Mapping the Sun's Alfvén surface with PUNCH

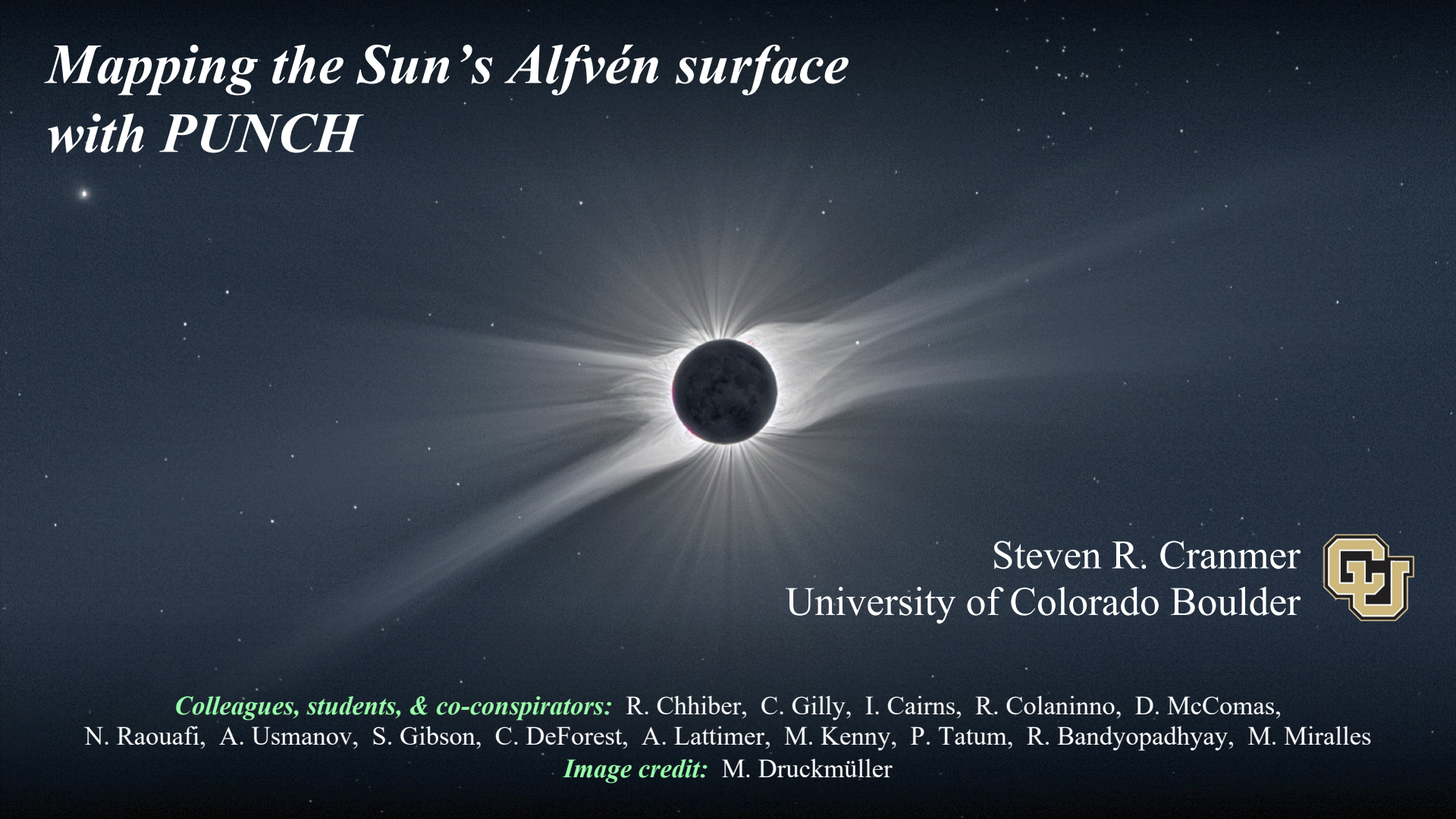

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Image credit: M. Druckmüller

