LiteBIRD

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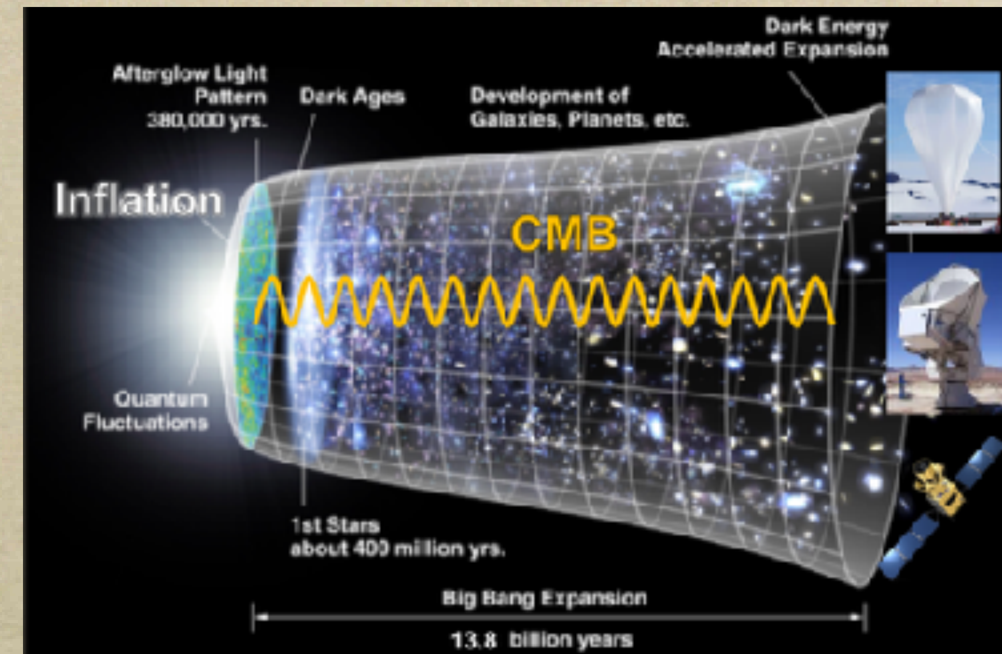
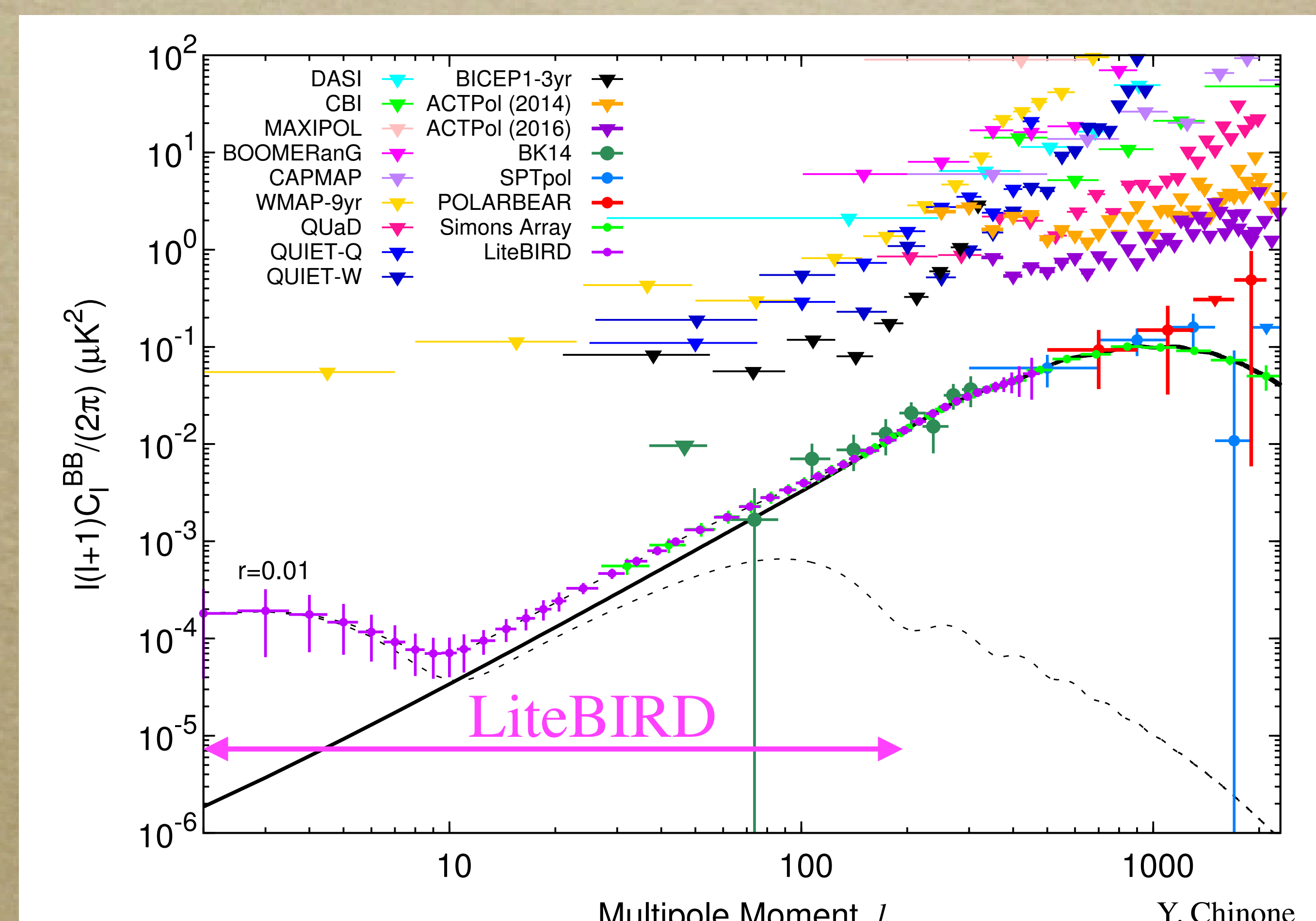
on behalf of the LiteBIRD Phase-A1 team

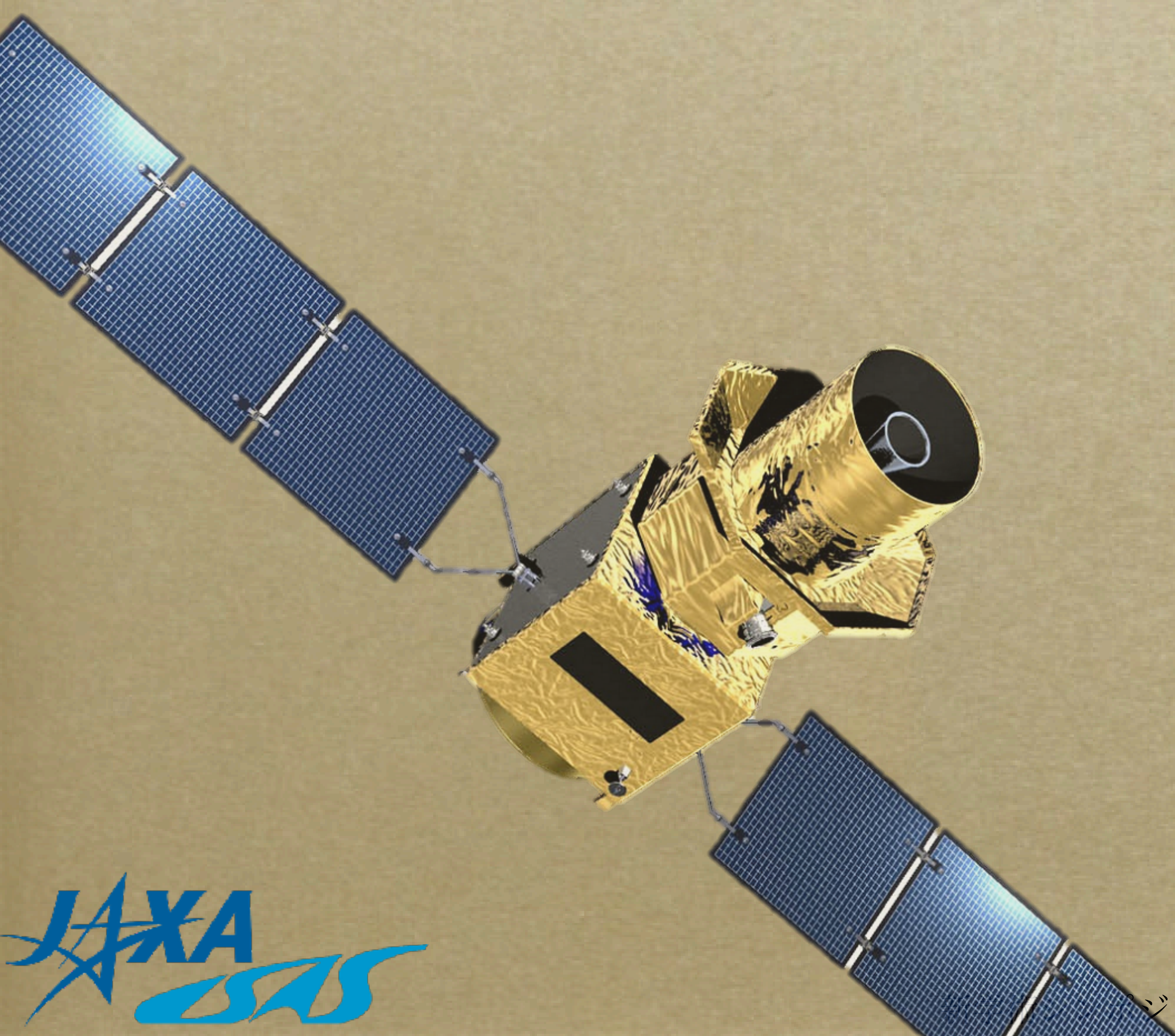
新学術シンポジウム, 10-12 Feb. 2018

LiteBIRD

LiteBIRD is a next generation CMB polarization satellite dedicated to probe the inflationary B-mode. The science goal is to measure the tensor-to-scalar ratio with the uncertainty of $\sigma(r) < 0.001$.







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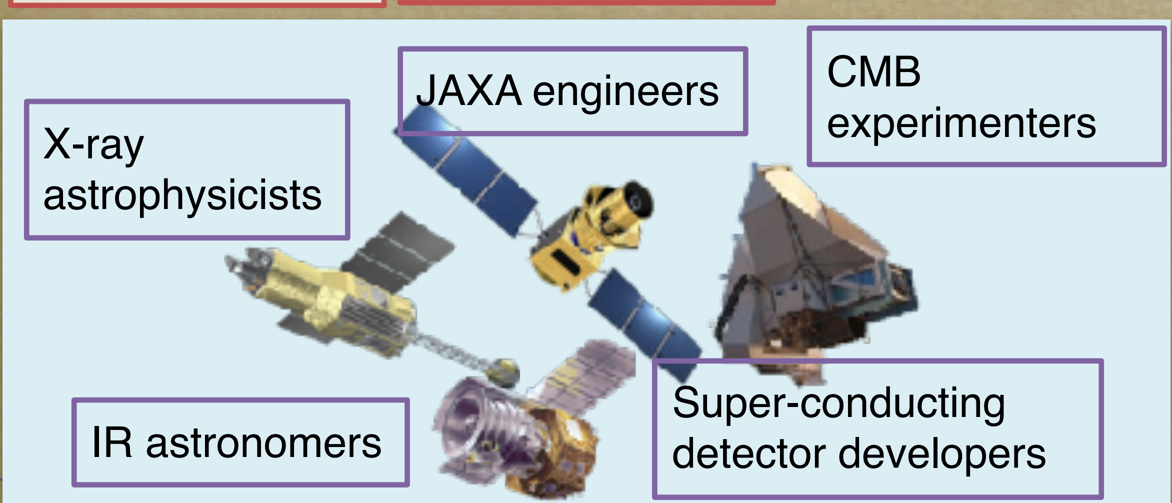
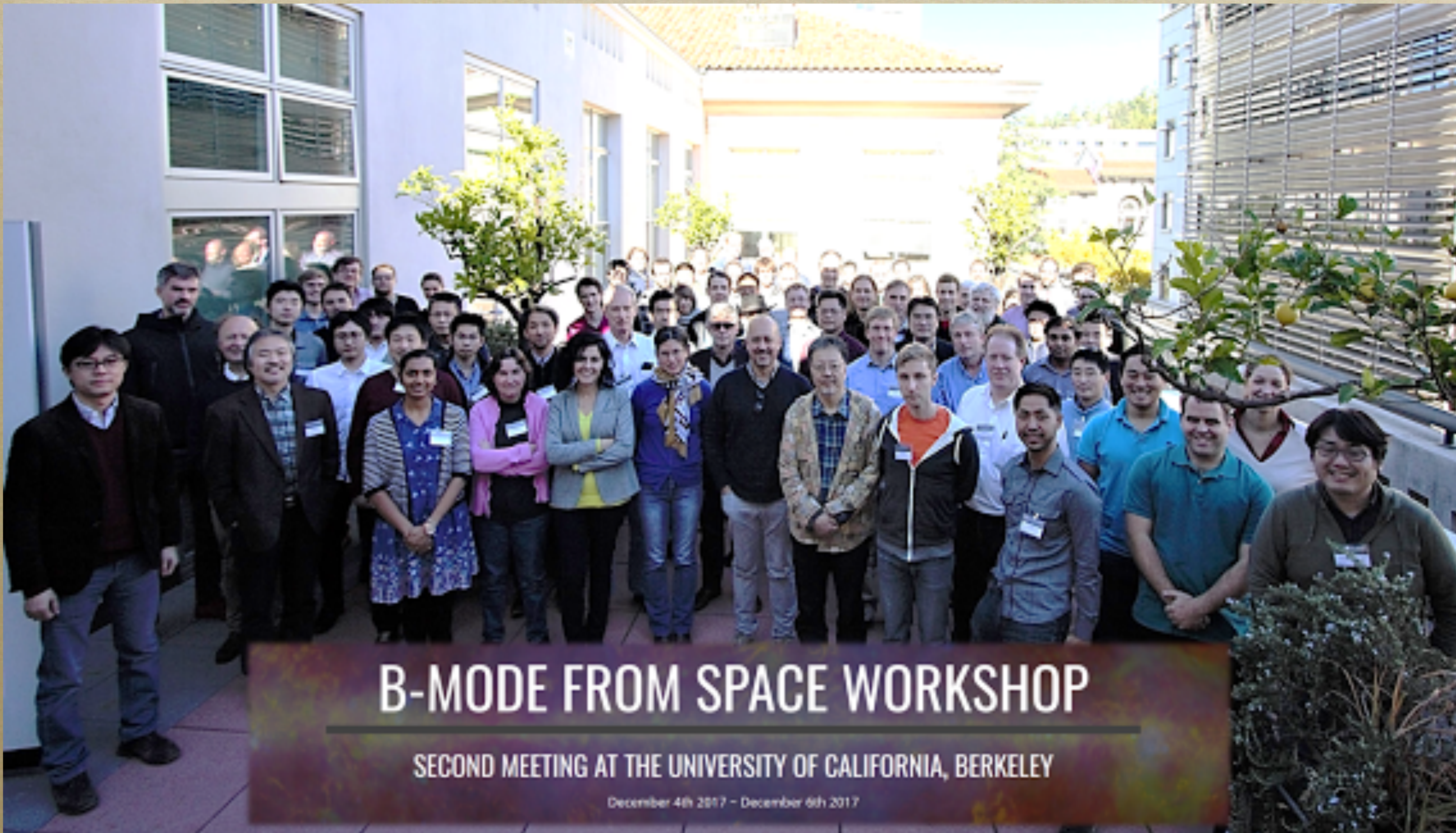


153 members, international and interdisciplinary (as of July 18, 2017)

Workshop & collaborator meeting



Full success of LiteBIRD

$\sigma(r) < 0.001$ for $r = 0$
All survey (for $2 \leq ell \leq 200$)*

- $\sigma(r)$ is the total uncertainty on the r measurement
  - including statistics, systematics, foreground, lensing, observer bias**
- Simple well-motivated inflationary models (single-large-field slow-roll models) have a lower bound on r, as Yuji mentioned
  - $r > 0.002$ from Lyth relation $r = \frac{1}{N^2}\left(\frac{\Delta\Phi}{m_{pl}}\right)^2 \approx 2\cdot 10^{-3}\left(\frac{\Delta\Phi}{m_{pl}}\right)^2$
- The above should be without subtracting the gravitational lensing effect
- Many inflationary models predict $r > 0.01$
  - it should be discovered with $> 10\ \sigma$
- No gravitational wave detection with LiteBIRD
  - exclude well-motivated inflationary models (i.e. $r < 0.002$ @ 95% C.L.)

