C.E. DeForest (PI), S.E. Gibson (PS),
R. Killough (PM), and the PUNCH team
SolO MADAWG, 13-Sep-2019

UNIFYING THE SUN & HELIOSPHERE IN THREE DIMENSIONS, WITH

PUNCH

U.S. NAVAL RESEARCH LABORATORY

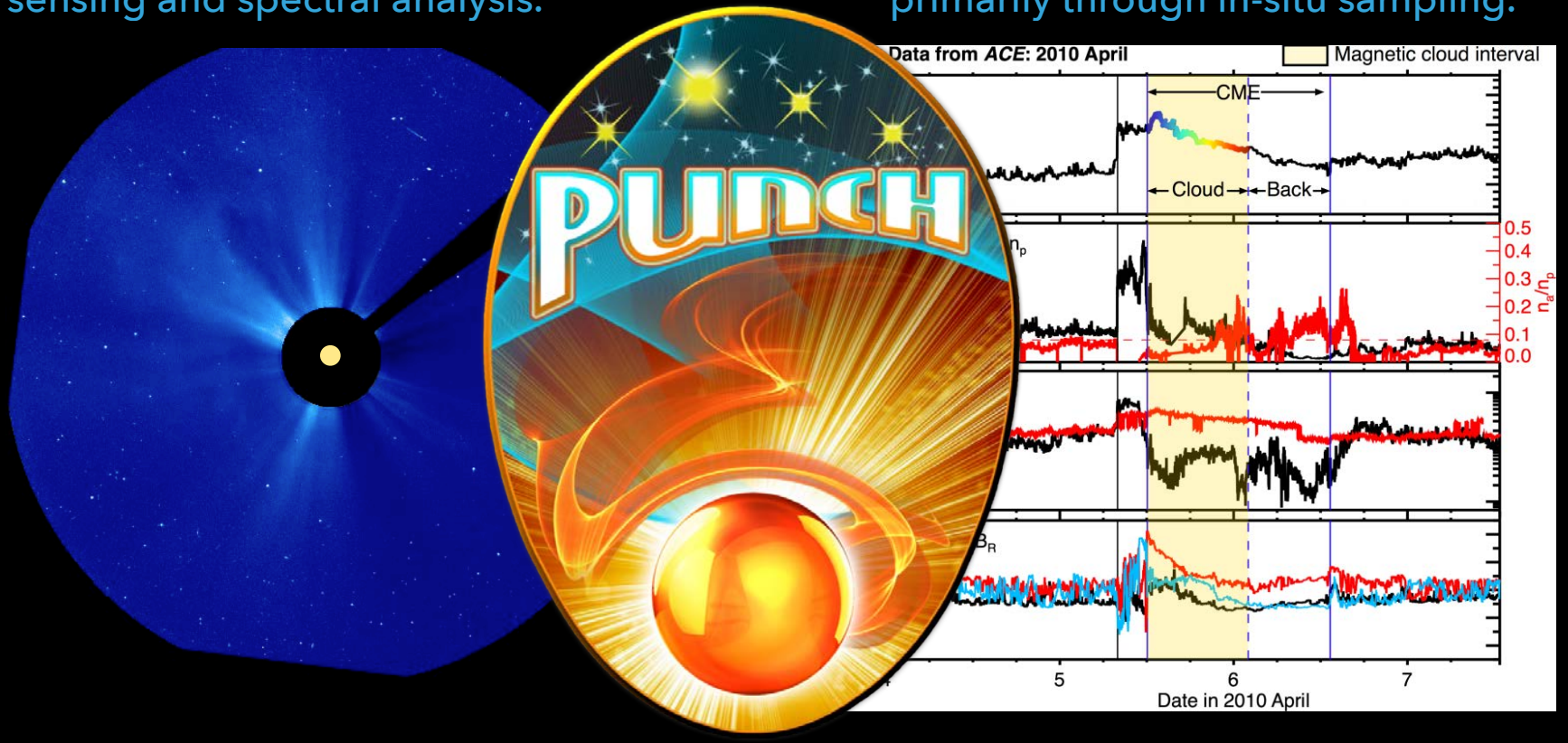
SwRI®

RAL Space

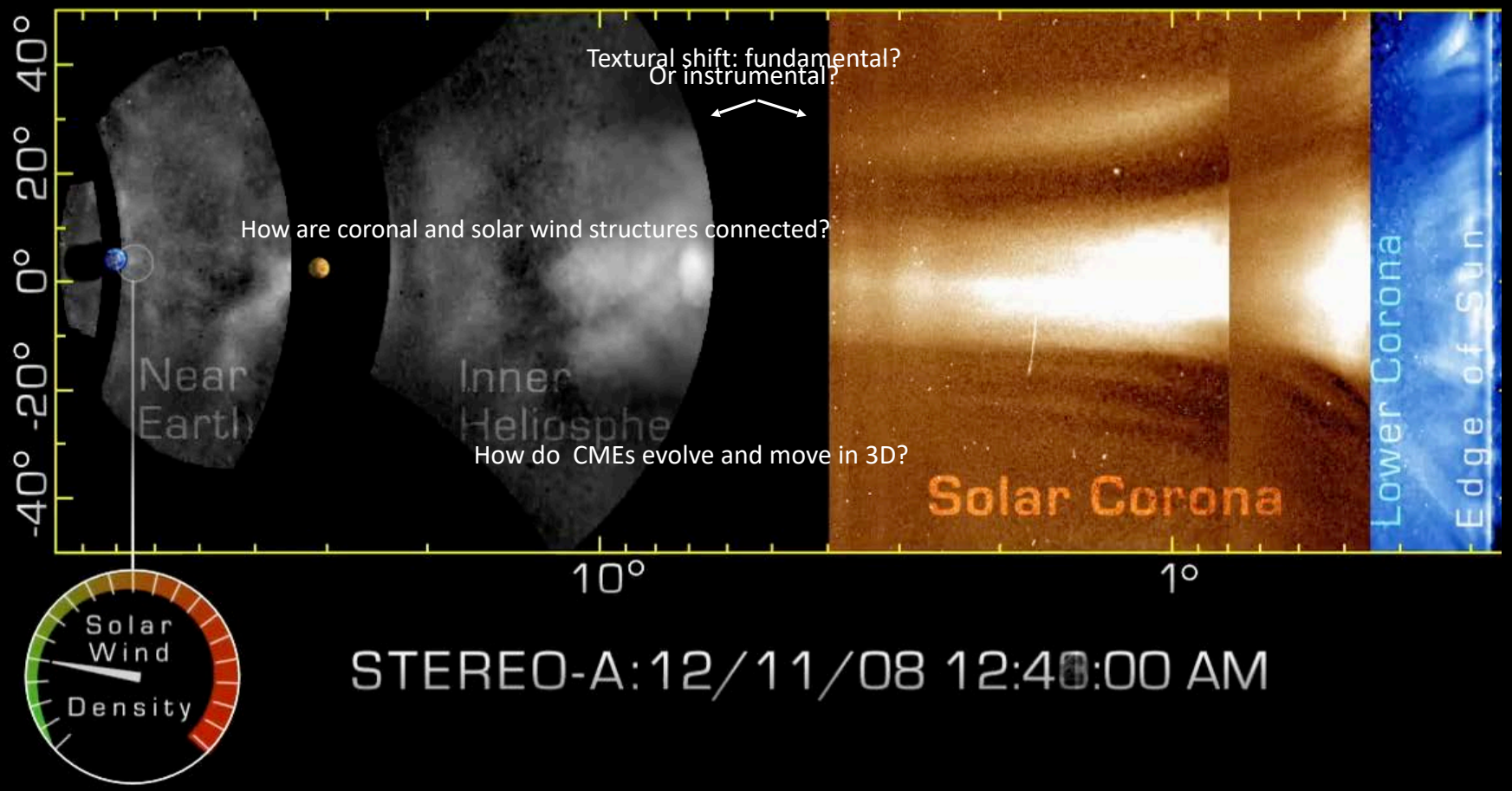
HELIOPHYSICS: ONE SCIENTIFIC FIELD, DIVIDED BY TECHNOLOGY

Solar physics studies the Sun and solar corona, primarily through remote sensing and spectral analysis.

Heliospheric physics studies the solar wind in interplanetary space, primarily through in-situ sampling.



THE HELIOSPHERE IS A SINGLE SYSTEM … CONNECTING THE SUN AND EARTH.



WHAT IS THE PUNCH SMALL EXPLORER MISSION?

