ASYMMETRIES IN THE EARTH'S DAYSIDE MAGNETOSHEATH: RESULTS FROM GLOBAL HYBRID-VLASOV SIMULATIONS

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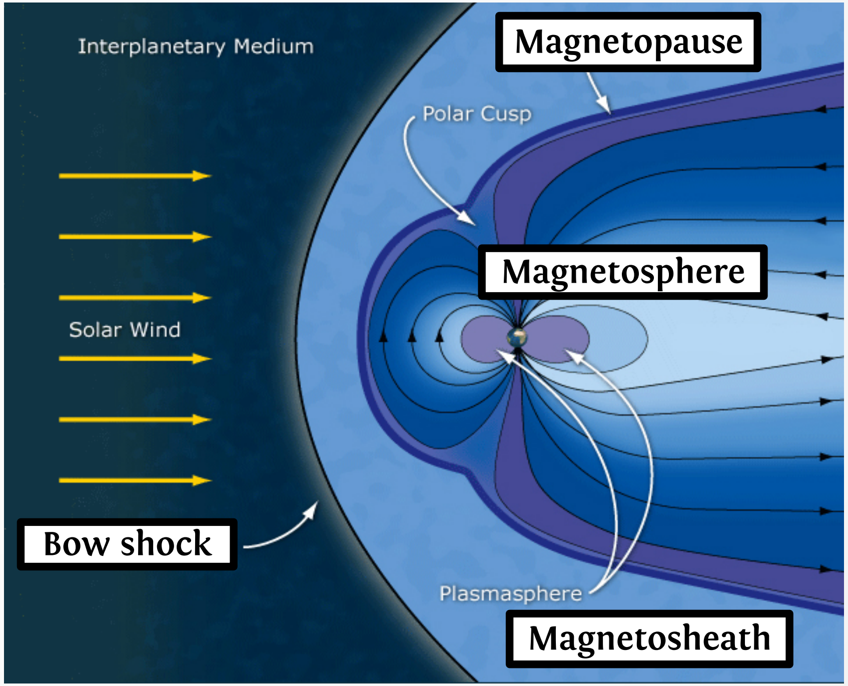
THE MAGNETOSHEATH PLAYS A KEY ROLE IN SOLAR WIND-MAGNETOSPHERE COUPLING

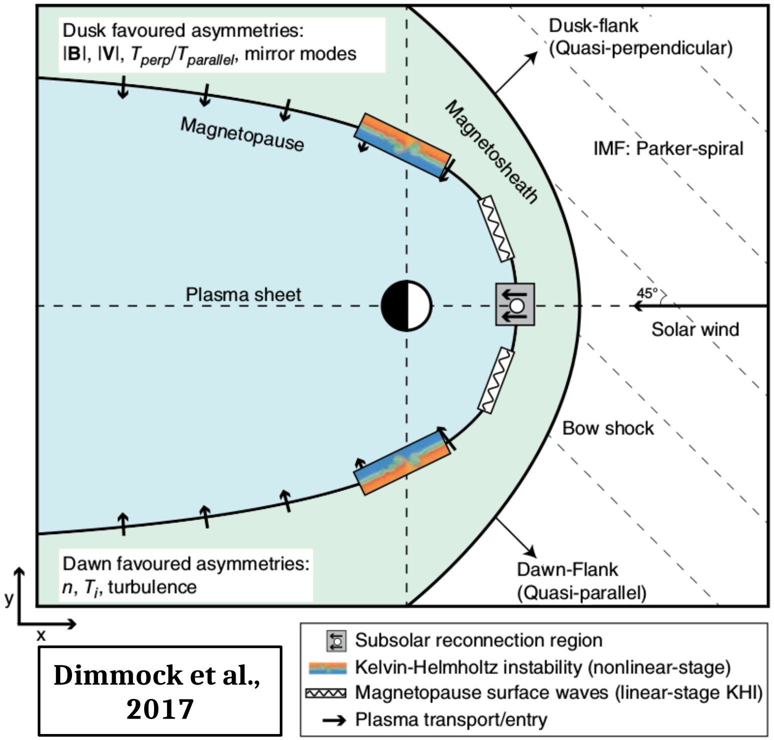
At the **interface between the solar wind and the magnetosphere**, the magnetosheath is filled with shocked solar wind plasma.

