Problems of the NLTE 1D modelling of the filament observed in Hα, Lα and the higher Lyman lines

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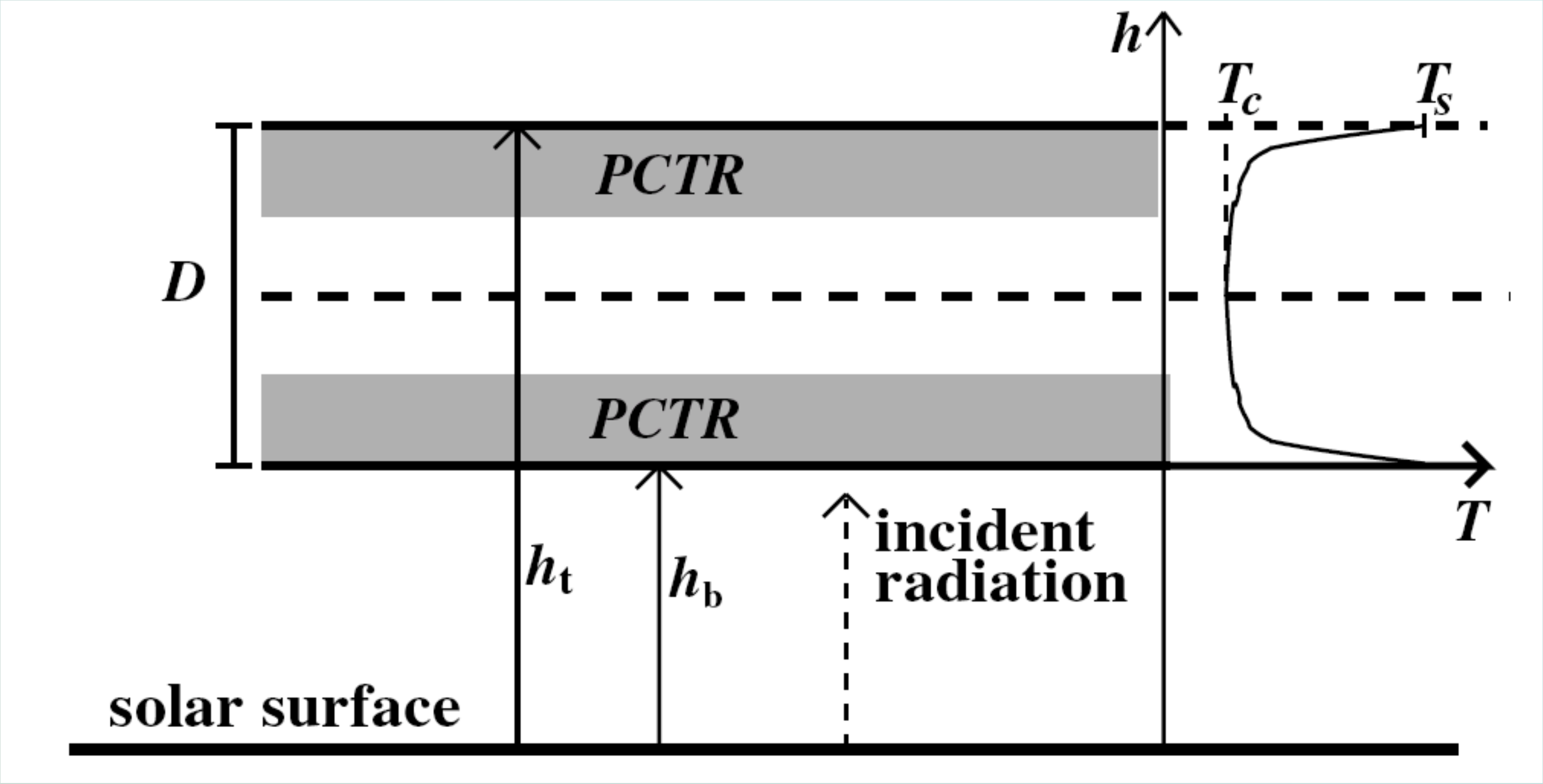
Non-LTE 1D modelling of filaments Hα

- 15 Oct 1999 – SoHO/CDS in EUV coronal, TR and chromospheric lines, SoHO/SUMER in Lβ, Lδ - L7, in Hα core by VTT/MSDP
- 5 May 2000 – SoHO/CDS in EUV coronal, TR and chromospheric lines, SoHO/SUMER in Lβ, Lε - L9 + Lyman continuum, Hα profiles from THEMIS/MSDP
- 27 May 2005 – SoHO/CDS in EUV coronal, TR and chromospheric lines, SoHO/SUMER in Lα - L9 + Lyman continuum, Hα profiles from HSFA2 spectrograph

Non-LTE 1D-slab model



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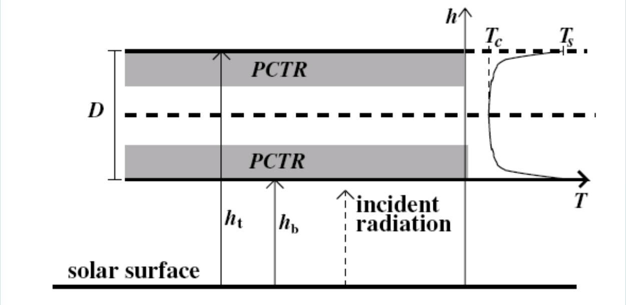


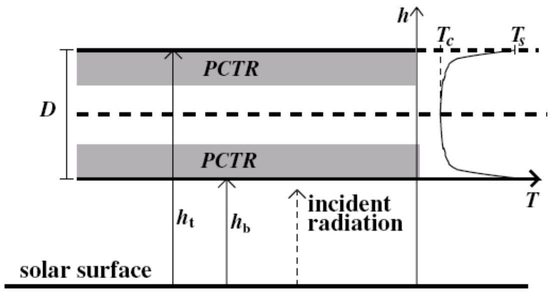
- the slab is irradiated only from the solar atmosphere beneath, i.e. no coronal radiation plays a role in our computations;
- there are two identical prominence-corona transition regions (PCTR), one on the top, another at the bottom of the slab;
- the temperature decreases from both surfaces to the slab interior symmetrically;
- the temperature gradient is steep in PCTRs, in the slab interior the temperature distribution is rather flat;
- the pressure is supposed to be constant in the whole slab (isobaric models);
- the micro-turbulent velocity is not larger than $10\ \mathrm{km\,s^{-1}}$ in the whole slab.

The temperature variation with height h across the slab is expressed by an empirical formula:

$$T(h) = T_c + (T_s - T_c)\left[1 - 4\frac{h}{D}\left(1 - \frac{h}{D}\right)\right]^{\gamma}, \qquad (2)$$

where T_s is the temperature at the surfaces of the slab, T_c the temperature in the slab interior, D the geometrical thickness and γ determines the temperature gradient. Larger γ means a steeper temperature rise and thinner PCTR.

Non-LTE 1D-slab model



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- h_b – height of the bottom border of the slab above the solar surface (in km);
- D – geometrical thickness of the slab (in km);
- T_s, T_c – temperatures at the border (at the edge between PCTR and corona) and in the interior of the slab;
- γ – temperature-gradient factor (see Eq. (2));
- p – gas pressure (uniform for our isobaric models);
- filling factor – a fraction of the geometrical thickness of the slab filled with cool EUV-filament plasma (not the whole volume of the filament is occupied by cool plasma). There can exist cavities with very low particle density or pores filled with hotter plasma. The presence of such inhomogeneities reduces the total geometrical thickness of the cool plasma responsible for absorption and this reduces the contribution of absorption to the intensity depression. Therefore D derived from the 3D structure is multiplied by a filling factor in the interval 0–1;
- v_t – turbulent velocity. We assume that it is not higher than 10 km s^{-1}. The hydrogen Lyman line profiles are almost insensitive to such low values of v_t. Therefore we considered an average value of 5 km s^{-1} for all models

Solving the RTE

- solution of 1D RTE using MALI method (Rybicky&Hummer 1991; Heinzel 1995; Paletou 1995)
- model of hydrogen atom with 12 levels + continuum
- partial-frequency redistribution (PRD) is assumed for the Lα and Lβ lines
- for the slab irradiation avg disc profiles of Warren et al. (1998) were used for Lβ and higher Lyman lines. For Lα OSO-8 profiles as in Heinzel (1995) are used.
- profiles of BG radiation for Lyman lines (radiation directly from beneath the filament) are reconstructed with method of Schwartz et al. (2006) using average disc profiles of Warren et al. (1998) for Lβ and higher Lyman lines and unpublished SUMER observations of Lα in QS area (Dammasch, 2006)

