Baffles and cryostat : Scattered light noise

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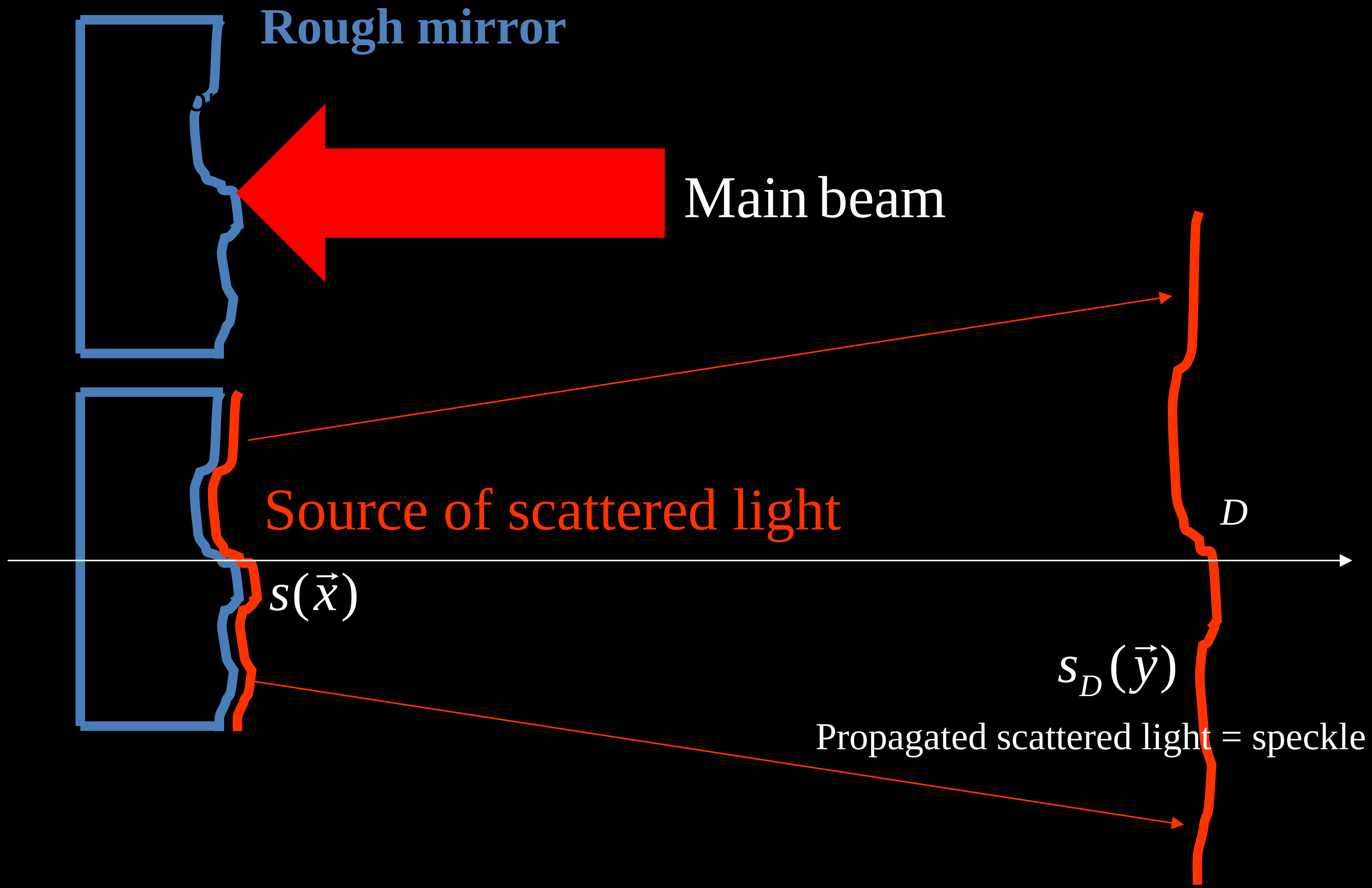


Autocorrelation Function of the speckle

$$C(D,\vec{x},\vec{x}\,') = \langle s_D(\vec{x}).s_D(\vec{x}\,') \rangle$$

Hypotheses :

Distribution of scattered light vs scattering angle :

$$p(\theta) \approx \frac{\kappa}{\theta^2}$$ For angles much larger than $$\theta_g = \frac{\lambda}{\pi w_0}$$

LSD of seismic motion :