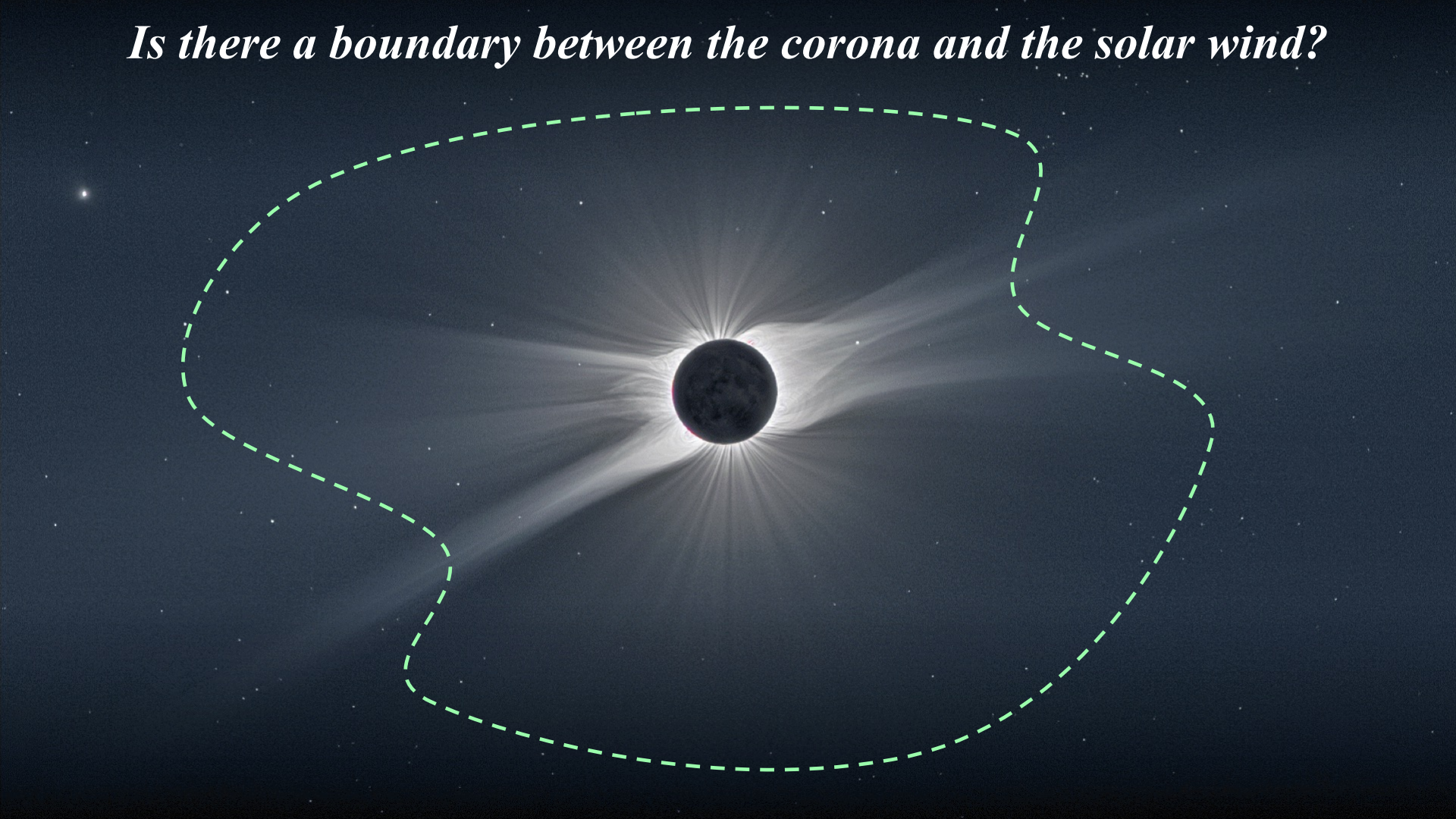
Mapping the Sun's Alfvén surface with PUNCH

PUNCH Working Group 1C: "What are the evolving physical properties of the Alfvén surface?"

Talk Outline:

1. What is it, and why do we care?
2. Where is it?
3. How will PUNCH help improve our understanding?

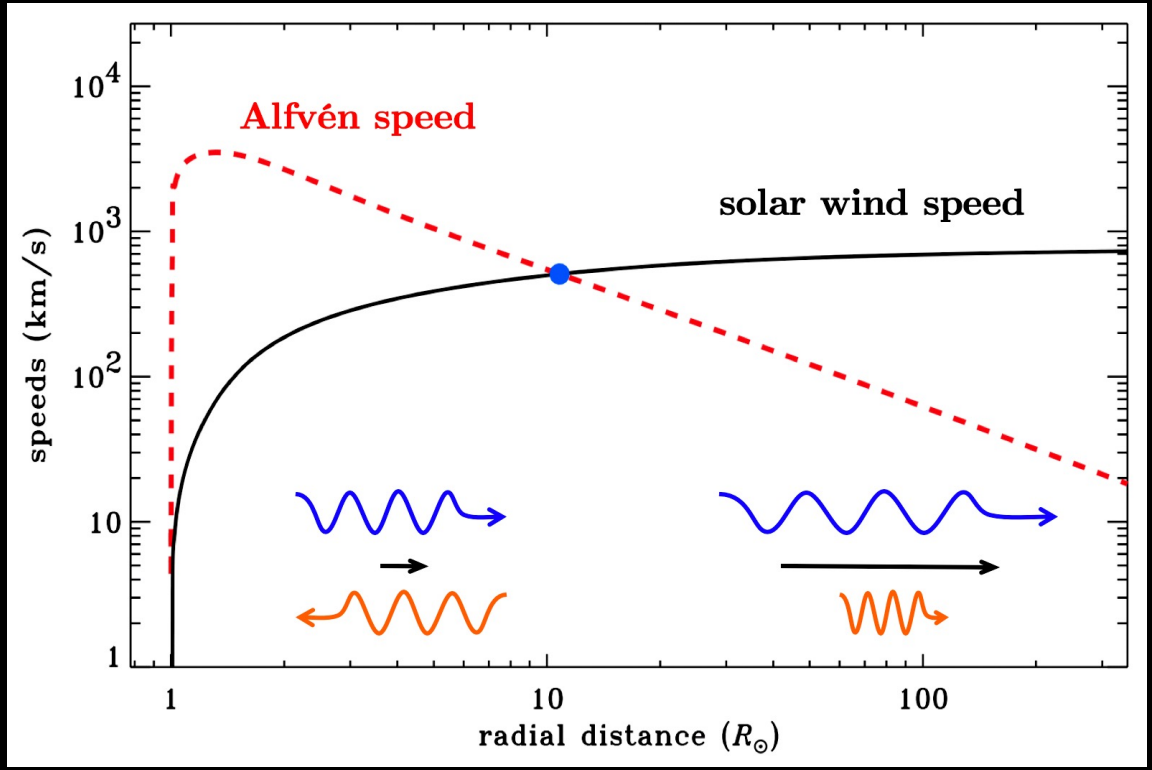
Is there a boundary between the corona and the solar wind?



Is there a boundary between the corona and the solar wind?

- The Alfvén surface (or Alfvén radius, or Alfvén zone) is a useful place to draw this distinction.

- Below r_A, information (waves) can propagate both in & out. Above r_A, the solar wind drags out both inward & outward modes, and information doesn't propagate back down to the Sun.