Explanation of the filling factor

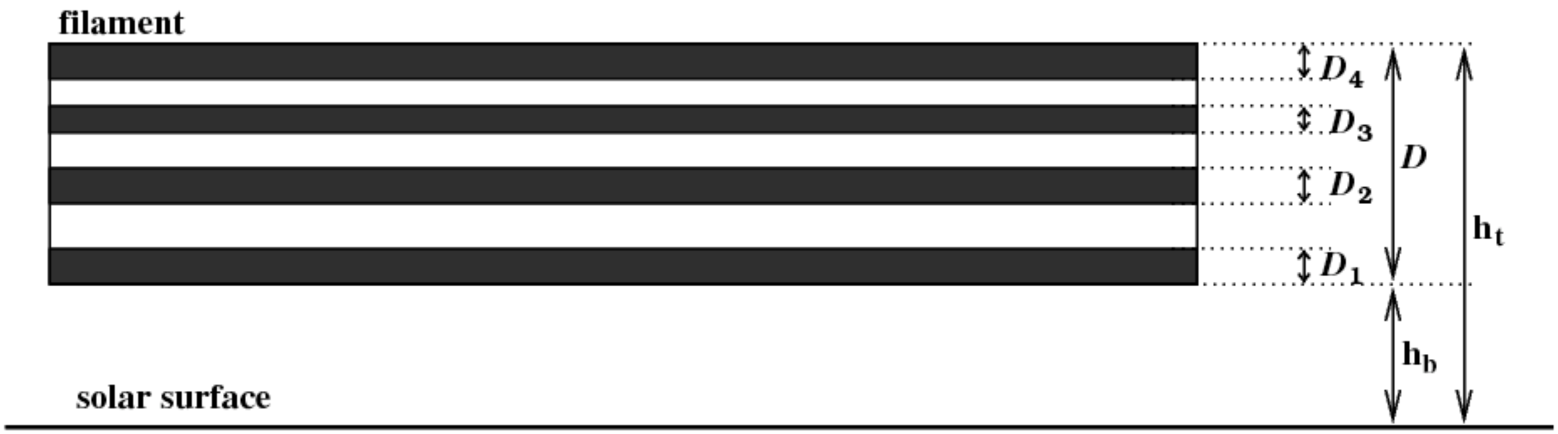
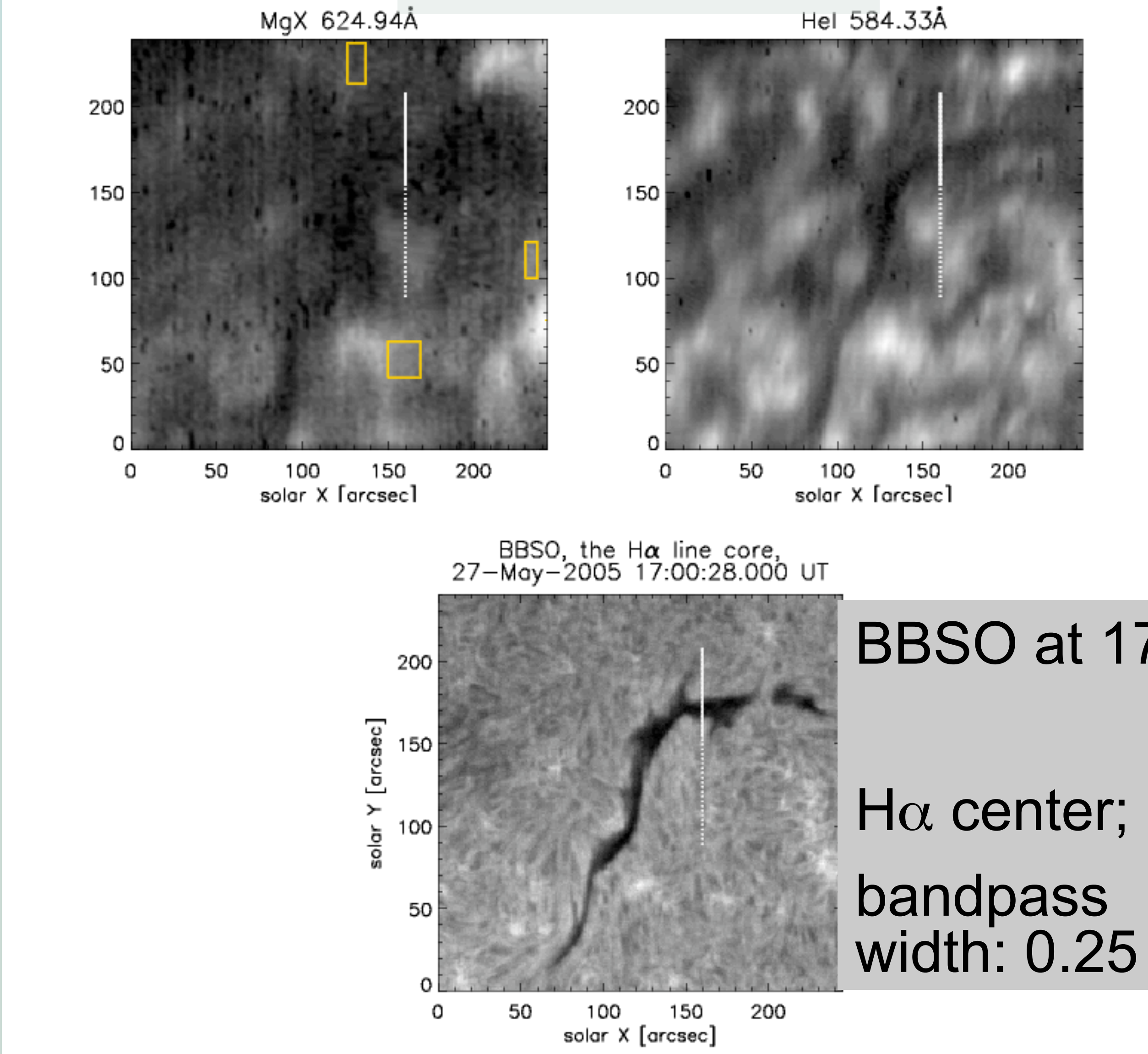


Figure 5. Scheme for understanding of the relation between total geometrical thickness D of the slab including cavities and the effective thickness $D_{\rm eff}$, where $D_{\rm eff}$ is sume of all layers filled with the cool prominence plasma: $D_{\rm eff} = D_1 + D_2 + D_3 + D_4$ for a case shown in the scheme. Then the filling factor f is a ratio $D_{\rm eff}/D$ expressing fraction of the slab filled with the prominence plasma. Quantities $h_{\rm b}$ and $h_{\rm t}$ are heigthts of the bottom and top of the slab, respectively. From fixed $h_{\rm t}$ in the case of a Hα filament, the height $h_{\rm b}$ is computed as $h_{\rm t} - D = h_{\rm t} - D_{\rm eff}/f$.

Filament on 27 May 2005

CDS at 17:14 UT



BBSO at 17:00

Hα center;

bandpass width: 0.25 Å

Filament from 27 May 2005

SUMER; 16:08 – 18:25 UT

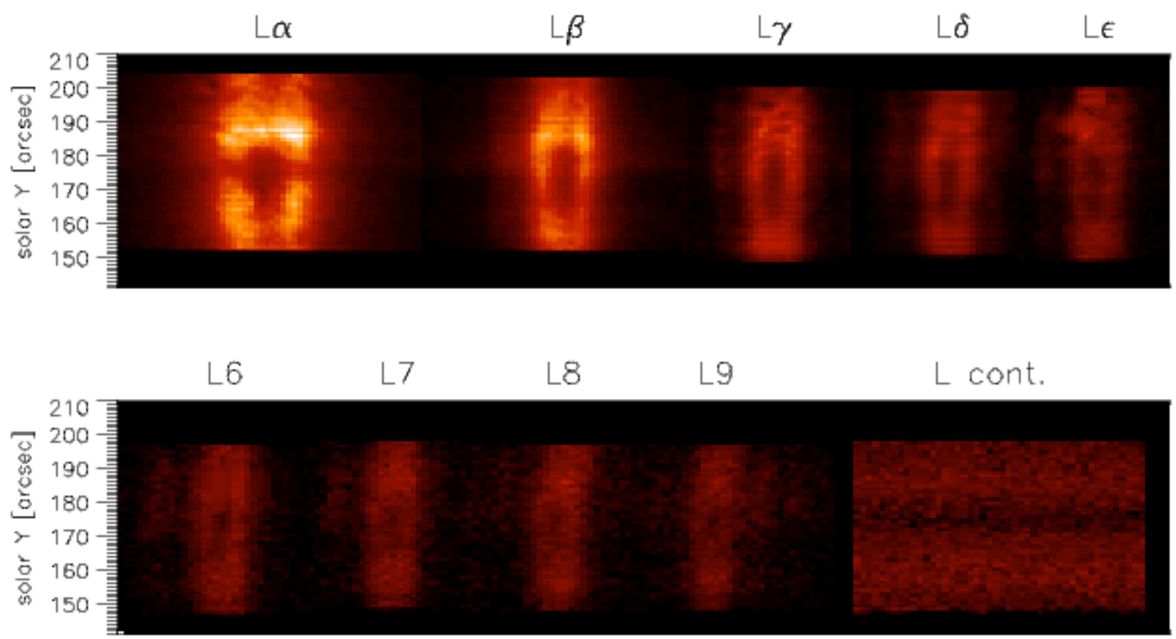
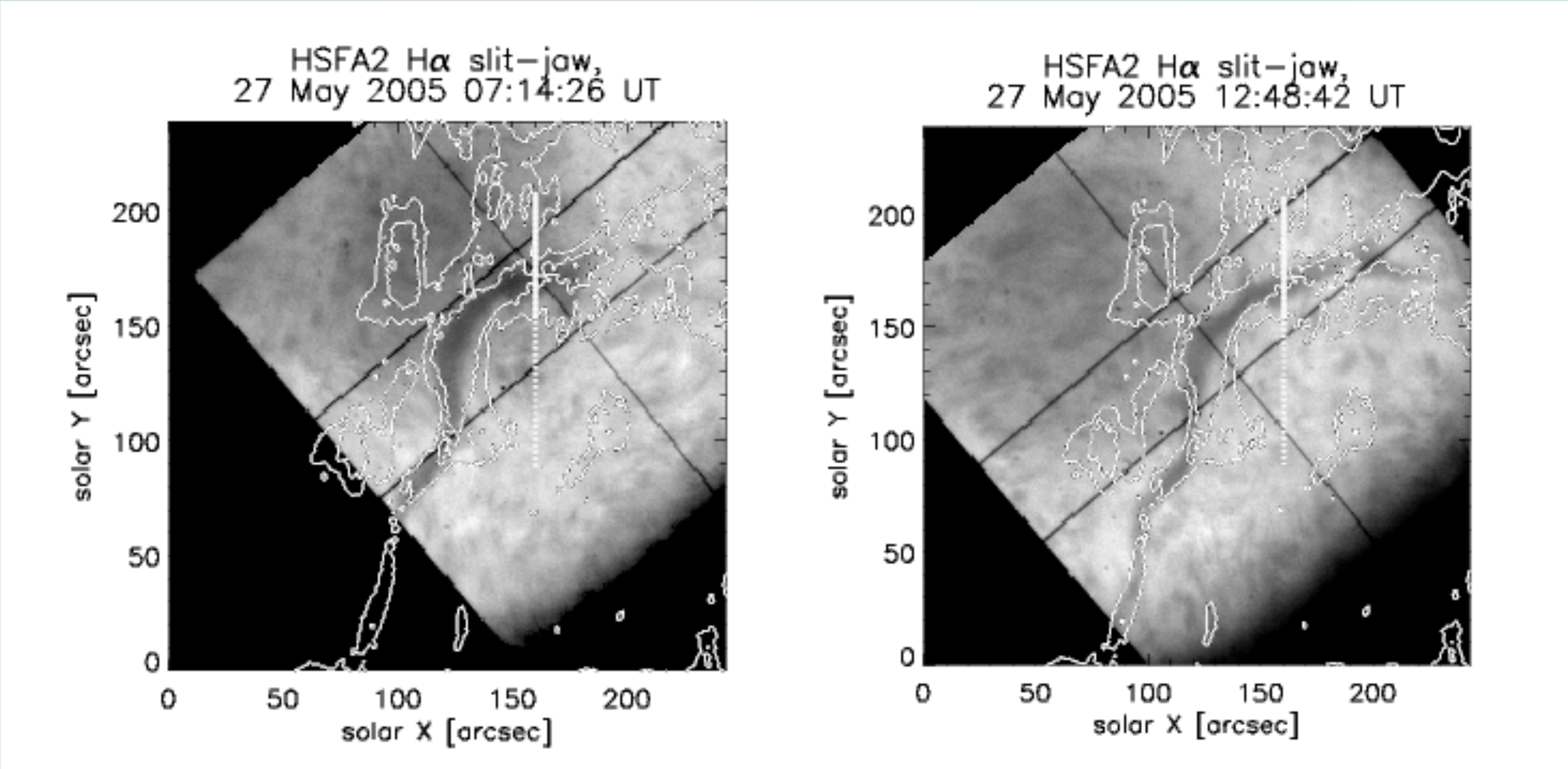


