LiteBIRD

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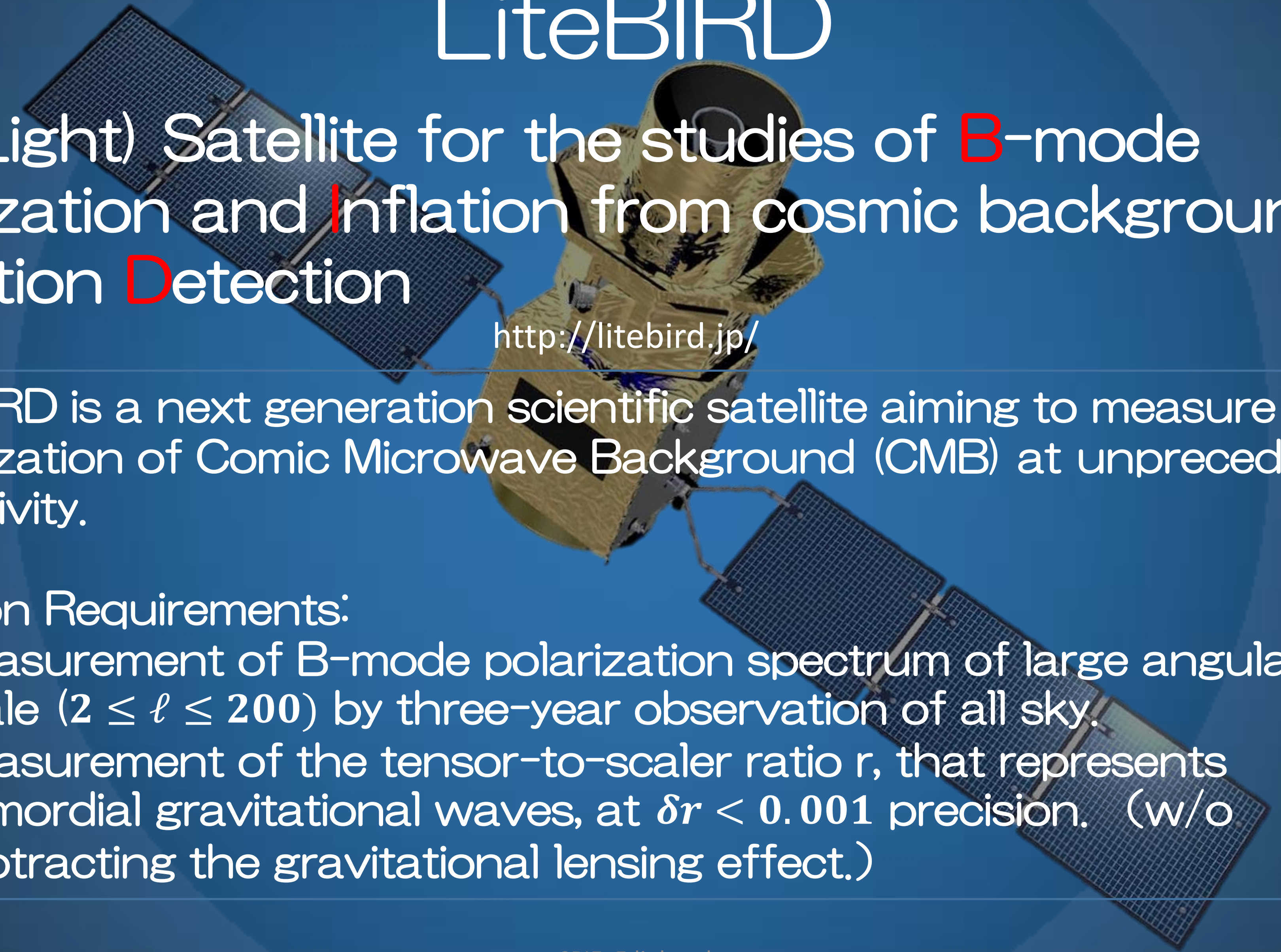
on behalf of the LiteBIRD WG

June 27, 2016

SPIE, Edinburgh

LiteBIRD



Lite (Light) Satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection

http://litebird.jp/

LiteBIRD is a next generation scientific satellite aiming to measure polarization of Comic Microwave Background (CMB) at unprecedented sensitivity.

Mission Requirements:

- Measurement of B-mode polarization spectrum of large angular scale ($2 \leq \ell \leq 200$) by three-year observation of all sky.
- Measurement of the tensor-to-scaler ratio r, that represents primordial gravitational waves, at $\delta r < 0.001$ precision. （w/o subtracting the gravitational lensing effect.）

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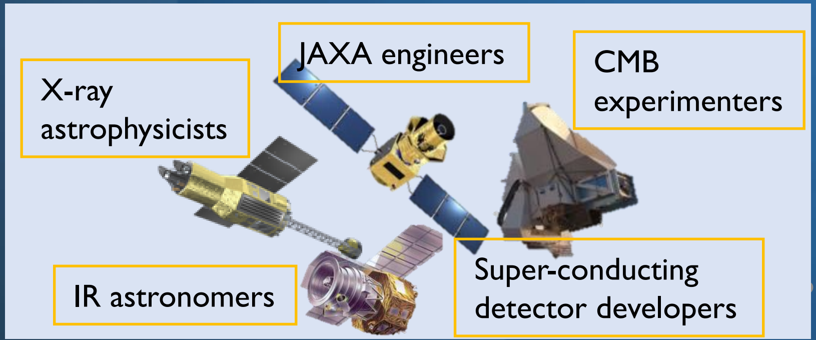
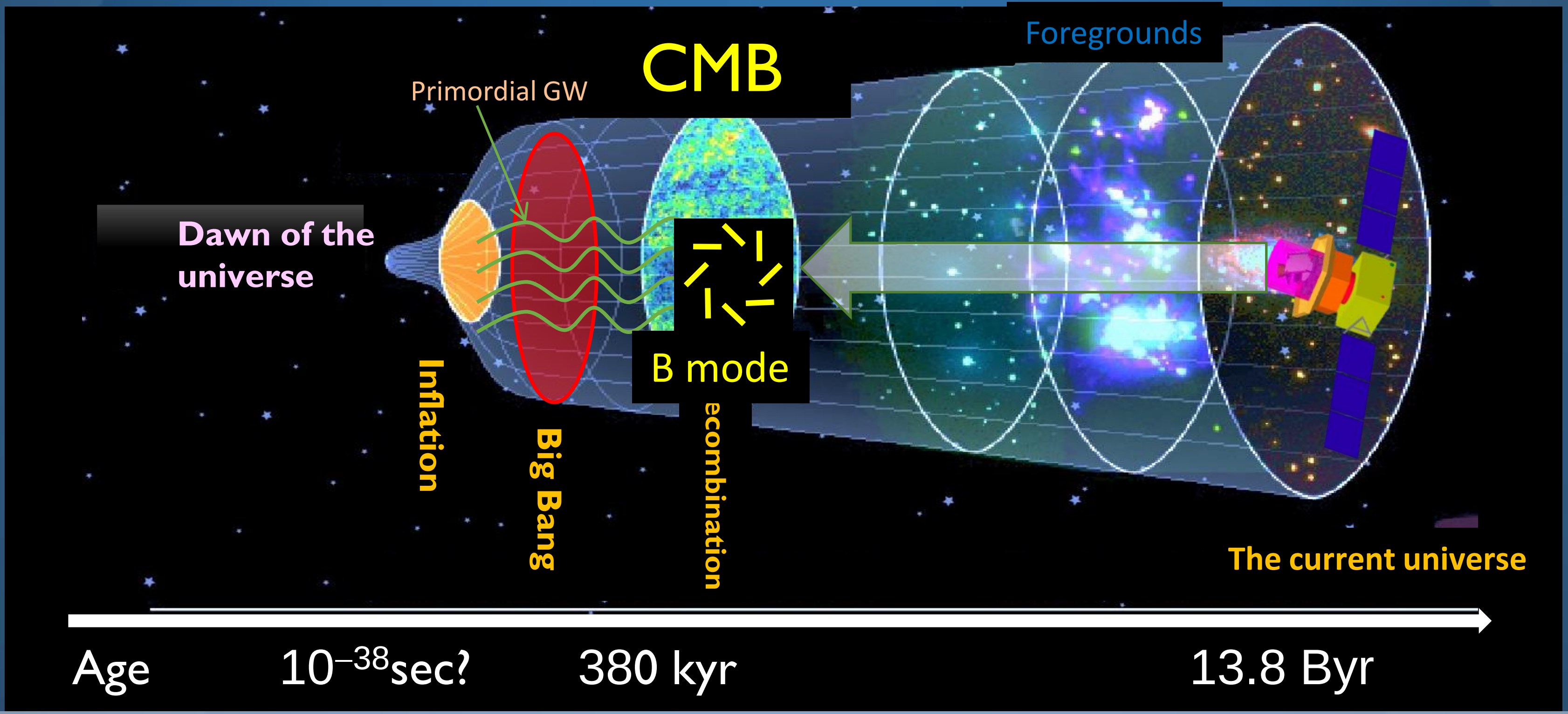
LiteBIRD working group



