JPSS-1 VIIRS Solar Diffuser Witness Sample BRF Calibration using a Table-top Goniometer at NASA GSFC

Jinan Zeng[1], James Butler[2], Xiaoxiong Xiong[2], and Nathan Kelley[3]

[1]Fibertek Incorporation, 13605 Dulles Technology Dr., Herndon, VA 20171
[2]Goddard Space Flight Center, Greenbelt, MD, 20771
[3]Science Systems and Applications Incorporation, Lanham, MD, 20706

Overview

1. Introduction to VIIRS and its Solar Diffuser
2. Experimental
   - ✦ Sample description
   - ✦ THR & BRDF measurement
   - ✦ Methodology and technical challenges
3. Results and discussion
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   - ✦ Relationship of reflectance factors (BRF/8°THR)
   - ✦ Clocking effect (Azimuth angle dependence)
4. Uncertainty budget
5. Summary

Introduction

——— VIIRS Solar Reflective Bands

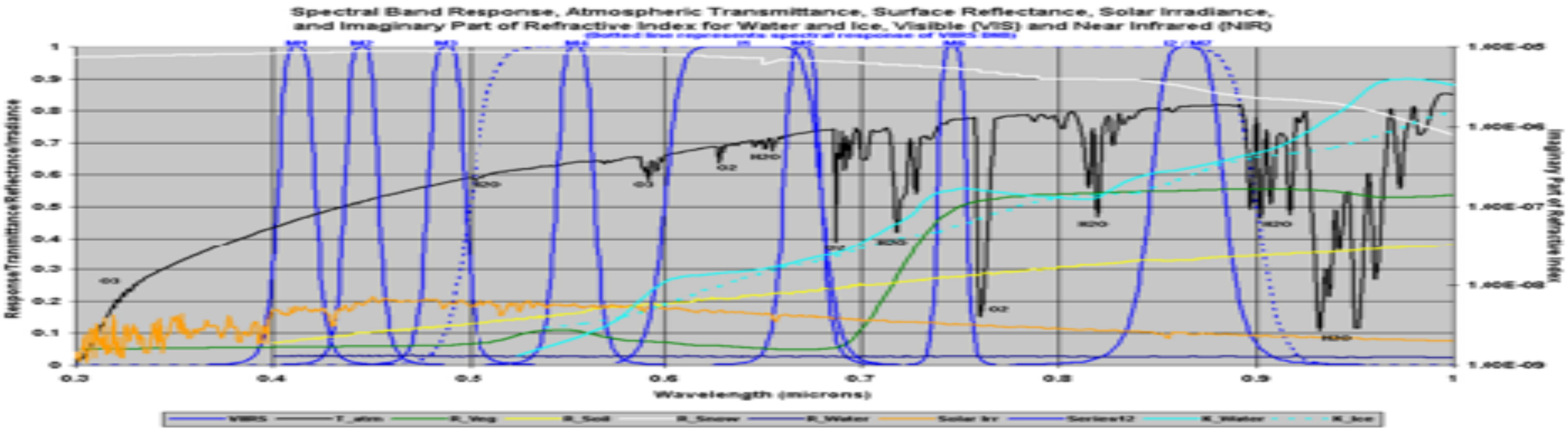


Figure 1: VIIRS Spectral Bands; Visible and Near Infrared

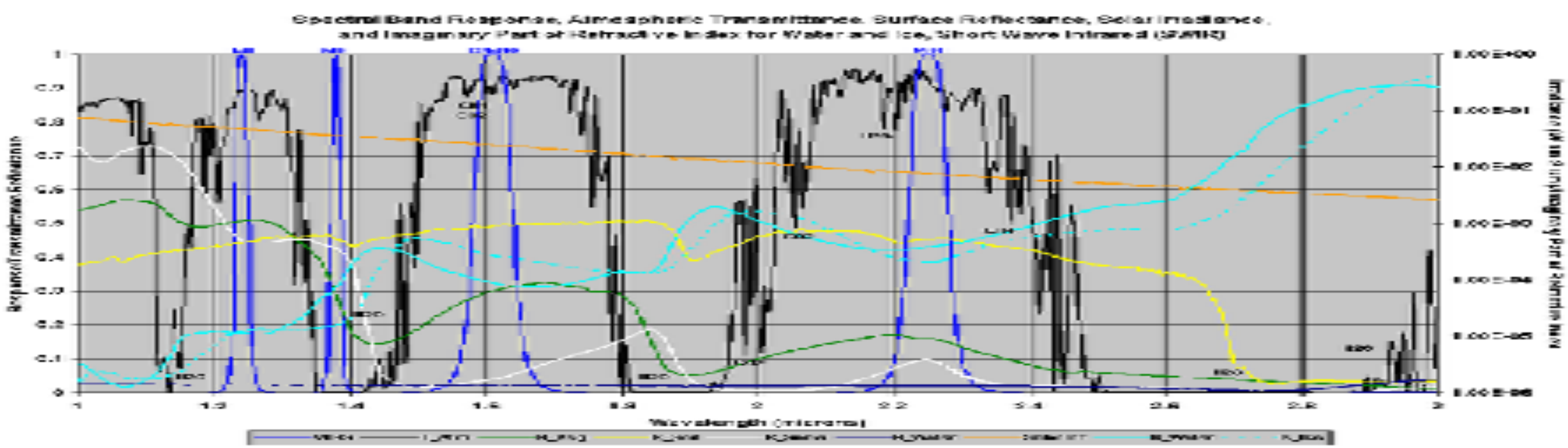
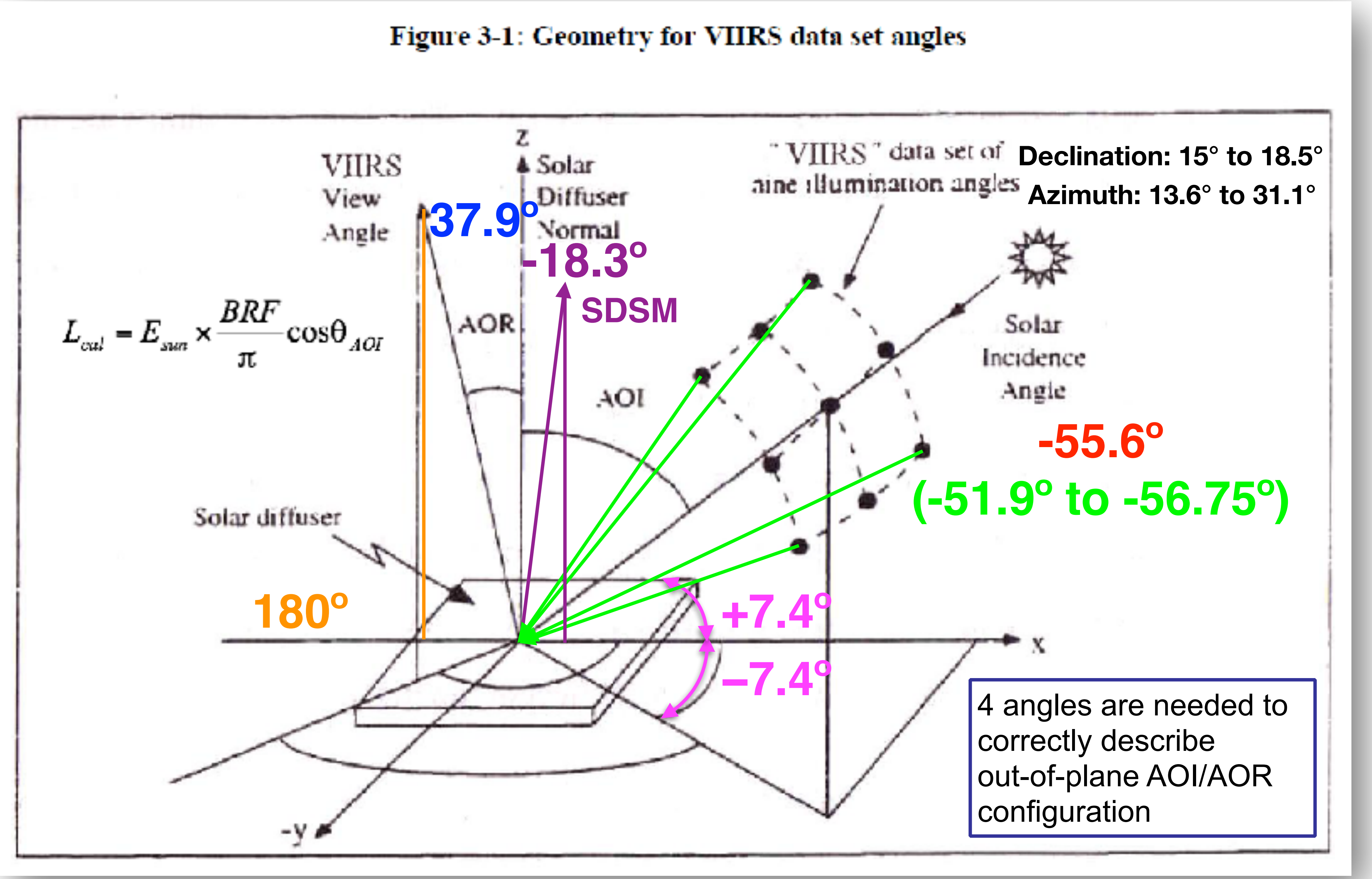


Figure 2: VIIRS Spectral Bands; Shortwave Infrared

422	538	617	714	906	1626

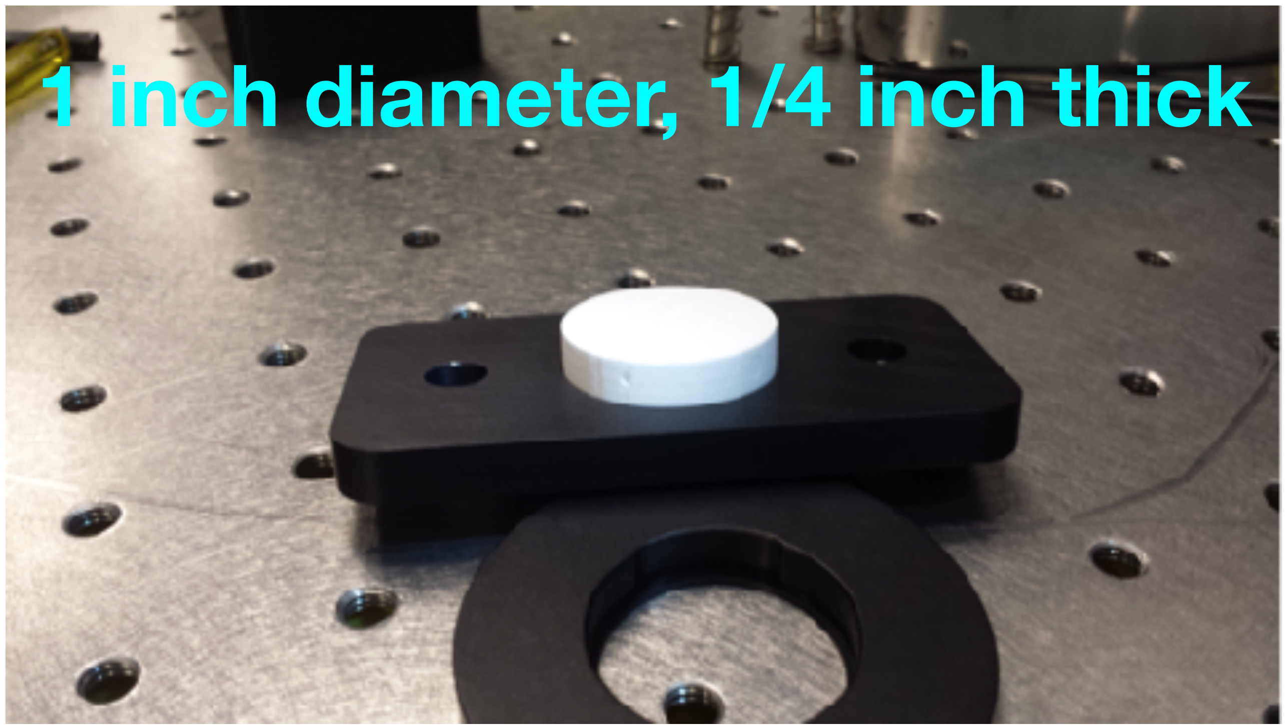
J1 VIIRS AOI/AOR in SD Coordinates



*Lessel & McClain, Proc. SPIE 6677 (2007)

