FRM4SOC-2 Workshop

Cal/Char of the DALEC Radiometer

Wojciech Klonowski

In-Situ Marine Optics

In-situ Marine Optics

- We manufacture precision optical sensors for the ocean research community.

Hyperspectral Sensors

DALEC
Autonomous Transecting Radiometer

USSIMO (Ed, Lu)
In-water Profiling Radiometers

µSPEC-LPT
Stand-alone logger for long term deployment

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- ***Multispectral and Single Channel Light Sensors/Loggers***

MS9
9 wavelength Irradiance and Radiance sensors

MS9-LPT
Stand-alone 9 Wavelength Light Logger

PAR
Photosynthetically Available Radiation Sensor

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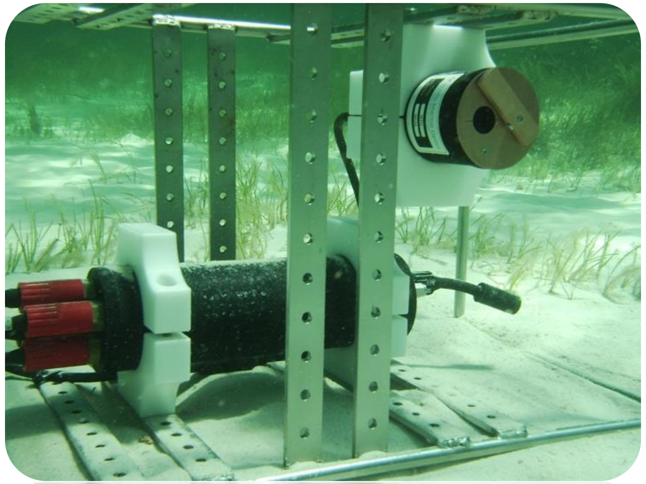
- ***Optical Backscattering Sensors***

SC3
3 wavelength backscattering and Fluorescence sensor

SC6-LPT
Stand-alone 6 Wavelength Bb/Fl Logger



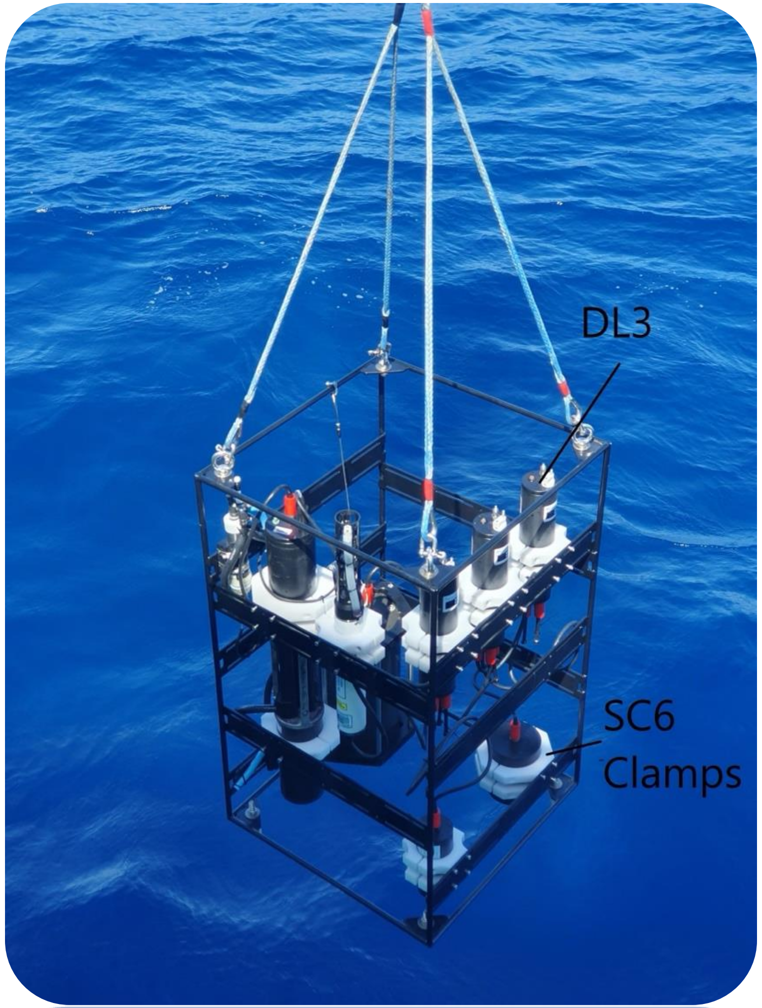
Turbidity/Fluorescence
NTU and various FL combinations

- ***Water Quality Sensors and Data loggers***

pHiDO
pH and DO sensor

DL3
3 Channel data logger/power manager
-supports AC9, ACS, Hydroscatt, etc.

CTD
CTD and 3 Channel data logger/power manager

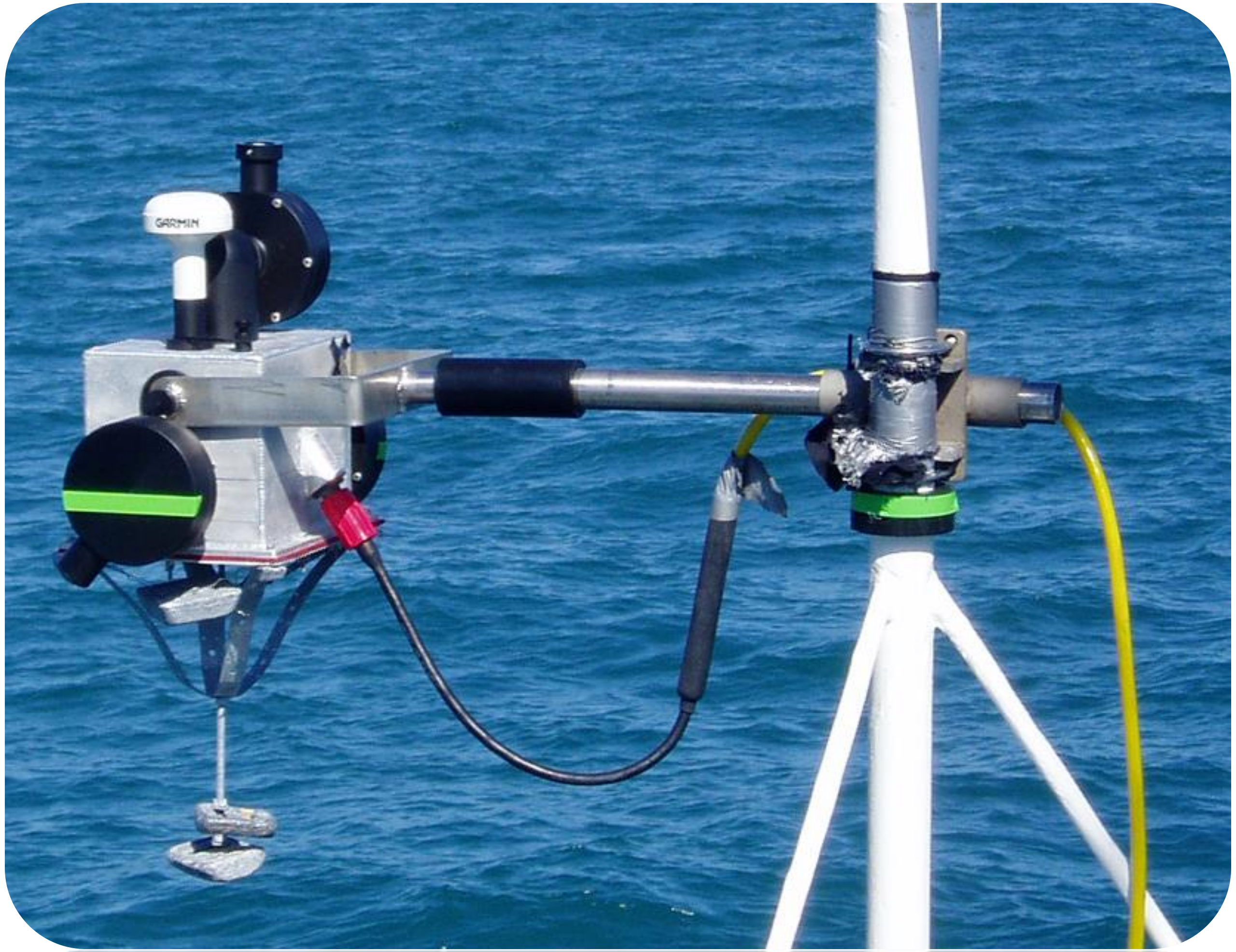


In-situ Marine Optics

- Started instrument development 20 years ago.
- At that time, we were undertaking our research in the field of Ocean Colour Satellite Remote sensing.
  - Matthew Slivkoff – Ocean Colour Remote Sensing of the Great Barrier Reef Waters.
  - Wojciech Klonowski - Hyperspectral Remote Sensing Applied to Shallow Coastal Waters.
- We had a need for ground truthing radiometers.

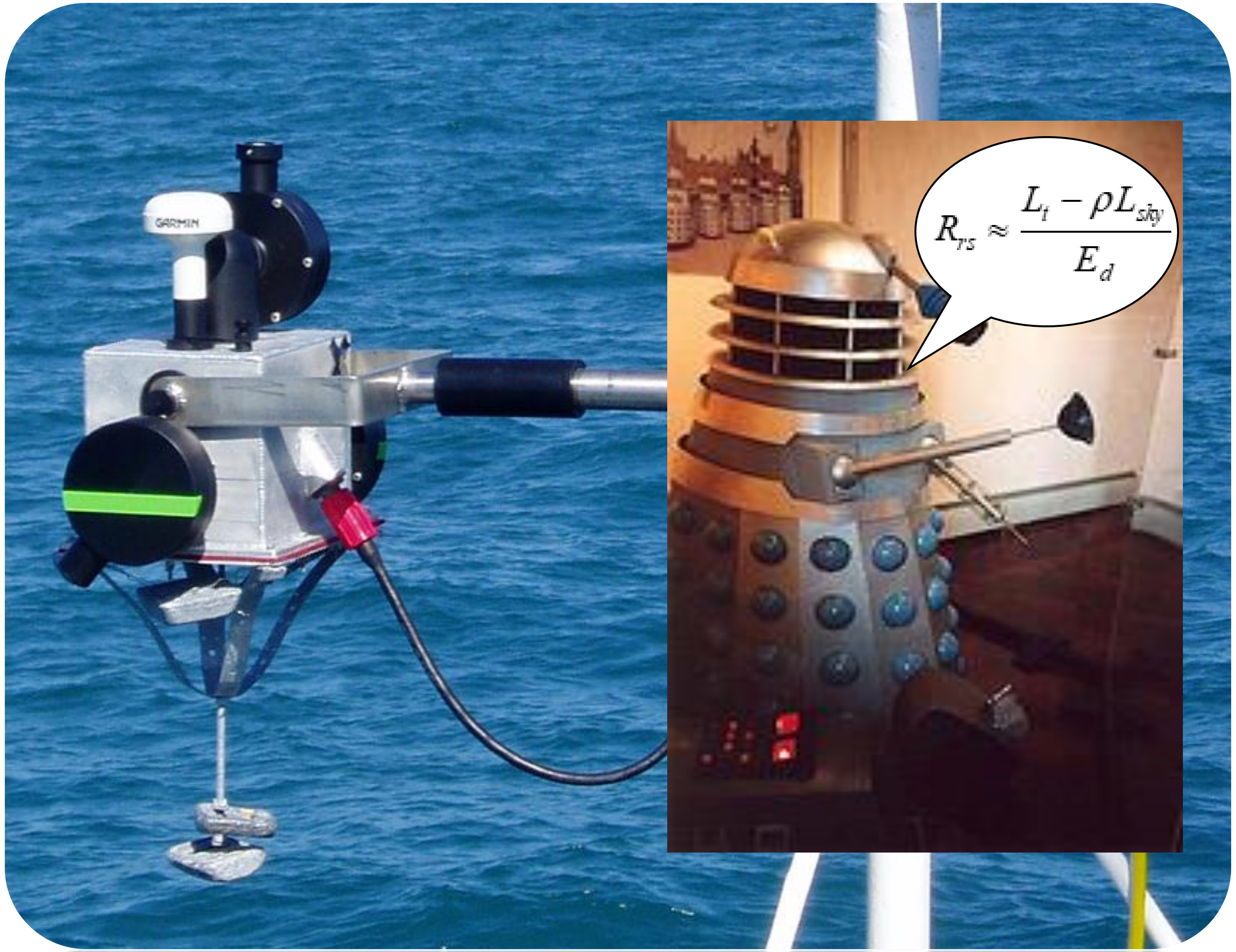
Sensor Development

- Continuous Transecting Radiometer for Ocean Colour Cal/Val research.
- All-in-one system approach.
- 3 x Zeiss MMS1 spectrometers (Ed,Lu,Lsky).
- Internal Microprocessor.
- Integrated GPS and IMU.



