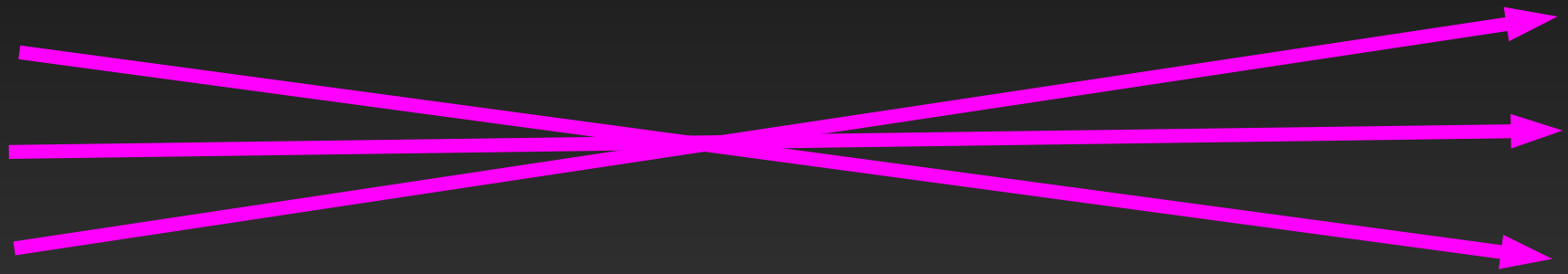
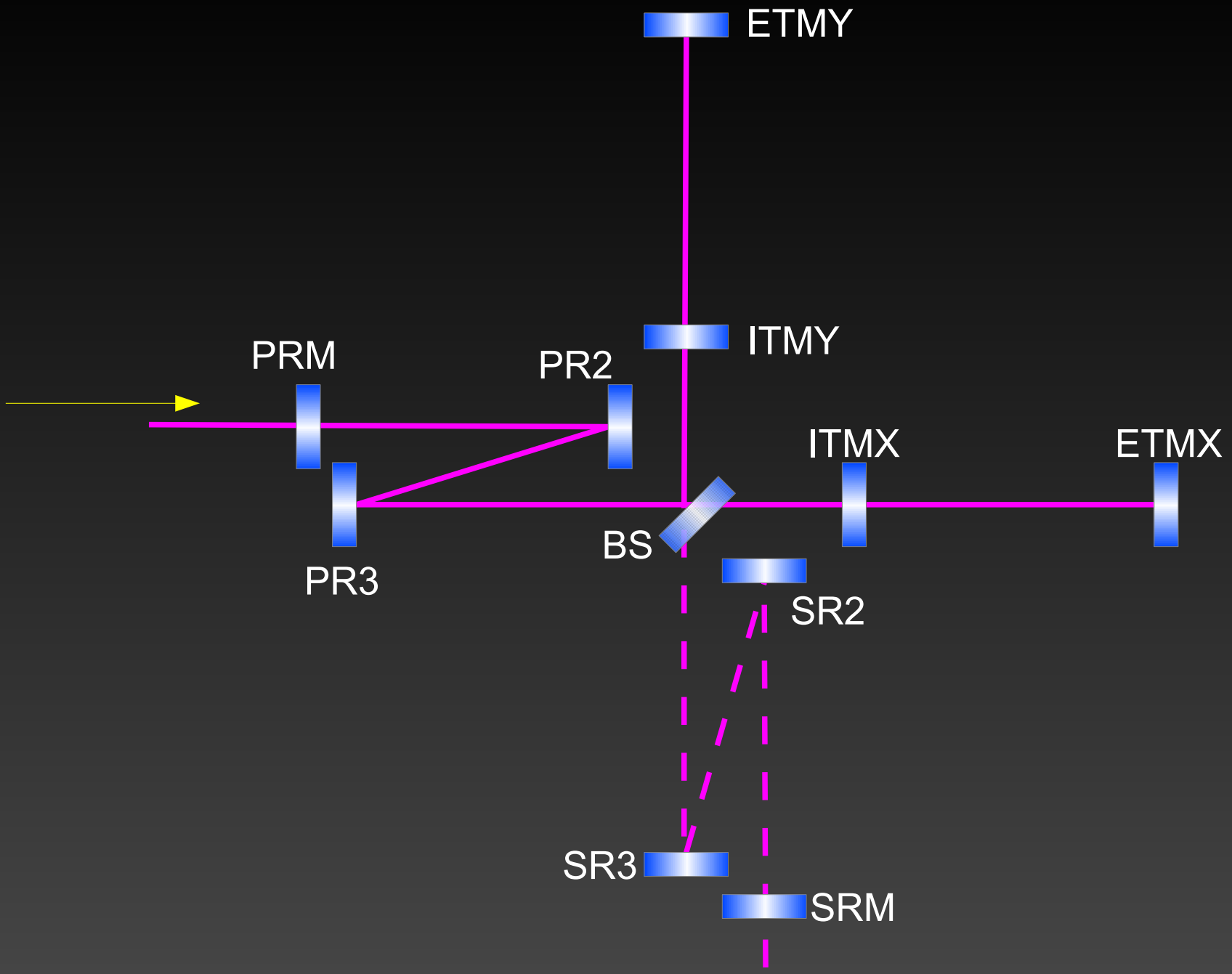
重力波検出器KAGRAの主干渉計開発

東大理 麻生洋一 他

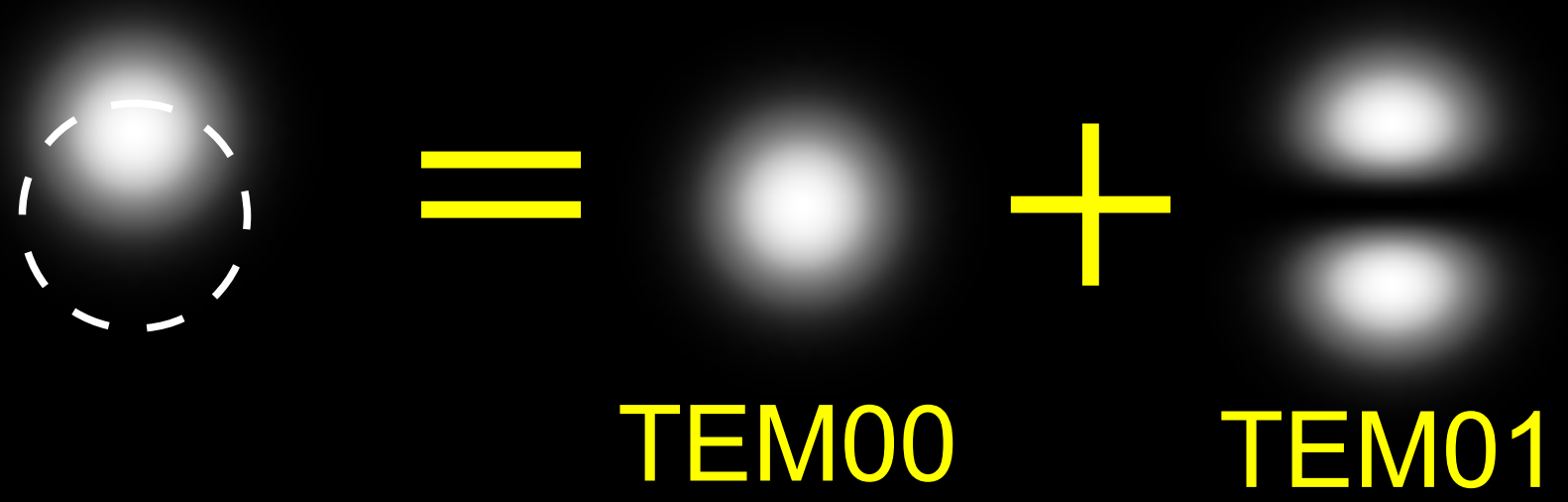
入射ビームは揺れている!!

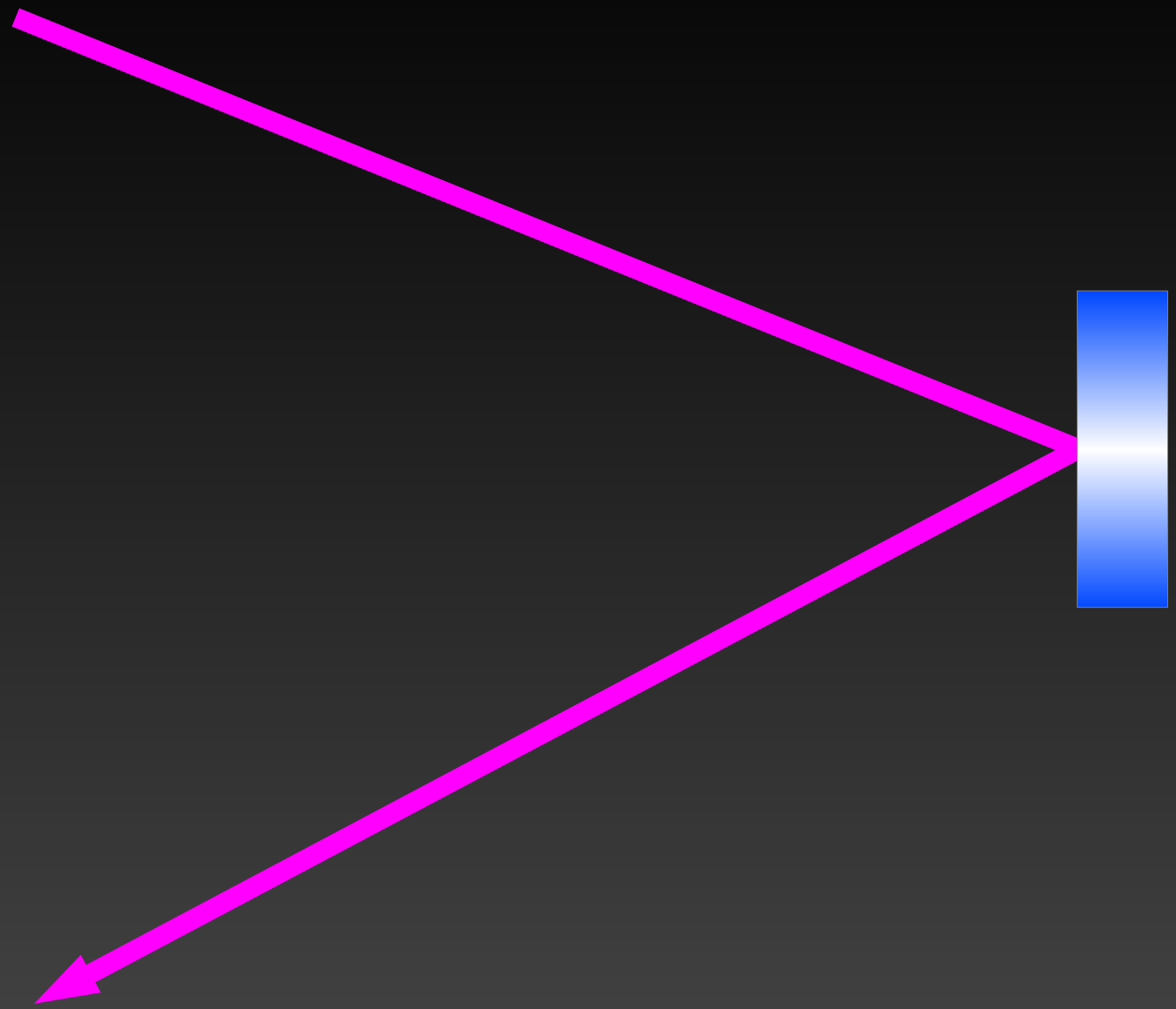



ETMY
ITMY
PRM
PR2
ITMX
ETMX
BS
PR3
SR2
SR3
SRM

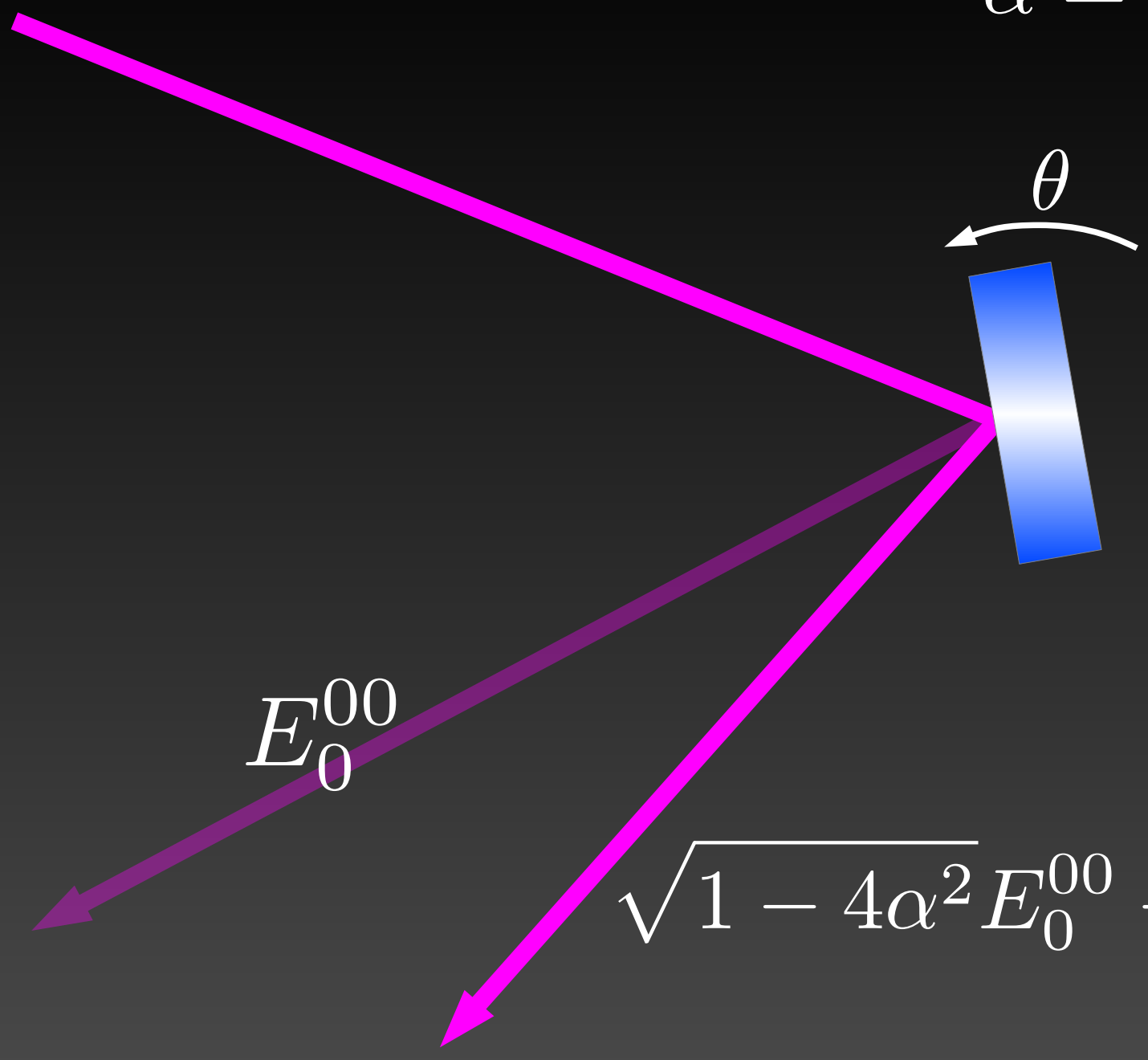
計算方法

Guido Mueller, *Optics Express*, **18**, 7118 (2005)