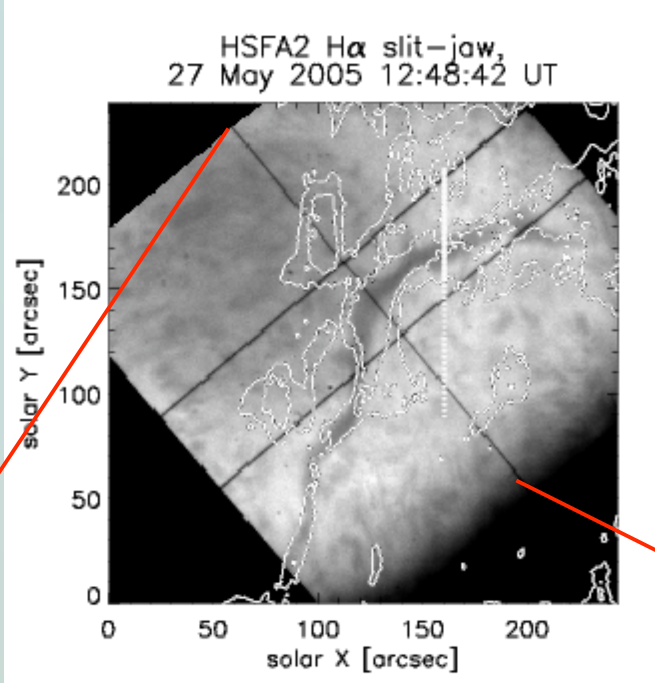
Figure 2. Spectra of hydrogen Lyman lines Lα – L9 and of the Lyman continuum between 905.5 and 907.5 Å observed by SUMER. Data from working part of the slit only are shown. Spectra are vertically reversed from the original spectrograph orientation – north is up. On ordinate the Y-position in the CDS-raster coordinate system (originally used in Fig. 1) is shown. This figure is composit of images of the Lyman line spectra while images were extracted from four SUMER observations made in four different times and spectral windows.

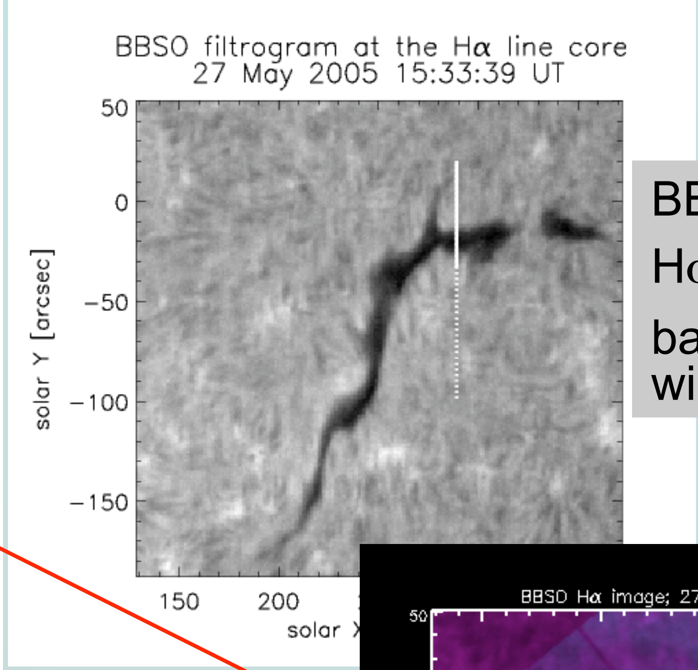
Filament from 27 May 2005

HSFA2; Hα slit-jaws



BBSO Hα filtrogram v HSFA2 Hα observations

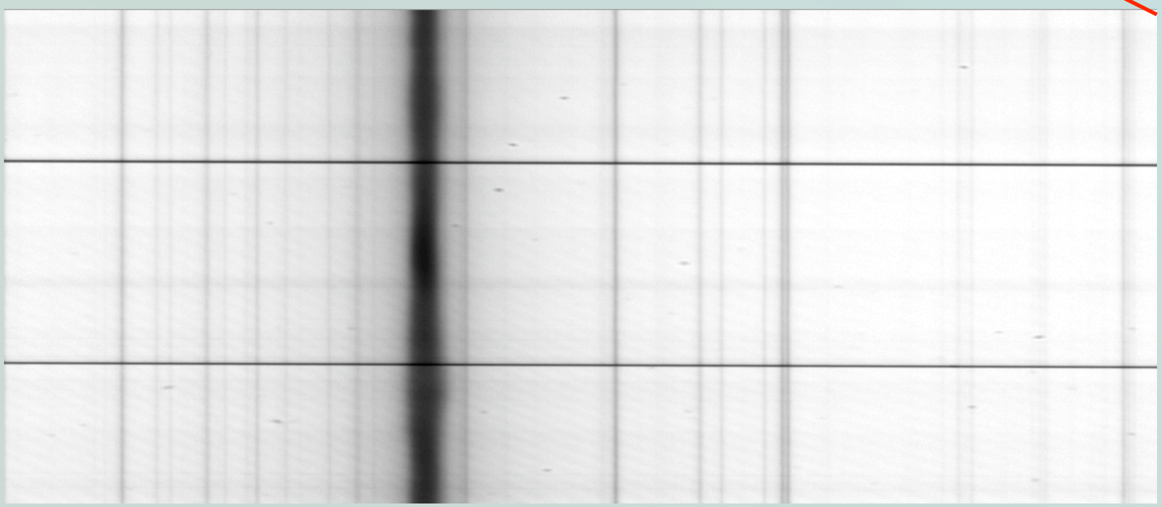


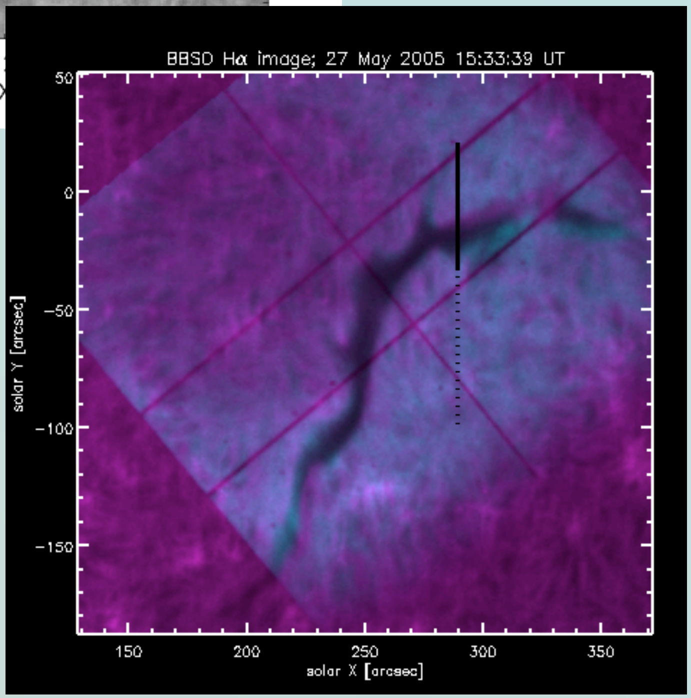


BBSO at 15:33

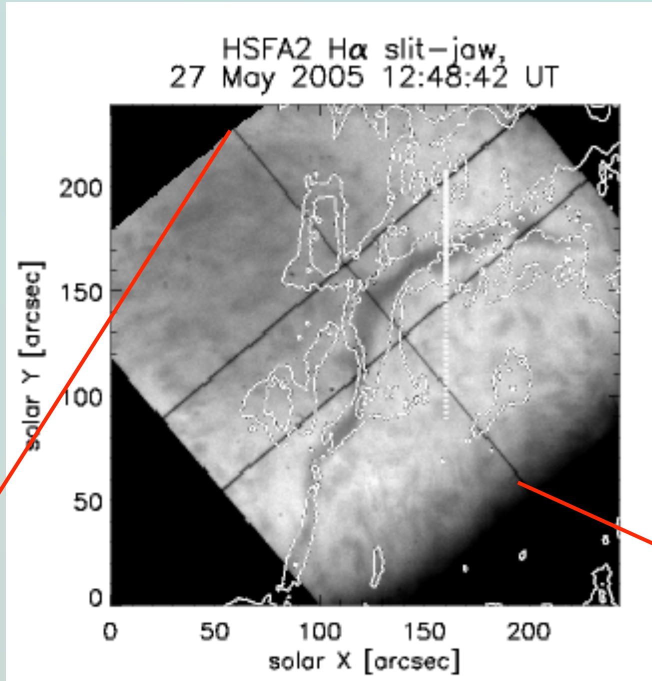
Hα center;

