Imperial College London

Science & Technology Facilities Council

Preparing to re-visit the inner heliosphere

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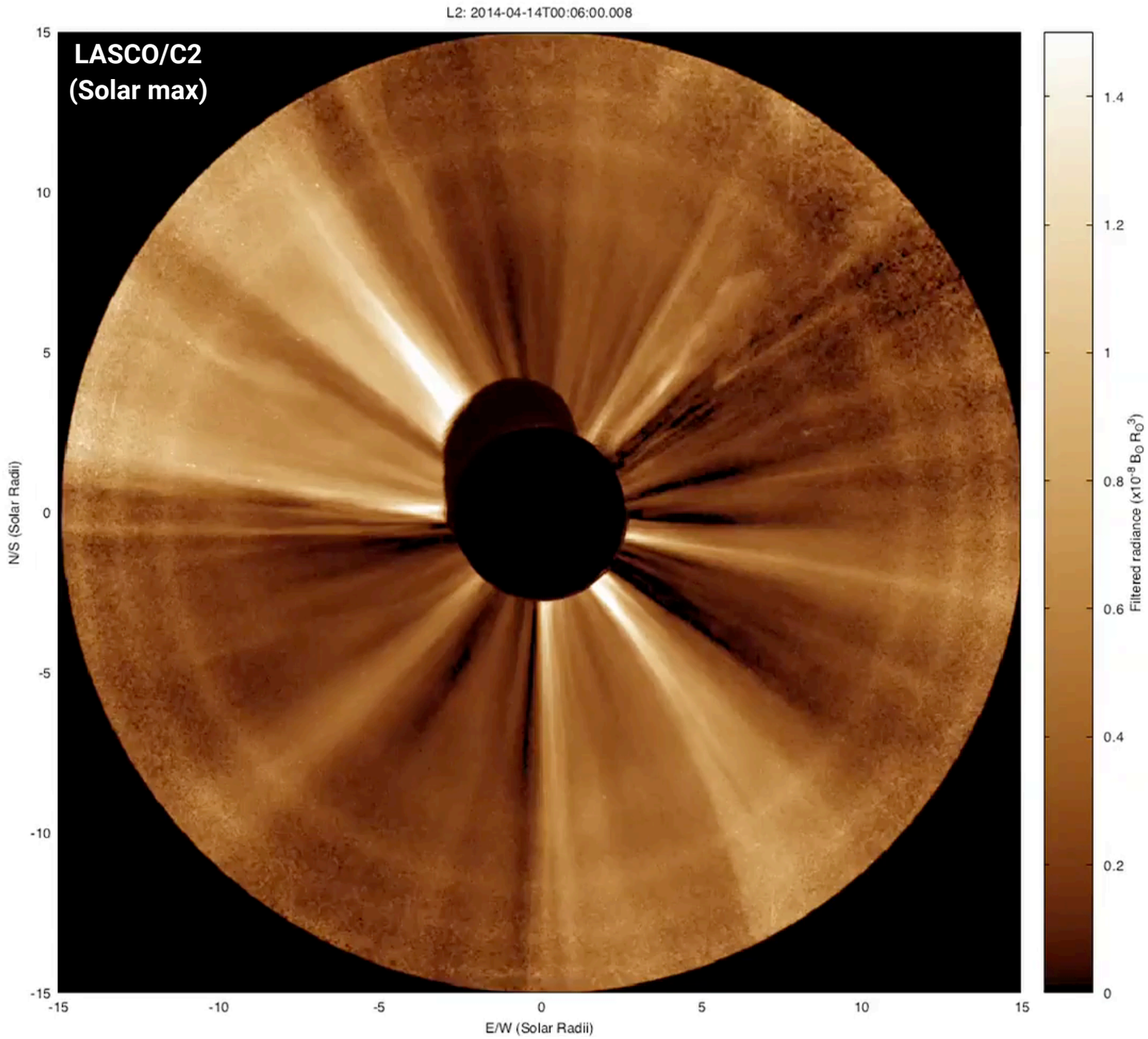
The Solar Wind



DeForest et al. 2018

At 1 AU

- n ~ 5 cm^{-3}
- v ~ 600 km/s
- T ~ 10^6 K

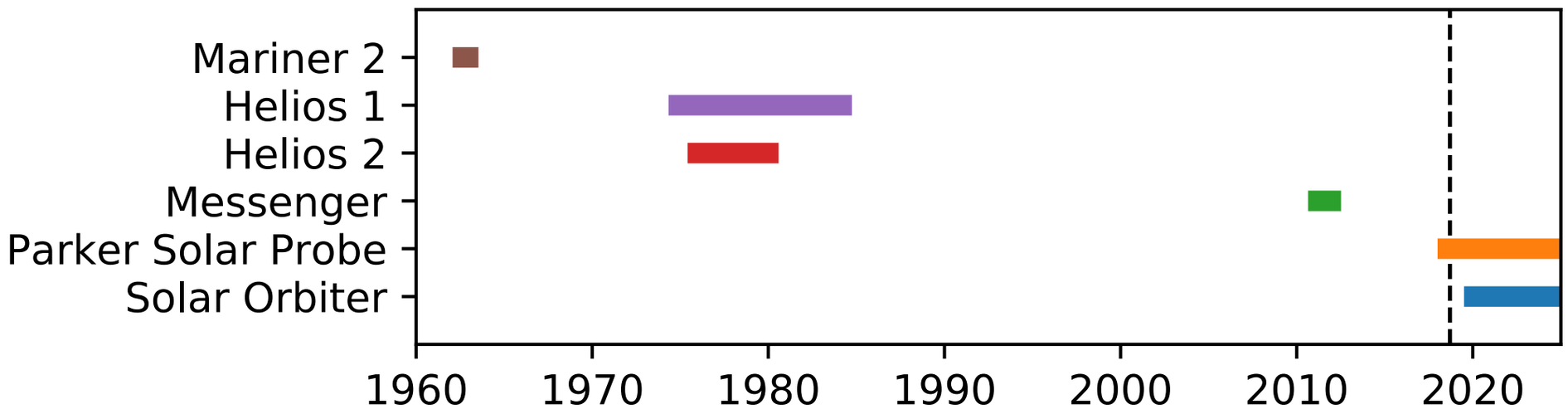
Open questions

3.1.1. What Are the Source Regions of the Solar Wind and the Heliospheric Magnetic Field?

3.1.2. What Mechanisms Heat and Accelerate the Solar Wind?

- In-situ measurements at 1 AU limited by processes that irreversibly erase information on source regions during transit
- To mitigate this, get close to the Sun
  → Solar Orbiter and Parker Solar Probe
- But we have been to the inner heliosphere before!

Measurements inside 1 AU



- Helios have the only comprehensive, archived in-situ measurements of the inner heliosphere to date
- Reprocessed to provide reproducible + reliable proton number densities, speeds, and temperatures (*Stansby 2018, arXiv*)

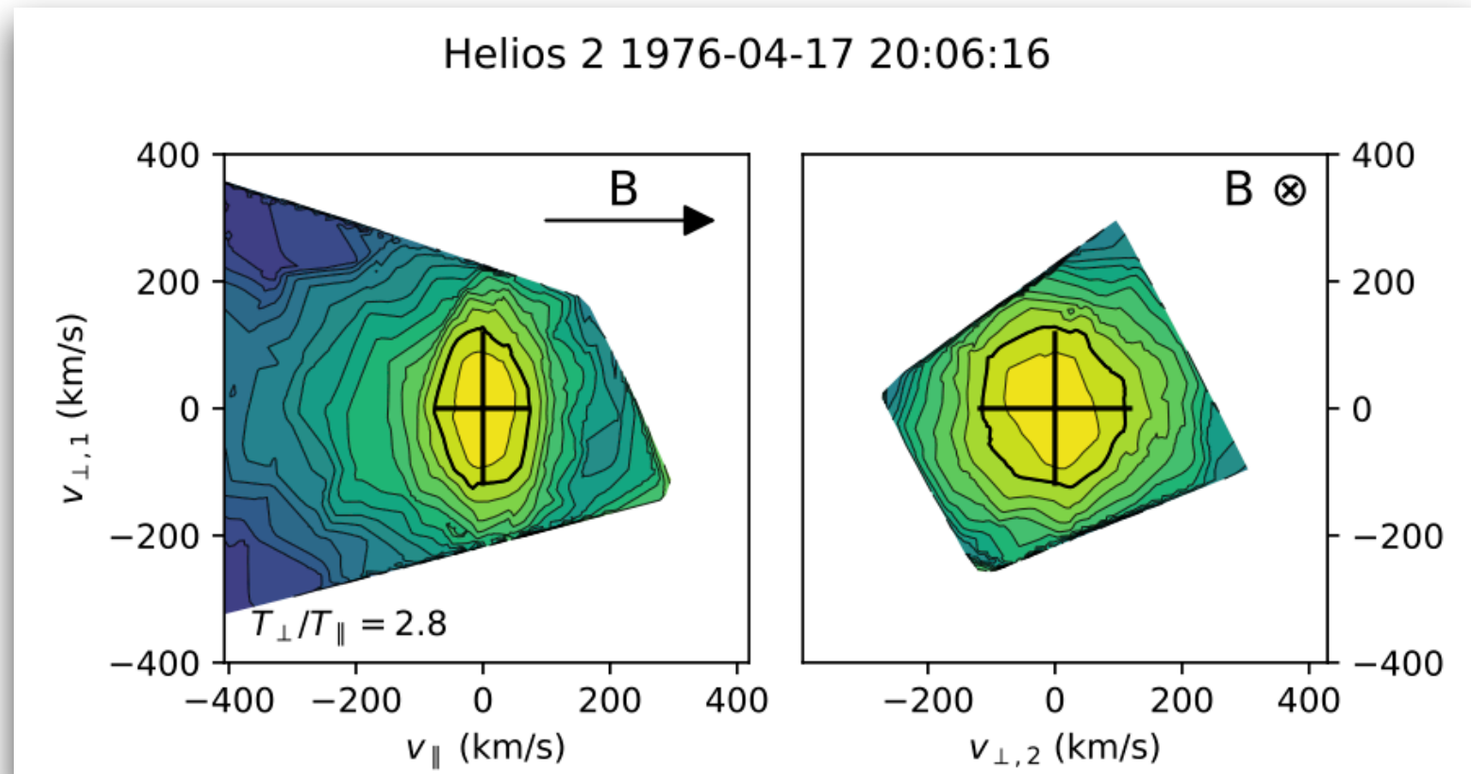
Mariner 2: *Neugebauer et al. 1962;* ***MESSENGER:*** *Gershman et al. 2012*

In-situ measurements

- All in-situ spacecraft typically measure
  magnetic field & **proton velocity distribution function**

- **Derive** number density, velocity, and temperatures

- New processing to extract Tperp, Tpar for entire Helios mission



$\longrightarrow$ $n_p, \mathbf{v}_p, T_{p\perp}, T_{p\parallel}$

(x 2,000,000)

