Preliminary Characterization Results: Fiber-Coupled, Multi-channel, Hyperspectral Spectrographs

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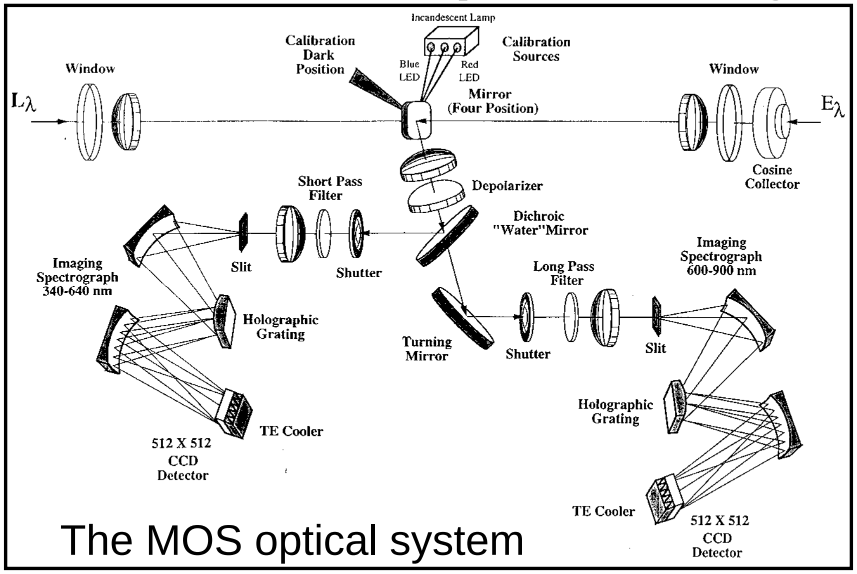
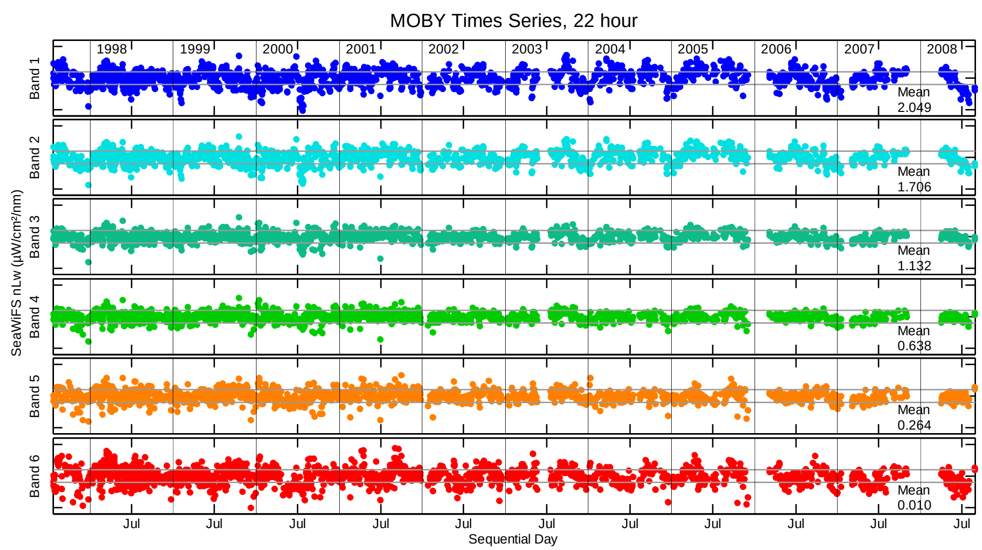
Marine Optical System & Data Stream



The MOS optical system

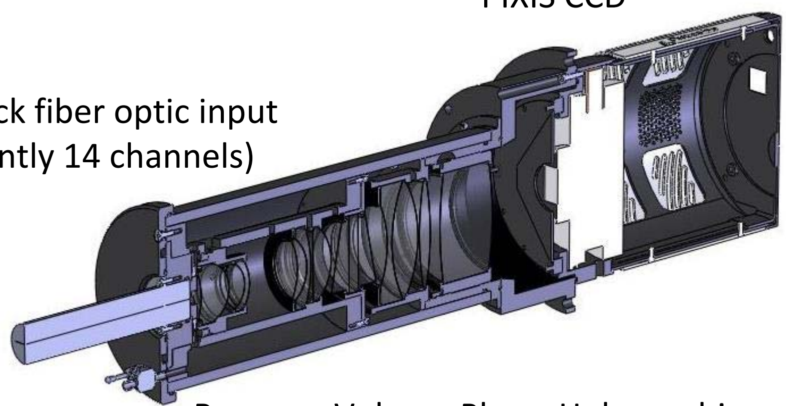
In MOS, light is input sequentially into the dual spectrographs using optical fibers and a rotating mirror assembly (in place of the cosine collector). The full slit is imaged onto CCD detectors. On a typical day, it took 27 min to acquire a full data set, with integration times of between 1 and 30 sec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



