UNIVERSITY
OF MIAMI

Cal/Val and MOBY

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MOBY TEAM (Carol Johnson, NIST, and Mark Yarbrough and many at Moss Landing Marine lab)

Ken Voss, Ocean Optics Summer class, 2021

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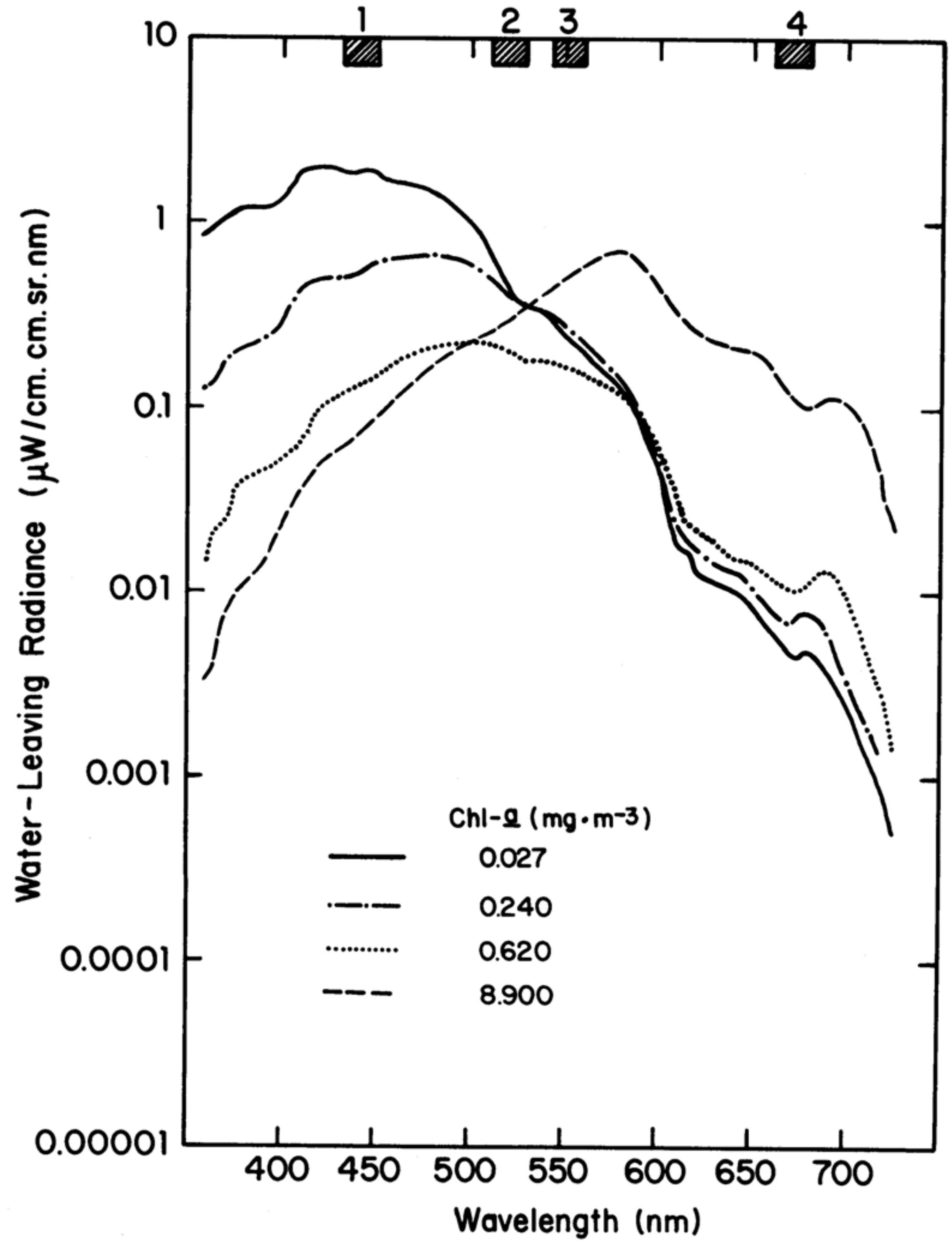
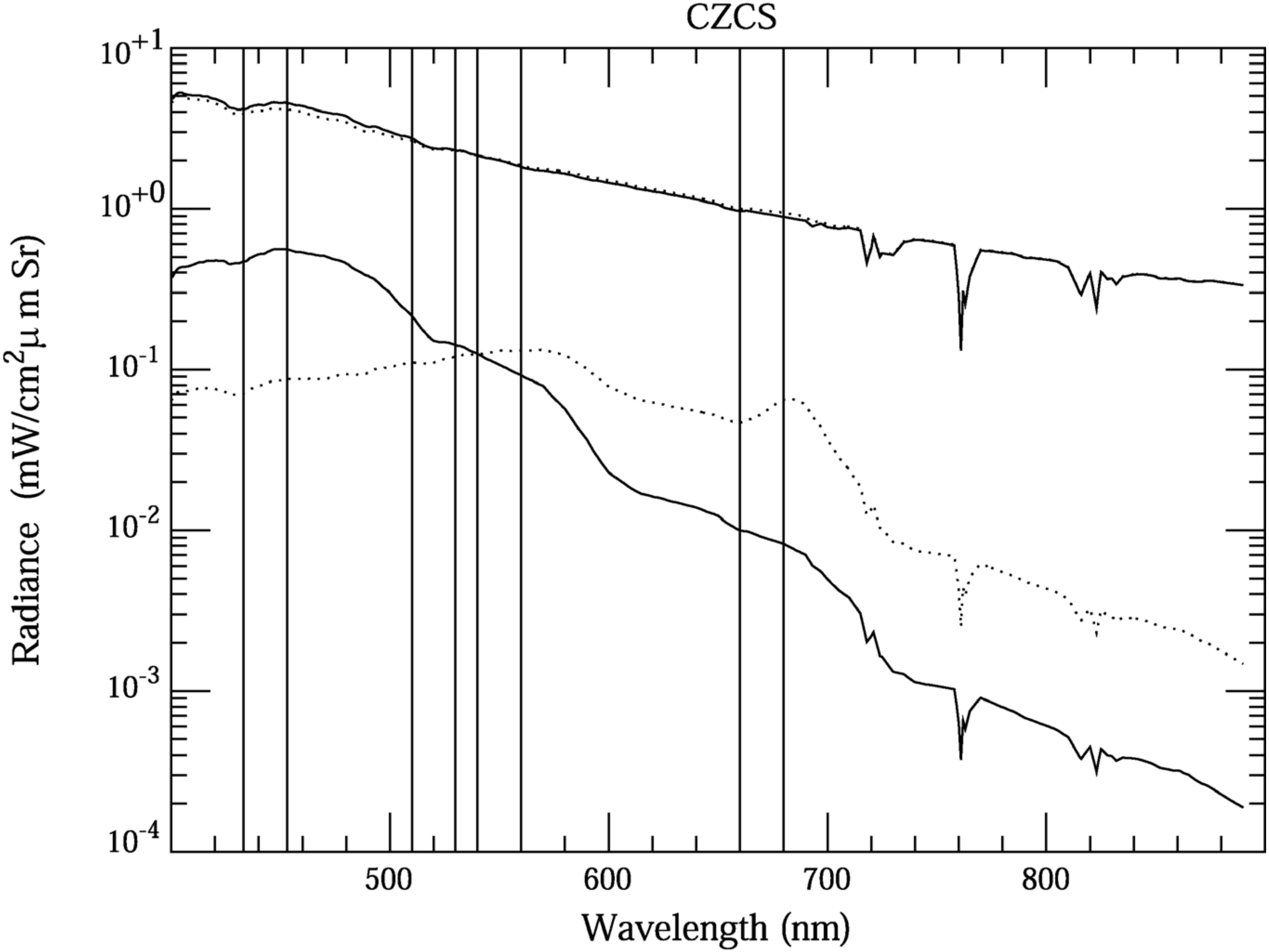
<u>Ocean Color opportunity:</u> Clarke, Ewing and Lorenzen's aircraft measurements (Science, 1970) pointed out relationships between surface Chl and the spectra of the water leaving the ocean.



From Gordon et al.1985, in Satellite Oceanic Remote Sensing

Ocean Color Difficulty



So accurate measurements of Lw are required to successfully retrieve products from satellite ocean color instruments, hence the title of this class: *Calibration and Validation for Ocean Color Remote Sensing*

1) Short history of the MOBY project and its beginnings

2) Current Status of the project

3) Future directions

The driving force for MOBY came out of CZCS experience

- CZCS launched 10/24/1978
- 3 post launch validation cruises:
  - Gulf of Mexico, R/V Athena (14 days)
  - Baja California, Gulf of California, R/V Velero IV (22 days)
  - East coast US, R/V Athena (25 days)
- These 61 days of ship time with 55 stations, resulting in only 9 stations suitable for calibration.

Leads Dennis Clark to the idea of an autonomous platform

- Collect and send back data daily
- Site requirements:
  - Reasonable clear sky statistics
  - Homogeneous waters with a clean atmosphere
  - Logistically possible (close to a source of ships, reasonable chance of low sea state)
  - Communication daily (cell phone)

MOBY timeline

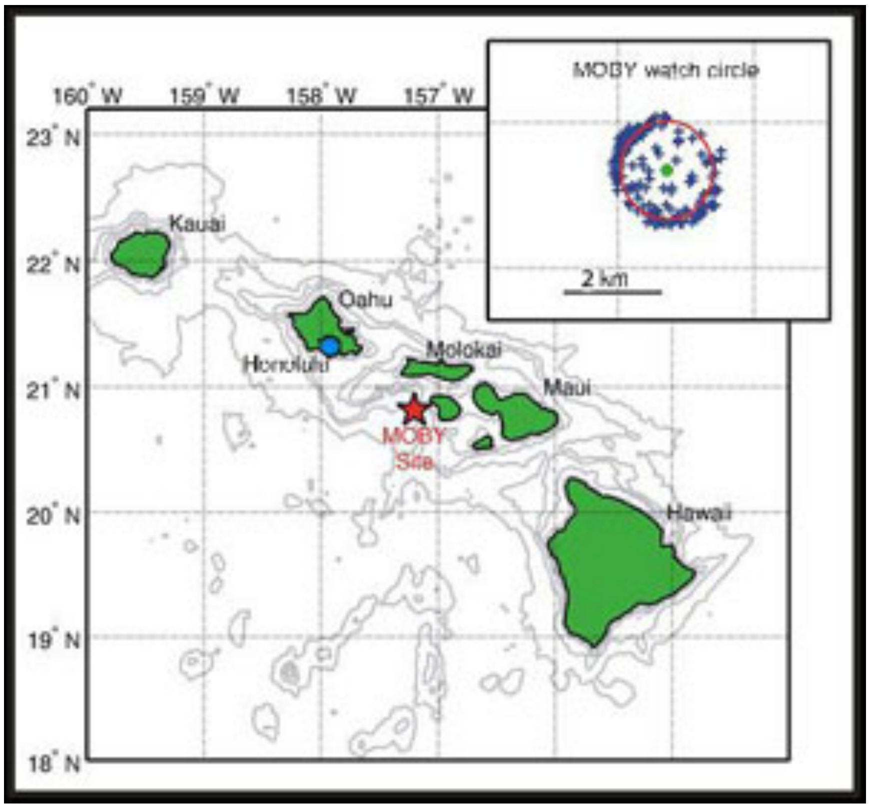
- Dennis begins development in 1985 (34 years ago)
- MODIS(NASA) funding started around 1990, then SeaWiFS provided accelerated funding in 1991.
- First prototype deployment in Monterrey, 1993 (26 years ago)
- Prototype in Hawaii, 1995
- Operational deployed in 1997 (22 years ago), funded by NASA.
- Funded by NOAA since 2007

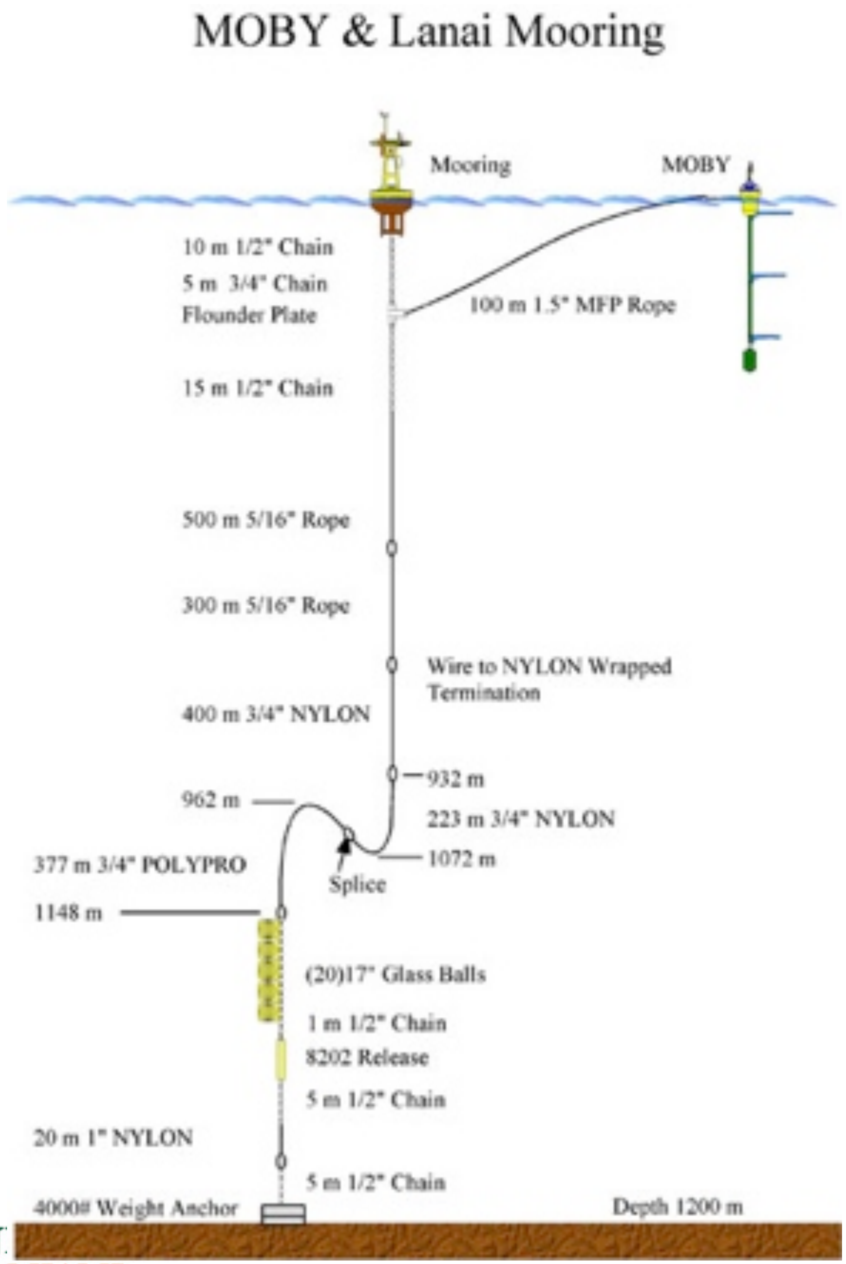
Basically 2 instruments have been in the field, operating alternately for 20+ years.

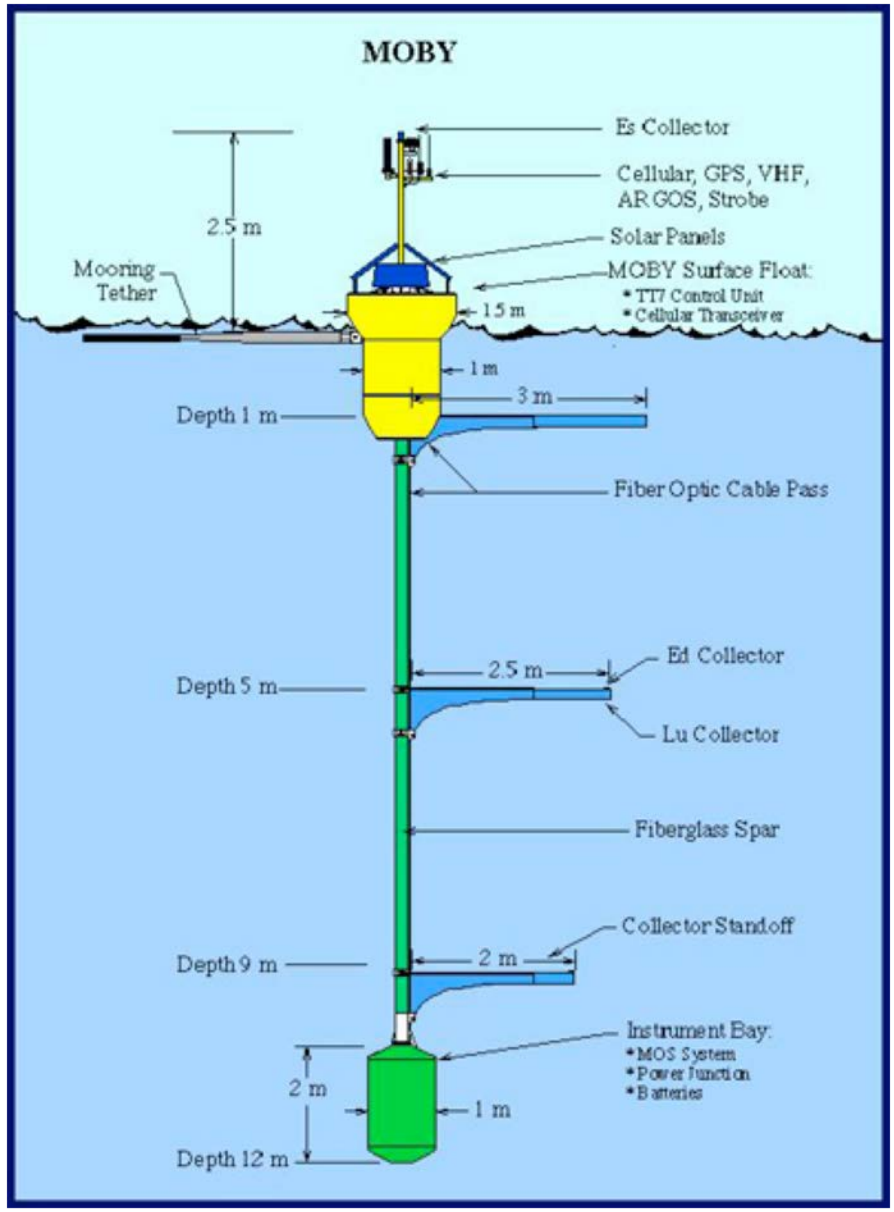
Site chosen was off of Lanai, Hawaii.

