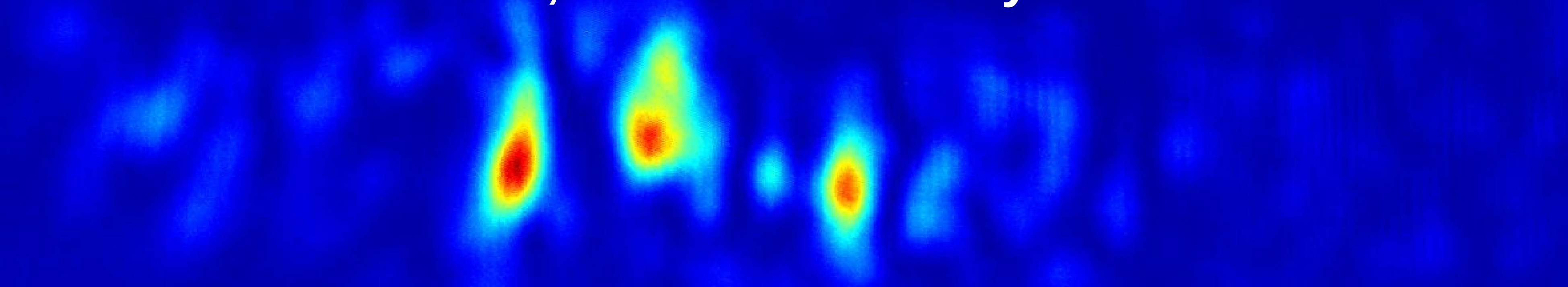
Measurements on the Scattering of Materials Used in KAGRA

– 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*
- **Measuring the Scattering**
  - *Characterization of Scattering*
  - *Setup of a Scatterometer*
  - *Titanium and SiC*
  - *Backscattering Measurements*
  - *Titanium, SiC, and Black Coatings*
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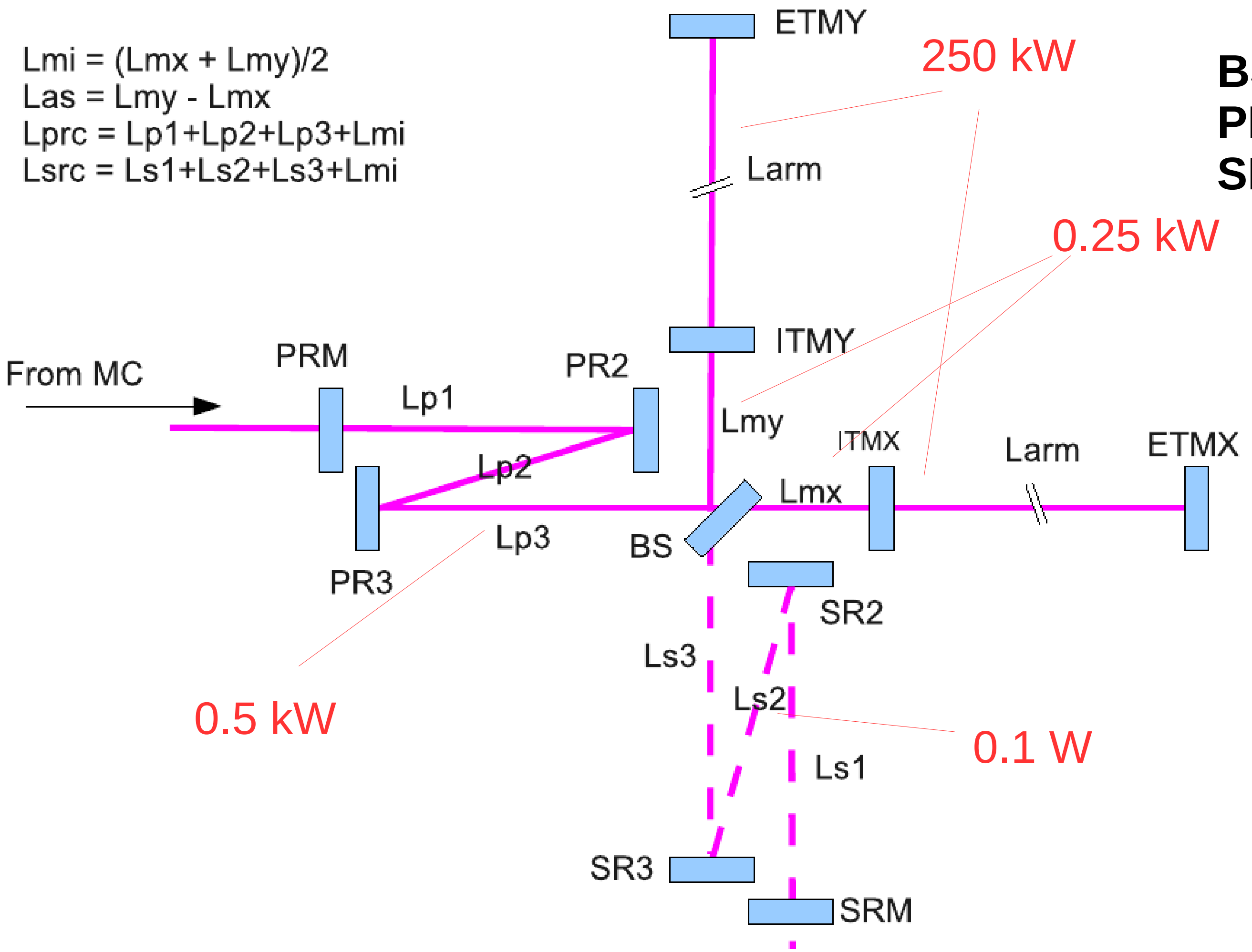
Introduction

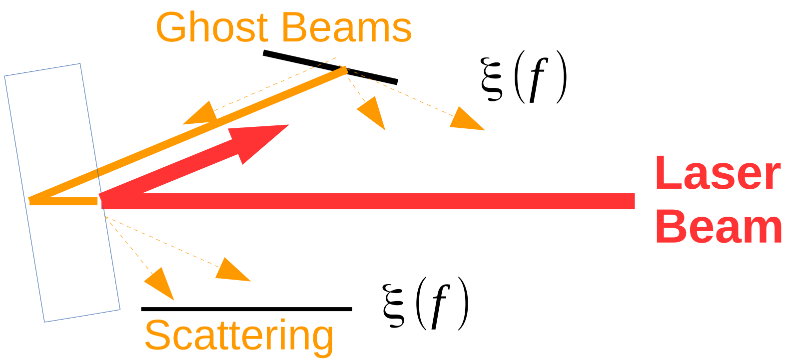
Principle Setup of the KAGRA Interferometer



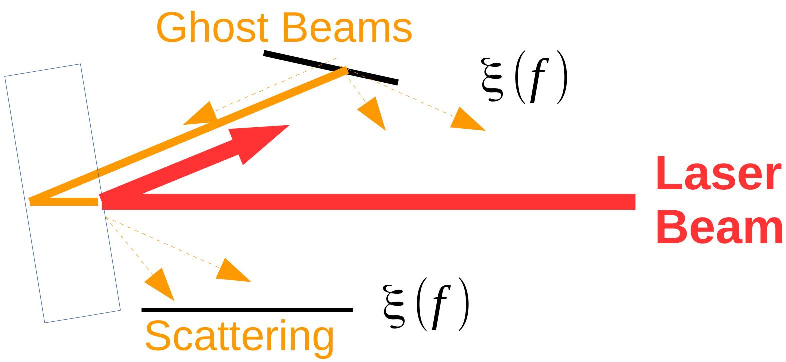
BS – Beam Splitter
PR – Power Recycling
SR – Signal Recycling

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:

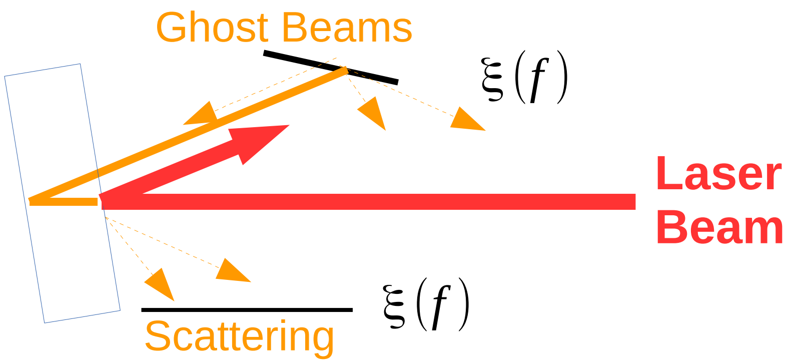
$$h_{rec} = \frac{\sqrt{2} \cdot \lambda}{L} \cdot \xi(f) \cdot \sqrt{\frac{I_{rec}}{P_{laser}}}$$

$I_{rec} \rightarrow \textit{Intensity of recoupled light}\,[W/m^2]$

$P_{laser} \rightarrow \textit{Power of laser beam}\,[W]$

$\xi(f) \rightarrow \textit{vibration noise spectrum}\,[m/\sqrt{Hz}]$

The Importance of Stray-Light Control



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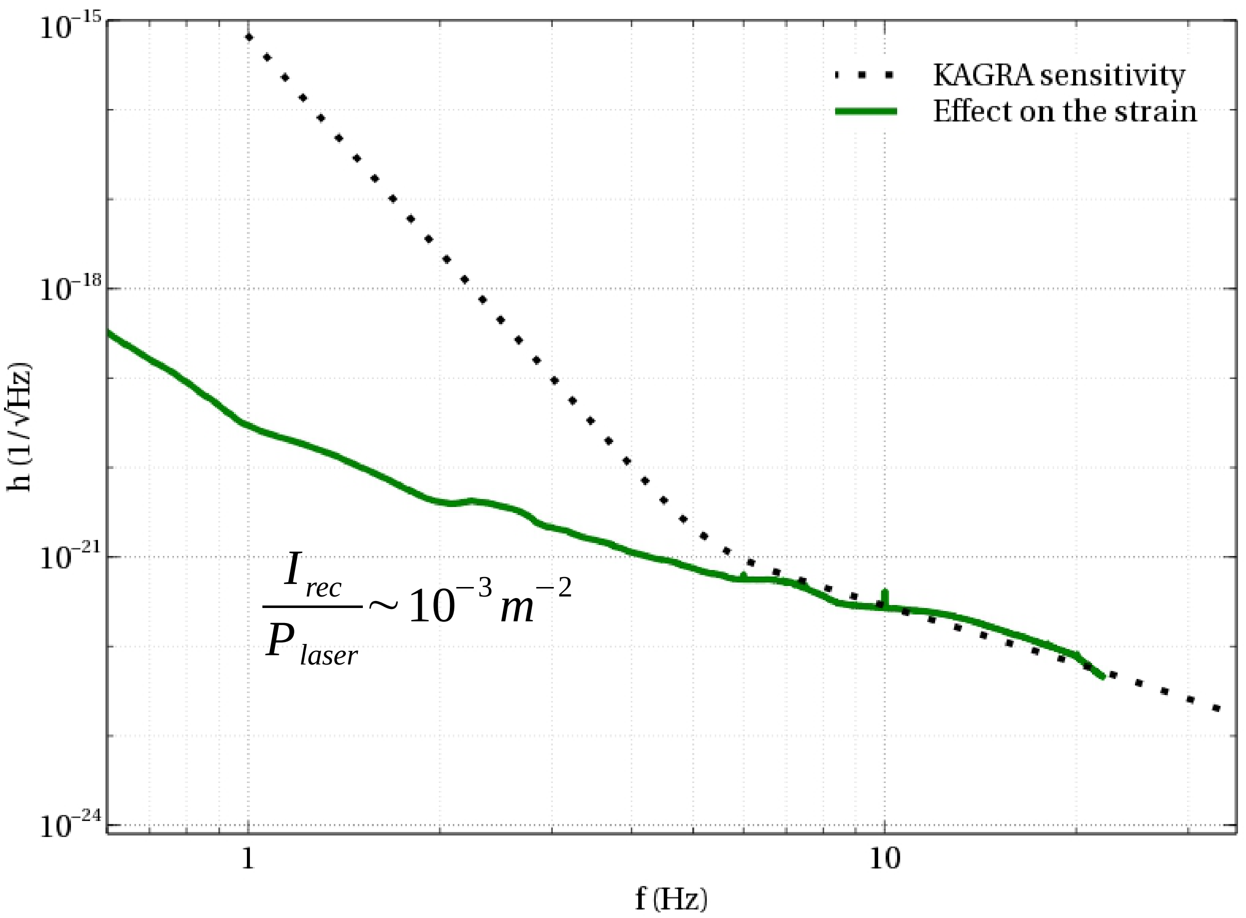

