Determining the dynamics and magnetic fields in the chromospheric He I 10830 Å triplet during a solar filament eruption

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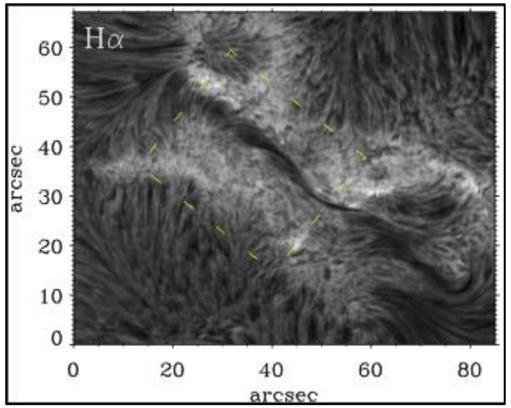
We investigate the dynamics and magnetic properties of the plasma, such as line-of-sight velocity (LOS), optical depth, vertical and horizontal magnetic fields, belonging to an erupted solar filament. The filament eruption was observed with the GREGOR Infrared Spectrograph (GRIS) at the 1.5-meter GREGOR telescope on 2016 July 3. Three consecutive full-Stokes slit-spectropolarimetric scans in the He I 10830 Å spectral range were acquired. The Stokes I profiles were classified using the machine learning k-means algorithm and then inverted with different initial conditions using the inversion code *HAZEL*. The erupting-filament material presents the following physical conditions: (i) ubiquitous upward motions with peak LOS velocities of ~73 km/s; (ii) predominant large horizontal components of the magnetic field, on average, in the range of 173-254 G, whereas the vertical components of the fields are much lower, on average between 39-58 G; (iii) optical depths in the range of 0.7-1.1. The average azimuth orientation of the field lines between two consecutive raster scans (<2.5 minutes) remained constant. The analyzed filament eruption belonged to the fast rising phase, with total velocities of about 124 km/s.

Context of the research

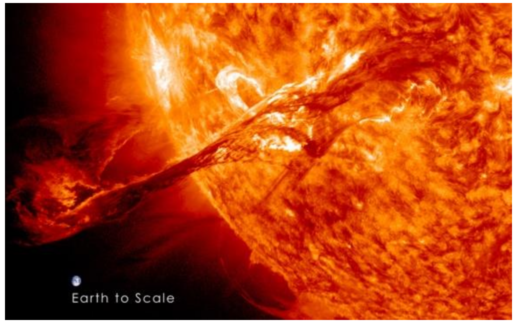


Solar filament

Kuckein et al. 2012 (A&A, 539)

1. Filaments are elongated structures formed of dense plasma that is located in the chromosphere and corona of the Sun.
2. They are sustained against gravity by the magnetic field lines. The topology of these field lines is often reported as a magnetic flux rope.
3. Disruptions of the magnetic field can produce the loss of equilibrium of the filament's structure producing an eruption.

Filament eruption

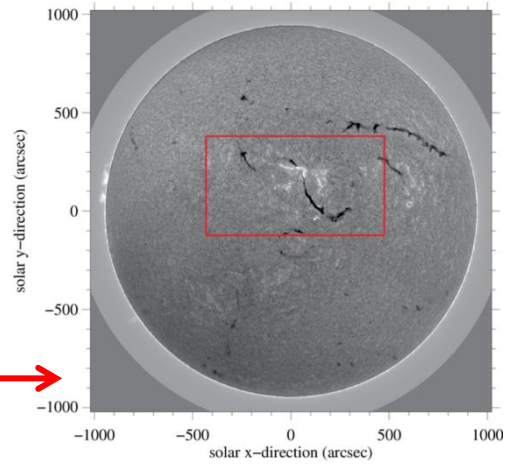


Credit: NASA/SDO/AIA

4. These disruptions are unpredictable and often associated with flares or coronal mass ejections (CMEs).
5. The present work characterizes the plasma properties of a filament during its eruption. The filament material was luckily observed with the ground-based 1.5-meter GREGOR telescope, located on the island of Tenerife, Spain.

