Investigating a New Framework of Solar Wind Formation via Entropy Cross Correlation Analysis

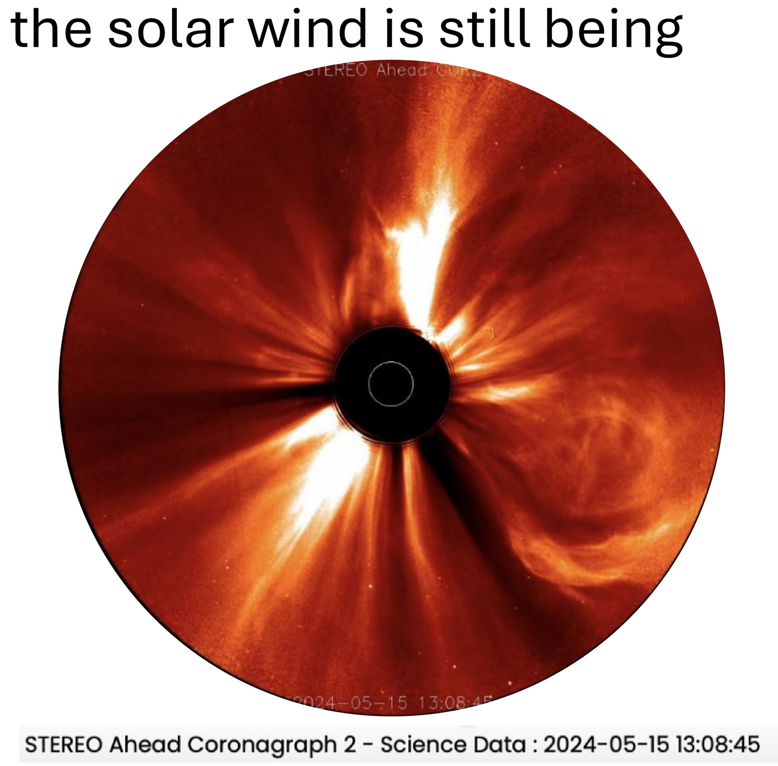
Aidan Nakhleh[1,2], Nicholeen Viall[1], Susan Lepri[2], Jim Raines[2]
[1]Nasa Goddard Space Flight Center, Greenbelt, MD USA [2]University of Michigan, Ann Arbor, MI USA
contact: naidan@umich.edu

Introduction

The solar corona expands and makes the solar wind

- $T_{corona} \approx 10^6$ K, v_{SW}~500 km/s at 1AU
- The active sun is a unique phenomenon
  - Fundamental plasma physics laboratory (remote and in-situ observations)
  - Capacity to affect Earth (space weather)
- How the corona produces the solar wind is still being understood

- Via cross-correlation analysis, we investigate the physics determining how (and where!) the solar wind is heated in and beyond the corona



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The Evolving Solar Wind Formation Framework

