New capabilities of diffuser calibration lab at GSFC NASA to support remote sensing instrumentation

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

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The on-orbit calibration with solar diffuser (SD) for the reflective solar band is significantly important for the operation of the satellite sensors, and sensor data record (SDR). Much efforts have been contributed to the pre-launch calibration for the solar diffuser, and its associated components. The BRDF measurement of the SD, and BTDF measurement for its associated components are required at different incident angles due to the solar season and from viewing angles based on the instrument geometry. The new diffuser calibration facility consists of two scatterometer instruments, one is the table-top version, and the other one is the robot-arm based version. The light sources for the new scatterometers are currently equipped with a 20 W supercontinuum fiber laser from 400 nm to 2500 nm, and two laser diode driven plasma lamp sources from 200 nm to 900 nm. The detection systems consist of Si and extended InGaAs detectors with low NEP down to 10^{-15} and 7×10^{-14} W/(Hz)$^{1/2}$, respectively, with/without input integrating sphere for light collection. The development of the table-top scatterometer has reached the final stage for optimization, meanwhile the 6-axis robot-arm has been scheduled to be delivered soon. The light source tests on the spectral output and a short term stability were conducted, and the preliminary results will be presented together with the discussion about the requirements of on-orbit calibration with solar diffuser.

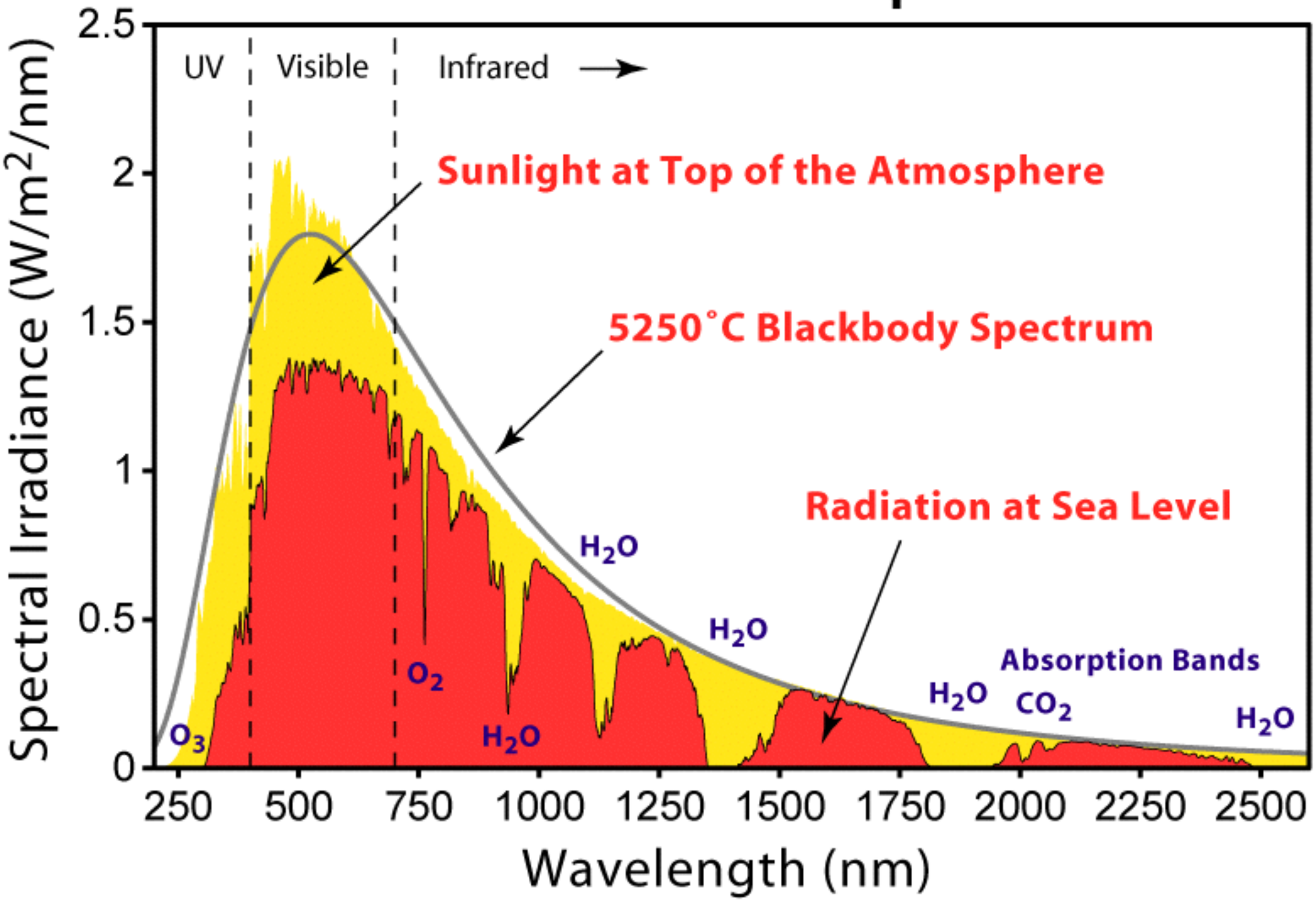
Keywords: BRDF, table-top based scatterometer, robot-arm based scatterometer, reflective solar band, solar diffuser, supercontinuum laser, laser diode driven plasma source, Si detector, and extended InGaAs detector

Outline

1. Motivation and goal
2. Requirement of measurements
3. New scatterometer and key components
4. Status of development
5. Preliminary test results
6. Summary and future work

1. Motivation and goal

Solar Radiation Spectrum



Reflective Solar Band (RSB)

Spectral tri-function automated reference reflectometer (STARR)

Description:

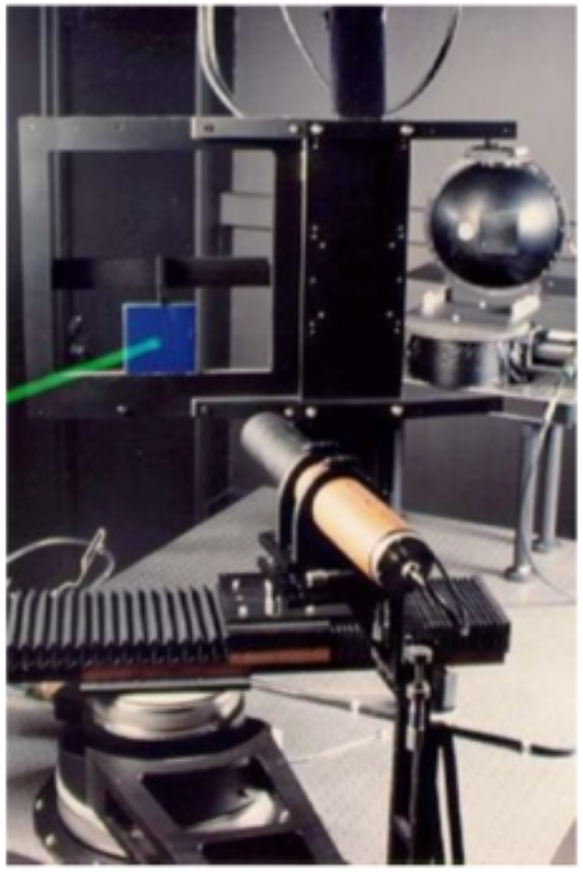
STARR is the national reference instrument for spectral reflectance measurements of spectrally neutral, non-fluorescent samples at room temperature.

The illuminator has two sources, a xenon (Xe) arc lamp and a quartz-tungsten-halogen (QTH) incandescent lamp, order-sorting filters, a shutter, a single-grating monochromator, a parabolic mirror, a chopper, and a polarizer. An in-plane goniometer is used for bi-directional measurements, meaning the sample normal, illumination axis, and receiver axis are all in a horizontal plane. The receiver is attached to the goniometer and has a precision aperture, a lens, and a photodiode detector, either silicon (Si) or extended indium-gallium-arsenic (InGaAs). An integrating sphere is used for directional-hemispherical measurements, and can accommodate Si and extended InGaAs photodiode detectors.

Specifications / Capabilities:

Conditions for reflectance measurements using STARR

	Bi-directional		**Directional-hemispherical**
	Specular	*Diffuse*	
Geometrical			
Illumination Angle	0° to +80°	0° to +80°	6° (specular included) 0° (specular excluded)
Viewing Angle	0° to +80°	0° to +80°	Hemisphere
Sampling Aperture	17 mm	17 mm	25 mm
Spectral			
Wavelength	250 mm to 2500 nm	250 nm to 1100 nm	250 nm to 2500 nm
Bandwidth	14 mm	14 nm	14 nm
Polarization	0° to 90°	0° to 90°	Slight
Sample Size	50 mm to 300 mm	50 mm to 300 mm	50 mm to 300 mm
Measurand			
Quantity	Reflectance	BRDF, Reflectance factor	Reflectance factor
Technique	Absolute	Absolute	Relative to PTFE
Range	0.001 to 1	0.001 to 1	0.001 to 1
Uncertainty (k=2)	0.1% to 0.2%	0.15% to 0.6%	0.15% to 0.6%



Contact

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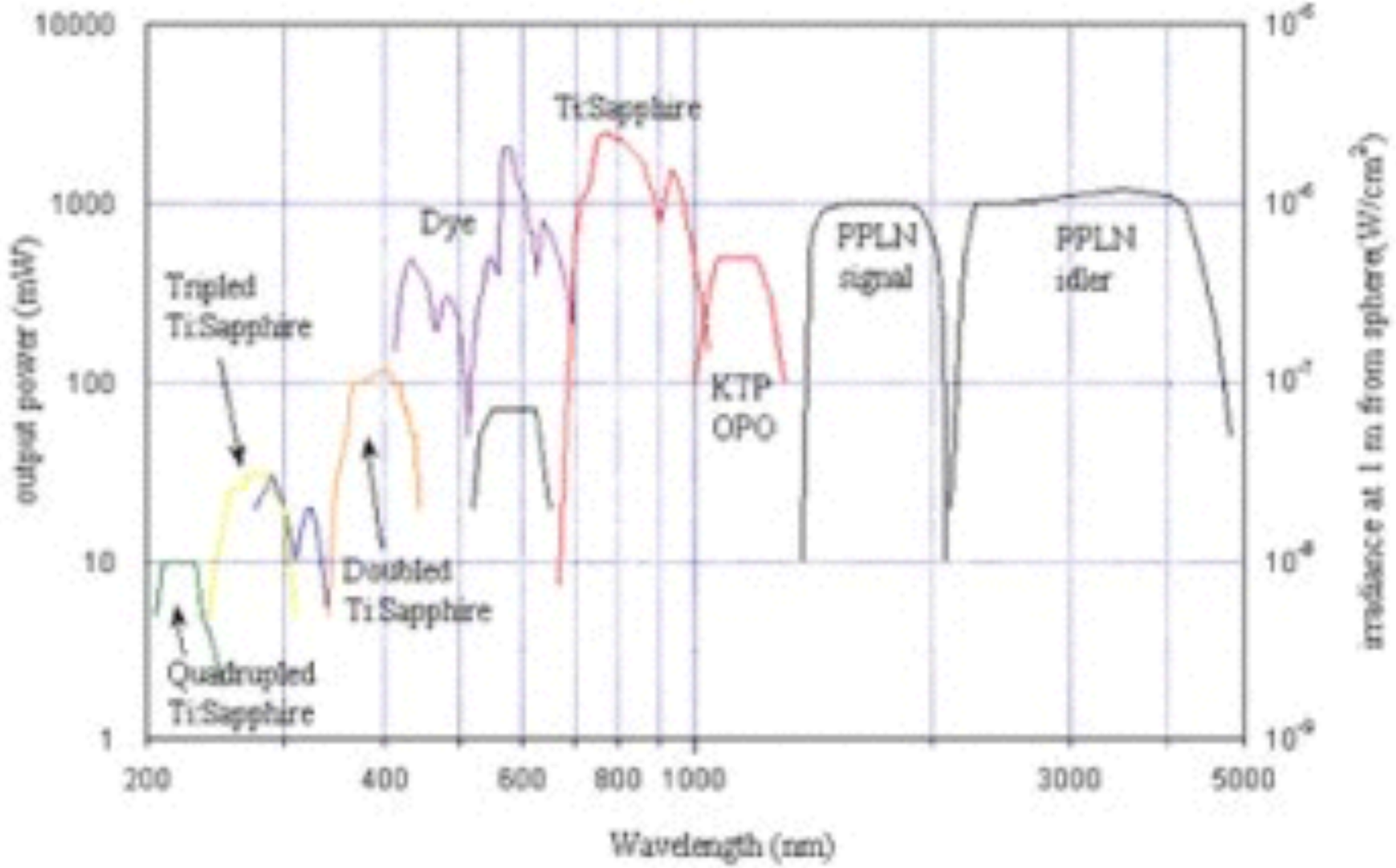
Phone: 301-975-6208
Email: ccooksey@nist.gov
Address:
100 Bureau Drive, M/S 8442
Gaithersburg, MD 20899-8442