Experimental

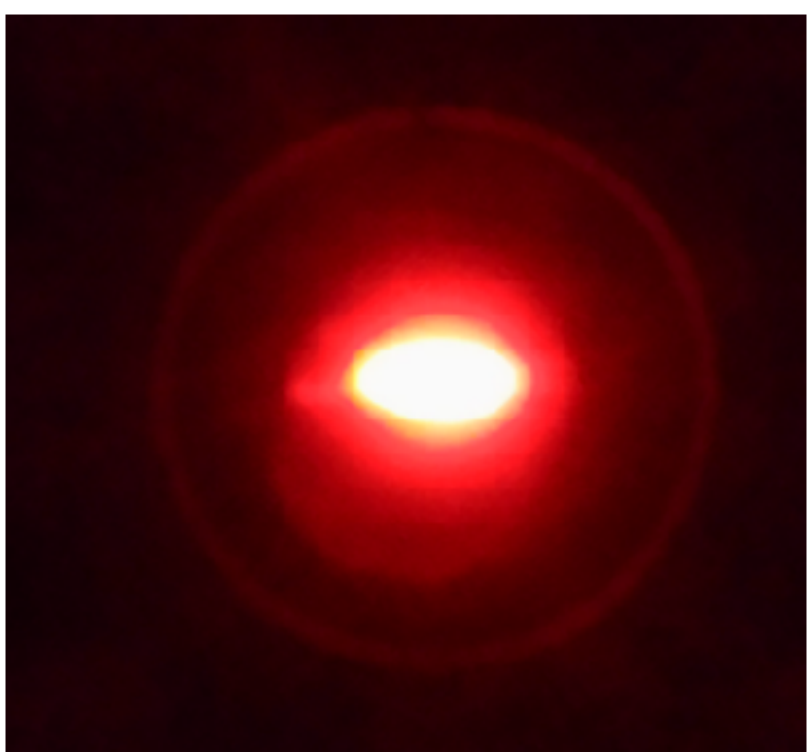
———J1VIIRS SDA Witness Sample



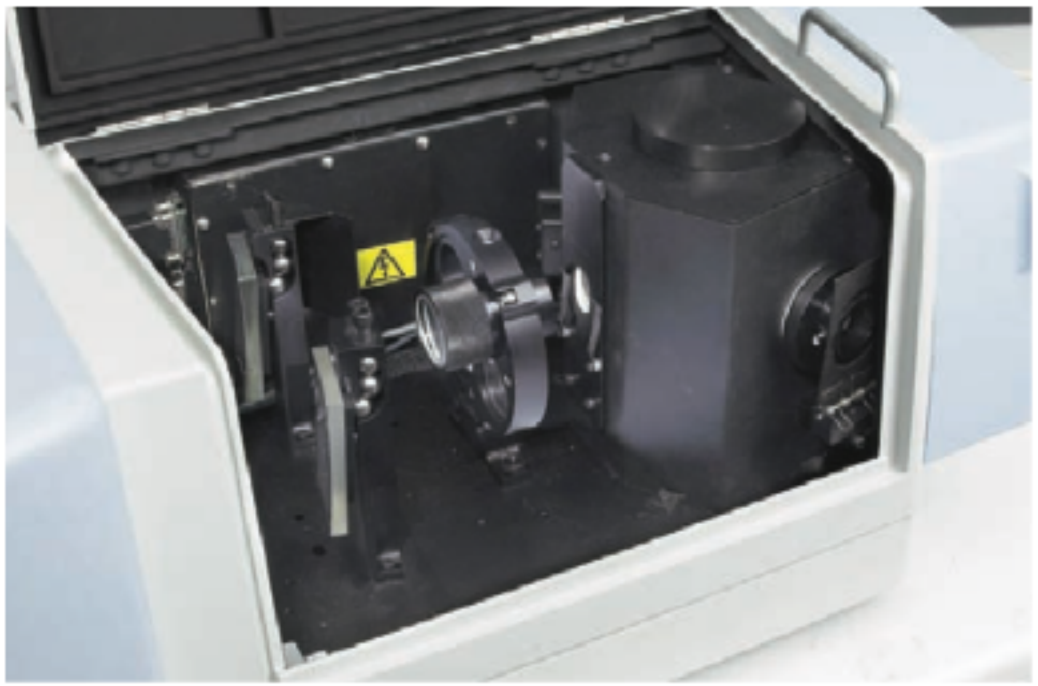
Front view

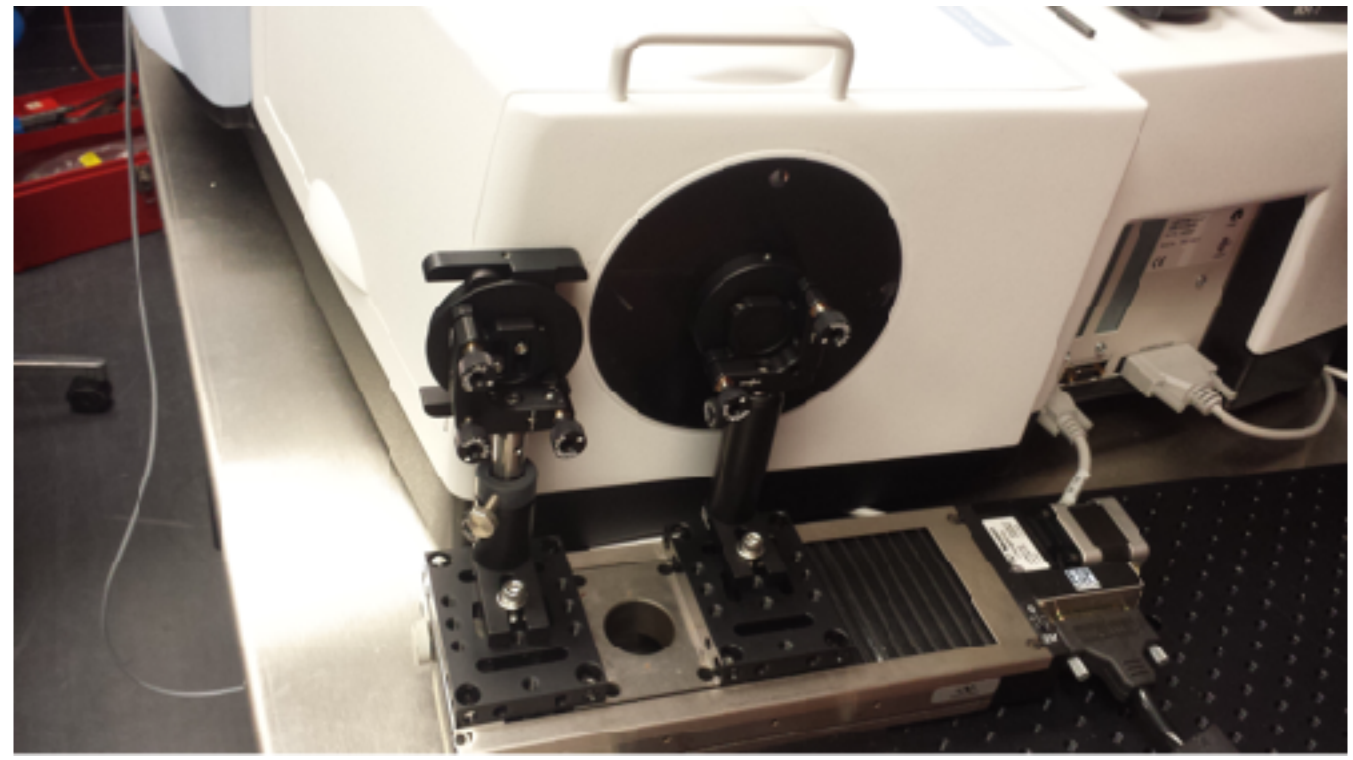
Sample transmission

Rear view



Experimental
———THR measurement instrument
(PE LAMBDA 1050)



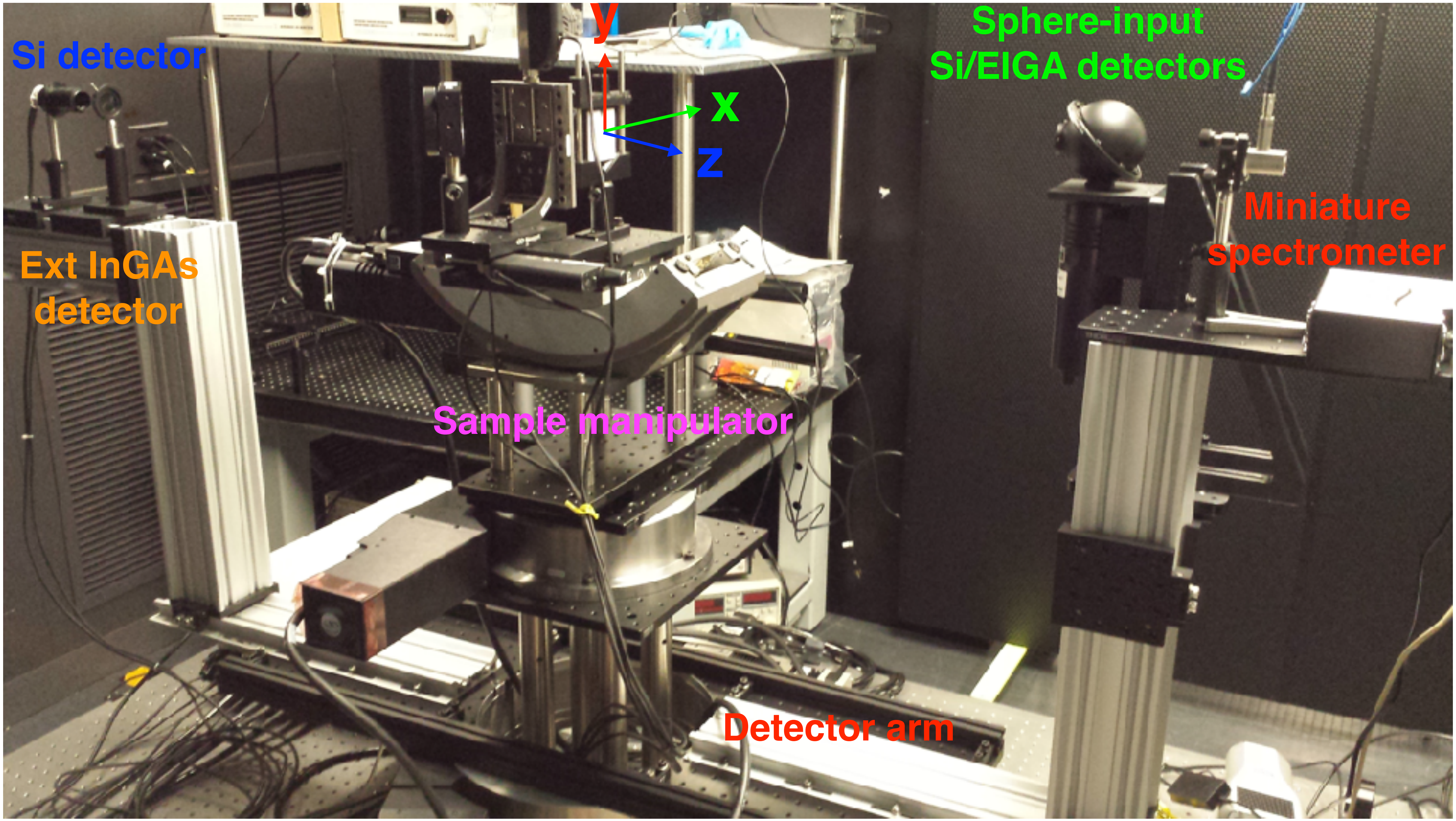


Light sources: Deuterium and Tungsten Halogen lamps
Double holographic grating monochromator
150 mm diameter integrating sphere
Spectral range: 200 to 2500 nm
Detectors: PMT and EX-InGaAs
Double beam mode in either specular included 8°/hemispherical or specular excluded geometry