139 members, international and interdisciplinary (as of Jun 27, 2016) 3

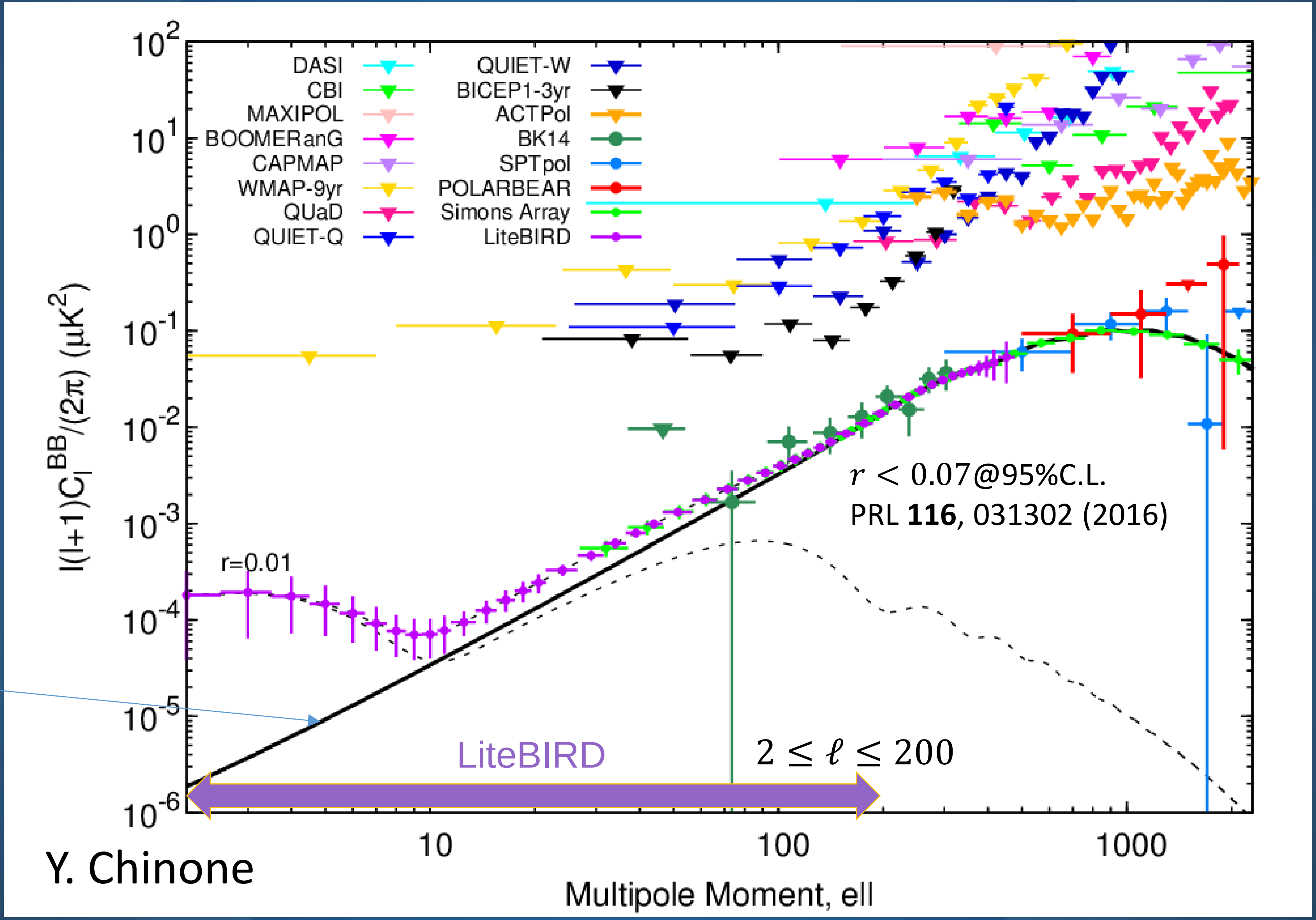
Goal： Verification of inflation using CMB

- Inflationary universe theory predicts generation of primordial gravitational waves.
- Primordial gravitational waves leave a large vortex-like patterns "inflation fingerprint" called B-mode on the CMB polarization map.
- LiteBIRD observes the CMB polarization by precisely scanning all sky in space.



LIGO observes classical gravitational waves.
CMB polarization targets "gravitational waves generated by quantum fluctuations in vacuum"

LiteBIRD Measurement Precision (at r=0.01）



B-mode spectrum due to gravitational lensing
~5 μK • arcmin

Why the $\delta r < 0.001$ goal?

- Many models predict $r>0.01$. → Discovery at $>10\sigma$.
- In case primordial gravitational waves are not seen:
  - Focus on models with less parameters (Occam's Razor)
  - Most single field slow-roll says

$$r \simeq 0.002 \left(\frac{60}{N}\right)^2 \left(\frac{\Delta\phi}{m_{pl}}\right)^2$$

Lyth relation

N: e-folding, m_{pl}: reduced Planck mass

  - If LiteBIRD achieves $r < 0.002$ (95%C.L.), those that satisfy $\Delta\phi > m_{pl}$ in the typical inflation models are rejected.
    - Important milestone in the goal to identify the correct models.
    - Possible to obtain similar results in more model-dependent analyses.