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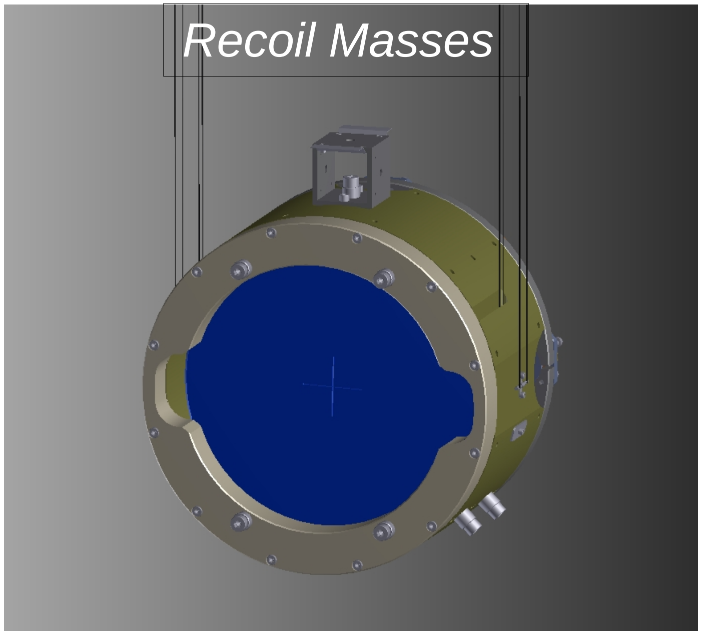
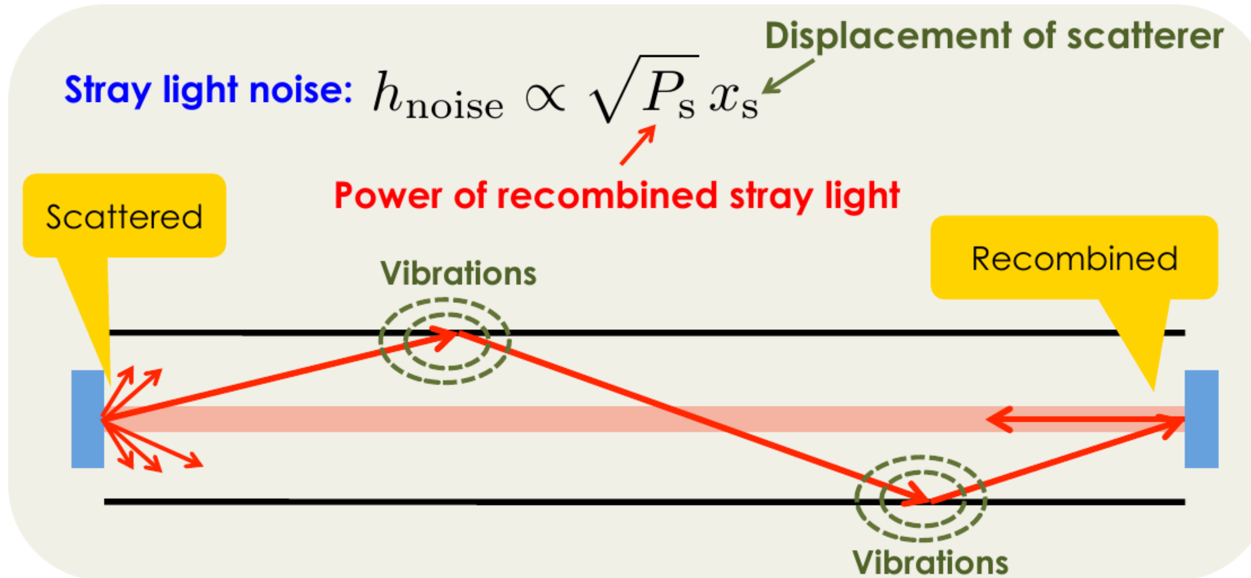
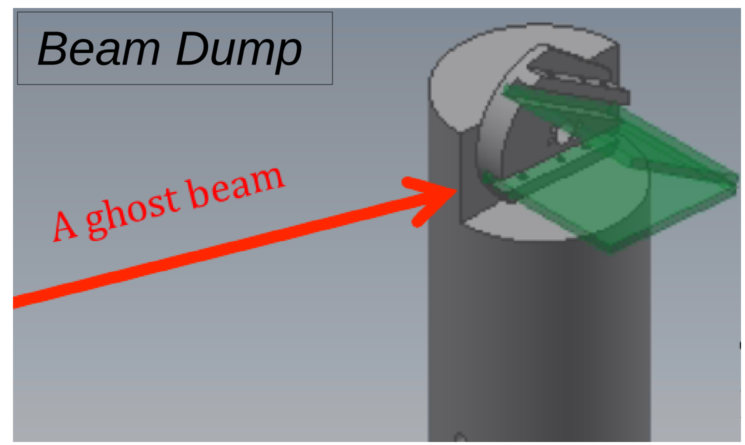
Where Scattering may Appear



Inner Walls



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

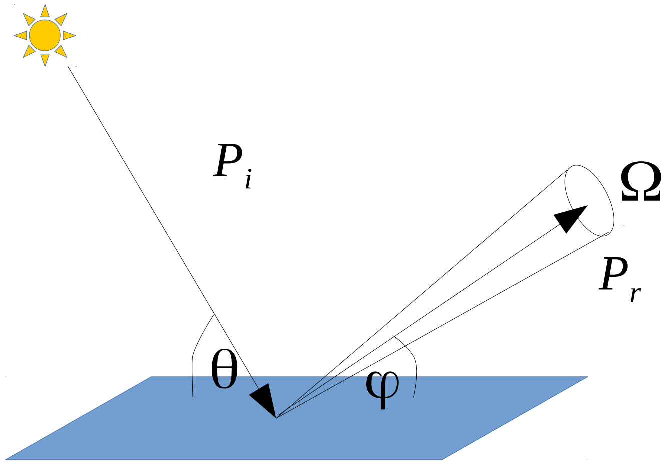


Credit: Tomotada Akutsu

Measuring the Scattering

Characterization of Scattering

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



Measuring the Scattering

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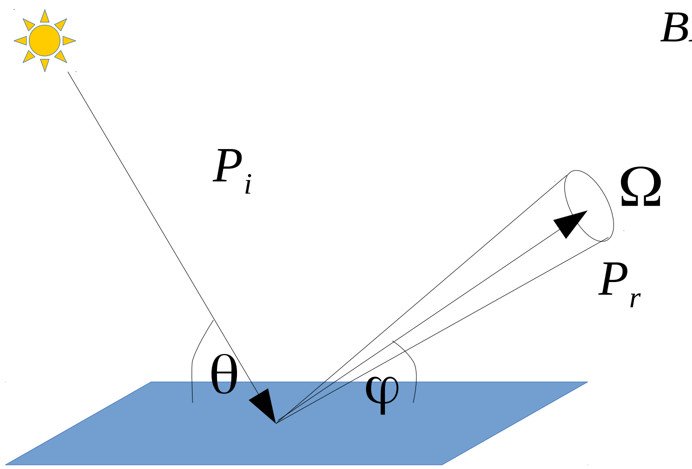
<u>BRDF (**B**idirectional **R**eflection **D**istribution **F**unction)</u>

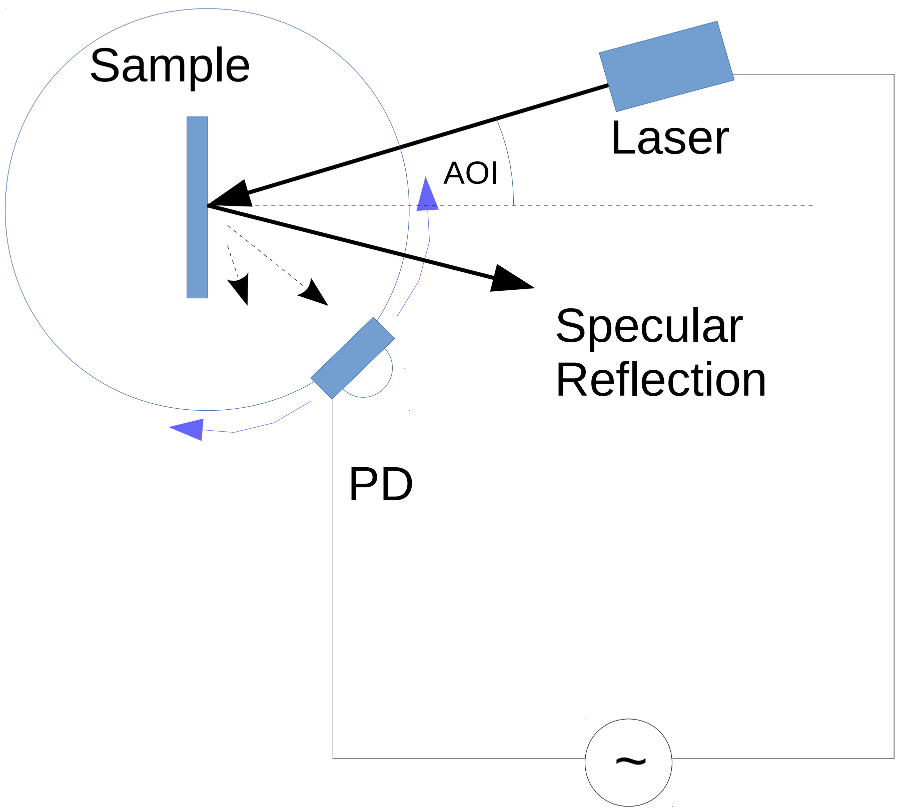


$$BRDF(\theta,\varphi)=\frac{\partial L_r(\varphi,I_r)}{\partial E_i(\theta,I_i)}; \quad L_r=\frac{\partial P_r}{\partial A\,\partial\Omega\cdot\cos(\varphi)}$$ → Radiance