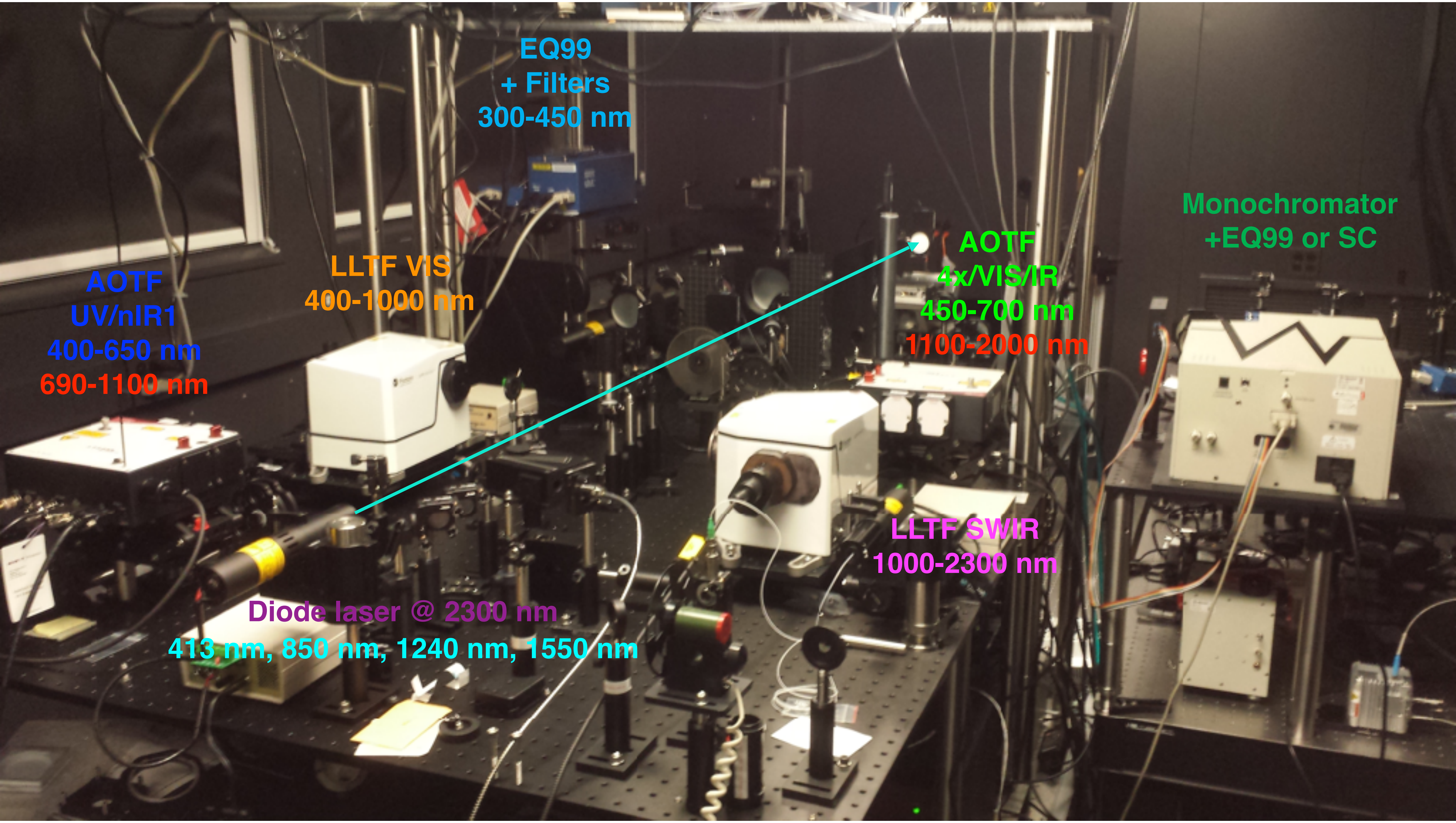
Experimental

———BRDF measurement instrument

Table Top Goniometer (TTG)

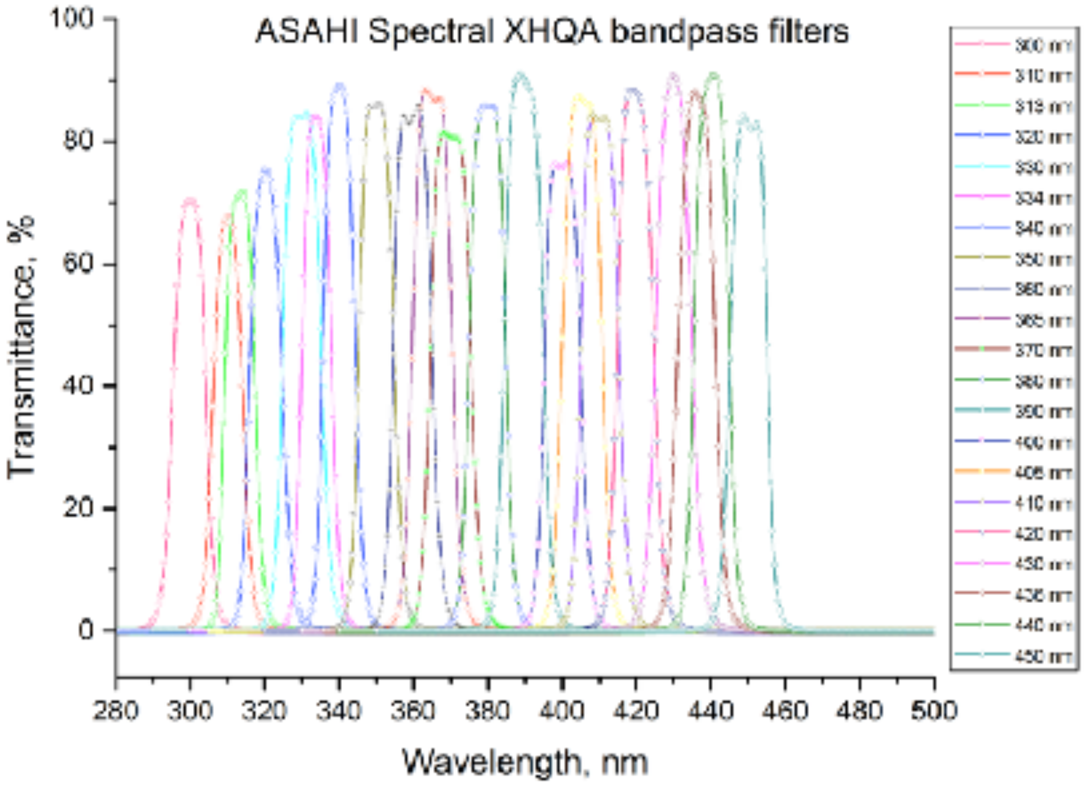


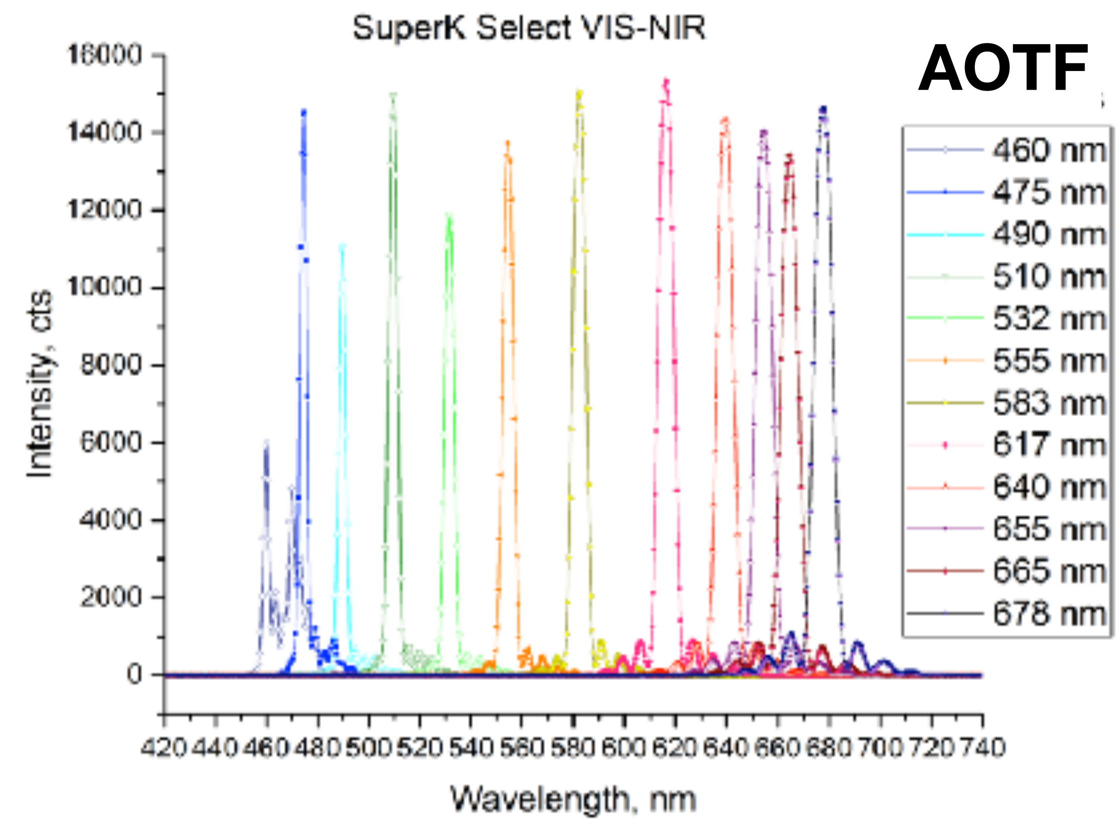
TTG Light Sources

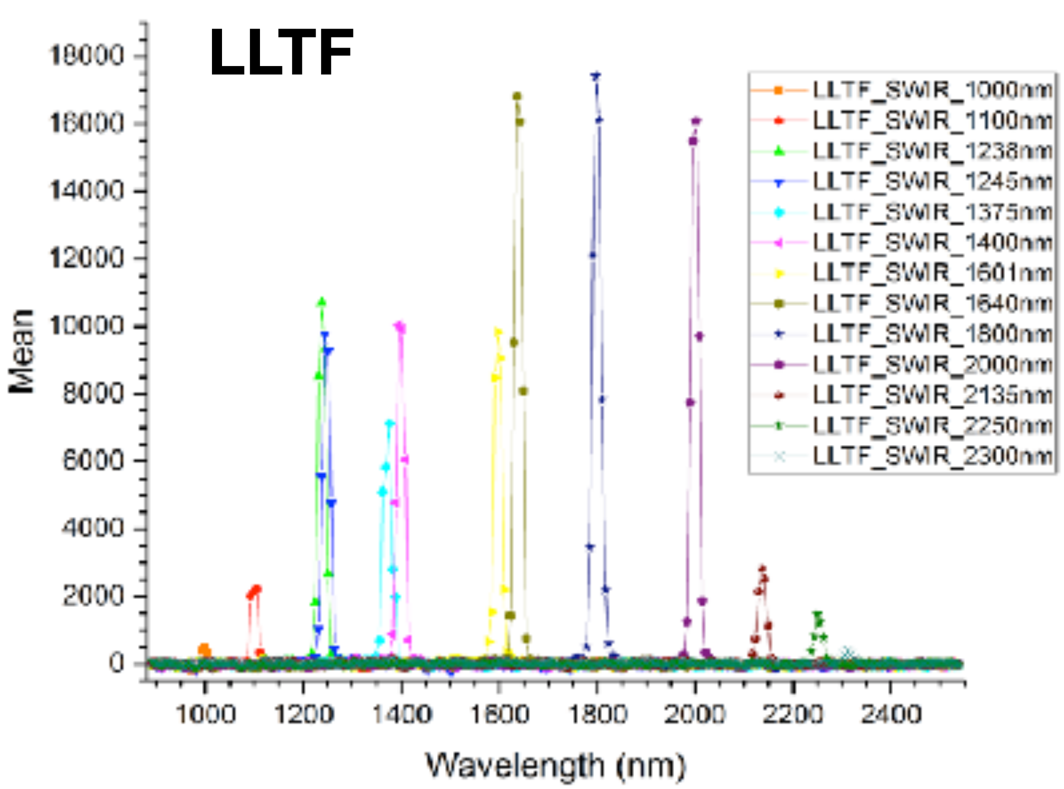


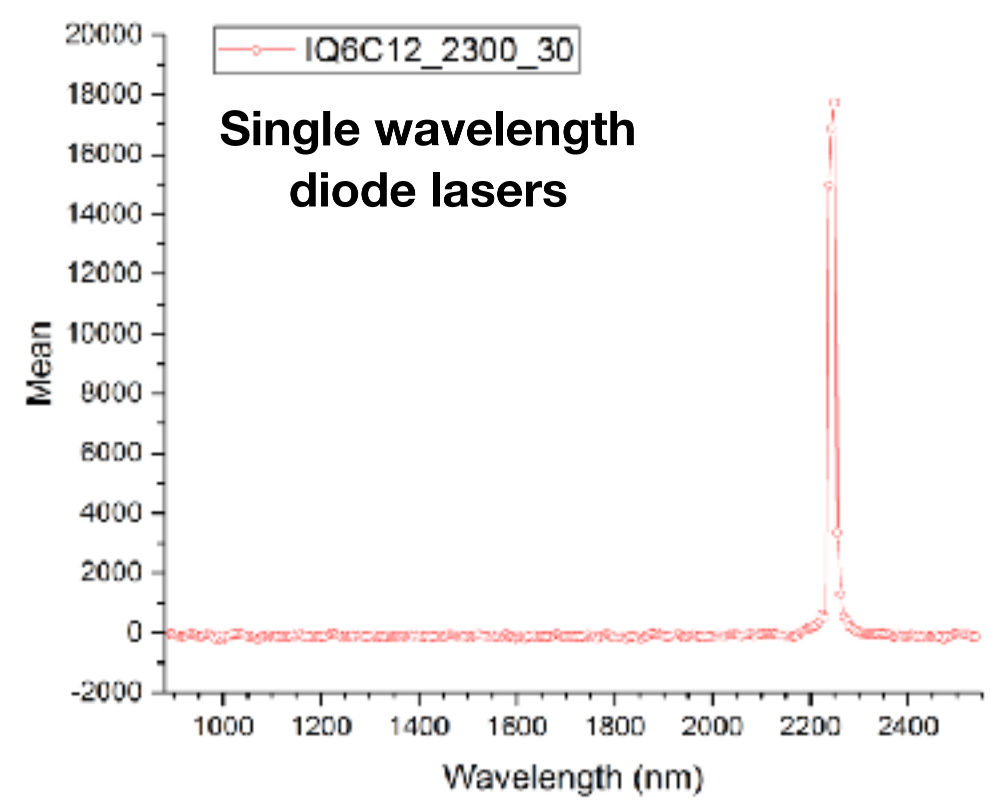
AOTF with power lock + multiple line output **LLTF automated line selection**