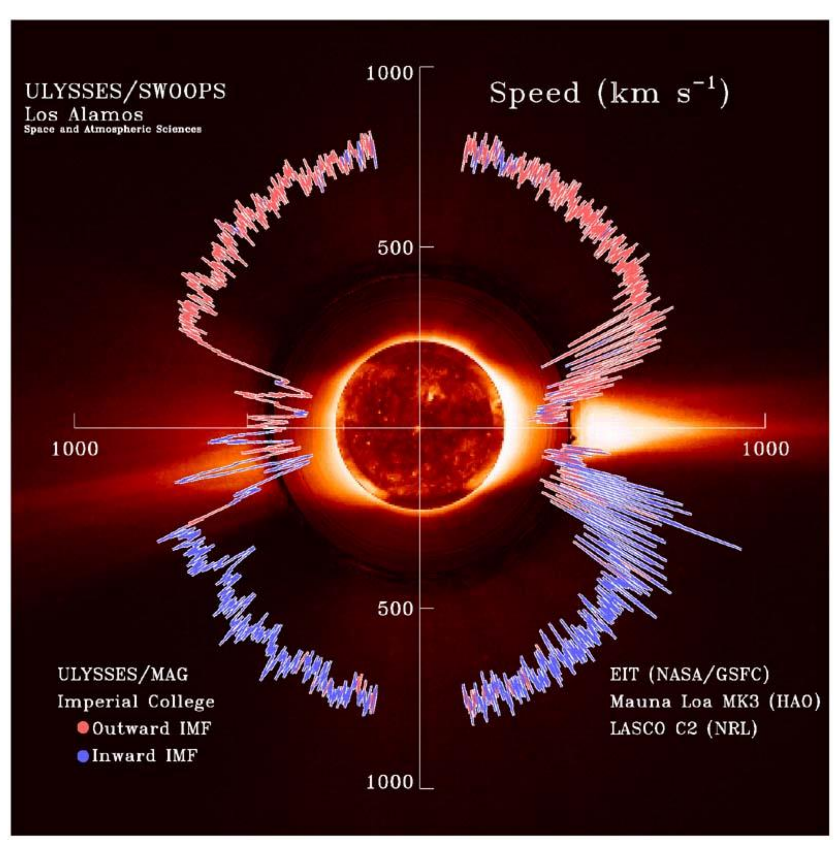
<u>Historical framework</u>

Coronal hole solar wind is fast, $v > 500 \frac{km}{s}$

- ➢ Open magnetic field lines

Coronal streamer wind is slow, $v < 500 \frac{km}{s}$

- ➢ Closed magnetic field lines

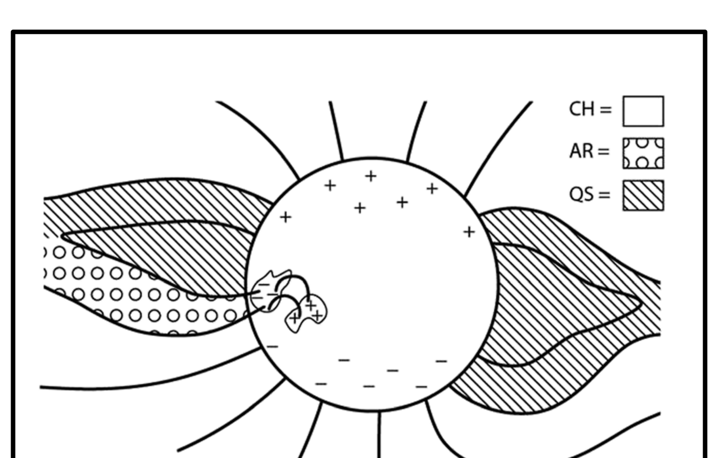


[1] McComas et al., 1998.

<u>New framework</u>

More source regions that interact with each other

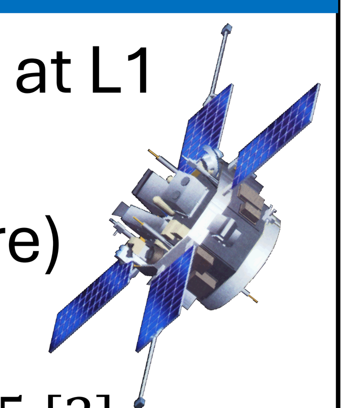
- **Quiet sun** (closed field lines)
- **Coronal holes** (open field lines)
- **Active regions** (high magnetic flux, closed or open field lines)



[2] Viall, Borovsky 2021.

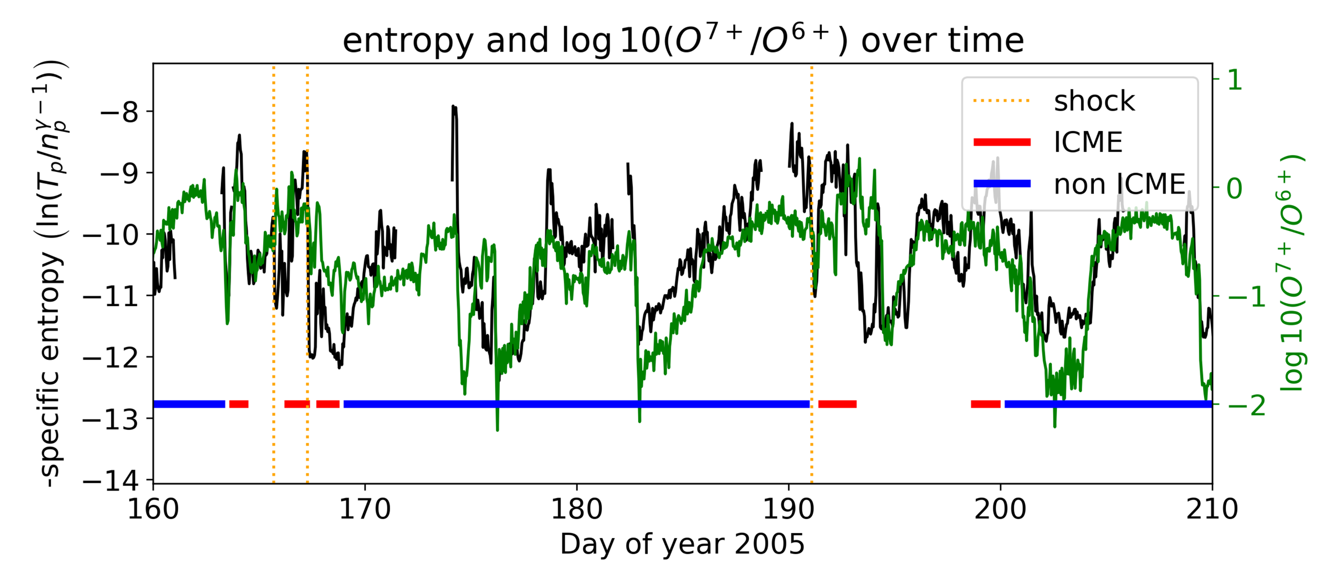
The Advanced Composition Explorer (ACE)