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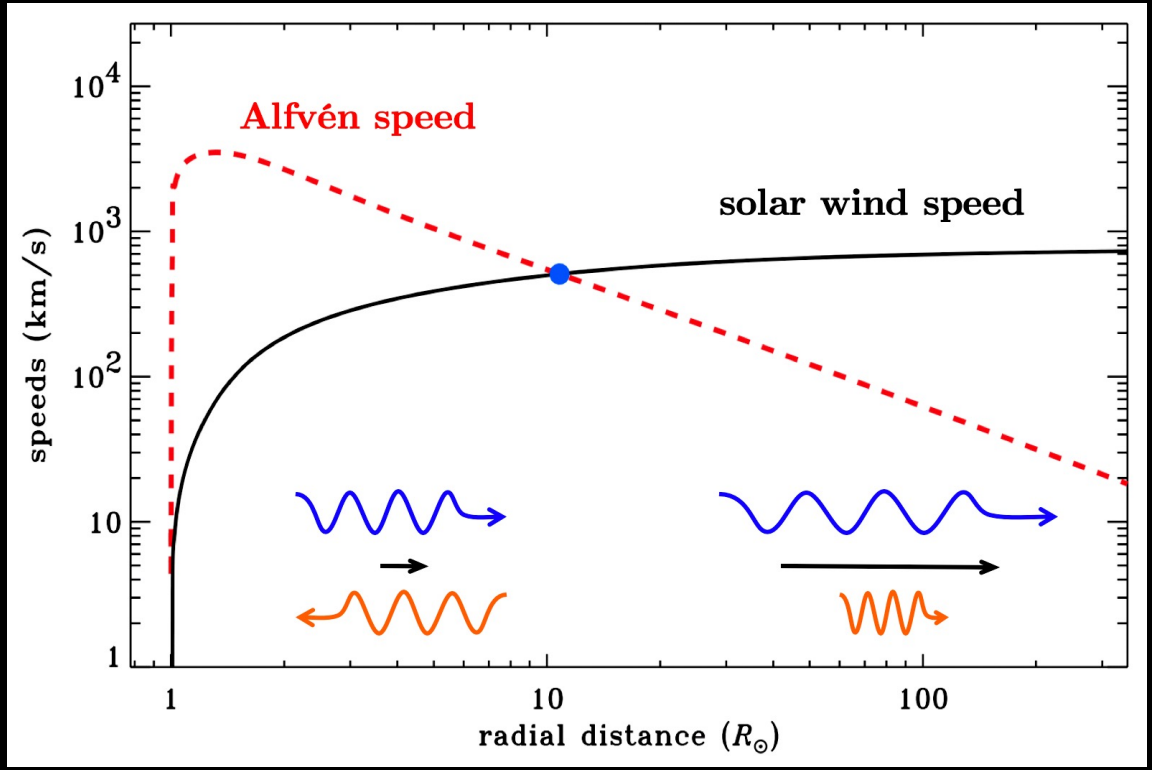
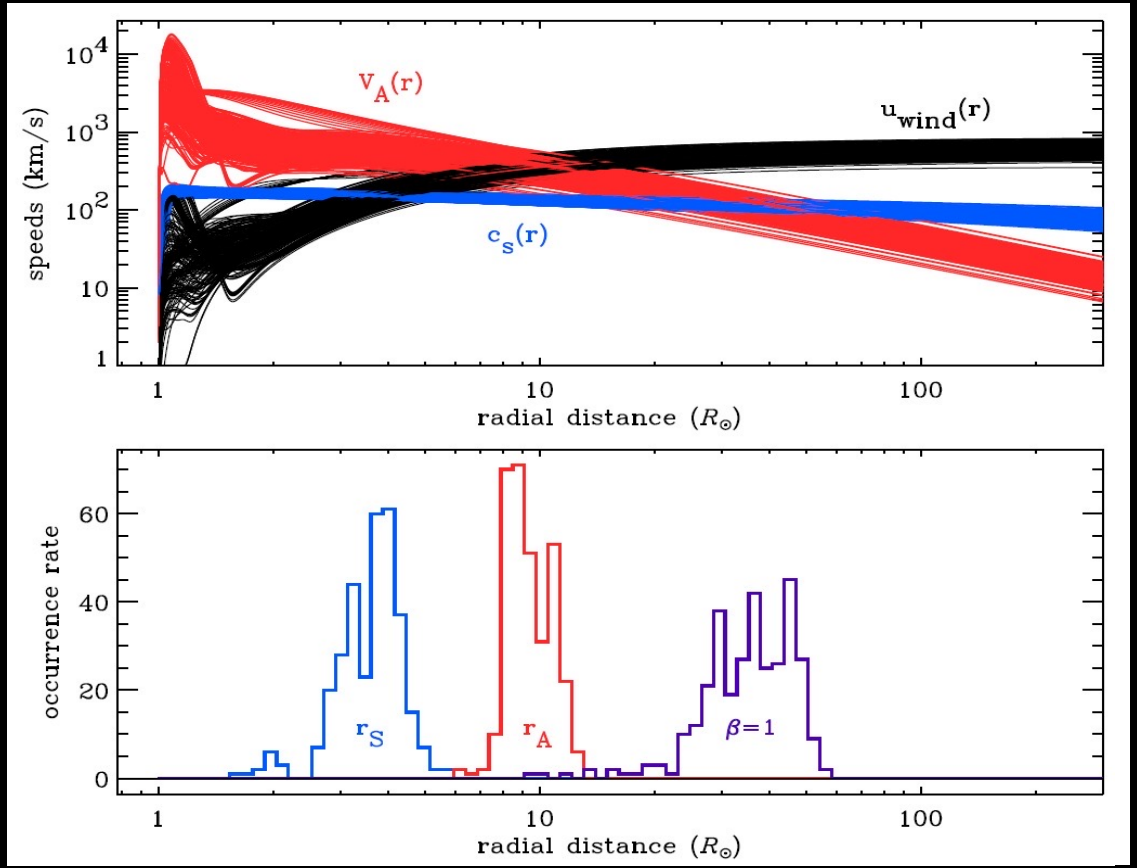
- It's the angular momentum "lever-arm" of the corona (Weber & Davis 1967).

