HySICS Balloon-Flight Performance and Inter-Calibration Expectations for CPF-HySICS

CLARREO Pathfinder Inter-Calibration Workshop

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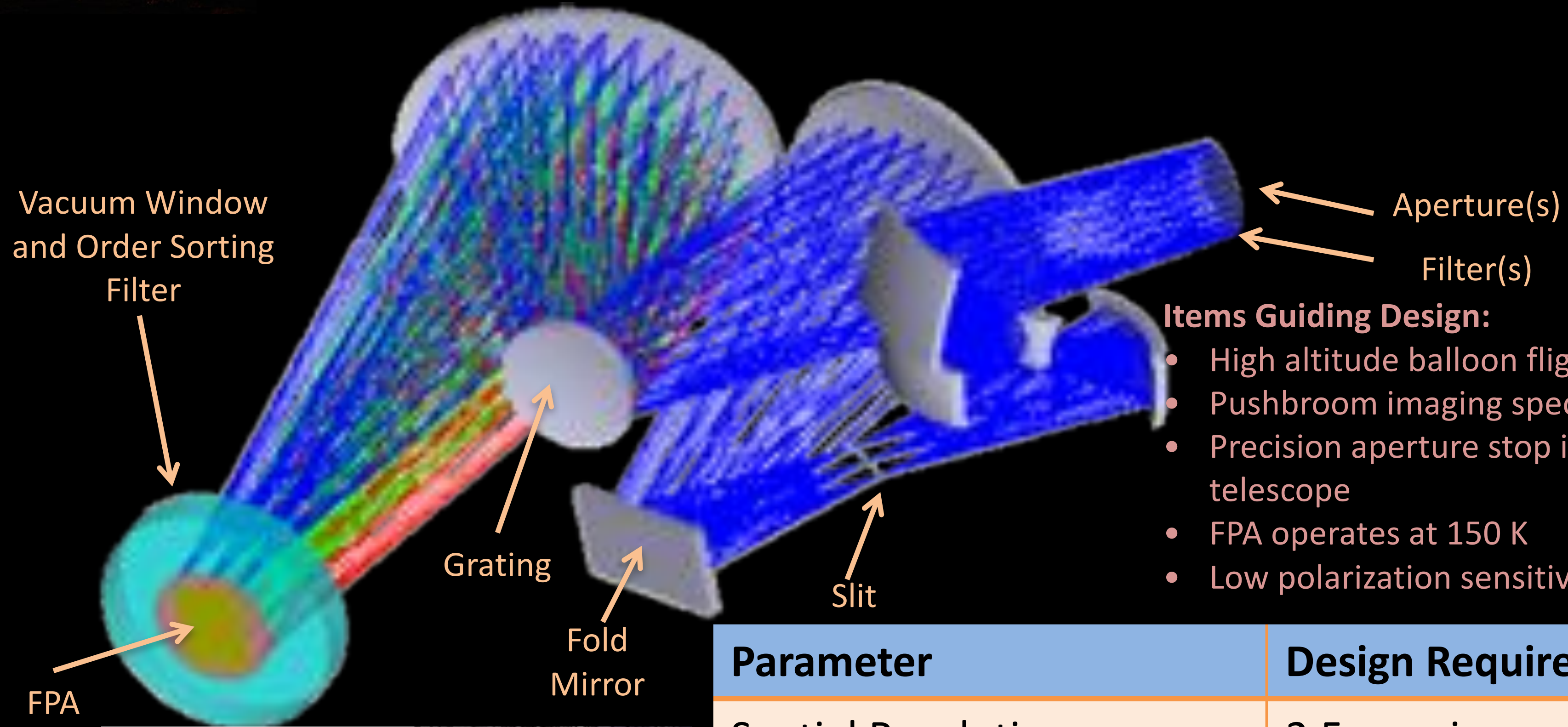
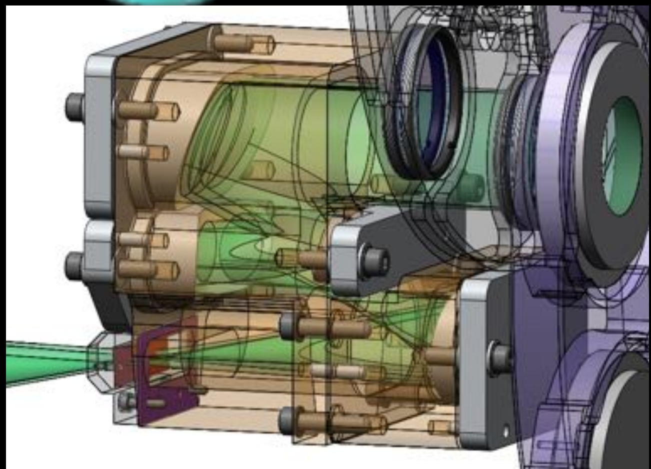
HySICS Instrument Optics

