Parker Two Workshop

June 21 – 24, 2022

Agenda

Tuesday, June 21, 2022

Sessions	Contributions	Speakers	Allotted Time (min.)	Time (EDT)
Conference Opening	Welcome and Logistics	Nour Raouafi	**5**	9:00-9:05
	APL Welcome & Conference Opening	Bobby Braun	**10**	9:05-9:15
	NASA HQ Update	Arik Posner	**10**	9:15-9:25
	Celebrating Eugene N. Parker	Boon Chye Low	**20**	9:25-9:45
Payload Updates	WISPR	Mark Linton	**10**	9:45-9:55
	FIELDS	Stuart Bale	**10**	9:55-10:05
	SWEAP	Justin Kasper	**10**	10:05-10:15
	ISOIS	Dave McComas	**10**	10:15-10:25
BREAK			**20**	10:25-10:45
Mission/ Observatory Updates	Solar Orbiter Update	Daniel Müller	**15**	10:45-11:00
	DKIST Update	Thomas Rimmele	**15**	11:00-11:15
	Parker Solar Probe Science: Where Do We Stand?	***Marco Velli***	**45**	11:15-12:00
BREAK			**60**	12:00-13:00
Connectivity and Sources Moderator: Sam Badman	***The Importance of Understanding the Time-Dependent, 3D Solar Corona for Accurate Connectivity and Source Determination in the Parker Solar Probe Era***	***Nicki Viall***	**30**	13:00-13:30
	The case for interchange reconnection as the driver of the solar wind	James Drake	**20**	13:30-13:50
	The First Flight 'through' the Corona: WISPR Imaging of Coronal Streamers from Within	Angelos Vourlidas	**20**	13:50-14:10
	On Flux Ropes Born in Helmet Streamers	Victor Réville	**20**	14:10-14:30
	Determining solar wind flow speed from stationary-point measurements from WISPR	Sam Van Kooten	**20**	14:30-14:50
	Mauna Loa Solar Observatory Coronagraph Observations: Connecting Parker Solar Probe Measurements to their Solar Sources	Joan Burkepile	**20**	14:50-15:10
BREAK			**20**	15:10-15:30
Poster Session P1: Poster Viewing in Gather.Town			**90**	15:30-17:00

DAY 1 END

Wednesday, June 22, 2022				
Sessions	**Contributions**	**Speakers**	**Allotted Time (min.)**	**Time (EDT)**
CMEs, Shocks, and SEP Acceleration Processes Moderator: Leng Ying	***Modelling solar energetic particles in the era of Parker Solar Probe***	***Erika Palmerio***	**30**	10:00-10:30
	Magnetic field line path length variations and effects on solar energetic particle transport	David Ruffolo	**20**	10:30-10:50
	Global Modeling of Broad-Longitude SEP Events	Jon Linker	**20**	10:50-11:10
	Multi-spacecraft modelling of multi-CMEs observed by WISPR on PSP	Iulia Chifu	**20**	11:10-11:30
	Energy partitioning from the chromosphere to the heliosphere in the October 28 2021 X flare and associated CME	Katharine Reeves	**20**	11:30-11:50
	Numerical Simulations of SEP dropouts and the Implications to PSP Observations	Fan Guo	**20**	11:50-12:10
BREAK			**50**	12:10-13:00
Energetic Particles Moderator: Mitchell Shen	***How PSP observations are changing our understanding of solar energetic particles***	***Christina Cohen***	**30**	13:00-13:30
	Energetic Particles Associated with Sub- and Super-Parker Spirals -- Signatures of the Dynamic History of Stretched and Switched-Back Magnetic Fields	Nathan Schwadron	**20**	13:30-13:50
	Suprathermal Ion Observations Associated with the Heliospheric Current Sheet Crossings by Parker Solar Probe During Encounters 7-10	Mihir Desai	**20**	13:50-14:10
	Can the lengths of magnetic field lines be determined from velocity dispersion in the onsets of impulsive SEP events?	Edmond Roelof	**20**	14:10-14:30
	Widespread 1–2 MeV Energetic Particles Associated with Slow and Narrow Coronal Mass Ejections: Parker Solar Probe and STEREO Measurements	Bin Zhuang	**20**	14:30-14:50
	Magnetic field topology of ICMEs from PSP in-situ measurements	Qiang Hu	**20**	14:50-15:10
BREAK			**20**	15:10-15:30
Poster Session P2: Poster Viewing in Gather.Town			**90**	15:30-17:00
Reception (Location B201 Patio)			**120**	17:00-19:00

DAY 2 END

Thursday, June 23, 2022				
Sessions	**Contributions**	**Speakers**	**Allotted Time (min.)**	**Time (EDT)**
Heating, Acceleration, and Turbulence (modeling) Moderator: Jean Perez	***Open problems in solar wind heating and acceleration***	***Anna Tenerani***	**30**	10:00-10:30
	Observations and Models of Proton and Alpha Particle Velocity Distribution in Sub-Alfvénic Solar Wind at PSP Perihelia	Leon Ofman	**20**	10:30-10:50
	Strategies for determining the energy transfer rate in MHD turbulence: isotropy, anisotropy, and spacecraft sampling	Yanwen Wang	**20**	10:50-11:10
	Anisotropic compressible MHD turbulence and comparison with Parker Solar Probe data	Senbei Du	**20**	11:10-11:30
	Semi-Empirical Multi-base Exospheric Model of the Solar Wind	Mihailo Martinovic	**20**	11:30-11:50
	Local proton heating at different magnetic discontinuities in the solar wind	Carlos Gonzalez	**20**	11:50-12:10
BREAK			**50**	12:10-13:00
Heating, Acceleration, and Turbulence (observations) Moderator: Kris Klein	***Observational Signatures of Cosmic Energy Flow with Parker Solar Probe: The First 11 Encounters***	***Jaye Verniero***	**30**	13:00-13:30
	Electron Distributions Observed by the Parker Solar Probe in the Near-Sun Fast Solar Wind	Jasper Halekas	**20**	13:30-13:50
	Observations of Sunward-Propagating Ion-Cyclotron Waves Below the Subalfvenic Surface	Kristoff Paulson	**20**	13:50-14:10
	Solar Wind Protons and Alphas Properties Close to the Sun: New Parker Solar Probe Observations	Parisa Mostafavi	**20**	14:10-14:30
	The Near-Sun Turbulence Mediated by Parametric Decaying Instability of Alfvén Waves	Zhaoming Gan	**20**	14:30-14:50
	The evolution of the magnetic field spectral index with heliocentric distance in the solar wind	Jack McIntyre	**20**	14:50-15:10
BREAK			**20**	15:10-15:30
Poster Session P3: Poster Viewing in Gather.Town			**90**	15:30-17:00

DAY 3 END

Friday, June 24, 2022

Sessions	Contributions	Speakers	Allotted Time (min.)	Time (EDT)
Switchbacks and Origins Moderator: Jon Linker	***Switchbacks with Parker Solar Probe***	***Ronan Laker***	**30**	10:00-10:30
	Magnetic Switchback Occurrence Rates in the Inner Heliosphere: Parker Solar Probe and 1 au	Francesco Pecora	**20**	10:30-10:50
	Statistical Properties of the Switchbacks Observed During the First 10 Encounters of Parker Solar Probe	Vamsee Krishna	**20**	10:50-11:10
	Switchbacks, microstreams and broadband turbulence in the solar wind	Tim Horbury	**20**	11:10-11:30
	Size Scale and Occurrence Rate of Coronal Jets and Similar Solar Features: Possible Solar Sources for Magnetic Switchbacks	Alphonse Sterling	**20**	11:30-11:50
	Patches of magnetic switchbacks: hints of their origins	Chen Shi	**20**	11:50-12:10
BREAK			**50**	12:10-13:00
Additional PSP Science Moderator: Phil Hess	***The View of the Corona from Within the Alfven Surface***	***Russ Howard***	**30**	13:00-13:30
	Translational Tomography of the Solar Corona	Megan Kenny	**20**	13:30-13:50
	Resolving when coronal mass ejections engulf PSP	Carlos Braga	**20**	13:50-14:10
	First joint STIX and LOFAR Observations of a Flare Event on 06 June 2020	Malte Broese	**20**	14:10-14:30
	Imaging of Venus by PSP/WISPR	Brian Wood	**20**	14:30-14:50
	PSP/SWEAP/SPAN-Ion observations of upstream pickup protons at Venus	Ali Rahmati	**20**	14:50-15:10
BREAK			**20**	15:10-15:30
Poster Session P4: Poster Viewing in Gather.Town			**90**	15:30-17:00

DAY 4 END

CONFERENCE END

Abstracts

Parker Solar Probe Science: Where Do We Stand?

M. Velli

Parker Solar Probe was launched to carry out the first in situ exploration of the outer solar corona and inner heliosphere with three overarching objectives:

1) Trace the flow of energy that heats and accelerates the solar corona and solar wind.
2) Determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind.
3) Explore mechanisms that accelerate and transport energetic particles

Direct measurements of the plasma in the closest atmosphere of our star have already produced significant surprises including the observation of the predominance of Alfvénic turbulence in solar wind streams, the presence of folds in the magnetic field called switchbacks that come in patches, magnetic reconnection in the forming heliospheric current sheets, anti-correlation of measured electron temperature with solar wind speed, and small-scale energetic particle events. Here I will review these observations in terms of the original objectives, discuss theories and models that provide an understanding of some of the observations, as well as the progress and potential pitfalls in the interpretation of other PSP results.

The case for interchange reconnection as the driver of the solar wind

J. F. Drake, S. D. Bale, M. Swisdak, S. Badman, C. M. S. Cohen, M. Desai, T. S. Horbury, D. Mitchell, O. Panasenco, T. D. Phan, N. E. Raouafi, M. Velli, & the PSP Science Team

The linkage of the periodicity of bursts of switchbacks seen in the PSP magnetic field data to the spatial periodicity of the magnetic field at the surface of the sun points to interchange reconnection as the driver of switchbacks. The corresponding enhancements in plasma pressure, wind speed, alpha abundance and energetic ions open the possibility that interchange reconnection could be the fundamental source of energy that drives the solar wind. The observations further suggest that interchange reconnection is nearly continuous in regions of the solar surface with multi-polar magnetic fields. We use the PSP data along with the basic characteristics of reconnection to deduce the local properties of interchange reconnection near the solar surface, including the characteristic strength of the reconnecting magnetic, the ambient density and the rate of reconnection and associated energy release. An important conclusion of the analysis is that coronal interchange reconnection is in the collisionless regime and that the energy released by interchange reconnection is sufficient to drive the wind. Analytical estimates are supported by particle-in-cell simulations of interchange reconnection that yield the basic properties of the reconnection outflow exhausts as well as the spectra of energetic electrons, protons and alpha particles, which take the form of powerlaws at high energy. The proton powerlaw index is around -7. Alpha spectra extend to higher energy than protons but have steeper spectra.

The First Flight 'through' the Corona: WISPR Imaging of Coronal Streamers from Within

A. Vourlidas, P. Liewer, S. Patsourakos, G. Stenborg, M. Linton, & R. Howard

Considered as the boundary between the corona and the heliosphere, the Aflvenic surface is traditionally set at around 20 Rs. On April 2021, Parker Solar Probe's (PSP) perihelion crossed this boundary reaching a heliocentric distance of 16 solar radii (Rs). The images of this first 'fly-through' of the corona captured by the WISPR cameras revealed a surprisingly number of coronal structures and variability that has only been increasing in the subsequent perihelia. In this paper, we attempt to put the WISR imaging of the corona 'from within' in context with the 1 AU imaging that we have been accustomed until now. WISPR detects significantly more structure within rather featureless streamers as seen from 1 AU. PSP crosses through several of those streamers that leave a distinct pattern in the WISPR movies. we estimate the location, size, and electron density content of some of these structures and demonstrate how WISPR observations can lead to quantitative descriptions of the 3D structure of the corona that are impossible to obtain from 1 AU.

On Flux Ropes Born in Helmet Streamers

V. Réville

The solar wind, in particular the slow component, harbors many dynamical structures. Density perturbations have been observed with coronagraphs and heliospheric imagers for more than 20 years. These so-called "blobs" seem to be released periodically from the low corona, in association with downflows that could be the signature of magnetic reconnection. In situ measurements have been able to associate (at least) part of these density structures to flux ropes, i.e. helical structures connected to the Sun. In this talk, I will review recent efforts to explain the origin of these structures and their relation to helmet streamers and the heliospheric current sheet (HCS). Using 2.5D and 3D simulations, I will show how helmet streamers are naturally unstable and lead, in a two-step process, to the release of flux ropes and density perturbations. The periodicity recovered in the simulations are consistent with observations and involve the ideal tearing mode at high Lundquist numbers. Comparing 3D MHD simulations with data of Parker Solar Probe and Solar Orbiter, I will show that a lot of the observed dynamics is consistent with numerous flux ropes born at the tip of helmet streamers and propagating close to the HCS. Finally, I will discuss the 3D structures of these flux ropes and the possible relation between the onset of the streamers instability and the thermal structure of the corona, controlled by the separatrice and quasi-separatrice network.

Determining solar wind flow speeds from stationary-point measurements with WISPR

S. Van Kooten

The WISPR instrument on Parker Solar Probe offers the first up-close view of the young solar wind, from a rapidly-changing field of view caused by the high velocity of the spacecraft and its close proximity to the structures being imaged. This unique vantage enables new types of analysis. We develop one such analysis, using the changing field of view as a tool to measure the outflow velocity of the solar wind near the spacecraft at heliocentric distances comparable to PSP's own position. Amid the outflowing plasma visible in WISPR image sequences, we detect the "stationary point," a position in the field of view where plasma features do not move in the image plane. This indicates plasma which will collide with or pass near the spacecraft, as that plasma is on an inward trajectory in the spacecraft frame. The angular position of this stationary point is a function of the known spacecraft velocity and the unknown plasma velocity, allowing the plasma velocity to be determined in neighborhoods of varying size near the spacecraft, complementary to in situ measurements at the spacecraft itself. This will help answer open questions regarding the nature and early evolution of the young solar wind. In this presentation, we will discuss the development of our technique and show initial results.

Mauna Loa Solar Observatory Coronagraph Observations: Connecting Parker Solar Probe Measurements to their Solar Sources

J. T. Burkepile, S. Tomczyk, B. Berkey, M. Cotter, G. de Toma, D. Gallagher, M. D. Galloy, S. E. Gibson, H. R. Gilbert, R. Graves, D. Kolinski, E. Landi, P. Oakley, L. Perez-Gonzales, S. Sewell, & P. Zmarzly

Parker Solar Probe (PSP) is providing revolutionary measurements of the newly formed and 'pristine' wind in sub-Alfvenic regions that are transforming our understanding of the processes that accelerate the solar wind and heat the Sun's corona. The National Center for Atmospheric Research (NCAR) Mauna Loa Solar Observatory (MLSO) operates two coronagraphs that view the low and middle corona, providing unique and important measurements and diagnostics of the coronal magnetic field and plasma properties. These data connect the novel PSP in-situ measurements to their coronal sources, and thereby enhance the scientific return from PSP data. MLSO operates the COSMO K-Coronagraph (K-Cor) that views the polarized white light corona from 1.05 to 3 solar radii with a 15 second time cadence, making it ideally suited for tracking the formation and propagation of Coronal Mass Ejections (CMEs). The new Upgraded Coronal Multi-Channel Polarimeter (UCoMP) was recently deployed to MLSO and is a significant upgrade to the Coronal Multi-Channel Polarimeter (CoMP). UCoMP obtains full Stokes polarization (Intensity, linear and circular polarization) over a wide wavelength range (530 to 1083 nm) with a field of view of 1.04 to 2 solar radii and a spatial resolution of 6 arcsec (3 arcsec / pixel). UCoMP explores the magneto-thermal structure of the corona and can be used to identify magnetic morphologies such as pseudostreamers and magnetic flux ropes. UCoMP data are important for the study of MHD waves in open and closed coronal structures and for investigating the energy build-up that leads to CMEs. These data connect the energy input into the corona with changes in the organization of closed and open magnetic fields that shape the solar wind and the structure of the heliosphere. We present UCoMP and K-Cor observations acquired during PSP perihelia and discuss their use with coronal models that can directly connect the MLSO coronal observations to the PSP measurements.

P1-01
PSP Solar Wind Sources at 13.3 Solar Radii

S. Badman

Parker Solar Probe (PSP) is now in an orbit of perihelion distance 13.3 solar radii, and as well as this record-breaking close approach is now super-rotates so fast with respect to the corona that it covers over 110 degrees in heliographic longitude in just a few days. This mission profile allows unprecedented probing of solar wind source regions and stream boundaries by taking a near instantaneous cut through a large swathe of the corona. In this presentation we give an overview of the sources and spatial structures observed by this new family of orbits. Of particular interest is the first (Encounter 10 from November 2021) in which direct correspondence between in situ solar wind velocity, source mapping and magnetic field line expansion factor is observed, punctuated by dips into sub-alfvenic wind while crossing from source to source.

P1-02

Multispacecraft Remote Sensing and In Situ Observations of the 2020 November 29 Coronal Mass Ejection and Associated Shock

C. Chen

We investigate the source eruption and the propagation and expansion characteristics of the 2020 November 29 coronal mass ejection (CME) and associated shock, which caused the first type II radio burst and the first widespread solar energetic particle (SEP) event of solar cycle 25, using remote sensing and in situ observations from multiple spacecraft. A potential-field source-surface model is employed to examine the coronal magnetic field configuration surrounding the source region. The CME flux rope and associated shock can be tracked from the early stage to the outer corona using extreme ultraviolet and white light observations. Forward models are also applied to determine the structures and kinematics of the CME flux rope and the shock near the Sun. The shock shows an ellipsoidal structure, expands in all directions, and encloses the whole Sun as viewed from both SOHO and STEREO A, which results from the large expansion of the CME flux rope and its fast acceleration. The structure and potential impacts of the shock are mainly determined by its radial and lateral expansions. The CME and shock arrive at Parker Solar Probe and STEREO A. Only based on the remote sensing observations, it is difficult to predict that whether and when the CME/shock would arrive at the Earth. From Wind in situ measurements and WSA-ENLIL simulation results, we confirm that the far flank of the CME arrives at the Earth with no shock signature. These results highlight the importance of multipoint remote sensing and in situ observations for determining the space weather impacts of CMEs. In addition, the shock ellipsoid fitting results can provide some key parameters for the study of the SEP acceleration.

P1-03

Analysis of Coronal Rays and Magnetic Flux Ropes near the Heliospheric Current Sheet using WISPR Observations for E8 and E10

P. C. Liewer, J. Qiu, R. Howard, G. Stenborg, A. Vourlidas, P. Penteado, J. R Hall, & P. Riley

WISPR, the wide-field, white-light Imager onboard Parker Solar Probe (PSP) observed a very dynamic, highly variable slow solar wind near the perihelia of the recent orbits. During these periods, WISPR observes coronal rays and magnetic flux ropes of various sizes passing through its field-of-view. We have developed and validated tools which can determine the 3D locations of magnetic flux ropes and coronal rays from sequences of WISPR images. Previous results suggest that the brightest coronal rays mark the heliospheric current sheet and that the magnetic flux ropes of various sizes may be signatures of reconnection near the current sheet. Here, we present and compare results from an analysis of images from both Encounter 8 (E8) and Encounter 10 (E10). WISPR has a fixed angular field of view, extending from 13.5° to 108° from the Sun and approximately 50° in the transverse direction. At perihelion of E8 and E10, the inner edge of FOV is approximately at 4 and 3 R_{sun}, respectively. In E8, PSP made multiple crossings of the heliospheric current sheet (HCS) near perihelion (R_p = 16 R_{sun}). In E10, while no HCS crossings were recorded, the in-situ data suggest PSP passed close to the HCS, again near perihelion (R_p = 13 R_{sun}). The technique we use determines coordinates and trajectories in both the Heliocentric Inertial and Carrington frames. Using the determined 3D coordinates of a ray or the trajectory of a flux rope from the WISPR images, we can compare with another coronagraph's view of the same feature by reprojecting the 3D feature onto a simultaneous image from the other telescope. We use images from the SOHO/LASCO/C3 and STEREO-A/COR2 coronagraphs. We also compare the locations to the location of the HCS as found in an MHD model. Comparing features seen from multiple viewpoints increases our understanding of the three-dimensional structure of the corona and, more specifically, the region near the heliospheric current sheet within 10-15 solar radii.