Tent constructed on UHMC site (now at the newer UHMC site different part of Honolulu)

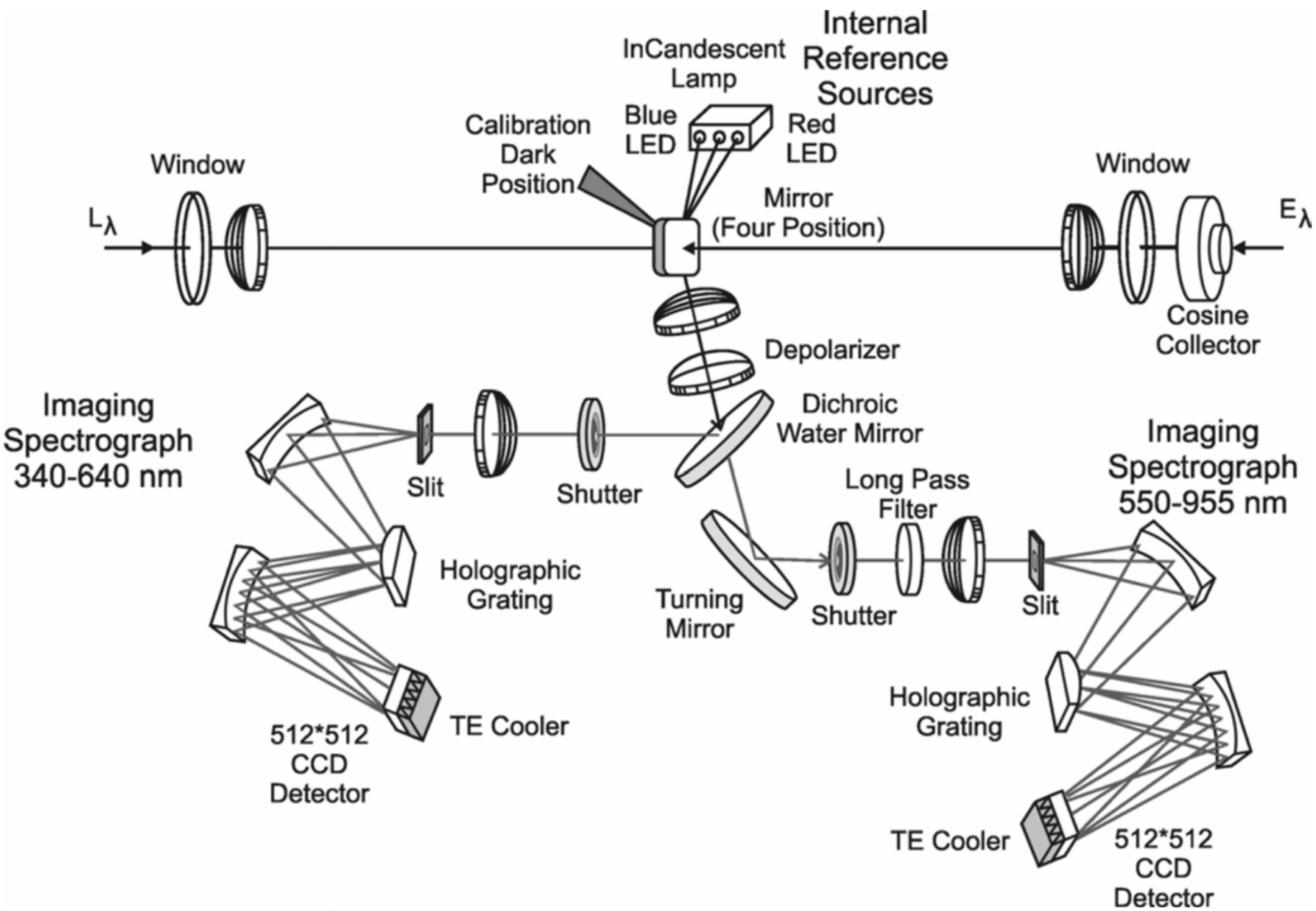
Ships available (now use a commercial ship, UH sold KoK)




MOBY & Lanai Mooring
Mooring
MOBY
10 m 1/2" Chain
5 m 3/4" Chain
Flounder Plate
100 m 1.5" MFP Rope
15 m 1/2" Chain
500 m 5/16" Rope
300 m 5/16" Rope
Wire to NYLON Wrapped Termination
400 m 3/4" NYLON
932 m
962 m
223 m 3/4" NYLON
1072 m
377 m 3/4" POLYPRO
Splice
1148 m
(20)17" Glass Balls
1 m 1/2" Chain
8202 Release
5 m 1/2" Chain
20 m 1" NYLON
5 m 1/2" Chain
4000# Weight Anchor
Depth 1200 m


MOBY
Es Collector
Cellular, GPS, VHF, ARGOS, Strobe
2.5 m
Solar Panels
Mooring Tether
MOBY Surface Float:
• TT7 Control Unit
• Cellular Transceiver
1.5 m
1 m
3 m
Depth 1 m
Fiber Optic Cable Pass
Ed Collector
2.5 m
Depth 5 m
Lu Collector
Fiberglass Spar
Collector Standoff
2 m
Depth 9 m
Instrument Bay:
• MOS System
• Power Junction
• Batteries
2 m
1 m
Depth 12 m

Schematic of Current MOBY



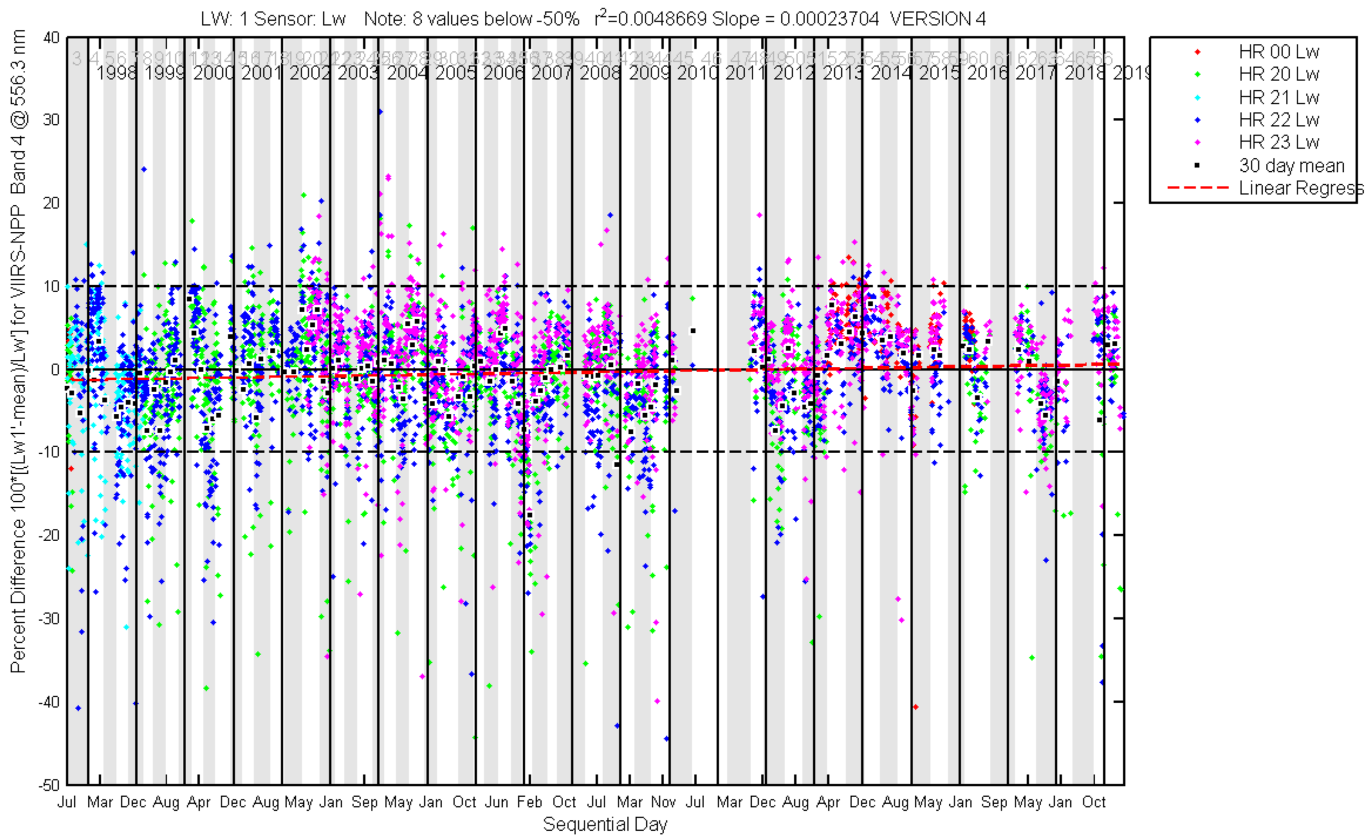
Hyperspectral,0.57 nm spacing in blue spectral region, 0.91 nm FWHM, and 1.2 nm FWHM in red.

Hyperspectral, with this much resolution, allows the same system (one site) to be used for multiple satellite sensor systems, including out-of-band response, to tie these systems together.

This system has been extensively characterized

- Stray light characteristics on SIRCUS (NIST) repeatedly measured, with corrections added to data
- Pre-post radiometric response with direct traceability to NIST scales and additional custom instruments monitoring of calibration sources
- Diver calibrations/cleaning monthly
- On board sources monitored
  daily
- Area around the site has been
  characterized

20 year time series (with repeating annual trend removed).



Note over the 18 years, there has been a change in the time of acquisitions, due to satellite mission requirements, now measurements are later in the day compared to earlier in the mission…causes an apparent trend in the data.

Data (with 1-3 day lag) openly available at NOAA Coastwatch site: https://coastwatch.noaa.gov/cw/field-observations/MOBY.html

Our current understanding of the MOBY uncertainties, first radiances:

Laboratory L(lambda)

ID	Component description	M1=410 nm	M2=443 nm	M3=486 nm	M4=551 nm
1	Reference source	0.81	0.72	0.61	0.53
2	Reference source drift	0.42	0.46	0.51	0.53
3	Uniformity of source	0.2	0.2	0.2	0.2
4	Interpolation to MOBY λ	0.2	0.15	0.03	0.03
5	Reproducibility, Pre/Post	1.43	1.12	0.95	0.87
6	Wavelength calibration	0.38	0.29	0.22	0.14
	RSS, Radiometric, 1-6	**1.76**	**1.46**	**1.27**	**1.02**

Going to Lu(lambda)

ID	Component description	M1=410 nm	M2=443 nm	M3=486 nm	M4=551 nm
7	Immersion	0.1	0.1	0.1	0.1
8	Stray Light Correction	1.79	0.6	0.24	0.55
9	calibration measurement uncertainty	0.51	0.21	0.22	0.12
10	in situ measurement uncertainty	0.88	0.74	0.76	1.03
11	integration time correction	0.15	0.15	0.15	0.15
12	instrument temperature correction	0.16	0.16	0.16	0.16
	RSS, Radiometric & Measurement (1-12), LuTOP	**2.72**	**1.77**	**1.53**	**1.68**

Then Es uncertainties

Laboratory

ID	Component description	M1=410nm	M2=443nm	M3=486nm	M4=551nm
1	Reference source	0.52	0.46	0.43	0.39
2	Reference source drift	0.77	0.75	0.69	0.67
3	Effects of EG&G bench	0.49	0.49	0.49	0.49
4	Interpolation to MOBY λ	0.1	0.1	0.1	0.1
5	Reproducibility, Pre/Post	1.14	0.92	0.76	0.69
6	Wavelength calibration	0.34	0.25	0.19	0.12
	RSS, Radiometric	**1.59**	**1.39**	**1.23**	**1.15**

Field

ID	Component description	M1=410 nm	M2=443 nm	M3=486 nm	M4=551 nm
7	Stray Light Correction	1.07	0.35	0.11	0.05
8	calibration measurement uncertainty	0.31	0.14	0.10	0.06
9	in situ measurement uncertainty	2.68	2.51	2.56	2.67
10	integration time correction	0.15	0.15	0.15	0.15
11	instrument temperature correction	0.16	0.16	0.16	0.16
	RSS, Radiometric & Measurement (1-11), Es	**3.31**	**2.91**	**2.86**	**2.92**

Finally derived Products

Lw

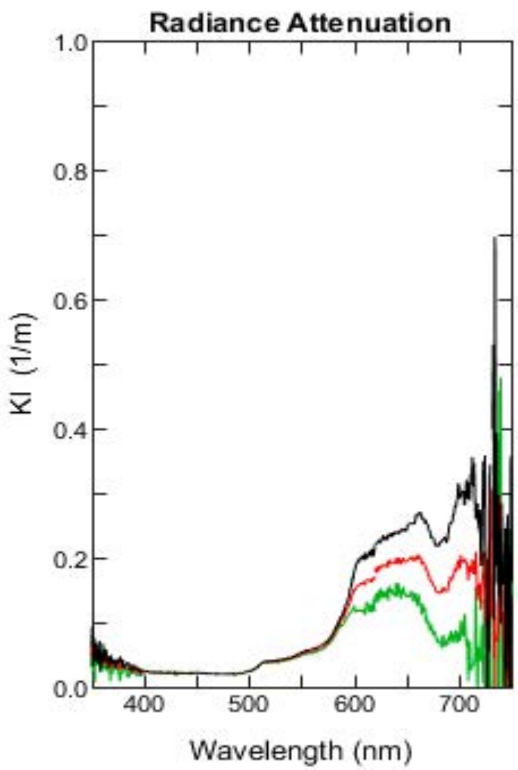
ID	Component description	M1=410nm	M2=443nm	M3=486nm	M4=551nm
1	Lu	2.72	1.77	1.53	1.68
2	f alpha to zero (tilt)	0.3	0.3	0.3	0.3
3	Kl zero to one	0.58	0.49	0.50	0.69
4	self shading	0.32	0.37	0.45	0.87
	RSS, (1-4), Lw	**2.81**	**1.90**	**1.70**	**2.03**

nLw, or Lwn

ID	Component description	M1=410nm	M2=443nm	M3=486nm	M4=551nm
1	Lw	2.81	1.90	1.70	2.03
2	Es	3.31	2.91	2.86	2.92
	RSS, (1-2), Lwn	**4.35**	**3.47**	**3.33**	**3.56**

What has worked?

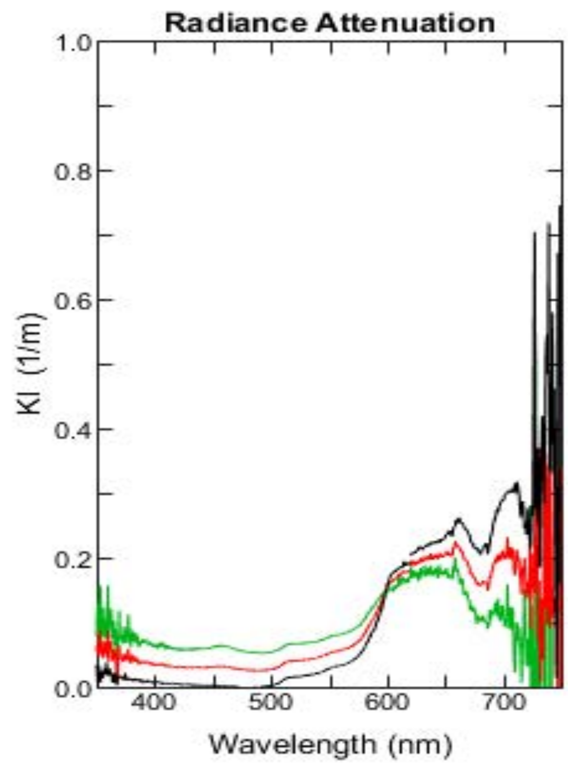
- 3 arms: KL between different arms is a very sensitive measure of relative calibrations.



Good on left,
bad on right.

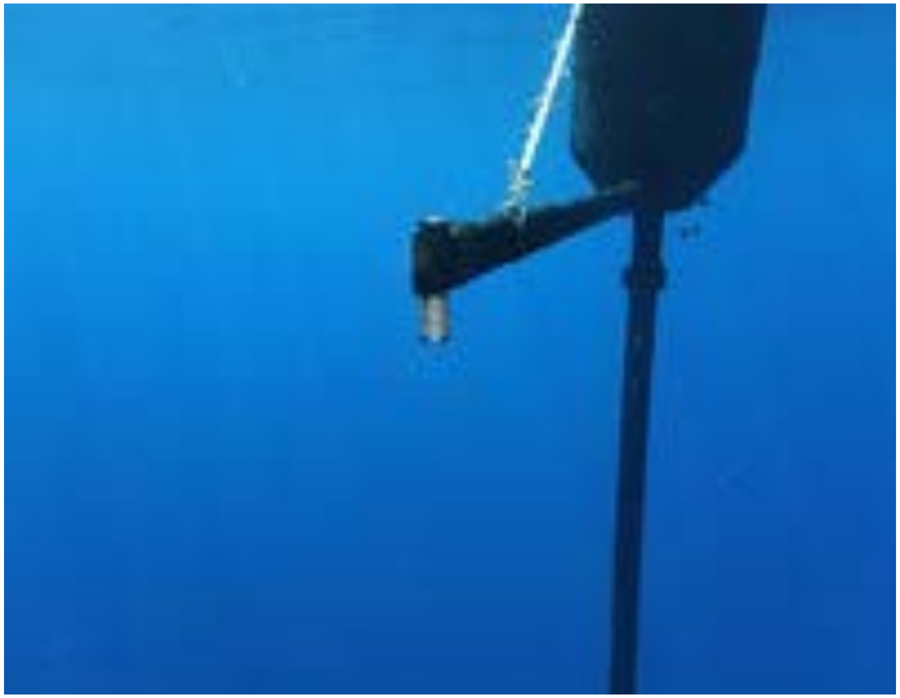
Black top-middle
Red top-bottom
Green middle-bottom

Maybe suspect middle arm cal?



