2022-03-30 UT 00:28:00

EUV & UV strands and variability associated with coronal rain

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INTRODUCTION

- Why is the corona increasingly filamentary, strongly variable and dynamic at cooler EUV and UV lines? [1]
- What determines the observed length scales of EUV strands? [2,3]

A look at the cool corona may provide the answers

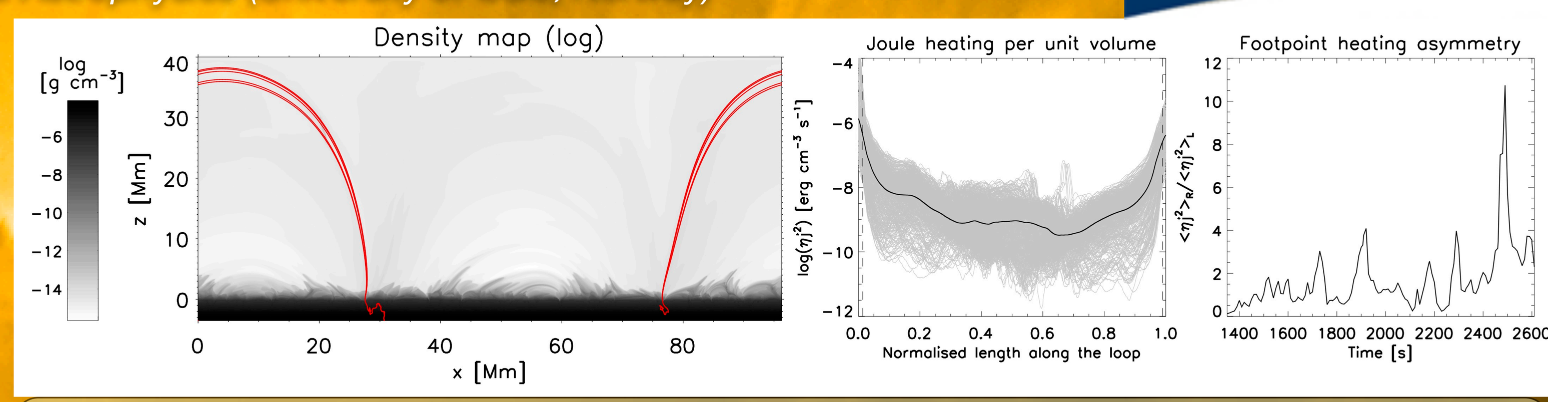
- *Coronal rain:* Partially ionised cool (10^4 — 10^5 K) & dense (10^{10} — 10^{12} cm^{-3}), occurring in a timescale of minutes in coronal loops [4]
- Origins: Thermal instability (TI) in coronal loops under thermal non-equilibrium (TNE) [5]. TI drives catastrophic cooling leading to the formation of condensations composing coronal rain [6]. The widths of condensations match the widths of observed EUV strands. Why?
- Conditions for TNE: Highly stratified, high-frequency heating with little asymmetry across footpoints [7]

METHODS

- 2.5D Radiative MHD high-resolution simulations with Bifrost: coronal rain produced self-consistently through Joule heating
- IRIS+AIA & SoLO/EUI HRI Observations

