

2013年5月29日

KAGRA ASC WFS信号への要求値

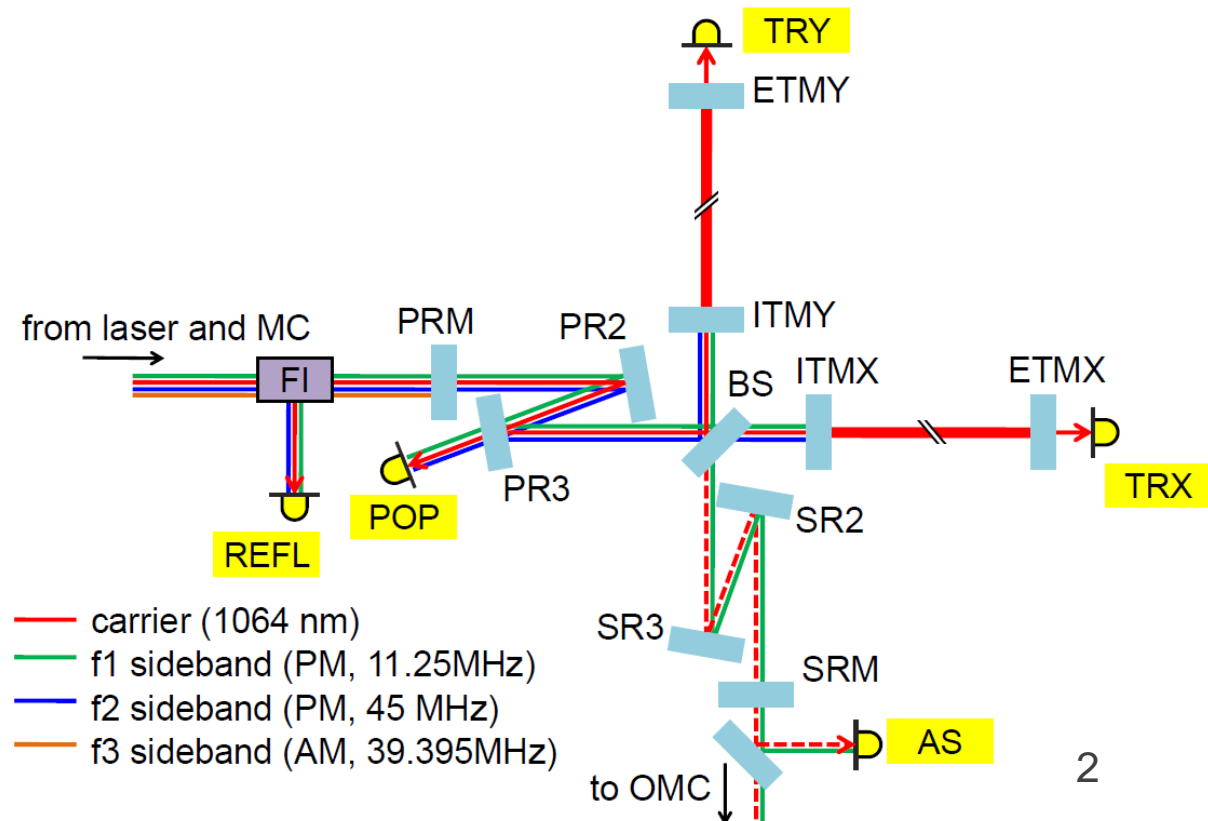
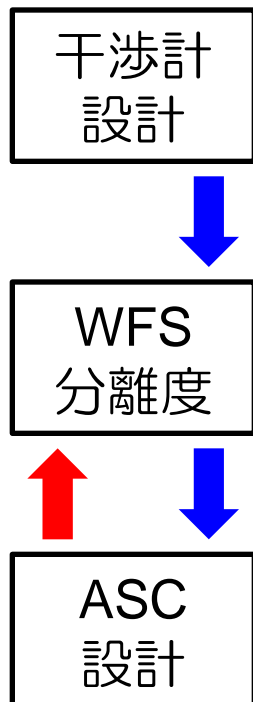
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安東研究室 博士課程2年

WFS信号への要求値計算

- WFS信号量や信号分離度への要求値を計算したい
- WFSショットノイズ(rad/rtHz)への要求値を求めればよい
- 干渉計設計が間違っていなかったか確認になる