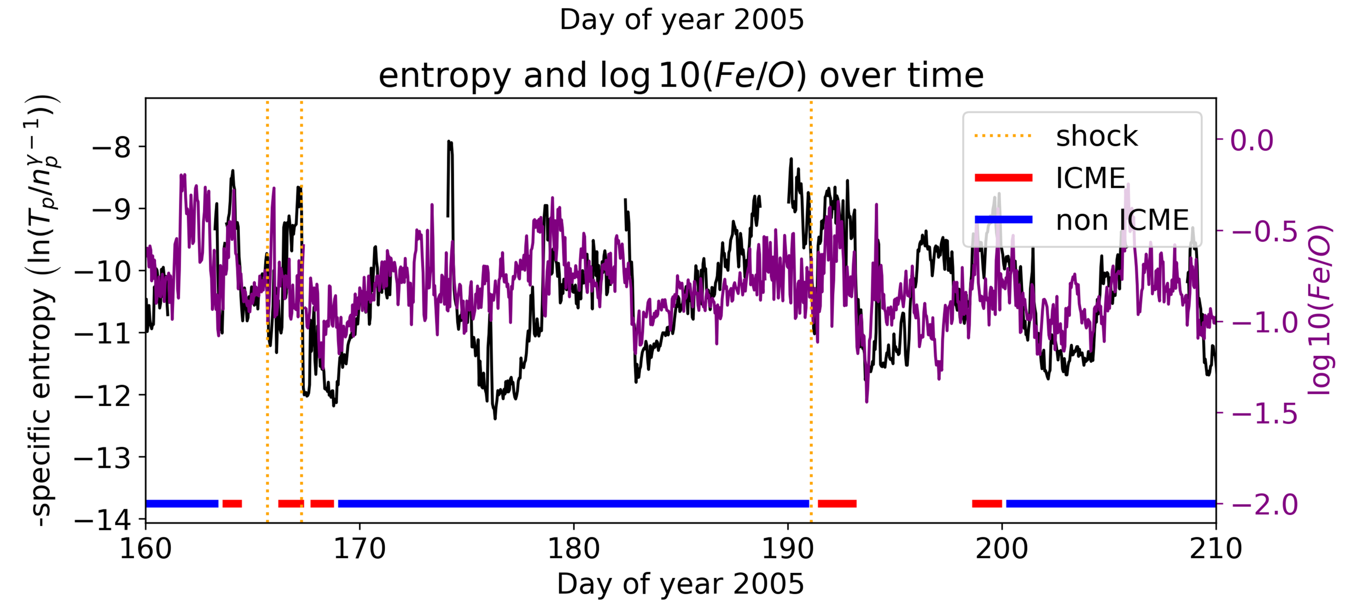
- Measures in-situ solar wind plasma data at L1
- SWEPAM studies H+ and He2+ particles
- SWICS studies heavy ions (C-Fe and more)



