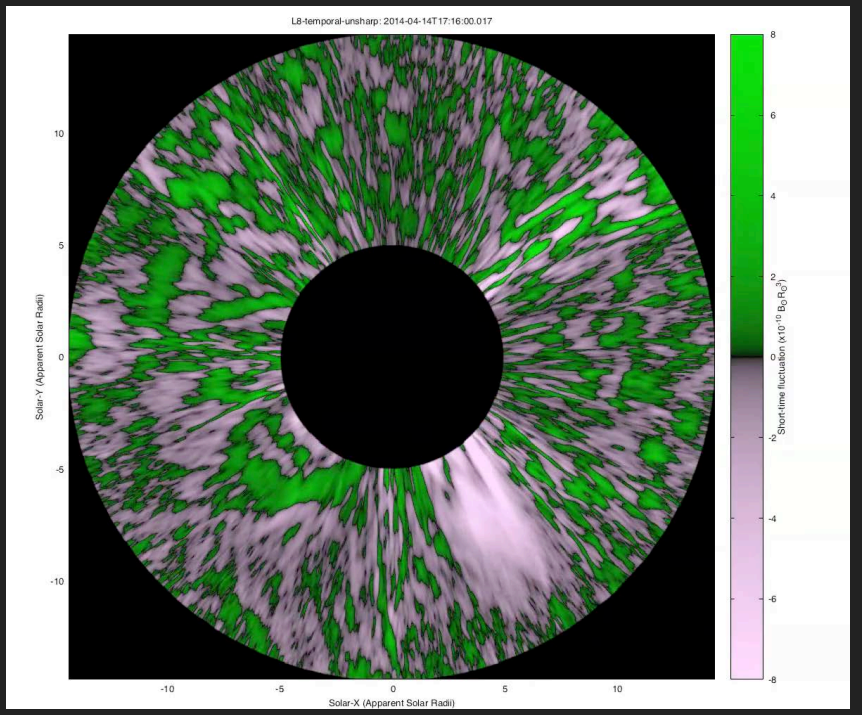
POLARIMETER TO UNIFY THE CORONA AND HELIOSPHERE



Sarah Gibson and the PUNCH team

Asia Pacific Solar Physics Meeting, February 2020

U.S. NAVAL RESEARCH LABORATORY

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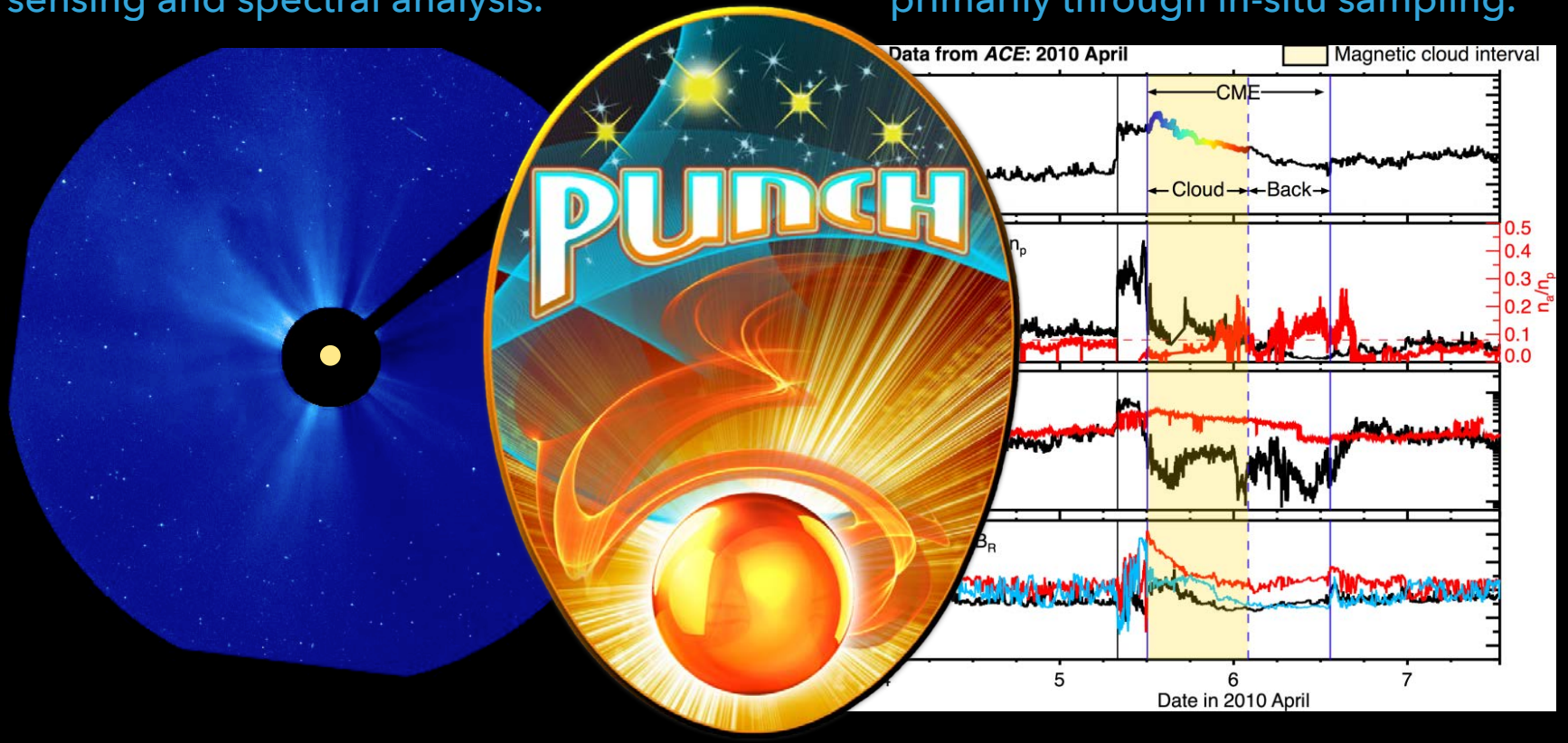
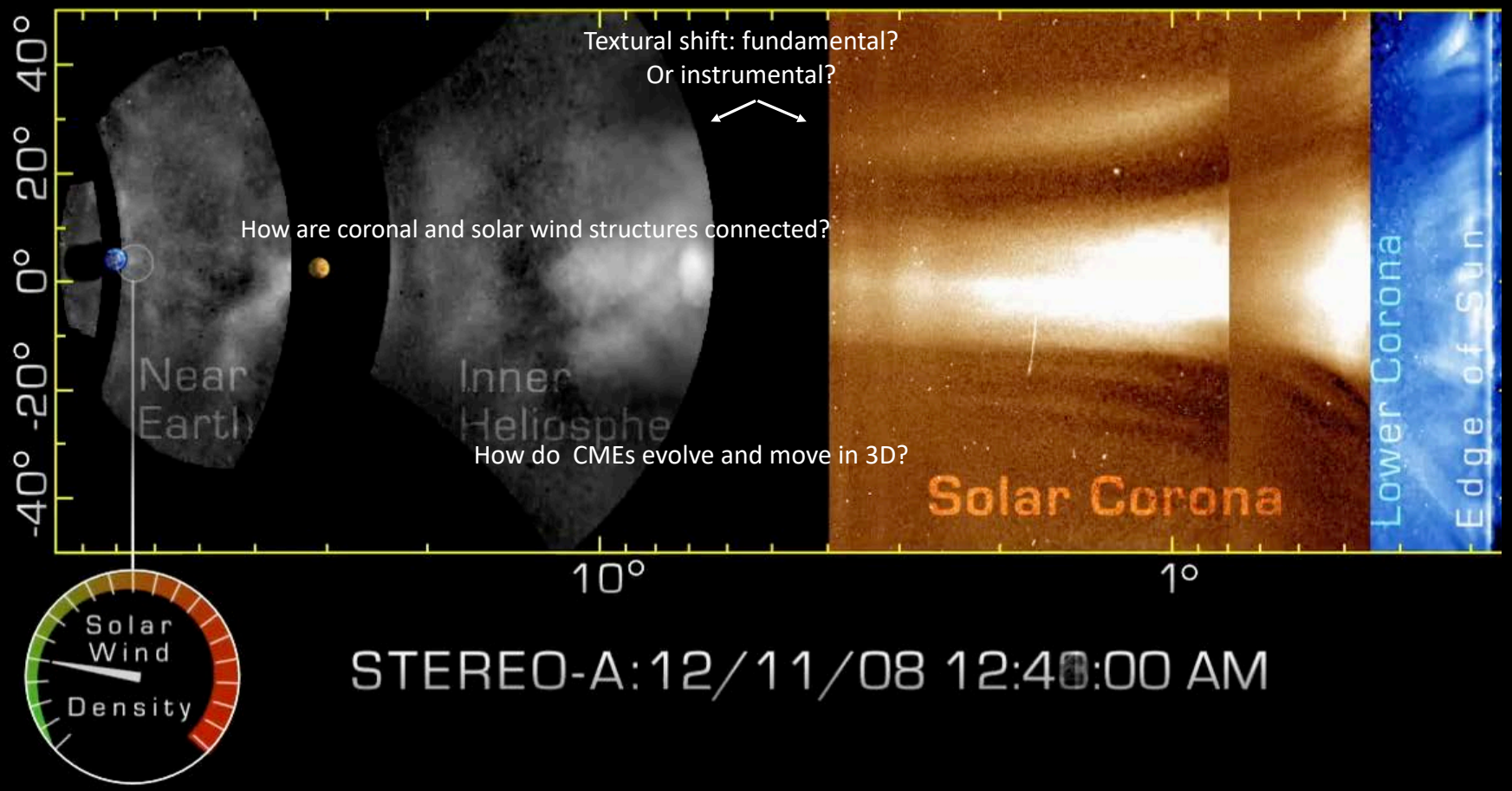
HELIOPHYSICS: ONE SCIENTIFIC FIELD, DIVIDED BY TECHNOLOGY

