LiteBIRD systematics

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Okayama University

2017/12/06 B mode from Space @ Berkeley

研究拠点形成事業
Core-to-Core Program

OKAYAMA UNIV.

Procedure of Systematic study

List up all the systematic items and put them to one place

↓

Implement individual systematics in a simulation with a map base, estimate B-mode power spectrum, and set requirements on the specification

↓

Combine all the systematics in map base, and evaluate delta r. The error budget assigned for systematics :delta r < 0.57 x 10^-3.

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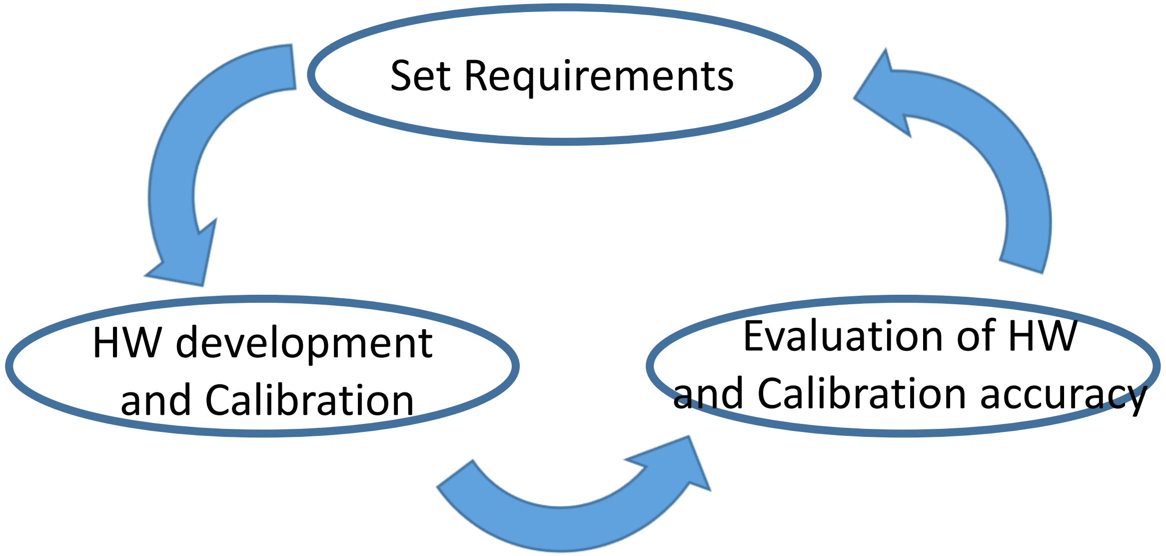
Combine all the systematics and FG removal in map base, given the calibration accuracy, and evaluate a single value of delta r.



History

- 2016/05/11 International Science Review in JAXA/ISAS
  - We showed a systematic table for options with and without HWP
  - Alpha=65 deg. was the baseline value, but needed to be examined.
- 2016/09/01 LiteBIRD Phase-A1 started
  - We submitted documents of Phase-A1 plan.
  - WBS was made
- 2017/01/23-25, LiteBIRD meeting at Montreal
  - 1/f noise study using MADAM was done by Ted Kisner (LBL) and Satoru Uozumi (Okayama U.), stating that HWP is needed to satisfy the full-success criteria.
  - Action items of the systematic study with HWP have been prepared (p.7)
- 2017/9/30, LiteBIRD global meeting
  - We have decided to use alpha=45 deg. for further studies
- 2017/10/23, Europe meeting
  - The systematic JSG activities were presented, collaboration with Europe people.

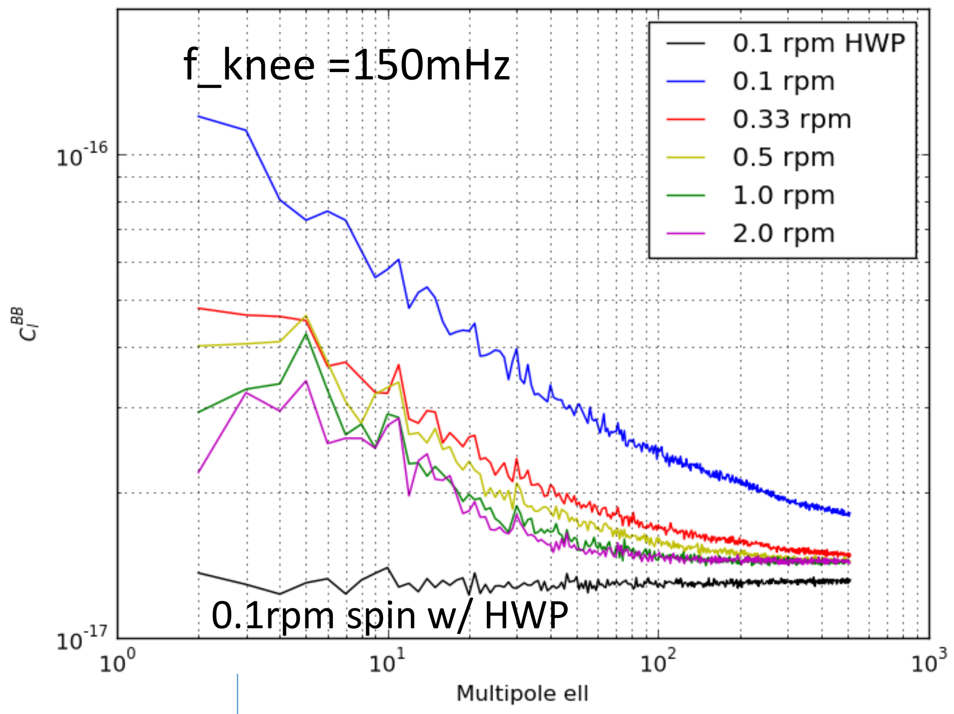
Summary of the systematics

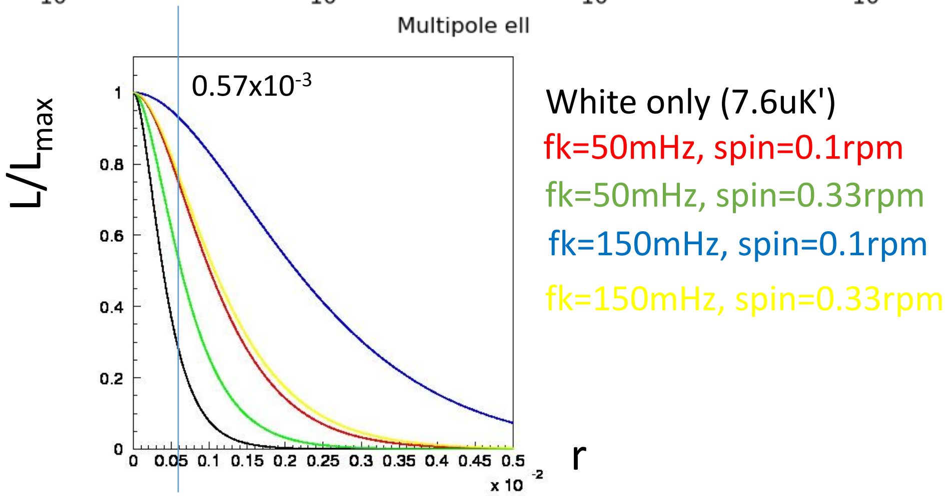
Category	Effect	Mitigation
Diff. gain	T -> B	Pol. Modulation
Diff. pointing	dT -> B	Pol. Modulation
Diff. beam width	dT -> B	Pol. Modulation
Diff. beam ellip.	dT -> B	Pol. Modulation
Pointing knowledge	E -> B	Star Tracker
Gain drift	E -> B	Gain calibration
Beam width drift	E -> B	Beam calibration
Pol. angle	E -> B	Cl_EB
1/f noise	Det. -> B	Pol. Mod. or Fast scan
Bandpass mismatch	T -> B	Pol. Modulation
Cosmic ray glitches	Det. -> B	Template subtraction
Time constant	Det. -> B	Calibration
Side-lobe	T -> B	Beam calibration
Half Wave Plate	T -> B, E -> B	Calibration

