Multi-input Fiber Optic Coupled Spectroradiometer and Applications in Ocean Color Measurement

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MOBY Project, Honolulu, Hawaii

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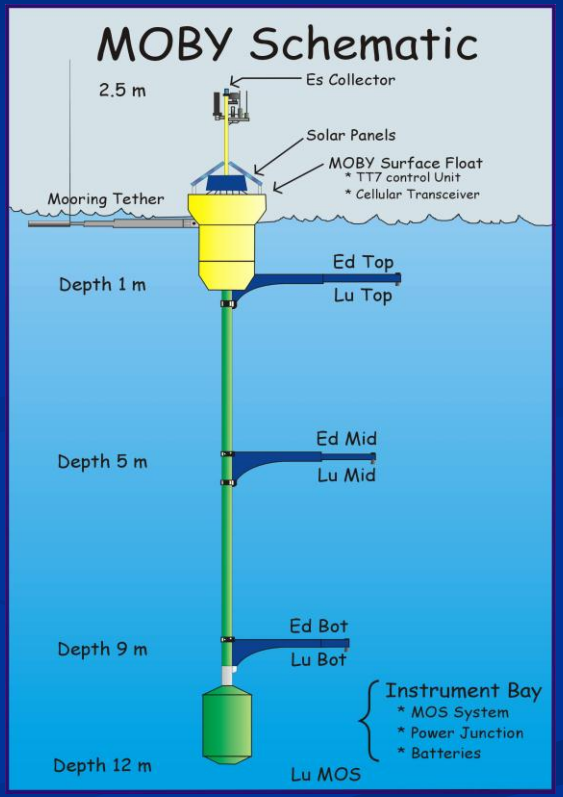
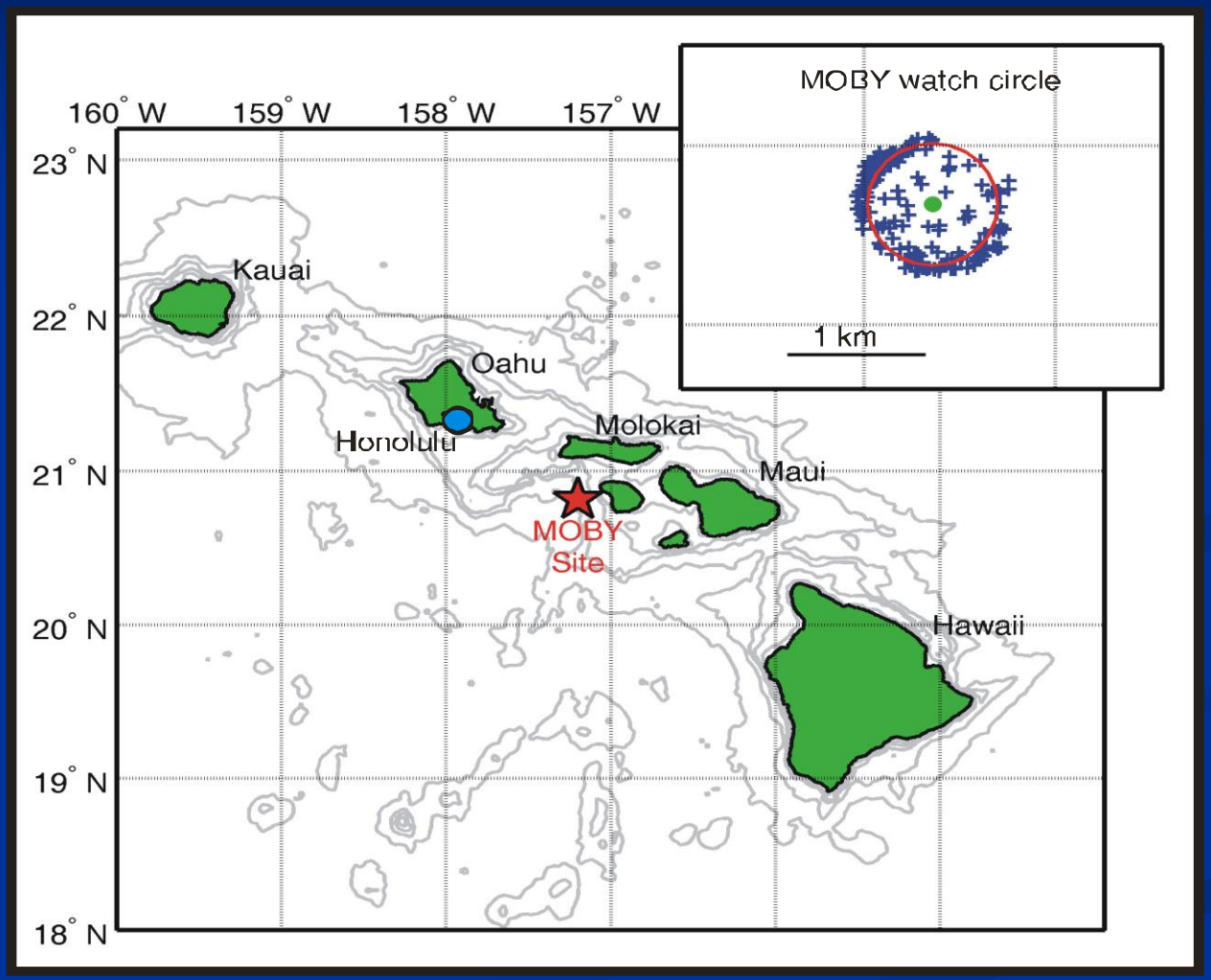
Marine Optical BouY



MOBY Lanai Study Area



MOBY Operations Site - Univ. Hawaii

Pier Side - 30,000 sq. ft

16 Portable vans/tent

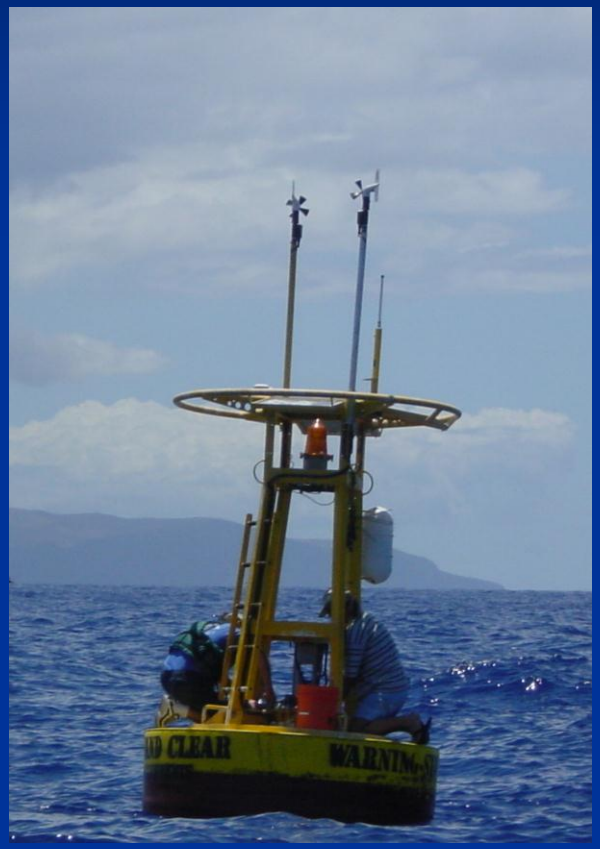
offices, shops, storage, labs (calibration, optics assembly, filtration)

