Preliminary results of solar diffuser BRDF measurements using a table-top goniometer at NASA GSFC

Jinan Zeng[1], Jim Butler[2], Leibo Ding[3], and Jack Xiong[2]

[1]Fibertek Incorporation, 13605 Dulles Technology Dr., Herndon, VA 20171

[2]Goddard Space Flight Center, Greenbelt, MD, 20771 USA

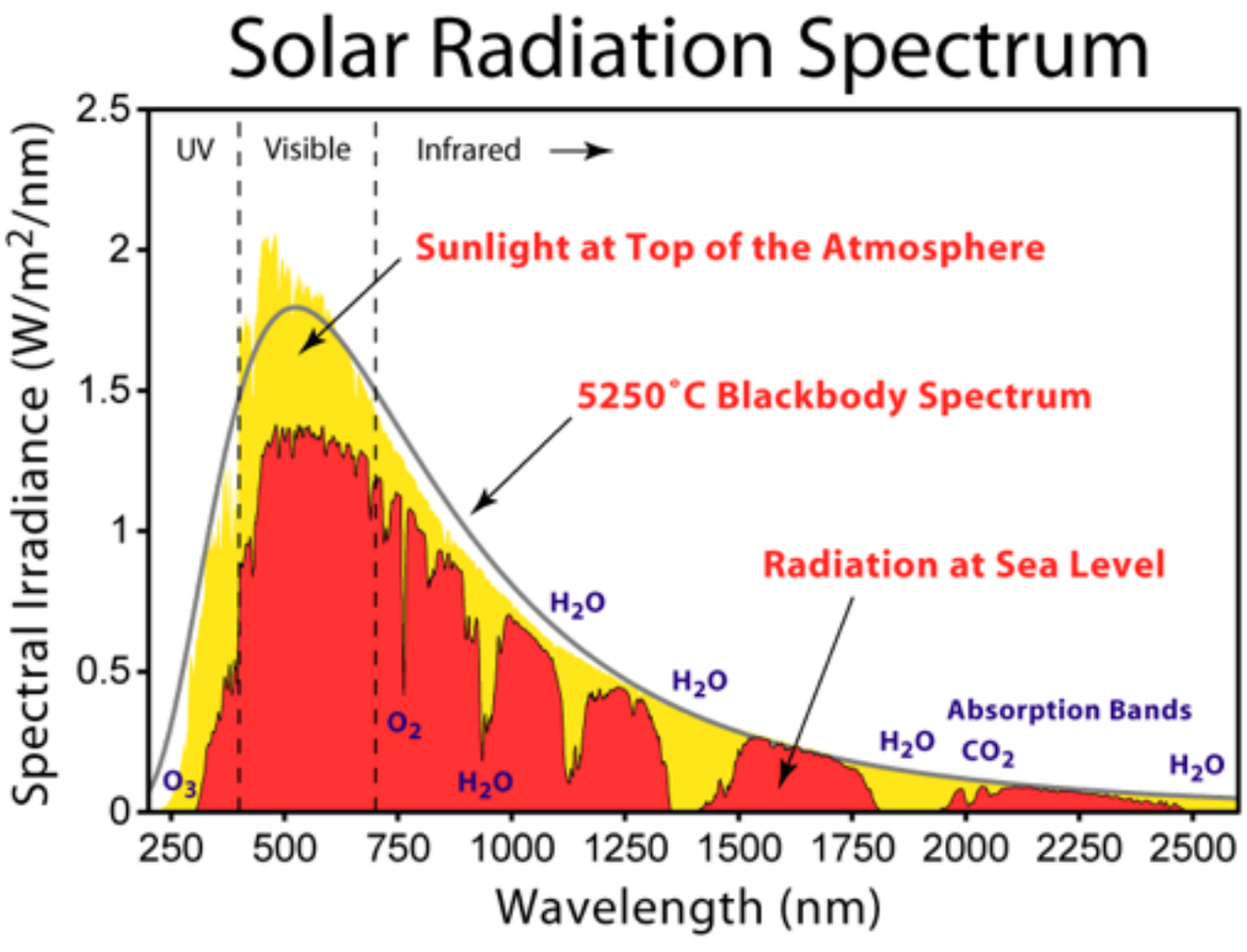
[3]Science Systems and Applications Incorporation, Lanham, MD, 20706 USA

Outline

1. Mission and short-term goals
2. Table-top goniometer
3. Preliminary test results
4. Summary and future work

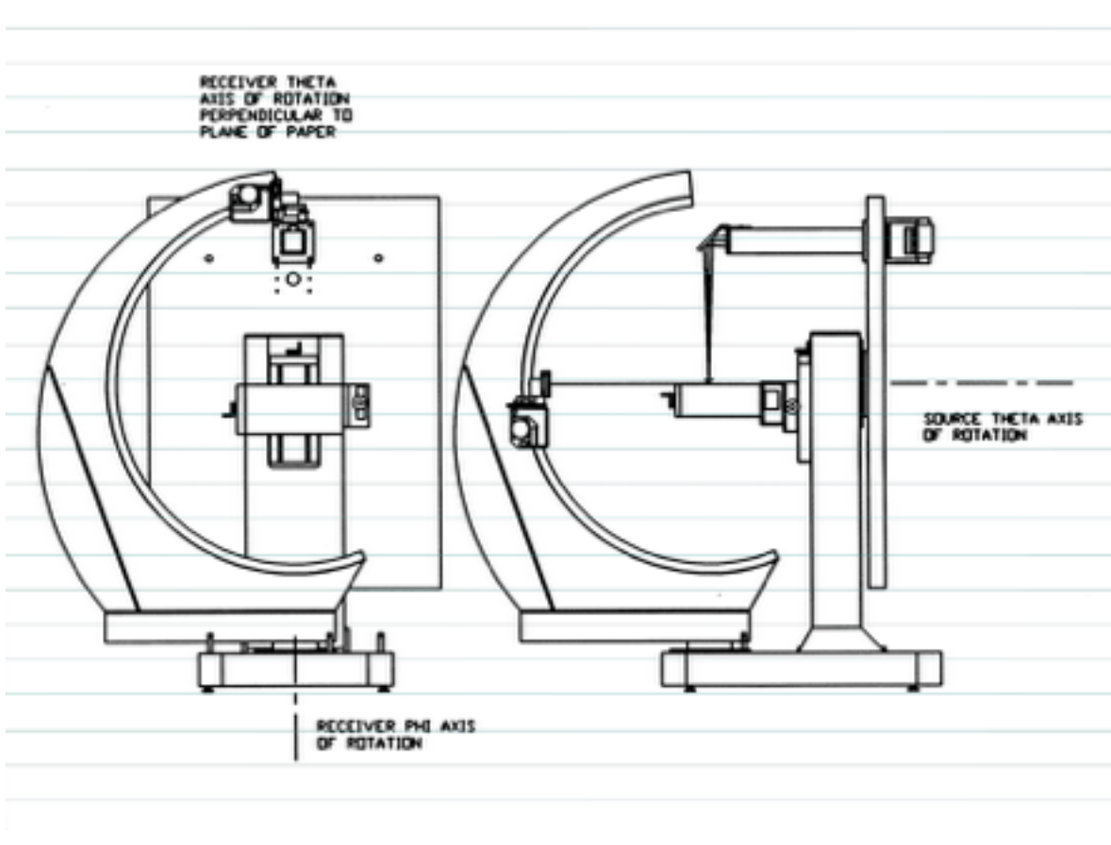
Mission and Goal

Support solar diffuser calibration in RSB for remote sensing instrumentation with NIST traceability



Reflective Solar Band (RSB)

Development of new generation scatterometers



Existing Diffuser Calibration Facility: DCaf DCL, GSFC

Current missions

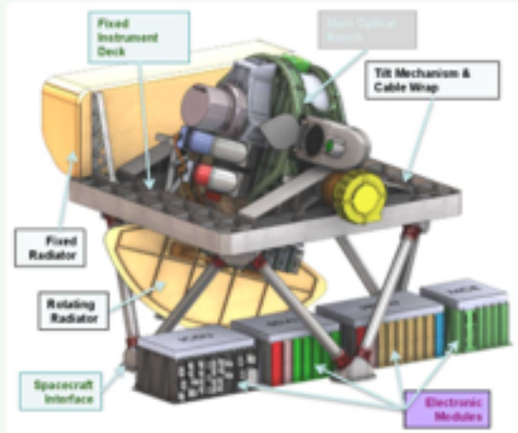
JPSS VIIRS

1. Wavelengths:
    a. 400, 550, 700, 850, 1000, 1200, 1600, 2250 (or filter wavelengths)
2. Measurements:
    a. 6 degree/directional hemispherical reflectance at above wavelengths
    b. BRDF
        i. Incident angles:
            1. Θ_i: -51.9 deg, -56.75 deg, and -55.6 deg.
            2. Φ_i: -7.40 deg, 0 deg, +7.40 deg.
        ii. Reflectance angles:
            1. VIIRS θ_s: 37.9 deg
            2. SDSM θ_s: -18.3 deg
3. Samples:
    a. 4 Space-grade Spectralon samples: one sample maintained in lab as a control and three other samples measured by our lab and others.

PACE

OCI Specifics:

- Single detector, rotating telescope scanner (like SeaWiFS)
- 20-degree tilt to avoid sun glint
- Monthly lunar calibration of all science detectors
- Ground sample distance ~ 1 square kilometer at nadir
- 5 nanometer (nm) resolution from 350 to 890 nm
- Plus short-wave infrared (SWIR) bands centered on:
    - 940, 1240, 1380, 1640, 2130 & 2250 nm
- Image artifacts <0.5% at calibrated, top-of-atmosphere radiances



View OCI Webinar

Table Top Goniometer

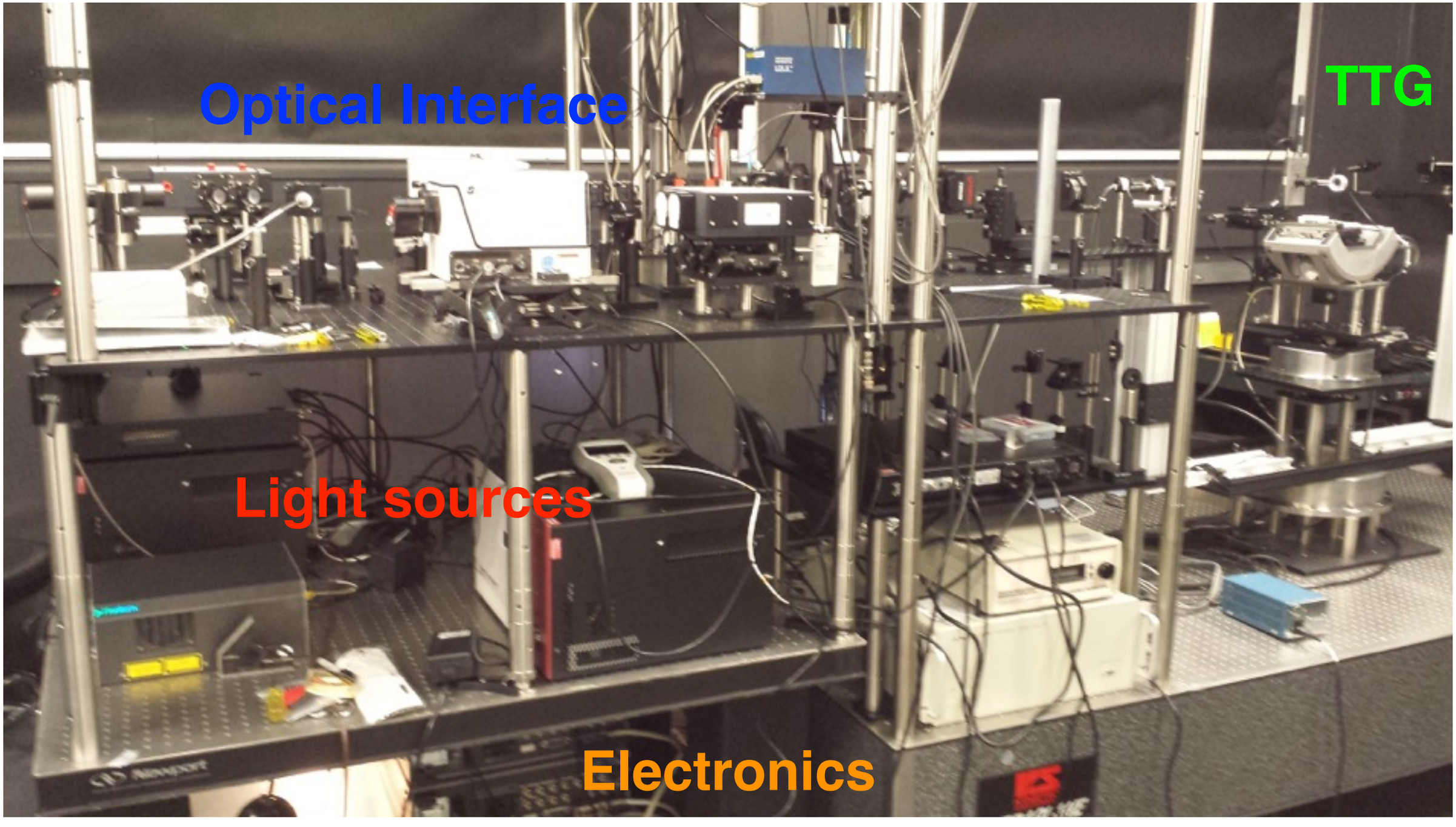
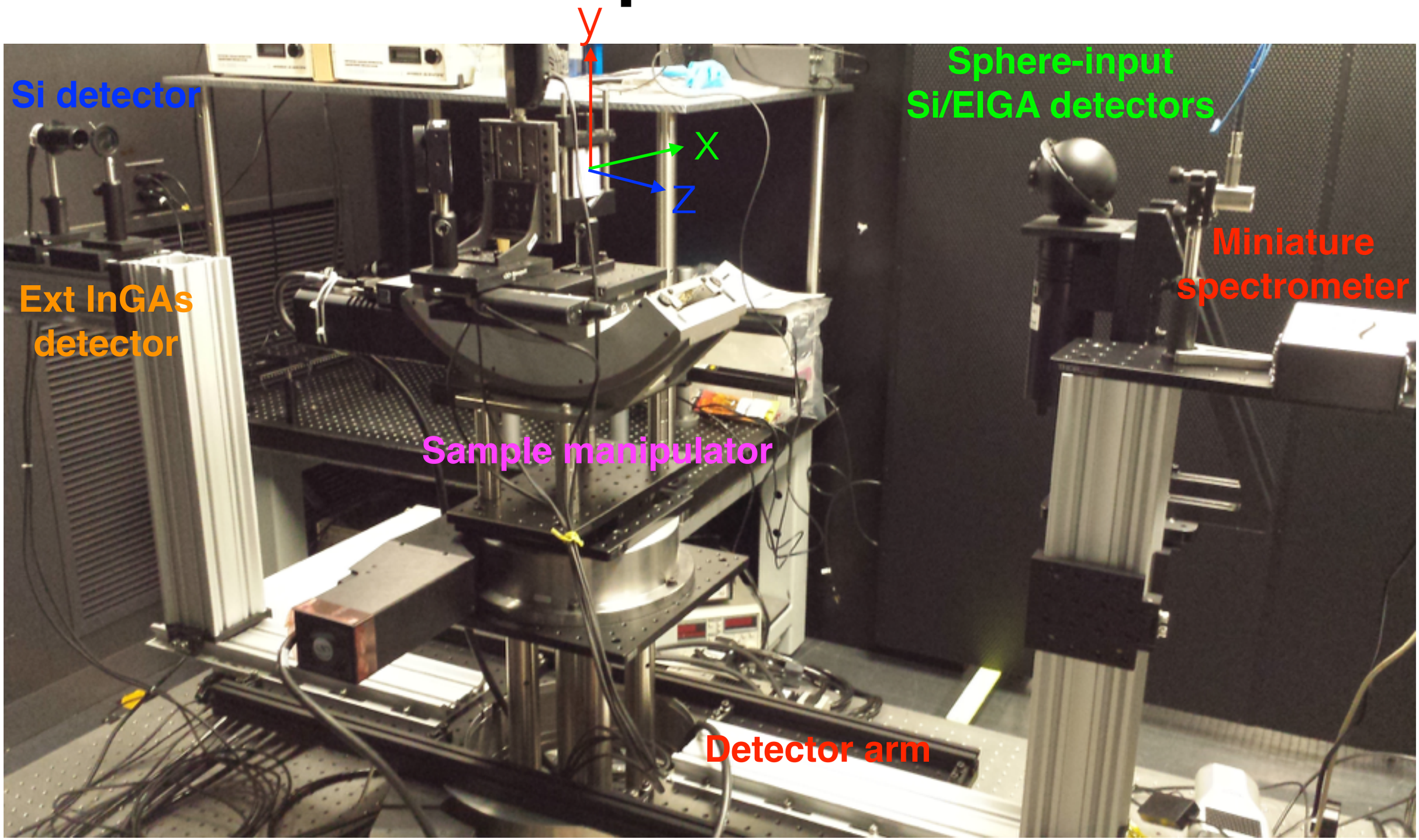


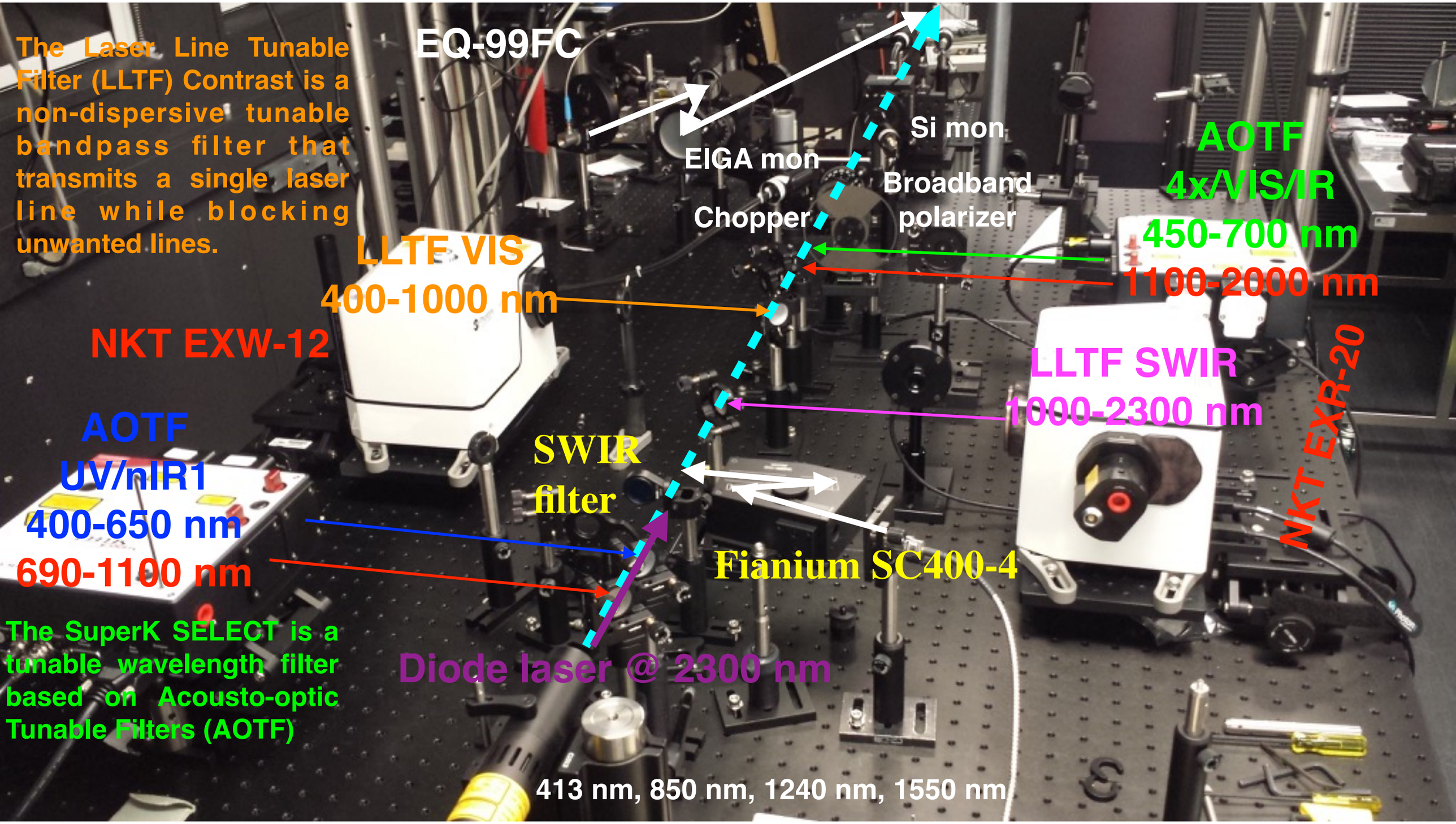
Table Top Goniometer



Current light sources for table-top goniometer

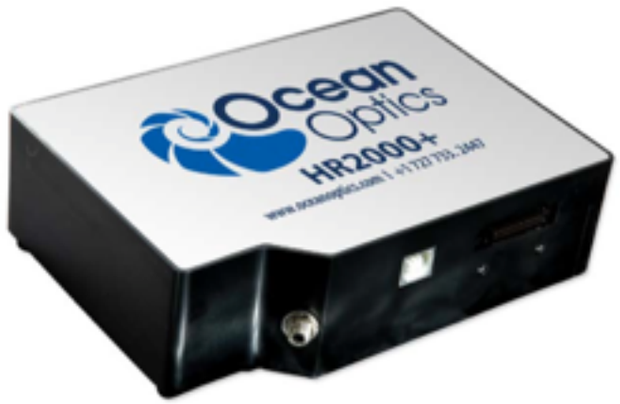
1. **Supercontinuum laser: NKT EXR20, EXW12 and Fianium WL-SC400-4**
2. **EQ99FC/EQ1500**
3. **LC8 Hamamatsu spot light**
4. **Power Technology, IQ diode lasers >20 mW (413 nm, 850 nm, 1240 nm, 1550 nm, 2300 nm)**