Spectral range, and out-of-plane capability

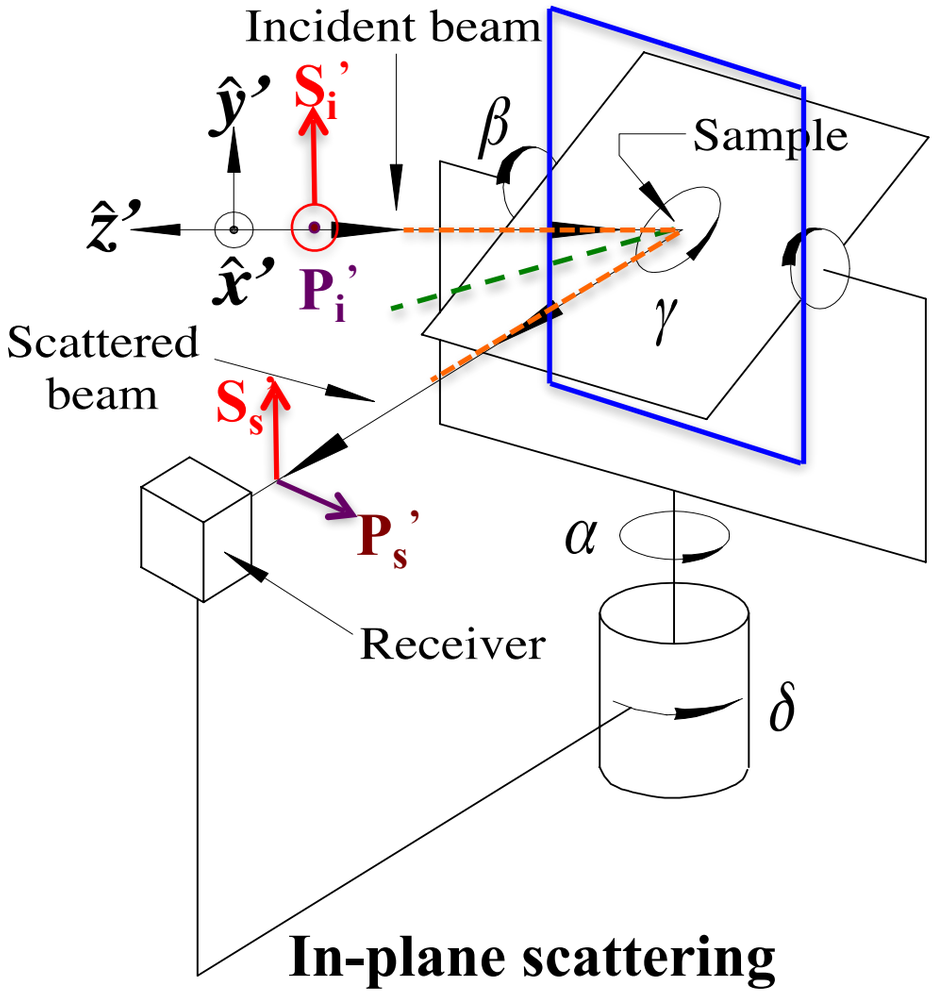


OPO tunable laser

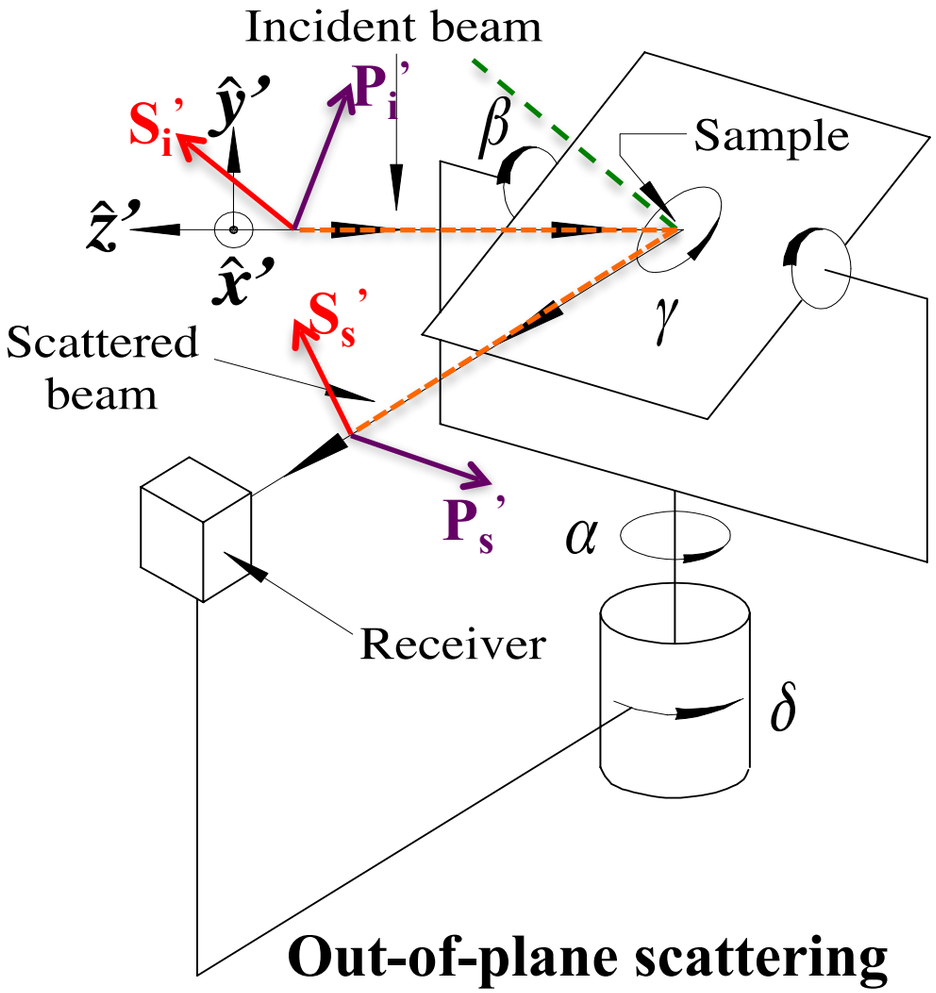
2. Requirement of measurements

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.

