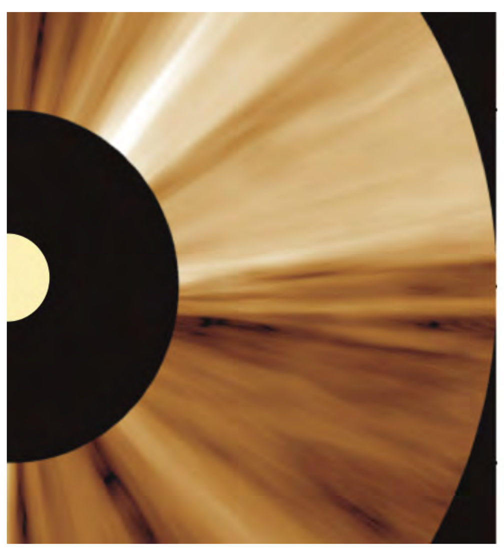
Imaging the Solar Wind in 3D with the PUNCH Constellation of Small Satellites

C.E. DeForest(1), A. Caspi(1), R.C. Colaninno(2), S.E. Gibson(3), D.M. Hassler(1), A.M. Henry(1), G.T. Laurent(1), R. Killough(1), and the PUNCH Team
(1) Southwest Research Institute (2) Naval Research Laboratory (3) Univ. Corp. for Atmospheric Research

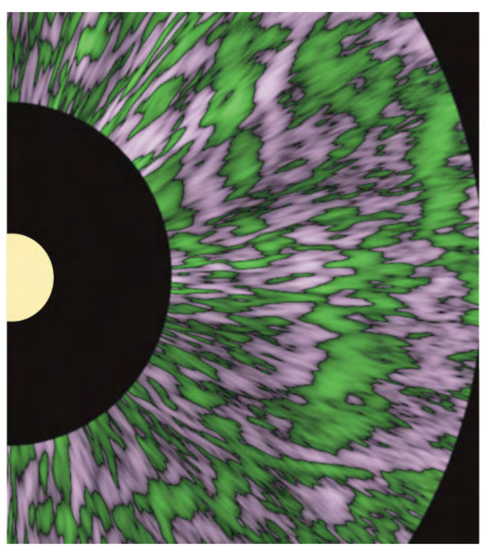
ABSTRACT: The Polarimeter to UNify the Corona and Heliosphere (PUNCH) is the latest Small Explorer mission being developed for NASA. Beginning in 2023, PUNCH will use polarized visible-light imaging to understand how the Sun's corona becomes the solar wind that fills our solar system. The space segment of the mission is a constellation of four small satellites (~50kg each) that work together to form a "virtual instrument" with a 90°-wide field of view centered on the Sun. The physical instruments comprise a coronagraph ("Narrow Field Imager", NFI) and three heliospheric imagers ("Wide Field Imager", WFI) that together sweep out the entire field of view. The instruments are sensitive to polarization, to enable imaging bright features in 3D using the physics of Thomson scattering. PUNCH is being built by a partnership of Southwest Research Institute, the U.S. Naval Research Laboratory, and the Rutherford Appleton Laboratory.

Mysteries of the Corona-Solar Wind Connection



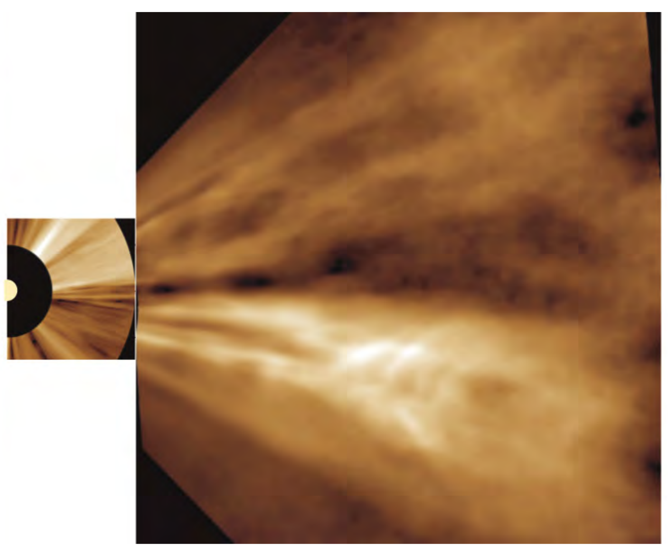
Detailed structure shapes the outer corona and young solar wind:

Recent results from STEREO/COR2 show that the transition to the solar wind is highly structured at all optically resolvable scales. This contrasts with current solar wind models that treat the flow as smooth. With 10x higher sensitivity than COR2, PUNCH reveals how this structure imprints on the solar wind.



