CME plasma diagnostics using

Metis coronagraph

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and the Metis team

Abstract

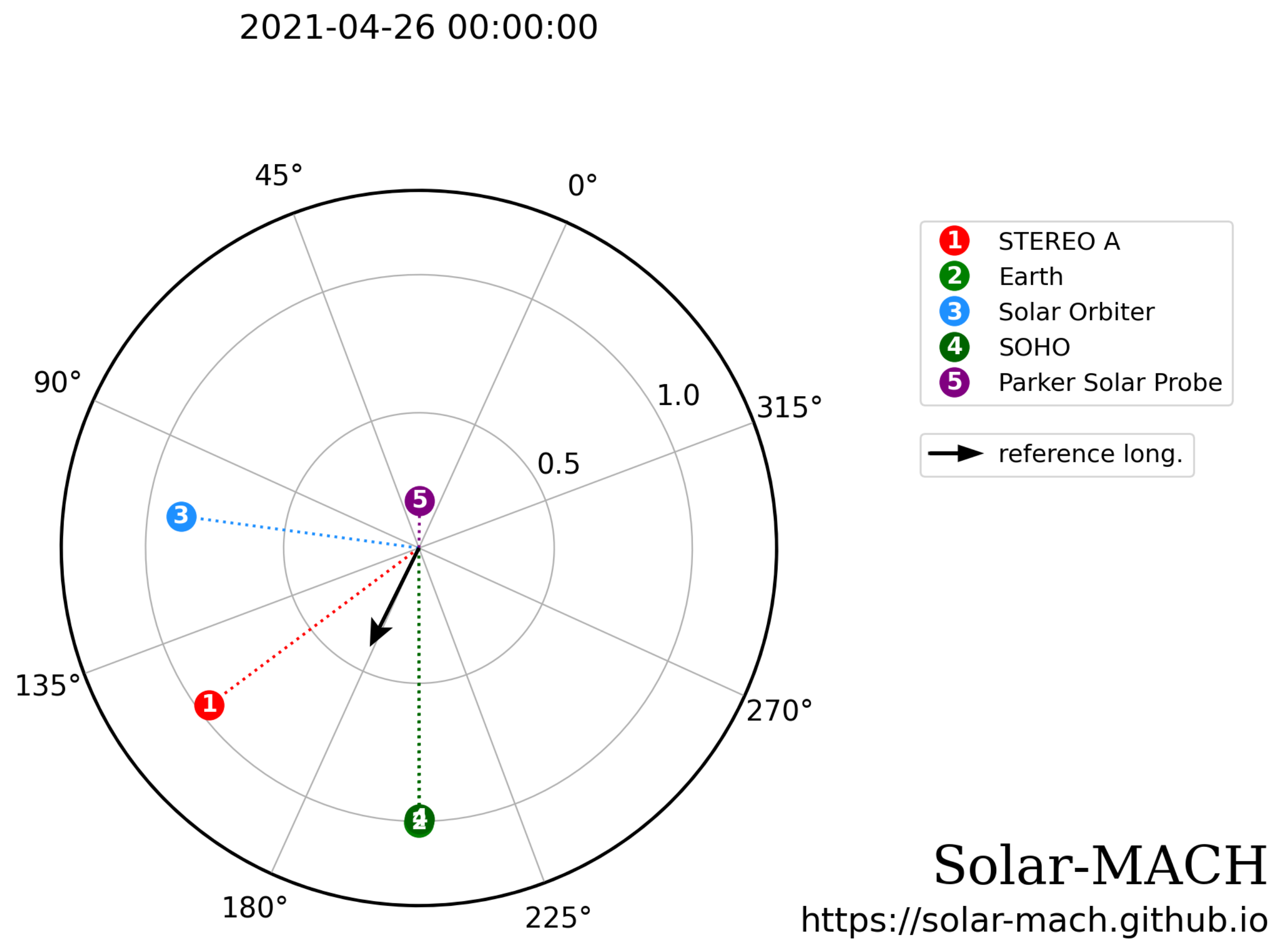
- determination of the physical parameters in the core of the CME, where a large eruptive prominence is detected at high altitude in the hydrogen Lα line and in visible light (VL), using the same diagnostic tool proposed for solar eclipses by combining hydrogen Hα and VL observations (Jejčič and Heinzel 2009)

- exploration of Metis data for one selected CME event occurred on April 25/26, 2021

- extension of the work by Heinzel et al. 2016, 2023, Russano et al. 2024

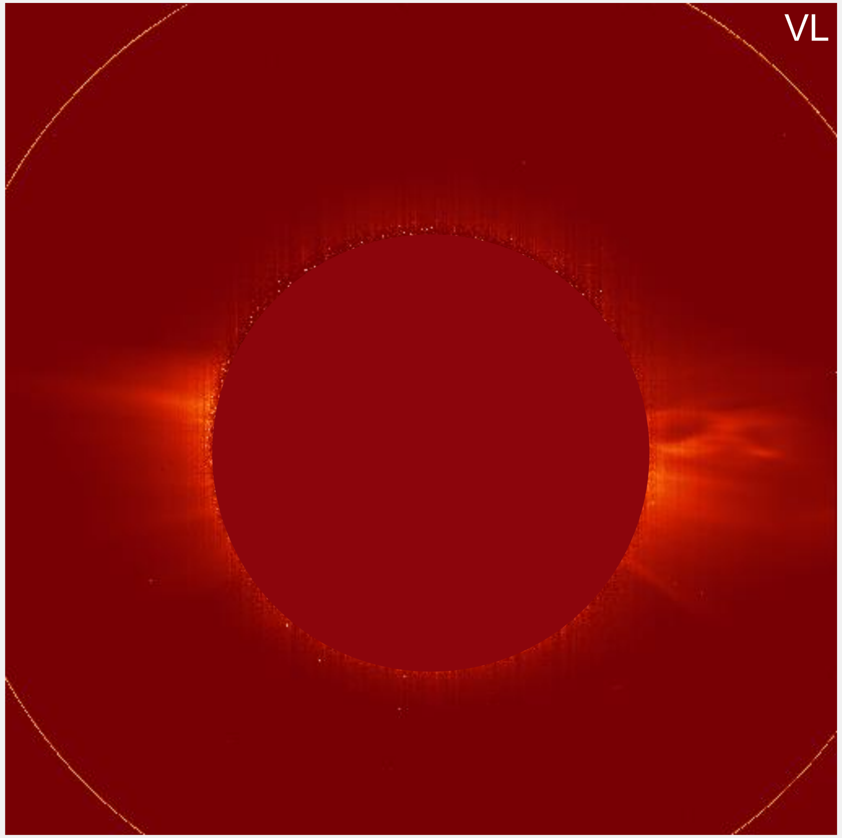
- future applications for Solar Orbiter Metis