Sensor Development

- Continuous Transecting Radiometer for Ocean Colour Cal/Val research.
- All-in-one system approach.
- 3 x Zeiss MMS1 spectrometers (Ed,Lu,Lsky).
- Internal Microprocessor.
- Integrated GPS.
- **D**ynamic **A**bove-water Radiance (***L***) and Irradiance (***E***) **C**ollector



DALEC Evolution

2007

- Compact Design
- Internal GPS

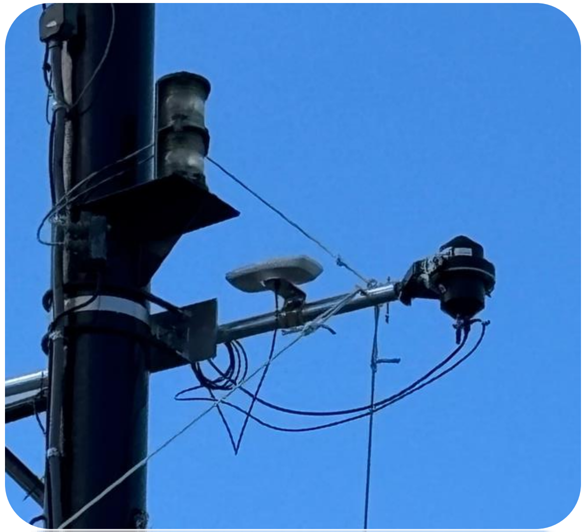
2010

- Ruggedised Design
- Internal IMU

2011

- Motorised collar
- RelAz tracking
- Internal Logging
- Rechargeable Li-Ion
- Temp sensors on each spec PD array

2024



- Ethernet Comms
- Blackened Pixels
- Independent sampling
- Automatic GearPos cal
- Satellite Compass/GPS

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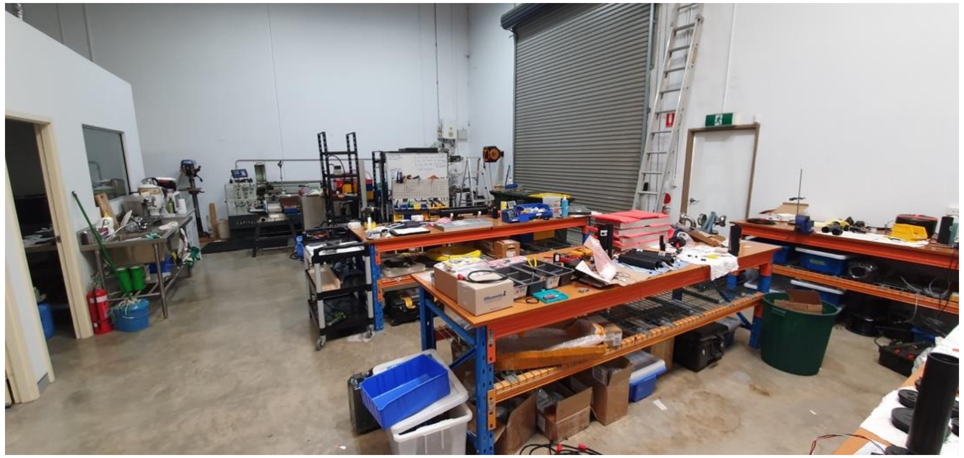
Manufacturing Facility



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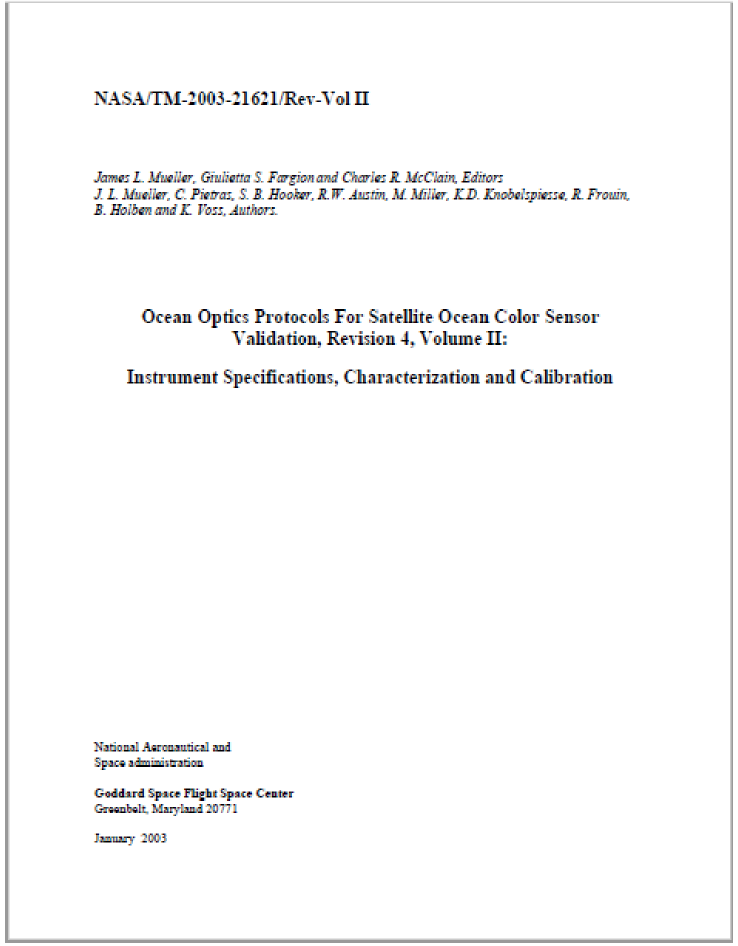
Optics Lab

- Closely follow “Ocean Optics Protocols”
- Dedicated Optics Lab
- FEL Lamps & Reflectance Plaques
- Annual Lamp replacements (NIST traceable)
- Precision Power Supply (<0.01% Amp)
- Monochromator
- Goniometer
- Routine Power Supply Checks
- Working Lamp Standard Monitoring



NASA/TM-2003-21621/Rev-Vol II

James L. Mueller, Giulietta S. Fargion and Charles R. McClain, Editors
J. L. Mueller, C. Pietras, S. B. Hooker, R.W. Austin, M. Miller, K.D. Knobelspiesse, R. Frouin, B. Holben and K. Voss, Authors.

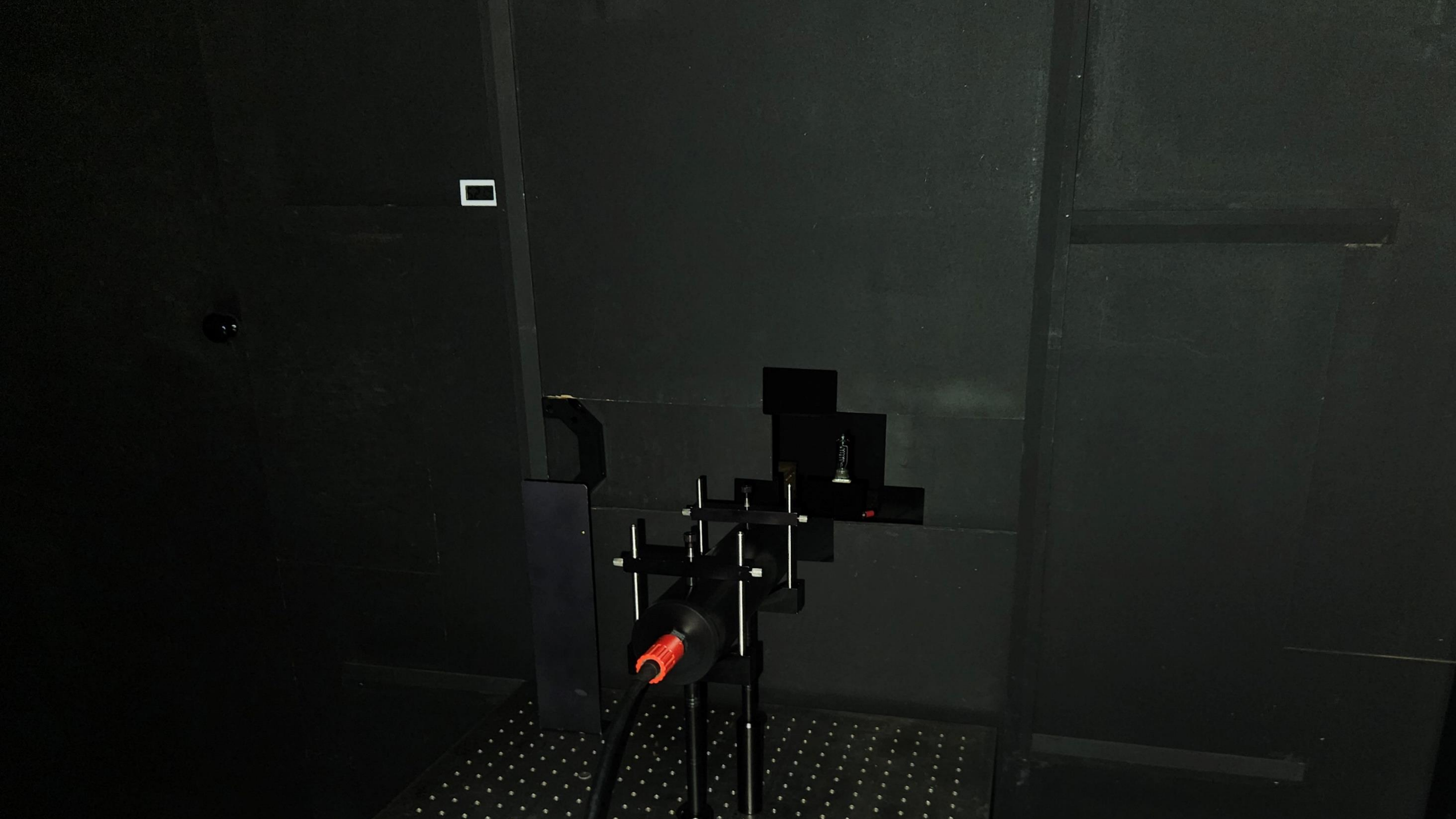
Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume II:

Instrument Specifications, Characterization and Calibration

National Aeronautical and
Space administration

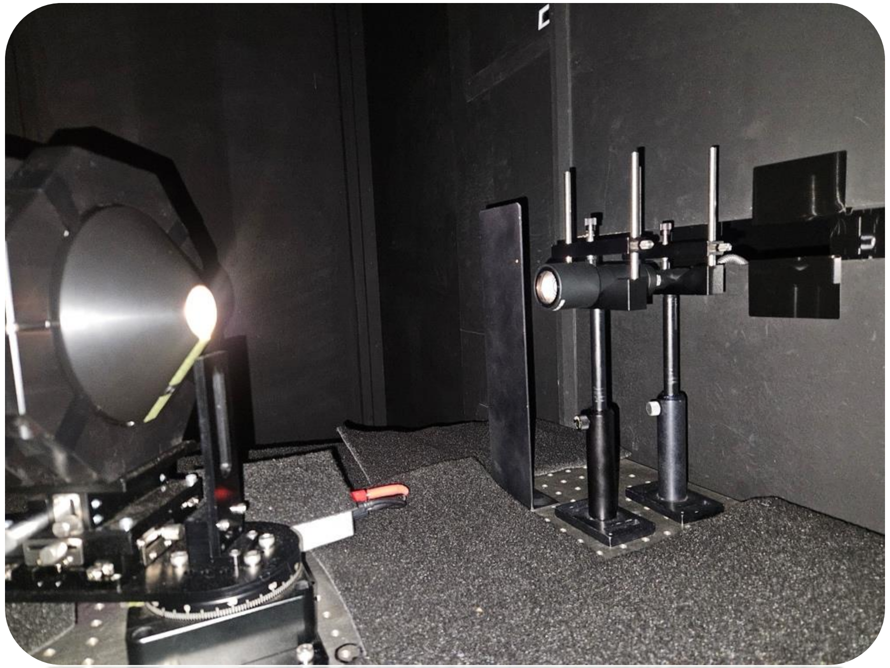
Goddard Space Flight Space Center
Greenbelt, Maryland 20771

January 2003



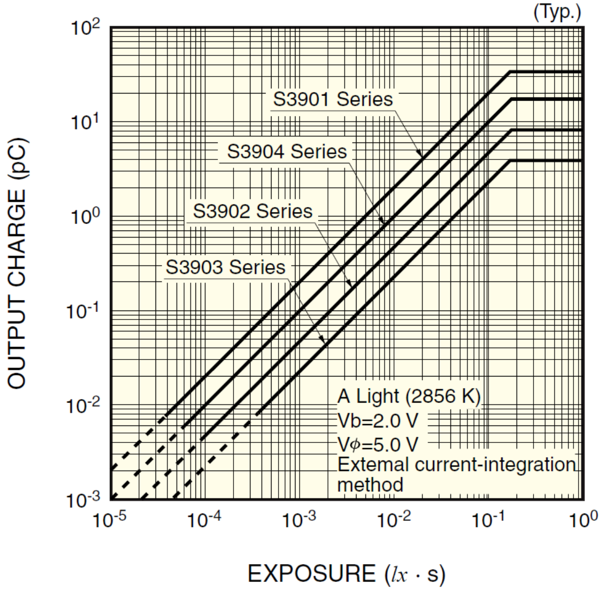
Angular Response

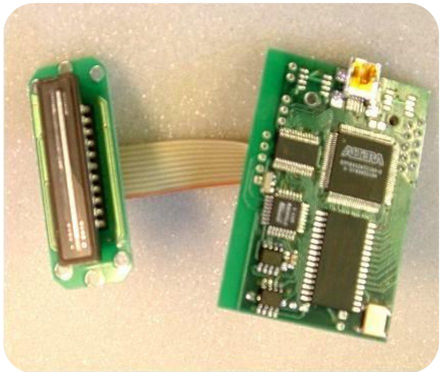
- Irradiance: Ø10mm Fused Silica Diffuser
  - Scattering from millions of tiny gas bubbles
- Goniometric measurements (Class-based)
- Cosine Error:
  - Typically, < 3% (0°– 65°) and < 10% (65° – 85°)
- Radiance: Quartz window
  - FOV (in air) = ~ 5° - 10° (Full)

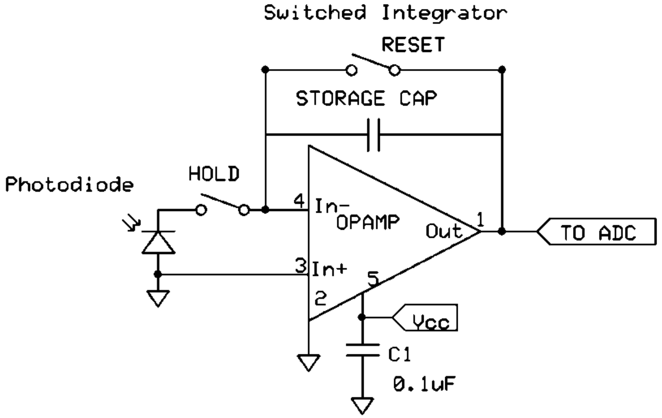


Spectrometer Electronics

- Zeiss MMS1 Spectrometer Module
- NMOS Array (40 blackened pixels)
- Current output type S3904
- Non-uniform countrate.
- $\frac{ADC_1}{Inttime_1} \neq \frac{ADC_2}{Inttime_2}$