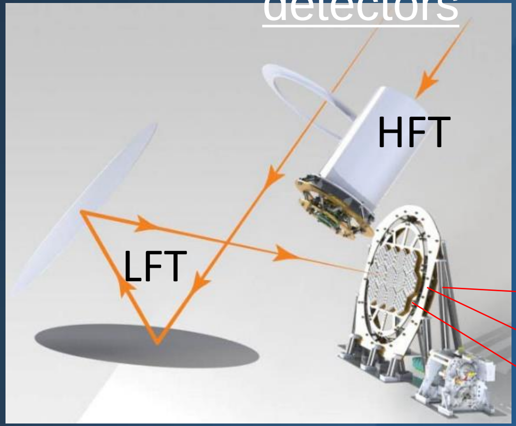
Achieving the Mission Requirements:

- All-sky survey in space
  - Observation at a large angular scale
  - No effects by atmosphere
- Statistical errors
  - Conduct three years of all-sky observation with 2,622 superconducting sensors, and achieve 2.5 μK・arcmin.
- Foreground removal
  - Observation of 15 bands between 40～400GHz
- Systematic errors
  - Mitigation with a Half Wave Plate (HWP)

Observation Apparatus Overview

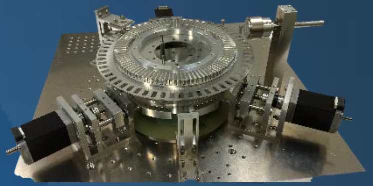
- Mission module benefits from heritages of other missions (e.g. Hitomi) and ground-based experiments (e.g. POLARBEAR).
- Bus module based on high TRL components