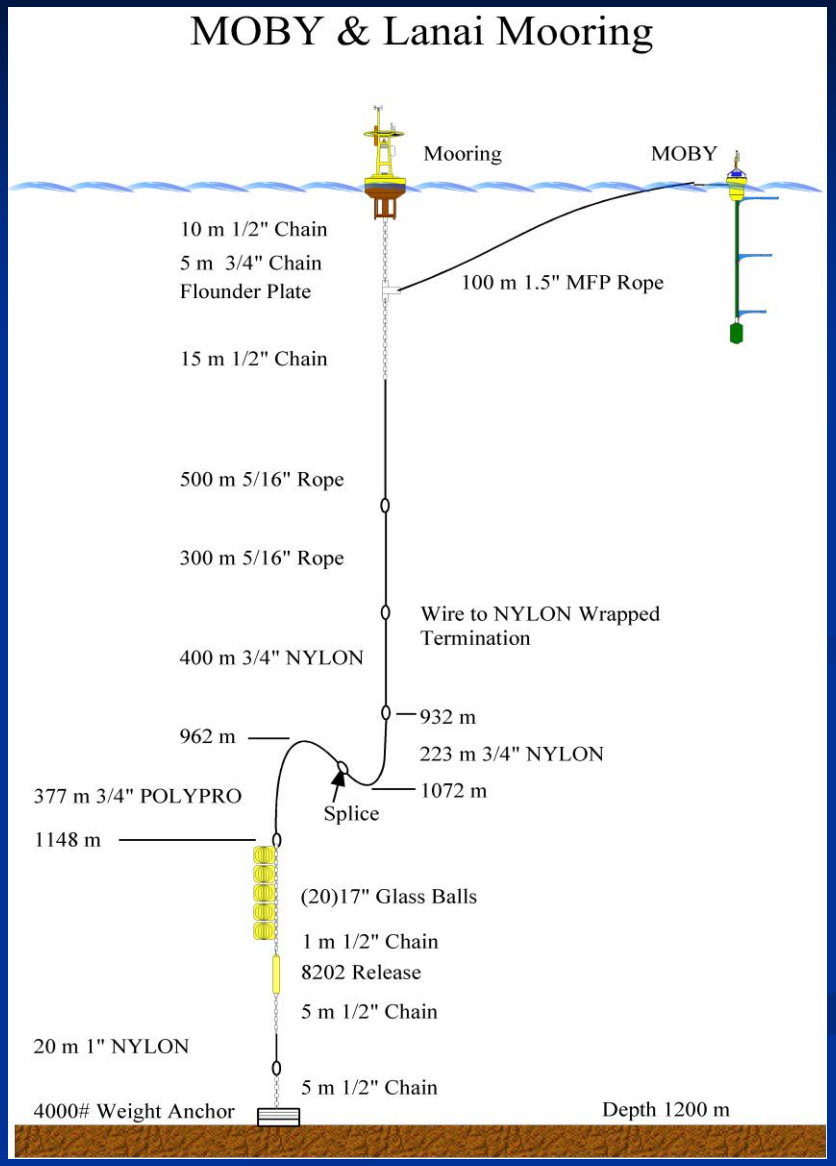
6 Shipboard Vans

3 labs - (wet, optics, data acquisition) power, storage, & office

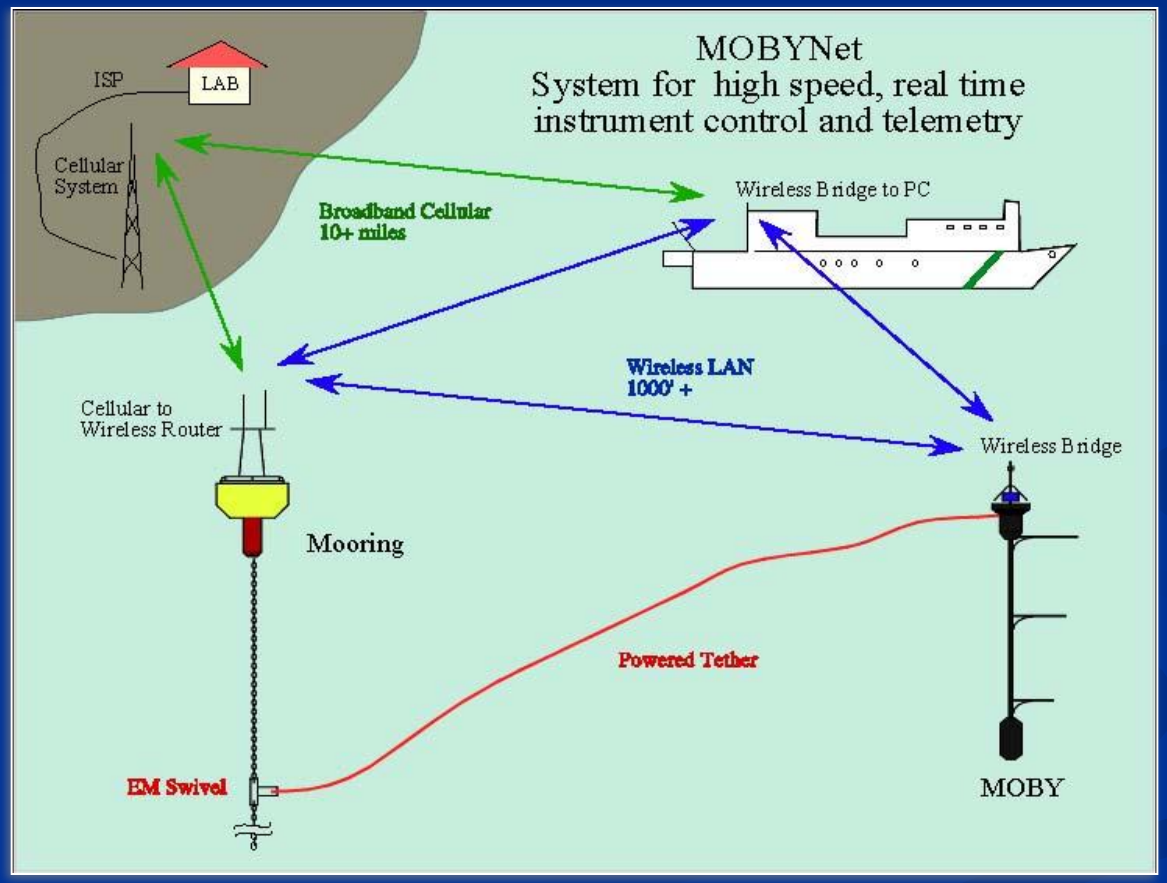
Pier side Support - cranes, machine shop.

