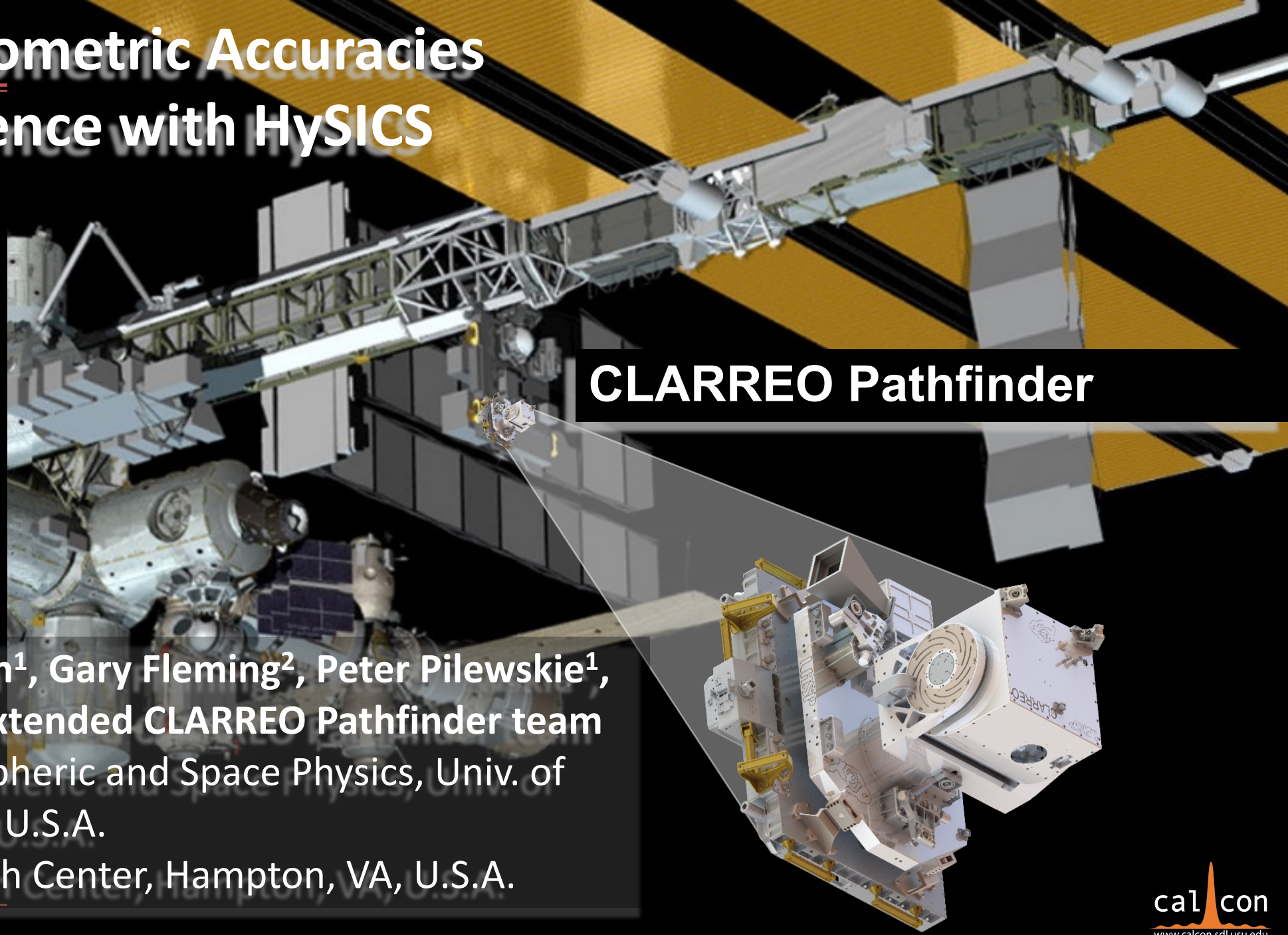
Improved Radiometric Accuracies for Climate Science with HySICS



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CalCon
Utah State Univ. & SDL, UT 24 Sept. 2020

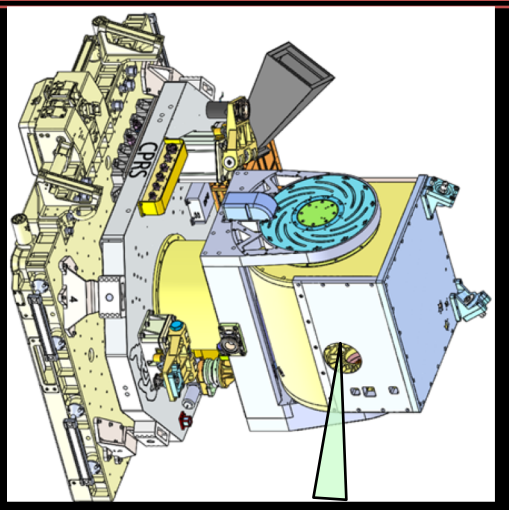
CLARREO Pathfinder – Description and Implementation

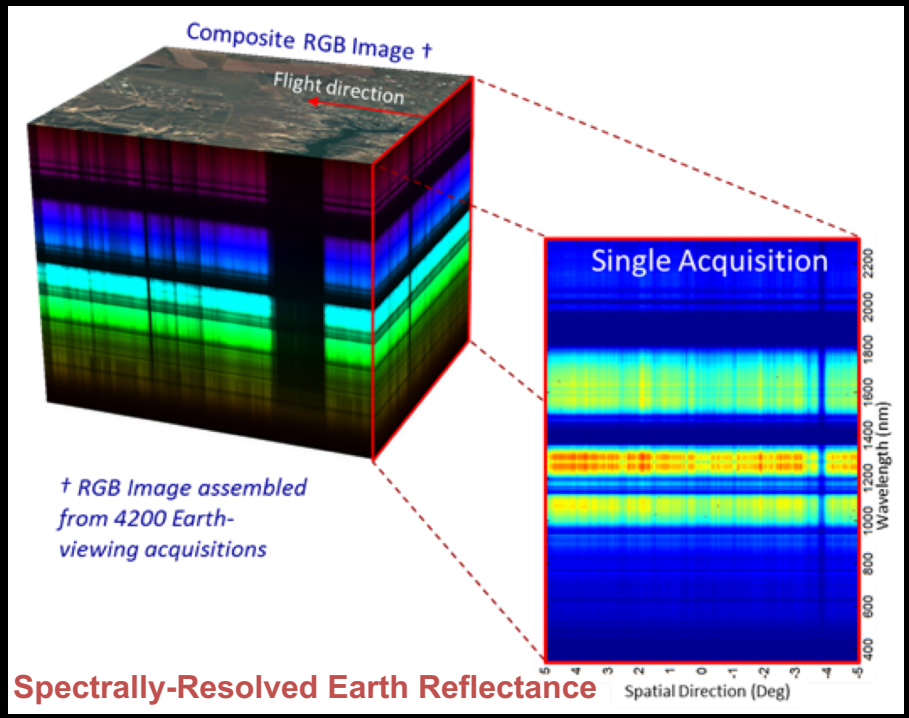
- CLARREO Pathfinder will demonstrate high-accuracy measurements of Earth-reflected solar radiances and radiance inter-calibrations within the reflected-solar spectral range

CLARREO: Climate Absolute Radiance and Refractivity Observatory

1. Demonstrate on-orbit, high-accuracy, SI-traceable calibrations for measurements of Earth-reflected radiances in solar-spectral region
   - 4-8 times better accuracies than current best-available sensors on-orbit
2. Demonstrate ability to transfer calibrations to other on-orbit sensors (VIIRS, CERES)

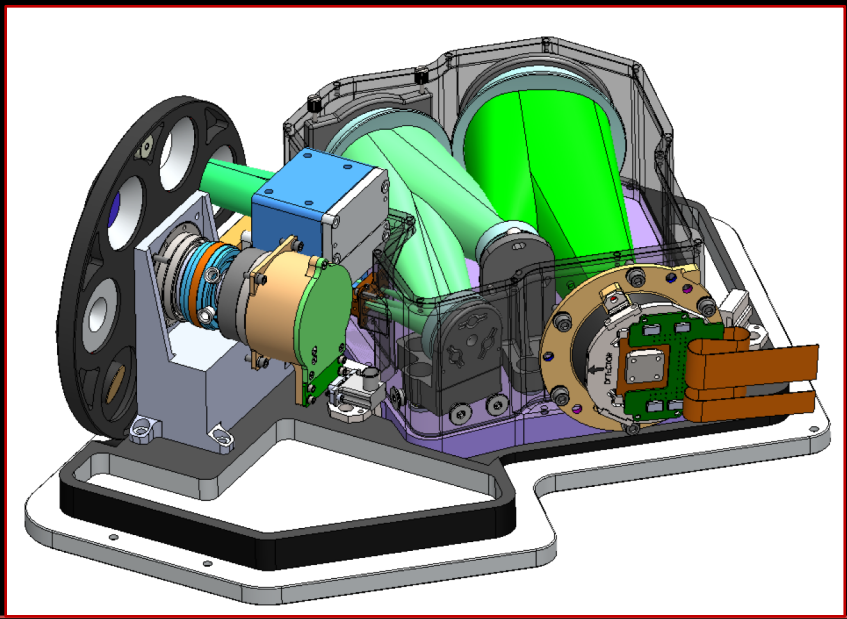
- Formulation, implementation, launch, operation, and analysis of measurements from a reflected-solar spectrometer deployed to the ISS
- Category 3 / Class D Mission with 1-year nominal mission life followed by 1 year of science data analysis
- Project is in Phase C (Fabrication)





