A Tale of Two Spacecraft: How Solar Orbiter and Parker Solar Probe are Working Together to Revolutionize our View of the Sun

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Solar Orbiter Community Building Webinars

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EXTREME EXPLORATION WITH SOLAR ORBITER AND PARKER SOLAR PROBE

esa

esa NASA

Solar Orbiter

42 million
kilometres to the Sun
at closest approach

10 instruments
to observe the turbulent solar surface, its hot outer atmosphere, and changes in the solar wind

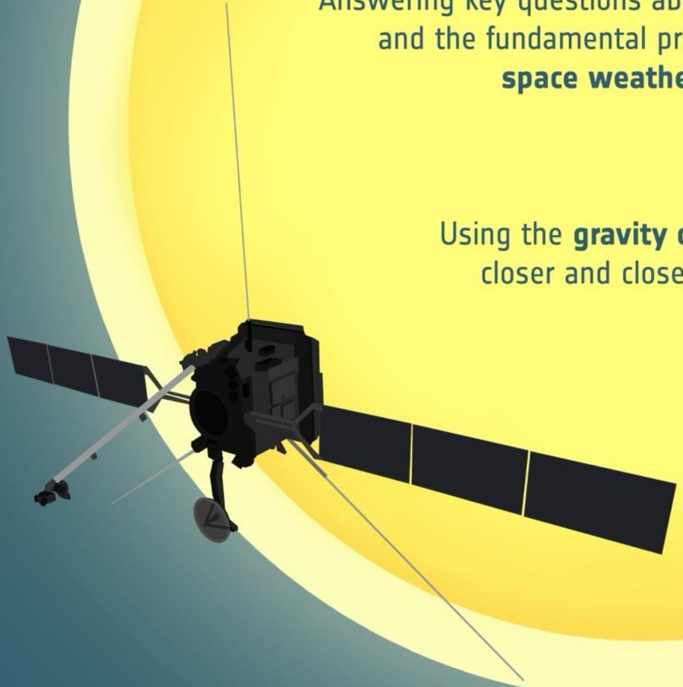
Combination of **in situ** and **remote sensing** observations

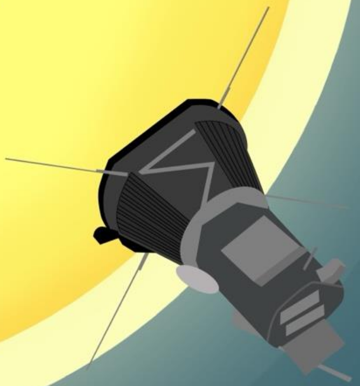
first images
of the Sun's poles: the key to understanding the Sun's activity and solar cycle

Providing **complementary measurements** and putting each other's **data in context**

Answering key questions about **how our star works** and the fundamental processes that lead to **space weather at Earth**

Using the **gravity of Venus** to get closer and closer to the Sun





NASA

Parker Solar Probe

6.2 million
kilometres to the Sun
at closest approach

4 instruments
to study magnetic fields, plasma, energetic particles and solar wind

Flies through the Sun's inner atmosphere to trace how energy flows through the corona

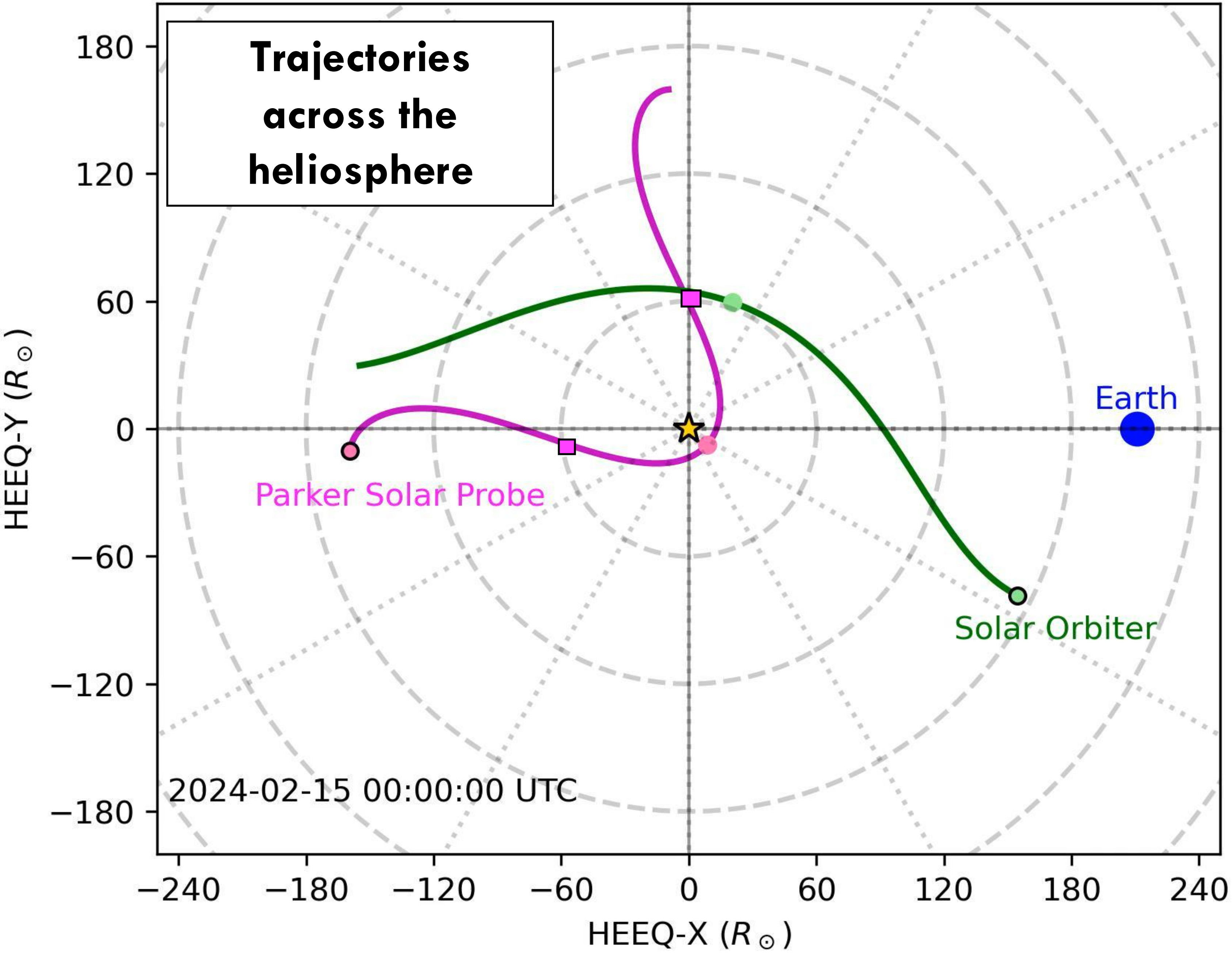
ESA | NASA solar orbiter

#SolarOrbiter #WeAreAllSolarOrbiters

Cover the inner heliosphere

- Often intercepting the same solar wind at various places in the heliosphere
- **Conjunction ideal for** examining
  - Radial evolution of coronal mass ejections or solar wind
  - Understanding the radial and longitudinal extent of energetic particles