RESULTS

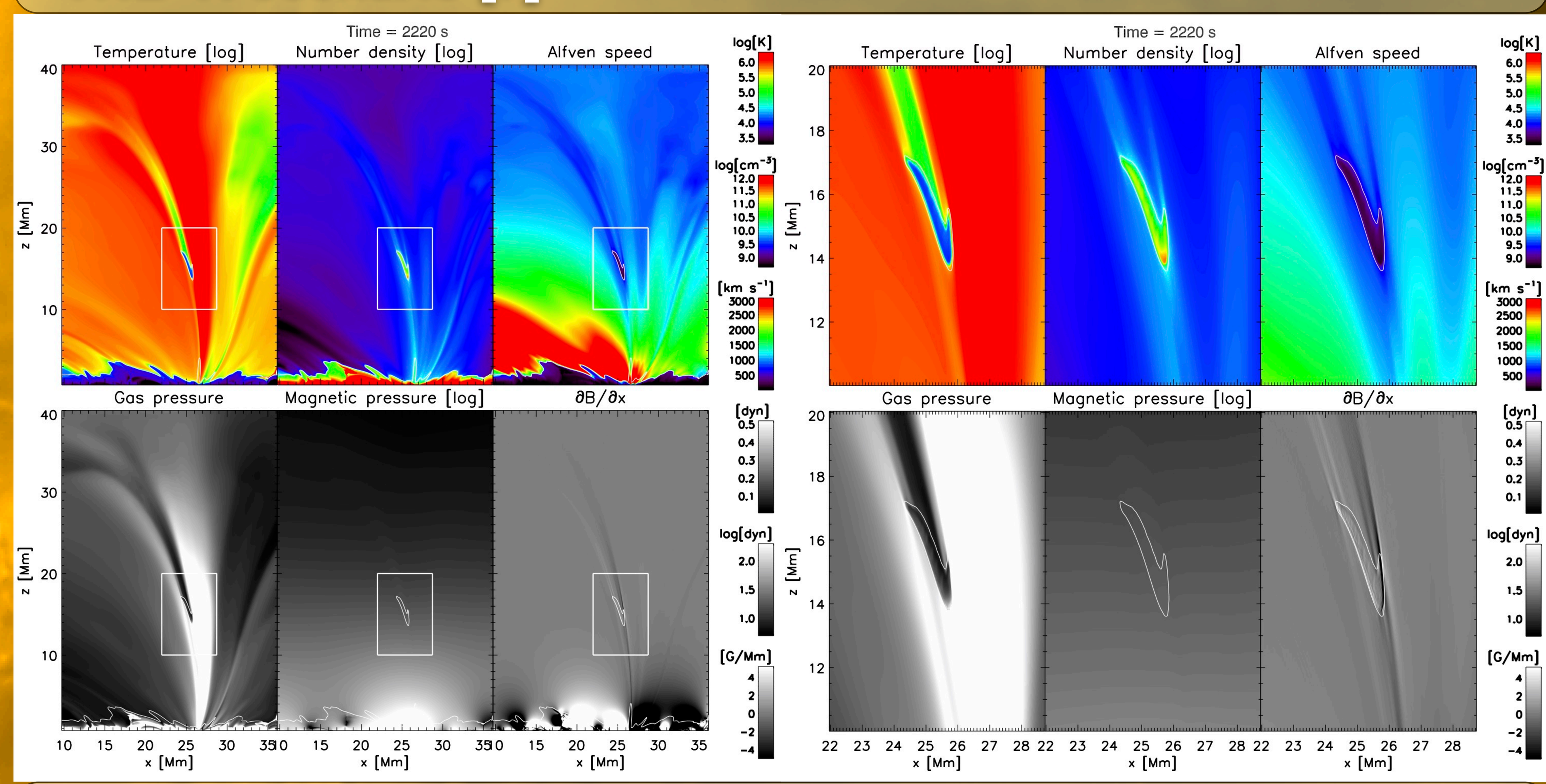
- Simulations: Antolin, Martínez-Sykora & Sahin, ApJL 926, 29 (2022)
- Observations: [8], Antolin+ in prep.