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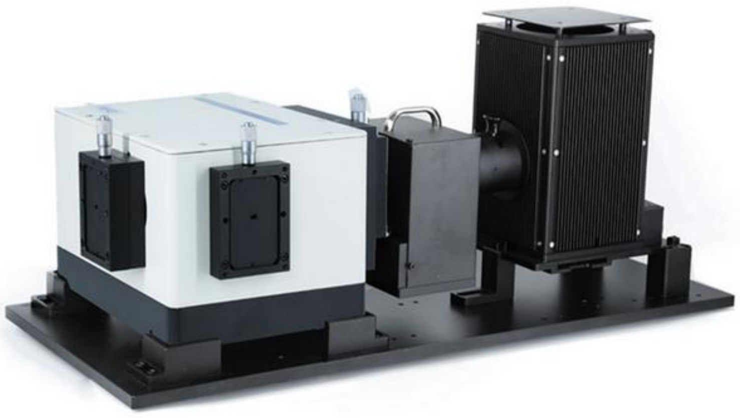
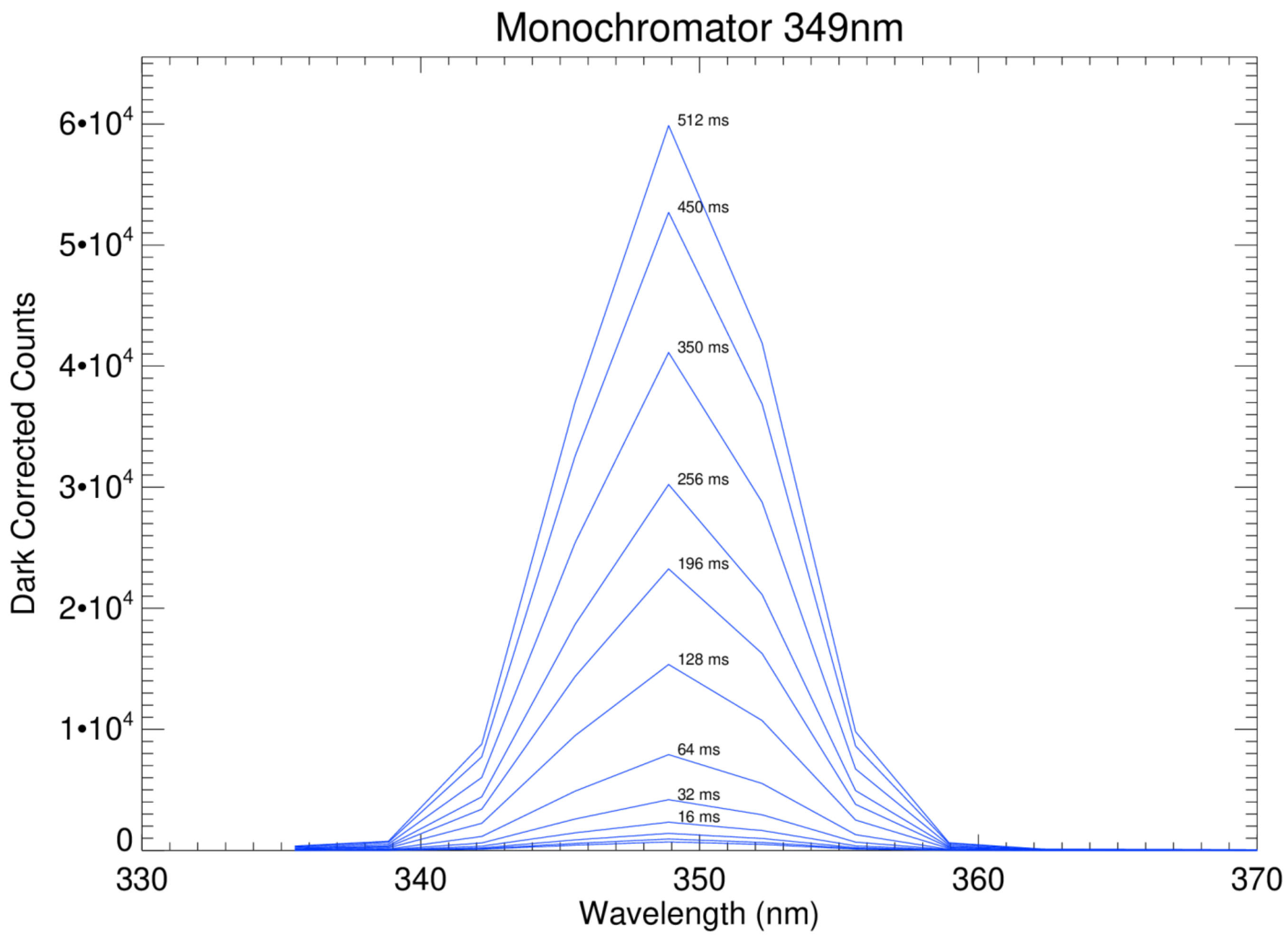
Monochromator Scans