- Measuring the wind speed at r_A gives $V_A \rightarrow B$ there, too.



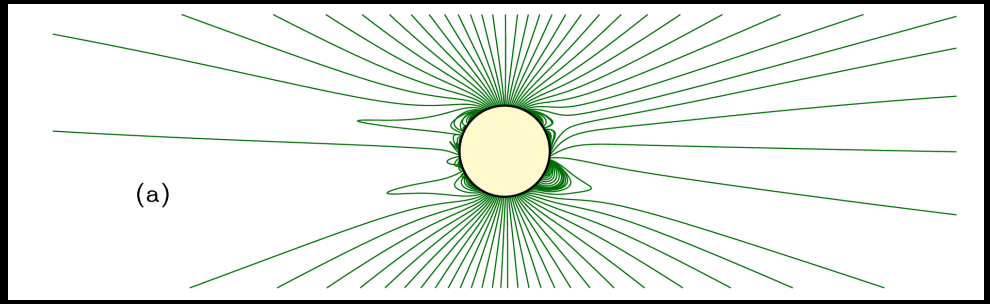
In reality, there's a range of critical radii

- Models: 318 runs of ZEPHYR for various types of magnetic flux configurations & wind speeds (Cranmer et al. 2007, 2013).
- Weber & Davis (1967) found that the Parker "sonic point" is the point beyond which slow-mode MHD waves cannot reach the Sun.
- There are separate radii for Alfvén & fast-mode MHD waves, but they differ in location by < 0.01 R_{sun} .



Is it also the "heliobase?"

- It's quite rare to find **closed** magnetic field lines above r_A, so this is often considered as the "source surface" for the heliosphere's magnetic flux.
- However, cusps of the largest streamers tend to occur no higher than ~2 to 3 R_s above the surface.
- Why not at r_A itself ?



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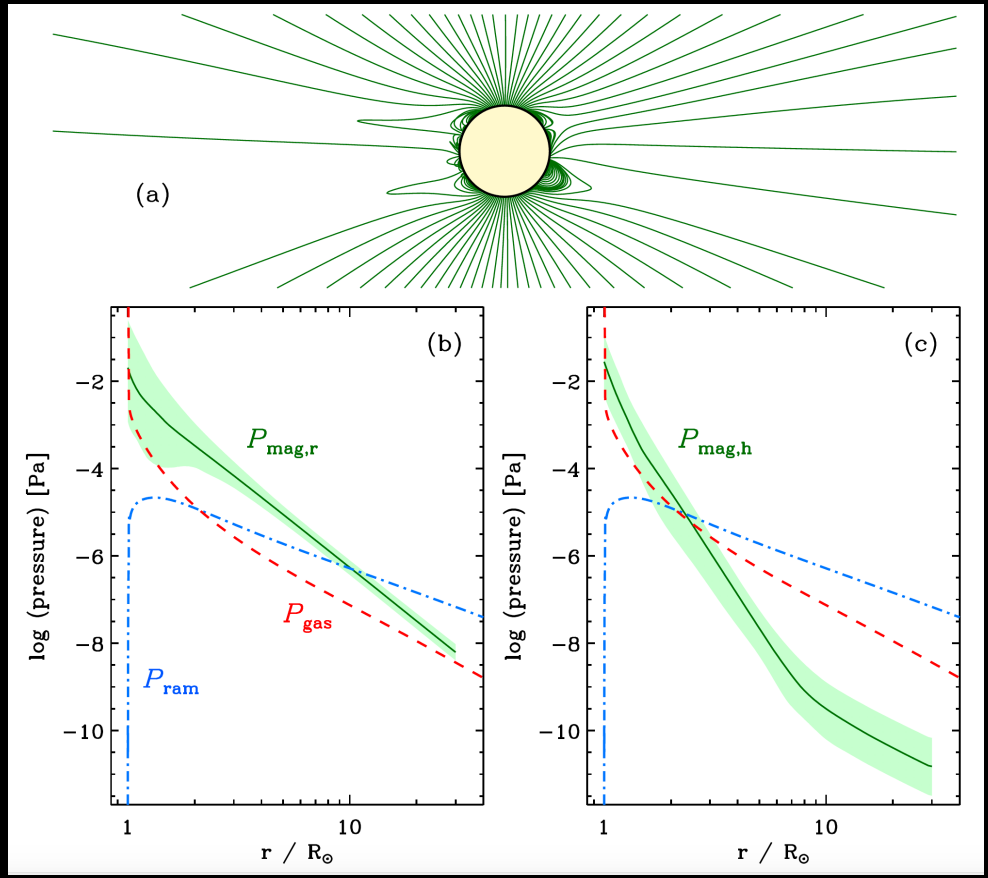
- However, cusps of the largest streamers tend to occur no higher than ~2 to 3 R_s above the surface.
- Why not at r_A itself ?
- Considering radial forces only, r_A is the only game in town.
- Field-line shapes depend more on the **transverse** force balance . . .