CLARREO Pathfinder Key Requirements and Expected Performance

- Spectral range
  - 350 – 2300 nm (323.5 – 2322 nm expected)
- Spectral sampling
  - 6-nm resolution (3-nm sampling) (3.13 nm expected)
- Spatial sampling
  - Cross- and along-track: 0.5-km IFOV at nadir from ISS orbit (400 km) (67" → 130 m IFOV expected)
  - Swath width: 70 km at nadir from ISS orbit (400 km) (10.126° FOV → 70.88 km expected)
- Radiometric accuracy of reflectance measurement
  - Spectrally resolved: 0.3% uncertainty
  - Spectrally integrated: 0.3% uncertainty
- Polarization sensitivity
  - Less than 1% from 350-1800 nm and less than 2% from 1800-2300 nm



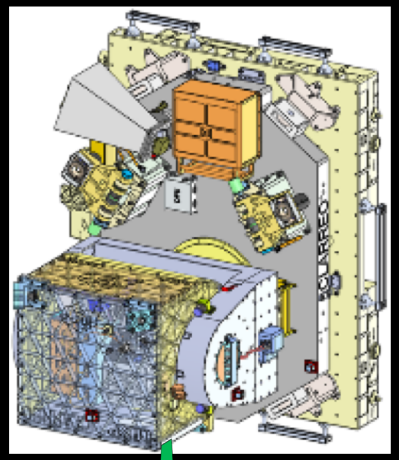
CLARREO HySICS Science Observations

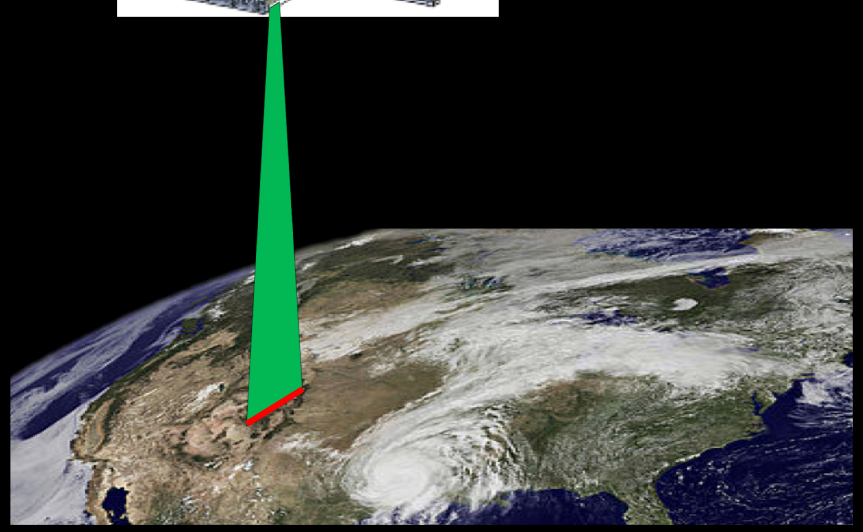
1. Acquire nadir scans with high radiometric accuracy and SI traceability capable of climate benchmarking
   - SI traceability comes from direct on-orbit measurements of spectral solar irradiance (SSI)
     - No diffusor or scatterer is used for SSI measurements
     - HySICS SSI measurements are referenced to those provided by the independently-operating Spectral Irradiance Monitor (SIM) to provide SI traceability
2. Provide inter-calibrations to other flight instruments in LEO or GEO
   - LEO: co-aligned, ~cotemporaneous observations with JPSS/VIIRS and CERES
   - GEO: co-aligned, cotemporaneous observations with GEO instruments
3. Acquire lunar radiances at various phase and libration angles

HySICS: HyperSpectral Imager for Climate Science

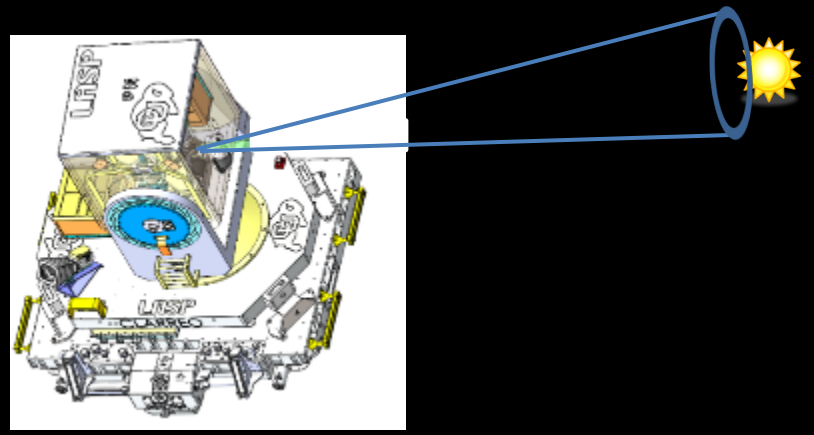
HySICS Reflectivity Measurement Is Traceable to Solar Irradiances

Step 1: Measure Earth scene radiance: $L_{obj}(\lambda)$, in *DN*





Step 2: Measure Spectral Solar Irradiance: $E_{Sun}(\lambda)$, in DN



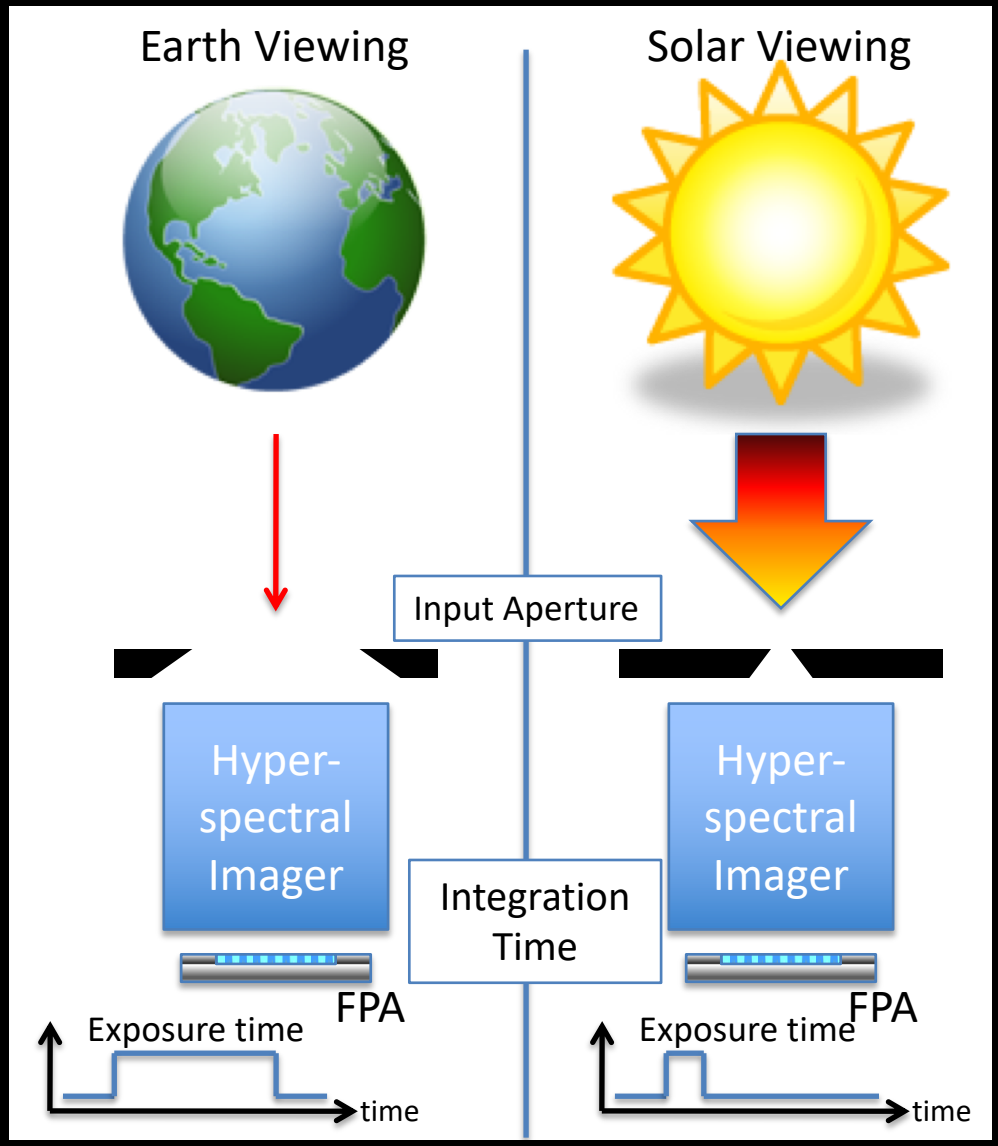
$$R_{obj}(\lambda) = \pi \frac{L_{obj}(\lambda) \cdot A(\lambda)}{E_{Sun}(\lambda)}$$

