Quiescent prominence investigations in the EUV-UV ranges

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Outline

- ✓ The prominence and QS spectral atlas
- ✓ Physical parameters
  - ✓ Non-thermal velocity
  - ✓ Differential Emission Measure
  - ✓ Energy budget
  - ✓ Plasma T from H-Lyman continuum
- ✓ Application to modeling
- ✓ Other hot topics on EUV quiet prominences
- ✓ Conclusions

The spectral atlas

The atlas: motivations

For a prominence study we need to consider:

- ✓ Partially ionized environment
- ✓ Radiative transfert
- ✓ Ambient emission
- ✓ Heterogeneous at small and large scales
- ✓ The fine structure is not resolved by the instruments

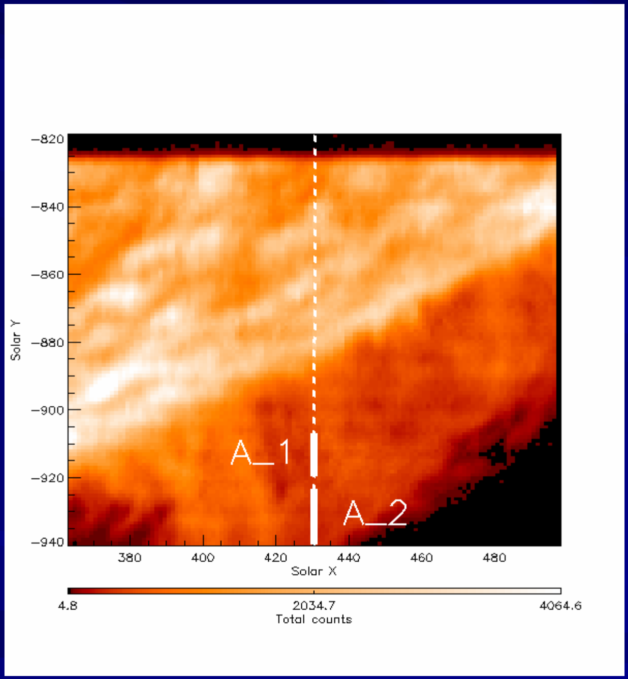
⇨ Spectroscopic diagnostics are essential (we use all the information of the emitted photons)

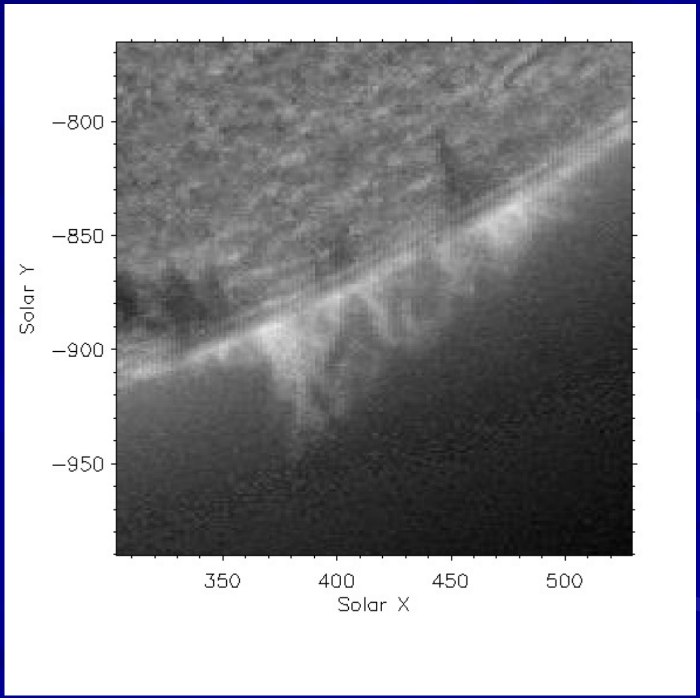
A spectral atlas*: to give reference values for the physical parameters of an extremely complex structure such as a prominence.*