***If you are interested in any of the plots I showed, I am happy to share code to reproduce them**



Parker Solar Probe operation

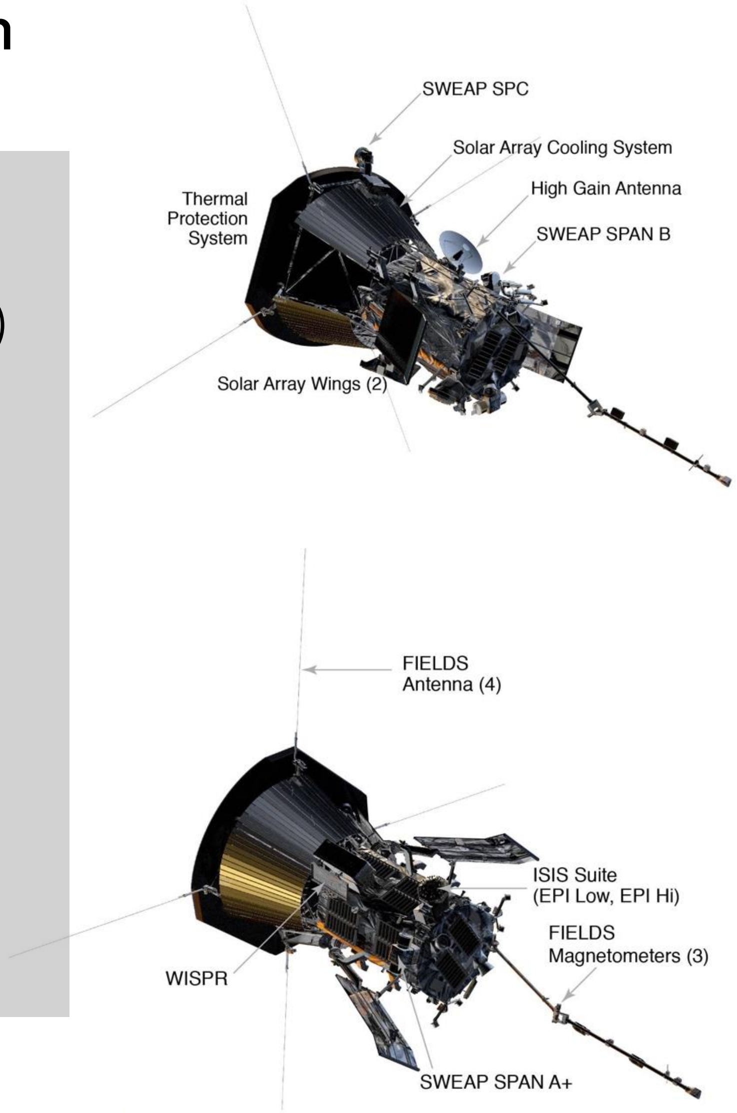
In situ

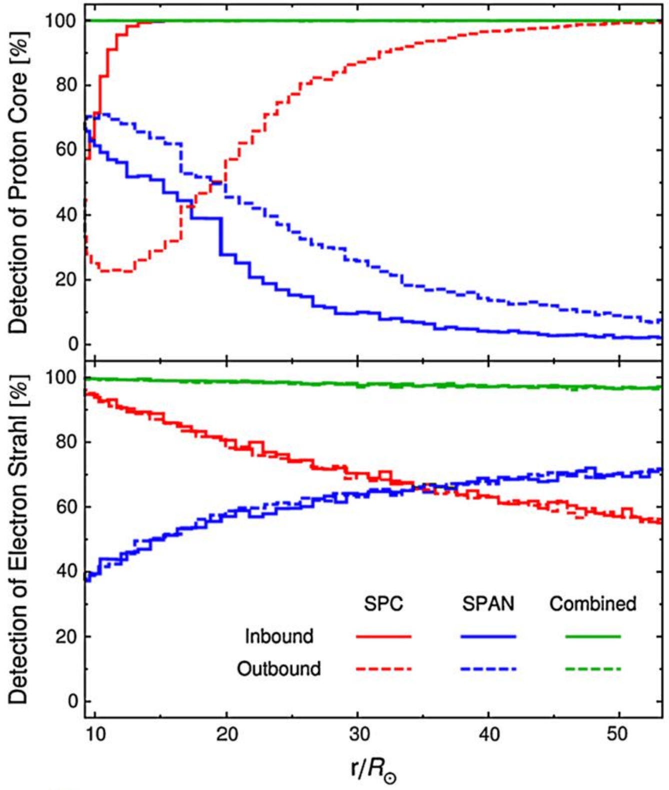
- **E** & **B** fields (FIELDS)
- Quasi-thermal noise electron density (FIELDS)
- Thermal plasma distributions and moments (SWEAP)
    - Solar Probe Cup (SPC)
    - SPAN A (ions) & B (electrons)
- Energetic Ion distributions and composition (IS⊙IS)

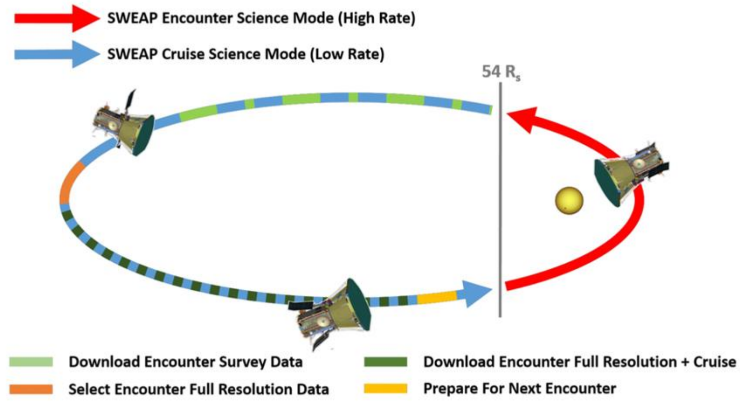
Remote sensing

- Wide-field Imager for Parker Solar Probe (WISPR)

Data products can be found at CDAWeb, or institutional websites:
SWEAP http://sweap.cfa.harvard.edu/Data.html,
FIELDS https://fields.ssl.berkeley.edu/data/,
IS⊙IS https://spp-isois.sr.unh.edu/Release-Notes.html,
WISPR https://wispr.nrl.navy.mil/wisprdata





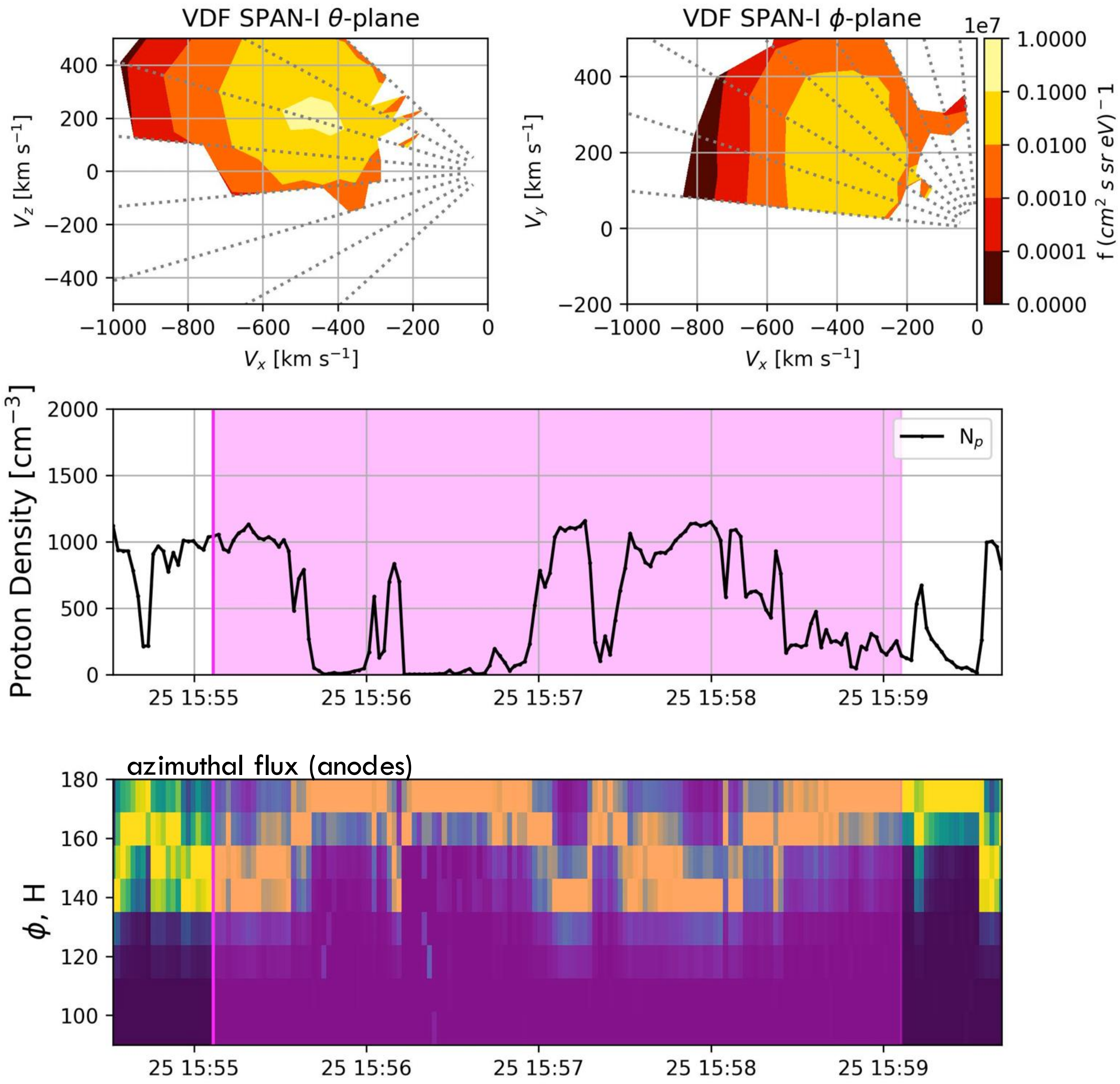


Kasper+2016

Consider the SPAN-I FOV during perihelion

Artificial dropouts in proton and helium density, are likely when their VDF is out of the instrument's FOV

