Optical Measurements and Calculations for KAGRA

– Performing Stray-Light Control –

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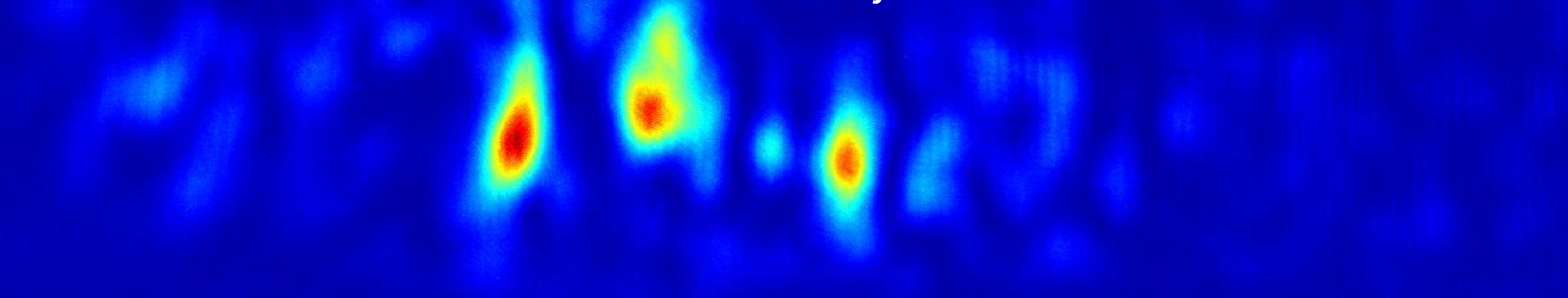
NAOJ
Gravitational Wave Project Office

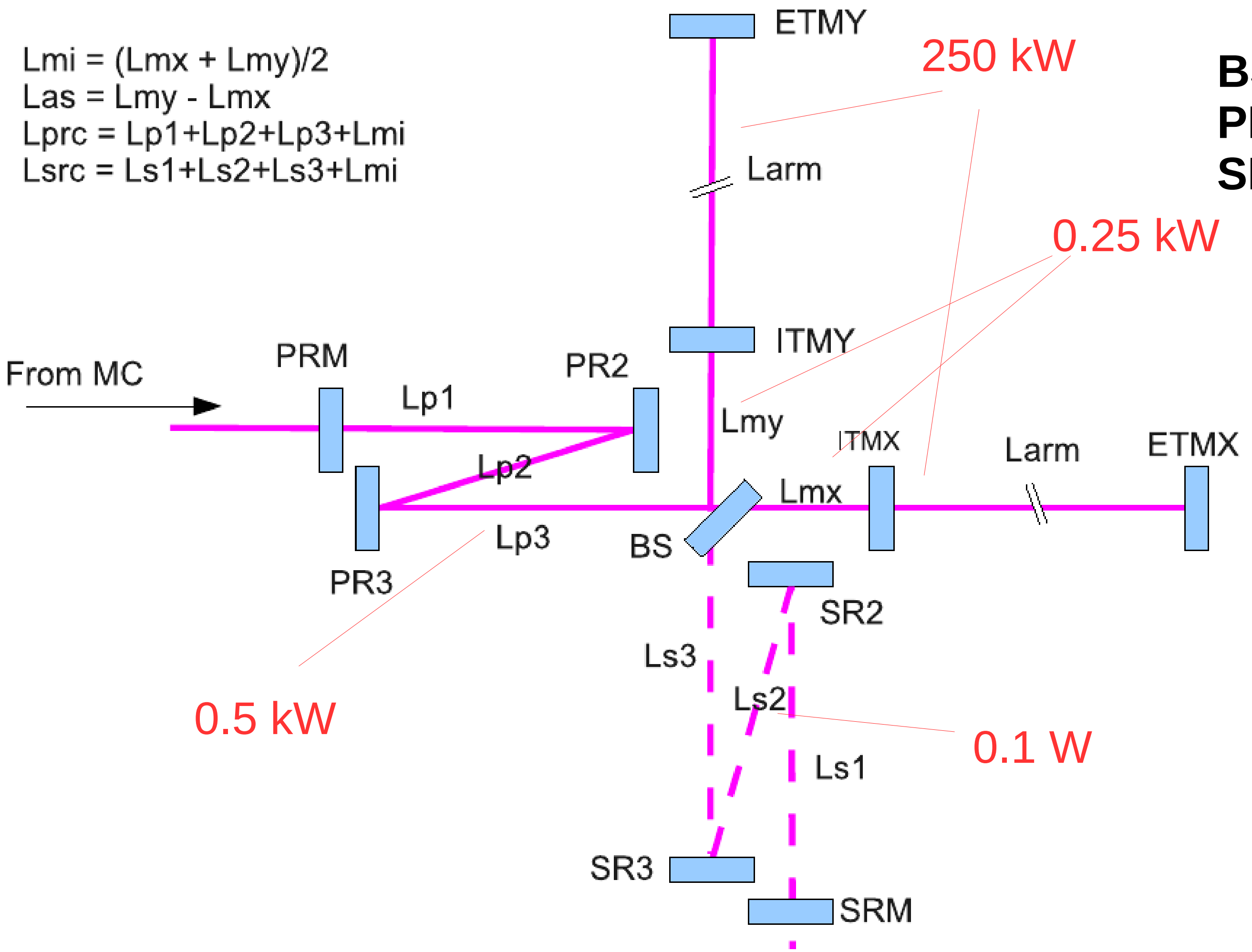


Outline

- **Introduction**
  - *Principal Setup of the Interferometer*
  - *The Importance of Stray-Light Control*
  - *Measurement and Characterization of Scattering*
  - *Backscattering measurements*
- **Scattering Light of the Recoil Masses of PR, SR and BS Mirrors**
  - *Seismic Noise in the Kamioka mine*
  - *(Maximal) Effect of the Recoil Mass on the GW-Strain*
- **Summary**

Introduction

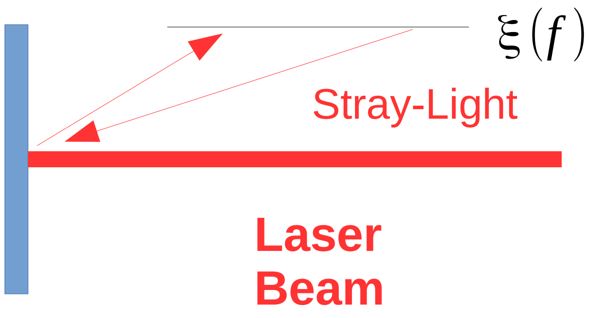
Principle Setup of the KAGRA Interferometer



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



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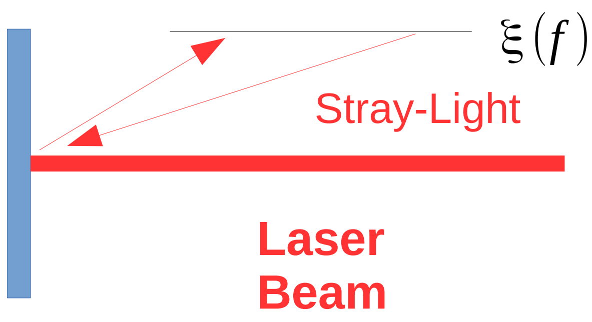

- KAGRA measures GW strain through phase differences
- Scattered and re-coupled light carries phase differences other than GW
- Effect of scattered light on gravitational wave strain:

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

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

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

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

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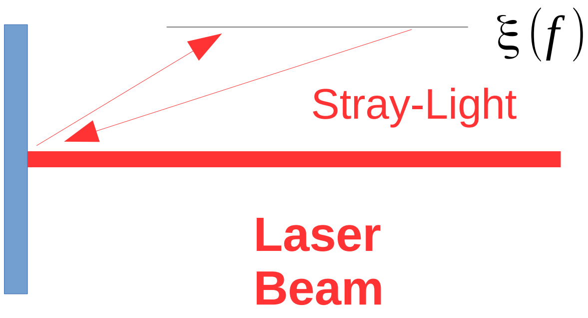

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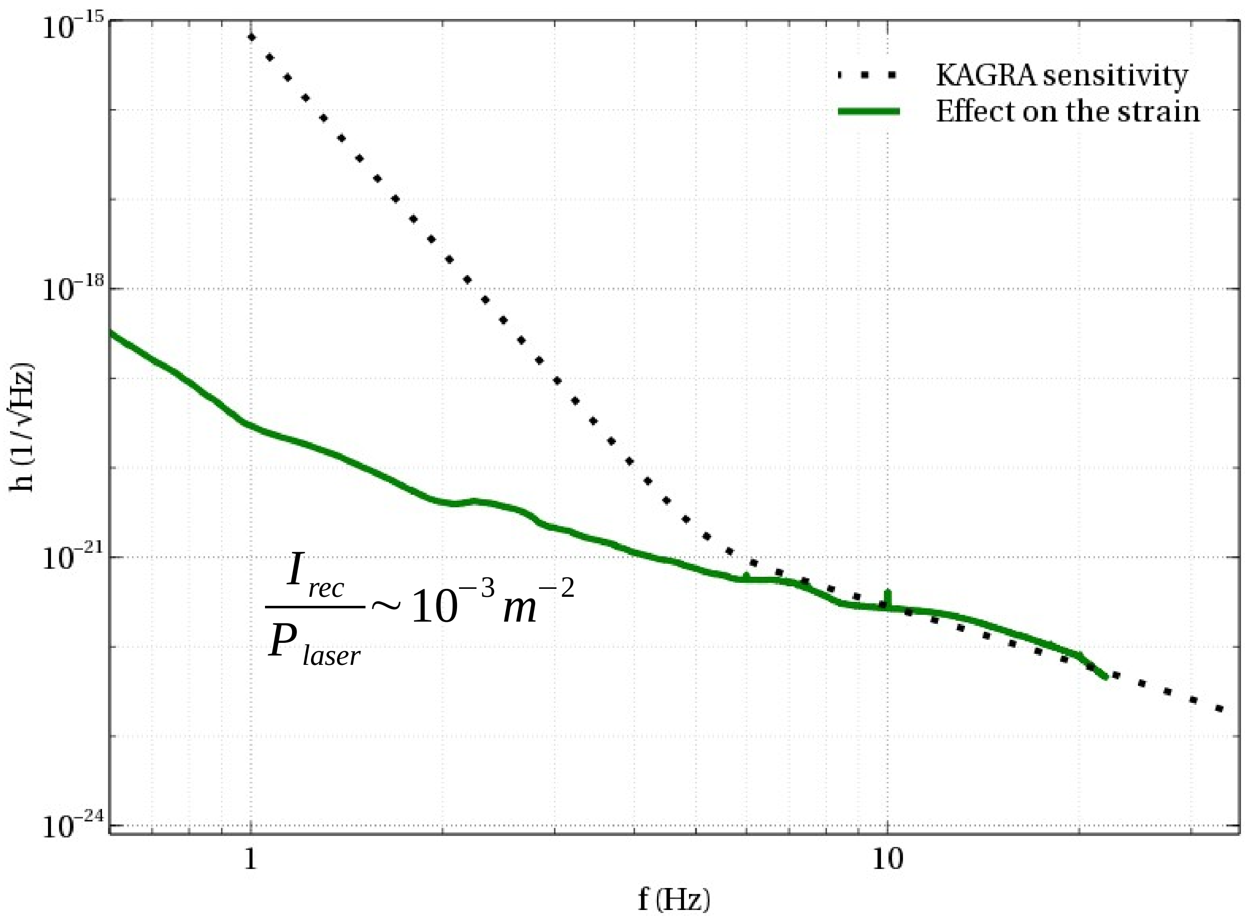
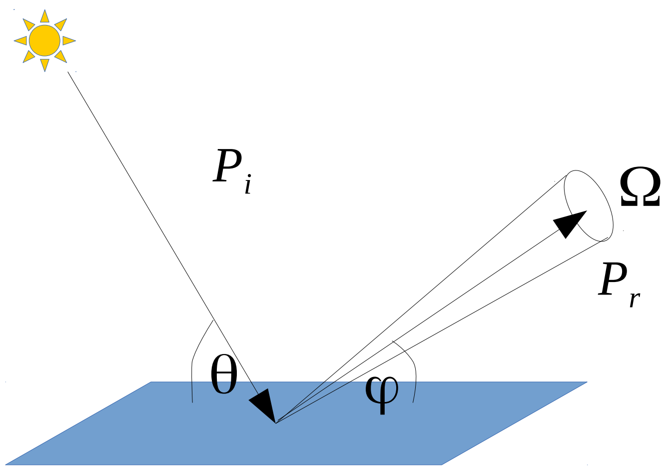


