Measurements on the Scattering of Materials Used in the Gravitational Wave Interferometer Detector KAGRA

– Performing Stray-Light Control –

Simon ZEIDLER, Tomotada AKUTSU, Yasuo TORII, Yoichi ASO, Raffaele FLAMINIO, and Kazuhiro YAMAMOTO[a]

NAOJ, ICRR Univ. of Tokyo[a]

NAOJ, Gravitational Wave Project Office

Outline

- **Introduction**
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  - *The Importance of Stray-Light Control*
  - *Where Scattering may appear*
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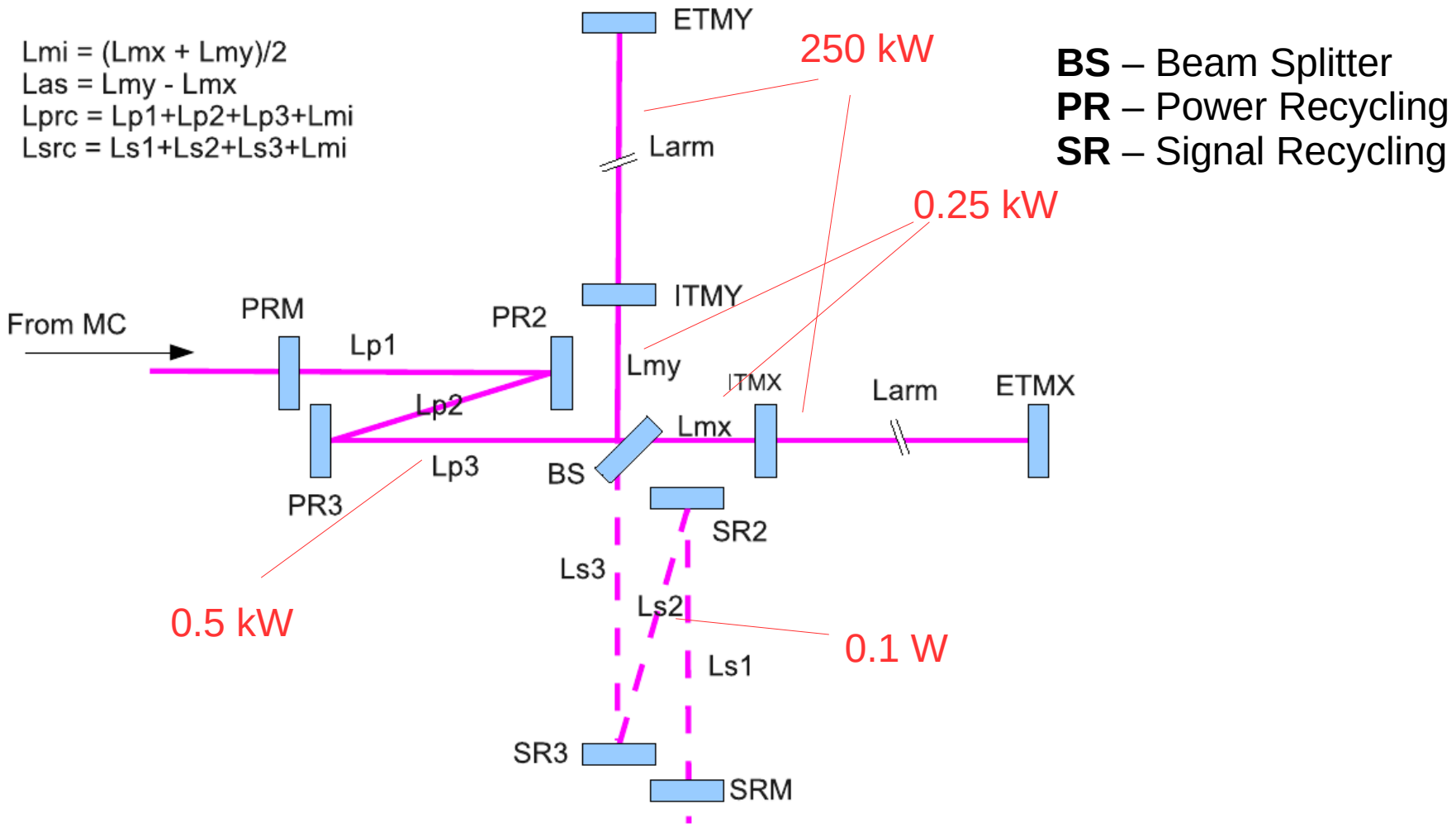
  - *Characterization of Scattering*
  - *Setup of a Scatterometer*
  - *Titanium and SiC*
  - *Backscattering Measurements*
  - *Titanium, SiC, and Black Coatings*
- **Summary**

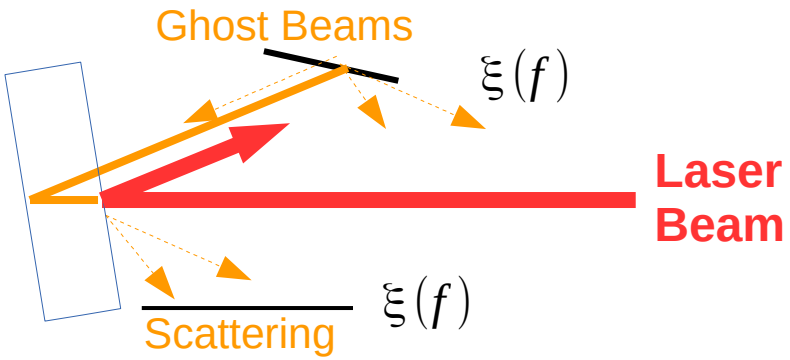
Introduction

Principle Setup of the KAGRA Interferometer

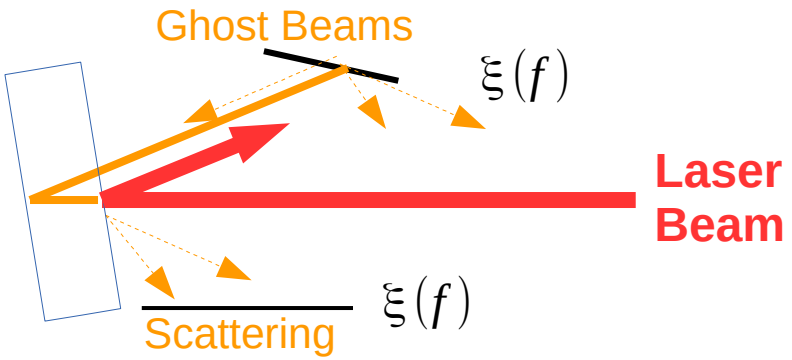


Schematic of the main interferometer and the naming convention of IFO parameters (from "KAGRA Main Interferometer Design Document" by Y. Aso)

The Importance of Stray-Light Control



The Importance of Stray-Light Control



- KAGRA measures GW strain through phase differences
- **Scattered light** and **ghost beams** may carry phase differences other than GWs
- Effect of scattered light on gravitational wave strain:

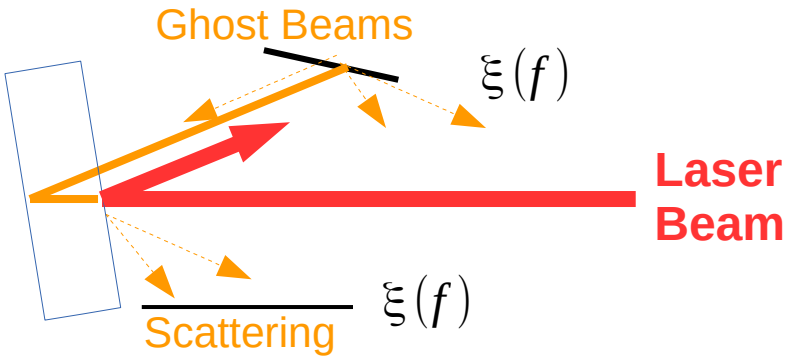
$$h_{rec} = \frac{\sqrt{2}\cdot\lambda}{L}\cdot\xi(f)\cdot\sqrt{\frac{I_{rec}}{P_{laser}}}$$

I_{rec} → *Intensity of recoupled light* $[W/m^2]$

P_{laser} → *Power of laser beam* $[W]$

$\xi(f)$ → *vibration noise spectrum* $[m/\sqrt{Hz}]$

The Importance of Stray-Light Control



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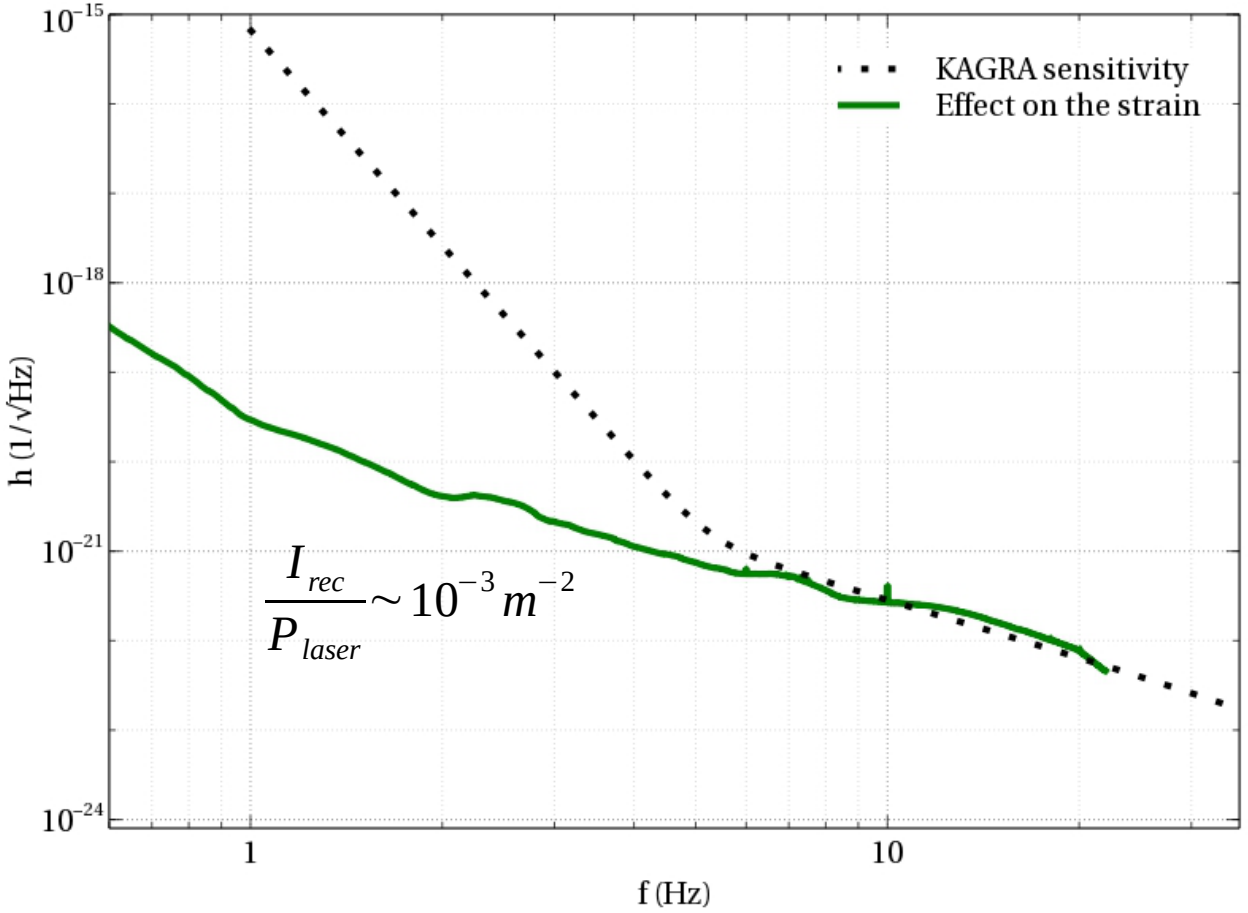