What has worked?

- 3 arms: Incorporates redundancy.



What it is supposed to look like

What we found, after noticing a large lack of signal from the LuTop measurement.

What has worked?

- 3 arms: KL between different arms is a very sensitive measure of relative calibrations. Incorporates redundancy.
- Dedicated long term personnel focused on QC/data reduction, calibration/characterization, and engineering/site management has been key.
- Weather accessibility a large fraction of the time very important(reduce wasted ship time).
- Close collaboration with NIST, from the beginning has enabled continual progress. Important to start this collaboration at the beginning.

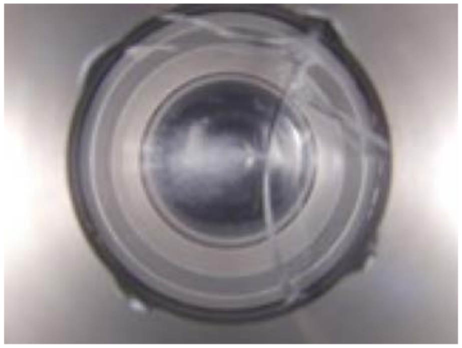
What has worked(2)

- As many references as you can get (internal lamps, LED's, etc.)
  - The ratio of our Pre/Post deployments is on average 1.007, instrument has been very stable
- Regions of spectral overlap (Blue and Red spectrograph overlap for +90 nm) allowed system checks. Learned about Straylight

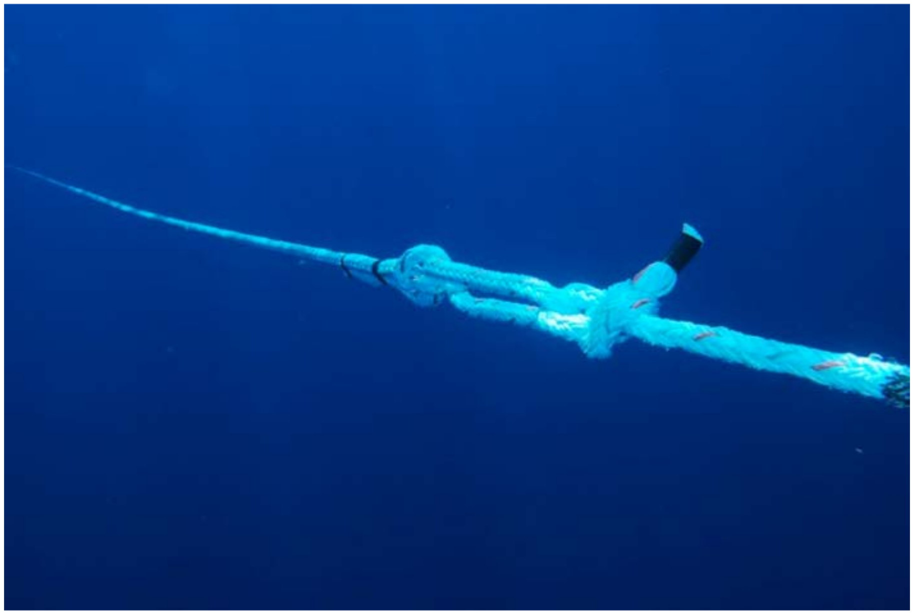
What has worked (3)

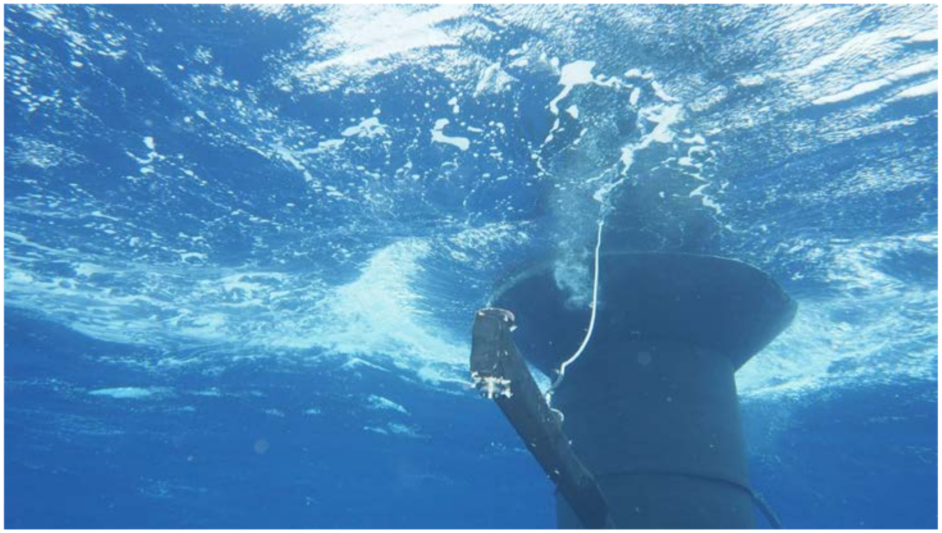
- Site far enough away from casual recreational boating.

Upper arm
Twisted, window
Cracked



Success or failure?





Improvements we wish we had, and are working towards

- Simultaneous measurements of radiometric parameters.
- Reduced stray light in system.
- Simultaneous measurement of auxiliary parameters (compass, tilt, roll) at high frequency.
- Increased resistance to bio fouling.

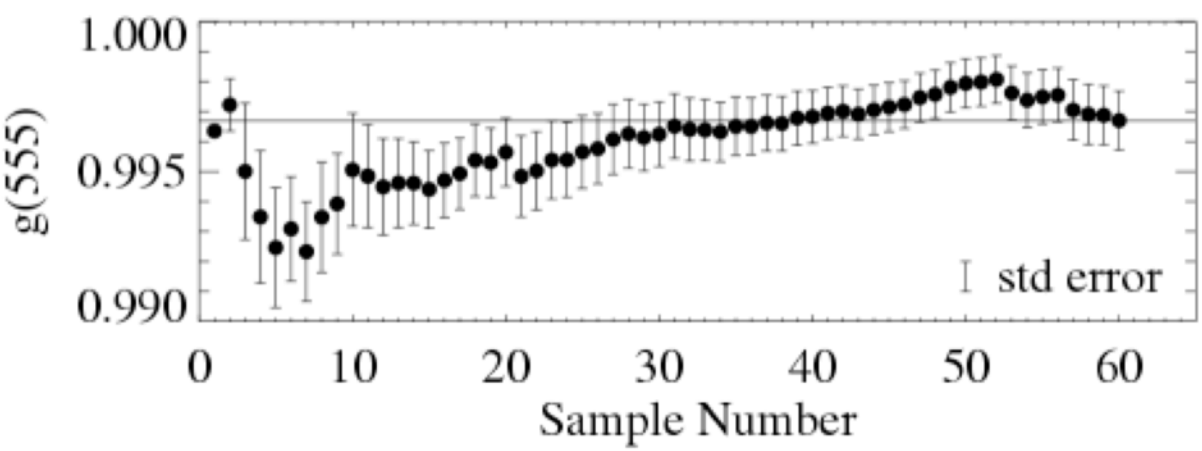
System Vicarious Calibration

- Calibration when sensor is in space, after all ground characterization, to fine-tune the calibration.
- Specific to the atmospheric correction as will be used in processing
- Includes calibration errors and Atmospheric correction errors
- Data has to be the highest quality
- Aim is to adjust the overall gain factor (g factor) correctly.

From Constant Mazeran presentation at ESRIN

Because the MOBY site is relatively uncomplicated, our estimated uncertainties can account for a significant portion of the variability in the vicarious gain factors…

lambda	**MOBY** $\left(\sigma_g^{IS}/\sigma_g\right)^2$ (%)
412	64.41
443	94.88
490	104.41
510	52.54
	22.08
	0.60



Werdell et al., 2006, Ocean Optics XVIII, http://oceancolor.gsfc.nasa.gov/cgi/obpgpubs.cgi

Take home: Improvements in the MOBY measurement can have a large effect on the vicarious calibration process.

MOBY (near) future improvements

NOAA supporting MOBY-Refresh: New optical system and buoy structure for the Lanai Hawaii site.

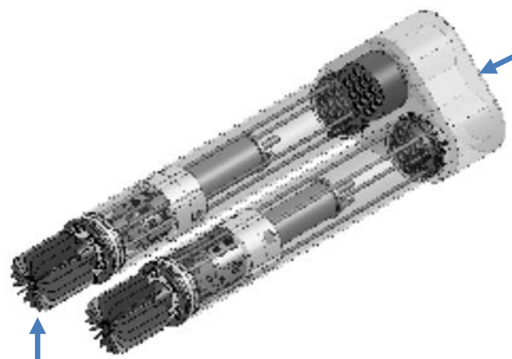
NASA supporting MarONet: Same, new, optical system and buoy structure to support an additional remote site.

NOAA supporting build of 3-4 MOBY-Refresh systems

NASA supporting build of 2 MarONet systems

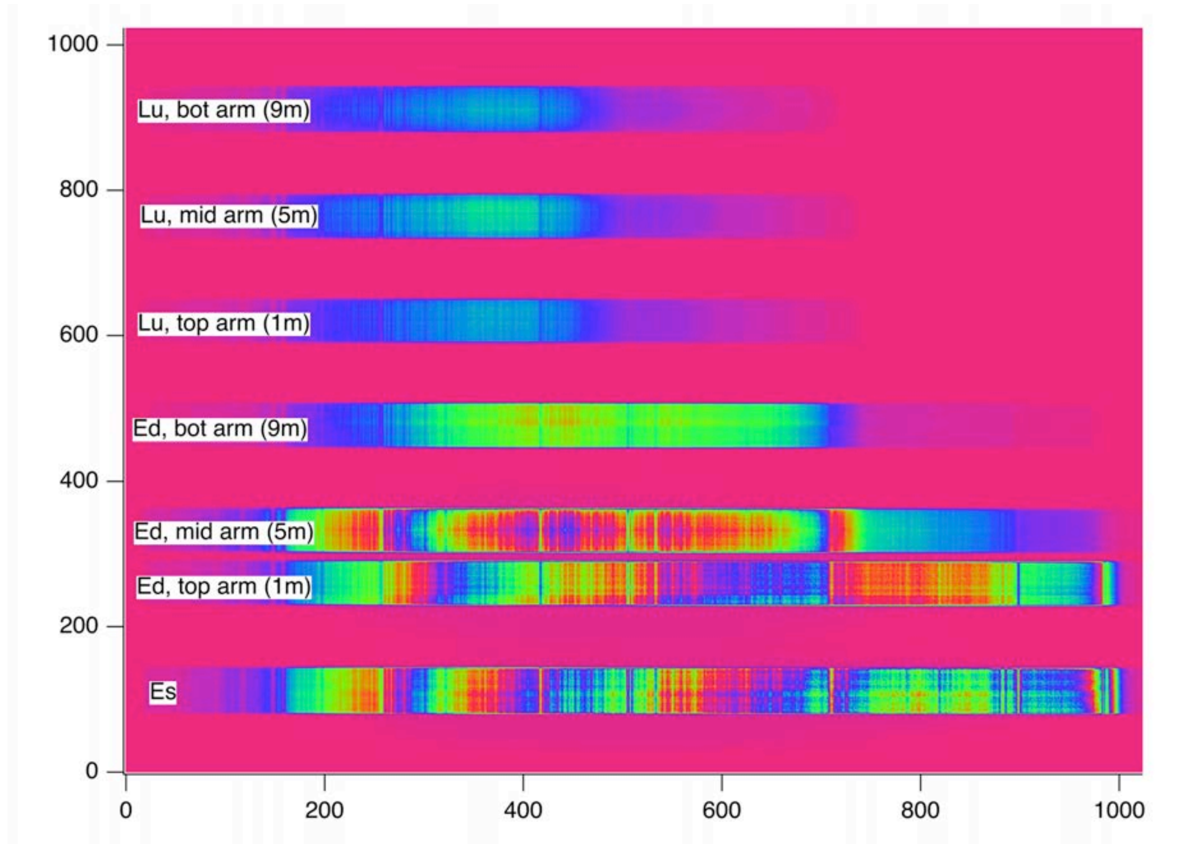
Specific NASA requirements:
Down to 350 nm for PACE
Structure that allows optical system to be removed intact
Structure fits into a 40' shipping container (at least once)
Stability source/monitor to verify instrument performance after shipping