Polarimetric measurement of BRDF



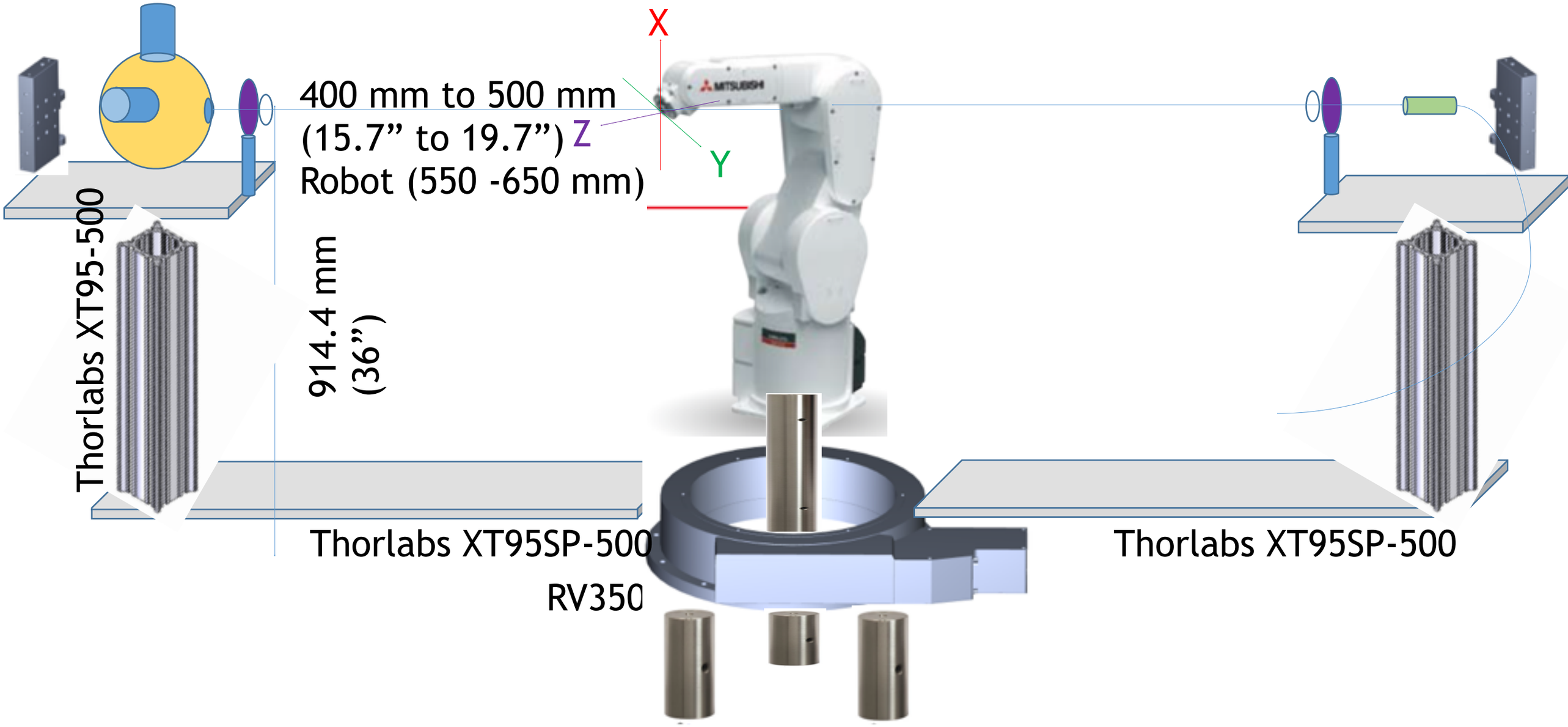
In-plane scattering



Out-of-plane scattering

3. New scatterometer and key components

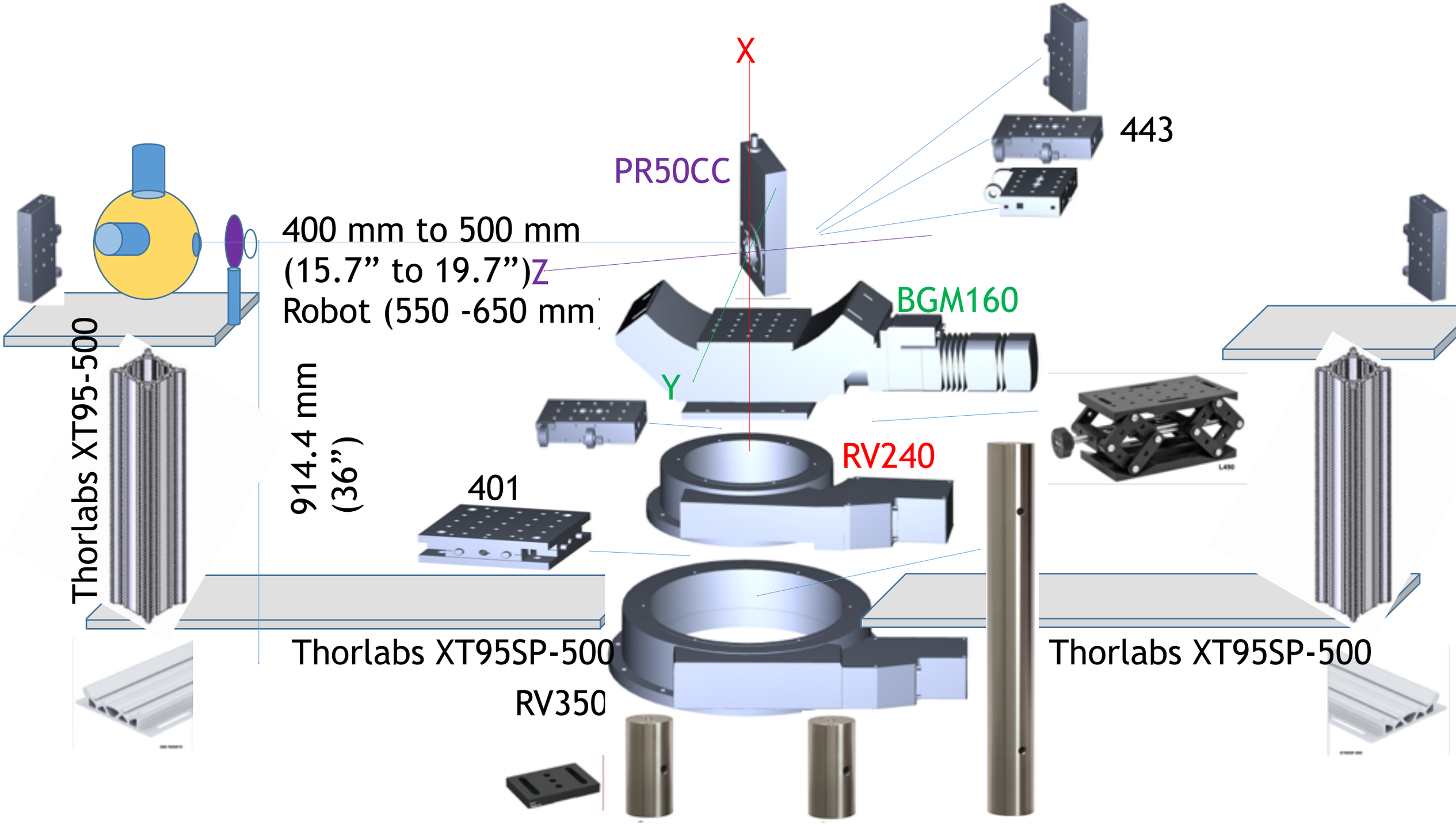
1. Robot arm based Scatterometer



Robot arm floor mount

Detector arm floor mount

2. Table top goniometer

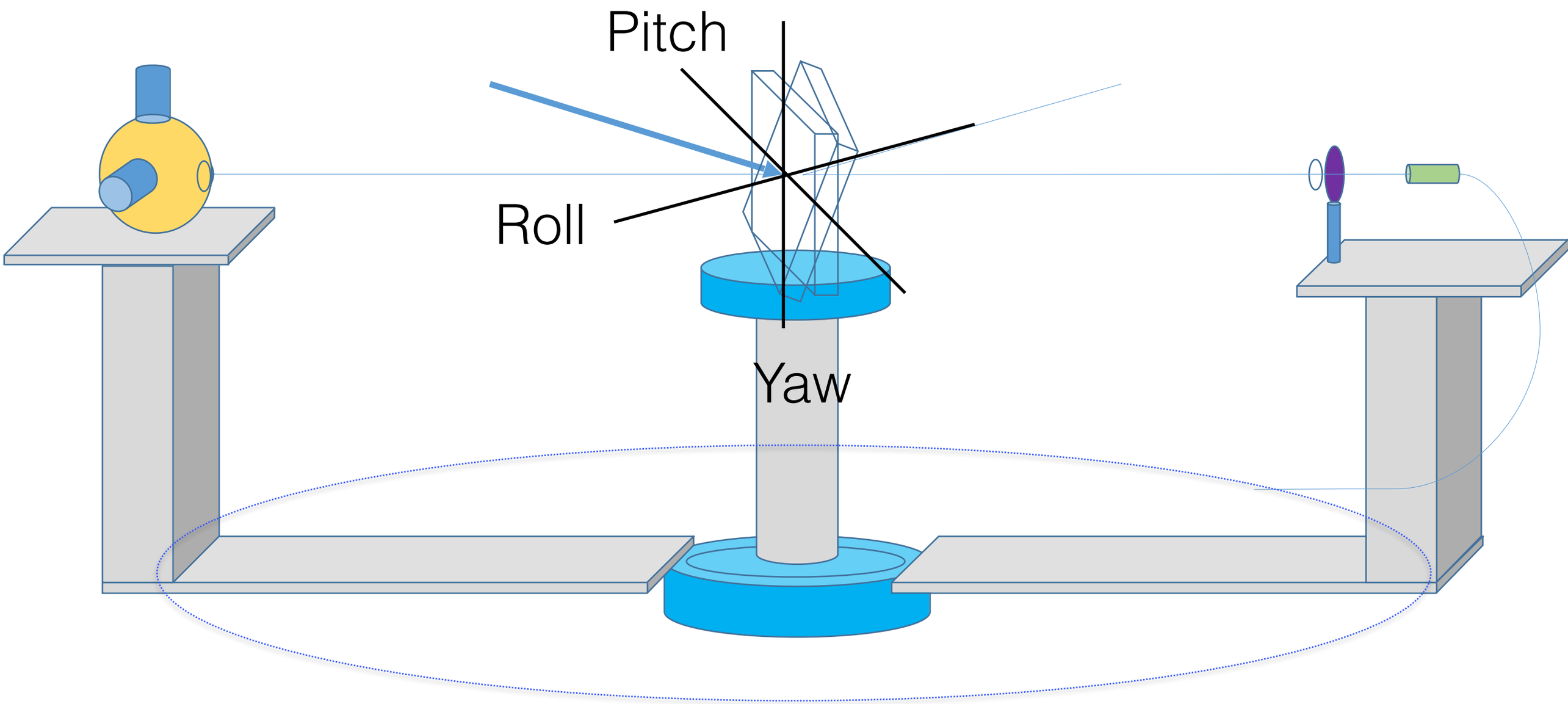


Detector arm floor mount

Goniometer floor mount

Methodology

Incident light fixed
Sample manipulation → in-plane/out-of-plane BRDF
In-plane detection



Technical specifications of goniometer

Incident angle: ±85°

Sample manipulation
Yaw: ±90°
Pitch: ±90°
Roll: ±180°

Detection angle: ±180°

Accuracy: 0.01°

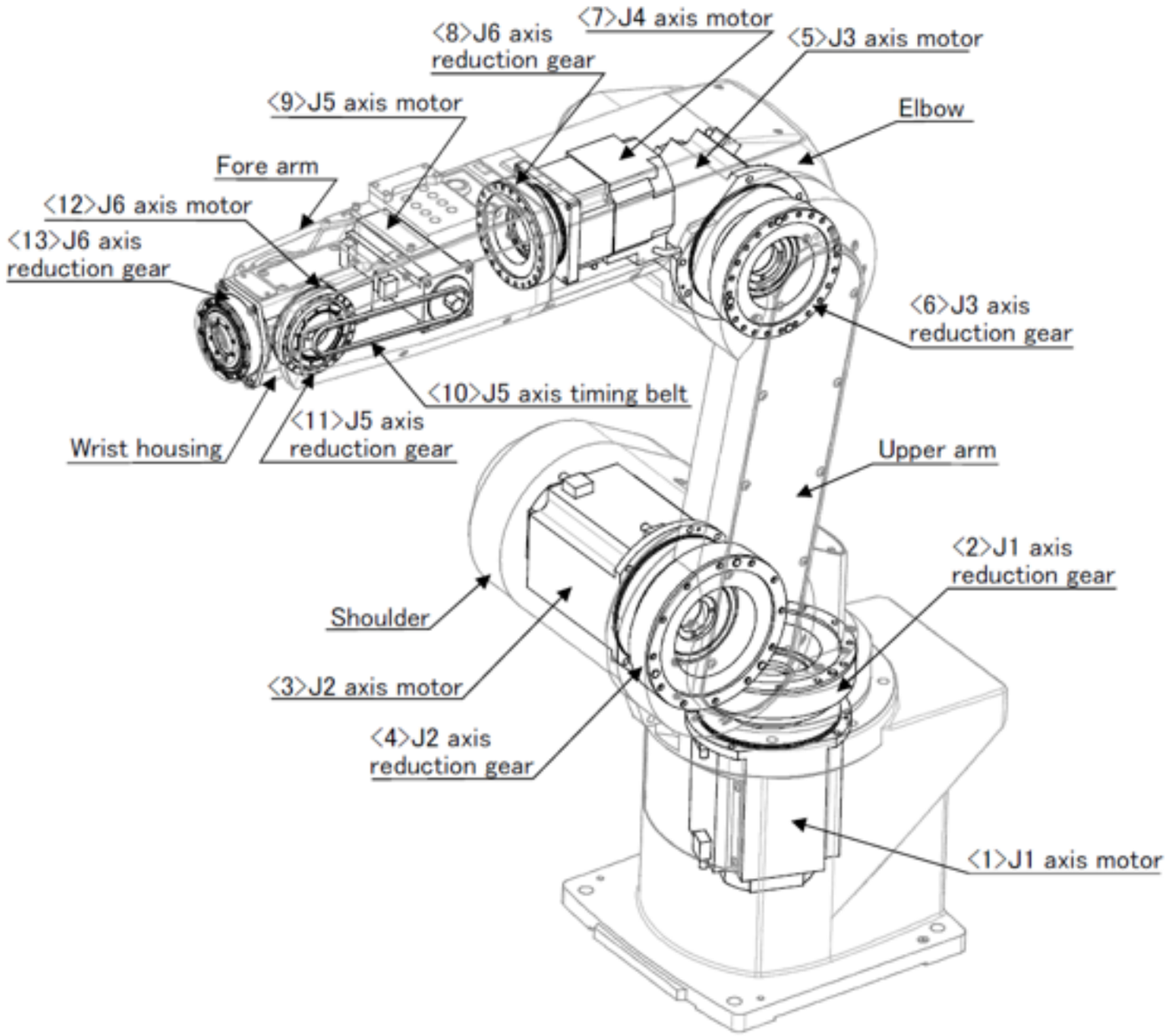


Fig 5-2 : Outline structure of robot arm

Specifications

*2: Limits on the operating range for the front part: When the J1-axis angle is inside the range of J1 ≥ +130° or J1 ≤ -140°, the operating range of the J2-axis is limited to -90° ≤ J2 ≤ +130°.
*3: Make sure to leave enough space open for cable connections between devices.
*4: Specify a thread engagement length of 10 to 9 mm.

Type		Unit	RV-13F(M)(C)	RV-13FL(M)(C)
Machine class			Standard/ Oil mist/ Clean	
Protection degree			IP40 (standard)/ IP67 (oil mist) *1/ ISOclass3 *7	
Installation			Floor type, ceiling type, (wall-mounted type *2)	
Structure			Vertical, multiple-joint type	
Degrees of freedom			6	
Drive system			AC servo motor	
Position detection method			Absolute encoder	
Maximum load capacity		kg	Maximum: 13 (Rated: 12) *8	
Arm length	NO1 arm	mm	410 + 550	565 + 690
Maximum reach radius		mm	1094	1388
Operating range	J1	deg	380(±190)	
	J2		240 (-90 to +150)	
	J3		167.5 (-10 to +157.5)	
	J4		400 (±200)	
	J5		240 (-120 to +120)	
	J6		720 (±360)	
Maximum speed	J1	deg/sec	290	234
	J2		234	164
	J3		312	219
	J4		375	375
	J5		375	375
	J6		720	720
Maximum composite speed *3		mm/sec	10450	9700
Cycle time *4		sec	0.53	0.68
Position repeatability		mm	±0.05	
Ambient temperature		°C	0 to 40	
Mass		kg	120	130
Tolerable moment	J4	Nm	19.3	
	J5		19.3	
	J6		11	
Tolerable amount of inertia	J4	kgm^2	0.47	
	J5		0.47	
	J6		0.14	
Tool wiring			Hand: 8 input points/8 output points (20 pins total) Serial signal cable for parallel I/O (2-pin + 2-pin power line) LAN X 1 <100 BASE-TX> (8-pin)) *5	
Tool pneumatic pipes			Primary: ϕ6 x 2 Secondary: ϕ6 x 8, ϕ4 x 4 (With wrist attached)	
Machine cable			7m (connector on both ends)	
Connected controller			CR750, CR751 (CR750: Japan, Europe, U.S.; CR751: Asia)	

*1: Please contact Mitsubishi Electric dealer since the environmental resistance may not be secured depending on the characteristics of oil you use.
*2: The wall-mounted specification is a custom specification where the operating range of the J1-axis is limited.
*3: This is the value at the surface of the mechanical interface when all axes are composited.
*4: The cycle time is based on back-and-forth movement over a vertical distance of 25 mm and horizontal distance of 300 mm when the load is 5 kg.
*5: Can also be used as a spare line (0.13 sq. mm, 4-pair cable) for conventional models. Provided up to the inside of the forearm.
*6: Select either controller according to your application. CR751-D: Standalone type, CR751-Q: iQ Platform compatible type.
*7: Preservation of cleanliness levels depends on conditions of a downstream flow of 0.3 m/s in the clean room and internal robot suctioning. A φ8-mm coupler for suctioning is provided at the back of the base.
*8: The maximum load capacity indicates the maximum payload when the mechanical interface is facing downward (+10° to the perpendicular).

Light sources

Light sources: Xenon, Laser-induced plasma lamp (D2 lamp)
Monochromater-based lamp source system , focus on 230 nm to 1000 nm first, Si detector
Requirement of power (1 mW), and stability (<1%)

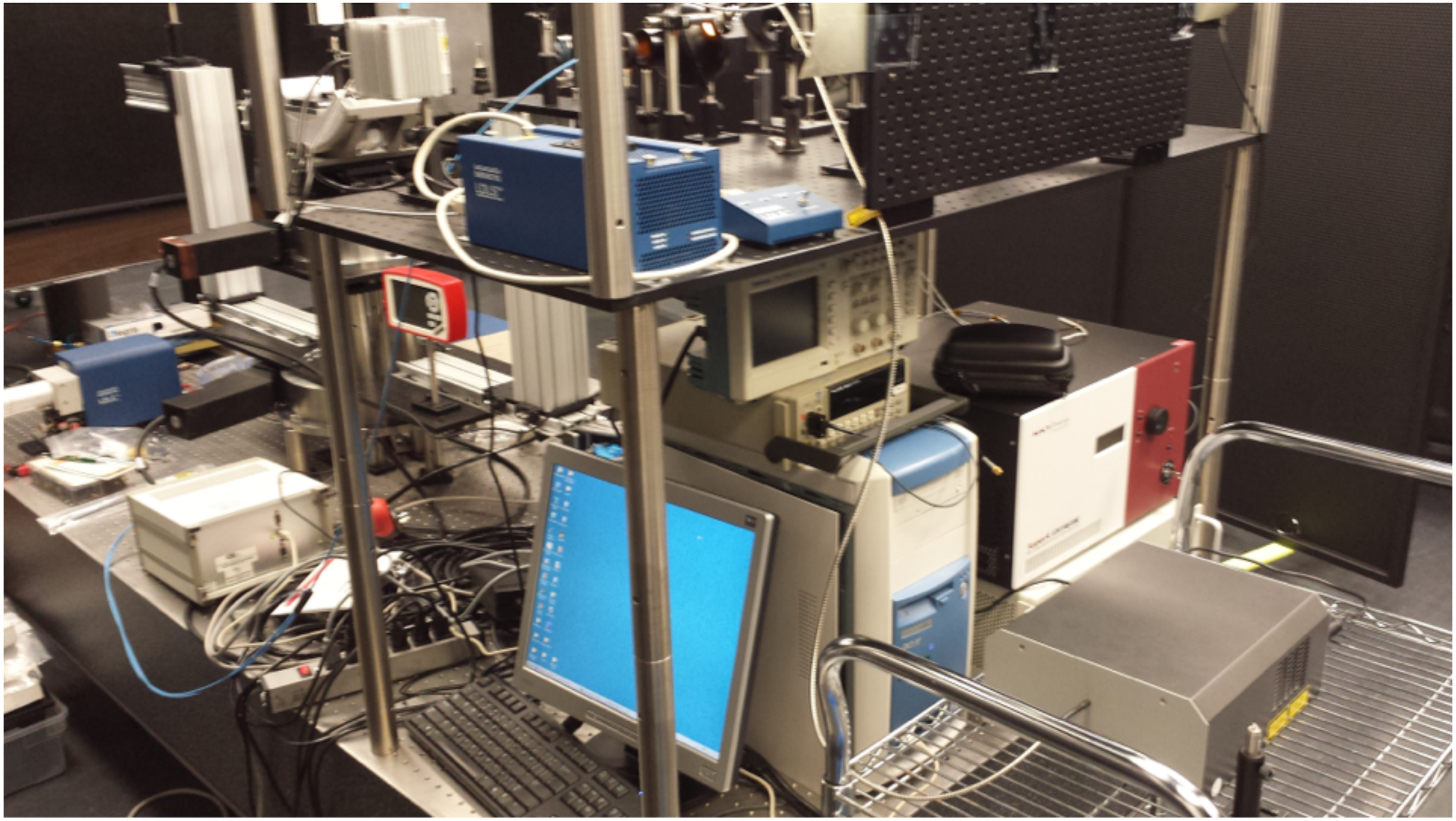
Design: Xenon – input optics – monochromator – spatial filter – monitor/polarization – sample

