# LiteBIRD

LNPC17, April 19-21 @ PACIFICO Yokohama

Satoru Uozumi (Okayama Univ.) *for the LiteBIRD Phase-A1 team*

# 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 ( by three-year observation of all sky.**
- **Measurement of the tensor-to-scaler ratio r, that represents primordial gravitational waves, at precision $\sigma_r < 0.001$ (w/o subtracting the gravitational lensing effect.)**

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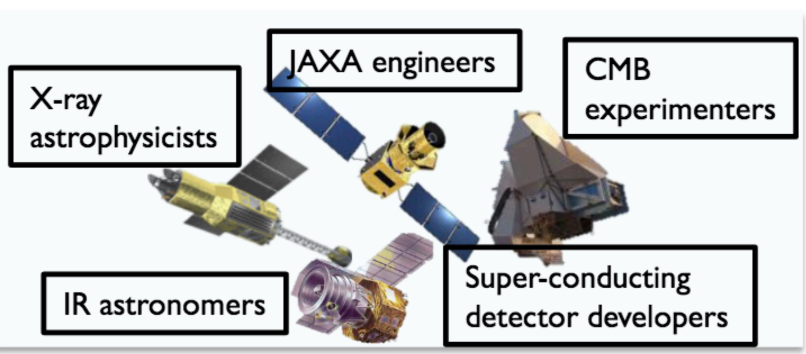
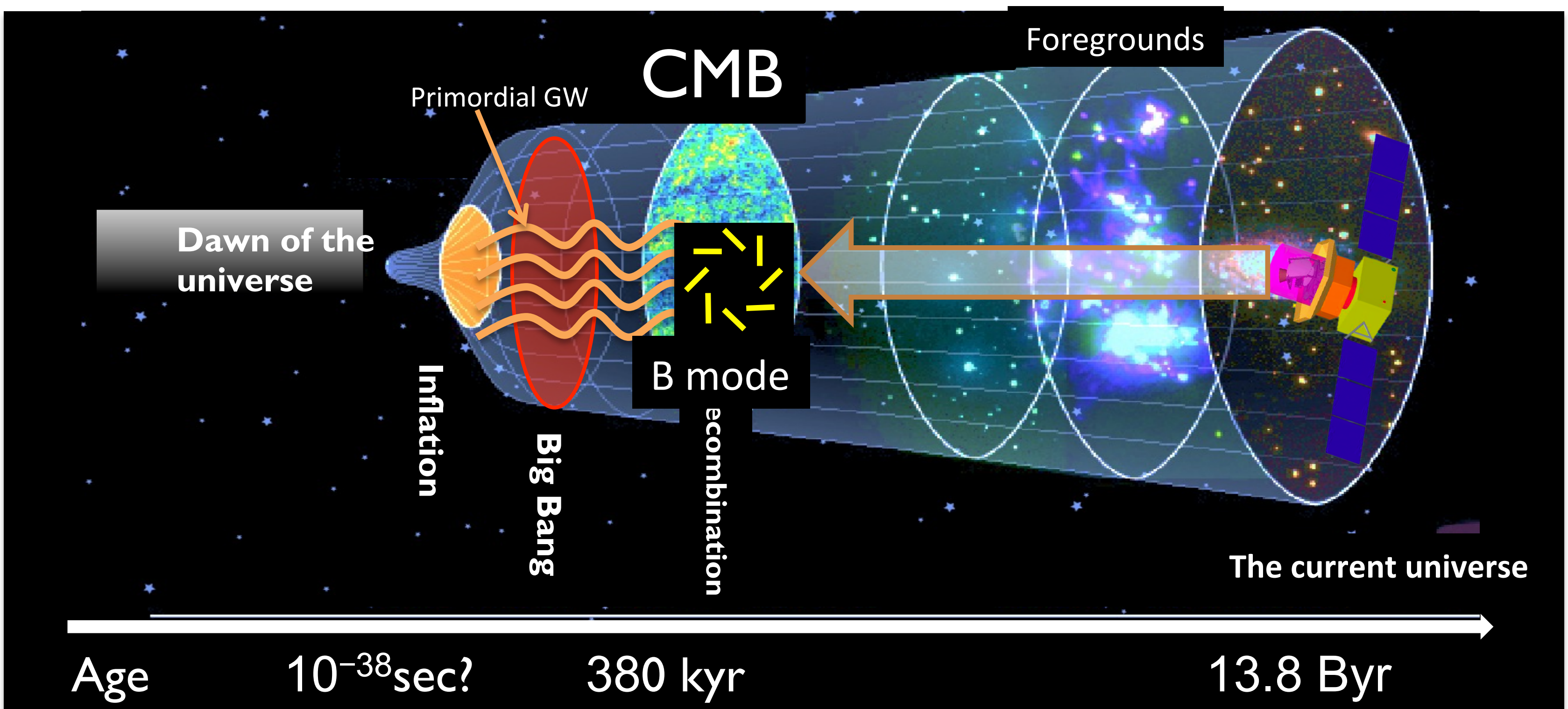



139 members, international and interdisciplinary (as of May 1, 2016)

# Mission Goal : Verification of inflation by detecting B-mode CMB



Mon. R. astr. Soc. (1981) 195, 467–479

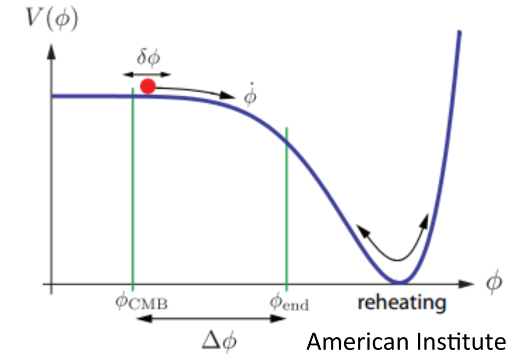
# First-order phase transition of a vacuum and the expansion of the Universe

Katsuhiko Sato *Nordita, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark**
*and Department of Physics, Kyoto University, Kyoto, Japan†*

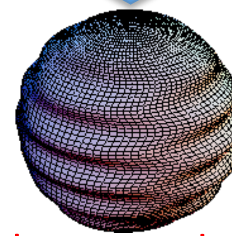
Received 1980 September 9; in original form 1980 February 21

**Summary.** The progress of a first-order phase transition of a vacuum in the expanding Universe is investigated. The expansion of bubbles of a stable vacuum is calculated simultaneously with the cosmic expansion with the aid of the following two simplified nucleation rates of bubbles $p$: (i) $p = p_T T_c \delta(T - T_c)$ in the hot Universe models, (ii) $p = 0$ for $n > n_c$ and $p = p_Q$ for $n < n_c$ in the cold Universe models, where $T$ is the cosmic temperature, $T_c$ the critical temperature, $n$ the cosmic number density of the fermions coupled to the order parameter of the vacuum, $n_c$ the critical density, and $p_T$ and $p_Q$ are parameters.

The following results are obtained: (1) If the nucleation rates are small and the vacuum stays at the metastable state for a long time, the Universe begins to expand exponentially. As a result, the progress of the phase transition is delayed more and more by the rapid cosmic expansion. In particular, in model (i), if $p_T$ is less than a critical value, the phase transition never finishes. (2) The lower limits of the nucleation parameter $p_T$ and $p_Q$ are obtained from observation of the number ratio of photons to baryons in the present Universe. (3) If the phase transition of the vacuum in SU(5) GUT is of first order or if there exists a hypothetical first-order phase transition of the vacuum in the very early stage in which baryon number is not conserved, the density and the velocity fluctuations created by the phase transition may account for the origin of galaxies.




American Institute of Phisycs. D. Baumman et Al.



Kamionkowski

If the inflation happened, it should make gravitational ripples in space.

PHYSICAL REVIEW D VOLUME 23, NUMBER 2 15 JANUARY 1981

## Inflationary universe: A possible solution to the horizon and flatness problems

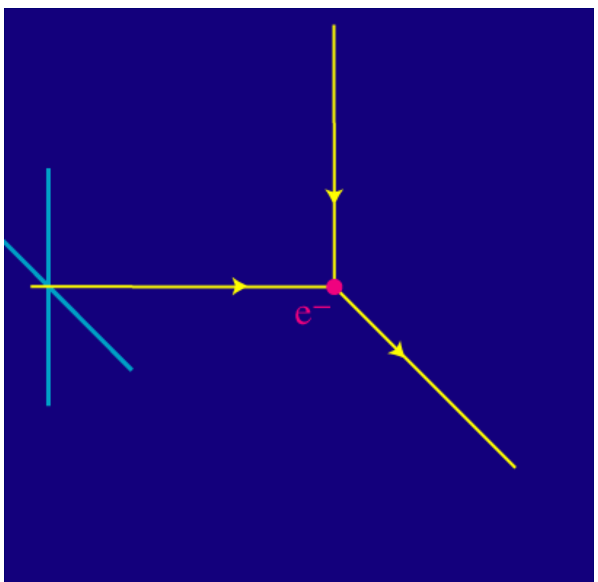
Alan H. Guth*
*Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305*
(Received 11 August 1980)

The standard model of hot big-bang cosmology requires initial conditions which are problematic in two ways: (1) The early universe is assumed to be highly homogeneous, in spite of the fact that separated regions were causally disconnected (horizon problem); and (2) the initial value of the Hubble constant must be fine tuned to extraordinary accuracy to produce a universe as flat (i.e., near critical mass density) as the one we see today (flatness problem). These problems would disappear if, in its early history, the universe supercooled to temperatures 28 or more orders of magnitude below the critical temperature for some phase transition. A huge expansion factor would then result from a period of exponential growth, and the entropy of the universe would be multiplied by a huge factor when the latent heat is released. Such a scenario is completely natural in the context of grand unified models of elementary-particle interactions. In such models, the supercooling is also relevant to the problem of monopole suppression. Unfortunately, the scenario seems to lead to some unacceptable consequences, so modifications must be sought.

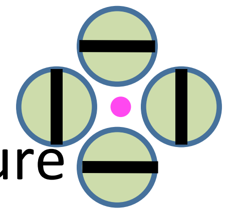
# CMB polarization @ recombination

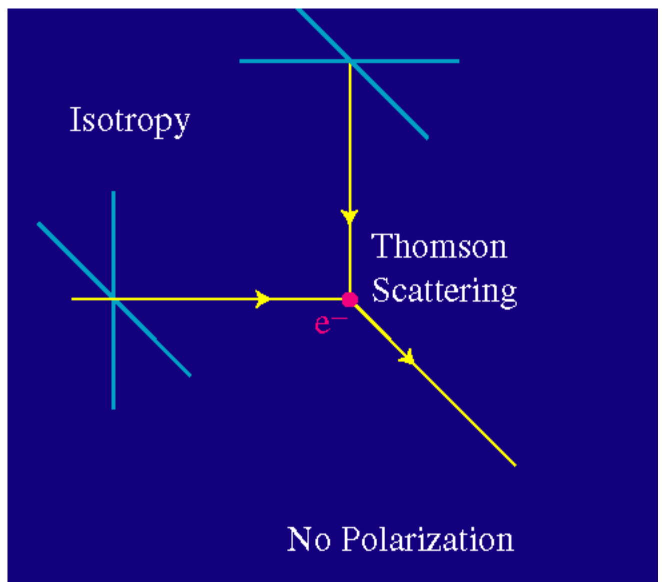
When space became transparent to radiation,
Thomson scattering gives polarization to freely travelling photons according to how surroundings are HOT and COLD.

