Scatterometer at NAOJ: applying material investigations for KAGRA

– Performing Stray-Light Control –

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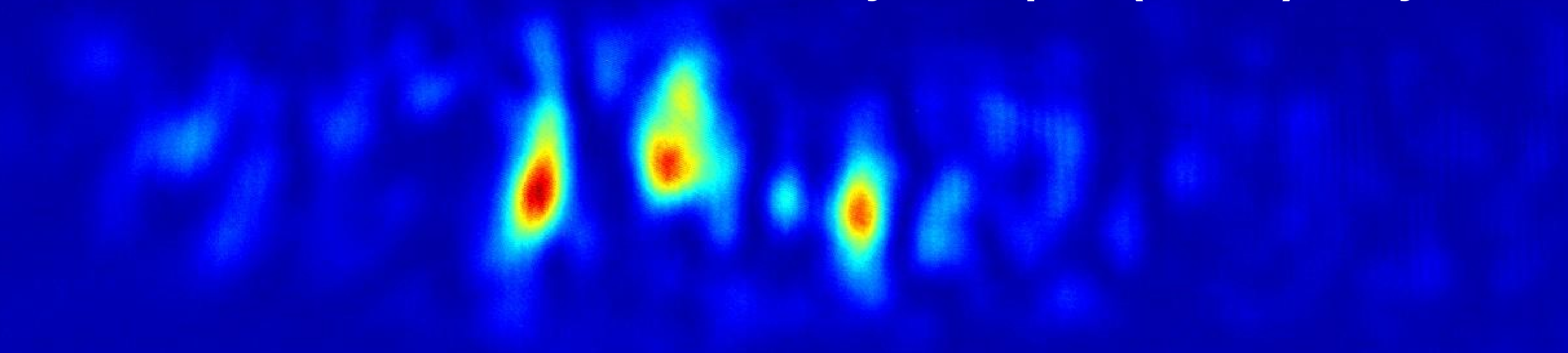
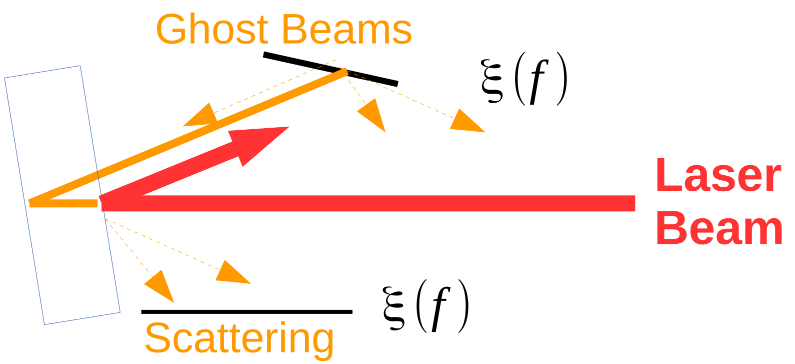
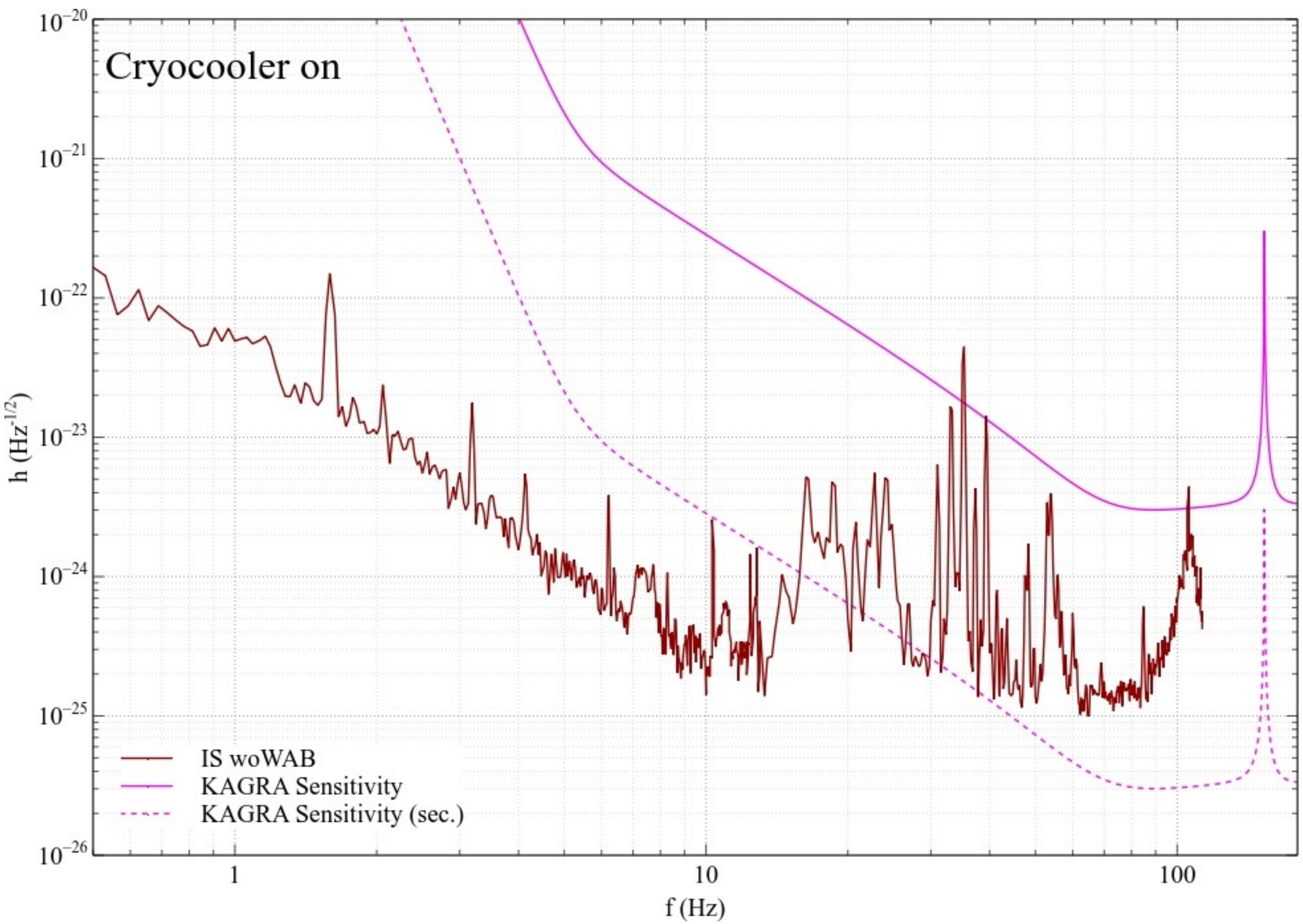