New capability of DCL scatterometers





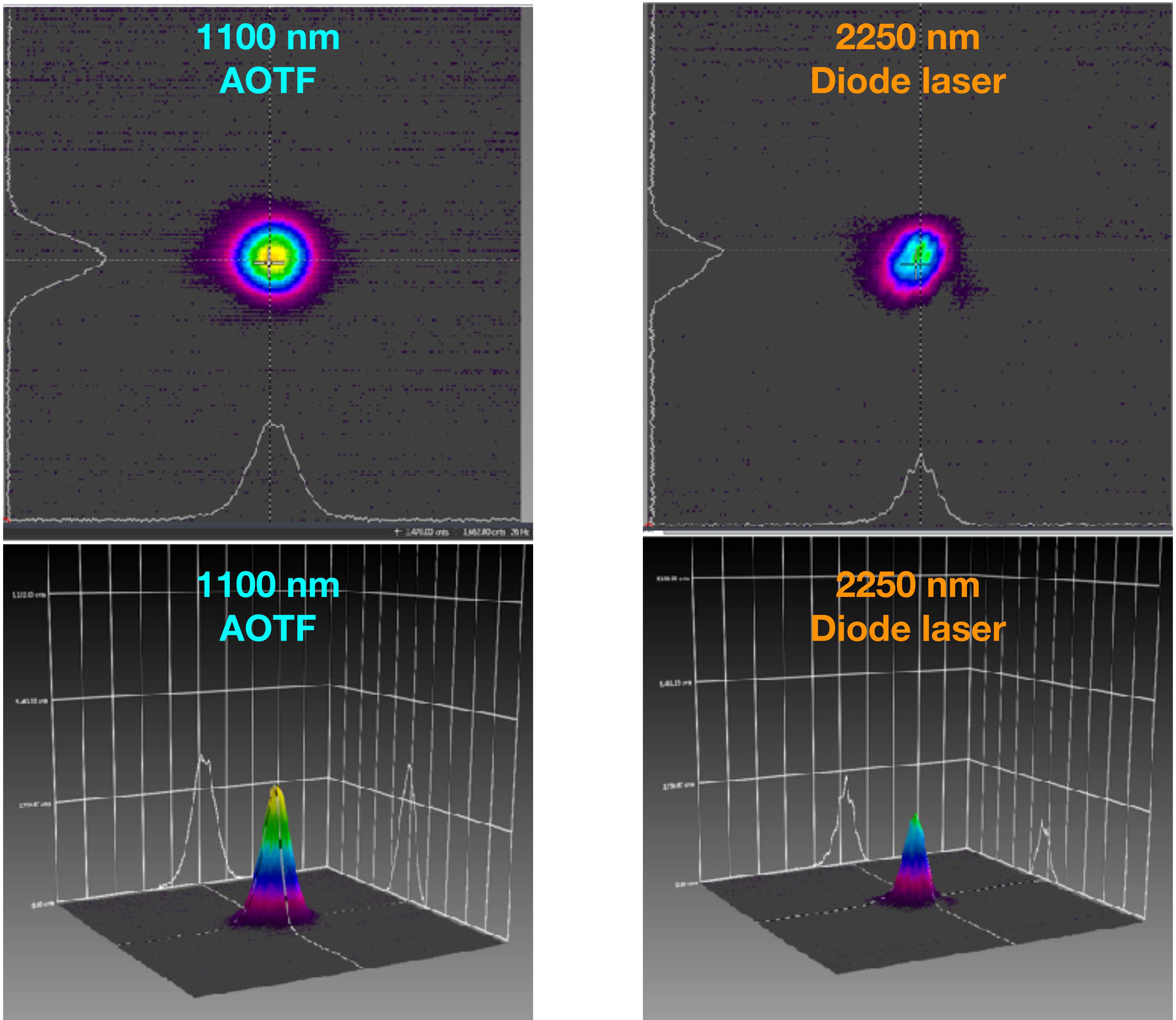




Wavelength coverage of BRDF measurement for J1 VIIRS SD Witness

Wavelength (nm)	Light Source	Bandwidth (nm)	Detector
410	Energetiq EQ-99 + filter	9	SiPD
440	Energetiq EQ-99 + filter	10	SiPD
488	SC Laser + AOTF	3.2	SiPD
500	SC Laser + AOTF	3.5	SiPD
555	SC Laser + AOTF	5	SiPD
672	SC Laser + AOTF	8	SiPD
700	SC Laser + AOTF	8	SiPD
746	SC Laser + AOTF	10	SiPD
865	SC Laser + AOTF	10	SiPD
1100	SC Laser + AOTF	12	Standard InGaAs
1238	SC Laser + AOTF	11	Standard InGaAs
1375	SC Laser + AOTF	12	Standard InGaAs
1601	SC Laser + AOTF	13	Standard InGaAs
1800	SC Laser + AOTF	16	Sphere input extended InGaAs
2000	SC Laser + AOTF	20	Sphere input extended InGaAs
2250	Diode laser	19	Sphere input extended InGaAs

Verification of beam size



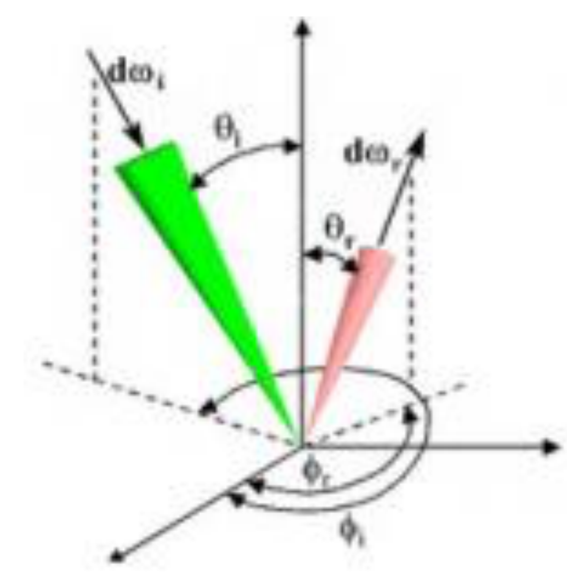
Experimental

———Methodology of BRDF Measurement

$$BRDF^{s}(\lambda)=\frac{(V^{s}(\lambda)-V^{d}(\lambda))/(V^{sm}(\lambda)-V^{d}(\lambda))}{(V^{r}(\lambda)-V^{d}(\lambda))/(V^{rm}(\lambda)-V^{d}(\lambda))}BRDF^{r}(\lambda)$$

0°/45°
NIST Ref ⇨ J1 SDWit ⇨ 0°/45° ⇨ 55.6°/37.9°/±24°
J1 SDWit

1. Spectralon material for sample (SD witness, space grade) and reference (20471-1-1, optical grade)
2. Cancellation of geometry parameter factor Ω
3. Interpolation/extrapolation of reference BRDF scale
4. Relative BRDF measurement



Bidirectional reflectance distribution function (BRDF)

$$f(\theta_i,\phi_i,\theta_r,\phi_r)=\frac{dL_r(\theta_r,\phi_r)}{dE_i(\theta_i,\phi_i)}$$

$$f_r=\frac{L_r}{E_i}=\frac{\Phi_r}{\Phi_i}\frac{r^2}{A_d\cos\theta_r}$$

$$\Omega=\frac{A_d}{r^2}$$

Experimental
———Technical challenges

- Limitation of beam spot on 1” diameter SD witness at AOI of 55.6°
- Unknown relative orientation between the SD witness and the SD assembly
- Realization of absolute BRDF from M1 to M11
- Azimuth angle dependence (Clocking effect)
- Increasing speckle effect at higher SWIR λs
- Effect of sample transmission

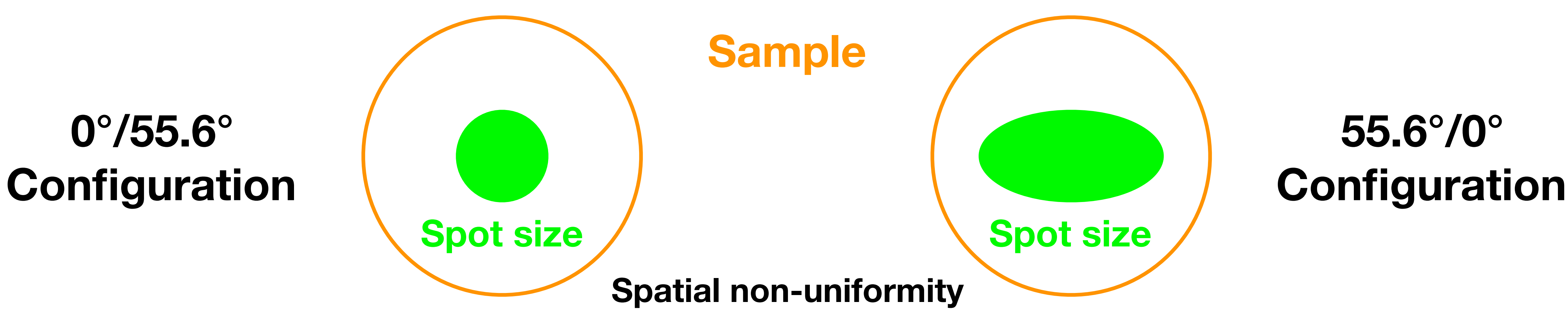
Results and discussions
———Validation of BRDF measurement using BRDF reciprocity

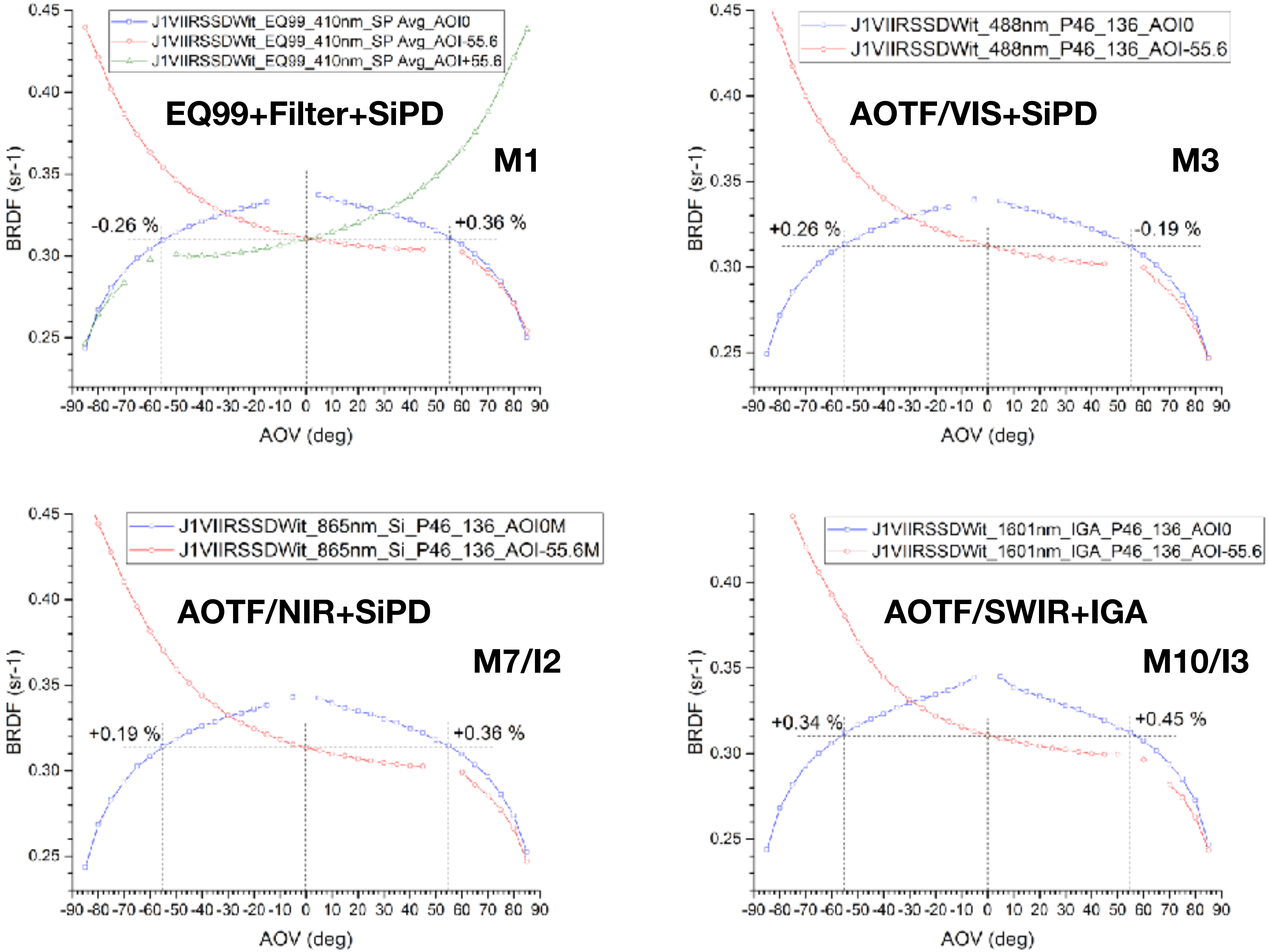
$$\mathrm{BRDF} = f_{\mathrm{r}}(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{dL_{\mathrm{r}}(\theta_i, \phi_i; \theta_r, \phi_r; E_{\mathrm{i}})}{dE_{\mathrm{i}}(\theta_i, \phi_i)}$$

