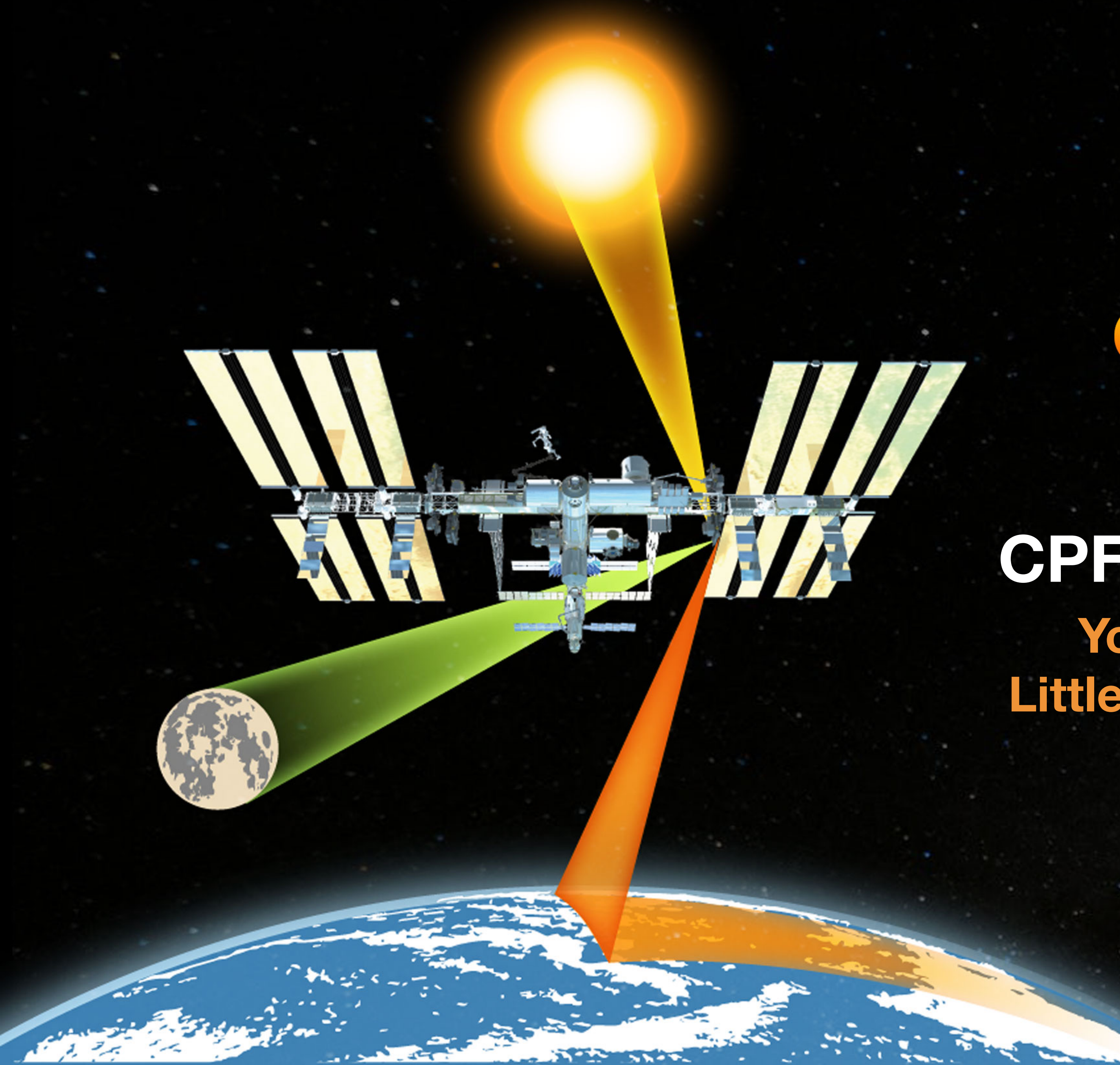

National Aeronautics and
Space Administration

CLARREO Pathfinder

Mission Update & CPF-CERES Intercalibration

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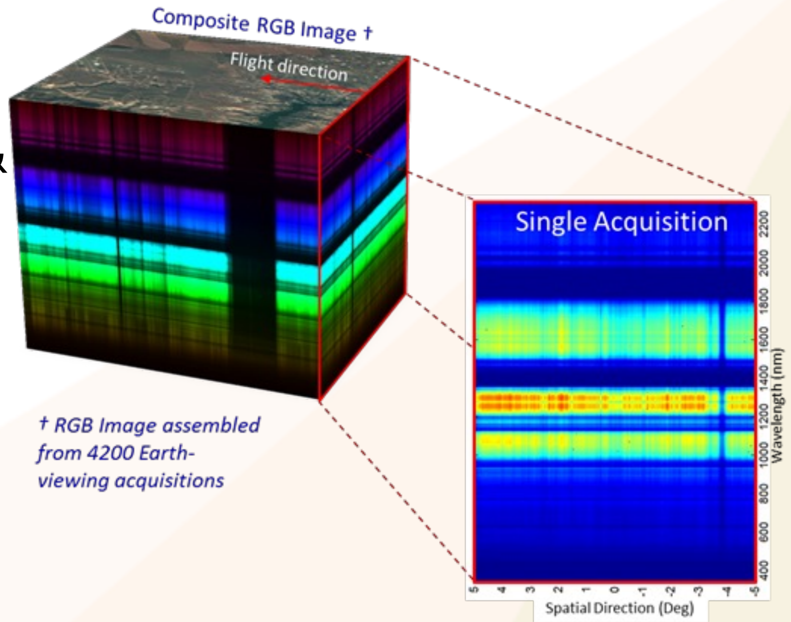
CLARREO Pathfinder on ISS: Summary

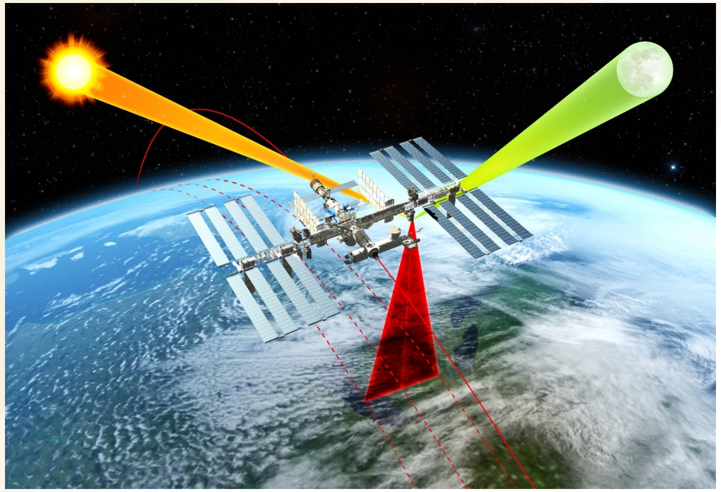
- **Mission Purpose:** Take climate-critical high accuracy measurements of Earth reflectance and intercalibrate with CERES (broadband) & VIIRS (multi-spectral) shortwave channels
- LASP-Led Reflected Solar Spectrometer (350 – 2300 nm) & Payload
- Nominally 1-year mission operations (but hopefully more!) + 1-year science data analysis
- Payload Readiness: ~Spring 2024
- Launch: TBD

Spectrally-Resolved Earth Reflectance



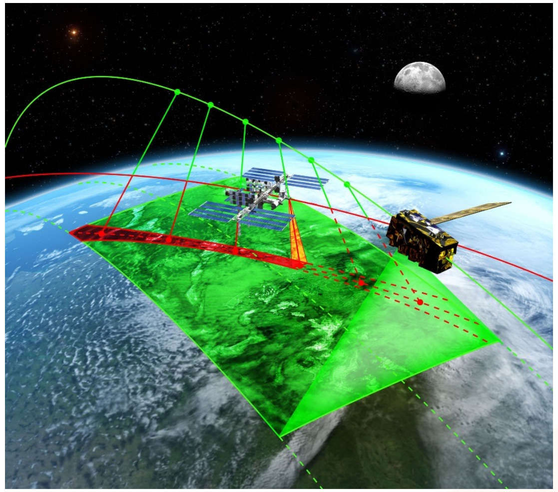
https://clarreo-pathfinder.larc.nasa.gov/

Objective #1: **High Accuracy SI-Traceable Reflectance Measurements**



Demonstrate on-orbit calibration ability to reduce reflectance uncertainty by a factor of ***5-10 times*** compared to the best operational sensors on orbit.