Stansby et al. 2018

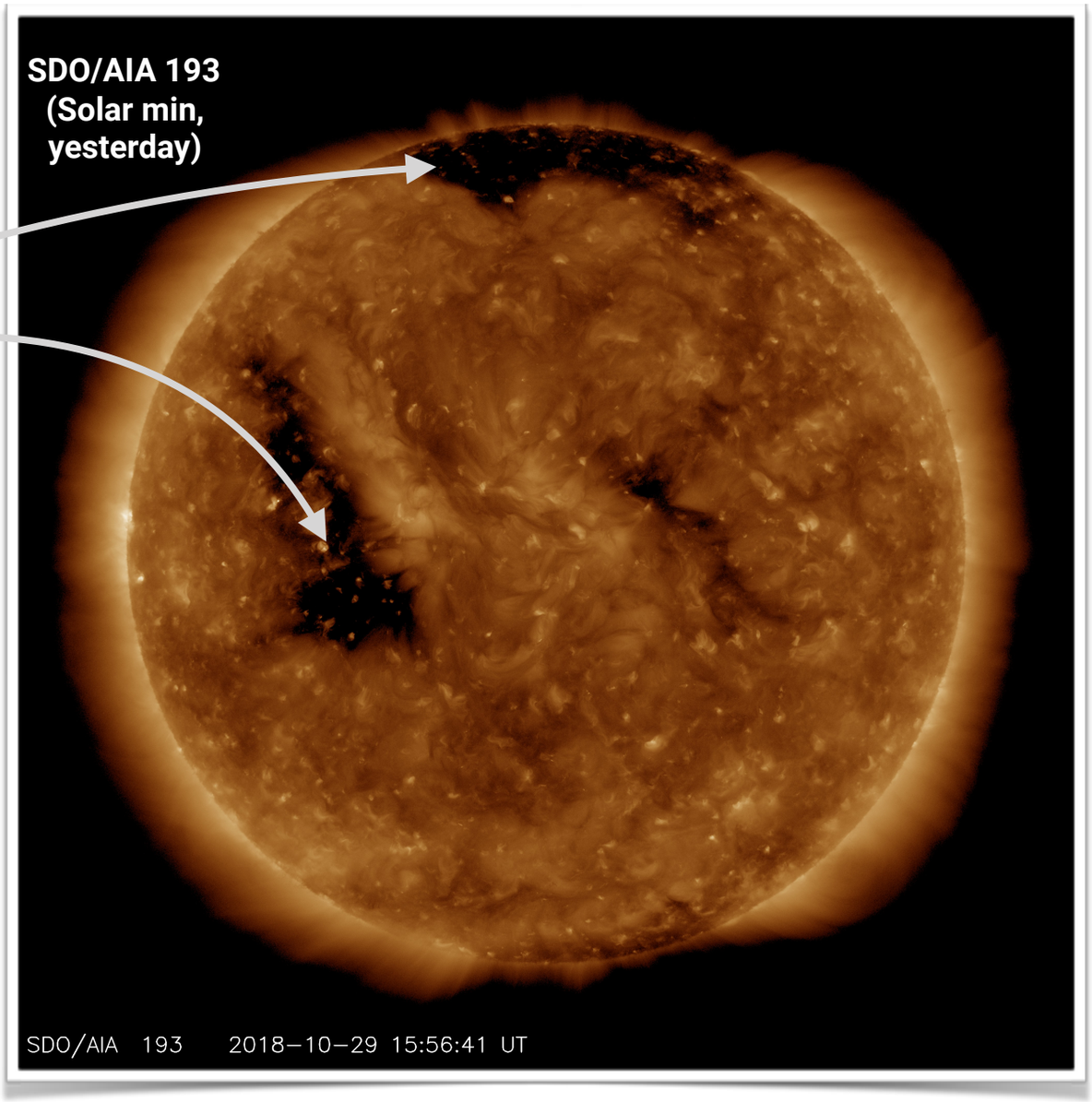
Solar wind sources

3.1.1. What Are the Source Regions of the Solar Wind and the Heliospheric Magnetic Field?

- Try to categorise in-situ solar wind measurements into different sources
- Been attempted before (e.g. Neugebauer et al. 2017), but only with 1 AU data
- Possible sources are
  - Coronal holes (centre + edges)
  - Active regions (e.g. *Harra et al. 2017*)
  - Small transients (e.g. *Sheeley et al. 1997*)

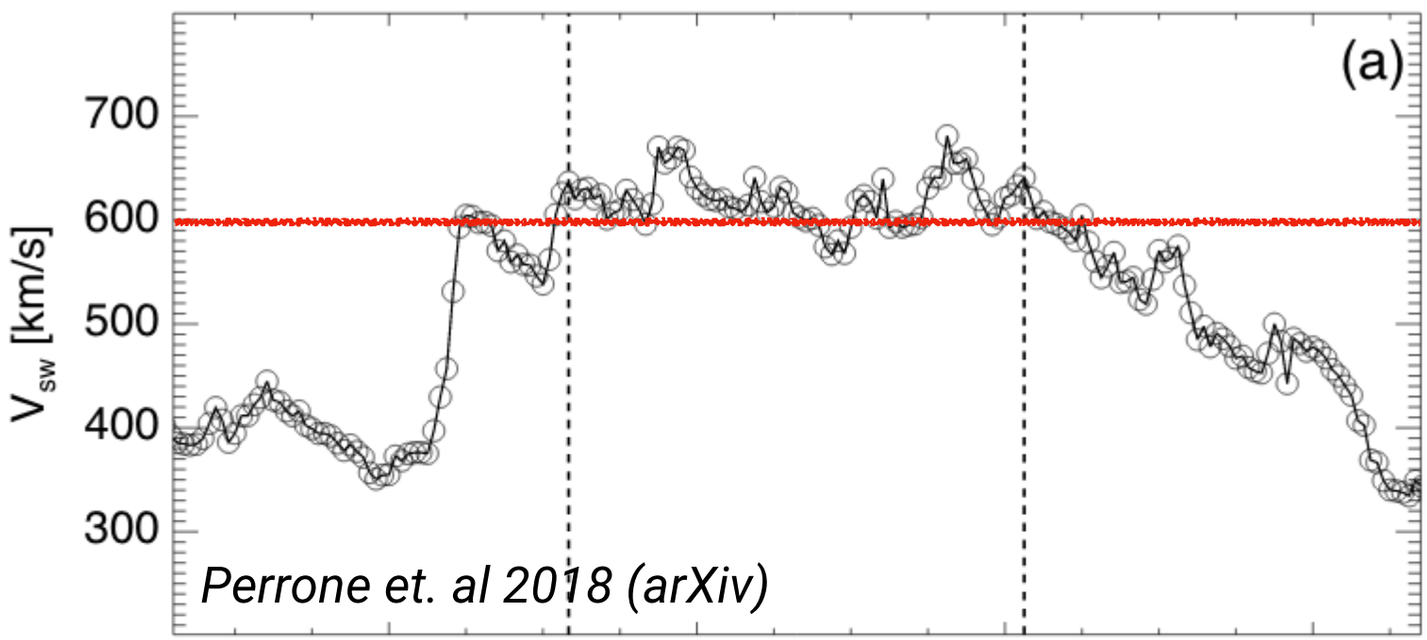
Fast/slow wind

- Long known “fast” wind comes from coronal holes
- Still working on where all the “slow” wind comes from…



Cutting by speed doesn’t work

- Fast/slow split is too simple for distinguishing solar wind
- A simple “cut” in speed selects wind with different sources

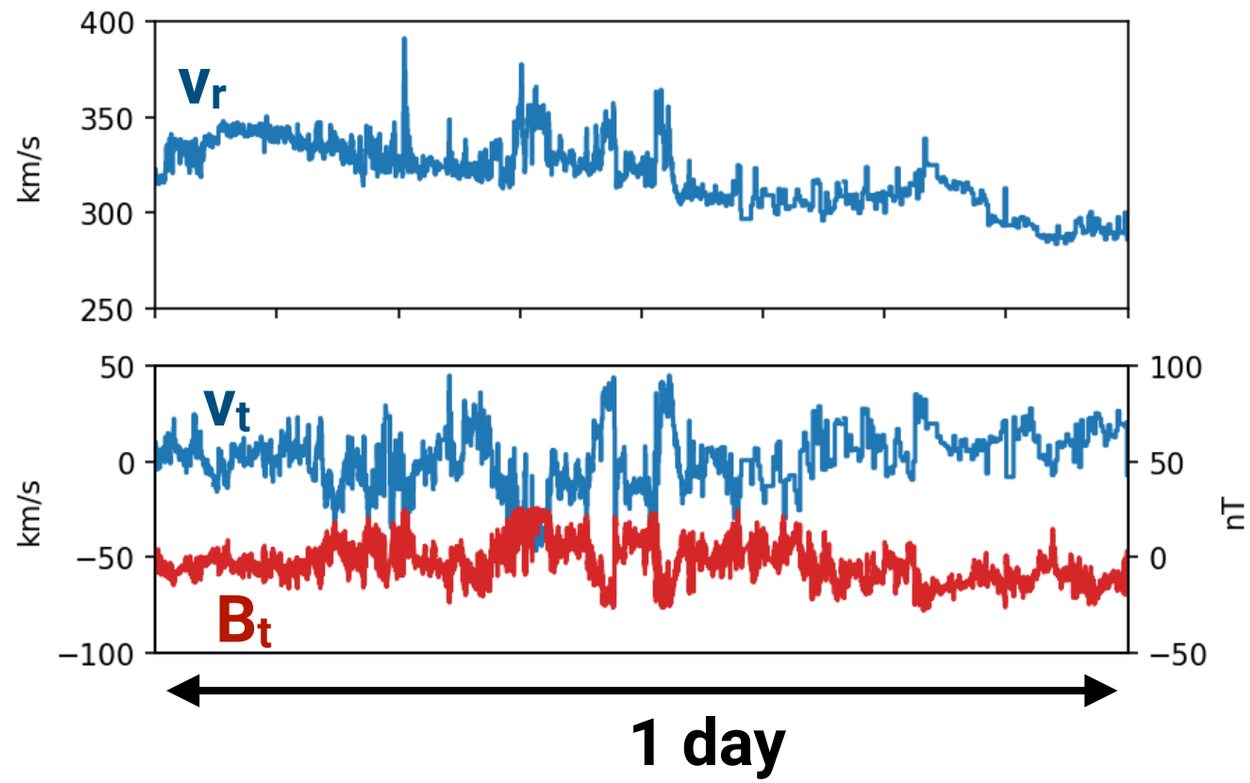


10 days

Cutting by speed doesn't work

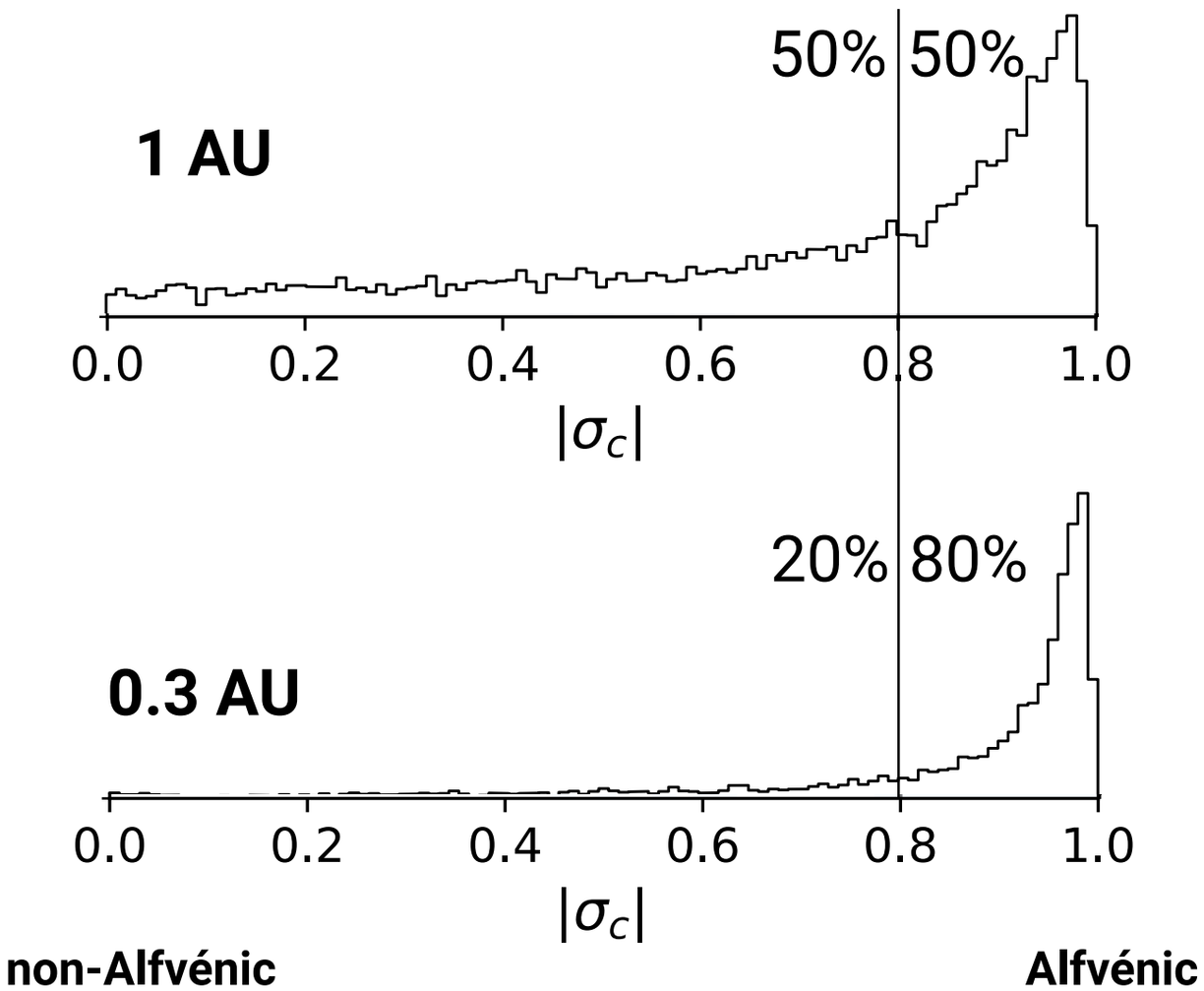
- All fast solar wind is a smooth flow + Alfvén waves