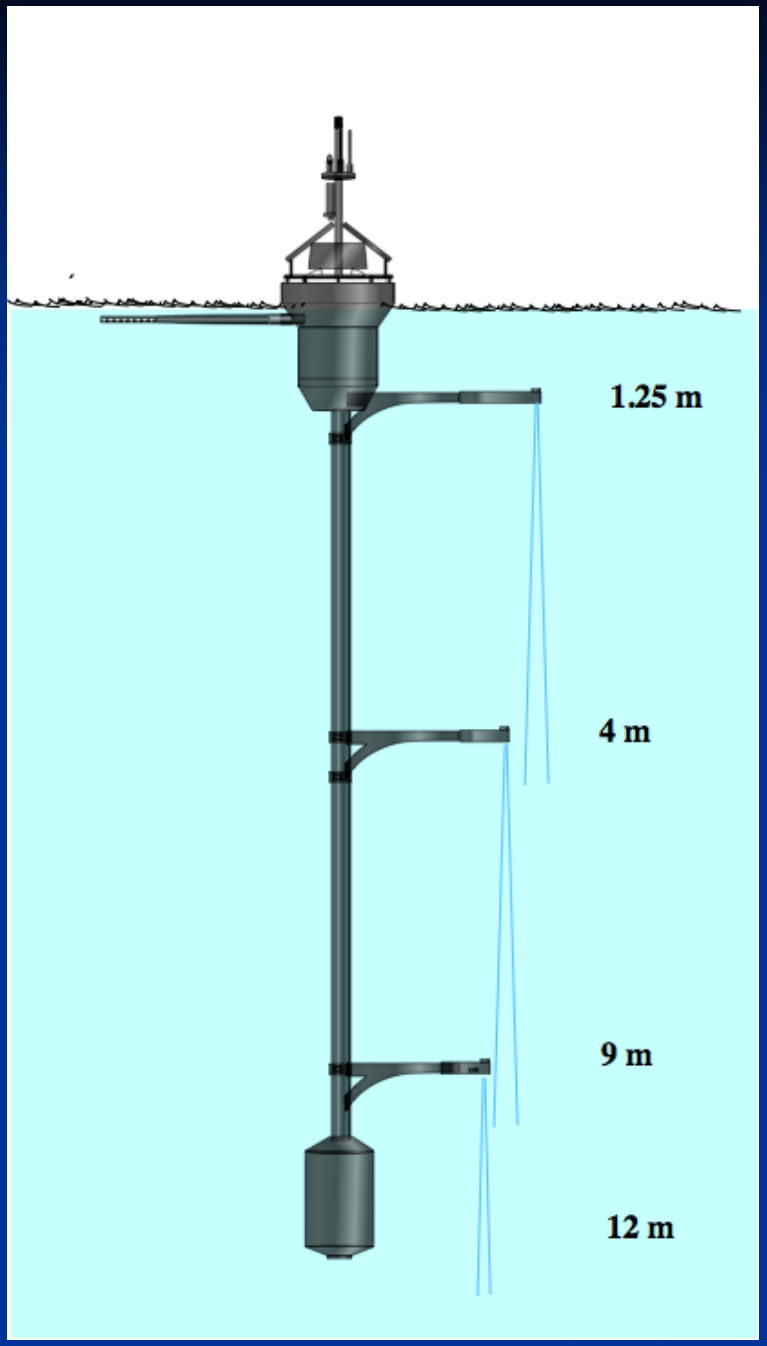
MOBY Lanai Mooring





Communications System Design: MOBYNet



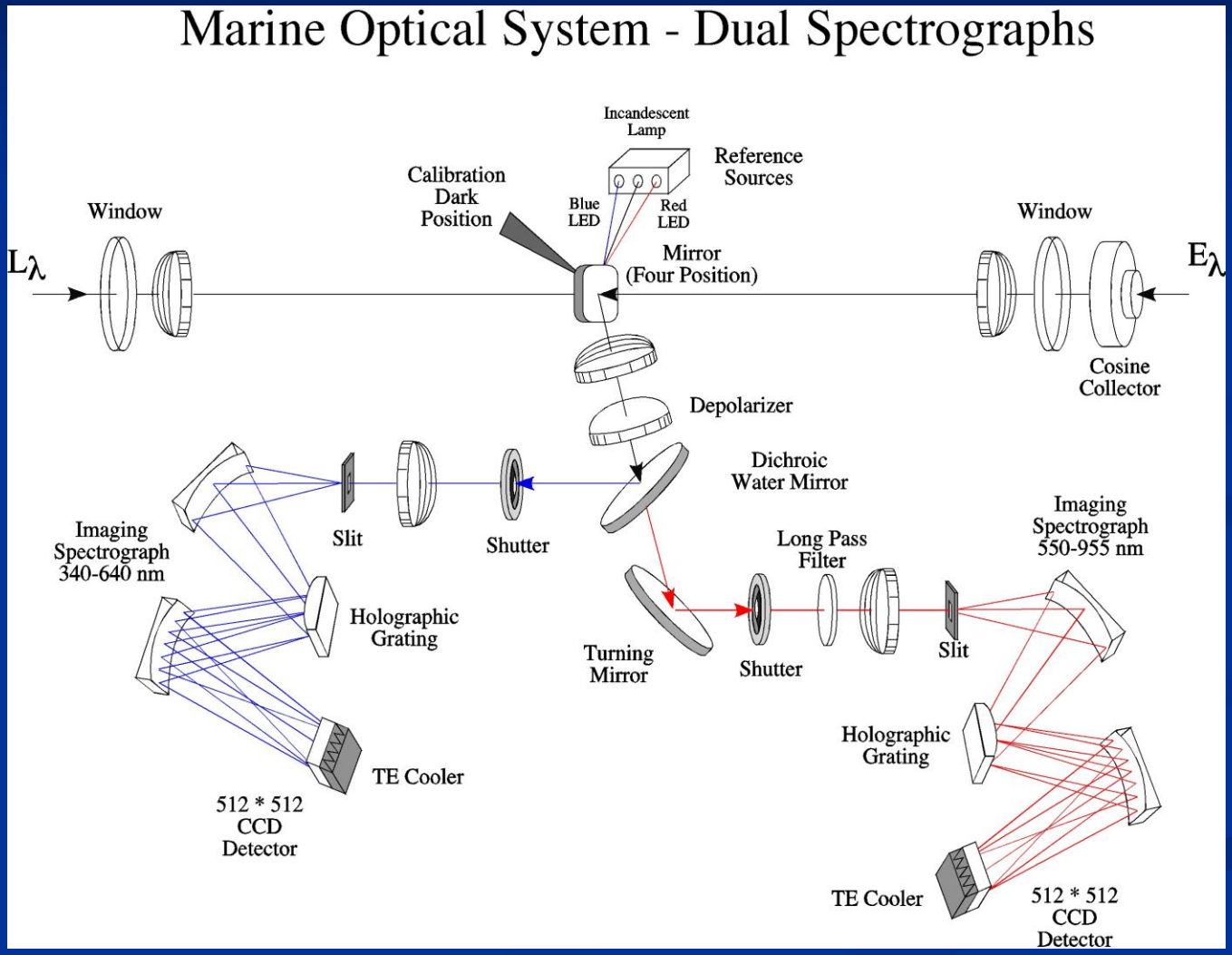


MOBY

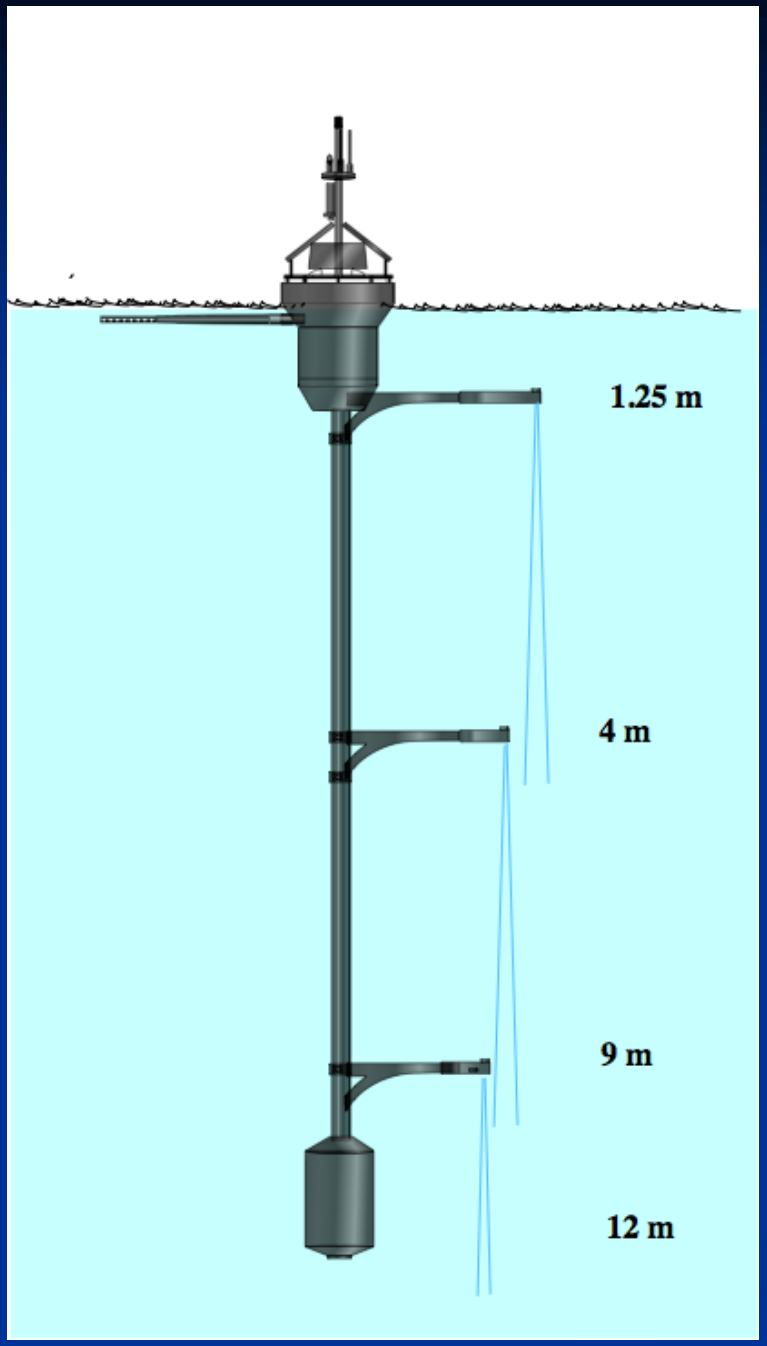
Satellite Vicarious Calibration Instrument

- Primary product, L_w
- Es
- Lu,Ed at 3 depths
- MOS radiometer
- Multiplexed fiber optic inputs
- Sequential Sampling

MOS Optical System



MOS Spectroradiometer and Fiber Optic Multiplexer



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MOBY Calibrations

- Pre- and Post- deployment calibrations every 4 months
- NIST calibrated standard lamps and spheres
- MOS spectrograph and each collector input stray light characterized on SIRCUS