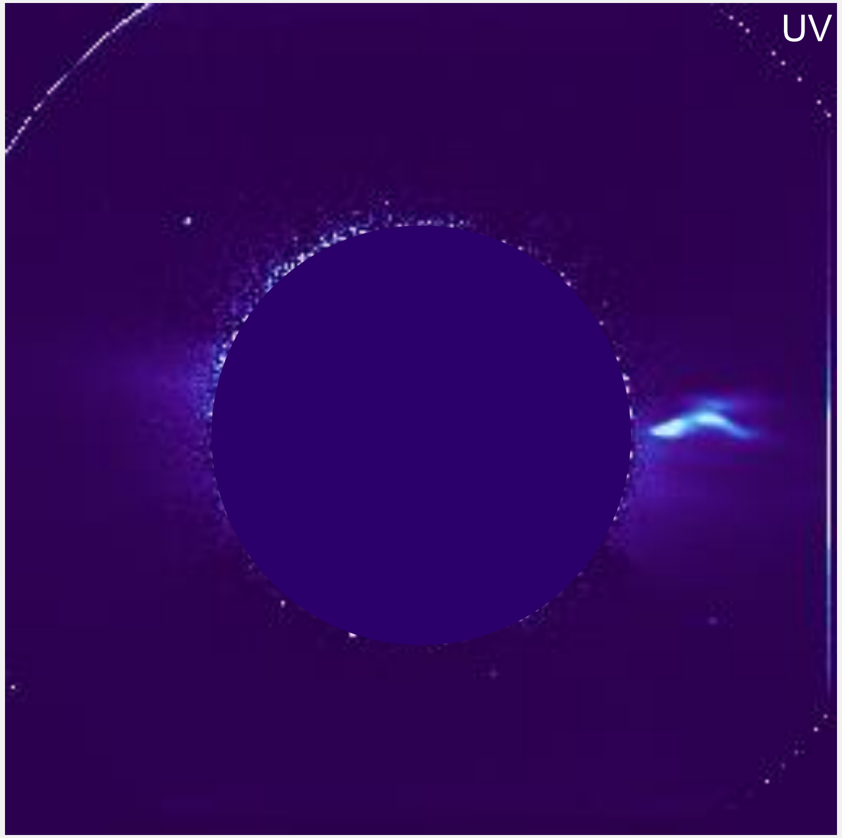
Position of the Solar Orbiter during Metis observations



25/26 April, 2021

Location and dynamics of the prominence





April 26, 2021 at 01:05 UT

$r = 5.3 – 9.5\ R_\odot$

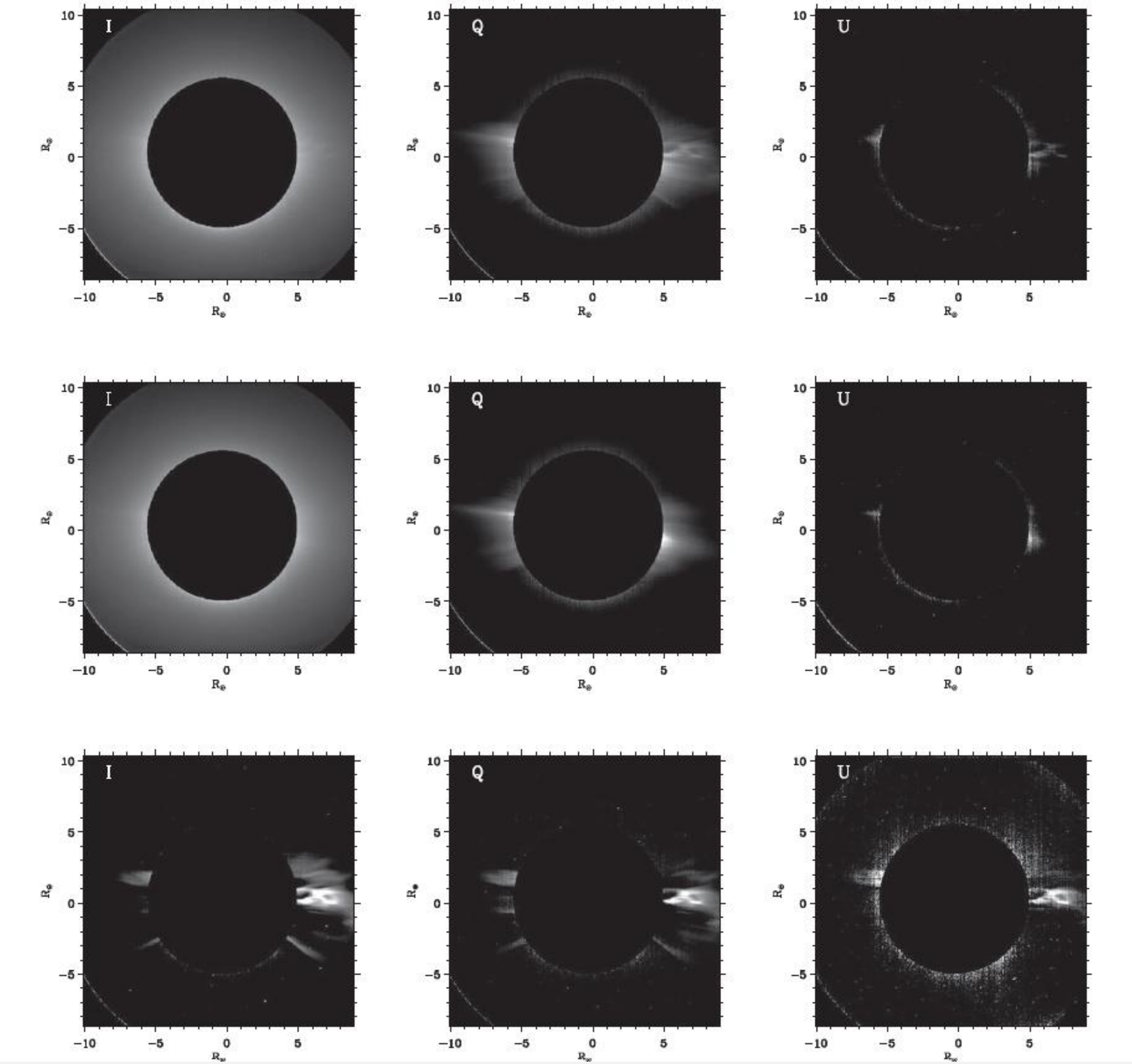
$v_{flow} = 177\ km\ s^{-1}$

$\alpha = 19.3^0$

Russano et al. 2024

Event date	Distance [au]	Annular FoV range [$R_\odot$]	Binning		DIT [s]		NDIT		T_{exp} [min]		Cadence [min]		Spatial scale [10^3 km px^{-1}]	
			VL	UV	VL	UV	VL	UV	VL	UV	VL	UV	VL	UV
25 Apr. 2021	0.87	5.3–11.2	4×4	4×4	30	60	15	15	7.5	15	30.5	16	29	59