- Heat shield obstruction
- Alfvenic fluctuations



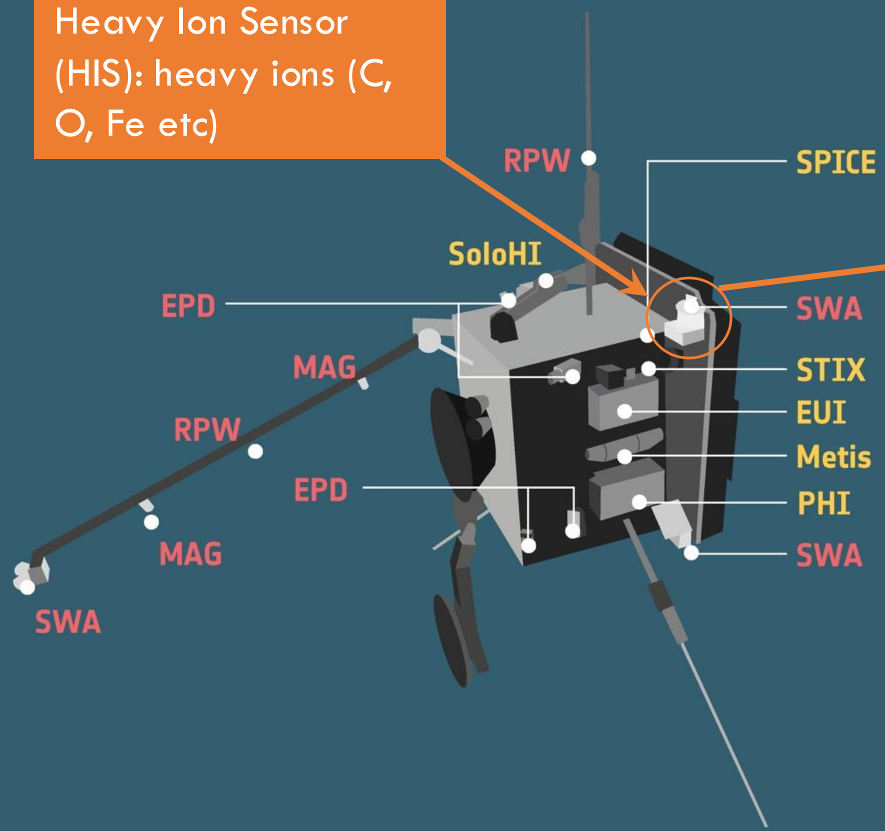
SPAN-I instrument details:
Livi+2022

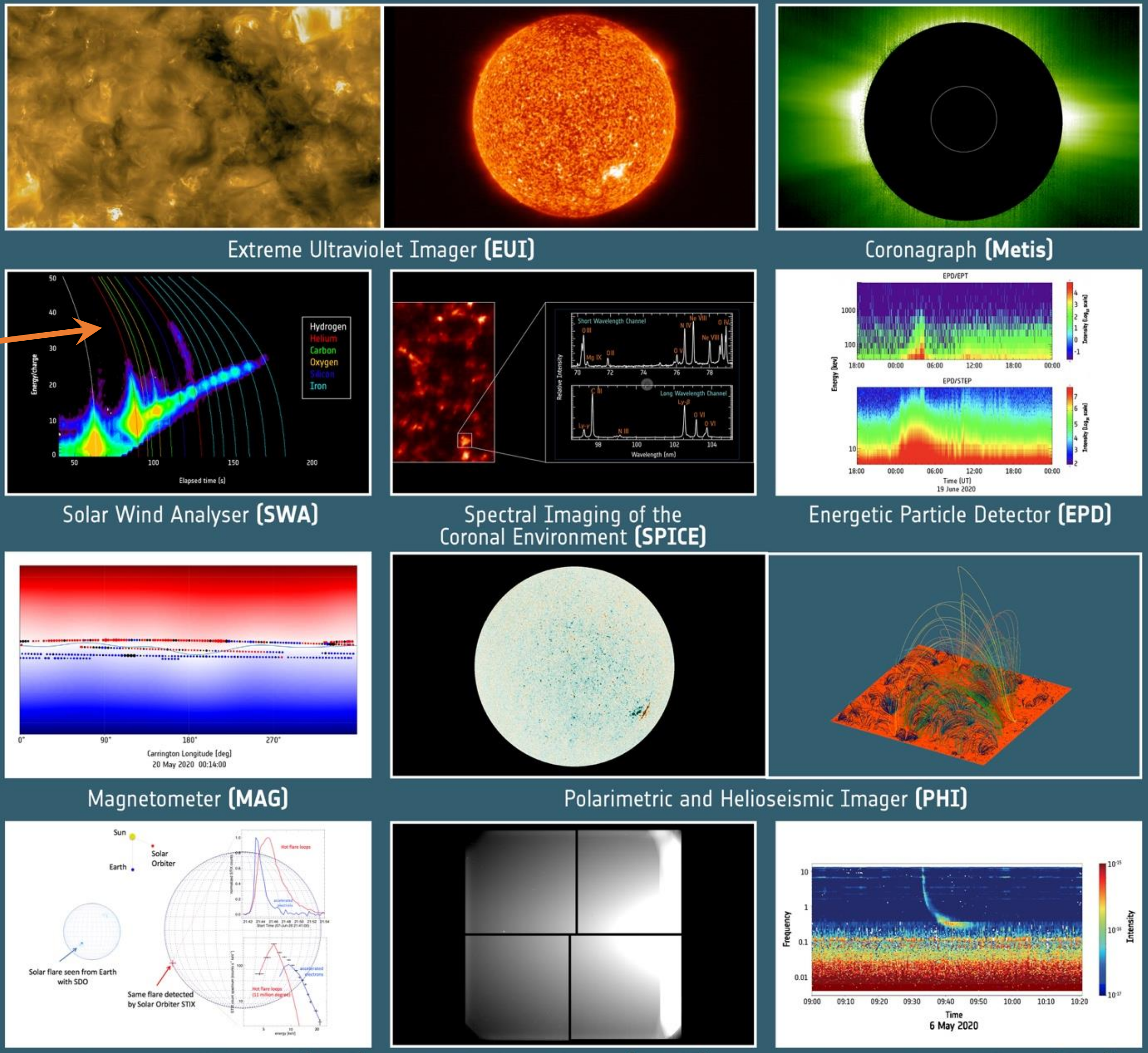
Plotting SPAN-I:
https://github.com/jlverniero/PSP_Data_Analysis_Tutorials

Plotting SPAN-e:
https://github.com/kpaulson/PSPGatewayHelp/tree/master/JupyterNotebook_Tutorials/PSP/SPANe_pitchAngleWalkthrough

SOLAR ORBITER FIRST IMAGES AND MEASUREMENTS

Heavy Ion Sensor (HIS): heavy ions (C, O, Fe etc)