Multi-chroic focal plane detectors

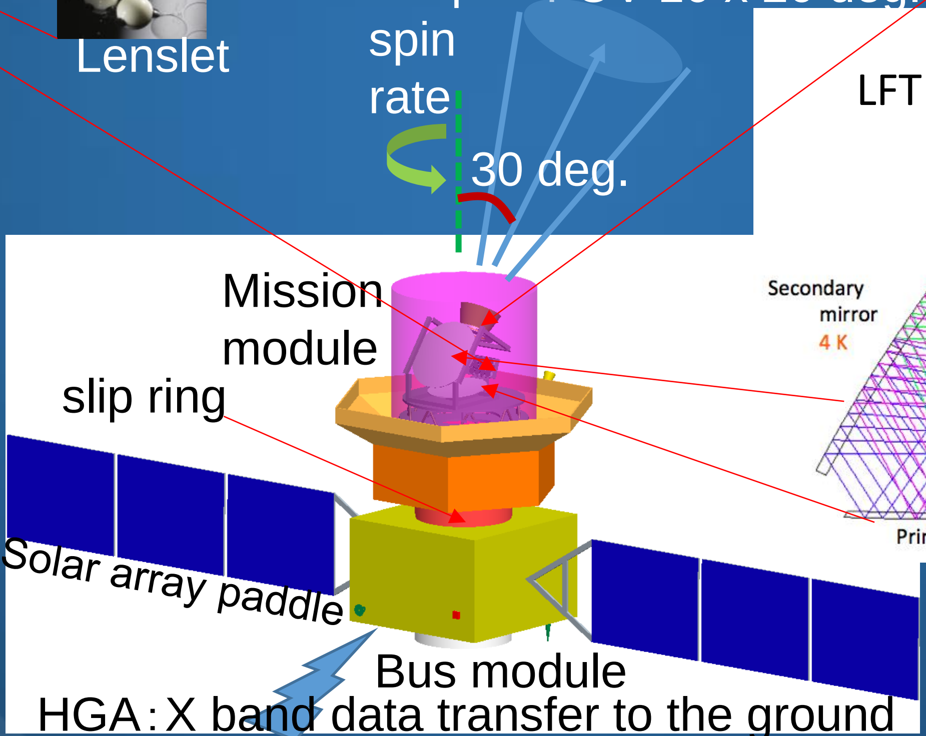


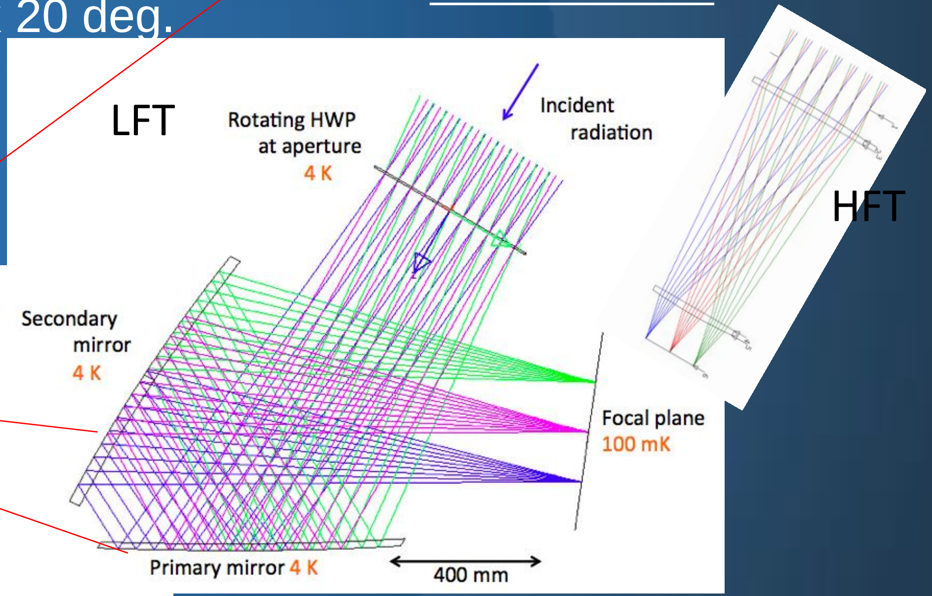
Lenslet

TES



Continuously-rotating half wave plate (HWPs) for LFT and HFT



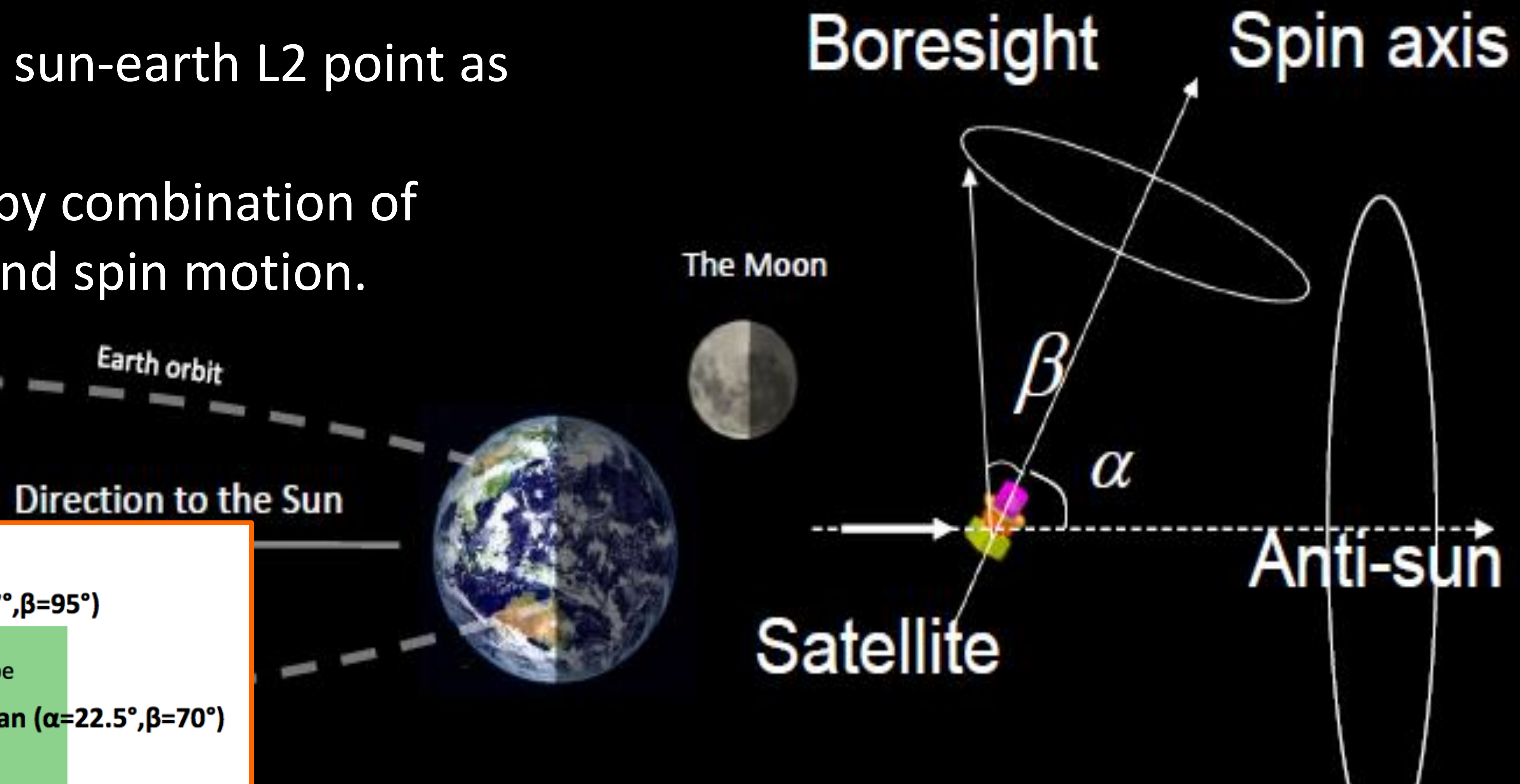


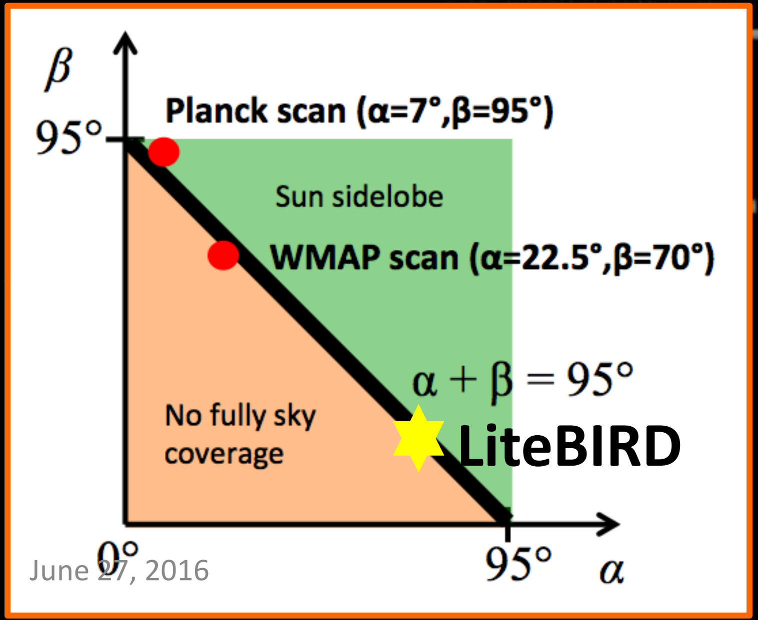
Mirrors at 4K

Cryogenics

- JT/ST and ADR

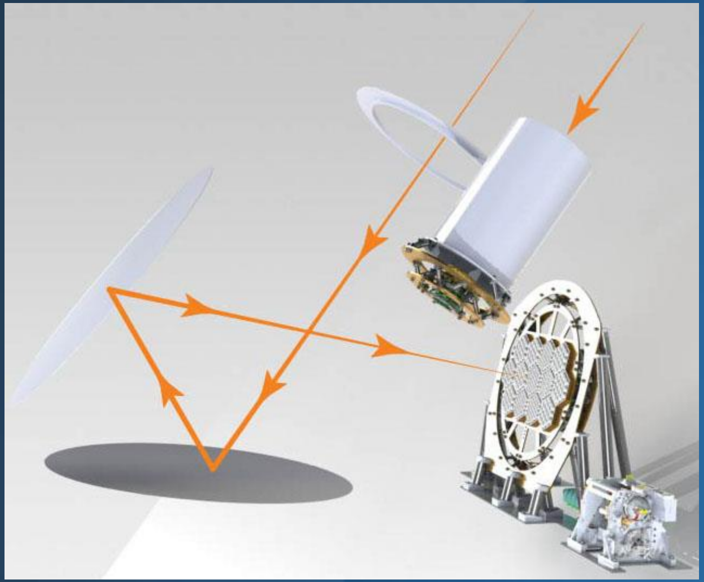
- Halo orbit at sun-earth L2 point as our baseline
- All-sky scan by combination of precession and spin motion.