Optical interface for multiple light sources



Light source testing results

Modular spectrometers

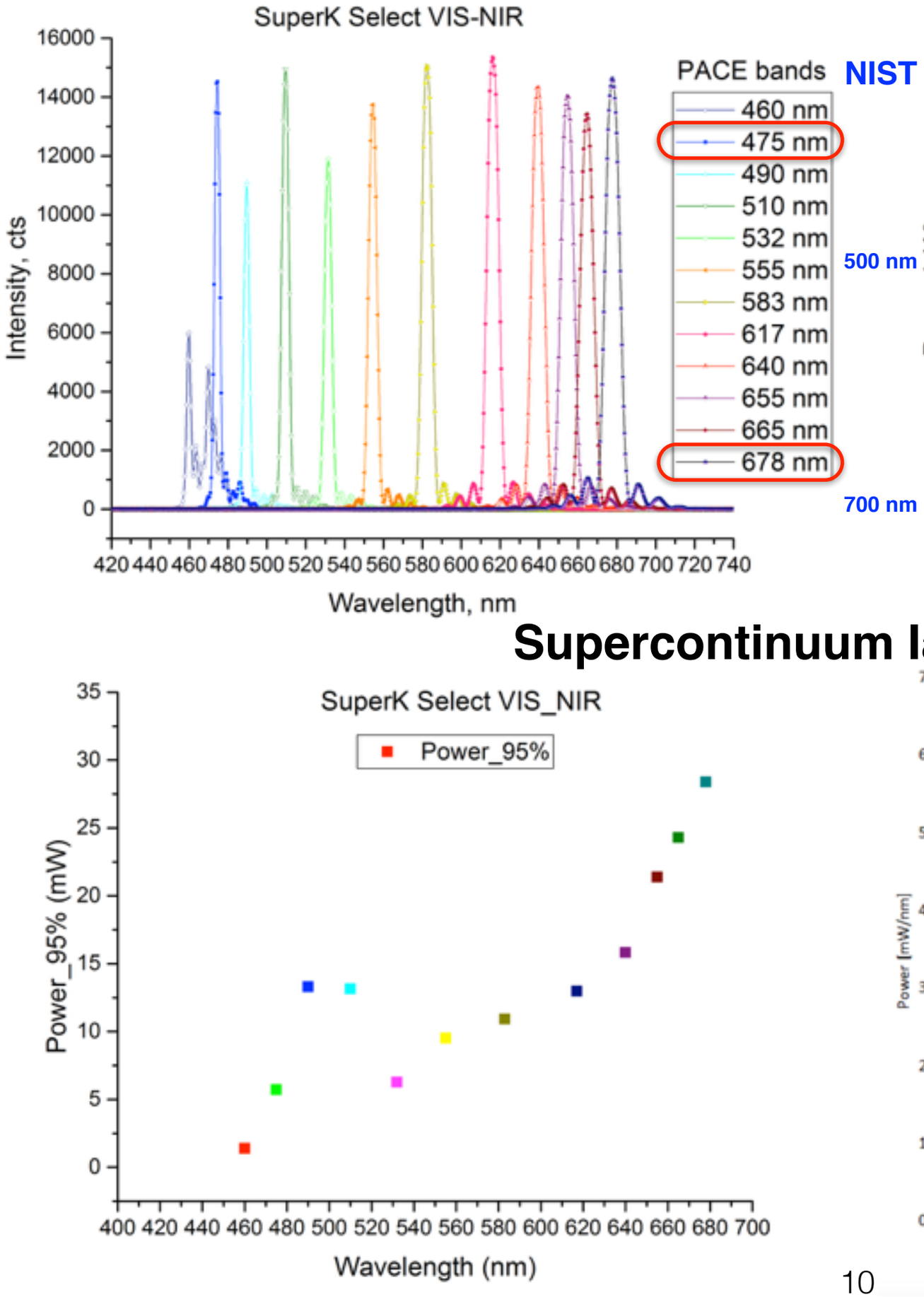


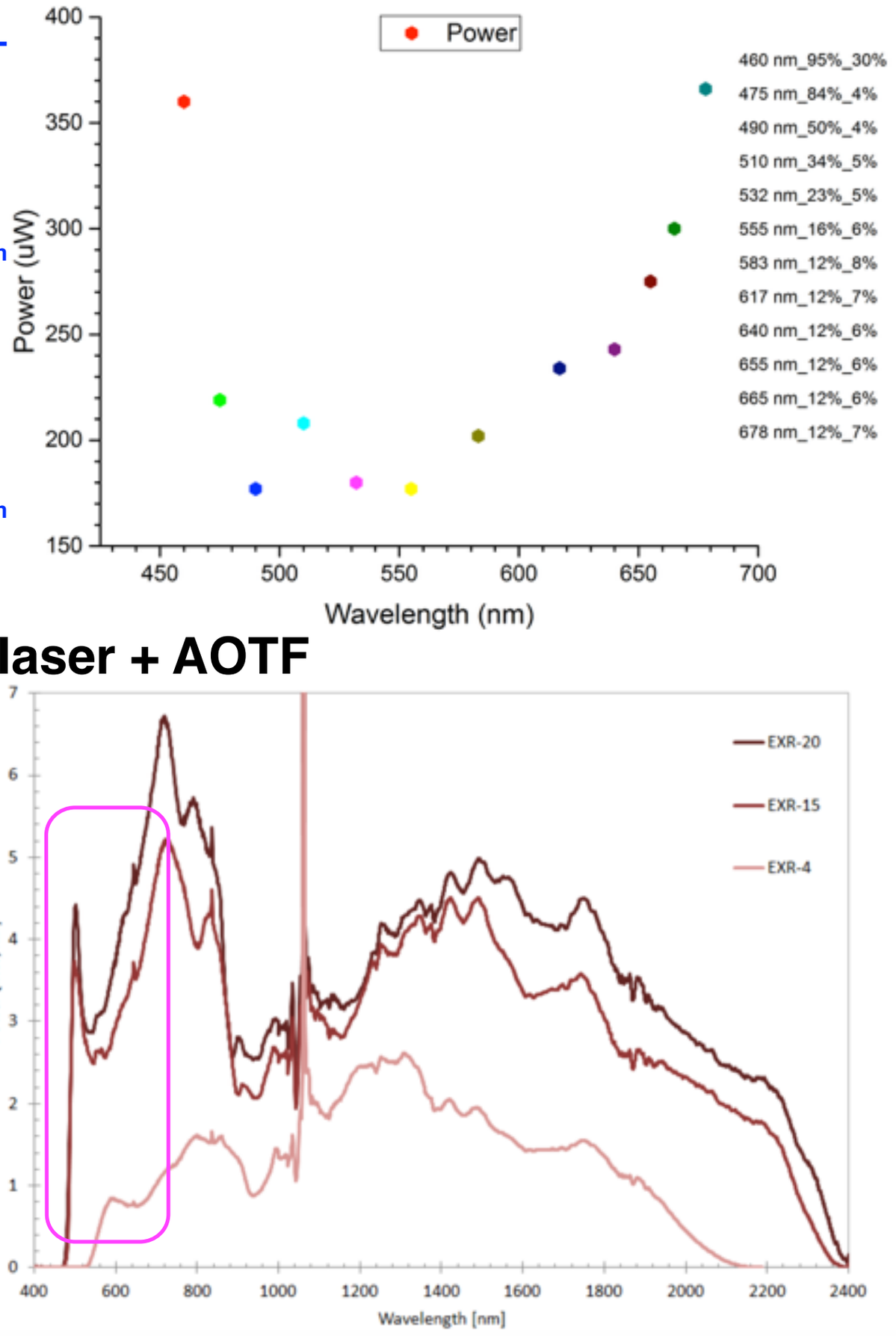
Ocean Optics HR2000+ High-speed Fiber Optic Spectrometer