P1-04

Determination of Coronal Ray Heliographic Coordinates using Images from WISPR/Parker Solar Probe

J. Qiu, P. C. Liewer, F. Ark, G. Stenborg, A. Vourlidas, P. Penteado, J. R Hall, & P. Riley

WISPR, the wide-field, white-light Imager onboard Parker Solar Probe (PSP) has a fixed angular field of view, extending from 13.5° to 108° from the Sun and approximately 50° in the transverse direction. In January 2021, on its seventh orbit, PSP crossed the heliospheric current sheet at a distance of 20 solar radii from the Sun. For several days around this time, WISPR observed a broad band of highly variable solar wind plasma and coronal rays. PSP was moving with an angular velocity exceeding that of the Sun and, thus, WISPR was able to image coronal rays as PSP approached and then passed under or over them. We have developed a technique that uses the change in apparent latitude of a ray as approached by PSP to determine its location in a heliocentric coordinate system. We used the technique to determine the coordinates of three coronal rays. The technique was validated by comparing the results to observations of the coronal rays from different viewpoints by the SOHO/LASCO/C3 and STEREO-A/COR2 coronagraphs. To help understand the relationship of the coronal streamers to the heliospheric current sheet, we also compare the locations of the coronal rays with the HCS location from the 3D MHD MAS code.

P1-05

An Extended and Fragmented Alfvén Zone in the Young Solar Wind

R. Chhiber

Motivated by theoretical, numerical, and observational evidence, we explore the possibility that the critical transition between sub-Alfvénic flow and super-Alfvénic flow in the solar atmosphere takes place in fragmented and disconnected subvolumes within a general Alfvén critical zone. The initial observations of sub-Alfvénic periods by Parker Solar Probe near 16 solar radii do not yet provide sufficient evidence to distinguish this possibility from that of a folded surface that separates simply-connected regions. Subsequent orbits may well enable such a distinction, but here we use a global magnetohydrodynamic model of the solar wind, coupled to a turbulence transport model, to generate possible realizations of such an Alfvén critical zone. Understanding this transition will inform theories of coronal heating, solar wind origin, solar angular momentum loss, and related physical processes in stellar winds beyond the Sun.

P1-06
Quiet Solar Wind Intervals in the Inner Heliosphere

T. Woolley

Since launching in 2018, Parker Solar Probe (PSP) has observed an abundance of structures in the near-Sun solar wind. These structures include discrete magnetic field switchbacks that are modulated into large scale patches, and quiet solar wind intervals that appear to separate these patches. To date, switchbacks and patches have been the focus of many studies using the early PSP data however, the quiet solar wind intervals remain relatively underexplored. In this work, we focus on these quiet solar wind intervals to gain a better understanding of their properties. Using both PSP and Solar Orbiter data, we investigate their duration, occurrence rate, and evolution out to 1au. We consider whether quiet solar wind intervals are consistent with transient or spatial structures before linking our findings to potential origins. Finally, we discuss how future PSP measurements at closer heliocentric distances can build on the work presented here.

P1-07

Connecting Solar Orbiter remote sensing observations and Parker Solar Probe in situ measurements with a numerical MHD reconstruction of the Parker spiral

R. Biondo, F. Reale, P. Pagano, A. Bemporad, & D. Telloni

In the last few years, the interest within and outside the scientific community regarding Space Weather and its effects has been growing, and so has the fleet of spacecrafts dedicated to the investigation of its associated phenomena in the heliosphere. Among them, NASA's Parker Solar Probe (PSP) and ESA-NASA's Solar Orbiter (SO) play a pivotal role. The first one is the very first spacecraft to probe the solar corona with in-situ measurements. The second one is the closest-to-the-Sun spacecraft to be provided with both in-situ and remote sensing instruments. A key feature of both missions is their cooperation, allowing to trace solar wind and transients from their sources on the Sun to the inner interplanetary space, in order to understand their evolution. Our goal is to accurately reconstruct the structure of the Parker's spiral and the relationships between coronal features observed remotely by the Metis coronagraph on-board SO and those detected in situ by PSP, at the time of the first PSP-SO quadrature that occurred on January 2021. To do so, we use the Reverse In-situ and MHD APproach (RIMAP), a hybrid analytical numerical method performing reconstructions of the interplanetary Parker Spiral constrained, in this application, to in-situ measurements of plasma density, speed, and magnetic fields measured by PSP around 0.1 AU. RIMAP (Biondo et al. 2021) solves the MHD equations close to the equatorial plane with the PLUTO code (Mignone et al. 2007), using the in-situ parameters analytically back-mapped as radial inner boundary conditions of a full-MHD simulation. Here, we used PSP measurements collected during the PSP-SO quadrature to reconstruct the interplanetary Parker Spiral with RIMAP from 5 to 60 solar radii, connecting the simulation profiles along a streamline to METIS measurements (covering 3-6 solar radii) of plasma density and speed. We show a comparison between the PSP in-situ measurements of the plasma quantities and the corresponding RIMAP along the PSP trajectory in order to assess the quality of the reconstruction of the Parker Spiral streamlines on the equatorial plane we performed, finding that our reconstruction catches the main structures PSP flew through. Then we show how the remote-sensing METIS radial profiles of density and speed derived inside a coronal sector in correspondence to a specific streamer in its FOV connect with the RIMAP profiles and thus with the PSP measurements collected as the spacecraft was crossing a slow wind stream. The magnetic connectivity between SO and PSP is hence verified with a MHD reconstruction derived directly by the in-situ data.

P1-08

Properties and evolution of small-scale magnetic flux ropes in the inner heliosphere

Y. Chen

We report small-scale magnetic flux ropes via the in situ measurements from the Parker Solar Probe. These flux ropes are detected by the Grad–Shafranov-based algorithm, with their durations and scale sizes ranging from 10 s to several hours and from a few hundred kilometers to 10^{−3} au, respectively. They include both static structures and those with significant field-aligned plasma flows. Most structures tend to possess large cross helicity, while the residual energy is distributed over wide ranges. We find that these dynamic flux ropes mostly propagate in the anti-sunward direction relative to the background solar wind, with no preferential signs of magnetic helicity. We showcase studies with reconstructed two-dimensional (2D) magnetic field configurations, which confirm that both the static and dynamic flux ropes have a common configuration of spiral magnetic field lines (also streamlines). Moreover, we examine the catalog of stream interaction regions or corotating interaction regions from the multi-point observations as reported in Allen et al. 2021. We also compare the flux ropes in different solar wind speeds within SIR intervals.

P1-09
Solar wind speed radial variation

C. Larrodera & C. Cid

In this research, the evolution of the probability distribution function of the solar wind speed with the radial distance is analyzed. We use measurements from the SWEAP instruments onboard the Parker Solar Probe spacecraft during the first nine orbits. The radial distance is divided in smaller slices to obtain the characteristic speed of each region. Our results show the evolution of the solar wind speed from 16 to 202 solar radii.

P1-10

Probing the Large-Scale Structure of the Solar Corona and Inner Heliosphere during Parker Solar Probe's first 10 Encounters.

P. Riley, C. Downs, R. Caplan, R. Lionello, J. Linker, S. Bale, T. Horbury, M. Linton, C. Owen, & M. Stevens

Since the beginning of the space era, our understanding of the physical processes that shape the structure of the inner heliosphere has increased dramatically. This is particularly true for periods surrounding solar minimum, which are generally devoid of transient activity, such as coronal mass ejections. This increased knowledge has been driven in large part by improvements in observations (both remote and in situ) as well as numerical models. Currently, with missions including Parker Solar Probe (PSP), Solar Orbiter, STEREO-A, BepiColombo, SDO, and SOHO, as well as Ground-based observatories, we have an unprecedented opportunity to both test and refine global numerical models of the solar corona and heliosphere. In this presentation, we make detailed model/data comparisons of PSP's first ten perihelia encounters, including all available remote and in situ observations, with the aim of (1) providing a more complete description of the large-scale structure of the 3-D heliosphere during solar minimum conditions; and (2) Connecting the observed structure with its inferred source(s) back at the Sun. We discuss what are the key limiters in our ability to improve the model comparisons and suggest possible solutions for them.

P1-11

Parker Solar Probe Observations of High Plasma Beta Solar Wind from Streamer Belt

J. Huang, J. C. Kasper, L. A. Fisk, M. M. Martinović, K. G. Klein, C. H. K. Chen, B. Lavraud, M. Liu, W. Sun, B. van der Holst, Z. Huang, D. Vech, T. Ďurovcová, M. D. McManus, J. L. Verniero, A. Rahmati, R. Livi, P. Whittlesey, D. E. Larson, T. Niembro, K. Paulson, M. Stevens, A. W. Case, M. Moncuquet, & S. D. Bale

The processes driving the acceleration and evolution of slow solar wind are still debated. The multiple source regions associated with the slow solar wind complicate a simple identification; the streamer belt is believed to be one possible source making it a suitable site to study the nature of slow solar wind. In general, the slow solar wind from the streamer belt forms a dense equatorial plasma sheet, namely the heliospheric plasma sheet (HPS), which is characterized by high plasma beta. The HPSs are quasi-steady structures that include small-scale structures like flux ropes, plasma blobs, magnetic reconnection exhausts, boundary layers. From previous studies, the HPSs and the small-scale structures therein are pressure-balanced structures, which means their total pressures are comparable to the ambient solar wind. However, with current PSP observations, we find that some streamer belt winds show increased total pressure in comparison with the ambient solar wind. Our results further indicate several different characteristics of these streamer belt solar wind: a) the total pressure enhancements suggest the increased plasma pressure exceeds the remarkable magnetic pressure reductions; b) the alpha abundance is generally low but the alpha-proton drift speed is larger; c) some intervals are mirror unstable; d) they have fine structures such as slow shocks, small-scale flux ropes, and magnetic switchbacks. We suggest these streamer belt solar wind streams are evolving, making them valuable for further investigations on the heating and acceleration of the slow solar wind.

P1-12

The supergranulation-scale stream structure and underlying acceleration profile of the emerging solar wind

S. Bale

Near one astronomical unit (1 AU) and in the outer heliosphere, the solar wind is observed to be a relatively homogeneous and highly turbulent flow that is punctuated occasionally by large-scale transient interplanetary structures such as coronal mass ejections (CMEs) and corotating interaction regions (CIRs). As the wind expands and accelerates away from the Sun, turbulent evolution destroys much of the original source structure leaving a relatively uniform flow field. Here we use measurements from the NASA Parker Solar Probe spacecraft to demonstrate that within ~0.2 AU of the Sun, the solar wind is structured into distinct 'streams' that are organized on angular scales of ~5 degrees longitude with respect to the solar surface. This angular scale is comparable to that of solar supergranulation convection cells which are also known to organize and concentrate the photospheric magnetic field. We argue that the discrete solar wind streams have their origins in the network magnetic field, which is also known to be associated with coronal jets and plumes. As a way to identify individual streams, we characterize a 'baseline' solar wind radial speed profile which is apparently functionally similar to the classical Parker solar wind model, after accounting for the discrete structure and high latitude of the wind sources. We use a Potential Field Source Surface (PFSS) instantiation to demonstrate supergranulation-scale mixed-polarity magnetic field structure near the footpoints of discrete streams measured by PSP during Encounter 06. We argue that the Parker Solar Probe instruments are measuring the acceleration of the solar wind in situ and we offer a comparison with the expectations of interchange reconnection as a wind energization mechanism at its source.

P1-13

Solar Wind Density Variability and Pressure Balance near the Sun

E. Conrad, J. Steinberg, R. Skoug, J. Broll, S. Du, H. Li, X. Fu, & Z. Gan

In this study, we present a statistical analysis of Parker Solar Probe (PSP) plasma data variability near the Sun during multiple encounters. We utilize rolling windows of 10- and 60-minutes to calculate the relative standard deviation (RSD) to determine variability around a localized mean on short-time scales. We perform this analysis on proton density and temperature, and electron temperature, and find that both proton parameters are more variable than electron temperature. We also calculate the proton, electron, magnetic, and total pressures and their RSDs. We find that there is more variability in each component than in the total pressure, indicating overall pressure balance. Proton pressure is the most variable, followed by electron pressure, then magnetic pressure. However, magnetic pressure variability can increase dramatically during switchback intervals. Proton and electron pressure variability tends to increase closer to the Sun, while magnetic pressure variability decreases closer to the Sun. We utilize peaks in pressure component RSDs to identify intervals where there is a sharp change in pressure, where we see time series evidence of total pressure balance.

P1-14

Solar Wind Simulations along the Parker Solar Probe Trajectory

D. V. Hegde, T. K. Kim, N. V. Pogorelov, C. N. Arge, & S. I. Jones

The solar wind (SW) is a crucial component of the space weather that forms the background to the propagation of solar coronal disturbances, such as coronal mass ejections (CMEs) and energetic particles, towards the Earth's orbit. Understanding the physical processes that occur in the SW plasma is necessary for forecasting space weather. On the other hand, Parker Solar Probe (PSP), which was launched on August 12, 2018, provides us with a unique set of in situ SW measurements at distances as close as the Sun's critical surface and below. This could help us in the validation of numerical MHD models of the solar corona and inner heliosphere. We perform simulations of the 3D global heliosphere using an empirically driven MHD model developed within the framework of the Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS) using the photospheric magnetograms as input. We compare our inner heliospheric SW simulations with in situ measurements along the PSP trajectory for completed orbits. Also, we evaluate the uncertainties in the predictions quantitatively based on some statistical approaches. This research helps us understand the SW acceleration and provides better constraints for our semi-empirical data-driven MHD model for space weather forecasting.

P1-15

Characterization of the Sub-Alfvénic Solar Wind Observed by the Parker Solar Probe

R. Bandyopadhyay, W. H. Matthaeus, D. J. McComas, R. Chhiber, A. Usmanov, PSP SWEAP Team, & PSP FIELDS Team

In the lower solar coronal regions where the magnetic field is dominant, the Alfvén speed is much higher than the wind speed. In contrast, the near-Earth solar wind is strongly super-Alfvénic, i.e., the wind speed greatly exceeds the Alfvén speed. The transition between these regimes is classically described as the "Alfvén point" but may in fact occur in a distributed Alfvén critical region. NASA's Parker Solar Probe (PSP) mission has entered this region, as it follows a series of orbits that gradually approach more closely to the Sun. During its 8th and 9th solar encounters, at a distance of about 16 solar radii from the Sun, PSP sampled four extended periods in which the solar wind speed was measured to be smaller than the local Alfvén speed. These are the first in situ detections of sub-Alfvénic solar wind in the inner heliosphere by PSP. We discuss the properties of these recently observed sub-Alfvénic solar wind, which may provide important previews of the physical processes operating at lower altitude.

P1-16

Coronal Currents Across Closed Field Lines in Source-Surface Models of the Heliosphere

M. Schulz

The source-surface method has long remained a valuable tool for modeling the Sun's magnetic field through the corona and heliosphere. Its usual formulation calls for representing the Sun's **B** field as the gradient of a magnetic scalar potential V expanded in external (to the Sun) and internal (to the source surface) spherical harmonics, with expansion coefficients that make V = 0 on the source surface, taken as a sphere of radius 1.6–2.5 solar radii (Schatten et al., Solar Phys. **6**, 442–455, 1969; Altschuler and Newkirk, Solar Phys. **9**, 131−149, 1969). This procedure makes **B** radial at the source surface, beyond which the strength of **B** is deduced from geometrically constructed field lines. A possible improvement (Schulz et al., Solar Phys. **69**, 83−104, 1978) would be to make the source surface non-spherical so as to reflect the underlying structure of the Sun's main magnetic field. In this construct the solar wind would flow not radially but rather along straight lines in the outward normal direction from the source surface, and the spherical-harmonic expansion coefficients can be computed by minimizing (over the entire source surface) either the mean-square tangential component of **B** or equivalently (Schulz, Ann. Geophysicae **15**, 1379–1387, 1997) the mean-square deviation of V from a constant equal to its mean value (usually zero). The premise (as usual) is that the magnetic field would control the flow of coronal plasma inside the source surface, whereas the solar wind would control the direction of the magnetic field outside. While ordinary source-surface models thus yield a realistic geometry for magnetic fields in the inner heliosphere, the noted intrinsic dichotomy leads to a possibly unwelcome discontinuity in the associated current density **J** transverse to **B** (from zero inside the source surface to nonzero outside). The present study explores a Green's function approach for smoothing-out this discontinuity in **J** by averaging over existing source surface models corresponding to a range of possible enclosed volumes for the source surface itself. Thus, for example, if $\tilde{B}^2$ denotes the square of the Sun's main magnetic field at spherical coordinates (r, θ, ϕ) and k is a "shape" parameter, one might envision (Schulz, 1997) a source surface of constant $F \equiv r^{-2k}\tilde{B}^2$ having the same volume as a sphere of radius r_0. However, instead of taking $r_0 = 2.5$ solar radii as I did then, one might let r_0 range from 2.0 to 3.0 solar radii and average the corresponding results for $\boldsymbol{B}(r, \theta, \phi; r_0)$ over this range of values for r_0.This could be a smoothly weighted average (with zero weight at the end-points and maximum weight at $r_0 = 2.5$ solar radii) if desired. A similar approach might help smooth the transition from sub-Alfvénic corotation of solar wind in the inner heliosphere to onset of a Parker-like spiral **B** field around 32 solar radii from the Sun's rotation axis.

P1-17
Sources of solar wind

Olga Panasenco, Marco Velli, Chen Shi, & Stuart Bale

Initial Parker Solar Probe results have shown that slow Alfvénic solar wind intervals appear to be a frequent, if not standard, component of the nascent solar wind inside 0.5 AU. In addition to the strong presence of Alfvénic fluctuations propagating away from the Sun, such intervals also display the huge oscillations known as switchbacks, where the Alfvénic fluctuation is accompanied by a fold in the radial magnetic field and a corresponding forward propagating radial jet. Switchbacks often come in patches, separated by short intervals depleted with fluctuations, and periods without switchbacks may also show a striking quiescence, with the magnetic field remaining mostly radial and very small amplitude velocity and magnetic field fluctuations. These observations pose a series of questions on the origins of the solar wind and the role of coronal structure, as well as of the evolution of fluctuations within the solar wind. Here we discuss how the sources of the solar wind measured in situ are related to photospheric magnetic network and large-scale solar coronal magnetic structures. In this presentation we use a wealth of remote sensing and in-situ measurements to pinpoint the sources of the solar wind observed by PSP and Solar Orbiter. We then discuss the origin and evolution of so called slow Alfvénic wind, the origins of switchbacks and sub-Alfvénic wind patches observed in situ at 13.3 Rs and further during PSP Encounters 1 – 11.

P1-18

Modeling the First Two Parker Solar Probe Encounters with ADAPT-WSA

S. Wallace, S. I. Jones, C. N. Arge, N. M. Viall, & C. J. Henney

Parker Solar Probe's (PSP) unique orbital path allows us to observe the solar wind closer to the Sun than ever before. Essential to advancing our knowledge of solar wind and solar energetic particle formation is identifying the source region of these observations at the solar surface. We report on modeling results for the first two PSP solar encounters derived using the Wang- Sheeley-Arge (WSA) model driven by Air Force Data Assimilative Photospheric Flux Transport (ADAPT) ensemble model maps. For each solar encounter, we derive the coronal magnetic field and the 1 Rs source regions of the PSP-observed solar wind. To help validate our results, we compare the model-derived solar wind speed and magnetic polarity with that observed at PSP. By coupling ADAPT with WSA, we are able to derive the evolution of the coronal magnetic field for periods in which PSP is on the far-side. In particular, we discuss the evolution of the mid-latitude coronal hole that PSP was connected to in the first encounter, and how this evolution affects the solar wind produced from this source region. We also derive time series of model-derived spacecraft separation from the heliospheric current sheet (HCS), magnetic expansion factor, coronal hole boundary distance, and photospheric field strength along the field lines estimated to be connected to the spacecraft. Lastly, we discuss what observations (if attainable) would have improved the accuracy of both the coronal field solution and the solar wind mapping of PSP observations back to their source at 1 Rs, and the importance of coordinated efforts from observatories at multiple vantage points in constraining and interpreting model results.