Measuring and Characterization of Scattering

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



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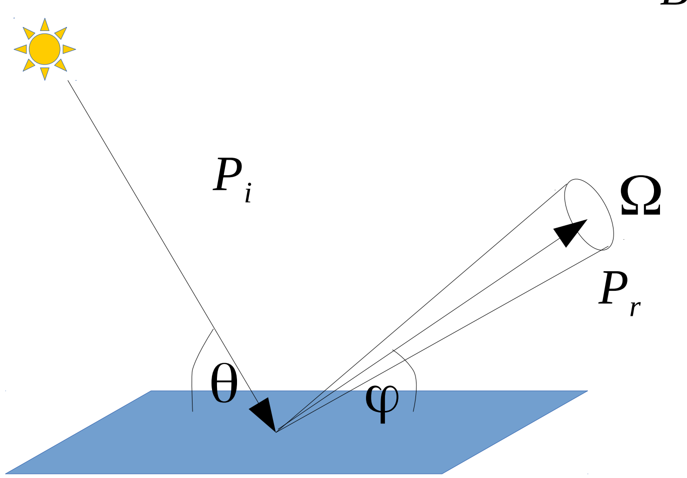
<u>BRDF (**B**idirectional **R**eflection **D**istribution **F**unction)</u>

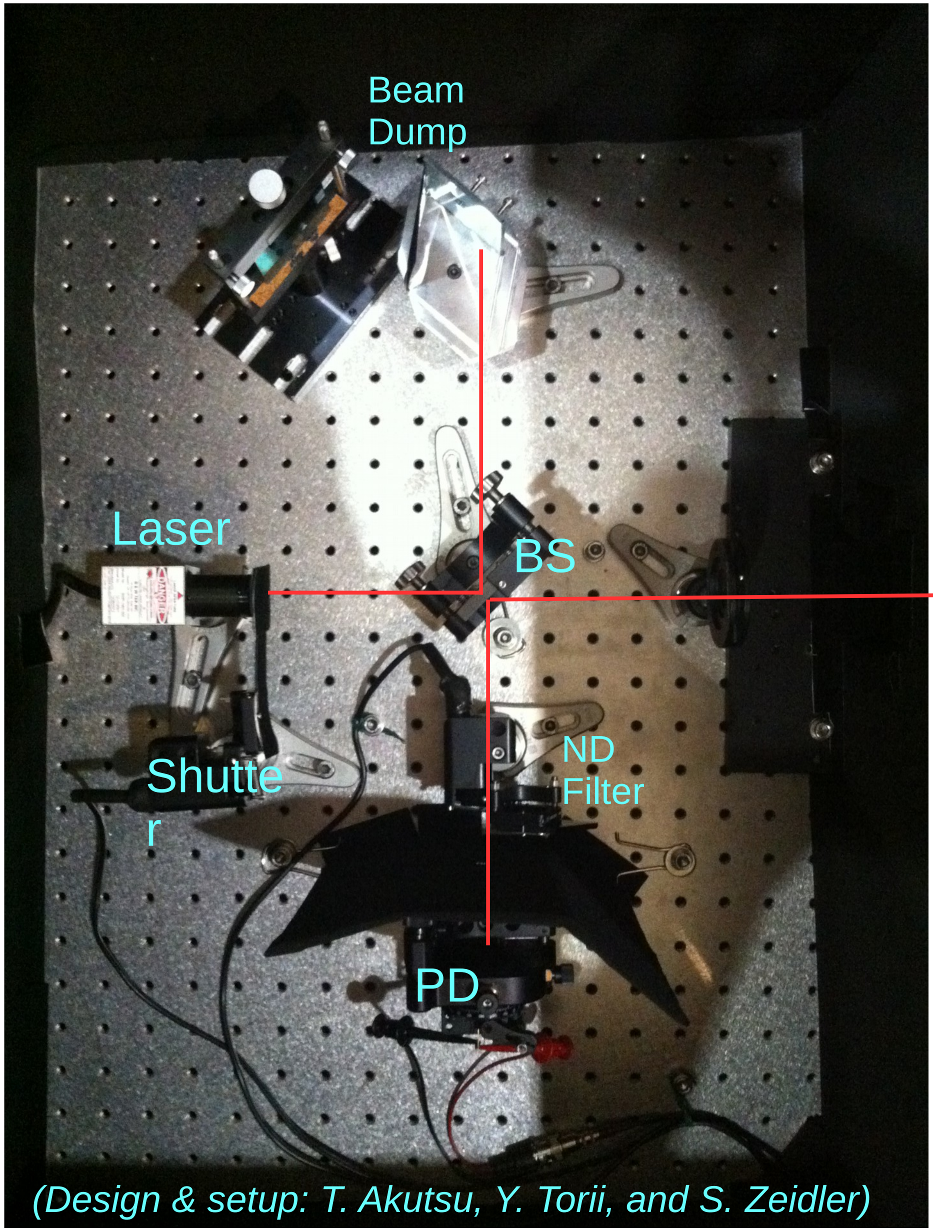
$$BRDF(\theta,\varphi)=\frac{\partial L_r(\varphi,I_r)}{\partial E_i(\theta,I_i)};\quad L_r=\frac{\partial P_r}{\partial A\,\partial\Omega\cdot\cos(\varphi)}$$ → Radiance

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

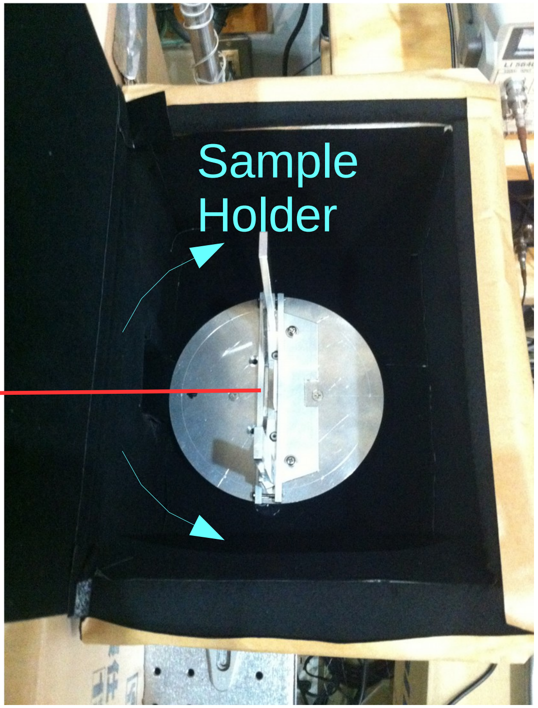


$$BRDF(\theta,\varphi)=\frac{\partial P_r}{\partial P_i\,\partial\Omega\cdot\cos(\varphi)}$$

Backscattering Measurements



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



<u>Measured materials:</u>

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

Calculating the BRDF from measured photocurrent of the photodiode:

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

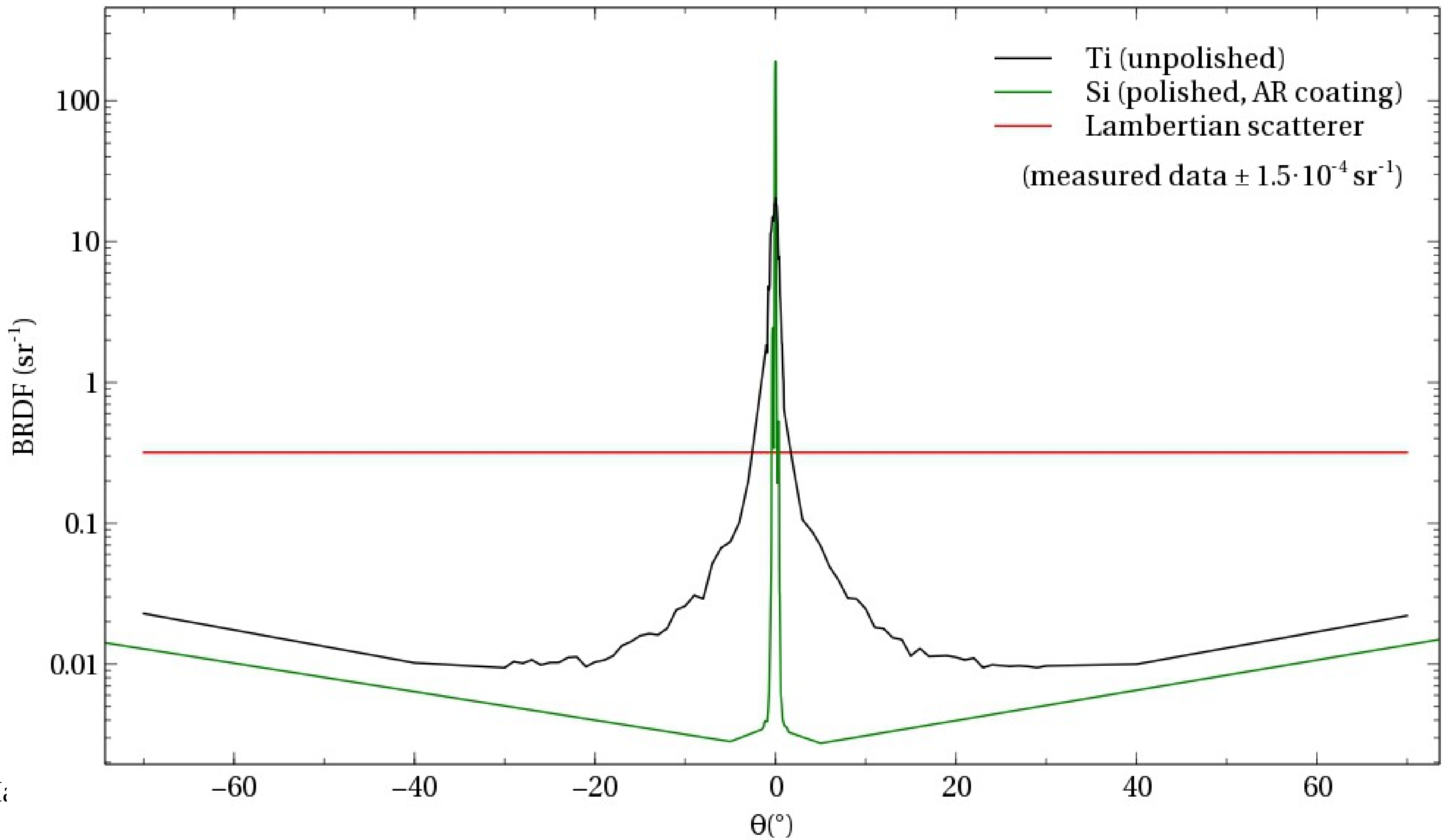
$I_{PD} \rightarrow$ *photocurrent*

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

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

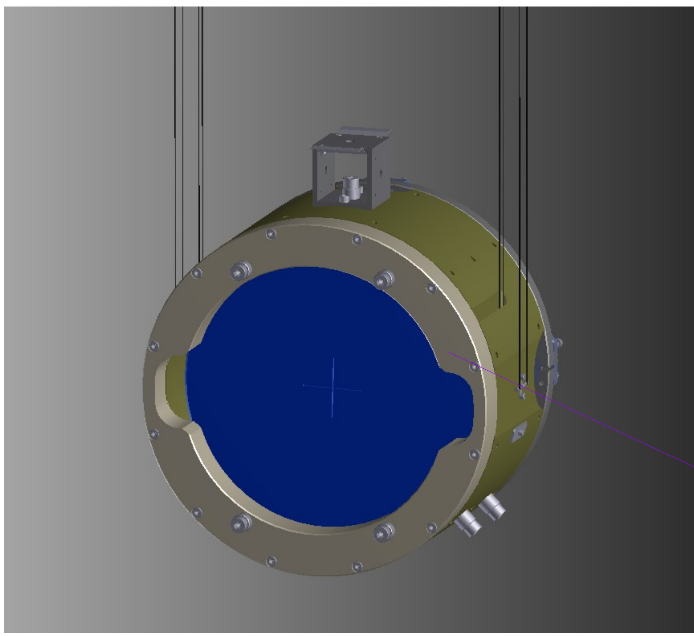
$\Omega \rightarrow$ *solid angle of scattered light reaching the PD*

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

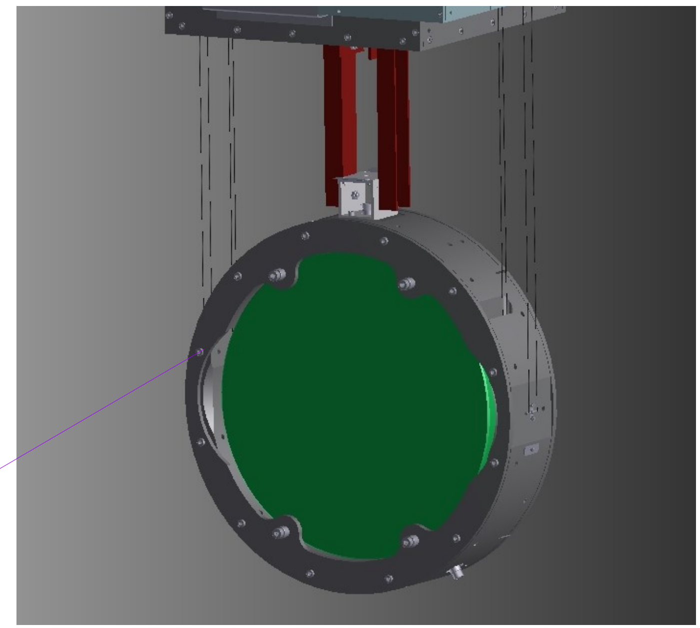


Numerical Calculations on Scattering Light

- Analytical calculations for the Distribution of Scattering Light is often not possible
  → complicated structure of surfaces
- Using “LightTools” for simulating the distribution of stray-light produced by the mirrors: PRM, PR2, PR3, SRM, SR2, SR3, and BS and their recoil masses

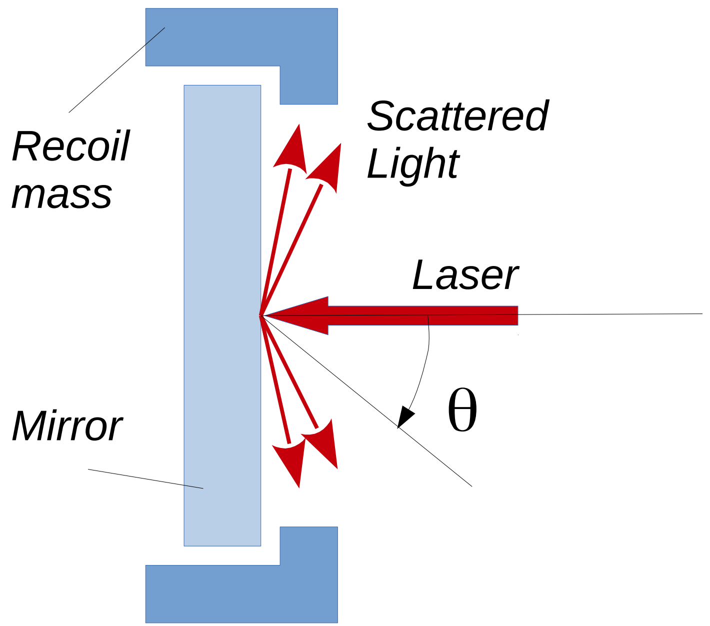


Titanium recoil mass



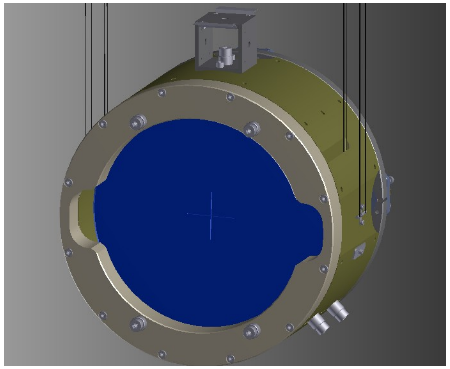
Principle mirror setup used for the PRM, PR2, PR3, SRM, SR2, and SR3 mirrors.

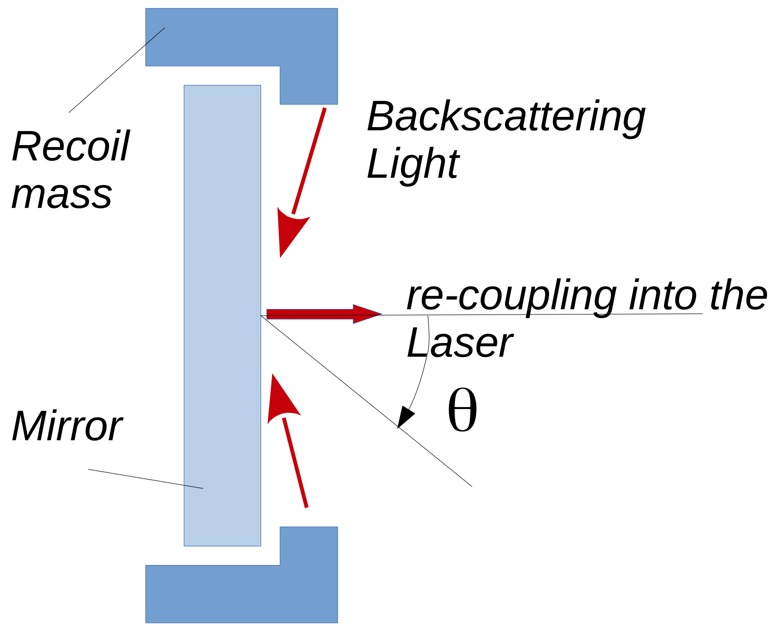
Principle mirror setup used for the BS mirror.



