On the million-degree signature of spicules

Souvik Bose

Lockheed Martin Solar & Astrophysics Lab/Rosseland Center for Solar Physics, University of Oslo

***Co-authors*:** Jayant Joshi, Paola Testa & Bart De Pontieu

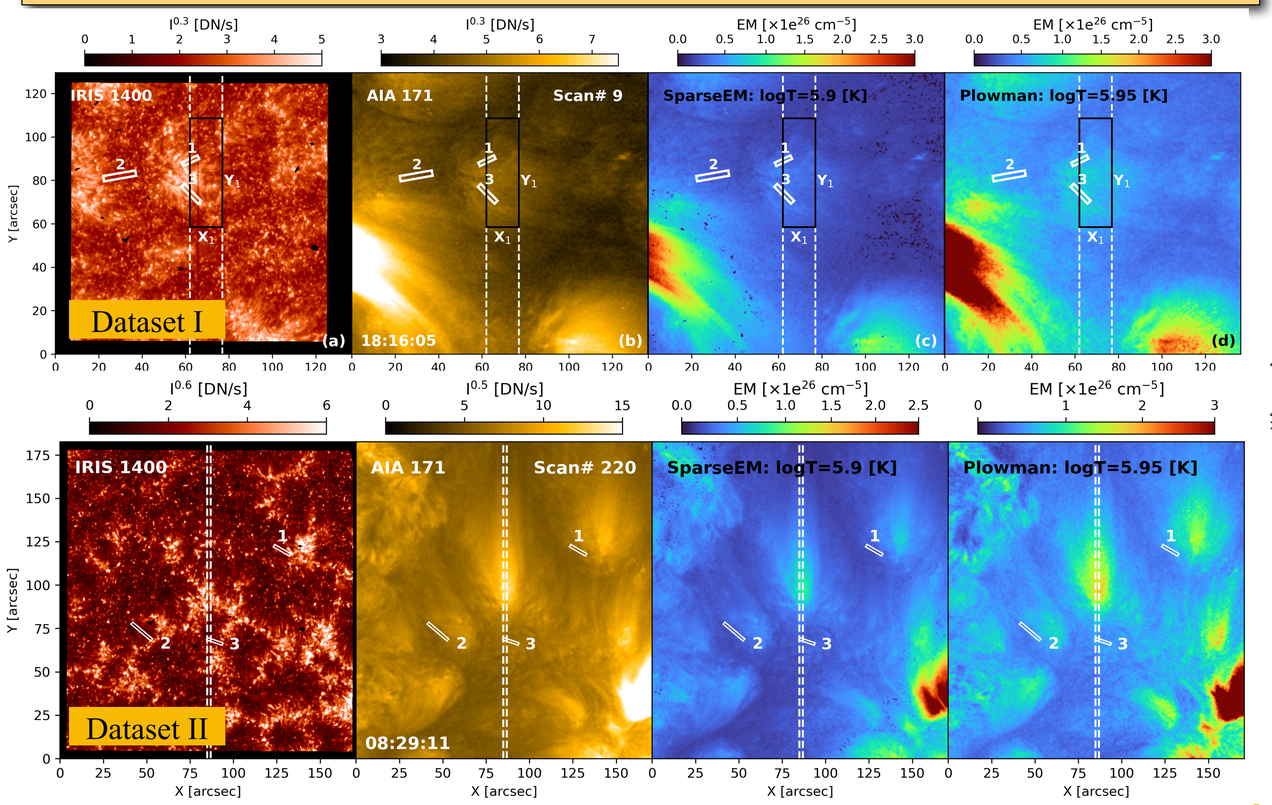
Email: bose@lmsal.com, under review in **ApJ**

Context

Spicules have been proposed as substantial contributors toward the mass-energy balance of the solar corona. While their transition region (TR) counterpart has unequivocally been established over the past decade, it remains contested how much spicular plasma is heated (*if at all*) to coronal temperatures.