- NIST validation program at Honolulu site
- Results in SI traceable measurements
- *In situ* cleaning and monitoring

Data uncertainty without MOBY

Median Percent Differences (MPD) with and without MOBY Calibration

Table 4. Validation of Vicarious Calibration Against Deep-Water *In Situ* Measurements

	Ratio[a]	MPD[a]	r^2	N[b]
$L_{wn}(412)$	1.002	11.8	0.930	188
$L_{wn}(443)$	0.950	15.5	0.873	318
$L_{wn}(490)$	0.942	12.2	0.817	318
$L_{wn}(510)$	0.957	10.6	0.579	164
$L_{wn}(555)$	0.968	14.8	0.827	318
$L_{wn}(670)$	1.347	64.7	0.595	306
C_a	0.994	26.1	0.875	149

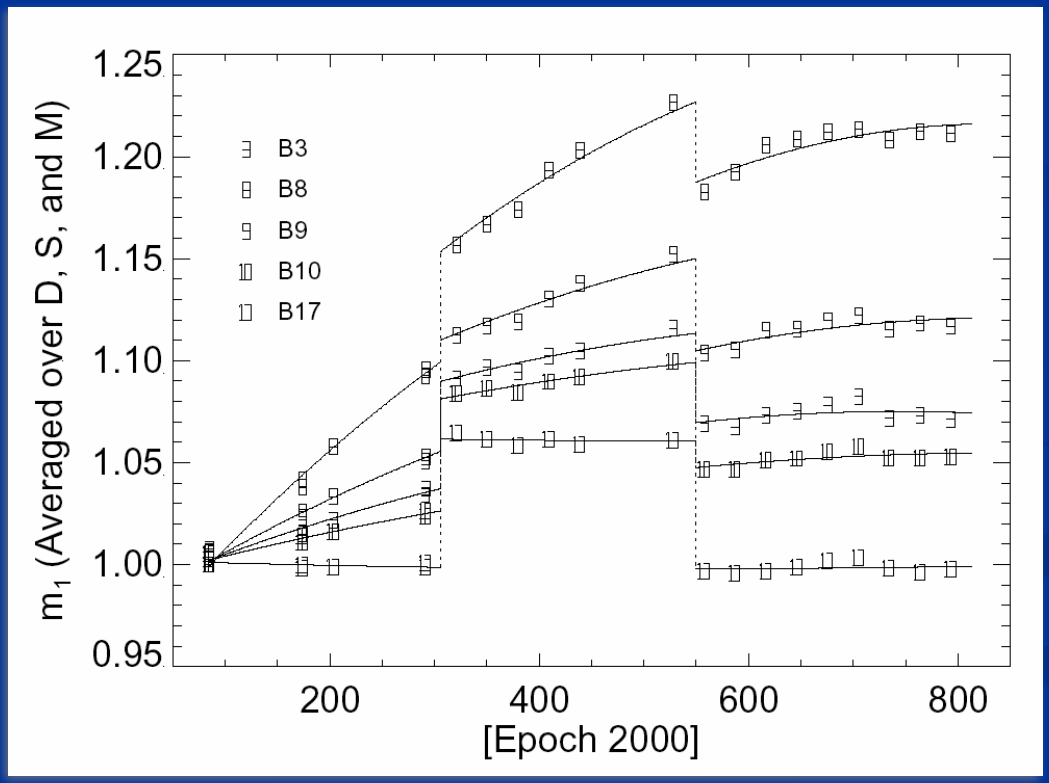
Table 5. Sensitivity of Deep-Water Validation to No Vicarious Calibration

