# *Mapping the Sun's Alfvén surface with PUNCH*

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*Image credit:* M. Druckmüller

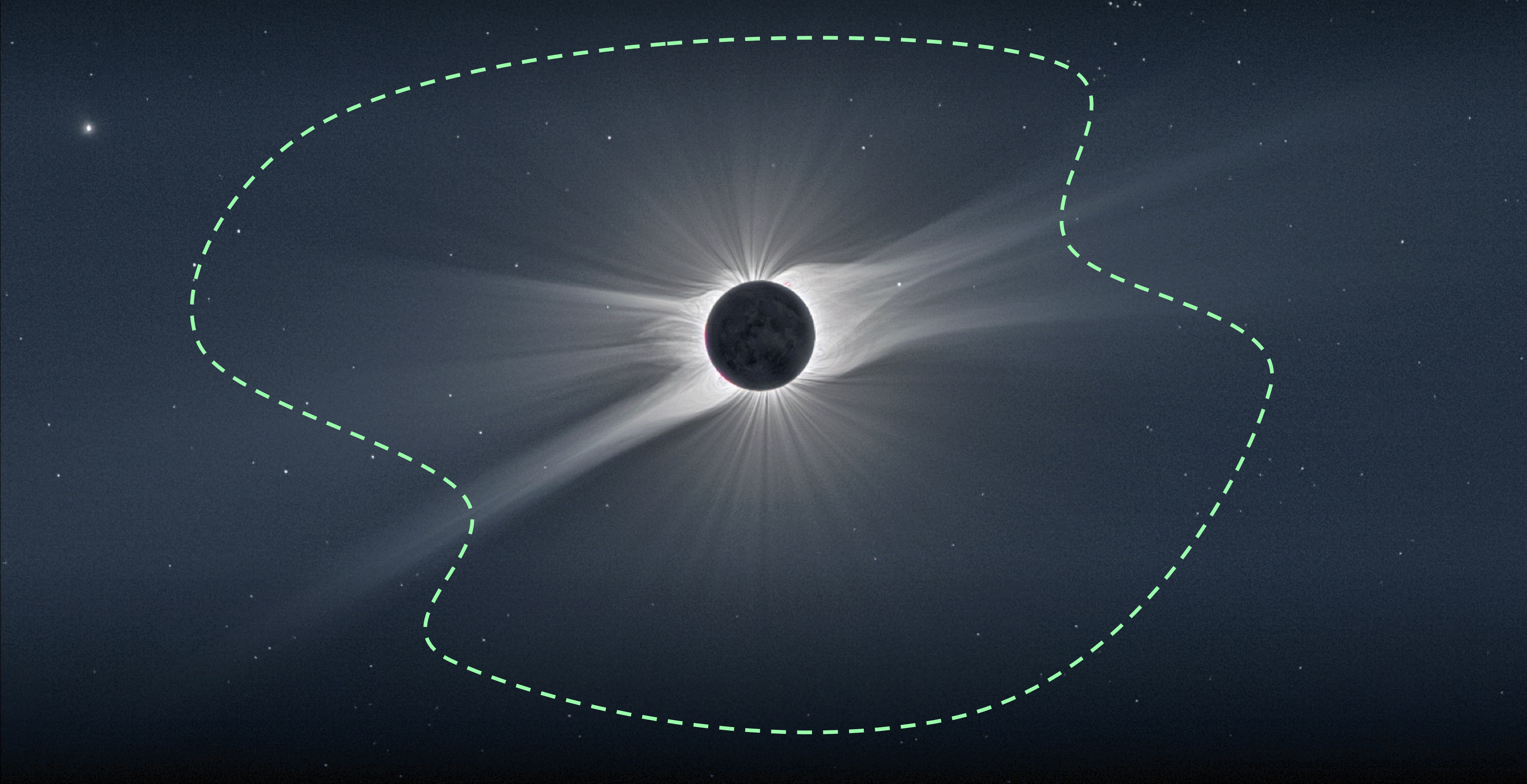
# *Mapping the Sun's Alfvén surface with PUNCH*

*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. <u>Where</u> is it?
3. How will PUNCH help improve our understanding?