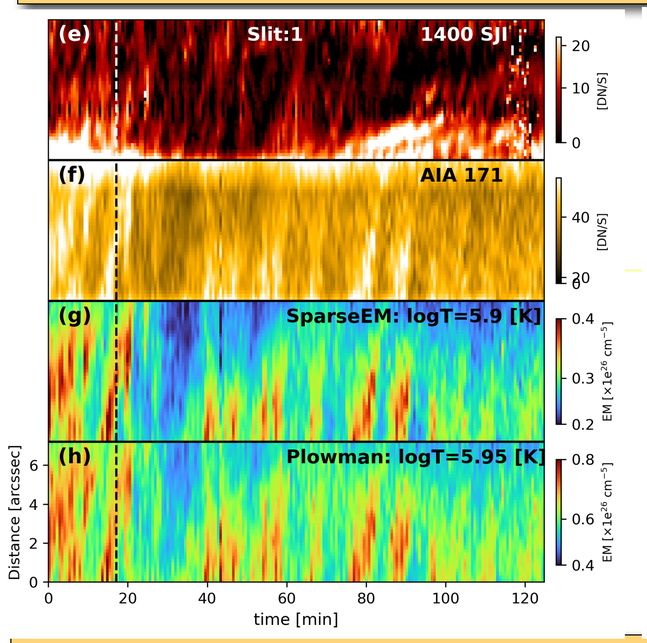
Using coordinated IRIS and SDO/AIA observations, this study probes the thermal structure of the spicular corona in an *unprecedented detail* with **Differential Emission Measure (DEM)** of the solar plasma at **1MK** computed using I) basis-pursuit and II) Tikhonov regularization techniques.

Observations: IRIS+SDO observations and EM maps

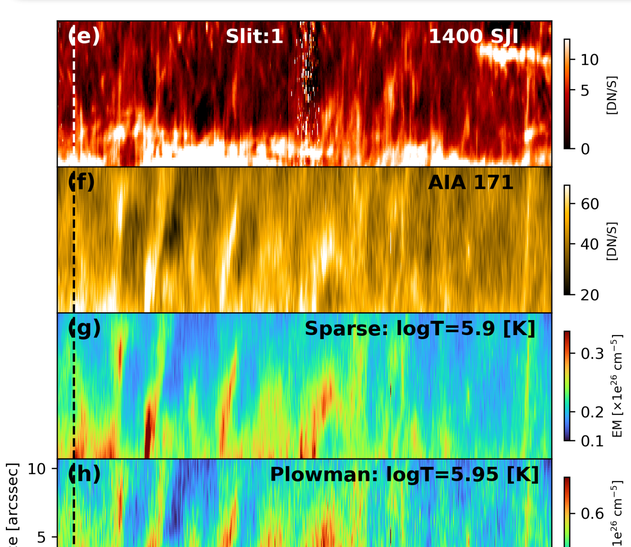


Overview of the coordinated Quiet-Sun and coronal hole **IRIS and SDO** datasets along with computed EM maps. Dashed lines show the IRIS rasters, white rectangular boxes are artificial slits and black bounded region is shown in the rasters. Animation available via the **QR code.**

Analysis from SJI: Spatio-temporal evolution across multiple (artificial) slits: Dataset I (Quiet-Sun)

