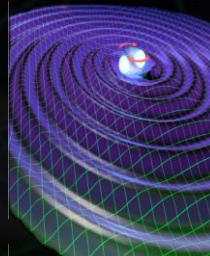


# Stray-Light Control in Interferometers

Masaki Ando (National Astronomical Observatory of Japan)  
Most materials by T. Akutsu, a leader of AOS subsystem



- Stray light noise (SLN) is like a ghost in an interferometer.
  - Most of interferometric GW antennas suffered from it in the final stage of commissioning. Sensitivities are often limited by SLN.
  - It is hard to identify the origin, and to mitigate SLN.
  - In TAMA, several set-ups were replaced or re-installed during noise-hunting process, hoping to reduce SLN.

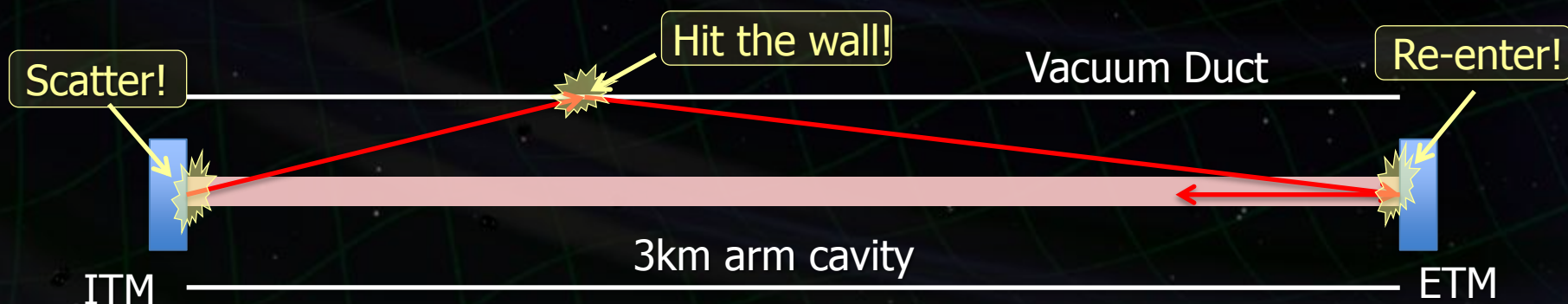


In large-scale interferometer, like KAGRA,  
we should consider about SLN from the design phase.

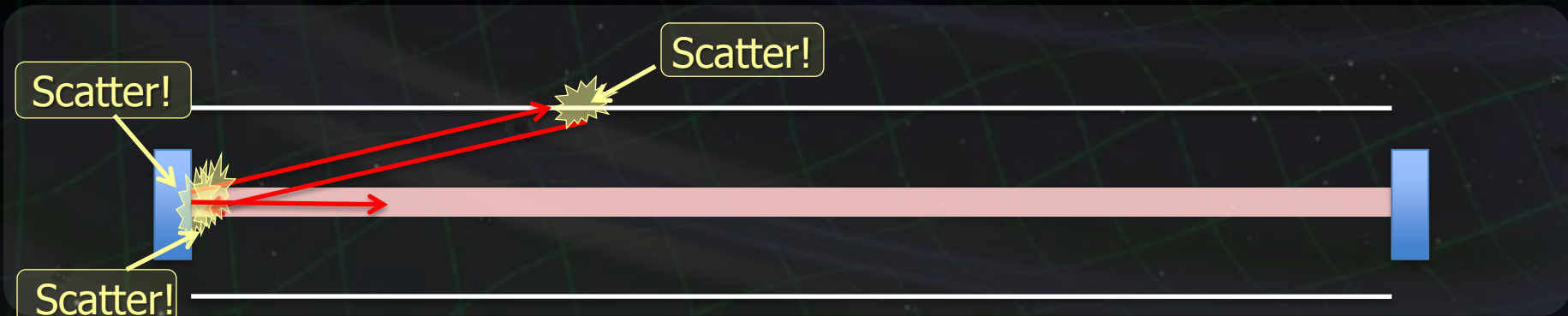
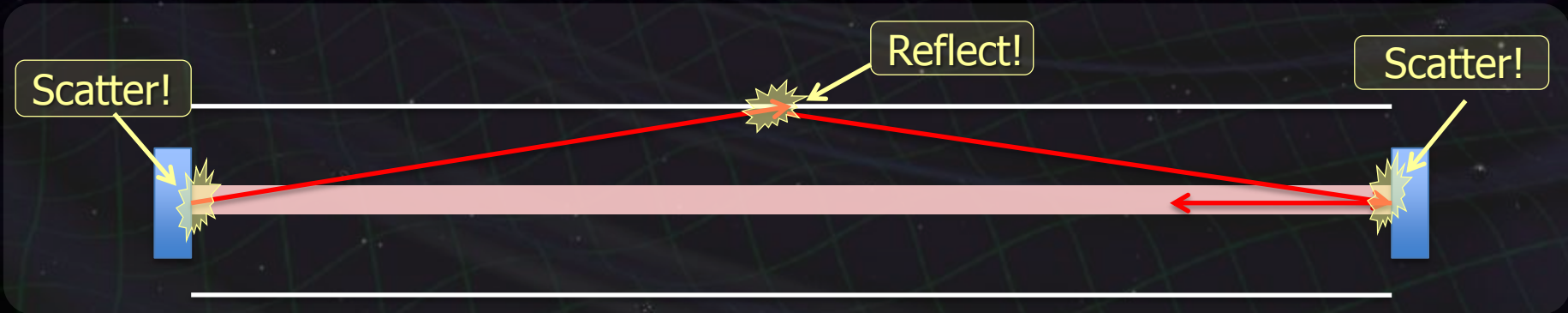
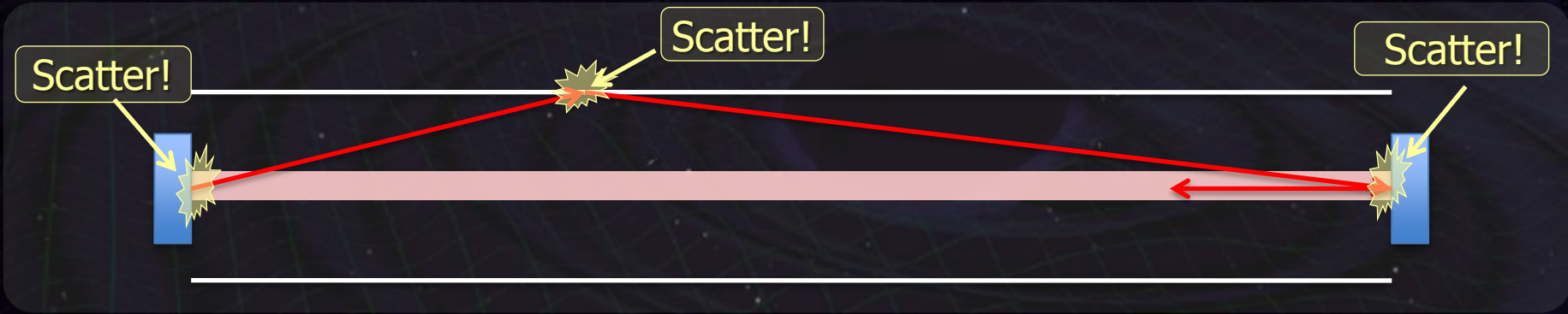