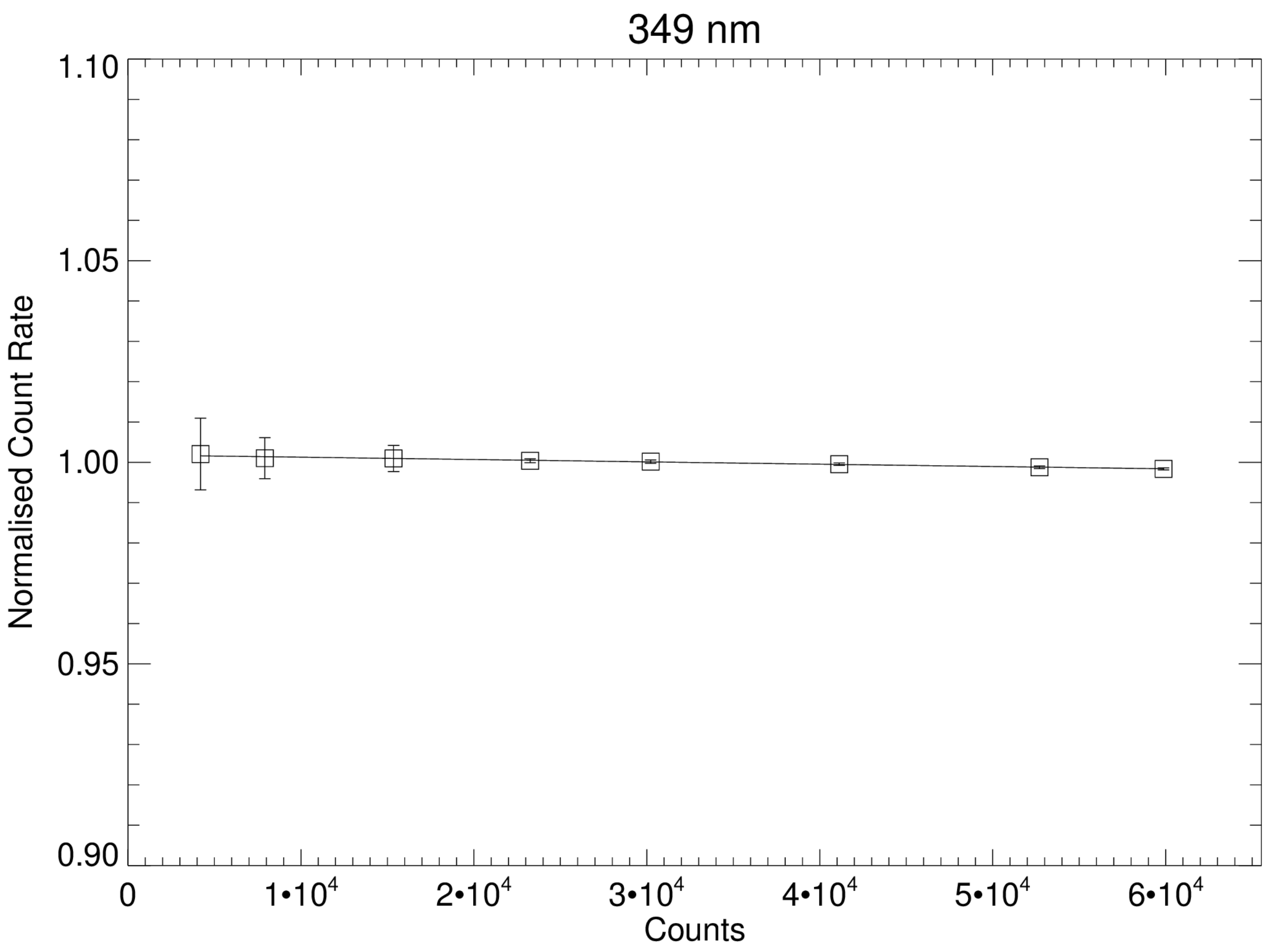




In-Situ Marine Optics

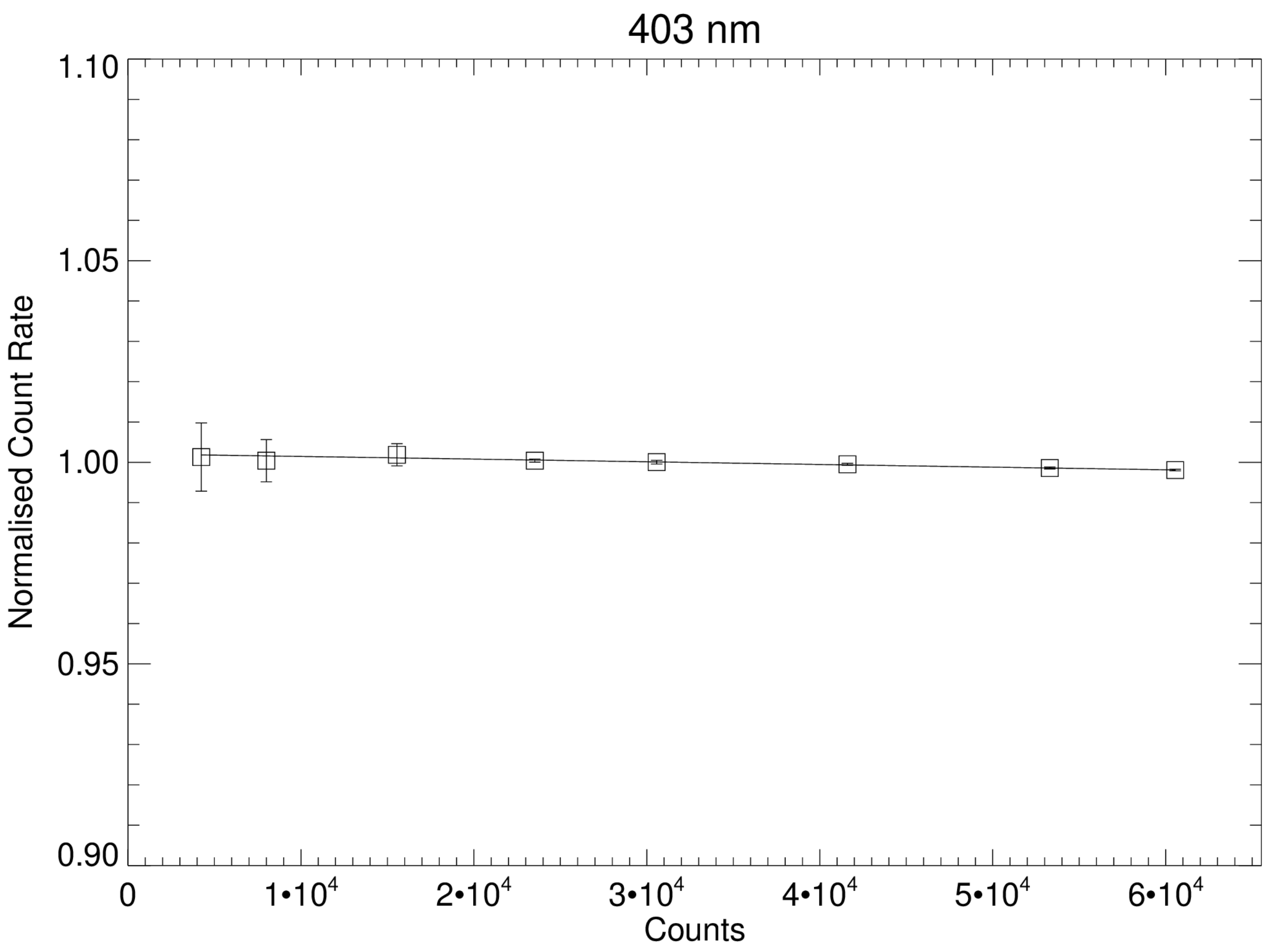
Integration Time Linearity

$$CR_i = \frac{(V_i - DC_i)}{\text{Inttime} + \Delta t}$$



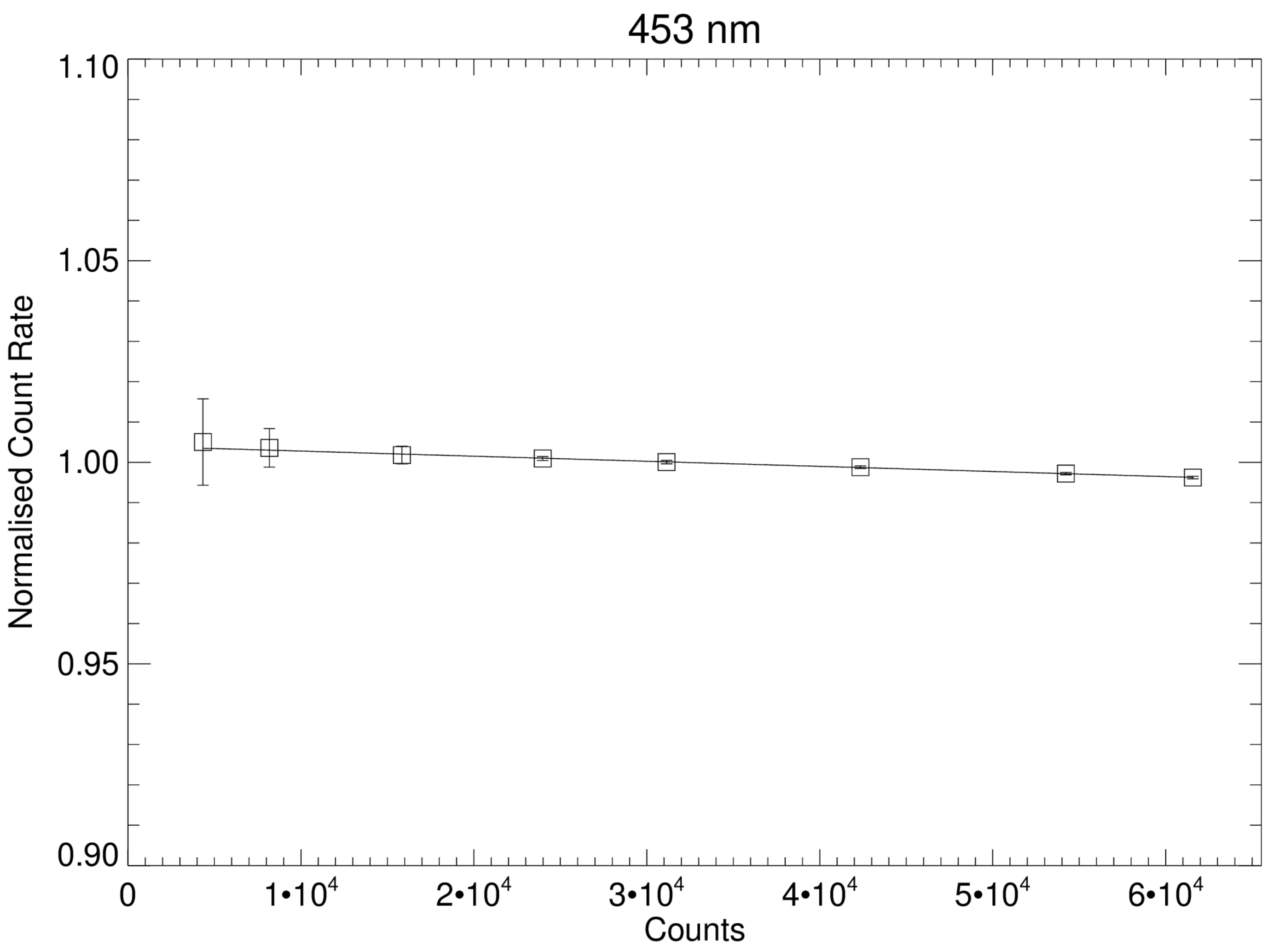
In-Situ Marine Optics

Integration Time Linearity

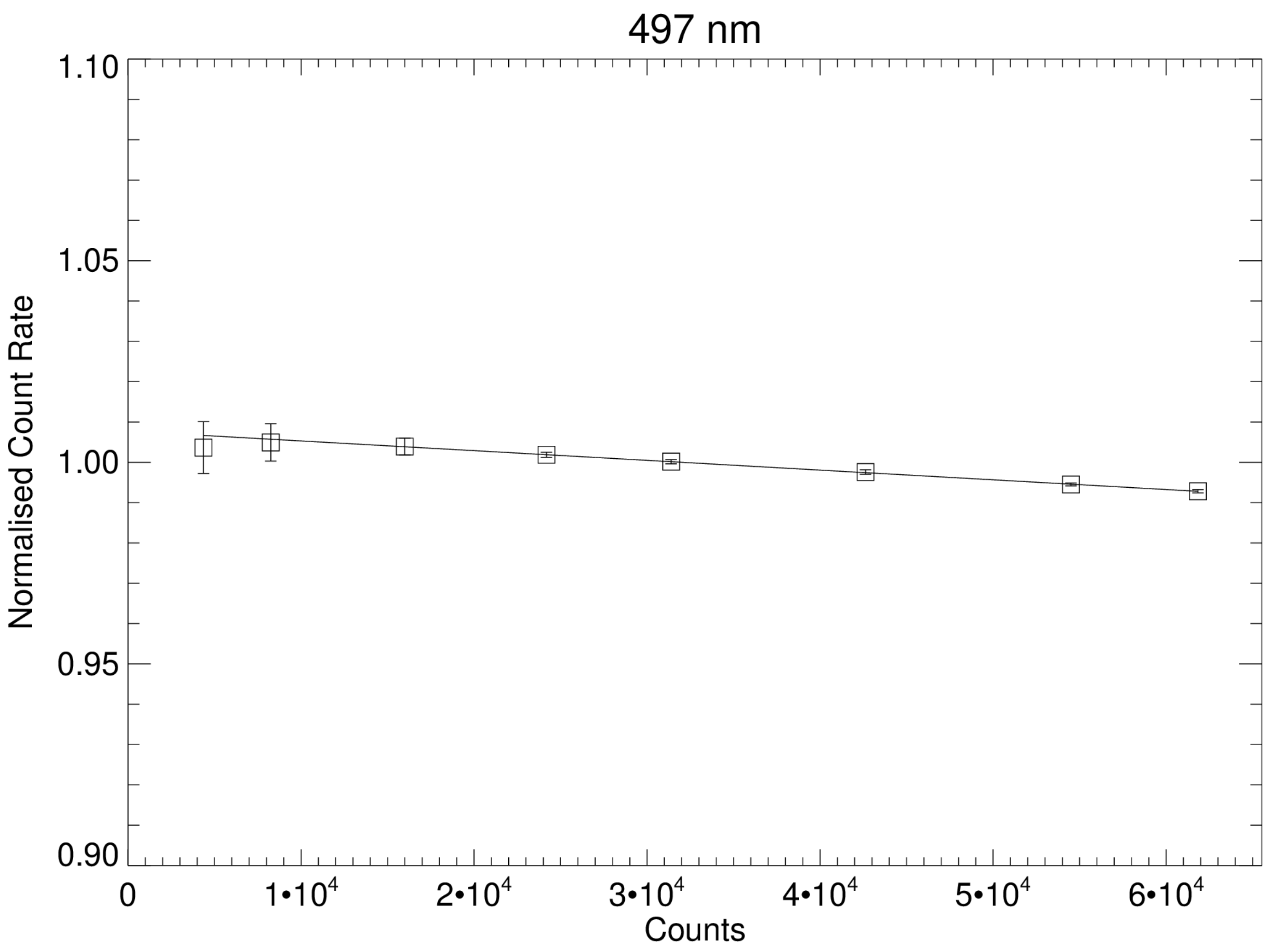


In-Situ Marine Optics

Integration Time Linearity

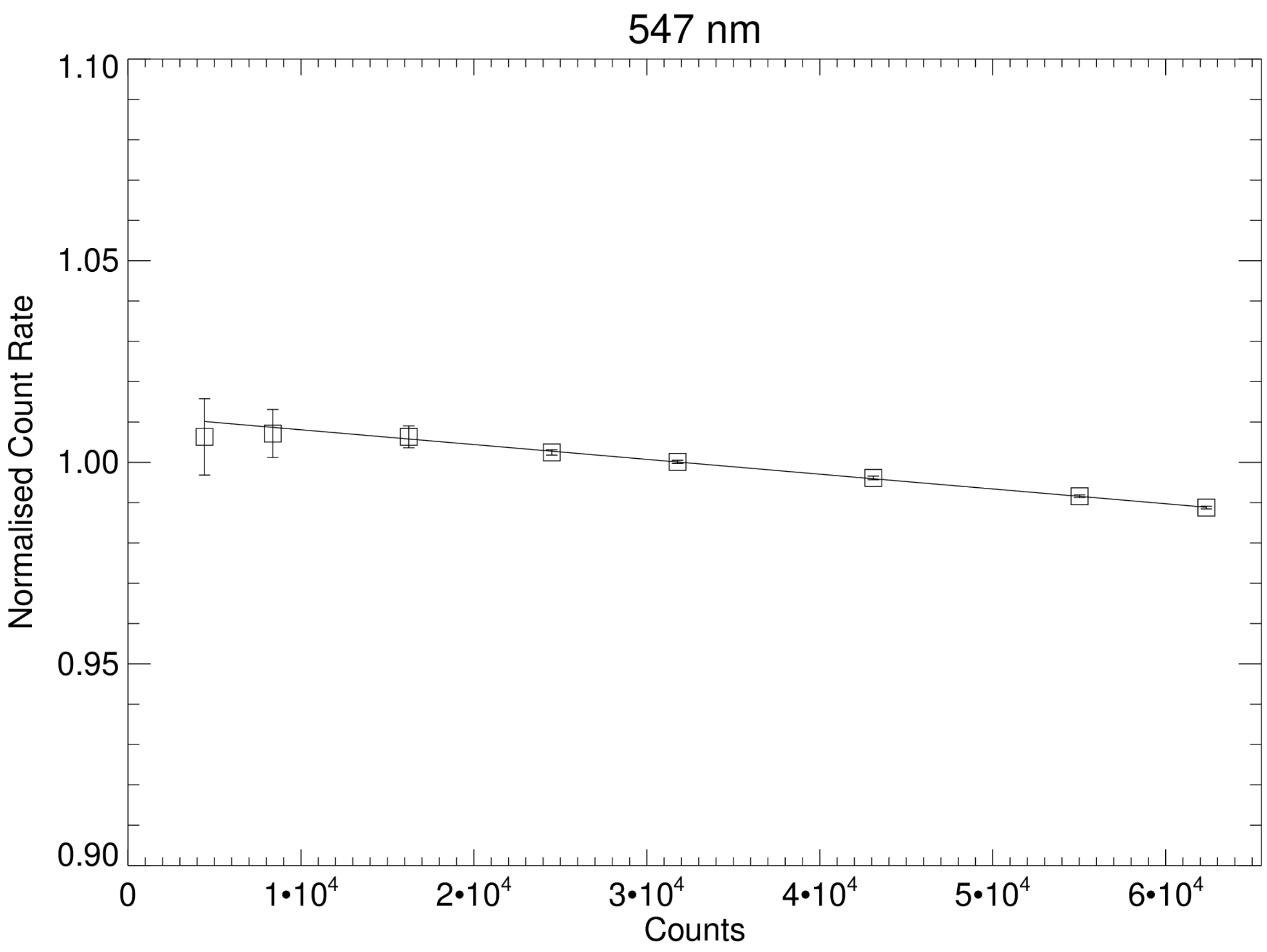


Integration Time Linearity

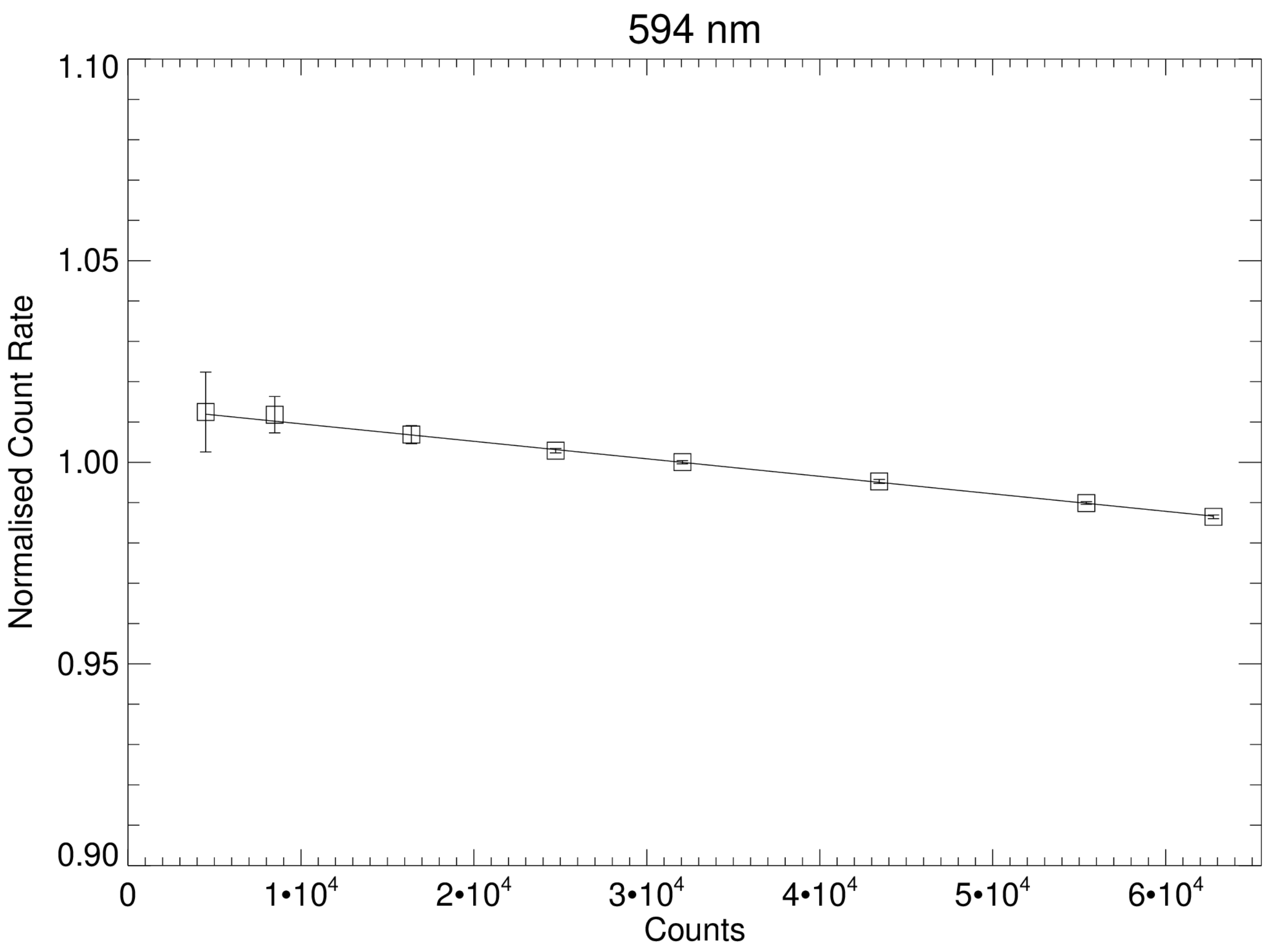


In-Situ Marine Optics

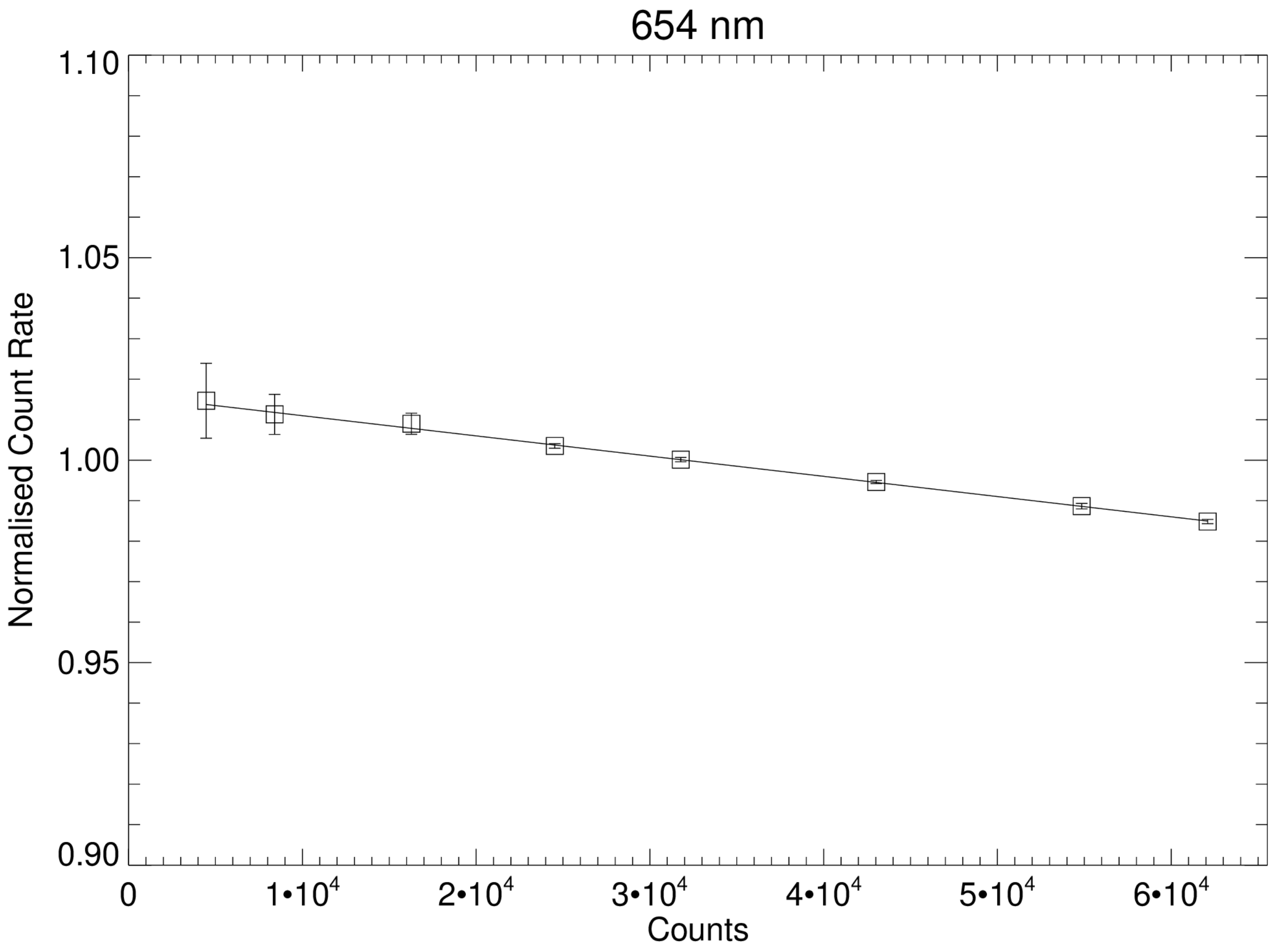
Integration Time Linearity



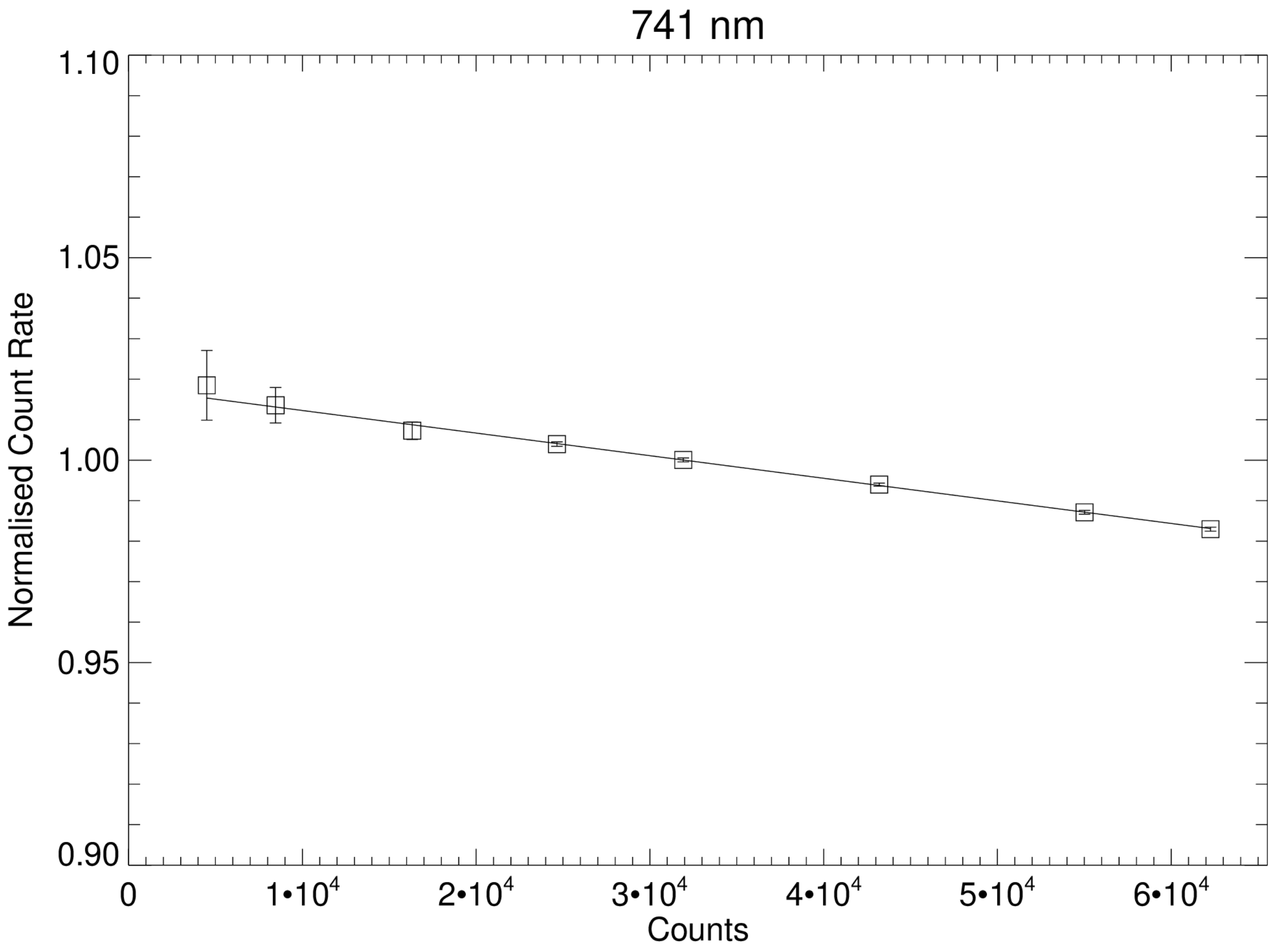
Integration Time Linearity



Integration Time Linearity

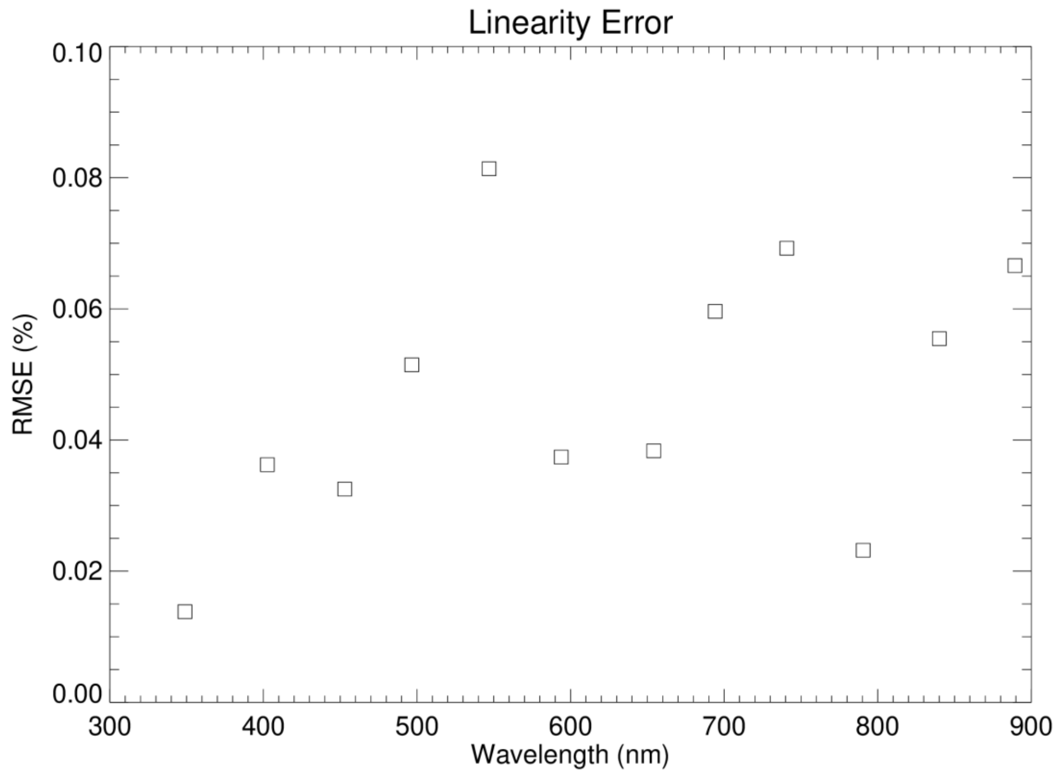


Integration Time Linearity



Linearity Correction