T: CMB 2.7K monopole, dT: CMB temp. anisotropies, E: E-mode pol, B: B-mode pol., Det.: Detector

Can the 1/f noise be mitigated with the existing de-striping?

Ted Kisner (LBL) and Satoru Uozumi (Okayama U.),





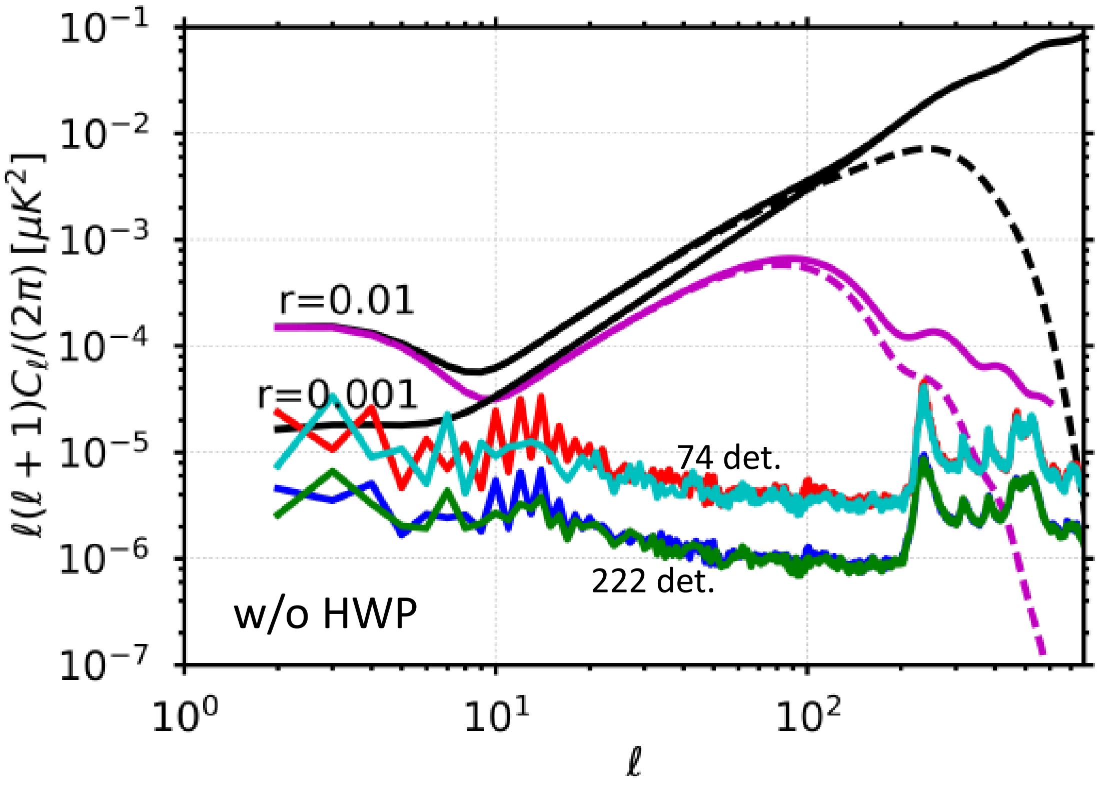
- The 1/f noise power spectrum is estimated using a simulation Toast/Madam in NERSC for various spin rate with and without HWP, shown in the left fig.
- In case the spin rate of 0.33 rpm, which is supposed to be the maximal achievable spin rate with the proposed S/C configuration, the increase in the power spectrum is a factor of 4 for f_knee=150mHz.
- We estimate delta r using a likelihood function.
- The results is summarized in the table below
- Lower fig. shows the likelihood function.

F_knee (Hz)	Spin rate (rpm)	Delta r (x10^{-3}) 68% C.L.
0	-	0.56
0.05	0.1	1.36
0.05	0.33	0.88
0.15	0.1	2.79
0.15	0.33	1.50

Bandpass mismatch systematics

Duc Thuong Hoang,[a,b] Guillaume Patanchon,[a] Martin Bucher,[a,c] Tomotake Matsumura,[d,e] Ranajoy Banerji,[a] Hirokazu Ishino,[f] Masashi Hazumi,[g,e,d,h] Jacques Delabrouille[a,i]

