PACE OCI Pre-launch ETU Spatial Characterization using Time-delay Mode

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Outline

- The Ocean Color Instrument (OCI) overview
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  - BBR (Band to Band Registration)
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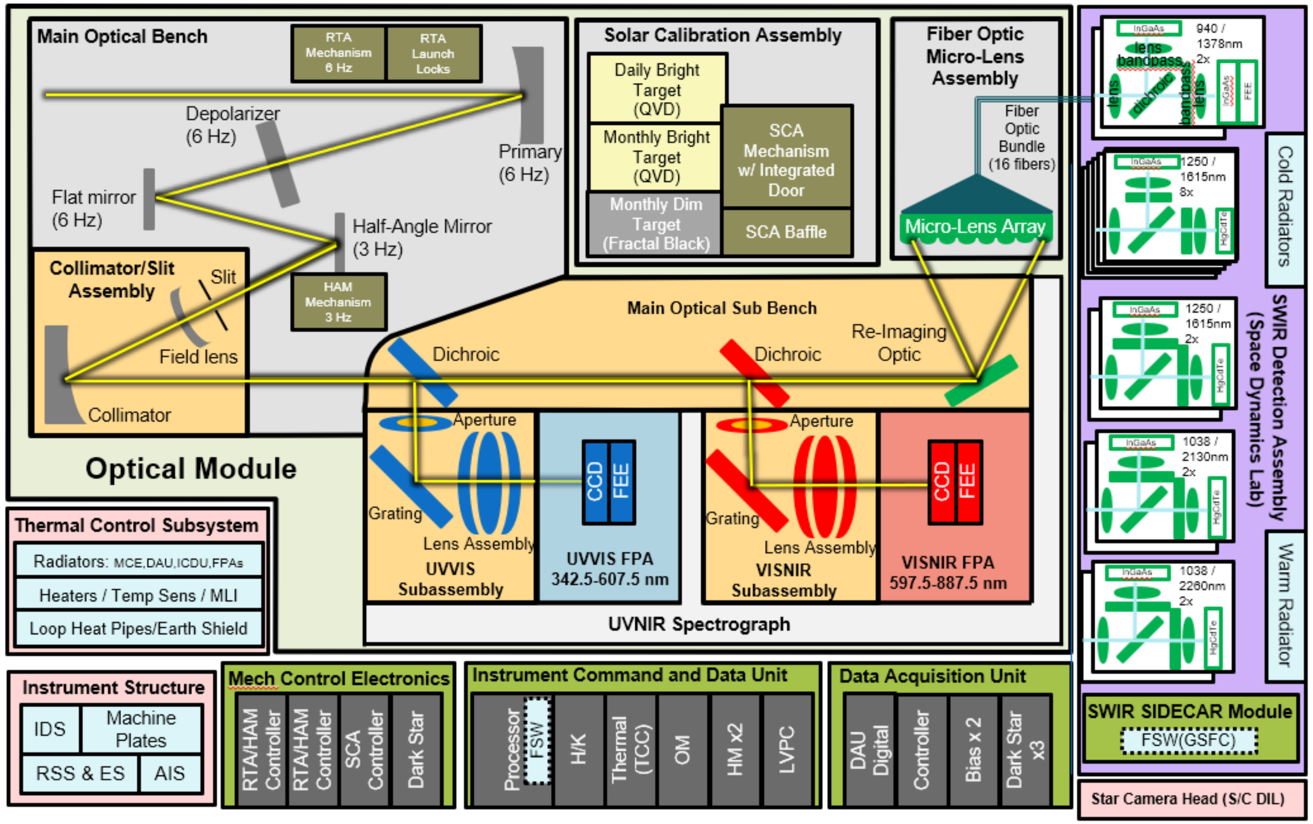
OCI Overview (I)

- **OCI is the primary sensor of upcoming NASA PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission**
- **OCI has a rotating telescope with hyperspectral radiometer**
- **A two-sided Half Angle Mirror (HAM) rotates at half the rate of the telescope**
- **Earth view (EV) range of ±56.5 degree from nadir**
- **Dark view (DV) at approximately 180 degree from nadir is recorded together with the EV data every scan**
- **Two gratings with two CCD detectors cover 340-885 nm with 5nm bandwidth**
- **The SWIR (Short Wave IR) Detector Assembly (SDA) covers 940, 1038, 1250 Standard Gain (SG), 1250 High Gain (HG), 1378, 1615 SG, 1615 HG, 2130 and 2260 nm bands**
- **32 SWIR InGaAs or HgCdTe detectors aggregate into above 9 bands to improve SNR.**
- **ETU (Engineering Test Unit) testing was completed in June 2021 with only red CCD and limited number of SWIR detectors.**



OCI Overview (II)