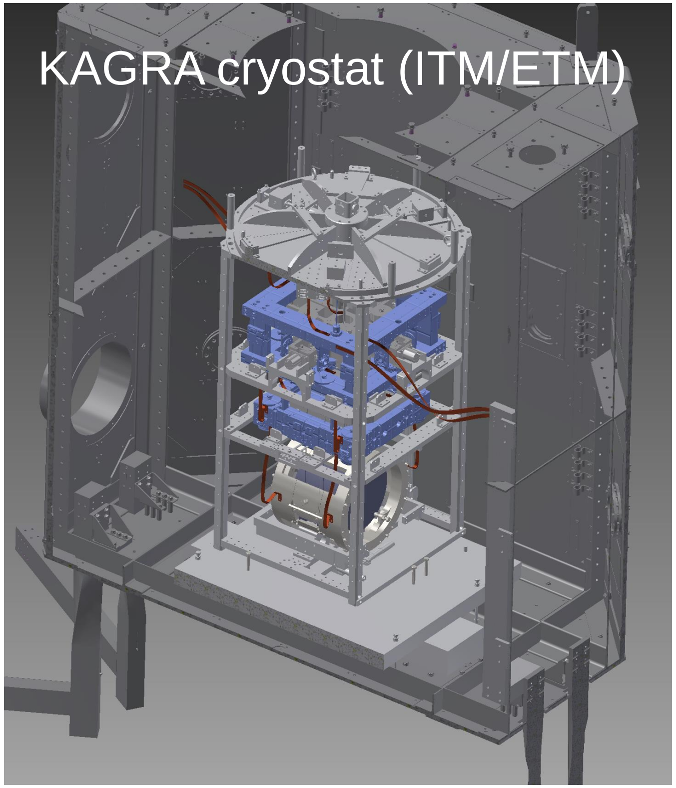
Gravitational Wave Project Office

Importance of Stray-Light Control

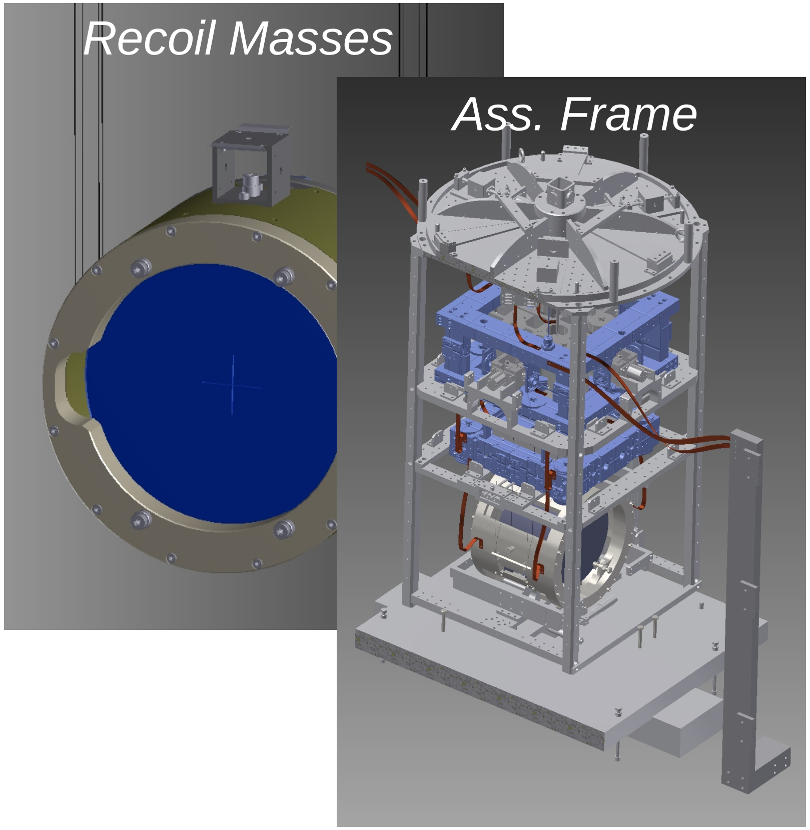


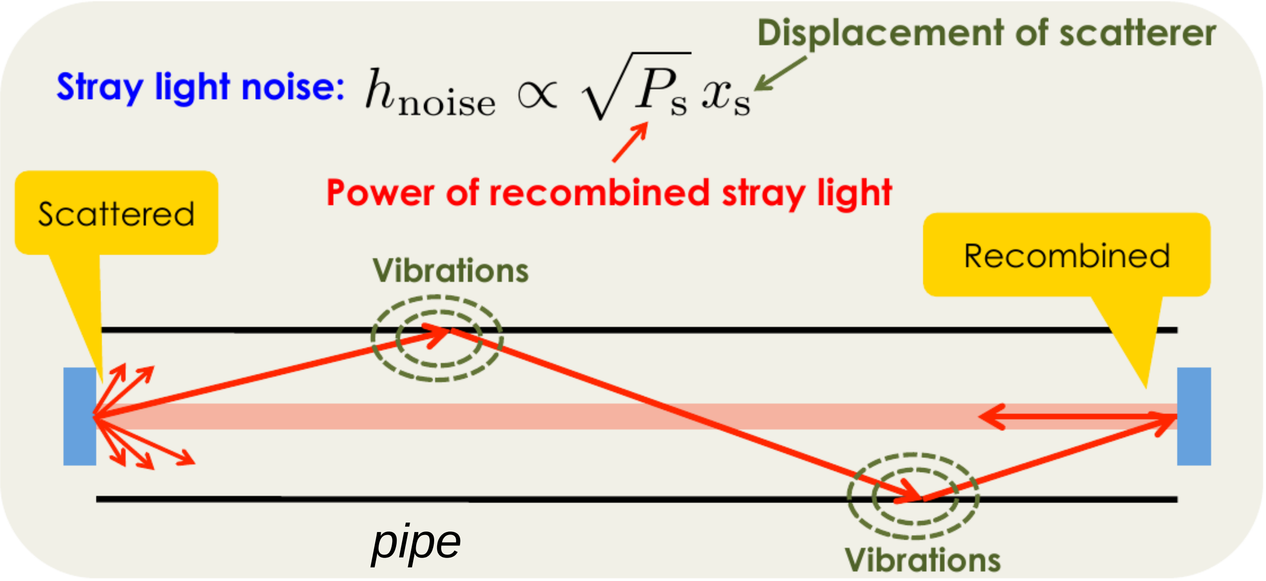
- Gravitational wave detectors measure strain through phase differences
- **Recoupled scattered light** and **ghost beams** may carry phase noise
- Effect of scattered light on gravitational wave strain:

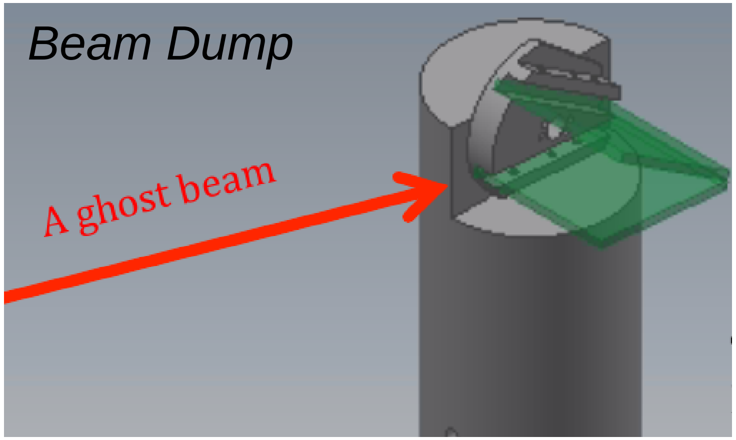




Where Scattering may Appear







- Basically, all surfaces produce scattering
- Most important parameters:
  - Suspension
  - Surface characteristics