arXiv::1706.09486, accepted for publication in JCAP



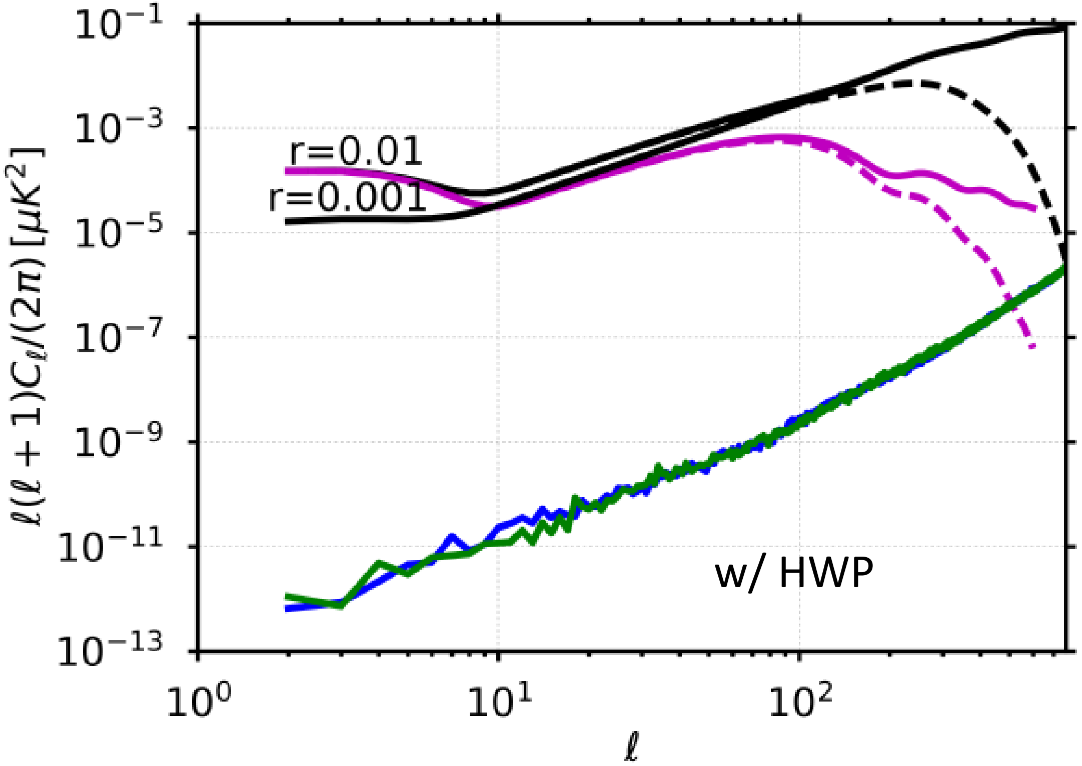


Figure 4. *EE* and *BB* leakage power spectra for $\alpha = 65°$, $\beta = 30°$, $\tau_{\rm spin} = 10$ min, $\tau_{\rm prec} = 96.1803$ min, and combining data for either 74 or 222 detectors. The red curve corresponds to *BB* with 74 detectors, the cyan to *EE* with 74 detectors, the blue to *BB* with 222 detectors and the green to *EE* with 222 detectors. The purple curve represents a model of primordial *B* mode power spectrum with fiducial cosmological parameters after Planck for $r = 0.01$, the black curves are including lensing for $r = 0.01$ and $r = 0.001$. The dashed curves show the effect of convolving with a 32 arcmin beam. This plot demonstrates the $1/N_{\rm det}$ dependance of the level of the power spectra.

Figure 7. ***EE* and *BB* leakage power spectra with rotating HWP** for $\alpha = 65°$, $\beta = 30°$ and spin period of 10 min with a HWP rotating at 88 rpm for 50 detectors.

Question: Do the HWP really improve the total systematic uncertainties?

Important to know the systematic uncertainties caused by the HWP.

Overall plan of HWP systematic Implementation in a simulation

Category 1

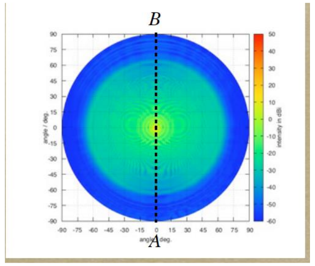
Implementation of HWP systematics in terms of a Mueller matrix.
Single frequency (integrated in frequency band with CMB spectrum), Gaussian beam

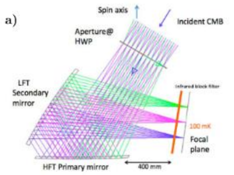
$$\begin{pmatrix} V_{II} & V_{IQ} & V_{IU} \\ V_{QI} & V_{QQ} & V_{QU} \\ V_{UI} & V_{UQ} & V_{UU} \end{pmatrix}$$

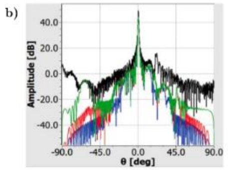
- Instrumental pol. (V_{IQ}, V_{IU}, V_{QI}, V_{UI})
- Pol. leakage (V_{QU}, V_{UQ})
- Reduction of total intensity (V_{II})
- Pol. efficiency (V_{QQ}, V_{UU})

Category 2

Introduce the realistic beam pattern including the side-lobe to simulate contamination from the intensive sources (galaxy, moon, earth, sun, etc.)

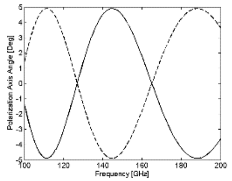


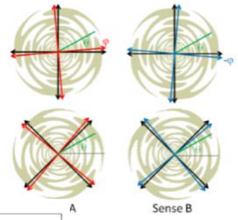


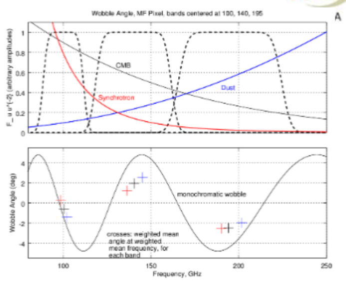


Category 3

Frequency dependence of phase difference, transparency and beam with FG removal.
Coupling to the detectors: wobble, non-linearity.
Cosmic ray glitches.
Cross talks, Time constant







Category 4

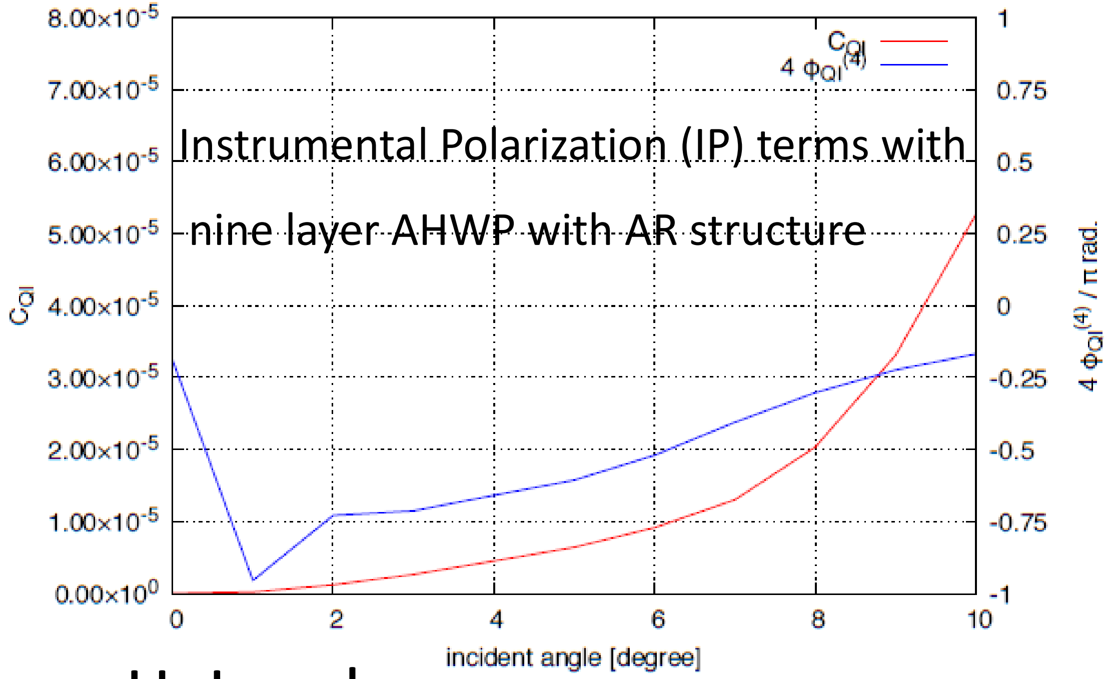
Time variation in gain, beam, noise, etc.
Gain diff. inter-band.
Common mode noise.
Pointing knowledge.
Ghost (btw. HWP and low pass filter, inside HWP)

Mueller matrix from RCWA simulation

Hiroaki Imada[1], Guillame Patanchon[2], and Hirokazu Ishino[3]
[1]ISAS/JAXA, [2]University Paris Diderot, APC Laboratory, [3]Okayama University.