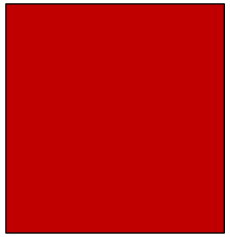
Hyperspectral bands (CCD detectors)

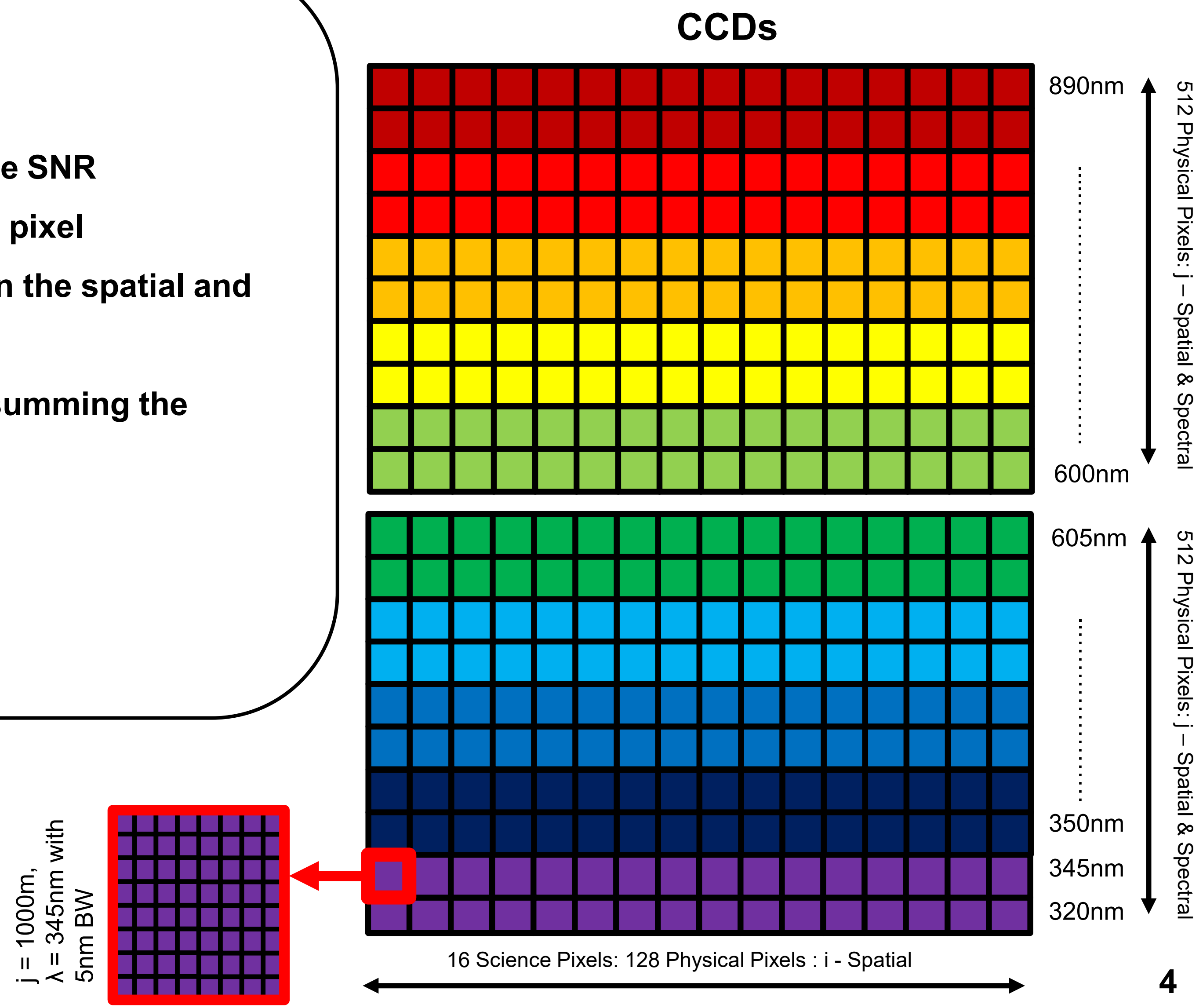
- 128 x 512 physical pixels, 128 for spatial, 512 for spectral
- A science pixel is 8x8 physical pixels aggregated to increase SNR
- 1 km at nadir with 5nm bandwidth, 5nm spacing for science pixel
- Higher resolution is possible using 1,2,4, or 8 aggregation in the spatial and spectral direction independently
- TDI (Time Delay Integration) is used in spatial direction by summing the pixels synchronized with the rotating telescope speed

SWIR bands (SWIR detectors with filter)

- Fiber-coupled multi band filter spectrograph
- SWIR detector size is a science pixel, 1 km at nadir