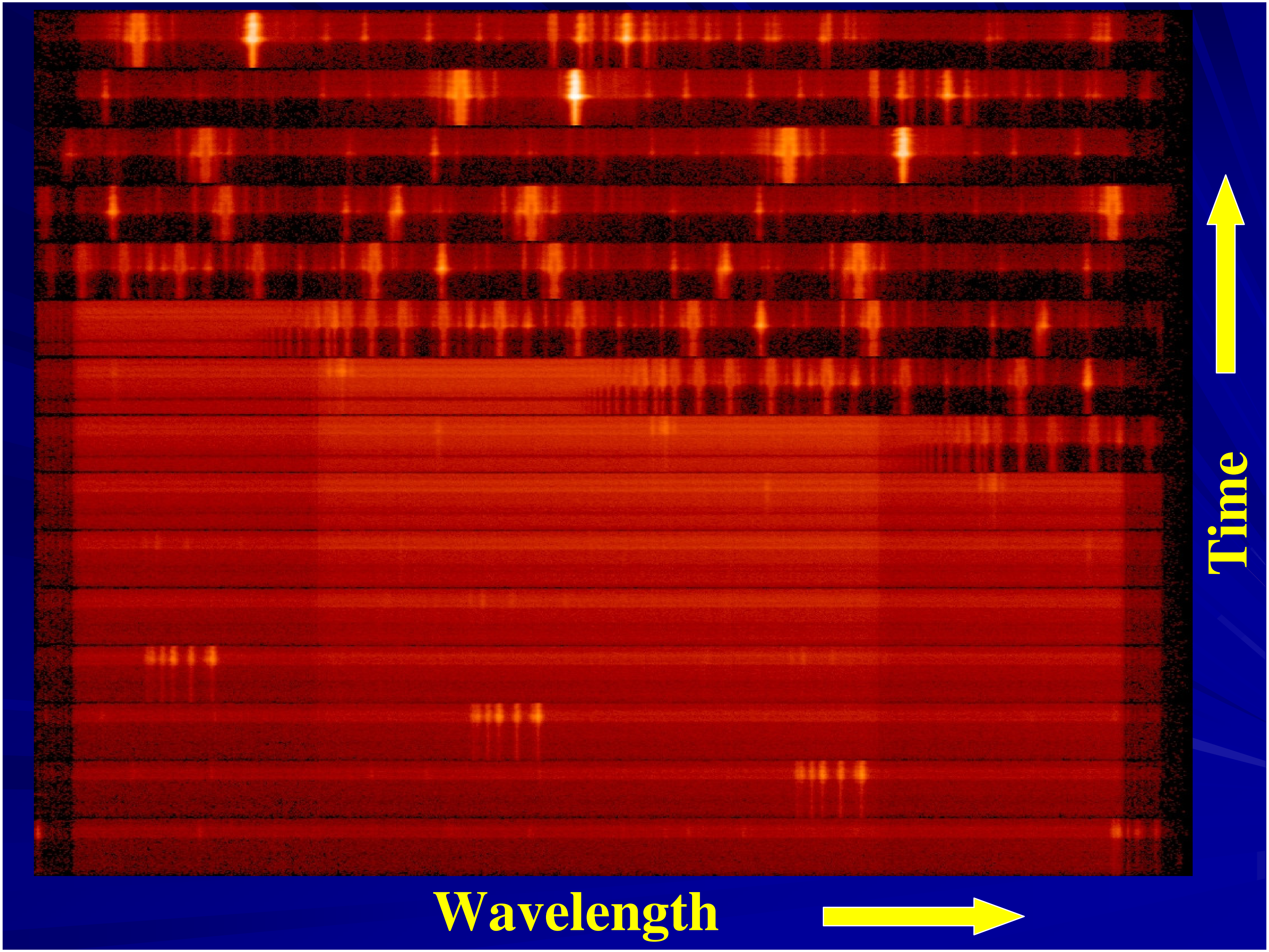
The data

- ✓ Prominence and QS 10/1999 (MEDOC #4)
- ✓ Spectral range: 800 - 1250 Å (SUMER det A, dx=1", dλ=0.044 Å)
- ✓ The spectral UV band covers the temperatures from the cool regions from the core of the prominence to the ambient corona.

