A solar source of Alfvénic magnetic field switchbacks: \textit{in situ} remnants of interchange reconnection on supergranulation scales

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- PFSS Modeling/mapping – Olga Panasenko, Sam Badman, Ronan Laker
- Ballistic mapping and Solar Orbiter analysis – Tim Horbury
- SPAN ion fits – Michael McManus, Lloyd Woodham
- SPAN electron fits – Jasper Halekas
- ISOIS/EPI-Lo measurements – Mihir Desai
Summary

- Microstreams, pressure-balanced structures -> funnels? plumes?
- Switchbacks are modulated in amplitude and occurrence on 3-5° angular scales
- Enhanced alpha abundance, wind speed, ion temperatures
- Depressed electron temperatures, magnetic field $|B|$
- Suprathermal ions to $\sim 85$ keV
- Pressure balance – spatial structure – highly evolved by 200 Rs
Encounter 06
Perihelion at 20 Rs
PFSS Connectivity on Sept 27, 2020

- Rss = 2.2 Rs
- PSP is connected to a southern coronal hole (CH) at around -60°
- Black contours are magnetic pressure at 14 Mm altitude
- Network magnetic field
PSP Encounter 06

Unipolar strahl

Modulations of $|B|$

Modulations of $n_{\text{tot}}$

Modulations of switchbacks

Modulations of $V_R$
Suprathermals, enhanced $A_{\text{He}}$ and higher Mach radial flows

- Suprathermal ions
- Alfven speed
- Proton core speed
- Proton beam speed
- Alpha speed
- Alpha flux/proton core flux
- Alpha abundance
- Radial field - switchbacks

Yellow bars for $A_{\text{He}} > 1\%$
Structures are pressure-balanced

- |B| R^2
- n_e R^2
- Electron pressure
- Magnetic field pressure
- Total pressure/\rho_s
- P/P_s
- Alpha abundance

Depressed |B|
Enhanced plasma pressure
Proton core pressure
Alpha pressure
Pressure balance
Ion temperatures are elevated, electron temperatures are depressed.
How do switchback patches evolve with distance?

• Encounter 6: PSP at 20 Rₚ, Orbiter at 208 Rₚ
  Both at similar latitude, cover same longitude range
• Ballistic map to 2.5Rₚ using measured solar wind speed
• Takes into account spacecraft motion; assumes corotating structures

Speed: **PSP**: structured, **Orbiter**: smooth

**Bₚ**: PSP: switchback patches, Orbiter: large scale folds

Spectra of speed and magnetic field variations with respect to source surface longitude

Speed: **PSP** microstreams (plumes?) smooth out by 1 AU at **Orbiter**

Magnetic field (angle to Parker spiral): peak at **PSP** (switchback patches) becomes large scale field variations: break in spectrum at **Orbiter**
B_T, B_N in upper panel
V_T, V_N in lower panel

|B| in upper panel
B_R in upper panel

A_He in lower panel
V_R in lower panel
Proton temperatures in lower panel
EPI-Lo ions in lower panel

Mapped ballistically into Carrington longitude

Yellow bars are enhanced A_He
Blue bars are hotter leading edge

• Structure is clustered near boundaries
• Switchbacks are clustered near leading edge
Polar representation
Superradial expansion gives $|B|$ depression in center
- $B_R \sim 1/r^2$
- $B_{(T,N)} \sim 1/r$
Observations

• Switchbacks are modulated on supergranulation angular scales
• Photospheric field has $B^2$ modulations on similar scales
• Pressure balanced – spatial structure at 20 Rs
• Structure is evolved out by 200 Rs
• Fast wind-like (higher) $A_{\text{He}}$ and lower strahl energy – frozen-in from source, associated with open magnetic field
• Higher $\beta$ and flow speed within structures
• Suprathermal ions to 85 ~keV
• Depressed $|B|$ – overexpansion of magnetic field below PSP – funnels
Conclusions?

• These are the solar wind remnants of coronal plumes/funnels and switchback occurrence and amplitude peaks within them
• This tells us something about the switchback source
  • Funnels at supergranulation boundaries
  • Network magnetic field
• This maybe tells us something about the switchback generation mechanism
  • Interchange reconnection at funnel/loop boundaries?
  • Alfven waves in overexpanding funnels?
• This maybe tells us something fundamental about coronal heating