- $k1_i = d1_i * (V_i - DC_i) + d0_i$
- V_i = signal counts, DC_i = Dark Counts
- $d1_i$=Linearity Correction Slope
- $d0_i$=Linearity Correction Intercept
- Corrected Count Rate (per pixel, *i*):
  - CR_i = $[(V_i - DC_i)/(\mathrm{Inttime} + \Delta t)]/\ k1_i$
  - Δt ranges from 4.0 to 4.2 ms



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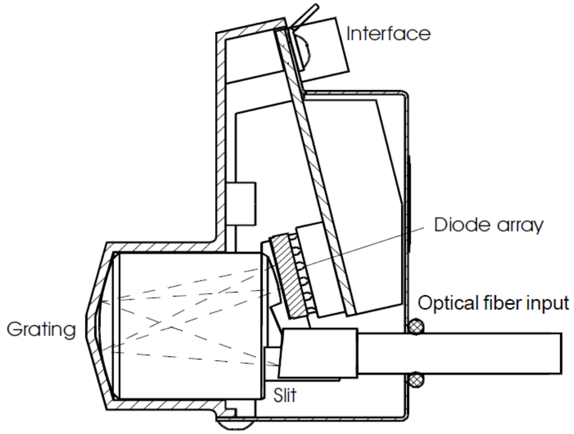
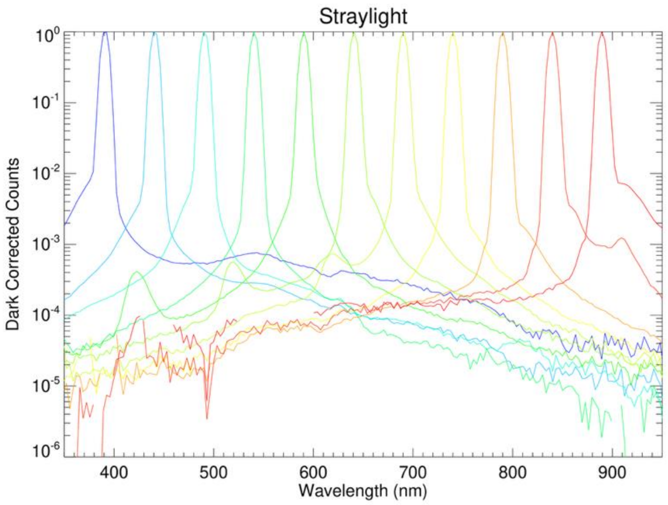
Stray Light

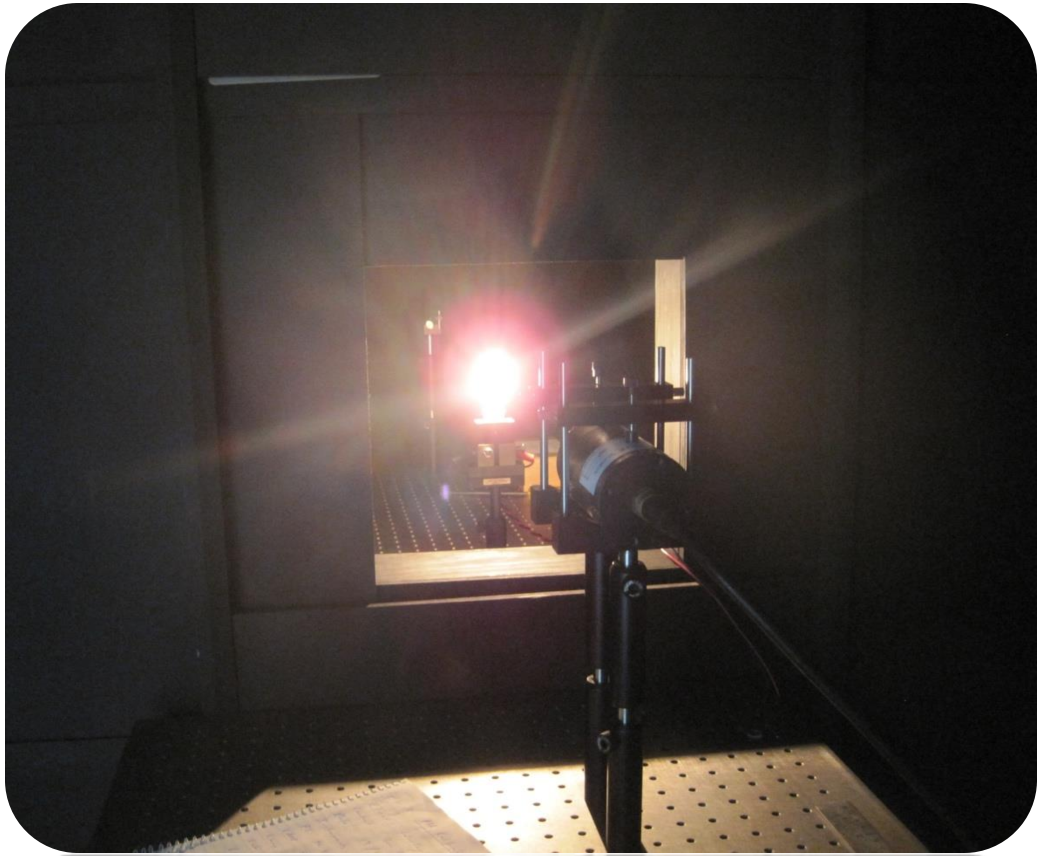
- Zeiss Stray light Specifications:
  - < 0.3 % (@ 310 nm, $NaNO_2$ 50 g/l)
- 1st order stray light correction is taken into account with radiometric calibration
- A stray light correction matrix can be computed from the line spread of monochromator or tuneable laser measurements for further correction.





