Specular BSDF Measurement Capability at NASA GSFC using a Table-Top Goniometer in Support of the Calibration of Remote Sensing Instruments

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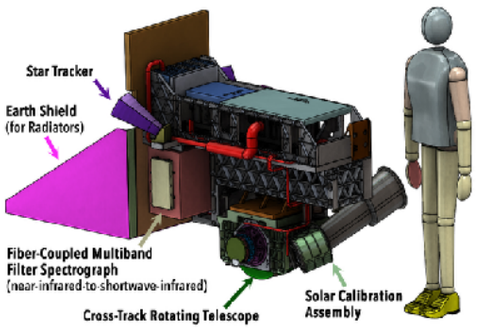
CALCON 2019
Logan, UT

Motivation

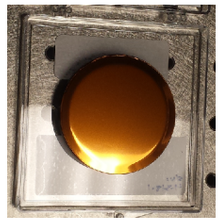
New BSDF measurement capability for specular/polished surface using TTG (Laser-based goniometer, large dynamic range, low instrument signature, flexibility to accommodate different optical surfaces)

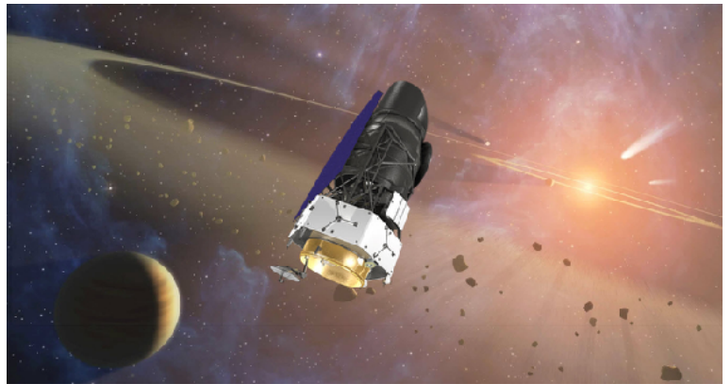
- **BRDF scales for specular/polished surface**
- **Methodology of extracting the parameters of ABg models by taking into account of deconvolution of light beam profile and detector aperture.**
- **Determination of roughness parameters for smooth surfaces (microroughness)**
- **Used to predict the stray light performance of an optical system**

PACE Plankton, Aerosol, Cloud, ocean Ecosystem



MLI: Multi-layer Insulation





WFIRST
Wide Field Infrared Survey Telescope

Dark mirror coating

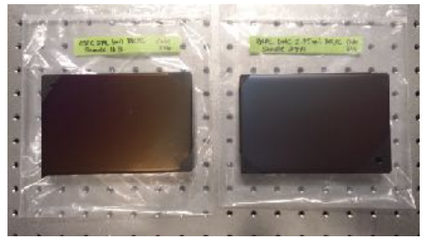
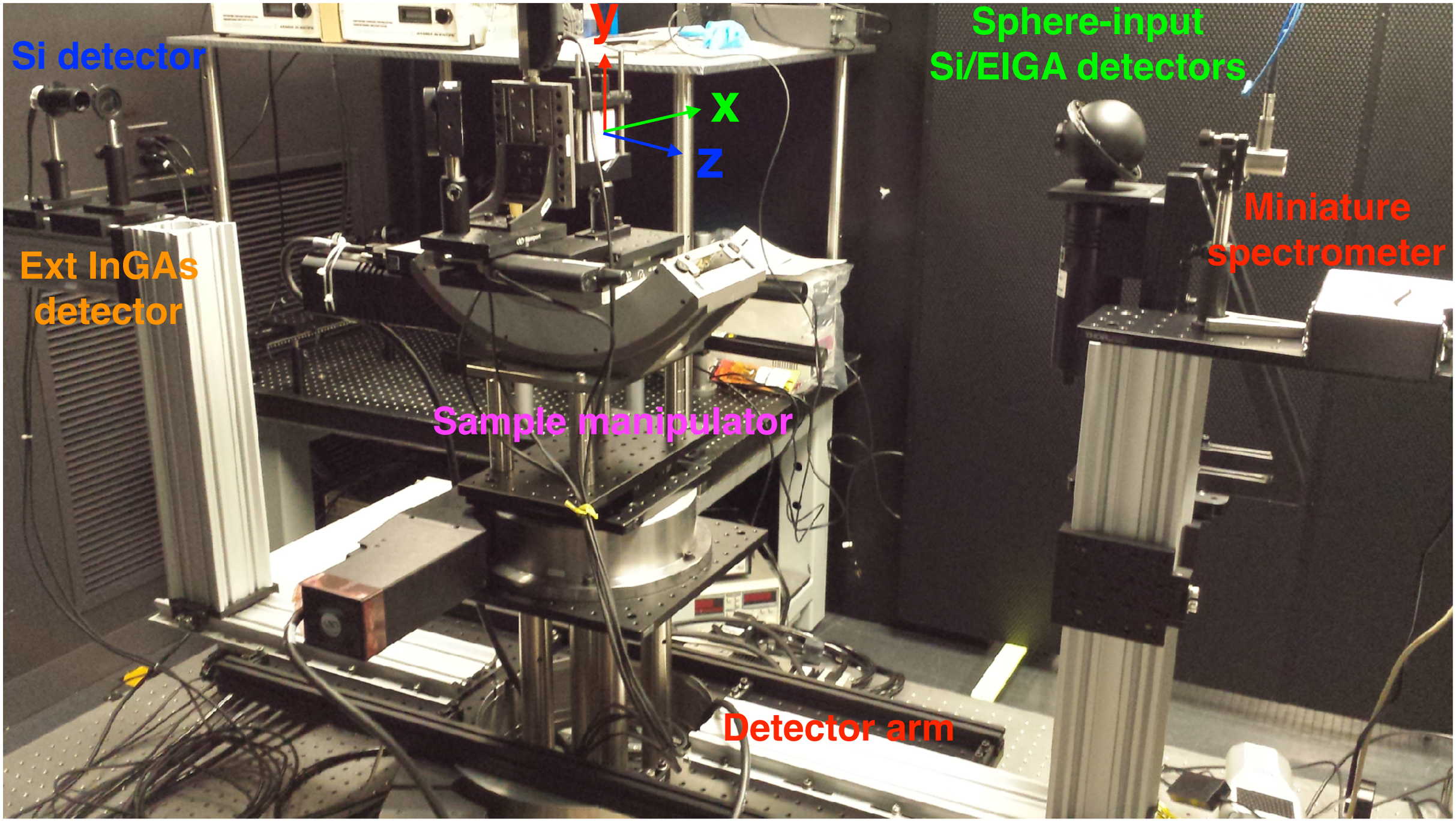
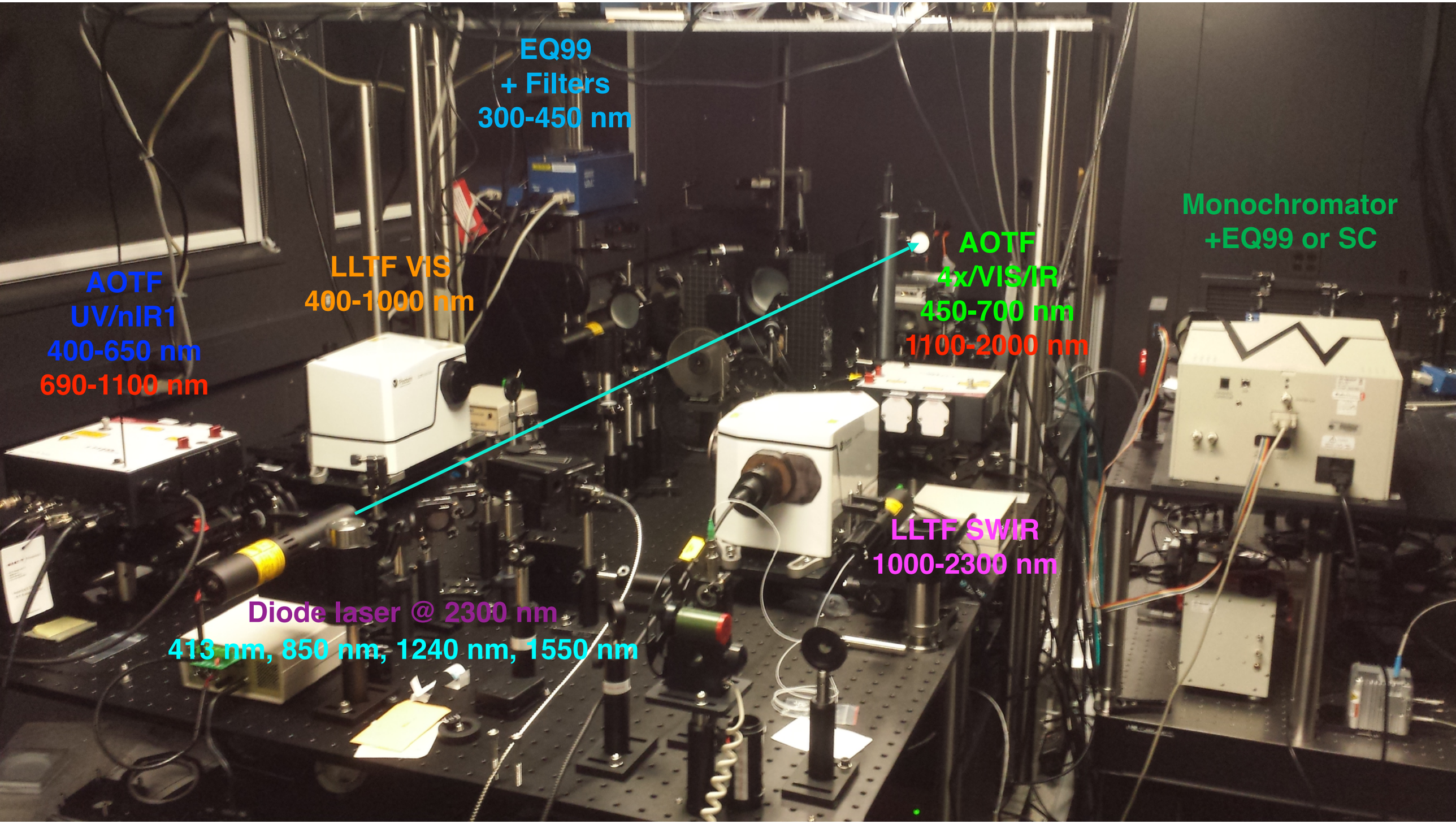


Table Top Goniometer (TTG)



TTG Light Sources



AOTF with power lock + multiple line output

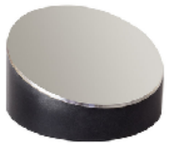
LLTF automated line selection

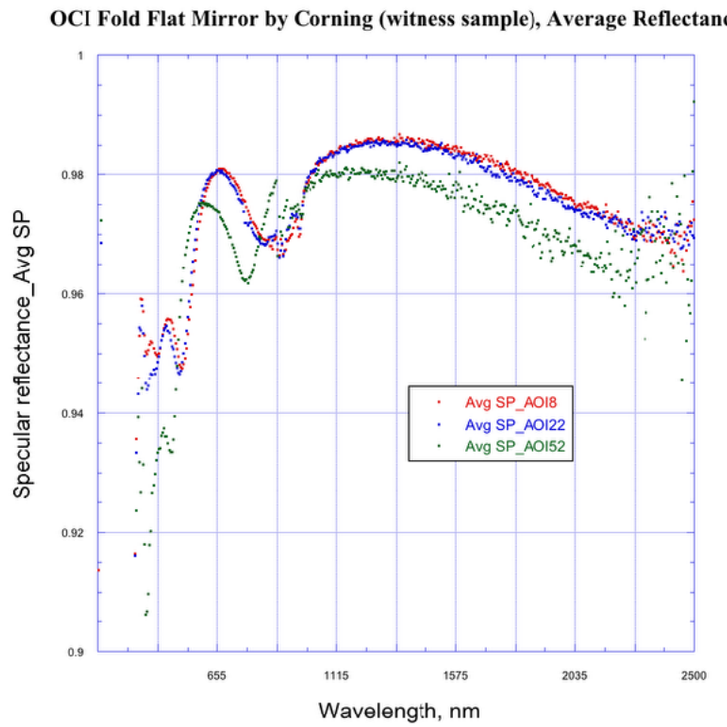
Summary of BSDF results from selected smooth surface samples

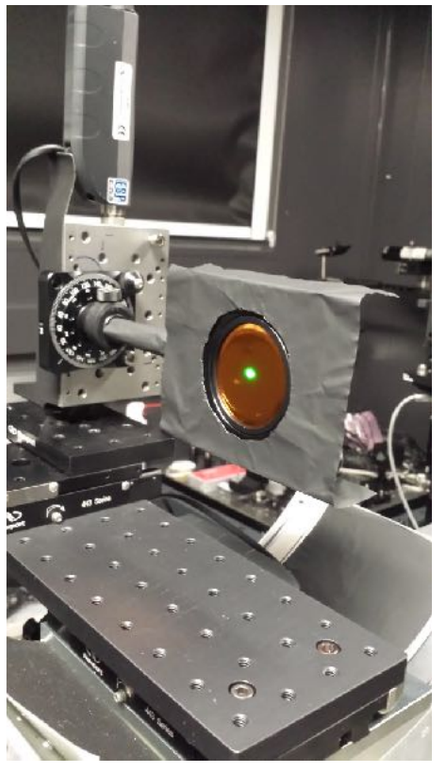
Smooth samples: Flat and curved surfaces