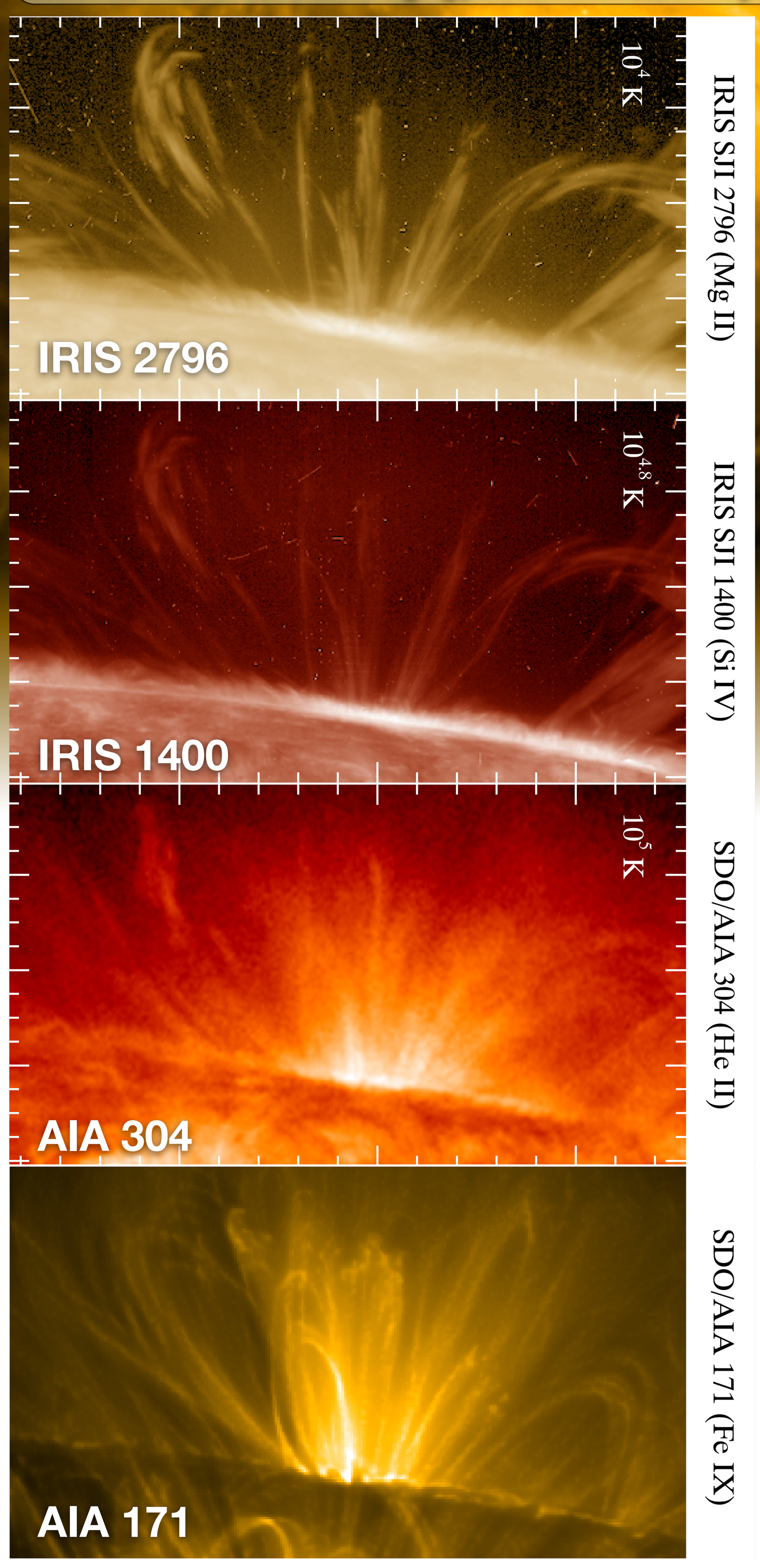


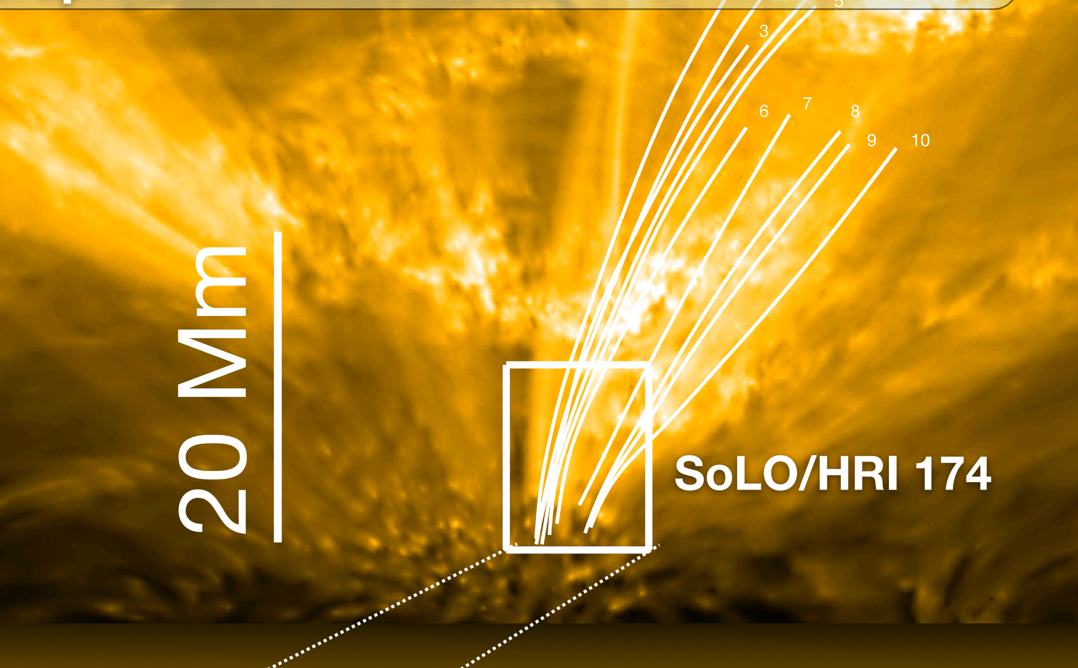
Active network |B|~190 G, $\Delta x = 14$ km, non-uniform resolution, up to TR; Periodic BC in x, open in z; Constant entropy inflow at $T_{eff} = 5780$ K; Optically thick radiation from non-LTE formulation with RADYN (Carlsson & Leenaarts 2012) & scattering (Skartlien 2000, Hayek+2010); Optically thin radiation in corona with CHIANTI (Del Zanna+ 2021)