=
+
TEM00
TEM01



$$\alpha = \frac{\pi w}{\lambda}\theta$$

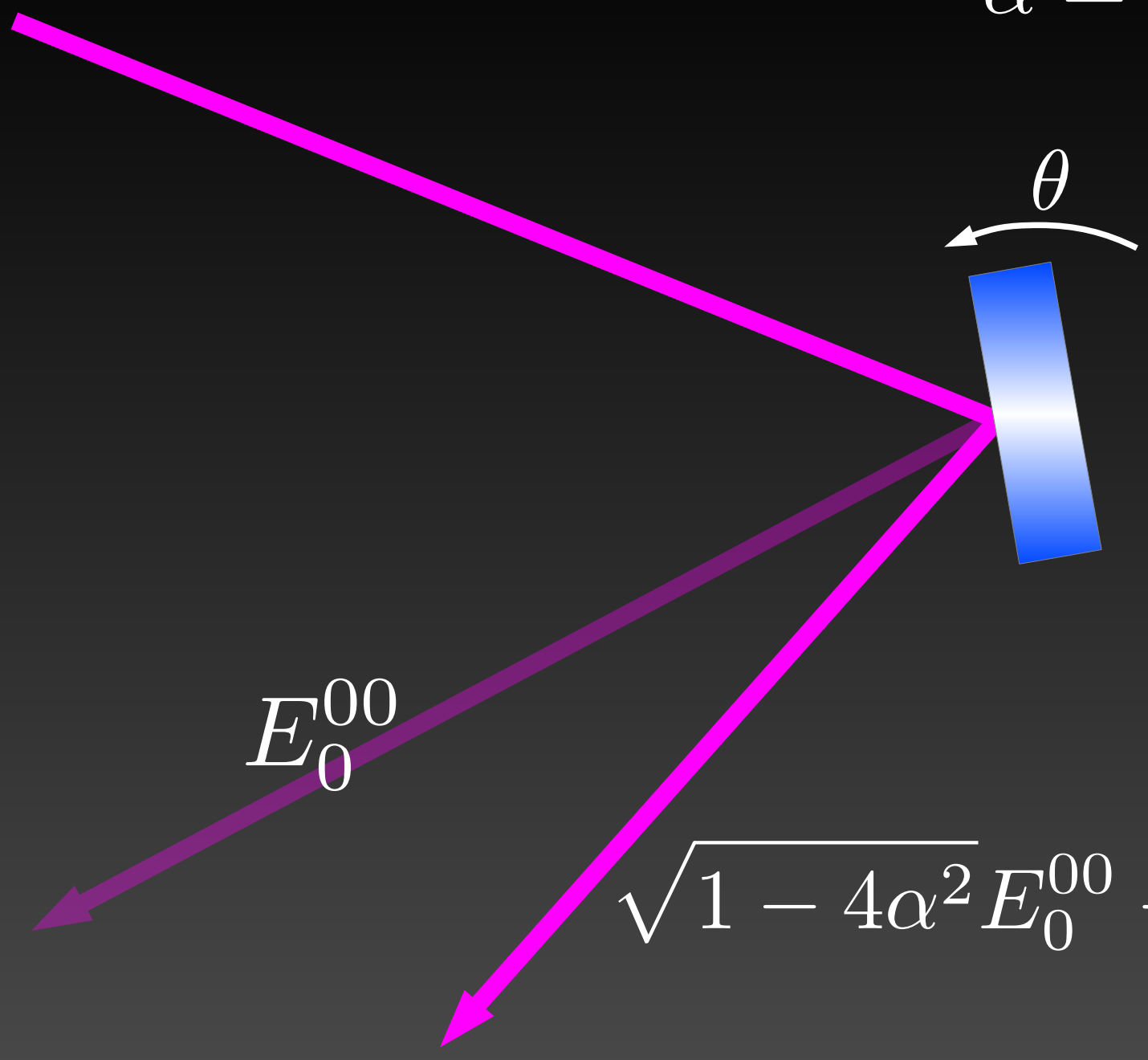


$$E_0^{nm} = A_0 \cdot \gamma_{nm}(x, y) \cdot e^{i\Omega t + i\phi}$$

$\gamma_{00}(x, y)$

$\gamma_{01}(x, y)$

$$\alpha = \frac{\pi w}{\lambda}\theta$$



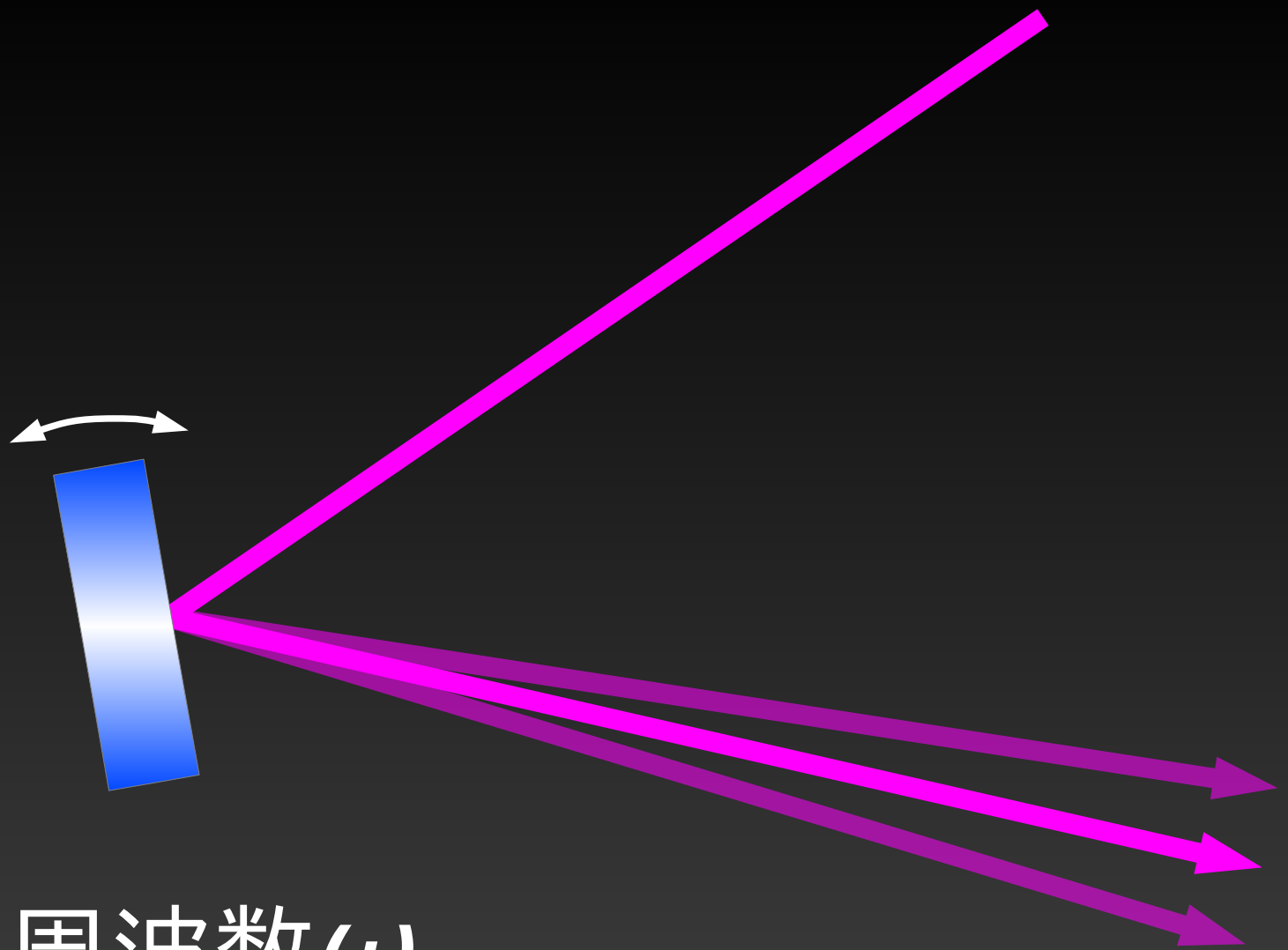
散乱行列

$$\begin{pmatrix} E^{00}_{0'} \\ \\ E^{01}_{1'} \end{pmatrix} = \begin{pmatrix} \clubsuit & \diamondsuit \\ \\ \heartsuit & \spadesuit \end{pmatrix} \begin{pmatrix} E^{00}_{0} \\ \\ E^{01}_{1} \end{pmatrix}$$

傾き θ のミラー

$$\begin{pmatrix} E_{0'}^{00} \\ \\ E_{1'}^{01} \end{pmatrix} = \begin{pmatrix} \sqrt{1-4\alpha^2} & 2i\alpha \\ \\ 2i\alpha & \sqrt{1-4\alpha^2} \end{pmatrix} \begin{pmatrix} E_{0}^{00} \\ \\ E_{1}^{01} \end{pmatrix}$$

$$\alpha = \frac{\pi w}{\lambda}\theta$$

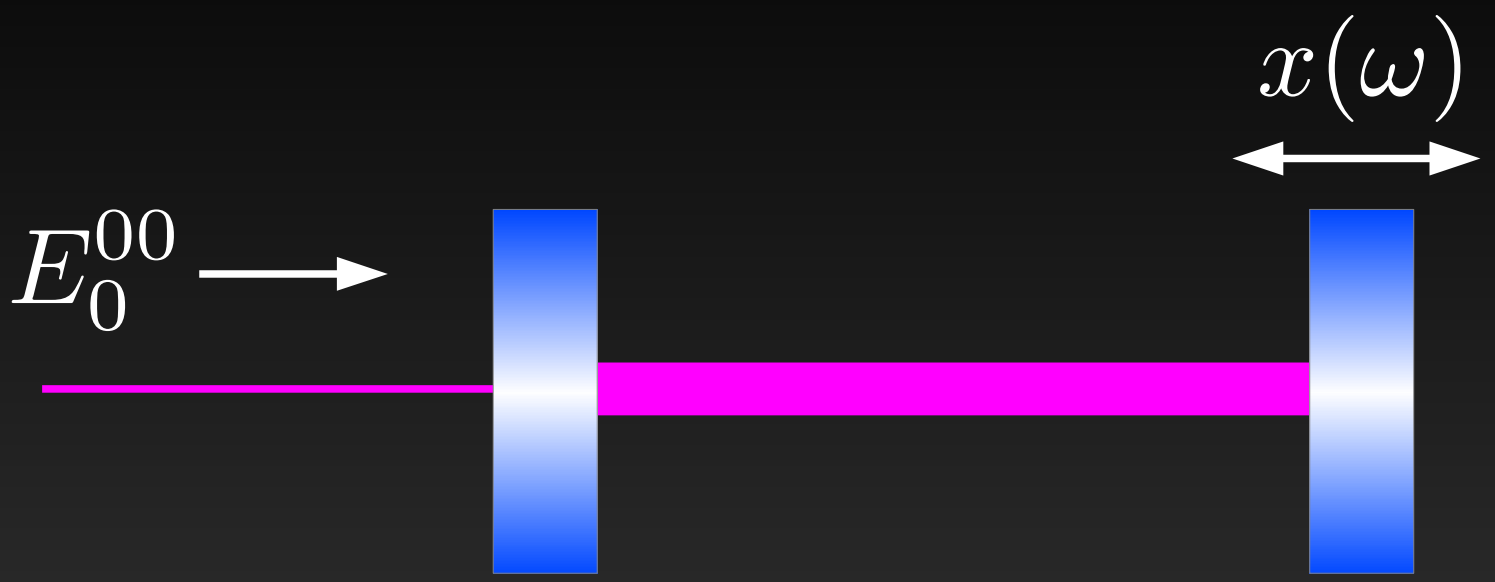


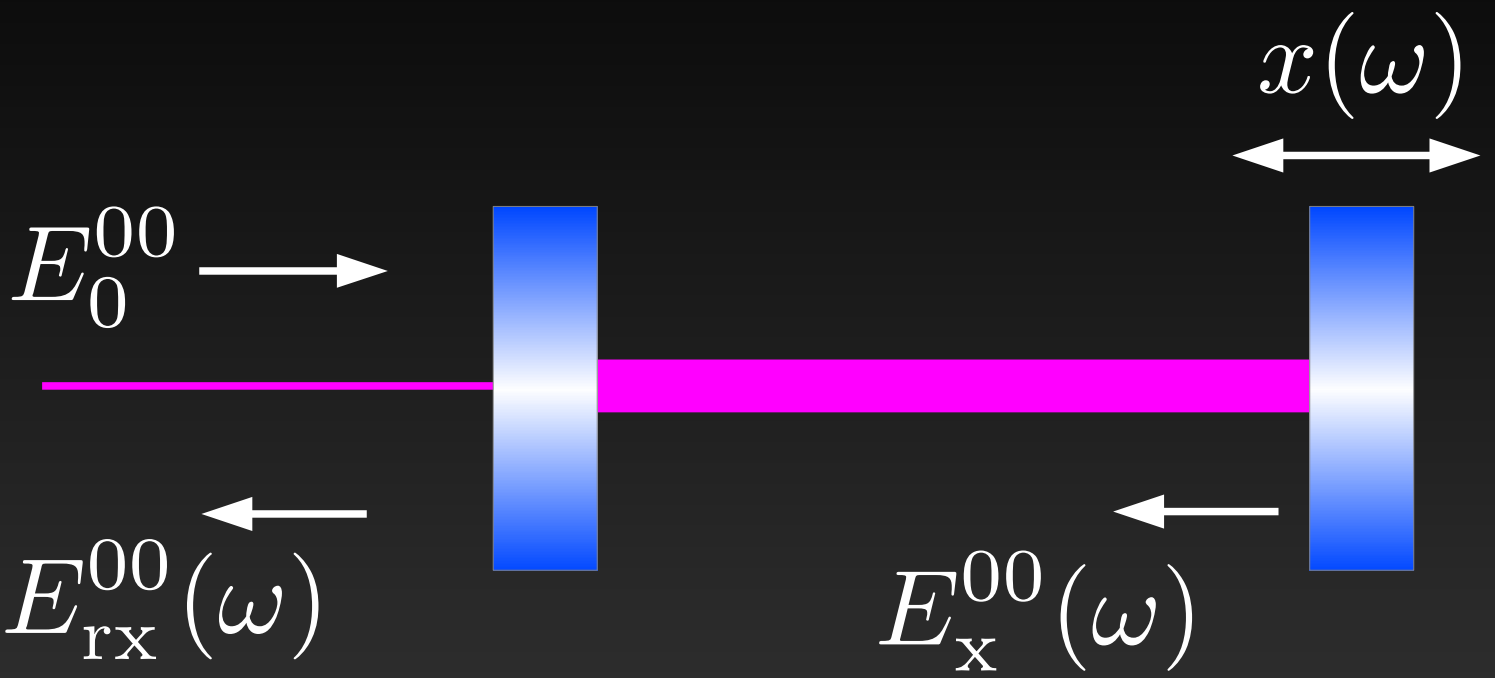
角周波数ω

±ωのサイドバンド生成

$$E_0^{00}$$

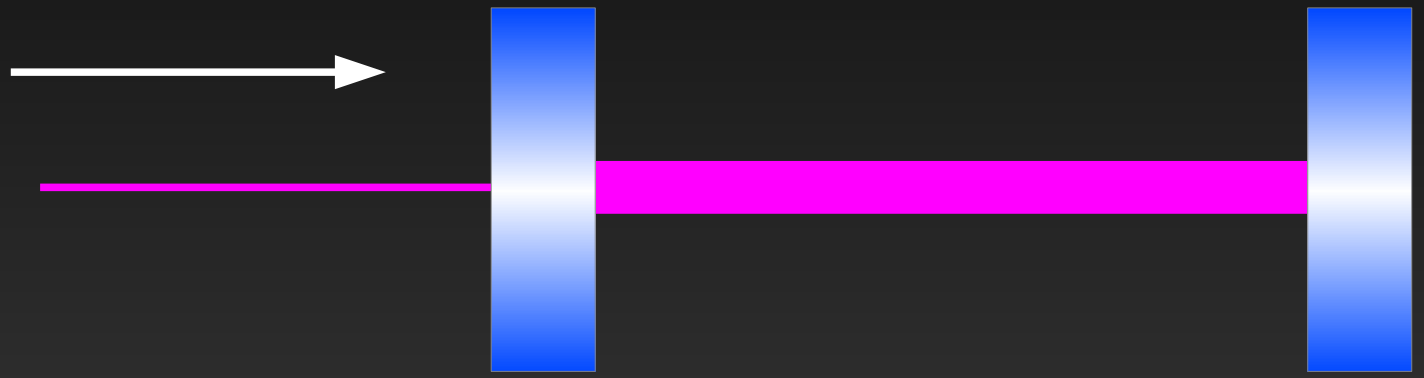
$$\longrightarrow E_{0'}^{00} + E_1^{01} e^{i\omega t} + E_1^{01} e^{-i\omega t}$$

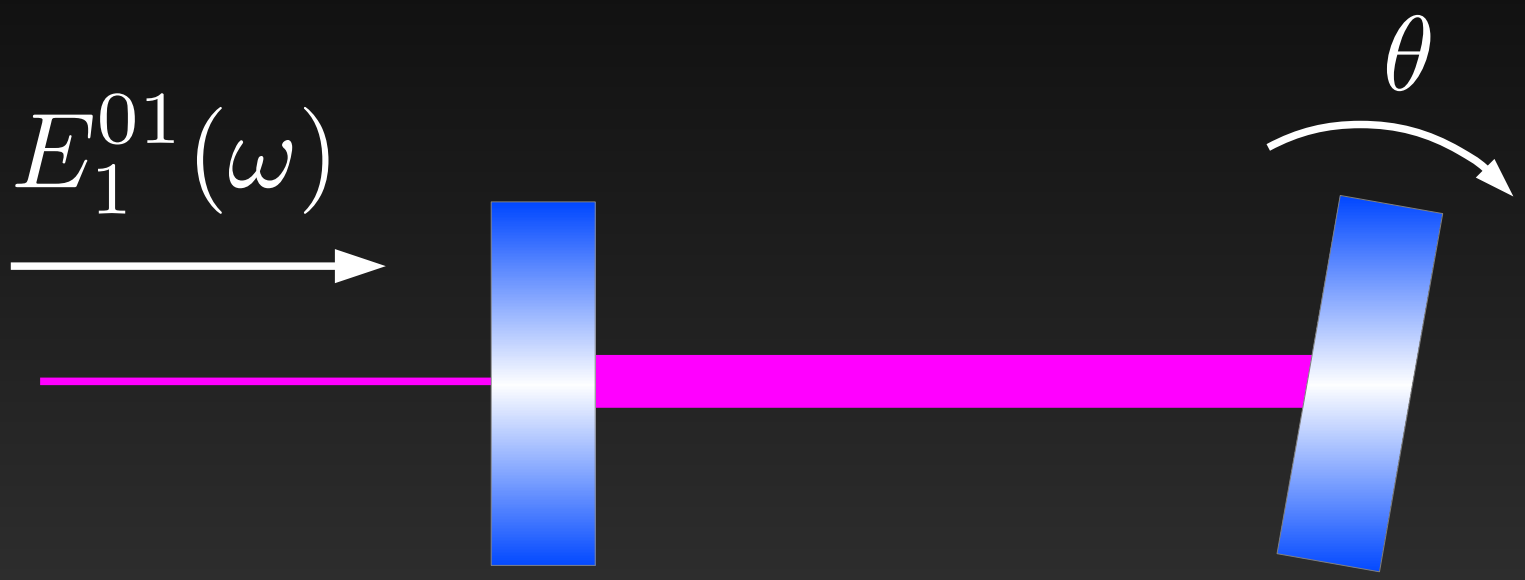

$x(\omega)$
E_0^{00}

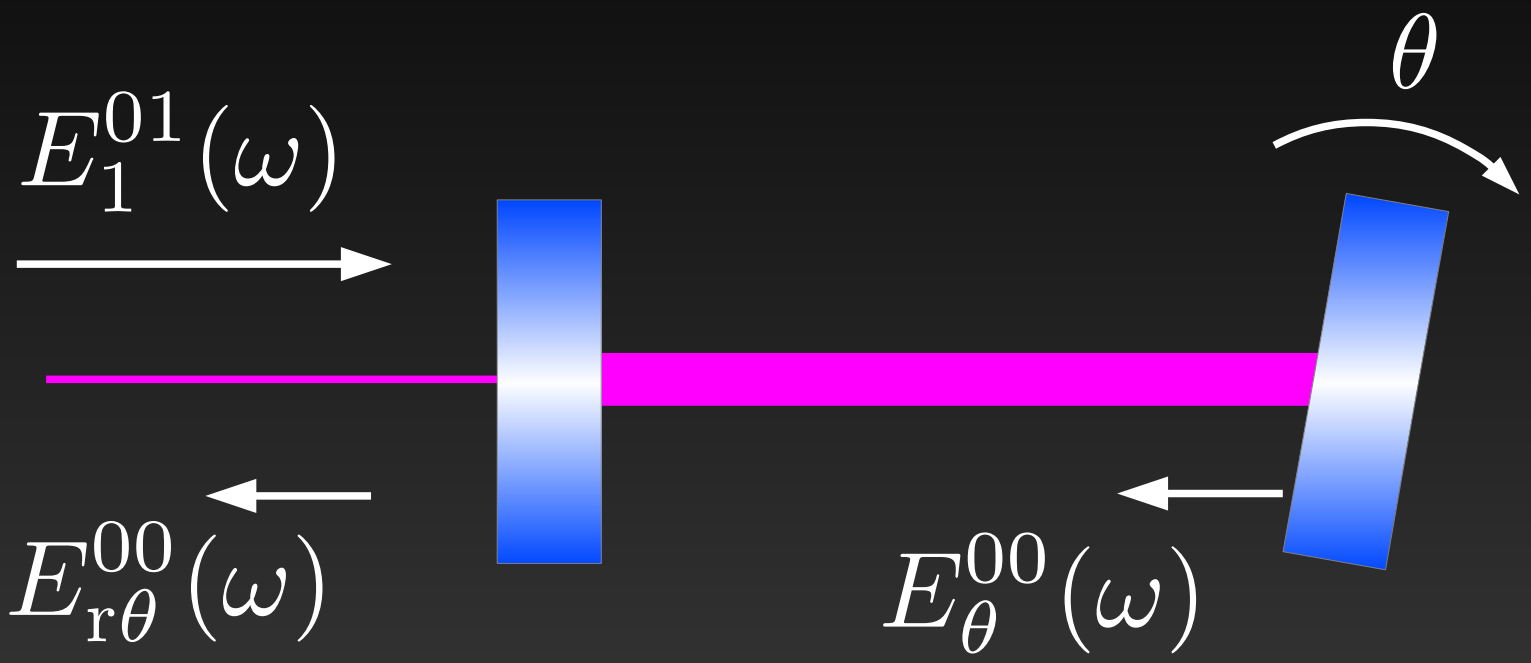

$x(\omega)$
E_0^{00}
$E_{\mathrm{rx}}^{00}(\omega)$
$E_{\mathrm{x}}^{00}(\omega)$