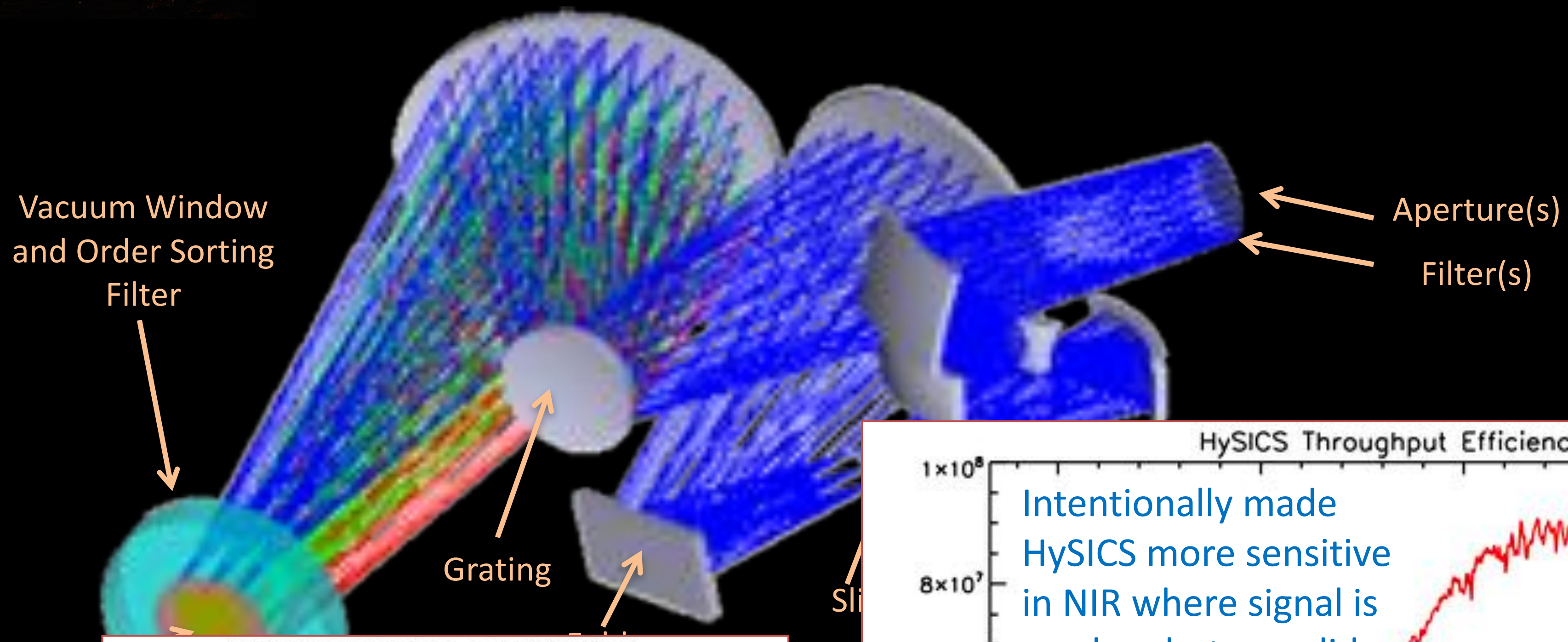


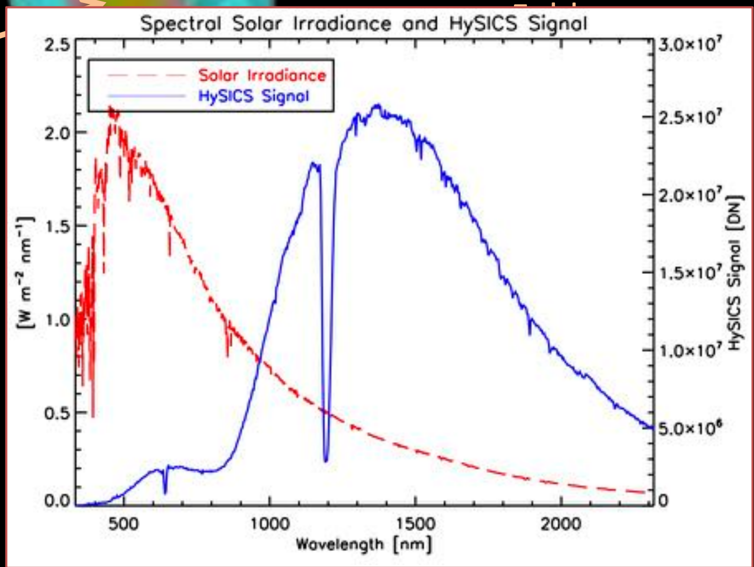
Items Guiding Design:
- High altitude balloon flight environment
- Pushbroom imaging spectrometer
- Precision aperture stop in front of the telescope
- FPA operates at 150 K
- Low polarization sensitivity

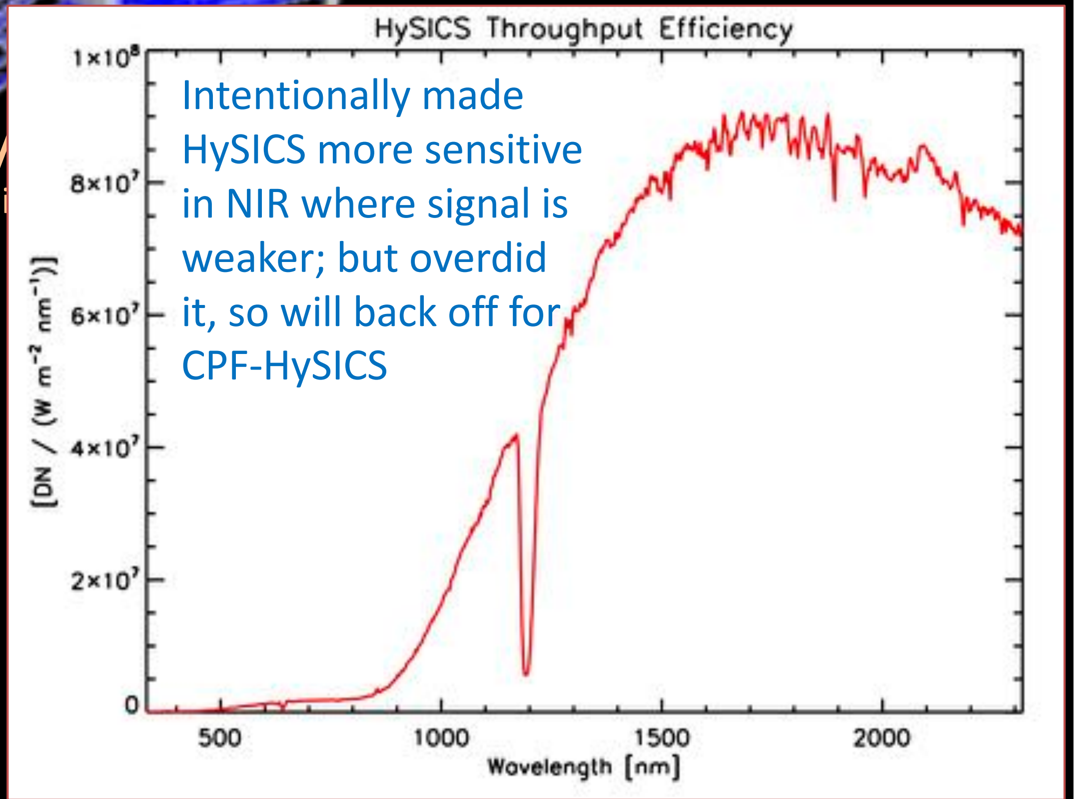


Parameter	Design Requirement
Spatial Resolution	2.5 arcmin
Field of View (cross track)	10°
IFOV	0.02°
Wavelength Range	350-2300 nm
Wavelength Resolution	6 nm, constant, Nyquist
Aperture	0.5, 10, 20 mm diameter