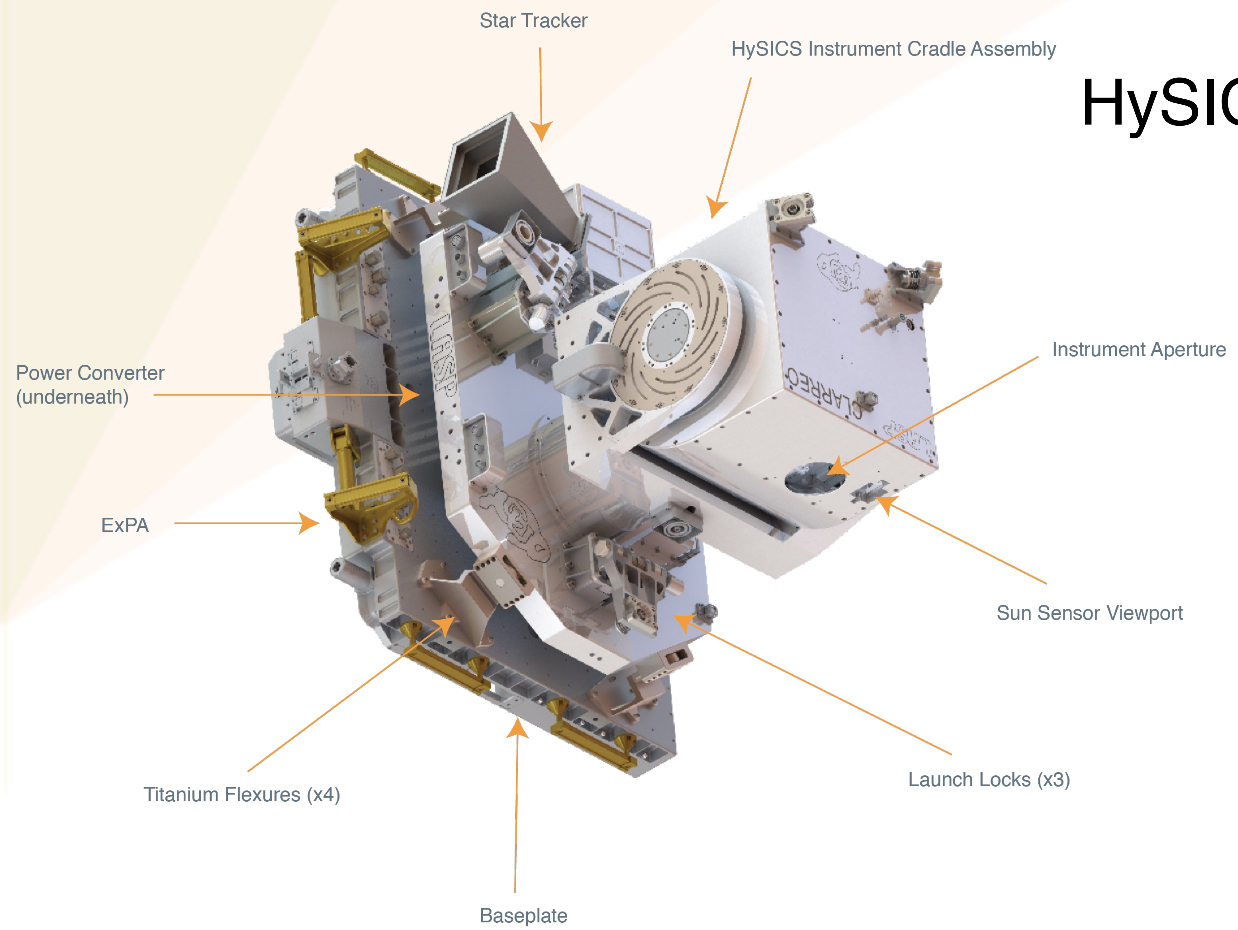
Objective #2: **InterCalibration Capabilities**



Demonstrate ability to transfer calibration other key RS satellite sensors by intercalibrating with CERES & VIIRS.

	Objective #1	**Objective #2**
Uncertainty	Spectrally-resolved & broadband reflectance: ≤0.3% (1σ)	Intercalibration Methodology Uncertainty: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for intercal, lunar obs Level 1B: Approx. consistent spectral & spatial sampling, best for science studies using nadir spectra	Level 4: One each for CPF-VIIRS & CPF-CERES intercal. Merged data products including all required info for intercal analysis