	$\bar{g}(\lambda)$	Ratio[a]	MPD[a]	r^2	N^b
$L_{wn}(412)$	1.0000	0.245	80.0	0.861	54
$L_{wn}(443)$	1.0000	0.447	55.4	0.799	111
$L_{wn}(490)$	1.0000	0.760	25.7	0.772	111
$L_{wn}(510)$	1.0000	0.753	24.7	0.665	45

From: Franz et al 2007

MODIS/Terra change to the calibration coefficients

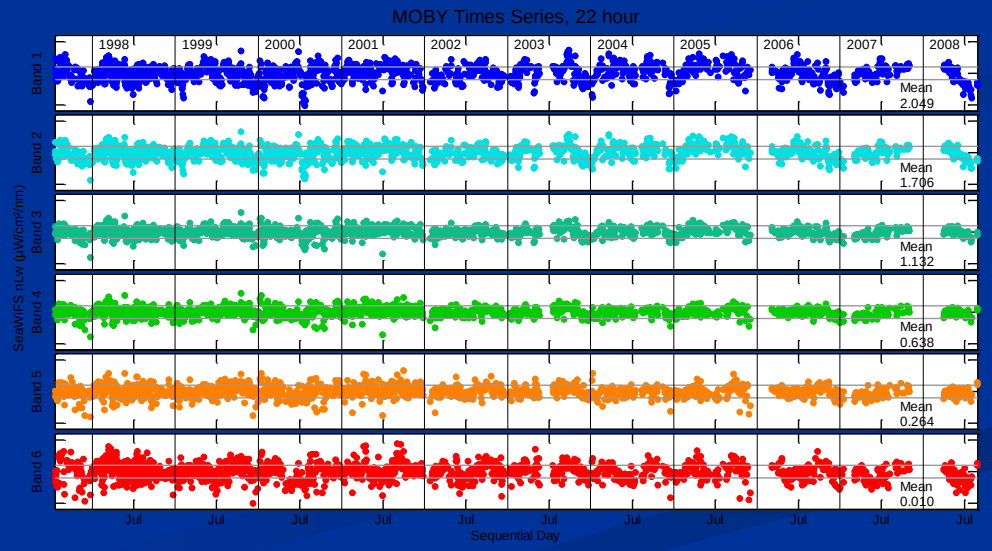
- "A-side" or "B-side" change to the calibration coefficients for the ocean color bands
- Increased precision benefit this program.
- Type A environmental uncertainties need to be reduced, to well below the 0.5 % level



Marine Optical System & Data Stream

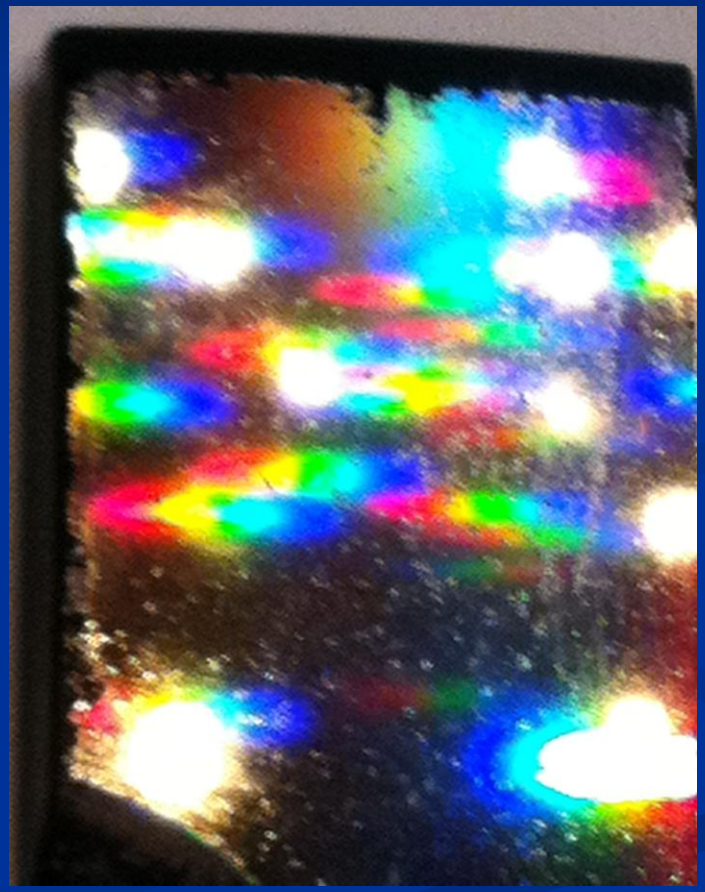
In MOS, light is input sequentially into the dual spectrographs using optical fibers and a rotating mirror assembly (in place of the cosine collector). The full slit is imaged onto CCD detectors. On a typical day, it took 27 min to acquire a full data set, with integration times of between 1 and 30 sec (Es vs Lu collectors) for the CCDs. A dark scan, three light scans, and a dark scan are taken at each channel.

