Polarimeter to Unify the Corona and Heliosphere

PUNCH-4 Science Meeting

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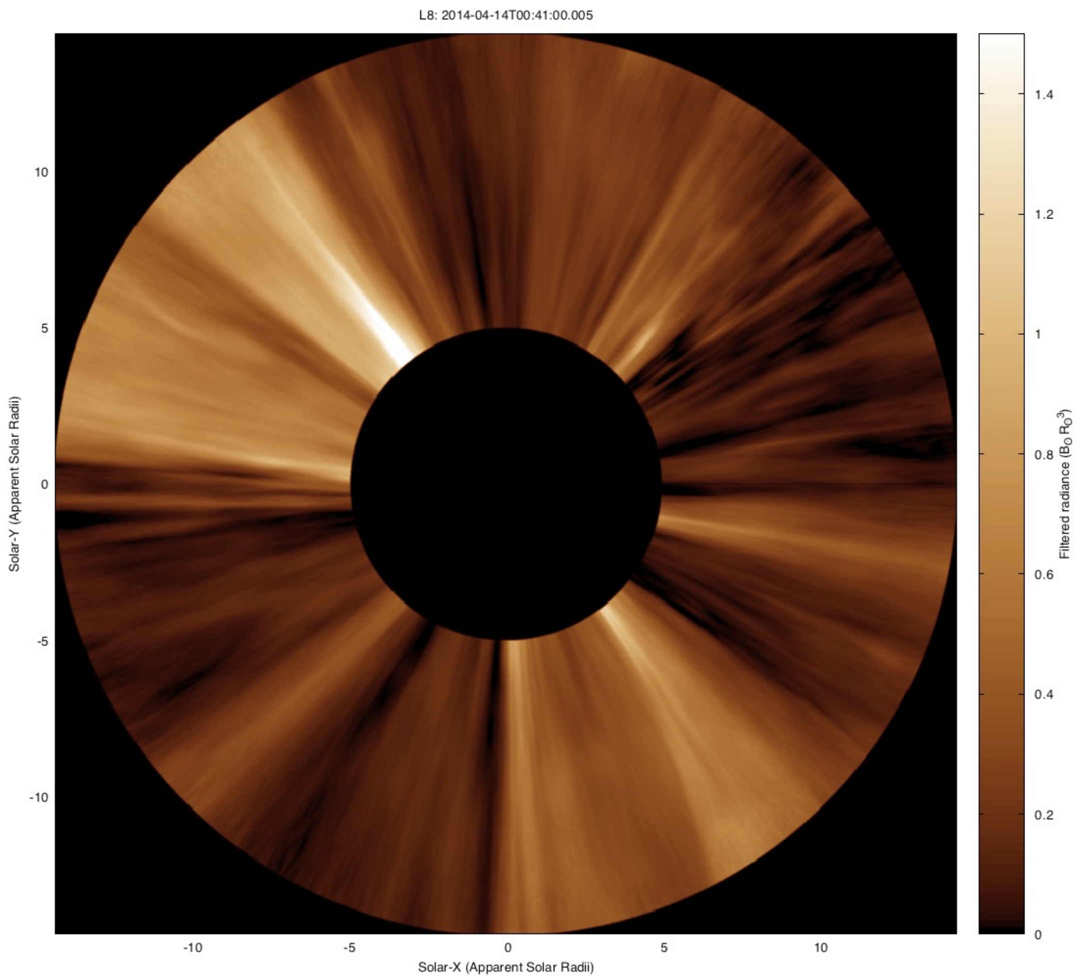
PUNCH Working Group 1B

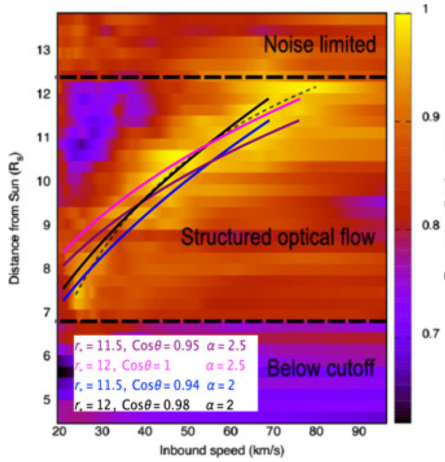
- PUNCH determines how much and what types of mesoscale structures are solar in origin, and how much and what types develops en route (e.g. the 'quiescent' but turbulent solar wind session)
- Answering these questions is important for:
  - Understanding solar wind formation
  - Providing critical insight into where and how kinetic energy becomes available to drive a turbulent cascade
  - Understanding the solar wind variability impacting Earth's magnetosphere and other inner planets



DeForest et al. 2018 deep field STEREO campaign is similar to PUNCH/NFI's resolution, demonstrating the structured solar wind PUNCH will measure

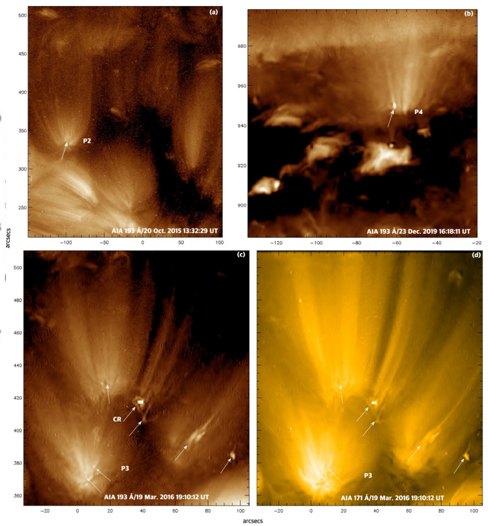
Magnetic Reconnection in the Solar Corona Creates a Plethora of Structures in the Heliosphere: Enormous Range of Conditions and Consequences

Nanoflares



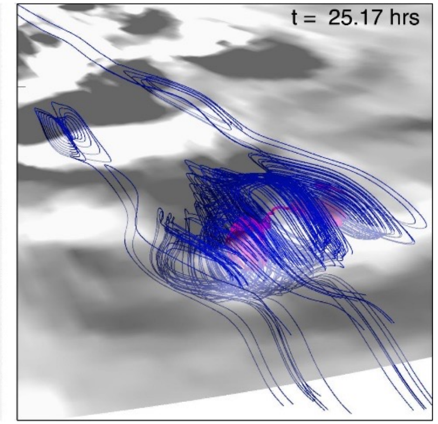
e.g. DeForest et al. 2014
Tenerani et al. 2016

Jets and Jetlets



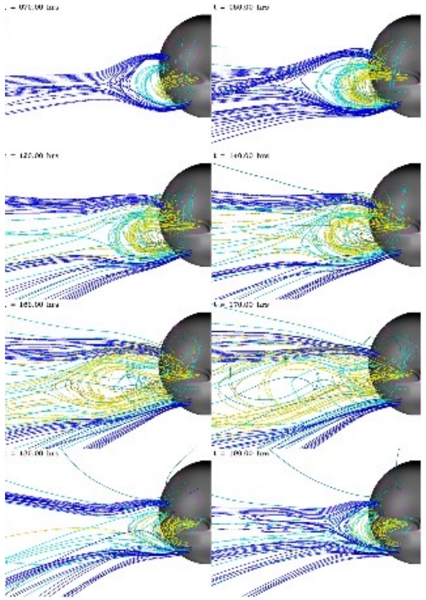
e.g. Kumar et al. 2022
Raouafi & Stenborg 2014
and see Nour's talk and
Alfonse's talk next

Helmet Streamer Blobs



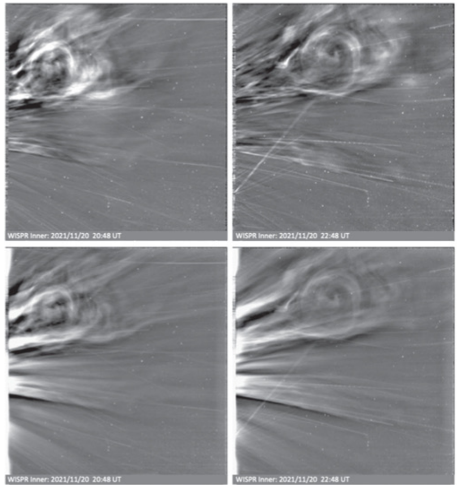
e.g. Rouillard et al.
Higginson et al. 2018

Stealth CMEs



e.g. Lynch et al. 2016
Palmerio et al.