# Mechanism of Stray-Light Noises

- Stray light occurs at various place in an interferometer.
  - Laser beam diffraction
  - Scattering on the surfaces and in substrate of optics
  - Small reflection on AR surfaces of optics
- Stray light hits something with vibration, such as wall of vacuum duct, and re-enter to the main laser beam.
- Changes in the optical-path length difference of the stray light cause phase noises on the main beam, which cannot be distinguished from GW signal.



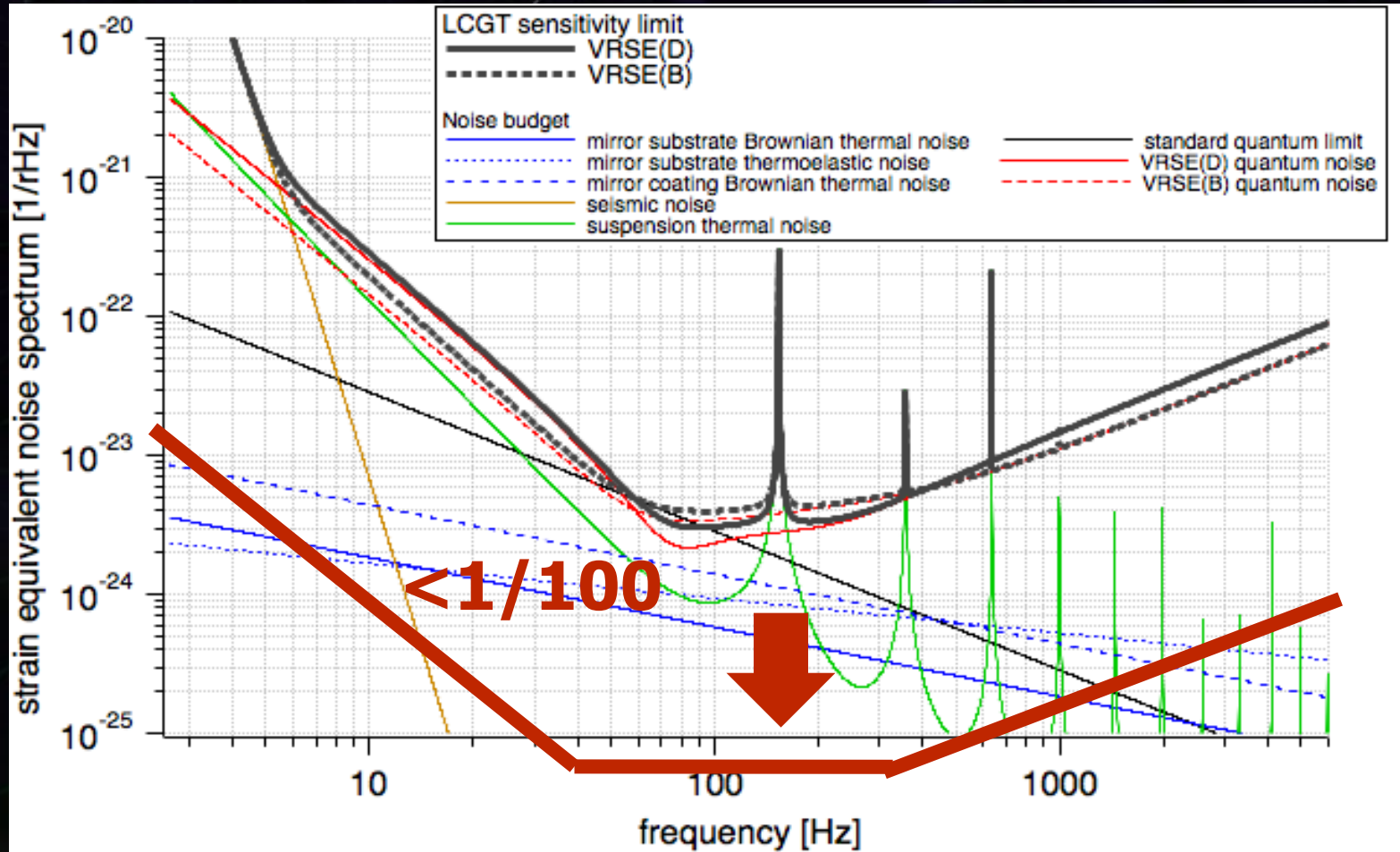
# Some Examples





# Requirement for SLN Level

- Safety margin of 2-orders are set, compared with KAGRA sensitivity curve



# Quantitative Estimation

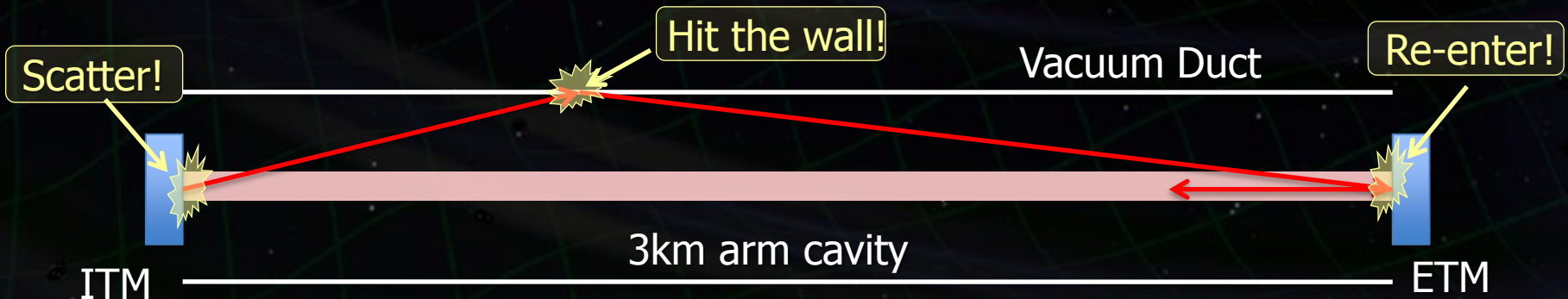
- SLN contribution to strain sensitivity.

$$\delta h_{\text{SLN}} = \frac{G}{L_{\text{arm}}} \sqrt{\frac{P_{\text{scatter}}}{P_{\text{main}}}} \delta\phi_{\text{scatter}}$$

Transfer function for re-entrance to the main beam [m/rad]

Amplitude ratio of produced stray light to the main beam

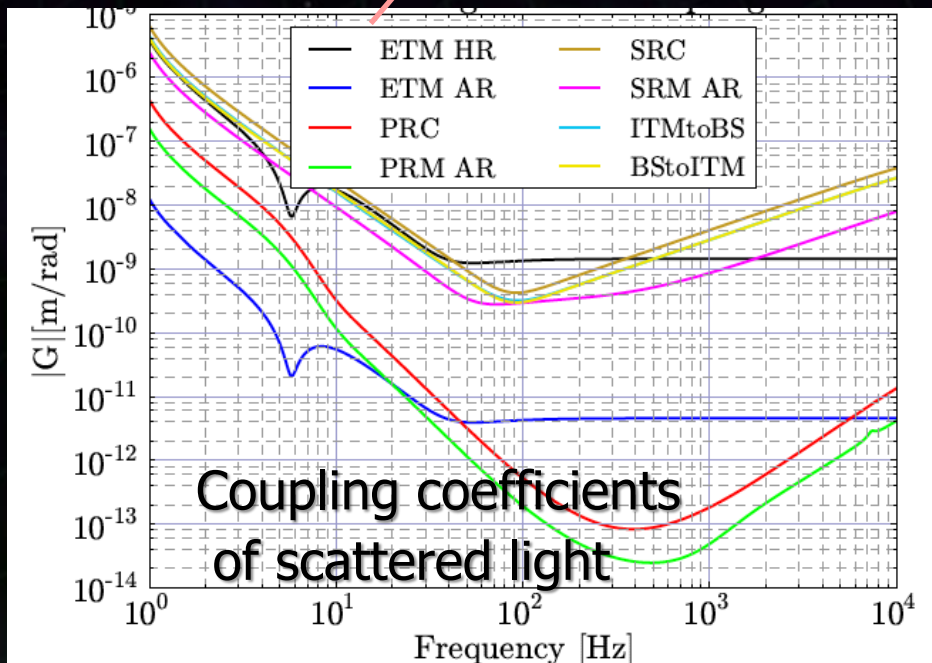
Phase fluctuation of stray light  
[Unit : rad/Hz<sup>1/2</sup>]





- SLN contribution to strain sensitivity.

$$\delta h_{\text{SLN}} = \frac{G}{L_{\text{arm}}} \sqrt{\frac{P_{\text{scatter}}}{P_{\text{main}}}} \delta \phi_{\text{scatter}}$$