SWIR

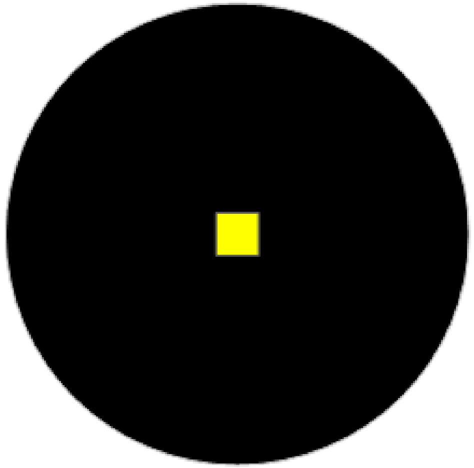




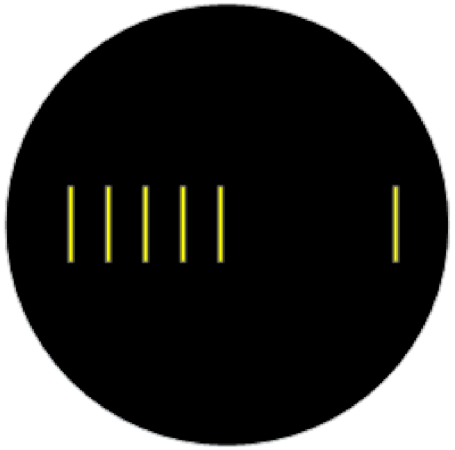
Test Configuration

LSF (Line Spread Function) Bench Optical Table

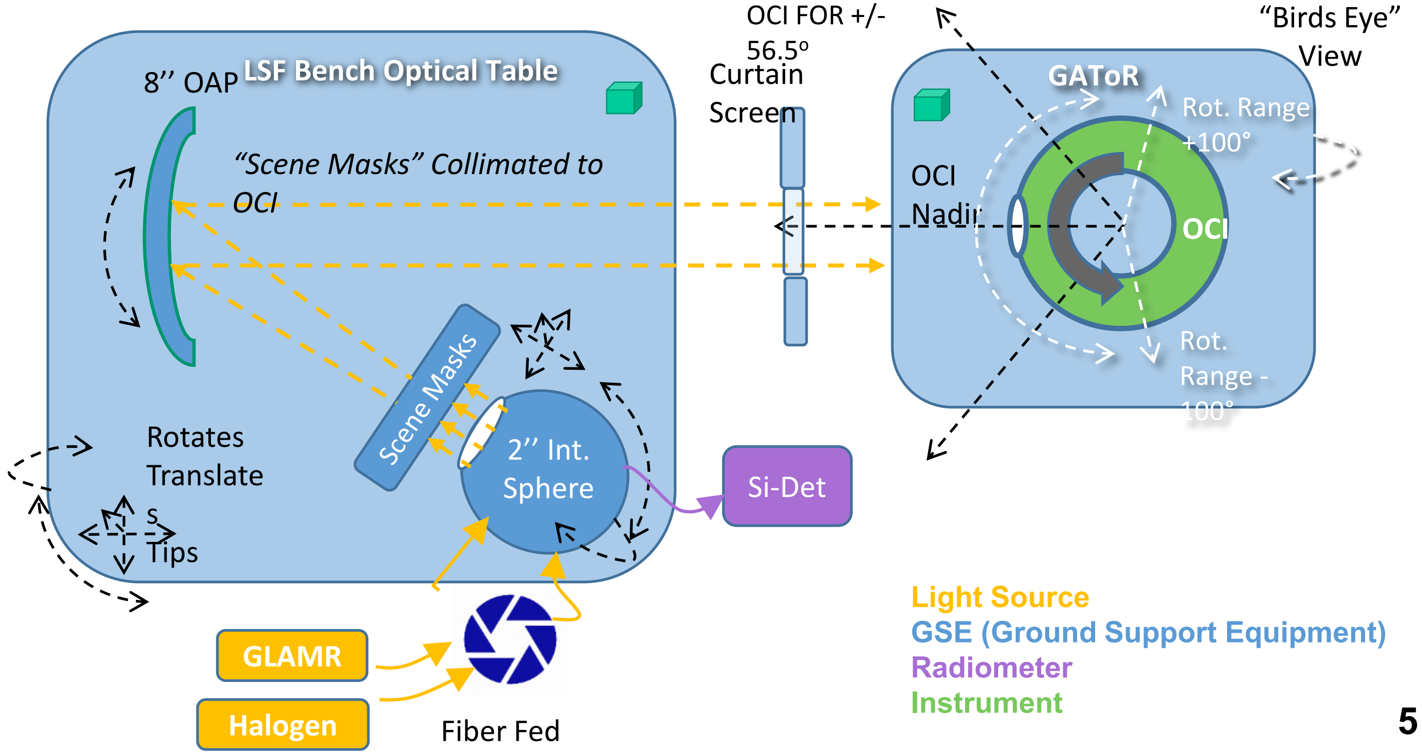
- **Light sources : Halogen lamp or GLAMR (Goddard Laser for Absolute Measurement of Radiance) fed by optical fiber**
- **Scene Masks : SP (Science Pixel) mask or MS (Multi-slit) mask with physical pixel size slits**
- **2-inch sphere and 8-inch OAP (Off Axis Parabola) mirror for collimated scene mask image**
- **OCI on GAToR platform which can rotate and tilt OCI with sub-physical pixel level pointing accuracy**