S. Parenti et al., 2004






Time
Wavelength

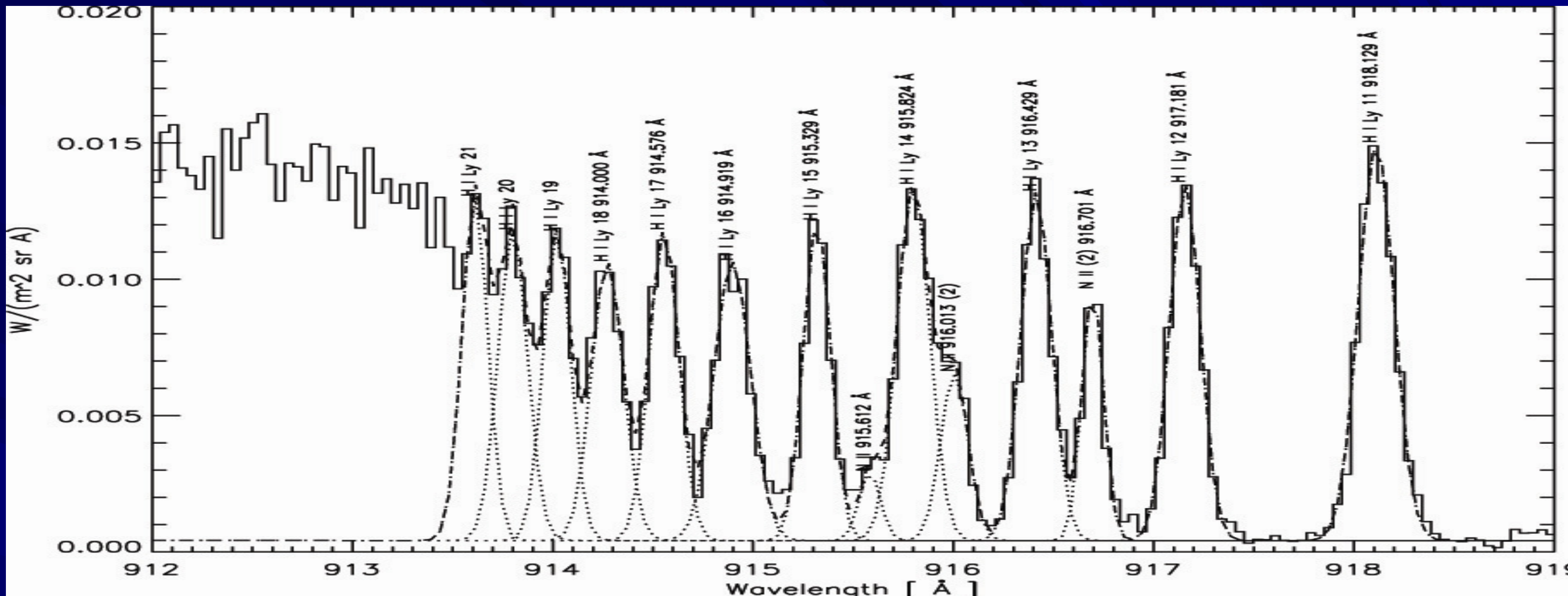
Data processing

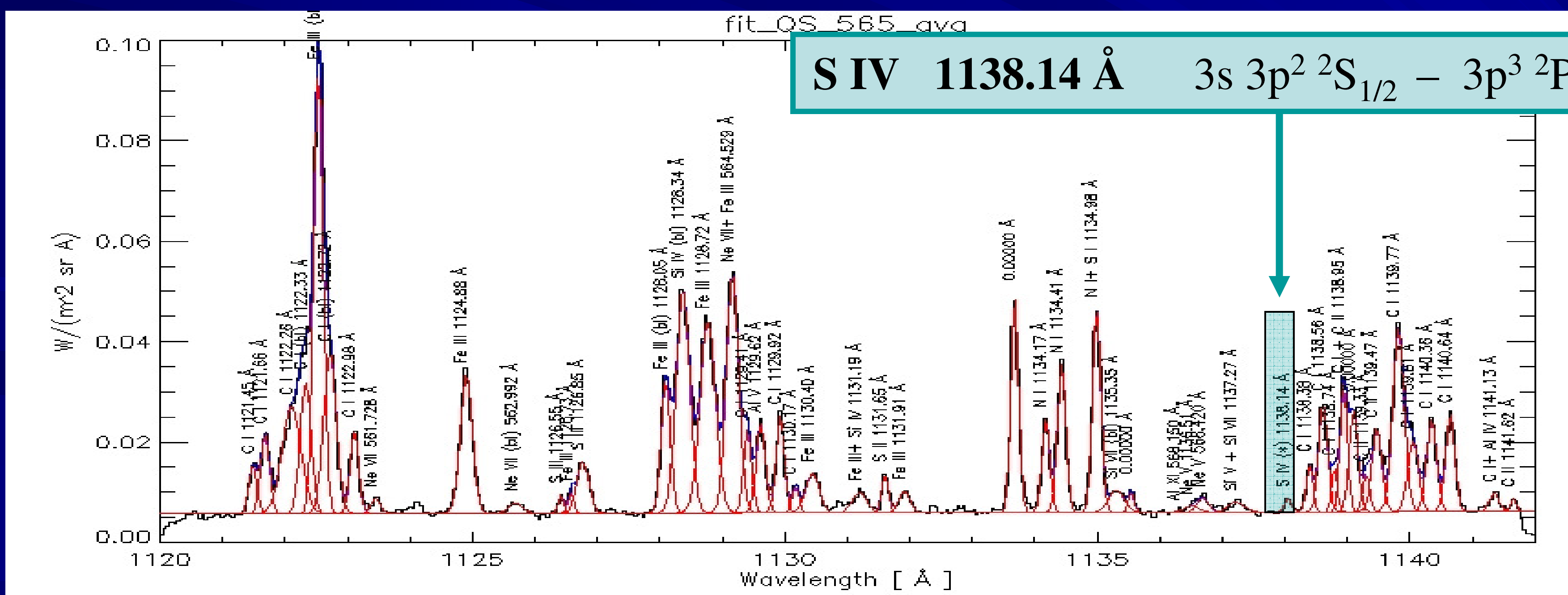
- ✓ Determination of the stray light contribution
- ✓ Wavelength calibration for each spectral window, for the QS and prominence independently.
- ✓ Measurement of the profile for more than 1500 lines for the three datasets (I, λ_o, FWHM).
- ✓ Line identification and radiometric calibration.
- ✓ About 40 new lines identified (mostly from ions at low ionization stage) between the QS and the prominence

First complete prominence atlas in the range 800-1250 Å

S. *Parenti, J-C Vial, P. Lemaire, 2004, 2005a*

The spectra





S IV 1138.14 Å $3s\,3p^2\;{}^2S_{1/2} - 3p^3\;{}^2P_{1/2}$

The final product

S. Parenti, J-C Vial, P. Lemaire, 2005a

Ion		Quiet Sun			Prominence I			Prominence II		
Si VII **	1135.3530	1135.300 b	1.332	0.286	1135.346 b	0.353	0.169	1135.387 b	0.146	0.165
**		1135.550	0.470	0.125	1135.410	0.427	0.323	1135.410	0.163	0.244
Al XI/2 **	568.1500				1136.422 b	2.755	0.111	1136.445 b	1.797	0.095
Ne V **	1136.5100	1136.523 b	0.260	0.178	1136.526 b	0.270	0.151	1136.520 b	0.233	0.174
Ne V/2 **	568.42	1136.702 b	3.712	0.086						
Si V -Si VII	1137.2670	1137.234 b	0.426	0.190	1137.154 b	0.044	0.079			
S IV (*)	1138.1400	1138.055 w	0.264	0.102						
C I	1138.3831	1138.396 i	1.137	0.119						
C I **	1138.5570	1138.614 i	3.696	0.161	1138.629 w	0.247	0.177	1138.616 w	0.198	0.164

Ion	λ_t (Å)	Transition	$\log T_{max}$	Ref.
Si VII	1135.3530	$2s^2\ 2p^2\ 3d\ ^4F_{3/2}–2s^2\ 2p^2\ 3d\ ^2S_{1/2}$	5.7	1
Al XI/2	568.1500	$1s^2\ 2s\ ^2S_{1/2}–1s^2\ 2p\ ^2P_{1/2}$	6.1	1
Ne V	1136.5100	$2s^2\ 2p^2\ ^3P_1–2s\ 2p^3\ ^5S_2$	5.6	2
Ne V/2	568.42	$2s^2\ 2p^2\ ^3P_0–2s\ 2p^3\ ^3D_1$	5.6	1
Si V - Si VII	1137.2670	$2p^5\ 3s\ ^3P_2–2p^5\ 3p\ ^1P_1$	5.5	1
S IV (*)	1138.1400	$3s\ 3p^2\ ^2S_{1/2}–3p^3\ ^2P_{1/2}$	5.0	1
C I	1138.3831	$2s^2\ 2p^2\ ^3P_0–2s^2\ 2p\ 6d\ ^3P_1$	<4.0	1
C I	1138.5570	$2s^2\ 2p^2\ ^3P_1–2s^2\ 2p\ 6d\ ^3P_0$	<4.0	1