Stokes images



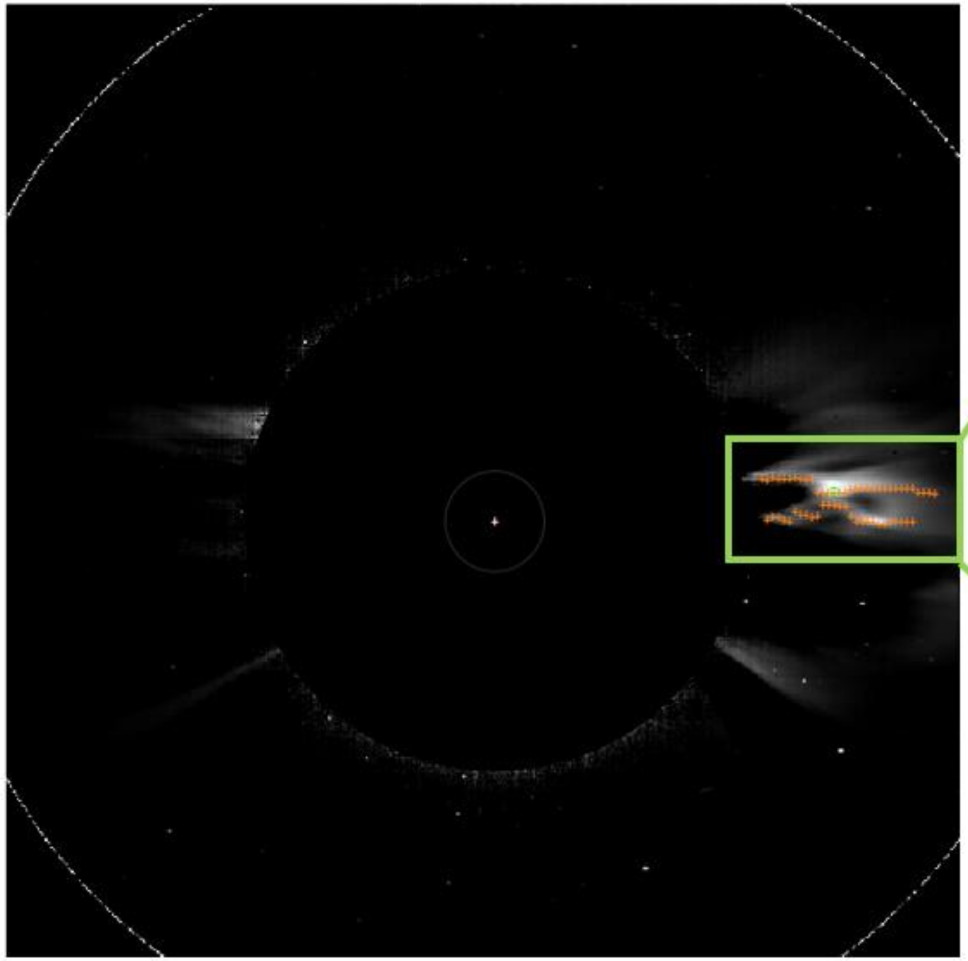
26/4/2021
1:05 UT

25/4/2021
15:05 UT

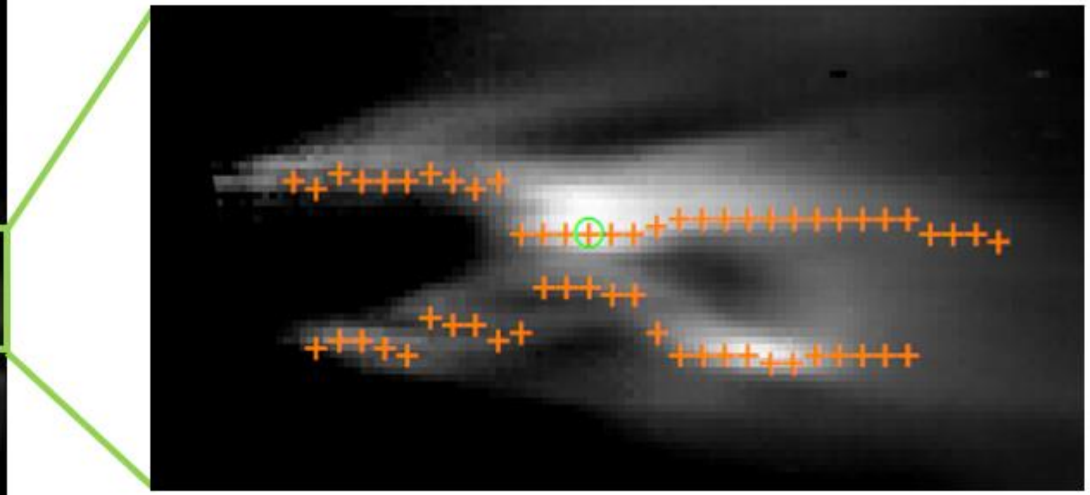
26/4/2021
1:05 UT

Heinzel et al. 2023

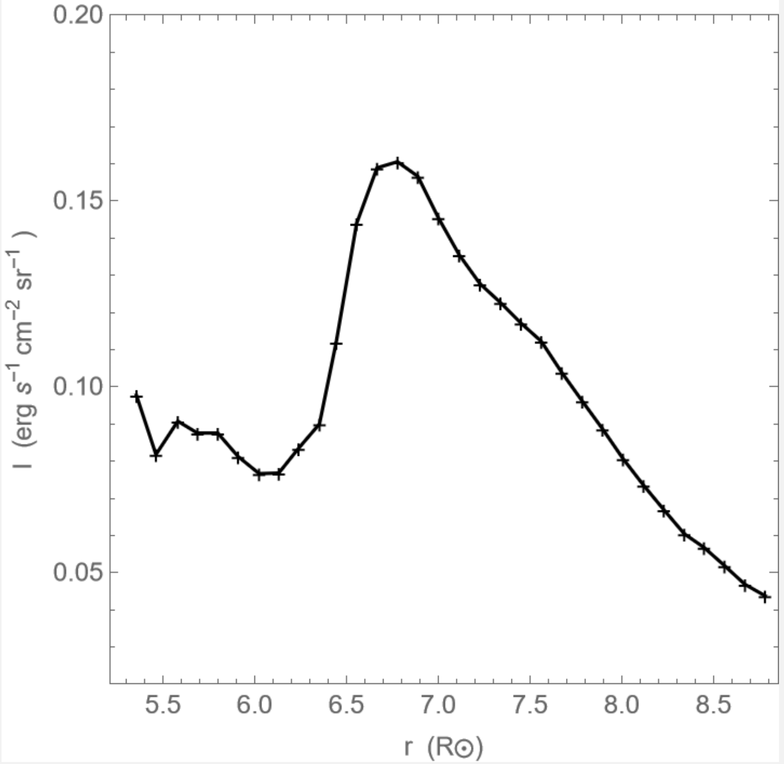
Selection of brightest pixels in Stokes I image

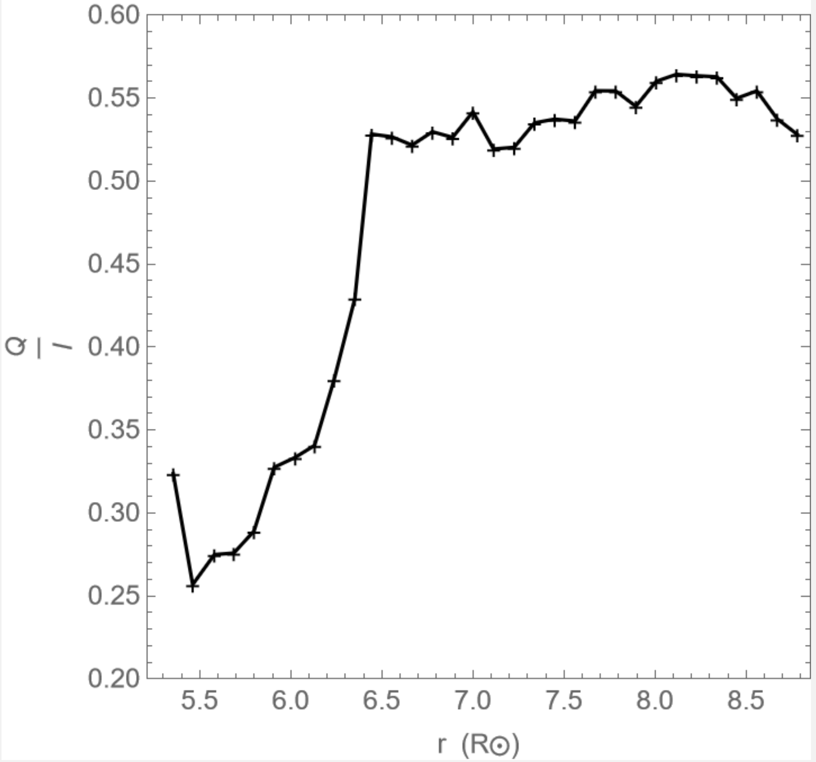


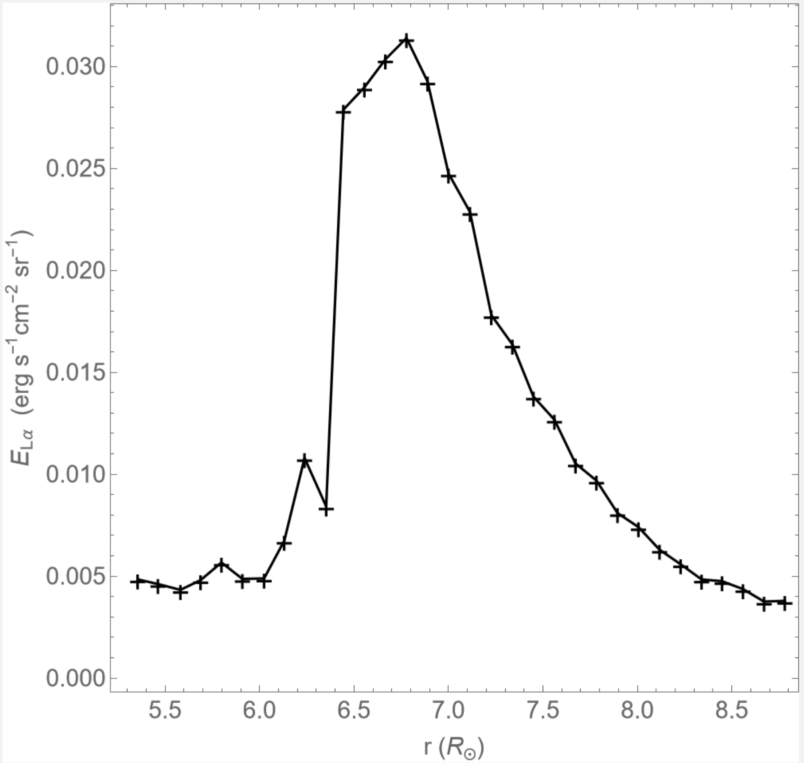
northern part of the prominence:
32 pixels