Detailed Assembly of spectrometers

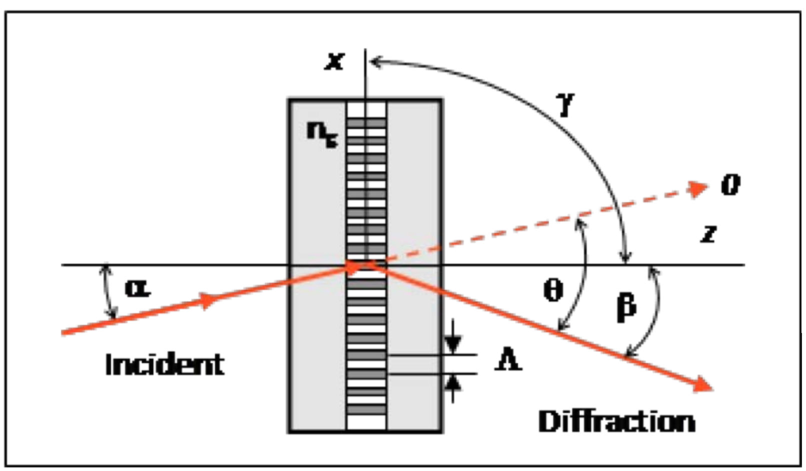


Splitter housing

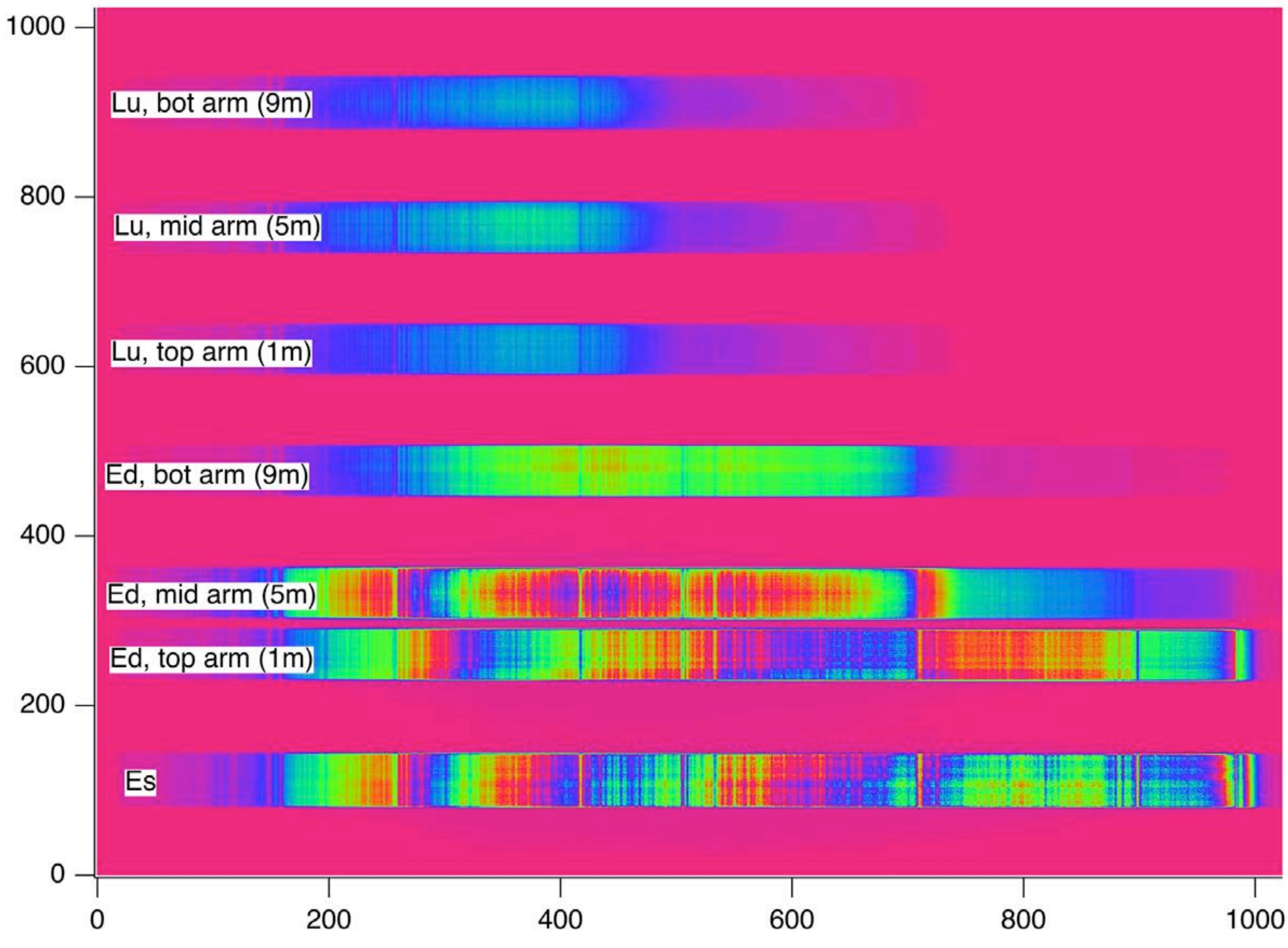
RSG and BSG spectrometers



In-line volume holograph

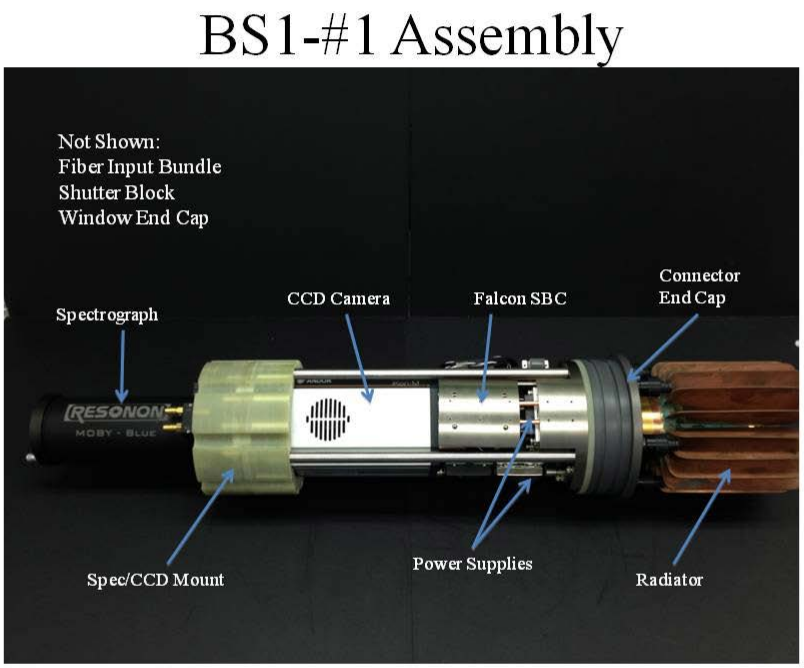


Allows simultaneous acquisition of all radiometric channels

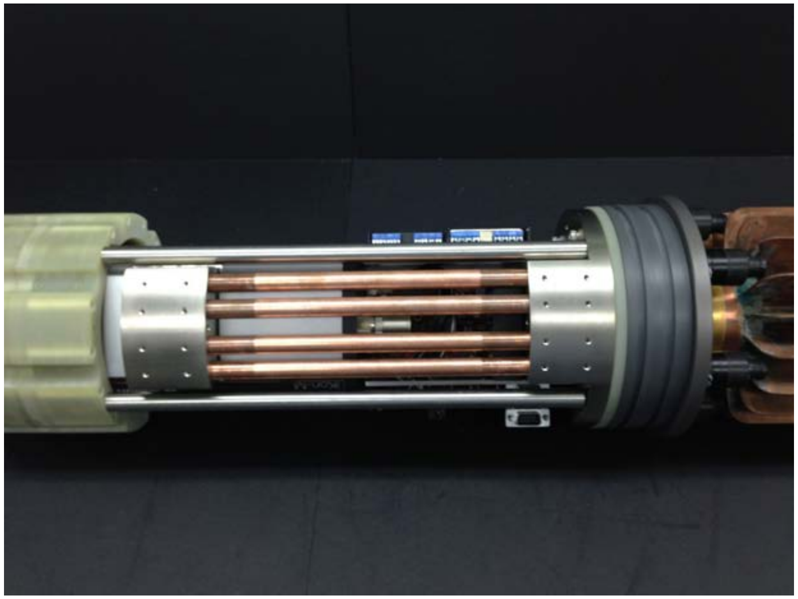


Assembly of spectrometers

Base spectrometer from Resonon (camera from Apogee)

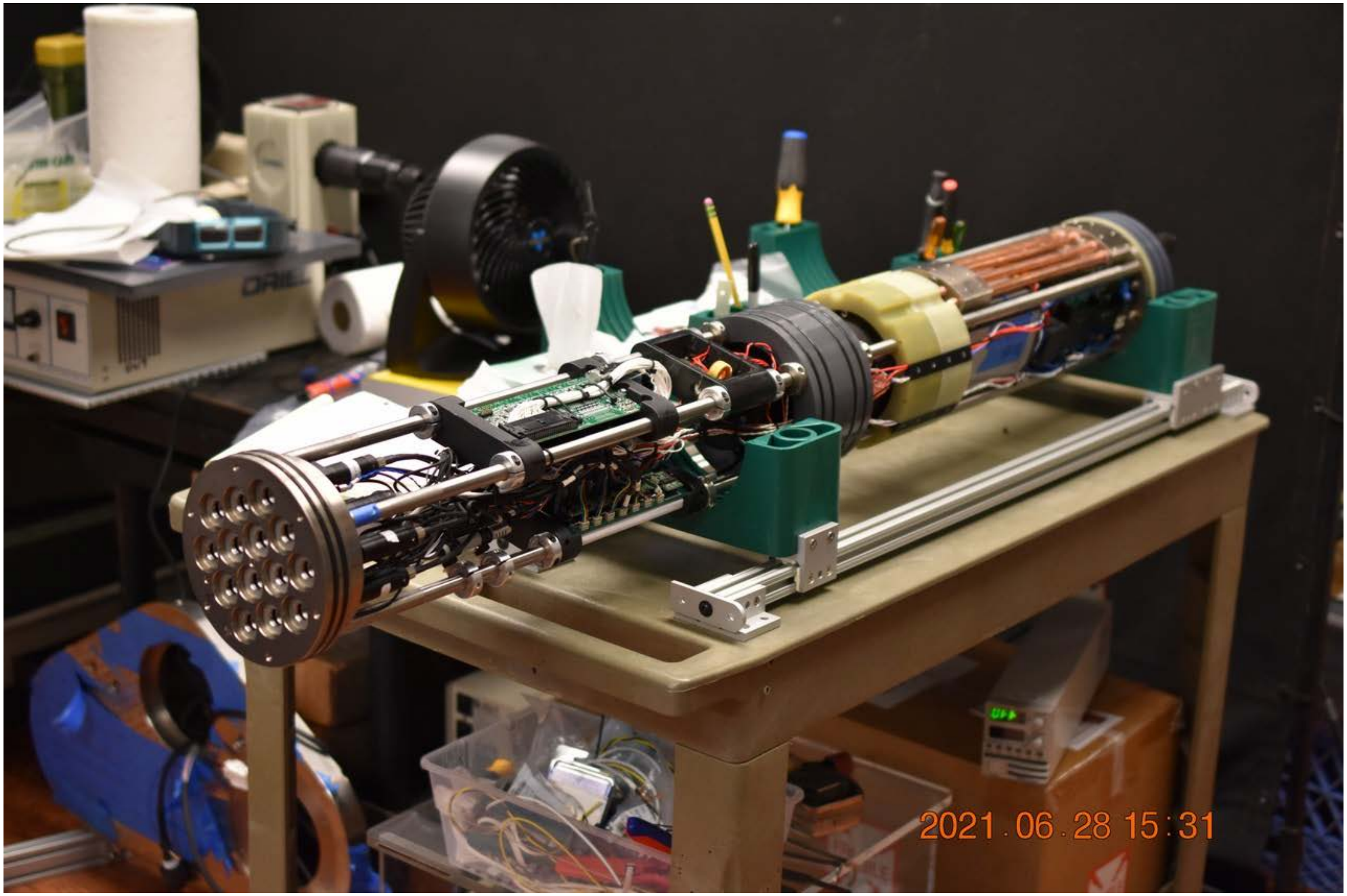


Spectrometer side assembled



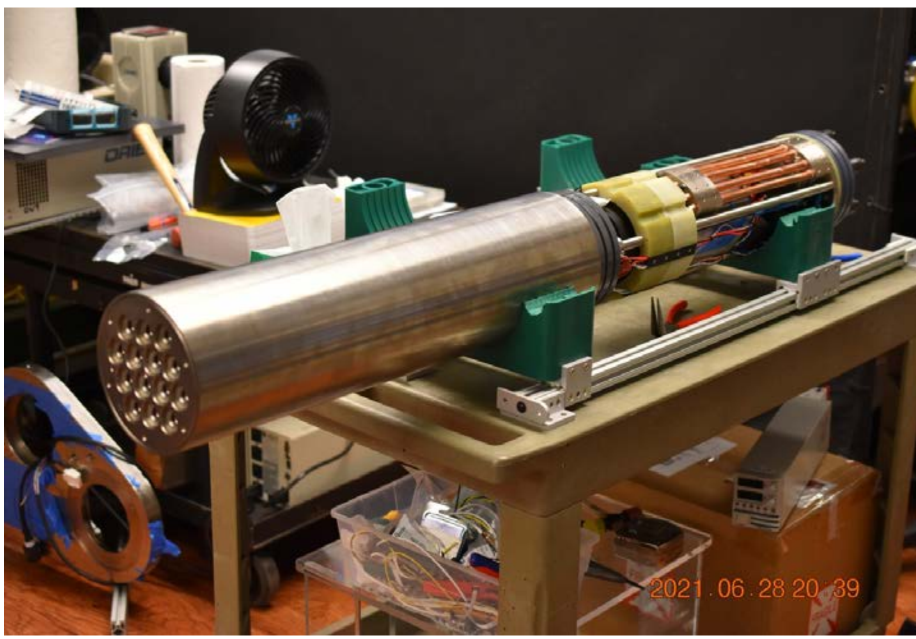
On left, shows thermally conductive tubes to bring heat from the camera to the back fins

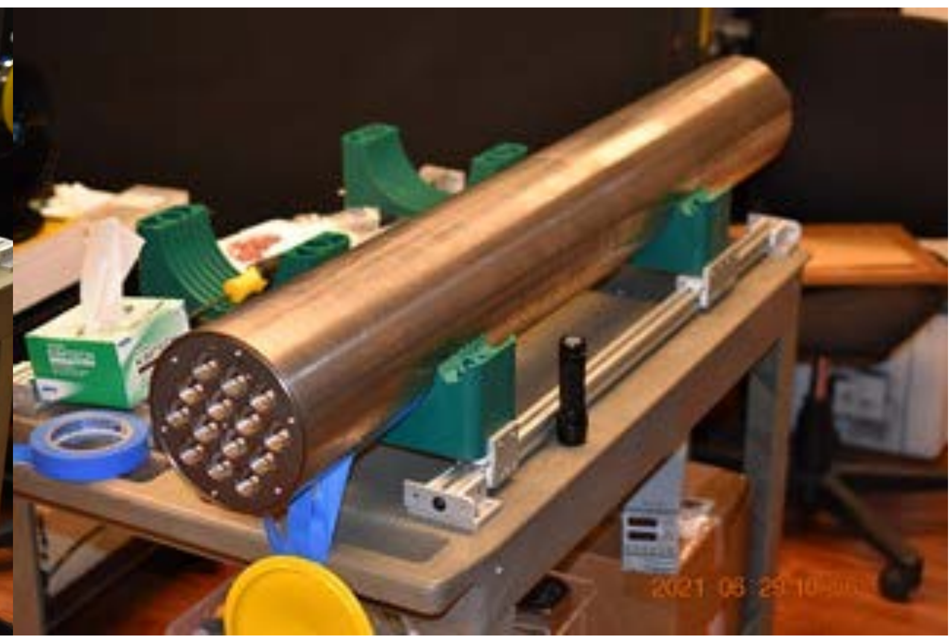
Here is the assembled Blue spectrometer. On the right side is the spectrometer, on the left shows the shutter plate, the collimator for each fiber, and the spectrometer pigtails all hooked up to the collimators.



After a lot of tests and required trouble shooting and correction, below are pictures of the blue spec. On the left is the titanium housing on one side of the system, on the right is the two piece titanium housing in place.

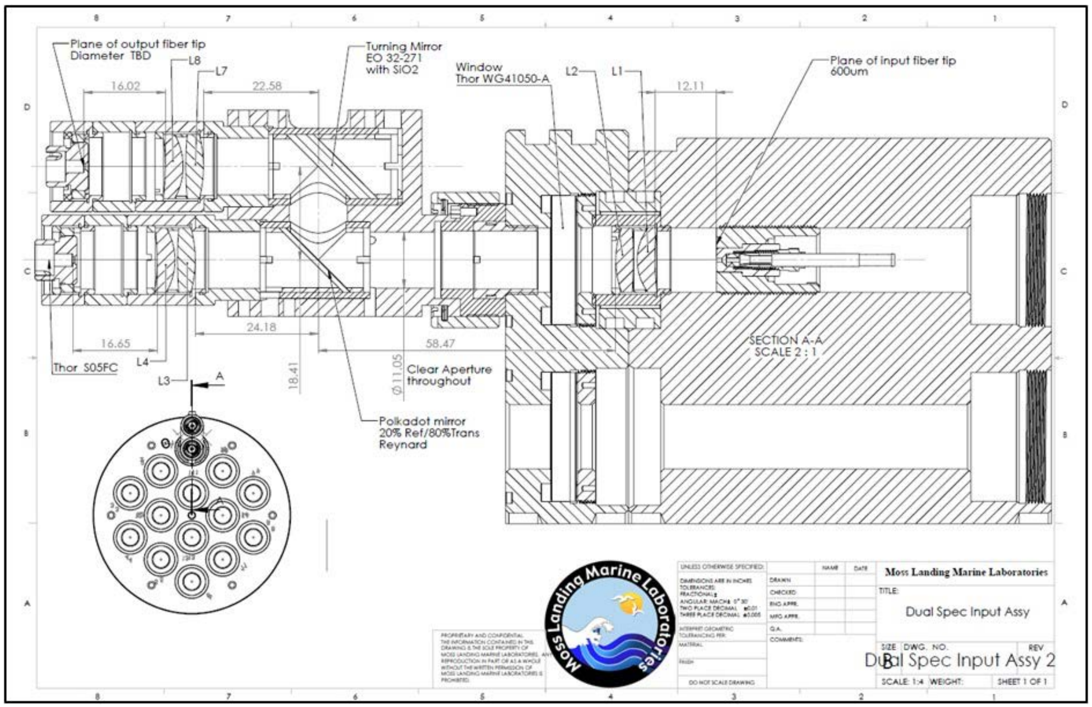
Next step is attaching this and the red spec to the splitter housing.

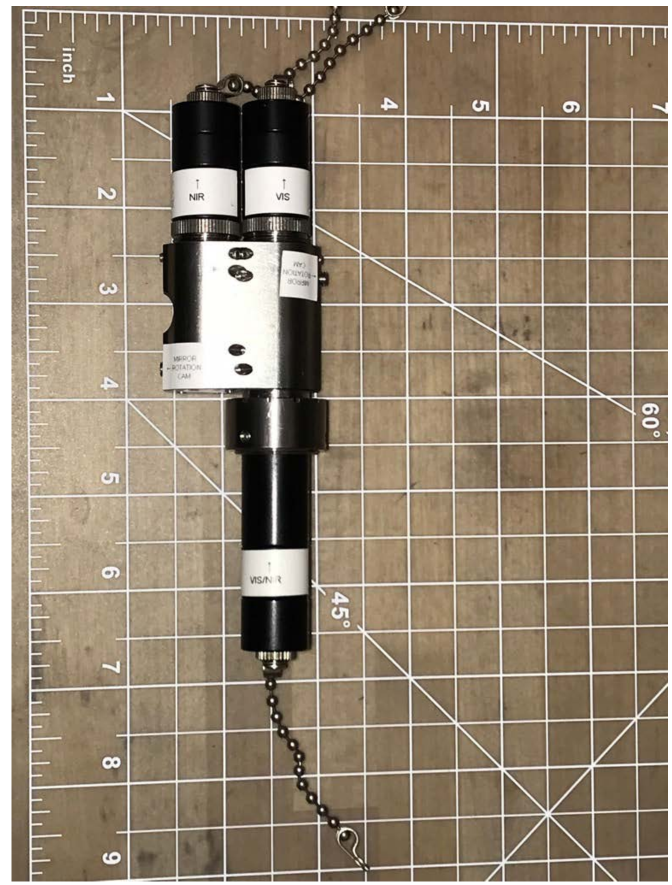




Splitters

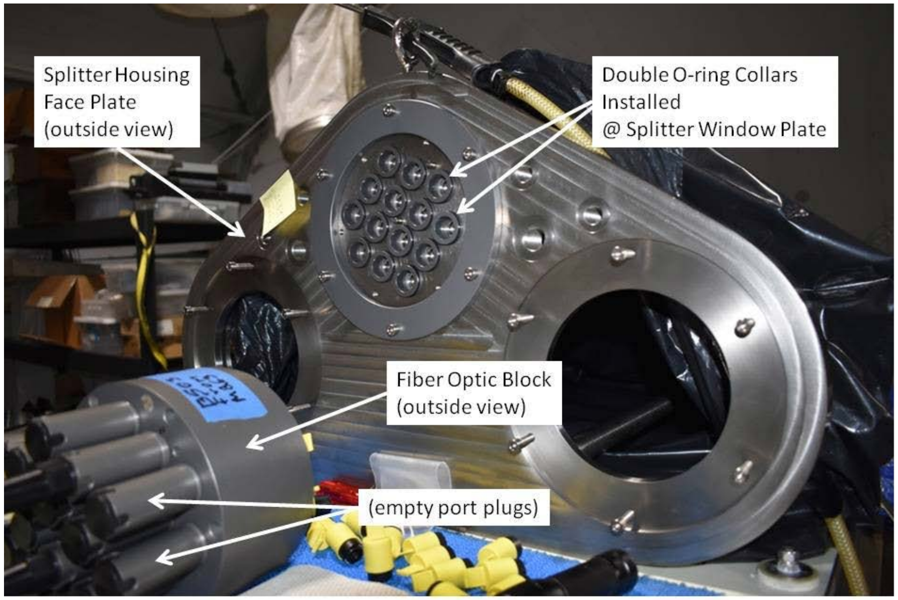
The splitters (which split the signal from the collector to the Red and Blue spectrometers) use a polkadot mirror. The throughput (reflected vs straight through) can be adjusted by the number of dots, so we can set it up to have more of the input light go to the red spectrometer vs the blue one, to offset the difference in spectral light field intensity. In our case we have 30% reflected (to blue spectrometer) while 70% is transmitted (to red spectrometer).

