# Multi-thermal nature of spicular downflows*

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## Context

Decades of observations since the launch of NASA's *Skylab* mission revealed the presence of persistent downflows ranging between 10—15 km/s in the solar transition region (TR). Despite several hypotheses from observations and simulations, the cause of such flows has remained a matter of debate.

This study explores the association of spicules in the context of understanding such downflows in the TR (and in the lower corona) with multi-wavelength, high-resolution observations spanning from the chromosphere to the corona. Theoretical interpretations are provided with the help of a 2.5D MHD simulation.

## **Observations:** SST (CRISP & CHROMIS)+IRIS+SDO

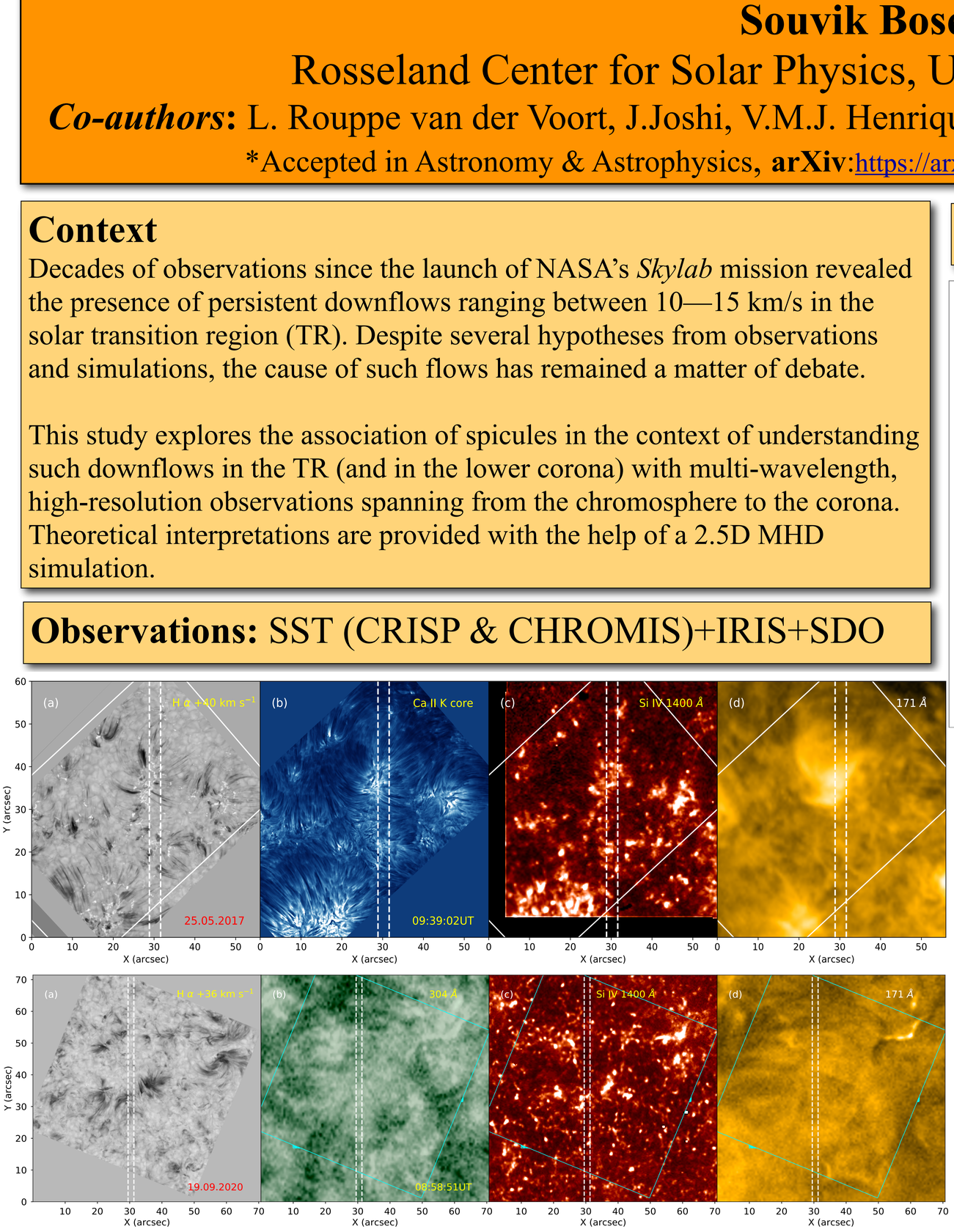


**Figure 1:** Overview of the coordinated **SST**, **IRIS** and **SDO** datasets used in the study. Animations are available via the **QR-code**.