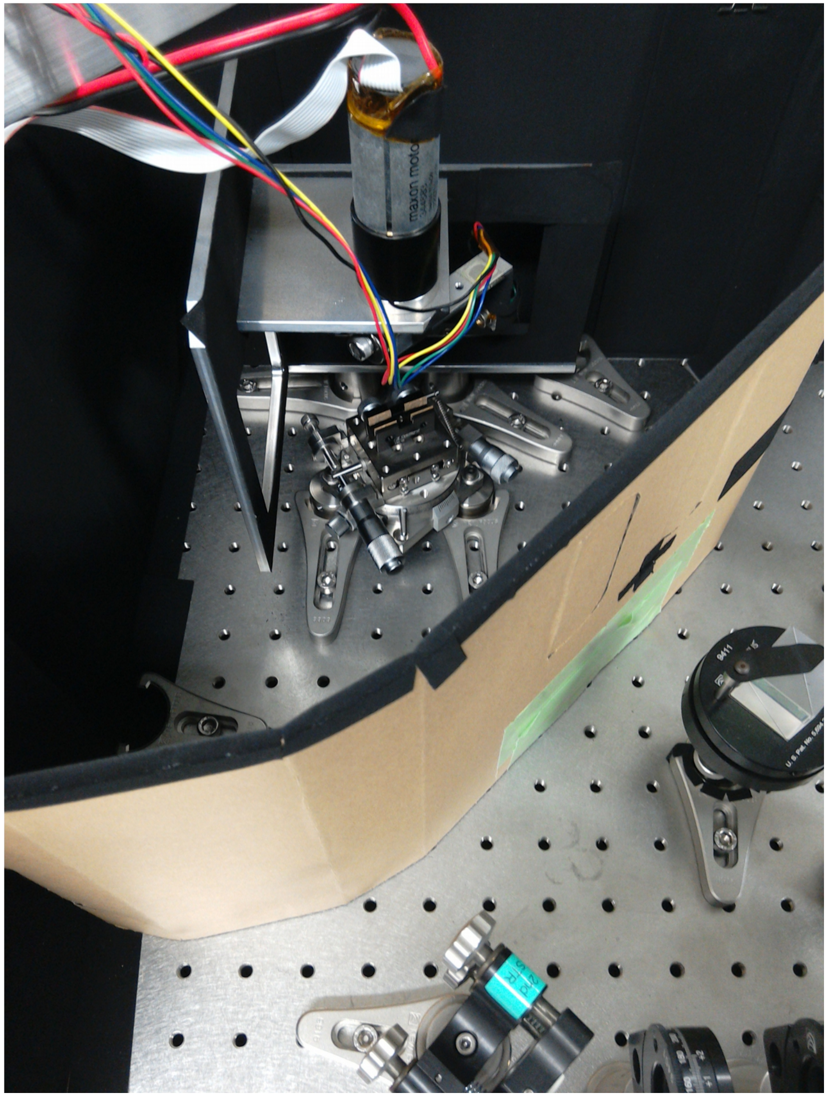
$$E_i=\frac{\partial P_i}{\partial A}$$ → Irradiance

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

Setup of a Scatterometer



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



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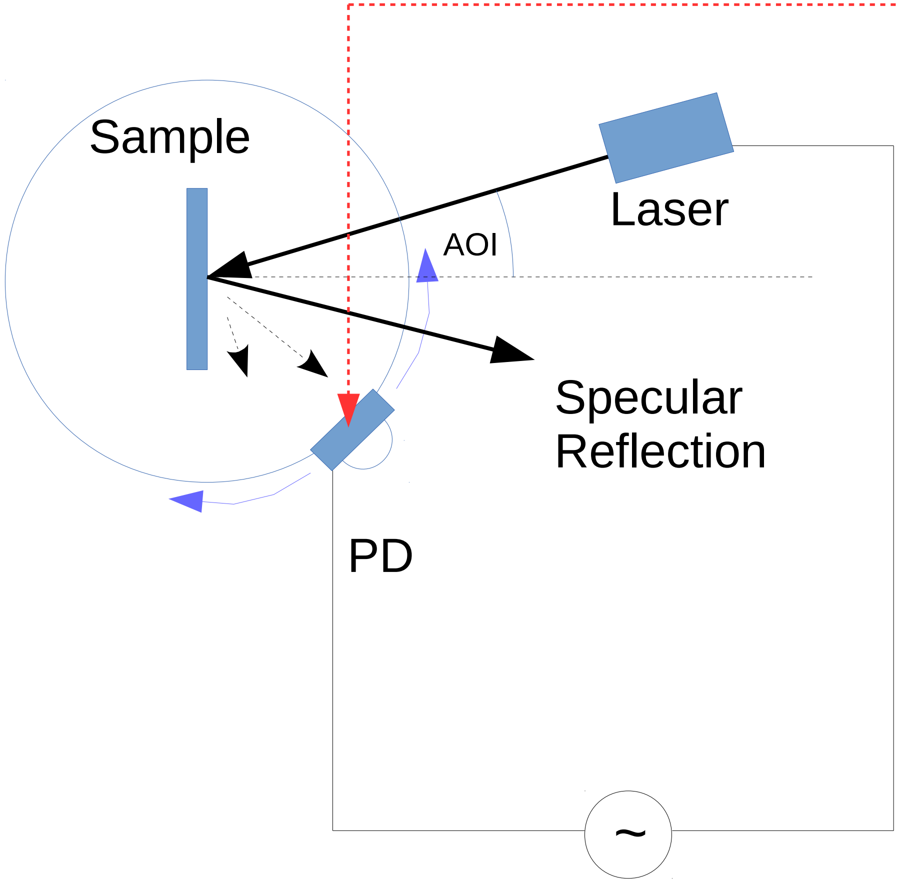

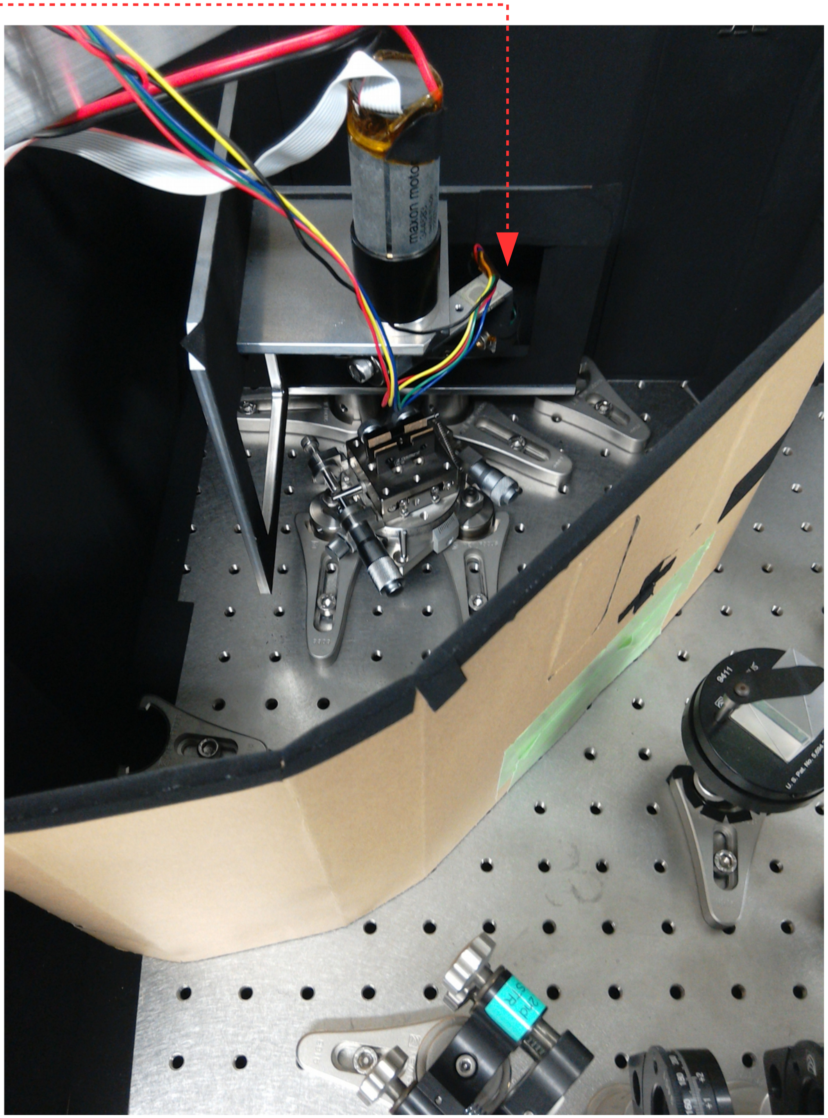

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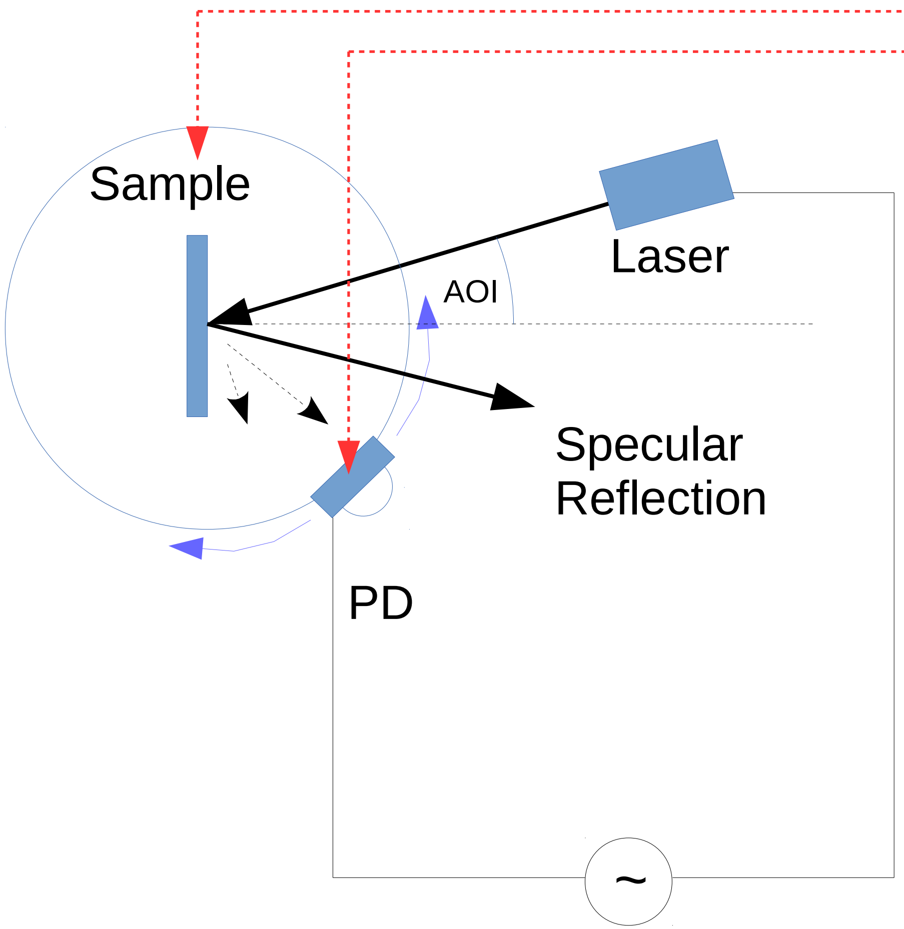

