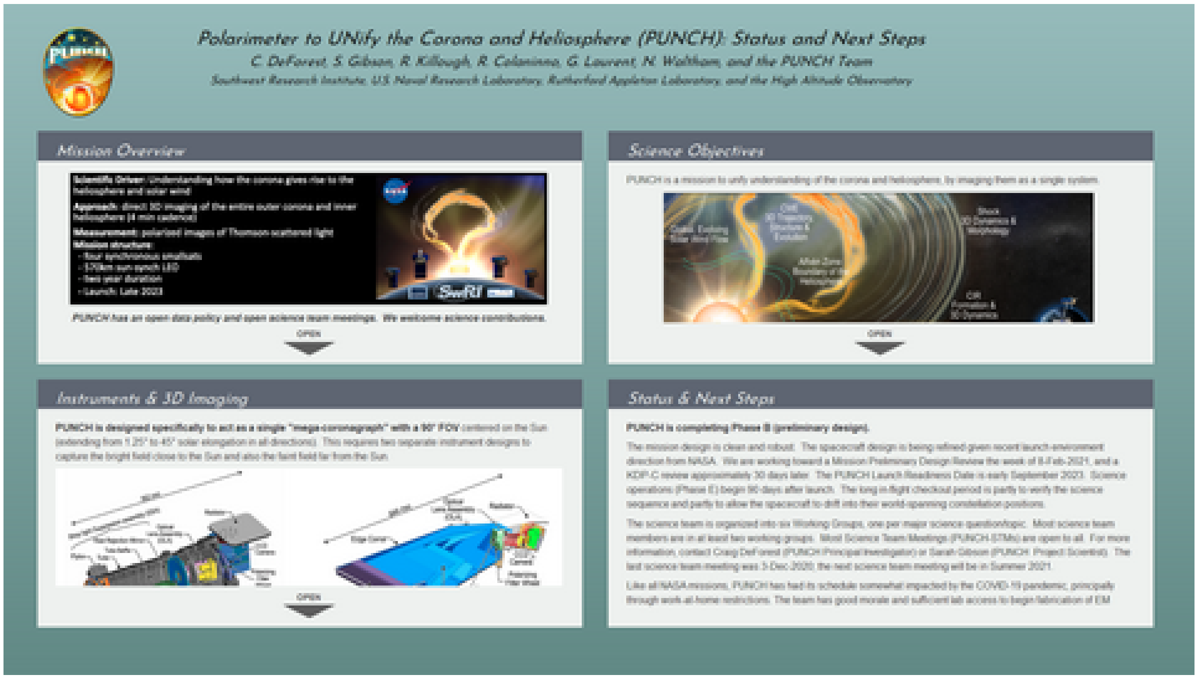
Polarimeter to UNify the Corona and Heliosphere (PUNCH): Status and Next Steps



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Southwest Research Institute, U.S. Naval Research Laboratory, Rutherford Appleton Laboratory, and the High Altitude Observatory

PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

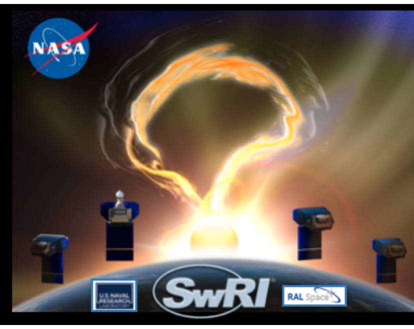
MISSION OVERVIEW

Scientific Driver: Understanding how the corona gives rise to the heliosphere and solar wind

Approach: direct 3D imaging of the entire outer corona and inner heliosphere (4 min cadence)

Measurement: polarized images of Thomson-scattered light

Mission structure:
- four synchronous smallsats
- 570km sun-synch LEO
- two year duration
- Launch: Late 2023