Big Flares and CMEs

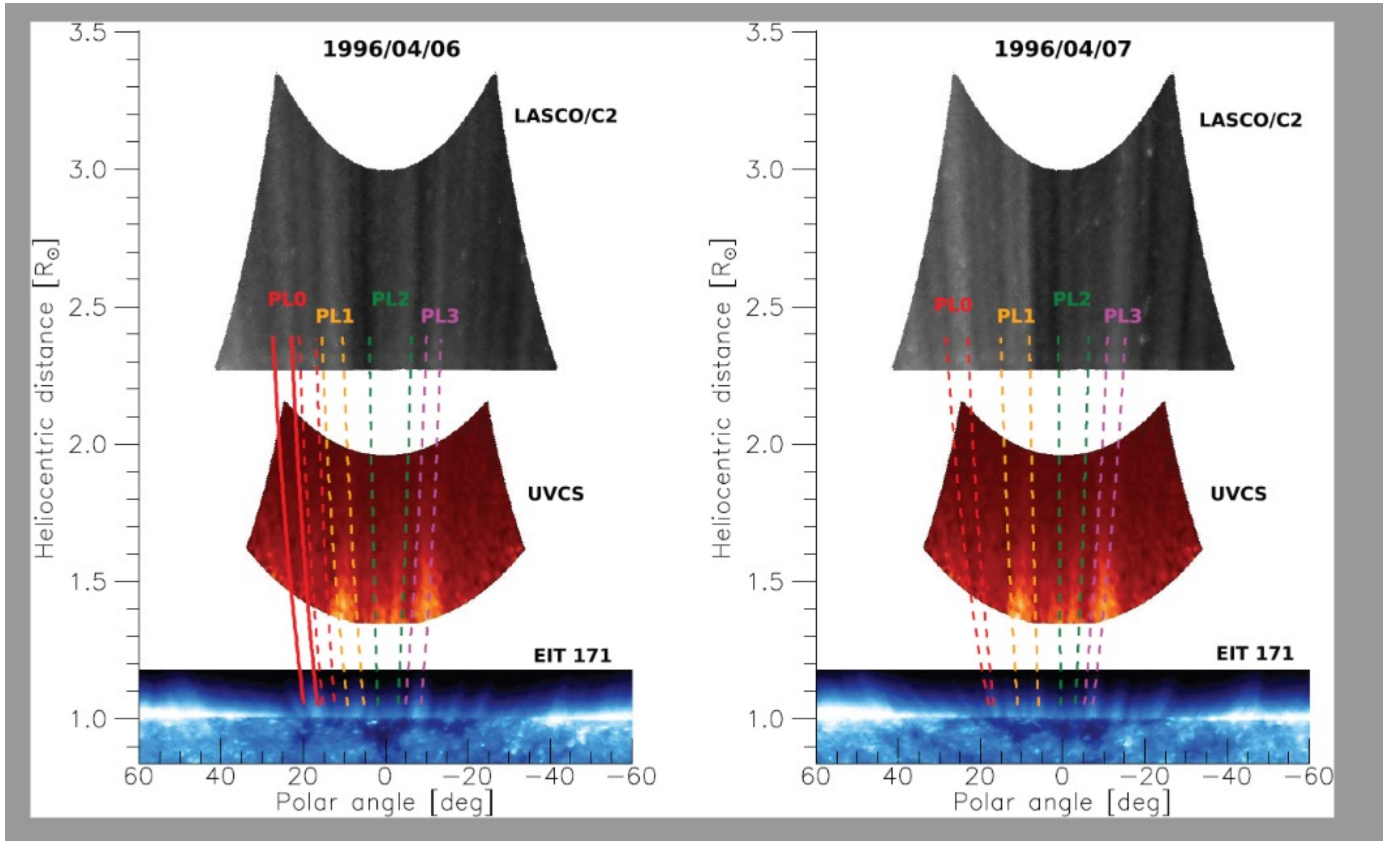


e.g. Howard et al. 2022
PSP/WISPR CME

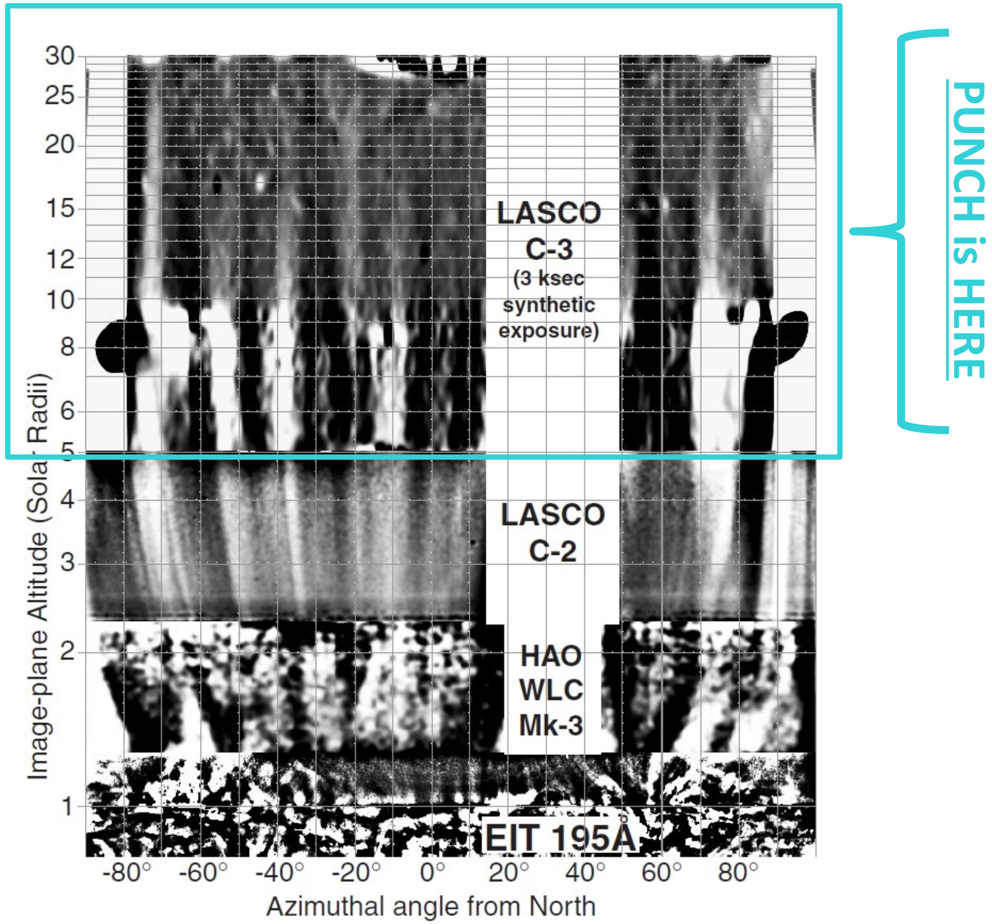
All examples of coronal reconnection, but there are enormous differences in:

- Magnetic topology - component reconnection; interchange reconnection; anemone; antiparallel
- Energy injection – small-scale flux emergence, AR-scale flux emergence, foot point mixing/shear on granular scales, foot point mixing/shear on super granular scales, shear from differential rotation…
- Energy released - spans nine (at least) orders of magnitude
- Mass released into the heliosphere – zero (open-open reconnection), 10^8 kg (Raouafi 2023 jetlets), up through 10^13 kg (CMEs)
- Periodicities – random/red noise, 3-5 min, 90 min, singular

PUNCH will Image Solar Plumes, which are Related to Jets and Jetlets (see Alfonse and Nour’s talks up next)