$$A(\lambda) = Aperture\ Ratio \cdot Integration\ Time\ Ratio\ [unitless]$$

HySICS On-Orbit Solar Cross-Calibration Measurement Concept

- Reference Earth radiances to solar irradiances
  - Reduction of input-aperture area (aperture attenuation)
    - Can achieve over 3 orders of magnitude of attenuation
      - 20 mm to 0.5 mm
  - Reduction of detector integration-time (integration-time attenuation)
    - Can achieve 2.7 orders of magnitude of attenuation
      - 66 ms to 0.121 ms
- Advantages of on-orbit solar cross-calibrations
  - The Sun is the most stable and best-known on-orbit light source
    - The solar irradiance is known to 0.2% via *SI-traceable, absolutely-calibrated* instruments, such as TSIS-1/SIM
  - Attenuation methods are *relative* measurements
    - No absolute measurements of solar or Earth irradiances by the HySICS are required

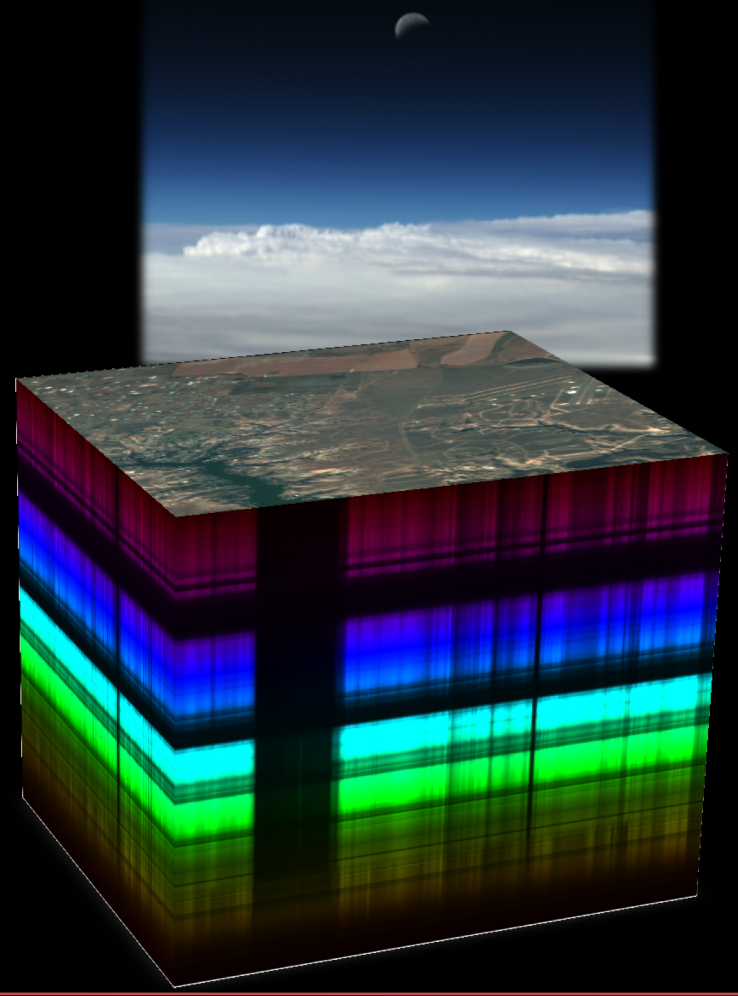
tests use NIST − calibrated photodiode for linearity $> 10^7$



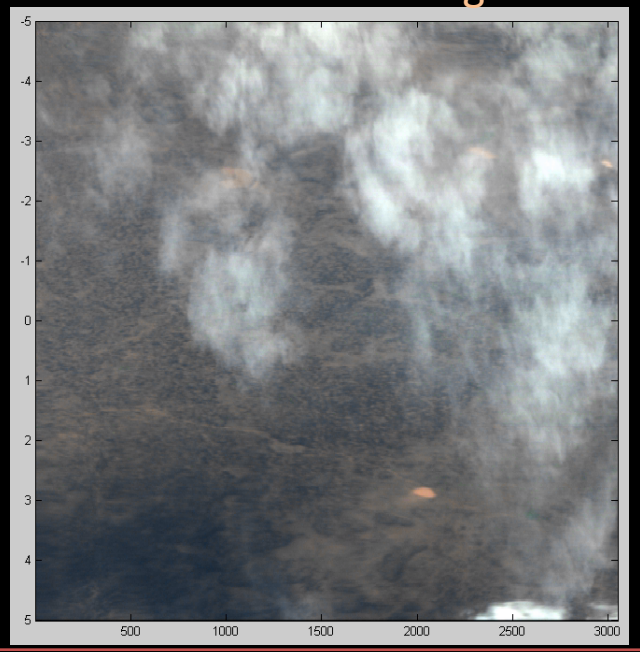
HySICS Was Demonstrated on Two High-Altitude Balloon Flights

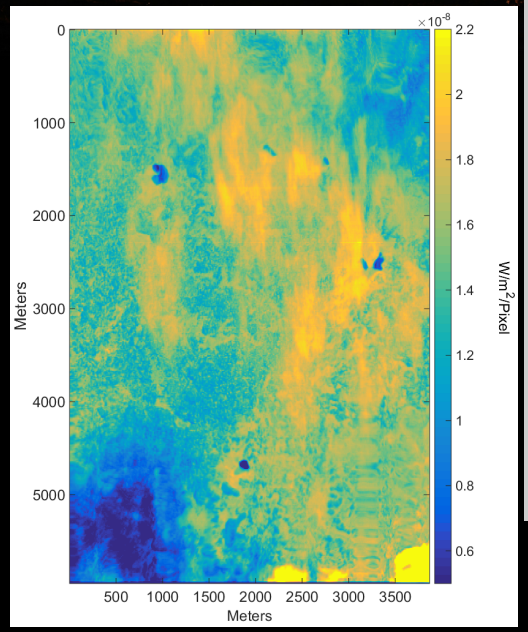
- Both flights operated out of Fort Sumner with support by NASA's Wallops Flight Facility (WFF) and NASA's Columbia Scientific Balloon Facility (CSBF)
  - Flight #1 was 29 Sept. 2013
  - Flight #2 was 18 Aug. 2014
  - 37-km (122,000') altitude