Irradiance Responsivity

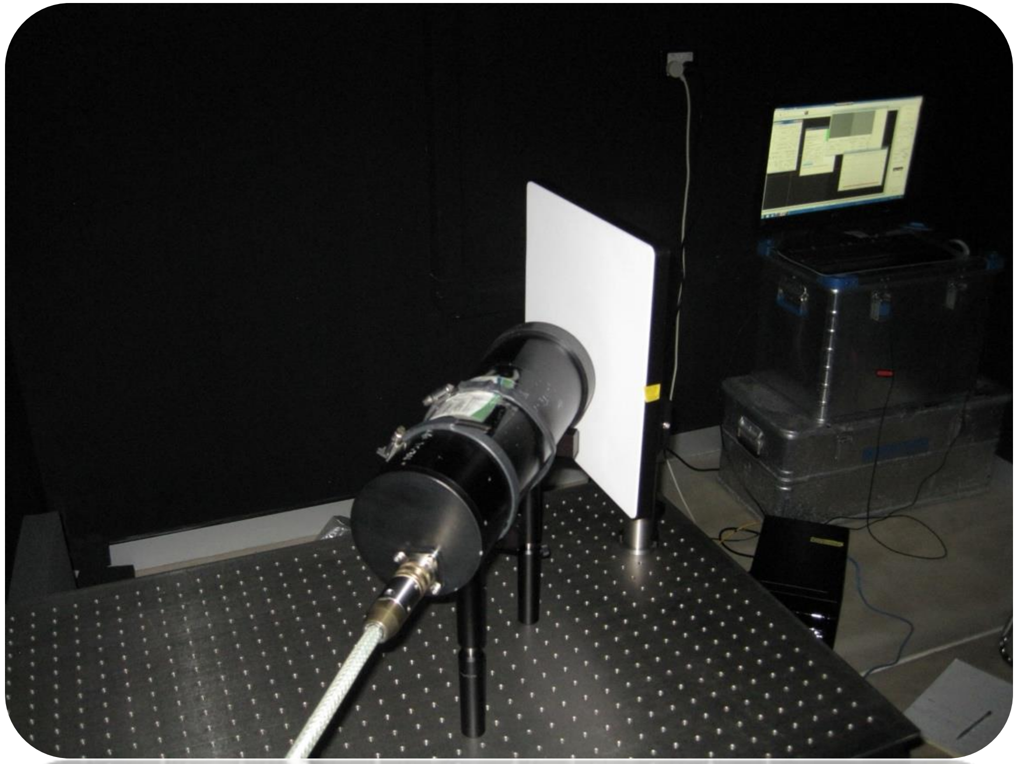
- 1000W FEL Lamp @ 50cm
- Lamp and Occult measurements are continuously collected with varying Integration times
- [2,4,8,16,32,64,128,256,512,…] ms
- Repeated for 3 nominal DALEC temperatures (15, 24 & 36°C)



In-Situ Marine Optics

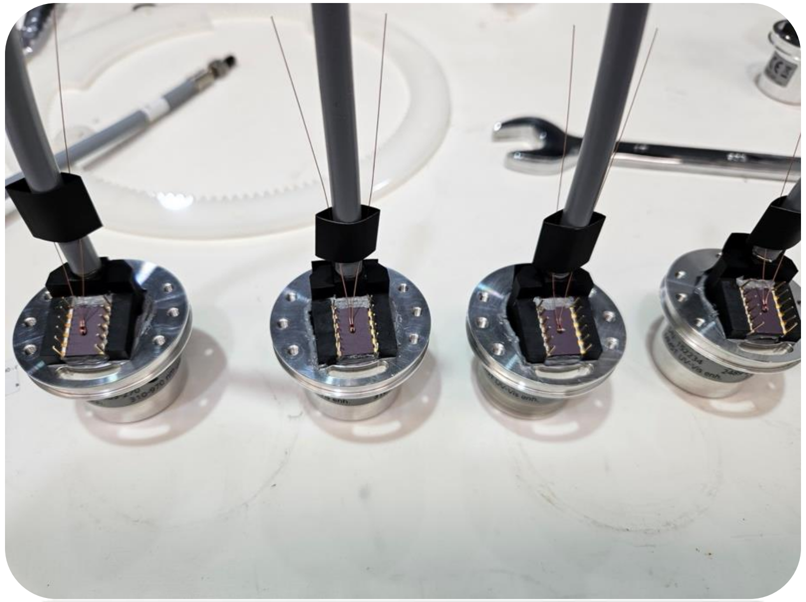
Radiance Responsivity

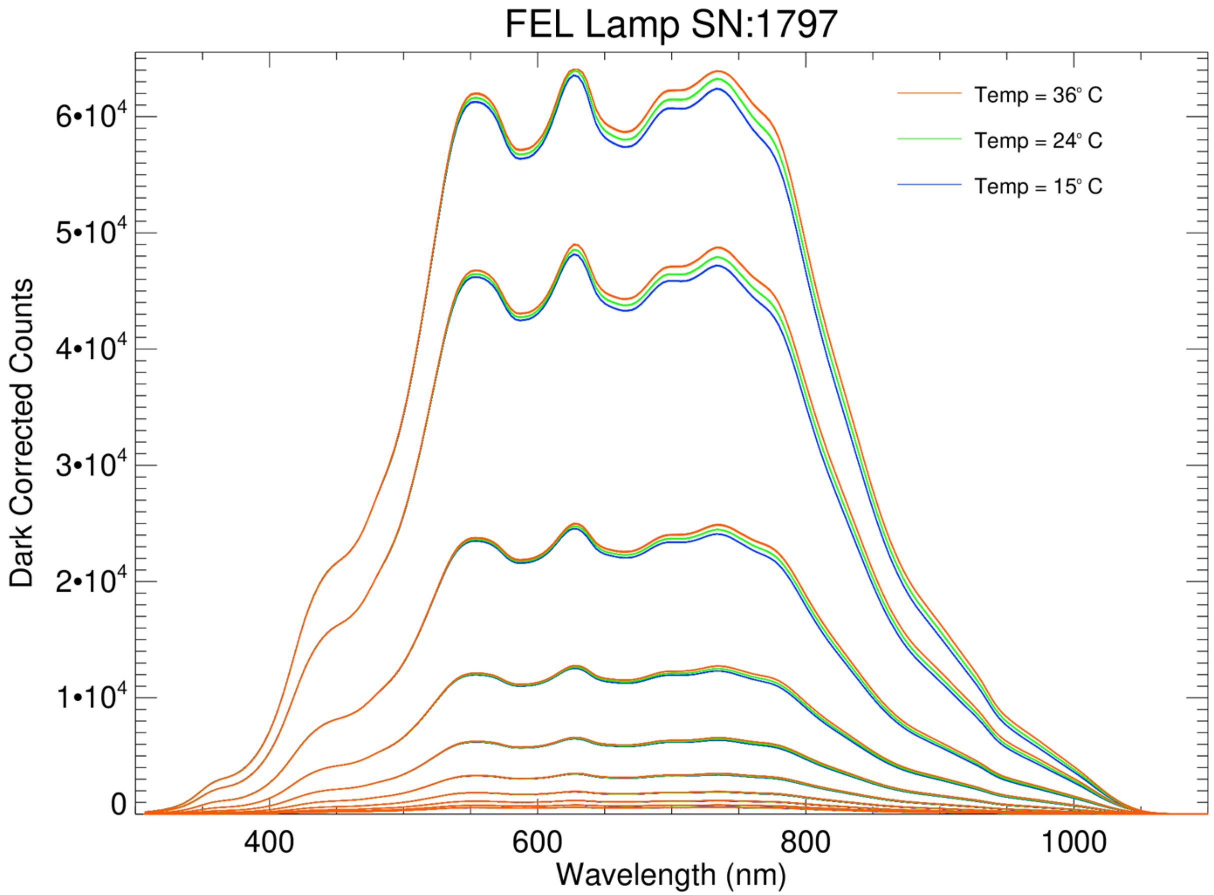
- 1000W FEL Lamp @ 150cm
- Spectral Plaque viewed at 40°
- Lamp and Occult measurements are continuously collected with varying Integration times
- [2,4,8,16,32,64,128,256,512,…] ms
- Repeated for 3 nominal DALEC temperatures (15, 24 & 36°C)



Temperature Correction

- Spectrometer temperature is taken from an NTC that is thermally bonded the S3904 module.

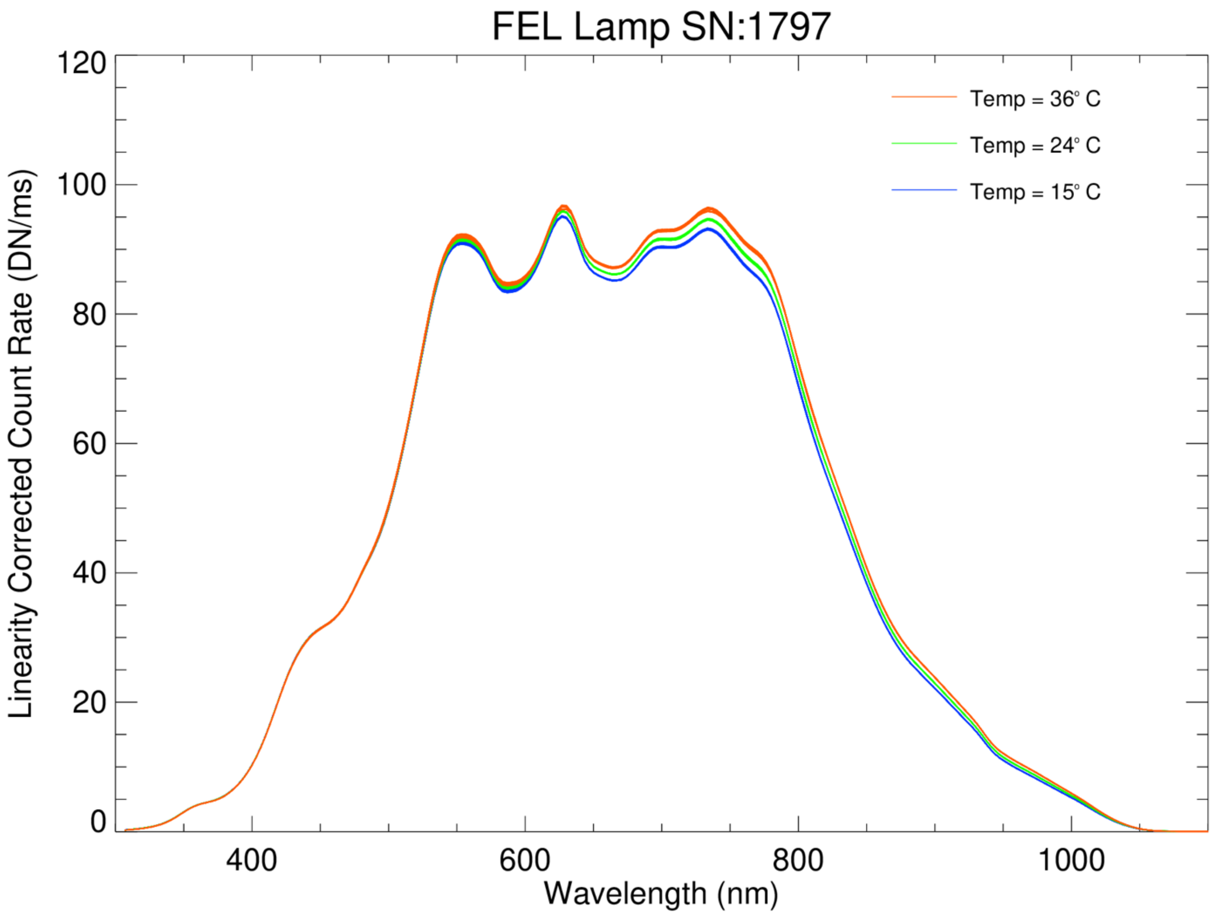




In-Situ Marine Optics

Temperature Correction

- Linearity Correction applied to all data.
- CR_i vs Temperature shows wavelength dependency.



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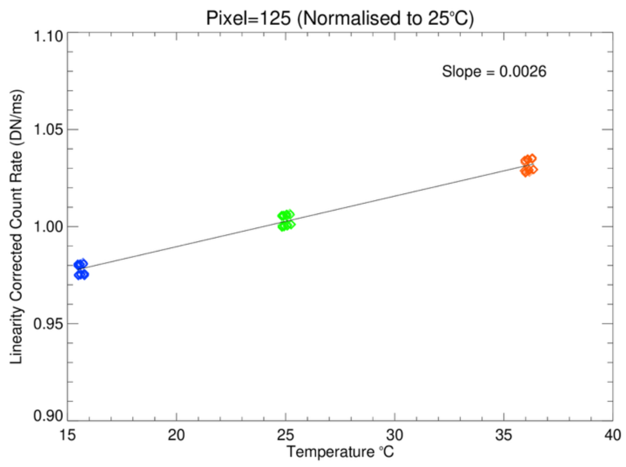
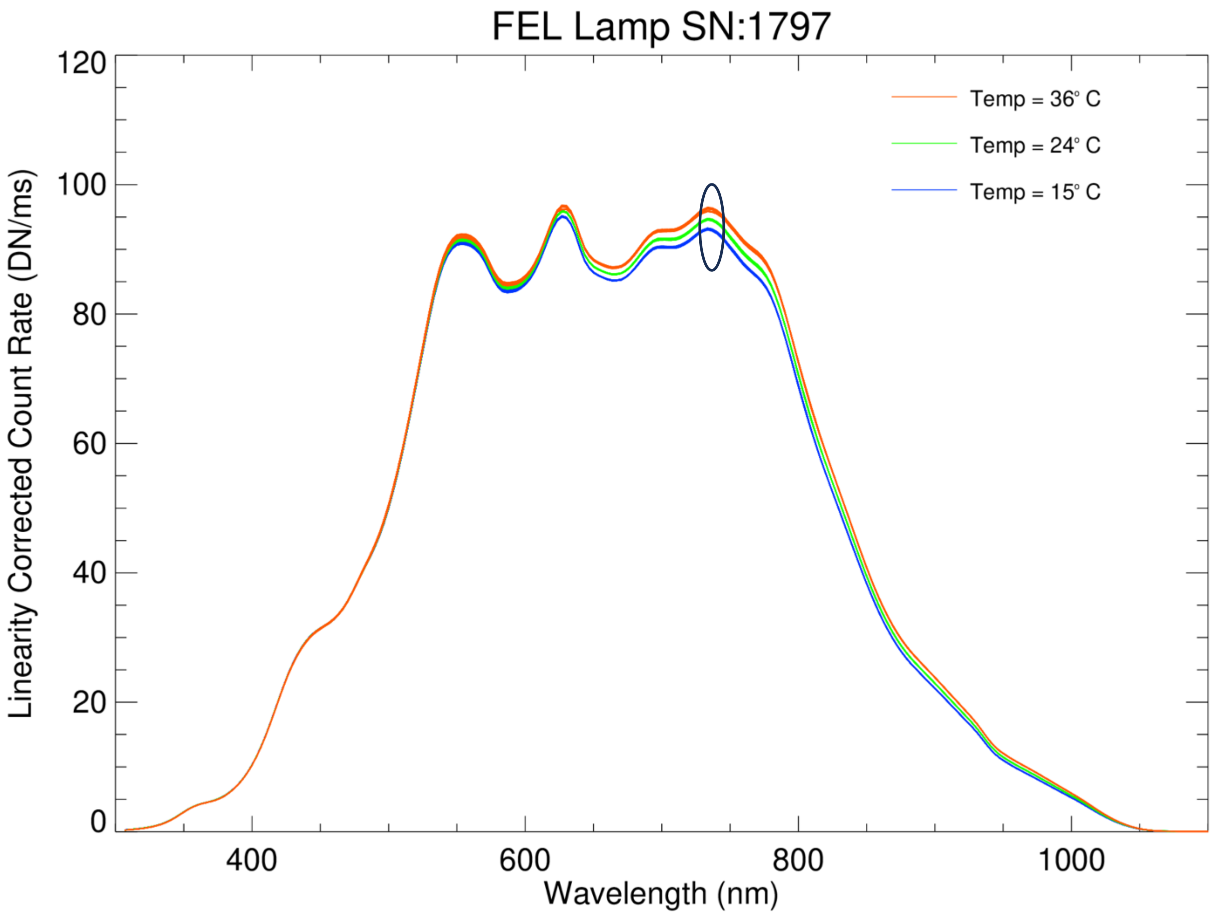