Models: http://www.predsci.com/mhdweb/

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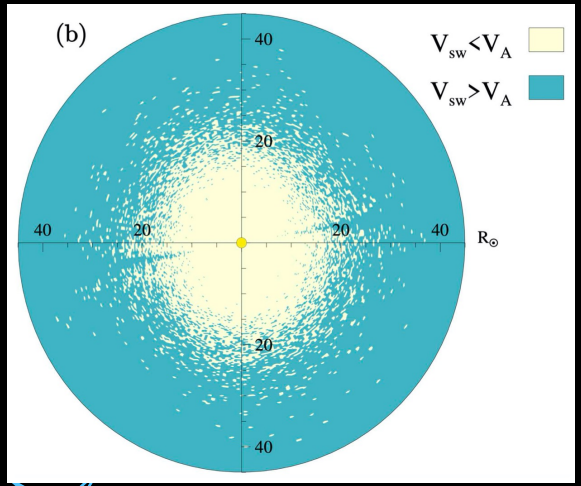
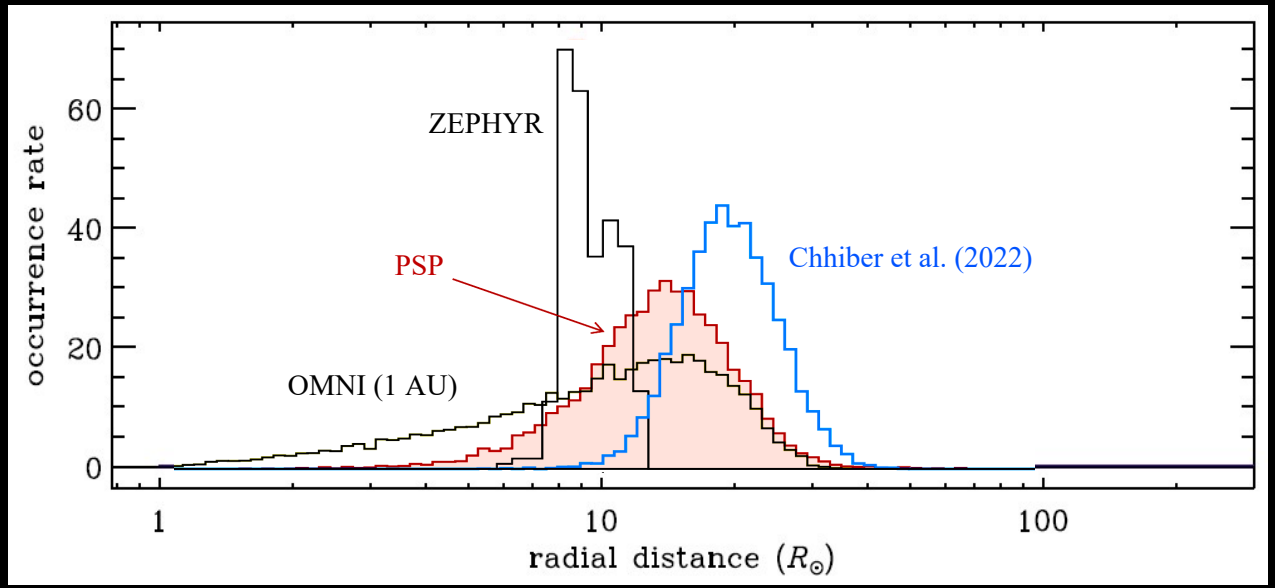
Models & simulations predict it . . .

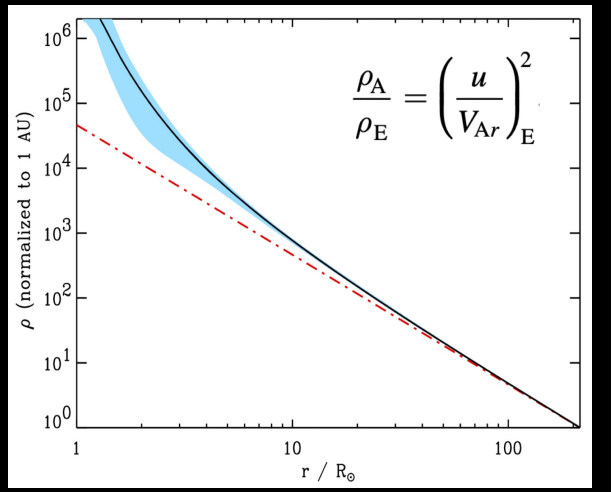
- Weber & Davis (1967) predicted it should fall between 15 and 50 R_s.
- Others have generally gone a bit lower (10 to 30 R_s) with lots of dependence on latitude, longitude, & solar activity (e.g., Pneuman & Kopp 1971; Keppens & Goedbloed 2000; Matt & Pudritz 2008; Cohen et al. 2009; Pinto et al. 2011; Cohen 2015; Chhiber et al. 2019, 2022).
- For more, see next talk . . .