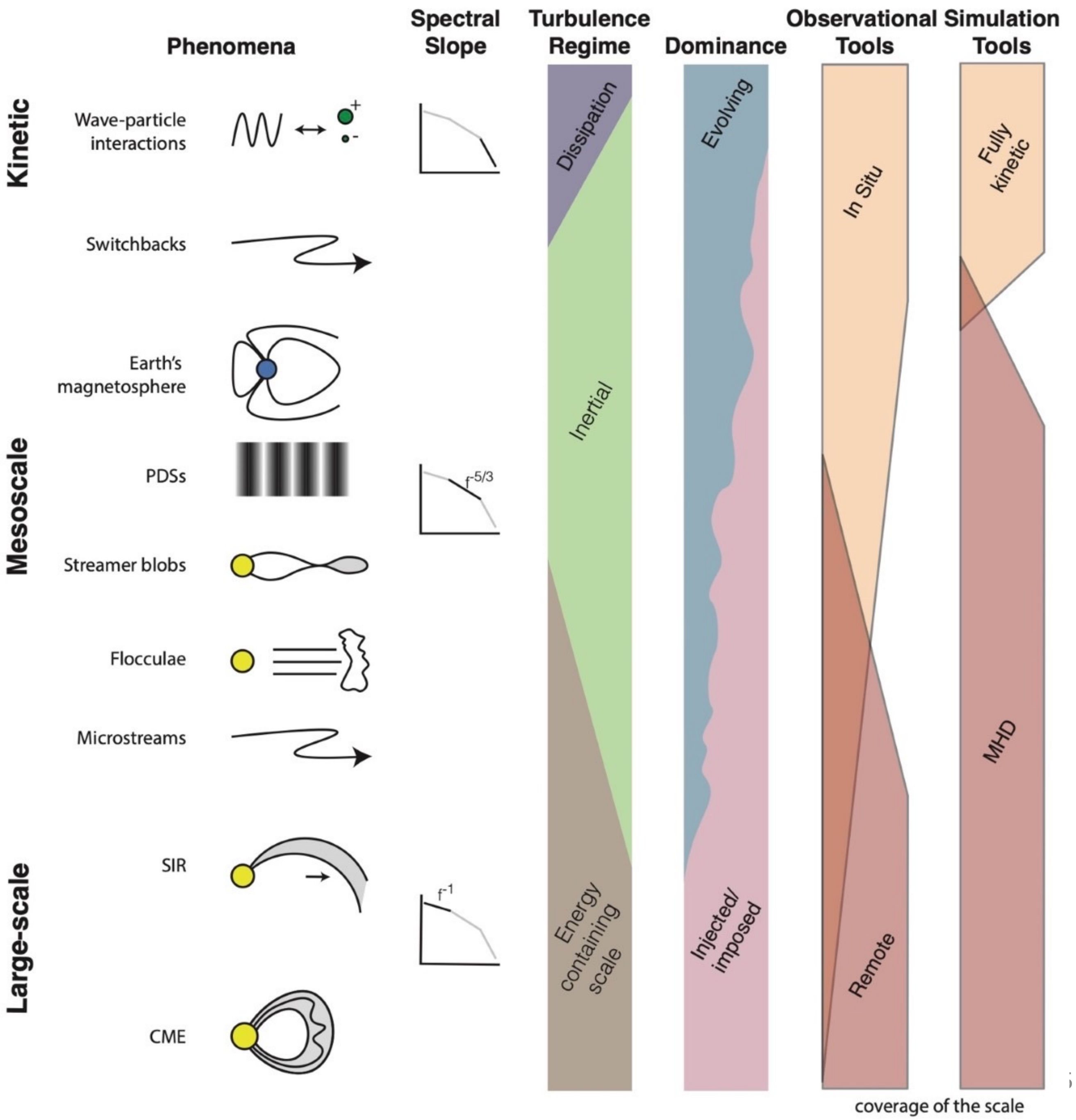


L. Zangrilli and S. M. Giordano 2020



Poletto 2015

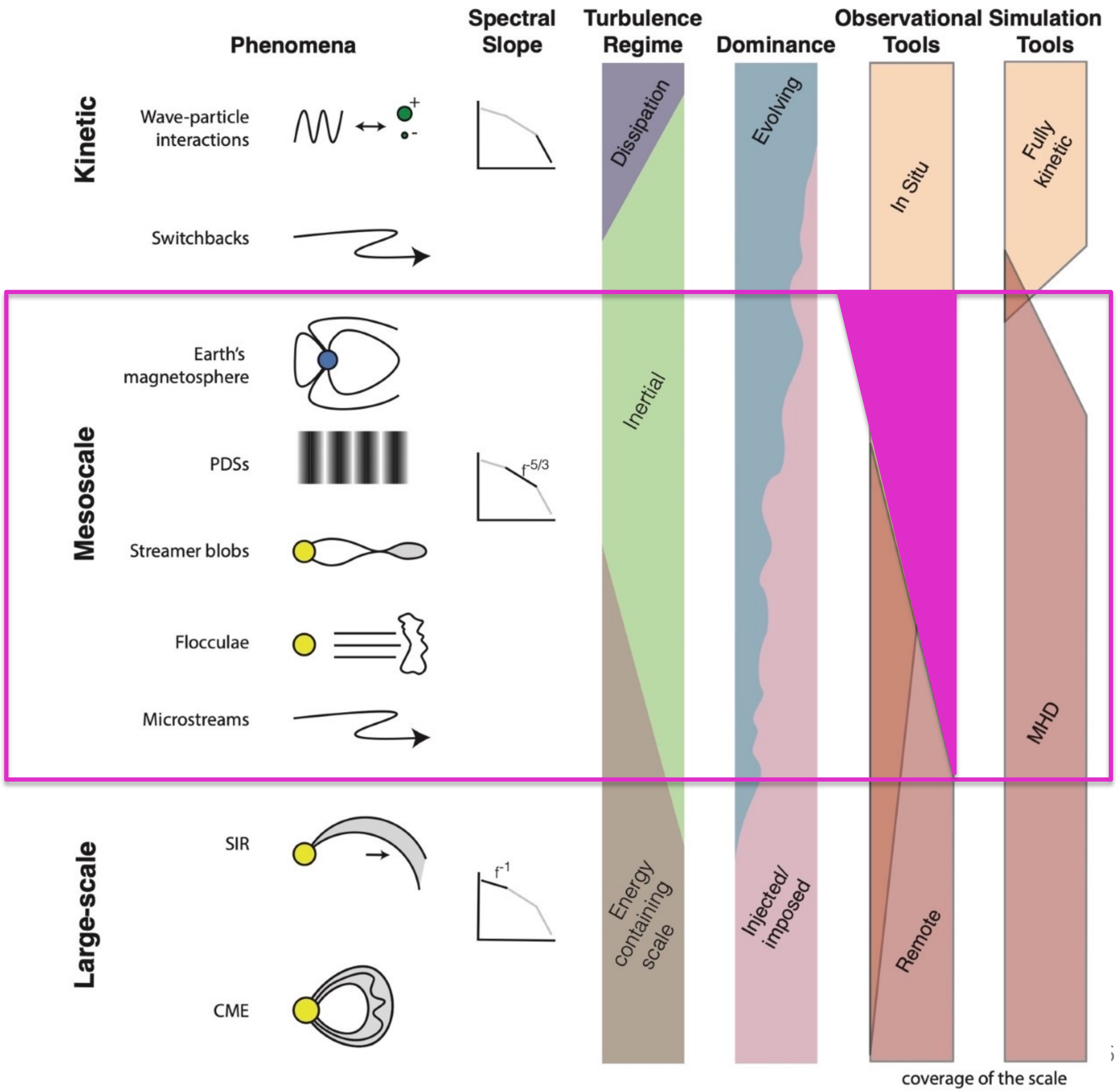
Mesoscale structures in the solar wind are injected/imposed from the Sun, and generated en route through turbulence/dynamics



Viall, DeForest & Kepko, Mesoscale Structures in the Solar Wind, 2021

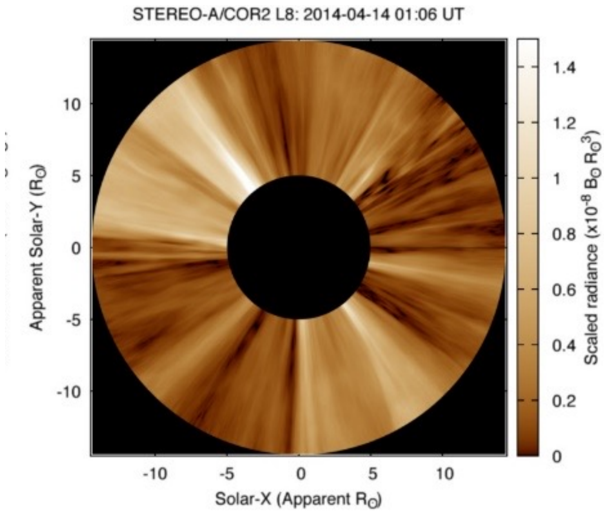
Mesoscale structures in the solar wind are injected/imposed from the Sun, and generated en route through turbulence/dynamics