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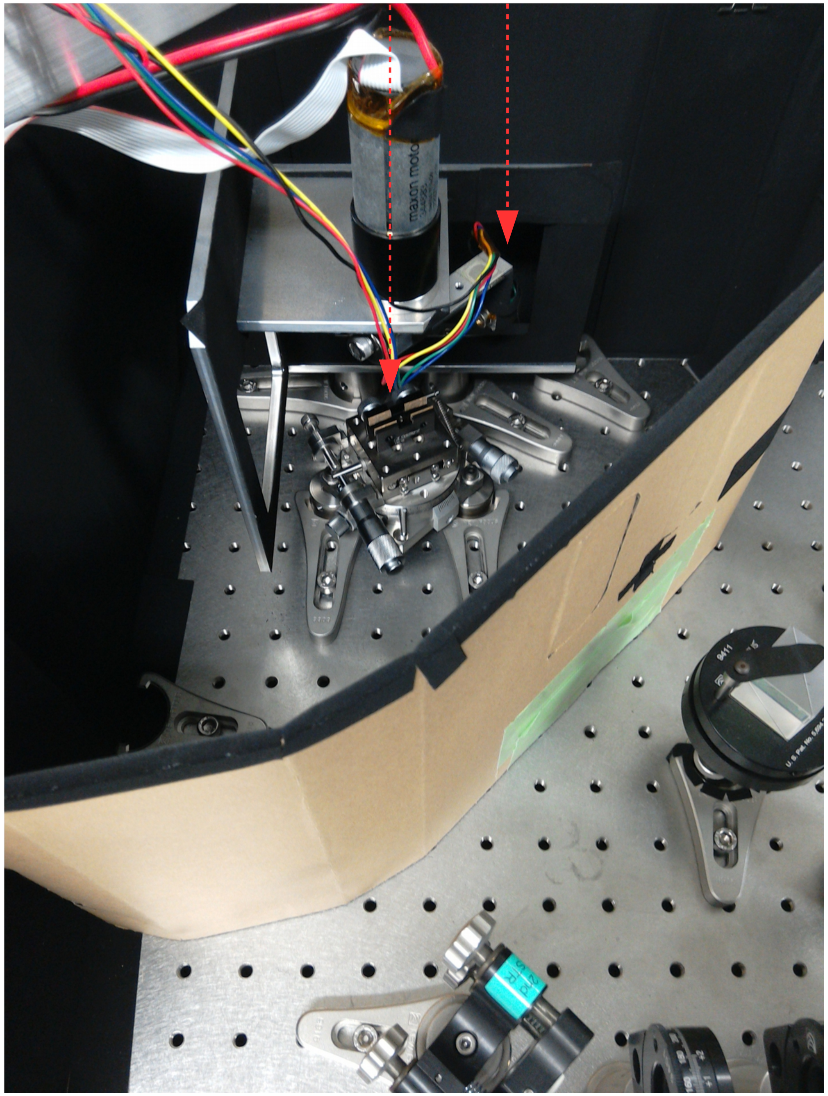

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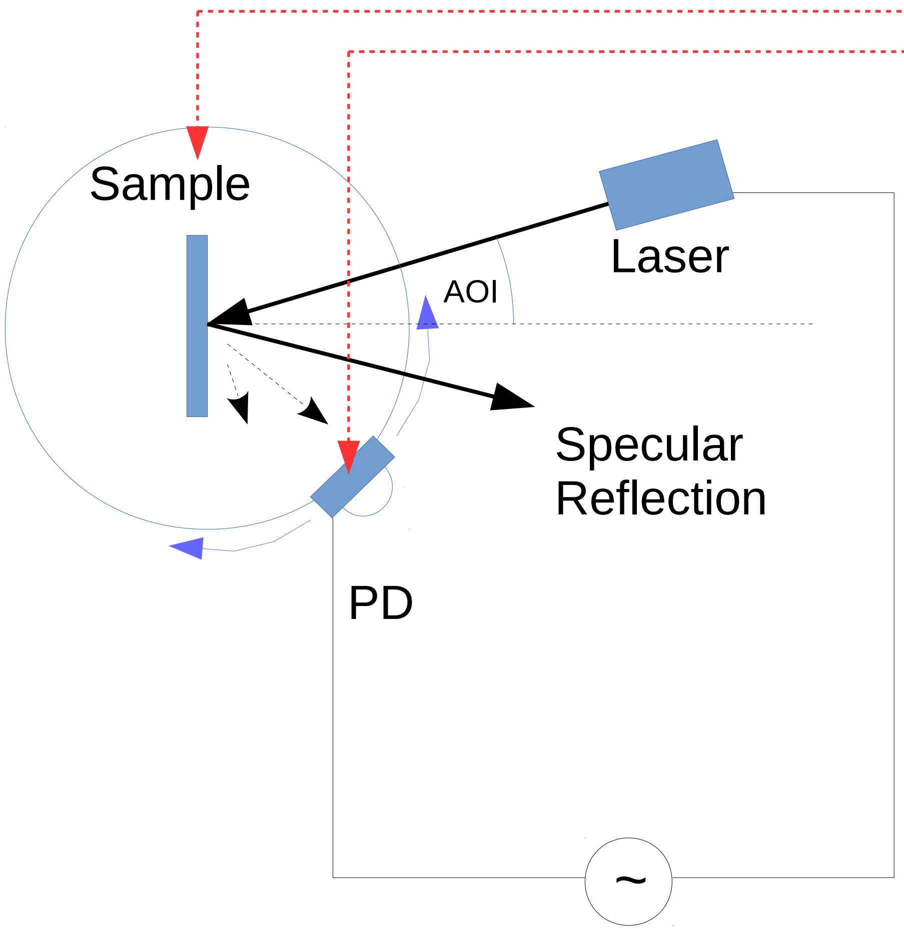