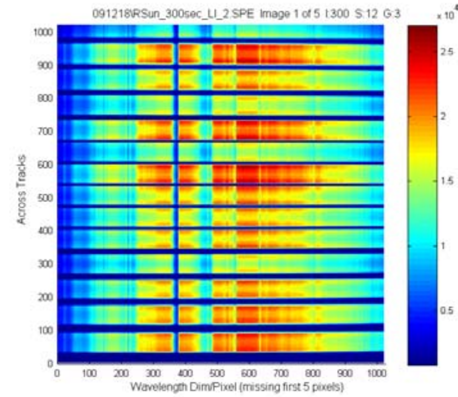
New Sensor – Simultaneous Acquisition

Princeton Instrument
PIXIS CCD

Romack fiber optic input
(currently 14 channels)

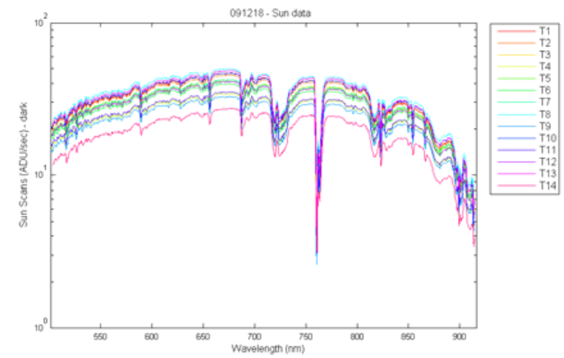


Resonon Volume Phase Holographic
(VPH) in line spectrograph

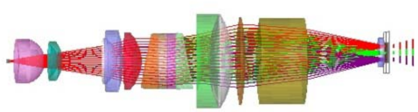


RILS image of
diffuse solar flux

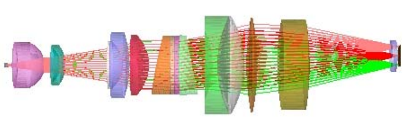
Average net
ADU/sec for
each channel



Blue In Line Spectrograph (BILS)



Red In Line Spectrograph (RILS)



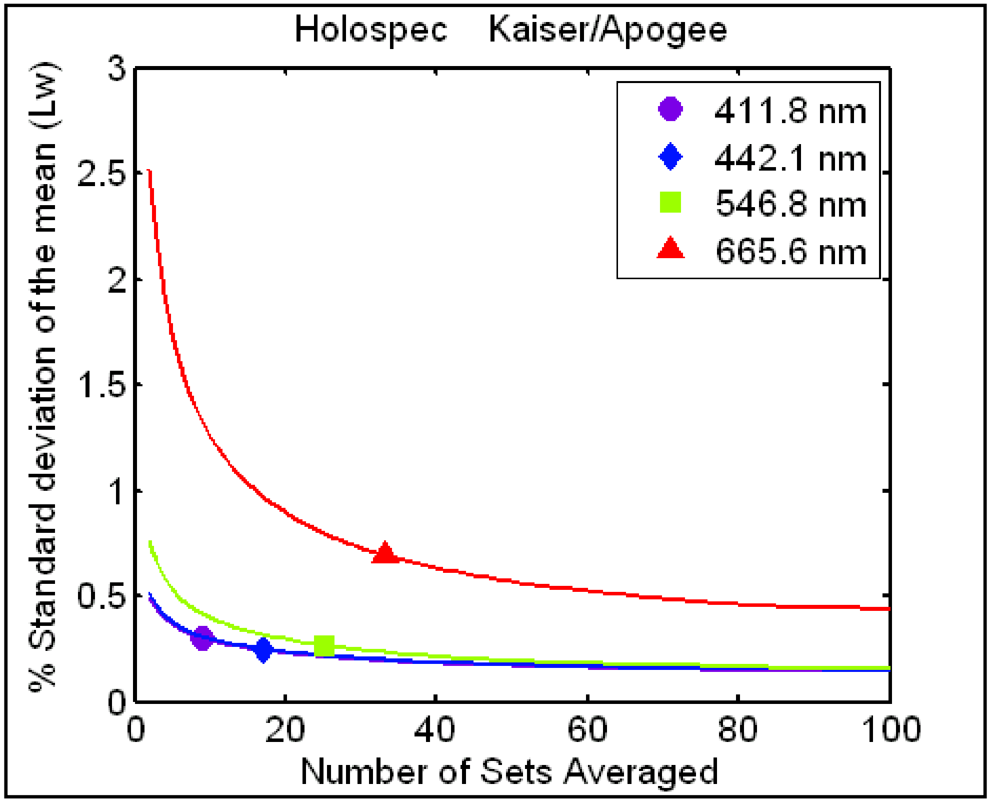
The inputs to the optical fibers are at the desired locations.
The fiber outputs are aligned vertically at the entrance slit.
The prism-grating-prism in-line optical system (Resonon, Inc.) images the different input channels at the same time on the CCD camera), spaced along the slit direction.

Project History & Status

- Breadboard two systems, SIRCUS characterization, field tests
  - JY CP140 spectrograph, Andor camera, 4 inputs
  - Kaiser Holospec, Apogee camera, 6 inputs
- Custom optical designs
  - Resonon spectrographs (blue and red), Romack input fiber bundles, and Princeton Instruments cameras are procured and operational
  - Characterizations well underway
- Testing of packaged field system Aug 2010

Simultaneous Systems & Sample Number

The simultaneous design places no restriction on the number of samples averaged. This is an advantage compared to MOBY, where the sequential measurements of Es, LuMid, Es, LuTop, Es, LuBot, Es, LuMOS, Es means an increase in number of samples would increase the time between these data collections, impacting the determination of Lw.