Test plan:
1. Power stability: Xe lamp, Out of the monochromator-based system (full scan repeated 10 times, or selected wavelengths)
2. Relative spectrum (Output power as a function of wavelength)
3. Power stability with feedback (repeat 1, 2)

Light sources: MIRA/MIRA OPO Laser, NKT SC Laser
Monochromater-based laser source system , 400 nm to 1000 nm, Si & Ext InGaAs detectors
Requirement of power (1 mW), and stability (<1%)

Design: Xenon – input optics – monochromator – spatial filter – monitor/polarization – sample

Test plan:
1. Power stability: Laser, Out of the monochromator-based system (full scan repeated 10 times for SC, or selected wavelengths)
2. Spectral stability
3. Power stability with feedback (repeat 1, 2)



Detectors

Gain	10^{10} to 10^{4} volts/amp
Range	Eight decades automatic or manual dial control
Output	0 to 10 VDC for each gain setting
Linearity	<0.25% non-linearity for all ranges
Temperature Variation	<5 ppm (parts -per-million) per degree Celsius
Noise	<20 microvolts on the 10^{10} range
Frequency Roll –Off	<10 Hz on 10_{10} range for output >1 volt
Length (Amplifier)	4.15 inches (10.5 cm)
Diameter (Amplifier)	2.5 inches (6.4 cm)
Length (TE Cooler control box)	12 inches (30.5 cm)
Width (TE Cooler control box)	11.3 inches (28.7 cm)
Height (TE Cooler control box)	4.5 inches (11.4 cm)
Temperature Stability	Short term (1 hr.) <0.001 °C, long term (24 hr.) <0.003 °C
Bipolar Output Current	+ 1.5 amp max
Maximum TEC Output Power	12 watts
Power	100-240 VAC, 50-60 Hz

About Gamma Scientific

With over 80 years of experience in developing light measuremeni instruments, Gamma Scientific is trusted by the world's leading organizations to provide accurate results.

Based in San Diego, Gamma Scientific manufactures laboratory grade spectroradiometers, spectrometers, spectrophotometers and integrating spheres.

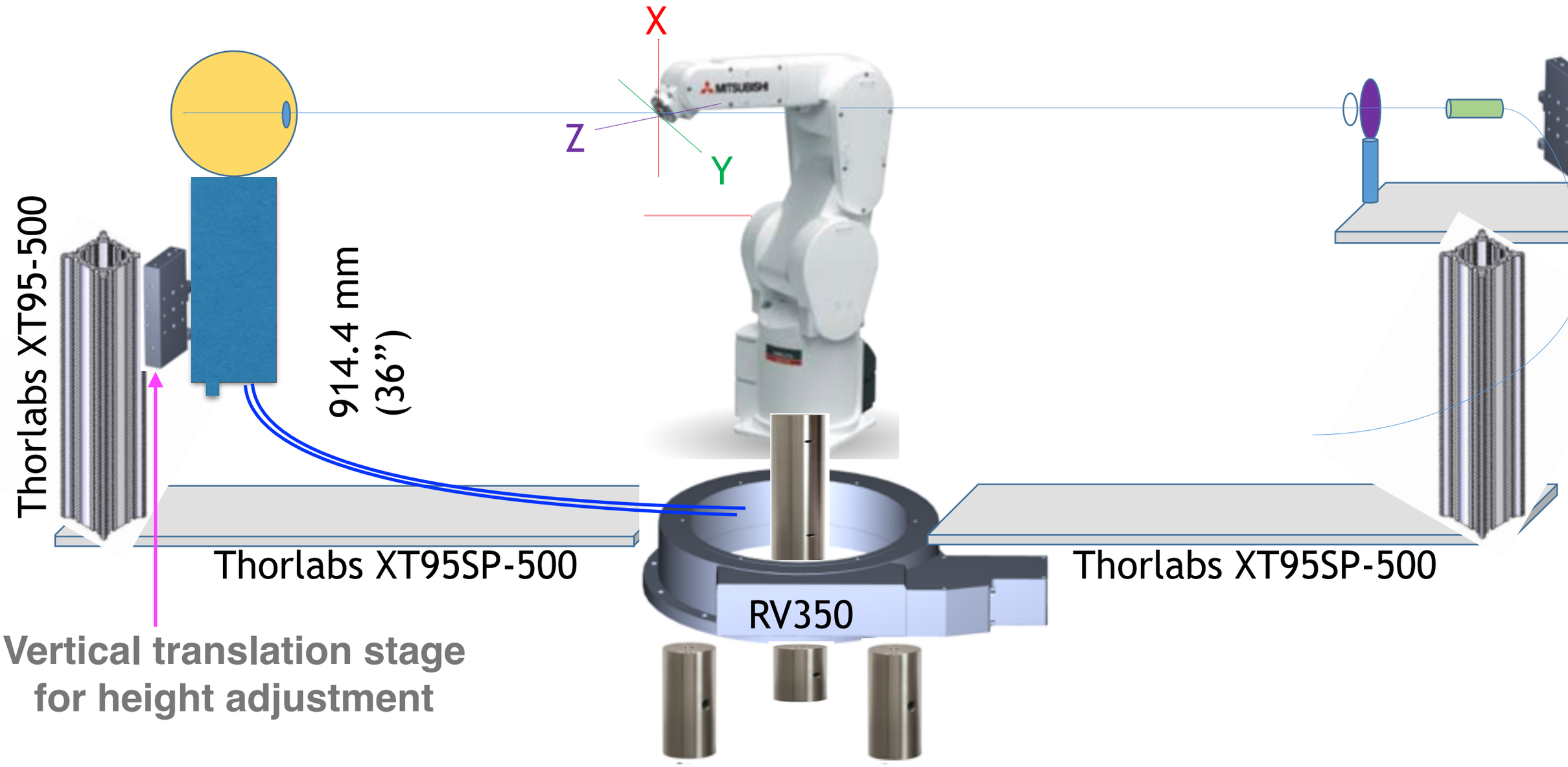
Gamma Scientific also operates an ISO 17025, NVLAP accredited laboratory performing ENERGY STAR, LM-79 and LM-80 tests for LEDs.

About UDT Instruments

Features

- Temperature stabilized silicon and InGaAs detectors available covering 200 – 2600 nm
- Temperature stabilized correction filters available
- High accuracy photopic correction f1'~0.8%
- ANVIS compatibility filters and lenses
- High sensitivity down to 10-15 Watts or 10-8 Lux
- 8 decades of dynamic range
- 0-to-10 volt output for each decade
- RS-232 computer control