Observations

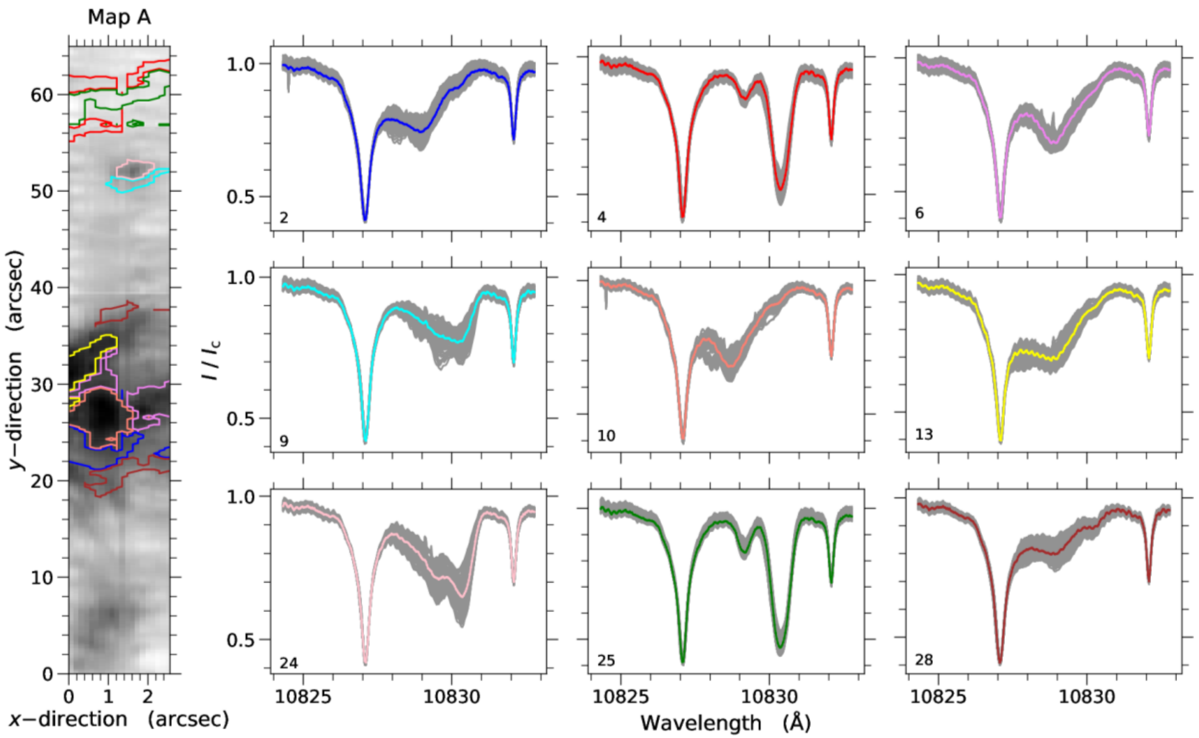
Telescope & date	Instrument	λ (Å)	# scans	Times (UT)	# steps	Eff. t_{exp} (s)
GREGOR 2016 July 3	Infrared Spectropolarimeter (GRIS)	He I 10830	3	A: 10:02 - 10:04 B: 10:05 - 10:07 C: 10:08 - 10:10	20	1



ChroTel overview (Hα)

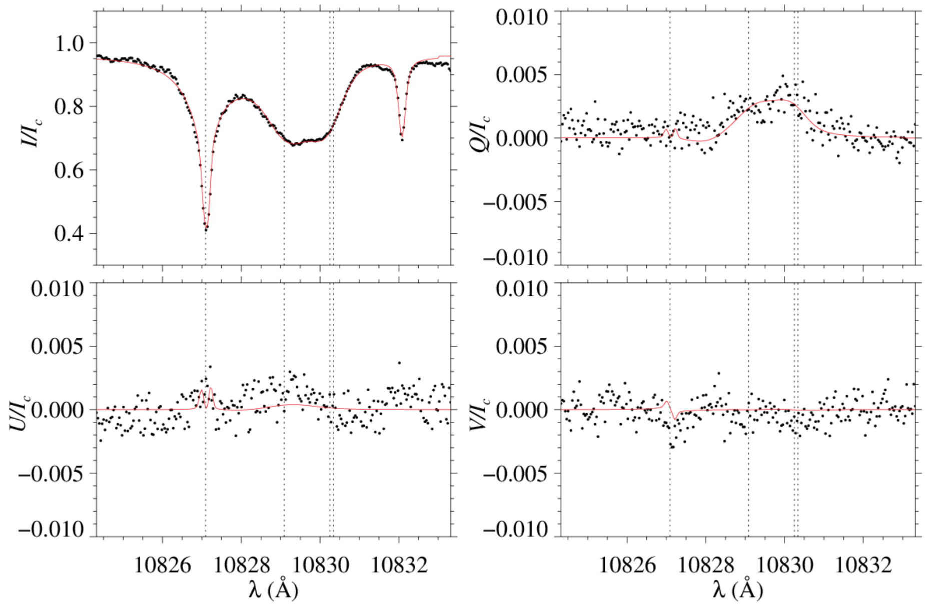
Methodologies

- Spectra classification using the machine learning *k*-means algorithm.
- In total 30 groups were selected, 9 are shown below.