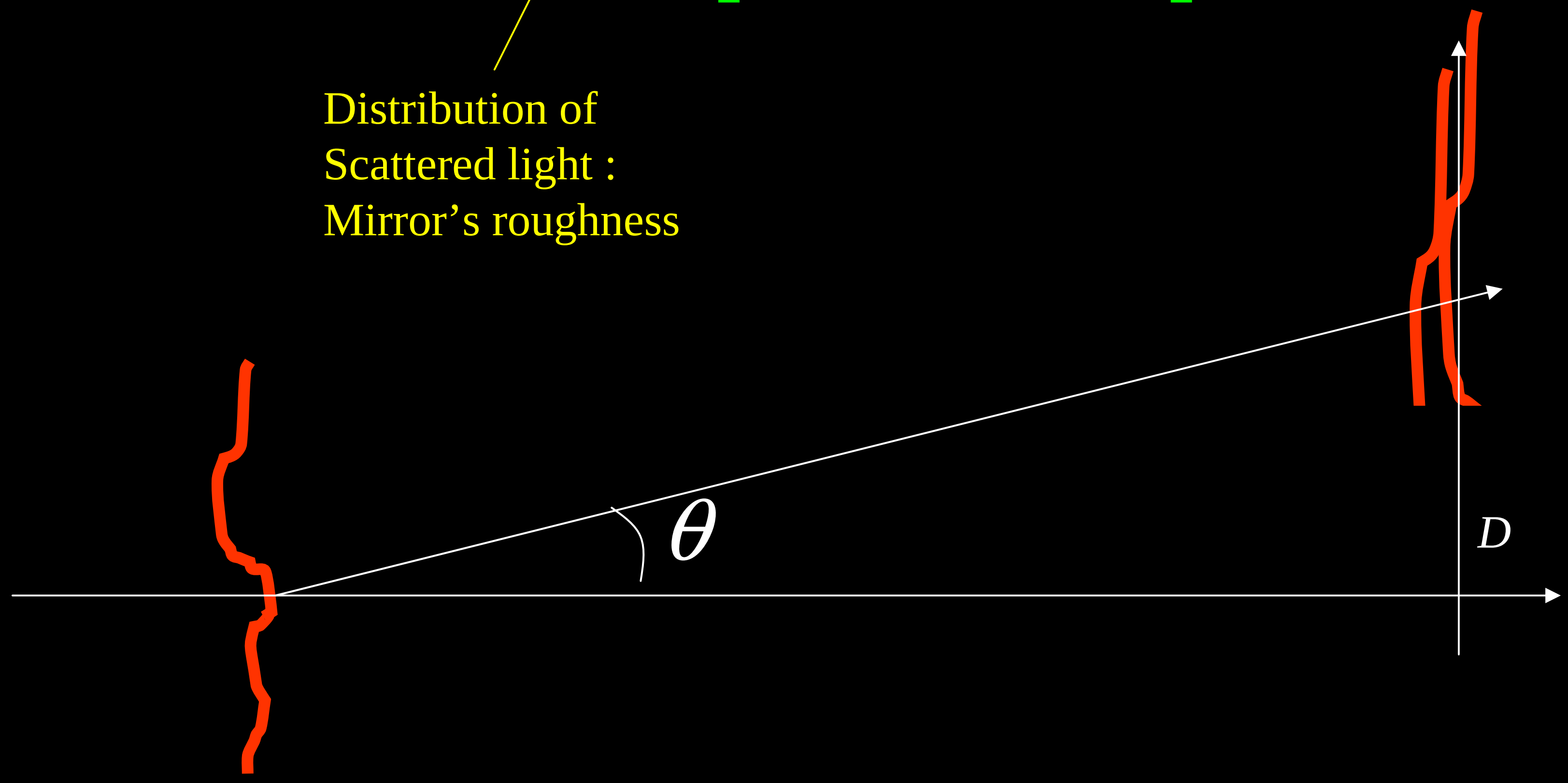
$$\delta x(f) \approx 10^{-8} \text{ m}/\sqrt{\text{Hz}} \left[\frac{10 \text{ Hz}}{f}\right]^2$$