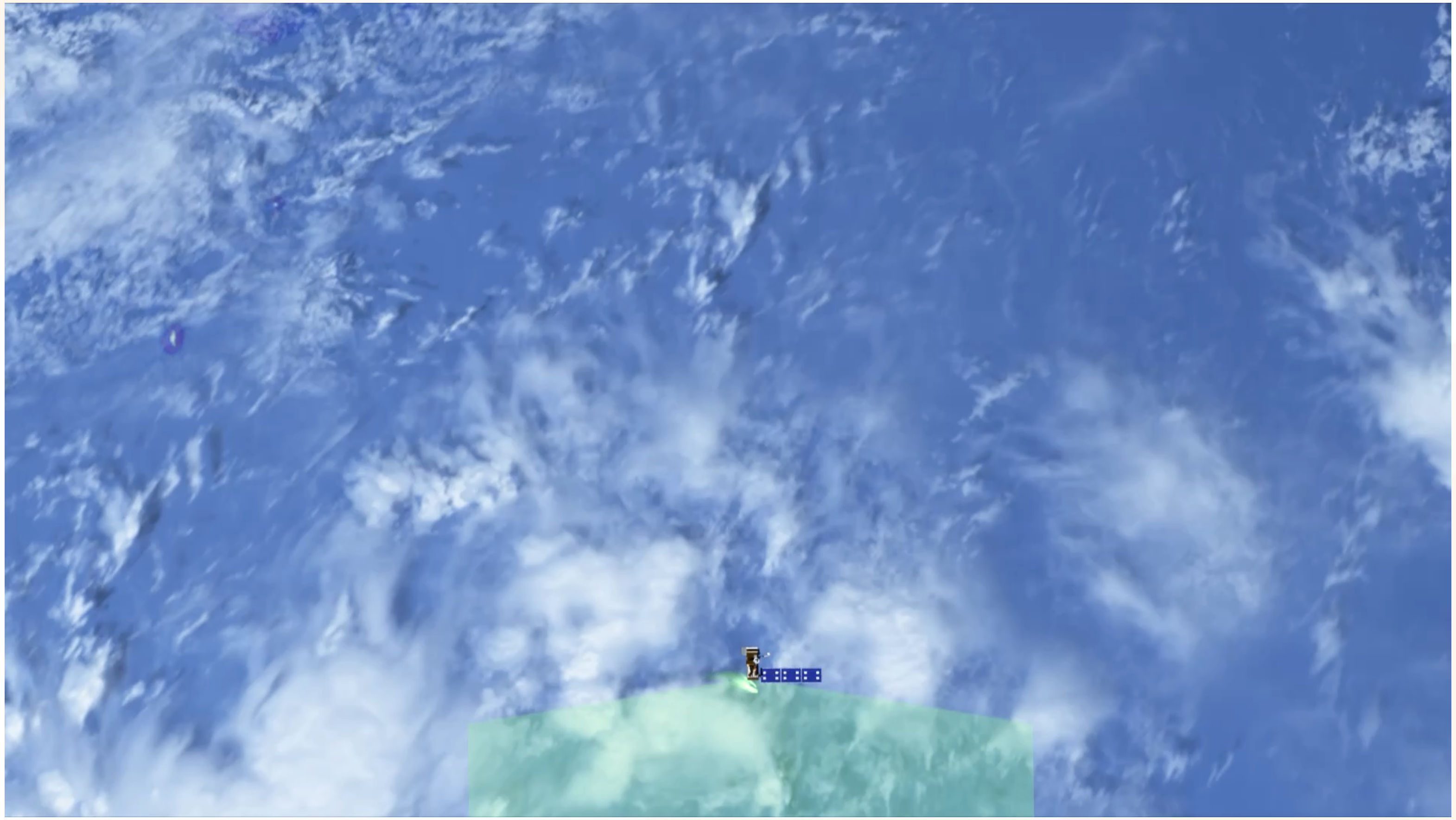
CLARREO Pathfinder Payload



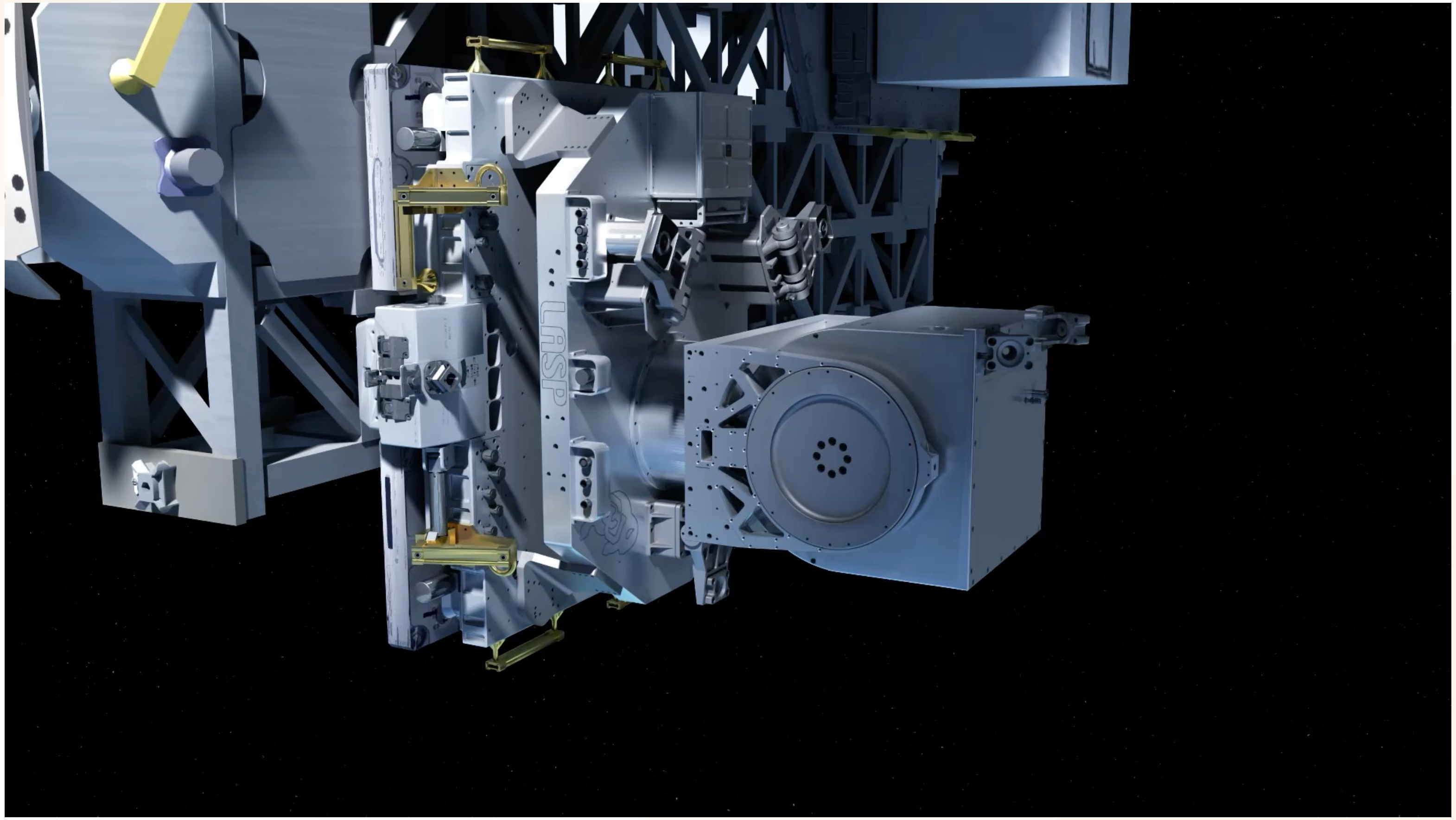
HySICS: Hyperspectral Imager for Climate Science

Radiometric Uncertainty	0.3% (1-sigma)
Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Sampling Rate	15 Hz