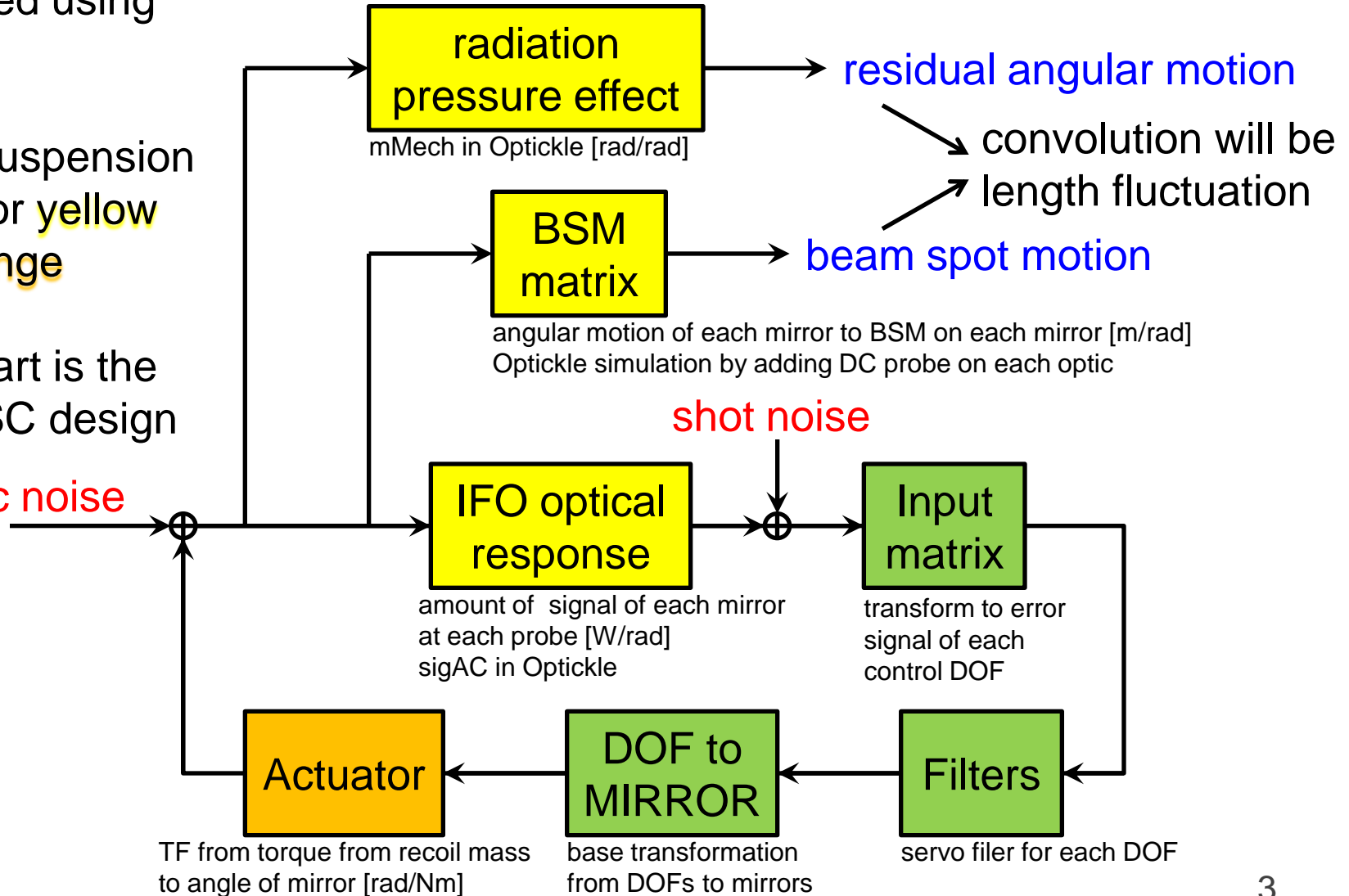
WFS制御モデル

yellow matrices are calculated using Optickle

needs suspension model for yellow and orange

green part is the main ASC design

seismic noise

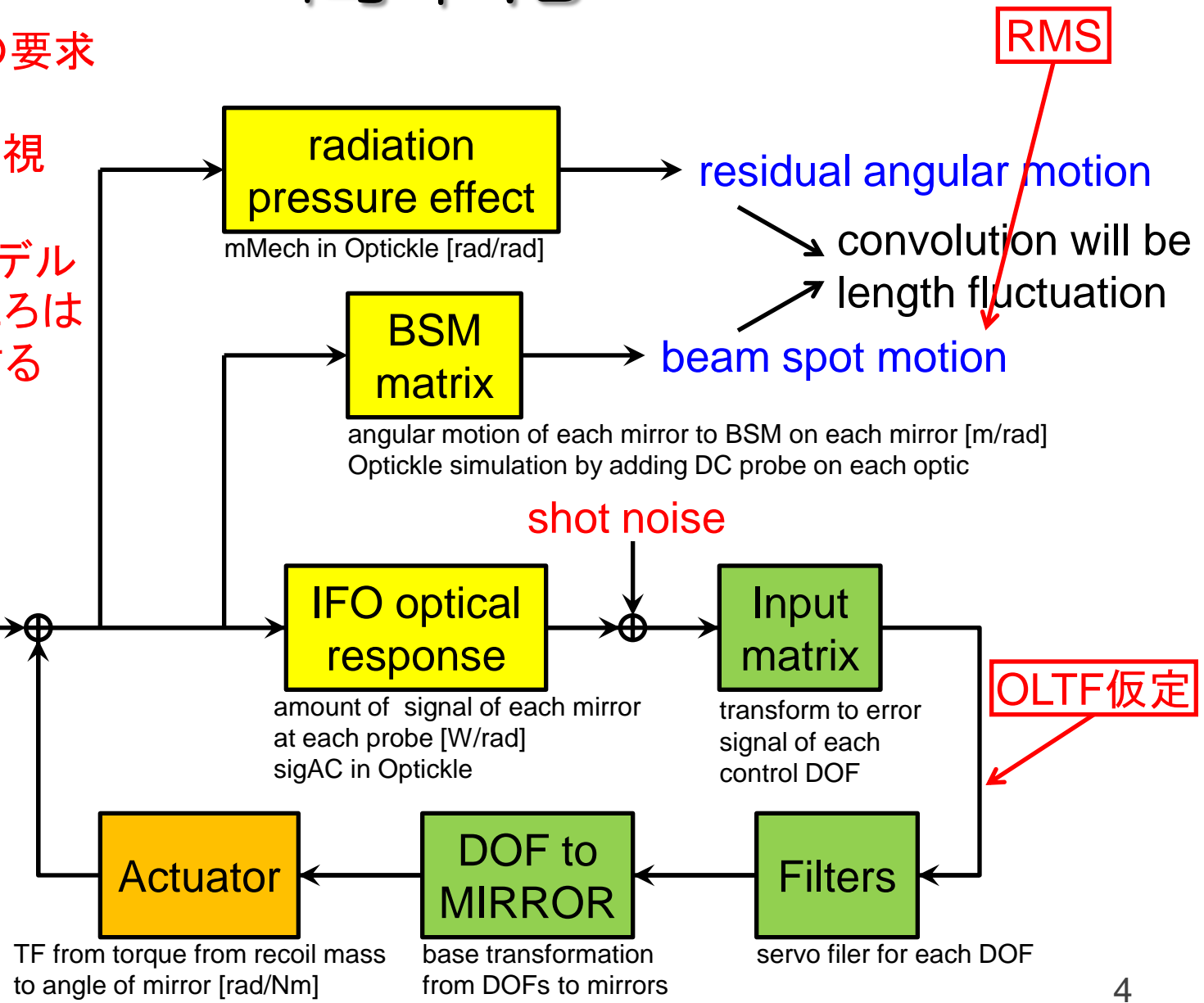


简单化

ショットノイズへの要求値が知りたい
→ その他は無視

サスペンションモデルが重要になるのは
とりあえず排除する

seismic noise
地面振動無視

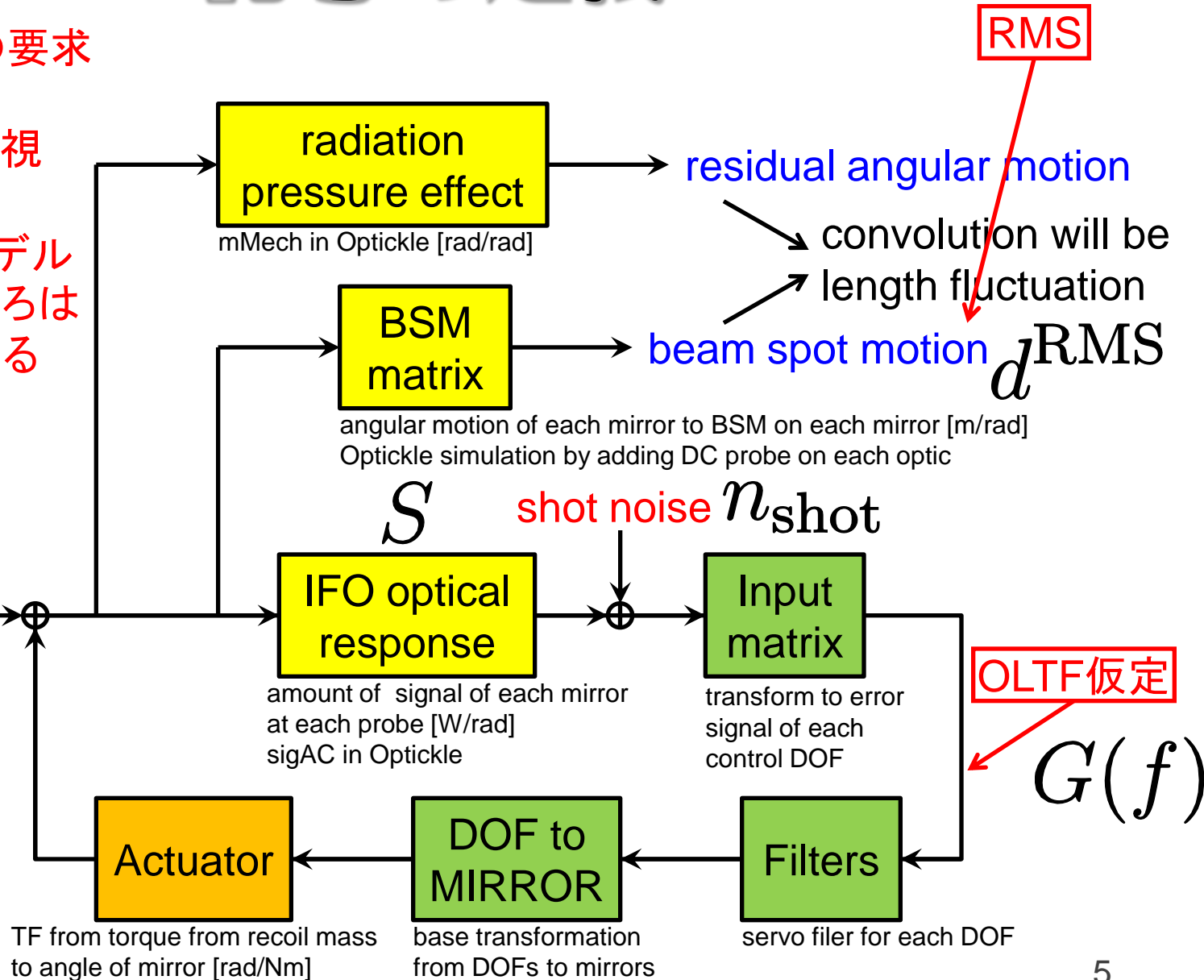


記号の定義

ショットノイズへの要求値が知りたい
→ その他は無視

サスペンションモデルが重要になるところは
とりあえず排除する

seismic noise
地面振動無視



要求値の計算方法

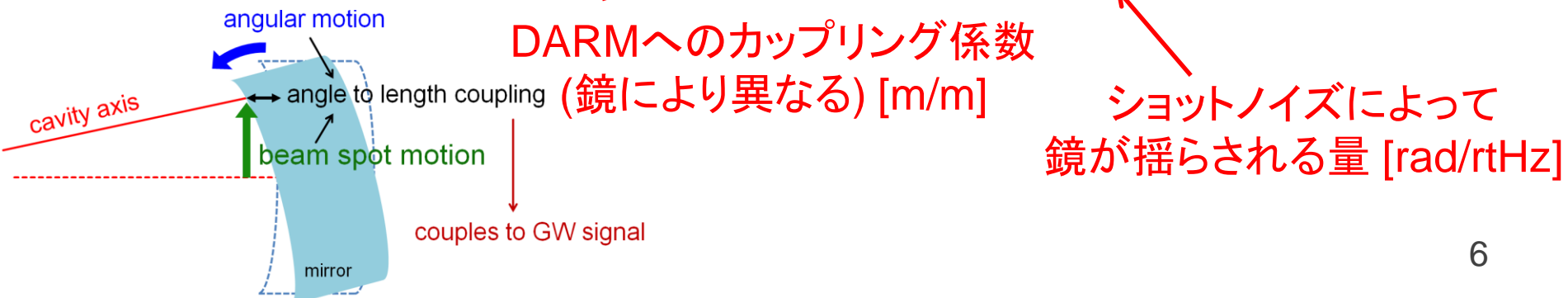
- ショットノイズを各鏡の揺れに直すと

$$\theta_{\text{shot}} = S^{-1} n_{\text{shot}}$$

(各QPDからのショットノイズは二乗和をとって、各鏡のショットノイズに直す)

- これが干渉計感度に及ぼす影響は

$$\delta L(f) = k(f) d^{\text{RMS}} \underbrace{\frac{G(f)}{1 + G(f)}}_{\text{shot noise}} \theta_{\text{shot}}$$



要求値の計算方法

- 干渉計感度を悪化させないためには

$$\delta L(f) < \underline{Lh(f)}$$

干渉計感度

- よって

$$\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1 + G(f)}{G(f)}$$

であればよい

- 右辺の最小値がショットノイズへの要求値

鏡でのミスセンタリング

- 光てこへの要求値は $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1+G(f)}{G(f)}$
各鏡でのビームスポットの揺れがRMSで1mm以下になるように、で決めた
- 各鏡を揺らしたとき、各鏡のビームスポットがどれだけずれるかをOptickleにより計算
 - beam spot motion行列(BSM)
 - 各鏡の揺れへの要求値が出る

BSM行列

- 各鏡のBSMが1mm以下になるよう各鏡の角度揺れへの要求値を計算すると.....

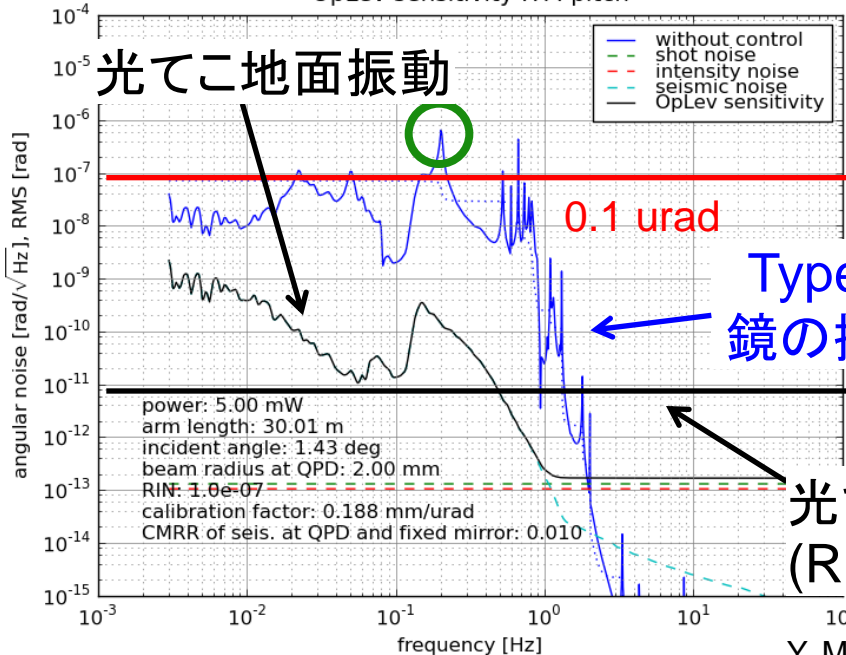
	ETMX	ETMY	ITMX	ITMY	BS	PR3	PR2	PRM	SR3	SR2	SRM
ETMX	0.2606	0.0010	0.4505	0.0006	0.0000	0.0009	0.0001	0.0001	0.0000	0.0000	0.0000
ETMY	0.0010	0.2606	0.0005	0.4505	0.0006	0.0009	0.0001	0.0001	0.0000	0.0000	0.0000
ITMX	0.4511	0.0005	0.2610	0.0003	0.0000	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
ITMY	0.0005	0.4511	0.0003	0.2610	0.0004	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
BS	0.0586	0.3917	0.0584	0.2377	0.0068	0.0608	0.0074	0.0037	0.0076	0.0009	0.0005
PR3	0.2295	0.2301	0.1473	0.1506	0.0197	0.0523	0.0064	0.0032	0.0053	0.0006	0.0003
PR2	0.0281	0.0282	0.0180	0.0184	0.0024	0.0064	0.0005	0.0003	0.0006	0.0001	0.0000
PRM	0.0306	0.0307	0.0197	0.0201	0.0027	0.0071	0.0006	0.0012	0.0007	0.0001	0.0000
SR3	1.8622	1.8638	0.4514	1.7133	0.3204	1.7873	0.2189	0.1085	0.8360	0.0994	0.0516
SR2	0.2214	0.2216	0.0537	0.2037	0.0381	0.2125	0.0260	0.0129	0.0994	0.0116	0.0060
SRM	0.2300	0.2302	0.0557	0.2116	0.0396	0.2207	0.0270	0.0134	0.1033	0.0120	0.0047