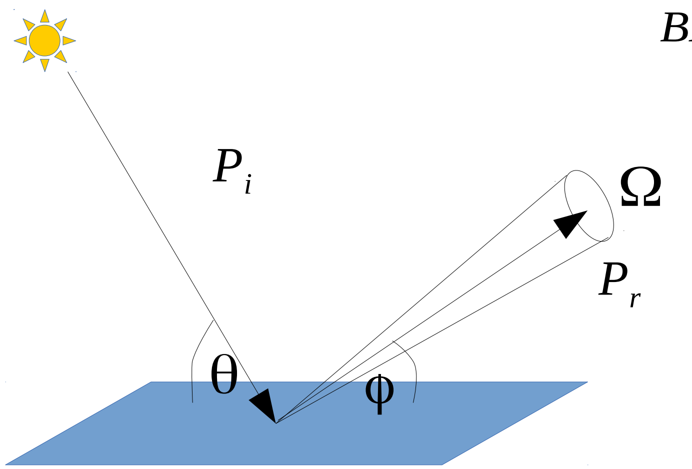
Measuring the Scattering

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

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

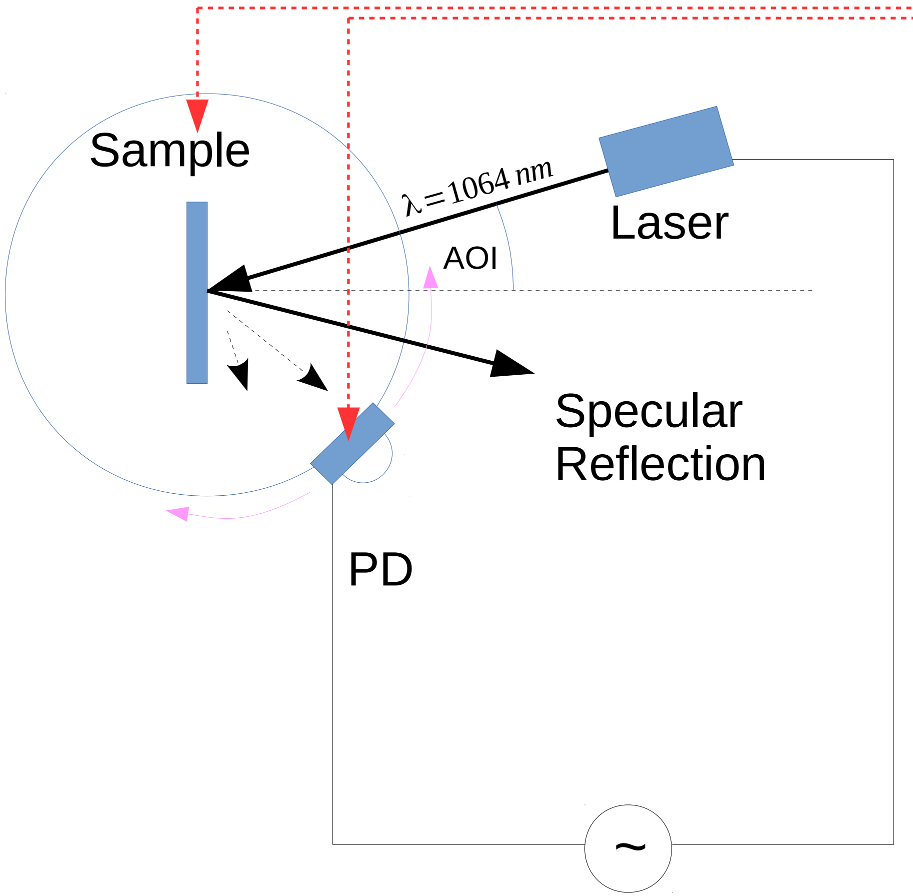
$$BRDF(\theta,\phi)=\frac{\partial L_r(\phi,I_r)}{\partial E_i(\theta,I_i)};\quad L_r=\frac{\partial P_r}{\partial A\,\partial\Omega\cdot\cos(\phi)}$$ → Radiance

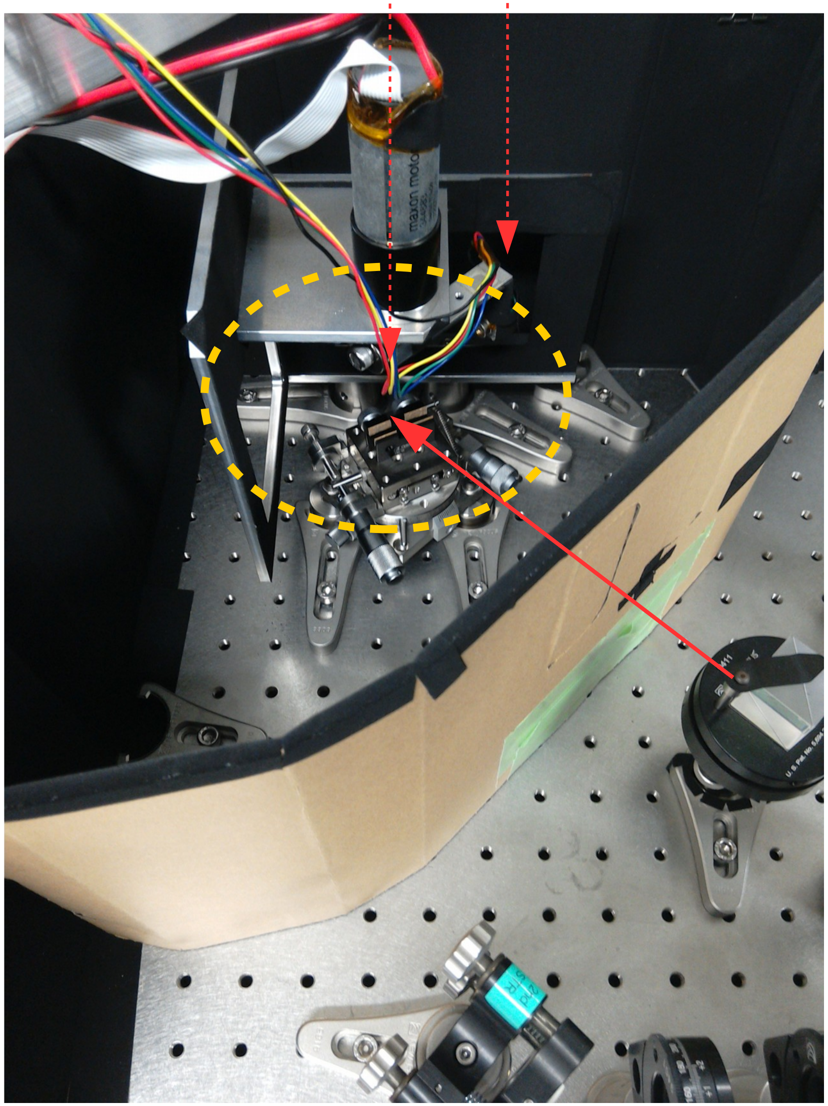
$$E_i=\frac{\partial P_i}{\partial A}$$ → Irradiance



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

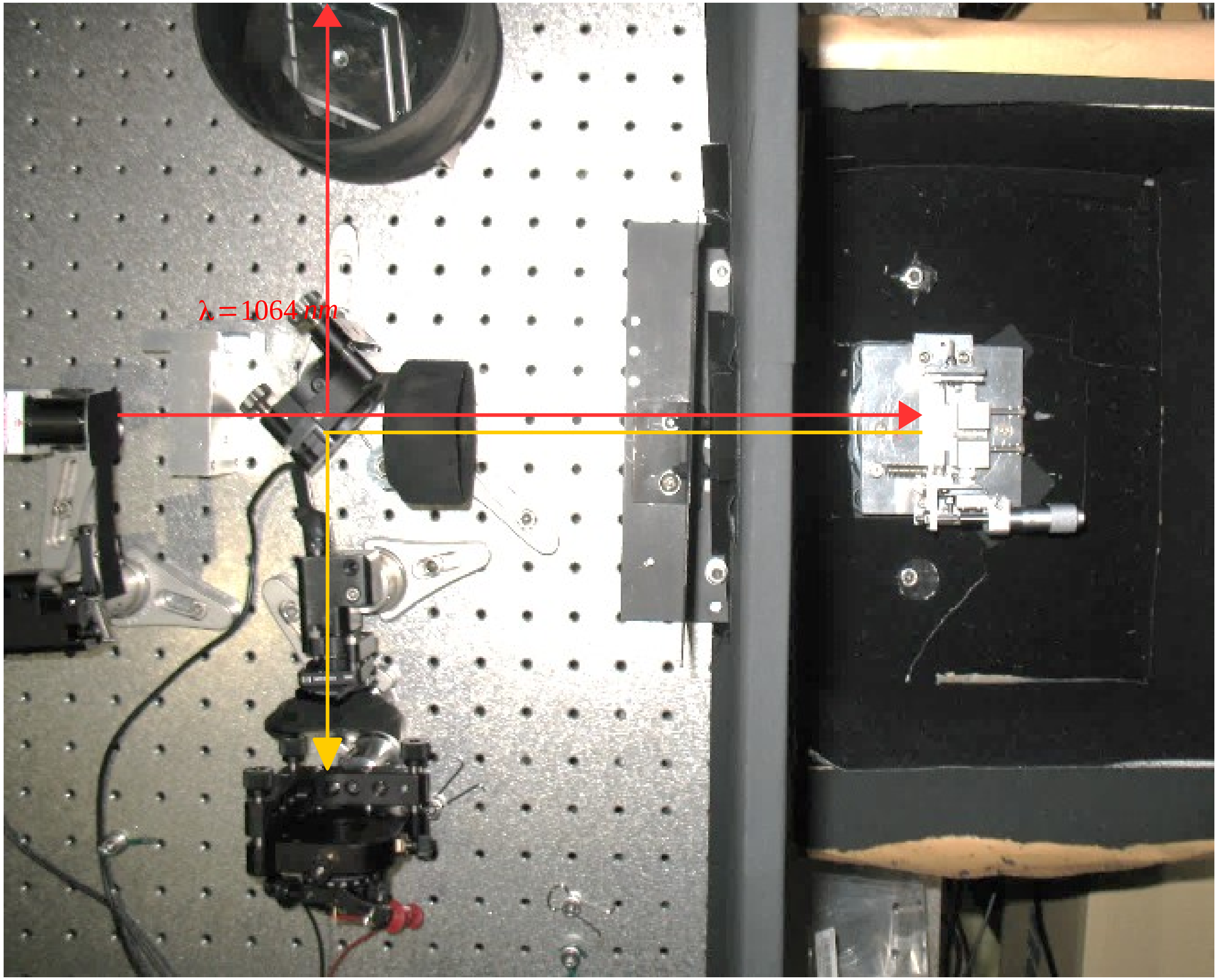
Setup of Hemispherical Scatterometer at NAOJ





