JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Stream Interaction Regions in the Inner Heliosphere: Insights from the First Four Orbits of Parker Solar Probe

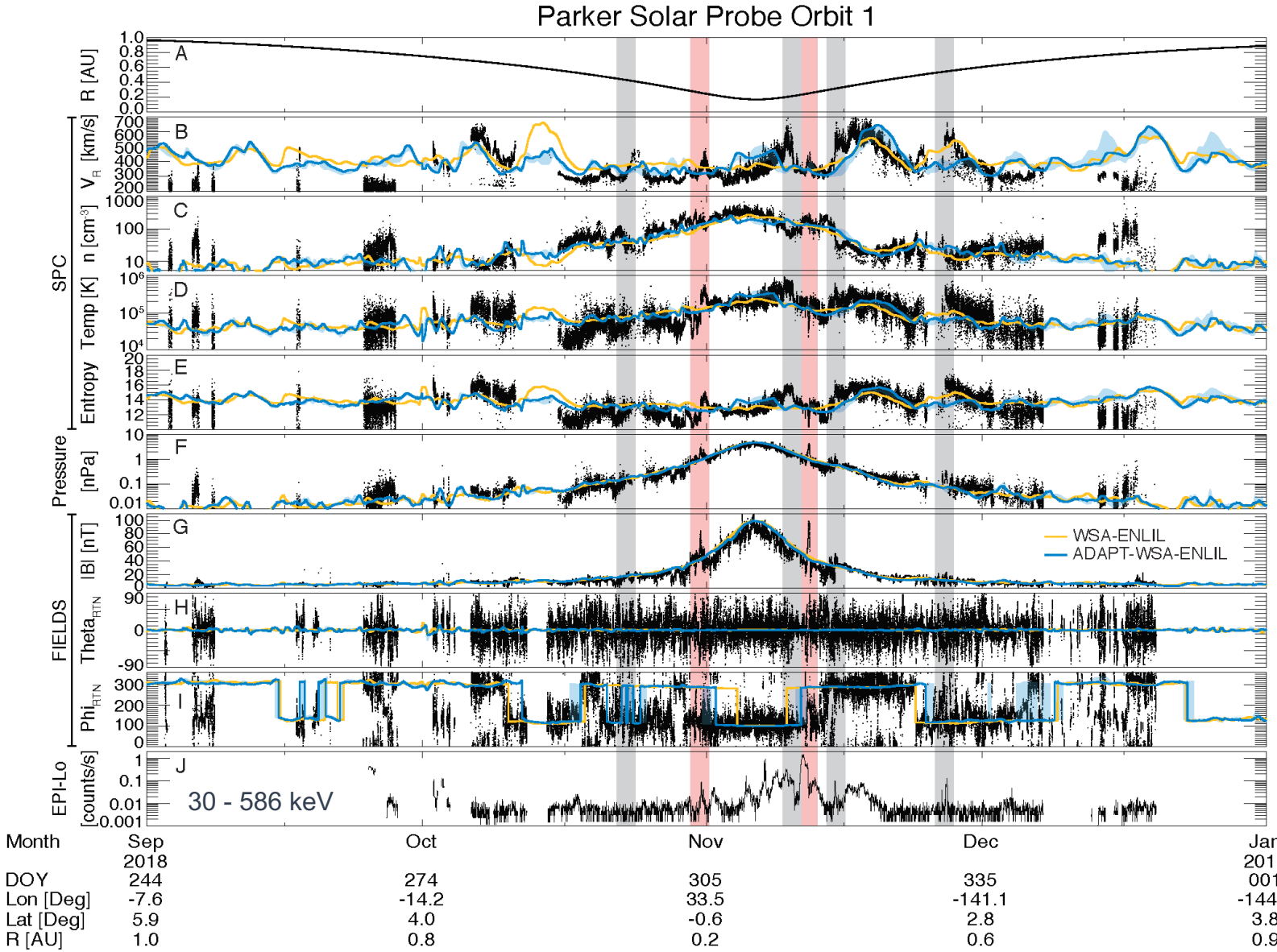
Robert C. Allen

George Ho, Lan Jian, David Lario, Dusan Odstrcil, Charles Arge, Sam Badman, Stuart Bale, Anthony Case, Eric Christian, Christina Cohen, Carl Henney, Matthew Hill, Shaela Jones, Justin Kasper, Kelly Korreck, David Malaspina, David McComas, Nour Raouafi, and Michael Stevens, SWEAP, ISOIS, & FIELDS teams

Recap of an event in our ApJS

Allen et al. (2020) Solar Wind Streams and Stream Interaction Regions Observed by the Parker Solar Probe with Corresponding Observations at 1au, *ApJS*, doi: 10.3847/1538-4365/ab578f.

Parker Solar Probe Orbit 1 Context

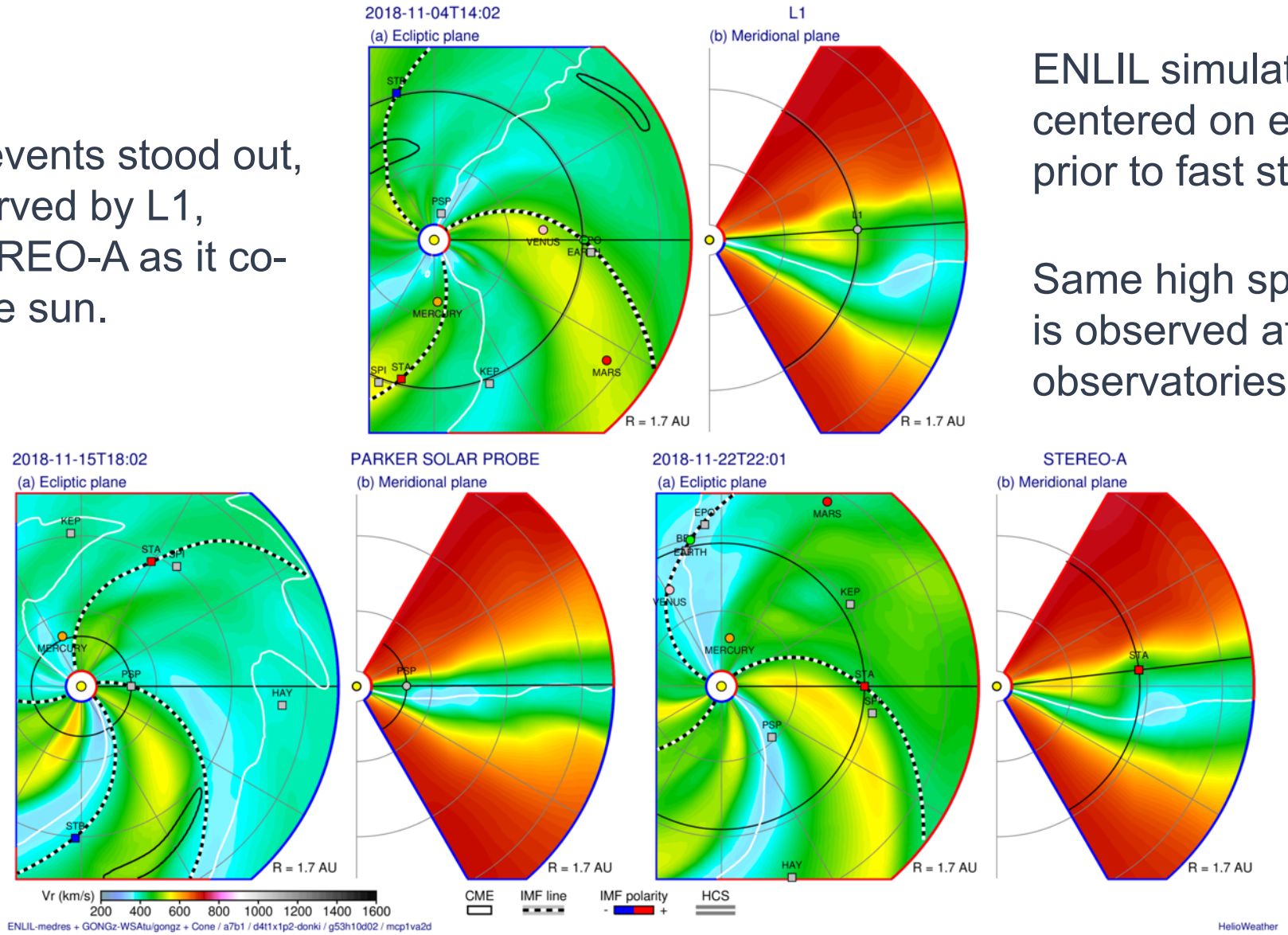


- **Using the first orbit of PSP, we found conjunctions of high speed streams observed by SWEAP with missions at 1 au (STEREO-A, Wind, and ACE).**

- Grey regions denote transitions to/from fast and slow streams studied in this paper.
- Red regions denote CME-associated intervals and were not discussed in this paper.
- Blue traces show results from GONG-ADAPT-WSA-ENLIL (ADAPT realization 7)
  - Shaded regions show the min-to-max range of results using realizations 0, 2, 7, and 9.
- Yellow traces show the results from GONG-WSA-ENLIL
- Prior to perihelion (Nov 5th) PSP is closer in longitude to L1
- After perihelion PSP is closer in longitude to STEREO-A.

