HyperOCR: Improving Characterization and Calibration

FRM4SOC Workshop on Calibration and Characterization of OC Radiometers, 20-22 May 2025

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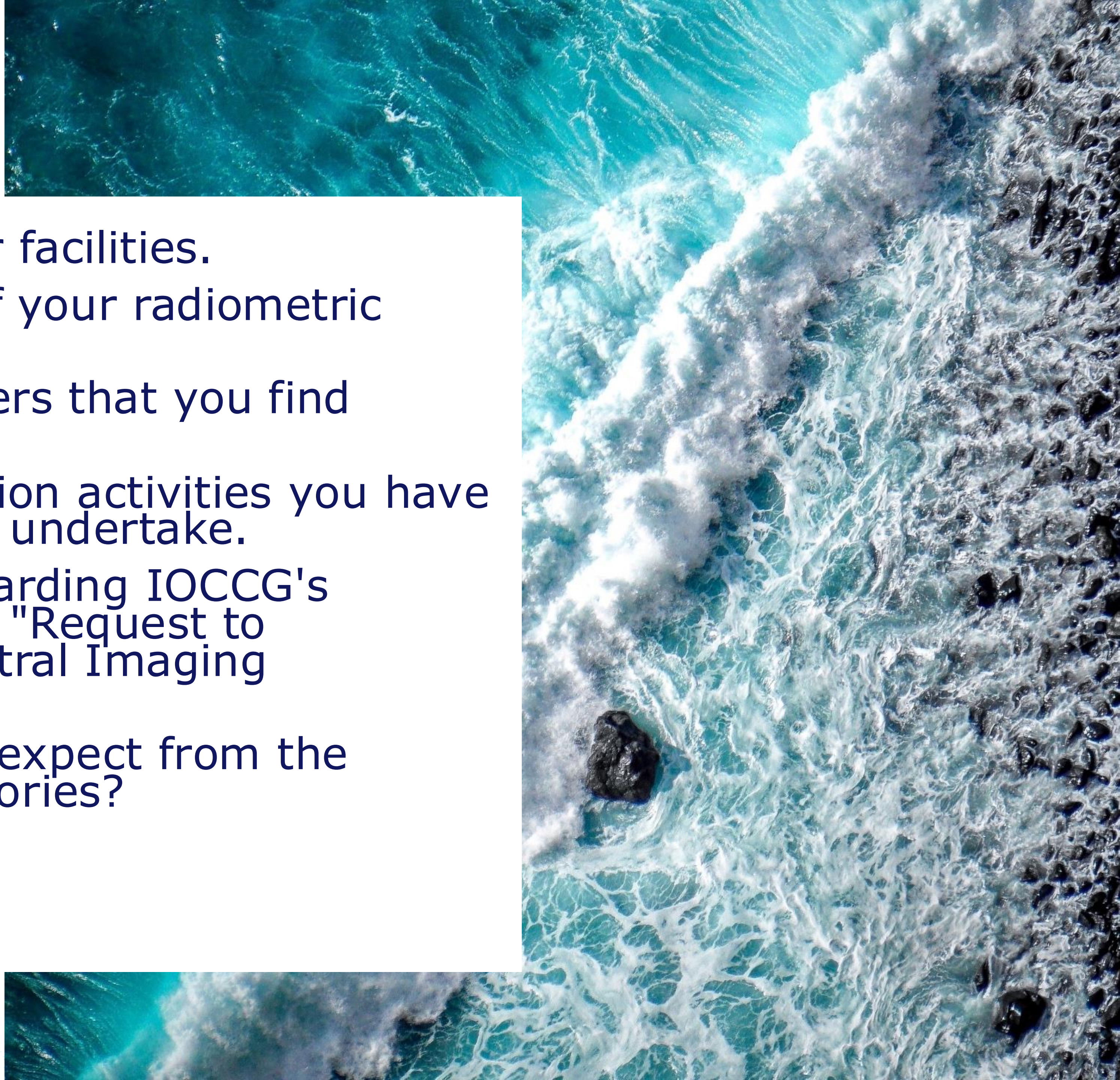
SEA·BIRD SCIENTIFIC

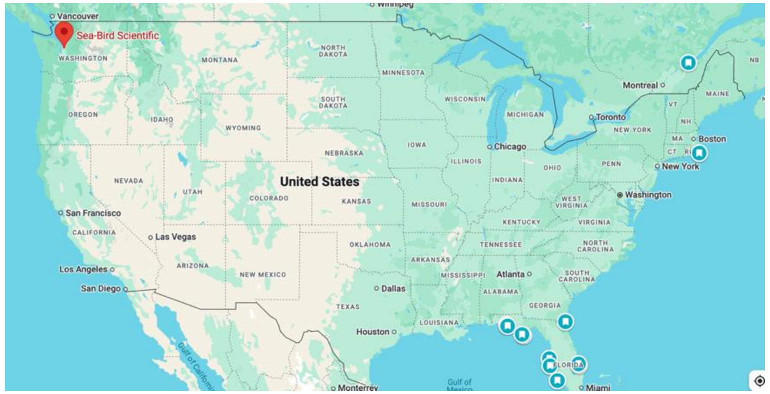
Overview

- Existing and planned cal/char facilities.
- Realisation and traceability of your radiometric scale.
- Parameters of your radiometers that you find critical for characterisation.
- Intercomparisons and validation activities you have already undergone or plan to undertake.
- Motivation and questions regarding IOCCG's Addendum to Protocol No. 3: "Request to Manufacturers of in situ Spectral Imaging Radiometers”
- What kind of support do you expect from the community and other laboratories?



Existing and Planned Characterization and Calibration Facilities

SBS Calibration Facility History



- **1990-Present**: Sea-Bird Electronics, Bellevue, WA
  - Calibration of physical and BGC ocean sensors
- **1992-2010:** WET Labs, Philomath, OR
  - Calibration of optical sensors (ECO, AC-9, C-Star, etc.)
- **1990-2011:** Satlantic, Halifax, NS, Canada
  - Radiometric sensor calibration
  - SIRREX-7 (1999), SIMRIC-1 (2001), REVAMP (2001), SIMRIC-2 (2002), ARC (2010)

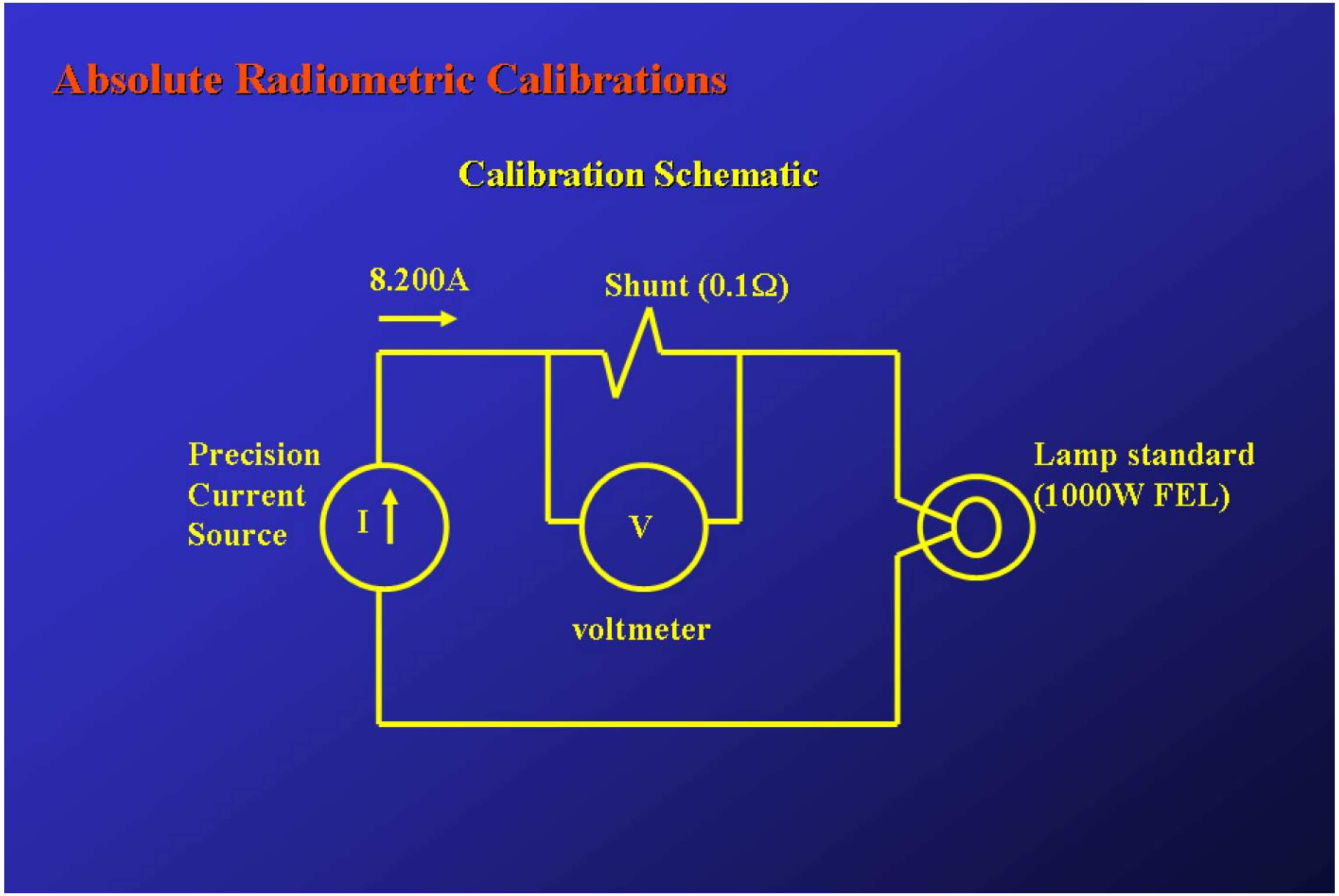
- **2010-2011:** Sea-Bird Scientific (Danaher) acquires WET Labs & Satlantic
- **2017:** FRM4SOC Phase 1 LCE-1, LCE-2
- **2017:** RADCAL-1: Internal LCE: Transfer Radiometric Lab from Halifax, NS to Philomath, OR
- **2022-2024**: FRM4SOC Phase 2 LCE
- **2022-2023:** RADCAL-2: Transfer Radiometric Lab from Philomath, Oregon to Bellevue, WA. Includes the same reference radiometers as LCE-1.

Realisation and traceability of the radiometric scale

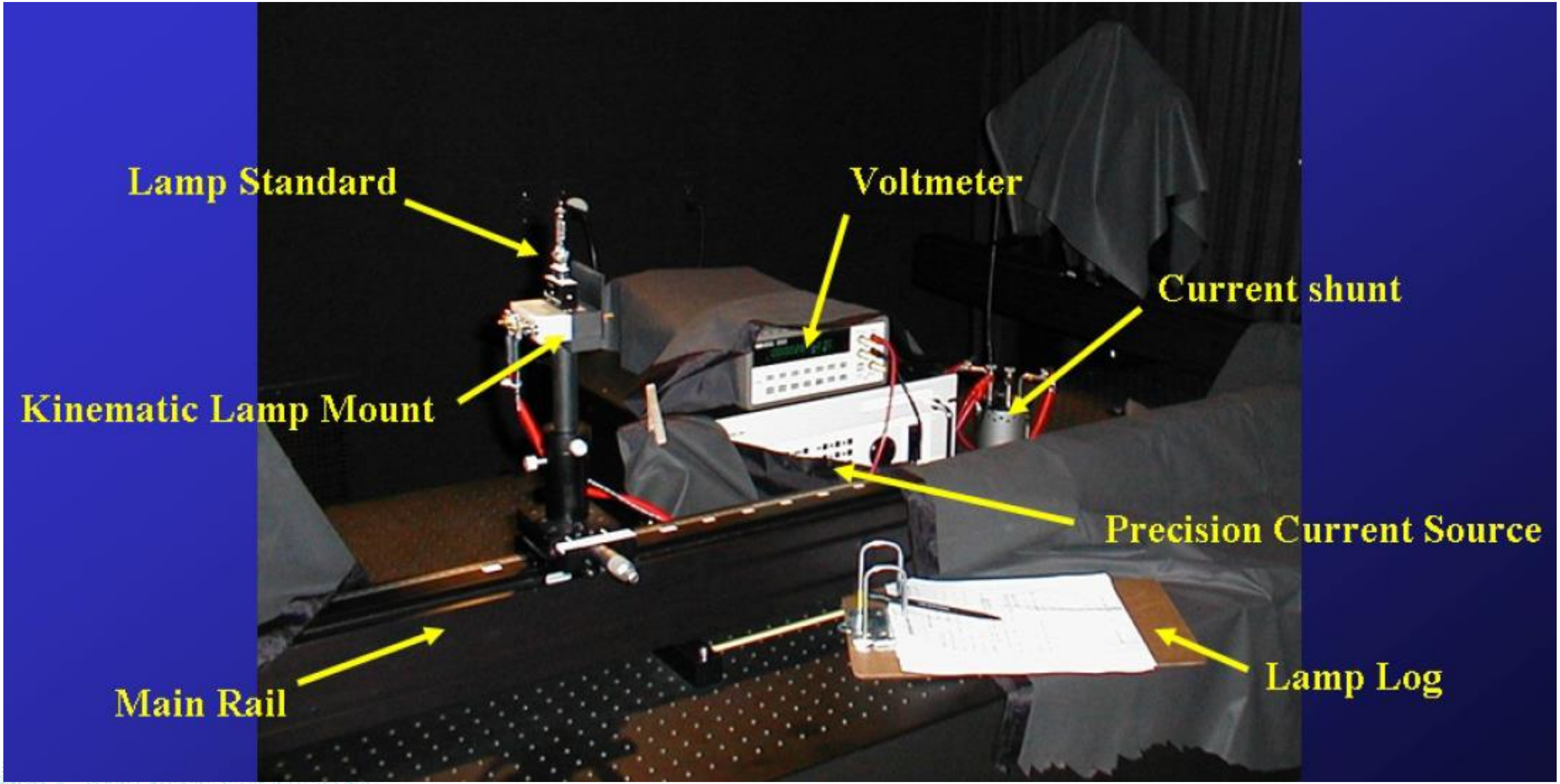
Equipment

Item	Model	NIST Traceable
1000-W Quartz-Halogen Tungsten Lamp	Optronic Laboratories Inc. OL FEL-M	X
Reflectance Plaque	Labsphere SRT-99-180 Calibration, uncertainty: Avian Technologies	X
Current Source	Optronic Laboratories Inc. OL83A	
Resistance Shunt	Leeds and Northrup Co. TE-611656	X
Multimeter	Keysight 34461A	X
He-Ne Laser (Class III)	Melles Griot LHRR-0500	
Sensor Rings	Custom	
V Blocks	Custom	
Plaque Mount	Custom	
Carrier	Oriel 11627	
Lamp Mount	Custom	
Laser Mount	Oriel 1440 and Custom	
Translator	Oriel 16121	
L Square	Starrett Exact RSA-24	X
Stainless Steel Ruler	*tbs*	X
Adjustable Aperture	Custom	
Optical rails (4 and 8 feet long)	Oriel 11160. Measurement uncertainty ±0.5 mm	
Computer	Standard PC	