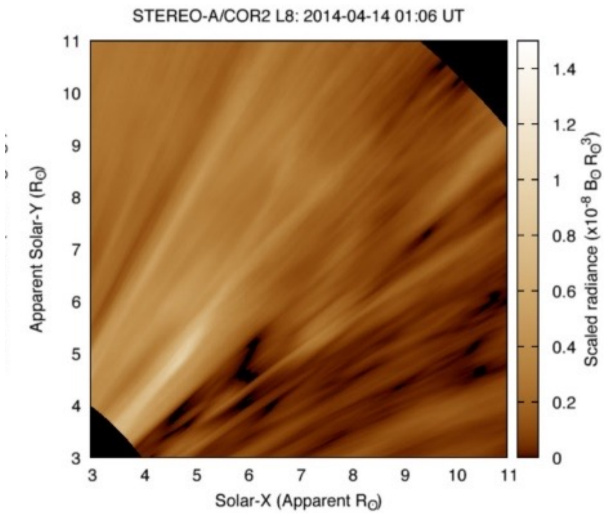
PUNCH fills in the missing coverage and resolution of mesoscales



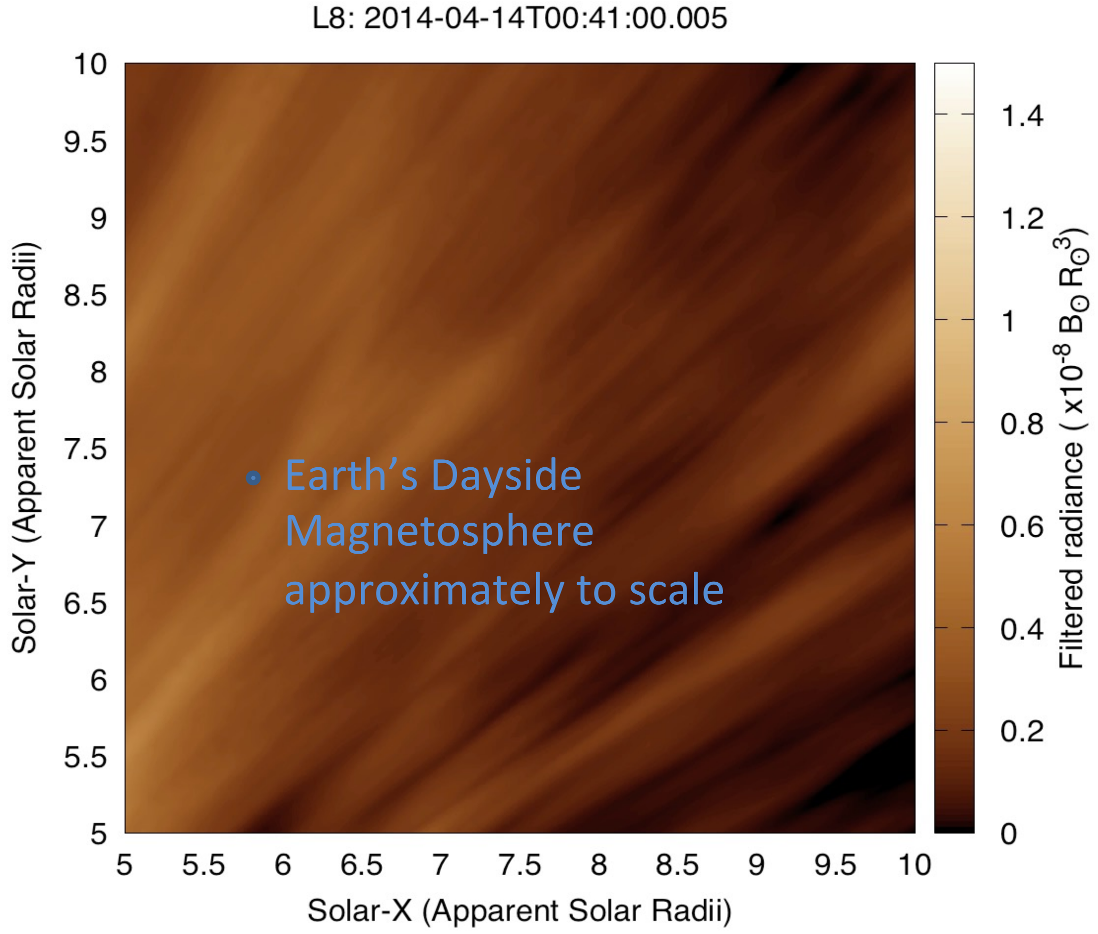
Viall, DeForest & Kepko, Mesoscale Structures in the Solar Wind, 2021