Requirements on

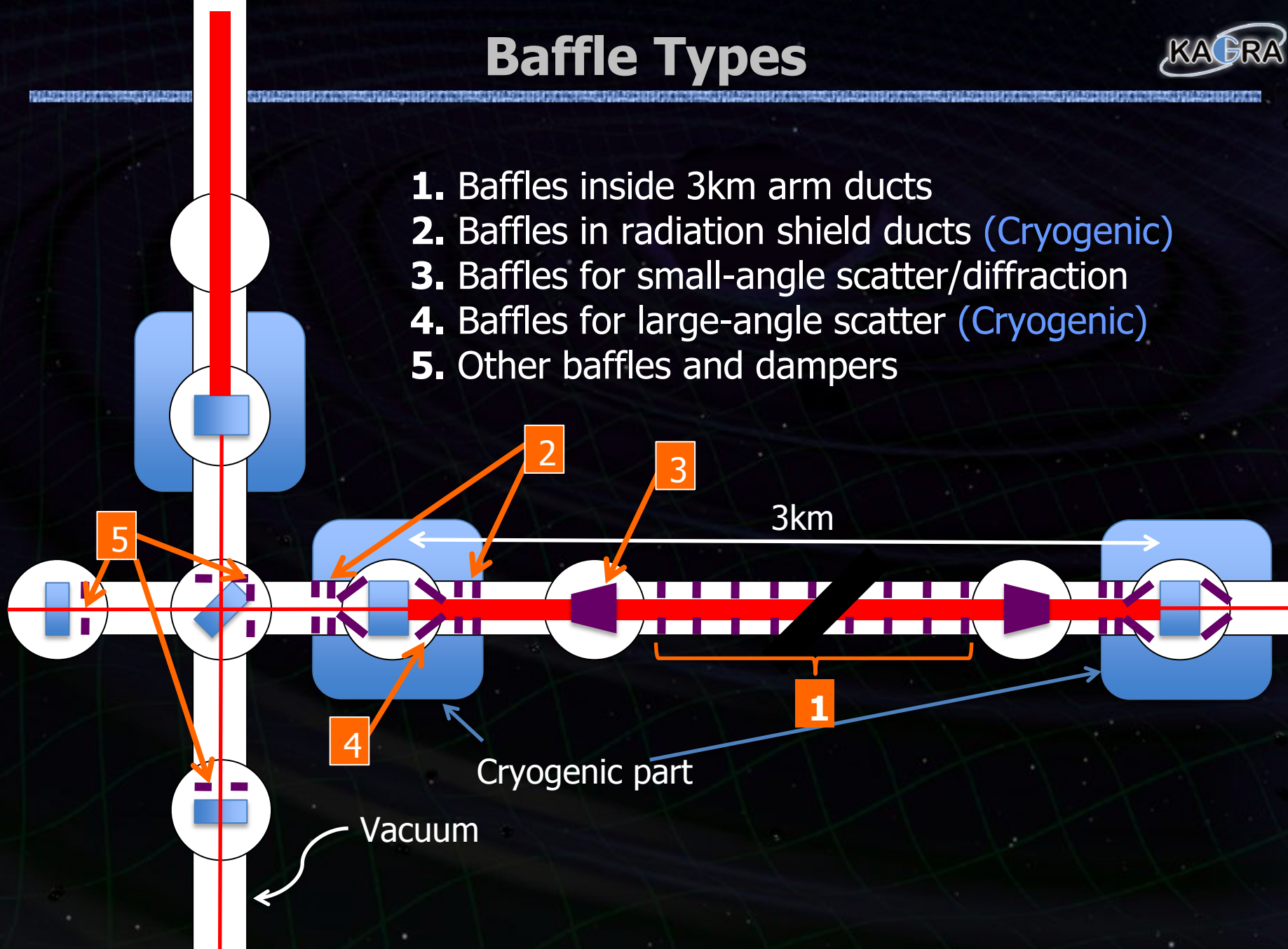
- Amount of scattered light
- Vibration isolation for mid-path components

- Strategy : Absorb most of the stray light by baffles.
- What we should consider about are ...
  - Quality of optics
    - Amount and angular dependence of stray light  
(Scatter on mirror surface, AR surface, Diffraction)
  - Optical design of baffles and installation positions
    - Ray-tracing and shape design
    - Surface treatment for better absorption
  - Vibration isolation of baffles.

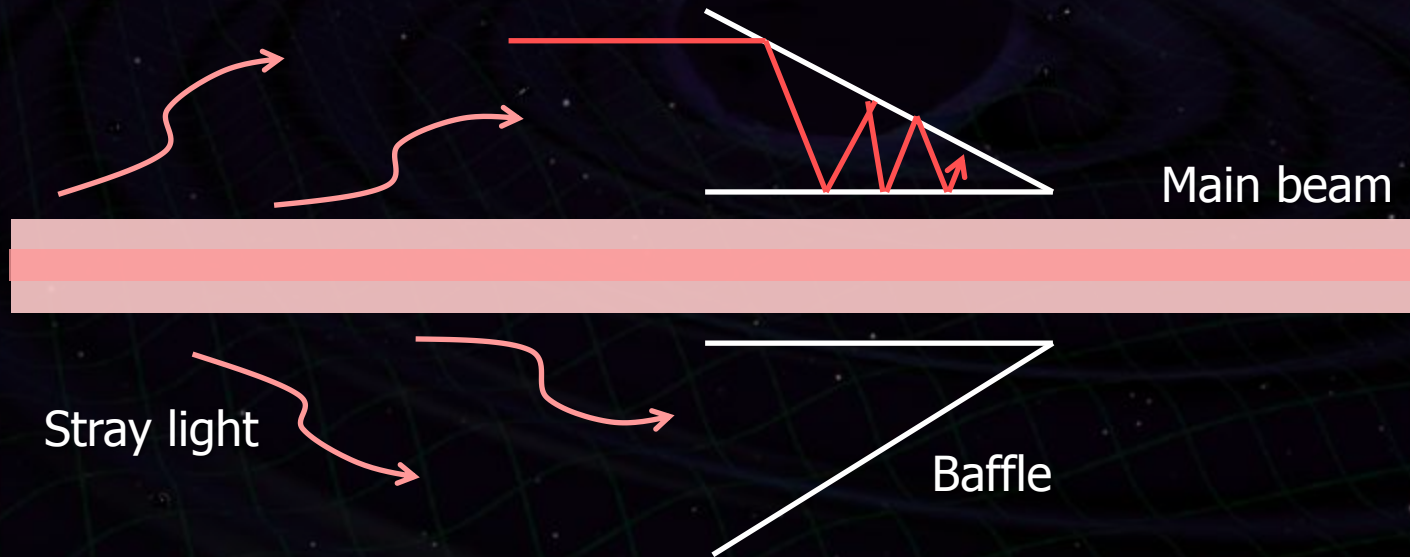


# Baffle Types

1. Baffles inside 3km arm ducts
2. Baffles in radiation shield ducts (Cryogenic)
3. Baffles for small-angle scatter/diffraction
4. Baffles for large-angle scatter (Cryogenic)
5. Other baffles and dampers