200 nm to 1100 nm

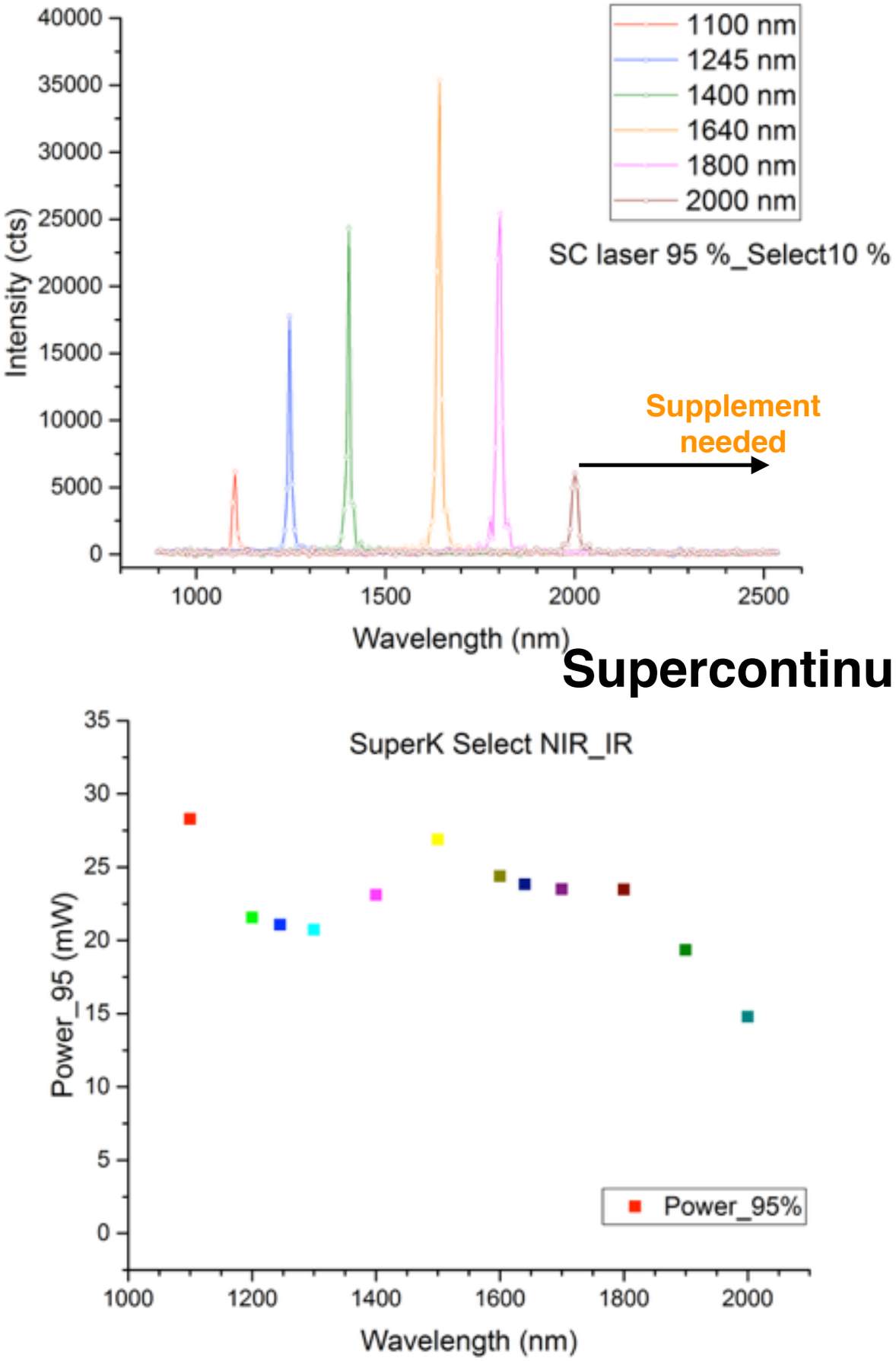
892 nm to 2530 nm

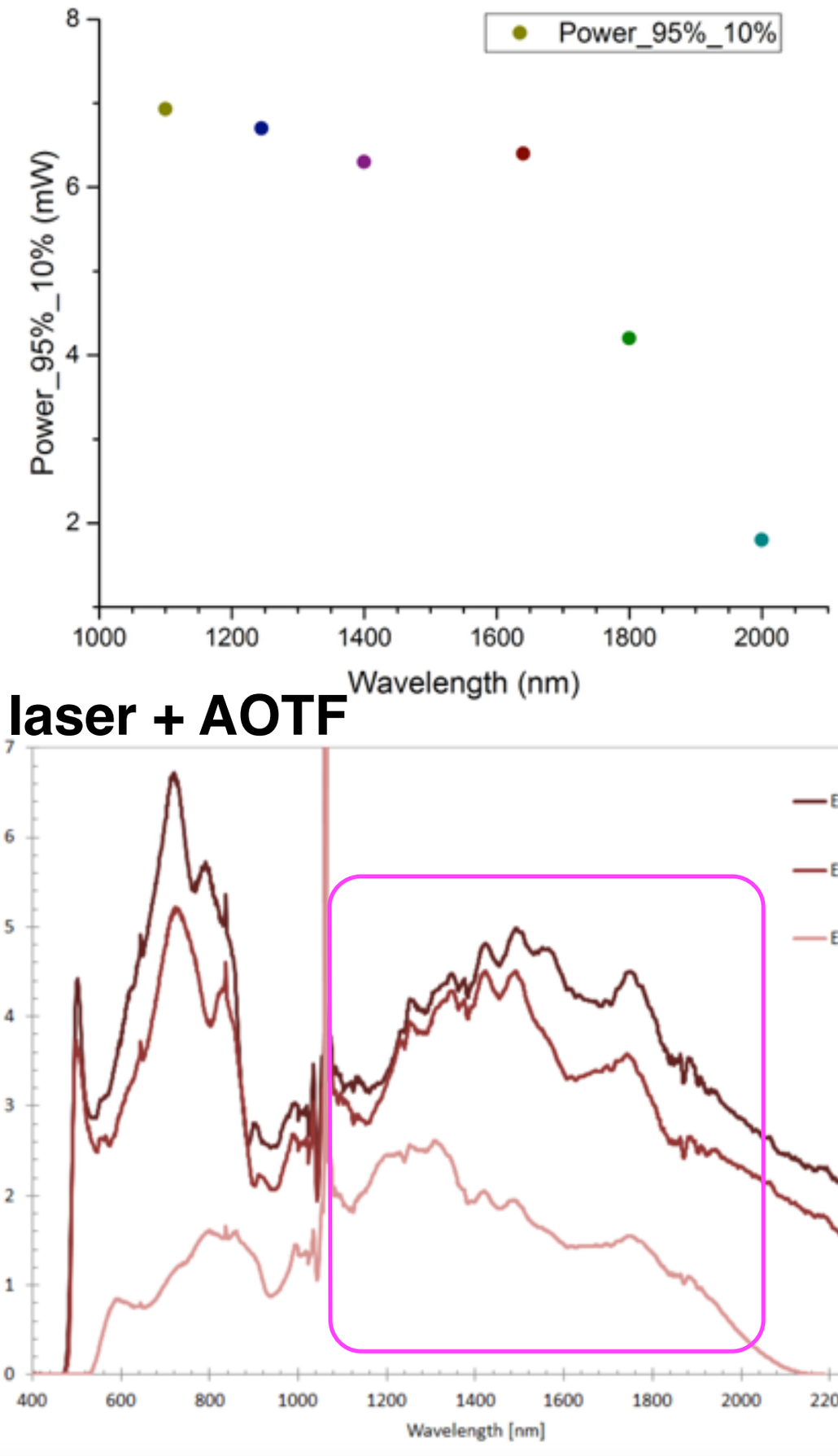
Supercontinuum laser + AOTF



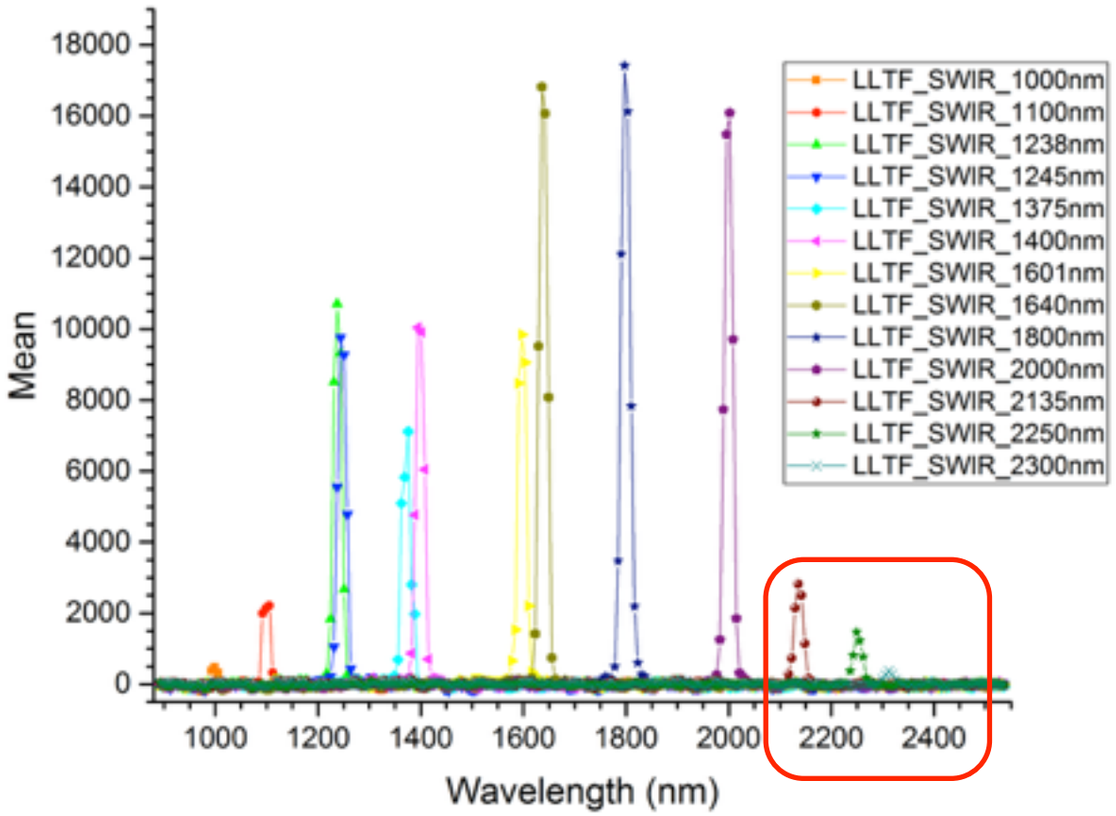


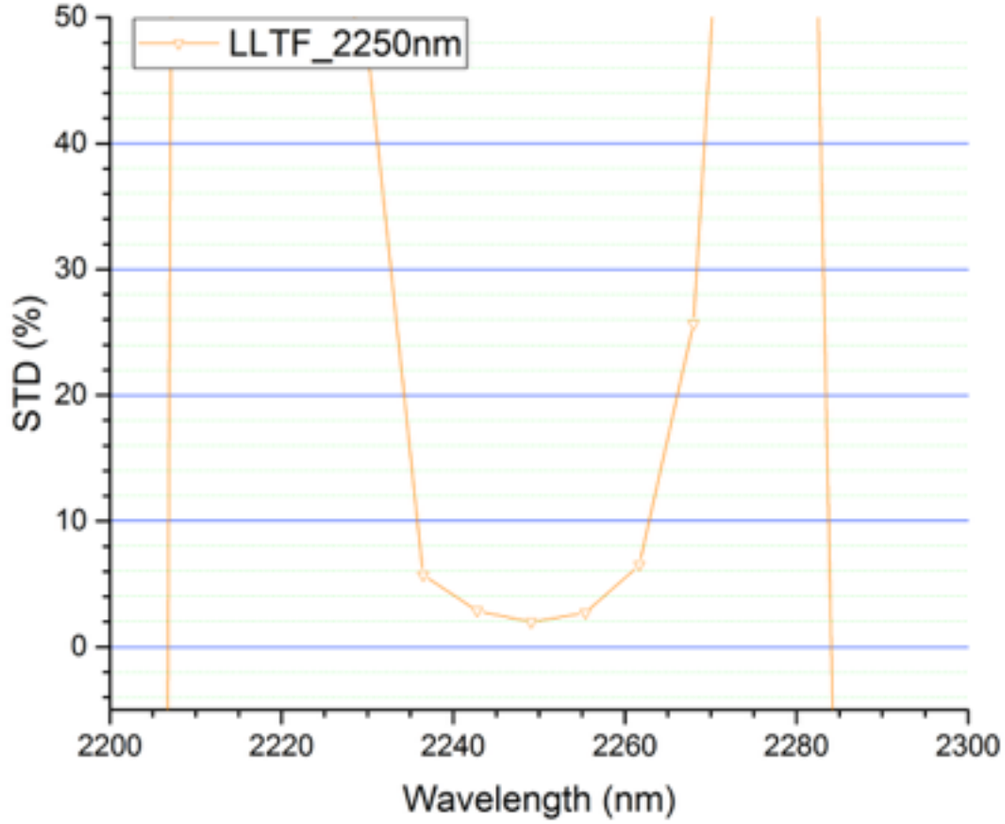
Supercontinuum laser + AOTF



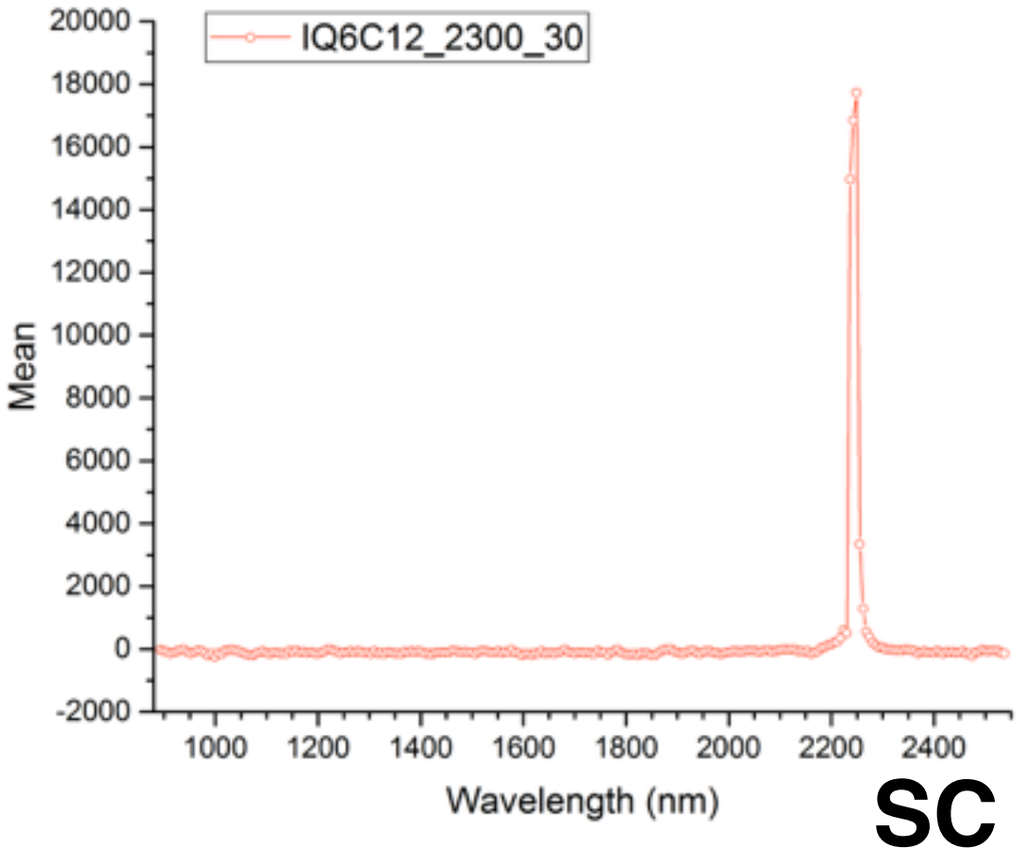


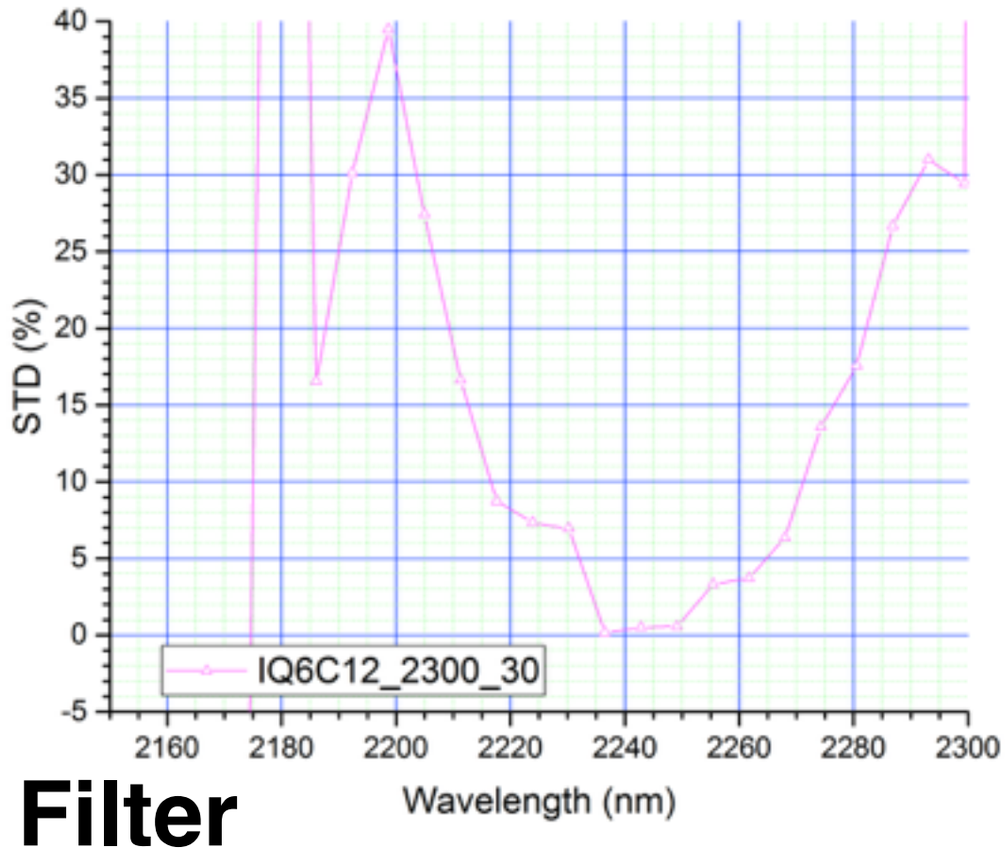
Supercontinuum laser + LLTF





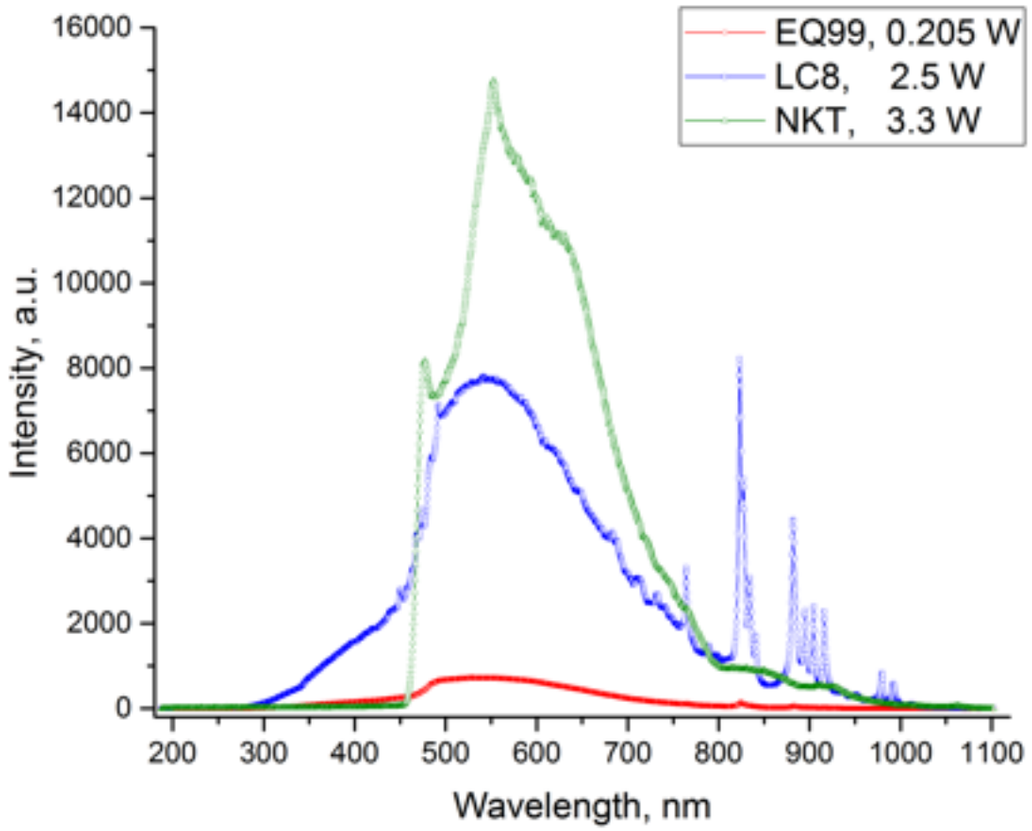
IQ laser

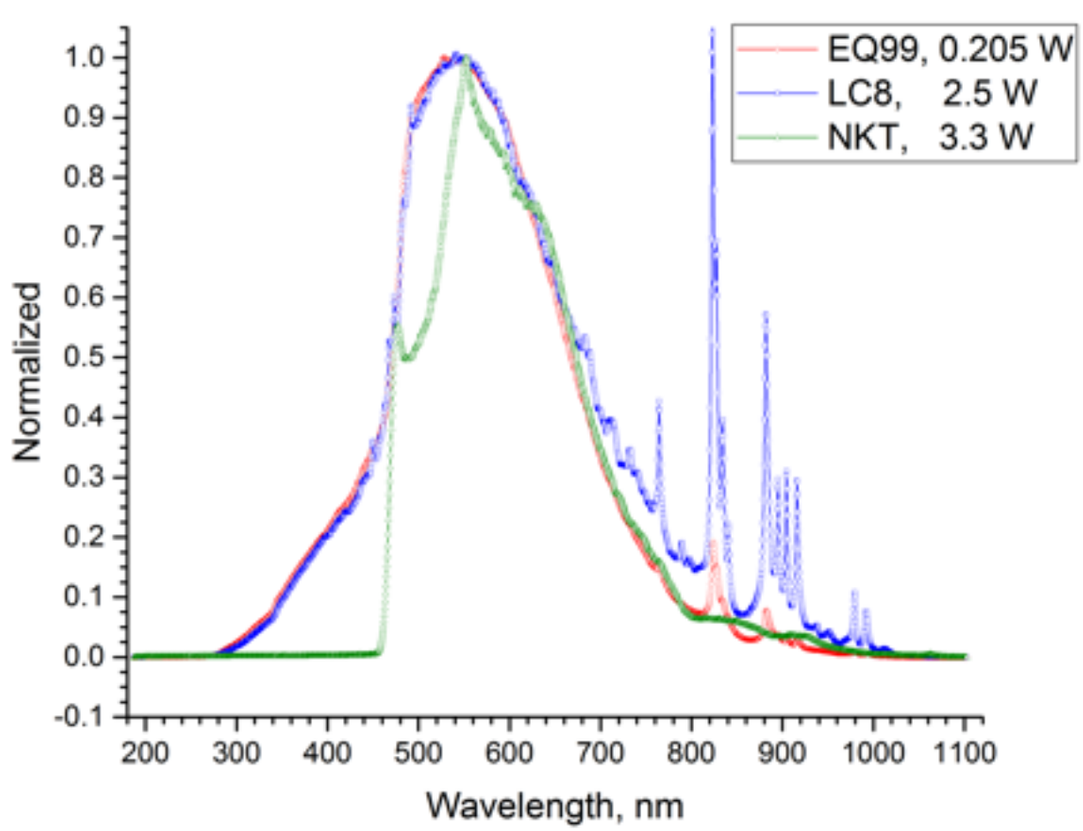


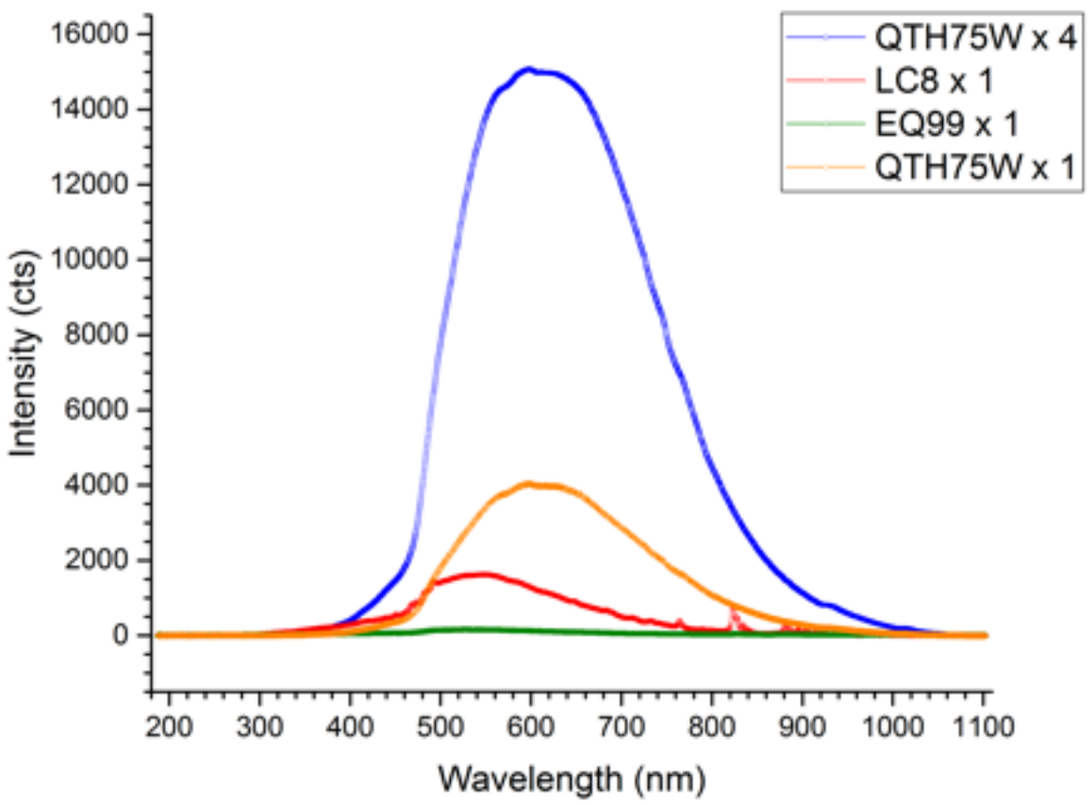


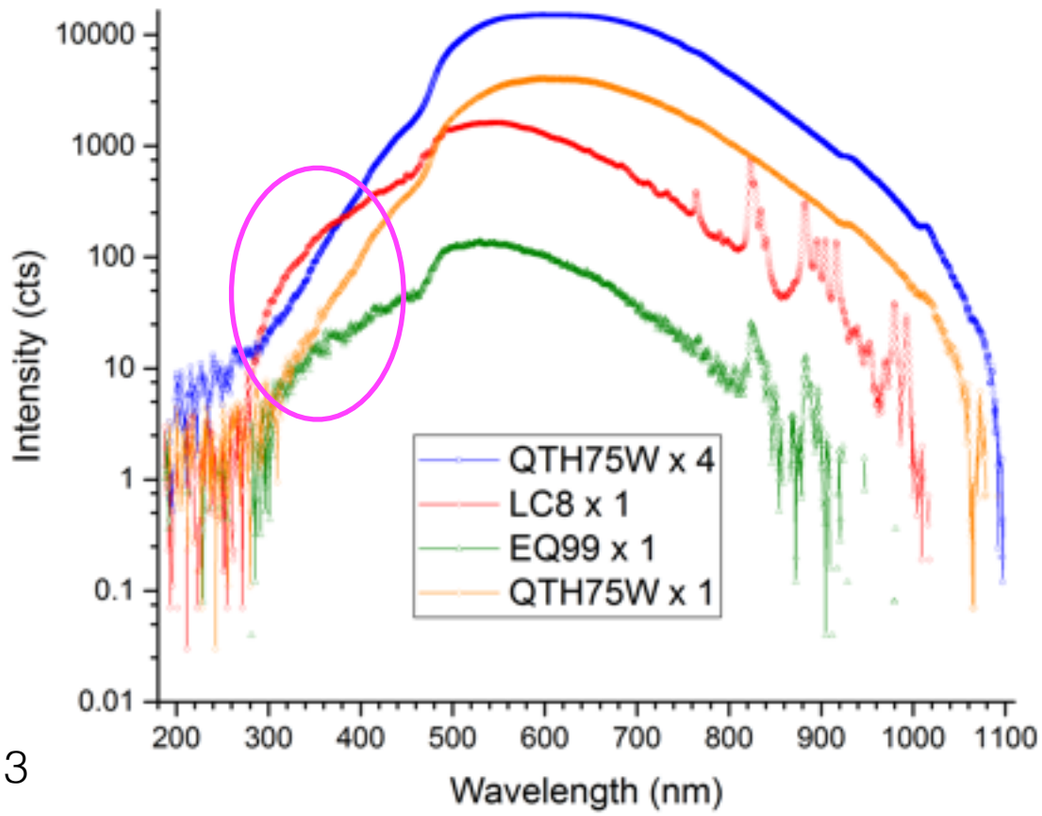
SC laser + Filter

Comparison of supercontinuum laser and lamp sources in UV-VIS-NIR

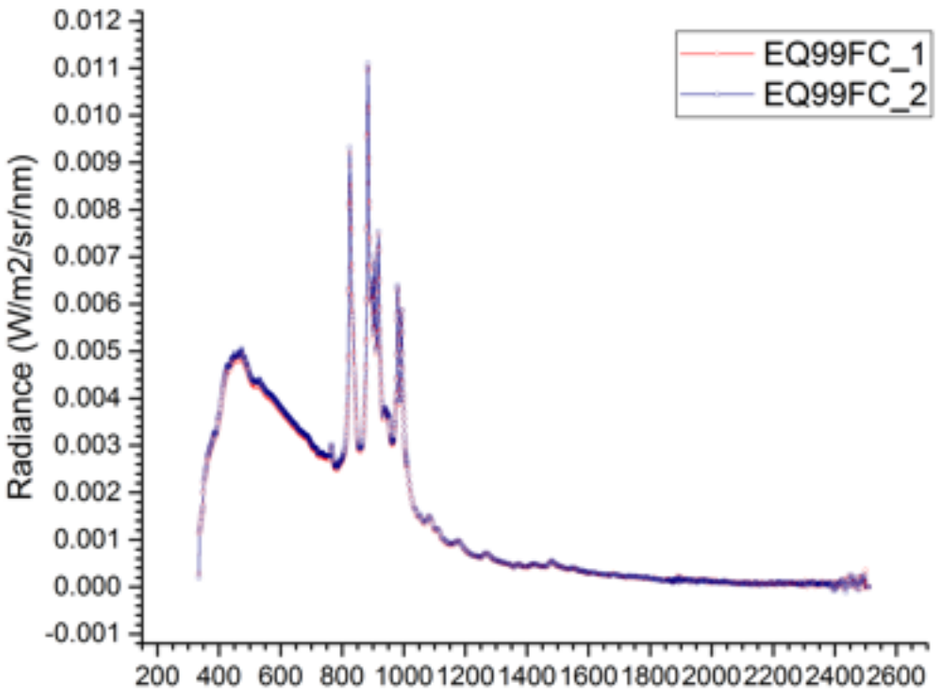


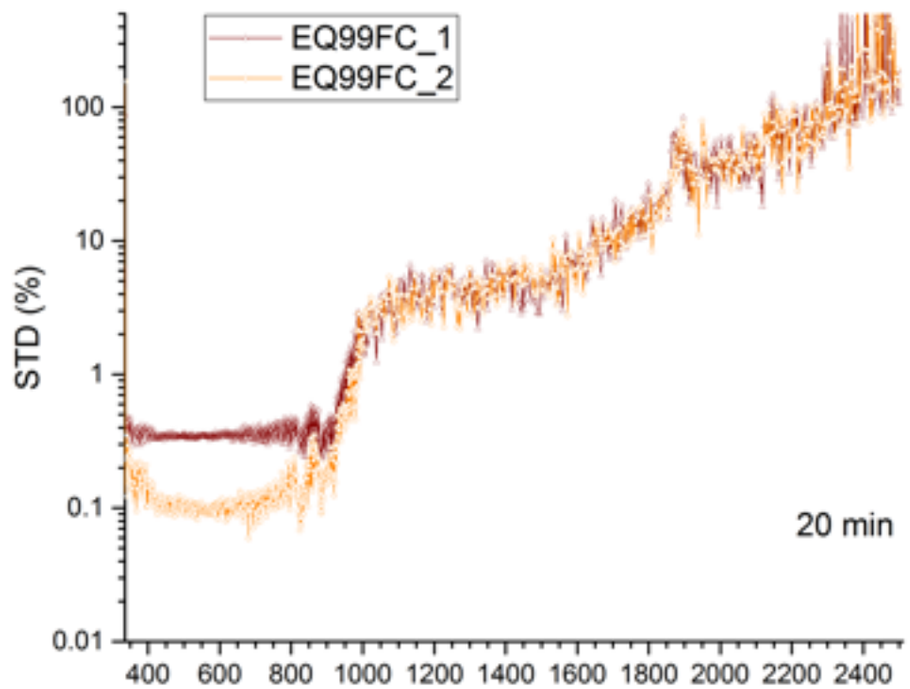


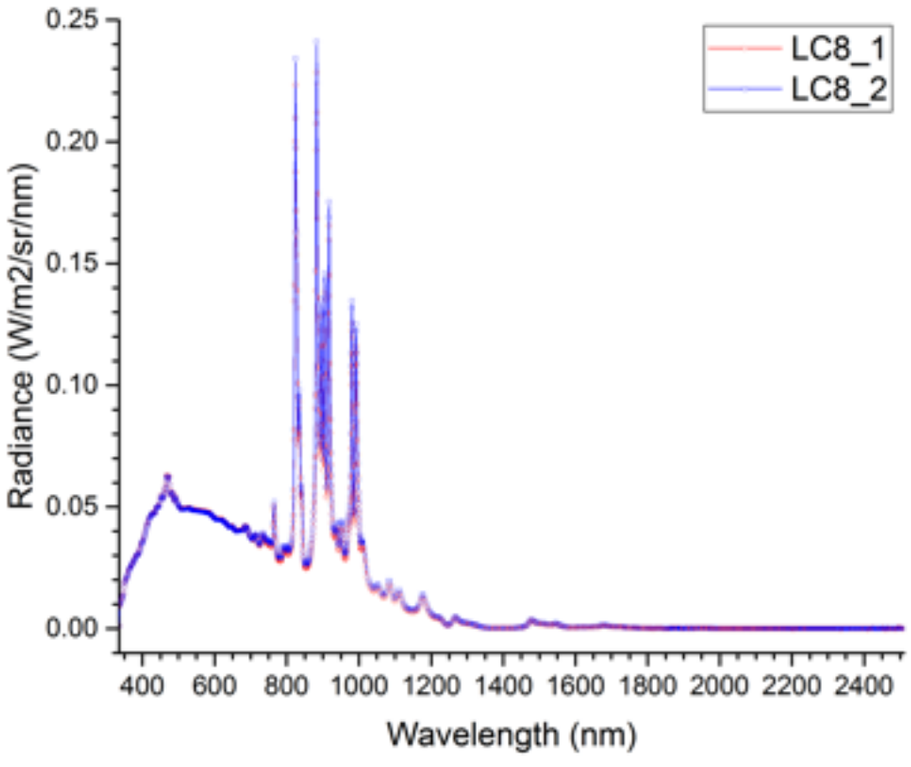


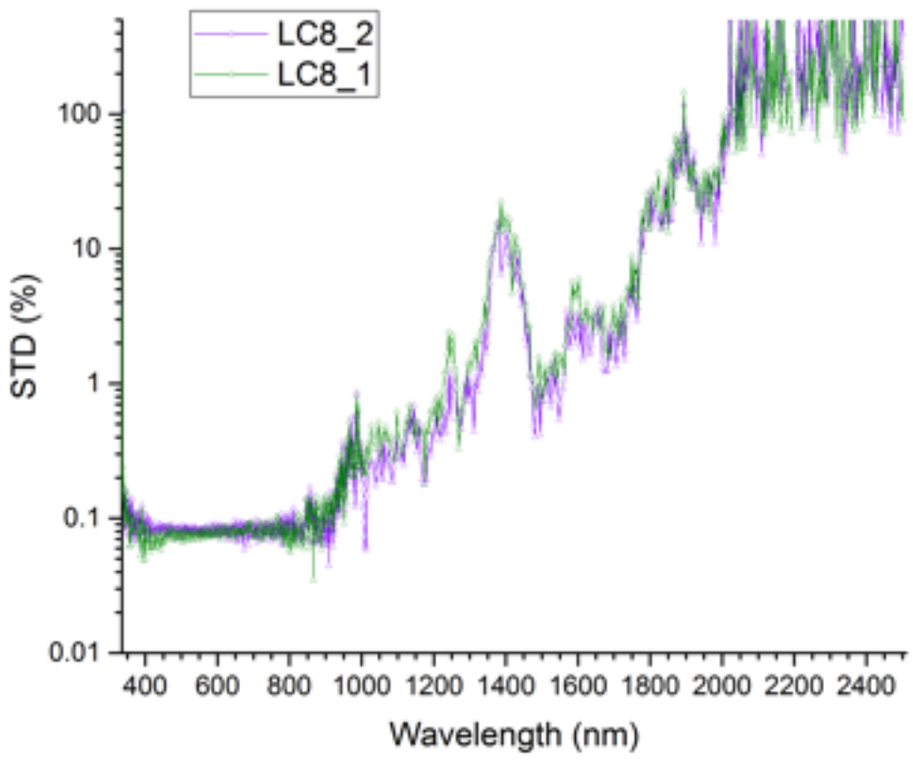


Stability of UV-VIS lamp sources



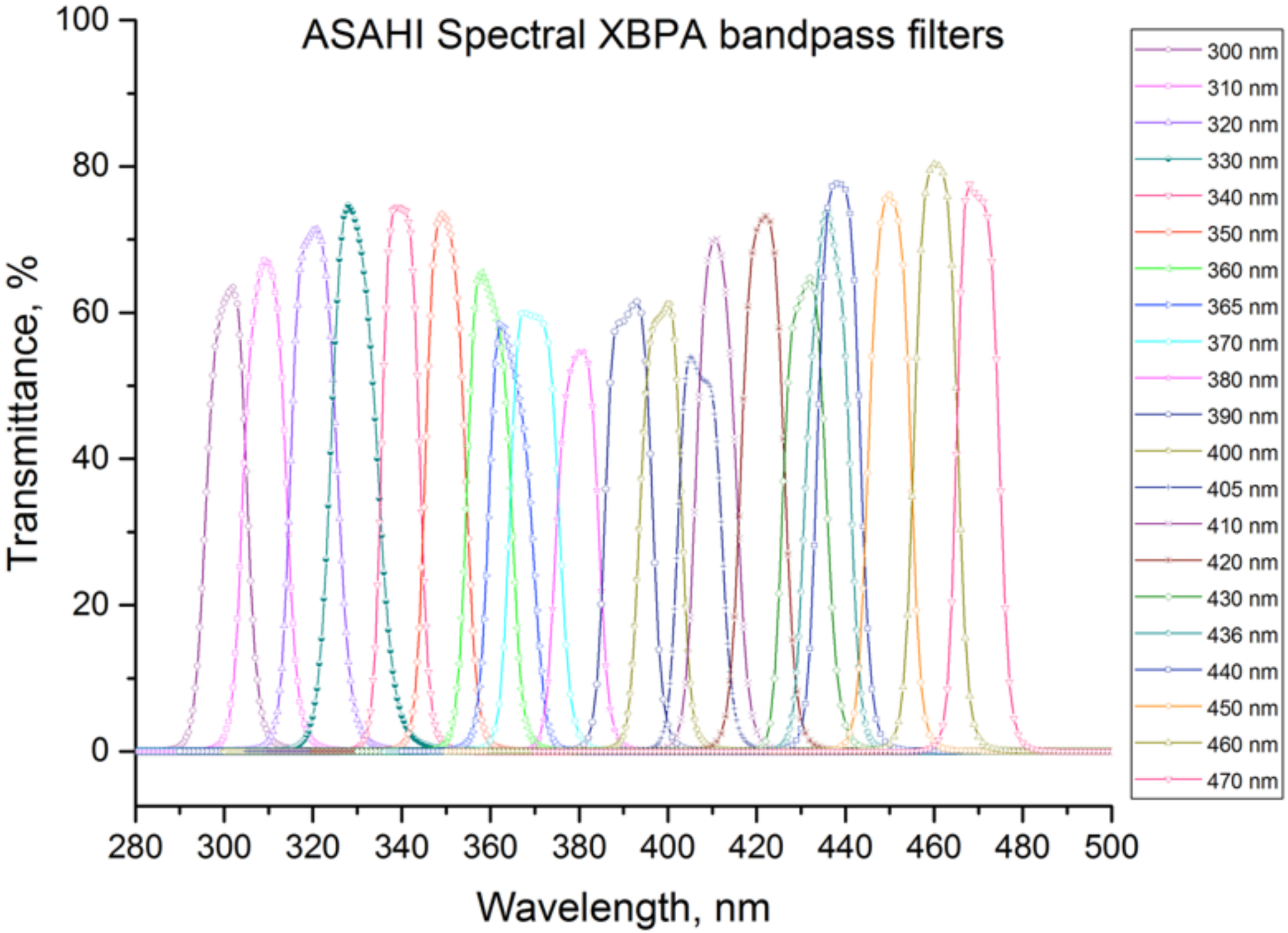






UV-VIS light sources

1. EQ99/1500 2. LC8



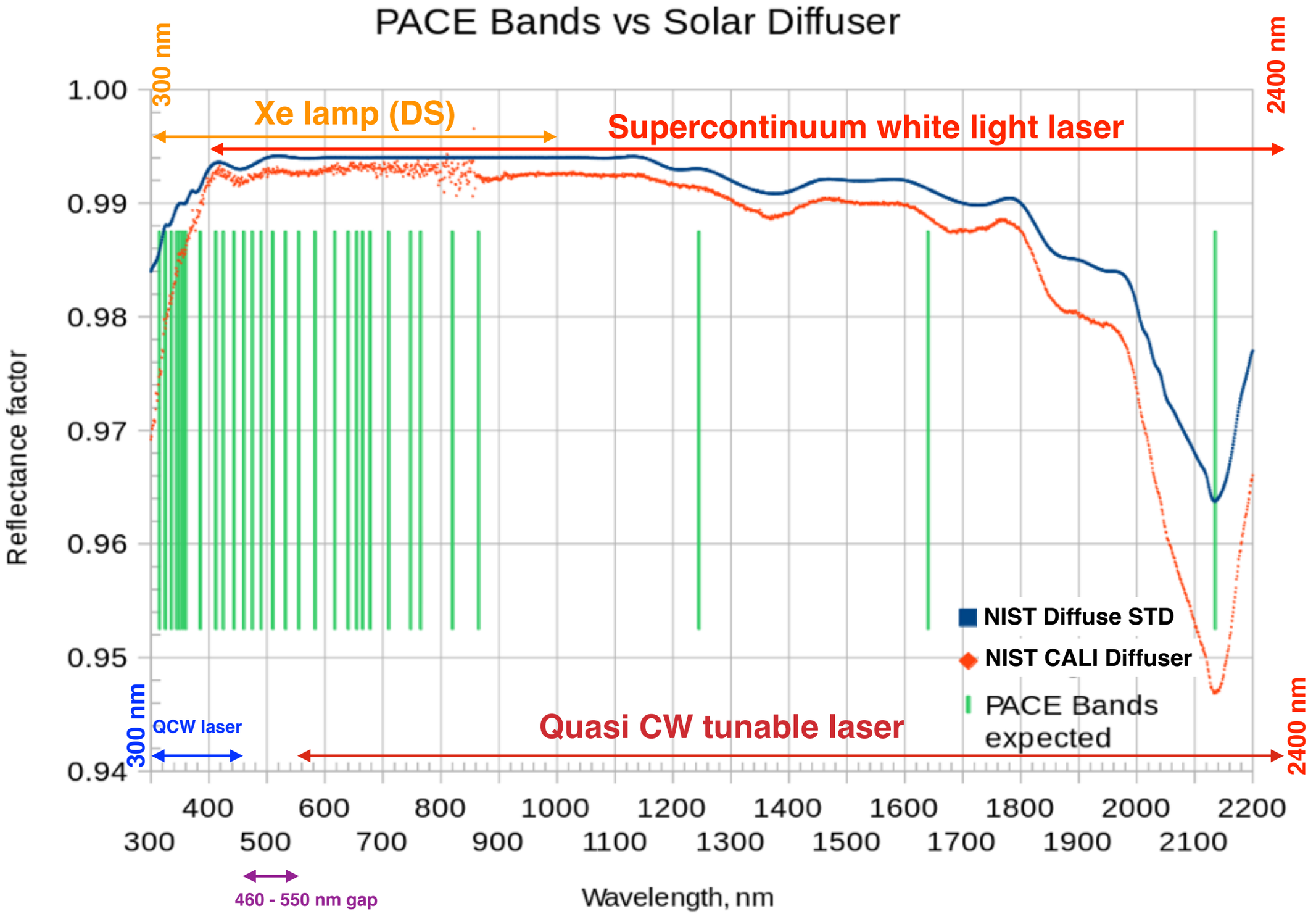
Light sources of TTG for VIIRS

Configuration 1:
Wavelengths: 250, 275, 300, 350, 400, 500, 700, 900, and 1100 nm;
Angles of incidence, θi: 0°, ±30°, ±45°, and ±60°
In-plane angles of scatter, θs: -60° to 60° in 10° steps, except where geometry is incompatible such as θi = θs.
Configuration 2:
Wavelengths: 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, 2200, 2300, 2400 and 2500nm;