In-Water Diver Cals



Aging Instrumentation

MOS radiometers are over 15 years old



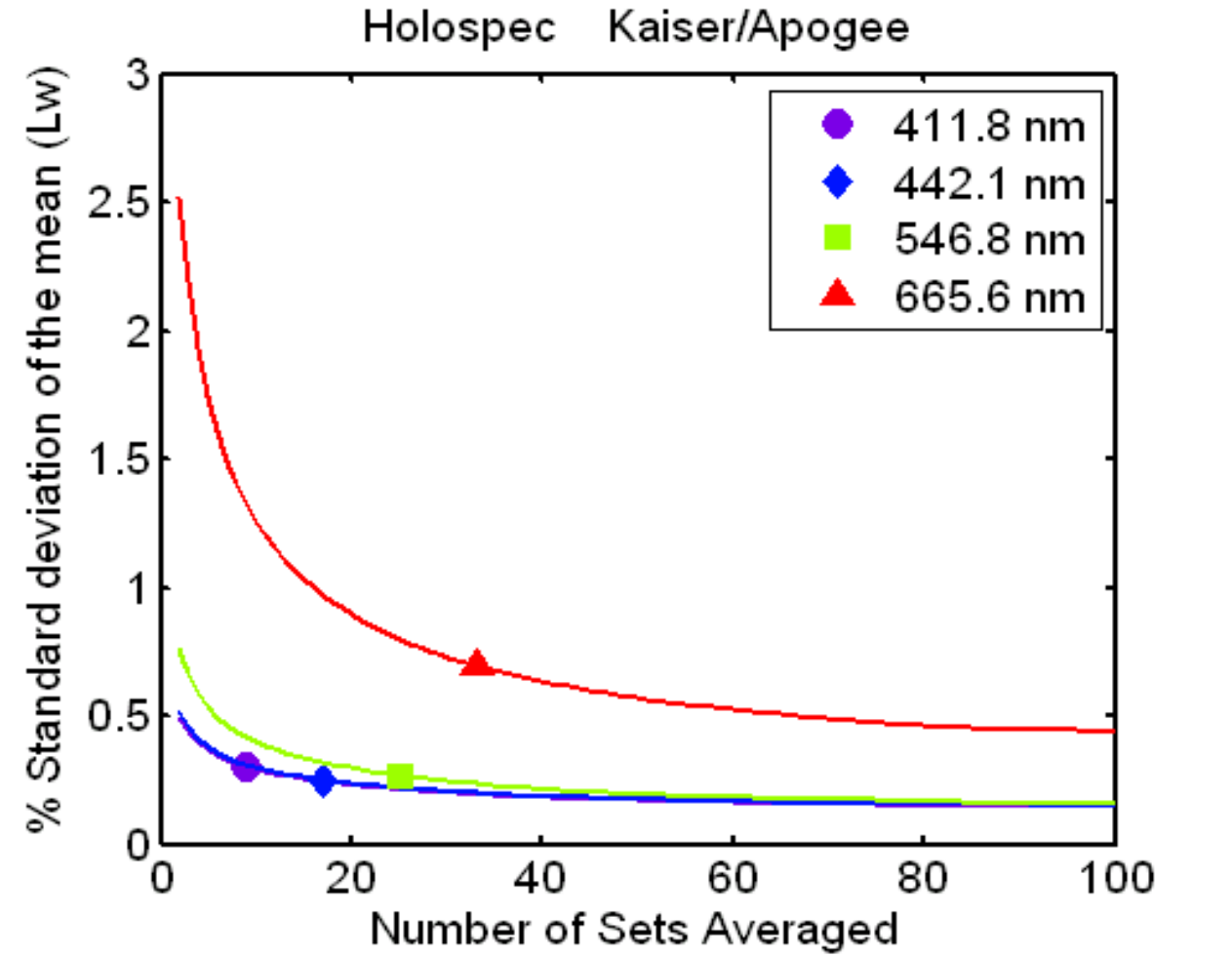
MOBY Uncertainty (k=1) in Lu(1m,λ)

MODIS-Terra

Uncertainty Component [%]	8	9	10	11	12	13
	411.8	442.1	486.9	529.7	546.8	665.6
Radiometric Calibration Source						
Spectral Radiance (NIST)	0.65	0.6	0.53	0.47	0.45	0.35
Stability	0.41	0.46	0.51	0.53	0.53	0.48
Transfer to MOBY						
Interpolation to MOBY wavelengths	0.2	0.15	0.03	0.03	0.03	0.03
Reproducibility	0.37	0.39	0.42	0.44	0.42	0.3
Wavelength accuracy	0.29	0.08	0.04	0.03	0.01	0.04
Stray light	0.75	0.3	0.1	0.15	0.3	0.3
Temperature	0.25	0.25	0.25	0.25	0.25	0.25
MOBY stability during deployment						
System response	1.59	1.3	1.19	1.11	1.08	0.92
In-water internal calibrations	0.43	0.42	0.44	0.46	0.51	0.55
Wavelength stability	0.132	0.138	1.122	0.816	1.368	0.65
Environmental						
Type A (good scans & good days)	0.8	0.83	0.87	1.02	0.64	1.31
Temporal overlap	0.3	0.3	0.3	0.3	0.3	0.3
In-water bio-fouling	1	1	1	1	1	1
Self-shading	1	1	1.2	1.75	2.5	12
*Self-shading (upon correction)***	*0.2*	*0.2*	*0.24*	*0.35*	*0.5*	*2.4*
Combined Standard Uncertainty	2.63	2.36	2.64	2.84	3.44	12.21
*Combined Standard Uncertainty***	*2.44*	*2.15*	*2.36*	*2.27*	*2.42*	*3.28*

#1-10 = Cals

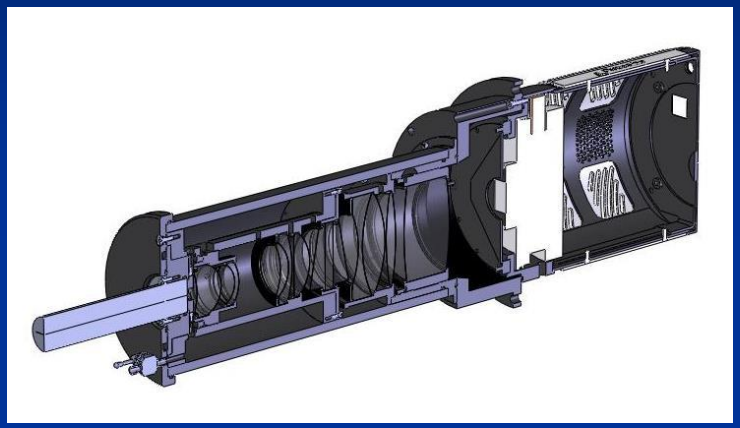
Increased sample rate



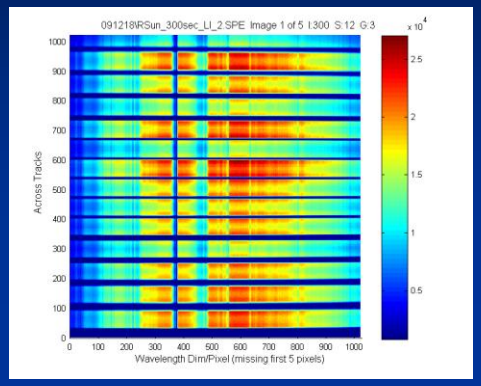
New Sensor – Simultaneous Acquisition

Romack fiber optic input
(currently 14 channels)