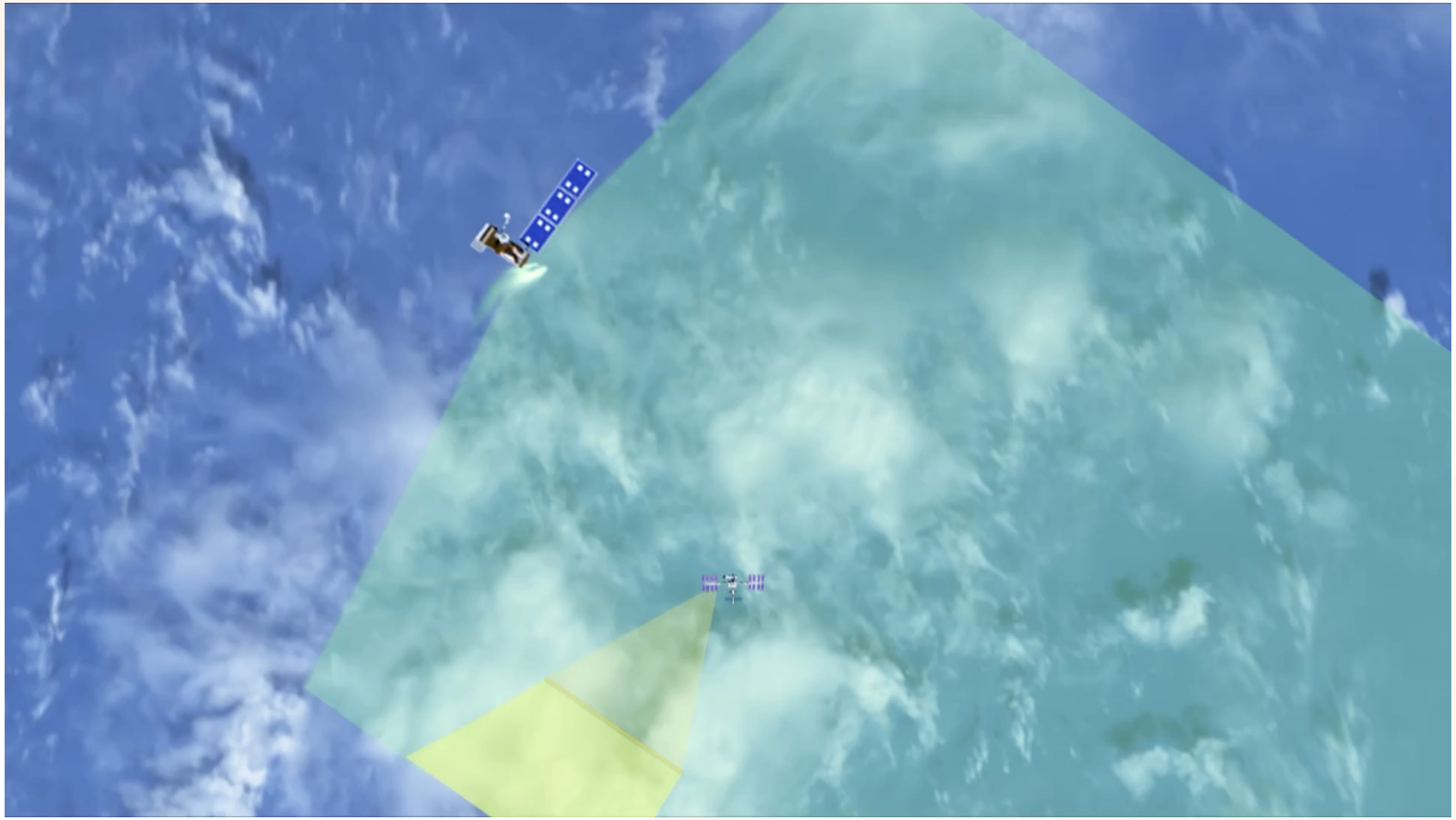
Each Intercal Event is Predicted…



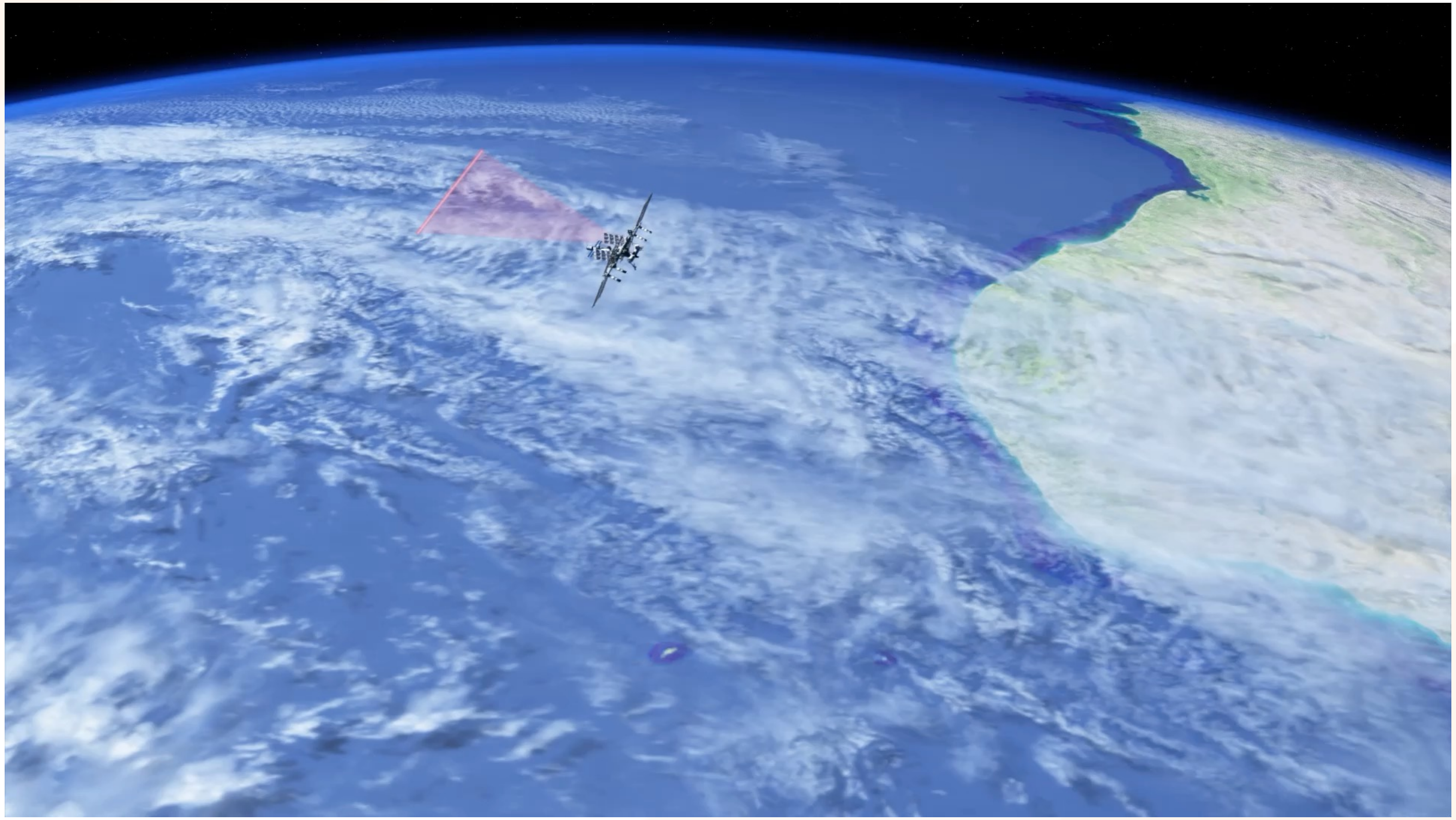
…so that we know when to point and at which azimuth and elevation angles.



Within 10 minutes, CPF points its boresight to match that of its intercal target.