Angles of incidence, θi: 0°;
In-plane angles of scatter, θs: 45°.

NIST BRDF Calibration

	Channel	λ_center (nm)	Spectral responsivity [DN/L_λ] [DN/(W/m2/sr/um)]	BW(um)	VIIRS response [DN/(W/m2/sr)]	GLAMR W/cm2/sr	GLAMR W/m2/sr	VIIRS DN (SIS)
EQ-99FC	M1	412	18.0	0.020	902	3.0E-05	0.3	271
	M2	445	20.6	0.018	1143	3.0E-05	0.3	343
AOTF VIS-nIR	M3	488	25.9	0.020	1295	3.0E-05	0.3	388
	M4	555	34.5	0.020	1724	3.0E-05	0.3	517
	M5	672	48.7	0.020	2436	3.0E-05	0.3	731
AOTF nIR	M6	746	77.2	0.015	5144	4.0E-05	0.4	2058
	M7	865	100.3	0.040	2508	4.0E-05	0.4	1003
	I1	640	4.7	0.080	59	3.0E-05	0.3	18
	I2	865	8.8	0.039	225	4.0E-04	4	898
AOTF IR	M8	1238	32.5	0.026	1250	1.0E-04	1	1250
	M9	1375	45.3	0.014	3236	1.0E-04	1	3236
	M10	1601	49.0	0.060	817	1.0E-04	1	817
	I3	1601	55.0	0.060	917	1.0E-04	1	917
DL LLTF SWIR	M11	2257	115.0	0.046	2500	0.0E+00	0	0

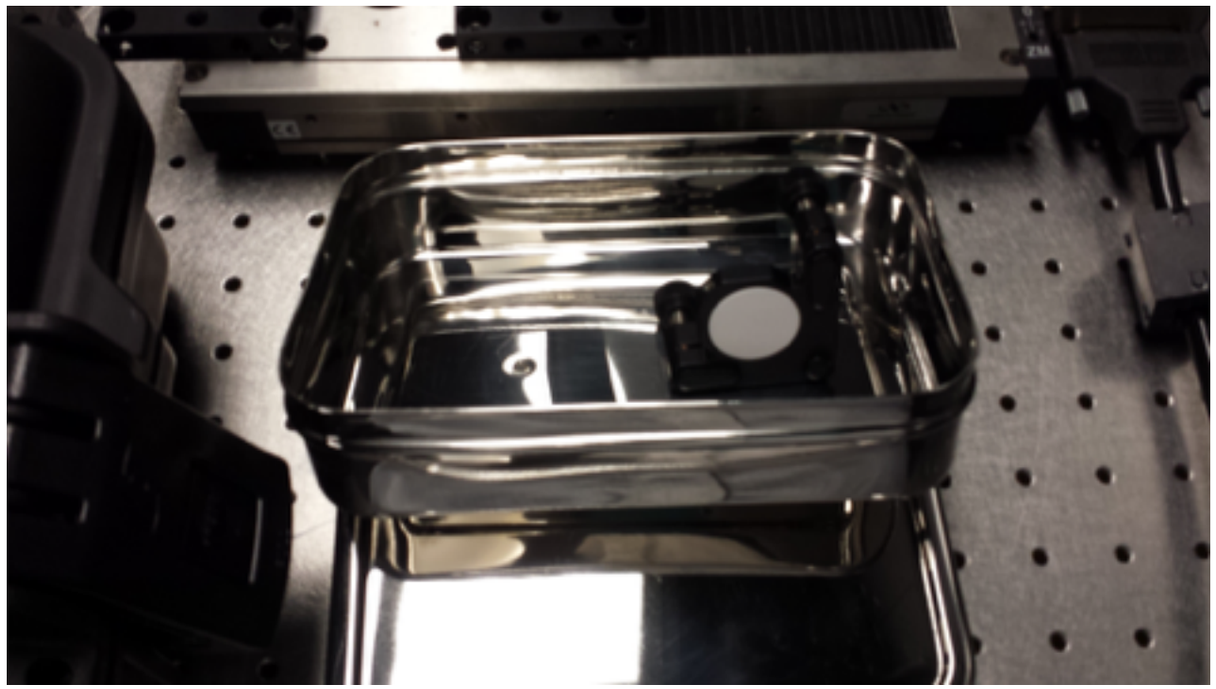
Light sources of TTG for PACE



Preliminary BRDF results with TTG
(Spectralon and Quartz Volume Diffuser, QVD)

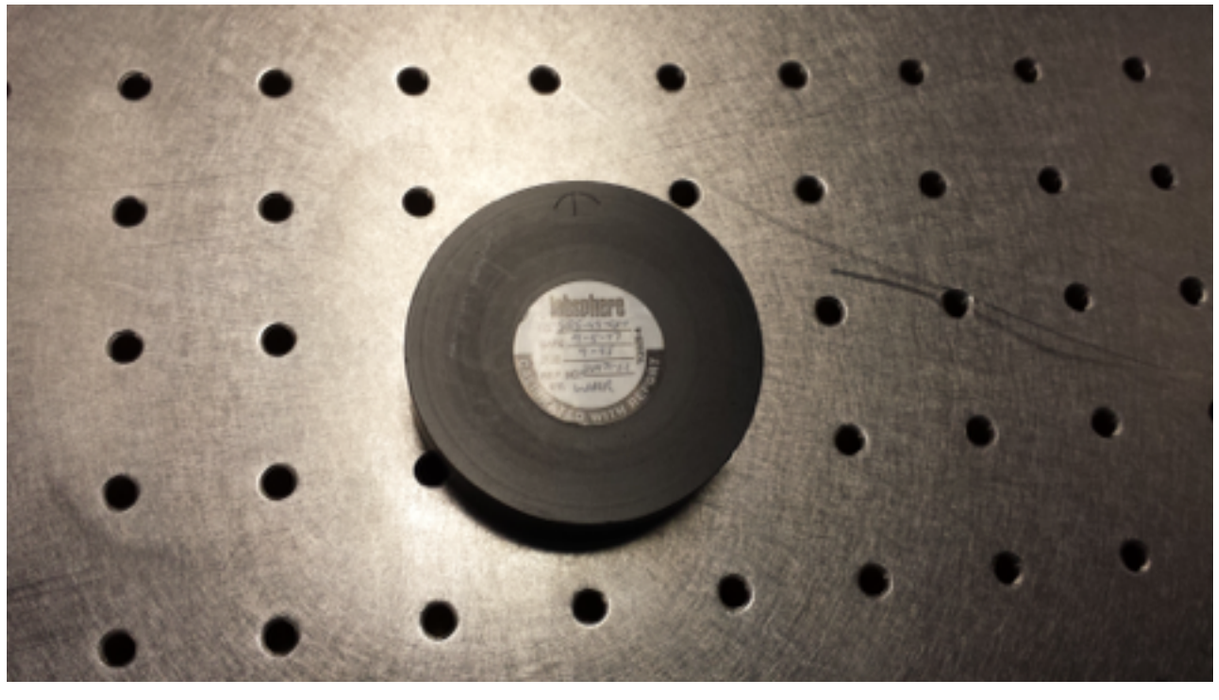
1. NIST traceable data validation
2. Scale transfer to different samples and wavelengths
3. BRDF cross-polarization average
4. Speckle suppression
5. Validation of BRDF results by comparing with DHR
6. Out-of-plane BRDF measurement
7. Uncertainty budget