PACE OCI

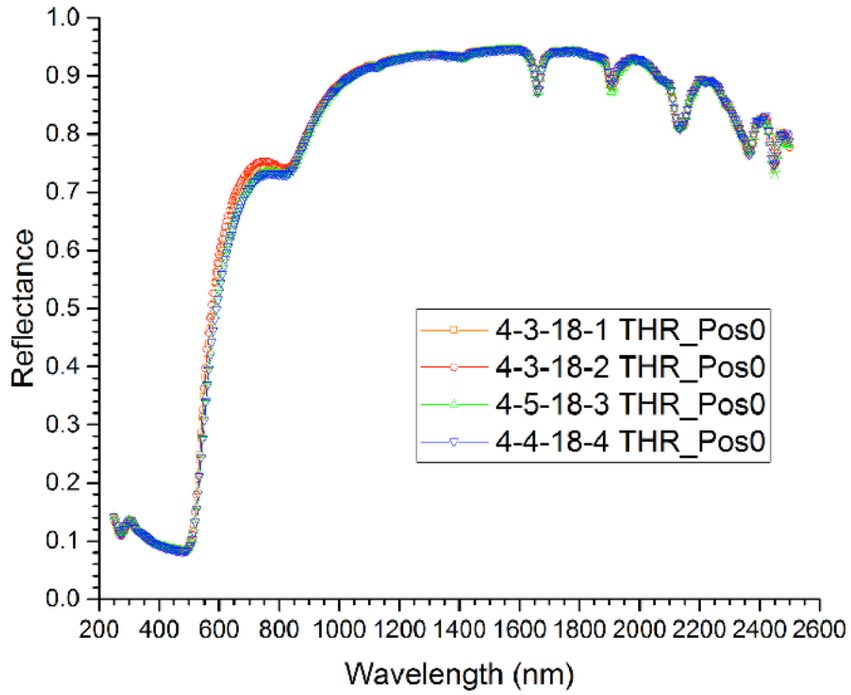
Flat mirror 

OAP 

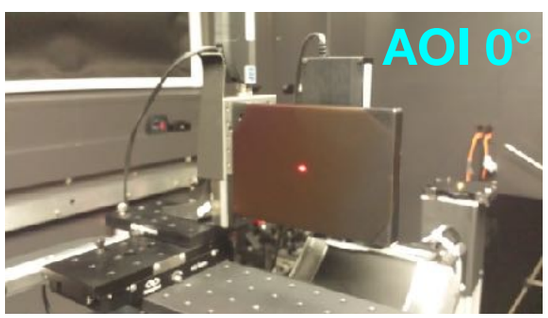


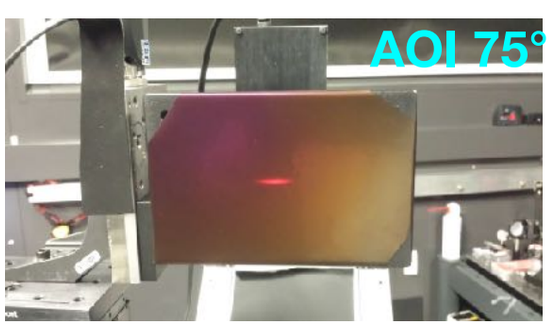


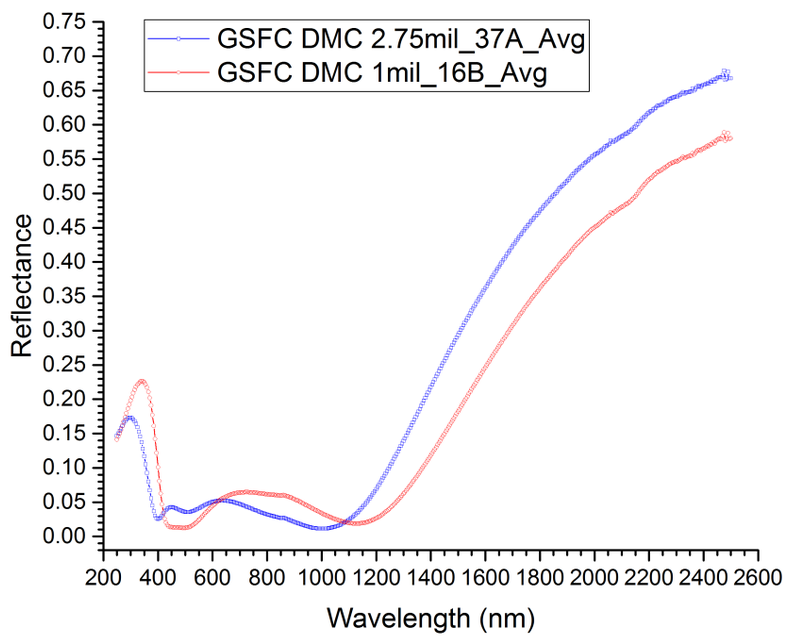
RestoreL MLI

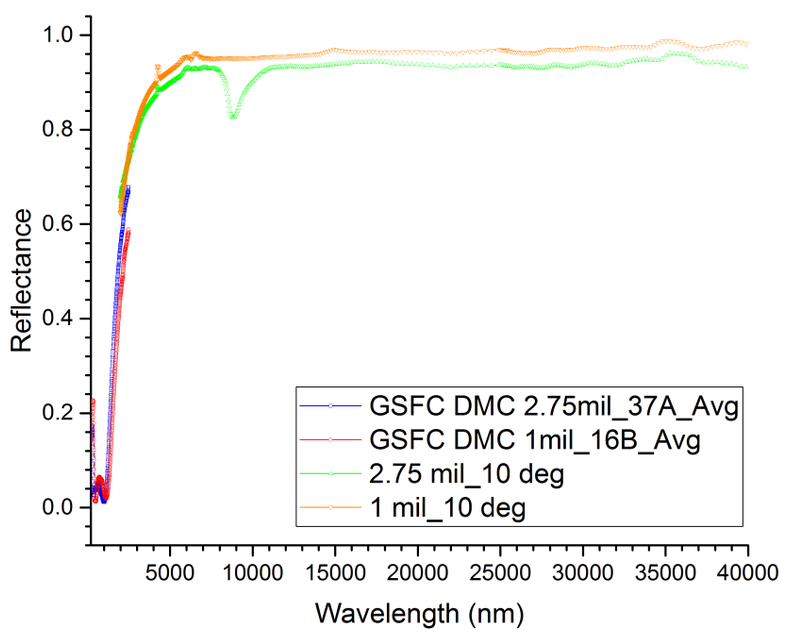


WFIRST DMC

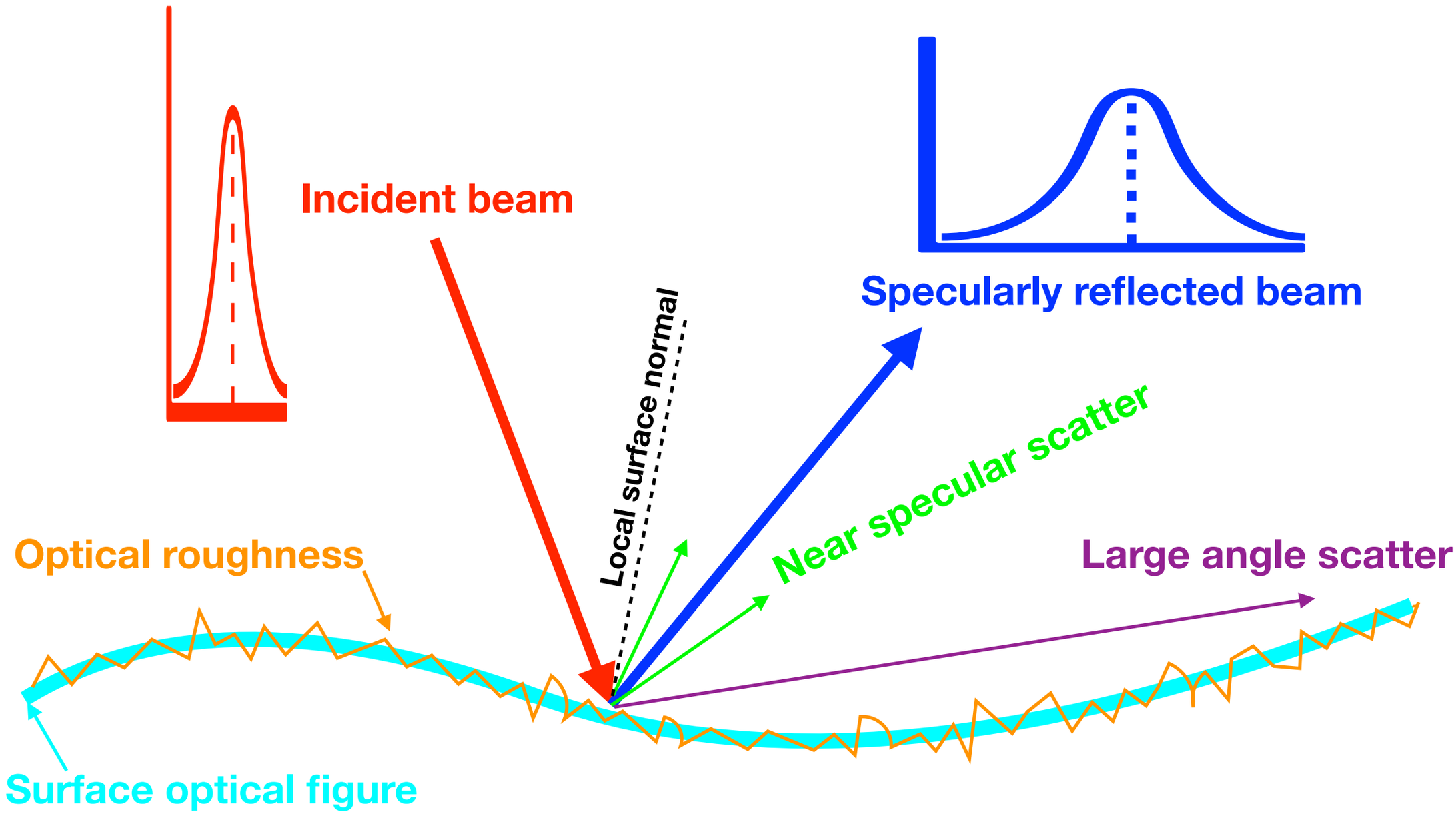




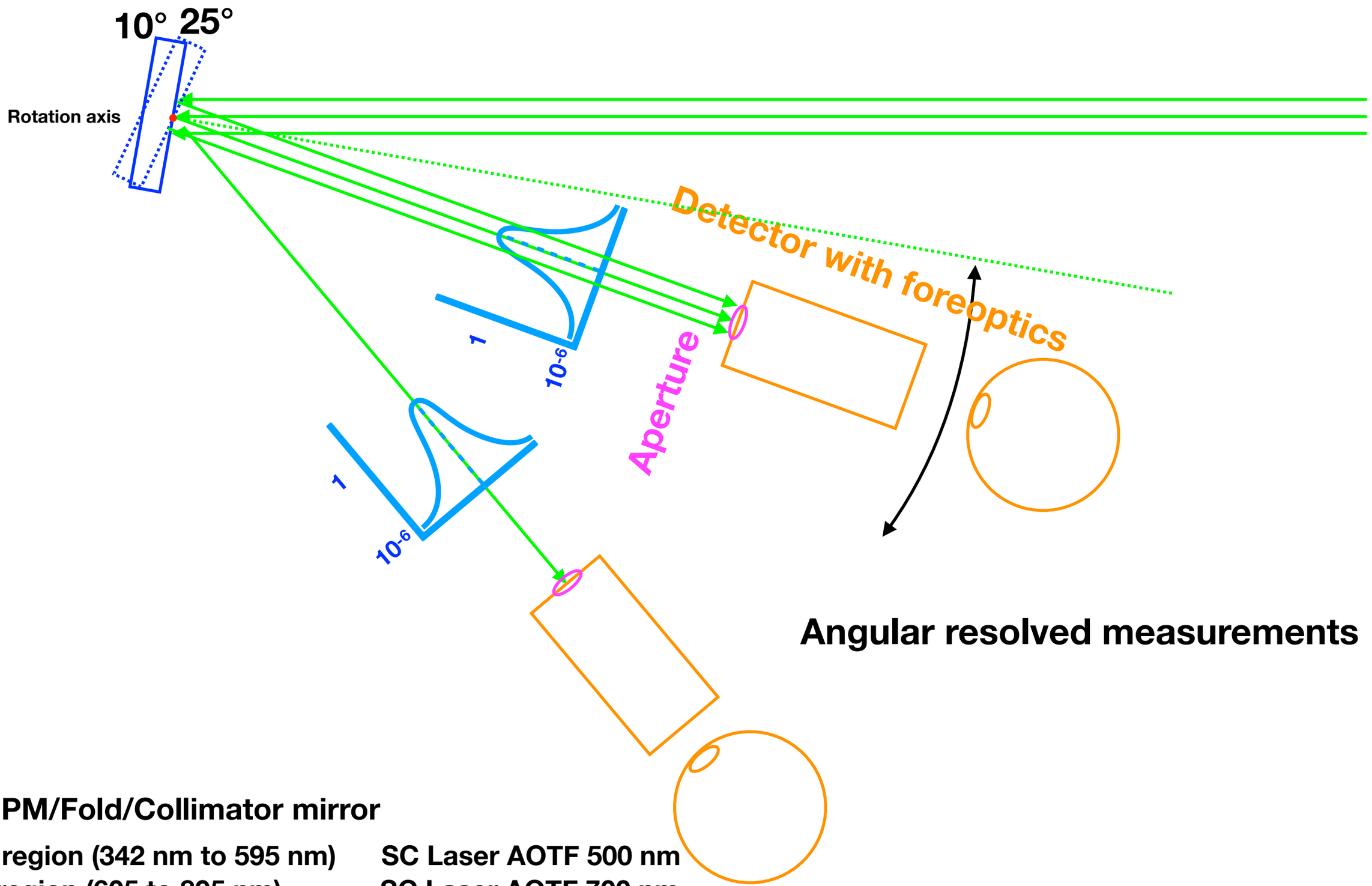




Scattering from smooth surface with optical figure and roughness



Schematic diagram of BSDF measurement for flat surface sample



Angular resolved measurements

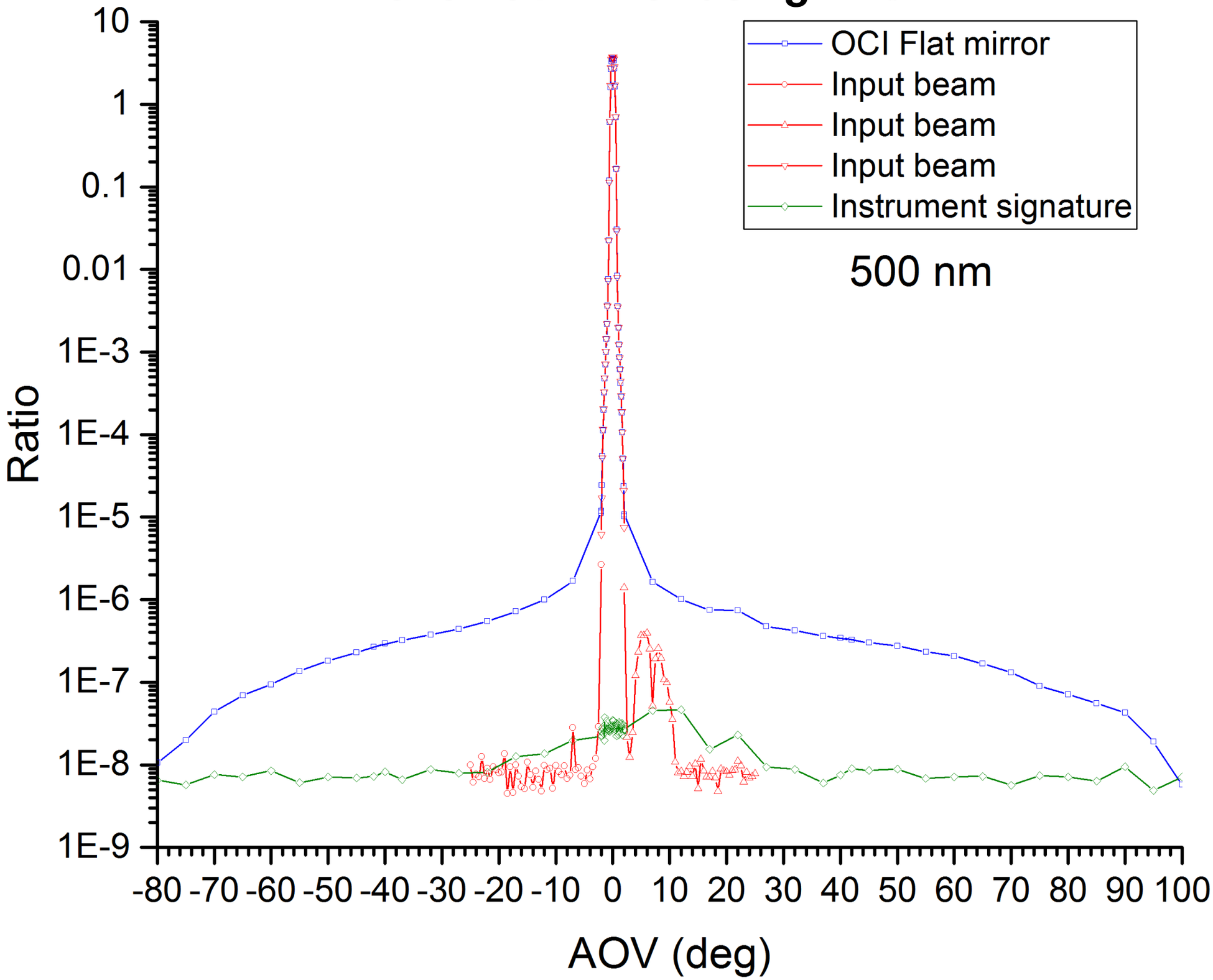
OCI PM/Fold/Collimator mirror

Blue region (342 nm to 595 nm)	SC Laser AOTF 500 nm
Red region (605 to 895 nm)	SC Laser AOTF 700 nm
SWIR region (2250 nm)	Diode laser

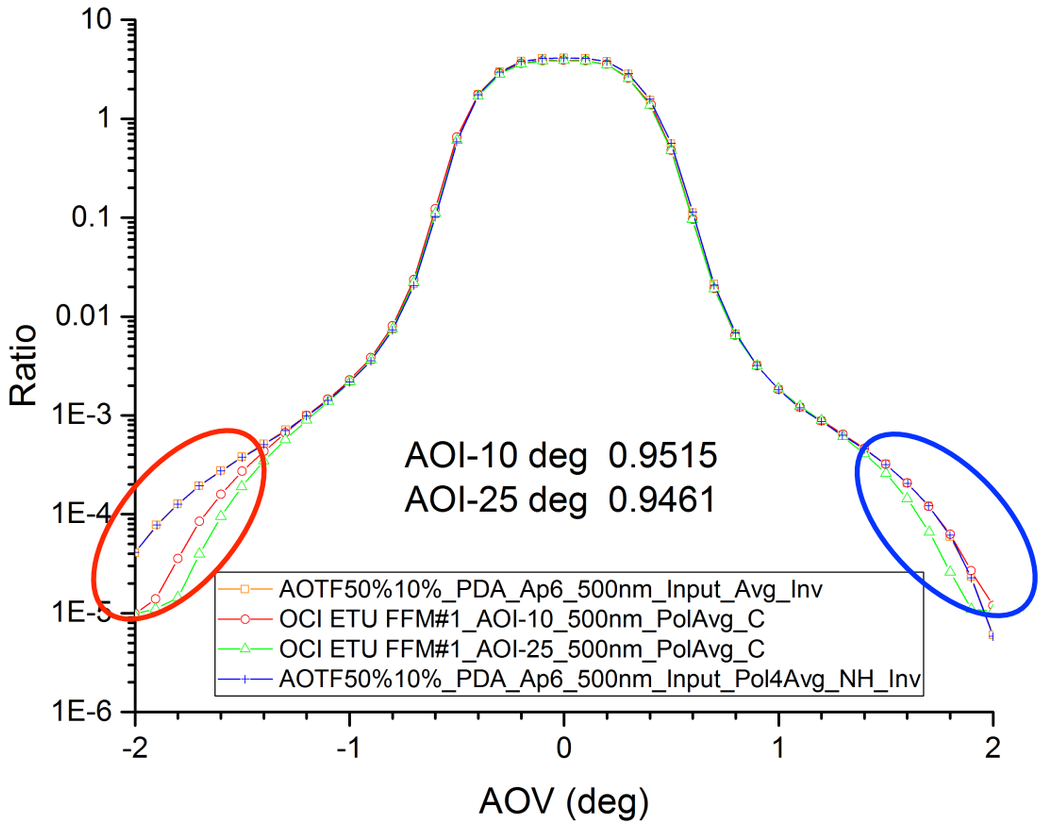
Validation of specular reflectance of the Flat Mirror from TTG

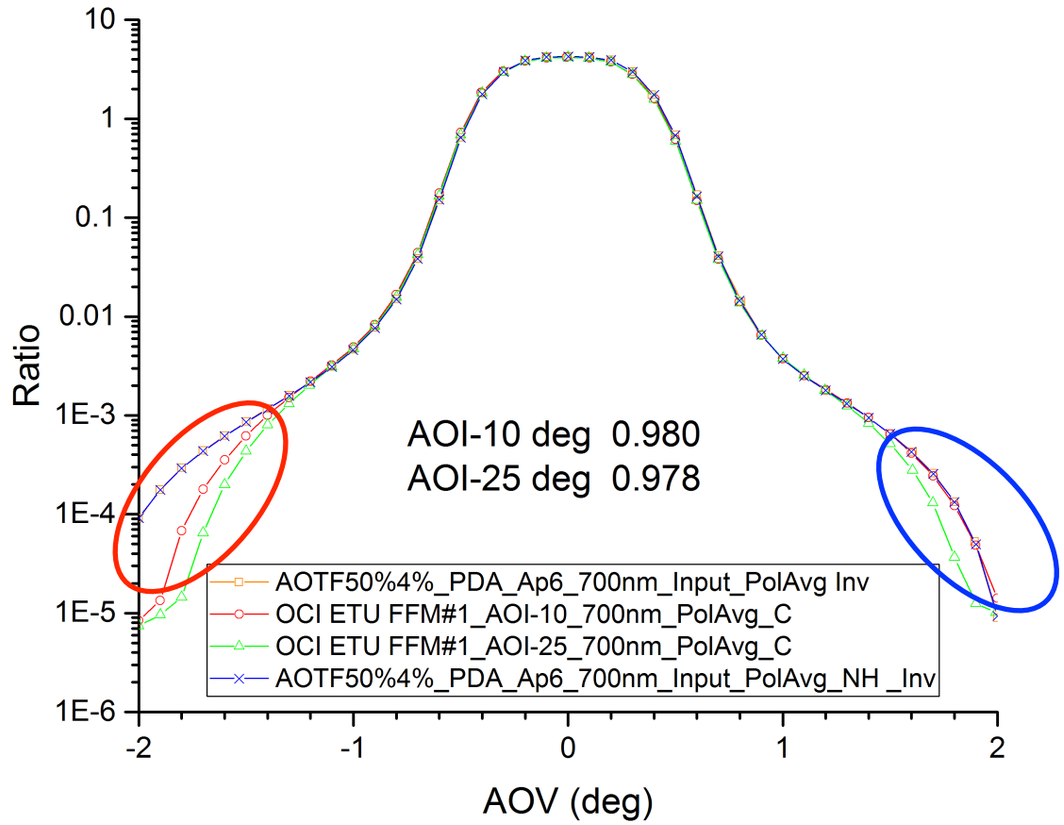
	10° (TTG)	8° (URA)	25° (TTG)	22° (URA)
500 nm	0.9515	0.9507	0.9461	0.9476
700 nm	0.980	0.9802	0.978	0.9794
2000 nm	0.975	0.9760	0.9774	0.9747

Comparison of signal levels of input, scatter, and instrument signature for a flat mirror using TTG



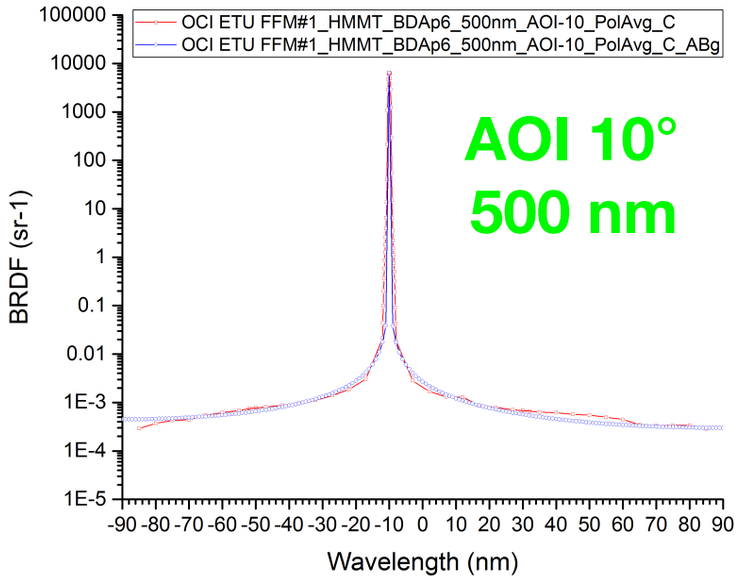
Comparison of input beam and reflected peak from a flat mirror

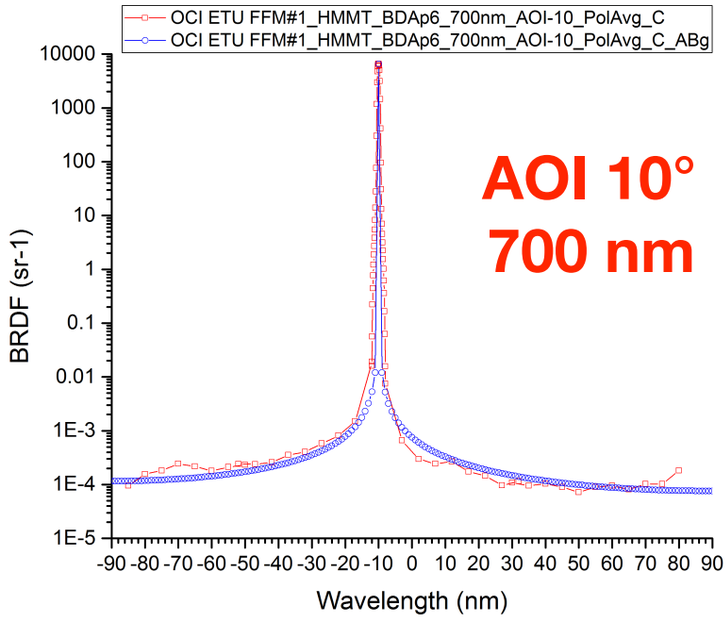


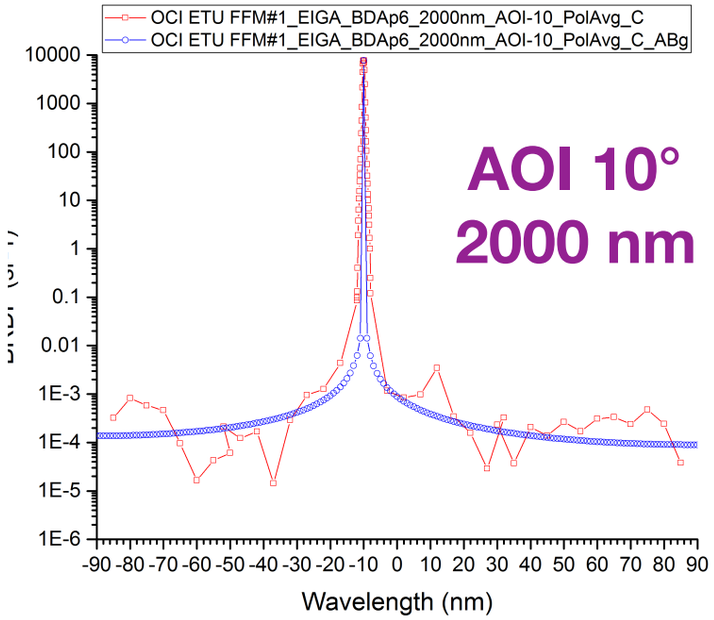


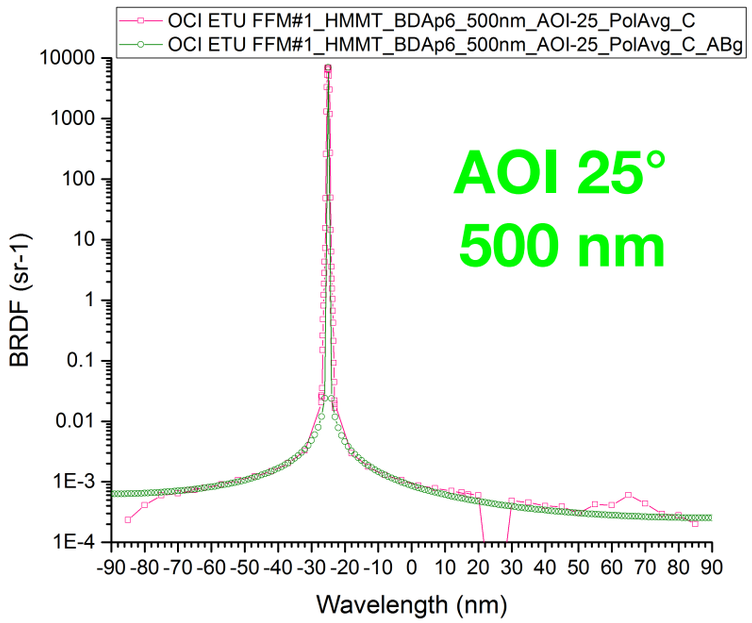
Case I

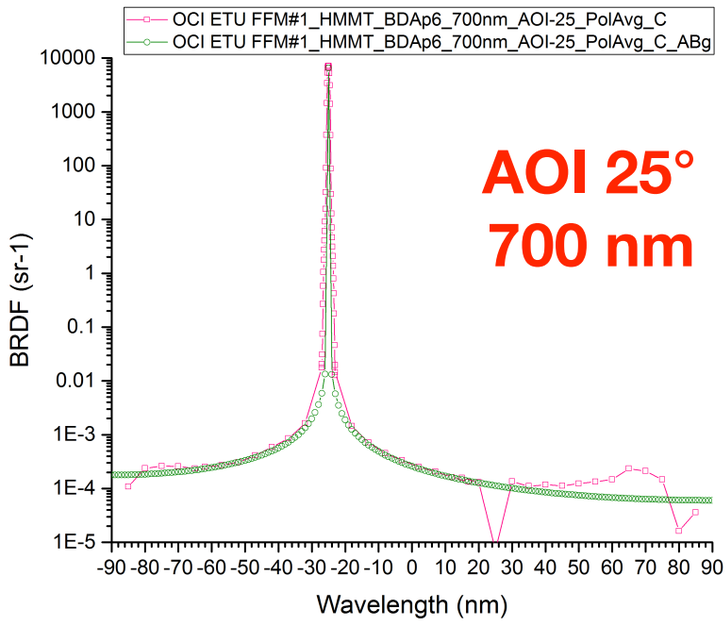
OCI flat mirror BSDF results at 500, 700 and 2000 nm and direct ABg model fittings