Princeton Instrument

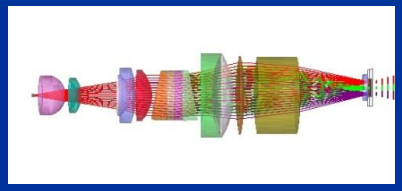


Resonon Volume Phase Holographic (VPH) in line spectrograph

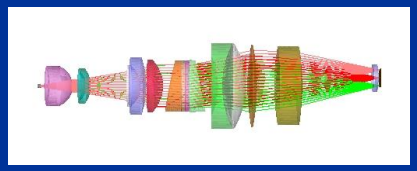


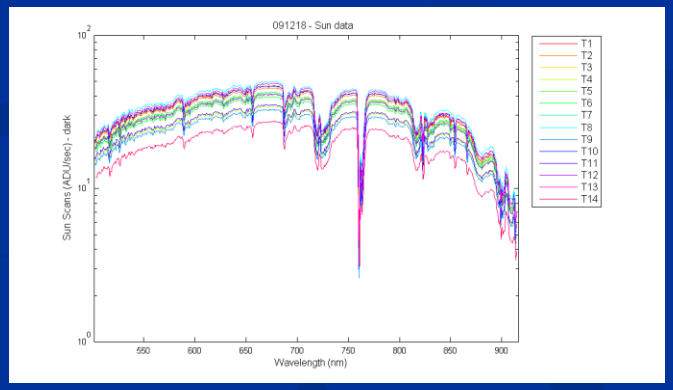
RILS image of diffuse solar flux

Blue In Line Spectrograph (BILS)



Red In Line Spectrograph (RILS)





Average net ADU/sec for each channel

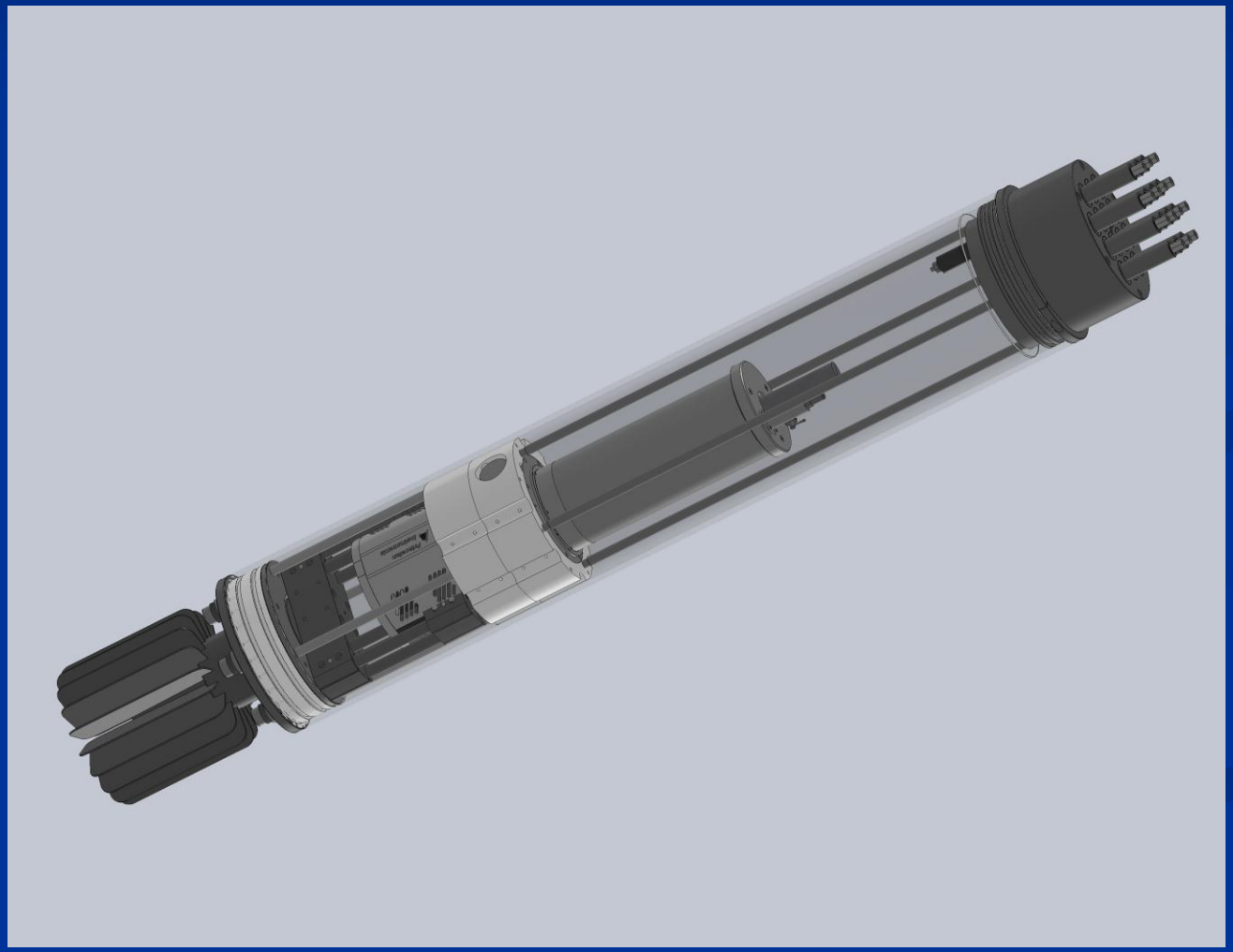
The inputs to the optical fibers are at the desired locations. The fiber outputs are aligned vertically at the entrance slit. The prism-grating-prism in-line optical system (Resonon, Inc.) images the different input channels at the same time on the CCD camera), spaced along the slit direction.

In-Line Spectrograph Parameters from Optical Design

Parameter	Blue	Red
Size, cm	13.7 x 41.7	13.7 x 43.2
Spectral coverage, nm	370 - 720	500 - 900
Spectral resolution, nm	0.34	0.39
Image at focal plane, mm	13 x 13	13 x 13
Slit dimensions, mm	13 x 0.025	13 x 0.025
Thermal effect, pixel/deg C	< 0.05 pixel	< 0.05 pixel
MTF @ 38 line pr / mm	76 at 545 nm	61 at 700 nm
Throughput, %	74.8 at 430 nm	72.5 at 700 nm
Ghosting / Stray Light	< 0.5% at 420 nm	< 0.6% at 520 nm

"Report on Blue and Red Imaging Spectrometers for MOBY," Michael Kehoe and Casey Dodge, Resonon, Inc.