Radiometric Efficiency Calibrated On-Orbit



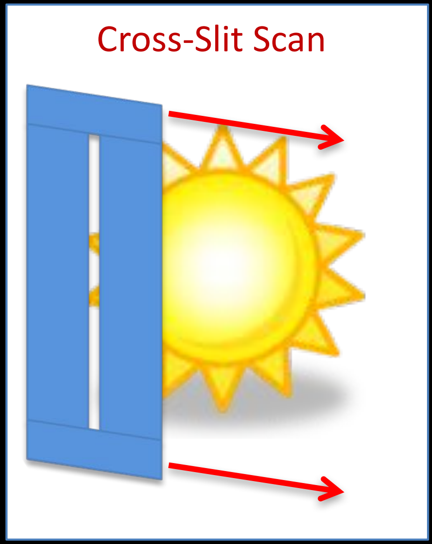


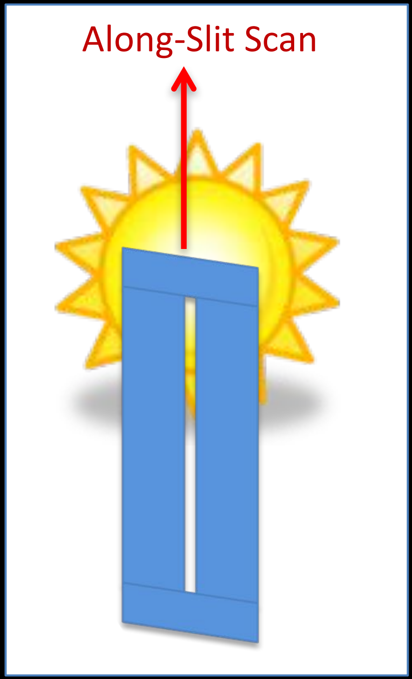


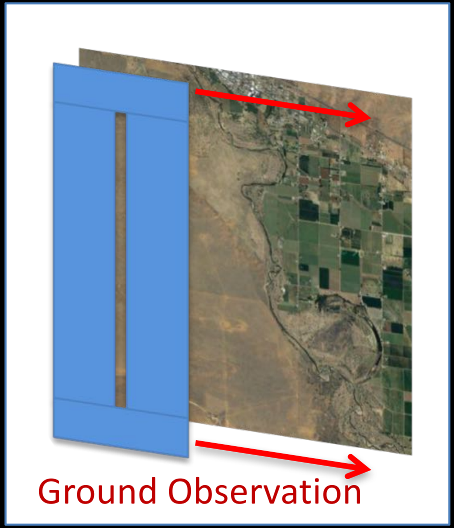
Science and Calibration Observations

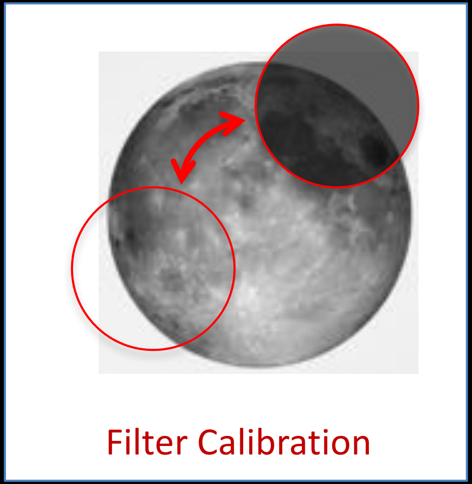
- Ground Observation
  - Acquire hyperspectral data from ground scenes
- Solar Irradiance Measurement (Cross-Slit Scan)
  - Measure spectral solar irradiance by integrating images after cross-slit scan of solar disk
- Flat-Field Calibration (Along-Slit Scan)
  - Scan slit smoothly along diameter of solar disk
  - Requires pointing accuracy of ~15 arcsec
- Calibrations using Moon
  - Filters: Place slit across Moon and acquire measurements with and without filters
  - Flat-field: along-slit scan using large aperture
    - *Drives yet more stringent pointing requirements*

Observations not possible through variable atmosphere, so need >30,000 m altitude









Expected Space-Flight Improvements

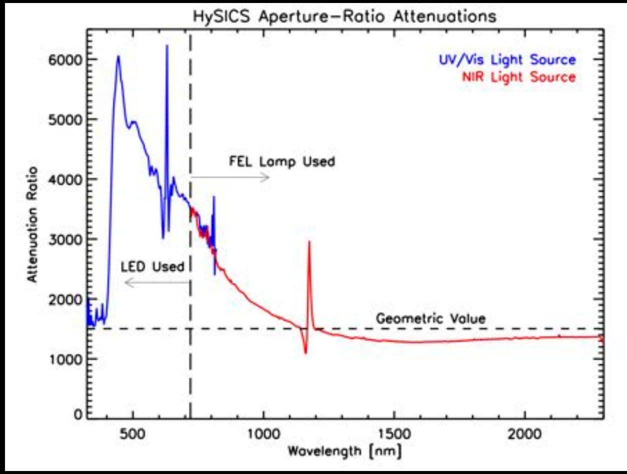
- Ability to acquire lunar calibrations at better phase angles
  - Will improve flat-field uncertainties using Earth-viewing optics
- Improved thermal stability
  - Provided by second cryo-cooler and more stable thermal environment
    - With partial air pressure, balloon environment is more difficult to control
  - Reduces background blackbody drifts and FPA sensitivity to variations
  - Improves calibration durations of FPA, imaging optics, and spectral scale
- <u>Much</u> broader spatial and temporal coverage

- But there are some added *un*-improvements in ISS implementation
  - Severe limitations on frequency of solar calibration opportunities due to occulting ISS structure
  - More high-frequency pointing jitter
  - Occasional non-observing times due to special ISS activities

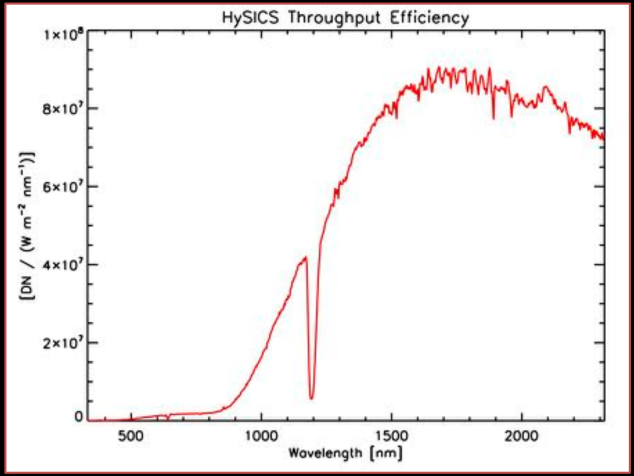
Planned Instrument-Specific Improvements