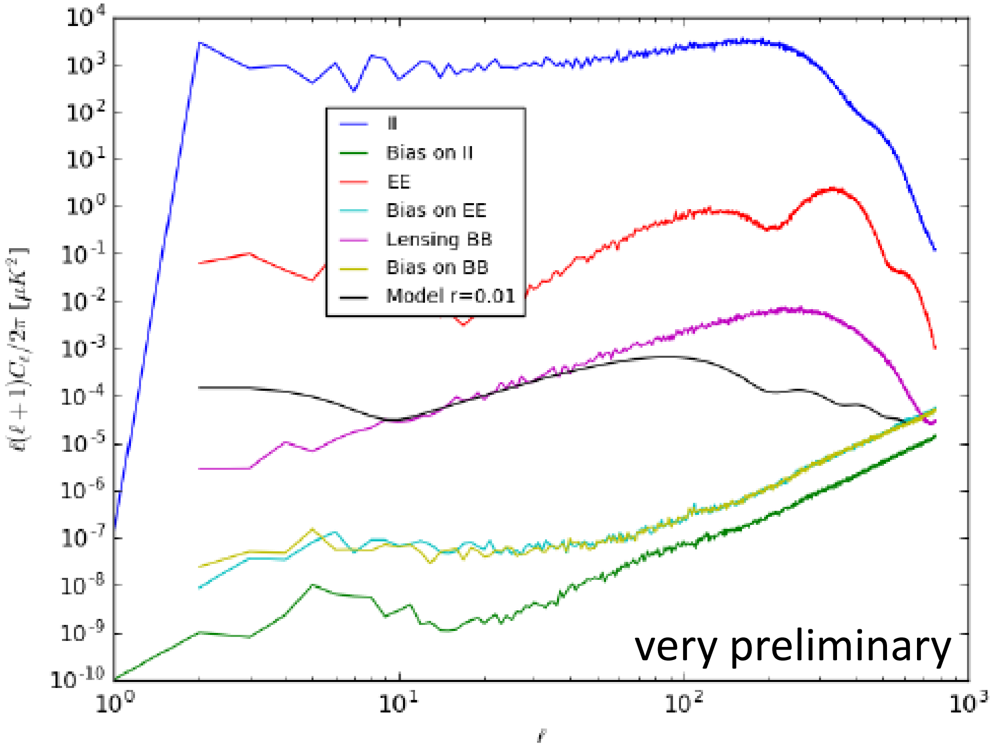
The HWP Muller matrix elements estimated by a simulation are expanded in a series of the HWP azimuth angle beta for the incident angle alpha:

$$M_{QI} = A_{QI}(\alpha) + B_{QI}(\alpha)\cos\left(2\beta + 2\phi_{QI}^{(2)}\right) + C_{QI}(\alpha)\cos(4\beta + 4\phi_{QI}^{(4)})$$



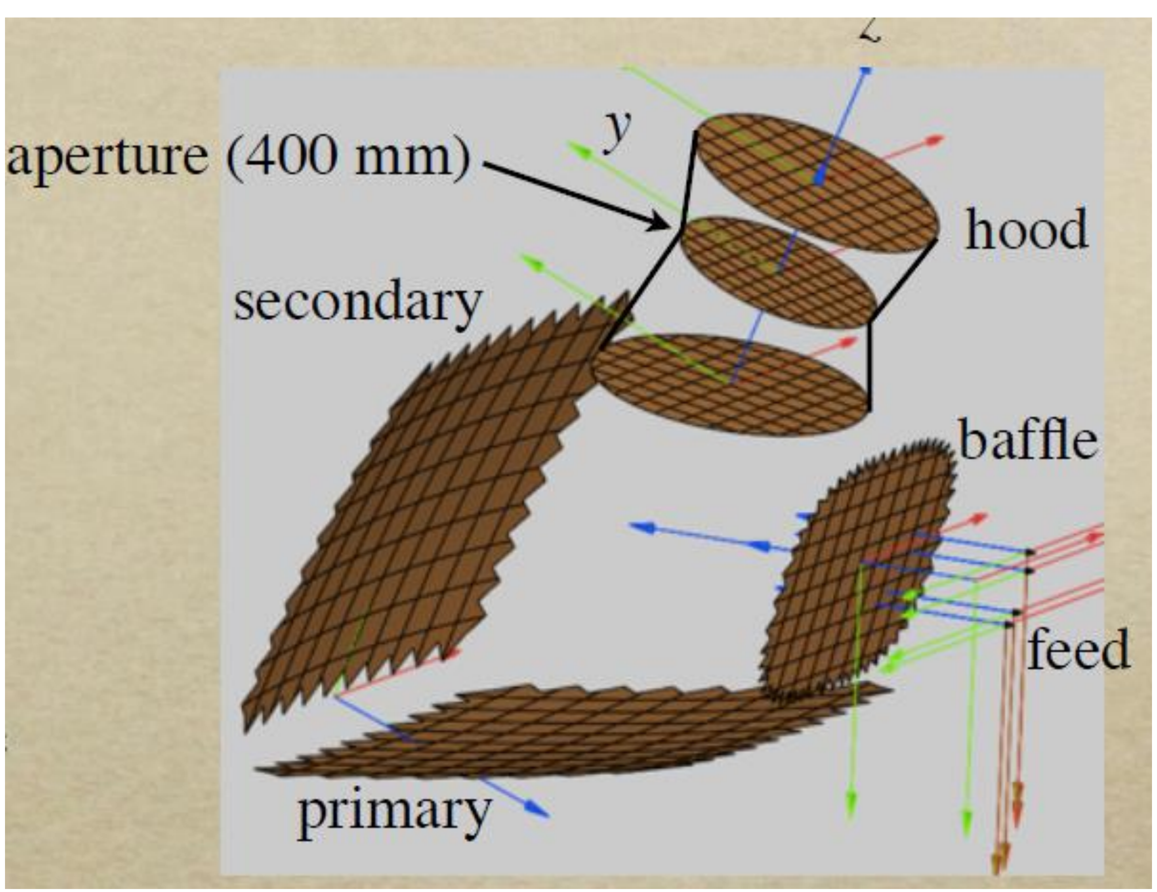
H. Imada

The HWP parameters from the RCWA simulation is injected to the Sanepic simulation to evaluate the systematic polarization power spectra.



