小型科学衛星LiteBIRDの全天スキャンの最適化とデータサイズの研究

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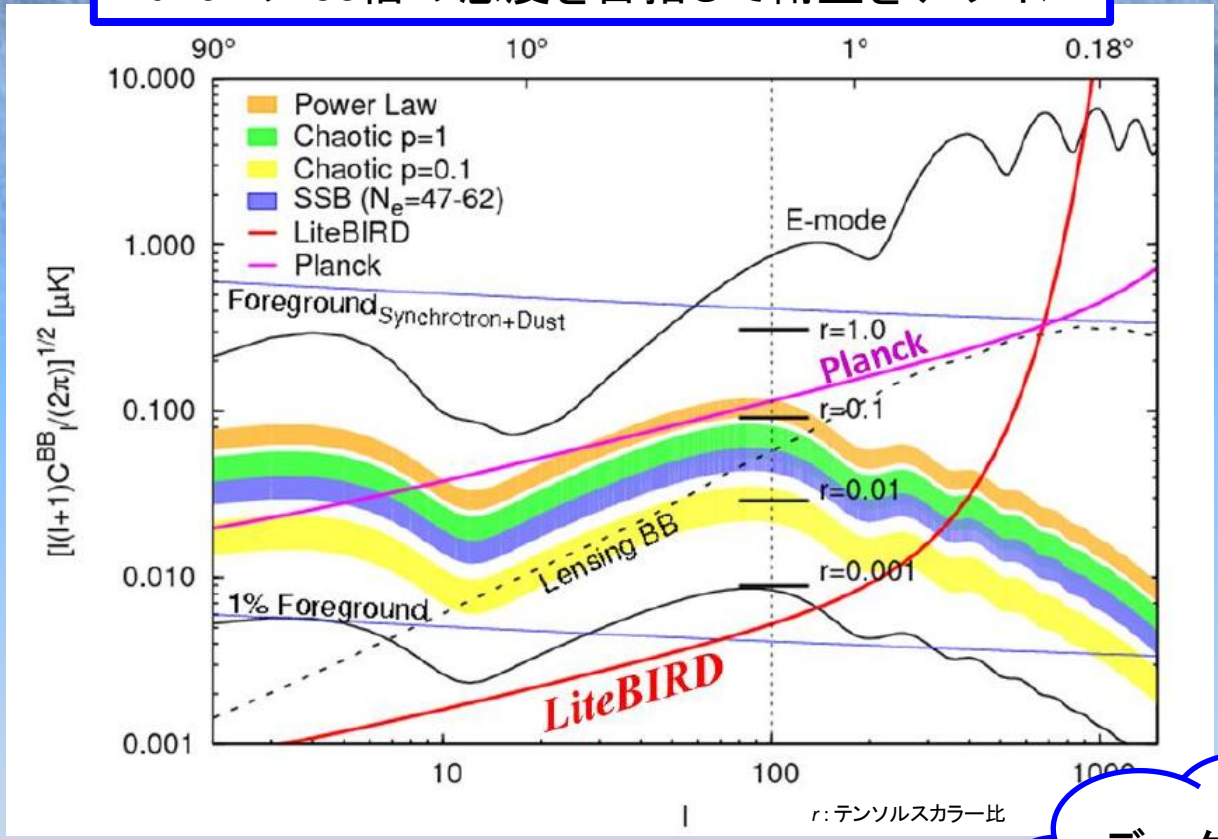
他LiteBIRD ワーキンググループ

