LiteBIRD

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

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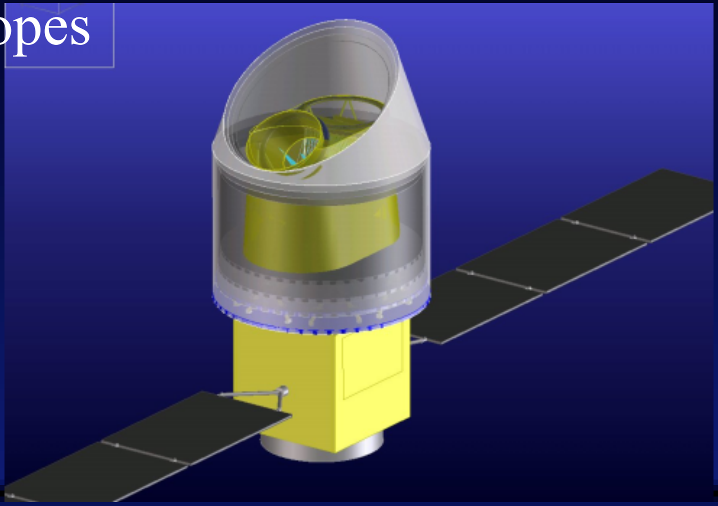
On behalf of the LiteBIRD working group

LiteBIRD project overview

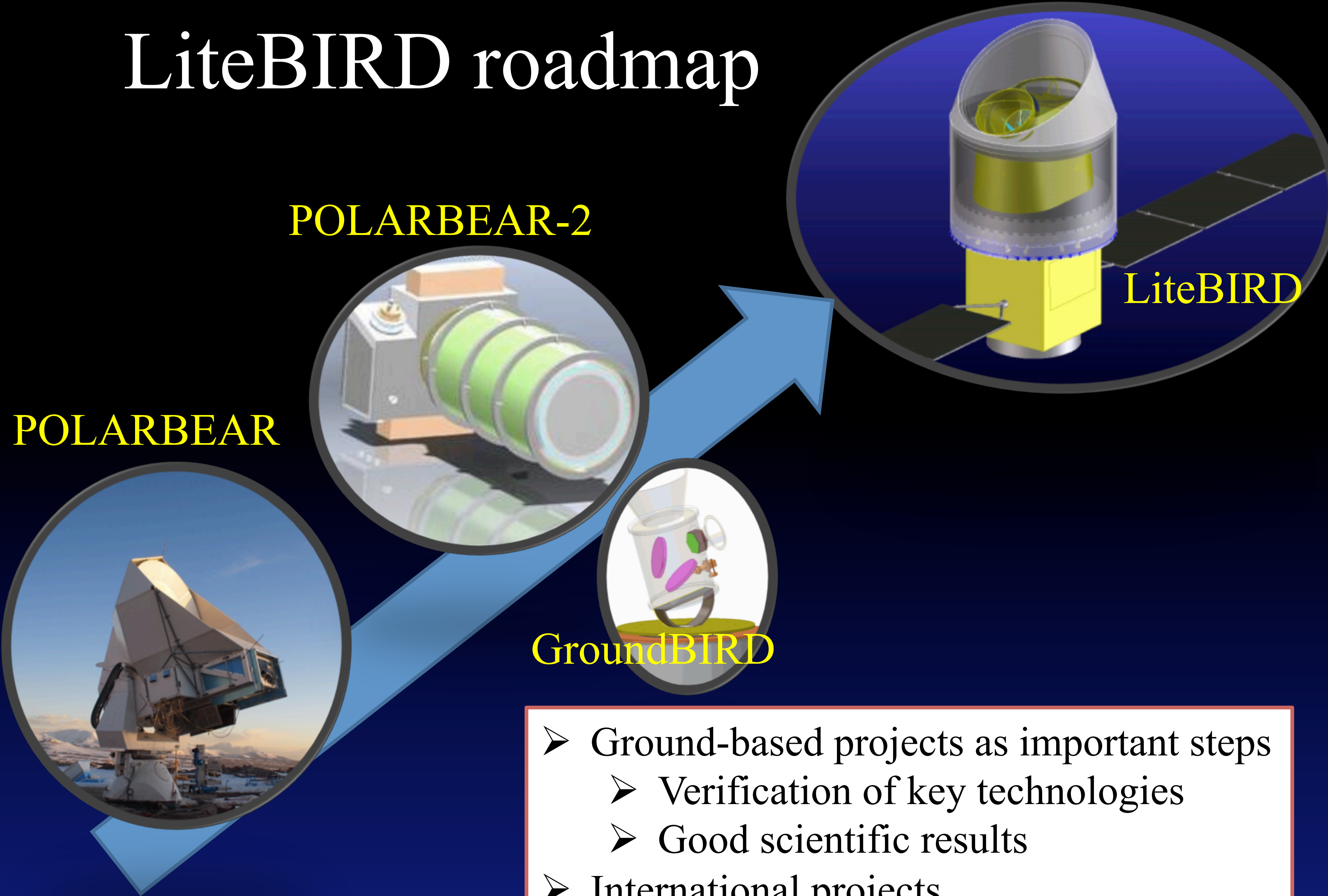
- Scientific goal

  CMB : Cosmic Microwave Background

  - Stringent tests of cosmic inflation at the extremely early universe
- Observations
  - Full-sky CMB (i.e. mm wave) polarization survey at a degree scale
- Strategy
  - Roadmap includes ground-based projects as important steps
  - Focus on signals of inflationary gravitational waves imprinted in CMB polarization
  - Synergy with ground-based super-telescopes
- Project status/plans
  - Working group authorized by SCSS, supported by JAXA
  - Mission definition review in 2013, target launch year ~2020



LiteBIRD roadmap



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

LiteBIRD working group

- 58 members (as of Aug.15, 2012)
- International and interdisciplinary

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C. Otani

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M. Hattori

+ Korea U. under consideration

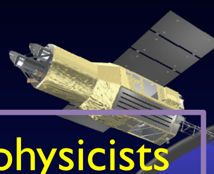
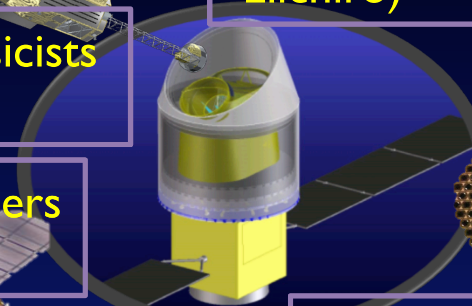
CMB experimenters (Berkeley, KEK, McGill, Eiichiro)

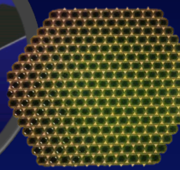
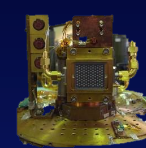
X-ray astrophysicists (JAXA)

Infrared astronomers (JAXA)

