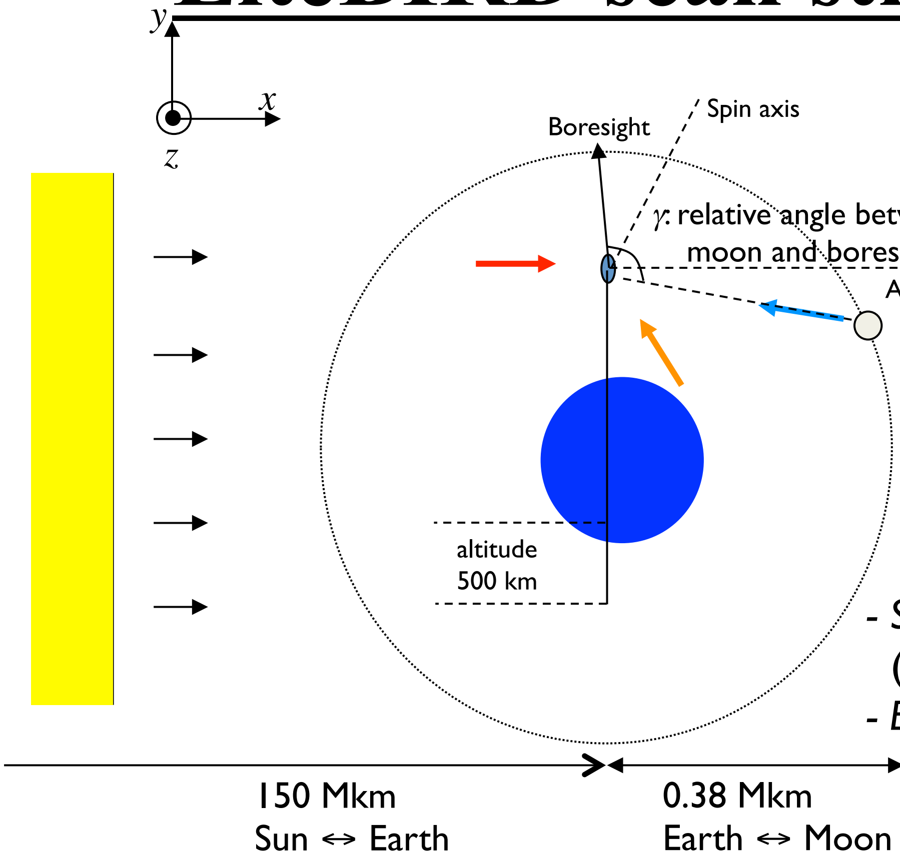


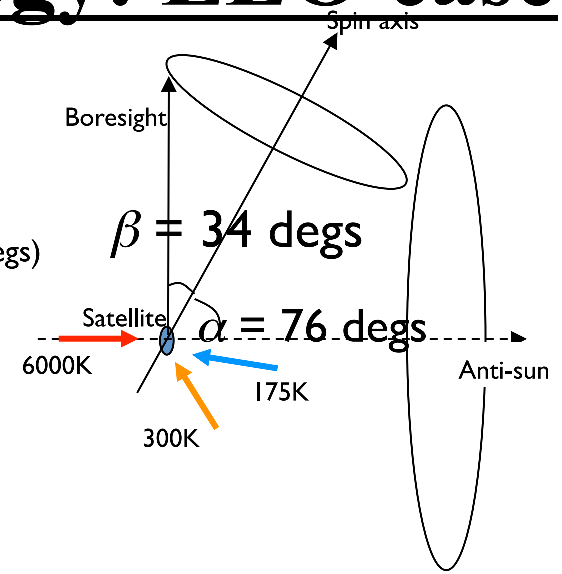
Major system requirements

Item	Requirements	Remarks
Orbit	LEO (~500km) or L2	Launch vehicle: Epsilon or H2
Observing time	> 2 years	
Weight	< 450kg	from Epsilon payload requirement
Power	< 500W	from JAXA's standard bus system
Total sensitivity	< 3μKarcmin	2μKarcmin as the design goal
Angular resolution	< 30arcmin for 150GHz	descoping requires justification
Observing frequencies	50-270 GHz (or wider)	≥ 4 bands
Modulation/Demodulation	HWP rotation > 1Hz	HWP = Half Wave Plate
1/f knee (f) × scan rate (R)	R/f > 0.06 rpm/mHz (e.g. R>1.2rpm for f=20mHz)	spec. for the case HWP stops
Telemetry	> 10GB/day	w/ Planck-type data suppression
Total systematic errors	< 18nK^2 on C^{BB} (l=2)	