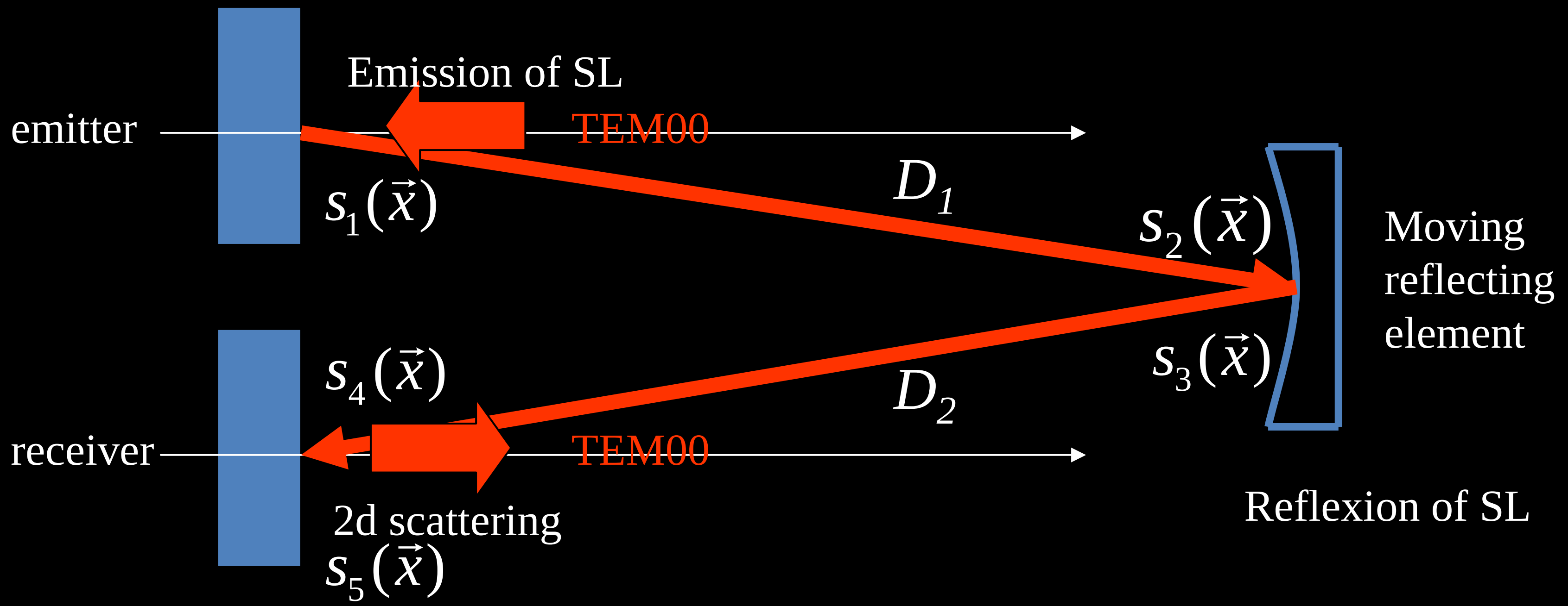
Integrated
Scatt. losses

Memory of the stored mode

$$C(D,\vec{x},\vec{x}\,') = \frac{\varepsilon}{2\pi D^2}\, p(\theta)\, \exp\left[-\frac{1}{2}\left(k w_0 \frac{\vec{x}-\vec{x}\,'}{2D}\right)^2\right] \exp\left[ik\frac{x^2 - x'^2}{2D}\right]$$

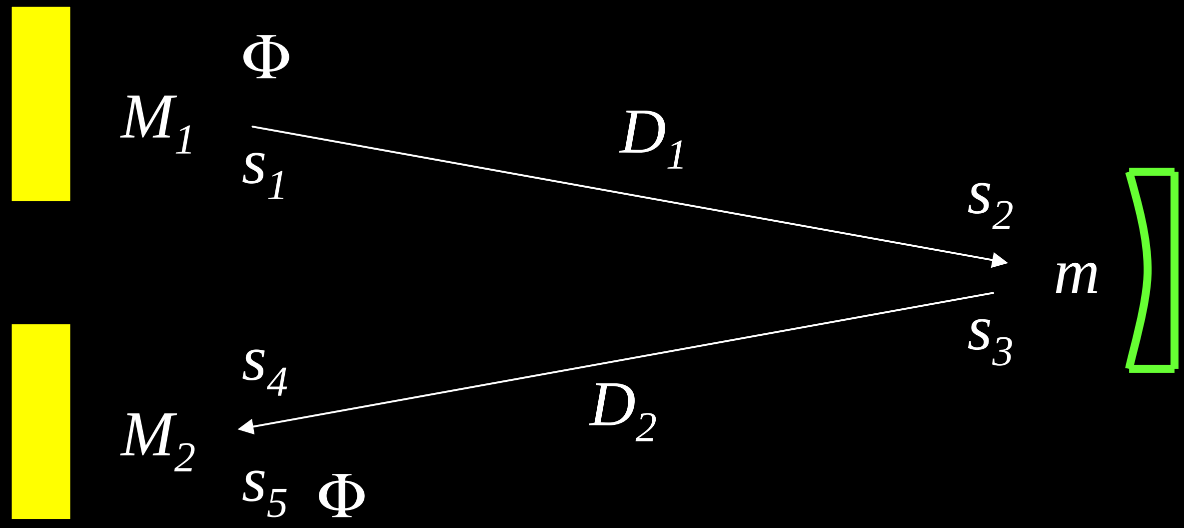
Distribution of
Scattered light :
Mirror’s roughness





Spurious (noisy) phase modulation caused by the coupling :

$$\gamma = < TEM00, s_5 >$$



$$\gamma = <\Phi, s_5> = <\Phi, M_2 P_2(m.s_3)> = <\Phi, M_2 P_2[m.P_1(M_1\Phi)]>$$

Coupling coefficient with TEM00 :

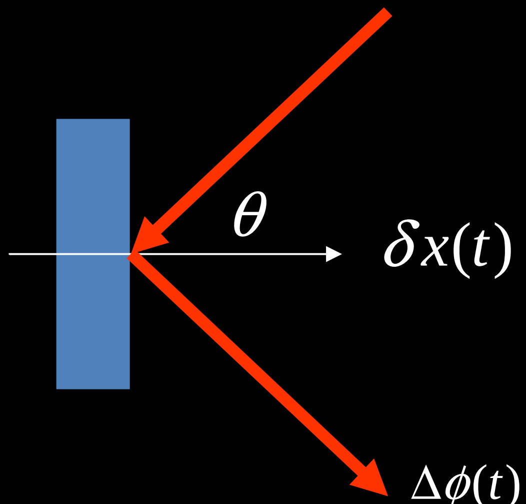
$$\gamma = e^{i\Delta(t)} \int m(\vec{x}) s_{D_1}(\vec{x}) s_{D_2}(\vec{x})\, d\vec{x}$$

Expectation value :

$$\left\langle \gamma\gamma^* \right\rangle = \int m(\vec{x}) m(\vec{x}\,')^* \left\langle s_{D_1}(\vec{x}) s_{D_1}(\vec{x}\,')^* \right\rangle \left\langle s_{D_2}(\vec{x}) s_{D_2}(\vec{x}\,')^* \right\rangle d\vec{x}\, d\vec{x}\,'$$