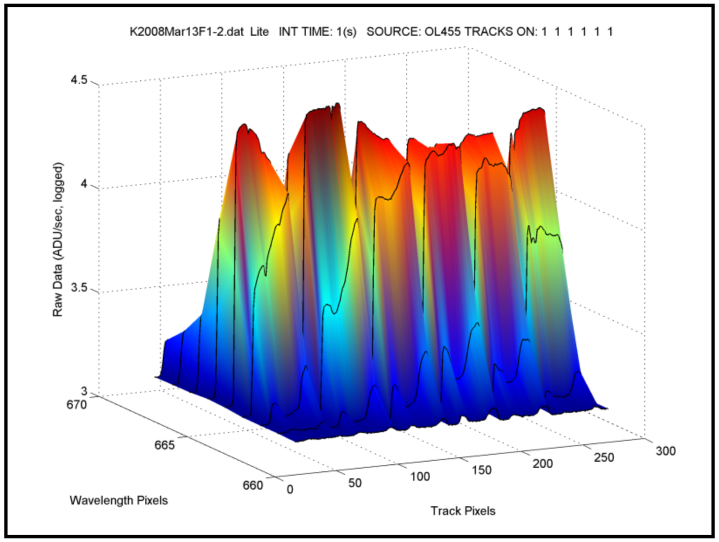


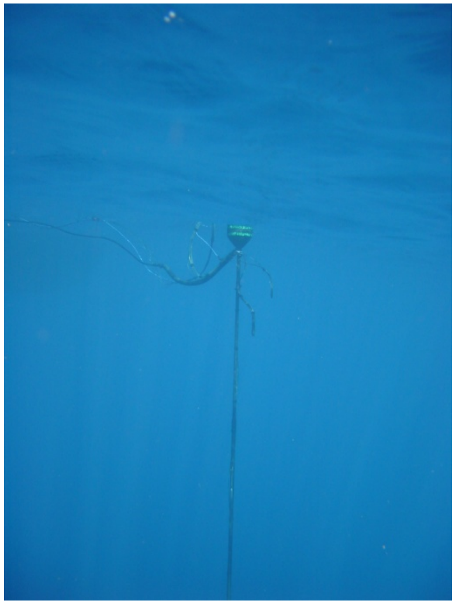
Band averaged results with a prototype 6-channel hyperspectral system tested in Case 1 waters off Oahu. Five to 100 scans were acquired with 4 sec integration times.

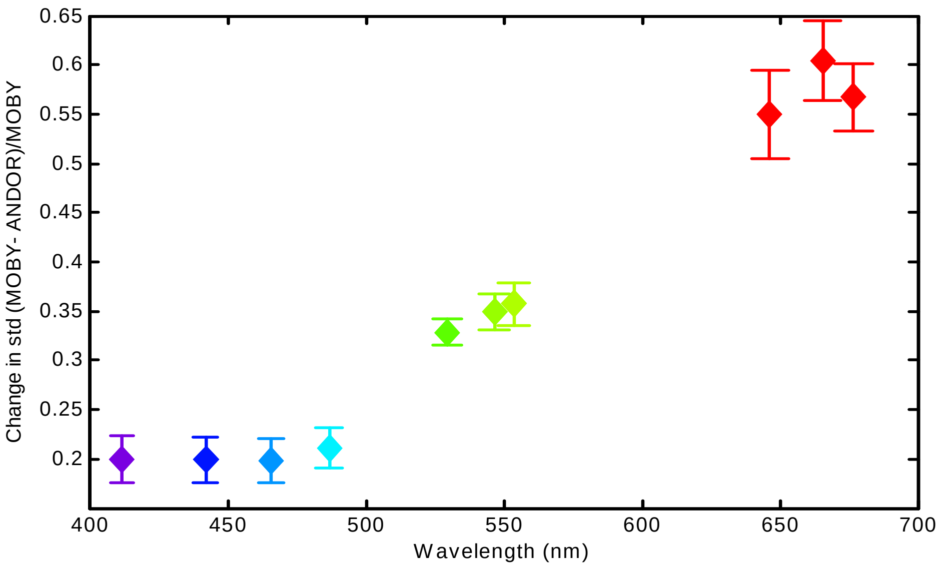
Yarbrough, M.A., S. Flora, M.E. Feinholz, T. Houlihan, Y.S. Kim, S.W. Brown, B.C. Johnson, K. Voss and D.K Clark (2007). “Simultaneous measurement of up-welling spectral radiance using a fiber-coupled CCD spectrograph.” Proc. SPIE 6680, 66800J-1 to 66800J-11.

Simultaneous Systems & Correlated Noise

The effect of correlations in the light field was investigated by deriving $L_w(\lambda)$ from four simultaneous $L_u(\lambda)$s (Kaiser/Apogee), and by randomly sampling the $L_u(\lambda)$ scans in time to simulate the current MOBY sampling statistics. The measurement uncertainty was reduced between 20% to 60% for the ocean color bands.