The magnetosheath regulates the **upstream conditions** for **magnetopause processes** (reconnection, Kelvin-Helmholtz instability)



THE MAGNETOSHEATH PARAMETERS DISPLAY PRONOUNCED DAWN-DUSK ASYMMETRIES

- These asymmetries are mostly due to the **different bow shock configuration** on the dawn (quasi-parallel) and dusk (quasi-perpendicular) flanks during Parker-spiral IMF *[Walsh et al., 2012; Dimmock & Nykyri, 2013; Dimmock et al., 2017]*
- **These asymmetries can influence plasma transport processes** at the magnetopause, such as the KHI *[Nykyri et al., 2017]*, and could partially explain the temperature asymmetry in the magnetotail *[Wing et al., 2005; Dimmock et al., 2015]*



Dimmock et al., 2017

- **Hybrid-Vlasov model** designed for **global magnetospheric simulations**
- Ions treated as **velocity distribution functions**, electrons are a charge-neutralizing fluid
- Most runs are currently 5D – 3D in velocity space and 2D in ordinary space
- Full description of the model: *Palmroth et al. [2018]*

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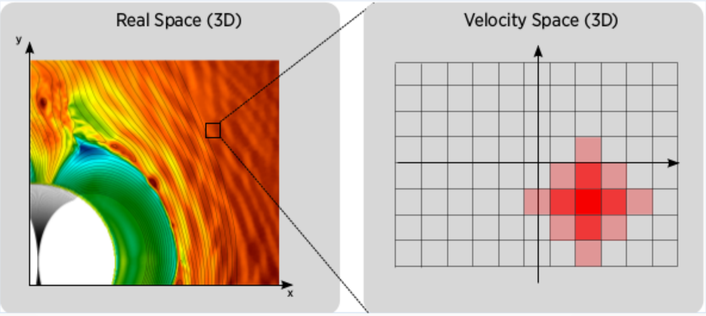
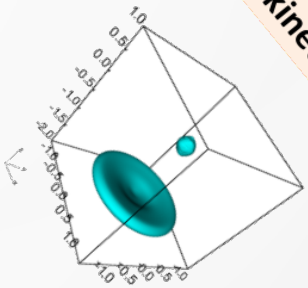




Noise-free multi-temperature kinetic physics!

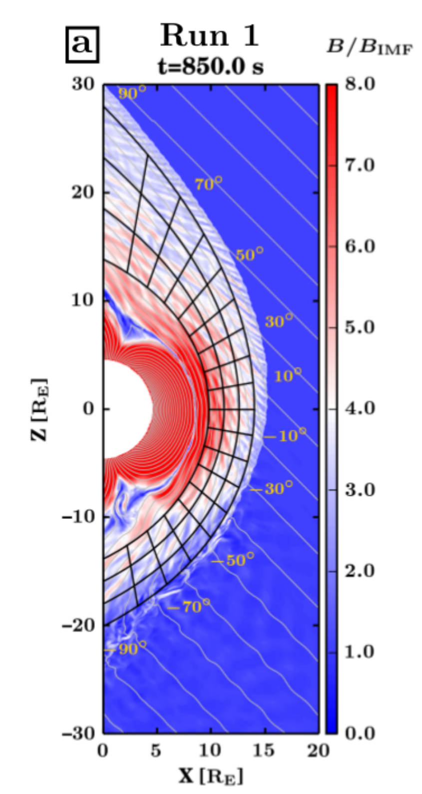
WE QUANTIFY MAGNETOSHEATH ASYMMETRIES IN A SET OF THREE VLASIATOR RUNS:

Run name	Simulation plane	IMF cone angle θ_{Bx}	IMF strength	M_A	n_{SW} $[cm^{-3}]$	$\mathbf{V}_{SW}$ $[kms^{-1}]$
Run 1	$x-z$ plane	$45°$	5 nT	6.9	1	$(-750, 0, 0)$
Run 2A	$x-y$ plane	$30°$	5 nT	6.9	1	$(-750, 0, 0)$
Run 2B	$x-y$ plane	$30°$	10 nT	3.5	1	$(-750, 0, 0)$

- Run 1: comparable with typical Parker-spiral IMF orientation
- Run 2A: lower cone angle
- Run 2B: lower Alfvén Mach number

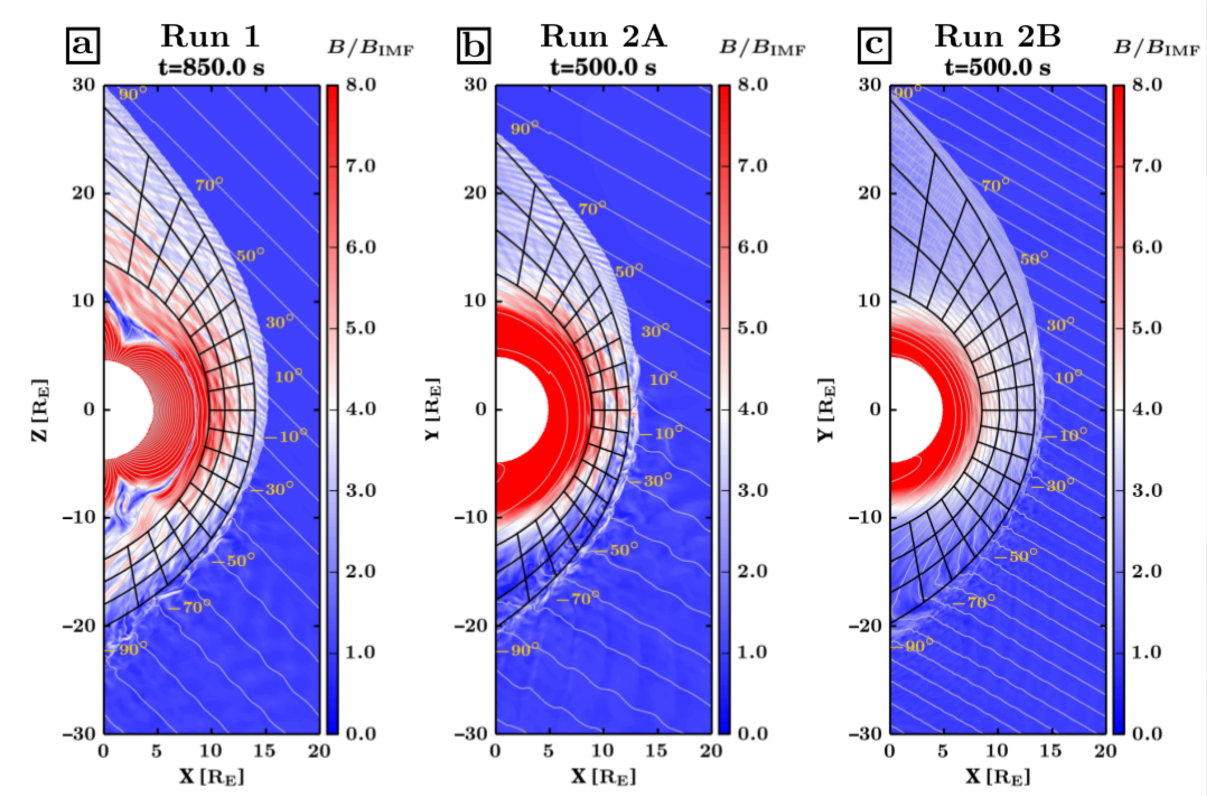
METHODOLOGY FOR QUANTIFYING MAGNETOSHEATH ASYMMETRIES

- We divide the magnetosheath in 18 azimuthal sectors (10° wide).
- We delineate the inner and outer magnetosheath boundaries with a model of the same form as the *Shue et al. [1997]* magnetopause model.
- We divide the magnetosheath into three sets of radial bins: inner, central and outer magnetosheath.
- We calculate the average magnetosheath parameters in each magnetosheath bin by performing a spatial average, inside the bin, and a temporal average, over 150 s of the simulation.