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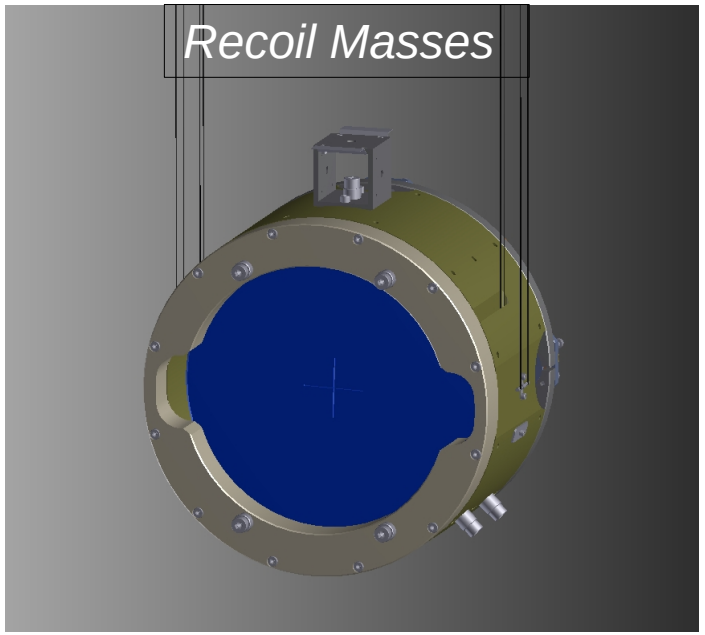
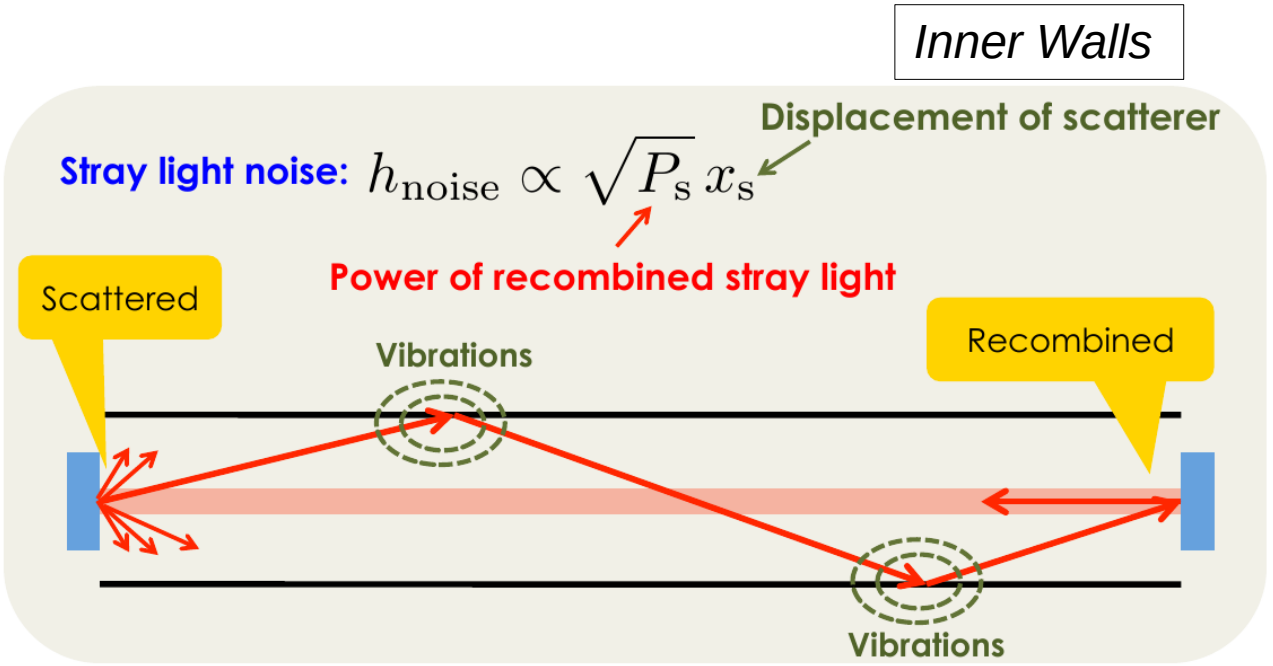
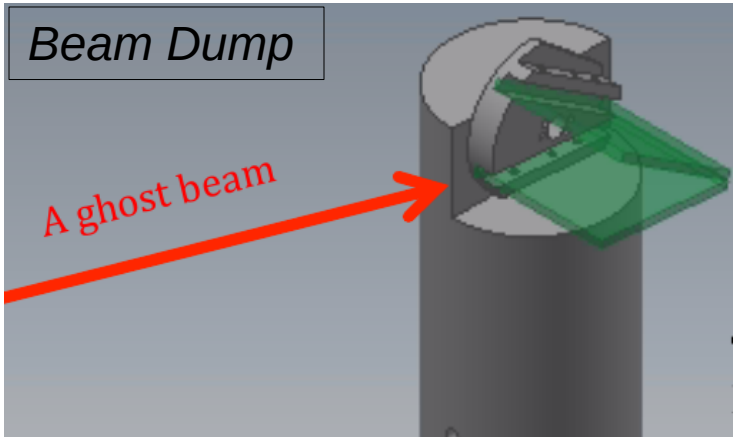
Where Scattering may Appear





- Basically, all surfaces produce scattering
- To find its impact on KAGRA, we need to know the characteristics of used materials

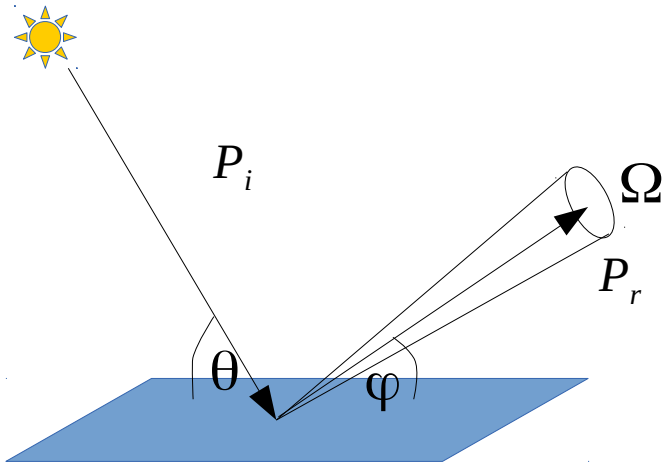


Credit: Tomotada Akutsu

Measuring the Scattering

Characterization of Scattering

- Scattering appears due to inhomogeneities of materials
- Surfaces (in reflection or transmission), inertial scattering (Rayleigh scattering), Compton scattering
- How to characterize scattering?



Measuring the Scattering

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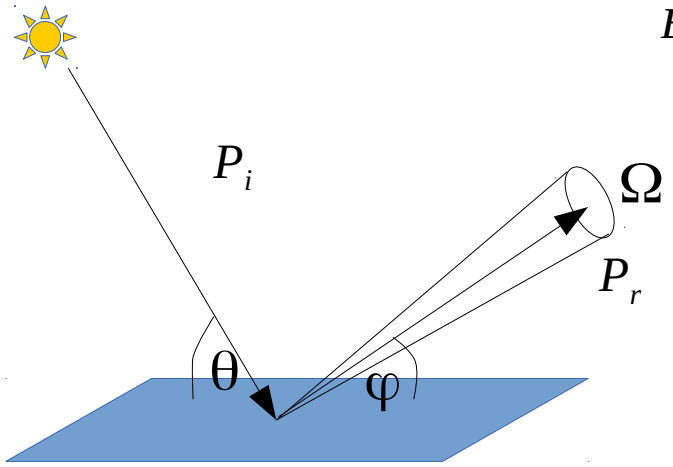
BRDF (**B**idirectional **R**eflection **D**istribution **F**unction)

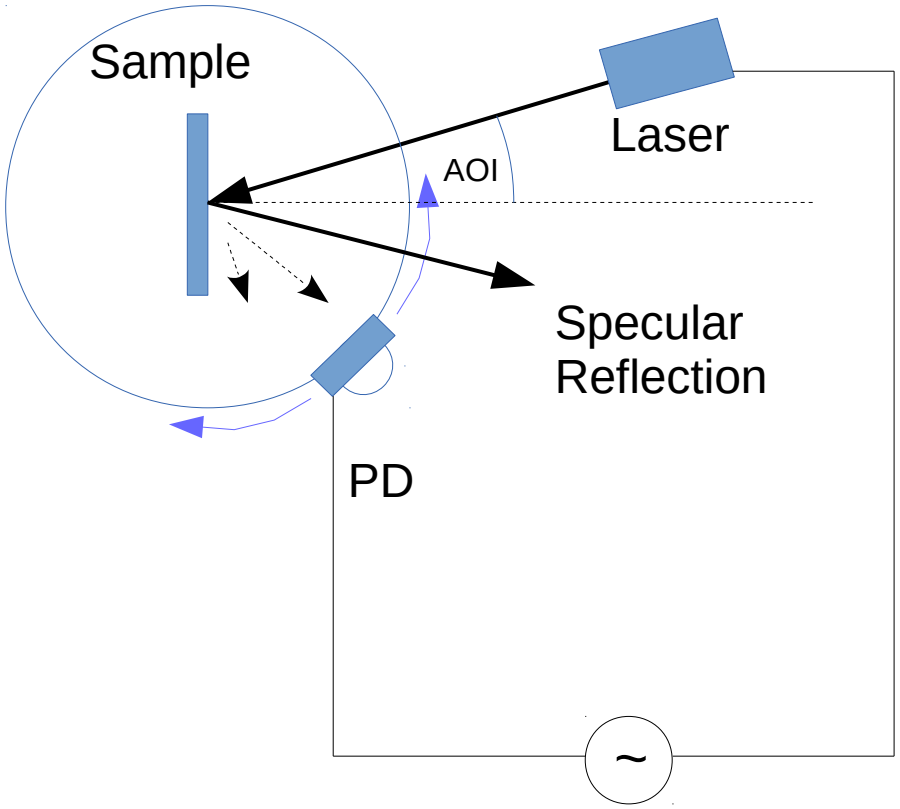


$$BRDF(\theta,\varphi)=\frac{\partial L_r(\varphi,I_r)}{\partial E_i(\theta,I_i)}; \qquad L_r=\frac{\partial P_r}{\partial A\,\partial\Omega\cdot\cos(\varphi)} \rightarrow \text{Radiance}$$