http://www.ias.u-psud.fr/medoc/science/parenti/intro.htm

Physical parameters

Non Thermal Velocities

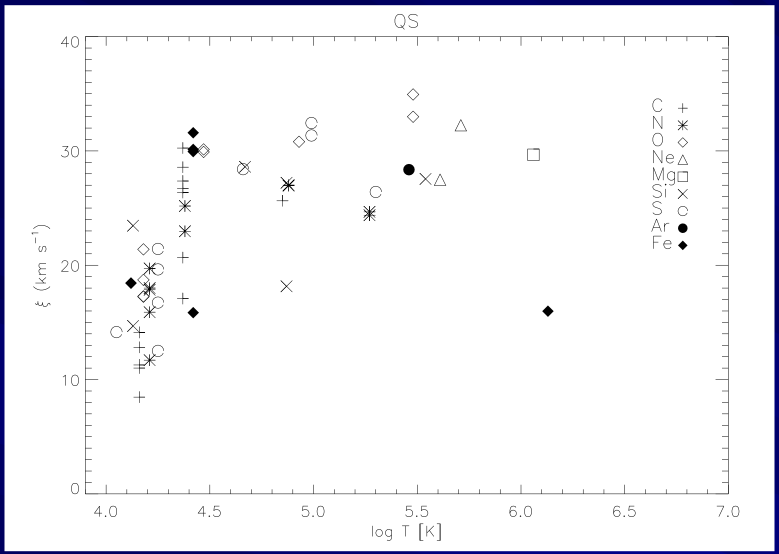
$$FWHM^2_{meas} = FWHM^2_{solar} + FWHM^2_{inst}$$

$$v = \frac{c}{\lambda}\frac{FWHM}{2\sqrt{2\ln 2}} \qquad v_{solar} = \sqrt{\frac{2kT}{M} + \xi^2}$$

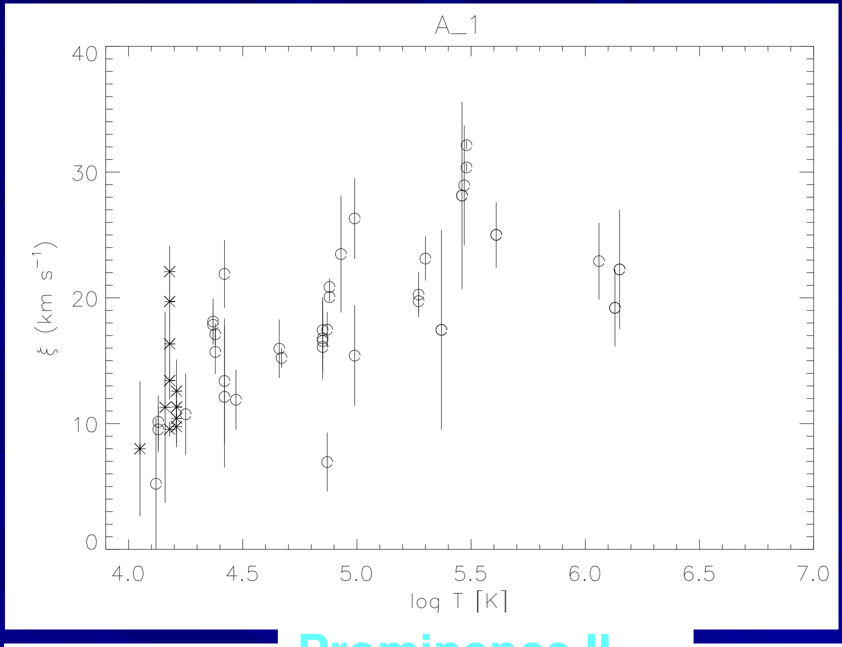
- ✓ Lines from allowed transitions, well isolated and intense
  - ✓ ~ 60 for the QS and ~ 45 for the prominence
  - ✓ 24 different ions from various elements
- ✓ T is for the maximum ionization fraction.

Non-Thermal Velocity

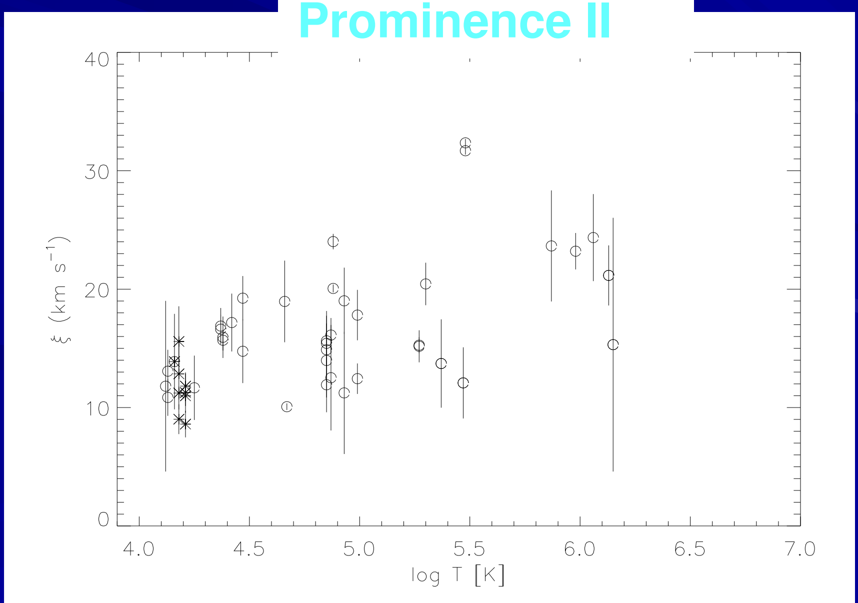
QS



Prominence I



Prominence II



- ✓ $NTV_p < NTV_{QS}$
- ✓ Different NTV gradient with T
- ✓ Absorption effects in the QS on low ionized ions