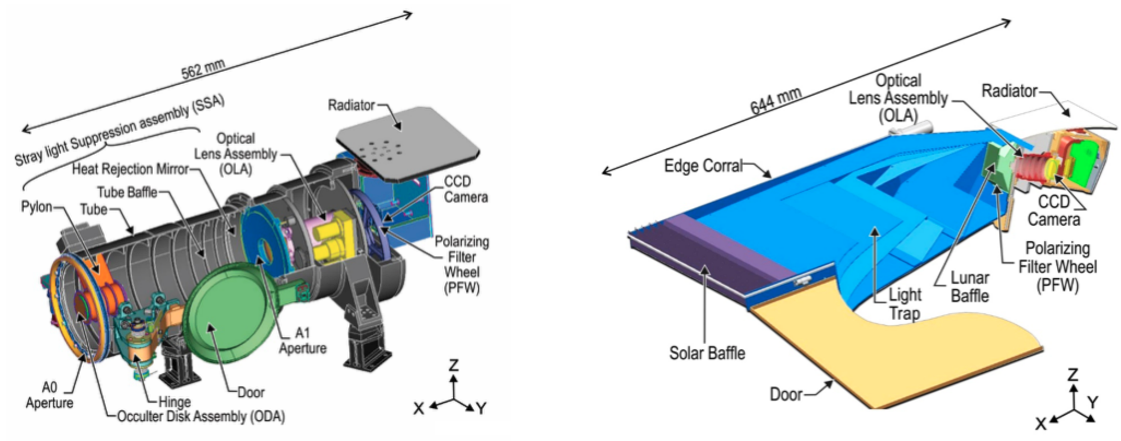


PUNCH has an open data policy and open science team meetings. We welcome science contributions.

For more mission info, visit the mission gateway website: https://punch.spaceops.swri.org (https://punch.spaceops.swri.org)

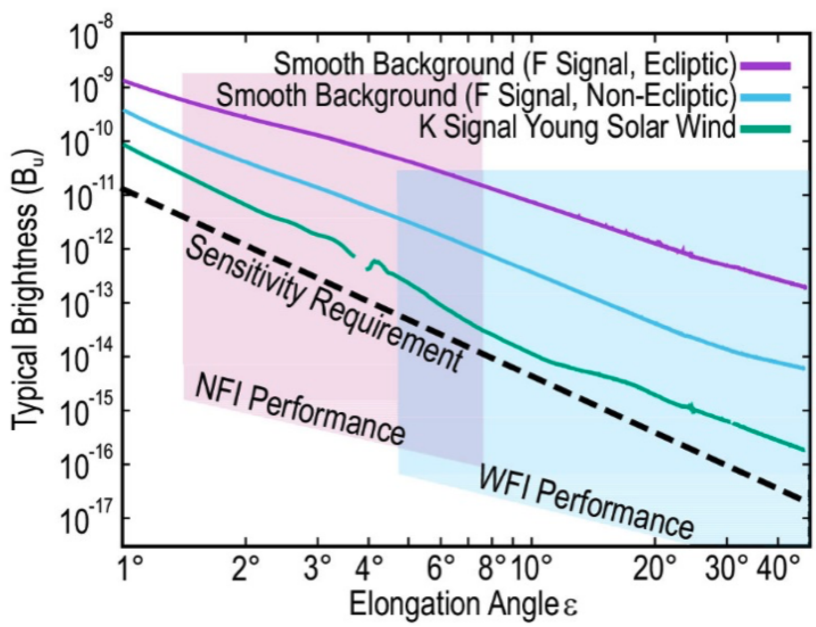
INSTRUMENTS & 3D IMAGING

PUNCH is designed specifically to act as a single "mega-coronagraph" with a 90° FOV centered on the Sun (extending from 1.25° to 45° solar elongation in all directions). This requires two separate instrument designs to capture the bright field close to the Sun and also the faint field far from the Sun.



LEFT: Narrow Field Imager (NFI) is an externally-occulted compact-design coronagraph from NRL, with FOV similar to SOHO/LASCO-C3 (1.25° - 8° from Sun center). RIGHT: Wide Field Imager (WFI; 3x) is based on the STEREO/HI instruments and analogous to NFI in linear geometry, with a 40° wide truncated-square FOV centered 25° from the Sun.

The two instruments are necessary because of the wide dynamic range across the PUNCH field of view. The K signal (Thomson-scattered light) varies by nearly five orders of magnitude across the field of view, and the much brighter background varies by over three orders. The WFI and NFI fields of view overlap by approximately 3°, to ensure good cross-calibration.



Removal of the background is critical, and PUNCH has several features (both in space and on the ground) to manage it. In particular, photometry across instruments is maintained at the 10^{-4} level.