SP mask

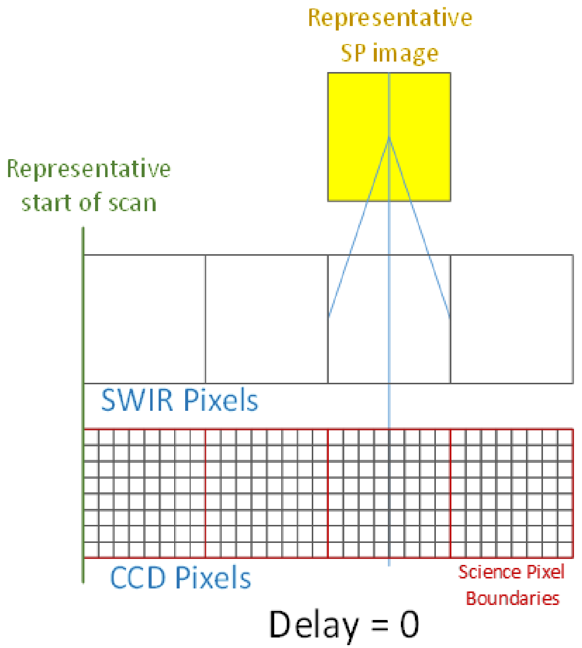


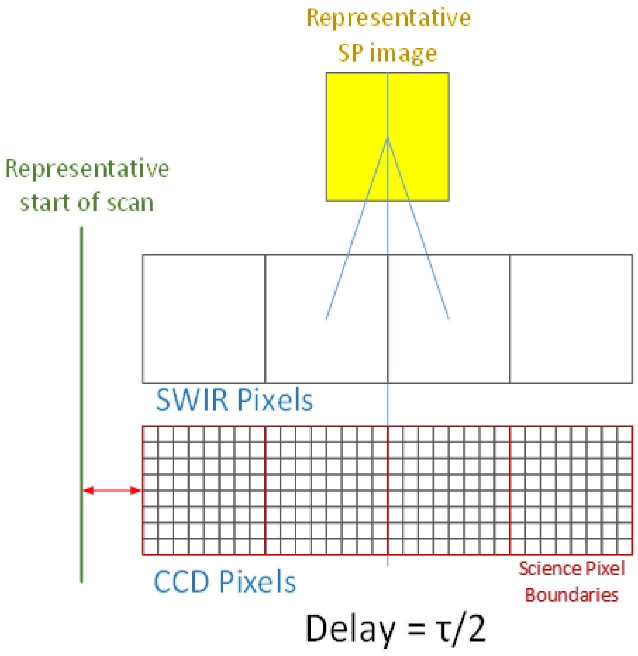
MS mask



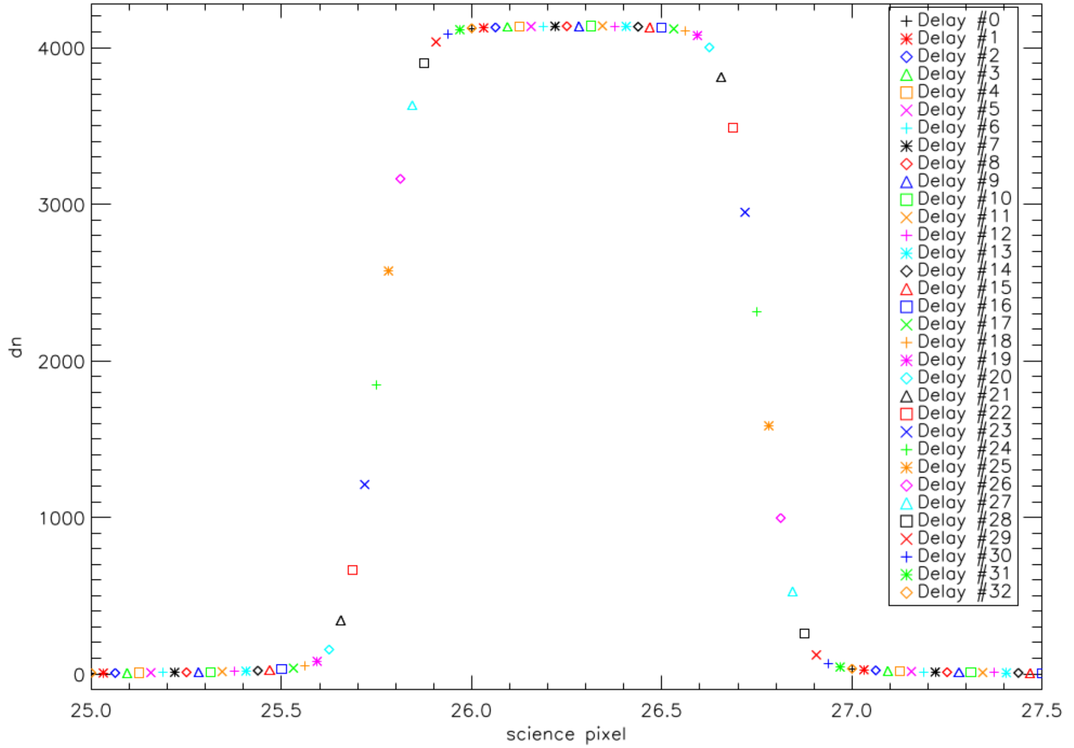
Time-delay mode

- OCI relies on the precise timing between its rotating telescope and detector assemblies
- When timing is synchronized, the earth observation is effectively stationary scan to scan for short period of time imaged by the OCI IFOV (Instantaneous Field of View)