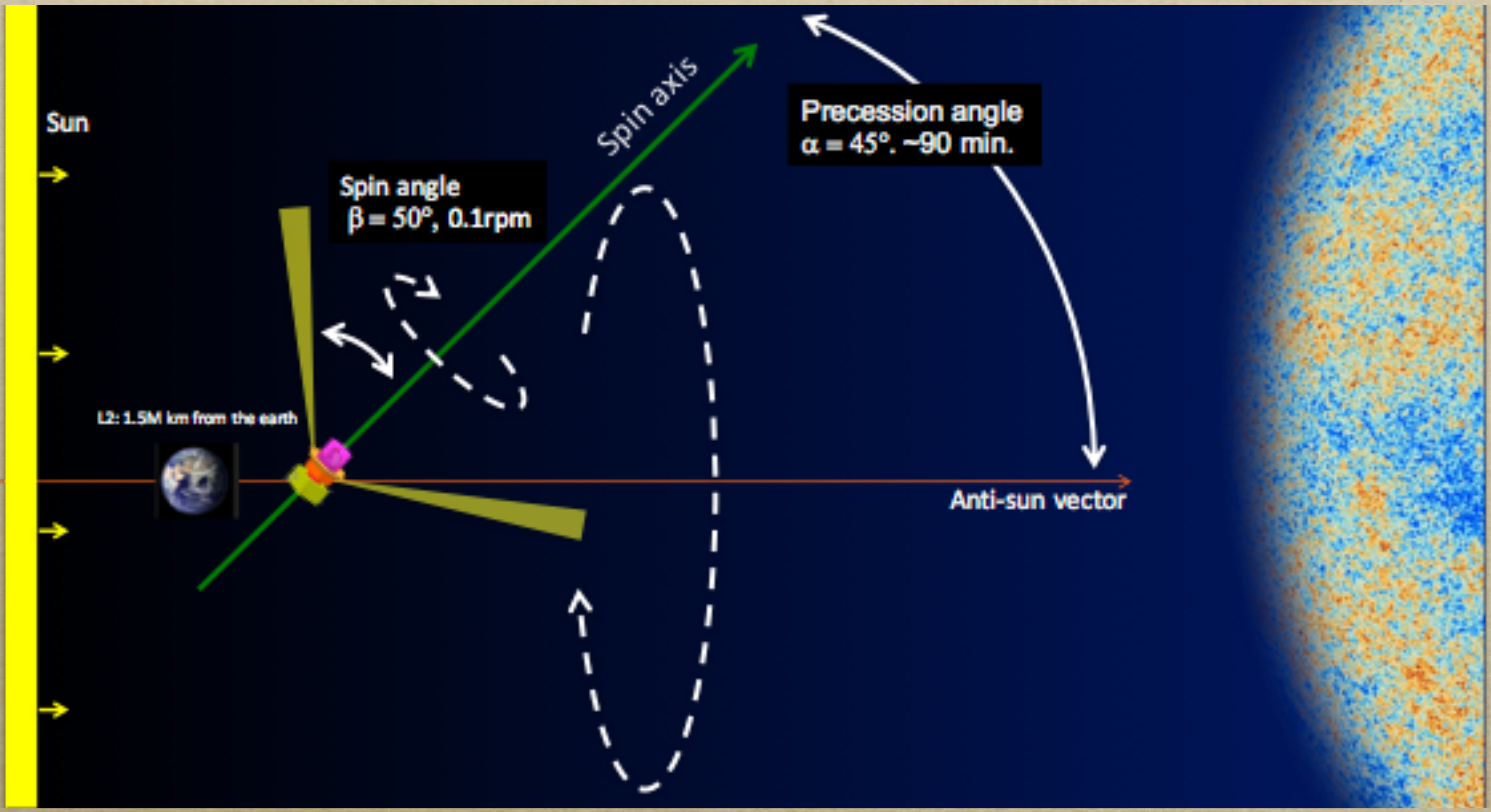
*More precise (i.e. long) definition ensures > 5σ r detection from each bump for r > 0.01
**We also use an expression δr = σ(r=0), which has no cosmic variance

Mission status

- LiteBIRD is one of the serious candidates for the Strategic L-class slot in middle of 2020s (the other is Solar-Power-Sail Trojan mission)
- Phase-A1 studies within ISAS/JAXA program started in September 2016 and will continue to August 2018 (2 years). Down selection for the L-class slot is then expected after Phase-A1.
- JAXA prefers focused missions for strategic large mission program
  - LiteBIRD is exactly a focused mission
- JAXA roadmap
  - Probing inflation from B-mode listed as one of top scientific objectives
- MEXT roadmap 2017 (August 2017)
  - proposed by Japanese Radio Astronomy community
  - endorsed by Japanese HEP community
  - LiteBIRD has been selected as one of 7 new large-scale projects

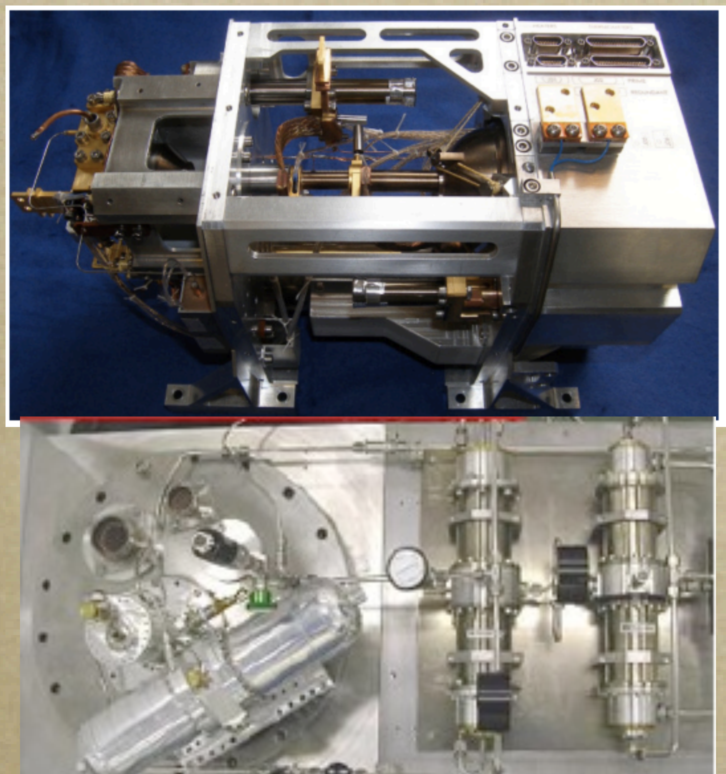
LiteBIRD is endorsed well

Observation strategy



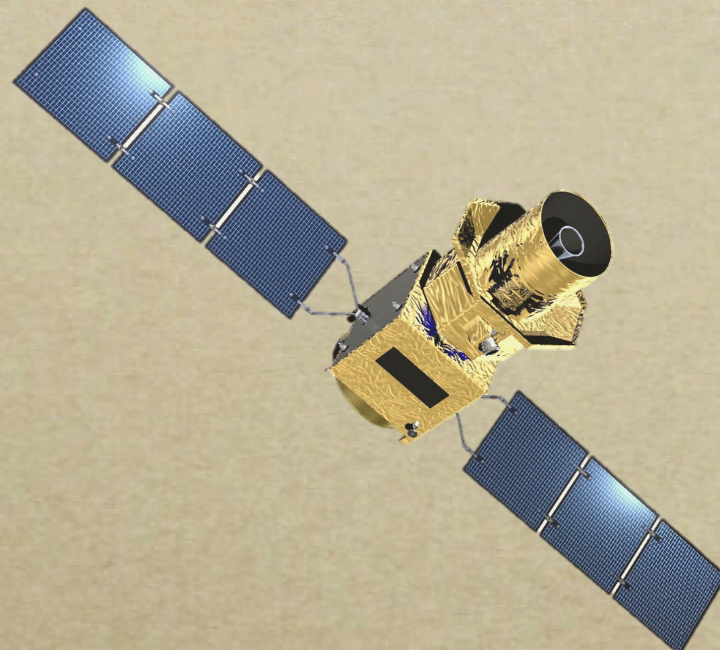
- Launch vehicle: JAXA H3
- Observation location: 2nd Lagrangian point
- Scan strategy: precession and spin, full sky
- Observation duration: 3 years
- Proposed launch date: Mid 2020's

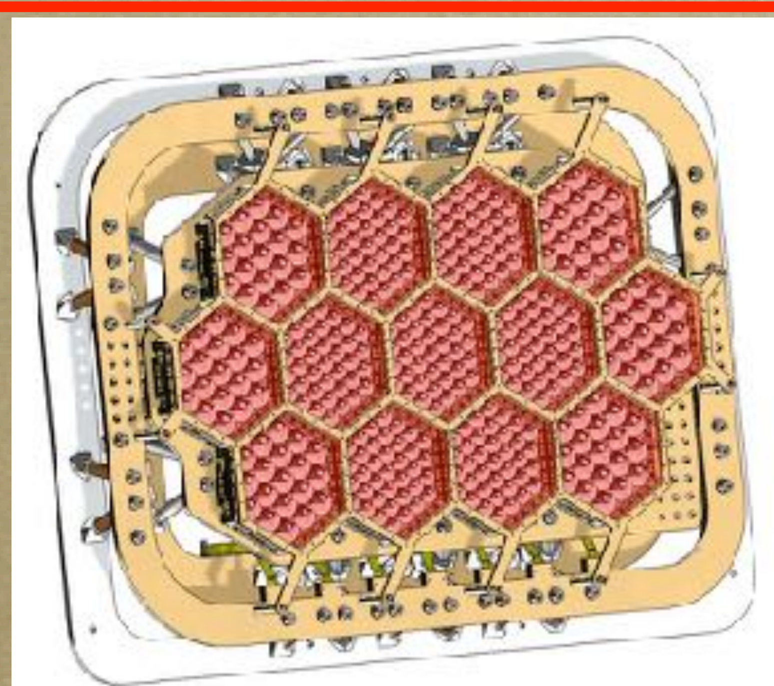
Mission system



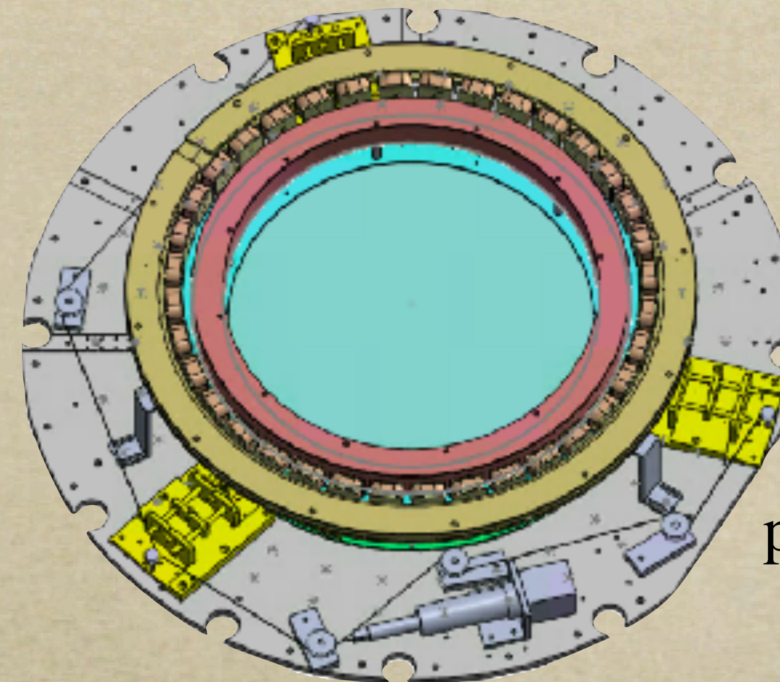
cryogenics

Yuto's talk

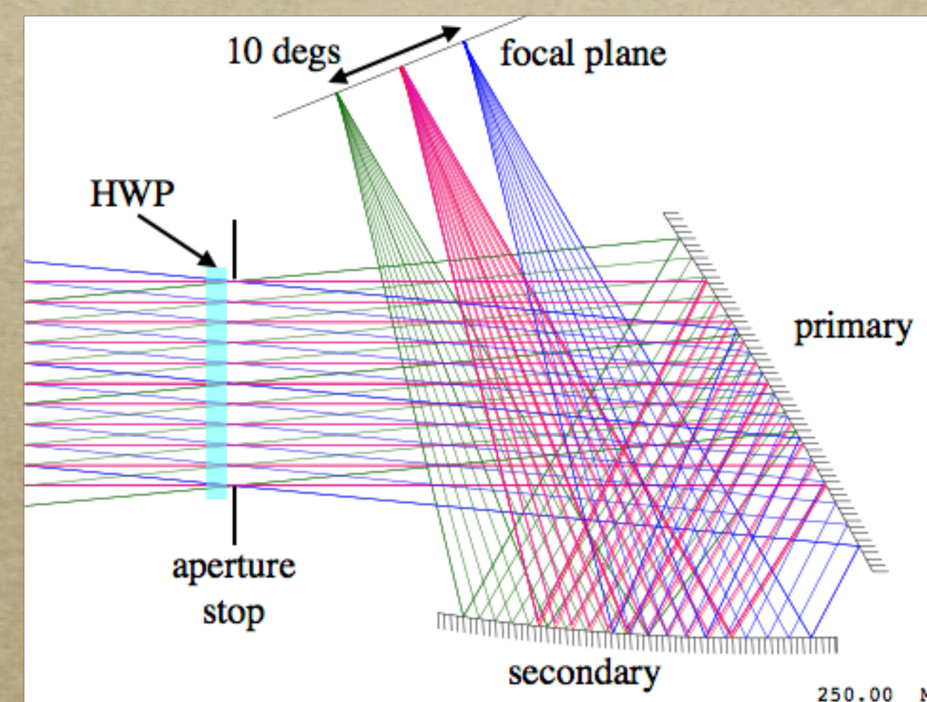




detector



polarization modulator (HWP)



two telescopes

my talk

Telescope requirements

- foreground removal requires a range of 34 - 448 GHz
  - Two telescopes are needed to cover the wide range of frequency
    - ➡ Low Frequency Telescope (LFT), High Frequency Telescope (HFT)
      - LiteBIRD European consortium is working on HFT
      - focusing on LFT in this presentation
- Requirements for LFT
  - frequency range: 34 - 270 GHz (subject to change)
  - size: 1.7 m x 1.0 m x 1.4 m
  - aperture: > 400 mm in diameter
  - temperature: < 10 K (telescope), < 4 K (stop), ~ 100 mK (focus)
  - detector: > 2000
  - FoV: > 20 x 10 deg^2
  - first element: a rotating half wave plate