P1-19
Suprathermal ions in fast and slow solar wind structures as measured by the Parker Solar Probe

M. A. Dayeh, M. J. Starkey, R. Bučik, & M. I. Desai

The interplanetary Suprathermal (ST) ion population is unambiguously thought to form the seed population from which solar energetic particle (SEP) events draw their accelerated material. The sources and acceleration of the ST population are among the major outstanding questions in heliospheric physics. There are currently two prevailing schools of thought that describe the ST population origin and acceleration. One school suggests that they originate from the SW and are accelerated by localized processes such as compressions, while the other suggests that they are partially remnants of previous solar transient events.

We utilize the unique plasma, magnetic field, and particle observations of Parker Solar Probe to examine the sources and the physical processes that describe the ST ions in slow and fast SW structures in the inner heliosphere. In particular, we identify the quiet times during the studied period and derive the ion properties and their associated distributions in slow and fast SW conditions. Preliminary results indicate that the ST population during fast SW periods is energized when compared to slow SW periods. If confirmed, these results indicate that the SW properties play a role in driving the energization and properties of the complex ST population.

P1-20

The preferential orientation of magnetic switchbacks, implications for solar magnetic flux transport

N. Fargette, B. Lavraud, A. P. Rouillard, V. Réville, S. D. Bale, & J. Kasper

Magnetic switchbacks in the solar wind are large deflections of the magnetic field vector, often reversing its radial component, and associated with a velocity spike consistent with their Alfvénic nature. The Parker Solar Probe (PSP) mission revealed that they were a dominant feature of the near-Sun solar wind. Where and how they are formed remains unclear and subject to discussion. Aims. We investigate the orientation of the magnetic field deflections in switchbacks to determine if they are characterised by a possible preferential orientation Methods. We compute the deflection angles $\psi = [\phi, \theta]^T$ of the magnetic field relative to the theoretical Parker spiral direction for encounters 1 to 9 of the PSP mission. We first characterize the distribution of these deflection angles for calm solar wind intervals, and assess the precision of the Parker model as a function of distance from the Sun. We then assume that the solar wind is composed of two populations, the background calm solar wind and the population of switchbacks, characterized by larger fluctuations. We model the total distribution of deflection angles we observe in the solar wind as a weighed sum of two distinct normal distributions, each corresponding to one of the populations. We fit the observed data with our model using a Monte-Carlo Markov Chain algorithm and retrieve the most probable mean vector and covariance matrix coefficients of the two Gaussian functions, as well as the population proportion. Results. We first confirm that the Parker spiral is a valid model for calm solar wind intervals at PSP distances. We observe that the accuracy of the spiral direction in the ecliptic is a function of radial distance, in a manner that is consistent with PSP being near the solar wind acceleration region. We then find that the fitted switchback population presents a systematic bias in its deflections, with a mean vector consistently shifted towards lower values of ϕ (−5.52 on average) and θ (−2.15 on average) compared to the calm solar wind population. This result holds for all encounters but E6, and regardless of the magnetic field main polarity. This implies a marked preferential orientation of switchbacks in the clockwise direction in the ecliptic plane, and we discuss this result and its implications in the context of the existing switchback formation theories. Finally, we report the observation of a 12-hour patch of switchbacks that systematically deflect in the same direction, so that the magnetic field vector tip within the patch deflects and returns to the Parker spiral within a given plane.

P1-21

Association of intermittency with electron heating in the near-Sun solar wind

C. Phillips

Magnetic energy dissipation is concentrated in regions of strong gradients, such as current sheets. Proton temperature has been shown to be preferentially enhanced near these coherent structures in turbulent plasmas. Recent PSP observations supported this for protons. We follow up these previous analyses with measurements of electron temperatures from PSP. We use the Partial Variance of Increments (PVI) method to identify coherent structures and use electron temperature derived from Quasi-thermal noise from the FIELDS. We find that electron temperatures are enhanced near high-PVI value regions, but the effect is weaker than that of protons.

Magnetic field line path length variations and effects on solar energetic particle transport

D. Ruffolo, W. Sonsrettee, P. Chuychai, A. Seripienlert, P. Tooprakai, A. Sáiz, W. H. Matthaeus, & R. Chhiber

Modeling of time profiles of solar energetic particle (SEP) observations typically considers transport along a large-scale magnetic field with a fixed pathlength from the source to the observer. Chhiber et al. (2021) pointed out that the path length along a turbulent magnetic field line is on average longer than that along the large scale field, and that the path along the particle gyro-orbit can be substantially longer again; they also considered the global variation in these quantities. Here we point out that variability in the turbulent field line path length can affect the fits to SEP data and the inferred mean free path and injection profile. To explore such variability, we perform Monte Carlo simulations based on representations of homogeneous 2D MHD + slab turbulence embedded in spherical geometry and trace trajectories of field lines, particle guiding centers, and full particle orbits, considering ion injection from a narrow or wide angular region near the Sun, corresponding to an impulsive or gradual solar event, respectively. We analyze our simulation results in terms of path length statistics within and among square-degree pixels in heliolatitude and heliolongitude at 0.35 and 1 AU from the Sun. We find systematic patterns in mean field line and particle pathlengths according to 2D turbulence structure and variations in the pitch angle scattering along different paths. We describe the effects of such path length variations on observed time profiles of solar energetic particles, both in terms of path length variability at specific locations and motion of the observer with respect to turbulence topology during the course of the observations. This research was partially supported by Thailand Science Research and Innovation grant RTA6280002 and the Parker Solar Probe mission under the ISOIS project (contract NNN06AA01C) and a subcontract to University of Delaware from Princeton University (SUB0000165). Additional support is acknowledged from the NASA LWS program (NNX17AB79G) and HSR program (80NSSC18K1210 & 80NSSC18K1648).

Global Modeling of Broad-Longitude SEP Events

Jon Linker, Ronald Caplan, Erika Palmerio, Nathan Schwadron, Matthew Young, Tibor Torok, Cooper Downs, Christina Cohen, & ISOIS Team

Solar Energetic Particles (SEPs) are typically associated with large solar eruptions. They are of fundamental scientific interest and can represent a significant space weather hazard as well. The unusually fast rise times of SEPs at locations distant from their apparent solar source that occurs in some events is a particularly puzzling phenomenon. We describe the application of Coupled MHD-Focused Transport simulations to two broad longitude events in the Parker Era (the 11/29/2020 and 10/28/2021 flare/CME events) using the SPE Threat Assessment Tool (STAT, e.g., Young et al. ApJ 909, 2021). We discuss the apparent role of large-scale separators and QSLs (the so-called S-Web) in the generation of SEPs at multiple heliospheric locations.
Research supported by NASA and NSF.

Multi-spacecraft modelling of multi-CMEs observed by WISPR on PSP

I. Chifu & V. Bothmer

When Parker Solar Probe (PSP) was approaching its 8 th perihelion, a series of three interacting CMEs were identified in the observations of the WISPR-I telescope on April 26. These CMEs were simultaneously observed in the STEREO-A/SECCHI/COR2 and HI and SOHO/LASCO/C2/C3 fields of view on April 25. We applied different methods for the 3D reconstruction of these objects in order to derive their physical properties and kinematics and to investigate eventual PSP encounters. WISPR imaged details of a small flux rope originating in the course of a series of sympathetic eruptions identified from SDO and STEREO-A/SECCHI/EUVI observations. In this study we present the results of the 3D reconstruction and the derived physical parameters for these events.

Magnetic field topology of ICMEs from PSP in-situ measurements

Q. Hu, Y. Chen, W. He, & C. Moestl

The Parker Solar Probe (PSP) mission, since its launch in 2018, has completed multiple orbits around the Sun, and returned a multitude of observations including in-situ measurements of magnetic field and plasma parameters. Among them, observational signatures of magnetic flux ropes over a range of scales including coronal mass ejection (CME) type of relatively large sizes are revealed. Some of them were also traversed by other heliospheric spacecraft missions at different but closely separated locations. We employ multiple flux rope modeling techniques to reconstruct their magnetic field configurations based on in-situ measurements obtained along the spacecraft path across the structure. In addition, we perform model-based correlation analysis between the measurements from two spacecraft when available in order to provide validations to the modeling result. We present the general characteristics of the flux rope configurations, and discuss the implications for the more general three-dimensional (3D) magnetic field topology related to the origin of these structures on the Sun.

Numerical Simulations of SEP dropouts and the Implications to PSP Observations

F. Guo, J. Giacalone, C. Cohen, L. Zhao, R. Leske, & M. Wiedenbeck

Sharp gradients of solar energetic particle (SEP) intensity, or “dropouts”, are one of the most intriguing phenomena in SEPs. We carry out a new numerical study where dropouts are produced due to energetic particles from a compact source region propagating in a turbulent magnetic field. In addition to previous findings, we have included SEP intensities in directions parallel and antiparallel to the mean magnetic field. Dropout may explain the anomalous onset and sharp variations of particle intensity of SEPs observed by Parker Solar Probe (PSP). Moreover, our simulations predict a radial dependence of the dropout duration, and there may even exist a “dead zone” where the dropout feature vanishes when PSP is close to the Sun.

Energetic Particles Associated with Sub- and Super-Parker Spirals -- Signatures of the Dynamic History of Stretched and Switched-Back Magnetic Fields

N. A. Schwadron, D. J. McComas, E. R. Christian, C. M. S. Cohen, M. I. Desai, M. E. Hill, C. J. Joyce, R. A. Leske, O. Malandraki, W. H. Matthaeus, R. L. McNutt, Jr, R. A. Mewaldt, D. G. Mitchell, J. T. Niehof, J. S. Rankin, T. Sharma, E. C. Stone, J. Szalay, & M. E. Wiedenbeck

Recently, Schwadron and McComas (2021) provided a simple geometric explanation for the source of switchbacks and associated large and one-sided transverse flows in the solar wind observed by Parker Solar Probe. The interpretation follows naturally from previous work that studied departures from the standard Parker Spiral magnetic field in the inner heliosphere. The more radial, Sub-Parker Spiral structure of the heliospheric magnetic field observed previously by Ulysses, ACE, and STEREO is created within rarefaction regions where footpoint motion from the source of fast into slow wind at the Sun creates magnetic field line connections across solar wind speed shears. The long duration of energetic particle enhancements following the passage of stream interfaces between the fast and slow solar wind indicates that particles stream in through the inner heliosphere more directly along magnetic field lines that form a Sub-Parker spiral structure due to magnetic footpoint motion at the Sun and shearing of the magnetic field in the rarefaction region behind the stream interface. In contrast to the footpoint motion associated with Sub-Parker spiral, when footpoints move from the source of slow wind into faster wind, a Super-Parker Spiral field structure is formed: below the Alfven critical point, one-sided transverse field-aligned flows develop; above the Alfven critical point, the field structure contracts between adjacent solar wind flows, and the radial field component decreases in magnitude with distance from the Sun, eventually reversing into a switchback. We use observations from Integrated Science Investigation of the Sun on Parker Solar Probe to associate energetic particle signatures with the Sub- and Super-Parker spiral structures. We discuss the implications for the dynamical evolution of these structures and implications for cosmic ray drift further out in the heliosphere.

Suprathermal Ion Observations Associated with the Heliospheric Current Sheet Crossings by Parker Solar Probe During Encounters 7-10.

M. I. Desai, D. G. Mitchell, D. J. McComas, J. F. Drake, T. Phan, J. R. Szalay, E. C. Roelof, J. Giacalone, M. E. Hill, E. R. Christian, N. A. Schwadron, R. L. McNutt Jr., M. E. Wiedenbeck,C. Joyce, C. M. S. Cohen, A. J. Davis, S. M. Krimigis, R. A. Leske, W. H. Matthaeus, O. Malandraki, R. A. Mewaldt, A. Labrador, E. C. Stone, S. D. Bale, J. Verniero, A. Rahmati, P. Whittlesey, R. Livi, D. Larson, M. Pulupa, R. J. MacDowall, J. T. Niehof, J. C. Kasper, & T. S. Horbury

We report observations of <100 keV/nucleon suprathermal (ST) H, He, O, and Fe ions in association with three separate crossings of the heliospheric current sheet that occurred near perhelia during PSP encounters 7-10. In particular, we compare and contrast the ST ion time intensity profiles, velocity dispersion, pitch-angle distributions, spectral forms, and maximum energies during the three HCS crossings. We find that these unique ST observations are remarkably different in each case, with those during E07 posing the most serious challenges for existing models of ST ion production in the inner heliosphere. In contrast, the ISOIS observations during E08 appear to be consistent with a scenario in which ST ions escape out of the reconnection exhausts into the separatrix layers after getting accelerated up to ~50-100 keV/nucleon by HCS-associated magnetic reconnection-driven processes. Finally, ST ions during the E09/E10 HCS crossing have properties that are somewhat similar to those seen during both E07 and E08 crossings, with ion intensities being higher outside the exhausts and the separatrices, but significant intensity increases are also observed inside the reconnection exhausts. We discuss these new observations in terms of local versus remote acceleration sources as well as in terms of expectations of existing ST ion production and propagation, including reconnection-driven and diffusive acceleration in the inner heliosphere.

Can the lengths of magnetic field lines be determined from velocity dispersion in the onsets of impulsive SEP events?

E. C. Roelof

Linear “edges” often appear in plots of inverse velocity (1/v) *vs.* time (t) for first-arriving solar energetic particles (SEPs) in impulsive events. The intercept (1/v=0) of the edge with the time axis at $t=t_0$ is taken as the (common) injection time for the SEPs, while the slope (1/s) is taken to be the inverse of the length (s) of the field line between the lower corona and the spacecraft. For decades, such analyses at 1AU have found (t_0) in agreement (or systematically displaced several minutes later) from the times of associated electromagnetic (EM) emission (hard x-rays, type iii radio, *etc.*). The usual derived values of (s) slightly exceeded 1AU (in agreement with a Parker magnetic field), but occasionally there were larger values. For recent events at PSP and other inner heliosphere spacecraft ($0.1<r<1.0$), larger $s>r$ discrepancies have not been uncommon, even with differing s-values (but similar t_0 values) among several spacecraft observing the same event. At ParkerONE (2021), I offered a theory that explained such large s-values (while preserving a common t_0), namely that SEPs with lower (v) are systematically injected later and higher in the corona, corresponding to acceleration and injection by the outward-moving shock of the associated CME. Subsequently, I re-examined the ACE/ULEIS energetic ion data (courtesy of Dr. Glenn M. Mason of JHU/APL) from the GLE event of 20 January 2005. The associated CME transit was only 36h, implying V>1000 km/s. ACE was magnetically well-connected to the flare site (GOES X7.1 at N12, W58) and the onset of the near-relativistic particles (neutron monitors and ACE/EPAM 175-315 keV electrons) was strongly anisotropic (beam-like) and in excellent agreement (within a few minutes) with the EM emission. Also, the lower-energy ions exhibited an identifiable edge in the (1/v) *vs.* t plot. The intercept ($t=t_0$) was in reasonable agreement with the EM emission. Remarkably, however, the slope of the edge yielded s=3.6AU! This large inferred field-line length is absolutely inconsistent with the prompt arrival of the near-relativistic SEPs (nearly time-coincident with the EM emissions). On the other hand, the pertinent observations of the extreme 20 January event are all quantitatively consistent my velocity-dependent injection theory (which therefore could also be applicable to the much, much smaller SEP events at PSP).

Widespread 1–2 MeV Energetic Particles Associated with Slow and Narrow Coronal Mass Ejections: Parker Solar Probe and STEREO Measurements

B. Zhuang, N. Lugaz, & D. Lario[2]

Large gradual solar energetic particle (SEP) events are thought to result from the acceleration of suprathermal seed particles in the corona to high energies (E>10 MeV nuc-1) by shocks associated with fast and wide coronal mass ejections (CMEs). Observations close to the Sun can lead to a better understanding of the role of suprathermal particles as seed populations for SEP events. Observational properties of suprathermal particles may be significantly different in the inner heliosphere compared to those near 1 au. From 2020 May 27 to June 2, four successive SEP events with proton intensity enhancements observed in the >1 MeV energy range were observed by the Integrated Science Investigation of the Sun (IS ⊙ IS) suite onboard the Parker Solar Probe (PSP). During this time PSP was at heliocentric distances between ~0.4 and ~0.2 au. The Ahead Solar TErrestrial RElations Observatory (STEREO-A) near 1 au also observed these events, but the associated particle intensity magnitude was much lower than that at PSP. We find that the SEPs should have spread widely in space due to the facts that (1) their source regions were distant from the nominal magnetic footpoints of both spacecraft and (2) the parent CMEs were slow (with angular width <30 °) and narrow (with speed ~300 km/s). We study the decay phase of the SEP events in the ~1-2 MeV proton energy range at PSP, and their decay-time constants were found to be around 10 hours to one day. With the decay phase analyses at STEREO-A, we discuss their different properties in terms of both continuous injections by successive solar eruptions and the distances where the measurements were made. This study suggests that seed particles can be continuously generated by eruptions associated with even slow and narrow CMEs spread over a large part of the inner heliosphere, and remain there for tens of hours, even if minimal particle intensity enhancements were measured near 1 au, which further highlights the importance of measuring and understanding seed particles in the inner heliosphere.

Energy partitioning from the chromosphere to the heliosphere in the October 28 2021 X flare and associated CME

K. Reeves & the HSO Connect Eruptions Team

The October 28 2021 X1.0 flare and associated CME was a powerful and well-observed event. During this event, Solar Orbiter was nearly in alignment with Earth, while Parker Solar Probe observed the eruption from a Carrington Longitude of 217 degrees and a radius inside the orbit of Venus. In this presentation we will show preliminary results of calculations of the energetics of this event including various pathways for energy release. We calculate the magnetic energy build up in the host region, AR 12887 from photospheric magnetograms, and compare with that from coronal magnetic fields derived from microwave imaging spectroscopy from EOVSA. We also compare with the magnetic energy and Poynting flux at PSP as derived from FIELDS and SWEAP measurements. We quantify the energy input as a function of time into the chromosphere during the flare using the ultraviolet footpoint calorimeter method. Data from EUV imaging and SolO/STIX are used to quantify the thermal and non-thermal energy partition during the flare. The CME kinetic energy evolution and shock structure is derived from EUV imaging and coronagraph measurements and in-situ plasma data from Wind. We also examine the energetic particles observed in-situ by various observatories, including PSP and SolO.

P2-01
How Parker Solar Probe can address the Origin of SEP Seed Particles: Flare-CME-SEP connection?

S. B. Shaik

Even after extensive studies on particle acceleration from flares and coronal mass ejections (CMEs), the origin of SEP (solar energetic particle event) seed particles and the connection between flares, CMEs, and SEPs are still unclear. Recent observations from ground-based radio instruments like Expanded Owens Valley Solar Array (EOVSA) have shown a new perspective of the standard flare model, having a flaring region with a large spatial scale of low-frequency microwave emission. These flares have shown that the accelerated particles can transport to a much bigger volume than observed at other high-energetic wavelengths. When flares and CMEs generate such a large spatial extent of accelerated particles, do they have any unexplored contribution in creating the seed particles? If yes, how can event to event variations explain the SEP conditions? To answer these questions, measurements from the instruments onboard the Parker Solar Probe (PSP) that span between the Sun and 1 AU can provide crucial information of the accelerated particles that can be smeared during the transport to the distant 1 AU in-situ observations. Heliospheric imaging observations, especially from the Wide-Field Imager for Parker Solar Probe (WISPR), can help probe the CME associated shocks near their origin in the inner heliosphere at $<10\ R_\odot$. They also help connect the coronal magnetic field at source locations to the heliospheric magnetic field configuration to understand the shock geometry, ambient environment and SEP favoring conditions. This study from the joint observations from PSP (WISPR-FIELDS-IS⊙IS), EOVSA, Solar Orbiter, STEREO, SOHO can probably answer the respective contributions of seed populations from the flare magnetic reconnection acceleration and CME associated shock acceleration.