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

Backscattering Measurements (Back-Scatterometer)



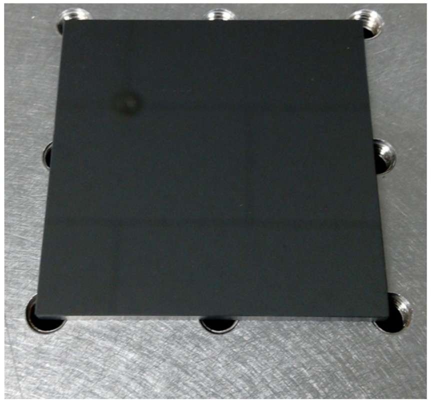
Measuring of what comes directly back!

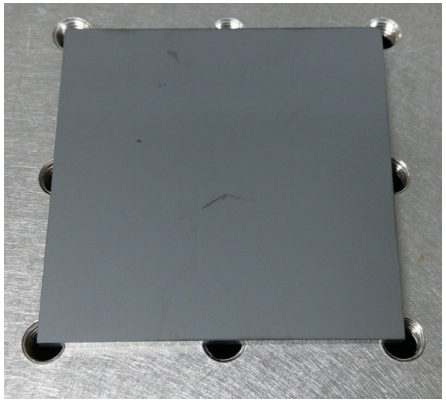
$$BRDF(\theta)=\frac{4\cdot I_{PD}(\theta)\cdot f_{PD}}{P_{laser}\cdot\Omega\cdot\cos(\theta)}$$

Materials for Stray-Light Control: SiC

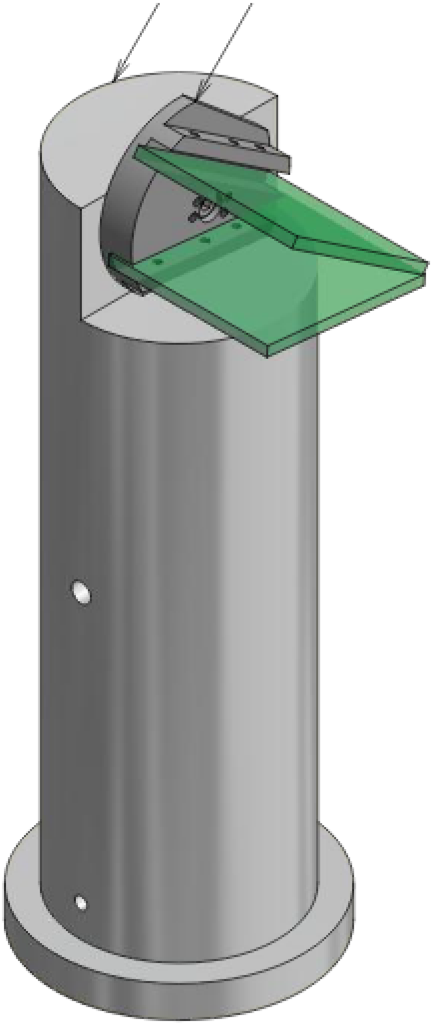
- Hard, thermally and chemically resistant material (sublimation temperature: ~2700°C)
- high thermal conductivity: 360 – 490 W/(m·K)
- low outgassing
- **high-power beam dumps** (e.g., close to Faraday isolator)

However, optical properties strongly depend on manufacturing process!





Different polishing methods
left: Ra ~ 2 nm; right: Ra ~ 11-18 nm

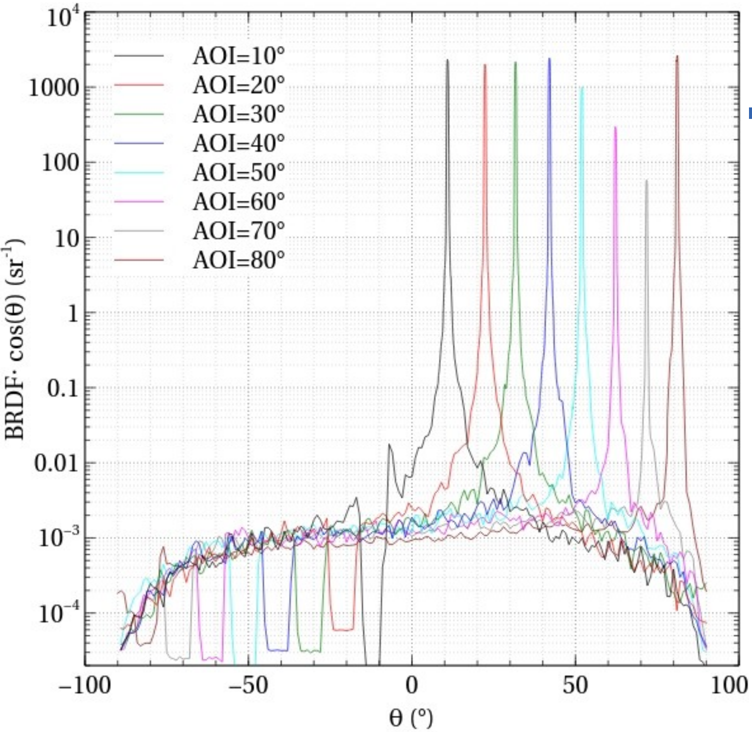


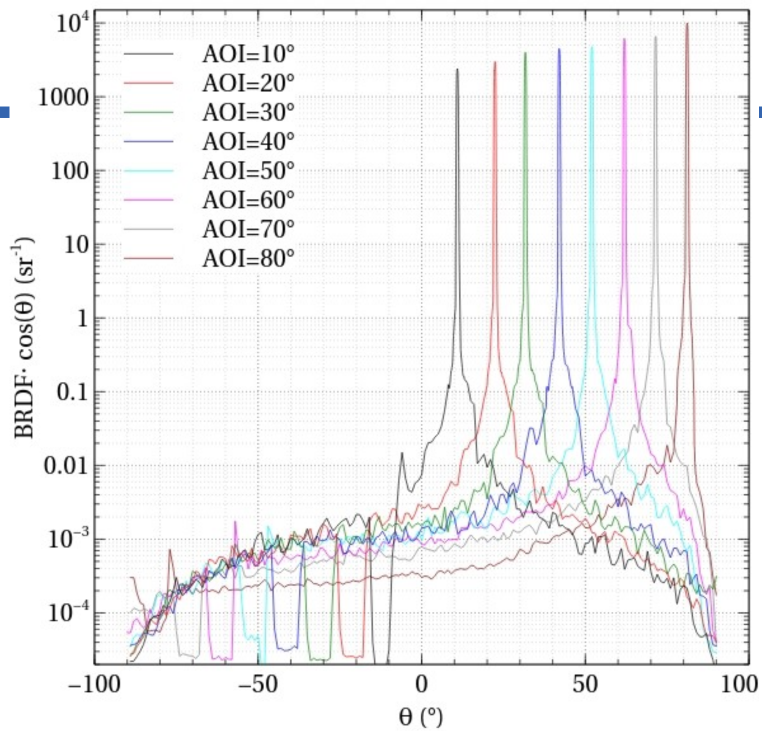
Beam dump design

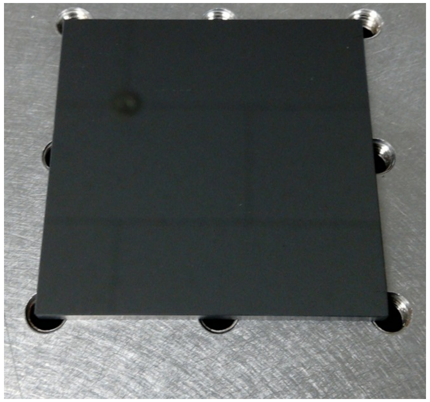
国立天文台 NAOJ National Astronomical Observatory of Japan