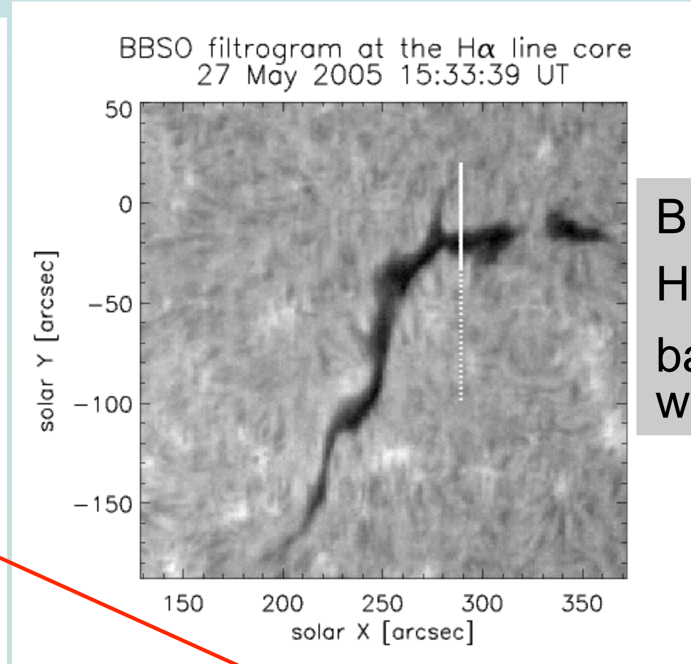
bandpass width: 0.25 Å





BBSO Hα filtrogram v HSFA2 Hα observations





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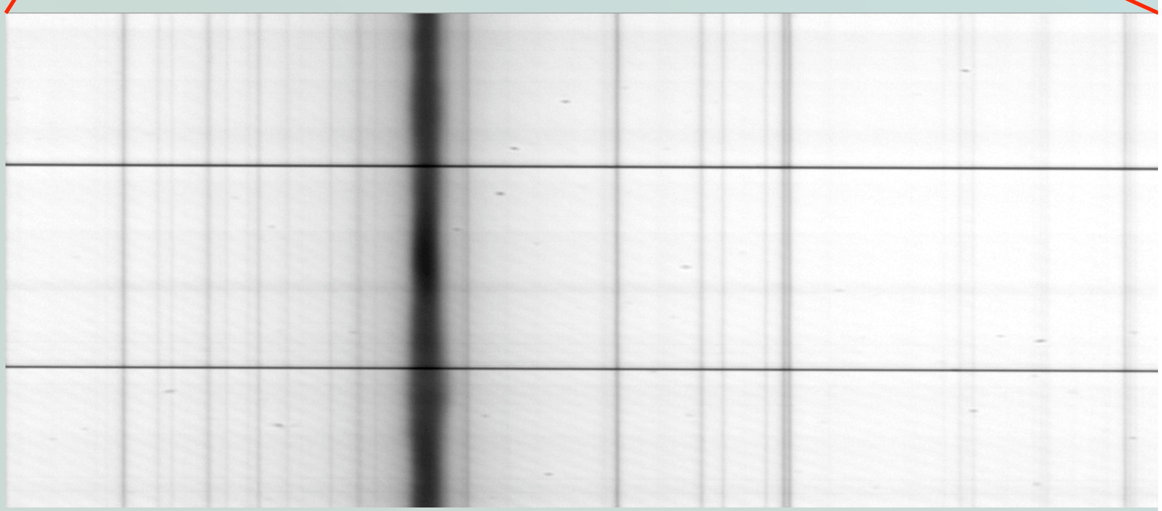

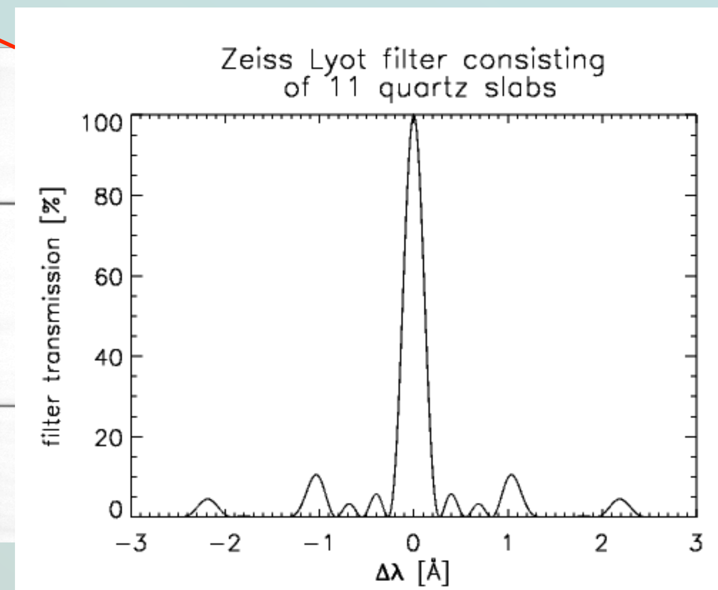

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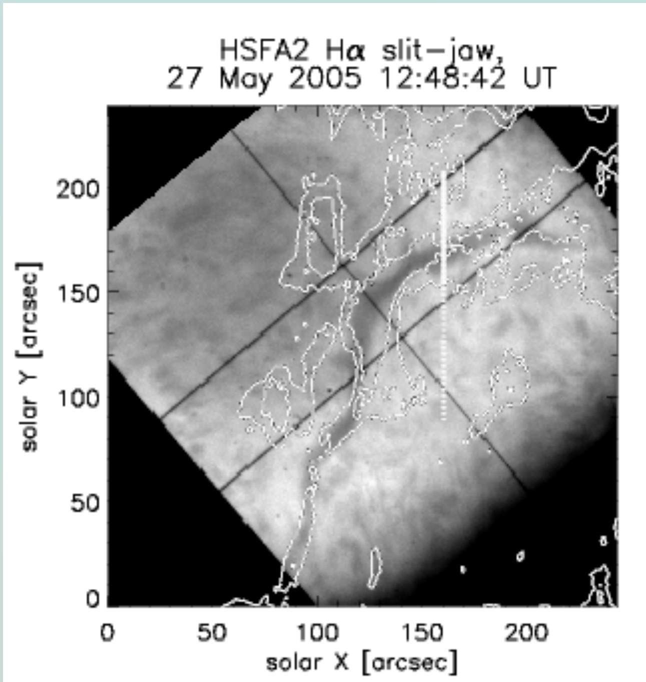
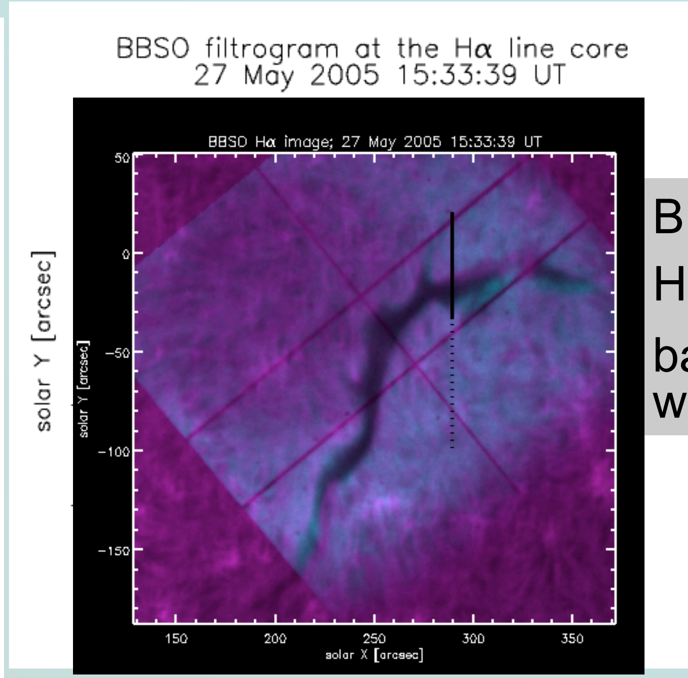
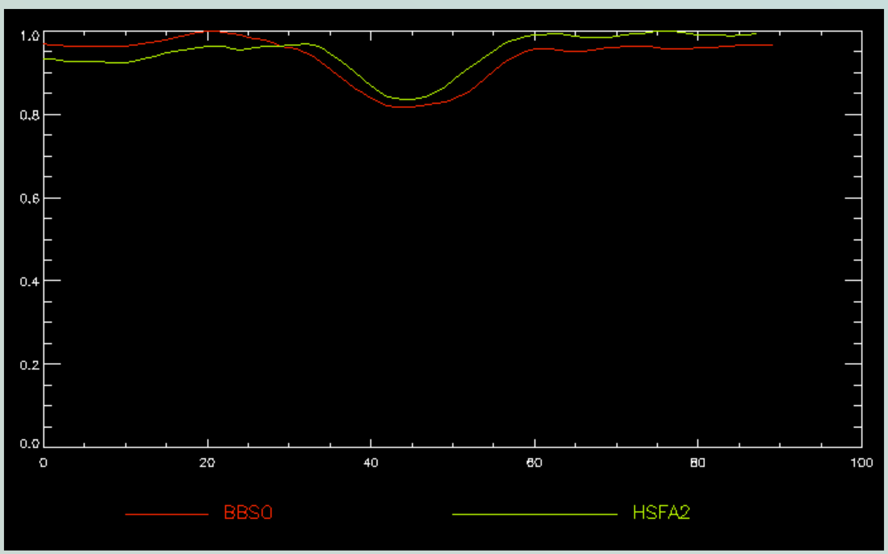
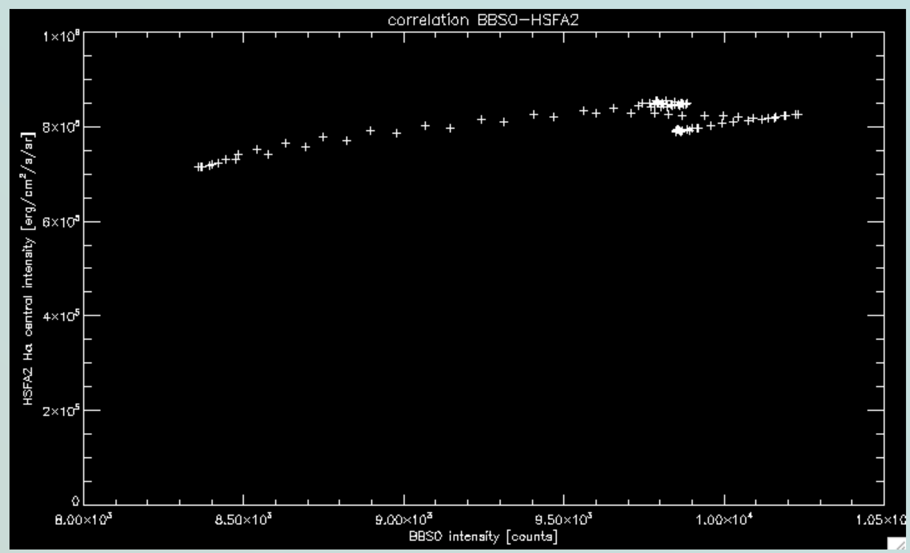