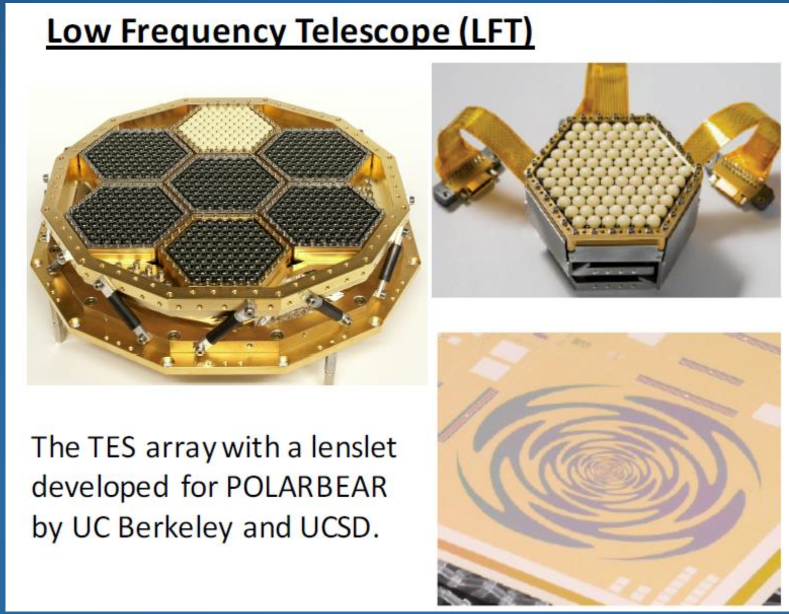


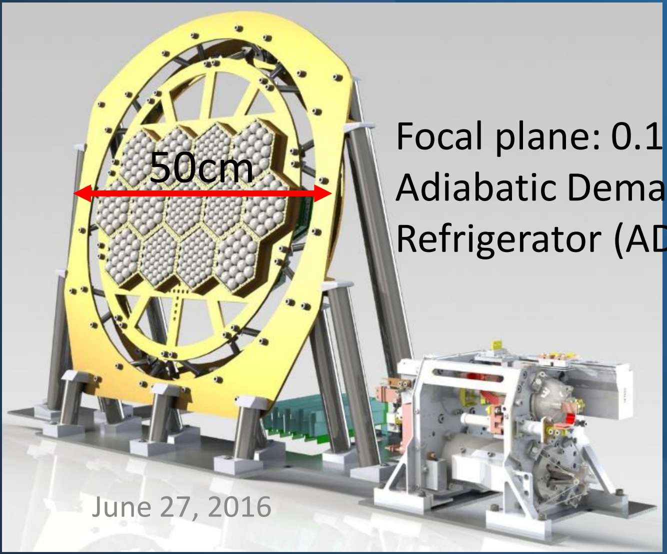


Precession angle α=65 deg.   90 min.~1day/1 rotation
Spin angle β=30 deg. ~10 min./1 rotation

Detector (Transition Edge Sensor, TES)







Focal plane: 0.1K provided by Adiabatic Demagnetization Refrigerator (ADR)

2622 TES bolometers cover 15 bands in the frequency range of 40 to 400 GHz.
Total sensitivity: 2.5 μK • arcmin with 3 years all sky observation with a margin factor of 1.7.

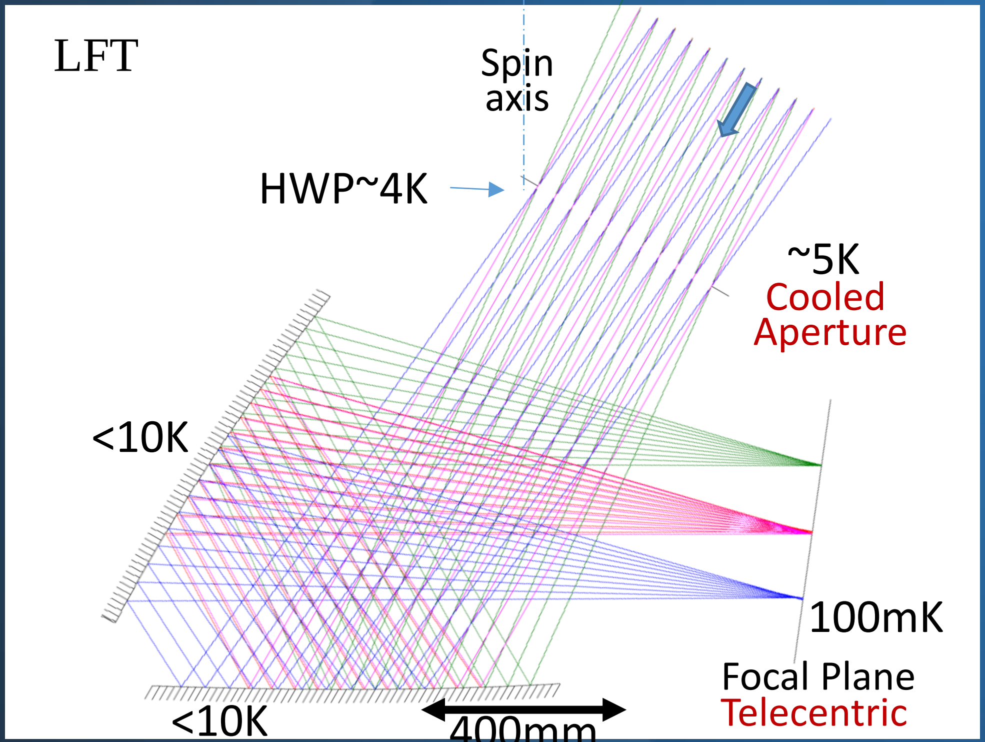
Optical System

H. Sugai et al.
Paper 9904-170

- Beam size : ~< 1 deg.
- FOV: 10 x 20 degs.
- Aperture Size: 40cm

- Cold Baffle and Mirrors
- Half-wave plate to modulate polarization
- Tele-centric

