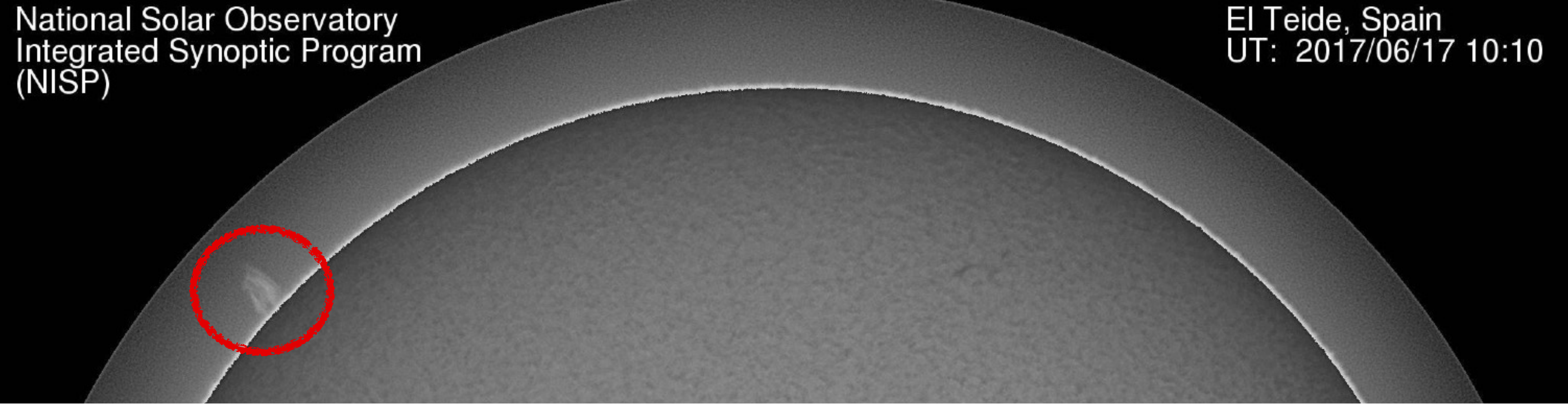

Observational Detection of Drift Velocity between Ionized and Neutral Species in Solar Prominences

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Introduction

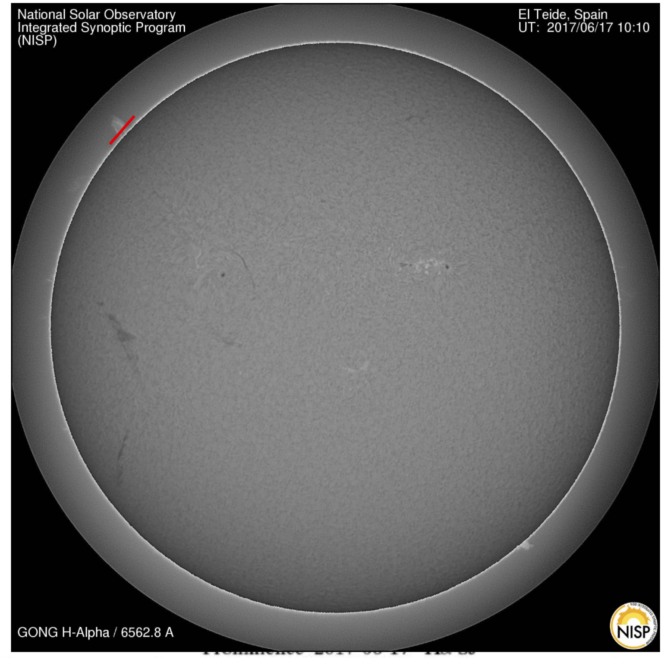
It has been stated for a long time that the solar atmospheric plasma is not in a neutral state nor in a fully ionized state. The direct influence of neutrals on the dynamics of solar plasma is a relatively new topic, which recently became the focus of many theoretical investigations (Arber 2007; Soler et al. 2010; Zaqarashvili et al. 2012; Khomenko et al. 2014, 2015, 2017, 2018; Cally & Khomenko 2015, 2018, Martínez-Sykora et al. 2017, 2019; Wiehr et al. 2021).