Simple Thomson scattering of electron

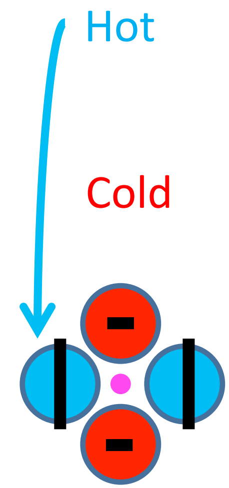


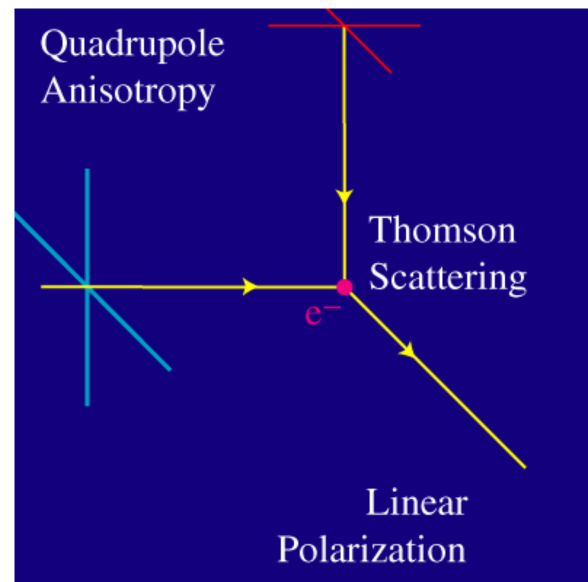

Surrounded by same temperature

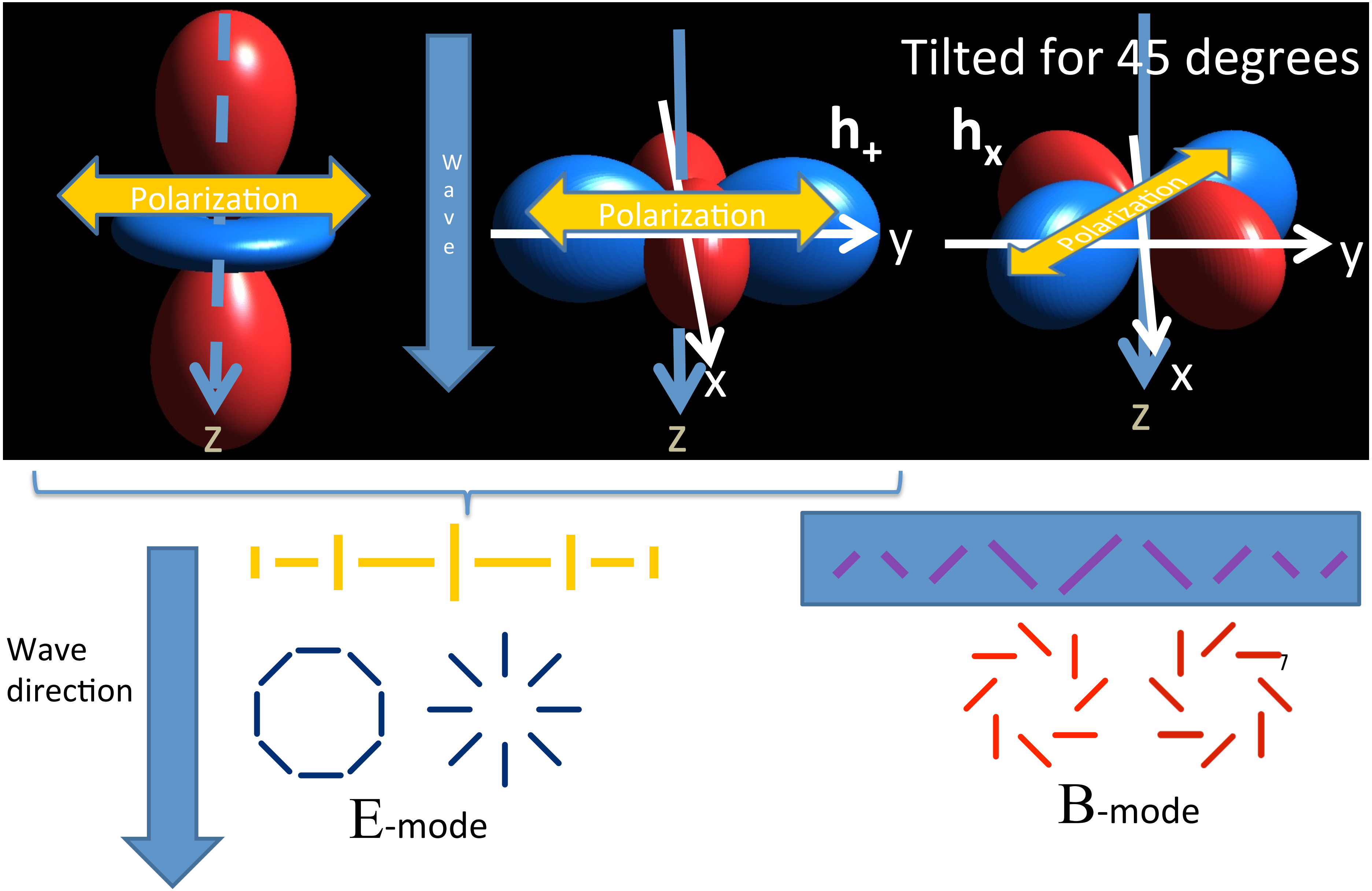





If temperature is biased…



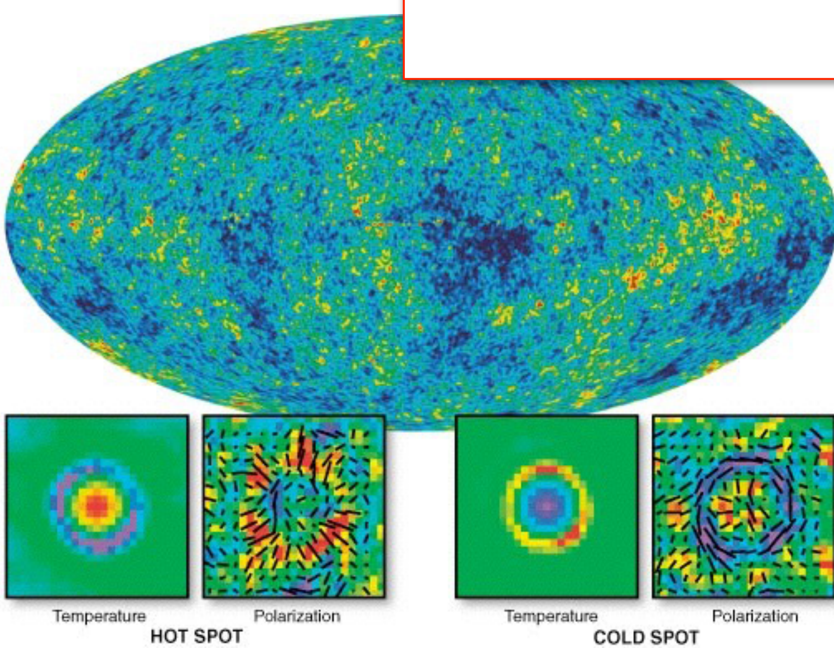

Tilted for 45 degrees
Polarization
W a v e
Polarization
y
$h_+$
$h_x$
Polarization
y
x
z
z
x
z
Wave direction
E-mode
B-mode
7

# Then what makes temperature bias?

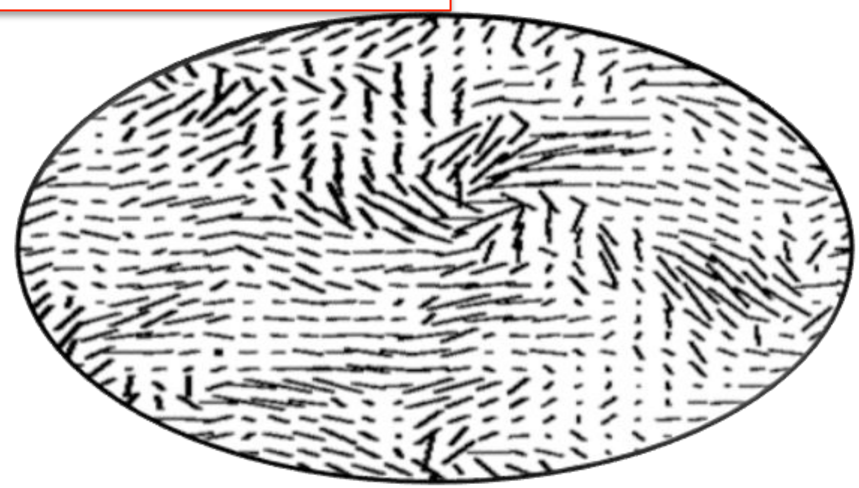
1. E-mode
   generated by
   fluctuation (
   and primord
- Dominant, we

2. B-mode
nly by
ravitational
r mode)
inflation theory
!

Tensor-scalar ratio
scalar mode / tensor mode
is expected to be very tiny
0.01~0.001!