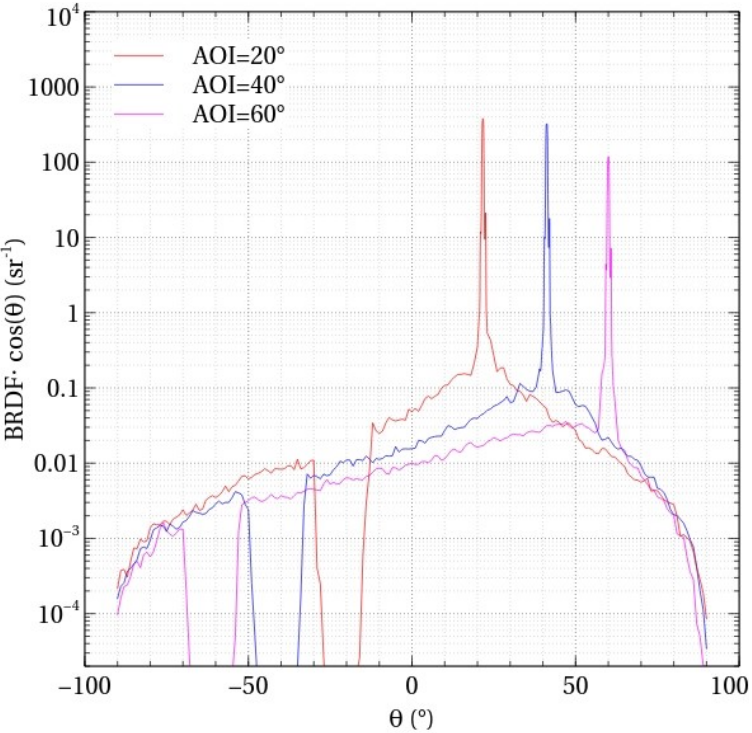
P-Polarization

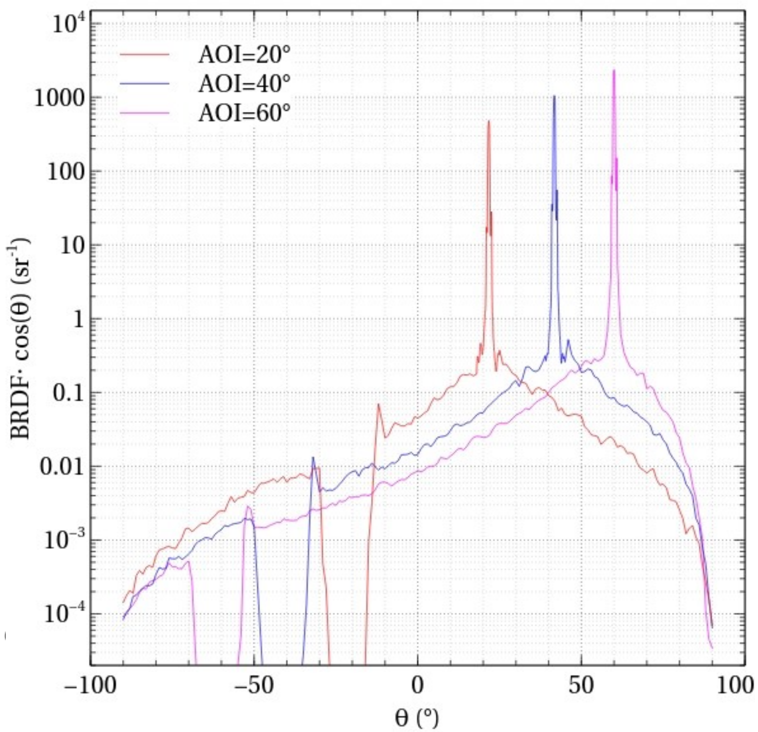
S-Polarization

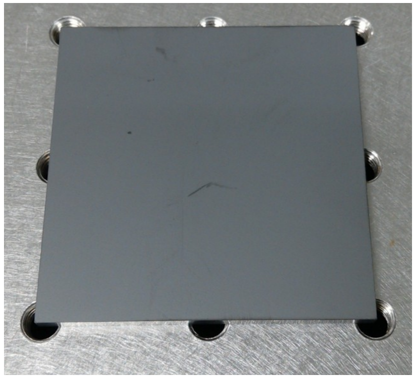


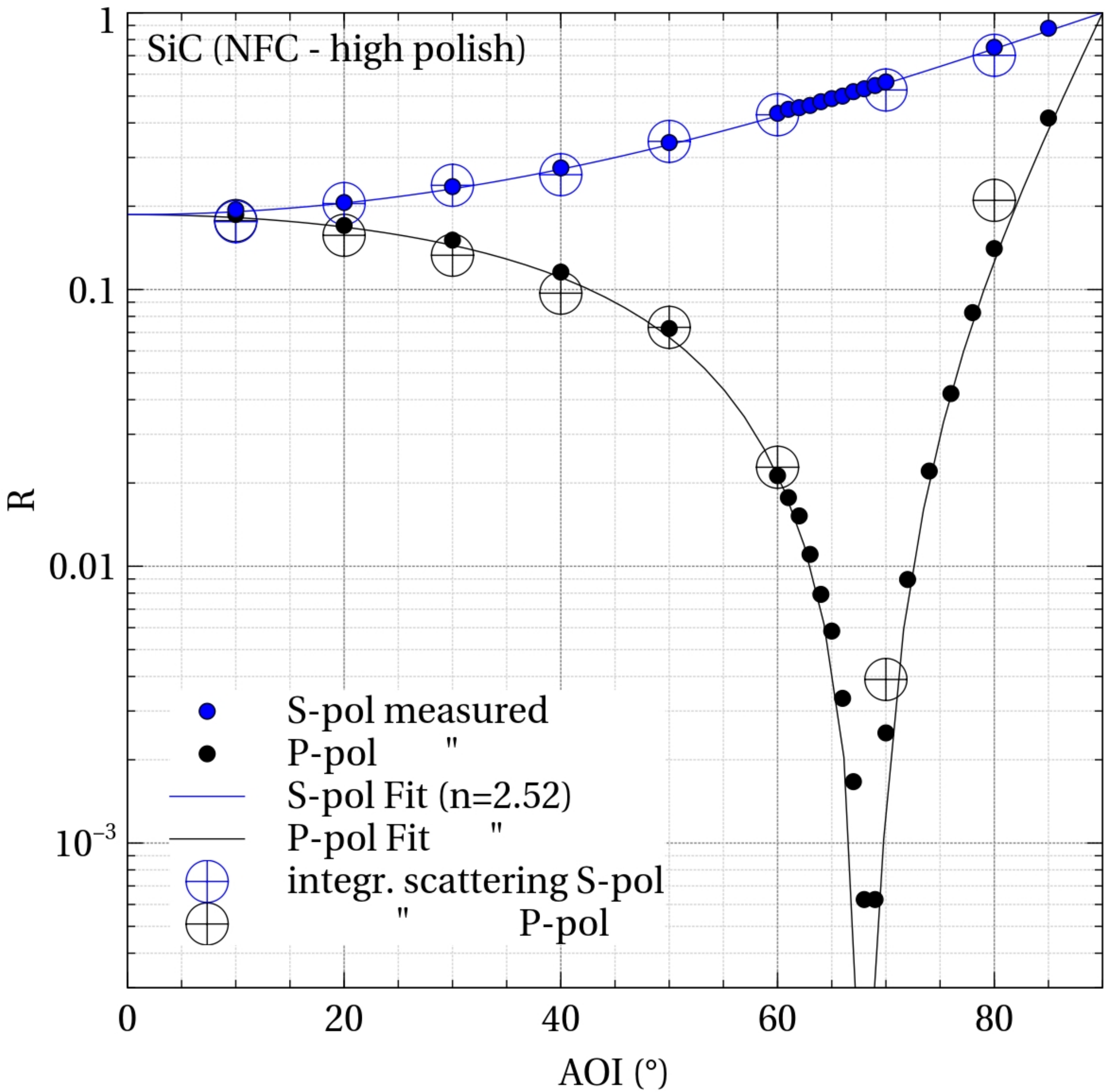






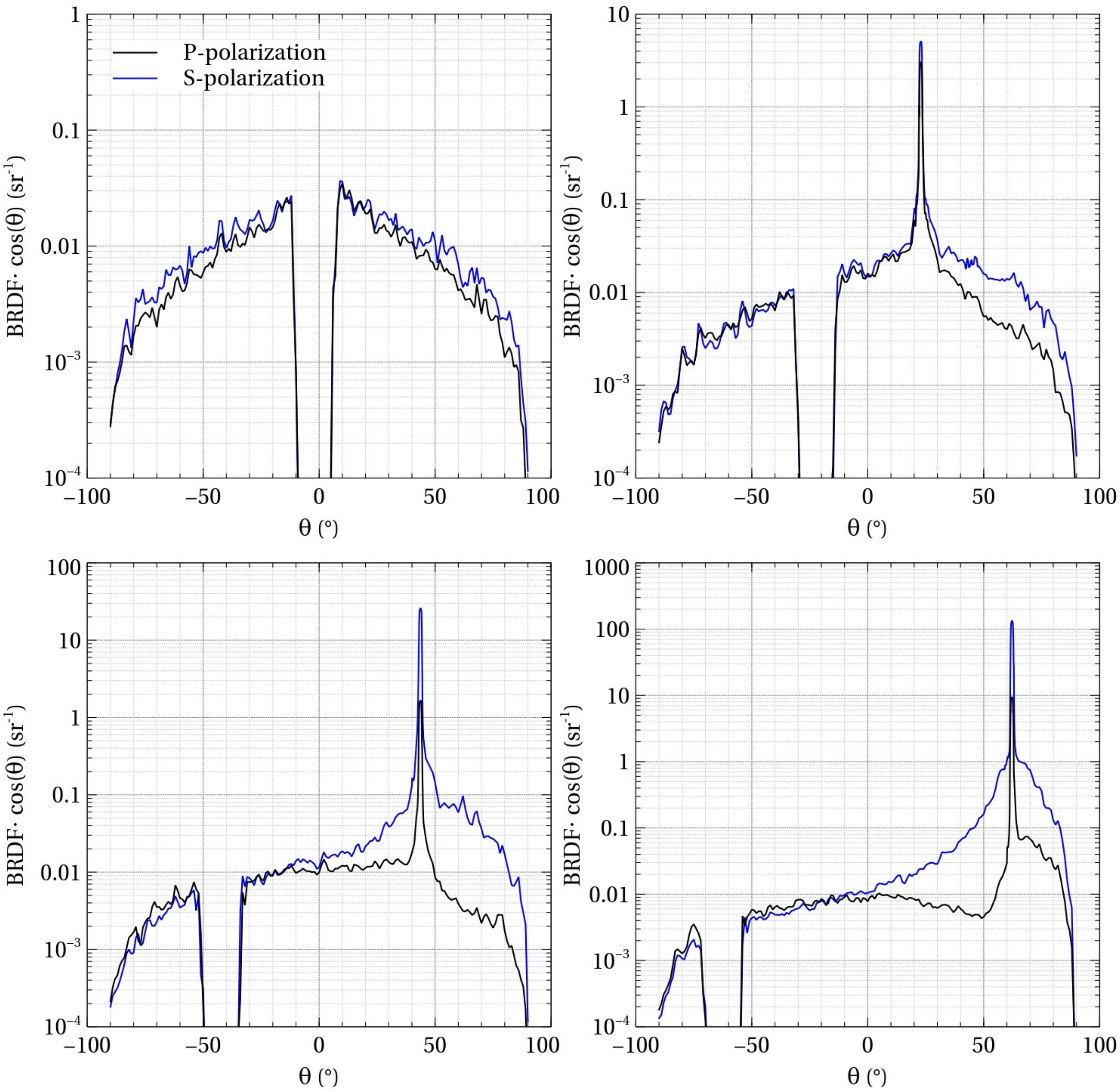