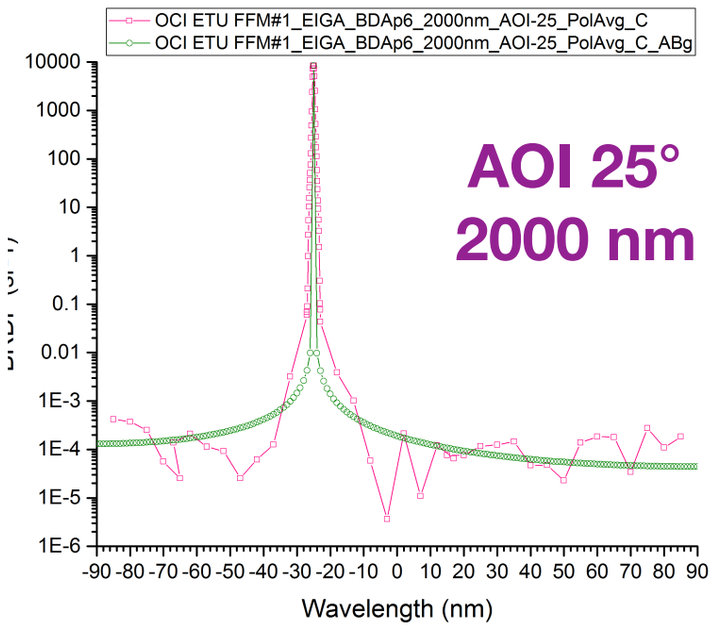






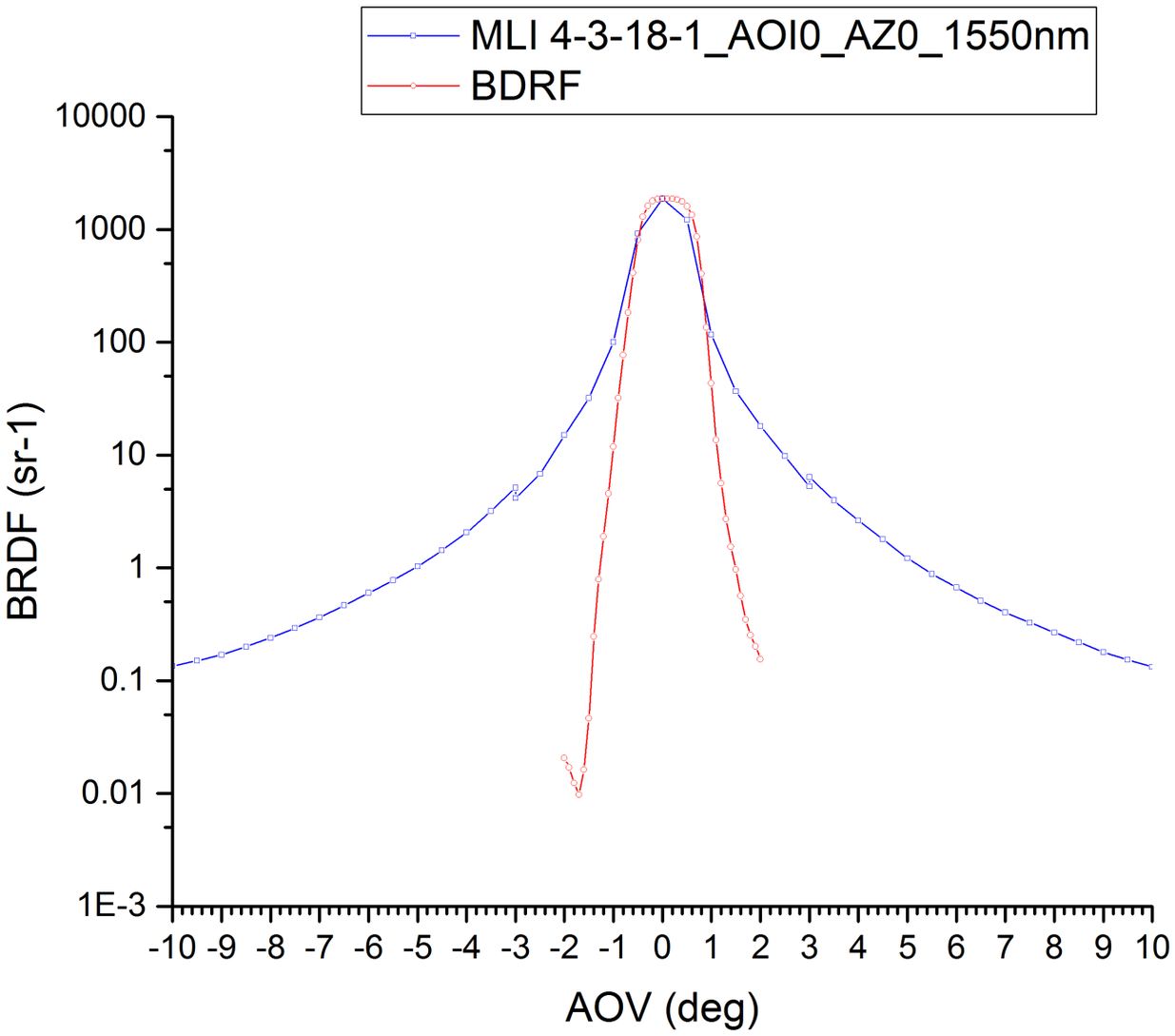


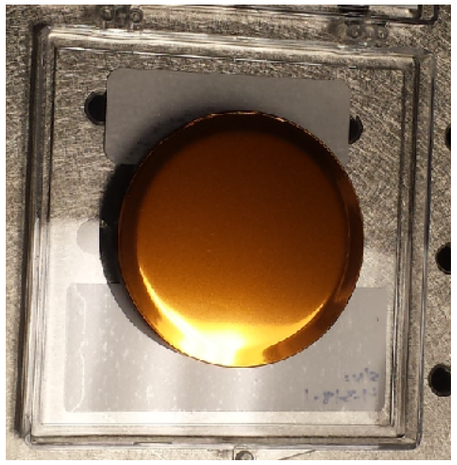




Case I

Comparison of input beam and reflected beam from MLI

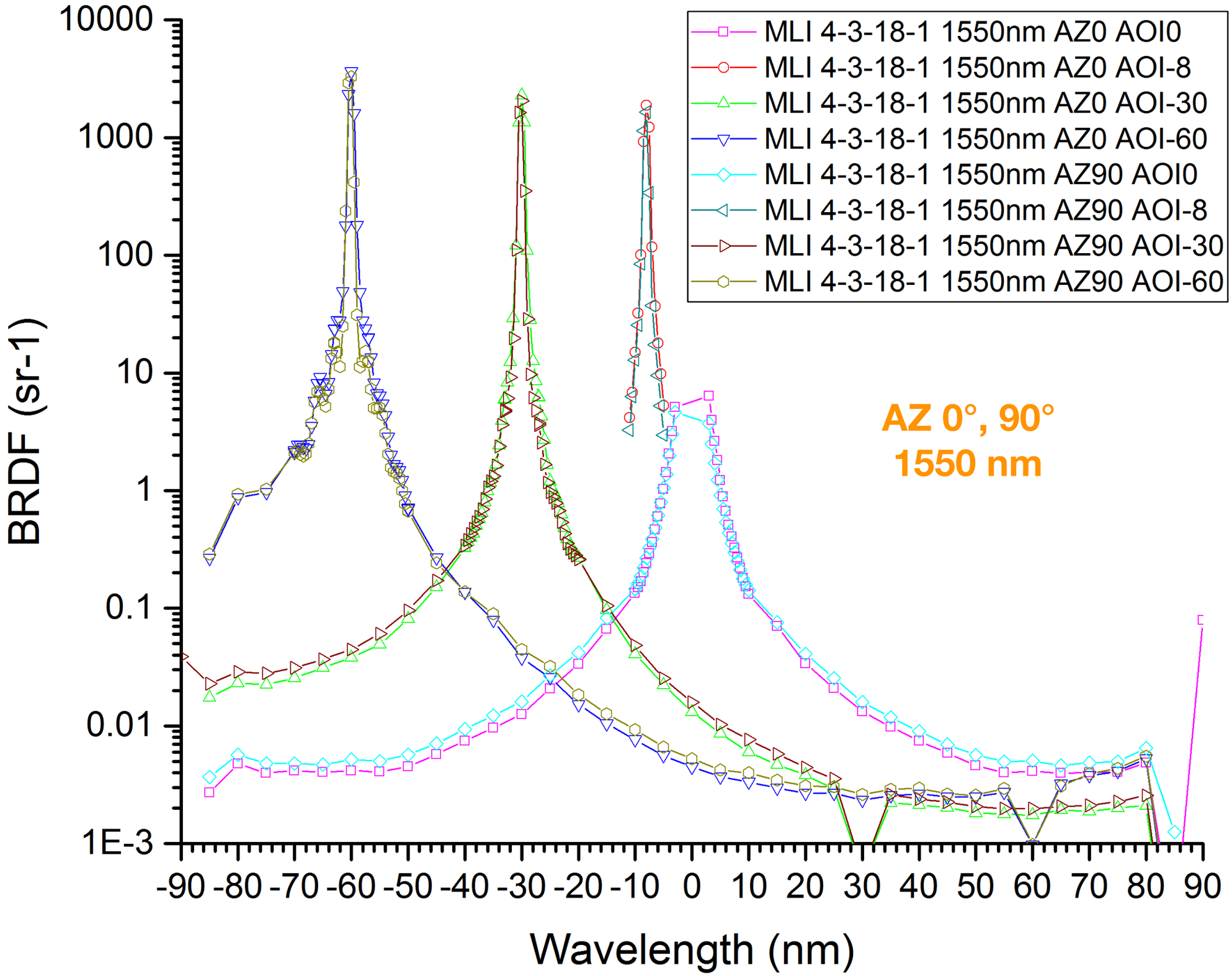




Case II Large surface optical figure

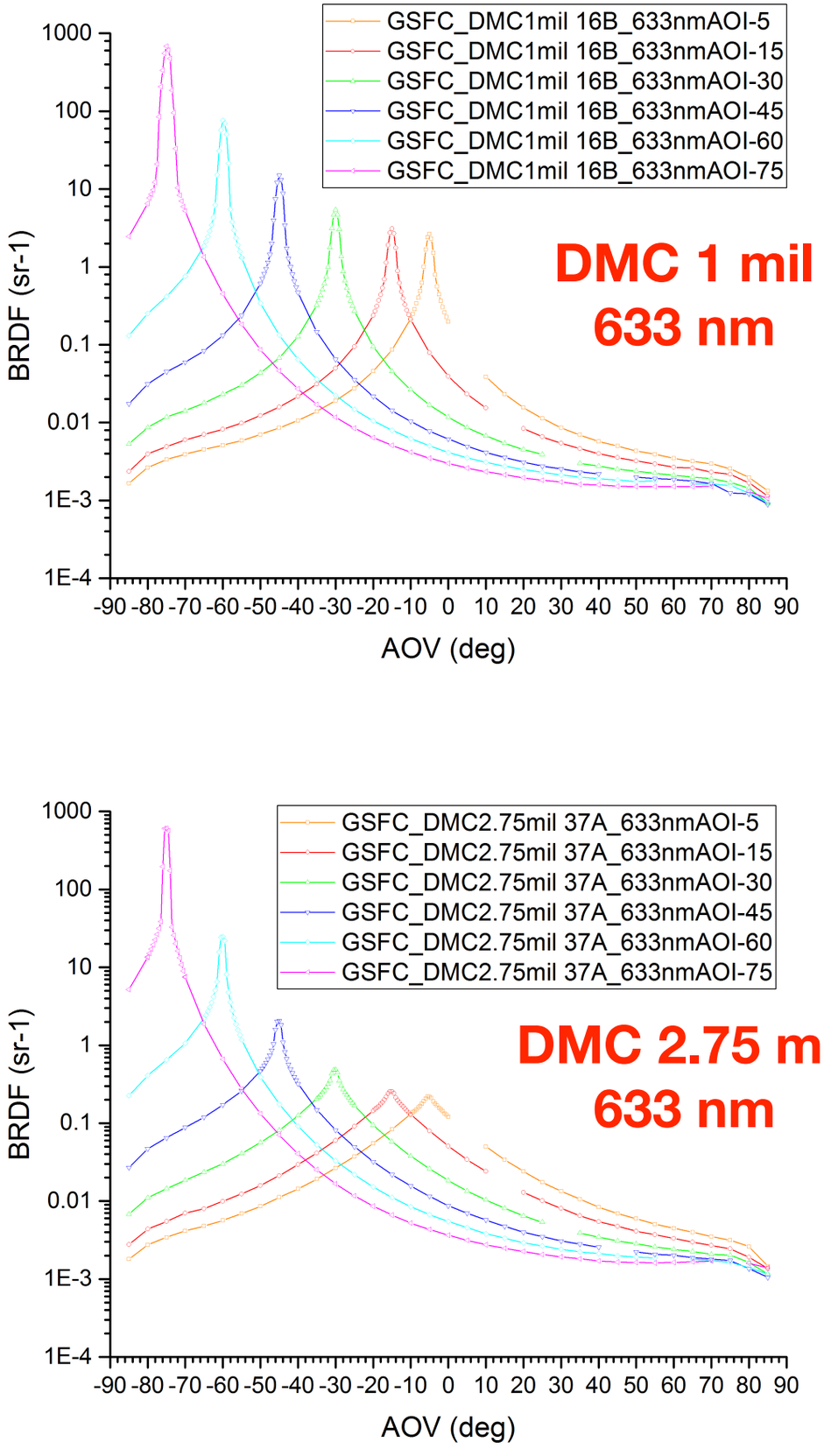
Input beam ~ Reflected peak

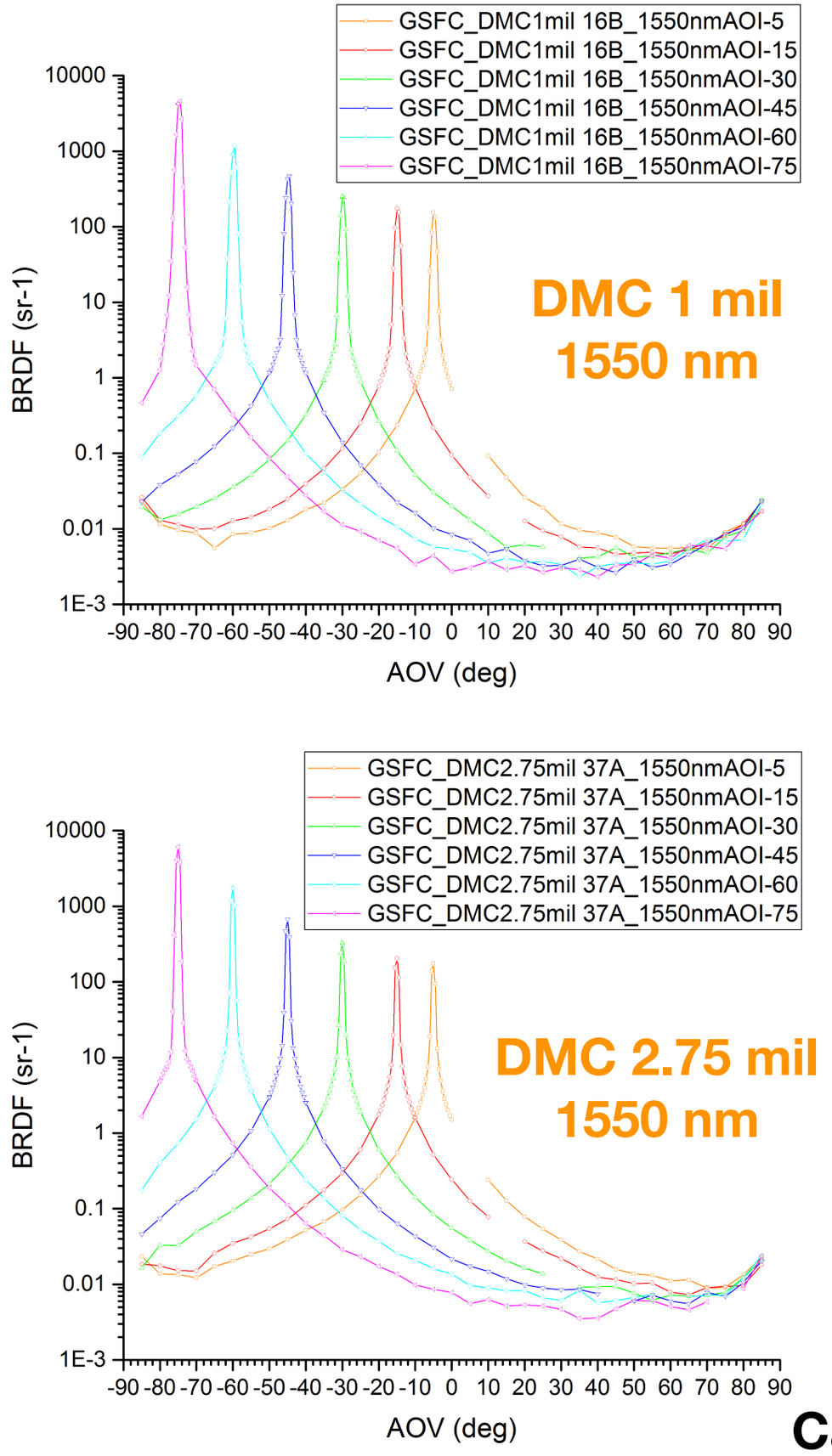
RestoreL MLI BSDF at 1500 nm with AOI 0, 8, 30, 60°



Case II

BSDF results at AOIs of 5, 15, 30, 45, 60, 75° of GSFC DMCs



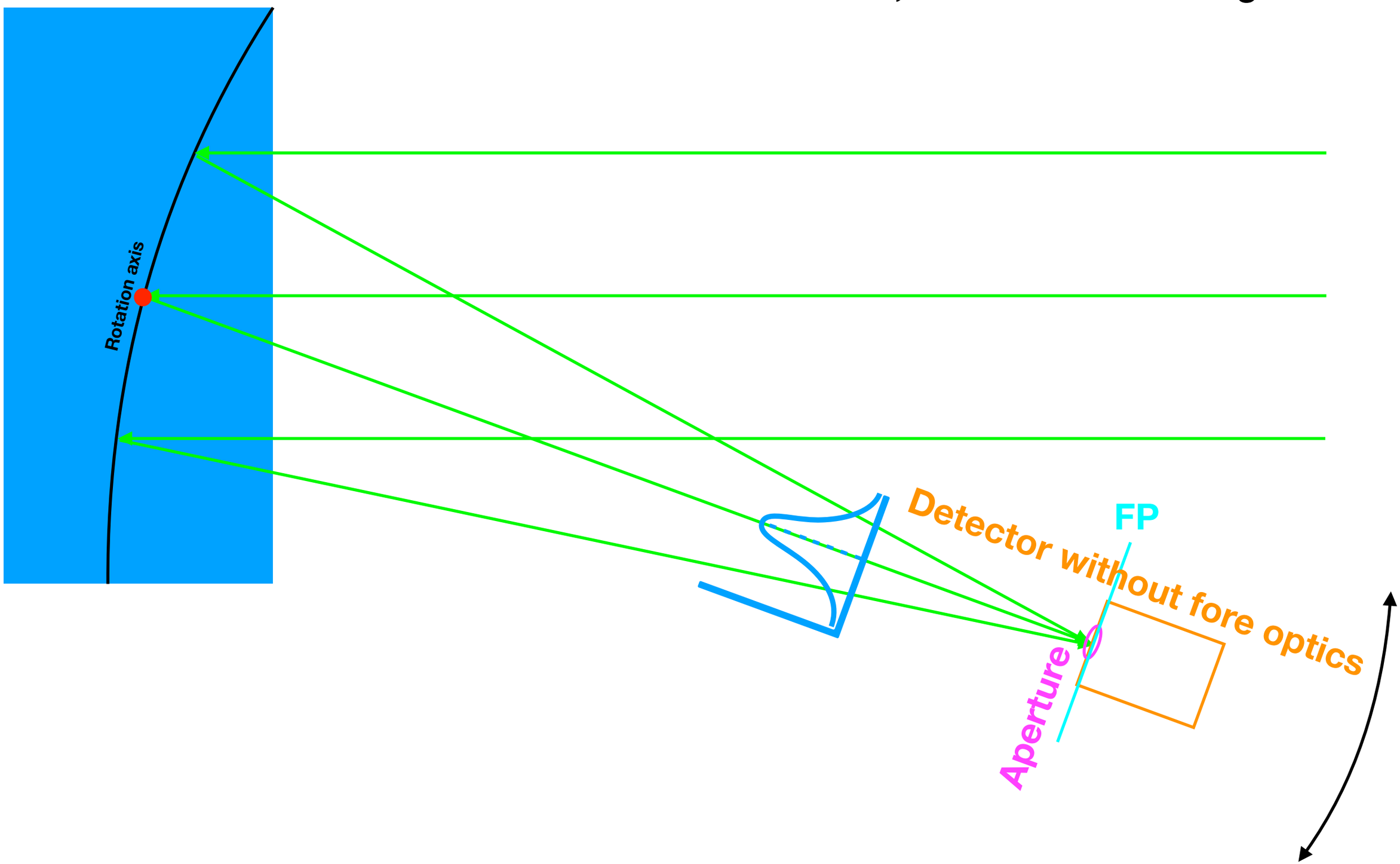


Case II

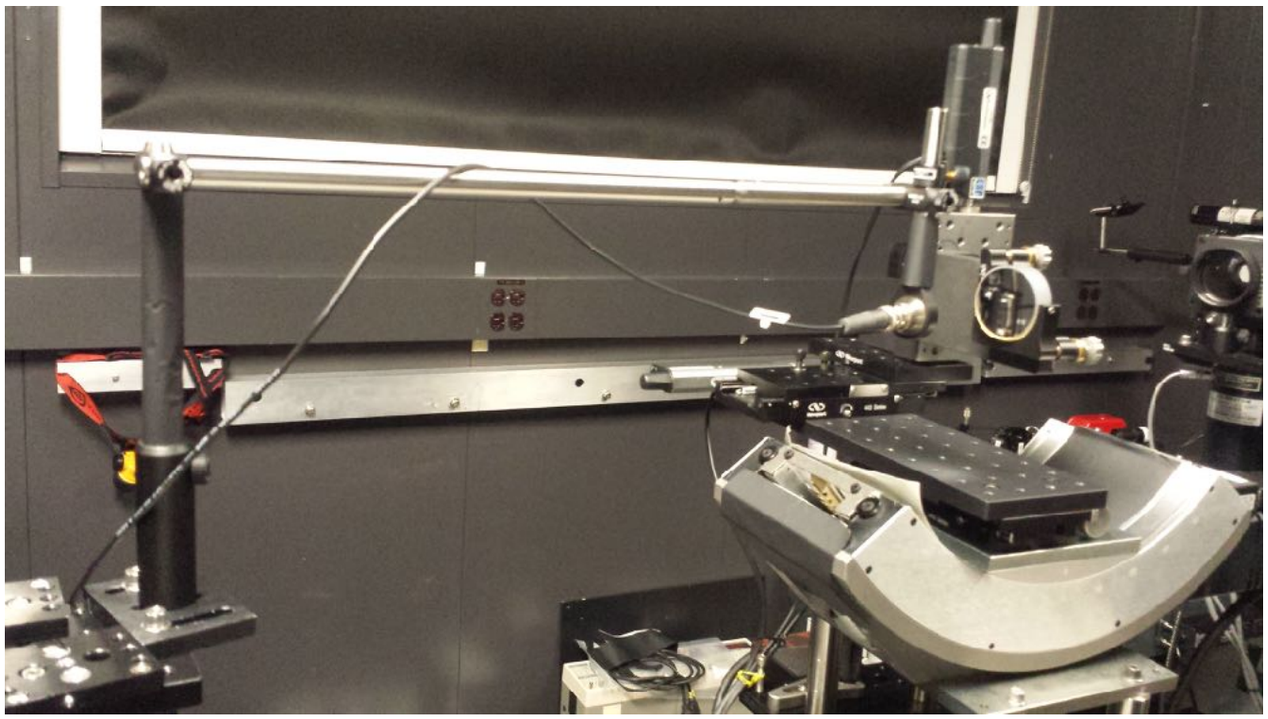
Schematic diagram of BSDF measurement for curved surface