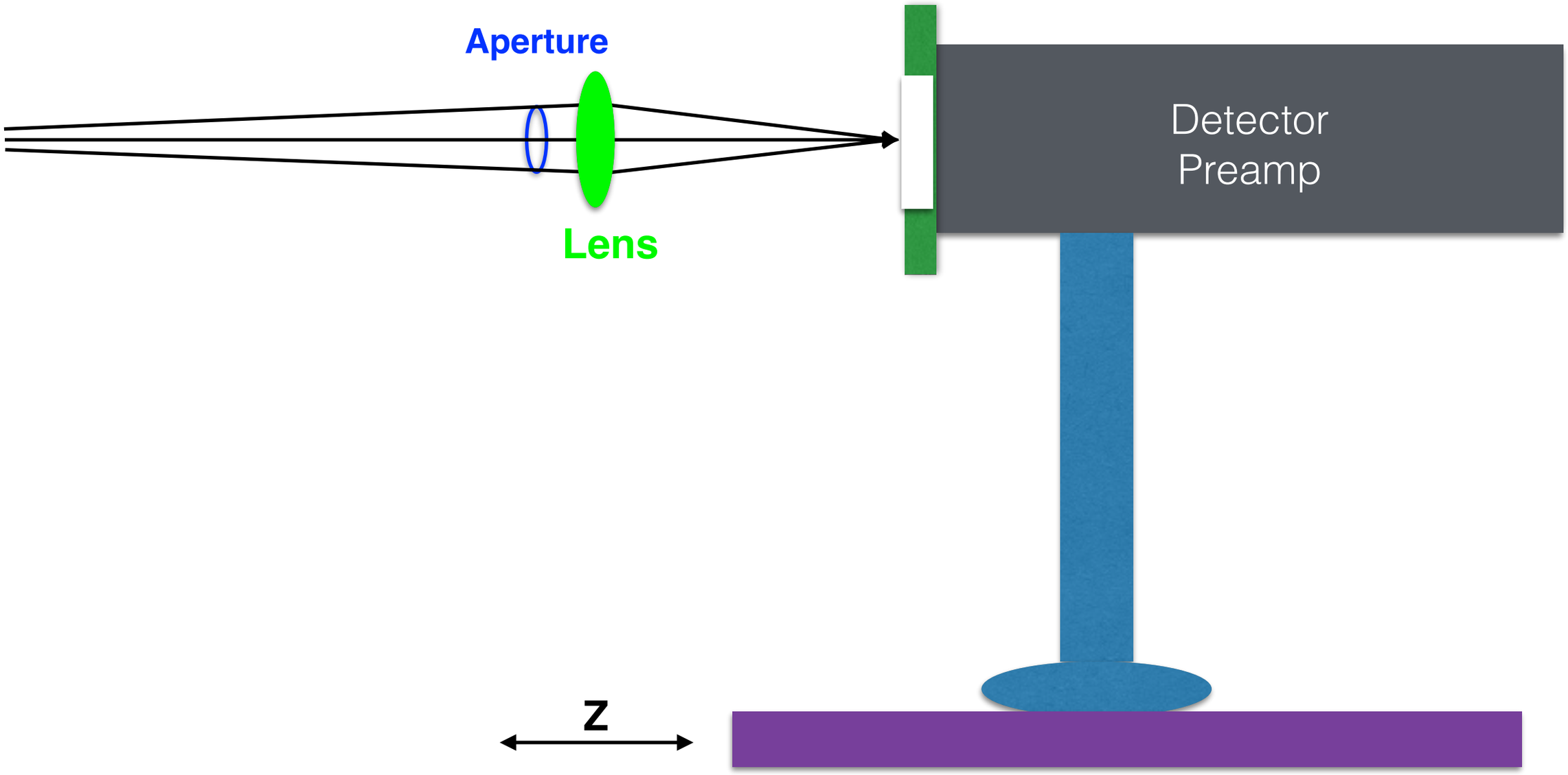
Robot-based Scatterometer



Robot arm floor mount

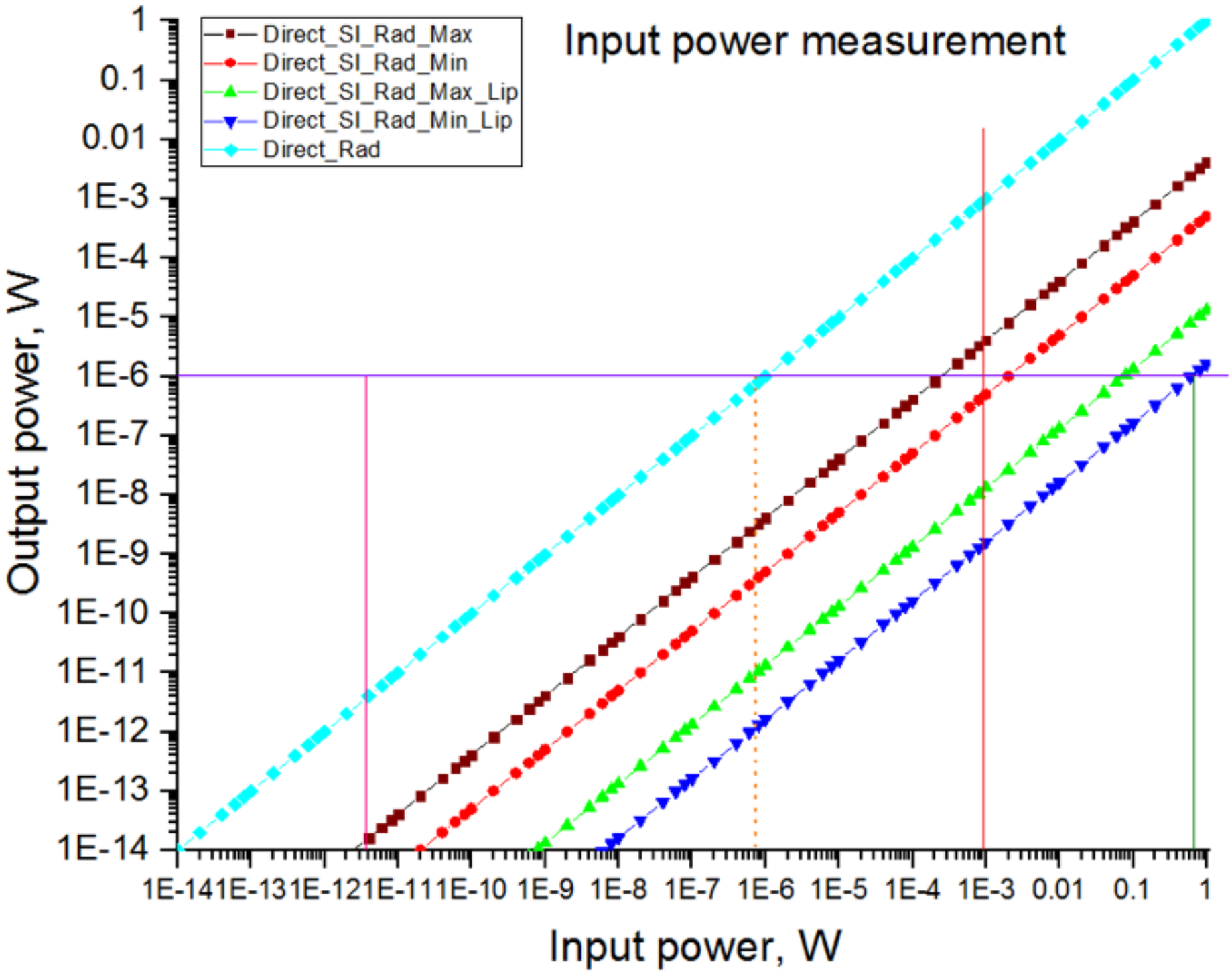
Detector arm floor mount

Receiver geometry

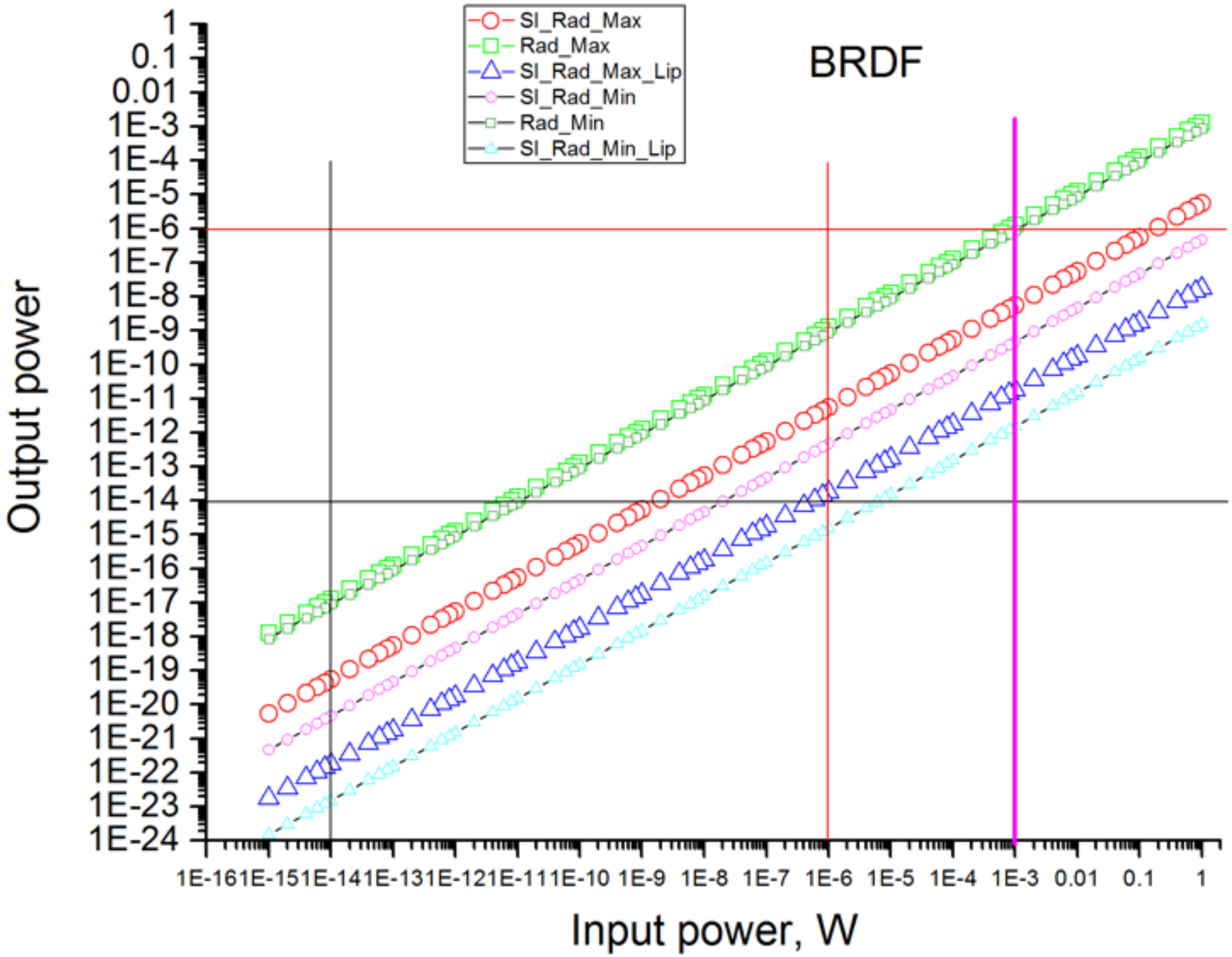


Translation stage in z direction

Signal level evaluation

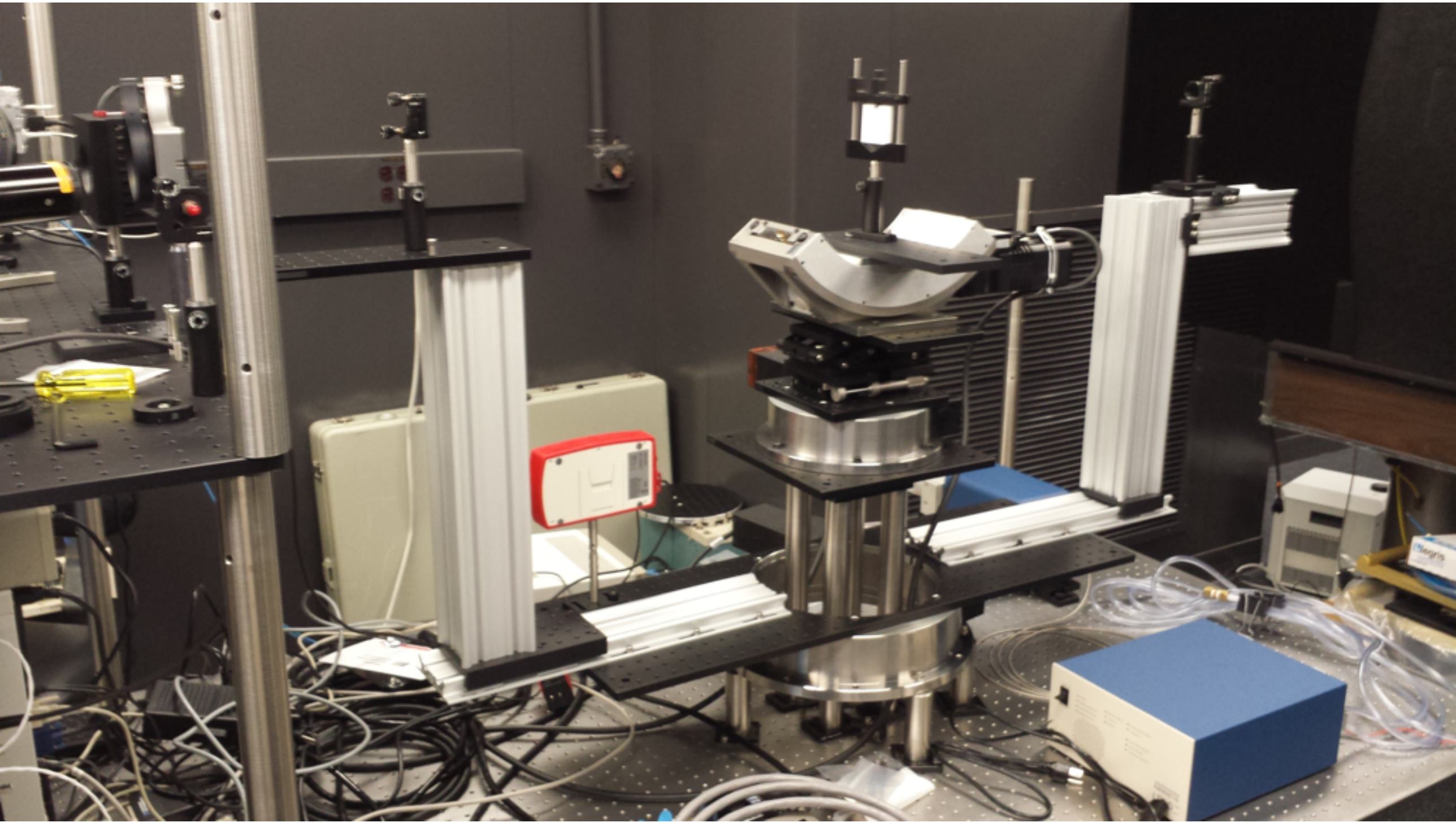


Signal level evaluation

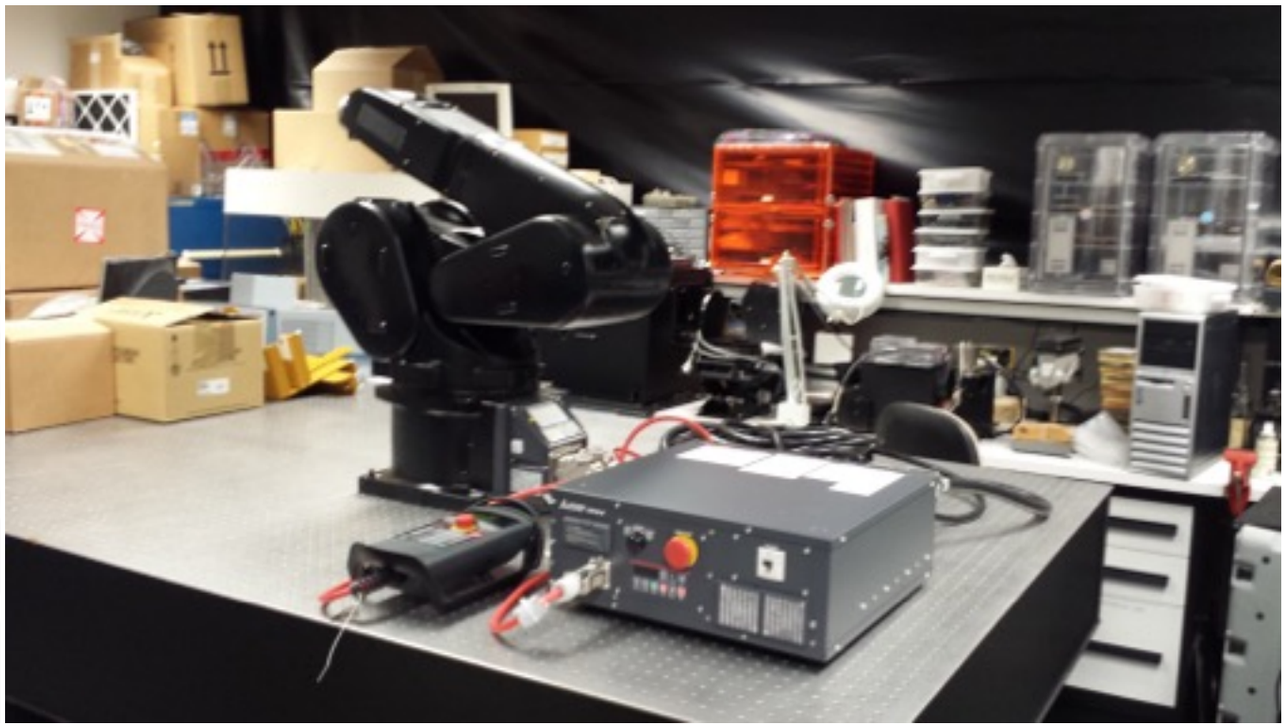


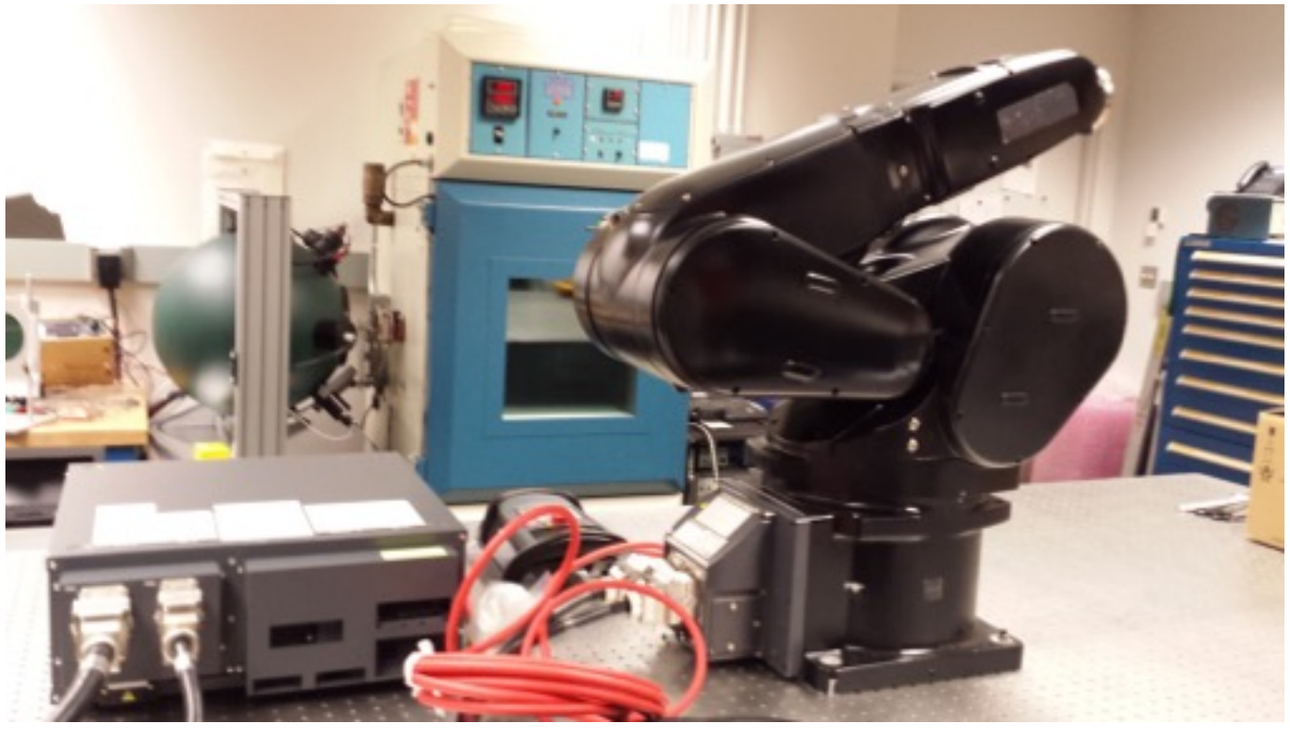
4. Status of development

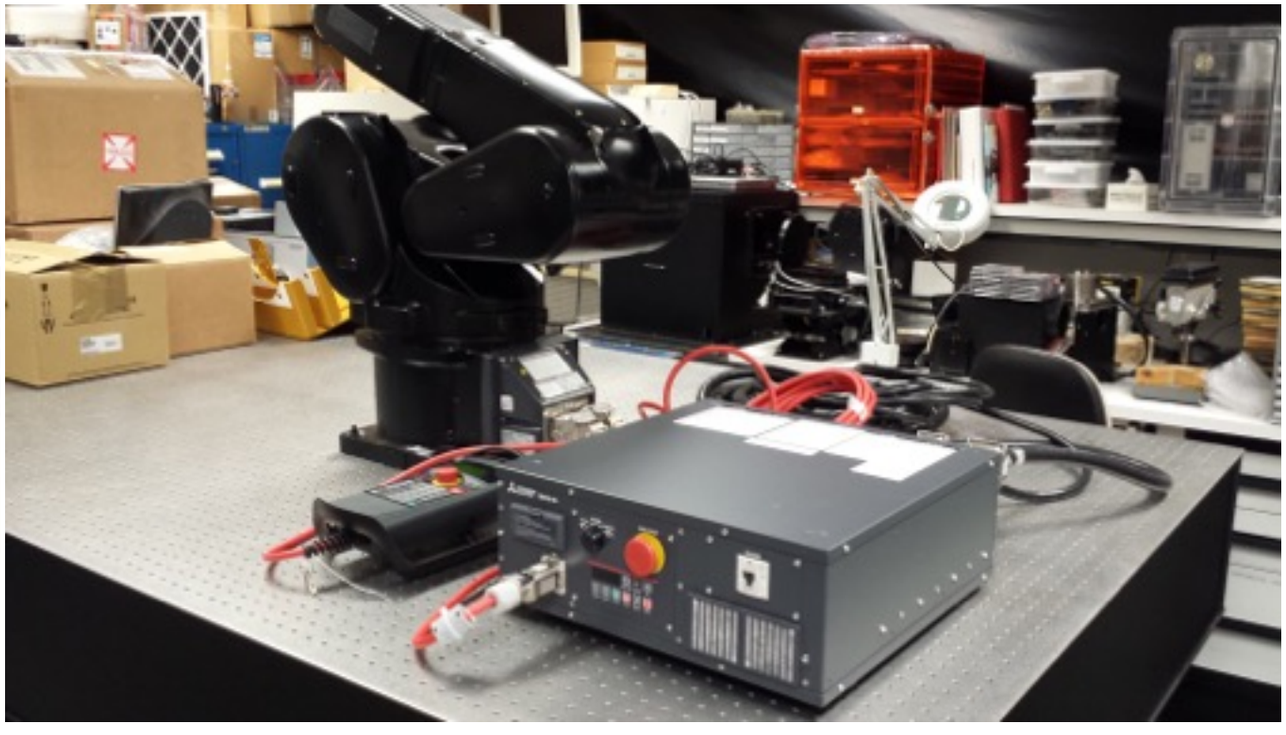
Table-top goniometer



RV-13FC with black paint of flat RAL 9011







Robot Controller delivery