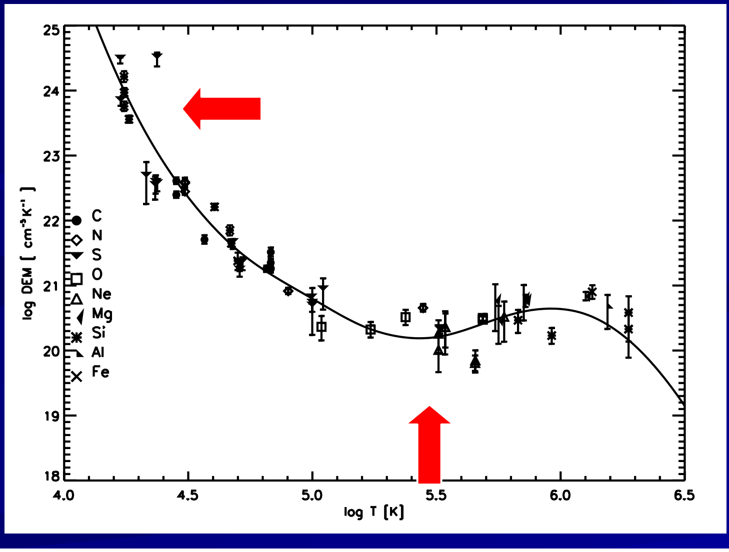
Parenti & Vial, 2007

The Differentiel Emission Measure

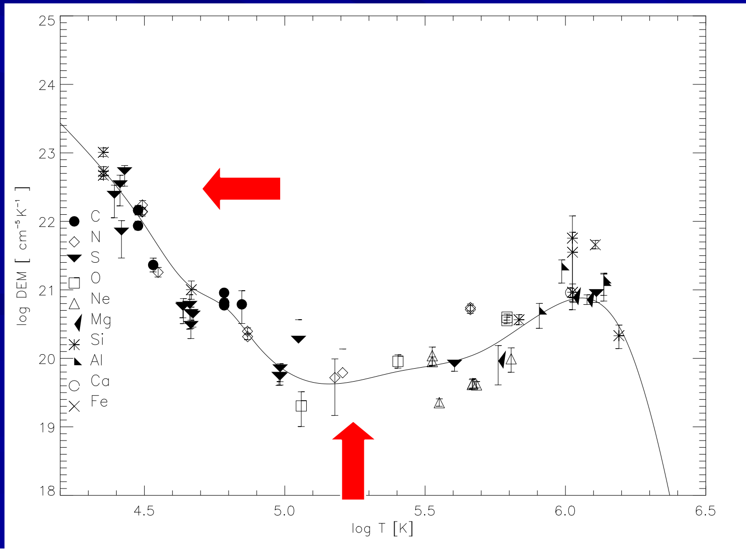
$$I_{obs} = \int G(T) DEM(T) dT \qquad DEM(T)dT = N_e^2 \frac{dh}{dT} dT$$

- ✓ Selection of lines : ~ 60 for each dataset
- ✓ CHIANTI (v 4.2) atomic database (Mazzotta et al. Ion fraction; coronal abundances)
- ✓ Inversion technique to estimate DEM(T)