These requirements are still subject to modifications in the feasibility studies

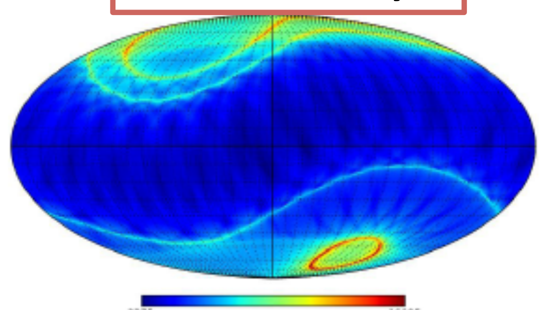
LiteBIRD scan strategy: LEO case



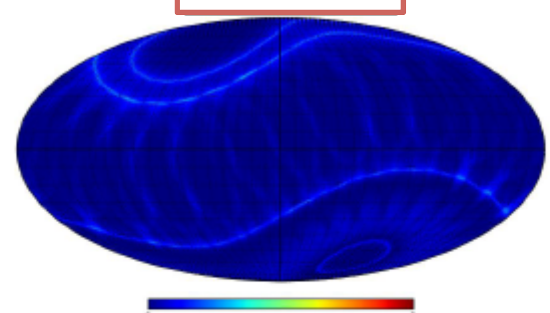


- *Spin axis rotation about anti-sun axis* (i.e. satellite period around the earth) f_s = *90 min*
- *Boresight axis rotation about spin axis* f_b ~ *0.6 rpm*

scan uniformity



cross link

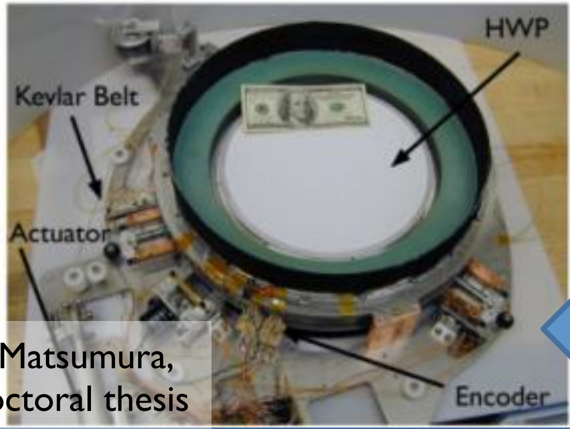


LEO

Uniformity and cross link nearly as good as those at L2

LiteBIRD optics

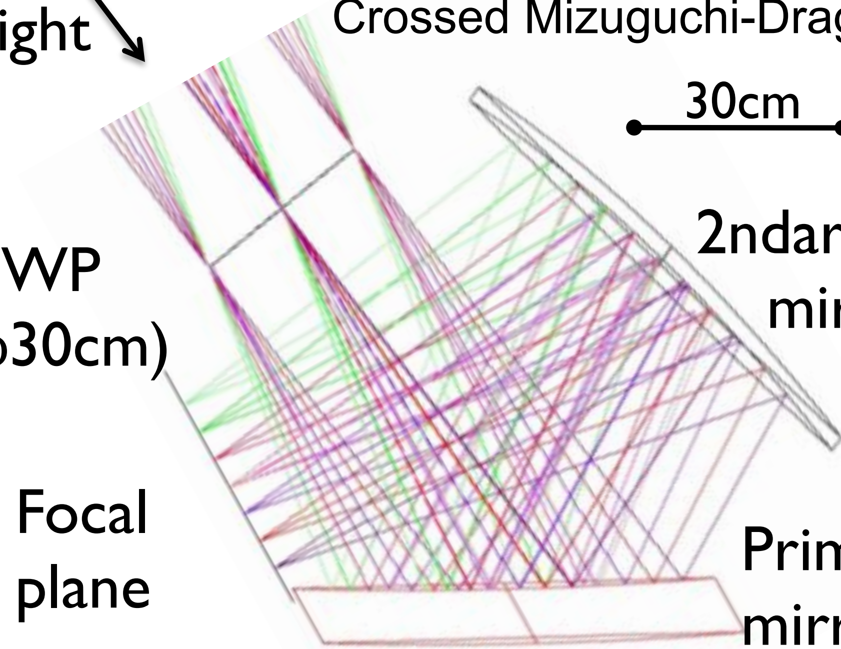
HWP example



T. Matsumura, doctoral thesis

- super-conducting bearing
- wide-band AR (EBEX)