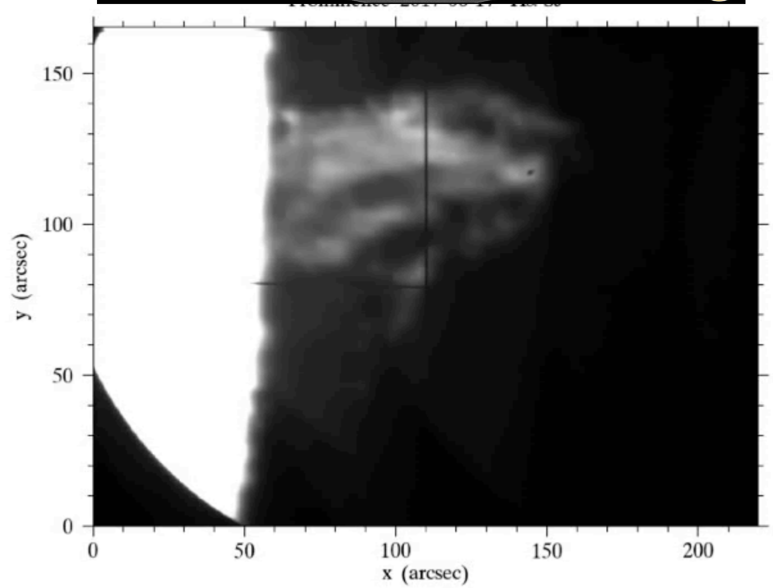
Solar plasma is composed of different species, and it can be considered that each of them behaves like a fluid interacting with the rest of species via collisions. When the collisional coupling is strong, the plasma mostly behaves as a single fluid. If this coupling weakens in certain processes, there might be deviations between the dynamical and thermal properties of the different species. Theoretical modelling (e.g. Popescu Braileanu et al. 2019a,b) suggests that the decoupling happens at very short temporal and spatial scales, of the order of kilometres and seconds.

To detect ion-neutral effects, it is necessary to measure as accurately as possible the velocity of different species at the same spatial position and simultaneously. Our aim is the detection of non-ideal ion-neutral effects in the solar plasma. The best candidate targets for this goal are spicules, surges, and the lower part of prominences.

Observations

- We observed a quiet Sun solar prominence at the east limb on June 2017 with the VTT
- Simultaneous spectral observations of the Ca II 8542 Å, Hα 6562.8 Å, and He D3 5875.6 Å lines
- The spectroscopic mode is selected to ensure a high cadence and S/N, which is needed to detect these effects
- Observing sequence ~90 min
- Same (PCO 4000) camera and detector was used to observe Hα and He D3 (spatial sampling of 0".35). Different camera (PCO 2004 Sensicam) to detect Ca II (spatial sampling of 0".47).
- 2500 frames, 250 scans of the structure of the prominence in 10 different scanning positions.
- Scanning step of 0."75. Cadence for every position 22.01 s.