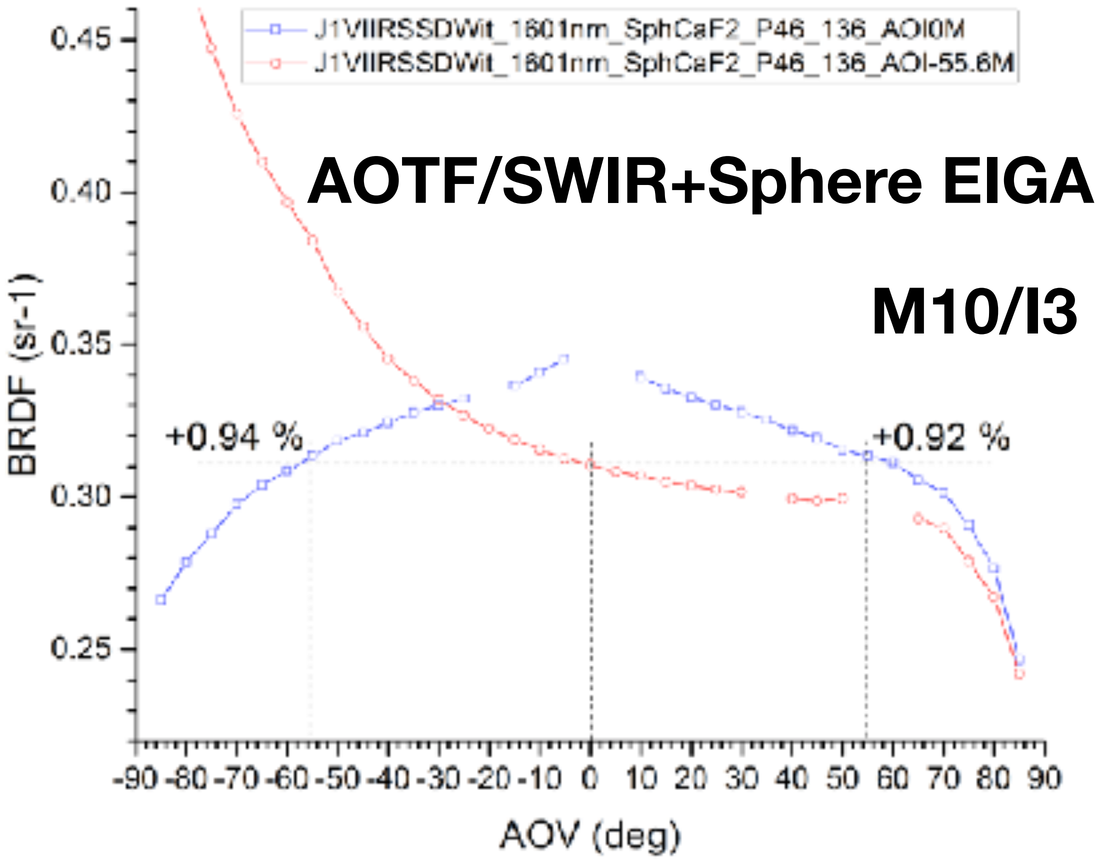
BRDF is the ratio of the differential reflected radiance to the differential incident irradiance, and has units of inverse steradians. If the surface does not polarize the incident flux and there are no magnetic fields present, then the Helmholtz reciprocity obeys.

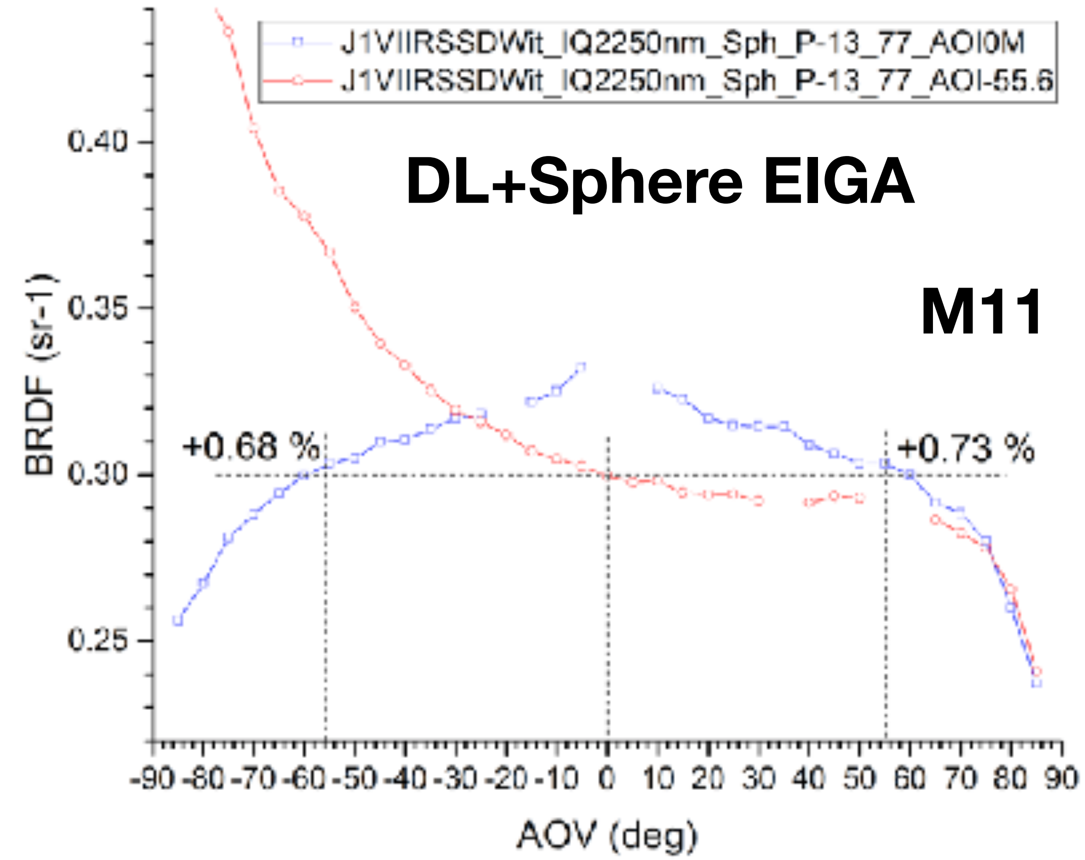
$$f_{\mathrm{r}}(\theta_1, \phi_1; \theta_2, \phi_2) = f_{\mathrm{r}}(\theta_2, \phi_2; \theta_1, \phi_1)$$

It is reliable enough to use as a check on the correct performance of experiments, in contrast with the usual situation in which the experiments are tests of a proposed law.




J1VIIRSSDWit_EQ99_410nm_SP Avg_AOI0
J1VIIRSSDWit_EQ99_410nm_SP Avg_AOI-55.6
J1VIIRSSDWit_EQ99_410nm_SP Avg_AOI+55.6
EQ99+Filter+SiPD
M1
-0.26 %
+0.36 %
J1VIIRSSDWit_488nm_P46_136_AOI0
J1VIIRSSDWit_488nm_P46_136_AOI-55.6
AOTF/VIS+SiPD
M3
+0.26 %
-0.19 %
J1VIIRSSDWit_865nm_Si_P46_136_AOI0M
J1VIIRSSDWit_865nm_Si_P46_136_AOI-55.6M
AOTF/NIR+SiPD
M7/I2
+0.19 %
+0.36 %
J1VIIRSSDWit_1601nm_IGA_P46_136_AOI0
J1VIIRSSDWit_1601nm_IGA_P46_136_AOI-55.6
AOTF/SWIR+IGA
M10/I3
+0.34 %
+0.45 %
BRDF (sr-1)
AOV (deg)
0.45
0.40
0.35
0.30
0.25
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90





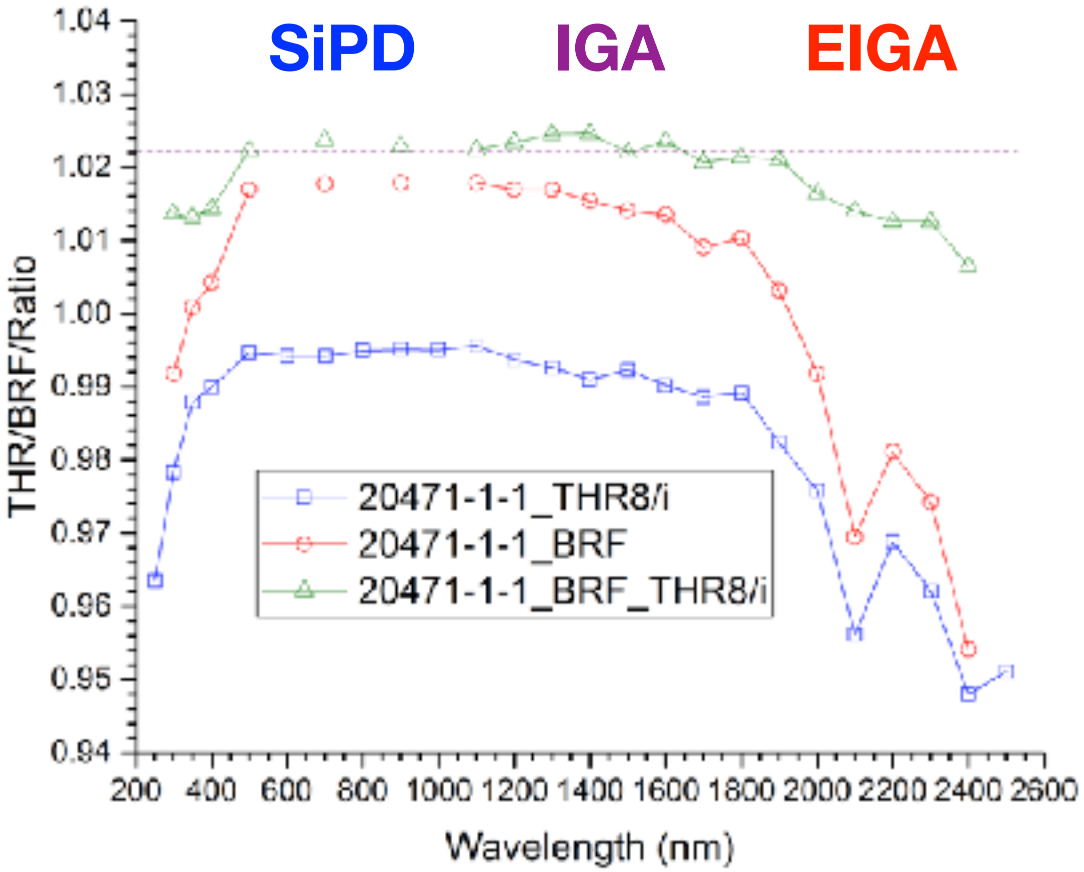
Speckle effect

$$BRF(\theta_i,\phi_i,\theta_r,\phi_r;\lambda,\sigma)=\pi\,\frac{S_r(\theta_i,\phi_i,\theta_r,\phi_r;\lambda,\sigma)}{S_i(\lambda;\sigma)}\times\frac{G_i(\lambda;\sigma)}{G_r(\lambda;\sigma)}\times\frac{D^2}{A_r\cos\theta_r}=\pi BRDF$$

