Project Details

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Topic: Understanding the Large-Scale Evolution of the Solar Wind

Project Title:
Non-linear Solar Wind Turbulent Heating from 0.08 to 5.2 AU

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Summary:
Describing the heating of the Sun's corona and the expanding solar wind is a central problem of modern heliophysics. Several heating mechanisms have been proposed, each expected to operate under different solar wind conditions.
Recent results from Parker Solar Probe (PSP) have shown one particular non-linear mechanism - Stochastic Heating (SH), driven by magnetic moment invariance breaking due to turbulence, is increasingly effective at lower radial distances from the Sun. Examination of the proton Velocity Distribution Functions (VDFs) below 0.25 AU during PSP Encounters 1&2 confirmed theoretical predictions for VDF shapes to change from standard Maxwellian to flattop distributions, as SH tends to primarily heat particles slower than the VDF thermal speed.
In parallel, recent results based on Helios observations have demonstrated that the level of ion scale turbulent fluctuations---regarded as another clear indicator of SH activity--- steadily decreases with radial distance, while also being enhanced in fast solar wind, more frequently measured close to the ecliptic around solar maximum. However, the Helios ion analyzers did not have the resolution required to confidently identify the VDF shapes. As the turbulence contains the information about in situ solar wind conditions along with traces of its evolution from the Sun, there was no conclusive way to distinguish if SH was operating at the point of measurement, or observed fluctuations are a remnant of the heating that happened days ago closer to the Sun.
In this project, we will use combined 45 years long survey of VDF and magnetic field data from Wind and Ulysses, enhanced with new high-resolution PSP and Solar Orbiter (SolO) measurements (available at CDAWeb and ESA Solar Orbiter Archive), to answer three crucial science questions (SQs):
1. How levels of SH in the inner heliosphere vary throughout three solar cycles?
2. Is the measured SH a genuine in situ process or a trace of near-Sun enhanced heating?
3. Is SH accompanied and/or affected by linear instabilities?
The proposed SQs are relevant to the FST Topic #3 Understanding the Large-Scale Evolution of the Solar Wind throughout the Heliosphere and through the Solar Cycle", its Goal #1 Utilize long-term measurements to quantify how the solar cycle impacts in situ plasma and magnetic field of the inner heliosphere" and Measurement of Success #2 Understanding and quantification of the impact of solar cycle variability on solar wind structures in the inner heliosphere".
To answer SQ1, we will extend the existing Helios SH analysis to Wind and Ulysses by using our already developed computationally efficient algorithms. These results will explain the solar cycle dependency of SH at various heliographic latitudes.
To understand if the estimated SH is happening in situ (SQ2), we will perform a statistical study of VDFs measured by Wind and Ulysses to estimate if they indeed exhibit flattop shape when SH is expected to be the dominant heating process. Some of the streams measured by Wind will be downstream of PSP and SolO, which will add another level of confidence as the large-scale statistical study will be enhanced by smaller multi-point case studies of tracked streams.
Finally, time-frequency analysis of turbulence will allow us to upgrade previous investigations of SH by differentiating low-frequency turbulent power that drives SH from coherent wave power, and investigate how SH is connected to plasma stability (SQ3). Using well established PLUME and ALPS dispersion solvers, we will be able to understand the profile of linear instabilities raised in regions where increased SH modifies the VDF, and quantify the energy transferred back from particles to fields via instabilities.
The described research will provide a confident, reliable model of the solar wind heating, bringing us closer to overall understanding solar wind thermodynamics throughout the solar cycle and at varying distances and latitudes.

Publication References:

no references