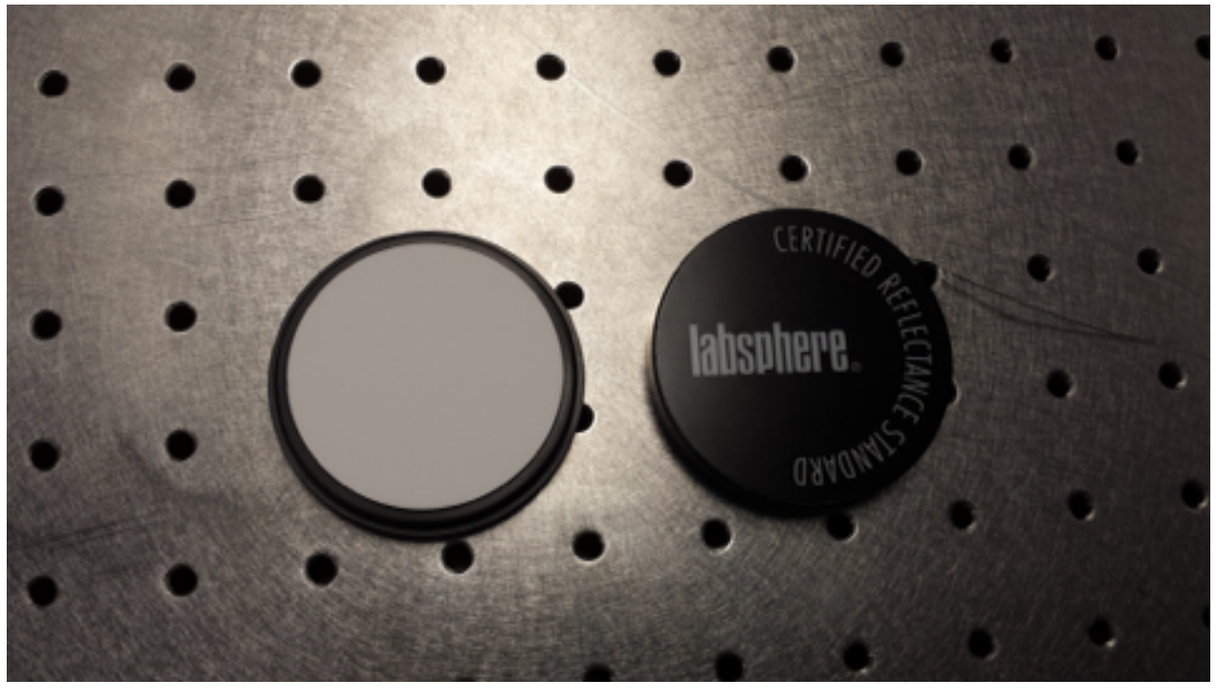
J1/F2 VIIRS SDA Witness Sample



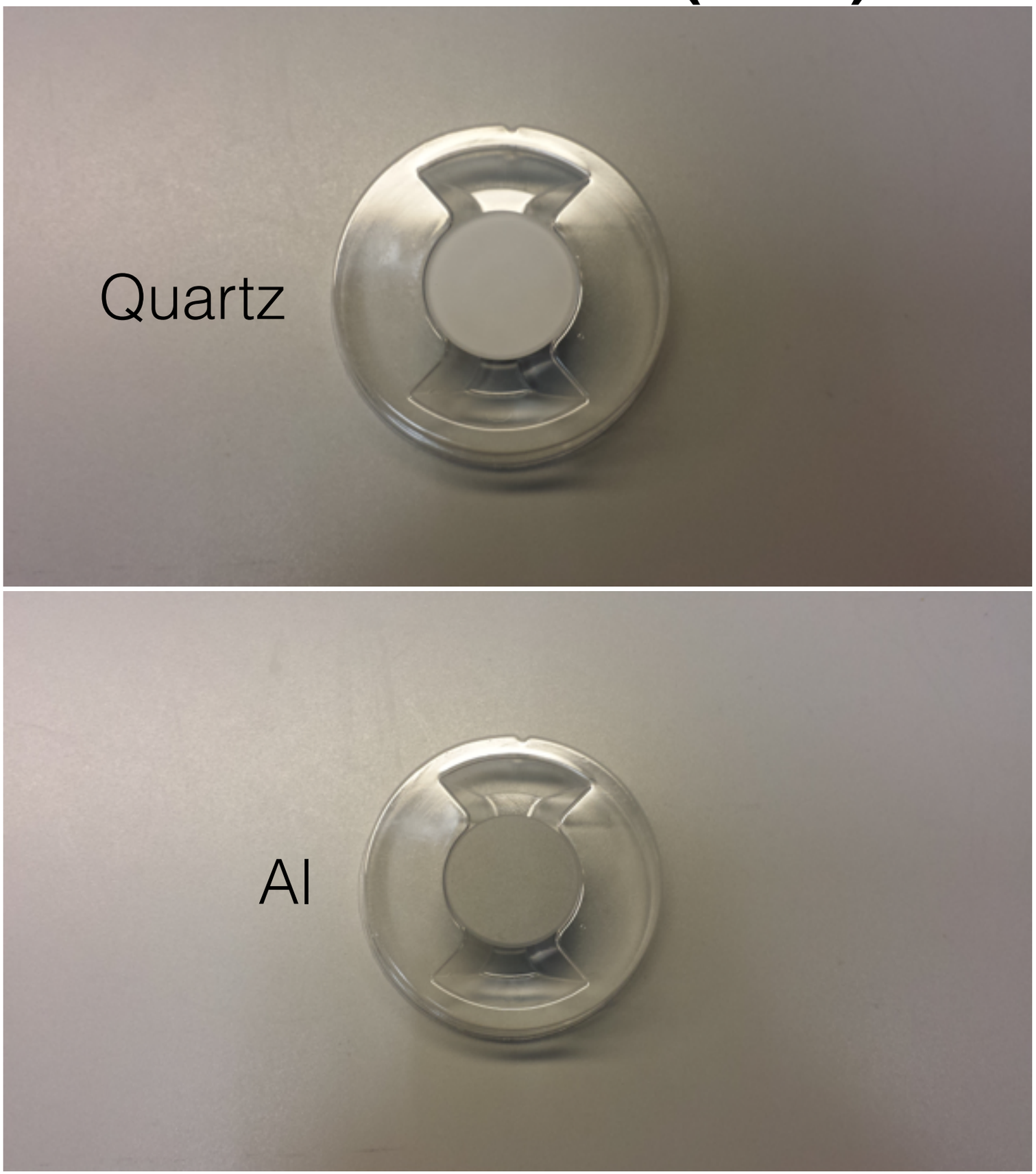
20471-1-1

NIST Calibration STND



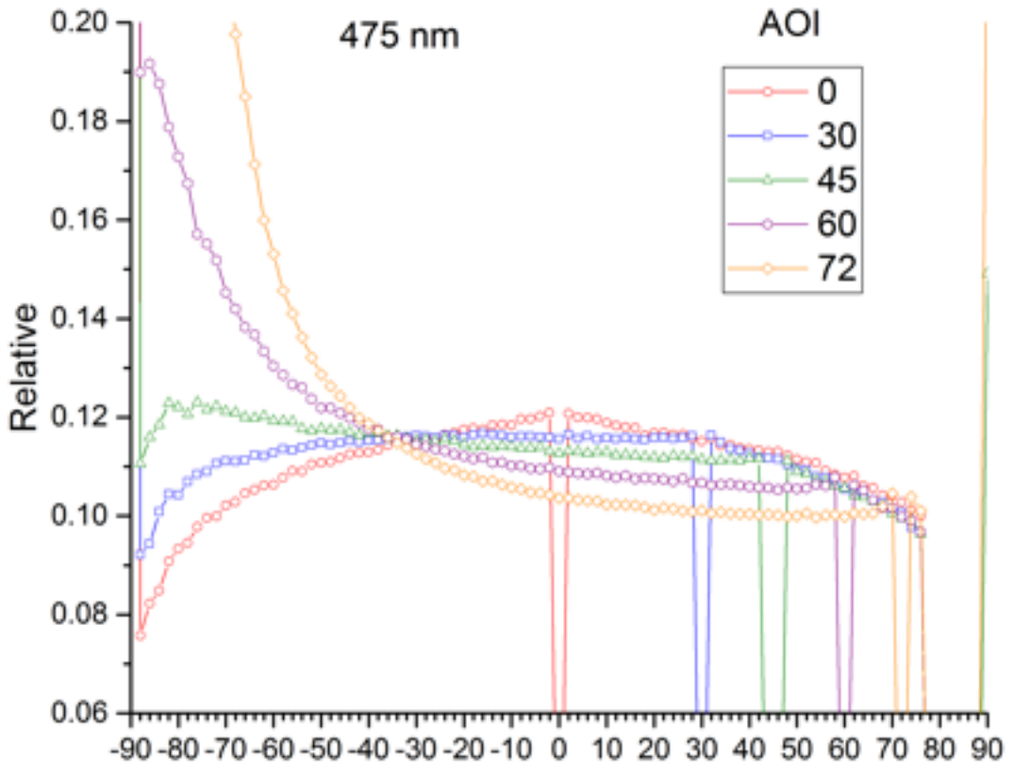


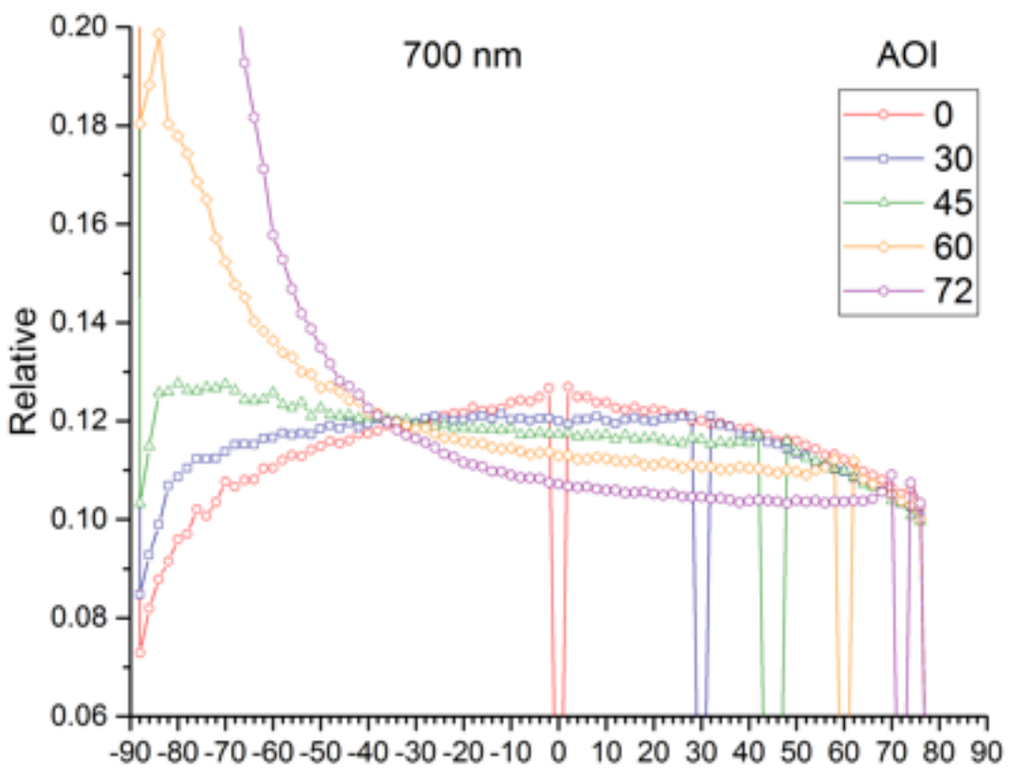
Quartz Volume Diffuser (QVD) Sample

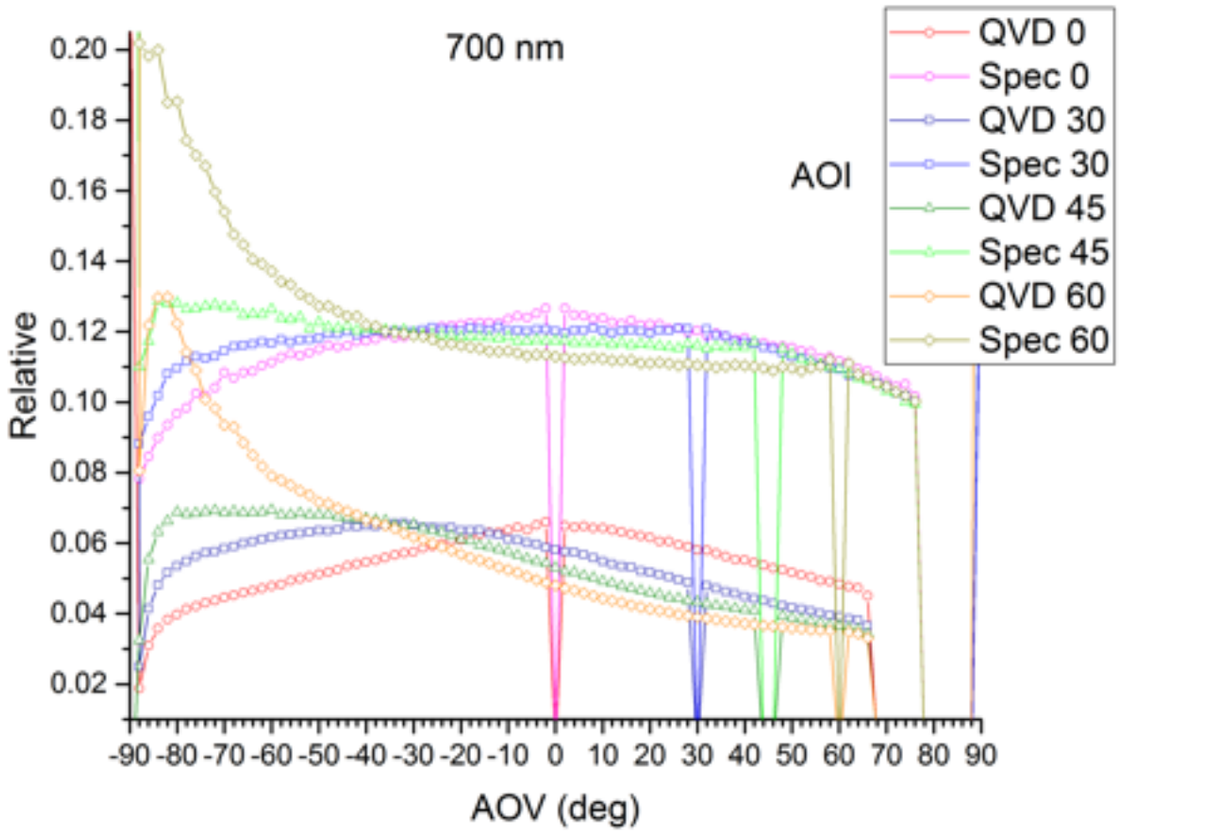


One of SD candidates

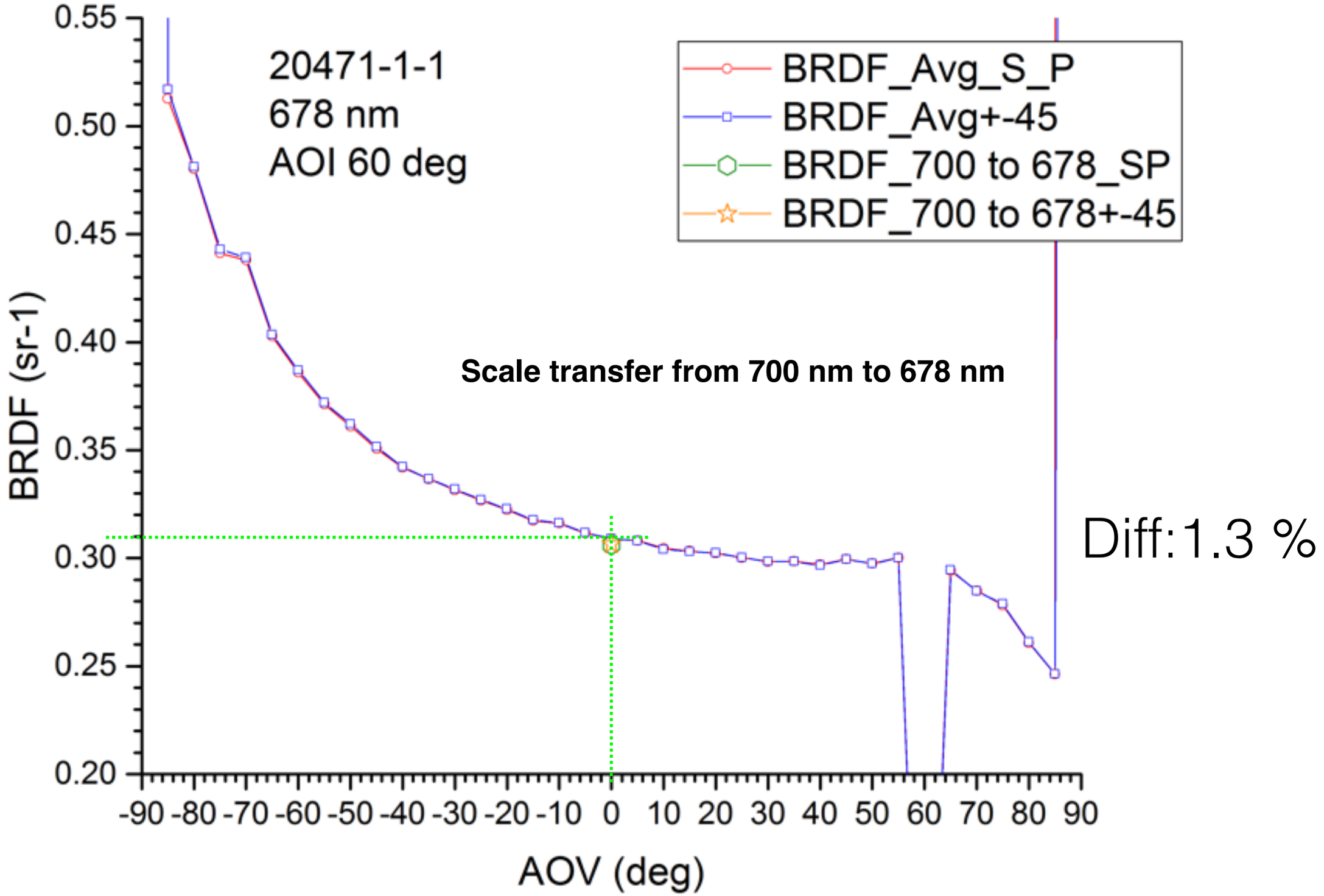
Relative BRDF of Spectralon and QVD





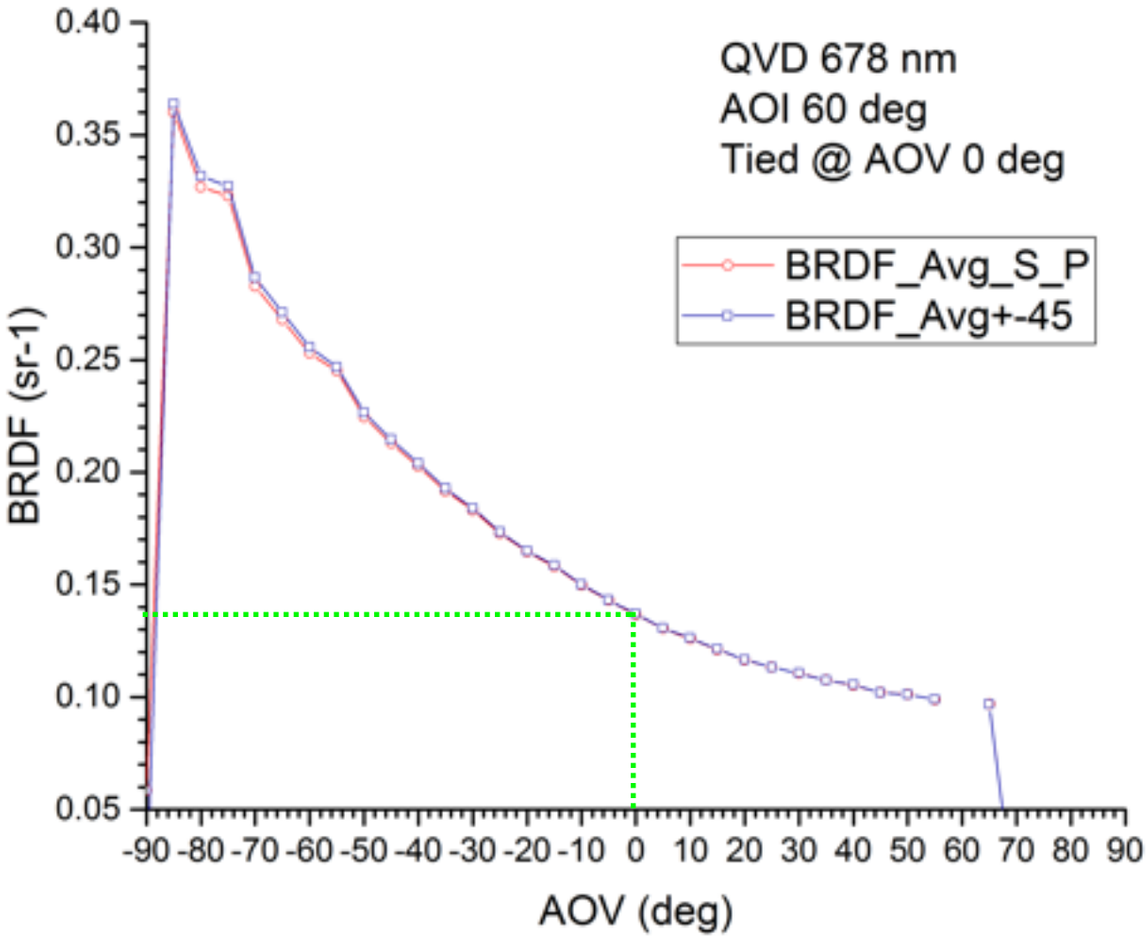


NIST Calibrated Spectralon

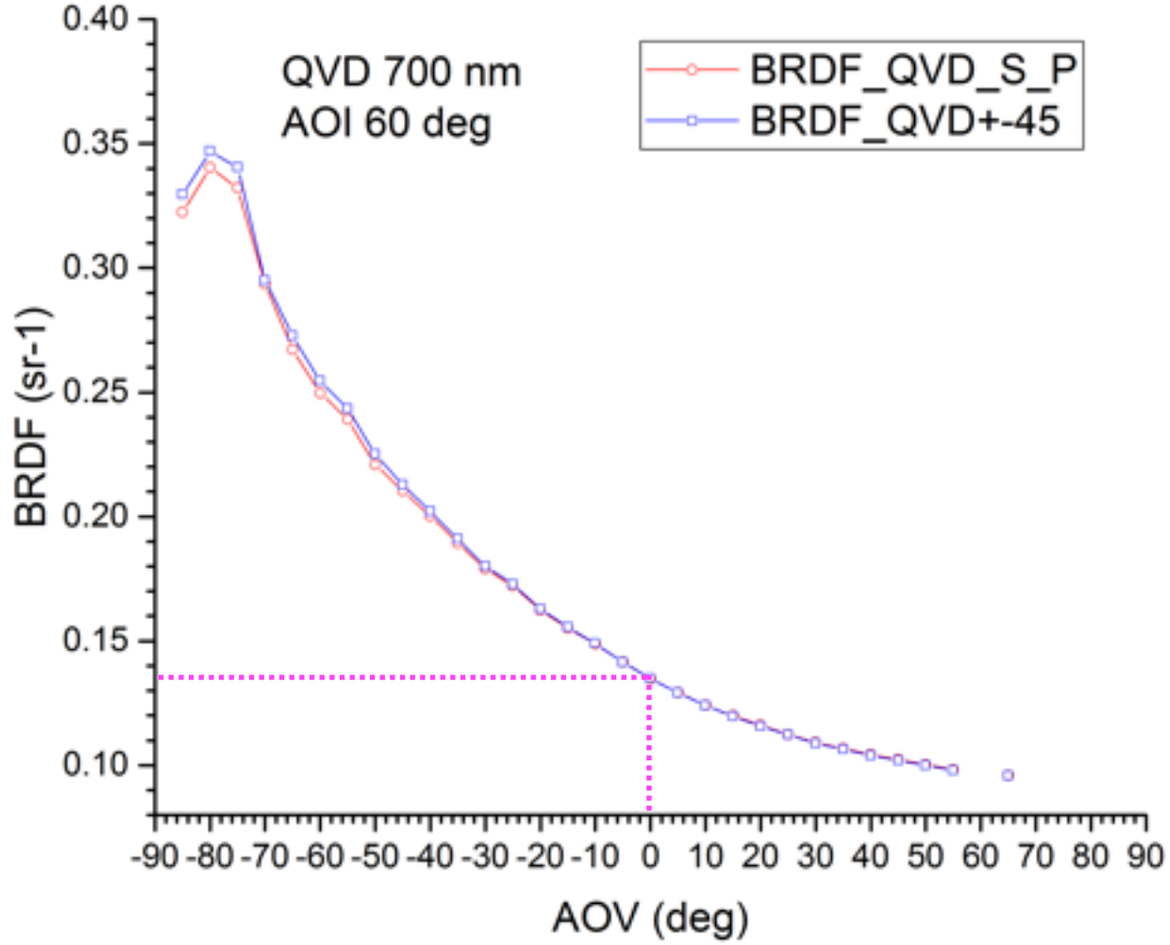


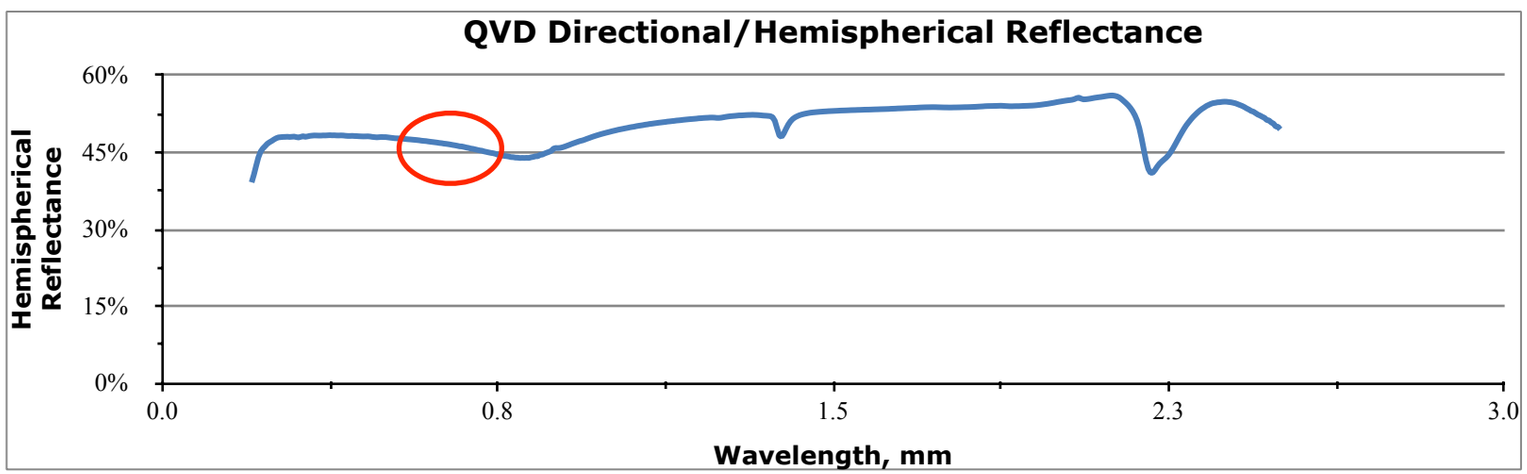
Absolute BRDF of QVD