MAGNETIC FIELD STRENGTH

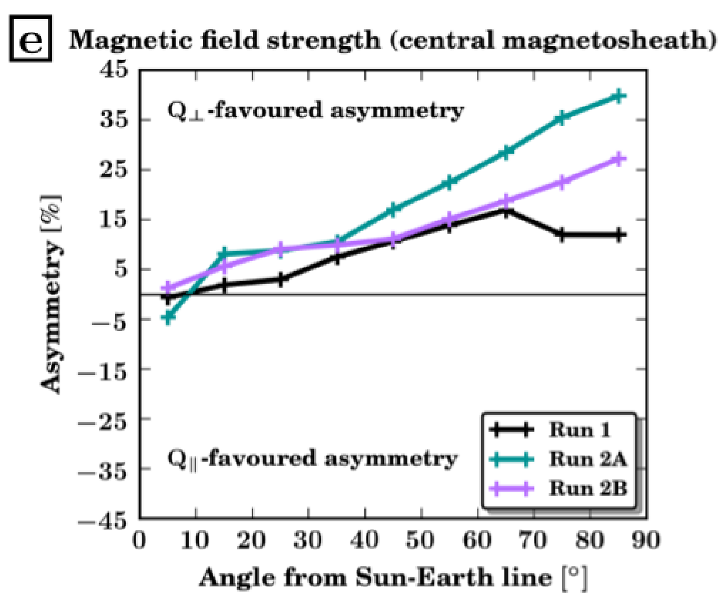
- $B_{Msheath} \leq 4B_{SW}$ just downtream of the bow shock, consistent with MHD theory
- Larger field increase deeper in the magnetosheath due to the field lines piling up in front of the magnetosphere
- Weaker magnetic field compression in the low Alfvén Mach number run (Run 2B)



Turc et al., submitted to Annales Geophysicae

MAGNETIC FIELD STRENGTH ASYMMETRY

- **Quasi-perpendicular-favoured asymmetry**, consistent with previous works *[Walsh et al., 2012; Dimmock et al., 2017]*
- Parker-spiral asymmetry level (in black) similar to that in the data (5-10% in *Dimmock et al., 2017*)
- More pronounced asymmetry when the cone angle is reduced from 45° to 30° because of the weak compression at the quasi-parallel shock
- **Less pronounced asymmetry at low M_A** due to the **reduced compression** at the quasi-perpendicular shock