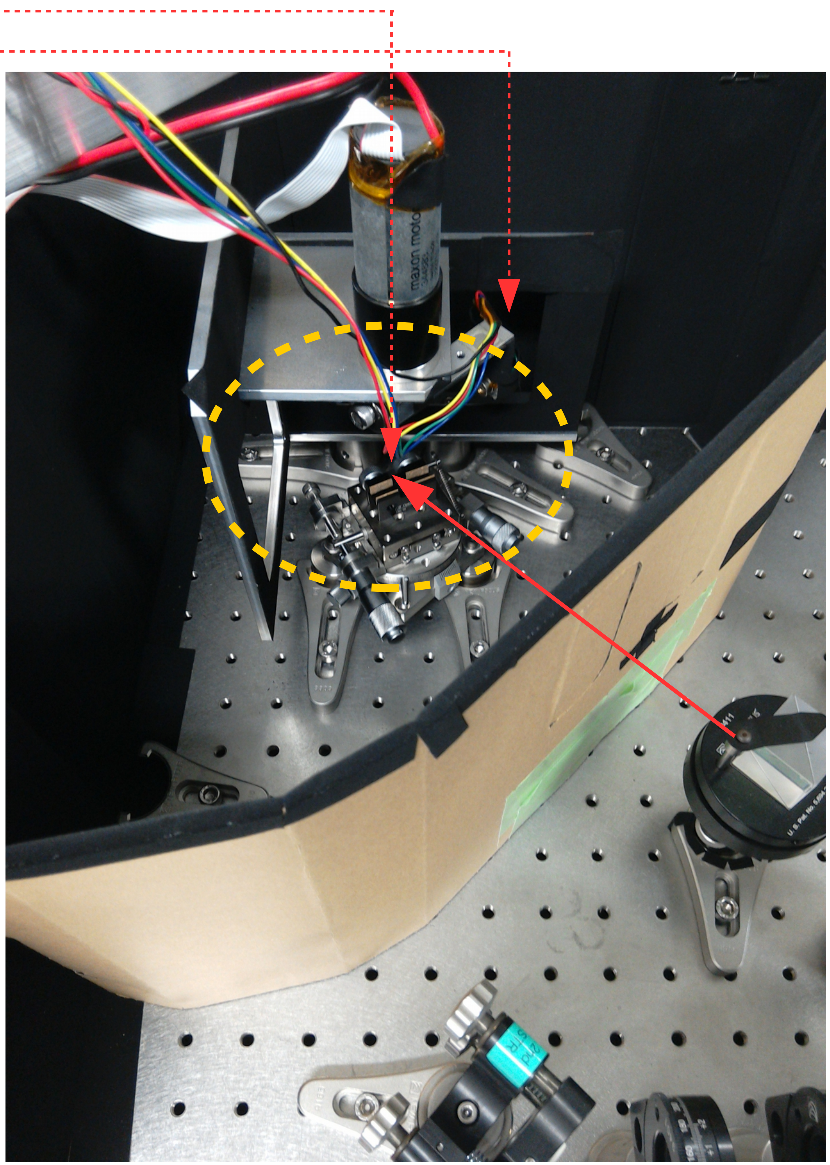

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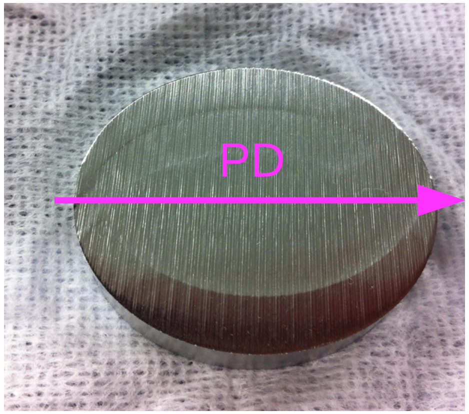
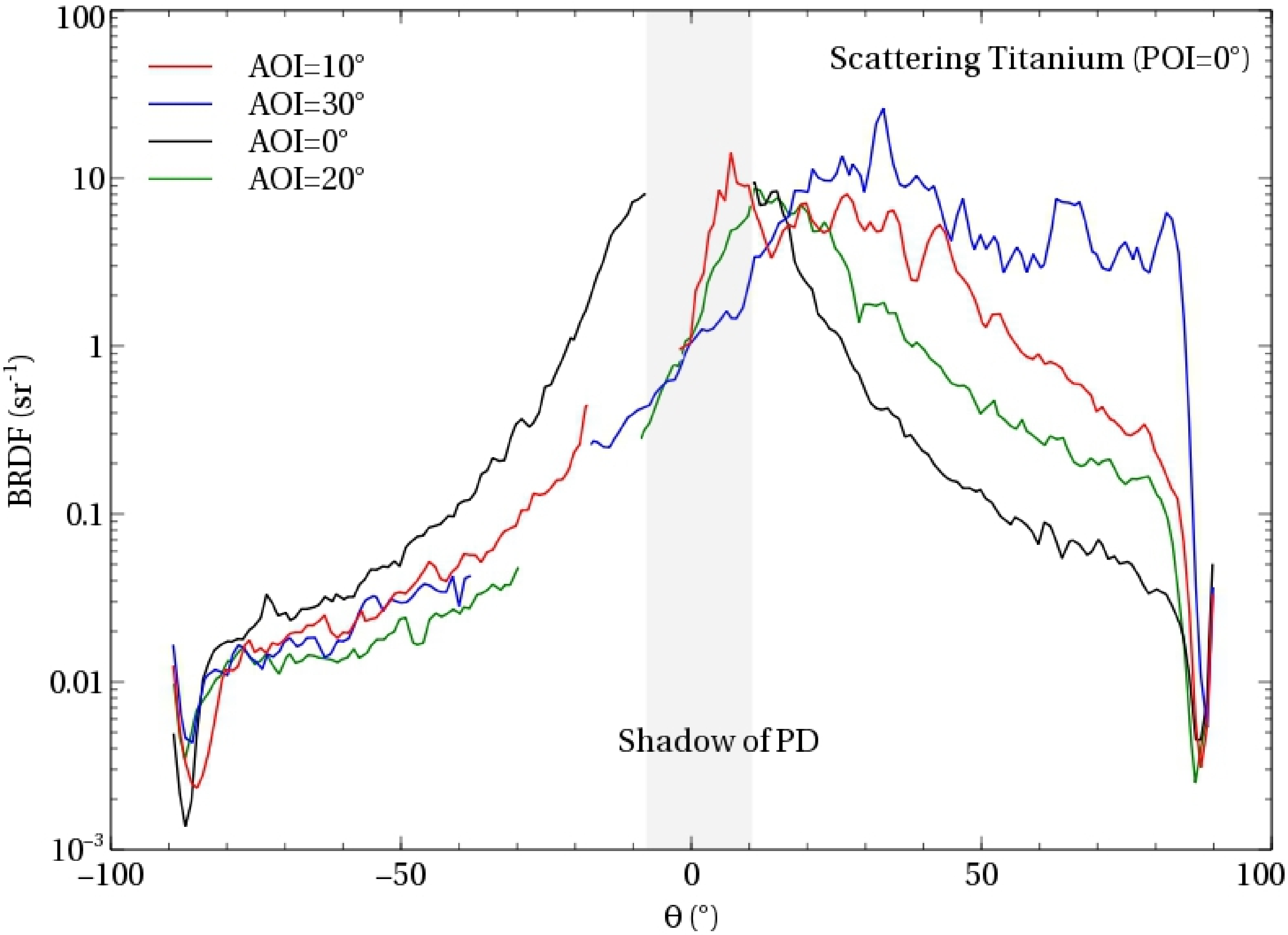
Titanium (cut, unpolished)

- used for simulating scattering effects of recoil mass (paper in prep.; JGW-P1504245-v1)





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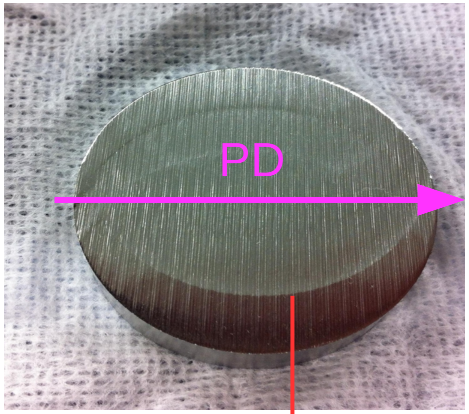