QS

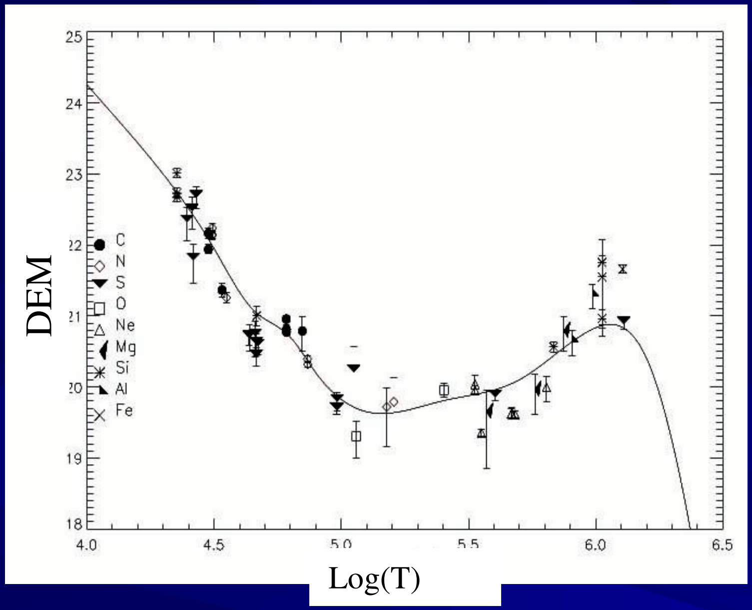


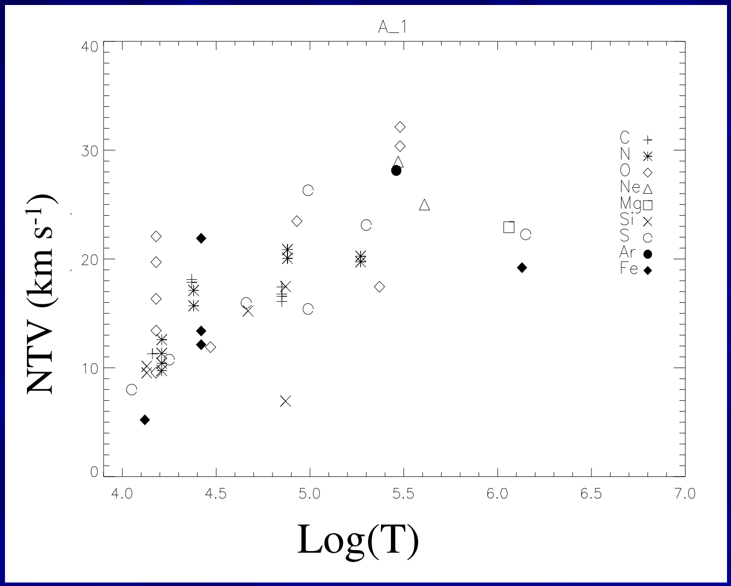
Prominence



Energy budget

Parenti & Vial, 2007, 2008



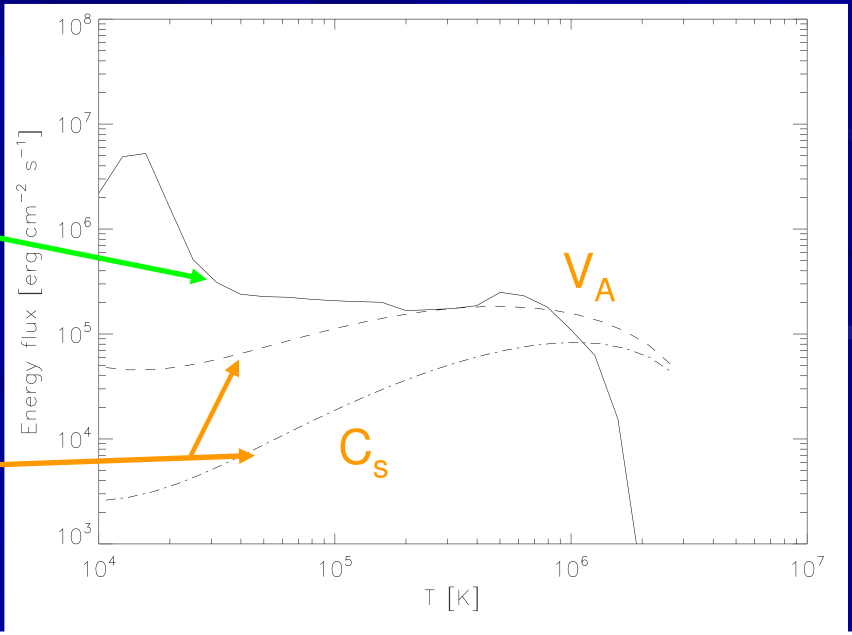


Radiative loss

$$L(T) = \int_{T}^{\infty} T' \, DEM(T') \, dT'$$

Energy flux by waves

$$F_A = \rho \, \xi^2 V_A$$



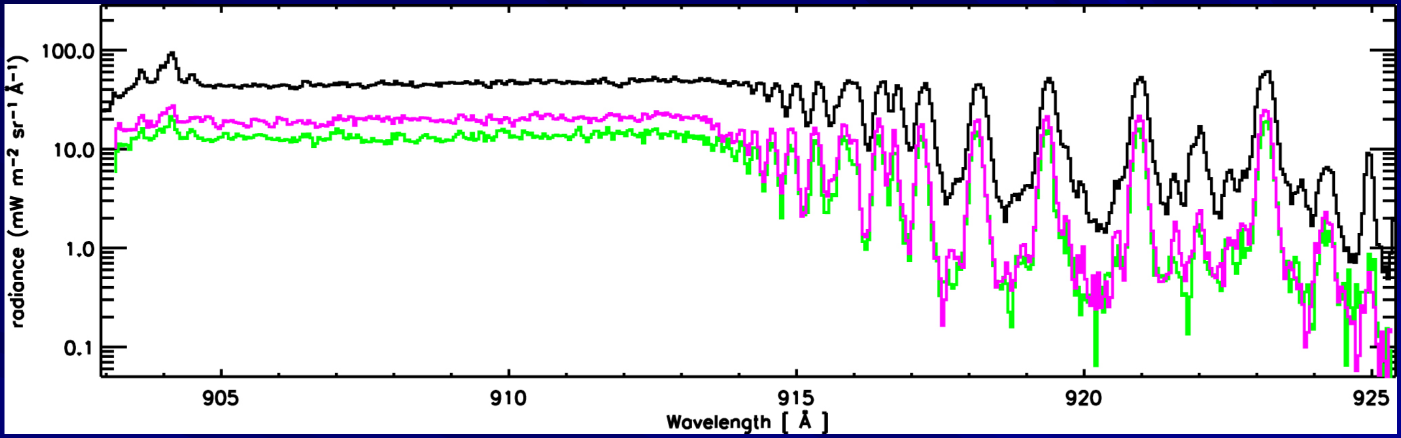
H-Lyman continuum

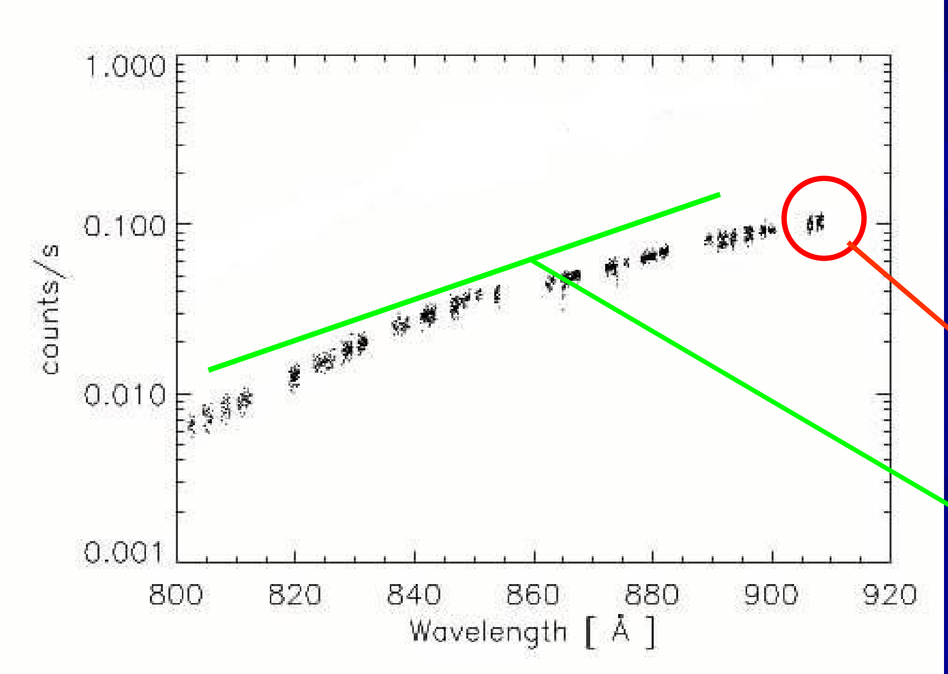
The H-Lyman continuum forms in the cooler core of the prominence through photon-ionization (by chromospheric incident radiation) followed by radiative recombination.