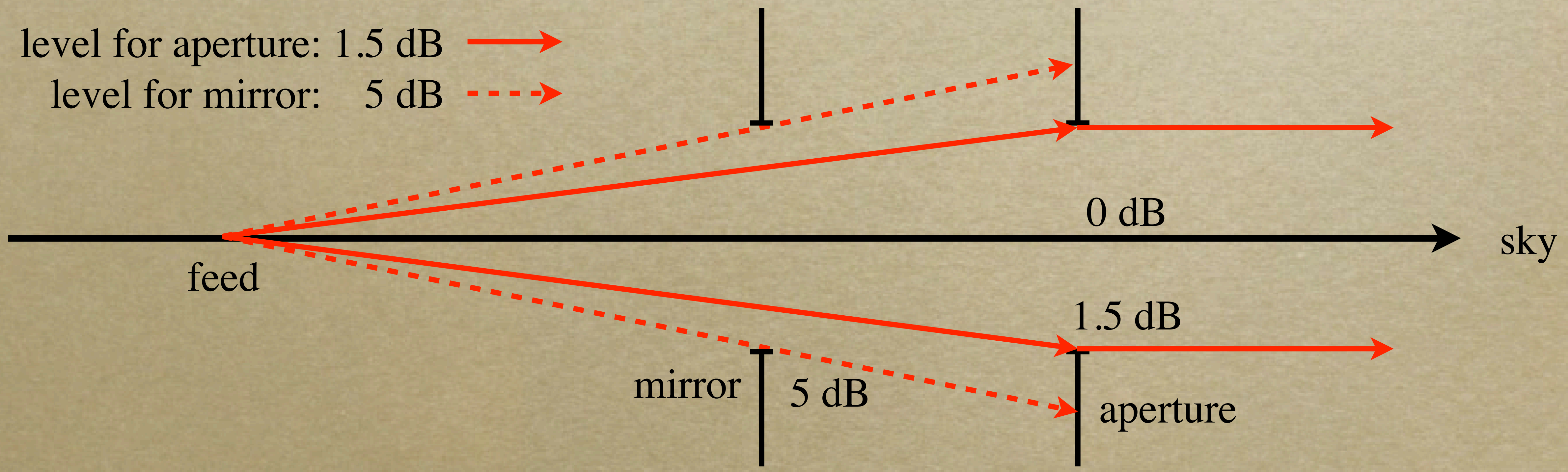
assuming the telescopes at 5 K, the stops at 2 K, 400-mm aperture for LFT, and 200mm for HFT

	center freq. (GHz)	fractional band width	number of detectors	sensitivity (μK-arcmin)	edge taper (dB)	beam size (arcmin)
LFT	40	0.30	152	53.4	1.5	67.3
	50	0.30	152	32.3	2.3	54.3
	60	0.23	152	25.1	3.4	45.8
	68	0.23	152	19.6	4.3	40.8
	78	0.23	152	[illegible]	5.7	36.1
	89	0.23	152	[illegible]	7.4	32.3
	100	0.23	222	15.6	4.1	27.7
	119	0.30	[illegible]	12.6	5.9	23.7
	140	0.30	[illegible]	8.3	8.1	20.7
	166	0.30	148	8.7	11.4	18.2
	195	[illegible]	222	6.7	15.8	16.3
	235	[illegible]	148	8.6	22.9	14.8
HFT	280	0.30	72	19.0	11.7	21.3
	337	0.30	108	21.9	11.8	17.9
	402	0.23	74	52.3	13.3	14.9
total			2276	3.2		

subject to change

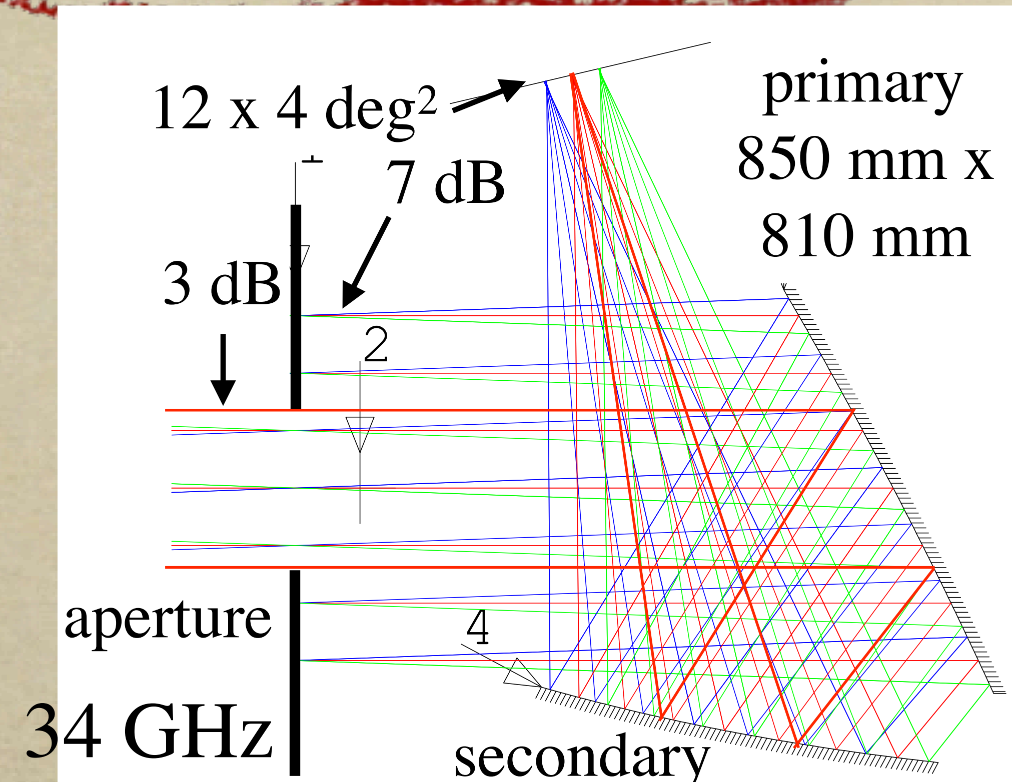
Factors to determine beam patterns

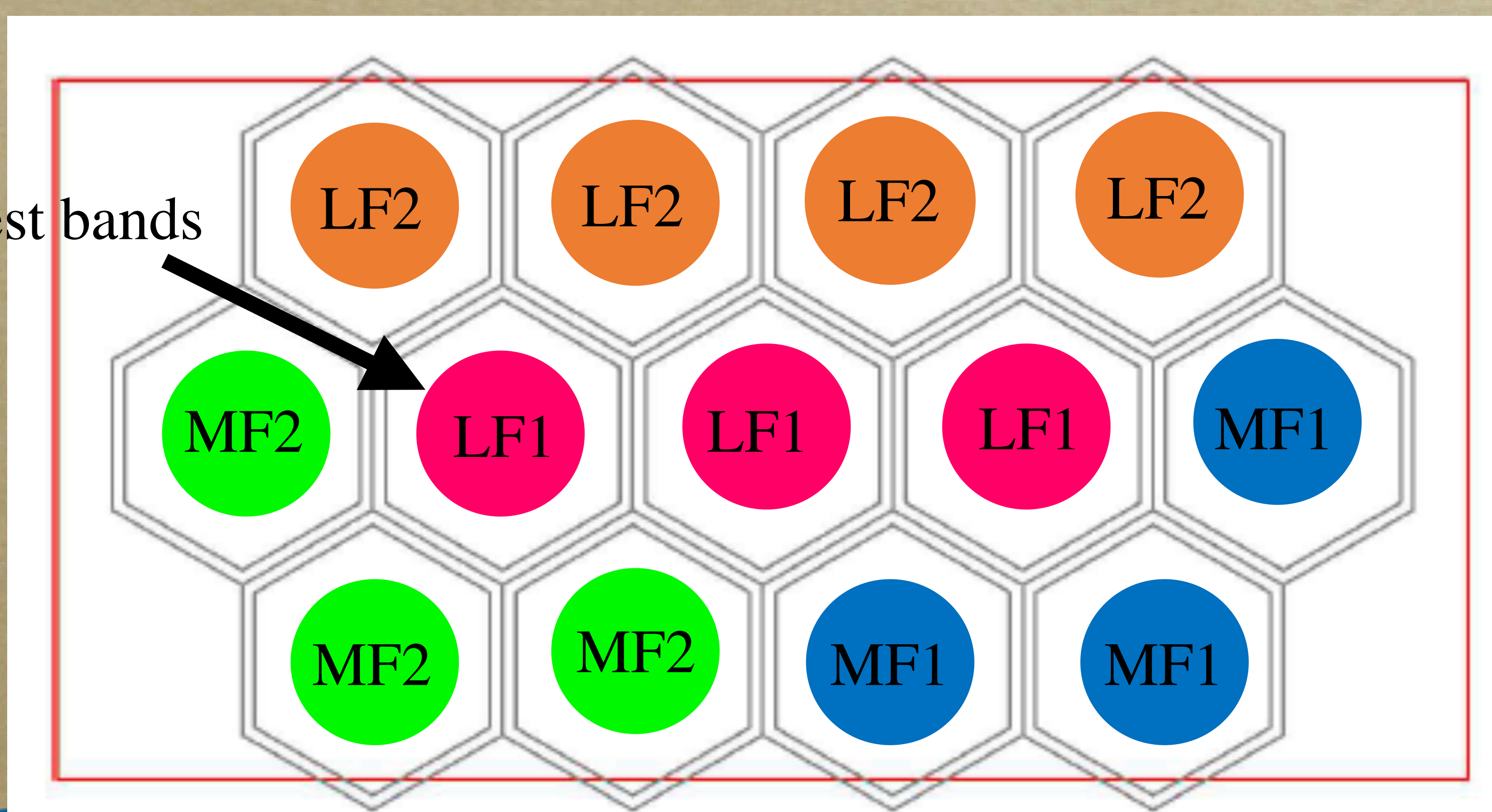
- ❖ Requirement of mirror size
  - serration at mirror edges is assumed
  - mirror size is set large in order that the beam intensity at edges is less than
    - ✓ 5 dB for the edge taper of 1.5 dB at aperture
    - ✓ 7 dB for the edge taper of 3 dB at aperture

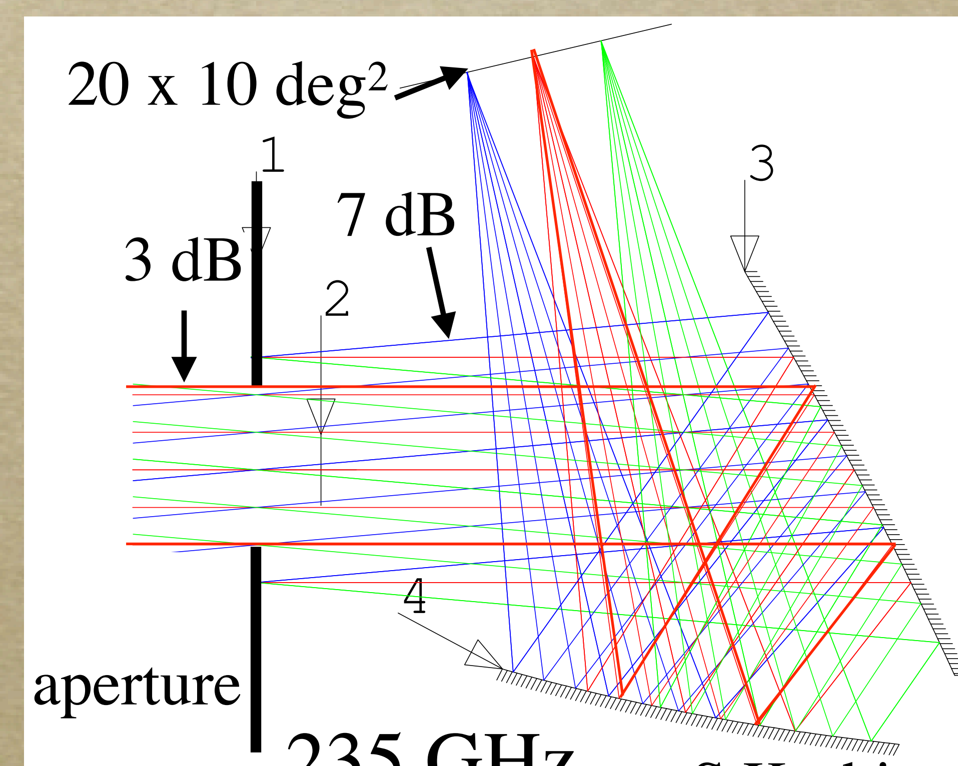


LiteBIRD LFT design study

❖ If the lens-let diameter is assumed to be 30 mm
- edge taper: 3.0 dB at 34 GHz
- mirror size:
  - ✓ ~ 800 mm x 800 mm (FoV of 12 x 4 deg^2)
  - ✓ sufficient for higher bands (20 x 10 deg^2)
- band arrangement