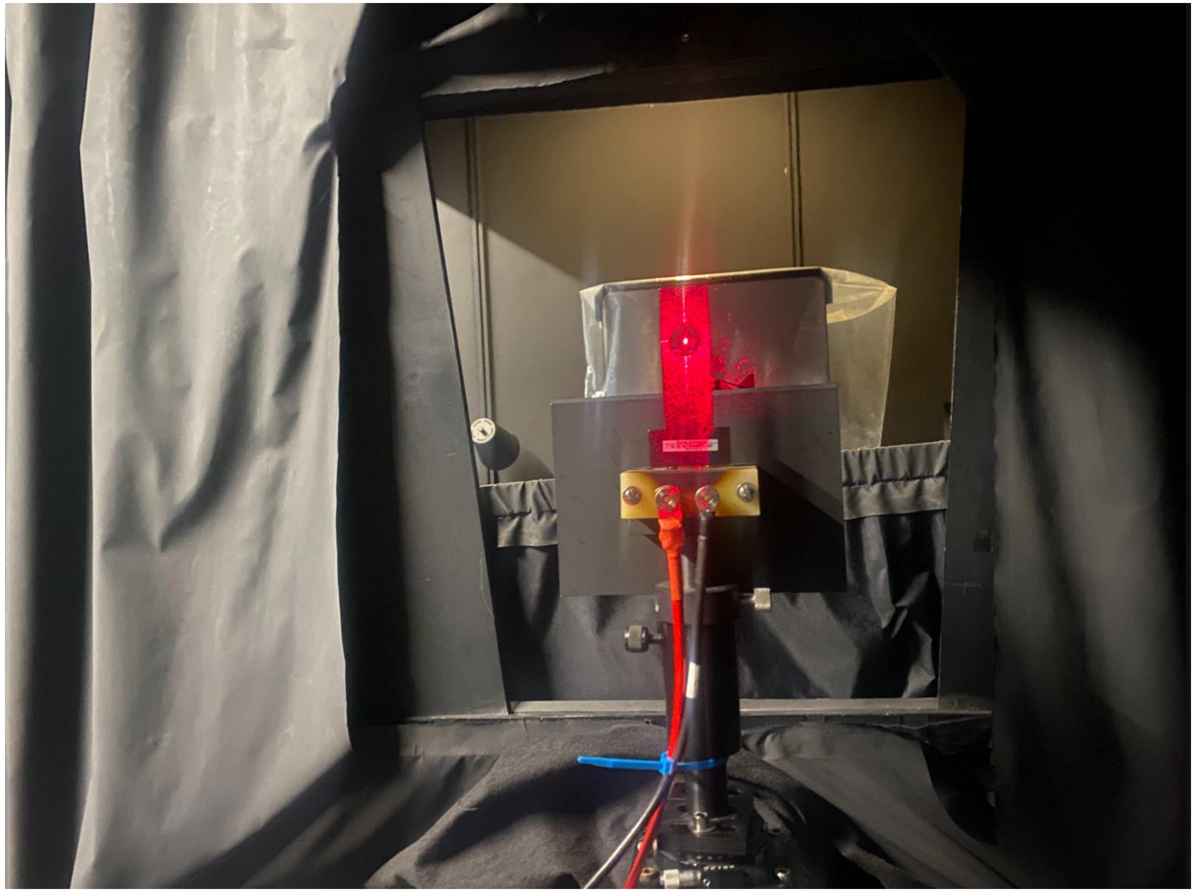
Lamp Circuit

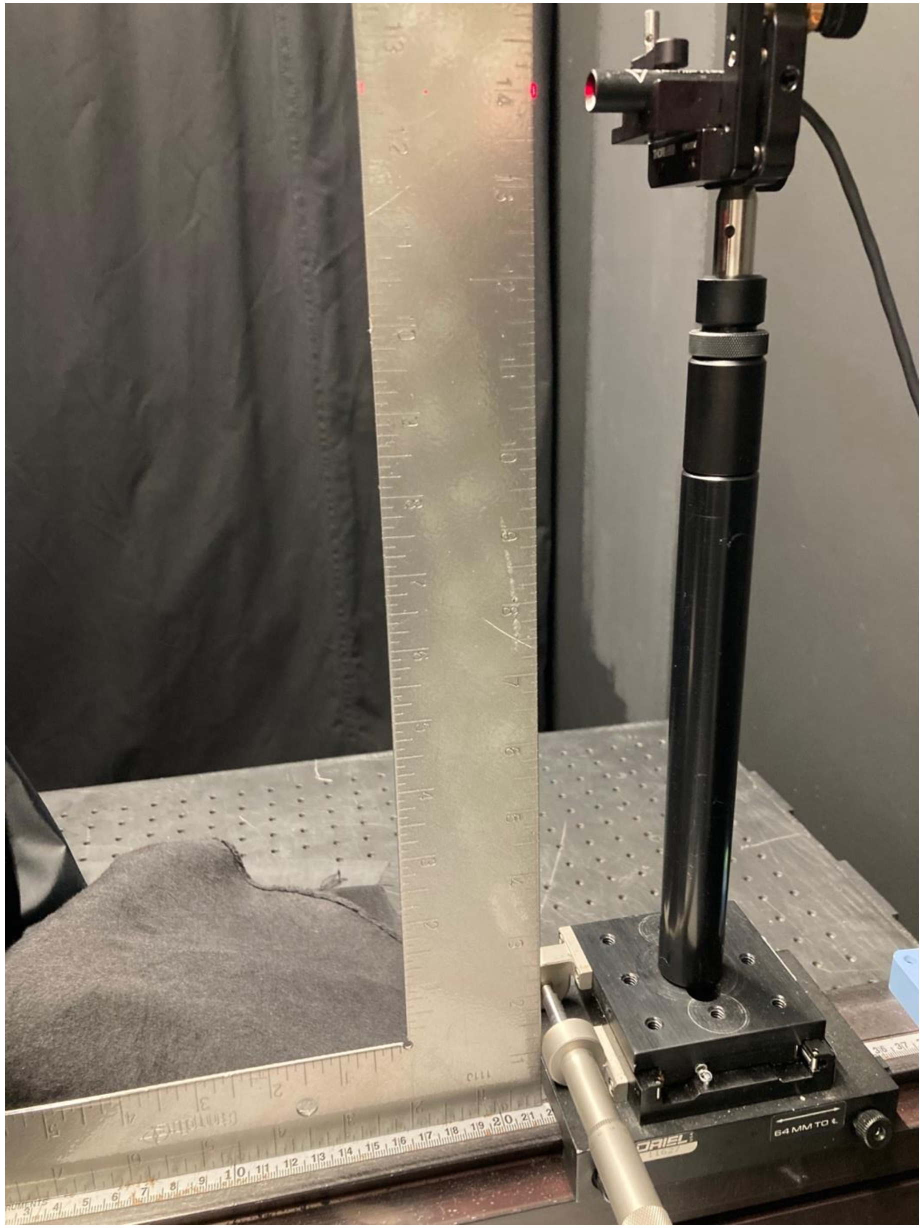


Equipment

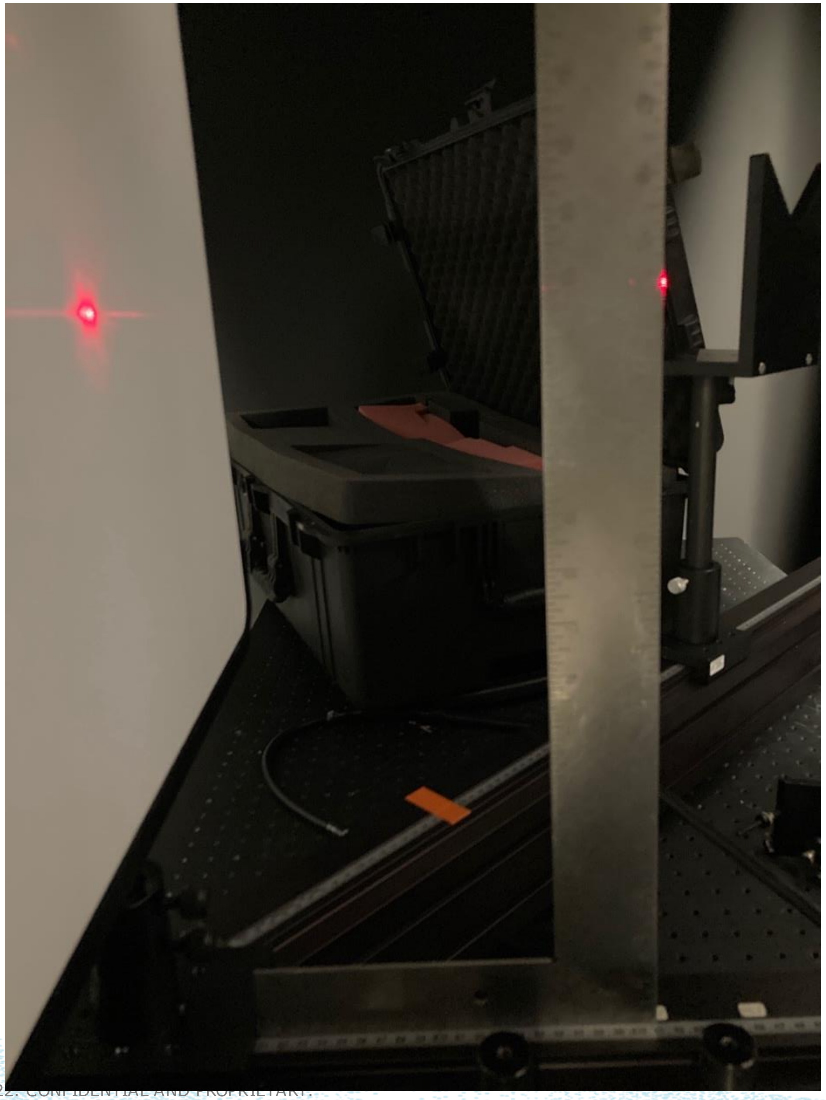

Lamp Standard
Voltmeter
Current shunt
Kinematic Lamp Mount
Precision Current Source
Lamp Log
Main Rail

Alignment Laser

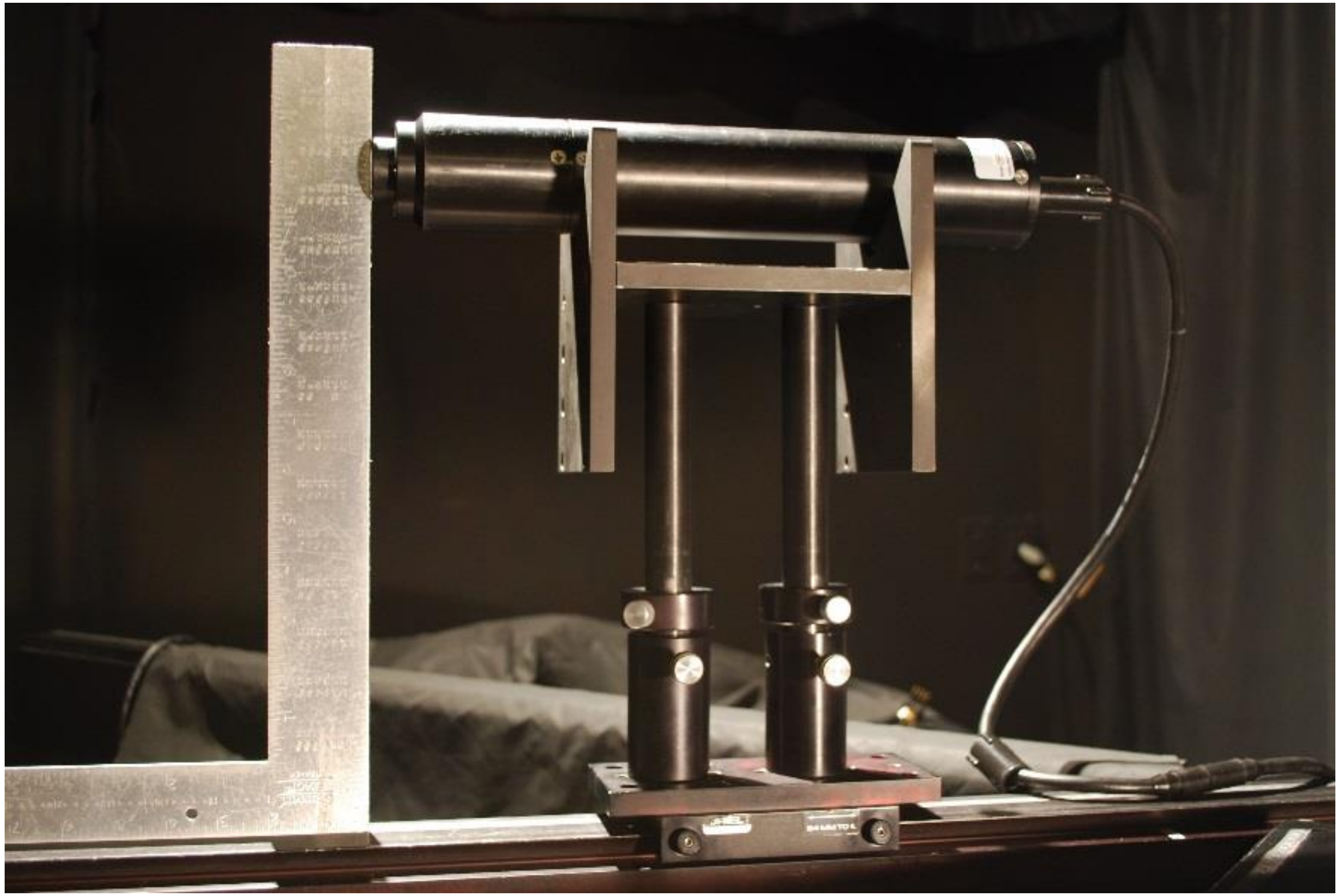


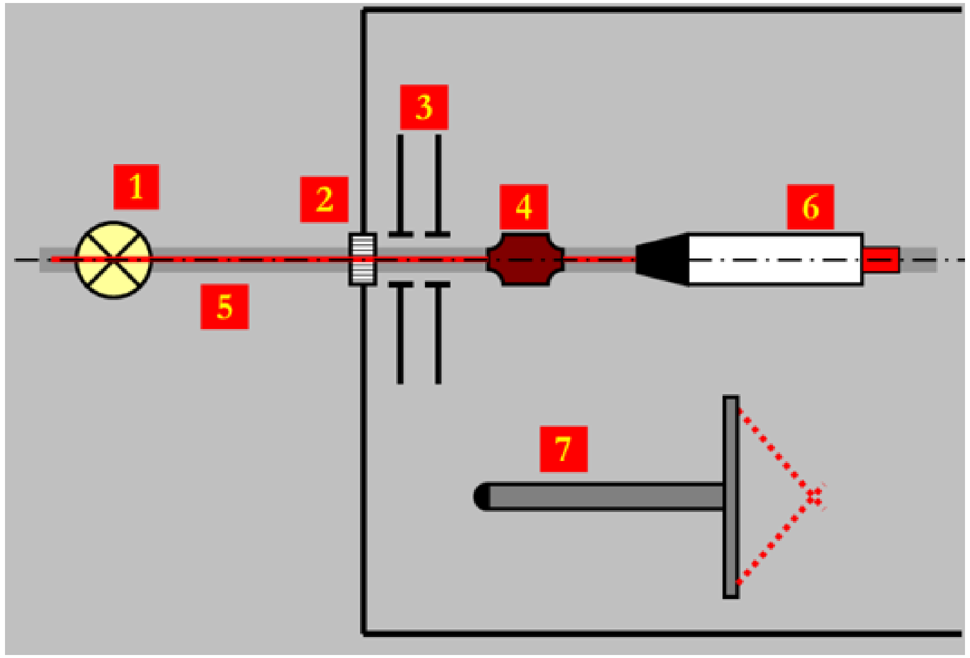


Laser alignment of reflectance plaque

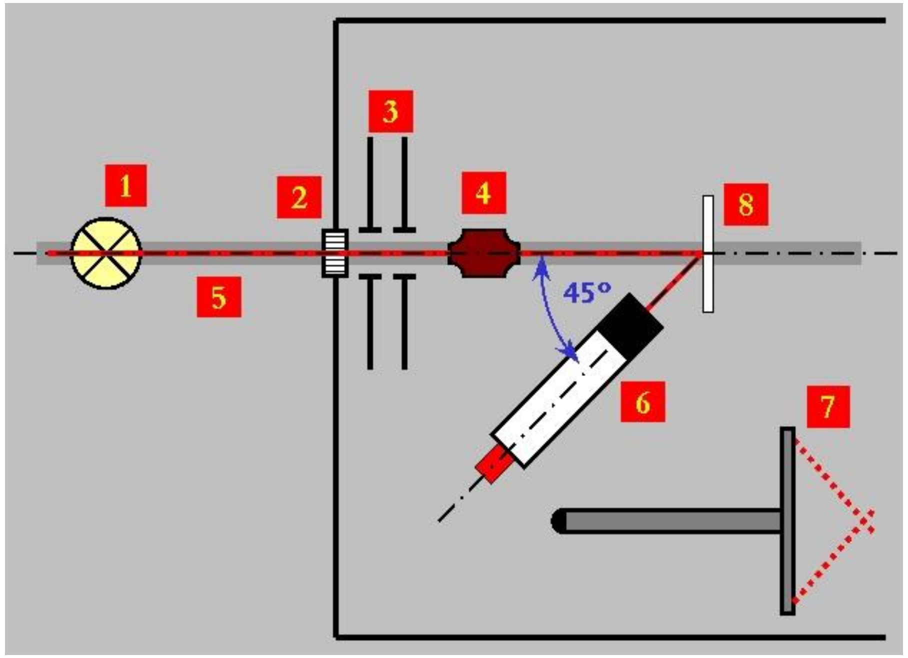


Irradiance Calibration – Custom V-blocks

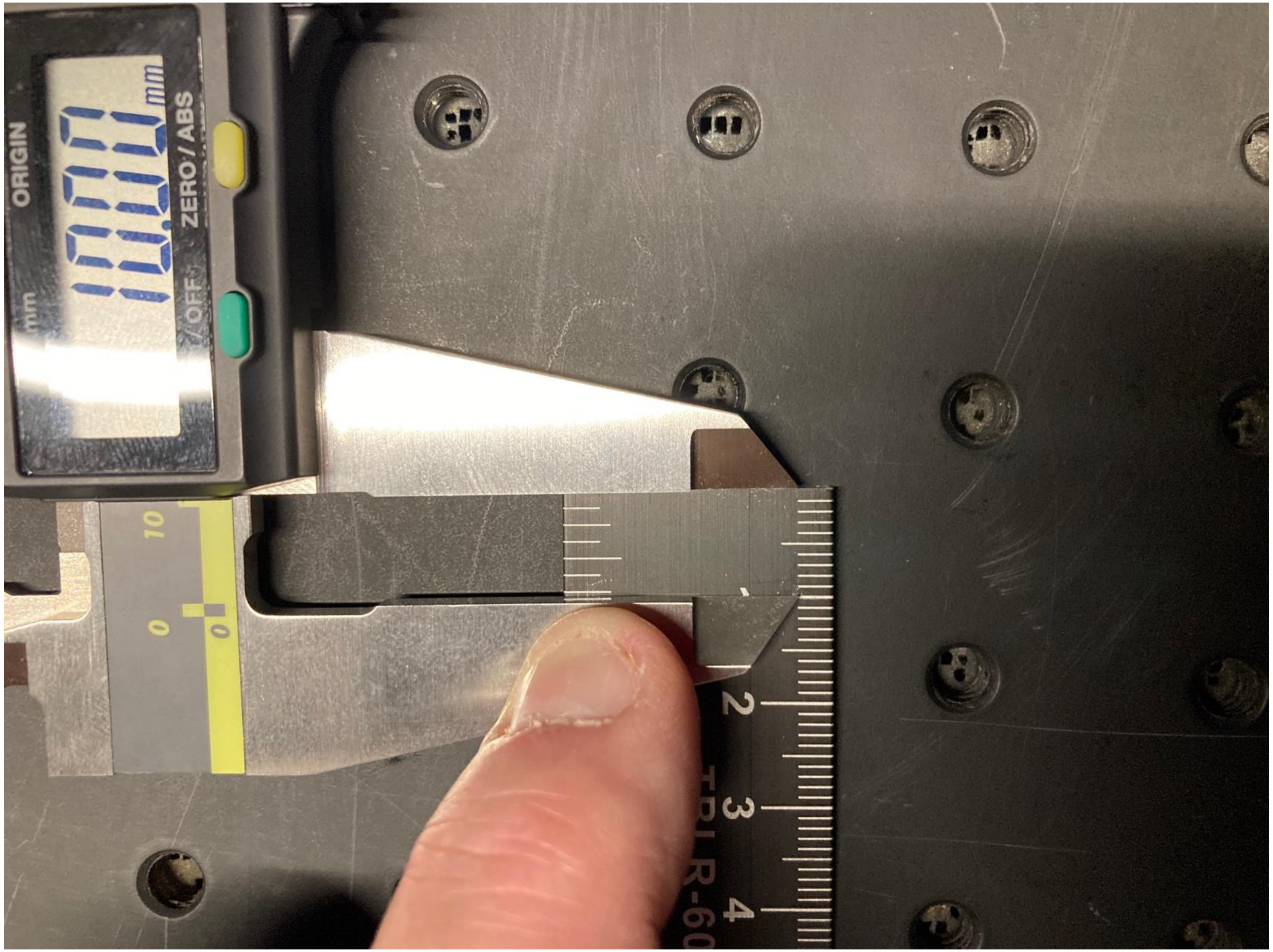




Radiance Calibration (Hypernav shown)



Distance uncertainty ±0.5 mm

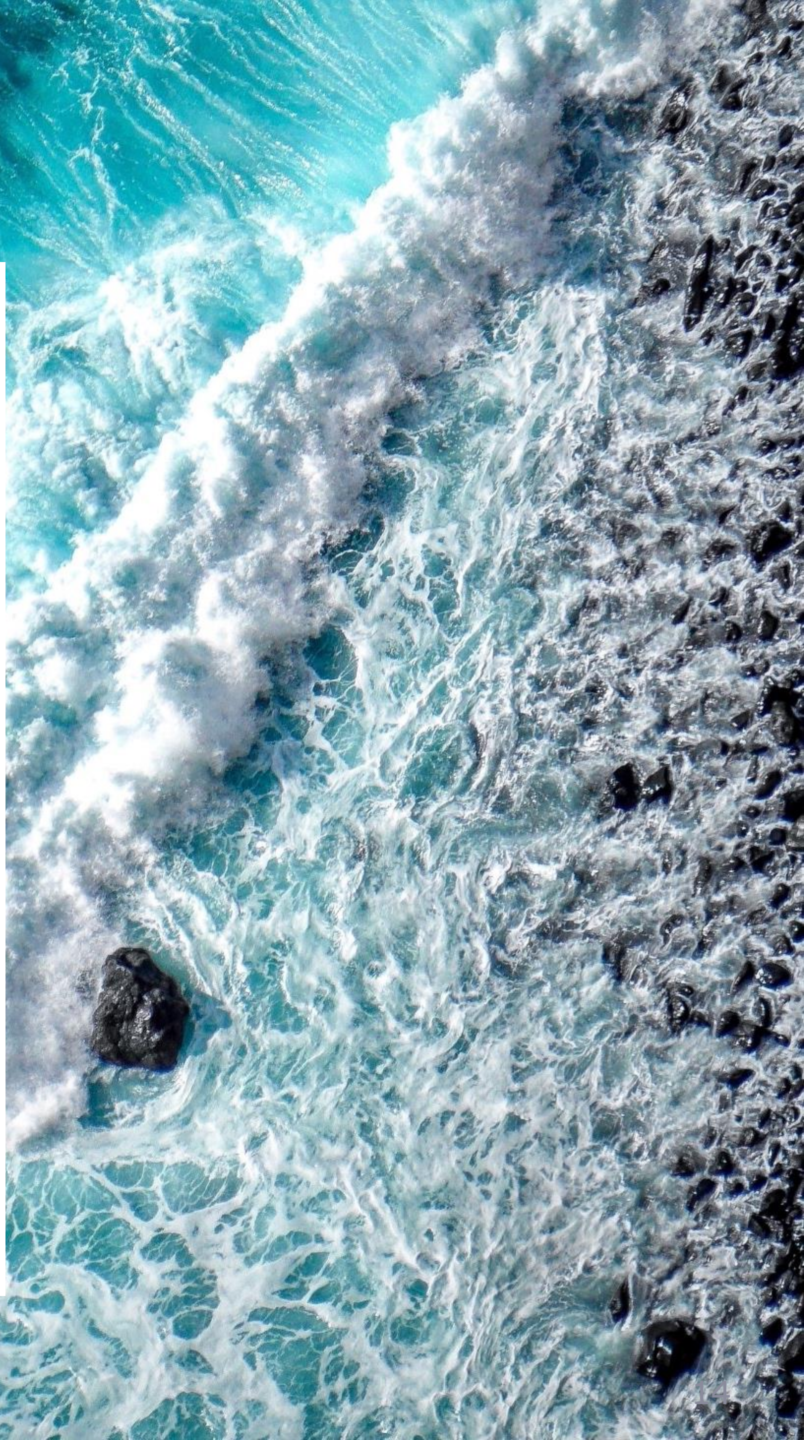


Note: Greater uncertainty with laser distance meters.