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

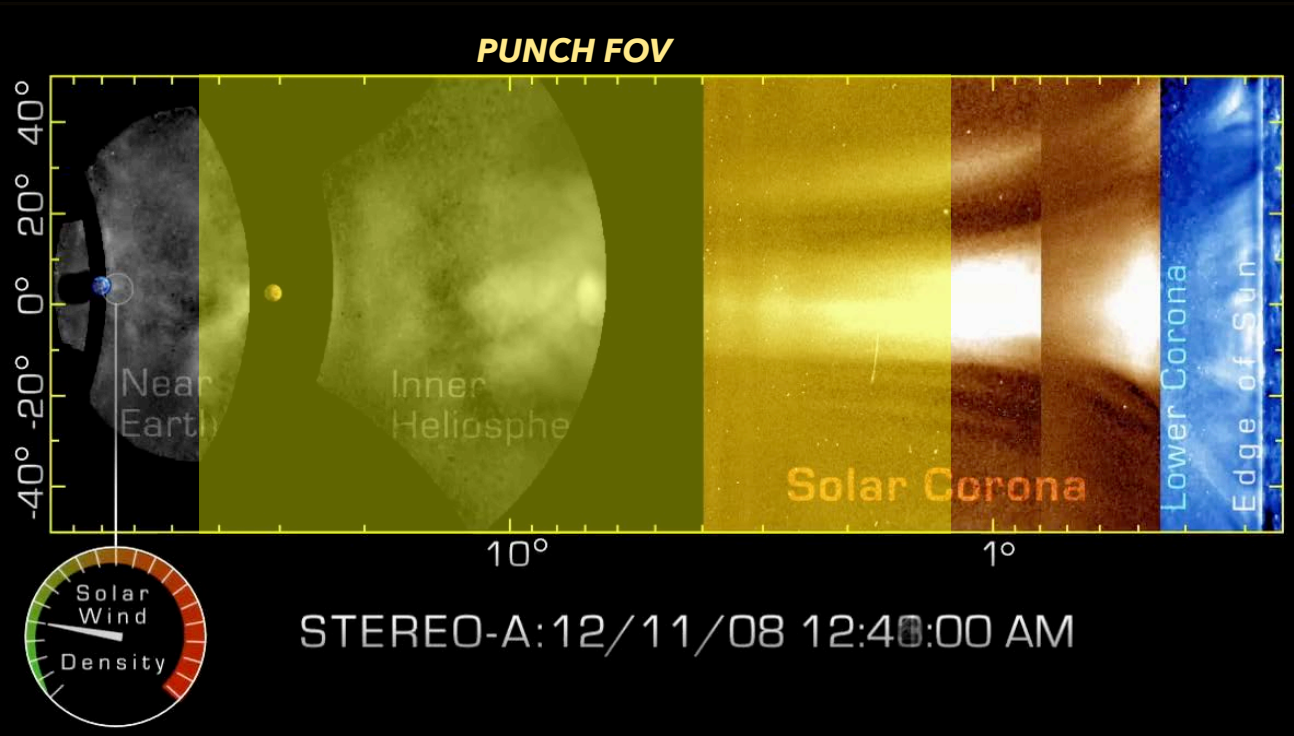
Approach: direct, continuous, 3D imaging of the entire outer corona and inner heliosphere

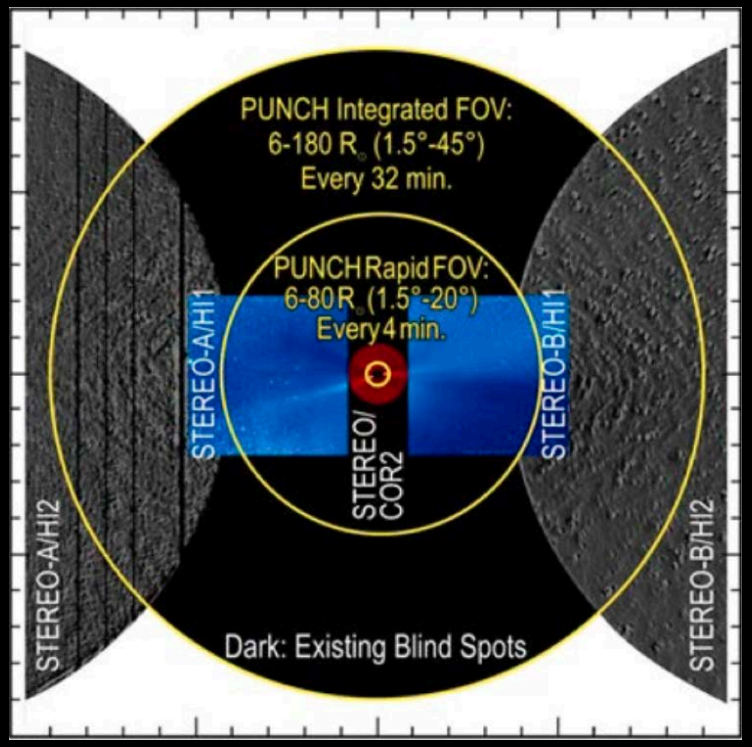
Measurement: polarized images of Thomson-scattered light

Mission structure:
- four synchronous smallsats
- 570km sun-synch LEO
- two year duration; launch Mar 2023 (tentative)

Status: Selected by NASA for flight. Phase B funding is anticipated in 2 weeks (Sep 2019).

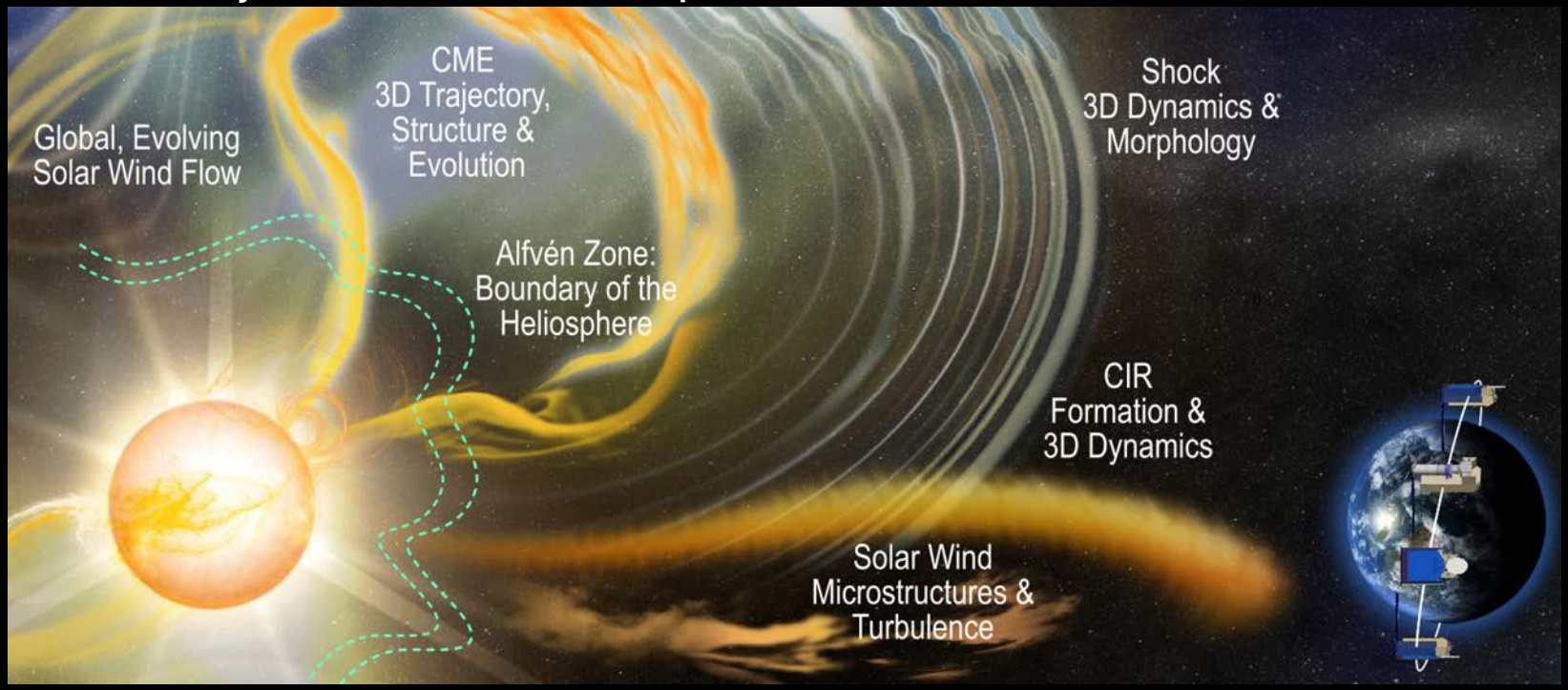
THE PUNCH FIELD OF VIEW: CONTINUOUS AND POLE-TO-POLE





PUNCH SCIENCE: FOCUSED ON UNIFICATION

PUNCH's **science goal:** comprehend the *cross-scale* physical processes – from microscale turbulence to the evolution of global-scale structures – that **unify the solar corona and heliosphere**.