腕のdetune量で大きく変わる
SRCの共振状態でも変わる

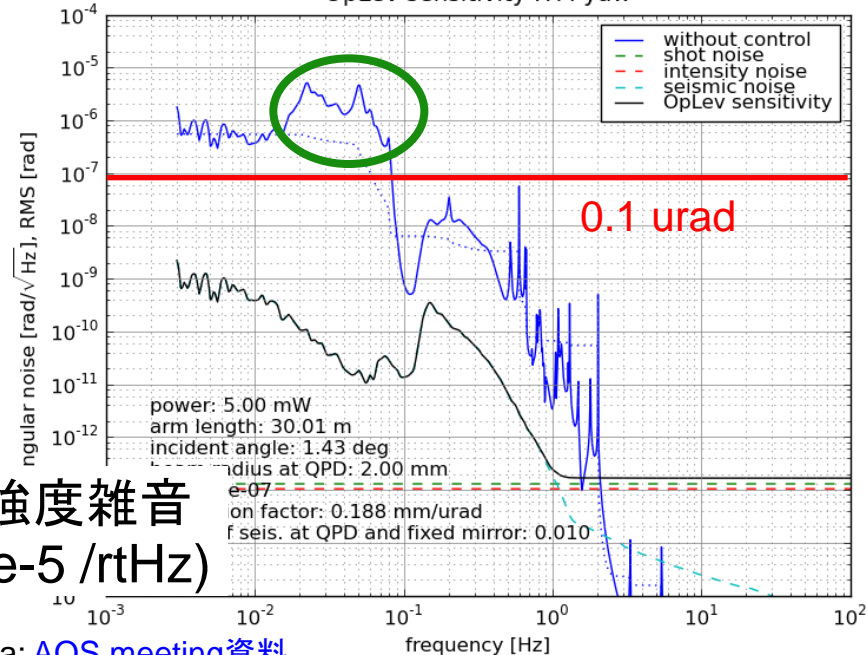
例えば、BSを揺らすと、SRMにおけるビーム
スポットが $0.0396 \times 10 \text{ mm/urad}$ ずれる

	ETMX	ETMY	ITMX	ITMY	BS	PR3	PR2	PRM	SR3	SR2	SRM
要求値(safety factorなし) [urad]											
req	0.22	0.22	0.22	0.22	0.31	0.06	4.57	9.22	1.20	10.1	19.4
サスペンションモデルによる制御前のRMS [urad]											
pitch	0.07	0.07	0.07	0.07	0.4	0.4	0.4	0.4	0.4	0.4	0.4
yaw	0.5	0.5	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9

OpLev sensitivity ITM pitch



OpLev sensitivity ITM yaw

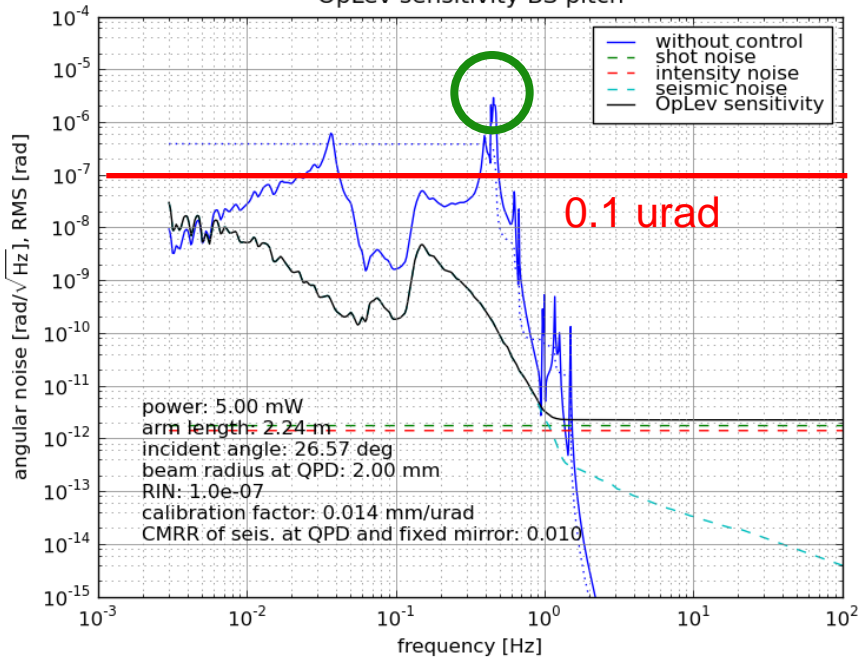


光てこ強度雑音
(RIN 1e-5 /rtHz)

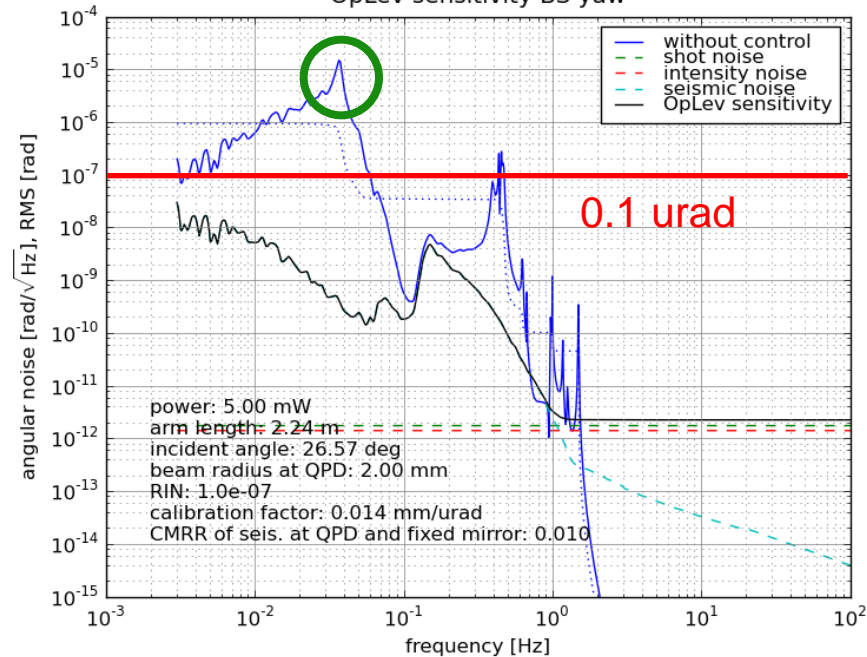
Y. Michimura: [AOS meeting資料](#)