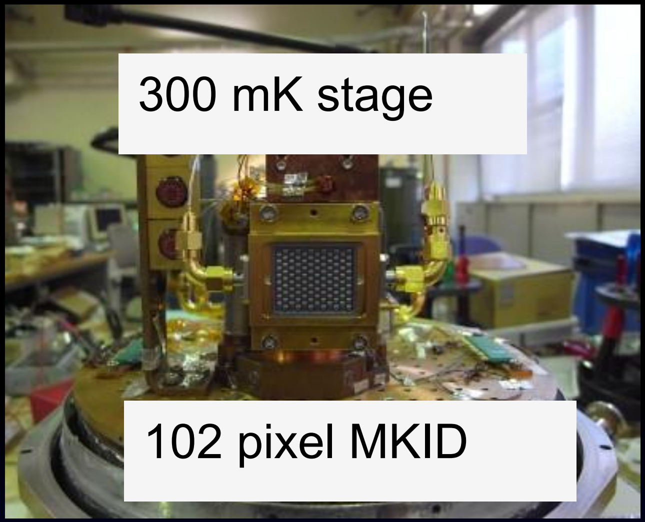
4K Reflective Optics

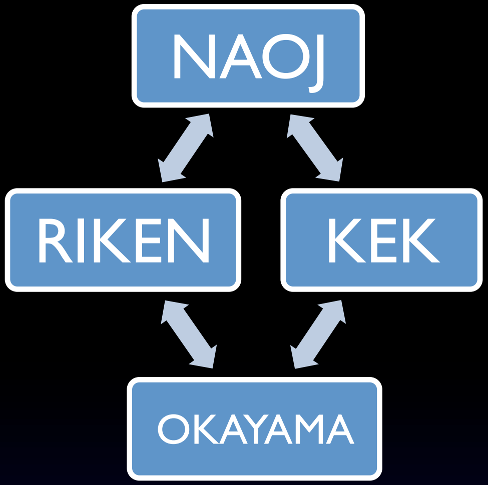


Prototype mirrors

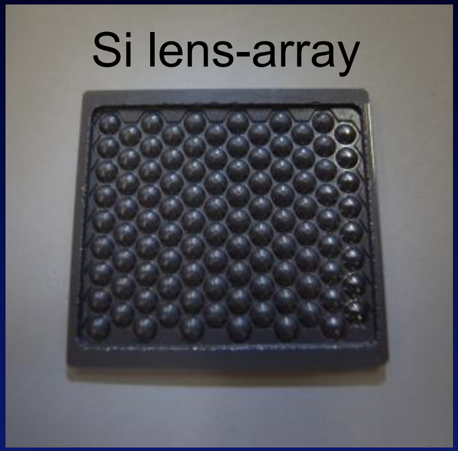
Mirror diameter ~60cm for ~0.5° angular resolution (@150GHz) is sufficient for both reionization and recombination bumps