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

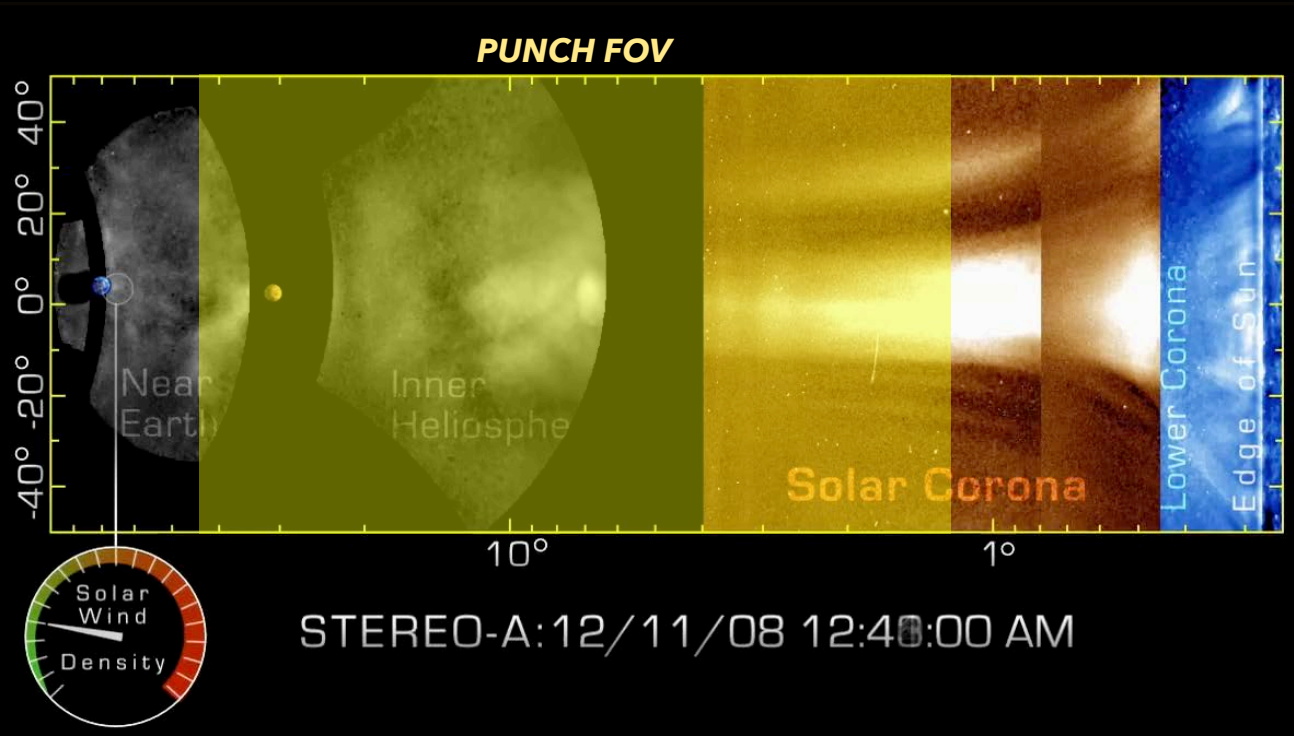
Approach: direct, continuous, 3D imaging of the entire outer corona and inner heliosphere

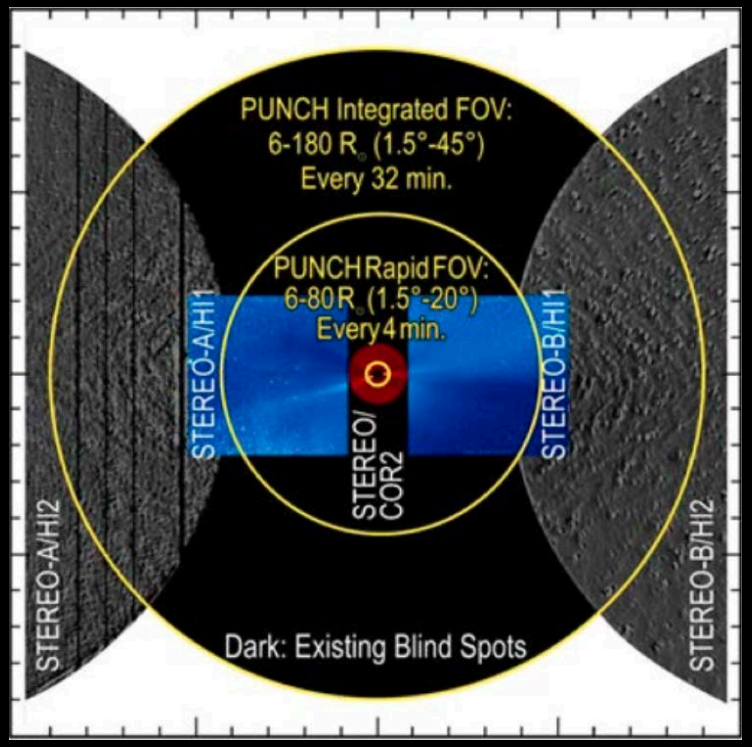
Measurement: polarized images of Thomson-scattered light

Mission structure:
- four synchronous smallsats
- 570km sun-synch LEO
- two year duration; launch early 2023

Status: Selected by NASA for flight. Phase B underway.

