Lessons learned from the calibration of the Ocean Color Instrument (OCI) on the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

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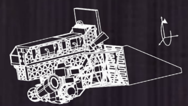
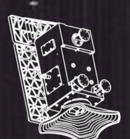
Acknowledgements: Joseph Knuble, **Eric Gorman**, **Brendan McAndrew**, **Jeremy Werdell**, NASA, United States**; Julia Barsi, Leland Chemerys, Kim Jepsen, Samuel Kitchen-McKinley, Jeffrey Mcintire**, Science Systems and Applications Inc., United States**; Robert Bousquet, Andrei Sushkov,** Genesis Engineering Solutions, Inc., United States; **Hyeungu Choi**, Global Science & Technology, United States; **Nicholas Collins**, Telophase Corporation, United States; **Robert Eplee, Shihyan Lee, Frederick Pa**tt, Science Applications International Corporation, United States; **Christopher Field**, Aurora Engineering, United States; **Ulrik Gliese**, KBR, United States; **Jacob Hedelius, Kenneth Squire**, Space Dynamics Laboratory, United States; **Bradley Tse**, Microtel, United States; **Eugene Waluschka**, Stellar Solutions, United States

December 1st, 2025; IOCS 2025, Ocean Colour Satellite Sensor Calibration

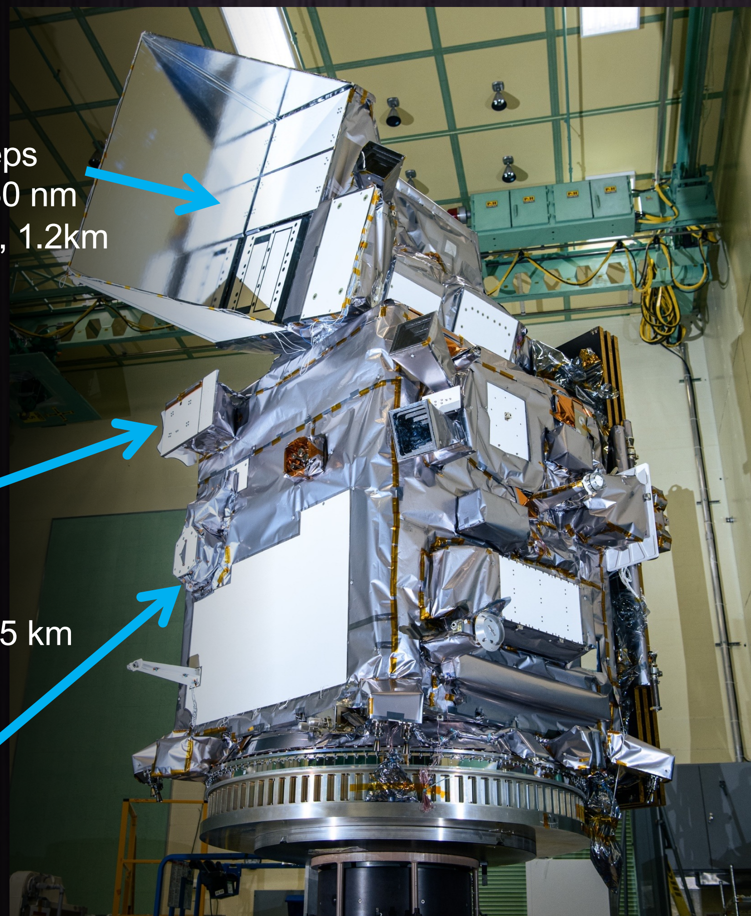


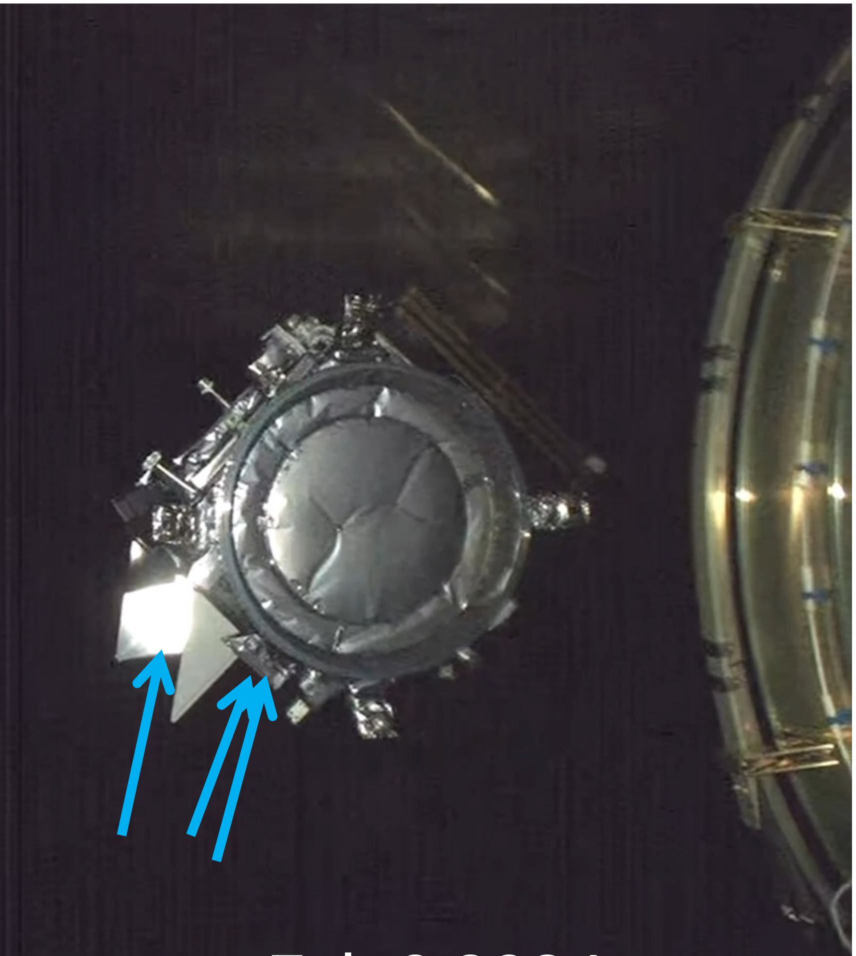
OCI
340-890 nm in 2.5 nm steps
7 discrete SWIR, 940-2260 nm
1-2 day coverage ±20° tilt, 1.2km