- Optics have matched passbands
- Cameras are operated in electronic frame-transfer mode for stable exposure time (~10^{-5} stability)
- The entire constellation is synchronized to ~1 second to avoid motion mismatch across cameras

• Each pair of fields of view (each pair of WFIs; and each WFI with NFI) overlaps to permit cross-calibration

• On-board stimulation lamps for the cameras maintain fine-scale photometric calibration; starfield maintains large-scale calibration

• Quartic-polynomial (not just linear) flat fielding reduces nonlinear effects by a factor of ~30x

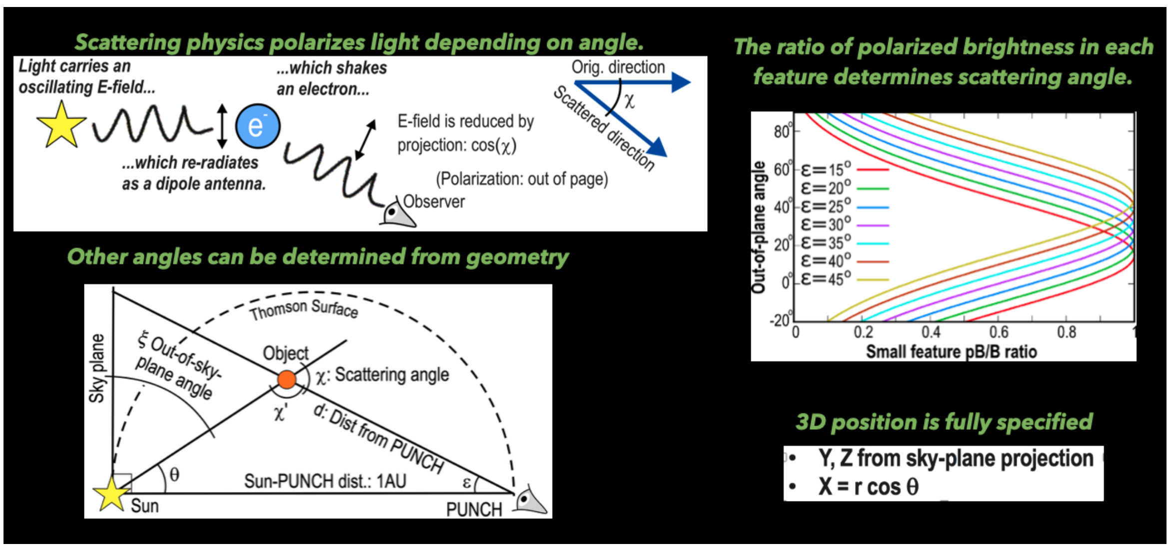
• Transfer PSF convolution is used to equalize the PSF of each instrument across its field of view, and to one another.

• Starfield correlation is used to co-align individual exposures to better than 1/30 pixel RMS

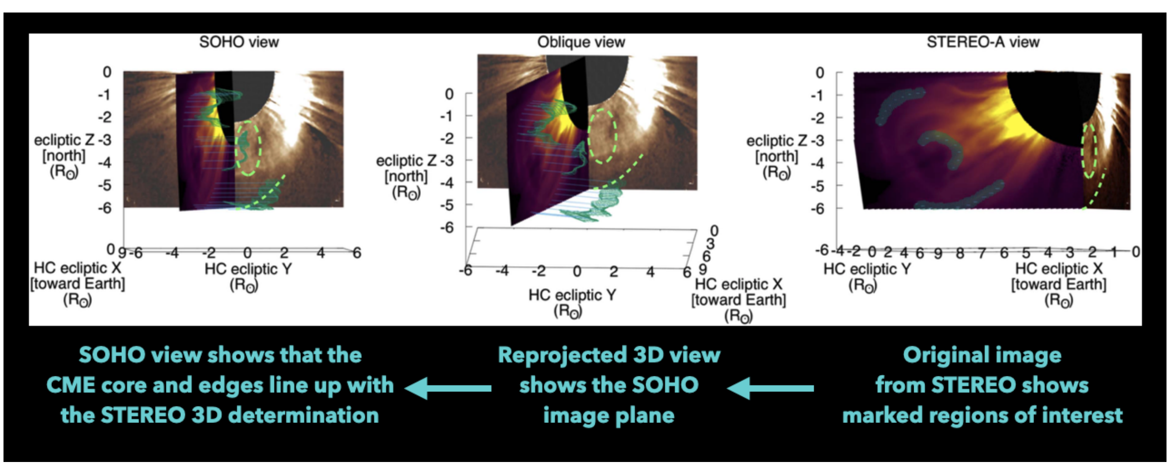
These measures allow algorithmic subtraction of the steady and slowly varying starfield and F corona, to produce full-constellation K corona mosaics with background sources suppressed by a factor of 3,000 or more.