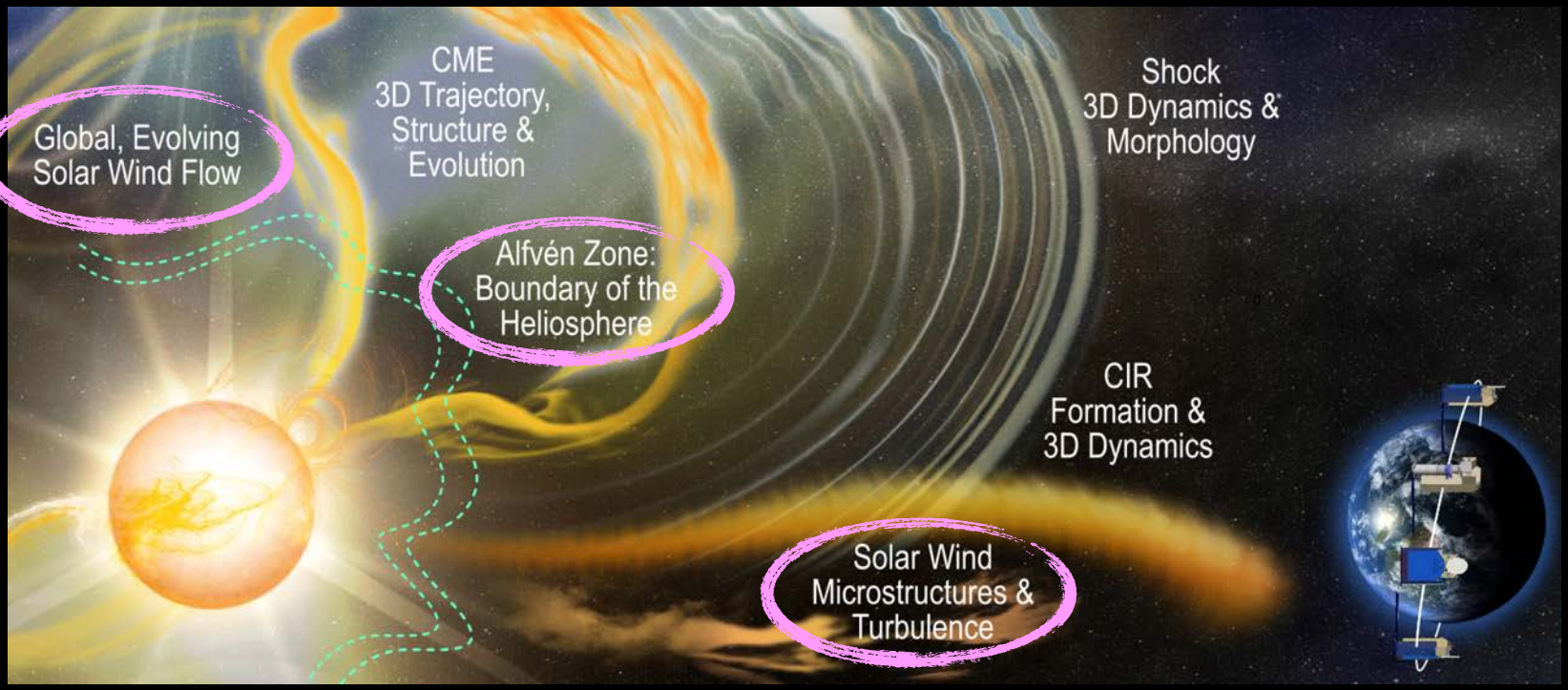
THE PUNCH FIELD OF VIEW: CONTINUOUS AND POLE-TO-POLE





PUNCH SCIENCE OBJECTIVE 1: AMBIENT SOLAR WIND

A



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

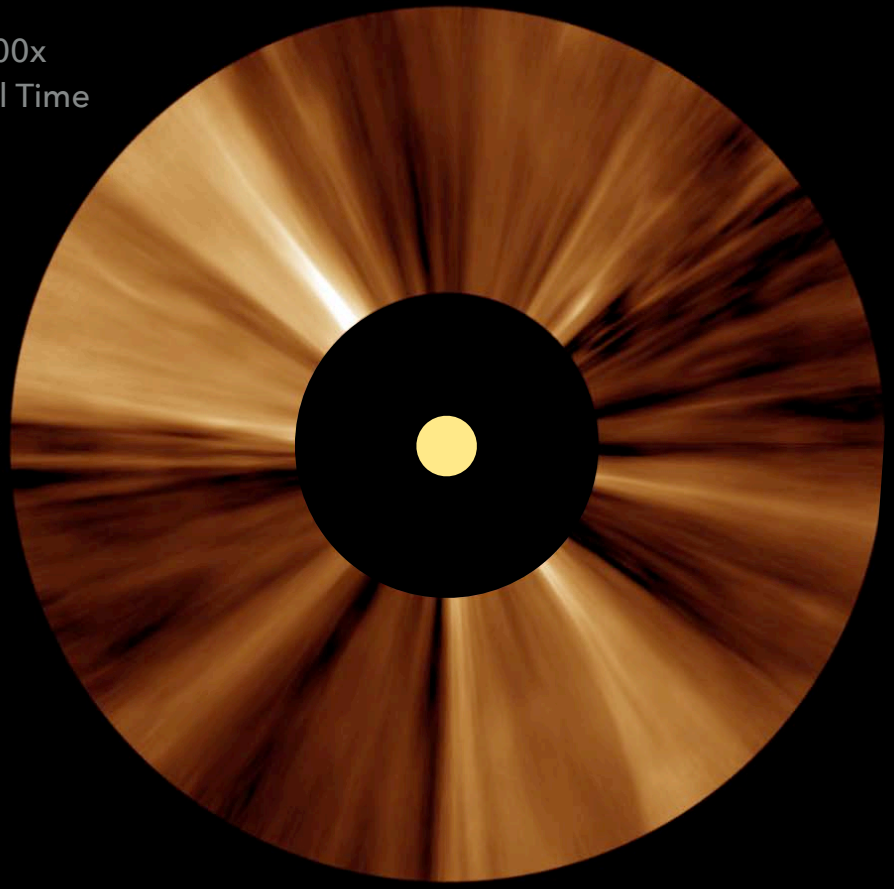
1A. How does the young solar wind **flow and evolve** on global scales?

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



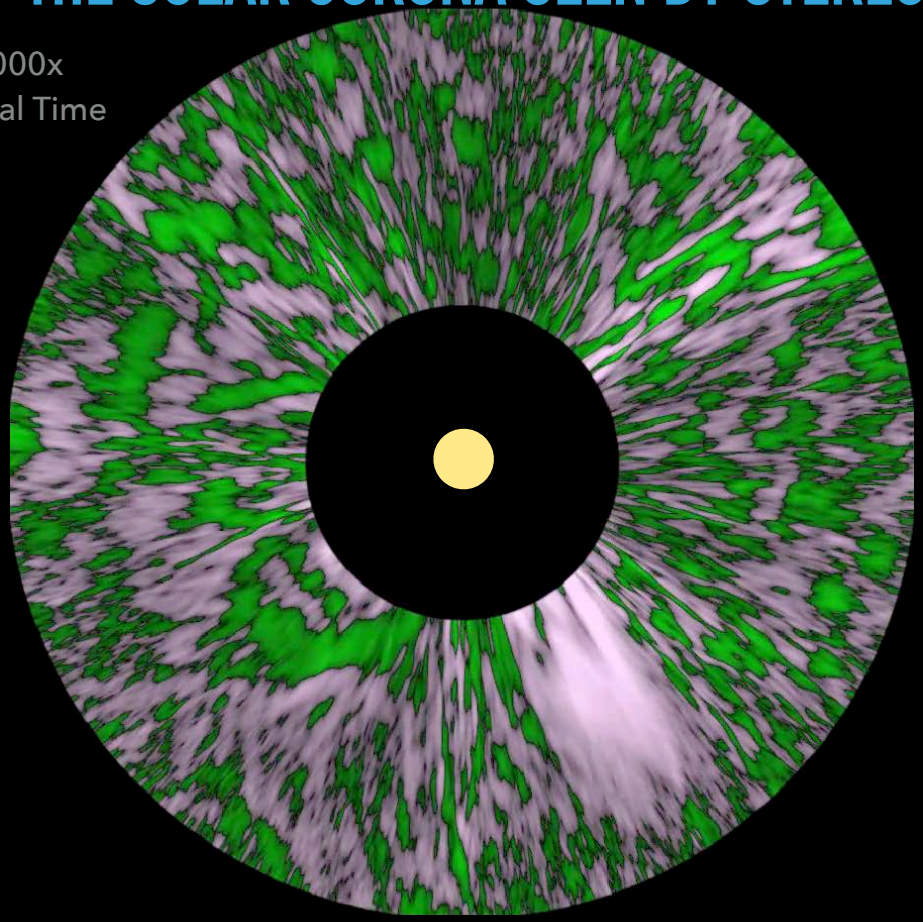
10 million miles

- 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: A DEEPER LOOK REVEALS… THE YOUNG SOLAR WIND IS A RIOTOUS TORRENT