HARP2 (UMBC)
440, 550, 670, 870 nm
10-60 viewing angles
wide swath polarimeter, 2.5 km

SPEXone (SRON)
380-770 nm in 2-4 nm steps
5 viewing angles
narrow swath polarimeter, 3 km





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OCI requirements during design phase:

- Level 1 requirements: define accuracy requirements for science products (e.g. for water leaving radiance / Rrs) (J. Werdell et al., 2019, Table 1)
- Level 2 requirements: define accuracy requirements for TOA radiance or reflectance products on observatory level (top level) (https://pace.oceansciences.org/docs/PACE-SYS-REQ-0019L_04-03-2023_DOORS.pdf, Table 2.19-2)
- Level 3 requirements: define accuracy requirements for measured radiance on instrument level (very detailed, e.g. SNR, polarization, temperature, temporal gain stability, etc.) (https://pace.oceansciences.org/requirements.htm)
- Connection from L1 to L2 established via global simulation using L2 uncertainties (A. Ibrahim, et al.,. "PyTOAST: A Python-based Simulator for Hyperspectral Ocean Color Observations and Uncertainty Assessment." San Francisco, USA, AGU23 (2023). https://agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1351967)
- Connection from L2 to L3: RMS sum of L3 uncertainties provides the top level L2 uncertainty (G. Meister, et al., Requirements for an advanced ocean radiometer, NASA/TM-2011-215883, Goddard Space Flight Center, Md., 40p., Oct. 2011.)

OCI image acquisition

- OCI is a rotating scanner, similar to SeaWiFS and VIIRS (rotating telescope and half angle mirror); rotation rate is 5.7Hz
- Image is acquired via motion of spacecraft in earth view mode (see picture below)
- Image is acquired via rotation of the spacecraft for lunar measurements

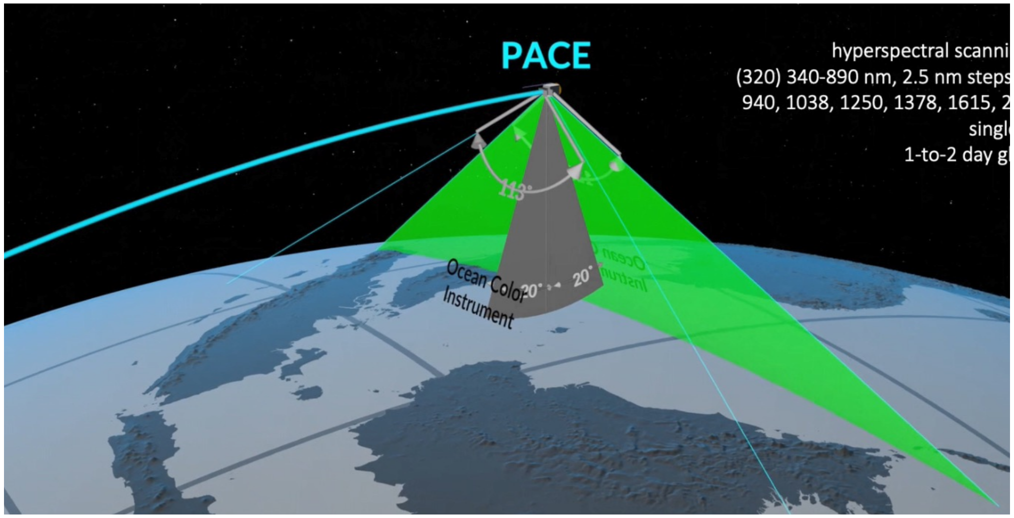
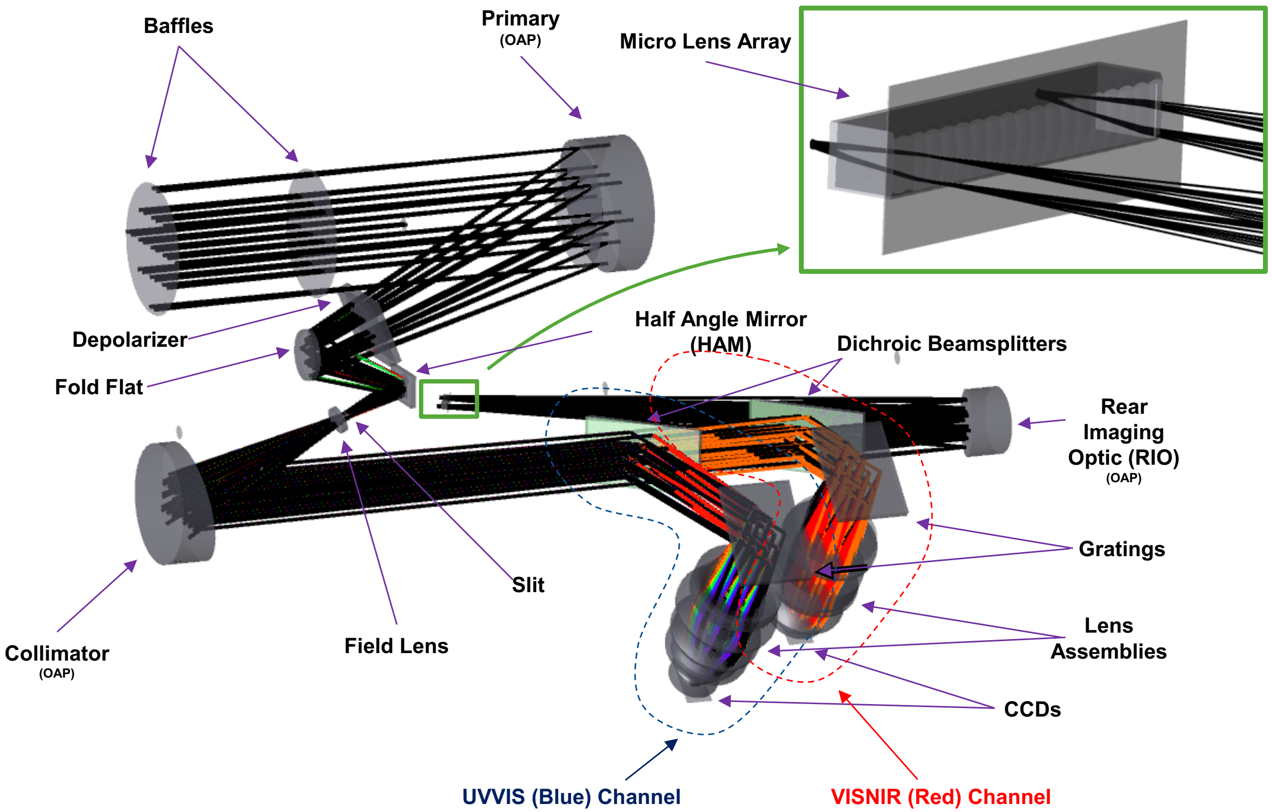