In terms of the speckle autocorrelation :

$$\Gamma \equiv \left\langle \gamma\gamma^* \right\rangle = \int m(\vec{x}) m(\vec{x}\,')^* . C(D_1, \vec{x}, \vec{x}\,') . C(D_2, \vec{x}, \vec{x}\,') d\vec{x}\, d\vec{x}\,'$$



Reflecting element

$$\Delta\phi(t) = \frac{4\pi}{\lambda}\cos\theta\,\delta x(t)$$

If $\delta x \ll \lambda$

PSD of SL-noise :

$$h(f) = \frac{\Gamma^{1/2}}{\sqrt{2}}\cos\theta\,\frac{\delta x(f)}{L}$$

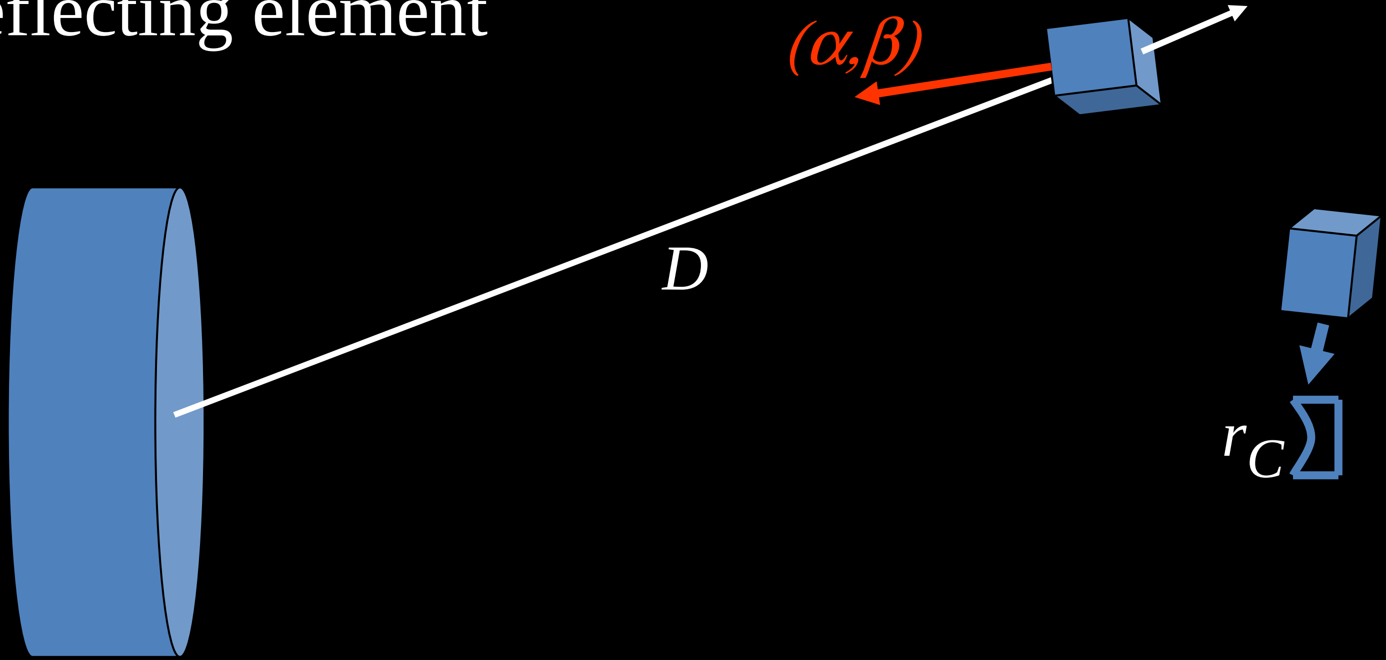
