# CLARREO PATHFINDER: MISSION OVERVIEW AND CURRENT STATUS

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## ABSTRACT

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder (CPF) mission consists of a high accuracy reflected solar spectrometer that will take measurements from the International Space Station for one year starting in 2023. CPF will demonstrate that its novel on-orbit absolute calibration approaches are capable of achieving 0.3% (1-sigma) radiometric uncertainty. Additionally, using its two-axis pointing gimbal which enables nearly-concurrent measurements matching look angles with other orbiting sensors, CPF will demonstrate a novel inter-calibration approach by inter-calibrating CERES and VIIRS. CPF is currently in its Final Design and Fabrication Stage and recently passed its Critical Design Review.

***Index Terms***— accuracy, reflectance, calibration, inter-calibration

## 1. INTRODUCTION

The (CLARREO) Pathfinder (CPF) mission [1] began in 2016 and consists of a reflected solar (RS) spectrometer that will be hosted on the International Space Station for one year of operations starting in 2023. CPF will demonstrate essential measurement technologies required to obtain high-accuracy RS climate observations.

## 2. MISSION OVERVIEW

CLARREO Pathfinder has two primary mission objectives. The first objective is to demonstrate on-orbit calibration approaches to achieve and maintain an unprecedented high accuracy with SI-traceability [2]. The second objective is to demonstrate a novel on-orbit inter-calibration approach [3] by inter-calibrating two other reflected solar sensors: Clouds and the Earth's Radiant Energy System (CERES) shortwave (SW) channel and Visible Infrared Imager Radiometer Suite (VIIRS) RS bands. CPF Level 0, Level 1, and Level 4 data will be publicly available through the Atmospheric Science Data Center (ASDC) at NASA Langley Research Center.

## 3. HYSICS INSTRUMENT

The CPF spectrometer is based on the HyperSpectral Imager for Climate Science (HySICS) instrument developed by the University of Colorado/Laboratory for Atmospheric and Space Physics in Boulder, CO [2]. HySICS is a pushbroom imaging spectrometer that is designed to have a radiometric uncertainty of 0.3% (1-sigma), which is a three to ten times improvement over existing spaceflight RS instruments and is achieved via direct, on-orbit measurements of the accurately known spectral solar irradiance.

HySICS has a 70 km swath at nadir that is comprised of 480 discrete measurement pixels. At each pixel location, HySICS simultaneously measures spectrally-resolved reflected radiance from 350 to 2300 nm with 3 nm sampling. After applying calibration factors, the data comprise "image cubes" which are the spatially- and spectrally-resolved measurements of Earth's solar reflectance and radiance.

Direct measurements of the Sun are taken using a 0.5 mm aperture and sufficiently short integration time. When HySICS observes the Moon or Earth, it uses a larger diameter aperture of 20 mm and longer integration time. Additional instrument characteristics are shown in Table 1.

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|---|---|
| **Radiometric Uncertainty** | 0.3% (1-sigma) |
| **Spectral Range** | 350 – 2300 nm |
| **Spectral Sampling/Resolution** | 3 nm/6 nm |
| **Polarization Sensitivity** | <1%, 350-1800 nm<br><2%, 1800-2300 nm |
| **Swath Width** | 10 degrees |
| **Spatial Resolution (nadir)** | 0.5 km |
| **Sampling Rate** | 15 Hz |

Table 1: Key characteristics of the CPF instrument.

Both the calibration and inter-calibration approaches will be enabled by the two-axis pointing capability of the instrument, as further described below. The high accuracy measurements from CPF will be a critical demonstration of the measurements needed to develop long-term climate-quality data sets.

## 4. NOVEL CALIBRATION APPROACH

Earth-observing instruments are calibrated on the ground prior to launch; after launch that pre-flight calibration is typically tracked to evaluate how it changes throughout the instrument's lifetime. After the instrument is launched into space, on-orbit resources that are either part of the instrument design (e.g. solar diffusers), the Earth system (e.g. pseudo-invariant targets like deep convective clouds or specific desert scenes), or celestial bodies (e.g. Sun, Moon, deep space) are used to monitor the instrument's sensitivity changes throughout its lifetime in a relative, rather than an absolute, sense.

Alternatively, CPF will achieve its unprecedented accuracy levels primarily with regular on-orbit calibration measurements of the Sun as an on-orbit absolute calibration reference. Figure 1 illustrates the three main operating modes of CPF: nadir (nominal mode, red), solar (orange), and lunar (green) observations. A key benefit of the two-axis pointing capability of the CPF payload is that HySICS is able to view the Sun, Moon, and Earth by way of the same optical path, enabling the novel on-orbit calibration approach and the achievement of the 0.3% radiometric uncertainty.

The instrument slit will be scanned perpendicularly across the solar disk to collect all solar power incident at the input aperture. Comparisons to known spectral solar irradiance provide the instrument's SI-traceable accuracy. Using this on-orbit solar reference, Earth reflectance measurements are radiometrically calibrated and will be distributed through the CPF Level 1 data products. The sun will also be used for flat field scans for both the 0.5 mm aperture and 20 mm aperture. These flat field scan measurements will be used to correct for pixel-to-pixel variations in detector sensitivity.