K. Agatsuma: [JGW-G1201388](#)

OpLev sensitivity BS pitch



OpLev sensitivity BS yaw



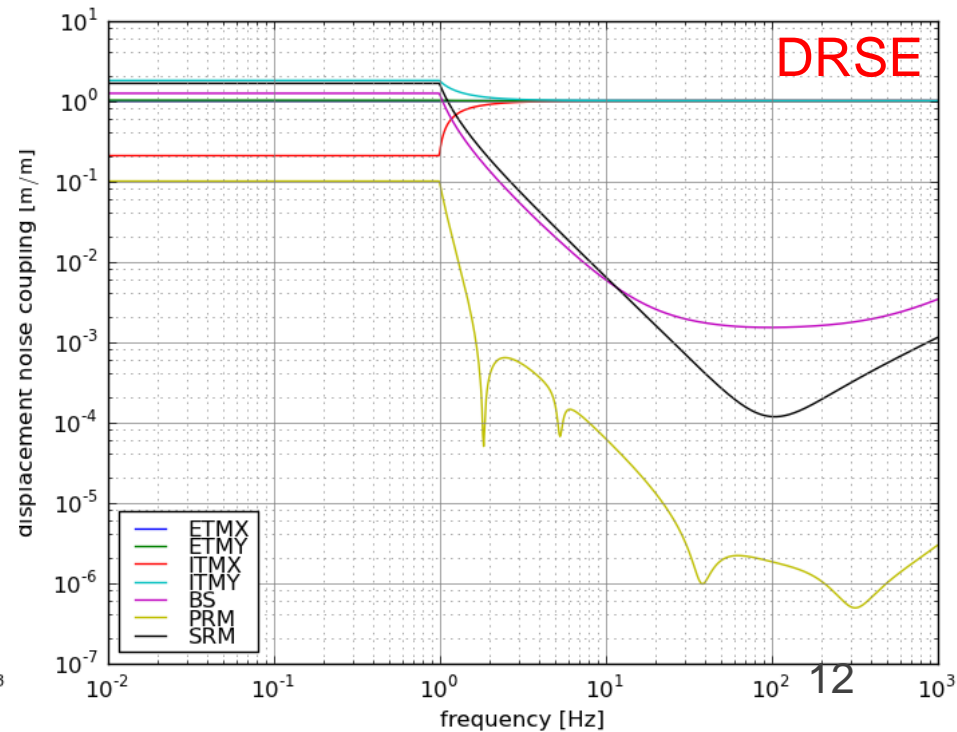
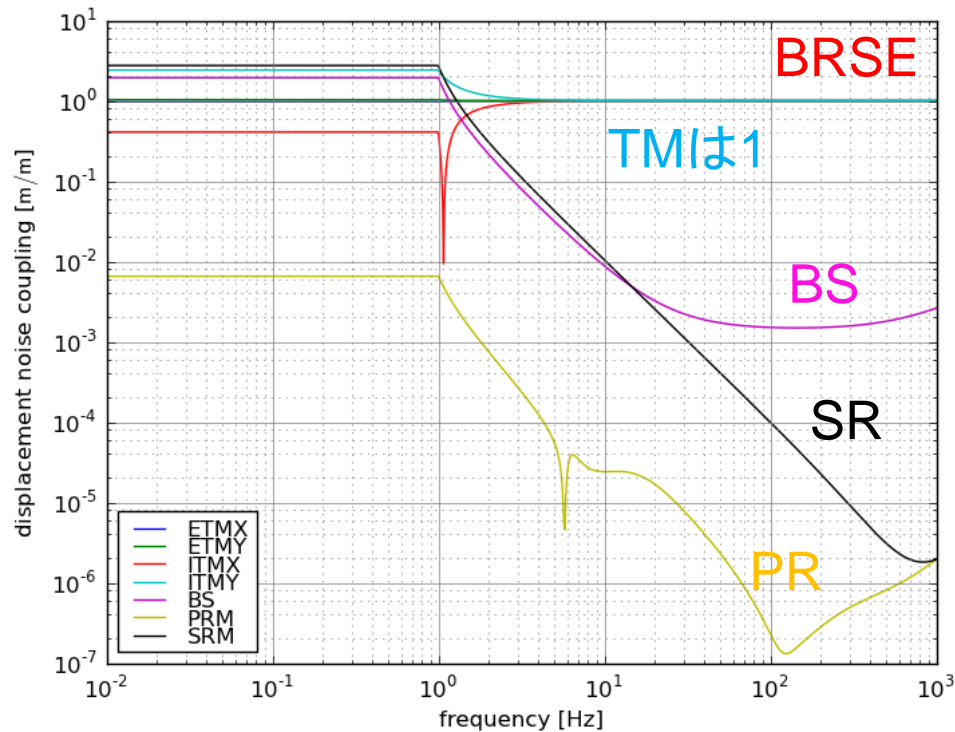
鏡でのミスセンタリング

- 光てこ感度で0.1 urad可能 $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1+G(f)}{G(f)}$
→ 各鏡上でビームスポットの揺れRMSで1mmは可能
- 麻生さんの計算によると入射ビームジッタは10nrad以下が要求値(2012年秋の物理学会)
- テストマス上ではビームスポットの揺れ0.1mmを仮定するのが妥当?
- DC的なミスセンタリングはditheringなどで0.1mm程度にできる

→ TMでは $d^{\text{RMS}} = 0.1 \text{ mm}$
その他の鏡では $d^{\text{RMS}} = 1 \text{ mm}$

DARMへのカップリング係数

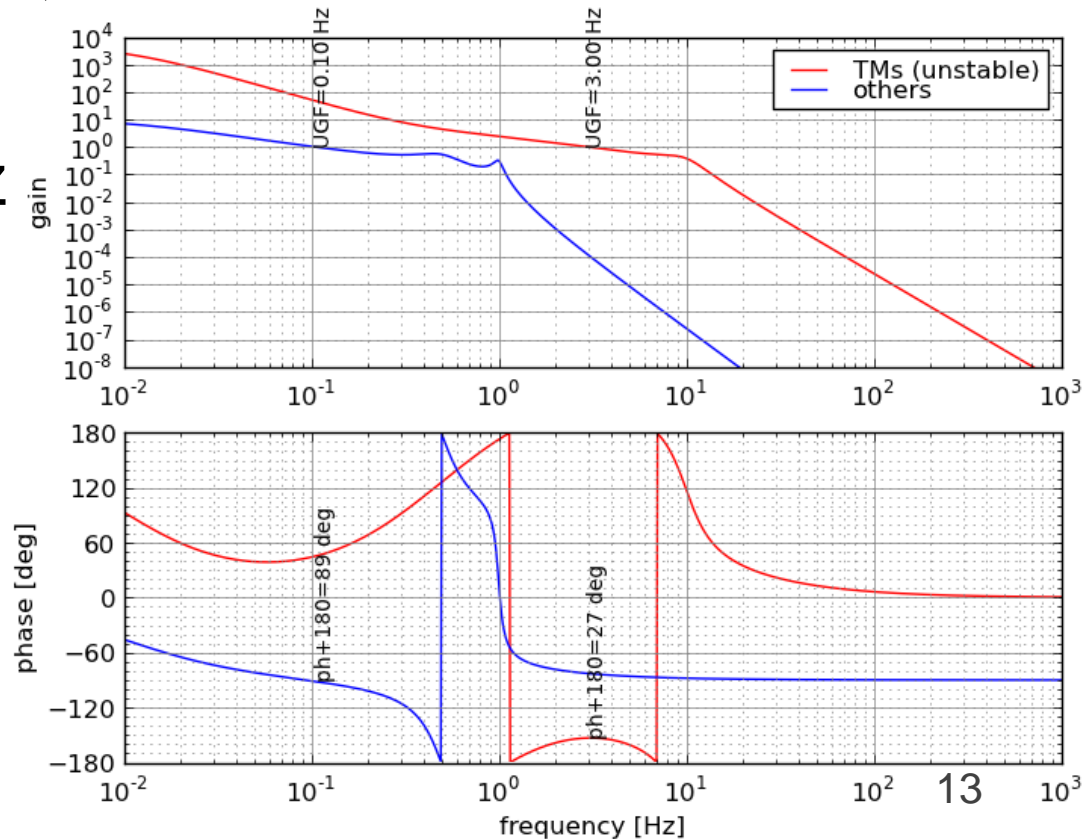
- 麻生さんの計算によると... $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}} k(f)} \frac{1 + G(f)}{G(f)}$
- 10Hz以下は観測帯域外なので
とりあえず外挿



オープンループ伝達関数

- Sidles-Sigg不安定性により $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1 + G(f)}{G(f)}$
 TMは不安定poleが1Hあたり
 →TMは UGF 3 Hz, cut-off 10 Hz
- その他はUGF 0.1Hz, cut-off 5Hz

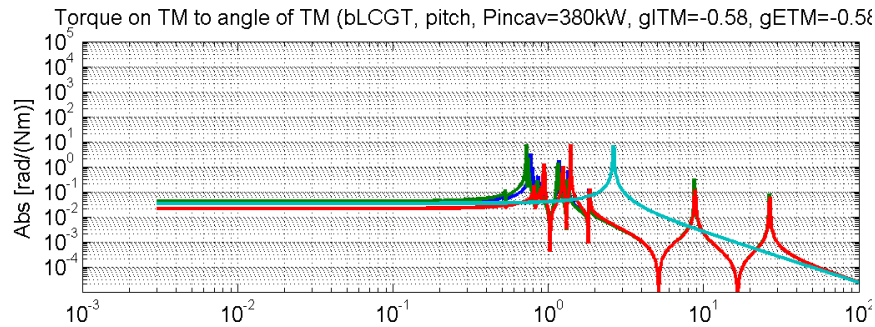
- 実際その他が0.1Hz
 でいいのか？
- micro seismicが
 WFSで潰せない



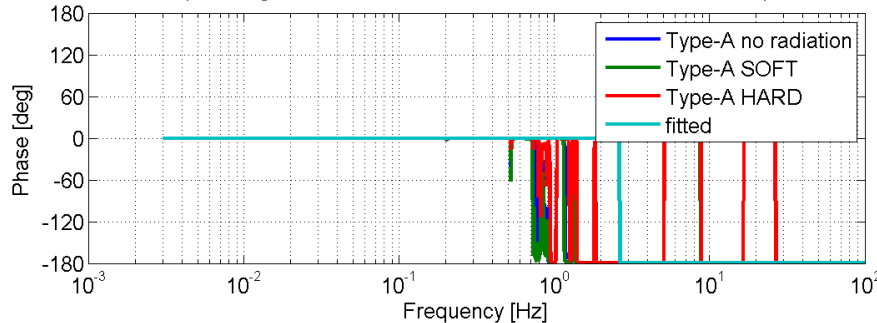
Sidles-Sigg不安定性

- 輻射圧による角度不安定性 $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1 + G(f)}{G(f)}$
- pitchは安定だが、yawのSOFTモードが不安定@1 Hz

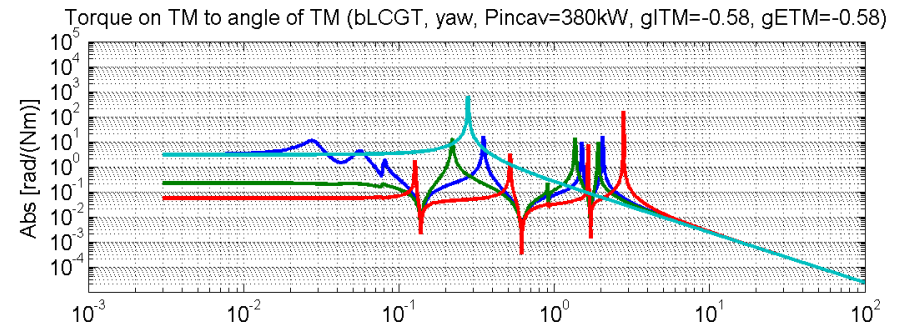
pitch



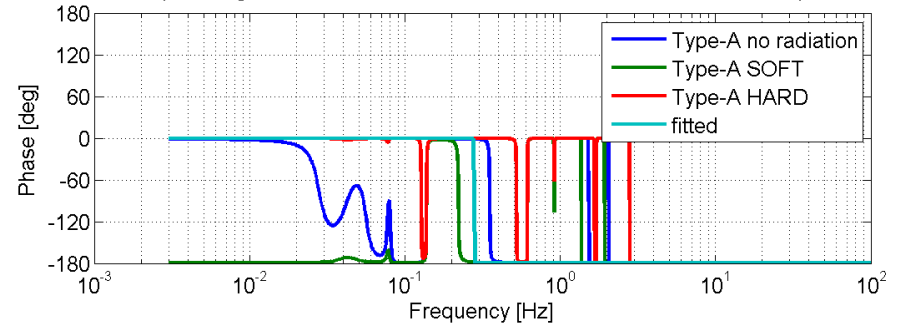
($I=0.11\text{kgm}^2$, $f_{\text{mech}}=2.62\text{Hz}$, $f_{\text{SOFT}}=2.40\text{Hz}$, $f_{\text{HARD}}=3.33\text{Hz}$)