Possible cases of coupling

1) Direct reflection from elementary spots
   IM→IM and EM→EM

1) Transmission EM→IM and IM→EM via
   inner baffle edge

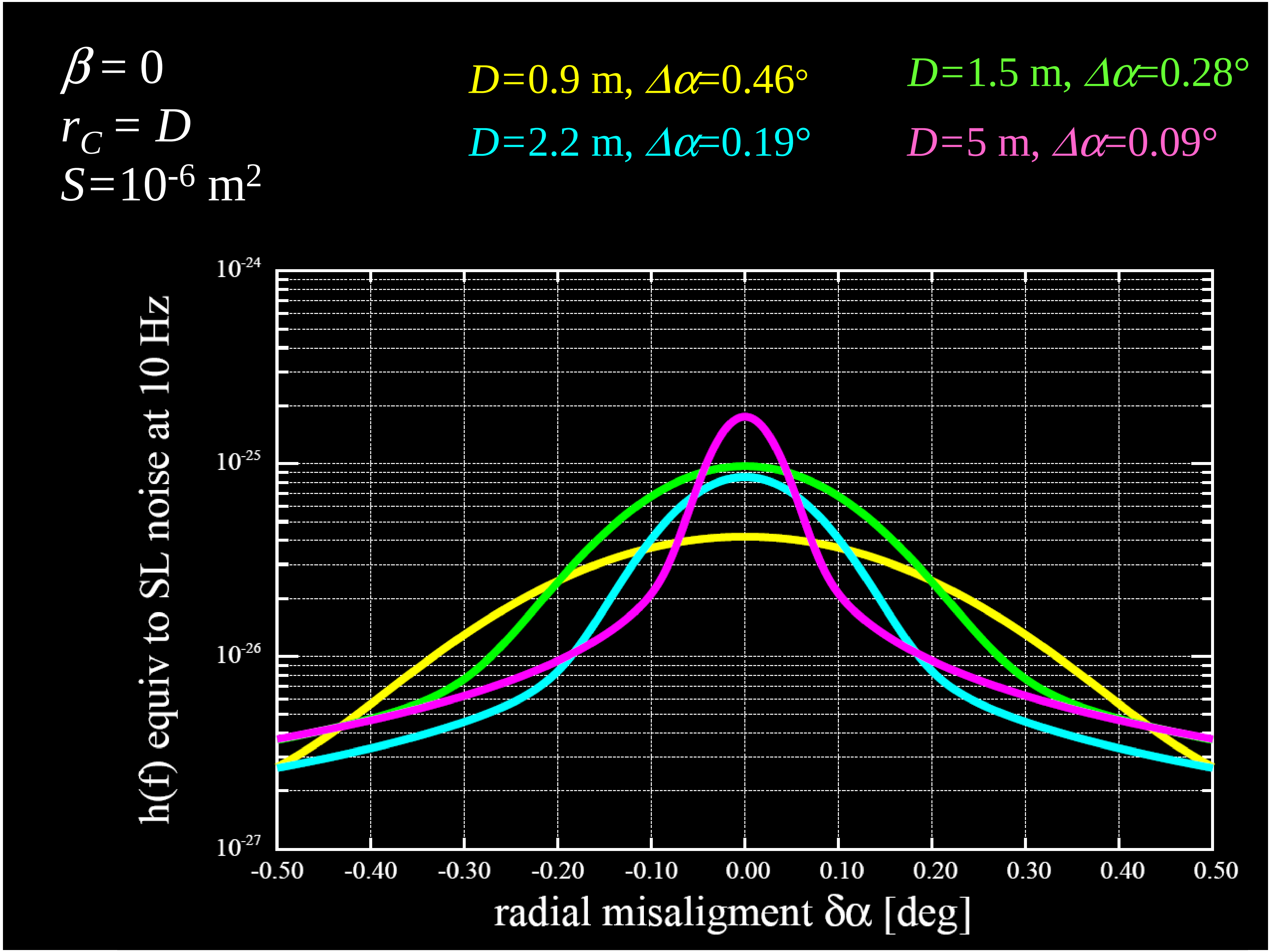
3) Transmission EM→IM and IM→EM via
   spots on the inner edge

Direct reflection
By reflecting element



Relevant parameters :

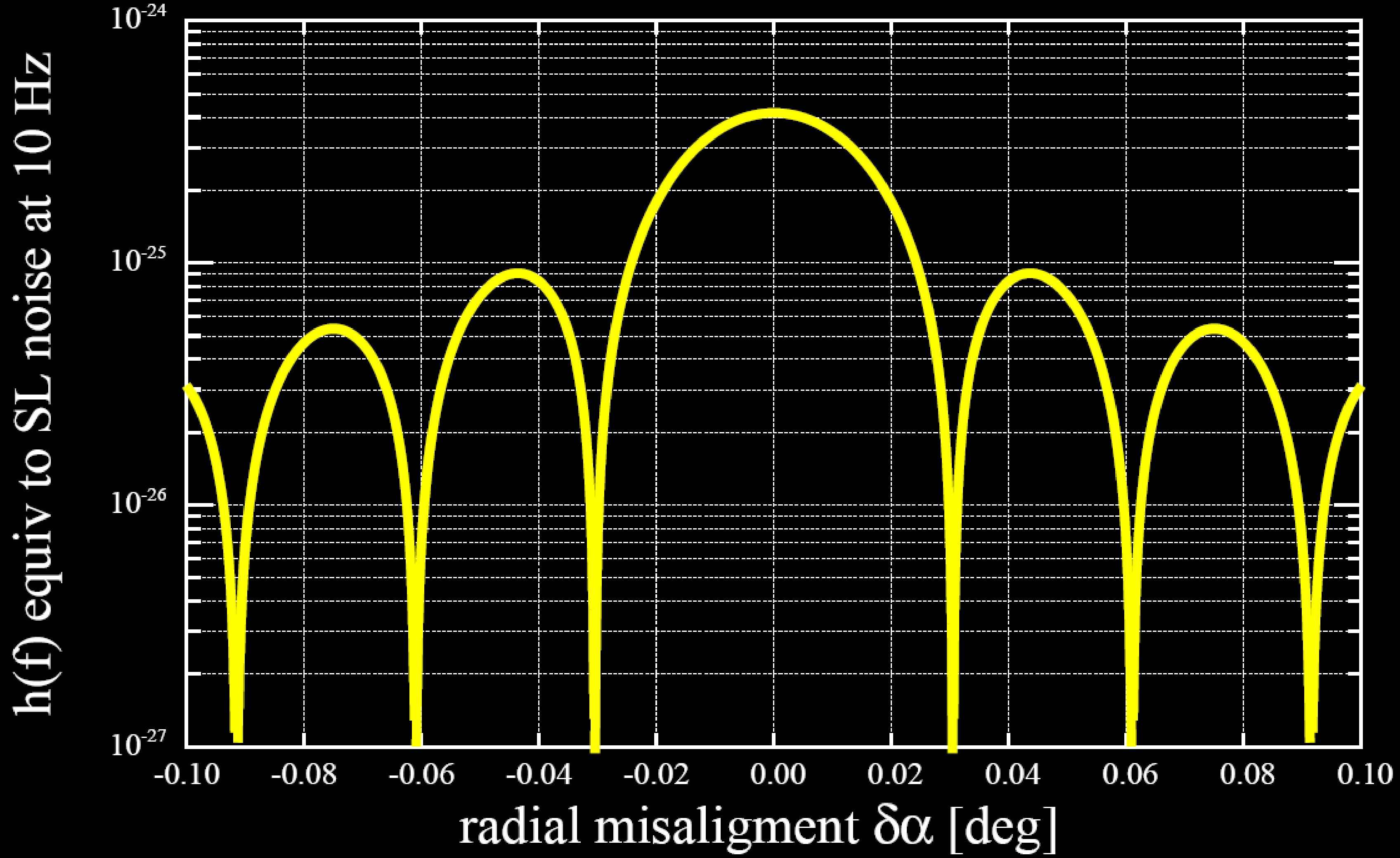
- -distance from mirror
- -Misaligment *(α,β)*
- -Mismatching r_C/D
- -Surface of the element