Goal for LiteBIRD

Planckの100倍の感度を目指して衛星をデザイン



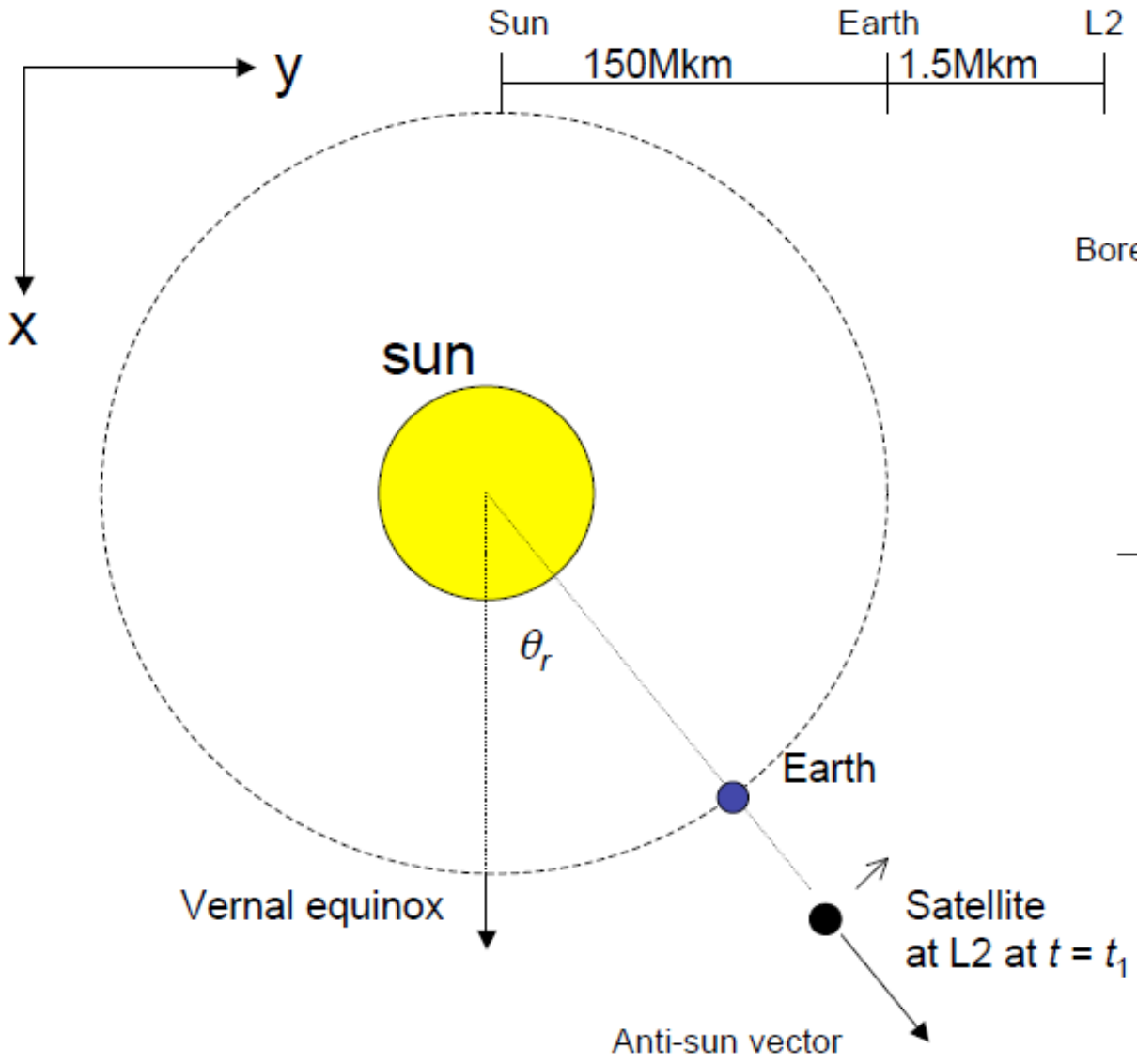
データ転送が成立するか？

検出器の数　2×10^3 pixels　←松村発表

scan strategy　spin rate等

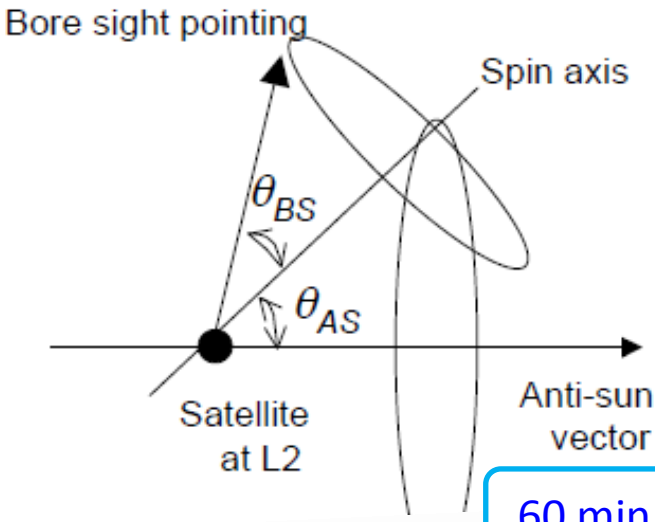
テレメトリのデータレート 利用可能な地上局、可視時間等で制限

L2 option

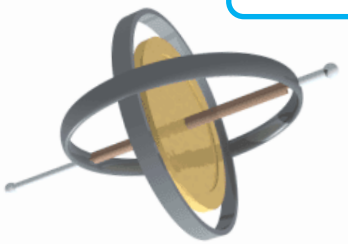


f_{knee} = 0.1 Hz
assuming TES

spin rate = 6 rpm



60 min



Sampling rates

データ圧縮をしないと.....

Freq [GHz]	Beam [arcmin]	Ndet [#]	Sampling Rate [Hz]	Data rate [kbps]
60	73	312	97	484
80	55	312	129	644
100	44	746	161	1921
150	29	434	244	1694
220	20	434	354	2458
total		2238		7201

