Solar Spicules and RBEs/RREs in MURaM simulations

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1. What are spicules and why do they matter?

Spicules are off-limb jet-like structures which appear to exhibit very fast propagation towards the upper solar atmosphere. They disappear with transition region counterparts indicating that they might play an important role in the mass and energy transport to the solar corona and transition region. Their on-disk counterparts are thought to be Rapid Blue and Red Shifted Excursions (RBEs and RREs). We use MURaM-ChE[1] simulations of an enhanced network region to probe their dynamics and structure.

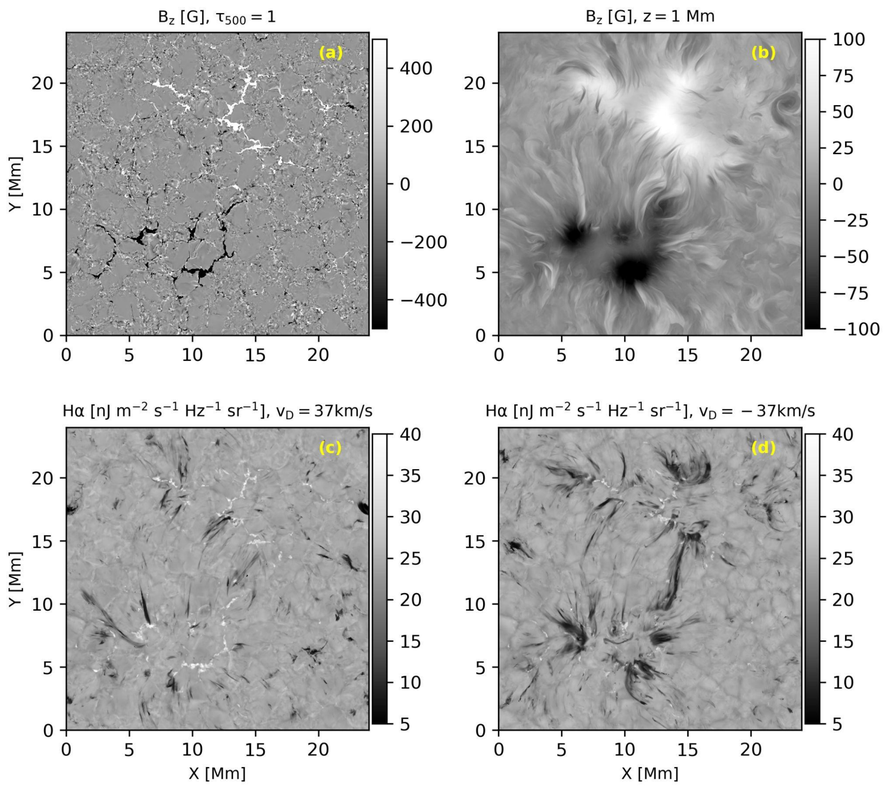
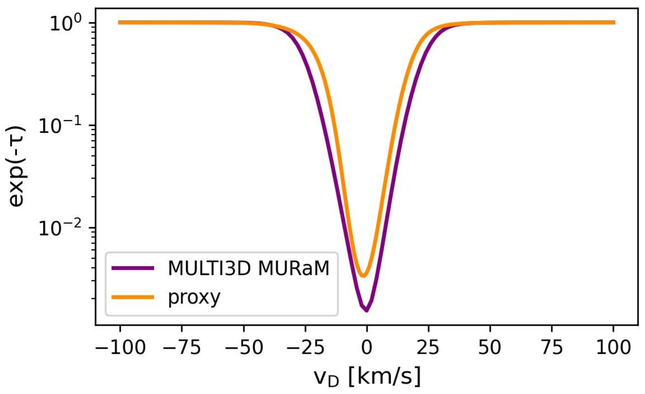


Figure 1. Top: Overview of the magnetic field configuration of the enhanced network. Bottom: RBEs and RREs identified with the MULTI3D synthesis.