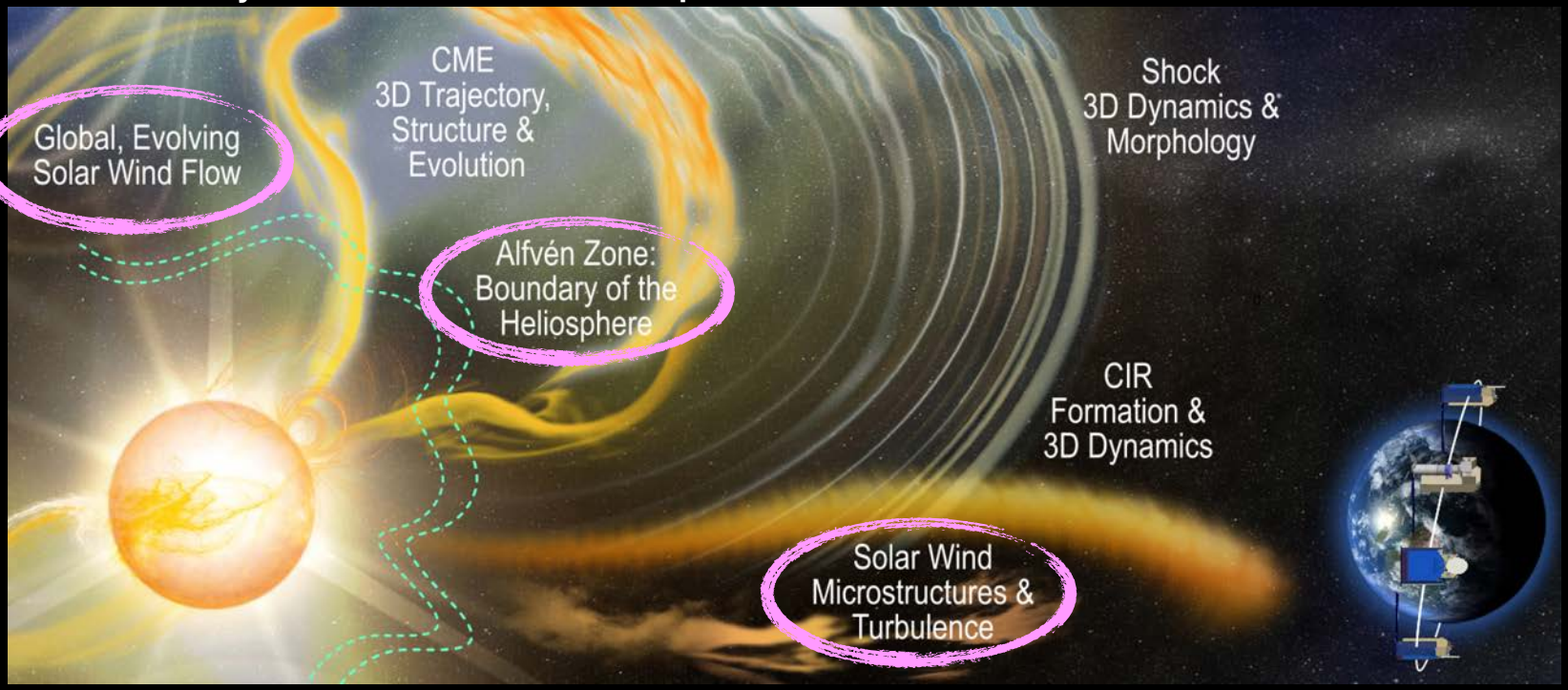


PUNCH's **Science Objectives:**

1. **Understand how coronal structures become the ambient solar wind.**
2. **Understand the dynamic evolution of transient structures in the young solar wind.**

PUNCH SCIENCE OBJECTIVE 1: AMBIENT SOLAR WIND

PUNCH's **science goal:** comprehend the *cross-scale* physical processes – from microscale turbulence to the evolution of global-scale structures – that **unify the solar corona and heliosphere**.



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

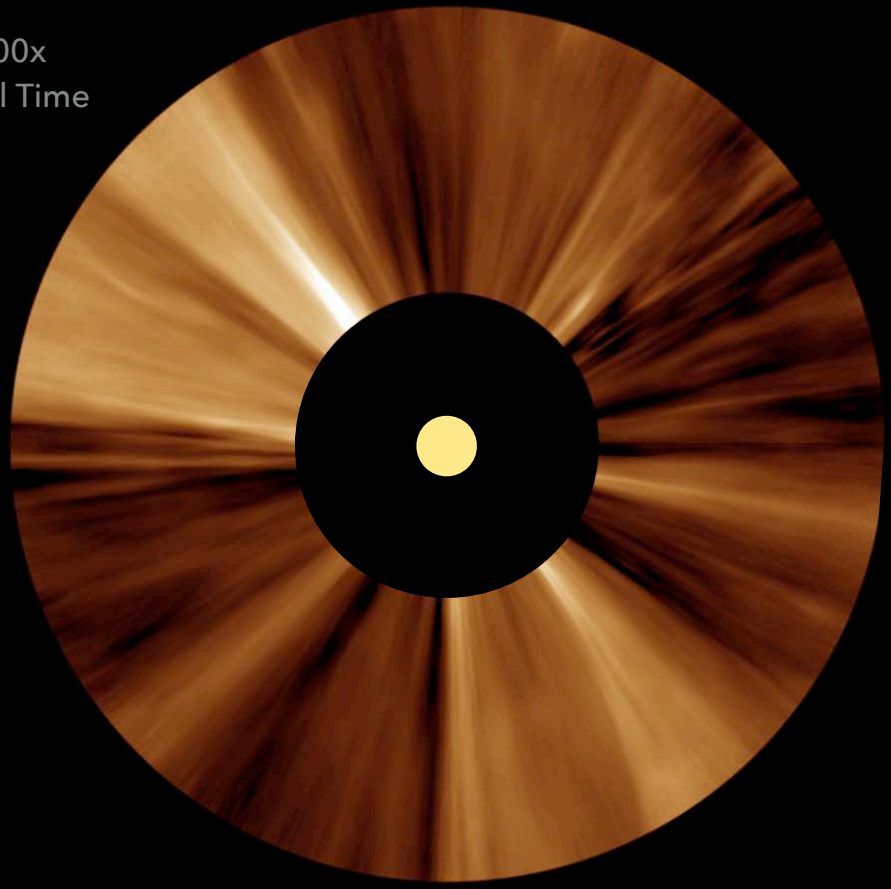
1A. How does the young solar wind **flow and evolve** on global scales?

1B. Where and how do **microstructures and turbulence** form in the solar wind?

1C. What are the evolving physical boundaries of the **Alfvén Zone**?