Extreme Ultraviolet Imager **(EUI)**

Coronagraph **(Metis)**

Solar Wind Analyser **(SWA)**

Spectral Imaging of the Coronal Environment **(SPICE)**

Energetic Particle Detector **(EPD)**

Magnetometer **(MAG)**

Polarimetric and Helioseismic Imager **(PHI)**

X-ray Spectrometer/Telescope **(STIX)**

Heliospheric Imager **(SoloHI)**

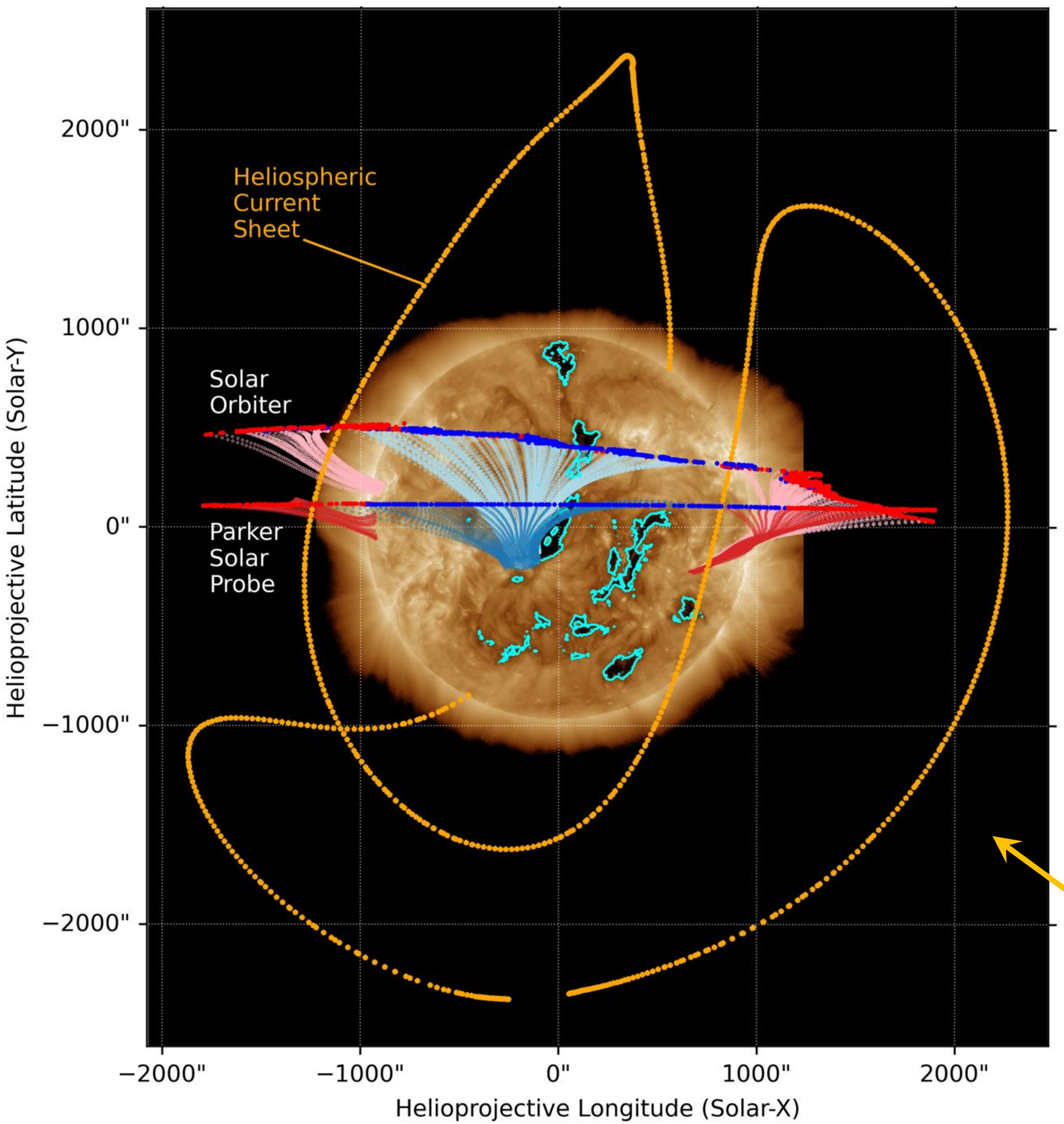
Radio and Plasma Waves **(RPW)**

The *in situ* instruments

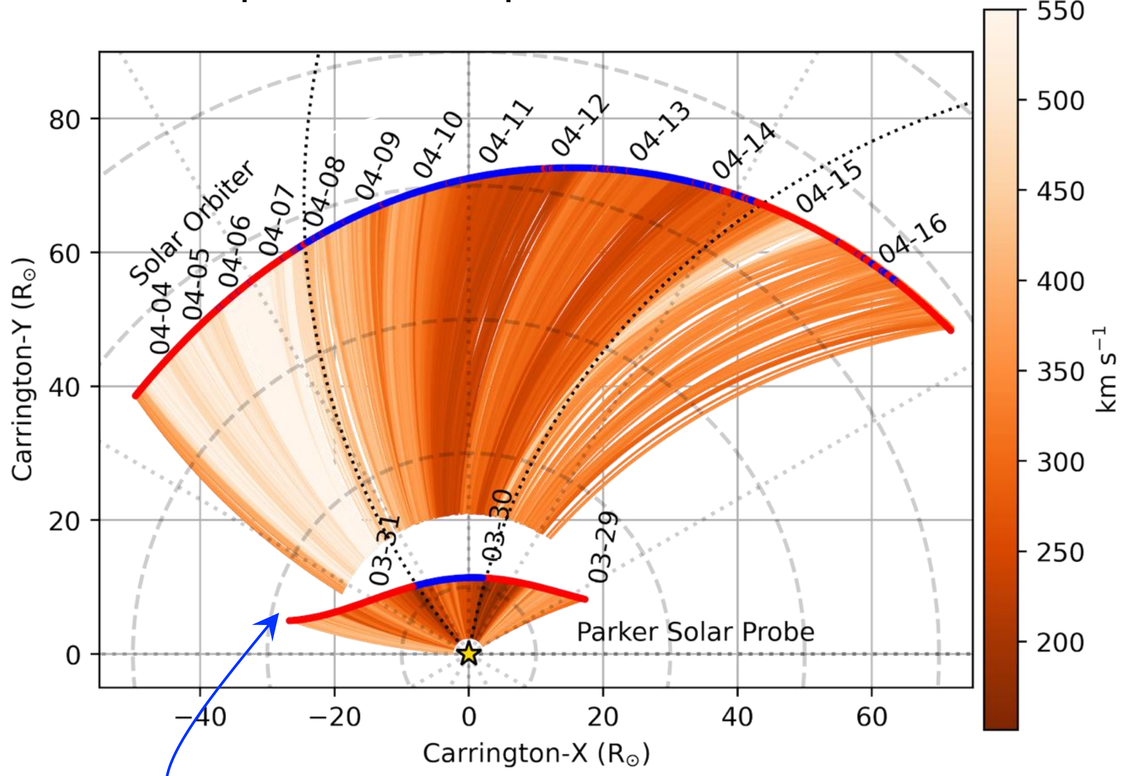
The remote-sensing instruments

#TheSunUpClose

Working together capturing sub-Alfvenic to super Alfvenic evolution



Linking observations from the Sun to spacecraft to spacecraft



Ballistic mapping along flow lines that form Archimedean spirals

PFSS extrapolations map projected spacecraft footpoints to the solar surface

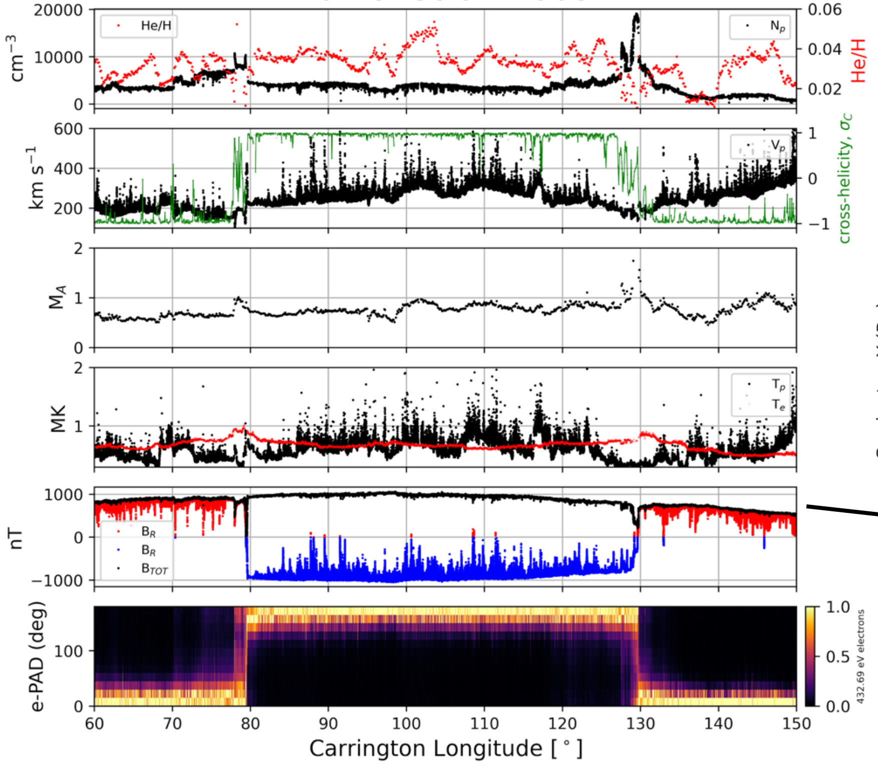
Also see:
Stansby+2019
Badman+2020