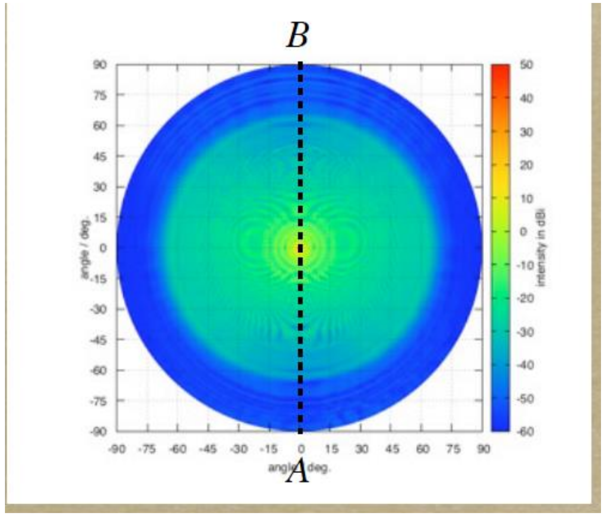
G. Patanchon

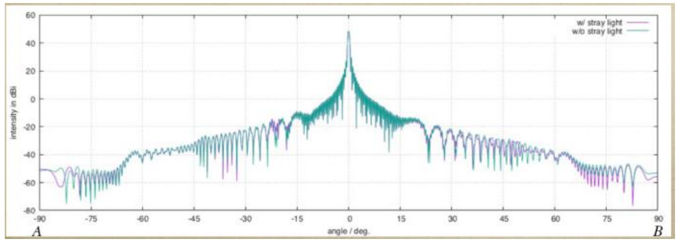
Beam Systematics



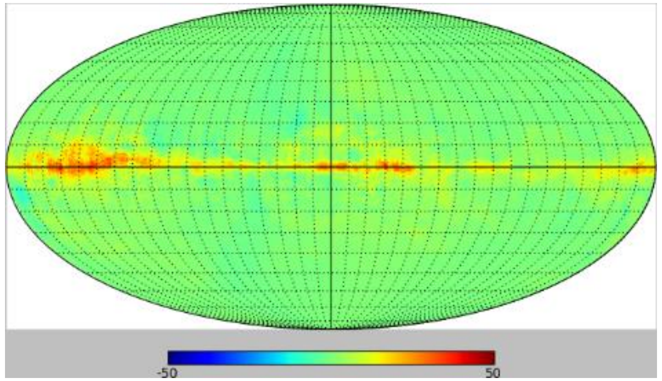
Low Frequency Telescope with a serration structure that mitigates the side-lobe contribution caused by the diffraction at the mirrors' edge. A GRASP simulation with the geometry is performed by H. Imada.

Obtained Beam pattern





FG map (H. Kanai)

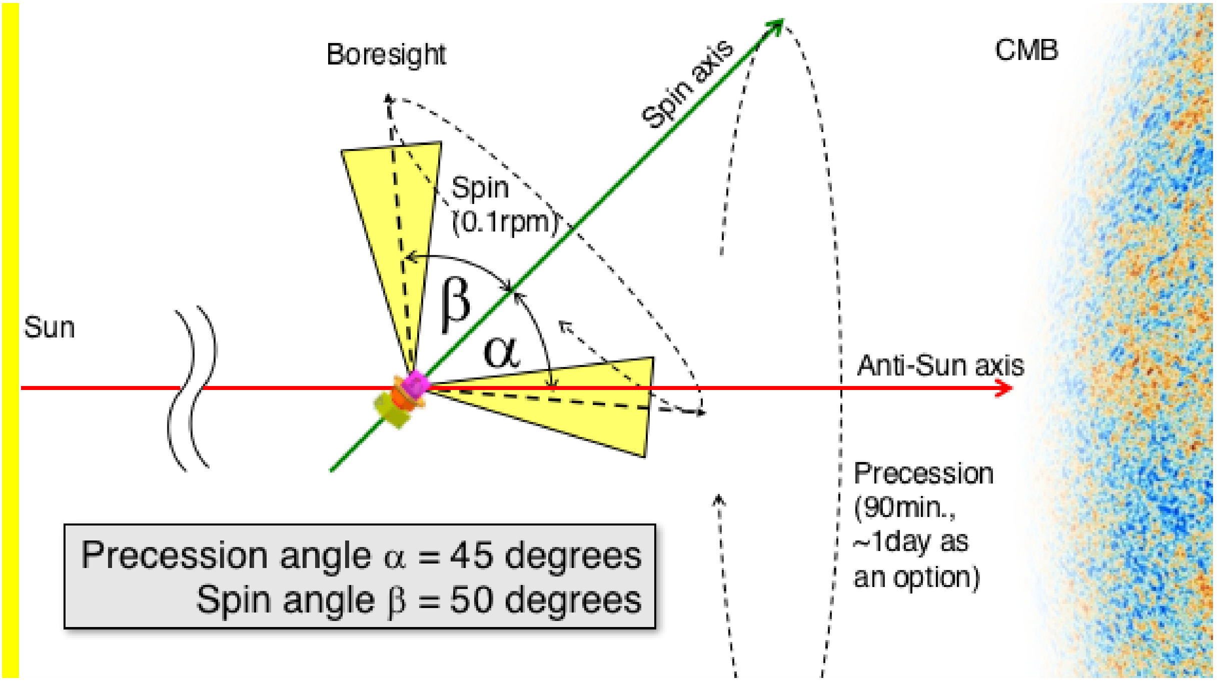


Foreground map scan is convolved with the beam pattern to obtain the reconstructed B mode power spectrum caused by the leakage from the side-lobe.

Under study by Ryo Nagata,

Scan Strategy

- Very important, as the scan is strongly related with the systematics for the CMB polarization measurements.