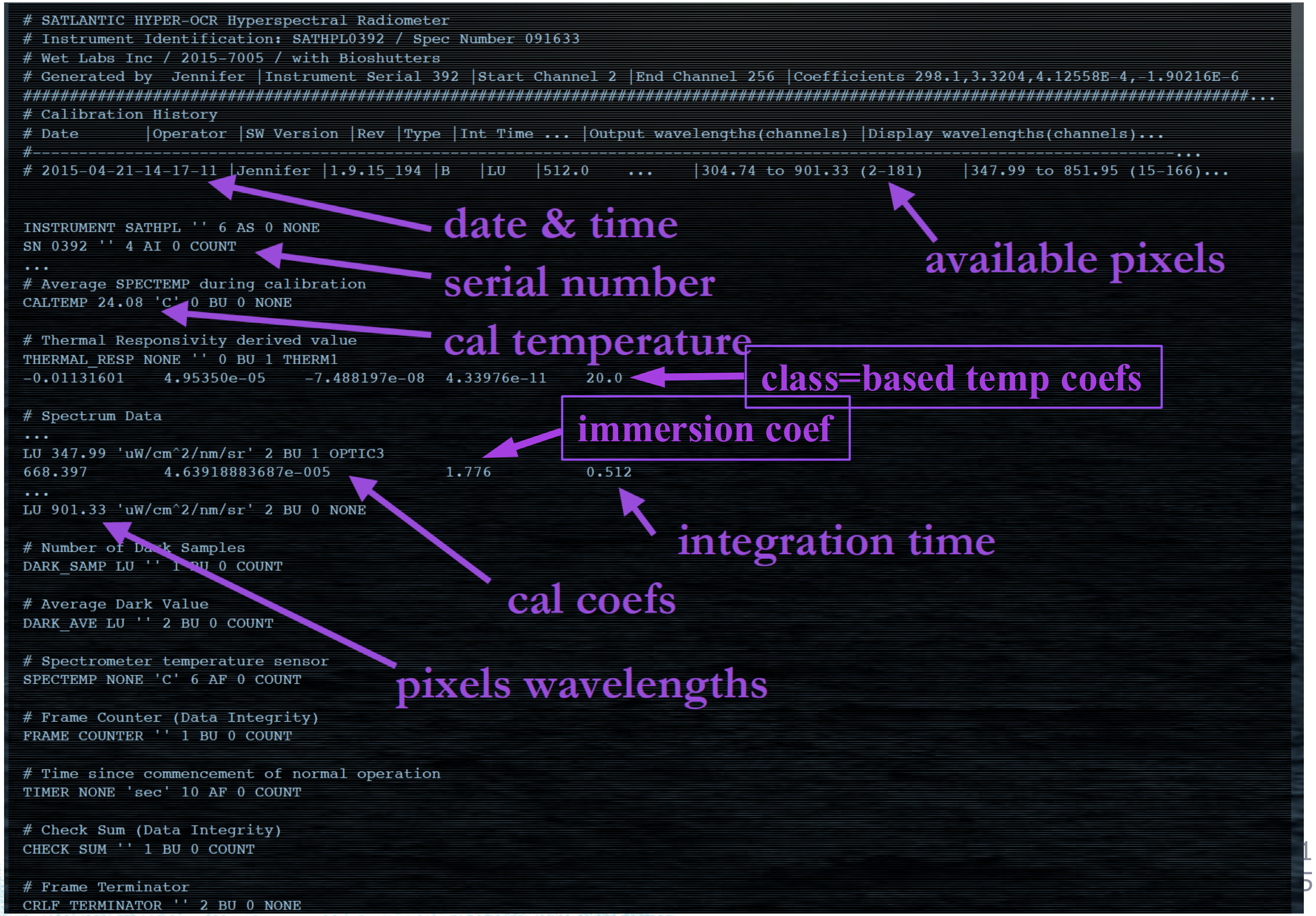
Suggestions ?

Calibration Results

- **.cal file**
  - Wavelength, scale factor, immersion coefficient, integration time
  - Calibration metadata
- **Intercomparison (reality check)**
  - Assures that production units are consistent with internal references
  - Implicitly checks scale factor and cosine response
    - Cosine error: Currently, only internal reference sensors are cosine-scanned (1°)
  - Radiance inside, Irradiance outdoors
  - Pass/Fail: within 5*% of reference* from 400-800 nm



HyperOCR cal file

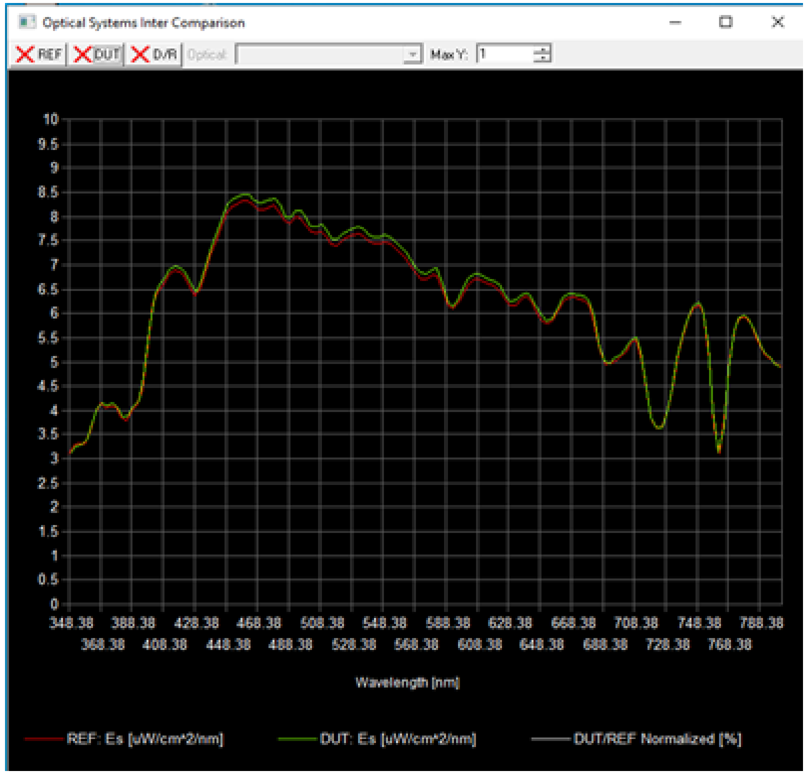


```
# SATLANTIC HYPER-OCR Hyperspectral Radiometer
# Instrument Identification: SATHPL0392 / Spec Number 091633
# Wet Labs Inc / 2015-7005 / with Bioshutters
# Generated by  Jennifer |Instrument Serial 392 |Start Channel 2 |End Channel 256 |Coefficients 298.1,3.3204,4.12558E-4,-1.90216E-6
##########################################################################################################################################...
# Calibration History
# Date        |Operator |SW Version |Rev |Type |Int Time ... |Output wavelengths(channels) |Display wavelengths(channels)...
#---------------------------------------------------------------------------------------------------------------------------...
# 2015-04-21-14-17-11 |Jennifer |1.9.15_194 |B    |LU    |512.0    ...    |304.74 to 901.33 (2-181)    |347.99 to 851.95 (15-166)...


INSTRUMENT SATHPL '' 6 AS 0 NONE
SN 0392 '' 4 AI 0 COUNT
...
# Average SPECTEMP during calibration
CALTEMP 24.08 'C' 0 BU 0 NONE

# Thermal Responsivity derived value
THERMAL_RESP NONE '' 0 BU 1 THERM1
-0.01131601     4.95350e-05     -7.488197e-08   4.33976e-11     20.0

# Spectrum Data
...
LU 347.99 'uW/cm^2/nm/sr' 2 BU 1 OPTIC3
668.397         4.63918883687e-005          1.776           0.512
...
LU 901.33 'uW/cm^2/nm/sr' 2 BU 0 NONE

# Number of Dark Samples
DARK_SAMP LU '' 1 BU 0 COUNT

# Average Dark Value
DARK_AVE LU '' 2 BU 0 COUNT

# Spectrometer temperature sensor
SPECTEMP NONE 'C' 6 AF 0 COUNT

# Frame Counter (Data Integrity)
FRAME COUNTER '' 1 BU 0 COUNT

# Time since commencement of normal operation
TIMER NONE 'sec' 10 AF 0 COUNT

# Check Sum (Data Integrity)
CHECK SUM '' 1 BU 0 COUNT

# Frame Terminator
CRLF TERMINATOR '' 2 BU 0 NONE
```

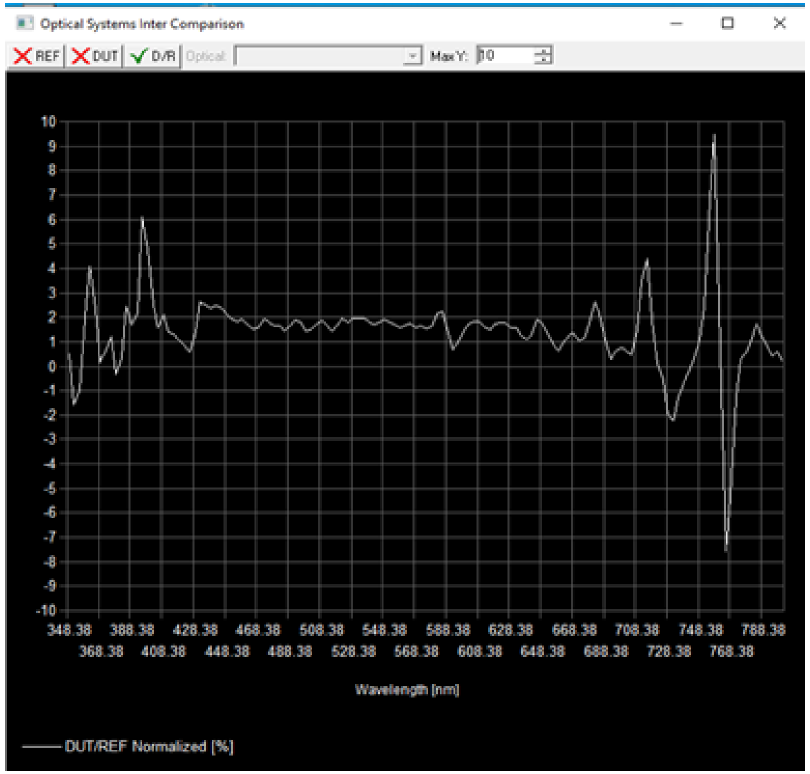
Intercomparison - E_d

Intercomparison - E_d

Spectra

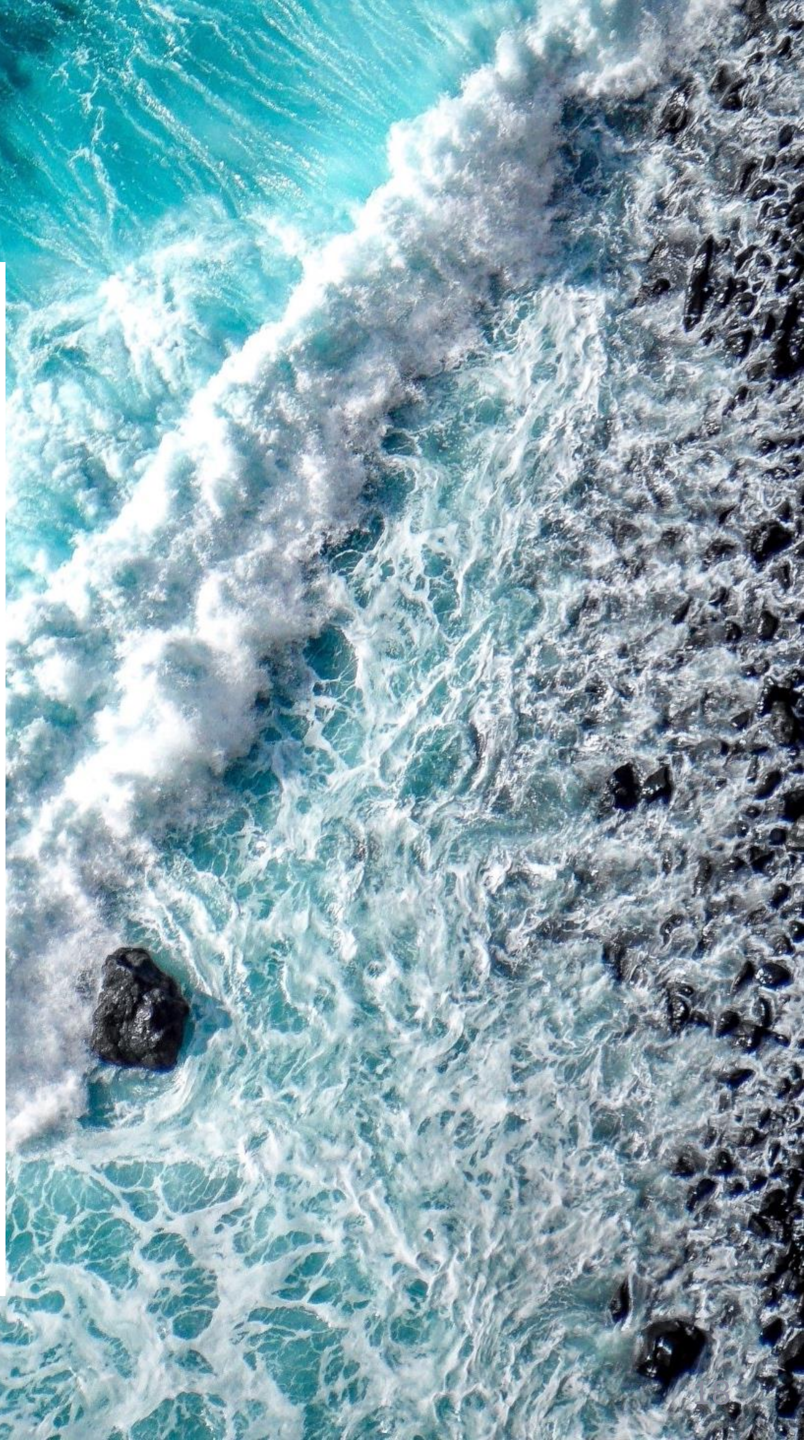


Relative Percent Difference < 5% 400-800 nm

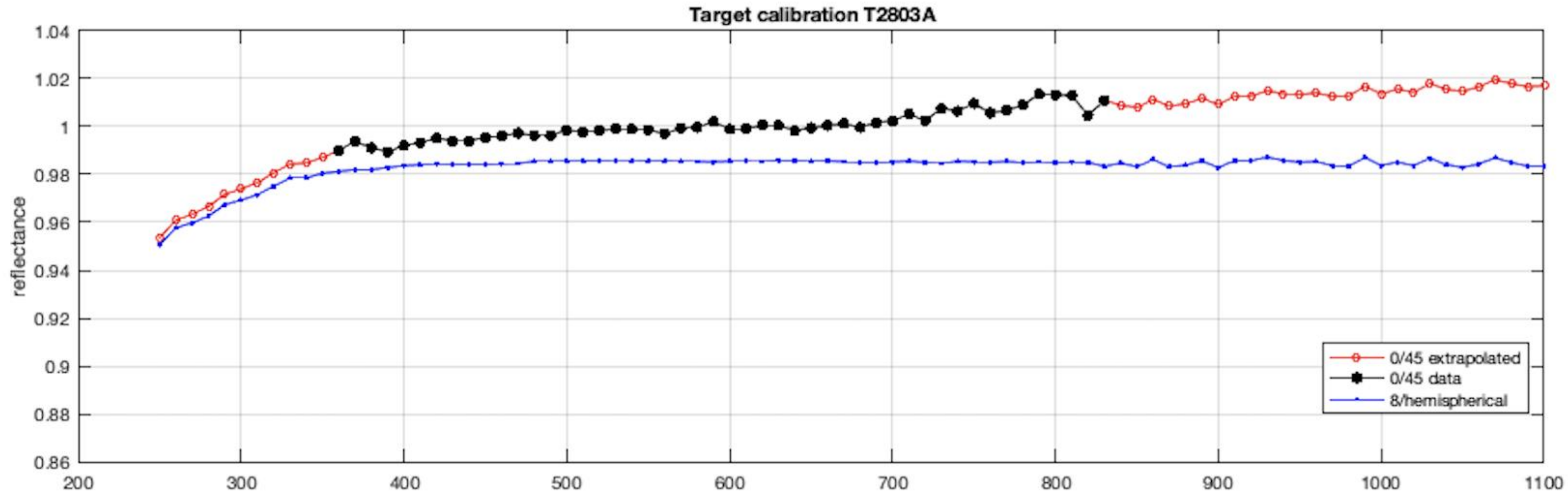


Traceability to SI Units (NIST)

- Irradiance Source
  - Lamp cert., uncertainty class-based ($W\ m^{-2}\ nm^{-1}$)
  - Current shunt (Ohms)
  - Digital voltmeters (Volts)
- Reflectance
  - Plaque cal cert., uncertainty class-based (reflectance)
- Distance measurement
  - Rulers (meters)
- Digital Storage Oscilloscope / Timer
  - Time (seconds)



Reflectance Plaque



Avian Technologies LLC
Calibration AT-20220902-2
SRT-99-180
s/n 99AA05-0822-2803
for
Sea-Bird

Wavelength (nm)	Deep Grey Reflectance Factor	Avian Technolgies Uncertainty	Pale Grey Reflectance Factor	Avian Technolgies Uncertainty	Aluwhite(98) Matte Reflectance Factor	Avian Technolgies Uncertainty	Published NIST 1995 PTFE Reflectance		Uncertainty
360	0.040	0.001	0.485	0.005	0.898	0.008	1.001	a	0.017
370	0.043	0.001	0.520	0.005	0.922	0.008	1.001	a	0.017
380	0.046	0.001	0.540	0.006	0.936	0.009	1.002		0.017
390	0.048	0.001	0.559	0.006	0.948	0.008	1.003		0.017
400	0.049	0.001	0.571	0.006	0.960	0.009	1.005		0.017
410	0.050	0.001	0.580	0.005	0.969	0.009	1.006		0.017
420	0.049	0.001	0.586	0.005	0.973	0.007	1.006		0.017
430	0.049	0.001	0.590	0.005	0.977	0.007	1.007		0.016
440	0.049	0.001	0.594	0.005	0.977	0.007	1.007		0.016
450	0.050	0.001	0.596	0.005	0.975	0.007	1.008		0.015

Cosine Error

Independent Assessment by Tartu Observatory

Class Specification

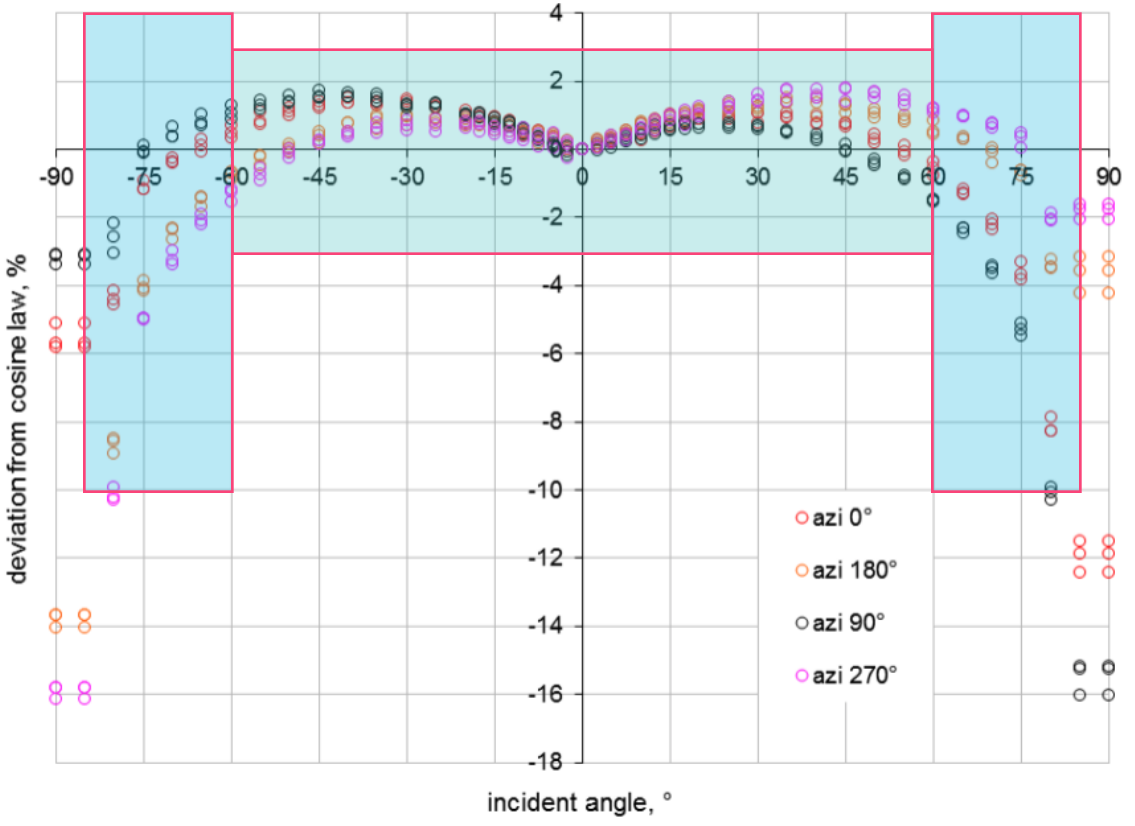


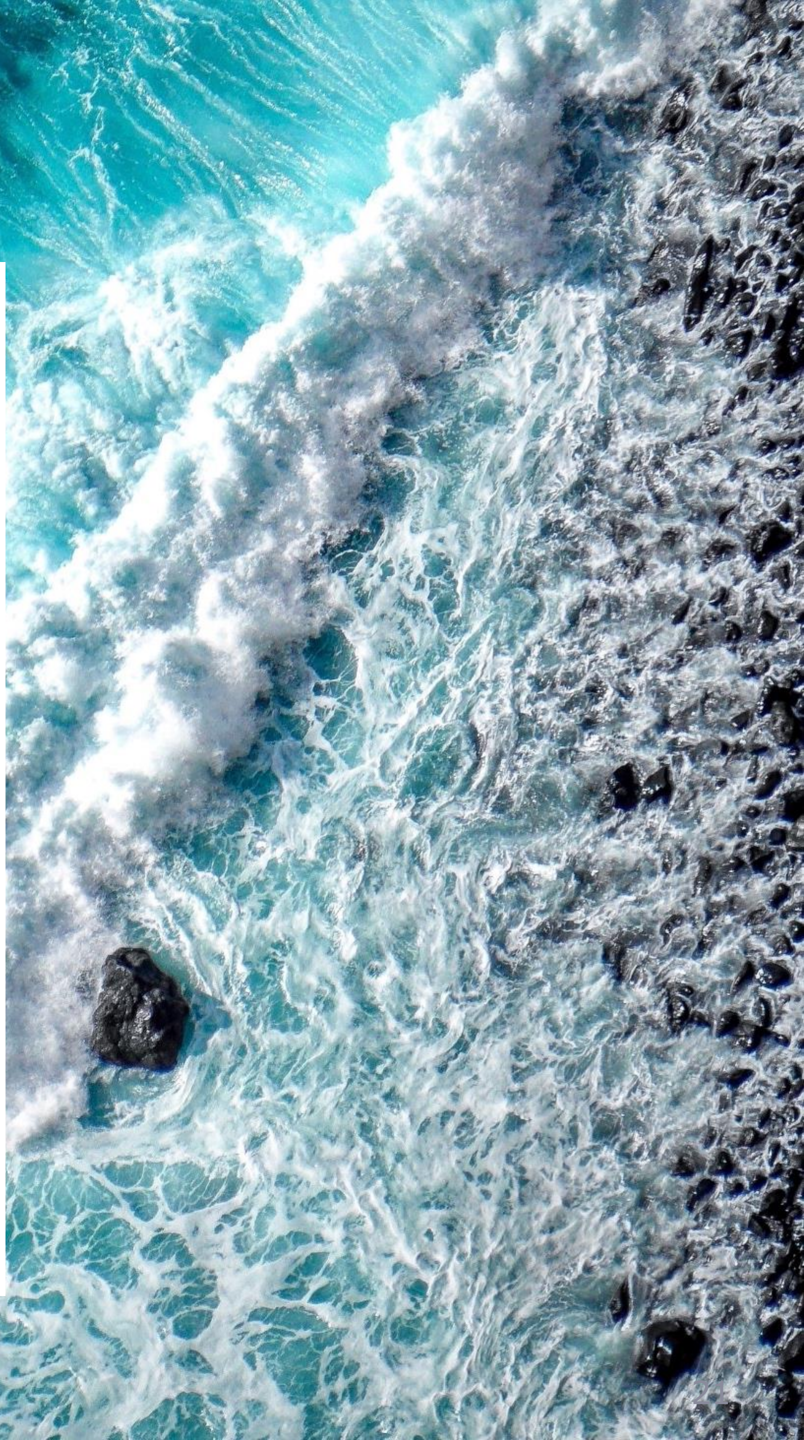
Figure 6-3. Angular response of a HyperOCR irradiance sensor (SAT2027).