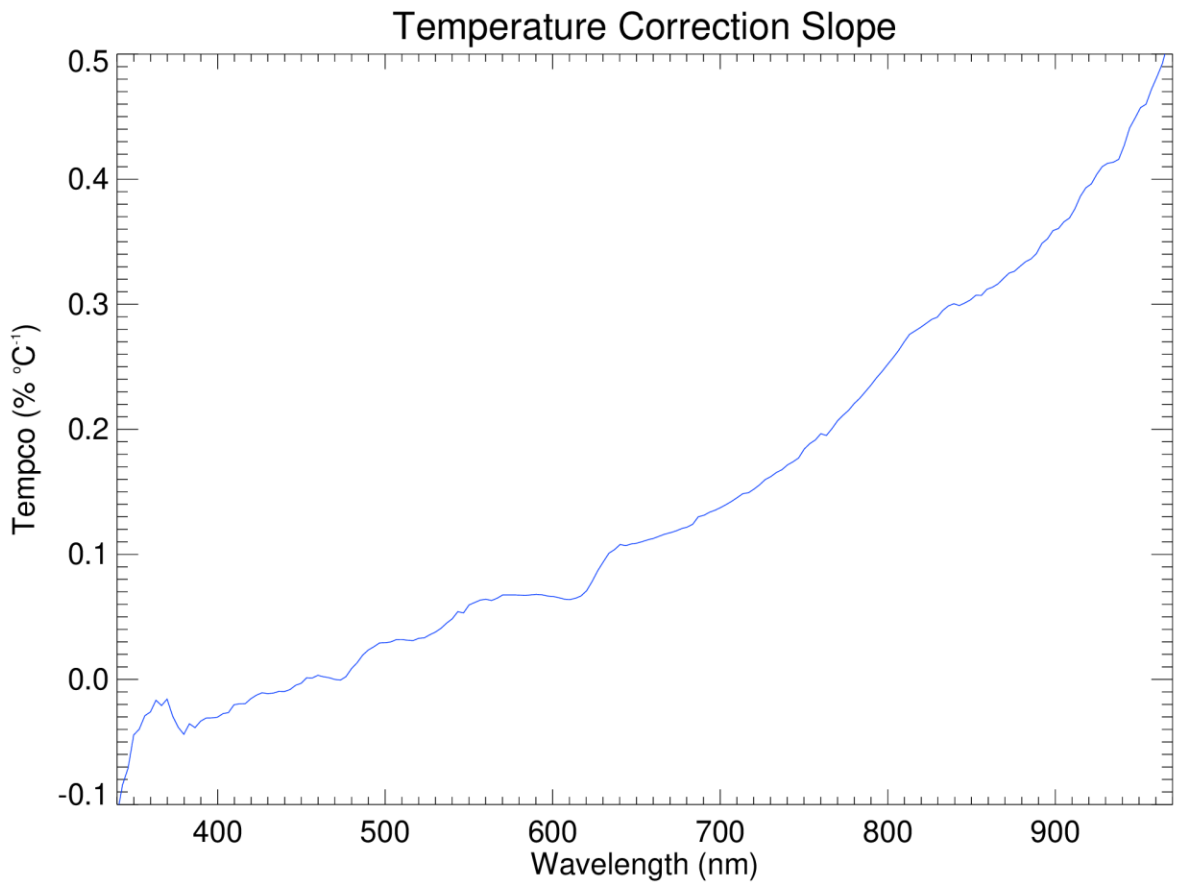


In-Situ Marine Optics

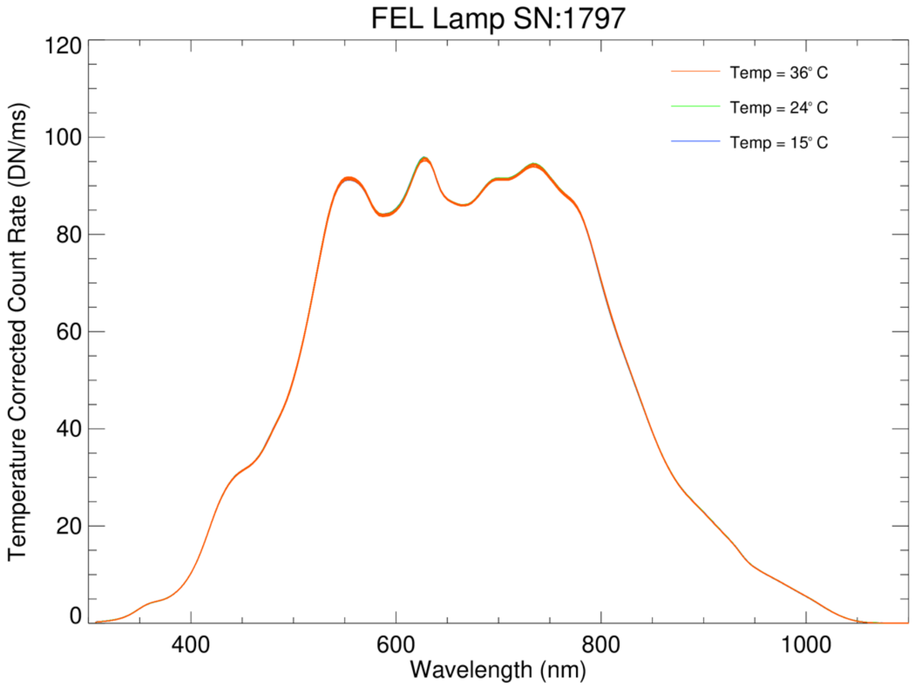
Temperature Correction

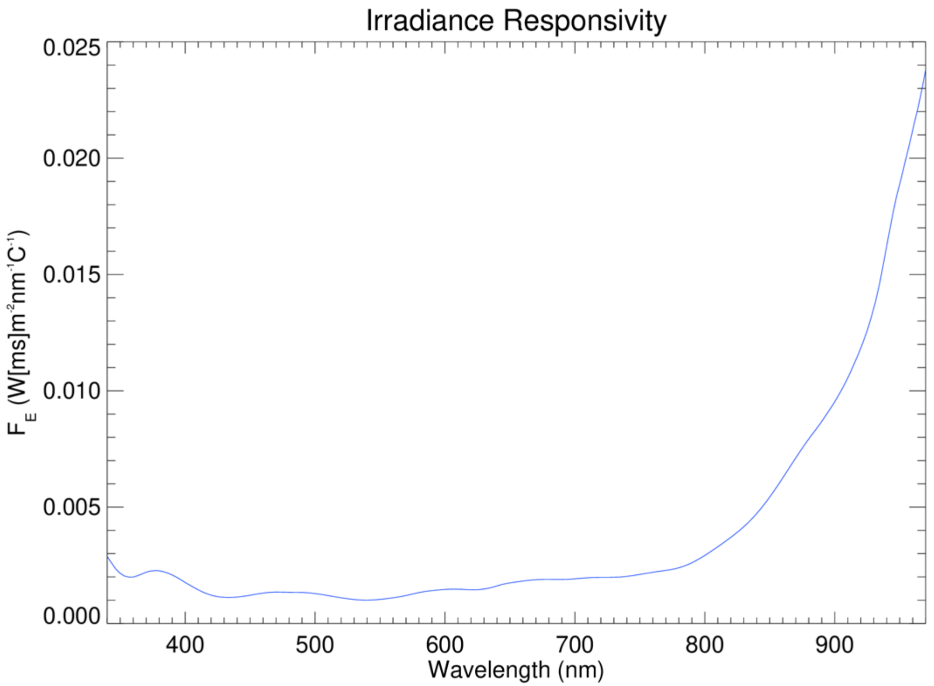
$$TC_i = \frac{CR_i}{Tempco_i[\mathrm{T} - T_{ref}] - 1}$$

$$T_{ref} = 24.0\ °\mathrm{C}$$



Irradiance Responsivity





$$F_E(\lambda) = \frac{E_r(\lambda)}{V_r(\lambda) - V_{amb}(\lambda)}$$

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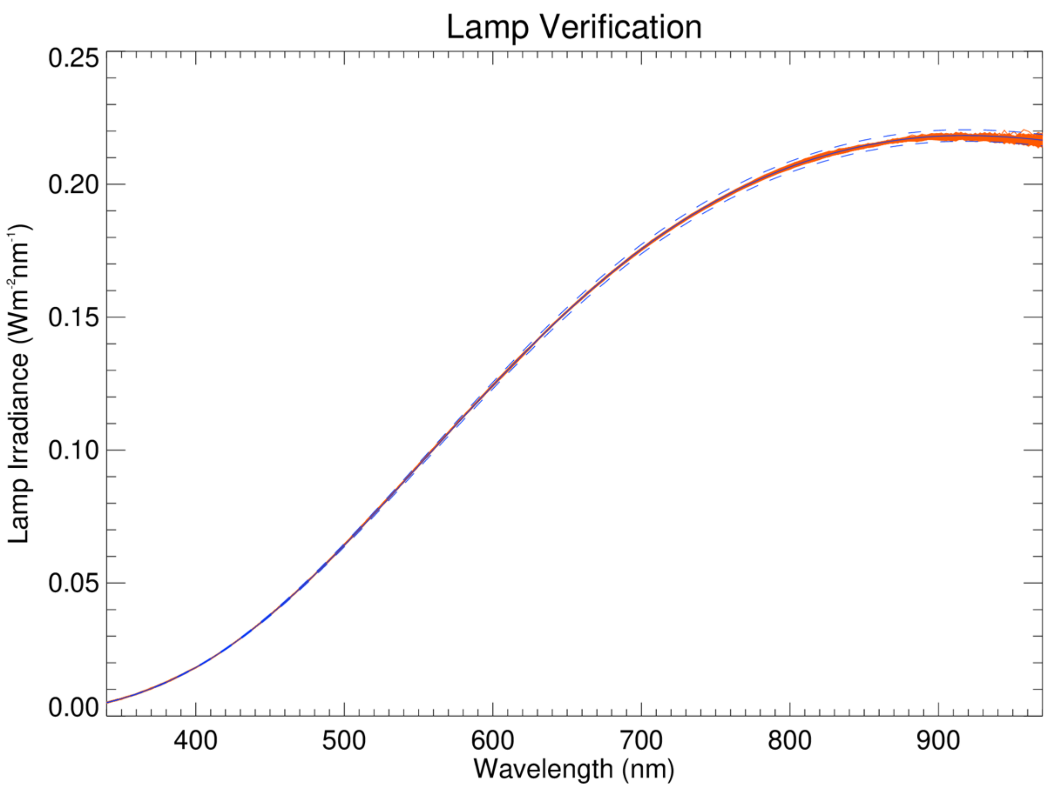
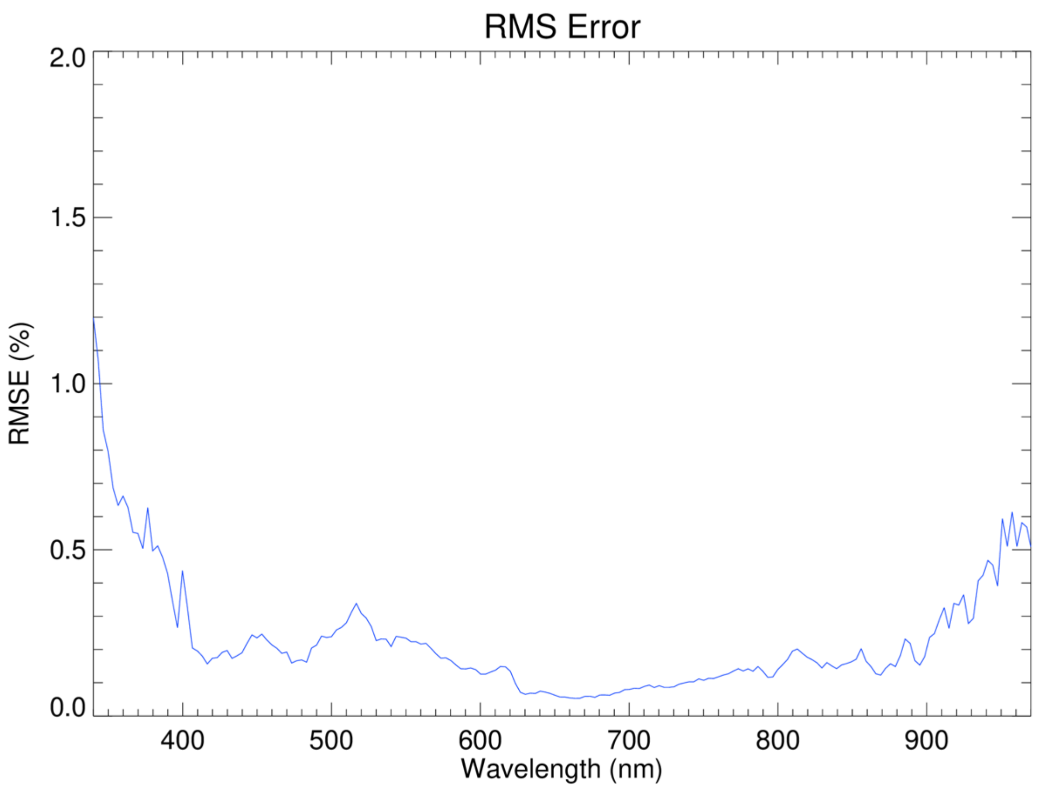
Lamp Verification