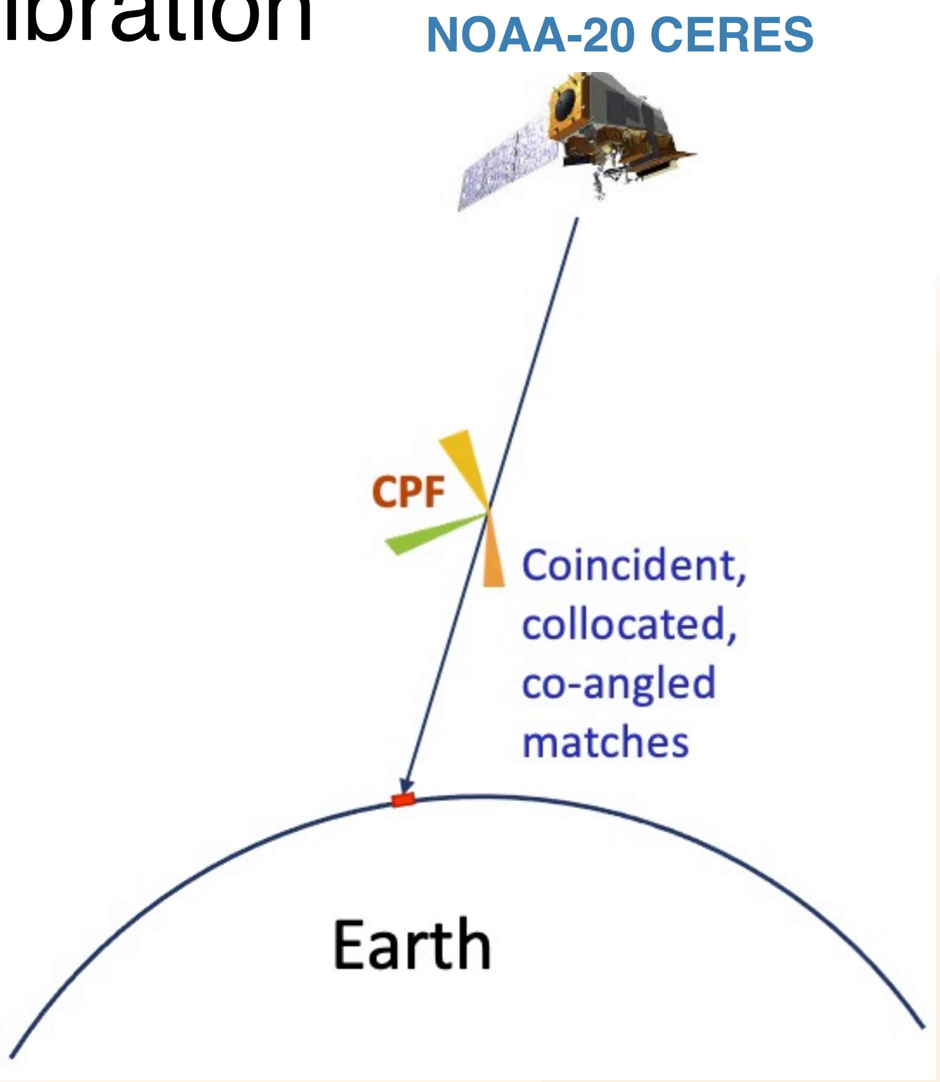


After the intercal event, CPF returns to its nominal operating mode: nadir.



CPF-CERES Instrument Intercalibration

- An idealized intercalibration setup has perfectly matched data in **time**, **space**, **angles**, and **wavelengths**
- Realistic intercalibration measurements have finite differences in sampling, thereby resulting in several sources of uncertainty
  - *Spatial mismatch*
  - *Angular differences (SZA, VZA, and RAA)*
  - *Spectral band differences*
- CPF will demonstrate a state-of-the-art intercalibration methodology mitigating the uncertainties from imperfect data matching
  - *2-axis pointing capability*



CPF-CERES Intercalibration Uncertainty Sources

CPF-CERES Intercalibration Uncertainty Sources

Spatial & Temporal Matching Noise

Spatial convolution of CPF spectral radiance within CERES footprints

Point Spread Function Knowledge

Applicable to CERES only

Spectral Matching

Difference in spectral coverage between CPF and CERES

Angular Adjustment

Imperfect angle matching between CPF and CERES

Monthly stability

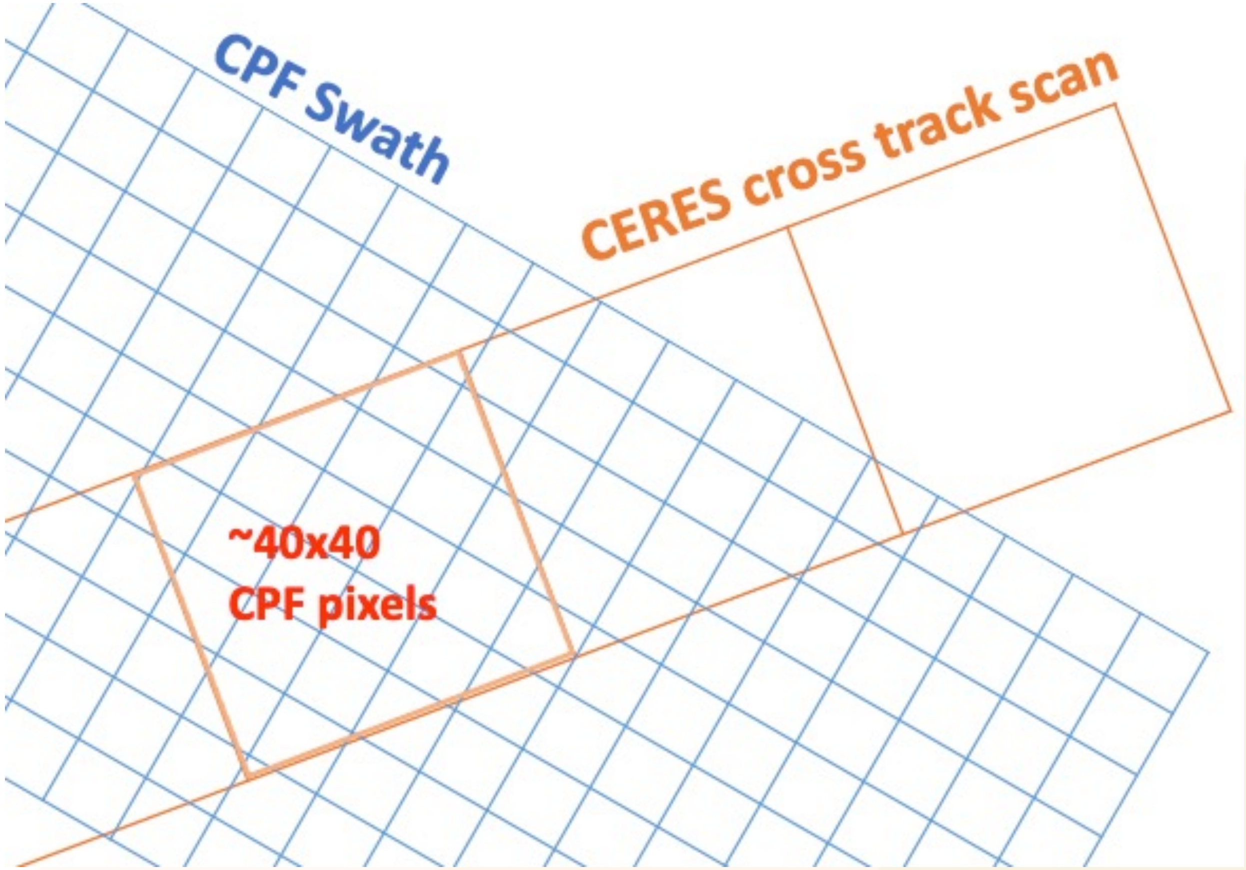
Uncertainty Contribution due to any variability in CERES calibration within a month

CPF-CERES Intercalibration Algorithms

- CPF employs different methods to reduce uncertainty impact of finite differences in sampling
  - *Spatial Differences*
    - Spatial Convolution of CPF footprints using CERES Point Spread Function for CPF to emulate CERES footprints
  - *Angular differences (SZA, VZA, and RAA)*
    - For pixels close to boresight: 2-axis pointing
    - For pixels off-boresight: Angular Adjustment Algorithm
  - *Spectral band differences*
    - VIIRS: 3 nm Spectral sampling of CPF hyperspectral measurements for spectral convolution
    - CERES: Leveraging spectral information to estimate the out of CPF band radiance