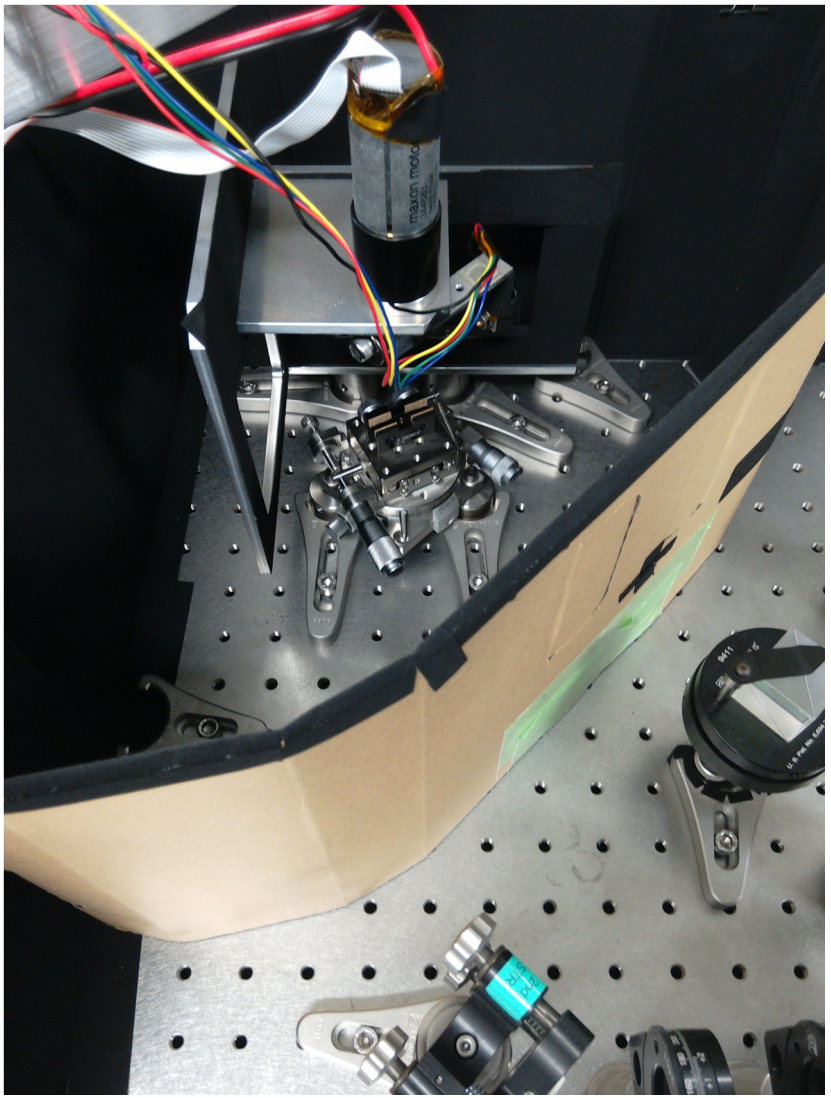
$$E_i=\frac{\partial P_i}{\partial A} \rightarrow \text{Irradiance}$$

$$BRDF(\theta,\varphi)=\frac{\partial P_r}{\partial P_i\,\partial\Omega\cdot\cos(\varphi)}$$

Setup of a Scatterometer



$$BRDF(\theta) = \frac{I_{PD}(\theta) \cdot f_{PD}}{P_{laser} \cdot \Omega \cdot \cos(\theta)}$$



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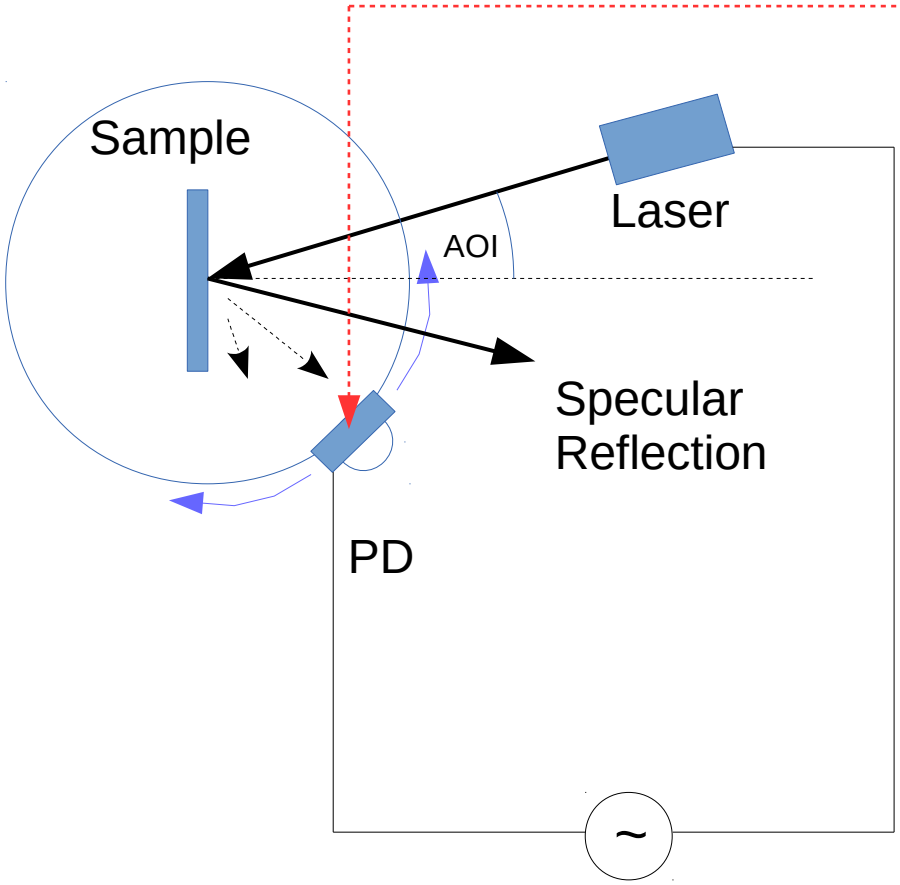

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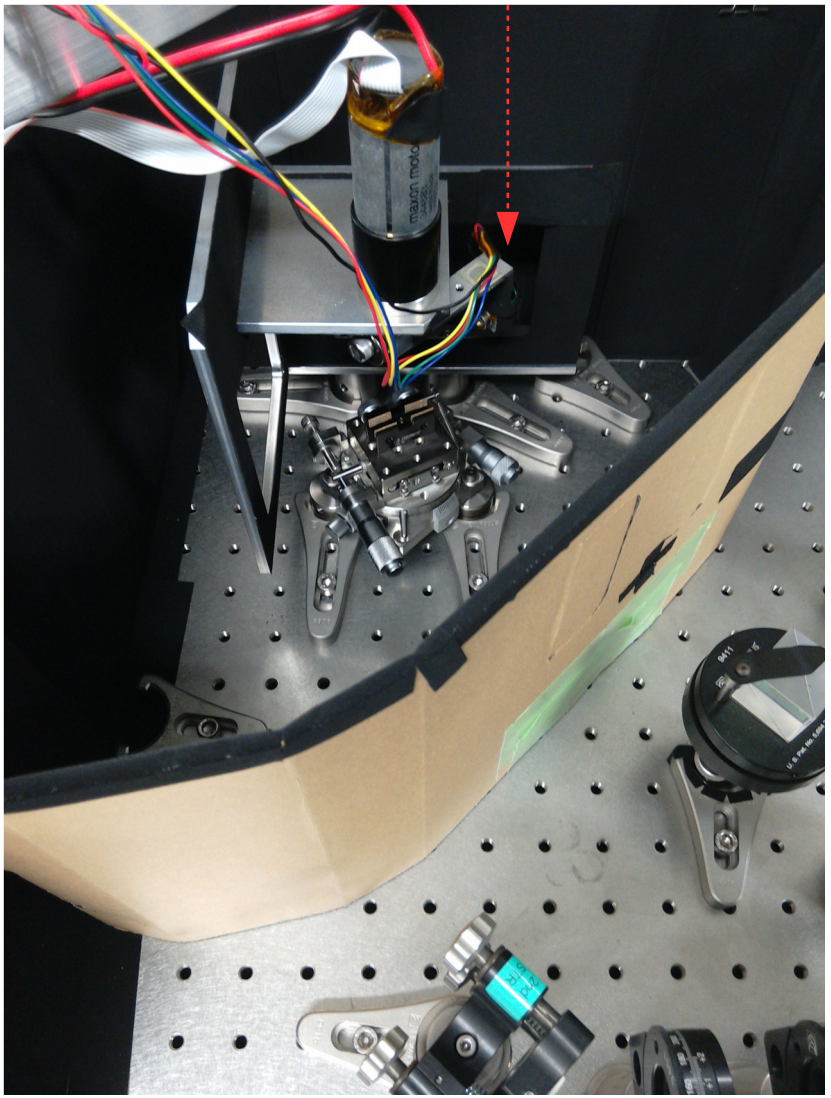

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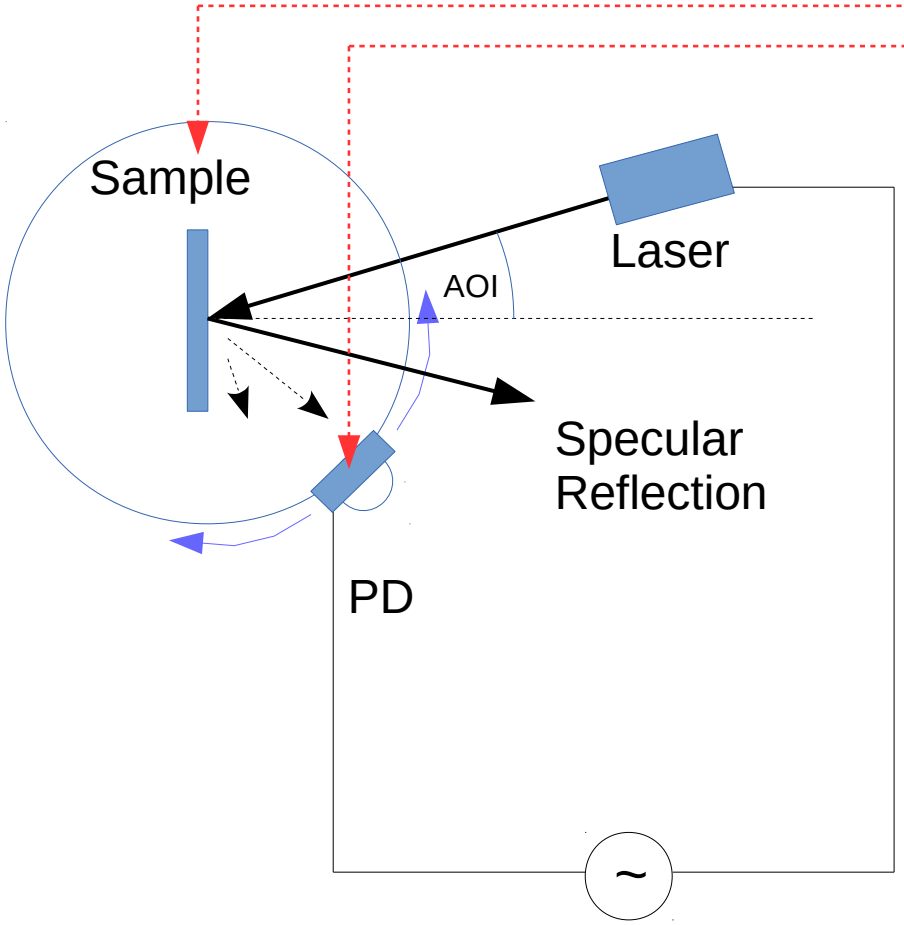