- Improved grating
  - Smoothly-varying dual-region design provides higher efficiencies in visible
  - Non-discretely regioned grating improves aperture-ratio corrections and solar flat-fields since grating efficiency using small-aperture is very different from that using large Earth-viewing aperture
  - Fused silica holographic grating reduces scatter
  - Lower induced polarization predicted

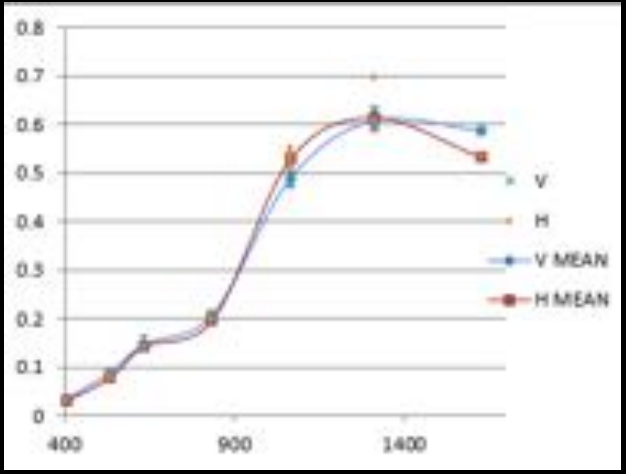
Aperture-Ratio Corrections



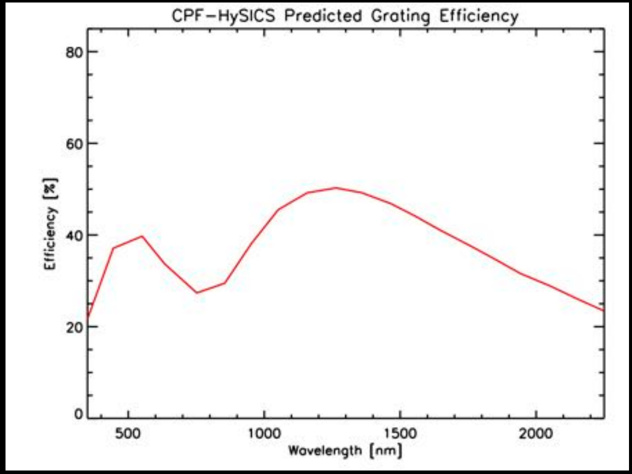
HySICS Net Efficiency



HySICS Grating Efficiency



CPF-HySICS Predicted Grating Efficiency



Planned Instrument-Specific Improvements

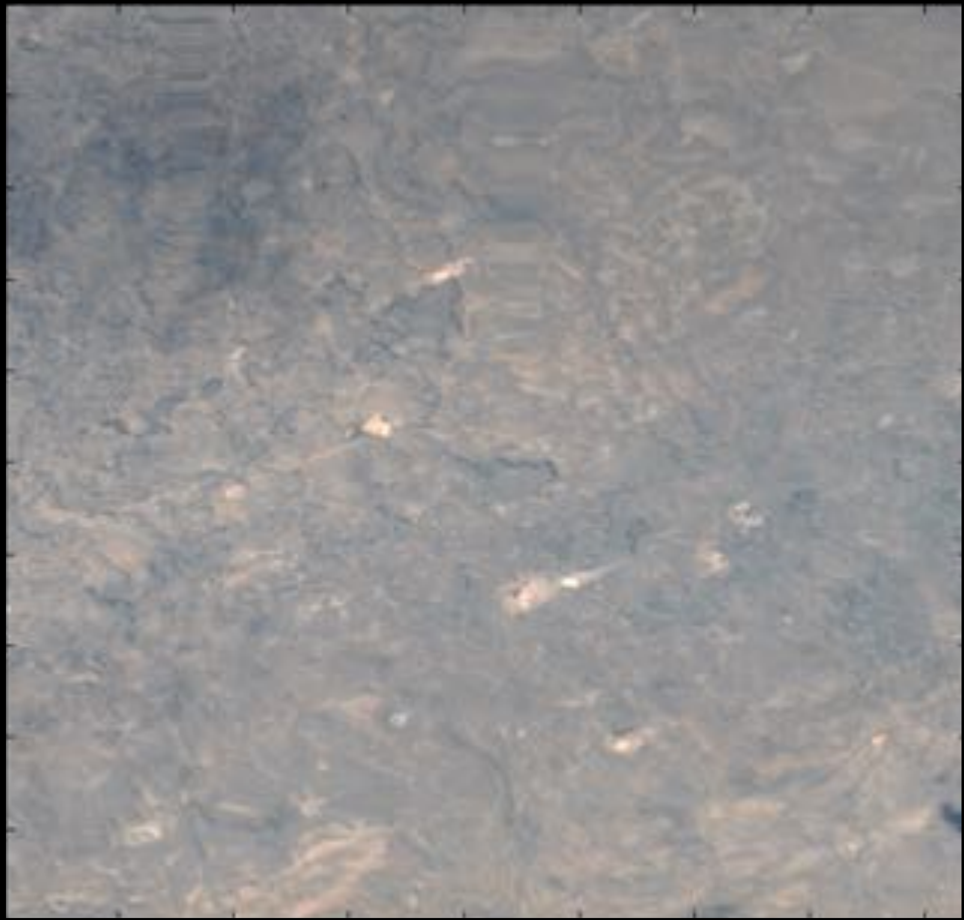
- Increase intrinsic FPA gain for improved ground-scene sensitivity
  - Increase pixel-well depth to reduce shot noise ~2.7x
  - Raise overall FPA gain 10x to better fill pixel wells from ground scenes
  - Define electronic gains separately for four different spectral regions to better flatten observed solar-signal levels
  - Include dark columns for better read-noise and dark measurements
- Improved lab calibrations for lower aperture-ratio uncertainties

Planned Instrument-Specific Improvements

- Eliminate spectral filters
  - Enabled by sufficiently broad and reproducible FPA linearity
  - Reduces mass, complexity, and on-orbit calibration requirements