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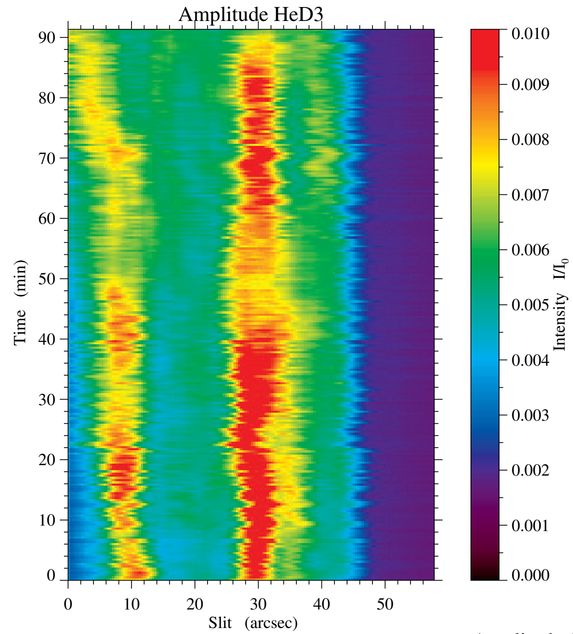
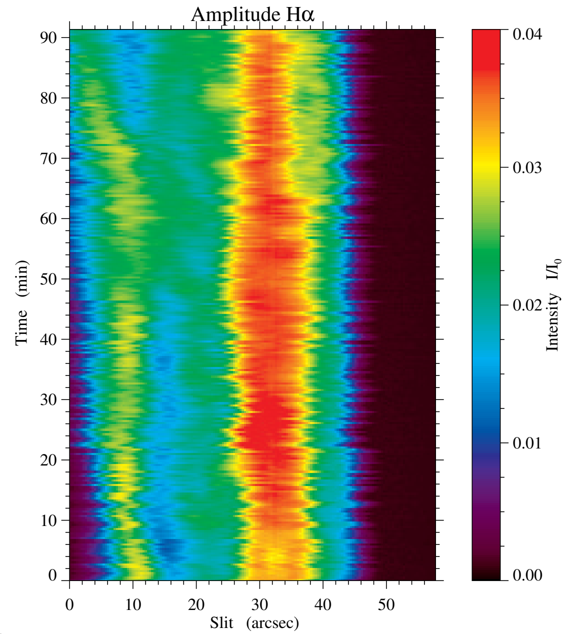
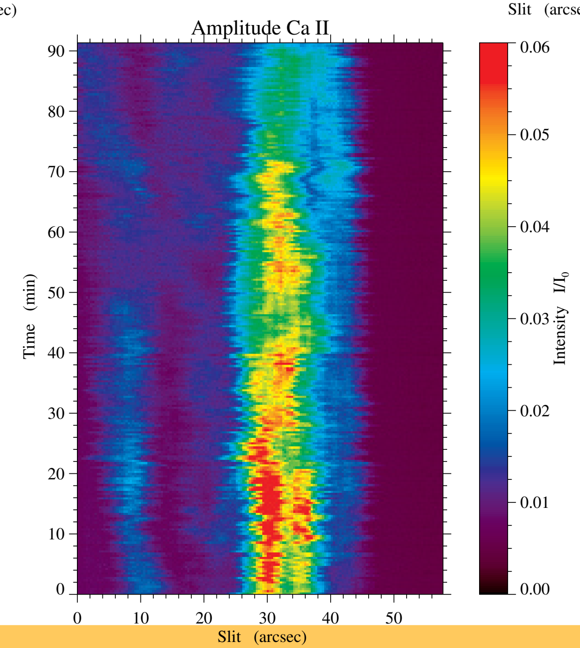
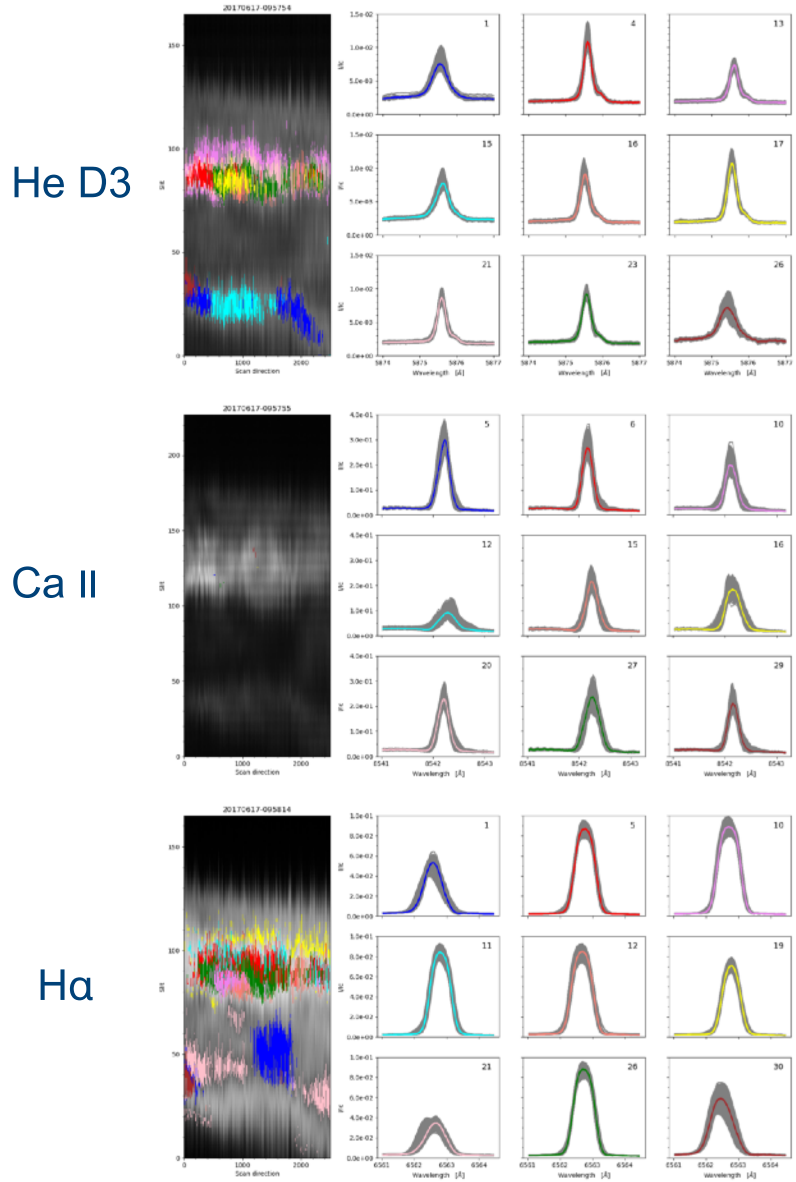