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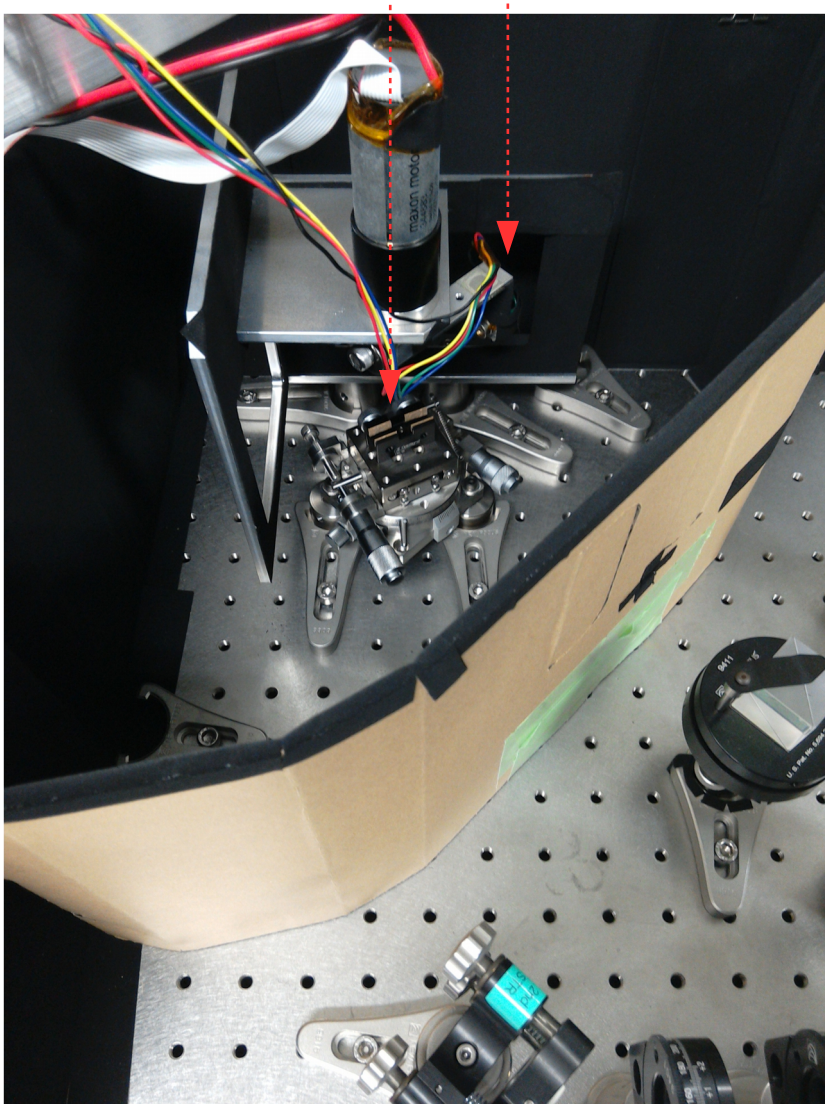

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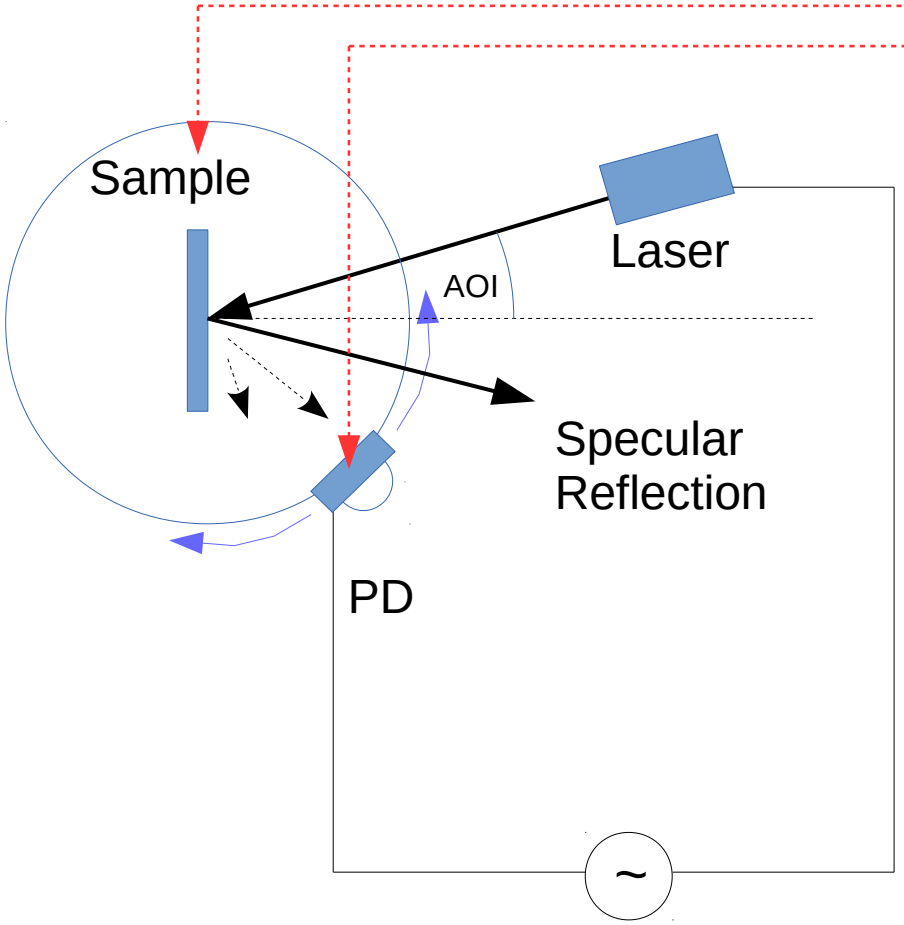

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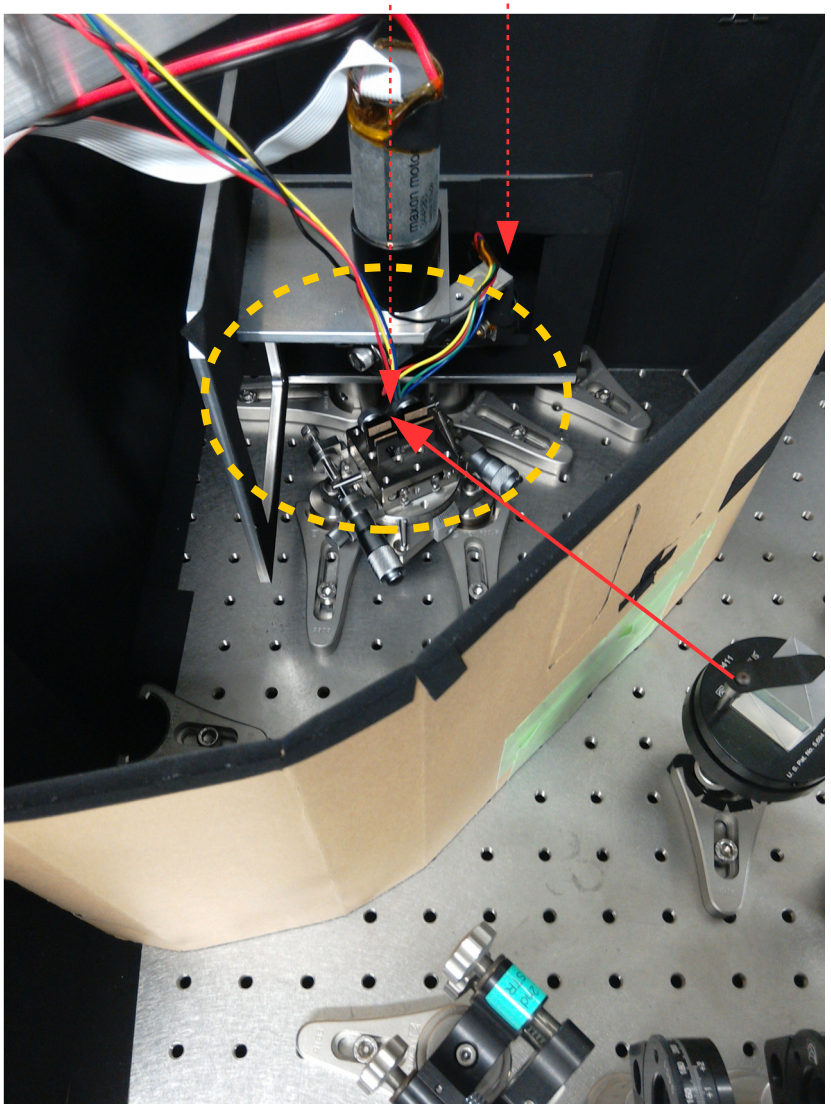
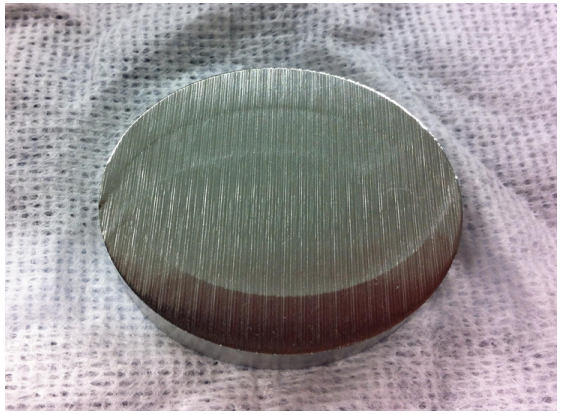
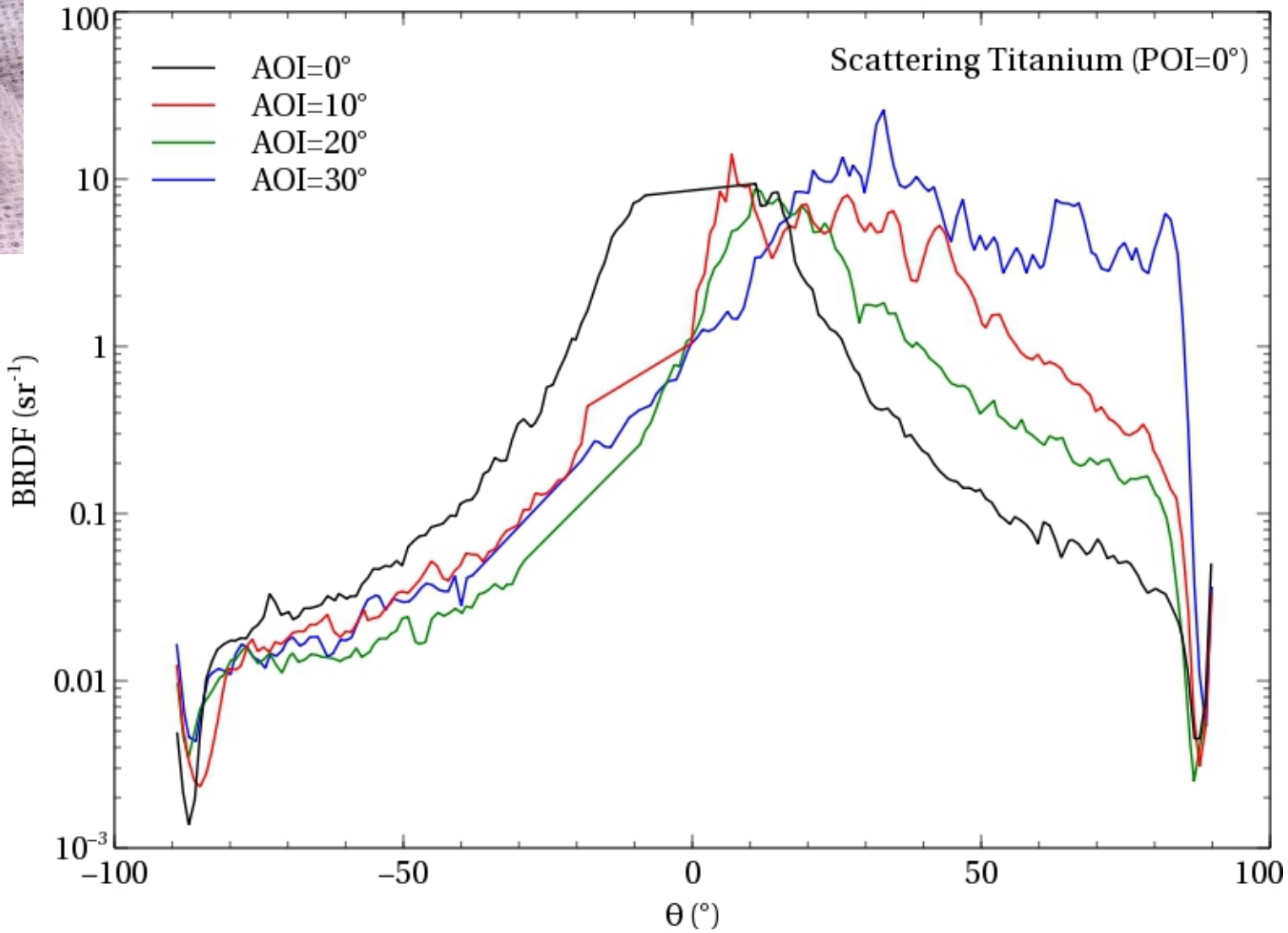