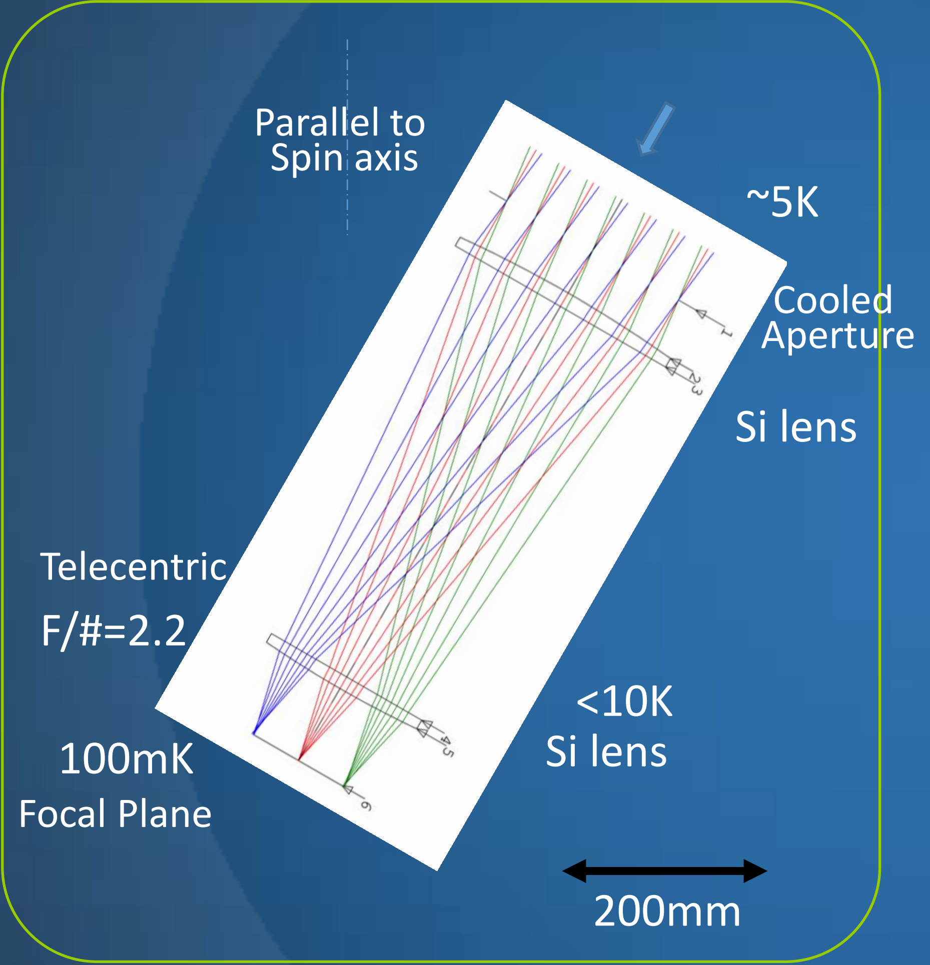
Crossed-Dragone Optical System



GRASP10 Simulation@60GHz, removing side-lobe w/ baffle

T. Matsumura, K. Kimura, N. Okada

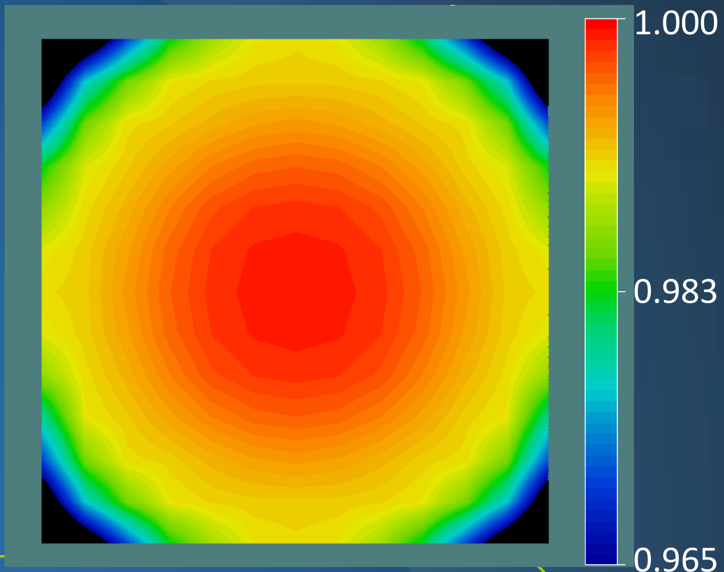
Design of high frequency telescope (HFT)



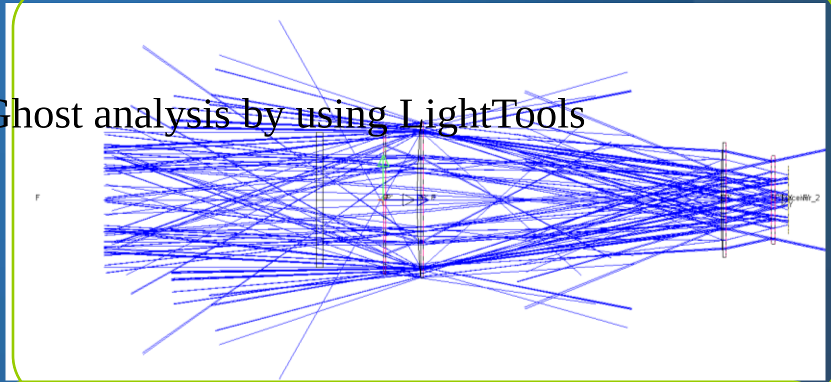
High Frequency (280-402GHz) telescope
Two plano-convex aspherical Si lenses (**φ<250mm**).

Cryogenically cooled entrance aperture to control sidelobe of feed.

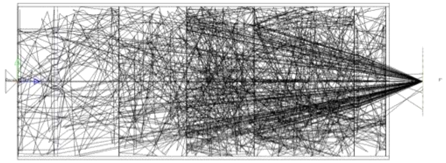
Strehl ratio @340GHz over **13x13deg^2**



Ghost analysis by using LightTools

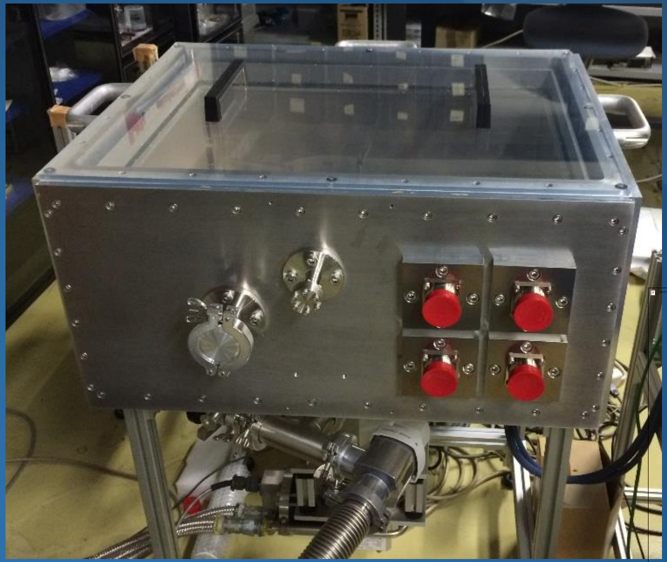


Stray Light analysis by using LightTools



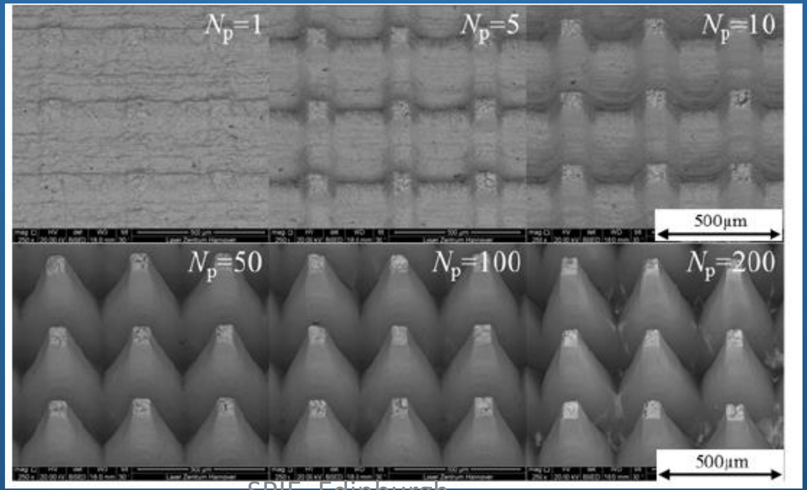
Continuous Rotating HWP

T. Matsumura et al.
Paper 9904-171



Test Cryostat

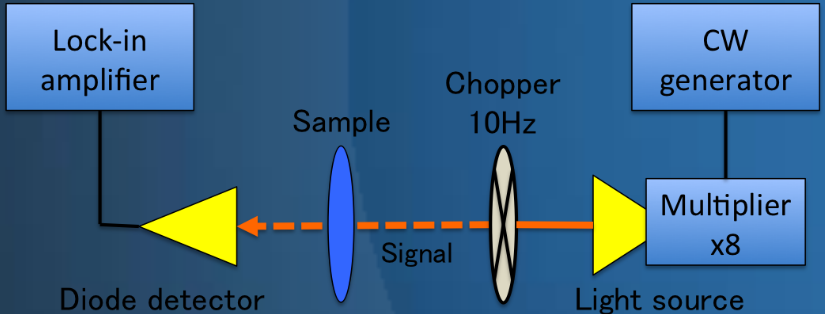
Anti-Reflection Coatings
for Sapphire Substrate