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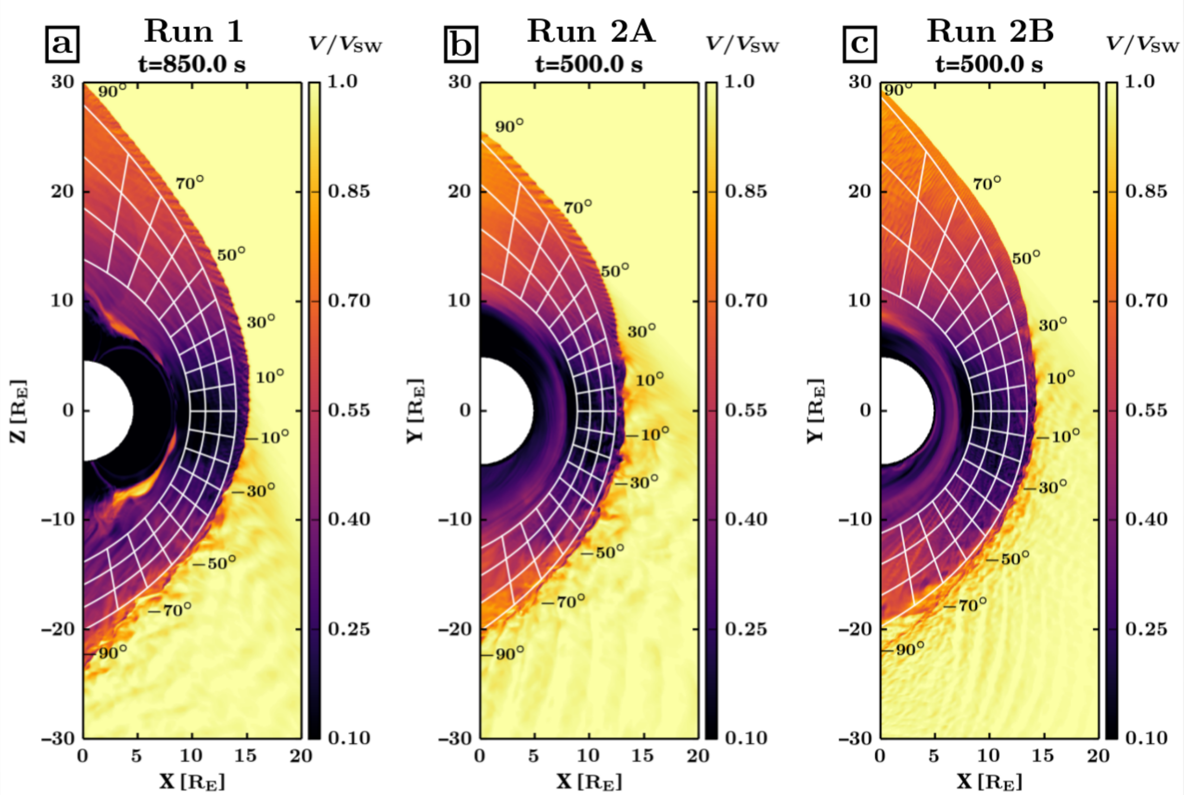
PLASMA BULK VELOCITY

- Bulk velocity close to zero near the magnetopause nose and faster flows towards the flanks, as expected.
- **Large variability** of the velocity in the **quasi-parallel magnetosheath**, due to foreshock processes
- **Reduced variability** of the quasi-parallel magnetosheath velocity at **low Alfvén Mach number**



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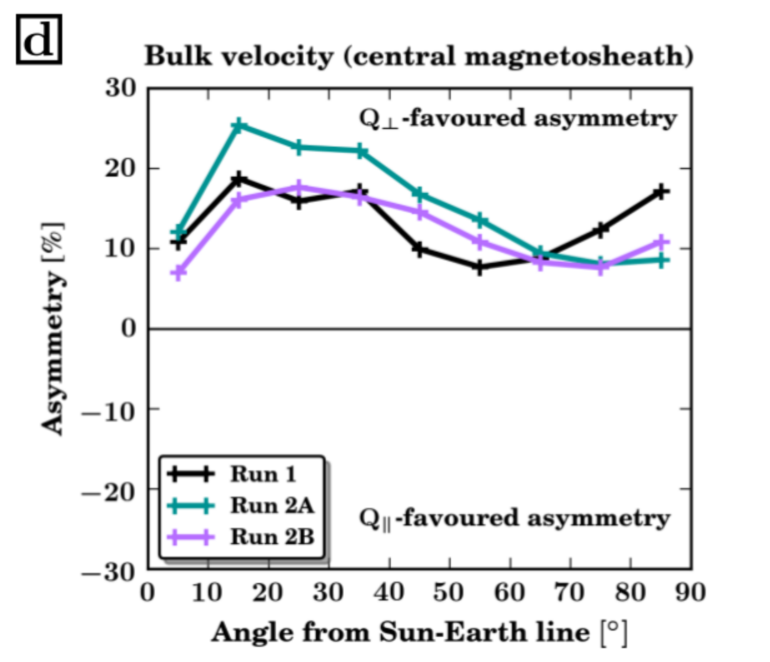
BULK VELOCITY ASYMMETRY