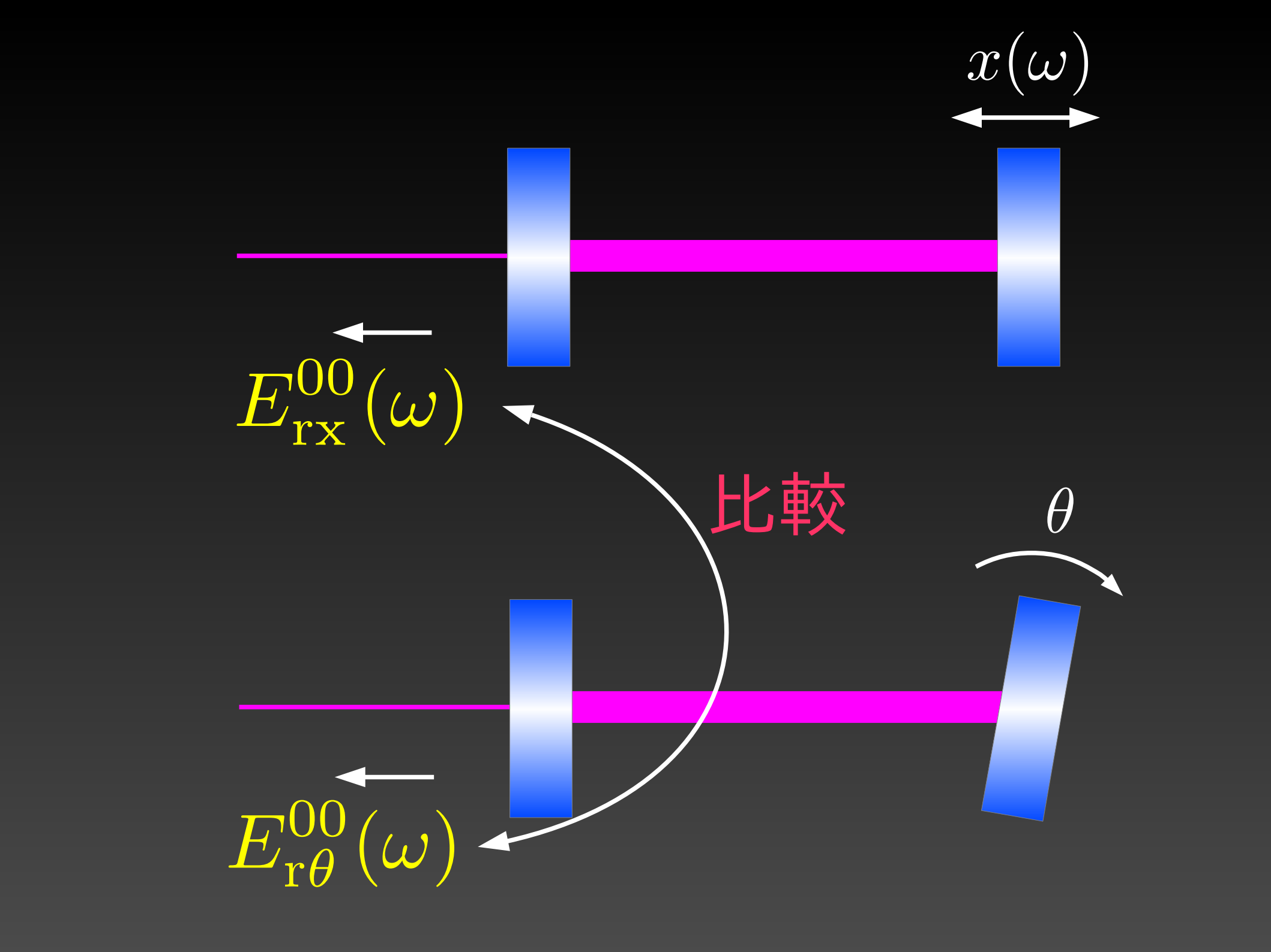
ビームジッタ サイドバンド

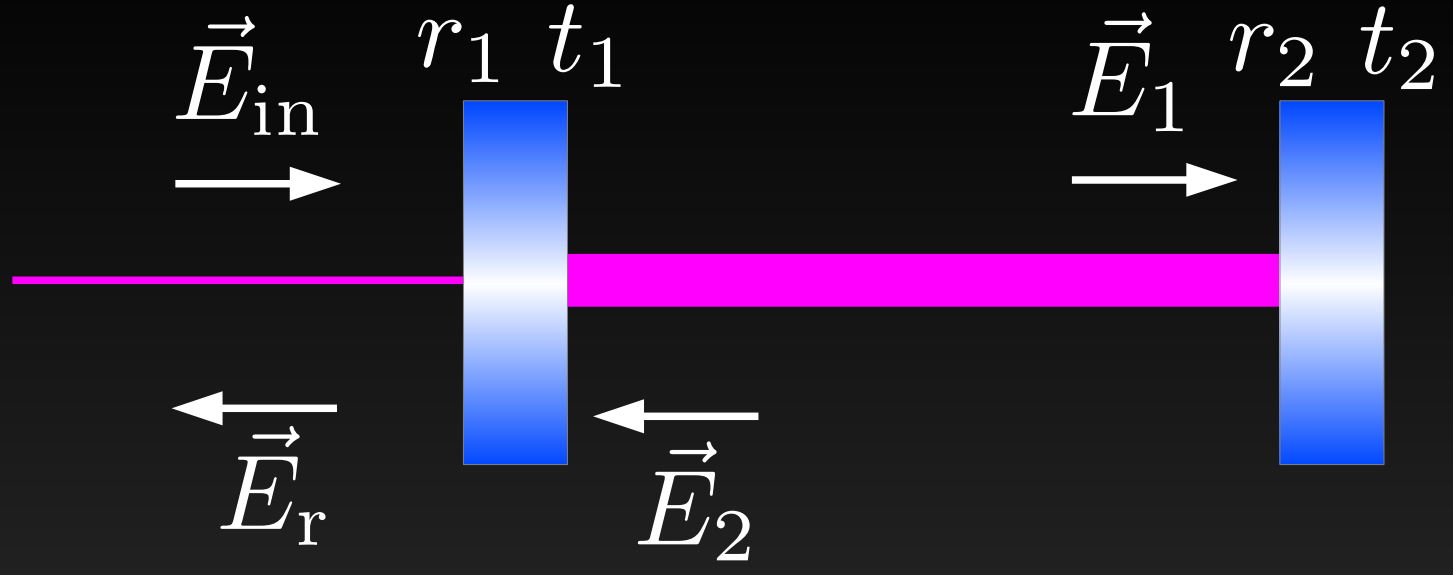
$$E_0^{00} + E_1^{01}(\omega) + E_1^{01}(-\omega)$$



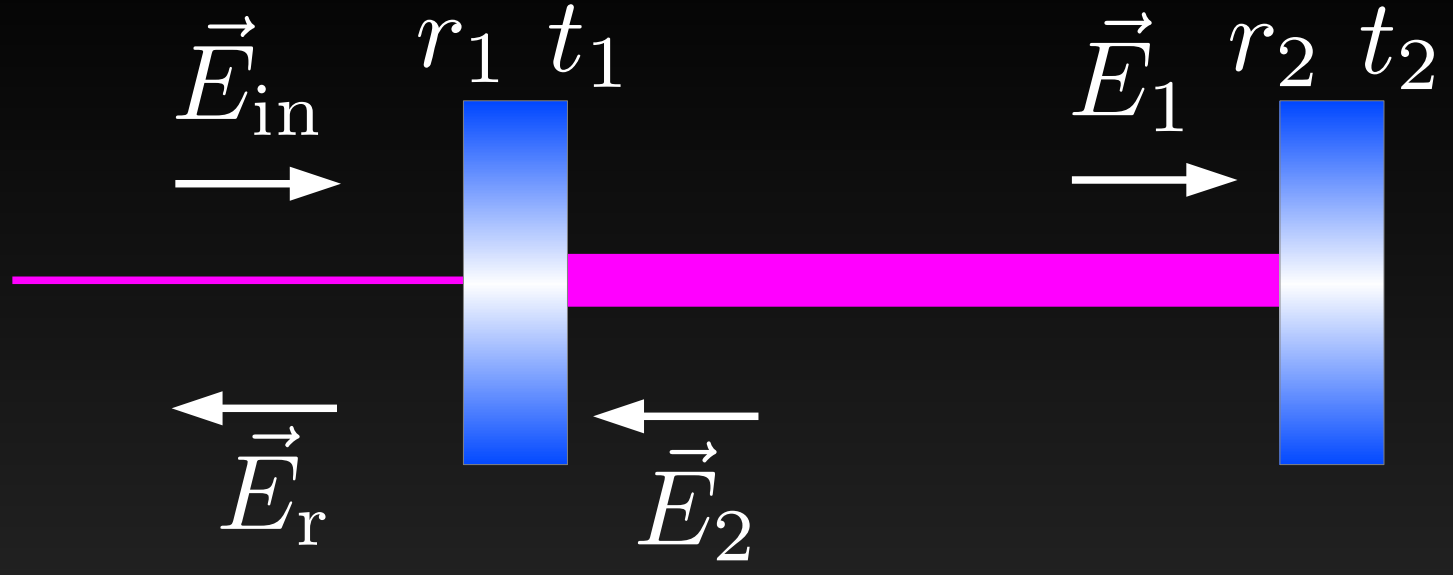

$E_1^{01}(\omega)$
θ


θ
$E_1^{01}(\omega)$
$E_{\mathrm{r}\theta}^{00}(\omega)$
$E_\theta^{00}(\omega)$

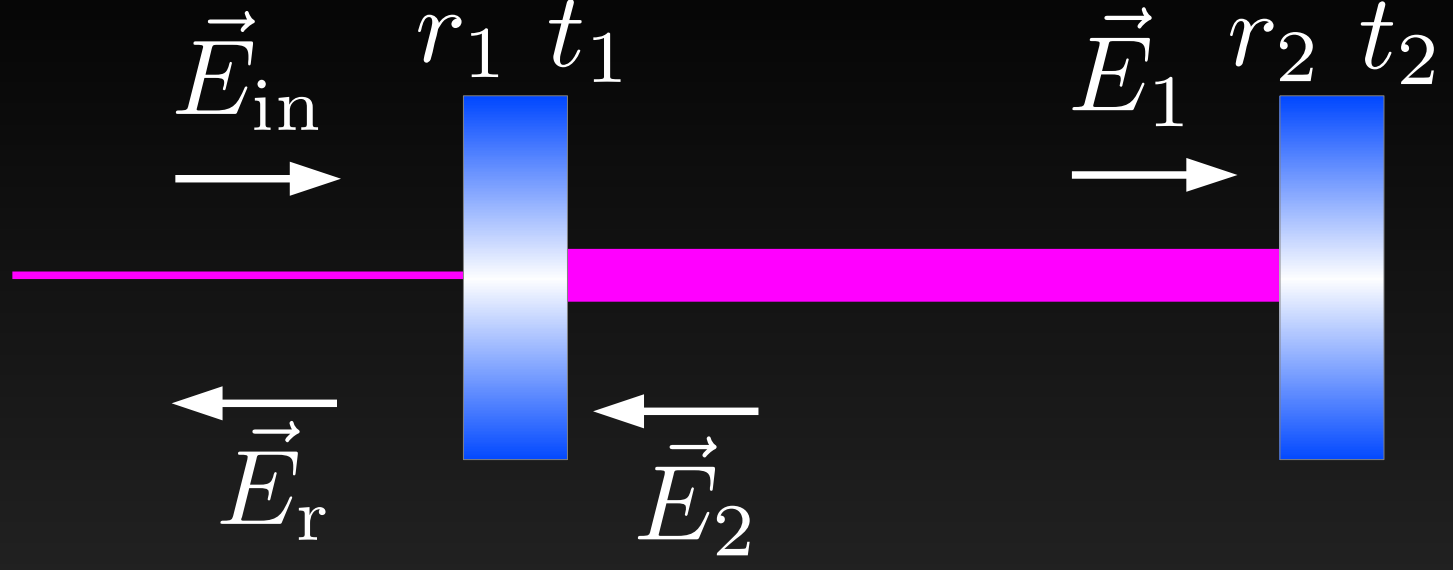

$x(\omega)$
$E_{\mathrm{rx}}^{00}(\omega)$
比較
θ
$E_{\mathrm{r}\theta}^{00}(\omega)$



$$\vec{E}_{\mathrm{in}} = \begin{pmatrix} E_{\mathrm{in}}^{00} \\ \\ E_{\mathrm{in}}^{01} \end{pmatrix}$$

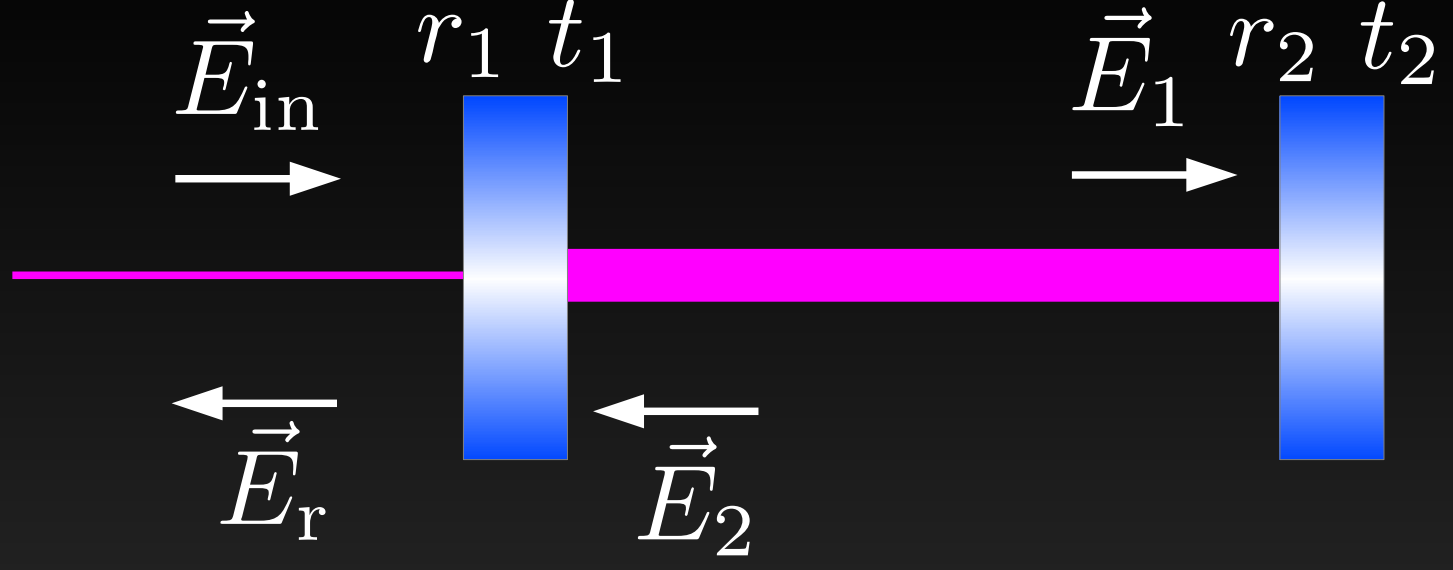


$$\vec{E}_1 = L \cdot R1 \cdot \vec{E}_2 + T1 \cdot \vec{E}_{\text{in}}$$



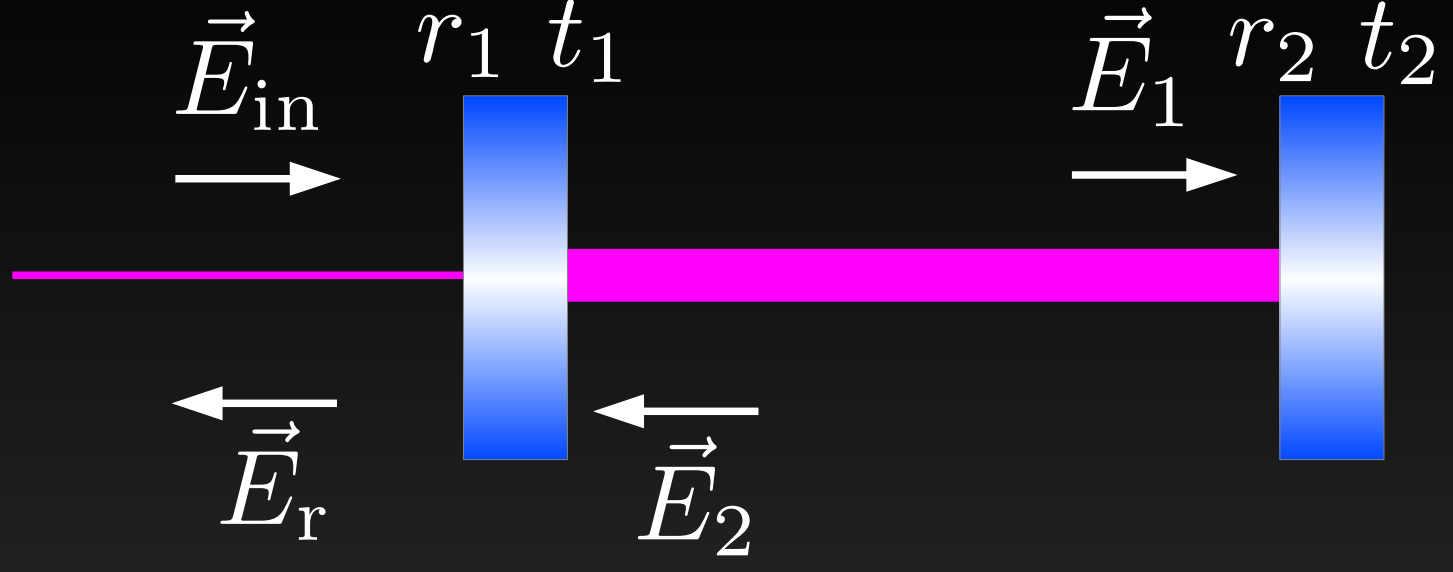
$$\vec{E}_1 = L \cdot R1 \cdot \vec{E}_2 + T1 \cdot \vec{E}_{\text{in}}$$

$$R1 = r_1 \begin{pmatrix} \sqrt{1-4\alpha^2} & 2i\alpha \\ 2i\alpha & \sqrt{1-4\alpha^2} \end{pmatrix}$$