T. Matsumura et al., Appl. Opt. 55 (2016)3502

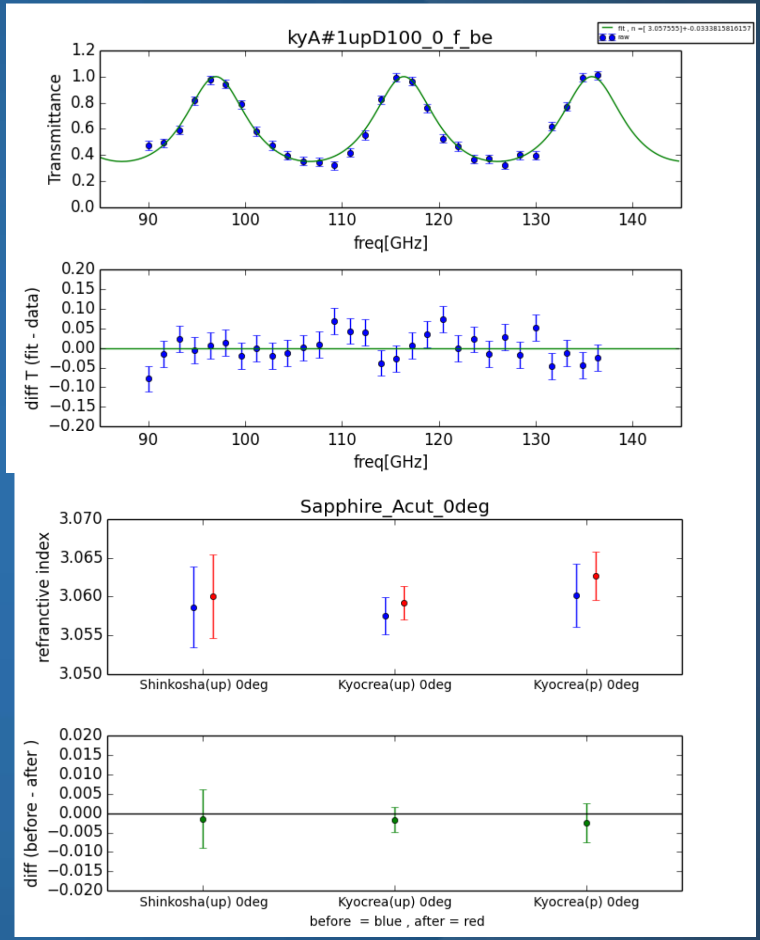
Proton Beam Irradiation Test

160MeV proton beam ~ 10krad irradiation @ NIRS



Millimeter wave transmittance measuring device @ ISAS

Example: Measurement of refractive index before and after irradiation on sapphire



Irradiation test done also for AR, superconducting detector, magnets, etc.

T. Matsumura, K. Komatsu, H.I, et al.

Frequency Dependence of the Foregrounds

Foreground Radiation Model（Planck Sky Model）

Synchrotron Radiation

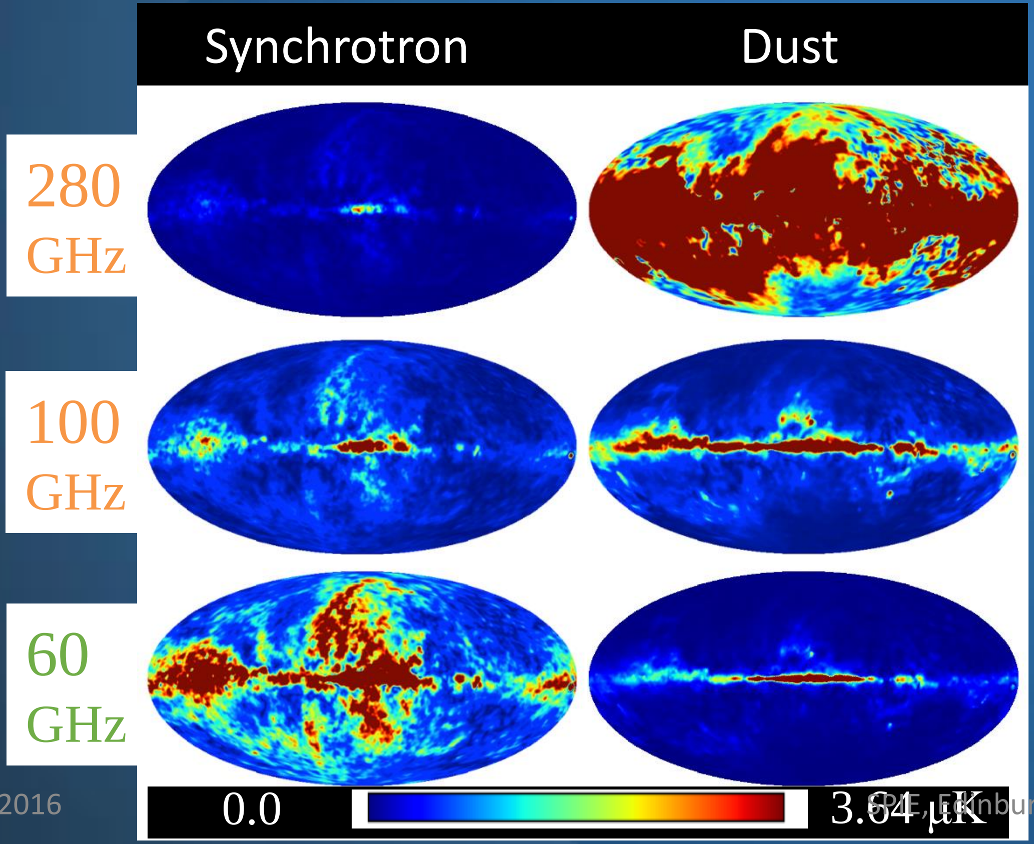
$$S(\nu, \hat{\boldsymbol{n}}) = \left(\frac{\nu}{\nu_*}\right)^{\beta_S(\hat{\boldsymbol{n}})} S(\nu_*, \hat{\boldsymbol{n}})$$

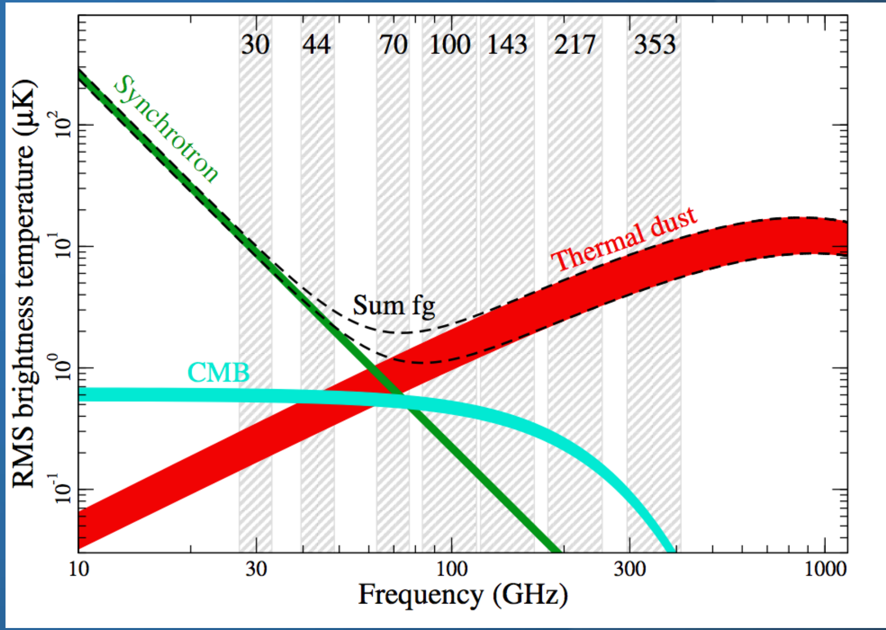
Dust Radiation

$$D(\nu, \hat{\boldsymbol{n}}) = \left(\frac{\nu}{\nu_*}\right)^{\beta_D(\hat{\boldsymbol{n}})} D(\nu_*, \hat{\boldsymbol{n}})$$