- Basic concept : absorption by multiple reflection



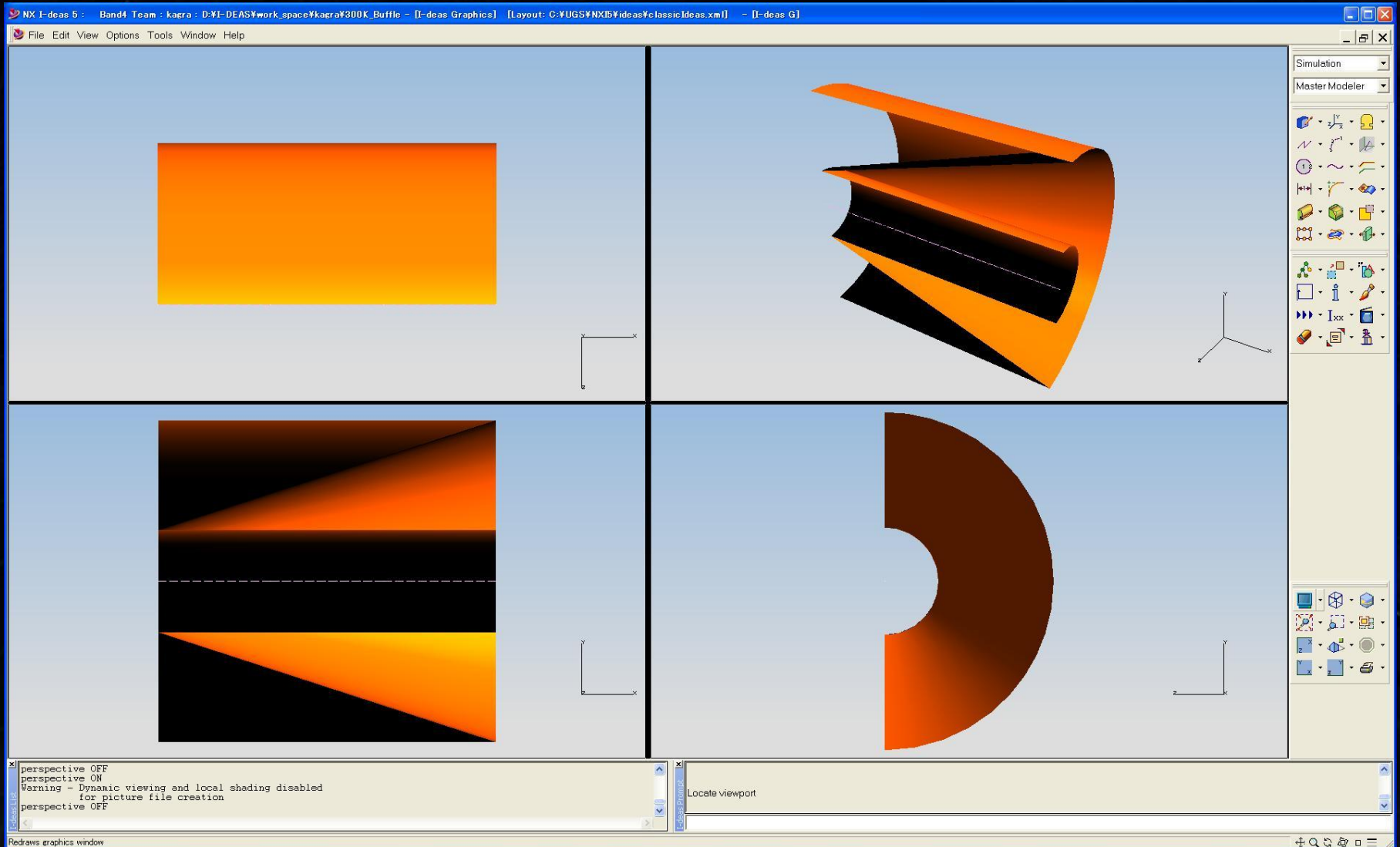
## Specifications

- Back reflection → Shape, Surface treatment
- Vibration isolation
- Production procedure, Cost, Size, Weight
- Vacuum and Cryogenic compatibilities, and Thermal conductivity



# Baffle Design

- Basic concept : absorption by multiple reflection



# Ray-Tracing Simulation

Zemax 12 EE - 33816 - C:\Users\dechertz\Documents\Zemax\SAMPLES\wide\_baffle\_20120817v31.zmx

File Editors System Analysis Tools Reports Macros Extensions Window Help

New Ope Sav Sas Bac Res NCE MFE MCE TDE Upd Upa Gen Wav L3n LSn Obv Rtc Dvr Rdb Dis Gmp Opt Glb Ham Tol Gla ABg Stv Xis Len Pre Chk Vop

Non-Sequential Component Editor

Edit Solves Tools View Help

Object Type	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	# Layout Rays	Power(Watts)	Wavenumber	Color #	X Half Width	Y Half Width	Source
1 Source Ellipse	0.000	0.000	0.000	0.000	-		40.000	0	0	125.000	125.000	
2 Cylinder Pipe	0.000	0.000	0.000	0.000	MIRROR		264.150					
3 Cylinder Pipe	171.700	0.000	0.000	0.000	MIRROR		264.150					
4 Cylinder Pipe	400.000	0.000	0.000	0.000	MIRROR		264.150					
5 Cylinder Pipe	400.000	0.000	0.000	0.000		200.000	125.000					
6 Cylinder Pipe	400.000	0.000	0.000	0.000		200.000	125.000					
7 Annulus	600.000	0.000	0.000	0.000		264.150	264.150	125.000				
8 Detector Rectangle	-1.000	0.000	0.000	0.000		300.000	300.000	1000		0	0	
9 Detector Rectangle	700.000	0.000	0.000	0.000		300.000	300.000	1000		0	0	