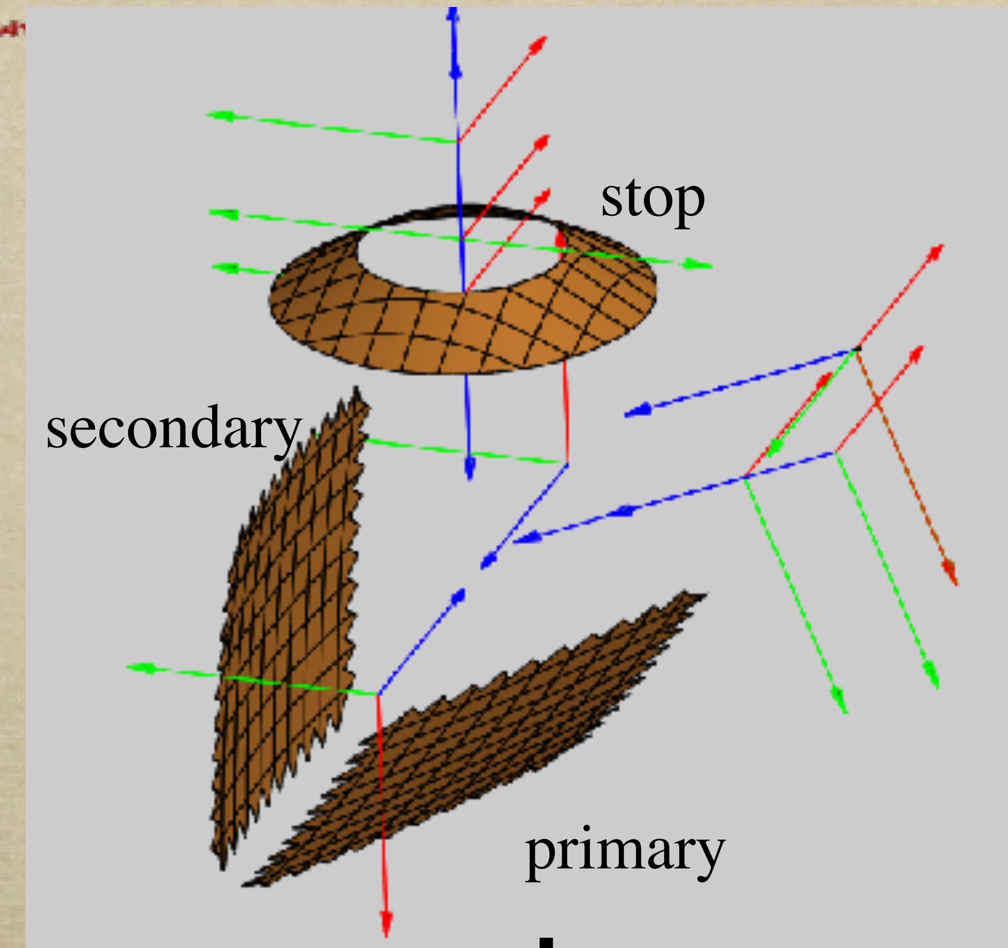


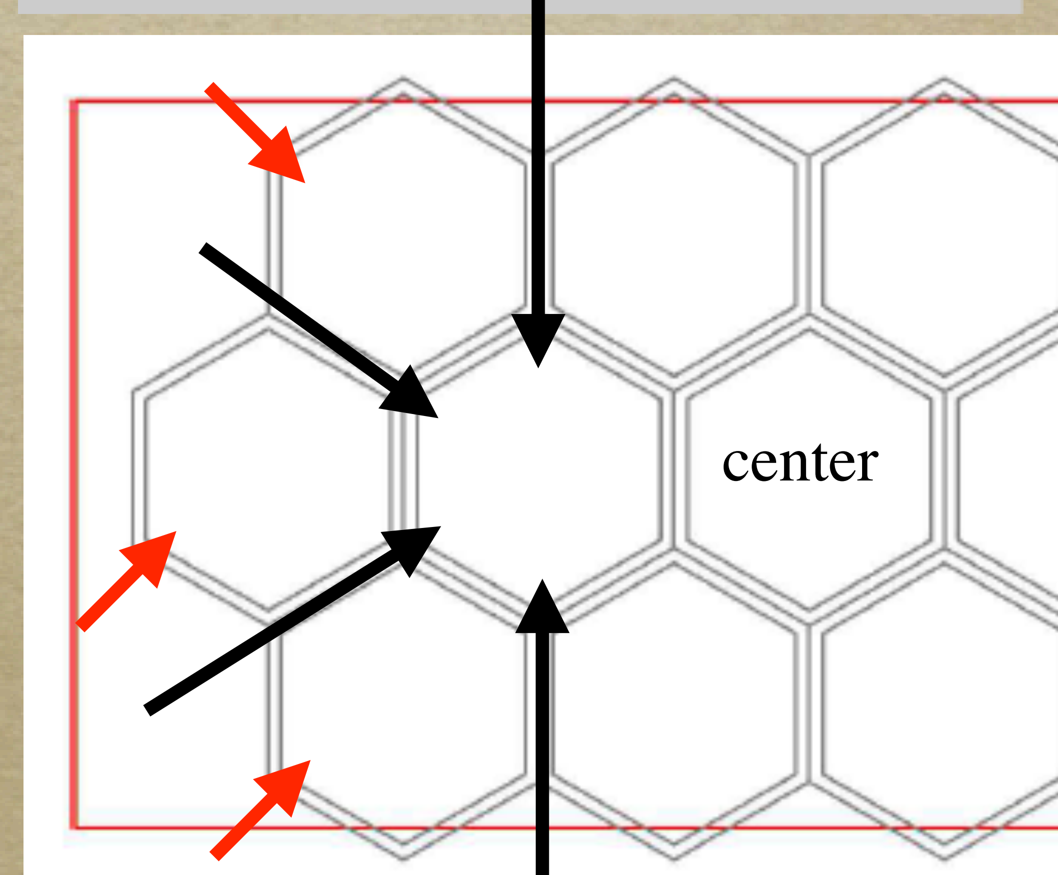


S.Kashima

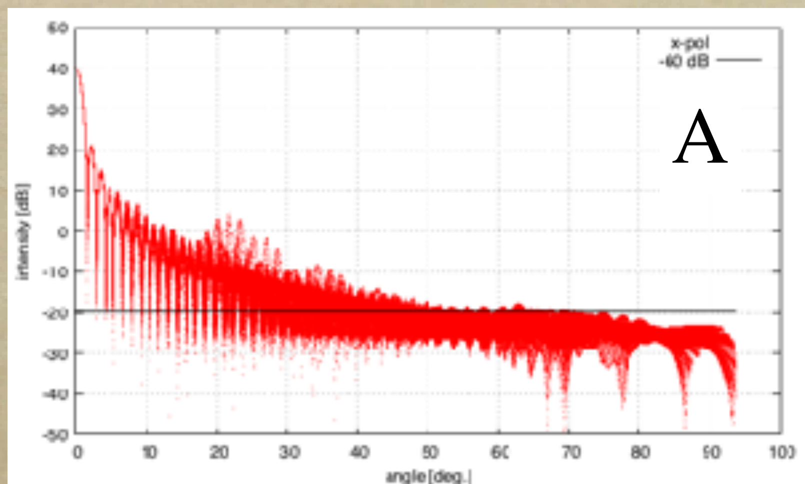
Beam patterns in the lowest bands

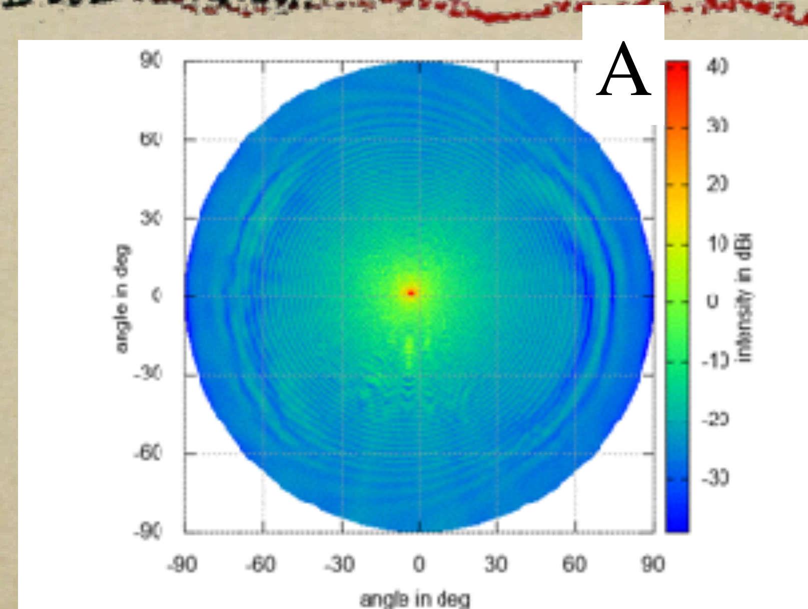
- ❖ Model
  - 400-mm aperture, F/3.5
  - three elements
    - ✓ two anamorphic aspherical mirrors w/ serration
    - ✓ a cold aperture stop
  - 34 and 42.5 GHz
  - elliptical Gaussian beam
    - ✓ corresponding to a 30-mm lens-let beam
    - ✓ 34 GHz at the black arrows
    - ✓ 42.5 GHz at the red arrows
- ❖ Stray light is included
  - up to triple bounces
    - ✓ e.g. feed -> secondary -> primary -> secondary -> aperture -> sky