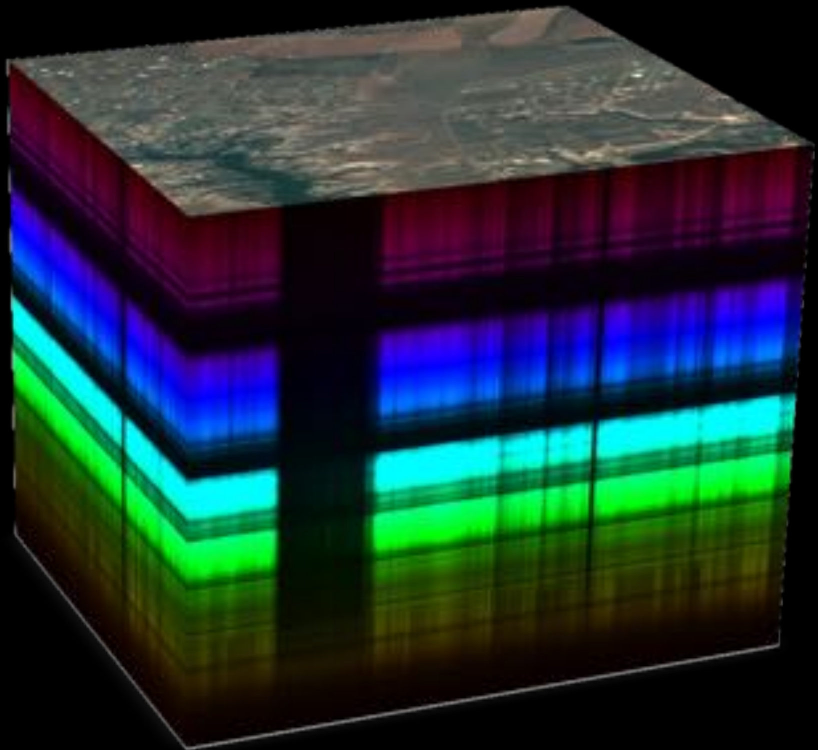
HySICS Ground Scans from Flight #2

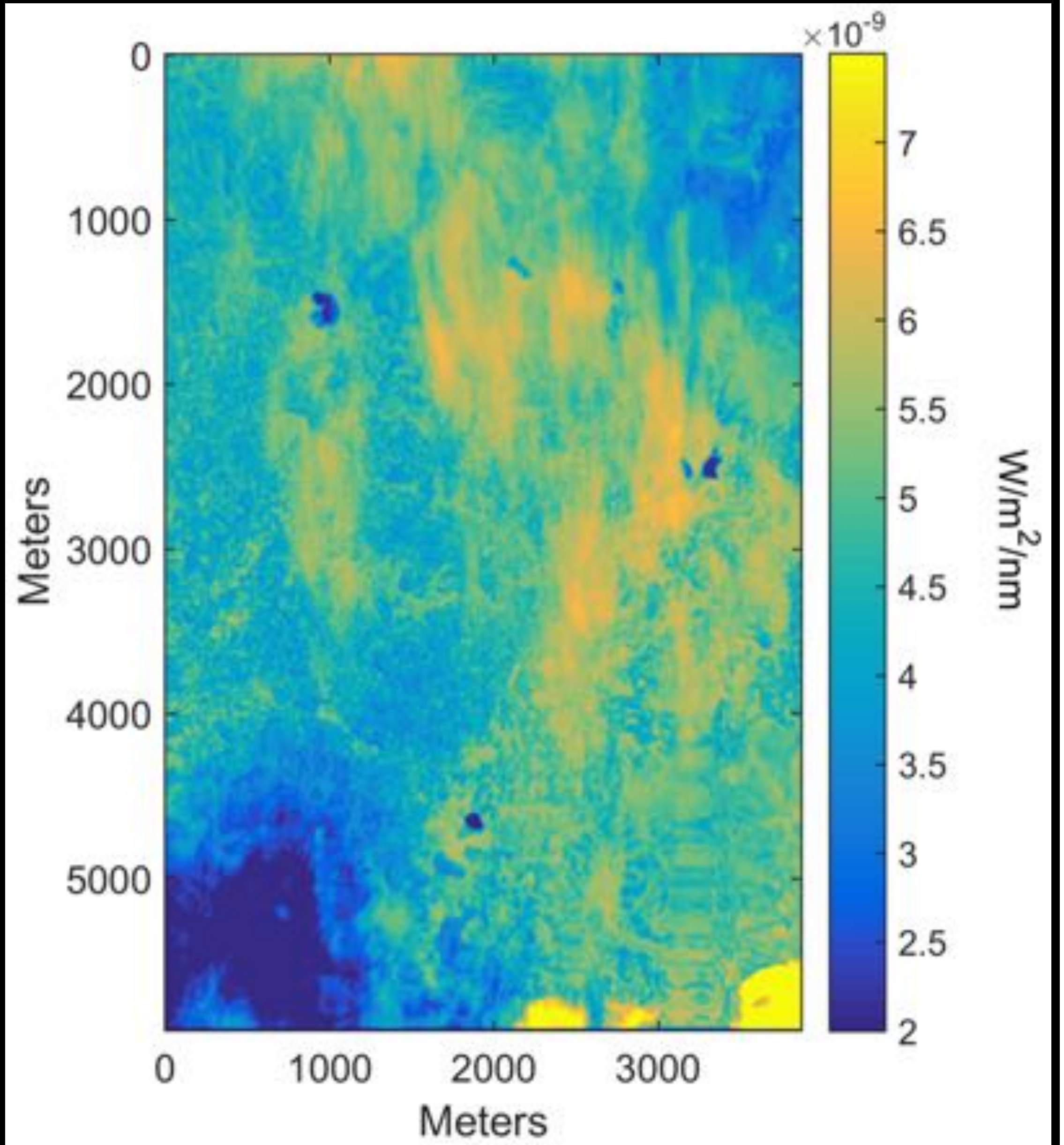
- Will have radiometrically-calibrated data cubes available for SDT