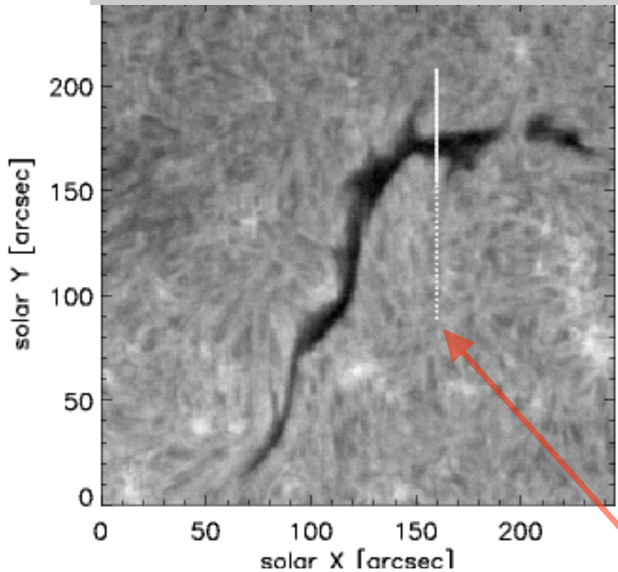


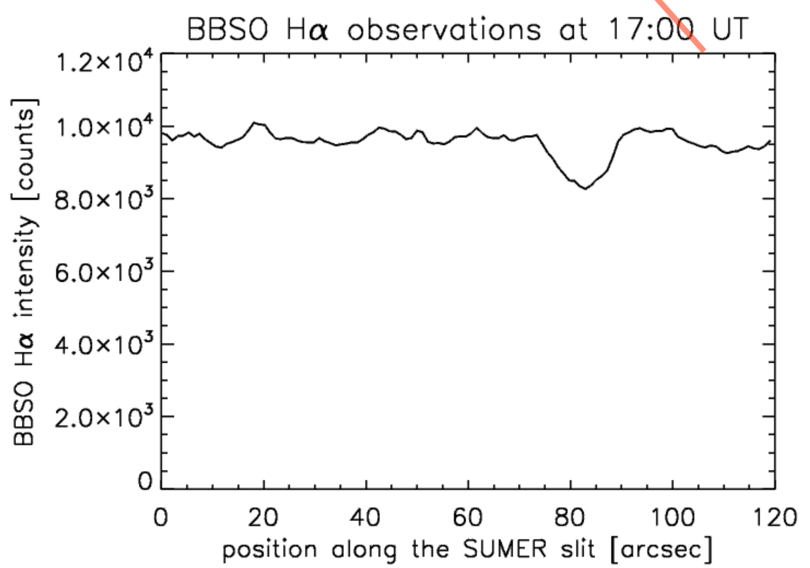
BBSO at 15:33
Hα center;
bandpass width: 0.25 Å



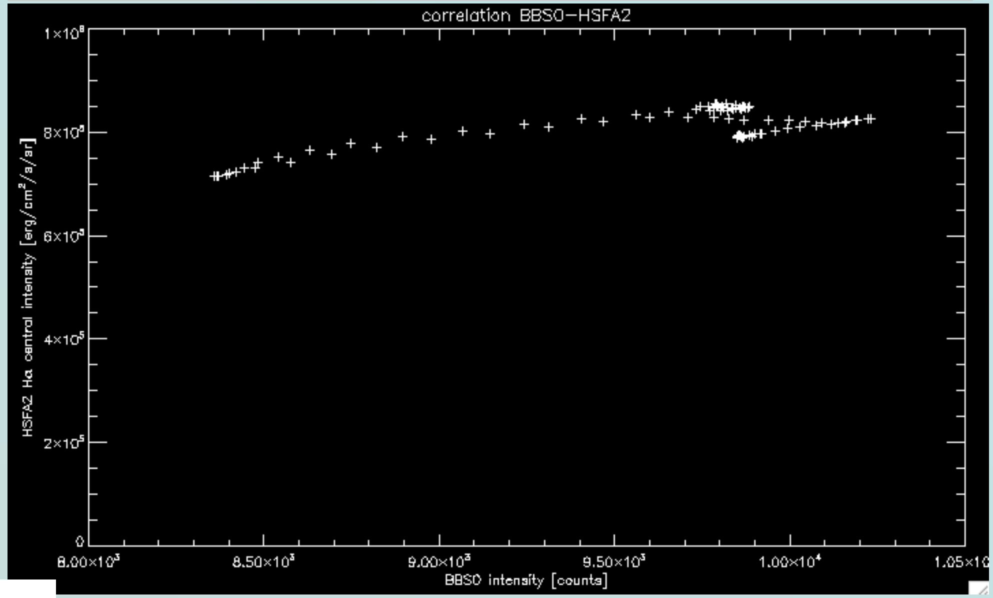


BBSO at 17:00
Hα center

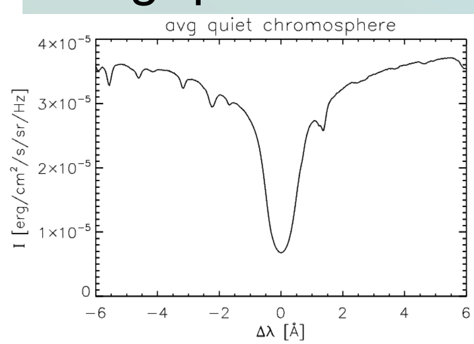




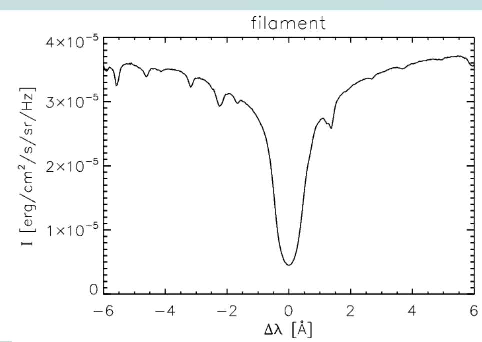
correlation plot HSFA2 Hα center versus BBSO at 17:00 UT



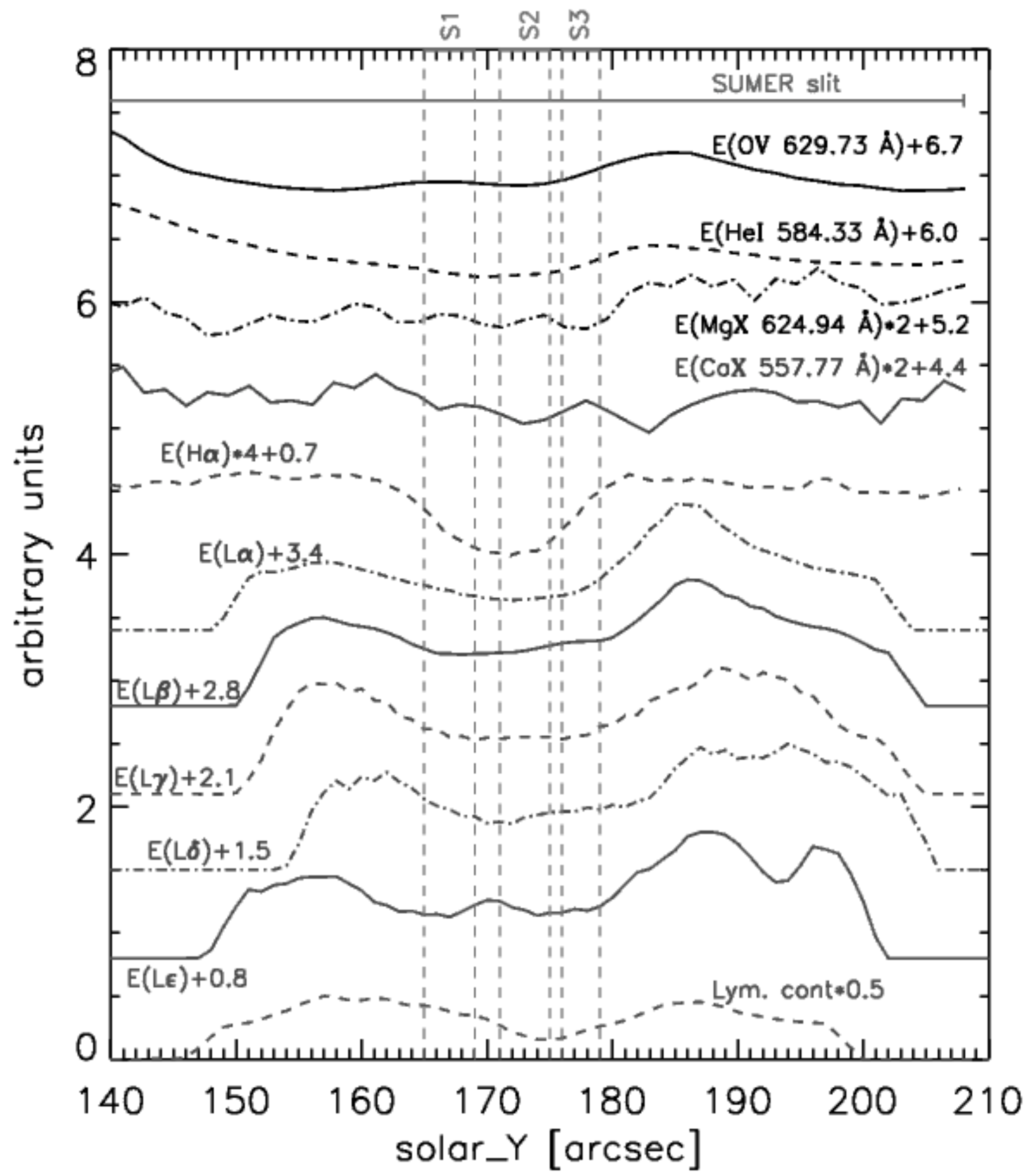
avg quiet chrom.



filament



Intensity distributions along the SUMER slit of different spectral lines observed by different instruments