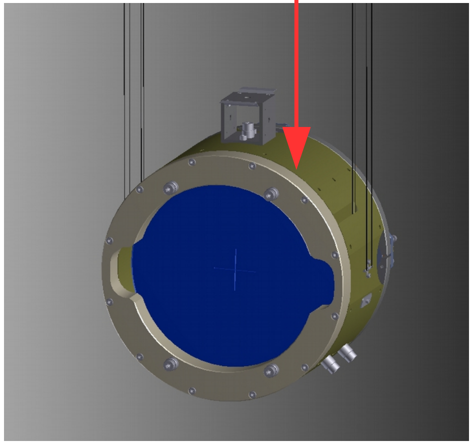

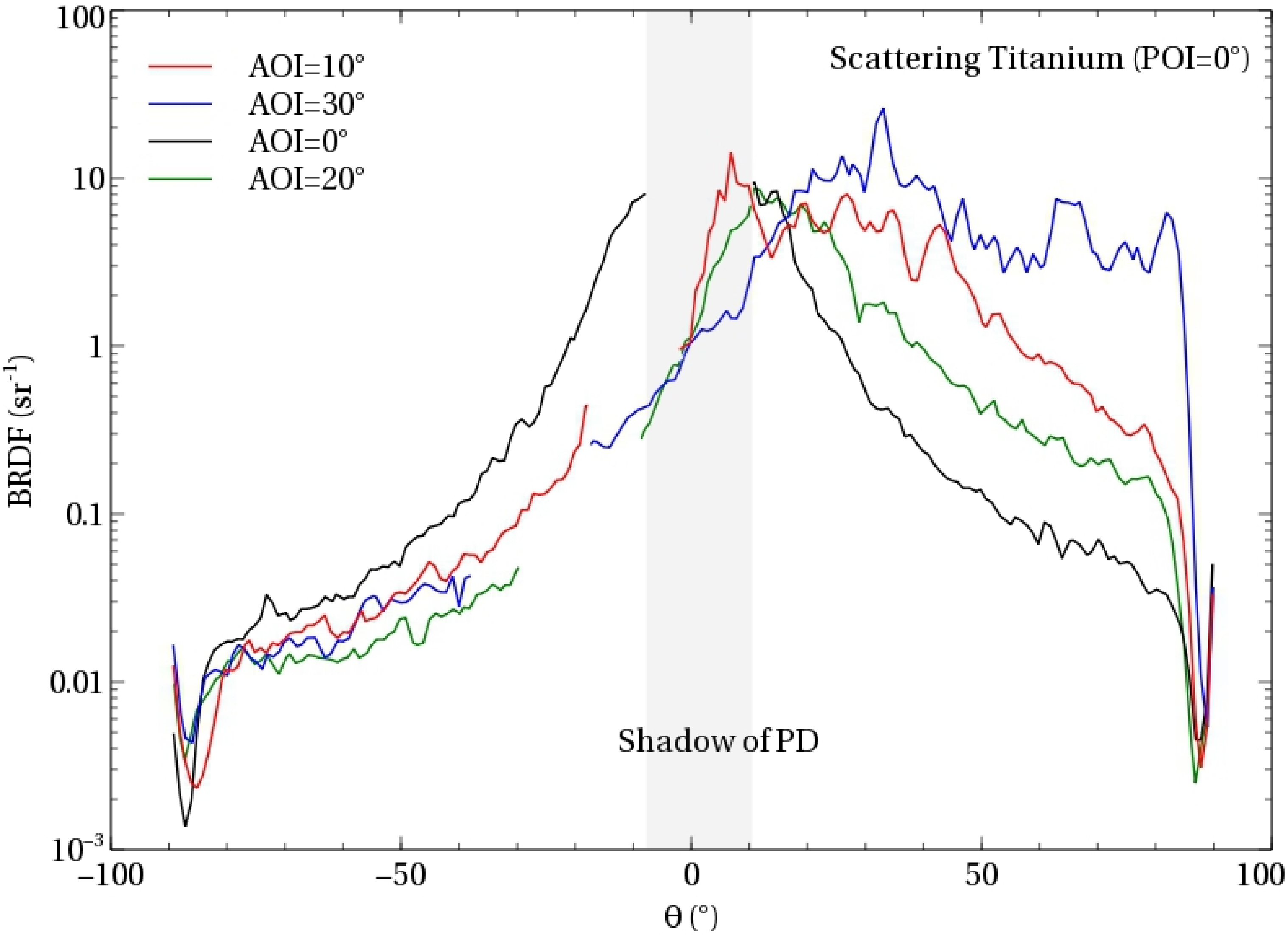

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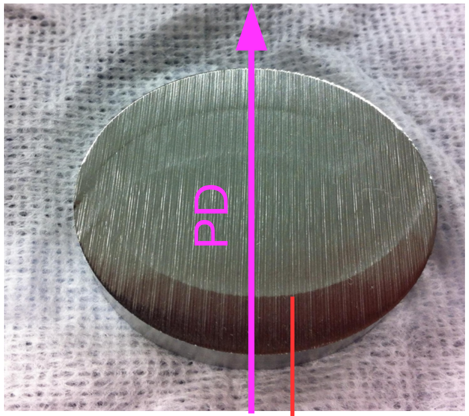
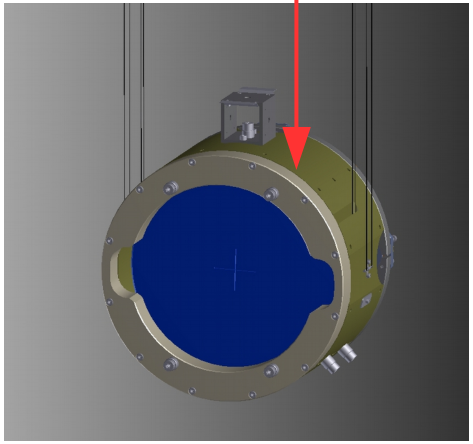
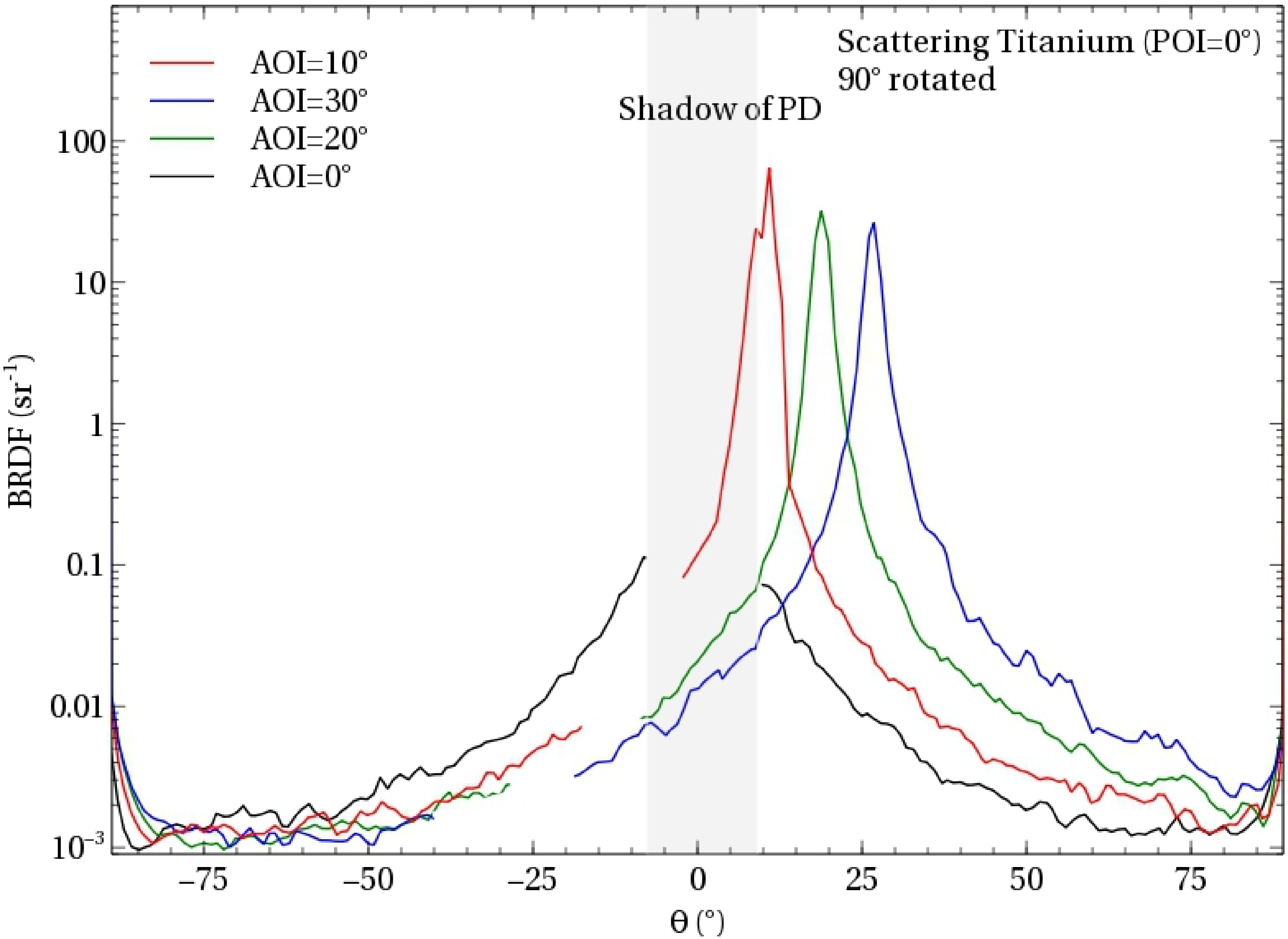
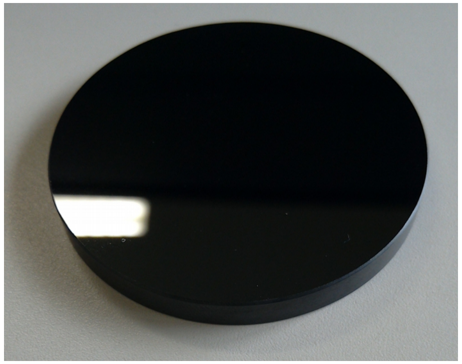
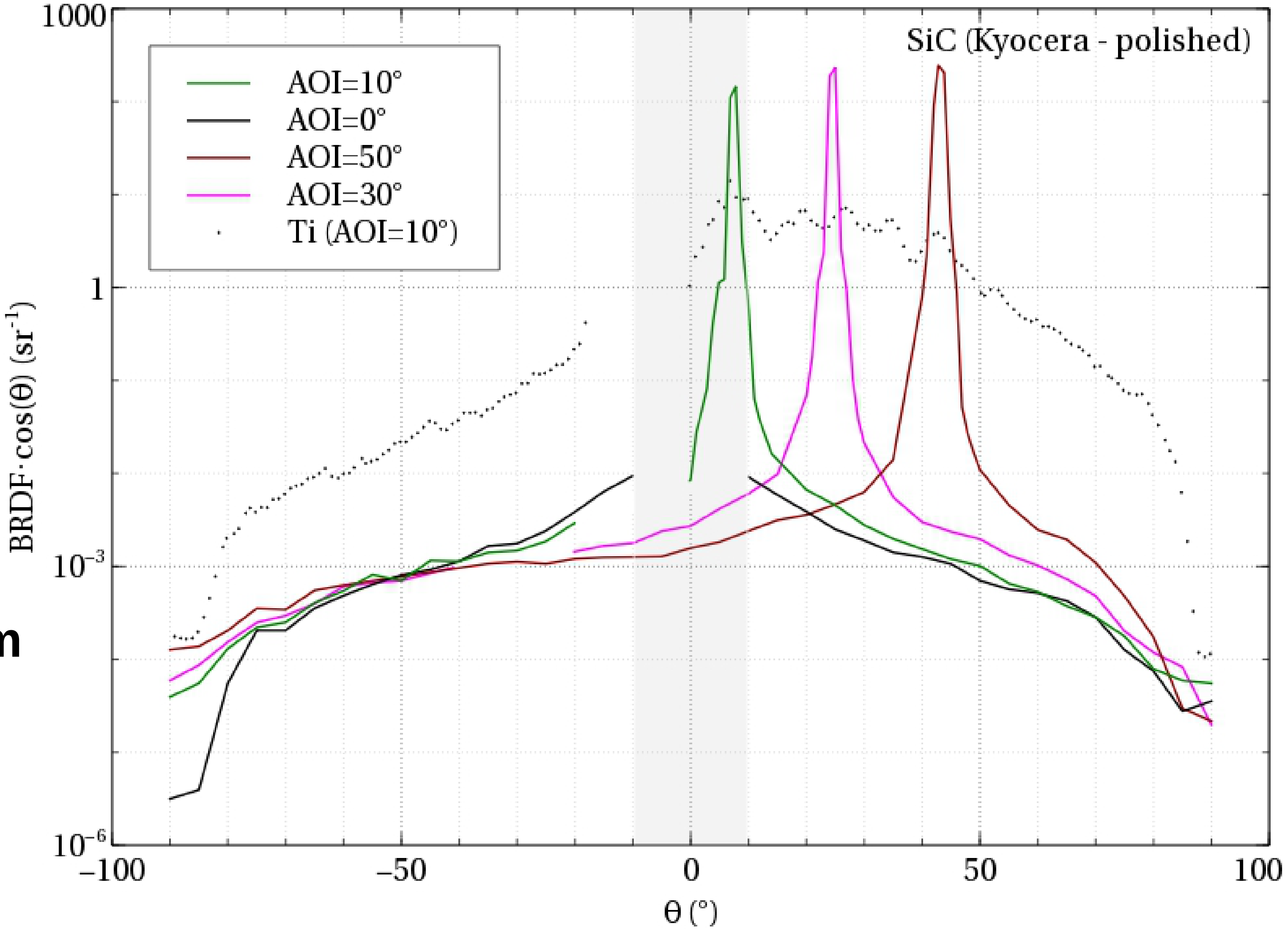






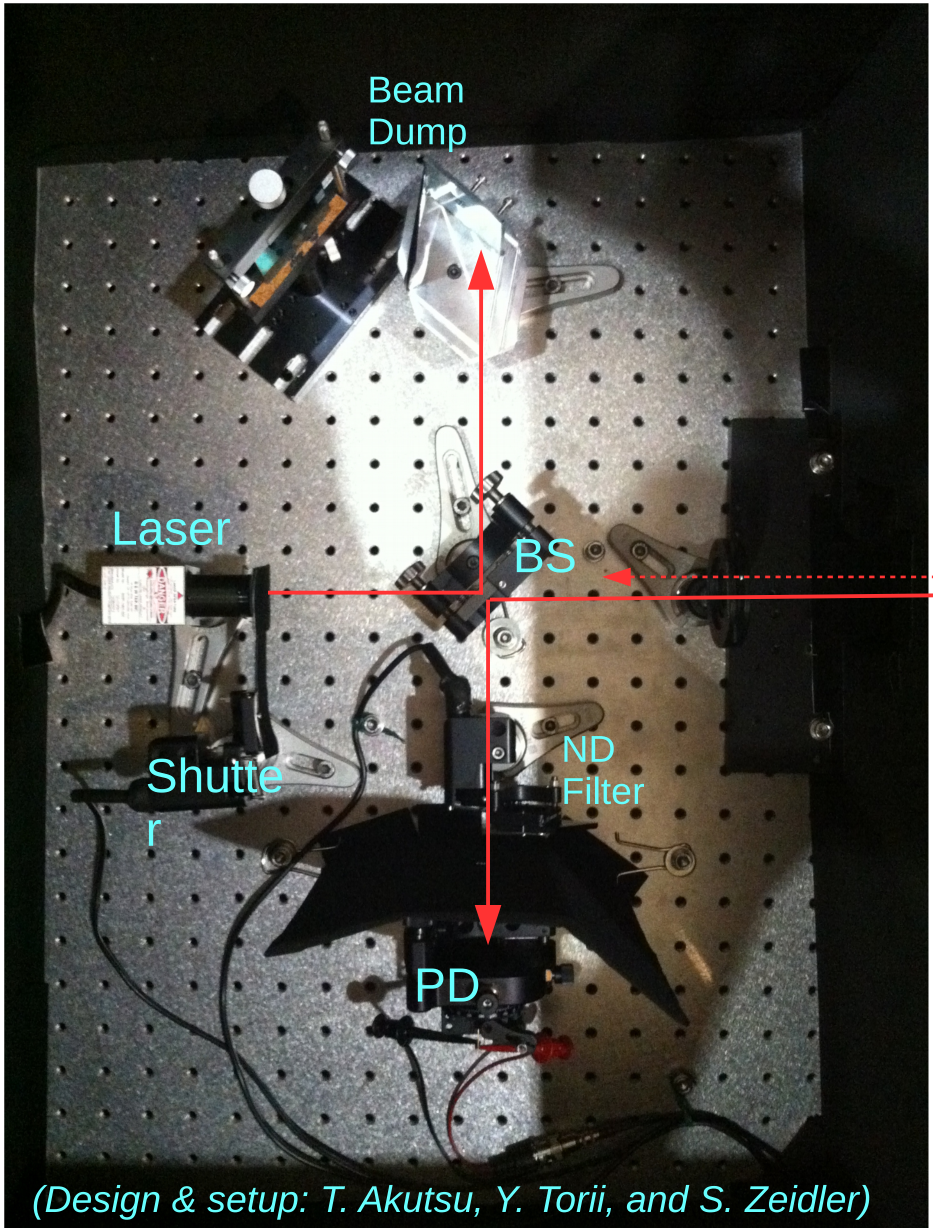
SiC (polished)

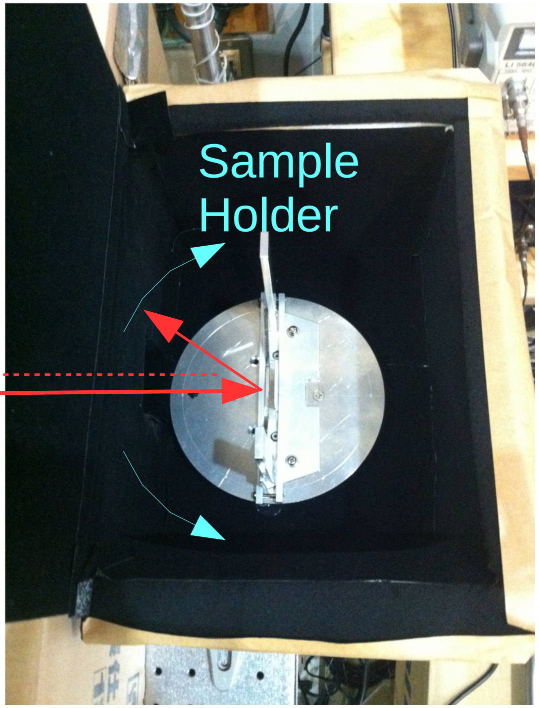




High-Power Beam Dumps

Backscattering Measurements (Back-Scatterometer)