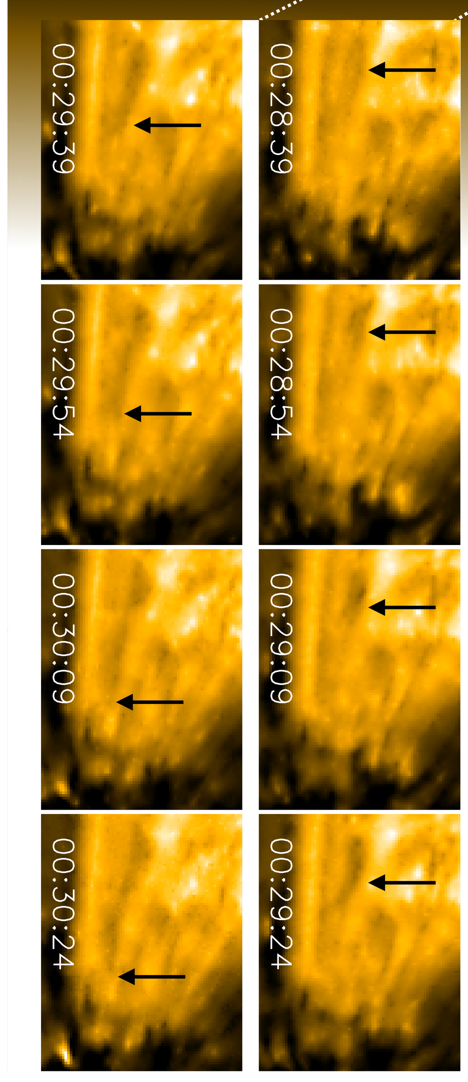
- **Strongly stratified ($Q_{apex}/Q_{footpoint}$ <0.1), high-frequency ($\tau < \tau_{rad}$) and little footpoint heating asymmetry (<3):**

➡**TNE-TI scenario [7]**

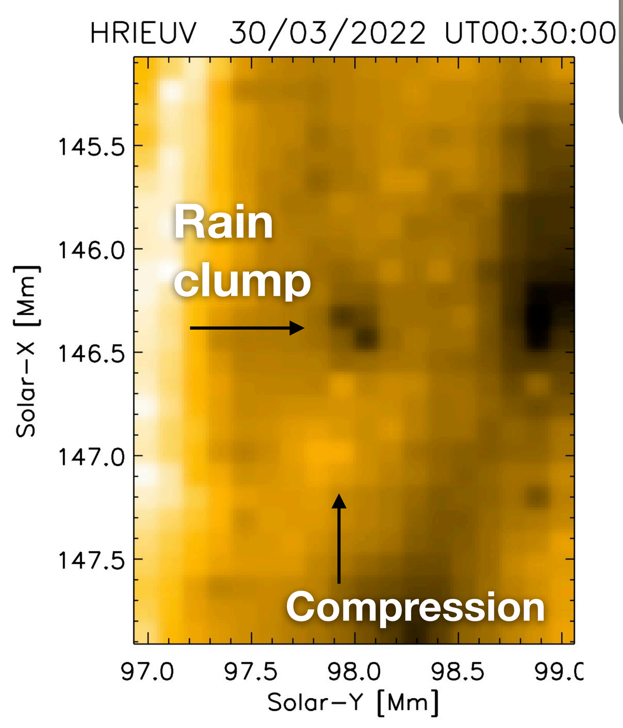








Coronal rain clumps observed in EUV absorption at very high resolution



- Catastrophic cooling:

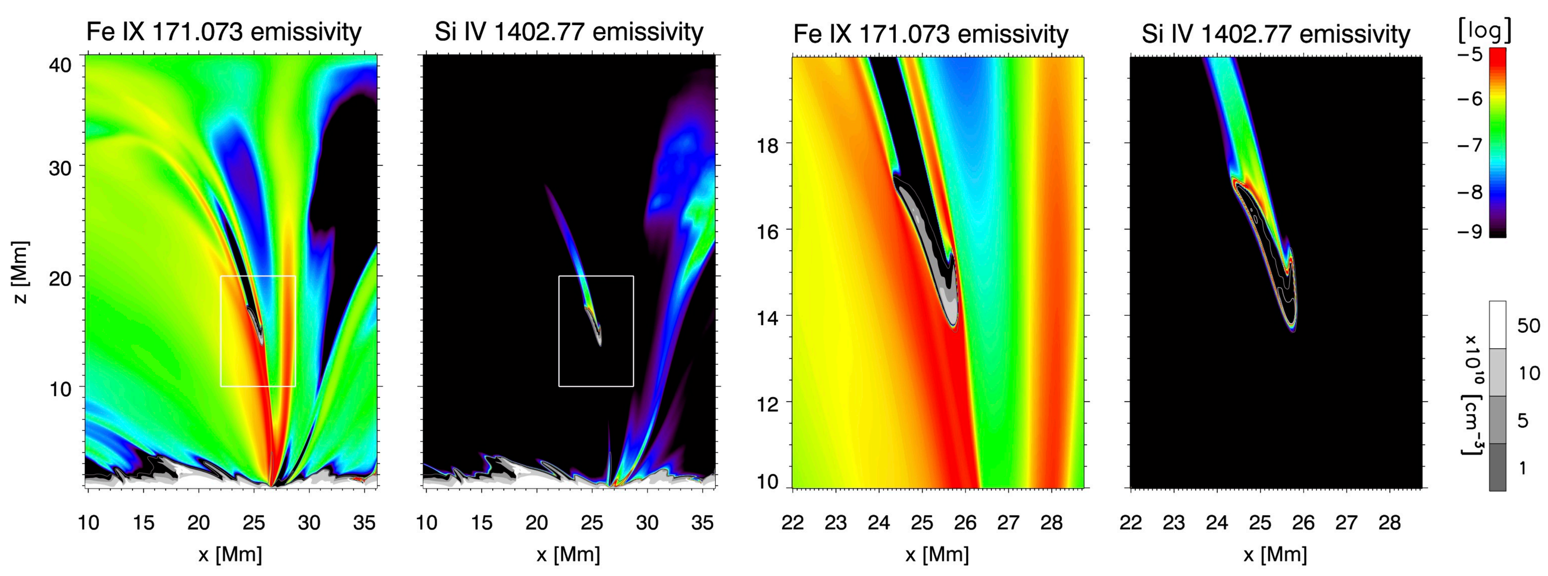
$$10^6\ \text{K} \rightarrow 2\times10^5\ \text{K} : 500 - 1000\ \text{K s}^{-1}$$

$$2\times10^5\ \text{K} \rightarrow 10^4\ \text{K} : 2000 - 5000\ \text{K s}^{-1}$$