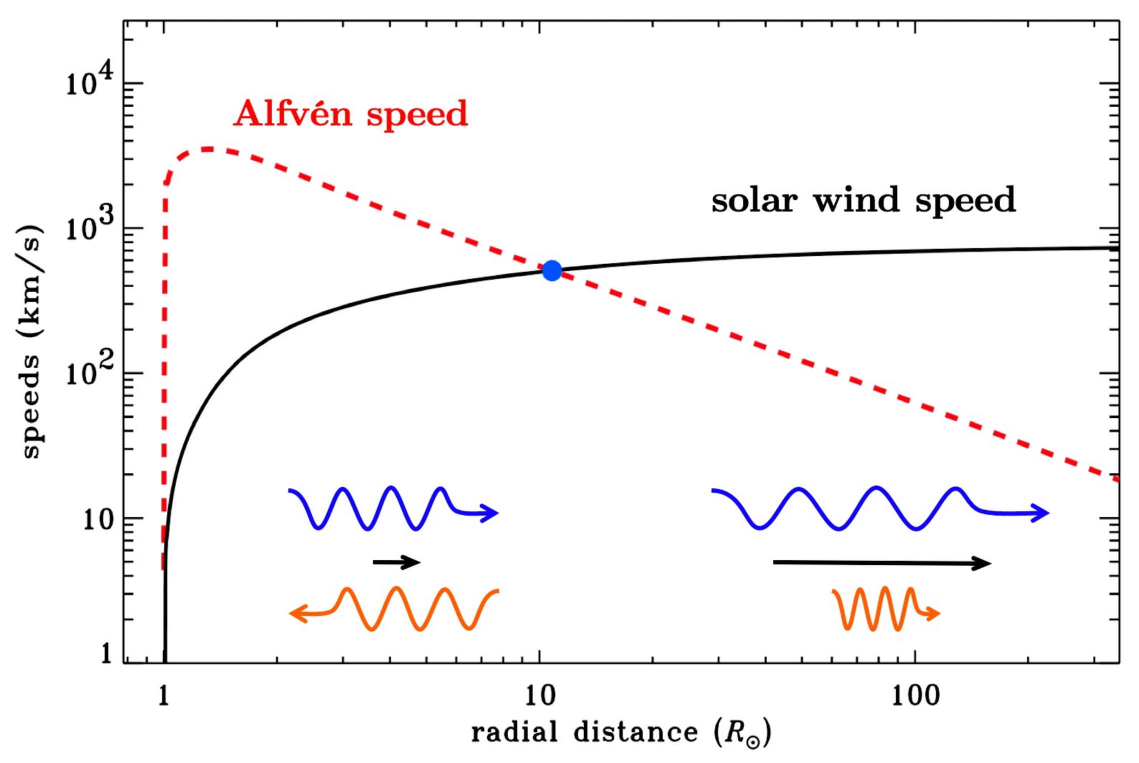
# *Is there a boundary between the corona and the solar wind?*