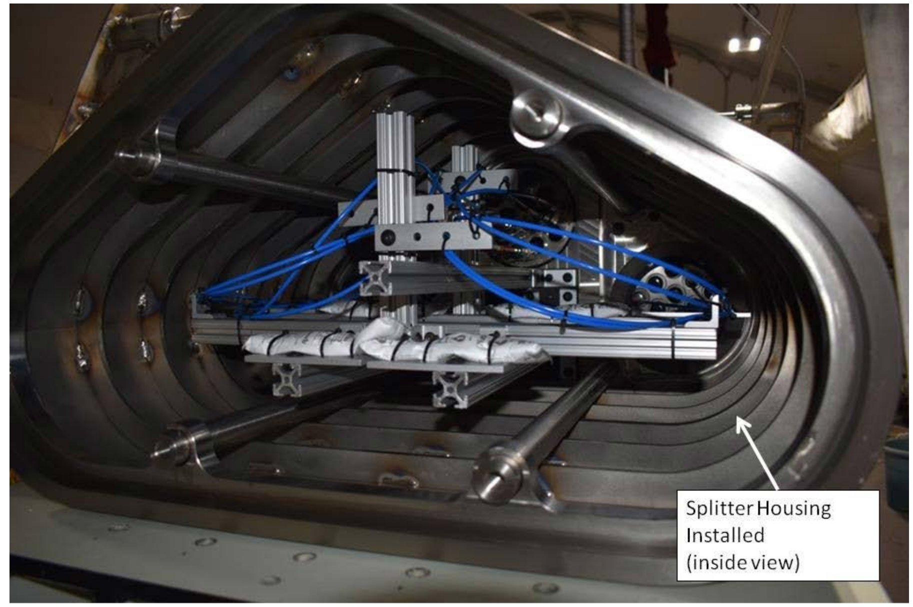


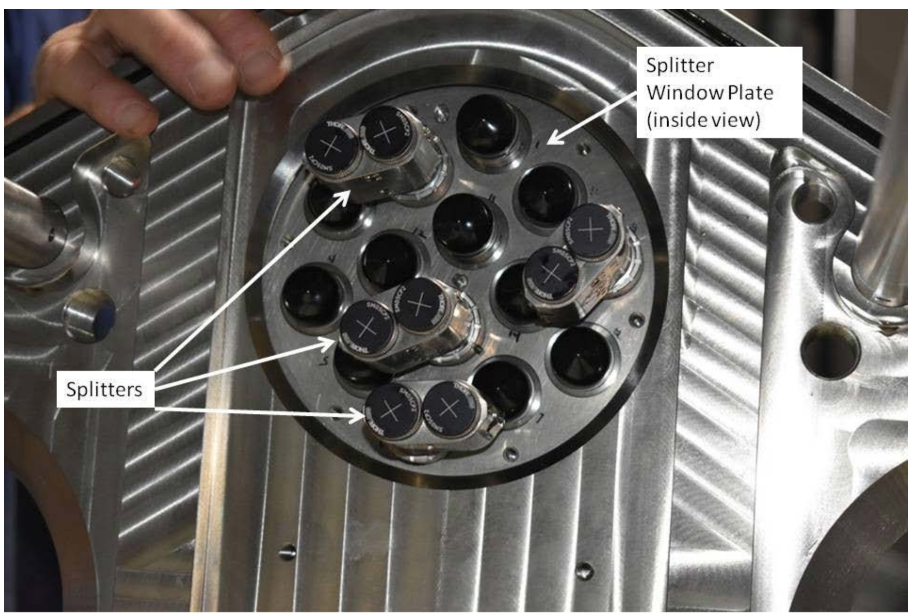


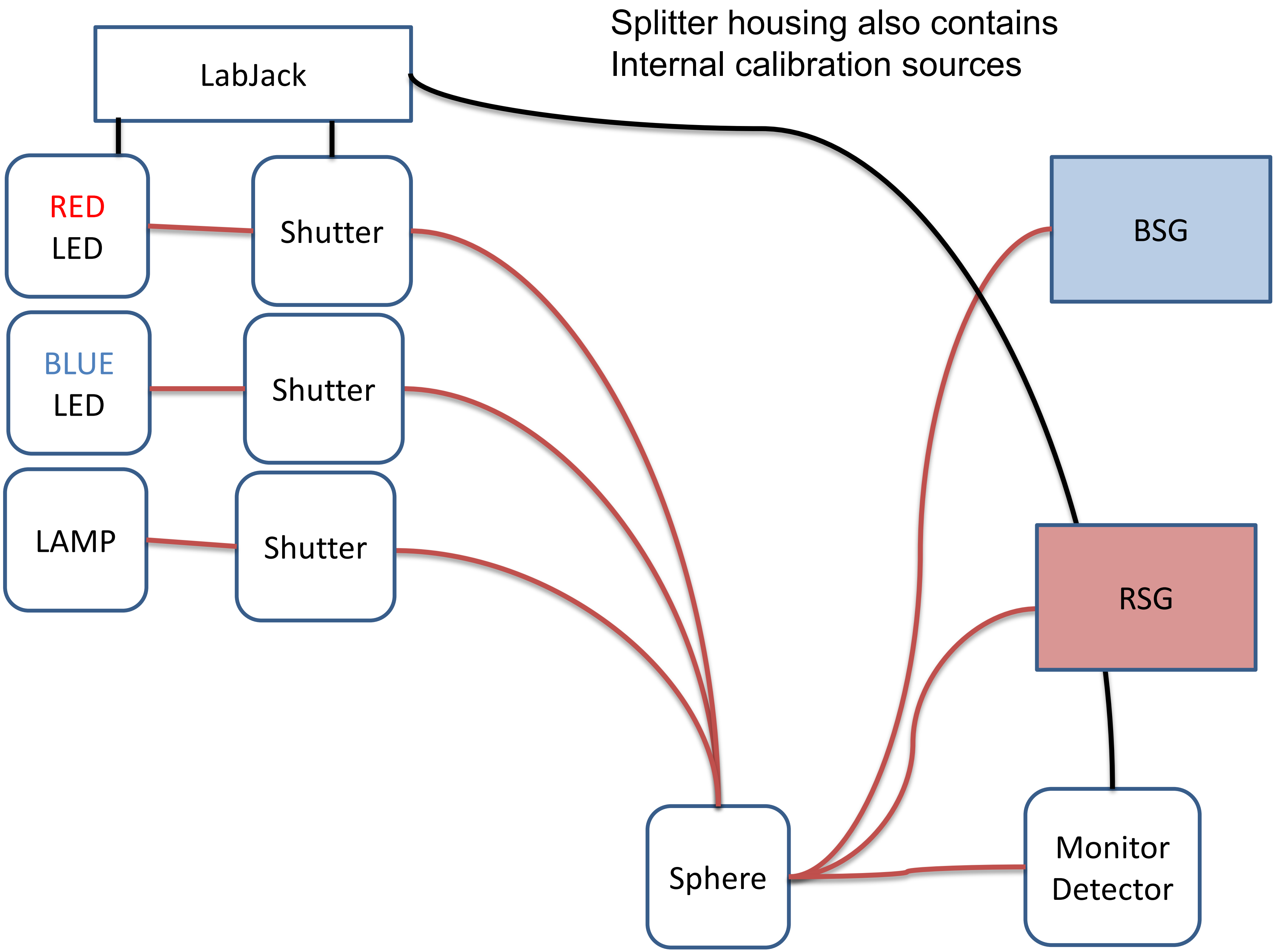
Each splitter must be aligned individually, note in the picture on the right, the NIR and VIS labels are reversed.

Example Splitter Housing assembly

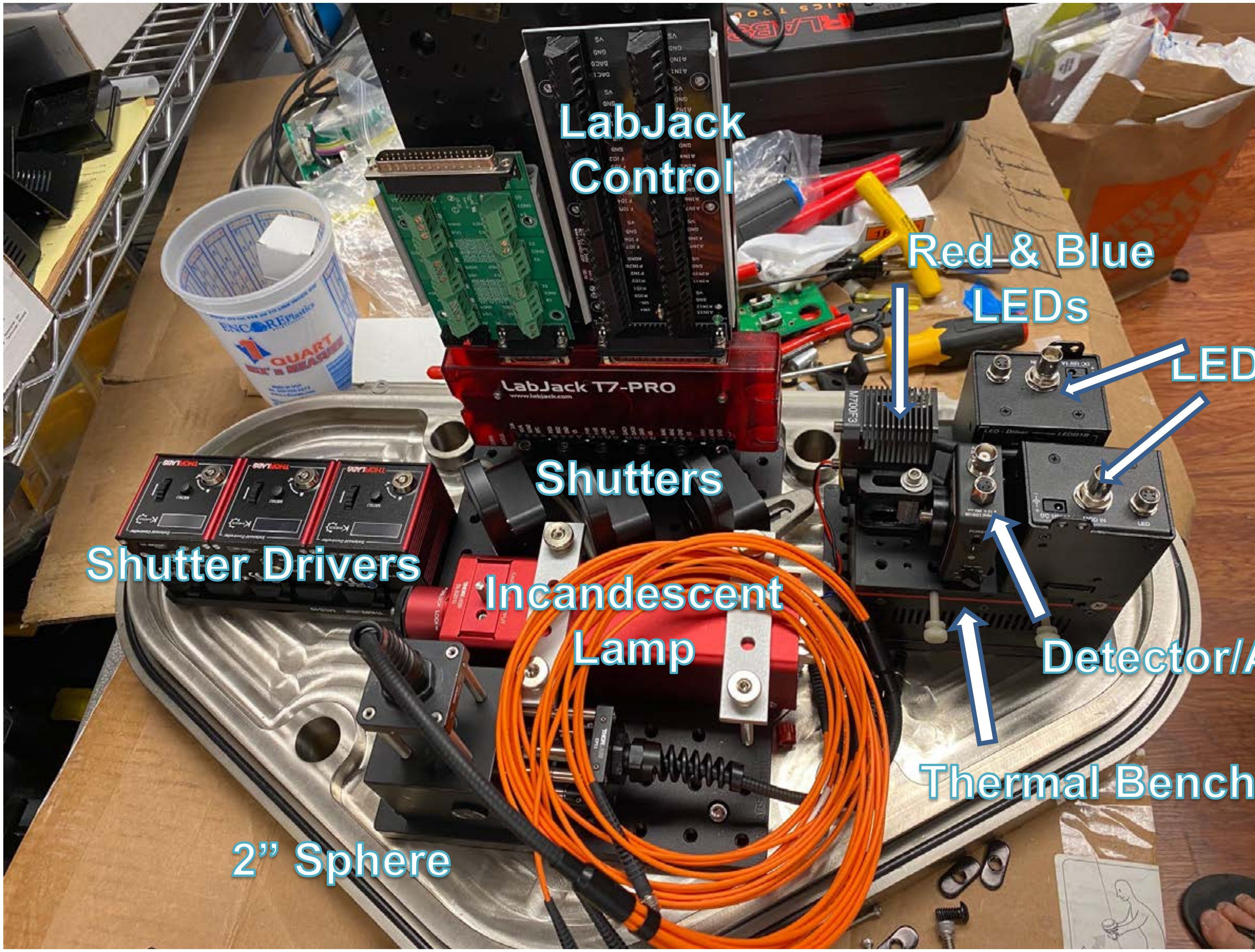




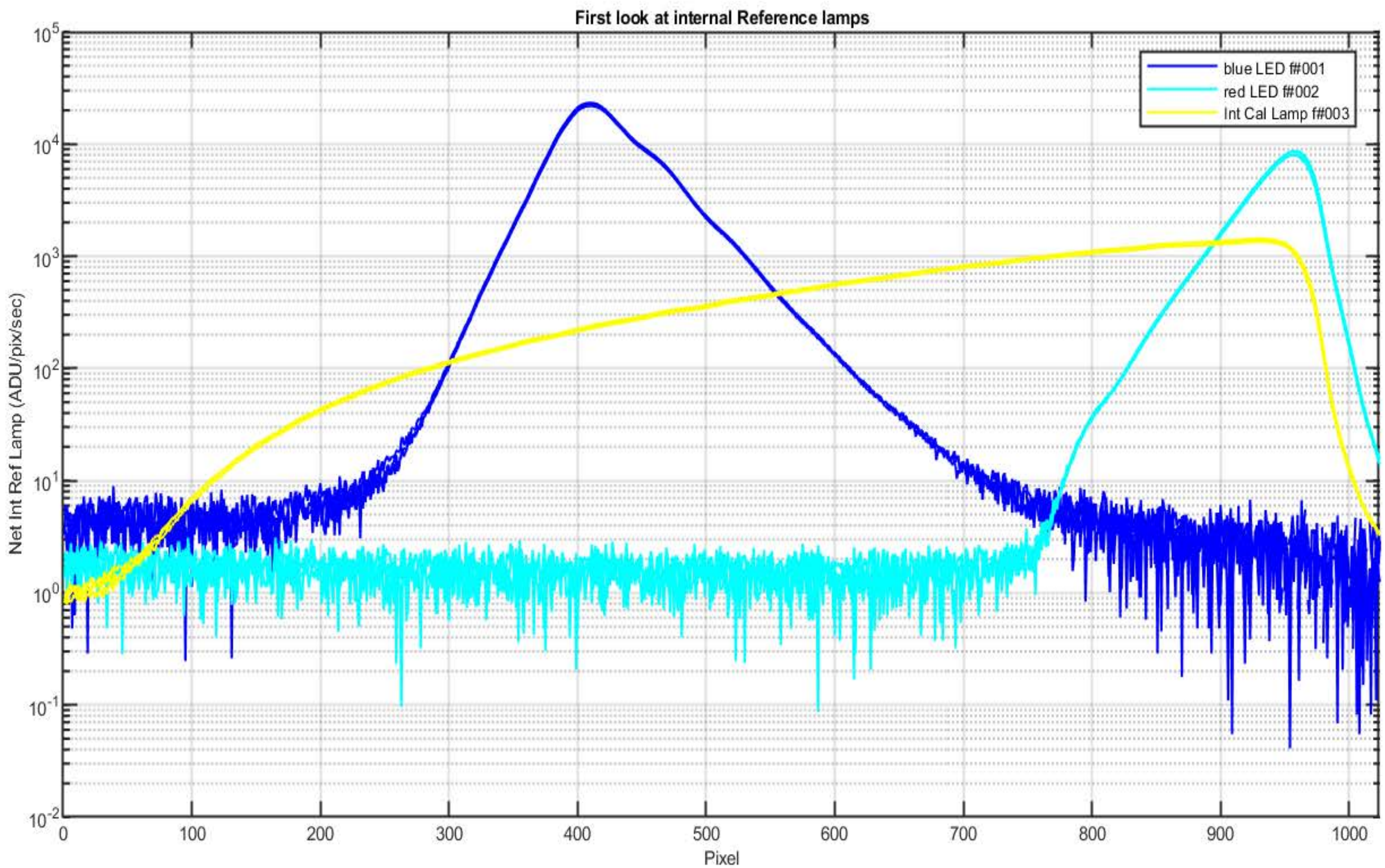



Splitter housing also contains
Internal calibration sources
LabJack
RED
LED
Shutter
BLUE
LED
Shutter
LAMP
Shutter
BSG
RSG
Sphere
Monitor
Detector

Internal calibration sources being built up for MarONet-1

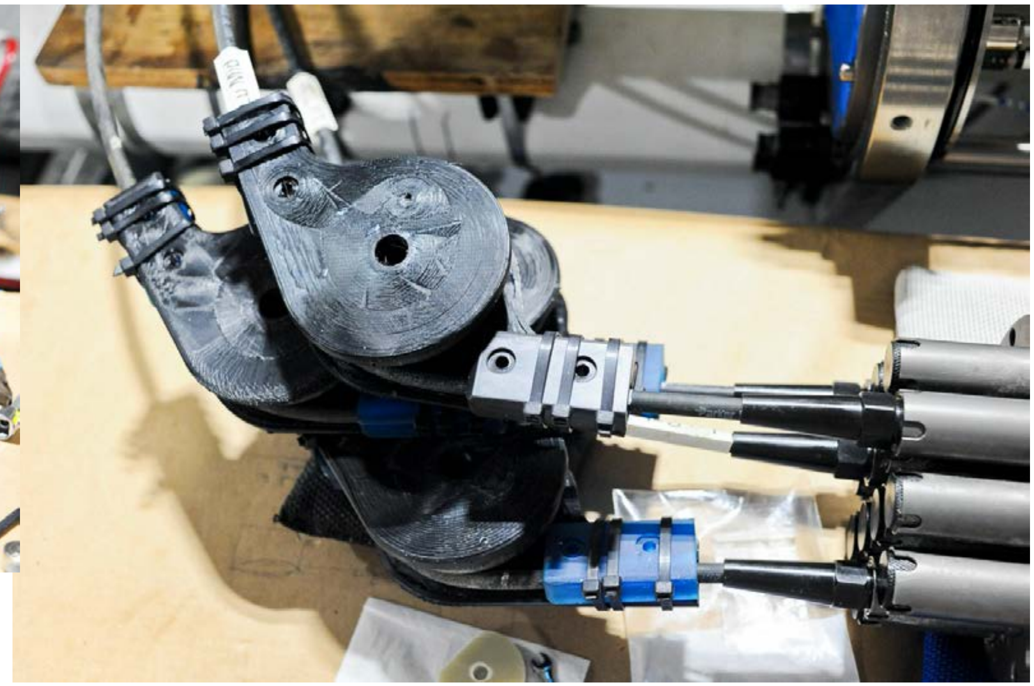


Sample data taken with BSG from light sources internal sources



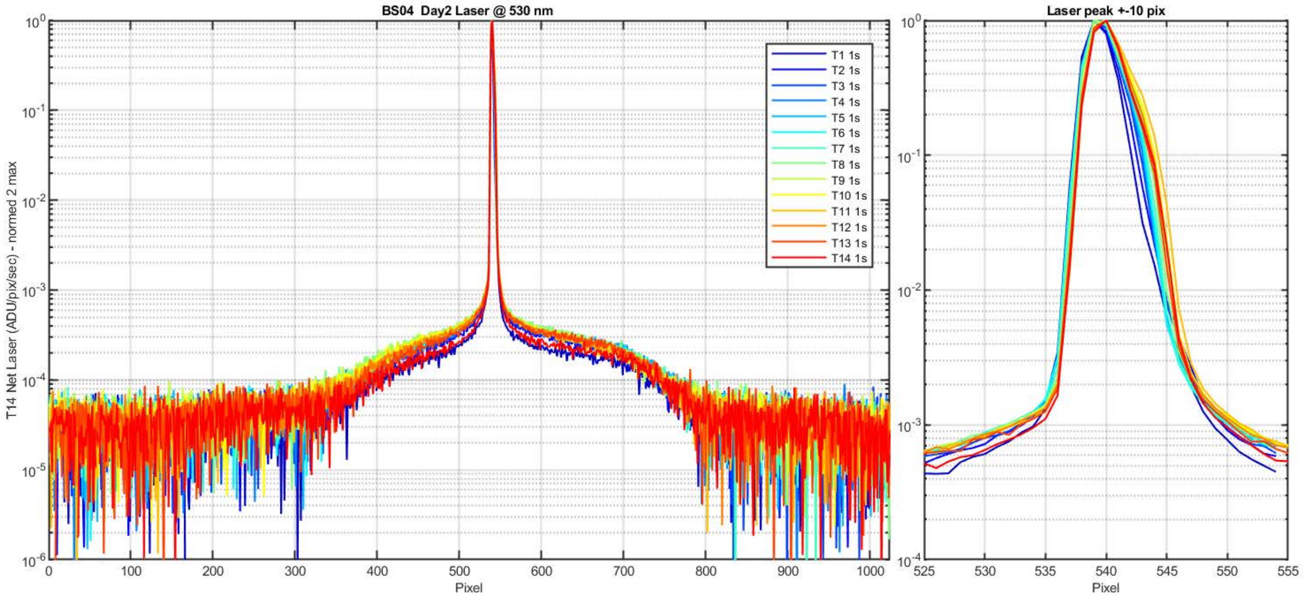
Blue is blue LED, aqua line is red LED, while yellow line is the incandescent light source.