In-Line Spectrograph Parameters from Optical Design

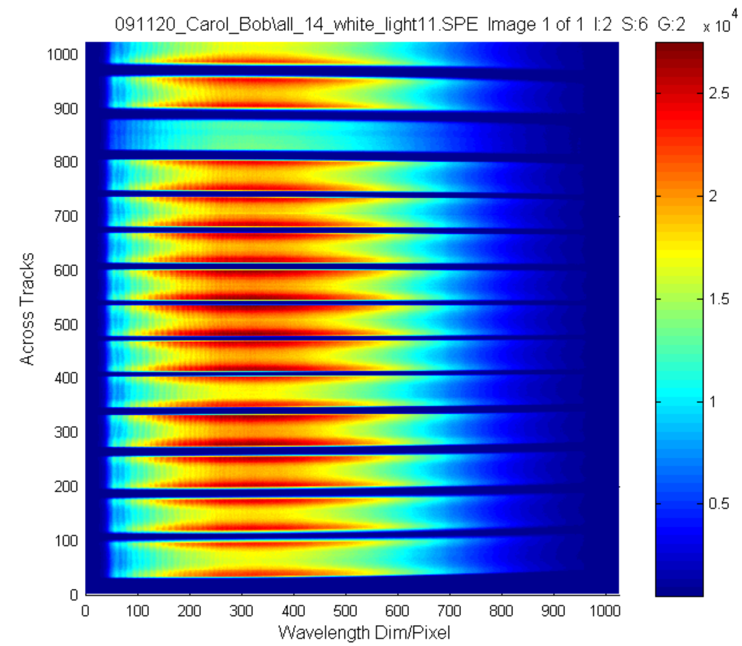
Parameter	Blue	Red
Size, cm	13.7 x 41.7	13.7 x 43.2
Spectral coverage, nm	370 - 720	500 - 900
Spectral resolution, nm	0.34	0.39
Image at focal plane, mm	13 x 13	13 x 13
Slit dimensions, mm	13 x 0.025	13 x 0.025
Thermal effect, pixel/deg C	< 0.05 pixel	< 0.05 pixel
MTF @ 38 line pr / mm	76 at 545 nm	61 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

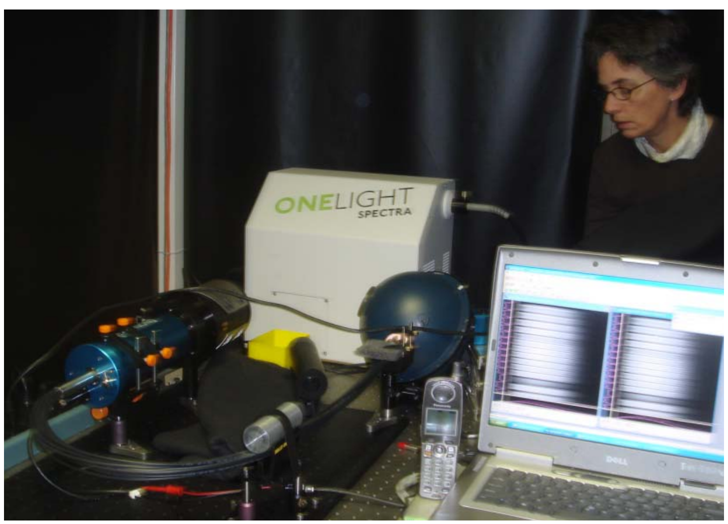
“Report on Blue and Red Imaging Spectrometers for MOBY,” Michael Kehoe and Casey Dodge, Resonon, Inc.

Characterization Results To Date

Two Spectrographs:

- Blue system: Romack fiber bundle (14 fibers, 800 μm core); Blue In-Line Spectrograph (BILS); Princeton Pixis 1024B back illuminated CCD (13 μm pixels)
- Red system: Romack fiber bundle (14 fibers, 800 μm core); Red In-Line Spectrograph (RILS); Princeton Pixis 1024BR back illuminated, deep depletion CCD (13 μm pixels)