JAXA engineers and Mission Design Support Group

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

LiteBIRD mission

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

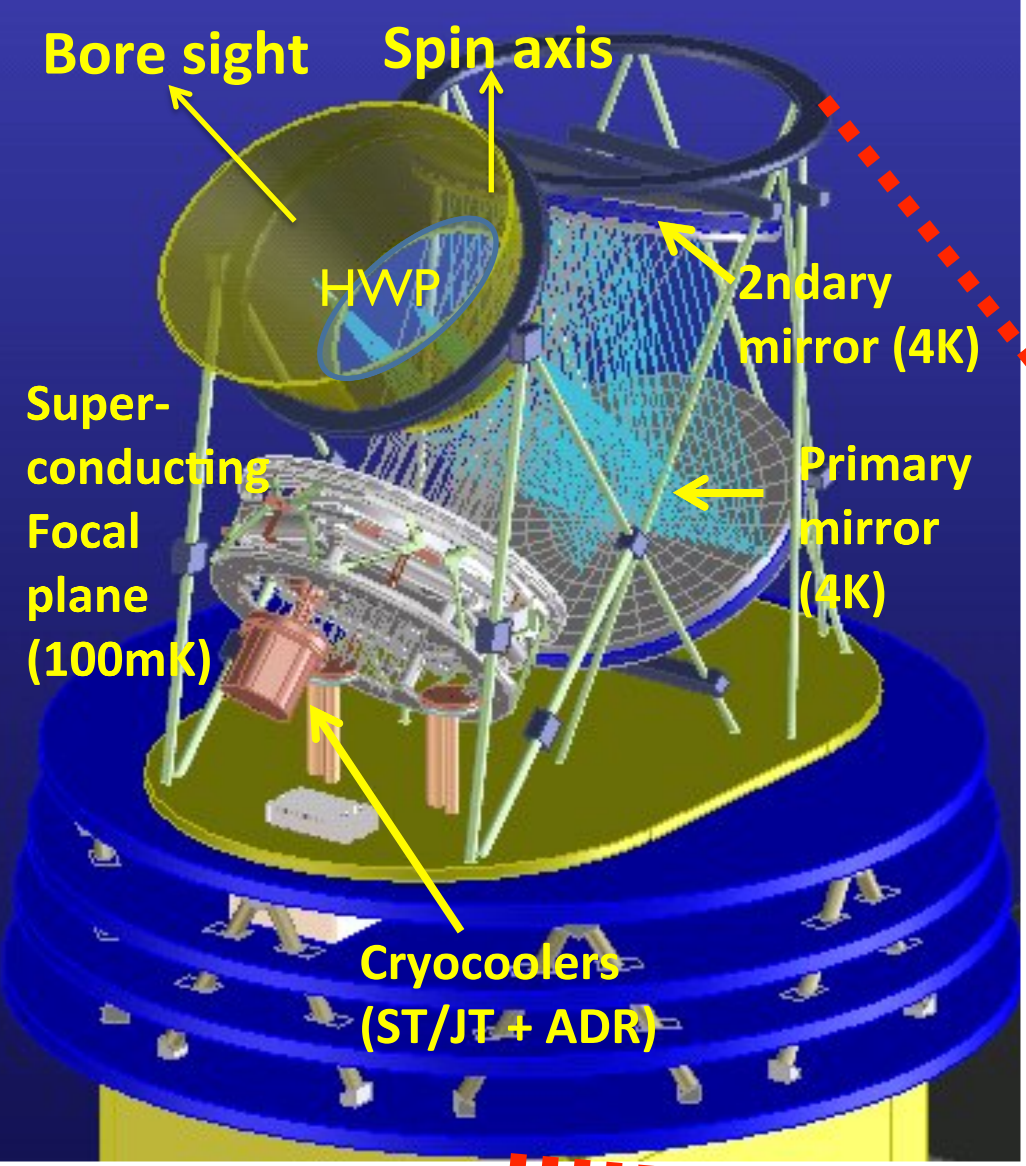
    (stat. ⊕ **syst.** ⊕ **foreground** ⊕ **lensing**) **$\delta r < 0.001$**

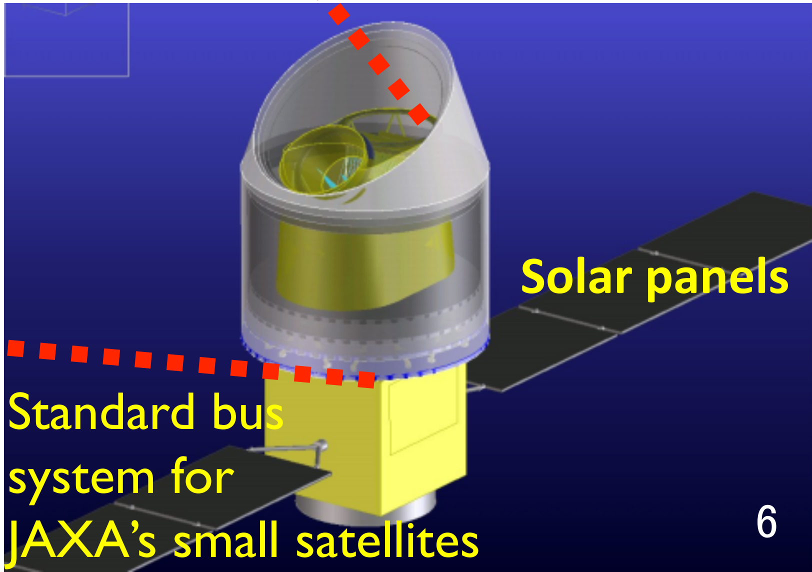
No lose theorem of LiteBIRD

- 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.
  - 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 !

Huge impact on cosmology in any case

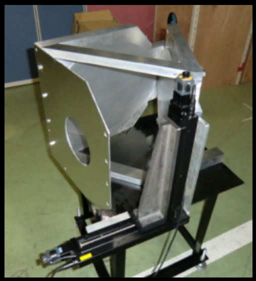
LiteBIRD system overview



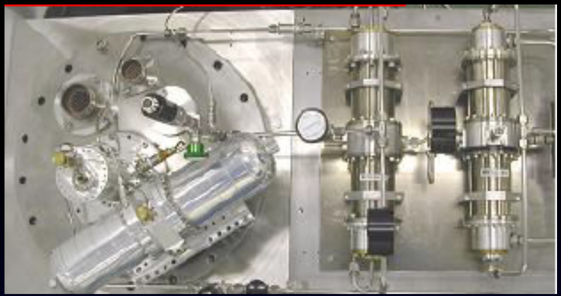


Three key technologies to make LiteBIRD light

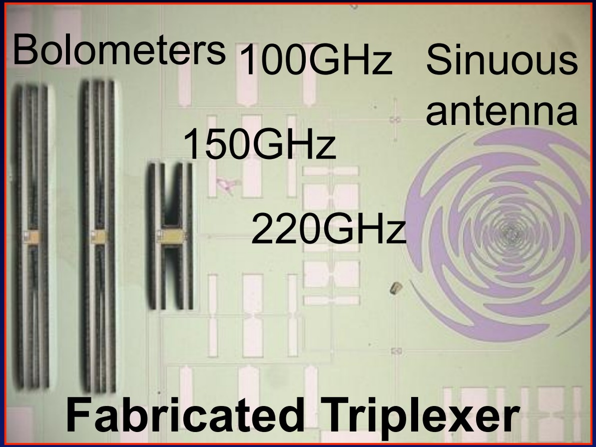
- Small mirrors (~60cm)
- Warm launch with mechanical coolers
  - Technology alliance with SPICA for pre-cooling (ST/JT)
  - Alliance with DIOS (X-ray mission) for ADR
- Multi-chroic focal plane
  - ~2000 TES (T_{bath}=100mK, $\delta\nu/\nu \sim 0.3$), or equivalent MKIDs
  - Technology demonstration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