Before we go into the splitters, light from each collector (particularly the radiance collectors) must go through a fiber mandrel. This forces the fibers into tight bends, which mixes up the fiber optic modes, and reduces effects of bending the fiber between the collector and the spectrometers.



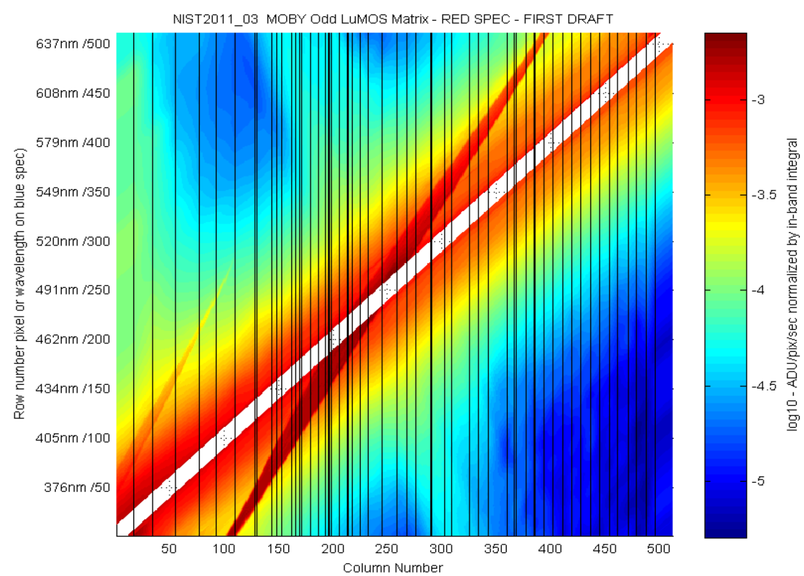
Bottom line is that the two spectrometers are currently in their titanium housings, having passed all tests.

Spectral Straylight



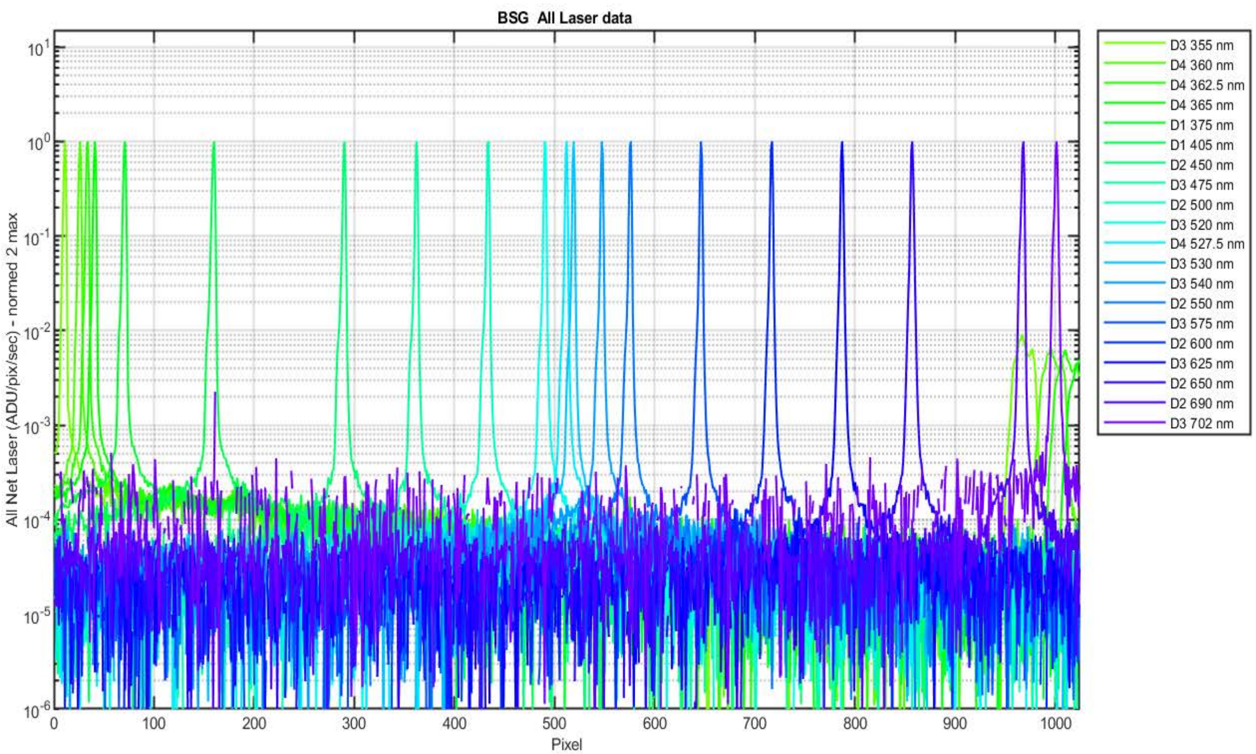
Data taken at many wavelengths, with single wavelength input, as in above example.

Laser system, allows computer control of output wavelength



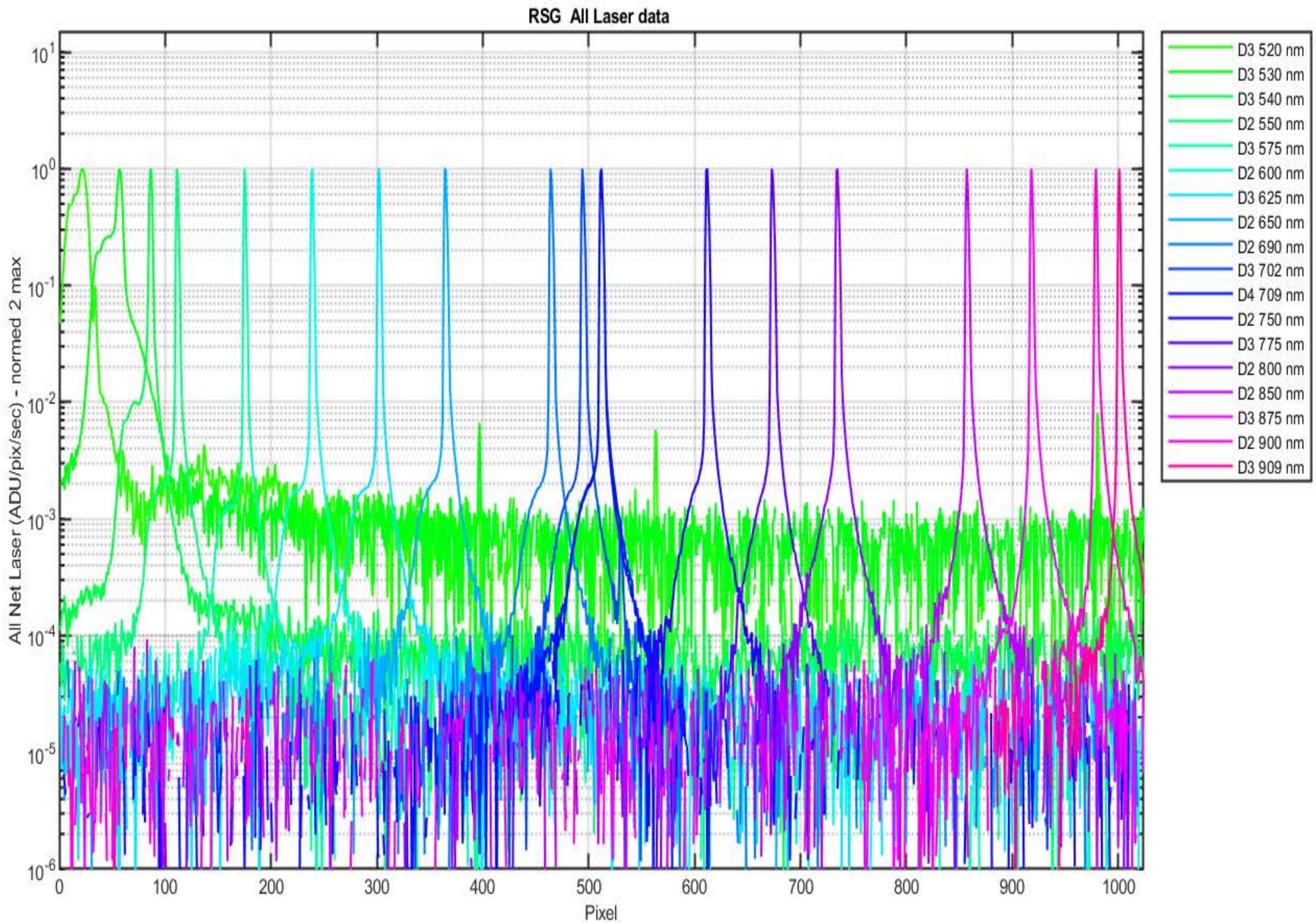
Final result (example is current MOS system)

As the systems have been constructed, we have been taking stray light data (individual laser lines) along the whole time of system construction. Below shows an example of the latest stray light laser lines for the blue system. Note that second order is showing up on the far right (340 showing up at about 680..not exactly the same place that first order would be for 680 nm, but second order does not follow the same spectral calibration as first order).

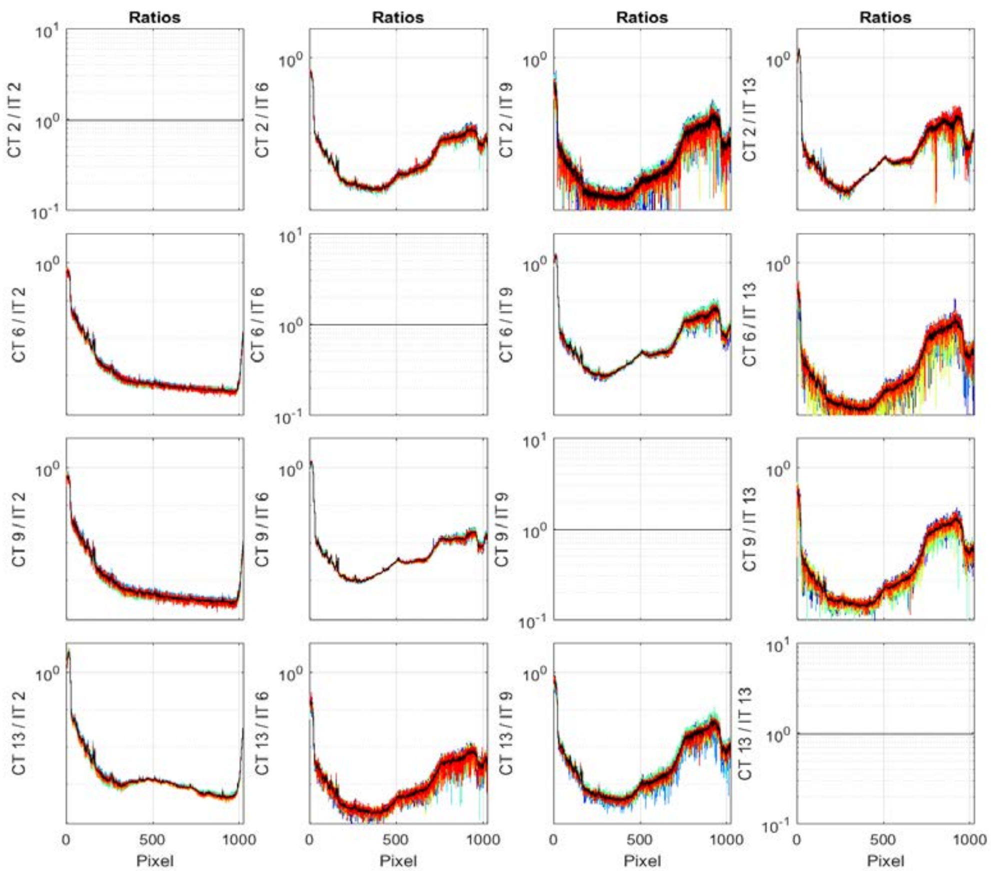


Remember? D sin(θ) = m λ…so θ_2= 2 θ_2 D is distance between slits, m is "order"

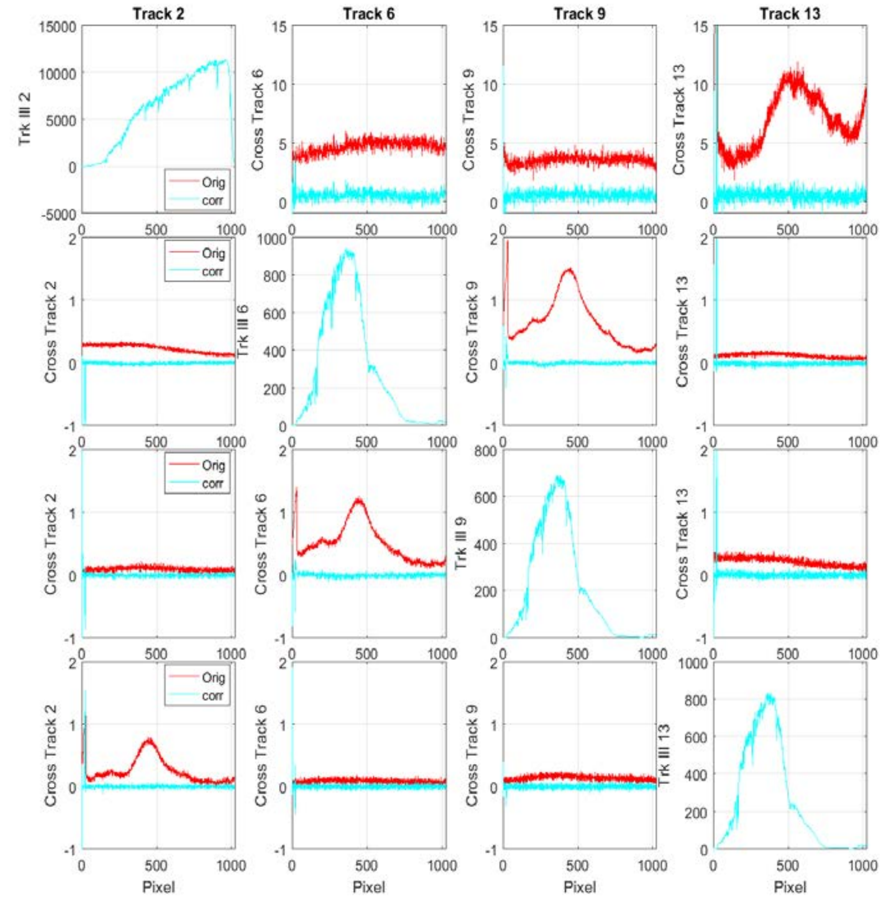
The same thing, but for the red spectrometer. The shoulder on the left (blue) side of each line is thought to be in the laser system, not straylight. This will complicate analyzing the data. We ran into a lot of problems with fluorescing in our Spectralon integrating spheres.



Spatial Straylight (or cross talk) characterization is best done at sea by individually turning on one track, and seeing the effect on the others. This replicates the spectra of the relevant light field

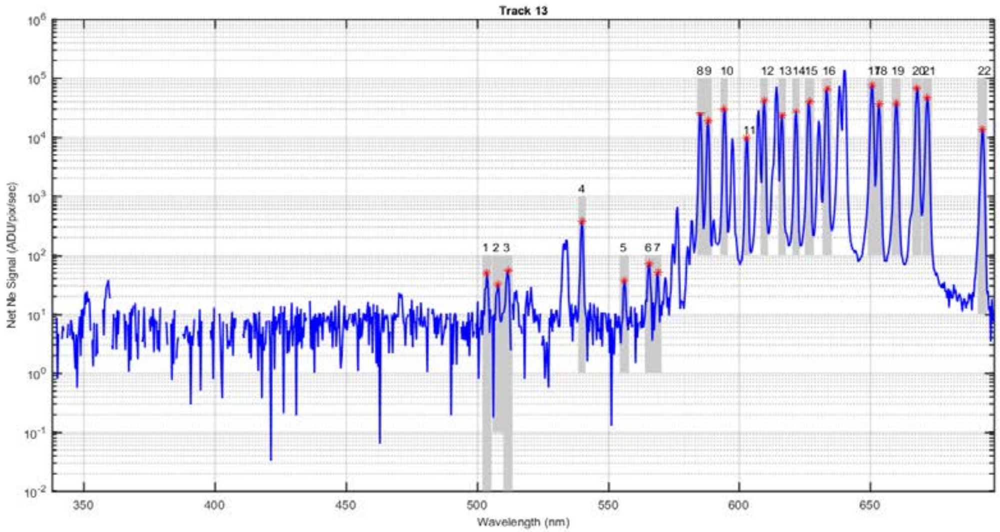


Example showing matrix to invert for cross track straylight on tracks 2, 6, 9, and 13.