P2-02
Model for the Time-Dependent Momentum Spectrum of Energetic Particles at Interplanetary Shocks Including Acceleration and Escape

T. Do, F. Fraschetti, & J. Kota

Charged particles in the heliosphere can be continuously accelerated by interplanetary shocks and eventually escape from these shocks without returning to it. Acceleration and escape are highly intertwined and both contribute to the shaping of the particle momentum spectrum at the shock. Diffusive Shock Acceleration, or DSA, has been very successful in describing several in-situ measurements. However, DSA does not include an energy-dependent escape from the upstream region. We expand upon DSA by including an energy-dependent particle escape (with no rigid spatial boundary) for the time-dependent acceleration at interplanetary shocks. We analytically and numerically solve a one-dimensional transport equation with a diffusion coefficient and an escape time that describes both the turbulence self-generated by the shock and the far upstream pre-existing turbulence (the case of both diffusion and escape time independent of position is solved as well). With these approximations, we derived expressions for the steady state energy spectrum, time-dependent energy spectrum, mean acceleration time in the presence of escape and compared with a numerical solution; we highlight the new predictions. From this model, we can better understand the mechanism of interplanetary shock acceleration and how this phenomenon energizes charged particles near the Sun and around other objects (for example, blazars and supernova remnants).

P2-03
Using WSIPR on Parker Solar Probe as a CME microscope in April 2021

V. Bothmer & I. Chifu

During the days from April 20 to 27, 2021, when Parker Solar Probe (PSP) was just 2 days ahead of its 8 th perihelion to a distance of 15,7 solar radii, more than 20 CMEs have been observed by the WISPR inner telescope on board PSP. The WISPR CME observations reveal unprecedented fine structures compared to white-light observations from near-Earth orbit taken with STEREO/SECCHI/COR2A/HI1A and SOHO/LASCO/C2/C3. We identified the source regions using EUV-data provided by SDO and STEREO/SECCHI/EUVI A. Here we present a summary of the basic CME kinematics and characteristics of their near-Sun evolution and interactions. The results have important implications for a better understanding of CME propagation into the heliosphere.

P2-04

3D Geometric study of CMEs observed by WISPR/ PSP.

E. Nikou, J. Zhang, M. Dupertuis, & S. Dhakal

PSP has given us the opportunity to observe, track and better understand the morphology and early evolution of coronal mass ejections (CMEs) due to its proximity to the Sun. In this study we focus on documenting and fitting CMEs viewed by WISPR. The graduated cylindrical shell model (GCS model) has been extensively used to replicate the flux rope geometry and depends on six free parameters that govern its shape, propagation direction and orientation. These are the aspect ratio, half angle, leading height, longitude, latitude and tilt angle. A fitting tool that is based on the GCS model and the MPFIT minimization IDL routine and combines multi-viewpoint white light observations from PSP, STEREO, and SOHO is used to fit the CMEs from one, two and three viewpoints. The fitting results of CMEs observed by PSP will be presented.

P2-05

Sheath and leading-edge characteristics of interplanetary coronal mass ejections using Helios and PSP data

M. T & V. Bother

Helios 1 and 2 data, covering the distance range from 0.3-1au, are extremely useful for getting more information about the characteristics of various substructures of interplanetary coronal mass ejections (ICMEs). We investigate a data sample of 40 events within the time range 1974-1981 with respect to characteristics of the ICME structures sheath, leading edge and magnetic ejecta. For comparison, we add a sample of 5 ICMEs observed with Parker Solar Probe during 2018-2021. We study the sheath density variations over distance and relate those to the ambient solar wind speed. The results show that the sheath is moderately anti-correlated with the solar wind speed ahead of the disturbance. We find that the sheath density may become dominant over the background solar wind density beyond ca 13Rs and that its size constantly increases with distance. The results are important for better understanding the CME mass evolution due to sheath enlargement. We derive an empirical relation between the sheath density and the local solar wind plasma speed upstream of the ICME shock. The empirical results might be used to model the sheath structure and with that enable to give more details about CME propagation in the inner heliosphere.

P2-06
Jovian electrons in the inner heliosphere

R.D. Strauss, N. Dresing, & J.P. van den Berg

Electron measurements from recent Parker Solar Probe (PSP) perihelia showed the presence of Jovian electrons. While this is not unexpected, the distribution of Jovian electrons in the very inner heliosphere has not been well studied in the past. Here we present simulations of Jovian electron intensities along selected spacecraft trajectories, including PSP, Solar Orbiter, BepiColombo, STEREO A, Earth (L1), and Mars/MAVEN. We are in the process of comparing the simulation results with spacecraft measurements, where available, for the year 2021. Using planned future trajectories, we also present simulations of what Jovian electron distributions these spacecraft may encounter in the future.

P2-07

Slow drifting features in interplanetary Type III radio bursts

M. Pulupa, S. D. Bale, & J. C. M. Oliveros

Type III solar radio bursts are generated by beams of electrons released during solar flares. Type III bursts which extend in frequency down to ~1 MHz and below are known as interplanetary (IP) Type IIIs. IP Type IIIs can only be observed from space, due to effects of the terrestrial ionosphere. We present Parker Solar Probe/FIELDS observations of several IP Type III radio bursts using data from the high frequency resolution "peak tracker" mode of the Radio Frequency Spectrometer (RFS). The peak tracker was designed to capture the plasma frequency peak during PSP Encounters. Far from the Sun, the plasma peak is too small to detect, and the peak tracker often captures the descending edge of IP Type III radio bursts. We use peak tracker data to characterize the frequency drift of fine structure features of Type III radio bursts, and compare to recent ground-based observations at higher frequencies (e.g. Reid and Kontar 2021).

P2-08
Jovian Electrons Observed by Parker Solar Probe/ISOIS/EPI-Hi

J. G. Mitchell, R. A. Leske, G. A. de Nolfo, E. R. Christian, D. J. McComas, M. E. Wiedenbeck, C.M.S. Cohen, M. E. Hill, A. W. Labrador, R. L. McNutt, R. A. Mewaldt, D. G. Mitchell, N. A. Schwadron, & J. R. Szalay

Energetic electrons of Jovian origin have been observed for decades throughout the heliosphere. The treatment of Jupiter as a constantly emitting point source of energetic electrons has made Jovian electrons a valuable tool in the study of transport of energetic electrons within the heliosphere. We present observations of Jovian electrons measured by the EPI-Hi instrument in the Integrated Science Investigation of the Sun (ISOIS) instrument suite on Parker Solar Probe at distances within 0.5 au of the Sun. These are the closest measurements of Jovian electrons to the Sun, providing a new opportunity to study the propagation and transport of energetic electrons to these low heliocentric radii. The presented Jovian electron enhancements are unique as they are characteristically briefer than those previously reported, likely due to the high orbital velocity and eccentricity of Parker Solar Probe resulting in rapidly changing magnetic connectivity. We also find that there are periods of nominal connectivity between the spacecraft and Jupiter in which expected Jovian electron enhancements are absent. We are investigating possible causes such as modulation from stream interaction regions (SIR) and the heliospheric current sheet.

P2-09

Energetic Particle Events Observed Jointly by the Expanded Owens Valley Solar Array and the Parker Solar Probe

M. Wang, B. Chen, S. Yu, D. Gary, & J. Lee

We report two energetic particle events observed jointly by the Expanded Owens Valley Solar Array (EOVSA) and the Parker Solar Probe (PSP) in April 2019 and July 2021. Both the events are associated with type III radio bursts that continue to the interplanetary space in the decameter–kilometer wavelength range (300 kHz–30 MHz) observed by multiple spacecraft including PSP/FIELDS, Wind/WAVEs, and STEREO/WAVES, and appears to reach the local plasma frequency at the PSP spacecraft. One event, associated with a GOES B3-class flare, coincides with an enhanced suprathermal electron population with an anti-sunward beam-like component as measured in situ by PSP/SWEAP. For the other event, which is associated with a GOES X1-class flare, PSP/IS⊙IS recorded a more energetic particle event with >1 MeV electrons and an enhanced ^{3}He/^{4}He ratio. These two in situ energetic particle events are both recorded by EOVSA, manifested in the dynamic spectrum as a group of impulsive microwave bursts. Aided by microwave imaging spectroscopy and magnetic modeling, we identify the source of the energetic particle events and discuss their transport from near the solar surface to the interplanetary space.

P2-10

Generalized non-linear Compton-Getting transformations applied to Parker Solar Probe energetic ion events

R. DeMajistre, E.C. Roelof

The interpretation of the energetic ion events measured by the ISOIS instruments requires the accounting for significant relative velocities (plasma frame/spacecraft frame), steep spectra and large pitch angle anisotropies. We present here applications of the generalized non-linear Compton-Getting transformation developed by Roelof (2020 J. Phys.: Conf. Ser. 1620 012017) to these data, transforming the spacecraft frame spectra into frames more conducive to physical interpretation, i.e., the frames at rest with respect to the plasma motion (**V**) or the motion of the magnetic field lines ($\mathbf{V}_{perp}=\mathbf{ExB}/B^2$). Within either frame, the energetic ion velocity distribution can be presumed to be gyrotropic, and we can obtain the pitch-angle distributions (PADs) at fixed energies in the moving frames. In our first applications, we compare ISOIS/EPI-Lo PADs from a weak-anisotropy Stream Interaction Region (SIR) with a much more anisotropic impulsive Solar Energetic Particle (SEP) event.

P2-11

Influence of Large-Scale Interplanetary Structures on the Propagation of Solar Energetic Particles: The Multi-Spacecraft Event on 2021 October 9

D. Lario, N. Wijsen, R. Y. Kwon, B. Sanchez-Cano, I. G. Richardson, D. Pacheco, E. Palmerio, M. L. Stevens, A. Szabo, D. Heyner, F. Carcaboso, N. Dresing, R. Gomez-Herrero, A. Aran, M. Brüdern, A. Afanasiev, R. Vainio, E. Riihonen, S. Poedts, Z. G. Xu, & A. Kollhoff

An intense solar energetic particle (SEP) event was observed on 2021 October 9 by multiple spacecraft distributed near the ecliptic plane at heliocentric radial distances R£1 au and within a narrow range of heliolongitudes. A stream interaction region (SIR), sequentially observed by Parker Solar Probe (PSP) at R=0.76 au and 48 deg east from Earth (i.e., E48), STEREO-A (at R=0.96 au and E39), Solar Orbiter (SolO; at R=0.68 au and E15), BepiColombo (at R=0.33 au and W02), and near-Earth spacecraft, regulated the observed intensity-time profiles and the anisotropic character of the SEP event. PSP, STEREO-A and SolO detected strong anisotropies at the onset of the SEP event, which resulted from the fact that PSP and STEREO-A were in the declining-speed region of the solar wind stream responsible for the SIR, and from the passage of a steady magnetic field structure by SolO during the onset of the event. By contrast, the intensity-time profiles observed near-Earth displayed a delayed onset at proton energies above ~13 MeV and an accumulation of protons at energies below ~5 MeV between the SIR and the shock driven by the parent coronal mass ejection (CME). Even though BepiColombo, STEREO-A, and SolO were nominally connected to the same region of the Sun, the intensity-time profiles at BepiColombo resemble those observed near Earth, with the bulk of low-energy ions also confined between the SIR and the CME-driven shock. This event exemplifies the impact that intervening large-scale interplanetary structures, such as corotating SIRs, have in shaping the properties of SEP events.

P2-12

Parallel Diffusion Coefficient as a function of Radial Distance from Parker Solar Probe Observations

Xiaohang Chen & Joe Giacalone

Diffusion Coefficients are used in transport equations to solve for the distribution of high-energy charged particles, such as cosmic rays and solar-energetic particles. They are a fundamental aspect of particle transport theory, however, remaining incompletely understood. Taking advantage of recent observations from Parker Solar Probe (PSP), we study the radial dependence of the parallel diffusion coefficients ($\kappa_{\parallel}$) based on quasi-linear theory, FIELDS and SWEAP data for the first six orbits of PSP. We find that the diffusion coefficients of high-energy particles exhibit a power-law relation of radial distance ($\kappa_{\parallel} \propto r^{\gamma}$) with the index γ depending on the energy of particles. Also, the momentum dependence of diffusion coefficient is consistent with the results obtained from a Kolmogorov power spectrum ($\kappa_{\parallel} \propto p^{4/3}$). This work will provide a reference of $\kappa_{\parallel}$ in the inner heliosphere which can be used to understand the acceleration and transport processes of solar energetic particles.

P2-13

Dispersive Solar Flare Ions Observed from Multi-MeV Down to the Solar Wind Thermal Population

D. Larson, A. Rahmati, R. Livi, P. Whittlesey, M. McManus, O. Romeo, J. Kasper, C. Cohen, D. McComas, E. Christian, N. Schwandron, M. Wiedenbeck, R. McNutt, M. Hill, D. Mitchell, M. Pulupa, & S. Bale

During Parker Solar Probe's 11th journey through the inner heliosphere, the ISOIS-EPI-Lo and SWEAP-SPAN-Ion instruments detected a dispersive ion event from a minor solar flare on February 27, 2022. A series of small type 3 radio bursts can be used to refine the onset time of the flare. Within minutes, ISOIS/EPI Low observed a significant increase in >1 MeV ions, and as time progressed, the peak of the distribution extended down to the low energy cutoff of the EPI Lo instrument. A few hours later, energetic ions are observed below the 20 keV high energy limit of the PSP-SWEAP-SPAN-Ion instrument and the dispersion is observed to continue down to below 2 keV - almost to the flow energy of the solar wind core plasma. This is the first time that energetic flare ions have been observed to extend to the thermal ion range. The unique orbit of PSP provides an excellent opportunity to study the spatial (and temporal) evolution of these energetic flare particles. We will discuss the implications of this observation.

P2-14

Near-Continuous Coronal Heavy Ion Acceleration Observed on Parker Solar Probe at Perihelion

D. G. Mitchell, M. I. Desai, C. M. S. Cohen, D. J. McComas, M. E. Hill, J.G. Mitchell, E. C. Roelof, R. L. McNutt Jr., J. Giacalone, E. R. Christian, W. H. Matthaeus, J. T. Niehof, N. A. Schwadron, S. Bale, J. C. Kasper, & P. Whittlesey

Over most perihelion segments of the Parker Solar Probe (PSP) orbit (inside about 20 solar radii) the Integrated Science Investigation of the Sun-Energetic Particle Instrument-Lo (ISOIS/EPI-Lo) observed significant non-dispersive intensities of ~100-1500keV 4He, O, Mg, Si, and Fe, both close to and distant from the Heliospheric Current Sheet (HCS), as determined in the PSP FIELDS and SWEAP instrument data. The ion angular distributions are strongly anisotropic away from the sun, and sometimes appear to be consistent with a conic distribution about the ~radial magnetic field, though to date this has not been resolved. Inside the HCS, the ion intensities are typically lower than in regions adjacent to it. The observations are consistent with continuous perpendicular heating of the ions closer to the sun on open magnetic field lines, over many hours (and large distances in apparent source surface longitudes). Given the apparently broad source surface connections and local minima inside the HCS, we argue that the hot ion source is not the HCS itself. Based on the shape of the ion spectra and the higher energies reached by higher Z (and higher charge state) ions, we suspect a heating mechanism that involves wave-particle interactions.

P2-15

Sources of energetic ions associated with CMEs: Multi-Spacecraft Analysis of the 2021 October 9 CME Event

Robert C. Allen, G. M. Mason, G. C. Ho, M. E. Hill, M. Stevens, D. G. Mitchell, C. M. S. Cohen, I. Hewins, J. Vievering, S. K. Vines, P. Mostafavi, M. Walker, A. Kouloumvakos, A. Vourlidas, S. Fleth, J. Rodríguez-Pacheco, R. F. Wimmer-Schweingruber, D. J. McComas, J. C. Kasper, & S. D. Bale

On 2021 October 9, four Heliophysics System Observatory (HSO) assets spanning ~50° in longitude captured a CME eruption and subsequent propagation in the inner heliosphere. Remote observations show a clear westward deflection of the CME due to complex coronal hole structures on the Sun. In situ observations revealed interesting longitudinal differences in energetic particle populations: Parker Solar Probe (PSP), which would have been more directly connected to the flaring active region that produced the CME, did not observe an energetic particle response when the CME reached the spacecraft. However, ACE, which was not well connected to the active region, observed locally accelerated ions during the CME-associated shock passage. STEREO and Solar Orbiter observations in between PSP and ACE also allow for measurements of locally accelerated ions along the CME, as well as comparisons of the longitudinal distribution of the flare-associated particles released from the active region. This poster investigates the variations in the arrival and intensity of ions associated with this CME, as well as compositional variations throughout the event between spacecraft.

Observations and Models of Proton and Alpha Particle Velocity Distribution in Sub-Alfvénic Solar Wind at PSP Perihelia

L. Ofman, L. Jian, J. Verniero, S. Boardsen, M. Stevens, & P. Mostafavi

The solar wind accelerates from the lower corona reaching the local Alfvén speed at typical distances on the order of 10-20 Rs (solar radii). Past models show that most of the solar wind acceleration occurs inside the sub-Alfvénic region. One of the major science goals of the Parker Solar Probe (PSP) mission is to trace the flow of energy that heats and accelerates the solar corona and solar wind, determining the choice of the closest approach to the sub-Alfvénic distance. Recently, Parker Solar Probe (PSP) traversed regions of sub-Alfvénic solar wind near perihelia in encounters E8-E10, and it is evident that the observed properties of the solar wind in these regions are considerably different from the super-Alfvénic wind. For example, the velocity and magnetic field variability associated with switch-backs were not detected, there are changes in relative abundances and drift of α particles with respect to protons. We use the available data of the magnetic field, kinetic wave activity from FIELDS instrument, and ion velocity distributions (VDFs) from the sub-Alfvénic regions to construct 2.5D and 3D hybrid models of proton-αsolar wind and investigate the transfer of energy between the particle species and the fields. The models provide the full 3D VDF structure of the ions, mitigating instrumental line-of-sight limitations. By combining observational analysis with the modeling results we gain insights on the heating and acceleration processes of the solar wind and trace the flow of energy on kinetic scales in the sub-Alfvénic regions close to the Sun.

Strategies for determining the energy transfer rate in MHD turbulence: isotropy, anisotropy, and spacecraft sampling

Y. Wang, R. Chhiber, S. Adhikari, Y. Yang, R. Bandyopahdyay, M. A. Shay, S. Oughton, W. H. Matthaeus, & M. E. Cuesta

The Kolmogorov "4/5" law in hydrodynamics has been extended to many systems of interest including magnetohydrodynamics (MHD), and compressible flows of the magnetofluid and ordinary fluid types. It is understood that implementations may be limited by the quantity of available data and by the lack of turbulence symmetry. Assessment of the accuracy and feasibility of such Yaglom-like relations is most effectively accomplished by examining the von Karman-Howarth equation in increment form, a framework from which the Yaglom laws are derived as asymptotic approximations. Using this approach, we examine the context of Yaglom-like laws for incompressible MHD in some detail. The simplest versions rely on the assumption of isotropy and the presence of a long inertial range, while related procedures generalize the same idea to arbitrary rotational symmetries. The simplified third order law is used in single spacecraft measurements to study the heating and acceleration in solar wind. Conditions for obtaining ''exact'' values of the dissipation rate from these laws based on several sampling and fitting strategies are investigated using results from simulations. The questions we address are of particular relevance to the sampling of solar wind turbulence by one or more spacecraft.

Anisotropic compressible MHD turbulence and comparison with Parker Solar Probe data

S. Du, H. Li, Z. Gan, X. Fu, E. Conrad, J. Steinberg, & J. Broll

We present 3D compressible MHD simulations of magnetized plasma turbulence. Comparison with in-situ observation can be achieved by sampling the simulation domain along virtual spacecraft trajectories. We investigate turbulent Mach number, relative density fluctuation, and magnetic compressibility based on simulation data. We find that different trajectories can exhibit a wide range of turbulence properties that simply result from sampling. We also find a systematic dependence on the angle between the sampling trajectory and the background magnetic field, which reveals the anisotropic nature of turbulence. These findings have implications for interpreting solar wind turbulence observations. Preliminary results from corresponding statistical analysis of Parker Solar Probe data will also be presented.