Integrated power of scattered light of high-quality mirrors:

$$\frac{P_{scatter}}{P_{input}} \approx 10^{-5}$$





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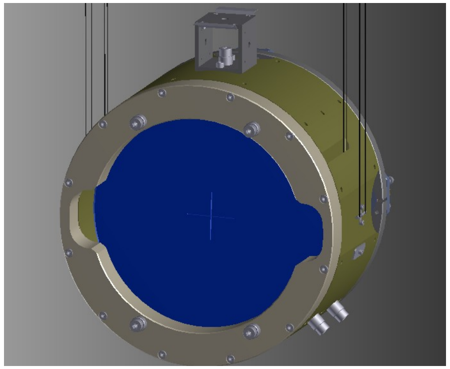

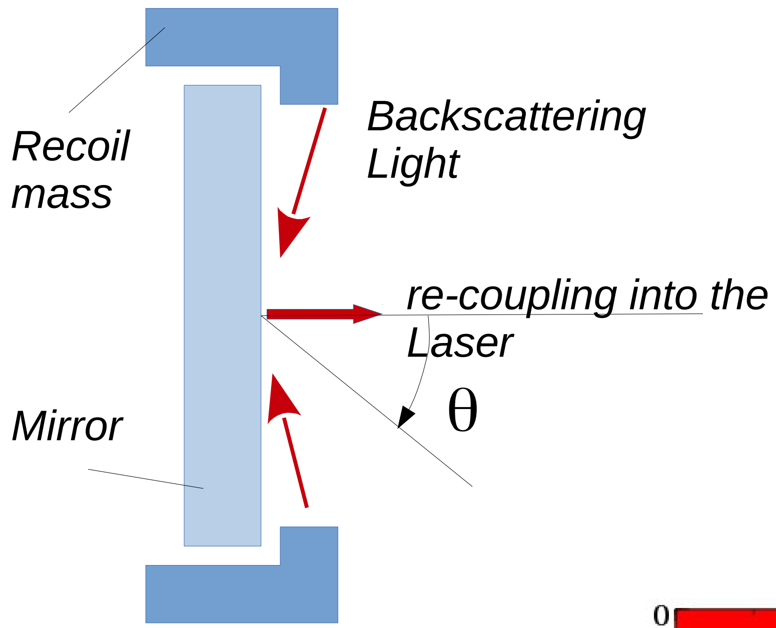

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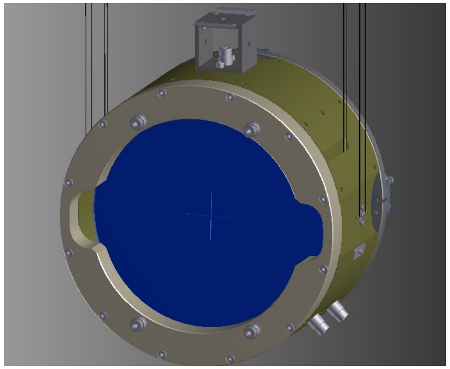

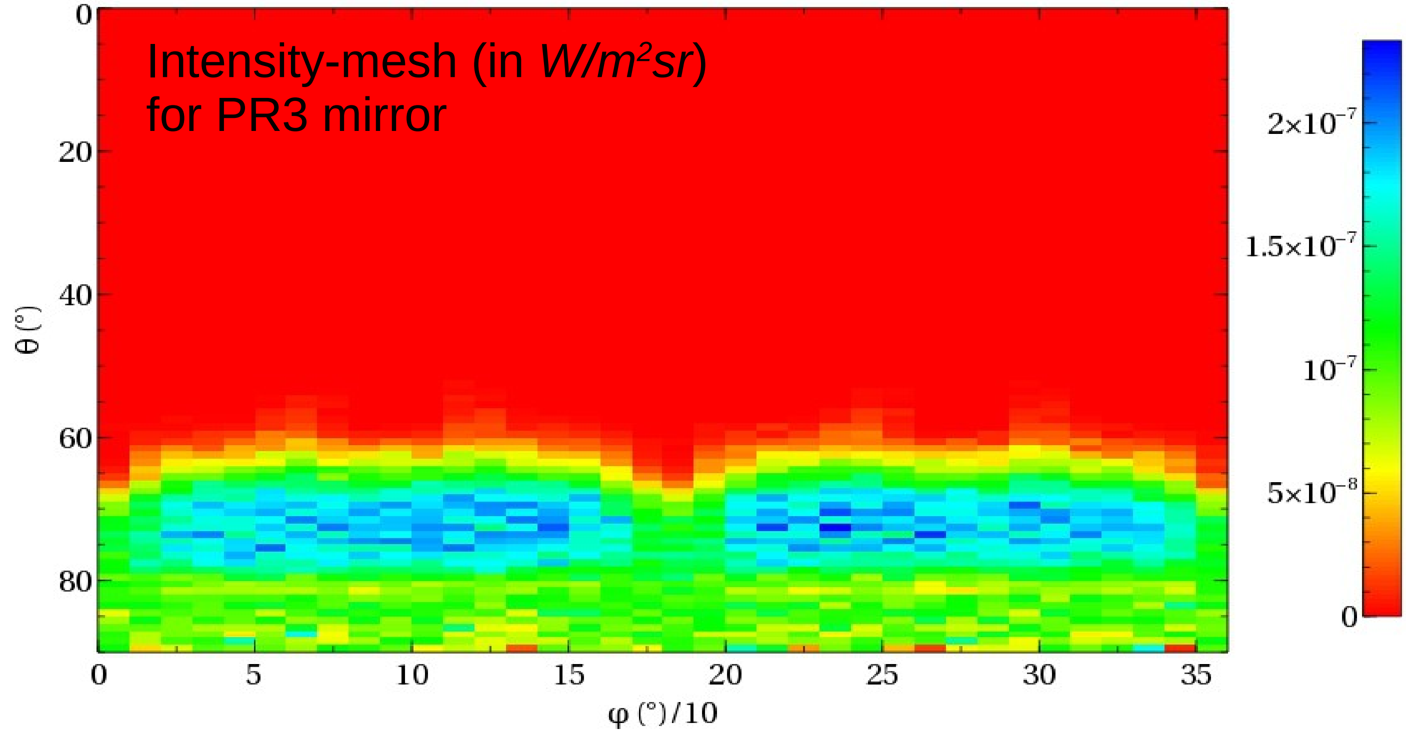

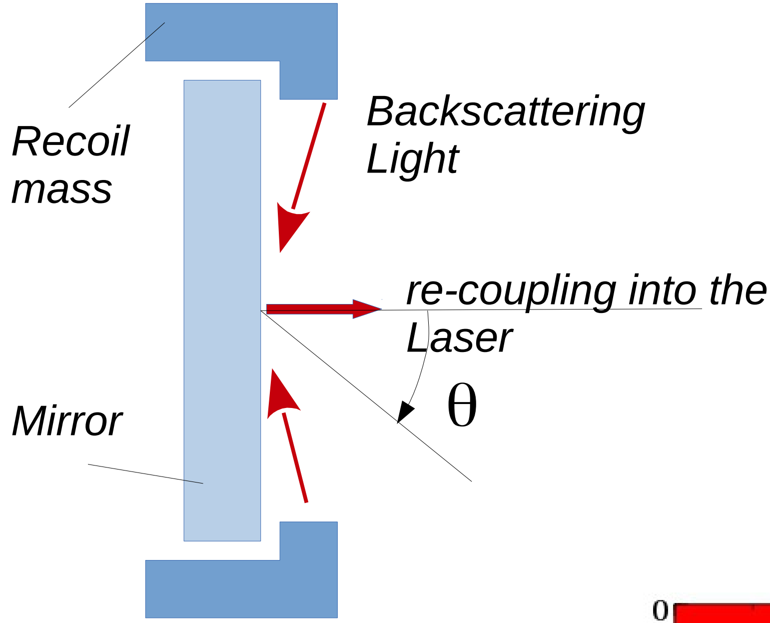

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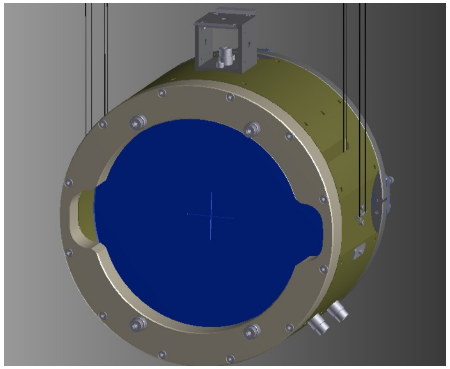

Effect on gravitational wave strain:

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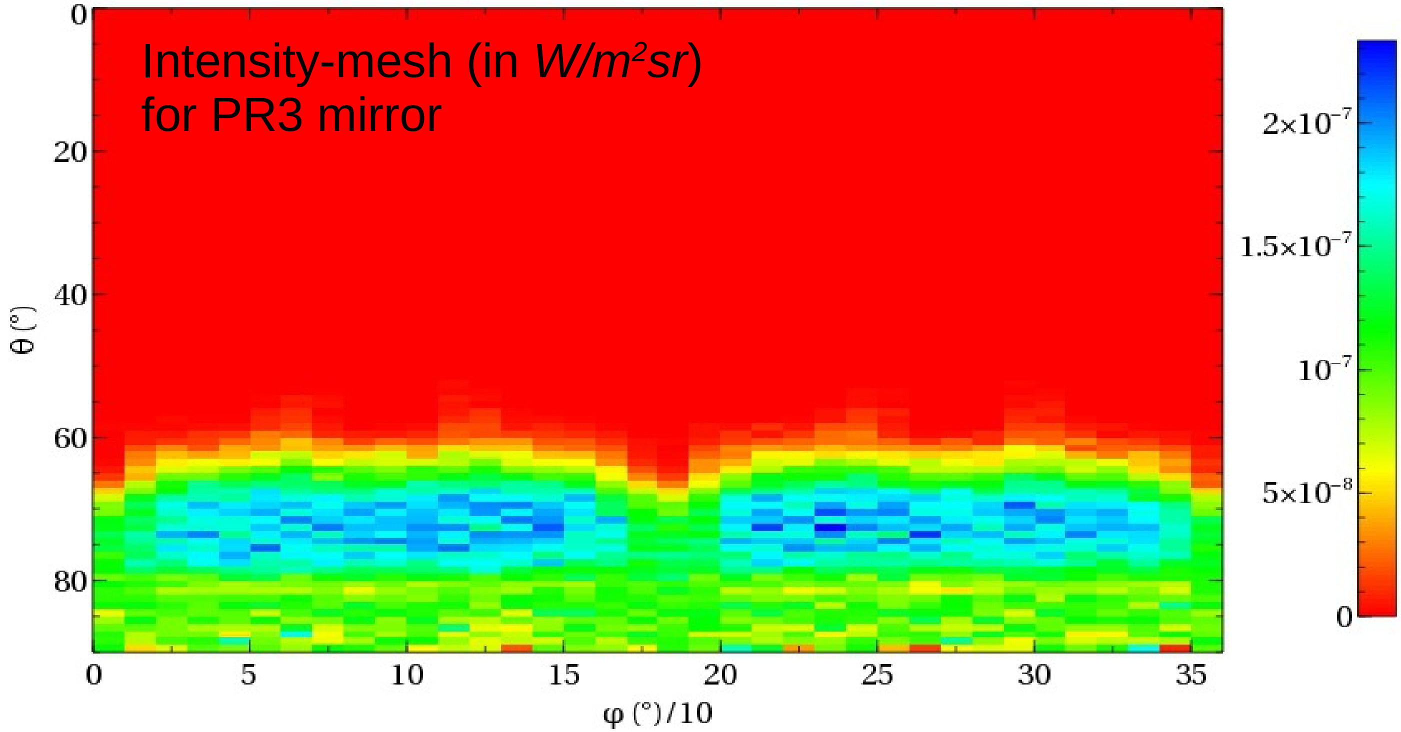
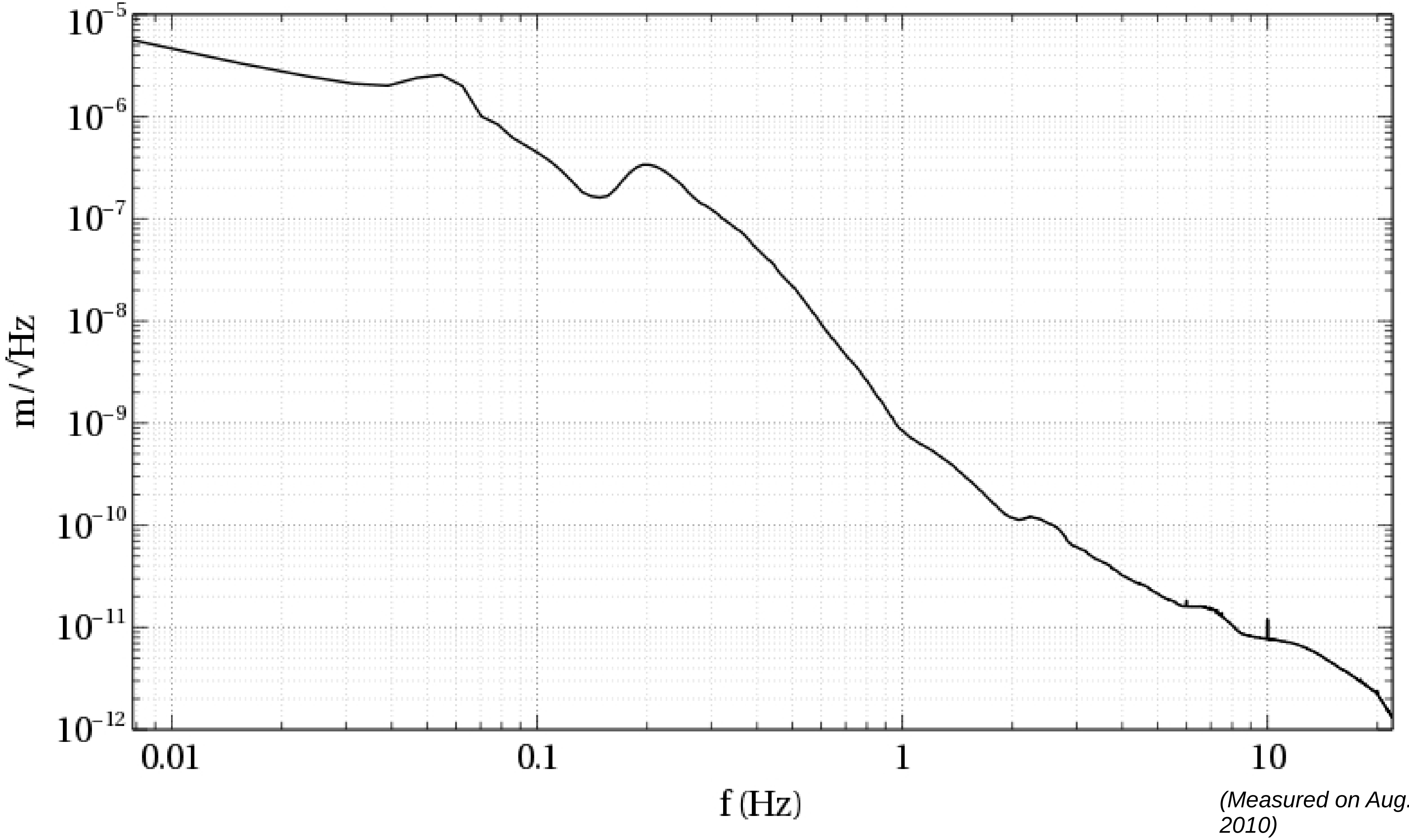
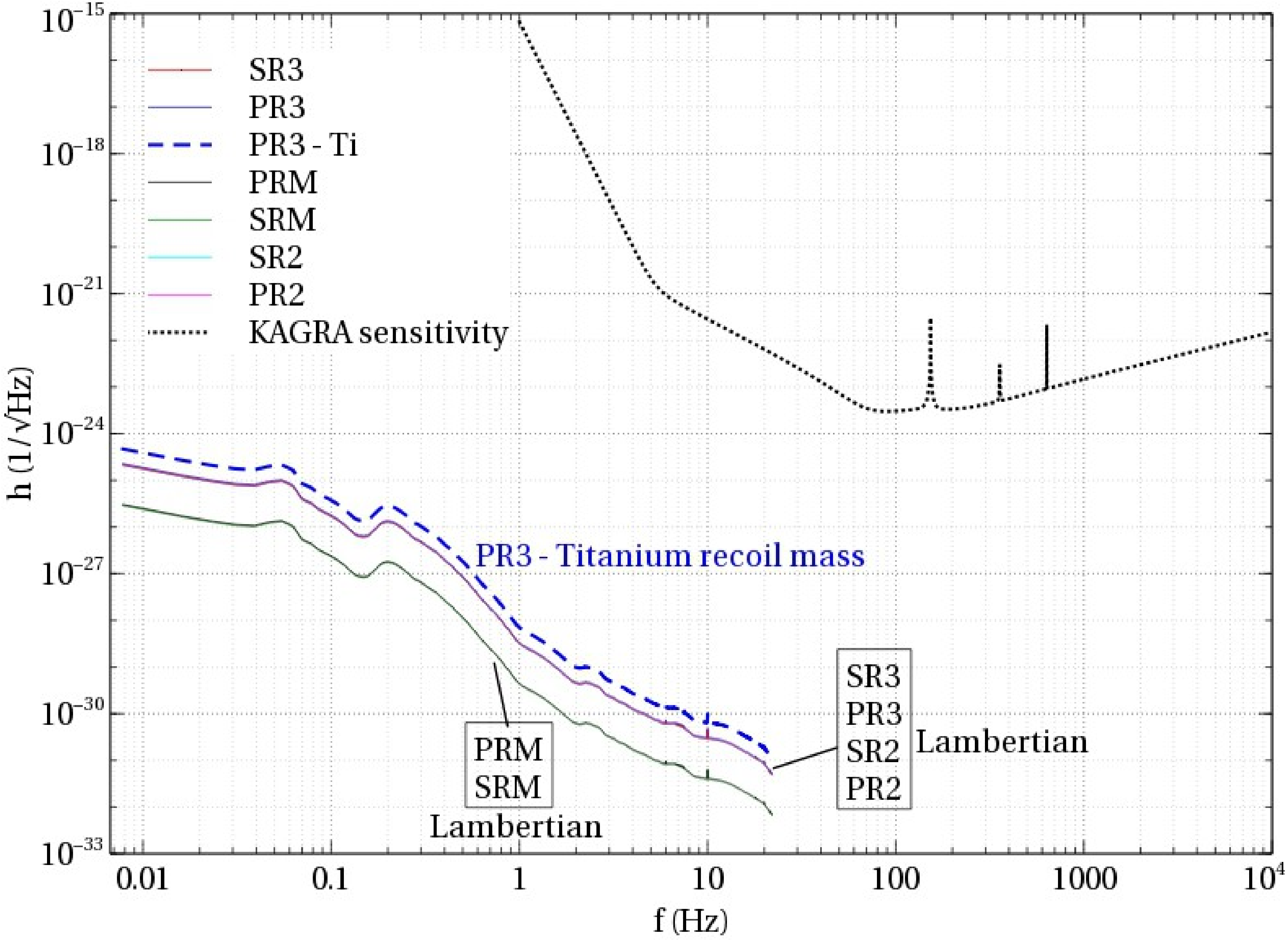


Seismic Noise in the Kamioka-Mine



(Measured on Aug. 2010)