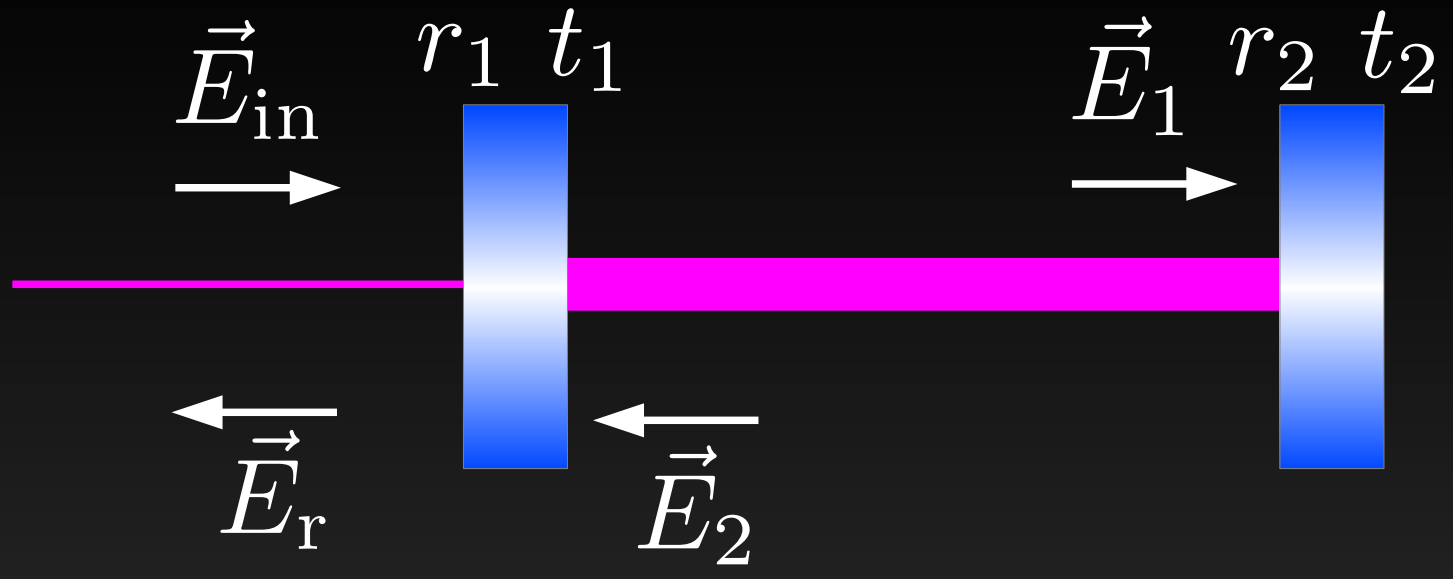
$$\vec{E}_1 = L \cdot R1 \cdot \vec{E}_2 + T1 \cdot \vec{E}_{\text{in}}$$

$$T1 = t_1 \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$



$$\vec{E}_1 = L \cdot R1 \cdot \vec{E}_2 + T1 \cdot \vec{E}_{\rm in}$$

$$L = \begin{pmatrix} e^{-i\omega L/c} & 0 \\ 0 & e^{-i\omega L/c + i\Phi_{\rm Gouy}} \end{pmatrix}$$

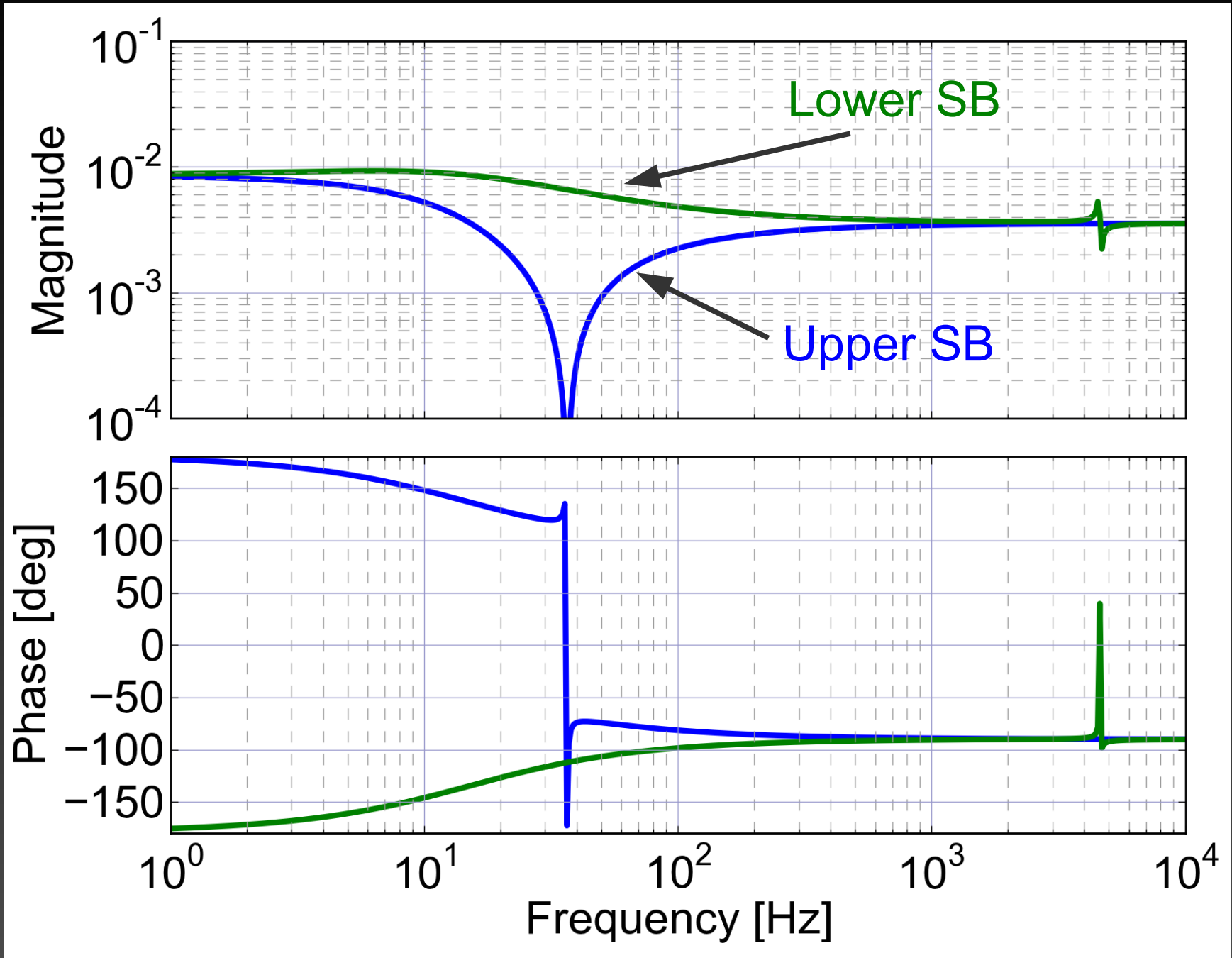


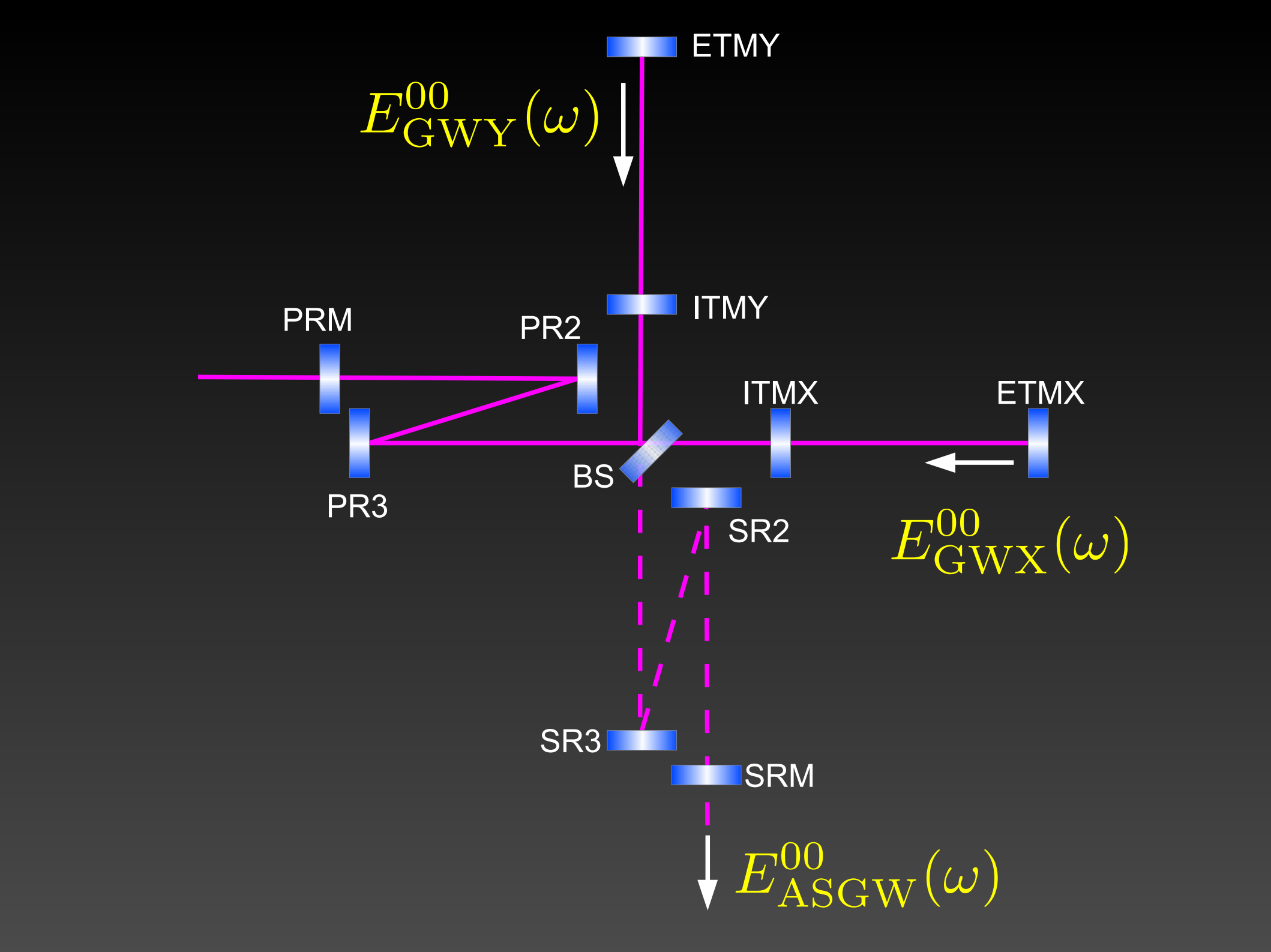
$$\vec{E}_1 = L \cdot R1 \cdot \vec{E}_2 + T1 \cdot \vec{E}_{\text{in}}$$

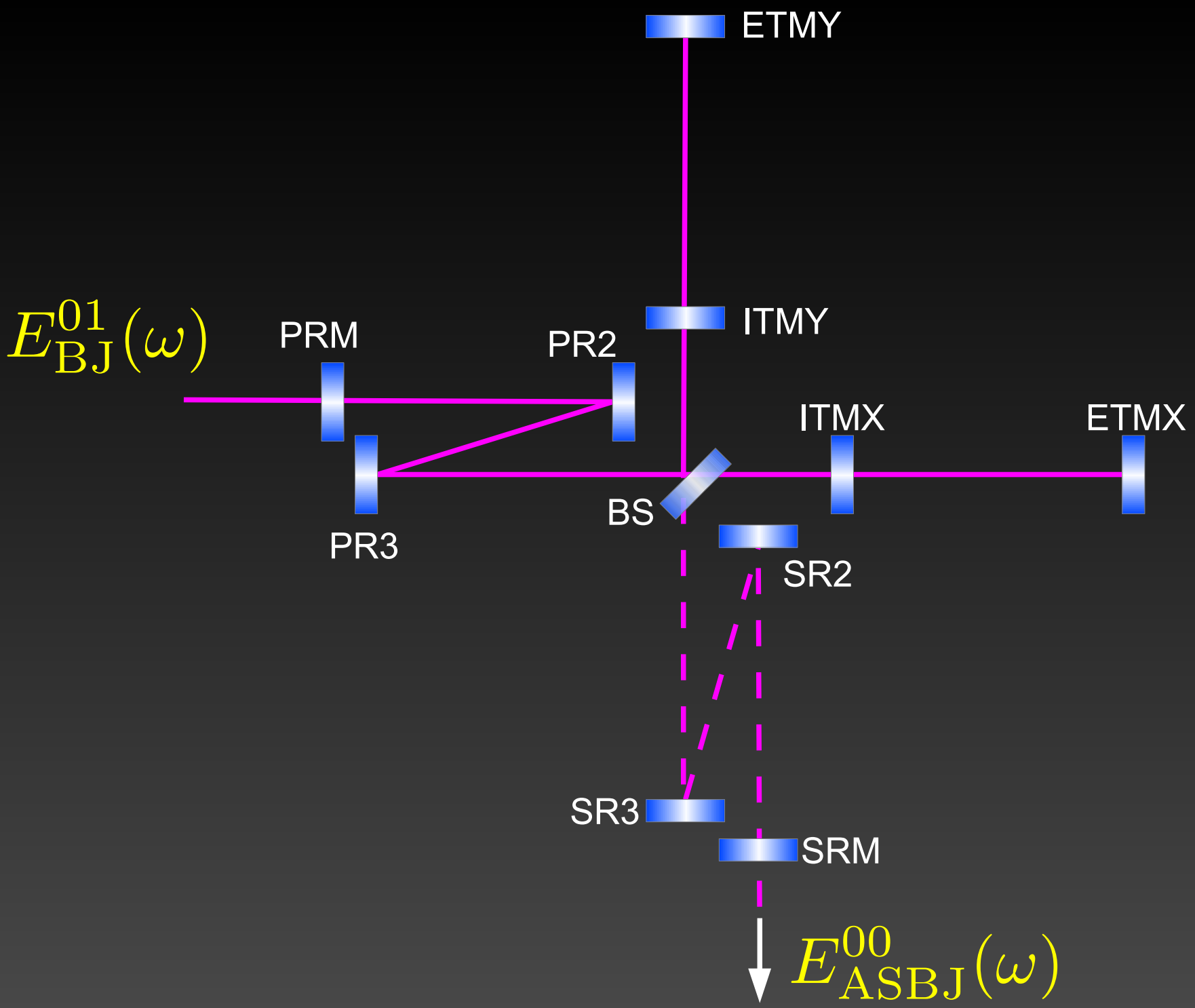
$$\vec{E}_2 = L \cdot R2 \cdot \vec{E}_1$$

$$\vec{E}_{\text{r}} = T1 \cdot \vec{E}_2 - R1_{\text{back}} \cdot \vec{E}_{\text{in}}$$

TEM01 -> TEM00 伝達関数
(ITM 傾き 10^{-8} rad)

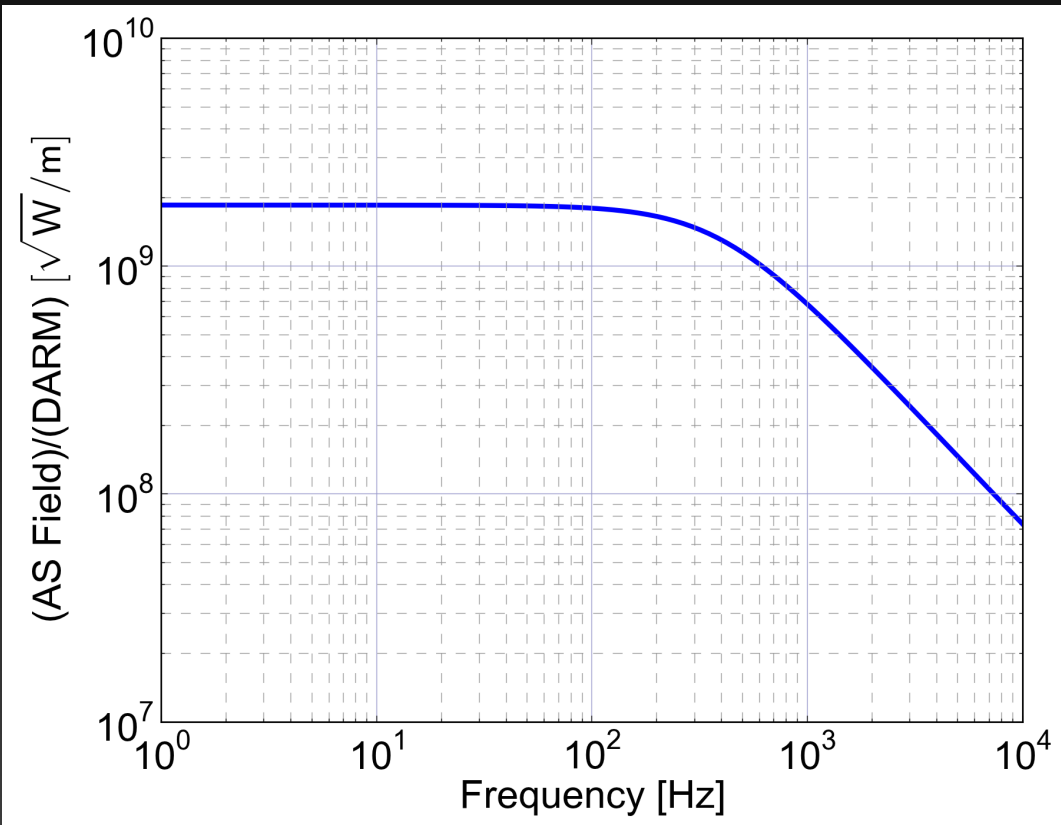



ETMY
$E^{00}_{\mathrm{GWY}}(\omega)$
ITMY
PRM
PR2
ITMX
ETMX
BS
PR3
SR2
$E^{00}_{\mathrm{GWX}}(\omega)$
SR3
SRM
$E^{00}_{\mathrm{ASGW}}(\omega)$

