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# Resonant scattering processes at work in an active region as detected in the transition region Si IV lines near 140 nm with IRIS

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Contributed Talk

1. Fundamental physical processes and modeling

# Resonant scattering processes at work in an active region as detected in the transition region Si IV lines near 140 nm with IRIS

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The emission spectrum of the solar transition region is analysed, most of the times, assuming that the photons are emitted only through the electronic collisions processes. As for resonant scattering, it is taken into account only in solar regions such as prominences or the corona. Line doublets formed in the transition region, such as the Si IV 1399Å, 1402Å, recorded with IRIS can be used, through their line ratio, to evaluate the importance of resonant scattering and of optical thickness. We present locations of active region NOAA 12529 where we detected cases with line ratios in the range of $2 < 1393/1402 \leq 3$ suggesting resonant scattering, as well as line ratios in the range of $1.3 \leq 1393/1402 \leq 1.6$ where optical thickness is important. Optical thickness is found along fibril-like structures while resonant scattering seems to be important in bright grains. For the profiles showing resonant scattering we were able to estimate physical parameters such as the electron densities ($10^9$ up to $10^{12}$ cm$^{-3}$). Our work suggests that radiation scattering should be taken into account when analyzing transition region lines.

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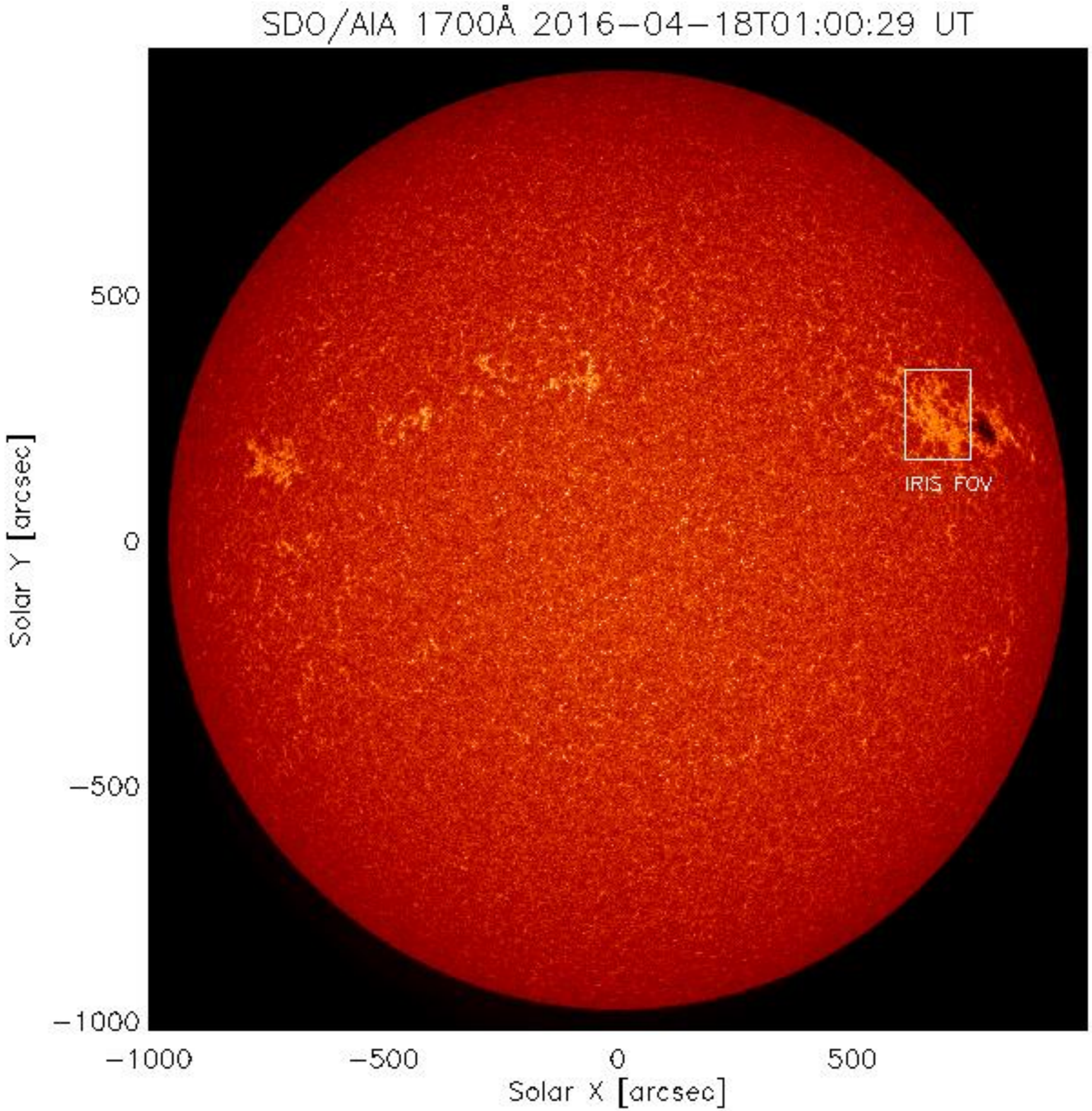
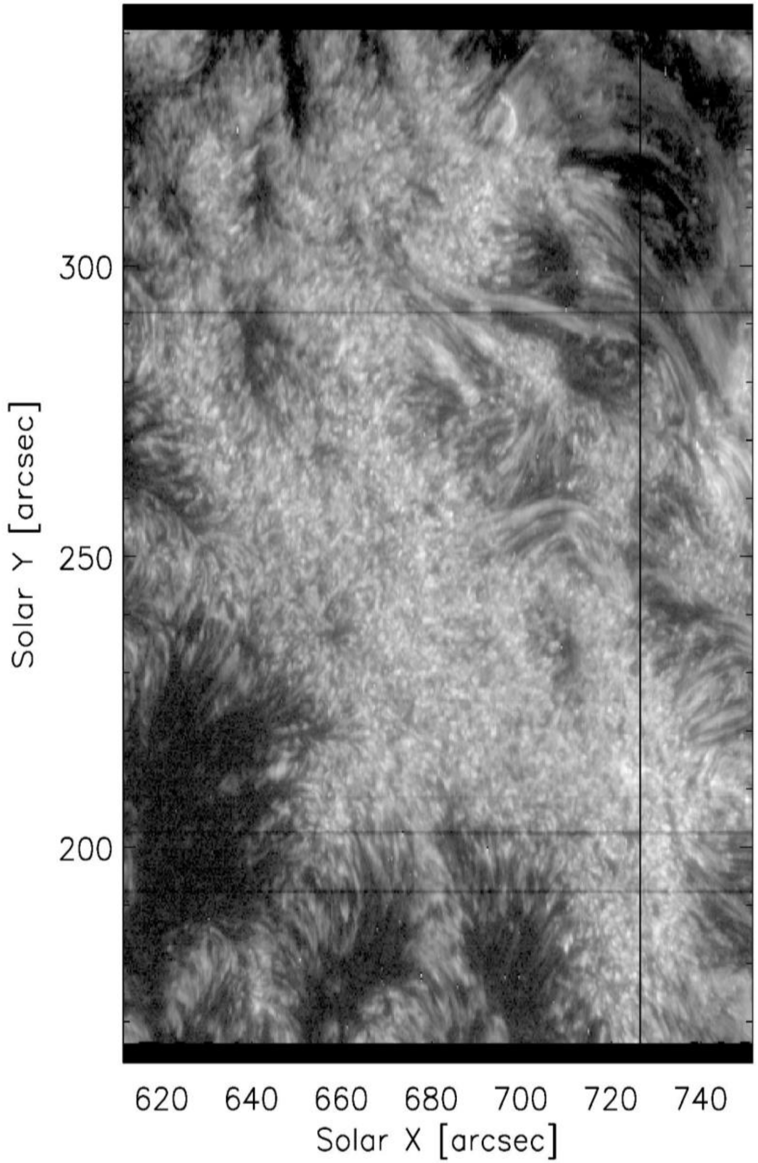
NOAA 12529