- Assuming a science pixel image period of τ, if OCI inserts $\tau/2$ time-delay then OCI observes half science pixel shifted image as the below left two figures
- For ETU testing, the increments of 1/4 physical pixel delay (1/32 science pixel delay) steps were used. The below right plot shows how the different time-delay collects are combined into a PSF. Note that the same symbol/color have the 1 science pixel spacing.



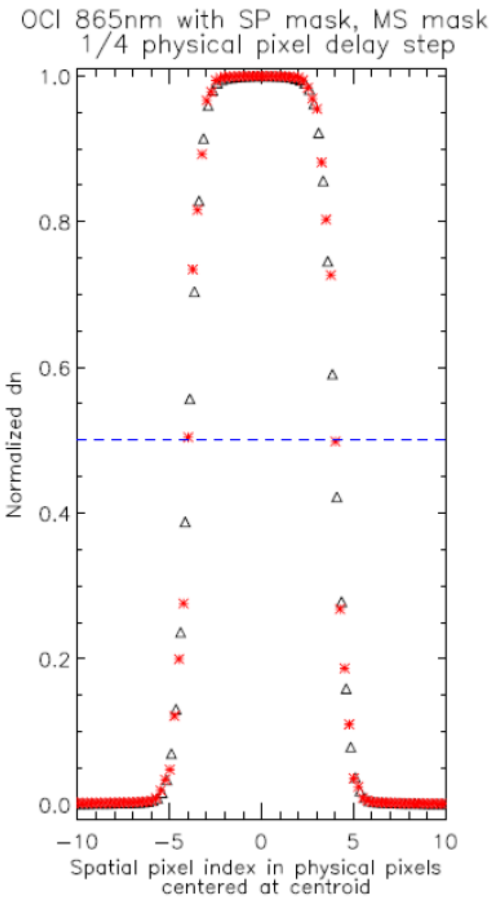


(CCD step 32, SWIR step 16)