End Result – Radiometric Ground Image

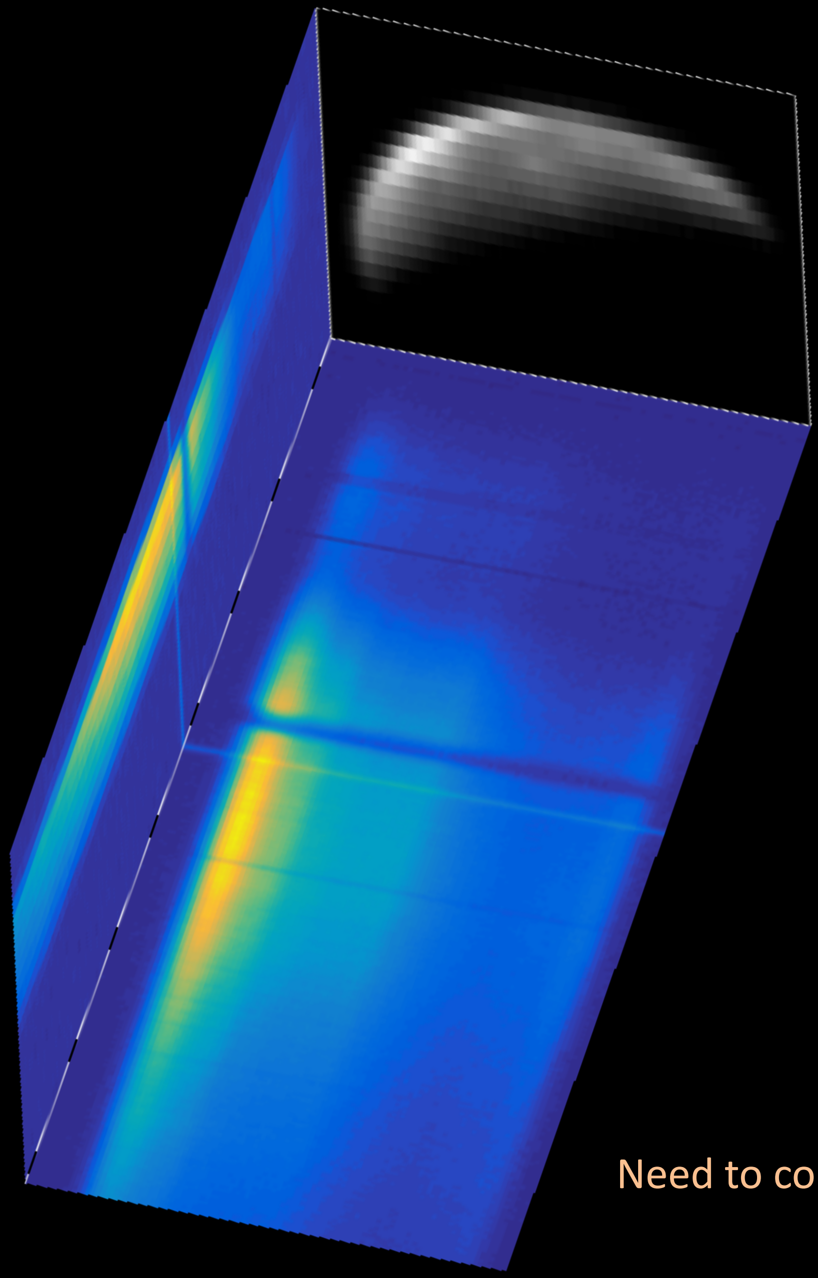
- Applying spectral solar irradiance calibrations to the HySICS data enables radiometrically-calibrated data cubes