yaw

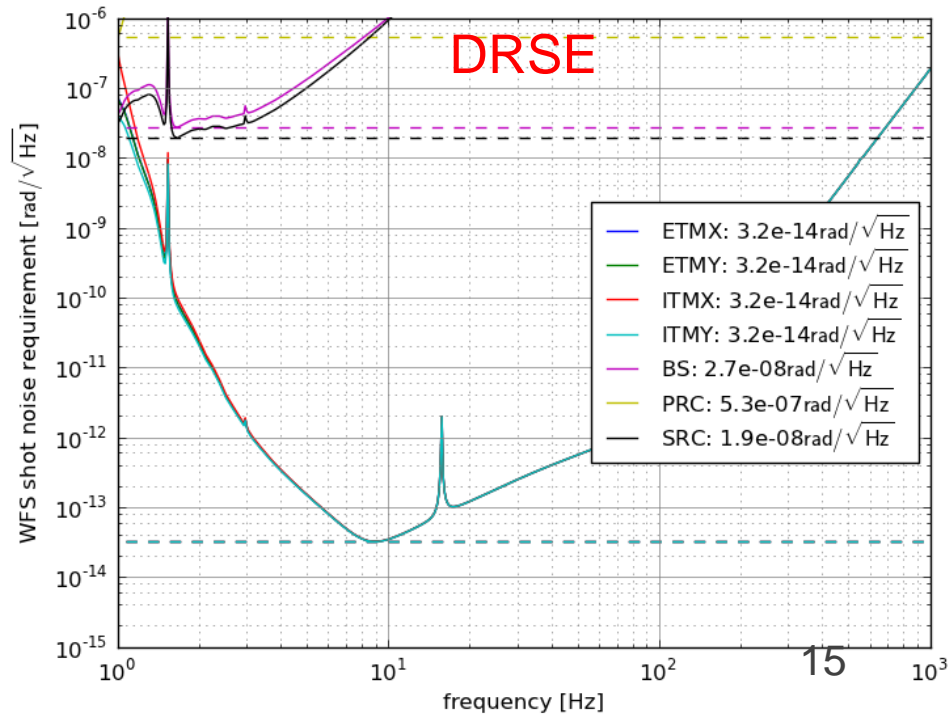
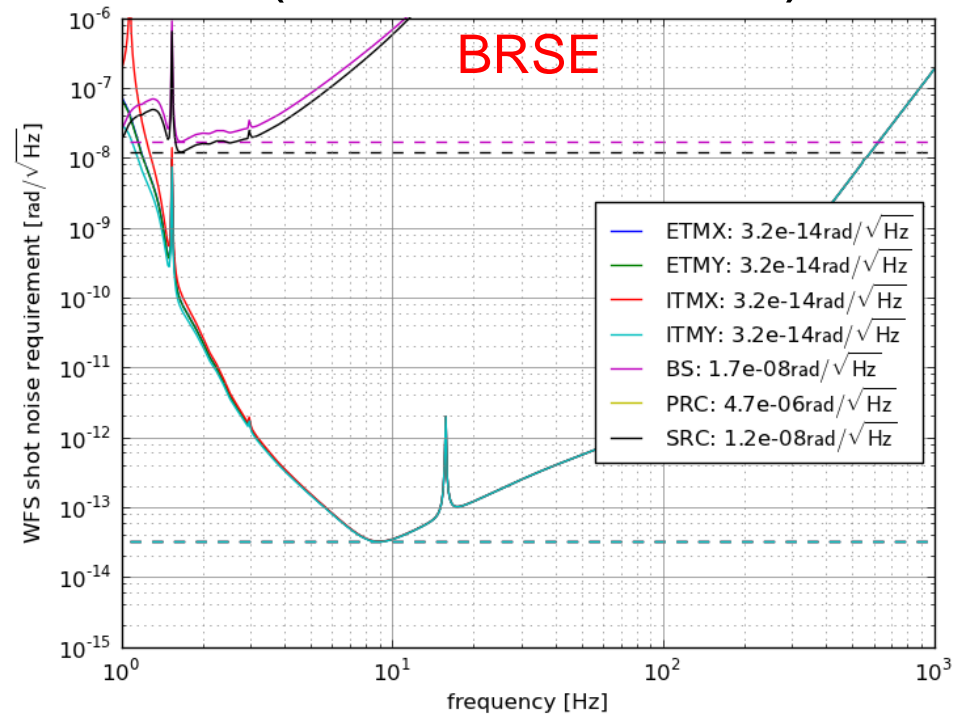


($I=0.11\text{kgm}^2$, $f_{\text{mech}}=0.28\text{Hz}$, $f_{\text{SOFT}}=0.00+1.02i\text{Hz}$, $f_{\text{HARD}}=2.06\text{Hz}$)



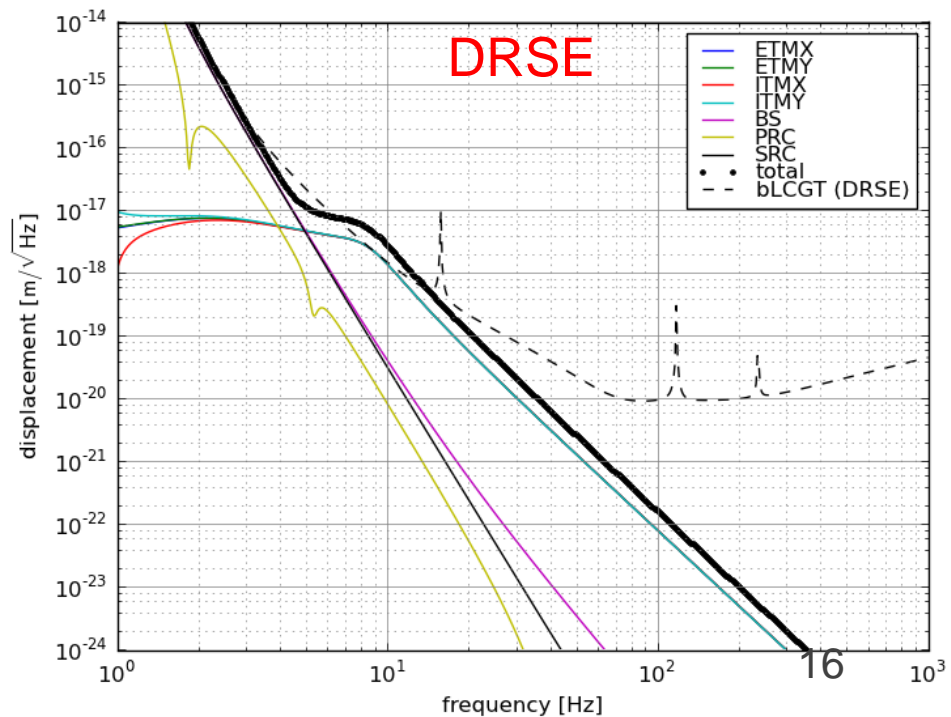
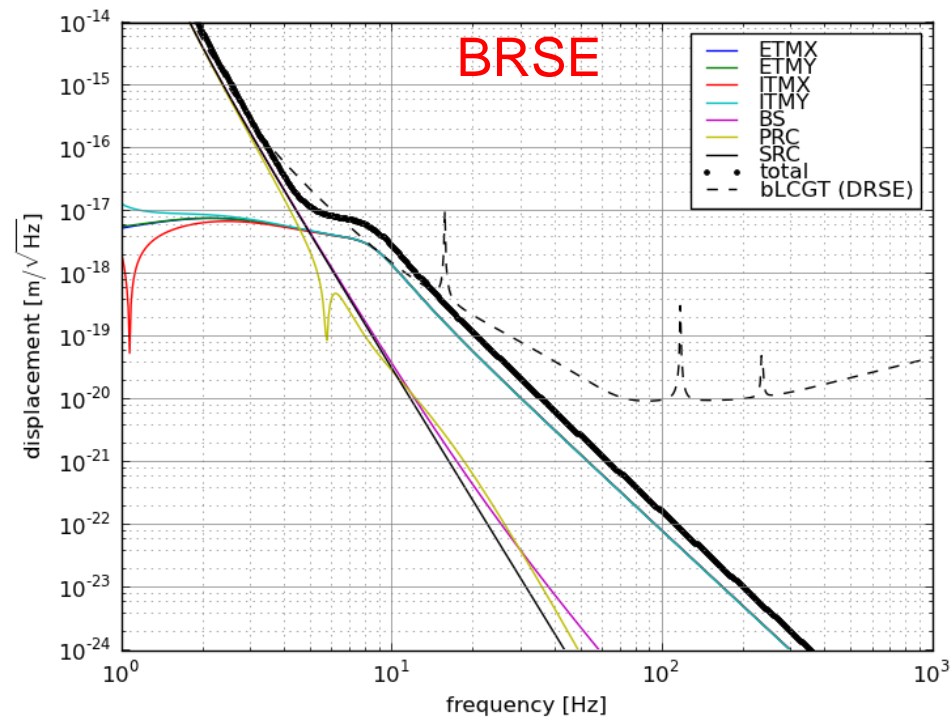
ショットノイズへの要求値

- とりあえずsafety factorなし $\theta_{\text{shot}} < \frac{h(f)L}{d^{\text{RMS}}k(f)} \frac{1+G(f)}{G(f)}$
- TMは $3.2\text{e-}14$ rad/rtHz
- その他は $1\text{e-}8$ rad/rtHz以上
- UGFを下げれば要求値は急激に緩くなる (UGFの4次とか)



要求値を満たした場合

- TMが10Hz付近で感度にぴったり
実際には4枚の鏡の合計なので、safety-factor
なしの要求値を満たしたただけではダメ
- その他はUGFがもっと低周波なので余裕



WFS再計算

- 最終決定した干渉計パラメータで
- BRSE/DRSE、腕に $\pm 1.3\text{pm}$ のdetune
これまではBRSE(SRCのdetuneなし)、腕のdetuneなし
腕の非対称性は入れていない

ITM=1.9km, ETM=1.9km, PRC=16.5deg, SRC=17.5deg, 16.875MHz, 45MHz

This is the parameter set chosen by the MIF group.