**Preliminary!!**

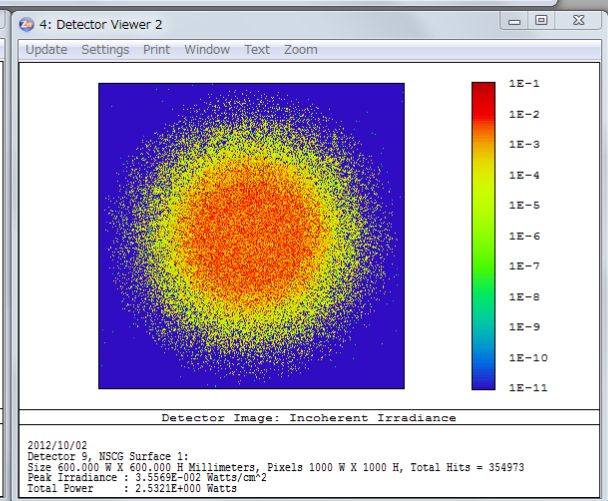
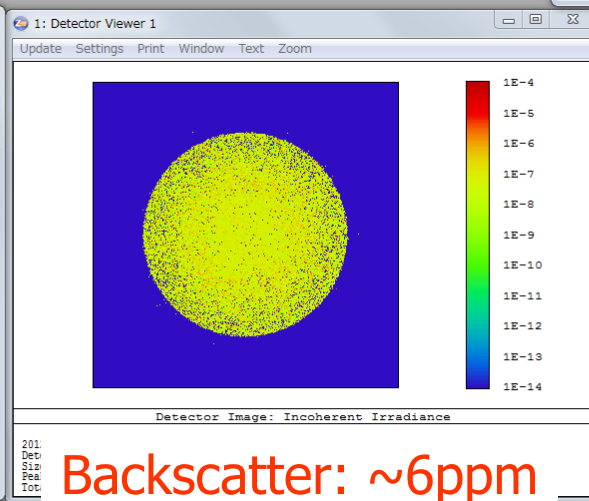
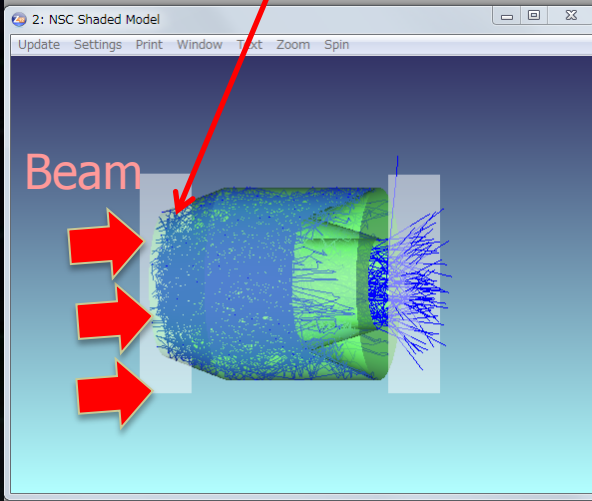
Simulated scatter

Incident Angle In Degrees

Reflection vs. Angle

2012/10/02  
Coating MGR\_BAFO on Object 3 Face 0  
Incident media: Air (1.0)  
Substrate: MIRROR  
Wavelength: 1.0640