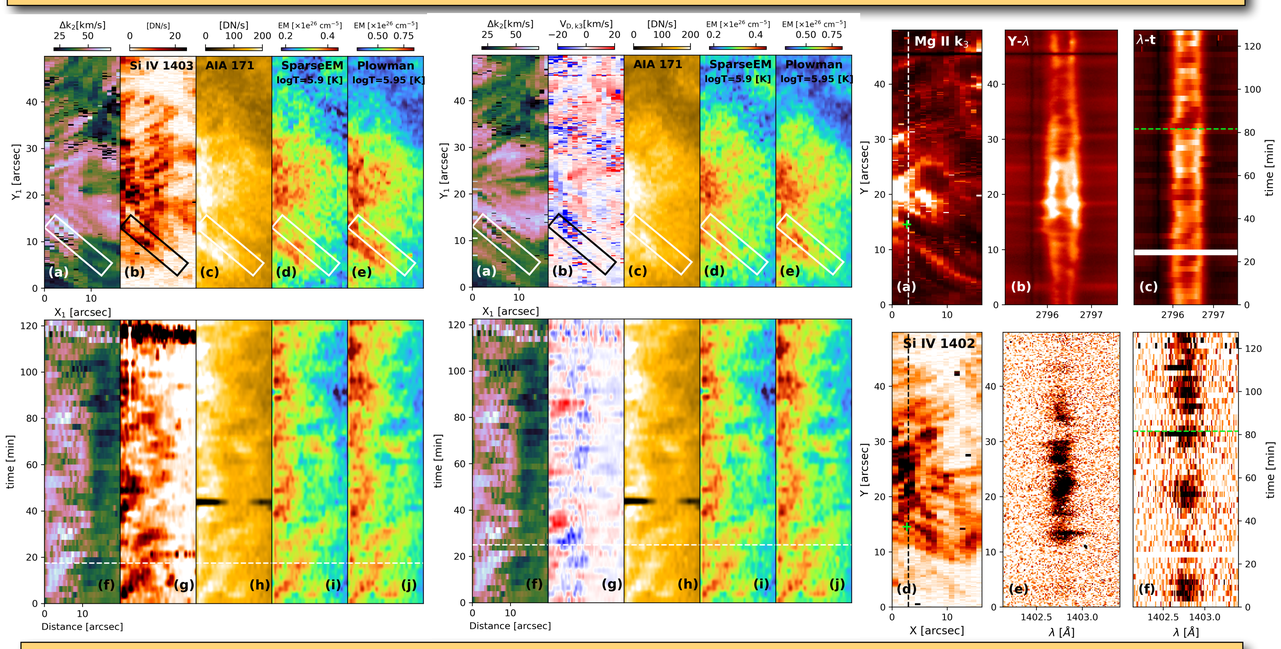


Analysis from SJI: Spatio-temporal evolution across multiple (artificial) slits: Dataset II (Coronal Hole)

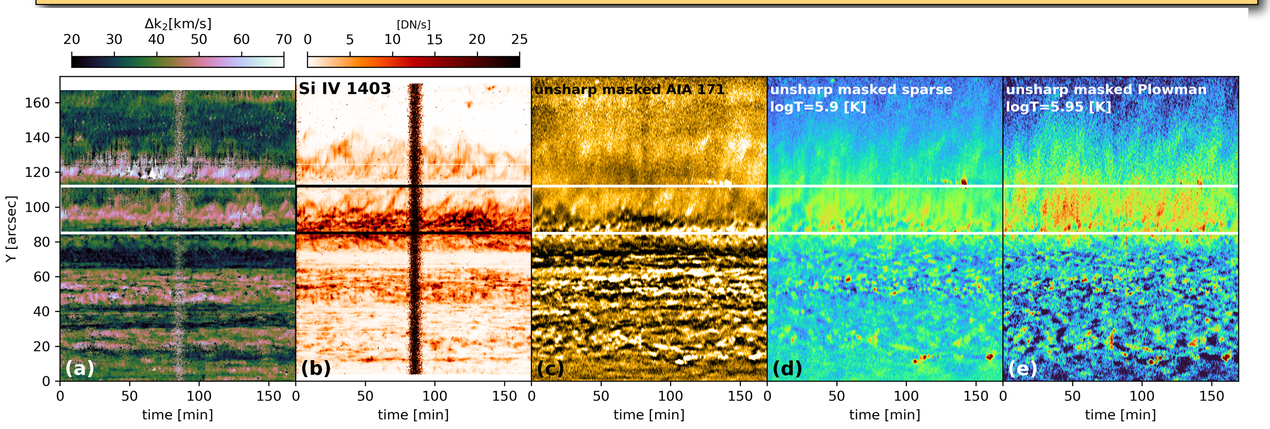


Spatio-temporal analysis from coordinated **IRIS slit-jaw (SJ), AIA 171** images, and derived **EM** maps show ubiquitous evidence of heating associated with spicular plasma to **~1MK.**

Analysis from rasters: Large sparse 16-step (dataset I)