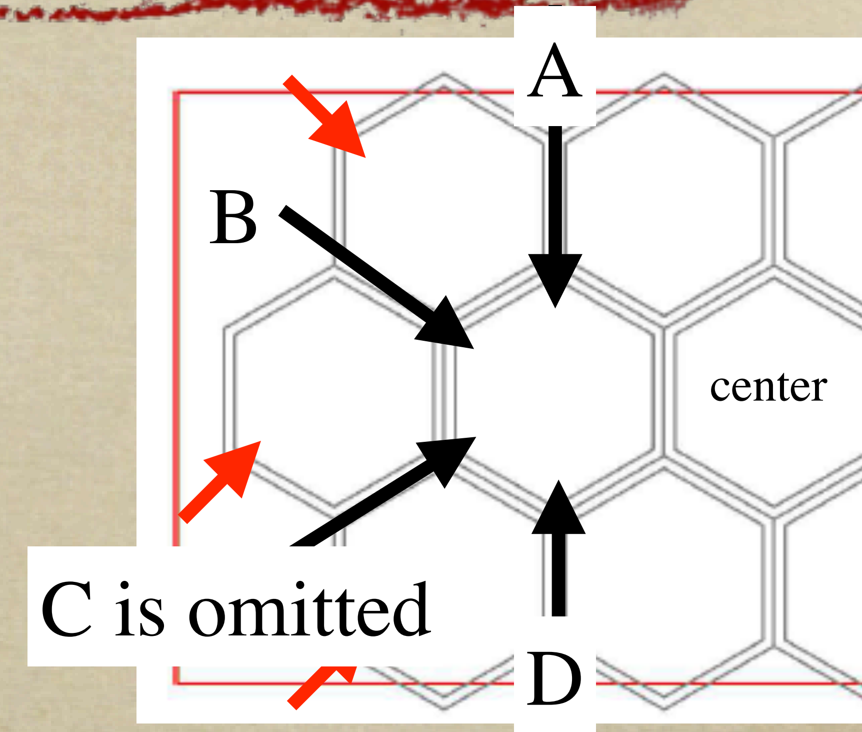


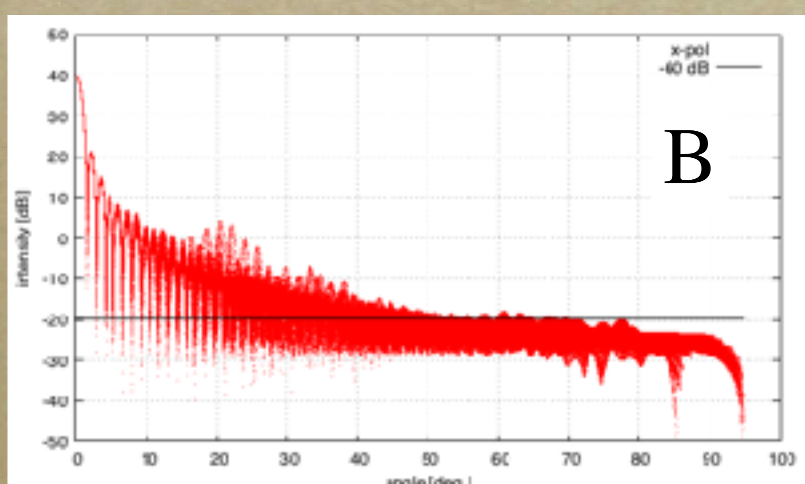


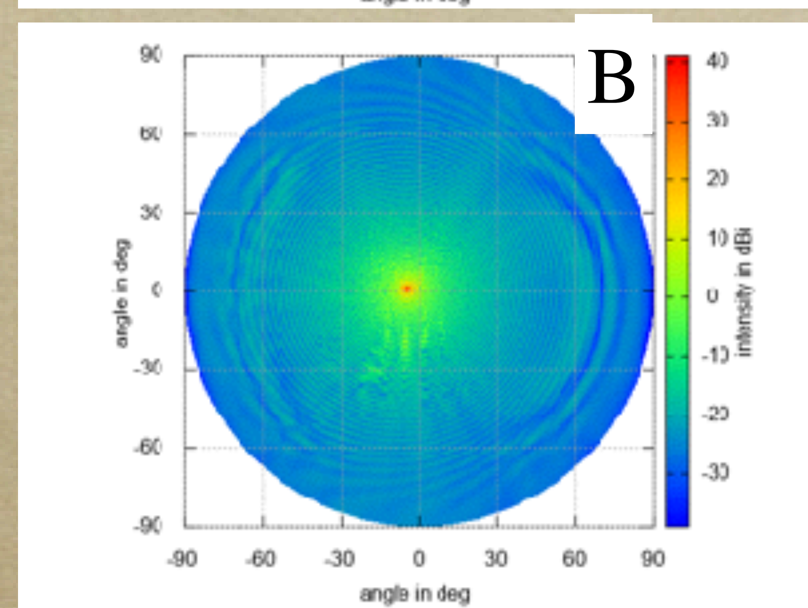
Beam patterns at 34 GHz

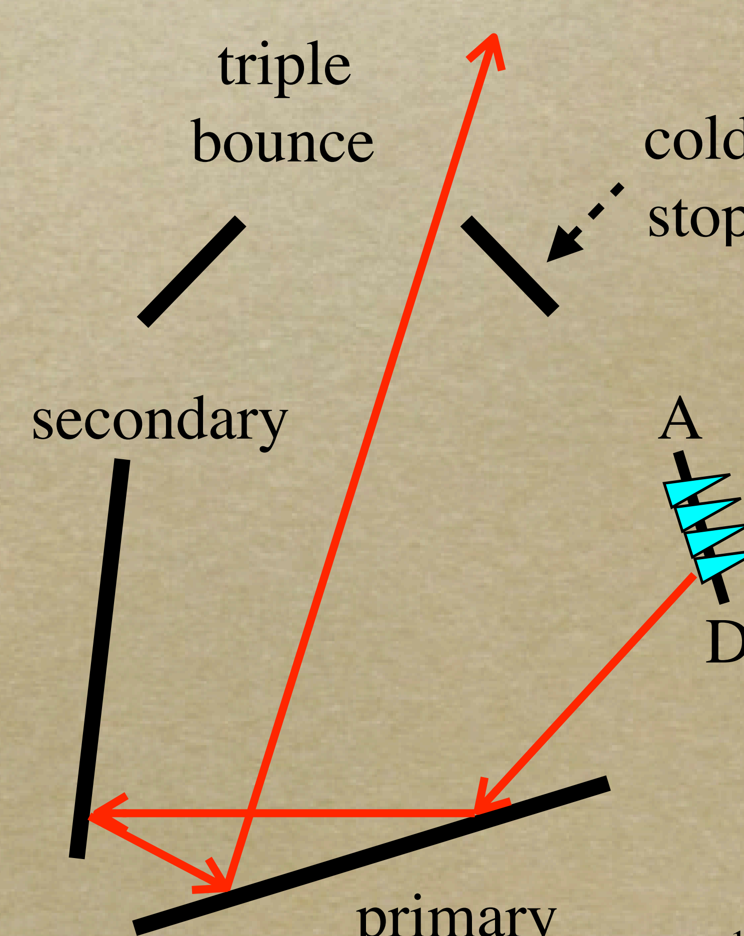


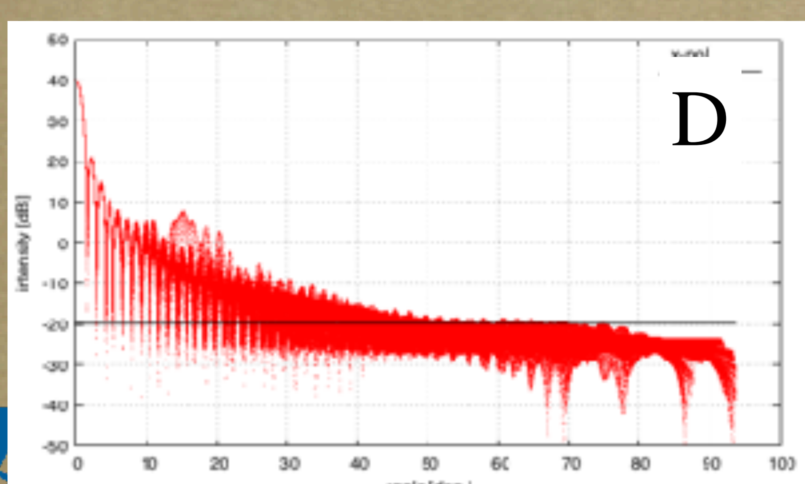


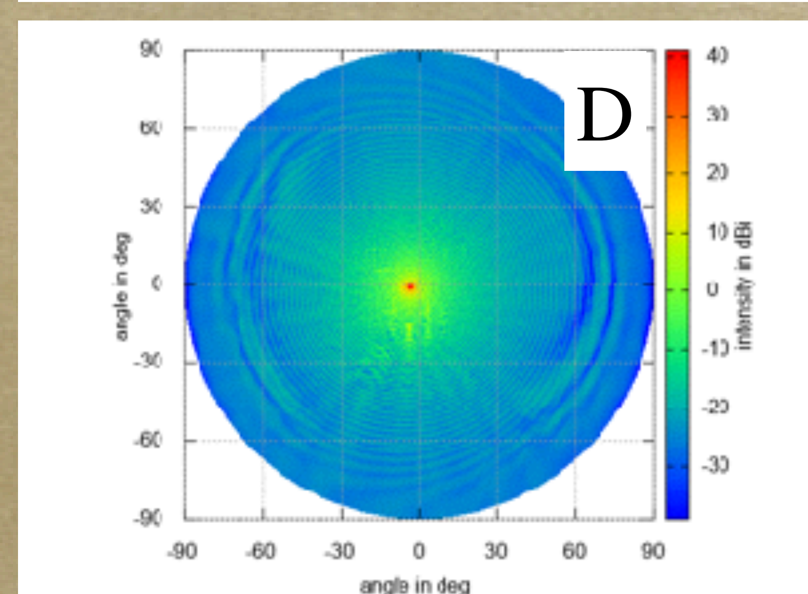




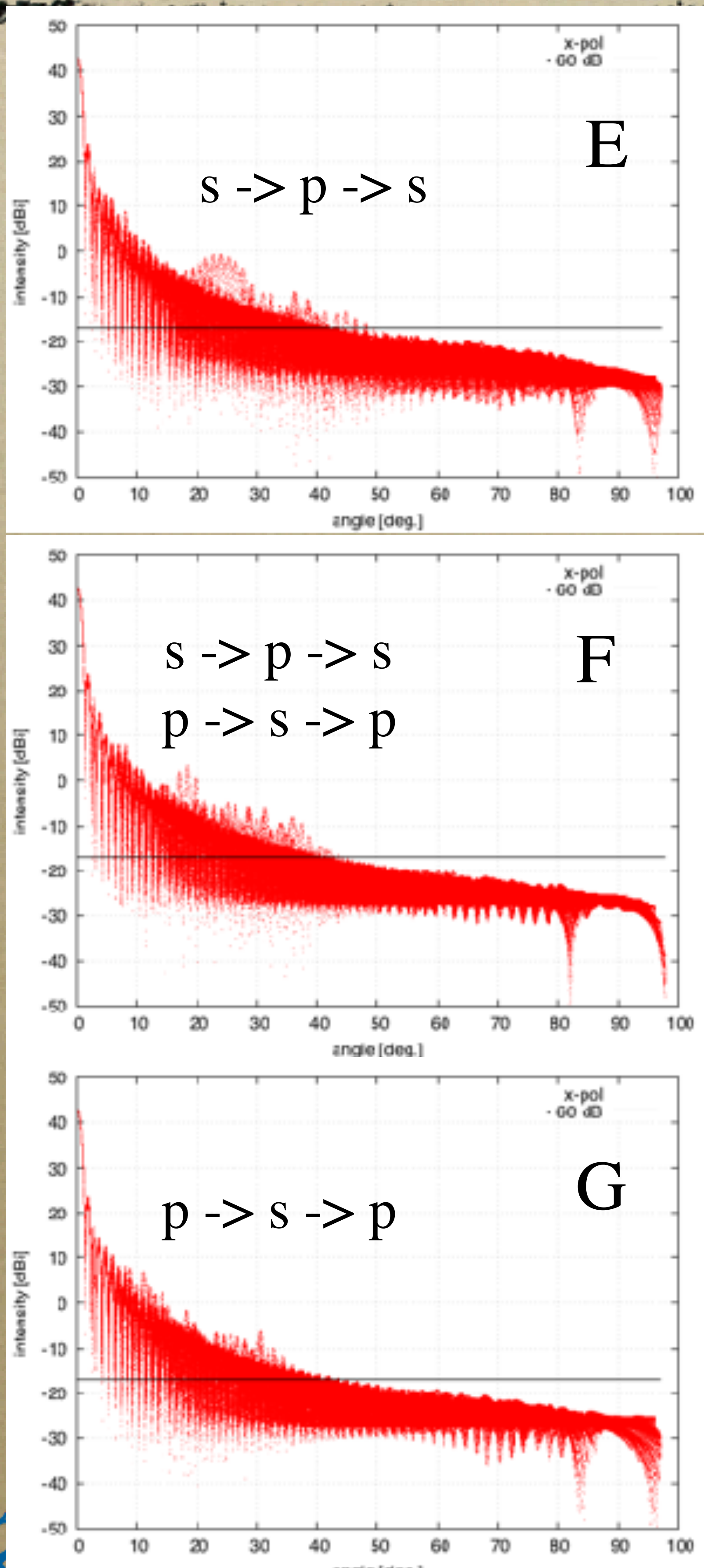


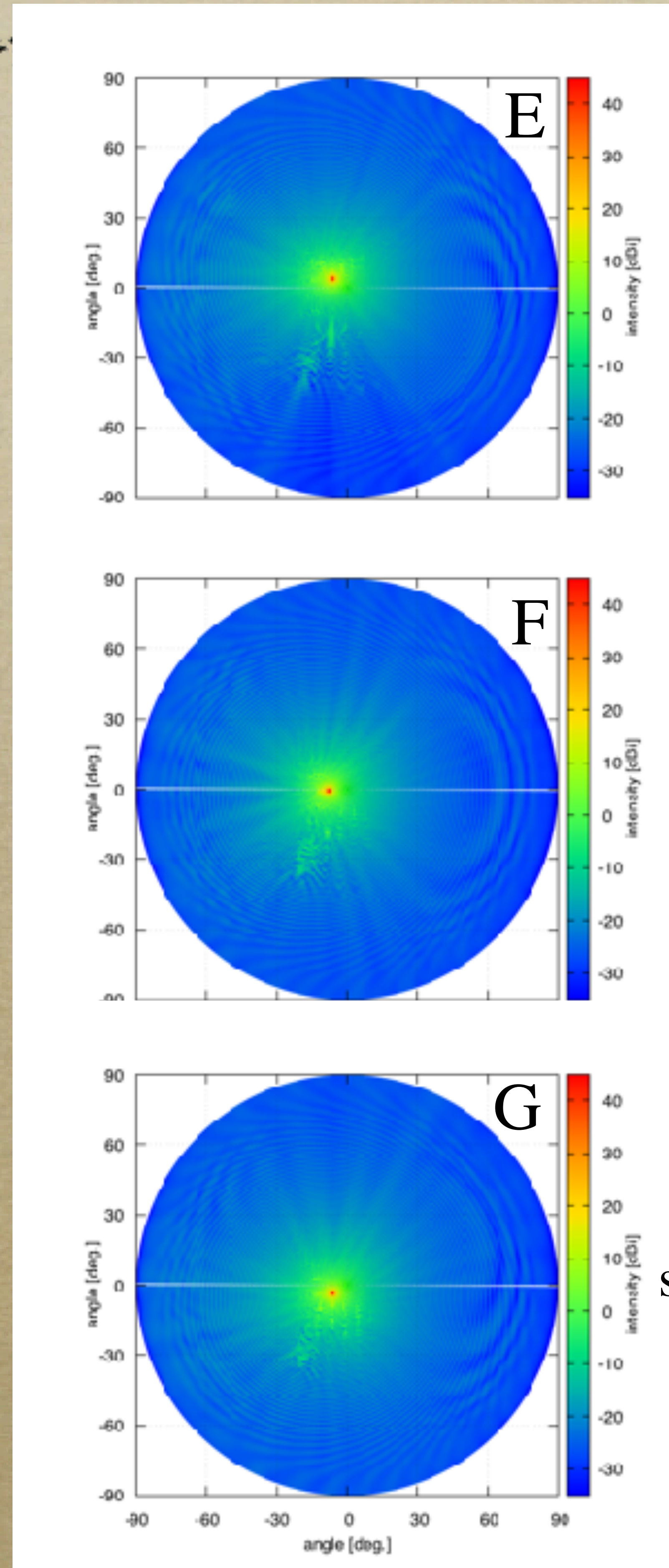


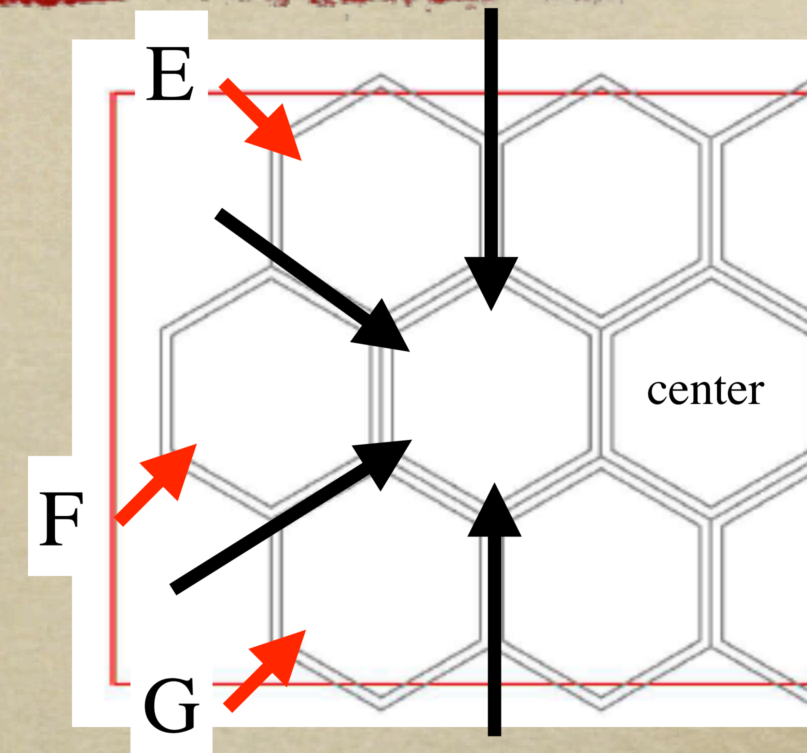


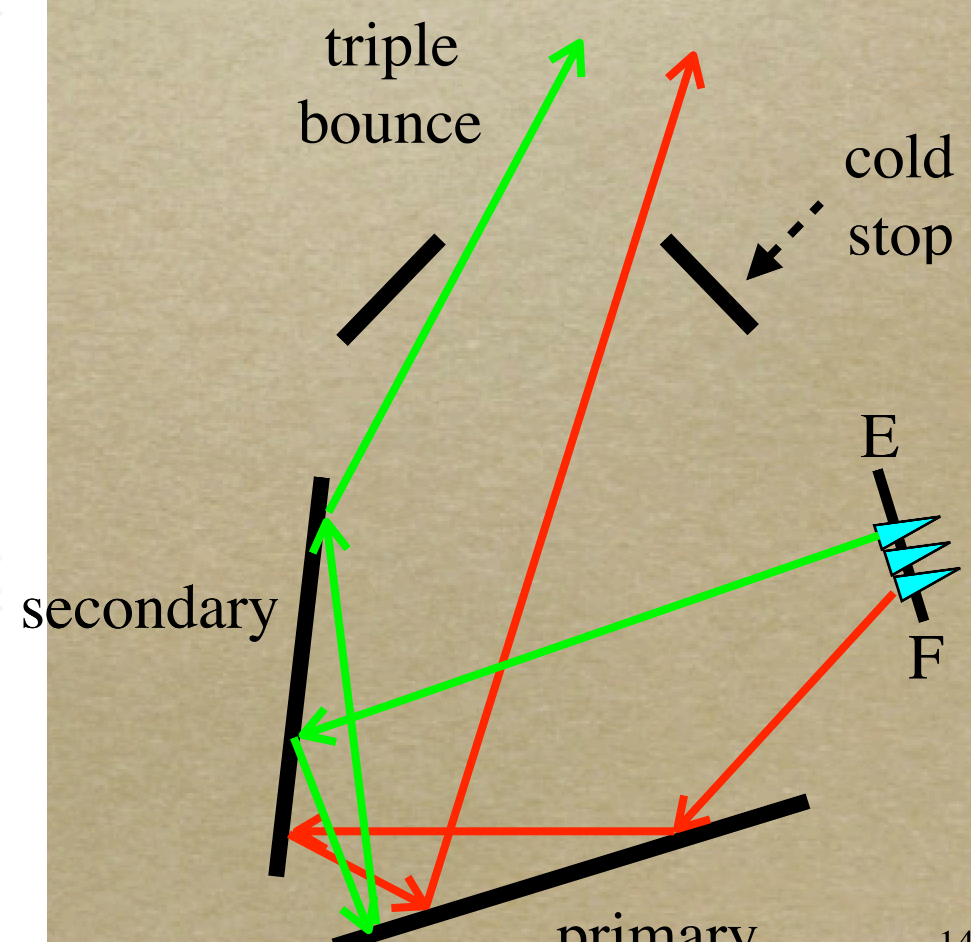


Beam patterns at 42.5 GHz



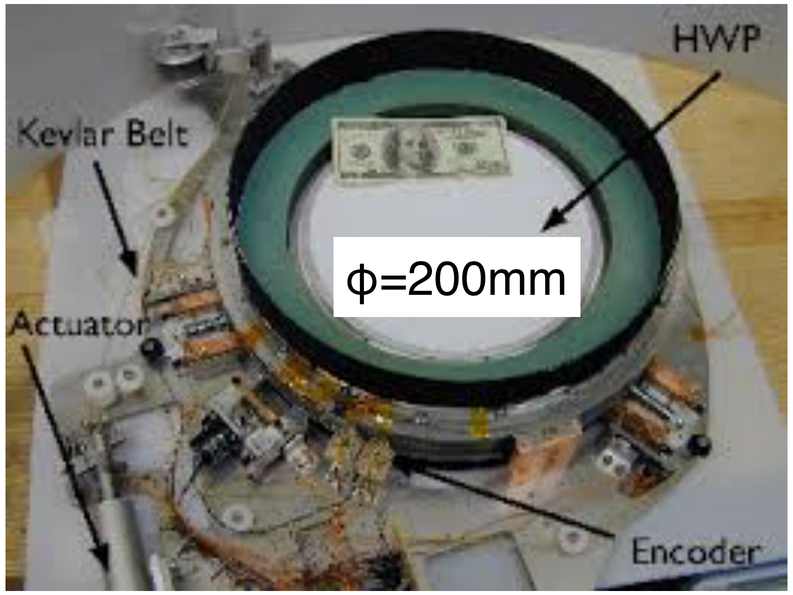






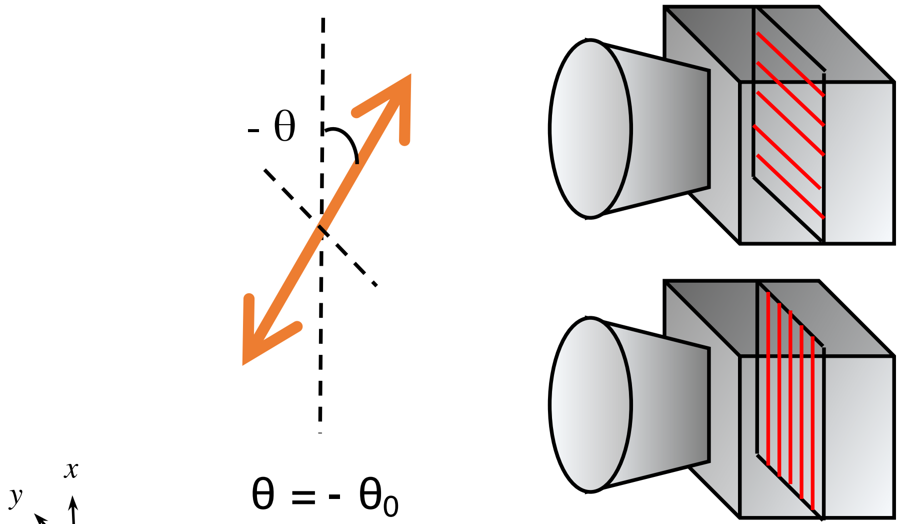
Polarization Modulator