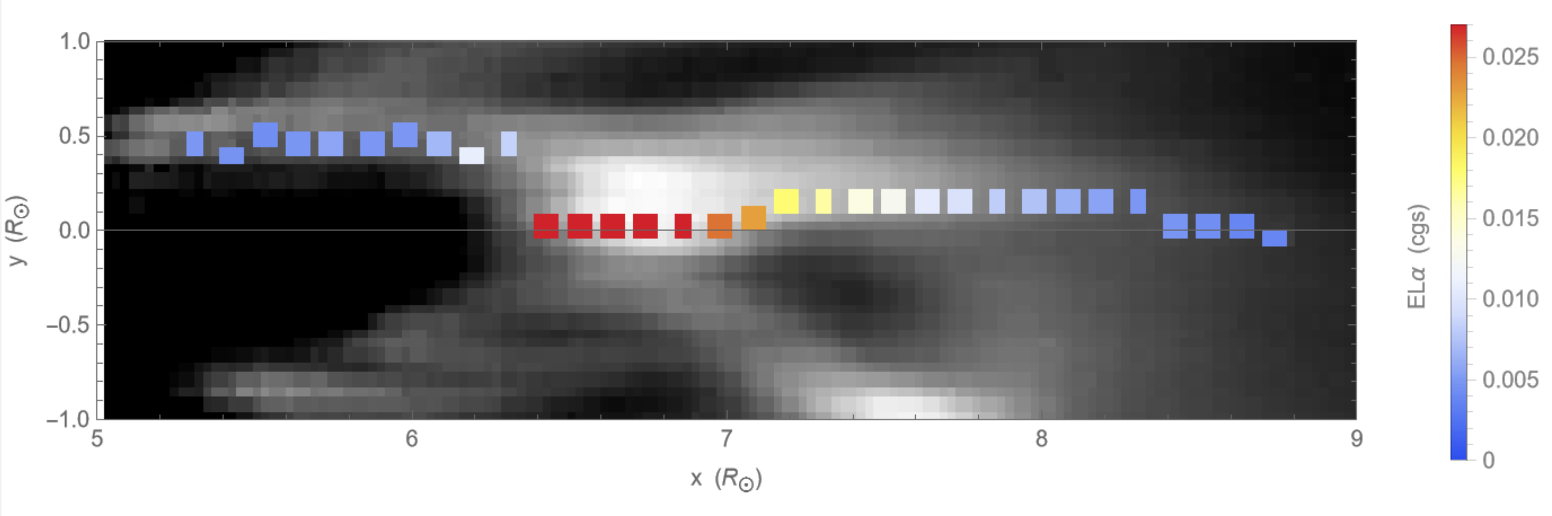
Metis observations

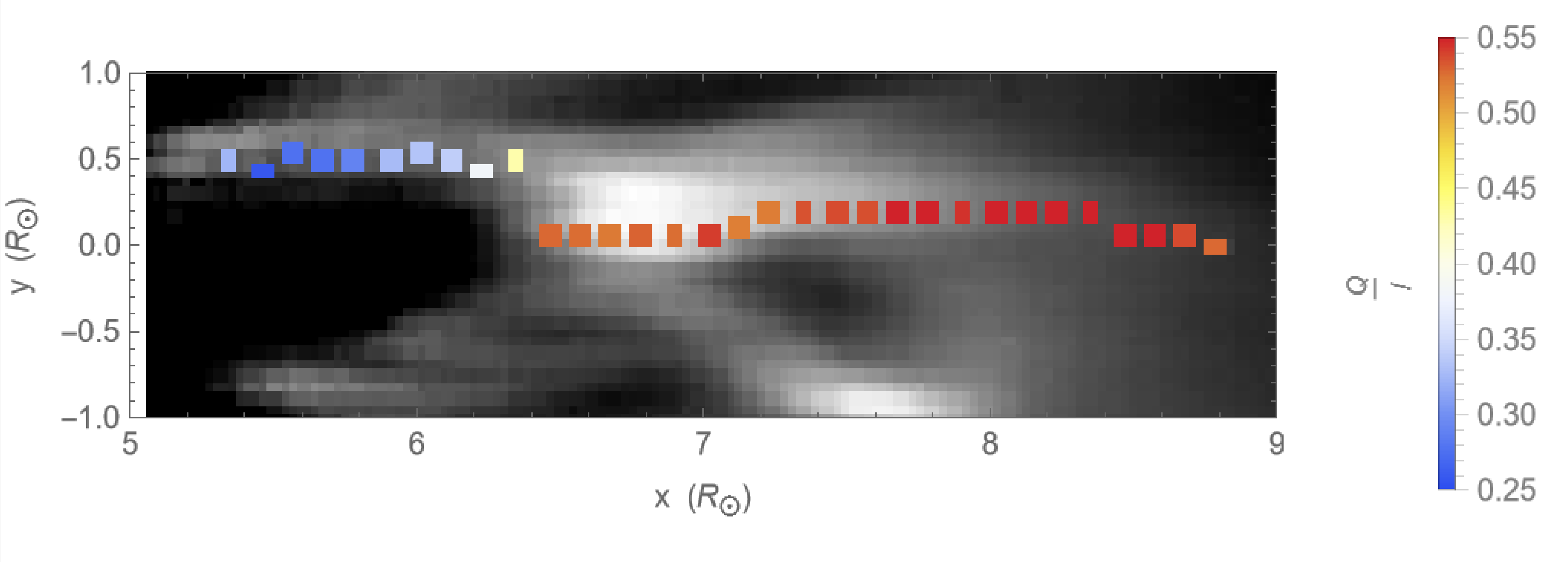






Metis observations





Column density

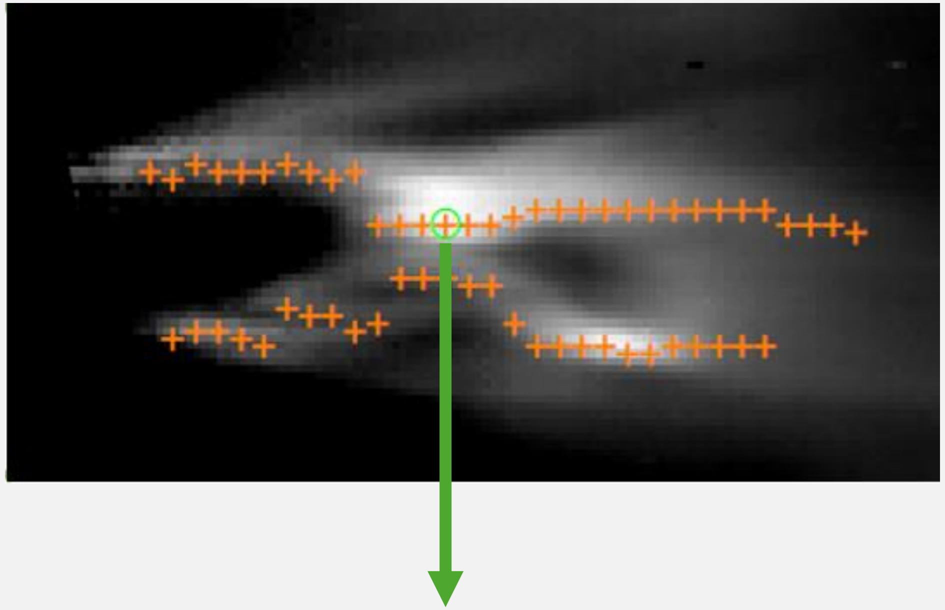
$$I = I_{\mathrm{VL}} + I_{\mathrm{D3}} = n_{\mathrm{e}} D_{\mathrm{eff}}\, \epsilon_{\mathrm{I}}^{\mathrm{VL}} + n_{\mathrm{He}} D_{\mathrm{eff}}\, \epsilon_{\mathrm{I}}^{\mathrm{D3}}$$

