3D inversion of solar prominences

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NLTE INVERSIONS

NLTE inversions solve radiative transfer under non-LTE to infer height dependent temperature, velocity, magnetic field and other parameters from spectropolarimetry; they are slow for large FOVs and omit spatial coupling.

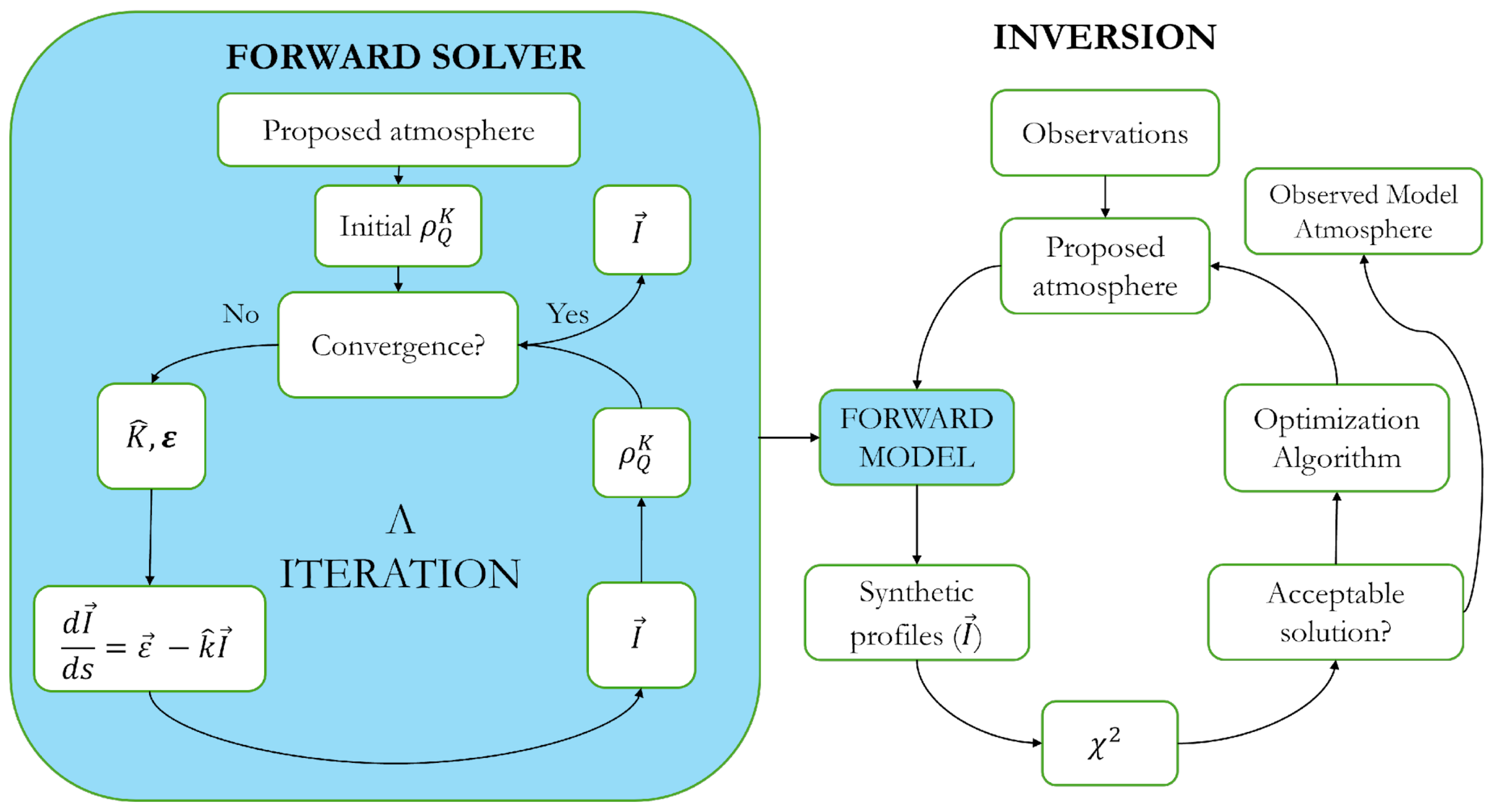

Figure 1. Schema of the traditional inversion method

FOV RECONSTRUCTION

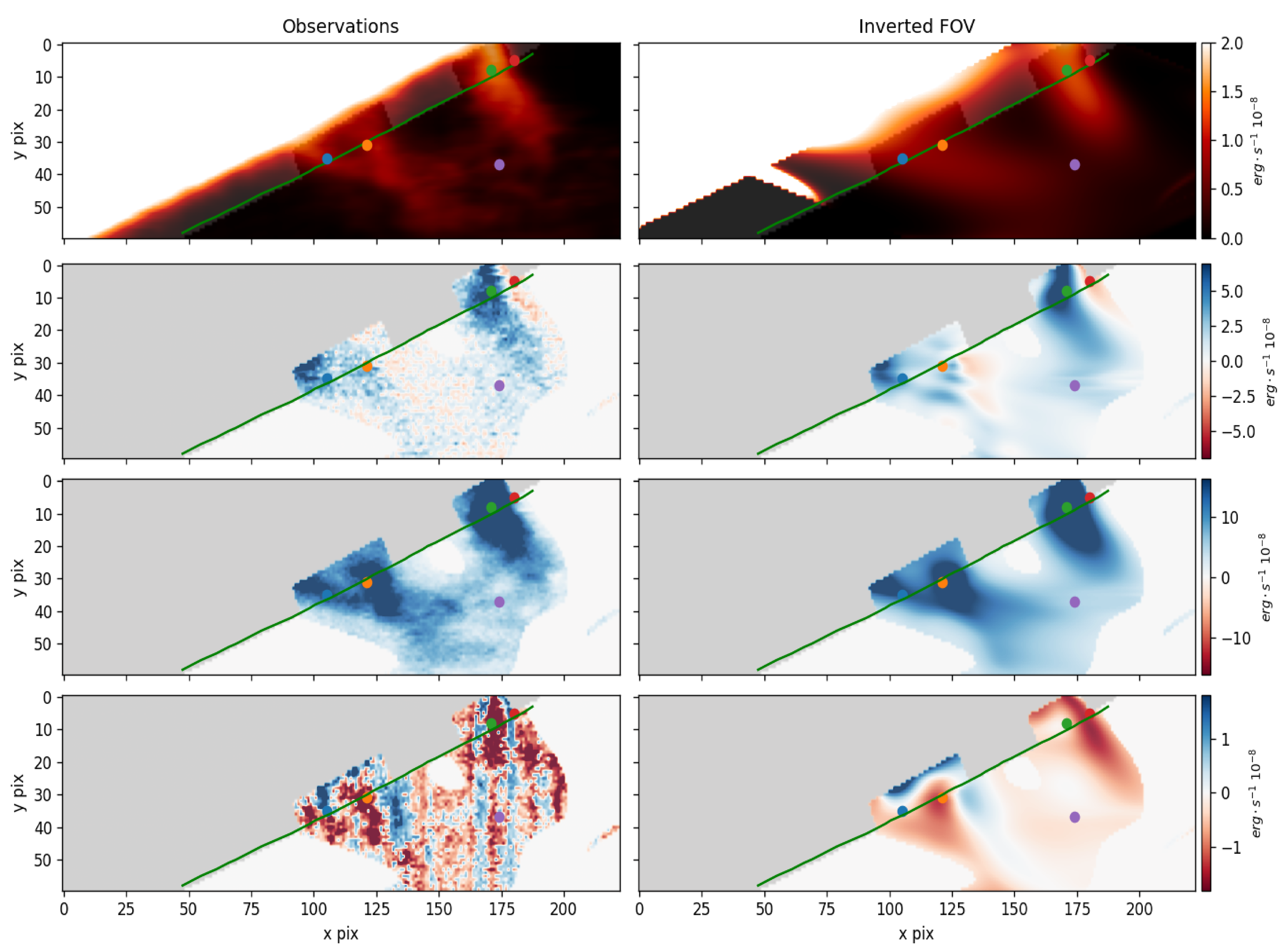

Figure 2. Intensity, Stokes Q,U,V (rows from top to bottom) at 10830.3 Å from the He I triplet. Left column are the observations and the reconstructed profiles from POLARIS are on the right. Green line indicates the reach of the spicules and the shaded grey area shows the region not included in the calculation of χ^2. Points where $I < 2.5 \cdot 10^{-6}\ erg\ s^{-1}$ are zeroed in Q, U, V, to remove low S/N pixels. Coloured circles indicate the location of the pixels whose profiles are shown in Fig. 4.