THE SOLAR CORONA SEEN BY STEREO/COR2 WITH MOTION FILTERING

8,000x
Real Time



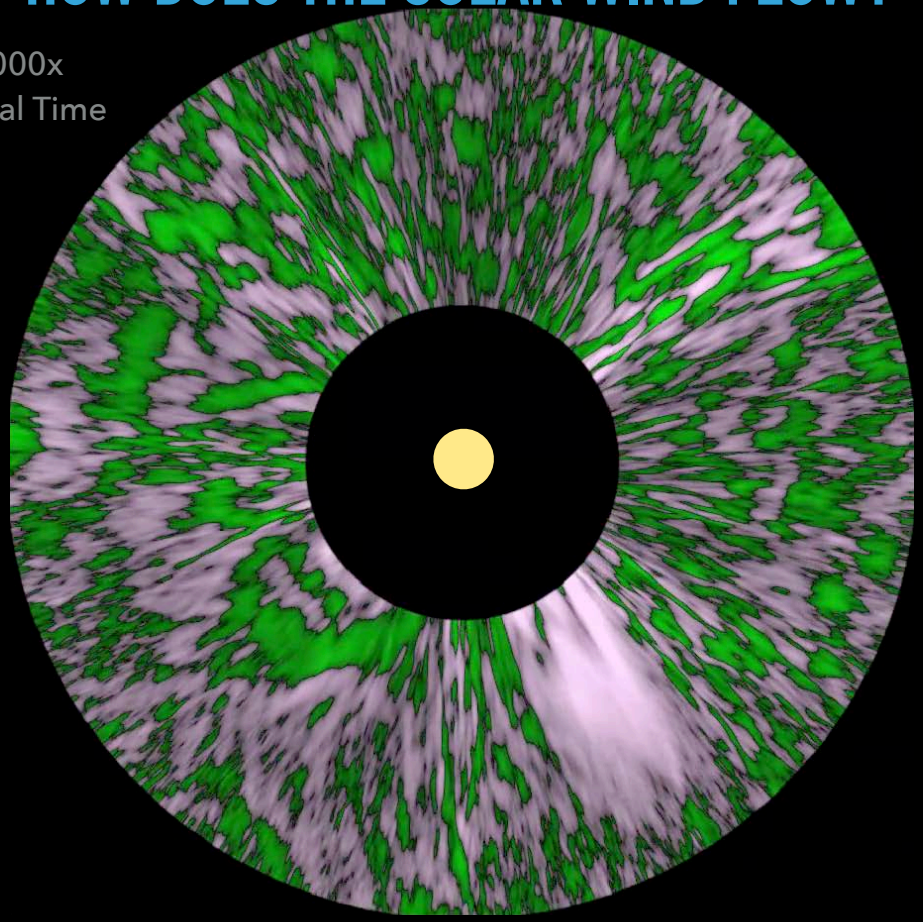
10 million miles

- 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

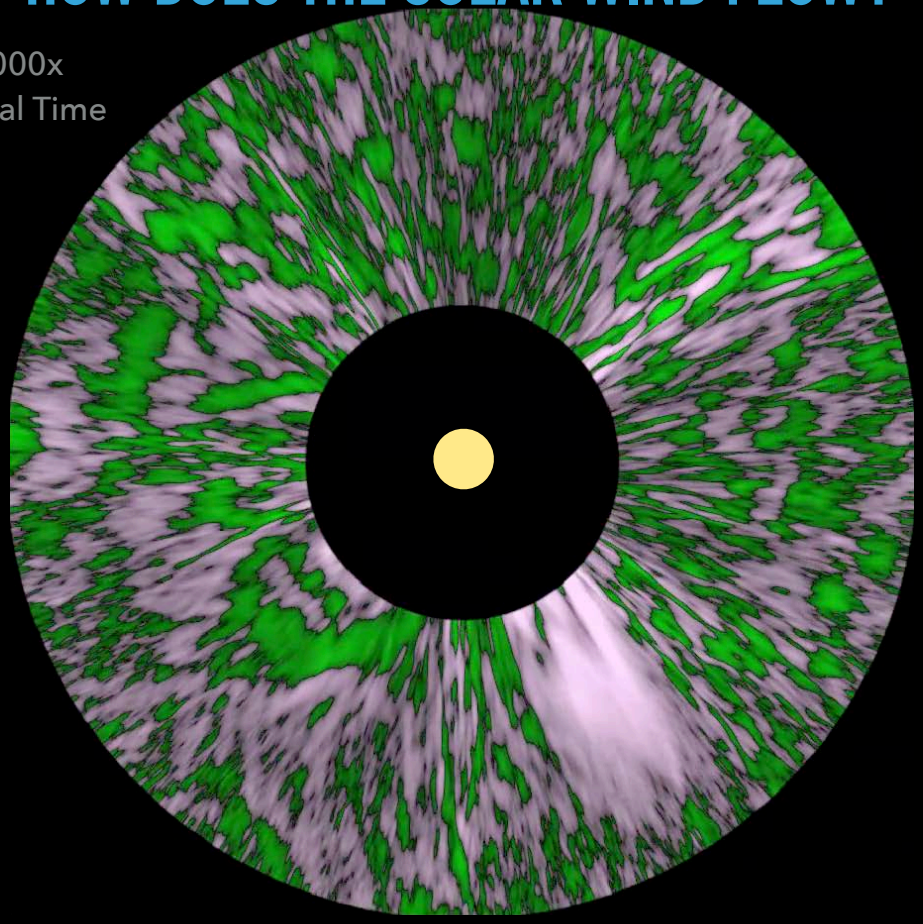


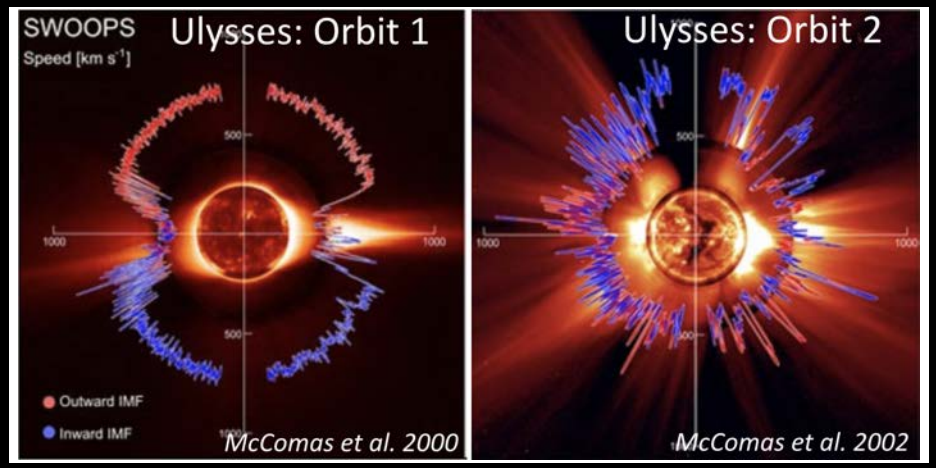
10 million miles

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

HOW DOES THE SOLAR WIND FLOW?

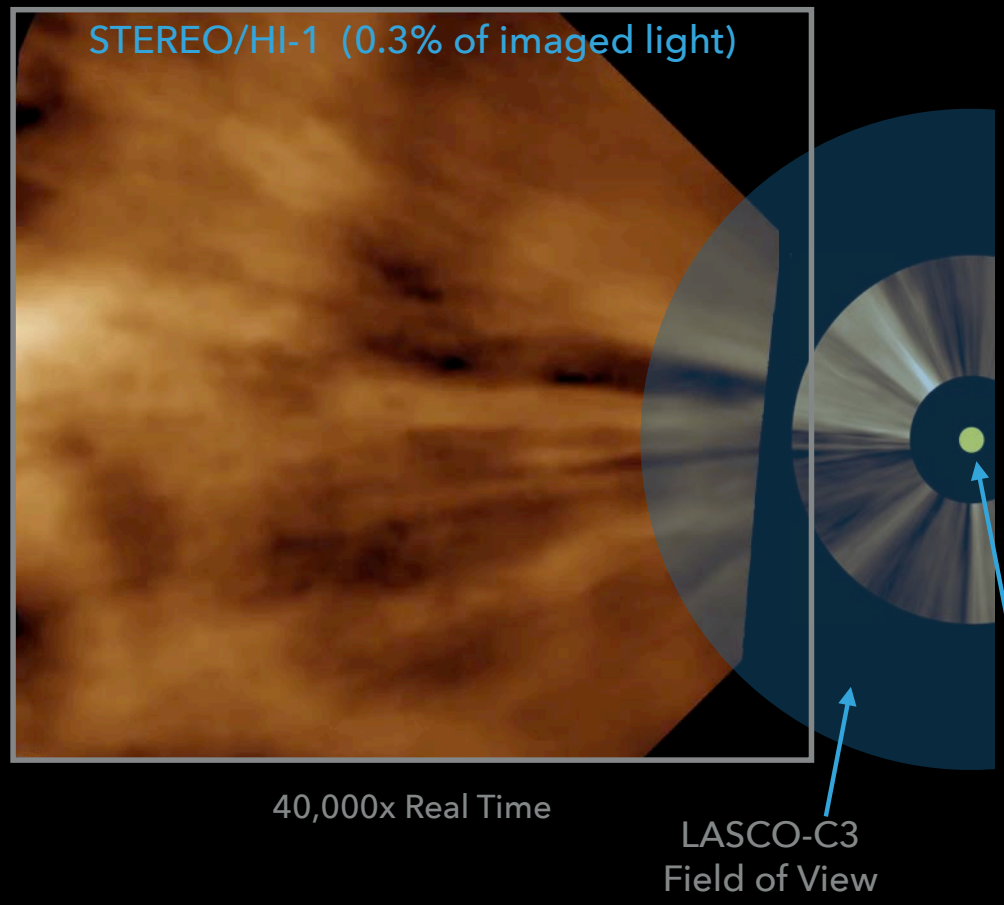
8,000x
Real Time





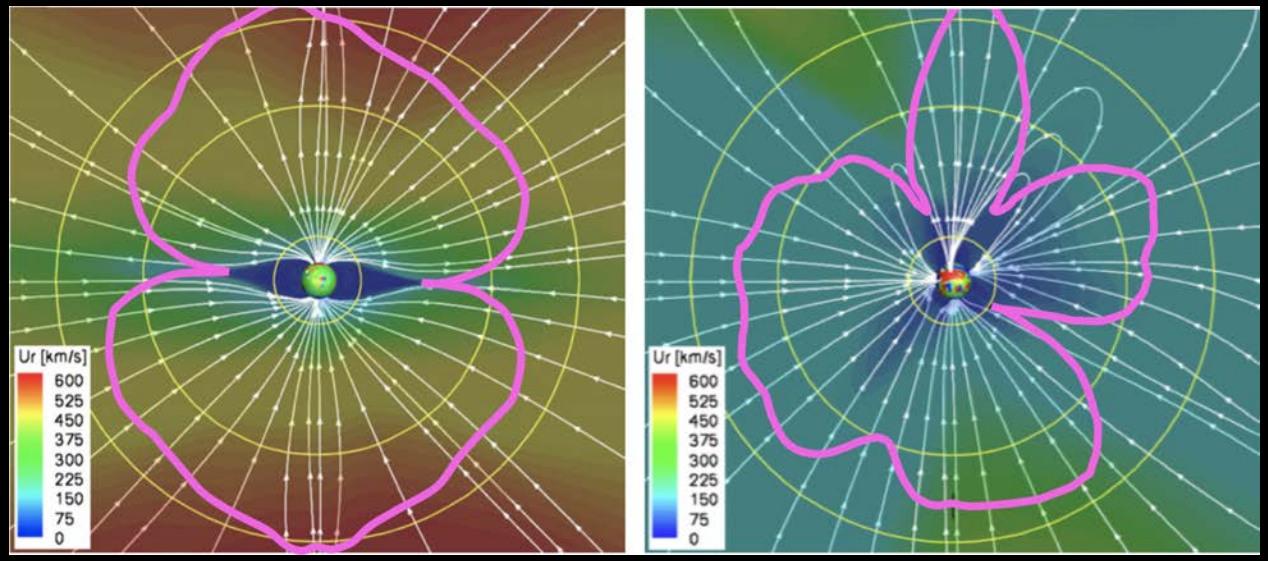
- Our best current data is from Ulysses … once every six years … at 1AU.