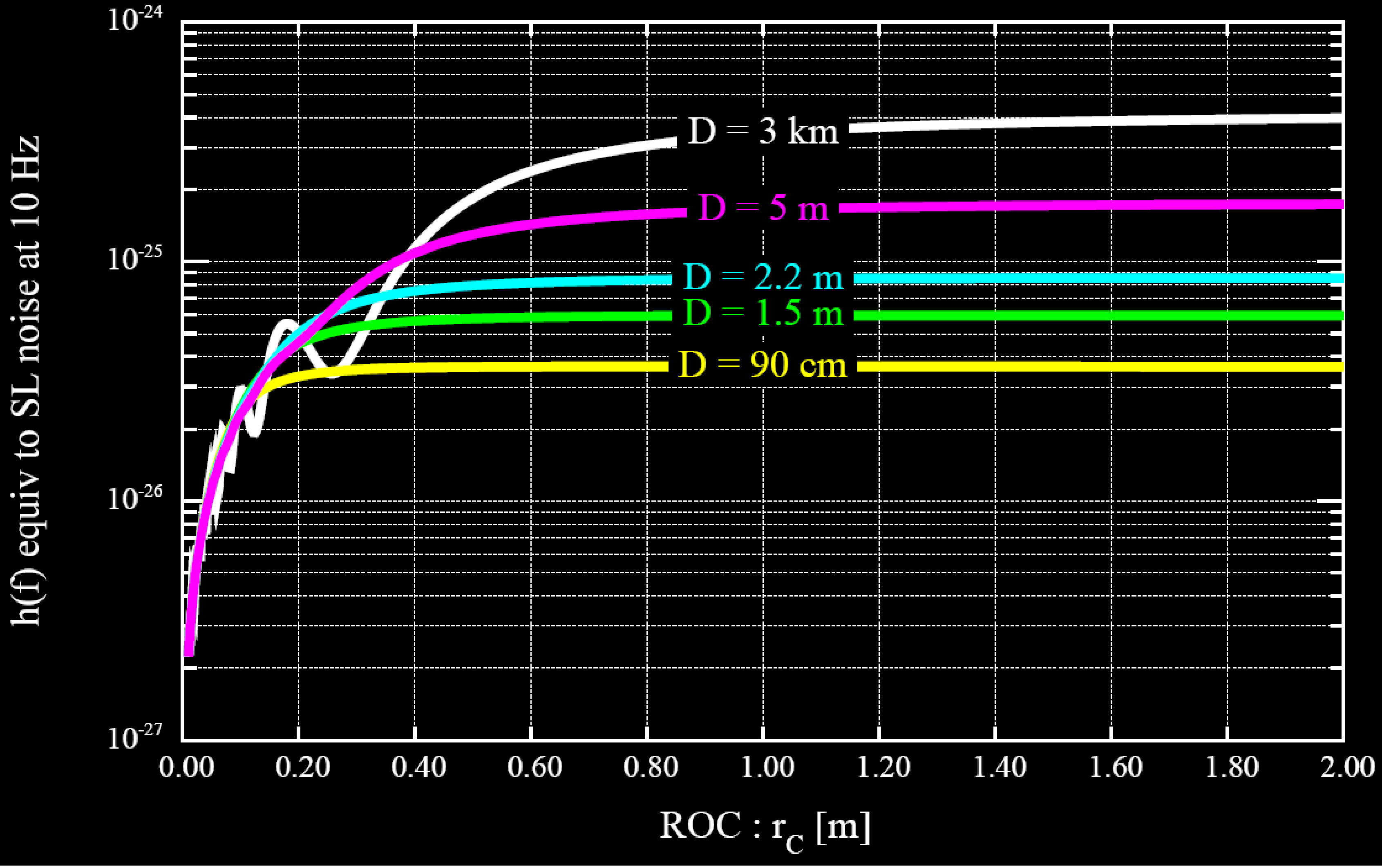
β = 0
r_C = D
S=10^-6 m^2
D=0.9 m, Δα=0.46°
D=1.5 m, Δα=0.28°
D=2.2 m, Δα=0.19°
D=5 m, Δα=0.09°
10^-24
10^-25
10^-26
10^-27
h(f) equiv to SL noise at 10 Hz
-0.50
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
radial misaligment δα [deg]