Temporal and Spatial matching noise

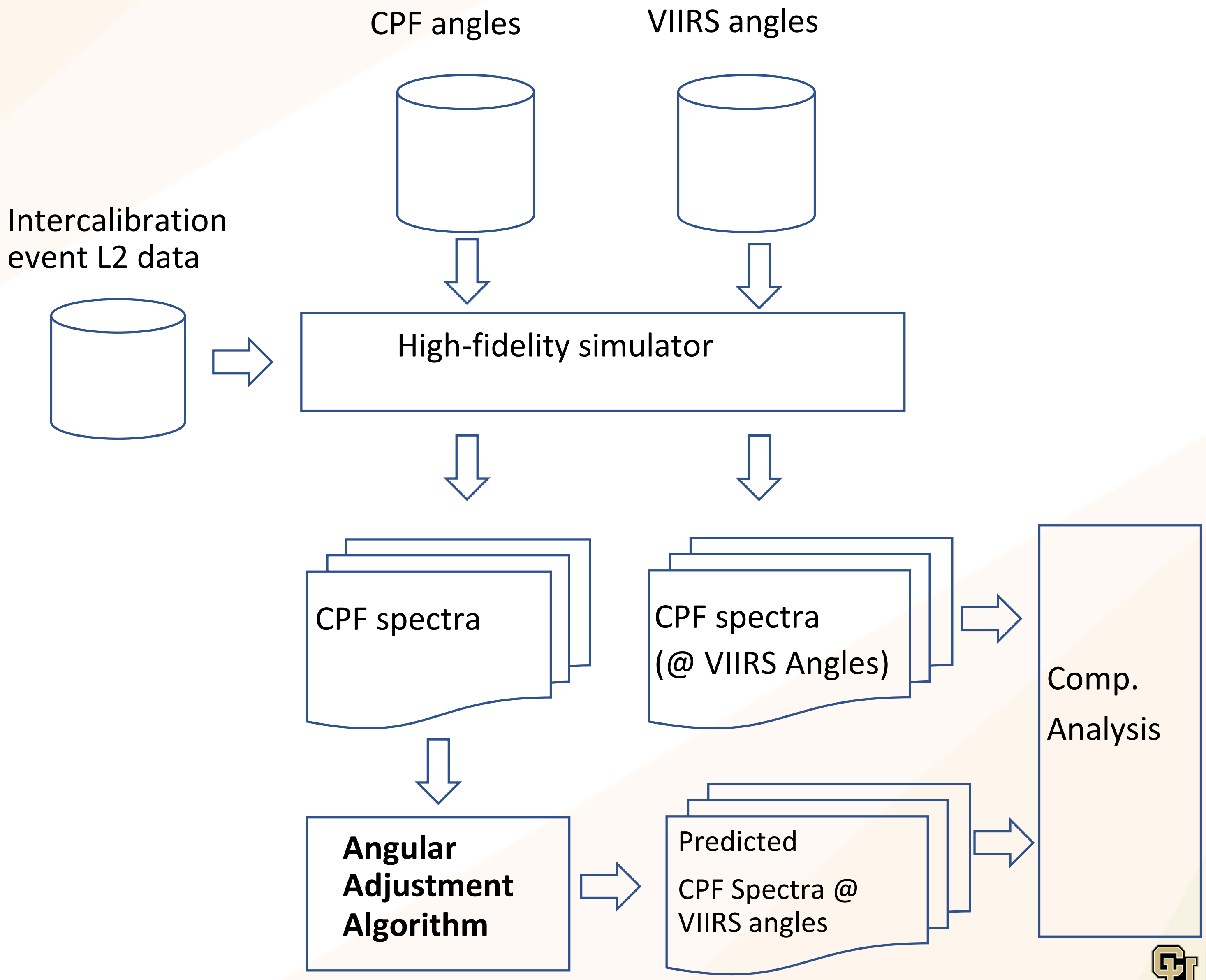
- Without sample aggregation, spatial mismatching is a prime contributor to uncertainty budget
- Intercalibration events will have different temporal differences between CPF & CERES
- CERES PSF used to spatially convolve CPF footprints within CERES footprints
- How many samples are needed each month to reduce spatial & temporal matching noise (assumed random) to 0.1%?
  - Estimated single sample matching noise of 10% -> Increases samples needed to 10K