Semi-Empirical Multi-base Exospheric Model of the Solar Wind

M. M. Martinovíc & K. G. Klein

The solar wind plasma is challenging to describe theoretically as it evolves from being fully collisional near the surface of the Sun to almost completely collisionless in the outer heliosphere. Exospheric theories provide a simplified description by setting a specific point in space—the exobase— where the plasma transitions from collisional to collisionless behavior, beyond which it is free to propagate with constant phase space density as described by Liouville's theorem. This paper revitalizes an unorthodox approach to exospheric modeling by setting velocity-dependent critical levels for escaping particles, rather than a single exobase. The previous work that uses similar methodology was limited by the Pannekoek-Rosseland description of ambipolar electric potential that scales with the gravitational potential and was not capable of producing observed solar wind velocities. By using the electric field derived from Parker Solar Probe observations, we show that solar wind velocities of up to 600 km/s can be described by a multi-base exospheric theory. Moreover, we demonstrate that proton beams, routinely observed in the solar wind, can emerge from this type of collisional filtering of ion population.

Local proton heating at different magnetic discontinuities in the solar wind

C. Gonzalez

Significant plasma heating is typically observed around magnetic discontinuities in the solar wind in a variety of plasma conditions. These include states characterized by balanced turbulence as well as by plasma and magnetic field fluctuations reminiscent of Alfven waves. In this work, the proton heating produced at different magnetohydrodynamic (MHD) discontinuities that occur in typical solar wind conditions is studied using Parker Solar Probe observations and 2D hybrid-kinetic simulations. We consider simulations of balanced turbulence that develop a variety of multi-scale structures such as fluxtubes, current-sheets and small-scale magnetic islands. We also consider simulations of a broad-band, parallel propagating Alfvénic wave packet that develops rotational discontinuities via phase-steepening. We focus our study on the local proton energization processes at coherent structures and their relation to plasma properties by comparing results from the two sets of simulations. By analyzing signatures of wave-particle interactions in phase space, we show that the partition of parallel and perpendicular proton heating depends on the type of discontinuity. These results contribute to the understanding of the role of different coherent structures in proton heating and energization, and of their implication on energy dissipation and particle energization in space plasmas.

Electron Distributions Observed by the Parker Solar Probe in the Near-Sun Fast Solar Wind

J. Halekas, P. Whittlesey, D. Larson, R. Livi, Berthomier, J. Kasper, T. Case, M. Stevens, S. Bale, M. Pulupa, & R. MacDowall

In the near-Earth interplanetary environment, the fast solar wind contains plasma with significantly different average properties than that observed in the slow wind. Notably, electron distributions in the fast wind at 1 AU characteristically have a more non-thermal (less Maxwellian) form. However, it remains unclear whether these observed differences result primarily from the different initial conditions in the corona or from the different evolution of the plasma during the expansion of the wind from its coronal source. For the majority of its mission to date, the Parker Solar Probe (PSP) has encountered slower wind near perihelion. However, on its tenth and eleventh orbits, PSP encountered relatively fast (>500 km/s) solar wind near perihelion. We investigate the characteristics of the electron distributions observed during these faster streams, including the properties of the core and supra-thermal populations, and compare to those observed in slower streams at comparable heliocentric distances. We also analyze the sunward electron deficit and its implications for the magnitude and structure of the ambipolar electric field in the near-Sun fast wind.

Observations of Sunward-Propagating Ion-Cyclotron Waves Below the Subalfvenic Surface

K. Paulson

During its 10th encounter of the near-Sun region, Parker Solar Probe crossed below the alfven surface for a period of several hours. While embedded in this subalfvenic flow, the spacecraft observed periods of ion-cyclotron wave activity on either side of an approach to the heliospheric current sheet. The propagation direction of this wave activity appears to alternate quasi-periodically between sunward and anti-sunward directions along the background magnetic field. Sunward-directed ion cyclotron waves are theorized to be a significant contributor to the heating of solar wind plasma through cyclotron resonances. We analyze the wave properties during this time period and the observed effects on local proton and alpha particle populations.

Solar Wind Protons and Alphas Properties Close to the Sun: New Parker Solar Probe Observations

P. Mostafavi, R. C. Allen, G. C. Ho, N. E. Raouafi, V. K. Jagarlamudi, S. Badman, J. Verniero, S. D. Bale, & J. C. Kasper

Protons and alpha particles are the two most abundant elements in the solar wind and usually have different velocities, densities, and temperatures. Investigating the alpha particle properties and how they differ from protons is essential in understanding the fundamental nature of solar wind. Parker Solar Probe (PSP) enables us to make direct in-situ measurements of the young solar wind closer than any spacecraft before. Initial statistical analysis of the PSP observations down to 0.09 au showed the super-acceleration of alpha particles close to the Sun, confirming the dependency of alpha-proton differential flow on solar wind speed and radial distance from the Sun (Mostafavi et al., 2022). Kasper et al. (2019) suggested that the preferential acceleration of the alpha particles occurs within the magnetically dominated region where the solar wind moves slower than Alfvén speed (i.e., Alfvénic critical surface). PSP crossed the Alfvén Surface during its 8th encounter and became the first spacecraft ever to sample the sub- Alfvénic solar wind close to the Sun. Since then, PSP has crossed/observed the sub-Alfvenic region multiple times during encounters 8-10. These unexplored regions enable us to investigate protons and alpha particles, and their properties close to the source of the solar wind acceleration for the first time. Here, we present the properties of protons and alphas close to the sun observed by PSP. We compare the properties of both protons and alphas in the sub-Alfvénic and super- Alfvénic regions. Further, we present the PSP connection to its source surface during these periods to understand the possible source of these variations.

The Near-Sun Turbulence Mediated by Parametric Decaying Instability of Alfvén Waves

Z. Gan, X. Fu, H. Li, S. Du, J. Steinberg, E. Conrad, & J. Broll

As the Parker Solar Probe (PSP) crossed the Alfvén surface, more near-Sun physics is to be revealed, e.g., the role of Parametric Decaying Instability (PDI) in energy dissipation and turbulence development. We examined the physical conditions within the Alfvén surface, especially the amplitude of fluctuations of magnetic fields and the plasma beta, which show that PDI of Alfvén waves is likely to occur. Aiming to study the signatures of PDI, we simulate the propagation of Alfvén waves under the near-Sun conditions in local periodic boxes and also in the context of global solar winds to address the effects of expansion. We study the variation properties of magnetic fields, velocity, and density associated with PDI, and compare them to PSP observations. Special attention is paid to the interplay between PDI and its turbulence background, i.e., its role in turbulence development, and vice versa the effects of turbulence background on the growth rate of PDI. This work is supported by the NASA/LWS project (Grant # 80NSSC20K0377).

The evolution of the magnetic field spectral index with heliocentric distance in the solar wind

J. R. McIntyre & C. H. K. Chen

The solar wind is known to contain a turbulent cascade and it is proposed that it plays a role in the heating and acceleration of the wind. An indicator of the nature of this turbulence is the magnetic field-perpendicular spectral index. Using data from the Parker Solar Probe (PSP) mission we are able to measure the spectral index across an unprecedented range of heliocentric distances. Common predictions for this index in incompressible magnetohydrodynamic (MHD) turbulence theory are -5/3, as predicted by models including the 1995 Goldreich-Sridhar anisotropic turbulence model, and -3/2, as predicted by models including the 2006 Boldyrev scale-dependent alignment model. At distances above approximately 0.6 au we find it to be consistent with -5/3 but find it to increase with decreasing radial distance to be consistent with -3/2 at distances below approximately 0.2 au, indicating unexpected changes in the turbulence close to the Sun. While Chen et al. 2020 also found this increase the data available at the time left it unclear as to whether the index would saturate as the Sun was approached, as is found to be the case in this work for the first time. By measuring also the 67ormalized cross-helicity and residual energy of the intervals used, and other properties of the solar wind known to vary with heliocentric distance, we separate the variation with distance from these parameters to present new insights into the physical mechanism responsible for this transition. Of these parameters the cross helicity was found to be the strongest candidate for the underlying parameter responsible for the transition.

P3-01
On the Markov property of the solar wind at subproton scales

S. Benella, M. Stumpo, G. Consolin, T. Alberti, & M. Laurenza

The interplanetary magnetic field carried out from the Sun by the solar wind displays fluctuations on a wide range of scales. While at large scales, say at frequencies below approximately 1 Hz, fluctuations display clear universal characteristics of fully developed turbulence with a well-defined Kolmogorov's like inertial range, the physical and dynamical properties of the small-scale regime as well as their connection with the large-scale ones are still a debated topic. In this work we investigate the near-Sun magnetic field fluctuations at sub-proton scales by analyzing the Markov property of fluctuations and recovering basic information about the nature of the energy transfer across different scales. By evaluating the Kramers-Moyal coefficients we find that fluctuations in the sub-proton range are well described as a Markovian process with Probability Density Functions (PDFs) modeled via a Fokker-Planck (FP) equation. Furthermore, we show that the shape of the PDFs is globally scale-invariant and similar to the one recovered for the stationary solution of the FP equation at different scales. The relevance of our results on the Markovian character of sub-proton scale fluctuations is also discussed in connection with the occurrence of turbulence in this domain.

P3-02

Does the magnetohydrodynamic turbulence close to the Sun evolve toward a hydrodynamic state at larger distances?

T. Alberti, S. Benella, G. Consolini, & M. Stumpo

The Parker Solar Probe mission provides a unique opportunity to characterize the topology of the solar wind at different heliocentric distances. Recent findings have shown the existence of a phase transition between singular and regular topological structures when moving away from the Sun. Here we provide, for the first time, a theoretical framework to explain this transition supported by observational results on the nature of the radial evolution of the magnetic and velocity field fluctuations across the inertial range. We find evidence of two different scenarios: a magnetically dominated up to 0.4 AU and a fluid–like at larger distances. The observed breakdown is the result of the radial evolution of intense stochastic magnetic field fluctuations that affects the distribution of inward/outward propagating fluctuations and the distribution between magnetic and kinetic fluctuations. The two scenarios can be reconciled with those of magnetohydrodynamic (MHD) and hydrodynamic (HD) pictures of turbulence in terms of the radial evolution of the Elsasser fields. The proposed picture is that of an evolving nature of the coupling between field components and not in terms of efficiency of the nonlinear term in generating a cascade mechanism. Our findings have important implications for turbulence studies and modeling approaches.

P3-03
Characterizing solar wind magnetic field fluctuations via entropy changes throughout the heliosphere: insights from Parker Solar Probe

M. Stumpo, G. Consolini, S. Benella, T. Alberti, & P. P. Di Bartolomeo

During the past fifty years, several properties of the solar wind magnetic field fluctuations have been investigated, by means of both spacecraft data and numerical simulations. From earlier space missions to more recent ones, a lot of attention has been paid to investigate the statistical properties of the different dynamical regimes in terms of statistics of increments, scaling law behavior, turbulence and intermittency and so on. While earlier space missions (e.g., Helios, Ulysses, ACE, Wind) allowed one to characterize the physical properties at MHD scales, the more recent ones (e.g., Cluster, MMS) can allow us to deeply investigate from sub-ion down to electron scales. Moreover, the recently launched Parker solar probe (PSP) can really be helpful to investigate how the dynamical properties of the solar wind evolve through the heliosphere (e.g. Chen et al., Alberti et al.). In the first part of this work, using the solar wind magnetic field data collected during the first and the second encounters of PSP to the Sun, we investigate how the properties of fluctuations evolve with the heliocentric distance by applying a generalization of Boltzmann H-theorem to open nonequilibrium systems, the Klimontovich' S-theorem (Klimontovich, 1987). Being a more proper characterization of the relative degree of order/disorder between the states of the system, the application of S-theorem allows us to better identify the physical quantity which acts as a control parameter. In the second part of the work, we discuss the results of an analysis of the complexity degree across the scales (from MHD to kinetic ones) in the case of a period when PSP is at 0.16 AU.

P3-04

Ion Acoustic Waves at the Interplanetary Shocks

M. Singh, F. Fraschetti, & J. Giacalone

Through various spacecraft observations, it is revealed that the ion-acoustic waves (IAWs) are commonly generated in the upstream, downstream, and ramp regions of the interplanetary (IP) shocks. It is also found, in contrast with theoretical predictions, that these IAWs have a finite growth rate although the electron-to-ion temperature ratio (T_e/T_i) is small. Thus, in order to explain these observations, we derived a linear dispersion relation of the IAWs at a shock profile prescribed by jump conditions. We investigate the conditions for the instability of IAWs in different regions of the IP shocks. The theoretical results are compared with the observed properties of the IAWs in different regions of the IP shocks. The effect of variation of the electron-to-ion temperature ratio (T_e/T_i), and the jumps in ion fluid velocities, ion number densities, and the electron temperatures across the shock is discussed. Thus, this study may be very helpful in understanding the generation of IAWs at the IP shocks.

P3-05

Langumuir-Slow Extraordinary Mode magnetic signatures: PSP observations and Vlasov-Maxwell simulations

A. Larosa

We present a statistical study of the Langmuir-Slow Extraordinary Mode, (sometimes called Zmode) observed by PSP, that reveals the presence of magnetic signatures for few tens of events out of thousands. A magnetic signature for these modes was inferred in previous work by looking at the polarization of the electric field, but actual and clear measurements are a novelty of the search-coil magnetometer (SCM) onboard PSP. We theoretically link their appearance to the intensity of the wave electric field and to the decrease of the refractive index due mainly to density inhomogeneities. The behaviour of the beam plasma interaction that generates these wave modes has been previously studied in the presence of density inhomogeneities with numerical simulations only in the electrostatic approximation (e.g. Kraff et al. 2013, ApJ). In order to study the full effect of the density fluctuations with respect to the presence of the magnetic signatures and to test our theoretical approach, we simulate the beam-plasma interaction in the electromagnetic case. Our study makes use of the fully kinetic Vlasov–DArwin (ViDA) (Pezzi et al. 2019, JPP) numerical code which is specifically designed to investigate small scales with high accuracy.

P3-06

Characterizing general discontinuity geometries and associated waves with improved minimum variance analysis

A. L. Brosius & J. L. Verniero

Parker Solar Probe is bringing us to previously unexplored regions of the heliosphere. Because space plasmas are not necessarily in equilibrium, plasma boundary crossings can provide a wealth of information about local and nonlocal processes. For example, wave analysis at planetary and interplanetary shocks indicates that shock features are more complex than previously thought. Waves at shocks can also help us understand nonlocal effects of space weather and boundary coupling. Minimum variance analysis (MVA) is a valuable method of characterizing wave geometry using relative component amplitudes. We have developed a novel algorithm, called Minerva, that improves upon traditional MVA by using an adaptive interval size, stringent planarity constraints, and polarization changes. Using Minerva with Venus Express and MMS spacecraft data has revealed wave boundary substructure in planetary foreshocks at Venus and Earth, respectively. These analyses demonstrate that Minerva can provide insights into identification of generalized discontinuity geometries and associated waves. We discuss application of the method to PSP data to characterize wave propagation across generalized discontinuities.

P3-07

Constant B and Spherical Polarization in the Expanding Solar Wind: 2D Hybrid Simulations of Alfvénic Turbulence

L. Matteini, A. Tenerani, M. Velli, A. Verdini, S. Landi, J. Stawarz, T. Horbury, & P. Hellinger

We present 2D simulations of Alfvénic turbulent fluctuations in the expanding solar wind. We focus on the generation of spherical polarisation of magnetic field fluctuations and the associated almost local constancy of the magnetic field intensity. We use 2D hybrid simulations of balanced Alfvénic turbulence, in the plane orthogonal to the main radial magnetic field B_0 coupled with solar wind expansion through the expanding box model. Although this is a reduced and simplified system (2D and vanishing cross-helicity) and our initial conditions do not capture the whole solar wind complexity, remarkably, these simulations are able to reproduce some of the main properties observed in the solar wind, such as: a) the plasma evolve towards a state of low total magnetic field fluctuations, $B \sim$ const., and a distinct spherical polarisation emerges as $\delta B/B$ increases due to expansion; b) this is achieved by the generation of field aligned radial fluctuations that suppress local $|\mathbf{B}|$ variations, leading to the spontaneous generation of one-sided fluctuations in the radial component B_R; c) when, due to expansion, the plasma reaches the regime $\delta B \sim B$, this dynamics produces large **B** deflections from the radial, leading to switchback-like local reversals of the magnetic field polarity; d) the overall evolution of spherical expansion and the scaling of the fluctuations found in the simulations agree well radial profiles observed in the solar wind, reaching a saturation of the relative amplitude of B_R fluctuations and of the level of spherical polarisation at larger distance, consistent with the data.

P3-08

Relative heating of ions and electrons in the young solar wind due to turbulent dissipation mediated by Landau damping

N. Shankarappa, K. G. Klein, & M. Martinovic

The relative heating of ions and electrons due to turbulent dissipation plays a crucial role in the thermodynamics of the solar wind and other plasma environments. Landau damping is one plausible mechanism for damping of the turbulent cascade. Parker Solar Probe (PSP) observations find that plasma beta is not significantly smaller than unity from the first several encounters, implying that Landau damping may be relevant. We consider a particular theoretical model, developed in Howes et al 2008, to determine relative heating rates as a function of observable plasma parameters when dissipation is mediated through Landau damping. The model considers a steady-state cascade of wavevector anisotropic turbulent fluctuations from the inertial to dissipation range, connecting the MHD and kinetic descriptions. Using magnetic field and thermal plasma observations from first two PSP perihelion, we distinguish high frequency circularly polarized waves from the low frequency turbulence and apply the cascade model to spectra constructed from the latter. We characterize how the relative heating rates vary as a function of radial distance, plasma conditions, and compare these results to previous analysis of heating rates using PSP observations, illuminating how energy is partitioned in the young solar wind. We find that the model efficiently and accurately describes the observed power spectrum over significant regions of encounters 1 and 2.

P3-09
Particle Acceleration in Magnetic Reconnection

H. Che

How magnetic reconnection efficiently produces a huge number of mildly relativistic energetic particles is an outstanding problem in solar physics and heliophysics. In particular, three major problems in solar particle acceleration have to be addressed: 1) the development of power-law energy spectra for both electrons and ions; 2) the "big number problem" of electrons. Recent observations discovered that the time to accelerate electrons to a power-law energy distribution in solar flares can be shorter than 50 ms while nearly the total number of electrons in the current sheet is accelerated in 1000s. 3) Observations suggest that the acceleration process of ions is related to the electrons'. In this talk, I will present a novel acceleration mechanism in magnetic reconnection. I will show how the velocity shear stored naturally in force-free currents of solar flares can drive an electron Kelvin-Helmholtz instability (EKHI) during magnetic reconnection. The EKHI efficiently accelerates electrons to a power-law energy spectrum with an index comparable to the observations in a few tens of ion gyro-periods (~ 0.1 ms for solar corona plasma). With the proceeding of reconnection, the EKHI induced Alfvenic turbulence can accelerate ions to broken power-law energy spectra.

P3-10
Localized sources of kinetic Alfvén waves in the near-sun solar wind

D. Malaspina, S. D. Bale, J. W. Bonnell, T. D. de Wit, K. Goetz, R. J. MacDowall, & Marc Pulupa

The near-Sun solar wind is full of Alfvénic fluctuations, including the large-scale magnetic field reversals known as switchbacks. At scale sizes at and below the ion inertial length, Alfvénic fluctuations become dispersive, supporting electric fields parallel to the background magnetic field. For solar wind plasma conditions, these dispersive fluctuations are kinetic Alfvén waves. Kinetic Alfvén waves are ubiquitous in the solar wind at 1 AU, and are hypothesized to be a critical component of turbulent energy dissipation. By examining electric and magnetic field data from Parker Solar Probe, we identify kinetic Alfvén waves in the near-Sun solar wind, quantify their occurrence and variability, and determine that they preferentially occur with orders of magnitude higher amplitude in some regions of solar wind compared to other regions. This correlation indicates that kinetic Alfvén waves, and possibly their ability to influence turbulent energy dissipation, become less homogeneously distributed in regions close to the Sun.