Prototype crossed Mizuguchi-Dragone mirror



2ST/JT BBM



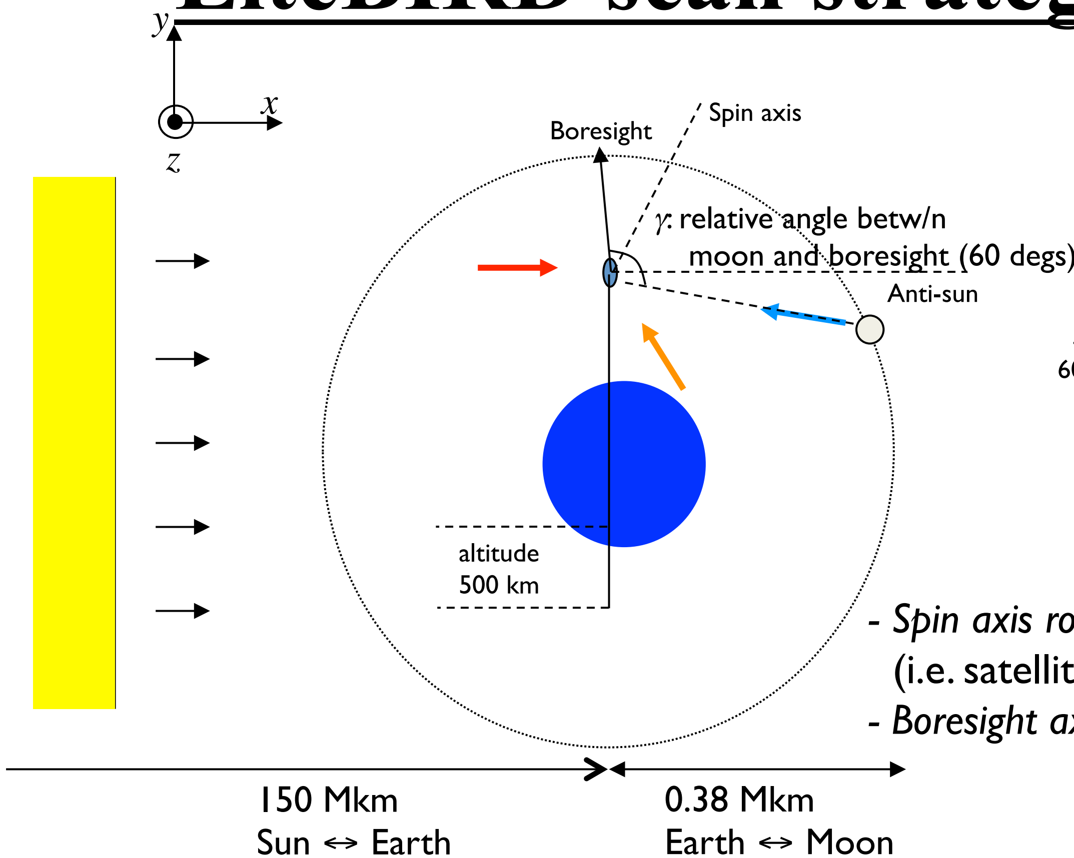
UC Berkeley TES option

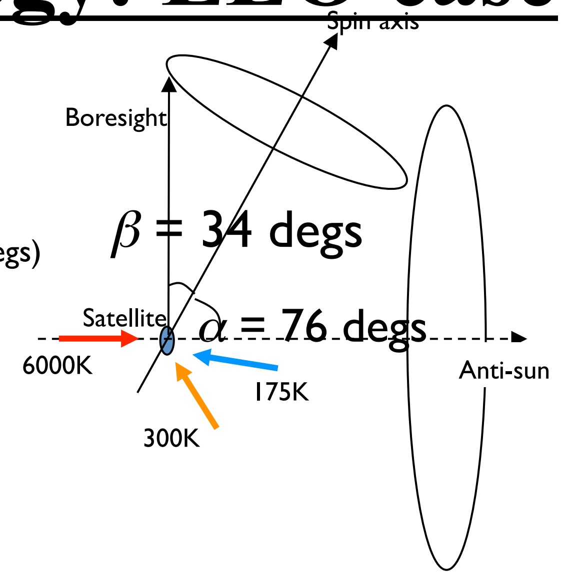
Major system requirements

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

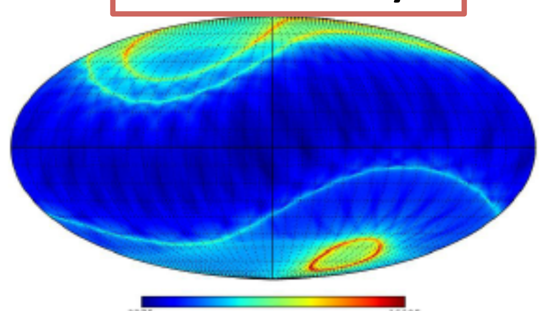
LiteBIRD scan strategy: LEO case



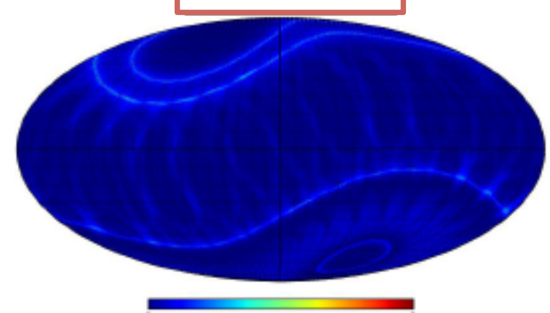


- *Spin axis rotation about anti-sun axis*
  (i.e. satellite period around the earth) f_s = *90 min*
- *Boresight axis rotation about spin axis* $f_b \sim$ *0.6 rpm*

scan uniformity



cross link

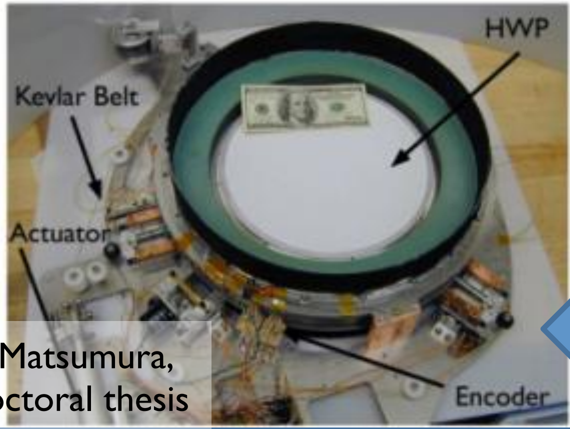


LEO

Uniformity and cross link nearly as good as those at L2

LiteBIRD optics

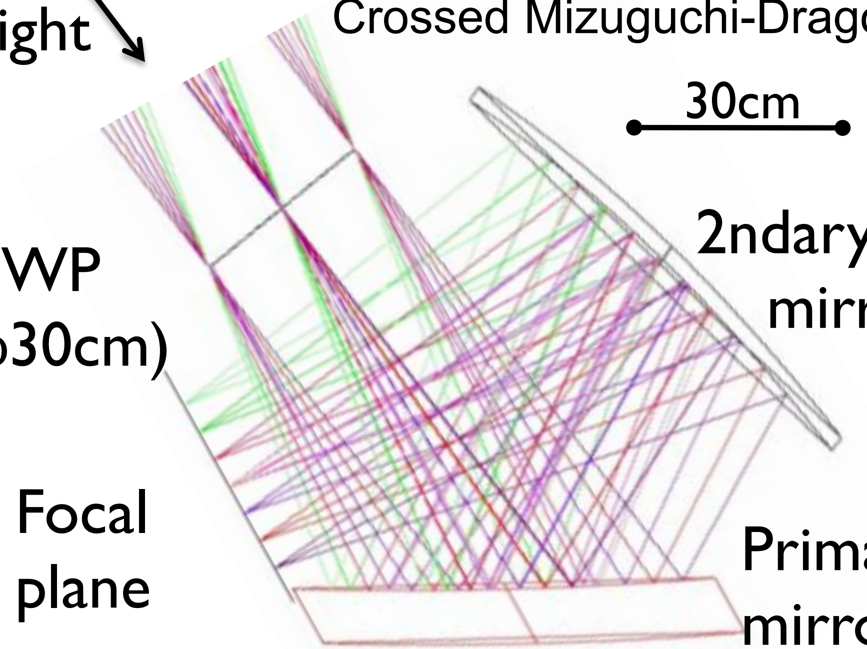
HWP example



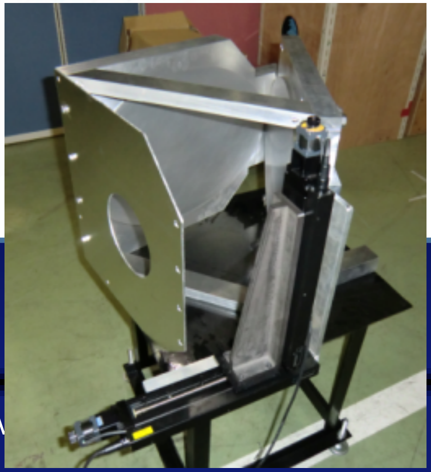
T. Matsumura, doctoral thesis

super-conducting bearing
wide-band AR (EBEX)

