The Heliospheric Current Sheet and Plasma Sheet
as seen with Parker Solar Probe

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PSP Theory Telecon, May 2020
Outline

• Introduction to the HCS and HPS
• Past observations from 1 AU
• Parker Solar Probes observations near Sun
• Model for the formation of the HPS
• Simulations
• Conclusions
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The Heliospheric Current Sheet (HCS)

- Current sheet that separates magnetic fields of opposite polarities from polar open fields

e.g. Smith et al. 1978
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- e.g. Smith et al. 1978
- e.g. Lavraud et al. (2020)

Global modelling of Réville et al. (2019)
The Heliospheric **Current Sheet** (HCS)

- **Current sheet** that separates magnetic fields of opposite polarities from polar open fields
- It extends into the heliosphere, keeping the imprints of solar magnetic geometry and, owing to solar rotation, forms a ballerina’s skirt

*e.g. Smith et al. 1978, Orcinha et al. 2019, Lavraud et al. (2020)*

Global modelling of Réville et al. (2019)
The Heliospheric Plasma Sheet (HPS)

• Observations at 1 AU show:
  → High-density, high-Beta region
  → Associated to nearby current sheet (HCS)
  → Nearby strahl electron directionality switch (true sector boundary)

e.g. Winterhalter et al. (1994)
   Wang et al. (1998, 2000)
The Heliospheric Plasma Sheet (HPS)

- Observations at 1 AU show:
  - High-density, high-Beta region
  - Associated to nearby current sheet (HCS)
  - Nearby strahl electron directionality switch (true sector boundary)
- Early ambiguity between slow wind (dense) and the HPS
- Exact nature of HPS remains unclear

E.g. Winterhalter et al. (1994)
Wang et al. (1998, 2000)
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Observations at 1 AU

- “Regular” HCS
- Flux ropes
- Density Blobs
- or combinations of the above

Sanchez-Diaz et al. (2017, 2019)
Observations at 1 AU

- Observations at 1 AU show:
  - “Regular” HCS
  - Flux ropes
  - Density Blobs
  - or combinations of the above

- But they are typically only observed individually, or in couples at best, owing to Parker spiral

Sanchez-Diaz et al. (2017, 2019)
STEREO observations at 1 AU

Example of density blob + flux rope

Sanchez-Diaz et al. (2019)
STEREO observations at 1 AU

Example of density blob + flux rope

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Parker Solar Probe observations: Orbit 1

• Context:
  → Several HCS crossings
  → Well reproduced by global modeling

Szabo et al. (2020)
Badman et al. (2020)
Réville et al. (2020)
Parker Solar Probe observations: Orbit 1

• Context:
  ➔ Several HCS crossings
  ➔ Well reproduced by global modeling

Szabo et al. (2020)
Badman et al. (2020)
Réville et al. (2020)
PSP HPS and HCS observations at 0.32 AU
1. Density enhancements associated with electron strahl dropouts, implying magnetic disconnection from the Sun
cf. Gosling et al. (2005)
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PSP HPS and HCS observations at 0.32 AU

2. Magnetic field decrease and Beta increase, consistent with magnetic reconnection
3. Density enhancements are about **twice** that in surrounding regions, suggesting **mixing of plasmas from each side of the HCS**

cf. Gosling et al. (2005)
PSP HPS and HCS observations at 0.32 AU

4. Speed enhancement with correlated $V$ and $B$ upon entrance and exit, consistent with the boundaries of a reconnection exhaust

eg. Gosling et al. (2005)
5. Presence of successive flux ropes, consistent with sequential release through reconnection eg. Sanchez-Diaz et al. (2019)
6. Frequent boundary layers just outside of exhaust, consistent with a reconnected topology eg. Lavraud et al. (2009)
PSP HPS and HCS observations at 0.32 AU

6. Frequent boundary layers just outside of exhaust, consistent with a reconnected topology eg. Lavraud et al. (2009)
PSP Flux ropes observations

PRELIMINARY:
- Similar orientation
- Same helicity
- Residual/bidir. electrons
PSP HPS and HCS during first orbit

During orbit 1, apart from reconnection exhausts, there is no other density structures near the HCS that may be called the Heliospheric Plasmas Sheet (HPS)

<table>
<thead>
<tr>
<th>#</th>
<th>TSB interval studied</th>
<th>N increases</th>
<th>Strahl dropout</th>
<th>Correlated V-B changes*</th>
<th>Flux ropes</th>
<th>N increase and dropout consistent</th>
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<tr>
<td>1</td>
<td>2018-10-09 12:00 - 2018-10-11 00:00</td>
<td>Several</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
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<td>2</td>
<td>2018-10-18 00:00 - 2018-10-18 09:00</td>
<td>Insufficient resolution, but magnetic bifurcation possibly indicative of reconnection at main current sheet.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>2018-10-20 00:00 - 2018-10-20 16:00</td>
<td>Complex HCS with TSB. Weak density signature and possible strahl dropout.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2018-10-27 20:00 - 2018-10-29 07:00</td>
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<td>5</td>
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<td>8</td>
<td>2018-12-05 06:00 - 2018-12-06 12:00</td>
<td>Complex HCS with TSB and insufficient resolution.</td>
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<td></td>
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</tr>
</tbody>
</table>

Table 1. List of the eight true sector boundary intervals during orbit 1, with associated properties as observed from particle and magnetic field data. The intervals given merely correspond to those studied and that encompass the relevant density enhancements nearby the TSB.
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Model for the release of density blobs and flux ropes

Sanchez-Diaz et al. (2019)
Lavraud et al. (2020)

Alternating release of density blobs and flux ropes as a result of sequential X-line formation at the tip of the helmet streamers, akin to magnetopause flux transfer events (FTEs)

eg. Raeder (2006), Pu et al. (2013)
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Global 2.5D simulation using the Pluto MHD code

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Parker Solar Probe shows that:

✓ Thanks to proximity to the Sun (more radial IMF), trains of blobs and flux ropes often observed near HCS (rather than single crossings)

✓ Density increases and suprathermal electron dropouts are systematically correlated (and often velocity increases)

✓ A model involving sequential magnetic reconnection at the tip of the Helmet streamers is consistent
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→ During PSP orbit 1, the Heliospheric Plasma Sheet (HPS) is purely defined as the exhaust (and its by-products) of reconnection

→ Note: different from notion of Plasma Sheet at planets