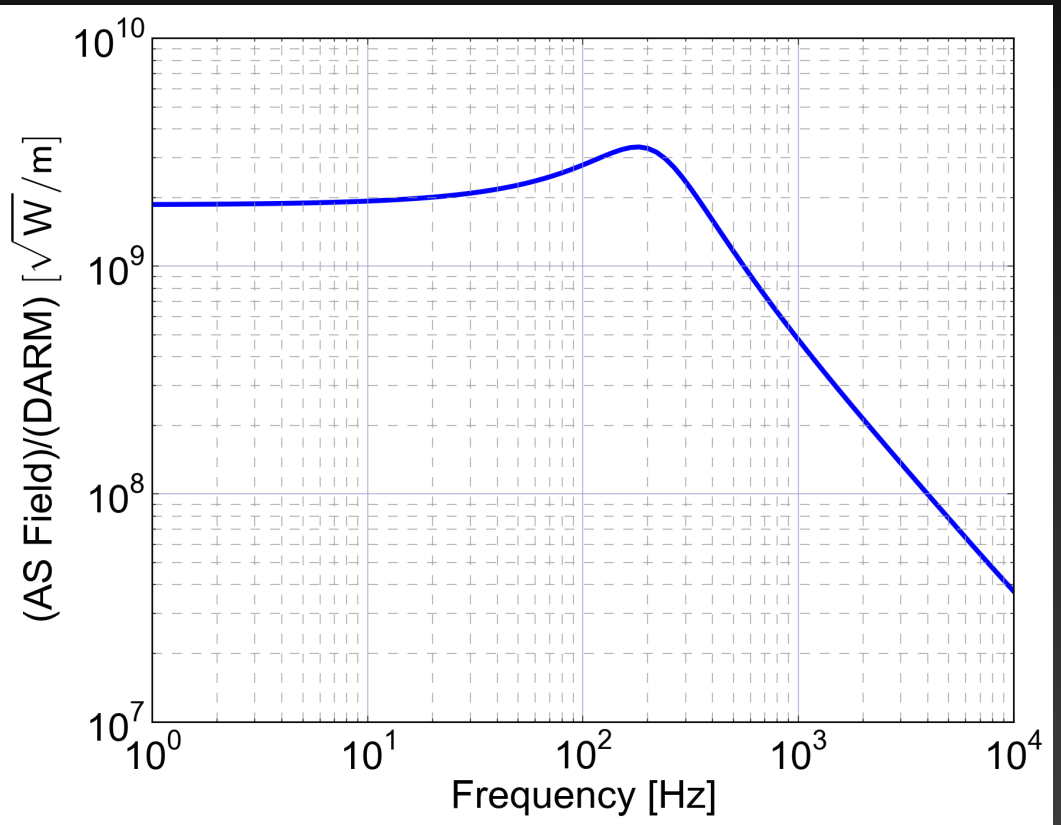

ETMY
$E^{01}_{\mathrm{BJ}}(\omega)$
PRM
PR2
ITMY
ITMX
ETMX
BS
PR3
SR2
SR3
SRM
$E^{00}_{\mathrm{ASBJ}}(\omega)$