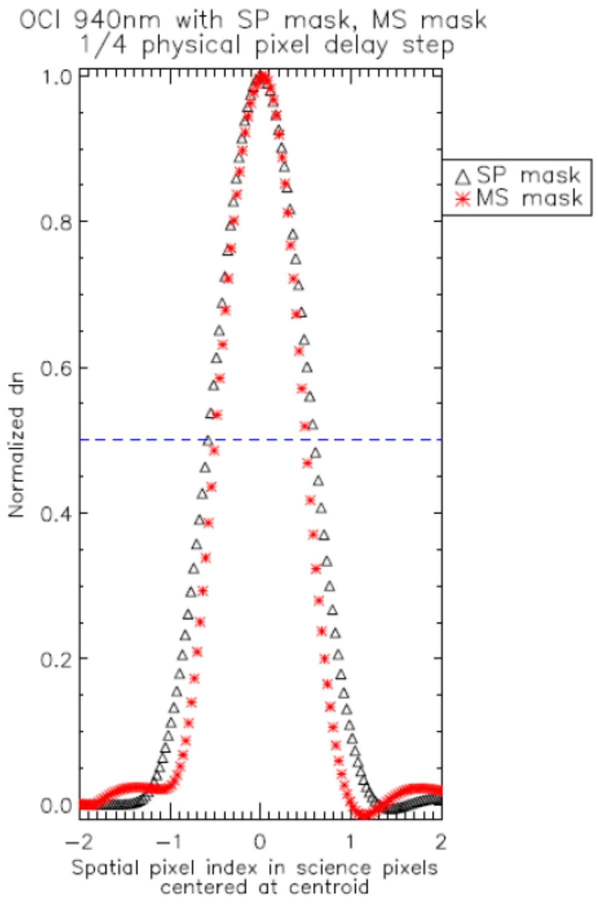


Data Analysis

- **Each delay-step measurement is collected 35 seconds and provide over 100 scans per HAM side**
- **Each delay-step measurement is processed by subtracting the average digital number (DN) of the dark view from the Earth view DN :** $dn = DN_{EV} - \overline{DN_{DV}}$
- **SP mask light source provides bigger IFOV measurement than MS mask because of a wide input source as shown in the right figure for SWIR band but CCD band does not show big difference because of small detector size**
- **MS mask is used for calculations of spatial PSF (Point Spread Function), IFOV, MTF (Modulation Transfer Function), and BBR (Band to Band Registration) due to narrow slit size of MS mask**
- **The last isolated slit of MS mask is used as a point light source**
- **SWIR hysteresis (the SWIR detectors' relative slow signal recovery) is shown in the right plot: the residual signal after the maximum signal response for SP mask and the residual signals before/after the maximum signal response for MS mask due to the initial 5 physical pixel slit responses**
- **For the flight unit test, a one physical pixel slit mask will be used for time-delay measurements to avoid the residual signal from the first 5 slits of MS mask**
- **For flight unit test, a SWIR hysteresis correction method is being developed and will be applied to the flight SWIR data**



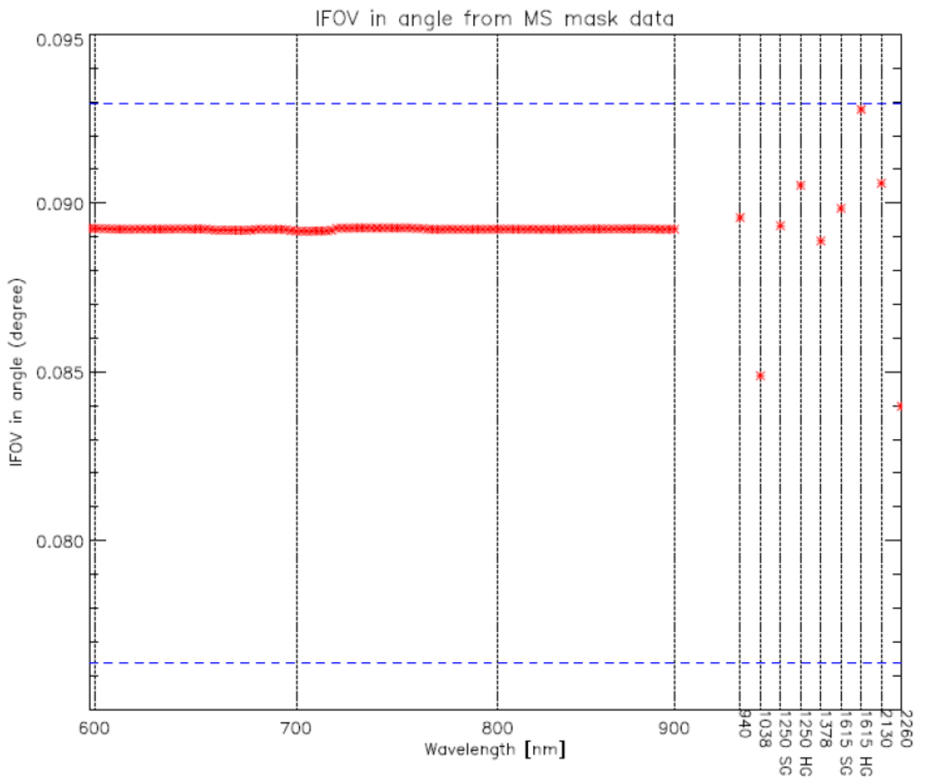
CCD band
(865 nm)



SWIR band
(940 nm)