- ✓ brightness temperature (T_B)
- ✓ color temperature (T_C)

These are essential parameters to model a non-LTE hydrogen atmosphere.

Method





$$L_\lambda(\mu = 1) \cong S_\lambda(\tau_\lambda = 1) = \frac{B_\lambda(T_c)}{b}$$

$$L_\lambda = \frac{2hc^2}{b\lambda^5}\exp\left(-\frac{hc}{\lambda k Tc}\right)$$

T_B

$T_C \sim T$ (< 15000 K)

Results

Parenti S., Lemaire P. & Vial J-C, A&A, 2005

	L_o	T_B	σ_{T_B}	T	σ_T	b	σ_b
QS (corrected)	62.2	6536	105	8753	10	452	11
Prom. A_1	23.0	6277	96	8281	281	438	301
Prom. A_2	24.8	6296	97	7564	231	67	44

- ✓ Dilution factor 0.37 ≈ 0.38 = I_{PRM}/I_{QS}
- ✓ Gouttebroze et al ('93) slab model:

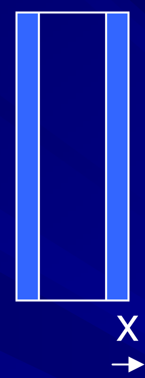
T = 8000 K ⇨ L_o=21 mW m^2 sr^{-1} Å^{-1}

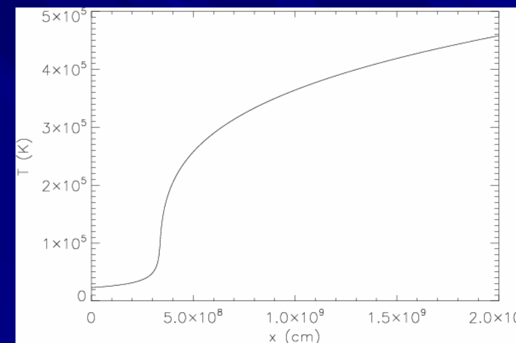
The emission of the prominence depends only from the incident chromospheric radiation.

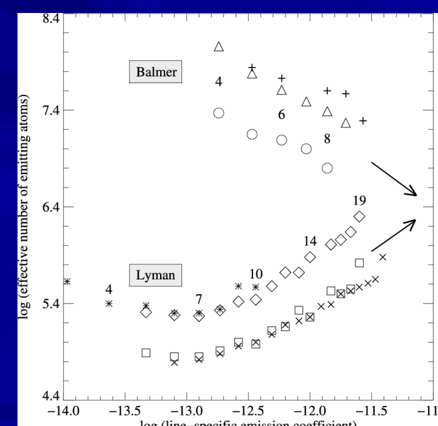
Other applications

To understand the PCTR: I

- Anzer & Heinzel 2008
  - DEM (T), n_e used to model 1D slab and study the heating.
  - Mechanical heating, conduction, dissipation by Alfven waves do not satisfy the required heating injection in the inner part of the PCTR
- Stellmacher & Wiehr 2008
  - Use the H-Lyman lines radiance to compare to the H-Balmer's.
  - Results: the two series are formed in different layers: the Lyman in the upper TR.

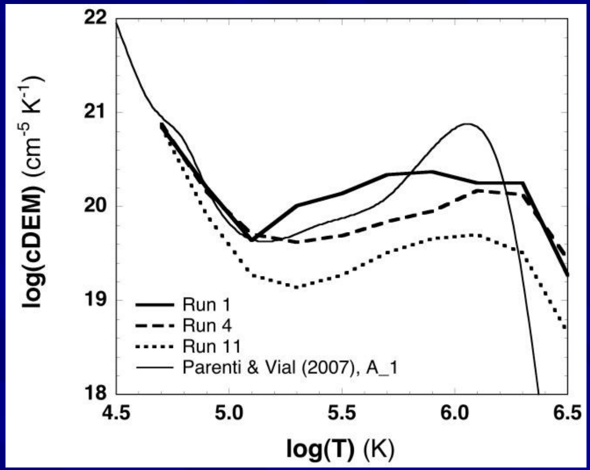






To understand the PCTR: II

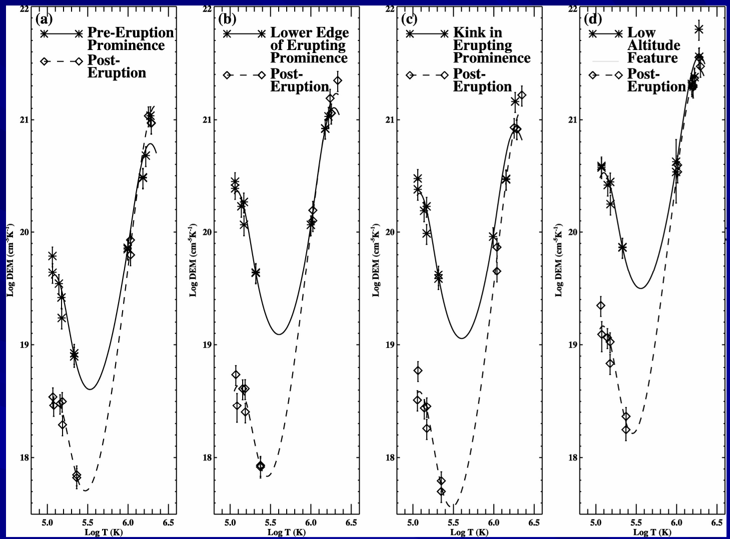
- Karpen & Antiochos 2008
  - Condensation formation by impulsive heating in 1D long loops.
  - Heating close to the footpoints with *dt* < τ_r better reproduces the observations.