1 sample : 16 bitを仮定

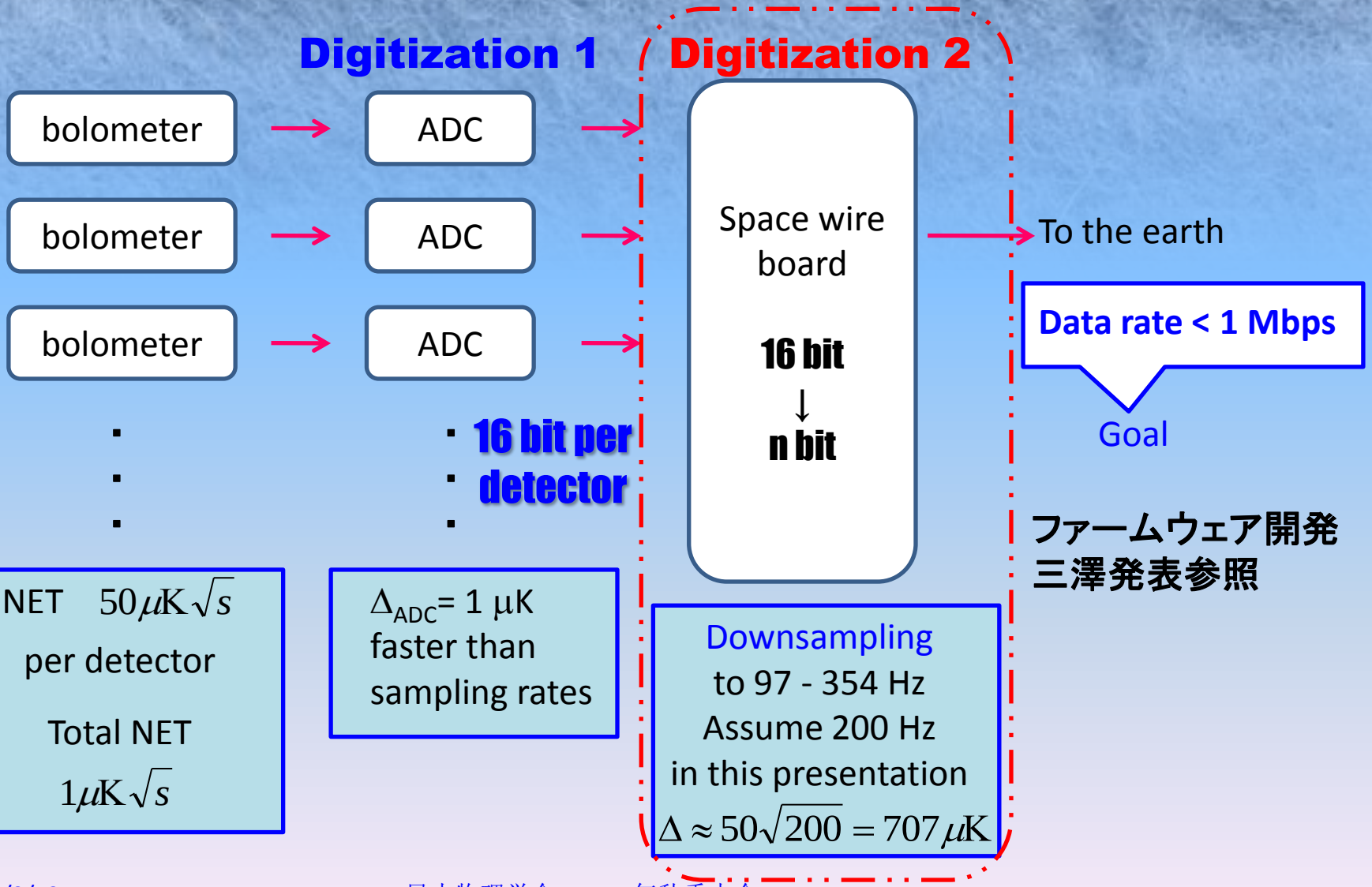
Sampling rate = 2 × Nyquist

Spin rate = 6 rpm

圧縮

X帯 4Mbps
可視時間 6h @ L2
→ < 1Mbps

Data Compression

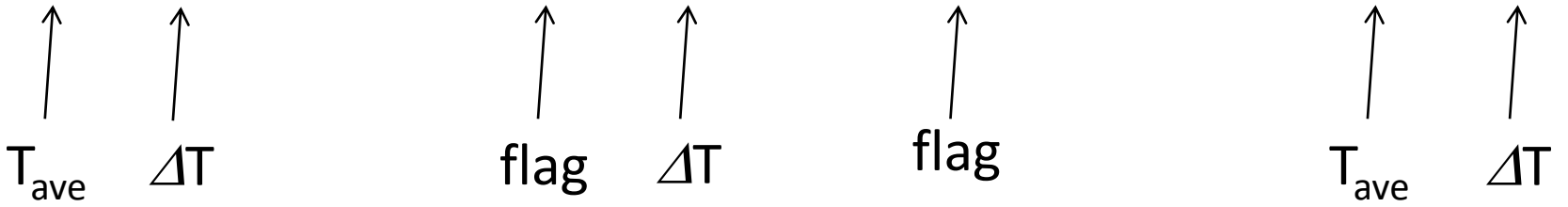


Compression Algorithm

16 bitから圧縮するには・・・

16 bit → 4 bit

16 bit | 4 bit | 4 bit | 4 bit | 0000 | 16 bit | 16 bit | 1111 | 4 bit | 4 bit | 16 bit | 4 bit |…



T_{ave} [μK]= N samples のTの平均値

$\Delta T = T - T_{ave}$ [μK]