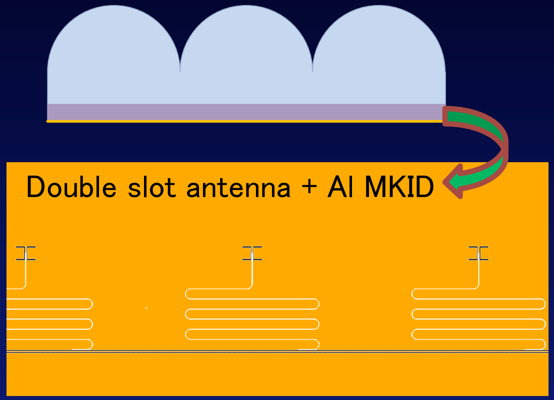
MKID option for higher MUX factor

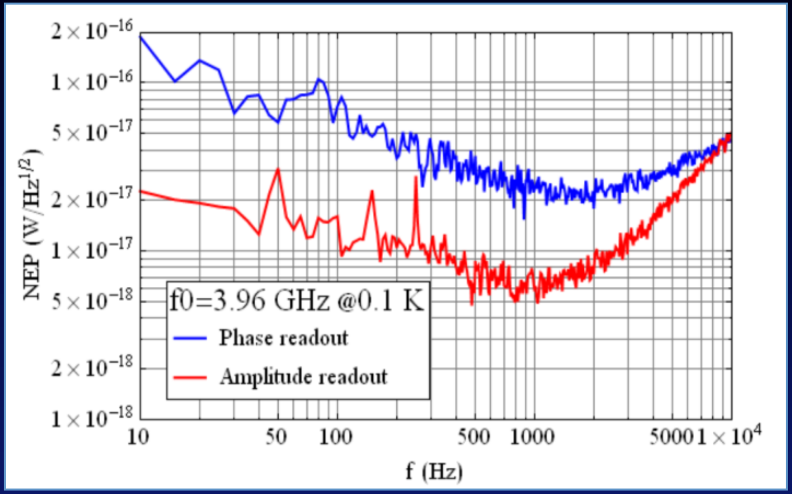




LiteBIRD is currently the guiding force for the MKID development in Japan

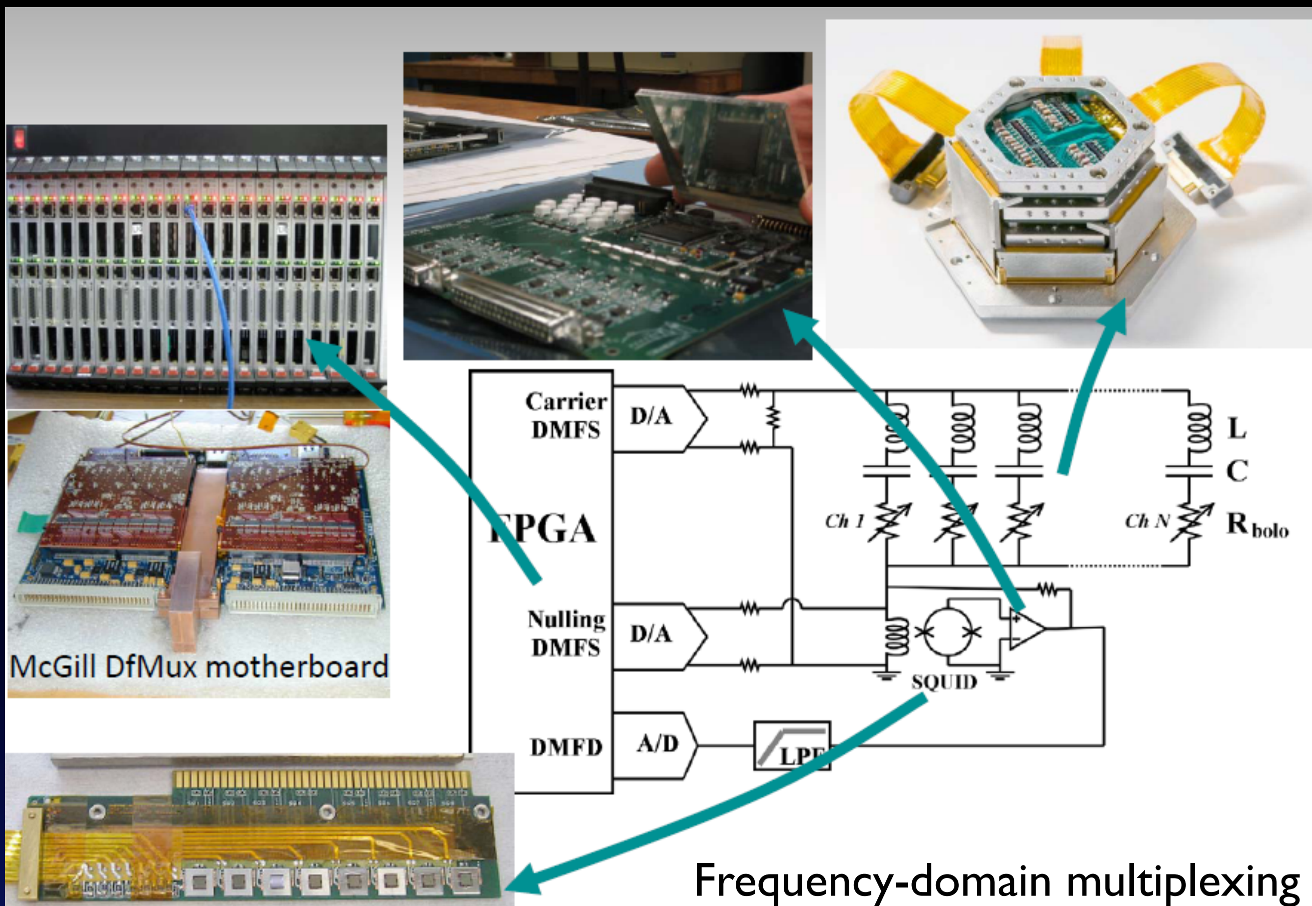






Electrical noise measurement
M. Naruse et al. 2012

TES signal multiplexing