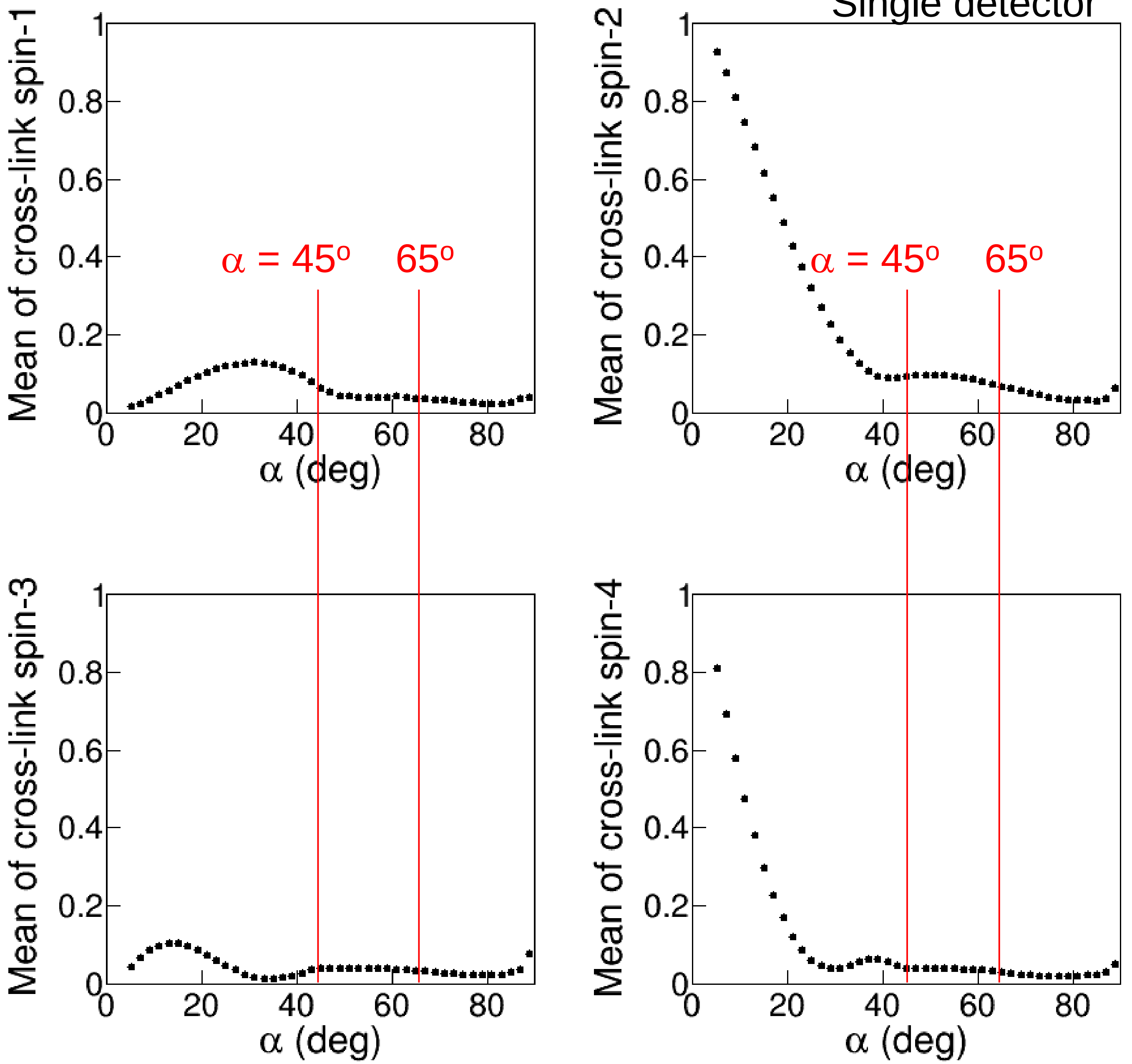


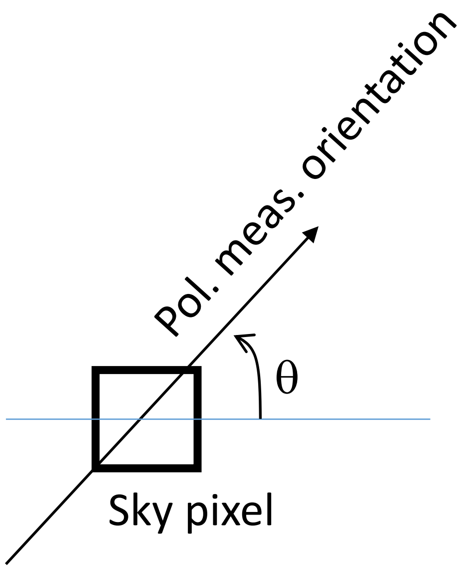
- LiteBIRD sky scan strategy is defined by three parameters :
  - Precession angle α (spin angle $\beta = 95^o - \alpha$)
  - Precession rate
  - Spin rate
- We also have two HWP revolution rates to tune.
- We compare two cases of α = 45 deg. and 60 deg. for details.

Cross-links v.s. α

Precession time = 1.51 hrs
Spin rate = 0.1 rpm
Single detector

S. Uozumi



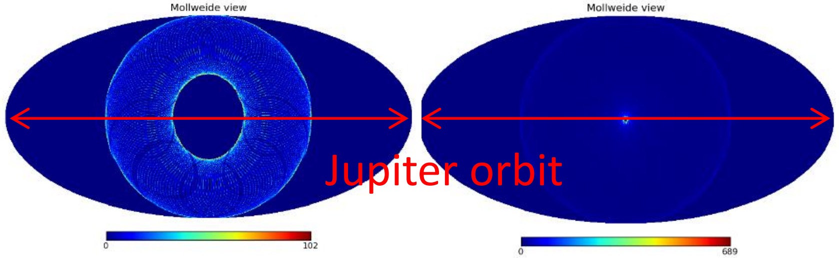


Cross-links spin n is defined as

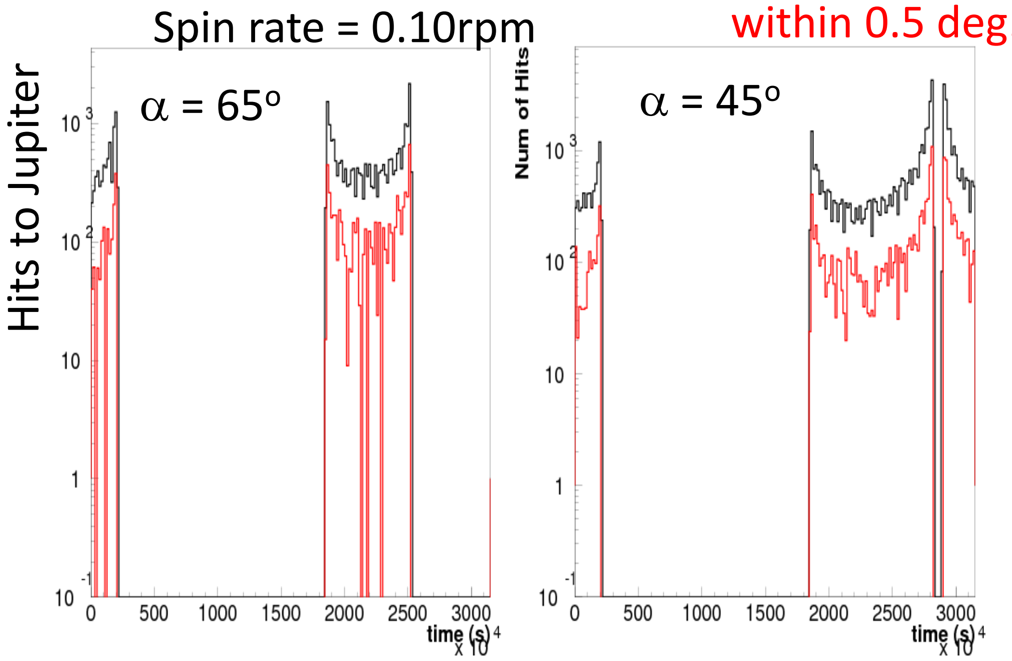
$$\langle \cos n\theta \rangle^2 + \langle \sin n\theta \rangle^2$$

Beam calibration with Jupiter

- Beam calibration is done using Jupiter (and other planets).
- More visible time of Jupiter gives more precise beam calibration.
- The Jupiter visible times are evaluated and compared between small and large-α.



Jupiter
within 1 deg.
within 0.5 deg.



Alpha	Spin (rpm)	0.5 deg.	1.0 deg.	5.0 deg.
65	0.10	3.56e2	1.46e3	3.77e4
	0.06	3.81e2	1.42e3	3.77e4
	0.02	3.49e2	1.51e3	3.88e4
45	0.10	7.13e2	2.99e3	7.78e4
	0.06	7.08e2	3.02e3	7.77e4
	0.02	6.24e2	2.78e3	7.84e4

H. Ishino

- Again for the beam calibration, the small-α shows twice more Jupiter visible time than the large-α case.