<http://gwwiki.icrr.u-tokyo.ac.jp/>

JGWwiki/LCGT/subgroup/ifo/MIF/OptParam

Lengths & Frequencies

f1	16.880962MHz (3*f2/8)	f2	45.015898MHz	f3	56.269873MHz (10*f2/8)
Larm	3000.0m	Lmc	26.639m		
Lprc	66.591m	Lsrc	66.591m	Las	3.3299m
Lp1	14.7615	Lp2	11.0661m	Lp3	15.7638m
Lmi	25m	Lmx	26.6649m	Lmy	23.3351m
Ls1	14.7412m	Ls2	11.1115m	Ls3	15.7386m
Folding Angle					

その他変更点

- SR2のWFSショットノイズを計算
- $\sqrt{2/\pi}$ 問題解決

Folding angle is an incident angle of the beam to the folding mirrors. The angle between incoming and reflected beams is twice the folding angle.

Radius of Curvatures (Positive for concave)

ITM	1900.0m	ETM	1900.0m		
PRM	458.1285m	PR2	-3.0764m	PR3	24.9165m
SRM	458.1285m	SR2	-2.9872m	SR3	24.9165m

Beam Spot Size (1/e² radius)

ITM	35.3mm	ETM	35.3mm		
PRM	4.457mm	PR2	4.457mm	PR3	36.639mm
SRM	4.308mm	SR2	4.328mm	SR3	36.666mm

REFL DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-5.94	1.67	0.14	-1.86	4.22	4.34	4.41	41.58	5.23	5.23	5.23
max ampli	-8.4E4	-2.3E5	-4.7E2	6.6E2	-7.0E4	-2.1E5	-2.5E4	-1.3E4	-6.3E3	-7.5E2	-3.9E2
Gouy	-88	-85	NaN	NaN	-48	-89	-89	-86	-89	NaN	NaN
ampli	-4.1E3	-9.5E3	NaN	NaN	-3.0E4	8.5E3	1.0E3	5.5E3	3.3E2	NaN	NaN
contami	4.82	1.95	NaN	NaN	9.06	3.03	24.74	2.81	78.07	NaN	NaN
N big sig	3	1	NaN	NaN	4	1	6	2	7	NaN	NaN

POP DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	16:88	13:58	14:19	12:51	-0.47	0.20	-87.05	-87.70	19:69	19:69	19:69
max ampli	-5.6E3	-3.4E4	-1.2E2	1.7E2	-8.7E2	-2.3E3	-3.8E3	-1.8E3	-2.3E2	-2.7E1	-1.4E1
Gouy	3	3	NaN	NaN	-76	-76	-76	-76	NaN	NaN	NaN
ampli	-3.8E3	-2.3E4	NaN	NaN	-1.5E2	-3.9E2	-2.6E3	-1.3E3	NaN	NaN	NaN
contami	7.79	1.28	NaN	NaN	31.32	12.33	1.85	3.78	NaN	NaN	NaN
N big sig	2	1	NaN	NaN	6	3	1	2	NaN	NaN	NaN

REFL_BDC

Gouy: -88.3deg (minimize CH)

REFL f1 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-85.59	86.86	-9.30	-9.32	-67.60	-80.18	-80.82	35.44	-84.77	-84.77	-84.77
max demod	0.02	0.09	89.50	89.37	-16.24	0.04	0.03	-0.10	-0.01	-0.01	-0.01
max ampli	-1.7E4	2.9E4	-2.0E3	1.8E3	2.5E3	1.3E4	1.6E3	-2.2E3	5.4E3	6.5E2	3.4E2
Gouy	-4	10	-4	-4	-2	-3	-3	4	81	81	NaN
demod	0	7	-88	-88	-87	0	0	1	-90	-90	NaN
ampli	-2.6E3	6.6E3	2.0E3	-1.8E3	1.3E3	2.8E3	3.5E2	-1.9E3	-1.2E1	-1.5E0	NaN
contami	3.88	1.68	2.65	2.89	3.98	3.14	25.49	4.07	11.20	94.16	NaN
N big sig	2	1	2	2	3	1	6	4	4	9	NaN

POP_BDC

POP f1 demodulation Gouy: -76.4deg (minimize CH)

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-70.19	-58.93	5.21	5.21	-61.39	-69.13	-69.19	-70.03	-70.31	-70.31	-70.31
max demod	0.01	-0.00	-89.96	-89.97	-12.71	0.01	0.01	0.01	-0.00	-0.00	-0.00
max ampli	2.6E3	-8.3E2	-5.1E2	4.6E2	-6.0E2	-3.7E3	-3.8E2	-1.9E2	-1.4E3	-1.6E2	-8.5E1
Gouy	31	20	-7	-7	-8	31	31	31	31	31	31
demod	0	0	-89	-89	0	0	0	0	0	0	0
ampli	-5.1E2	-1.6E2	-4.9E2	4.5E2	-3.3E2	5.4E2	6.7E1	3.6E1	2.7E2	3.2E1	1.7E1
contami	3.08	1.59	2.59	2.82	3.91	2.90	23.52	43.97	5.84	49.09	94.52
N big sig	2	1	2	2	3	1	5	6	3	7	8

REFL f2 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-86.42	88.37	89.66	88.04	-74.65	-76.36	-78.10	24.54	-83.07	-83.07	-83.07
max demod	-0.05	-0.00	-0.01	-0.01	0.08	0.04	0.01	-0.17	-0.01	-0.01	-0.01
max ampli	6.1E4	-1.9E5	-7.8E2	1.1E3	-1.1E4	-3.4E4	-4.6E3	1.2E4	2.2E0	2.6E-1	1.3E-1
Gouy	87	57	NaN	NaN	87	87	87	1	NaN	NaN	NaN
demod	90	89	NaN	NaN	90	90	90	-86	NaN	NaN	NaN
ampli	-8.9E1	-2.9E3	NaN	NaN	-4.9E1	-1.4E2	-1.7E1	8.2E2	NaN	NaN	NaN
contami	3.45	1.28	NaN	NaN	6.25	2.17	17.65	1.12	NaN	NaN	NaN
N big sig	2	1	NaN	NaN	3	1	4	1	NaN	NaN	NaN

POP_A1Q

Gouy: -8deg

POP f2 demodulation

POP_B1I

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-70.62	-60.23	-76.02	-77.54	-69.92	-69.97	-70.01	-70.83	-68.61	-68.61	-68.61
max demod	89.94	89.96	-89.96	-89.96	89.94	89.94	89.94	89.93	-89.96	-89.96	-89.96
max ampli	-4.5E3	1.4E3	9.2E0	-1.2E1	2.6E3	7.6E3	9.4E2	4.7E2	2.4E-2	2.9E-3	1.5E-3
Gouy	14	16	69	69	2	24	24	14	NaN	NaN	NaN
demod	4	16	69	69	2	24	24	14	NaN	NaN	NaN
ampli	-5.5E1	6.1E1	-1.4E-1	1.9E-1	-1.7E1	-2.4E2	-3.0E1	-5.9E0	NaN	NaN	NaN
contami	3.45	1.28	65.86	48.03	6.26	2.17	17.63	32.12	NaN	NaN	NaN
N big sig	2	1	6	5	3	4	5	4	NaN	NaN	NaN

REFL_A2I

Gouy: 88.4deg (maximize CH)

AS_BDC

Gouy: -83.7deg (minimize CS, CH)

AS DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-6.40	6.30	10.83	6.69	-5.64	5.95	5.89	5.23	7.30	7.46	-45.22
max ampli	-2.1E3	-1.9E3	2.1E3	9.5E3	-4.9E2	-2.7E3	-3.3E2	-1.6E2	-1.3E3	-1.5E2	-8.1E1
Gouy	-79	-79	-84	45	-83	-79	-79	-83	85	NaN	-83
ampli	-1.2E2	-1.1E2	-1.2E2	5.3E3	-7.5E1	-1.7E2	-2.1E1	-3.6E0	-1.9E2	NaN	-4.6E1
contami	9.68	10.35	2.93	2.18	4.48	6.82	55.03	93.69	15.68	NaN	7.38
N big sig	3	4	1	1	2	8	10	6	6	NaN	3

POP_A2Q

TRX DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-57.74	28.65	-57.65	28.74	70:31	0.36	0.28	-0.48	7.37	7.37	7.37
max ampli	-1.7E4	3.3E4	-1.7E4	3.3E4	-1.3E0	-3.7E1	-4.6E0	-2.2E0	9.0E-1	1.1E-1	5.6E-2
Gouy	-61	32	-61	32	NaN	NaN	NaN	NaN	NaN	NaN	NaN
ampli	-1.2E4	2.3E4	-1.2E4	2.3E4	NaN	NaN	NaN	NaN	NaN	NaN	NaN
contami	2.02	2.00	2.02	2.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN
N big sig	2	1	1	2	NaN	NaN	NaN	NaN	NaN	NaN	NaN

AS_ADC

AS f1 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-7.32	4.59	10.85	6.68	74.26	6.08	6.02	5.35	7.38	7.46	-19.76
max demod	-89.99	90.00	89.97	-89.96	83.43	89.97	89.97	89.97	-89.97	-89.97	89.94
max ampli	-2.8E2	-2.5E2	7.4E3	-3.4E4	3.5E2	-2.0E2	-2.5E1	-1.2E1	3.5E2	4.1E1	-2.0E1
Gouy	-83	-82	-84	7	-83	-83	-83	NaN	-83	NaN	-83
demod	-7	-8	8	0	-17	-7	NaN	NaN	-8	NaN	-8
ampli	-1.8E0	1.6E0	-1.5E2	-2.2E1	5.3E1	-1.3E0	NaN	NaN	-1.4E0	NaN	1.2E0
contami	25.84	44.54	1.62	1.14	2.82	36.39	NaN	NaN	34.63	NaN	40.89
N big sig	4	4	1	1	2	6	NaN	NaN	5	NaN	7

TRY DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-57.74	28.65	-57.65	28.74	-2.37	0.41	0.34	-0.42	7.40	7.40	7.40
max ampli	-1.7E4	3.3E4	-1.7E4	-3.3E4	-2.5E1	-3.7E1	-4.6E0	-2.2E0	-9.0E-1	-1.1E-1	-5.6E-2
Gouy	-61	32	-61	32	NaN	NaN	NaN	NaN	NaN	NaN	NaN
ampli	-1.2E4	2.3E4	1.2E4	-2.3E4	NaN	NaN	NaN	NaN	NaN	NaN	NaN
contami	2.02	2.00	2.02	2.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN
N big sig	2	1	1	2	NaN	NaN	NaN	NaN	NaN	NaN	NaN