SIR Observed at L1, PSP, and STEREO-A

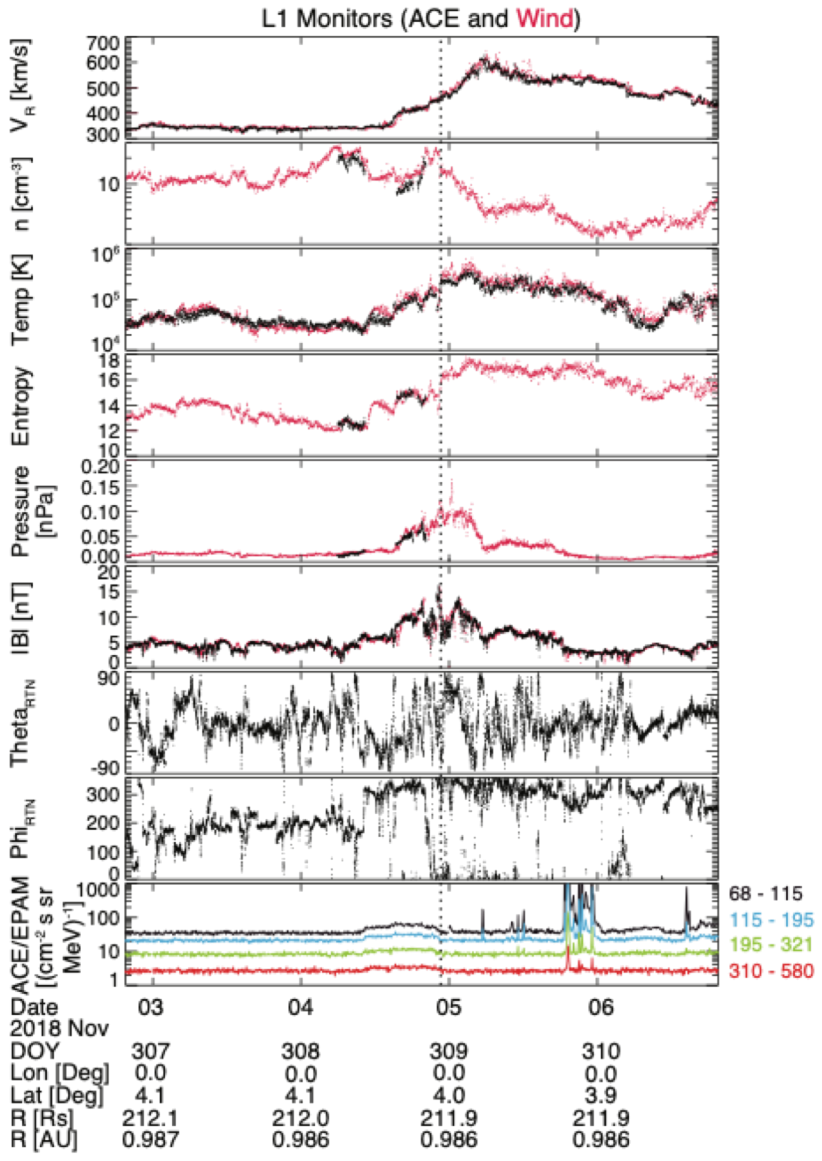
One of these events stood out, as it was observed by L1, PSP, and STEREO-A as it co-rotated with the sun.

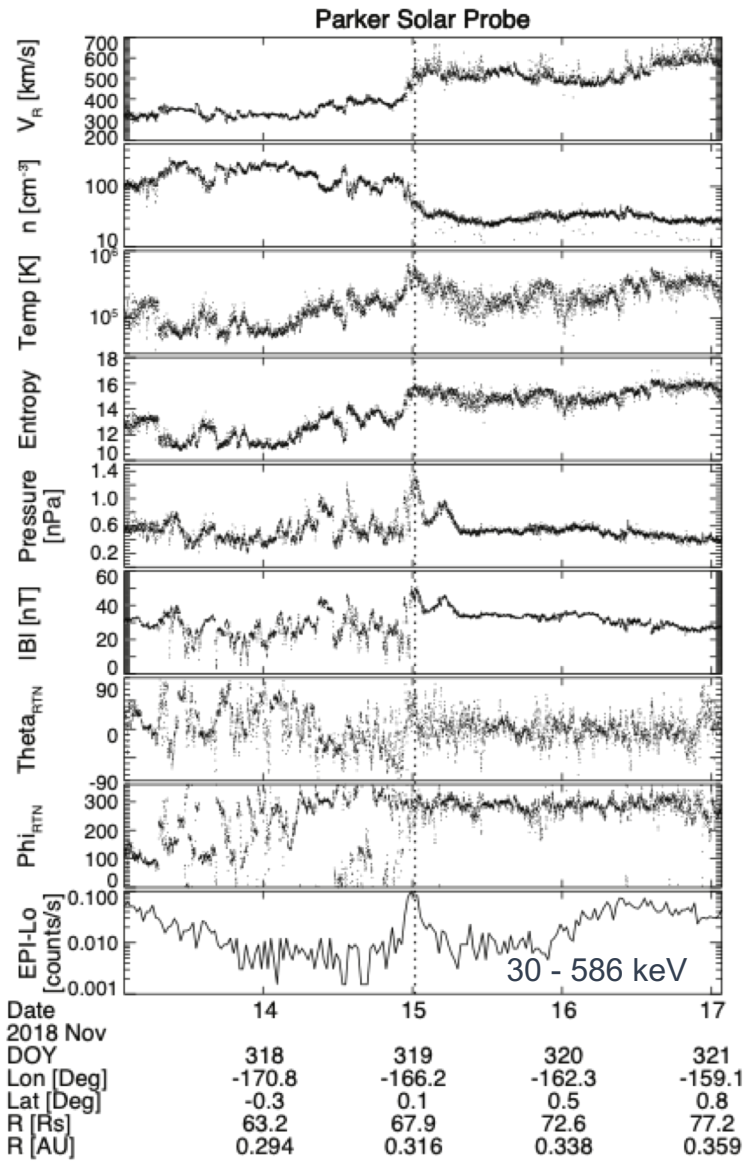


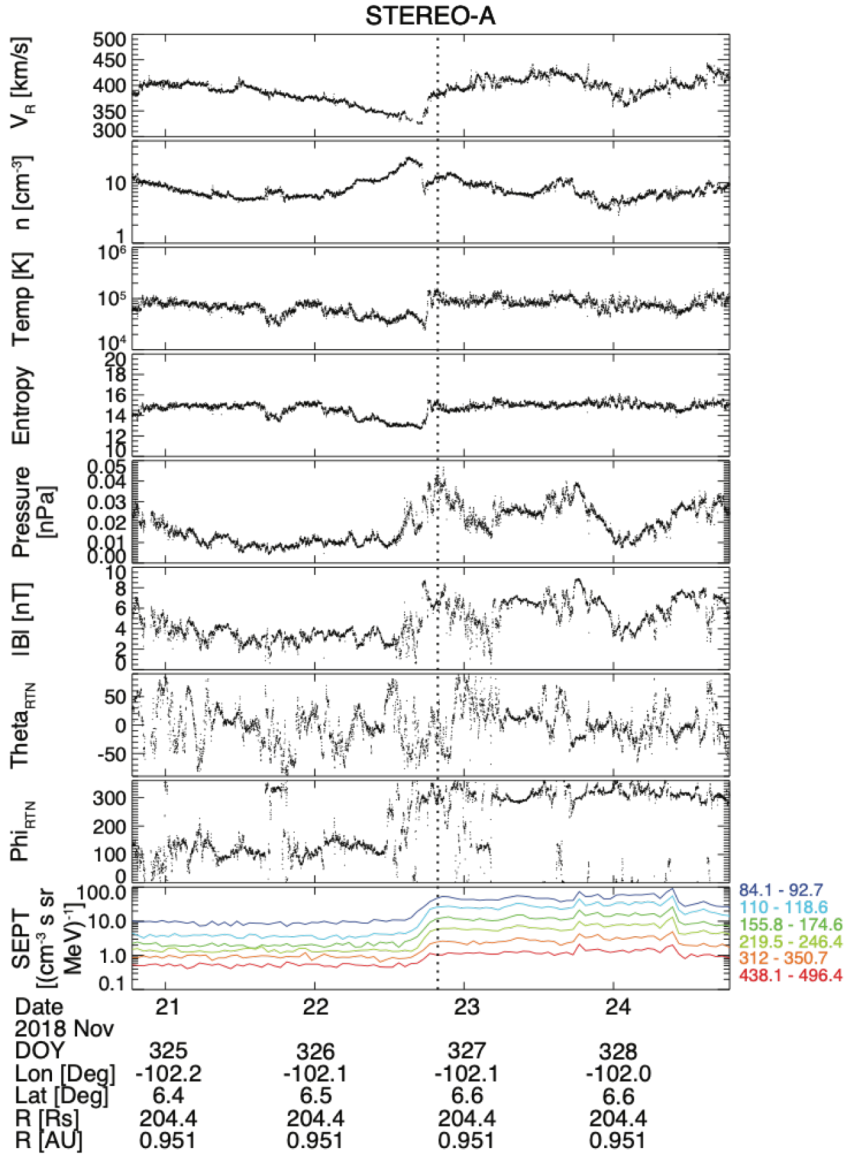
ENLIL simulations centered on each location prior to fast stream arrival:

Same high speed stream is observed at all three observatories

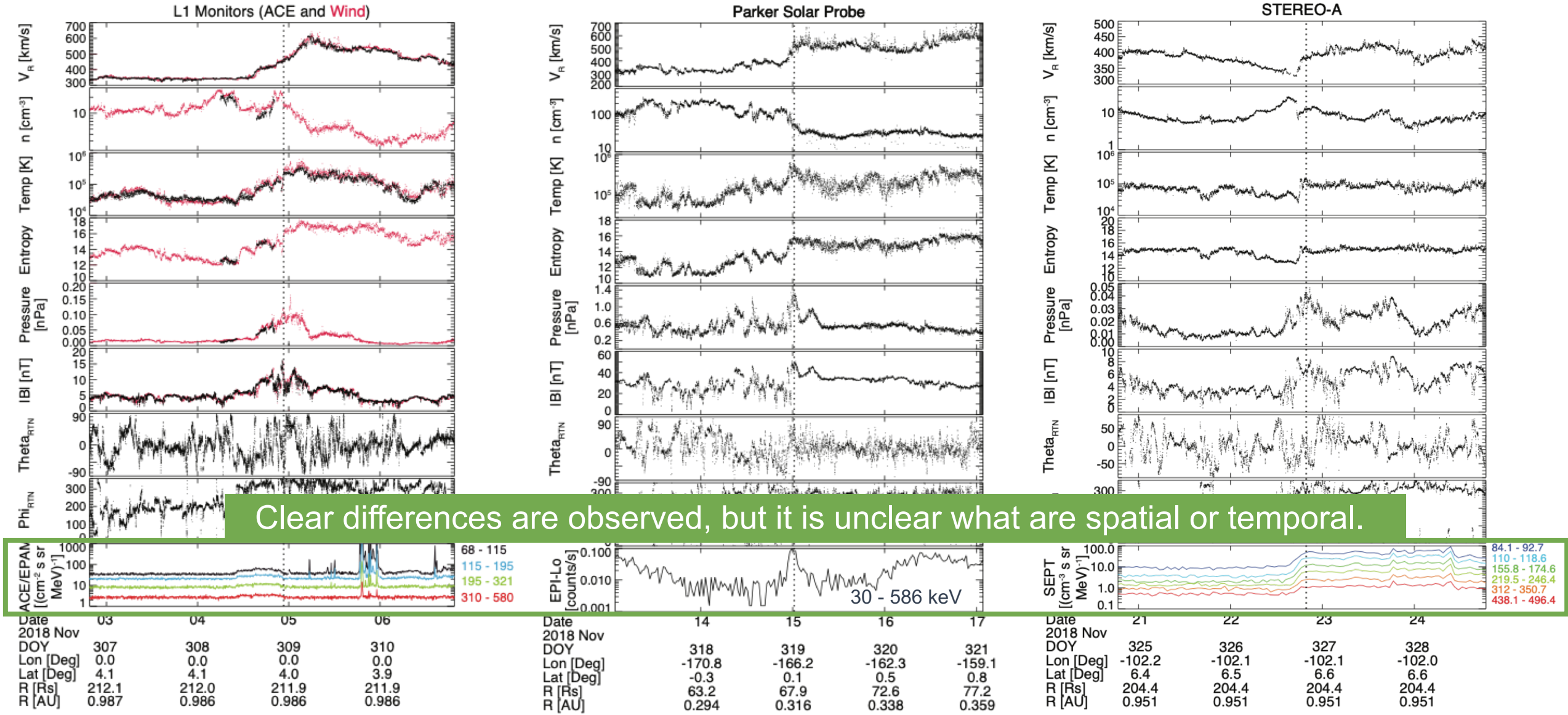
Comparing an SIR at Different Locations/Times







Comparing an SIR at Different Locations/Times



Clear differences are observed, but it is unclear what are spatial or temporal.

New event from extending our conjunction list

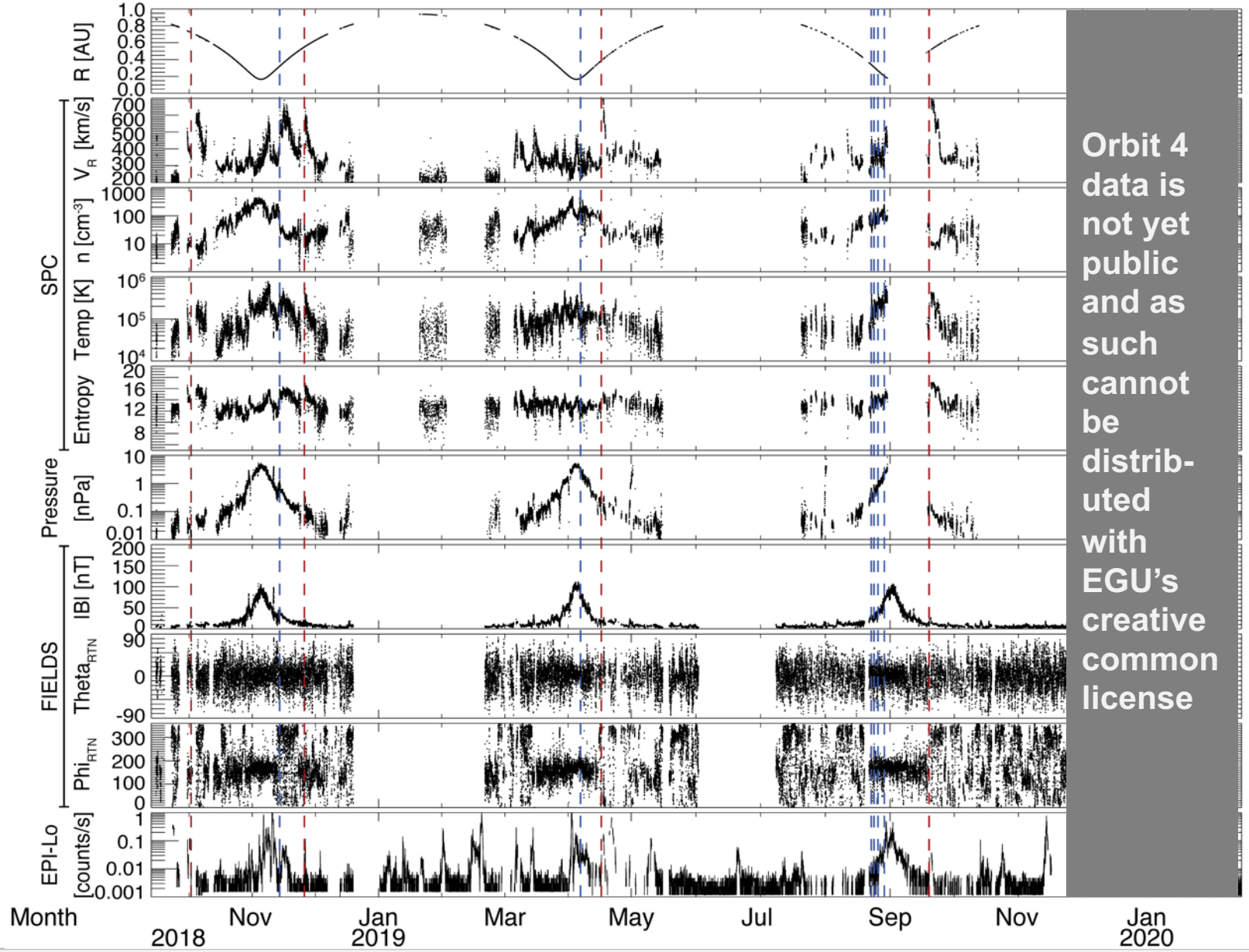
We have extended our event list through orbit 4.

One event stood out in particular, which is what we will be discussing here.