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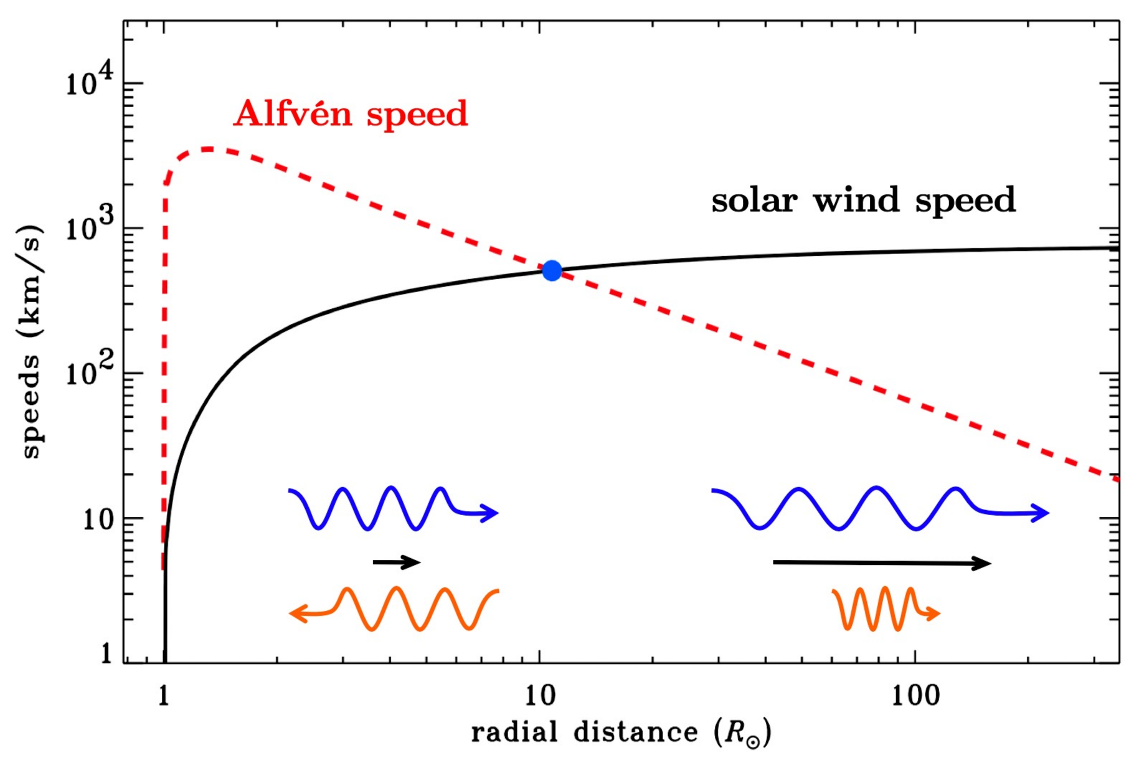
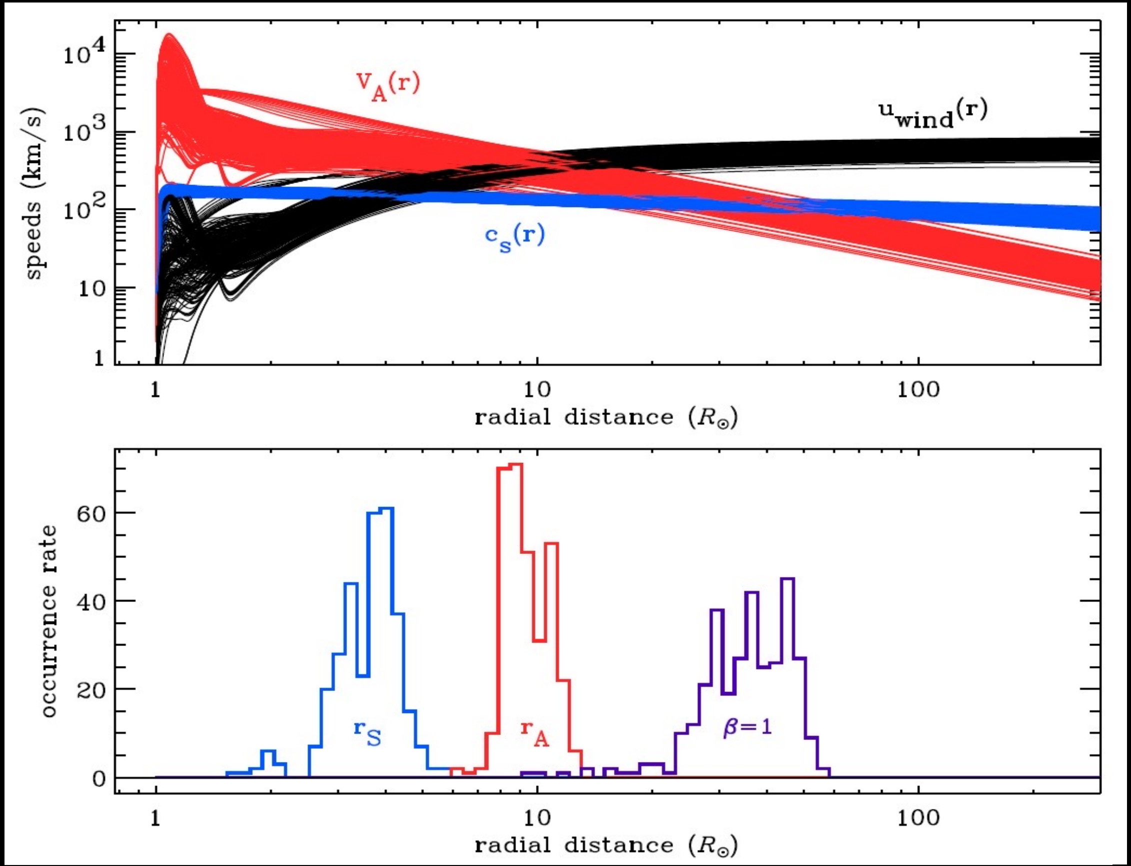
- It's the angular momentum "lever-arm" of the corona (Weber & Davis 1967).

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



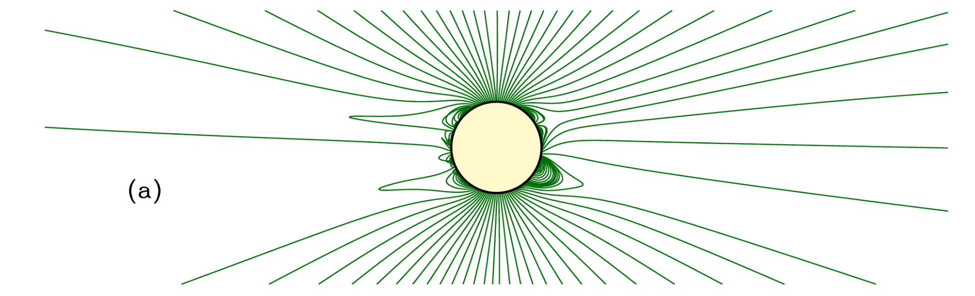
# *In reality, there's a range of critical radii*