Earth Limb and Moon

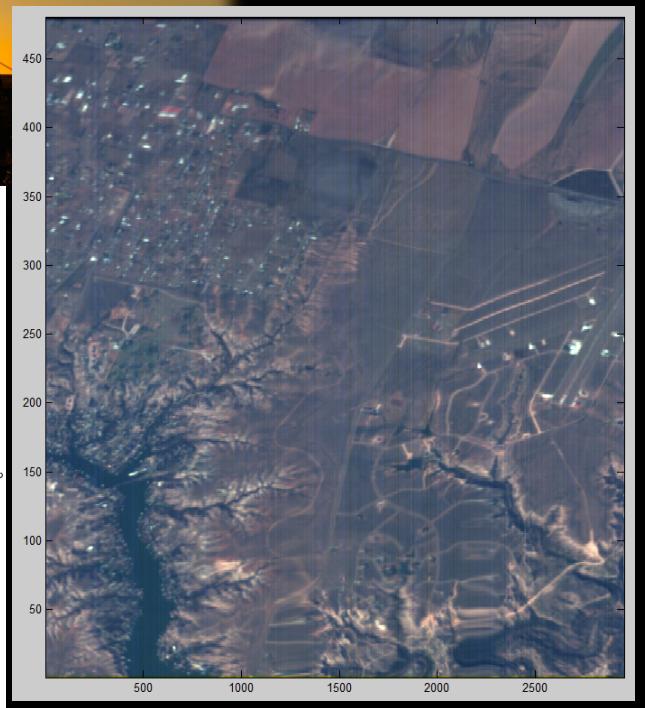


Ground Scan from Flight #2





Fully Calibrated Ground Scene at 1233 nm

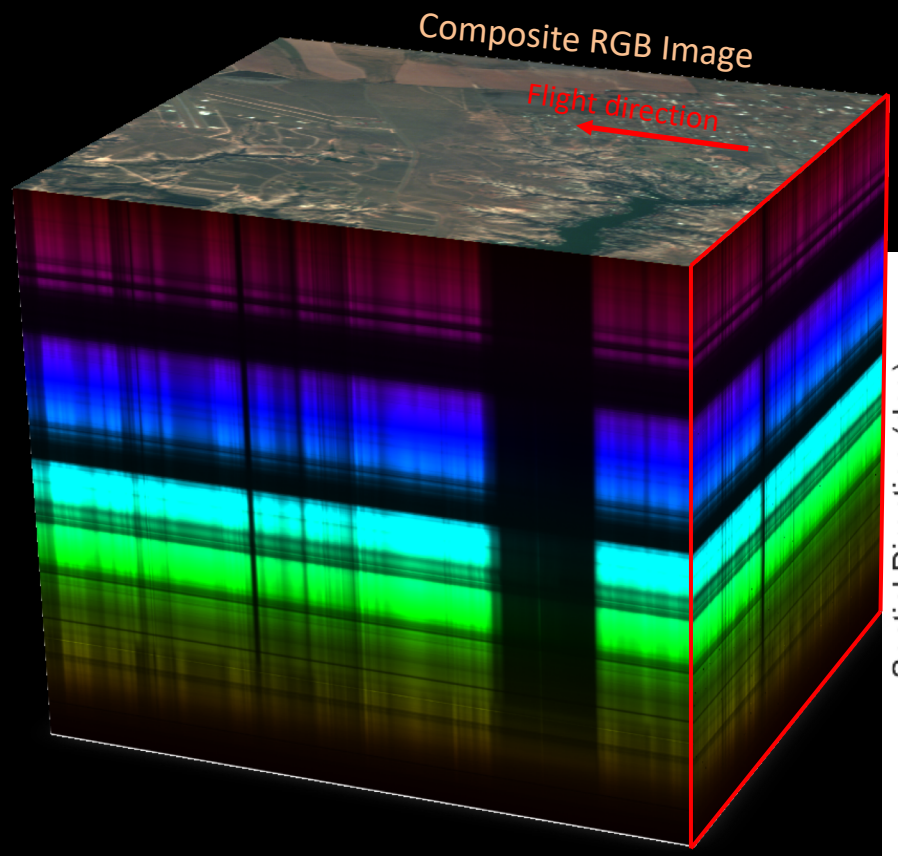


Ground scan (13:25:30)

R = 653 nm, G = 535 nm, B = 457 nm

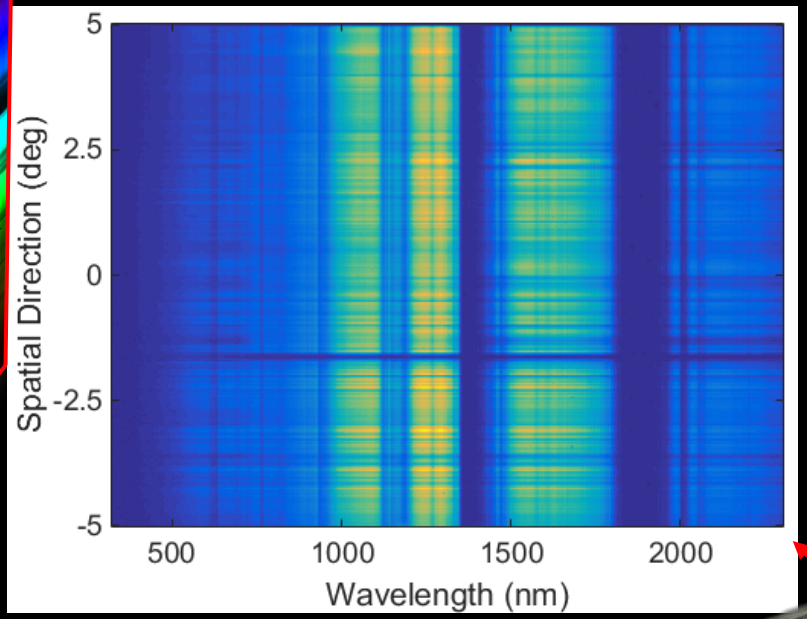
HyperSpectral Instrument for Climate Science (HySICS)

- The HySICS is a push-broom imaging Offner spectrometer with 480 spatial and 640 spectral pixels

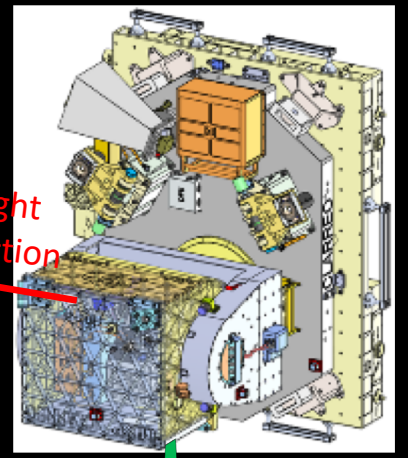


RGB Image assembled using 4200 Earth-viewing acquisitions from HySICS balloon flight #1

Single Acquisition

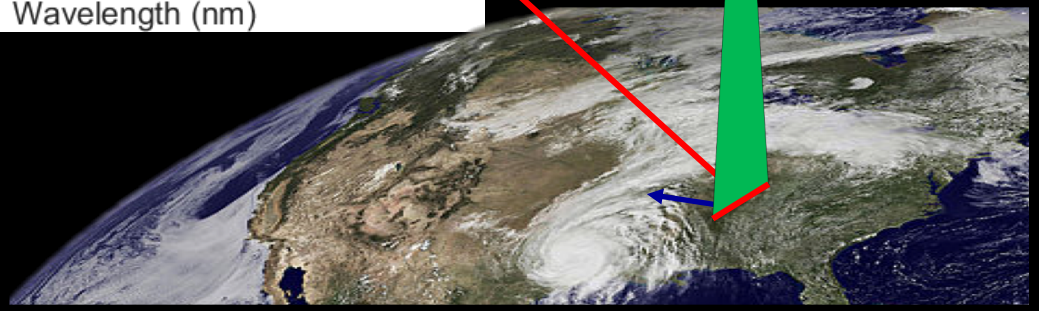


CLARREO Pathfinder



Flight direction

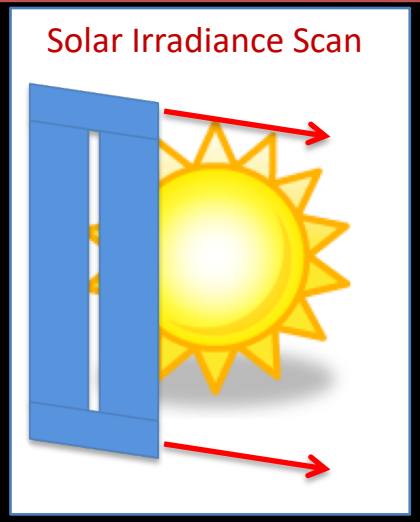
Slit projection (10° FOV)

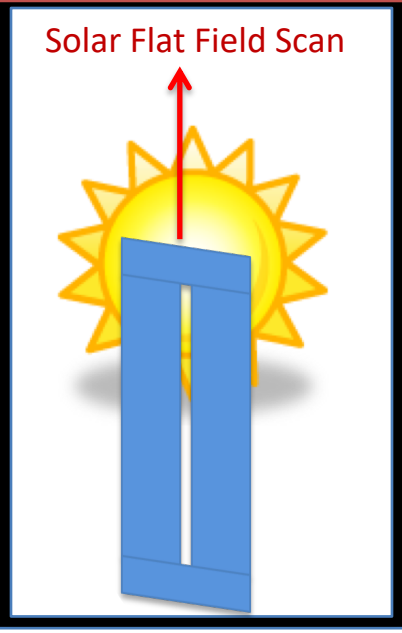


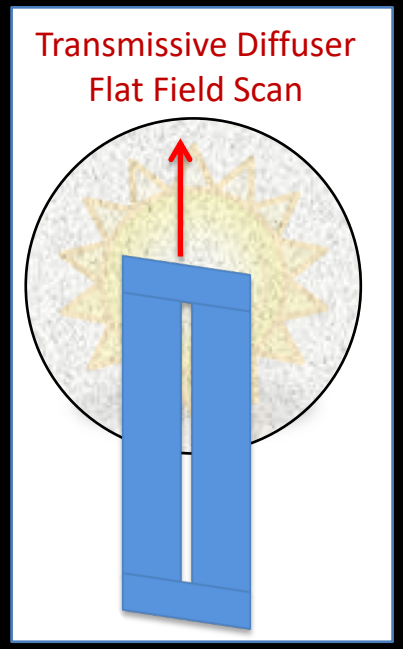
Goal: Measure spectral reflectivity (and radiance) for each 0.5 x 0.5 km pixel (binned)