PROFILE FITINGS

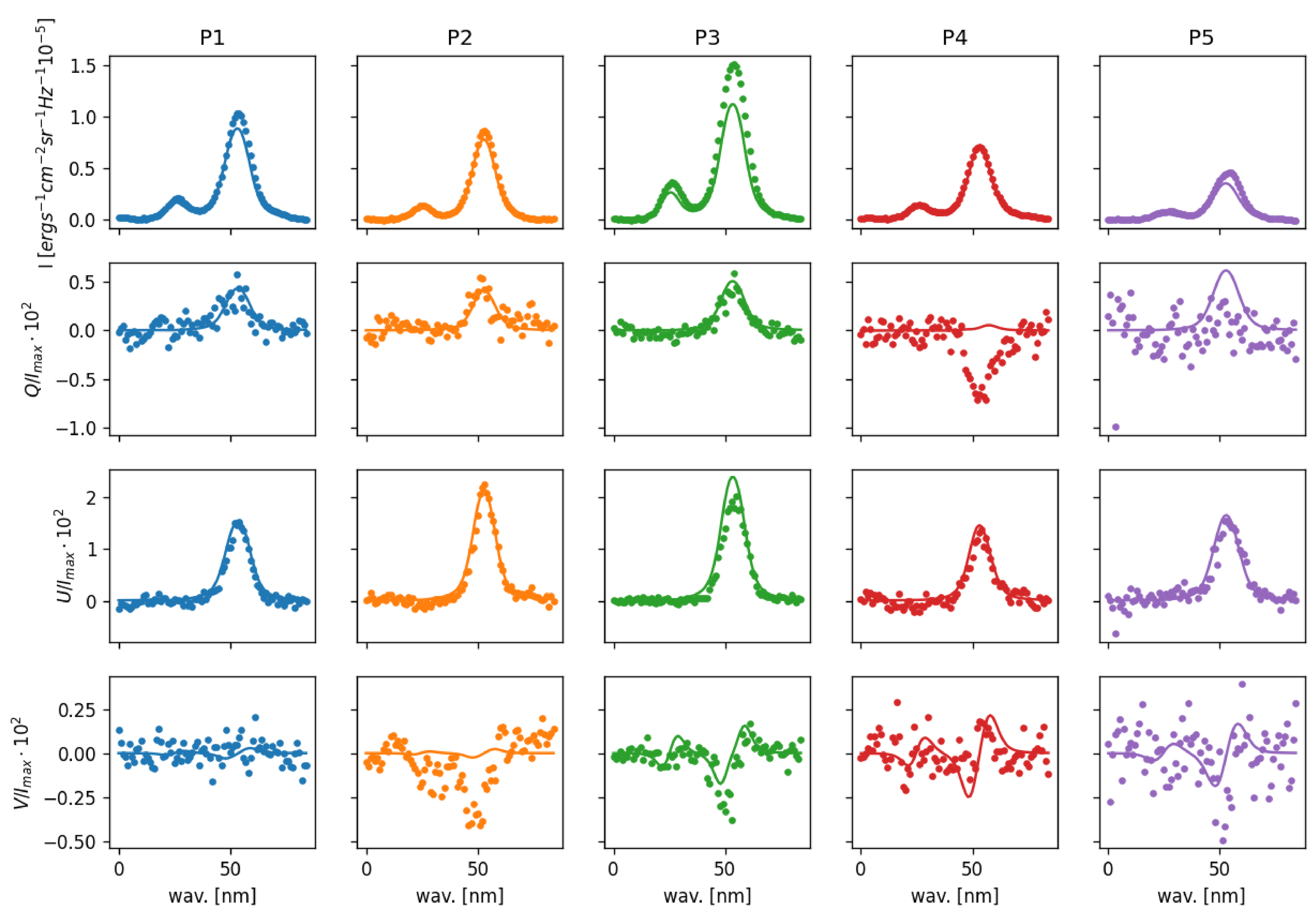

Figure 4. Intensity, Stokes Q,U,V (rows from top to bottom) for the observations (circles) and the inversion fit (solid curves). From left to right, pixels selected at different positions in the FOV, indicated with circles in Fig. 3 with the same colour.

UNCONSTRAINED MESHFREE INVERSIONS

Unconstrained minimization casts the NLTE inversion as one large optimization over atomic (populations or radiation tensors) and MHD (T, ρ, v, B) variables without enforcing self-consistency at each step. A single cost function χ² plus physical consistency penalties at randomly sampled “pilot points” and other physics constraints (e.g, ∇·(ρv)=0 or ∇·B=0), weighted by λ and γ, is minimized via stochastic gradients, vastly cutting per-iteration cost and helping avoid local minima without full Λ-iterations. This idea can remind to the optimization of a neural network for data D, with parameters θ.

$$\mathcal{L}(D;\theta) = \chi^2(D;\theta) + \lambda\mathcal{L}_\Lambda(\theta) + \gamma\mathcal{L}_L(\theta)$$

3D meshfree inversion replaces per pixel grid parameters with global basis function expansions for both MHD fields (ψ) and atomic tensors (ξ), cutting parameter count from $O(N^3)$ to the number of basis coefficients $(M_\psi + M_\xi)$, usually much smaller. Its complexity drops from $O(N^3 N_\lambda N_\Omega)$ to $O((M_\psi + M_\xi)(N_\lambda N^3 + N_\Lambda N_\Omega N_\lambda N + N_L))$, making it orders of magnitude faster and more memory-efficient for high-resolution, low-variability data. New POLARIS code implements this via long-characteristic pilot-point regularization and even provides free forward synthesis when MHD coefficients are fixed.