SBS Class-Based Characterisations

Thermal Responsivity: Class-based L vs. E

THERM1	Special factored polynomial for thermal responsivity sensors.
Coefficients	**m_0 m_1 m_2 m_3 T_r**
Application	$I^{\lambda} = \alpha^{\lambda}_{Tc} C^{\lambda}_{Tm} \left(\frac{1+(T_c - T_r)(m_0 + m_1\lambda + m_2\lambda^2 + m_3\lambda^3)}{1+(T_m - T_r)(m_0 + m_1 + m_2\lambda^2 + m_3\lambda^3)} \right)$ where: α is the optical sensor intensity value when sensor was calibrated, T_c is the temperature (in C) when sensor was calibrated, C is the optical sensor dark corrected count during sampling, T_m is the measured temperature (in C) during sensor sampling, λ is the wavelength of the optical sensor.
Notes	All data types are valid with THERM1, except AS. Only one calibration line is allowed. The resultant fitted value is a floating-point number.

Thermal Responsivity derived value
THERMAL_RESP NONE '' 0 BU 1 THERM1
-0.011316014.95350e-05-7.488197e-08 4.33976e-1120.0



Class-Based Characterisations

- SBS Thermal Coefficient Model is optimistic

Guidelines for individual OCR full characterisation and calibration FRM4SOC2-D8

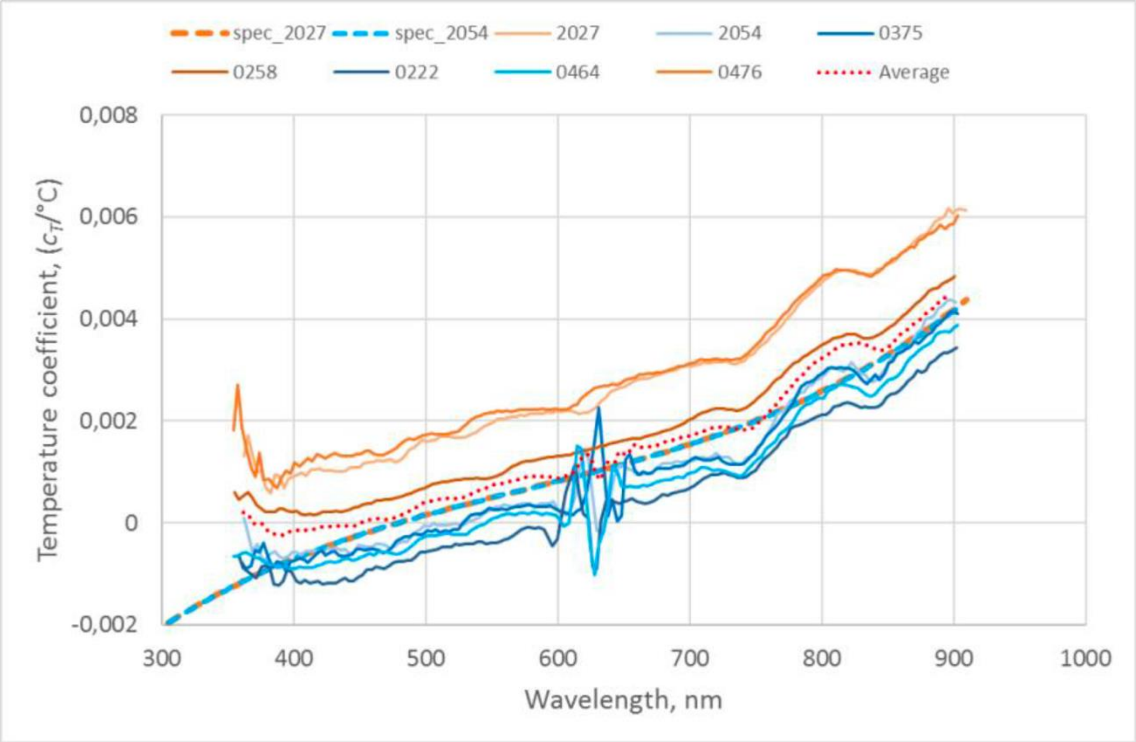
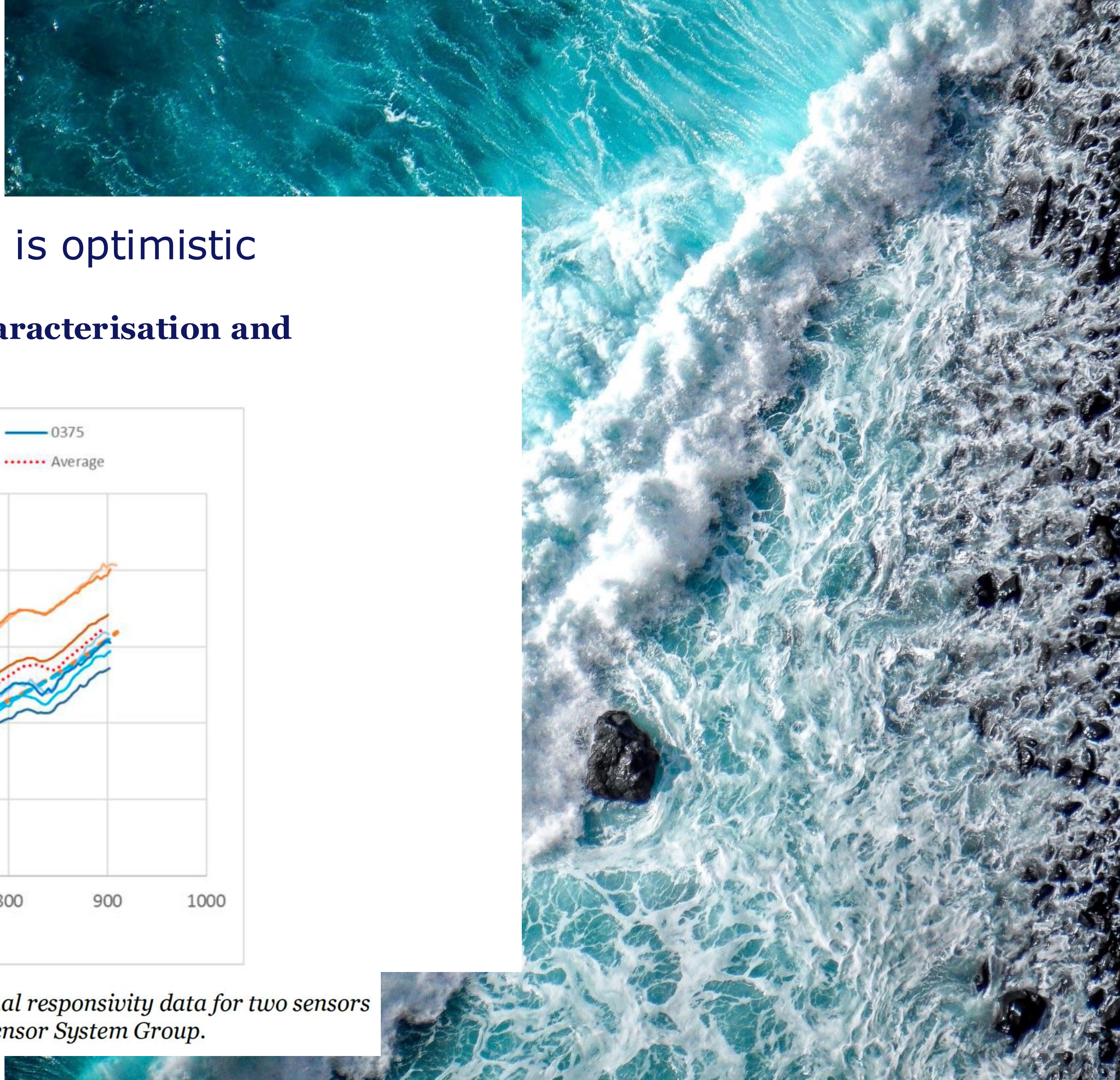


Figure 6-9. Thermal coefficients of seven HyperOCR sensors and thermal responsivity data for two sensors calculated according to the guidance of the Seabird's *Sensor System Group.*



Stray Light: SBS Class-Based Characterization

Tartu: HypeOCR SAT2073

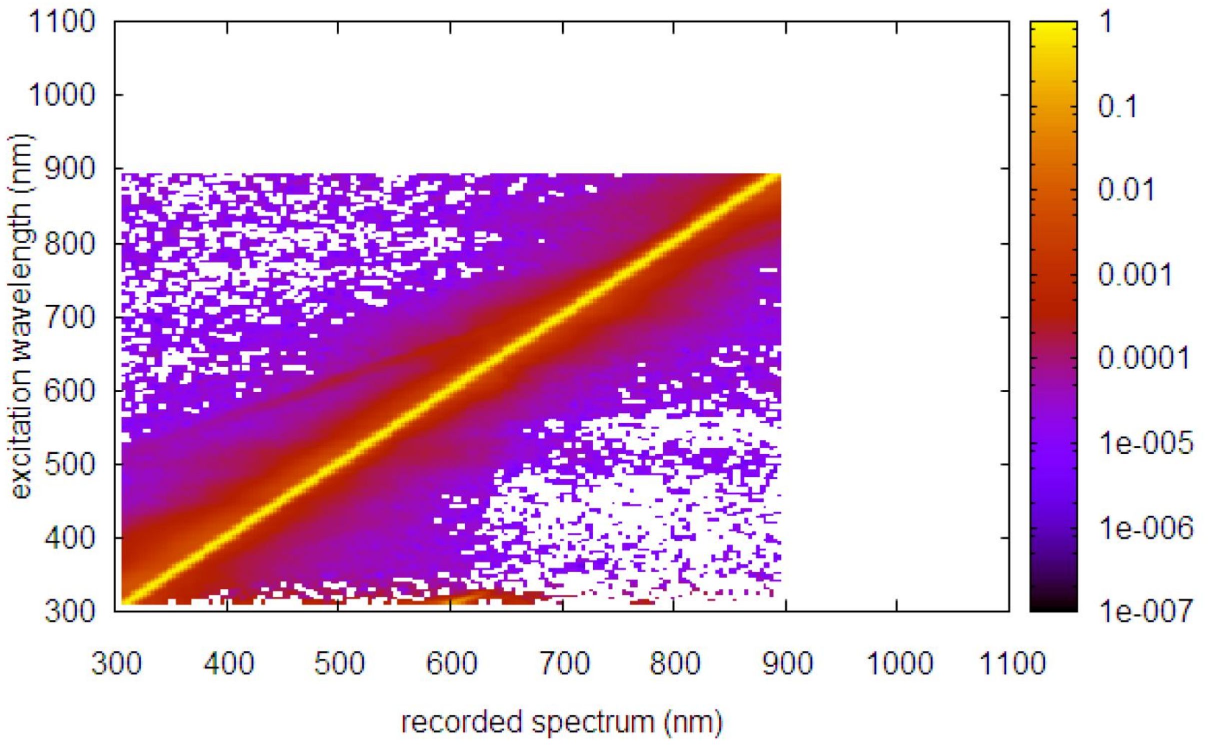
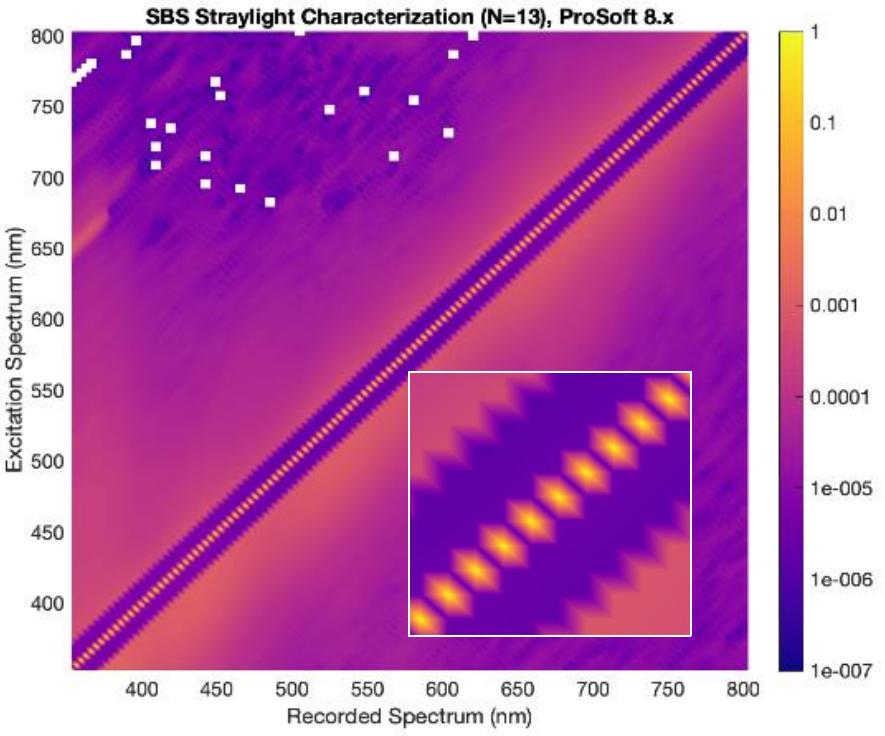


Figure 6-2. Stray light matrix of a HyperOCR radiance sensor (SAT2073). Diagonal values of the SLM are narmalised to 1.

SBS: Generic (Class-Based, N=13,NIST SIRCUS)

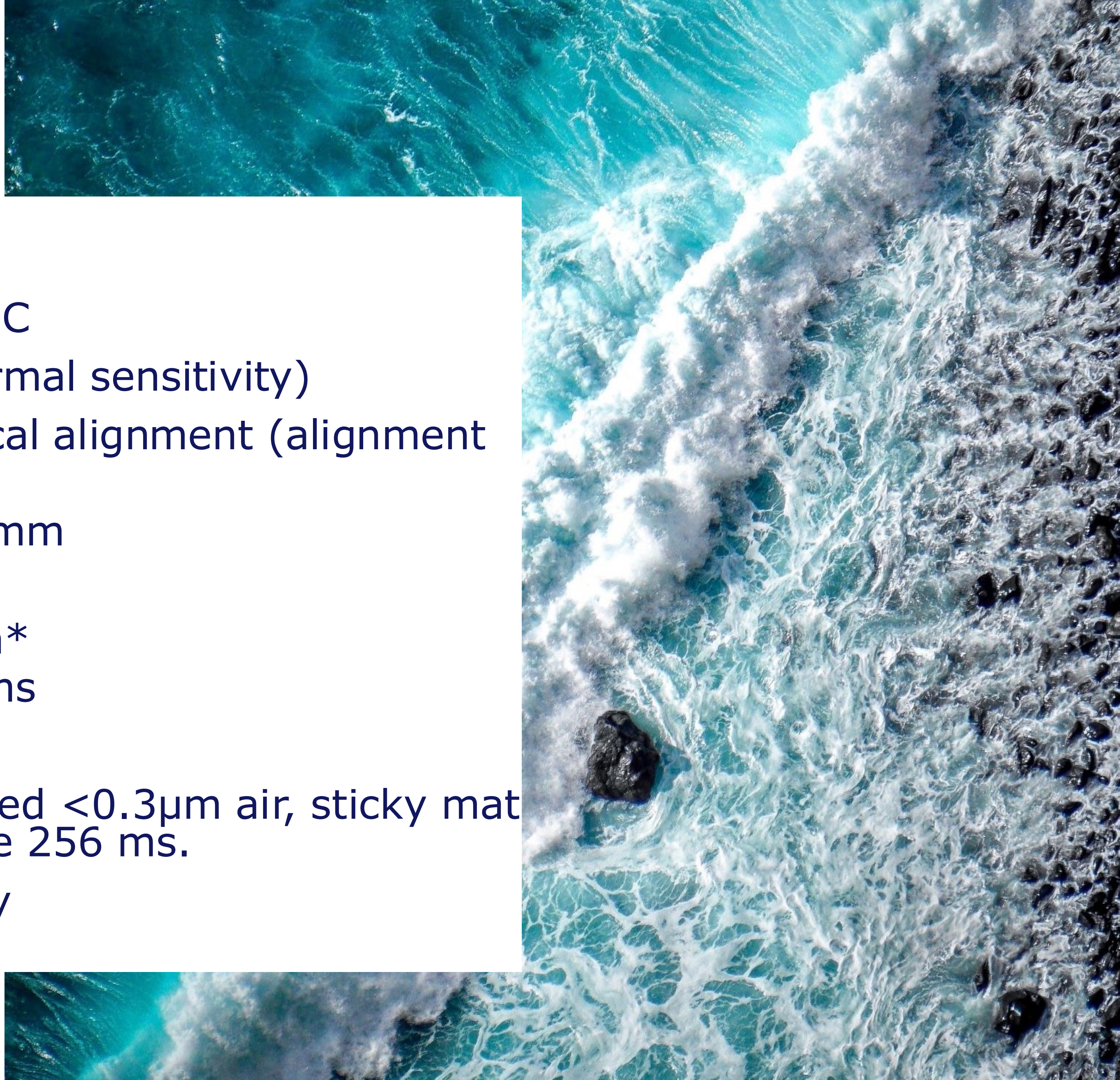


Parameters of SBS radiometers critical for characterisation

Parameters Critical for Characterisation

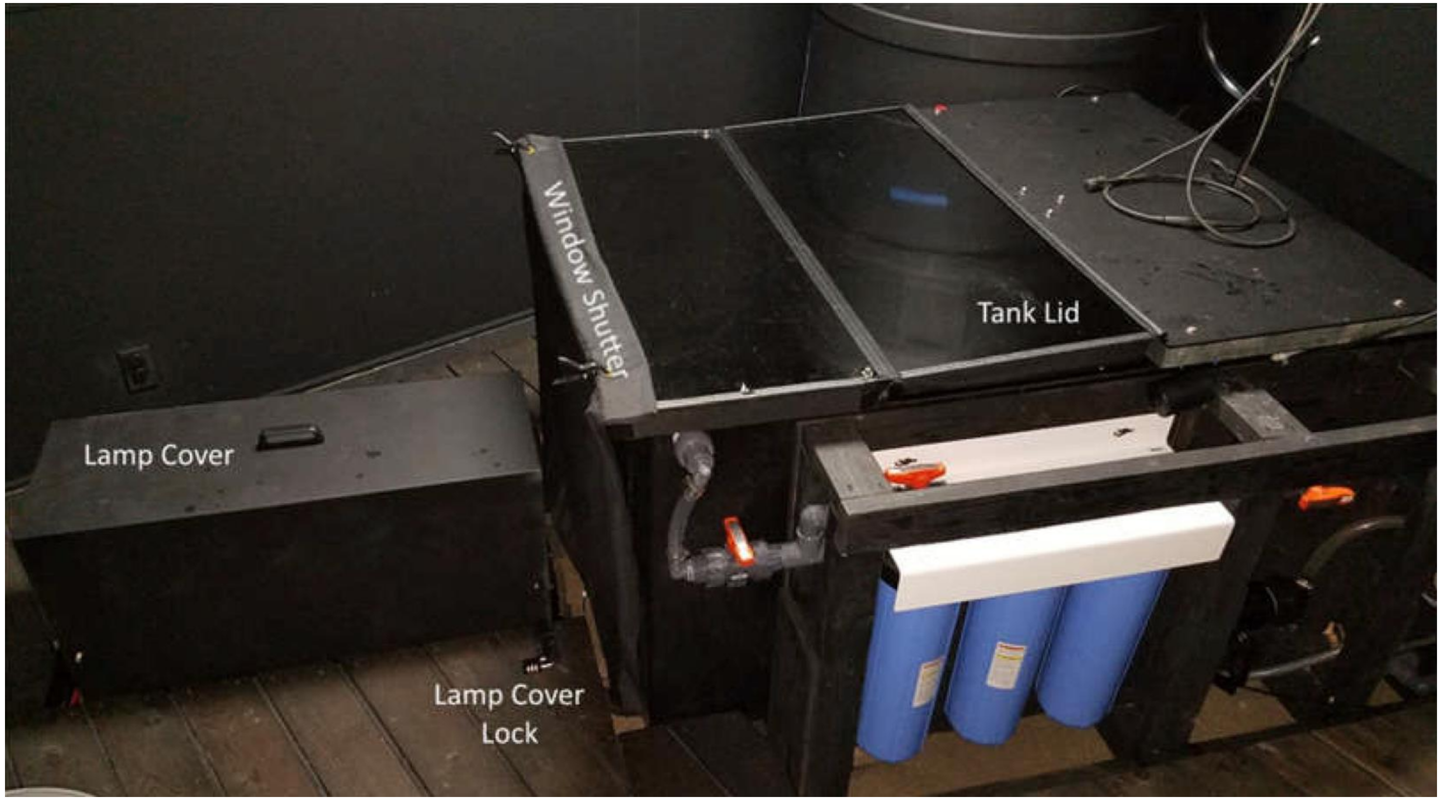
- Stable Cal Lab Temperature: ±0.5°C
- Instrument warm up: >5 min (thermal sensitivity)
- Lamp - Rail – Instrument mechanical alignment (alignment laser)
- Plaque-Radiometer Distance ±0.5 mm
- Consistent integration times
    - Typ. 512 ms to avoid saturation*
    - Except for L_i, L_t 3° FOV: 2048 ms
- Baffling to reduce stray room light
- Dust-free environment: HEPA-filtered <0.3µm air, sticky mat