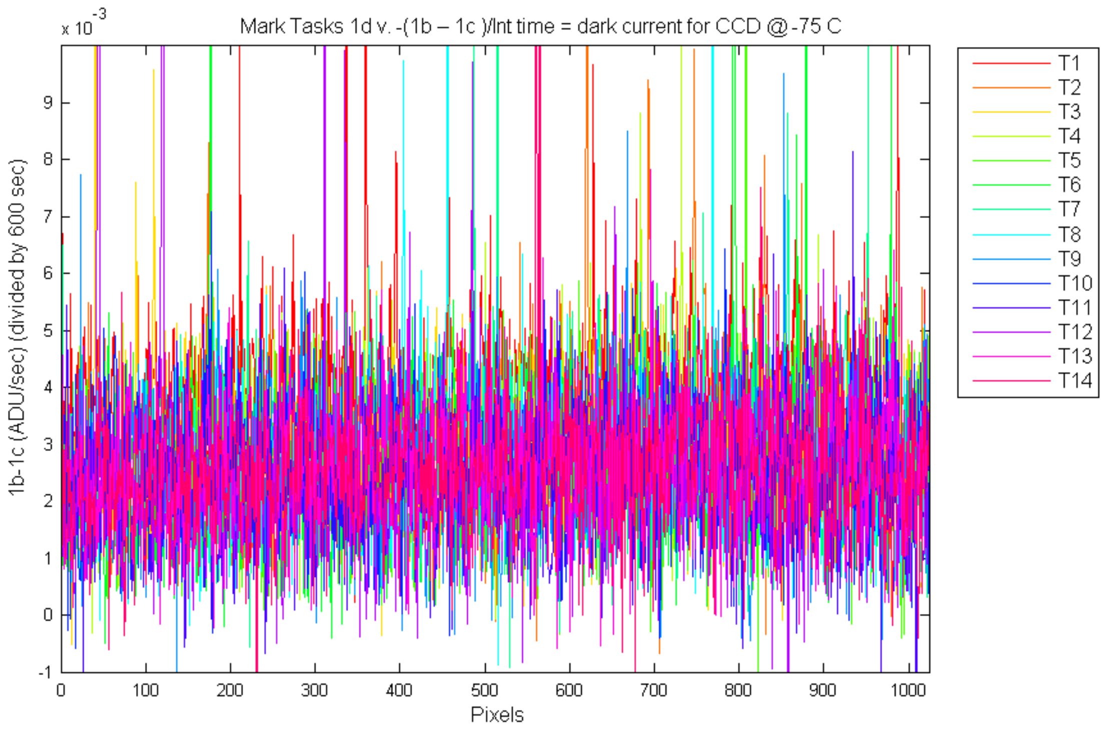
Tests to date:

- noise, wavelength calibration, spectral stray light, imaging behavior, system response

Noise

CCD Camera System Features

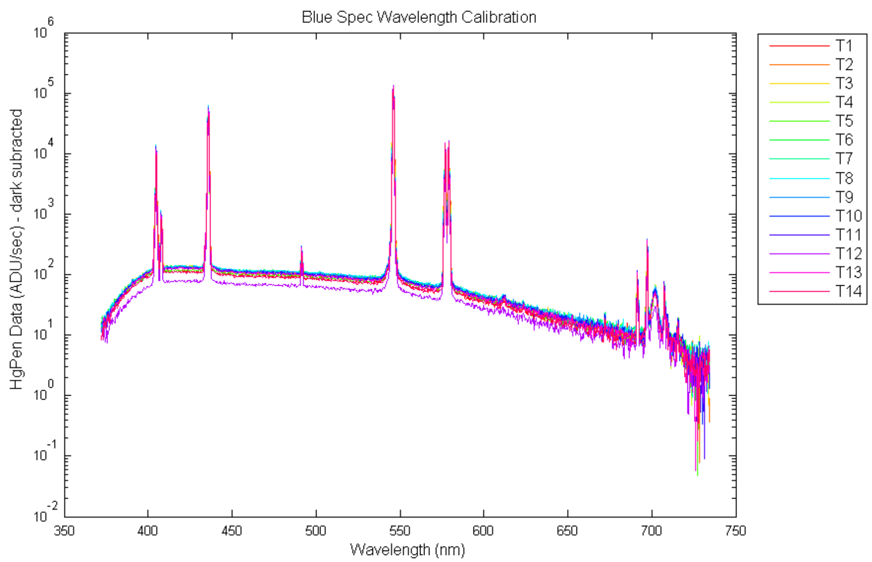
- Fast & Slow digitization rate; three gain settings (number of electrons to get one ADU)
- four stage TEC holds CCD at -75°C
- ~ 600 ADU built-in offset



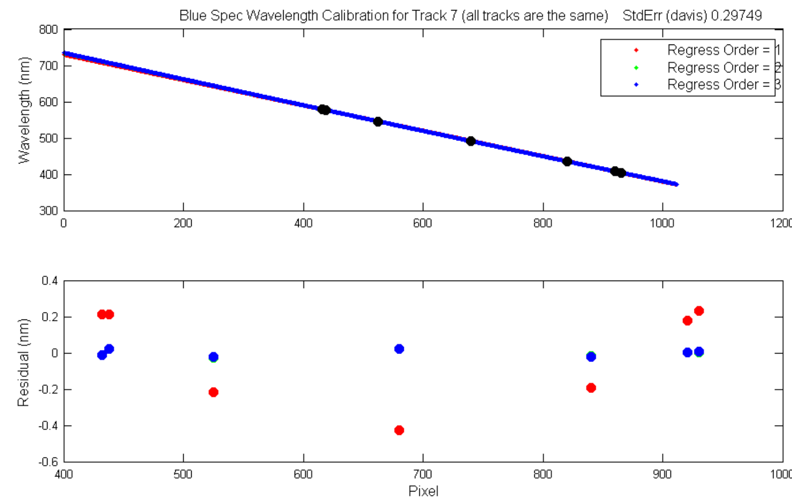
Tests showed

- low dark count rate, μ=0.0028, σ=0.0011 ADU/sec (track 7)
- digitization at 2MHz vs 100kHz did not compromise dark noise