- 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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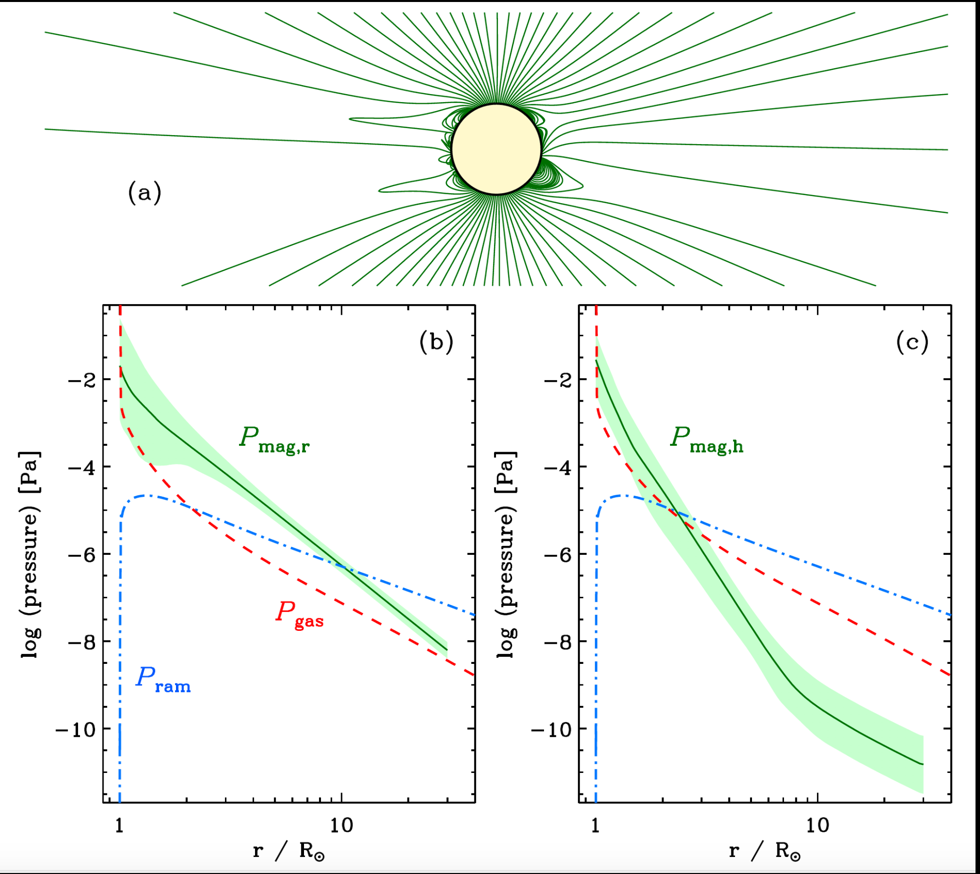
- Why not at $r_A$ itself ?
- Considering radial forces only, $r_A$ is the only game in town.
- Field-line shapes depend more on the **transverse** force balance . . .




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

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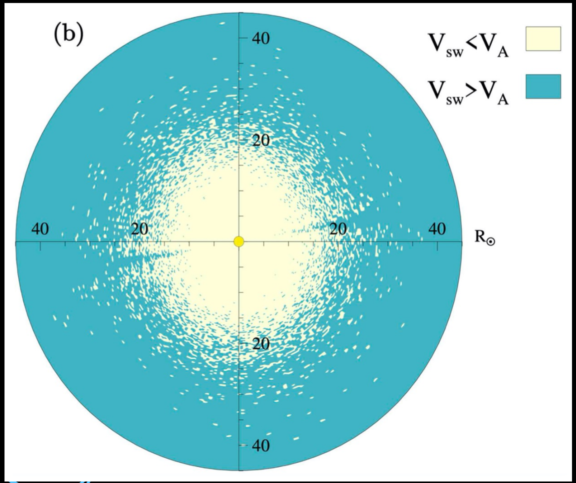
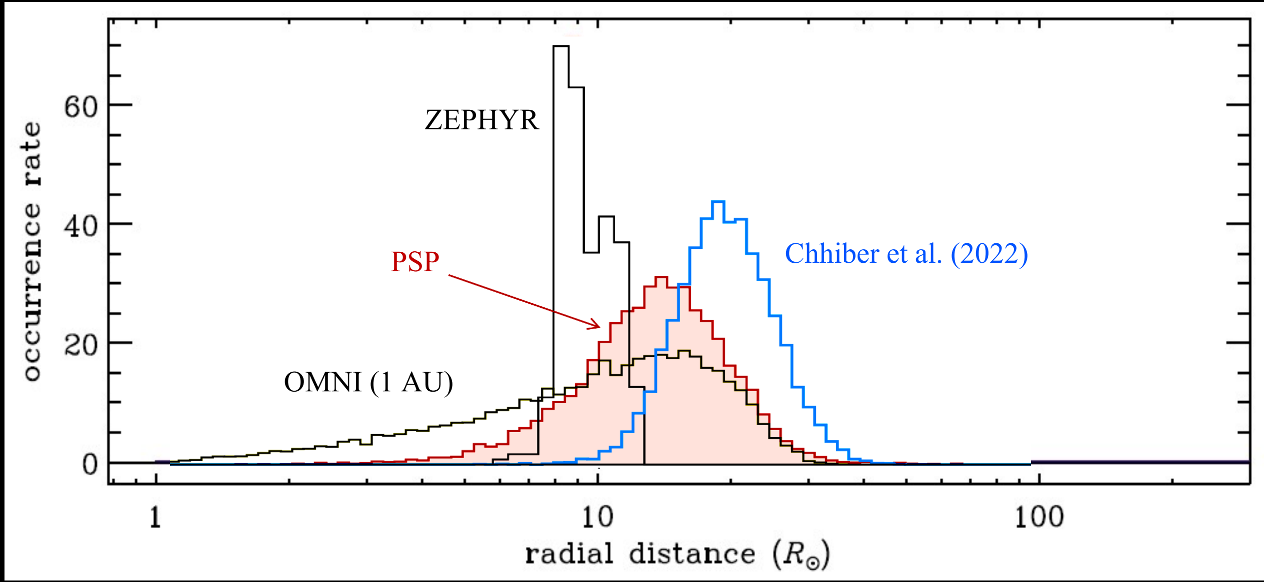
# *Models & simulations predict it . . .*