  * Future 2nd integration time will be 256 ms.
- Cosine Collector Design and Quality



HyperOCR Cosine Characterization

- Custom cosine scanner, ±90 @1° resolution
- Characterize 10-20% from lot



HyperOCR Cosine Characterization

- Custom cosine scanner, 1° resolution
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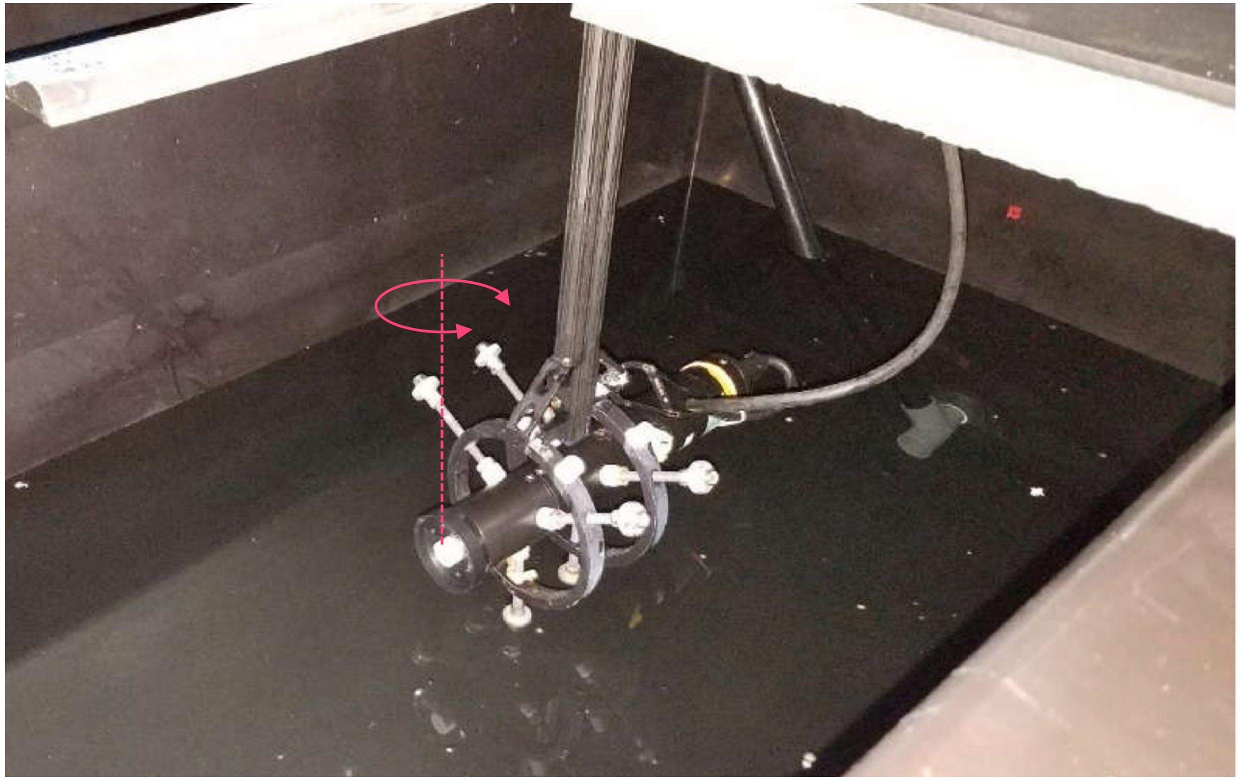


OCR Cosine Characterisation

Table-top cosine scanner scans subset of incoming diffuser lots

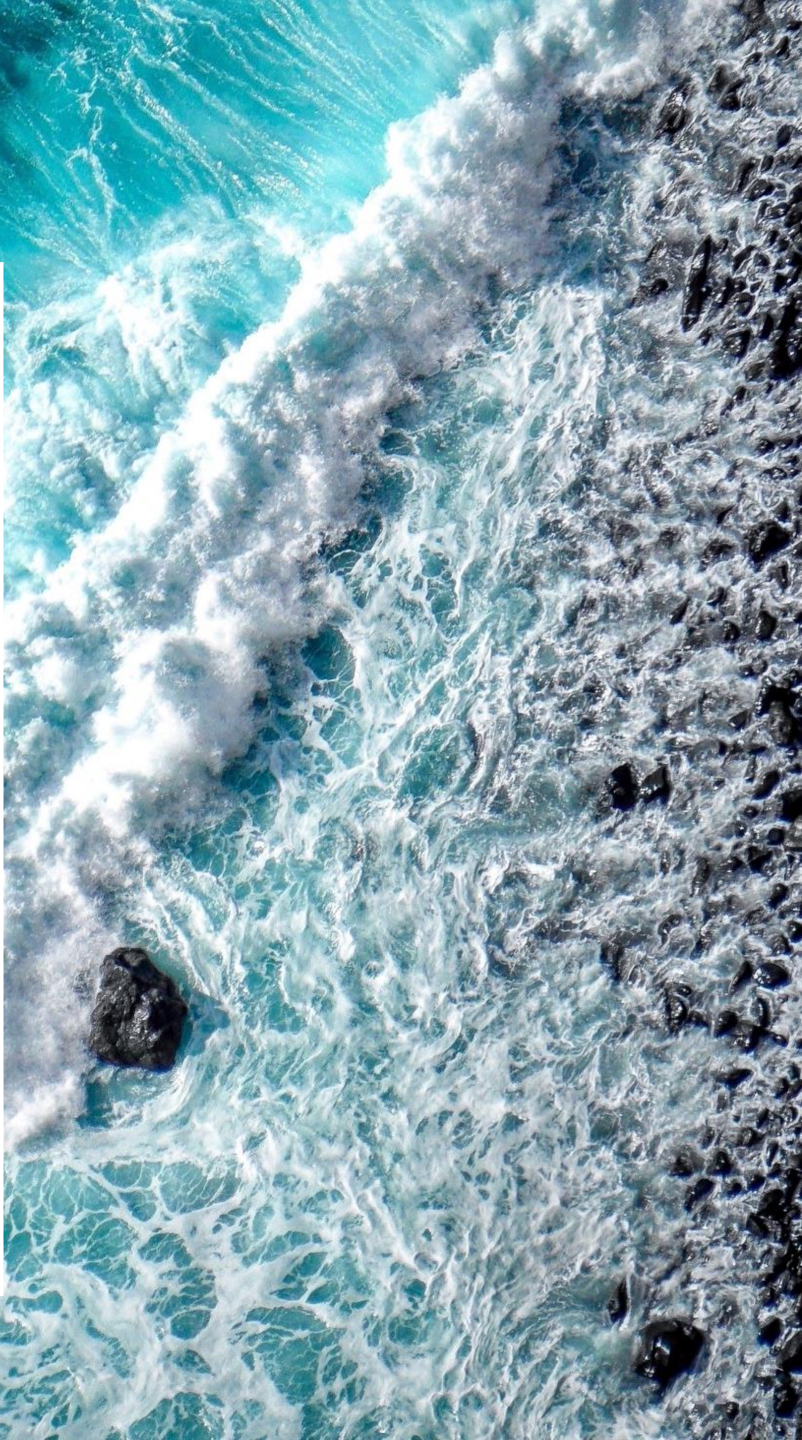
- 10 angles from ±80°/±60°/±40°/±0°

Intercomparison - L

Intercomparisons and validation activities you have already undergone or plan to undertake.

SBS Calibration Facility History

- **1990 - Present**: Sea-Bird Electronics, Bellevue, WA
  - Calibration of physical and BGC ocean sensors
- **1992 – 2010:** WET Labs, Philomath, OR
  - Calibration of optical sensors (ECO, AC-9, C-Star, etc.)
- **1990 - 2011:** Satlantic, Halifax, NS, Canada
  - Radiometric sensor calibration
  - Participation in SIRREX-7 (3/1999), SIMRIC-1 (4/2001), REVAMP (2001), SIMRIC-2 (3/2002), ARC (7/2010)
- **2010-2011:** Sea-Bird acquires WET Labs & Satlantic
- **2017:** FRM4SOC Phase 1 LCE-1, LCE-2
- **2017:** RADCAL-1: Internal LCE to support move of Radiometric Lab from Halifax, NS to Philomath, Oregon.
- **2022-2024**: FRM4SOC Phase 2 LCE
- **2022-2023:** RADCAL-2: Internal LCE to support move of Radiometric Lab from Philomath, Oregon to Bellevue, WA
  - Same reference radiometers as LCE-1 and more



Emerging SBS Uncertainty Budget

- FRM4SOC Phase 2 Laboratory

	Sensor	Uncertainty component	Header field names	Reference	Equations for k=1 uncertainty u_i
1	Irradiance	Responsivity coefficient $\Re$	urc_rel	GUM	$\mathrm{SF} = \frac{E}{LD}, \Re = \frac{1}{\mathrm{SF}}, \quad u_{rc,rel} = \sqrt{u_{LD,rel}^2 + u_{E,rel}^2}$
2	Radiance	Responsivity coefficient $\Re$	urc_rel	GUM	$\mathrm{SF} = \frac{L_p}{LD}, \Re = \frac{1}{\mathrm{SF}}, \quad u_{rc,rel} = \sqrt{u_{LD,rel}^2 + u_{Lp,rel}^2}$
3	Both	Light - Dark	uLD, uL, uD, LD, L, D, Lraw, Draw, L_D0mean, D_D0mean	SBS TriOS GUM	$L = L_{raw}/G_c,\ D = D_{raw}/G_c$ $L = (L_{raw} - D_{0,L})/(65535 * G_c), D = (D_{raw} - D_{0,D})/(65535 * G_c)$ $LD = L - D, \quad G_c = t/t_0$ $u_{LD,rel} = \frac{u_{LD}}{LD}, \ u_{LD} = \sqrt{u_L^2 + u_D^2}, \quad u_L = \frac{\sigma_L}{\sqrt{N_{ave}}}, \quad u_D = \frac{\sigma_D}{\sqrt{N_{ave}}}$
4	Radiance	Plaque radiance L_p D = 130 cm	uLp_rel	GUM	$u_{L_p,rel} =$ $\sqrt{uR_{p,rel}^2 + uE_{fel,rel}^2 + uE_{align,rel}^2 + uE_{lc,rel}^2 + uE_{dist,rel}^2 + uE_{I,rel}^2 + uE_{age,rel}^2}$
5	Irradiance	Irradiance E D = 50 cm	uE_rel	GUM	$u_{E,rel} = \sqrt{uE_{fel,rel}^2 + uE_{align,rel}^2 + uE_{lc,rel}^2 + uE_{dist,rel}^2 + uE_{I,rel}^2 + uE_{age,rel}^2}$
6	Both	Interpolation		White 2017	Propagated directly to uRp_rel and uEfel_rel during interpolation. Summary: Uncertainty of an interpolated point is simply the weighted sum of the known uncertainties of the measured data points, with spline interpolation coefficients as weights. *Wavelength uncertainty is ignored:* $u_\lambda = 0$.
7	Radiance	Plaque reflectance R_p	uRp_rel	NIST Avian Technologies	$uR_{p,rel} = \sqrt{uR_{p,Avian,rel}^2 + uR_{ref,NIST,rel}^2}$ $uR_{p,Avian,rel}$ = (Avian Calculated 0°/45° Uncertainty, k=2) / 2 $uR_{ref,NIST,rel}$ = (NIST 1995 PTFE reference, k = 2) / 2
8	Both	Lamp E_{fel}	uEfel_rel	Optronic	$uE_{fel,rel}$ from Optronic Laboratories data sheet.
9	Both	Shunt	uEshunt_rel	Kuusk 2017 D-130	$uE_{shunt,rel} = 0.002\%$
10	Both	Alignment	uEalign_rel	Kuusk 2018 D-130	$uE_{align,rel} = 0.1\sqrt{N_{sources}}\%$ $= 0.17\%, N_{sources} = 3 \ (L_p: lamp, plaque, sensor)$ $= 0.14\%, N_{sources} = 2 \ (E: lamp, sensor)$
11	Both	Lamp center	uElc_rel	Yoon 2012 SBS 2017	$uE_{lc,rel} = 0.27\% \ (E)$ $= 0.10\% \ (L_p)$
12	Both	Distance	uEdist_rel	GUM	$uE_{dist,rel} = 2\frac{u_D}{D}\sqrt{N_{sources}}, \ N_{sources}$ $= 2 \ (lamp + plaque/sensor)$ $= 0.063\%, D = 130 \text{ cm} (L_p)$ $= 0.163\%, D = 50 \text{ cm} \ (E)$ Assume uniform distribution $\delta_d = \pm 0.5 \ mm \rightarrow \ u_D = \delta_d/\sqrt{3}$
13	Both	Lamp current	uEI_rel	SBS 2017b	$uE_{lamp,rel} = \frac{\partial E_{fel}(\lambda)}{\partial I}\delta I$, where: Sensitivity coeff $\frac{dE_{fel}(\lambda)}{dI}$ derived by experimentally varying lamp current $\delta I = 0.1$ mA from observation of shunt current during calibrations
14	Both	Lamp aging	uEage_rel	Bernhard & Seckmeyer 1999	$uE_{age,rel} = \frac{0.6}{\sqrt{3}} T_{lamp}/50 \ \%$, where: $T_{lamp} =$ cumulative number of lamp hours, recorded in FEL lamp logAssumes uniform distribution of lamp change over 50 hours.

RADCAL-1: – Uncertainty of Repeat calibrations at each site

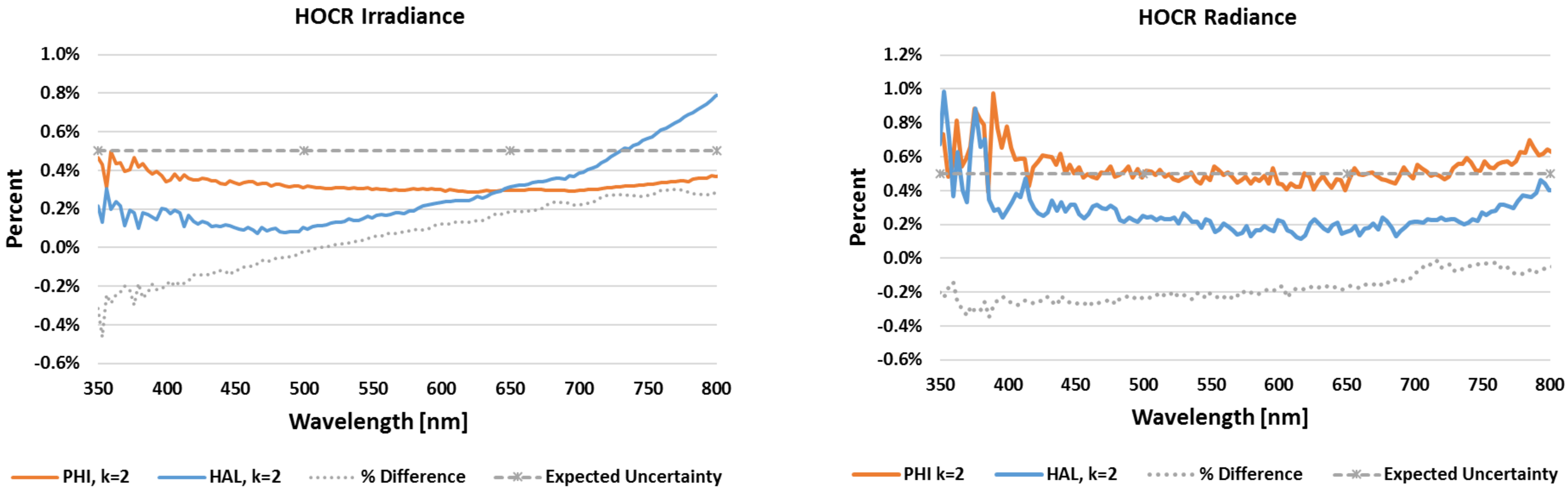
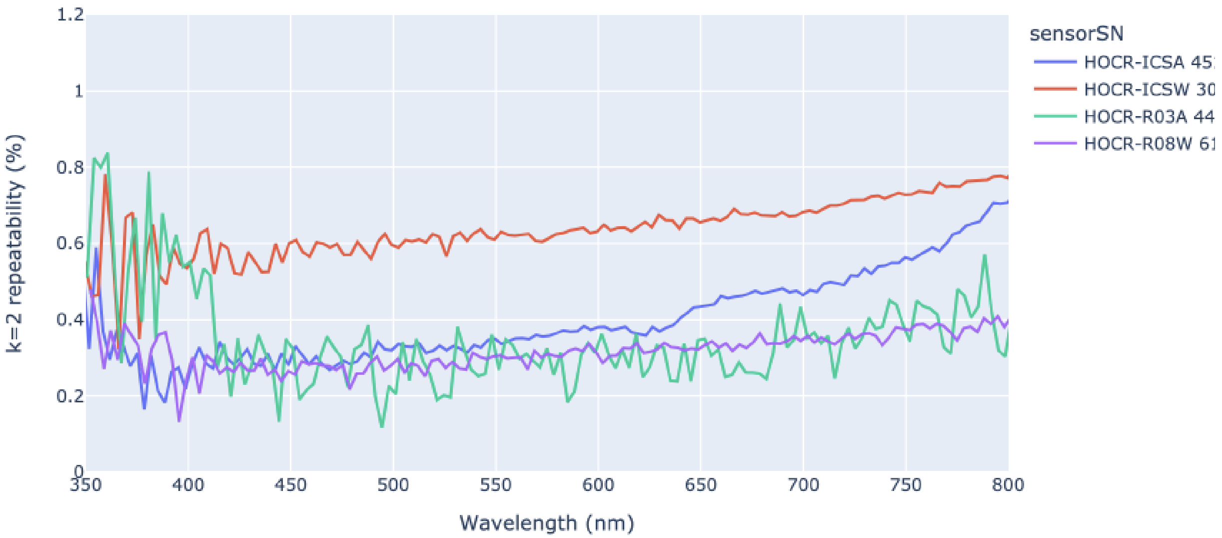