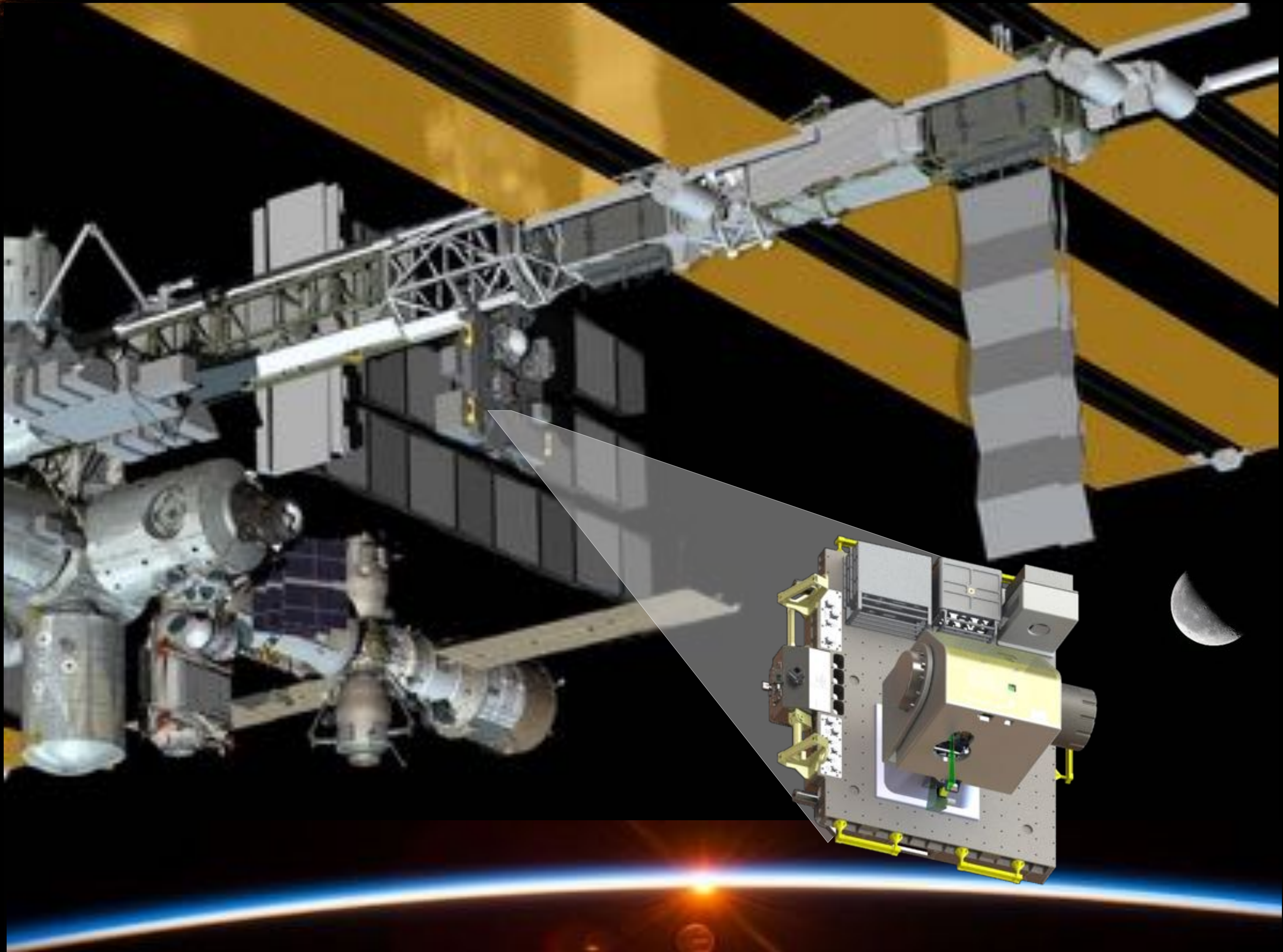
Earth Limb Scans Acquired from HySICS

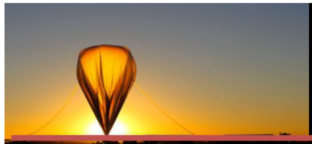
Lunar Data Cube from HySICS Flight #2



Need to compare to ROLO values

CPF-HySICS Integrated on ISS





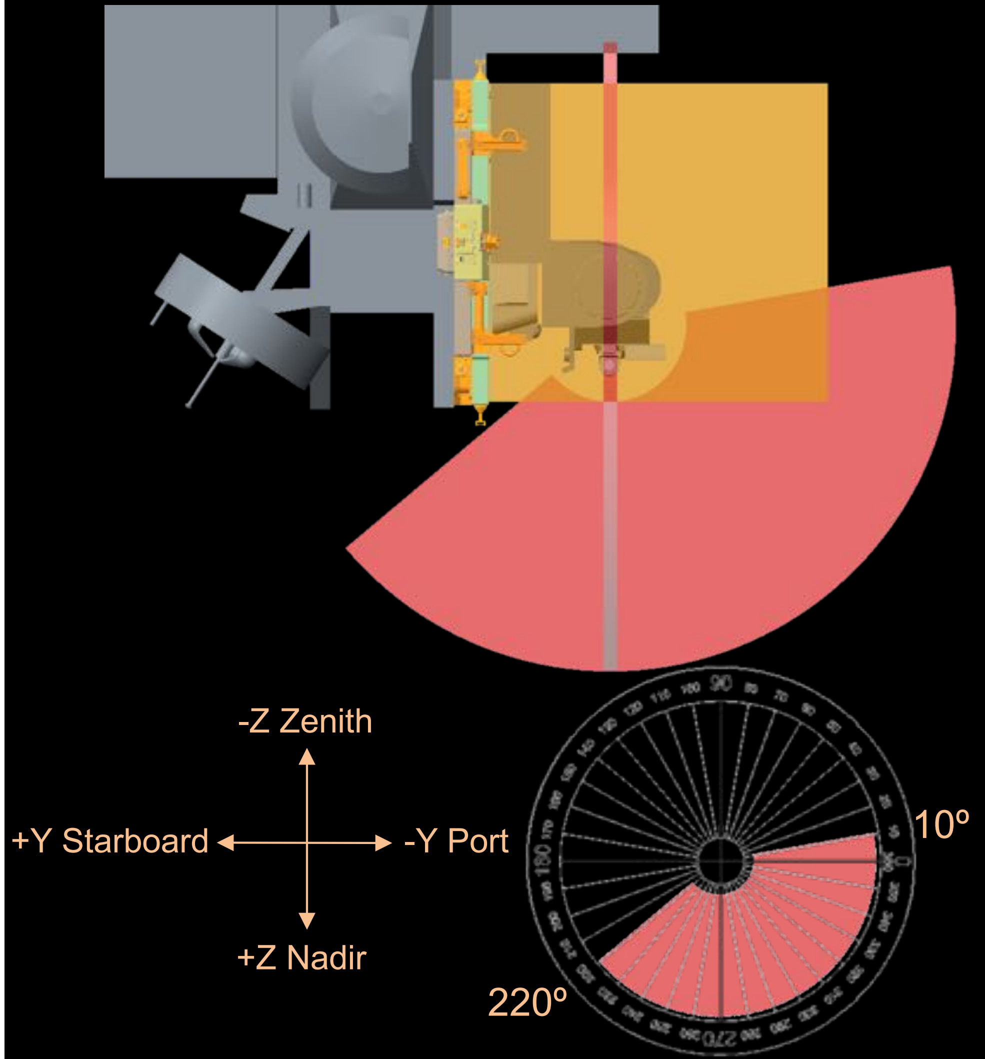
Target Inter-Calibration Options

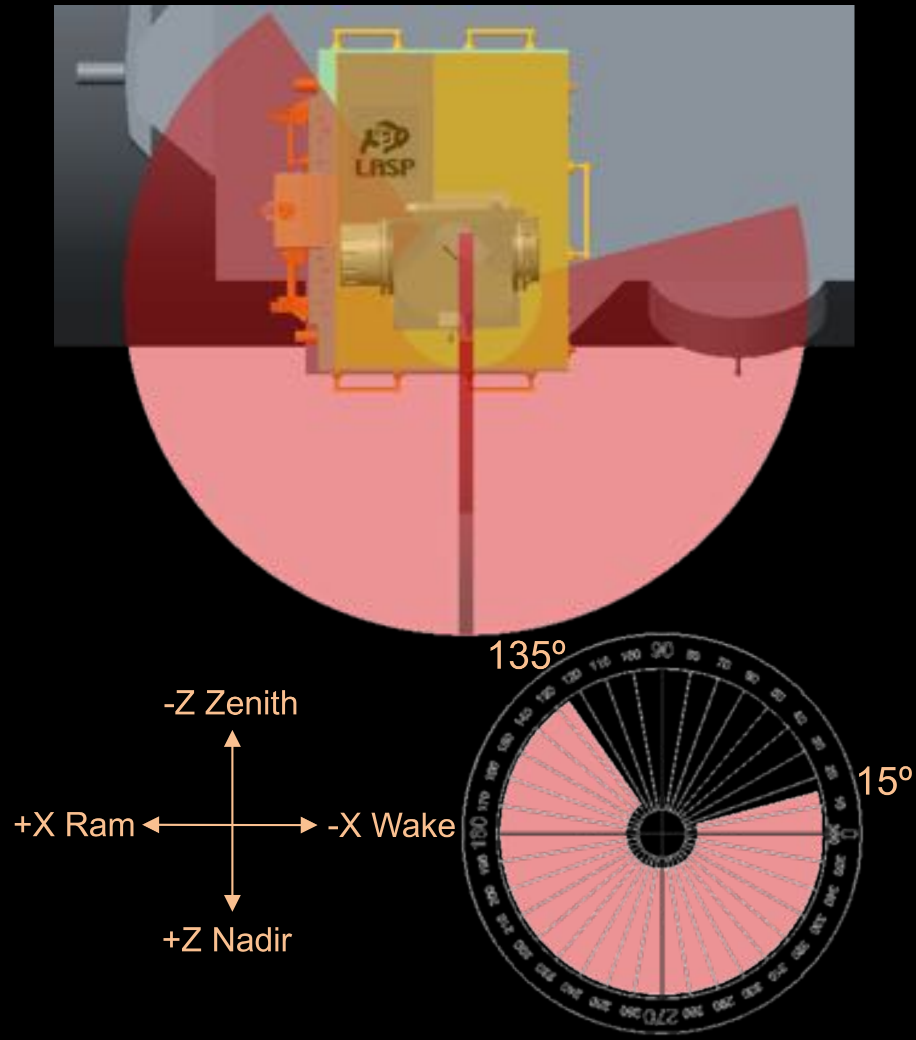
- Ground
  - Continuous spectral coverage over spatial- and spectral- range and resolution of instrument
  - Scenes viewable from ISS orbit
  - Many target scenes will likely already be part of normal operations
    - But coordination recommended for simultaneous observations
- Moon
  - Signal most favorable near 0° phase
  - Few limitations on observing times
- Sun
  - Measurements part of frequent HySICS calibrations
  - May be able to help transfer solar radiance measurements from another instrument to on-orbit irradiance reference