Titanium (cut, unpolished)





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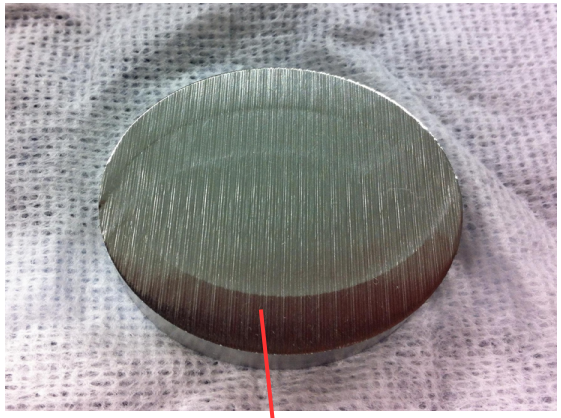

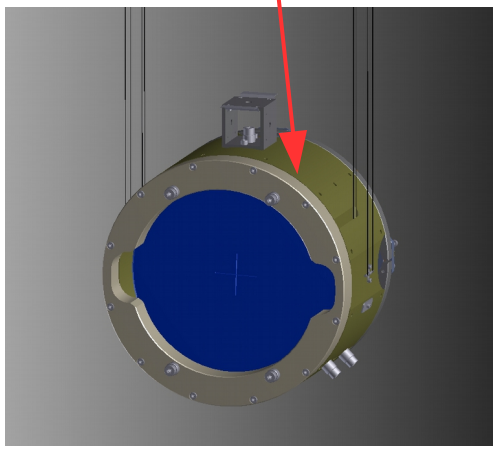

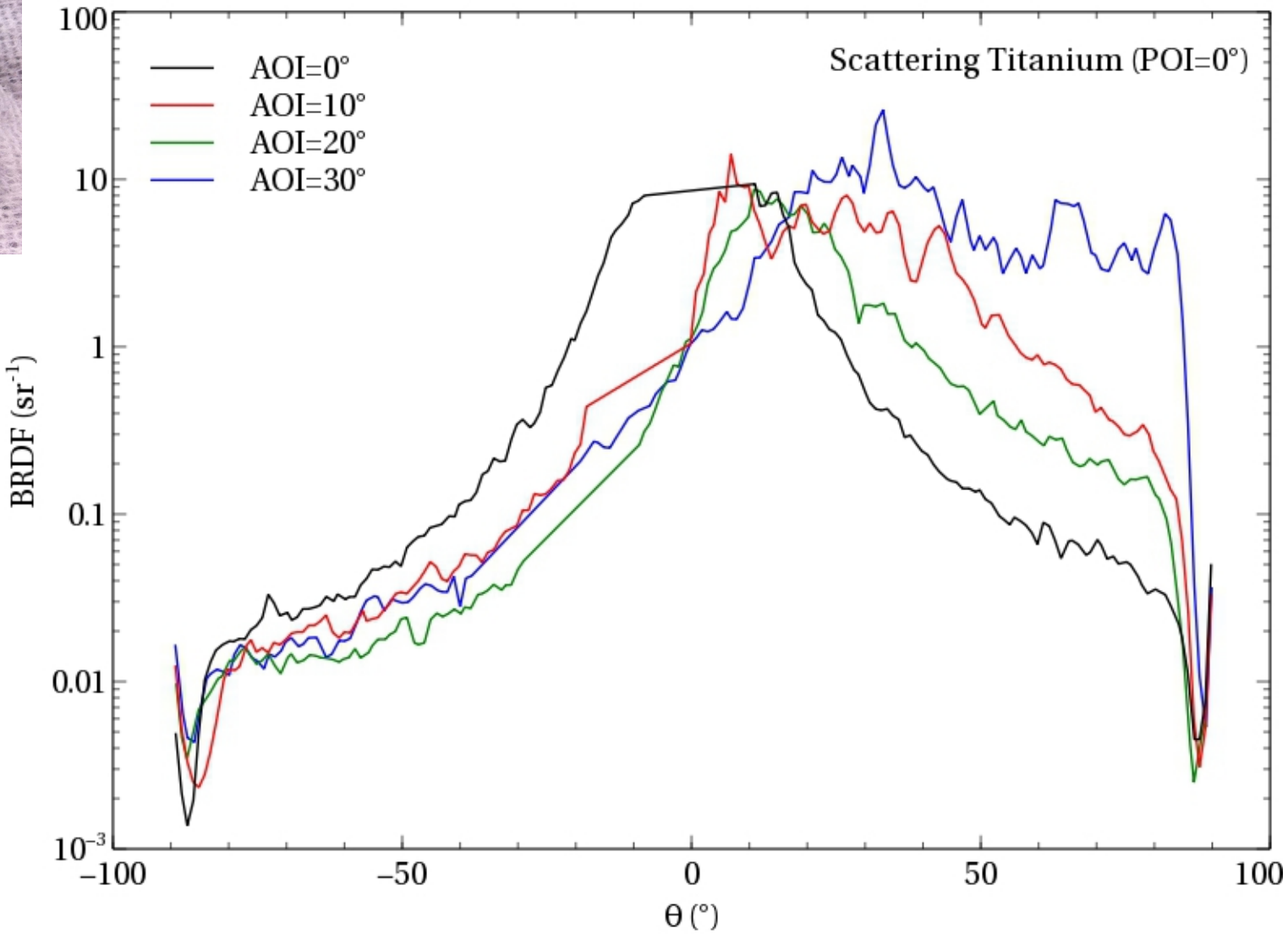