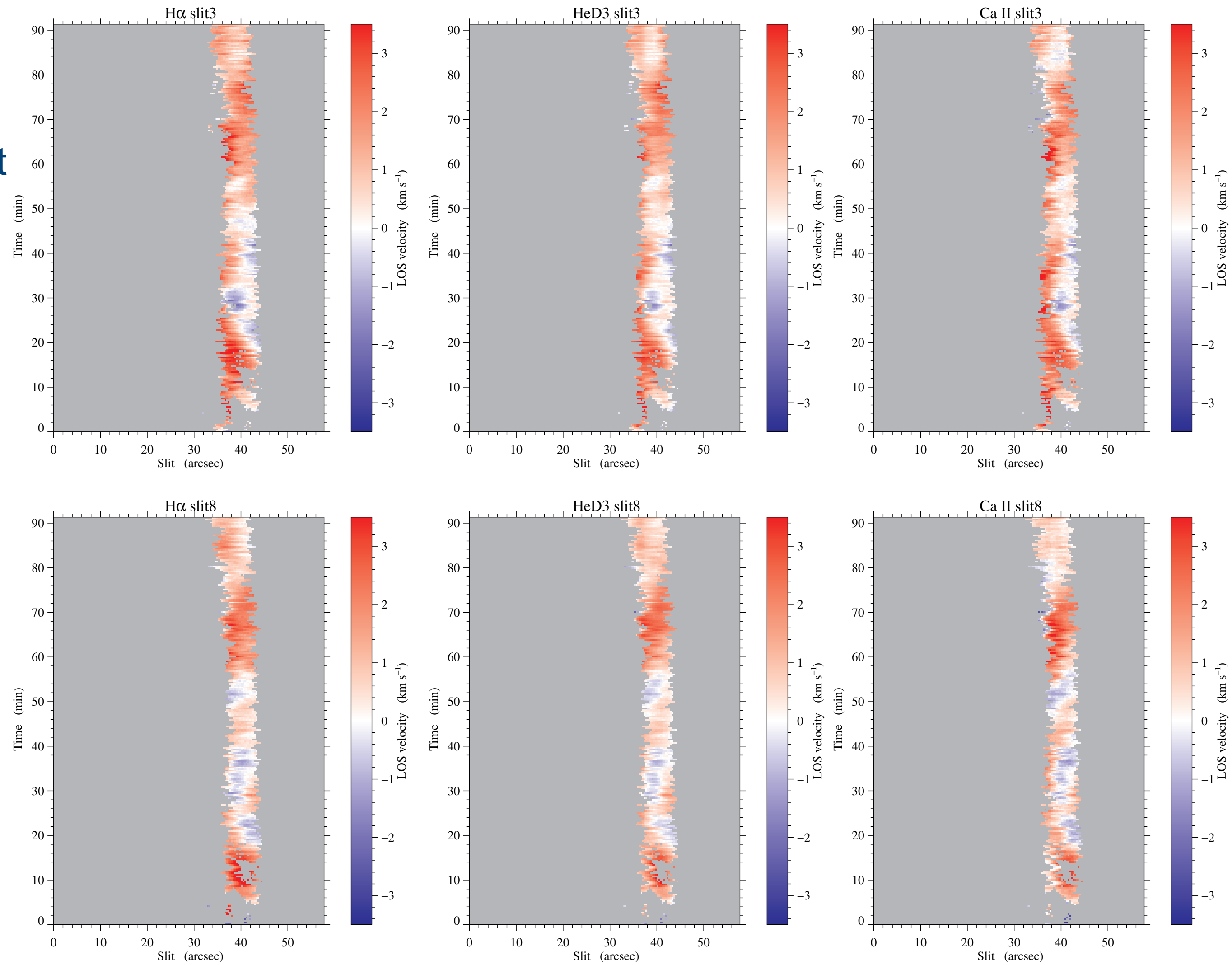
Spectral classification

- A wide variety of Stokes I profiles with different shapes were found in the three spectral profiles
- Many of the spectral profiles present double peaks. Probably, there are two atmospheric components located in the same resolution element
- We need to calculate the LOS velocities for the three spectral lines. We should avoid rare spectra or with very high amplitude (optically thick)
- We used k-means clustering, an unsupervised machine learning algorithm, to classify the different types of Stokes I profiles into similar groups (scikit-learn library from python)
- The k-means technique is often used to group common spectral profiles in large data sets (see, e.g., Pietarila et al. 2007; Viticchié & Sánchez Almeida 2011; Panos et al. 2018; Robustini et al. 2019; Sainz Dalda et al. 2019; Kuckein et al. 2020; Nobrega Siberio et al. 2021)