Frequency-domain multiplexing

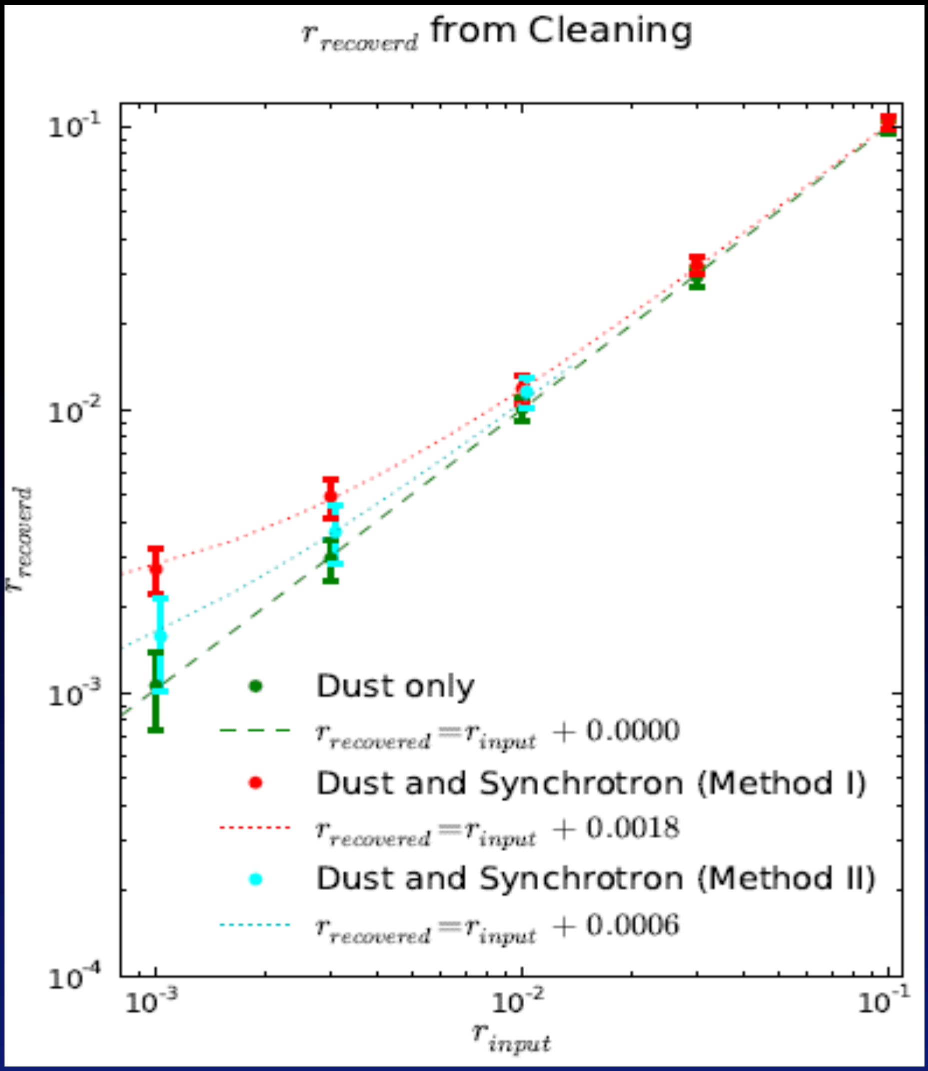
Frequency-domain multiplexing (MUX) used in POLARBEAR, SPT, EBEX etc. (8-16 MUX)

toward LiteBIRD

Replace analog feedback loop with Digital Active Nulling (DAN) to achieve 64 MUX led by McGill University (supported by CSA)