Image from U. Gliese, IGARSS 2023. See backup for full citations.

OCI Optical System (from U. Gliese, IGARSS 2023)



Signal is acquired via time-Delay Integration (TDI) in scan direction (16:1 for CCDs, 8:1 to 2:1 for SWIR bands)

Radiance Calibration Equation

$$Lt = K1*K2(t)*(1-K3(T-Tref))*K4(\theta) *K5(dn)*Kp*dn$$

- Lt = Radiance, unit: W /(m^2 µm sr)
- K1 = absolute gain factor; unit: (W /(m^2 µm sr))/dn
- K2(t) = relative gain factor as a function of time t; unitless
- K3 = temperature correction [(deg C)$^{-1}$] (vector)
- T = Temperatures measured at relevant locations [deg C] (vector)
- Tref = Reference Temperature [deg C]
- θ =scan angle [deg]
- K4 = (θ) response versus scan ; unitless
- K5 = nonlinearity factor ; unitless
- dn = dark-corrected instrument counts

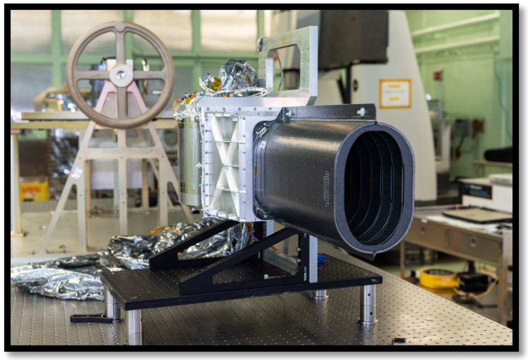
Kp: polarization correction applied in Level-2 code (correction needs TOA radiance polarization information)

K1, Kp and K3-K5 have been derived for all bands prelaunch

- K2 is derived on-orbit from solar diffuser and lunar measurements

Solar Diffuser

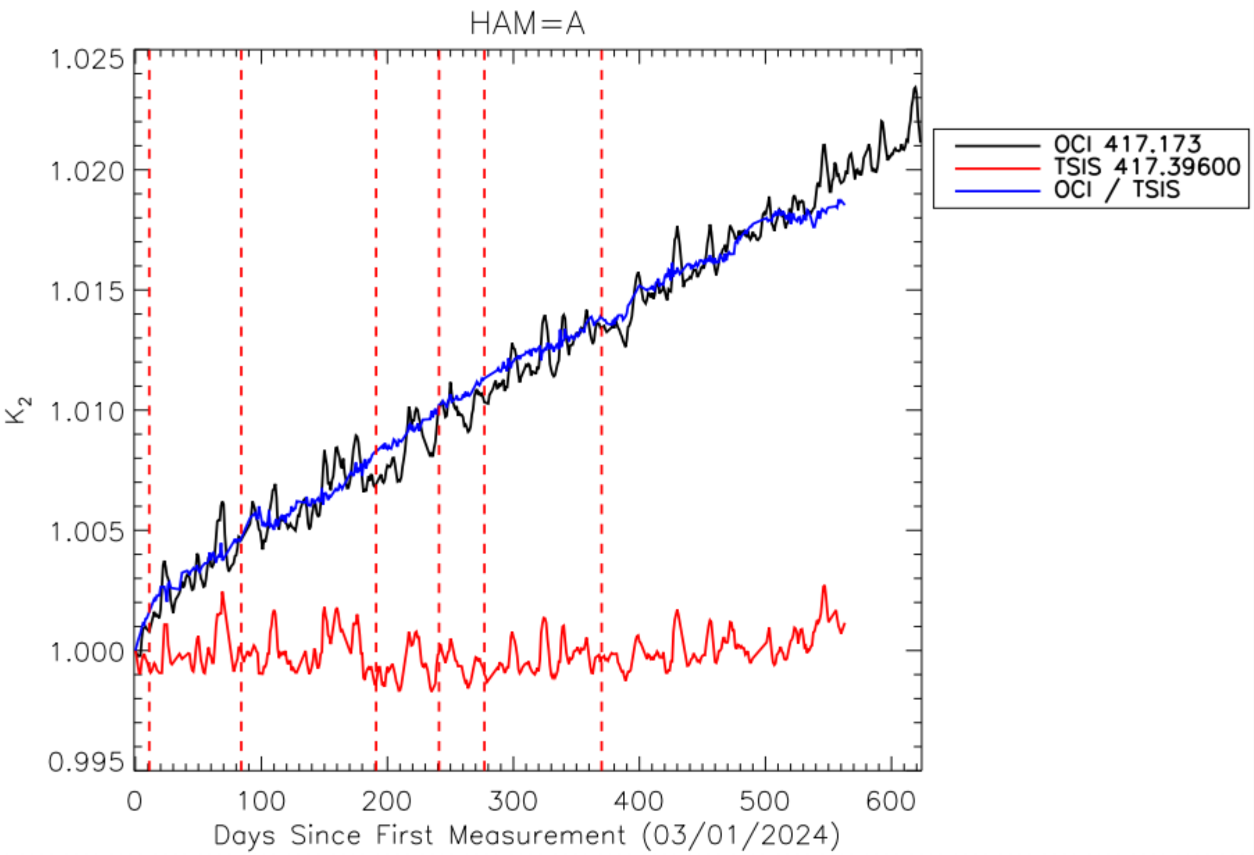
- Daily/monthly for short/medium term (up to 2 years) tracking of radiometric gain changes
- 3 diffusers (2 bright, one dim for linearity) mounted on a 3-sided wheel, see picture (top)
- Baffle eliminates earthshine, see picture (bottom)
- Long term tracking via lunar irradiance measurements
- Quartz Quasi Volume Diffuser (QVD) will degrade much less on-orbit in the UV than e.g. Spectralon
- Volume scattering leads to undesirable spatial variation of surface brightness (brighter in the middle): **DIFFICULT CHARACTERIZATION!**