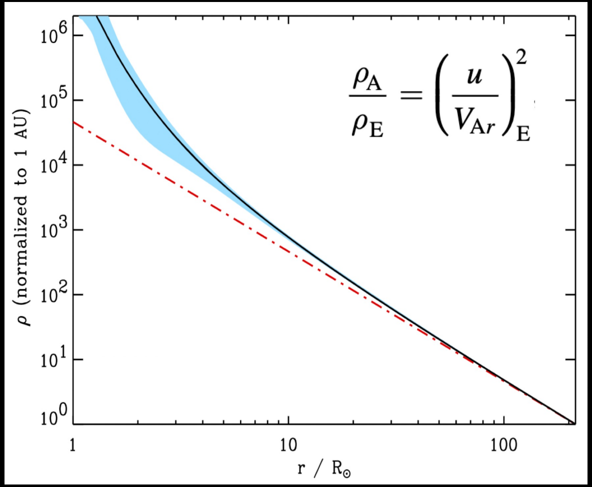
- Weber & Davis (1967) predicted it should fall between 15 and 50 $R_s$.
- Others have generally gone a bit lower (10 to 30 $R_s$) with lots of dependence on latitude, longitude, & solar activity (e.g., Pneuman & Kopp 1971; Keppens & Goedbloed 2000; Matt & Pudritz 2008; Cohen et al. 2009; Pinto et al.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