(Maximal) Effect of the Recoil Mass on the GW-Strain



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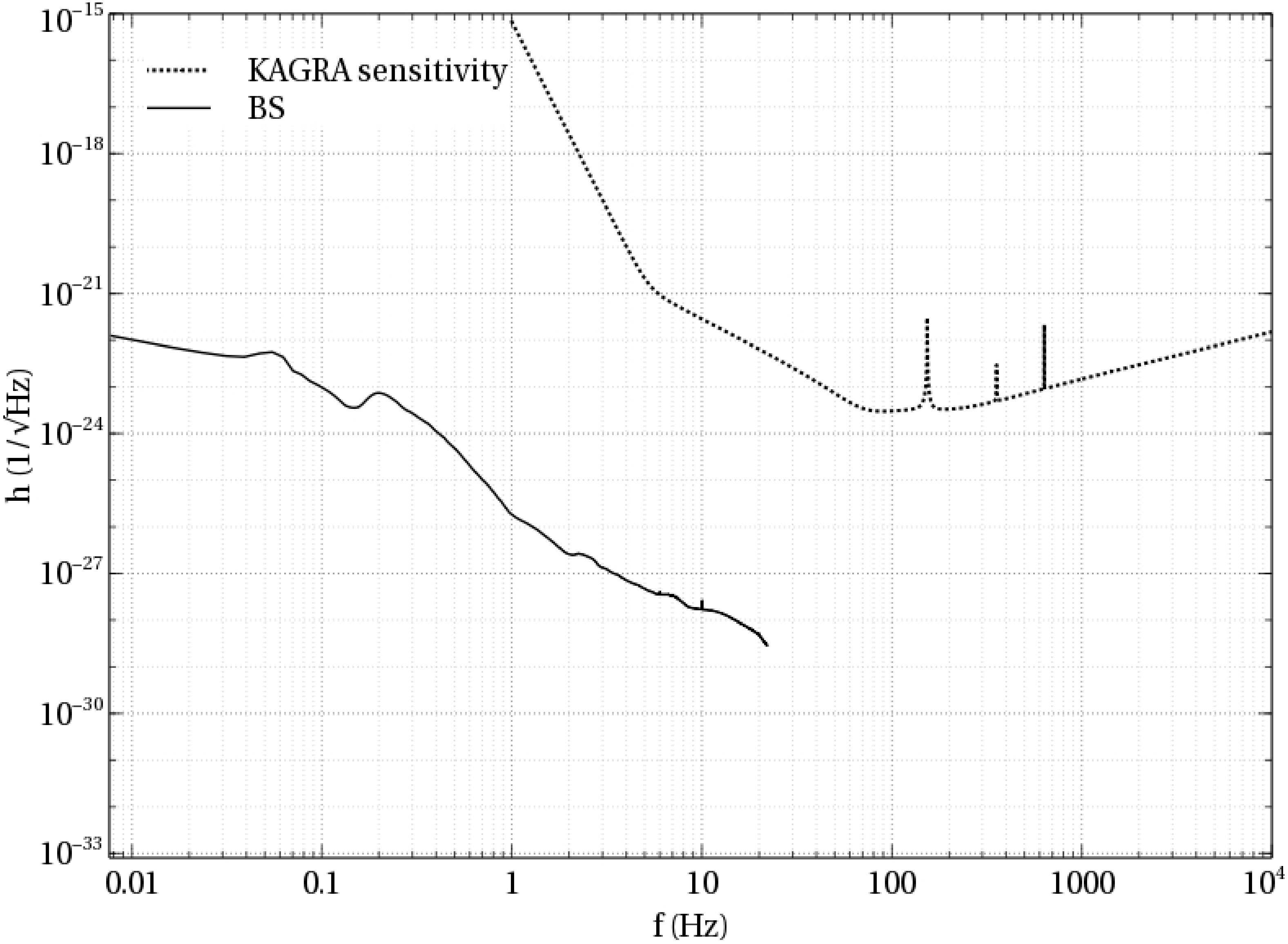
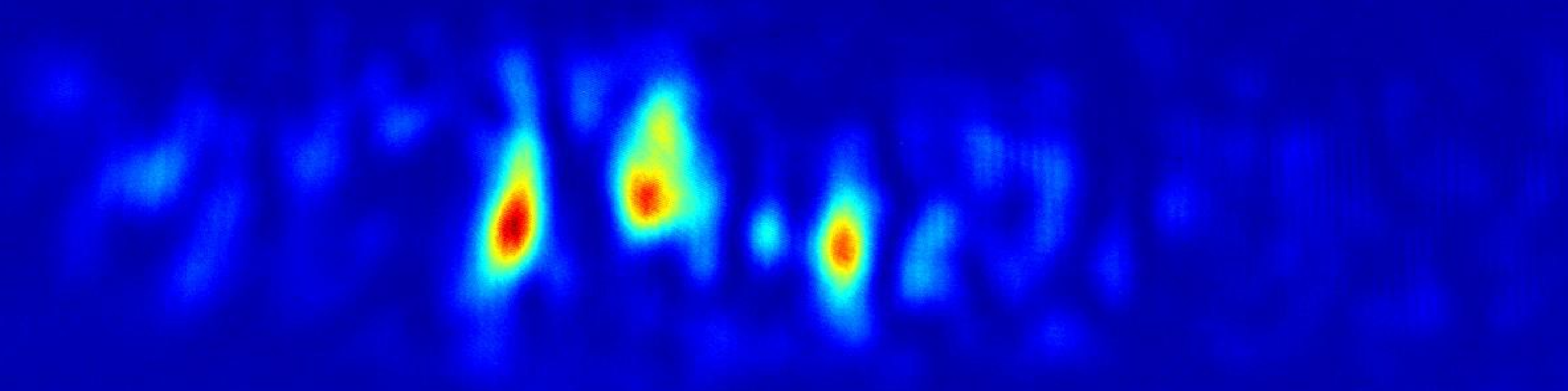


Summary

- Establishing of **scatterometers** for measuring the scatter-properties of different materials
- Efficient tool for testing the suitability of specific materials for, e.g., beam dumps, metals,...
- Application of the measured properties on numerical simulations
- Using the Software “LightTools” for simulation of the scattering of light on the **recoil masses** of the mirrors used in KAGRA
- The results show: **negligible effect** on the sensitivity of KAGRA

Thank you for your attention!

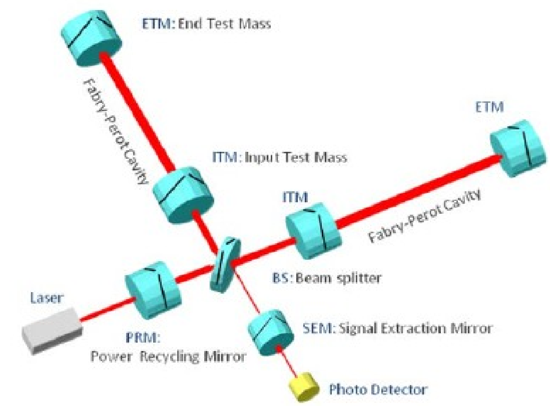


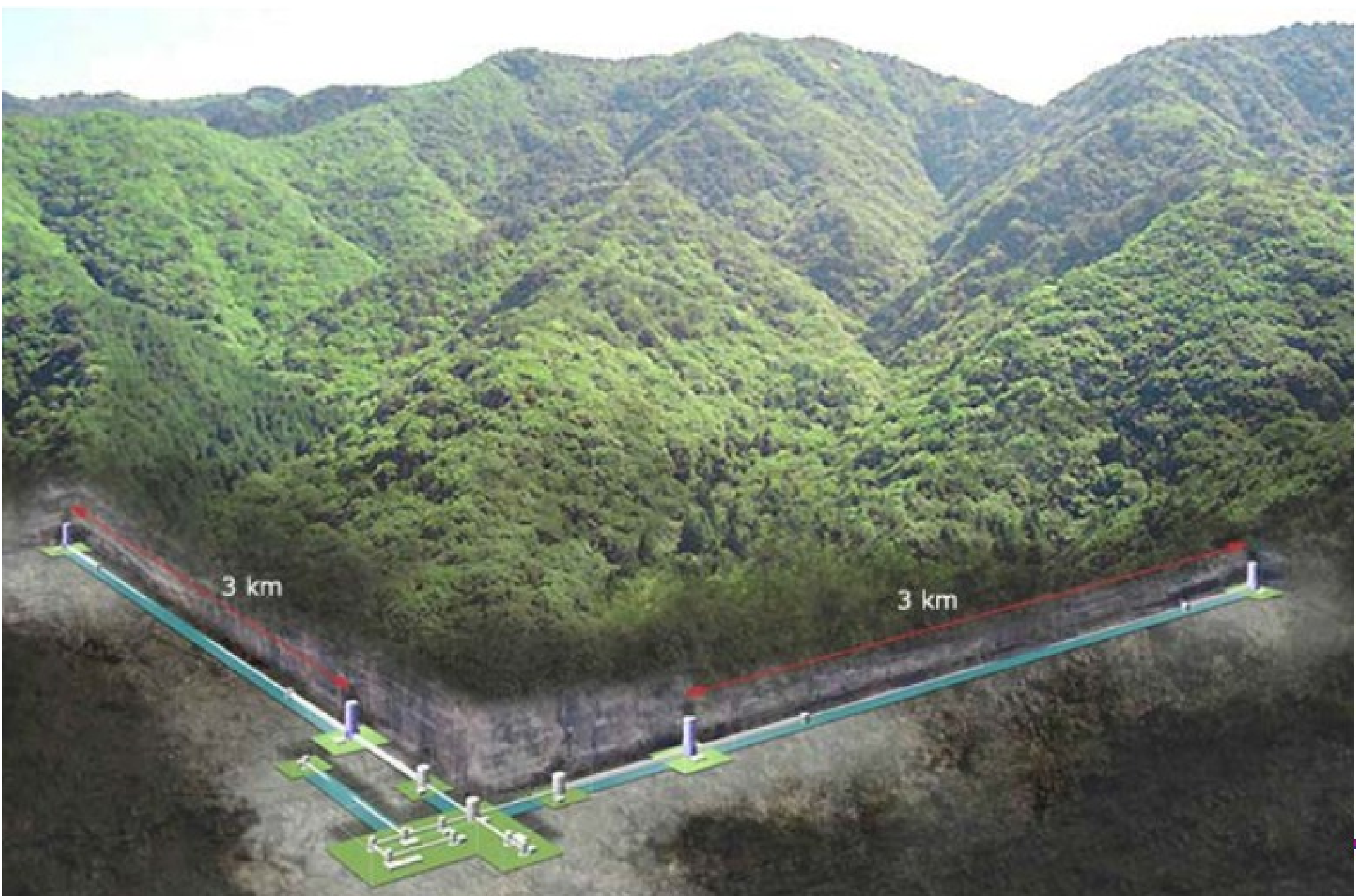
Outlook

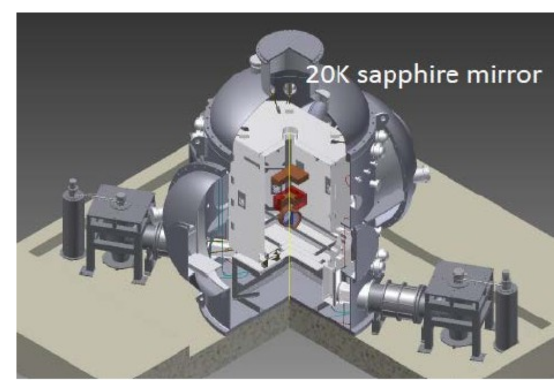
- **SolBlack is magnetic!**
  → testing the influence on other (magnetic) components
- Simulations for the “**Doughnut-Baffle**” in front of the cryo-duct shield
  → Do we need a beam dumper?
  → Which material?
- Simulations for the **other mirrors/optical components** which which are surrounded by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