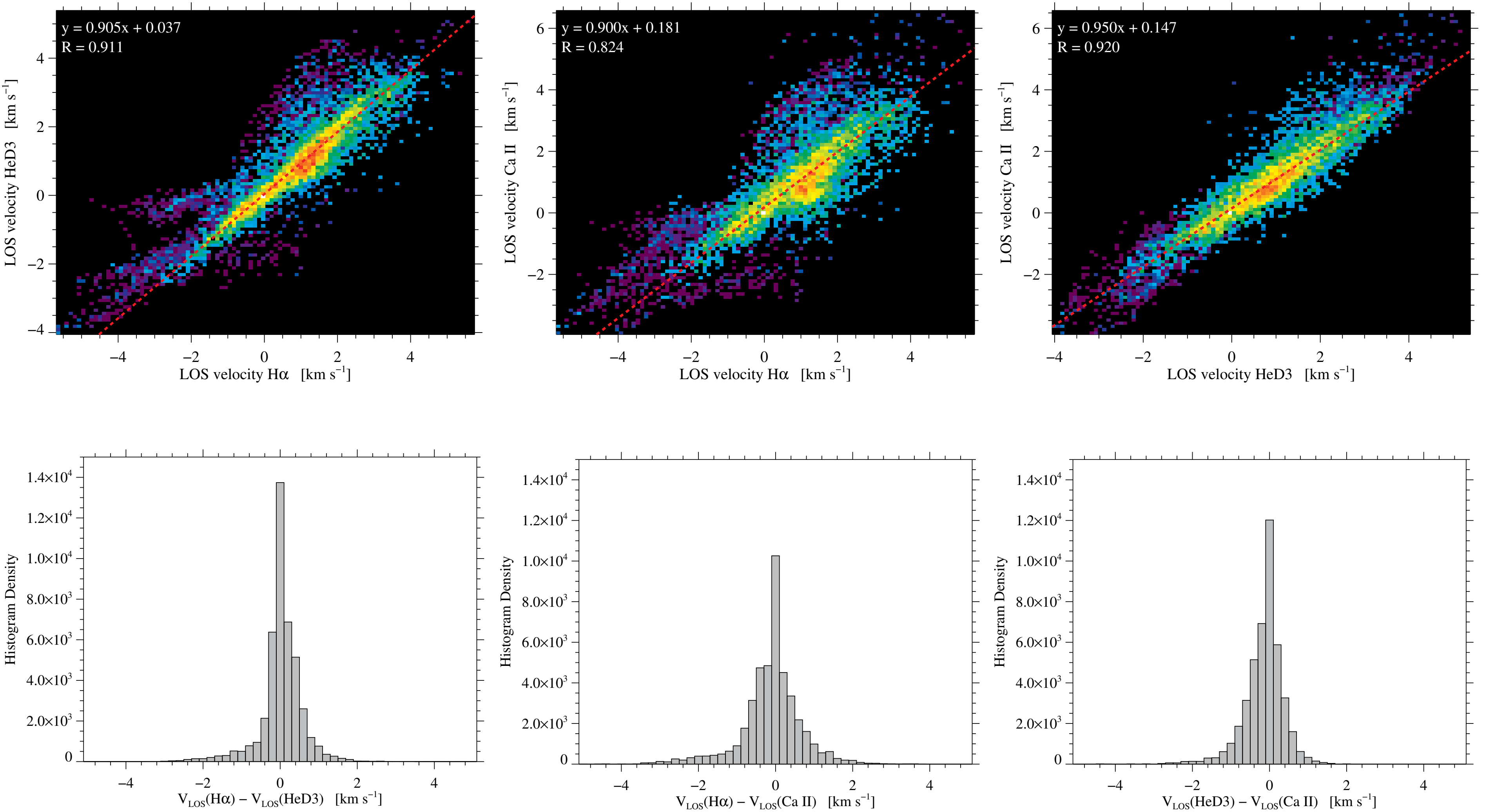
LOS velocities

- Ca II profiles fitted with a Gaussian, and He D3 with a double Lorentzian using the Levenberg– Marquardt least-squares minimization. The line core of Hα was fitted with a polynomial fit (2nd order)
- We used an average flat profile to perform the wavelength calibration. The zero reference is inferred from an average profile within the prominence. We excluded rare or optically thick profiles in Hα
- Examples of LOS velocity maps of slit positions 3 and 8