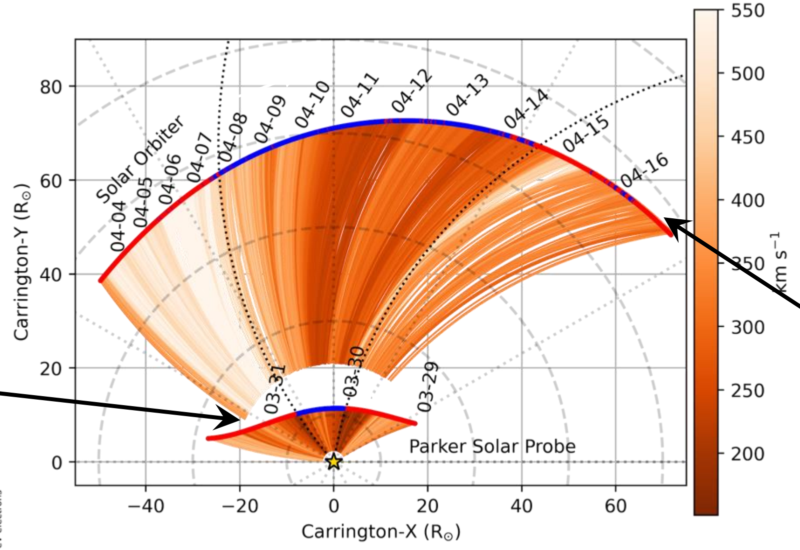
PFSS modeling:
https://github.com/STBadman/PSP_Scholars_Tutorial/blob/main/PFSS_Tutorial.ipynb

Working together capturing sub-Alfvenic to super Alfvenic evolution

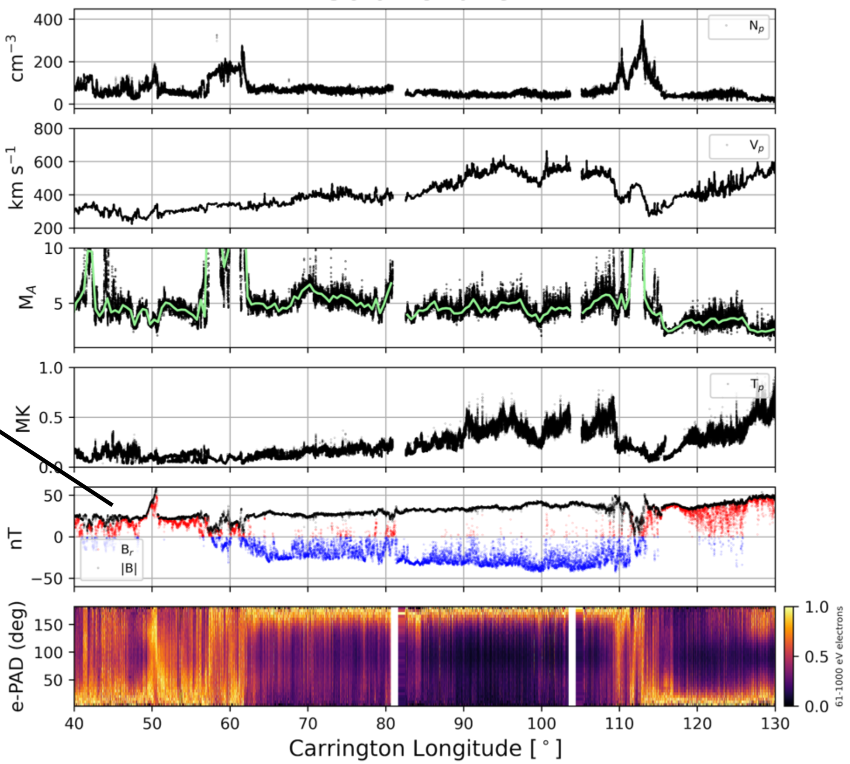
Sampling the same solar wind streams at different stages of evolution

Parker Solar Probe





Solar Orbiter



List of studies capitalizing on Parker and Solar Orbiter conjunctions and quadrature:

Heating and acceleration of fast solar wind (**Rivera, Badman+2024, *Science***)

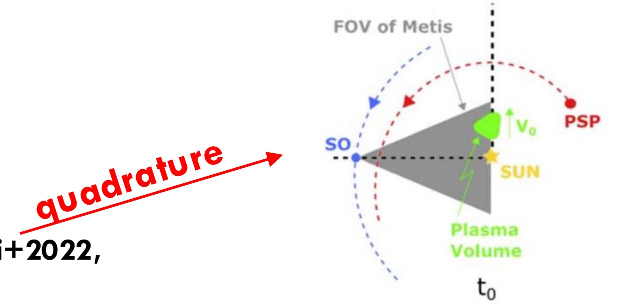
Heavy ion composition of solar wind and their sources (**Ervin+2024**)

Heavy ion and electron temperature of magnetic switchback patches (**Rivera+2024**)

Acceleration of slow and Alfvenic slow solar wind (**Rivera+2025**)

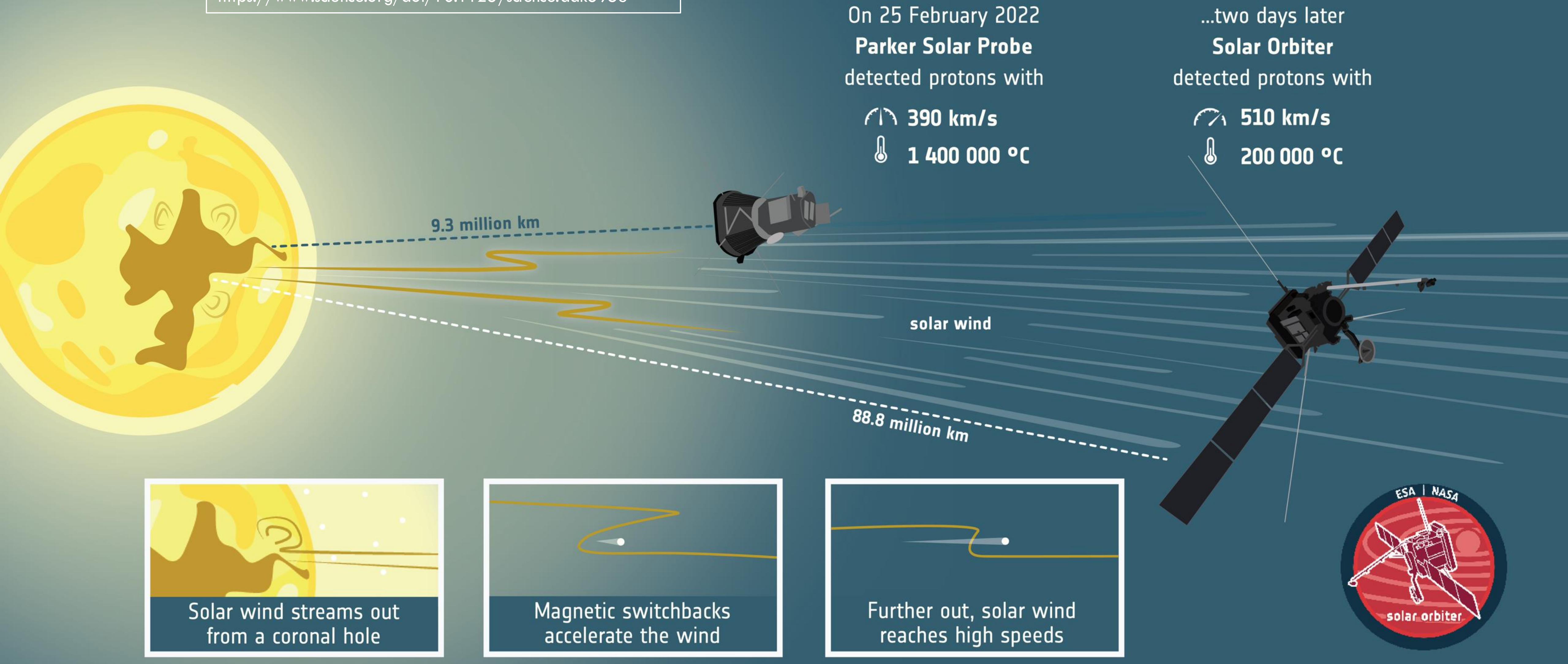
Radial evolution of turbulence (**Telloni+2021a, Perrone+2022, Silwal+2025**)