SIR/CIR event list methodology

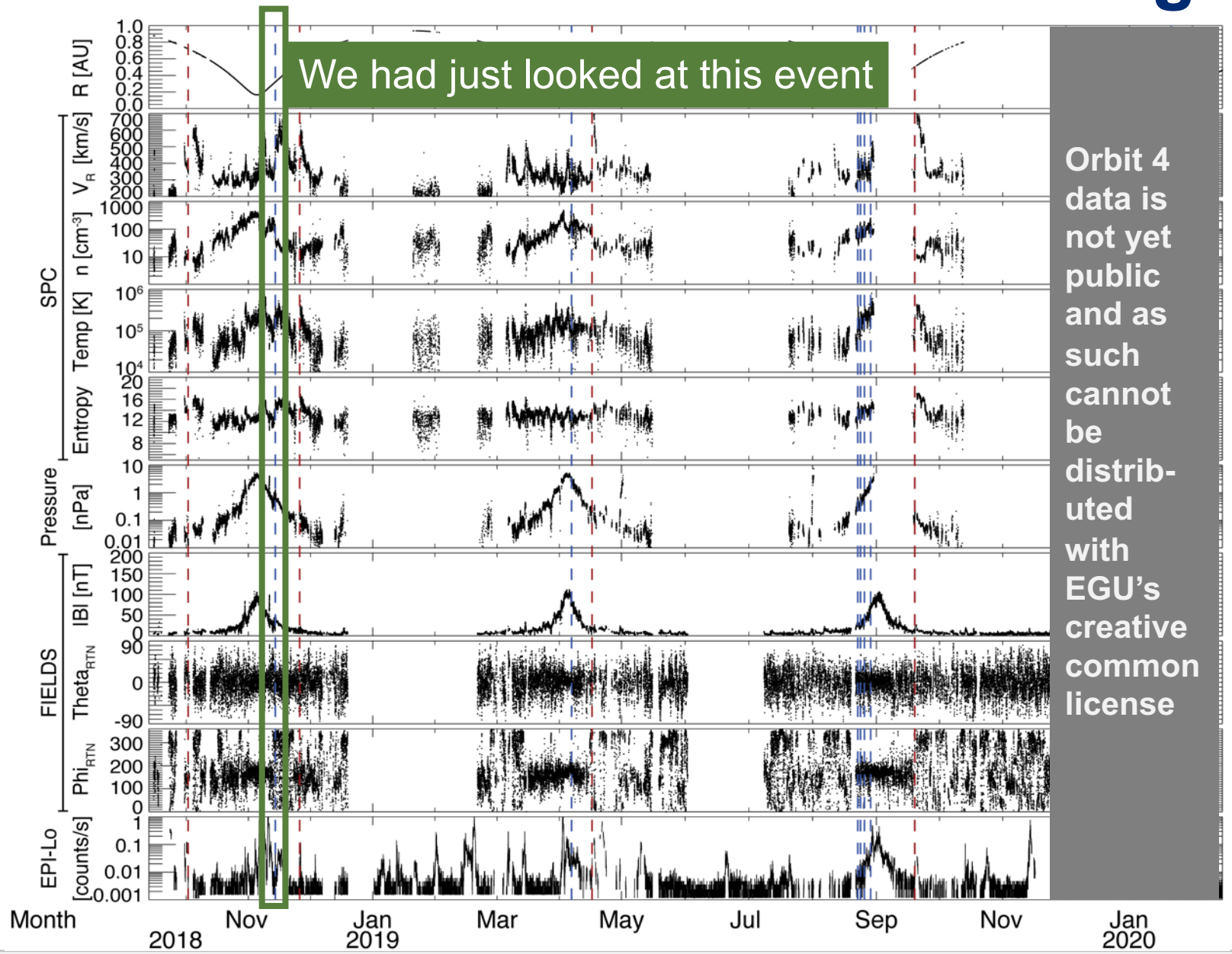
- Using similar criteria based on *Jian et al.* (2006; 2013) we look for events that match most of the following criteria:
  - Velocity increase
  - Pressure peak at the interface
  - Compression of density ahead of interface
  - Peak in magnetic field magnitude during velocity increase
  - Temperature and entropy increase from slow to fast solar wind
  - Tangential flow deflection around the interface
- The events are given an ambiguous counter from 0 to 2
  - 0: Clean event, no data gaps (example from previous slides)
  - 1: Clean events, some data gaps before/after the velocity increase (currently no events in this category)
  - 2: Missing some desired data/larger data gaps during velocity increase (example in upcoming slides)
- Any SIR/CIR observed at PSP is analyzed to see if it was also seen at STEREO-A and/or ACE/Wind.
  - Future orbits will also be checked against Solar Orbiter
- This list with initial statistics will be submitted soon. The list will be housed on the PSP Science Gateway (sppgway.jhuapl.edu), and updated with the public data releases.

SIRs and CIRs in Orbits 1 through 4



- SIRs and CIRs on list are marked by vertical dashed lines.
  - List is still preliminary and subject to refinement.
- Clean events without data gaps (ambiguous marker = 0) are blue.
- Events with data gaps (ambiguous marker = 2) are red.
- Several large velocity increases are seen that are not on the list, usually related to a CME.
- We will now focus on one of the ambiguous events observed in orbit 3.

SIRs and CIRs in Orbits 1 through 4



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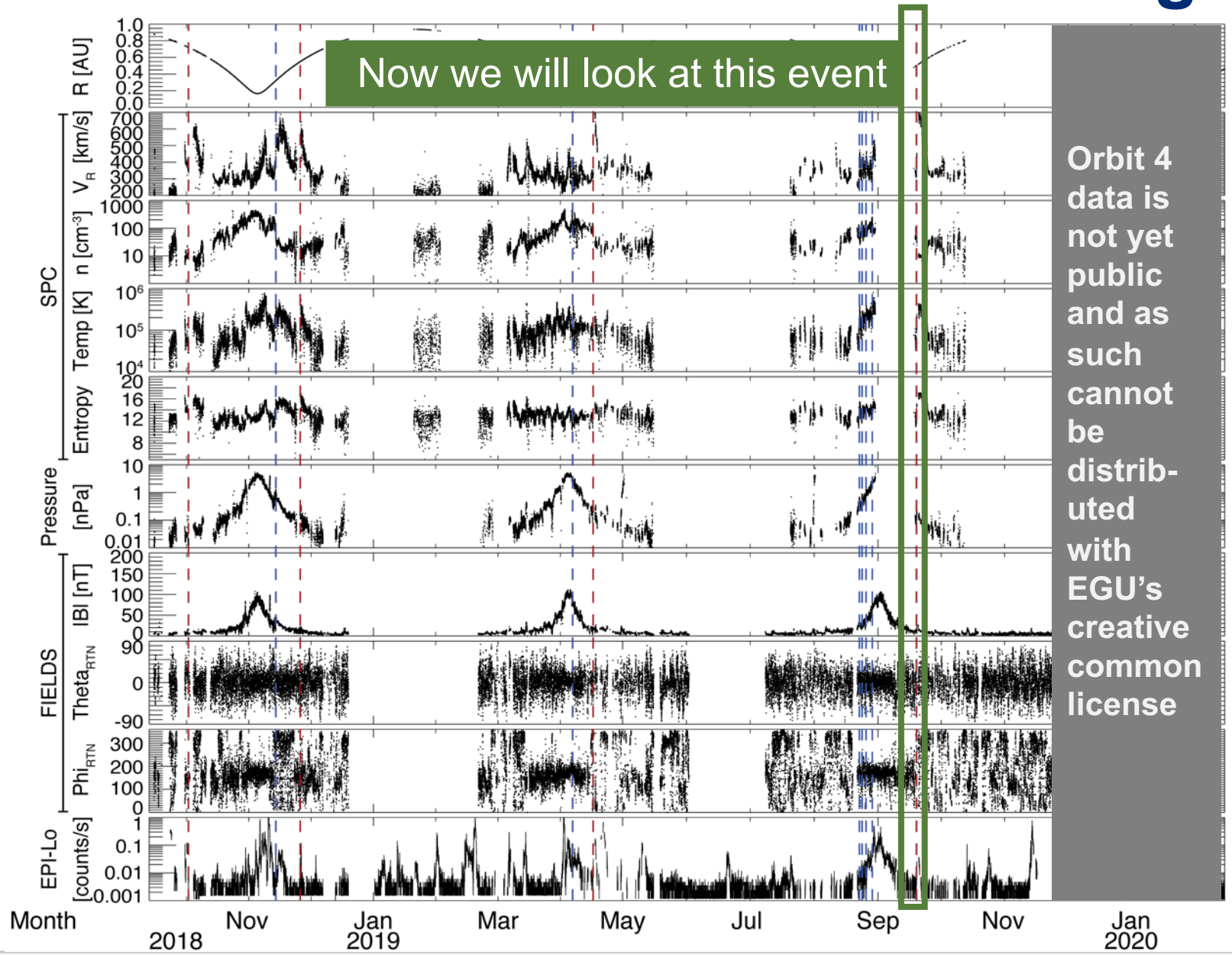

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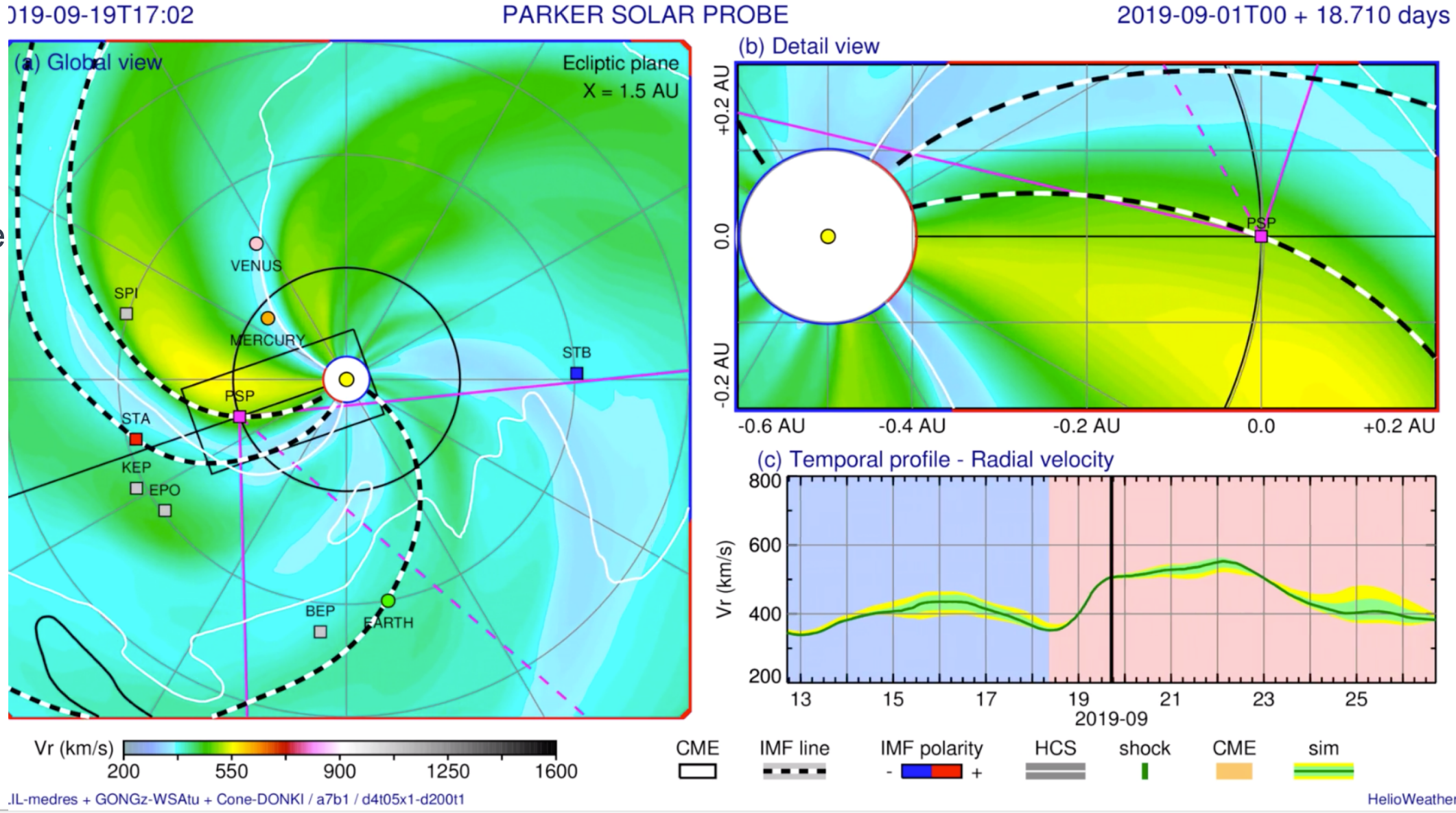
ENLIL for Event