- ✓ The polarization modulator significantly mitigate low frequency noise and systematics by modulating incident polarization signal.
- ✓ The modulation is realized by a continuous rotating half-wave plate (HWP).
- ✓ The HWP temperature has to be keep < 10K to minimize a heat loading to detectors.

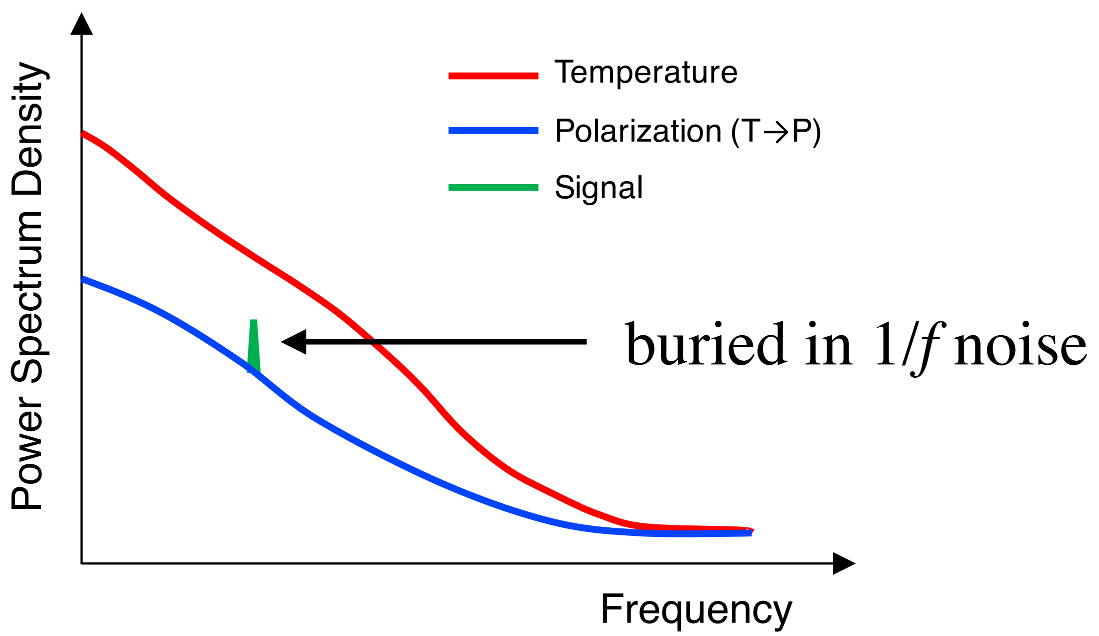


EBEX Polarization Modulator

w/o Polarization Modulator



Linear polarization sensitive detector



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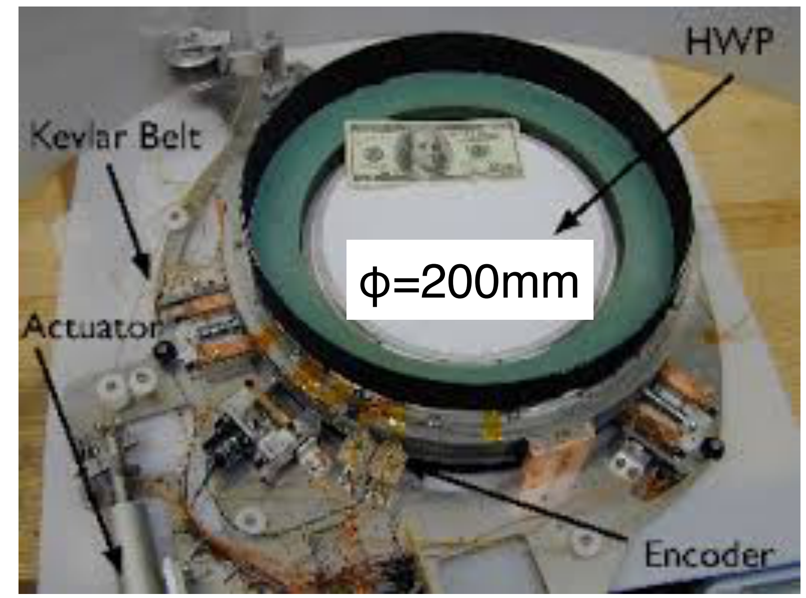
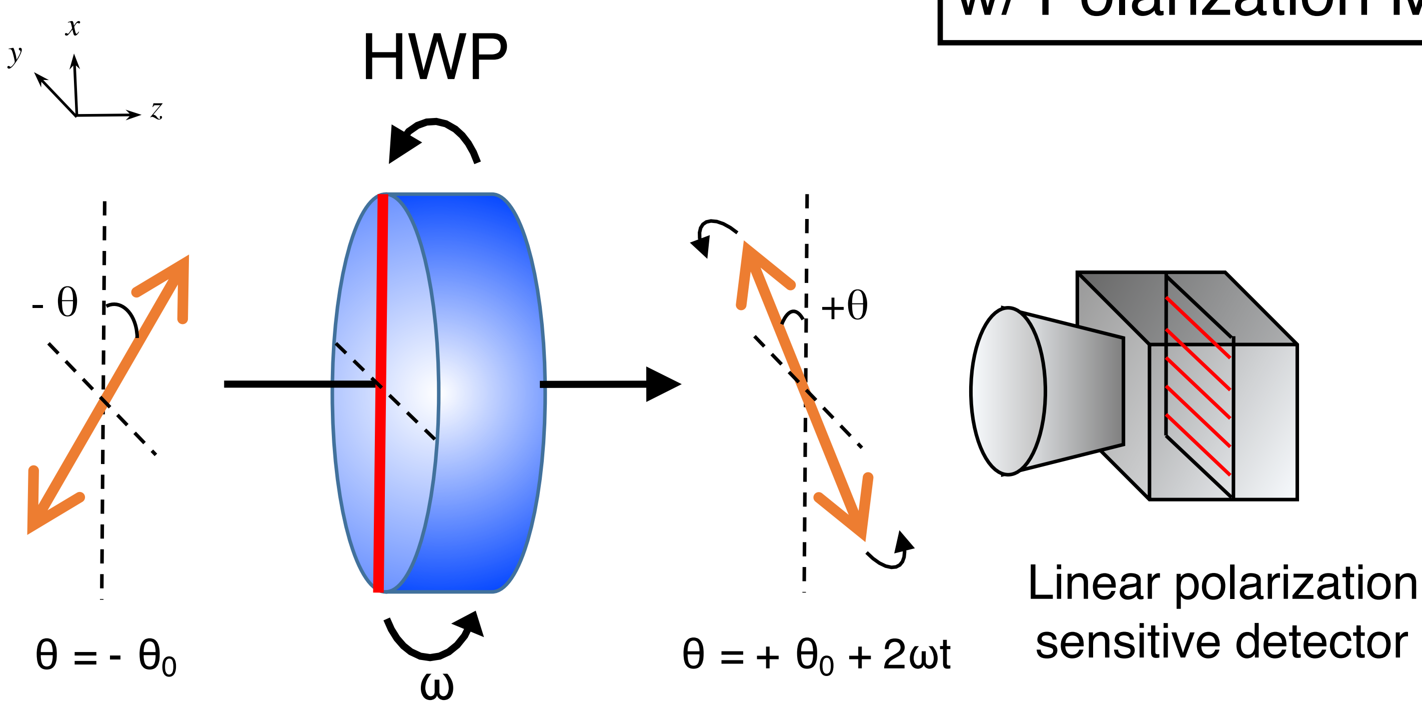
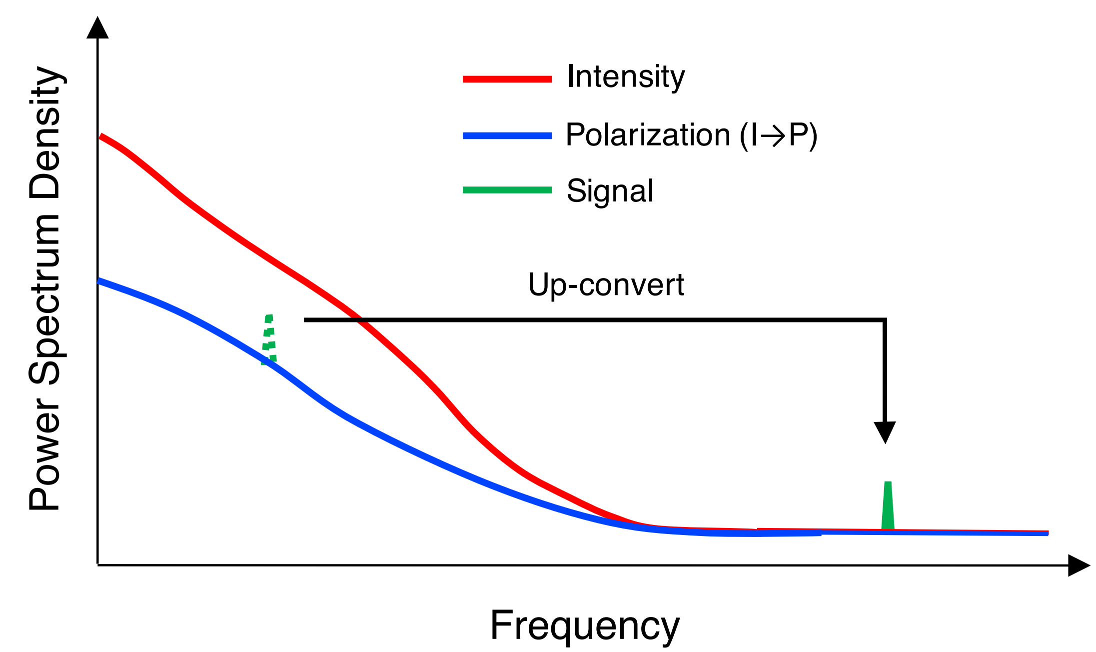