4K Reflective Optics



Prototype mirrors

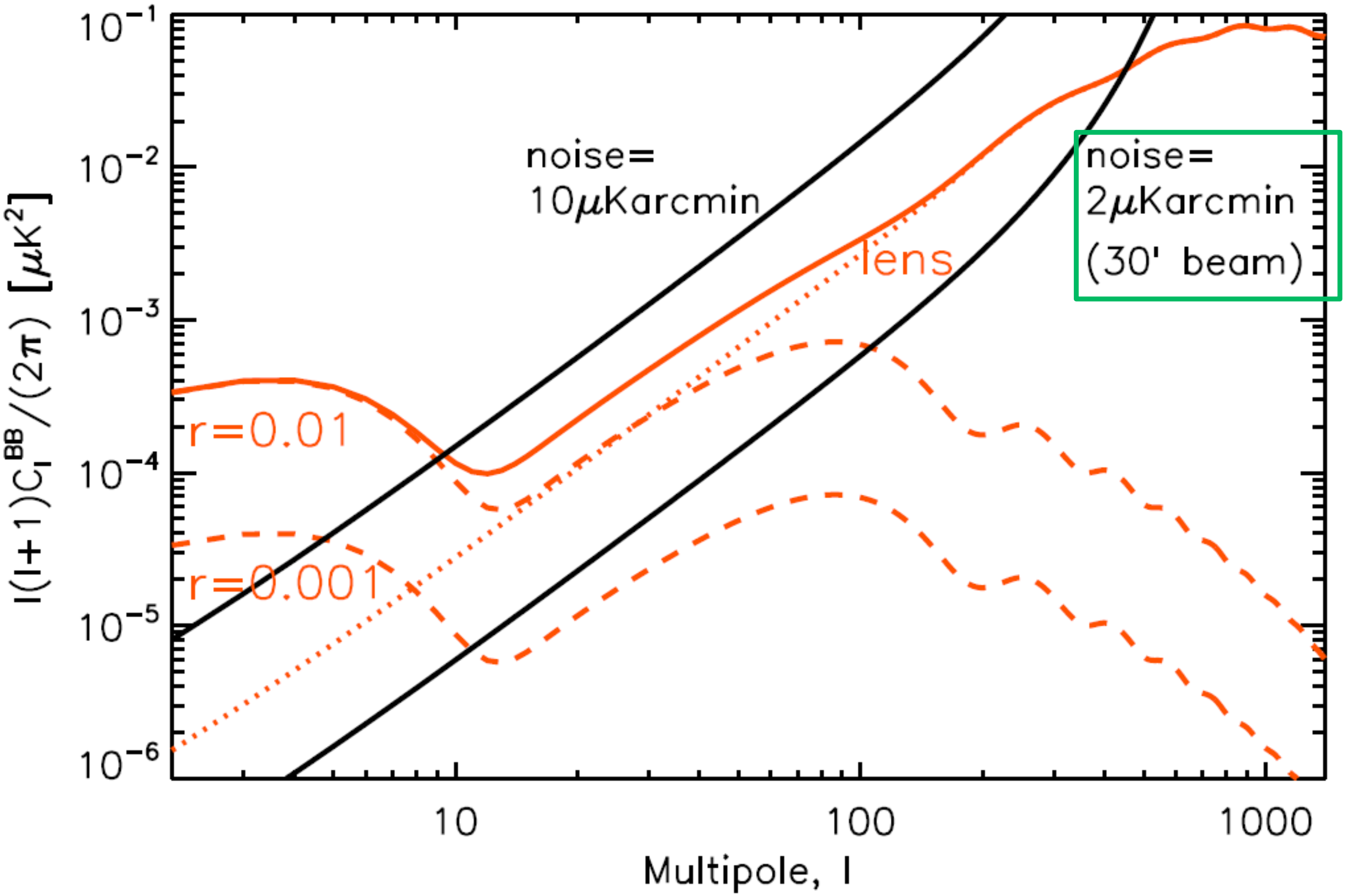


Mirror diameter ~60cm for ~0.5° angular resolution (@150GHz) is sufficient for both reionization and recombination bumps

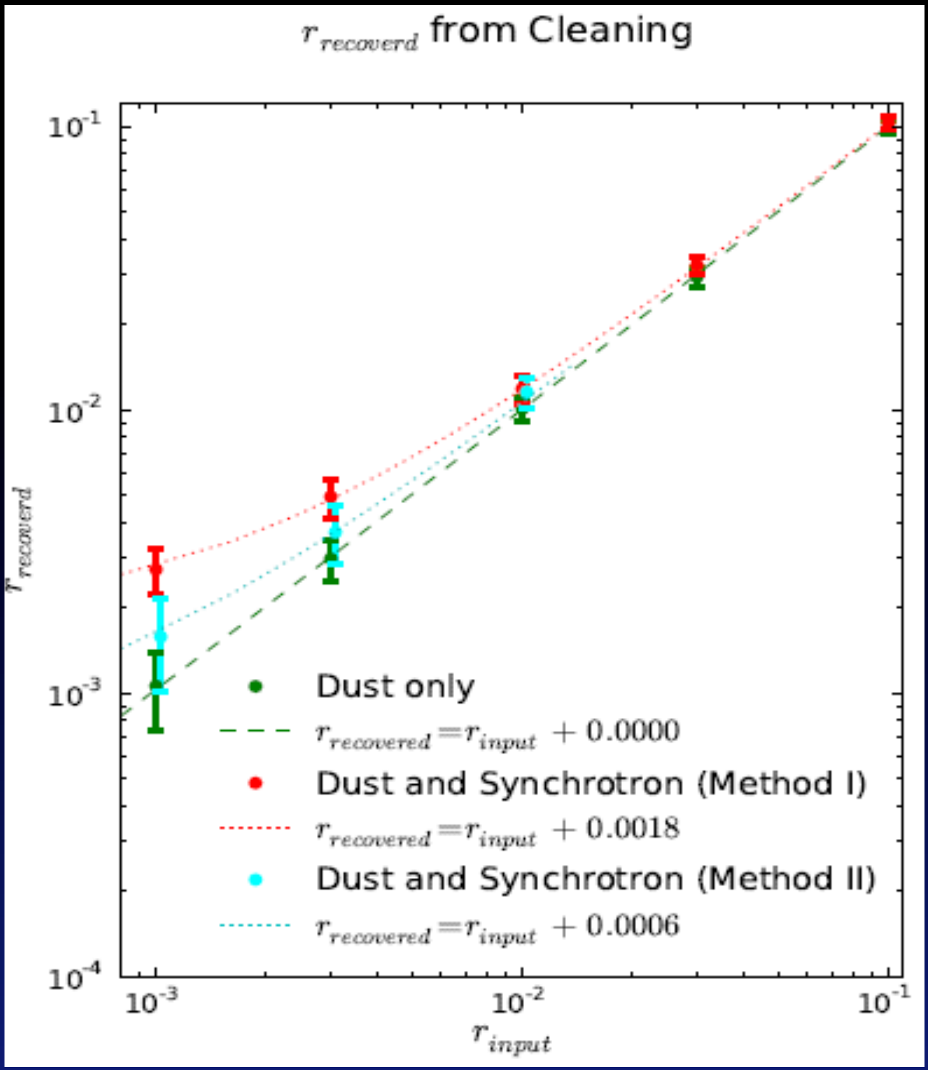
Focal plane requirement

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

To be well below "lensing floor"