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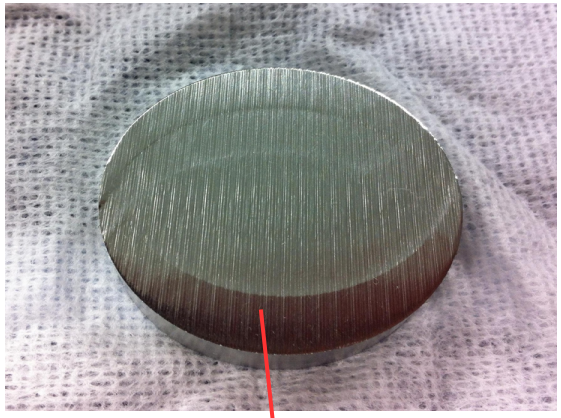
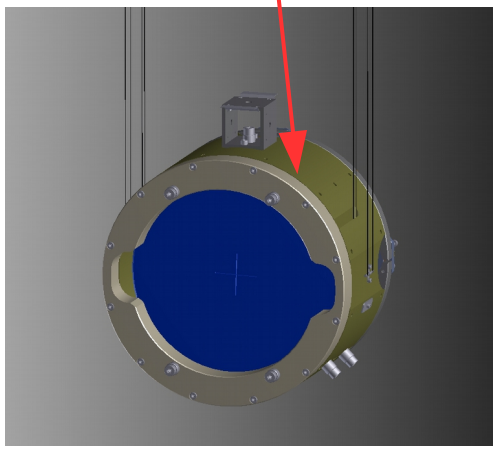
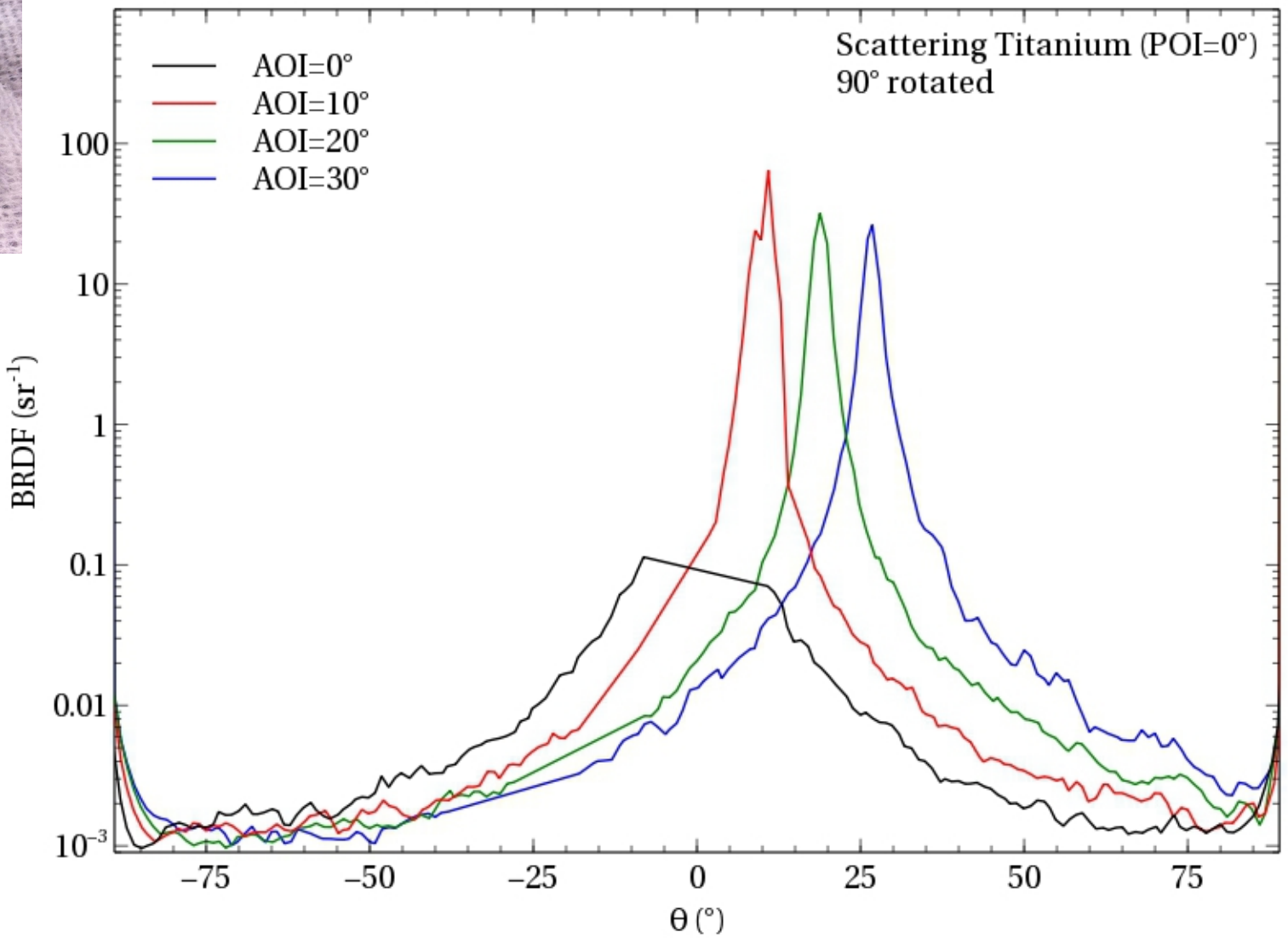
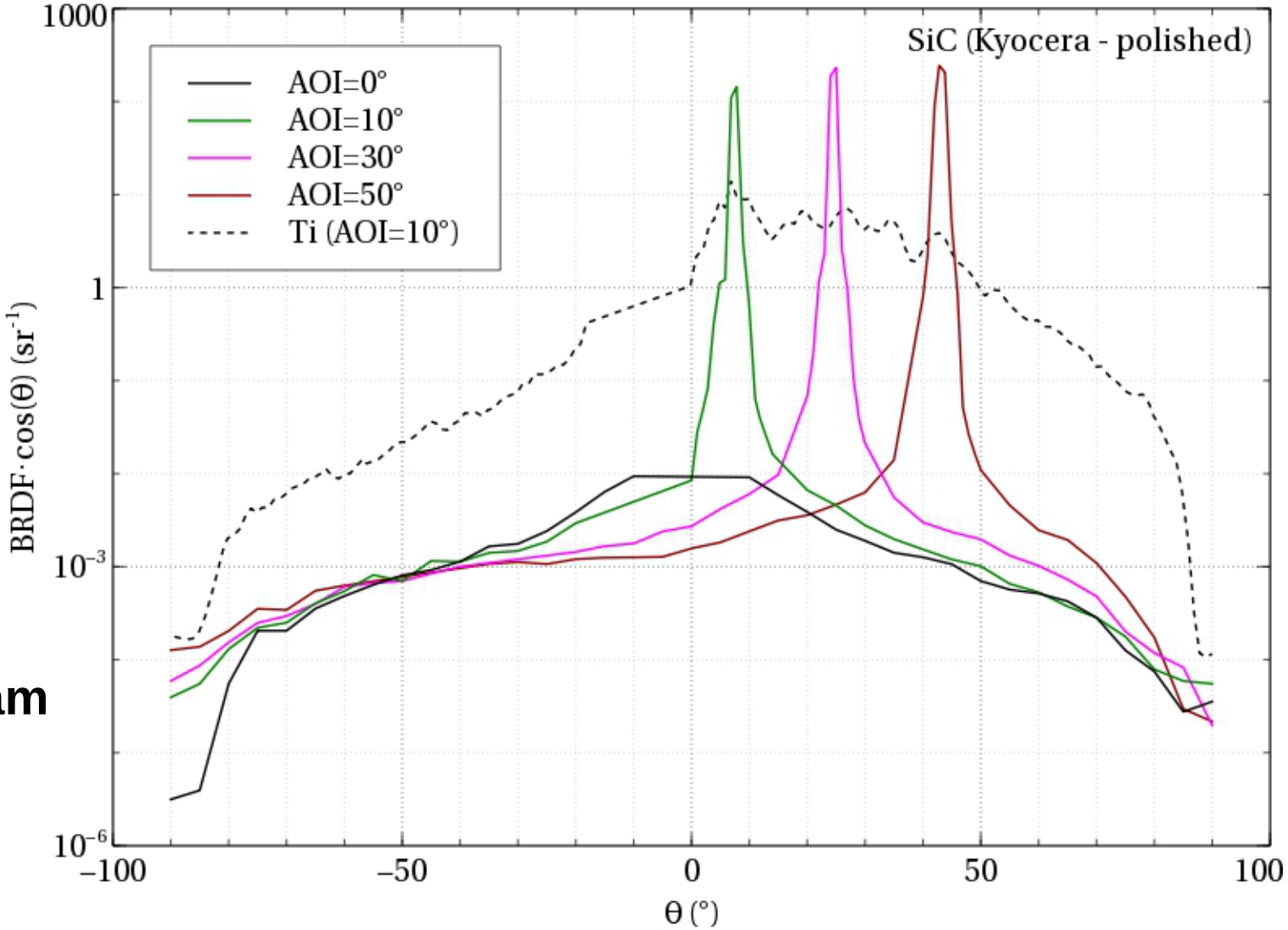




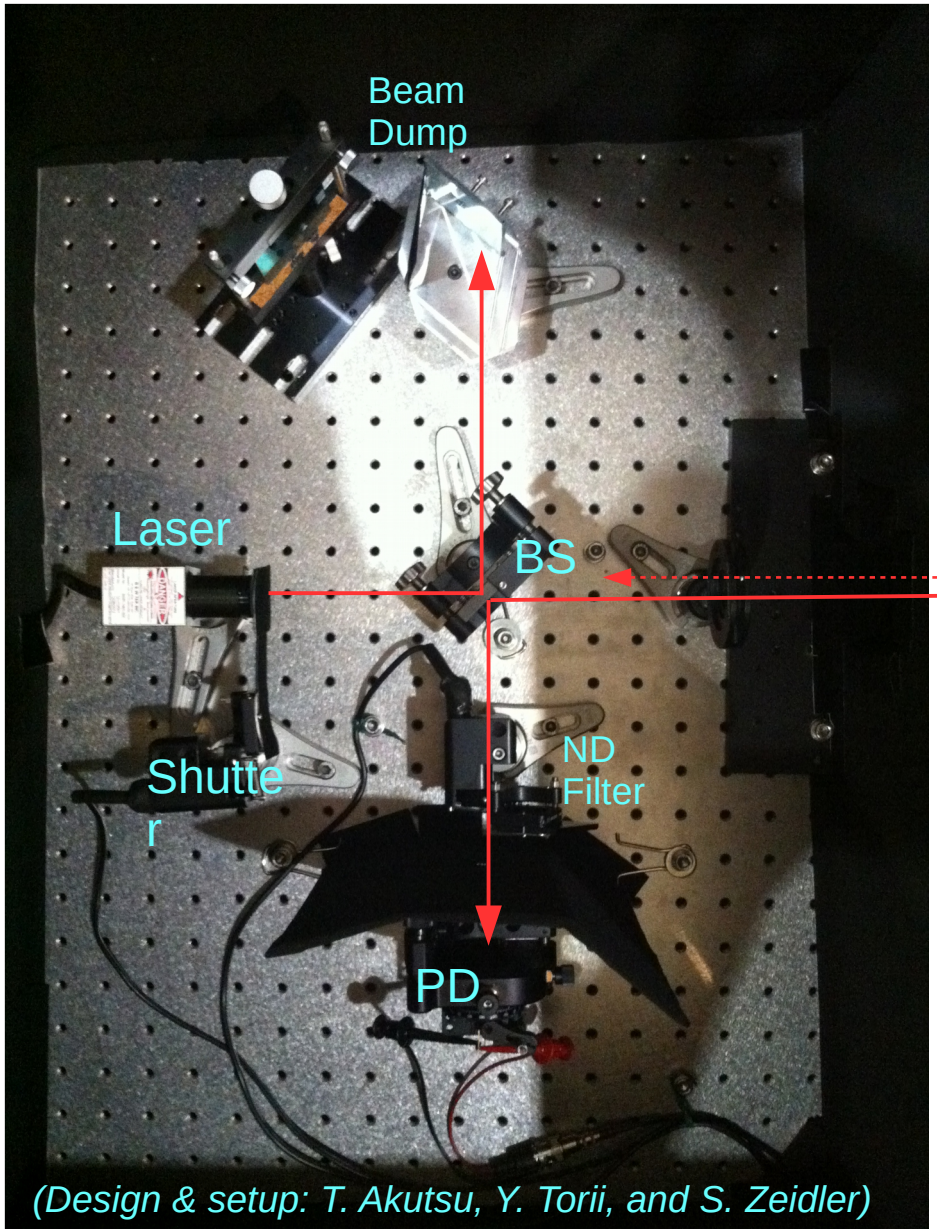


SiC (polished)