<u>Plasma Parameters</u>

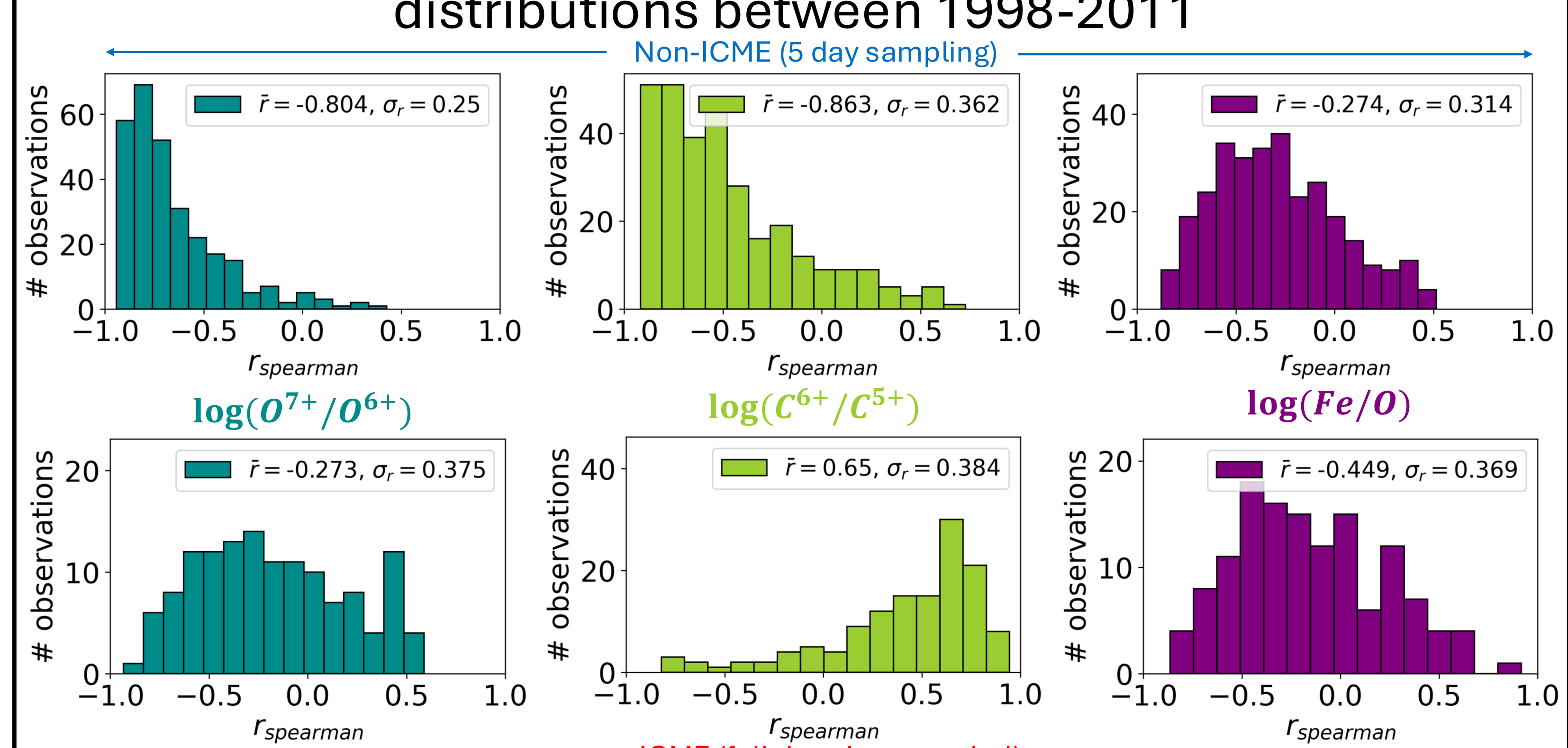
- ➢ **Proton Specific Entropy**: $S = C_v \ln(\frac{T}{n^{\gamma-1}}), \gamma \approx 1.5$ [3]
  - quantifies heating and expansion
- ➢ $\boldsymbol{Fe/O}$: abundance ratio of Iron to Oxygen
  - First ionization potential (FIP) fractionation effect, traces **upper chromospheric physics (~10,000 km)**
- ➢ $\boldsymbol{O^{7+}/O^{6+}}$: ratio of densities between 7th and 6th charge states of Oxygen
  - Freeze-in effect, traces **lower corona physics (~0.5$\boldsymbol{R_\odot}$)**