$$Q = Q_{\mathrm{VL}} + Q_{\mathrm{D3}} = n_{\mathrm{e}} D_{\mathrm{eff}}\, \epsilon_{\mathrm{Q}}^{\mathrm{VL}} + n_{\mathrm{He}} D_{\mathrm{eff}}\, \epsilon_{\mathrm{Q}}^{\mathrm{D3}}$$

$$\gamma = \frac{\epsilon_{\mathrm{Q}}^{\mathrm{VL}} - \frac{Q}{I}\,\epsilon_{\mathrm{I}}^{\mathrm{VL}}}{\frac{Q}{I}\,\epsilon_{\mathrm{I}}^{\mathrm{D3}} - \epsilon_{\mathrm{Q}}^{\mathrm{D3}}} = \frac{n_{\mathrm{He}}}{n_{\mathrm{e}}}$$

$$N_{\mathrm{e}} = \frac{I}{\epsilon_{\mathrm{I}}^{\mathrm{VL}} + \gamma\, \epsilon_{\mathrm{I}}^{\mathrm{D3}}}; \quad N_{\mathrm{e}} = n_{\mathrm{e}} D_{\mathrm{eff}}$$

VL: 580-640 nm; HeI D3 line: 587.7nm

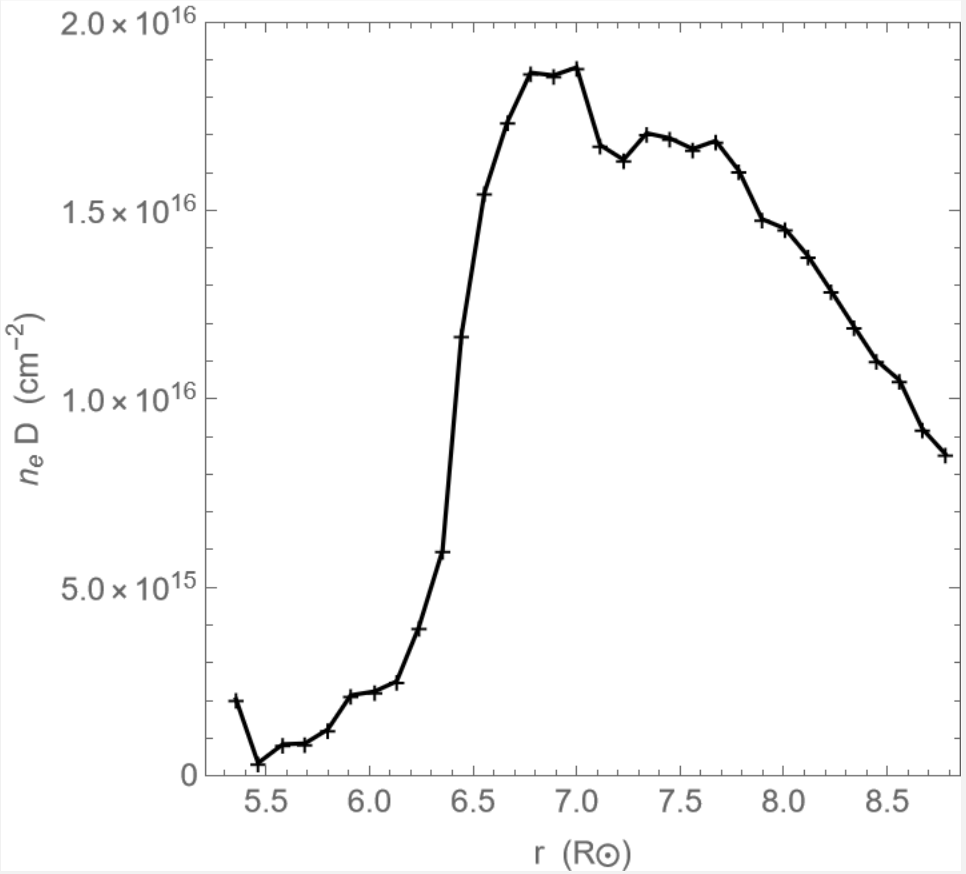


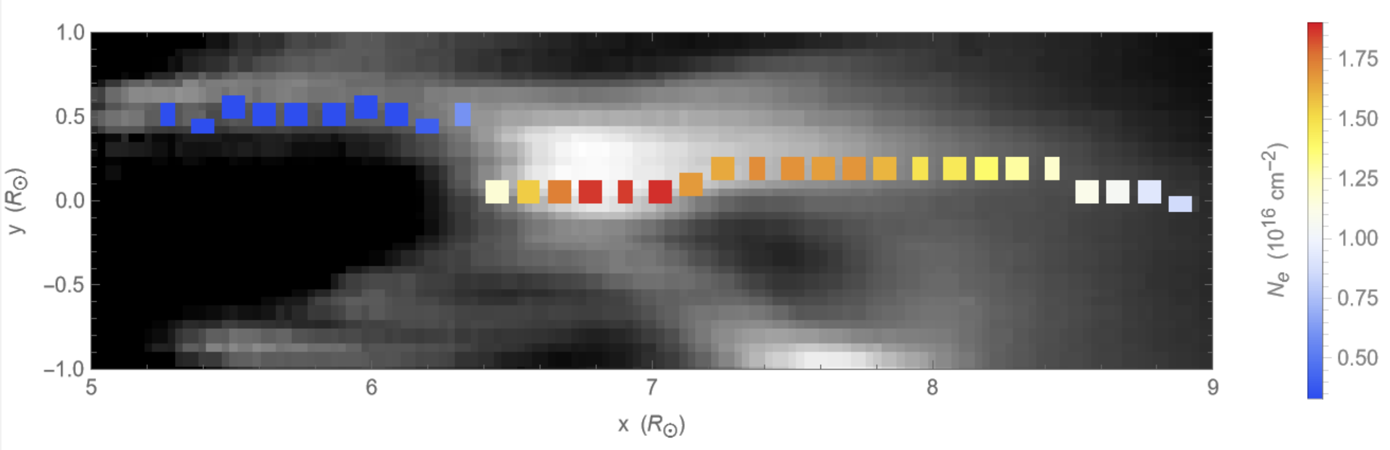
brightest pixel:

D3 contribution: 51 %

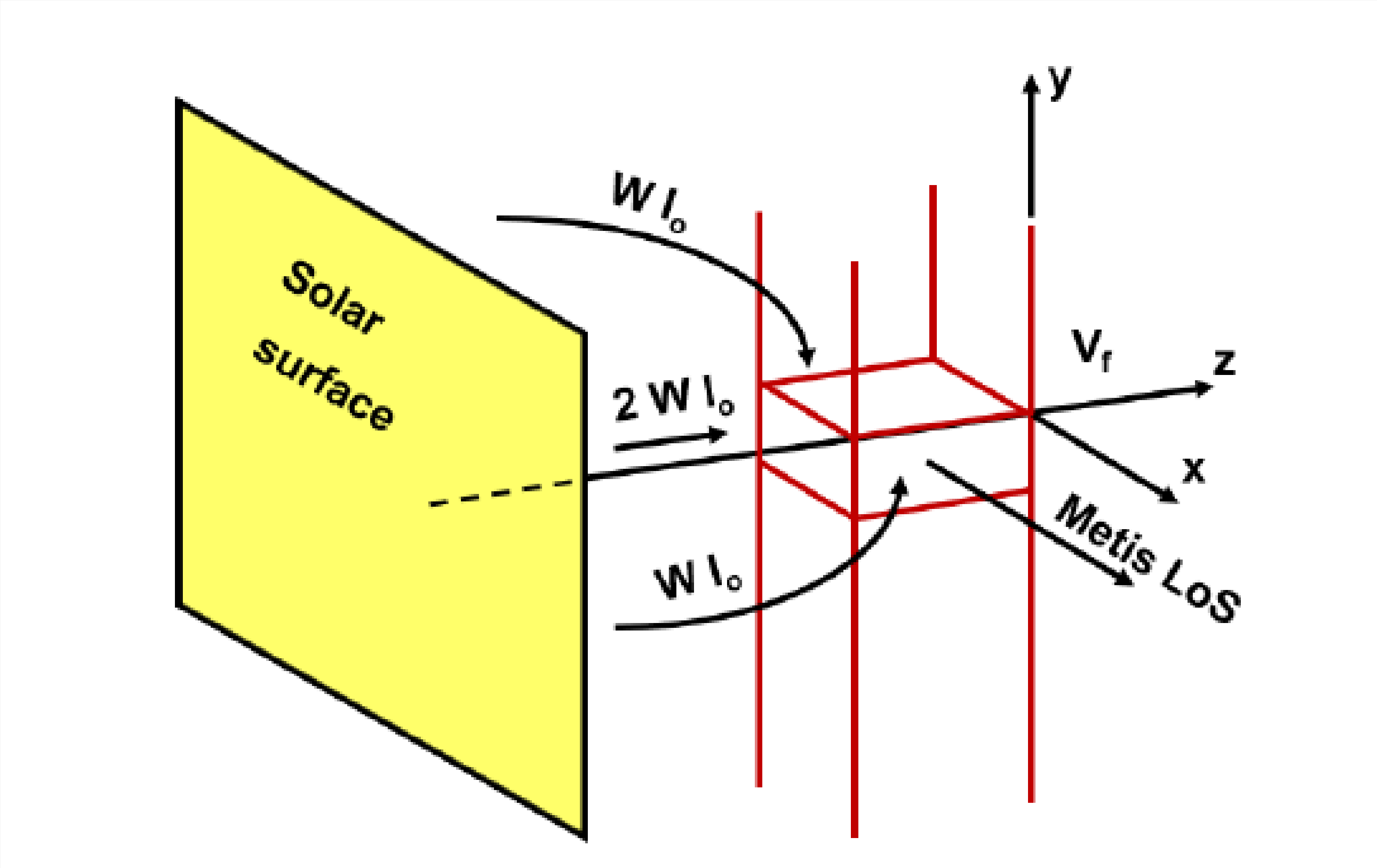
VL contribution: 49 %

Pure column density





2D NLTE prominence model – MALI code



T = const

p = const

Heinzel & Anzer 2001

MALI NLTE transfer code

- 2D-slab geometry (extendable to 3D)
- prominence or a CME-core is approximated by a 2D isothermal-isobaric slab model (generalization to PCTR)
- radiative transfer and statistical-equilibrium equations for a 5-level + continuum hydrogen atom
- height-velocity dependend radiative boundary conditions (including photoionization by external radiation)
- fast numerical solution using the ALI techniques
- partial redistribution scattering in H Lyman lines
- **Doppler dimming effect in Lyman lines included**

NLTE code parameters

Input parameters:

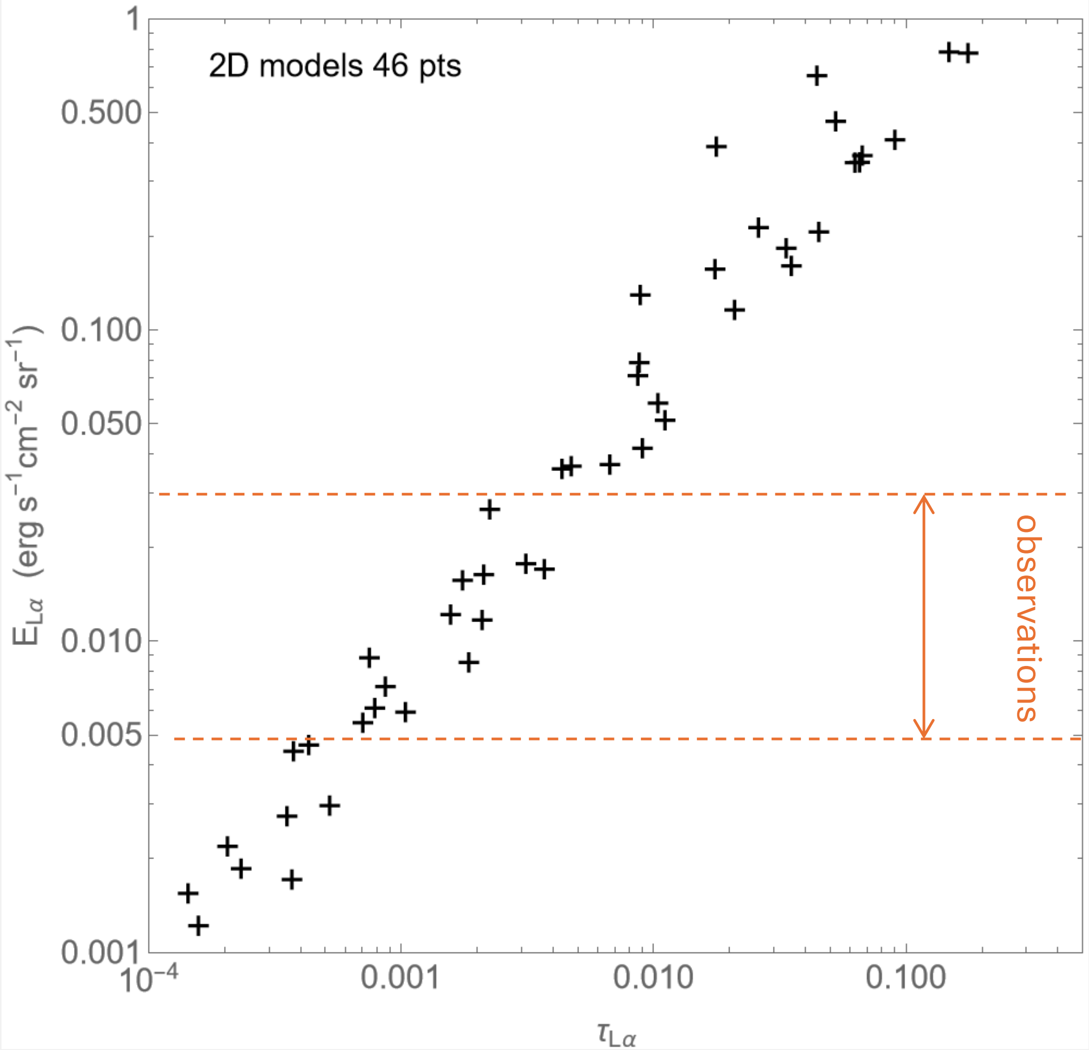
- T: 20, 30, 60, 100 kK
- p: $5 \cdot 10^{-6}$, 10^{-6}, $5 \cdot 10^{-5}$, 10^{-5}, $5 \cdot 10^{-4}$, 10^{-4}, 10^{-3} dyn cm^{-2}
- D_{eff}: 1000, 5000, 10 000, 30 000 km
- v_{f} : 177 km s^{-1}
- H: 6.7 R_{S}
- v_{t} : 10 km s^{-1}