EBEX Polarization Modulator

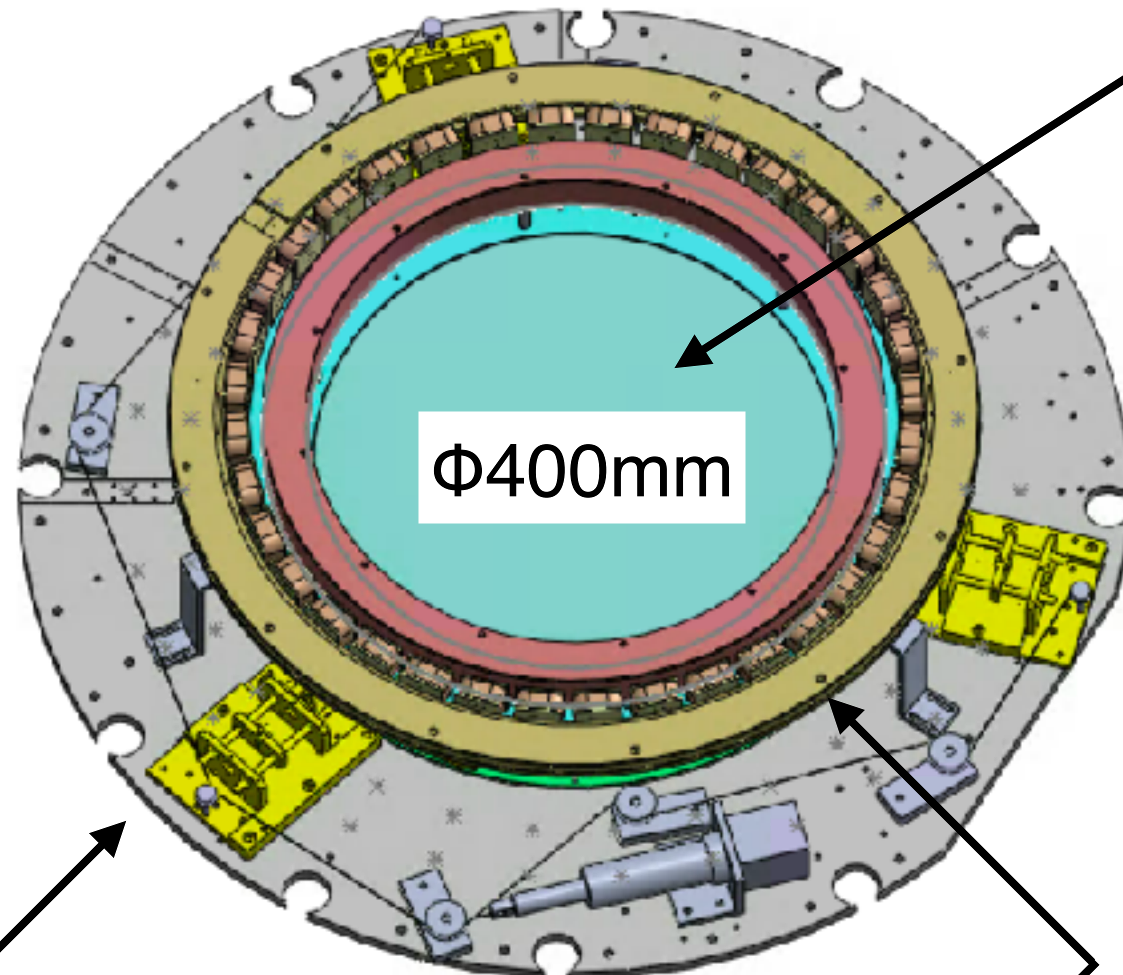
w/ Polarization Modulator



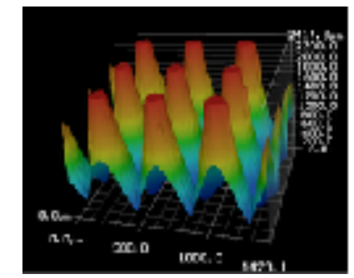


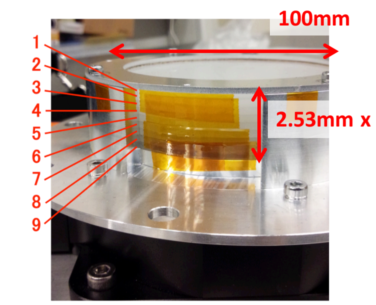
Demonstration Model

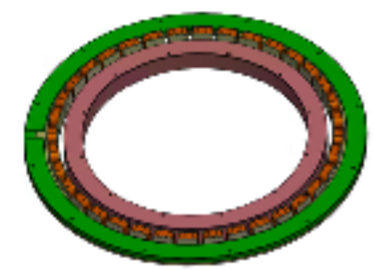
ϕ~1m 4K cryostat



Broadband Half-wave Plate



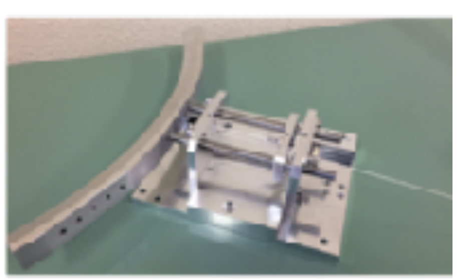


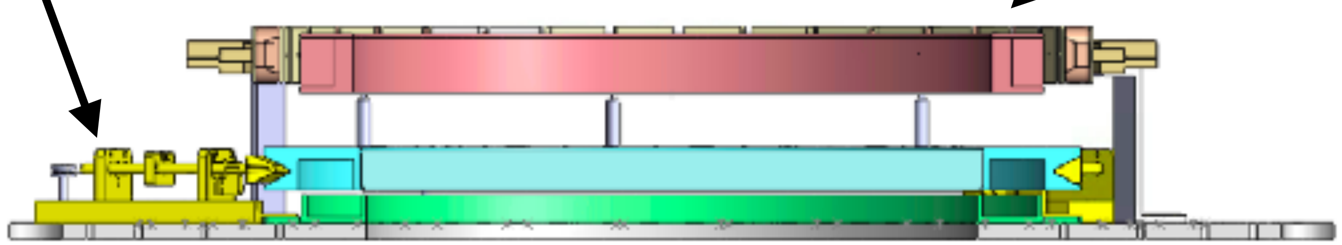


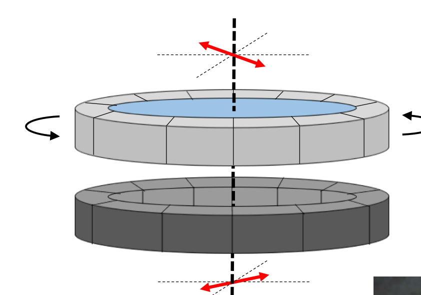
Cryogenic Synchronous Motor

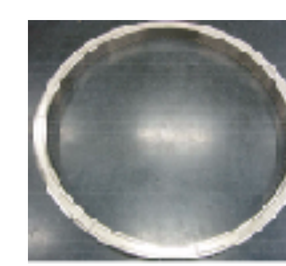
Encoding System

Holding Mechanism





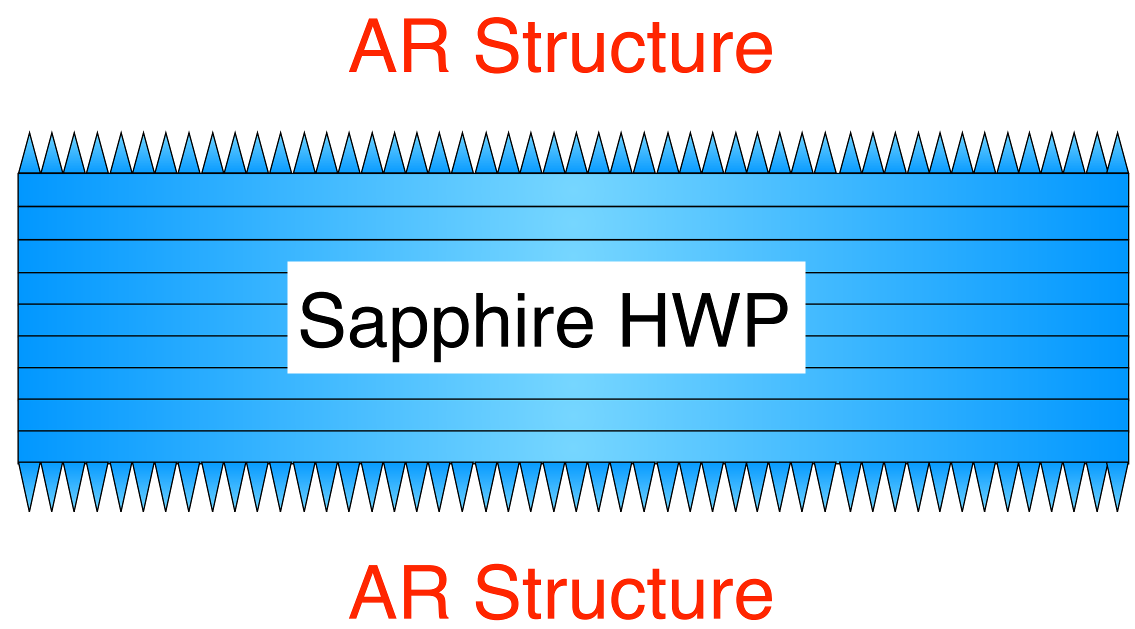


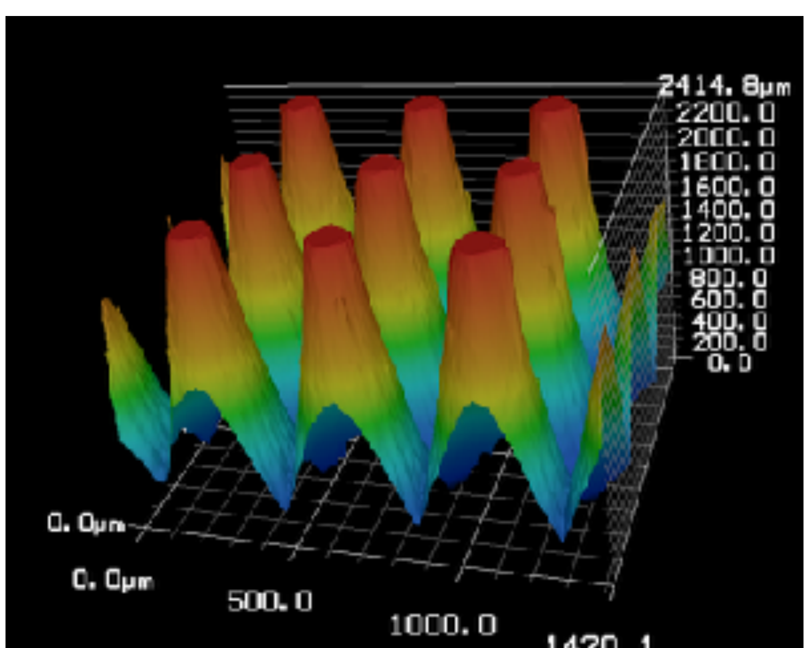


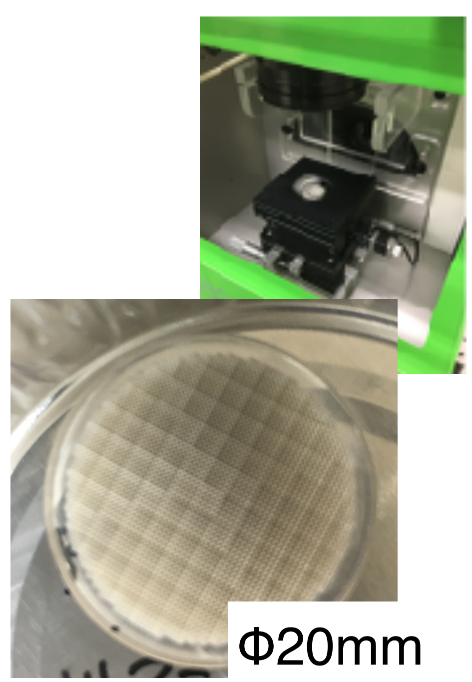
Superconducting Magnetic Bearing

Anti-Reflection Structure

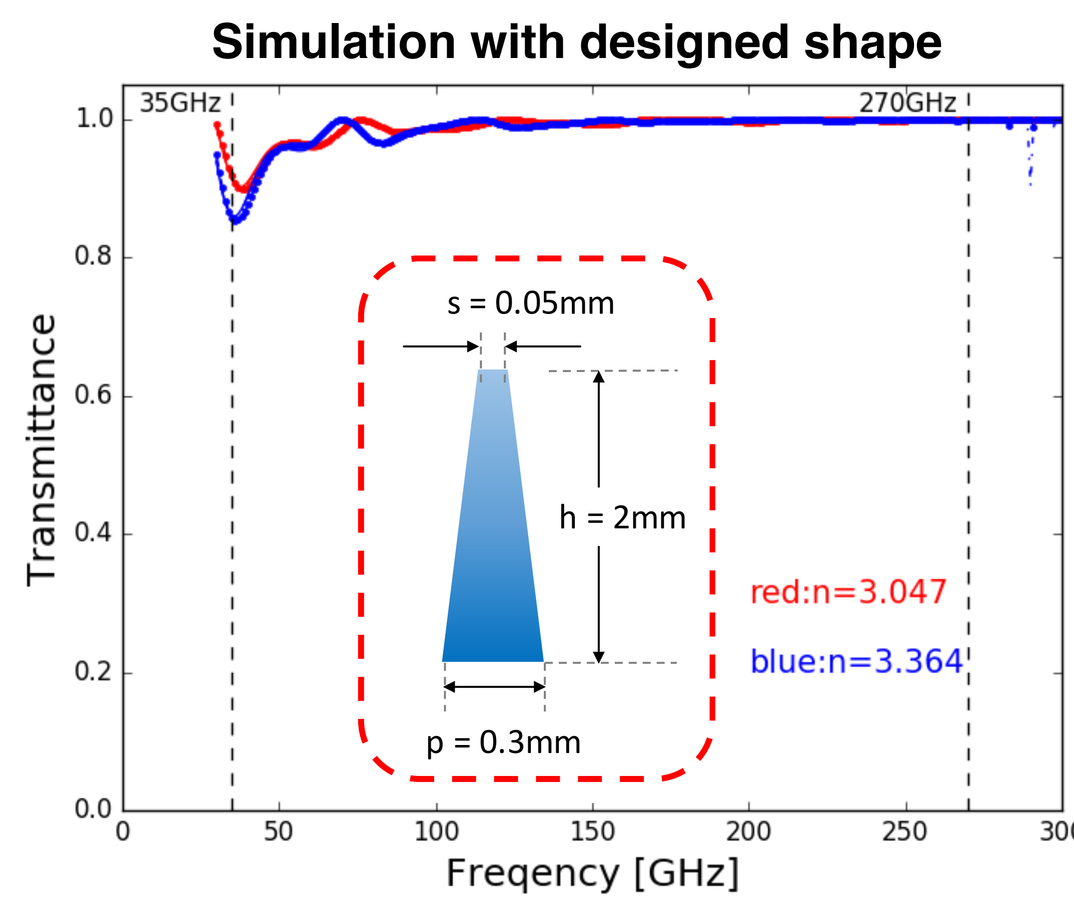
- ✓ The AR structure is introduced on a surface of the sapphire HWP to cover 34-270GHz.
- ✓ We are developing **moth-eye based sub-wavelength structure** using laser machining technique.
- ✓ High transmittance is expected with designed shape, and the feasibility is experimentally verified with a small prototype sample.
- ✓ We are optimizing laser parameters to reduce the processing time to make Φ400mm.