The KAGRA Project

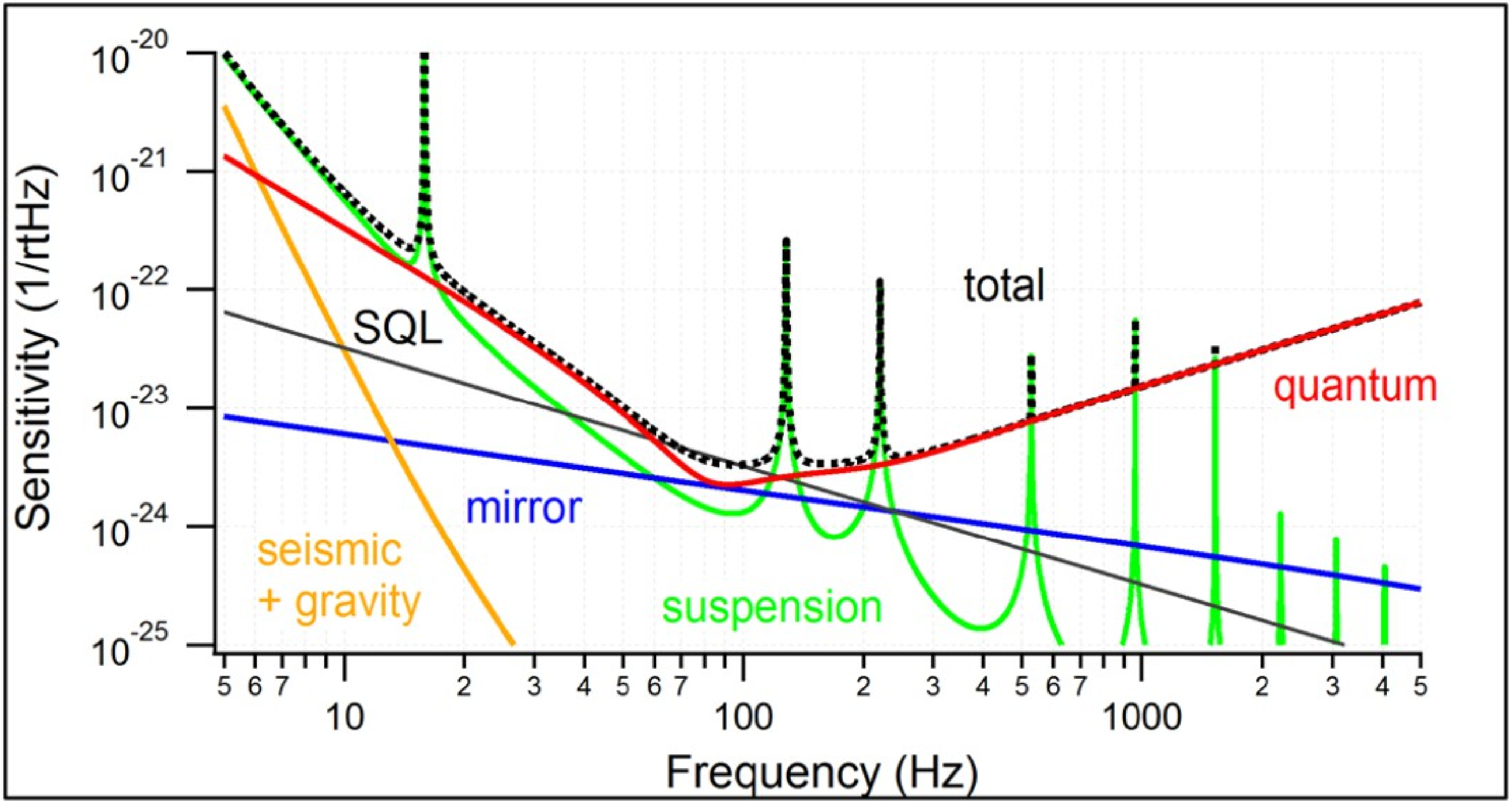
- 3 km long Gravitational-Wave-Detector in the Kamioka mine
- First cryogenic, underground interferometer detector
  - ➔ Reduction of thermal and seismic noise





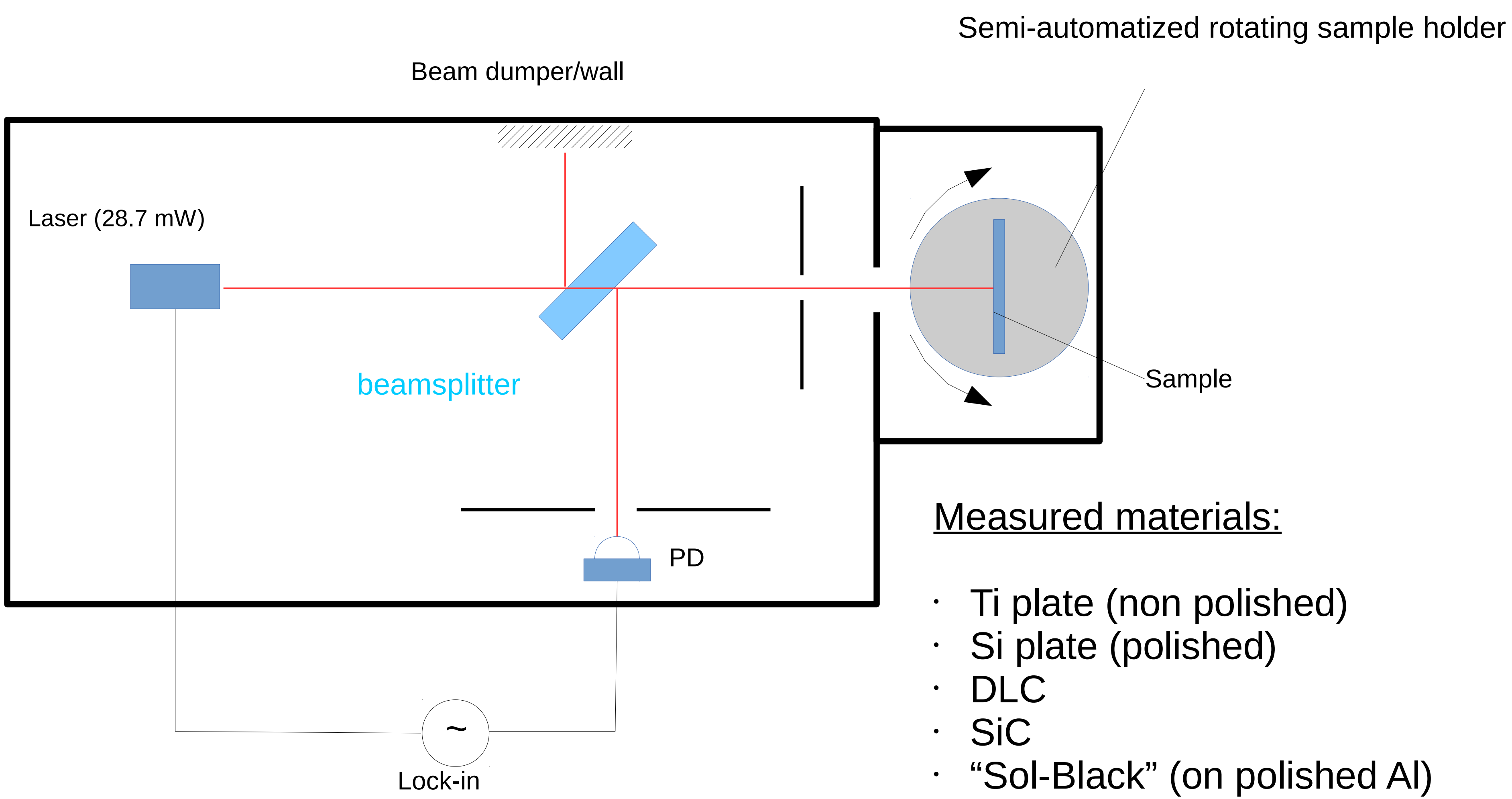


Sensitivity of KAGRA



- 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)

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- DLC
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Basic Application: Analyzing Beam-Dumper

Beam-dumper (and black coatings) shall effectively absorb stray-light

- Black
- Vacuum and cryo compatible
- No disturbing properties (magnetic fields, chemical reactivity, etc.)
- (reasonable prize)

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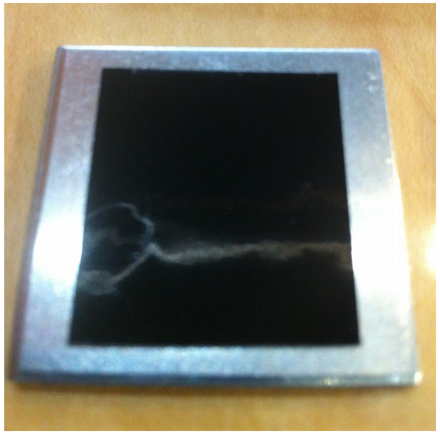
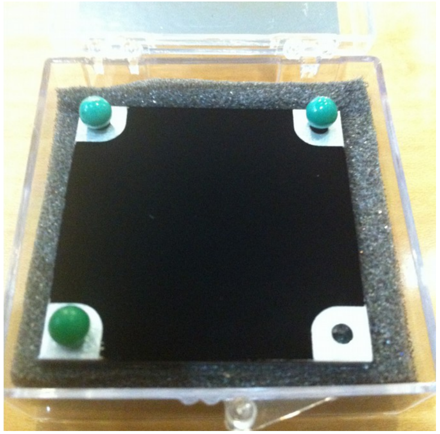
"SolBlack" on Aluminum