- **Quasi-perpendicular-favoured asymmetry**, consistent with previous works [*Walsh et al., 2012; Dimmock et al., 2017*].
- Parker-spiral asymmetry level slightly larger than in spacecraft measurements (5-10% in *Dimmock et al., 2017*)
- **No significant change in the asymmetry level** when changing the cone angle or the Alfvén Mach number



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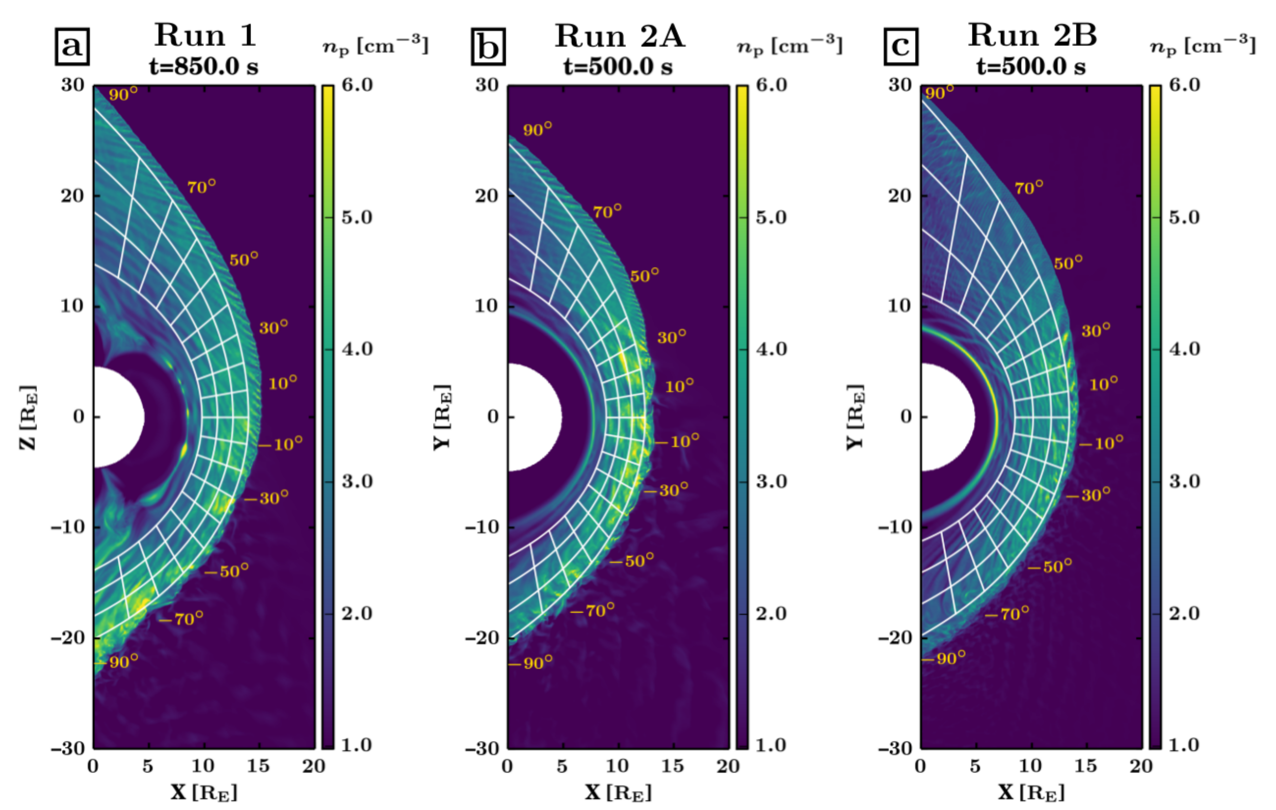
ION DENSITY