Multi-input Fiber Optic Spectroradiometer

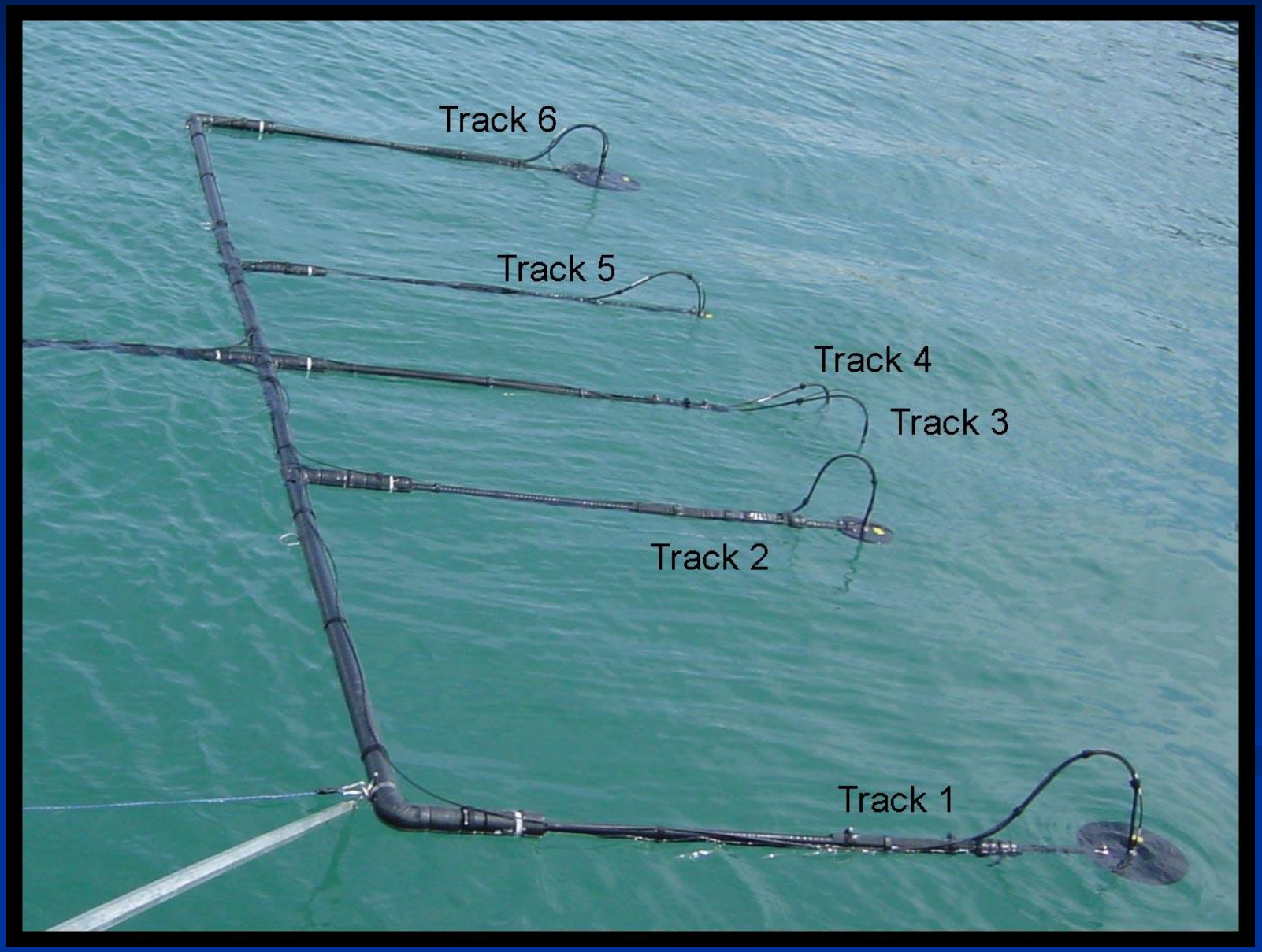


Multi-input Fiber Optic Spectroradiometer

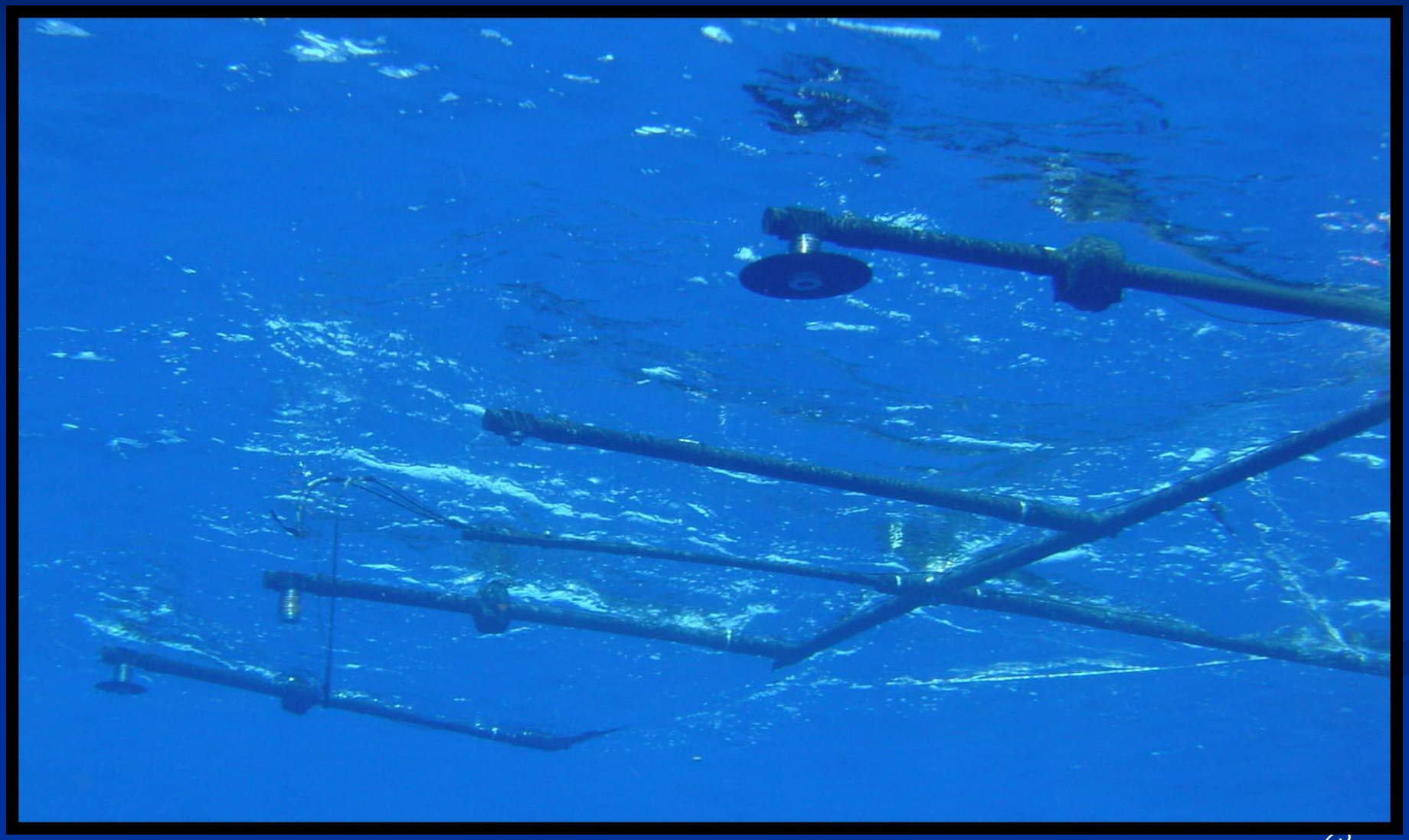
Unique Benefits of MOBY-C

- Supports ViCal of multiple satellites
- High data rate provides less data exclusion
- Geometry minimizes self shading errors
- Methodology for optimum Lw measurements
- Configurable for a range of OC applications
- One instrument provides up to 16 inputs

Self-shading Experiment



Self-shading Experiment



Self-shading Experiment