Σ 100

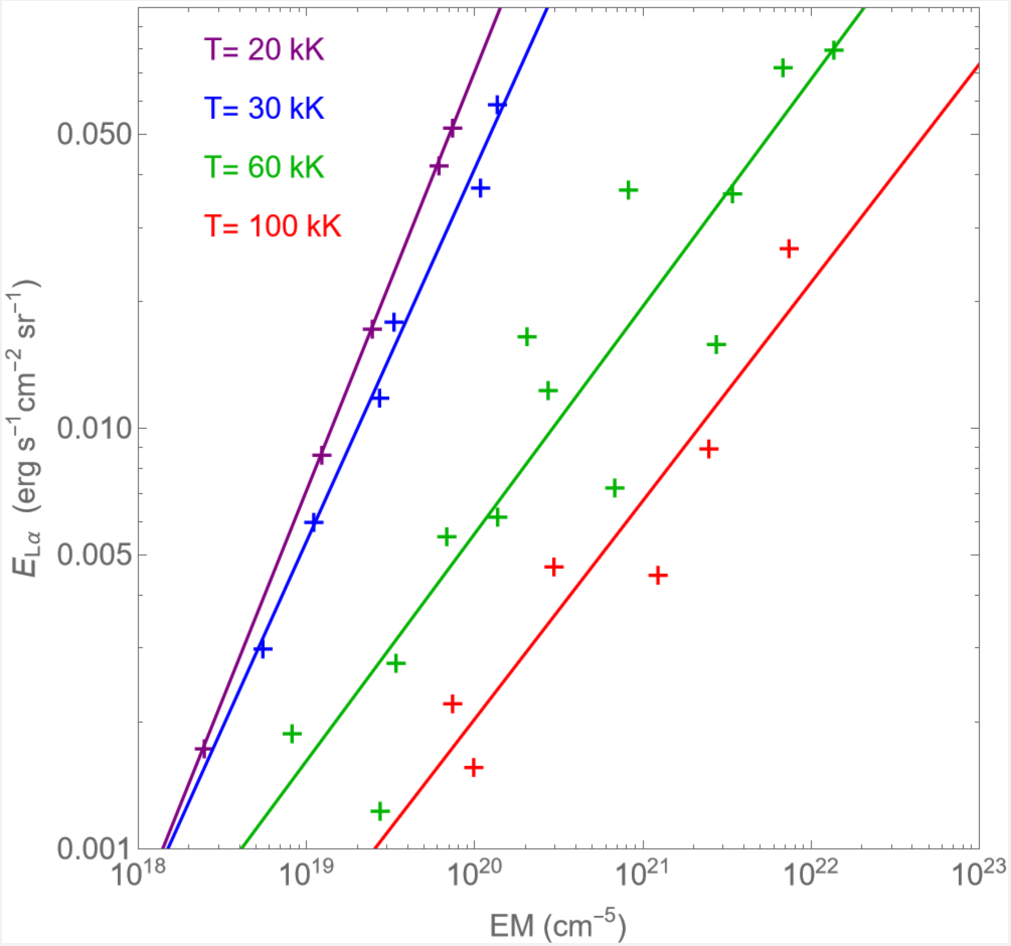
Output parameters:

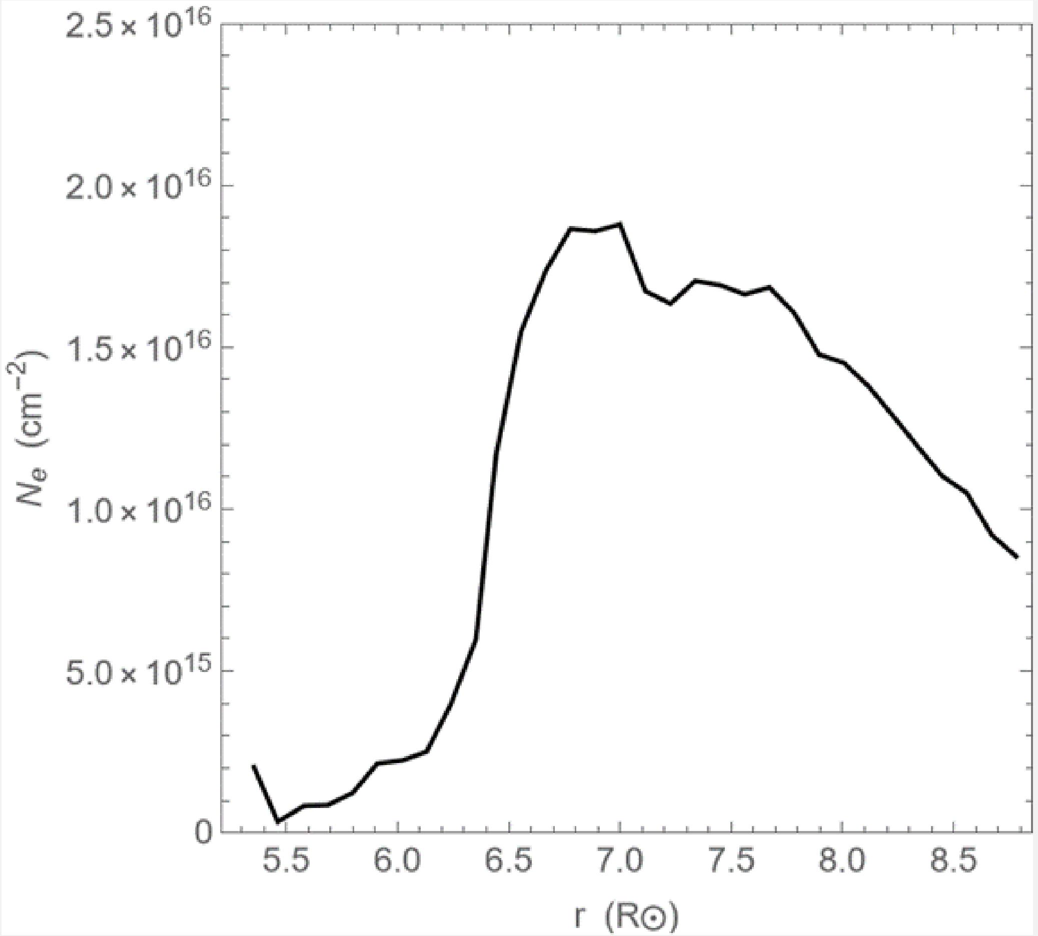
- $E_{\mathrm{L}\alpha}$, $\tau_{\mathrm{L}\alpha}$
- n_{e}, n_1, n_2
- radiative and collisional rates
- line profiles of $L\alpha$ line
- E_{VL}