INVERSION RESULTS

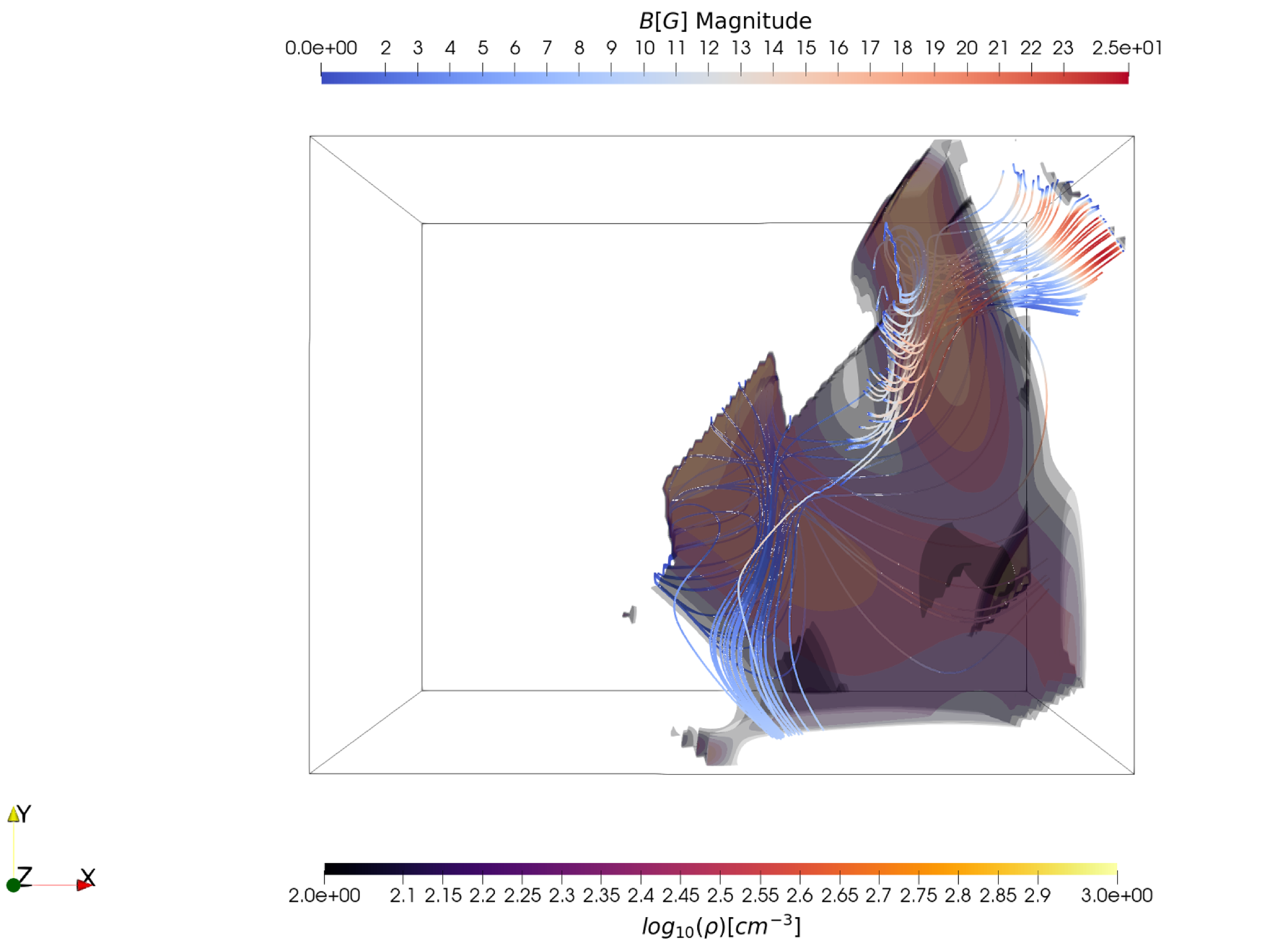

Figure 3. contour plot of the different density isosurfaces with the integrated magnetic field lines.