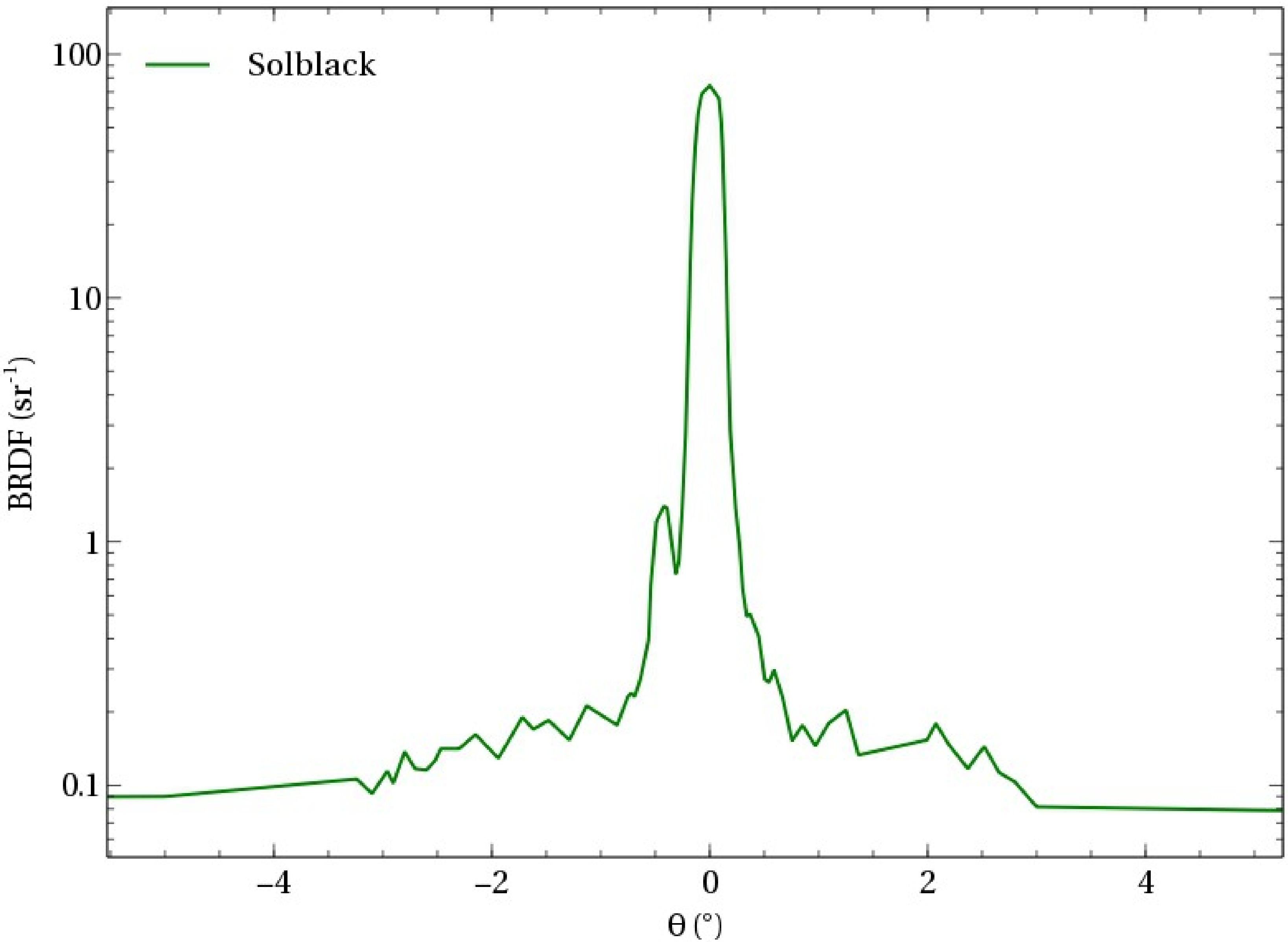
"Spectral Black"

"Metal Velvet"



"VantaBlack" (blackest material on earth)

BRDF of Chosen Beam-Dumper Materials



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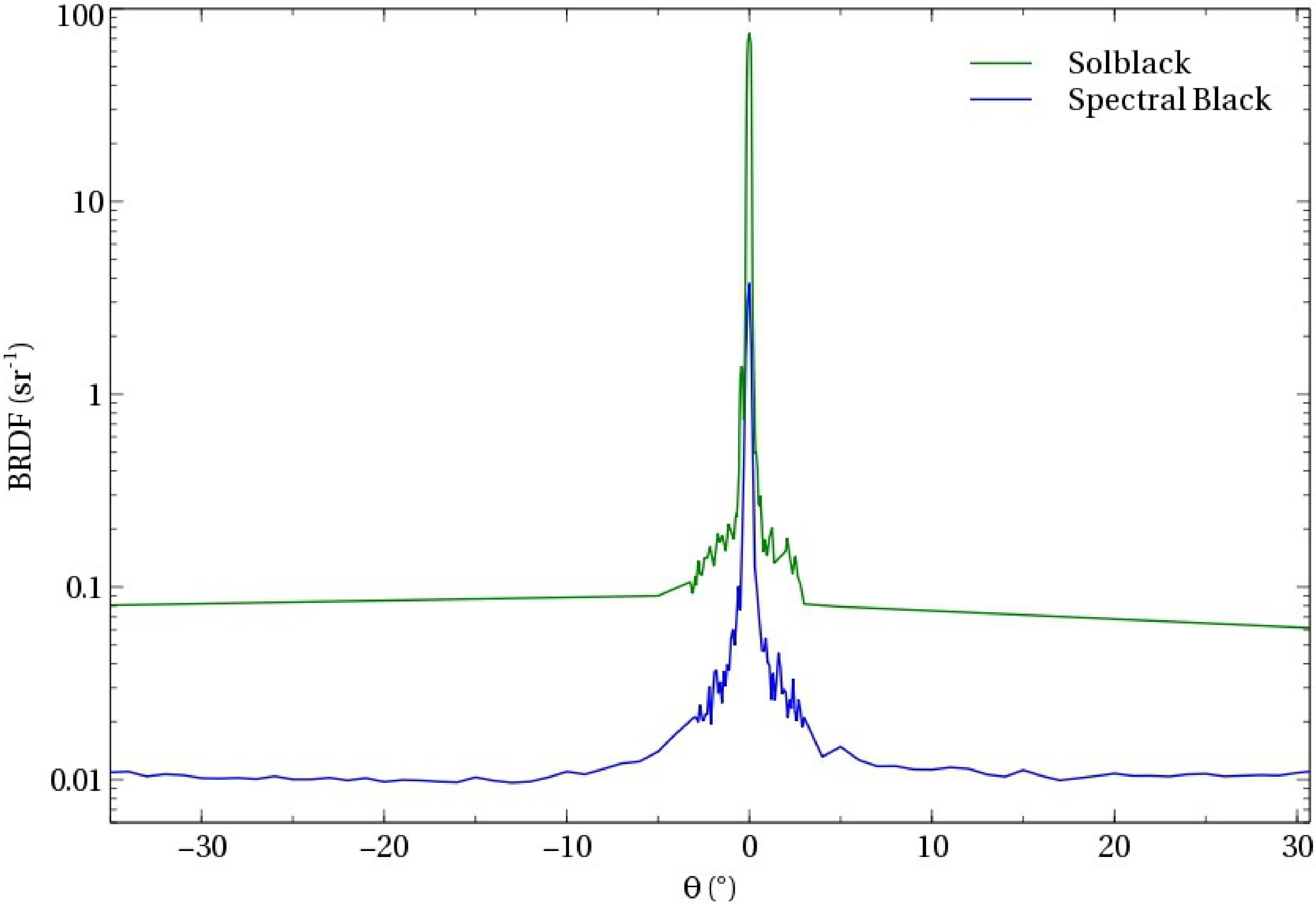

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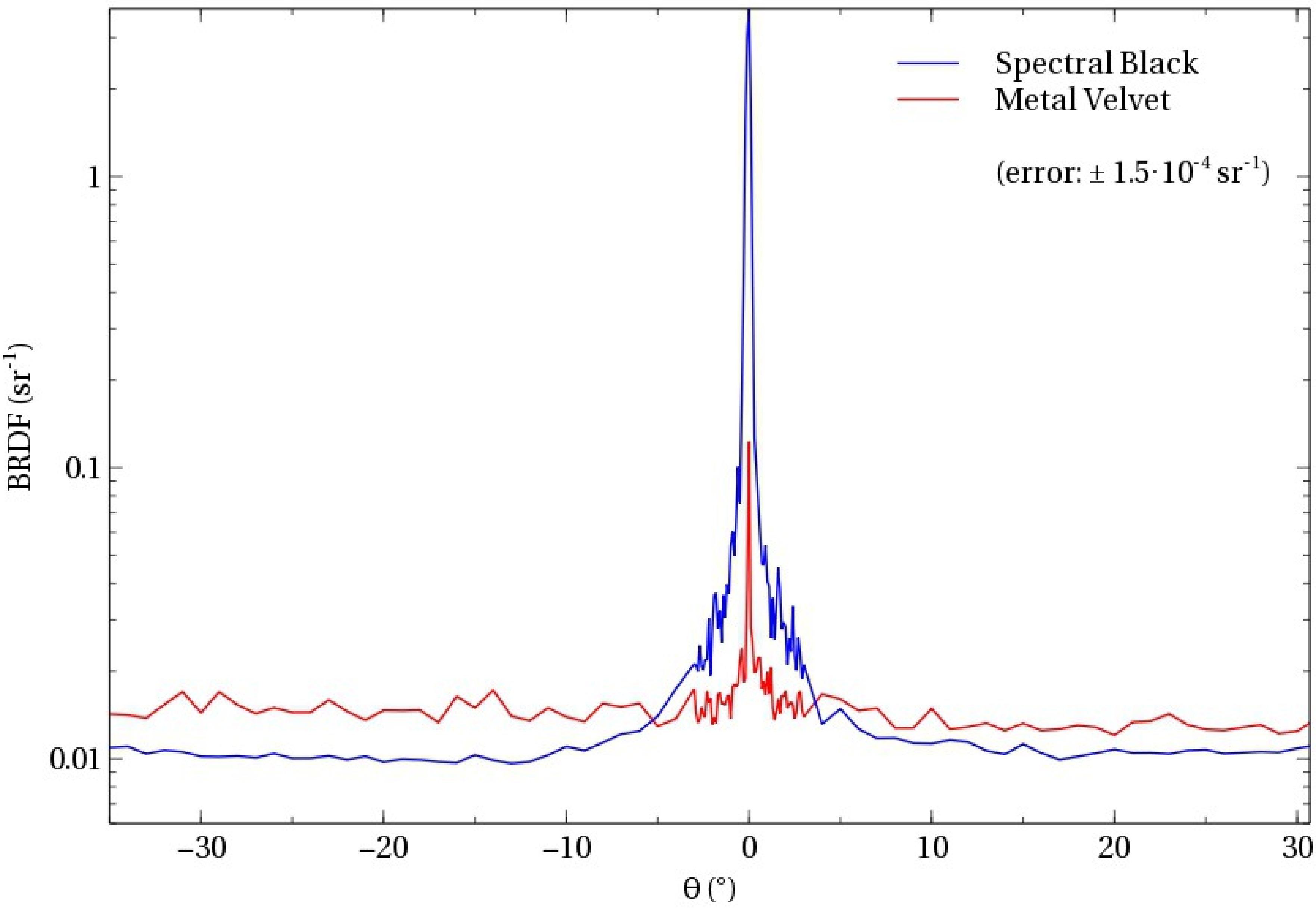

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