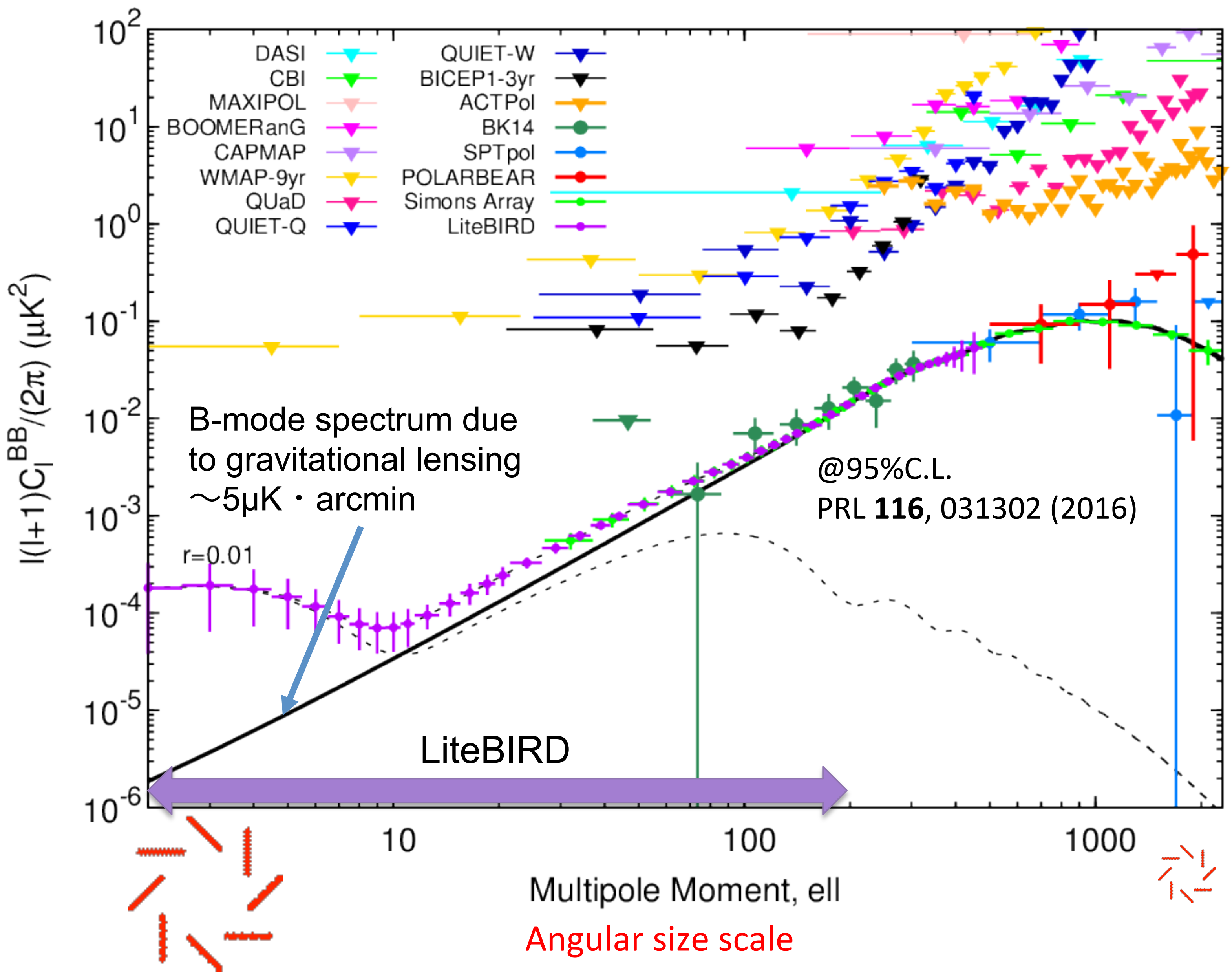



Measured both by WMAP, Planck (WMAP Komatsu et al.)



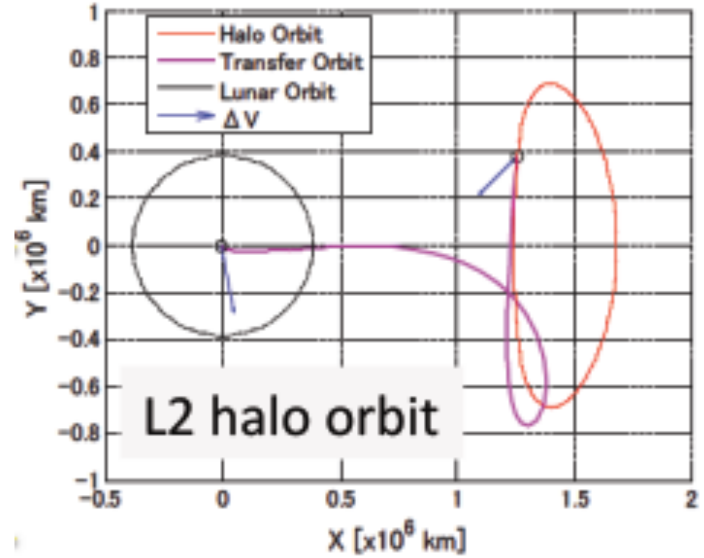
Should look like this?

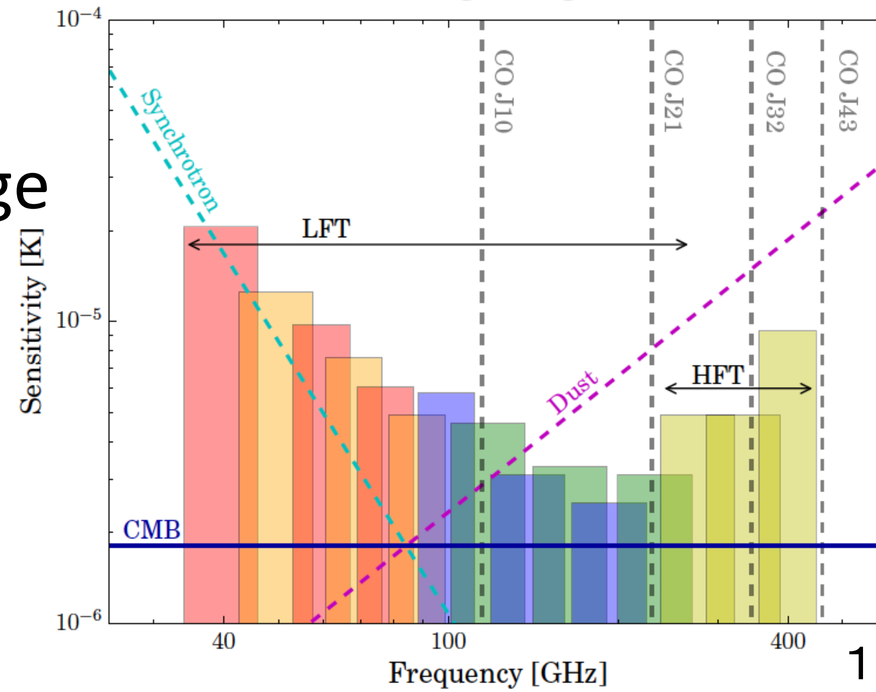
# LiteBIRD Measurement Precision (at r=0.01)



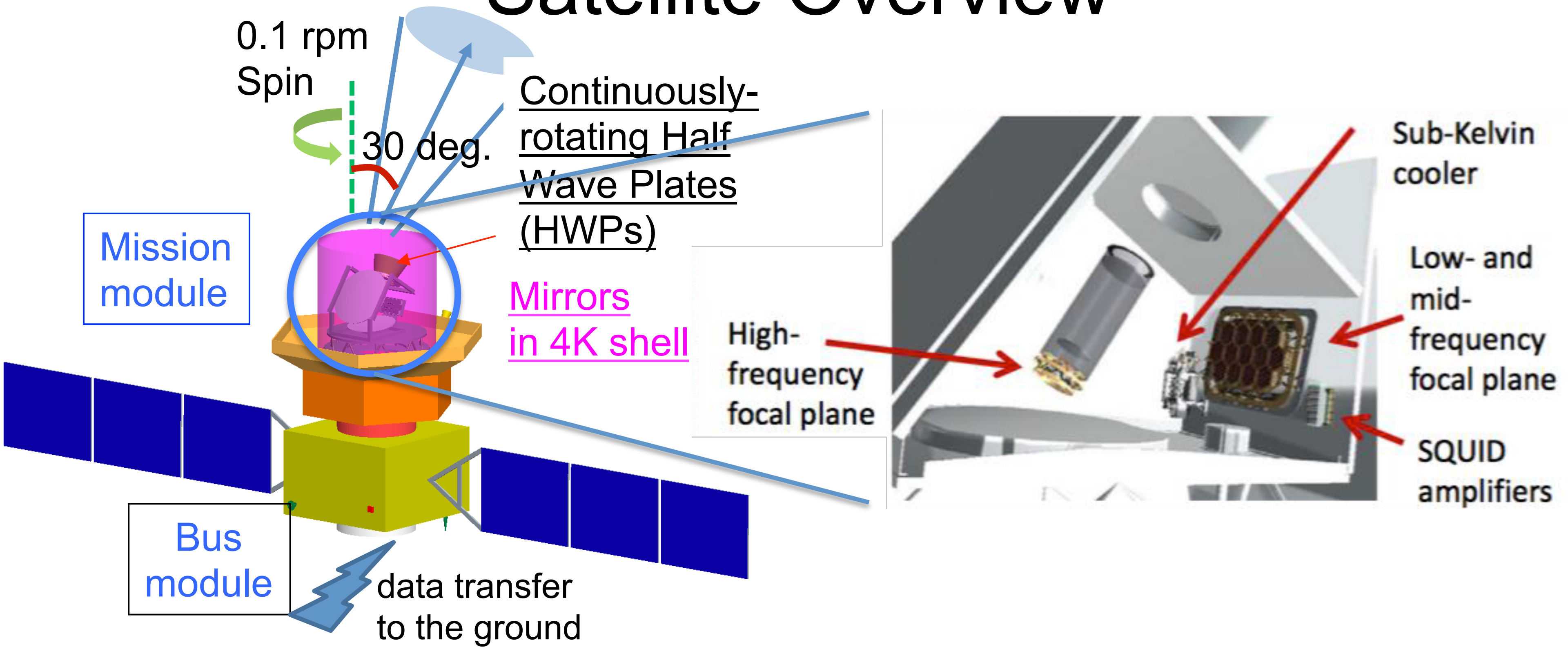
# Mission specification

- Operation at Lagrange-point 2
- Full-sky scan
- Optimized for large-angle polarization structure from primordial B-mode signal
- High detector sensitivity: 3 μK arcmin with margin
- Wide frequency band coverage (40-400 GHz, 15 bands)
- Launch around 2025-2027
- 3 years operation



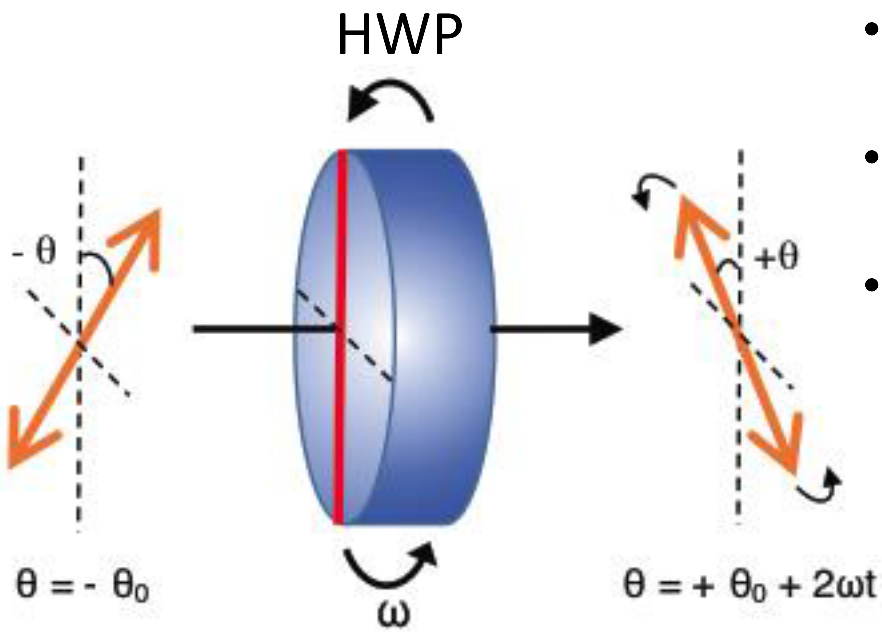



# Satellite Overview




- Satellite consists of two modules : low-temp. mission part and normal-temp bus part.
- Rotating HWP modulates incoming signal.
- Two complementaly optics : LFT and HFT to cover wide freq. bands.
- Optics are kept under 4K by JT/ST and ADR cryogenics.
- Superconducting detectors (TES) are arranged on focal planes.