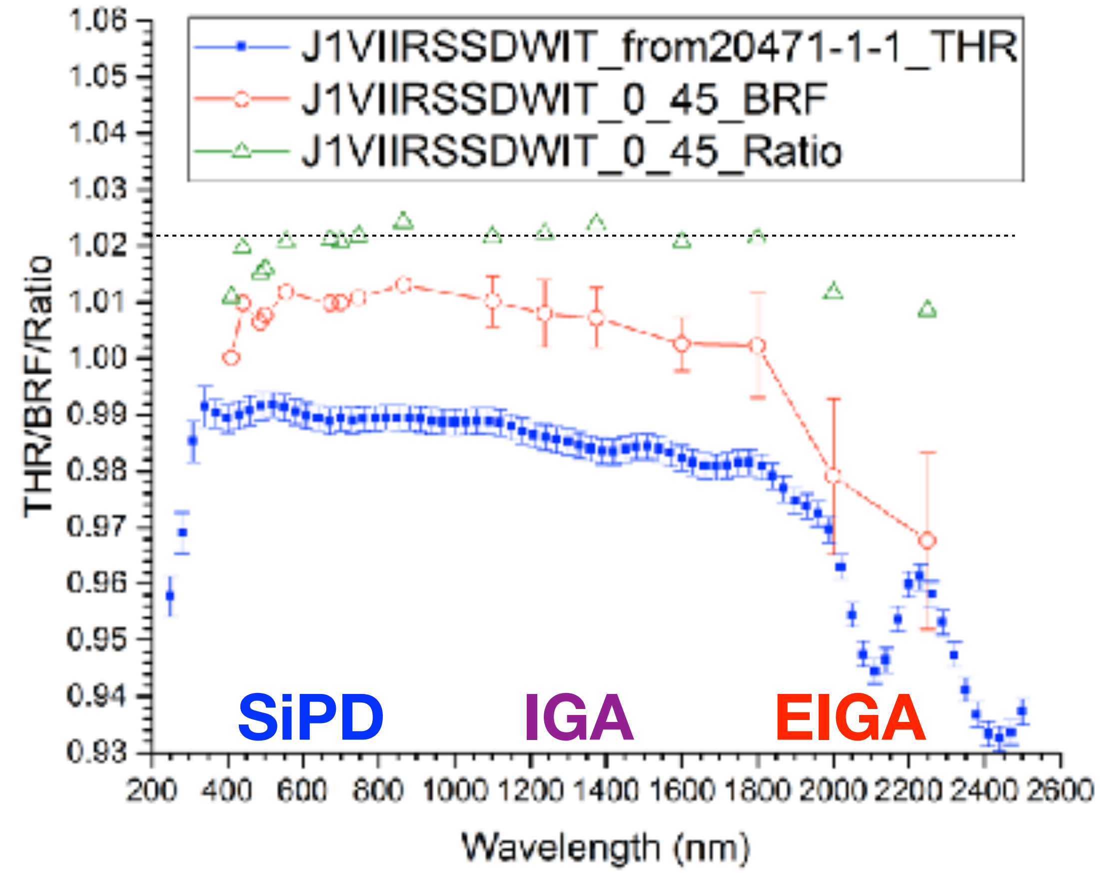
Results and discussions

———Relationship of 8°/THR and BRF in configuration of 0°/45°

NIST Traceable Ref 0°/45°



J1 VIIRS SD Witness 0°/45°



1. Howard W. Yoon, David W. Allen, George P. Eppeldauer, Benjamin K. Tsai,"The extension of the NIST BRDF scale from 1100 nm to 2500 nm," Proc. SPIE 7452, Earth Observing Systems XIV, 745204 (21 August 2009)

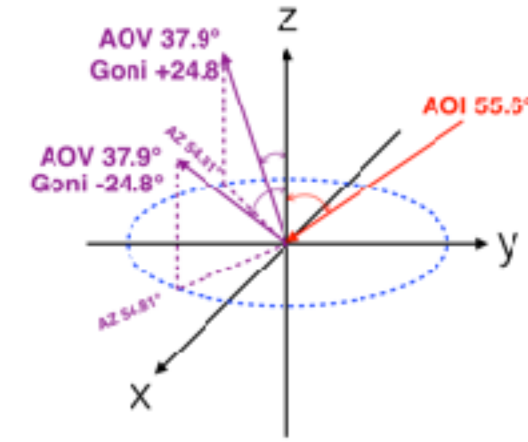
400 to 1600 nm, constant ratio, 1600 to 2500 nm changed, 0°/45°

2. Georgi T. Georgiev, James J. Butler, Kurt Thome, Catherine Cooksey, Leibo Ding, "Establishing Brdf Calibration Capabilities Through Shortwave Infrared," Proc. SPIE 10402, Earth Observing Systems XXII, 104021N (5 September 2017)

900 to 1900 nm, constant ratio, 1900 to 2500 nm changed, 0°/45°

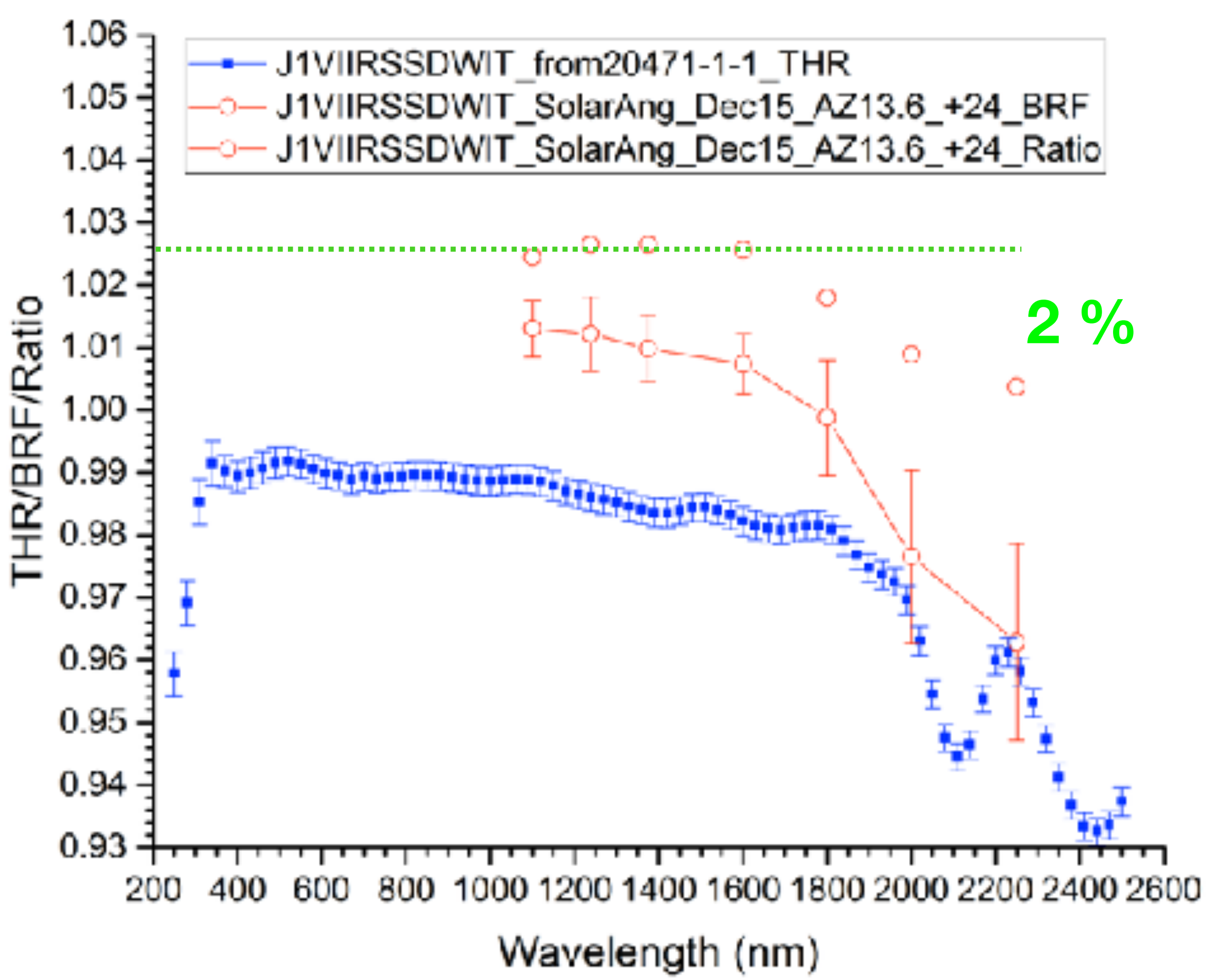
Results and discussions

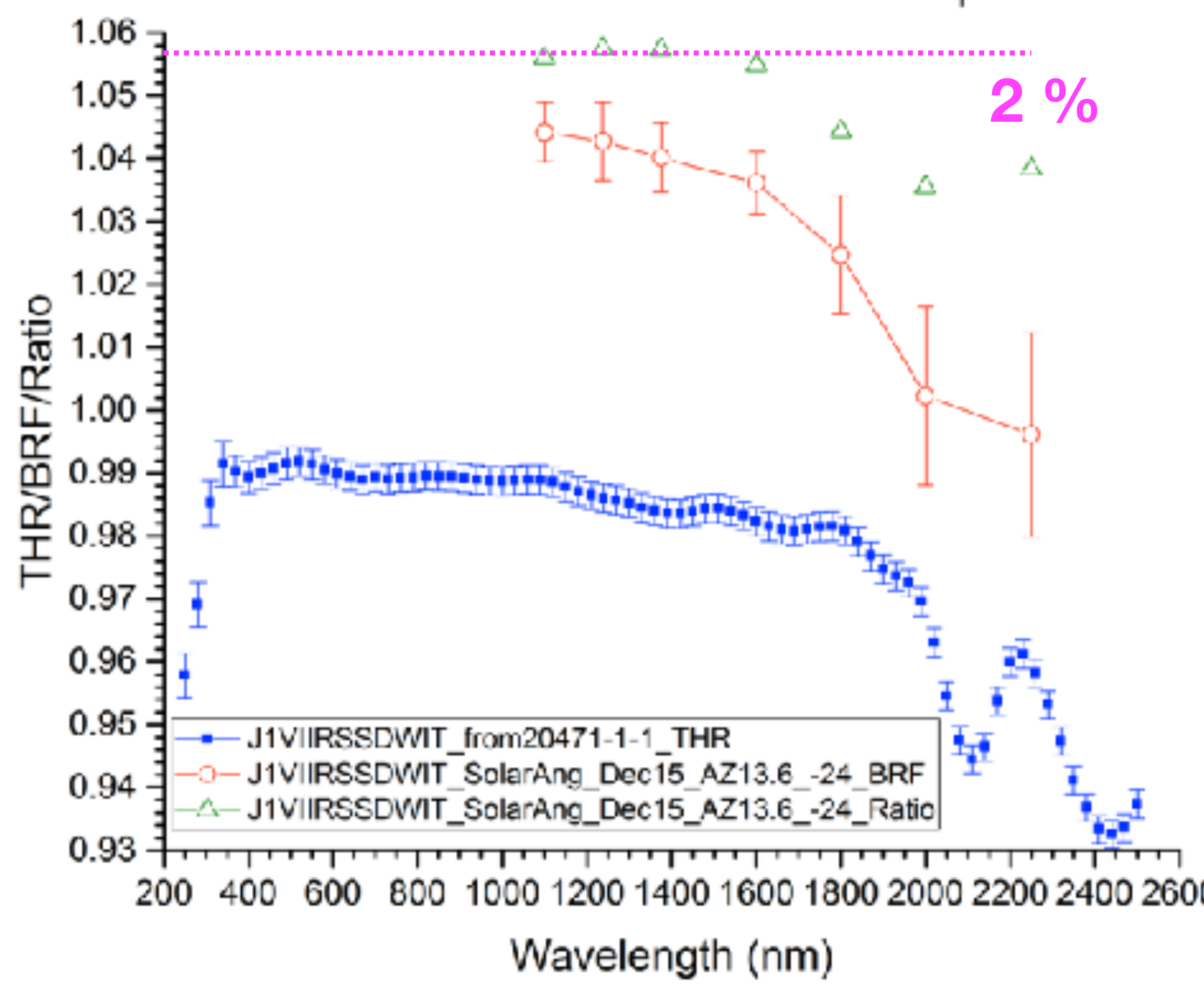
———Relationship of 8°/THR and BRF in configuration of Az13.6°/Dec15°