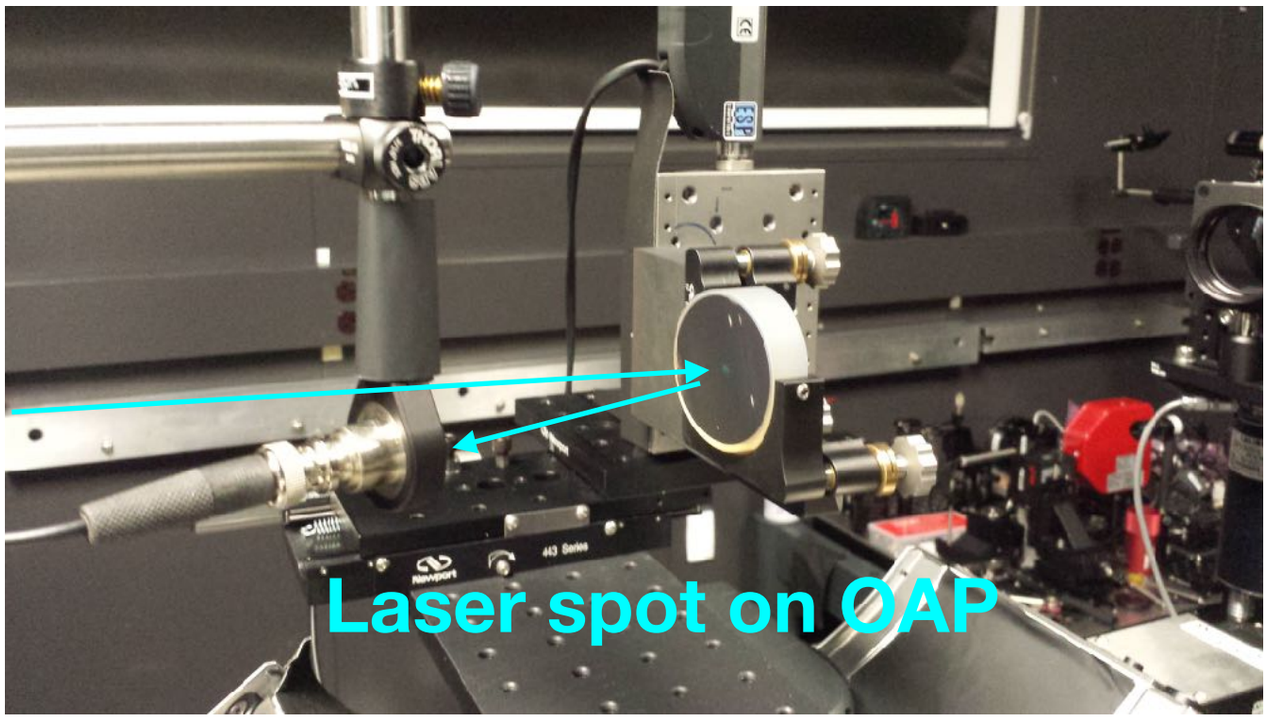
20.1° OAP

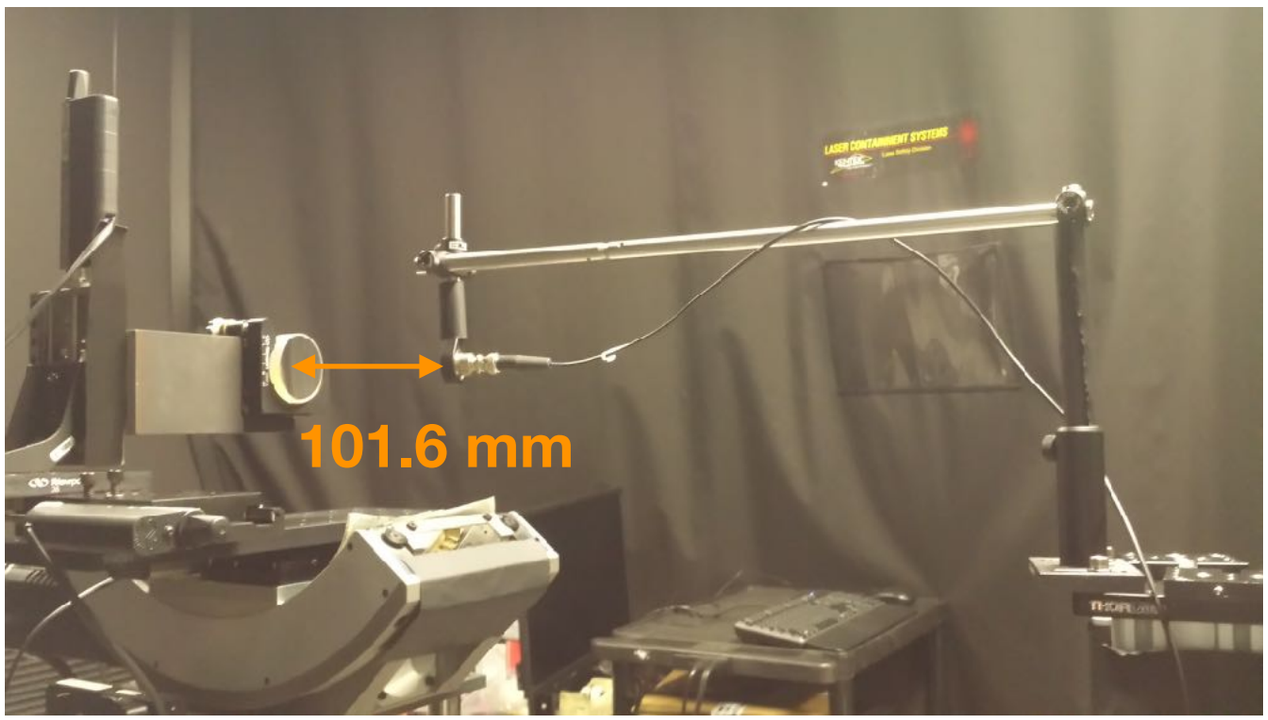
A radius of curvature of 203.2 mm., 101.6 mm focal length

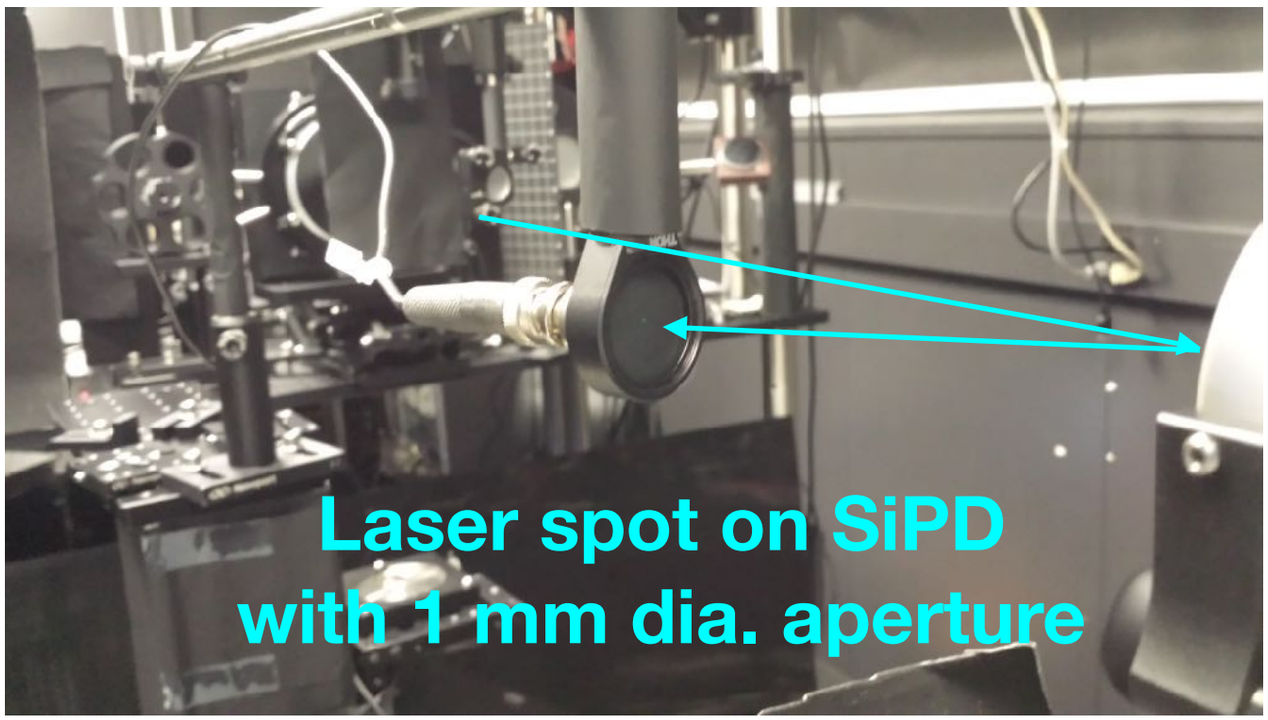


Setup of BSDF measurement for OAP mirror

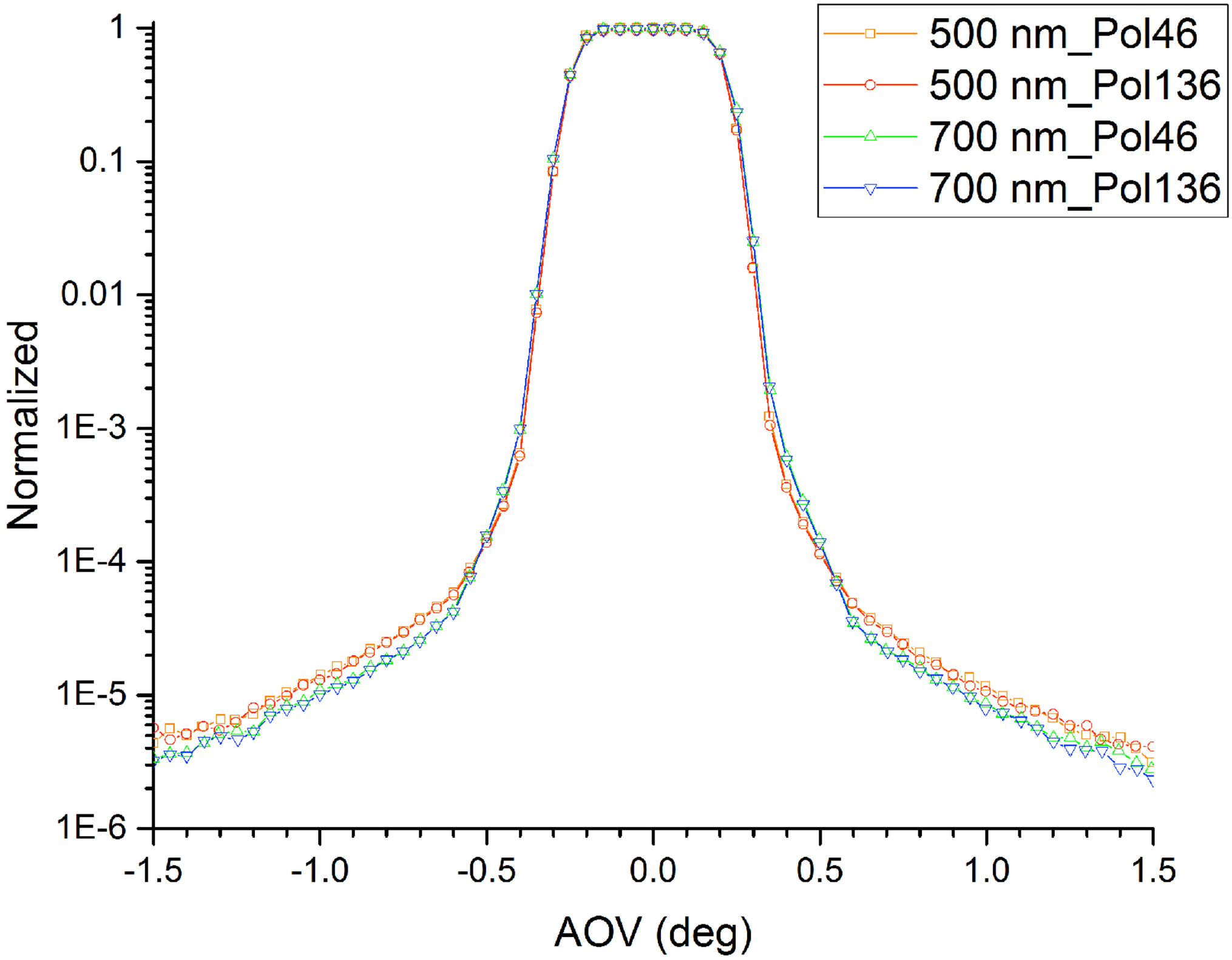








Reflected peak profile of OCI OAP mirror



BSDF data analysis using ABg model

1. Direct ABg model fittings
2. Determination of ABg parameters using deconvolution

ABg model

The ABg model is widely used to describe scatter from smooth optical surfaces in most optical design and engineering software. The model is typically written:

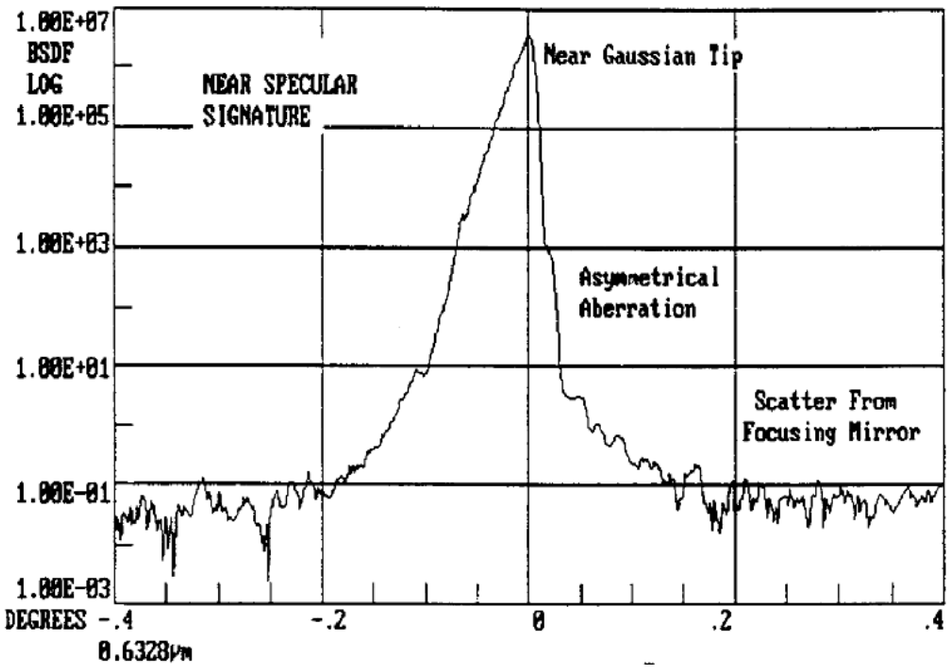
$$BSDF(\beta - \beta_0) = \frac{A}{B + (\beta - \beta_0)^g}$$

where

$$\beta = \sin\theta_{scatter} \qquad \beta_0 = \sin\theta_{specular}$$

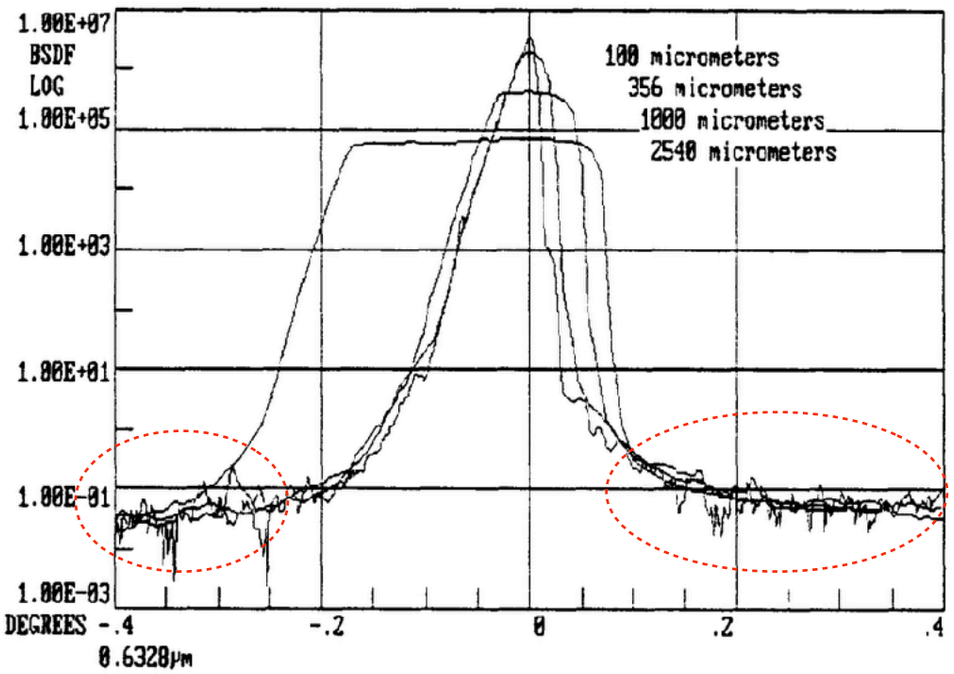
A, B, and *g* are the specific model parameters. The ratio of the A and B parameters is equal to the peak bidirectional scattering distribution function (BSDF) in the specular direction. The angle at which the BSDF transitions from a constant value to a power-law falloff is given by $B^{1/g}$. The slope *g* is identical to the power-law falloff of the 2-D power-spectral density (PSD) of the surface roughness.

Instrument signature and aberration.