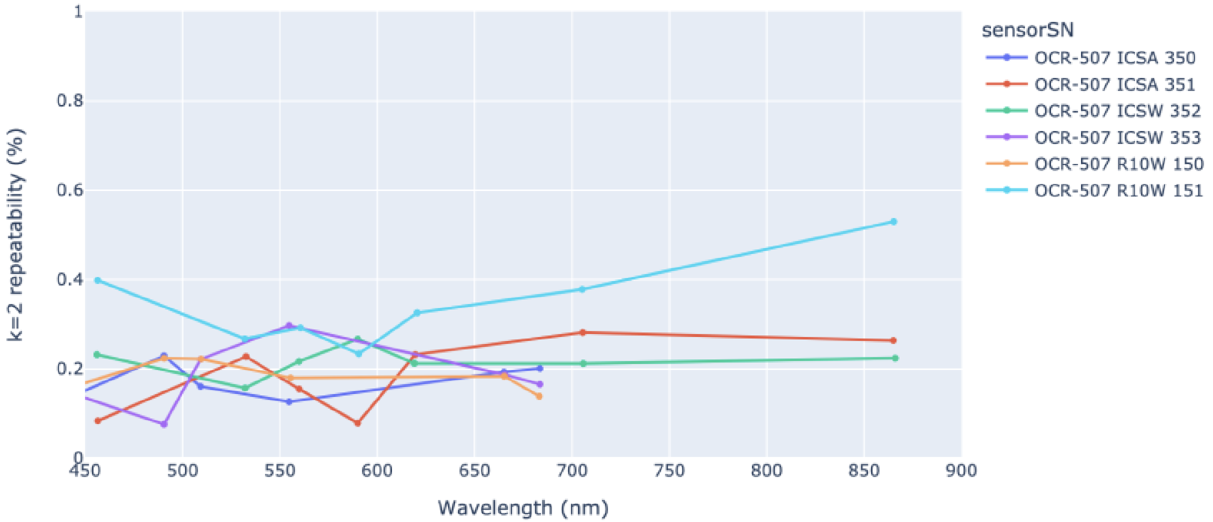
Figure 2: A. Uncertainties for repeated calibrations of HOCR irradiance sensors ($k = 2$) for HAL (blue line) and PHI (orange line) sites. B. Uncertainties for repeated calibrations of HOCR radiance sensors ($k = 2$) for HAL (blue line) and PHI (orange line) sites. The percent difference of PHI relative to HAL site (gray dots) and expected uncertainties for use of the same equipment (gray asterisks, dashed line) are also shown x`x

RADCAL-2: – Uncertainty of Repeat calibrations at each site

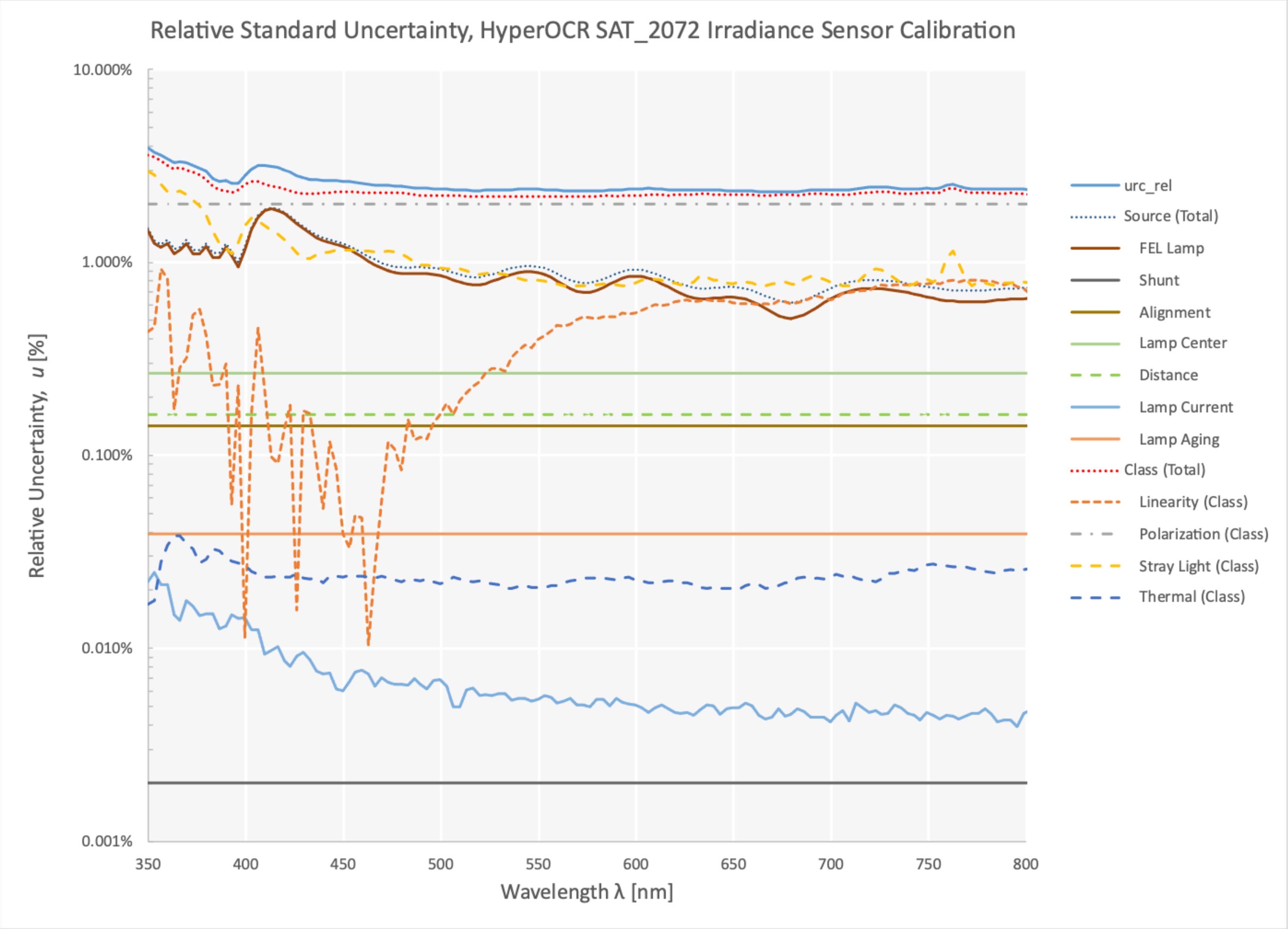
HOCR K=2 Repeatability, BEL3



OCR K=2 Repeatability, BEL3



FRM4SOC Phase 2 LCE Uncertainty Budget – with HyperCP class uncertaintIESs ---



Motivation and questions regarding IOCCG's Addendum to Protocol No. 3: "Request to Manufacturers of in situ Spectral Imaging Radiometers"

Innovations in ocean color from space, aircraft, towers, etc.

IOCCG Protocol 3 Addendum: June 2024

Sea-Bird agrees to:

- **Provide absolute calibration coefficients with associated uncertainties.* This is most pressing**. The calibration uncertainty associated with the radiometer absolute response is essential. It is required to provide traceability to SI. Without these, users may not be able to achieve the FRM standard.

- ☑ **Participate in comparison experiments with national metrology institutes** and/or secondary calibration laboratories. Such experiments can provide metrology support on laboratory standards, laboratory set up, and ensure metrological compatibility of the absolute calibration coefficients.

- ☑ **Help to propagate FRM guidelines, procedures and tools**. Information can be provided in radiometer manuals and in direct communication with customers about existing FRM resources, such as additional characterisations and enhanced calibrations needed to achieve the FRM standards, and guidance tothe IOCCG and FRM4SOC documentation to ensure that manufacturers, calibration labs, and users have an unambiguous understanding.

* "absolute calibration coefficients with associated uncertainties." Clarify…

Continuing the journey with the radiometric community: FRM4SOC D-27

"(D-27) is intended to inform radiometer manufacturers about a list of requirements to meet the FRM standard"

IR1M. Responsivity Uncertainty

IR2M. Straylight/out-of-band response uncertainty.

IR3M. Angular response uncertainty.

IR4M. Non-linearity correction / uncertainty

IR5M. Thermal response correction

IR6M Polarisation uncertainty

IR7M. Dark signal removal uncertainty

IR8M. Temporal response

IR9M. Wavelength scale uncertainty

Report uncertainties

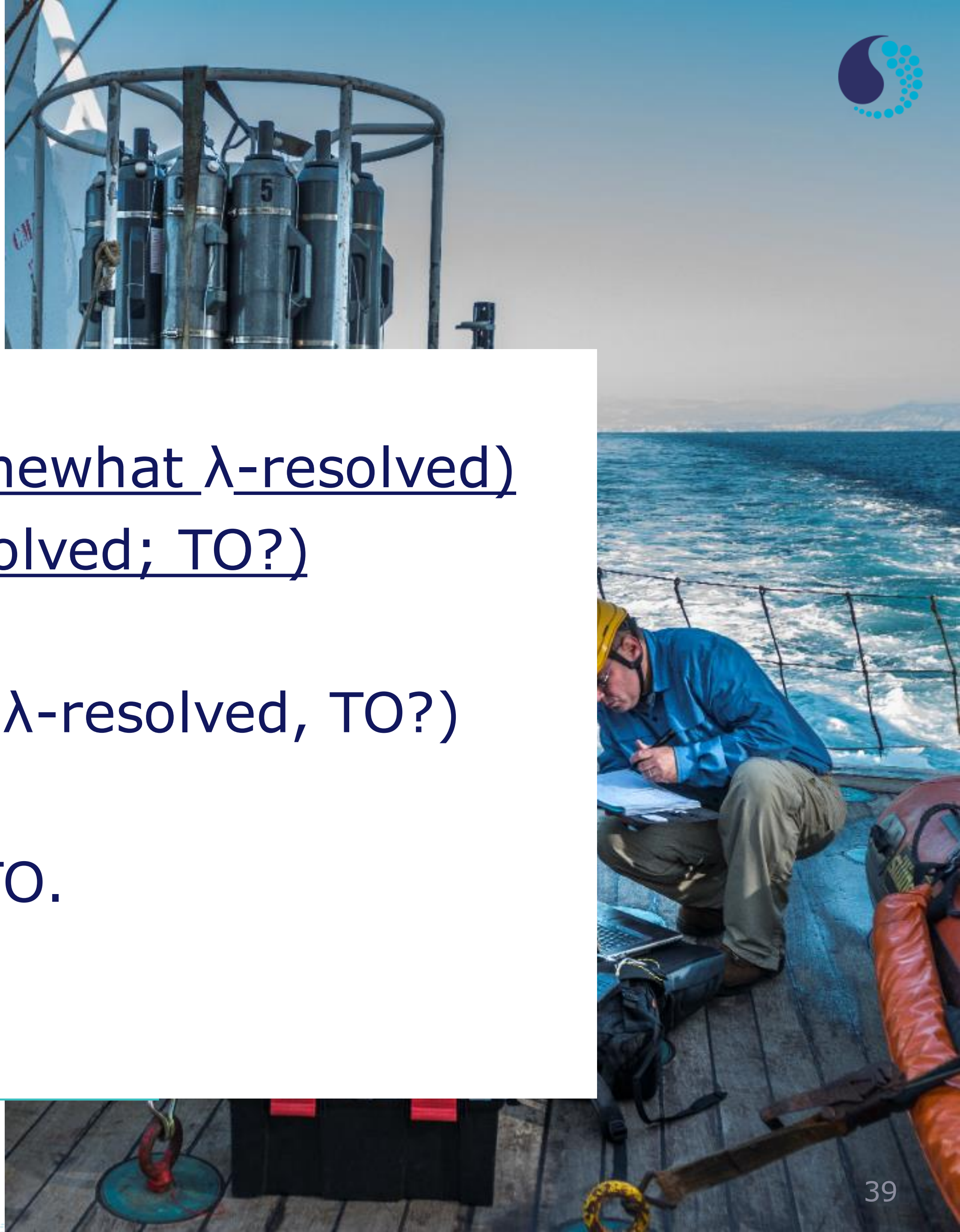
8.10. Determination of the temporal response

To be updated in the following versions of this document (D-12).

HyperCP: Class-based uncertainties available for HyperOCR E, L

- **STAB:** Long-term stability: 1%
- **POLAR:** Polarisation: 0.6 – 2.0% (somewhat λ-resolved)
- **STRAY:** Straylight: 0.7– 2.5% (λ-resolved; TO?)
- **LINEAR:** Linearity: 2%
- **THERMAL:** Thermal response: c_T, u_{c_T} (λ-resolved, TO?)

- Need to verify with internal data and TO.



Summary

	Sensor-Specific	Occasional	Initial	Class-based
Radiometric responsivity	.cal / CALDATA			
Spectral response		X / Zeiss		
Out-of-Band & Stray Light				STRAYDATA*
Immersion factor (irradiance)				X / .cal / ?
Immersion factor (radiance)				X / .cal / ?
Angular response	*** (cosine)			specification
Linearity	*CALDATA***			X
Integration time				Verify design
Temperature Response	*X / THERM1*			X
Polarization sensitivity				TO?
Dark signal	X / shutter			
Temporal response				
Pressure effects				

	Regular	Occasional	Initial	Class-based
Radiometric responsivity	X			
Spectral response		X		
Out-of-band & stray light		X		
Immersion factor (irradiance)			X	
Immersion factor (radiance)				X
Angular response			X	
Linearity				X
Integration time				X
Temperature response				X
Polarization sensitivity				X
Dark-signal	X			
Temporal response				X
Pressure effects				X

* SBS and Tartu have class-based characterizations (reconcile)

** Provide $S_1, S_2, \sigma_{S_1}, \sigma_{S_2}$: data and stdev for two integration times

*** Extra fee? TO?

Continuing the journey with the radiometric community: D-27

IR1M. Responsivity Uncertainty

IR2M. Straylight/out-of-band response uncertainty. Class-based SLM with uncertainty.

IR3M. Angular response uncertainty. Class-based (cosine) based on cosine spec. Others tbd.

IR4M. Non-linearity correction / uncertainty based on FidRadDB CALDATA.

IR5M. Thermal response correction (THERM1 equation) Thermal sensitivity uncertainty (Tartu)

IR6M Polarisation uncertainty (Tartu Obs?)

IR7M. Dark signal removal uncertainty FidRadDB CALDATA)

IR8M. Temporal response

IR9M. Wavelength scale uncertainty

8.10. Determination of the temporal response

To be updated in the following versions of this document (D-12).

Continuing the journey with the radiometric community: FRM4SOC D-27

"(D-27) is intended to inform radiometer manufacturers about a list of requirements to meet the FRM standard"

- **DR1M.** Each measurement result shall be linked to an OCR instrument, identified by serial number, and for which a document is available describing the SI traceable calibration and characterisation history.

- **DR2M.** Each measurement result shall be linked to a document describing the detailed methodology used to estimate uncertainties IR1-IR9M, including all relevant equations, physical models and their associated parameters.

Metadata, Methods

8.10. Determination of the temporal response

To be updated in the following versions of this document (D-12).

instrument.seabirdhub.com

News C N ECO V2 prototype... SBE Argo Takuvik Ham Home PVST

Search by Platform | Search by Sensor

Sensor Serial Number

0490

Sensor Model

MCOMS_FLBBCD

Sensor Type

BACKSCATTERINGMETER_BBP700

Format

Argo

View Metadata | Download .json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{
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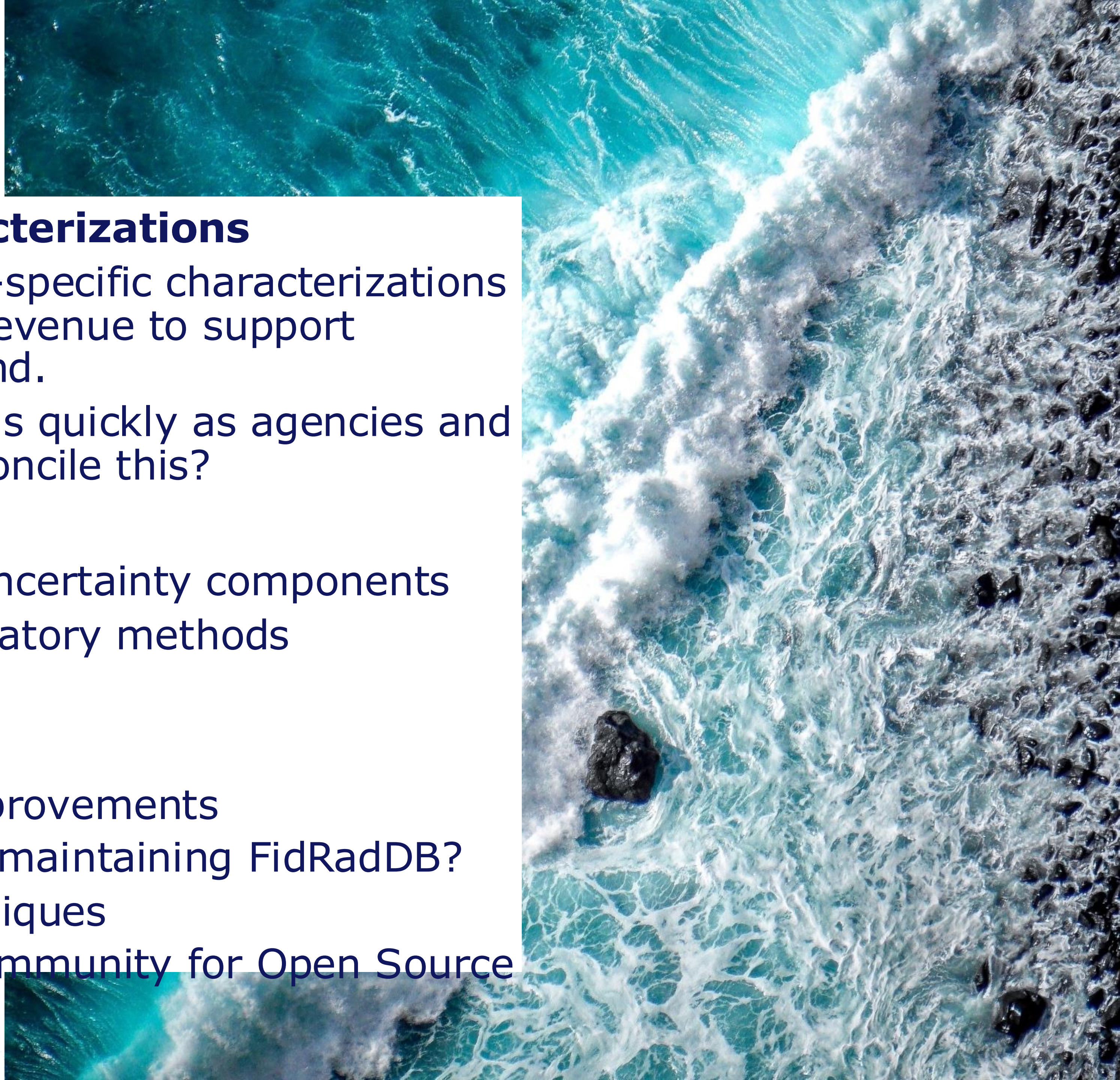
What kind of support do you expect from the community and other laboratories?

Innovations in ocean color from space, aircraft, towers, etc.