WHERE DOES THE SOLAR WIND BEGIN?



- Current instruments can just barely identify the top of the solar corona.
- The "β=1 surface", where the Sun's magnetic field becomes too weak to stabilize the flow in the solar wind ~10° (40 R⊙) from the Sun.
- Bright radial structures fade into "fluffy" dense clouds (turbulent eddies) – possible origins of fluctuations detectable in-situ.
- PUNCH will determine whether differences across gap indicate turbulence onset, or if they arise from instrumental differences

IDENTIFYING THE MYSTERIOUS ALFVÉN ZONE

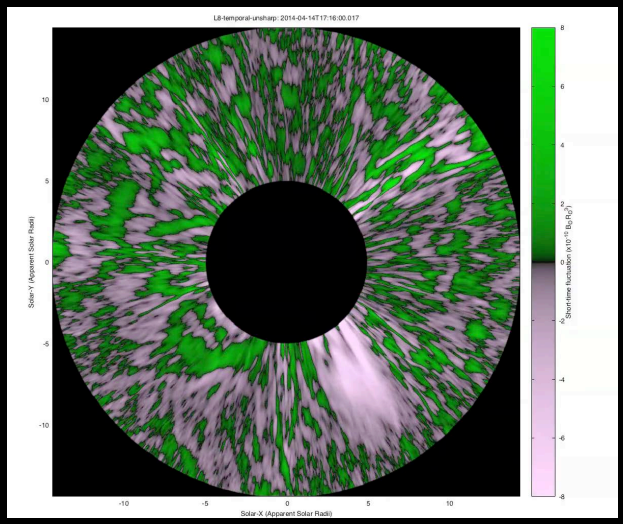


A natural dynamical boundary where the solar wind disconnects from the solar corona.

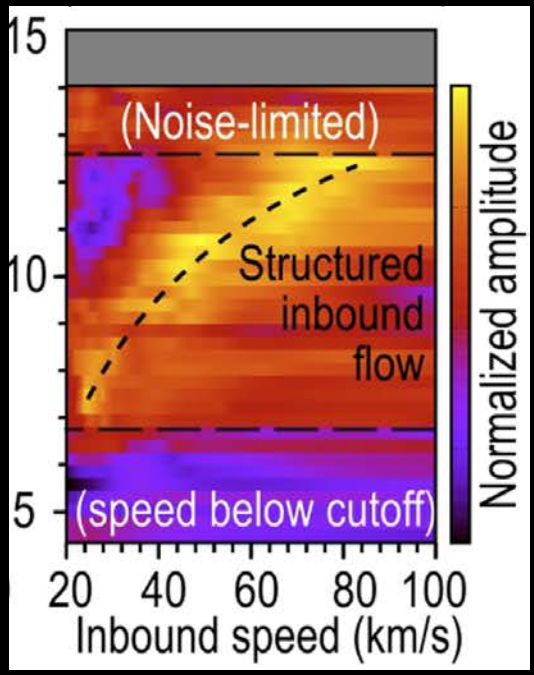
- Location where speed of the solar wind exceeds that of the fast MHD waves
- It is complex and changes with solar magnetic evolution
- It has never been observed; models are largely unconstrained

IDENTIFYING THE MYSTERIOUS ALFVÉN ZONE

- Since the Alfvén speed depends on density, the “riotous torrent” seen in the COR2 deep-exposure campaign indicates there is likely a fractal “Zone” rather than a surface.



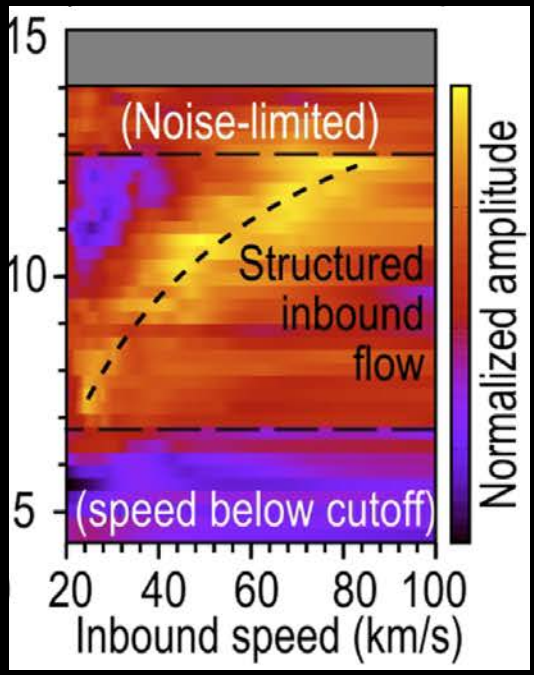
IDENTIFYING THE MYSTERIOUS ALFVÉN ZONE



- No measurement of magnetic field is required.
- Above the Alfvén zone all plasma must propagate outwards. Below, motion in both directions is possible
- Fourier in/out filtering can be used to identify wave speed directly.

IDENTIFYING THE MYSTERIOUS ALFVÉN ZONE

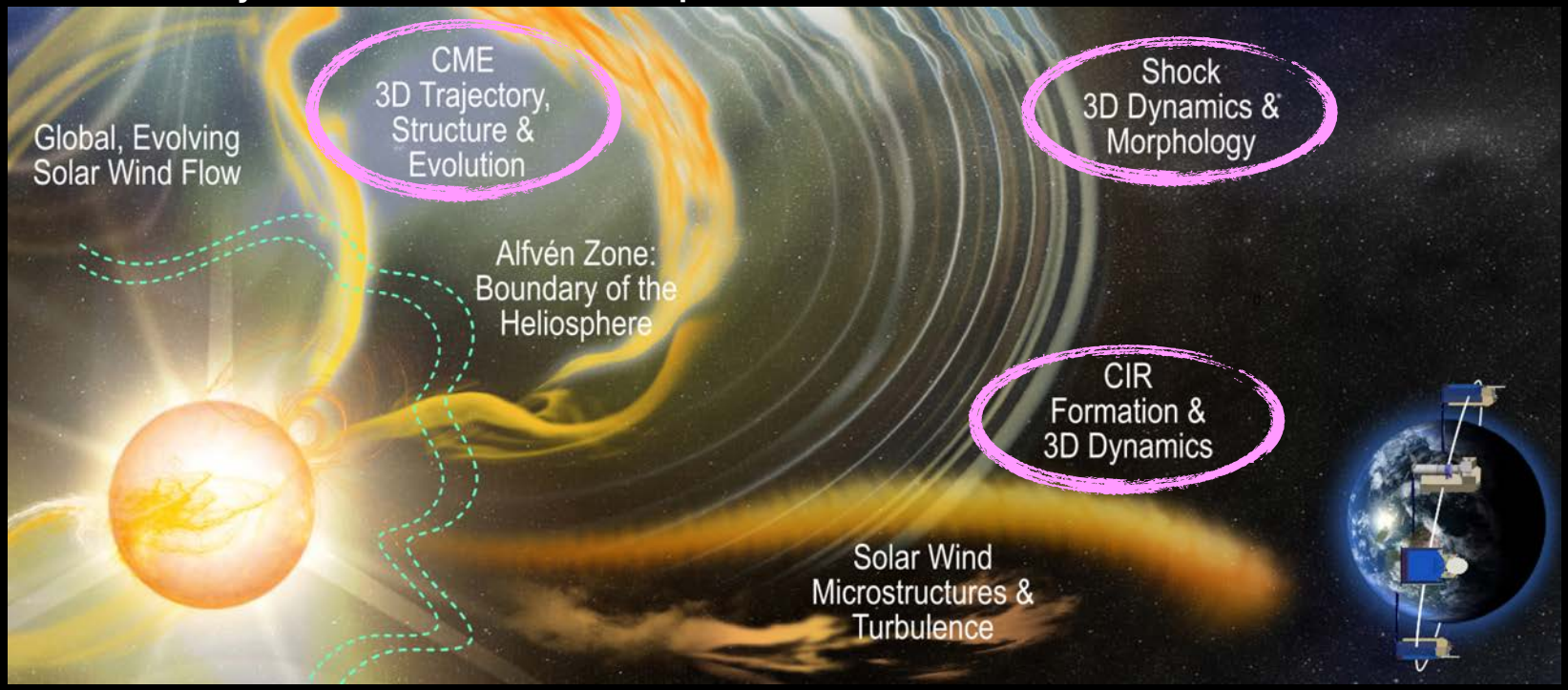
- **Existing observations yield lower limits on Alfvén zone.** STEREO COR2 analysis detected inward motions for all heights with detectable signal.
- Zone > 15 R for streamer, > 12 R for coronal hole.