A high speed stream was observed when PSP and STEREO-A were near-radially aligned

May allow for a study of the radial evolution of CIR with little source or temporal variation.



PSP Observation

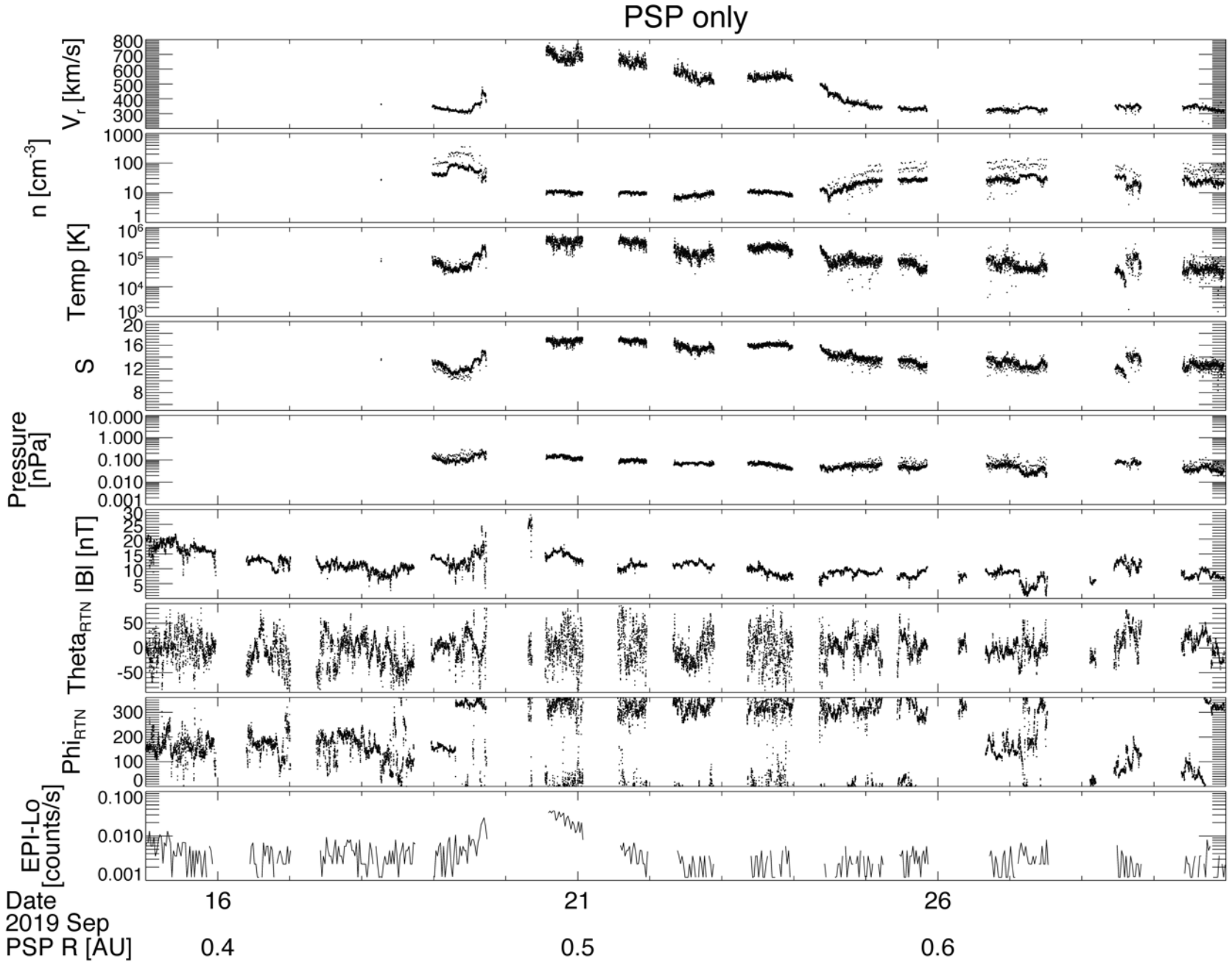
CIR is observed at PSP at ~0.5 au after encounter

CIR was observed shortly after SPC came back online

Many unfortunate gaps due to telemetry downlink

However, general structure is visible!

Example of event with an ambiguous marker set to 2 due to data gaps.