System integration

1. Sources:
   a. Monochromator-based source from 200 nm to 2500 nm
   Laser-induced plasma, Xenon, Supercontinuum source
   b. OPO tunable lasers
   c. Fourier transform source
2. Detectors and data acquisition (Si, and Ex-IGA)
3. Motion Control

I. Detector arm: a. Rotation ring b. Heavy-duty rotation stage

II. Sample manipulation: a. Goniometerb. Robot arm

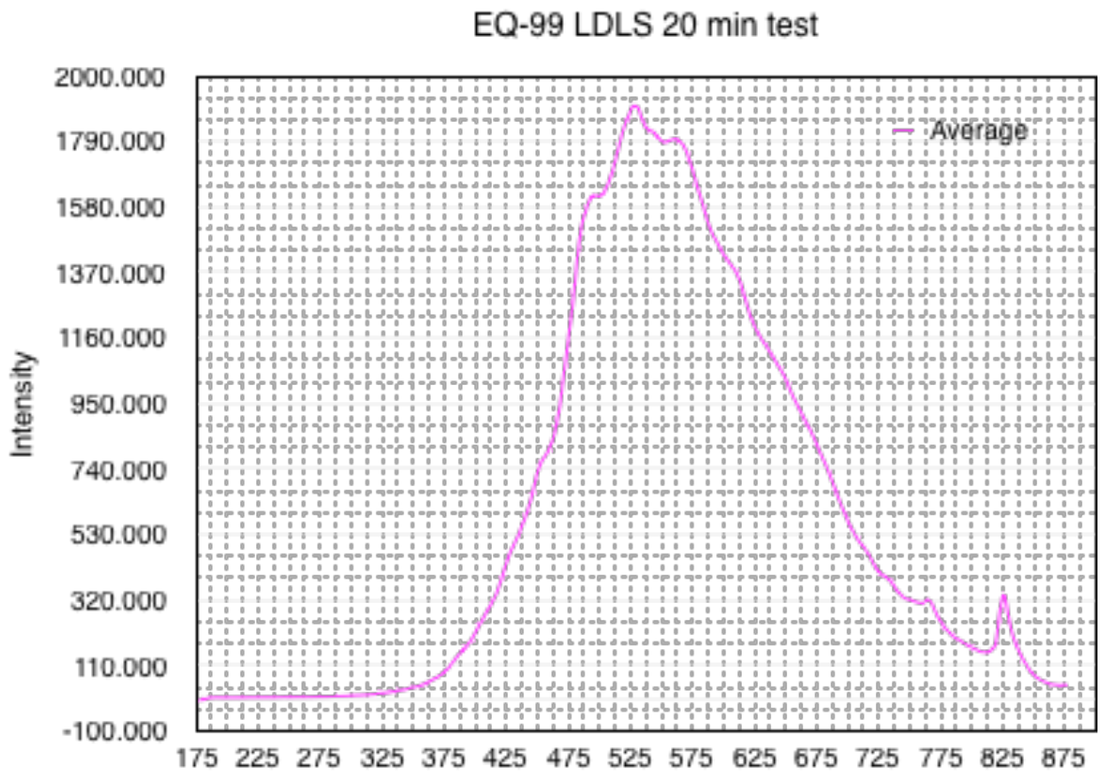
4. Software development
5. Alignment and test
6. Validation of system, and determination of uncertainty

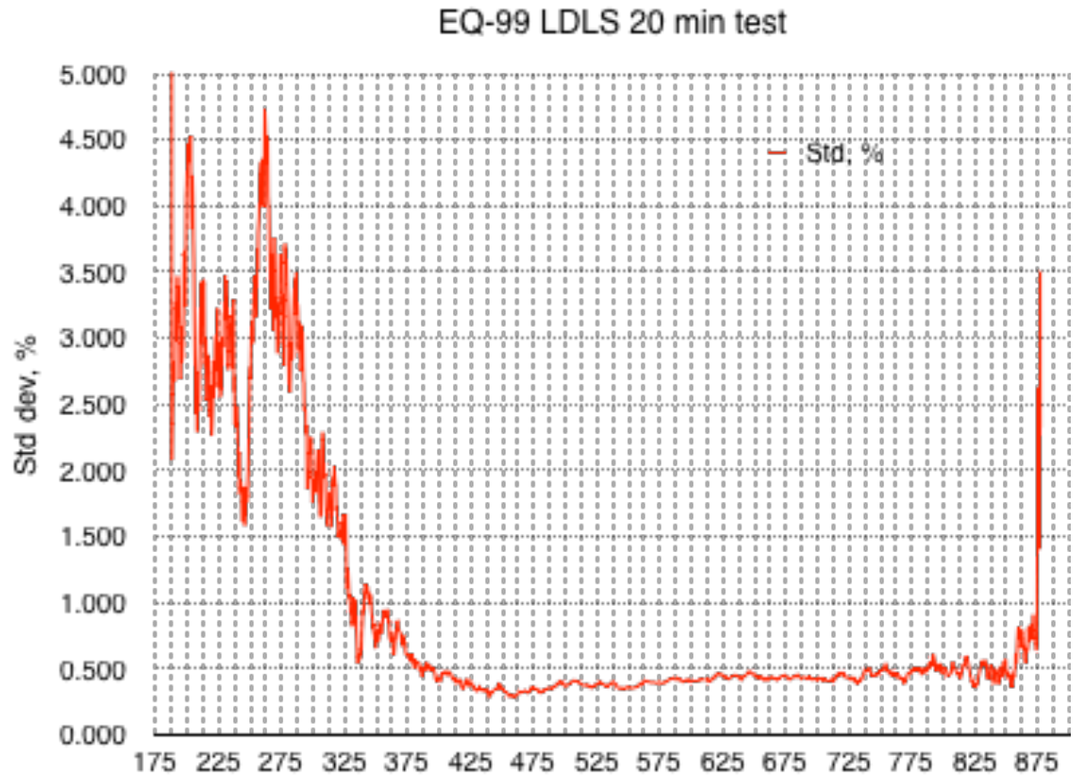
Sub-systems ––→ Operational Scatterometer