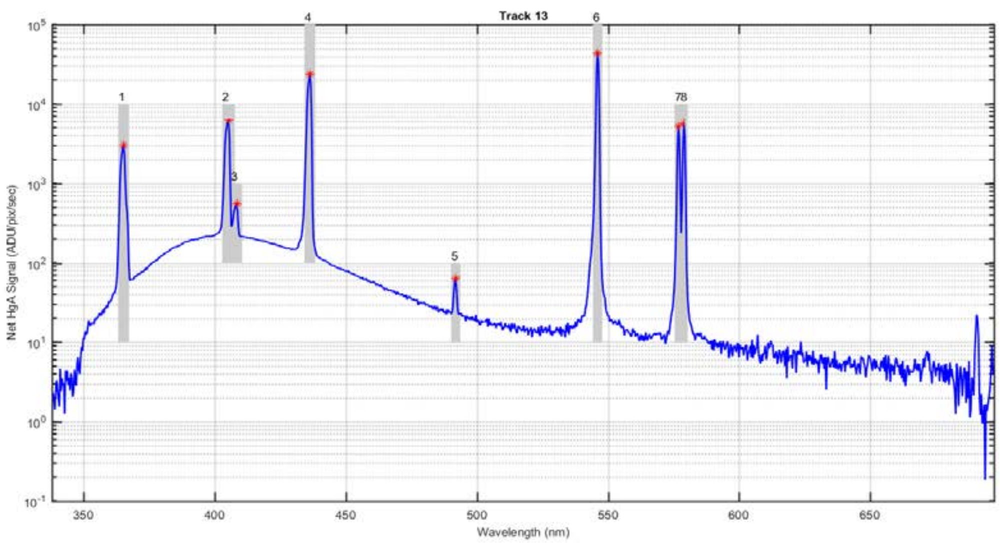


Showing data corrected with matrix, off diagonal elements should be zero, and have been corrected to be zero by using the matrix on the left.

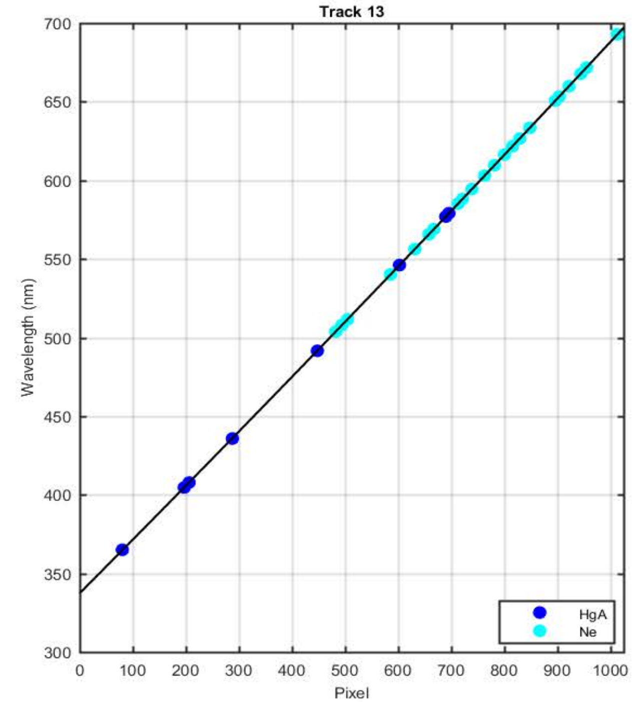
Wavelength calibration done with gas pen lamps



Neon



HgA lamp



Has to be done for each track, can be checked in the field with Fraunhofer lines. We have done this with preliminary measurements on the bare spectrometers, it will be done while the system is in the thermal tanks in the next few weeks.

Initial thermal characterization of complete optical system.

Our first test results on a prototype system were enlightening

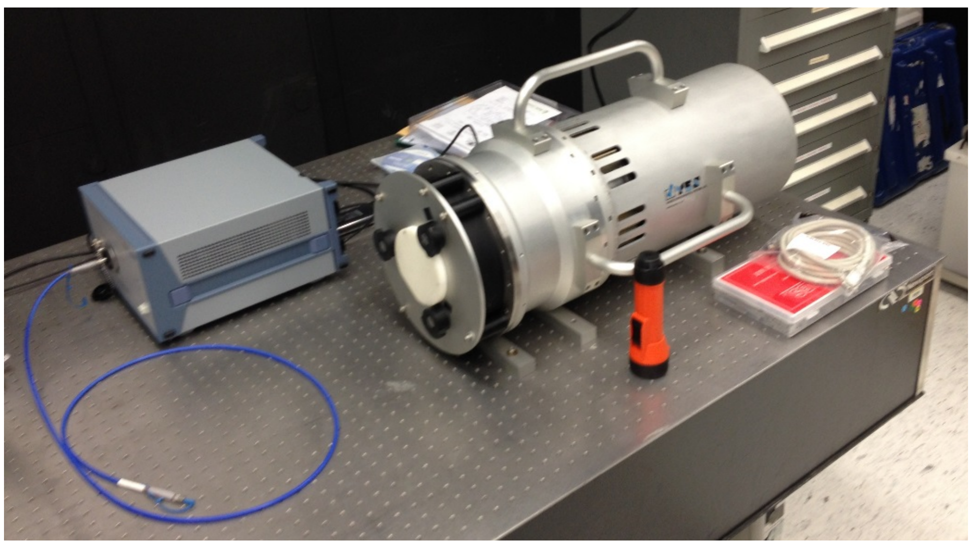
An insulated tank and water heating/cooling system was built that could hold the entire instrument, intact, to be able to do full system characterization, with controlled water temperatures.

Stability source and monitor

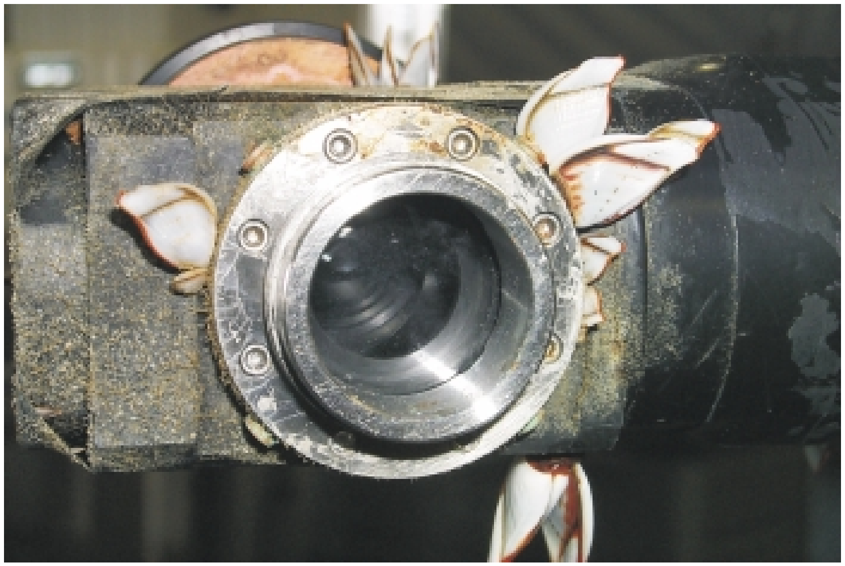
We have been working with two devices to use as a stability source, the Satellite quality monitor (SQM-5002, Yankee Scientific), and a hyperspectral, fiber-coupled radiometer (CAS140, Konica-Minolta) as the stability monitor.

Several tests and modifications were made to the devices over this period.

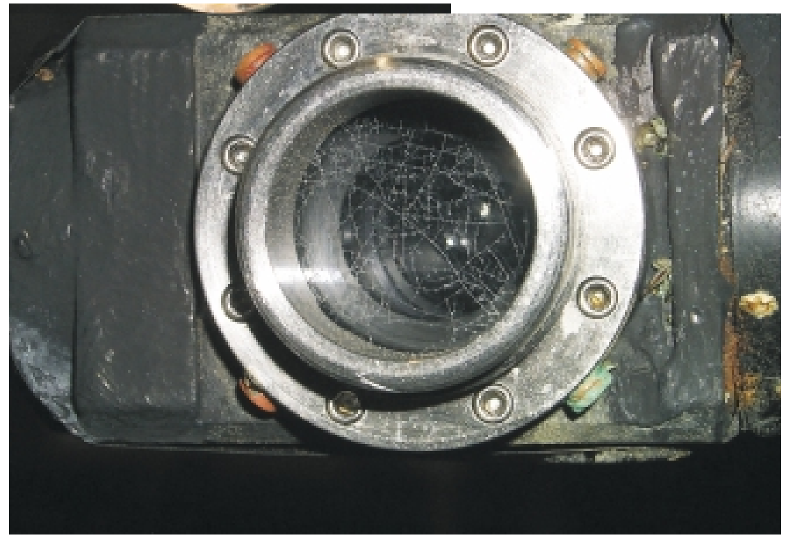
The CAS is on the left, the SQM is on the right.



Bio fouling, very bad cases



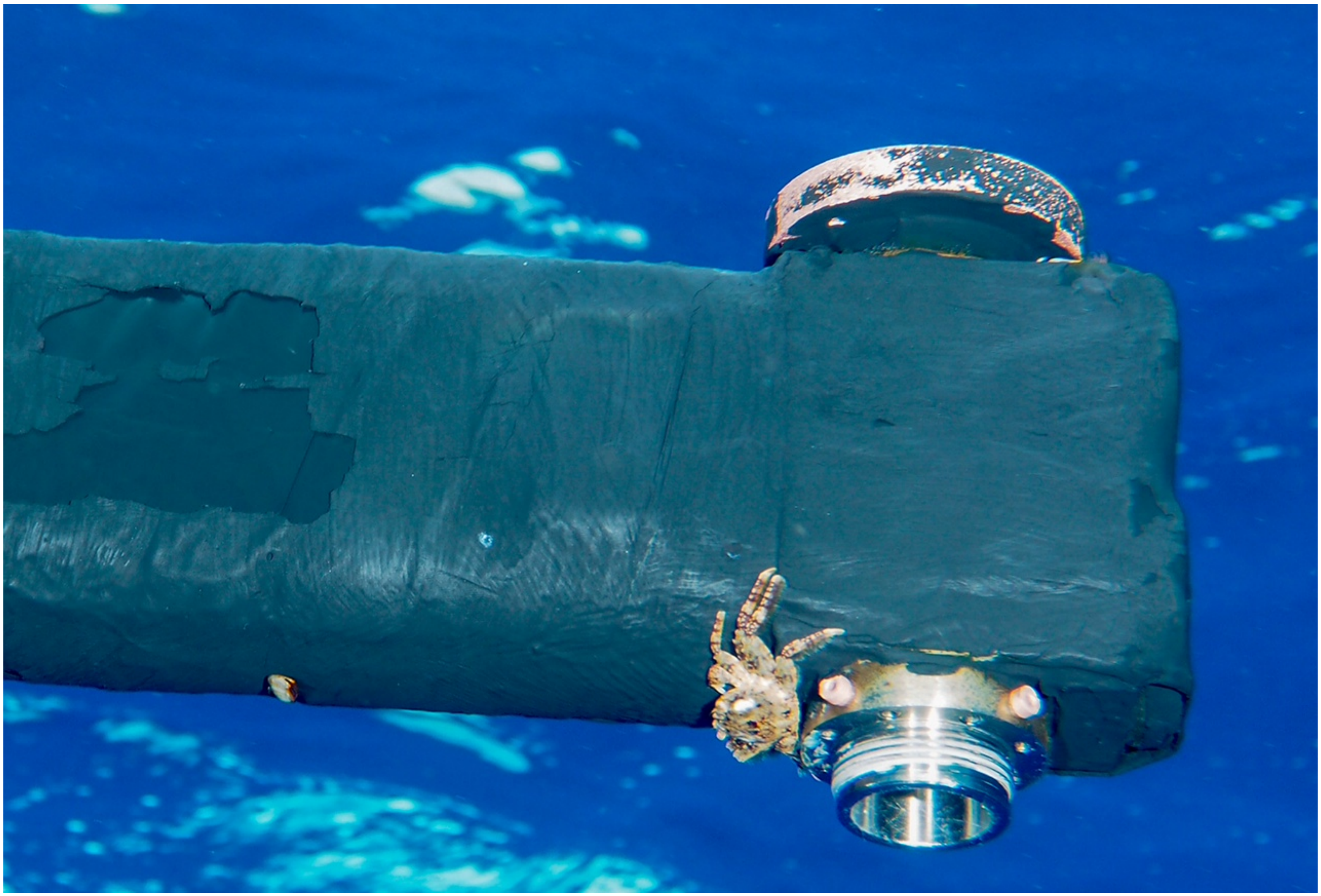
Deployment M217
6/2/2001 – 9/25/2001



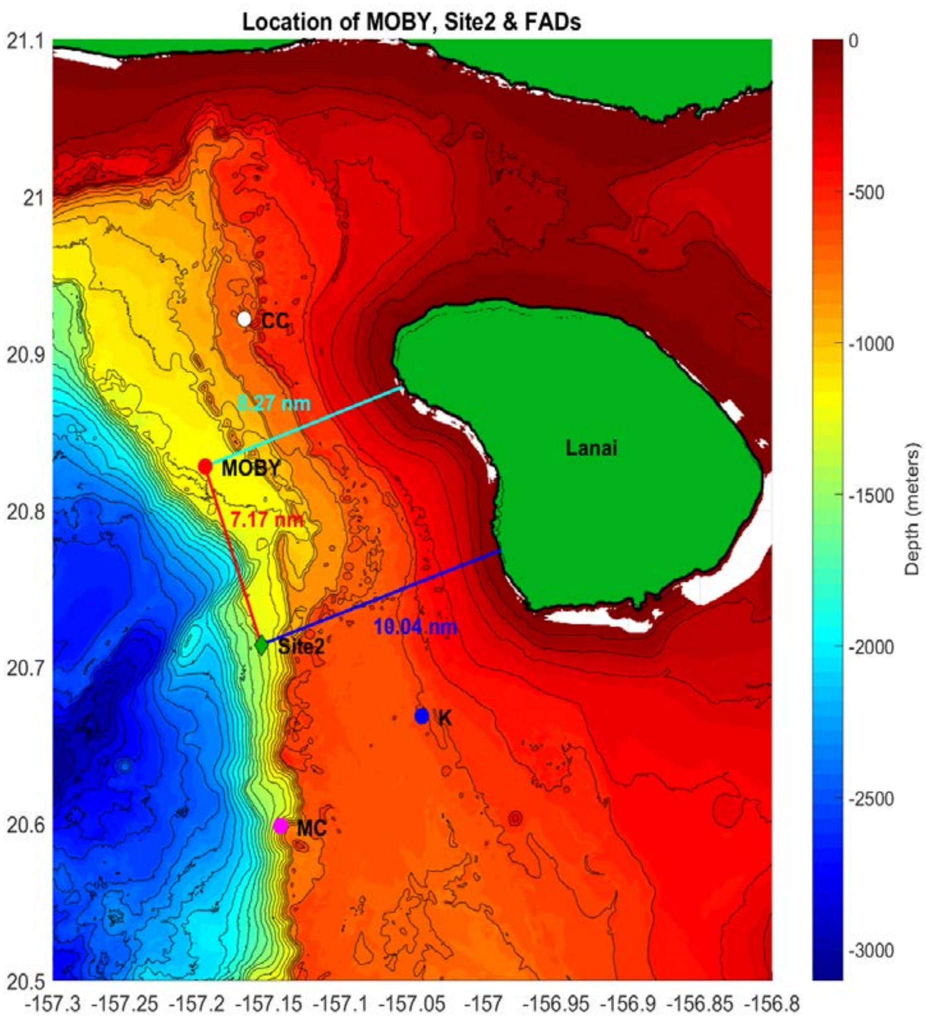
Deployment M225
11/12/2003 – 2/3/2004

- Add UV Led Bio fouling unit to radiometer heads. Illuminate window with 285 nm.

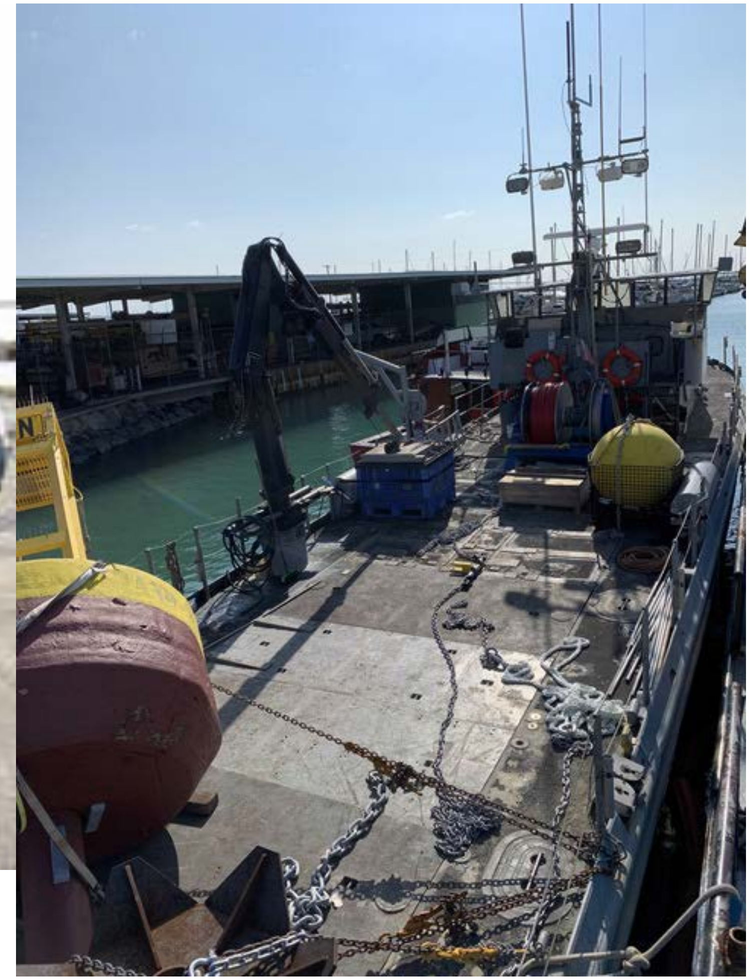
Will be difficult to stop these....