## MHD simulation from Bifrost

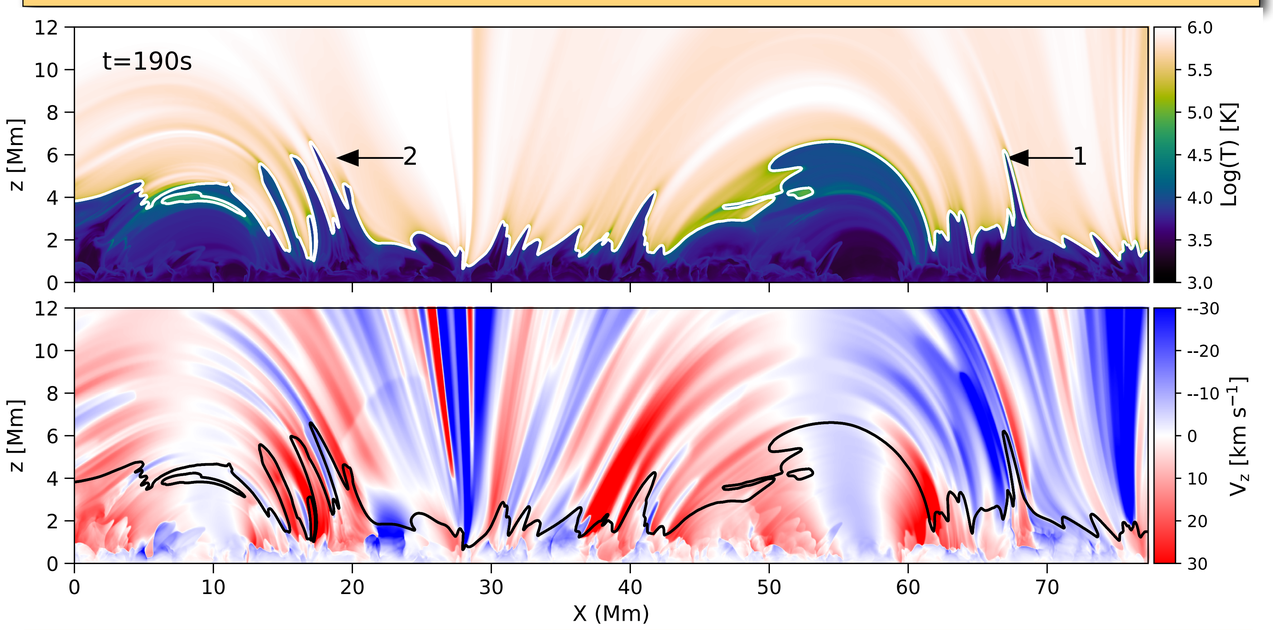


**Figure 2:** Overview of the temperature (top row) and velocity (bottom row) maps of the spicule simulation from Martínez-Sykora et al. (2017). The spicules numbered 1 and 2 are analyzed further in this poster and in the paper. An animation is available via the **QR-code.**

## Multi-thermal nature: space-time evolution

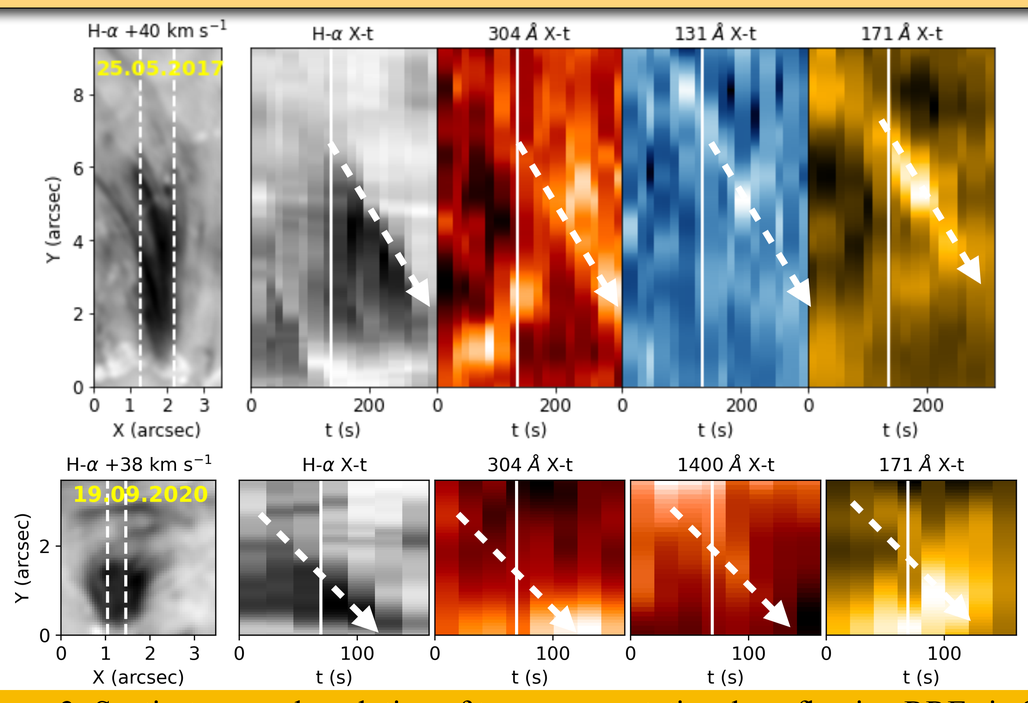


**Figure 3:** Spatio-temporal evolution of two representative downflowing RREs in SST, IRIS and SDO channels, showing their ***multi-thermal*** nature. Animations of their evolution are available via the **QR-code.**