Foreground removal and observing bands



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

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

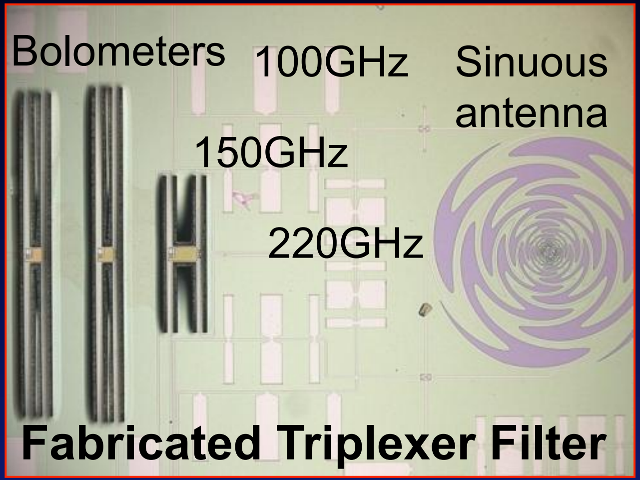
pixel-based polarized foreground removal
(model-independent)
very small bias
r~0.0006
with 60,100,240GHz (3 bands)

LiteBIRD band selection for multi-chroic pixels

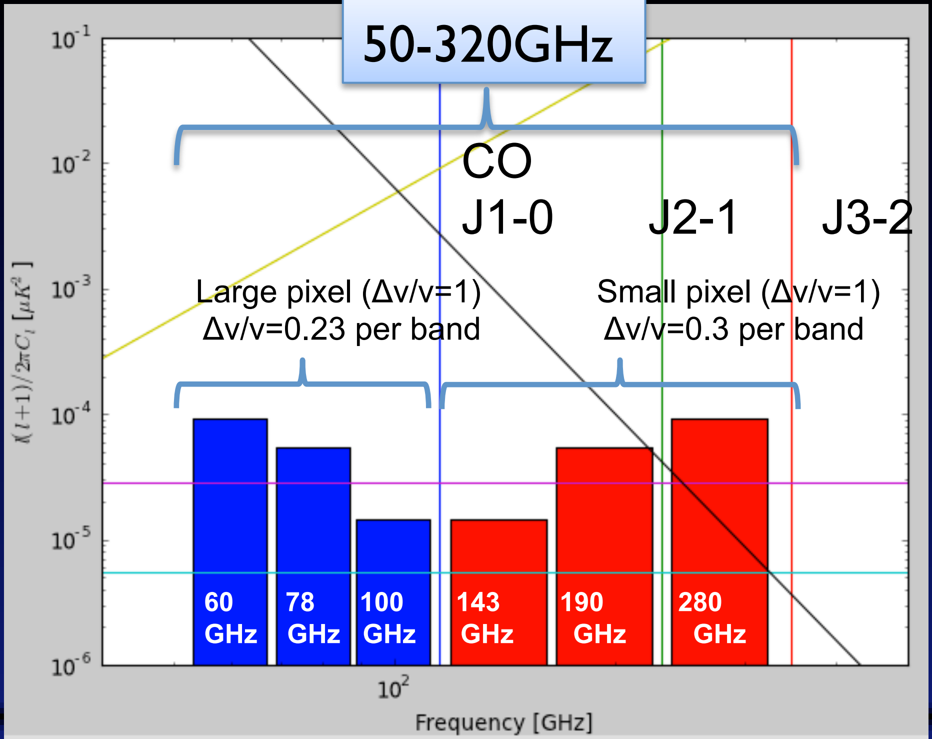
We chose the band locations with the following reasons.

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.