Box size (x,y,z): 24 Mm x 24 Mm x 24 Mm; Time series: 10 mins
Resolution: 23.4 km x 23.4 km x 20 km; Cadence: ~ 6 s

2. Detection of spicules: Hα proxy

We construct an Hα proxy (exp(-τ)) based on an escape probability using the computed optical depth τ. This works well to identify Hα wing features.



On disk:
P(z) = exp(-τ)

At limb:
P(s) = 1-exp(-τ)

Figure 2. Spatially averaged escape probability profile for the proxy compared with the MULTI3D synthesis for a single snapshot

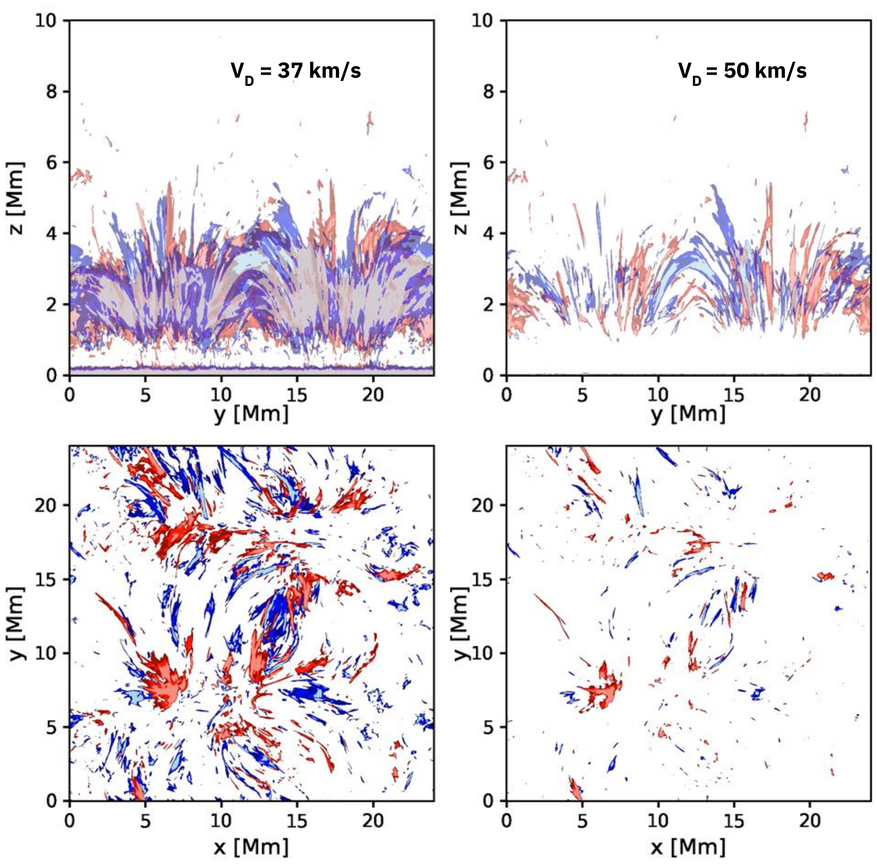


Figure 3. Spicules (top) and RBEs/RREs (bottom) identified with the proxy. Blue/Red shifted features are coloured with blue/red respectively at two Doppler shifts.

- The features are produced self-consistently without any imposed driving.
- With larger Doppler shifts we find fewer prominent features, which also holds true for their observed counterparts[5].