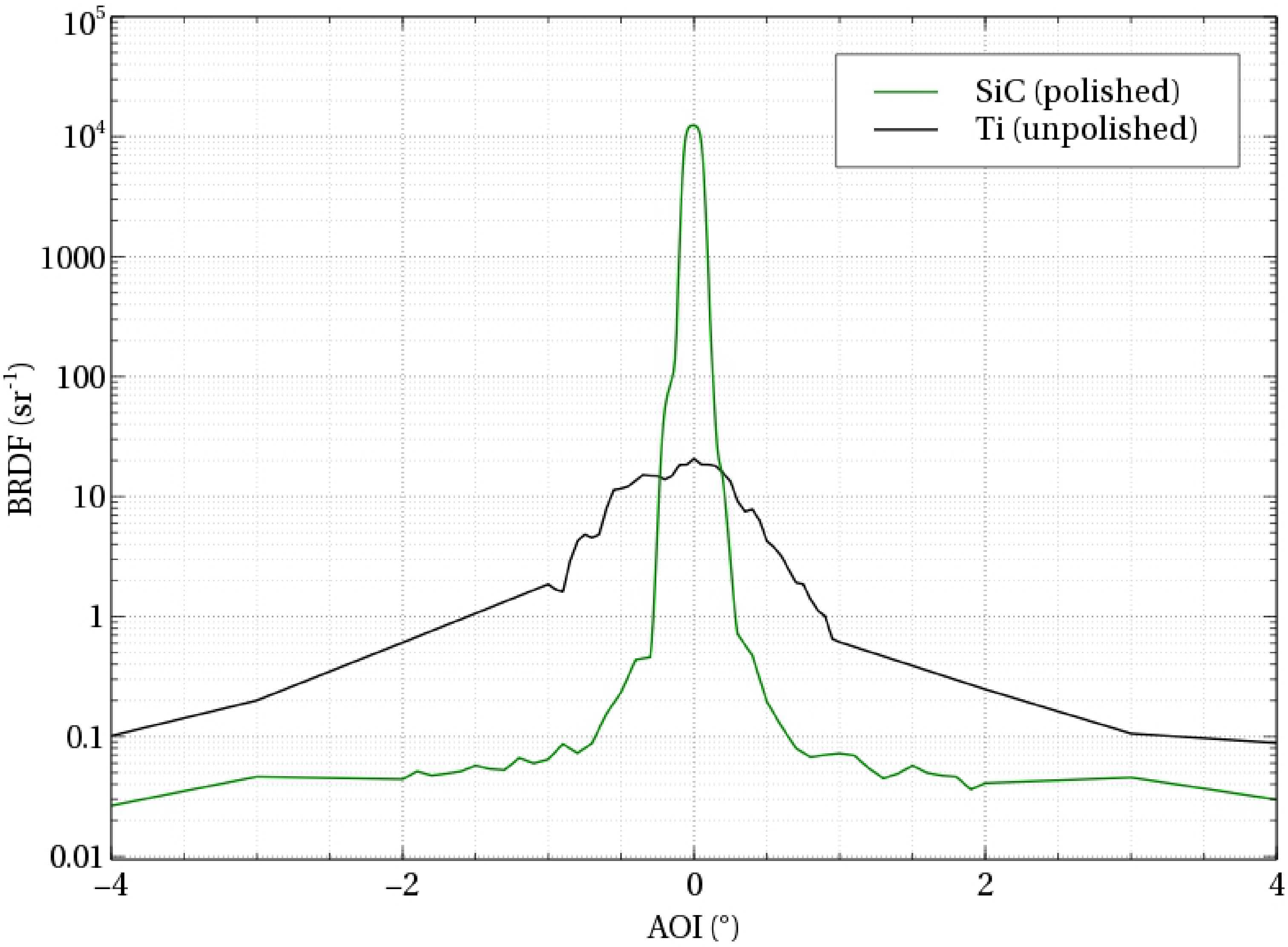




Measuring of what comes directly back!

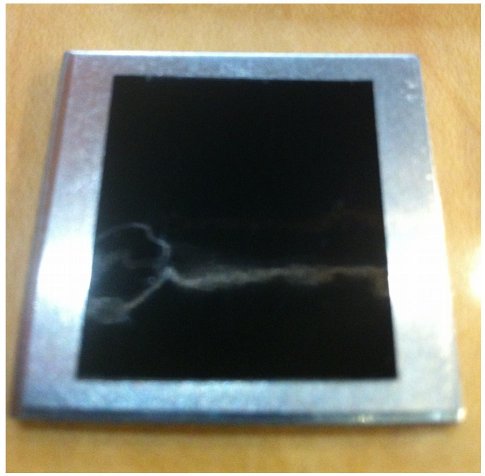
$$BRDF(\theta) = \frac{4 \cdot I_{PD}(\theta) \cdot f_{PD}}{P_{laser} \cdot \Omega \cdot \cos(\theta)}$$

Backscattering of Titanium and SiC



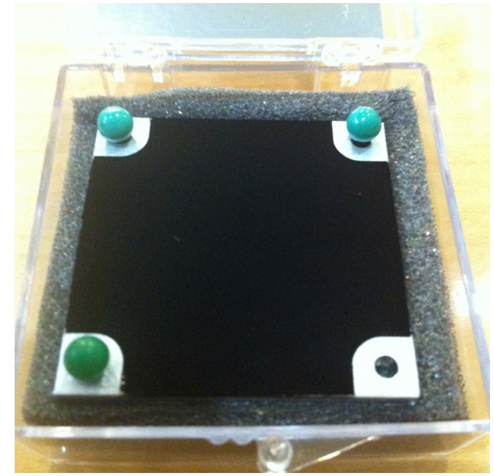
Backscattering of (Black) Coatings

“SolBlack” on Aluminum



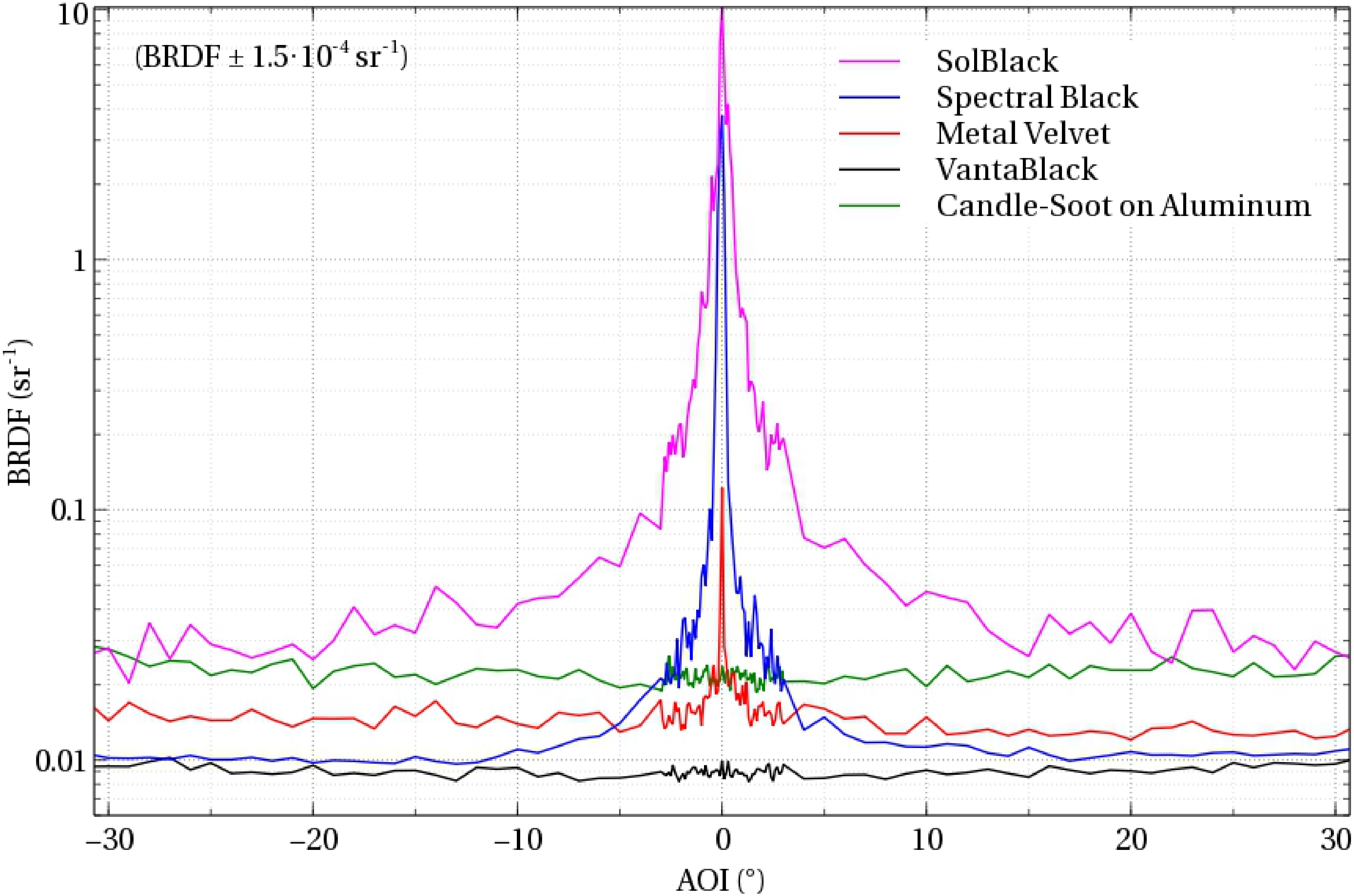
“Spectral Black”

“Metal Velvet”



“VantaBlack” (blackest material on earth)

- Coating materials and candidates for baffles and sensitive parts of KAGRA
- Need to have very low backscattering
- Concrete application: coating of Doughnut-Baffles



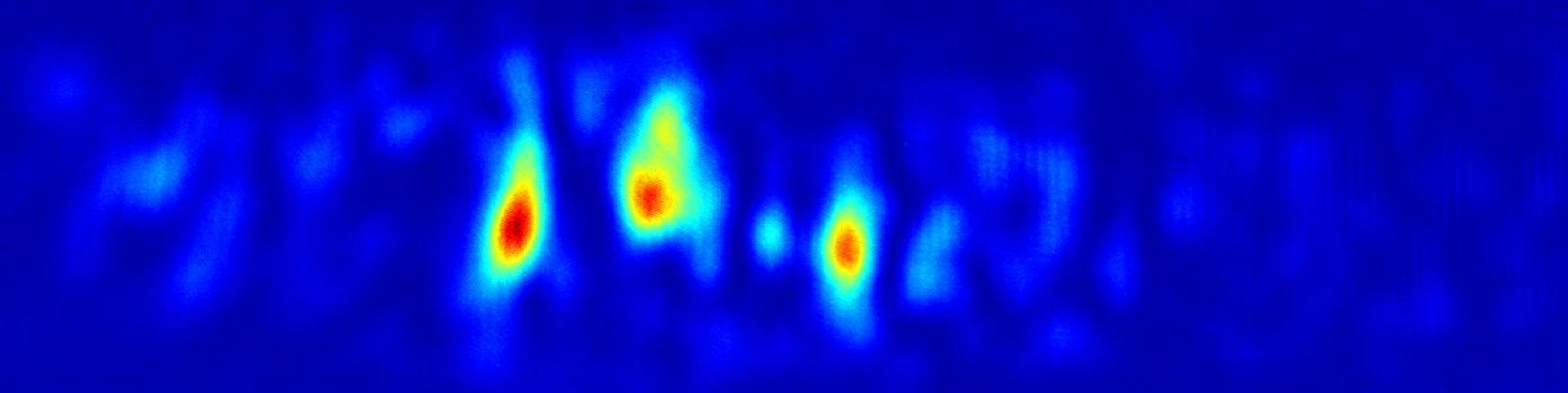
For avoiding back-scattering effects from mirrors on sensitivity of KAGRA:

BRDF of surrounding material < 10^3 sr^{-1}

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!