Connecting extended coronal remote observations with Metis to Parker Solar Probe (**Telloni+2021b, Adhikari+2022, Telloni+2023**)



MAGNETIC WAVES POWER HIGH-SPEED SOLAR WIND

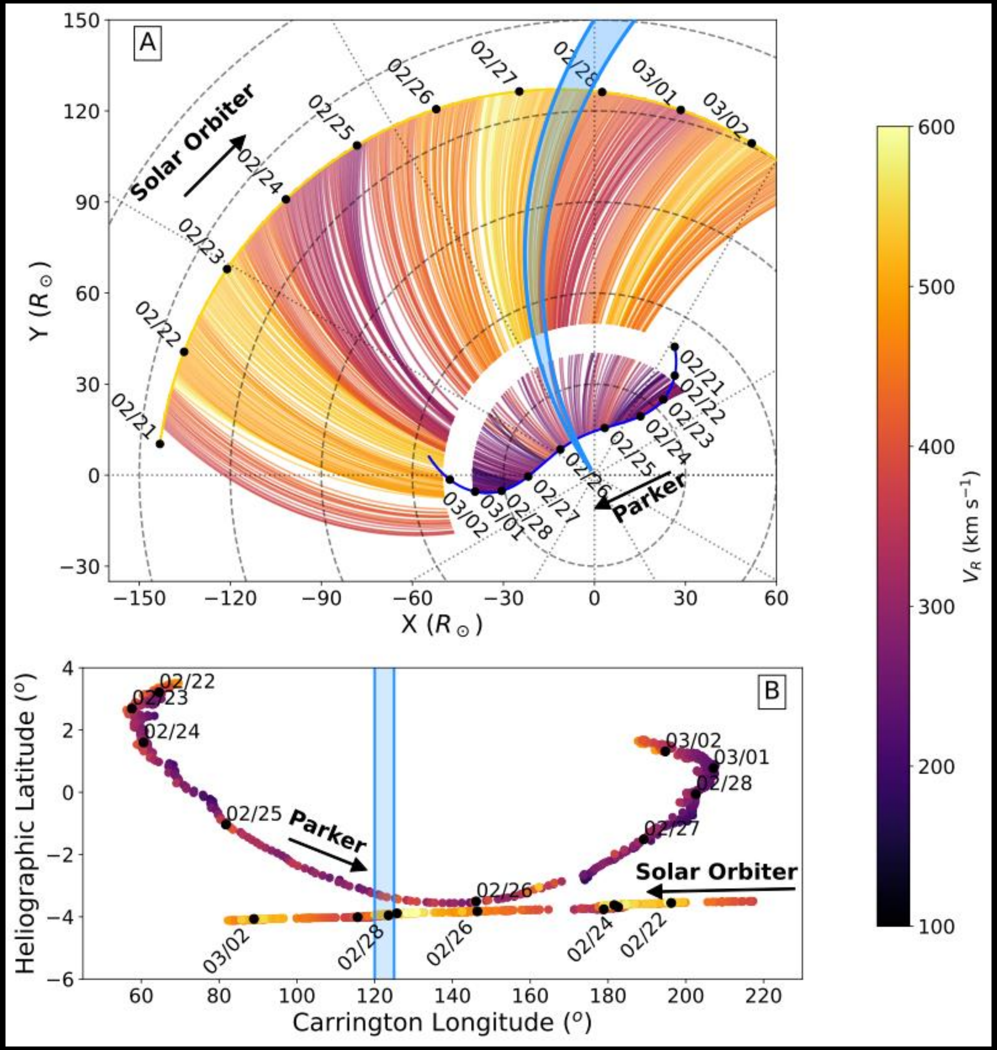
Rivera, Badman+2024, *Science*
https://www.science.org/doi/10.1126/science.adk6953

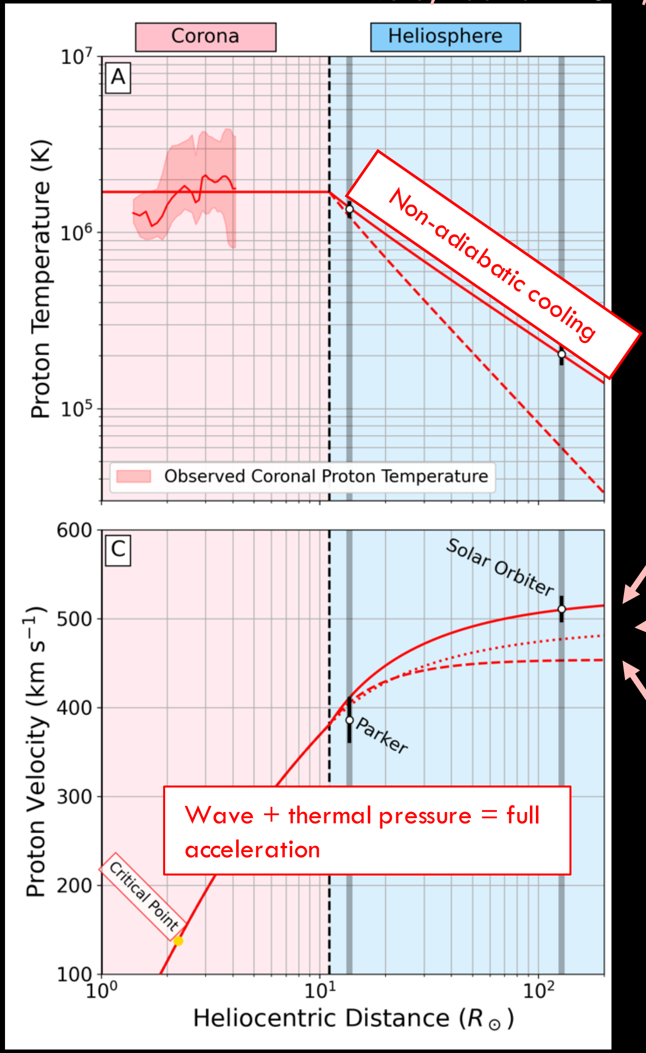


Heating and acceleration of solar wind by large-amplitude Alfven waves

Rivera, Badman+2024, *Science*

Line up in longitude and latitude





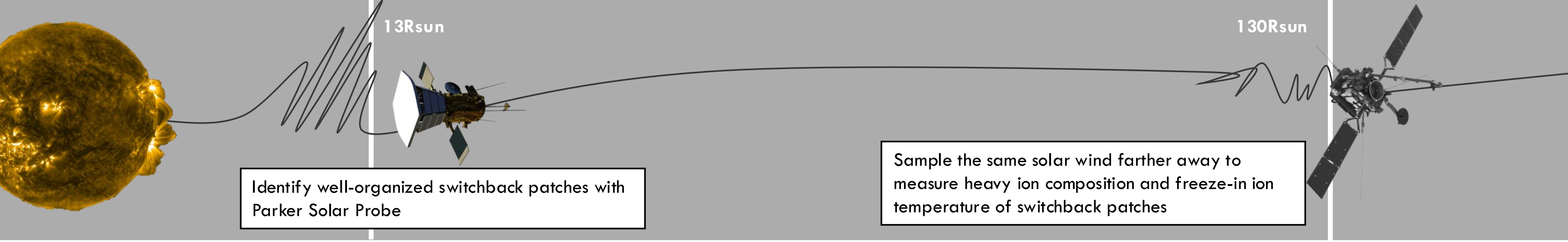
Main takeaway: Full acceleration of fast solar wind could only be achieved through the non-adiabatic thermal pressure and wave pressure gradients together