- Recent work has found similar structure within slow wind
  (D'Amicis et al. 2015, 2016)



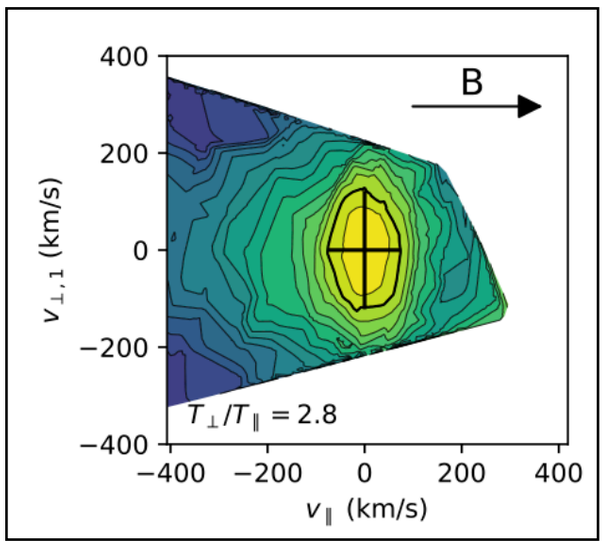
- Maybe Alfvénicity is a more physical separator of wind types?

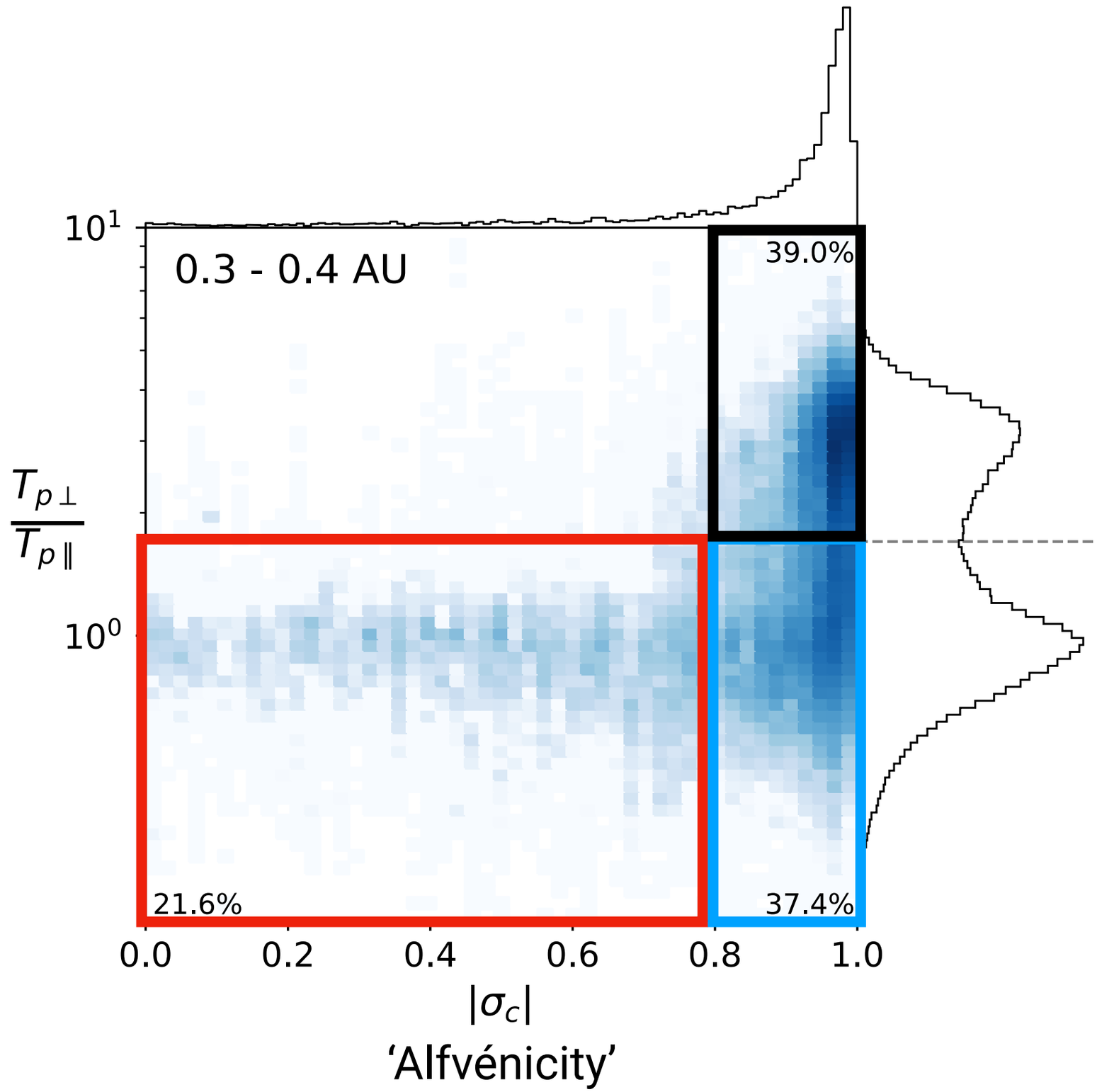
Radial variation of Alfvénicity



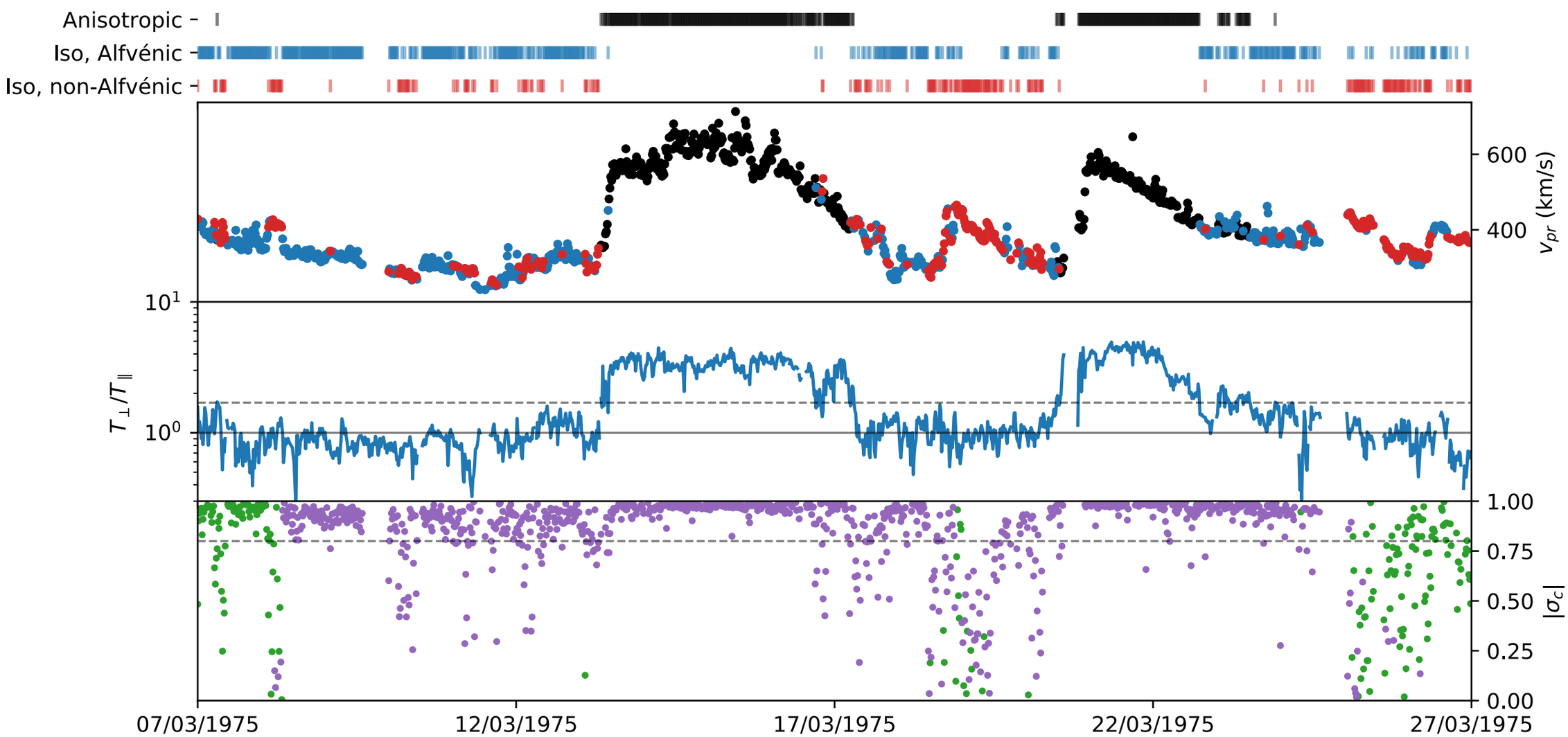
- All Helios data at solar minimum
- Properties at 1 AU not reflective of solar source properties!