THE SOLAR CORONA SEEN BY STEREO/COR2

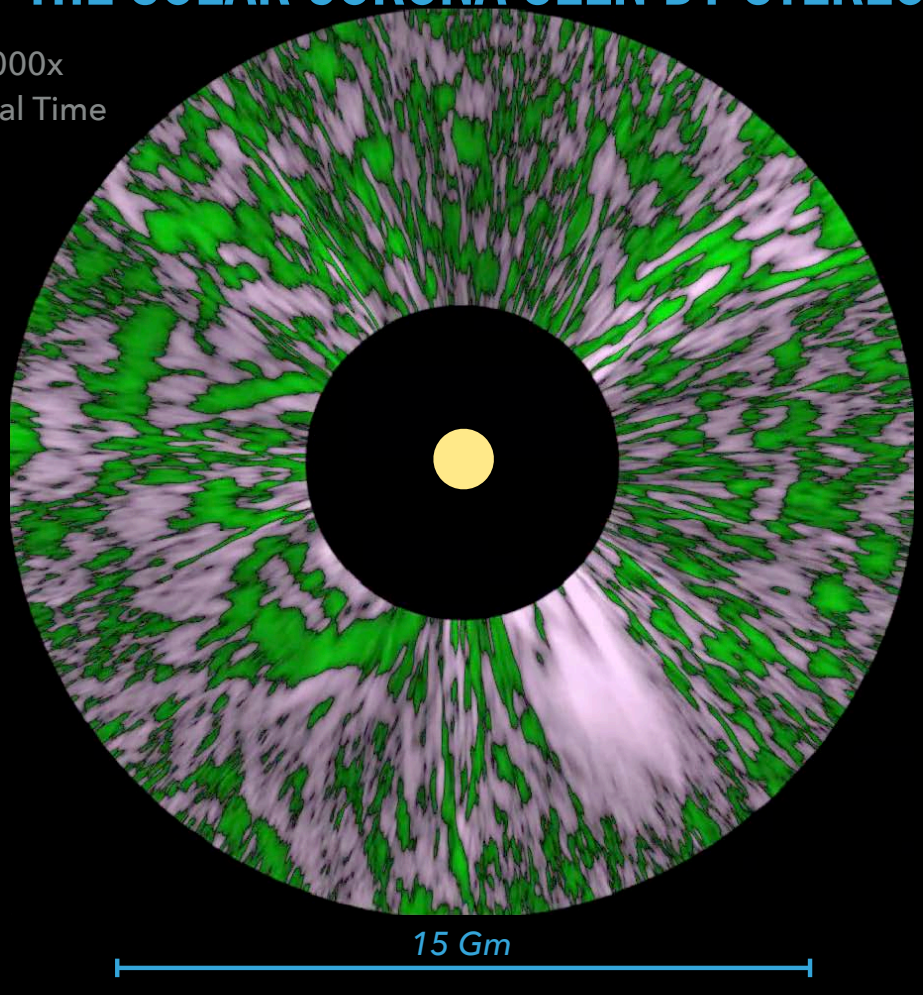
8,000x
Real Time



- Outflow is visible everywhere because of small moving features.
- The outer corona is dominated by fine “woodgrain” structure.
- Smooth background and stars removed; movie is 3% of imaged light.

THE SOLAR CORONA SEEN BY STEREO/COR2 WITH MOTION FILTERING

8,000x
Real Time

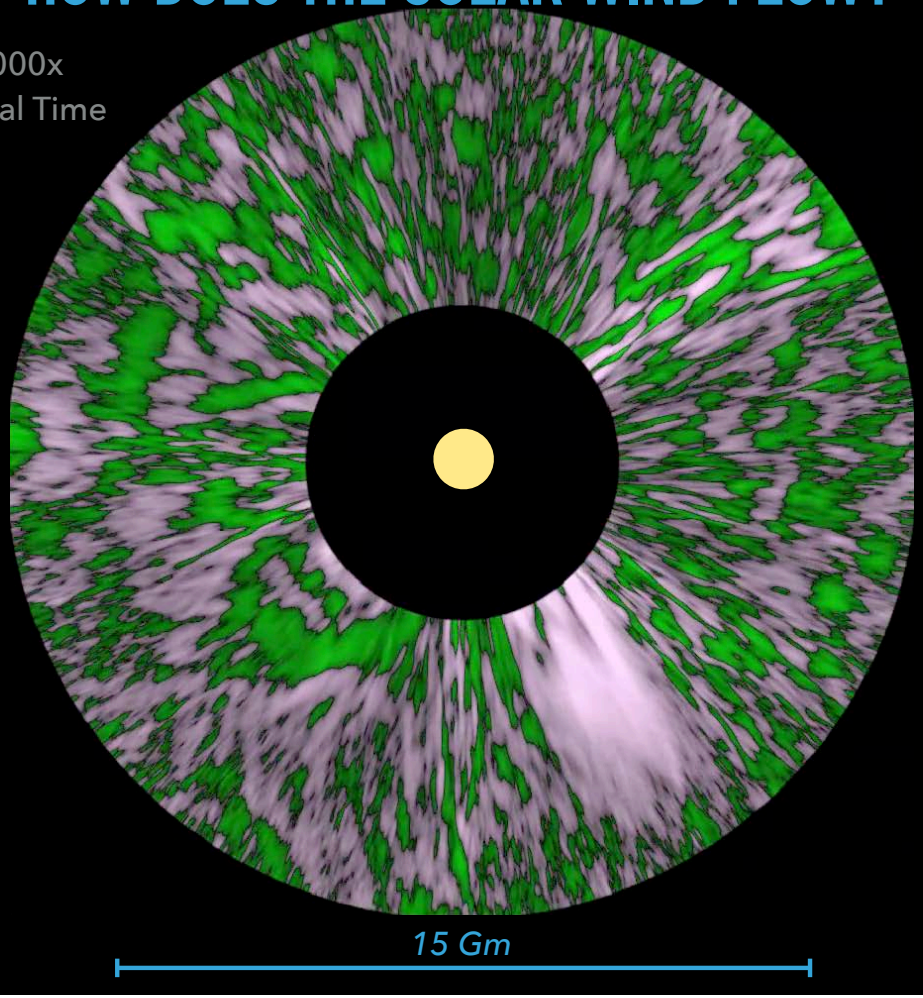


- Outflow is visible everywhere because of small moving features.
- The outer corona is dominated by fine “woodgrain” structure.
- The outer corona is a riotous torrent of blobs and variable streams: the young solar wind.

THE YOUNG SOLAR WIND REVEALED

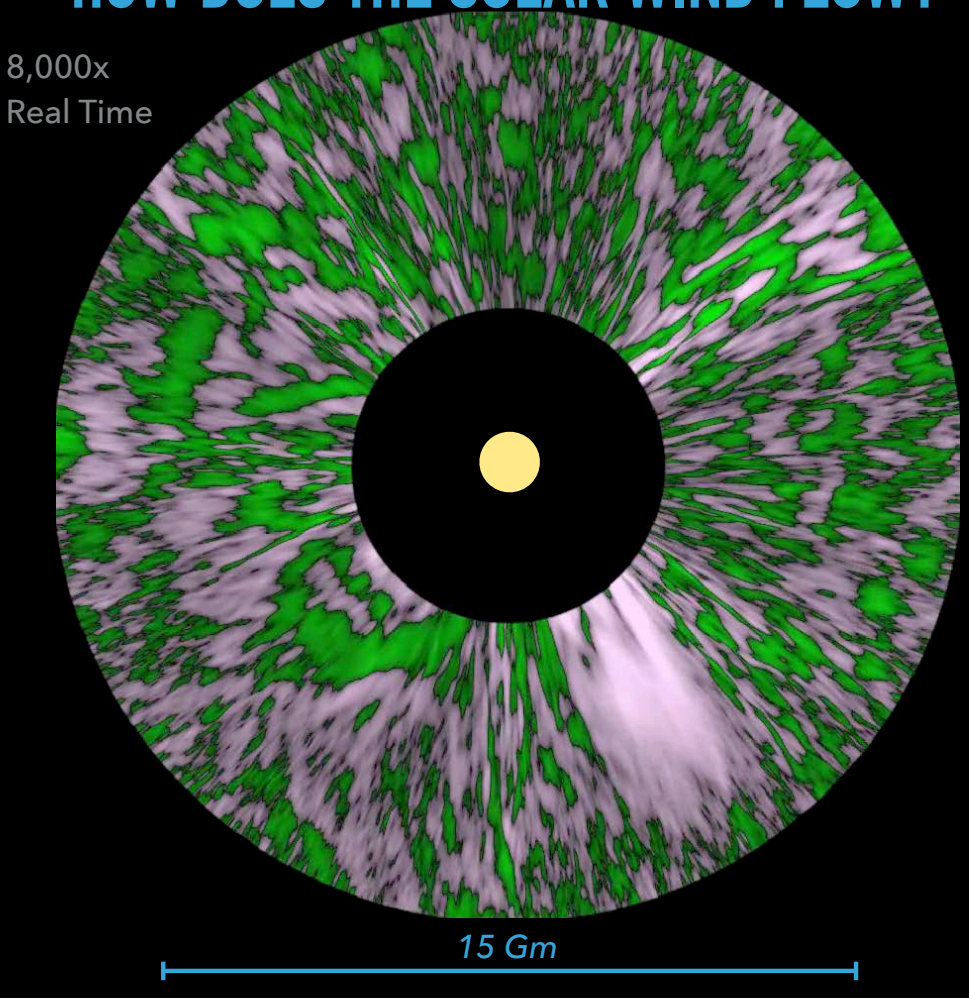
HOW DOES THE SOLAR WIND FLOW?