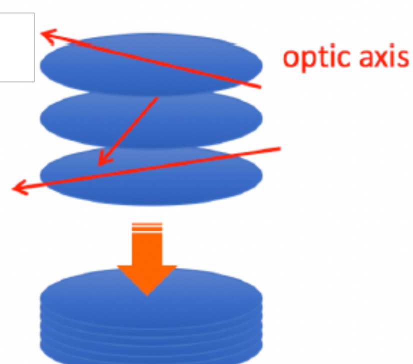
# Rotating Half Wave Plate



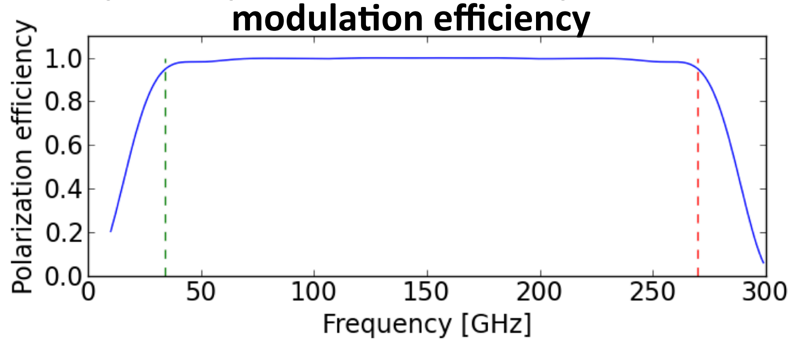

JPS_Sep2016_23aSR-9, Sakurai et al.

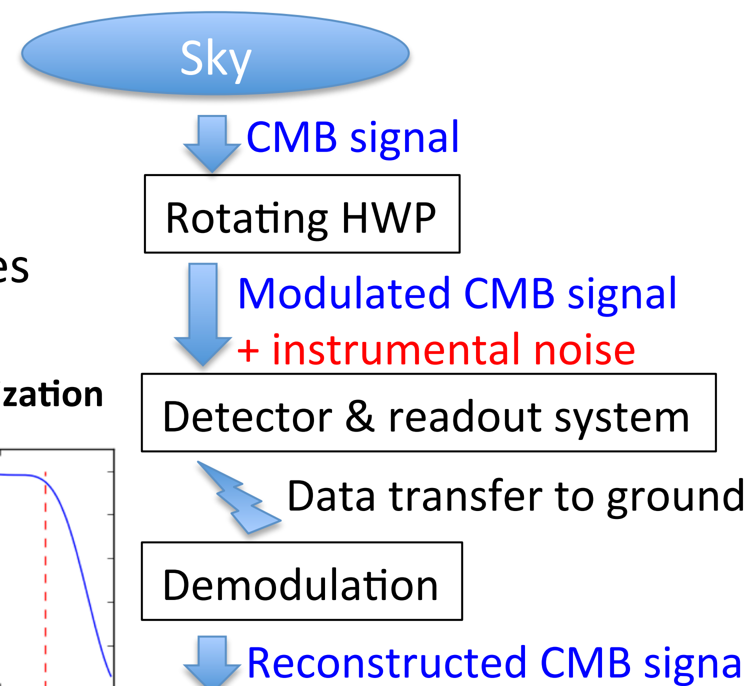
- HWP changes direction of polarization with respect to a fixed axis.
- Modulation of CMB signal by rotating HWP reduces 1/f noise.
- Other instrumental systematics can be greatly reduced by rotating HWP.

- Stacking several layers of rotating HWP makes freq. bandwidth wider.




**Expected performance of the polarization modulation efficiency**

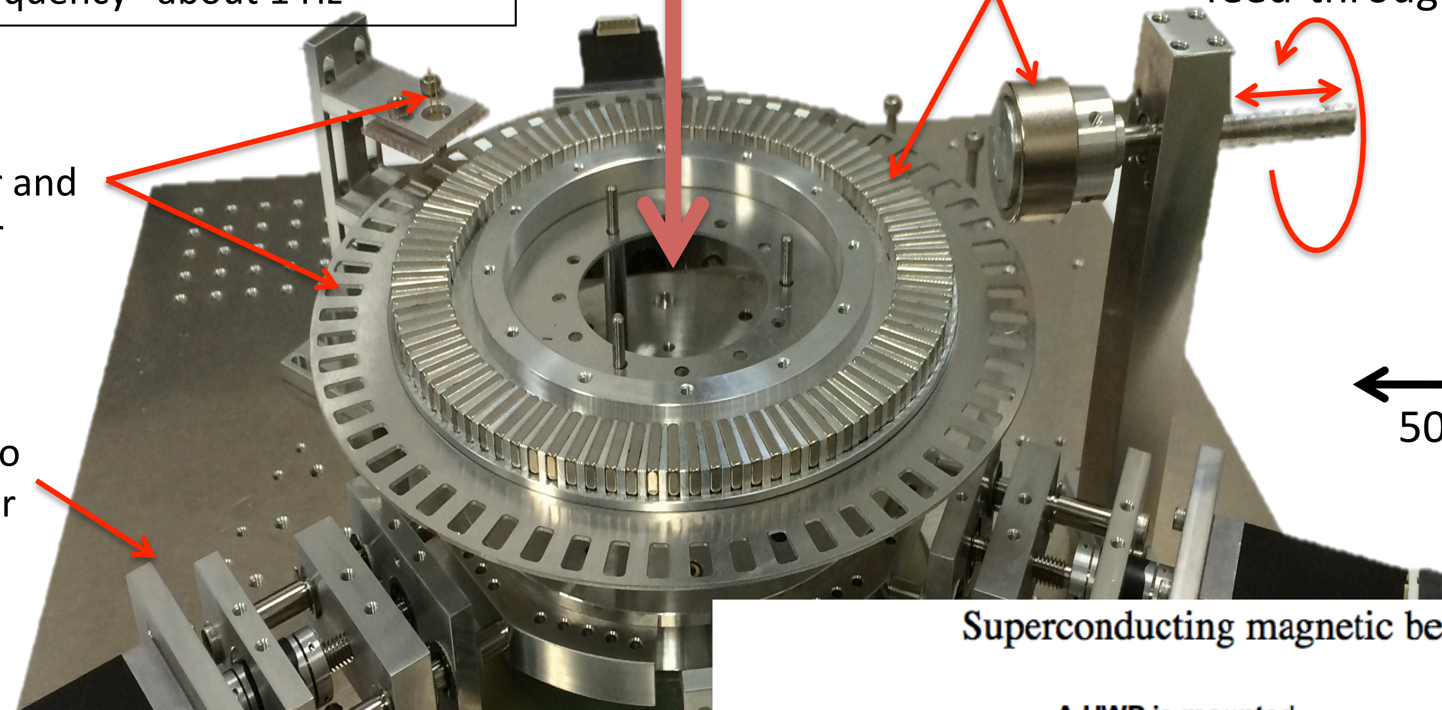


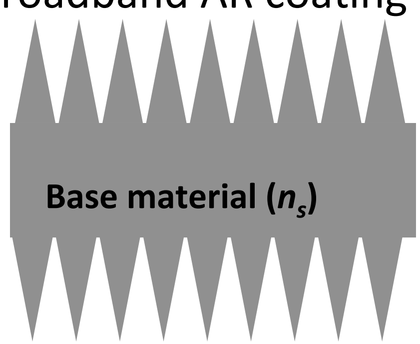
# HWP Small diameter prototype rotational mechanism

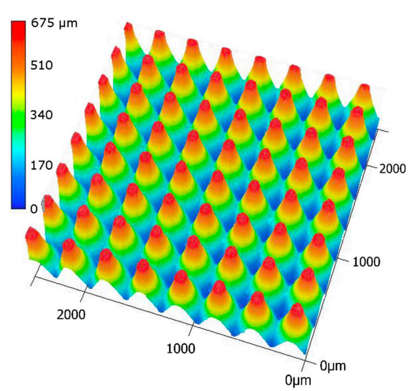
Aperture (a half-wave plate diameter)
Φ50mm
Operation temperature <10 K
Rotational frequency about 1 Hz

The shaft is coupled to a motor mounted outside of the cryostat via linear/rotational feed-through.

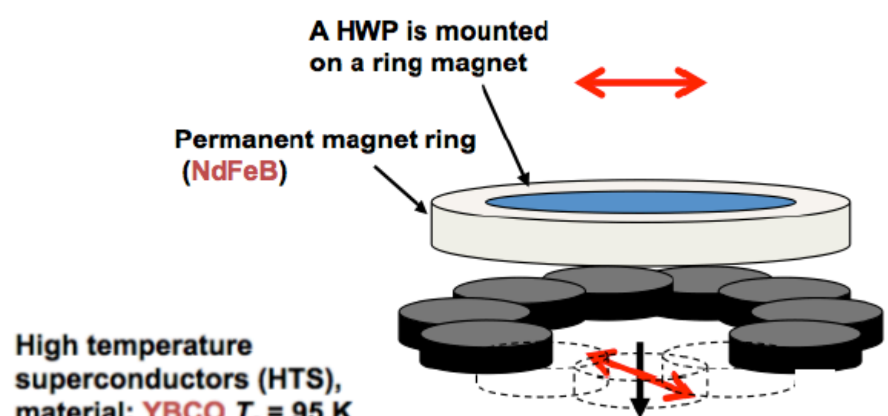



Broadband AR coating



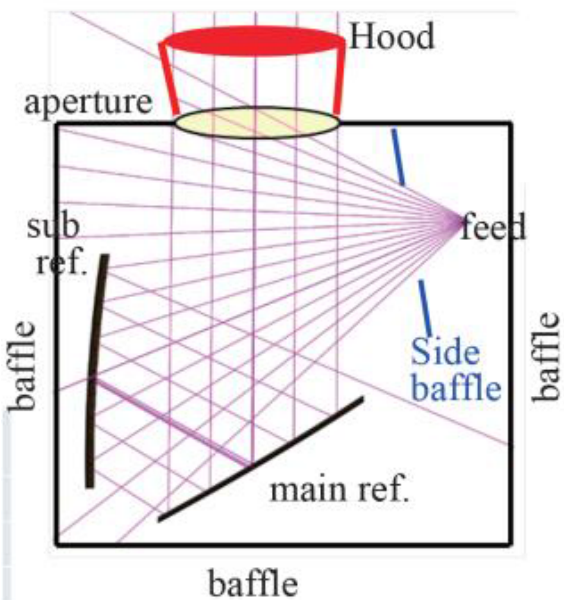

Superconducting magnetic bearing (SMB)