Alfvénic wind at 0.3 AU



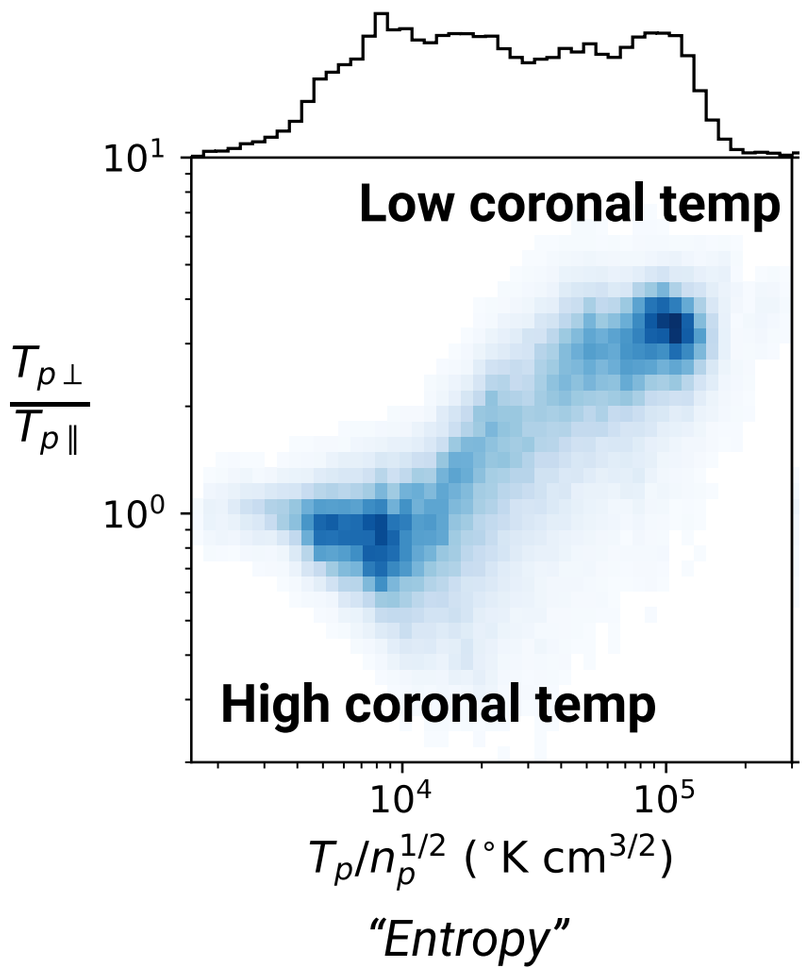


Classification timeseries



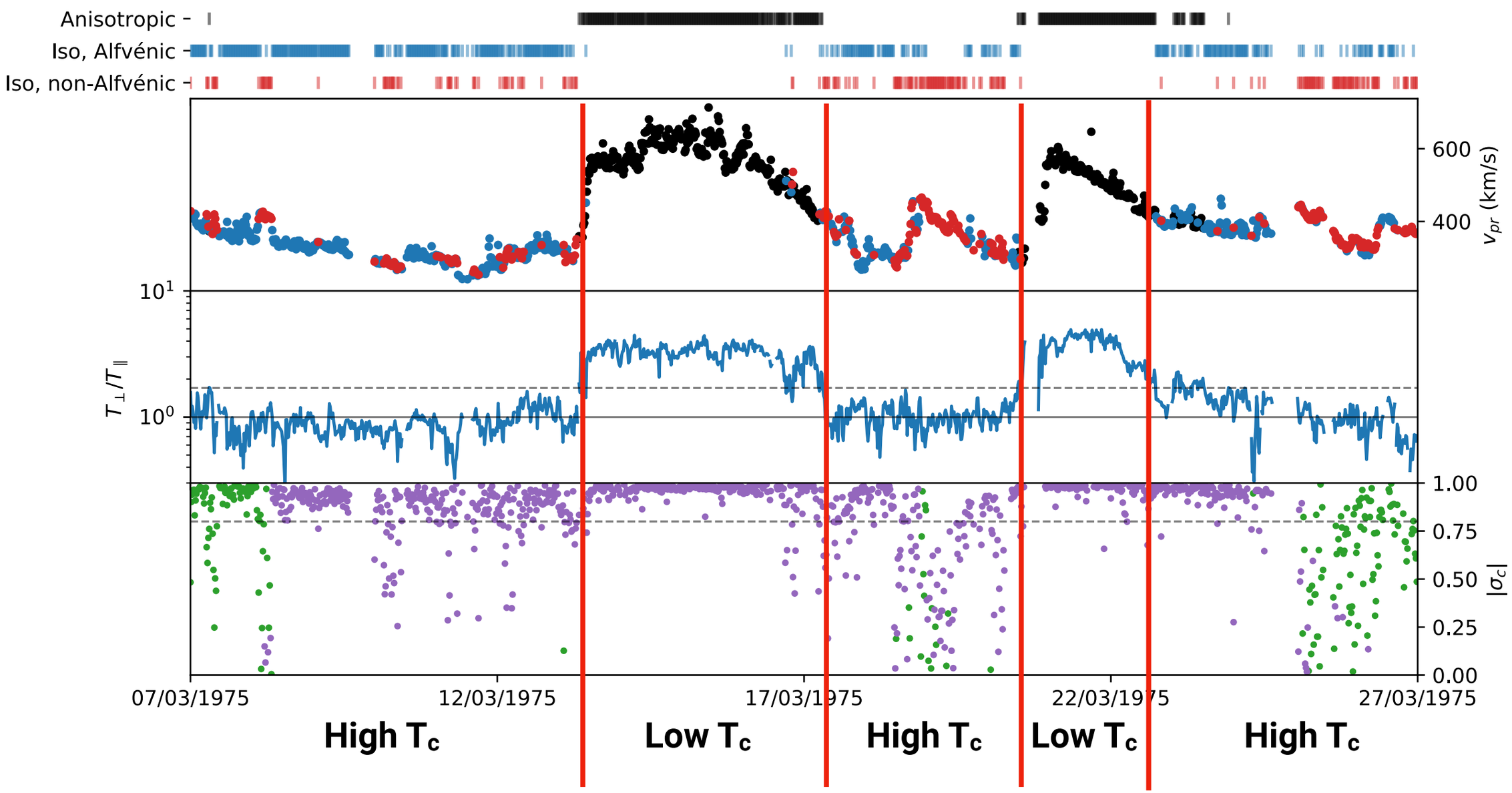
20 Days

Using $T_\perp/T_\parallel$ to infer composition



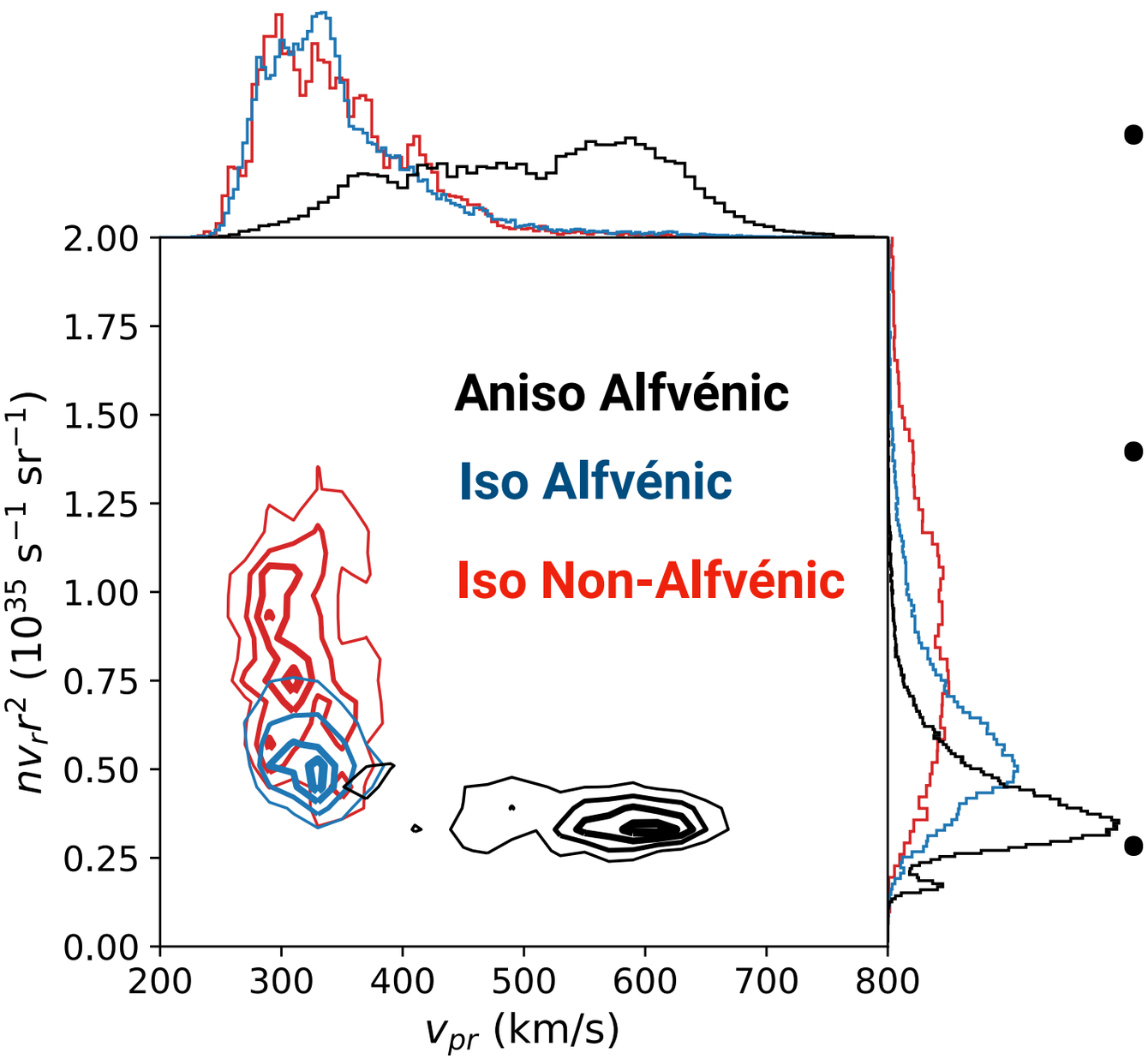
- Ulysses and ACE show entropy and O^{7+}/O^{6+} are statistically correlated
  [Pagel et. al. 2004, Stakhiv et. al. 2015, 2016]
- Also sharp O^{7+}/O^{6+} boundaries at leading + trailing edges of high speed streams
  [Burton et. al. 1999, Borovsky et. al. 2016]
- Helios saw **sharp anisotropy boundaries** in the **leading and trailing edges** at 0.3 AU

Classification timeseries



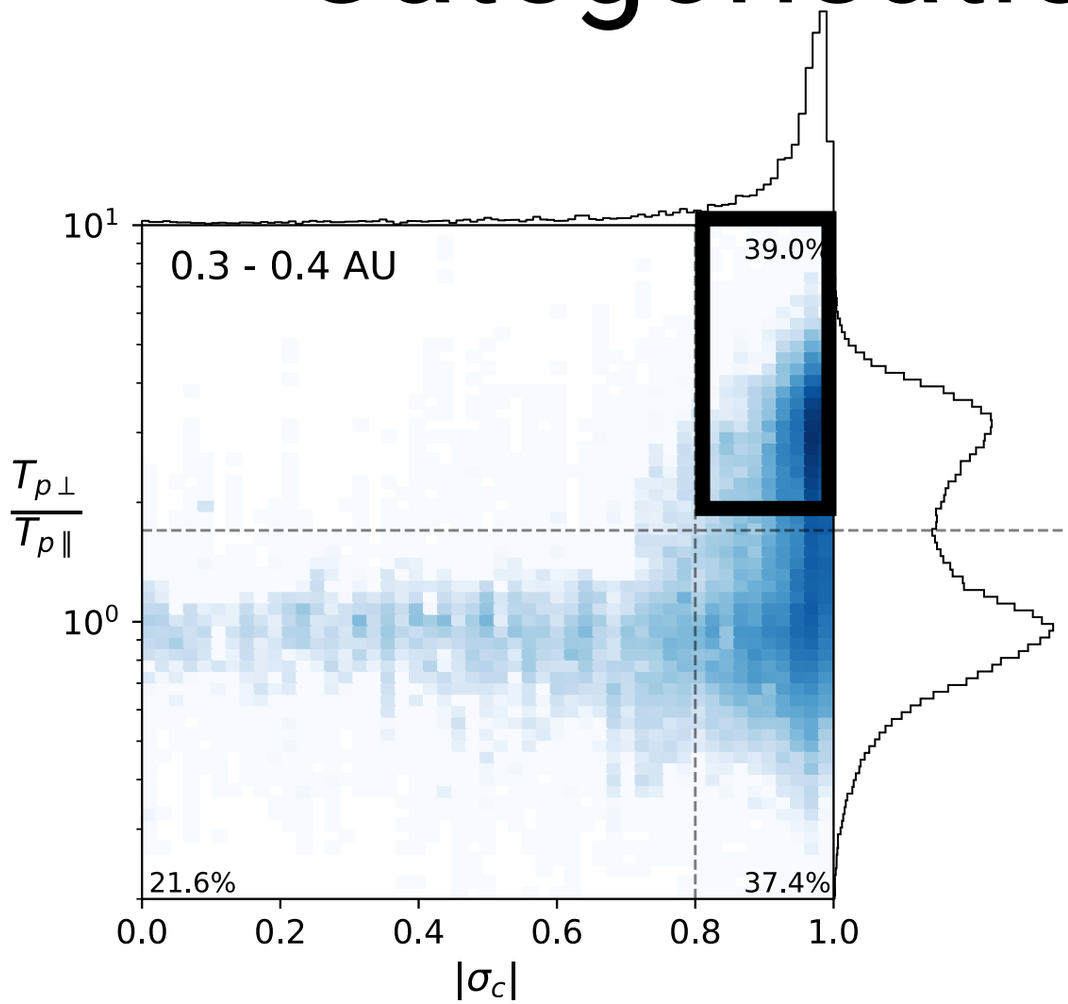
20 Days

Speed + mass flux of the 3 categories



- Distinction between slow/fast blurred at intermediate speeds
- Alfvénic wind has steady mass flux → continuous release on open field lines
- Non-Alfvénic wind has varying mass flux → transient release on closed lines