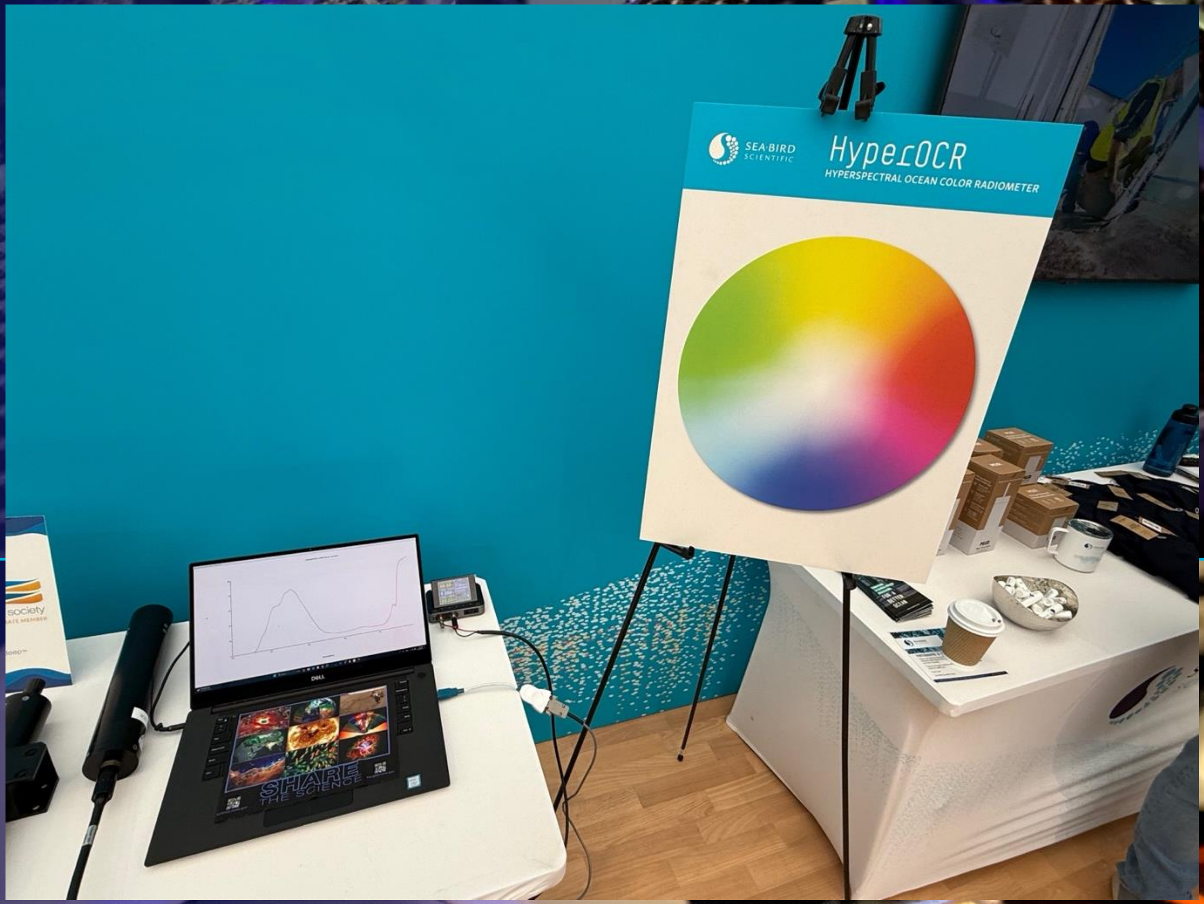
Community / Lab Support

- **Carryout Sensor-specific characterizations**
  - SBS may not find many sensor-specific characterizations cost-efficient, i.e., insufficient revenue to support investment given overall demand.
  - SBS may not be able to move as quickly as agencies and community wants? How to reconcile this?
- **Guidance on:**
  - Implementation of FRM4SOC Uncertainty components
  - Best Practices / Improved laboratory methods
  - Calibration equipment selection
- **Continued FRM4SOC Program**
  - Hold more LCE's to validate improvements
  - EU: Long-term commitment to maintaining FidRadDB?
  - Vetting of new calibration techniques
  - Call for support from vendor community for Open Source Community Processors
- **Fairness and Transparency**



Aitäh!

Eric Rehm
erehm@seabird.com



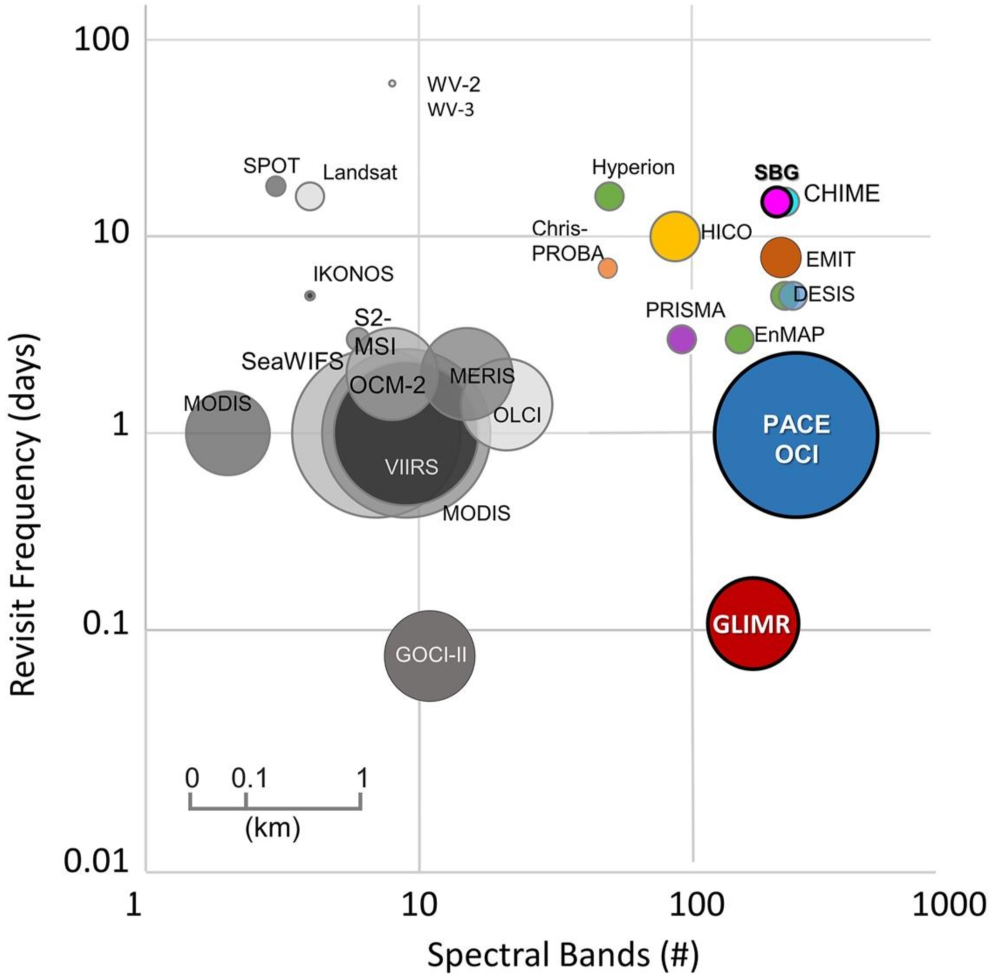
HyperOCR

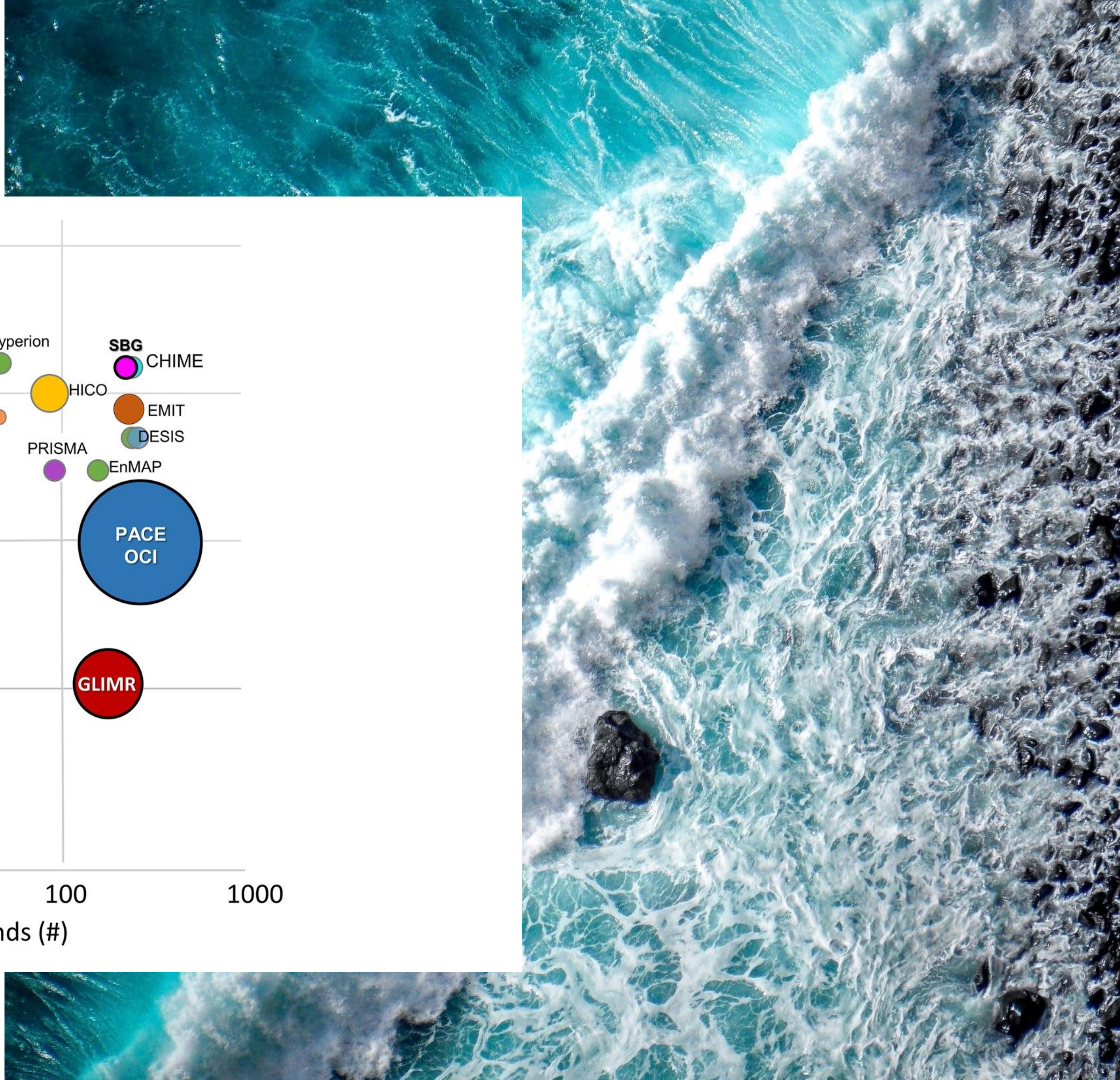
Why?

	HyperOCR Specifications	IOCCG Recommendations
Spectrograph range	305-1100 nm	
Factory calibration	350 - 800 nm (900 nm)	380-900 nm
Spectral sampling	3.3 nm	1-3 nm
Spectral accuracy	0.3 nm	0.1 – 0.3 nm
Spectral resolution	10 nm	3-10 nm
Stray light	< 1e-03 (correctable to 1e-05)	1e-05
Detectors	256 channel photodiode array	
Entrance Slit	70 x 2500 μm	
Noise Equivalent Irradiance (NEI) (@ 500 nm @ 1024 ms)	0.0010 *air* μW cm^{-2} nm^{-1} 0.0015 *water*	
Noise Equivalent Radiance (NER) (@ 500 nm @ 1024 ms)	5.3e-05 *air* μW cm^{-2} nm^{-2} sr^{-1} 9.0e-05 *water*	
Irradiance cosine error	3% 0-60°, 10% 60-85°	
Radiance Field of View (FoV)	$\theta_{1/2} = 3^\circ\ air,\ 8^\circ\ water$	
Frame Rate	3 Hz @ 128 ms int. time	
Integration time	128 – 2048 ms (adaptive gain)	

IOCCG International Ocean Colour Coordinating Group

PACE & Hyperspectral Missions



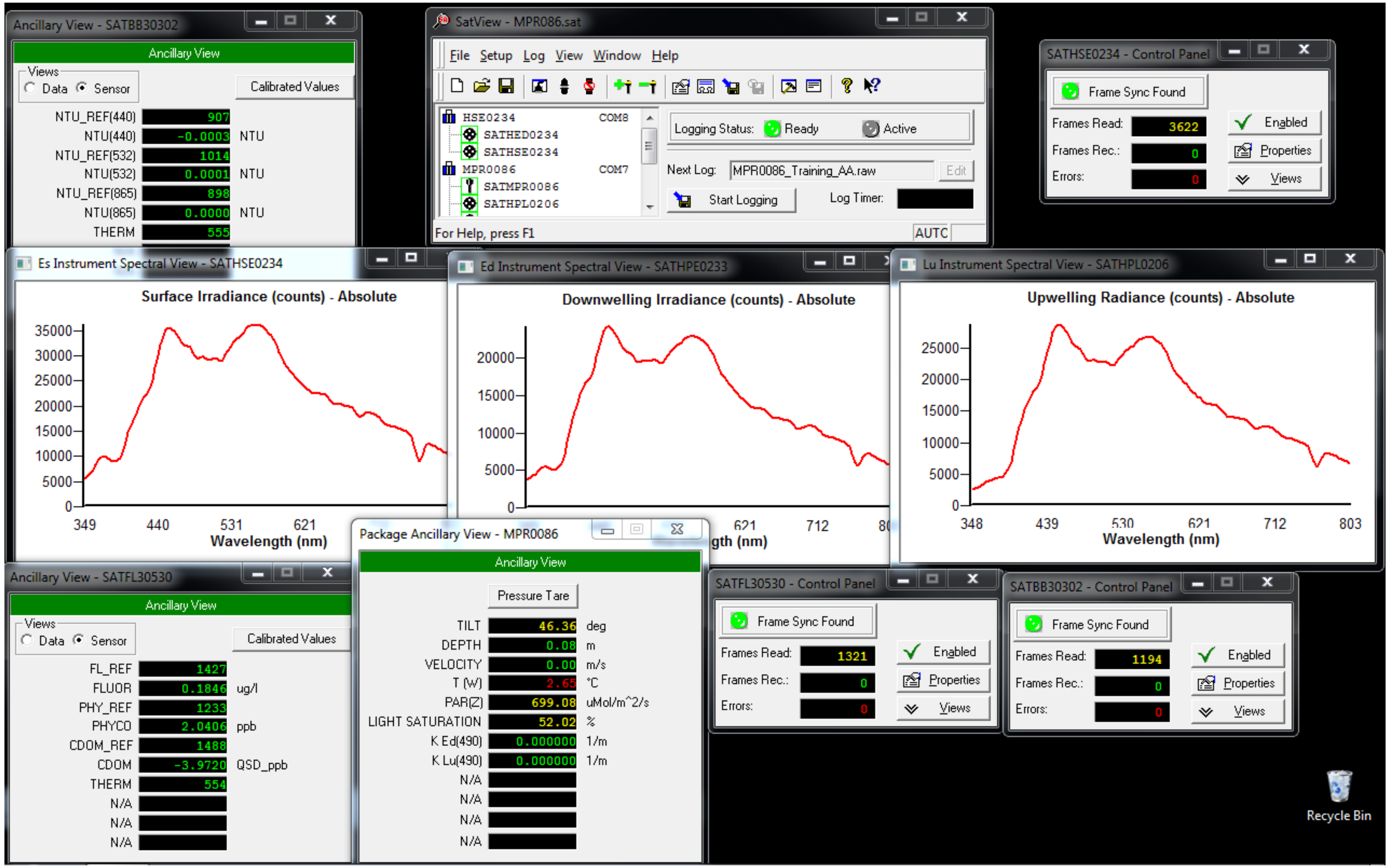


HyperOCR

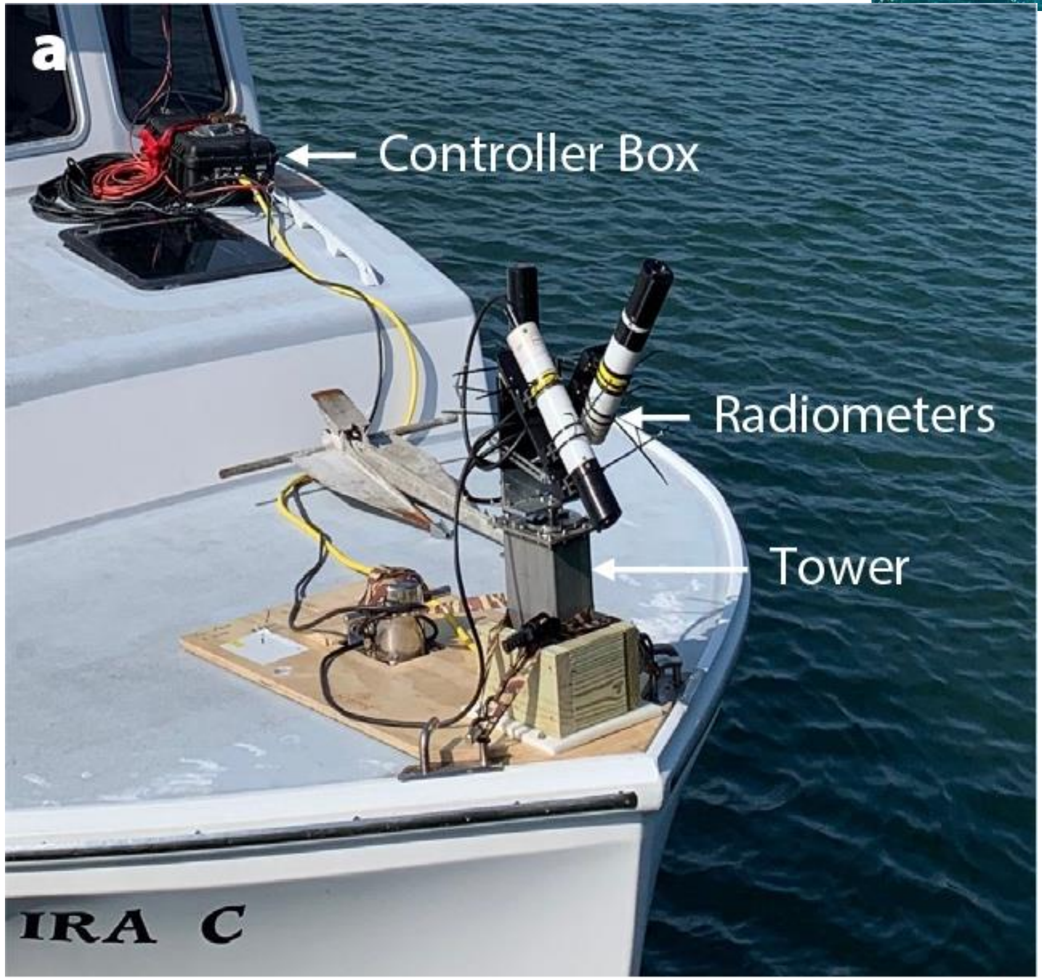
How does it work?