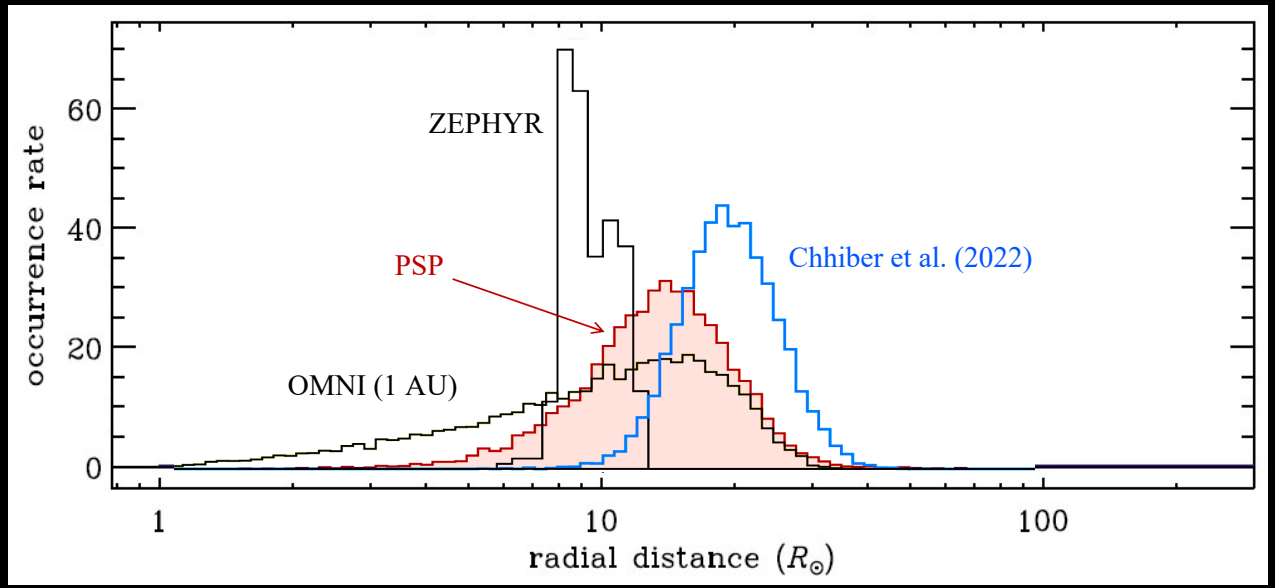




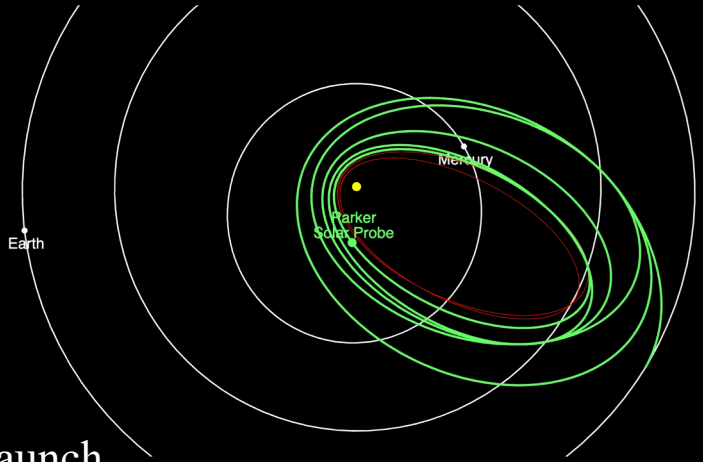
Extrapolation from in situ data

- If we fold in some assumptions about the radial behavior of $u(r)$ & $V_A(r)$, we can take measurements of these quantities at 1 AU (or elsewhere) and **extrapolate** to where they meet (Marsch & Richter 1984; Exarhos & Moussas 2000; Katsikas et al. 2010; Goelzer et al. 2014; Tasnim & Cairns 2016; Tasnim et al 2018; Kasper & Klein 2019; Liu 2021; Verscharen et al 2021).

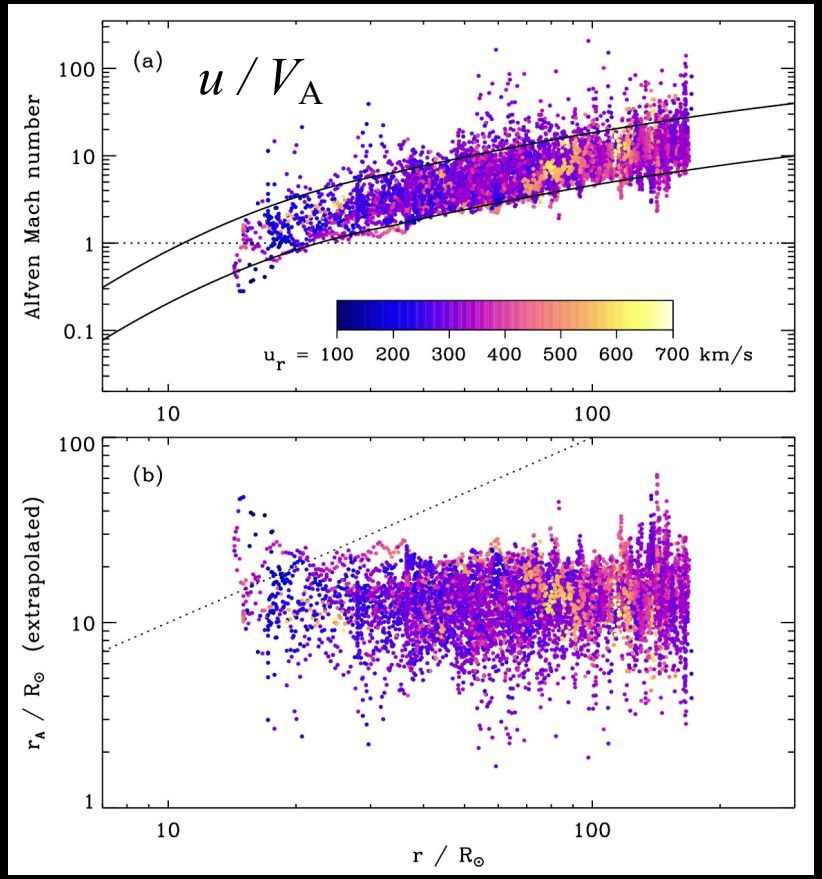




Parker Solar Probe has been to the other side!