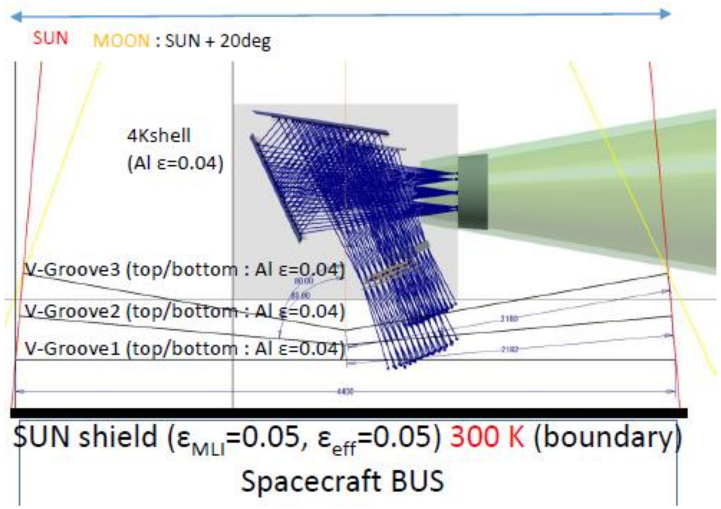
Large-alpha or small-alpha?

S. Uozumi

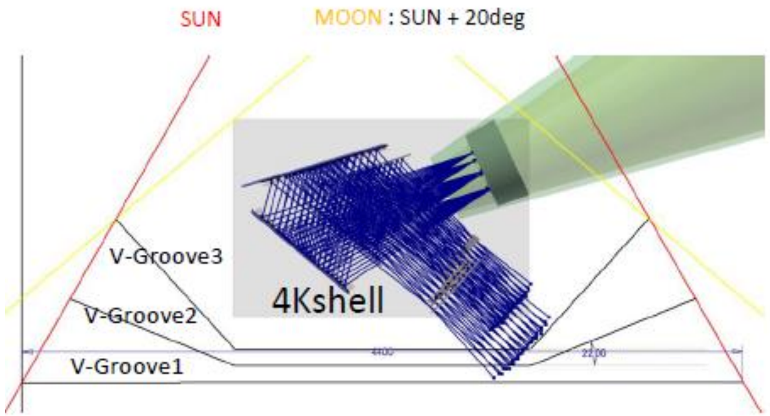
Items	Alpha=65°/Beta=30°	Alpha=45°/Beta=50°	Comments
Cross links	○	○	Large-α is slightly better than smaller-α
Hit uniformity	Larger hole, smaller RMS	Smaller hole, Larger RMS	Hits concentrate more around center hole w/ small-alpha option
Revisit time uniformity	△ (larger gaps in Δt dist.)	○	Hole size also affects to revisit time
Gain calib. w/ CMB dipole	△	○	~10% better with small-alpha option
Beam calibration w/ Planets	△	○	Planet visible time ~x2 longer with small alpha-option
1/f noise mit. w/o HWP	△	△	(Case for HWP is broken) no specific difference
Thermal (External Interfaces)	**Earth+moon to 4K**: 0mW **Sun to outer shell**:794W **Shadow**: TBC	**Earth+moon to 4K**: 0mW **Sun to outer shell**: 911W **Shadow**: TBC	Light from earth/moon, Heat radiation plates, Shadow around the aperture Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45
Thermal (Internal Interfaces)			Optical system support structure, Thermal Interfaces among the cold mission components, Thermal distribution
Optics	**Baffle requirements**: h>300mm	**Baffle requirements**: h>300mm	Side-lobe, Support Structure, Stray light Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45
Solar panel	Requirement: > 3894 W	Requirement: > 4990 W	Sizing
Telemetry			Antennas for X/S bands
Thruster/propellant	**Propellant**: 542.0kg (Lissajous)	**Propellant**: 255.9kg (Halo)	Position of Thruster, amount of propellant
Reaction Wheel			Specification
HWP			Position/Angle
Refrigerators	2ST × 3 + JT × 2	2ST × 3 + JT × 2	Positions, Interfaces, Thermal conduction, Vibration
Focal plane detector			Thermal interfaces, Length of harness
Cost			
mass	**4K shell + absorbers + mag shield**: 83.3kg	**4K shell + absorbers + mag shield**: 89.4kg	Values for α=65 are in the case of on Lissajous orbit , no orbit dependencies when α=45

Note on the scan strategy

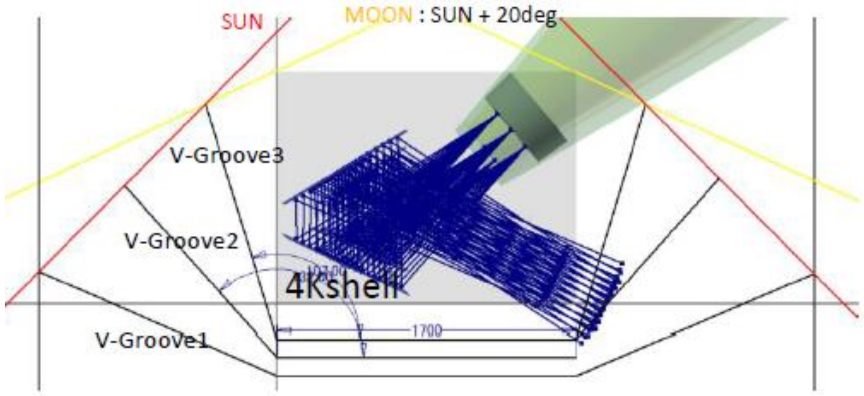
- We still do not reject possibilities to have the α values less than 45 deg.
  - Need more tuning for the five parameters to decide the final values in terms of not only the systematic studies but also the hardware constrains.
  - Thermal condition is under investigation by T. Hasebe.



α=5, β=90 deg.



α=30, β=65 deg.



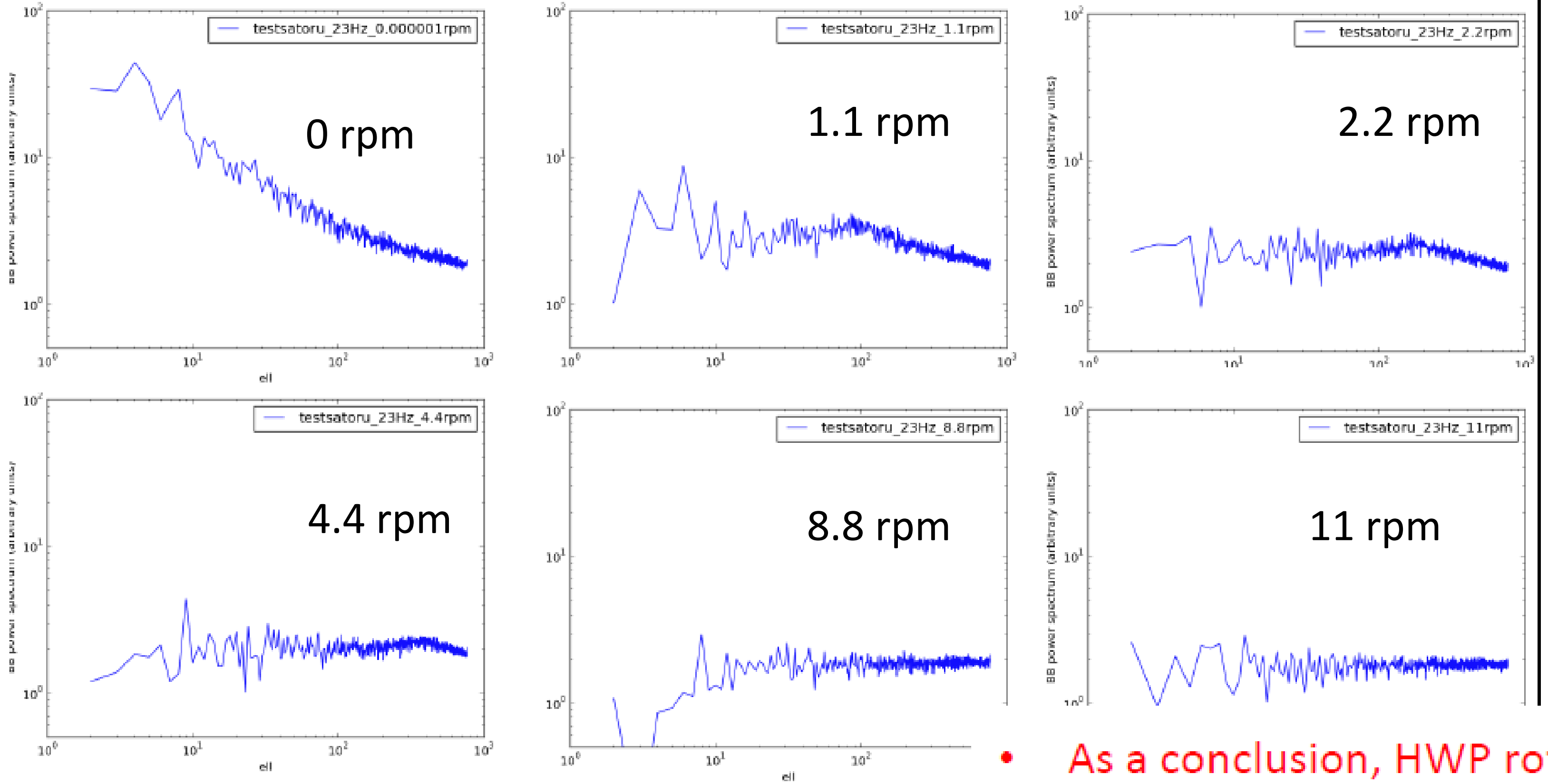
α=45, β=50 deg.