3. Results: Statistics, Driving and Dynamics

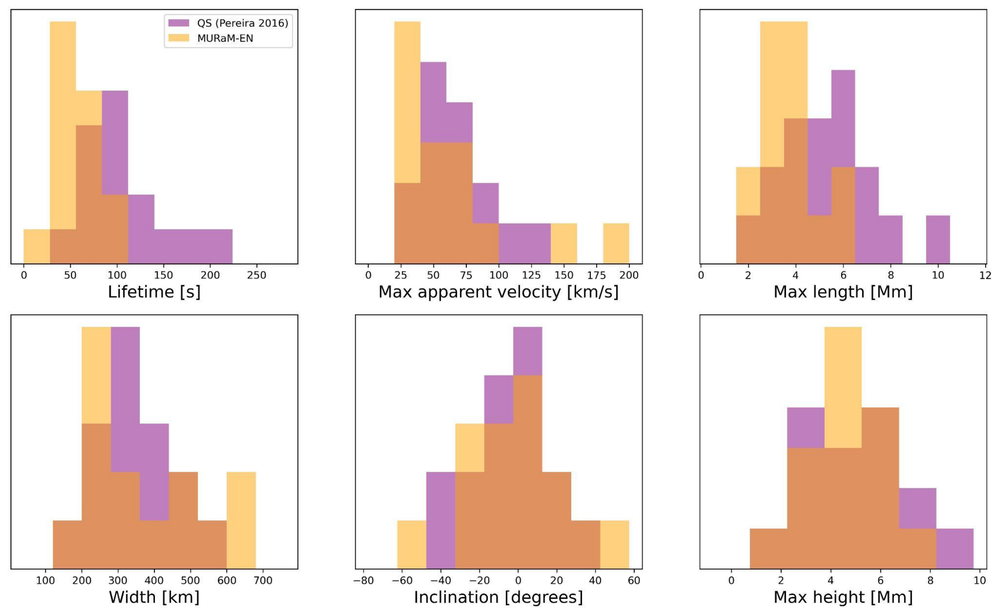


Figure 4. Histograms of spicule properties in Quiet Sun Hinode observations (QS)[5] versus the enhanced network MURaM-ChE simulations (MURaM-EN)

- We calculate a number of properties of the observed spicules, to compare with the observations of Pereira et al. (2014)[5]
- We focus on the faster (type II) spicules to understand their driving mechanisms.

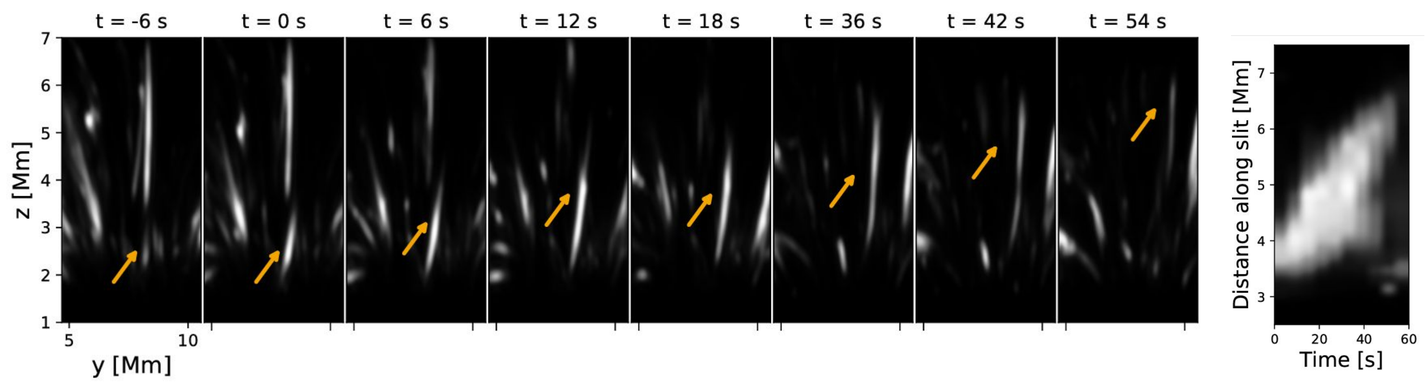


Figure 5. Evolution of a type II spicule in the MURaM-ChE enhanced network simulation, identified with the Hα proxy at a Doppler shift of 50 km/s.