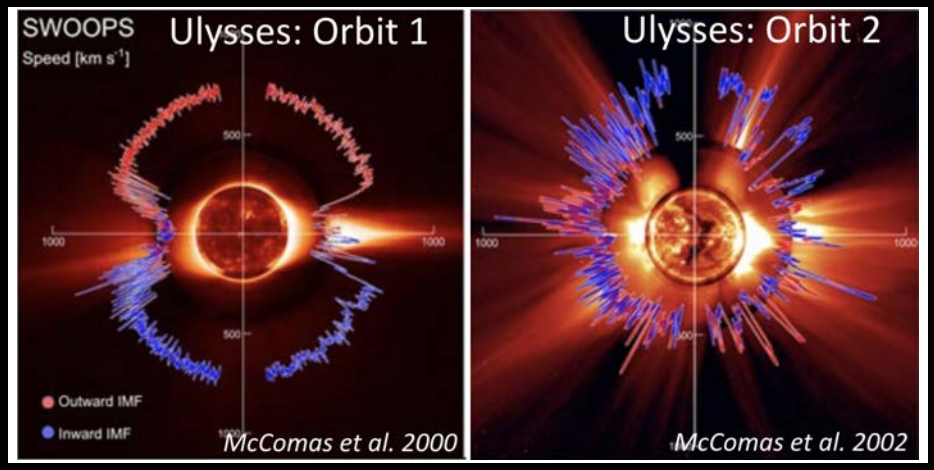
8,000x
Real Time



- Outflow is visible everywhere because of small moving features.
- PUNCH exploits these features to map the flow of the young solar wind near the Sun every six hours.

HOW DOES THE SOLAR WIND FLOW?

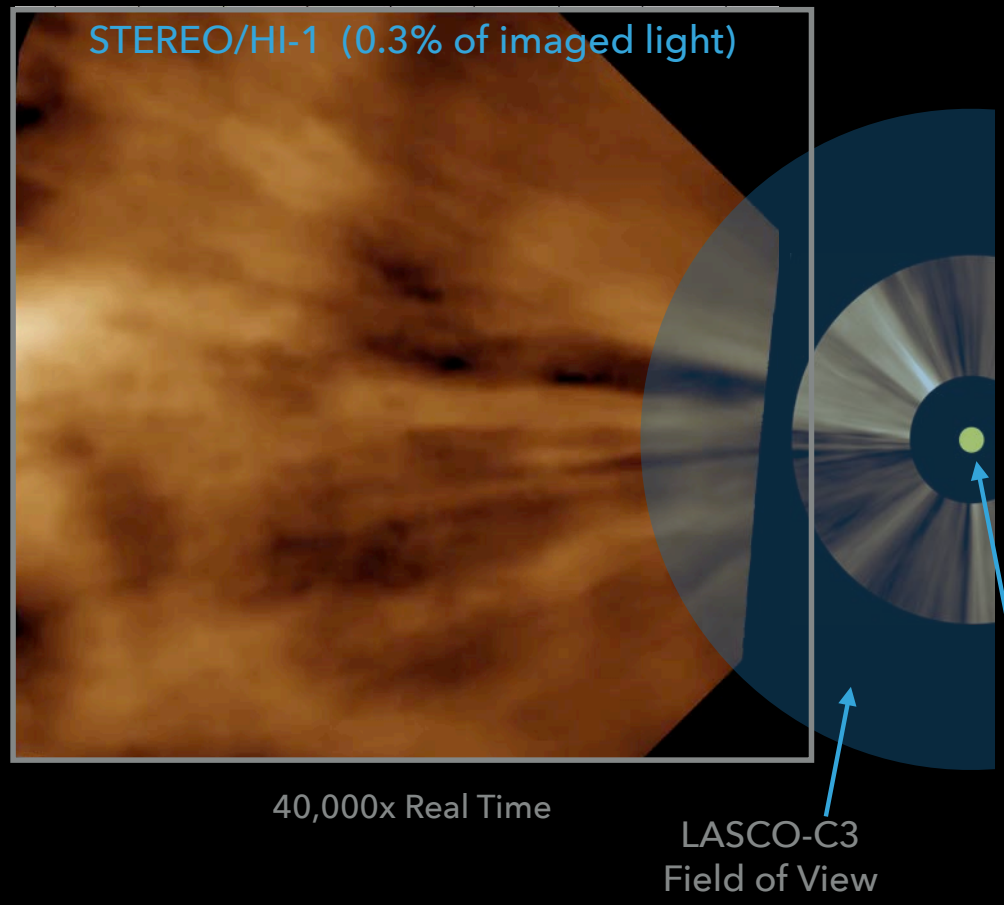




- PUNCH exploits these features to map the flow of the young solar wind near the Sun every six hours.
  - Our best current data is from Ulysses … once every six years … at 1AU.

THE SOLAR CORONA BECOMES THE TURBULENT SOLAR WIND

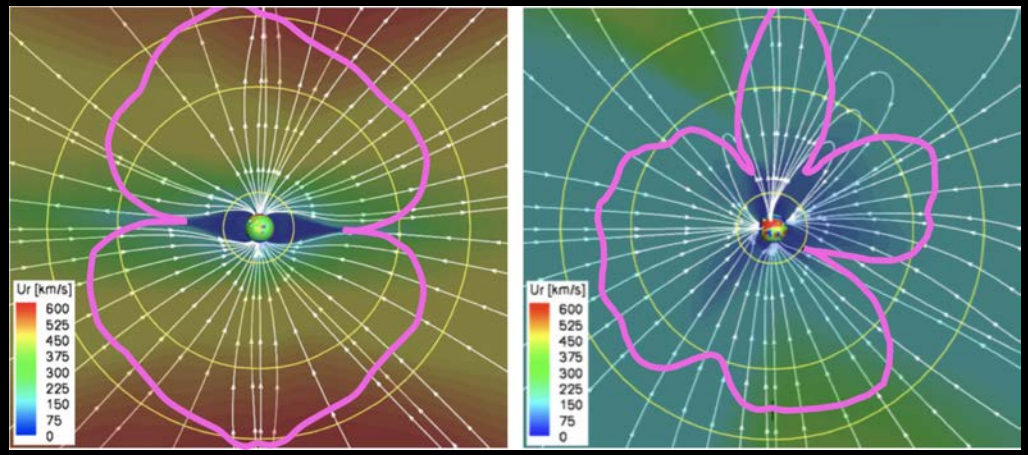
DOES TURBULENT ONSET MARK THE TOP OF THE SOLAR CORONA?

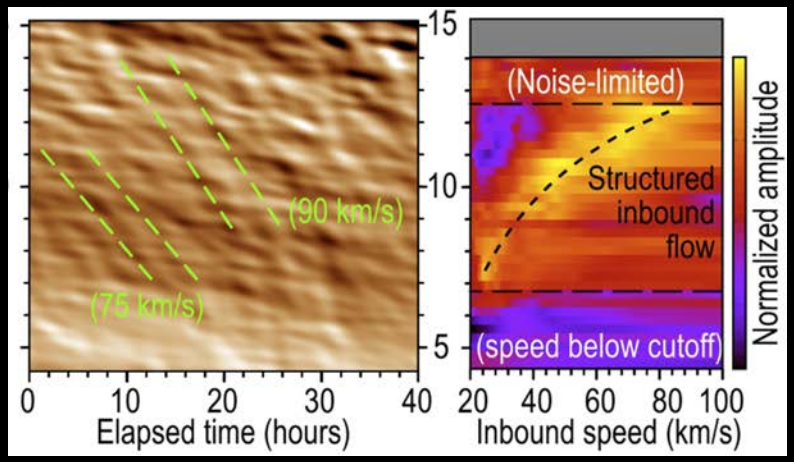


- Current instruments can just barely identify the visual top of the solar corona.
- The corona ends ~10° from the Sun.
- Bright radial structure fades into “fluffy" dense clouds that are detectable in-situ.
- PUNCH will determine why and how.