Interpolated scale transfer

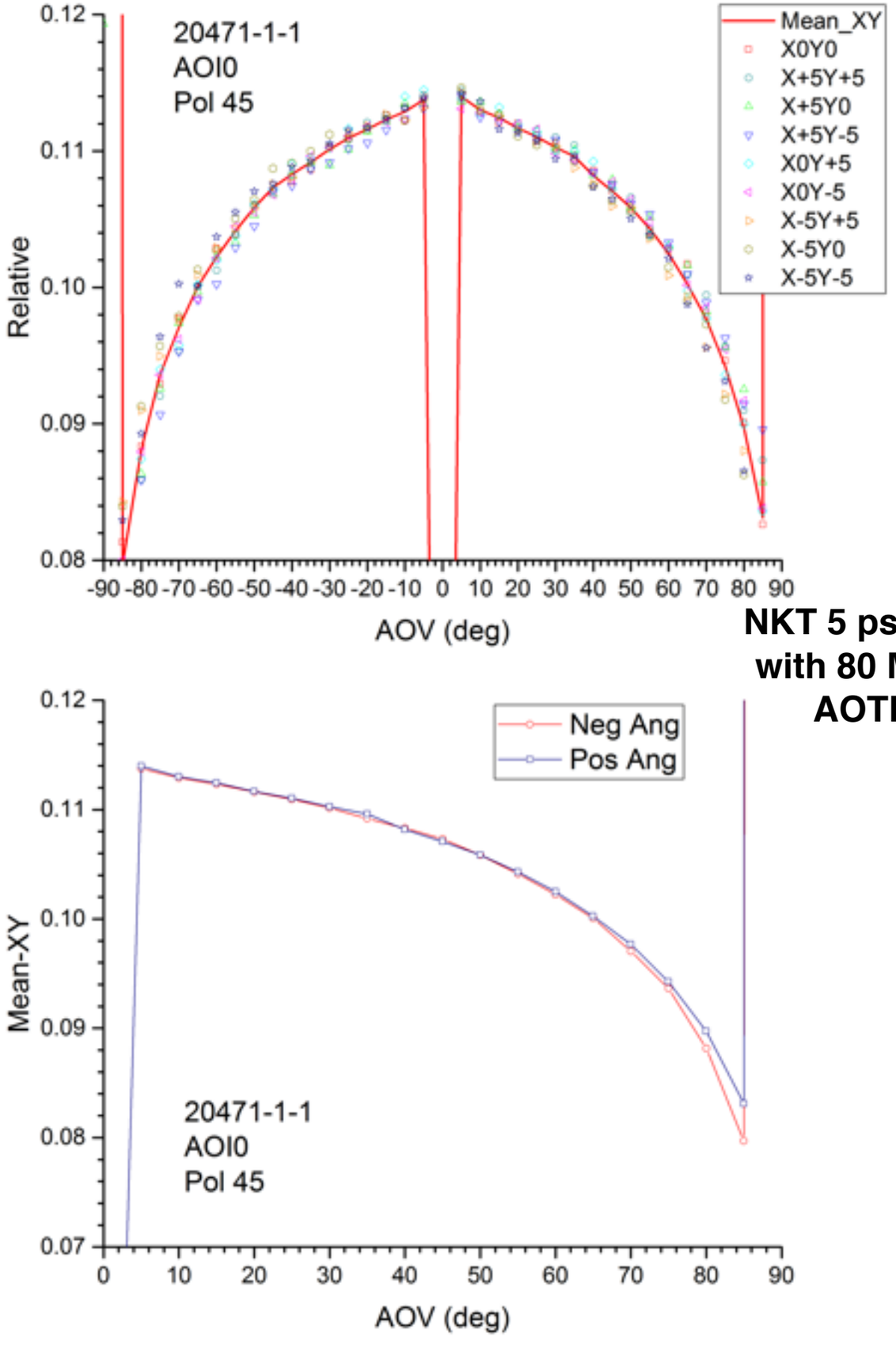


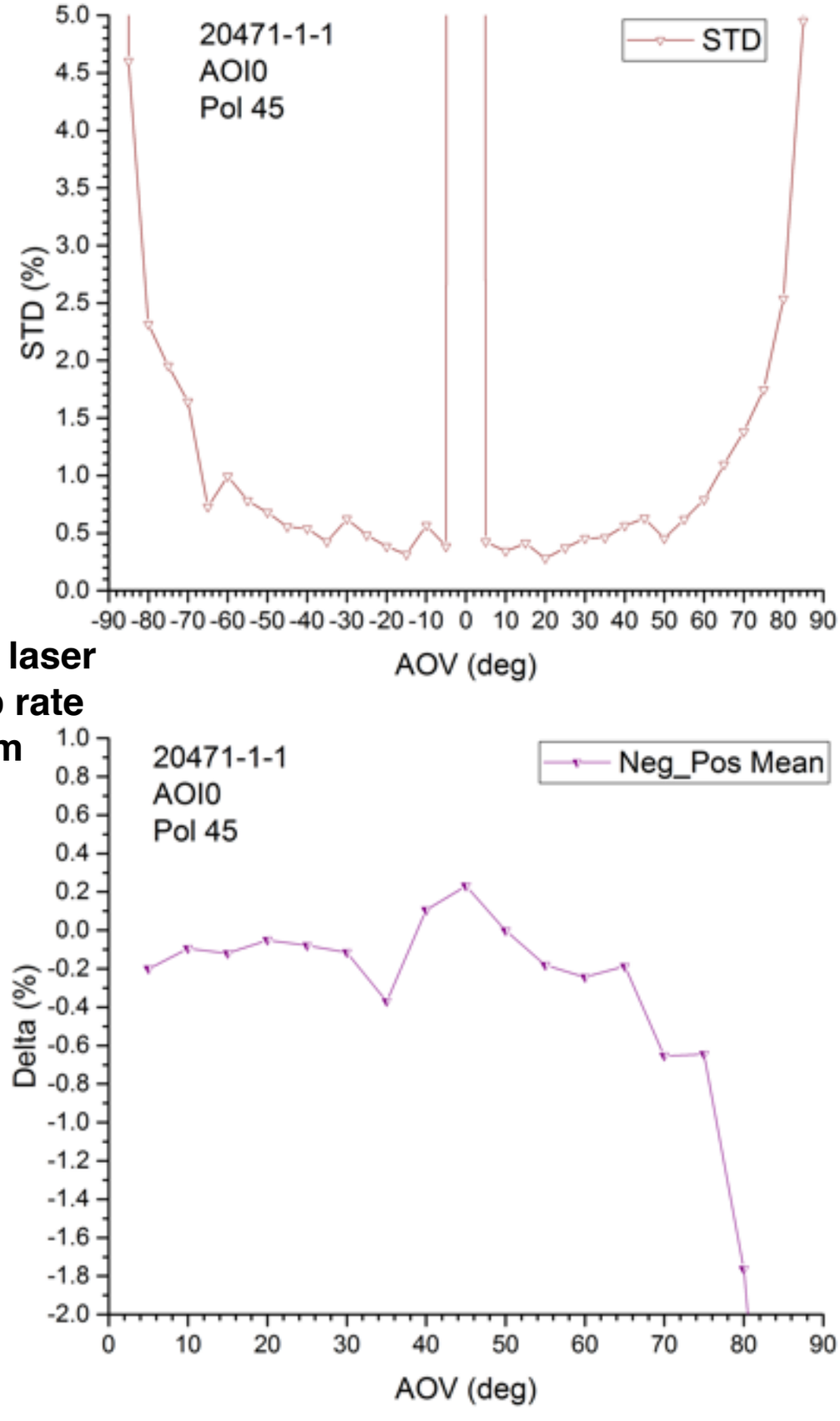
Direct scale transfer





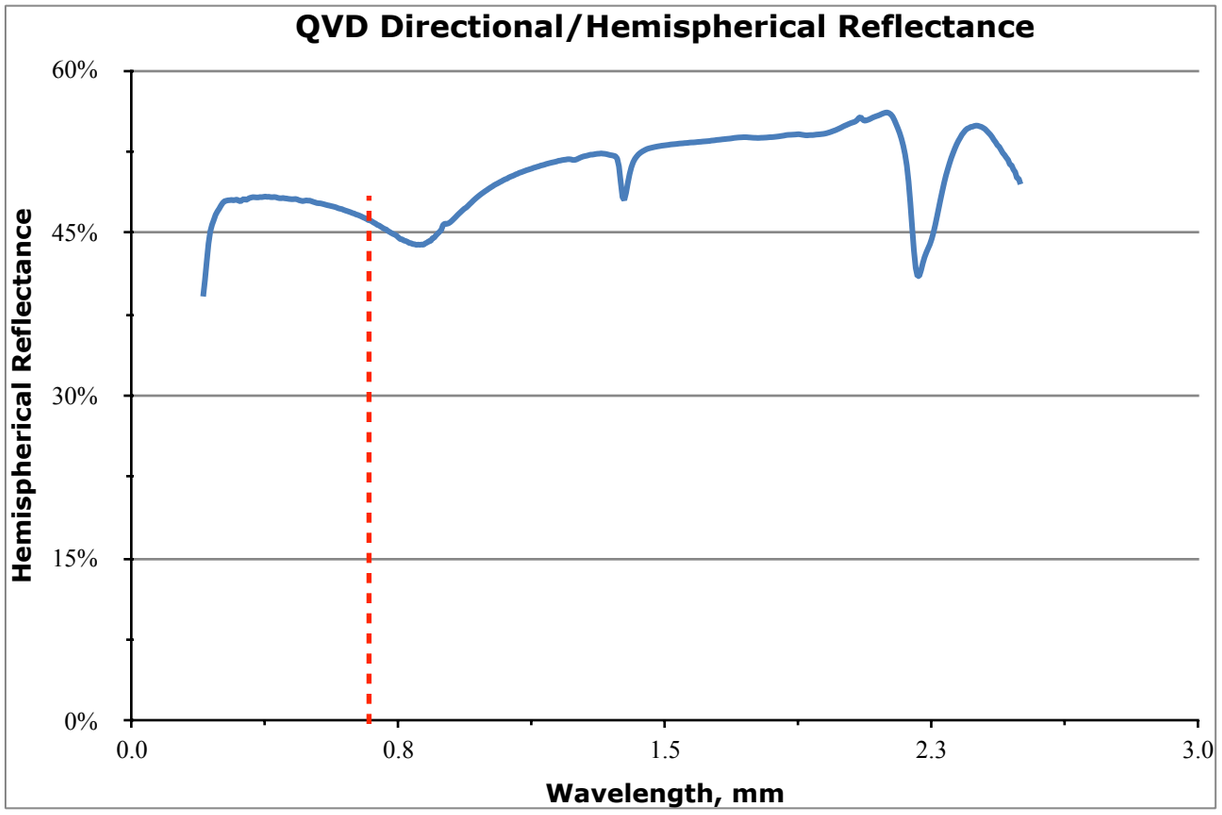
BRDF Speckle Suppression

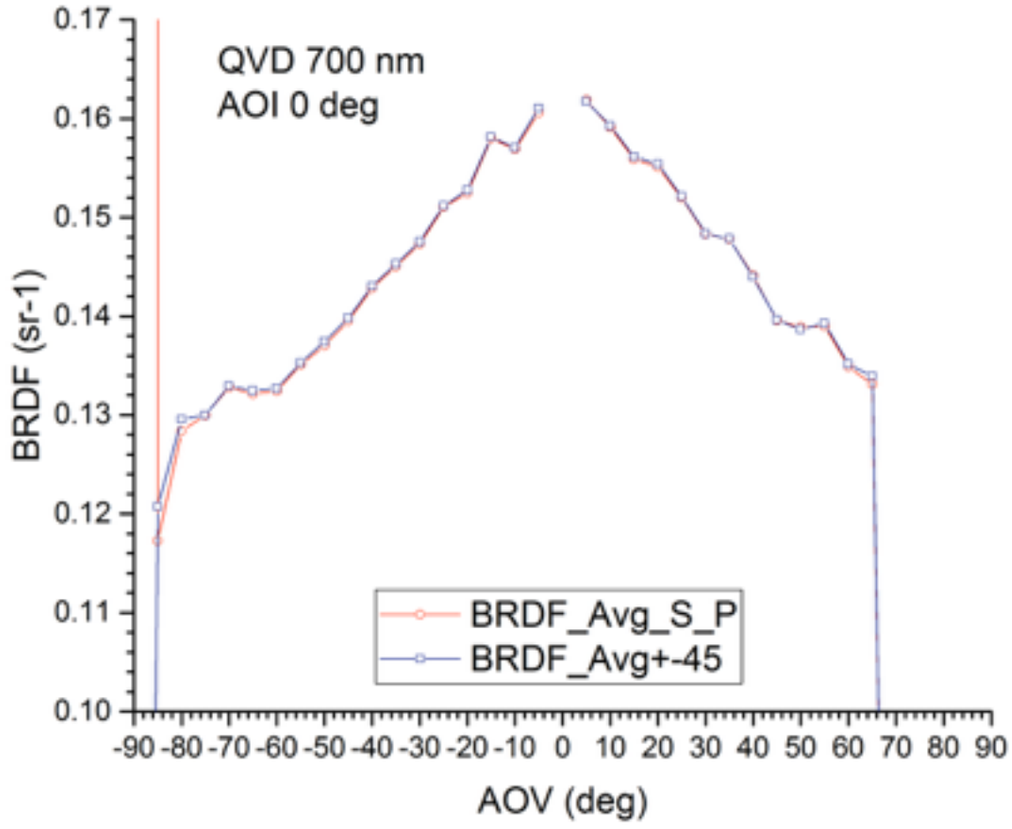




NKT 5 ps ML SC laser with 80 MHz rep rate AOTF 475 nm

DHR validation with BRDF results



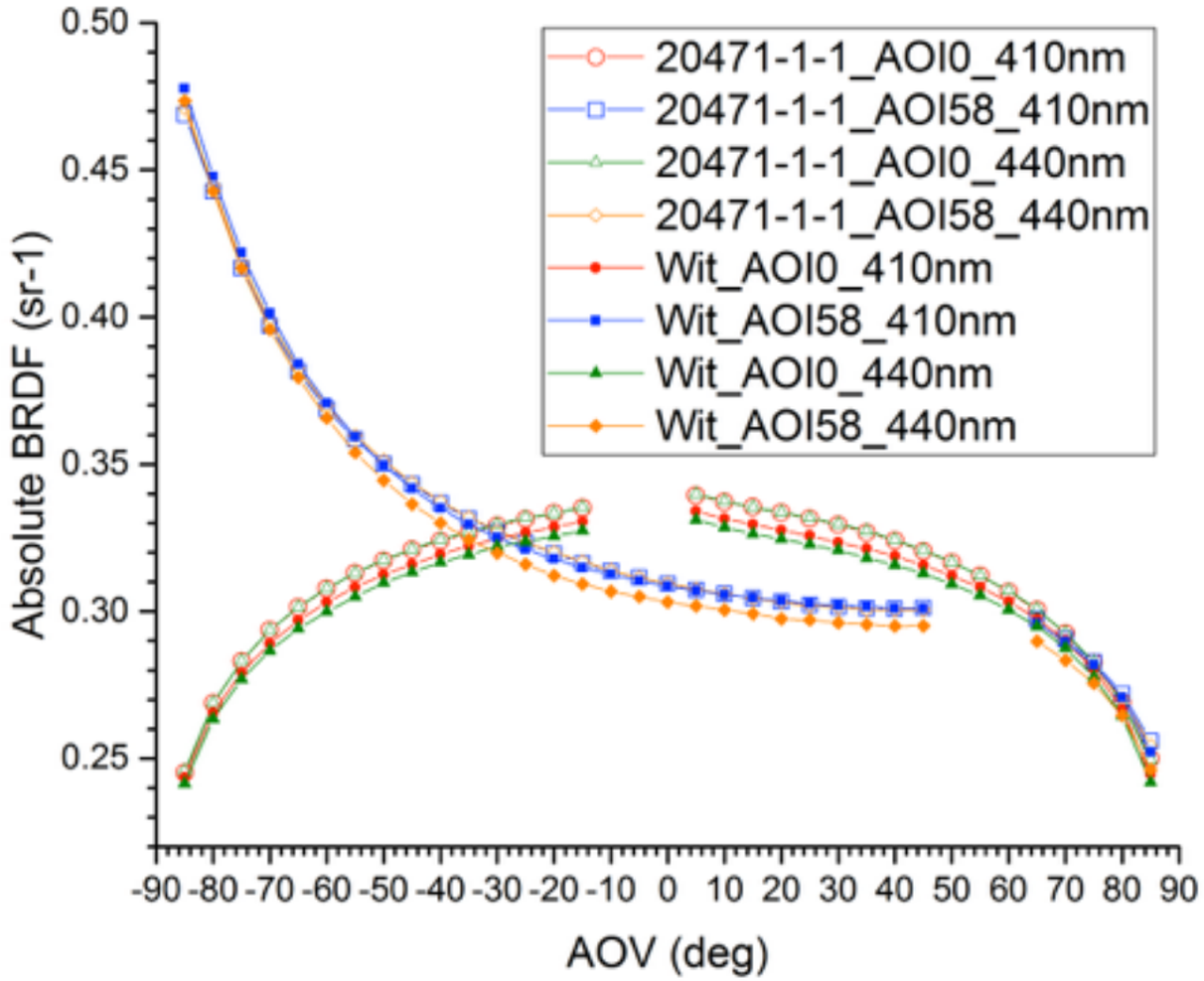


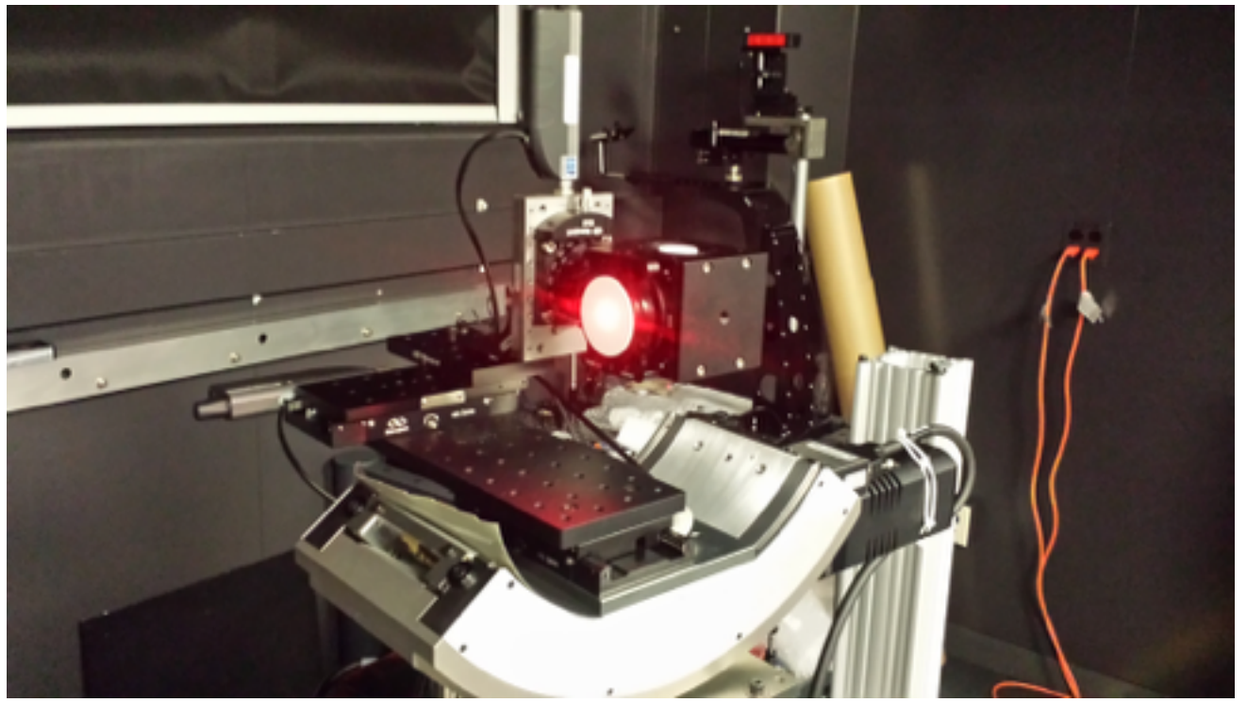
QVD DHR: 0.456 @ 700 nm

QVD BRDF integration
0.447

Diff 0.009

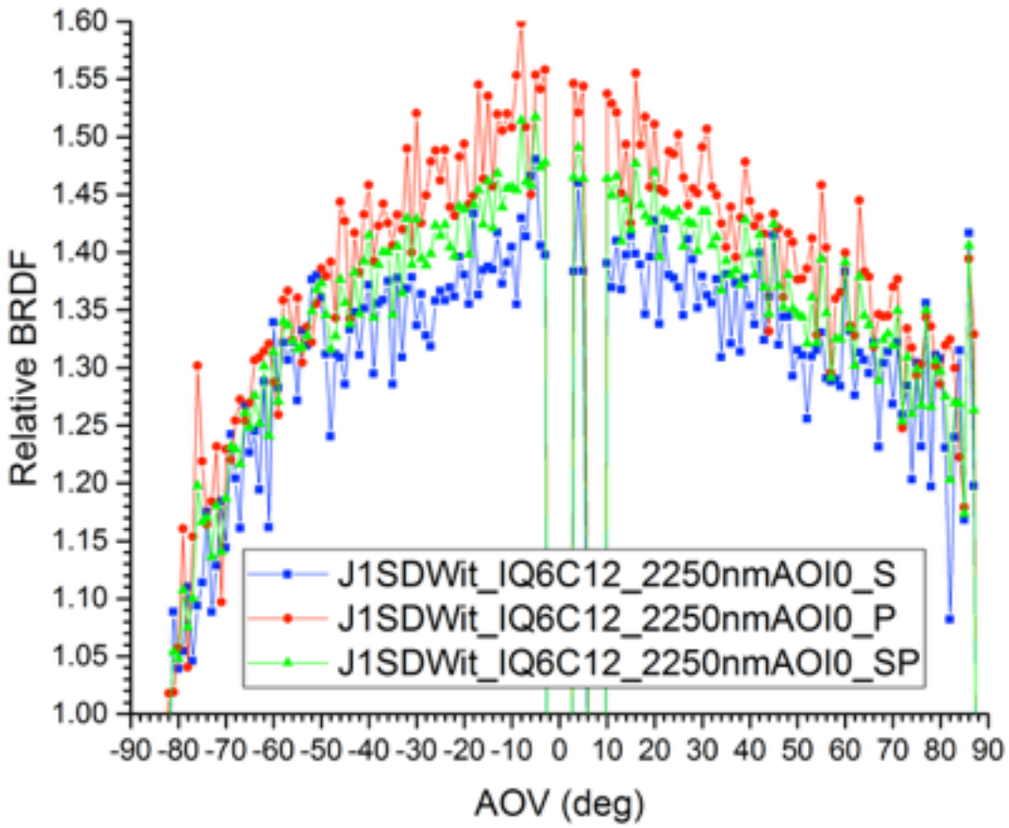
Preliminary BRDF results for J1 VIIRS SD Witness