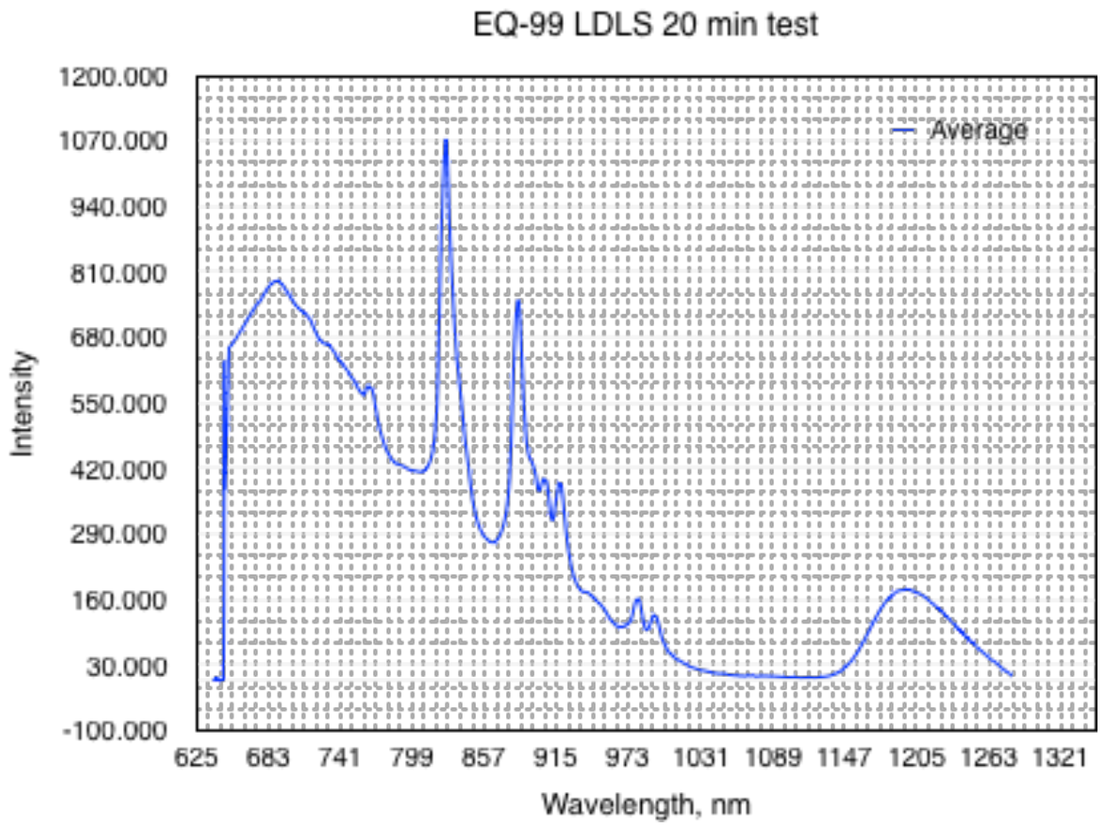
Instrument validation

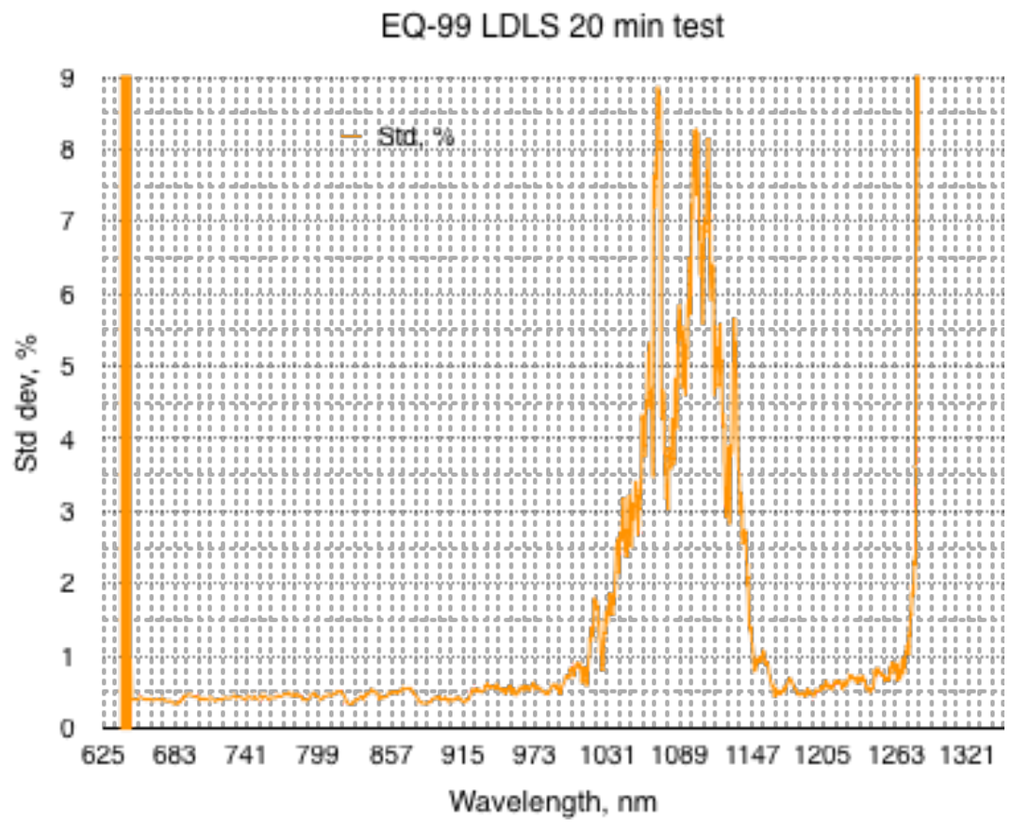
1. Instrument validation is done by comparison of Spectralon sample measured at NIST
2. Comparison to the existing validated system

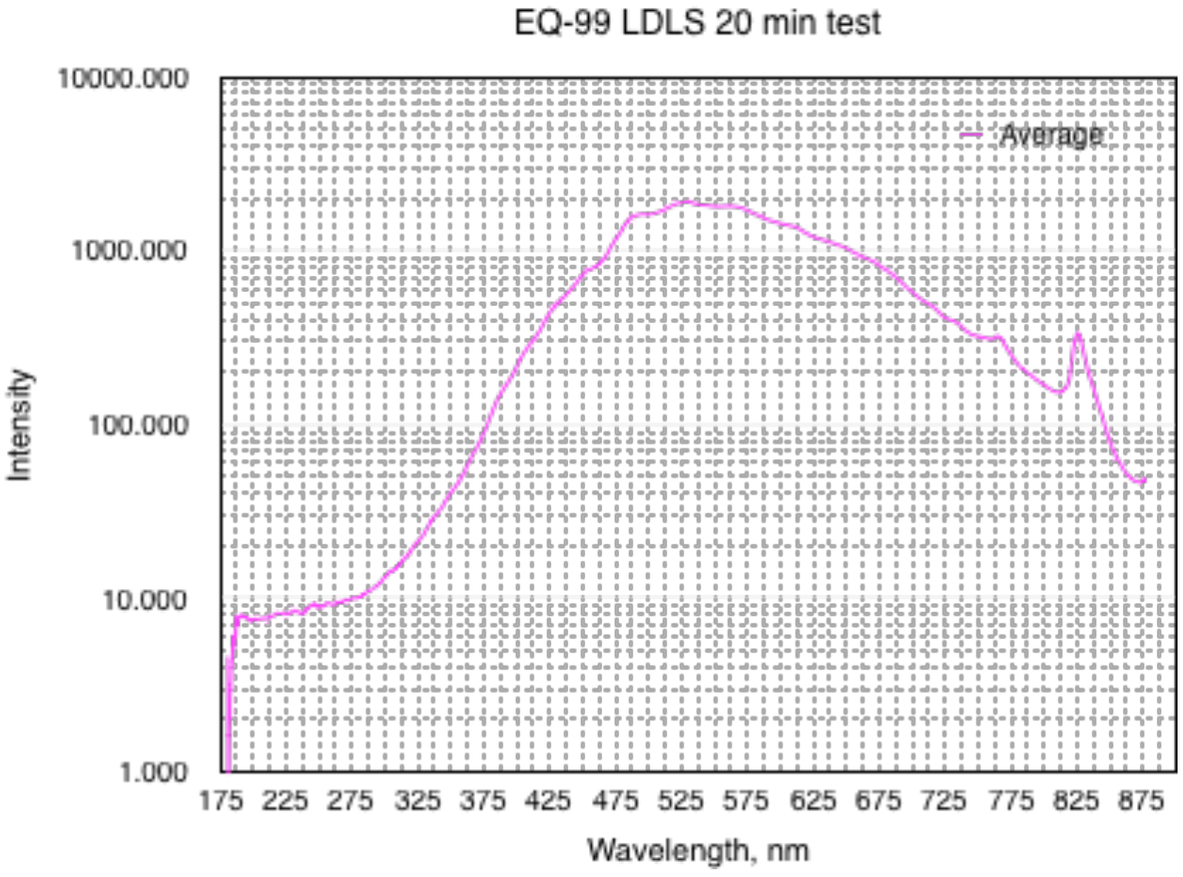
5. Preliminary test results

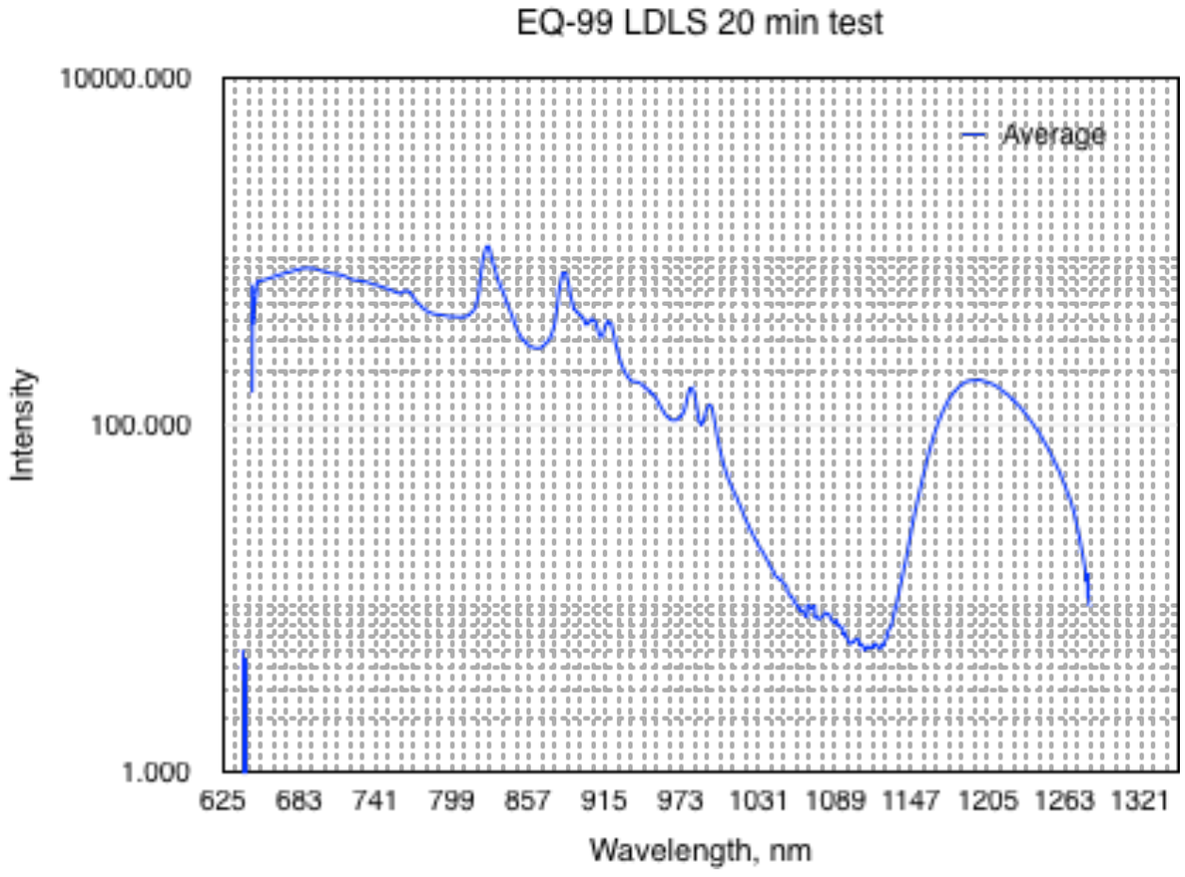

EQ-99 LDLS 20 min test
Average
Intensity
2000.000
1790.000
1580.000
1370.000
1160.000
950.000
740.000
530.000
320.000
110.000
-100.000
175 225 275 325 375 425 475 525 575 625 675 725 775 825 875
Wavelength, nm

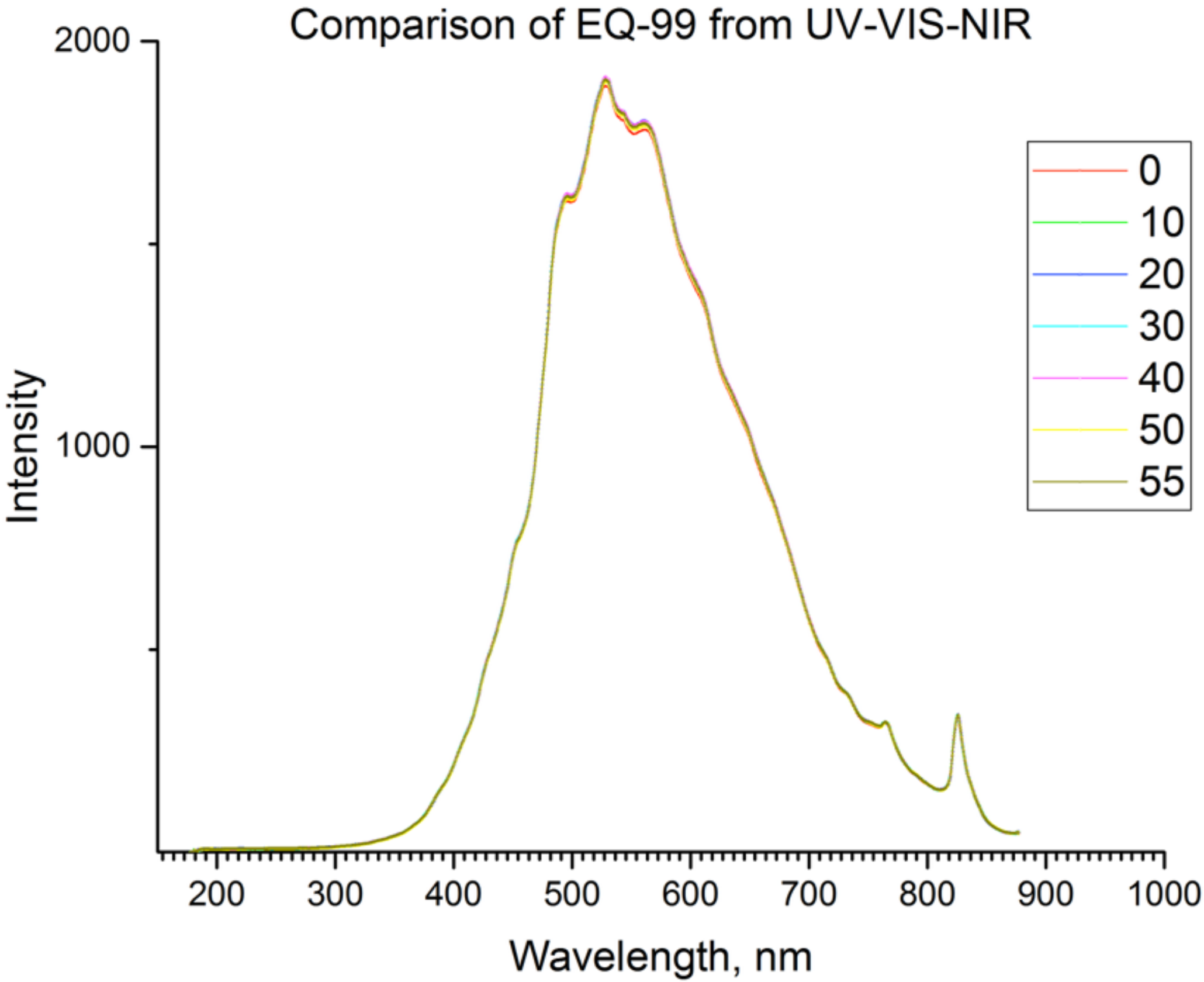

EQ-99 LDLS 20 min test
Std, %
Std dev, %
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
175 225 275 325 375 425 475 525 575 625 675 725 775 825 875
Wavelength, nm