Categorisation conclusions

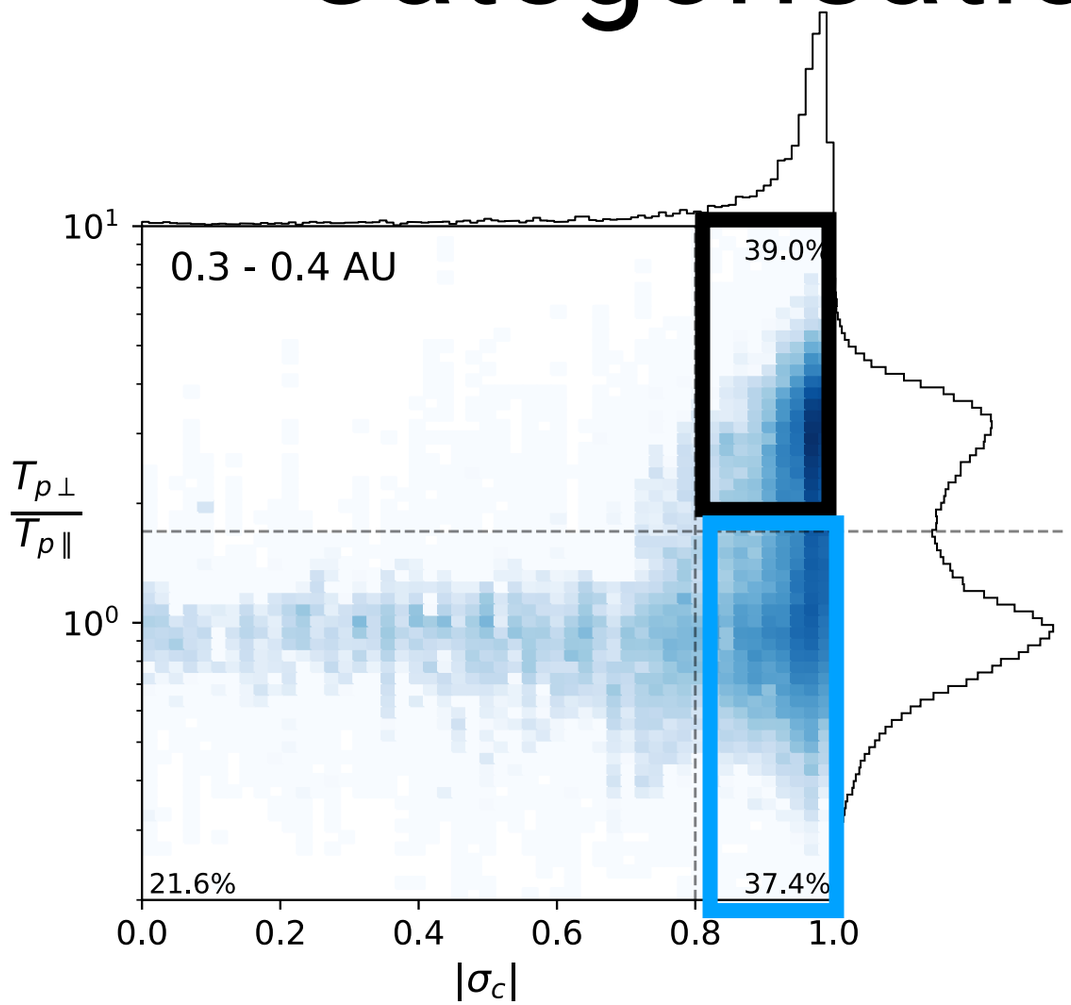


Coronal holes

- Low coronal temp
- Constant mass flux
- Includes high speeds

Stansby et al. 2018

Categorisation conclusions



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Active regions/CH edges

- High coronal temp
- Alfvénic + constant mass flux

⇒ quasi-steady open flux

Stansby et al. 2018

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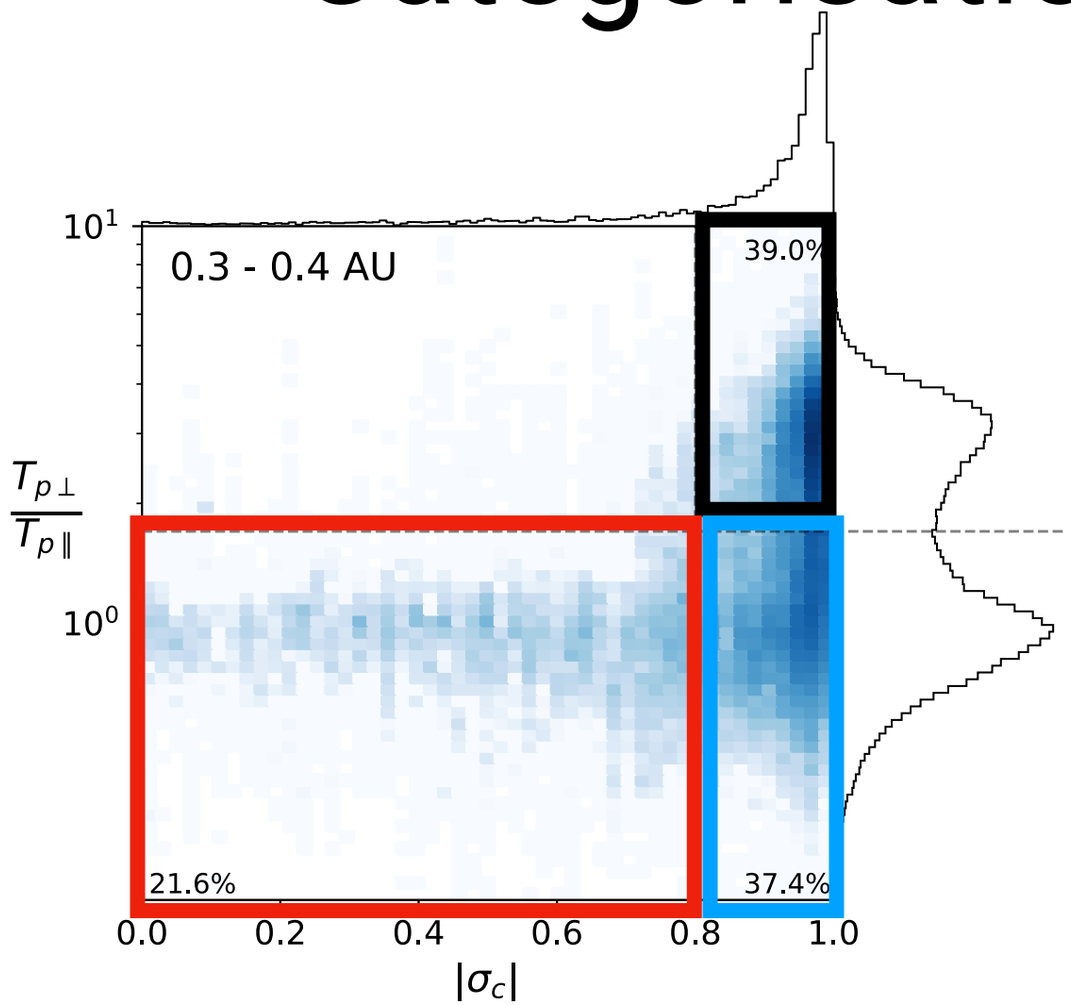

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Small transients

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- non-Alfvénic + variable mass flux

⇒ intermittent source

Stansby et al. 2018

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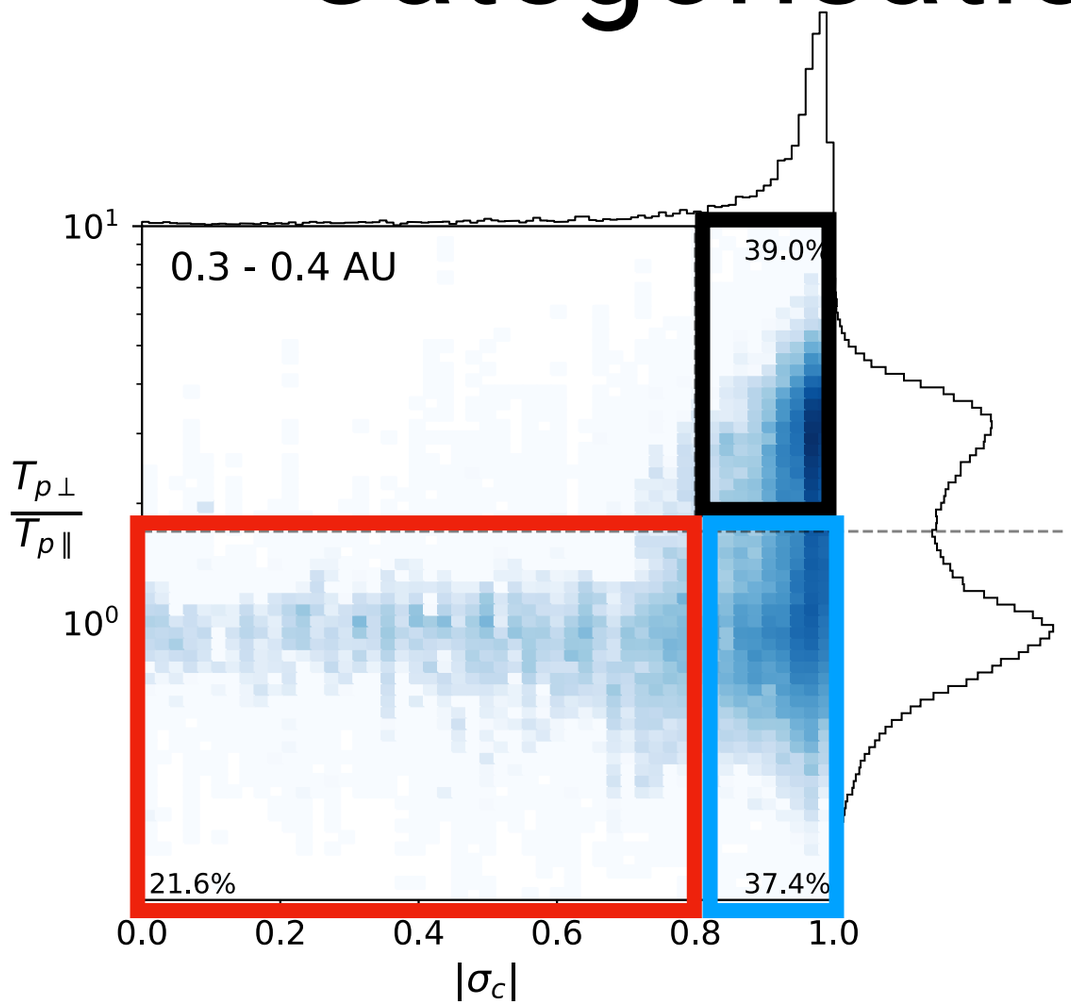

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- non-Alfvénic + variable mass flux

⇒ intermittent source

- A **testable prediction** of contributions of different sources to the solar wind (at solar min)

Stansby et al. 2018

Coronal heating

3.1.2. What Mechanisms Heat and Accelerate the Solar Wind?

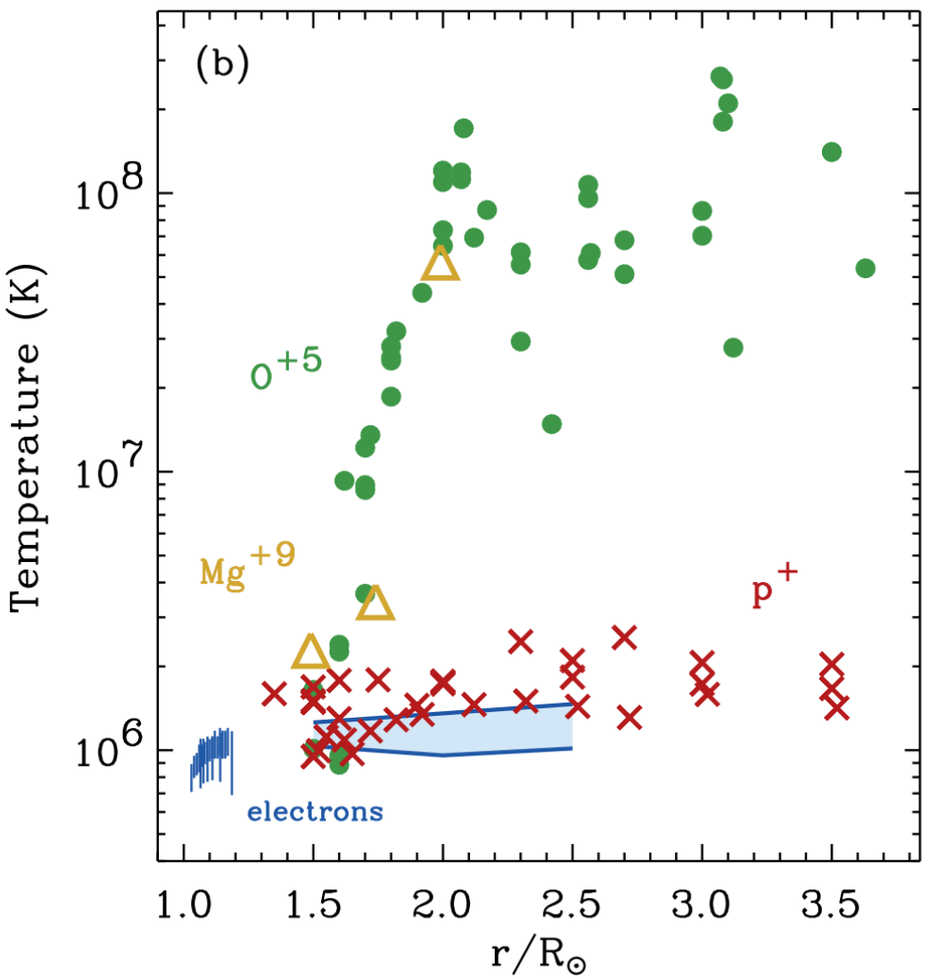
- One line of attack: see how heating affects different ions