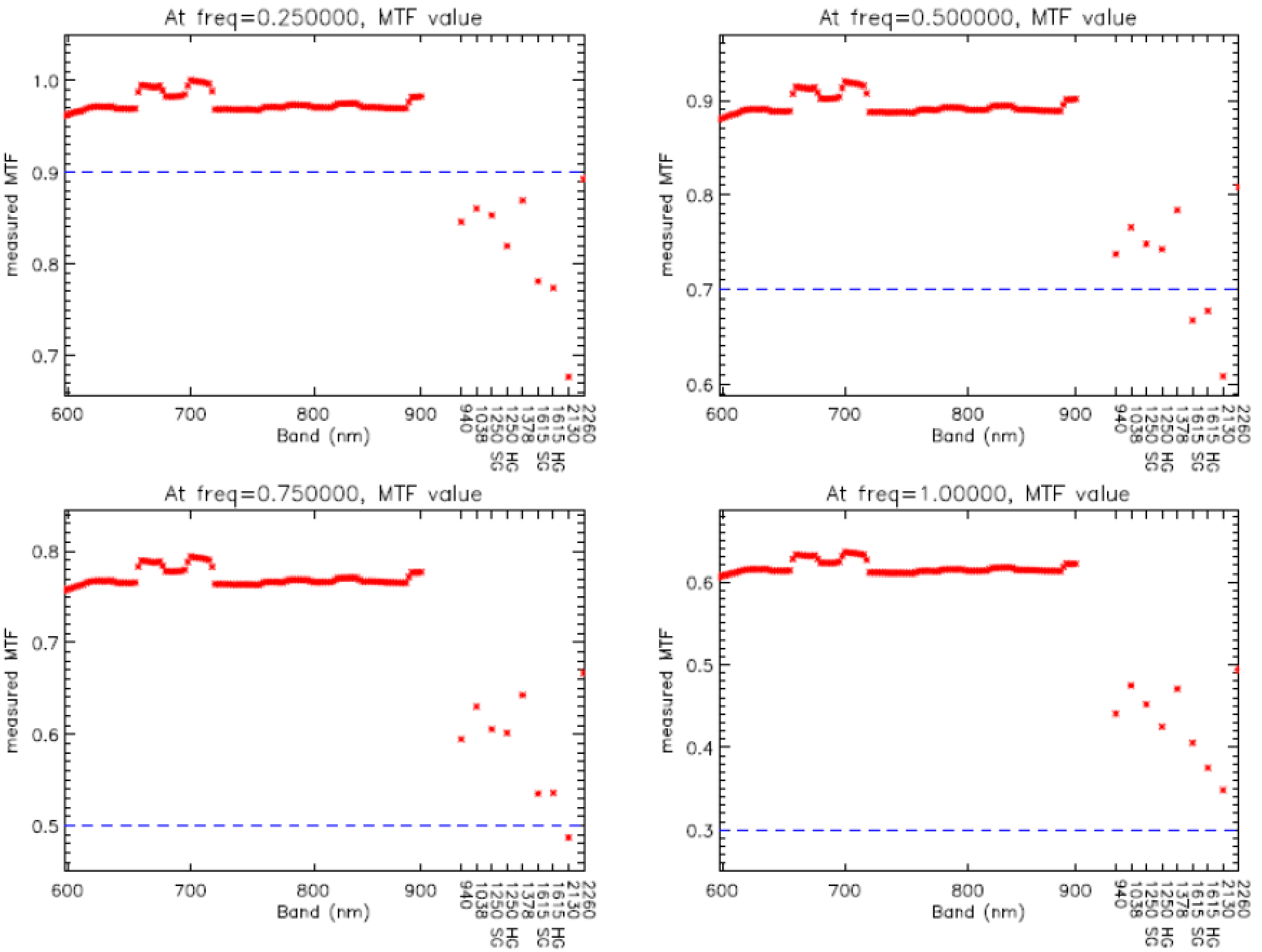
Results : Spatial PSF and IFOV

- **PSF is the response of an imaging system to a point source**
- **IFOV is calculated from a one science pixel PSF's full width half maximum (FWHM)**
- **FWHM is the distance between half maximum positions of the PSF in angle**
- **PSF is calculated by aggregating 8 of OCI's physical pixel responses from MS mask to make 1 science pixel response because OCI's requirements for IFOV, MTF, and BBR are based on science pixel response**
- **Right plot shows the calculated IFOV values for all red CCD bands and SWIR bands, with the IFOV requirements by blue dashed lines.**
- **Each SWIR detector shows a different IFOV, but all are within the required range from 0.076 degree to 0.093 degree**