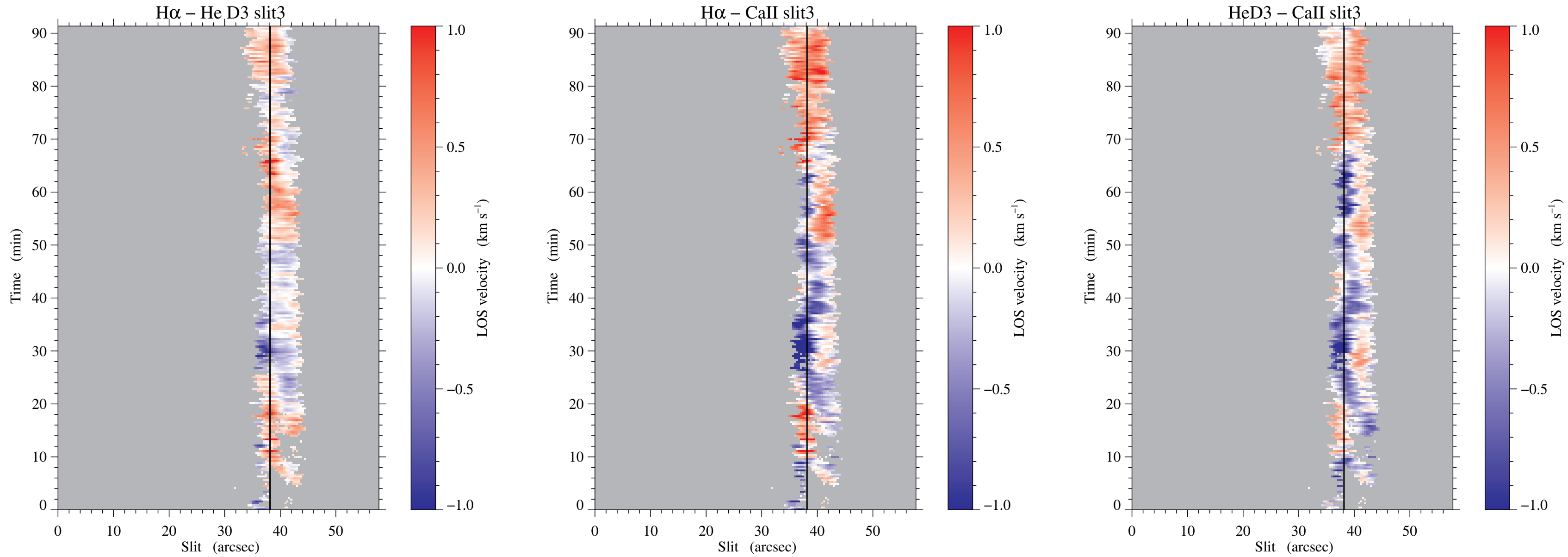
Hα He D3 Ca II

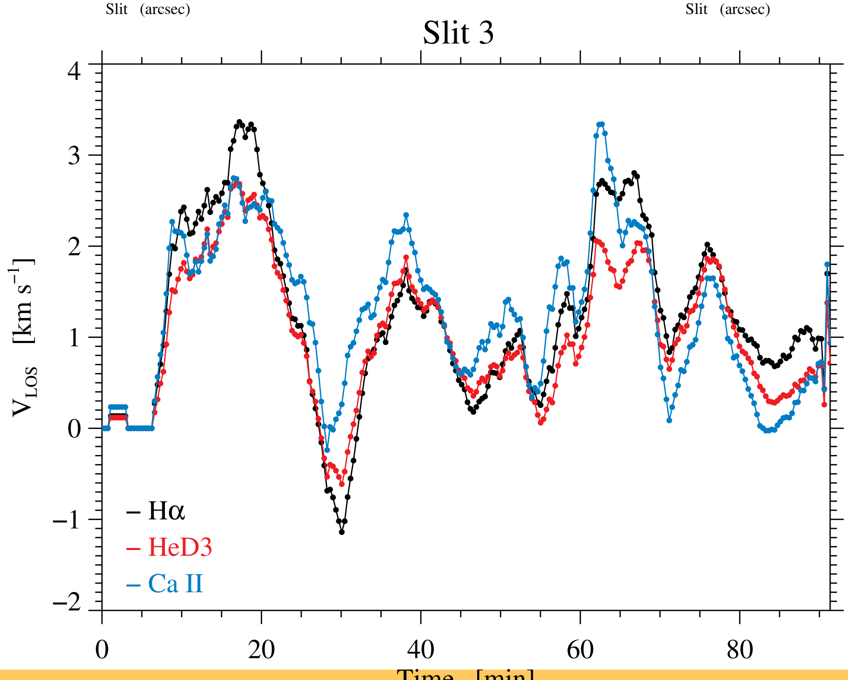
Compare neutrals and ions LOS velocities



- We compare all the velocities calculated of every slit (10 in total) in time. We exclude rare profiles and profiles where Hα was optically think

Compare neutrals and ions LOS velocities





- We selected one position to see the velocity changes in time
- We applied a smooth to follow the velocity trend in time
- The Ca II LOS velocities (ionized) are often shifted in time comparing to the neutral velocity profiles.
- The Hα velocities are different with respect to the others the first few minutes

Conclusions and Outlook

- To detect ion-neutral effects, it is necessary to measure as accurately as possible the velocity of different species at the same spatial position and simultaneously

- We observed a quiet solar prominence at the east limb on June 2017 with the VTT

- Simultaneous spectral observations of the Ca II 8542 Å, Hα 6562.8 Å, and He D3 5875.6 Å spectral lines

- LOS velocities of neutrals are similar, while the ionized LOS velocities are slightly different

- We are going to analyze the possible physical differences between the neutrals and ionized spectral lines. What is the opacity in the regions where the LOS velocity of the ionized spectral line is different?

- What is happening in the regions where the amplitude of Hα profiles is higher?

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