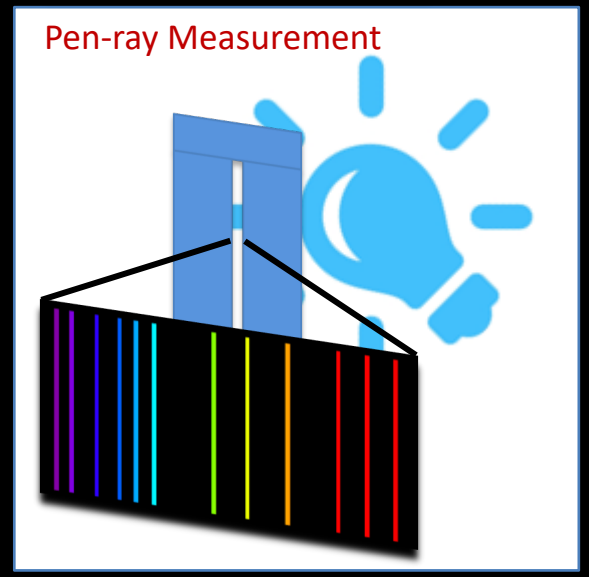
Most On-Orbit Calibrations Are Relative, so Immune to Degradation

- Solar-Irradiance Scan
  - Cross-slit scan of the Sun, collecting all the power incident at the input aperture
- Solar Flat-Field Scan
  - Relative gain measurement of each pixel in the instrument using the solar-viewing aperture (0.5-mm diameter)
- Transmissive Diffuser Flat-Field Scan
  - Relative gain measurement of each pixel in the instrument with the Earth-viewing aperture (20-mm diameter)
- Pen-ray Measurement
  - Absolute measurement of atomic spectrum from a Hg-Ar light source for wavelength calibrations



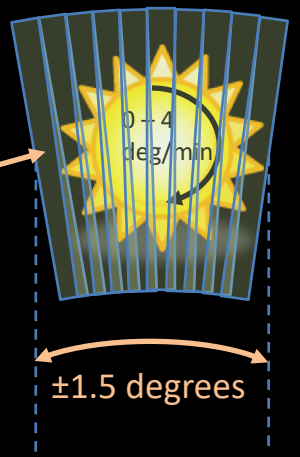






Spectral Solar Irradiance (SSI) Measurement from HySICS

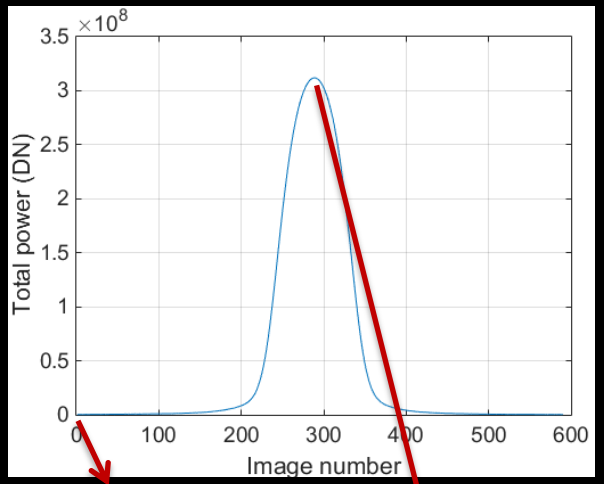
Slit motion with 2-axis gimbal and motion of ISS (not to scale)

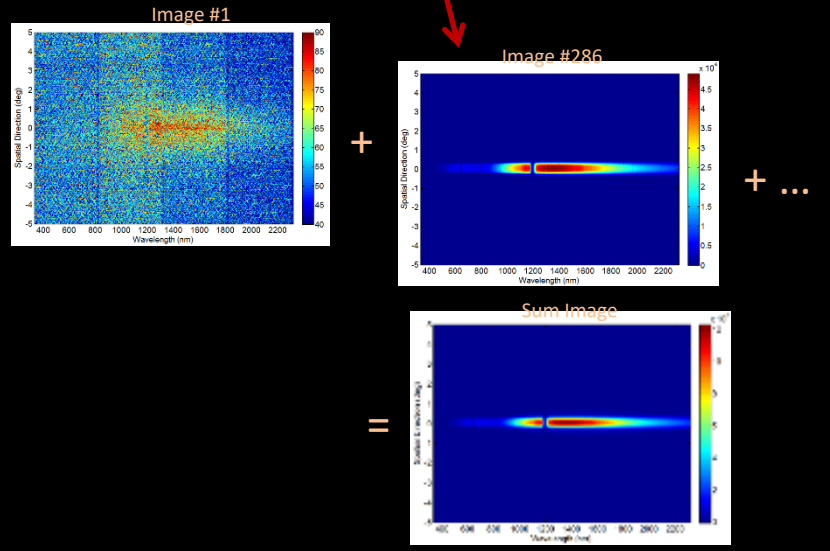


Boresight relative to Sun center is known from HFSS (High-speed Fine Sun Sensor)

Scan rate: 0.078 degrees/second (or ~4 images per solar point)

Across-slit scan of the Sun (from HySICS balloon flight)

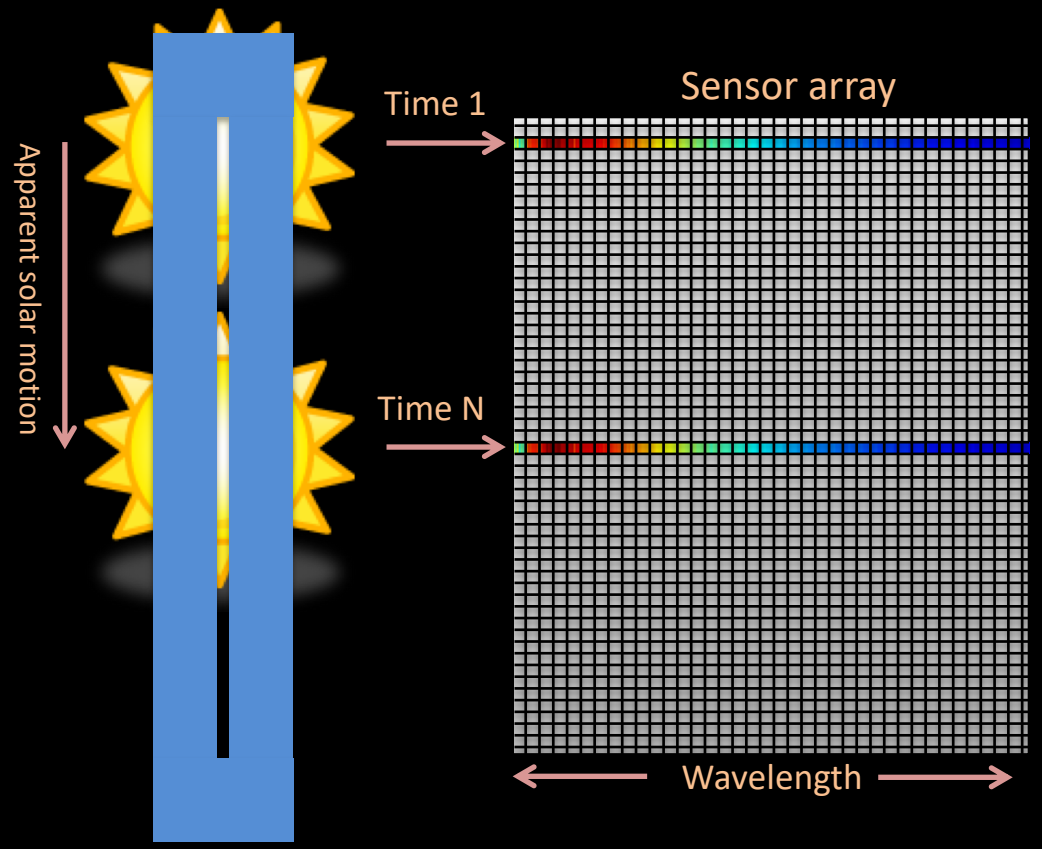




- SSI measurement collects as much of the solar irradiance as possible, scanning 1.5 degrees in both directions from the center of the Sun
- The solar disk is (intentionally) oversampled
  - These portions are inversely scaled by their oversampling factor