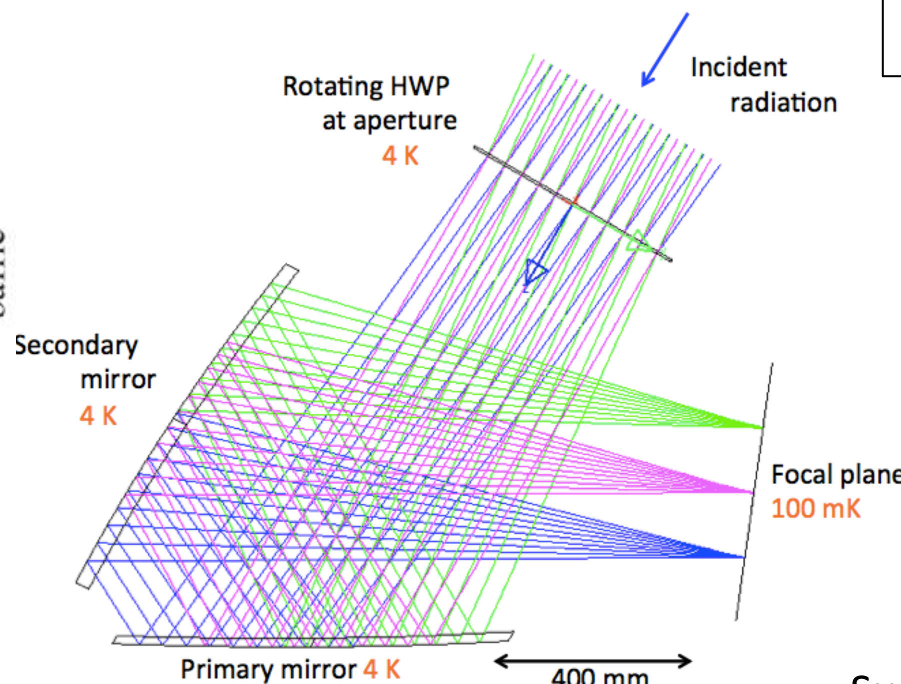
# Optical System

- Beam size：< 1 deg. at all the observing band
- FOV: 10 x 20 degs.

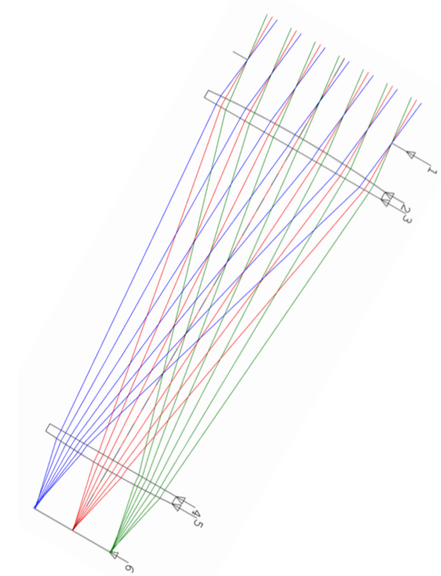
- Aperture Size: 40cm
- Covered by 4K shell
- Cold Baffle and Mirrors




Low-Frequency Telescope (LFT)
Crossed-dragone compact structure

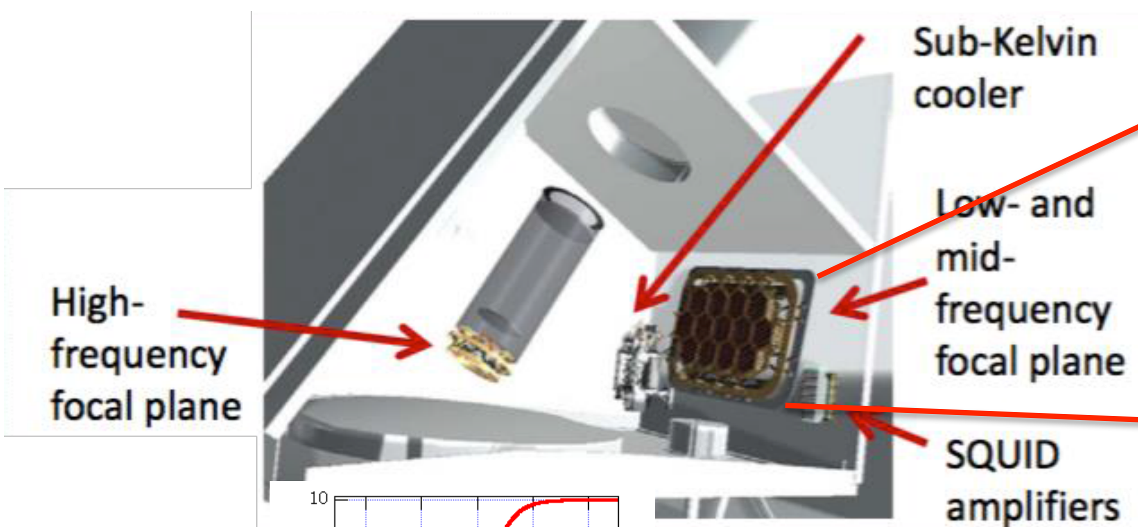



High-Frequency Telescope (HFT)
refractive telescope

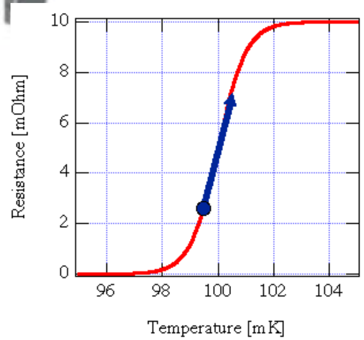


Sugai et al. (2016)

# Focal Plane Detectors

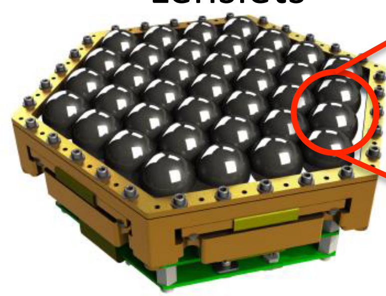


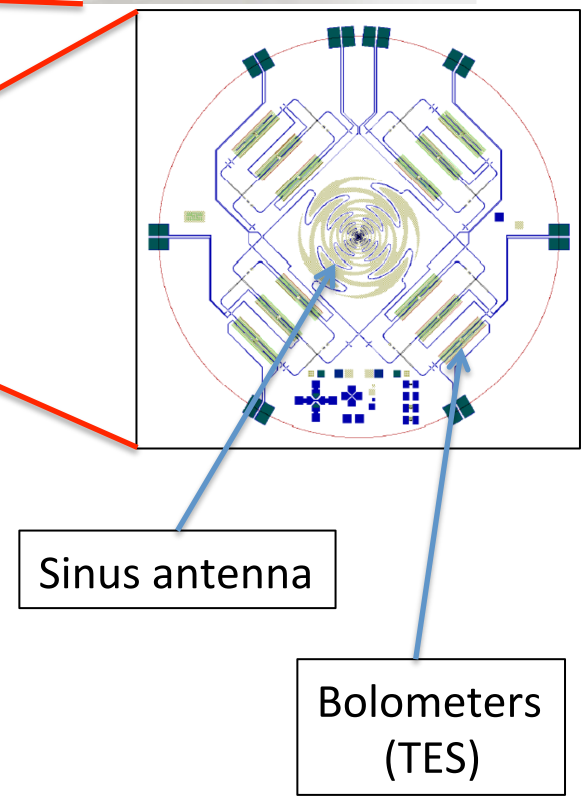

TES behavior




http://web.mit.edu/figueroagroup/ucal/ucal_tes/

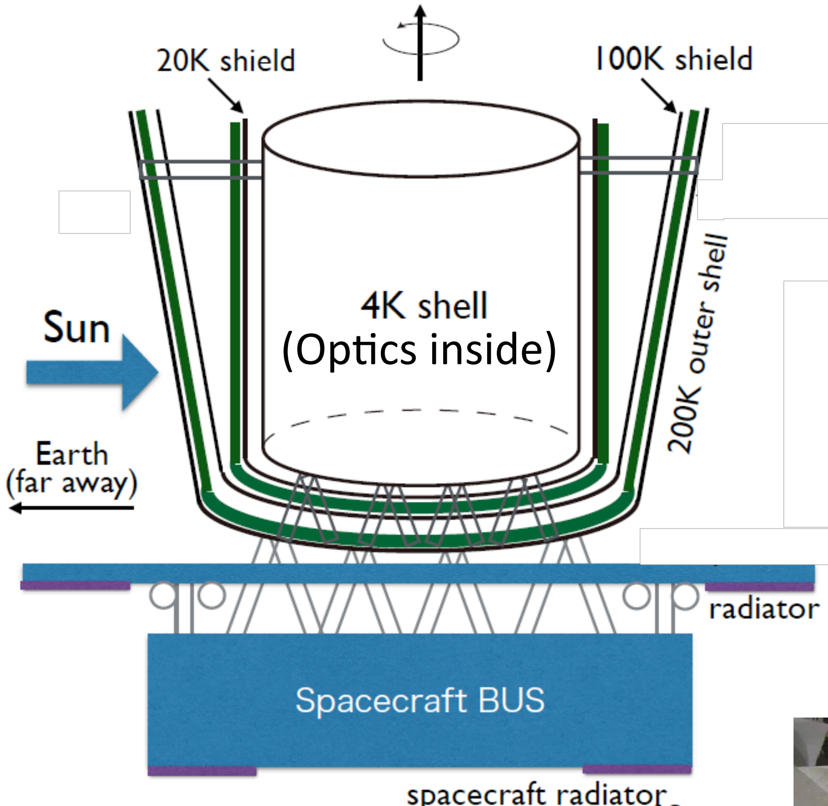
Lenslets



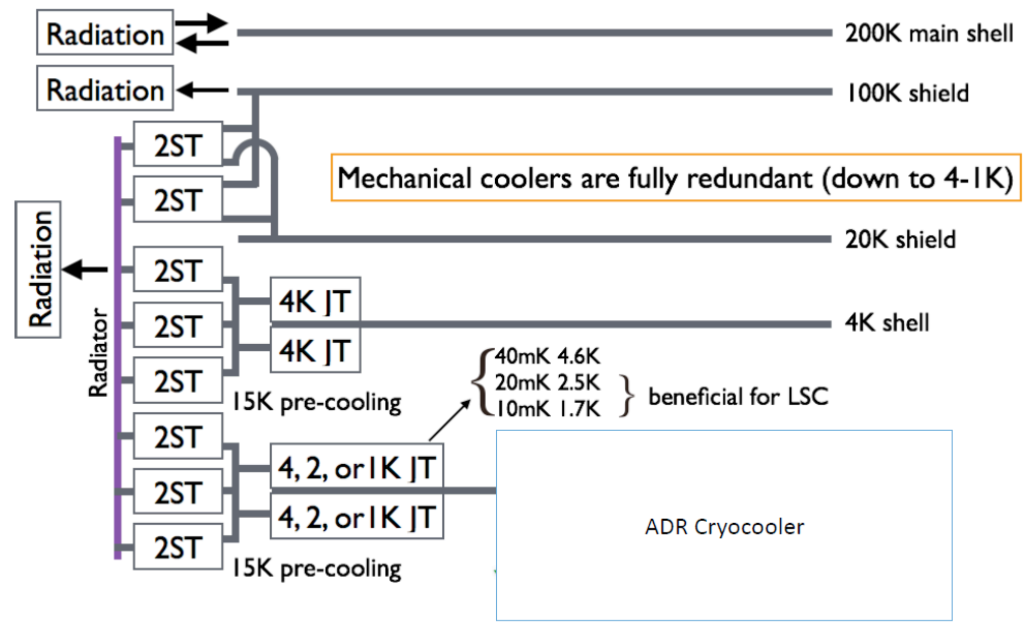



- Focal planes consist of arrays of detectors
- Each detector array covers certain freq. band
- Behind lenslet antenna and bolometers are arranged
- Bolometers (Transition Edge Sensors) are cooled to ~100mK to detect signals
- Signal readout from Bolometer by SQUID