Note: Squares are not drawn to scale

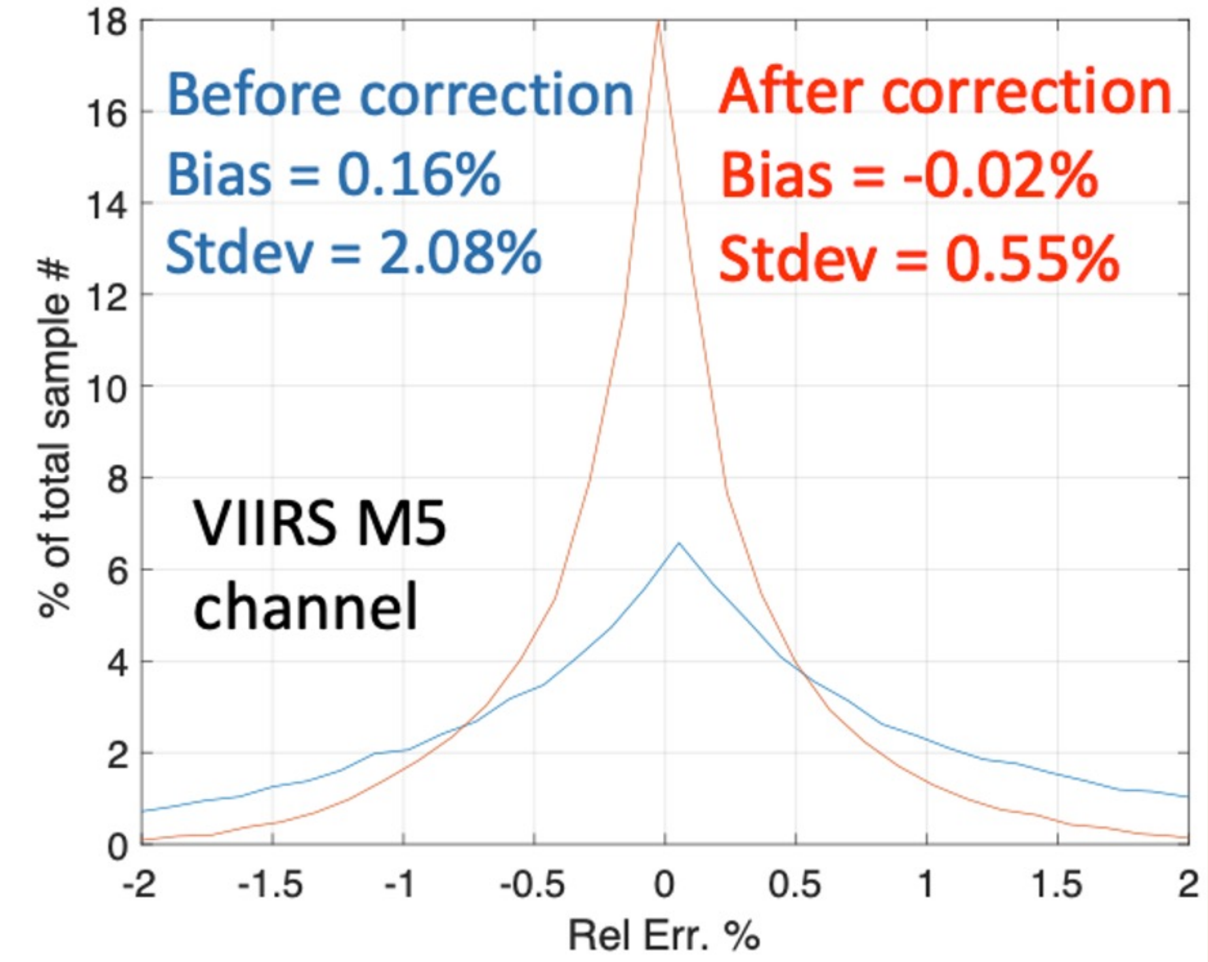
CPF-CERES Angular Adjustment

Process for evaluating angular adjustment algorithm



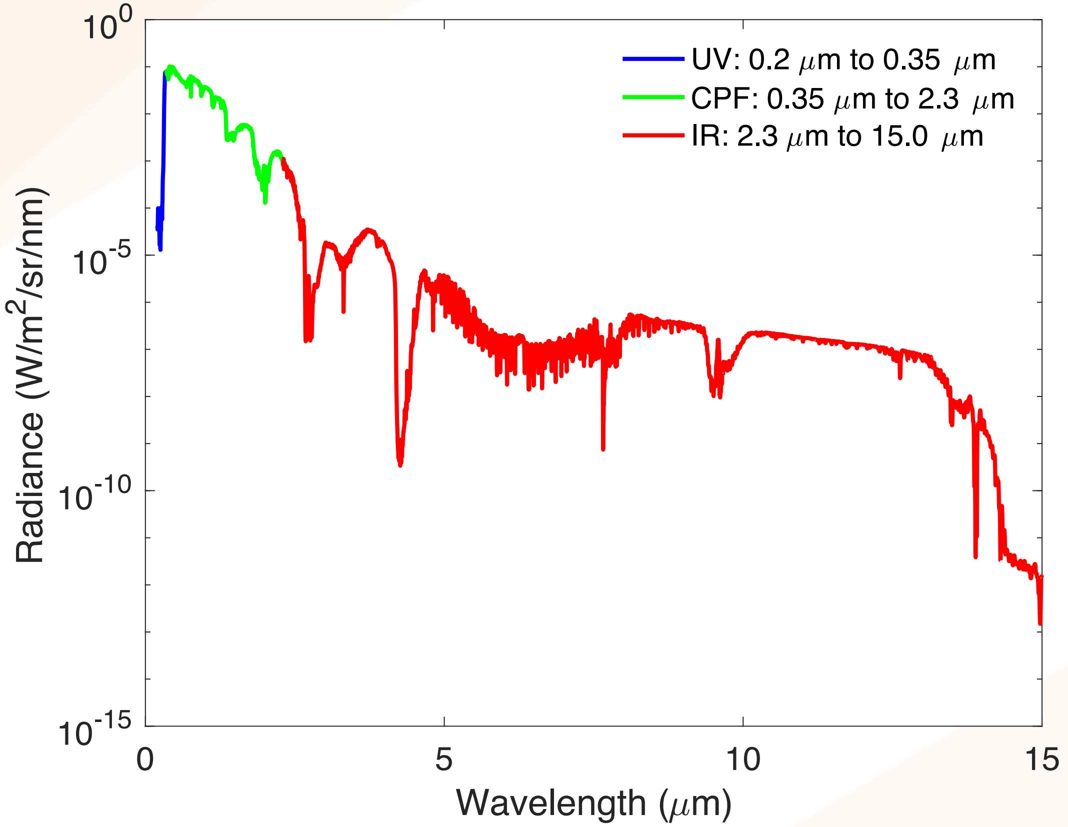
CPF-CERES Angular Adjustment

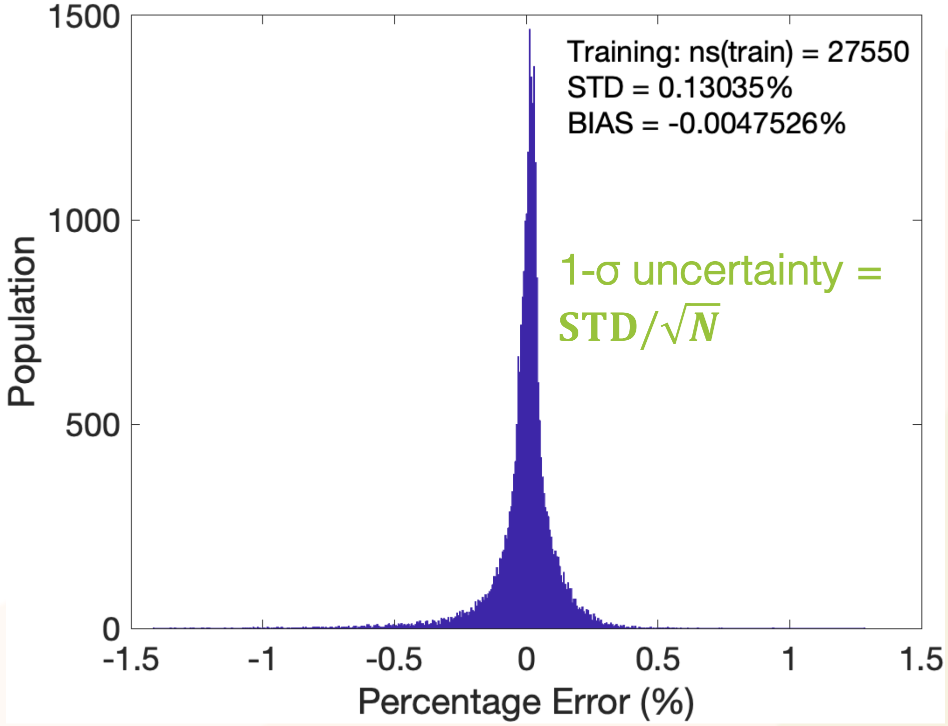
- Unaddressed angular differences contribute both *random* and *systematic* uncertainties
- PCRTM-based algorithm for angular adjustment developed that leverages spectral correlations to predict what CPF would have measured with same sun-view geometry as target (CERES)
- Angular correction LUTs generated based on thousands of simulated CPF-like radiance spectra (randomly chosen) at different angular conditions



