Periodic Solar Wind Density Structures and their Relationship to Coronal Heating and Dynamics

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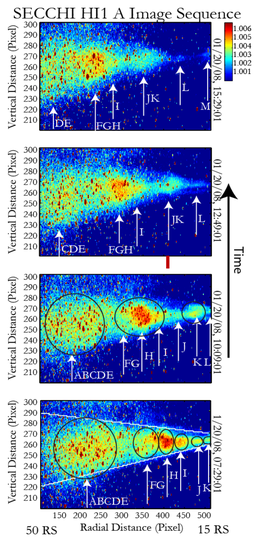
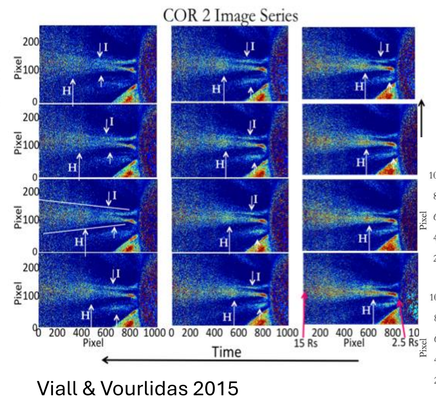
Introduction

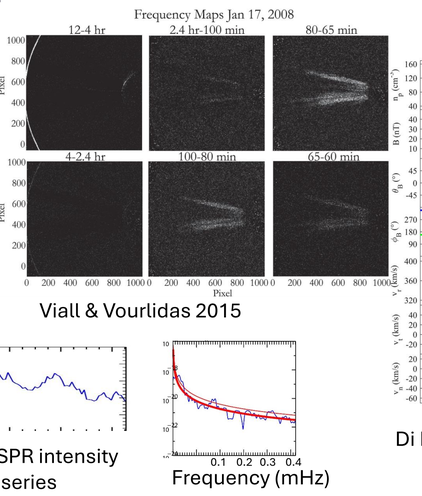
Periodic density structures are a type of solar wind mesoscale structure observed throughout the inner Heliosphere.