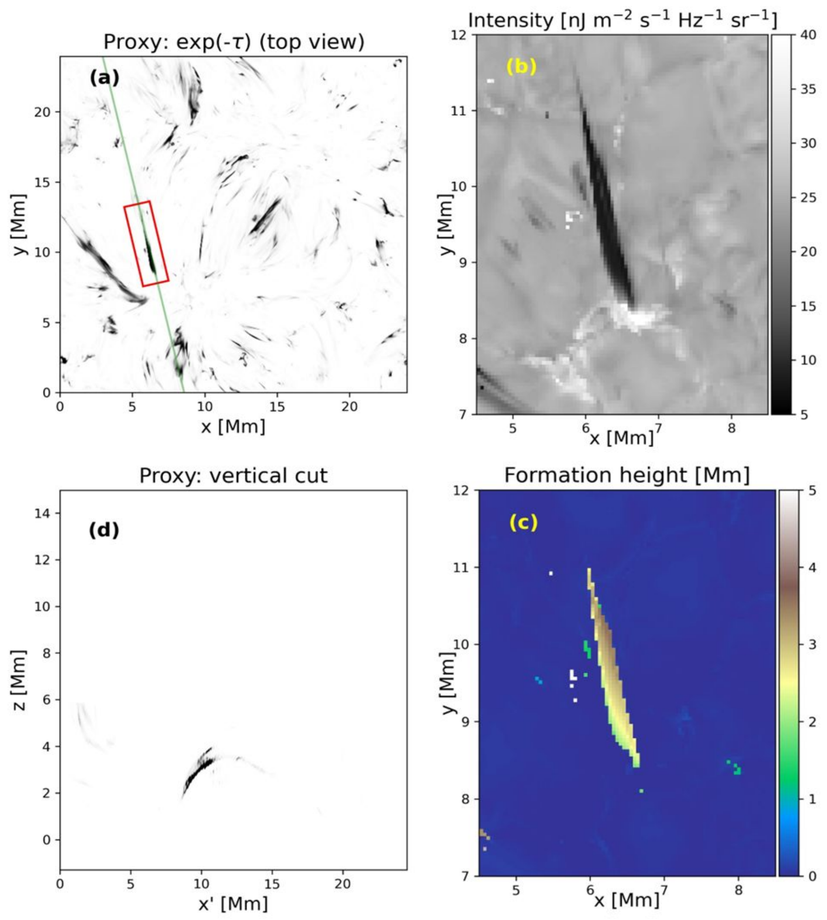
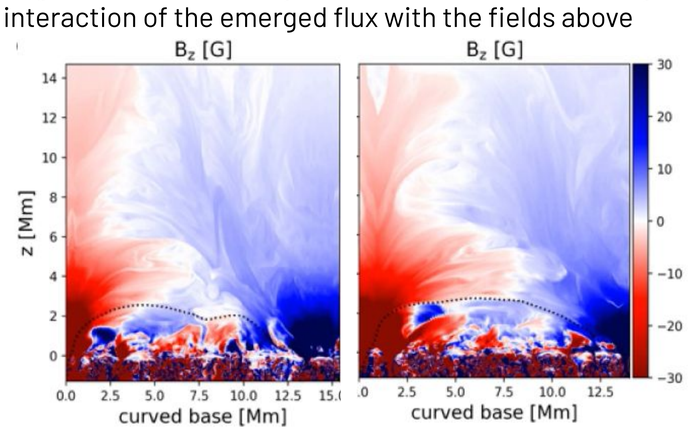


Figure 6. Left: RBE feature detected using proxy.

- The formation height information is inferred by the proxy.
- The straight feature on-disk is a projection effect from a loop like structure viewed from the top.
- It is driven by a magnetic reconnection event following flux emergence.

Figure 7. Bottom: Magnetic field evolution showing the interaction of the emerged flux with the fields above