AS_A1Q

Gouy: 6.7deg (maximize DH)

TRX_ADC, TRY_ADC

Gouy: -61.4deg (minimize CH, DH)

WFS Sensing Port (BRSE)

WFS Sensing Matrix (BRSE)

WFS Sensing Matrix [W/mrad]

(Gouy phases at POP A:-8.0, POP B:-76.4 REFL A:88.3, REFL B:-88.4, AS A:6.7, AS B:-83.7, TR A:-61.4 deg)

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
TRX_ADC	-9.23	0.40	-9.23	0.38	0.00	-0.01	-0.00	-0.00	0.00	0.00	0.00
REFL_A2I	-52.89	-143.42	-0.56	0.83	8.28	25.80	3.60	4.37	-0.00	-0.00	-0.00
TRY_ADC	-9.23	0.40	9.23	-0.38	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00
AS_A1Q	0.21	-0.20	6.78	25.40	0.11	-0.16	-0.02	-0.01	-0.28	-0.03	-0.01
POP_A1Q	0.02	-0.01	0.36	-0.36	0.26	-0.02	-0.00	-0.00	-0.01	-0.00	-0.00
POP_A2Q	-1.55	0.73	-0.00	0.00	1.00	2.86	0.35	0.17	-0.00	-0.00	-0.00
POP_BDC	-0.17	-0.01	0.00	0.00	-0.12	-0.30	-2.09	-1.02	0.01	0.00	0.00
REFL_BDC	-3.42	0.31	-0.01	0.02	1.80	5.54	0.68	4.65	0.22	0.03	0.01
POP_B1I	1.95	-0.69	0.00	-0.00	-0.46	-2.43	-0.30	-0.15	-1.09	-0.13	-0.07
AS_ADC	1.08	-1.08	1.35	5.04	-0.27	-1.53	-0.19	-0.09	-0.72	-0.08	-0.03
AS_BDC	-0.00	0.00	-0.09	-0.03	-0.06	-0.01	-0.00	-0.00	0.01	0.00	-0.04

REFL DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-14.29	-5.00	-1.35	-3.74	-1.78	-6.09	-6.14	27.47	-68.00	-68.00	-68.00
max ampli	-5.8E4	-1.8E5	-3.6E2	5.1E2	-5.6E4	-1.7E5	-2.0E4	-9.6E3	-1.4E4	-1.6E3	-8.5E2
Gouy	-85	22	NaN	NaN	76	22	22	84	85	85	85
ampli	-6.6E3	-1.1E5	NaN	NaN	-8.4E3	-1.0E5	-1.2E4	-3.7E3	8.7E3	1.0E3	5.4E2
contami	-3.82	2.69	NaN	NaN	7.22	2.96	24.72	6.76	2.91	24.44	47.07
N big sig	-2	1	NaN	NaN	3	2	5	3	1	6	7

POP DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	16:26	13:53	13:91	13:67	-1:08	-0:98	-87:23	-87:90	18:78	18:78	18:78
max ampli	-5.5E3	-2.5E4	-8.8E1	1.3E2	-6.8E2	-1.8E3	-3.0E3	-1.5E3	-1.4E2	-1.6E1	-8.5E0
Gouy	-3	3	NaN	NaN	-76	-76	-76	-76	NaN	NaN	NaN
ampli	-3.8E3	-1.8E4	NaN	NaN	-1.3E2	-3.2E2	-2.1E3	-1.0E3	NaN	NaN	NaN
contami	-6.22	1.33	NaN	NaN	30.77	11.92	1.86	3.79	NaN	NaN	NaN
N big sig	-2	1	NaN	NaN	6	3	1	2	NaN	NaN	NaN

REFL_BDC

Gouy: 85.0deg (minimize CH)

REFL f1 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-0.70	-18.71	10.14	7.21	-68.25	-67.31	-78.50	85.10	-52.96	-52.96	-52.96
max demod	-0.09	0.07	-71.42	-63.84	-2.32	-0.13	-0.27	0.11	-0.02	-0.02	-0.02
max ampli	1.9E4	9.1E4	8.9E2	-9.4E2	2.3E3	9.7E3	1.0E3	4.8E3	3.9E3	4.7E2	2.4E2
Gouy	-77	14	-33	-33	-50	71	71	71	-77	-77	NaN
demod	-90	25	-90	-90	-90	2	2	2	-90	-90	NaN
ampli	-4.1E1	6.9E4	5.8E2	-5.9E2	2.7E2	-7.2E3	-8.9E2	4.6E3	1.7E1	2.0E0	NaN
contami	-3.77	1.30	2.96	2.95	4.14	3.24	26.24	5.05	9.21	77.46	NaN
N big sig	-1	1	2	2	3	1	4	3	4	10	NaN

POP_BDC

Gouy: -76.5deg (minimize CH)

POP f1 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-45.51	-5.60	27.90	27.90	-34.52	-38.04	-52.73	-52.26	-38.33	-38.33	-38.33
max demod	-0.08	0.14	-89.07	-88.81	-9.15	-0.00	-0.10	-0.10	-0.01	-0.01	-0.01
max ampli	1.6E3	-1.5E3	-2.1E2	2.1E2	-4.5E2	-2.2E3	-3.5E2	-1.7E2	-9.8E2	-1.2E2	-6.1E1
Gouy	-84	52	-38	-38	-38	85	53	53	85	85	NaN
demod	-1	1	90	90	90	1	1	1	2	2	NaN
ampli	-1.0E3	-8.1E2	8.7E1	-8.7E1	6.3E1	1.2E3	9.6E1	4.6E1	5.4E2	6.4E1	NaN
contami	-3.34	1.44	2.74	2.73	3.78	2.92	13.01	27.18	6.61	55.60	NaN
N big sig	-2	1	2	2	3	1	3	4	3	7	NaN

REFL f2 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-87.10	88.32	89.37	89.19	-74.83	-76.53	-78.25	24.52	-80.90	-80.90	-80.90
max demod	-0.05	-0.00	-0.01	-0.01	0.07	0.04	0.01	-0.18	-0.02	-0.02	-0.02
max ampli	5.3E4	-1.4E5	-5.6E2	8.1E2	-8.7E3	-2.7E4	-3.7E3	9.9E3	2.2E0	2.6E-1	1.3E-1
Gouy	-84	57	NaN	NaN	84	84	84	1	NaN	NaN	NaN
demod	-90	89	NaN	NaN	90	90	90	-86	NaN	NaN	NaN
ampli	-8.3E1	-2.2E3	NaN	NaN	-4.7E1	-1.4E2	-1.7E1	6.5E2	NaN	NaN	NaN
contami	-3.54	1.33	NaN	NaN	6.19	2.15	17.46	1.09	NaN	NaN	NaN
N big sig	-2	1	NaN	NaN	3	1	4	1	NaN	NaN	NaN

POP_A1Q

Gouy: -38deg

POP f2 demodulation

POP_B1I

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-70.77	-61.55	-76.36	-76.48	-69.92	-69.97	-70.01	-70.83	-66.44	-66.44	-66.44
max demod	89.94	89.96	-89.92	-89.93	89.94	89.94	89.94	89.93	-89.97	-89.97	-89.97
max ampli	-3.4E3	1.2E3	6.5E0	-9.7E0	2.1E3	6.1E3	7.5E2	3.8E2	2.4E-2	2.8E-3	1.5E-3
Gouy	-25	19	69	69	13	13	4	8	NaN	NaN	NaN
demod	-18	49	-69	-69	4	4	3	3	NaN	NaN	NaN
ampli	1.7E2	1.3E2	-9.5E-2	1.4E-1	-2.1E1	-6.2E1	-7.6E0	-3.1E0	NaN	NaN	NaN
contami	-3.54	1.32	74.23	51.20	6.20	2.15	17.43	31.40	NaN	NaN	NaN
N big sig	-2	1	6	5	3	1	4	5	NaN	NaN	NaN

REFL_A2I

Gouy: 88.3deg (maximize CH)

AS_BDC

Gouy: -83.4deg (minimize CS, CH)

AS DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-6.74	6.57	11.83	8.35	-12.84	6.29	6.23	7.20	7.55	7.70	-40.10
max ampli	-1.2E3	-1.2E3	2.4E3	8.8E3	-2.9E2	-1.7E3	-2.0E2	-1.0E2	-8.4E2	-9.7E1	-5.1E1
Gouy	-78	-78	-83	77	-82	-79	-81	NaN	-78	NaN	-82
ampli	-7.8E1	-8.0E1	-1.4E2	2.3E3	-7.2E1	-9.7E1	-7.0E0	NaN	-4.6E1	NaN	-2.7E1
contami	-11.07	10.74	2.96	1.87	4.64	7.27	58.26	NaN	18.86	NaN	12.40
N big sig	-5	4	2	1	2	2	9	NaN	6	NaN	5

POP_A2Q

TRX DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-62.75	27.31	-62.62	27.40	72.18	0.35	0.28	-0.49	9.53	9.53	9.53
max ampli	-1.3E4	2.5E4	-1.3E4	2.5E4	-1.3E0	-3.0E1	-3.6E0	-1.8E0	8.9E-1	1.1E-1	5.5E-2
Gouy	-63	27	-63	27	NaN	NaN	NaN	NaN	NaN	NaN	NaN
ampli	-9.2E3	1.8E4	-9.2E3	1.8E4	NaN	NaN	NaN	NaN	NaN	NaN	NaN
contami	-2.03	2.00	2.02	2.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN
N big sig	-2	1	1	2	NaN	NaN	NaN	NaN	NaN	NaN	NaN

AS_ADC

AS f1 demodulation

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-6.25	6.49	-19.39	-22.89	39.26	33.23	33.17	34.06	-9.76	-9.85	-30.14
max demod	89.81	89.90	-89.67	-89.95	89.58	89.92	89.92	89.92	89.89	89.89	89.86
max ampli	1.8E2	-1.6E2	-7.2E3	2.7E4	2.8E2	-1.4E2	-1.8E1	-8.7E0	-2.6E2	-3.0E1	-1.6E1
Gouy	-68	68	23	68	22	68	68	68	68	68	NaN
demod	-4	-4	0	0	-4	-4	-4	-4	-4	-4	NaN
ampli	-6.5E0	5.5E0	-1.3E1	-2.0E2	-7.9E0	8.8E0	1.1E0	5.4E-1	4.2E0	4.9E-1	NaN
contami	5.26	6.27	1.69	1.16	2.91	3.86	31.58	63.84	8.14	69.42	NaN
N big sig	-2	3	1	1	2	1	7	5	10	12	NaN