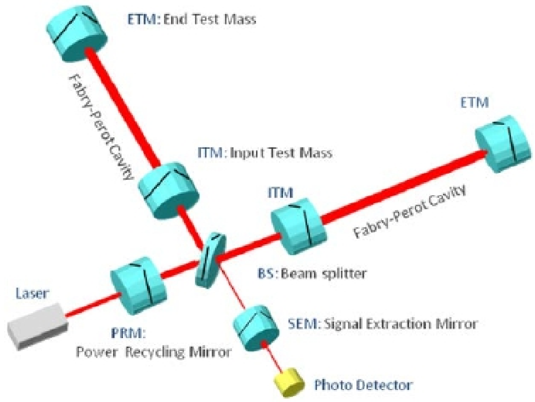


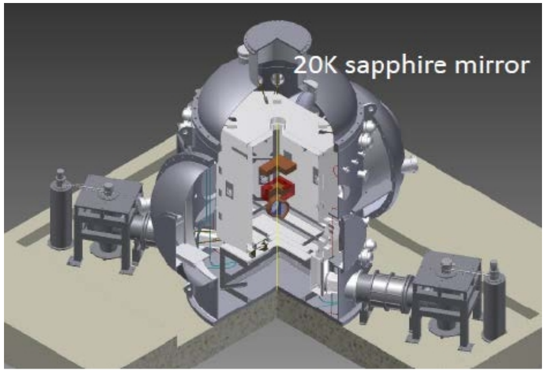
Outlook

- **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**

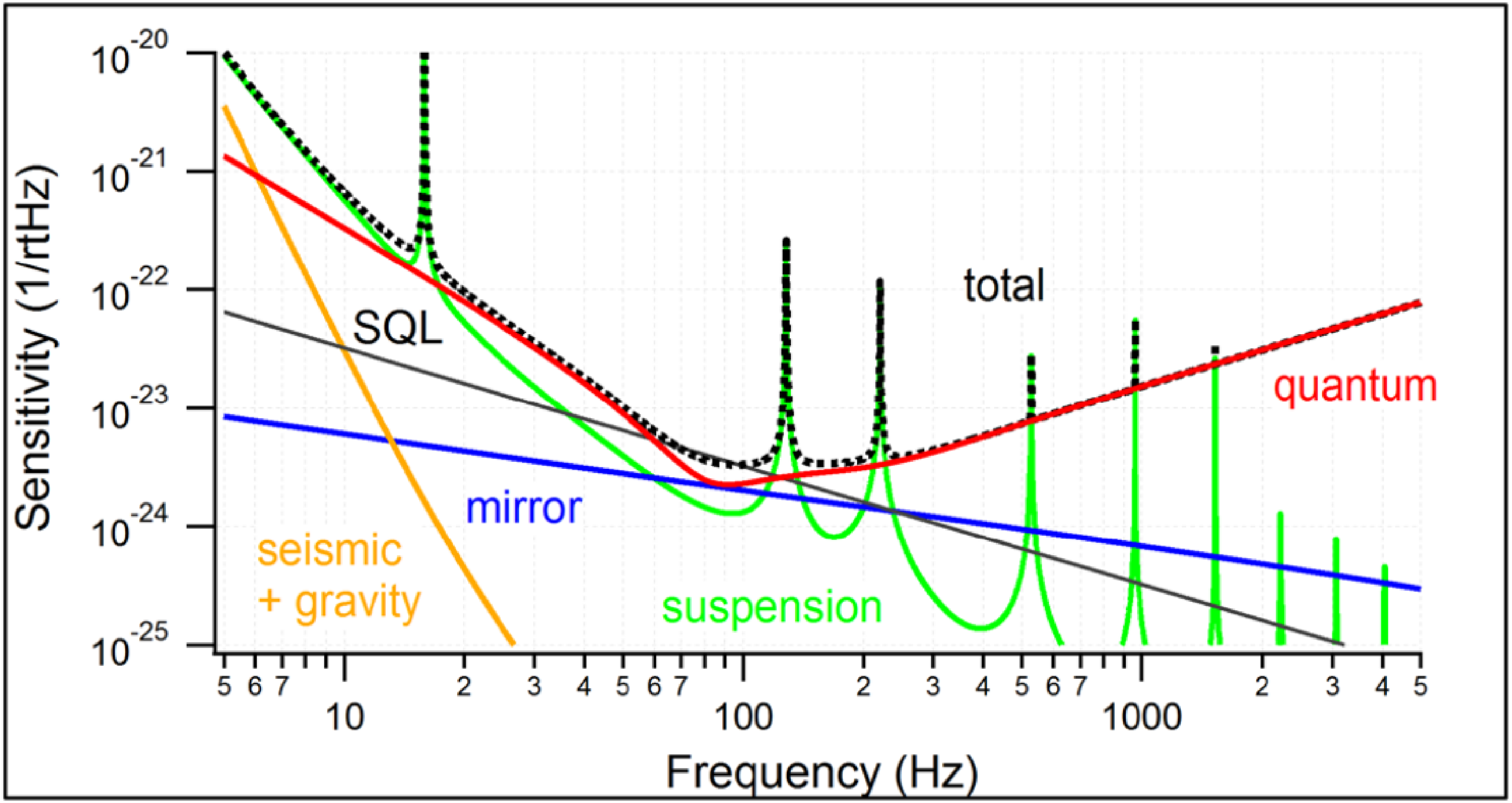
The KAGRA Project

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



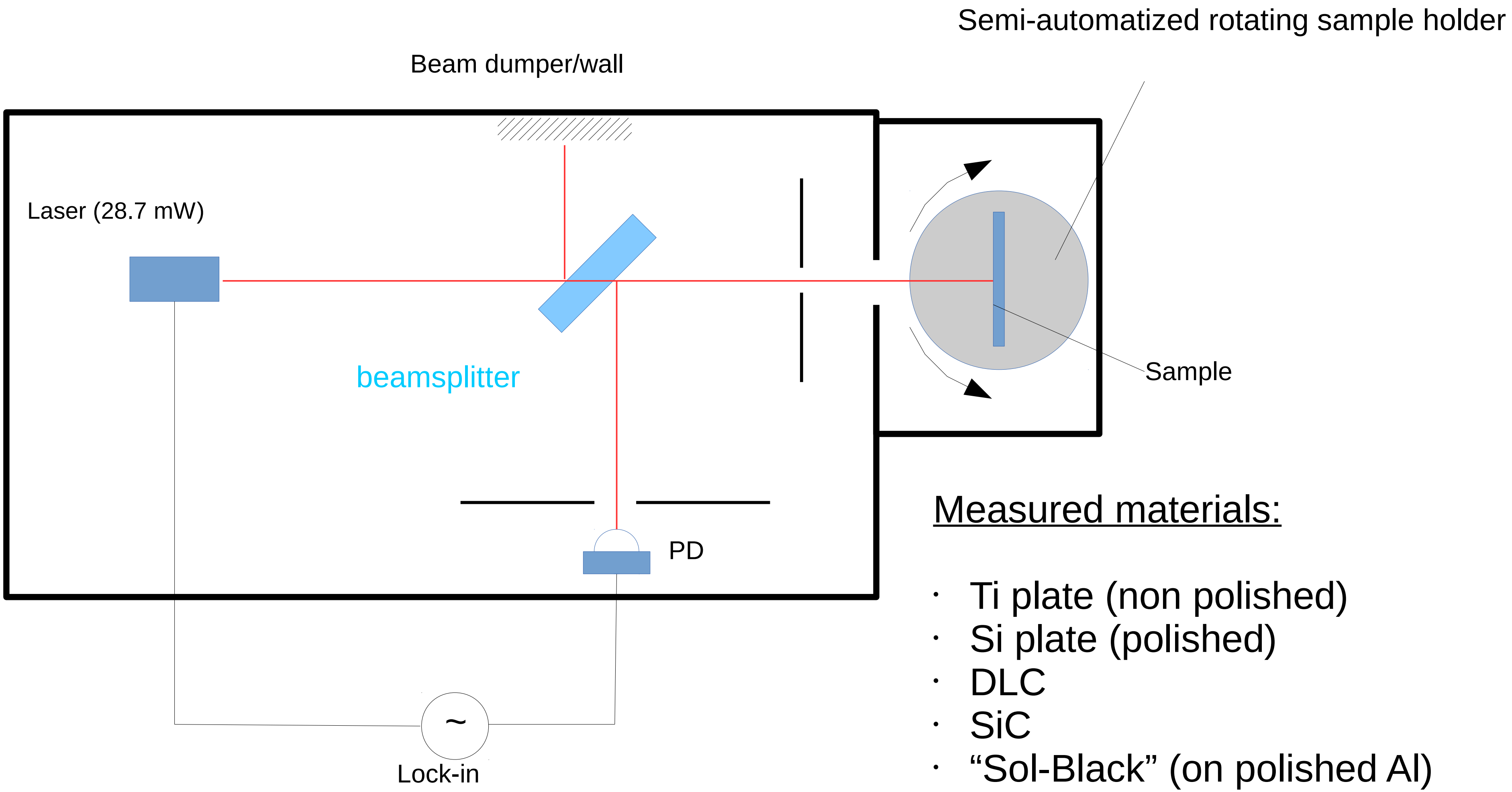


Sensitivity of KAGRA



- 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)

<u>Measured materials:</u>

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

$I_{PD} \rightarrow photocurrent$

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

$P_{laser} \rightarrow Power\ of\ the\ laser\ hitting\ the\ sample$

$\Omega \rightarrow solid\ angle\ of\ scattered\ light\ reaching\ the\ PD$

$\theta \rightarrow incident\ angle\ of\ the\ laser\ hitting\ the\ sample$