Other hot topics

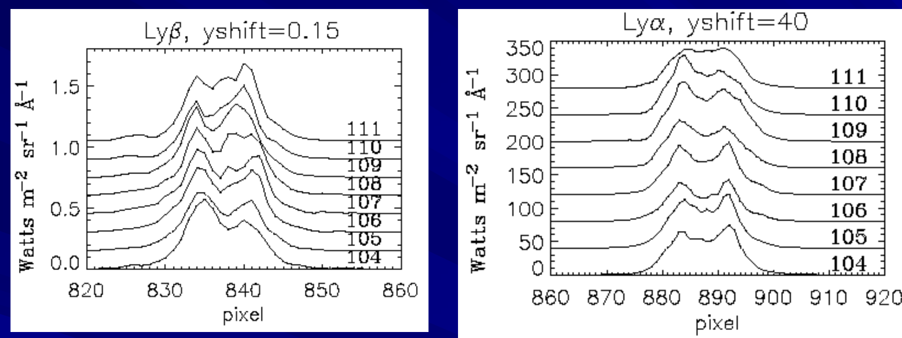
The shape of the DEM

- Kucera & Landi 2008
  - Erupting prominence
  - TRACE, SUMER, Hα
  - H-continuum absorption & low level heating at the prominence base (affecting only low TR lines).

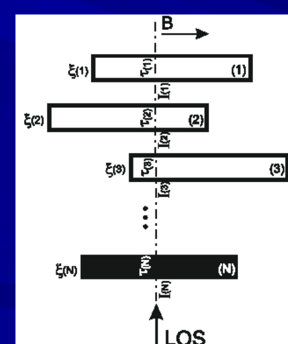


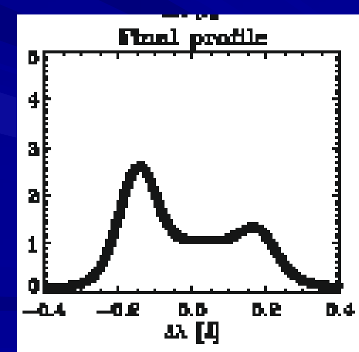
Fine structure through H-Lyman profiles

- Observations: Vial et al. 2007



- Model: Gunár et al. 2008
  - Multi-thread model with dynamics and non-LTE





Open questions

- ✓ PCTR plasma properties: implications in the stability and energetic
  - ✓EUV absorption (mass)
  - ✓Small scale structure and its dynamics
  - ✓Heating

Observations needed

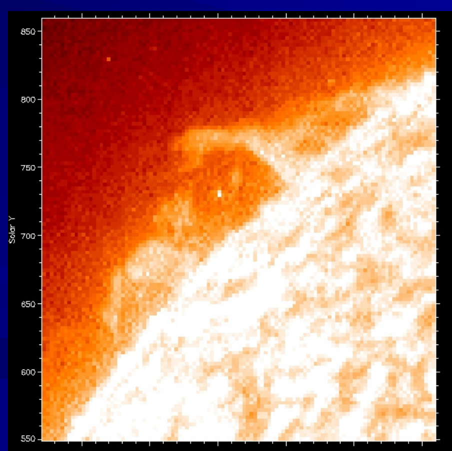
- ✓Higher temporal and spectral resolution
- ✓Better T coverage: HOP/JOP…

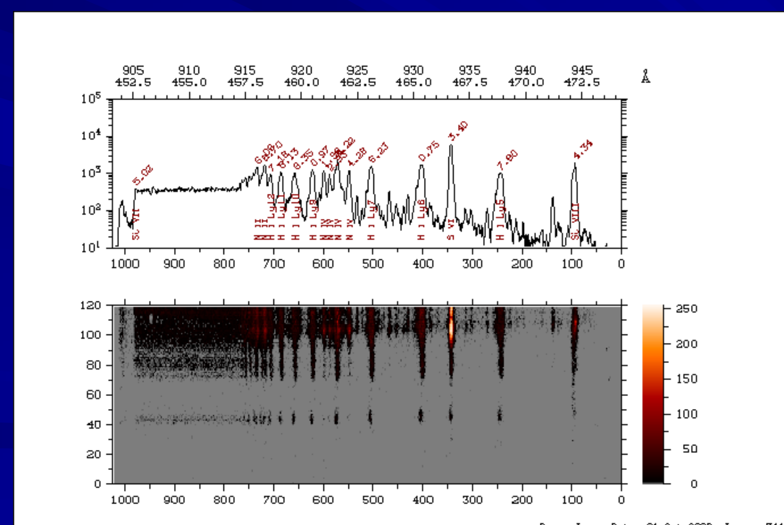
Ongoing Projects

JOP 207/HOP 82

- ✓ Eruptive and quiescent prominences Atlas with SOHO and Hinode (Parenti, Labrosse, Vial)
  - Spectral atlas with SUMER, CDS, EIS; SOT, UVCS
  - H and He absorption
  - Plasma parameters

October 2008





HOP 73

- ✓ Quiescent Prominence Structure and Dynamics (Berger et al.)

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