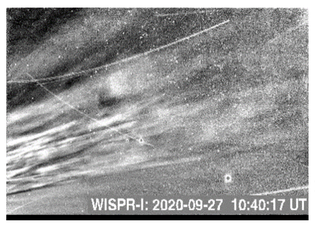
Viall et al. 2010



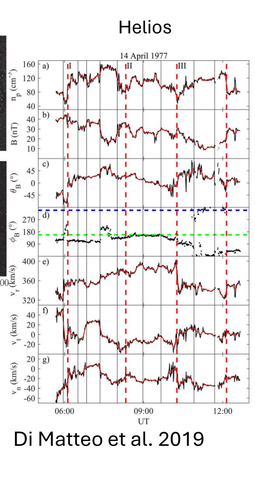
Viall & Vourlidas 2015



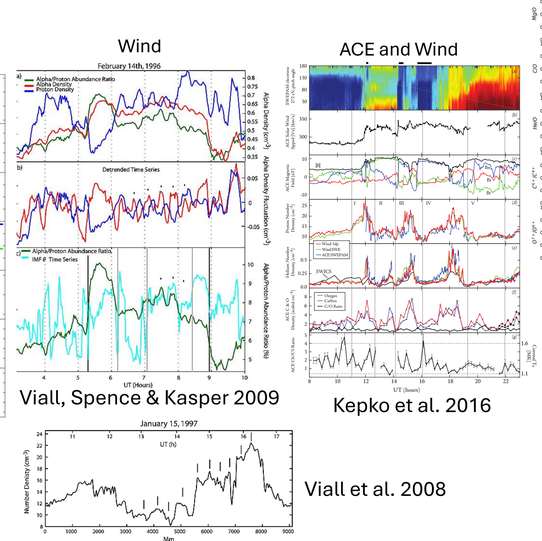
Viall & Vourlidas 2015



24-hour WISPR intensity time series



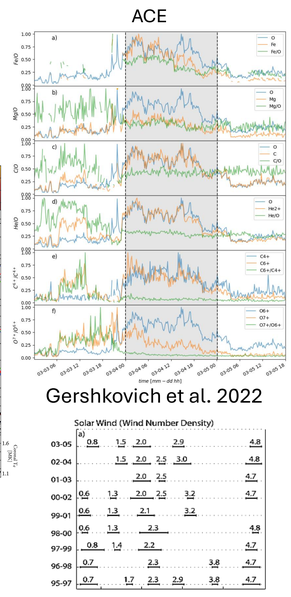
Di Matteo et al. 2019



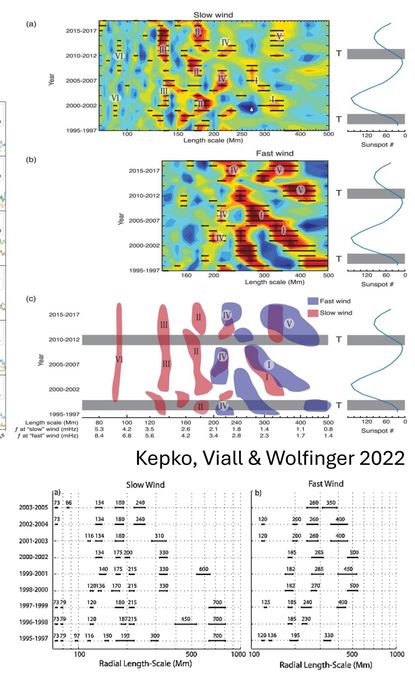
Viall, Spence & Kasper 2009

Kepko et al. 2016

Viall et al. 2008



Gershkovich et al. 2022



Kepko, Viall & Wolfinger 2022

Viall et al. 2008

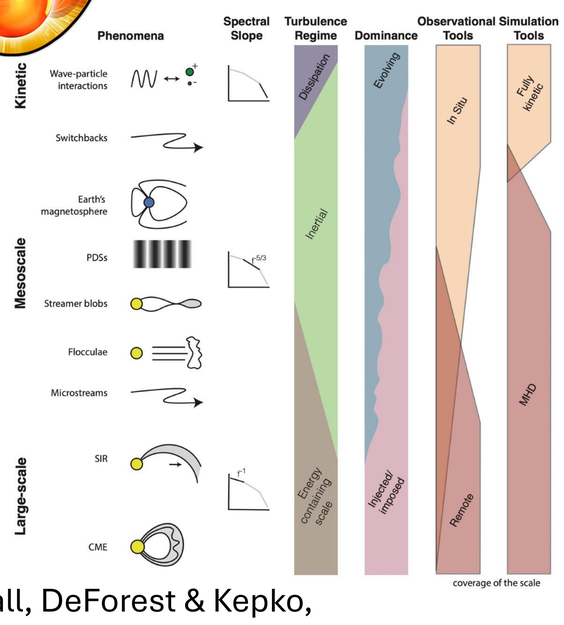
- Observed **remotely in white light between 2.5 and 50 Rsun**
- Trains of density enhancements spaced periodically (defined with Fourier analysis); intensity time series from pixel slits
- Frequencies of ~0.1-5.0 mHz (a couple of hours to 3 minutes)
- Structures advect with the solar wind flow, length scales of 100s Mm- 1000s Mm
- Structures accelerate with the slow(ish) wind up to ~30 Rsun

- Observed **in situ between 0.3 and 1.0 AU**
- Often multiple embedded periodicities
- Composition changes (alpha/proton, charge state, FIP, Sulfur/Oxygen…) confirm that periodic density structures are created in the solar corona and survive to 1 AU
- Associated magnetic field variations confirm structure interpretation (e.g. often flux ropes, PBS) and rules out propagating waves or wavey HCS

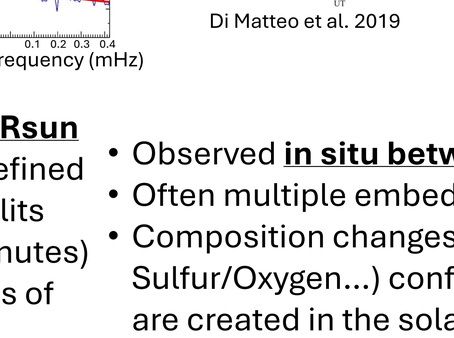
- Periodic density structures occur in a lot of the ‘slow’ wind at 1 AU, and some of the ‘fast’ wind (ecliptic, >550 km/s)
- Some scales of the periodicity are common, while others are different between ‘fast’ and ‘slow’ wind
- One set evolves with solar cycle and another set that turns on/off at the Terminator

PUNCH will Image Periodic Density Structures and Track their Evolution

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).



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



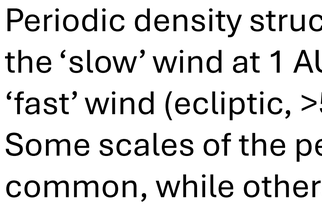
DeForest et al. 2018 deep field STEREO campaign is similar to PUNCH/NFI’s resolution, demonstrating the structured solar wind PUNCH will measure

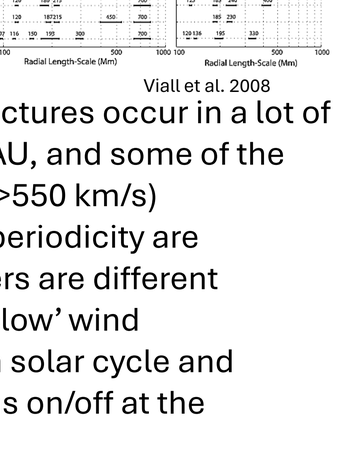
This is important for:
- Understanding solar wind formation
- Providing critical insight into where and how kinetic energy becomes available to drive a turbulent cascade
- Understanding the solar wind variability impacting Earth’s magnetosphere and other inner planets