THE SOLAR CORONA BECOMES THE YOUNG SOLAR WIND

IDENTIFYING THE MYSTERIOUS ALFVÉN ZONE

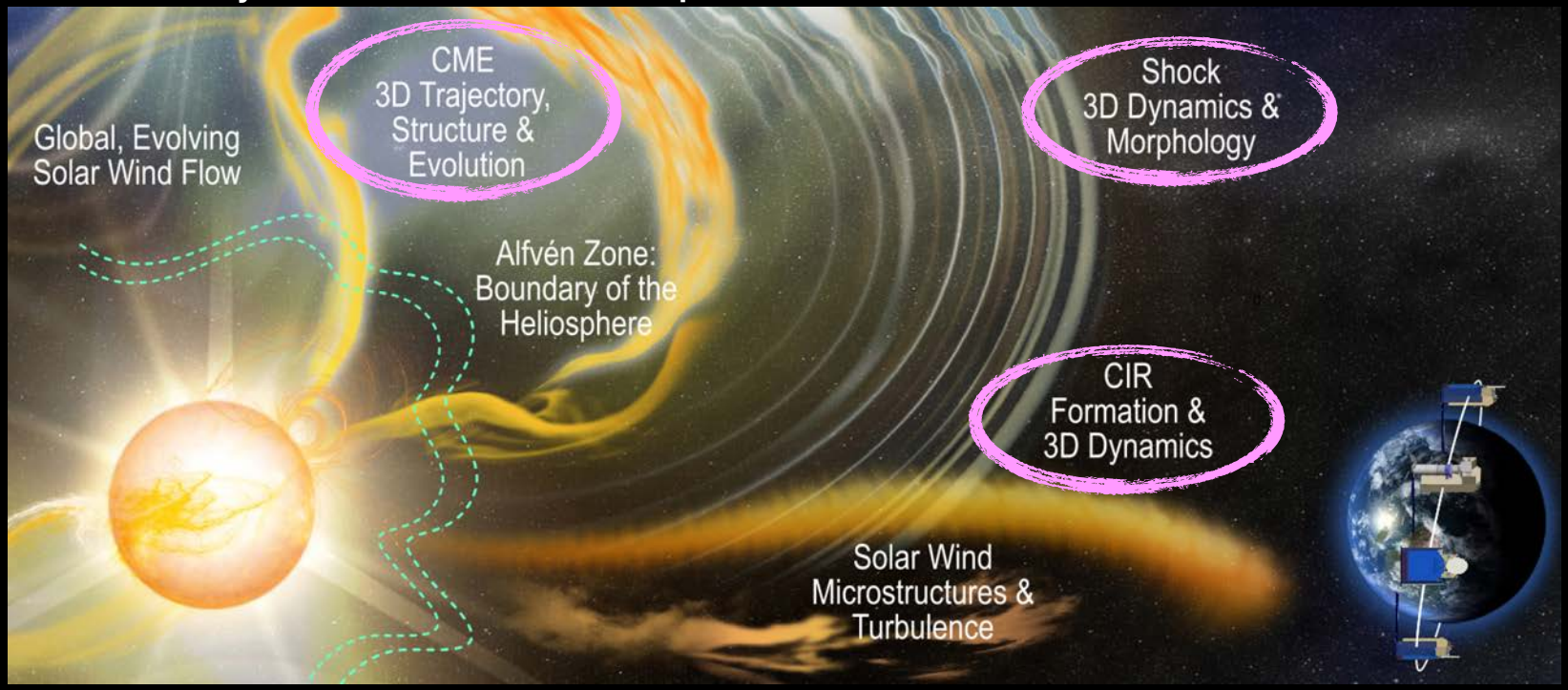




- Alfvén zone / Alfvén surface models remain nearly unconstrained.
- PUNCH maps the Alfvén zone by identifying inbound features
- Fourier in/out filtering is used to identify wave speed directly.

PUNCH SCIENCE OBJECTIVE 2: TRANSIENT STRUCTURES

PUNCH's **science goal:** comprehend the *cross-scale* physical processes – from microscale turbulence to the evolution of global-scale structures – that **unify the solar corona and heliosphere**.

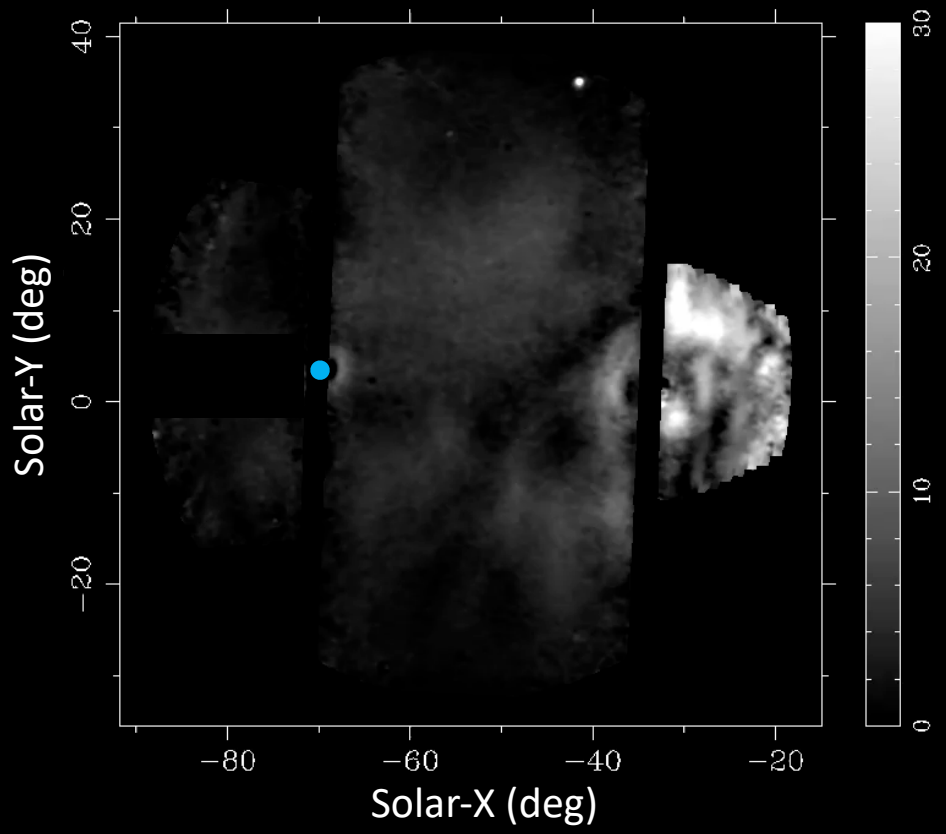


Objective 2: Understand the dynamic evolution of transient structures in the young solar wind.

2A. How do **coronal mass ejections** (CMEs) propagate and evolve in the solar wind?
2B. How do quasi-stationary **corotating interaction regions** (CIRs) form and evolve?
2C. How do **shocks** form and interact with the solar wind across spatial scales?

CIRS: THE MOST COMMON GEOEFFECTIVE SPACE WEATHER

CIR observed by STEREO/HI2

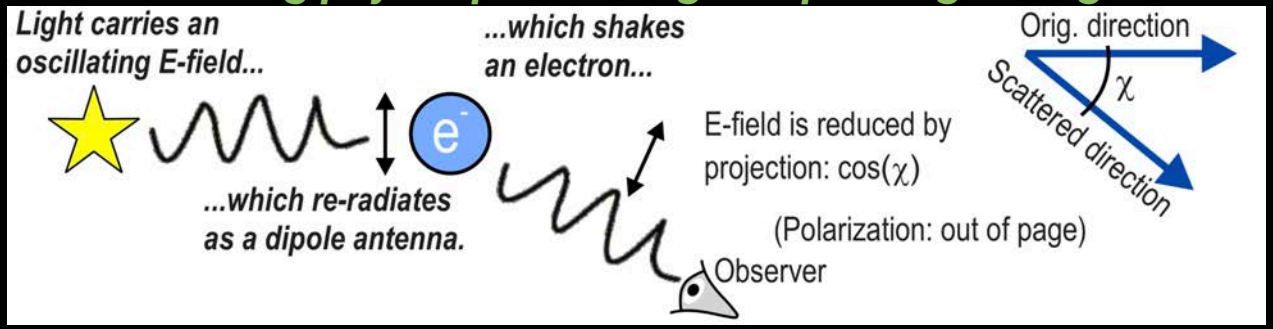


- CIRs cause geomagnetic effects more frequently than CMEs
- CIRs have mostly been studied using in-situ analyses and modeling
- Early CIR movies reveal new phenomena.