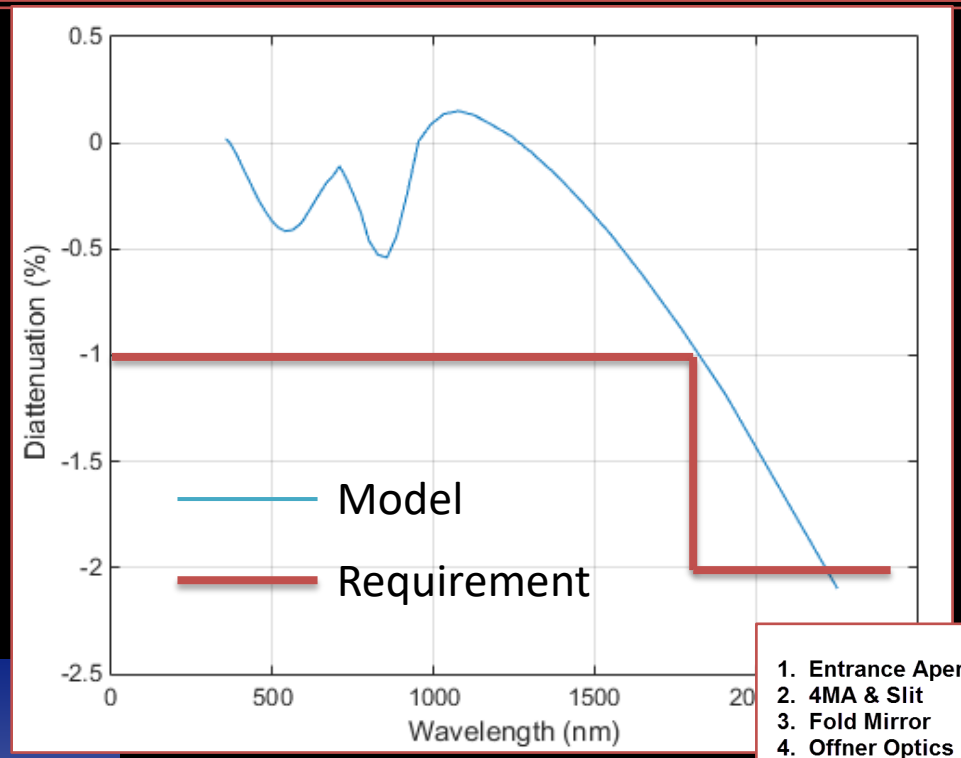
On-Orbit Solar Flat-Field (0.5-mm Aperture)

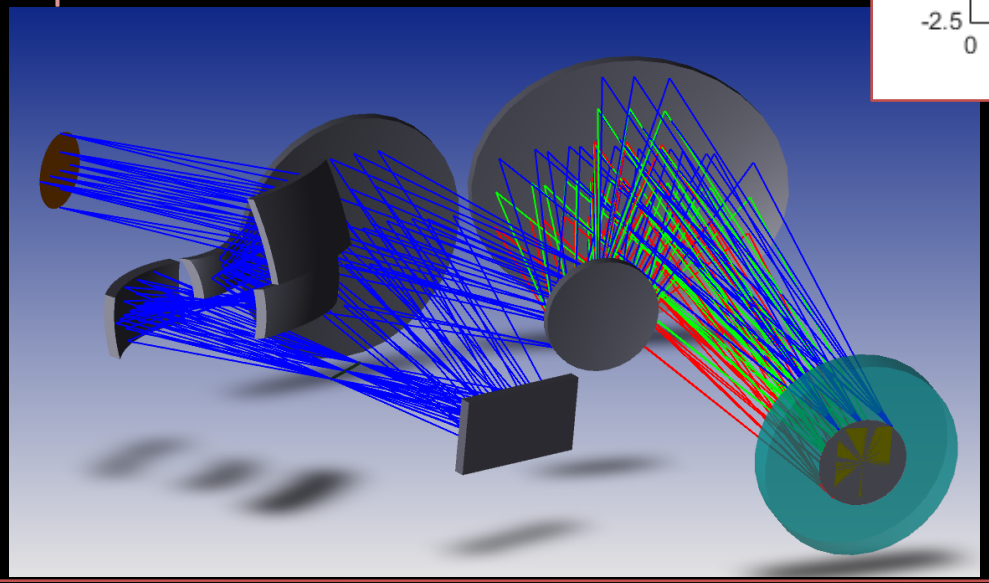
- Goal: Put the same light field on every pixel within the slit
- Determines the relative response of each pixel and field angle through the optical system
- Solar flat field
  - Slit FOV (along slit): 10˚
  - Solar extent: ~0.5˚
  - Scan range of motion: ±6˚
  - Scan rate: 0.078 deg/sec
    - Oversampling factor: 4

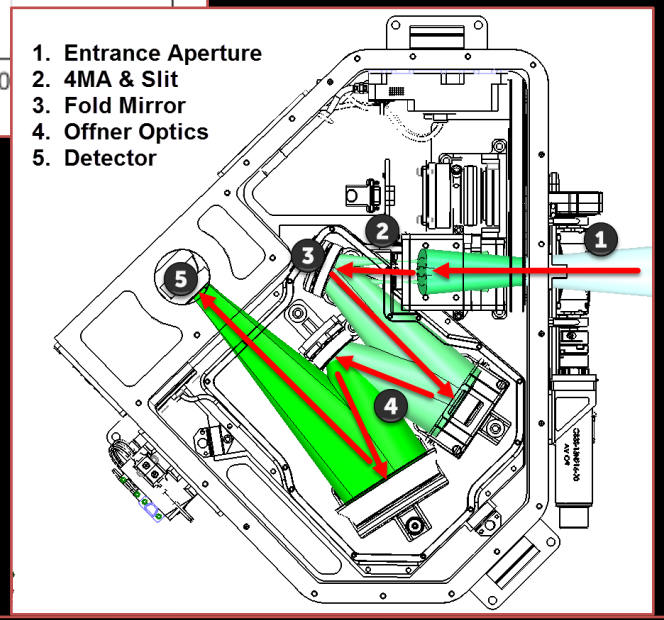


The HySICS Has Low Inherent Polarization Sensitivity

- 4MA plane is “vertical”
  - TE polarization is favored for 4 bounces
- Offner plane is “horizontal”
  - TM polarization is favored for 4 bounces
  - Reduces instrument polarization sensitivity
- Requirements
  - <|1%| from 350 to 1800 nm
  - <|2%| from 1800 to 2300 nm