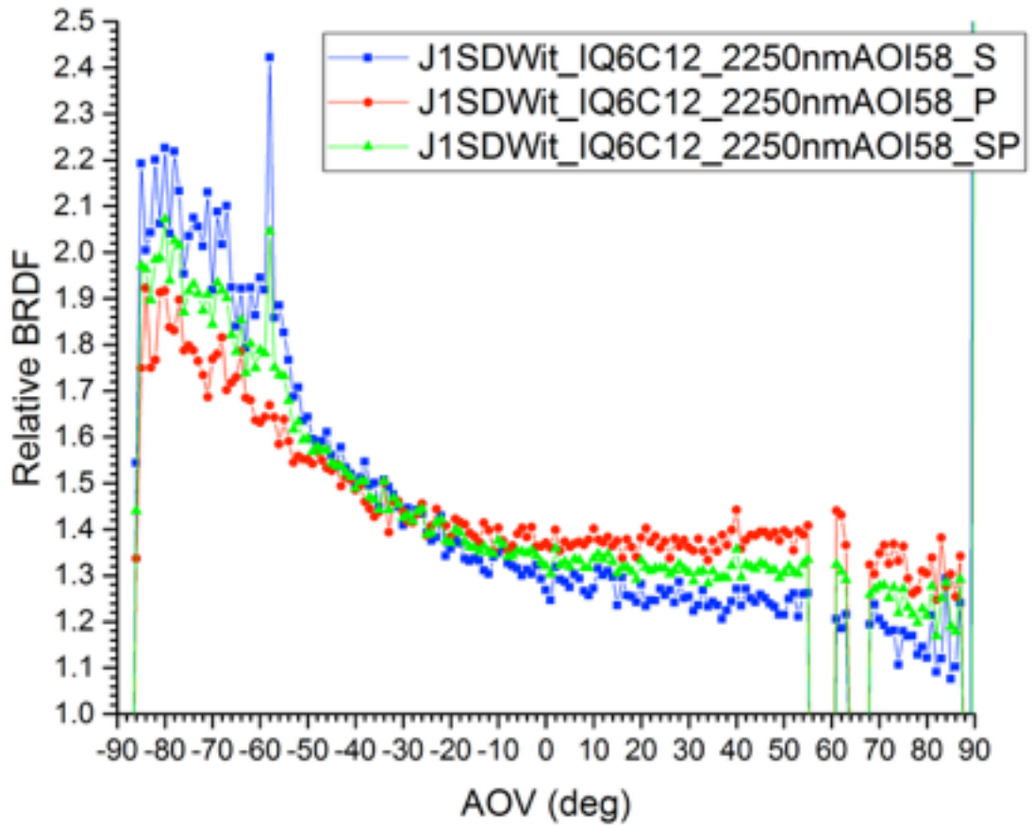


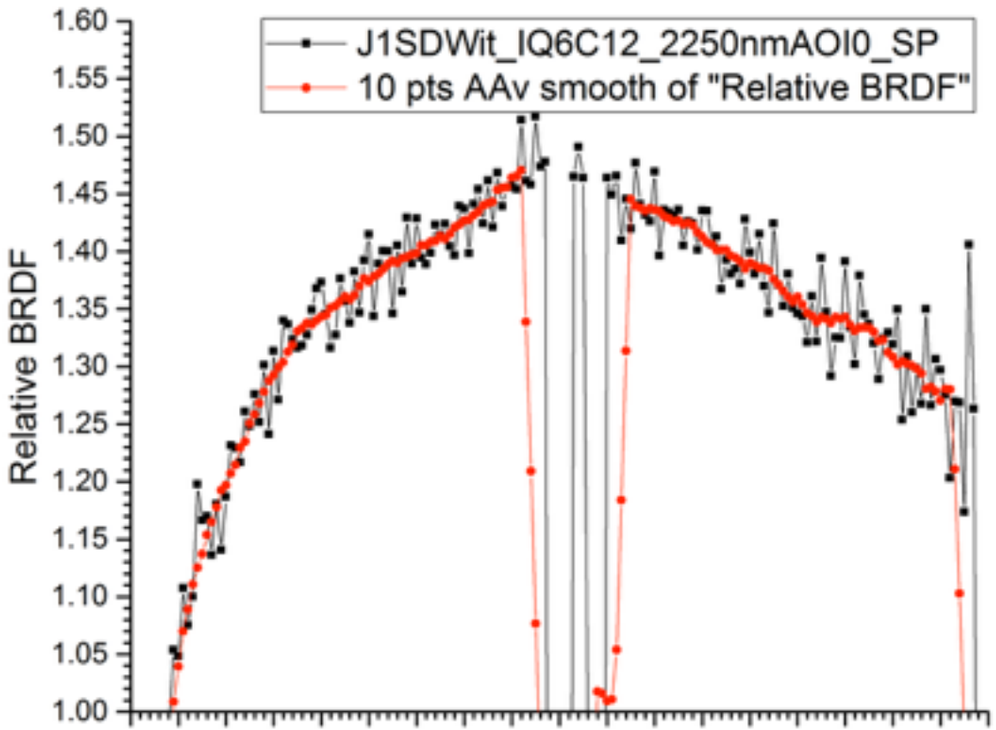


EQ-99FC + Filter

Preliminary BRDF results for J1 VIIRS SD Witness







IQ6C12 Diode laser 2250 nm

Component of uncertainty of absolute BRDF

1. Source stability	< 0.5 %
2. Wavelength	< 0.1 %
3. Stray light	< 0.1%
4. Incident signal	< 0.25 %
5. Scattered signal	< 0.25 %
6. Aperture area	< 0.2 %
7. Distance	< 0.2 %
8. Viewing angle/Incident angle	< 0.4 %
9. Z position	< 0.1 %
10. Detector linearity	< 0.1 %
11. Repeatability	< 0.5 %
Total	0.95 % (k=1)

Summary

1. Test of light sources for TTG
2. Preliminary BRDF measurements using TTG
   - ✶NIST traceable validation for Spectralon and QVD (Absolute BRDF and DHR)
   - ✶Speckle suppression
   - ✶Uncertainty budget of BRDF

Future work

1. Support SD BRDF calibration for PACE
2. BRDF measurements for J1 VIIRS SD Witness sample

Backup slides

Light source of TTG for PACE

Table 3.1: Requirements for center wavelengths λ_{CW}, bandwidth (BW), SNR at L_{typ}, typical radiances (L_{typ}), and maximum radiances (L_{max}) of the nominal 26 multispectral bands. Radiance units are W/(m^2 μm sr). Values are taken from Table 2 in the ACE Ocean Biology White Paper, Appendix[23]. The SeaWiFS (SeaW) SNR are given for comparison. For each band, its spectral classification (ultraviolet (UV), visible (VIS), near infrared (NIR), and short wave infrared (SWIR)) is provided.

Band	λ_{CW} [nm]	BW [nm]	SNR (req.)	SNR* (SeaW)	L_{typ}	L_{max}	Spectral region
1	350	15	300		74.6	356	UV
2	360	15	1000		72.2	376	UV
3	385	15	1000		61.1	381	UV
4	412	15	1000	897	78.6	602	VIS
5	425	15	1000		69.5	585	VIS
6	443	15	1000	967	70.2	664	VIS
7	460	15	1000		68.3	724	VIS
8	475	15	1000		61.9	722	VIS
9	490	15	1000	1010	53.1	686	VIS
10	510	15	1000	1000	45.8	663	VIS
11	532	15	1000		39.2	651	VIS
12	555	15	1000	870	33.9	643	VIS
13	583	15	1000		38.1	624	VIS
14	617	15	1000		21.9	582	VIS
15	640	10	1000		19.0	564	VIS
16	655	15	1000		16.7	535	VIS
17	665	10	1000	570	16.0	536	VIS
18	678	10	1400		14.5	519	VIS
19	710	15	1000		11.9	489	VIS
20	748	10	600		9.3	447	NIR
21	765	40	600	522	8.3	430	NIR
22	820	15	600		5.9	393	NIR
23	865	40	600	364	4.5	333	NIR
24	1245	20	250		0.88	158	SWIR
25	1640	40	180		0.29	82	SWIR
26	2135	50	100		0.08	22	SWIR

*: SeaWiFS bands have bandwidths of 20nm for the VIS bands, 40nm for the NIR bands.

EQ99/1500
LC8+L8253

HeCd laser

315 nm
325 nm
335 nm
345 nm
355 nm

Ti:Sapphire
THG > 30 mW

Ti:Sapphire
SHG > 50 mW

OPO-NIR-SHG
> 50 mW

Nd:YAG SHG

Dye R6G

Dye DCM

Ti:Sapphire
Fundamental
~ 1 W

DL 870 nm

DL 1240 nm

DL 2300 nm

DL 415 nm

NKT EXR12/20
SuperK Select

Up to 31 bands

Development of new generation scatterometers

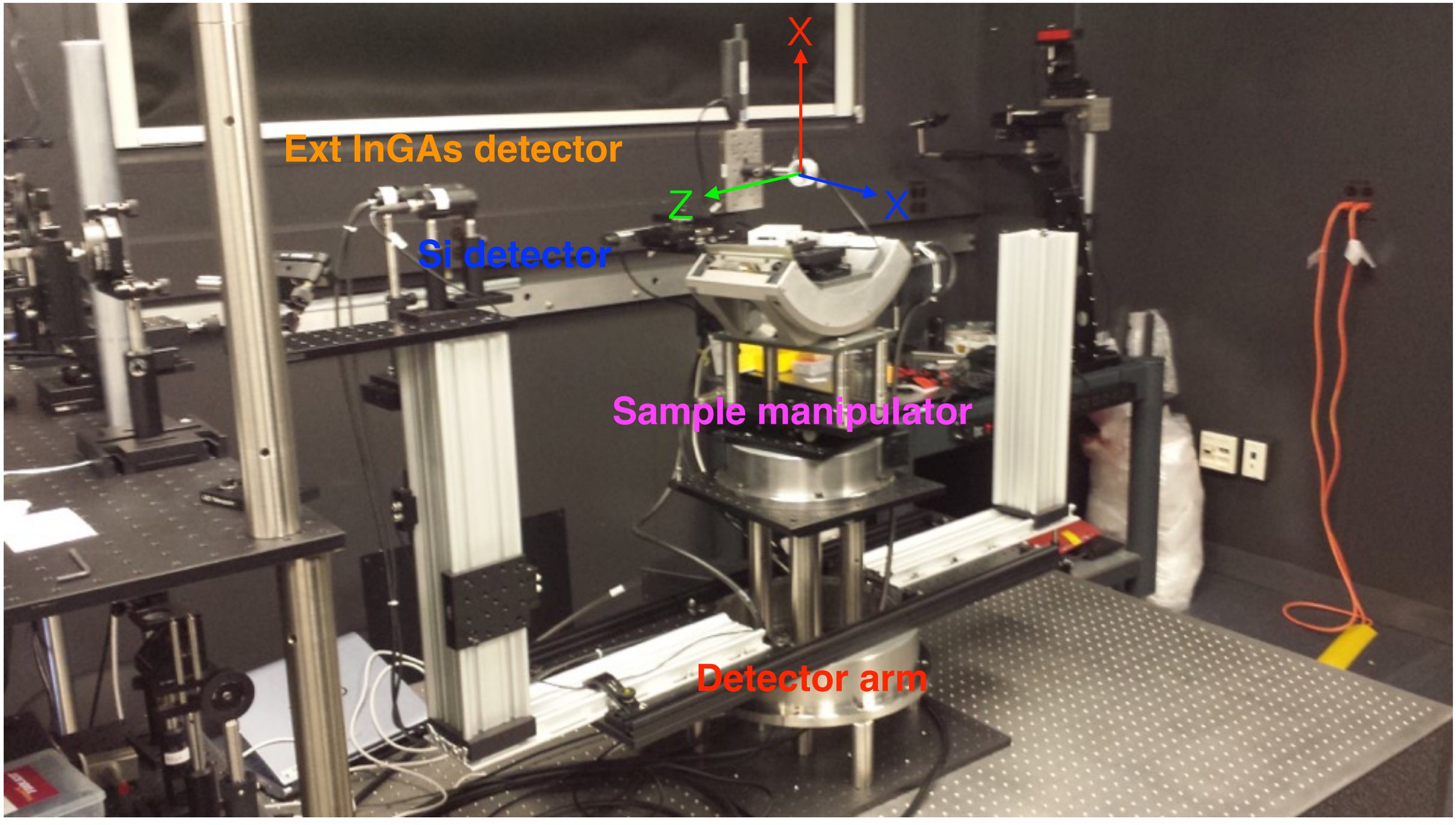
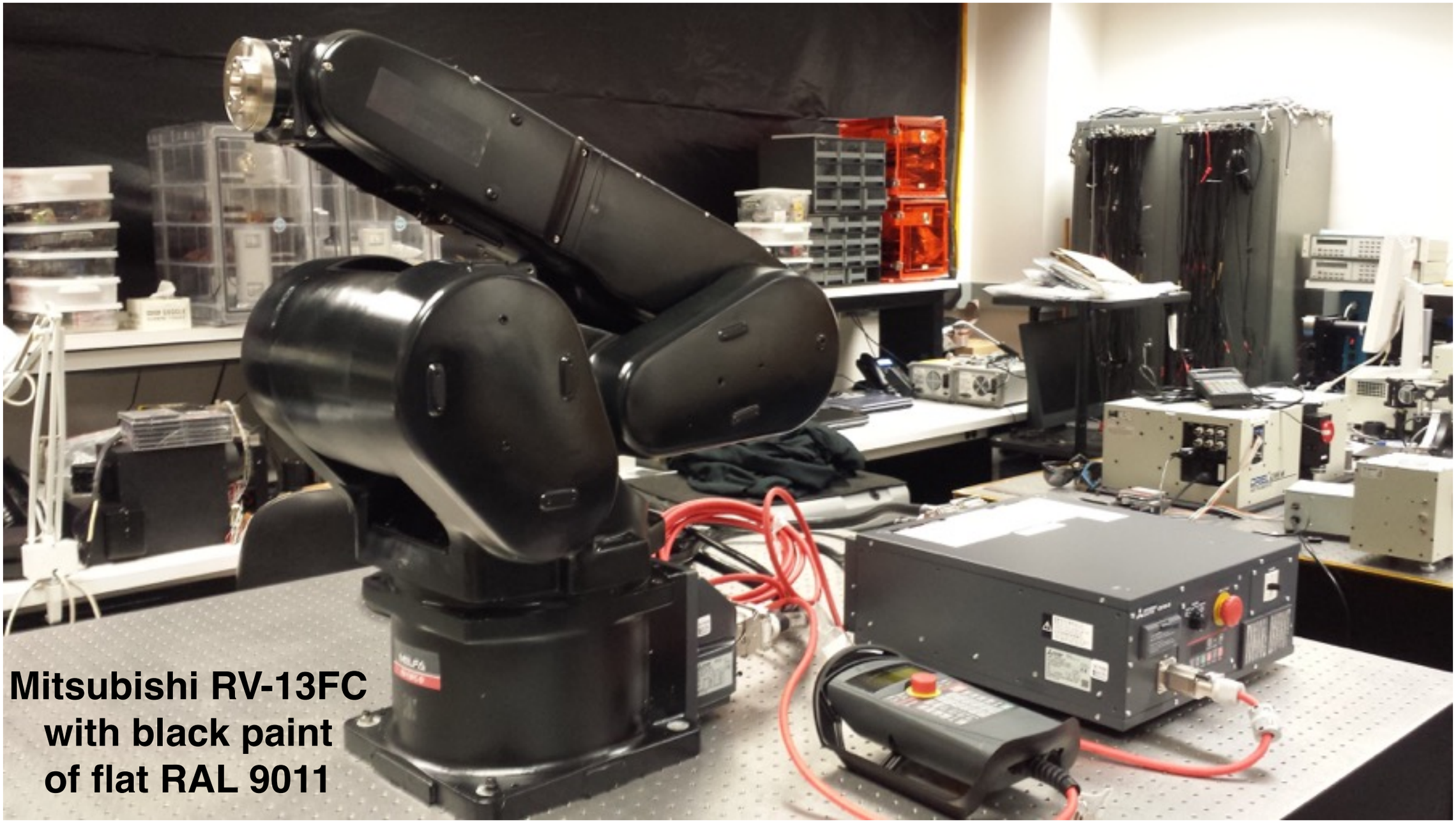
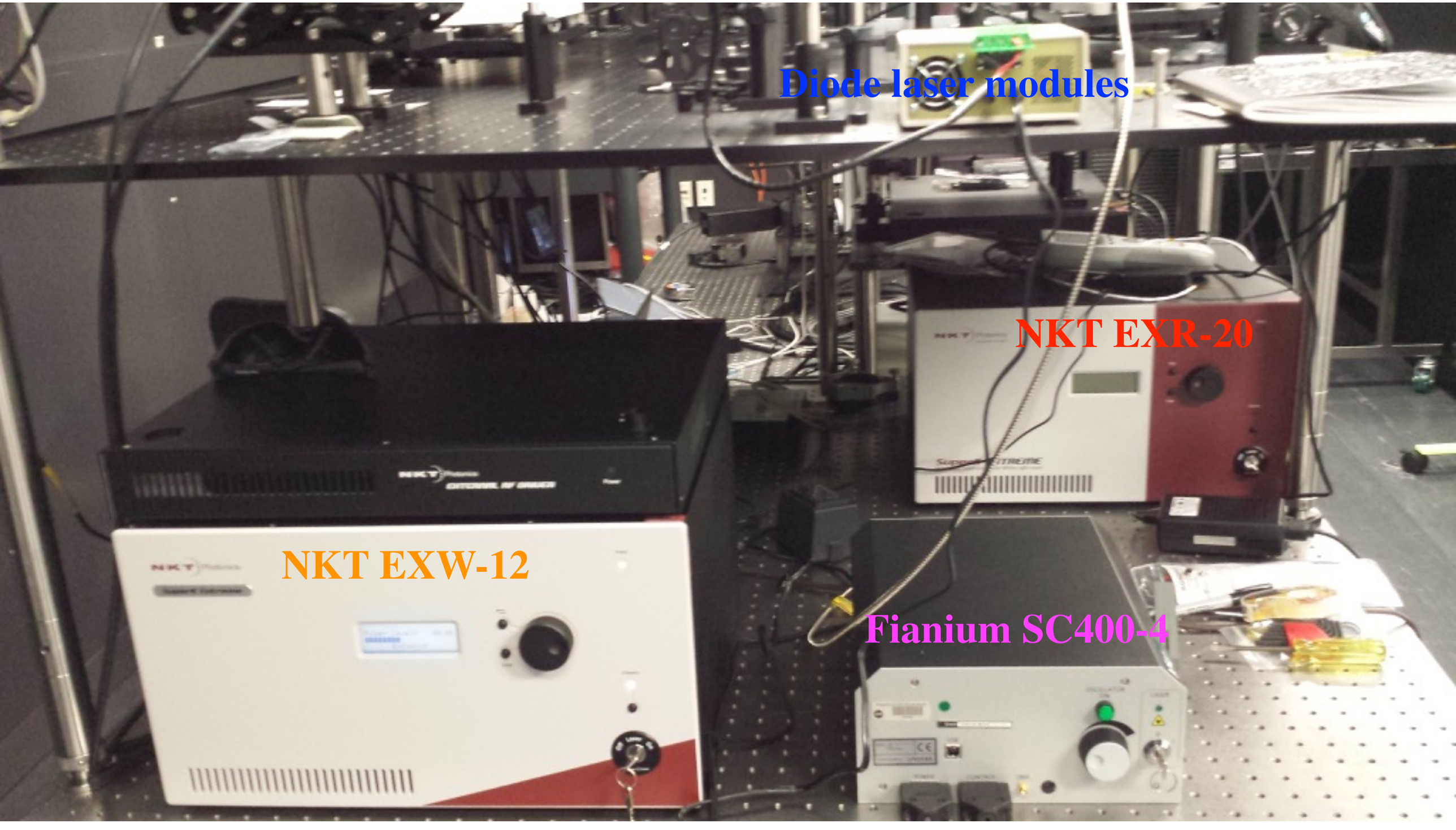