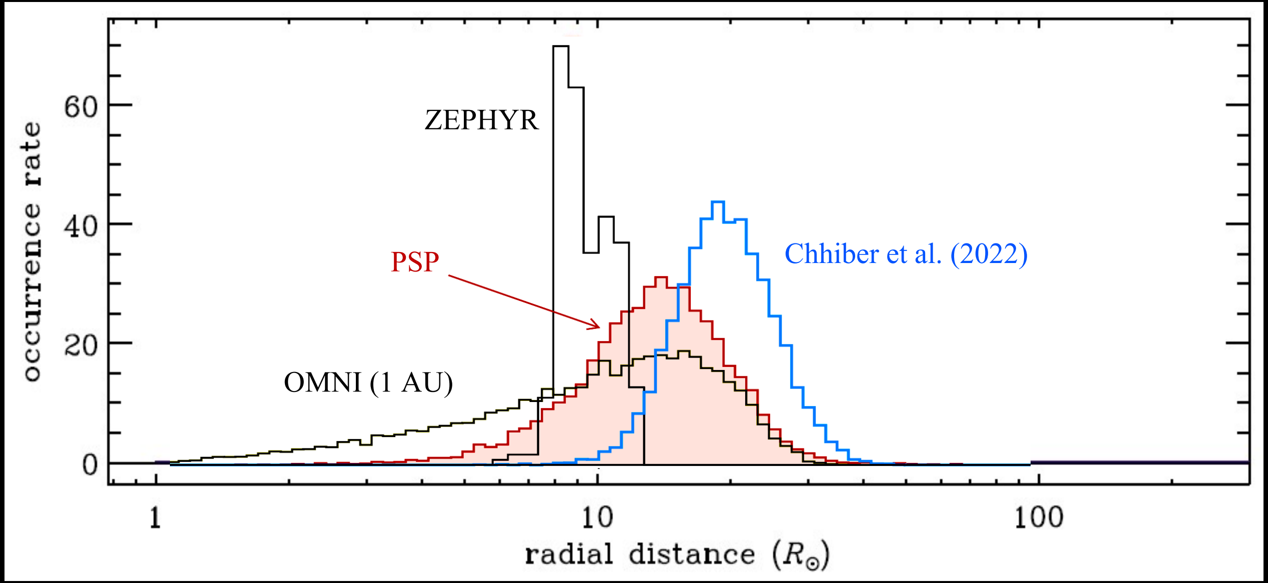


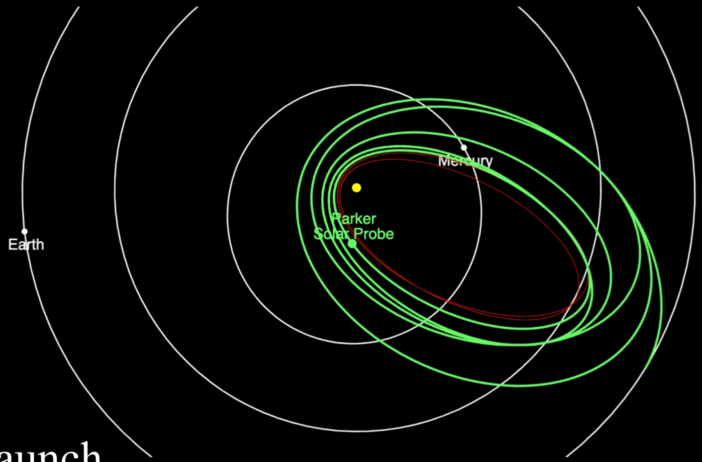
# *Extrapolation from in situ data*

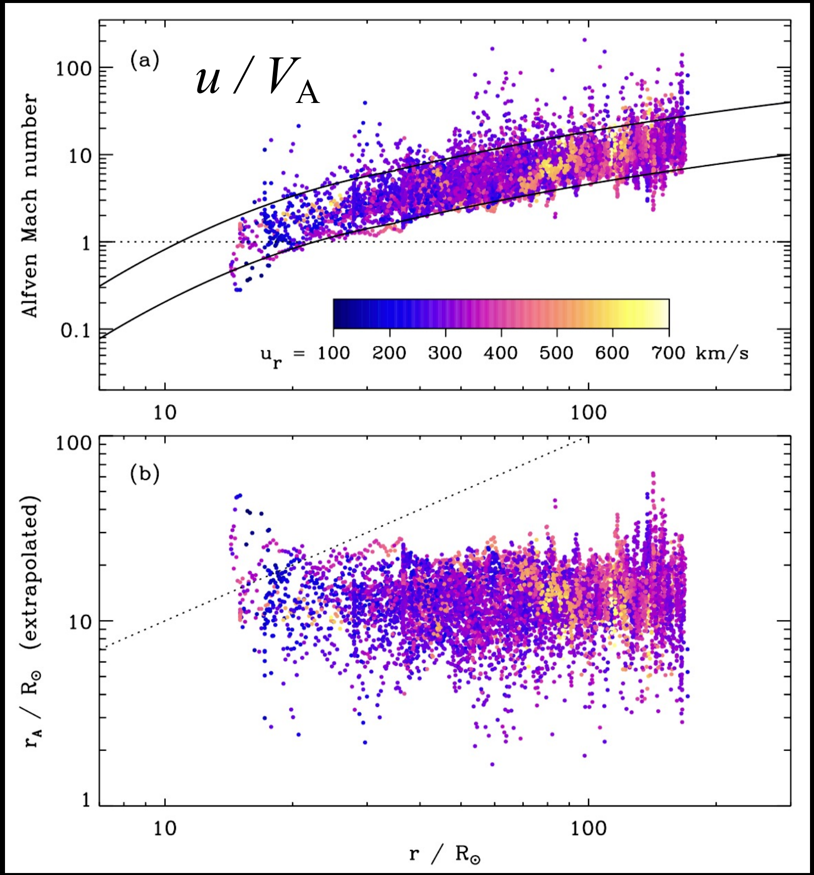
- If we fold in some assumptions about the radial behavior of $u(r)$ & $V_A(r)$, we can take measurements of these quantities at 1 AU (or elsewhere) and **extrapolate** to where they meet (Marsch & Richter 1984; Exarhos & Moussas 2000; Katsikas et al. 2010; Goelzer et al. 2014; Tasnim & Cairns 2016; 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 $R_{\text{sun}}$)
- Apr. 2021: Perihelion 8 (16 $R_{\text{sun}}$);
  **first crossing** of the Alfvén surface
- Mar. 2023: Perihelion 15 (13.3 $R_{\text{sun}}$)
- Dec. 2024: Perihelion 22 (9.9 $R_{\text{sun}}$)