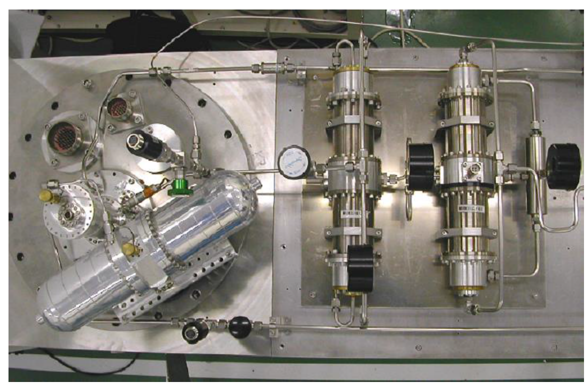
# Cryogenic system




## Cryogenic system above 2 K



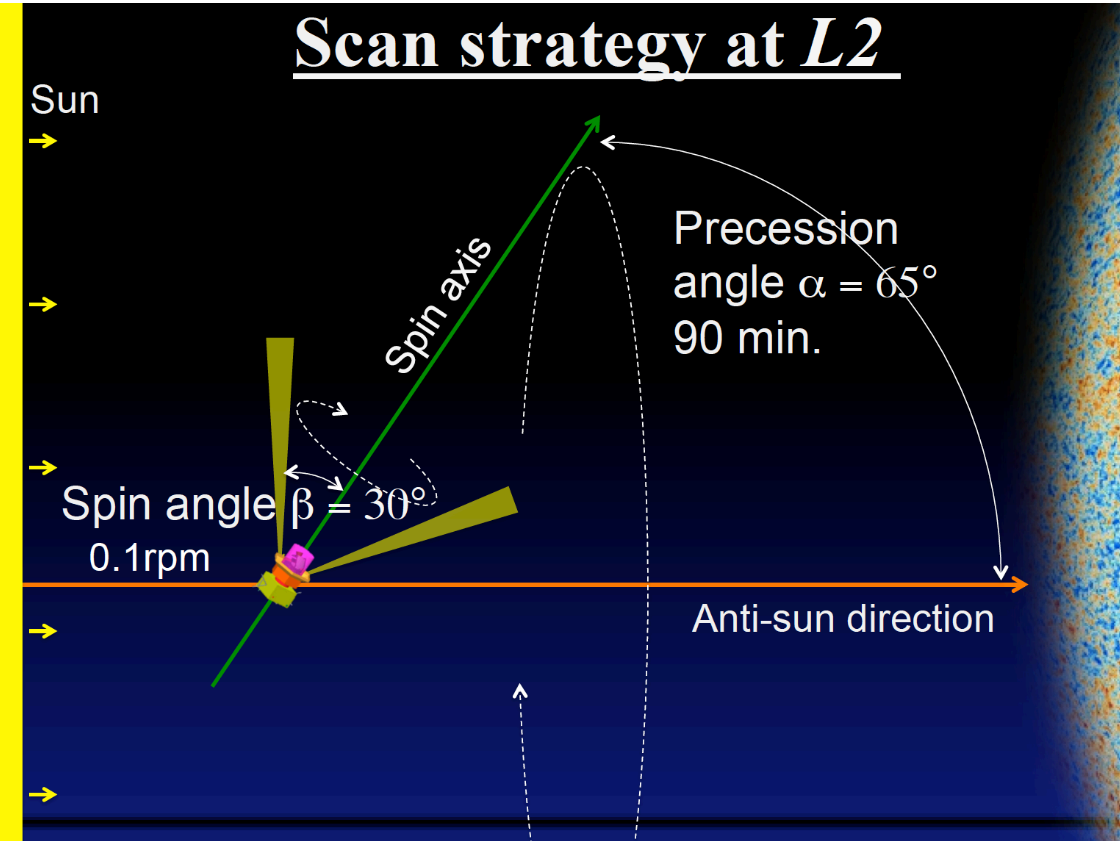

- Cryogenic system consists of JT/ST and ADR coolers.
- Covering optics in 4K shell is important to reduce thermal noise.



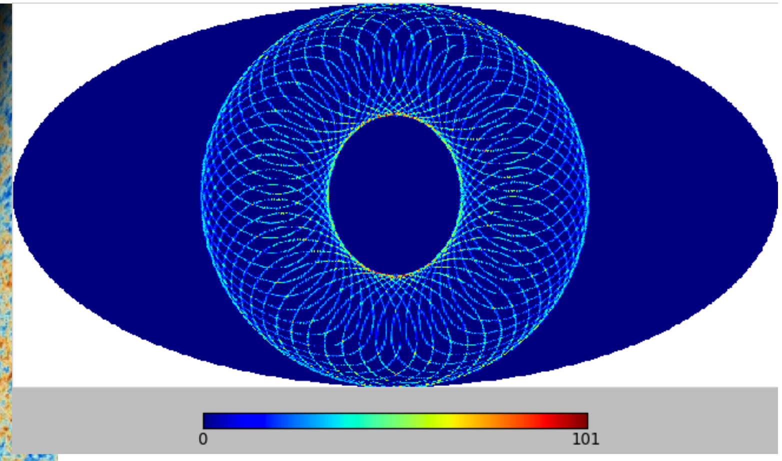
JT and ST coolers

ADR cryocooler

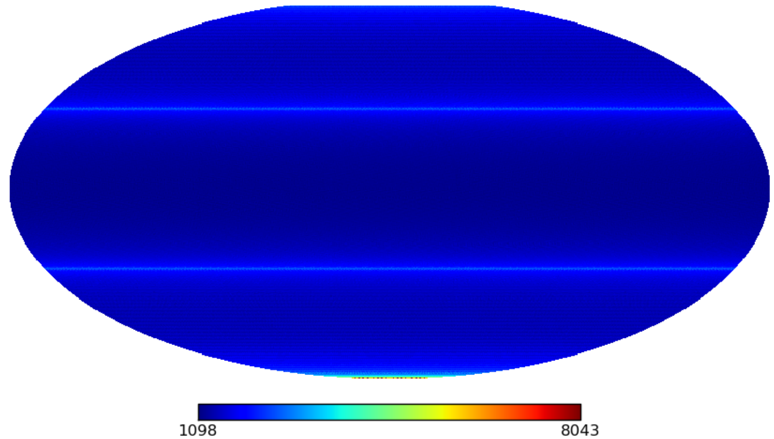
# All Sky Scan Strategy




One precession



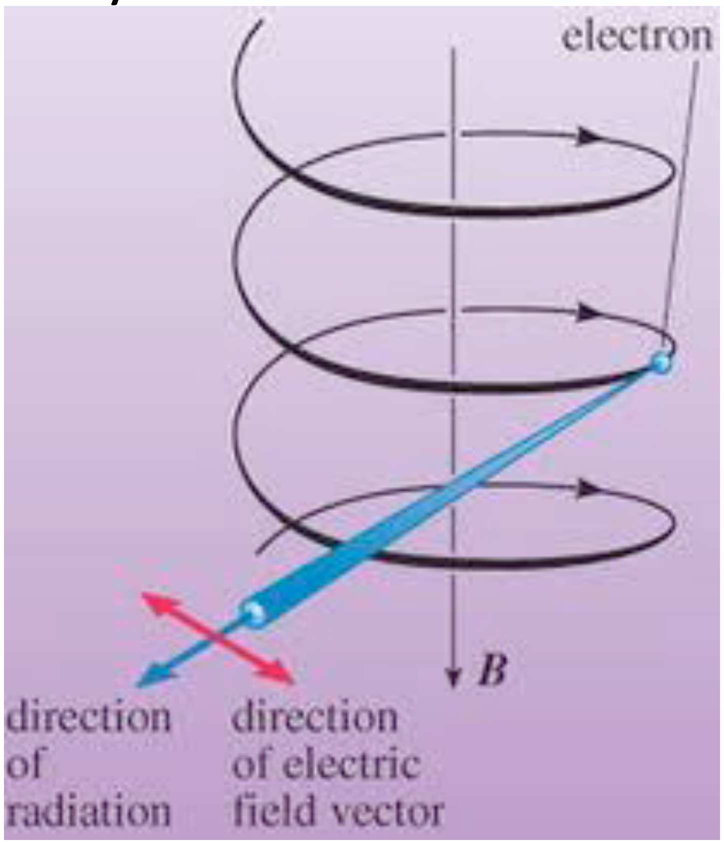

One-year hitmap



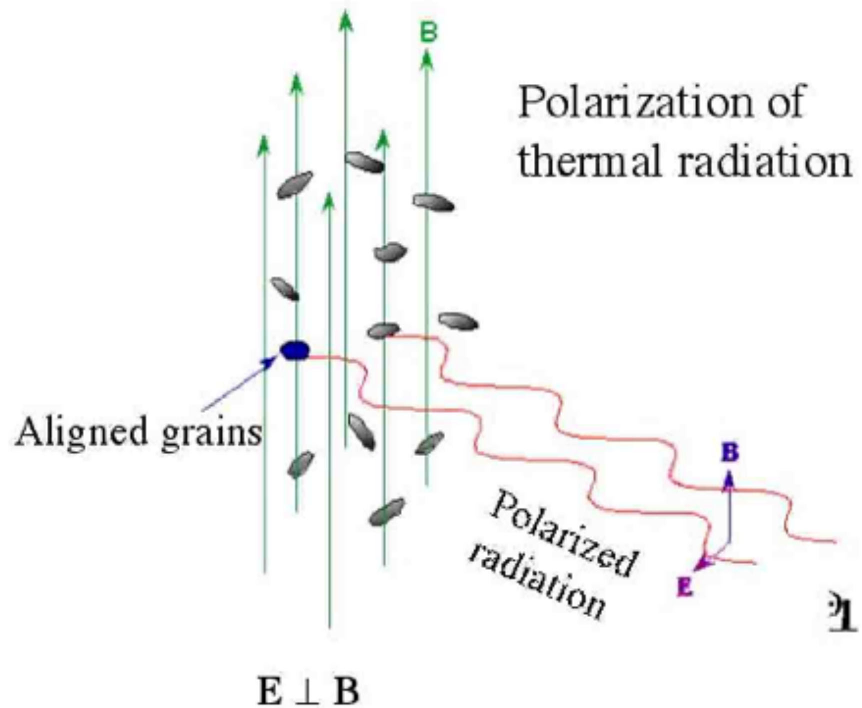

- Precession + spin angle < 95 deg. for full anti-sun direction scan
- Satellite scans all sky at L2 combining “precession” and “spin” motion