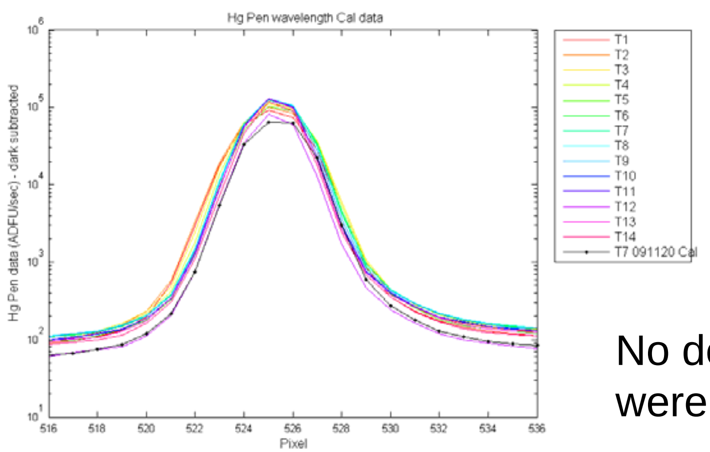
Wavelength Calibration w/ Hg Lamp



Coverage 372 to 734 nm, step 0.354 nm

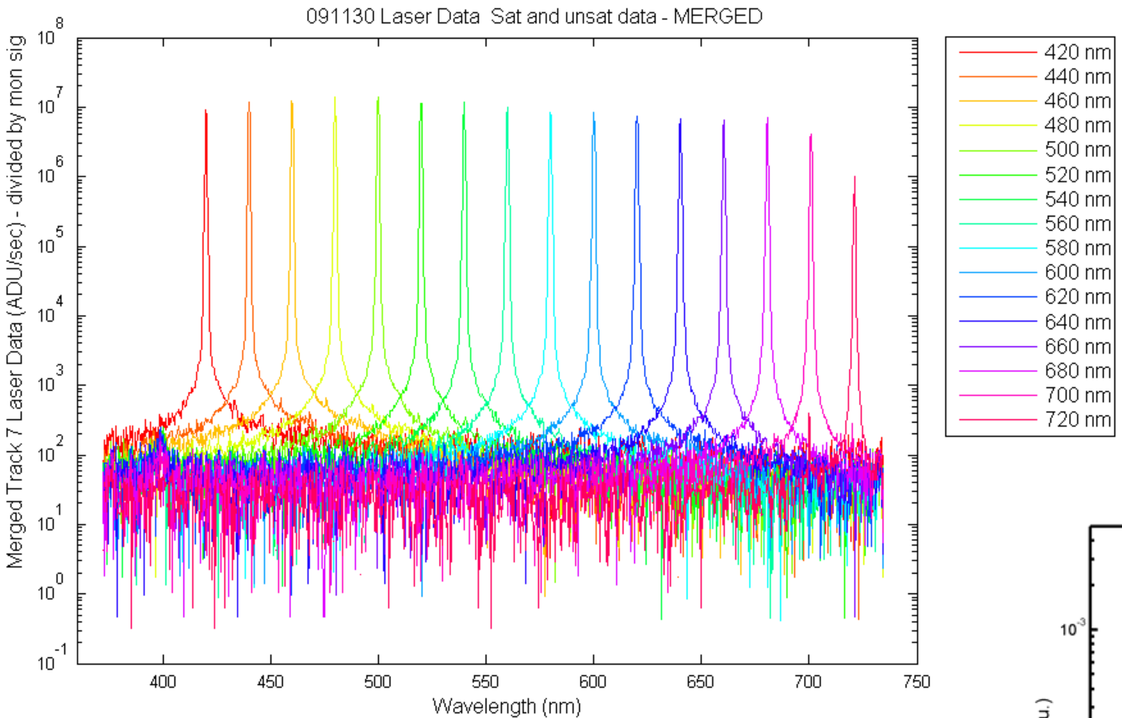


Preliminary fits to polynomials



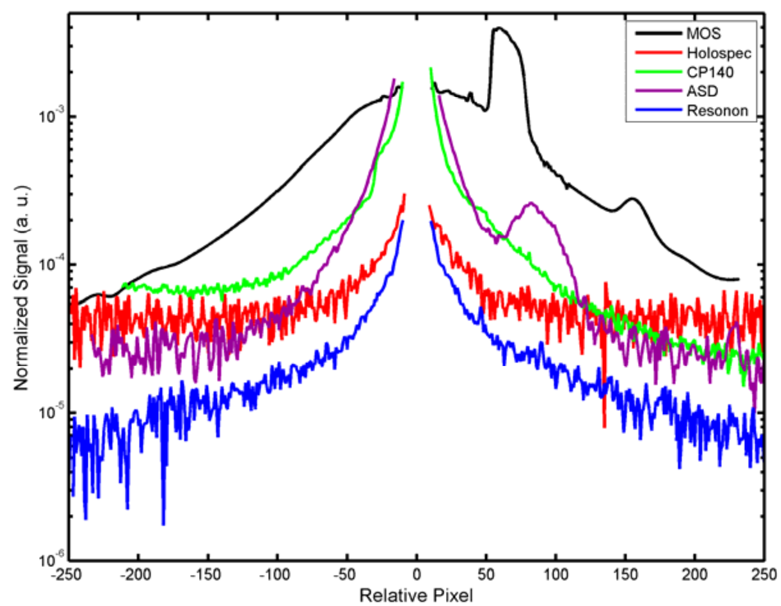
No dependence with track – if smile were an issue we would see this here