$$L_{cal} = E_{sun} \times \frac{BRF}{\pi} \cos\theta_{AOI}$$

J1 VIIRS SD Witness





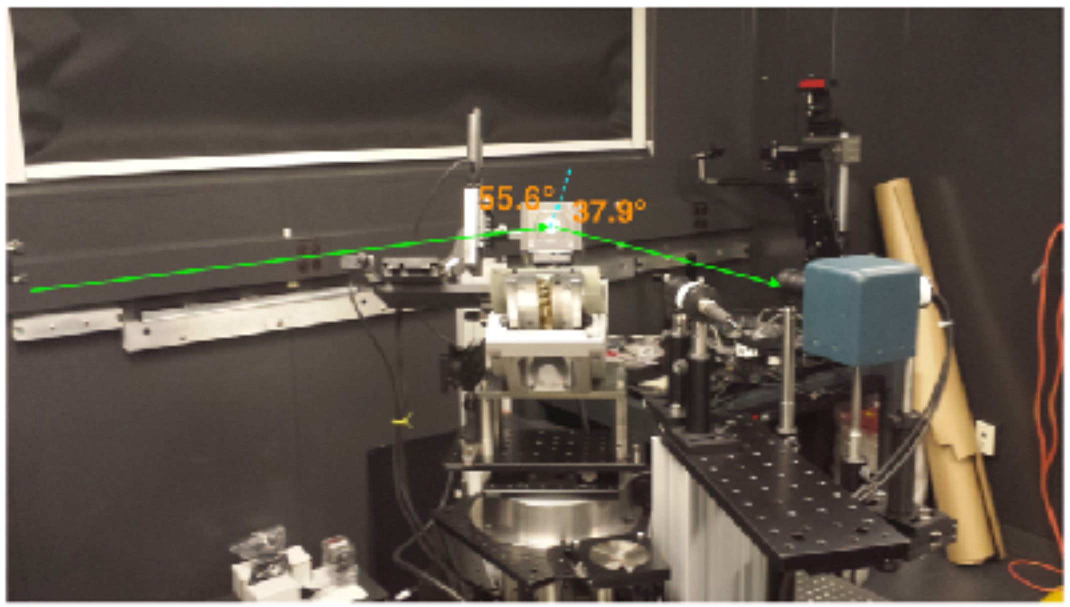
IGA EIGA

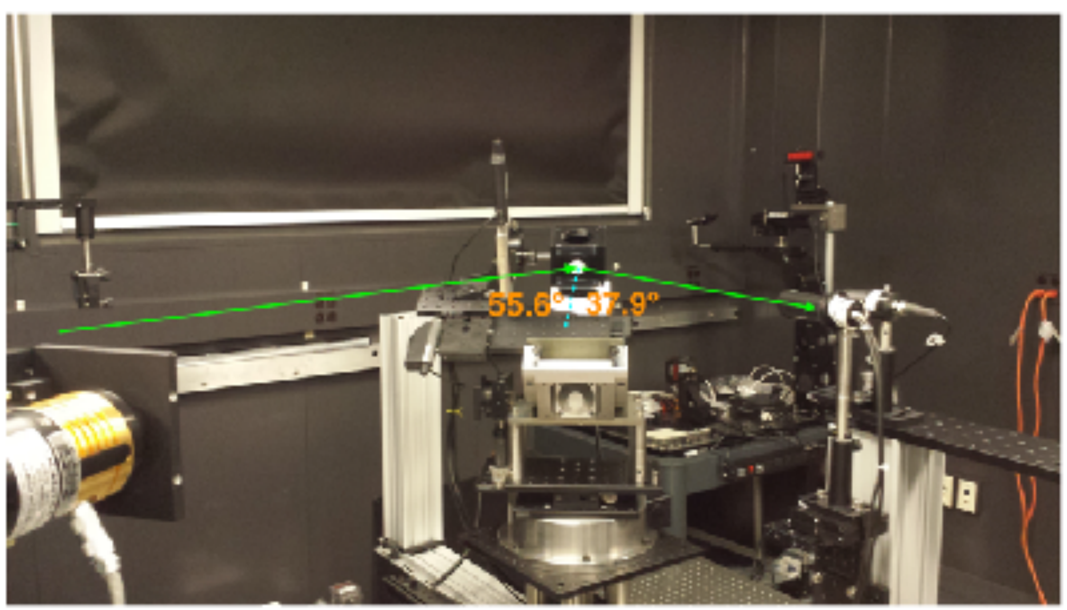
422	538	617	714	906	1626

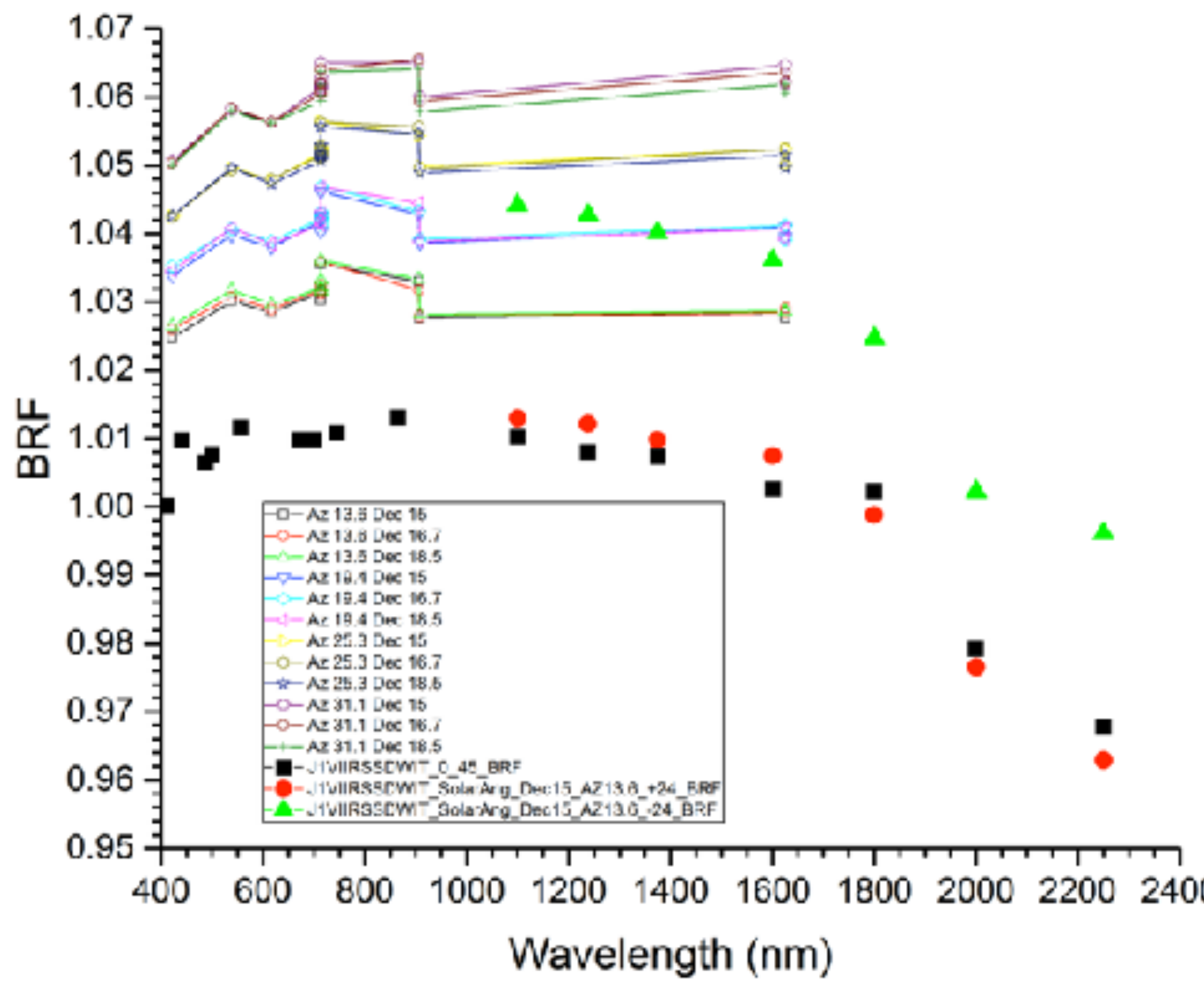
IGA EIGA

Results and discussions

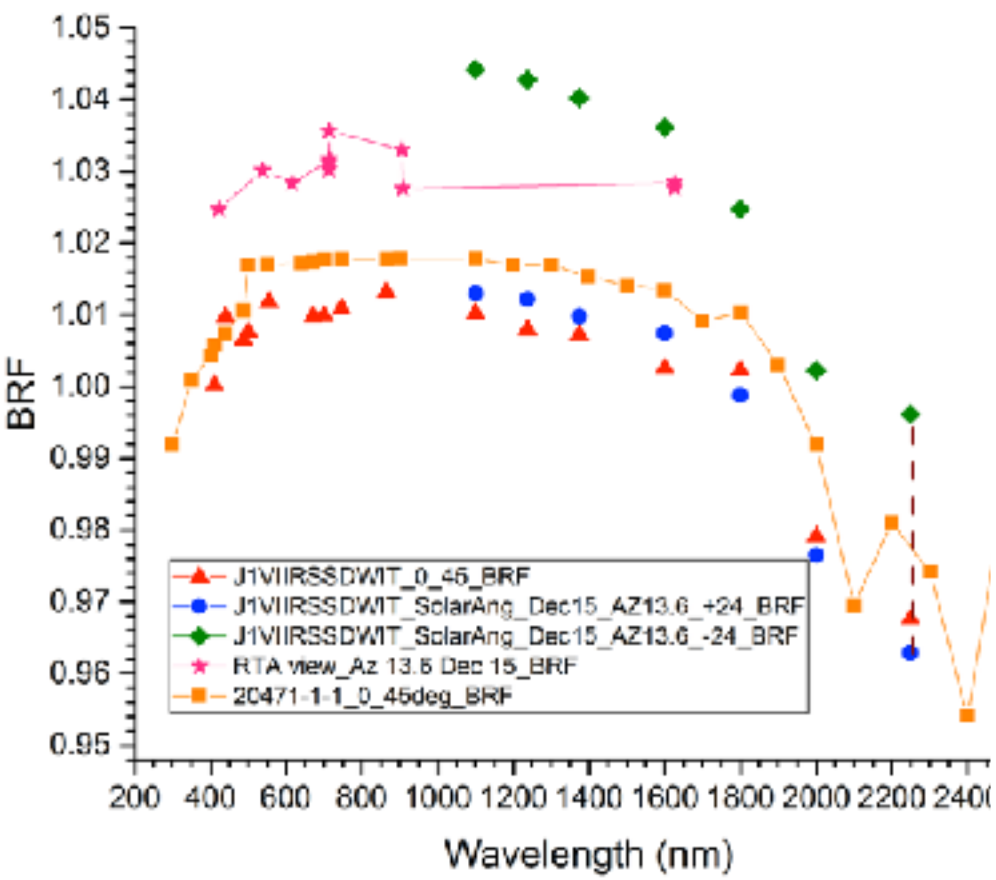
———Azimuth angle dependence (Clocking effect)