Polytrope with Alfven wave forcing

Polytrope (non-adiabatic)

Adiabat

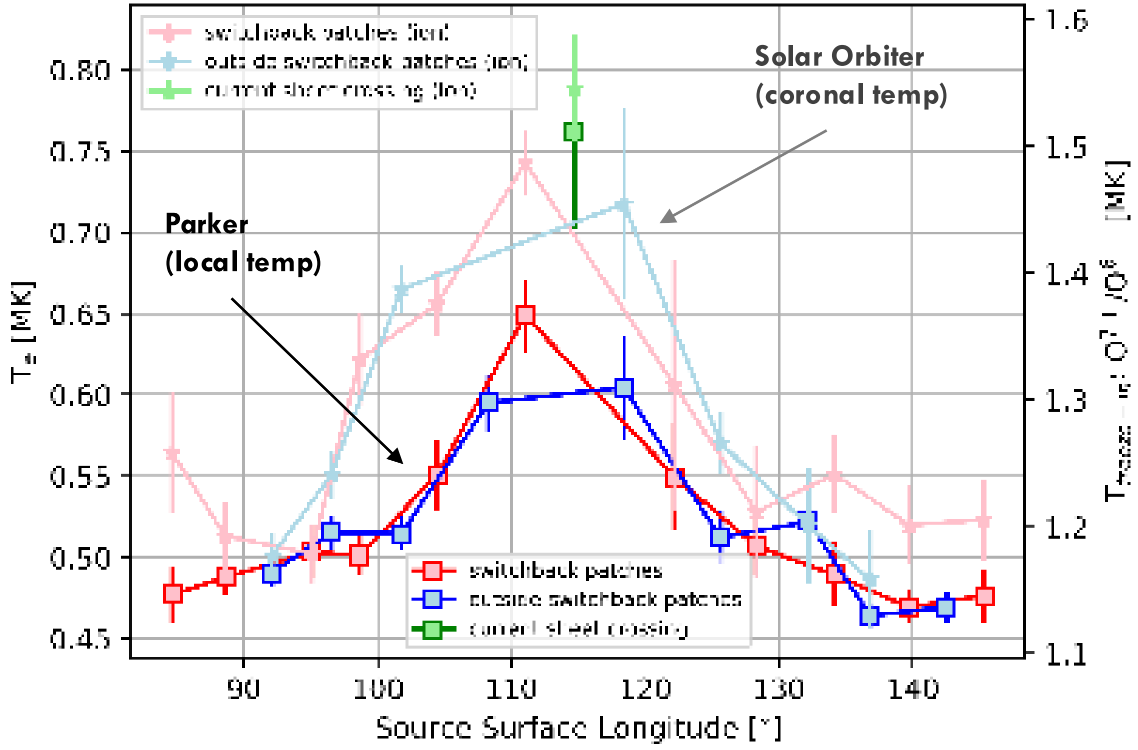
Companion papers:
Acceleration of slow and Alfvenic slow solar wind **(Rivera+2025)**
Radial evolution of turbulence **(Perrone+2022, Silwal+2025)**
Connecting extended coronal remote observations with Metis to Parker Solar Probe **(Telloni+2021, Adhikari+2022, Telloni+2023)**