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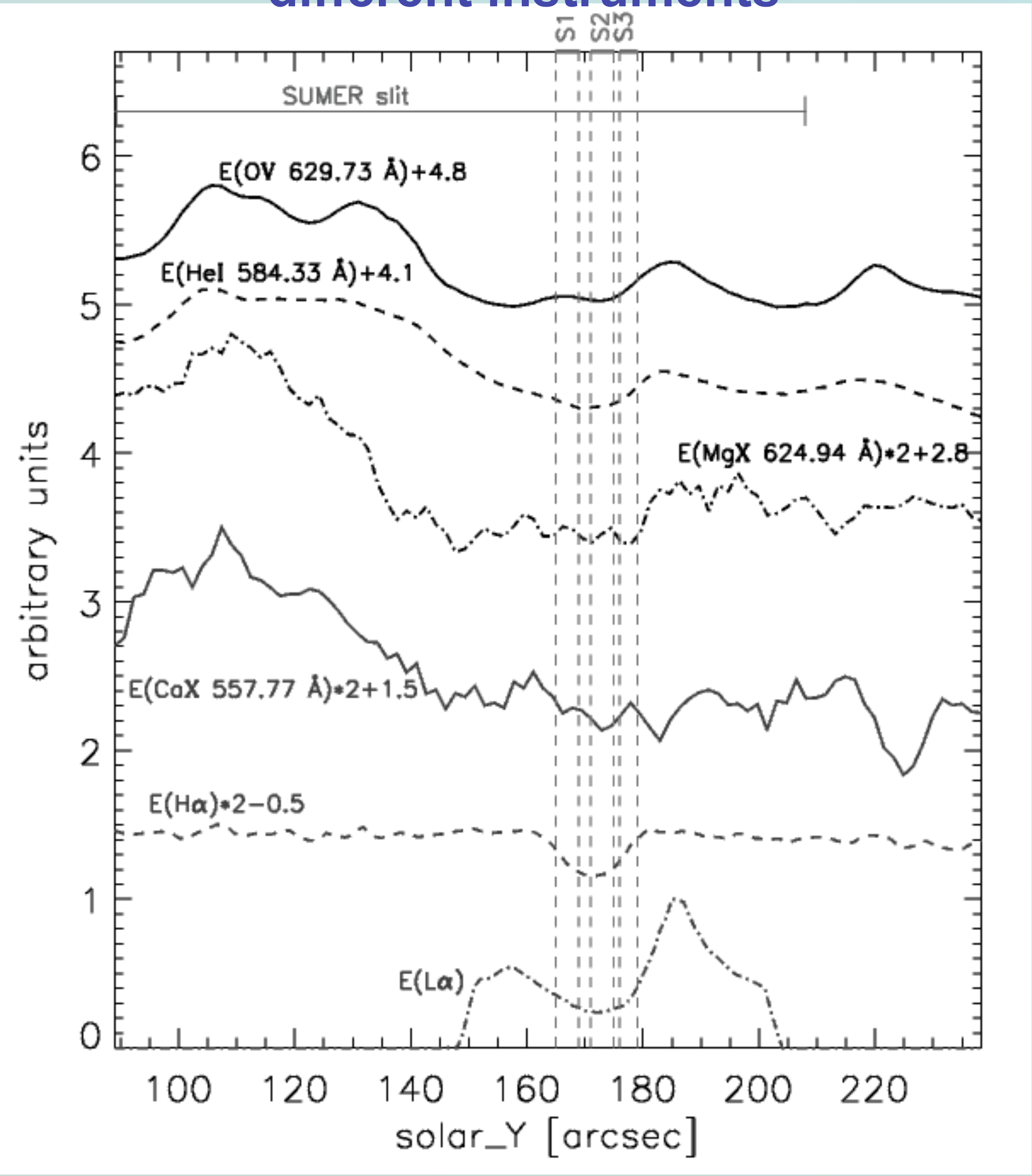
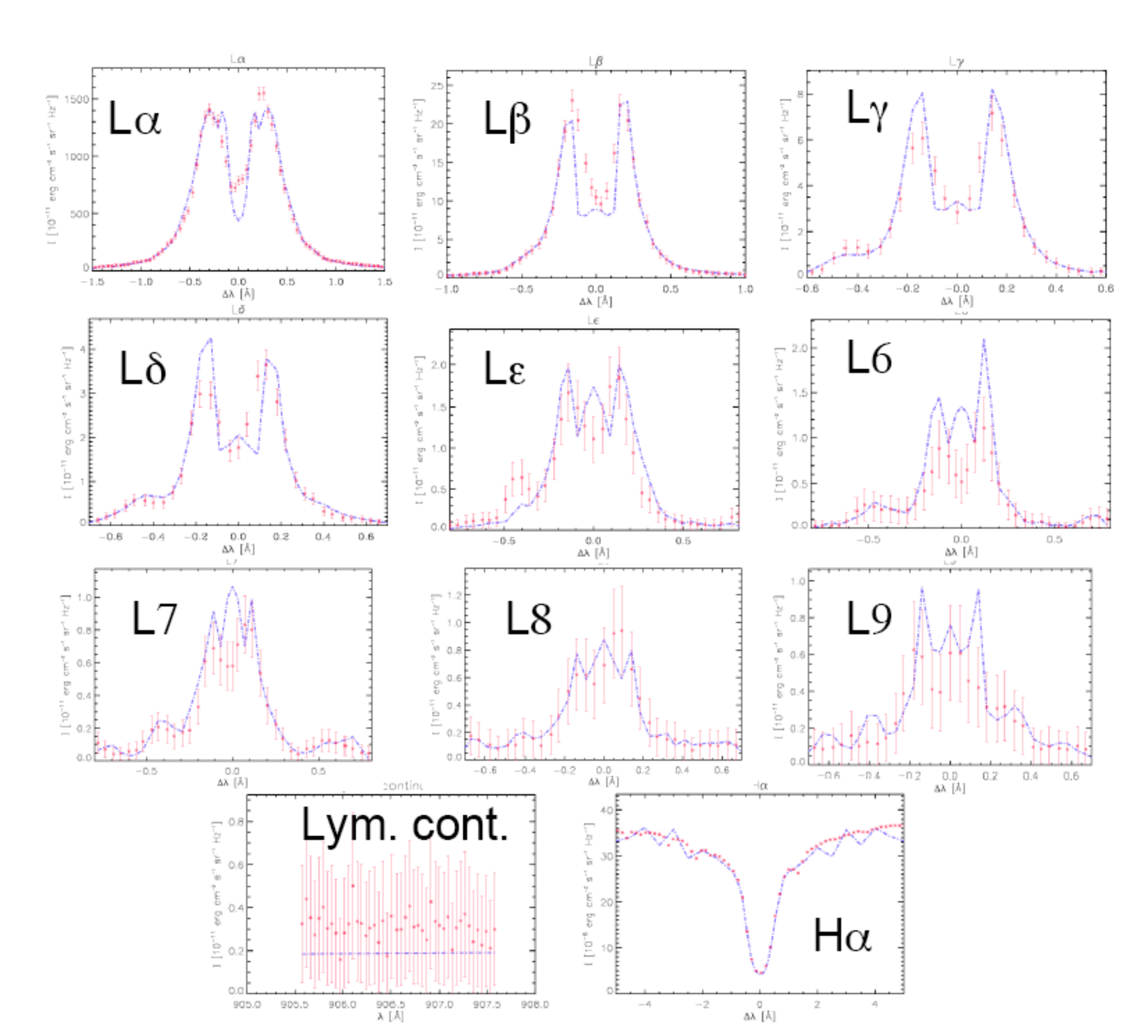
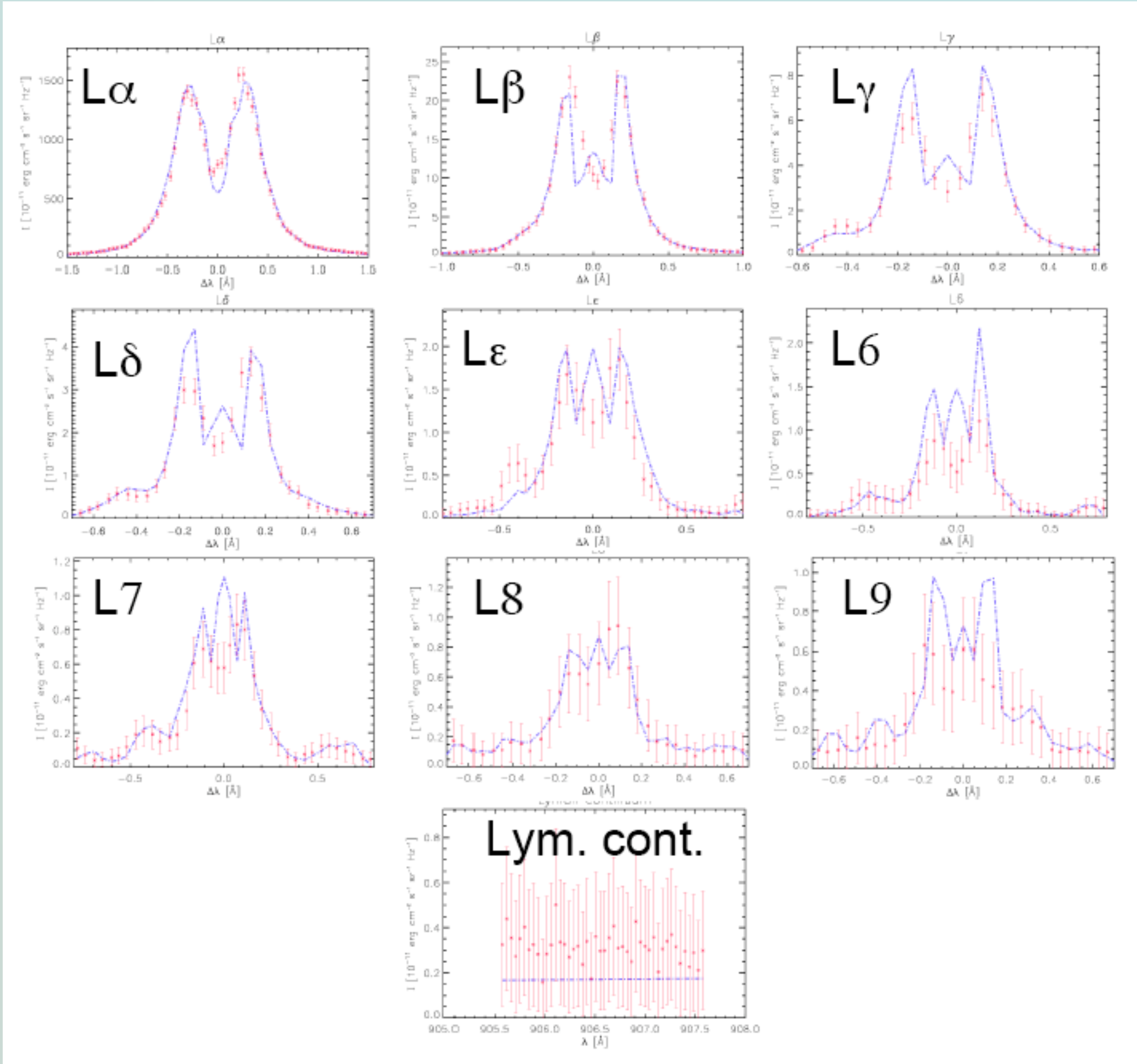