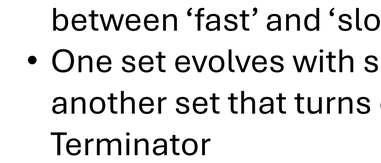
The Mesoscales that PUNCH Measures are >= the Dayside Magnetosphere

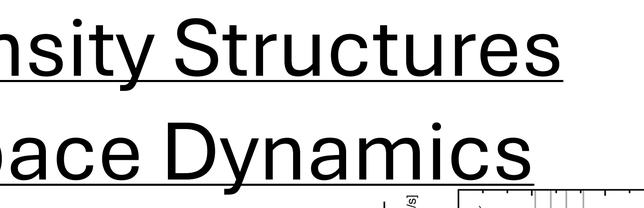
1 Solar Radii = 0.25 degrees
PUNCH resolution requirement inner is 3’ ~ 140 Mm
140 Mm advecting at 400 km/s = 350s (6 minutes)

Periodic Density Structures Drive Geospace Dynamics







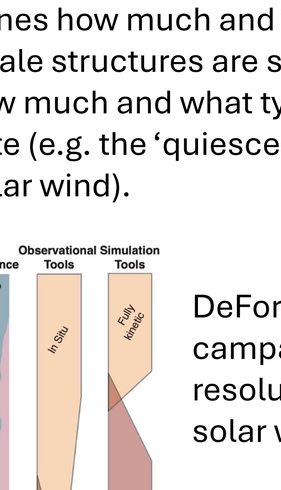


Pitch Angled Resolved Electron flux plot for 2014 Jan 02 MagEIS A16:15 to 24:00UT exhibit same periodicities as PDSs and ULF waves in the magnetosphere.

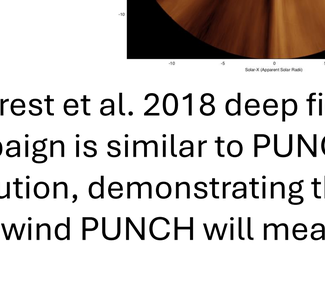
Relationship to Coronal Heating and Dynamics

In one example where we were able to ap to the solar source, periodic density structures comes from large, decayed AR; the multipolar newly emerged AR doesn’t make solar wind periodic density structures (that survive to 1 AU)

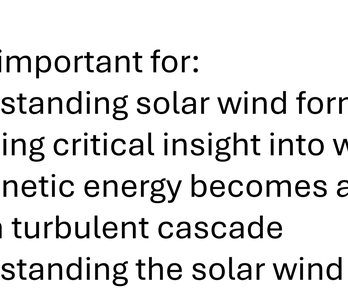
Samantha Wallace; WSA-ADAPT



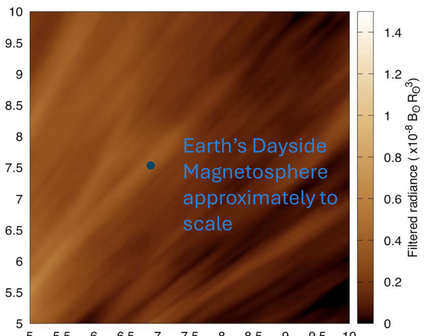
Occurrence distribution of periodic mesoscale solar wind structures calculated with 25 years of Wind data match the 1-4 mHz transverse oscillations observed in the corona.



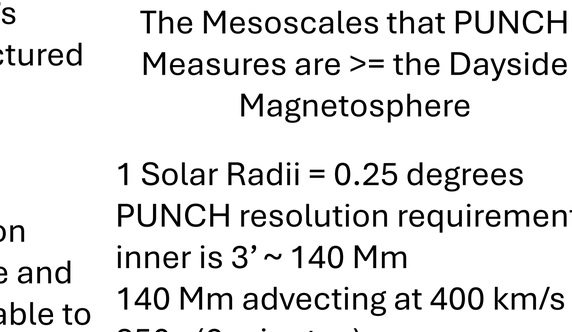
Morton et al. 2019



Occurrence distributions of alpha/proton variations in periodic density structures suggest that helmet streamers (associated with the HCS) create a population of periodic density structures at ~90-minute periodicity through magnetic reconnection; they survive to 1 AU.



Viall & Borovsky 2022



Kepko, Viall & Di Matteo, 2024

Conclusions

- The corona often emits solar wind as periodic trains of density structures, which manifest as discrete periodicities in Fourier analysis.
- Magnetic reconnection releasing closed-field plasma is an important aspect of the formation of periodic density structures: Lower frequencies caused by reconnection of helmet streamer loops; higher frequencies seem to be wider spread and may involve periodically-driven interchange reconnection related to jetlets and/or Morton et al. Alfvenic oscillations and/or Cattell et al. radio bursts
- Periodic density structures advect through the inner heliosphere, reach 1 AU and drive magnetospheric dynamics.