wide\_baffle\_20120817v31.zmx  
Configuration 1 of 1



Backscatter: ~6ppm

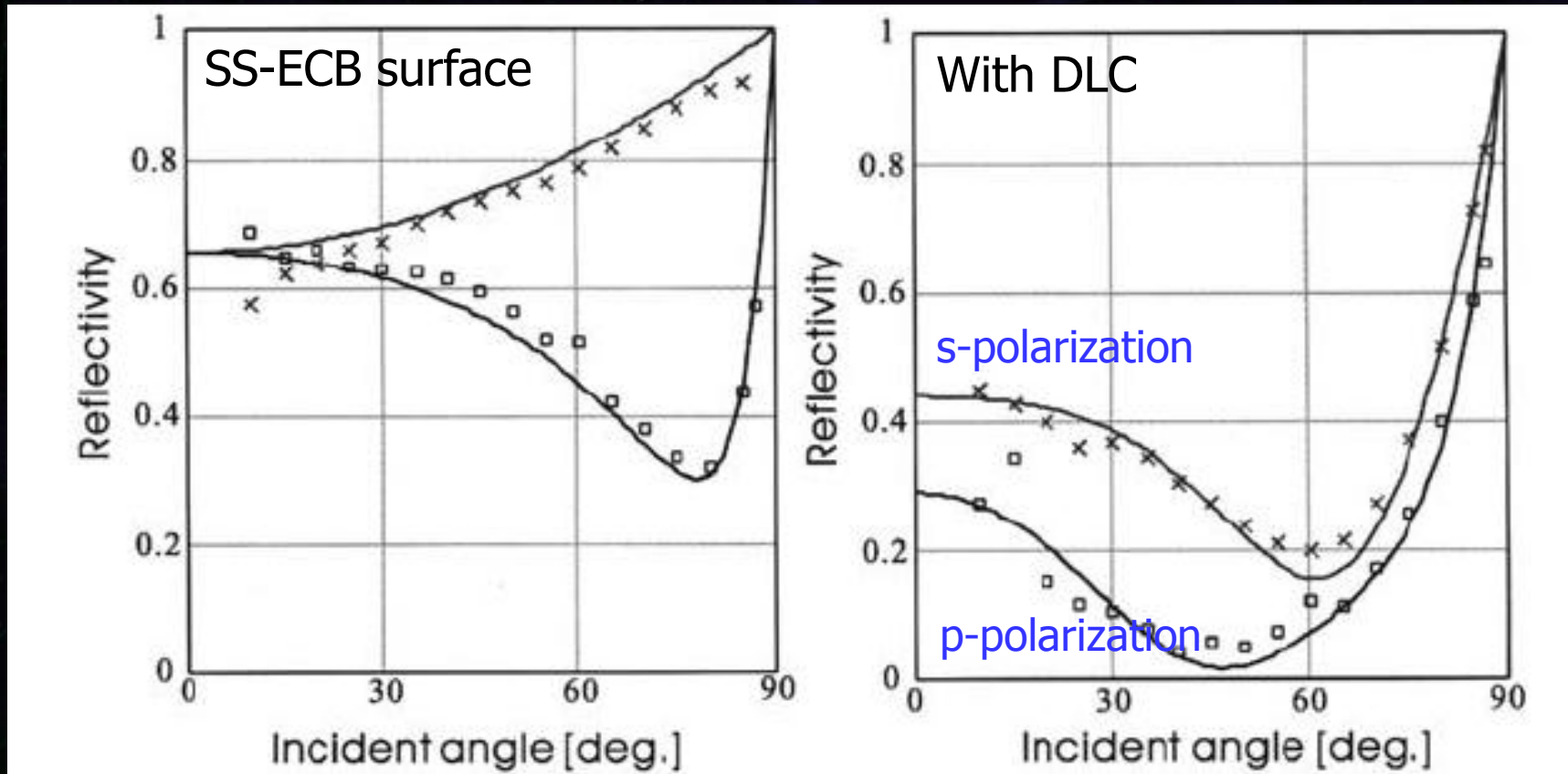


- Under investigation
- Candidate : Diamond-like Carbon (DLC)
  - Heritages in TAMA300
    - \* Vacuum and cryogenic compatibilities
    - \* Small scatter (peculiar reflection)
  - Difficulties : Rather high reflectivity ( $\sim 40\%$ )  