- Aug. 2018: Launch
- Nov. 2018: Perihelion 1 (36 R_{sun})
- Apr. 2021: Perihelion 8 (16 R_{sun});
  first crossing of the Alfvén surface
- Mar. 2023: Perihelion 15 (13.3 R_{sun})
- Dec. 2024: Perihelion 22 (9.9 R_{sun})



Coronagraph imaging can see inflows, too

- The corona is full of small density inhomogeneities (“blobs”) that flow in & out.
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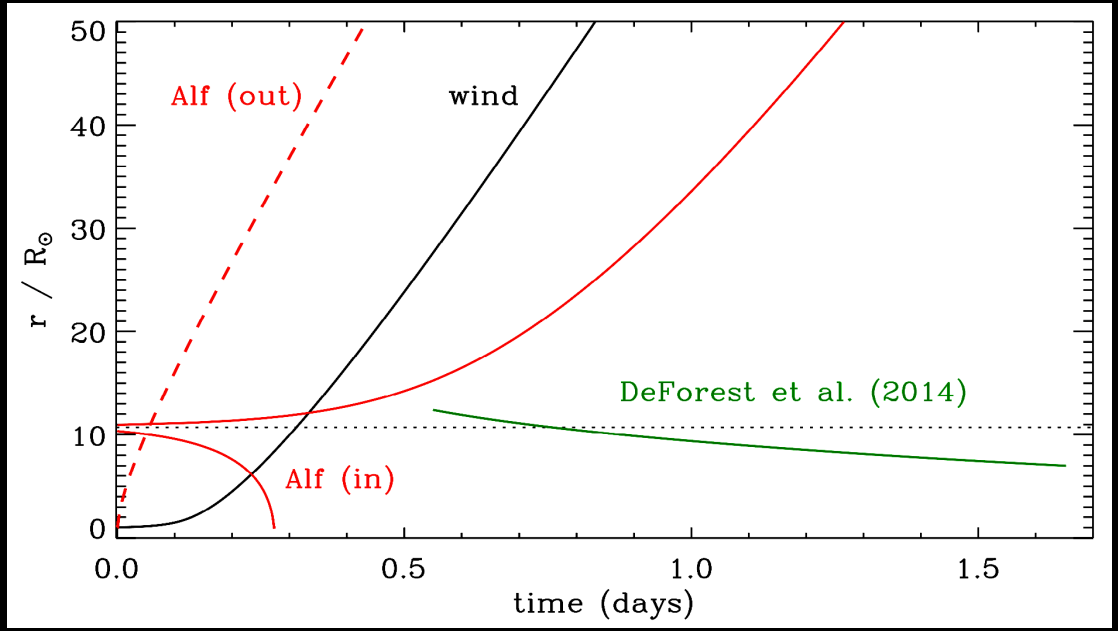

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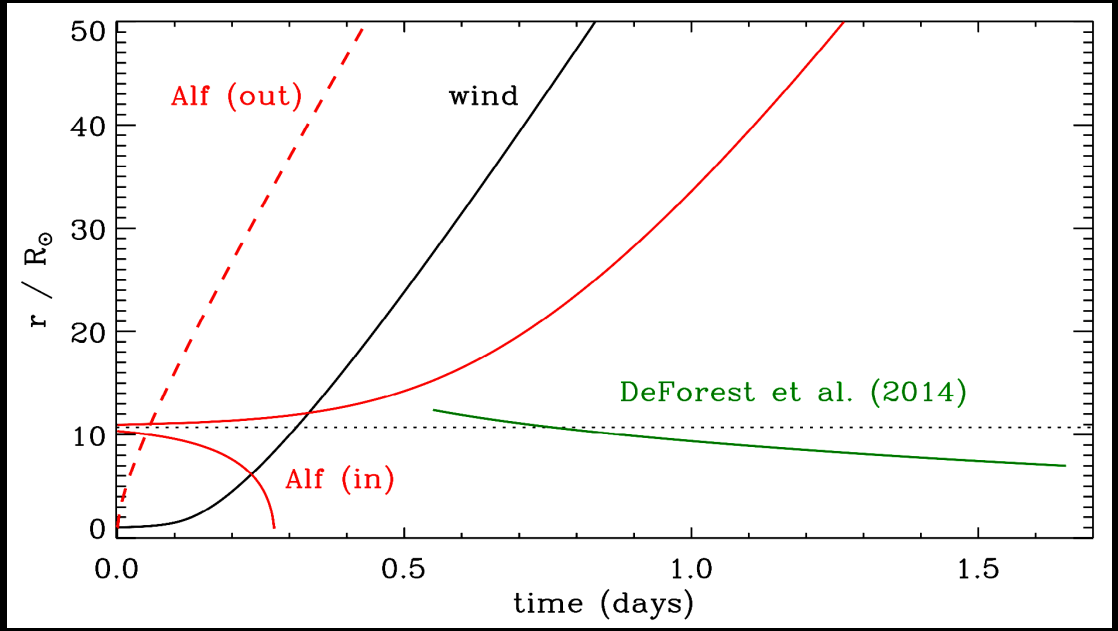
- DeForest et al. (2014) saw a few examples of **inflow** (12 to 7 R_{sun}), but the kinematics didn't match MHD-wave expectations:
- Theoretical models abound (see Tenerani et al. 2016; Cranmer et al. 2021), and they hint that the blobs may be gaining mass by **"snowplowing"** plasma in front of them. Are they reconnection exhausts? Kelvin-Helmholtz vortices? Supra-Alfvénic shocks?
- We need more examples . . .



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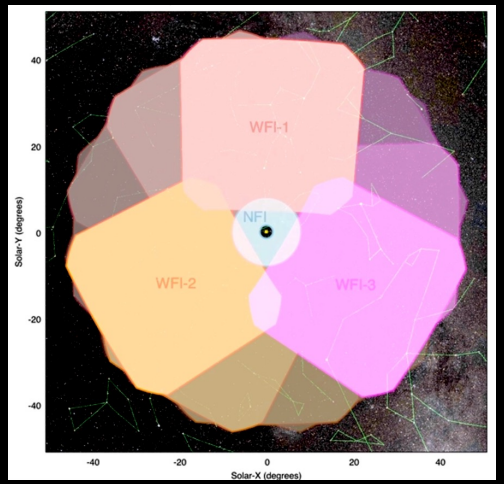
PUNCH flow tracking