A large variety of spectral shapes are seen during the filament eruption (multiple atmospheric components, strong blueshifts, etc.).

- The 30 groups were inverted with different initial guess atmospheres to improve the convergence of the inversion code HAZEL*.
- From the inversions we obtain: optical depth (τ), LOS velocity (v_{LOS}), horizontal (B_{hor}) and vertical magnetic field (B_{ver}), and azimuth (χ).

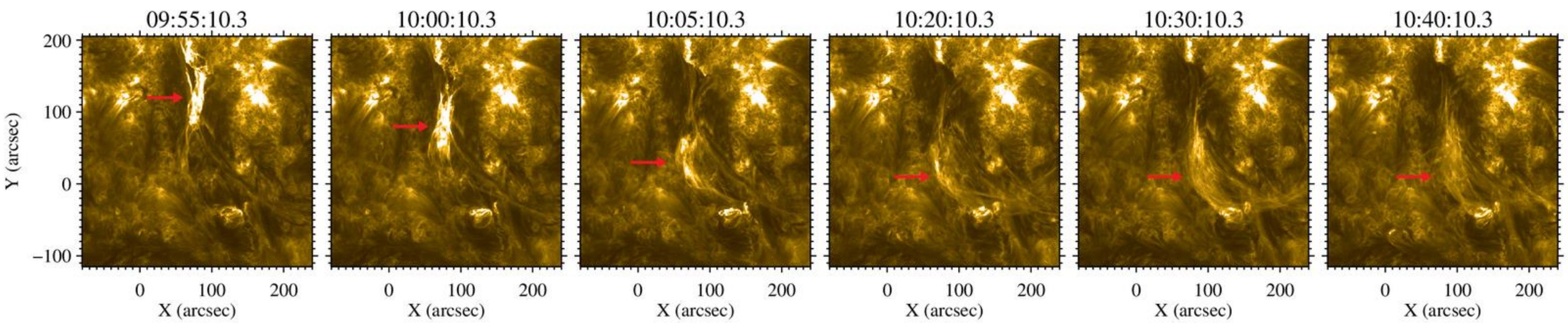


Stokes profiles from a pixel belonging to the ejected plasma. Dots are observed profiles, while the red line is the fit achieved with the HAZEL code.*