The Mesoscales that PUNCH Measures are >= the Dayside Magnetosphere





DeForest et al. 2018

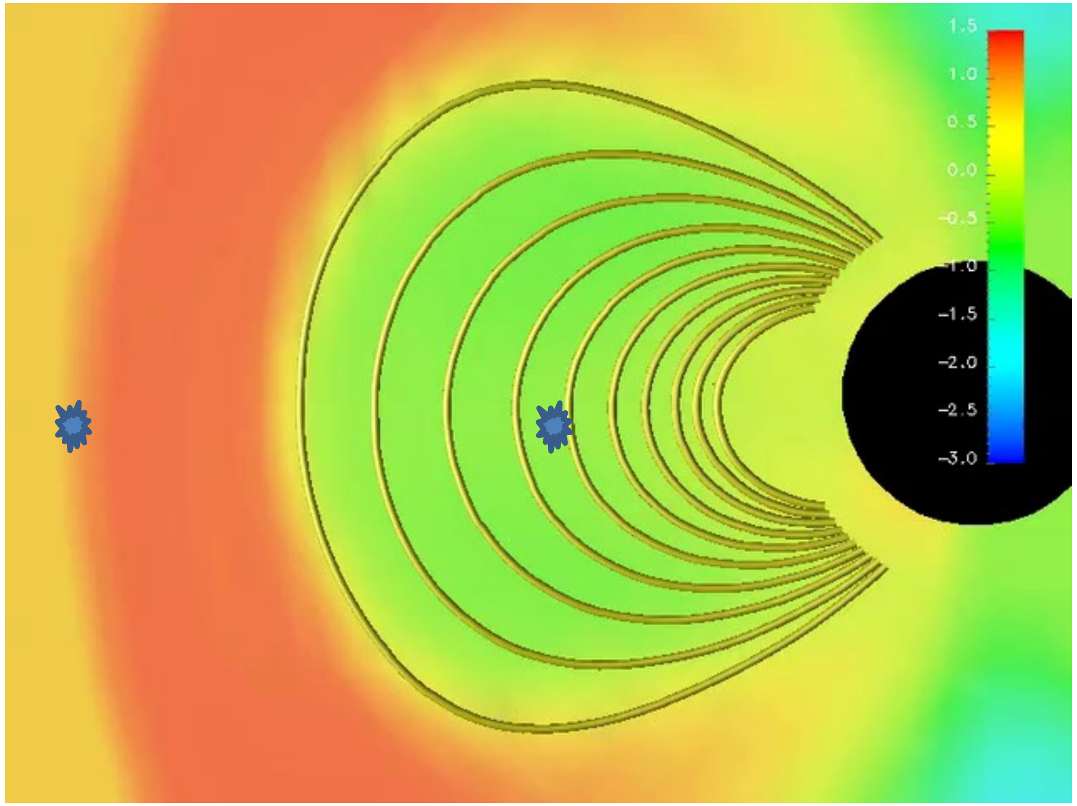


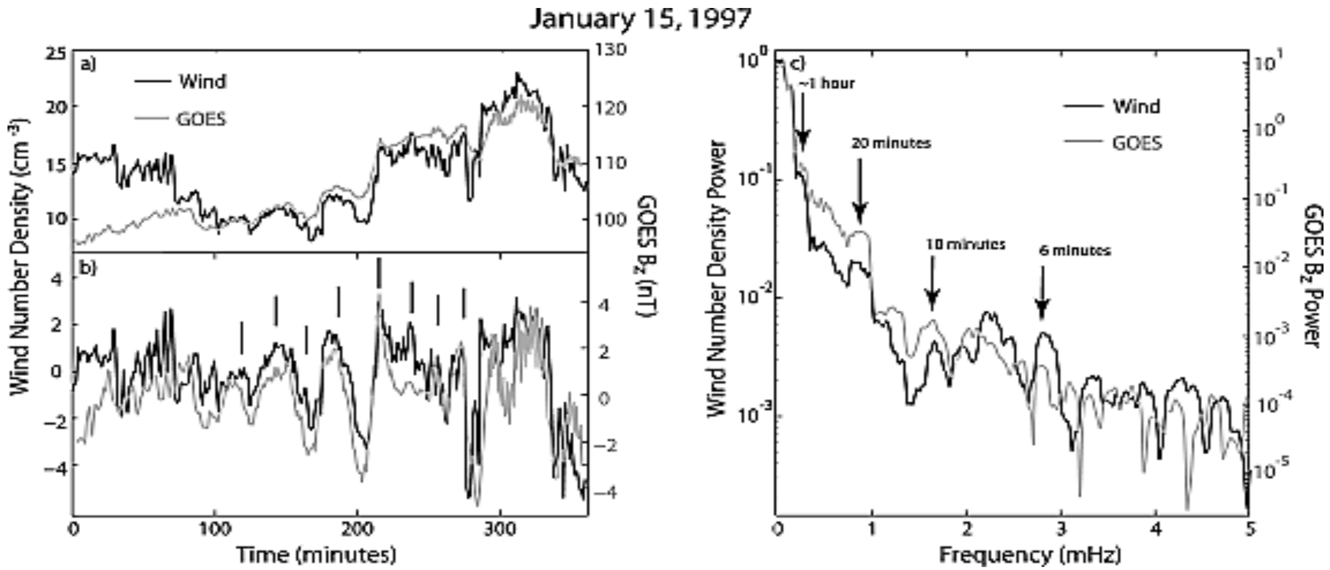
1 Solar Radii = 0.25 degrees
PUNCH resolution requirement inner is 3' ~ 140 Mm
140 Mm advecting at 400 km/s = 350s (6 minutes)

Many solar wind structures are periodic dynamic pressure structures, and they drive oscillations in Earth's magnetosphere

20+ year old mystery: What causes the solar wind to have periodic density structures?

[We speculated probably something from the Sun…]





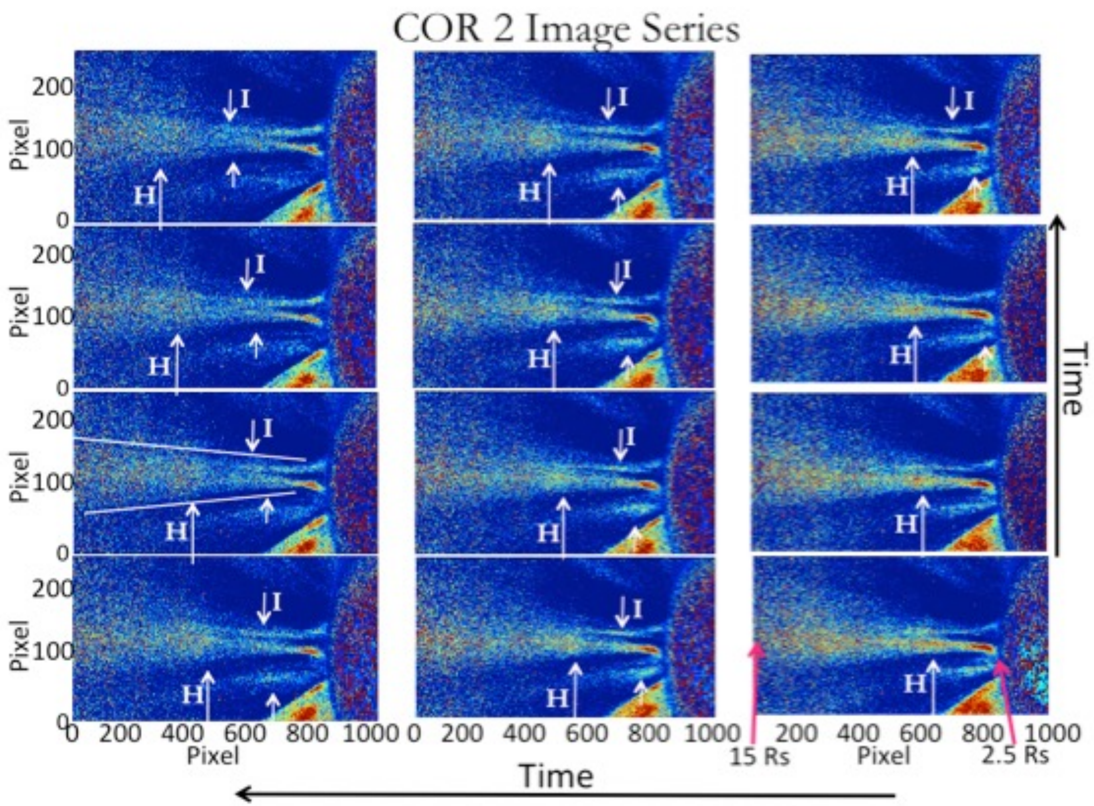
Viall, N. M., Kepko, L., and Spence, H. E. (2009), Relative occurrence rates and connection of discrete frequency oscillations in the solar wind density and dayside magnetosphere, *J. Geophys. Res.*, 114, A01201, doi:10.1029/2008JA013334.

Kepko et al. 2002 discovery event

Kepko and Spence 2003 speculated on a Solar Plume source… but connecting 1 AU measurements to solar sources is hard!

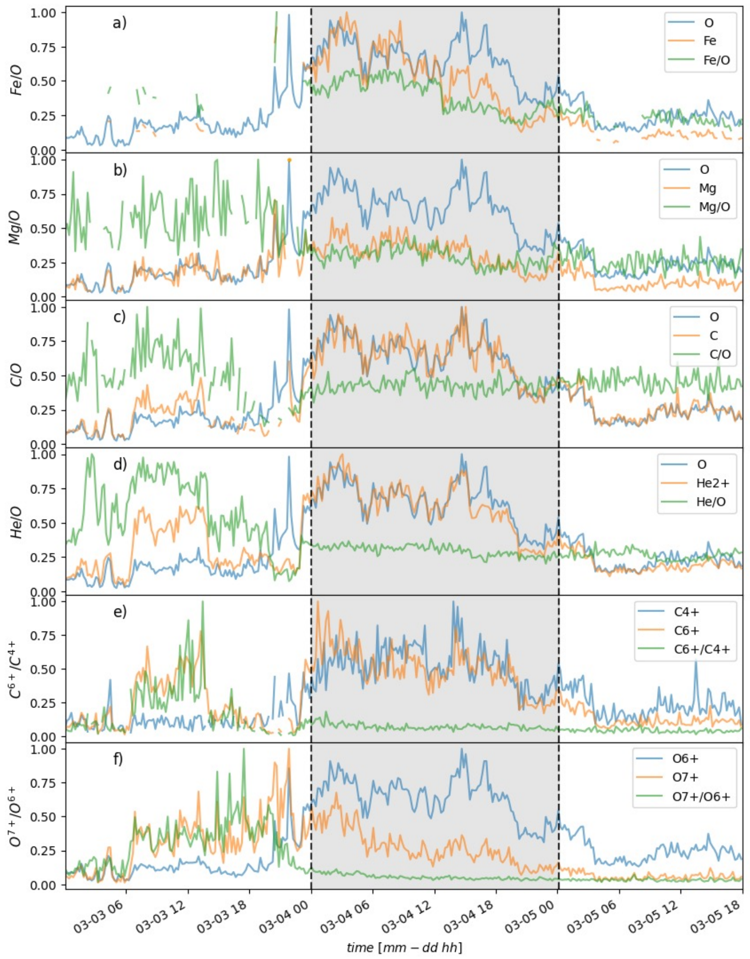
’Using measurements from the SOHO Extreme Ultraviolet Imaging Telescope (EIT), ***DeForest and Gurman* [1998]** presented observations of outward propagating quasi-periodic sound waves in solar plumes that had a period of T = 10–15 min (f = 1.1–1.7 mHz), which is near one of the CMS frequencies. Using the white light channel (WLC) of the Ultraviolet Coronograph Spectrometer (UVCS), ***Ofman et al.* [1997**, **2000]** showed periodic variations in the polarized brightness (a measure of the electron density) of coronal hole plumes at a solar distance of 1.9 $R_{\odot}$. An example of these periodic brightness variations is shown in **Figure 20**. This figure is adapted from ***Ofman et al.* [2000]** and shows the average of nine consecutive ∼1 hour Fourier transforms of the polarized brightness. Clear peaks are present at f = 0.7, 1.3, and 2.4 mHz. We point out that the plume observations of ***Deforest and Gurman* [1998]** and ***Ofman et al.* [1997**, **2000]** are in the polar regions of the Sun, not near the equator, where the solar wind observed by the Wind spacecraft likely originated.’