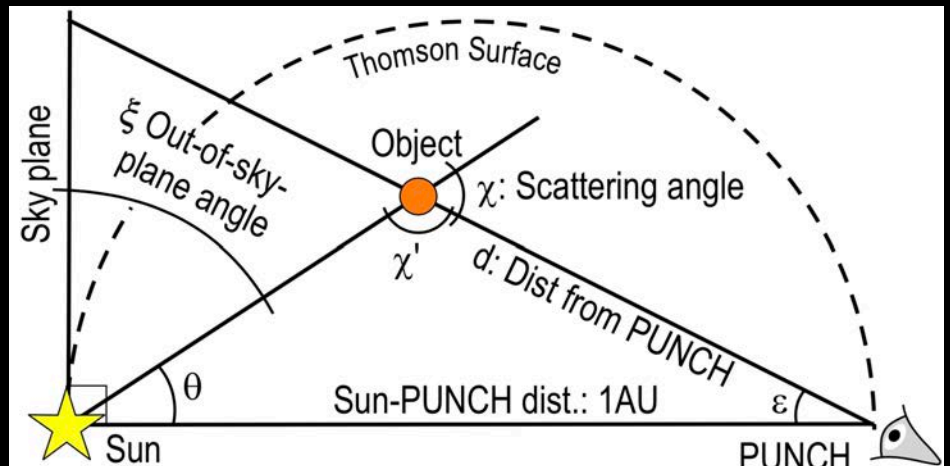
- Shock front evolution in 3D affects direction, strength, and potentially SEP productivity – but is largely unmeasured.

3D IMAGING WITH POLARIZATION

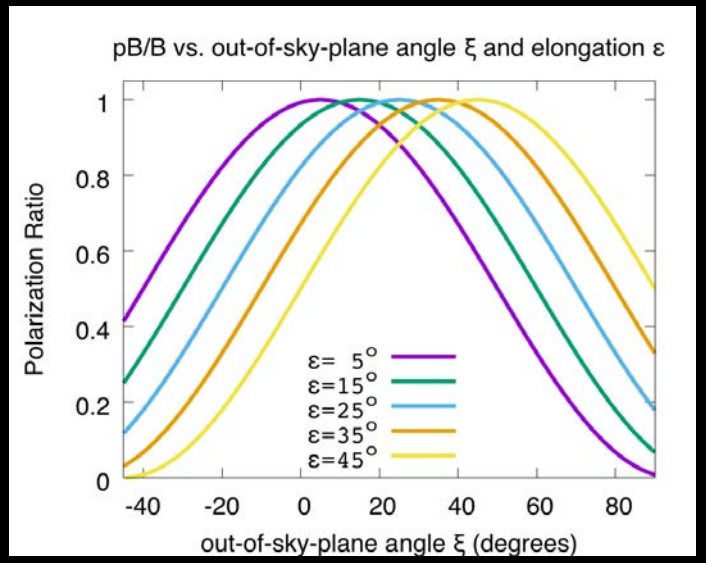
Scattering physics polarizes light depending on angle.



Geometry relates scattering angle to 3D location.

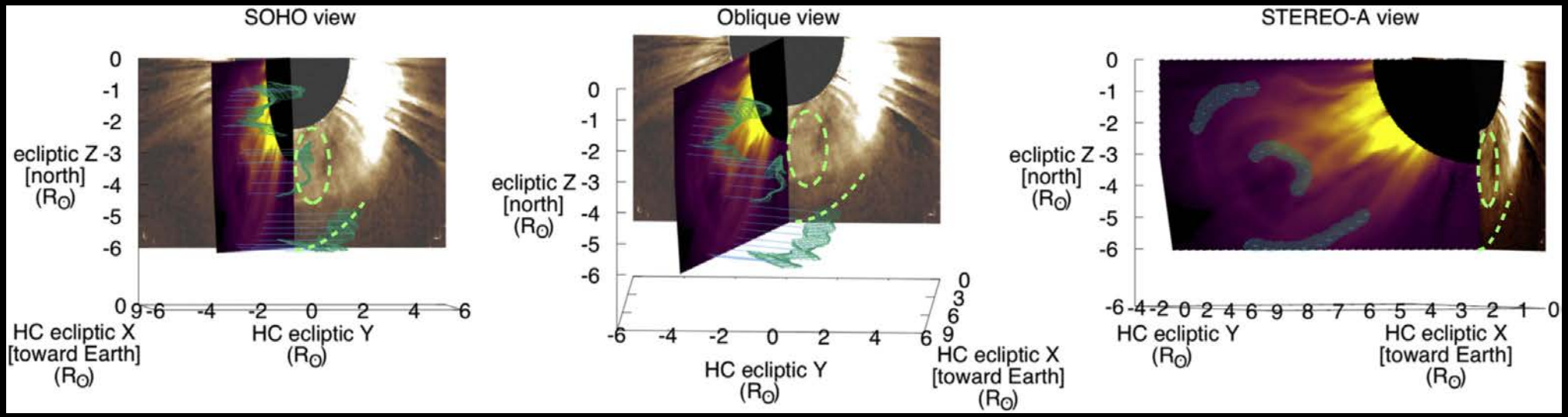


The ratio of polarized brightness in each visible feature determines that feature's location.



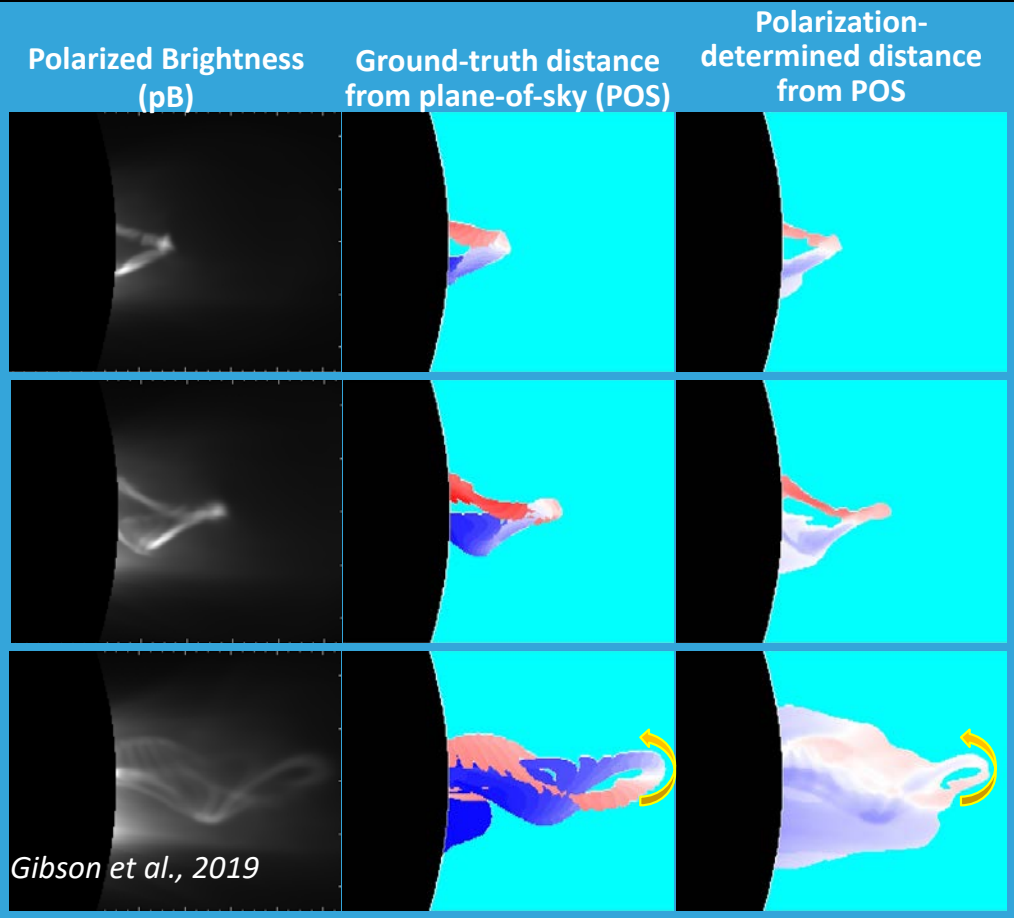
CME TRACKING: VALIDATED BY DIRECT OBSERVATION

POLARIZED IMAGING TRACKS CMES IN 3D



3D polarization analysis matches stereoscopy!