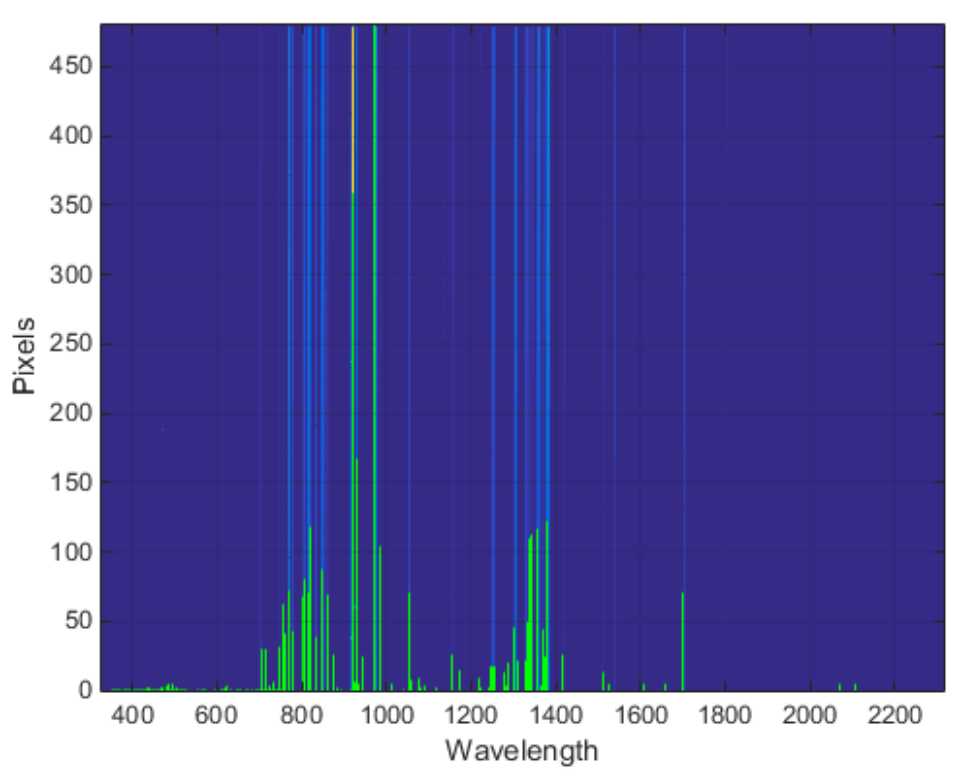


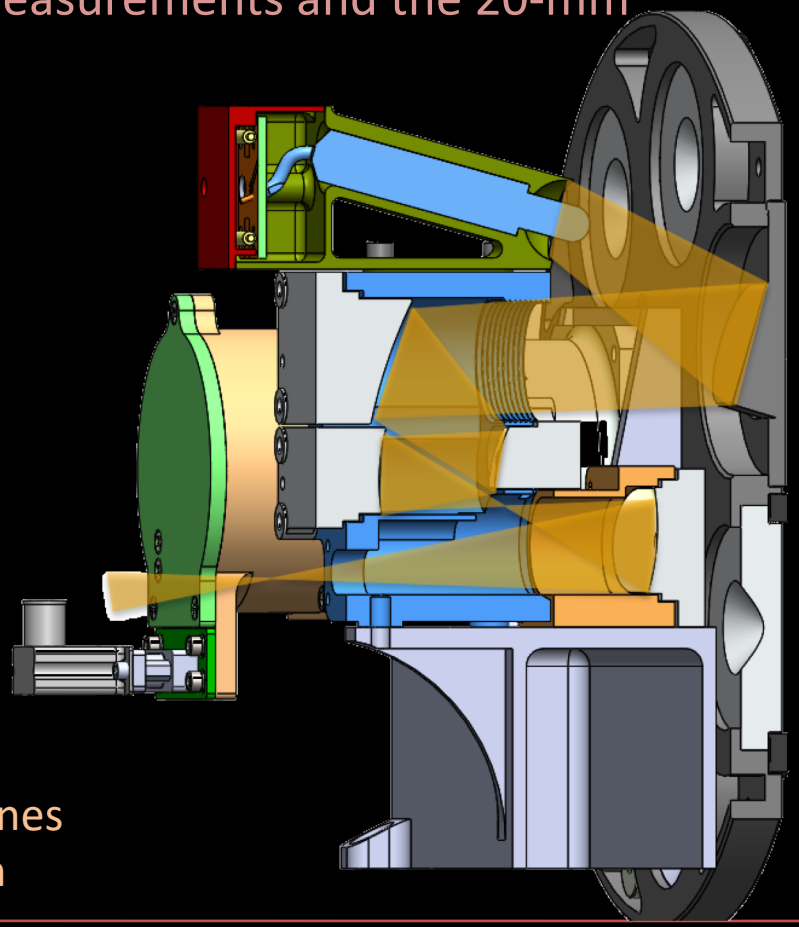


Pen-ray Provides On-Orbit Spectral Calibrations

- Internal Hg-Ar pen-ray illuminates mirror mounted on aperture wheel
  - Covers 10-degree angular spread (instrument FOV)
- Aperture-wheel reflector has projected area equivalent to 20-mm aperture
  - Ensures that instrument line shape is the same between the pen-ray measurements and the 20-mm aperture measurements

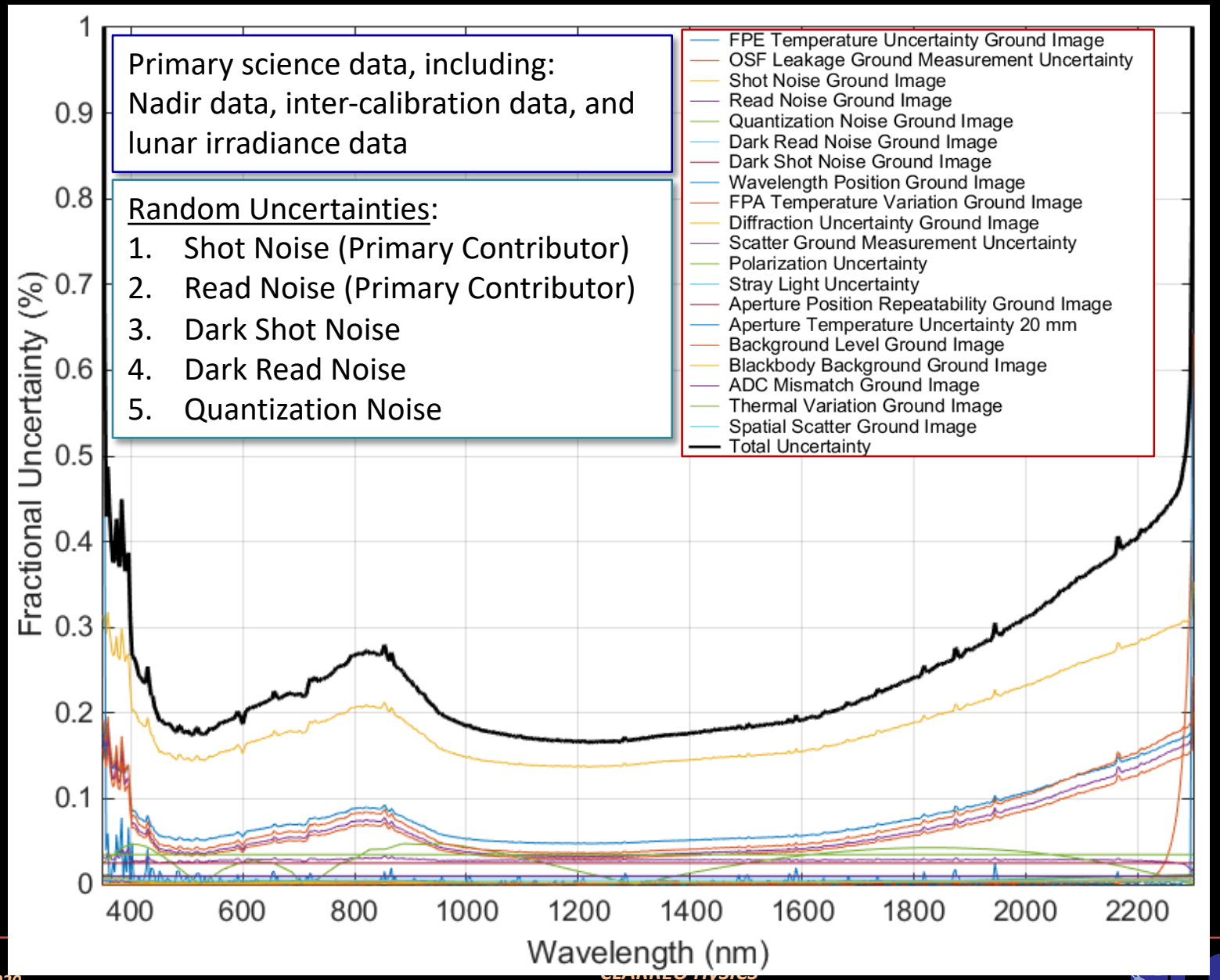
HySICS Balloon Flight Pen-ray Measurement



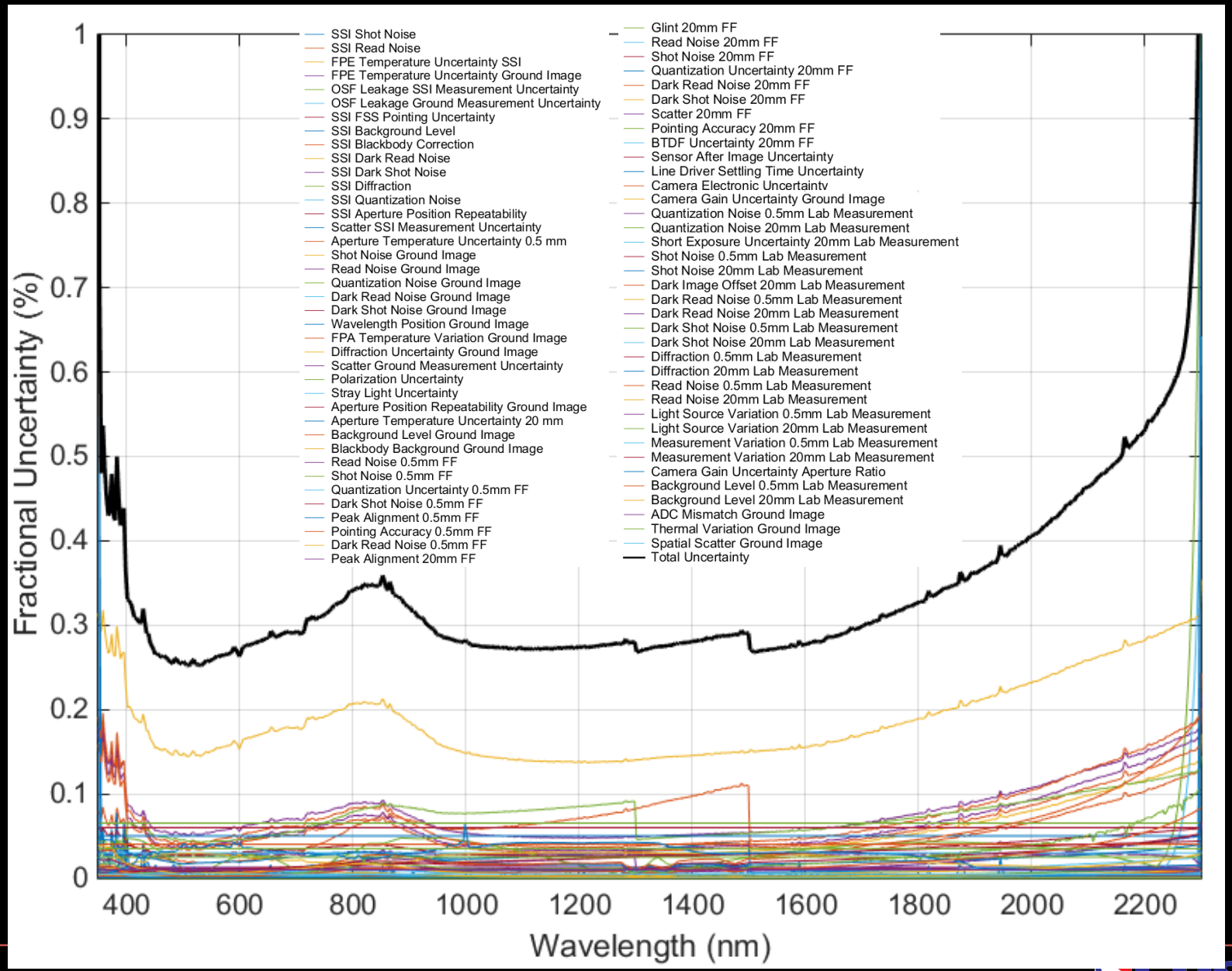


Atomic Ar spectral lines are overlaid in green

Ground Measurement (Single Pixel)