Large-scale (~1-2 hour) Periodic Solar Wind Density Structures Come from the Sun and survive to 1 AU: PUNCH will Measure their evolution through the inner heliosphere



Viall & Vourlidas 2015

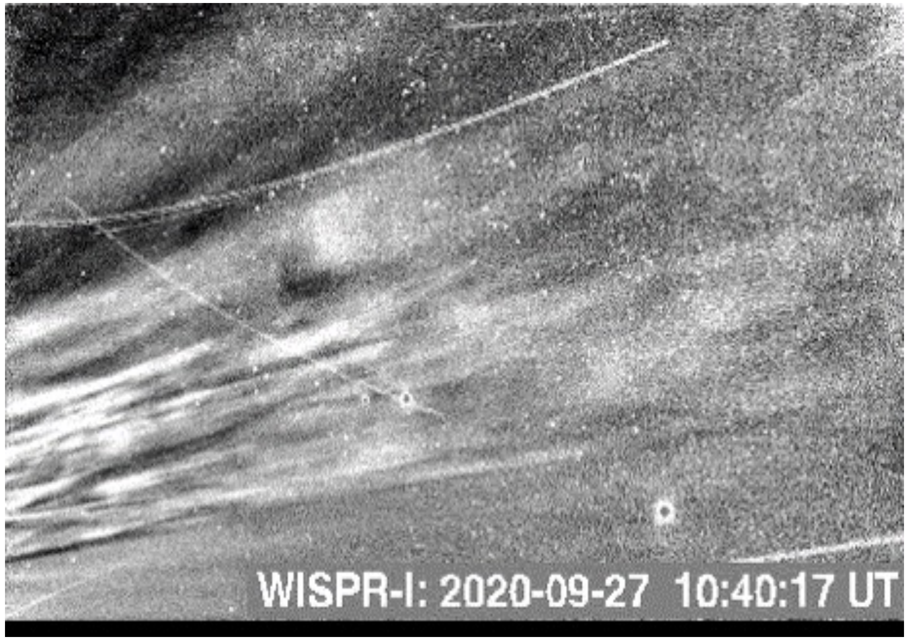
STEREO COR2/HI1 shows solar wind periodic mesoscale structures have a characteristic periodicity ~1-2 hours, and are formed at the HCS/helmet streamers

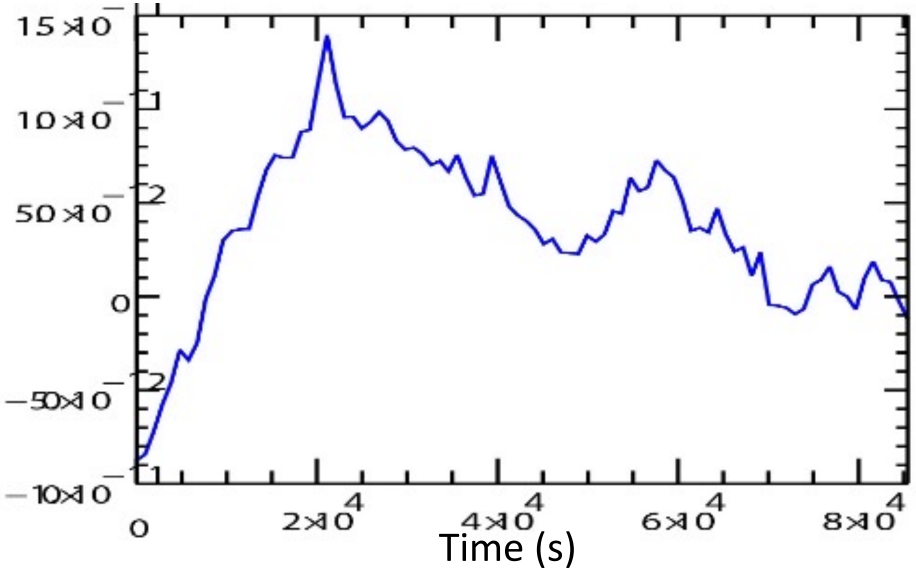


Elemental abundance variations measured by ACE shows that Earth-impacting solar wind periodic mesoscale structures were formed in the corona (Gershkovich et al. 2022). Gershkovich, Lepri, Viall, Kepko and DiMatteo, (Solar Physics, 2023) found ~ 90 min, and ~30min to be characteristic periodicities in ACE statistics

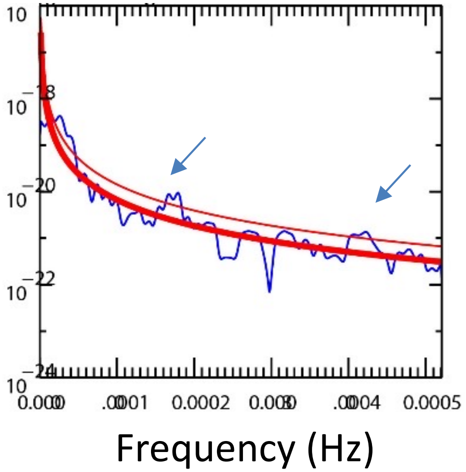
WISPR Images Solar wind released through periodic reconnection

Encounter 6, Synoptic (15-min) Data





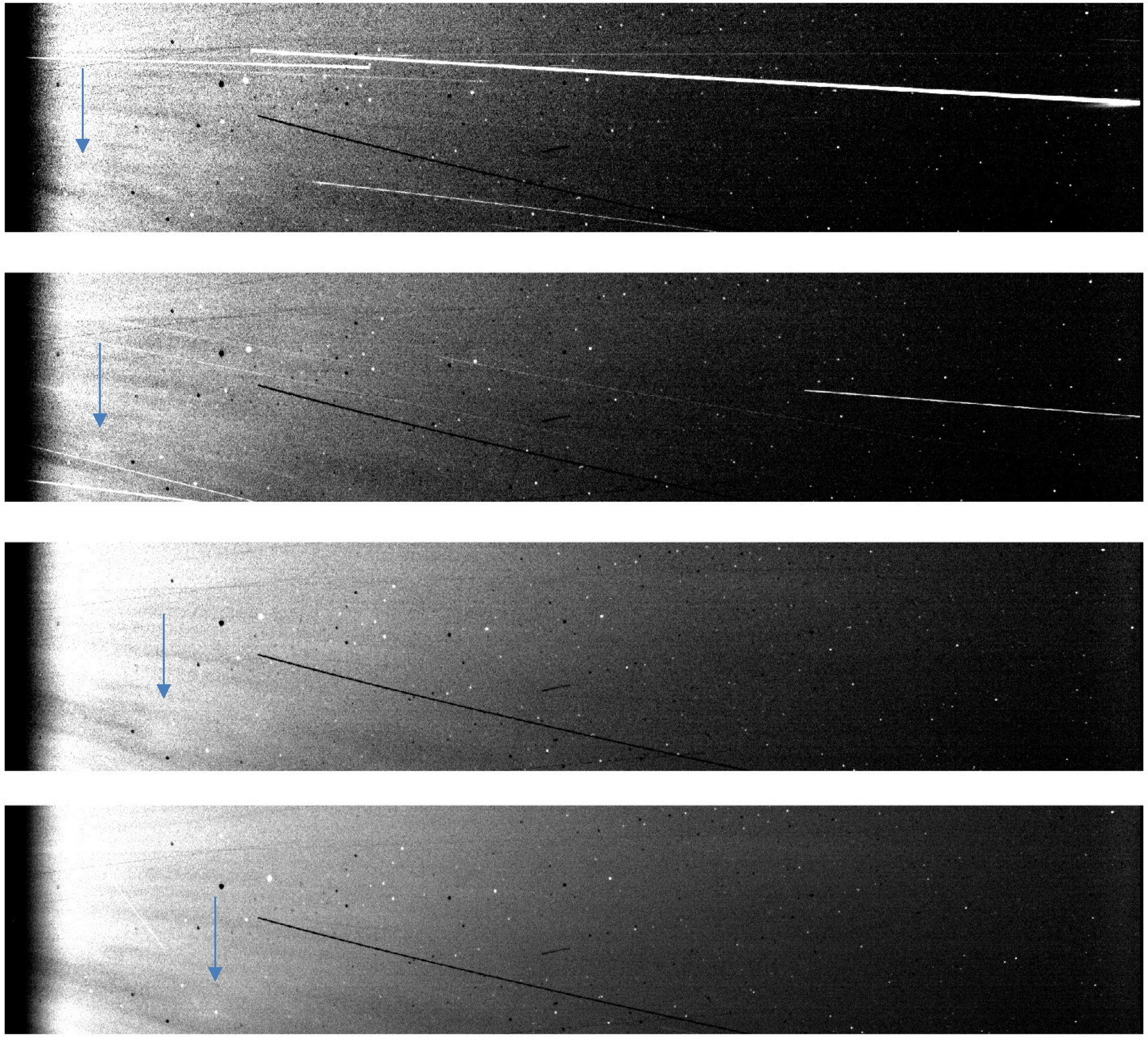
24-hour intensity time series from 10-pixel tall, one pixel wide slit near inner edge