The 1/f noise BB spectrum for various HWP revolution rate with Sanepic

S. Uozumi, G. Patanchon

- 1/f noise elimination v.s. HWP rotation rate is evaluated using Sanepic (coded by Guillaume)

Sanepic B spectra after demodulation
Input : white + 1/f noise (f_{knee}=0.05 Hz)
Single detector



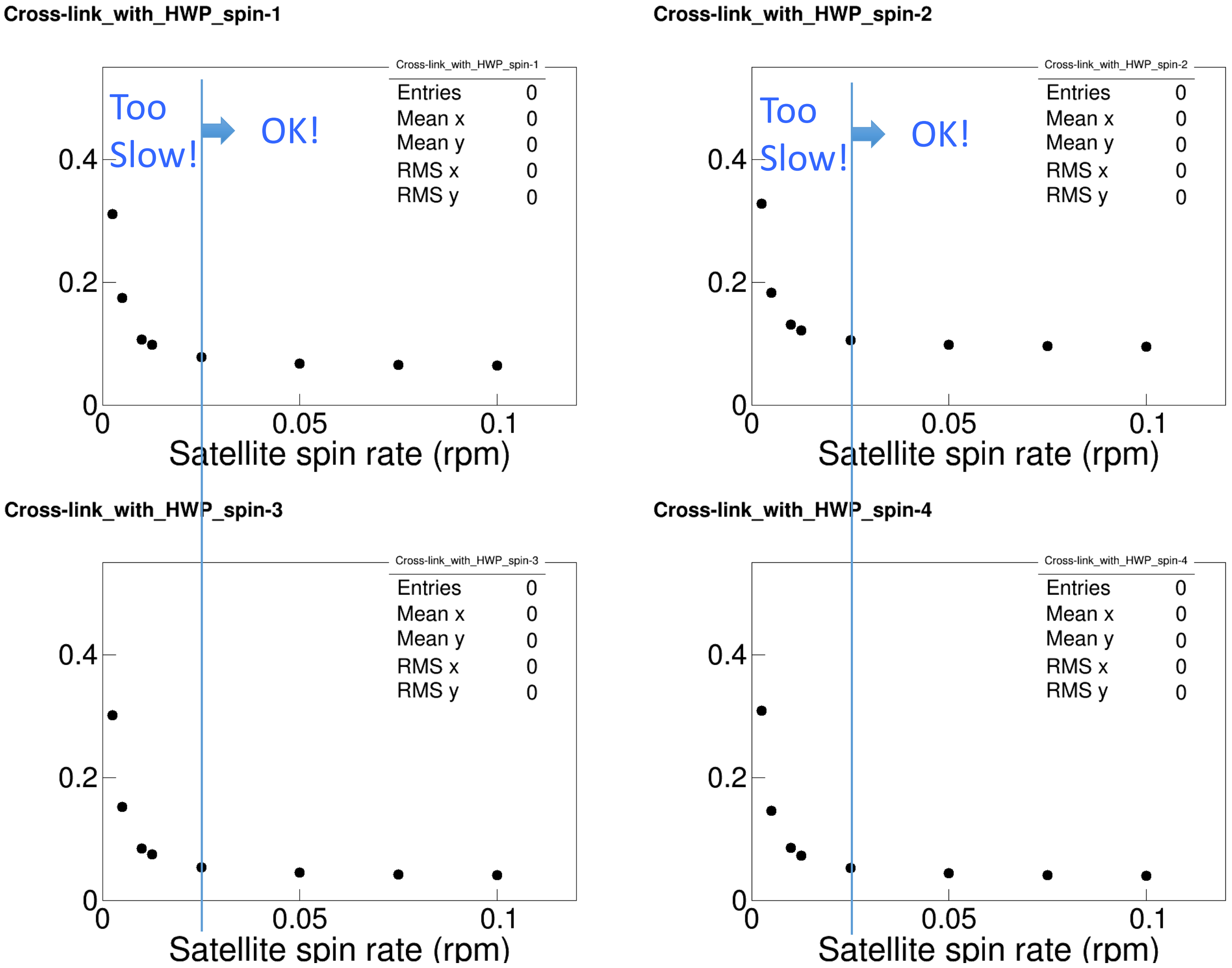
Preliminary

The current baseline revolution rate is 88 rpm.

- As a conclusion, HWP rotation rate about > 10 rpm is enough for our purpose (case for f_{knee}=0.05 Hz)!
- Might not correlate with satellite spin& precession rates.
- f_{knee} = 0.15 Hz will be tested soon.

Cross-link v.s. Satellite spin rate (small-α case)

S. Uozumi



Preliminary

Summary

- Concept development with HWPs is pushed forward
  - 1/f noise mitigation seems to be insufficient to satisfy the requirements with the existing software
  - Bandpass mismatch studies also show the significant reduction of the systematics with HWP
- Needs to estimate the HWP systematics
  - We have listed up possible systematic items.
    - The Mueller matrix of the nine layer HWP with AR is calculated using a RCWA simulation.
    - The Instrumental Polarization effect is estimated in terms of the B mode power spectrum.
    - Beam effect is being evaluated
- LiteBIRD scan strategy
  - Precession angle α = 45 deg. is chosen as the current baseline.
  - Need more study to optimize not only from the systematics but also from the hardware constrains.