Solar Diffuser Lessons (Re-)learned:

- characterize BRDF prelaunch as you fly (reflectance spatially inhomogeneous due to volume scattering)
- measuring at constant view/incidence angle successfully removed one source of uncertainty
- Solar irradiance variations are noticeable on the 0.2% level

On-orbit K2 measurements: daily solar diffuser and TSIS agree well



- Measurements for 417nm
- Same short term pattern in OCI (black) and TSIS (red), ratio (blue) is smooth
- Largest peak is at day 70, ~0.2%.
- Ignore vertical red lines (instrument reboot, etc.)

Spectral calibration accuracy

- Very good spectral agreement for Fraunhofer lines when comparing predicted (solar diffuser BRDF and E_sun) and measured (GLAMR) line positions (RMS of 0.14nm), see Robert E. Eplee Jr., Jeffrey W. McIntire, Shihyan Lee, Gerhard Meister, "Initial on-orbit spectral calibration of the PACE Ocean Color Instrument," Proc. SPIE 13143, Earth Observing Systems XXIX, 131430O (3 October 2024); https://doi.org/10.1117/12.3028084

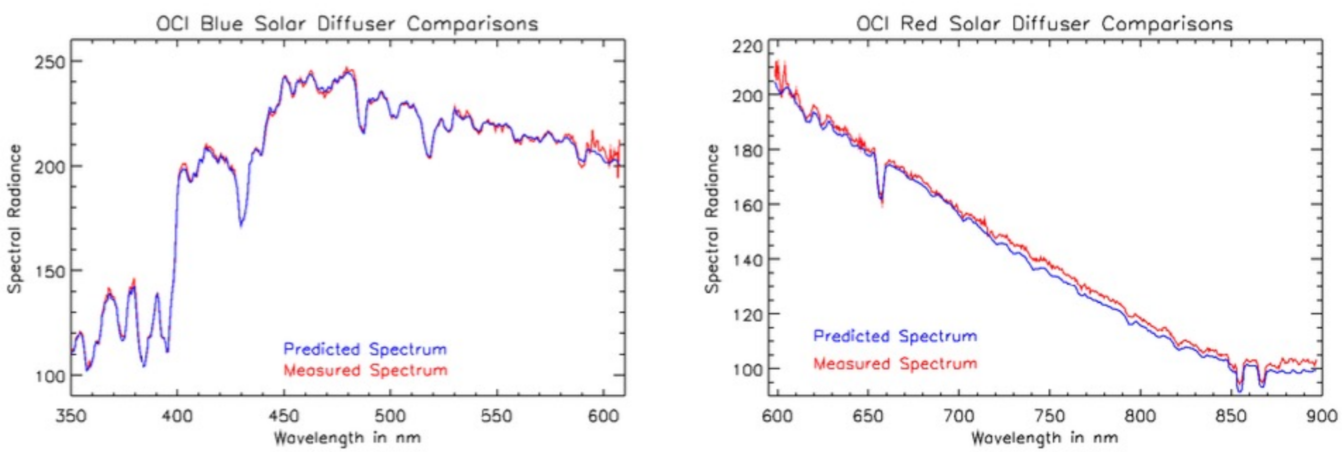
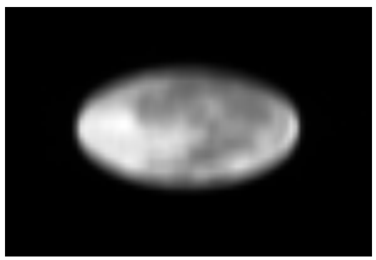


Figure 2. **OCI Measured and Predicted Spectrum Comparisons** a) UVVIS spectrum comparisons. b) VISNIR spectrum comparisons.