UC Berkeley TES option



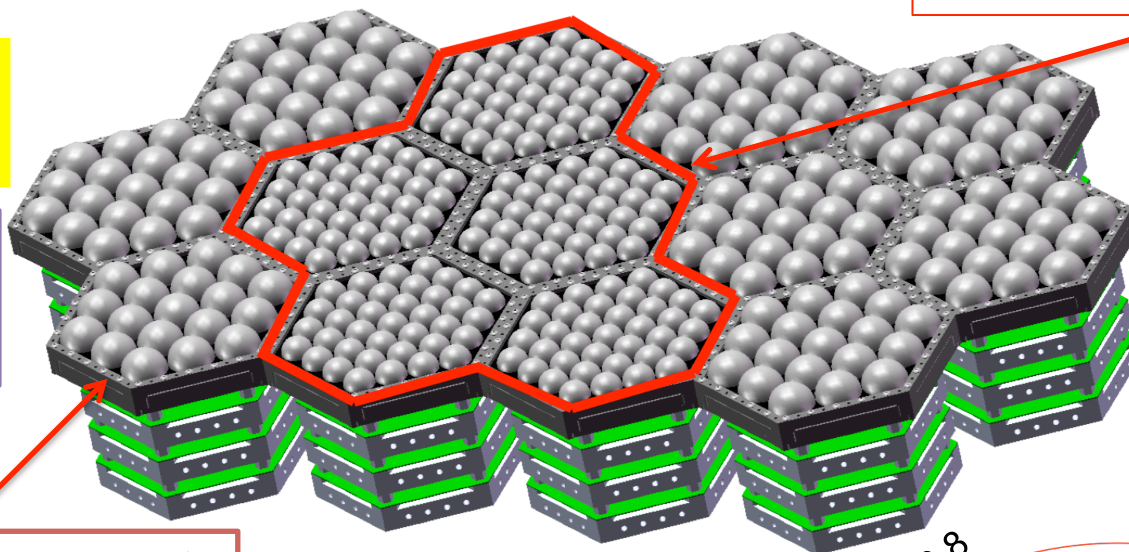
LiteBIRD focal plane design

tri-chroic（140/190/280GHz）

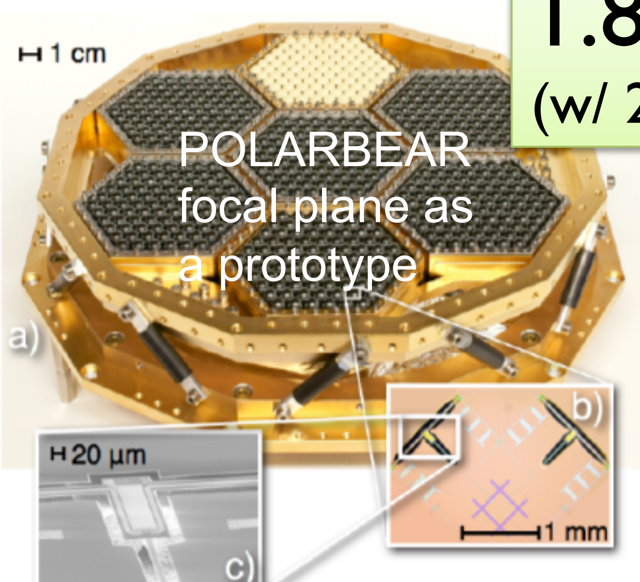
UC Berkeley TES option

2022 TES bolometers

T_{bath} = 100mK

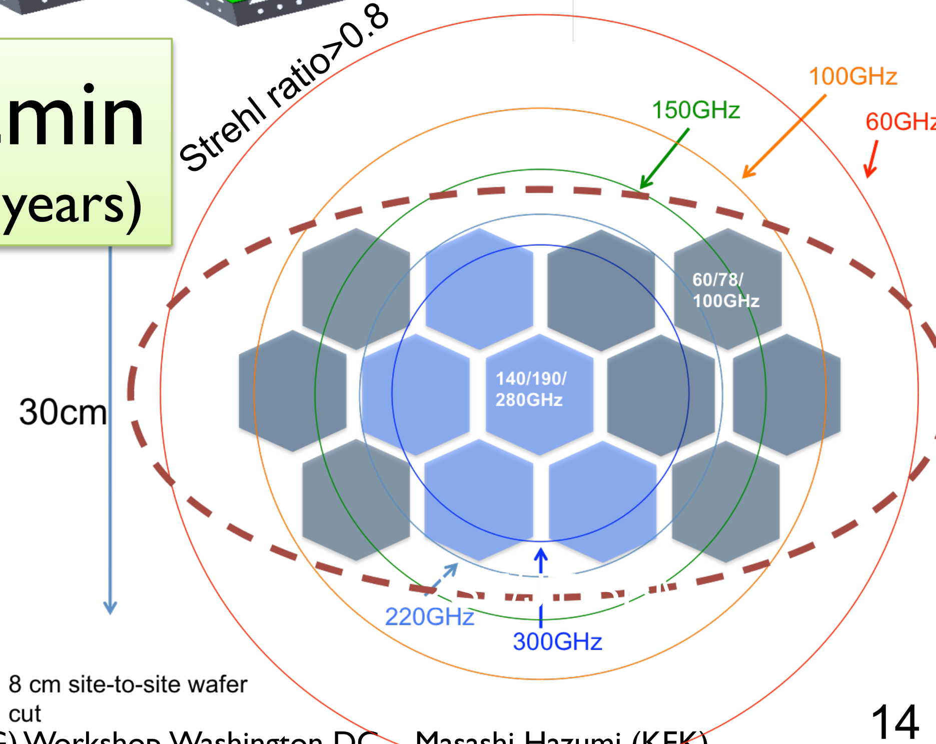


tri-chroic（60/78/100GHz）



POLARBEAR focal plane as a prototype

1.8μKarcmin
(w/ 2 effective years)



LiteBIRD focal plane design

UC Berkeley TES option

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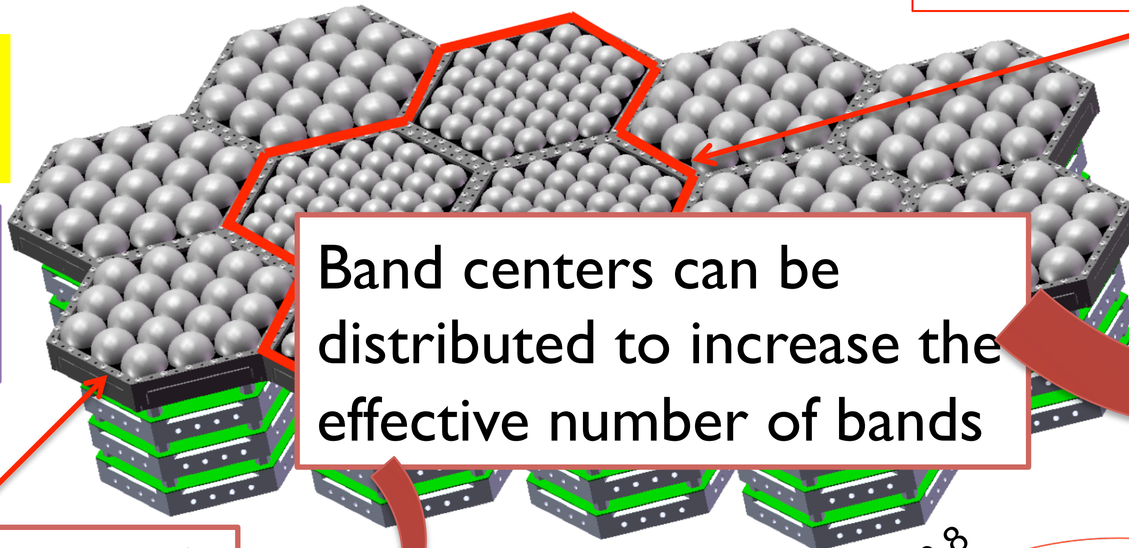
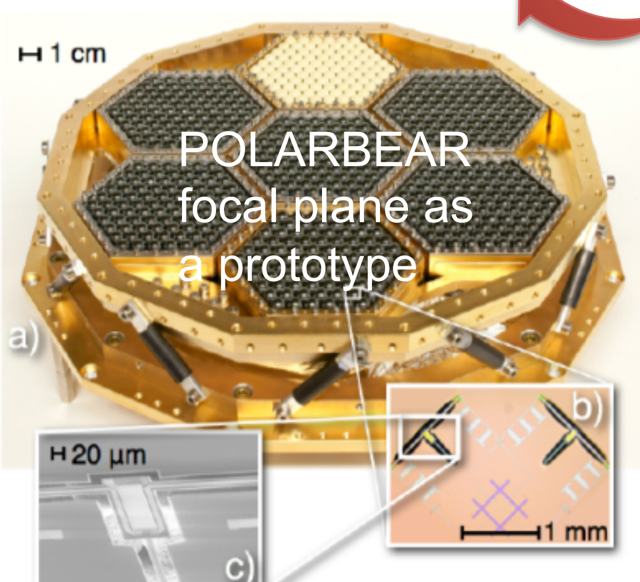
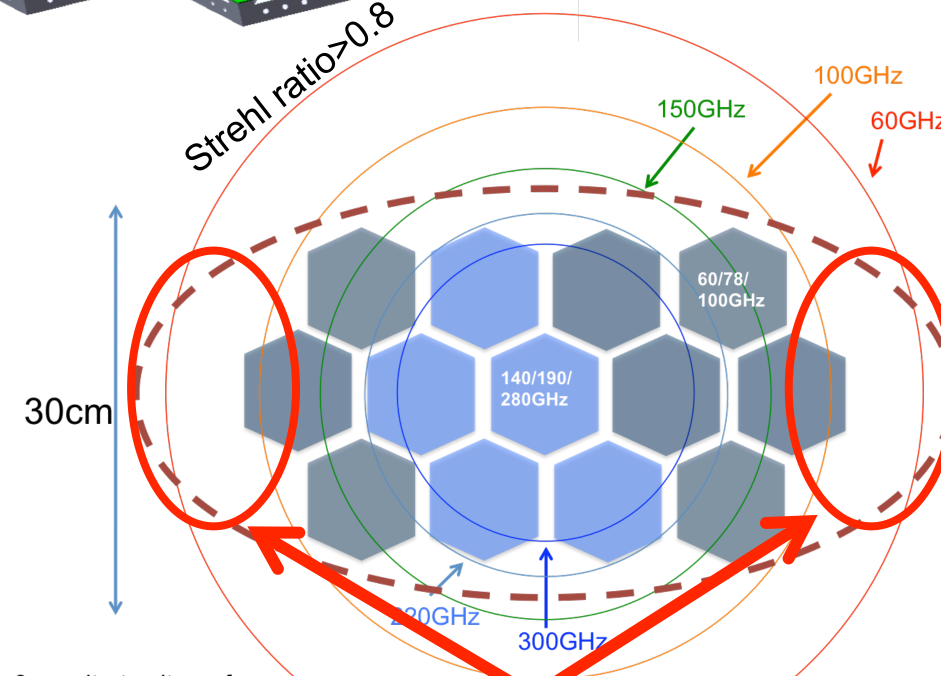