Large-area coating
- Other candidates : black platings
  - Low reflectivity ( $\sim$ a few % @1064nm)
  - Large-area coating



# Diamond-like Carbon (DLC)

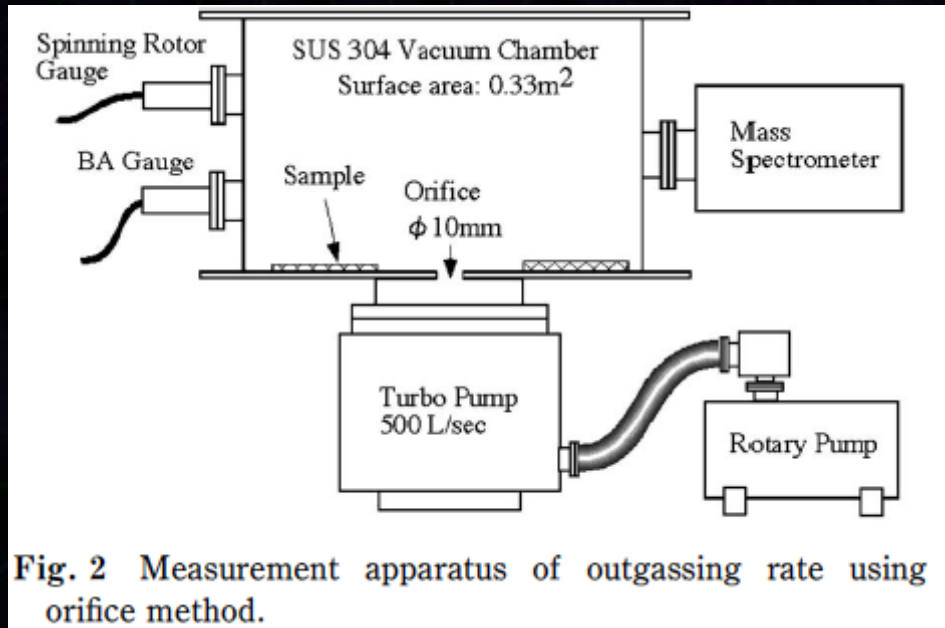
## Results of surface reflectivity measurements



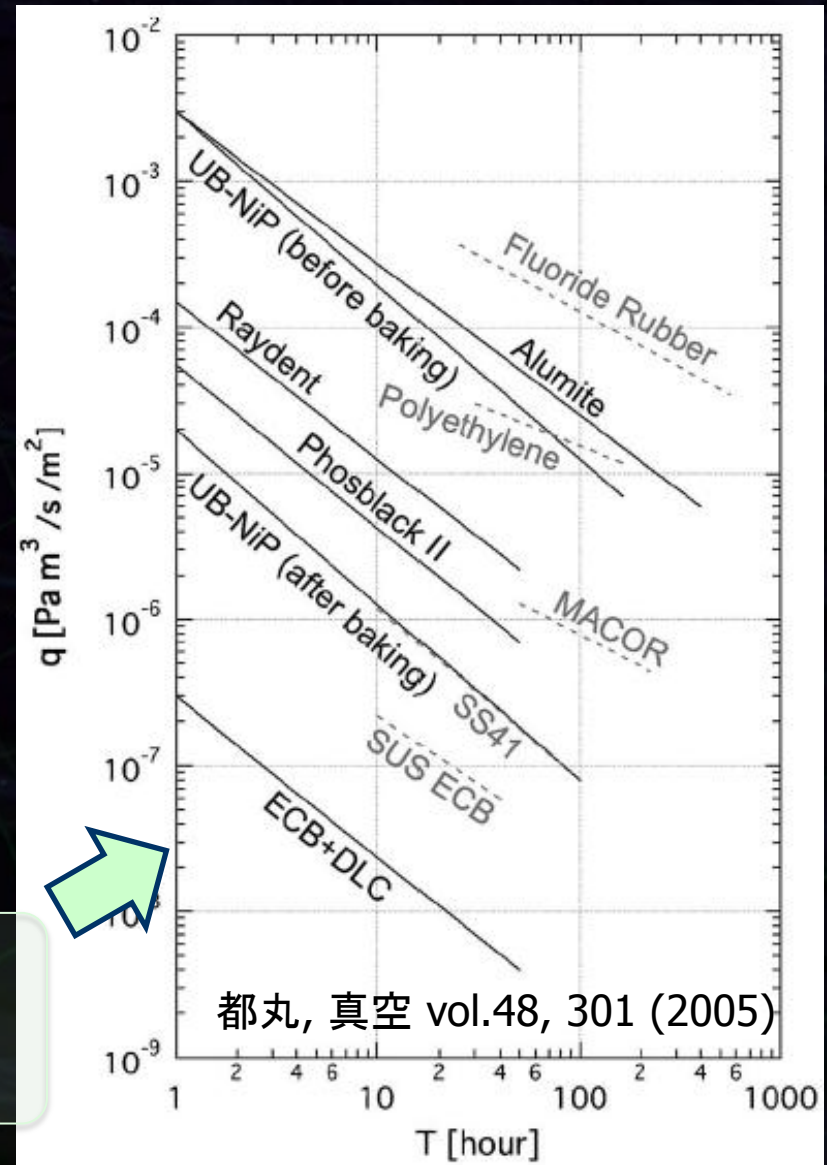
R. Takahashi, Y. Saito et al., Vacuum 73, 145 (2004)