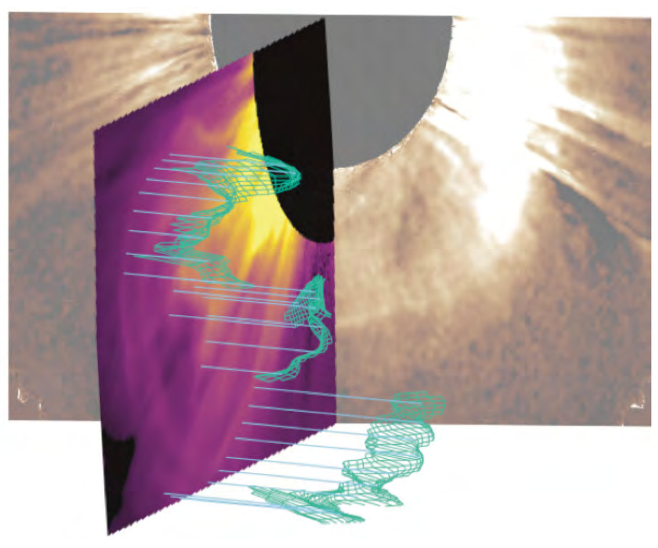
Intermittent structure traces solar wind flow & causes variability at Earth:

Flow in the outer corona is highly variable. Intermittent ejecta may comprise up to 100% of the outflowing plasma. PUNCH is uniquely able to routinely track all of these features in 3D, to trace the origin of the solar wind, identify late-stage acceleration, and determine the role of ejecta in the solar wind as a whole.



The Alfven zone and onset of turbulence mark the elusive base of the heliosphere:

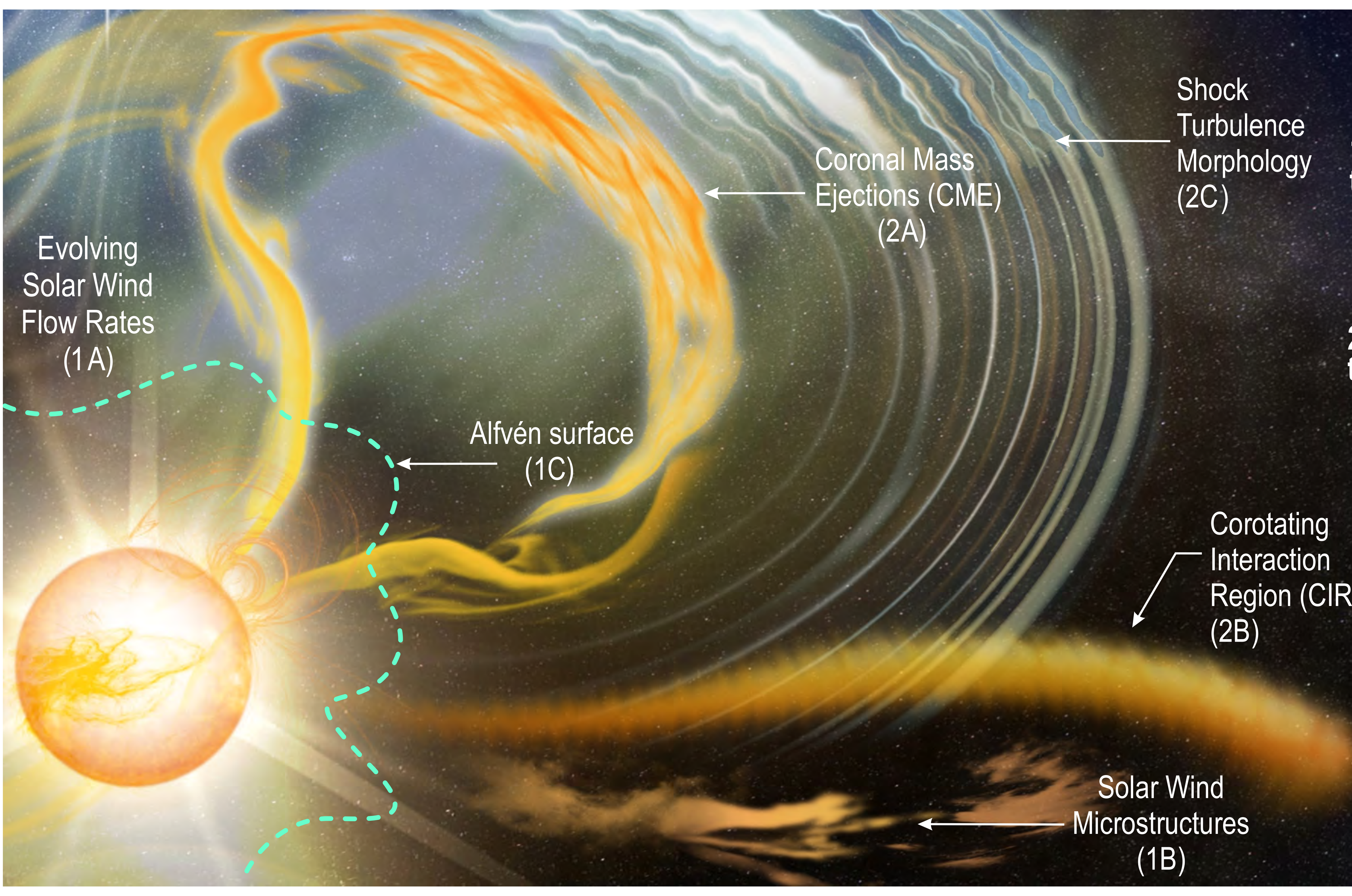
The transition from structured coronal flow to isotropic turbulent flow marks the outer boundary of the corona and the inner boundary of the solar wind. The newly-discovered Alfven zone determines the Sun's open flux budget and shapes the solar wind. PUNCH explores the otherwise inaccessible cross-scale physics of this "discovery space" and the plasma's journey from corona to solar wind.