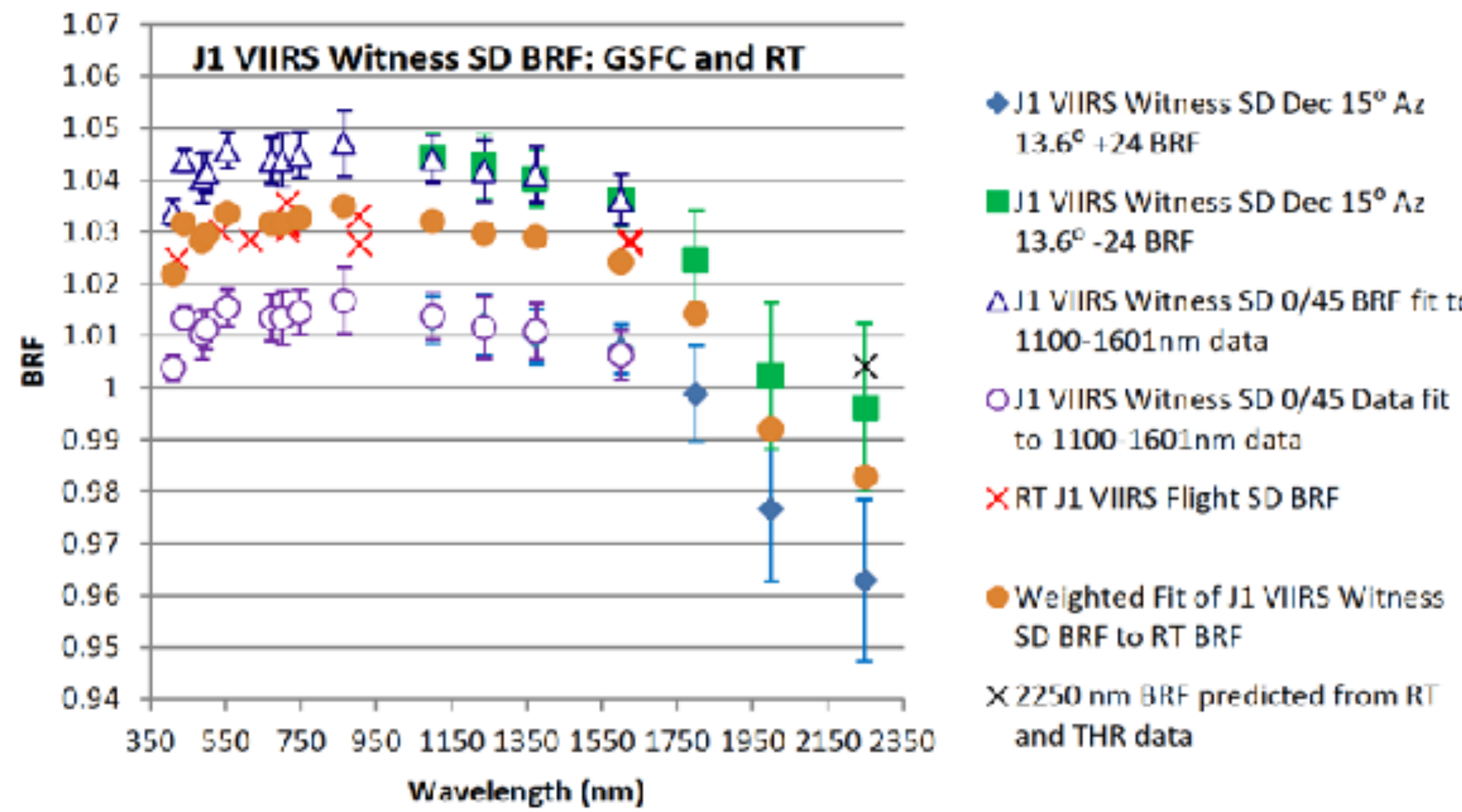






Results and discussions





Uncertainty budget

Uncertainty component	1100 nm	1238 nm	1375 nm	1601 nm	1800 nm	2000 nm	2250 nm
BRDF Ref	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Transfer_0_45_between NIST to J1 SD	0.001	0.0024	0.0027	0.0011	0.0044	0.0049	0.005
Transfer_0_45 to SolarAng Dec15_AZ13.6	0.0017	0.0015	0.0013	0.0017	0.0037	0.004	0.0035
Speckle	0.0037	0.0049	0.004	0.004	0.007	0.0125	0.015
View angle	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Linearity	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Wavelength	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Alignment	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Repeatability							
Combined Unc (k=1)	0.004505552130427	0.005894064811316	0.005263078946776	0.004777028364998	0.009207062506576	0.014106027080648	0.016277899127344

Summary

- Completion of BRDF measurements for JPSS1 VIIRS Solar Diffuser Witness to support the uncertainty analysis for SD BRF calibration
- Investigation of following topics:

1. BRDF reciprocity of 0°/55.6° and 55.6°/0° configuration
2. Relationship of 8° THR and BRF extended to out-of-plane 55.6°/37.9°
3. Clocking effect

- Good agreement with the SDA BRF results, Uncertainty 1~2 % (*k*=1)

Proc. of SPIE Vol. 10402 104021N-7, 2017

ESTABLISHING BRDF CALIBRATION CAPABILITIES THROUGH SHORTWAVE INFRARED

Georgi T. Georgiev[a], James J. Butler[b], Kurt Thome[b], Catherine Cooksey[c], Leibo Ding[d]

[a]NASA Langley Research Center, Hampton, VA23666, e-mail: georgi.georgiev@nasa.gov

[b]NASA Goddard Space Flight Center, Greenbelt, MD 20771

[c]National Institute of Standards and Technology, Gaithersburg, MD 20899

[d]Science Systems and Applications, Lanham, MD 20706

ABSTRACT

Satellite instruments operating in the reflective solar wavelength region require accurate and precise determination of the Bidirectional Reflectance Distribution Functions (BRDFs) of the laboratory and flight diffusers used in their pre-flight and on-orbit calibrations. This paper advances that initial work and presents a comparison of spectral Bidirectional Reflectance Distribution Function (BRDF) and Directional Hemispherical Reflectance (DHR) of Spectralon*, a common material for laboratory and on-orbit flight diffusers. A new measurement setup for BRDF measurements from 900 nm to 2500 nm located at NASA Goddard Space Flight Center (GSFC) is described. The GSFC setup employs an extended indium gallium arsenide detector, bandpass filters, and a supercontinuum light source. Comparisons of the GSFC BRDF measurements in the shortwave infrared (SWIR) with those made by the National Institute of Standards and Technology (NIST) Spectral Tri-function Automated Reference Reflectometer (STARR) are presented. The Spectralon sample used in this study was 2 inch diameter, 99% white pressed and sintered Polytetrafluoroethylene (PTFE) target. The NASA/NIST BRDF comparison measurements were made at an incident angle of 0° and viewing angle of 45°. Additional BRDF data not compared to NIST were measured at additional incident and viewing angle geometries and are not presented here. The total combined uncertainty for the measurement of BRDF in the SWIR range made by the GSFC scatterometer is less than 1% ($k = 1$). This study is in support of the calibration of the Radiation Budget Instrument (RBI) and Visible Infrared Imaging Radiometer Suit (VIIRS) instruments of the Joint Polar Satellite System (JPSS) and other current and future NASA remote sensing missions operating across the reflected solar wavelength region.

Keywords: BRDF, Calibration, RBI, JPSS, Reflectance, Remote Sensing.

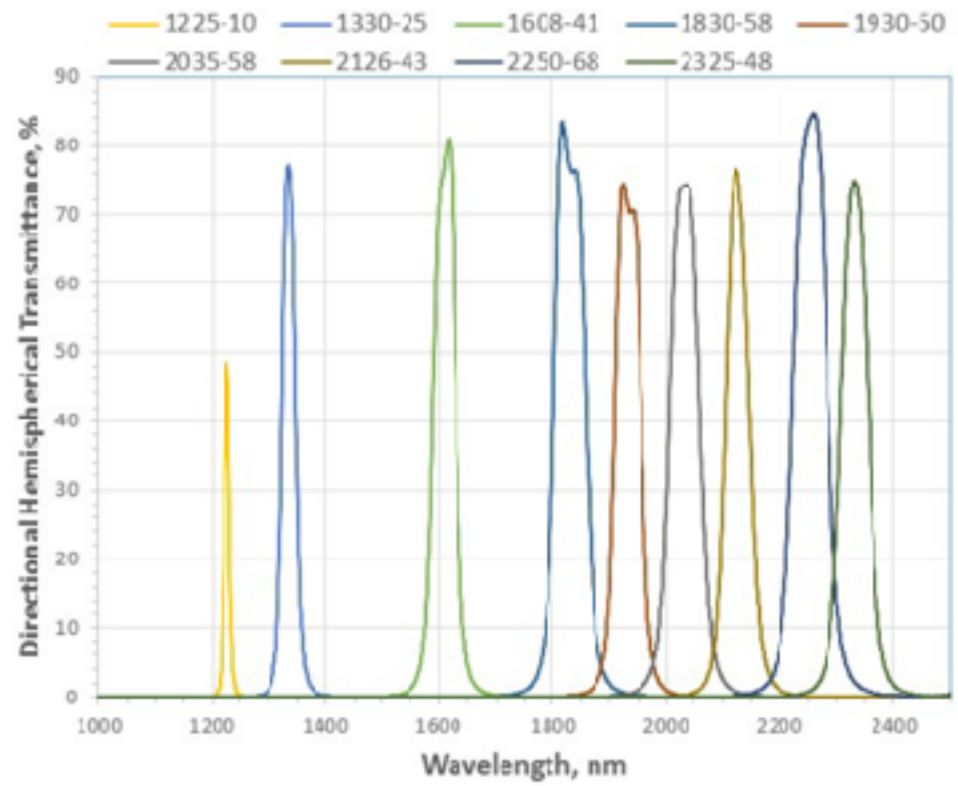


Fig.6. Spectralon bandpass filters 8° directional hemispherical transmittance

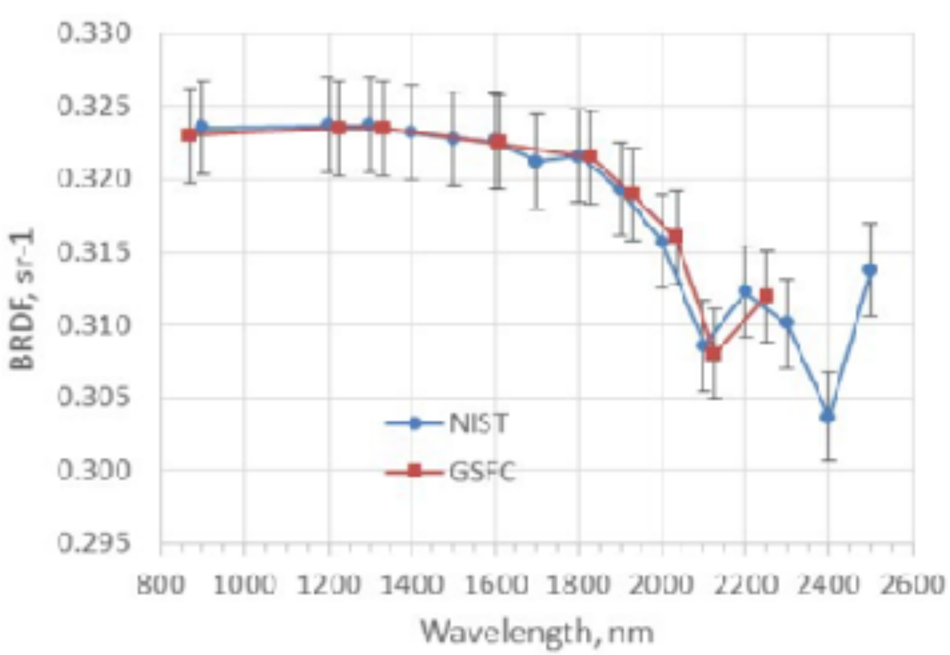


Fig. 7: BRDF measured by NIST and GSFC at 0° incident angle and 45° scatter angle

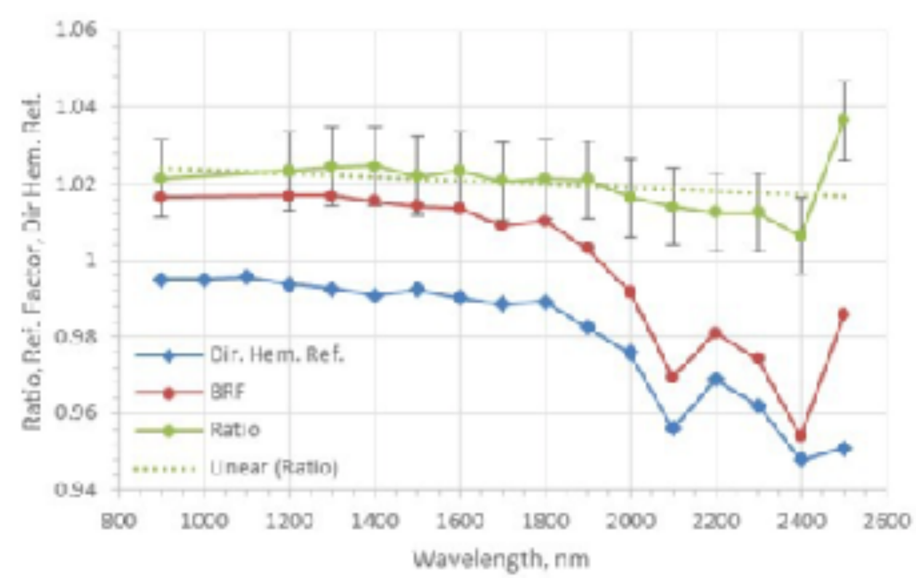


Fig. 8: BRF data at 0°/45° geometry, the directional/hemispherical data and the ratio between them