Results

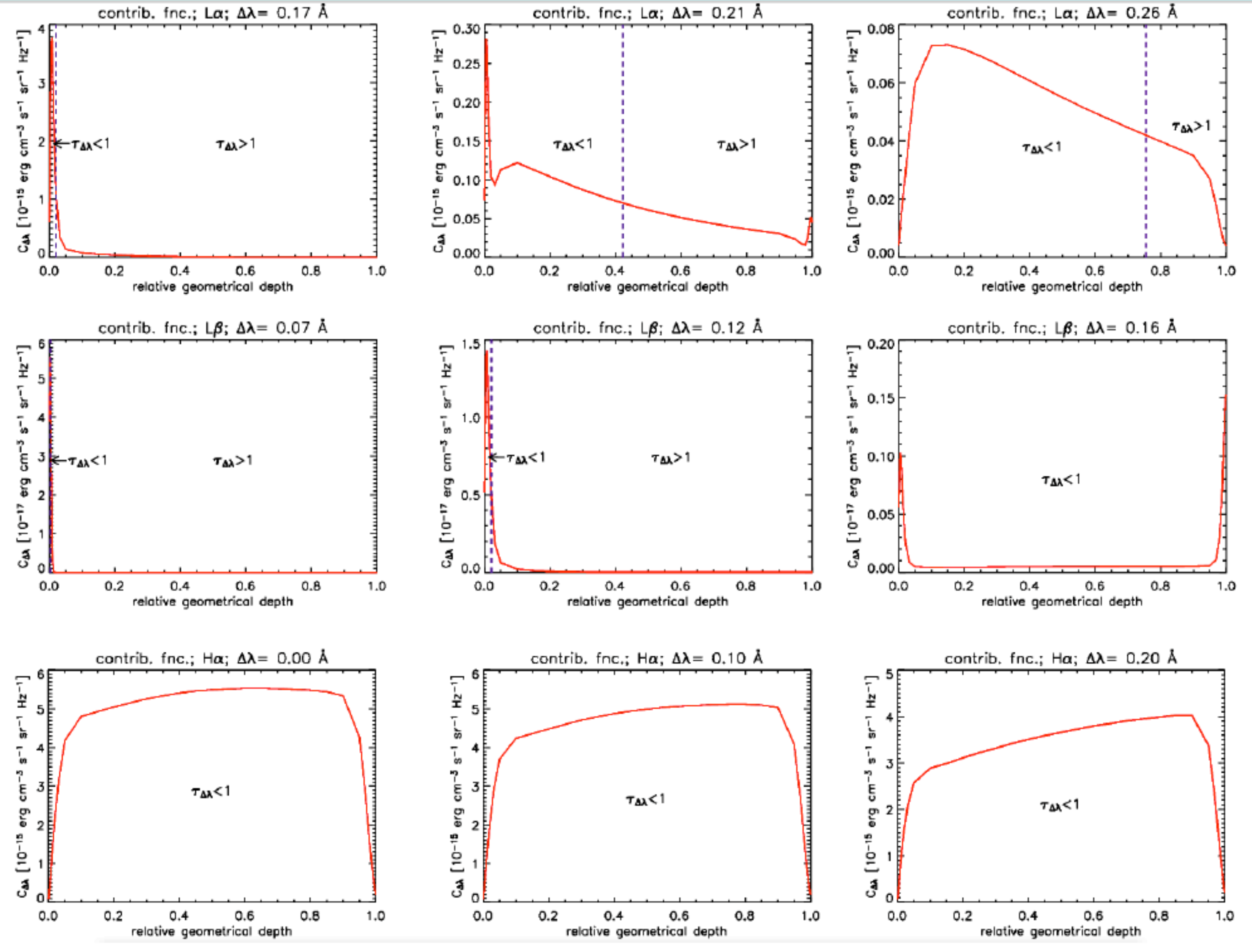
Fitting observed profiles for the darkest central part (S2) of the filament channel



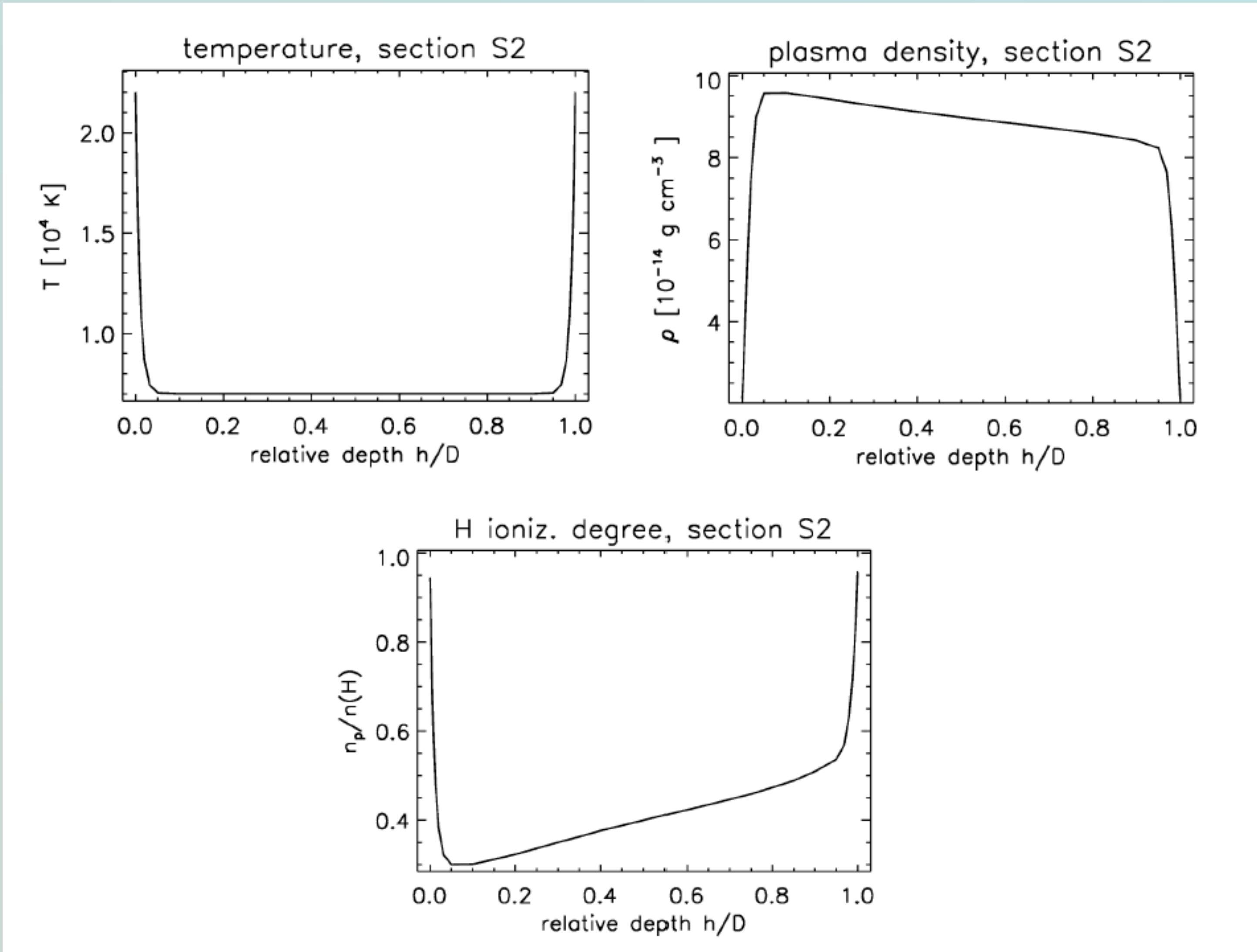
Fitting observed profiles for the darkest central part (S2) of the filament channel