DARM -> GW Sideband @ AS Port

BRSE

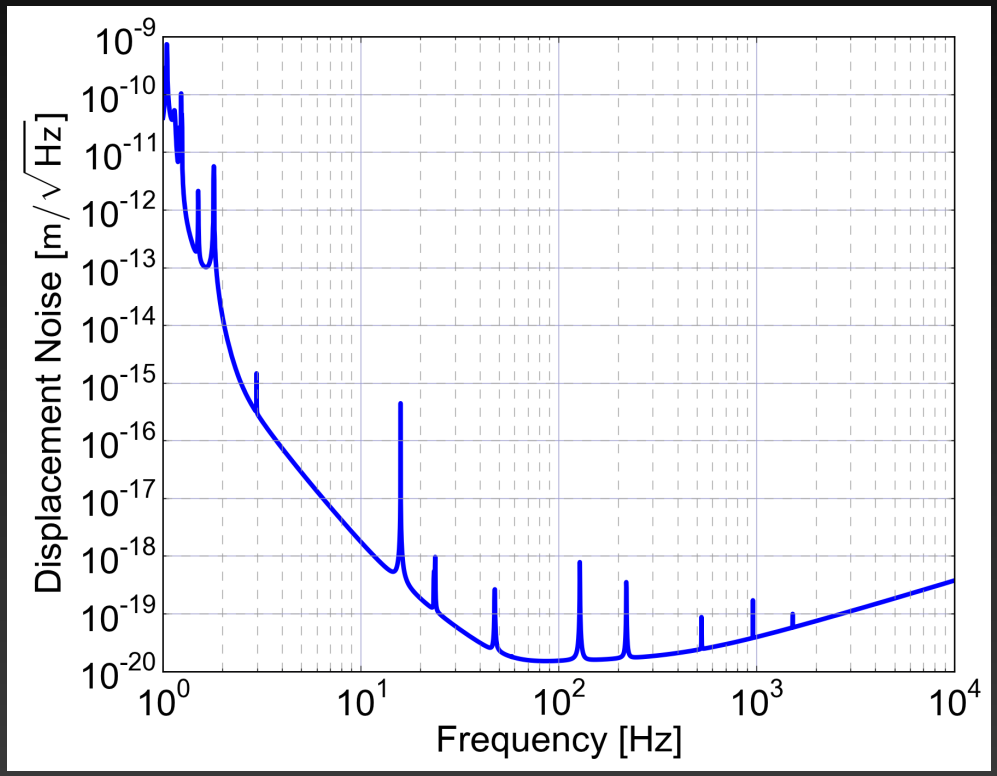


DRSE

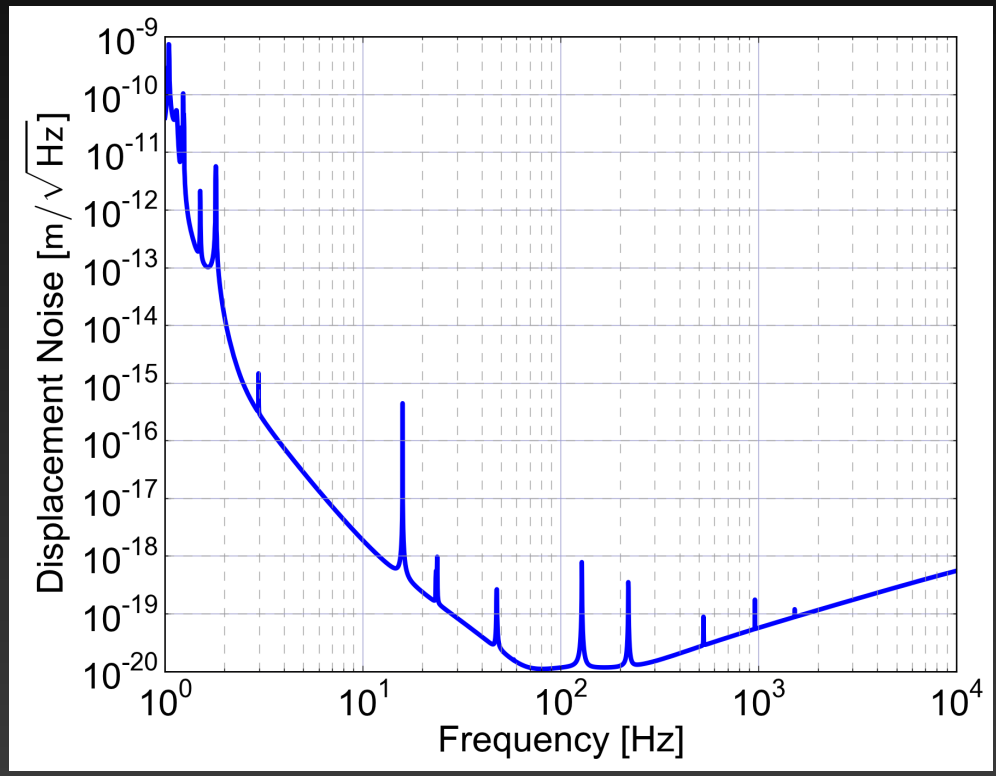


KAGRA変位換算雑音

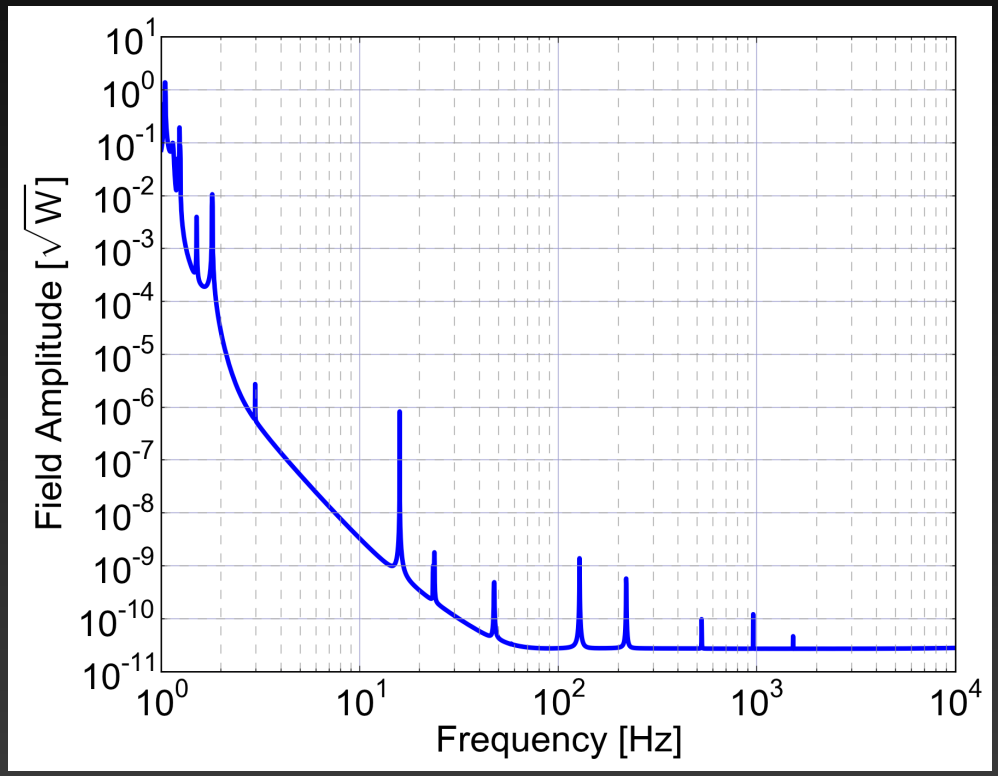
BRSE

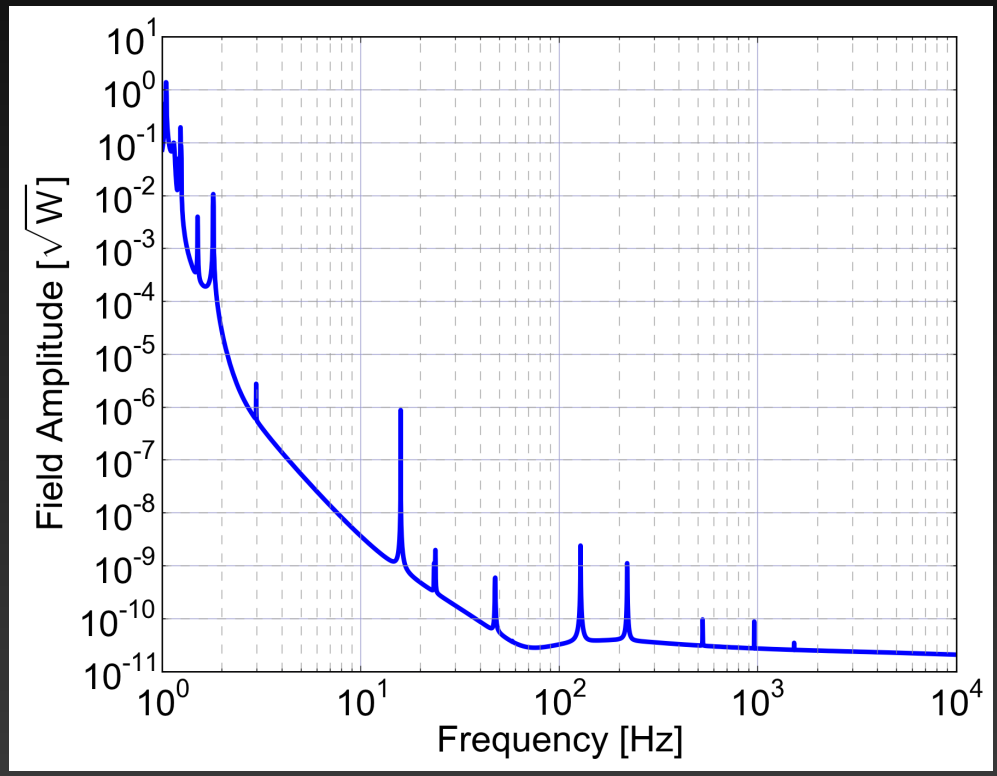


DRSE



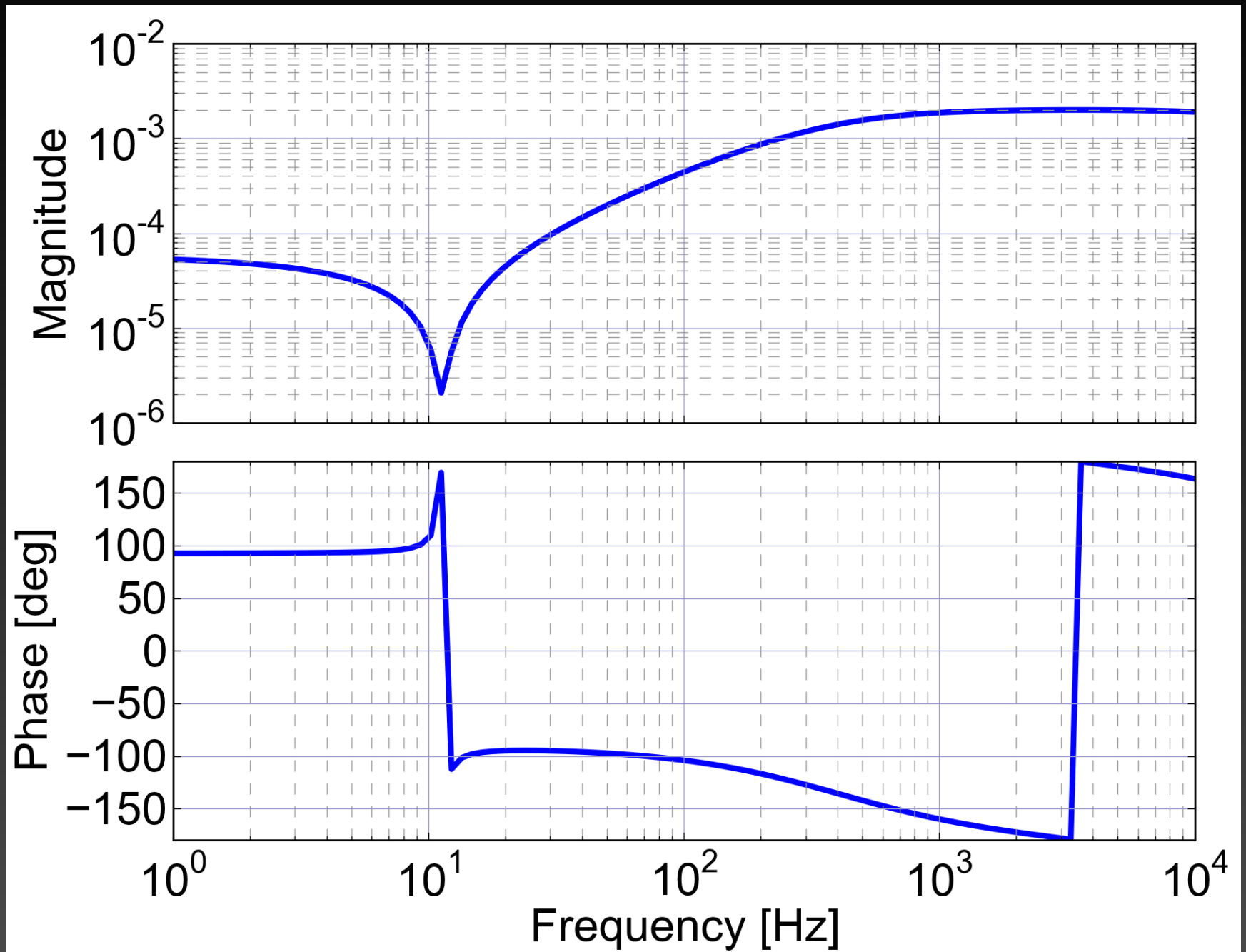
GW Sideband Amplitude @ AS Port



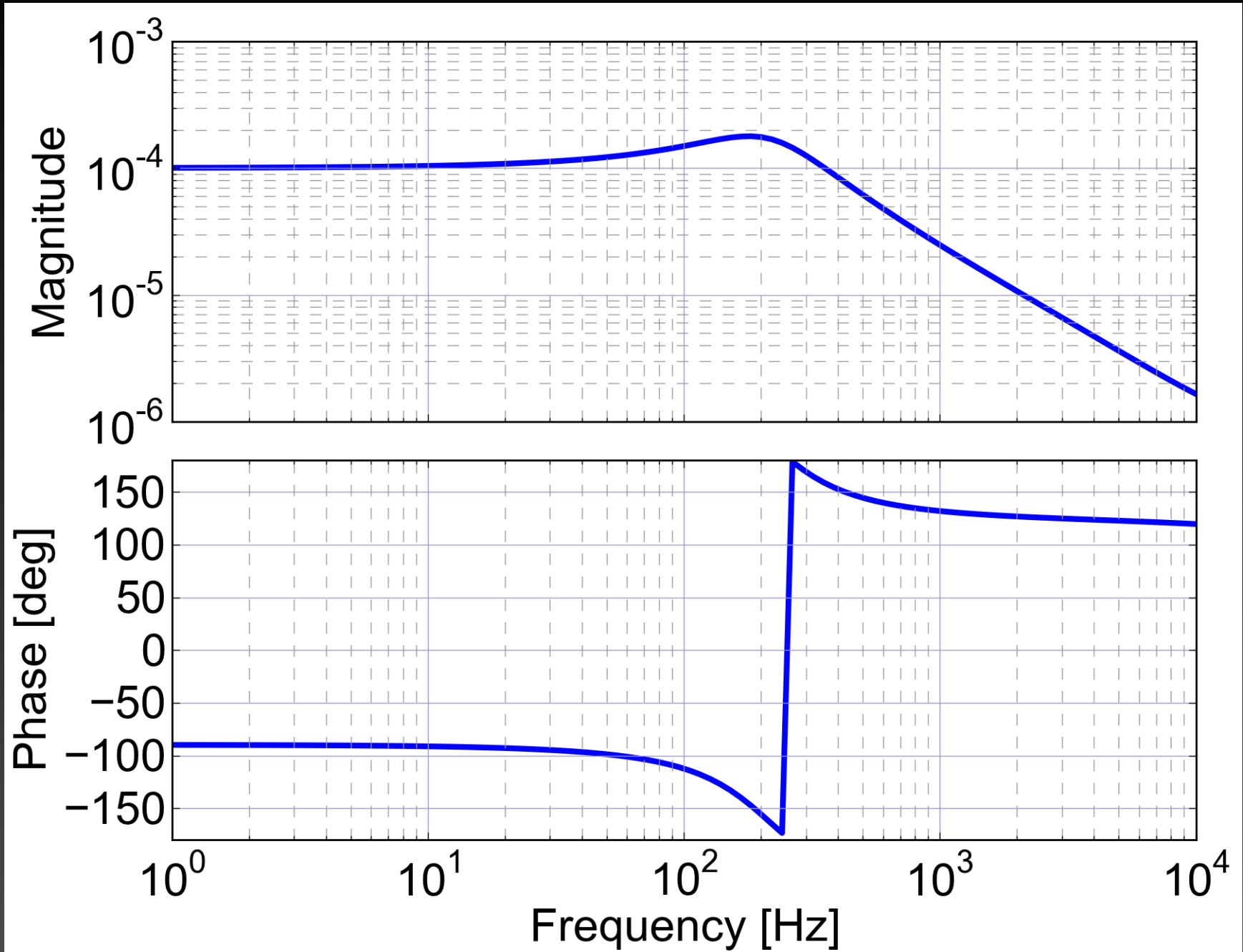


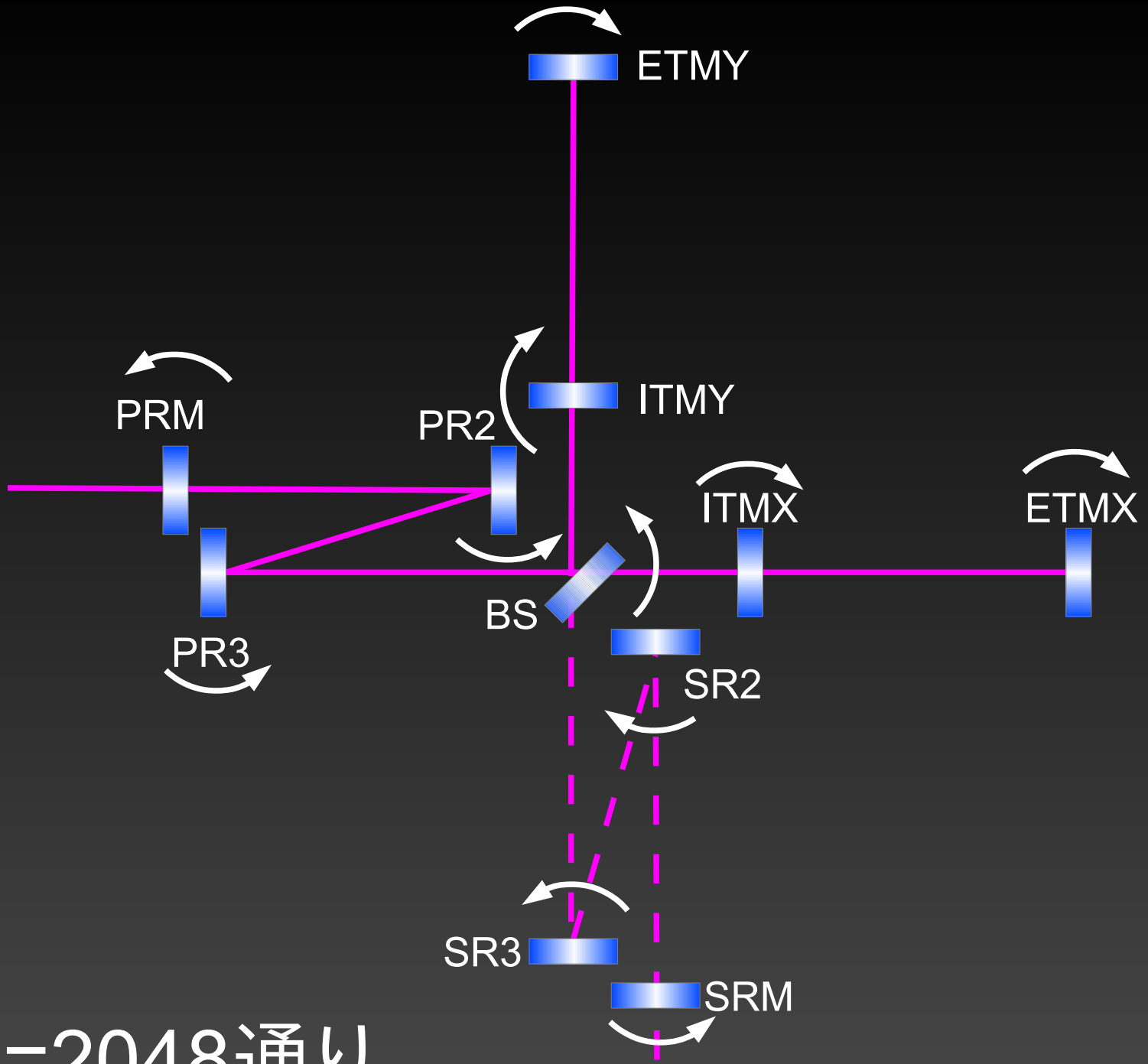
入射パワー1Wに換算

TEM01 @ Input -> TEM00 @ AS Port
(BRSE, ITM差動傾き10^{-8} rad)



TEM01 @ Input -> TEM00 @ AS Port
(DRSE, ETM差動傾き10^{-8} rad)