CPF-HySICS Ground Observations

CPF-HySICS Field of Regard

- HySICS mounted on ELC-1 Site 3
  – Analysis does not include occultations by other ISS components





CPF-HySICS Pointing Accuracies

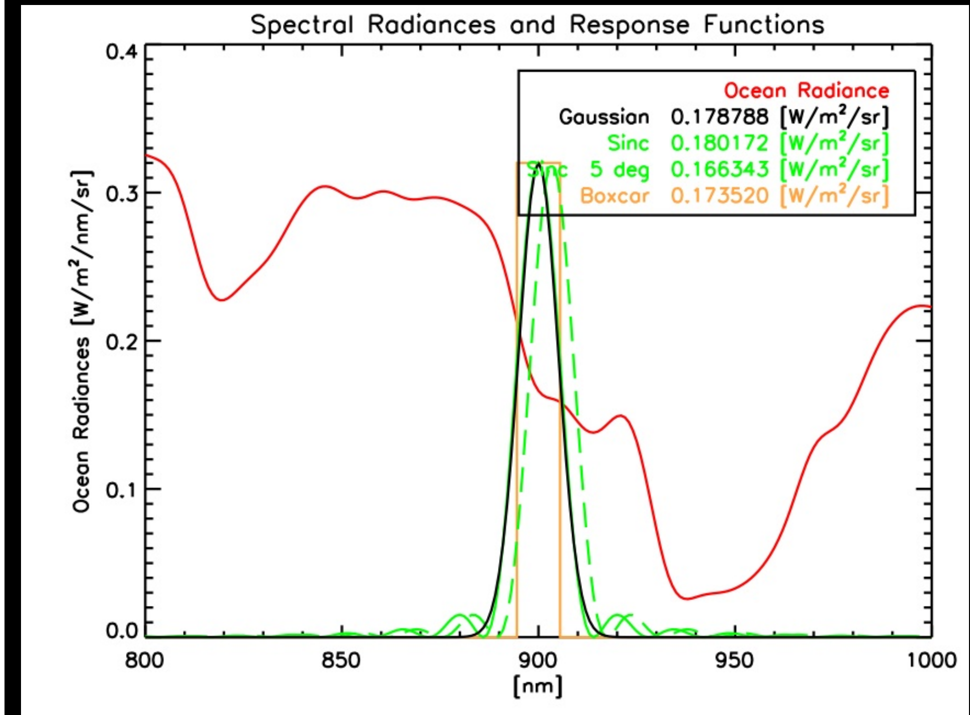
- IMU helps compensate for low- and mid-range frequency ISS jitter
  - Inertial measurement unit (IMU) provides 100-Hz angular-rate feedback to stabilize instrument platform on ISS to <10% pixel blur (~30 m on ground)
- CPF-HySICS Pointing System is Alt/Az
  - Cannot accommodate roll about instrument boresight
  - Can slew at ½° /second for inter-calibrations

- **Ground observations**: Geolocation knowledge <150 m (1σ) from star tracker in conjunction with ISS attitude knowledge
  - Star tracker provides 5-Hz attitude knowledge to 3 arcsec (1σ)
  - ISS attitude knowledge (<1 Hz) is larger limiter for ground observations
- **Lunar pointing**: Star Tracker and IMU provide <3 arc-seconds (1σ) knowledge of HySICS with respect to the moon
- **Solar pointing**: FSS provides <2 arc-seconds (1σ) knowledge of HySICS with respect to the Sun at 200 Hz

Inter-Calibration Thoughts – Spectral Response

- HySICS-provided spectral radiances are only useful for inter-calibrations where other instrument has *a priori* known relative spectral response

(presented at May 2009 SDT)



$$s^2 = s_r^2 + s_l^2 + s_p^2 + s_{spatial}^2$$

Radiometric uncertainty from CLARREO

$$s_r \approx 0.2\%$$

Spectral response function uncertainty

$$s_l \propto \Delta l_{CLARREO} / \Delta l_{cal\_instrument}$$

$$\approx 5\% \times \Delta l_{CLARREO} / \Delta l_{cal\_instrument}$$

Polarization uncertainty

$$s_p \approx (\text{scene polarization}) \times (\text{instrument polarization sensitivity})$$

$$s_p \approx 20\% \times 2\% \approx 0.4\%$$

Inter-Calibration Thoughts – Polarimetry

- Polarimetric inter-calibration advantages
  - Could inter-calibrate another instruments' polarization sensitivity if sufficient differing polarization-state scenes could be viewed with identical look angles
  - Helps bound radiometric uncertainties from other instrument
- Polarization-sensitivity is not addressed by CPF
  - *Polarimetry comes at the expense of radiometric accuracy* (May 2016 SDT)
- Selection of scenes having low polarization simplifies radiometric cross-calibration without need for polarimetry
  - This is CPF plan, benefitting from HySICS's low polarization sensitivity

HySICS' View of Instrument Team

Thank

you!