- Magnetosheath density ‹ 4 times the solar wind density in the quasi-perpendicular magnetosheath, consistent with MHD theory
- **Large variability of the density** in the quasi-parallel magnetosheath, due to **foreshock processes**
- **Reduced density fluctuations** at **low Alfvén Mach number** (Run 2B)



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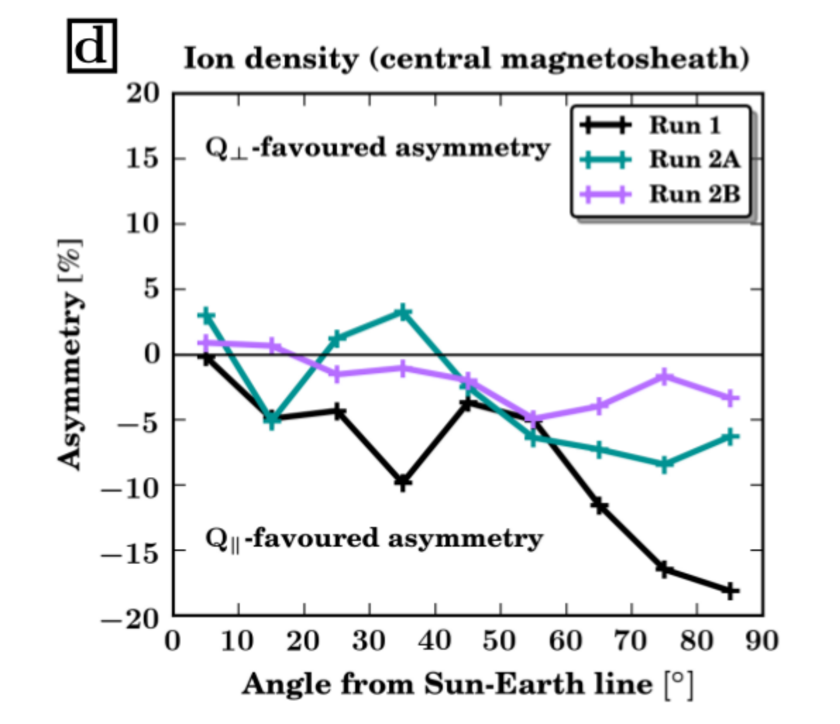
ION DENSITY ASYMMETRY

- **Mostly quasi-parallel-favoured asymmetry**, consistent with previous works *[Paularena et al., 2001; Walsh et al., 2012; Dimmock et al., 2017]*
- **Large variability** of the density asymmetry, even during **completely steady upstream conditions** → reverse polarity in some azimuthal bins
- Median value of the asymmetry closer to 0 at **low Alfvén Mach number** → **less pronounced asymmetry** overall, but with significant local variations



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CONCLUSIONS:
VALIDATION OF THE SIMULATION RESULTS

The magnetosheath asymmetries in our Vlasiator runs are in **good agreement with statistical spacecraft observations**:

- Same polarity (quasi-perpendicular or quasi-parallel-favoured)
- Levels of asymmetry larger in the simulation, due to the single set of upstream conditions in each run ≠ compilation of observations with vastly different solar wind parameters [see also Walsh et al., 2012]

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CONCLUSIONS: VARIABILITY OF MAGNETOSHEATH ASYMMETRIES

- When the cone angle is reduced from 45° to 30°, the **magnetic field asymmetry is more pronounced**, while the density and velocity asymmetry levels are unchanged.
- At low Alfvén Mach number, the **magnetic field asymmetry level decreases**, and the **variability** of the magnetosheath **density and velocity** is **reduced**, due to weaker foreshock processses.
- **Large variability** of the plasma **density** even for completely **steady upstream conditions** in our simulation, in particular in the quasi-parallel magnetosheath → could explain the vastly different levels of density asymmetry quantified in previous observational studies

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