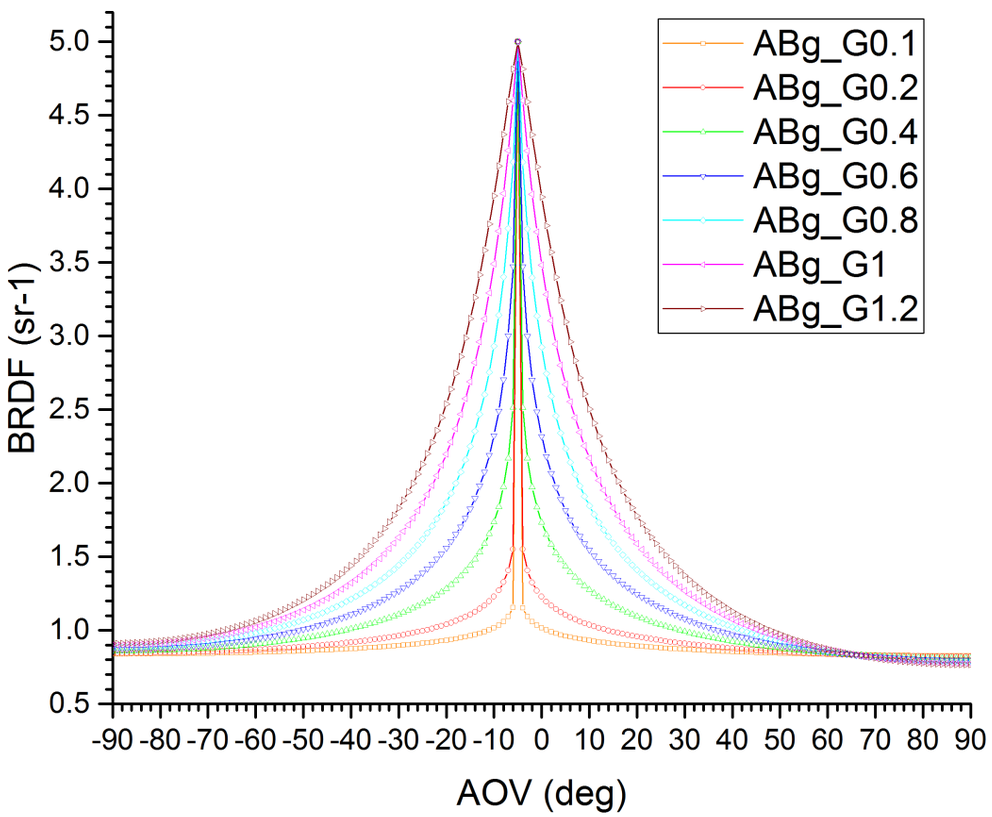


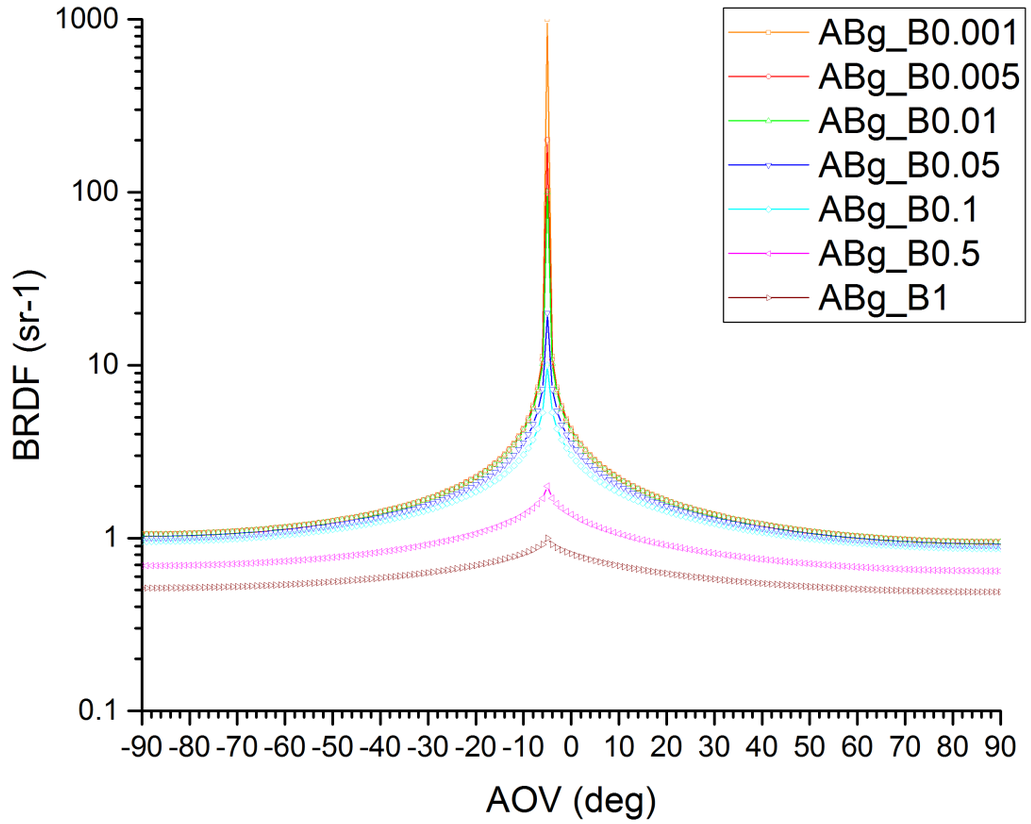
"Optical Scattering" by John Stover

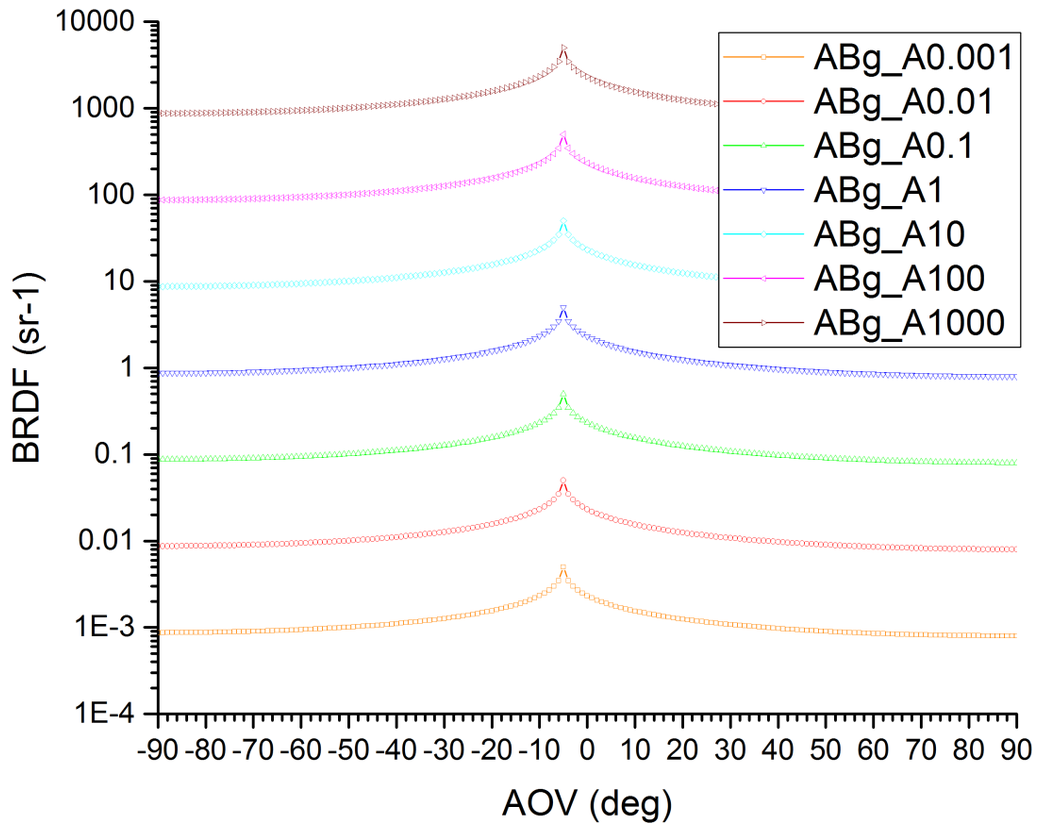
The effect of aperture convolution on signature measurements.



ABg model simulation

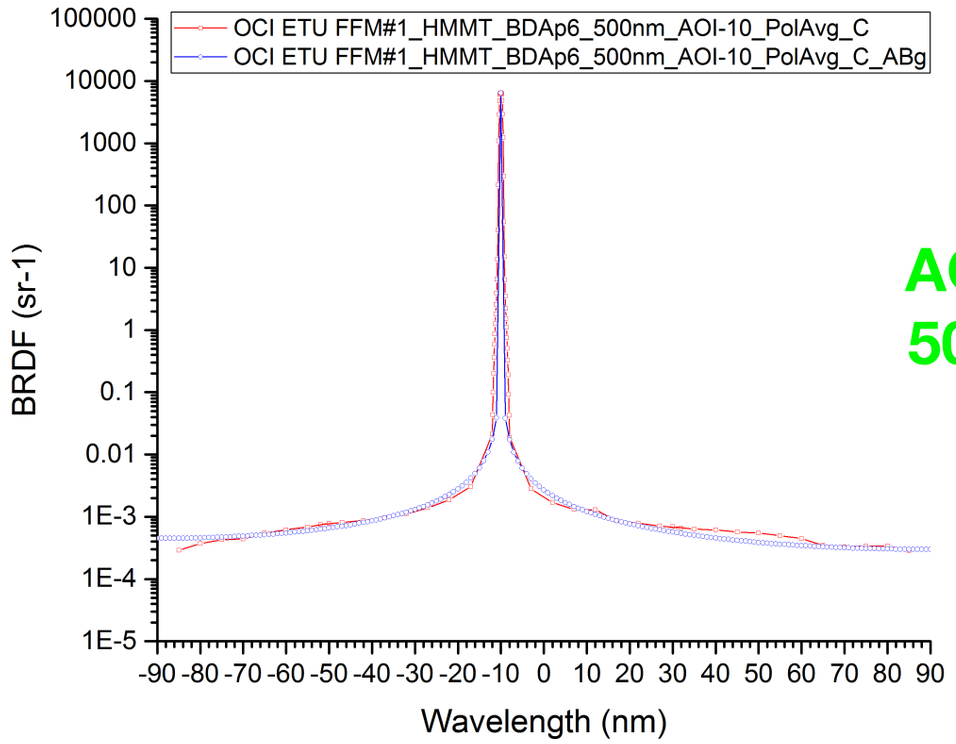




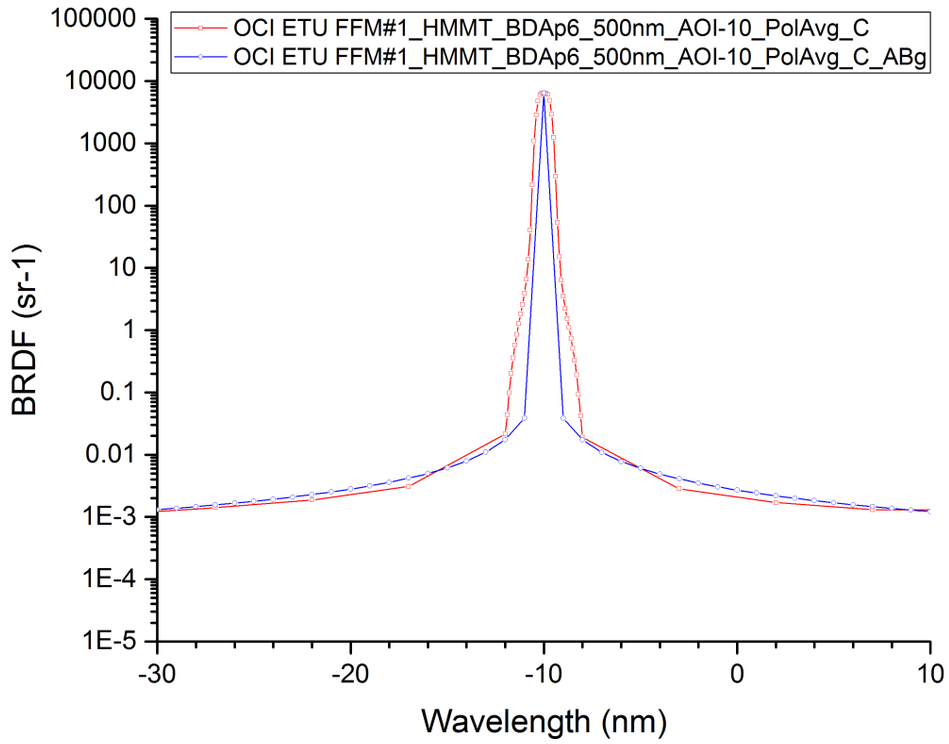


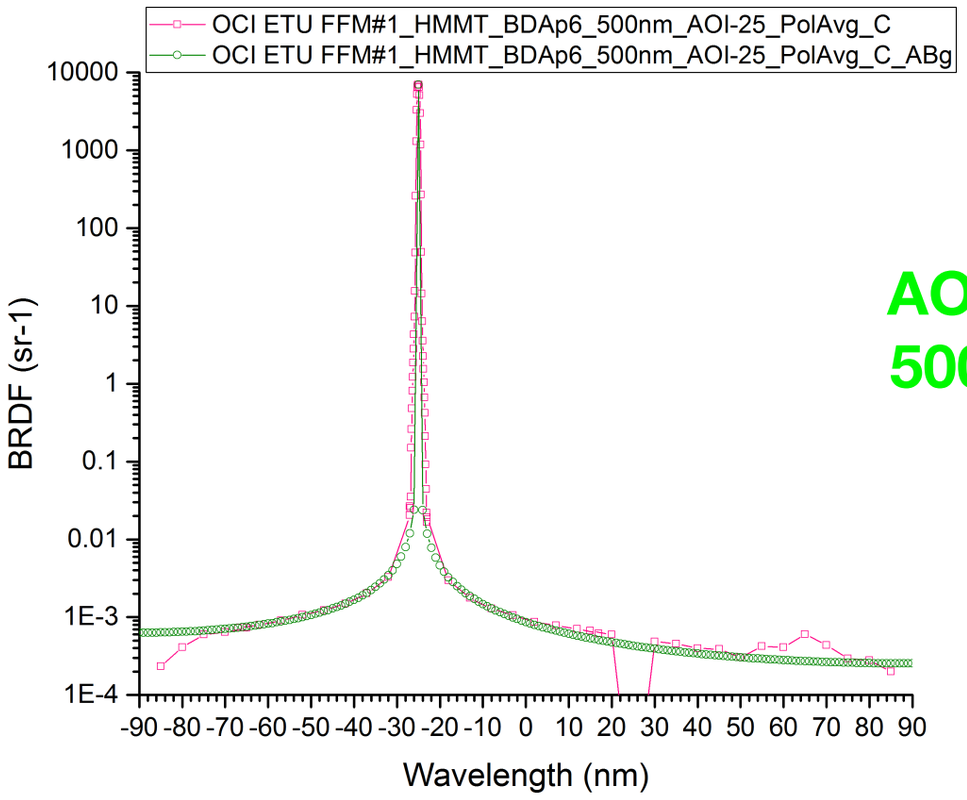
1. Direct ABg model fittings

OCI flat mirror BRDF data and direct ABg model fitting

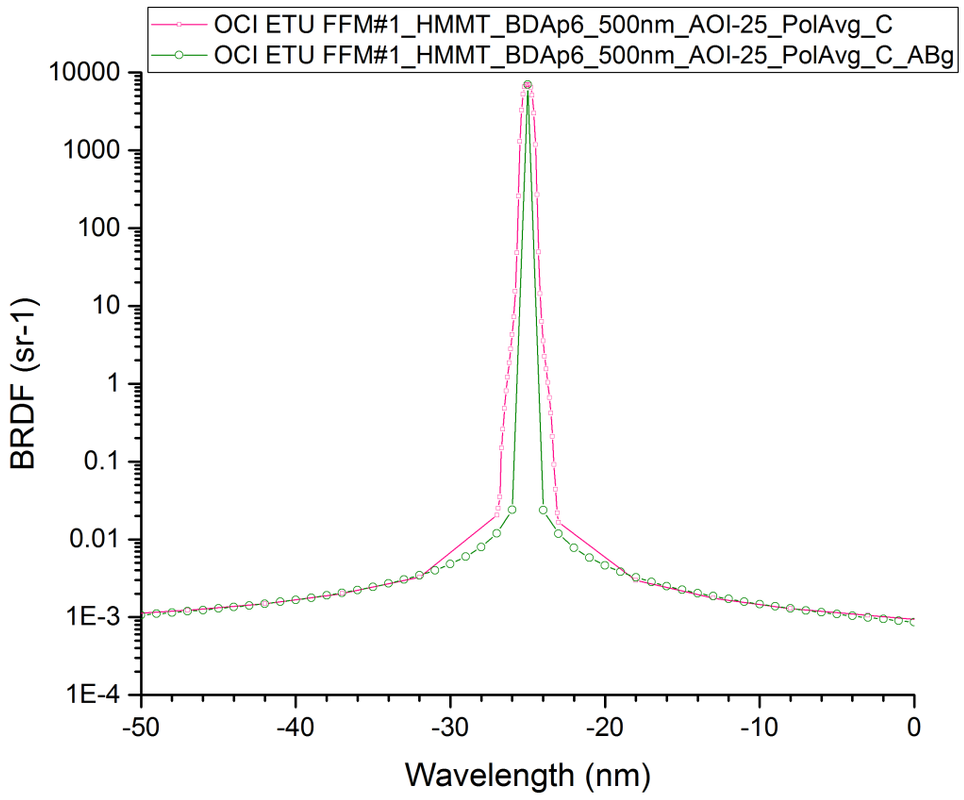


AOI 10°
500 nm

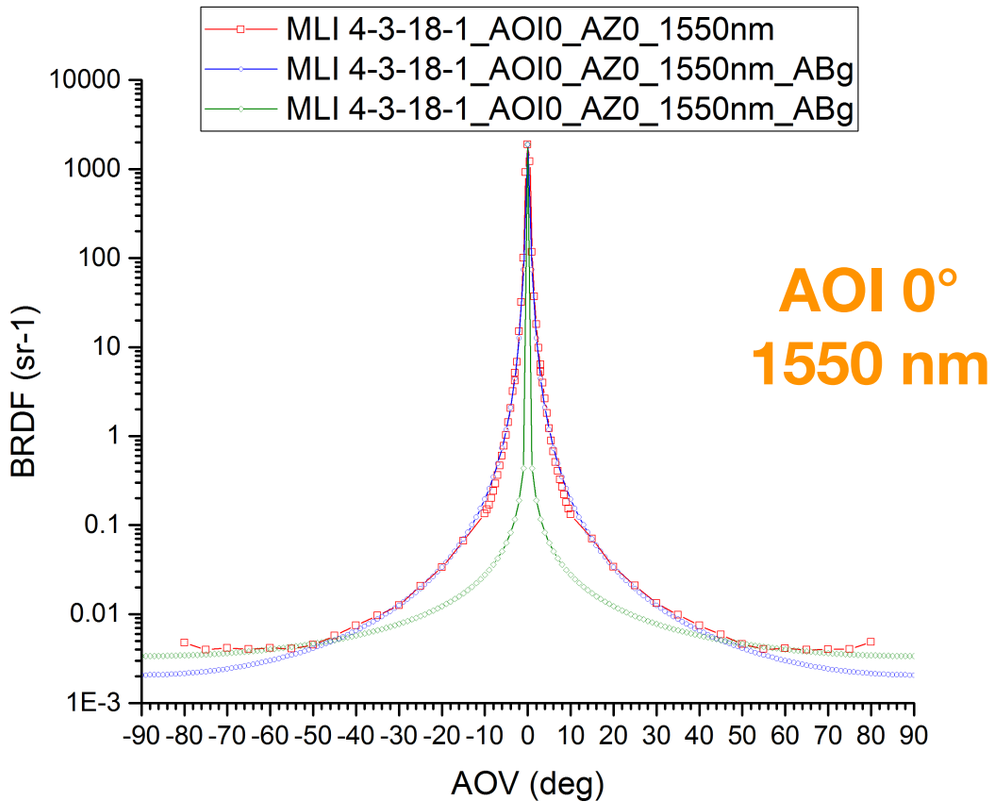


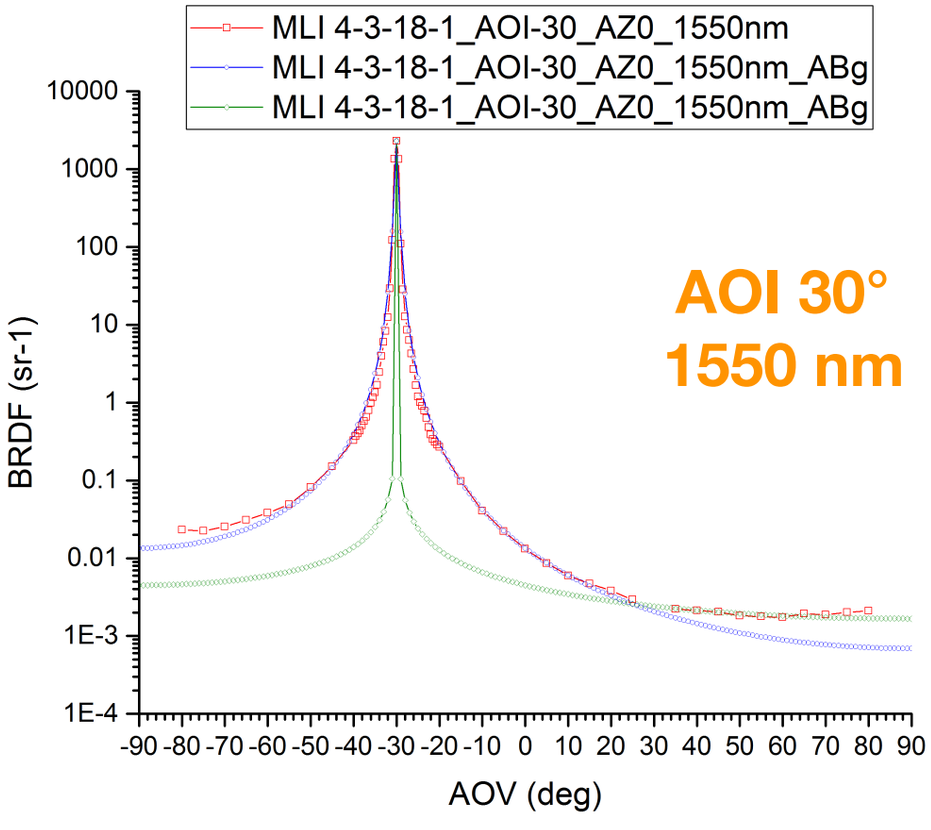


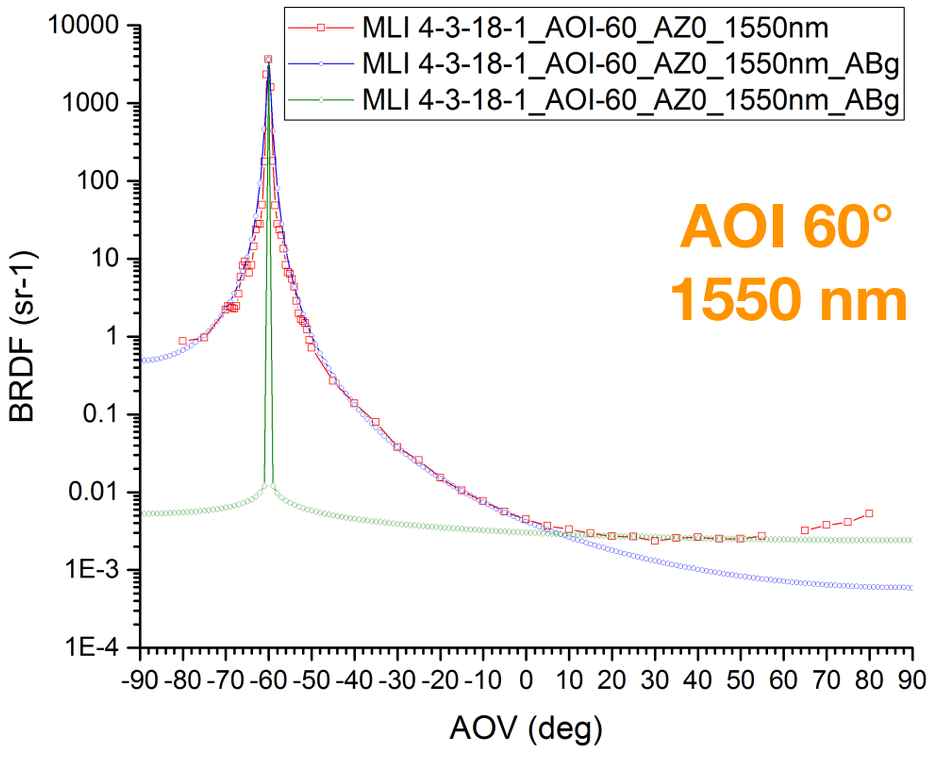
AOI 25°
500 nm



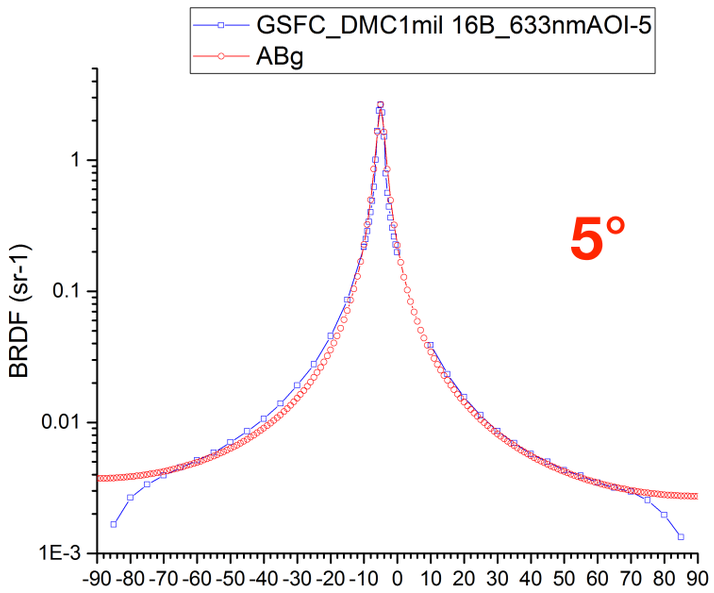
RestoreL MLI BRDF data and direct ABg model fitting