## Multi-thermal nature: space (spectral)-time evolution

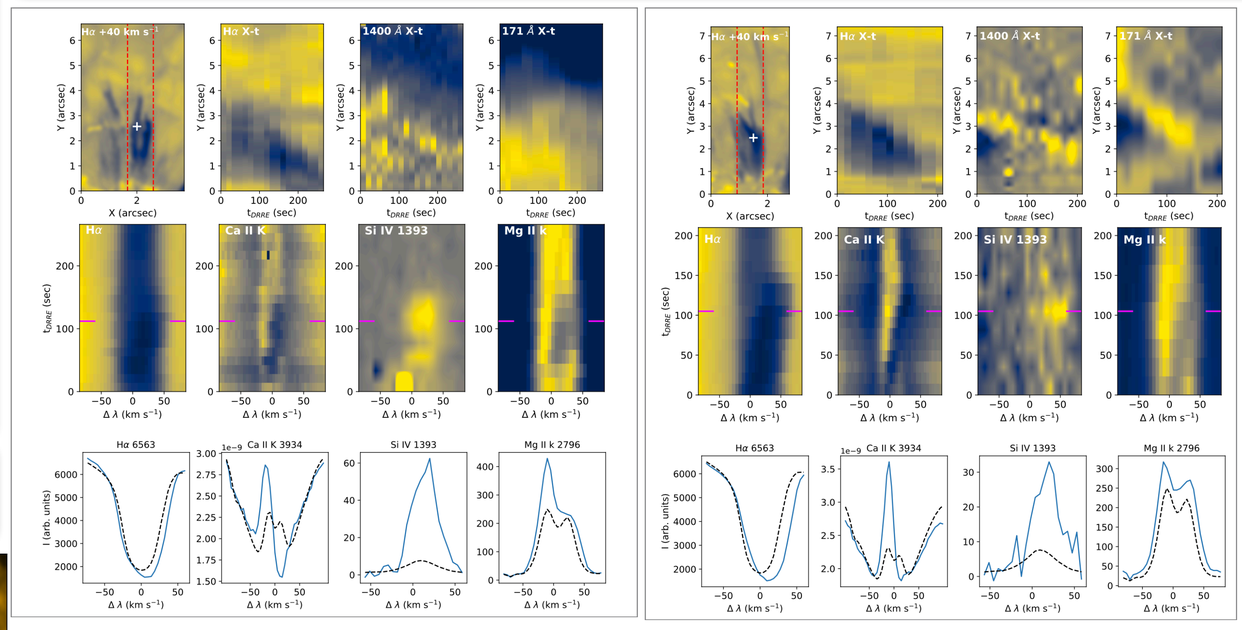


**Figure 4:** Spatial and spectral signatures across the chromospheric (H-alpha, Ca II K and Mg II k) and TR (Si IV) channels of two different downflowing RREs from SST and IRIS observations. Note the co-temporal redward excursion asymmetry in the spectral-time panels.