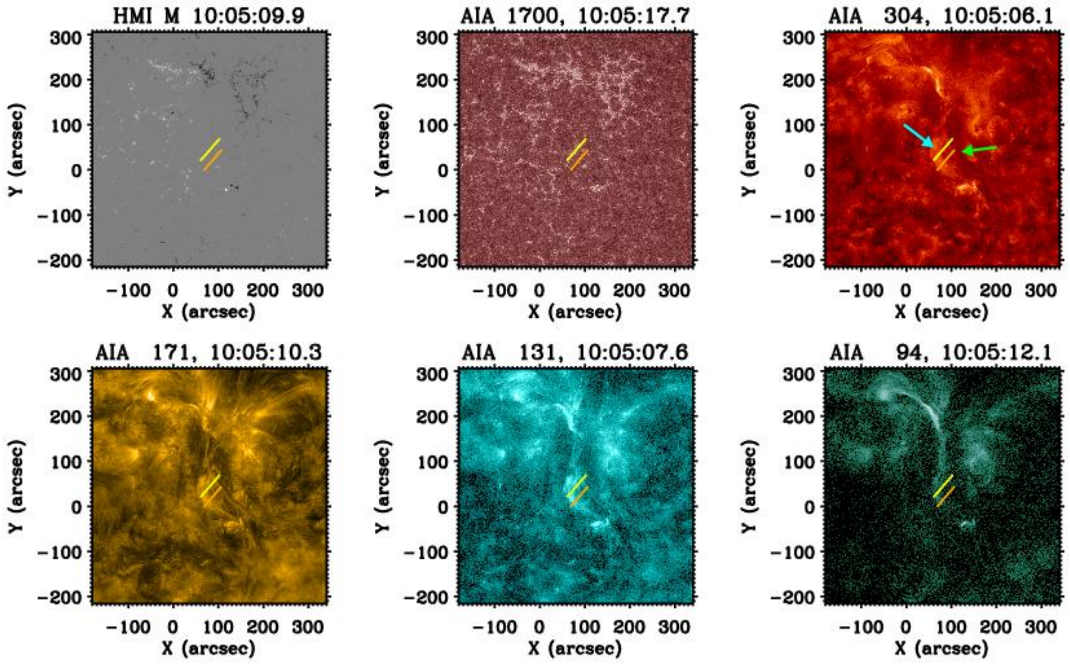
*https://github.com/aasensio/hazel2

Results

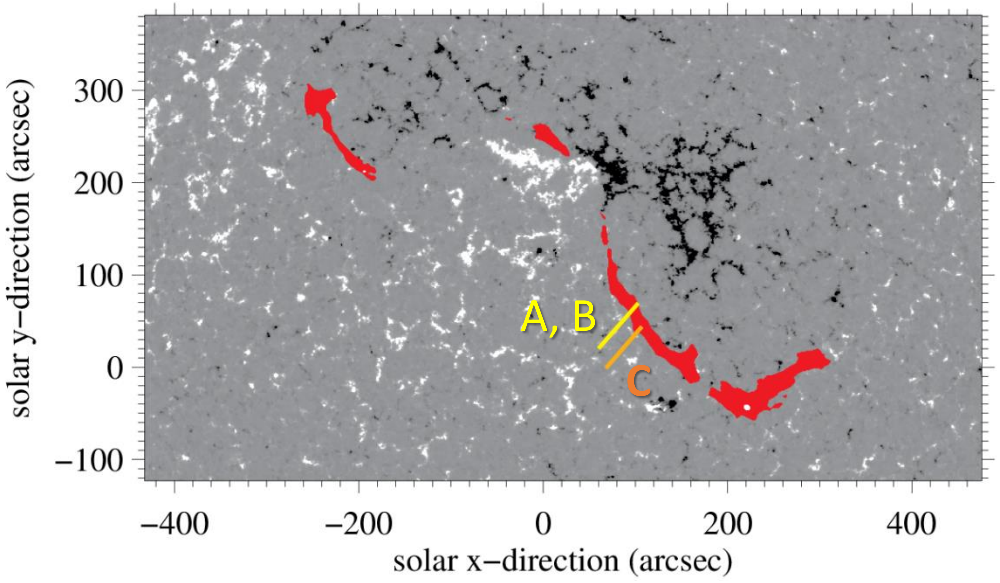
Time of our GREGOR observations



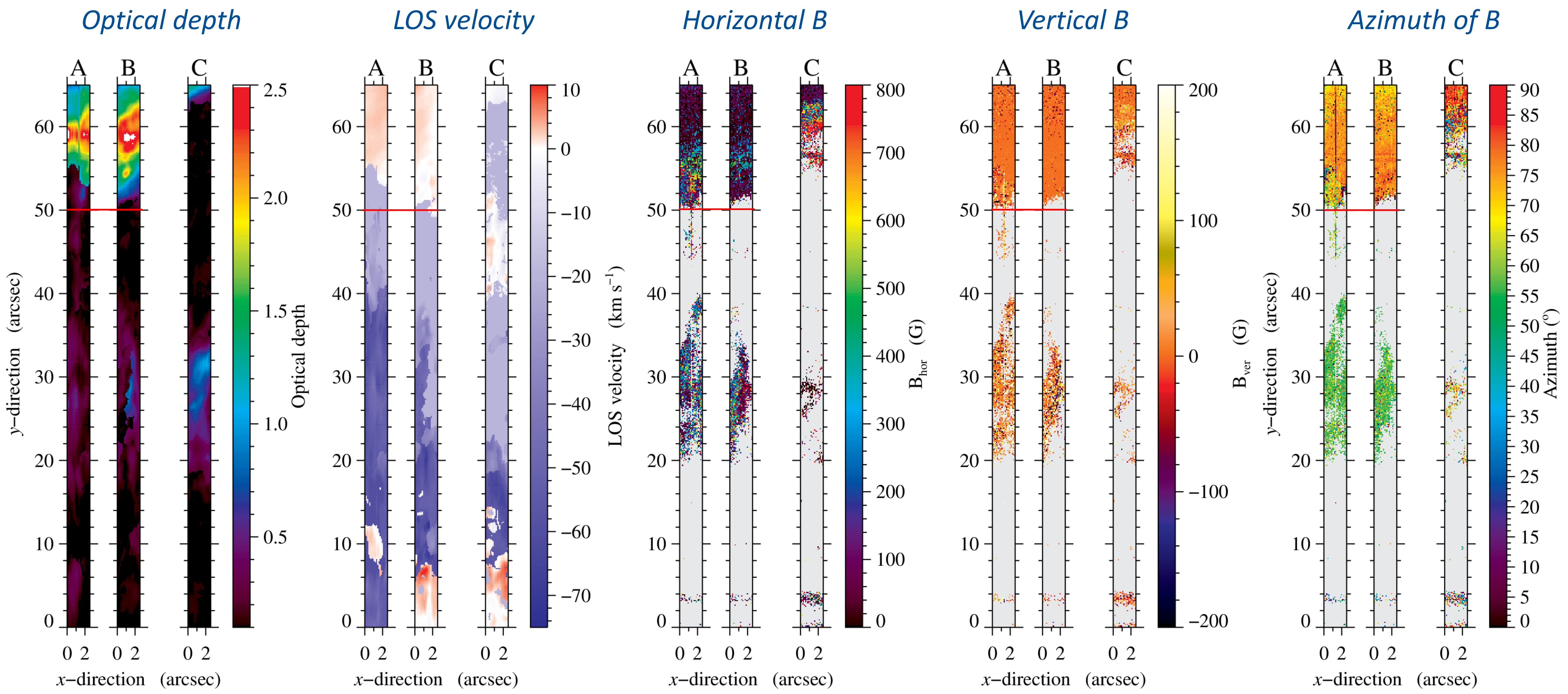
AIA 171 Å time evolution. Panels 1-3: fast rising phase; panels 4-6: slow untwisting phase., of the filament