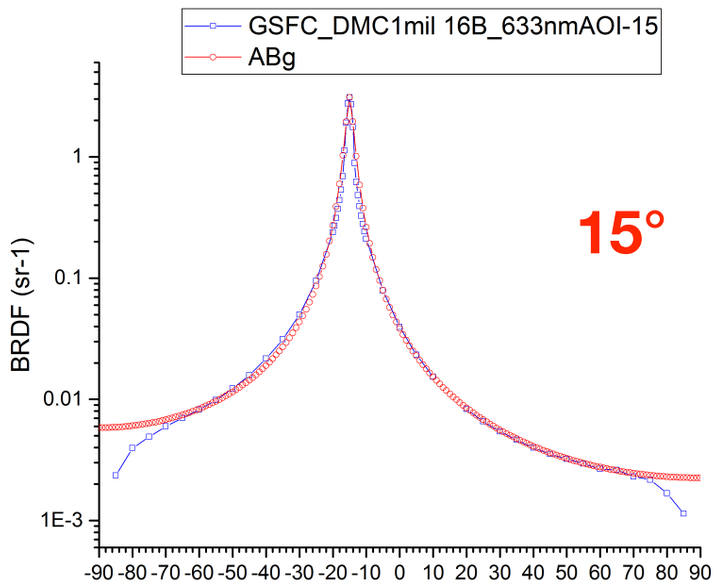


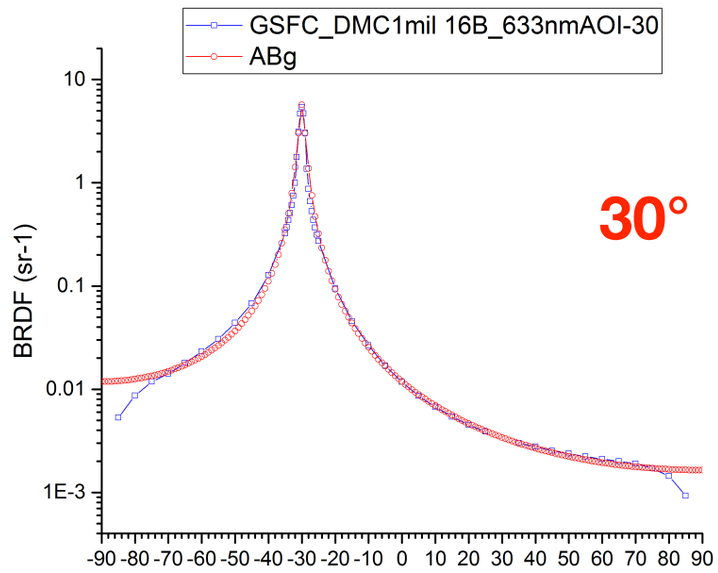


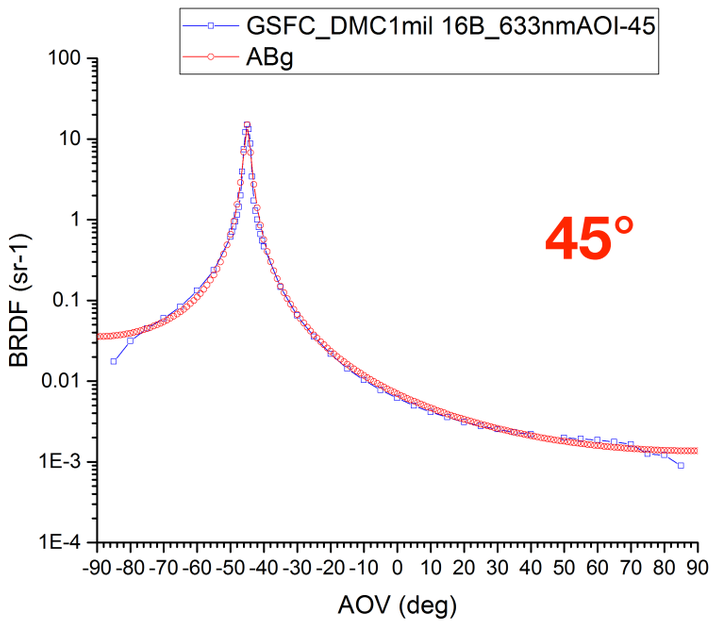


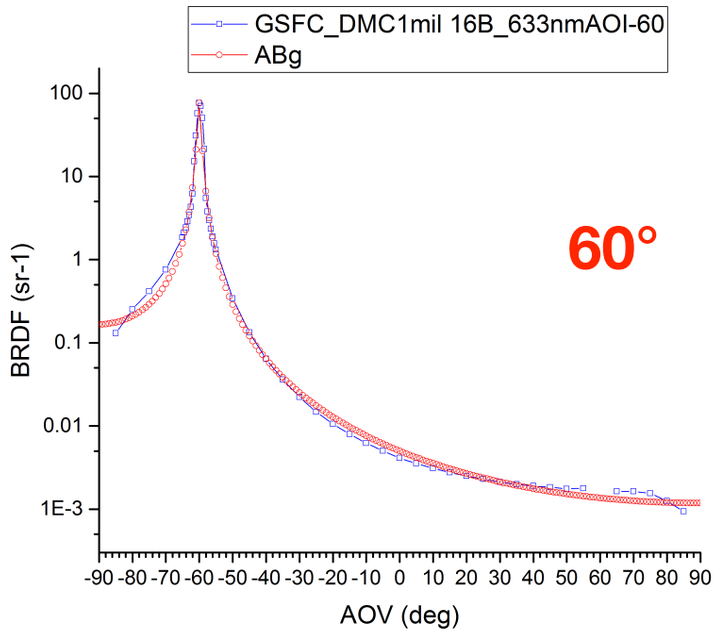
633 nm BRDF results of GSFC DMC 1 mil at AOIs of 5, 15, 30, 45, 60, 75° and direct ABg model fittings

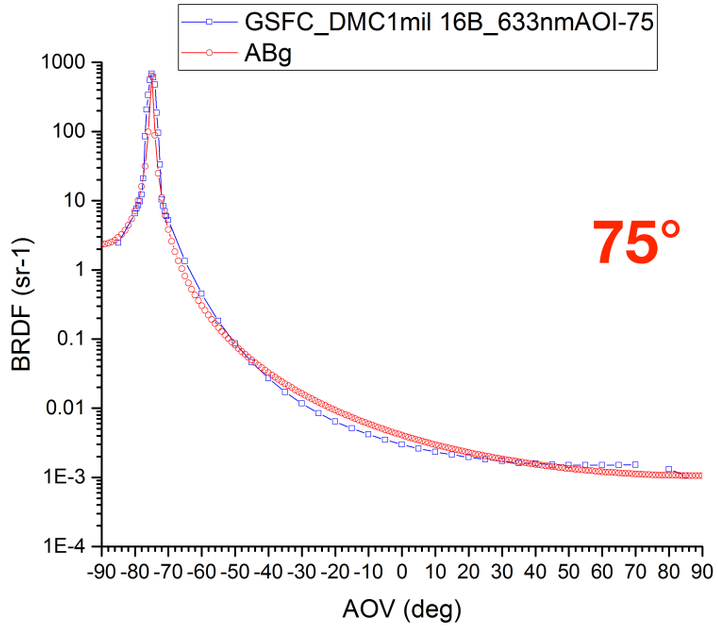




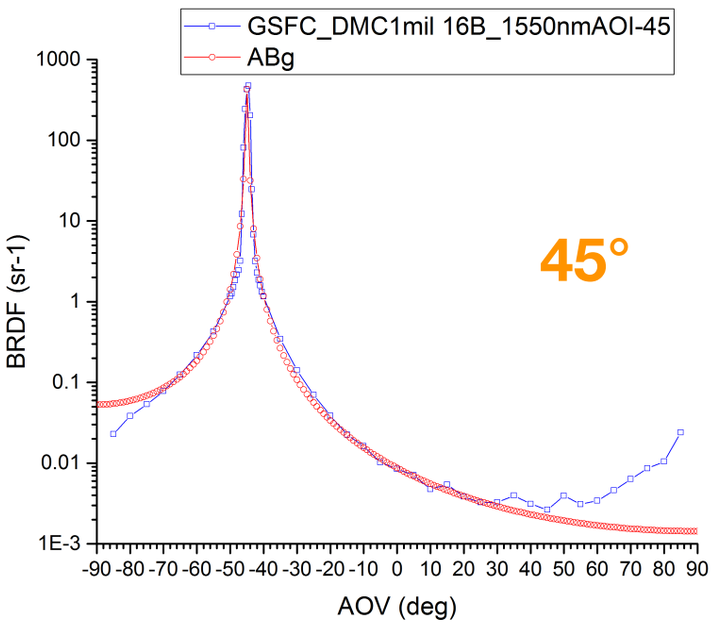


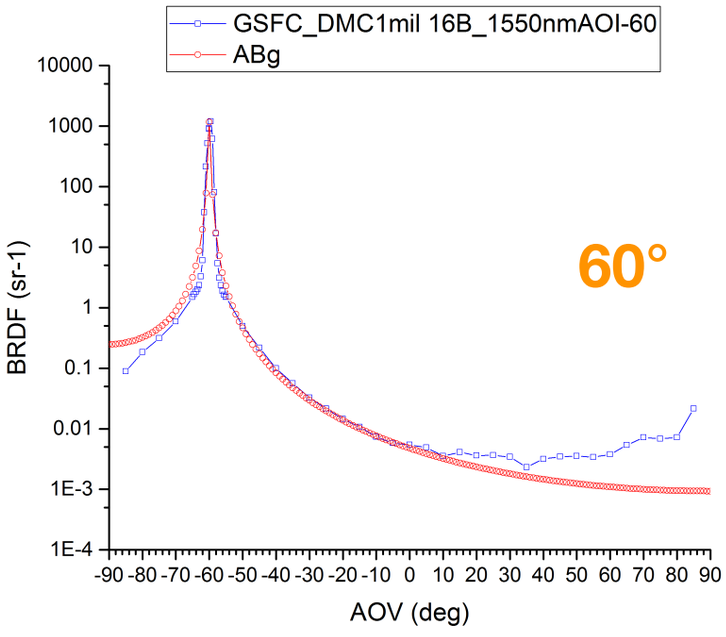


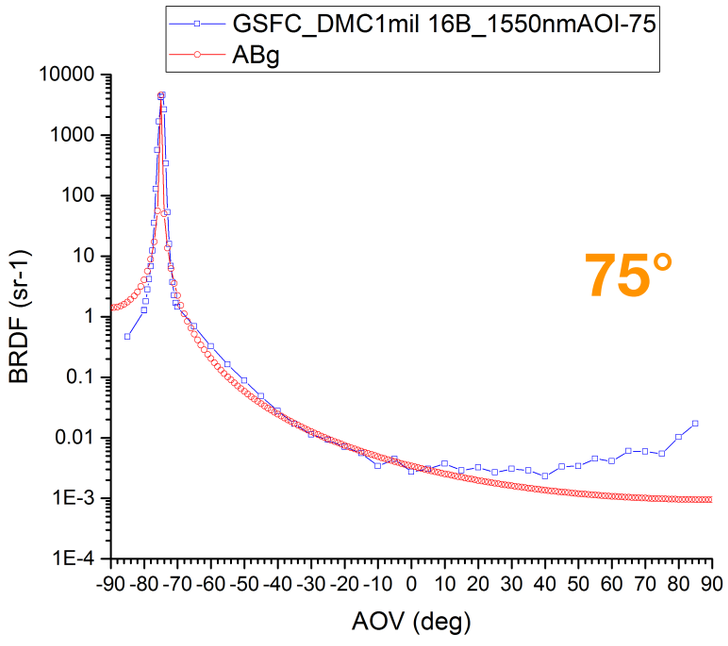




1550 nm BRDF results of GSFC DMC 1 mil at AOIs of 5, 15, 30, 45, 60, 75° and direct ABg model fitting

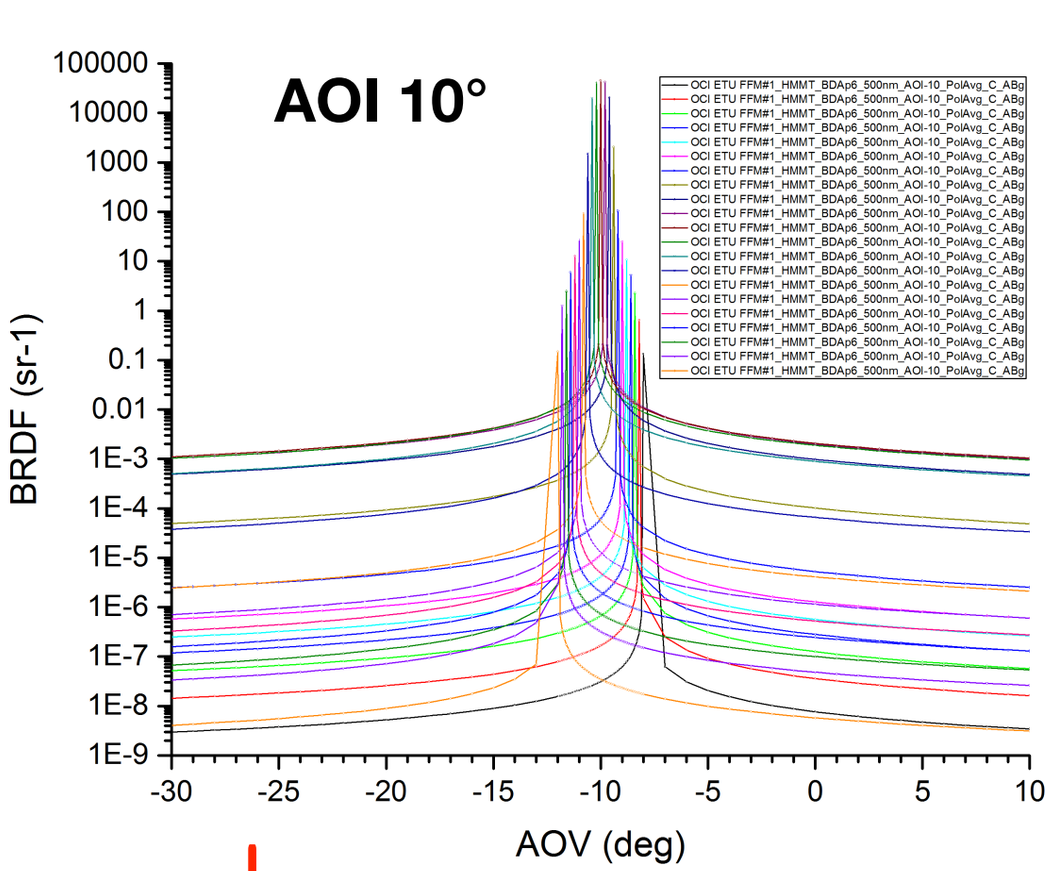


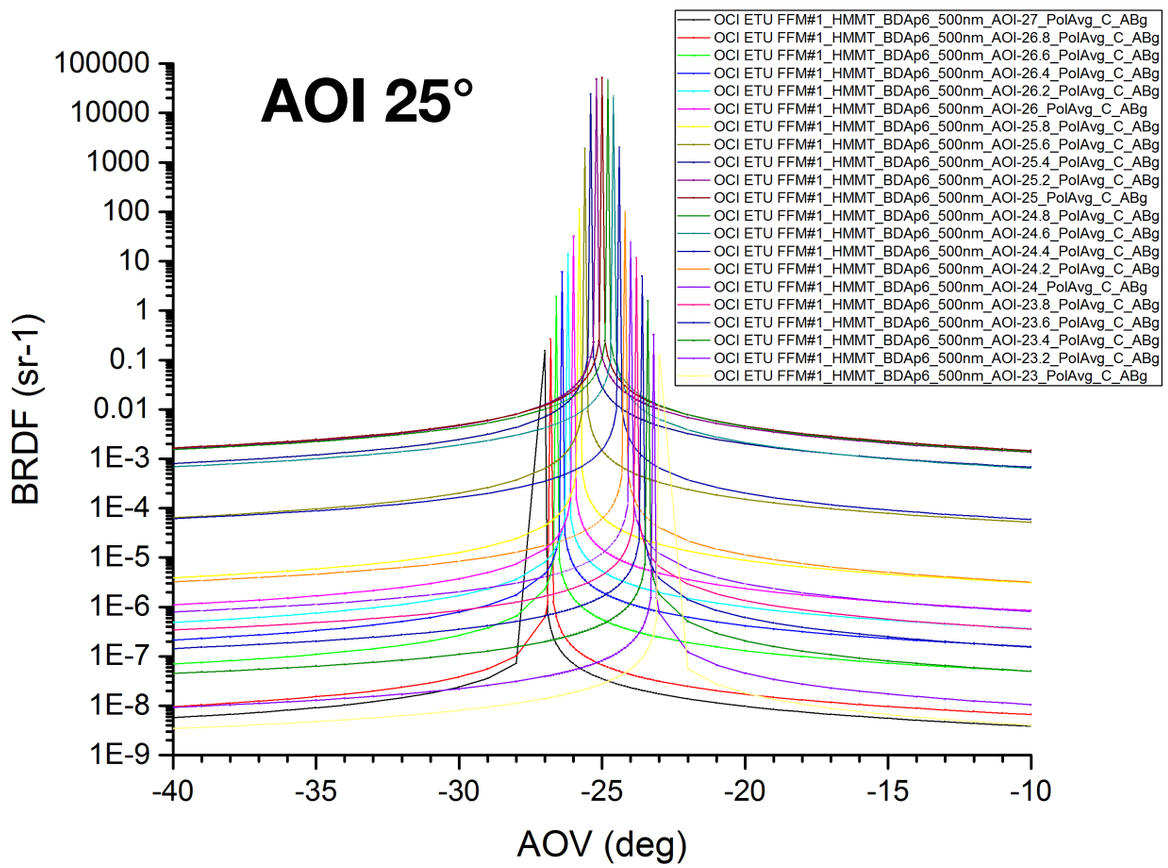


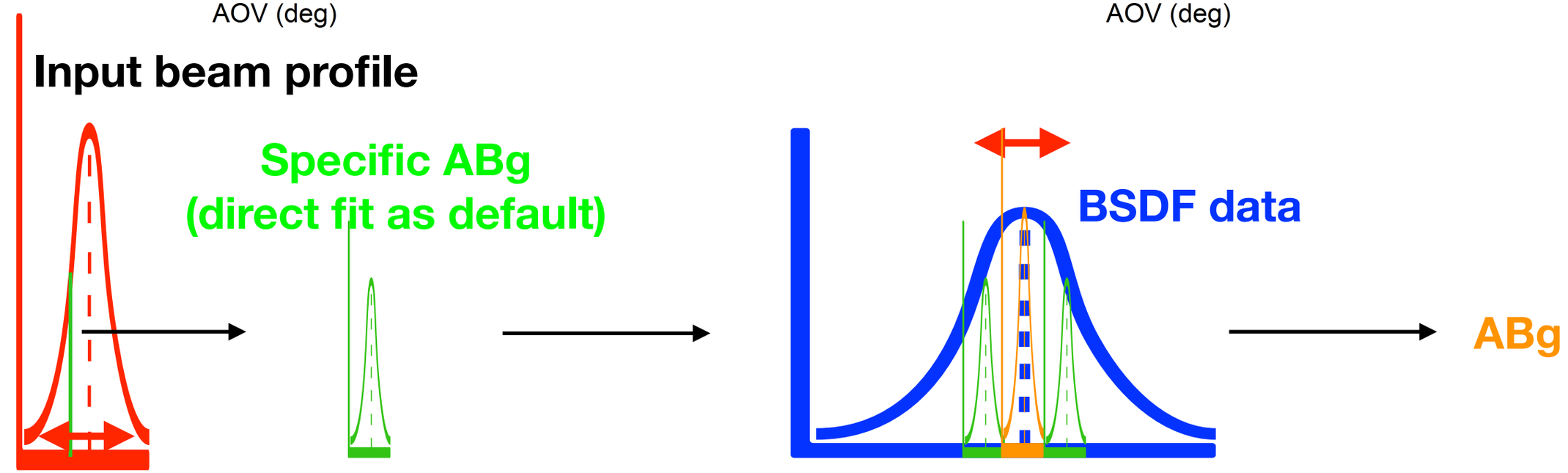


2. Determination of ABg parameters using deconvolution

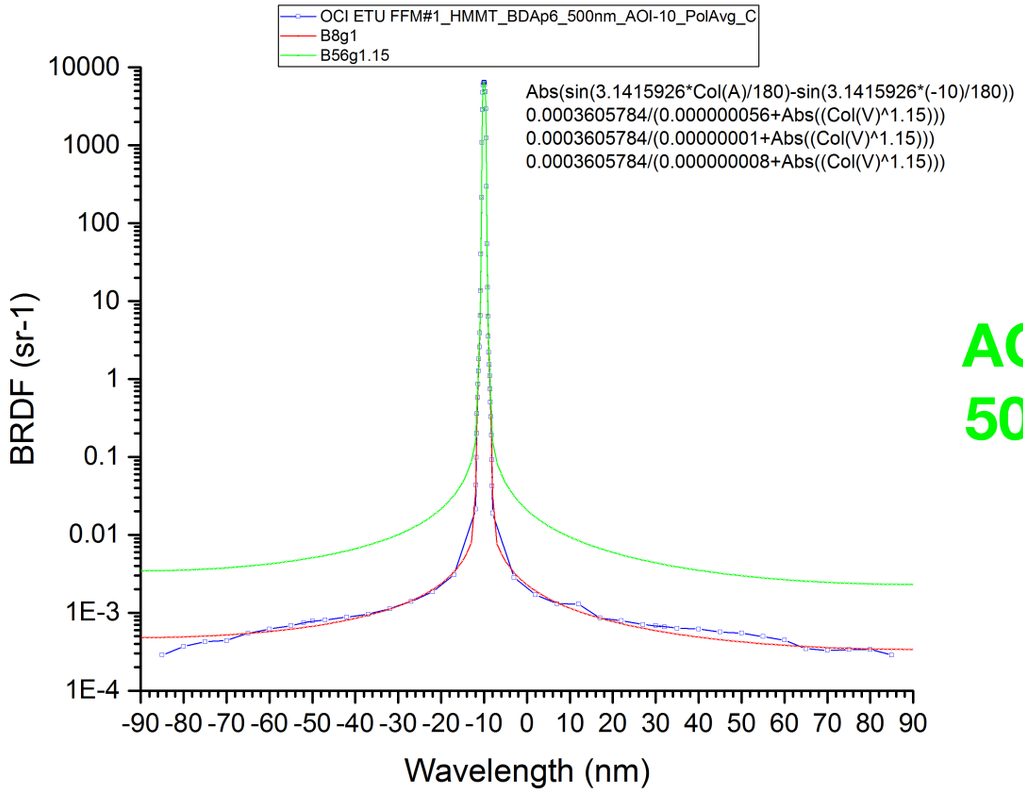
ABg model fitting of BSDF data at 500 nm from OCI flat mirror with deconvolution