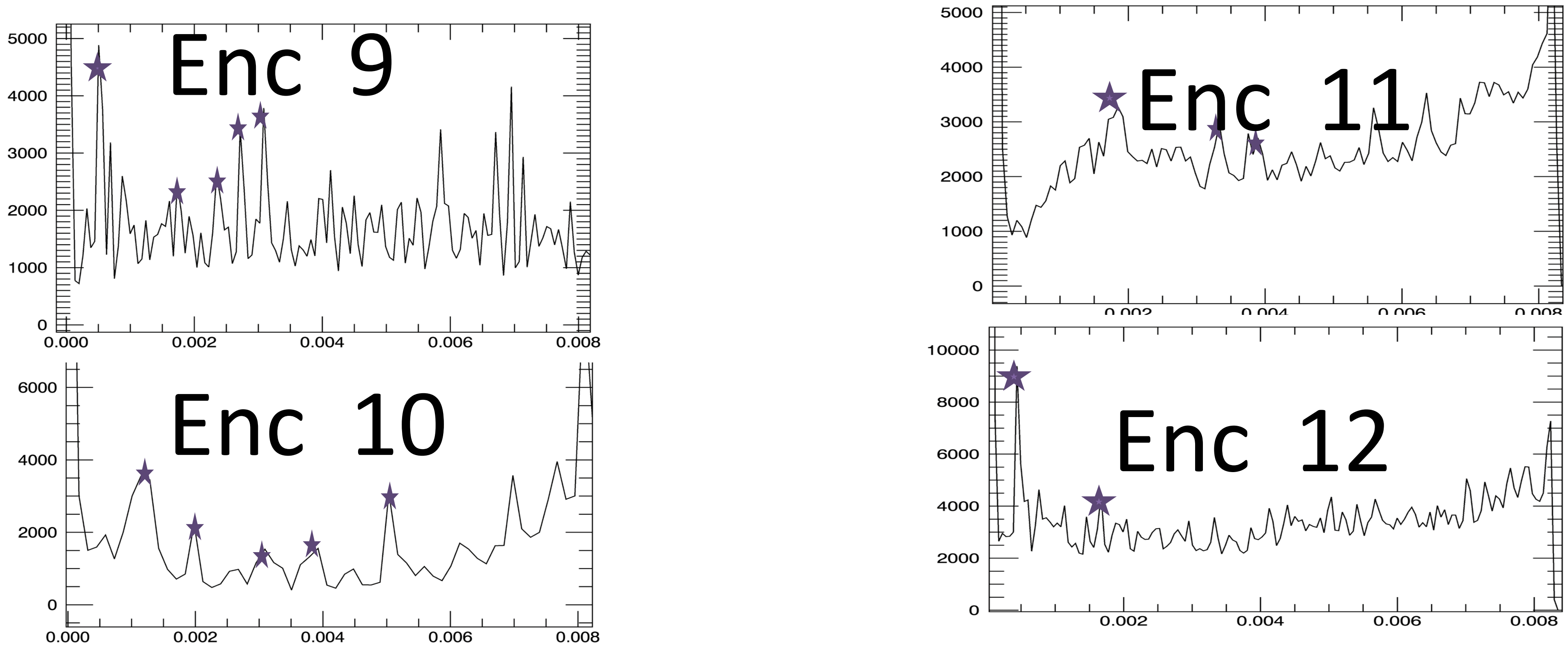
Discrete frequencies identified at
100 min = 0.17 mHz
40 min = 0.42 mHz

- The corona often emits blobs of solar wind as a periodic train of density structures, which manifest as discrete enhancements (periodicities) in Fourier analysis.
- **Open source Fourier analysis tools available and we will help teach you! DiMatteo et al. 2022**
- The periodicities are likely due to fundamental properties of magnetic reconnection during the release of solar wind (Reville et al., 2020, ApJ, 895, 20; Reville et al., 2022, A&A, 659A.110R).

WIPSR high cadence data pushing the limits (way beyond requirements) but the SNR looks good Enc 11; This demonstrates the smaller structures we will image with PUNCH

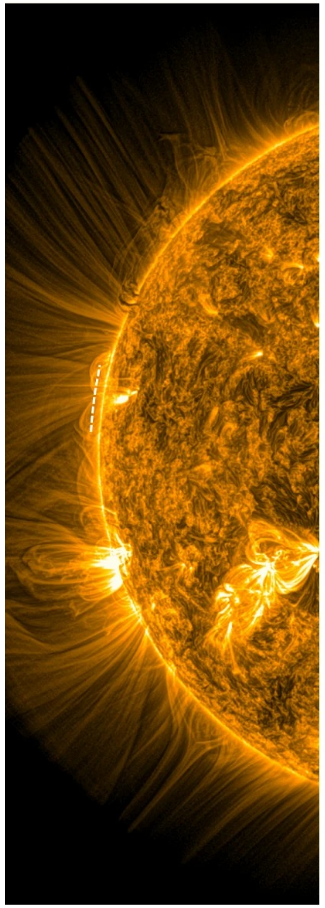


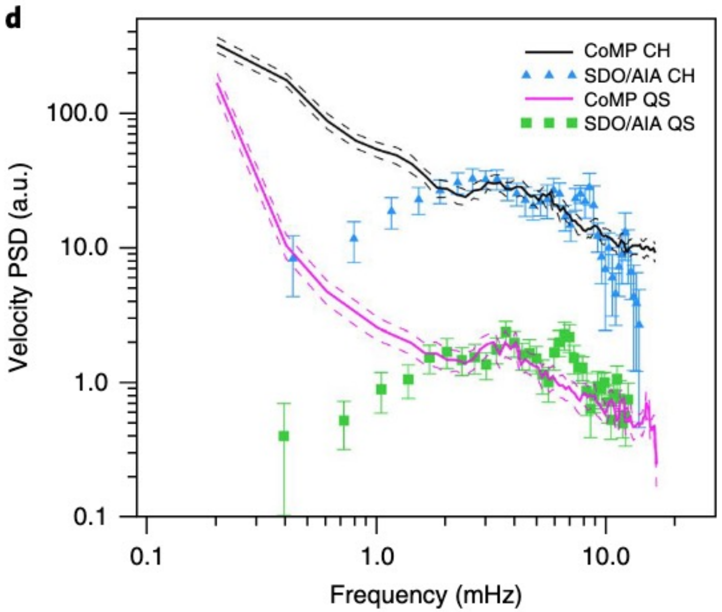
- We have analyzed WISPR high cadence data for Encounters 9, 10, 11, and 12 for periodic density structures.
- Many instances of discrete periodicities at frequencies between ~1 mHz and 5 mHz, or ~15 min – 3 min.
- **First time** white light imagers have ever had the cadence to identify periodicities between 1-5 mHz.
- Same periodicity density structures observed at 1 AU in situ measurements; evidence pointed to the solar corona as the formation mechanism, and they are important for magnetosphere dynamics (e.g. Viall et al. 2008; Viall et al. 2009a; Viall et al. 2009b; Kepko et al. 2021).
- Likely a different mechanism than the lower ~90 minute frequencies.