4 bitにおさまらないとき・・・

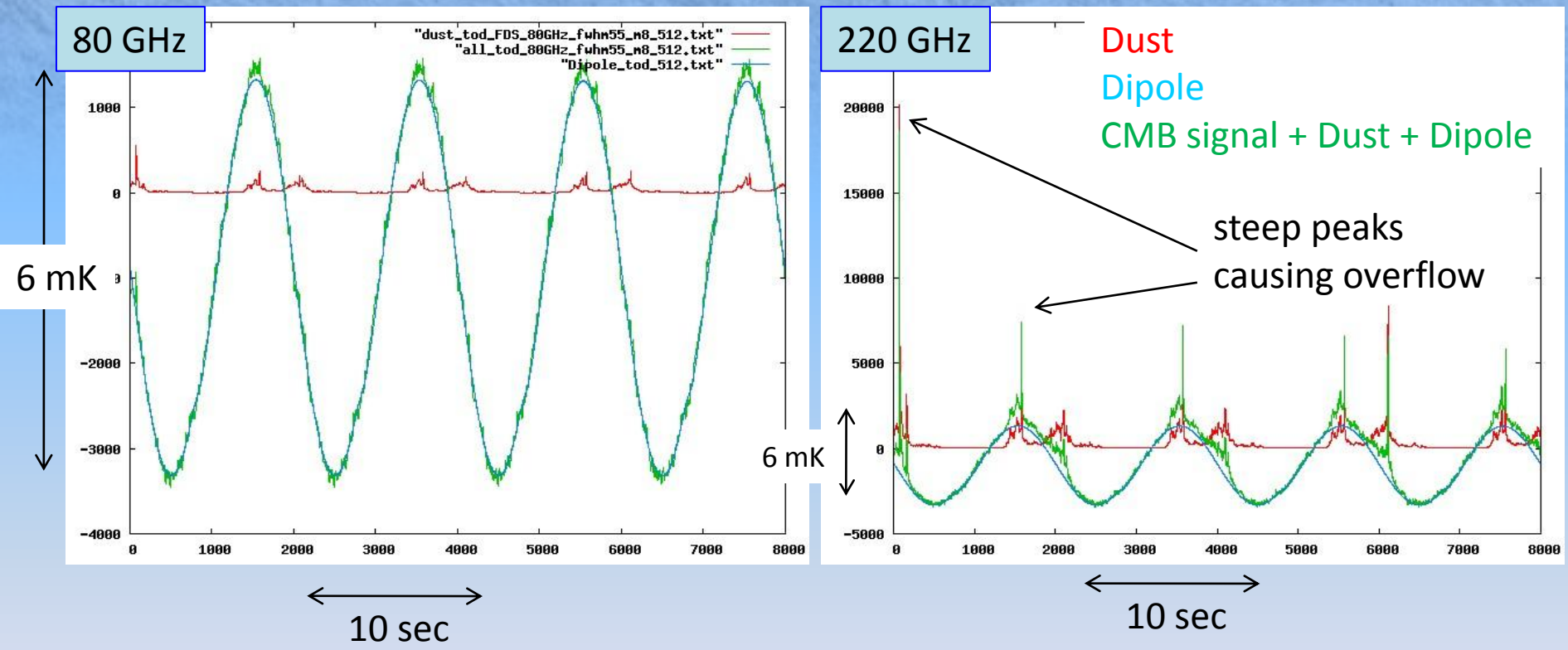
銀河面、宇宙線等のスパイク状シグナル等

$|\Delta T| > 707\ \mu K \times 14/2 = 4949\ \mu K$

4 bitのflagを立て、16 bitで出力

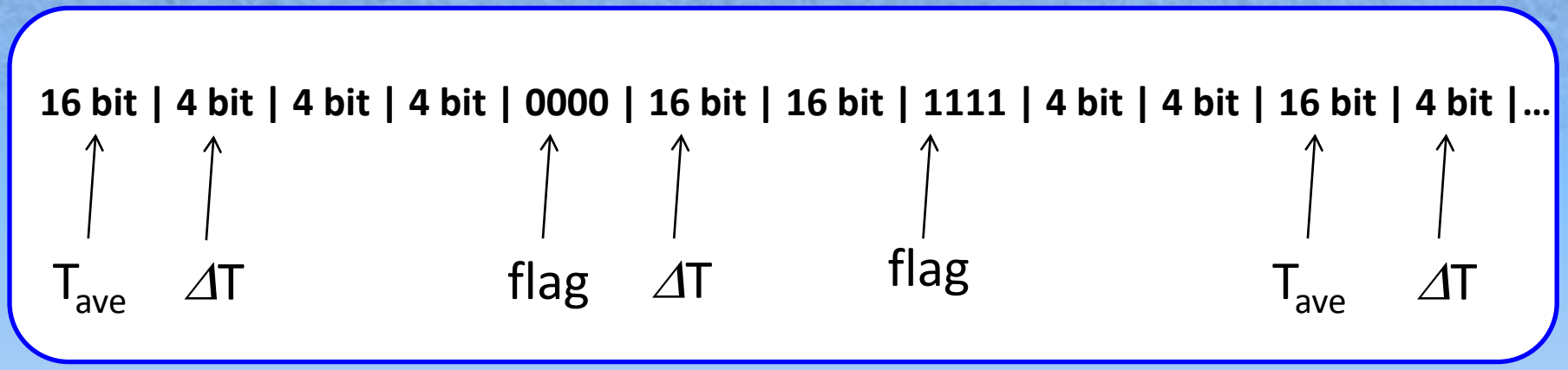
Compression algorithmのチェック
Data rateの試算