# *Coronagraph imaging can see inflows, too*

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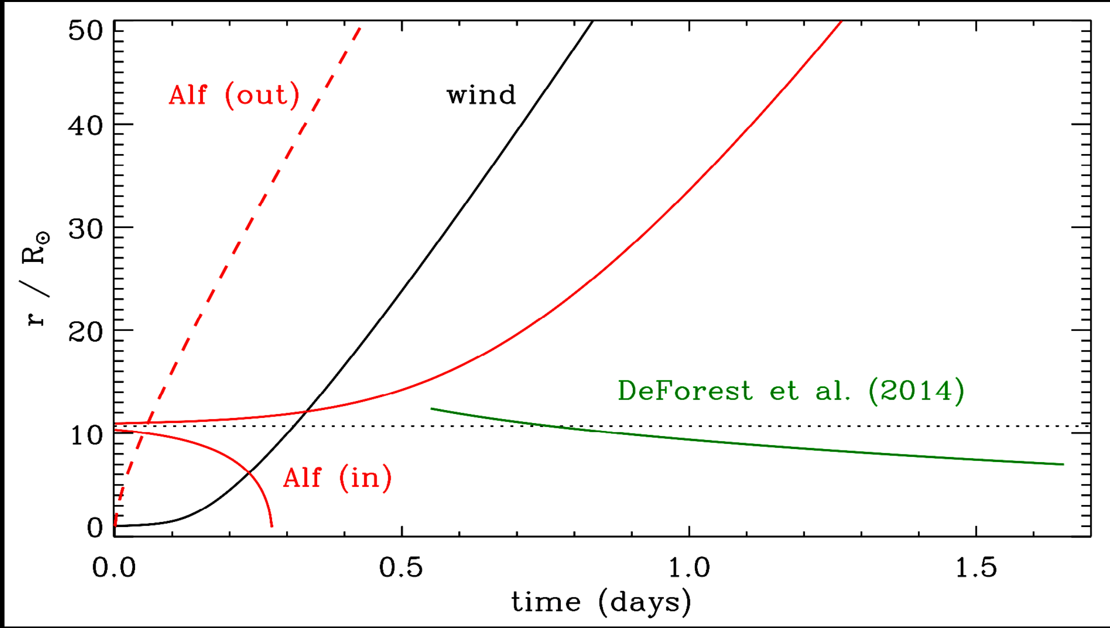

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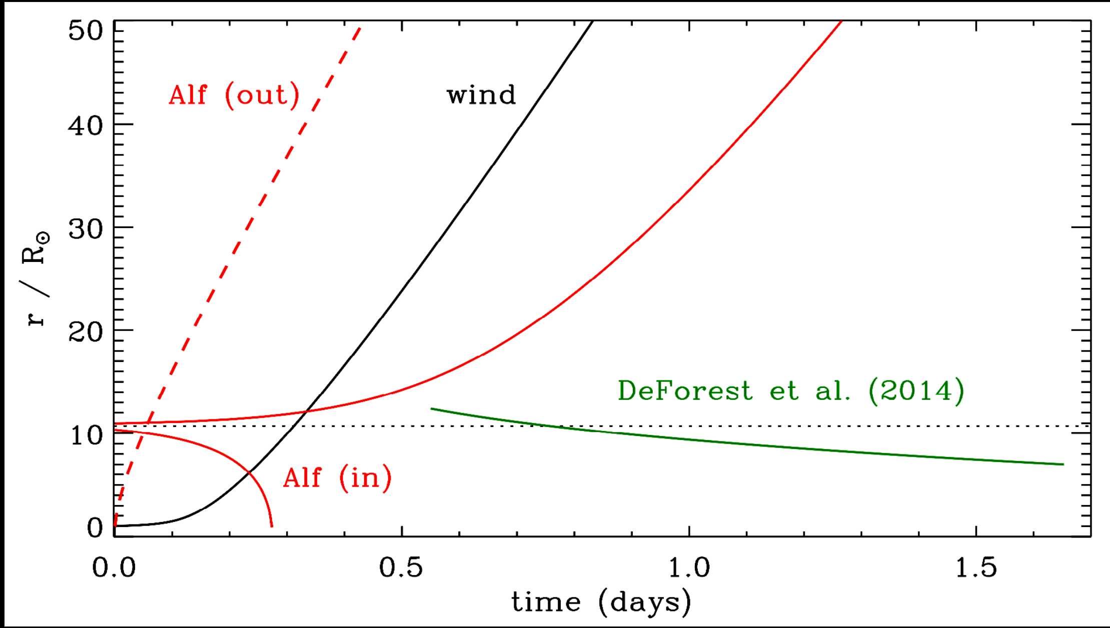


- Theoretical models abound (see Tenerani et al. 2016; Cranmer et al. 2021), and they hint that the blobs may be gaining mass by **"snowplowing"** plasma in front of them. Are they reconnection exhausts? Kelvin-Helmholtz vortices? Supra-Alfvénic shocks?
- We need more examples . . .