P3-11

Scale-Dependent Alfvenicity of Super-Alfvenic and Sub-Alfvenic Solar Wind Observed by Parker Solar Probe

P. Thepthong, P. Pongkitiwanichakul, D. Ruffolo, R. Bandyopadhyay, W. H. Matthaeus, & T. N. Parashar

Alfvénicity is a well-known property of much of the solar wind, in which magnetic and velocity fluctuations are highly correlated. Data from the Parker Solar Probe enable us to probe Alfvénicity closer to the Sun than before, in both super-Alfvénic and sub-Alfvénic solar wind, using 2nd-order structure functions and other quantities derived from magnetic and velocity increments as functions of time lag. We introduce a method to estimate and subtract noise from the velocity structure function, allowing estimates of Alfvénicity to be extended to smaller scales, confirming a general pattern that the Alfvén ratio and residual energy increase for decreasing scale size. We also identify the frequency that contributes most to the 2nd-order structure function for a given time lag, providing a way to directly compare functions of time lag and Fourier spectra.
This research has been supported in part by grant RTA6280002 from Thailand Science Research and Innovation, by grant RGNS 63-045 from the Office of the Permanent Secretary, Ministry of Higher Education, Science, Research and Innovation, and the Parker Solar Probe mission under the ISOIS project (contract NNN06AA01C) and a subcontract to University of Delaware from Princeton University.

P3-12

JHU APL Parker Two Conference Abstract - Poster Session Title: Characterization of Strahl Electron Scattering in the Solar Wind Observed by PSP

O. Romeo, D. Larson, P. Whittlesey, A. Rahmati, R. Livi, & S. Badman

We aim to investigate the mechanisms that control solar wind acceleration and energy balance in the near-Sun environment through Parker Solar Probe (PSP) in-situ observations. These processes are theorized to be strongly influenced by the solar wind heat flux and ambipolar electric field, both of which are dependent on electron velocity distribution functions (VDFs). While the electron core and halo components of the distribution are nearly isotropic, the strahl is represented by a beam population that is more anisotropic and typically magnetic field aligned. Due to this asymmetry and non-thermal nature, the electron strahl dominates the overall heat flux in the near-Sun environment. The population's beam-like shape can be modified from adiabatic focusing by the magnetic field or electron pitch-angle scattering due to Coulomb collisions and/or plasma instabilities. As PSP is the closest spacecraft to ever orbit the Sun, we can study the evolution of the electron strahl over a large range of heliocentric distances under varying solar wind conditions. The onboard Solar Probe ANalyzer Electron (SPAN-E) instruments have measured electron energy distributions at heliocentric distances between 13 and 80 solar radii in the inner heliosphere. We perform fits on these distributions using SPAN-E and FIELDS data to obtain the strahl direction and angular width for energies between 100 and 1200 eV and orbital encounters 1-9. It is important to note that the strahl direction is determined independently of the magnetic field, which can allow an alternative method for inter calibration with the magnetic field instrument. To characterize the causes of strahl scattering, we also obtain measurements of the electron density, electron temperature, and solar wind velocity from these fits to compare with the strahl angular widths. We find the strahl beam to narrow with increasing electron energy. Additionally, the strahl width is dependent on heliocentric distance, heliospheric current sheet distance, SW velocity, electron density, and electron collisional age. From these results, an empirical model of the strahl is developed, primarily involving effects from Coulomb collisions and wave scattering.

P3-13

Parker Solar Probe Observations of Turbulence in the Near-Sun Solar Wind and Solar Corona

C. Chen

Since its launch, Parker Solar Probe has allowed us an unprecedented opportunity to understand how solar wind turbulence works up close to the Sun, and the role that it plays in shaping the solar wind that we see. In this talk, I will describe what we have learnt so far from the first 10 orbits of PSP, but in particular I will focus on the most recent orbits where PSP crossed into sub-Alfvenic wind and saw clear changes in the turbulence properties. In general we have seen that getting closer to the Sun the turbulence amplitudes increase, the imbalance increases, the compressibility decreases, and all spectra take a $-3/2$ index - however, within the sub-Alfvenic wind many of these trends have reversed or changed, revealing interesting differences in the coronal turbulence. I will also discuss these results in the context of solar wind acceleration - in general, PSP has shown that the properties of the solar wind fluctuations quantitatively match expectations for a wave/turbulence-driven solar wind, for both fast and slow open field regions, although in streamer belt wind additional processes may be required. The recent encounters allow these models to be tested within the magnetically-dominated corona itself for the first time, in a variety of types of wind, and the implications of this will be discussed.

P3-14
Parker Solar Probe measurements of the solar wind proton kinetic break scale

S. Lotz, A. E. Nel, R. T. Wicks, O. W. Roberts, N. E. Engelbrecht, R. D. Strauss, G. J. J. Botha, E. Kontar, & S. D. Bale

Using the fifth PSP encounter observations, we examine the radial dependence of the solar wind proton kinetic break scale. We find that this break scale is well described by the proton cyclotron resonance with Alfvénic waves. The break frequency compares well with the power law estimation of previous studies, and shows an increase with a decrease in heliocentric distance. For the spectral index of the inertial turbulence range we find a very weak radial dependence, and considering the associated uncertainties the spectral index is consistent with either the Kolmogorov or Iroshnikov-Kraichnan value. For the index of the proton dissipation range, however, we find a steeper index at the smallest radial distance (close to the Sun) and a gradual flattening as the turbulence evolves away from the Sun.

P3-15
The turbulent properties of the sub-Alfvénic solar wind measured by the Parker Solar Probe

L.-L. Zhao, G. P. Zank, D. Telloni, M. Stevens, J. C. Kasper, & S. D. Bale

For the first time, Parker Solar Probe observed sub-Alfvénic solar wind where the solar wind bulk speed drops below the local Alfvén speed for an extended period of time. Here, we report on the turbulent properties of the sub-Alfvénic region. We analyze the turbulence correlation length and the energy transfer and compare the results with nearby super-Alfvénic regions. Since the Alfvén speed is larger or comparable to the solar wind speed in the intervals studied, we use a modified Taylor's hypothesis to account for wave propagation. We find that the wave propagation speed affects the analysis of correlation lengths of the forward and backward propagating modes. In the sub-Alfvénic region, the correlation length of the z- mode is shorter than that of the outward propagating z+ mode, although the correlation time of z− mode is about 10 times larger than that of z+ mode. For the energy transfer, we use both incompressible and compressible formulations to calculate the energy flux based on third-order structure functions. The incompressible energy cascade rates for the forward and backward propagating modes are computed separately using the modified Taylor's hypothesis. The averaged compressible cascade rate is higher in the sub-Alfvénic interval than the nearby downstream super-Alfvénic region, which may be due to the lower fluctuation amplitude in the latter super-Alfvénic interval. Longer incursions of PSP in the sub-Alfvénic winds in the future will give us better statistics.

P3-16

Verification of von Karman similarity hypothesis using Elsässer correlation functions from ACE data

S. Roy, R. Chhiber, S. Dasso, M. E. Ruiz, & W. H. Matthaeus

A major development underlying hydrodynamic turbulence theory is the von Karman similarity hypothesis, which states that the two-point correlation functions undergo a continuous transformation based on a universal functional form and a re-scaling of energy and a characteristic length. The analogous similarity property has not been explicitly verified in solar wind turbulence. Here, we analyze a large ensemble of Elsässer correlation functions computed from ACE data at 1 AU, to examine whether the two-point correlation functions undergo a collapse to a similarity form anticipated from von Karman's hypothesis applied to weakly compressive magnetohydrodynamic turbulence. This provides for the first time a firm empirical basis for employing the similarity decay hypothesis for Elsässer correlations, which represent the incompressive turbulence cascade. This approach is of substantial utility in space turbulence data analysis, and adopting von Karman-type heating rates in subgridscale and dynamical modeling. An extension of this study using PSP data is under progress, which will allow us to investigate the validity of this hypothesis as a function of heliocentric distance.

P3-17

Applying a Scale-Filtered Correlation to Faraday Cup Data: A Frequency-and-Velocity Resolved Method for Characterizing the Resonant Impact of Waves

K. Klein

Waves are observed in the turbulent plasmas and near structures such as shocks and sites of magnetic reconnection. Characterizing the role these waves play in the acceleration and heating of the solar wind in the near-Sun environment is one of the open science questions Parker Solar Probe was designed to address. In this work, we describe an analysis technique, the scale-filtered correlation, that combines velocity-resolved measurements of the fluctuating particle distribution function with time-filtered measurements of the magnetic field to identify the presence and action of these waves. Such a technique will identify what role wave-like fluctuations play in the solar wind and other plasma systems, taking advantage of the rich sets of velocity distribution function measurements available from spacecraft missions, and is complementary to the 'traditional' field particle correlation method. If waves are present, our technique can distinguish between various theoretical candidates which have been proposed through a comparison to the appropriate dispersion relations. We first demonstrate the technique on numerical simulations, and then apply the method to in situ observations of particle distributions from SWEAP/SPC and magnetic fields from the Fields magnetometers.

P3-18

PSP and Wind Observations of Ion-Scale Cyclotron Waves and Their Relationship with Solar Wind Ions

L. K. Jian, S. Boardsen, M. Stevens, L. Ofman, H. Y. Wei, J. Verniero, B. L. Alterman, & D. Larson

Using the high-cadence magnetic field data from the Parker Solar Probe (PSP) and Wind missions, we have done extensive surveys of ion-scale cyclotron waves in 2018 – 2021. These circularly-polarized waves are in the frequency range near the local proton and alpha-particle cyclotron frequencies. They are left-hand or right-hand polarized in the spacecraft frame, propagating in the direction near the local magnetic field. Using the solar wind proton and alpha particle data from the PSP and Wind missions, we study how the wave properties (occurrence rate, wave power, wave frequency, etc.) vary with solar wind ion velocity distributions, which are quantified by ion parameters such as the proton and alpha particle drifts as well as the temperature anisotropies of each ion populations. From the large database of wave events, we statistically study the radial evolution of these wave properties and ion parameters in the inner heliosphere, covering from about 0.08 AU (about 17 solar radii) to 1 AU. Our investigation using the solar wind plasma as a natural laboratory would improve the understanding of wave-particle interactions at ion kinetic scales.

P3-19
MHD turbulent power anisotropy in the inner heliosphere

L. Adhikari, G. P. Zank, L.-L. Zhao, & D. Telloni

We study anisotropic magnetohydrodynamic (MHD) turbulence in the slow solar wind measured by Parker Solar Probe (PSP) and Solar Orbiter (SolO) during its first orbit from the perspective of variance anisotropy and correlation anisotropy. We use the Belcher & Davis (1971) approach and a new method that first decomposes a vector into parallel and perpendicular vectors. On using both methods, we calculate the perpendicular/transverse and parallel turbulence energy and correlation length relative to the mean magnetic field direction. The parallel turbulence energy is regarded as compressible turbulence, and the perpendicular turbulence energy as incompressible turbulence, either 2D or Alfvénic. We obtain the observed 2D and slab energy in forward and backward propagating modes, fluctuating magnetic and kinetic energies, normalized cross-helicity and residual energy, Alfvén ratio, and the 2D and slab correlation length corresponding to the Elsässer energies, magnetic field fluctuations, velocity fluctuations, and the residual energy in regions for which the angle θ_UB between the mean solar wind flow speed and mean magnetic field satisfies either 65 deg < θ_UB < 115 deg, or 0 deg < θ_UB < 25 deg (155 deg < θ_UB < 180 deg), respectively. We find that the 2D turbulence component is not typically observed by PSP near the perihelion, but the 2D component dominates turbulence in the inner heliosphere. We compare the detailed theoretical results of a nearly incompressible (NI) MHD turbulence transport model (Zank et al. 2017) with the observed results of PSP and SolO measurements, finding good agreement between them.

P3-20
Isotropization and Evolution of Energy-Containing Eddies in Solar Wind Turbulence: Parker Solar Probe, Helios 1, ACE, WIND, and Voyager 1

M. E. Cuesta, R. Chhiber, S. Roy, J. Goodwill, F. Pecora, J. Jarosik, W. H. Matthaeus, T. N. Parashar, & R. Bandyopadhyay

We examine the radial evolution of correlation lengths perpendicular and parallel to the magnetic field, computed from solar wind magnetic-field data measured by Parker Solar Probe (PSP) during its first eight orbits, Helios 1, Advanced Composition Explorer (ACE), WIND, and Voyager 1 spacecraft. Correlation lengths are grouped by an interval's alignment angle defined as the angle between the magnetic-field and solar wind velocity vectors. The parallel and perpendicular angular channels are 0 to 40 degrees and 50 to 90 degrees, respectively. We observe an anisotropy in the inner heliosphere within 0.4au, with the perpendicular correlation length greater than the parallel correlation length by a factor of 1.3 at 0.1au. The anisotropy reduces with increasing heliocentric distance and the correlation lengths roughly isotropize within 1au. Results from ACE and WIND support a reversal of the anisotropy, such that the perpendicular correlation length is smaller than parallel correlation length by a factor of 0.75 at 1au with no condition on solar wind speed. This study provides insights regarding the radial evolution of turbulence in the heliosphere. We also emphasize the importance of tracking the changes in sampling direction in PSP measurements as the spacecraft approaches the Sun, when using these data to study the radial evolution of turbulence. These classifications can prove to be vital in understanding the more complex dynamics of the solar wind in the inner heliosphere and can assist in improving related simulations.

P3-21

Ion Heating by Compressible Turbulence in the Solar Wind near the Sun

X. Fu, Z. Gan, S. Du, H. Li, E. Conrad, & J. Steinberg

The solar wind turbulence becomes more compressible as it gets closer to the Sun, characterized by enhanced density fluctuations, as seen by the Parker Solar Probe. Increased compressibility is a possible consequence of lower plasma beta and higher turbulent Mach number closer to the sun. The density fluctuations, especially those associated with compressible waves, are subject to kinetic damping that can contribute to heating of ions in the solar wind. In this study, we carry out 3D hybrid simulations (kinetic ions and fluid electrons) of low-beta compressible turbulence in near-the-Sun region. We show that density fluctuations can be generated by nonlinear interactions of incompressible Alfven waves, as well as the parametric decay instability of Alfven waves. We investigate the correlation between density fluctuations and ion heating in the processes. We are also trying to identify observational evidence of these processes in PSP data and compare them to simulation results. The study will advance our understanding of the role of compressible turbulence in solar wind heating and acceleration.

P3-22

Sunward, Anti-Sunward, and Counter-Streaming Whistler Waves in Magnetic Holes of the Solar Wind

S. Karbashewski, O. Agapitov, & H. Y. Kim

Observations of the young solar wind at ~35.7 $R_\odot$ by the Parker Solar Probe mission reveal the existence of intensive plasma wave bursts with frequencies between 0.02–0.20 f_{ce} (tens of Hz to ~300 Hz) in the spacecraft frame. The bursts are collocated with local minima of the magnetic field magnitude on boundaries of magnetic switchbacks – structures that contain rapid deflections of the magnetic field direction. The observed waves are identified as electromagnetic whistler waves. The observed whistlers propagate in Sunward [1], anti-Sunward [2], and counter-streaming orientations during different burst events. Being generated in the solar wind flow the waves experience significant Doppler downshift (Sunward) from ~0.2–0.4 f_{ce} down to less than 0.1 f_{ce} and upshift (anti-Sunward) from ~0.2–0.4 f_{ce} up to ~0.5 f_{ce} in the spacecraft frame. Their peak amplitudes can be as large as 1 to 4 nT, where such values represent up to 20% of the background magnetic field and are largest when parallel to the background magnetic field but also appear at oblique angles up to ~60°. We have evaluated the properties of these waves and find (i) the generation of these waves is supported by a modified electron distribution with increased transverse temperature anisotropy inside the magnetic holes; and (ii) the Sunward propagating whistler waves efficiently interact with the high energy solar wind electrons (up to 1 keV) scattering the strahl population of suprathermal electrons into a halo population [3] due to the most efficient cyclotron resonance interaction.

[1] O.V. Agapitov, T. Dudok de Wit, F.S. Mozer, et al., Astrophys. J. Lett. 891, L20 (2020)
[2] C. Cattell, A. Breneman, J. Dombeck, B. Short, et al., Astrophys. J. Lett. 911, L29 (2021)
[3] G. T. Roberg-Clark, O. Agapitov, J. Drake, and M. Swisdak, Astrophys. J. 887, 190 (2019)

P3-23

Properties of low-turbulence, quiescent solar wind and the unique particle and wave properties found within

B. Short

Data from the Parker Solar Probe mission has revealed the existence of quiescent solar wind regions: that is, regions of solar wind with very low amplitude turbulent magnetic field fluctuations. Originally identified in a survey of harmonic plasma waves near the electron cyclotron frequency (f_{ce}), these regions are associated with several modes of plasma waves. It is observed that these harmonic f_{ce} waves occur exclusively within these quiescent regions, and therefore can be used as markers for quiescent regions. A blob-finding algorithm is used to identify near-f_{ce} harmonic wave intervals, and thereby locate quiescent regions in Encounters 1-6. We carry out a superposed epoch analysis of these quiescent regions, and compare their bulk solar wind properties with regions of solar wind just before and after. It is found that the quiescent regions contain minimal magnetic field variation relative to solar wind before and after and are entirely devoid of magnetic switchbacks. Moreover; in the quiescent wind, the magnetic field closely follows the theoretical Parker Spiral, while neighboring regions just outside prefer more radial orientations, providing a clear picture about the magnetic geometry of these regions. Quiescent regions also show significant ion temperature anisotropy enhancements (15-25%) relative to the non-quiescent solar wind. The properties of quiescent solar wind regions provide clues about the solar origins of these regions, and by quantifying the properties of near-Sun solar wind devoid of switchbacks, these regions can bound the role that switchbacks play in the regulation of solar wind temperature.

P3-24
Field Particle Correlation with PSP Electron Data

D. McGinnis

Turbulent heating likely plays a significant role in the evolution of the solar wind, but the precise mechanisms by which large scale electromagnetic fluctuations are damped to energize plasma particles, and the conditions under which they occur, remain largely unknown. Several mechanisms have been proposed, and Parker Solar Probe (PSP) provides the ideal platform for seeking confirmatory observational evidence in the young solar wind where heating must still be occurring. Using measurements of the velocity distribution function and the electric field, the field particle correlation (FPC) technique generates characteristic signatures of particle energization which can be used to identify the mechanism of heating. Here we present the application of the FPC technique in a search for evidence of electron Landau damping in PSP SPAN-E data. We discuss data selection criteria, particularly in the context of obtaining measurements of the parallel electric field and SPAN-E distribution functions in its various instrument operational modes and present the results of our analysis.

P3-25

Characteristics of Multi-Scale Current Sheets in the Solar Wind at 1 AU Associated with Magnetic Reconnection and the Case for a Heliospheric Current Sheet Avalanche

S. Eriksson, M. Swisdak, J. M. Weygand, A. Mallet, D. L. Newman, G. Lapenta, L. B. Wilson III, D. L. Turner, & B. Larsen

Wind spacecraft measurements are analyzed to obtain a current sheet (CS) normal width d_{cs}-distribution of 3374 confirmed magnetic reconnection exhausts in the ecliptic plane of the solar wind at 1 AU. The d_{cs}-distribution displays a nearly exponential decay from a peak at d_{cs}=25 *di* to a median at d_{cs}=85 di and a 95th percentile at d_{cs}=905 *di* with a maximum exhaust width at d_{cs}=8077 *di*. A magnetic field Θ-rotation angle distribution increases linearly from a relatively few high-shear events toward a broad peak at $35^{o}<\Theta<65^{o}$. The azimuthal φ-angle of the CS normal direction of 430 thick $d_{cs}\geq500$ *di* exhausts are consistent with a dominant Parker-spiral magnetic field and a CS normal along the ortho-Parker direction. The CS normal orientations of 370 kinetic-scale $d_{cs}<25$ *di* exhausts are isotropic in contrast, and likely associated with Alfvénic solar wind turbulence. We propose that the alignment of exhaust normal directions from narrow $d_{cs}\sim$15-25 *di* widths to well beyond $d_{cs}\sim$500 *di* with an ortho-Parker azimuthal direction of a large-scale HCS is a consequence of CS bifurcation and turbulence within the HCS exhaust that may trigger reconnection of the adjacent pair of bifurcated CSs. The proposed HCS-avalanche scenario suggests that the underlying large-scale parent HCS closer to the Sun evolves with heliocentric distance to fracture into many, more or less aligned, secondary current sheets due to reconnection. A few and wide exhaust-associated HCS-like CSs could represent a population of HCSs that failed to reconnect as frequently between the Sun and 1 AU as other HCSs.