Time Ordered Data



今回のシミュレーションではwhite noise, 1/ f noiseは考慮していない

何個のデータを平均すればいい？



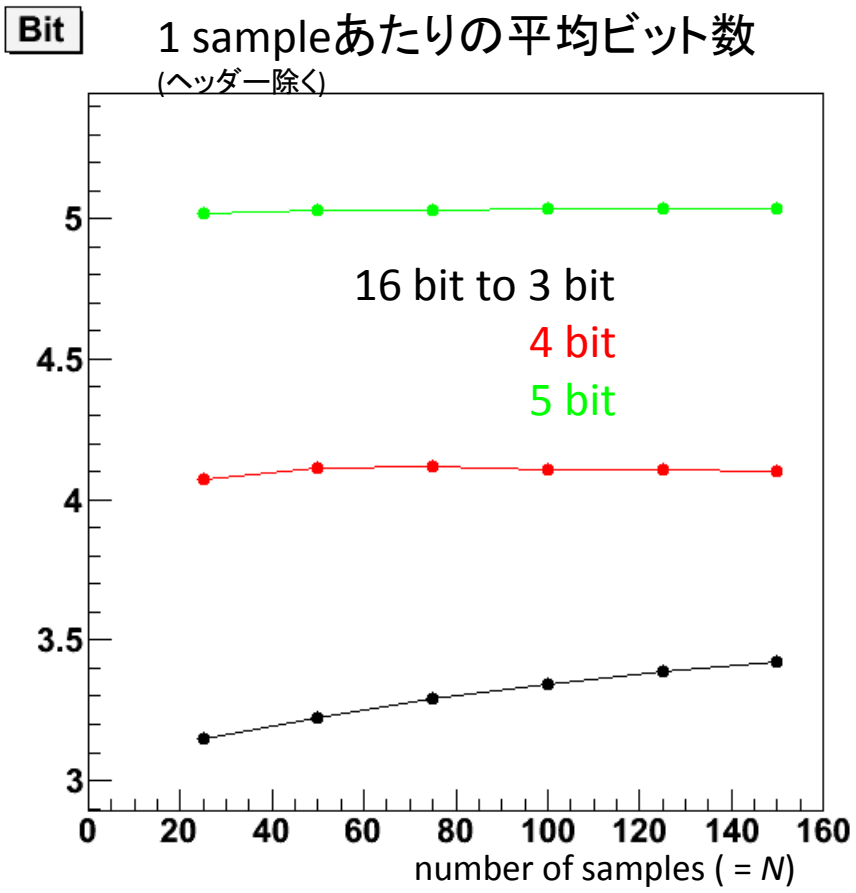
決めたい値

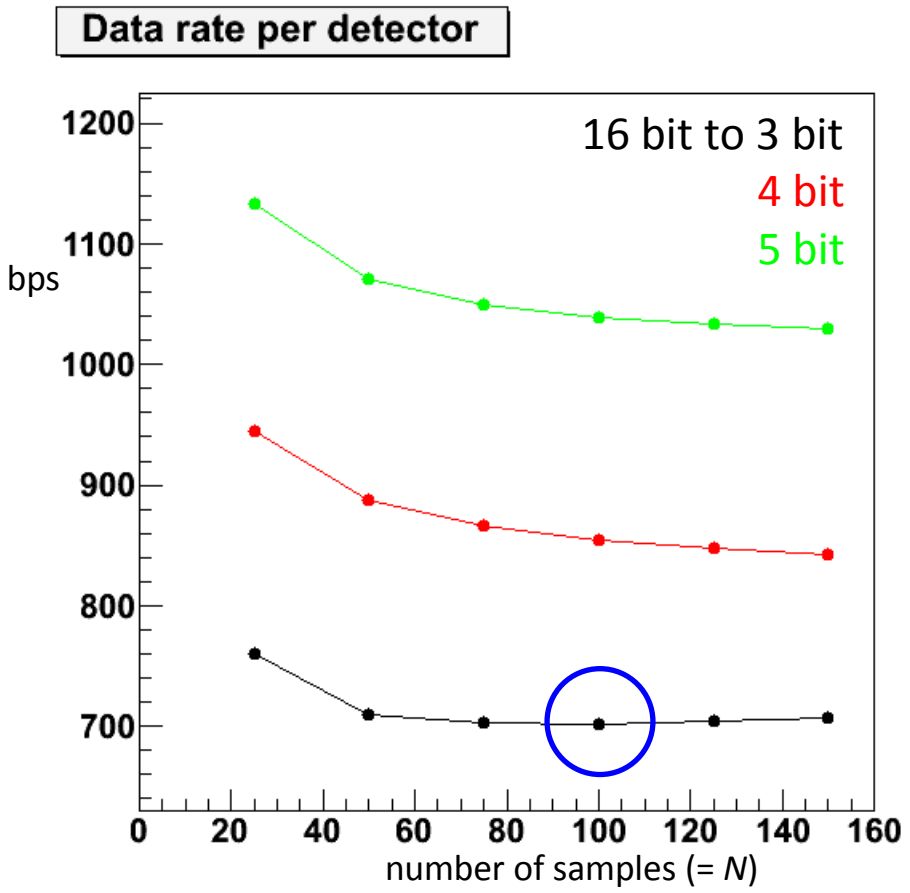
T_{ave} [μK]= N samples のTの平均値

$\Delta T = T - T_{ave}$ [μK]