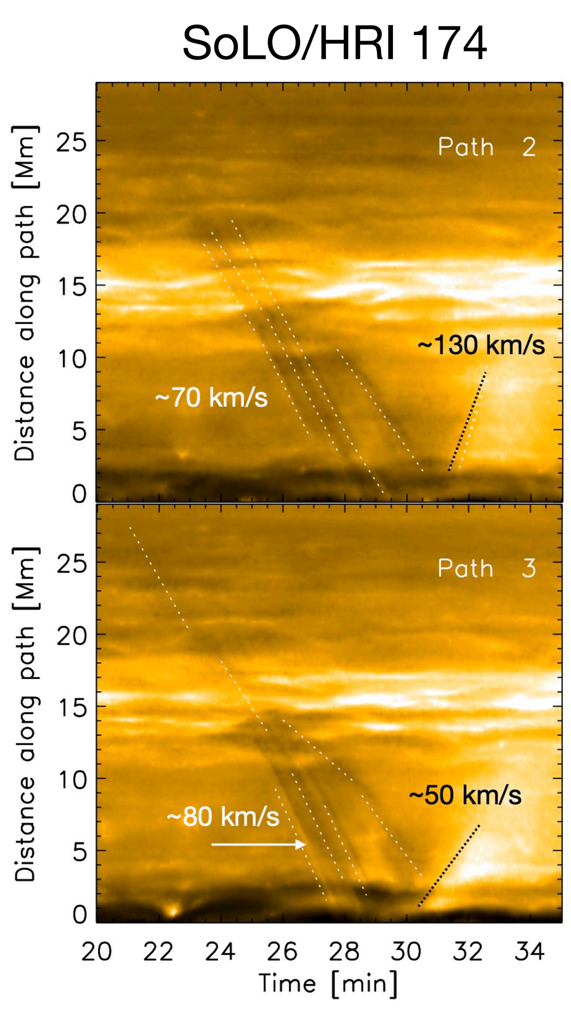
- Thermal instability is triggered: loss of pressure and formation of condensation
- Multi-thermal & inhomogeneous. Strong deformation due to shear flows and density inhomogeneities in clump.
- Very cool (7000 K) & high density core (10^{12} cm^{-3}) at head (falls fastest): gas pressure effect [9]
- Chromospheric core width ~ 100-200 km in agreement with high-res Hα observations with NST & SST [10,11]

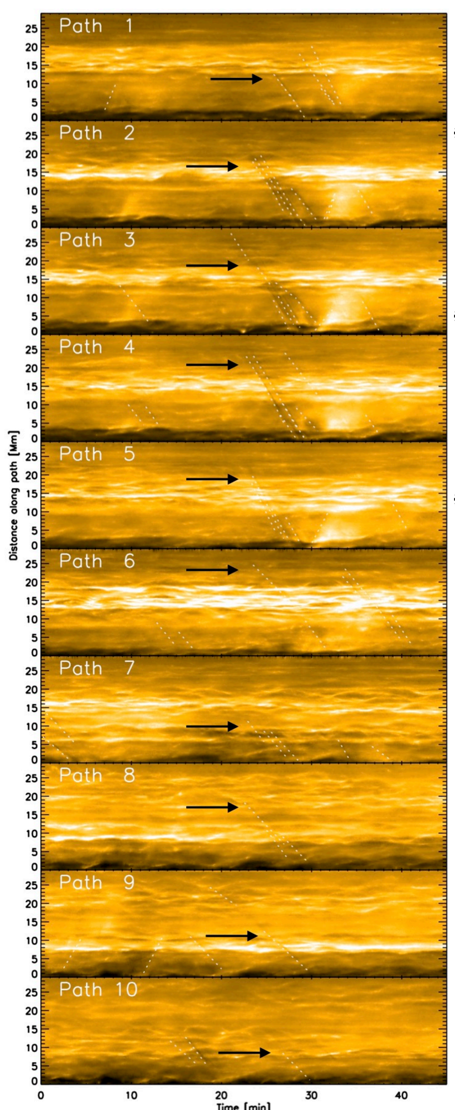
➡Current ground-based instrumentation resolve the bulk of the rain

- Elongated warm tail: $T = 10^{4.2} - 10^{4.5}$ K, $n = 10^{10.5} - 10^{11.2}$ cm^{-3}
- Very thin CCTR (Condensation Corona Transition region) ~ 100 km
- Fundamental magnetic strands form: loss of pressure produced by TI and flux freezing brings magnetic field lines together during the formation of coronal rain (similar effect in ISM/ICM! [12]



- Compression ahead of rain as it falls observed with SoLO/HRI 174
- Impact: very short (~20 s) and bright UV/EUV bursts, in agreement with IRIS [13] and SoLO/HRI observations
- After impact: rebound shock+flow, in agreement with SoLO/HRI 174 observations (Antolin+ in prep.)
- Strongly emitting Fe IX 171.073 Å plume-like, filamentary structure, in agreement with observations
- Emitting thin sheath around the rain and wake in TR due to CCTR
  - Long filamentary structure in TR lines (40 Mm)
  - Link between rain strand and observed coronal strands with Hi-C [3,11]





CONCLUSIONS

- **TI plays a major role in observed filamentary structure and variability of the corona in EUV-UV spectrum**
- **Widths of UV-EUV strands: elemental scale of heat transport in corona? Likely set by magneto convection processes**
- **Rain bulk distribution currently resolved in observations?**

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