PSP COMPLEMENTARITY: GLOBAL VIEW OF ALFVÉN ZONE

PUNCH SCIENCE OBJECTIVE 2: TRANSIENT STRUCTURES

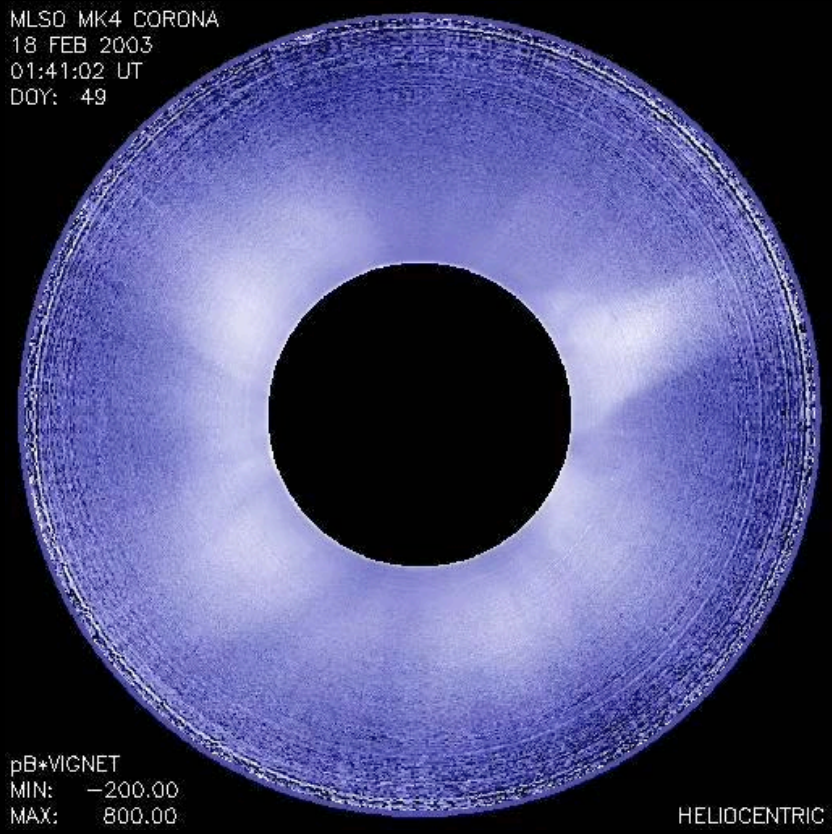
PUNCH's **science goal:** comprehend the *cross-scale* physical processes – from microscale turbulence to the evolution of global-scale structures – that **unify the solar corona and heliosphere**.



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?

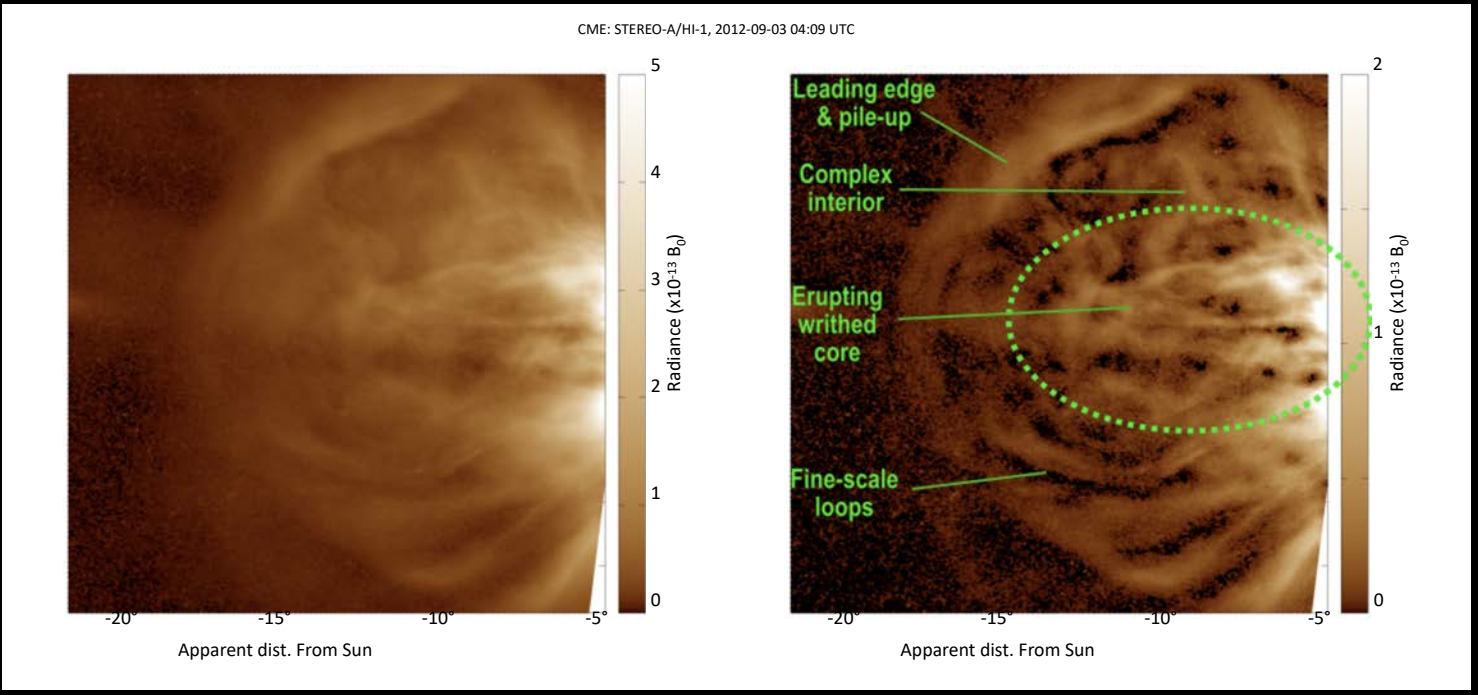
TRACKING CMES' EVOLVING STRUCTURE IN 3D



- CMEs are quite complex
- Interior structure evolves - even rotates - as the CME propagates