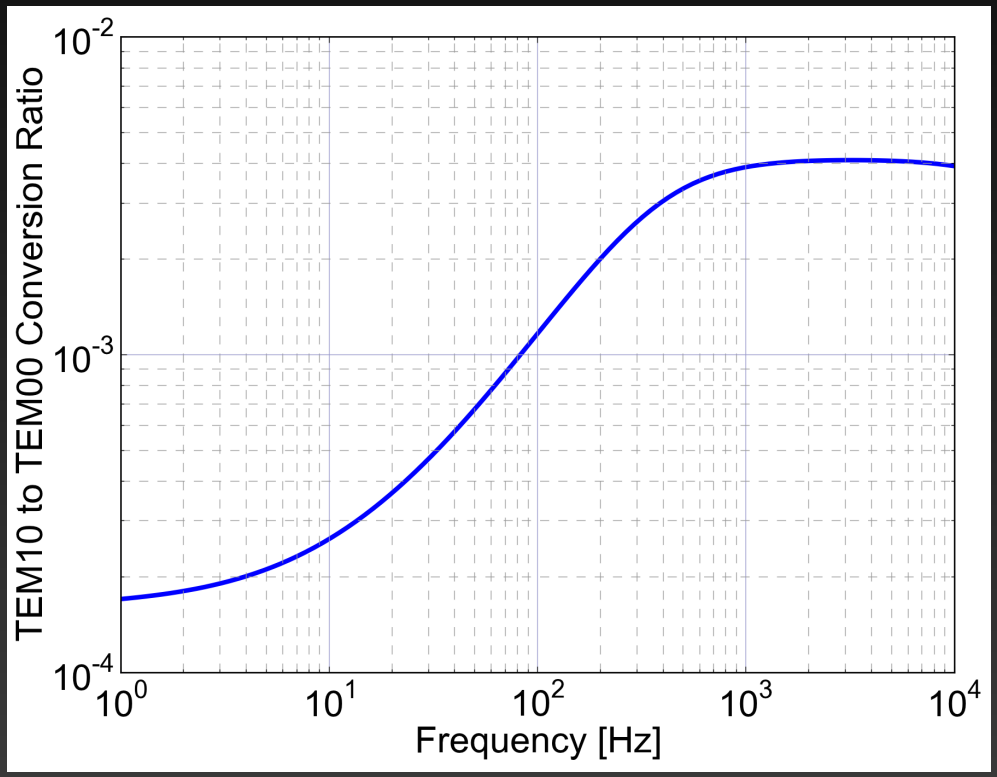




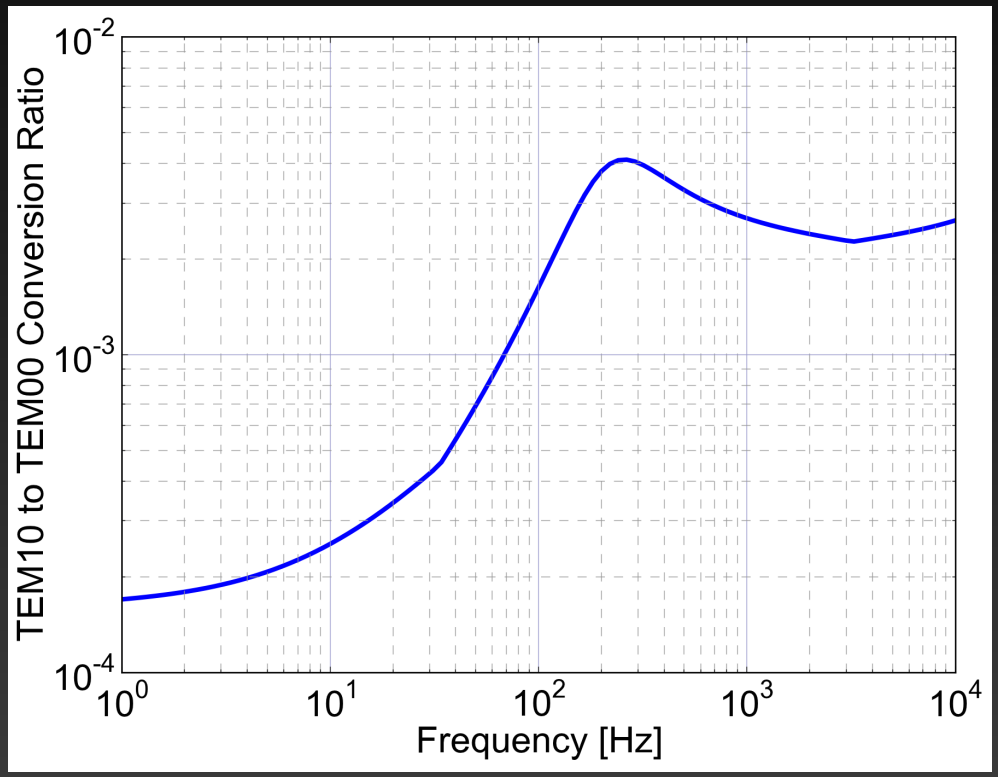
2^{11}=2048通り

TEM01 -> TEM00 伝達関数 最大値

BRSE

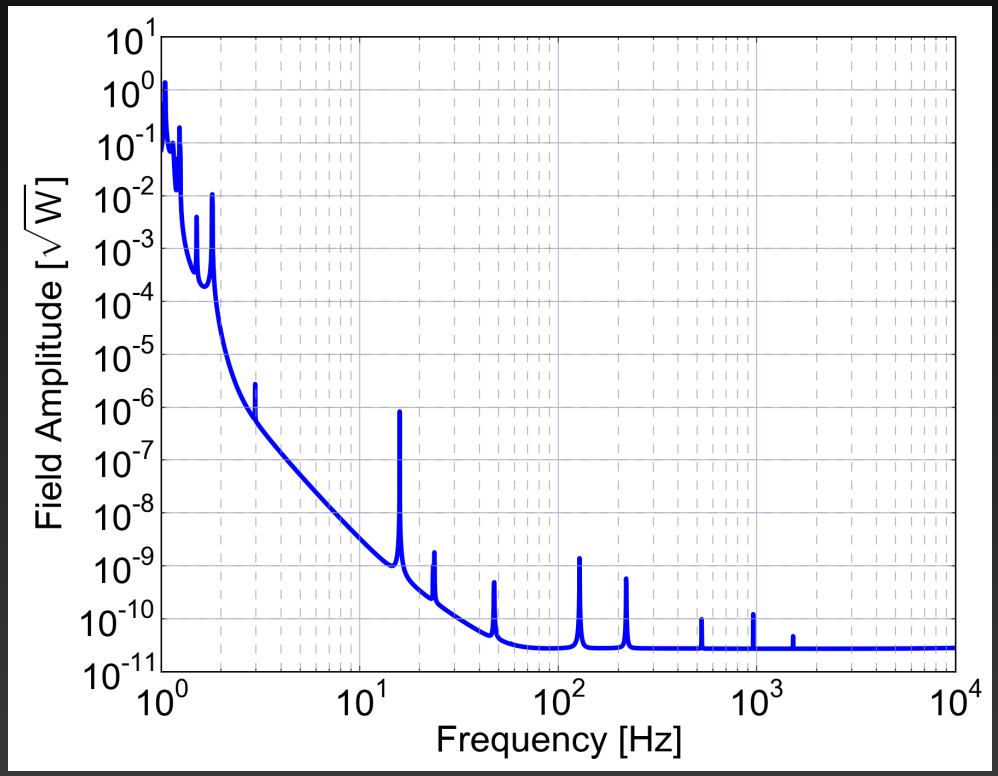


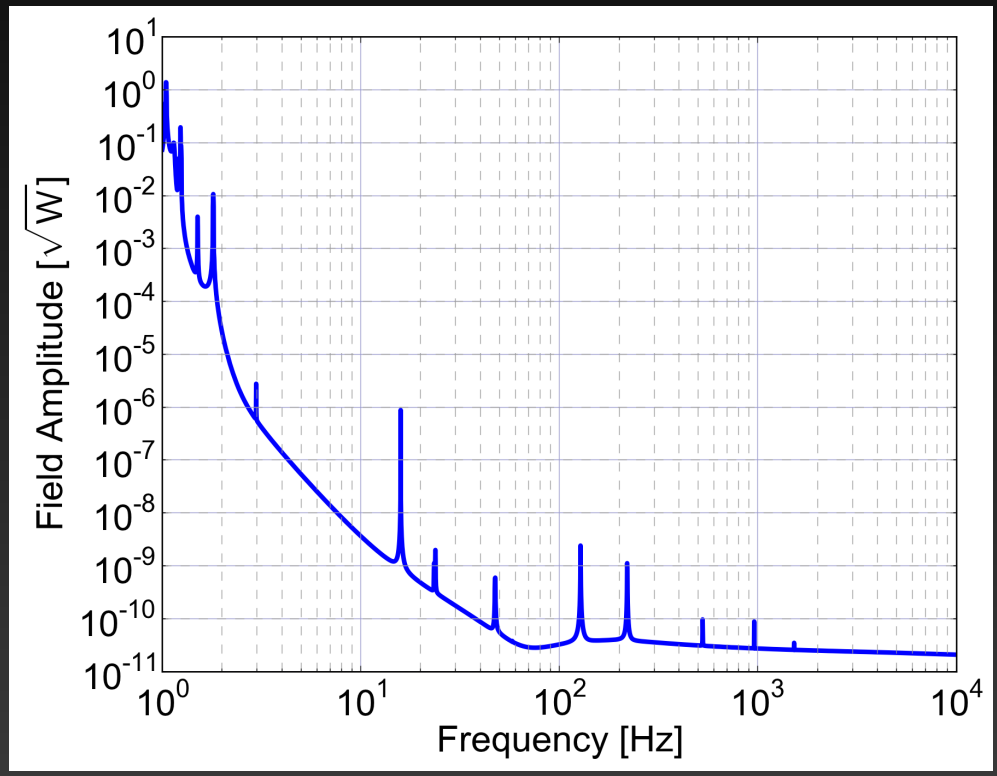
DRSE



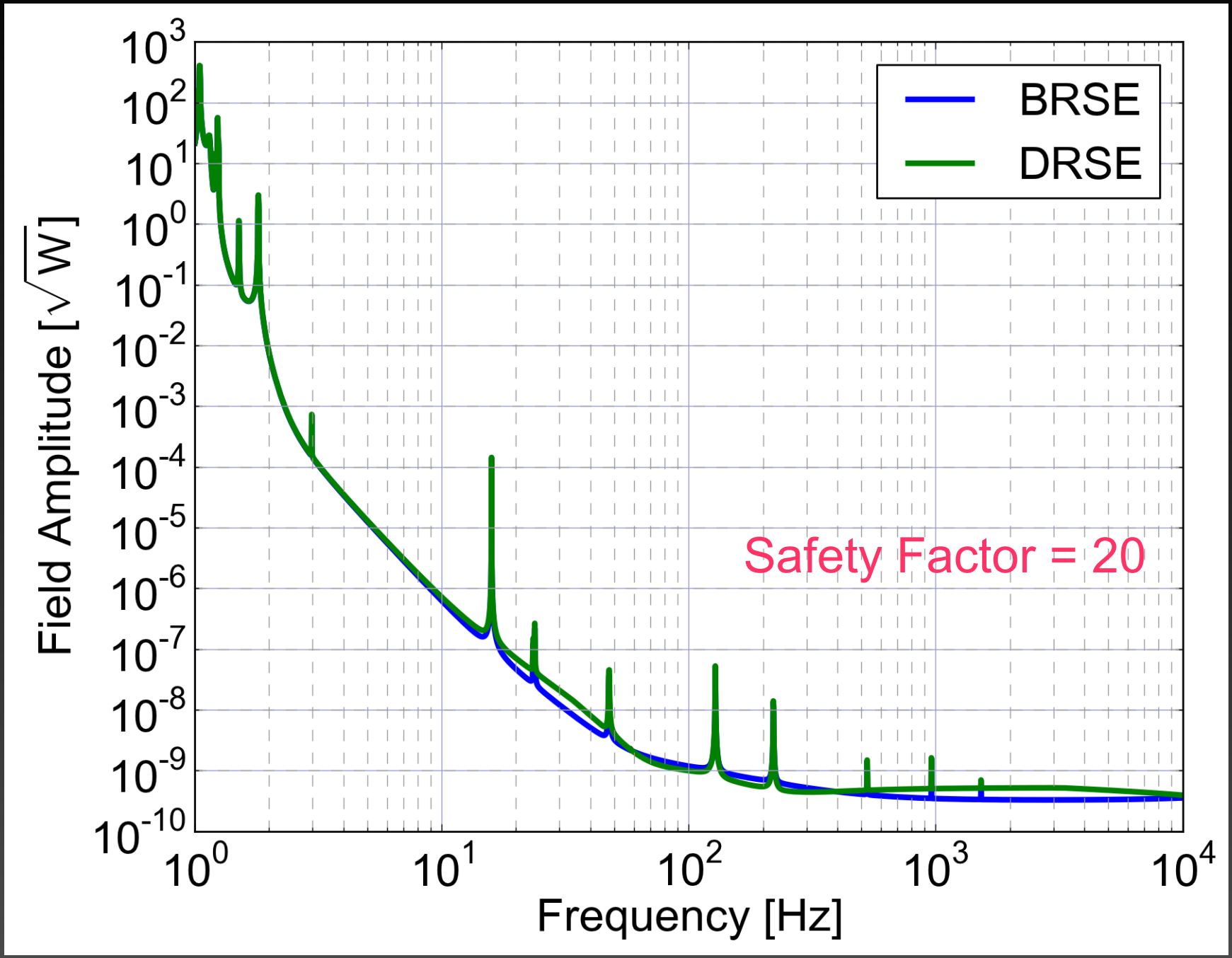
各鏡の傾きは10^{-8}rad

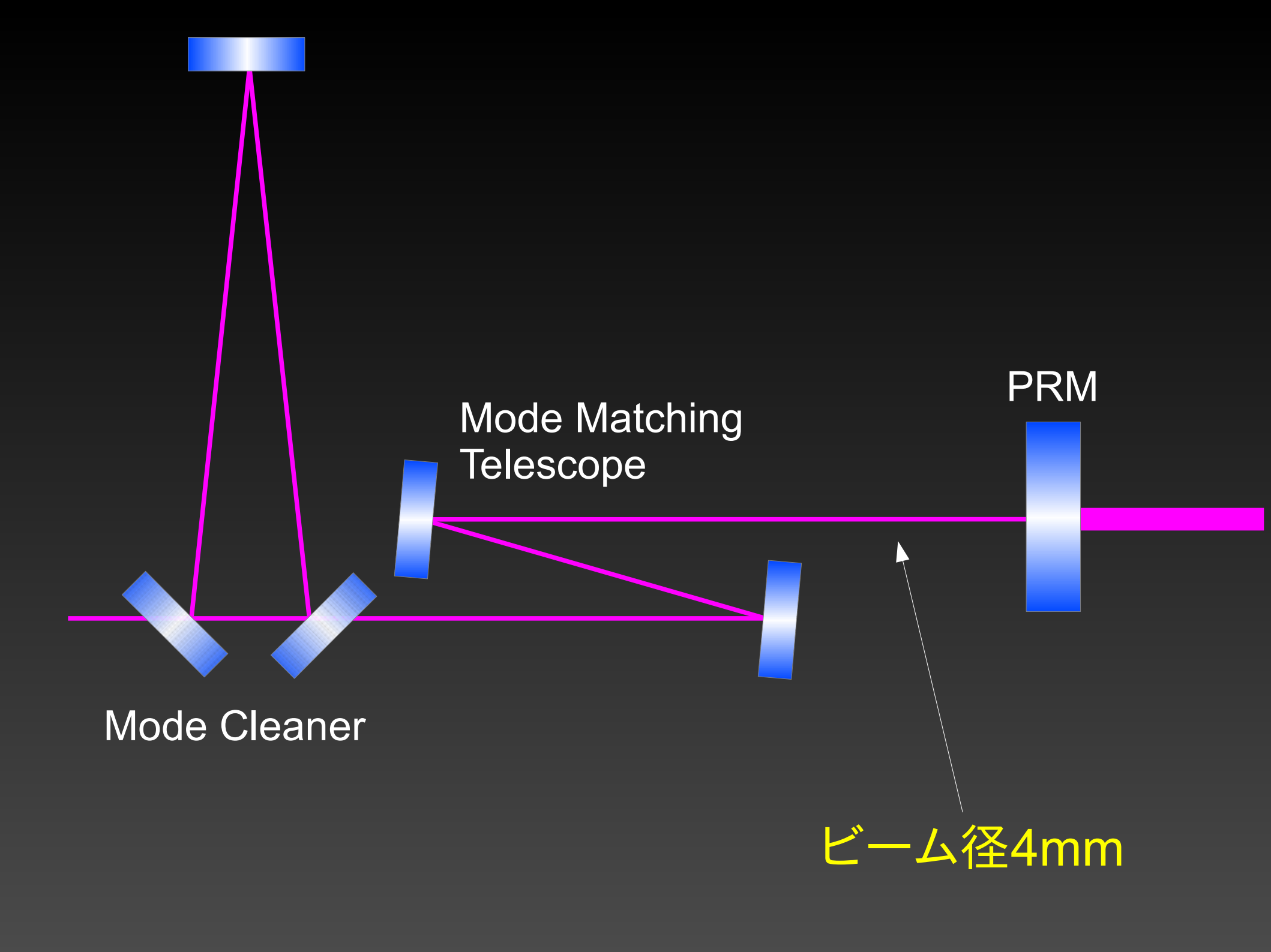
GW Sideband Amplitude @ AS Port



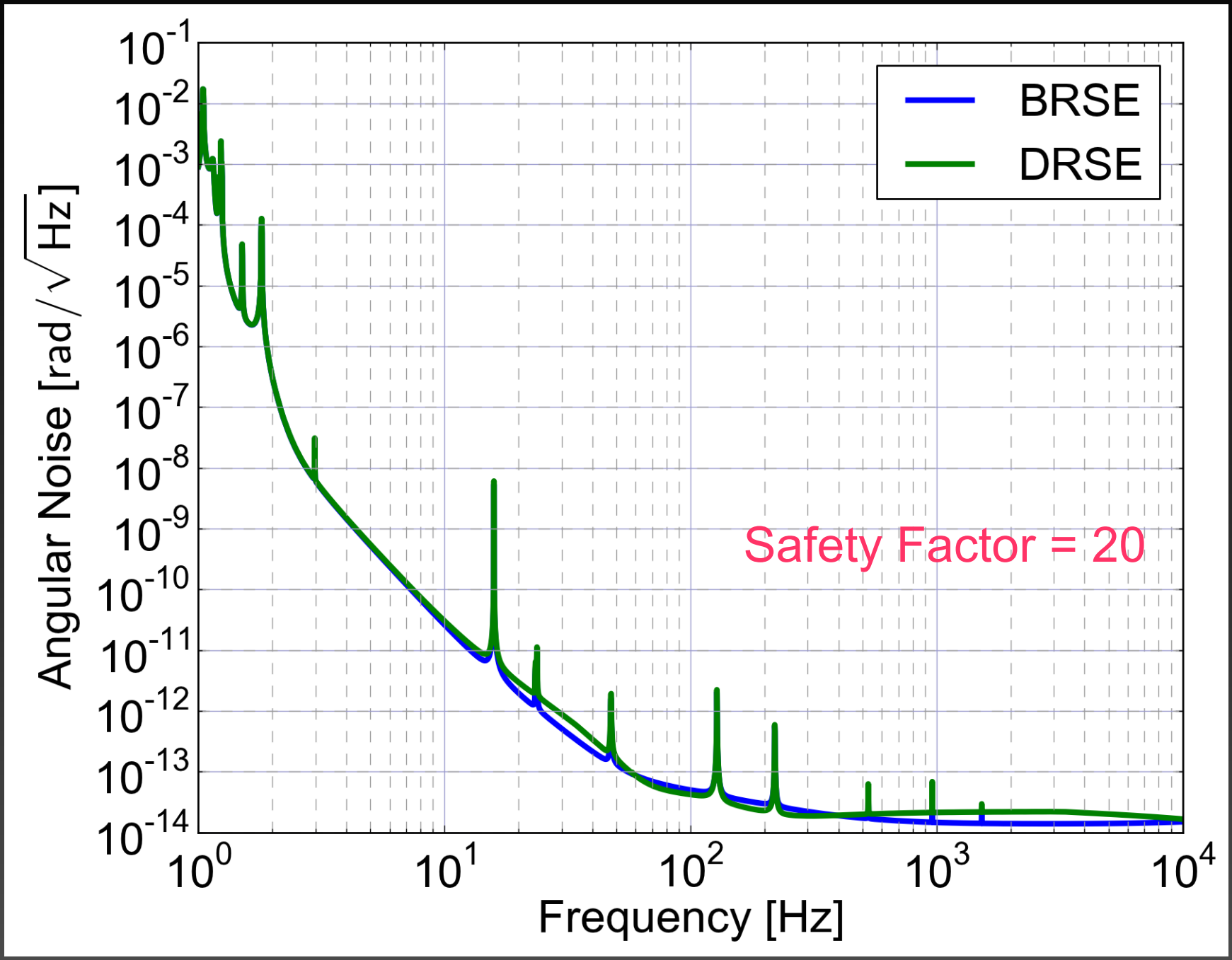


入射TEM01振幅への要求値(入射パワー1W)