Band centers can be distributed to increase the effective number of bands

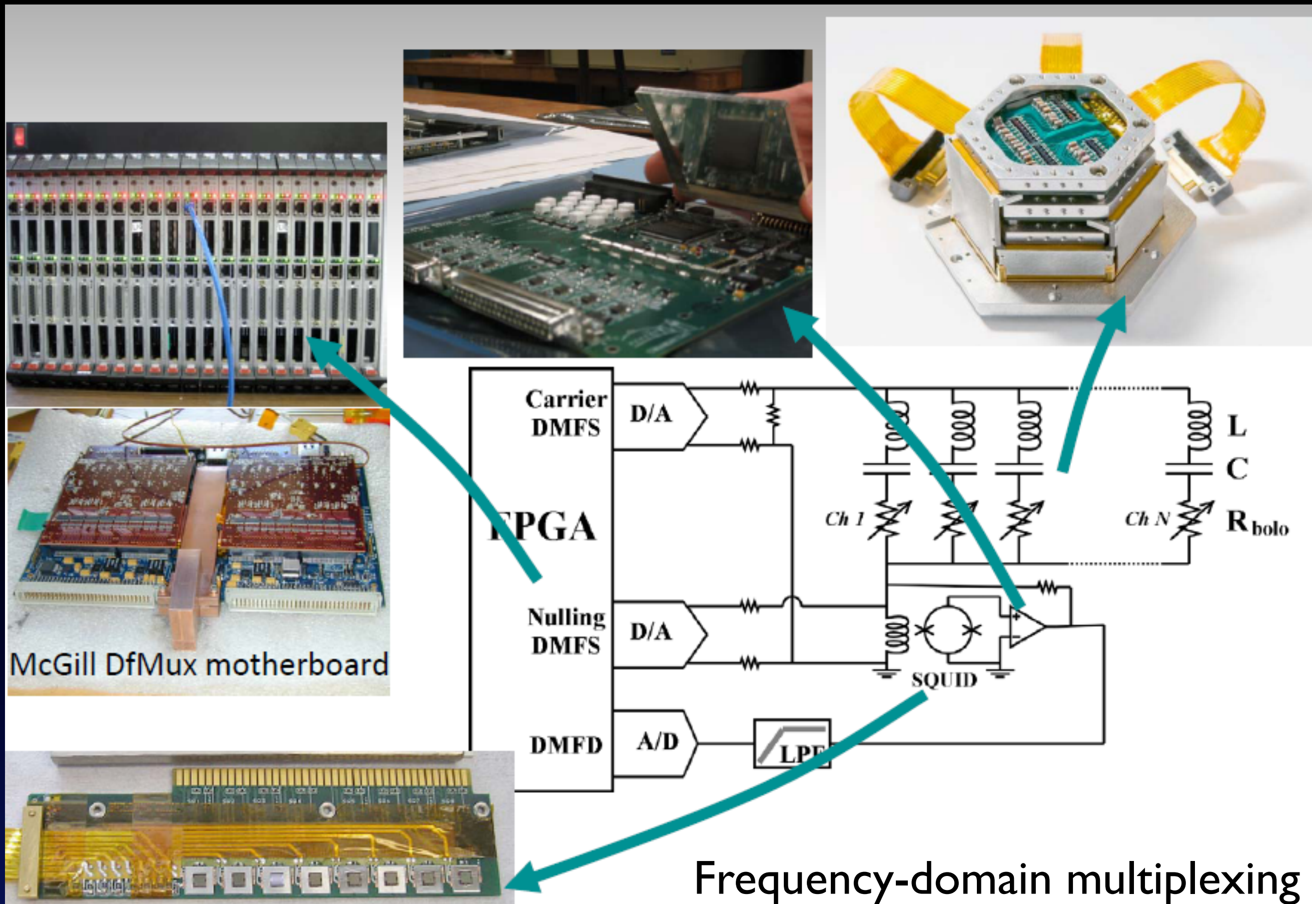
tri-chroic (60/78/100GHz)





More space to place <60GHz detectors

TES signal multiplexing



Frequency-domain multiplexing

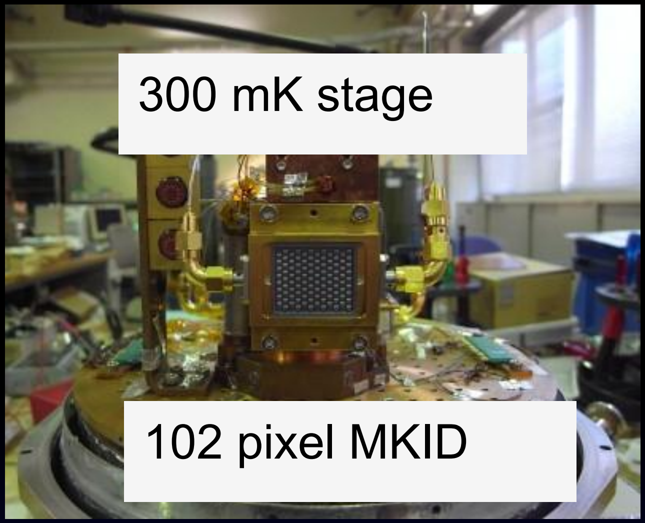
Frequency-domain multiplexing (MUX) used in POLARBEAR, SPT, EBEX etc. (8-16 MUX)