Lα intensities



Graphical method





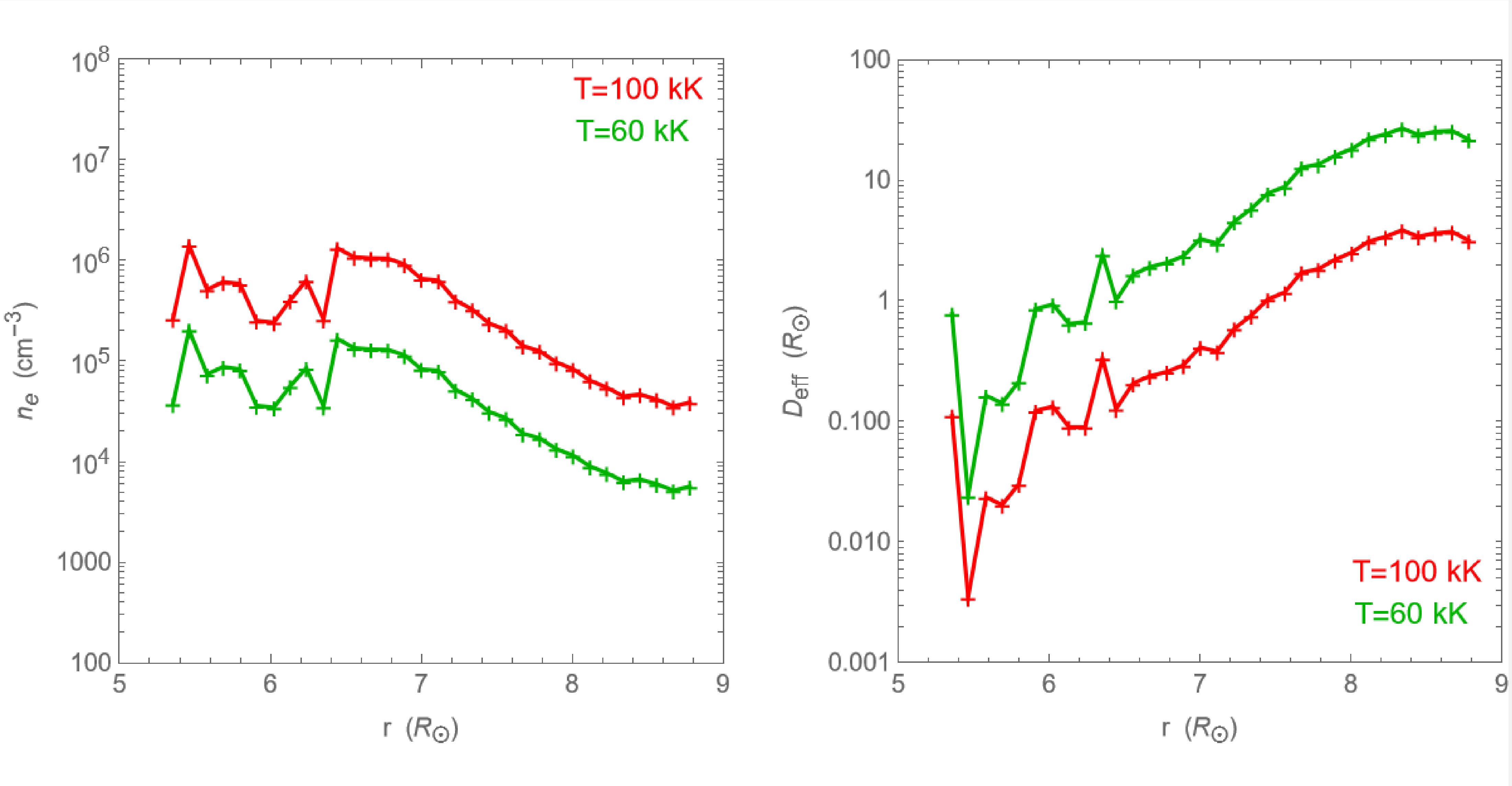
$$EM = n_e^2\, D_{\mathrm{eff}}$$

$$n_e = \frac{EM}{N_e}$$

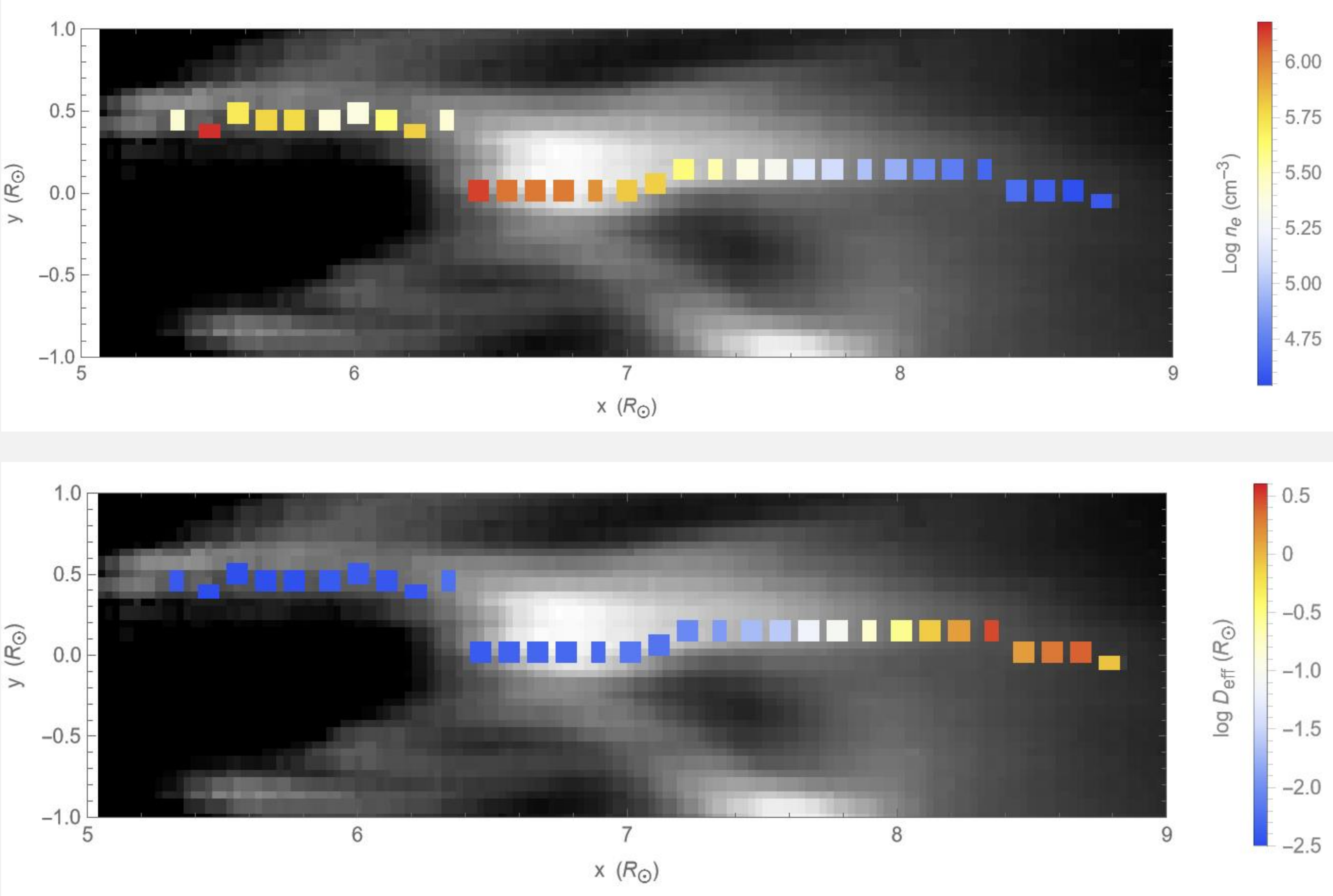
$$D_{\mathrm{eff}} = \frac{N_e}{n_e}$$

Jejčič & Heinzel 2009

Results



2D maps at 100 kK



Comparison of the temperature for the brightest pixel

- Susino & Bemporad (2016)

collisional ionization equilibrium + simultaneously observed VL and Lα data $\rightarrow$ temperature

- Input parameters:

i= 19.3^0	D_{eff}= 178000 km	d= 7.7 $R_\odot$	V_f= 177 km/s
n_e= $1.04 \cdot 10^6$ cm^{-3}	E_{VL}= $1.0561 \cdot 10^{-10}$ /2 MSB	$E_{L\alpha}$= $1.987 \cdot 10^9$ phot/s/cm²/sr	

- Output parameter:

total brightness: T> 200 kK	HeI D3 contribution subtracted: T = 130 kK

Conclusions

- we have introduced a graphical method using the *EM* at a given temperature from observed $L\alpha$ intensity and N_e from *VL* in Stokes *I* and *Q* observations to obtain n_e and D_{eff}
- we demonstrate how n_e and D_{eff} depend on temperature of the structure. The higher the temperature the lower the D_{eff}
- in the future, we plan to use the theoretical relation *Q/I (T)* (Heinzel et al. 2020) at a height in which the prominence is located, assuming the typical gas pressure relevant for the observed $EL\alpha$, to estimate the temperature at a given pixel
- see talk of Petr Heinzel on Helium emission in eruptive prominences