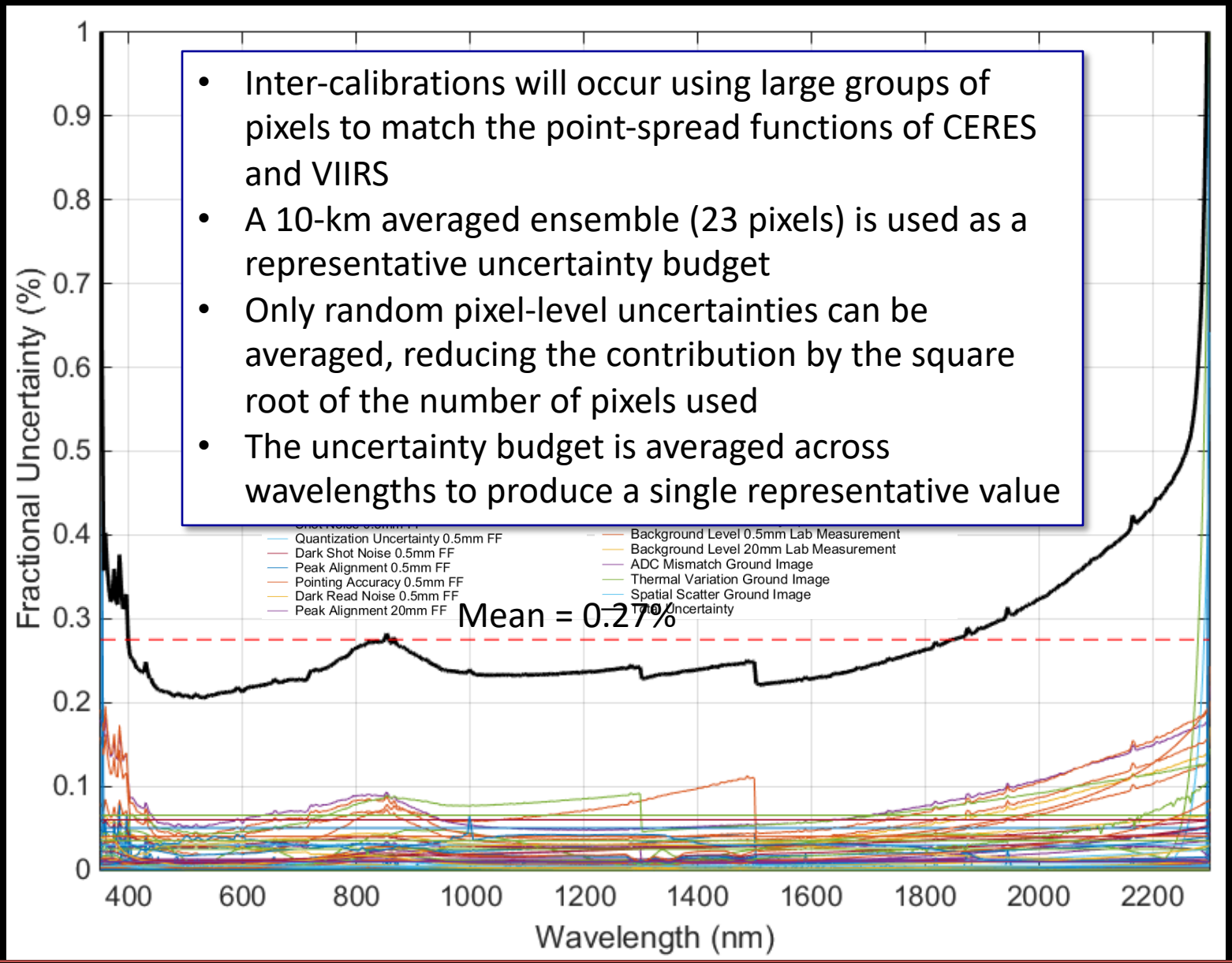


The Uncertainty Budget: Single Pixel



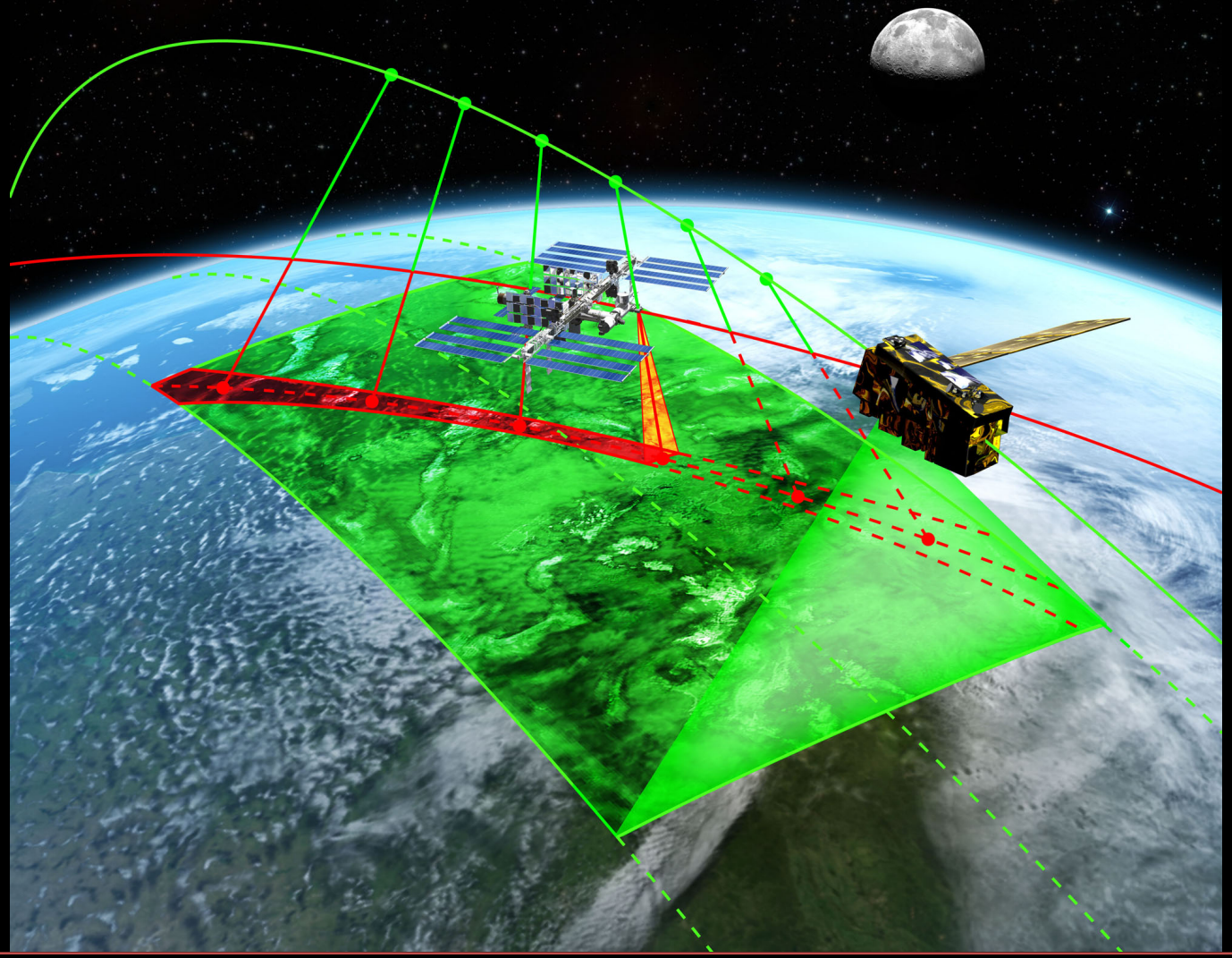
The Full Uncertainty Budget (10-km average)

- Inter-calibrations will occur using large groups of pixels to match the point-spread functions of CERES and VIIRS
- A 10-km averaged ensemble (23 pixels) is used as a representative uncertainty budget
- Only random pixel-level uncertainties can be averaged, reducing the contribution by the square root of the number of pixels used
- The uncertainty budget is averaged across wavelengths to produce a single representative value



Demonstrate Intercalibrations with CERES and VIIRS

and other IOO's (instruments of opportunity)



CLARREO Pathfinder – Summary

- CLARREO Pathfinder will demonstrate high-accuracy SI-traceable measurements of Earth-reflected solar radiances and radiance inter-calibrations to other on-orbit instruments
  - 350 to 2300 nm spectral range with 6-nm resolution
  - 0.3% radiometric uncertainties
- Balloon-flight-proven HySICS to be deployed to the ISS in 2023