GREGOR DATA

We exploited the high spatial resolution and resolution power of the German GREGOR telescope at Tenerife Observatory, to observe off–limb filaments and prominences in the He I 10830 Å and Ca II 8542 Å lines. With a 2 million–CPU-hour allocation on the Gauss supercomputer, we will invert these new data using POLARIS to retrieve magnetic and thermodynamic parameters at unprecedented fidelity, leveraging the improved resolution and signal-to-noise to reduce inversion uncertainties.

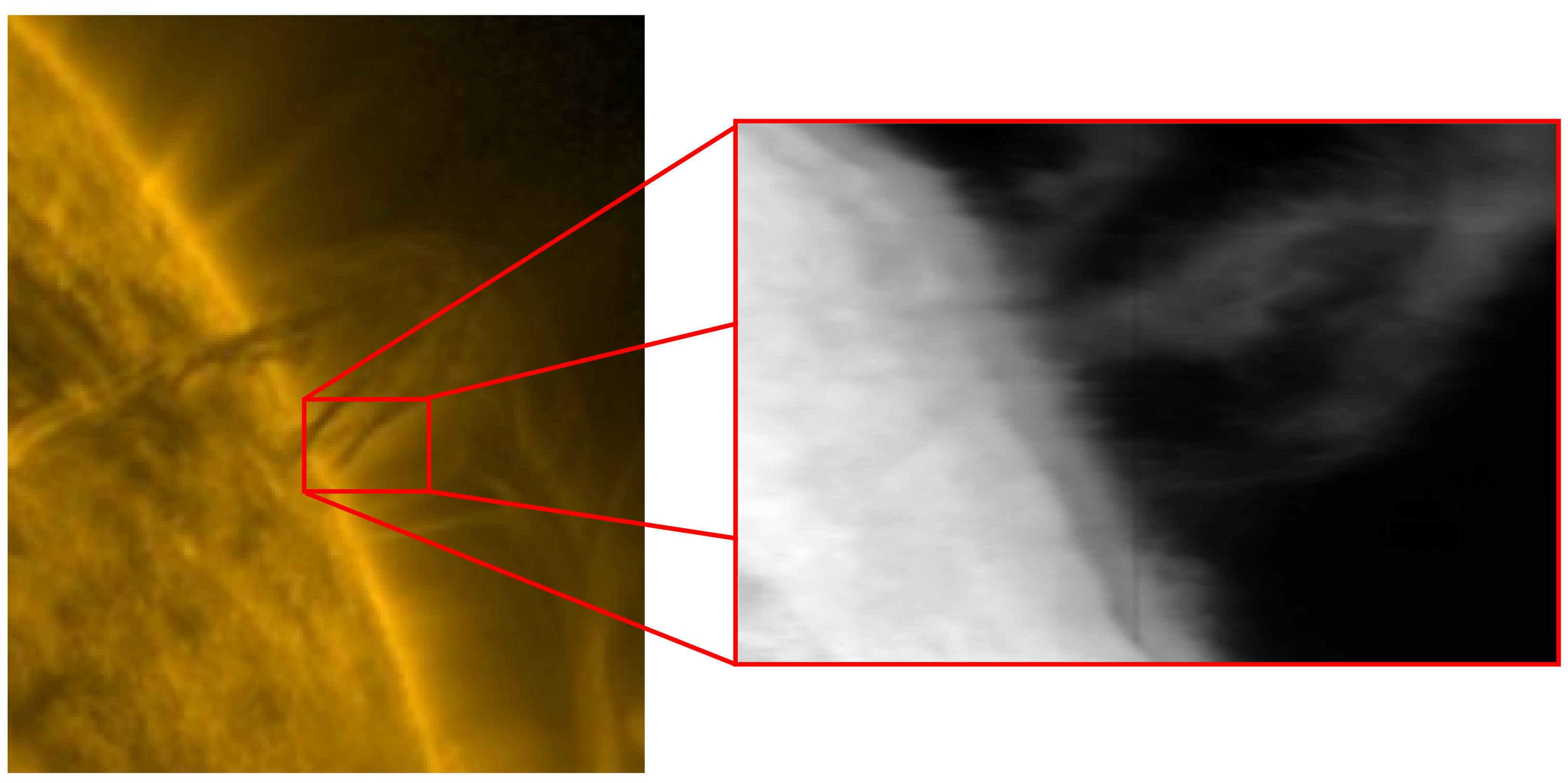

Figure 5. preliminary preview of the data taken with the GRIS instrument at the GREGOR telescope. Left image context image at 171 Å by the SDO satellite. Right side GREGOR telescope scan at the peak of the He I triplet.