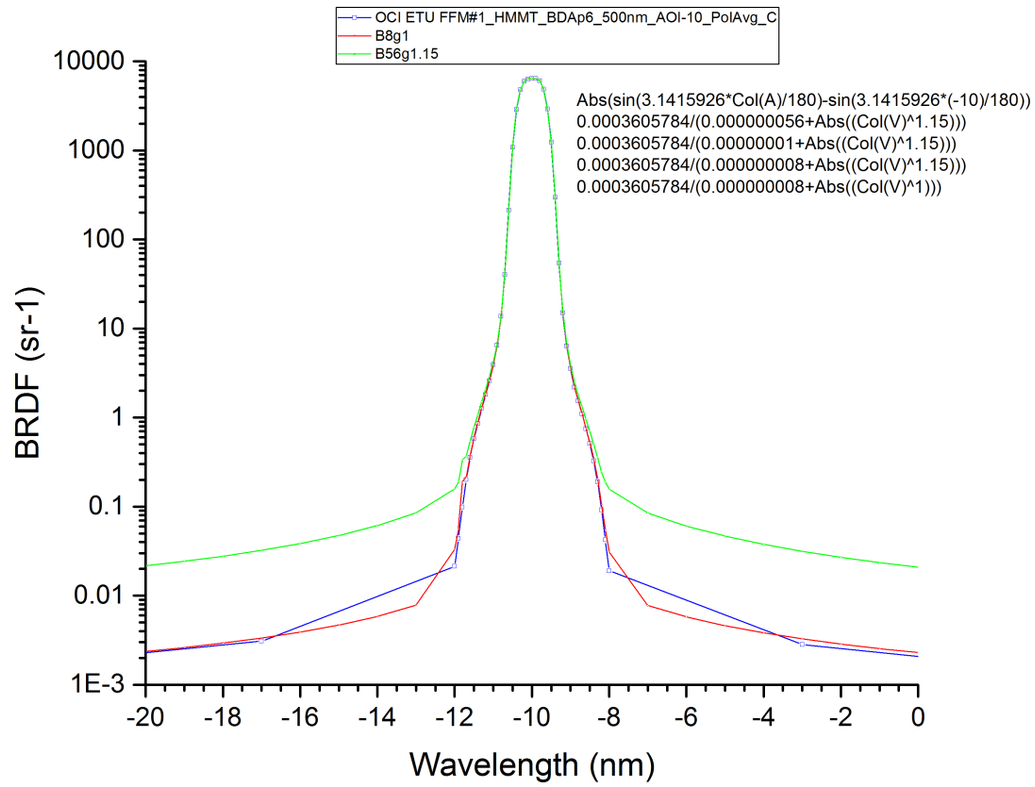




Comparison of OCI Flat mirror BSDF ABg fittings w/wo deconvolution

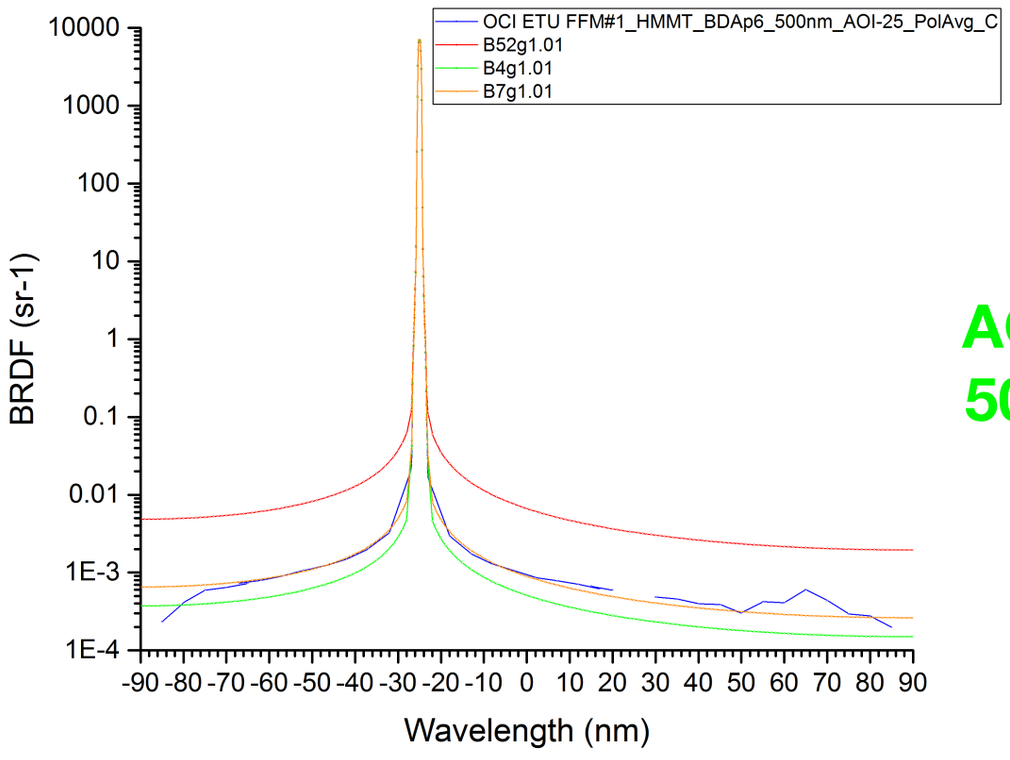


AOI 10°
500 nm

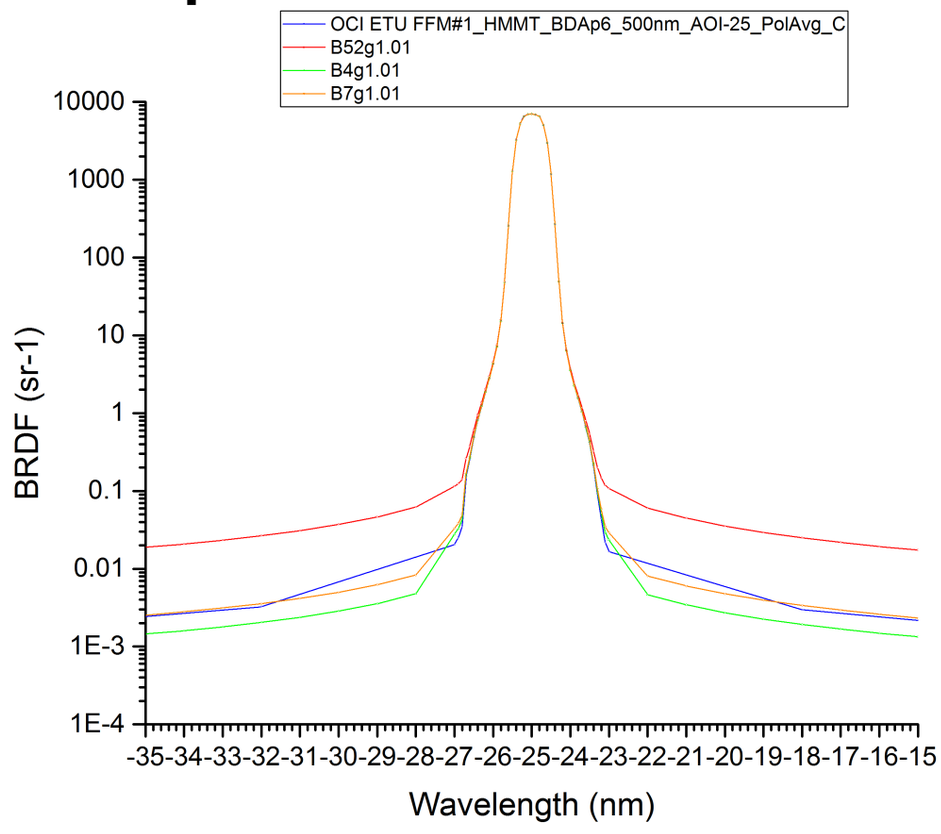


Case I Small surface optical figure

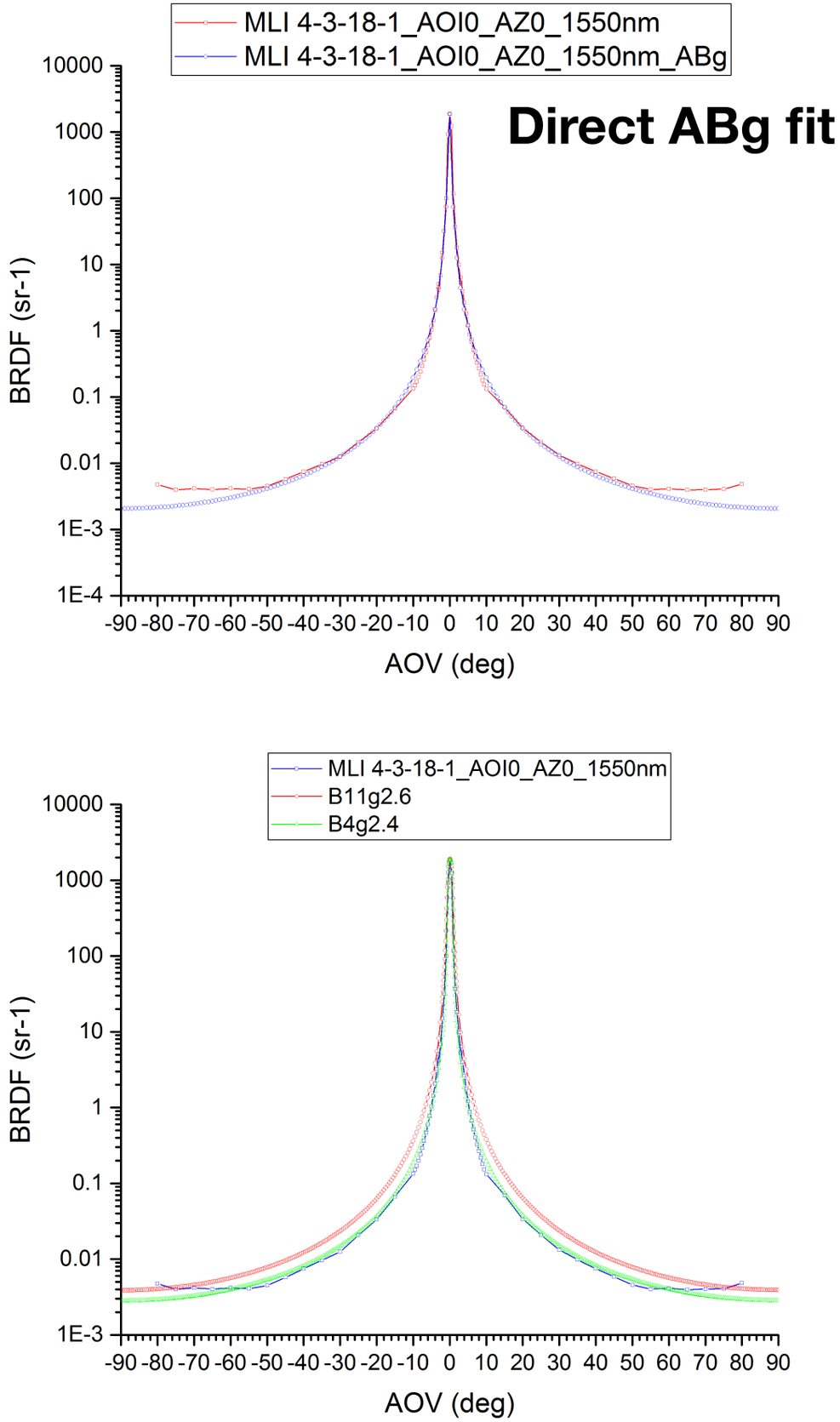
Input beam = Reflected peak



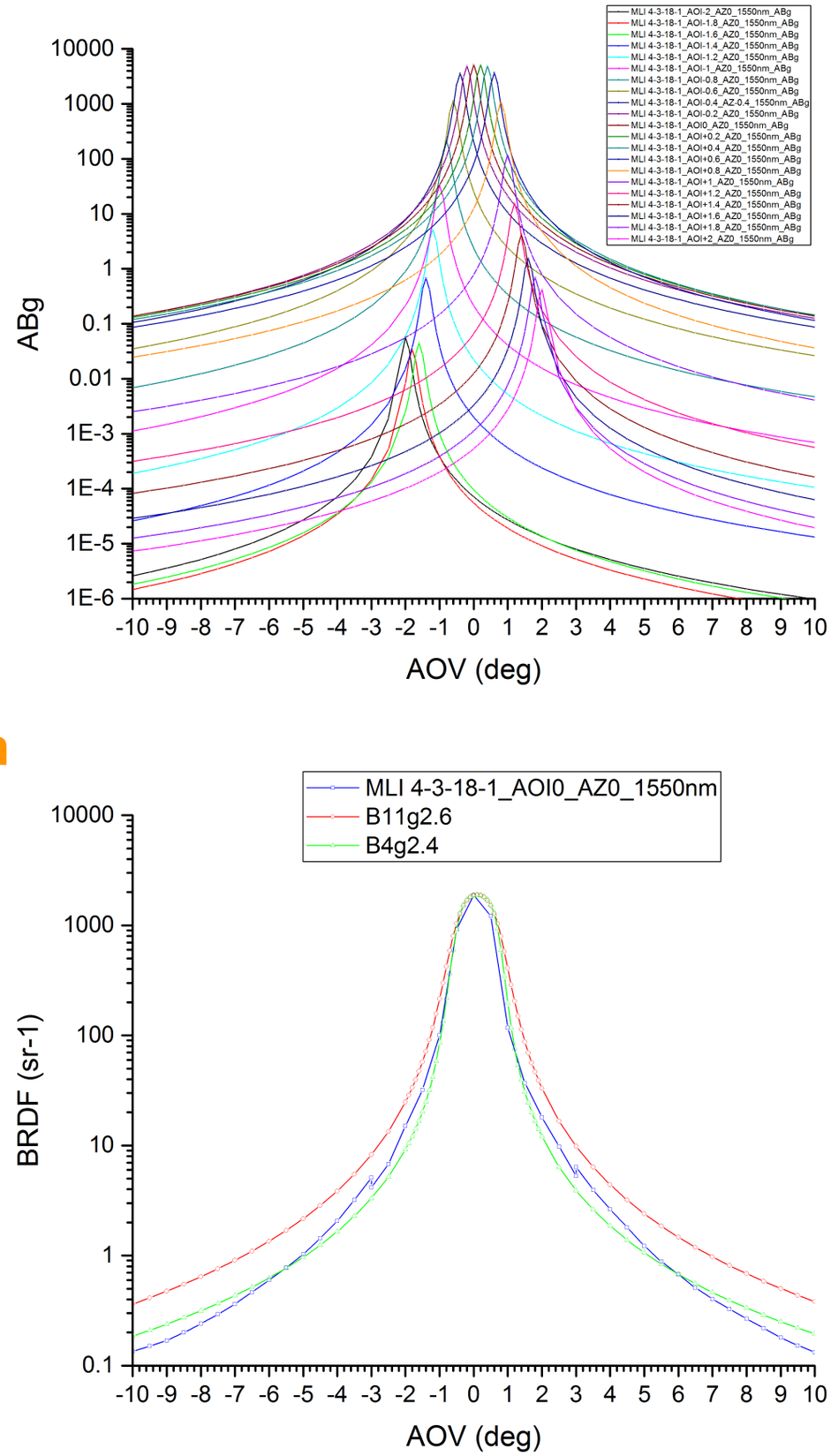
AOI 25°
500 nm



Comparison of MLI BSDF ABg fittings w/wo deconvolution



AOI 0°
1550 nm



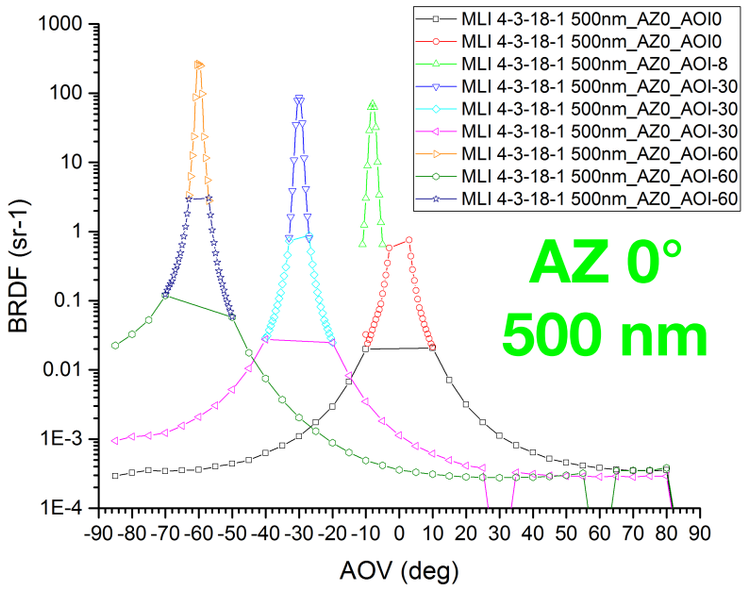
Summary

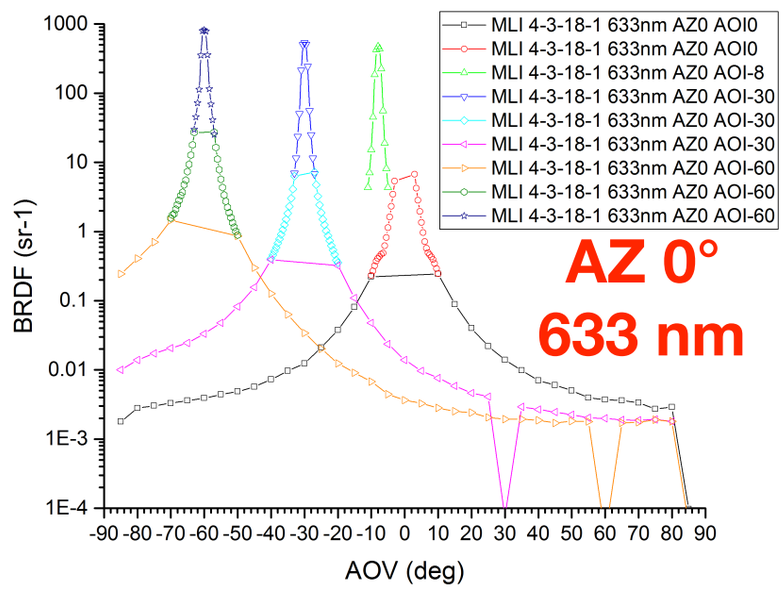
- **New BRDF measurement capability for specular/polished surface using TTG**
- **Instrument signature, huge dynamic ranges of signal level, flexible setups for flat/curved mirrors**
- **Determination of ABg parameters by taking into account of deconvolution of light beam profile and detector aperture for two specific cases**

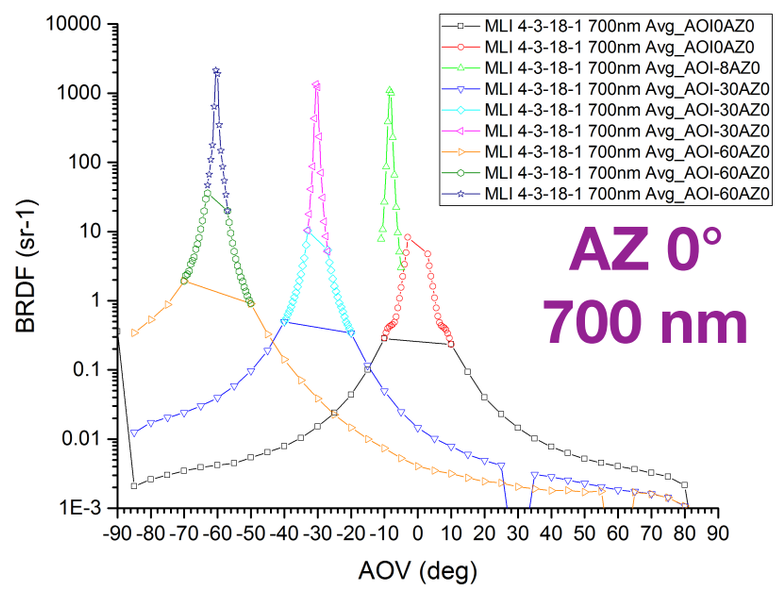
In the future

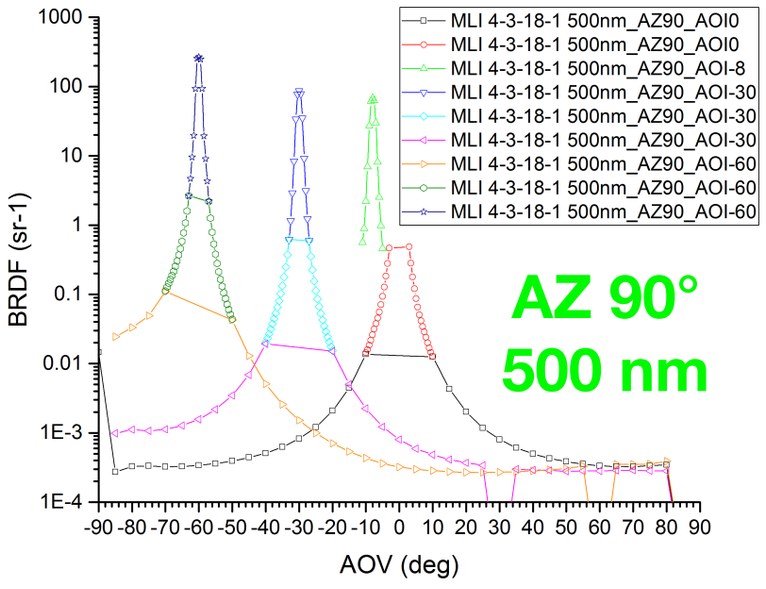
- **Establishment of BSDF scale for specular/polished surface materials**
- **Validation of extracted ABg parameters using other methods**
- **Determination of roughness parameters for smooth surface (microroughness)**
- **Prediction of stray light performance of an optical system**