$\beta(\hat{\boldsymbol{n}})$: Spectral Index

Parameter to indicate freq. dependency of foregrounds. （different value for each direction）



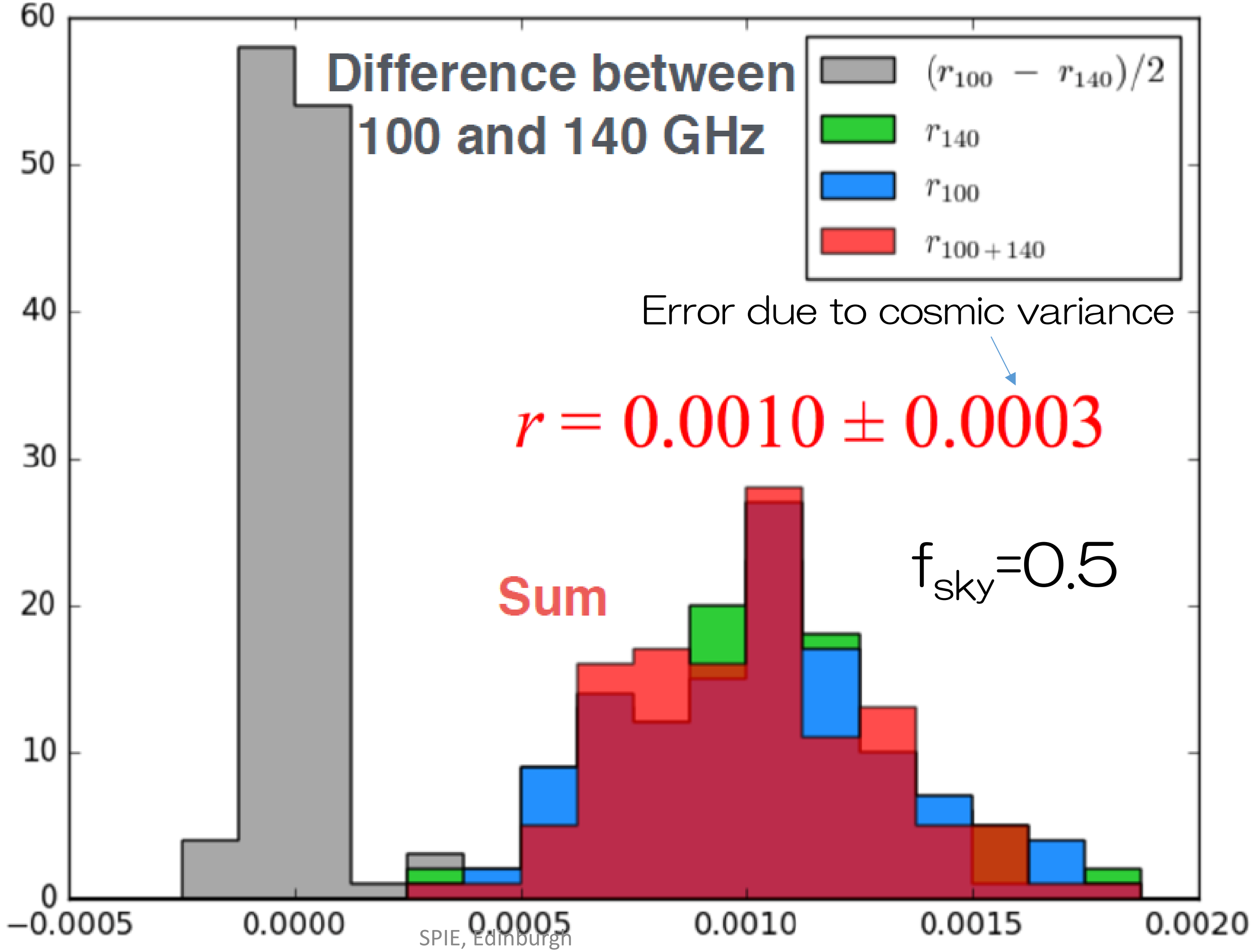


↑ Difference of freq. dependencies of foregrounds and CMB polarization strength.

Planck 2015 results. I.

Dust+Synchrotron Results

w/o Noise



T. Yamashita,
K. Ichiki,
N. Katayama,
E. Komatsu

Systematic uncertainties

- The HWPs modulate the polarization of incoming light
  - allowing us to use a single pol. sensitive detector to measure Q and U
  - mitigating the leakage from temperature to polarization and the 1/f noise
- Remaining systematics:
  - The leakage from E mode to B mode
    - Polarization angle of detector
    - Pointing knowledge
  - Other systematics
    - Side-lobe
    - Cosmic ray glitches
    - HWP
  - Simulation studies are bei
    determination of the spacecraft specification

		Requirements	Exp. Meas. Error
12	Pointing knowledge of bore-sight	< 3 arcmin	0.23 arcmin
13	Abs. pol. angle	< 1 arcmin	1 arcmin

- A candidate of JAXA's next strategic large missions, aiming to launch in 2024-2025.
- LiteBIRD selected as one of the top-priority projects in Master Plan 2014 by Science Council of Japan.
- LiteBIRD chosen as one of ten new projects in MEXT Roadmap 2014 for Large-scale Research Projects.
- Formal proposal submitted to the ISAS, JAXA in Feb., 2015. First evaluation is passed. Starting the conceptual design phase-A1 in FY2016.
- The US LiteBIRD team has submitted a proposal to NASA's missions of opportunity in Dec. 2014 to supply the focal plane detectors and a sub-Kelvin refrigerator system. It passed the first evaluation, and conceptual study (Phase A) is ongoing.
- Targeted launch date is in JFY 2024.

Summary

- LiteBIRD is a satellite designed to measure the gravitational wave strength at $\delta r<0.001$ by precisely observing the CMB B-mode polarization.
- It measures B-mode power spectrum in the range of $2 \leq \ell \leq 200$ at 2.5 μK • arcmin sensitivity by observing all-sky with 2622 superconducting detector sensors for three years.
  - Remove foreground radiation in observation frequency range of 40～400GHz with 15 bands.
  - Estimation of systematic errors/calibration accuracy using simulation and requirements of the satellite specifications currently under evaluation.