$$C(\tau_\lambda, \lambda) = \eta(\tau_\lambda, \lambda)\, \exp(-\tau_\lambda)$$



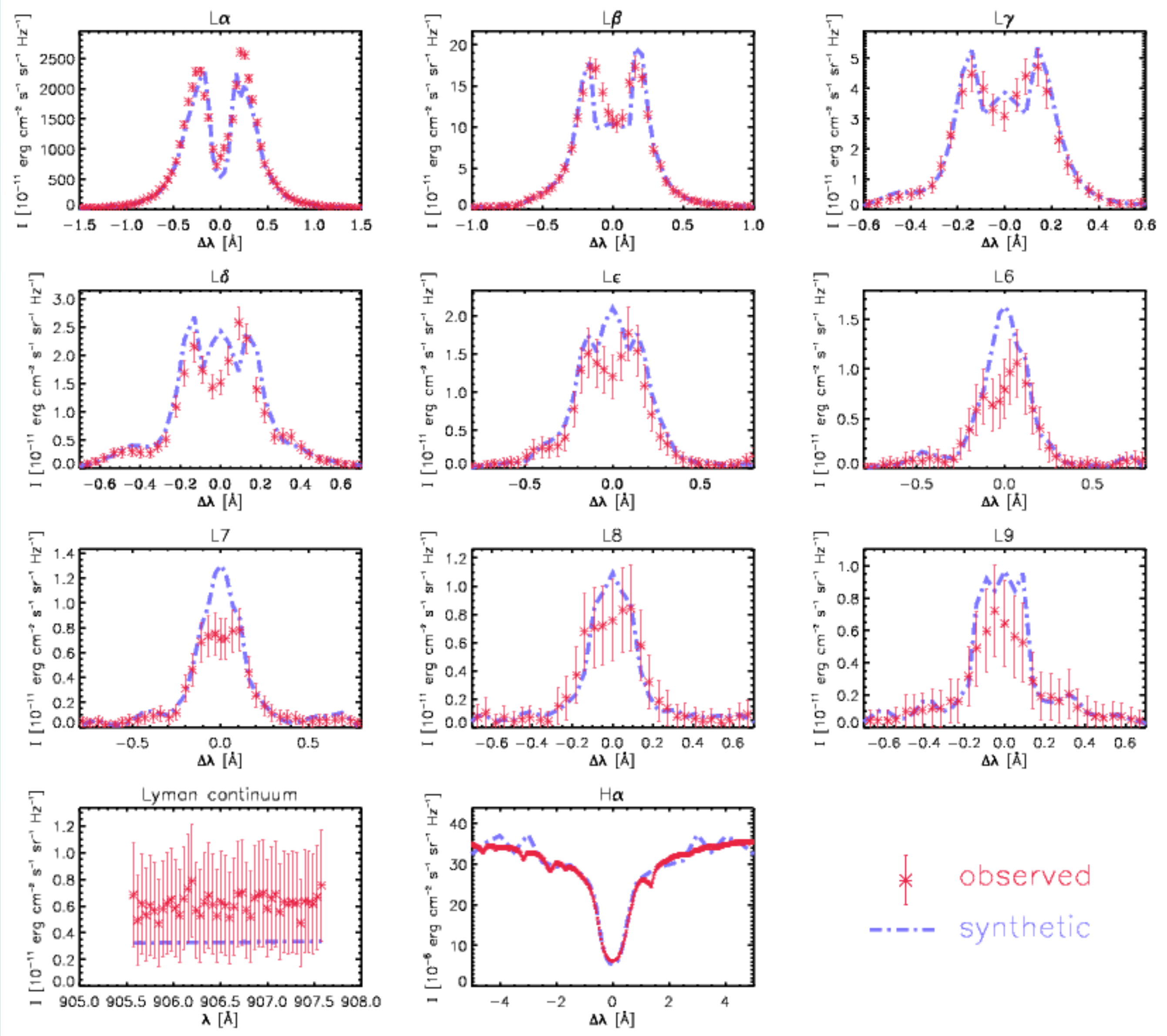
Plasma properties for the S2 section



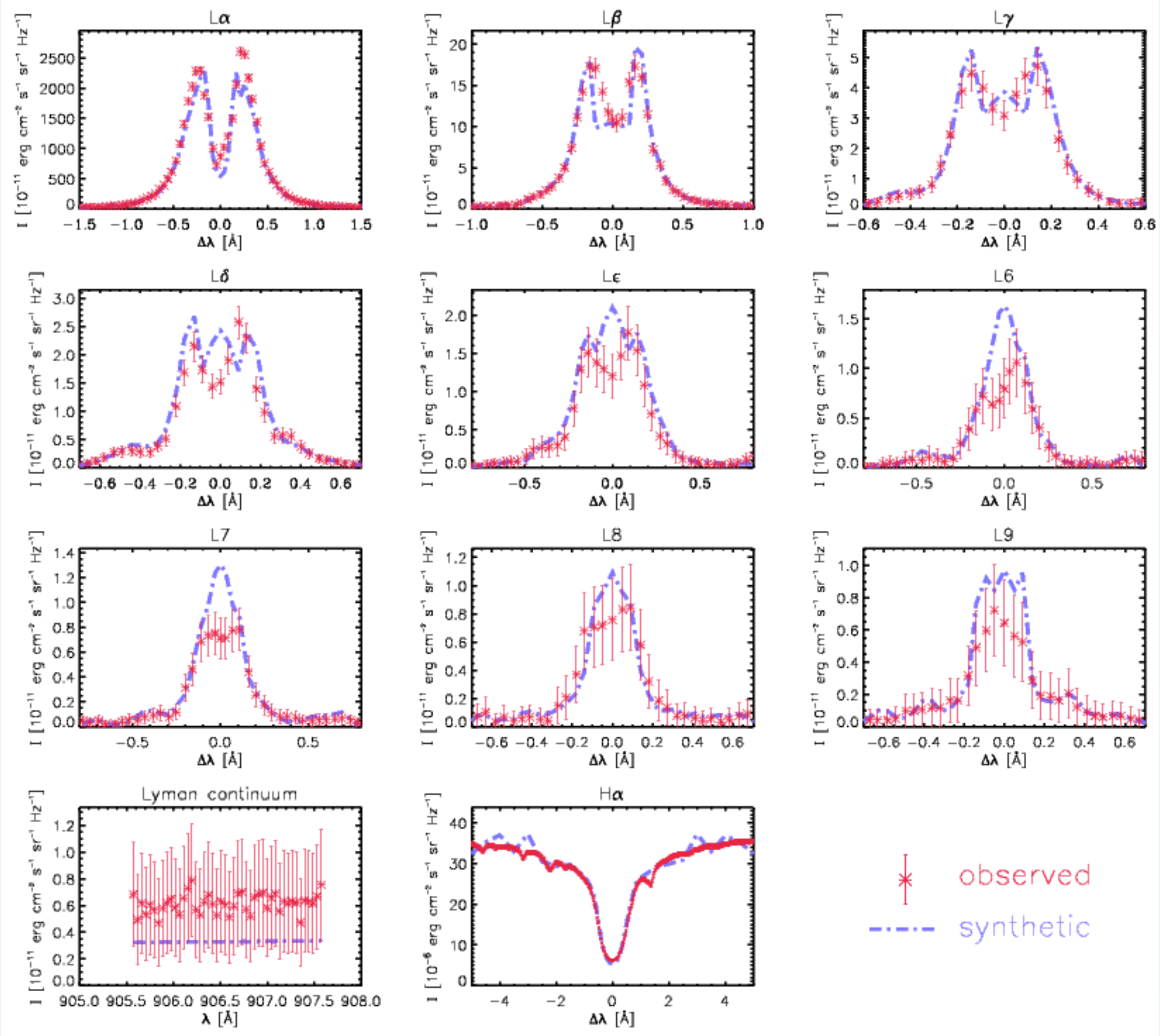
- **for very dark Hα filament (section S2) reasonable results:**
  - rather high optical thickness (dark structure in also Hα)

    τ_{912}=36 ; τ_o(Hα)= 1.1
  - large bottom height (31000 km), small geometrical thickness only of 9500 km, small filling factor of 0.2
  - large temperature gradient in PCTR, small PCTRs (occupy only 10 -- 20% of *D*)
  - temperature in the filament interior is 7000 K
  - temperature in the slab edge 23000 K
  - high gas pressure 0.06 dyn cm^{-2}
  - hydrogen ionization degree 0.3 -- 0.5 in the slab interior

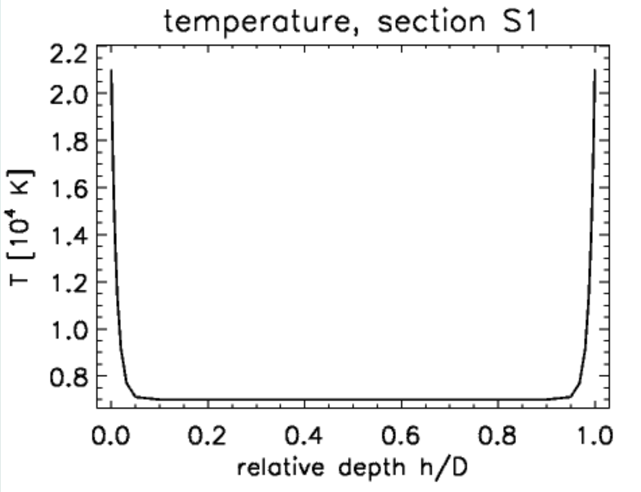
Fitting observed profiles for the section S1 at edge of the filament channel

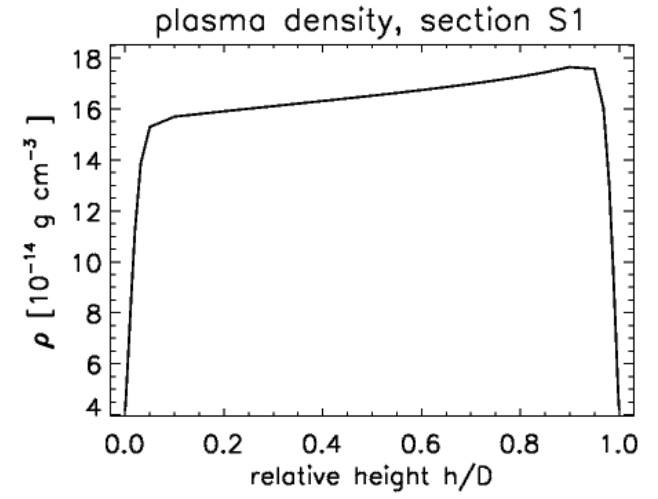


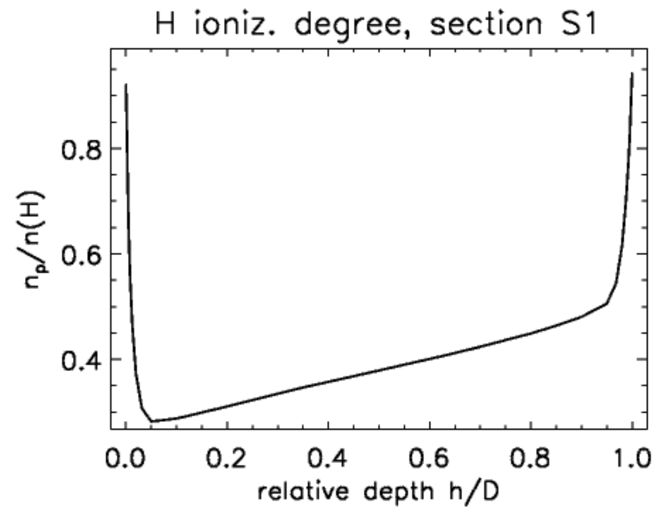
Fitting observed profiles for the section S3 at other edge of the filament channel



Plasma properties for the S1 section







- **for edge of the filament channel (sections S1, S3):**
  - values of optical thickness (dark structure in also Hα)

    τ_{912}=12 -- 13 ; τ_o(Hα) ≈ 0.5
  - different bottom heights ranging from 1000 -- 35000 km, and to them corresponding geom. thickness of 37000 -- 500 km and filling factor of 0.01 -- 1.0, D_{eff} ten times smaller than for S2

  ⬇SIMILAR AS FOR THE FILAMENT_CHANNEL INTERIOR ⬇
  - large temperature gradient in PCTR but smaller than in the darkest filament-channel interior (S2), small PCTRs similar as for the section S2
  - temperature in the filament interior is 8000 K
  - temperature in the slab edge 23000 K
  - high gas pressure ≈ 0.1 dyn cm^{-2}
  - 2-times larger plasma density,
  - hydrogen ionization degree 0.3 -- 0.5 in the slab interior

Summary of the results

continuation

- plasma density in all sections ranges from 10^{-14} to 10^{-13} g cm^{-3}
- ionization degree ranges from 0.3 to 1, in S1 it 0.5 in the slab interior

- D_{eff} (summary geometrical thickness filled with the cool filament plasma) is rather small: 500 -- 5000 km
- gas pressure in sections S2 is around 0.06 dyn/cm^2, in S1, S3 it is little higher 0.1 dyn/cm^2
- presence of Lα is important for correct estimation of the temperature gradient in PCTRs
- presence of Hα profiles is important for correct estimation of the geometrical thickness of the slab and of the filling factor