- In-situ measurements of heavy ions only at > 1 AU (until SO) (e.g. *Tracey et al. 2016*)

- Remote sensing of different heavy ions (SOHO/UVCS, Hinode/EIS, e.g. *Hahn et al. 2013*, *Cranmer et al. 2008*)

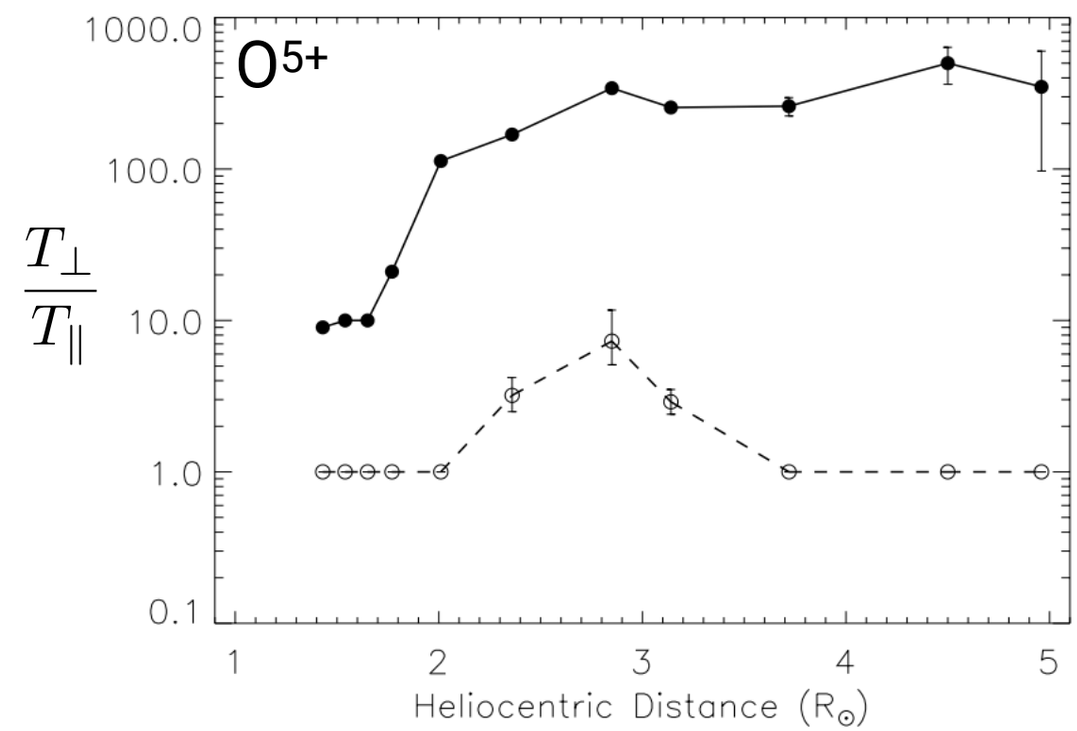
Preferential heating

Heaving ion heating
$(T_i > T_p)$



SOHO/UVCS; *Cranmer et al. 2017*

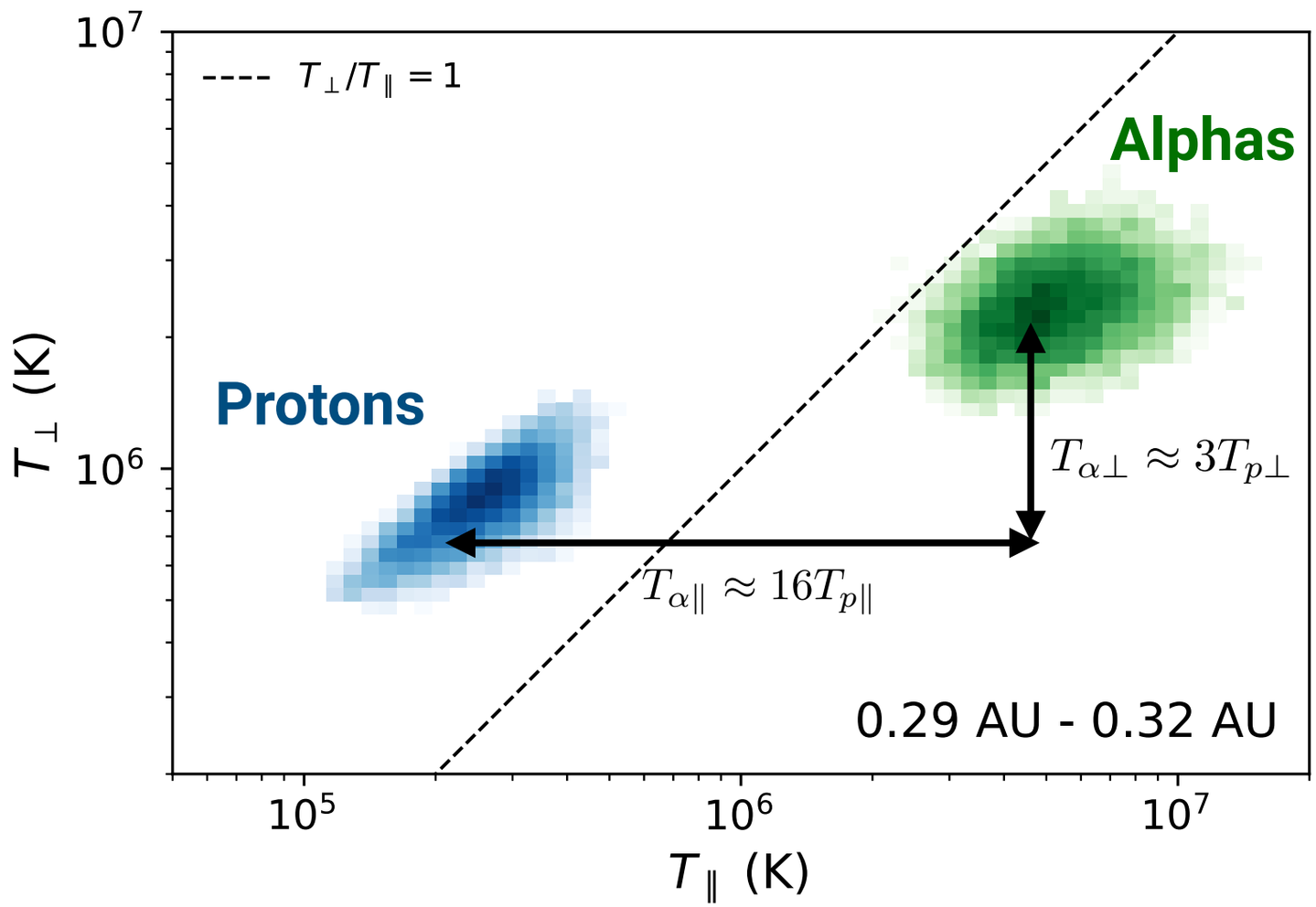
Perpendicular heating
$(T_\perp > T_\parallel)$



SOHO/UVCS; *Telloni et al. 2007*

(brand new results!)

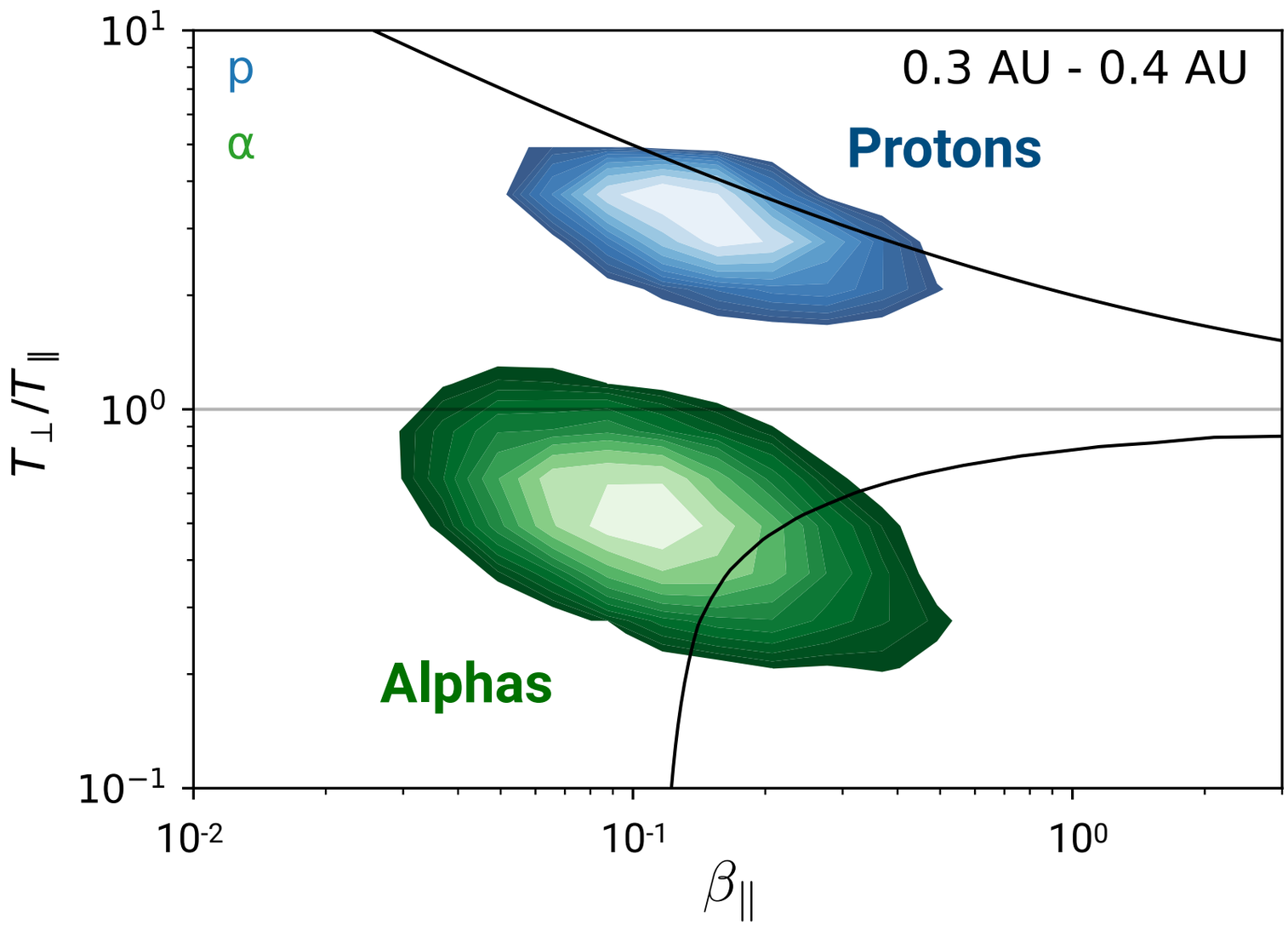
Fast wind He^{2+} at 0.3 AU



- He^{2+} does undergo preferential heating…
- … but is **less** anisotropic than protons
- An important new constraint for coronal heating theories?

(brand new results!)