# Foreground removal

Synchrotron emission

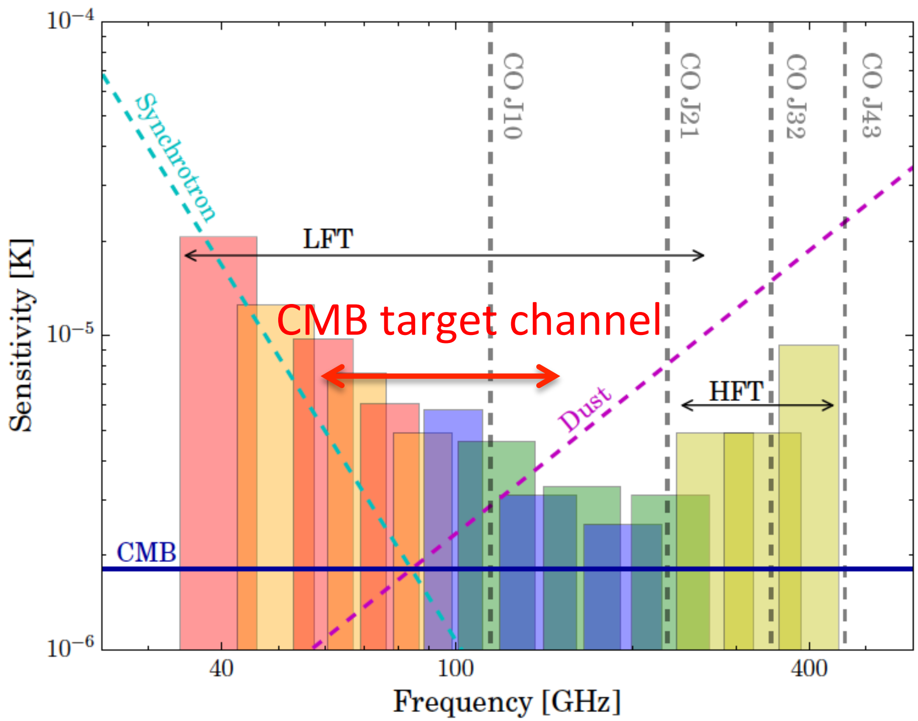


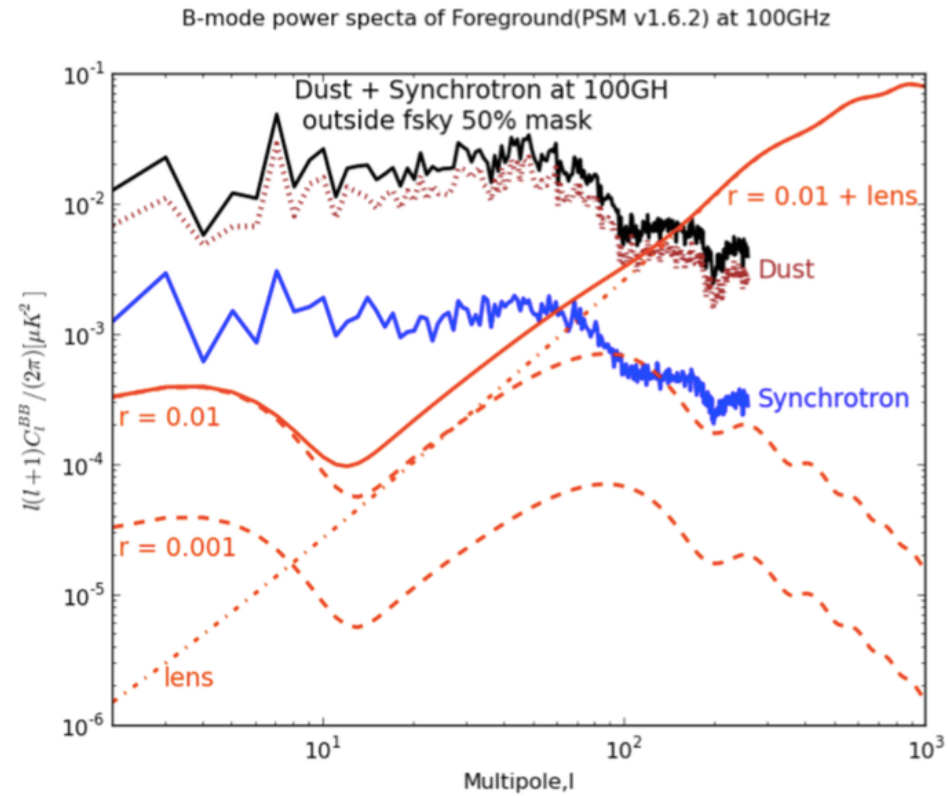

Dust emission




- Polarized signals generated by
  - Synchrotron radiation of electron in B field (appears Low Frequency)
  - Thermal dust radiation (appears in high frequency)
- Multi-band measurement allows to remove those foregrounds from the CMB signal

# Foreground removal (cont'd)

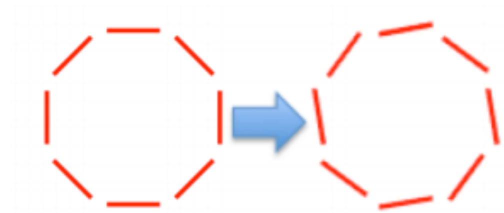


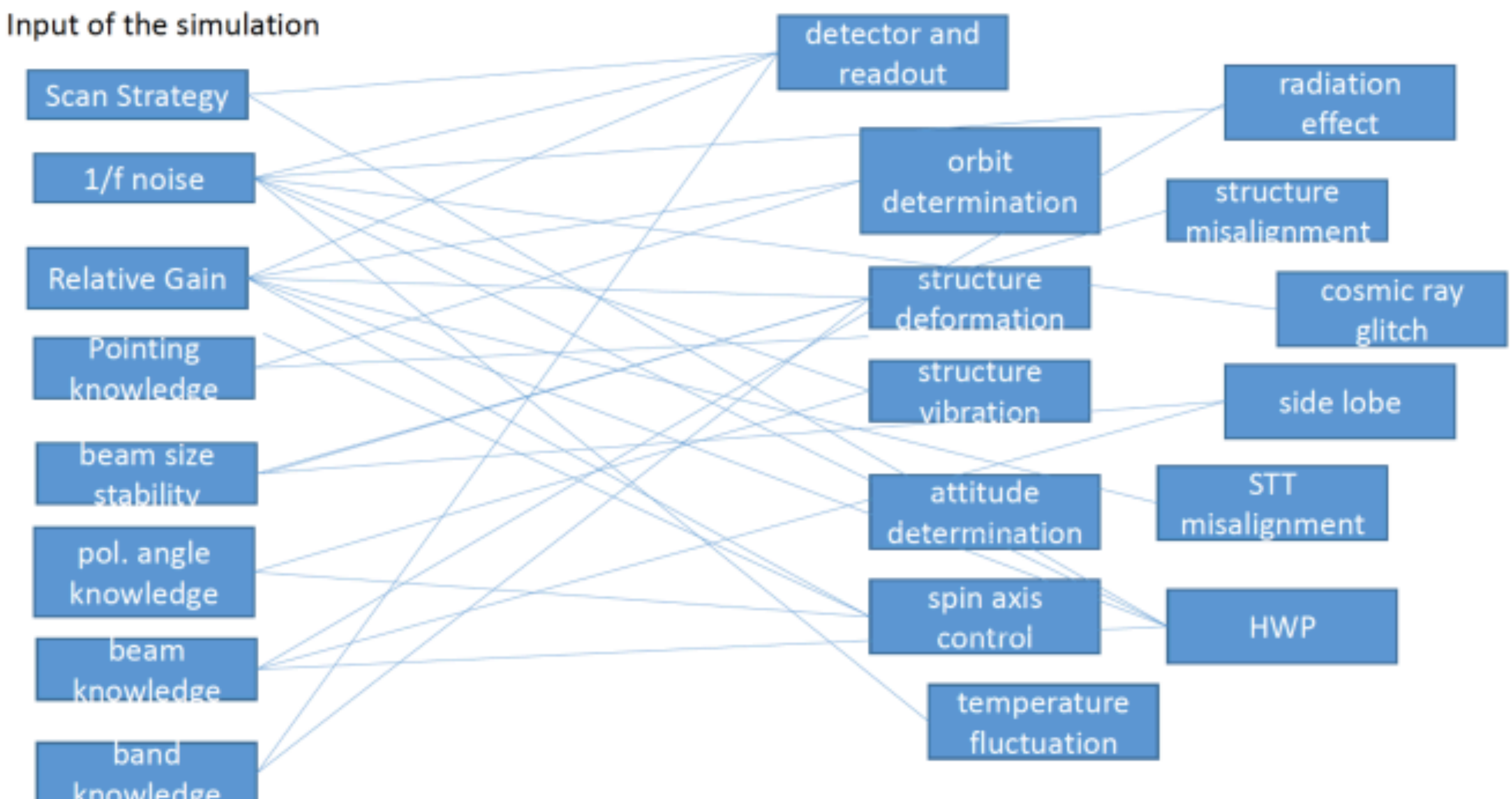




- Measure foreground spectra in many frequency bands to make "FG template" in CMB channel to remove them
- LiteBIRD has ~20 bands measurement capability to precisely determine foreground shape in the target CMB channel
- Very important to keep required sensitivity of $\sigma_r$

# Systematic uncertainties

- Systemstics is a major driver to achieve $\sigma_r$ <0.001.
- It's complicated !
  - 1/f noise
  - Polarization effect by optical instruments
  - Beam effect
  - And more…