Berkeley-KEK-McGill-NIST

Foreground removal and observing bands

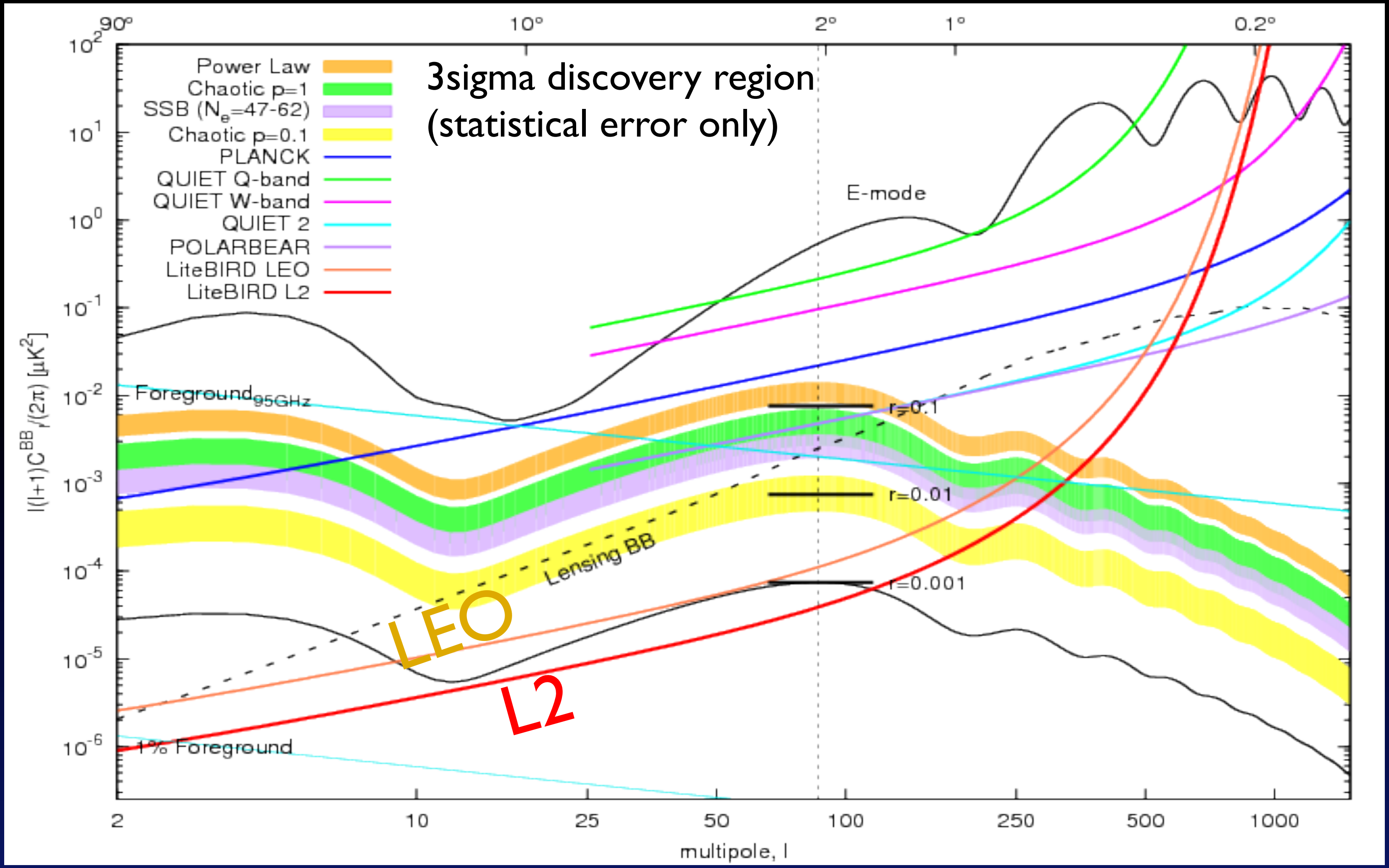


- Foreground removal
  → ≥4 bands in 50-270GHz

N. Katayama and E. Komatsu, ApJ 737, 78 (2011) **(arXiv:1101.5210)**

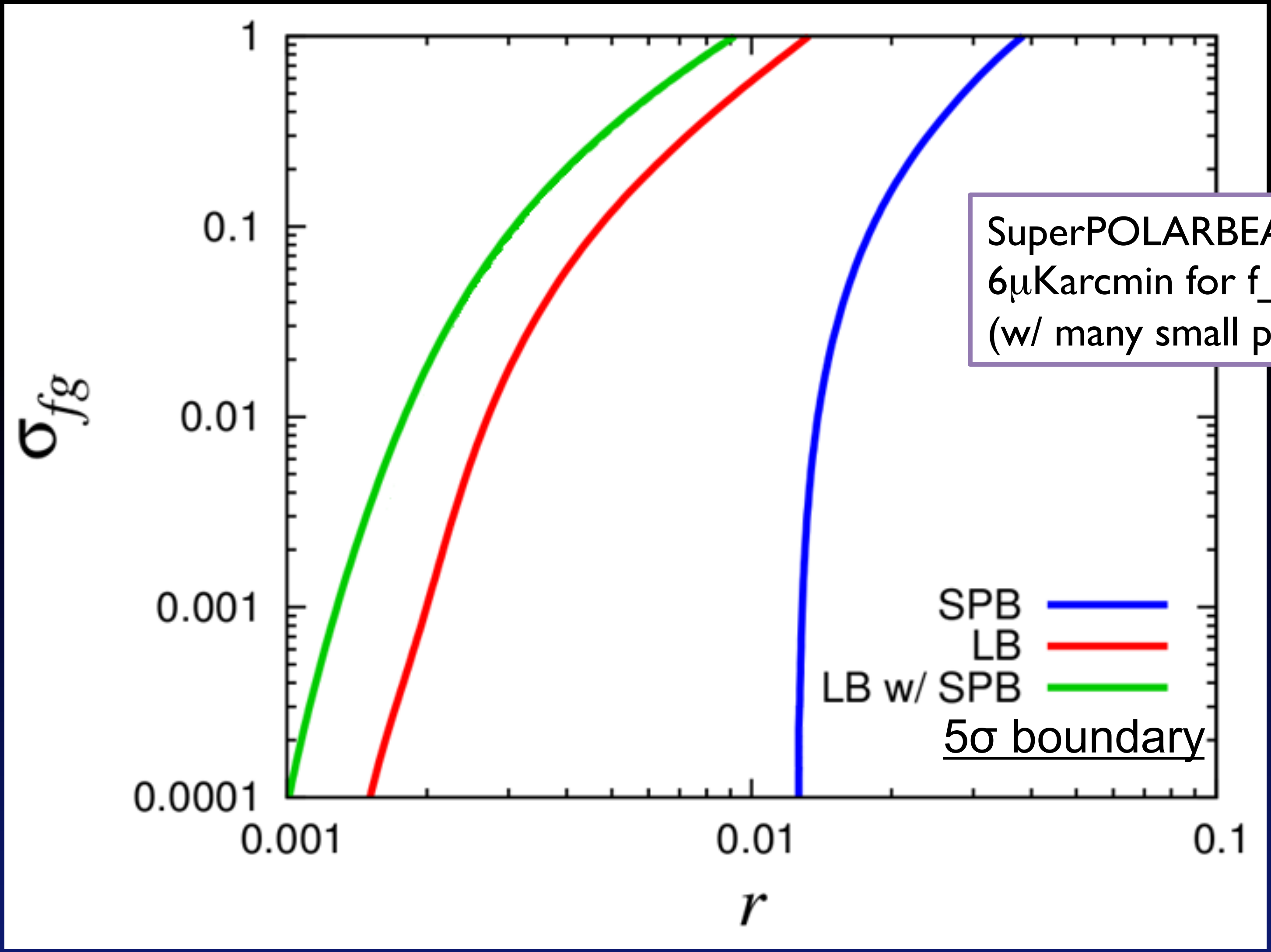
pixel-based polarized foreground removal **(model-independent)**
very small bias
r~0.0006
with 60,100,240GHz (3 bands)

L2 vs. LEO



Both cases satisfy the requirement on statistical error

Delensing with SuperPOLARBEAR



SuperPOLARBEAR assumes 6μKarcmin for f_sky = 0.75 (w/ many small patches)

Funding

- "Cosmic Background Radiation" selected as one of "innovative areas for research" by MEXT (PI: M. Hazumi)
  - JFY2009 – JFY2013: 14.3M$
  - QUIET, POLARBEAR, LiteBIRD, CIBER etc.
  - http://cbr.kek.jp/index_en.html
- Joint budget request (KEK, NINS) in consideration
  - ~100M$ needed (+ launch cost)
- International collaboration should be pursued actively.
  - R&D matching fund (e,g, from NASA) will help a lot
  - Launch not limited to Epsilon or H2 depending funding progress

Support from research communities

- Japanese High Energy Physics (HEP) community has identified CMB polarization measurements and dark energy survey as two important areas of their "cosmic frontier".
  - http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
- Japanese radio astronomy community also expressed their support to LiteBIRD.
- Cosmology community (theory) is also supporting LiteBIRD and contributing to the science case.
- SCSS added "fundamental physics" as a target for space programs in next 20 years

Conclusion

- CMB polarization will be the frontier in post-Planck era
  - Best probe to discover primordial gravitational waves
  - Unique tests of inflation and quantum gravity
- The goal of LiteBIRD is to search for primordial gravitational waves with the sensitivity of $\delta r<0.001$, for testing all the representative inflationary models.
- The strategy of LiteBIRD is to focus on r measurements. The powerful duo (LiteBIRD and ground-based super-telescopes) will be the most cost-effective way.
- No show-stopper in design studies so far. Technology verification in ground-based projects in next ~3 years will be crucial. The LiteBIRD roadmap includes such ground-based projects.