Lunar measurements

- OCI measures lunar irradiance twice a month, at +/- 7deg phase angle during the dark side of the orbit via a pitch/slew/roll maneuver
- OCI LOS is steered a few degree below the moon, slowly sweeps across the moon, stops, and slowly sweeps back
- Sweep speed is highly controlled (oversampling factor of 4)



OCI lunar measurements at -7deg phase angle

- Additionally, OCI moves LOS to the center of the moon and stares for ~30 seconds to acquire a scan line with a high contrast signal for SWIR band characterization

Trending from lunar measurements

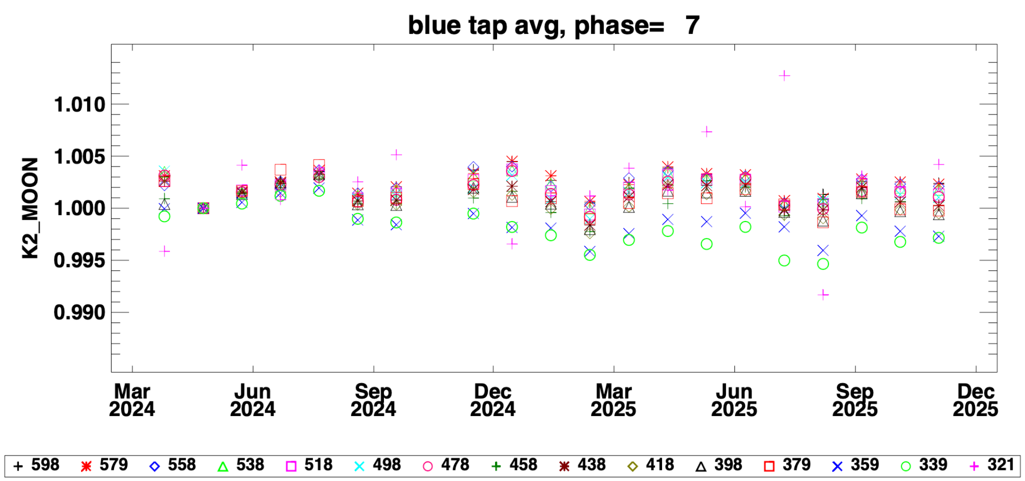
Residuals relative to the temporal trend derived from the solar diffuser (K2)

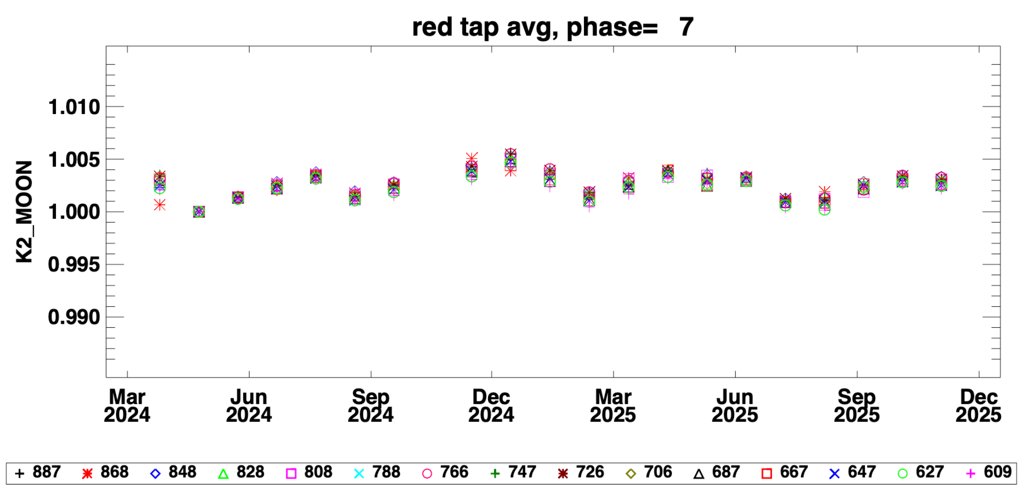
Left: blue FPA (<600nm), averaged over taps (20nm)

Right: red FPA (600nm-900nm) , averaged over taps (20nm)

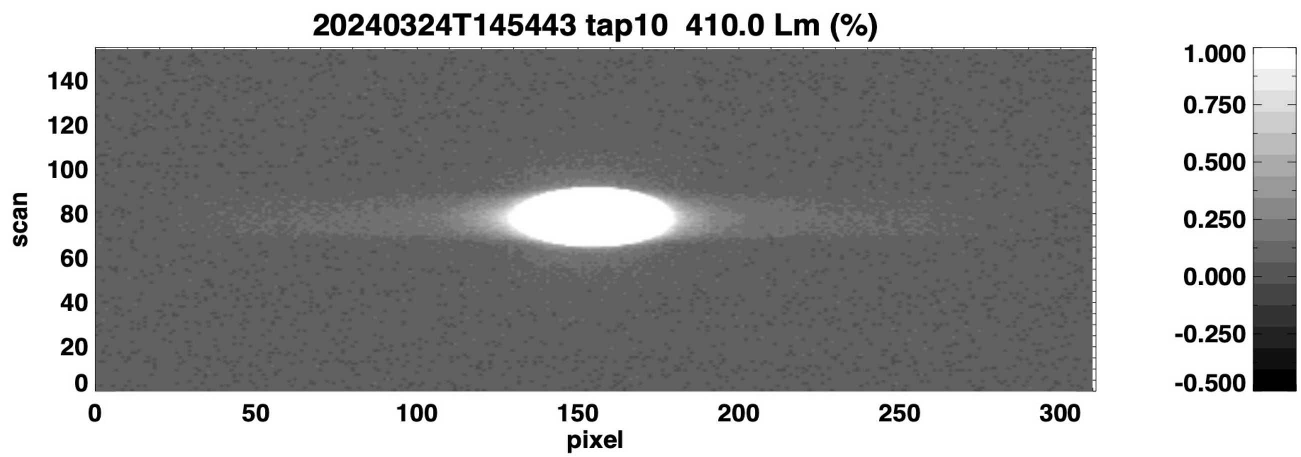
Variation of +/-0.2%, as expected from uncertainty of individual lunar measurements