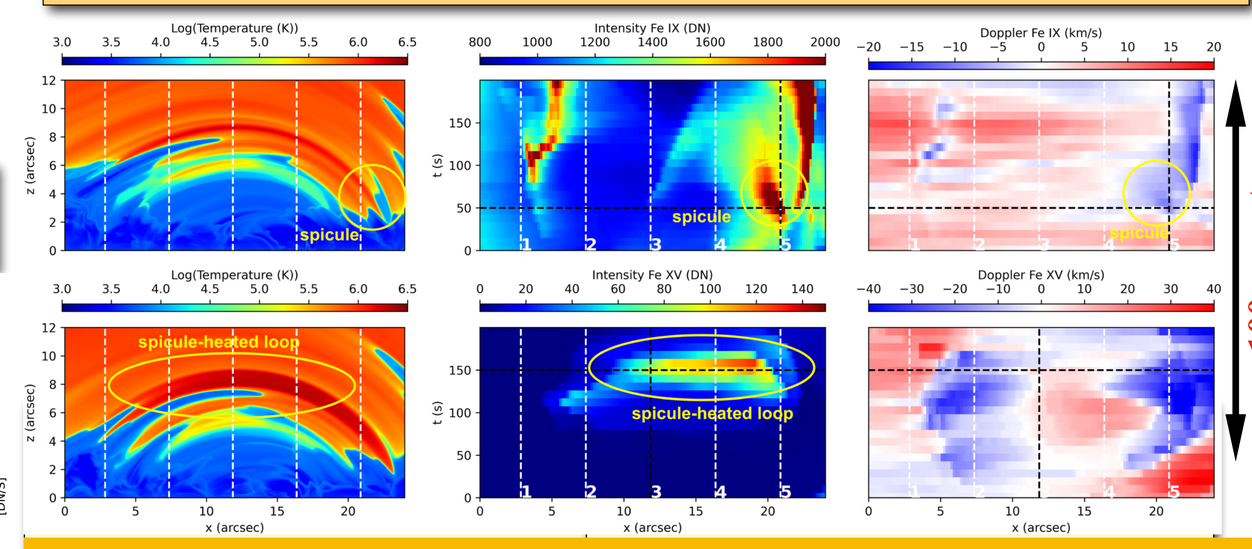


Analysis from rasters: Very large dense 4-step (dataset II)



Raster maps generated from coordinated IRIS, AIA and EM maps show clear spatio-temporal coherence among chromospheric spicules (*RBEs/RREs*), TR *network jets* and *PCDs* in the corona. Animation of the upper row is available via the **QR code.**

2.5D r-MHD simulation and MUSE perspective



Advanced MHD models (Martinez-Sykora et al. 2020, De Pontieu et al. 2022) predict heating associated with chromospheric spicules is a complex, multi-scale process that can be studied with MUSE's multislit spectroscopy at high cadence.

Summary and major conclusions

- Analysis of QS and CH regions with coordinated chromospheric, TR and coronal datasets reveal **ubiquitous** signatures of spicules/network jets associated with coronal counterparts.
- EM maps at **~1MK** also reveal the presence of numerous small-scale jets that have a clear spatio-temporal coherence with spicules observed in the IRIS passbands.
- Detailed space-time analysis of such events show rapidly outward propagating spicules with **2x—3x** times the background emission.
- In-depth analysis, based on **isothermal** approximation and **filter-ratio** diagnostics, suggests that the minimum temperature associated with spicular plasma at ~1 MK is **~500 kK**.
- Our findings **are consistent** with an existing 2.5D MHD simulation that predicts heating and mass-loading associated with spicules to coronal temperatures via ambipolar diffusion
- Observations with the upcoming **MUSE** mission will further aid to firmly establish if any heating along coronal loops is linked to spicular injection at its base.

Selected References:

- **Cheung et al. 2015**, *Thermal Diagnostics with AIA on-board SDO.*
- **De Pontieu et al. 2022,** *Probing the physics of the solar atmosphere with MUSE I. Coronal Heating*
- **Bose et al. 2024 submitted**, *On the million degree signature of spicules.*