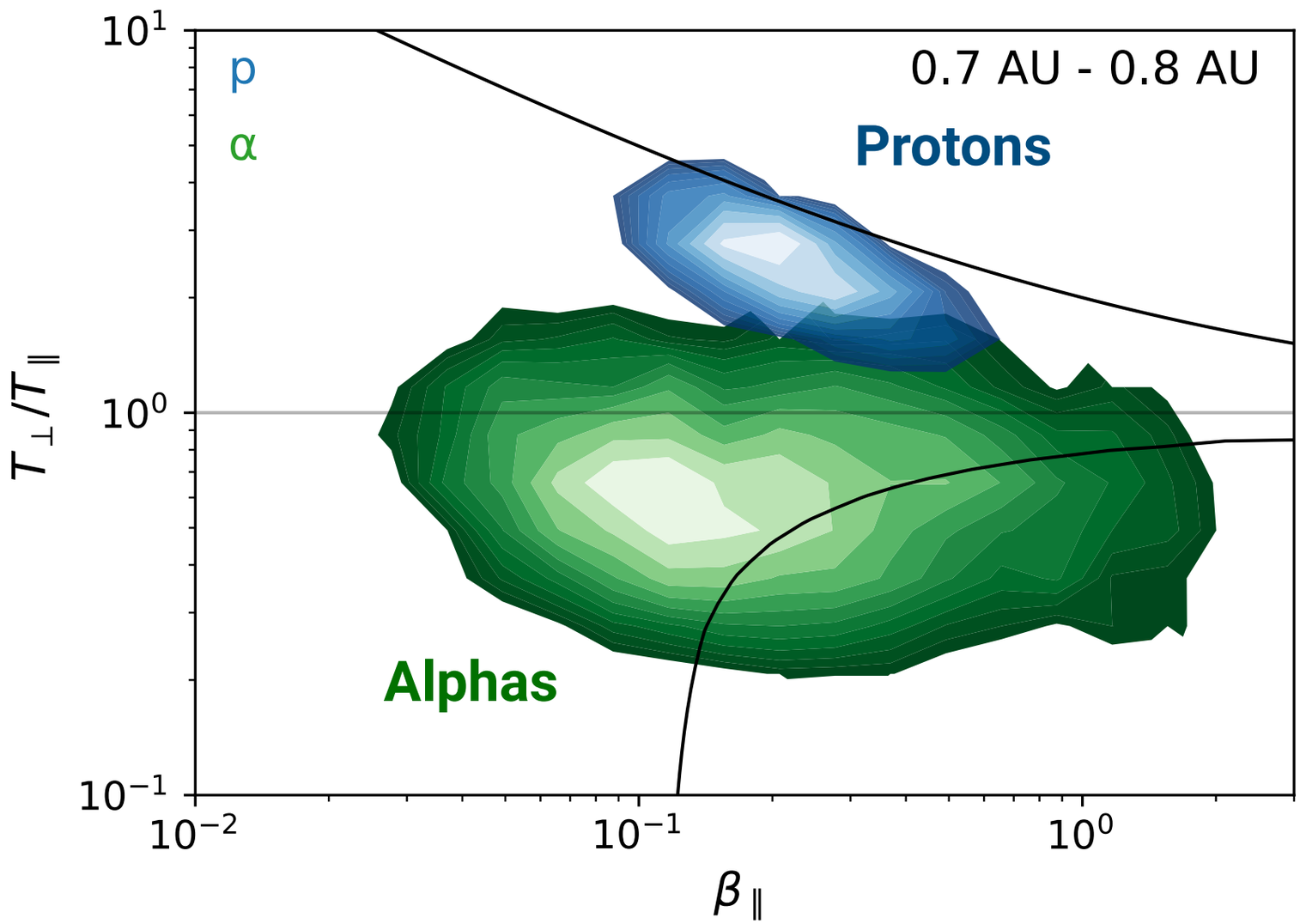
Fast wind He^{2+} at 0.3 AU



- He^{2+} anisotropy << proton anisotropy
- He^{2+} becomes unstable ~ 0.3 AU

(brand new results!)

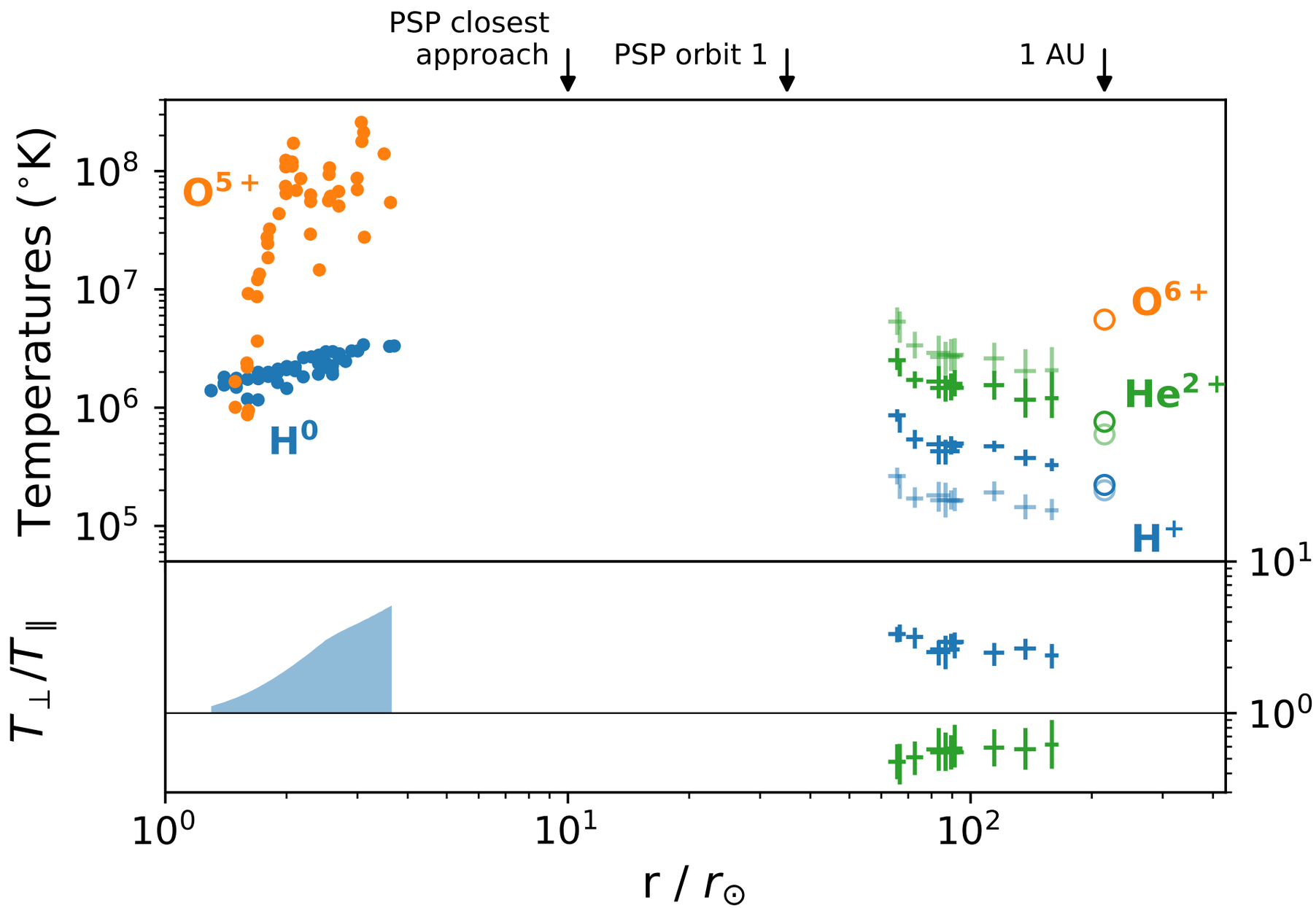
Fast wind He^{2+} at 1 AU



- He^{2+} restricted by instability curves
- Strong non-adiabatic evolution inside 1 AU
- Irreversibly affects alpha temps measured at 1 AU

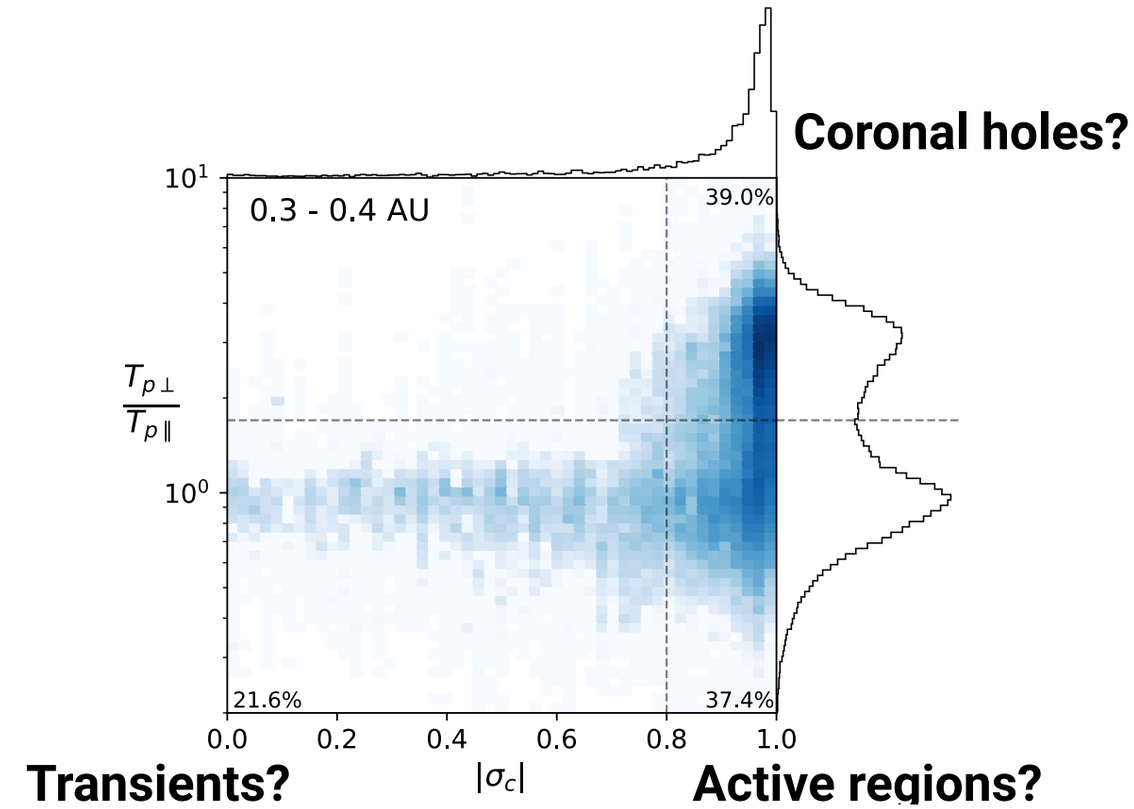
(brand new results!)