CME INTERIOR STRUCTURE

TRACKING CMES' EVOLVING STRUCTURE IN 3D

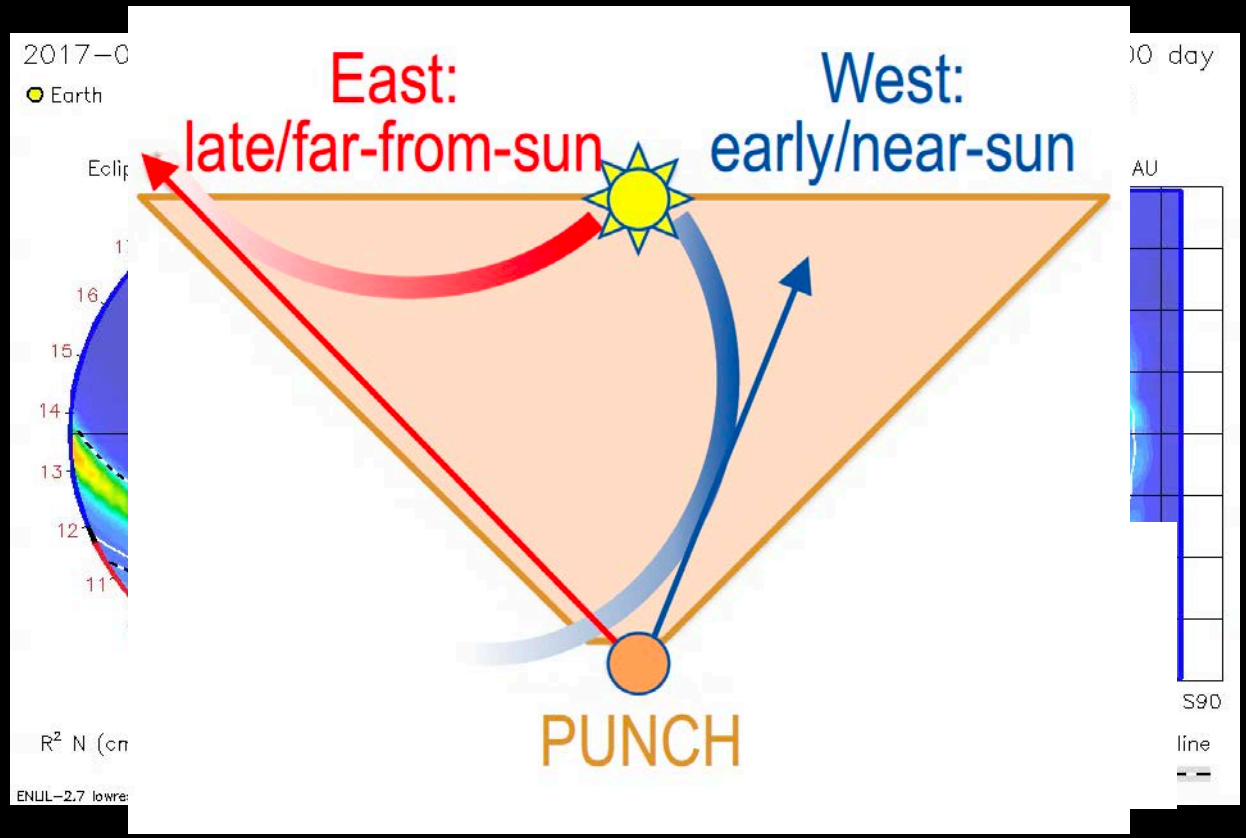


- CMEs are quite complex
- Interior structure evolves - even rotates - as the CME propagates
- PUNCH has 10X higher sensitivity - will see little flux ropes
- PUNCH has polarization at all heights

PSP COMPLEMENTARITY: GLOBAL (TIME/SPACE) ANALYSIS OF LITTLE FLUX ROPES

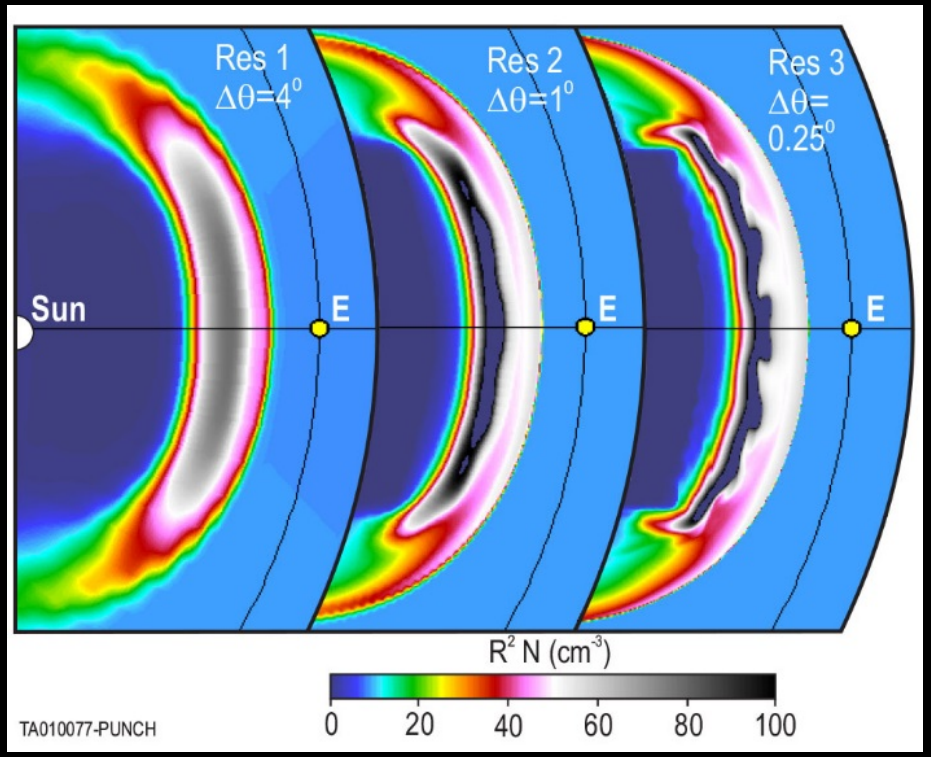
PUNCH MOVES BEYOND A PLANAR PERSPECTIVE ON COROTATING INTERACTION REGIONS

- Understanding CIR formation and wind/streamer interaction is critical to predicting spiral angle and impact time with the earth
- Shock onset in CIRs is not well understood
- CIRs are believed to launch strong waves near their source region as pileup begins, but measurements are sparse
- **PUNCH's wide field of view allows observations both close to and far from the Sun**



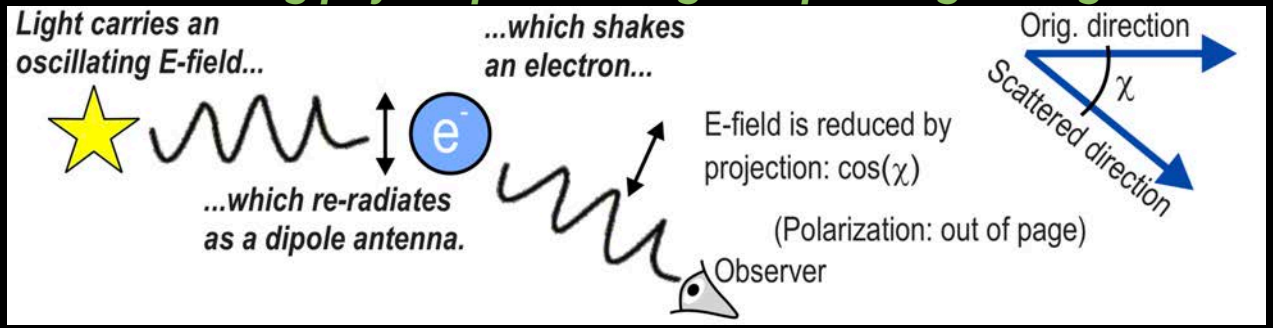
PUNCH PROVIDES A CROSS-SCALE PICTURE OF SHOCK DYNAMICS

- Simulations suggest that CME are strongly affected by turbulent instabilities across their shocks.
- Corrugations of shock fronts may be responsible for the acceleration of solar energetic particles (SEPs) and type II radio bursts
- The current generation of coronagraphs and heliospheric imagers are not designed to capture shock evolution, interactions and possible instabilities, due to sensitivity and motion blur effects.
- **PUNCH observes global shock structure and resolves shock-turbulence interactions.**

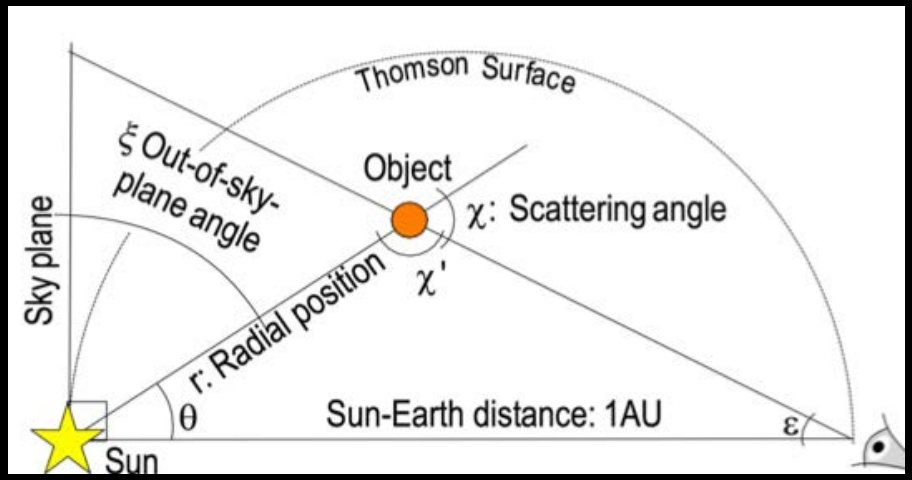


3D IMAGING WITH POLARIZATION

Scattering physics polarizes light depending on angle.



Other angles can be determined from geometry



The ratio of polarized brightness in each visible feature thus determines scattering angle.