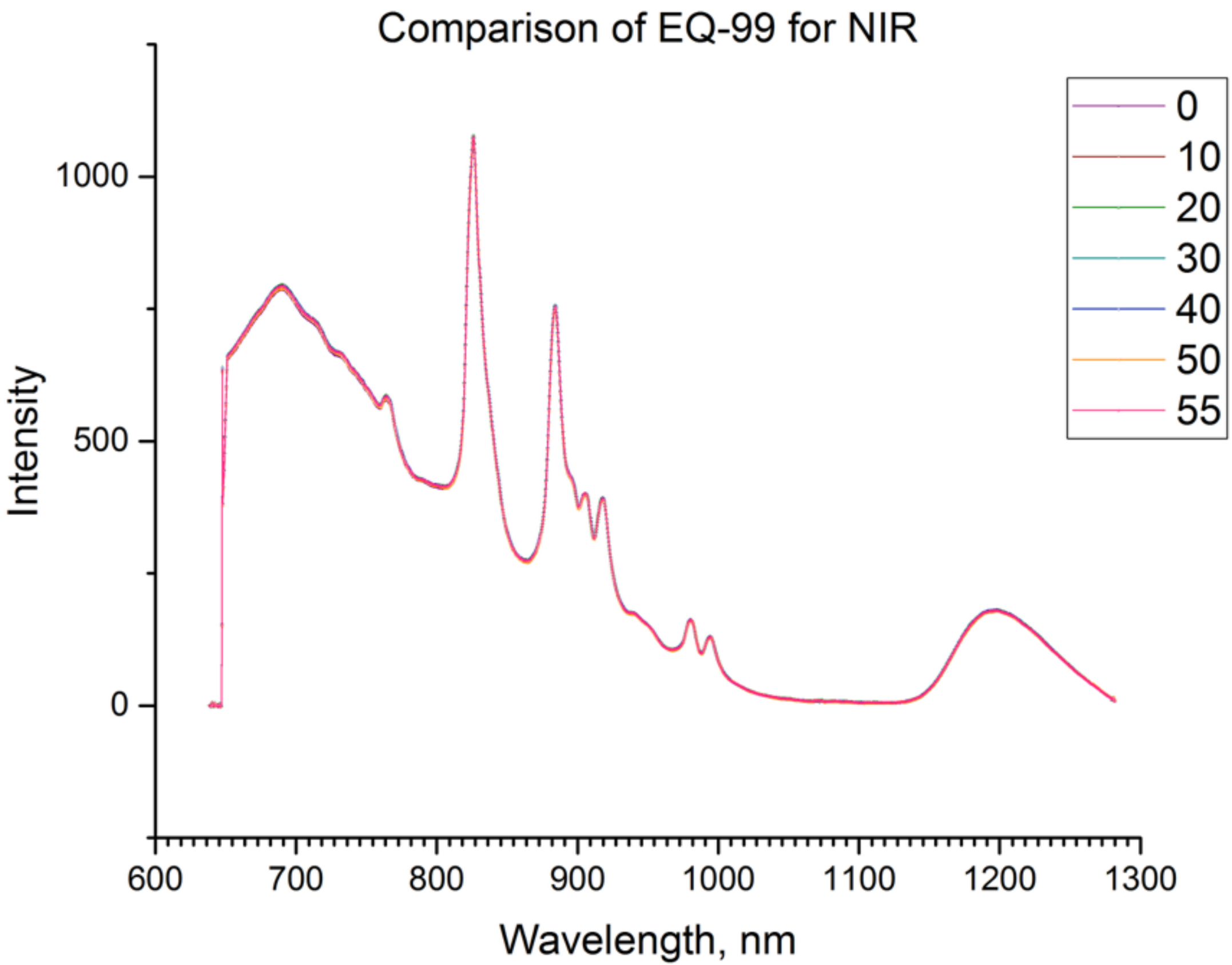

EQ-99 LDLS 20 min test
Average
Intensity
1200.000
1070.000
940.000
810.000
680.000
550.000
420.000
290.000
160.000
30.000
-100.000
625 683 741 799 857 915 973 1031 1089 1147 1205 1263 1321
Wavelength, nm


EQ-99 LDLS 20 min test
Std, %
Std dev, %
9
8
7
6
5
4
3
2
1
0
625 683 741 799 857 915 973 1031 1089 1147 1205 1263 1321
Wavelength, nm


EQ-99 LDLS 20 min test
Average
10000.000
1000.000
100.000
10.000
1.000
Intensity
175 225 275 325 375 425 475 525 575 625 675 725 775 825 875
Wavelength, nm

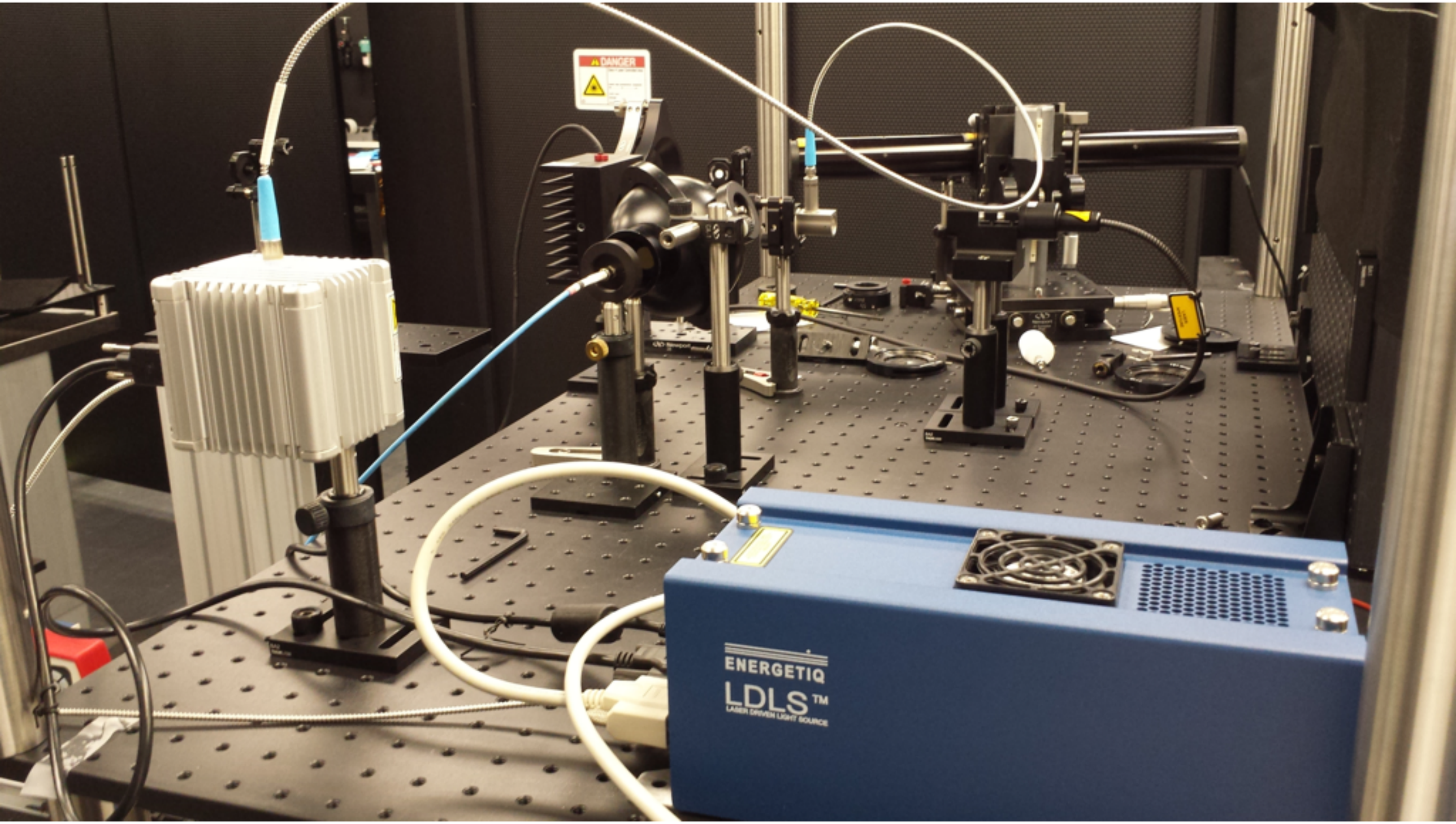

EQ-99 LDLS 20 min test
Average
10000.000
100.000
1.000
Intensity
625 683 741 799 857 915 973 1031 1089 1147 1205 1263 1321
Wavelength, nm


Comparison of EQ-99 from UV-VIS-NIR
Intensity
2000
1000
200
300
400
500
600
700
800
900
1000
Wavelength, nm
0
10
20
30
40
50
55

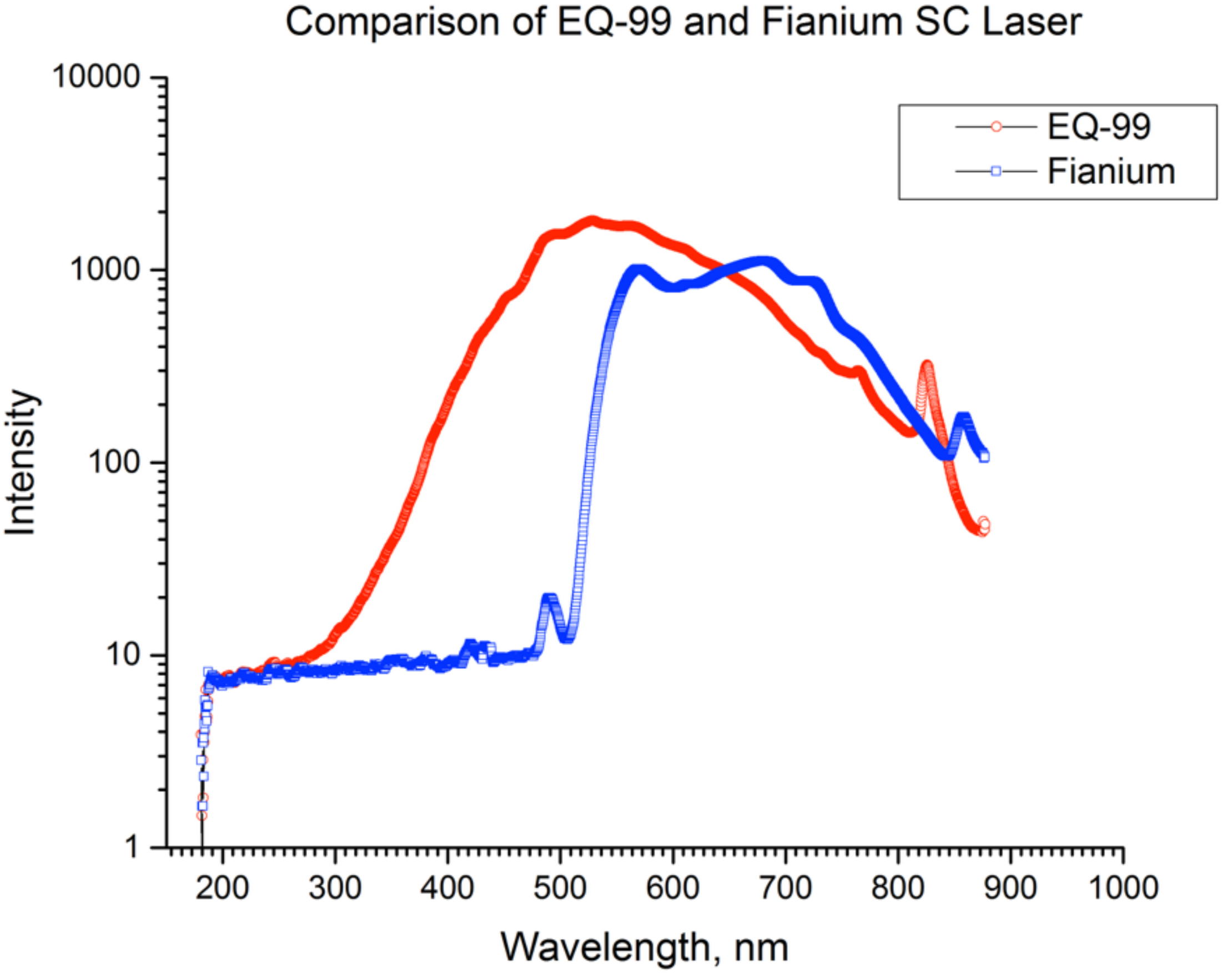

Comparison of EQ-99 for NIR
Intensity
1000
500
0
600
700
800
900
1000
1100
1200
1300
Wavelength, nm
0
10
20
30
40
50
55

Energetiq Tech

EQ-99


DANGER
ENERGETIQ
LDLS™
LASER DRIVEN LIGHT SOURCE

Fianium SC Laser


Comparison of EQ-99 and Fianium SC Laser
EQ-99
Fianium
Intensity
10000
1000
100
10
1
200
300
400
500
600
700
800
900
1000
Wavelength, nm

6. Summary and future work

- Two types of scatterometers are being established to support on-orbit solar band calibration.

- Some of key components of the new system have been implemented, and some of them will be delivered soon.

- Preliminary tests have been conducted.

- System integration and instrument validation are needed.