P3-26

Empirical double expansion solar wind model using Parker Solar Probe and Helios measurements

J.-B. Dakeyo

Classifying solar wind observations by HELIOS in several populations sorted by bulk speed, has revealed constant and slight accelerations of the wind as it expands away from the Sun in the 0.3 – 1 AU radial range. The faster the wind is, the smaller is this acceleration. Recent measurements from Parker Solar Probe (PSP), which have been added closer to the Sun, show that the HELIOS populations can nicely be extrapolated back to the Sun. For instance, the well-established bulk speed/proton temperature (u, Tp) correlation, together with the acceleration of the slowest winds, are clearly visible in the PSP data. Based on the previous classifications, we present results of empirical Parker-like models for which the solar wind undergoes a double expansion: isothermal in the corona, then polytropic after the sonic point, with polytropic indices corresponding to the observed temperature gradients. Such models are useful because they allow to establish a differentiated energy balance for the heating of the wind and for the acceleration separately.

P3-27

Taylor microscale and effective Reynolds number near the Sun from PSP

C. Phillips

In classical hydrodynamic turbulence, the Taylor microscale represents the characteristic scale of the smallest coherent structures not dominated by dissipative forces. While the solar wind is weakly collisional, it can be approximated as a magnetohydrodynamic (MHD) fluid at scales much larger than the kinetic scale. The MHD methodologies can be applied to the solar wind in this regime. During its first encounter, NASA's Parker Solar Probe (PSP) recorded high cadence magnetic field data in the young solar wind, approaching closer to the Sun than any previous spacecraft. Here, we use this data to calculate the Taylor microscale and effective Reynolds number at an average radius of 36.3 Rs. We find the Taylor microscale and Reynolds number to be smaller than near-Earth values, implying a less developed solar wind with very small-scale dissipative processes near the Sun.

P3-28

What is the role of whistler waves in shaping of the solar wind electron distribution function between 0.17 and 1 AU?

L. Colomban, M. Kretzschmar, V. Krasnoselskikh, C. Froment, M. Maksimovic, D. Graham, Y. Khotyainsev, L. Berĉiĉ, O. Agapitov, M. Berthomier, & T. Dudok de Wit

In the solar wind, the electron distribution function is composed of different populations (core, halo, strahl) whose proportions surprisingly varies as a function of distance. Whistler waves, electromagnetic waves around 0.1 fce, are thought to play an important role in shaping the electron distribution function, in particular by diffusing particles from the energetic populations to the less energetic ones. However, there are no clear evidence that whistler waves are sufficiently present nor that the diffusion is effectively at work. To assess the role of whistler waves, we first analyzed the data of the Solar Orbiter and Parker Solar Probe mission between 0.17 and 1 AU to detect and characterize the waves in the plasma frame, as a function of distance and solar wind velocity. Next, we computed the scattering coefficients for different waves properties, which allows us to determine which parameters are efficient for the scattering and the evolution of the diffusion between 0.17 and 1 AU.

P3-29

Evolution of magnetic turbulence in the inner heliosphere - Observations from PSP and SolO ranging from the Alfvén region up to 1 AU

N. Sioulas

This study investigates the evolution of magnetized solar wind turbulence by using a merged Parker Solar Probe (PSP) and Solar Orbiter (SolO) dataset that spans the entire inner heliosphere covering heliocentric distances between $0.06 \lesssim R \lesssim 1$ au. The radial evolution of the magnetic field spectral index is examined by fitting the spectrum as a function of scale, normalized in units of either the radially dependent ion inertial scale d_i or the ion gyroradius ρ_i. Scale-dependent variation of the spectral index, even within the inertial range, is observed. That is, progressively steeper spectra are recovered with the involvement of smaller spatial scale. This result suggests the violation of self-similarity, and is indicative of a scale dependent energy transfer rate. More importantly, our results indicate that the steepening of the magnetic spectrum observed by recent studies may be attributed to the fact that ion scales migrate to smaller frequencies with increasing heliospheric distance. It is shown that when the magnetic spectrum is fitted within a constant range in the wavenumber domain normalized in units of ion inertial length, only a moderate evolution of the magnetic spectral index is observed. By examining the rate of magnetic energy decay, we show that the inertial range is built from the smaller to the largest scales and expands to larger scales as the solar wind propagates outwards.

Switchbacks with Parker Solar Probe

R. Laker

Switchbacks are sharp reversals in the magnetic field direction and have been observed with earlier spacecraft close to the Sun (Helios) and at high latitudes (Ulysses). They are folds in the magnetic field, rather than changes in magnetic polarity and are Aflvenic structures where a deflection in the magnetic field creates a spike in the velocity. Switchbacks have become an active area of research following their dominance of the early Parker Solar Probe measurements in 2018. Their high occurrence rate, along with an enhancement in proton velocity, means that they could be an important part of solar wind acceleration and heating. This led to several theories regarding their formation, which can be broadly grouped into in-situ versus ex-situ generation. In this talk I will attempt to summarise the current state of switchback research, for both the in-situ observations and their generation mechanisms, with an emphasis on how they link together. Finally, I will explore what the community should strive to achieve in order to further our understanding of these complex structures.

Magnetic Switchback Occurrence Rates in the Inner Heliosphere: Parker Solar Probe and 1 au

F. Pecora, W. H. Matthaeus, L. Primavera, A. Greco, R. Chhiber, R. Bandyopadhyay, & S. Servidio

The subject of switchbacks, defined either as large angular deflections or polarity reversals of the magnetic field, has generated substantial interest in the space physics community since the launch of Parker Solar Probe (PSP) in 2018. Previous studies have characterized switchbacks in several different ways, and have been restricted to data available from the first few orbits. Here, we analyze the frequency of occurrence of switchbacks per unit distance for the first full eight orbits of PSP. In this work, events that reverse the sign of the magnetic field relative to a regional average are considered switchbacks. A significant finding is that the rate of occurrence falls off sharply approaching the sun near 0.2 au ($\sim$ 40 $R_\odot$), and rises gently from 0.2 au outward. The analysis is varied for different magnetic field cadences and for different local averages of the ambient field, confirming the robustness of the results. We discuss implications for the mechanisms of switchback generation. A publicly available database has been created with the identified reversals.

Statistical Properties of the Switchbacks Observed During the First 10 Encounters of Parker Solar Probe

V. K. Jagarlamudi, N. E. Raouafi, S. Bourouaine, P. Mostafavi, A. Larosa, & J. C. Perez

The Parker Solar Probe (PSP) spacecraft, launched to reveal the secrets of the Sun by measuring the solar wind plasma parameters as close as 10 solar radii, has revealed the ubiquitous presence of large magnetic field deflections. These structures can be identified as the deflections from the parker spiral and are usually referred to as Switchbacks (SB). Using the first 10 encounters data from the SWEAP and FIELDS instrument suite onboard PSP, we investigated the statistical properties of the SB structures between 13 and 70 Solar Radii. We present how the SB's are distributed radially and how the plasma properties of the SB regions vary from the non-SB regions. Using the observed SB properties, we discuss the requirements for SB generation, their possible source of origin, and their generation mechanisms. In our study, we propose the possible reasons behind the predominant observation of SB's in the PSP data compared to other spacecraft data.

Switchbacks, microstreams and broadband turbulence in the solar wind

T. Horbury, S. D. Bale, D. Larson, M. D. McManus., S. Livi, J. Kasper, R. Laker, L. Matteini, N. E. Raouafi, M. Velli, L. D. Woodham, & T. Woolley

Switchbacks are a striking phenomenon in near-sun coronal hole flows, but their origins, evolution and relation to the broadband fluctuations seen farther from the Sun are unclear. We aim to determine the scales of variability of switchbacks and, using measurements of the same solar wind stream at two distances, investigate statistically if switchback variability is related to the larger scale properties of fluctuations near 1 AU. We use the near-radial line-up of Solar Orbiter and Parker Solar Probe during the latter's sixth perihelion encounter in September 2020 when both spacecraft were in wind from the Sun's Southern polar coronal hole. Using the measured solar wind speed, we map measurements from both spacecraft to the source surface and consider the variations with source Carrington longitude of parameters such as velocity, density, composition and fluctuation levels. The patch modulation of switchback amplitudes at Parker at 20 solar radii was associated with speed variations similar to microstreams and corresponds to solar longitudinal scales of around 5-10 degrees. At Orbiter near 1 AU, this speed variation was absent, probably due to interactions between plasma at different speeds during their propagation. The alpha particle fraction, which has recently been shown to vary with patches at 20 solar radii, varied in the same way at 1 AU. The switchback modulation scale of 5-10 degrees, corresponding to a temporal scale of several hours at Orbiter, was present as a variation in the average deflection of the field from the Parker spiral. While limited to only one stream, these results suggest that in coronal hole flows, switchback patches are related to microstreams, perhaps associated with supergranular boundaries or plumes. Patches of switchbacks appear to evolve into large scale fluctuations, which might be one driver of the ubiquitous turbulent fluctuations in the solar wind.

Size Scale and Occurrence Rate of Coronal Jets and Similar Solar Features: Possible Solar Sources for Magnetic Switchbacks

A. C. Sterling & R. L. Moore

Large-scale solar eruptions, such as those producing typical solar flares and coronal mass ejections (CMEs), typically begin with the eruption of a highly sheared magnetic field structure or flux rope above a photospheric magnetic neutral line, often carrying a typical chromospheric-material filament. More recently it has been found that many coronal jets begin with eruption of a “minifilament,” similar to but of smaller size scale than typical filaments, and which erupt from shorter neutral lines than those of typical filaments. Thus, coronal jets appear to be scaled-down versions of the same type of eruptive process that makes large-scale eruptions. Coronal jets, however, occur much more frequently than large scale eruptions. Here we revisit our previous suggestion (Sterling & Moore 2016, Sterling et al. 2020) that large-scale eruptions and coronal jets fit on a power-law distribution of occurrence rate verses filament size. In that work we argued that this distribution may continue to the size scale of spicules, under the hypothesis that some fraction of spicules are due to eruptions of “microfilaments” that are still much smaller than, and which erupt much more frequently than, the minifilaments that erupt and produce coronal jets. We emphasize that jet-producing erupting minifilaments are of size scale about 10^4 km, which is comparable to, albeit about a factor of three smaller than, the size of a typical supergranule. We would expect a hypothetical spicule-producing erupting microfilament to be of size scale a few x10^2 km, and thus perhaps slightly smaller than but still comparable to the size of granules. Thus, our proposal that so-produced coronal jets and spicules are sources of PSP-observed switchbacks (Sterling & Moore 2020; Neugebauer & Sterling 2021) fits recent PSP observations that the distribution of switchback widths inferred from the observed durations of switchbacks has two peaks, one mapping to solar-surface supergranule widths (Fargette et al. 2021, Bale et al. 2021) and the other to solar-surface granule widths (Fargette et al. 2021).

Patches of magnetic switchbacks: hints of their origins

C. Shi

Parker Solar Probe (PSP) has shown that the solar wind in the inner heliosphere is characterized by the quasi omni-presence of magnetic switchbacks, local backward-bends of magnetic field lines. Switchbacks also tend to come in patches, with a large-scale modulation that appears to have a spatial scale size comparable to supergranulation on the Sun. Here we analyze data from the first ten encounters of PSP focusing on different time intervals when clear switchback patches were observed by PSP. We show that the switchbacks modulation, on a timescale of several hours, seems to be independent of whether PSP is near perihelion, when it rapidly traverses large swaths of longitude remaining at the same heliocentric distance, or near the radial-scan part of its orbit, when PSP hovers over the same longitude on the Sun while rapidly moving radially inwards or outwards. This implies that switchback patches must also have an intrinsically temporal modulation most probably originating at the Sun. Between two consecutive patches, the magnetic field is usually very quiescent with weak fluctuations. We compare various parameters between the quiescent intervals and the switchback intervals. The results show that: (1) Quiescent intervals are typically less Alfvénic than switchback intervals. (2) The magnetic power spectrum is usually shallower in quiescent intervals. (3) The correlation between alpha-particle abundance and switchback patches can be either positive or negative. We propose that the temporal modulation of switchback patches may be related to the “breathing” of emerging flux that appears in images as the formation of “bubbles” below prominences in the Hinode/SOT observations.

The View of the Corona from Within the Alfven Surface

R. Howard, G. Stenborg, A. Vourlidas, M. Linton, P. Hess, B. Gallagher, N. Rich, P. Liewer, V. Bothmer, A. Rouillard, K. Battams, R. Colaninno, N. Viall, S. Patsourakis, P. Riley, J. Linker, C. Braga, A. Thernisien, C. DeForest, A. Higginson, & N. Raouafi

Since its launch on August, 2018, the Parker Solar Probe (PSP) has used five close fly-bys of Venus to gradually reduce its perihelion distance from the initial perihelion of 35 Rsun on 5 November, 2018 to the lowest perihelion of 13.3 Rsun achieved on 21 November 2021 in Orbit 10. This perihelion will be the same for the next seven orbits. The Orbit 10 perihelion pass occurred from 16 to 25 November 2021 and has enabled very unique observations of the solar corona by the Widefield Instrument for Solar PRobe (WISPR). At the perihelion of 13.3 Rsun, the WISPR field of view is 3.1 – 25 Rsun. The detailed views of the CMEs and outflows are revealing new features including the details of the CME flux rope, the collision and resulting interactions between a fast CME overtaking a slower one. In addition to this dynamic activity, enhanced scattering from dust in the orbit of asteroid/comet Phaethon is seen for several days.

Translational Tomography of the Solar Corona

M. Kenny

We present early steps toward "translational tomography" of the solar corona: using successive WISPR image sequences to reconstruct coronal structure proximal to the spacecraft track. We first apply our method to a pre-flight simulation of a WISPR flythrough and then to actual WISPR image sequences near perihelion. Our method relies on known perspective changes due to the rapid trajectory of PSP through the solar corona during encounters. This method allows us to extract feature location and large-scale structure near the track of the spacecraft itself. To produce the inversions we neglect local proper motions and model the apparent kinematics of a stationary solar wind feature, from WISPR's point of view. This family of analytic functions serves as a partial basis for the vector space of WISPR image sequences; a simple change-of-basis operation yields the initial tomogram, which locates streamer structure with respect to the orbital track. For initial analyses, this tomogram corresponds to the ribbon of material whose length runs along the track of the spacecraft and whose width runs perpendicular to that track (locally horizontal). We present the basics of the method, using two different geometric models of the spacecraft trajectory, and initial test results from a pre-flight model and three recent perihelion passes. Future work includes regularization of basis elements and improvement of the basic proof-of-concept inversions. The tool will grow in utility as the orbital distances decrease in future encounters.

Resolving when coronal mass ejections engulf PSP

C. R. Braga & A. Vourlidas

The association of coronal mass ejections (CMEs) with their in-situ counterparts (ICMEs) has not yet been entirely resolved. In-situ measurements have been unavailable in the corona, where remote sensing is available. Multiple processes can occur while the CME propagates up to the in-situ measurement locations further into the heliosphere, including deformation, erosion, deflection, and interaction with other structures. The lack of observations and limited understanding of these processes result in significant discrepancies between CME properties derived lower in the corona and their corresponding ICME measurements. The advent of PSP is finally closing this gap. The time elapsed between remote sensing and in-situ observations can be less than 10 hours if the CME-PSP angular separation is small. In this project, we develop a methodology to determine if and when a CME engulfs PSP. We apply it to a CME observed by WISPR on PSP on November 19-20, 2021 during PSP's 10th encounter. We reconstruct the CME combining PSP/WISPR observations with two additional observatories: STEREO and SOHO. These observatories provide constraints to determine the CME propagation direction and size in 3D. The CME follows a self-similarly expanding flux rope model while observed by remote sensing, and we extrapolate its tridimensional position for the subsequent hours. We found that the CME engulfs PSP a few hours after WISPR observations while the spacecraft is below 20 solar radii.We hope the results from this study motivate the community to look for unforeseen ICME signatures in the corona during PSP crossings. CMEs in-situ signatures may differ in the corona when compared to their interplanetary counterparts. This issue has received limited attention up to now. This approach may also help identify flank hits, which frequently do not have obvious signatures.

First joint STIX and LOFAR Observations of a Flare Event on 06 June 2020

M. Broese

A joint analysis approach is used to study flare signatures both in the low and higher corona. STIX, AIA and Low Frequency Array (LOFAR) data provide an extensive picture about different aspects of flare characteristics. Recent data by the STIX instrument complement the picture of accelerated electrons, which propagate along magnetic field lines towards the Sun. These observations are linked to the LOFAR data, which contain information about the electrons propagating away from the Sun through the corona above the active region. Although, the active region and its thermal evolution (Differential Emission Measure (DEM) reconstruction of AIA data), flare accelerated electrons and their radio traces (LOFAR, STIX) are in principle all associated with the energy release during the flare process, they are often studied separately. Hence, the investigation of possible relations is part of this project. Solar magnetic fields as a binding element between low and high corona, accelerated electrons and heated flare loops are included in the analysis via a Potential Field Source Surface (PFSS) model. The idea of this project is to trace the flow of energy that heats the solar corona and accelerates solar energetic particles. We plan to extend this analysis by using also Parker Solar Probe data, therefore a participation in the conference would be very beneficial for my PhD project.

Imaging of Venus by PSP/WISPR

B. E. Wood

Naval Research Laboratory, Space Science Division, Washington, DC 20375, USA

I will review the results of PSP/WISPR imaging of Venus during the third and fourth flybys on 2020 July 11 and 2021 February 20, respectively. On the nightside of Venus, the WISPR images remarkably penetrated the thick Venusian atmosphere and observed thermal emission from the surface. This is the first time the surface of Venus has ever been successfully imaged in the optical, though this thermal emission has previously been seen in infrared images of the nightside, particularly by the Venus Express and Akatsuki missions. A model of the thermal emission assuming a surface temperature of 735 K propagated through a model atmosphere for Venus successfully reproduces the observed WISPR count rates. In addition to the thermal emission, we also seen O2 nightglow emission at the limb of the planet. A final chance for PSP/WISPR to image the nightside of Venus will occur during the seventh and final flyby on 2024 November 6. This encounter will take PSP much closer to the planet, and will present both unique opportunities and unique problems for WISPR's attempts to obtain additional images of the planet.

PSP/SWEAP/SPAN-Ion observations of upstream pickup protons at Venus

A. Rahmati, D. Larson, R. Livi, P. Whittlesey, M. McManus, O. Romeo, J. Verniero, J. Kasper, S. Bale, M. Pulupa, K. Goetz, & the SWEAP & FIELDS teams.

During two of Parker Solar Probe's Venus flybys (VGA2 and VGA3), the SWEPA/SPAN-Ion instrument detected proton distributions that resembled those of pickup protons, with ring-beam distributions and energies as high as four times the solar wind proton energy. The source of these pickup protons at Venus is the ionization of the extended neutral exosphere of the planet. The trajectories of the pickup ions can be analytically modeled and convolved with instrument Field of View (FOV) to construct modeled proton distributions, allowing us to conduct model comparisons with the measured pickup ions fluxes. Using these model-data comparisons, the hydrogen neutral densities upstream of Venus can be reconstructed at distances on the order of a few proton gyro-radii, which would help constrain the hydrogen escape rates from Venus. In this work, we use a pickup ion model that employs the measured vector components of the solar wind velocity and interplanetary magnetic field (IMF) to simulate the trajectories of pickup ions. A key data input in calculating the trajectories of pickup ions is the three components of the IMF, measured in the solar wind by the MAG instrument on PSP. Due to the sensitivity of pickup ion trajectories to the direction and magnitude of the magnetic field, the accuracy of the measured components of the IMF plays a key role in determining what part of the pickup ion ring-beam distribution would be in the FOV of SPAN-Ion. Preliminary analysis indicates that the measured proton 3D distributions do not perfectly match the modeled distributions. In this work, a few theories that would potentially explain this offset between the data and the model results are proposed and will be explored in detail, which include:

- The possibility that the measured pickup protons are no longer in a perfect ring-beam distribution due to pitch-angle scattering into shell-like distributions.
- Pickup protons that were born in a different magnetic environment and drifted into the one measured by PSP/MAG.
- The possibility of the presence of an offset in the measured magnetic field.
- Shock-drift acceleration of upstream solar wind protons.
- Solar wind proton beams.