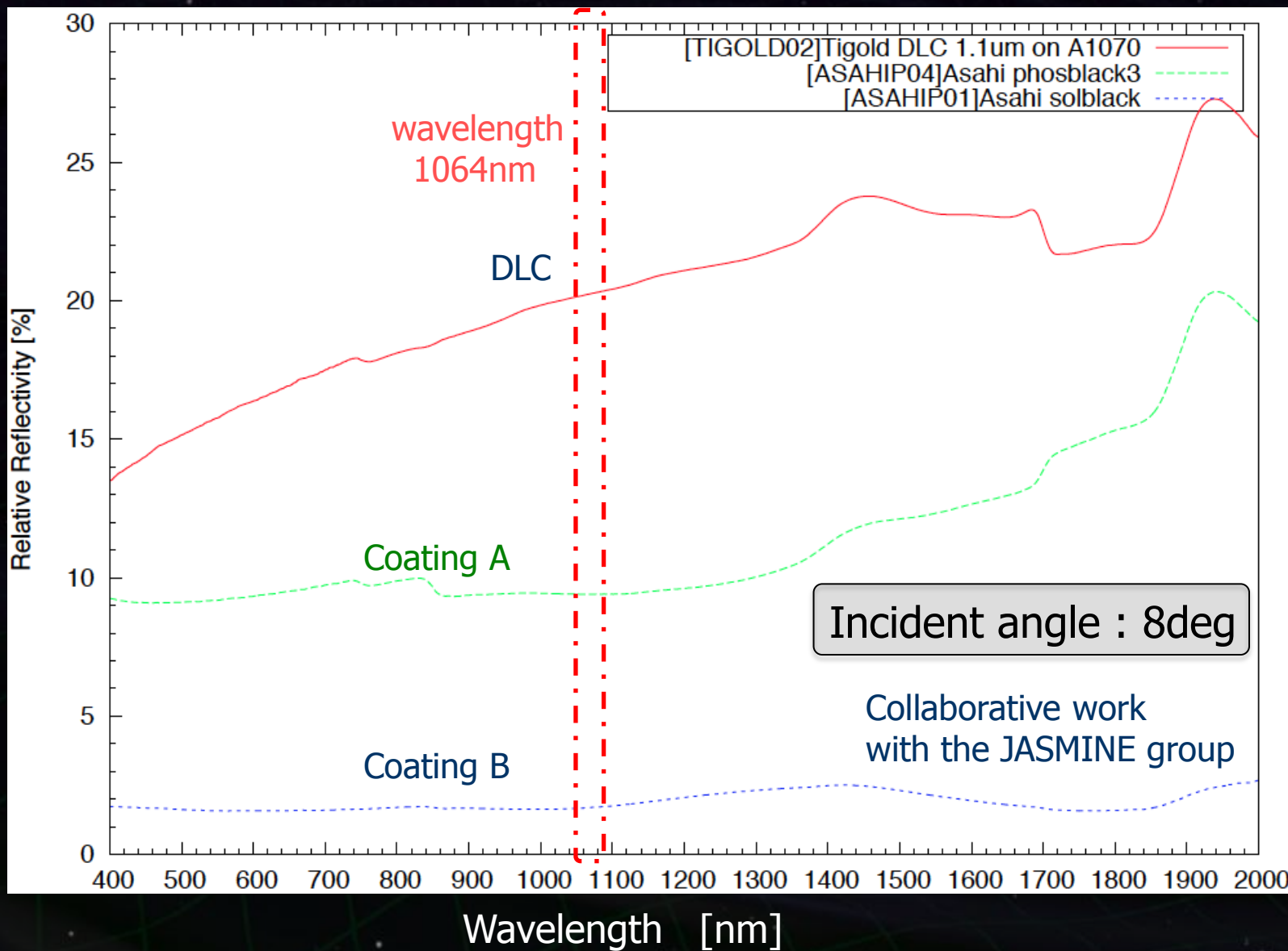
## Results of out-gassing measurement



DLC has lower out gasses  
(Depends on surface polish)



# Other Coating Candidates





- Mechanical design and prototype tests
  - FEM modeling for distortion
  - Construction procedure
- Optical design
  - Ray-tracing simulation
  - Systematic survey measurements for surface properties of various coatings and their vacuum compatibilities.