Polarized imaging reveals how CMEs and solar wind structures move and evolve in 3D

CMEs and other ejecta are fundamentally 3D objects. Deep-field polarized imaging with PUNCH reveals the 3D details of these structures for the first time, revealing: interior evolution; flux rope chirality (tied to leading-edge Bz); 3D propagation, acceleration and possible deflection; and solar wind interaction of CMEs and ejecta.

PUNCH 3D results have immediate and obvious application (R2O) to space weather forecasting.



PUNCH Science Objectives

1. Understand how coronal structures become the ambient solar wind.

- Map evolving solar wind flow
- Identify microstructure and turbulence
- Locate the Alfvén surface

2. Understand the dynamic evolution of transient structures in the young solar wind.

- Track CMEs and their evolution in 3D
- Measure CIR formation & evolution
- Determine large-scale shock dynamics

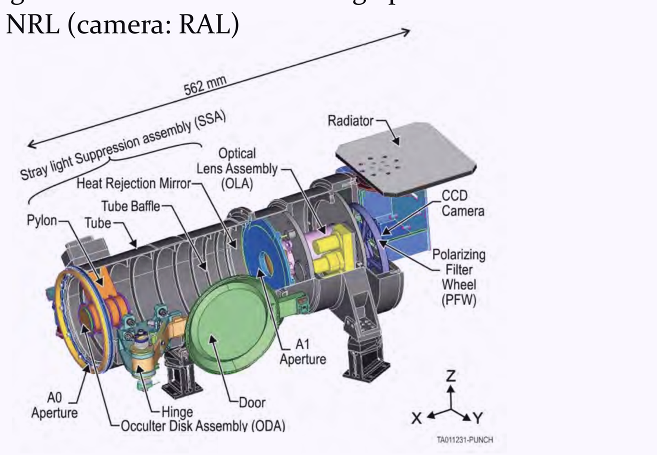
PUNCH Mission Profile

Mission Structure	1+3 constellation of smallsats
Orbit	600km 6am/6pm Sun-synch LEO
Launch	2023 Q1
Duration	2 years (+90 days commissioning)
Spacecraft type	3-axis stable; propulsion for orbit trim
Development Strategy	Spacecraft are interchangeable; each carries one PUNCH camera
Concept of Operations	Full-field imaging, 4 min. cadence (No targeting, no campaigns), Synchronous across constellation
Field of View	All position angles, 1.25°-45° from Sun (90° dia.). NFI: 1.25°-8.0°; WFI: 5°-45°
Wavelength Range	White light (450-750 nm)
Data Products	Full field image mosaics (B and pB) Coronal close-up images (B and pB) Background-subtracted "K" images (B/pB) Solar wind flow maps
Data Distribution	Via VSO and SDAC; open data policy