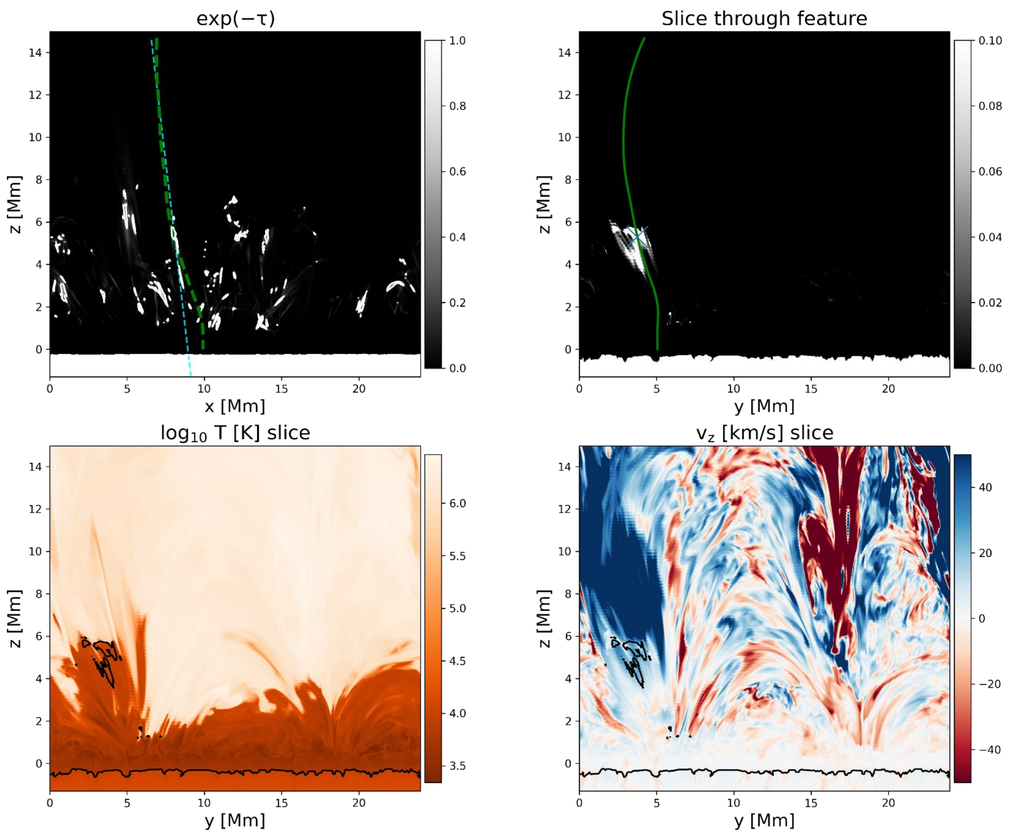
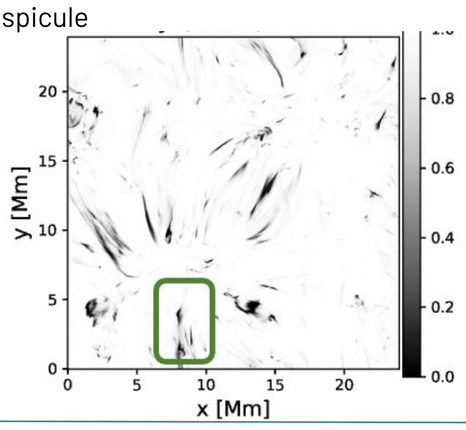


Figure 8. Left: Sheet-like structure of a fast spicule (apparent speed of ~190 km/s).

- Plasma aligns in the line-of-sight as a sheet to produce a sharp spicule-like observed feature.
- The fast apparent speed is not mass motion. Rather it is an illusion created by the rippling of a sheet in the line of sight.

Figure 9. Bottom: RBE counterpart of the spicule



4. Key takeaways

- The Hα proxy is much faster than MULTI3D (~seconds vs. 10^5 CPU hours) for identifying wing features.
- It detects spicules and RBEs/RREs with realistic statistics.
- Features are driven by magnetic activity at the base (flux emergence, Lorentz forces).
- We study their 3D structure and Doppler shift biases when interpreting spicules in observations.

5. References

[1] **Przybylski, D., Cameron, R., Solanki, S. K., et al.** 2022, Astronomy amp; Astrophysics, 664, A91 [2] **Leenaarts, J. & Carlsson, M.** 2009, in Astronomical Society of the Pacific Conference Series, Vol. 415, The Second Hinode Science Meeting
[3] **Leenaarts, J., Carlsson, M., & Rouppe van der Voort, L.** 2012, The Astrophysical Journal, 749, 136 [4] **Pereira, T. M. D., De Pontieu, B., & Carlsson, M.** 2012, The Astrophysical Journal, 759, 18 [5] **Pereira, T. M. D., De Pontieu, B., Carlsson, M.**, et al. 2014, ApJ, 792, L15