Data Processing

```
; DALEC Gen6 Calibration File (In-situ Marine Optics)
; File Created: Thu Feb 20 10:55:35 2025
; Calibration Date: 17/02/2025
; Lamp Standard: F-1797
; Spectralon Target: SRT-99-12
  DALEC serial number: 13
  Ed spectrometer module: 152237
  Lu spectrometer module: 152239
  Lsky spectrometer module: 144460
;
; Variable list:
;   Ed = downwelling irradiance (W/m^2/nm)
;   Lu = Upwelling radiance (W/m^2/sr/nm)
;   Lsky = downwelling sky radiance (W/m^2/sr/nm)
;   V = spectrometer measurement digital counts (16 bit)
;   DC = spectrometer dark current digital counts (16 bit)
;   Inttime = spectrometer integration time (ms)
;   Temp = spectrometer temperature (°C)
;   a0 = Ed sensor radiometric responsivity coefficients in air (W.ms/m^2/nm/°C/digital count)
;   b0 = Lu sensor radiometric responsivity coefficients in air (W.ms/m^2/sr/nm/°C/digital count)
;   c0 = Lsky sensor radiometric responsivity coefficients in air (W.ms/m^2/sr/nm/°C/digital count)
;   Ed_lambda = Ed sensor pixel wavelengths (nm)
;   Lu_lambda = Lu sensor pixel wavelengths (nm)
;   Lsky_lambda = Lsky sensor pixel wavelengths (nm)
;   DeltaT_Ed = Ed sensor integration time offset (ms)
;   DeltaT_Lu = Lu sensor integration time offset (ms)
;   DeltaT_Lsky = Lsky sensor integration time offset (ms)
;   Tempco_Ed = Ed sensor temperature correction coefficients
;   Tempco_Lu = Lu sensor temperature correction coefficients
;   Tempco_Lsky = Lsky sensor temperature correction coefficients
;   d0 = Ed spectrometer linearity correction slope
;   d1 = Ed spectrometer linearity correction yint
;   e0 = Lu spectrometer linearity correction slope
;   e1 = Lu spectrometer linearity correction yint
;   f0 = Lsky spectrometer linearity correction slope
;   f1 = Lsky spectrometer linearity correction yint
;
; Spectrometer linearity and Tref coefficients for each channel:
;
    d0 = 1.004223e+000
    d1 = -4.794811e-007
    e0 = 1.003856e+000
    e1 = -4.430054e-007
    f0 = 1.004355e+000
    f1 = -4.893656e-007
    Delta_T_Ed = 4.185059e+000
    Delta_T_Lu = 4.219235e+000
    Delta_T_Lsky = 4.164492e+000
    Tref = 2.400000e+001
;
; Calibration file usage:
;
;    K1=d1*(V-DC)+d0
;    K2=e1*(V-DC)+e0
;    K3=f1*(V-DC)+f0
;    Ed=a0*((V-DC)/(Inttime+DeltaT_Ed)/K1)/(Tempco_Ed*(Temp-Tref)+1)
;    Lu=b0*((V-DC)/(Inttime+DeltaT_Lu)/K2)/(Tempco_Lu*(Temp-Tref)+1)
;    Lsky=c0*((V-DC)/(Inttime+DeltaT_Lsky)/K3)/(Tempco_Lsky*(Temp-Tref)+1)
;
; Pixel,    Lambda_Ed,          a0,   Tempco_Ed,    Lambda_Lu,          b0,   Tempco_Lu,  Lambda_Lsky,          c0,  Tempco_Lsky
     0, 3.43264e+002, 2.60402e-003,-6.58915e-004, 3.40723e+002, 1.75211e-004,-8.57611e-004, 3.40793e+002, 2.10571e-004,-1.16477e-003
     1, 3.46588e+002, 2.34158e-003,-6.35607e-004, 3.44052e+002, 1.59099e-004,-8.31321e-004, 3.44118e+002, 1.89501e-004,-1.13235e-003
     2, 3.49912e+002, 2.15530e-003,-6.12560e-004, 3.47381e+002, 1.47067e-004,-8.05362e-004, 3.47442e+002, 1.72954e-004,-1.10032e-003
     3, 3.53237e+002, 2.03897e-003,-5.89768e-004, 3.50710e+002, 1.40598e-004,-7.79729e-004, 3.50768e+002, 1.57904e-004,-1.06868e-003
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     6, 3.63214e+002, 2.04893e-003,-5.22870e-004, 3.60703e+002, 1.45777e-004,-7.04724e-004, 3.60749e+002, 1.33141e-004,-9.76038e-004
     7, 3.66541e+002, 2.12151e-003,-5.01045e-004, 3.64036e+002, 1.52258e-004,-6.80332e-004, 3.64077e+002, 1.32918e-004,-9.45893e-004
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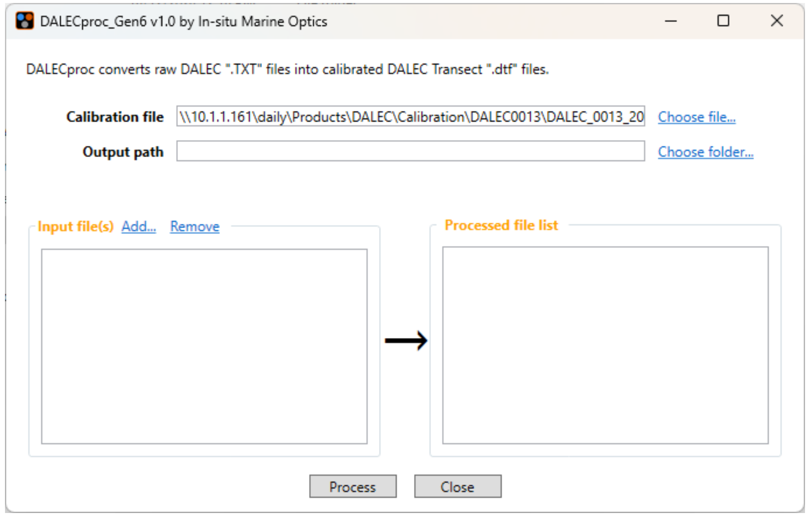


HyperCP

Field Comparisons

- 2016 – 2017: IMOS “Radiometry Task Team” – David Antione (Curtin)

IMOS Integrated Marine Observing System

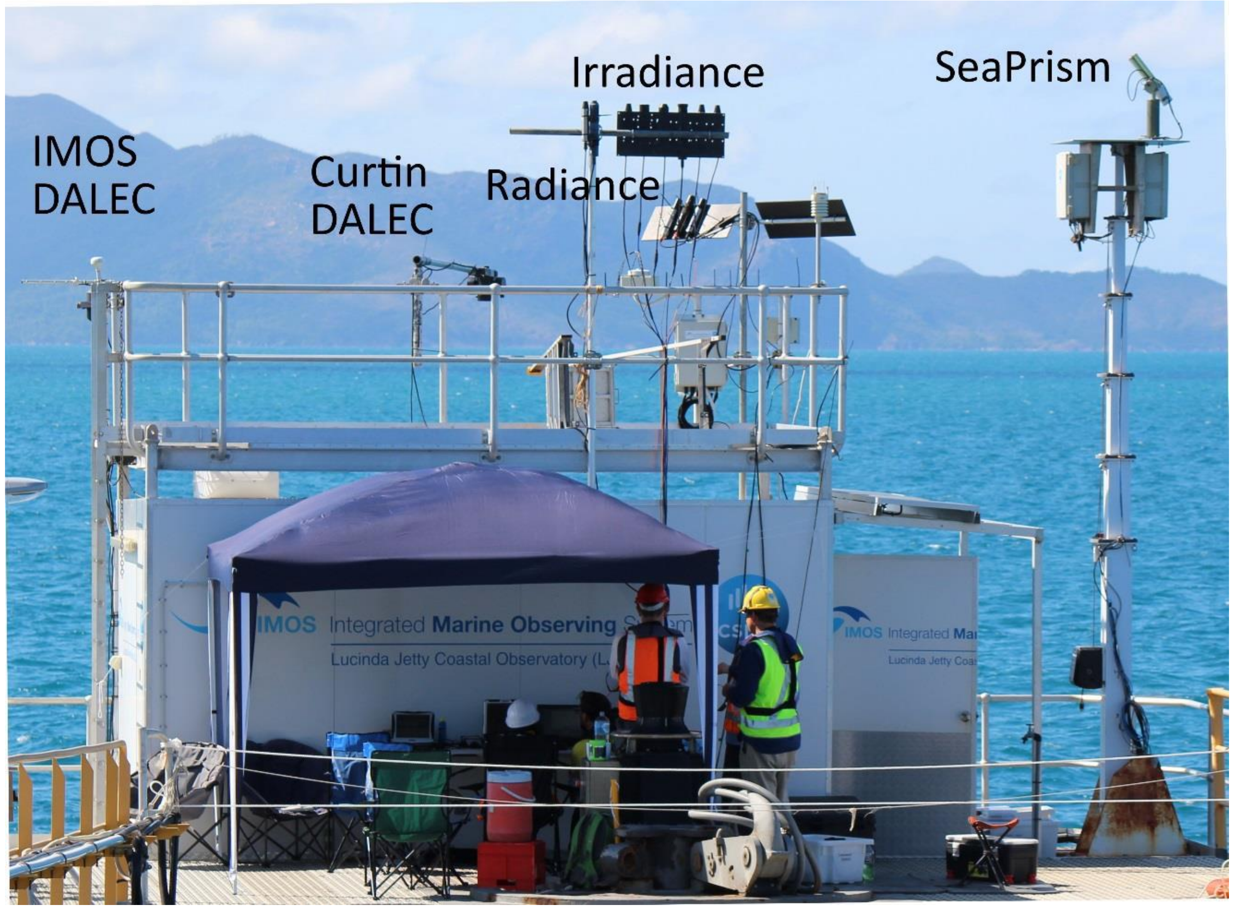
The aims of the laboratory experiment were:

- To consistently calibrate all radiometers to be subsequently used in the field for this experiment, so that differences due to inconsistent calibrations do not confuse the comparison of results
- To perform characterisation experiments in order to better understand how these instruments respond to environmental conditions and to various levels of radiance or irradiance
- To provide some training to non-specialist members of the RTT about the radiometric calibration process to build national capacity

The aims of the field experiments at LJCO were:

- To bring together the community for an inter-comparison of radiometry measurements at a well-characterized site, i.e., the Lucinda Jetty Coastal Observatory (LJCO)
- Use that opportunity to further build capacity by training the community in best practice for deployment of, and data processing from, radiometers.

Field Comparisons



- Findings
  - Field sensor temperatures up to 20 degrees higher than in Lab calibrations.
  - Temperature-specific calibration minimised error.
  - Differences in cosine response errors were highlighted in the time series data over the course of the day.
  - Environmental conditions impacted the accuracy of comparisons against the SEAPRISM

In-Situ Marine Optics

Field Comparisons

Uncertainty assessment of unattended above-water radiometric data collection from research vessels with the Dynamic Above-water Radiance (L) and Irradiance (E) Collector (DALEC)

David Antoine,[1,2,*] **Matthew Slivkoff,**[3] **Wojciech Klonowski,**[3] **Charles Kovach,**[4] **and Michael Ondrusek**[5]

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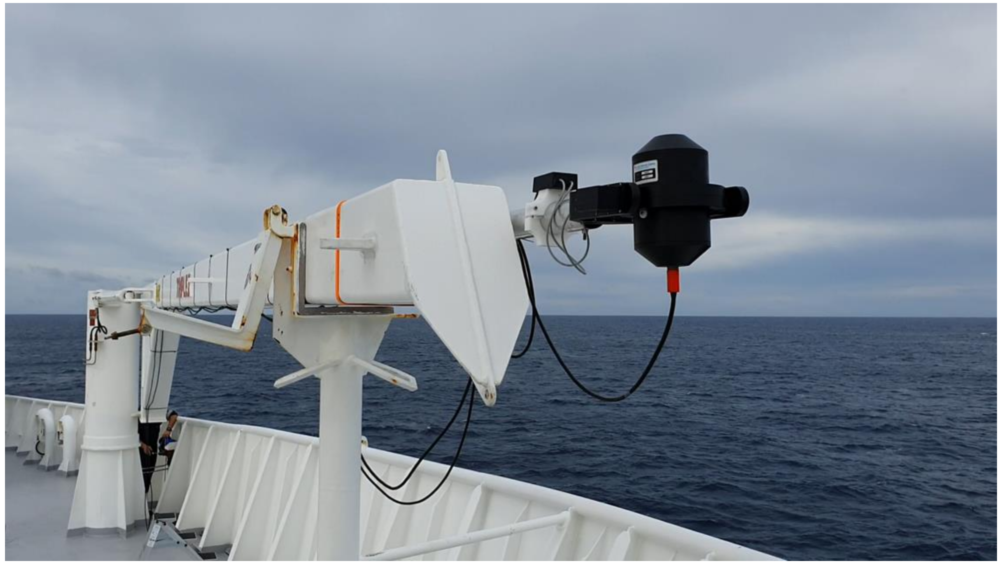
Abstract: We used above- and below-water radiometry measurements collected during a research voyage in the eastern Indian Ocean to assess uncertainties in deriving the remote sensing reflectance, R_{rs}, from unattended above-water radiometric data collection with the In-Situ Marine Optics Pty. Ltd. (IMO) Dynamic Above-water Radiance (L) and Irradiance (E) Collector (DALEC). To achieve this, the R_{rs} values derived from using the latest version of this hyperspectral radiometer were compared to values obtained from two in-water profiling radiometer systems of rather general use in the ocean optics research community, i.e., the Biospherical Instruments Inc. Compact Optical Profiling System (C-OPS) and the Seabird HyperPro II. Our results show that unattended, carefully quality-controlled, DALEC measurements provide R_{rs} for wavelengths < 600 nm that match those derived from the in-water systems with no bias and a dispersion of about 8%, provided that the appropriate technique is used to quantify the contribution of sky light reflection to the measured signal. The dispersion is larger (25-50%) for red bands, which is expected for clear oligotrophic waters as encountered during the voyage, where $\sim 2\ 10^{-5} < R_{rs} < \sim 2\ 10^{-4}\ sr^{-1}$. For comparison, the two in-water systems provided R_{rs} in agreement within 4% for wavelengths < 600 nm.



In-Situ Marine Optics

Future OCR cal/char

- Investigate linearity correction coefficients vs temperature
- Automate stray light characterisation for each spectrometer module
- Polarization sensitivity
- Evaluate new spectrometers modules

New Developments

*nimo*SPEC

- Miniaturise hyperspectral radiometers.
- Low self-shading
- ø 42mm x 170mm
- Rapid samplerate up to 50Hz
- Internal Logging (128GB)
- Rechargeable Li-Ion Battery
- No cables required
- Bluetooth BLE