Polarization ratio:

PR = (1-p)/(1+p), where p=pB/B

$$PR = B_R/B_T = 1 - F(r) * \sin^2\chi.$$

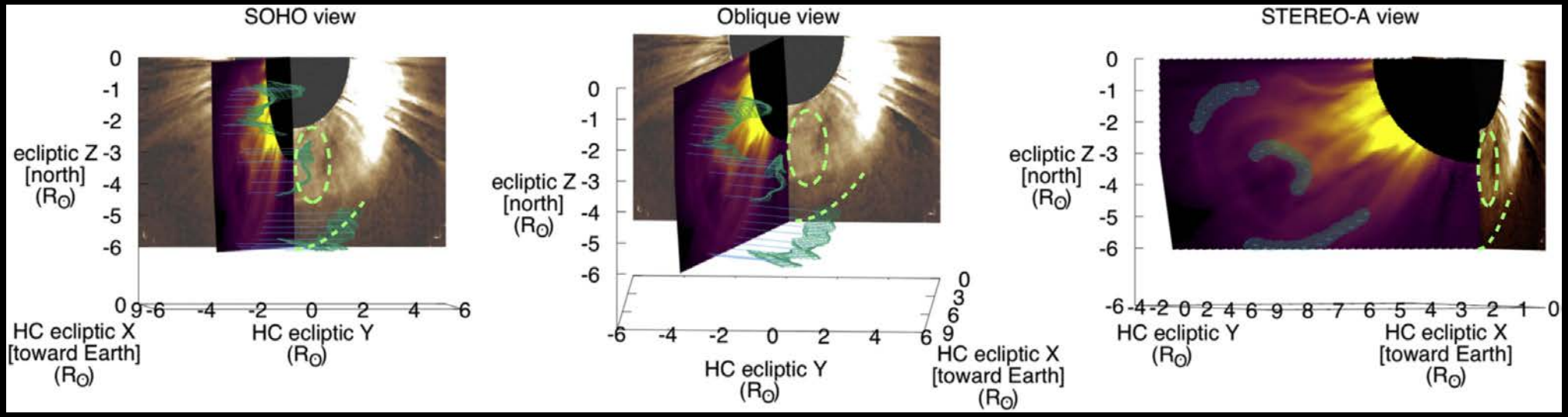
For a point-source Sun (> 2-3 $R_\odot$):

$$\chi \approx \text{acos}(\sqrt{PR}).$$

3D position is fully specified

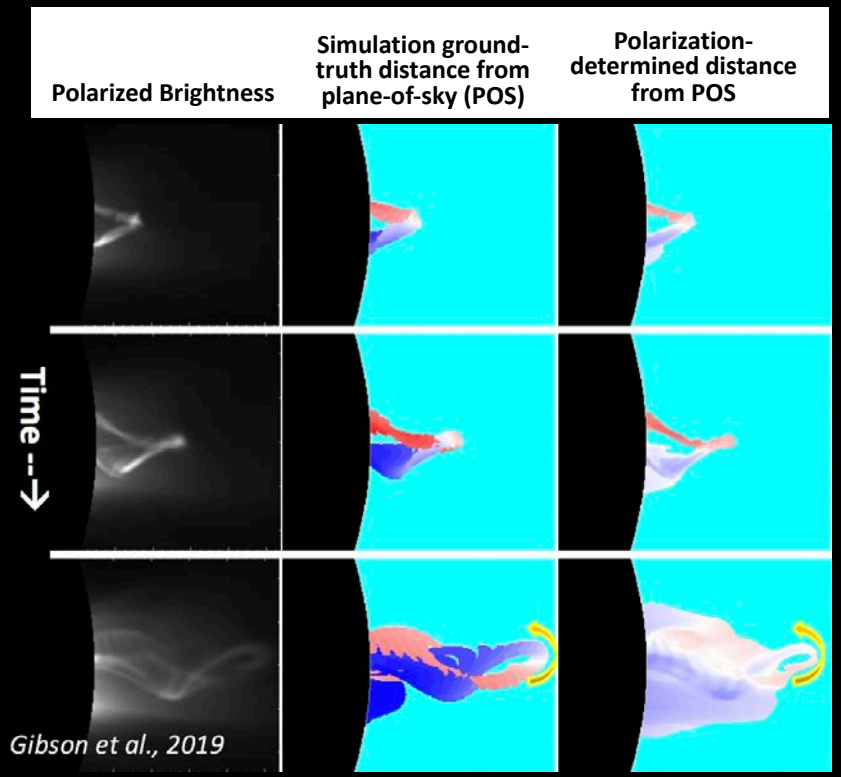
- **Y, Z from sky-plane projection**
- **X = r cos θ**

3D IMAGING WITH POLARIZATION



3D polarized imaging matches stereoscopy!

3D IMAGING WITH POLARIZATION



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

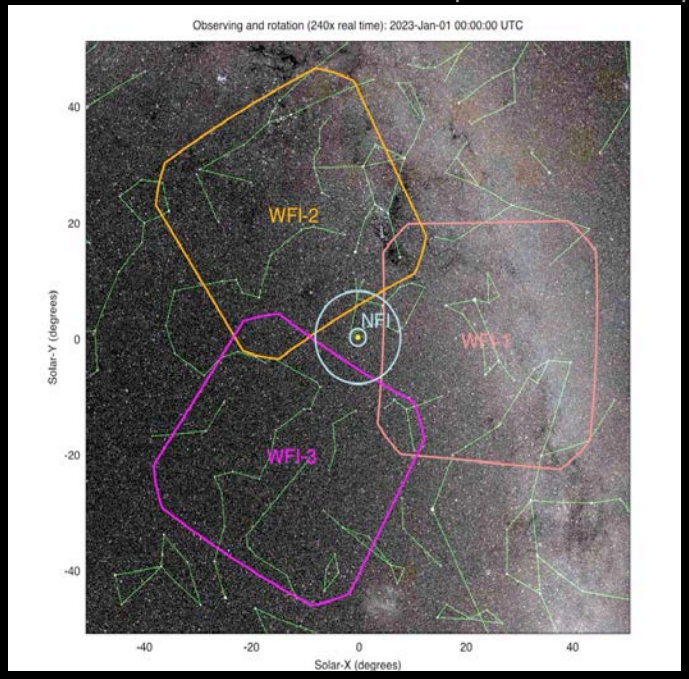
Front (red) vs. back (blue) is clear.

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

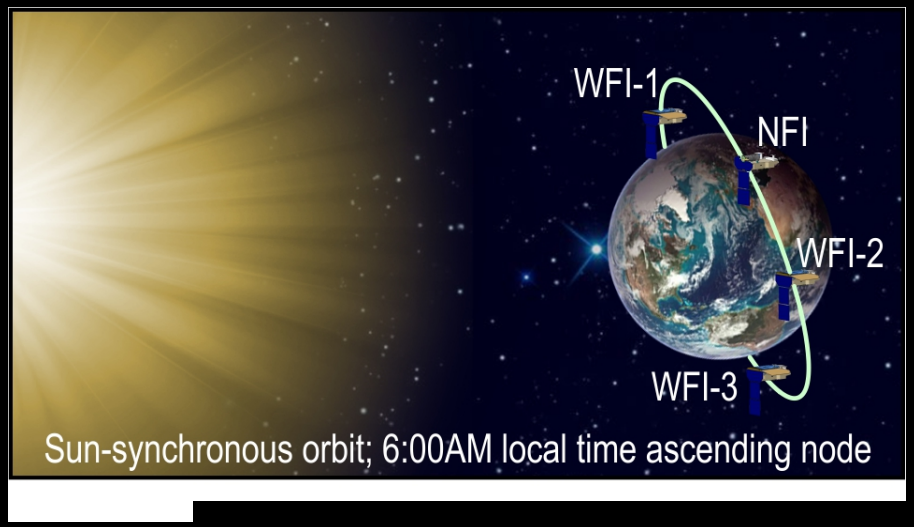
3D polarized imaging diagnoses chirality!

LEO ORBIT AND CADENCE DRIVE A CONSTELLATION SOLUTION

PUNCH sweeps its full FOV 3x per orbit



Three WFIs are 120° apart; NFI is unconstrained



PUNCH LAUNCH SEQUENCE

U.S. NAVAL RESEARCH LABORATORY

SwRI

RAL Space

PUNCH WILL:

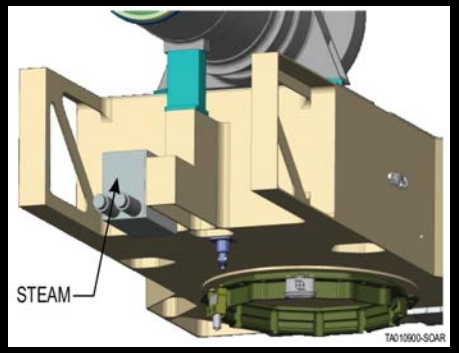
- Derive daily global solar wind maps
- Quantify large-scale turbulent onset
- Observe the uncharted Alfvén zone
- Track CME substructure and chirality
- Track CIR formation and evolution
- Characterize cross-scale shock dynamics

STEAM – PUNCH

Full-Sun, time-resolved SXR & HXR spectrometer

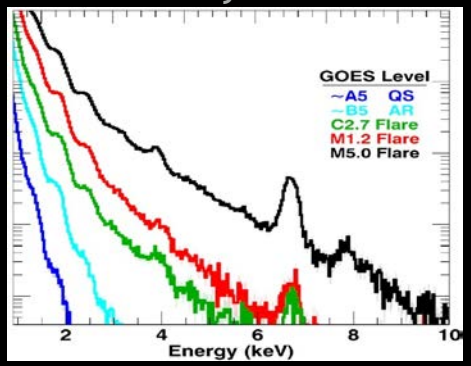
- Led by Colorado Space Grant Consortium
- Science Mentor at CU Boulder
- Engineering Mentorship at SwRI
- Students participate in 7120.5E reviews
- Scientifically relevant project

STEAM rides with NFI



Direct Hands-On Experience

Scientifically Useful Data



SwRI heritage