まめに平均をとったほうが、データは4 bitにおさまる確率は上がるが
T_{ave}(16 bit)も増える

Data size and rate



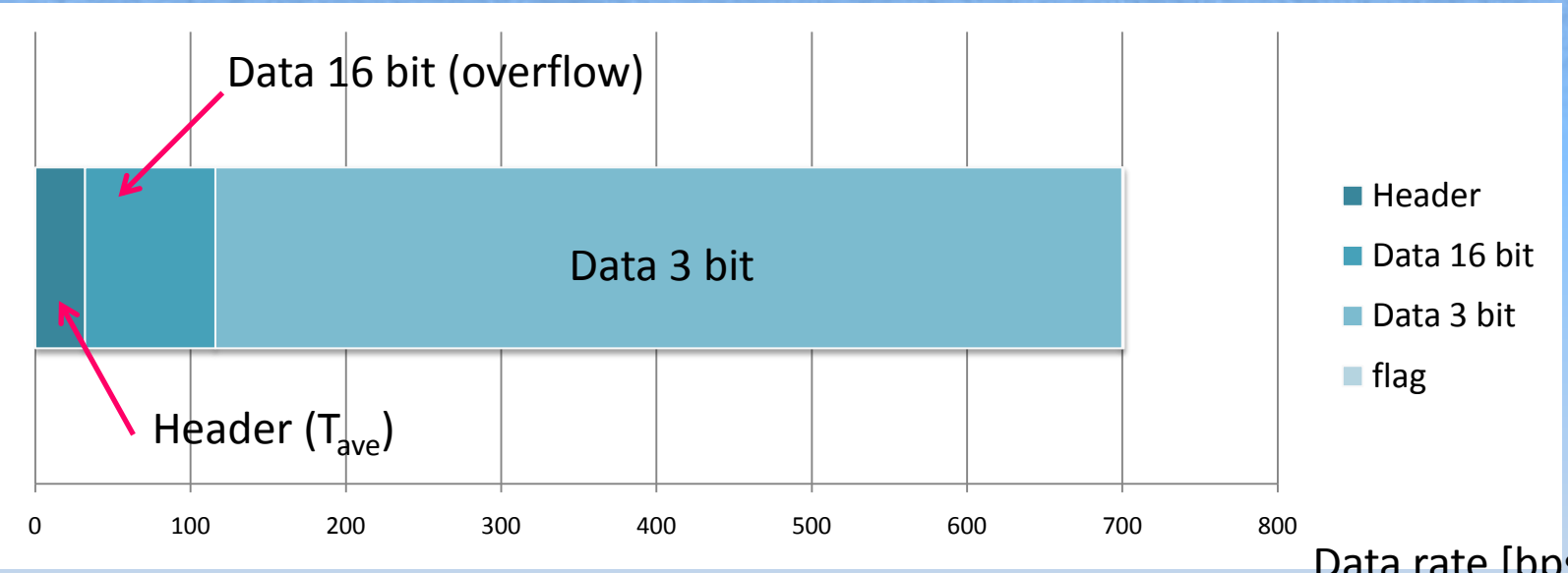


N個のサンプルを使って平均値を計算
差をn bit (n = 3 or 4 or 5) で送る

春分点　220 GHz
1h スキャン

Data Budget

Data rate per detector



春分点　220 GHz

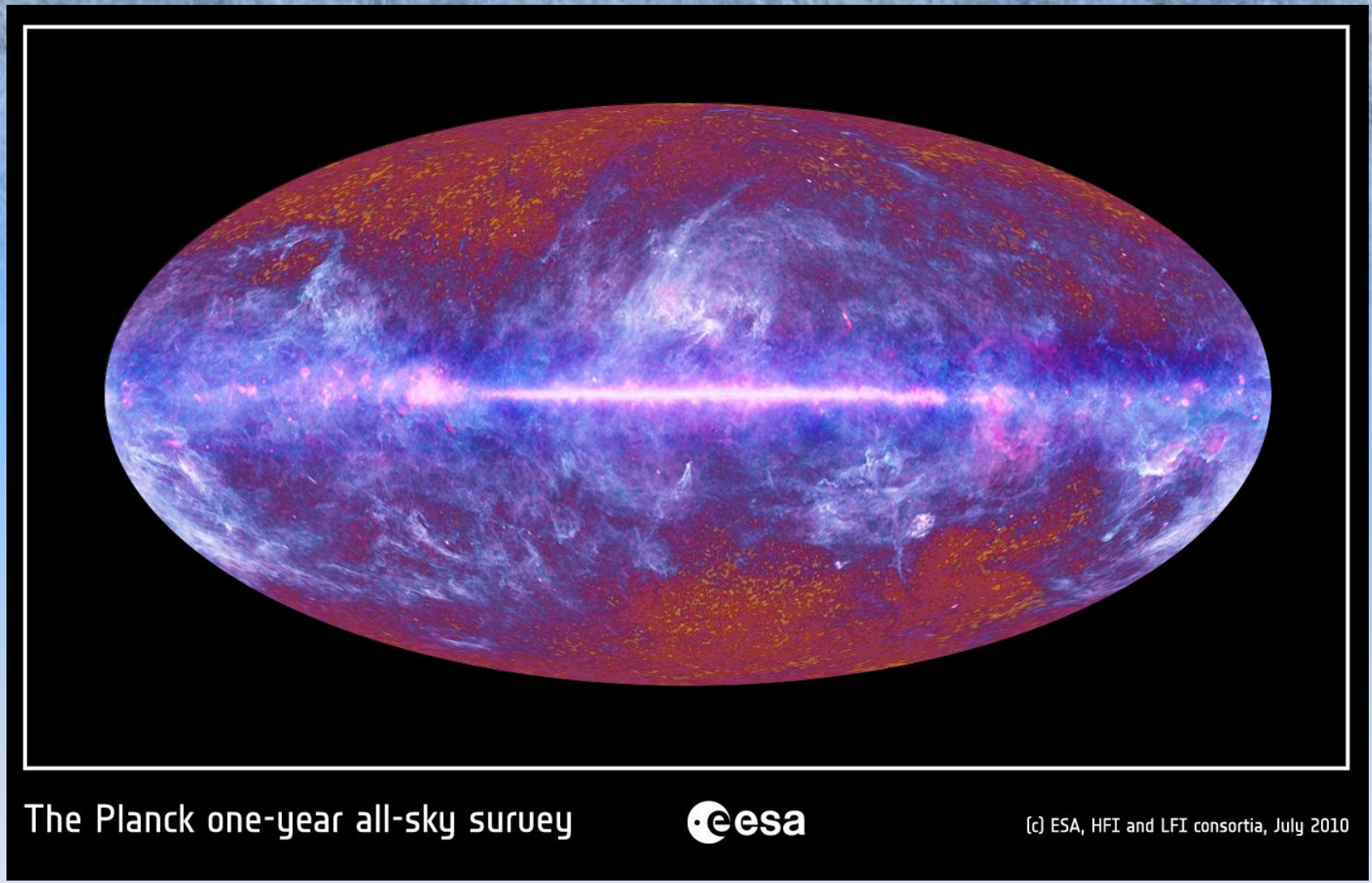
Conclusion

Freq [GHz]	Beam [arcmin]	Ndet [#]	Sampling Rate [Hz]	圧縮前 Data rate [kbps]	圧縮後 Data rate [kbps]
60	73	312	97	484	96
80	55	312	129	644	127
100	44	746	161	1921	381
150	29	434	244	1694	343
220	20	434	354	2458	539
total		2238		7201	1486

Compression rate : 20.6 %

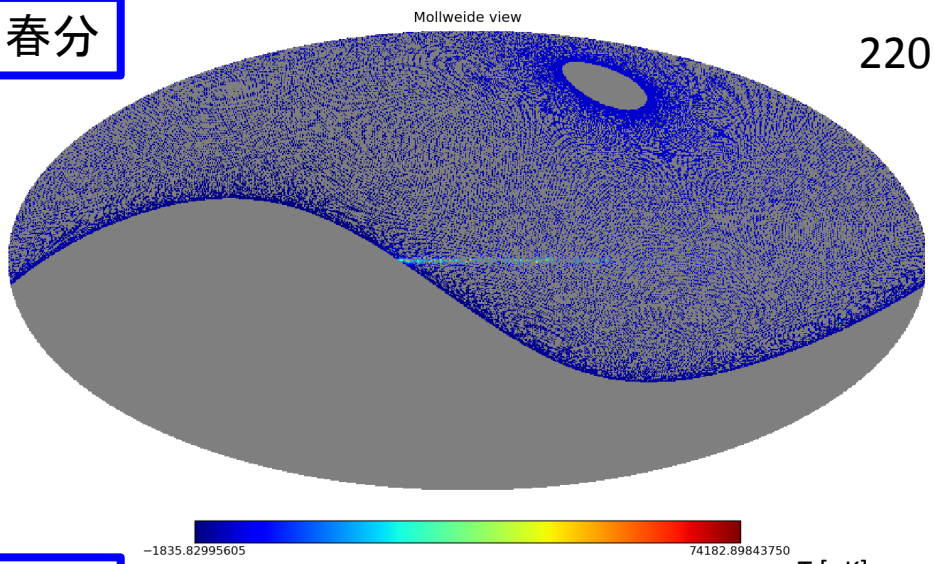
最適化に向けて
- ✓spin rateを3 rpmにできないか？
- ✓total data rateを2 Mbpsにできないか？
- ✓Half wave plateの導入(0.25 – 0.5倍に削減可能)?
- ✓検出器数の最適化
- ✓さらなるデータ圧縮

backup


The Planck one-year all-sky survey
esa
(c) ESA, HFI and LFI consortia, July 2010

Scan (1 hour)