## Comparison with MHD simulation: synthetic observables

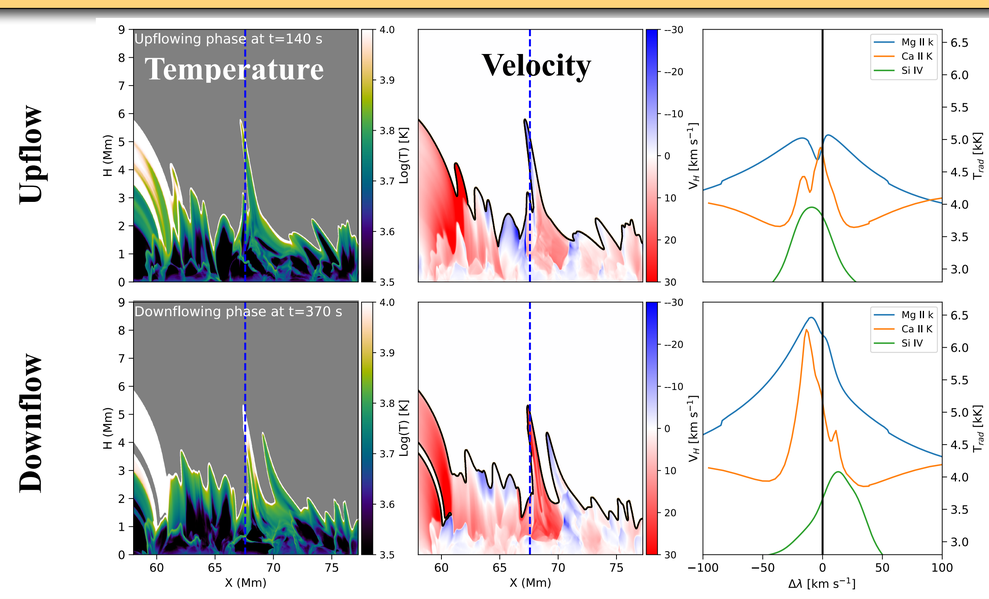


**Figure 5:** Synthetic Ca II K, Mg II k and Si IV spectra obtained from the MHD simulation for the upflowing (top row) and downflowing (bottom row) phases of spicule 1 in Figure 2.

## Comparison with MHD simulation: downflows along a loop

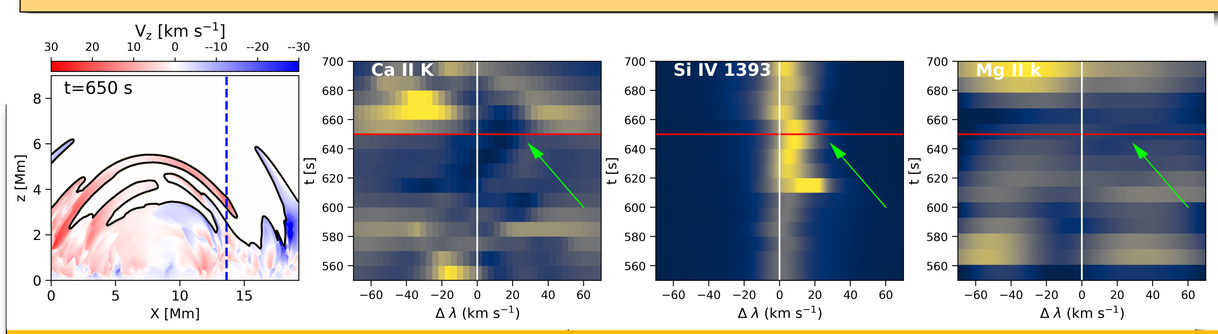


**Figure 6:** Multi-thermal spicular downflow along a loop-like structure and its associated synthetic spectral-time evolution from a simulation perspective. Animation via **QR-code.**

## Atmospheric Heating

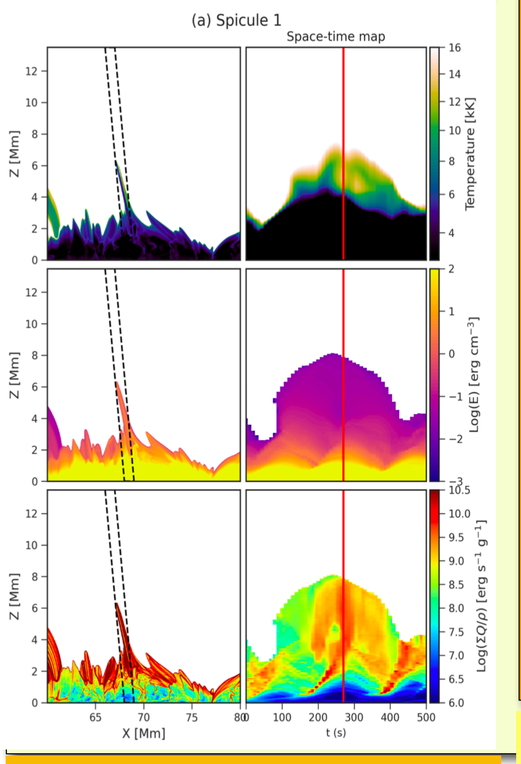


**Figure 7:** Heating of the solar chromosphere associated with spicules during the **downflowing** phase. Animation is available via the **QR-code.**

## KEY FINDINGS

- Ample occurrences of rapid **chromospheric** spicular downflows (termed as ***dowflowing RREs***, see also Bose et al. 2021a).
- Visible across multiple wavelength channels.
- Wide thermal coverage ranging from cooler chromospheric to hotter TR (and coronal) temperatures.
- TR Dopplershifts associated with downflowing RREs comparable with the average redshifts observed in the TR.
- Distinctive match between simulations and observations.
- Contribution towards apparent heating of the solar atmosphere.

**Major Conclusion:** This study presents evidence that unambiguously links the abundant downflows observed in the form of spicules in the chromosphere with their TR and lower coronal counterparts — which was missing in the pioneering studies such as Pneumann & Kopp (1977) and McIntosh et al. (2012).