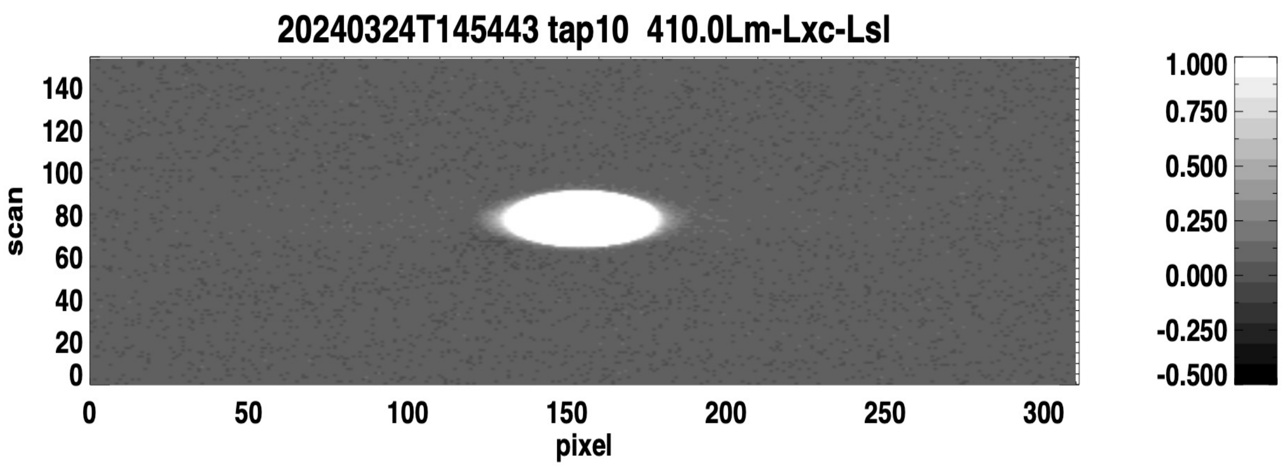
Possible trend in short wavelengths for blue FPA (monthly SD degradation?)





Straylight/crosstalk in lunar measurements





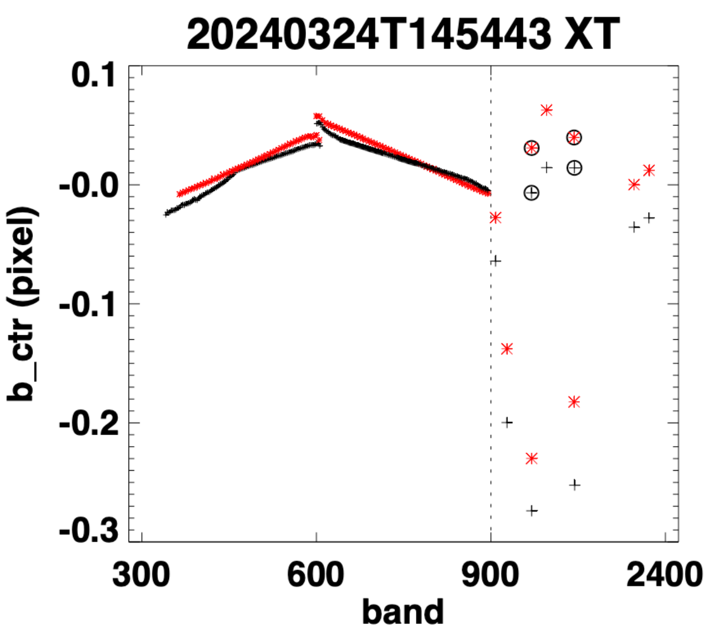
Scaled from -0.5% (black) of the peak to +1% (white)

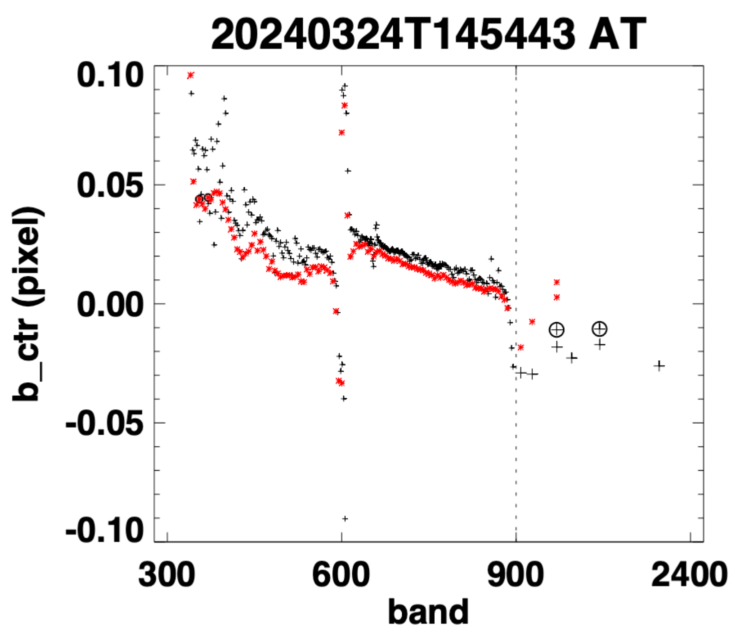
- Top: no correction
- Bottom: after correction for straylight and crosstalk
- Averaged over 20nm around 410nm (one tap)
- We are working on the implementation of this correction

BBR from lunar measurements

Band-to-band registration (BBR)