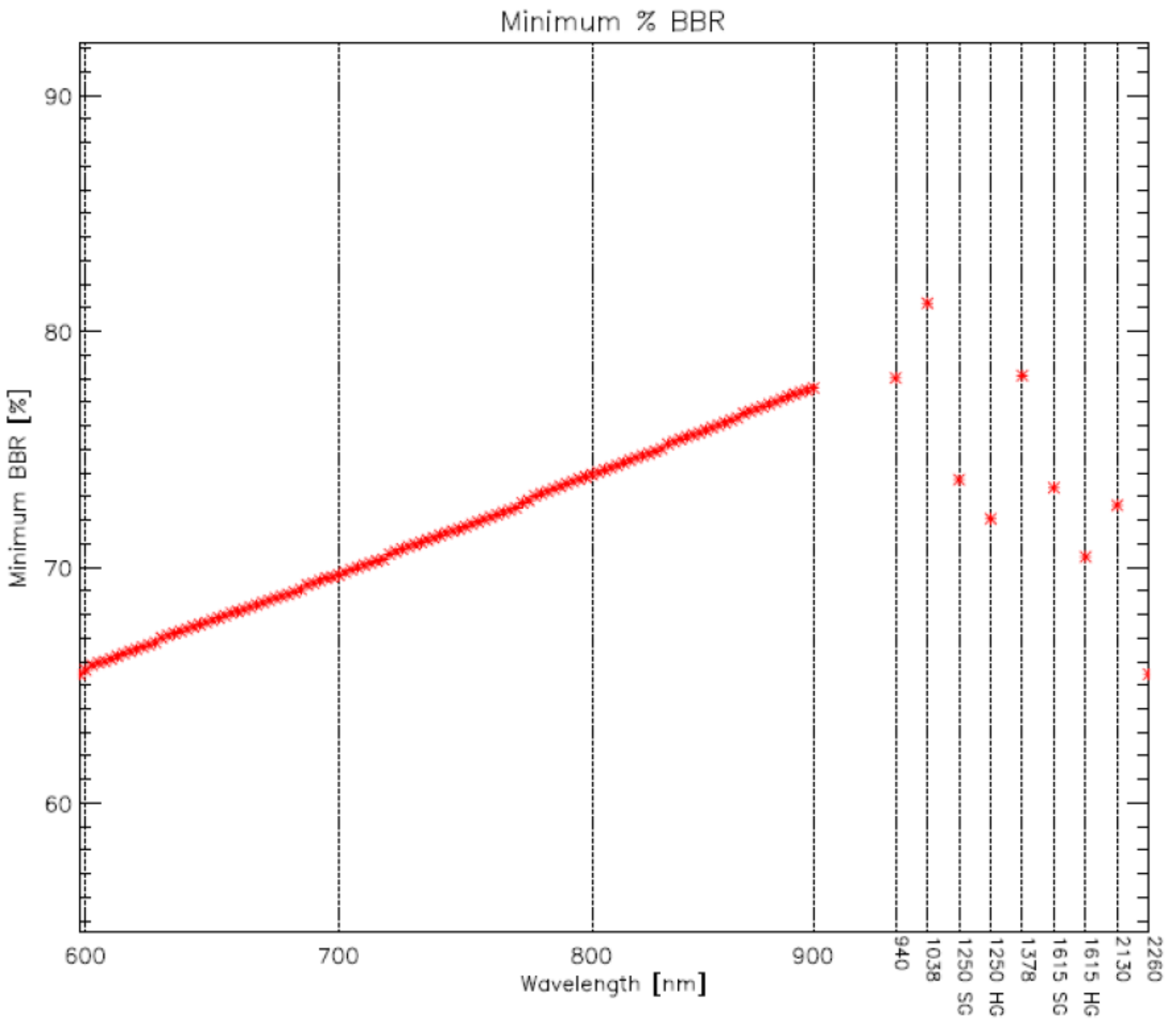
Results : Spatial MTF

- MTF is calculated from the normalized Fourier transform of the PSF
- OCI's MTF requirement is measured at specific frequency ratios: 0, 0.25, 0.5, 0.75, and 1
- The spatial frequency unit for the MTF requirement is in fractions of Nyquist frequency (frequency/Nyquist frequency)
- MTF is normalized at a frequency of 0 which means that MTF at zero frequency is always 1
- Right plot shows the calculated MTF values at frequency ratios of 0.25, 0.5, 0.75, and 1 with requirement values shown by blue dashed lines and the requirement is to be above the blue dashed lines.
- All VIS-NIR bands meet the requirements, but many SWIR bands do not meet the requirements because the SWIR hysteresis causes a long tail of unrecovered signal
- For flight test, MTF values will be calculated from single physical pixel slit mask to reduce SWIR hysteresis



Results : Spatial BBR

- OCI's spatial BBR requirement states that the BBR between any two bands shall be greater than 80% of one IFOV, which is very close to 1 science pixel size
- The center of the PSF for each band is calculated and used to estimate the BBR
- The right plot only shows the minimum % BBR for each band, i.e., the worst BBR between one band and all other bands.
- Without SWIR bands, VIS-NIR (red CCD) bands have very good BBR (more than 87%)
- The SWIR bands have independent detectors and readout electronics with detector specific delay so there are significant differences within the spatial SWIR band centers
- For flight unit testing, OCI will be programmed such that the CCD centers are as close as possible to the centers of SWIR bands, but a few SWIR bands still may not meet the BBR requirements



Conclusion

- The OCI ETU test showed the usefulness of time-delay mode for spatial sub-pixel level measurements and successfully demonstrated that time-delay mode worked properly as planned
- Time-delay mode was an especially useful test mode for SWIR bands due to their 1 science pixel native resolution
- For the upcoming flight unit test campaign, time-delay mode will also be used to characterize along-track PSF and MTF using a slanted slit scene mask