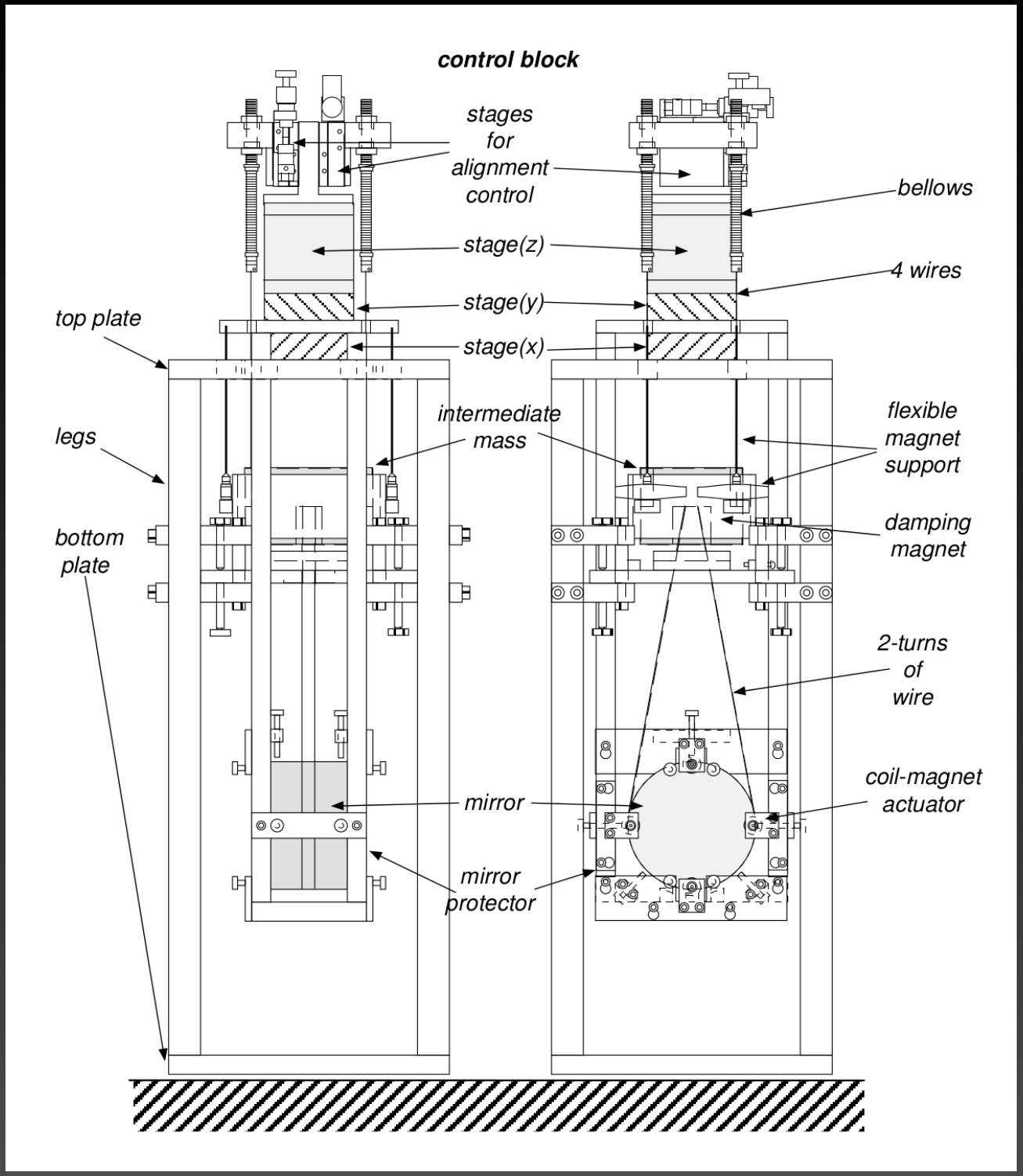



PRM
Mode Matching
Telescope
Mode Cleaner
ビーム径4mm

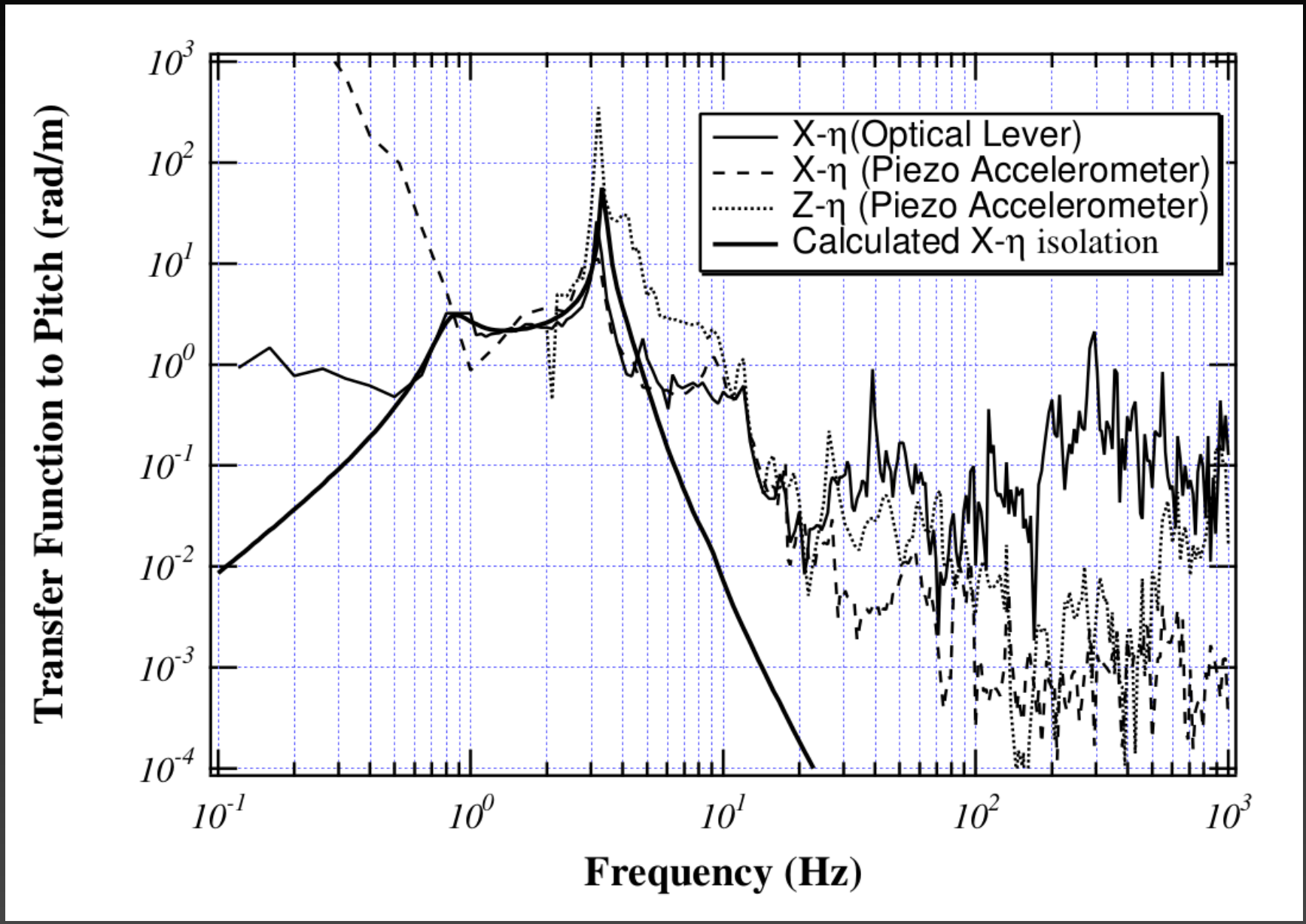
入射光学系回転雑音要求値



TAMA Suspension

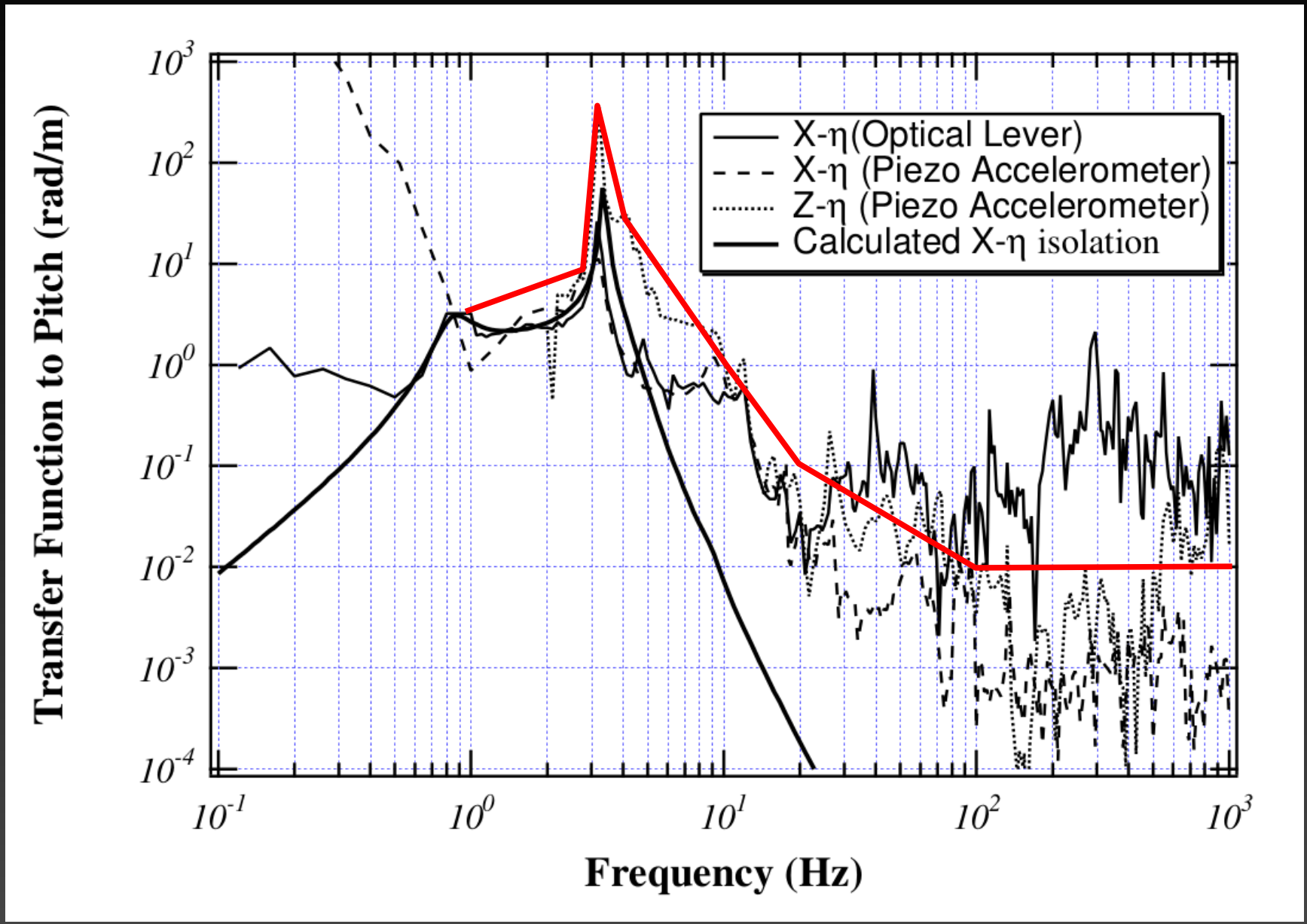


TAMA Suspension 並進->Pitch 伝達関数

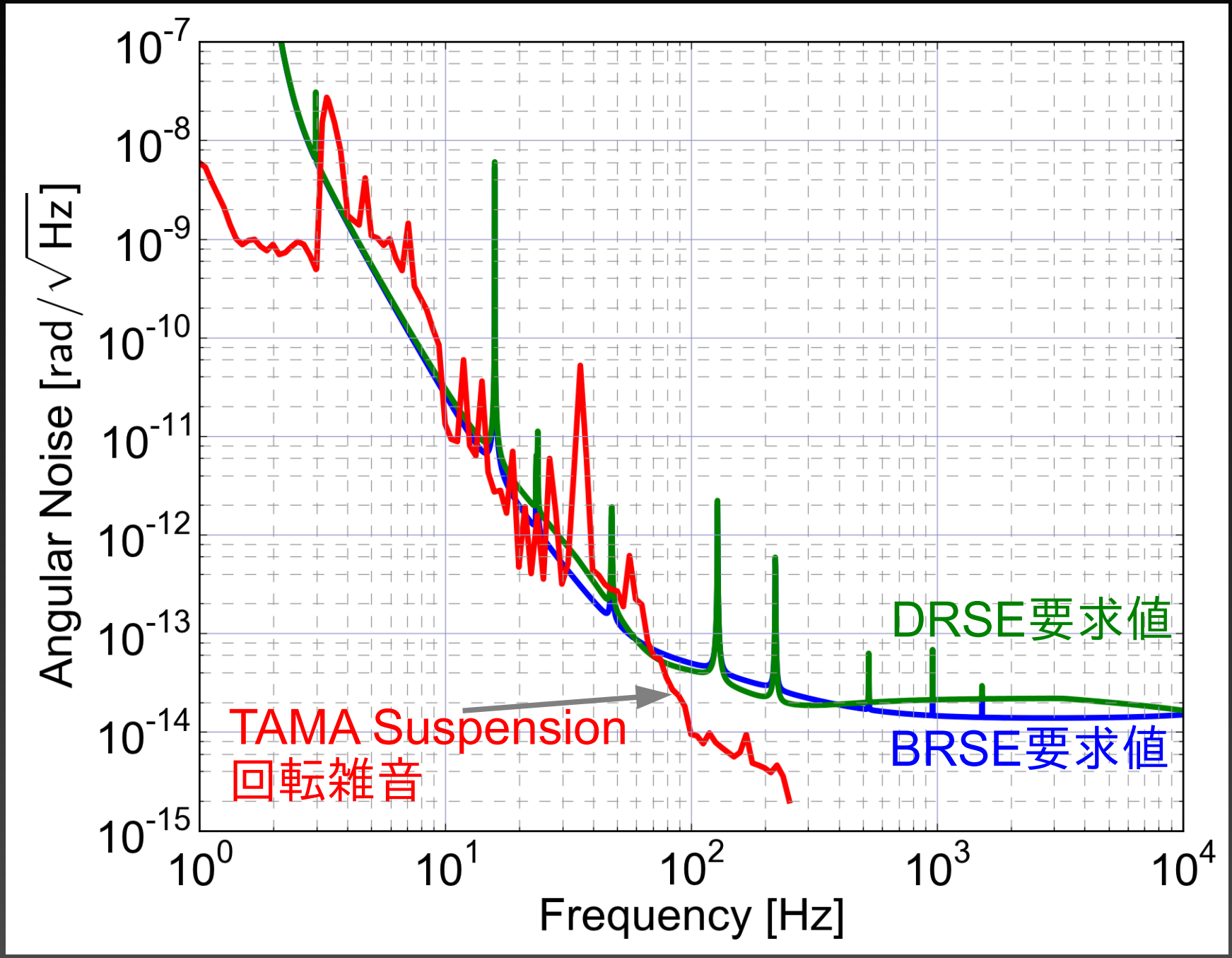


新井宏二 修論

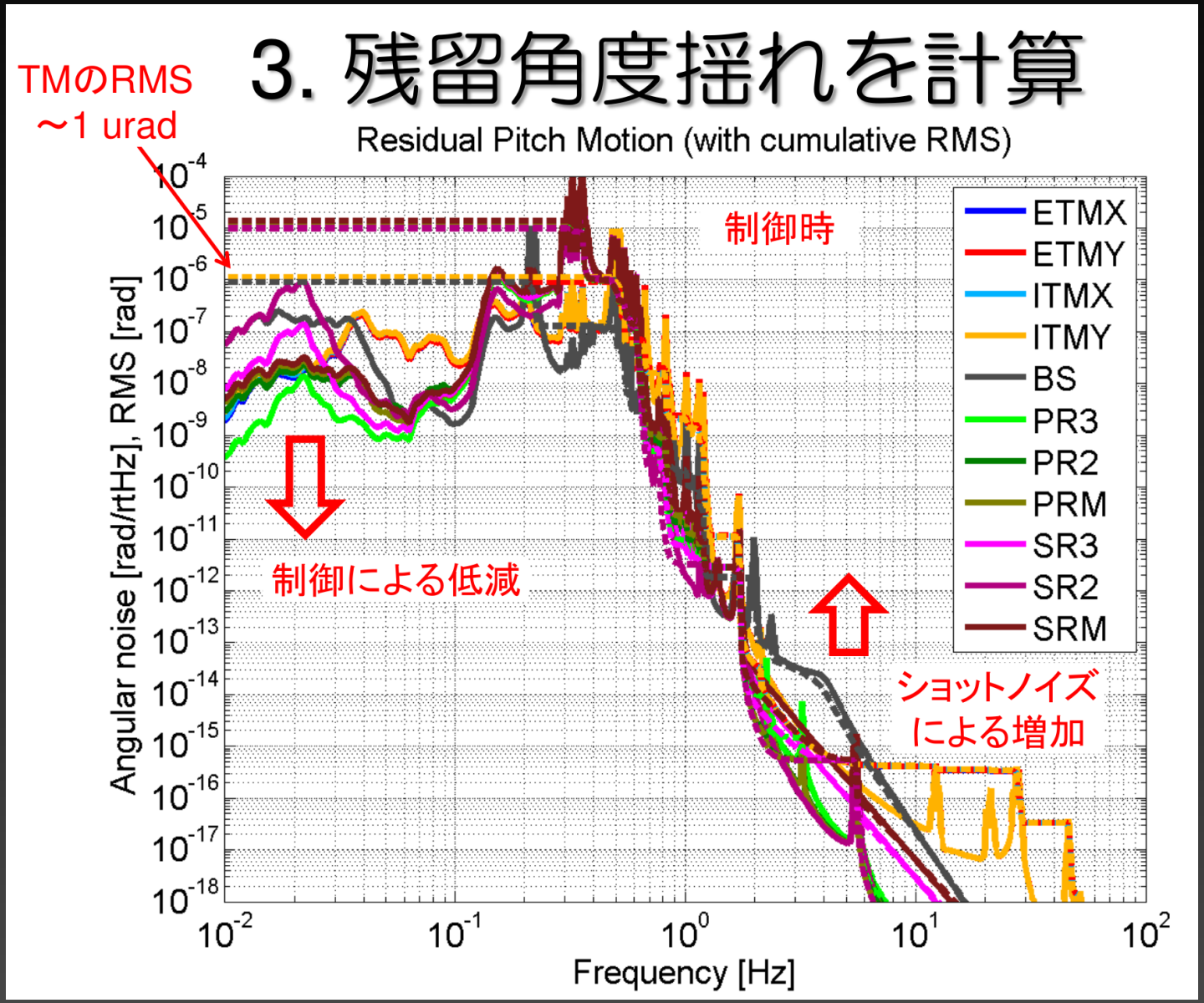
TAMA Suspension 並進->Pitch 伝達関数



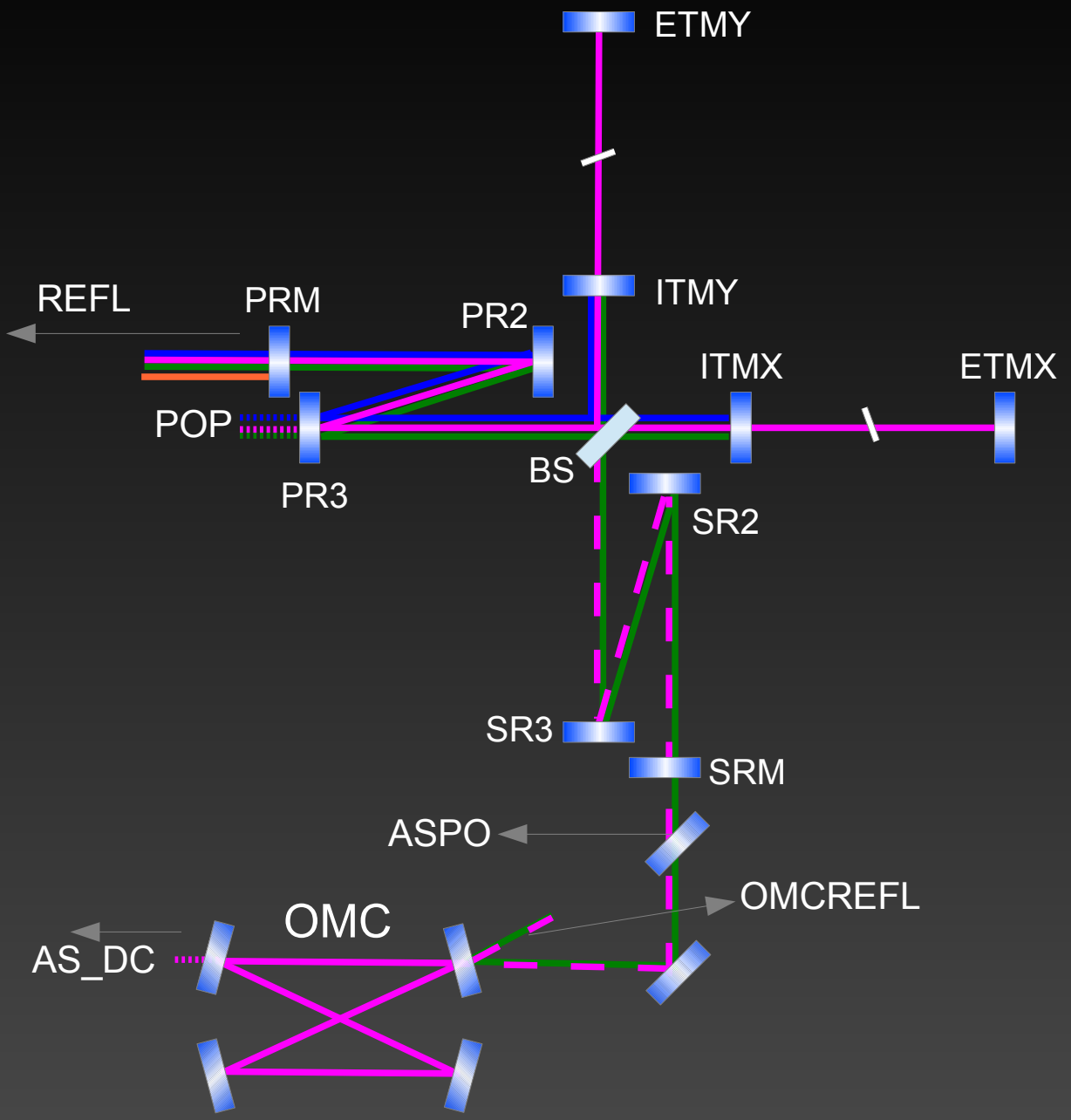
推定回転雑音 vs 要求値



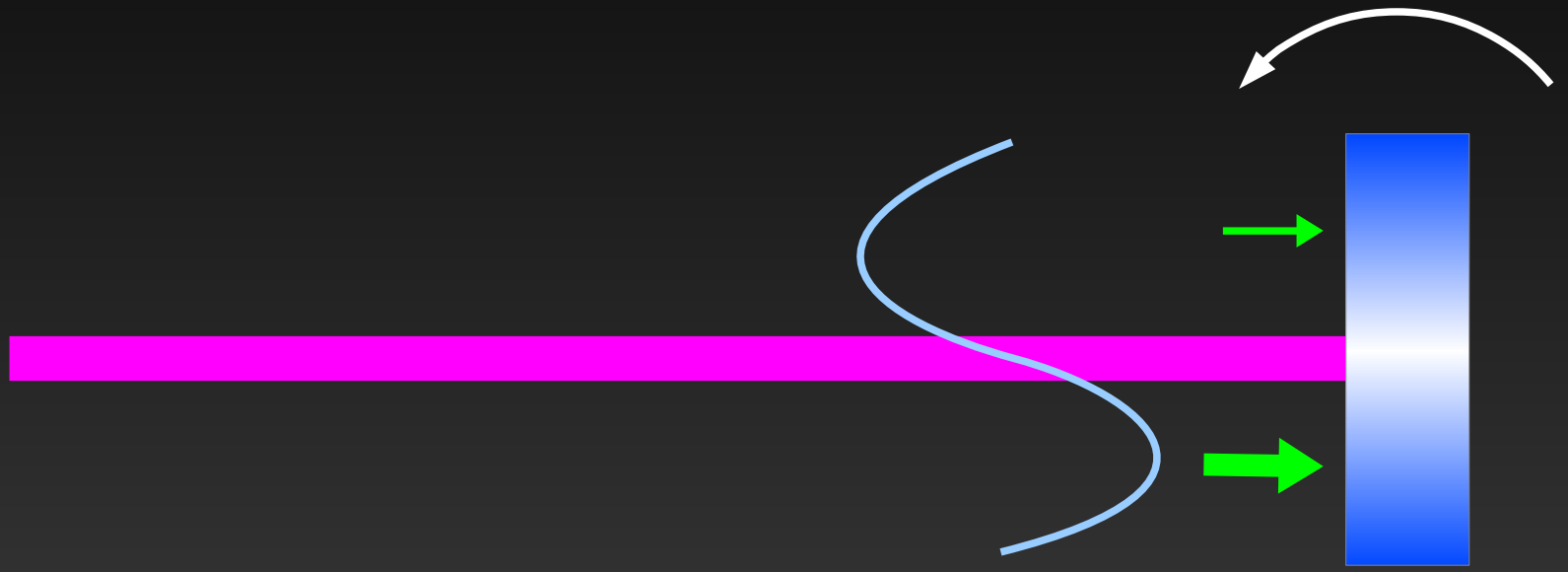
干渉計ミラーの傾きRMS < 10^{-8} rad



RF SBはまだ考慮していない



輻射圧効果



結論

主干渉計サスペンションの回転防振が重要

RMS < 10^{-8} rad