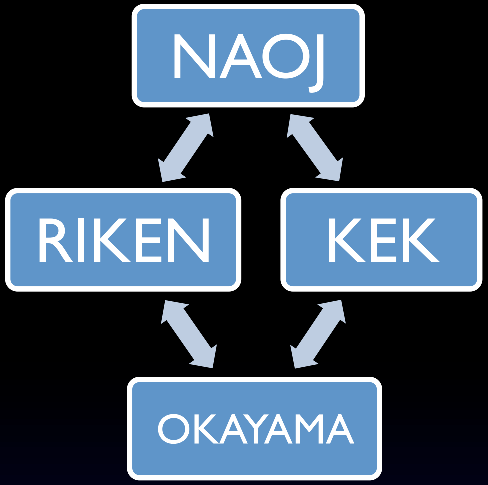
toward LiteBIRD

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

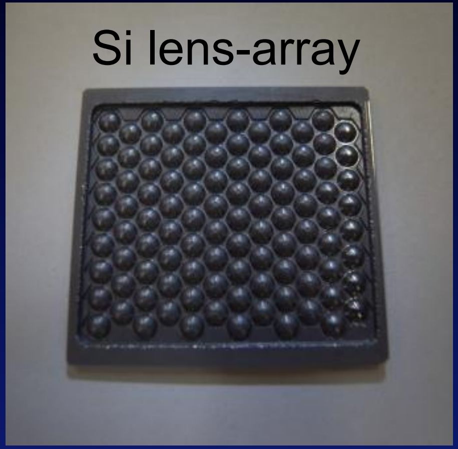
Berkeley-KEK-McGill-NIST

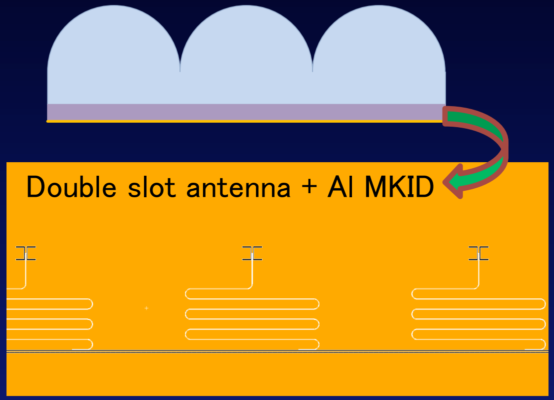
MKID option for higher MUX factor

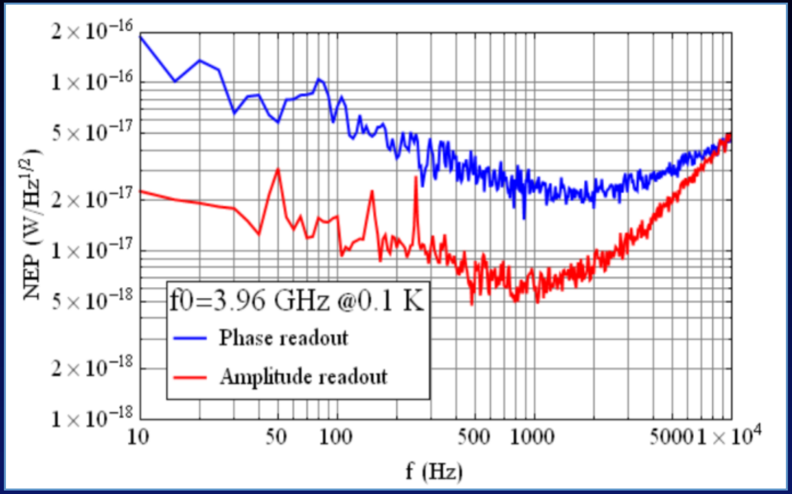




LiteBIRD is currently the guiding force for the MKID development in Japan

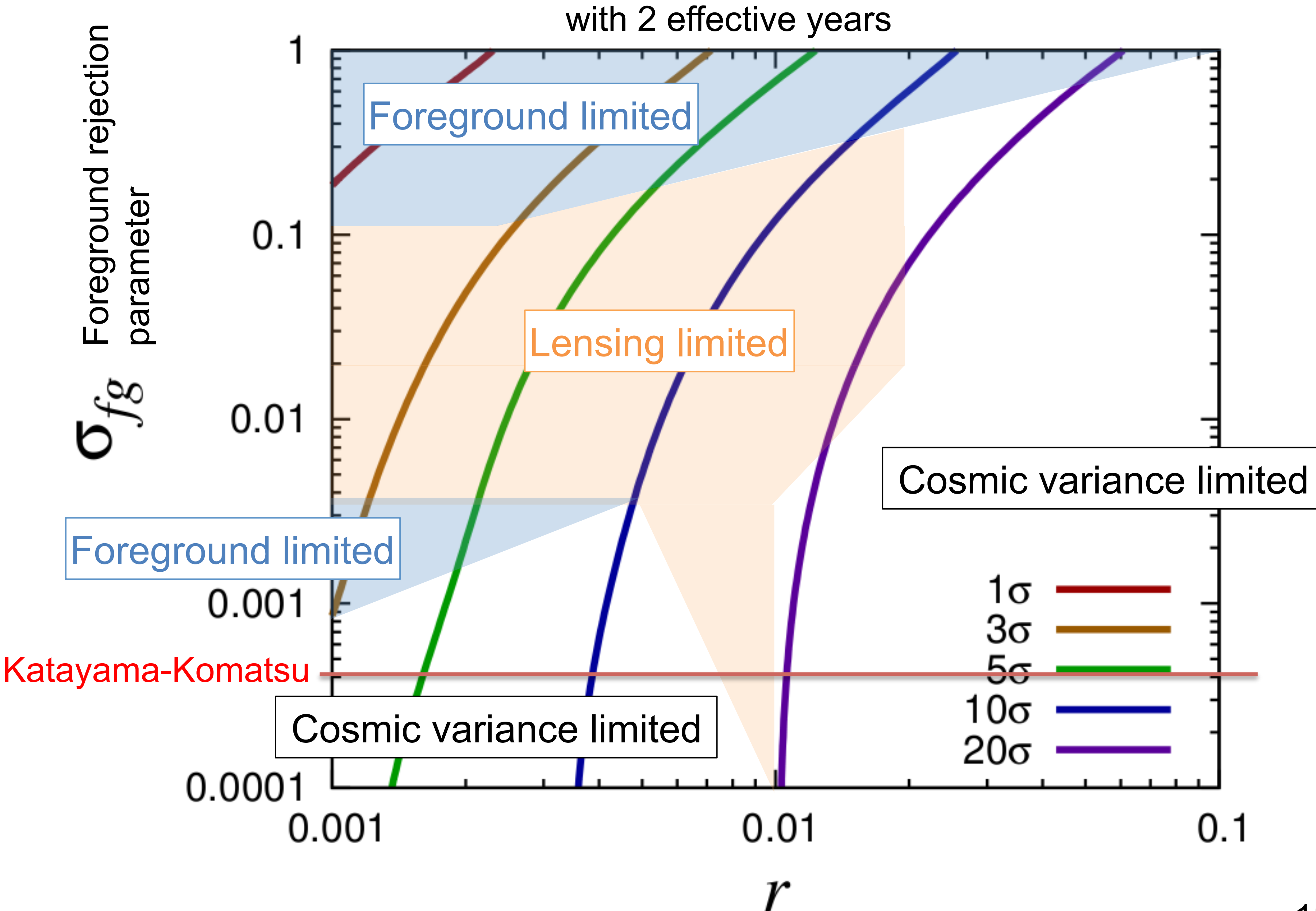




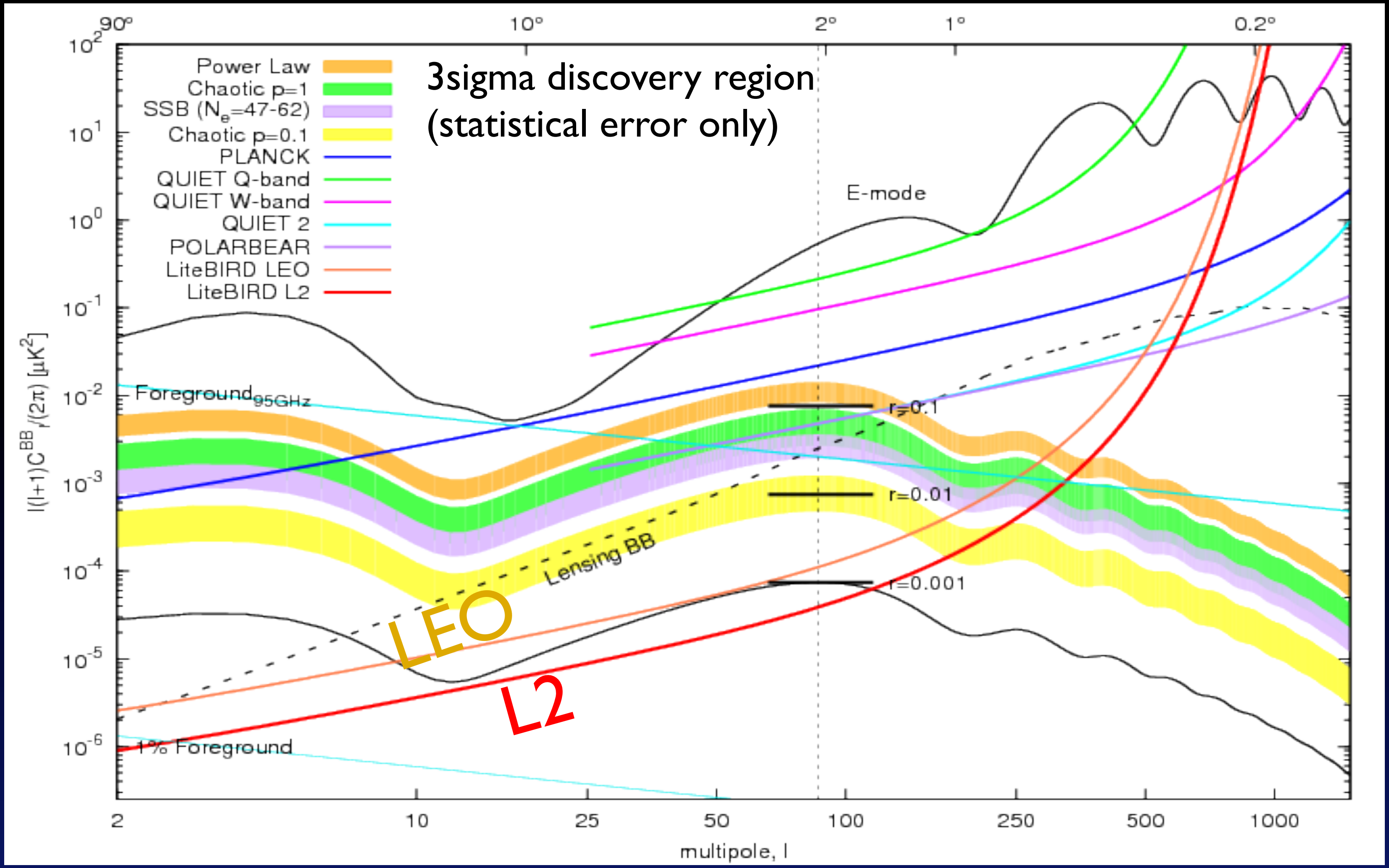


Electrical noise measurement
M. Naruse et al. 2012

Expected sensitivity on r



L2 vs. LEO



Both cases satisfy the requirement on statistical error

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

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.
  - Detector development matching fund 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.

Contacts

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