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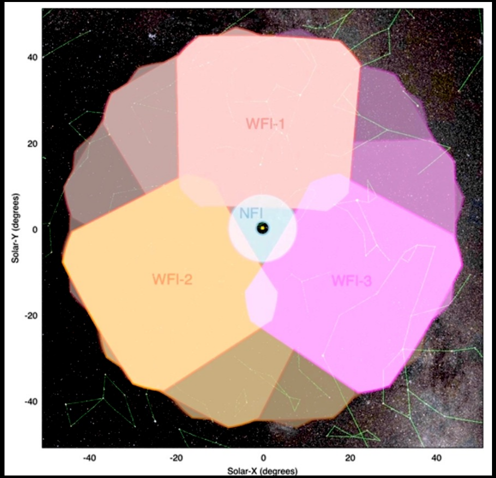
# *PUNCH flow tracking*

- 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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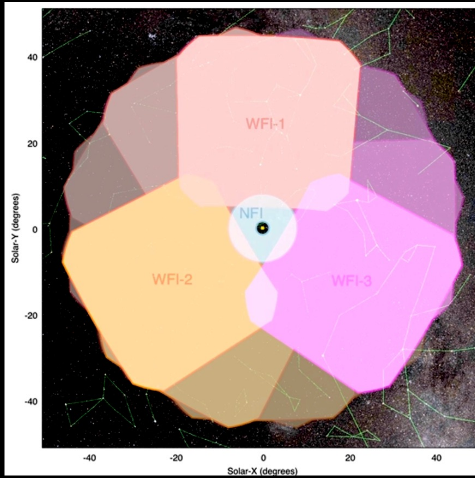
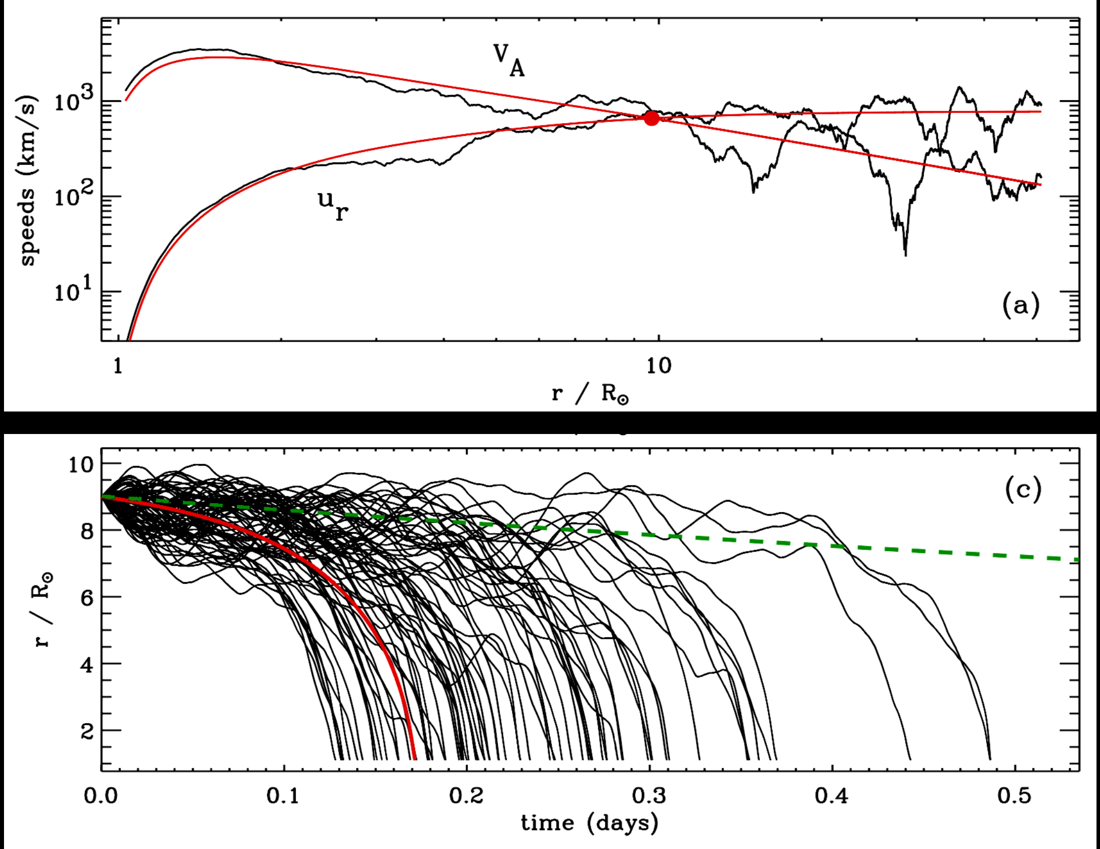
    - (some) 3D localization via polarization
- Working Group 1C is thankful for all the work being done by Working Group 1A !
- Will the decelerating inbound features seen by DeForest et al (2014) be just the “tip of the iceberg?”  Will lower-contrast features not undergo so much snowplowing?  What will 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 . . .