PUNCH Instruments

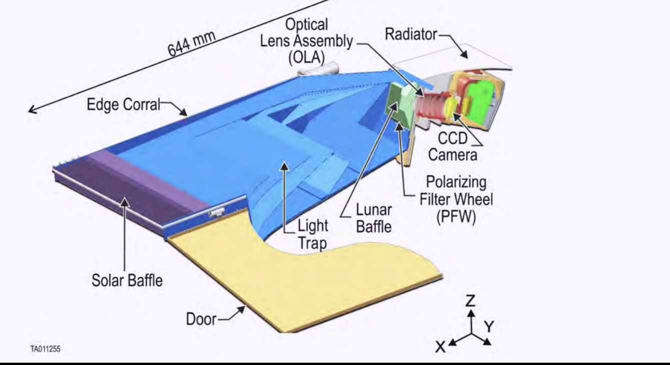
Narrow Field Imager (NFI): Externally occulted coronagraph

- Single stage design is simplified compared to STEREO/COR2
- FOV is 1.25° to 8° from Sun
- Polarizing filter wheel behind focusing optics
- Made at NRL (camera: RAL)

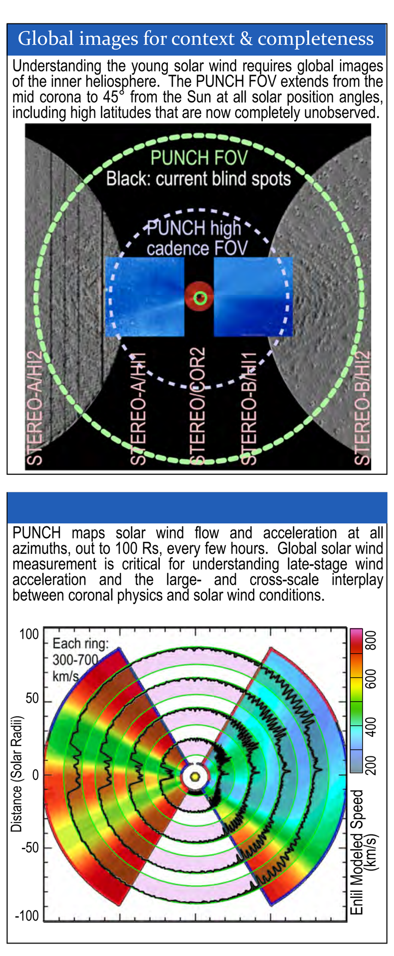


Wide Field Imager (WFI) x3: Heliospheric imager