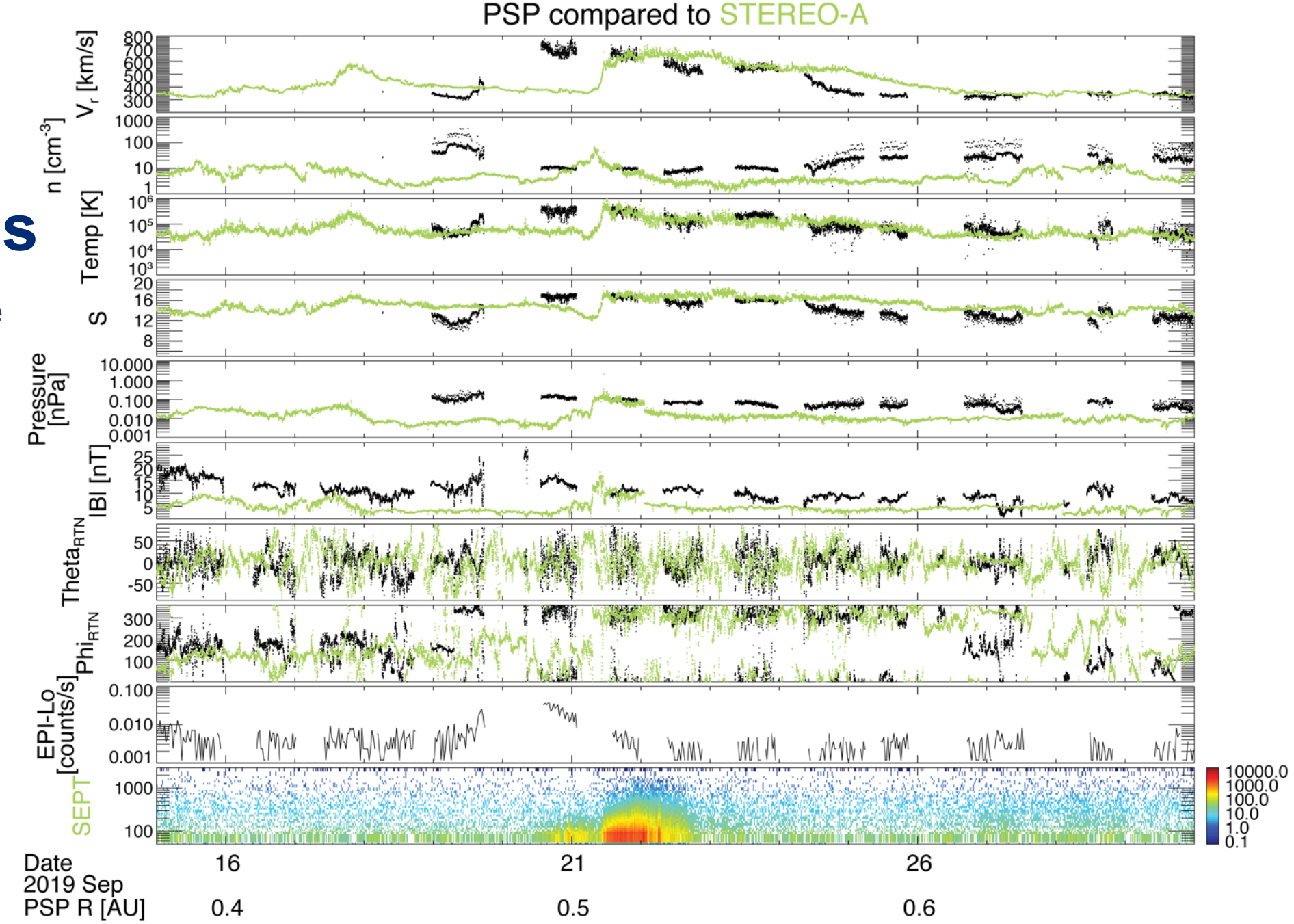


PSP and STEREO-A Observations

STEREO observed the CIR a little over a day and a half after PSP

The structure looks very similar as observed at PSP

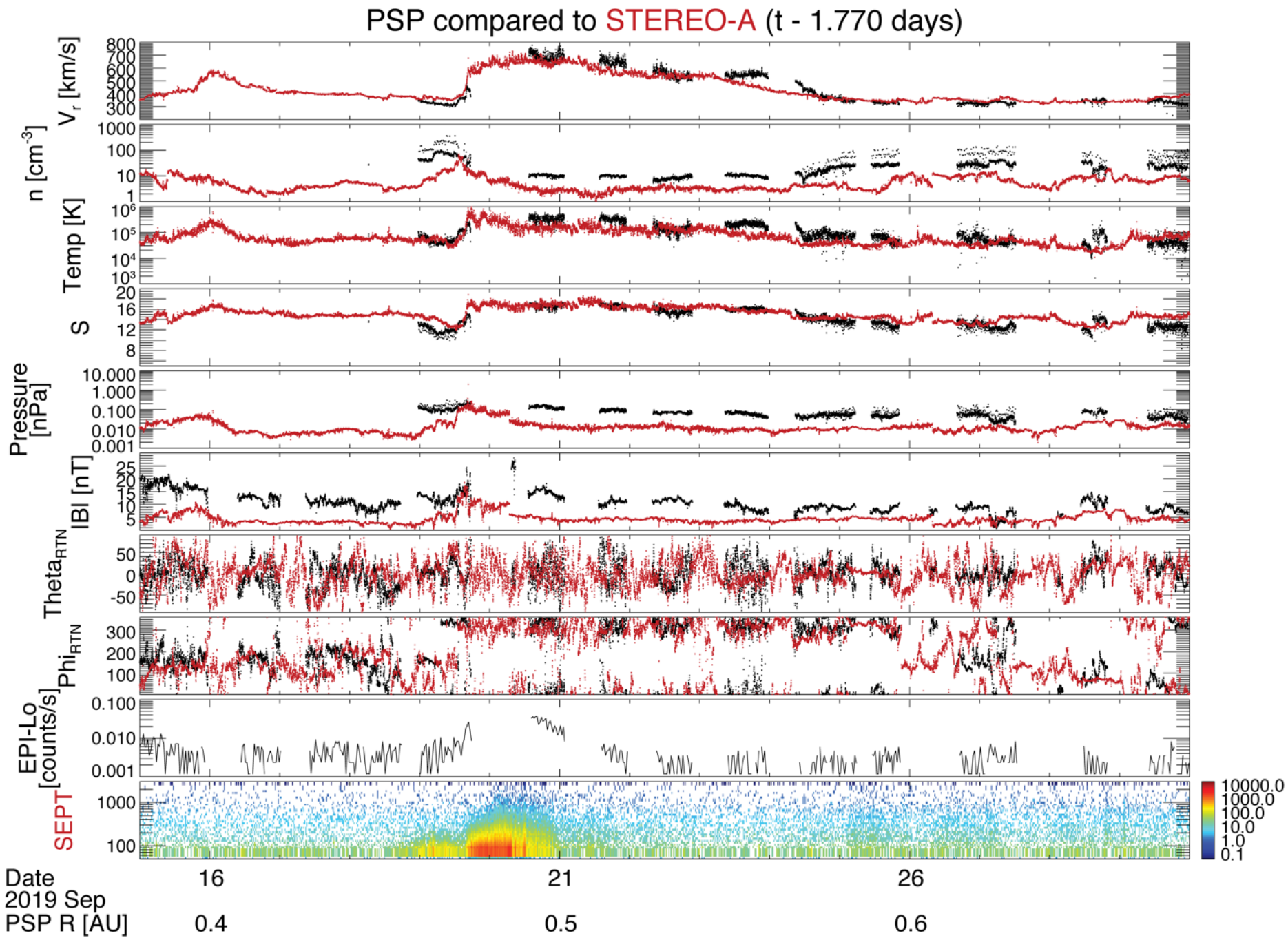
(Not shown, this is the third solar rotation in which STEREO-A observed this structure, making it a CIR)



PSP and Time-Shifted STEREO-A Observation

Time-shifting the STEREO-A observations back by 1.77 days lines up the timing of the CIR very well.

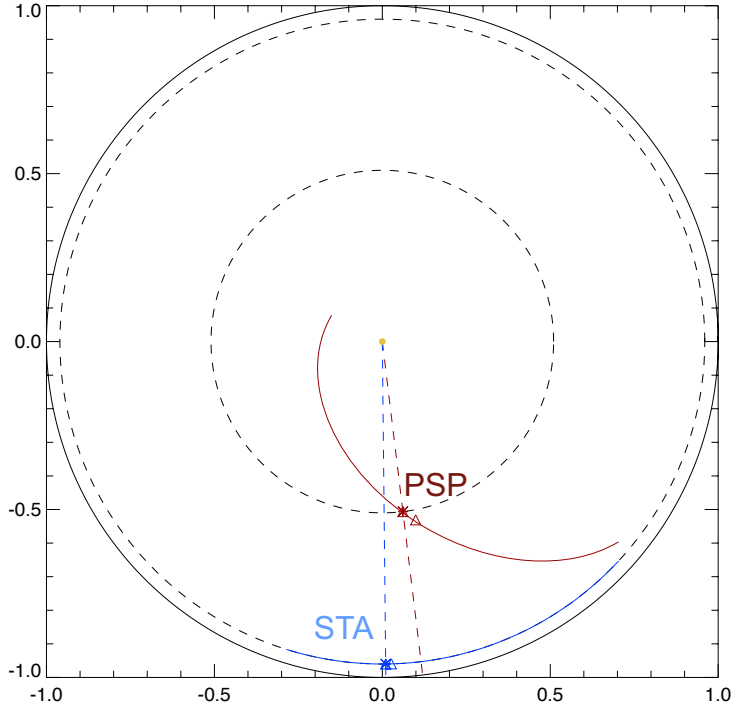
Next slide looks at this time-shift more…



Delving deeper into the lag time

- Ignoring the effects of longitude, the ballistic radial lag time is only 1.69 days
  - Using a speed of 468 km/s (mid point of slow and fast wind).
  - There would be a discrepancy of 0.08 days if ignoring differences in Longitude – close!
- STEREO-A is behind PSP in longitude
  - The CIR should have reached STEREO-A faster than a simple radial ballistic lag time
  - Using 14.6 degrees/day co-rotation, and treating the CIR as a rigid structure, the CIR should arrive at STA 0.39 days faster than simple radial ballistic propagation.
    - Resulting in a predicted lag time of 1.3 days
      - Including both the longitudinal difference and the ballistic radial lag, there is a discrepancy of 0.47 days.
- Could this is an effect of latitudinal differences?
  - Not likely, the two spacecraft are only 0.26 degrees apart in latitude.

Perhaps this is evidence of the CIR structure not being a rigid interface.



Solar wind radial velocity	468 km/s
Radial distance	0.45617082 au
Ballistic radial lag	1.69 days
Longitudinal difference	-5.7147005 degrees (HGI)
Co-rotation speed	~14.7 degrees/day
Co-rotation lag	-0.39 days
Total lag time	1.30 days