Laser Characterization on SIRCUS

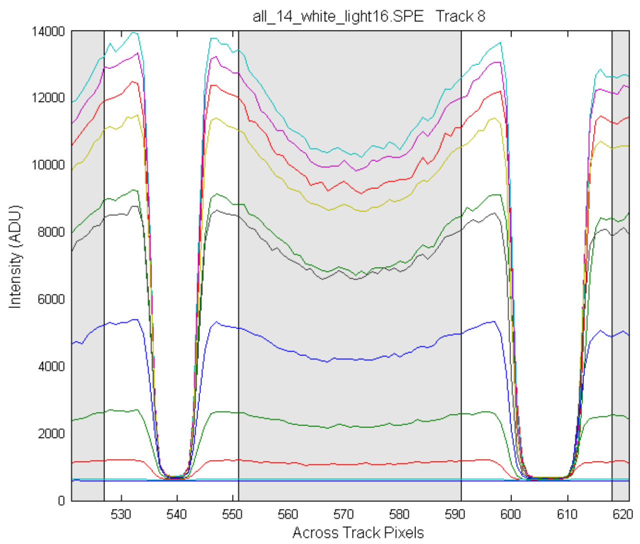


BILS initial testing on SIRCUS; focus was on Track 7. Results are very encouraging, both in spectral and spatial dimension: ~10^{-5}.

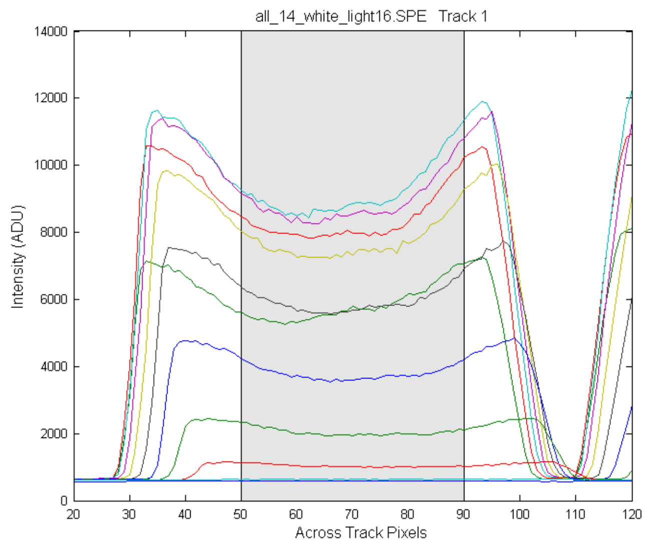
The spectral stray light is the best we've seen so far for a single grating system. BILS is 20x better than MOS in terms of integrated area.



Imaging Behavior



Track 8

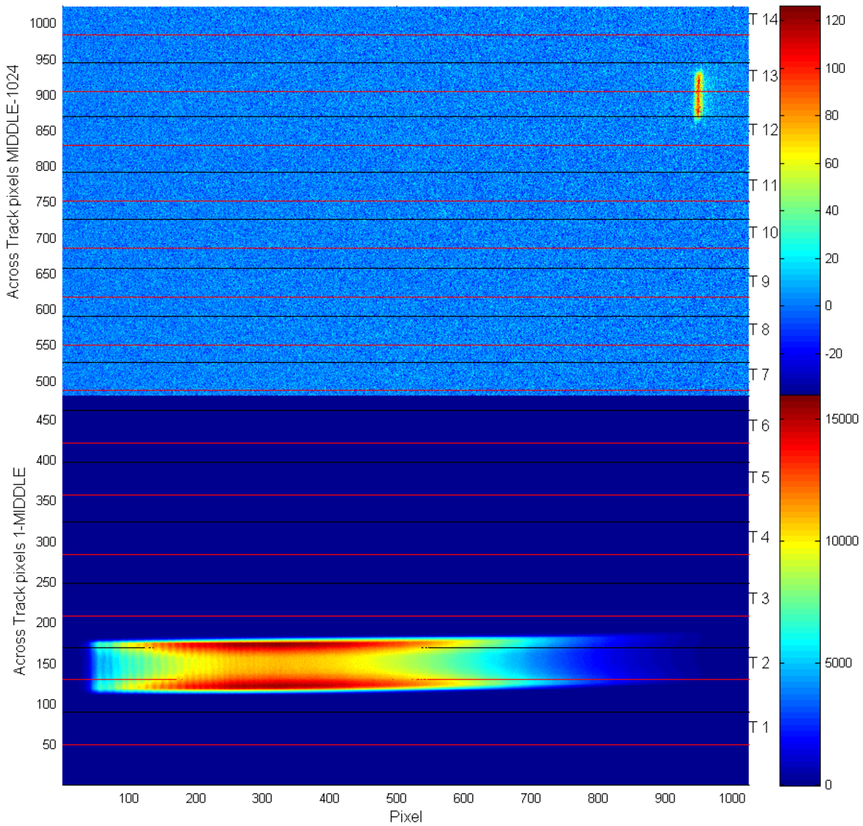


Track 1

There is measureable keystone, which affects our planned on-chip hardware binning (a method to reduce noise and increases dynamic range). This can be corrected by optimizing the optical design in the final systems.