Case of input zone baffle → End mirror

D=3000 m, *Δα*=0.04°



ROC of the reflecting element



Conclusions for small reflecting defects :

-Unsensitive to ROC of the zone

-Sensitive to the distance

-Sensitive to the pointing error

Summary

$$D = 0.9\ \text{m} : h(f) = 4.18\ 10^{-26} \left[\frac{10\ \text{Hz}}{f}\right]^2 \text{Hz}^{-1/2},\quad \Delta\alpha = 0.46°$$

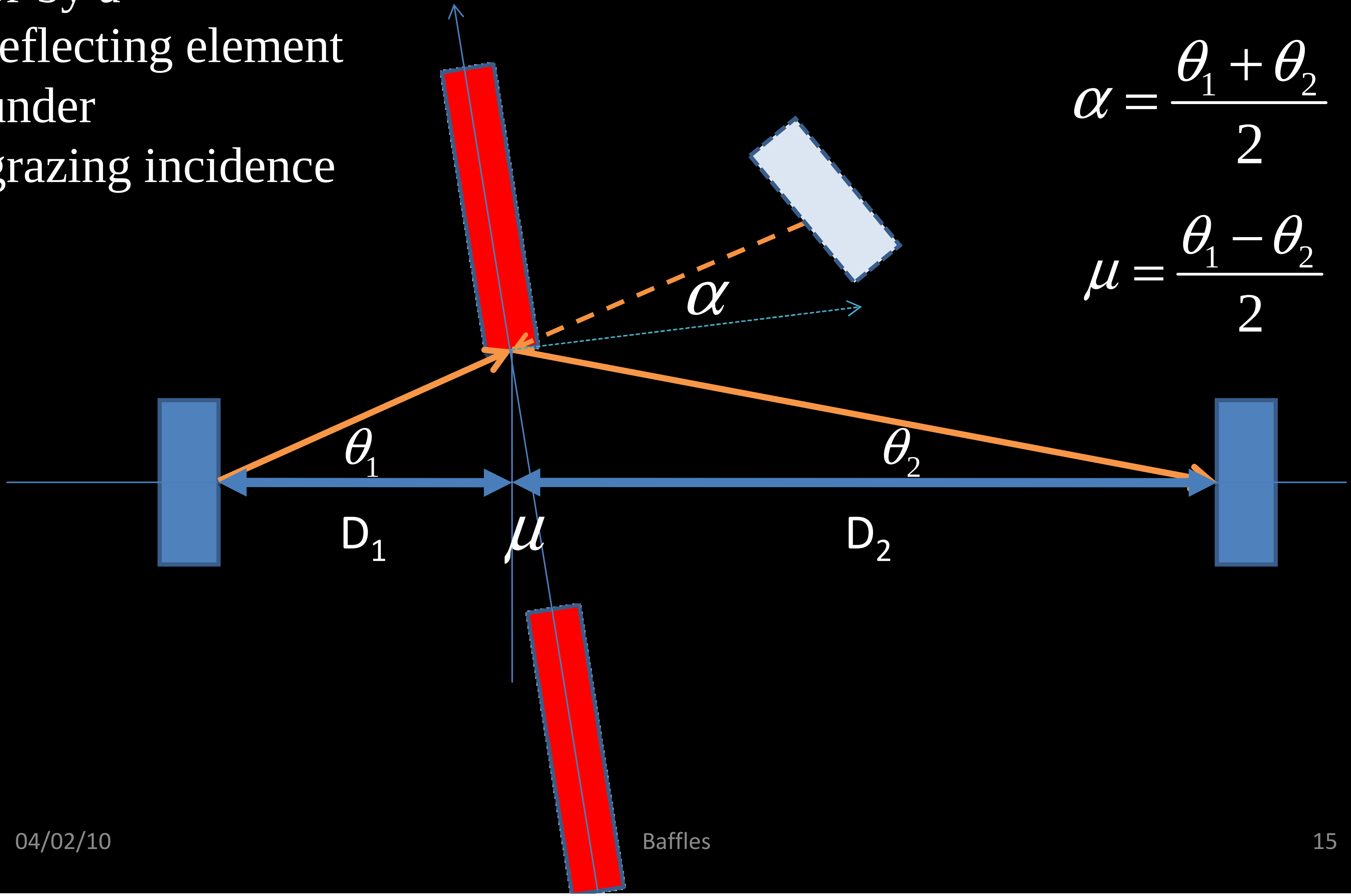
$$D = 1.5\ \text{m} : h(f) = 9.71\ 10^{-26} \left[\frac{10\ \text{Hz}}{f}\right]^2 \text{Hz}^{-1/2},\quad \Delta\alpha = 0.28°$$

$$D = 2.2\ \text{m} : h(f) = 8.53\ 10^{-26} \left[\frac{10\ \text{Hz}}{f}\right]^2 \text{Hz}^{-1/2},\quad \Delta\alpha = 0.19°$$

$$D = 5\ \text{m} : \quad h(f) = 1.75\ 10^{-25} \left[\frac{10\ \text{Hz}}{f}\right]^2 \text{Hz}^{-1/2},\quad \Delta\alpha = 0.09°$$