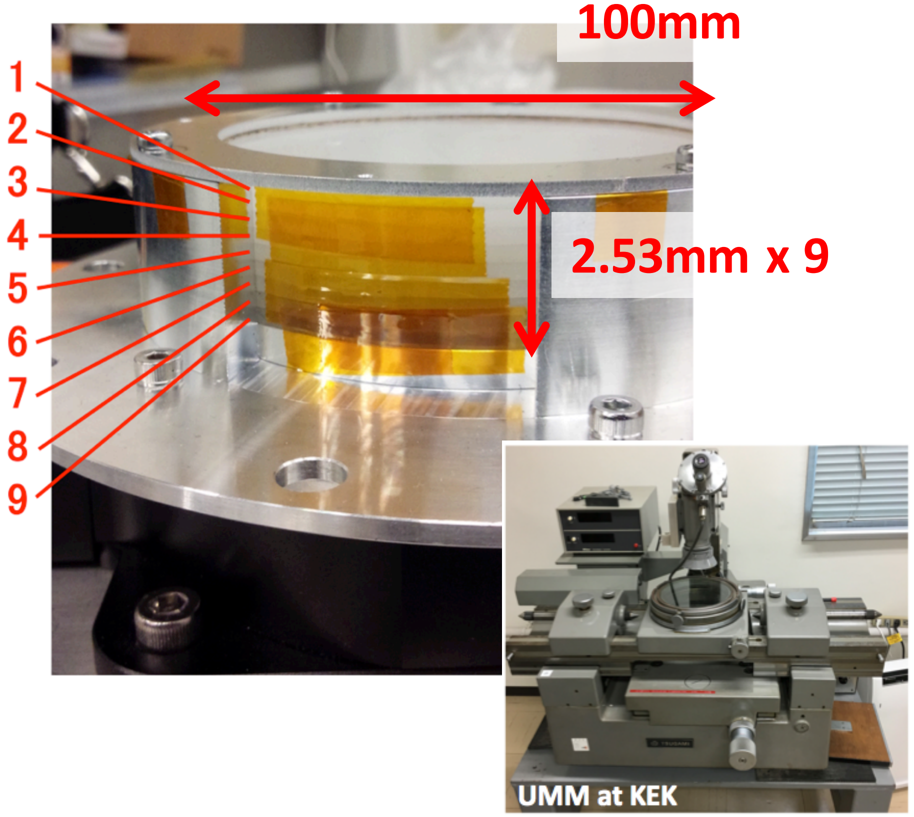


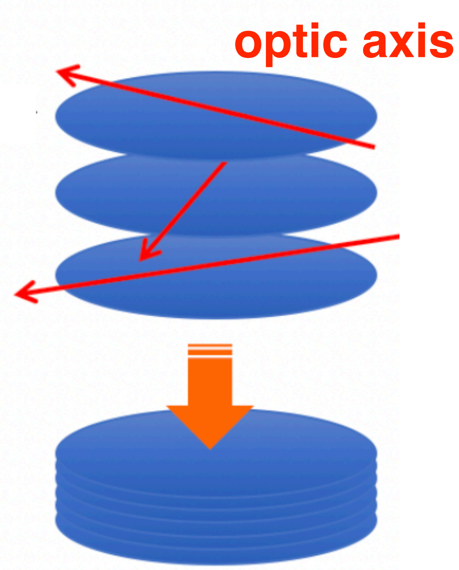
Φ20mm



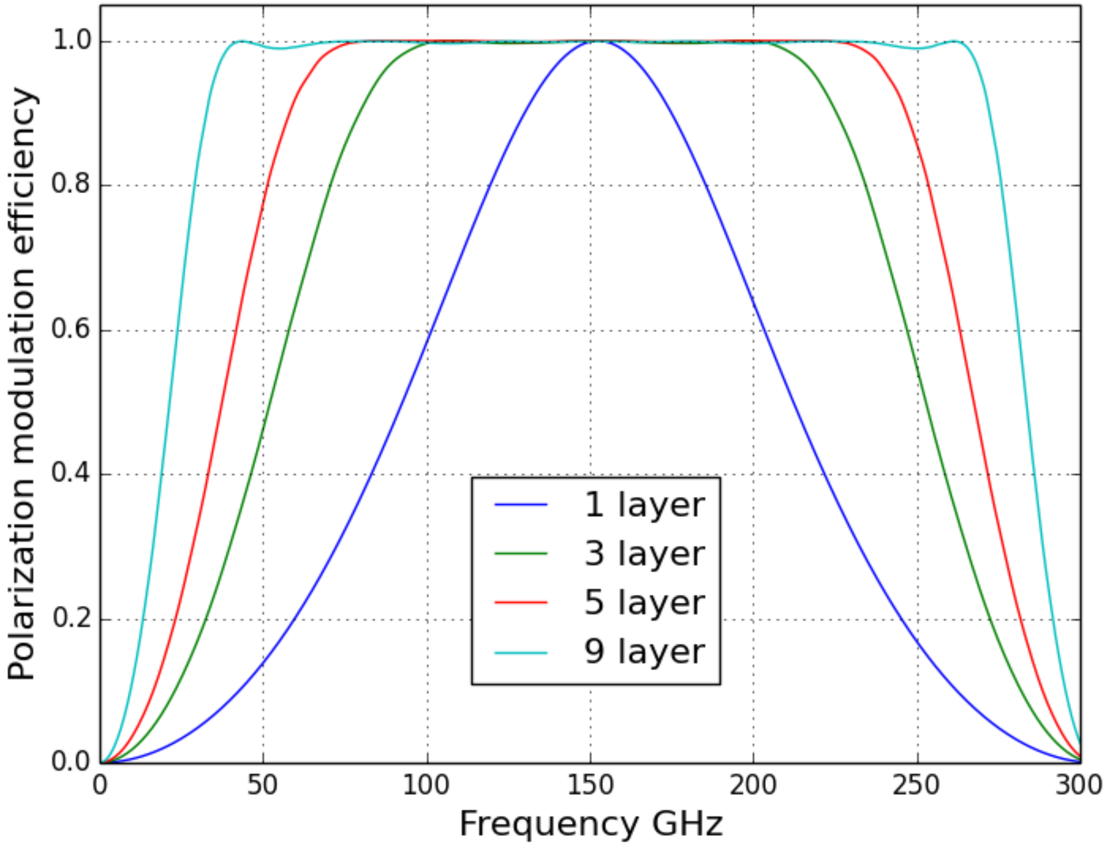
Achromatic HWP

- ✓ The modulation efficiency of a single-layer sapphire HWP is effective only for one frequency.
- ✓ The broadband is feasible assembling multiple layers with offset optical axis (Achromatic HWP).
- ✓ We designed a 9-layer Achromatic HWP to keep high modulation efficiency at 34 - 270 GHz.
- ✓ We fabricated a small prototype and the performance is consistent with the prediction.



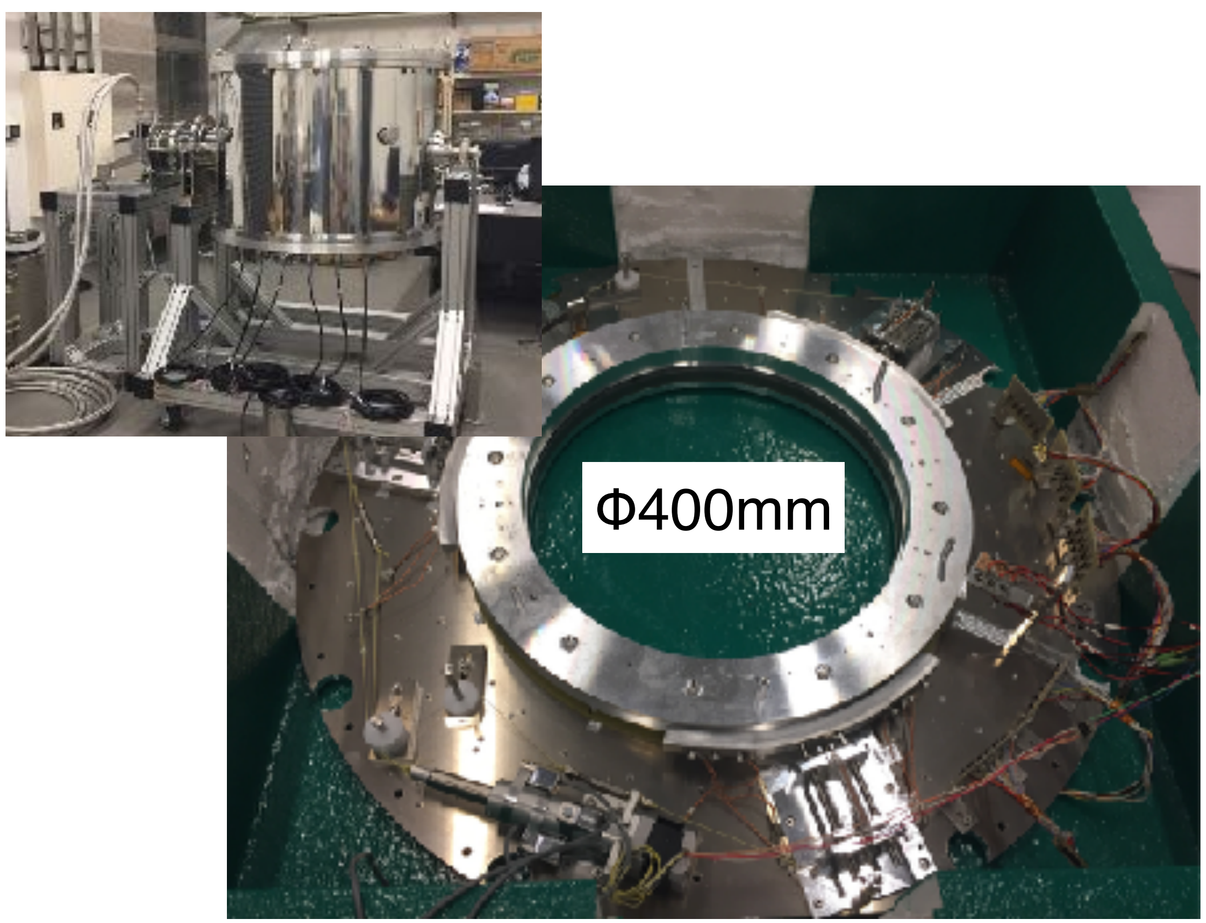


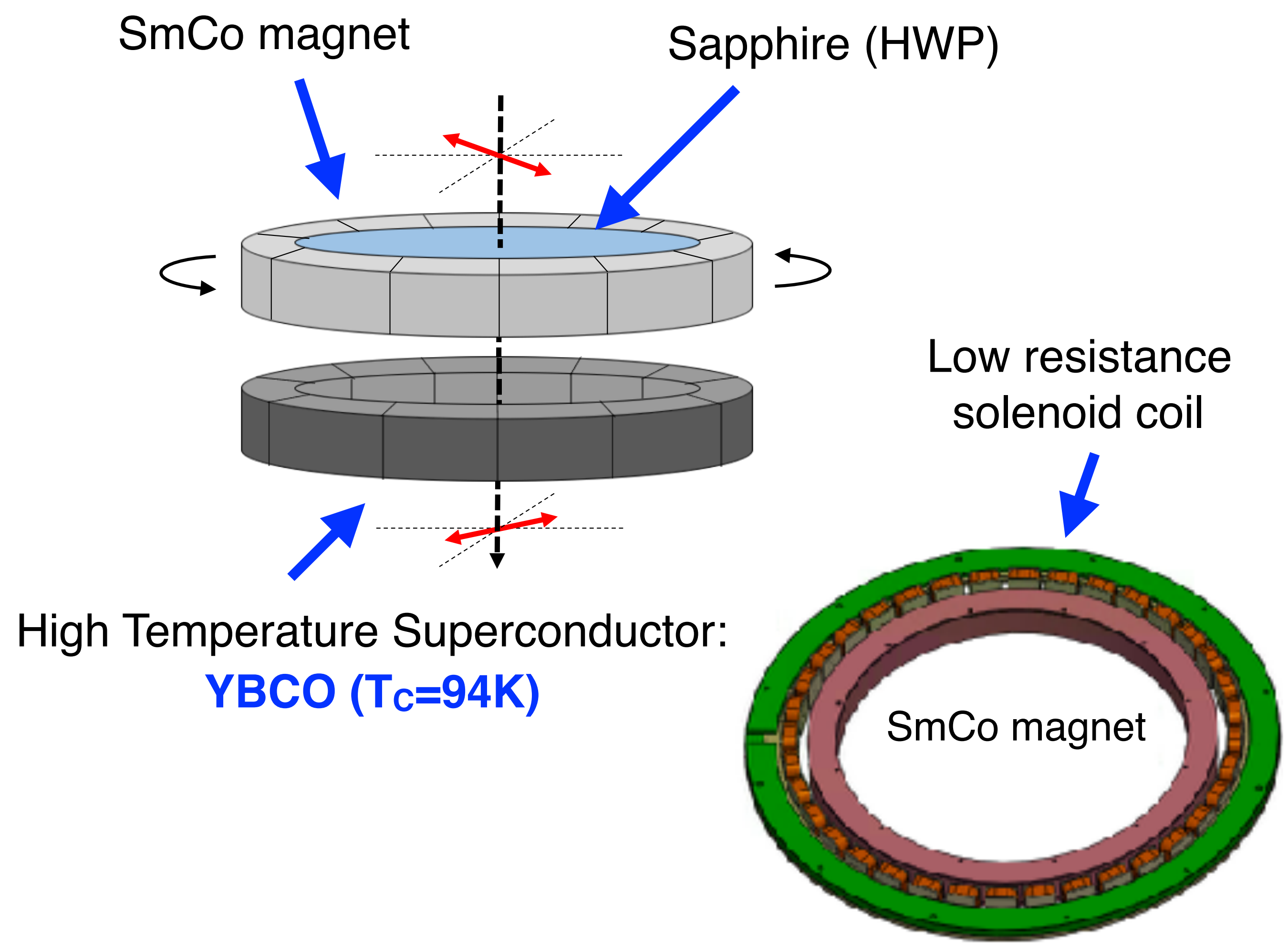
performance with ideal case



Cryogenic Rotation Mechanism

- ✓ The rotation mechanism is required to give a stable HWP rotation with minimum heat dissipation below 10K environment.
- ✓ We constructed a flight representative demonstration model with ϕ400mm inside a large 4K cryostat at Kavli IPMU.
- ✓ The current focused development point is to minimize heat dissipation with using contactless bearing and motor: superconducting magnetic bearing and synchronous motor.





Summary

- ❖ LiteBIRD Overview
  - a next generation satellite for CMB polarization
    - ✓ with the uncertainty of $\sigma(r) < 0.001$ ($2 \leq$ ell ≤ 200, 3-year observation)
    - ✓ launched in mid 2020s w/ H3 rocket to L2
  - JAXA's strategic L-class mission candidate, currently in Phase-A1
    - ✓ one of top-priority science goals in JAXA roadmap
  - international Project : Japan, US, Canada, Europe
- ❖ Low Frequency Telescope (LFT)
  - Diffraction at mirror edges can cause additional side lobes
    - ✓ serration, band arrangement on the focal plane can mitigate
  - Stray light was found
- ❖ Half Wave Plate (HWP)
  - a demonstration model (ϕ400) for rotation mechanism was constructed
  - AR structure was fabricated, and high transmittance is expected
  - high modulation efficiency was achieved with a small prototype
  - development focuses on minimizing heat dissipation