In-flight temperature changes are expected to cause small shifts in instrument optical alignment, resulting in shifts in wavelength scale and thermal background. Wavelength scale shifts can cause errors around high gradient spectral features, such as at the edge of absorption lines. A HgAr pen-ray lamp with known spectral atomic lines between 400 nm and 2100 nm will accompany the instrument. Measurements of lamp will be used to determine the wavelength scale of the instrument regularly throughout its lifetime. The instrument will also take dark space measurements to determine the residual blackbody radiation emitted by the instrument. See [2] for additional details of the HySICS instrument and calibration design.

The ability of HySICS to take the necessary on-orbit calibration measurements makes the instrument robust to the on-orbit degradation that can plague absolute calibrations of instruments.

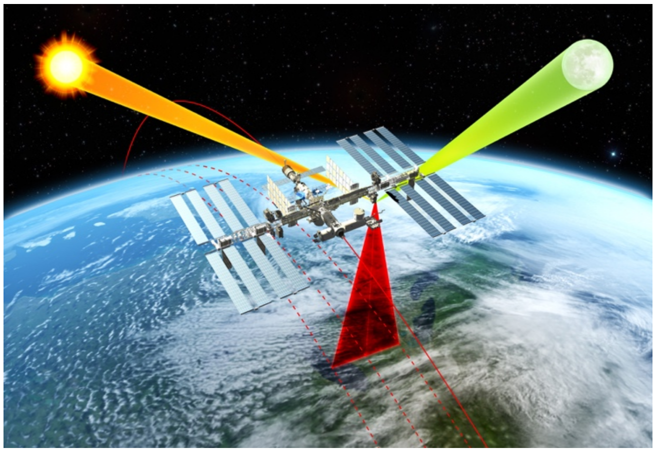

Figure 1: An illustration of key CLARREO Pathfinder observation modes: nominal operation at nadir (red) and direct solar (orange) and lunar (green) observations. The solar and lunar scans are two of the observations modes that will be used for regular on-orbit calibration of the CPF instrument.

## 5. INTER-CALIBRATION

By measuring spectral radiance and reflectance with high accuracy, the CPF instrument will be able to serve as an on-orbit radiometric calibration reference for other operational Earth-viewing reflected solar sensors. CPF will demonstrate this capability by inter-calibrating the SW channel of CERES and RS bands of VIIRS. Two-axis pointing, a spectral range of 350-2300 nm, and spectral sampling of 3 nm enable the CPF instrument to provide nearly coincident temporal (within 10 minutes), spatial, angular, and spectral matching observations with inter-calibration targets, providing sufficient sampling to reduce random errors [4]. Figure 2 shows the CPF instrument matching its boresight to that of either the CERES or VIIRS instrument on JPSS-1, indicated by the overlapping red and green lines and shaded areas.

The CPF inter-calibration team is developing a series of algorithms that will be used to construct CPF-VIIRS and CPF-CERES Level 4 data products that will include all the information needed to conduct the inter-calibration data analysis. These algorithms include the spatial convolution, spectral convolution, and angular corrections needed to account for the spatial, spectral, and angular differences between CLARREO Pathfinder and each of its target (CERES & VIIRS) inter-calibration measurements. The mission requirement for the uncertainty contribution from these algorithms is 0.3%, in order to not exceed the radiometric uncertainty of the CPF instrument [5].

The inter-calibration data analysis will refine knowledge of the CERES and VIIRS effective offsets, gains, non-linearities, spectral responses, and polarization sensitivity (VIIRS only).

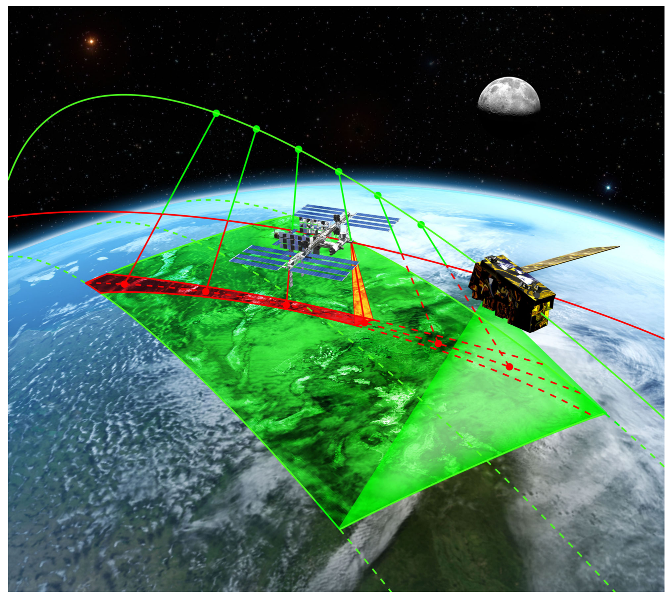

Figure 2: Illustration of the CPF on ISS inter-calibration approach showing how nearly-concurrent measurements from CPF as the reference (red swath shows CPF line-of-sight) and measurements taken by the CERES and VIIRS on JPSS-1 (green swath).

## 7. CPF CURRENT STATUS

The CPF passed its Critical Design Review (CDR) in March 2020 and is currently in the midst of the Final Design and Fabrication Phase. The System Assembly, Integration, and Test phase is currently scheduled to begin in late summer 2021. The current plan is for the CPF mission to be operational starting in 2023. The CPF project status will continue to be updated at https://clarreo-pathfinder.larc.nasa.gov/.

## 8. REFERENCES

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