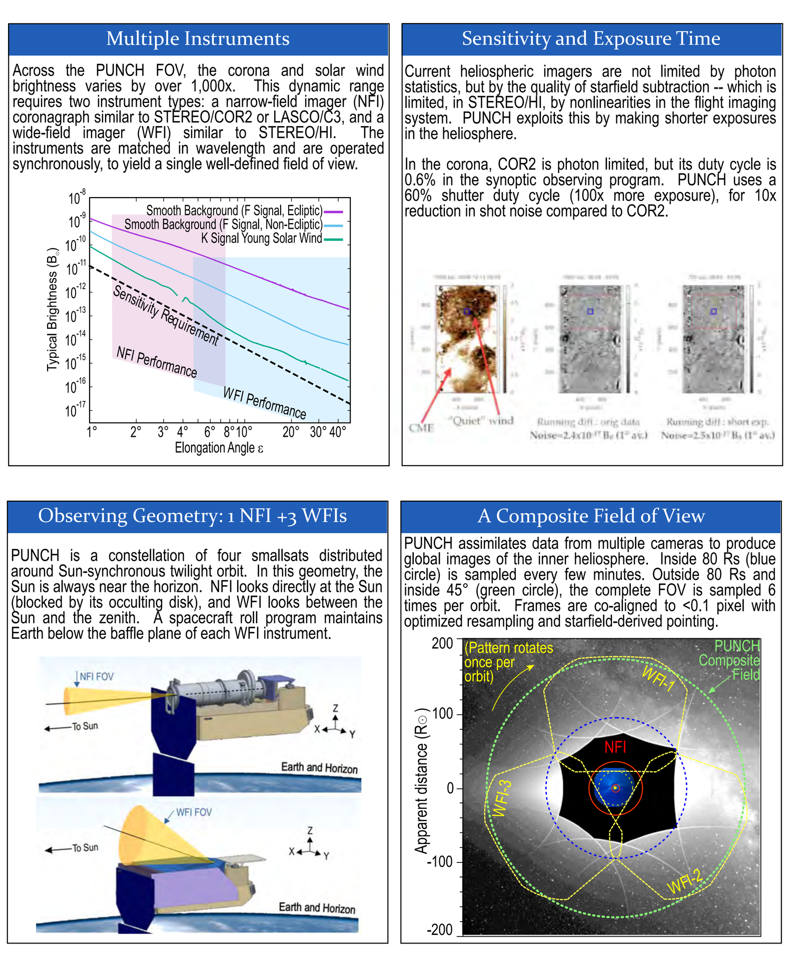
- Linear corral baffle design includes lunar rejection features
- FOV is 40° truncated square (5° to 45° from Sun)
- Polarizing filter wheel ahead of focusing optics
- Made at SwRI (camera: RAL)



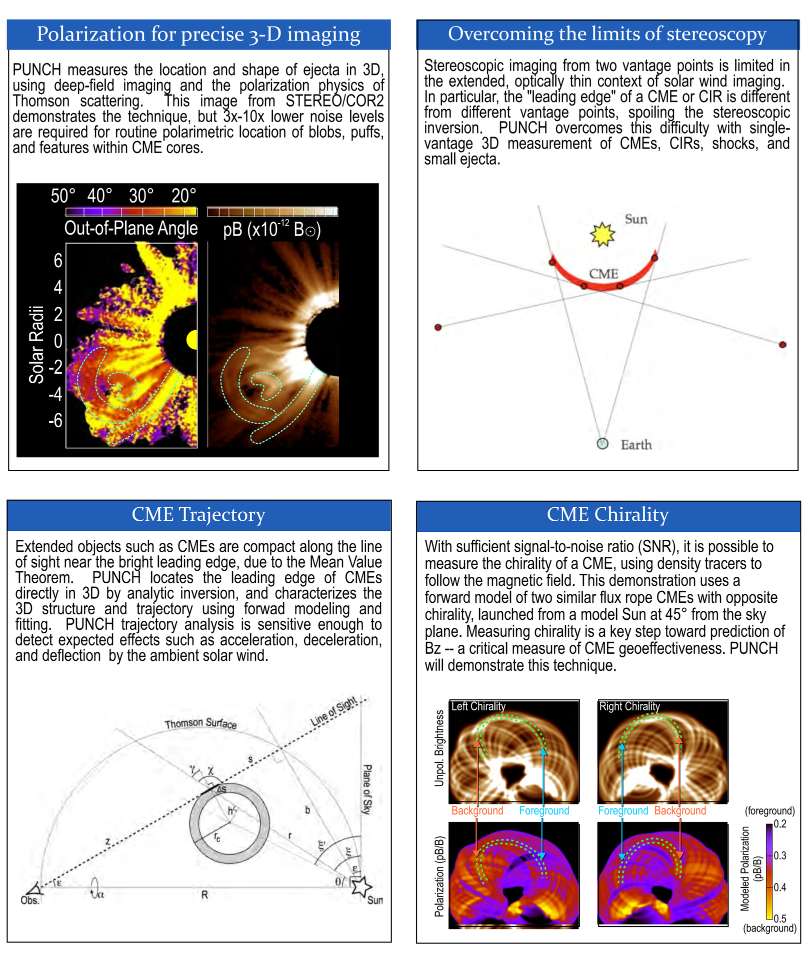
FOV and wind maps



One "virtual instrument", 4 cameras



3D imaging via polarization



How PUNCH Reveals 3D Structure