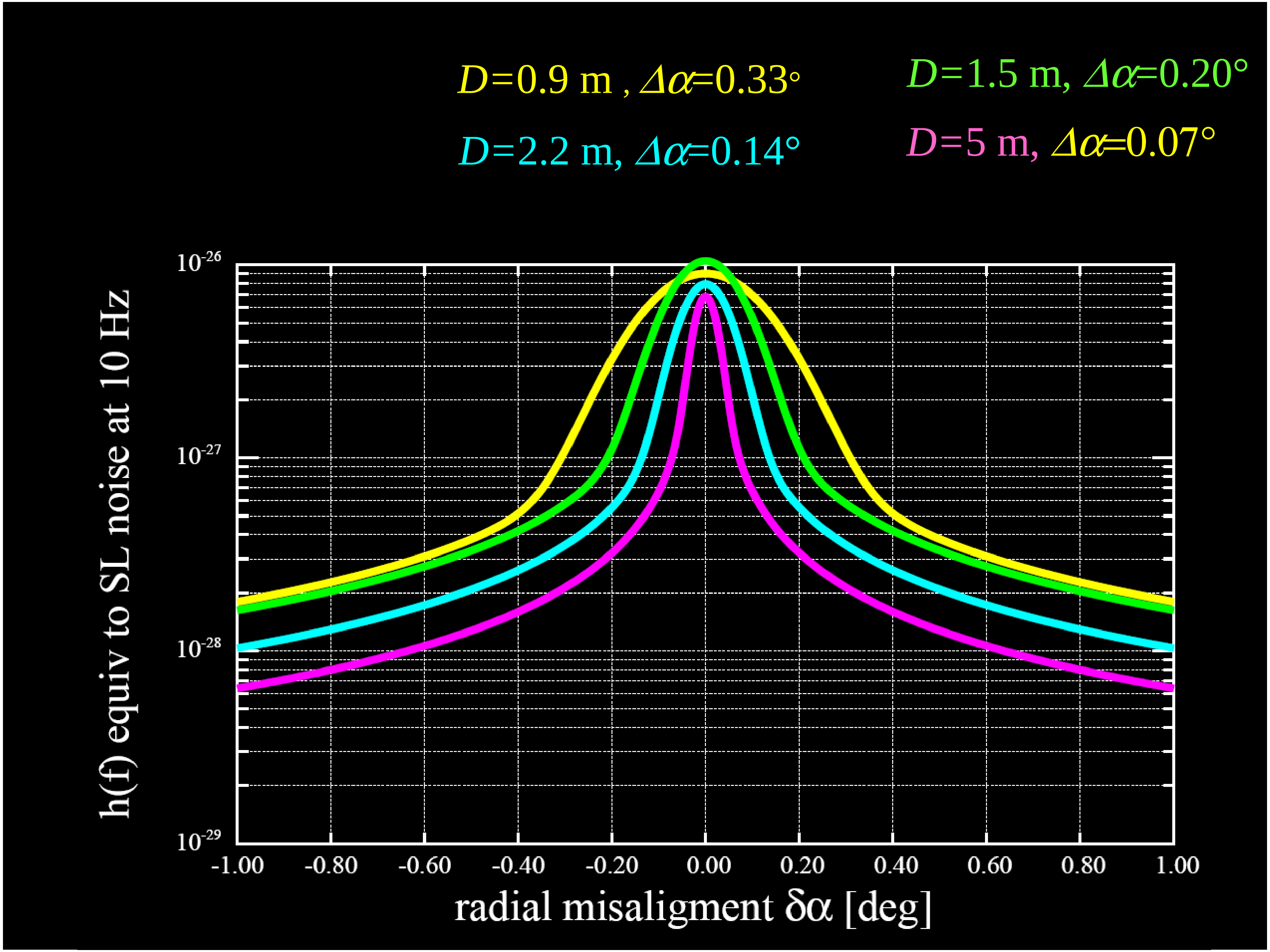
$$D = 3\ \text{km} : h(f) = 4.17\ 10^{-25} \left[\frac{10\ \text{Hz}}{f}\right]^2 \text{Hz}^{-1/2},\quad \Delta\alpha = 0.04°$$

Reflexion of scattered light by the inner edge of a baffle or by a reflecting element under grazing incidence



$$\alpha = \frac{\theta_1 + \theta_2}{2}$$

$$\mu = \frac{\theta_1 - \theta_2}{2}$$



D=0.9 m , Δα=0.33°
D=1.5 m, Δα=0.20°
D=2.2 m, Δα=0.14°
D=5 m, Δα=0.07°
10^-26
10^-27
10^-28
10^-29
h(f) equiv to SL noise at 10 Hz
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
1.00
radial misaligment δα [deg]