3D imaging uses the polarization properties of Thomson scattering.

The process is described in DeForest, Howard & Tappin 2013 (https://www.boulder.swri.edu/~deforest/ewExternalFiles/The%20Astrophysical%20Journal%202013%20Deforest-1.pdf).

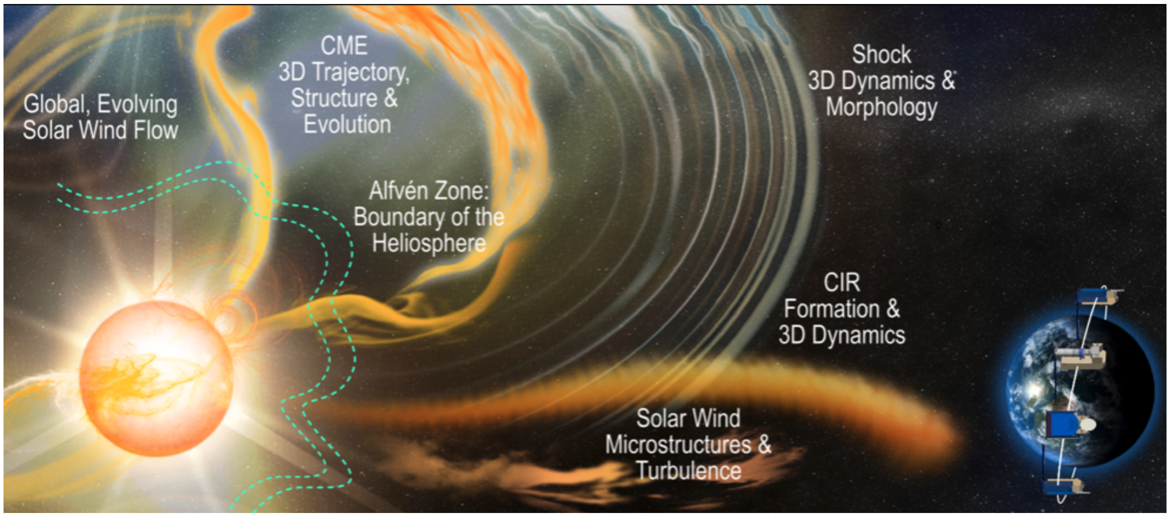


The process has been vetted using STEREO data (DeForest, de Koning & Elliott 2017 (https://www.boulder.swri.edu/~deforest/ewExternalFiles/DeForest%20et%20al.%20-%202017%20-%203D%20Polarized%20Imaging%20of%20Coronal%20Mass%20Ejections%20Ch.pdf)):



SCIENCE OBJECTIVES

PUNCH is a mission to unify understanding of the corona and heliosphere, by imaging them as a single system.



Solar physics and solar wind physics have historically been separated by detection technology. Solar physicists have used remote sensing (imaging, spectroscopy, and radio detection) to analyze the star. Solar wind physicists have used in-situ sampling of the solar wind to determine its composition and draw inferences about its physical state and structure. Neither technique gives a complete picture -- and, until now, they have left an unmeasurable gap in the outer recahes of the solar corona and inner reaches of the heliosphere. This gap has not been well explored nor well measured ... until now. Parker Solar Probe is flying through the outer portion of the corona. PUNCH will bring photometric imaging and structure and flow analysis into the solar wind itself, making the invisible solar wind ... visible.