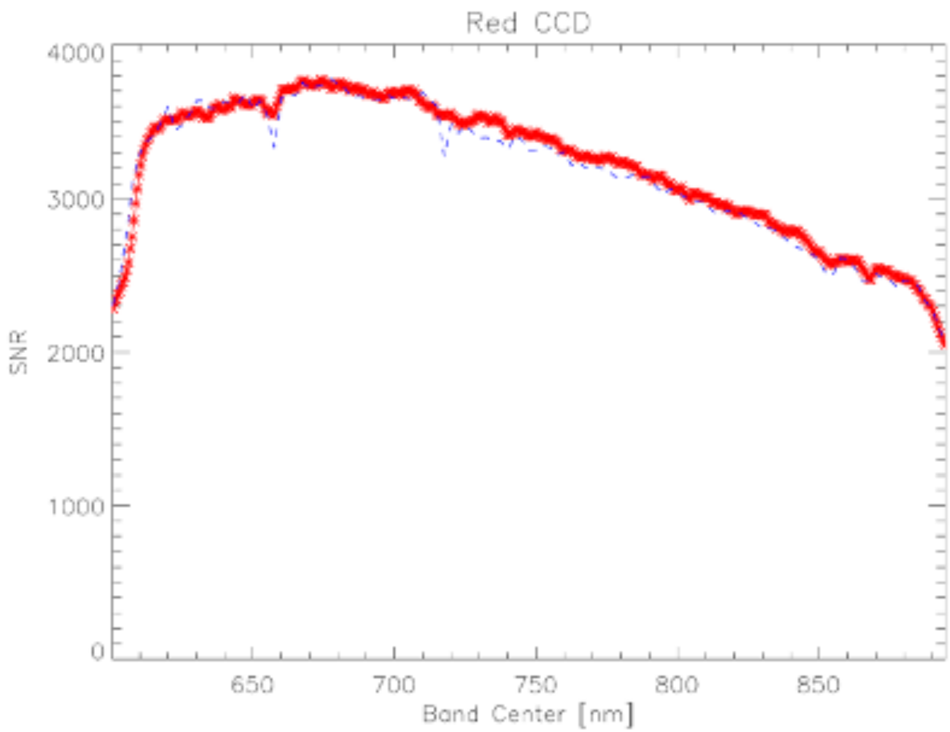
- XT – cross track
- AT – along track
- Black/red – different HAM sides
- Generally well within 0.1 pixels (except for SWIR XT), similar to prelaunch measurements

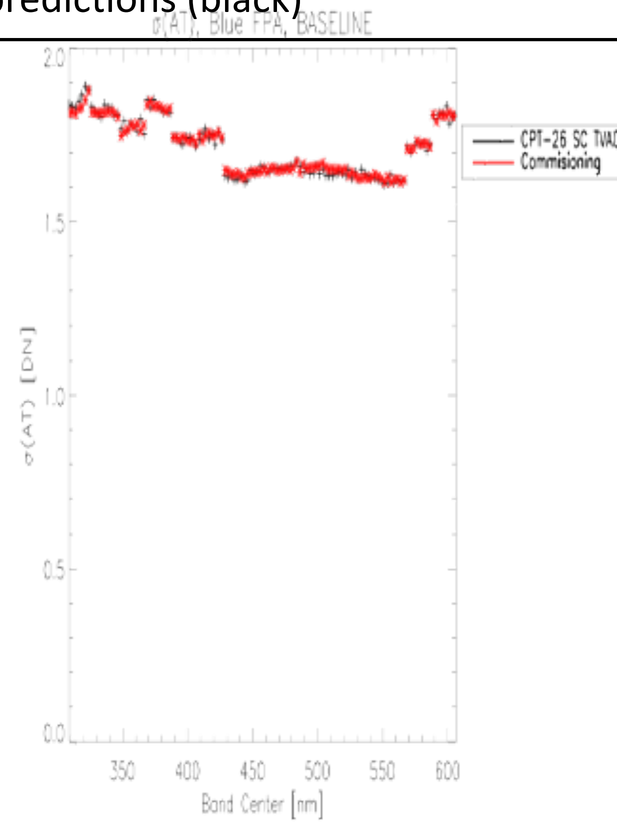




SNR on-orbit: verified

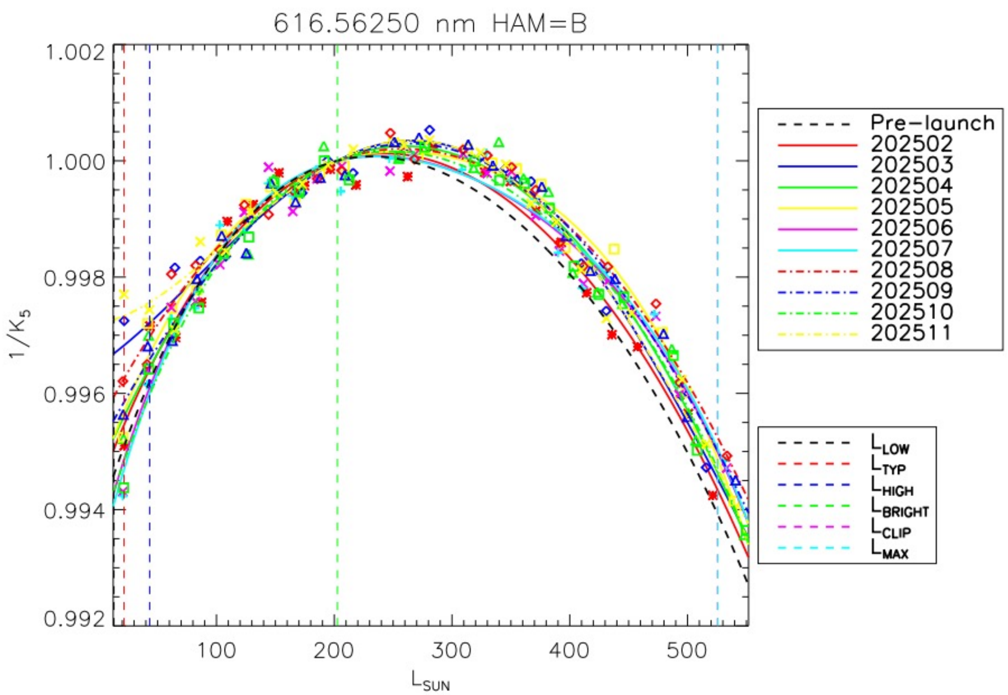
- Left: SNR for on-orbit bright solar diffuser measurements (red) agrees with prelaunch predictions (blue)
- Right: Noise for dark signal (red) agrees with prelaunch predictions (black)