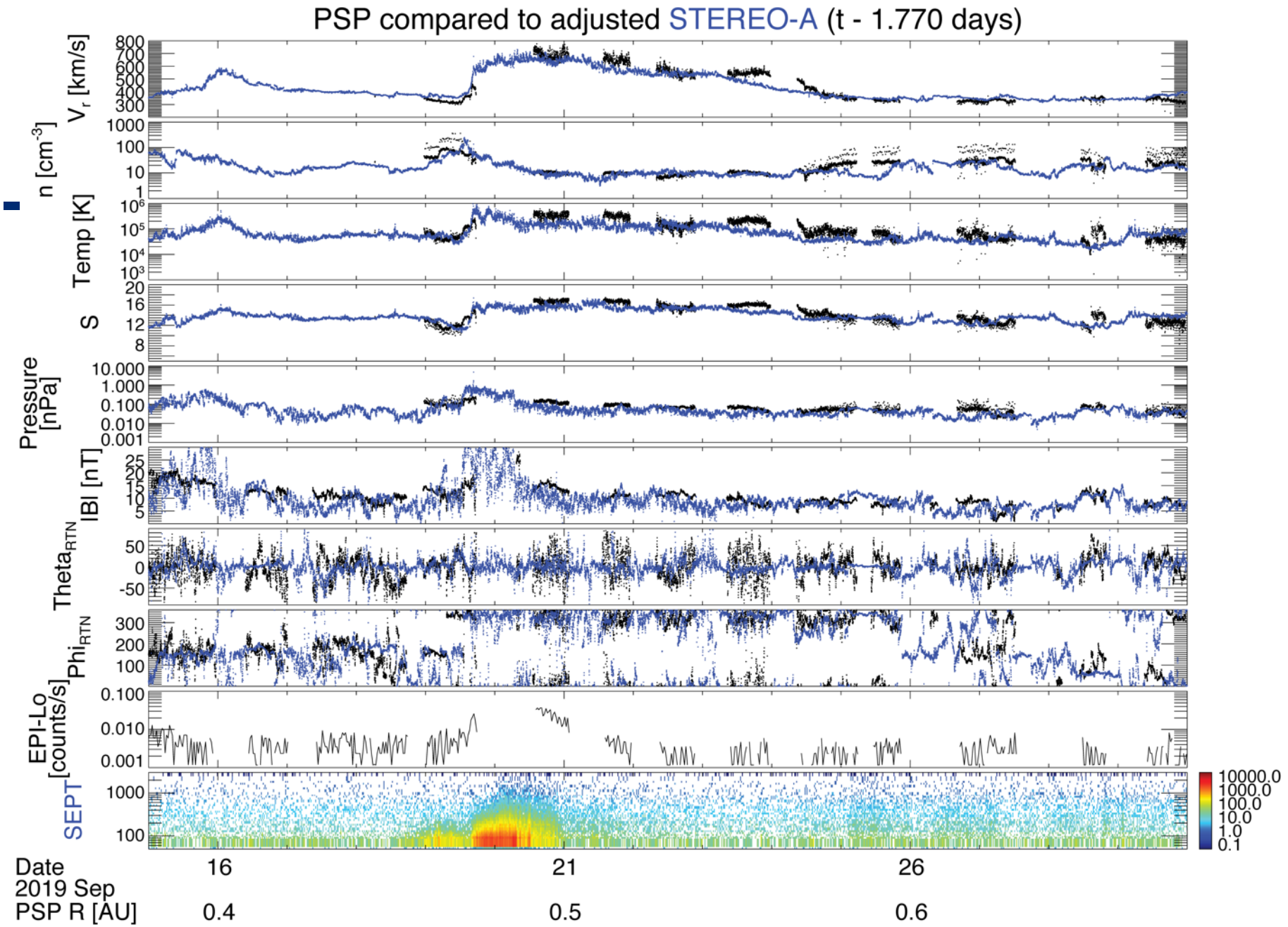
PSP and Time- and Spatially-Shifted STEREO-A Observations

Adjusting the time-shifted values for radial distance:

$n \propto 1/r^2$
$Br \propto 1/r^2$
$Bt \propto 1/r$

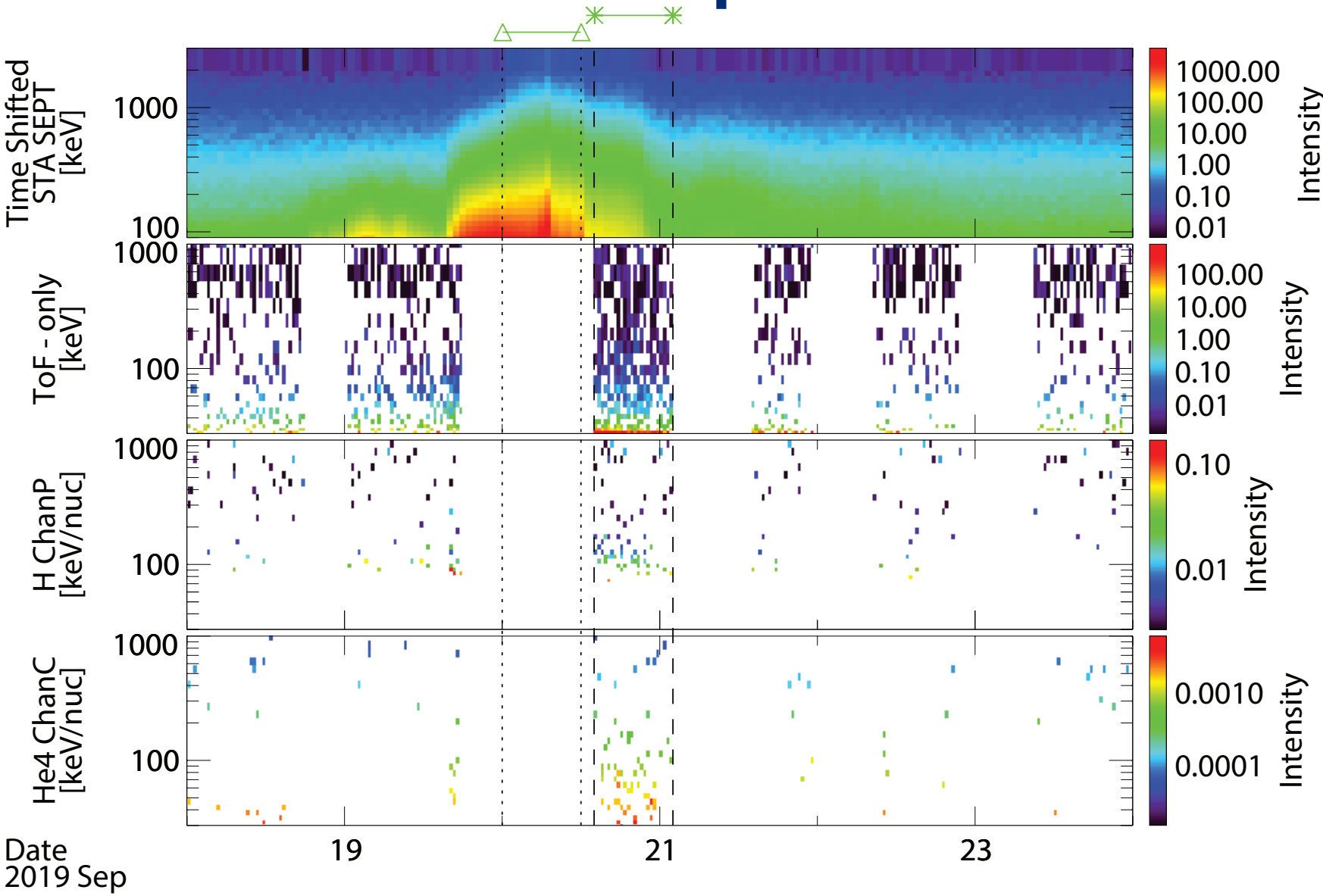
The structures match very well!