- PUNCH will produce visible-light images between 6 and 180 R_s, with cadences between 4 minutes ($r < 80\ R_s$) and 35 minutes (entire FOV).
- To measure flow speeds of inflowing & outflowing features, we use:
  - well-tested flow-tracking algorithms
  - spatio-temporal Fourier filtering
  - (some) 3D localization via polarization



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  - well-tested flow-tracking algorithms
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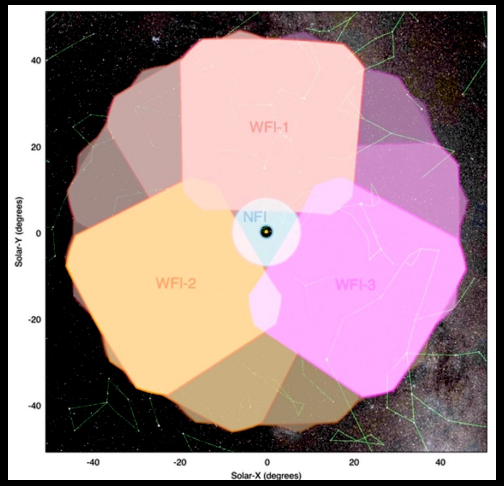
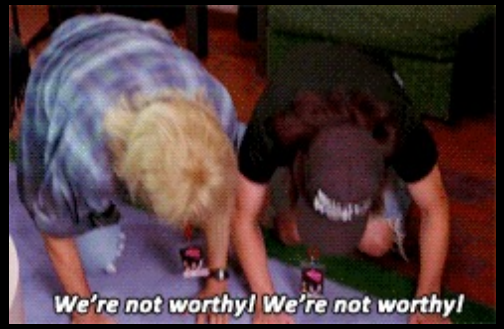
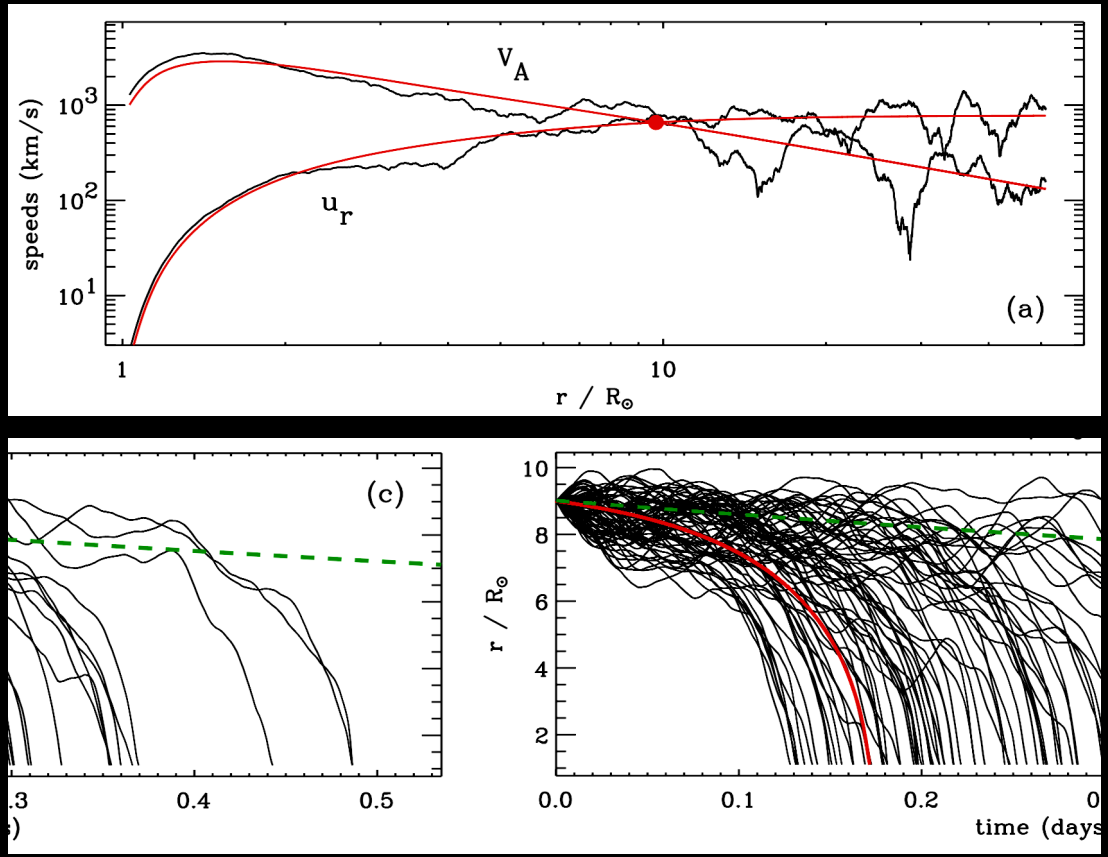
  - (some) 3D localization via polarization
- Working Group 1C is thankful for all the work being done by Working Group 1A !
- Will the decelerating inbound features seen by DeForest et al (2014) be just the "tip of the iceberg?" Will lower-contrast features not undergo so much snowplowing? What will the lifetimes of these features tell us about the solar wind & turbulence?





The "frothy Alfvén zone"

- Together with Working Group 1B, we will also use PUNCH to probe MHD turbulence and stochasticity in the vicinity of the Alfvén surface.
- Turbulence produces time-varying "froth" such that r_A bobs up & down and there can be multiple places where $u=V_A$.
- In fact, the **decelerated** inflow seen by DeForest et al. (2014) may be explainable because bobbing up & down **delays** the inflow...



Conclusions

- Using PUNCH to locate the Alfvén surface --- and to probe the dynamics of turbulent parcels in its vicinity --- will improve our understanding of coronal heating & solar wind acceleration.

- Coordination with other instruments/missions/telescopes could be the "secret sauce" that provides even more multi-scale context & insight . . .