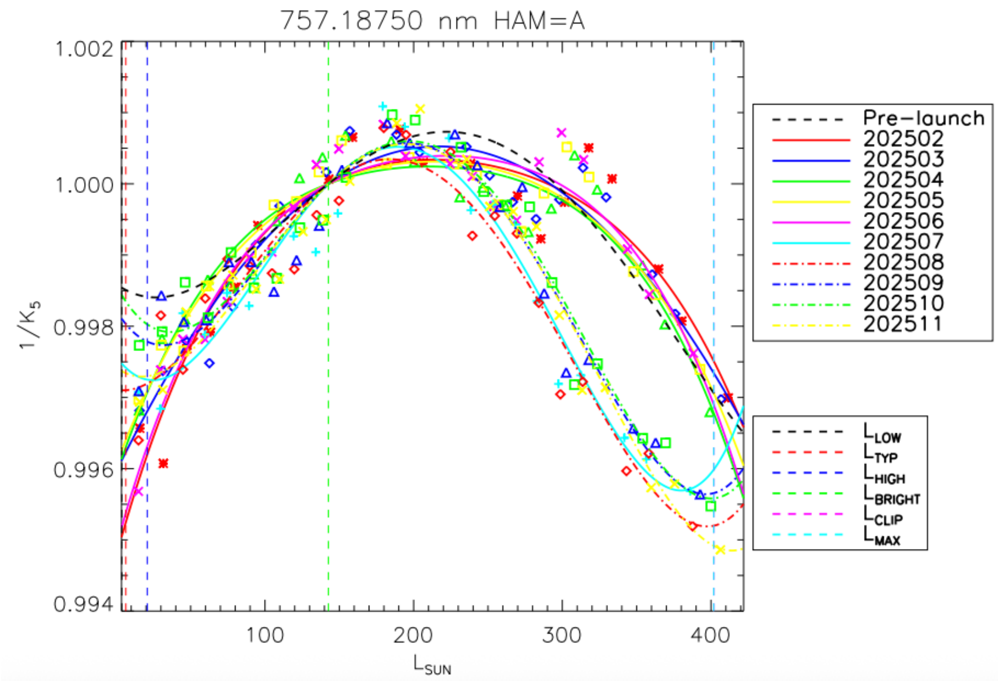




Linearity on-orbit: verified (but changing?)

Linearity measurements as a function of radiance for two bands from the red FPA. The lines are fits to the measurements, the latter are shown as symbols. The vertical dashed lines are different predefined radiance levels.

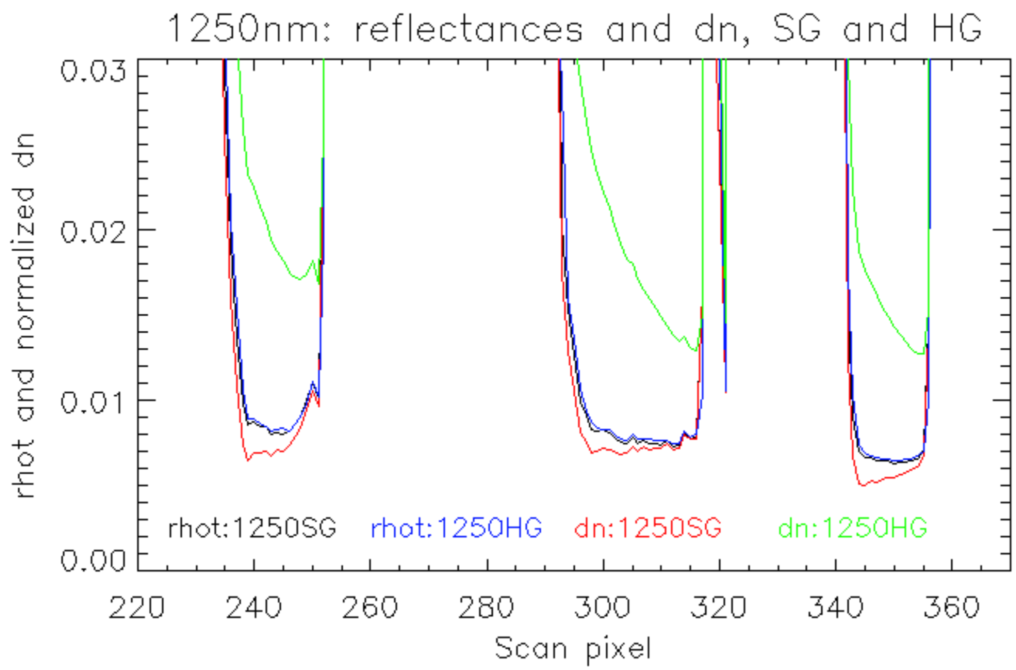




SWIR band hysteresis: verified with cloud scene

- This plot shows measured dn and reflectances for the 1250nm SG and 1250nm HG bands as a function of along scan 1km pixels. The dn (no correction applied) after scan pixel 230 show a large decrease (green line) or a small increase (red line). The reflectances (black and blue lines, hysteresis correction applied) are more stable over ocean, as expected. The SG and HG reflectances are also very consistent relative to each other. The same can be seen after scan pixels 290 and 340.

Agreement after correction (rhot) is excellent considering the magnitude of the correction!



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Lessons learned:

- It is critical to be able to trace requirements from the science product goals to the instrument performance/uncertainty (incl. random vs systematic errors)
- Even significant instrument performance deficiencies can sometimes be corrected with accurate characterization and correction algorithms
- Characterize solar diffuser 'as you fly'
- Lunar measurements are extremely useful for long term trending and instrument characterization (straylight, BBR)
- Redundancy is important (linearity, hysteresis, solar/lunar, lunar sweeps, two solar diffusers)