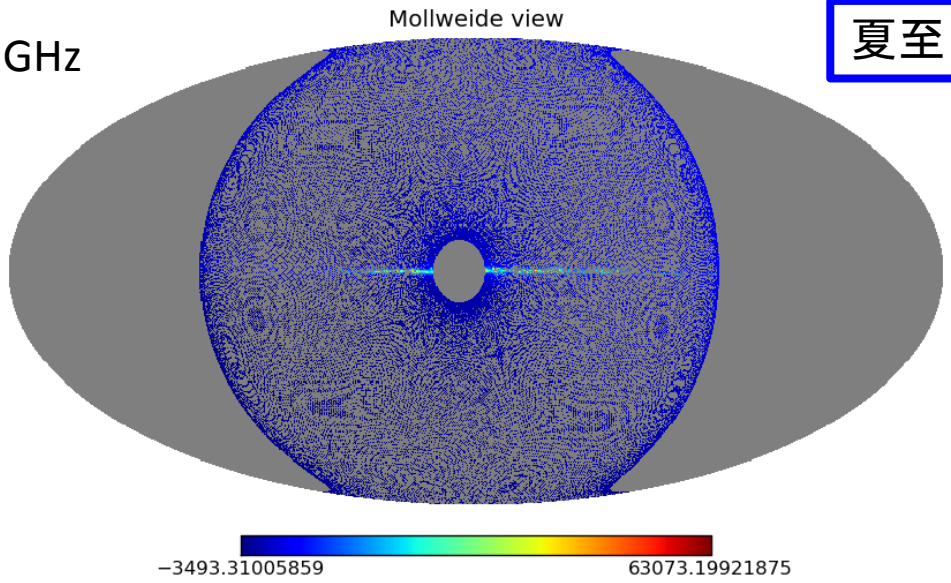
春分



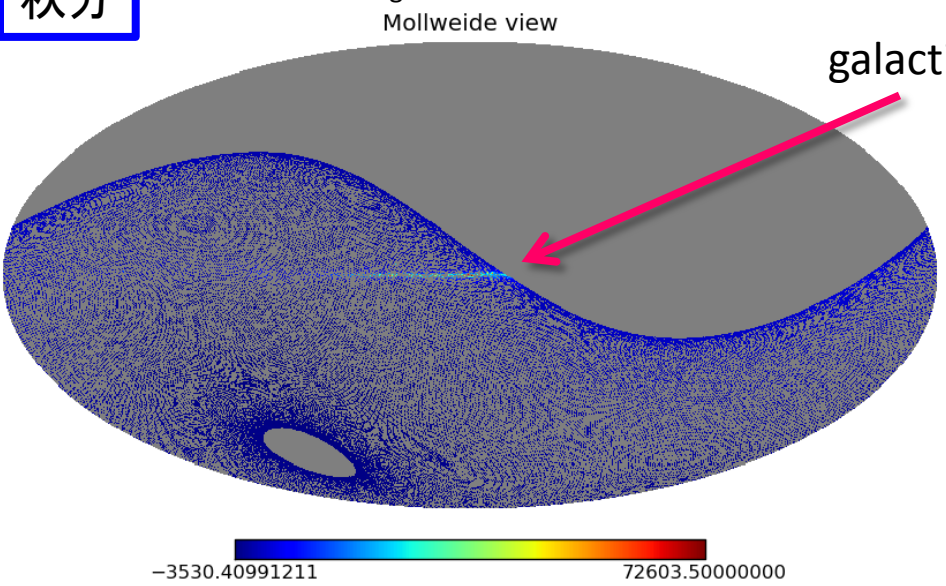
220 GHz

T [μK]