The PUNCH science goal is organized into two science Objectives, that ramify into six well-formed science questions the mission is designed specifically to address. The questions are summarized by the topics in the figure above. The objectives are:

1. The Ambient Solar Wind: Understand how coronal structures become the ambient solar wind.

The outer solar corona marks several critical transitions in the flow of the solar wind: from sub-Alfvénic to super-Alfvénic; from low-β to near-unity β; and from striated, radially structured flow to turbulent, "flocculated" or "puffy" flow. The outer corona itself is very highly structured, with measurable striations that correspond to the scale of intergranular magnetic flux concentrations at the surface of the Sun, and dynamic. The outer reaches of the corona are not a smooth laminar flow but a riotous torrent of ejecta and variations speeding outward to become the ambient solar wind. PUNCH will, for the first time, provide optically limited (rather than noise limited) imaging of this region and its evolution, to determine how the corona changes as it becomes the solar wind. PUNCH will also provide the first global solar wind flow maps on a cadence of hours, to determine how solar wind flow varies with time around the Sun.

2. The Dynamic Solar Wind: Understand the dynamic evolution of transient structures in the young solar wind.

Understanding "large transient structures" is the thrust of space weather science. Variations in density, speed, and magnetic field are responsible for space weather science at Earth. Large transient structures in the solar wind include CMEs, corotating interaction regions, and shocks. All three are associated with various kinds of space weather events. Understanding how coronal structures evolve as they cross the solar system (as CMEs) is an important missing link to understanding space weather at Earth and elsewhere. Corotating interaction regions are the most common source of geomagnetic storms, but remain poorly understood largely because it is difficult to measure either their large-scale structure or their origin region near the Sun. Shocks are well understood from the standpoint of 1-D physics, but real shocks are more complex, with 3D structuring and shape instabilities that may affect both the shock itself and its production of solar energetic particles.

PUNCH will address these topics and more. For more details, and to connect with the science team, visit the mission gateway website at https://punch.spaceops.swri.org (http://punch.spaceops.swri.org).

STATUS & NEXT STEPS

PUNCH is completing Phase B (preliminary design).

The mission design is clean and robust. The spacecraft design is being refined given recent launch environment direction from NASA. We are working toward a Mission Preliminary Design Review the week of 8-Feb-2021, and a KDP-C review approximately 30 days later. The PUNCH Launch Readiness Date is early September 2023. Science operations (Phase E) begin 90 days after launch. The long in-flight checkout period is partly to verify the science sequence and partly to allow the spacecraft to drift into their world-spanning constellation positions.

The science team is organized into six Working Groups, one per major science question/topic. Most science team members are in at least two working groups. Most Science Team Meetings (PUNCH-STMs) are open to all. For more information, contact Craig DeForest (PUNCH Principal Investigator) or Sarah Gibson (PUNCH Project Scientist). The last science team meeting was 3-Dec-2020; the next science team meeting will be in Summer 2021.

Like all NASA missions, PUNCH has had its schedule somewhat impacted by the COVID-19 pandemic, principally through work-at-home restrictions. The team has good morale and sufficient lab access to begin fabrication of EM equipment including the EM detectors at Rutherford Appleton Labs in the UK.

ABSTRACT

The Polarimeter to UNify the Corona and Heliosphere (PUNCH) is a NASA Small Explorer mission, to understand the solar corona and young solar wind as a complete system. Science objectives are to measure and understand how the ambient solar wind arises from the corona, and to understand how transient events (such as CMEs) propagate and evolve in the inner heliosphere. PUNCH uses direct, global, spatially continuous, three dimensional imaging in polarized visible light, to observe the outer corona and inner heliosphere as elements of a single, connected system. PUNCH comprises four matched and synchronized small-satellite observatories, operating as a "virtual instrument" to image Thomson-scattered light from low-Earth orbit. PUNCH is the first coronal and solar wind imaging mission designed specifically to produce 3D images from a single vantage point using the polarization properties of Thomson scattering. In addition, it will produce routine, several-times-per-day maps of solar wind flow throughout the top of the corona and bottom of the inner heliosphere, based on motion analysis of the image stream. PUNCH has an open data policy and is seeking scientific engagement throughout the heliophysics community.

PUNCH is wrapping up its Phase B (preliminary design), and is working toward a 2023 launch for a two-year nominal mission. We present a very brief overview of the mission, describe current status and next steps, and indicate how to engage with the PUNCH science team and upcoming mission.