Table Top Goniometer

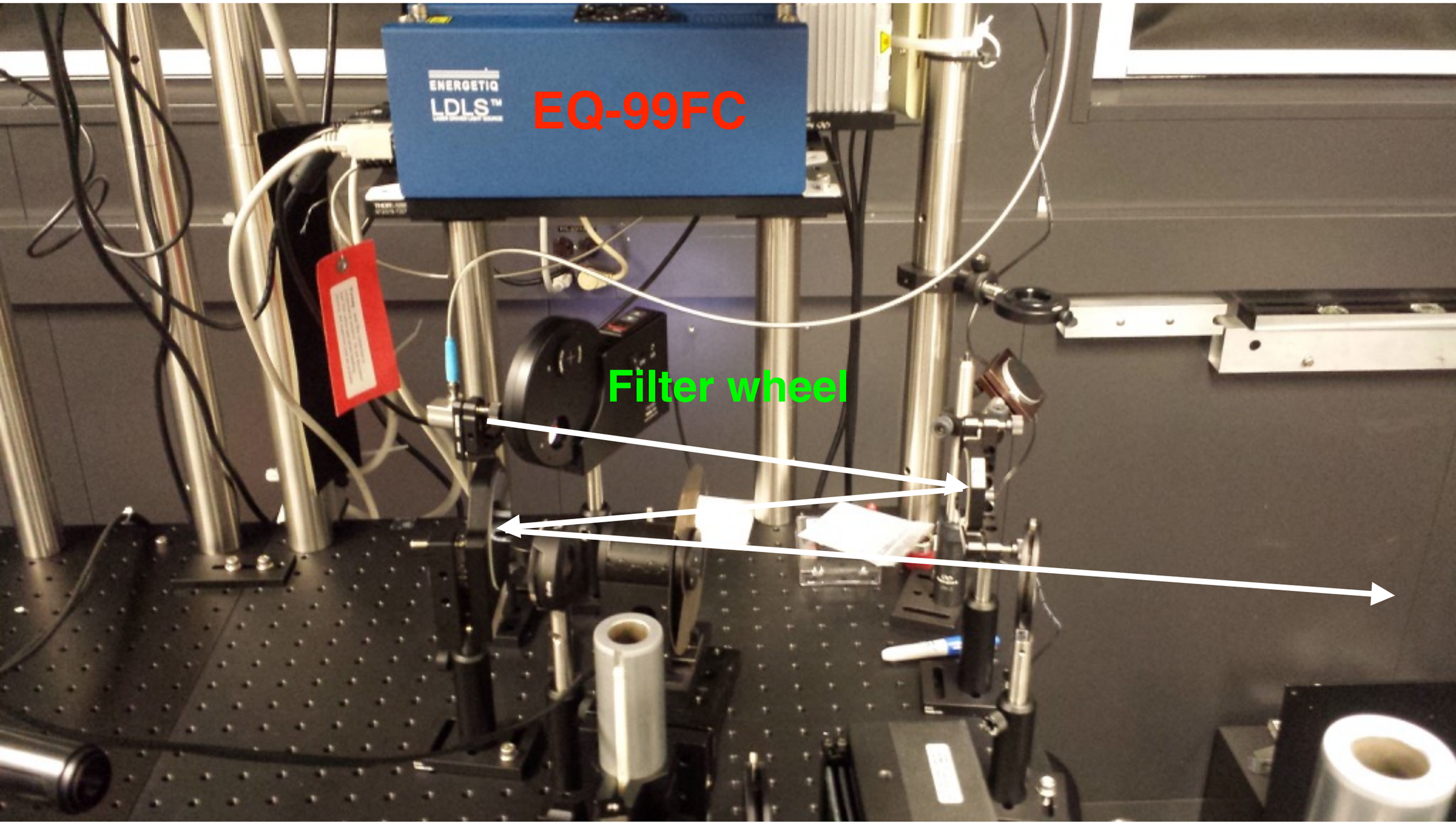
Development of new generation scatterometers



Robot arm based scatterometer


Diode laser modules
NKT EXR-20
NKT EXW-12
Fianium SC400-4

Laser-driven lamp source

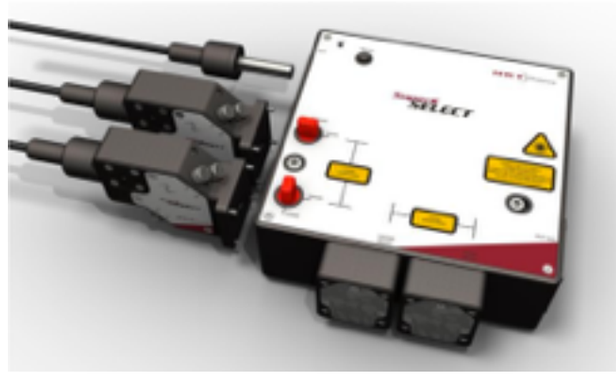


NKT SC laser and Super Select AOTF

Specifications

Number of Tunable Lines	1 – 8 (per AOTF)
Filter Bandwidth* of AOTF (UV-VIS)	1,8 – 8,5nm
Filter Bandwidth* of AOTF (VIS 1x / VIS 4x)	0,5– 1,85nm / 2,5 – 8,5nm
Filter Bandwidth* of AOTF (VIS-nIR)	3,5 – 14nm
Filter Bandwidth* of AOTF (nIR 1 / nIR 2)	1,8 – 5nm / 2,6 – 9,6nm
Filter Bandwidth* of AOTF (IR)	6,4 – 19,8nm
AOTF Deflection Efficiency	> 90 % (1-8 channel operation)
Polarization	Linear
Output Mode	Fiber or free space collimated
Mechanical Shutter	Integrated for both ports
Laser Safety Interlock	Integrated

* Collimated free space output; FWHM bandwidth



The Power Lock options enables you to lock the power output of the SuperK SELECT via a build in photo detector.

Options | Specifications

The full spectrum from any NKT Photonics Supercontinuum system can be covered thanks to two options:

	Tunable Wavelength Range	Channel Spectral Bandwidth
LLTF Contrast VIS	400-1000 nm	<2.5 nm
LLTF Contrast SWIR	1000-2300 nm	<5 nm

Supercontinuum lasers (NKT EXR-12/20, Fianium WL-SC-400-4)

250 nm

EQ99/EQ1500

Xe lamp

QTH Lamp

Diode lasers

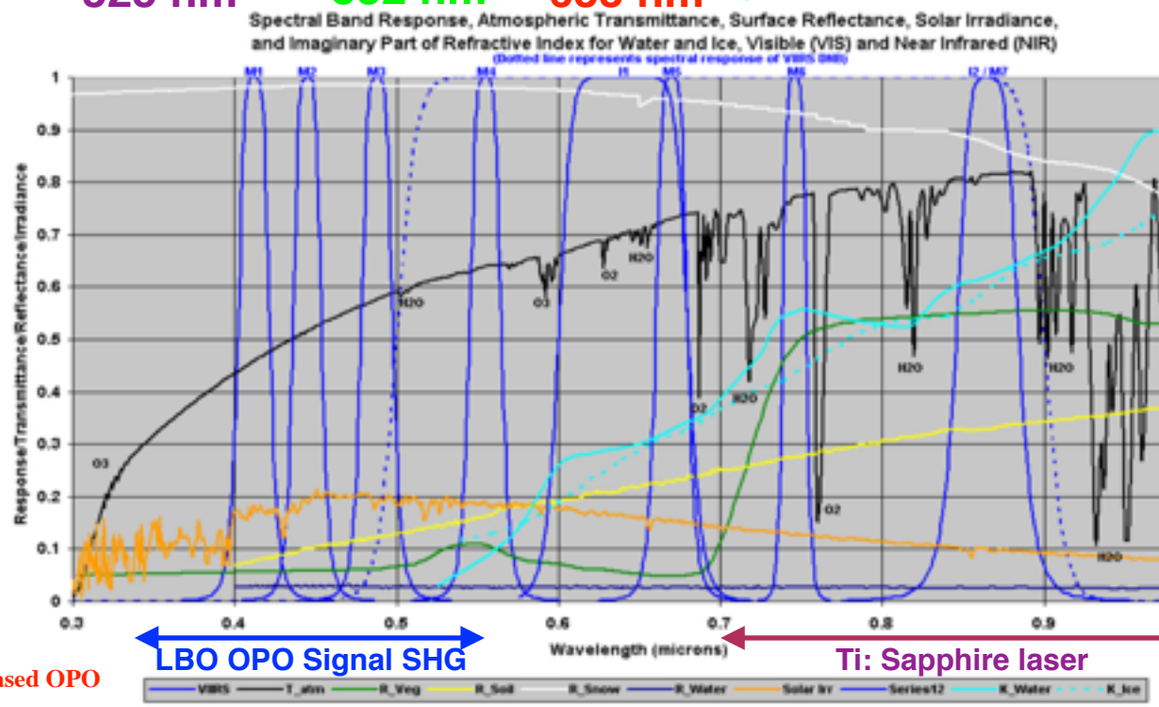
413 nm, 850 nm, 1240 nm, 1550 nm, 2300 nm

HeCd laser 325 nm

Nd:YAG 532 nm

HeNe laser 633 nm

FTIR



LBO OPO Signal SHG

Ti: Sapphire laser

Dye lasers

LBO based OPO

OPO-NIR-SHG: 380-560 nm

OPO-NIR-Idler: 1000-1120 nm, 1200-1900 nm

OPO-SWIR-Idler: 1000-1250 nm

OPO-SWIR-SHG: 500-600 nm

Figure 1: VIIRS Spectral Bands; Visible and Near Infrared

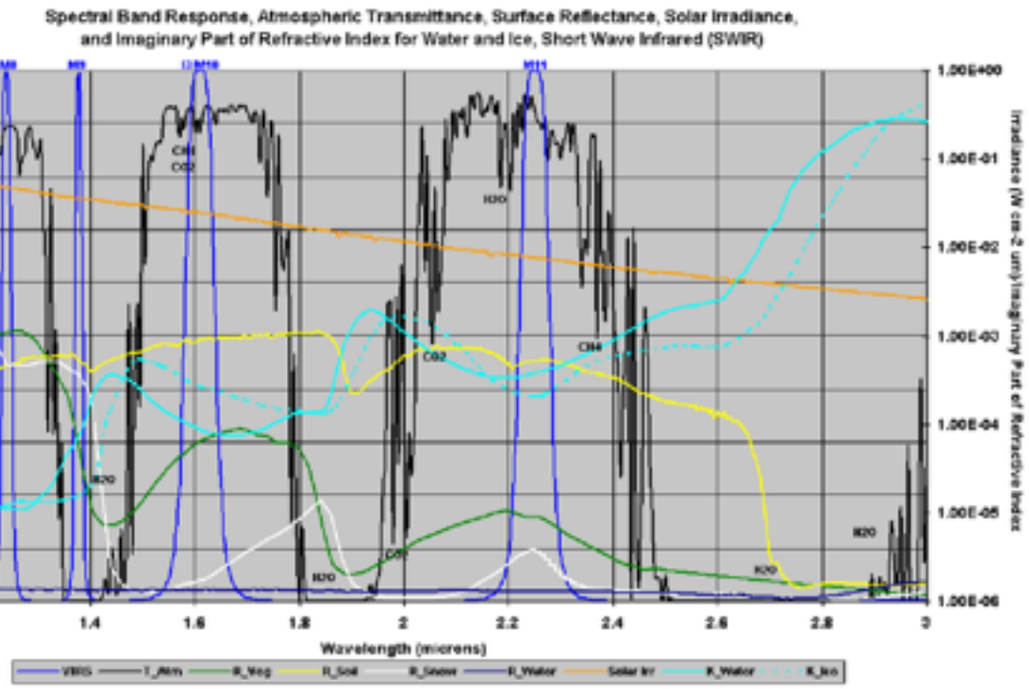
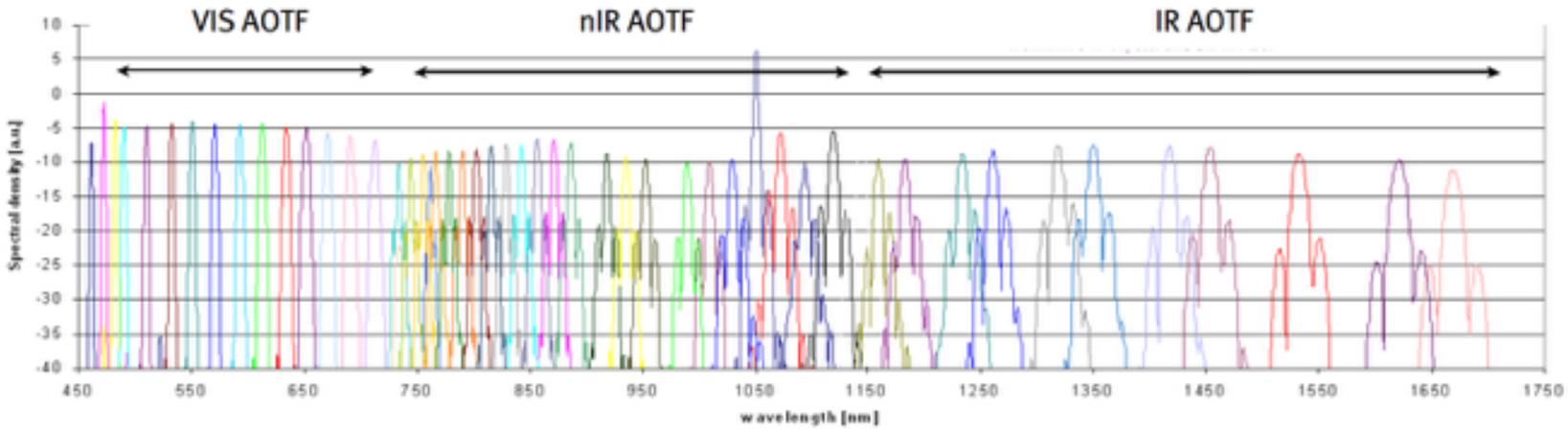


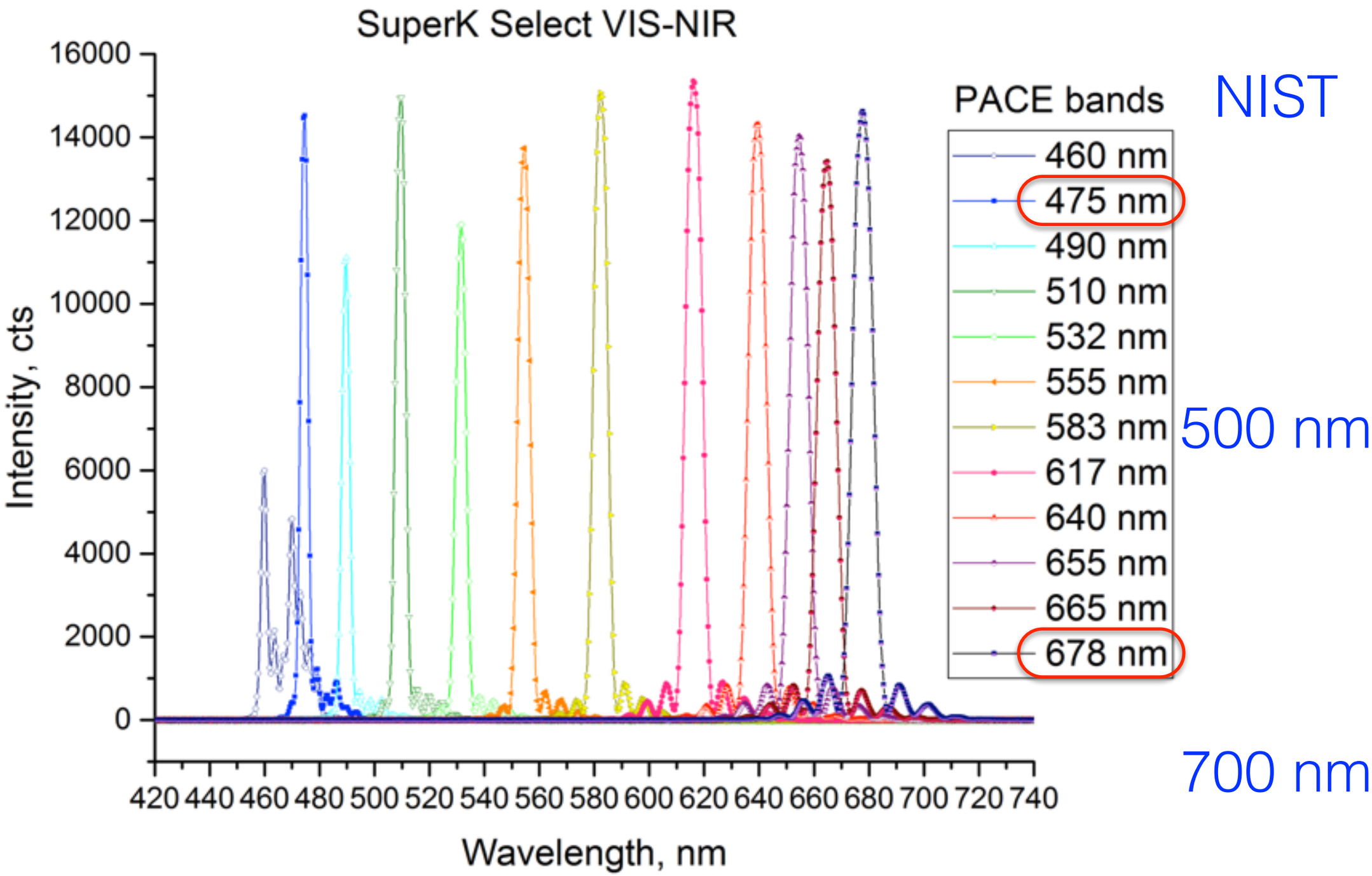
Figure 2: VIIRS Spectral Bands; Shortwave Infrared



SuperK Select

EKSPLA pulsed laser

Wavelength selection

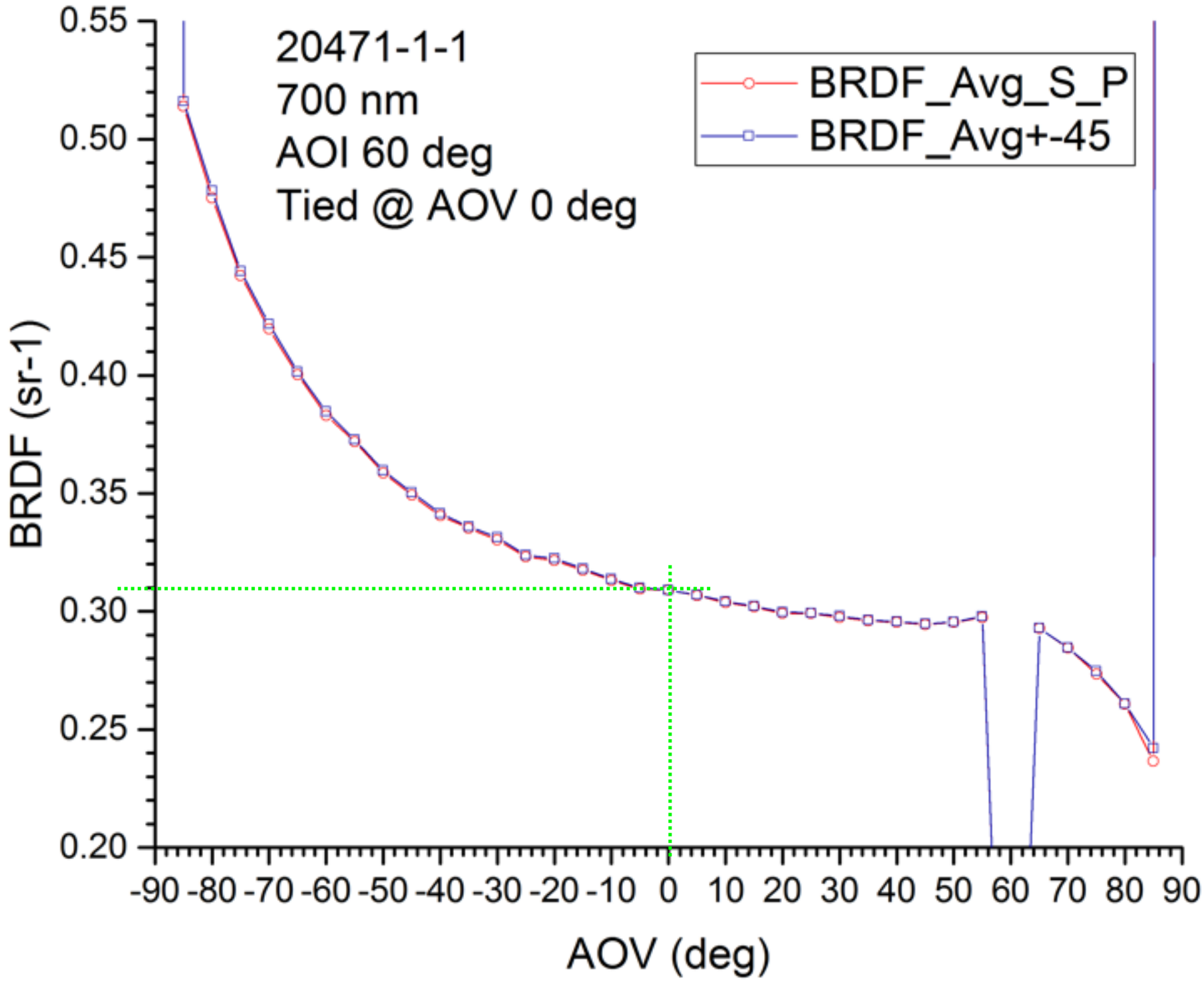


NIST

500 nm

700 nm

NIST Calibrated Spectralon



NIST BRDF data interpolation for Absolute BRDF