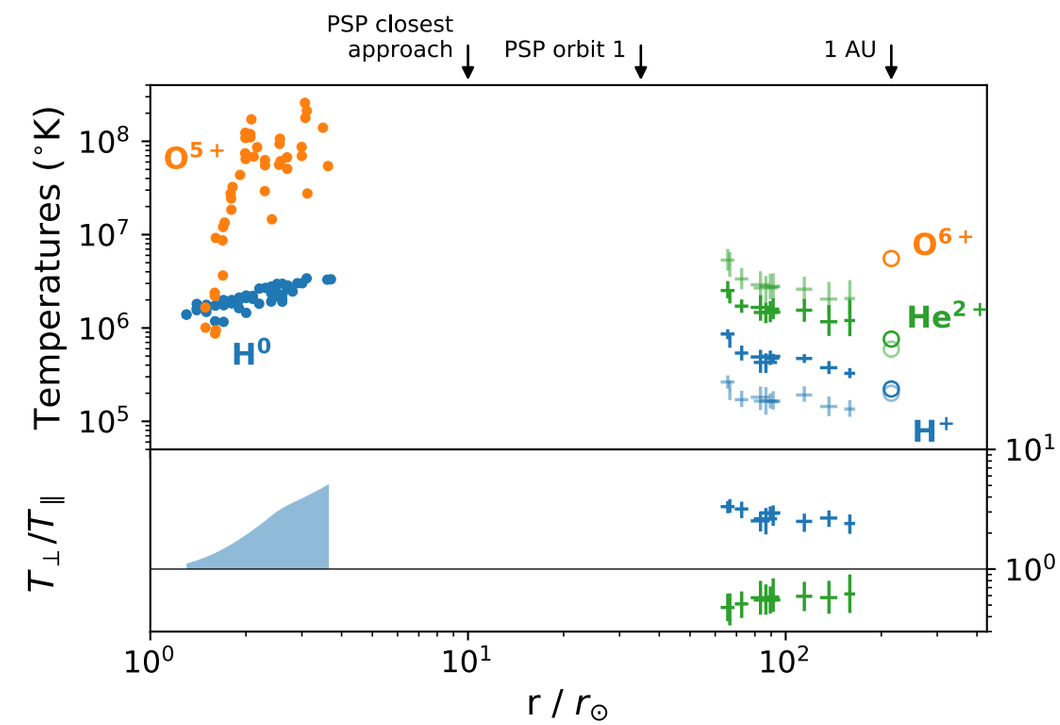
Radial evolution of ions



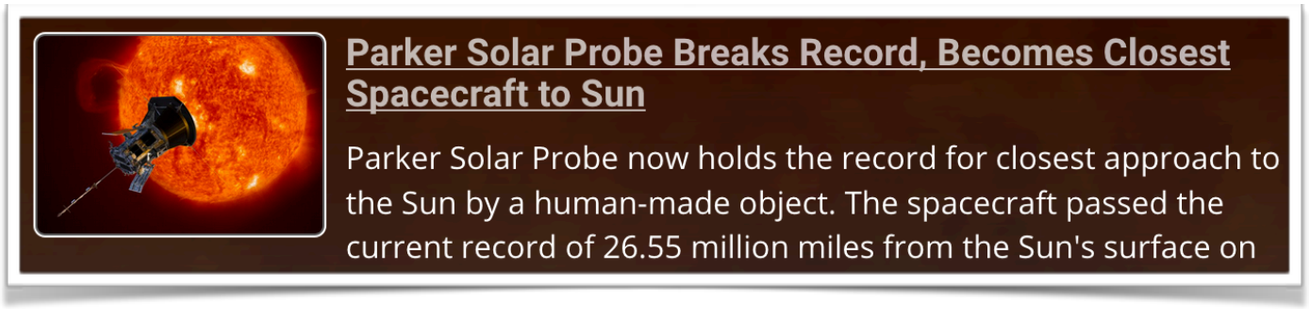
Conclusions

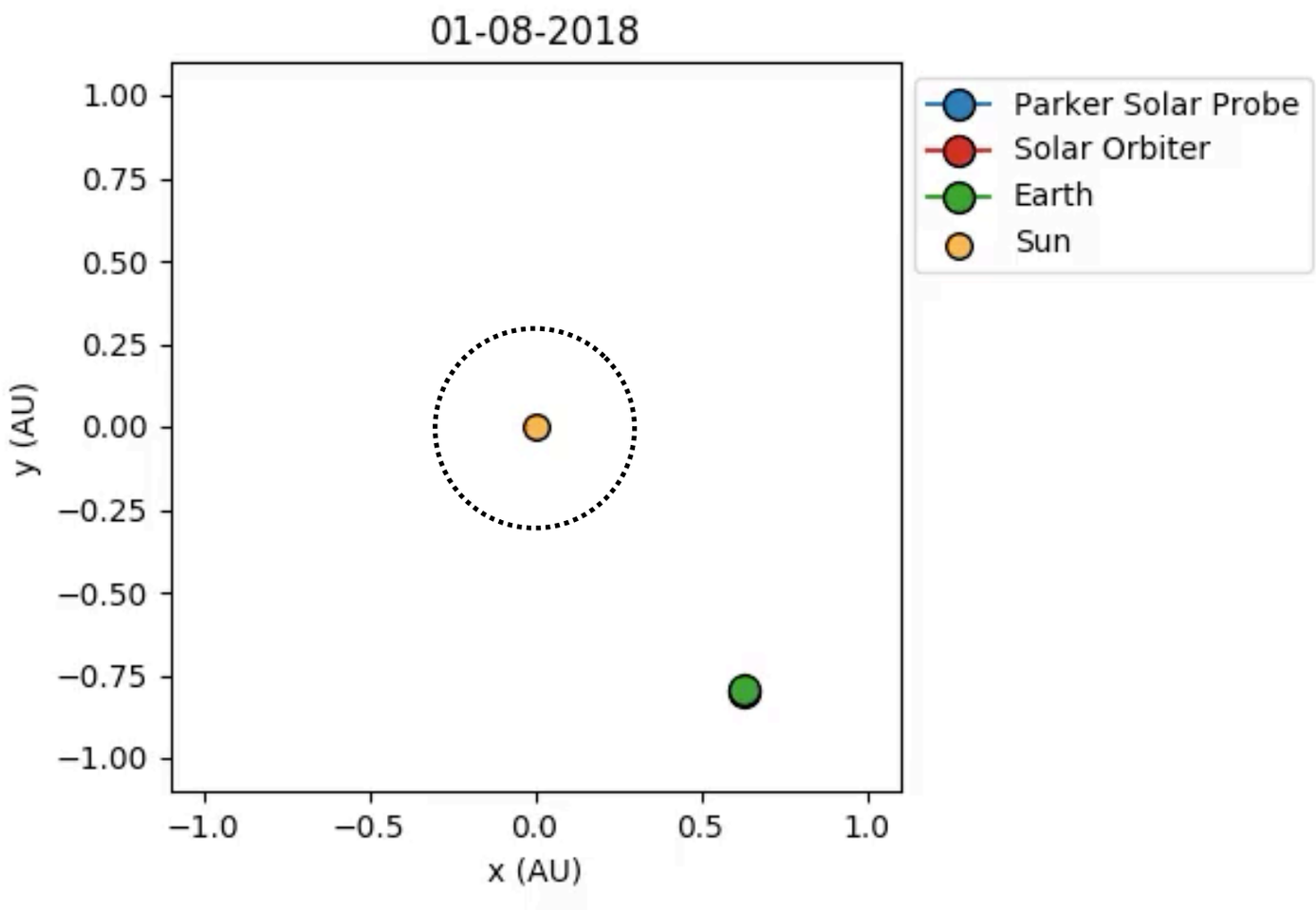
- Properties measured in-situ at 1 AU may **not** reflect solar sources
- Developed **testable** scheme for categorising solar sources
- Measured alpha temperatures inside 1 AU
- Alphas have opposite anisotropy to protons(!)





The Future: PSP & SO





- **Parker Solar Probe:**
  - (very) close to the Sun (0.05 AU)
  - High quality in-situ observations
- **Solar Orbiter**
  - 3D heavy ion VDFs
  - Lots of cameras!

Conclusions

- Properties measured in-situ at 1 AU may **not** reflect solar sources

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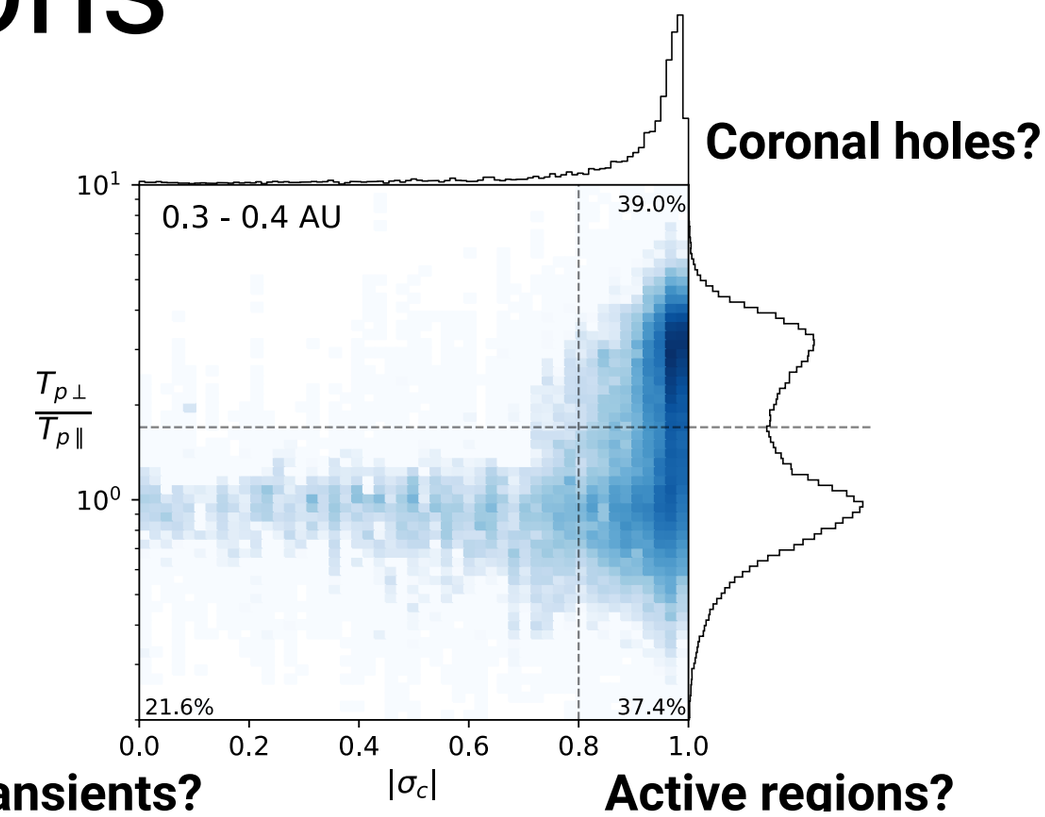
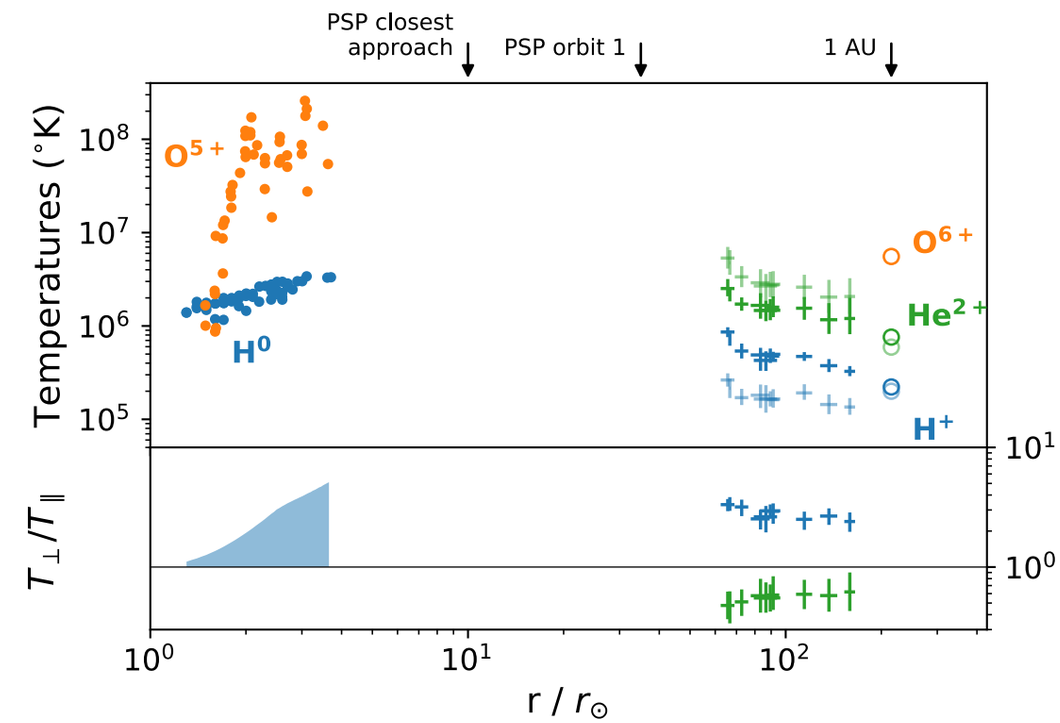
- Alphas have opposite anisotropy to protons(!)





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Bibliography

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- **Solar wind categorisation** - Stansby+ 2018 (https://doi.org/10.1093/mnras/sty2814)

- **MESSENGER solar wind** - Gershmann+ 2012 (http://doi.wiley.com/10.1029/2012JA017829)

- **Solar wind movies** - DeForest+ 2018 (http://iopscience.iop.org/article/10.3847/1538-4357/aac8e3)

- **Alfvénic slow wind** - D'Amicis+ 2015 (http://stacks.iop.org/0004-637X/805/i=1/a=84)