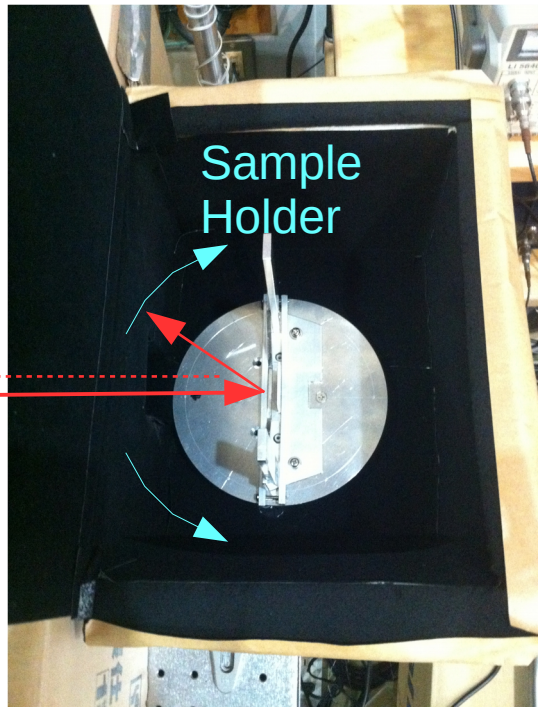


High-Power Beam Dumps

Backscattering Measurements (Back-Scatterometer)



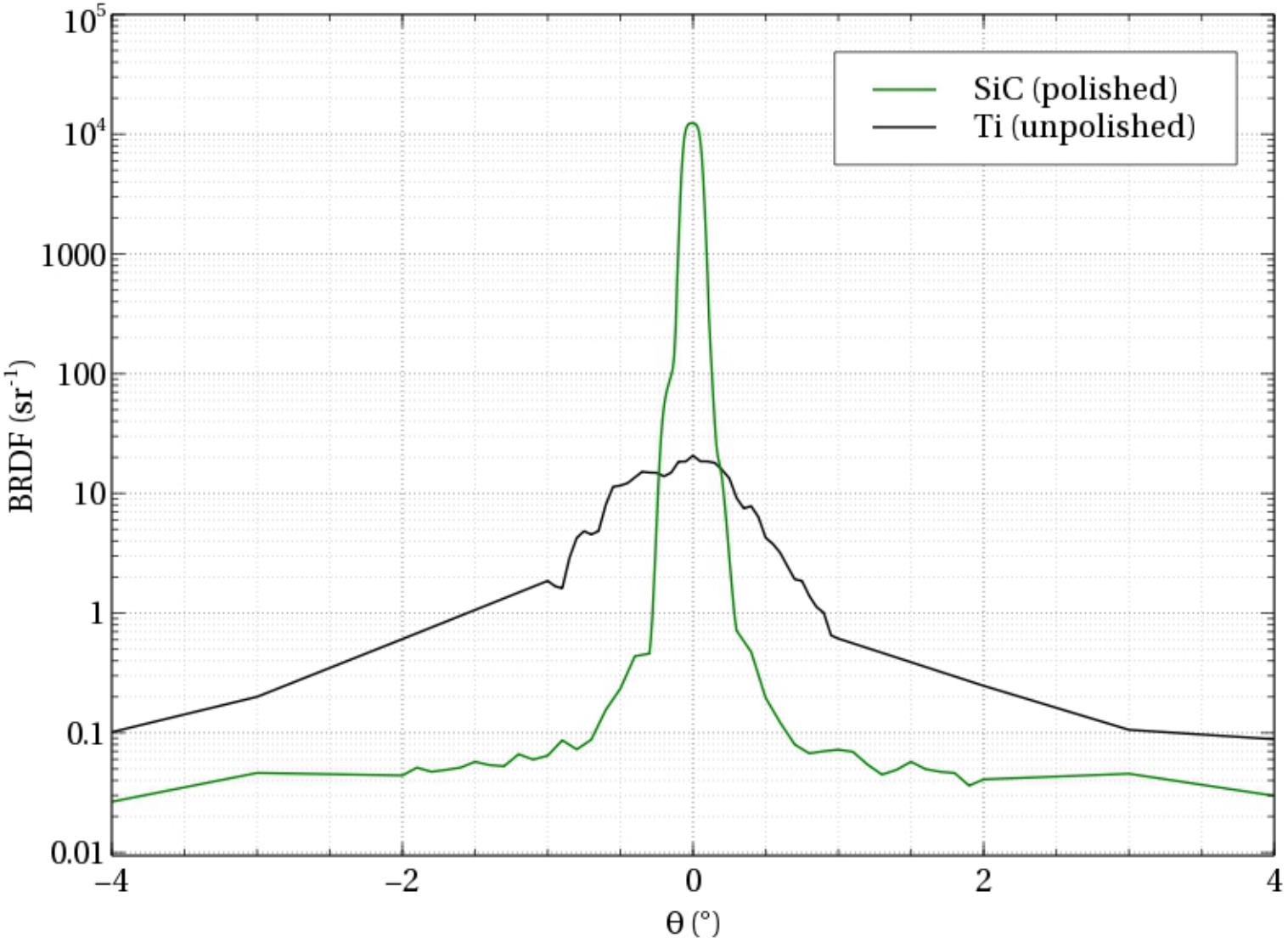
(Design & setup: T. Akutsu, Y. Torii, and S. Zeidler)



Measuring of what comes directly back!

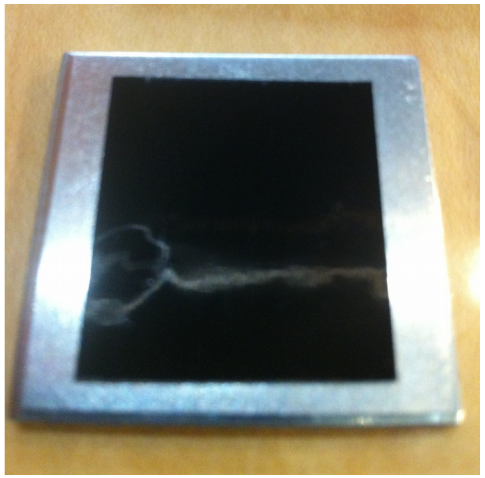
$$BRDF(\theta) = \frac{2 \cdot I_{PD}(\theta) \cdot f_{PD}}{P_{laser} \cdot \Omega \cdot \cos(\theta)}$$

Backscattering of Titanium and SiC



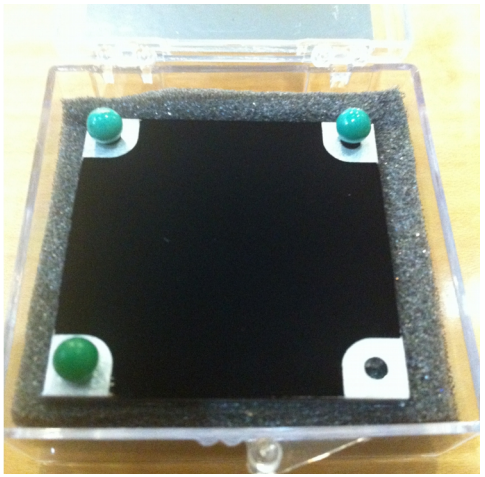
Backscattering of (Black) Coatings

“SolBlack” on Aluminum



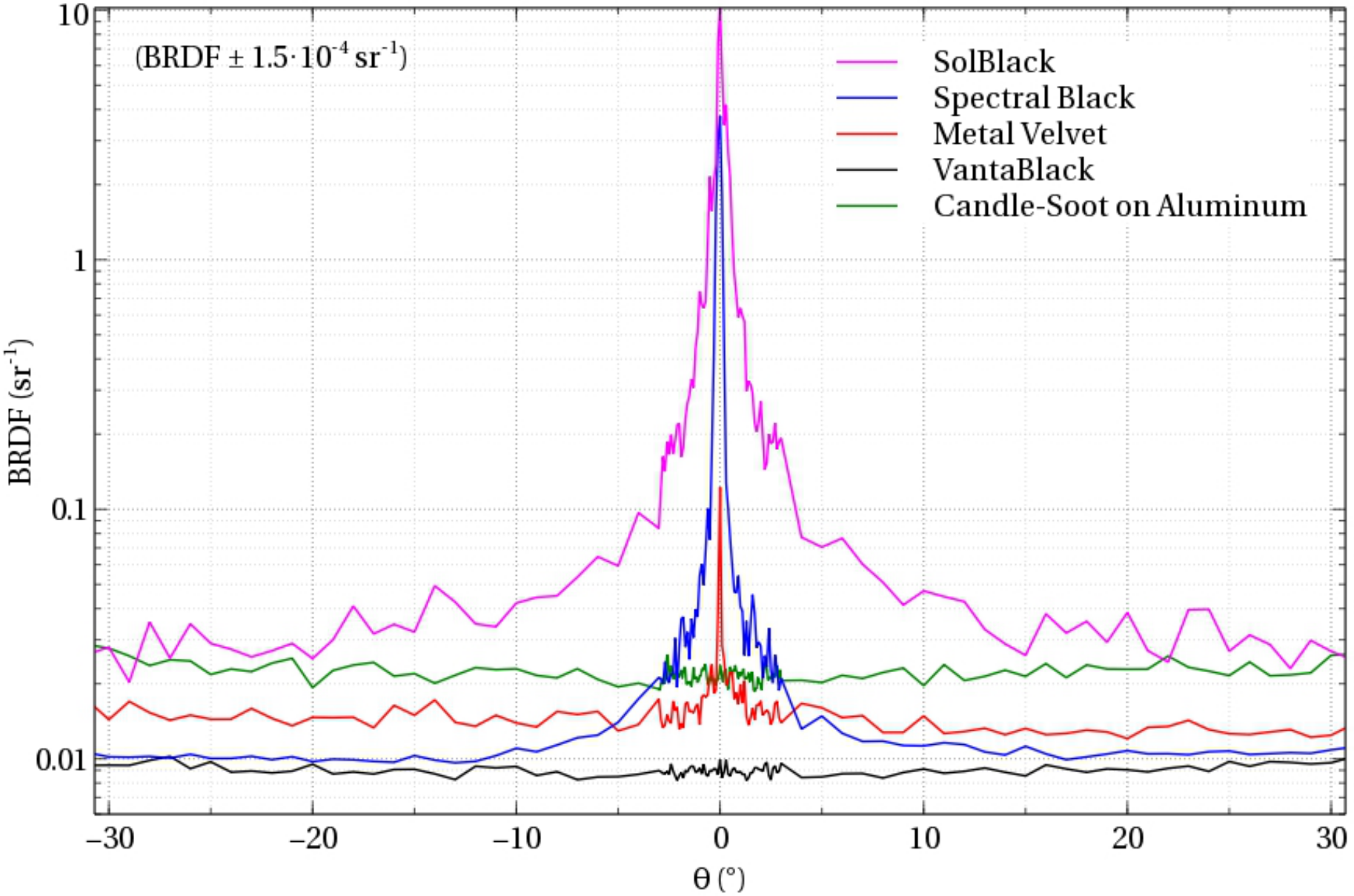
“Spectral Black”

“Metal Velvet”



“VantaBlack” (blackest material on earth)

- Coating materials and candidates for baffles and sensitive parts of KAGRA
- Need to have very low backscattering


(BRDF ± 1.5·10^-4 sr^-1)
SolBlack
Spectral Black
Metal Velvet
VantaBlack
Candle-Soot on Aluminum
BRDF (sr^-1)
10
1
0.1
0.01
−30
−20
−10
0
10
20
30
θ (°)

Summary

- Developed devices for measuring the scattering properties of any material (surface)
- Scattering + Backscattering
- Materials analyzed: Titanium, SiC, “SolBlack”, “Spectral Black”, “Metal Velvet”, “VantaBlack”
  - ➔ Should suppress scattering
  - ➔ Information are applied in simulations regarding scattering of structures like baffles and its impact on KAGRAs sensitivity
- Ongoing improvement of devices
- Ongoing research and data gathering

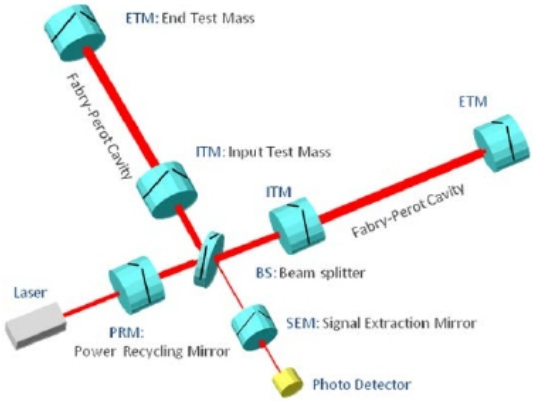
Thank you for your attention!