P4-01

Switchbacks in the Young Solar Wind: Electron Evolution Observed inside Switchbacks between 0.125 AU and 0.25 AU

R. Nair, J. S. Halekas, P. L. Whittlesey, D. E. Larson, R. Livi, M. Berthomier, J. C. Kasper, A. W. Case, M. L. Stevens, S. D. Bale, R. J. MacDowall, & M. P. Pulupa

Switchbacks are localized reversals of the radial component of the magnetic field in the solar wind. In this study, we investigate the electron distributions inside switchbacks, focusing primarily on the suprathermal populations (halo and strahl electrons) and how their characteristics change within switchbacks. We explore electron parameters in relation to the angle of rotation of the magnetic field from radial, to determine whether electron distributions observed within switchbacks have any differences from those outside of switchbacks. Our observations reveal several trends in the suprathermal electron populations inside switchbacks. We find that the sunward deficit in the electron velocity distribution function (eVDF) typically observed near the Sun is filled in at larger switchback rotation angles. This results in the suprathermal electron density and heat flux in the anti-strahl direction changing from a negative to a positive value. On many days, we also find that the halo density increases with switchback rotation angle, suggesting that the growth of the halo fills in the sunward deficit. The increase in suprathermal electron flux in the anti-strahl direction seen in switchbacks with larger rotation angles may indicate the operation of enhanced scattering mechanisms inside switchbacks. A possible explanation is some form of wave-particle interaction that scatters strahl electrons into the halo inside switchbacks.

P4-02

Evidence of Current-Driven Behavior at Switchback Boundaries Observed by Parker Solar Probe

A. P. Rasca, W. M. Farrell, P. L. Whittlesey, R. J. MacDowall, S. D. Bale, & J. C. Kasper

The first solar encounters by the Parker Solar Probe revealed the magnetic field to be dominated by short field reversals in the radial direction referred to as “switchbacks.” While radial velocity and proton temperature were shown to increase inside the switchbacks, |B| exhibits very brief dropouts only at the switchback boundaries. Brief intensifications in spectral density measurements near the electron plasma frequency, f_{pe}, have also been observed at these boundaries, indicating the presence of plasma waves triggered by current systems in the form of electron beams. We perform a correlative study using observations from the Parker FIELDS Radio Frequency Spectrometer (RFS) and Fluxgate Magnetometer (MAG) to compare occurrences of spectral density intensifications at the electron plasma frequency (f_{pe} emissions) and |B| dropouts at switchback boundaries during Parker's first and second solar encounters. We find that only a small fraction of minor |B| dropouts are associated with f_{pe} emissions. This fraction increases with |B| dropout size until all dropouts are associated with f_{pe} emissions. This suggests that in the presence of strong |B| dropouts, electron currents that create the perturbation in |B| along the boundaries are also stimulating plasma waves such as Langmuir waves.

P4-03

Does intermittent interchange reconnection launch switchbacks into the solar wind?

P. F. Wyper, A. K. Higginson, C. R. DeVore, S. K. Antiochos, D. I. Pontin, R. B. Scott, S. Masson, & T. Pellegrin

The origins of magnetic switchbacks have been hotly debated since the first perihelion of Parker Probe revealed their abundance within the near-Sun solar wind. One idea that has attracted attention is that switchbacks could be formed by interchange reconnection in the solar corona. In this work we test this hypothesis using adaptively-refined, ultra-high resolution, 3D MHD simulations of interchange reconnection occurring at a pseudostreamer. Surface motions are used to stress the null of the pseudostreamer, which initially collapses into a Sweet-Parker-like current layer before becoming violently unstable to plasmoid formation. We find that plasmoids repeatedly form and are ejected from the layer leading to a continual modulation of the solar wind within the stalk of the pseudostreamer. This modulation takes the form of many small-scale torsional Alfven wave-like perturbations but crucially does not include any reversals of the radial field component. Our study therefore suggests that although intermittent interchange reconnection at pseudostreamers could be a source of significant variability, it is unlikely to launch switchbacks directly into the solar wind.

P4-04

Size Comparison of Solar Flux Tubes and Solar Wind Switchbacks

J. Lee

Recent studies suggest that the magnetic switchbacks (SBs) detected by the Parker Solar Probe (PSP) carry information on the scales of solar supergranulation and granulation. We test this claim against high-resolution H-alpha images obtained with the visible spectro-polarimeters (VIS) of the Goode Solar Telescope (GST) in Big Bear Solar Observatory (BBSO). Small elongated features in the coronal hole boundary visible in the H-alpha blue-wing but absent in the red-wing images are regarded as ejecting flux tubes. We mark density-enhanced sections of individual flux tubes along chromospheric networks, and read out their lengths, diameters, and locations. The inter-distances between adjacent flux tubes are in two scales, 0.18 and 1.1 degrees, which are close to but a bit smaller than large and medium scales of SBs. The aspect ratios of the dense section of flux tubes are found as high as 8-30, comparable to those of SBs. The number distributions of lengths, diameters, and inter-distances of flux tubes are confined to narrower ranges bounded by characteristic scales unlike the much-extended waiting time distribution of SBs. These results suggest that SBs may have originated from the chromosphere, but additional processes of aggregation, cascade, and volume-filling expansion are needed to broaden the chromospheric scale distribution to the SB scale distribution.

P4-05

Statistical Study of Ejections Near Corona Hole Boundaries As Possible Source of Solar Wind Switchbacks

N. Huang

Magnetic field switchbacks are discovered to be ubiquitous in the solar wind using in-situ data from Parker Solar Probe (PSP). Several scenarios have been proposed in theoretical studies to explain the origin of these switchbacks, among which the small-scale activities in the solar atmosphere are plausible drivers, directly or secondarily. Meanwhile, Fargette et al. (2021) studied the temporal and spatial scale of switchbacks, and suggested their relationship with granulation and supergranulation of the sun. The statistical properties of the small-scale energy release events would be important to measure their eligibility as candidate of switchback source. We survey small-scale ejections, such as coronal jets and mini-filament eruptions, at and near the boundaries of coronal holes. Full disk extreme ultraviolet (EUV) images and Hα far bluewing images are used to identify the activities in the corona and chromosphere, respectively. We will report the statistical distribution of latitude, lifetimes and occurrence frequencies of these activities observed during the PSP Encounters 4, 5 and 8, and compare them to the switchbacks patches in corresponding period.

P4-06
Generation of whistler waves at switchback boundaries in the young solar wind

H. Y. Kim, O. V. Agapitov, & S. Karbashewski

Observations of the solar wind by the Parker Solar Probe (PSP) mission reveal the existence of intensive plasma wave bursts with frequencies below 0.1 fce (from tens of Hz to a couple of hundred Hz in the spacecraft frame) collocated with the local minima of the magnetic field magnitude at switchback boundaries (localized sudden deflections of the magnetic field). An unusual feature of these whistler waves in the solar wind is their propagation direction. The higher frequency whistler waves propagate sunward contrary to the lower frequency MHD waves predominantly propagating from the sun. We have determined the properties of plasma waves collocated with dips of magnetic field magnitude related to switchback boundaries and revealed the waves generation mechanisms using the hybrid PIC plasma model. Measurements from PSP and pressure balance within the magnetic dip determine the particle distribution functions. The dominant generation mechanism is the cyclotron resonance interaction with the trapped particles in the magnetic dip with high thermal anisotropy resulting in quasi-parallel sunward propagating whistlers of high amplitude. The wave parameters are in good agreement with parameters of whistlers collocated with magnetic dips at switchback boundaries observed by PSP at 25-35 solar radii.

P4-07

The structure of switchbacks in the solar wind: the effects of their generation and evolution

O. Agapitov, J. F. Drake, M. Swisdak, H. Y. Kim, S. Karbashewski, F. S. Mozer, & T. D. Phan

A major discovery of Parker Solar Probe (PSP) was the presence of large numbers of localized increases in the radial solar wind speed and associated sharp deflections of the magnetic field - switchbacks (SB). A possible generation mechanism of SBs is through magnetic reconnection between open and closed magnetic flux near the solar surface, termed interchange reconnection that leads to the ejection of flux ropes (FR) into the solar wind. Observations also suggest that SBs undergo merging, consistent with a FR picture of these structures. The role of FR merging in controlling the structure of SBs in the solar wind is explored through direct observations, analytic analysis, and numerical simulations. Analytic analysis reveals key features of the structure of FRs and their scaling with heliocentric distance R that are consistent with observations and demonstrate the critical role of merging in controlling the structure of SBs. FR merging is shown to energetically favor reductions in the strength of the wrapping magnetic field and the elongation of SBs. A further consequence is the resulting dominance of the axial magnetic field within SBs that leads to the observed characteristic sharp rotation of the magnetic field into the axial direction at the SB boundary. Finally, the radial scaling of the SB area in the FR model suggests that the observational probability of SB identification should be insensitive to R, which is consistent with the most recent statistical analysis of SB observations from PSP.

P4-08

The Effect on Geospace Environment of Small-scale Magnetic Flux Ropes in the Solar Wind

Y. Shin, S. Noh, N. Huang, G. Bizos, H. Farooki, M. Desai, K.-E. Choi, H. Wang, & H. Kim

Small-scale magnetic flux ropes (SMFRs), a bundle of twisted field lines, are frequently observed from multiple spacecraft in the solar wind over a wide range of region from 0.29 to 8 au [Chen & Hu, 2020]. Since it is widely known that rotating magnetic field structure is favorable for build-up, release and transport of free energy, there is a significant point to look into transient energy transfer near the boundary between SMFRs and the Earth's magnetosphere. However, their interaction has not yet been widely studied even if it may play an important role to energy transfer from the solar wind to Earth's magnetosphere. As our pilot study found that there is a statistically similar trend of occurrence rates of SMFRs and substorms, we perform a statistical analysis by comparing between SMFRs and geospace response in terms of duration, magnitude, scale size, and orientation of SMFRs. We also use particle data from MMS to investigate geomagnetic activity and plasma characteristics both outside and within the Earth's magnetosphere during passages of SMFRs. We here propose a comprehensive observational and technical effort to understand the transport of small-scale transient from the solar wind to the Earth's environment. We target key candidates for such events, including SMFRs, substorms, and in-situ observations obtained from magnetospheric missions.

P4-09
Solar Orbiter: Here comes the Sun

D. Müller, Y. Zouganelis, A. De Groof, A. Walsh, D. Williams, T. Nieves-Chinchilla, & D. Lario, on behalf of the Solar Orbiter team

The ESA/NASA Solar Orbiter mission started its nominal mission phase in November 2021 and will have its first close solar encounter at 0.32 au in March 2022. By combining high-resolution imaging and spectroscopy of the Sun with detailed in-situ measurements of the surrounding heliosphere, Solar Orbiter will enable us to determine the linkage between observed solar wind streams and their source regions on the Sun. Over the course of the 10-year mission, the highly elliptical orbit will get progressively more inclined to the ecliptic plane. Thanks to this new perspective, Solar Orbiter will deliver images and comprehensive data of the unexplored Sun's polar regions and the side of the Sun not visible from Earth. This talk will provide a mission status update, summarise the science operations performed during the first close perihelion as well as the plans for the next one in October 2022, and show first data.

P4-10
Whole Heliosphere and Planetary Interactions

S. E. Gibson, D. Kolinski, R. C. Allen, G. de Toma, L. Qian, & B. J. Thompson

Whole Heliosphere and Planetary Interactions (WHPI) is an international initiative focused on the solar minimum period that aims to understand the interconnected sun-heliospheric-planetary system. The simpler magnetic configuration and infrequency of Coronal Mass Ejections (CMEs) makes solar minimum an ideal time to follow how the solar magnetic and radiative output propagates through the heliosphere and affects the Earth and planets' atmospheres and magnetospheres. WHPI currently involves more than 600 solar, heliospheric, geospace, and planetary researchers, with monthly colloquia and show-and-tell tutorials, a special session at the Fall 2020 AGU, a workshop in 2021 with more than 200 registered participants, and multiple campaigns in support of Parker Solar Probe perihelia. A topical AGU Journals Special Issue is currently soliciting papers. These and other activates are coordinated via the WHPI web page (https://whpi.hao.ucar.edu/).

P4-11
Remote Sensing Observations of Solar Eruptions with a Range of Sizes and Energies

P. Hess

Imaging data from new instruments, including PSP/WISPR and SO/SoloHI, have allowed for observational coverage with unprecedented resolution in the region within .25 AU of the Sun. This improved observational capability has allowed for imaging of outflows of a variety of spatial scales and speeds. WISPR in particular has made frequent observations of outflows coming from the cusp of helmet streamers and propagating through the heliospheric current sheet (HCS). The largest of these are commonly considered to be coronal mass ejections (CMEs), but the similarity in observable features in the spectrum of these outflows raises the possibility that common physical processes operating on different scales cause outflows with a wide range of energetics and sizes. While the CMEs are frequently studied and understood to be a disruption within the solar wind, the frequency with which these smaller eruptions occur and the lack of evidence that they exist at 1 AU as unique, coherent structures, mean such outflows must regularly occur, evolve and possibly merge to comprise a significant portion of the steady solar wind. We present observational examples, from both remote sensing data and in situ data at PSP, to highlight the full process of these eruptions and structural analysis of outflows of different sizes with supporting observations from throughout the heliosphere.

P4-12

Solar Orbiter's first close encounter with the Sun: preparation of the coordinated science campaigns

Y. Zouganelis, D. Mueller, A. De Groof, A. Walsh, & D. Williams

After a Cruise Phase of 21 months, Solar Orbiter entered its first scientific orbit on 27 November 2021 after a Gravity Assist Manoeuvre (GAM) by the Earth. The spacecraft entered a highly elliptical orbit that will bring it up to its first close perihelion on 17 March 2022, at 0.32 au from the Sun. In the following years, further GAMs by Venus will lead it even closer to the Sun and also out of the ecliptic plane. Solar Orbiter's main goal is to study the connection between the solar activity close to the star's surface and its effects as seen in the heliosphere, the bubble-like region of space under the Sun's influence including all solar planets. Therefore, its main scientific goals can only be achieved by coordinated observations of both the 6 remote-sensing telescopes onboard, observing the dynamic Sun, and the 4 in situ instruments measuring the effects in the solar wind surrounding the spacecraft. This coordination takes careful planning and optimisation of the mission resources, in order to fully exploit the capabilities of this exciting mission. In this contribution, we present the science operations as planned for the first year of nominal mission phase, i.e., the first two orbits. By the time of the Parker Two Conference, Solar Orbiter will have made its first close encounter and most of the data from the perihelion will have arrived!

P4-13

Calibration of the SWEAP/SPC experiment and development of joint SPC/SPAN-Ai data products

M. L. Stevens, A. Case, K. Paulson, T. Niembro-Hernandez, J. C. Kasper, R. Livi, D. Larson, P. Whittlesey, A. Rahmati, & Kelly Korreck

The Solar Probe Cup instrument is the sun-pointed element of the Solar Wind Electrons Alphas and Protons experiment on board Parker Solar Probe, and the primary source of thermal ion measurements outside of closest approach. The purpose of this poster is to illustrate the calibration of the instrument, to contextualize the measurement uncertainties and data flags, and to communicate the status of joint data analysis and future data products. We demonstrate the on-orbit calibration of the SPC instrument through contemporary encounters with respect to effective collecting area and energy ranging, which are the two factors that determine accuracy of proton density and radial speed measurements. We then demonstrate the angular calibration of the instrument, which includes mitigation of the anomalous crosstalk between sensitive elements that has been observed from Encounter 5 to the present. We compare partial phase-space distribution measurements from SPC and SPAN-Ai to confirm that off-radial flows are properly measured at the edges of the respective instrument fields of view. Finally, we demonstrate the level 4 data products in development that will combine these fields of view.

P4-14
Following a prominence eruption from Sun to Parker Solar Probe with multi-spacecraft observation

T. Niembro, K. K. Reeves, D. B. Seaton, P. Hess, D. Berghmans, & V. Andretta on behalf of the HSO Connect Eruptions, PSP/FIELDS-SWEAP-WSPR & Solar Orbiter Collaborations

In the early hours of 2021 April 25, the Solar Probe Cup on-board Parker Solar Probe (PSP) registered the passage of a solar wind structure characterized by a clear and constant alpha to proton density ratio above 6% during three hours. The alpha contribution remained present but faint and intermittently within a twelve-hour window. In this work, we report the helium-enriched plasma structure from the Sun to PSP combining multi-spacecraft remote sensing and *in-situ* measurements. We identify a prominence as the likely source, visible in both STA/EUVI and SO/EUI. The associated CME was observed in STA/COR2, and SO/SoloHI and reached PSP when it was located at 46 $R_\odot$, 8 hours after the spacecraft registered a crossing of the heliospheric current sheet. Except for the extraordinary alpha ratio enhancement, the CME showed ordinary plasma signatures and a complex magnetic field with an overall enhancement. The PSP/WISPR images show a structure entering the field of view a few hours before the *in-situ* crossing followed by repetitive transient structures that are the result of flying through the CME body. We believe this to be the first example of a CME being imaged by PSP/WISPR directly before and during being detected *in-situ*.

P4-15
PSP Measurements of Electron Shot Noise on a Current Biased Antenna

W. Ember, M. Pulupa, & S. D. Bale

Electron shot noise is observed when electrons impact a spacecraft antenna. The FIELDS antennas on the Parker Solar Probe (PSP) are current biased to improve the antenna response to low frequency electric fields. The applied current bias varies slowly with solar distance, and is rapidly varied during periodic calibration activities known as bias sweeps. We present PSP/FIELDS Radio Frequency Spectrometer (RFS) data during antenna bias sweeps, quantifying the effect of bias current on the electric field shot noise spectrum. Observing changes in electron shot noise given variation current can improve determination of electron parameters from quasi-thermal noise spectroscopy.

P4-16

Venus Ionospheric Measurements by the SWEAP-SPAN-Ion Sensor on Parker Solar Probe.

R. Livi, D. E. Larson, A. Kasper, S. Curry, M. McManus, A. Rahmati, & O. Romero

We present observations of all 5 Venus Gravity Assists made by the Solar Wind Electrons Alphas and Protons experiments on the Parker Solar Probe mission, which has finished its ninth close encounter around the sun. Part of SWEAP is the SPAN-Ai ion sensor, which is designed to measure the full 3D ion velocity distribution function of individual solar wind ions using an electrostatic analyzer and a time-of-flight mass discriminator. During the PSP close flyby of Venus, the SPAN-Ai sensor measured the Venusian magnetosheath and ionosphere. The former contained perturbed solar wind ions (Protons and Alphas) with high temperatures while at closest approach several new populations of heavier ions appeared at much lower energies. The energy of the heavy ions, combined with the ram velocity of the spacecraft clearly indicate that the spacecraft traversed the Venusian ionosphere. In this presentation we will discuss ion measurements that were made during the VGAs, specifically showing their respective densities, temperatures, and velocity vectors, including an analysis of solar wind measurements before and after the flyby. These remarkable Venus gravity assists will help us understand the origins and the mechanism that shapes the Venusian environment.

P4-17

SPDF Support for PSP and Solar Orbiter Missions

L. Jian & R. Candey

As NASA's active and permanent archive for non-solar heliophysics data, the SPDF (Space Physics Data Facility) has been archiving and serving the *in-situ* data from PSP (87 datasets) and Solar Orbiter missions (72 science datasets and 17 low latency datasets). We present the usage statistics of these data and introduce recent additions of metadata function at SPDF. In addition, we report the status of the SPASE (Space Physics Archive Search and Extract) and DOI (Digital Object Identifier) registry of these datasets.