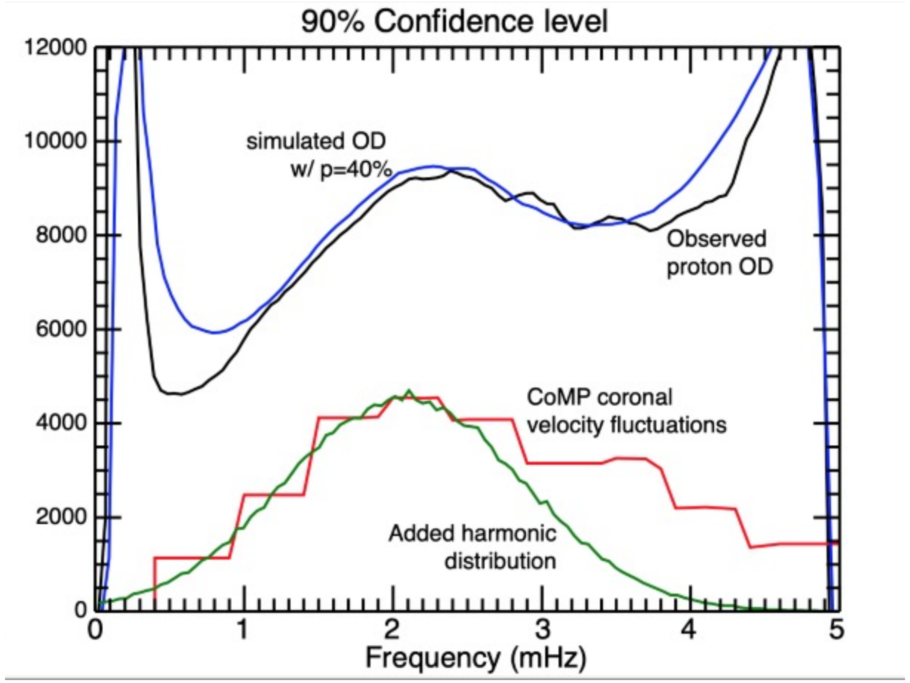


Occurrence distribution of periodic mesoscale solar wind structures in alpha/proton measurements at 1 AU (i.e. formed at the Sun) calculated with 25 years of data match the 1-4 mHz transverse oscillations observed in the corona:
Periodic driven reconnection-released solar wind

a



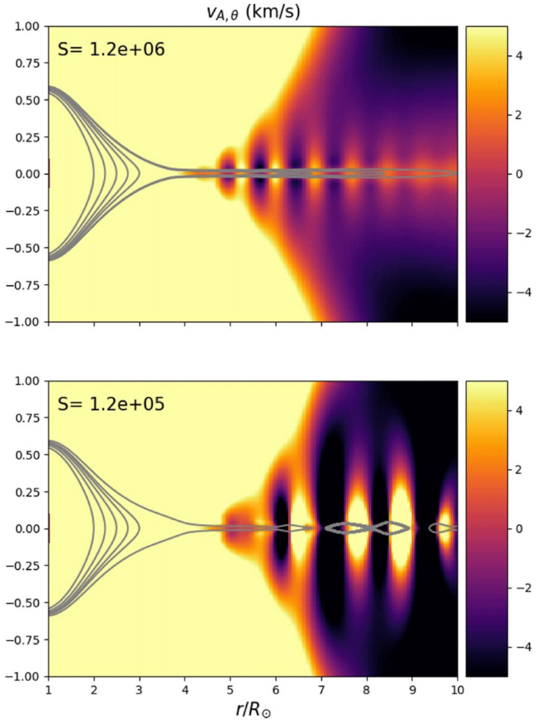




Morton et al, 2019

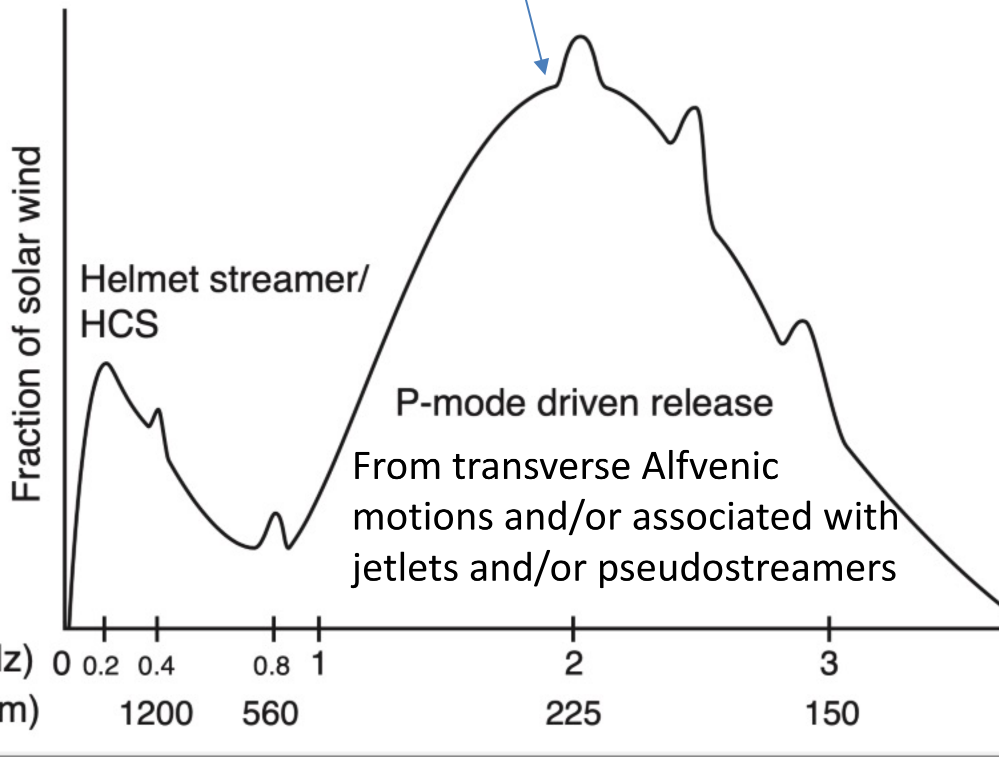
Kepko, Viall and DiMatteo, under review in JGR

(at least) Two kinds of periodic reconnection-released solar wind; PUNCH will image many of these structures

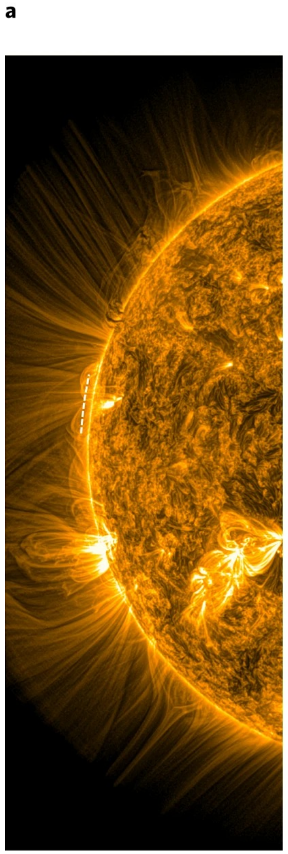


Reville et al. 2022

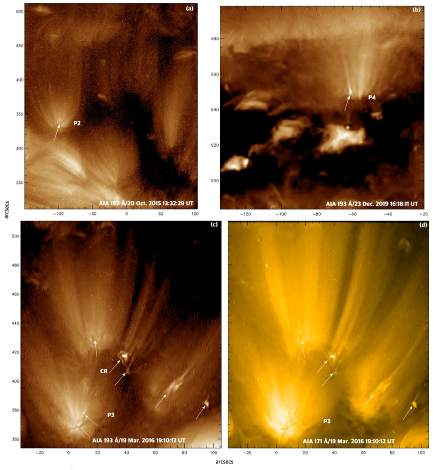
NFI Nyquist



From transverse Alfvenic motions and/or associated with jetlets and/or pseudostreamers



Morton et al 2019



Kumar et al 2022

Kepko, Viall and DiMatteo, under review in JGR

PUNCH's SNR and Resolution will Provide Measurements of a Multitude of Solar-Created Structures

PUNCH will image Streamers Blobs, Periodic Density Structures, Pseudostreamer outflows, Plumes, and Jet/Jetlet outflows.

PUNCH will also determine their evolution and relationship with turbulence en route to 1 AU.