夏至

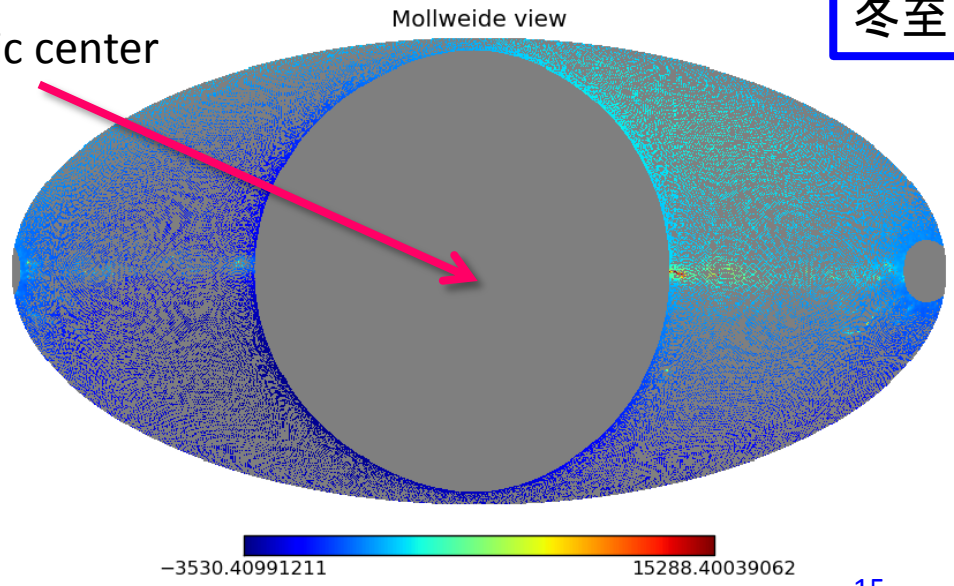


秋分



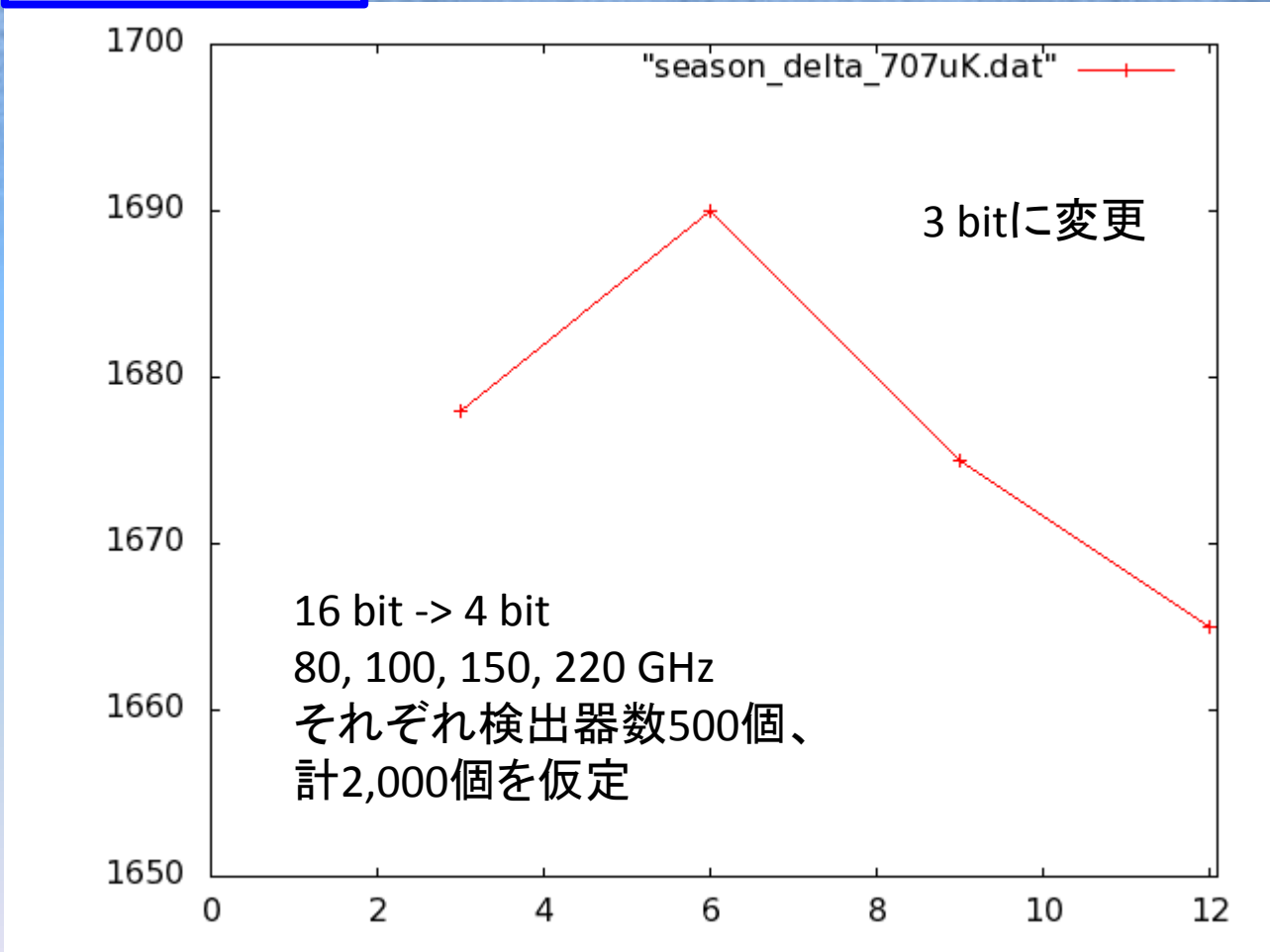
galactic center

冬至



季節依存性

Data rate [kbps]

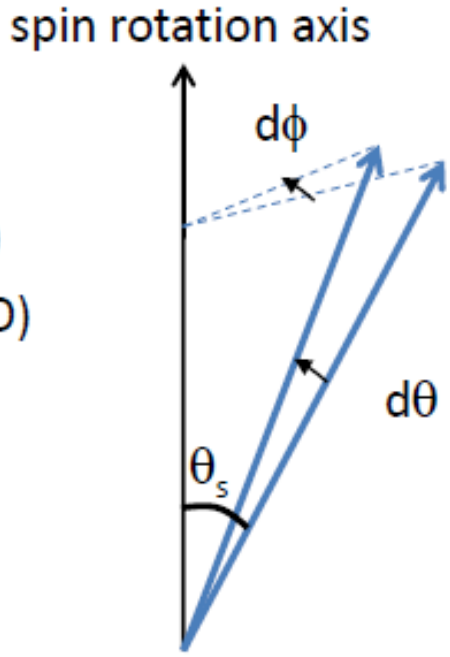


how to calculate

bolometer 1/f noise ~100 [mHz]

the dipole signal modulation need to be faster than the 1/f noise.
hence the spin rotation is ω_s = 60[s] x 0.1 [Hz] = 6 [rpm]

the spin cone angle θ_s = 55 degrees. (for L2)
θ_s = 34 degrees (for LEO)



from the left figure $d\theta = \sin\theta_s \, d\phi$

hence, $d\theta/dt = \sin\theta_s \, d\phi/dt = \omega_s \sin\theta_s$ =1769.4[arcmin/s] (L2)

$d\theta/dt = \sin\theta_s \, d\phi/dt = \omega_s \sin\theta_s$ =1207.7[arcmin/s] (LEO)

the beam crossing time = $\Delta\theta$ / $d\theta/dt$ [s]
where $\Delta\theta$ is the FWHM of the beam.

the sampling is carried out 4 times (= 2 x Nyquist)
during the beam crossing, therefore the sample rate is

$\nu_s = 4 \, d\theta/dt \; / \; \Delta\theta$

the detector response time should be faster than $\tau_{req} = 1/2\pi \times \Delta\theta / d\theta/dt$

with three half wave plates

Freq [GHz]	Beam [arcmin]	N_{det} [#]	ν_{pol} [Hz]	t_{req} [ms]	HWP [rpm]	sample rate [Hz]	data rate [kbps]
60	77	400	3.8	14	57	16	25.6
100	46	600	6.4	8	96	26	62.4
250	19	200	15.5	3	233	62	49.6
total		1200					137.6

with a single HWP

Freq [GHz]	Beam [arcmin]	N_{det} [#]	ν_{pol} [Hz]	t_{req} [ms]	HWP [rpm]	sample rate [Hz]	data rate [kbps]
60	77	400	15.5	3	233	62	99.2
100	46	600	15.5	3	233	62	148.4
250	19	200	15.5	3	233	62	49.6
total		1200					297.6

how to calculate

sampling rate $\nu_s = 4 \times \nu_{pol}$ (2 x Nyquist x pol. modulation)

signal polarization modulation $\nu_{pol} = N \times d\theta/dt / \Delta\theta$

N= 10 is the sampling during the beam crossing.
(need a simulation to determine this?)

assume spin rate is 0.1 rpm. (same as EPIC, need to be checked)

$d\theta/dt = 29.5$ [arcmin/s]

the detector response time should be faster than $\tau_{req} = 1/4\pi\nu_s$

HWP rotation is $\nu_{pol} / 4$

EPIC requires a 1/f noise knee < 2.5Hz pre-demodulation.
we are not sure what it means...