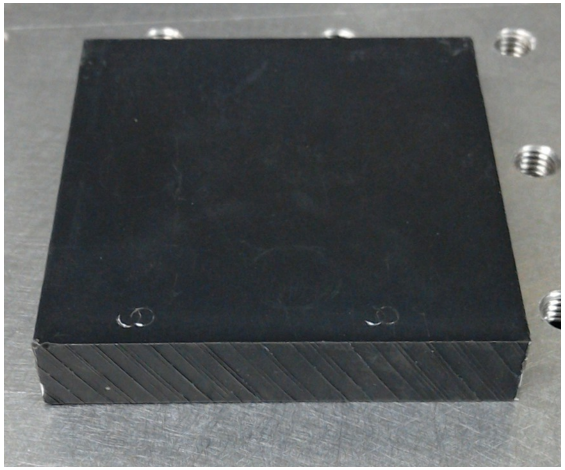




SiC (NFC - high polish)
1
0.1
0.01
10^{-3}
R
0
20
40
60
80
AOI (°)
S-pol measured
P-pol "
S-pol Fit (n=2.52)
P-pol Fit "
integr. scattering S-pol
" P-pol

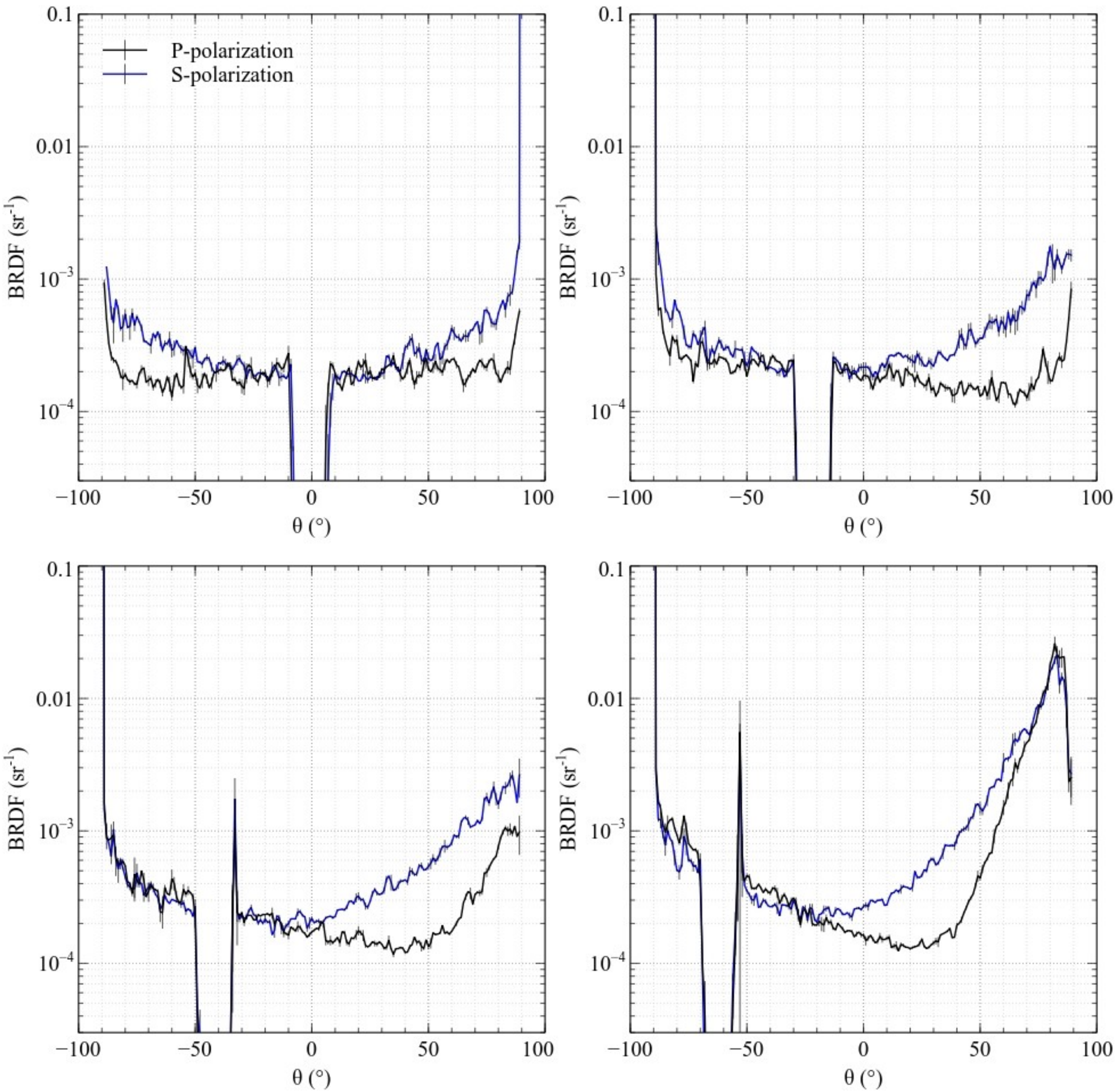
Materials for Stray-Light Control: “Solblack”