IDENTIFYING CHIRALITY IN A MODELED COMPLEX ERUPTION



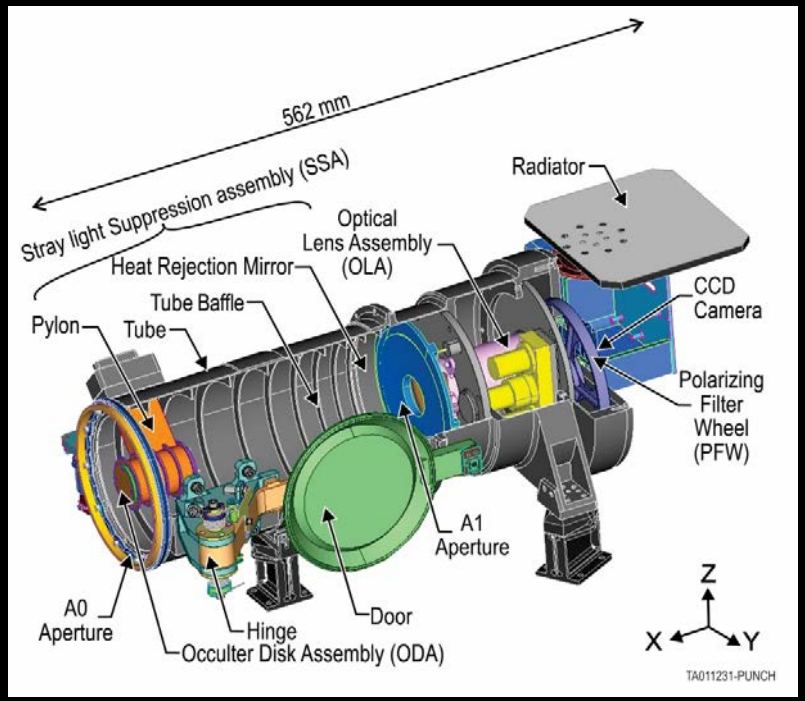
Test chirality technique with MHD erupting-flux-rope model (Fan 2018)

Front (red) vs. back (blue) is clear.

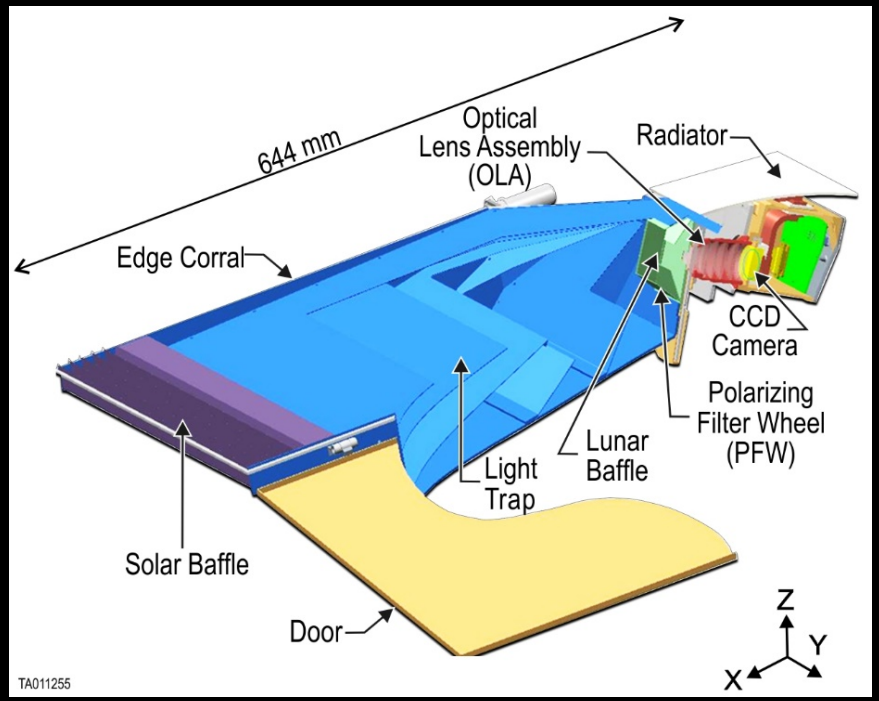
Circulation about axis correctly identifies a left-handed flux rope.

TWO TYPES OF POLARIZING CAMERA COVER THE PUNCH FOV

1x NFI: Compact Coronagraph design
Naval Research Laboratory

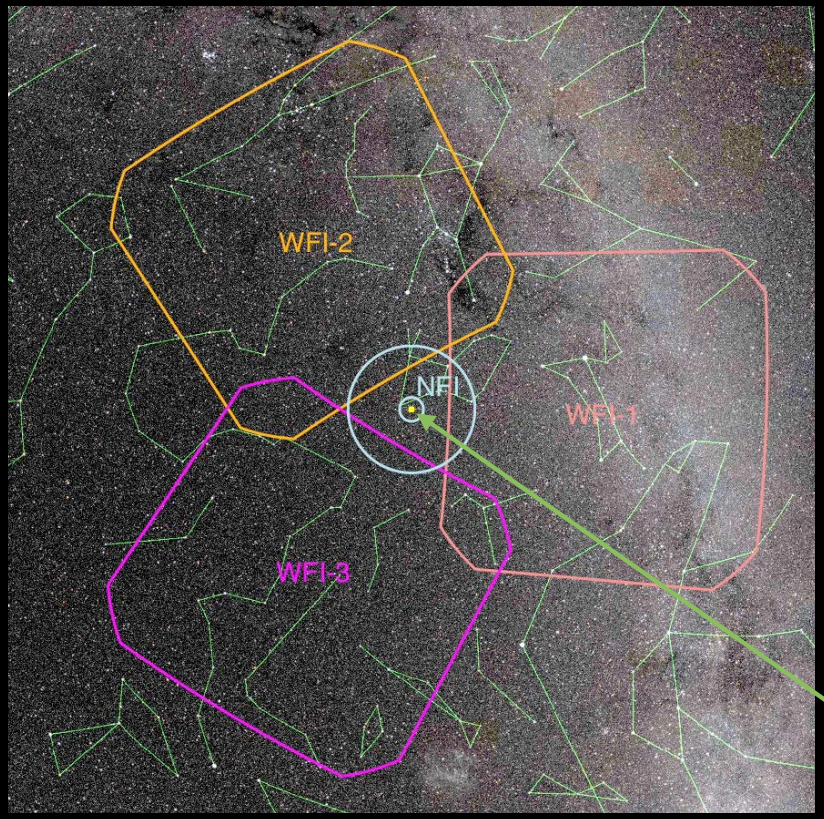


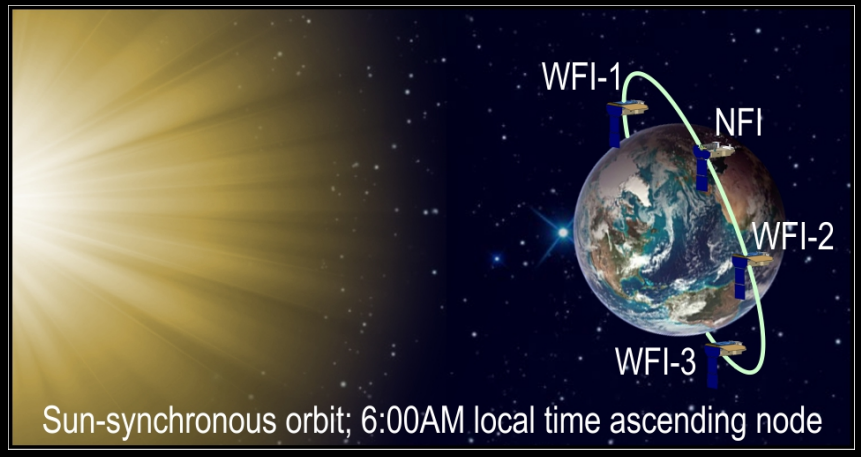
3x WFI: Heliospheric Imager design
Southwest Research Institute



COMBINING FOUR CAMERAS INTO A SINGLE VIRTUAL INSTRUMENT

PUNCH MERGES IMAGES TO CREATE A SINGLE LARGE FOV





- The PUNCH spacecraft fly in formation 120° apart in orbit.
- Each spacecraft rotates every 8 minutes to match its orbital motion.
- Exposures are combined on the ground.

PUNCH LAUNCH SEQUENCE

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PUNCH - SOLAR ORBITER SYNERGIES

- 3D imaging of density tracers aids understanding of SolO-Sun connectivity.
- 3D tracking of CMEs & CIRs provides vital context from outside the SolO-Sun line.
- For some passes, PUNCH will directly image solar wind *as it passes over SolO*.

- PUNCH data provide universal context imaging (no campaigns; 4 minute cadence).
- PUNCH has an open data policy: typical latency, camera to VSO, is under a week.

PUNCH IT!

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