HMI & AIA overview during the filament eruption.



Average HMI magnetogram. The filament, before it erupted (09:39 UT), appears as filled red contours. The slits of maps A, B and C appear as yellow and orange lines.



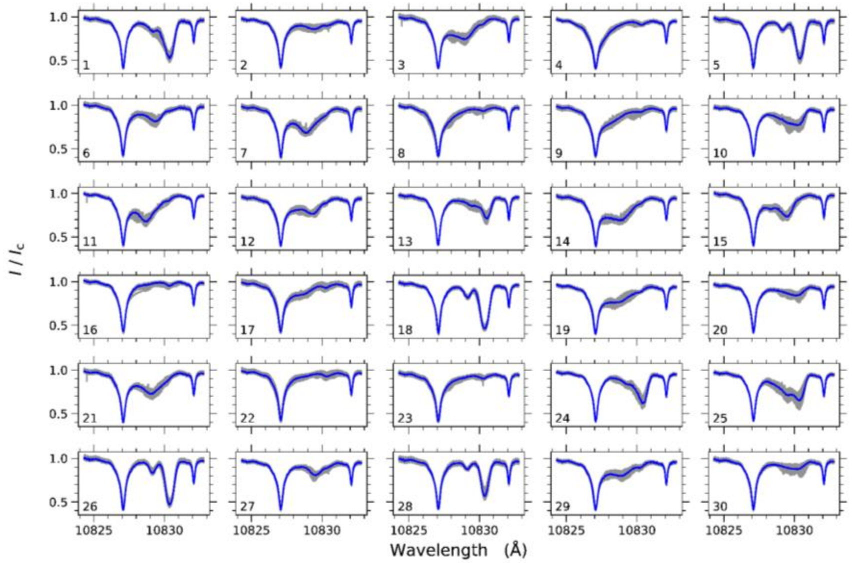
Inferred physical parameters for maps A, B and C (slits shown in slide before). The upper FOV (y>50 arcsec) in maps A and B belong to the filament at rest, while below y<50 arcsec the plasma belongs to the erupted filament.

Conclusions and prospects for the future

- We have shown that spectral classification, such as the used machine-learning *k*-means algorithm, significantly improves the results of inversion codes such as HAZEL, when many different types of profiles are present in the data.

- The physical quantities retrieved from the ejected plasma show: strong upflows of up to 73 km/s and predominantly horizontal magnetic fields, on average between 173-262 G, which is untypically high for quiescent filaments. The magnetic field lines were smoothly organized, showing a low dispersion, of the order of 11°, in the azimuth angle. The orientation remained stable within two consecutive observed maps (A and B). This indicates no rotation of the field lines at fast time scales below ~2.5 min, during the fast-eruption phase. In our case, the untwisting phase of the filament started about 15 min after the filament eruption started.

k-means spectra classification



Kuckein et al. 2020 (A&A, accepted)

- Filament eruptions are rarely observed with ground-based telescopes. This work, although limited by the small FOV, provides valuable information about the plasma properties in such eruptions. More observations of this kind are highly desirable to understand the dynamic and magnetic properties, and more important, to push forward our understanding in predicting filament eruptions.

All figures and the complete study can be read in Kuckein et al. 2020 (A&A, accepted): https://arxiv.org/abs/2006.10473