Site Survey results for the position we could use (out of shipping lanes and submarine operating zones) was in an area with a sloped bottom.

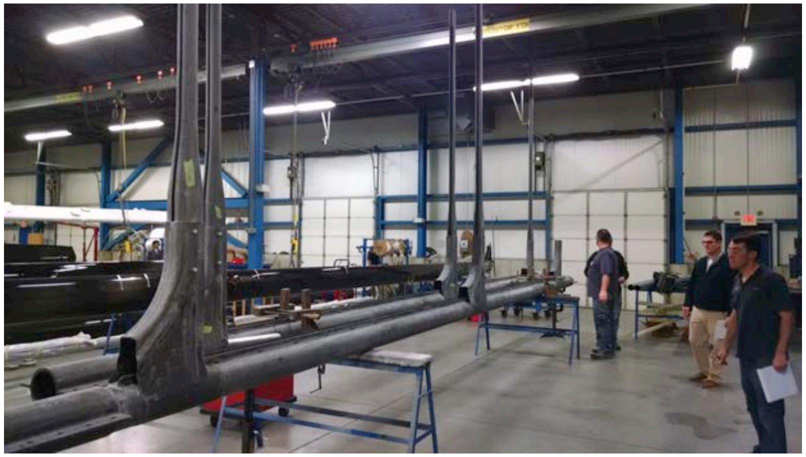


The measurements confirmed the site depth and location. Agreement with old bathymetry is within 20m depth for the most part. So we could be confident of the depth where the mooring was going to be placed.



Mooring was deployed on January 20th. Pictures above show the mooring buoy (used an old one we had, but refurbished it), the mooring buoy on the ship, and then to the left, the mooring at the site. It has stayed in a stable position since the time it was deployed.

MOBY-Net structure has been designed and built:

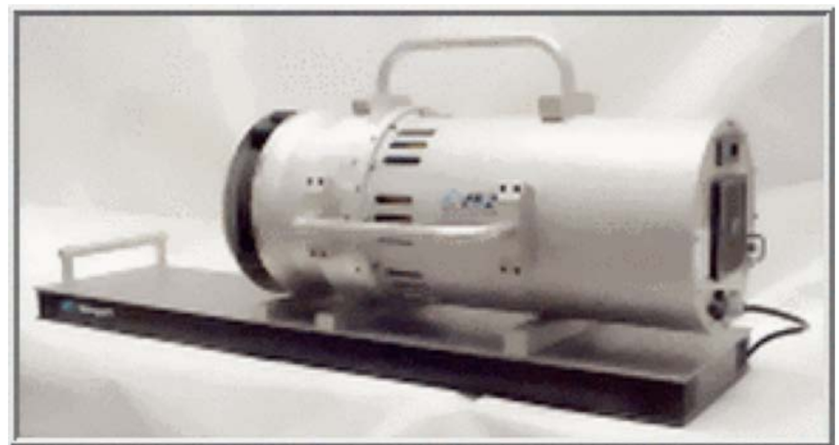


Above, main Spar with arms fitted in place.

To right: close up of end of spar with irradiance and radiance collectors fitted.

Instrument Systems CAS 140CT system to be used for monitoring stability source.

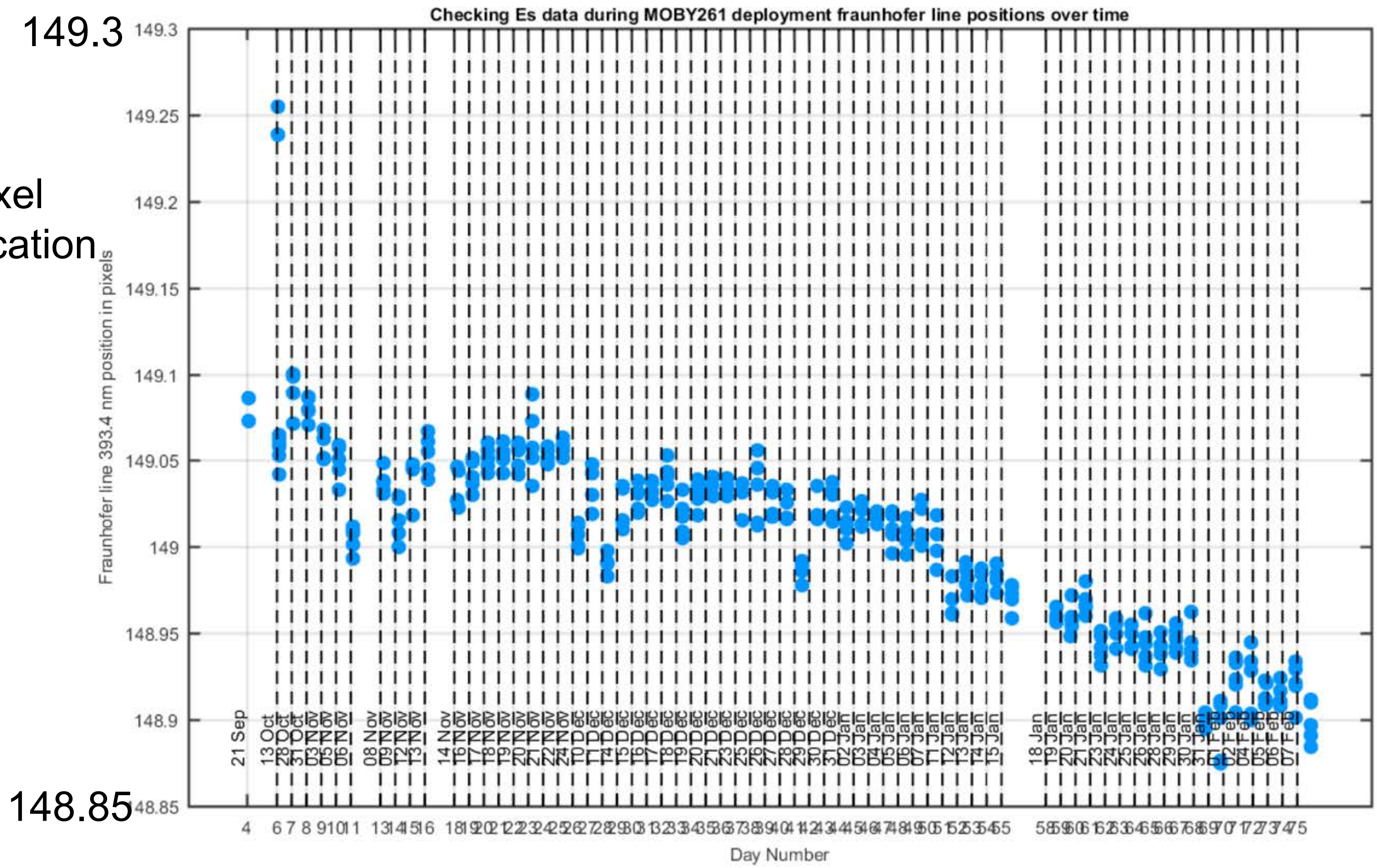
Yankee Environmental Systems SQM – 5002 source that we will be using as the stability source. It also has internal detectors (two filtered detectors, one unfiltered) to monitor the lamp rings and integrating cavity. (system originally designed for SIMBIOS)



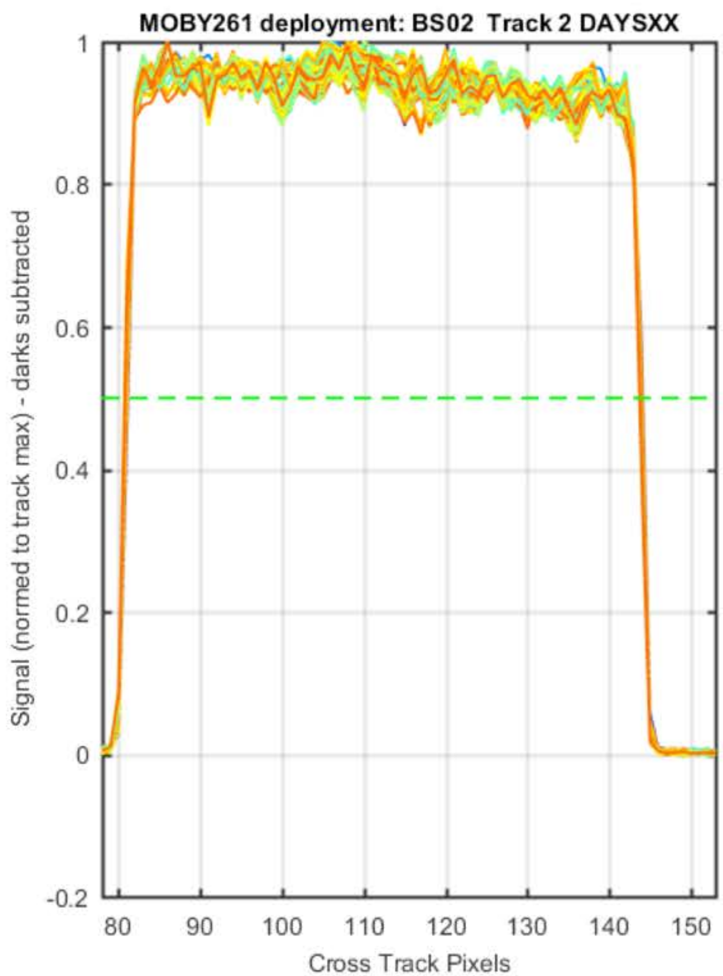
Between the source (with its internal monitors), the external radiometer, and MOBY-Net we should be able to monitor MOBY stability pre/post deployment and after shipping and installation, 2% goal.

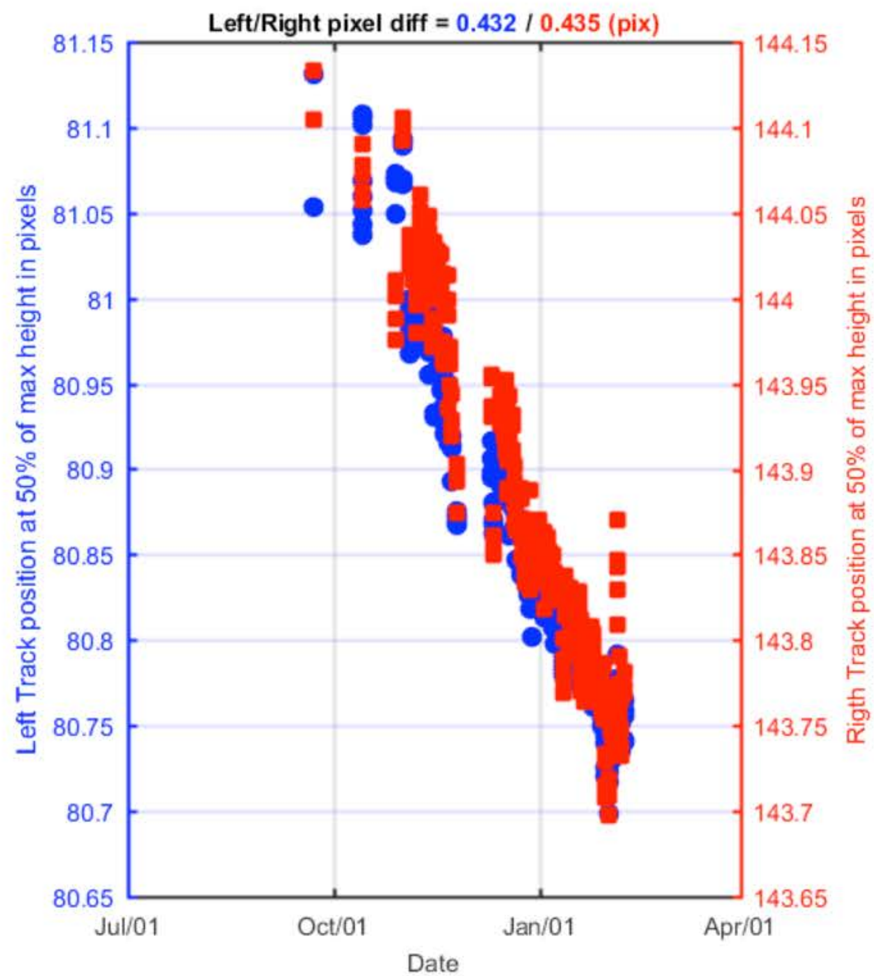
The Blue spectrometer from the new optical system is being operated on MOBY during deployments:

System has been very stable in both spectral registration (Less than 0.1 nm shift over 4 month deployment, as registered with Fraunhofer lines).

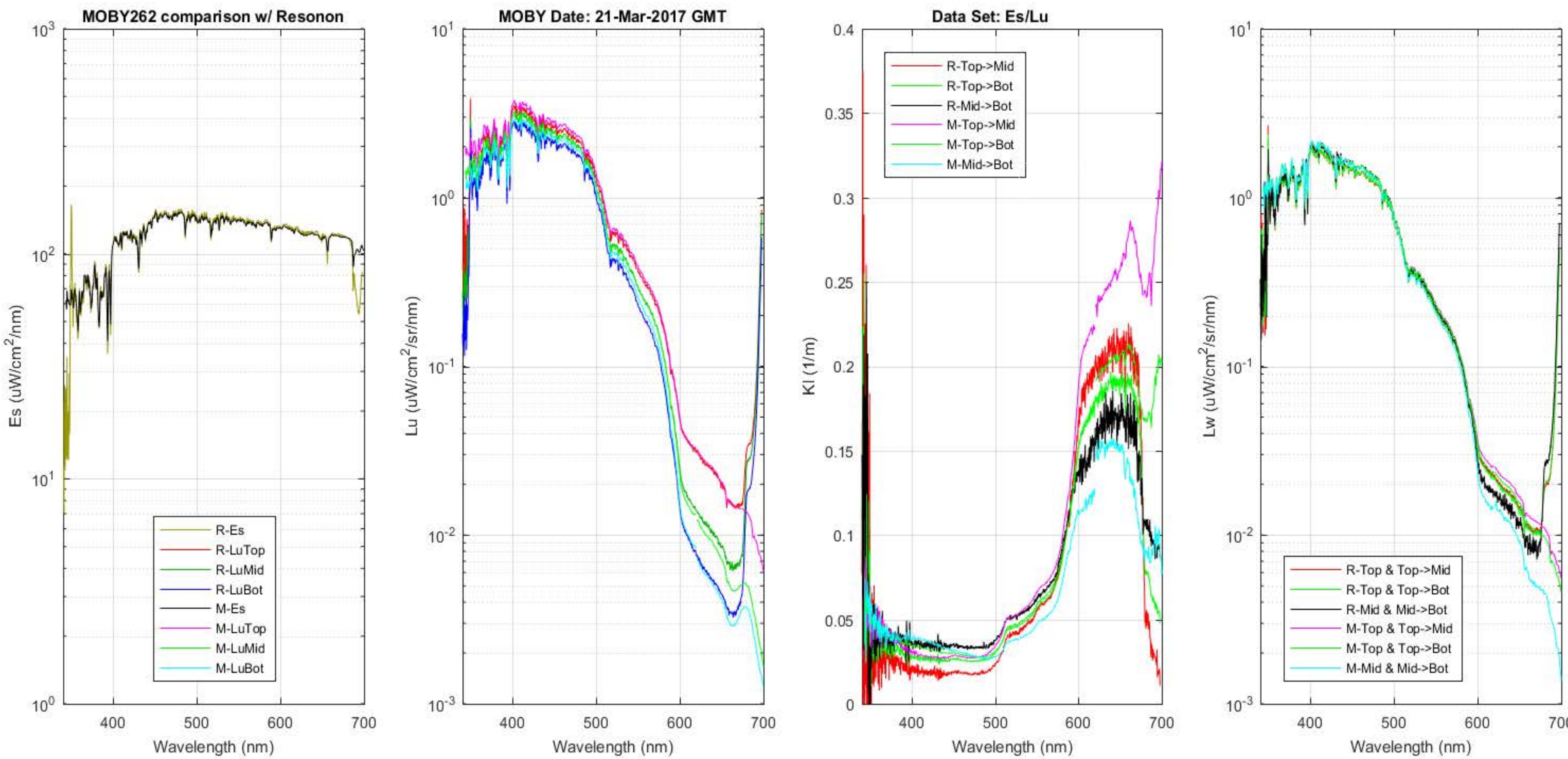


And stable in the track dimension (less than 0.5 pixel shift over 4 months):





Comparison of Heritage and new system



Scheme envisioned

- Selection of additional site with sufficient logistical/technical support for instrument assembly and deployment, at this site proposed for Perth, Australia.
- Two MOBY hull structures on site. Allows more efficient use of ship time..one cruise to deploy and retrieve system.
- While the optics for one instrument is in field, the other is being sent back for calibration (with traveling source/monitor)…the Netflix part.
- Data forwarded to central location for common processing with MOBY/Hawaii.
- Central/common calibration and characterization site.

Last two items are requirements of the INSITU-OCR White paper

Conclusions

- MOBY has provided vicarious calibration data for virtually all ocean color sensors (that can see it) since 1997.
- Now we have an 24 year time series that allows us to look for trending, improve our understanding of the uncertainties and other aspects of the data stream.
- Thanks to the dedicated group of people at Moss Landing, NIST, and NOAA this program has kept going with very high standards.
- Also, just as importantly, we need to thank the continued support of NASA and NOAA, and many dedicated people in these agencies for their support over the many years.

What did I do on my day off....

Floating again.