There is an obvious non-uniformity in the spatial (slit) direction, the “saddle.” This effect appears stable and is under investigation: partial coherence at the slit or spatial mode effects in the short fibers used in the test? All results shown here were averaged over the 41 rows between the vertical lines indicated.

Inter-reflections in BILS

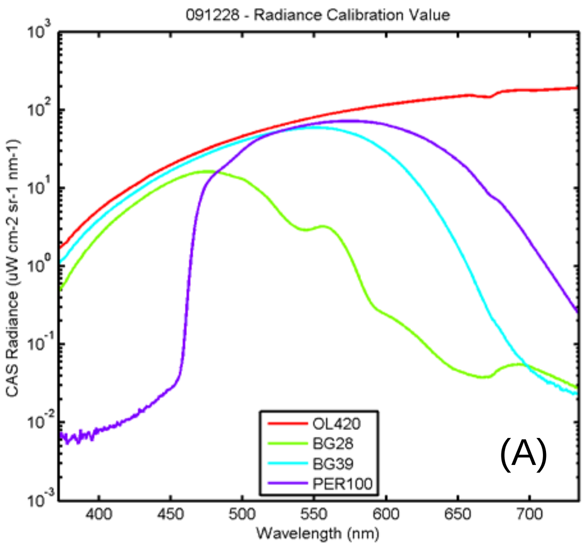


Track 2 illuminated, artifact on Track 13: Note scale change in this split image (100 ADU vs 15,000 ADU)

We discovered that there is an artifact that appears in the same wavelength region (~410 nm) independent of the wavelength of the input flux and paired with the track illuminated: light on 1 shows on 14, light on 2 shows on 13, ... light on 7 shows on 7, etc.

The explanation by Resonon's modeling is dispersed light reflecting off the CCD is recombining upon reentry into the prism/grating/prism assembly (e.g, as in a double subtractive system), and then being imaged in zero order. This inter-reflection is caused by a protective coating of SiO_2 that will not be used in a final production system.

System Response & Preliminary Stray Light Correction Algorithms



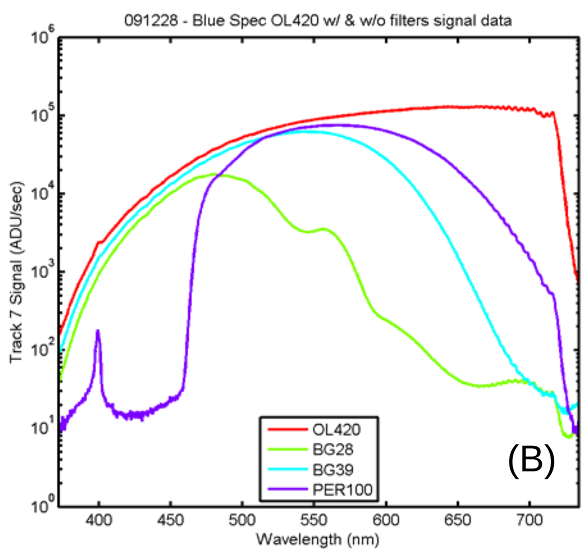
A preliminary SLC matrix was determined from the SIRCUS data. Validation data were acquired using various sources (filtered lamp; LED, laser). No SLC corrections are applied to the data shown here.

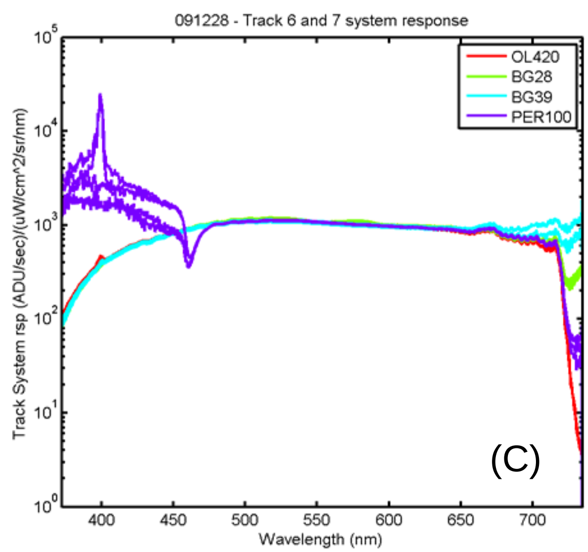
(A)the known L(λ) for this validation source;

(B)the net ADU/sec for BILS;

(C)the derived system response from B/A

Note: A and B are not that different for PER!





The responses disagree in regions where stray light (or the artifact) is contributing strongly. This will be removed with the SLC and algorithm.

Conclusion

- We’re on track; no hardware show stoppers for a superb sensor for field radiometry
- Team members:
  - NIST (Johnson, Saunders, Li, Clark, Parr)
  - MLML (Yarbrough, Feinholz, Flora, Houlihan)
  - Resonon (Kehoe, Dodge, Swanson)
  - UM (Voss)
- Implementation for MOBY-C depends on funding profile