Zeiss MMS 1

SatView : Es, Ed, Lu

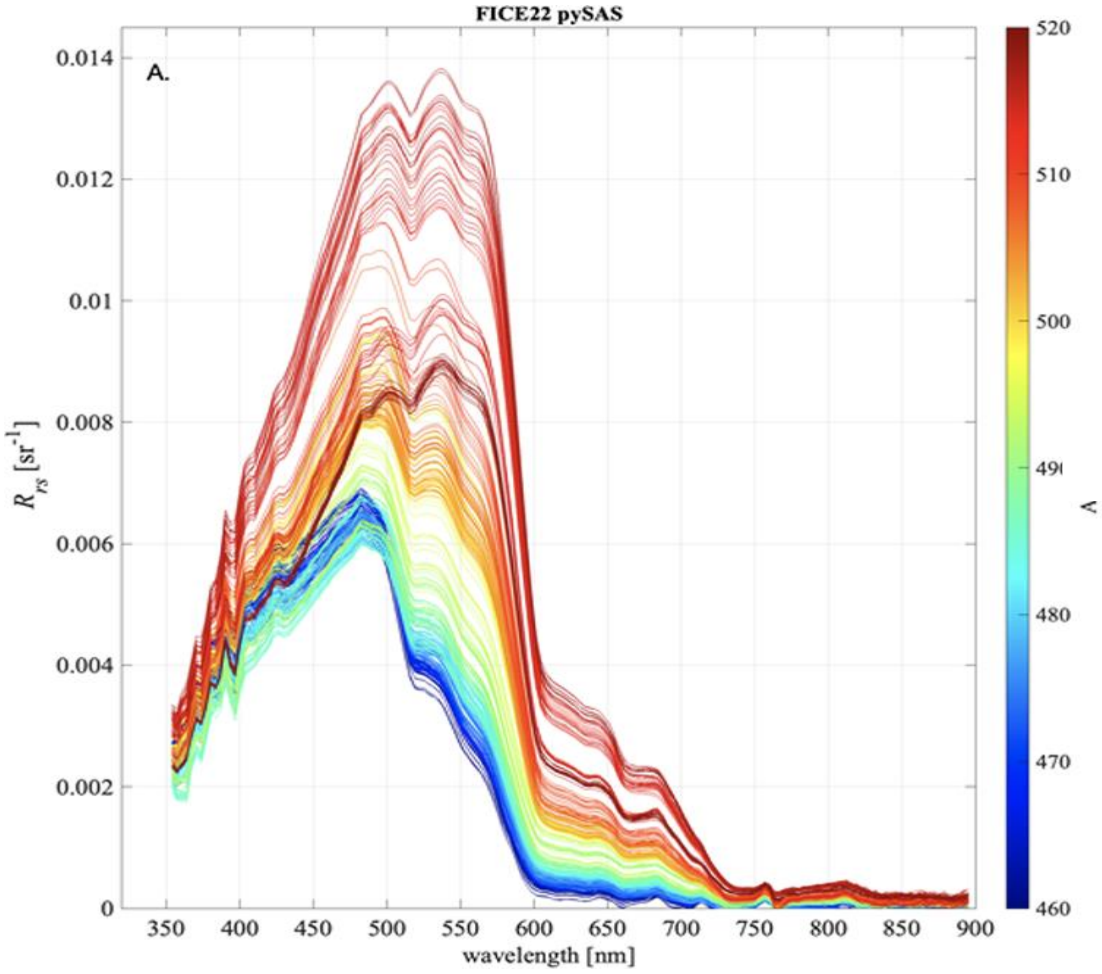


pySAS

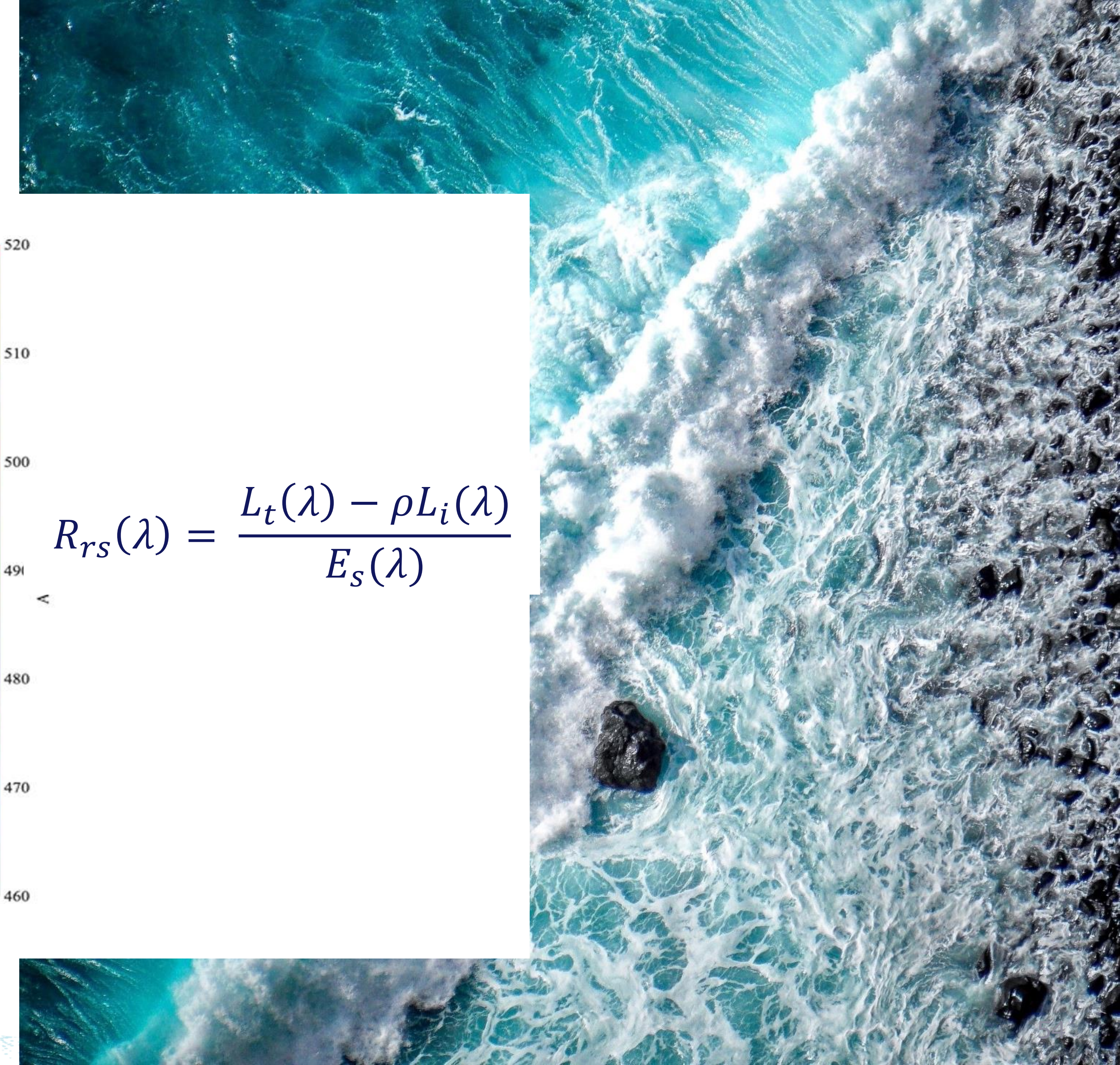


Open Source pySAS https://doi.org/10.5670/oceanog.2022.210

$R_{rs}(\lambda)$ from pySAS



$$R_{rs}(\lambda) = \frac{L_t(\lambda) - \rho L_i(\lambda)}{E_s(\lambda)}$$

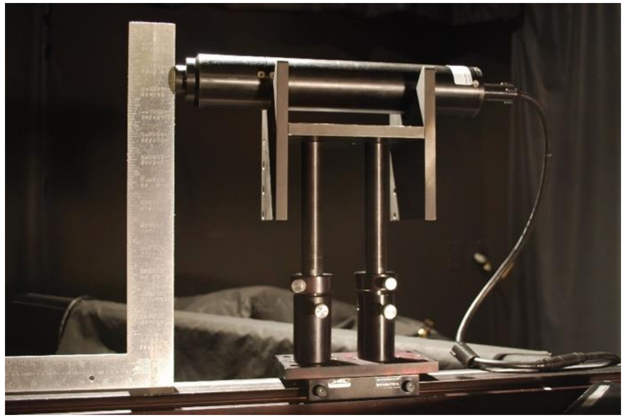


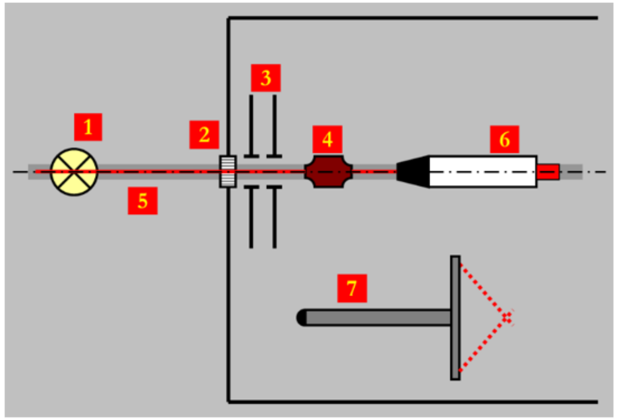
Tillson et al. 2025

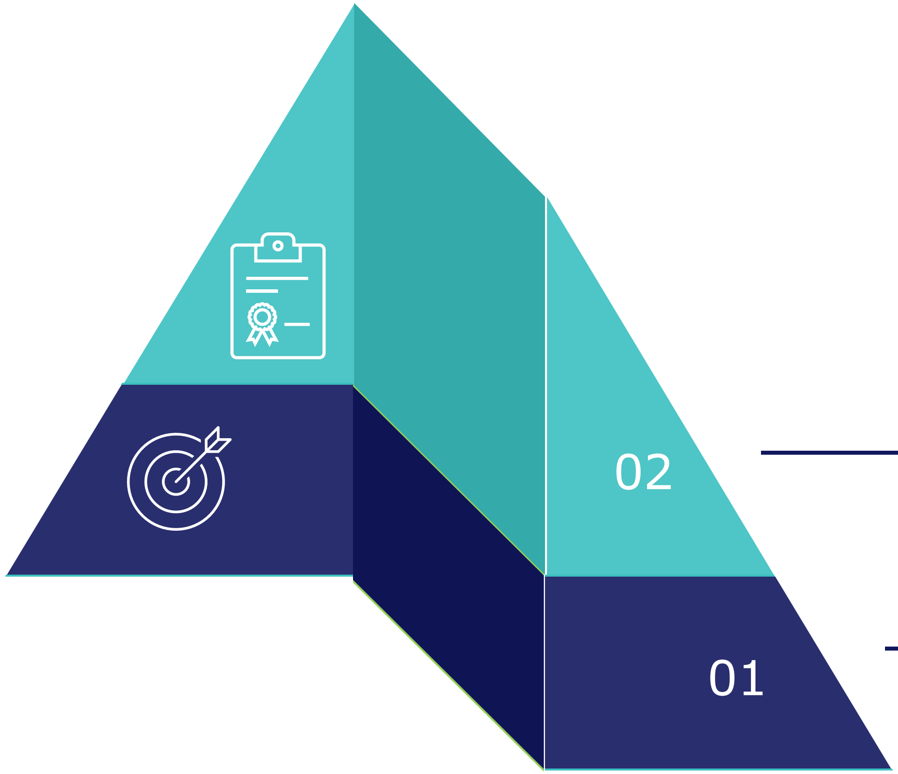
HyperOCR

Measurement Traceability

Radiometric Traceability: Irradiance $E(\lambda)$





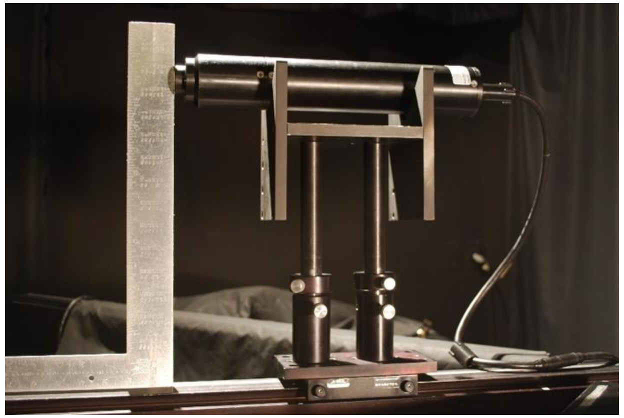


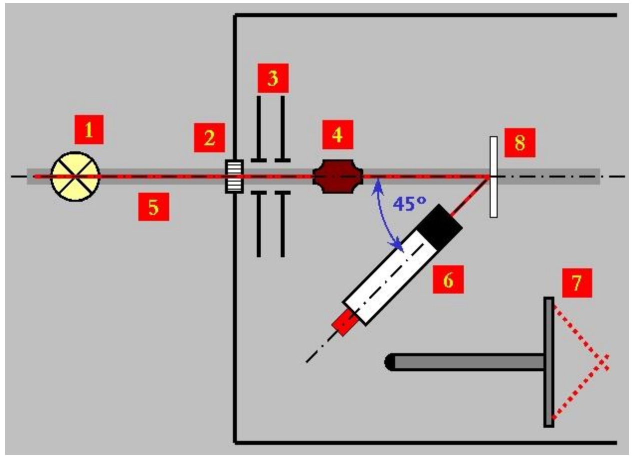
NIST Traceable Irradiance Source

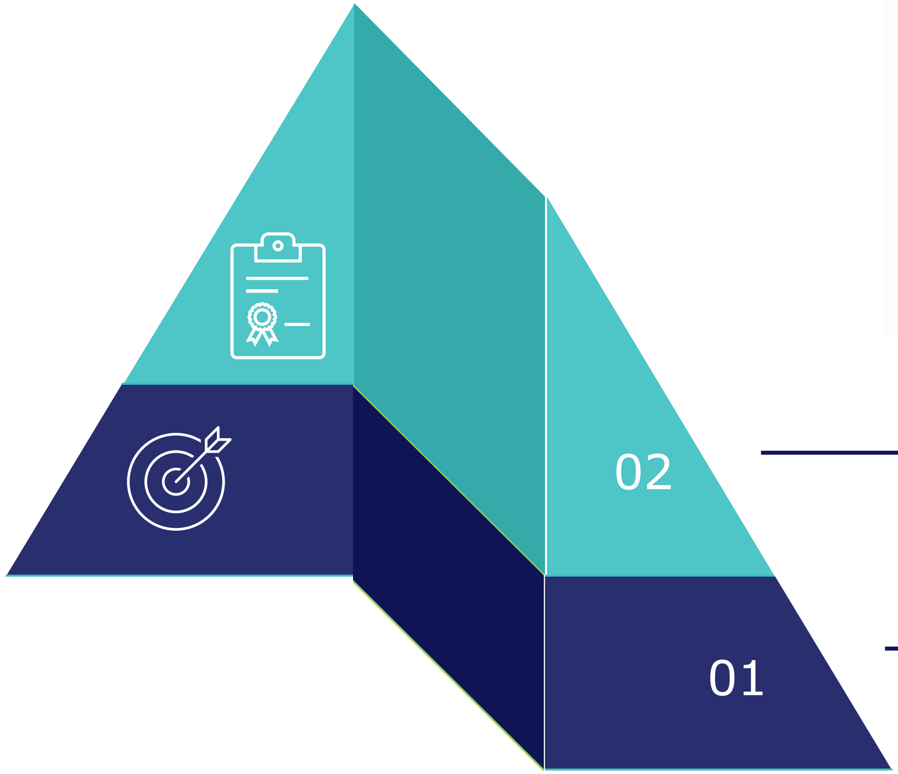
Known Irradiance $E(r,\lambda) = \dfrac{E(0,\lambda)}{r^2}$

Radiometer Sensors

Radiometric Traceability: Radiance *L(λ)*







- NIST Traceable Irradiance Source $E(r,\lambda)$ and NIST Traceable Reflectance Plaque $\rho(\lambda)$

  Known Radiance $L(\lambda) = \rho(\lambda) \cdot E(r,\lambda)$

- Radiometer Sensors

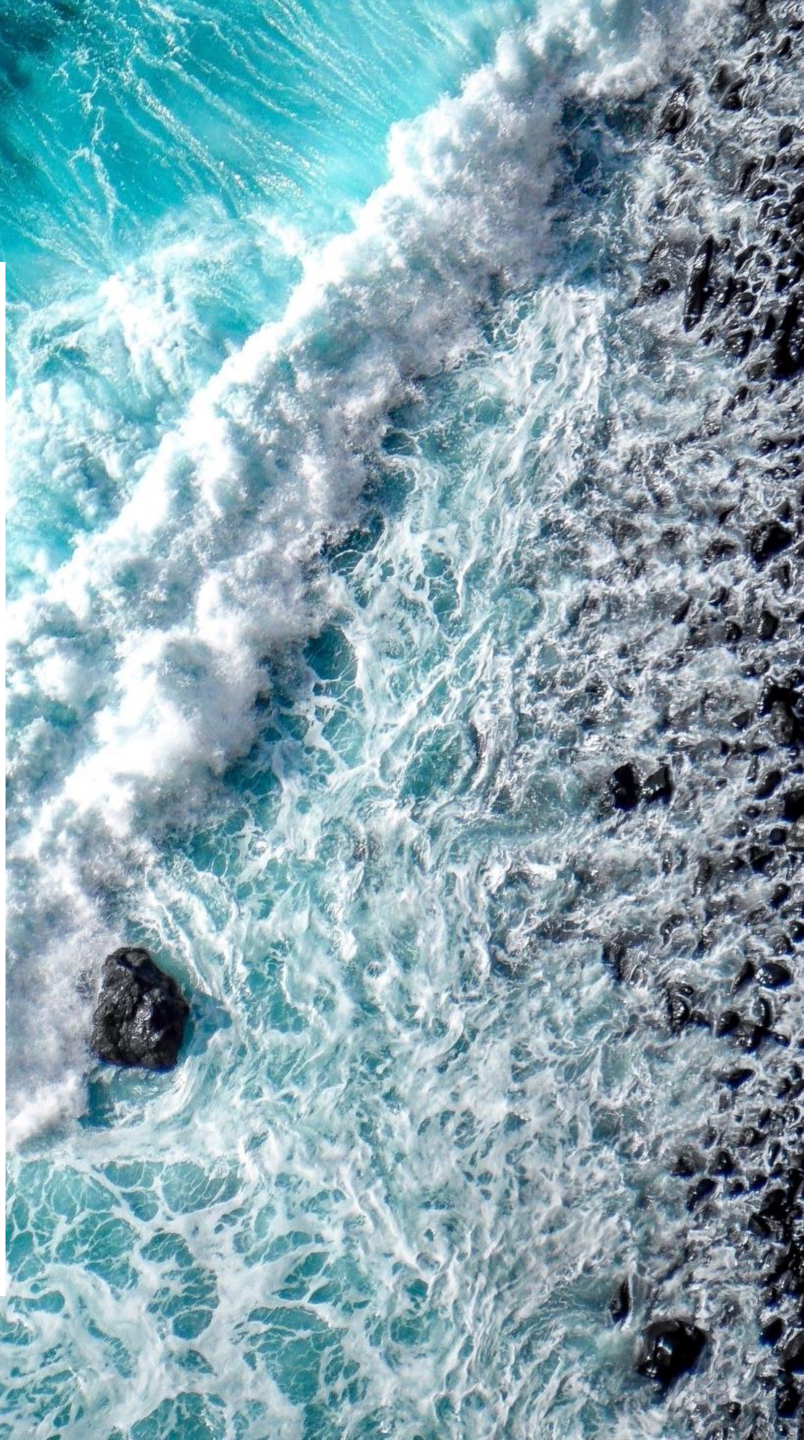
SBS Sensor-Specific Characterisations

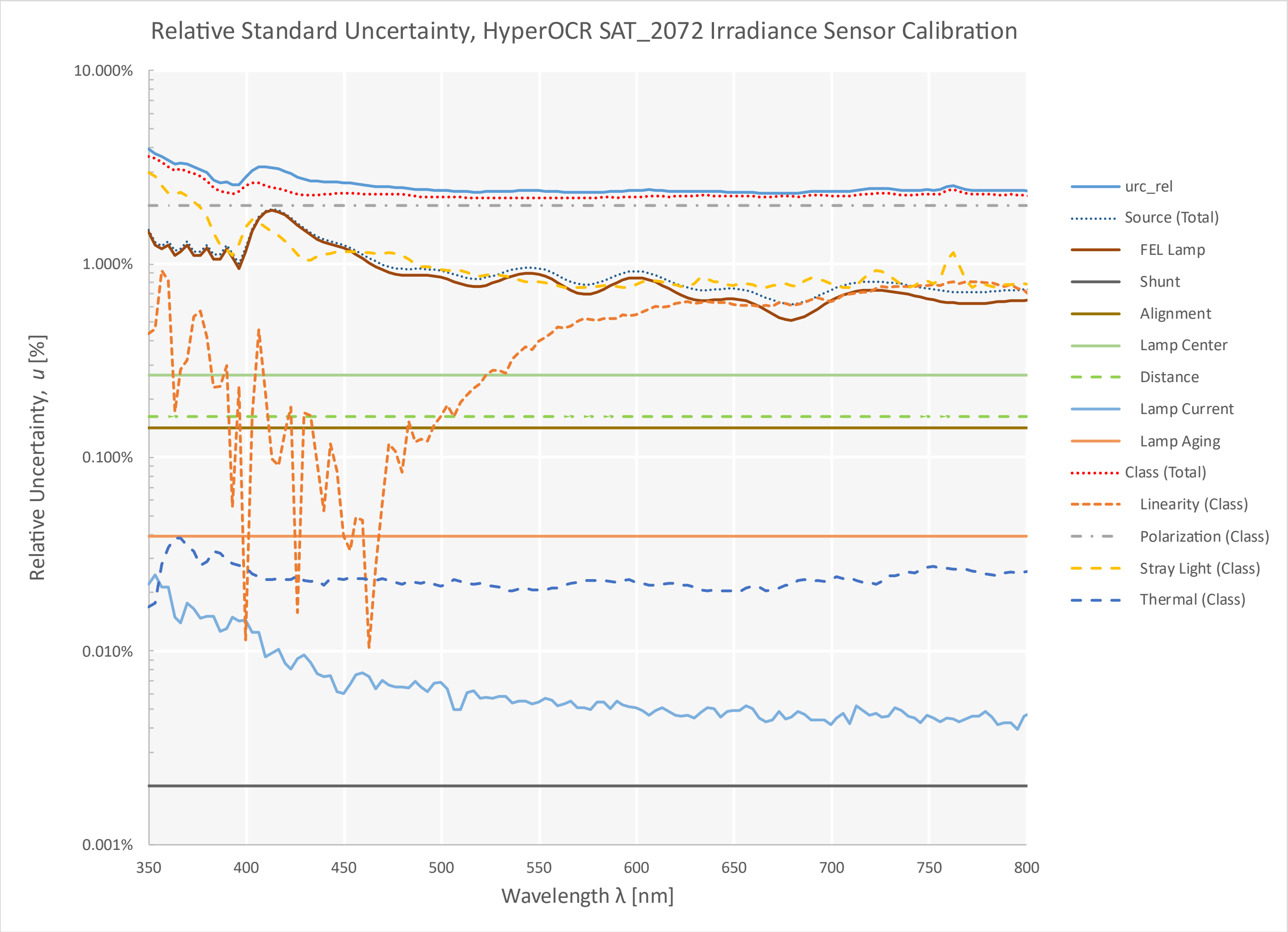
- **Scale Factor = 1/Responsivity**

- **TBS** in caldata: End of **Q4 2024**:
  - DN_{Light} and DN_{Dark} @ 2 integration times
  - $u(DN_{Light})$, $u(DN_{Dark})$ @ 2 integration times (512 ms, 256 ms)
  - Submit ADCAL to FidRadDB and customer

- **TBS: Date unknown**
  - Lamp and plaque data to FidRadDB

- **ProSoft 8.x** can accept a sensor-specific stray light matrix.




Relative Standard Uncertainty, HyperOCR SAT_2072 Irradiance Sensor Calibration
10.000%
1.000%
0.100%
0.010%
0.001%
Relative Uncertainty, u [%]
350
400
450
500
550
600
650
700
750
800
Wavelength λ [nm]
urc_rel
Source (Total)
FEL Lamp
Shunt
Alignment
Lamp Center
Distance
Lamp Current
Lamp Aging
Class (Total)
Linearity (Class)
Polarization (Class)
Stray Light (Class)
Thermal (Class)