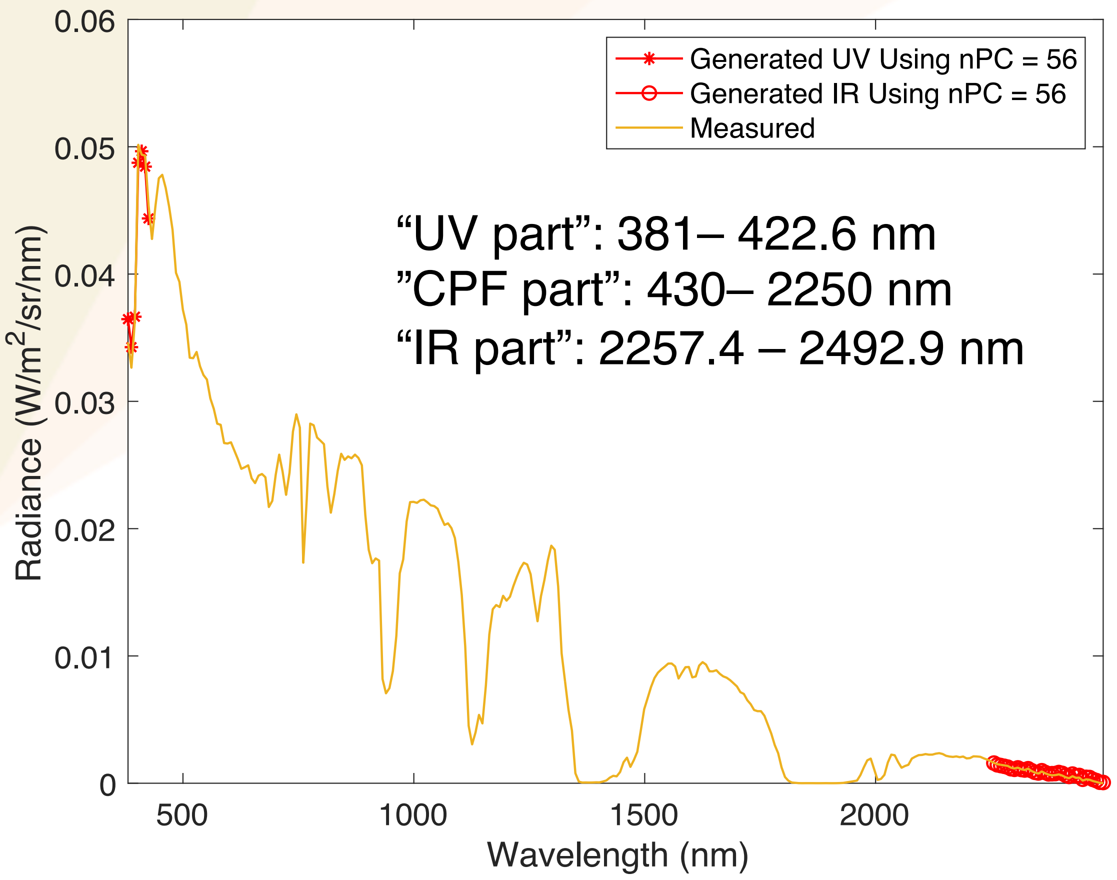
CPF-CERES Spectral range extension

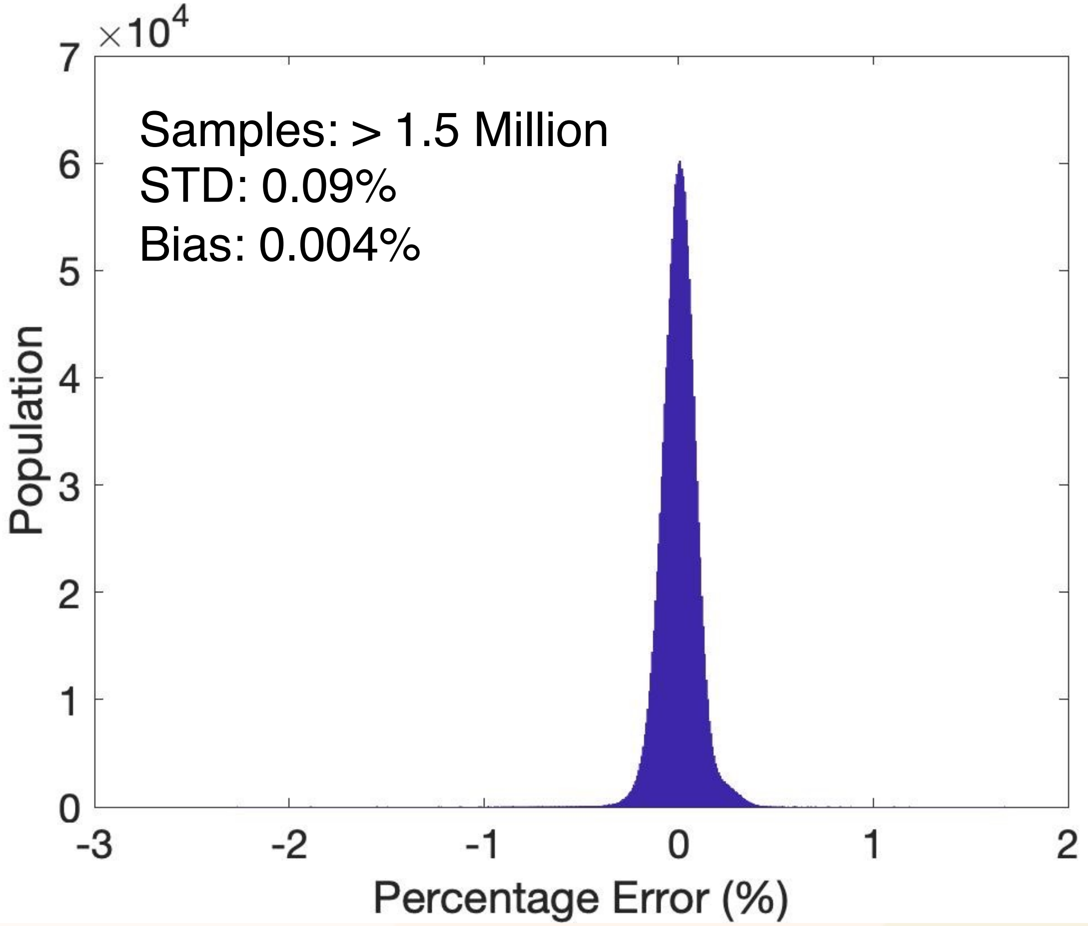
- CPF measurements must be extended from 350-2300 nm to match CERES spectral range
  - For comparison with CERES unfiltered radiance: 200 nm – **15 um**
  - For comparison with CERES filtered radiance: 200 nm - **5 um**
  - Spectral gap filling algorithm relies on spectral correlation among CPF bands
- Anticipated **1-σ uncertainty < 0.1%**





CPF-CERES Gap-Filling: Validation With EMIT





CPF-CERES Intercalibration Uncertainty Sources

CPF-CERES Intercalibration Uncertainty (0.22%)

- **Spatial & Temporal Matching Noise (0.1%)**
  Spatial convolution of CPF spectral radiance within CERES footprints
- **Point Spread Function Knowledge (<0.1%)**
  Applicable to CERES only
- **Spectral Matching (0.1%)**
  Difference in spectral coverage between CPF and CERES
- **Angular Adjustment (0.1%)**
  Imperfect angle matching between CPF and CERES
- **Monthly stability (<0.1%)**
  Uncertainty Contribution due to any variability in CERES calibration within a month

CPF-CERES Intercalibration Outcomes

- Scaling/slope and offset
- Assessment of sensor linearity response
- Evaluation of scan angle dependence
  - Quarterly or bi-annual basis; depends on sample size per scan angle
- Evaluation of spectral degradation of SW channel in orbit
  - Scene-stratified intercalibration analysis: Quarterly bi-annual basis
- Improved CERES SW radiances in terms of CPF radiometric reference
  - Impact of applying the scaling factors to CERES SW radiances

Other Reasons to be excited about CPF

Novel Measurements: CLARREO Pathfinder will be ***the first*** Earth-observing mission with its combination of high accuracy, spectral range, spectral resolution, ***and*** spatial resolution.

Other Reasons to be excited about CPF

Novel Measurements: CLARREO Pathfinder will be ***the first*** Earth Science mission with its combination of high accuracy, spectral range, spectral resolution, ***and*** spatial resolution.

- High accuracy measurements critical for detecting climate trends
  - e.g. Development of climate benchmark prototypes
- Wealth of possibilities for additional RS hyperspectral science studies
  - e.g. New and complementary retrieval algorithms
- Reference intercalibration capabilities are far-reaching across Earth Science measurements
  - Intercalibrating (some) concurrently operational RS sensors
  - Support for **GSICS**: Global Space-based Inter-Calibration System
  - Improved characterization of The Moon & pseudo-invariant calibration targets (improving past instruments' calibration)