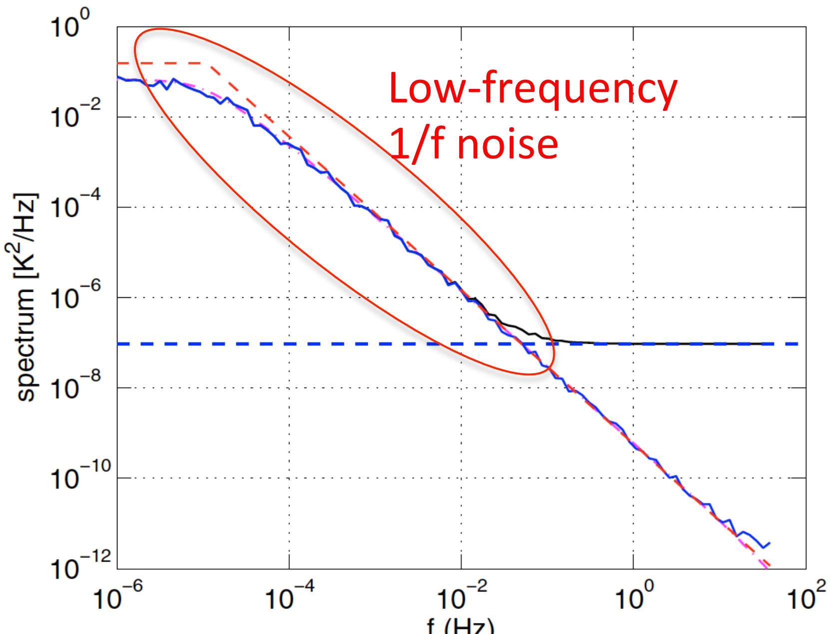



may be more "unknown unknowns"

# Systematic uncertainties (Some major sources)

- 1/f noise

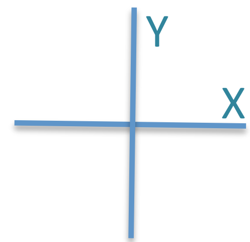
It can be reduced by HWP,
However still gives non-trivial effect



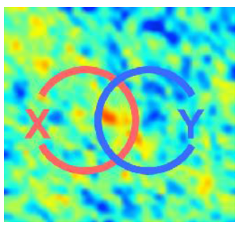

A&A 510, A57 (2010)

- Differential beam effect

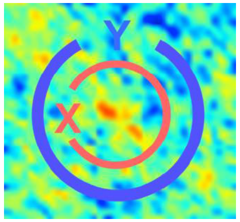
Assume a pair
of pol. detector X, Y



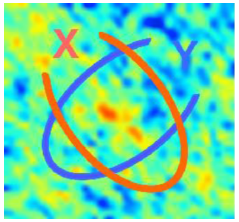

Pointing



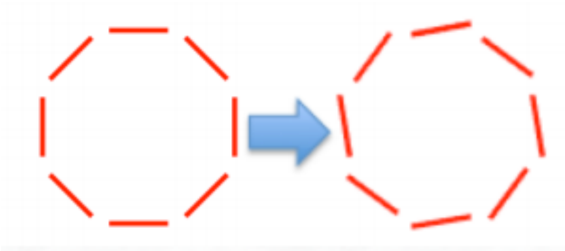

width



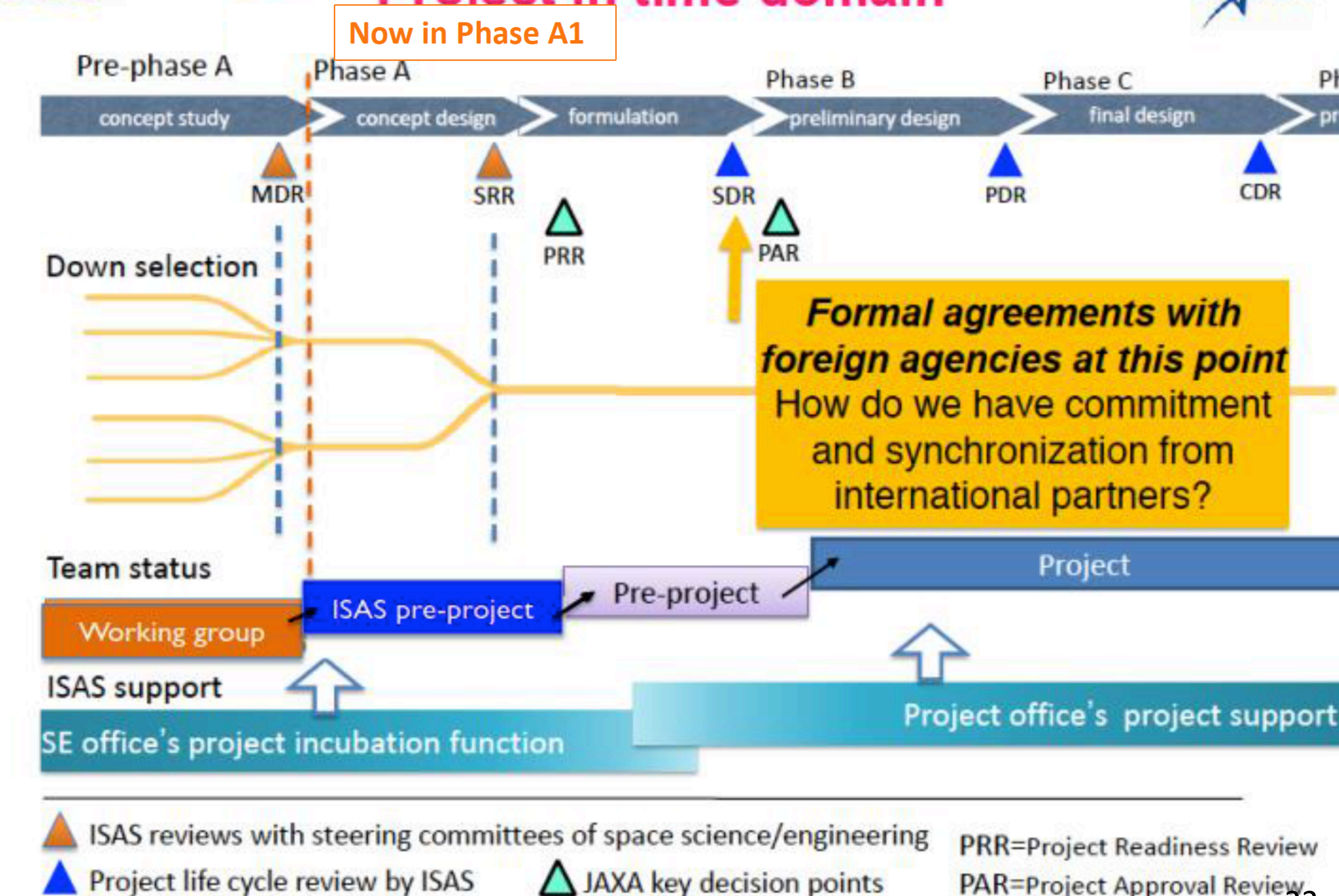

elipticity



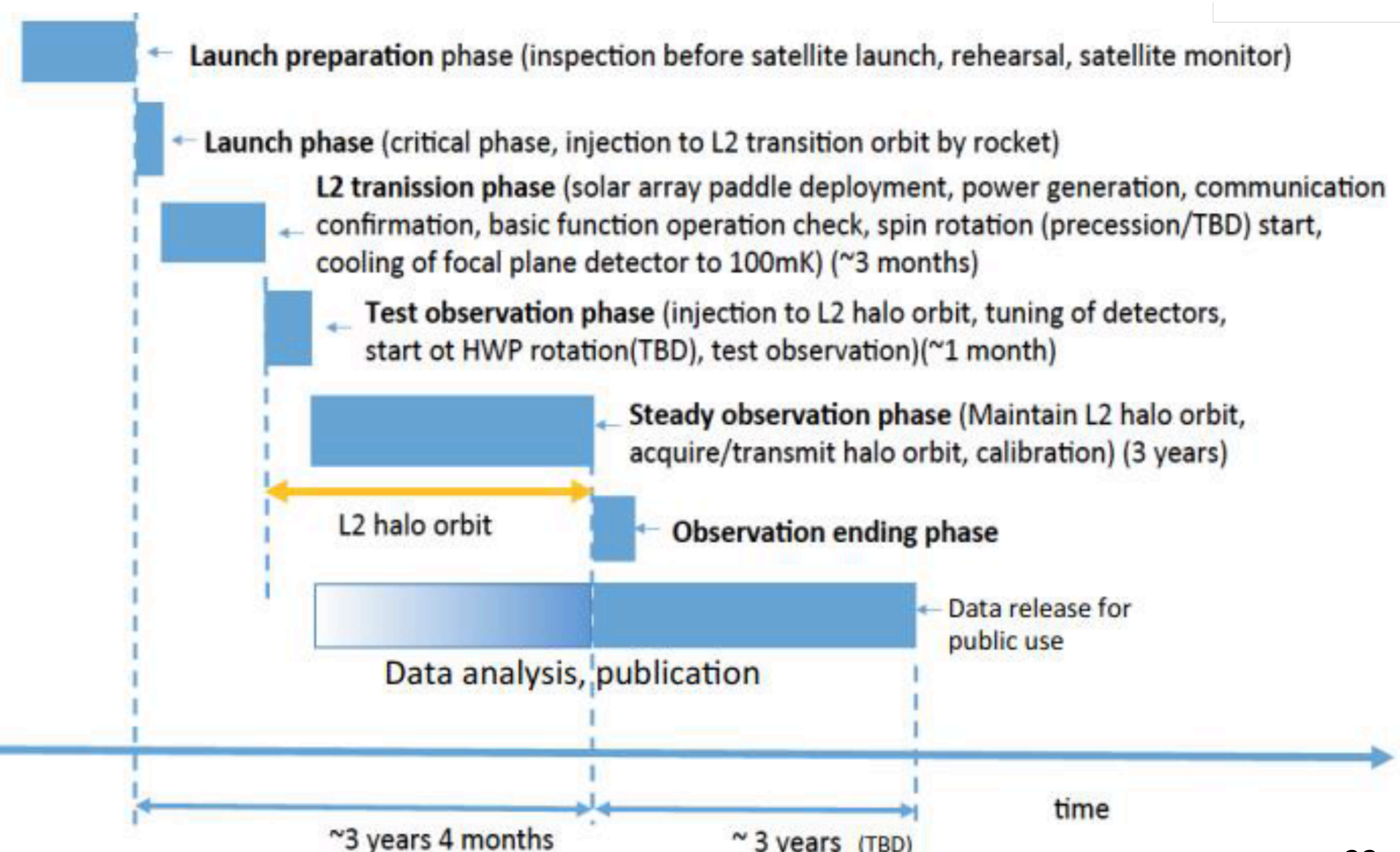

- Those make leakage to T, E mode → B mode, causing systematics
- Estimation and reduction of systematics are



# Project in time domain



# Project in time domain after launch



# Summary & Plan

- Detecting B-mode CMB is a challenging mission
- Observation from space by LiteBIRD satellite provides ultimate environment for the CMB polarization measurement
- Many challenging technologies
  - Half-wave plates, superconducting detectors, etc…
- Very exciting physics – top-down energy scale search from extremely high energy proving inflation theory !