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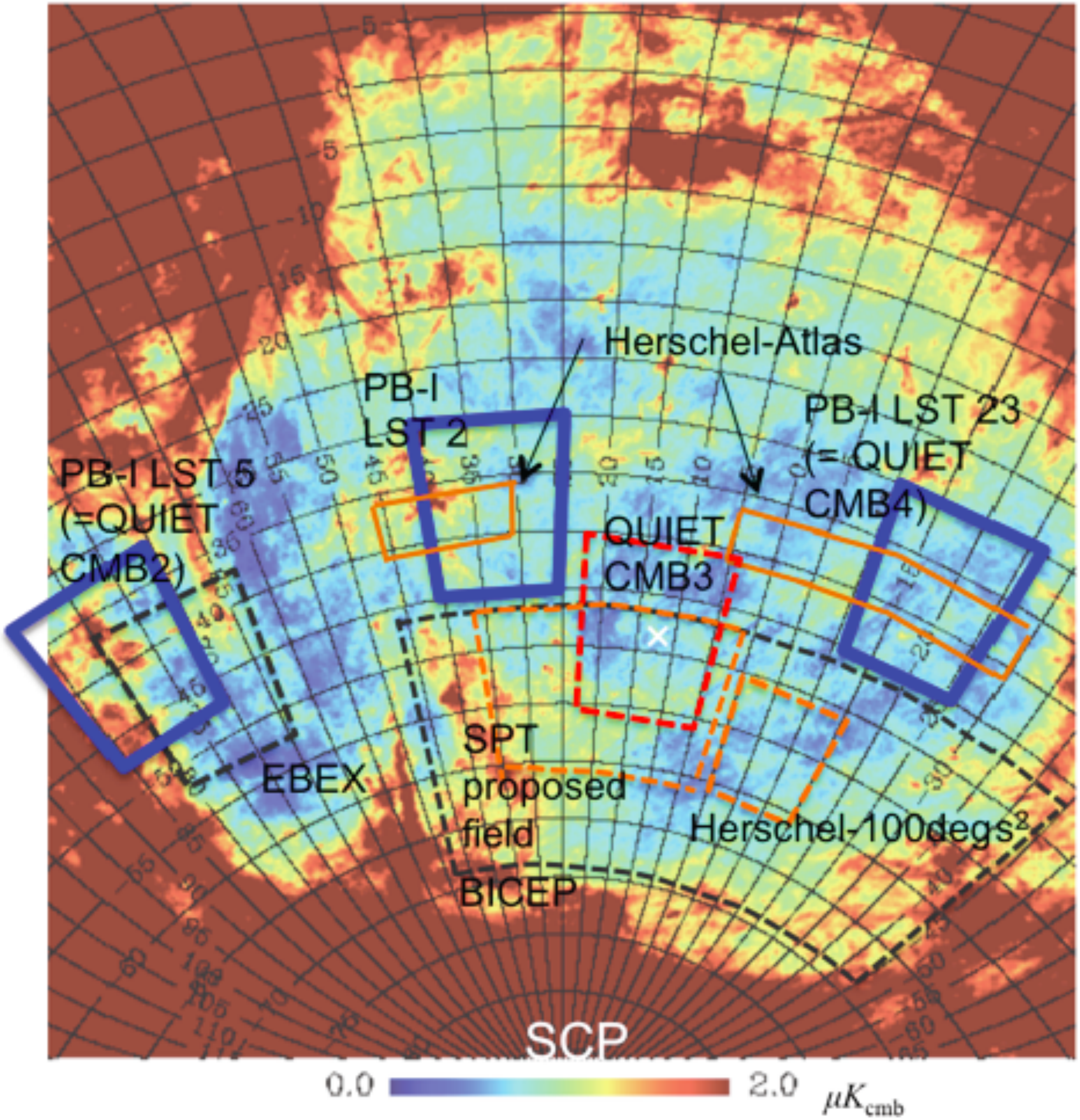
Herschel-Atlas
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