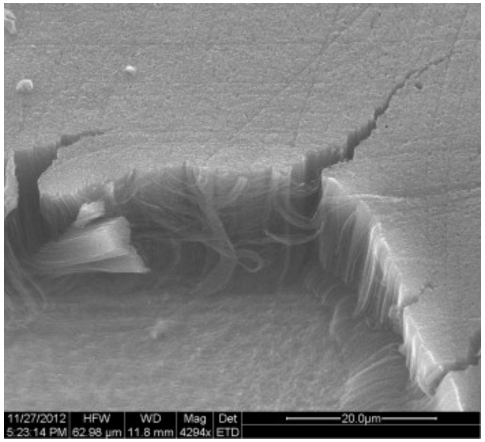




- Phosphor-Nickel based coating on anodized Aluminum
- Main “black-coating” material for AOS in KAGRA
- Cheap
- Large surfaces easily coated

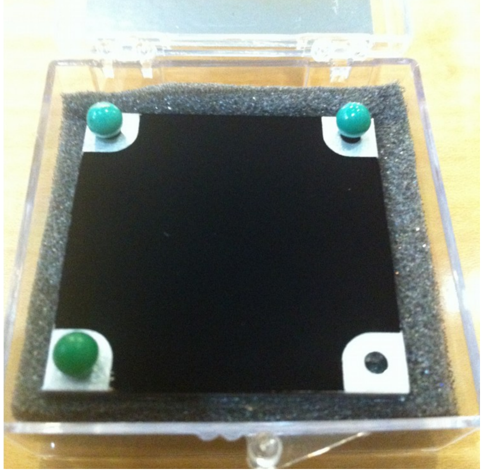
Materials for Stray-Light Control: VANTA-Black



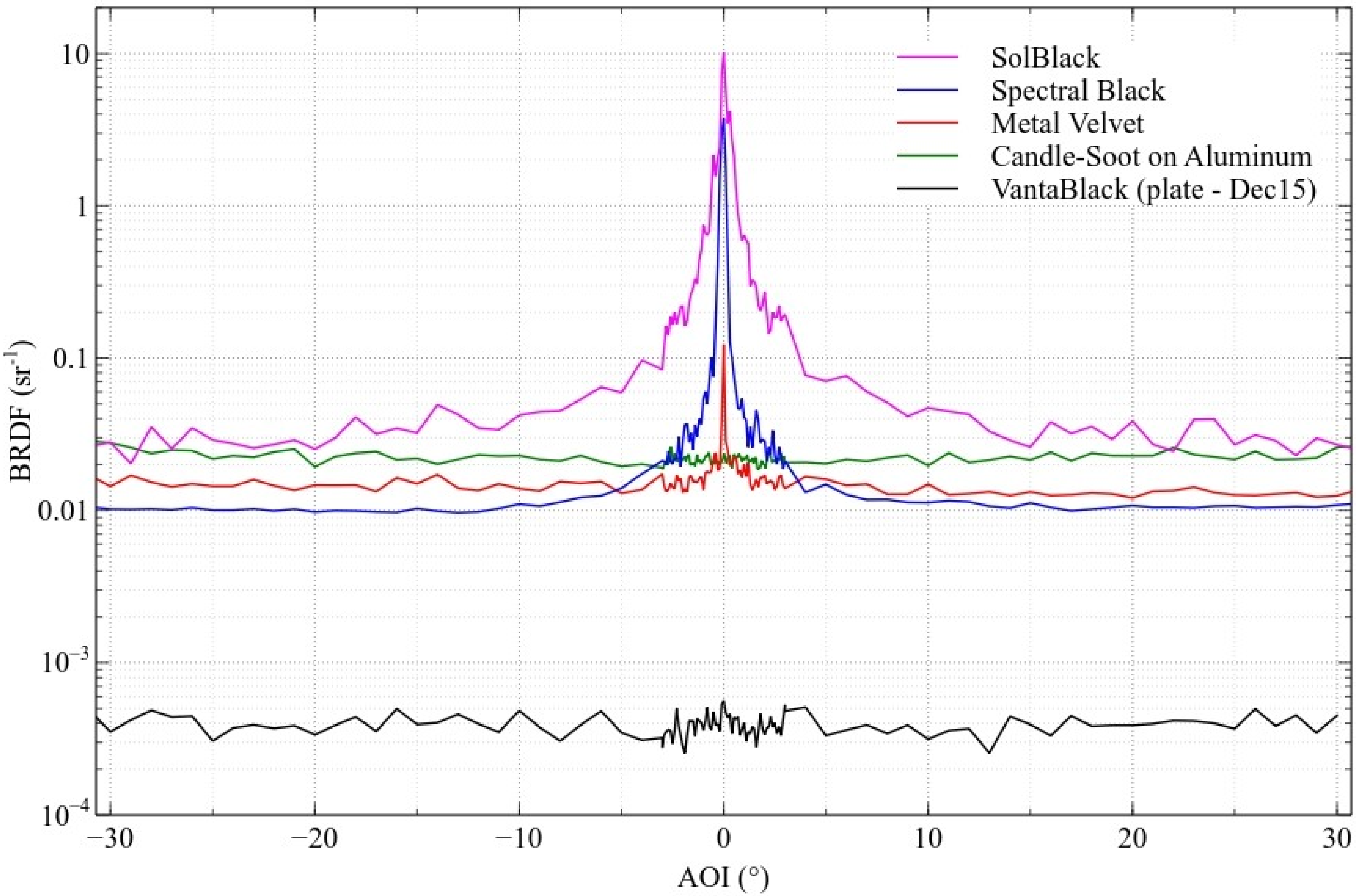


Nanotube array developed in 2014 by Surrey-NanoSystems ©

- 20-30 μm long carbon nanotubes
- low outgassing
  → 10^{-5} Pa·m^3·s^{-1}·m^{-2}
- No specular reflection!



Direct Back-Scattering Comparison



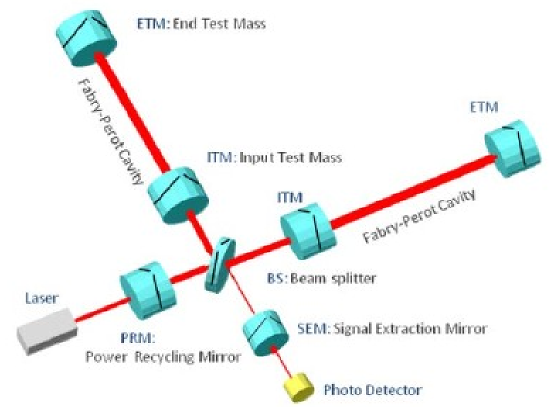
Summary

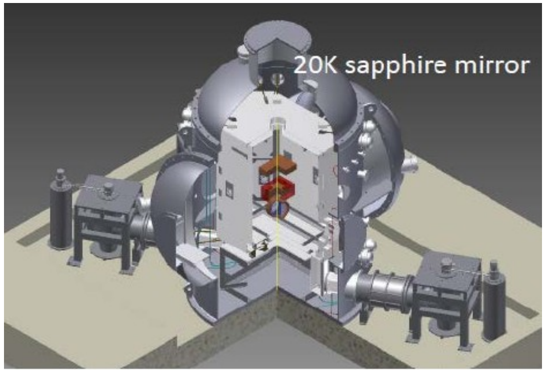
- Developed devices for measuring the scattering properties of any material (down to 10^{-5} sr^{-1})
- Characterization of materials that are of interest for AOS
- SiC, “SolBlack”, VANTA-Black, …
- Characterization of coated mirrors (amorphous; crystalline)

Thank you for your attention!