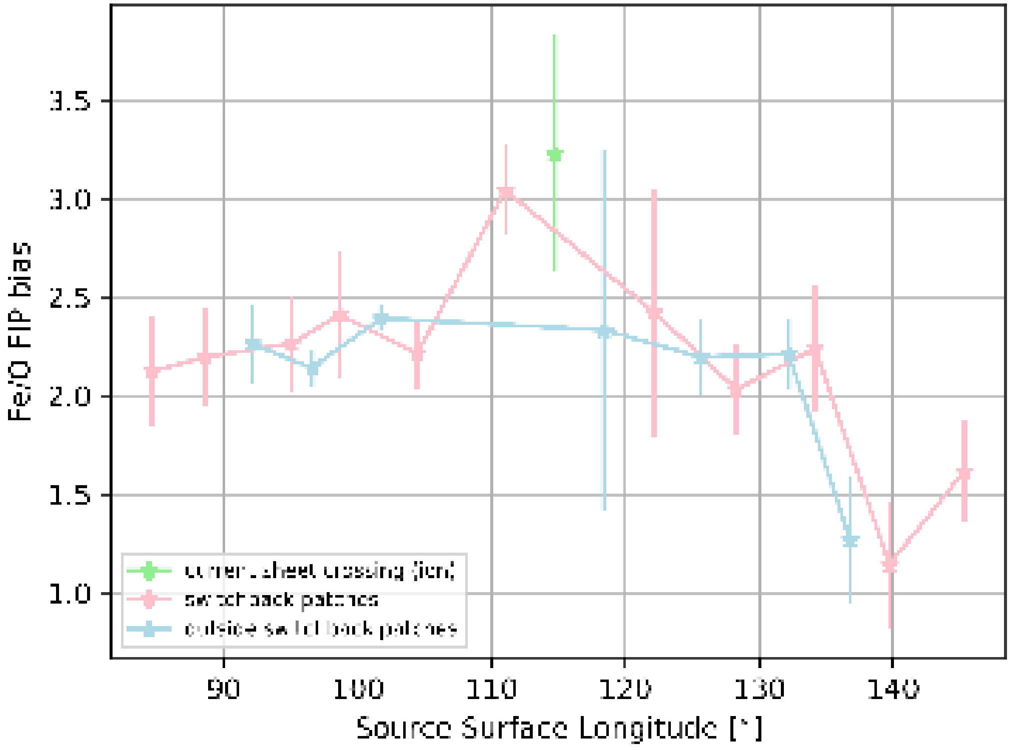


Magnetic switchbacks originate from boundaries of coronal holes

Ion ratios and elemental composition

Rivera+2024b

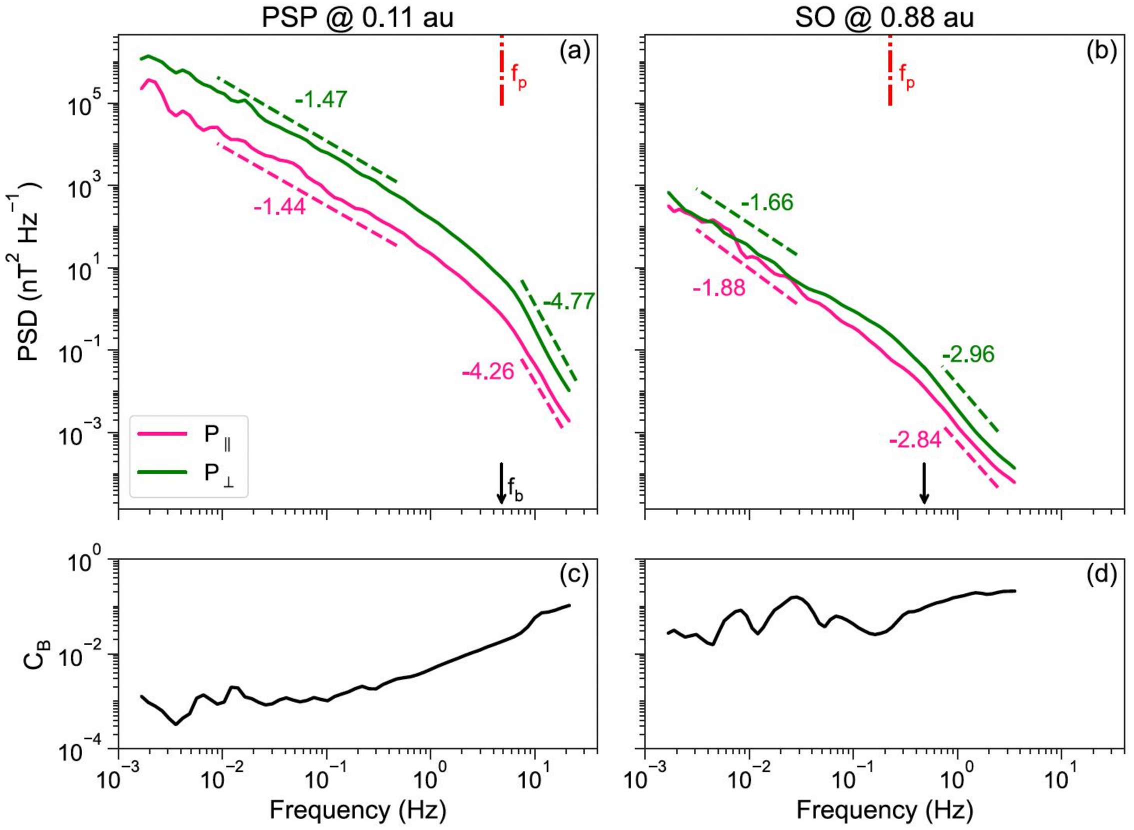


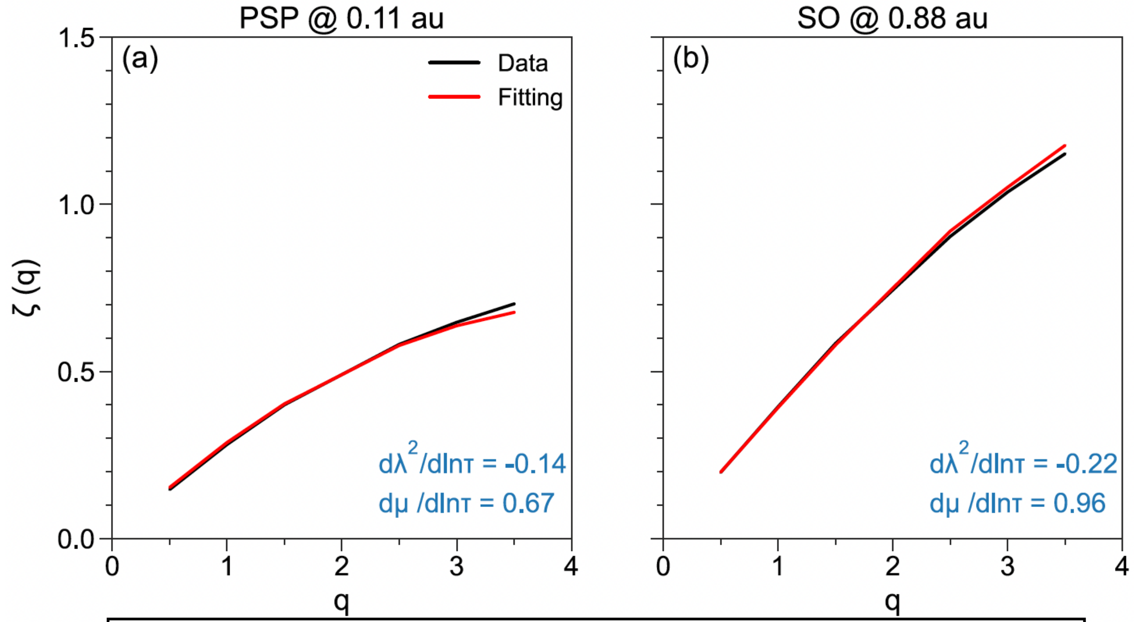


Companion paper: Heavy ion composition of solar wind and their sources (**Ervin+2024**)

Radial Evolution of Solar Wind Turbulence

Silwal+2025

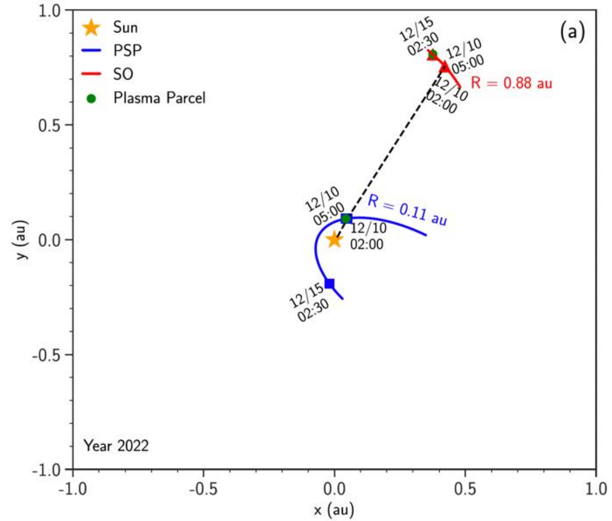




Scaling exponent of the structure function vs. order q in the MHD inertial range

(1) the trace PSD of magnetic fluctuations steepens in the inertial range and flattens in the dissipation range with increasing radial distance
(2) the spectral break shifts to lower frequencies at Solar Orbiter
(3) the Castaing model reveals multifractal intermittency in the inertial range, with slightly weaker intermittency at Solar Orbiter

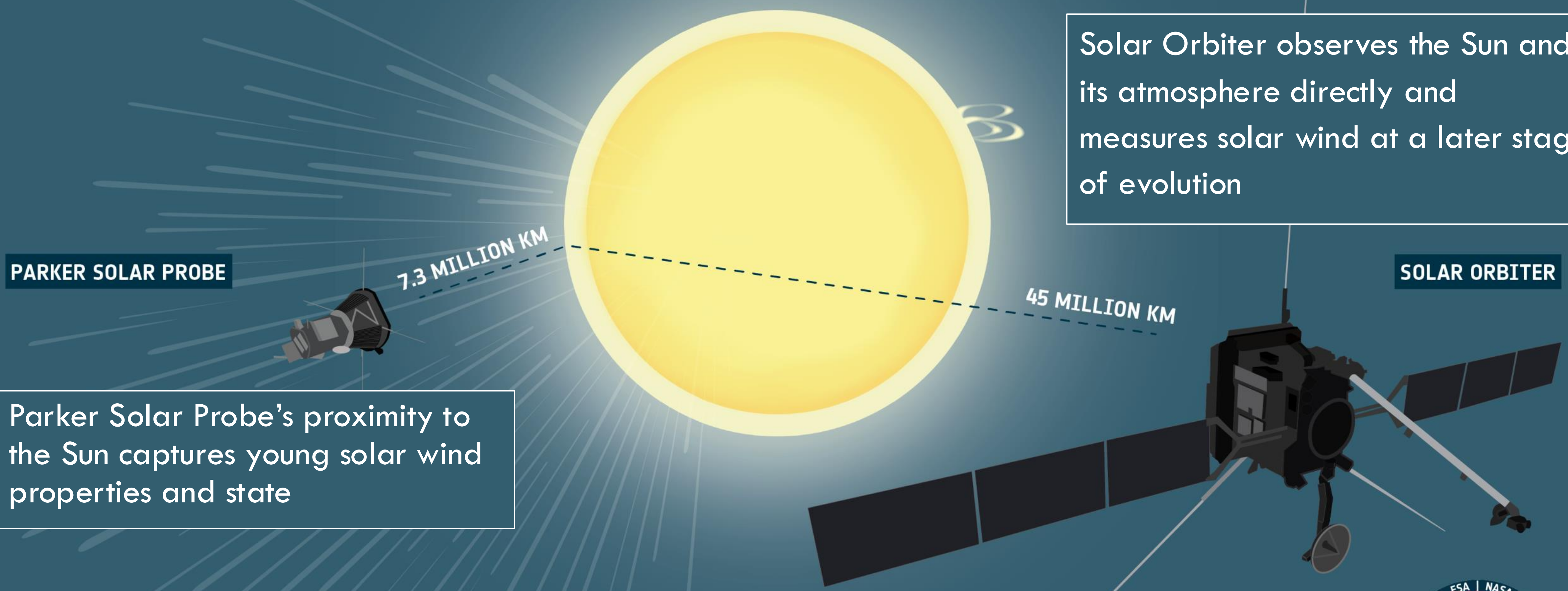
Companion papers: Radial evolution of turbulence (Telloni+2021, Perrone+2022)



TEAMING UP TO STUDY THE SOLAR WIND

esa

Solar Orbiter observes the Sun and its atmosphere directly and measures solar wind at a later stage of evolution



Parker Solar Probe's proximity to the Sun captures young solar wind properties and state

Their combined observations tell us about where the solar wind originates on the Sun and how it evolves through space – addressing outstanding fundamental questions in solar physics

ESA | NASA solar orbiter

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yeimy.rivera@cfa.harvard.edu

Future orbits for conjunction studies

High latitude passes with Solar Orbiter will provide more multi-point analysis of the solar wind and magnetic structure

More diverse spacecraft lineups

If you are interested in any of the plots I showed, I am happy to share code to reproduce them

Solar Orbiter – Webinar 9:
yeimy.rivera@cfa.harvard.edu