Density pile-up and pressure enhancement are seen to be more pronounced at STA



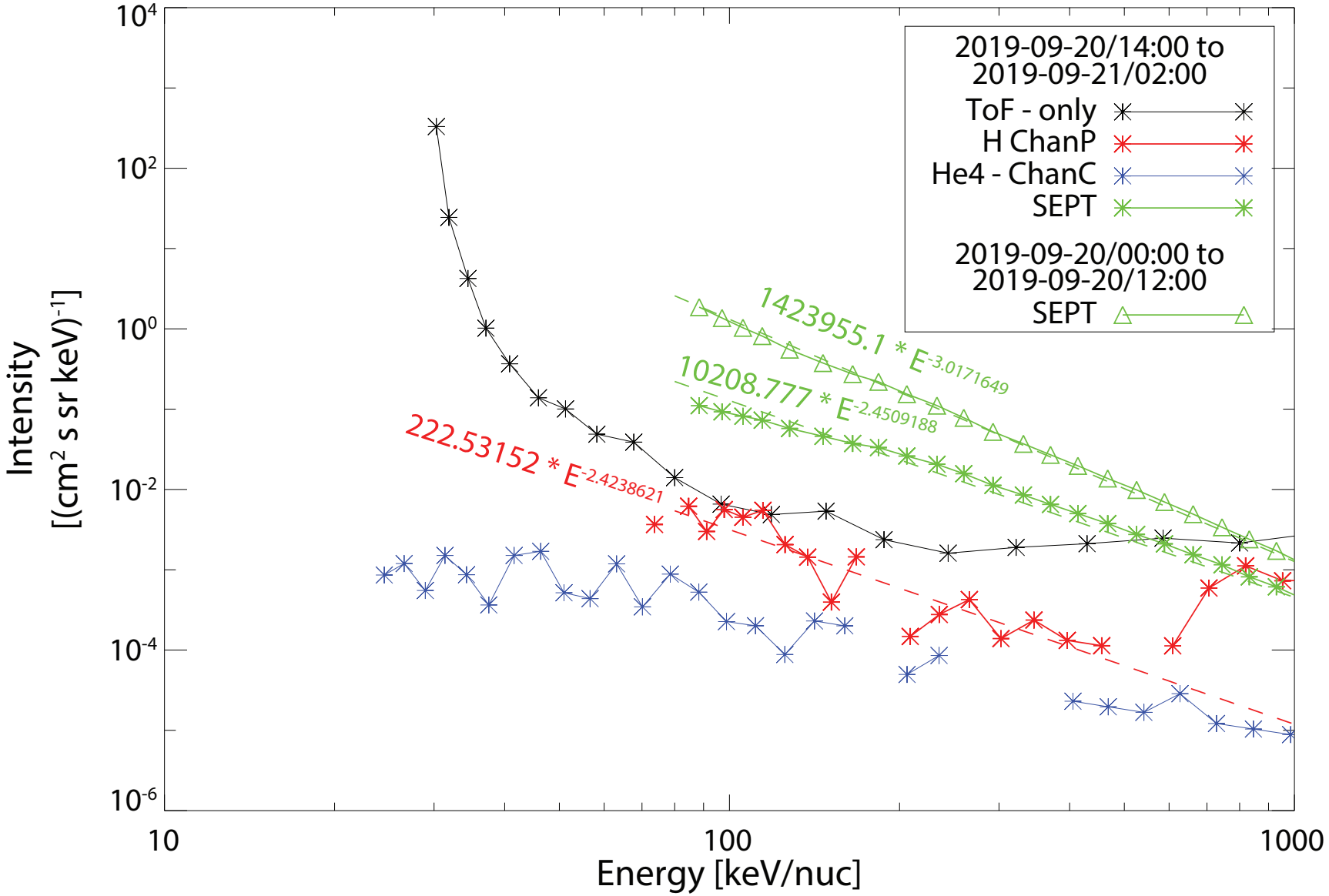
PSP EPI-Lo observations in more depth

- We take two time slices to look at the particle spectra.
  - From 2019-09-20/00:00 to 2019-09-20/12:00
    - Only STEREO-A SEPT (time shifted) data is available.
  - From 2019-09-20/14:00 to 2019-09-21/02:00
    - Both STEREO-A SEPT (time shifted) and EPI-Lo data is available.
    - EPI-Lo observed flux in ChanT (ToF-only), ChanP (H^+), and ChanC (for ^4He).



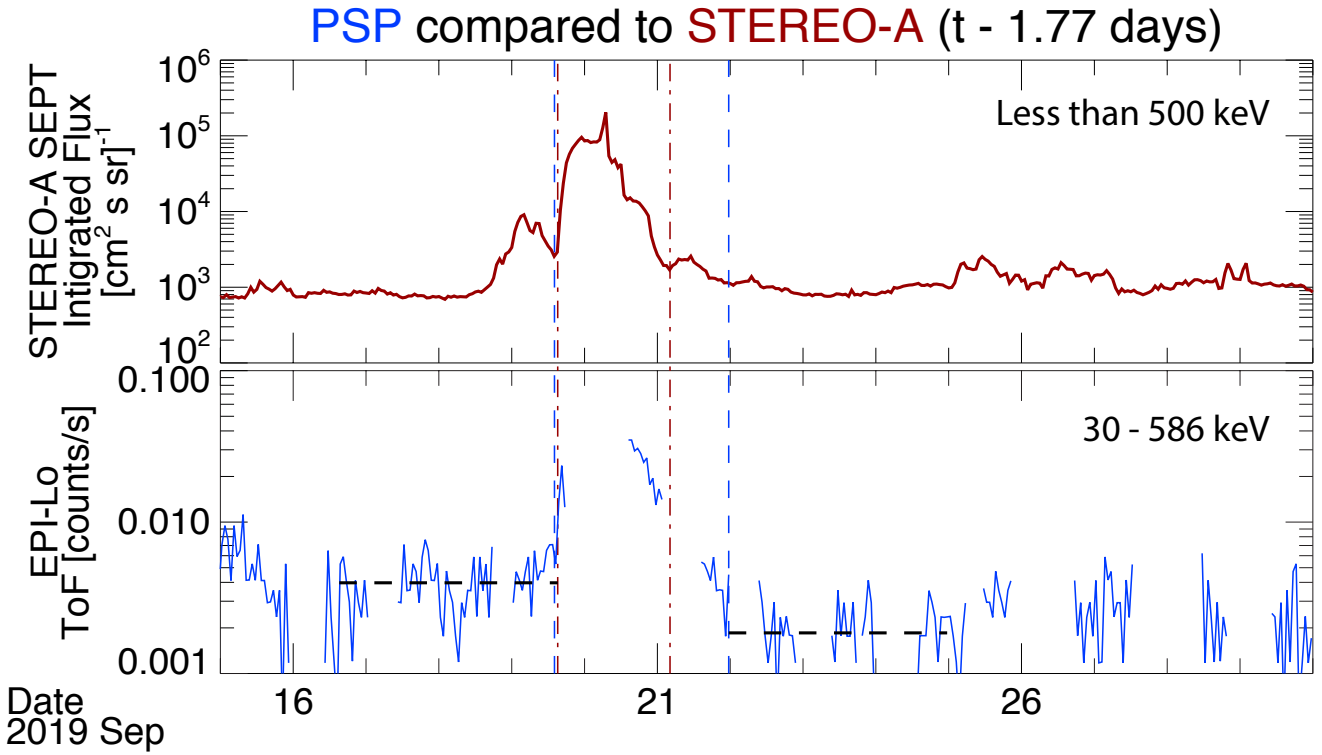
PSP EPI-Lo vs. STEREO-A SEPT

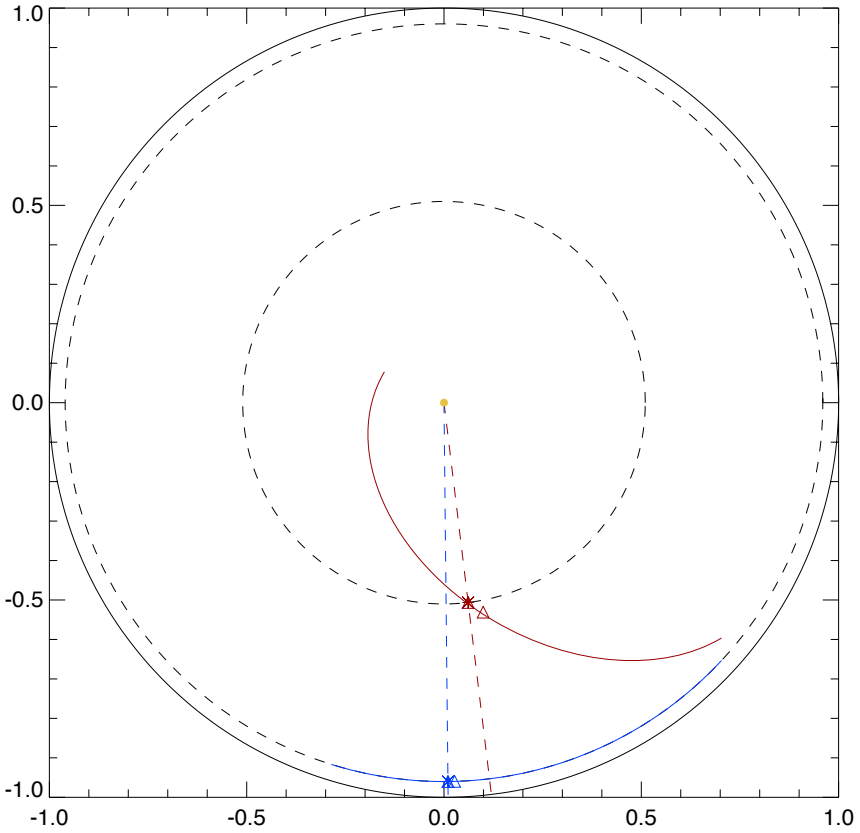
- Spectra from the two intervals are denoted by:
  - From 2019-09-20/14:00 to 2019-09-21/02:00
    - Shown by asterisks
  - From 2019-09-20/00:00 to 2019-09-20/12:00
    - Shown by triangles
- Power-law fits shown for:
  - SEPT
    - energies < 1000 keV/nuc
  - EPI-Lo – ChanP H^+
    - energies < 600 keV/nuc
- The flux at STEREO-A is higher
- The spectral slopes at STEREO-A and ChanP during the (*) time period are remarkably similar.
- However, the STEREO-A spectral slope is seen to have evolved throughout the SIR.



Longitudinal width of energetic particle observations

- PSP observed suprathermal particles for 29.34° in Carrington longitude
- STEREO-A observed suprathermal particles for 20.21° in Carrington longitude
- The extra 9.13° could be due to the effects of perpendicular diffusion
  - STEREO-A is closer to the shock that is accelerating ions
  - PSP is further from the shock, so there is more time and space for perpendicular diffusion to spatially broaden the suprathermal particle enhancement.





S/C	Start Long.	Stop Long.	Difference in Long.
STA	292.63°	272.42°	20.21°
PSP	273.80°	244.46°	29.34°

Summary and next steps

- The apparent time-lag in observations is 1.77 days
  - Simple radial ballistic propagation would predict arrival after 1.69 days.
  - Including longitudinal effects would predict an arrive lag of 1.3 days.
  - The better agreement from ignoring the longitudinal effects could suggest the CIR structure is not a rigid surface.
- The suprathermal spectral slopes at PSP and STEREO-A are seen to be quite similar
- The flux of suprathermal particles at PSP is lower than at STEREO-A
  - Suggesting some loss processes from scattering.
- The suprathermal enhancement at PSP is observed over a larger longitudinal range than at STEREO-A.
  - We are currently investigating this, but it could be due to perpendicular diffusion across field lines.

- Comparisons between PSP and observatories at 1 au are well suited to detangle the spatial/temporal evolution of SIRs/CIRs in the inner heliosphere.
  - We have seen examples of both
- We are currently building up a catalog of PSP observed SIRs/CIRs with conjunction observations at 1 au to conduct both event studies and eventually a statistical study of the spatial/temporal evolution of SIRs/CIRs.
- We are also currently looking into the energetic particles during these events to study suprathermal ion acceleration in, and transport into, the inner heliosphere.

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