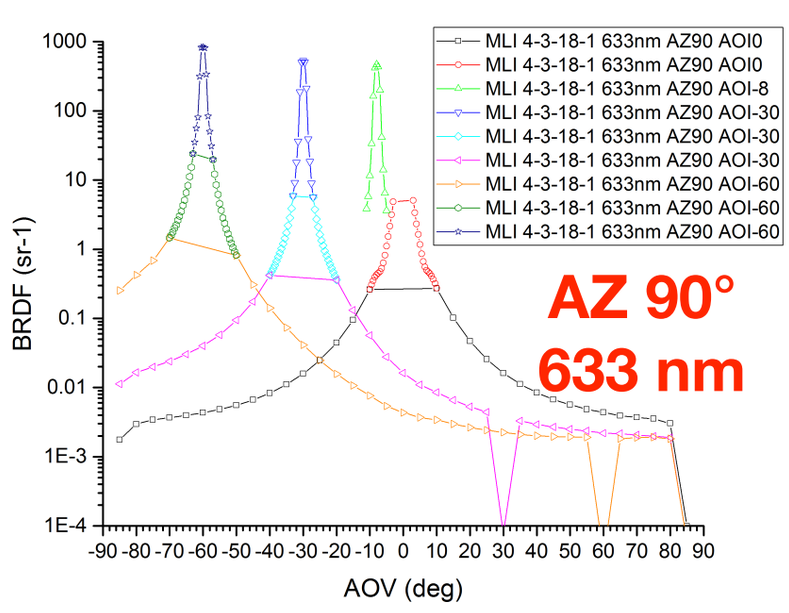
RestoreL MLI BSDF at 500, 633 and 700 nm with AOI 0, 8, 30, 60°

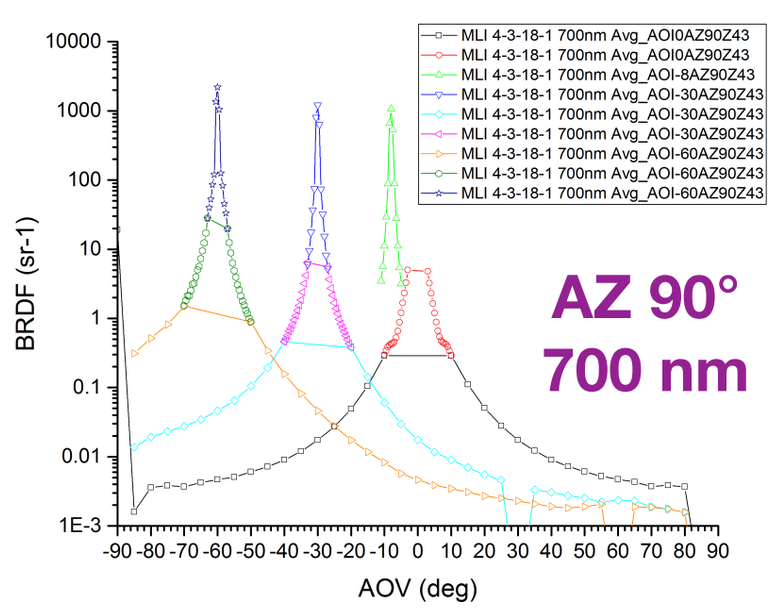




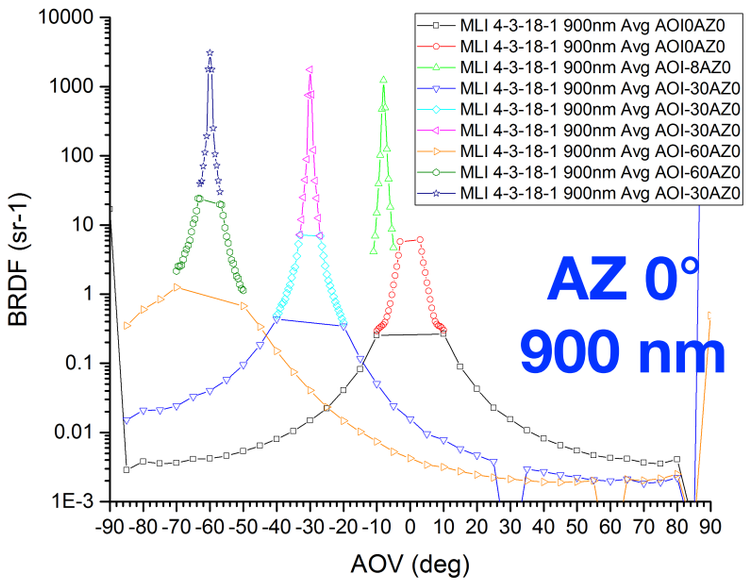


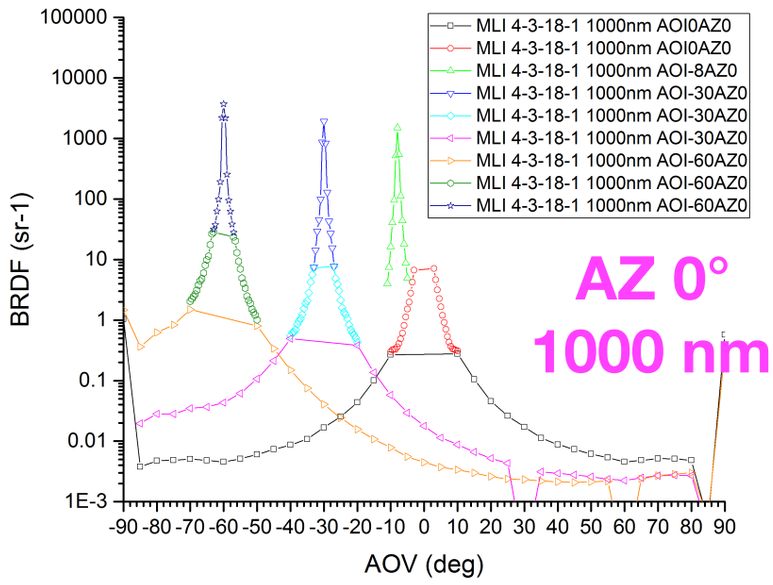


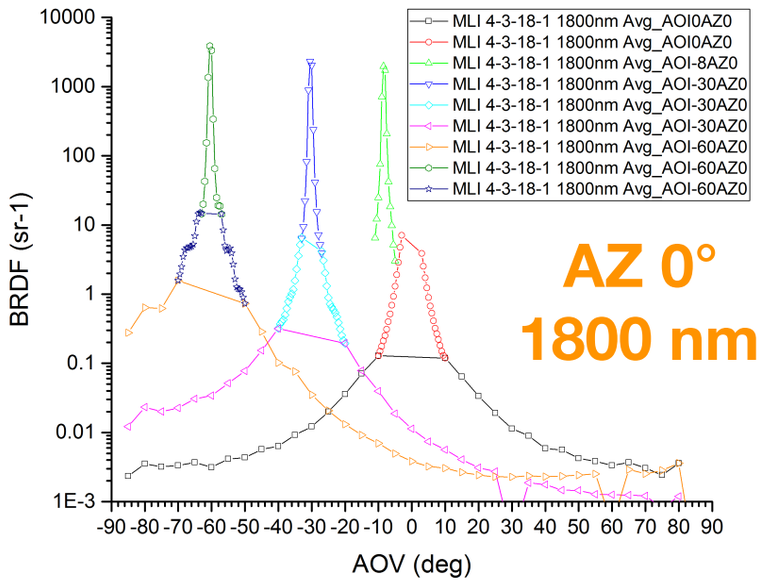


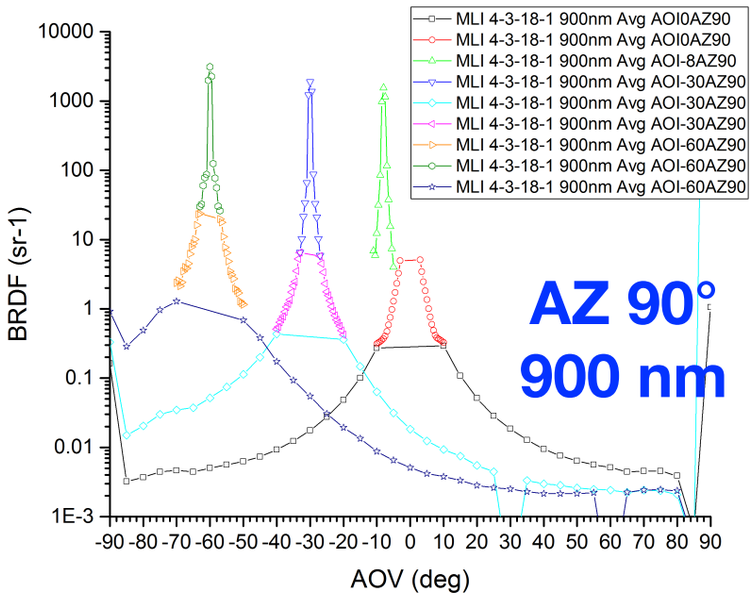


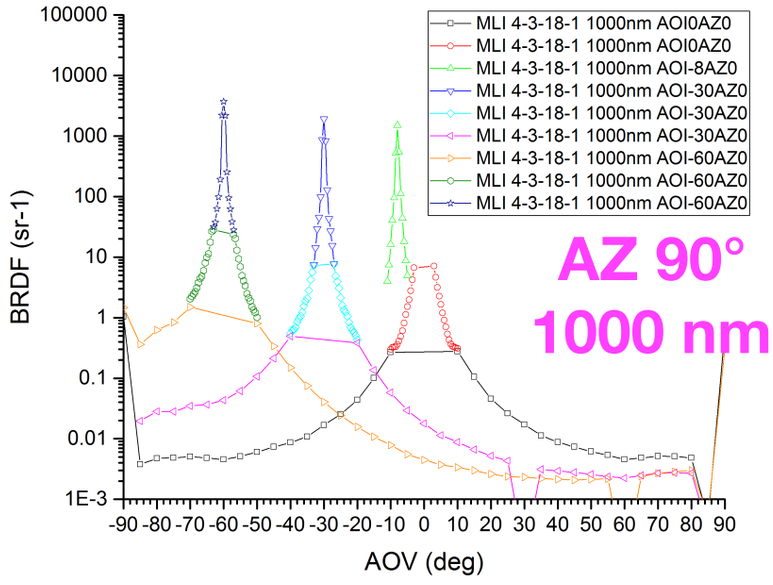
RestoreL MLI BSDF at 900, 1000 and 1800 nm with AOI 0, 8, 30, 60°

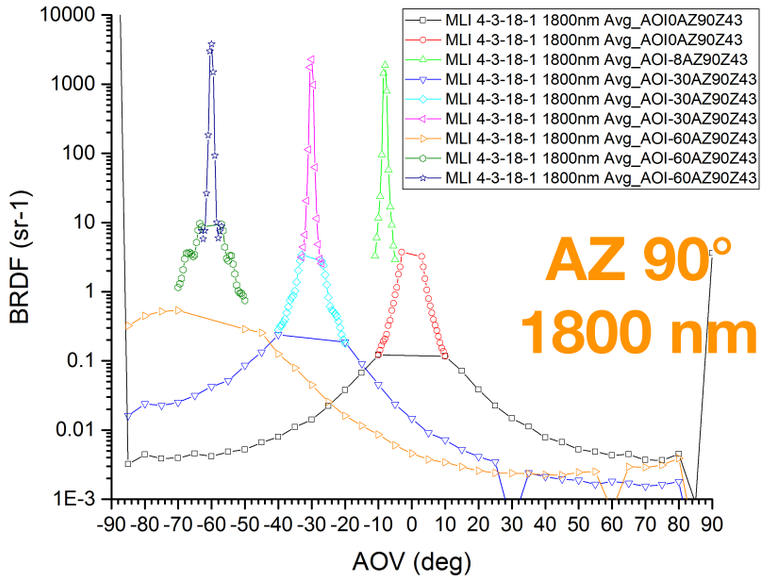




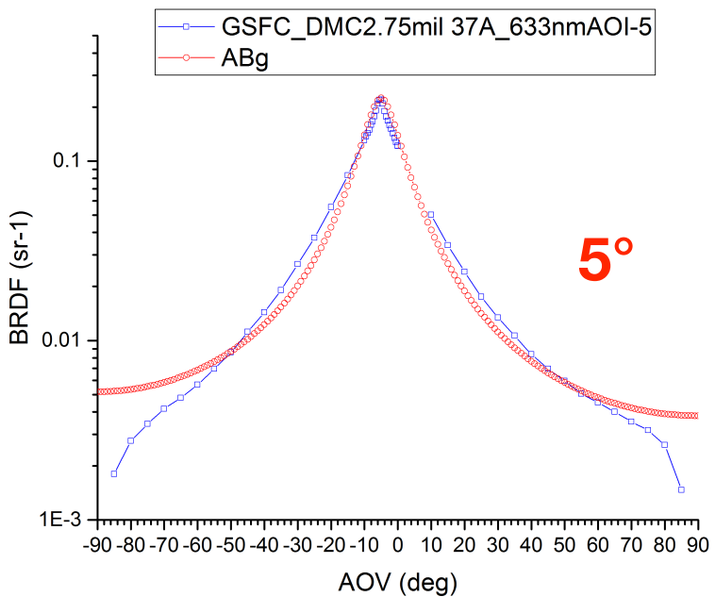


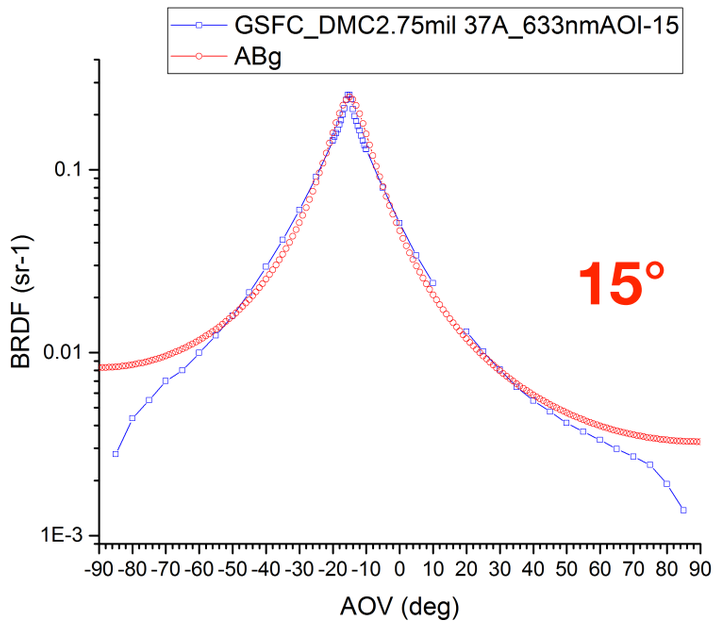


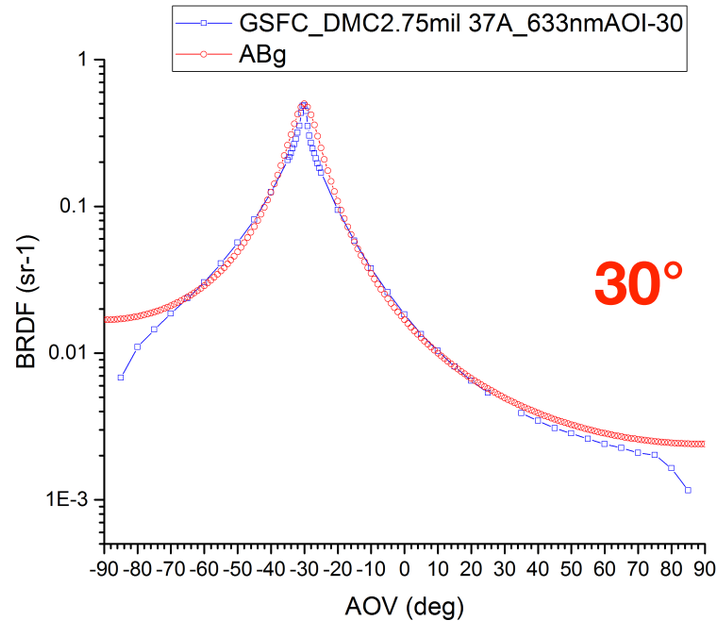


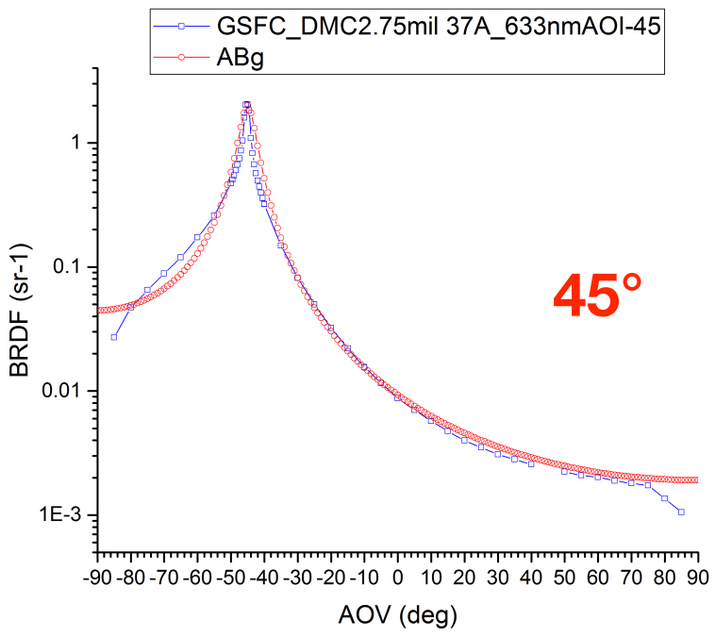


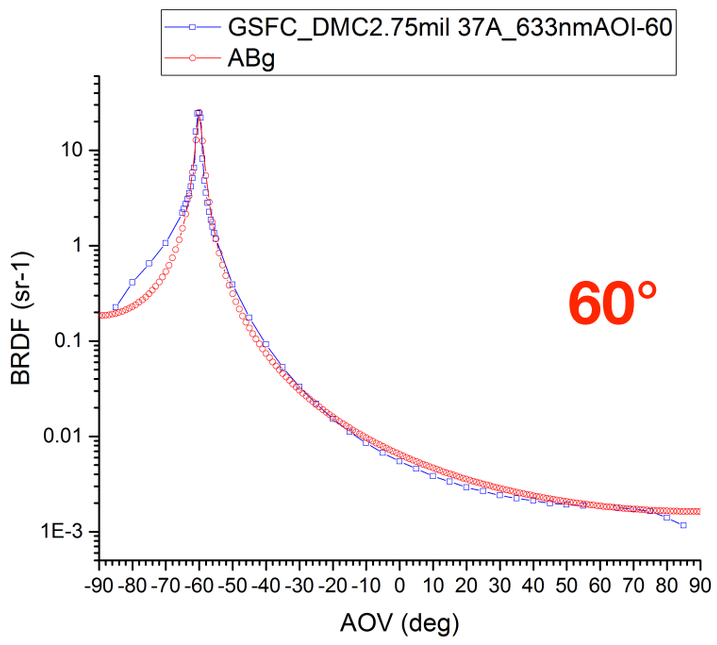
633 nm BRDF results of GSFC DMC 2.75 mil at AOIs of 5, 15, 30, 45 60, 75° and direct ABg model fitting

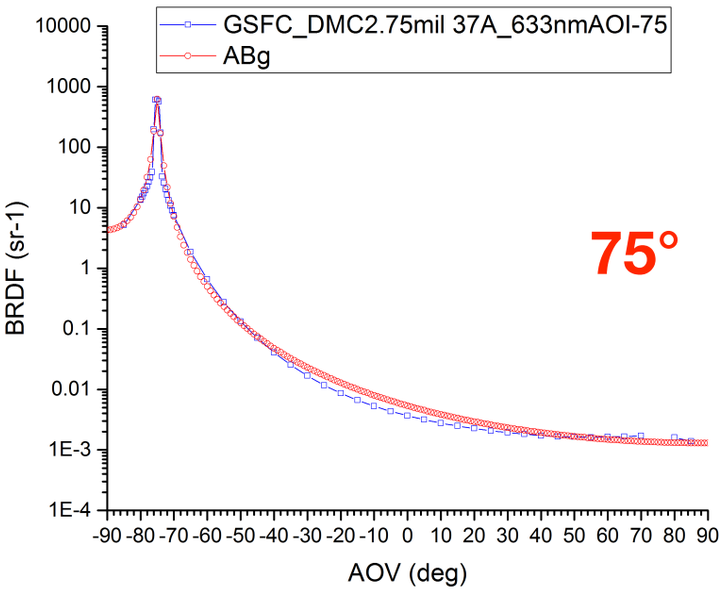












1550 nm BRDF results of GSFC DMC 2.75 mil at AOIs of 5, 15, 30, 45, 60, 75° and direct ABg model fitting