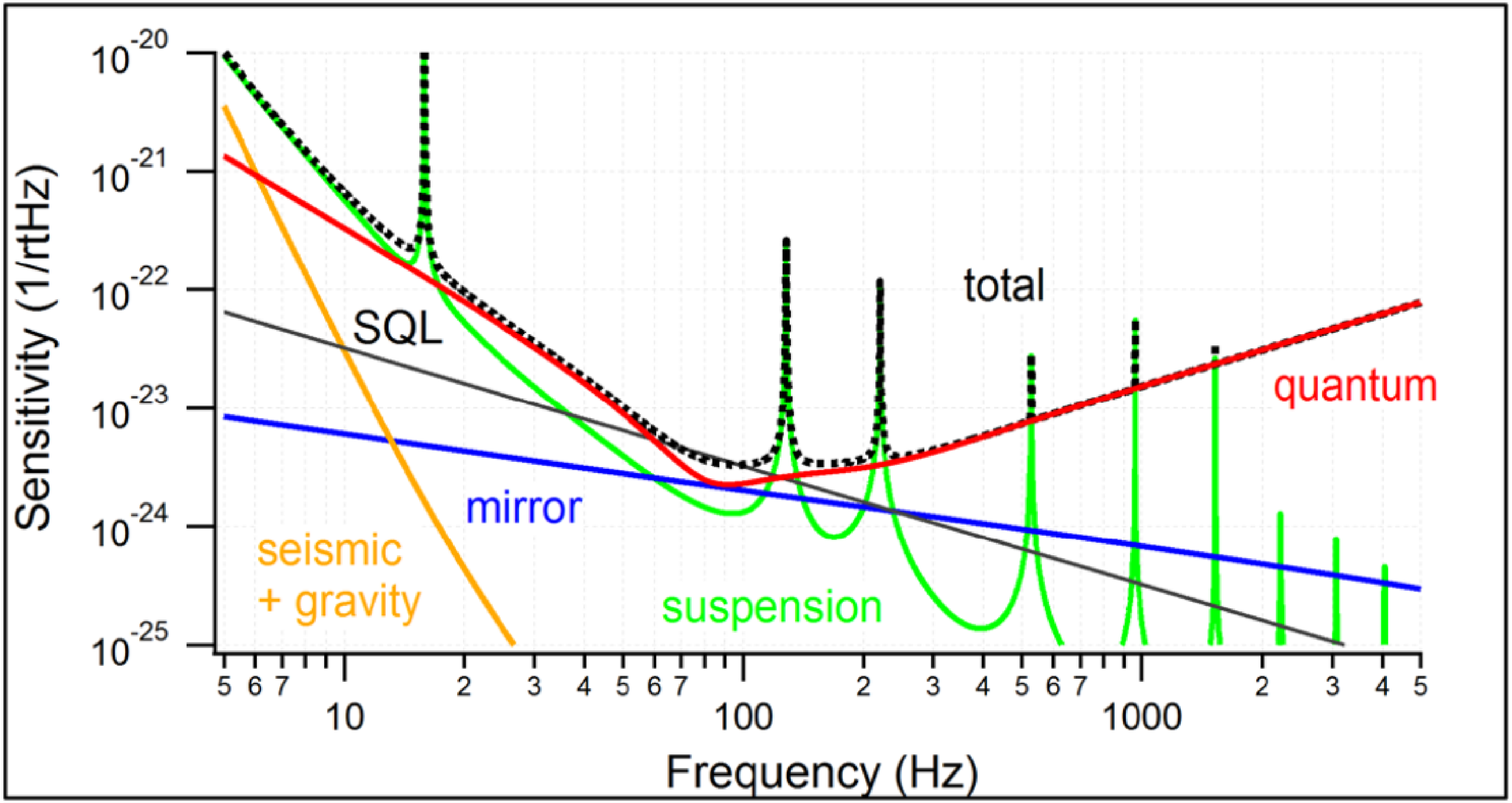
The KAGRA Project

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



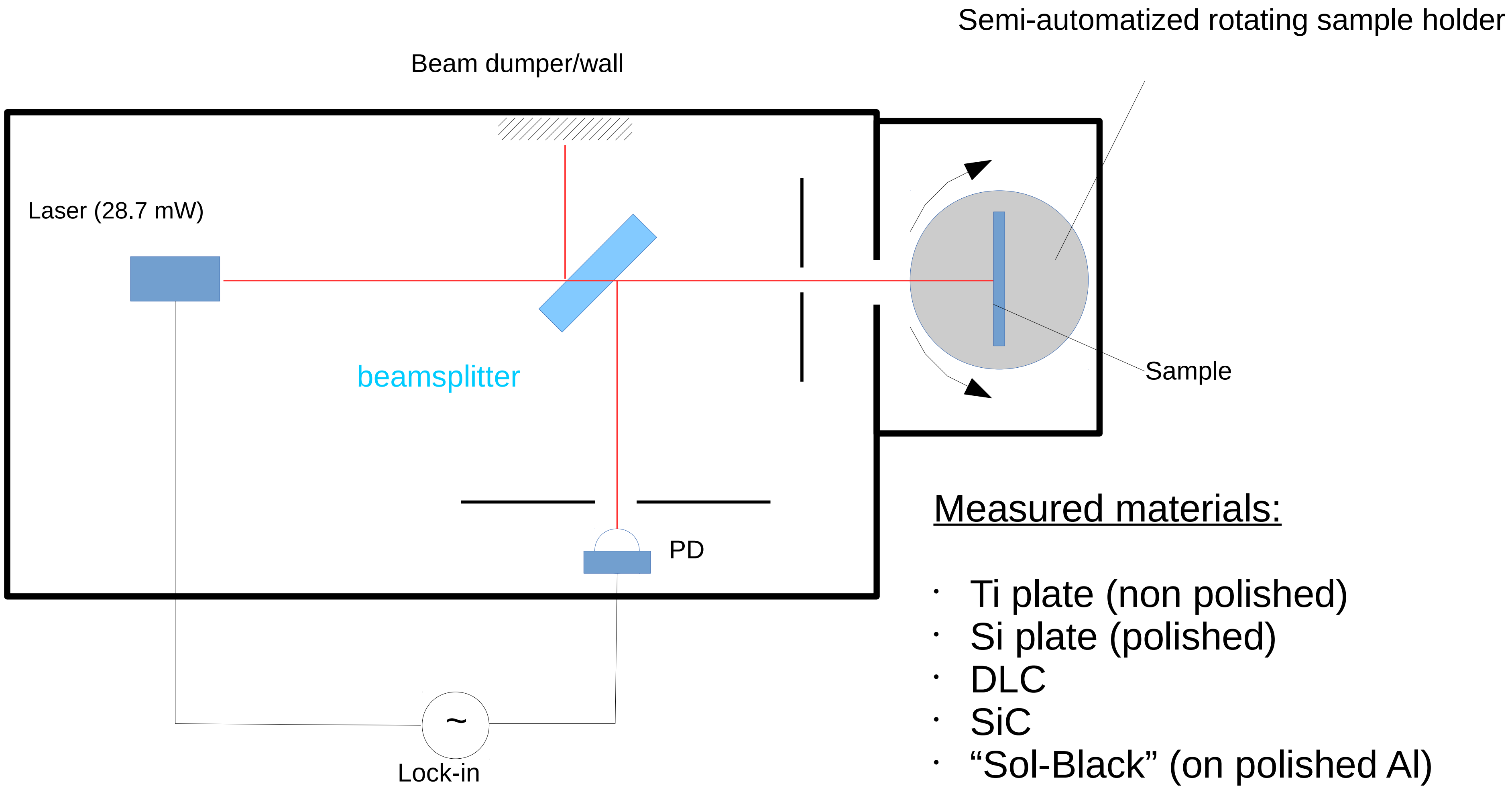


Sensitivity of KAGRA



- 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”)