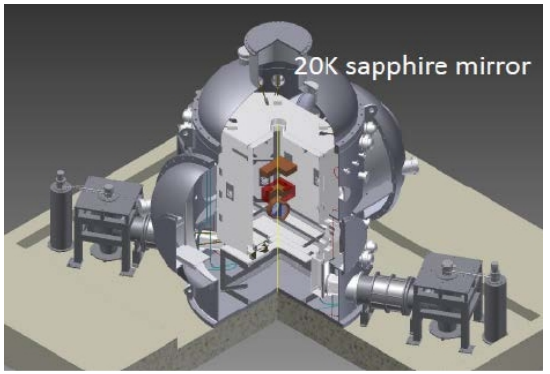
Outlook

- **SolBlack is magnetic!**
  → testing the influence on other (magnetic) components
- Simulations for the “**Doughnut-Baffle**” in front of the cryo-duct shield
  → Do we need a beam dumper?
  → Which material?
- Simulations for the **other mirrors/optical components** which which are surrounded by recoil masses
- Development and design of **BRT**

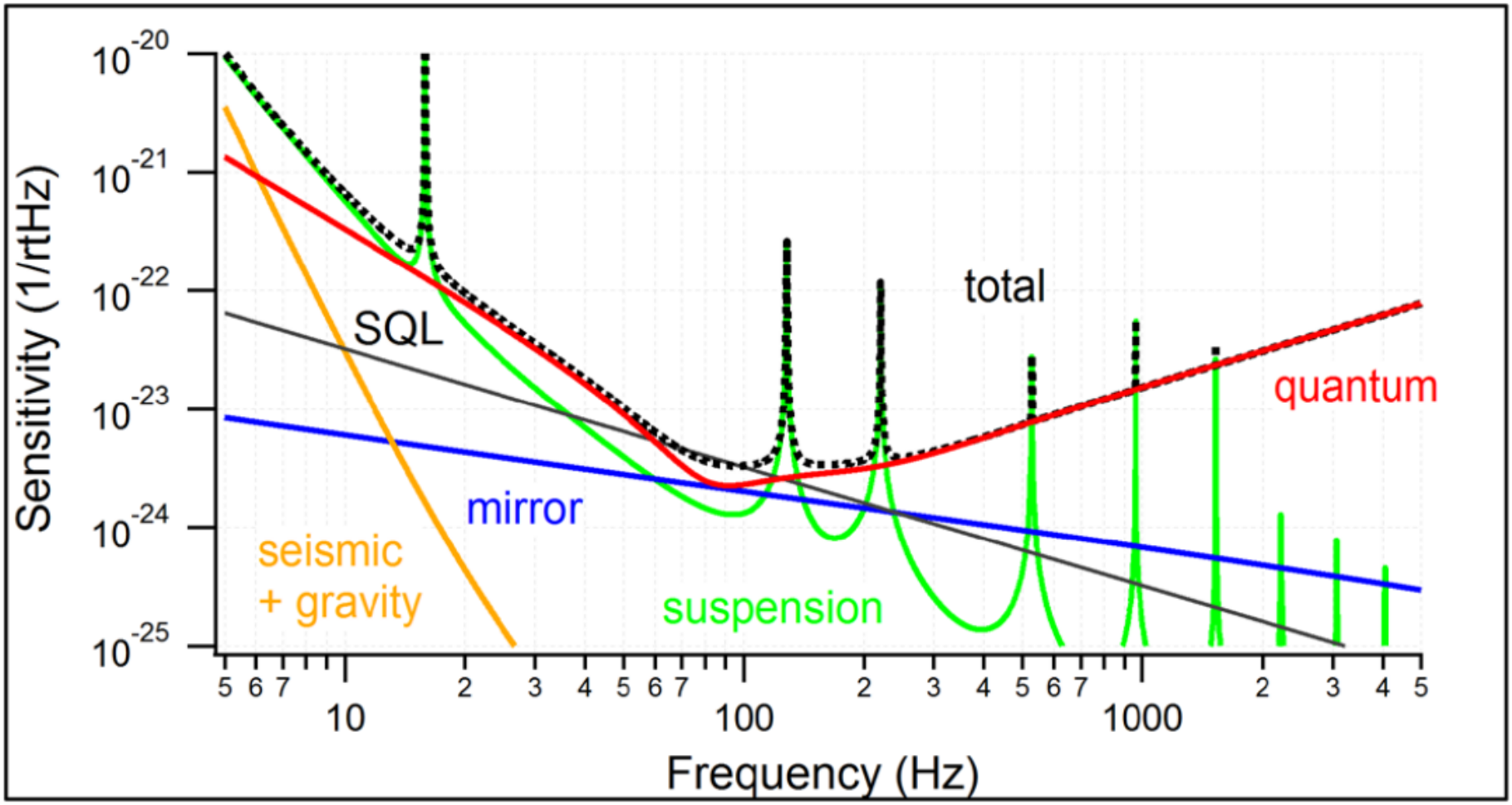
The KAGRA Project

- 3 km long Gravitational-Wave-Detector in the Kamioka mine
- First cryogenic, underground interferometer detector
  - ➔ Reduction of thermal and seismic noise



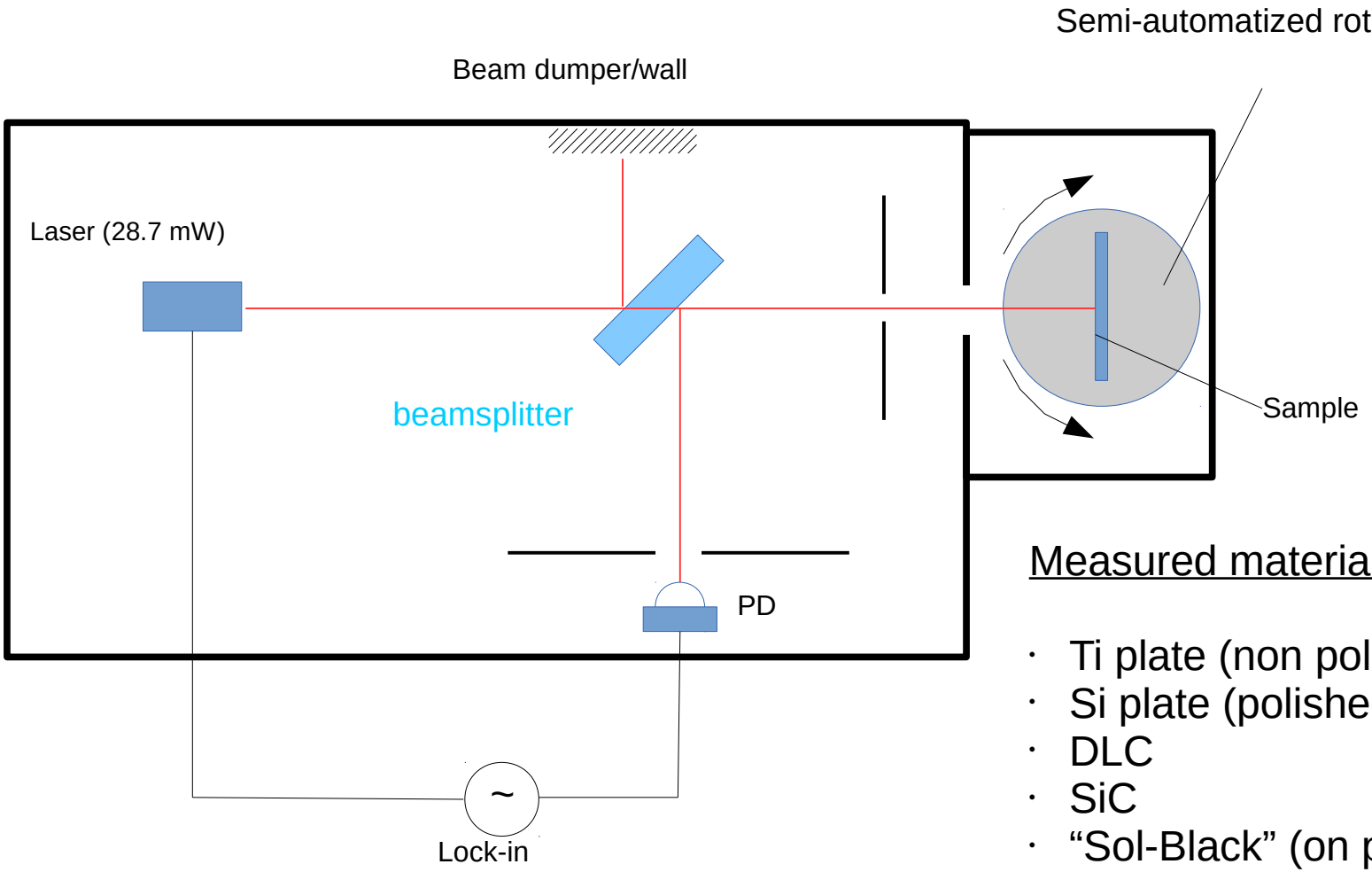


Sensitivity of KAGRA



- Able to detect Gravitational Waves from Neutron Star Binaries up to 150Mpc distance
- Comparable to Advanced LIGO in the USA

Backscattering Measurements



(Design & setup: T. Akutsu, Y. Torii, and S. Zeidler)

Measured materials:

- Ti plate (non polished)
- Si plate (polished)
- DLC
- SiC
- “Sol-Black” (on polished Al)
- “Specral Black” (“Acktar”)
- “Metal Velvet” (“Acktar”)
- “Vanta Black” (“Surrey NanoSystems”)

I_{PD} → *photocurrent*

f_{PD} → *linear factor of power / current ratio* $(1.264\,W/A)$

P_{laser} → *Power of the laser hitting the sample*

Ω → *solid angle of scattered light reaching the PD*

θ → *incident angle of the laser hitting the sample*