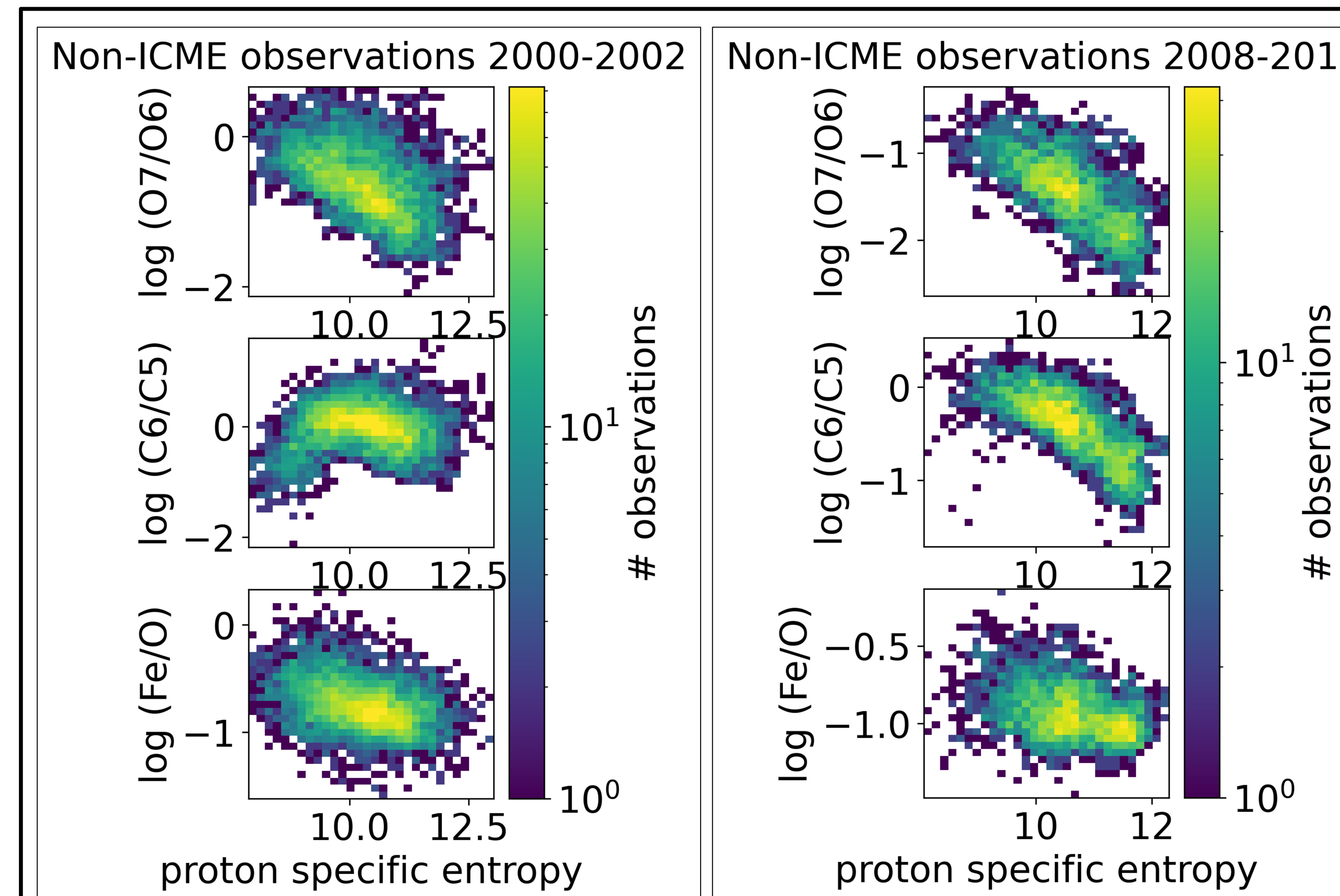




Results

Sampled correlation coefficients for entropy-heavy ion distributions between 1998-2011





distribution	r_{sp}, solar maximum	r_{sp}, solar minimum
$S - \log10(\frac{O^{7+}}{O^{6+}})$	-0.547	-0.688
$S - \log10(\frac{C^{6+}}{C^{5+}})$	-0.073	-0.748
$S - \log10(\frac{Fe}{O})$	-0.375	-0.336

- Energy partitioning that enhances coronal collisionality ($\frac{O^{7+}}{O^{6+}}, \frac{C^{6+}}{C^{5+}}$) may also govern entropy in the solar wind
- Constraint placed on heating that increases entropy (coronal location and mechanism)

Conclusions and Next Steps

- Heavy ion composition provides insight into where entropy is set in the corona
- Correlations probe where heating of solar wind occurs, in or beyond the corona
- ICMEs uniquely impact specific entropy
- More instruments to analyze
  - SWEPAM cannot differentiate $T_\parallel$ and $T_\perp$
- What really is entropy?

References

Integrated Space Weather Analysis system: https://ccmc.gsfc.nasa.gov/tools/iSWA/
[1] McComas, D. J., et al. "Ulysses' return to the slow solar wind." *Geophysical Research Letters* 25.1 (1998): 1-4.
[2] Viall, Nicholeen M., and Joseph E. Borovsky. "Nine outstanding questions of solar wind physics." *Journal of Geophysical Research: Space Physics* 125.7 (2020): e2018JA026005.
[3] Totten, T. L., J. W. Freeman, and S. Arya. "An empirical determination of the polytropic index for the free-streaming solar wind using Helios 1 data." *Journal of Geophysical Research: Space Physics* 100.A1 (1995): 13-17.