TRY DC

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
max Gouy	-62.75	27.32	-62.62	27.40	-3.09	0.42	0.35	-0.42	9.56	9.56	9.56
max ampli	-1.3E4	2.5E4	-1.3E4	-2.5E4	-2.0E1	-3.0E1	-3.6E0	-1.8E0	-8.9E-1	-1.1E-1	-5.5E-2
Gouy	-63	27	-63	27	NaN	NaN	NaN	NaN	NaN	NaN	NaN
ampli	-9.2E3	1.8E4	9.2E3	-1.8E4	NaN	NaN	NaN	NaN	NaN	NaN	NaN
contami	-2.03	2.00	2.03	2.01	NaN	NaN	NaN	NaN	NaN	NaN	NaN
N big sig	-2	1	1	2	NaN	NaN	NaN	NaN	NaN	NaN	NaN

AS_A1Q

Gouy: -22.9deg (maximize DH)

TRX_ADC, TRY_ADC

Gouy: -62.7deg (minimize CH, DH)

WFS Sensing Port (DRSE)

WFS Sensing Matrix (DRSE)

WFS Sensing Matrix [W/mrad]

(Gouy phases at POP A:-38.0, POP B:-76.5 REFL A:88.3, REFL B:85.0, AS A:-22.9, AS B:-83.4, TR A:-62.7 deg)

	CS	CH	DS	DH	BS	PR3	PR2	PRM	SR3	SR2	SRM
TRX_ADC	-9.24	-0.01	-9.24	-0.03	0.00	-0.01	-0.00	-0.00	0.00	0.00	0.00
REFL_A2I	-52.89	-143.41	-0.56	0.81	8.28	25.81	3.60	4.37	-0.00	-0.00	-0.00
TRY_ADC	-9.22	-0.01	9.23	0.03	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00
AS_A1Q	0.16	-0.14	7.18	26.88	0.13	-0.08	-0.01	-0.00	-0.25	-0.03	-0.02
POP_A1Q	-0.00	0.00	0.09	-0.09	0.06	0.00	-0.00	-0.00	0.00	0.00	0.00
POP_A2Q	-2.84	1.13	-0.01	0.01	1.79	5.17	0.63	0.32	-0.00	-0.00	-0.00
POP_BDC	0.19	0.02	0.00	-0.00	-0.12	-0.31	-2.08	-1.02	0.01	0.00	0.00
REFL_BDC	-6.61	0.05	-0.02	0.01	-2.22	2.23	0.28	-3.63	8.69	1.03	0.54
POP_B1I	1.41	-0.49	0.00	-0.00	-0.34	-1.76	-0.32	-0.16	-0.77	-0.09	-0.05
AS_ADC	0.74	-0.74	1.37	5.35	-0.20	-1.03	-0.13	-0.06	-0.51	-0.06	-0.03
AS_BDC	-0.00	-0.00	-0.15	-0.19	-0.07	-0.01	-0.00	0.00	0.01	0.00	-0.03

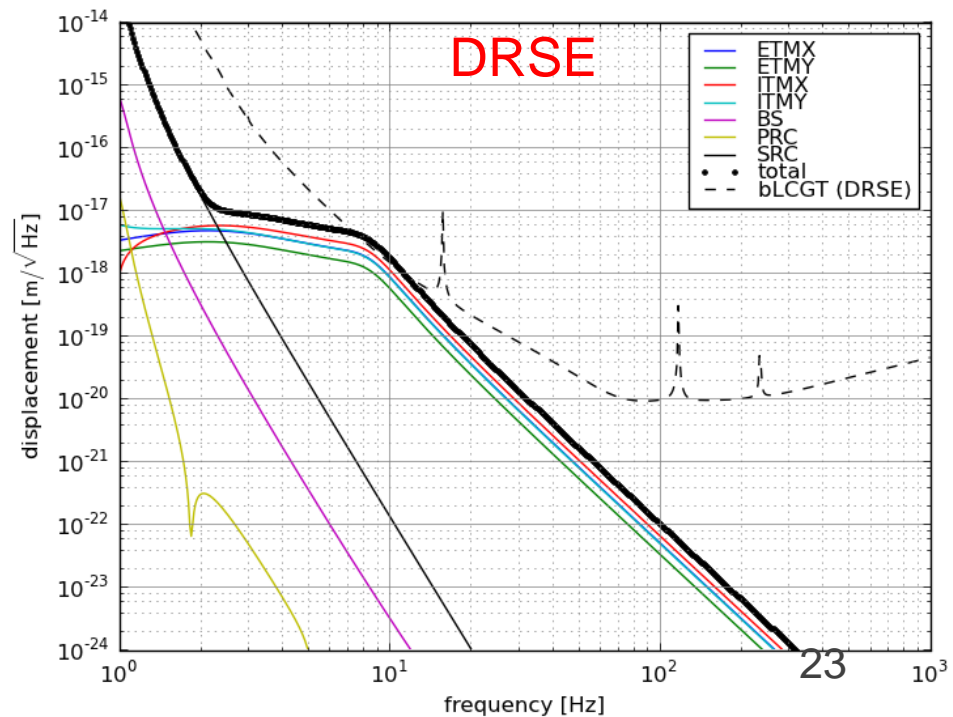
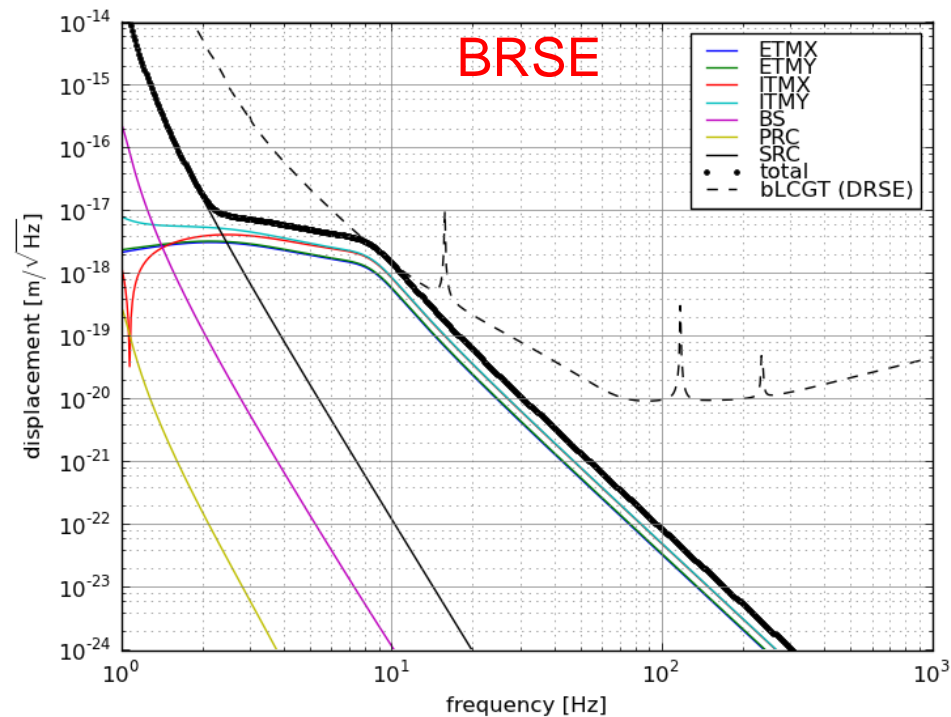
WFS shot noise計算値

- safety-factorなしの要求値は満たしているが、ギリギリ
- 光てこよりは良い
- SR系は実際には無理にSR2を分離しない方が良い

	BRSE req	BRSE sim	DRSE req	DRSE sim	oplev intensity
ETMX:	3.2E-14	1.32E-14	3.2E-14	2.03E-14	2.E-11
ETMY:	3.2E-14	1.37E-14	3.2E-14	1.34E-14	2.E-11
ITMX:	3.2E-14	1.97E-14	3.2E-14	2.64E-14	2.E-11
ITMY:	3.2E-14	2.00E-14	3.2E-14	1.99E-14	2.E-11
BS:	1.7E-08	5.25E-13	2.7E-08	2.17E-12	2.E-10
PR3:	4.7E-06	1.88E-13	5.3E-07	7.50E-13	3.E-10
PR2:	4.7E-06	7.14E-14	5.3E-07	2.22E-13	3.E-10
PRM:	4.7E-06	6.31E-14	5.3E-07	4.28E-13	3.E-10
SR3:	1.2E-08	5.44E-12	1.9E-08	9.36E-12	3.E-10
SR2:	1.2E-08	4.68E-11	1.9E-08	8.39E-11	3.E-10
SRM:	1.2E-08	1.00E-12	1.9E-08	4.77E-12	3.E-10

感度への影響

- ショットノイズの計算値から感度への影響を計算
- やはり4枚合計すると10 Hzで感度に接してしまう



まとめ

- ビームスポットのずれRMS
TMは0.1 mm
その他は 1 mm
- オープンループ伝達関数
TMはUGF 3 Hz, cut-off 10 Hz
その他はUGF 0.1 Hz, cut-off 5 Hz
- で計算するとWFSショットノイズは
TMは3倍の余裕しかない
その他は3桁以上余裕ある
→ TMが厳しい
- ビームスポットの揺れが上記になる保証は今回の計算ではしていない(見込み、というだけ)

できること

- あと3倍余裕を持たすには.....
 - TM上のビームスポット揺れを0.03 mmにする
厳しいっぽい
 - UGFを2 Hzくらいにする
不安定@1 Hzなので理論上可能だが、
共振ピークが2 Hz付近にたくさんあるので
実際は厳しい
- aLIGOでは.....
 - TM上で0.05 mm、その他1 mm以下 (Fig. 21)
 - TMのUGF 4 Hz、その他0.1 Hz (Fig. 18)
 - やはり10 Hzで感度に接している (Fig. 24)
(L. Barsotti & M. Evans: [LIGO-T0900511](#))