Observing date :
April 18, 2016

Starting time :
01:14:09 UT
Ending time :
02:16:05 UT



Intensity image Si IV 1393Å IRIS  raster




FOV  140  x 186”
Exp time  = 8 s,   dx=0.33”

## Diagnostic possibilities using **Doublets (Si IV 1393Å, 1402Å)**

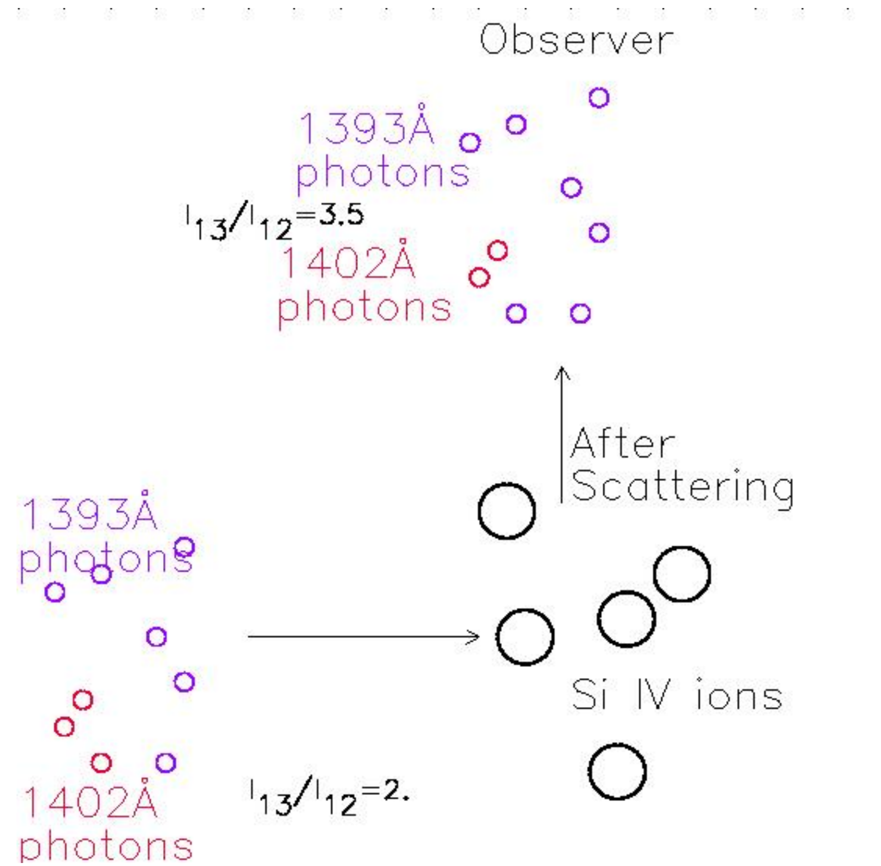
Intensity line ratio Si IV 1393Å/1402Å ($I_{13}/I_{12}$)

$I_{13}$ : Si IV 1393Å Intensity
$I_{12}$ : Si IV 1402Å Intensity

$I_{13}/I_{12} = 2$ : Optically thin + electron collisions

$I_{13}/I_{12} > 2$ : Resonant scattering + electron collisions

$I_{13}/I_{12} < 2$ : Optical thickness




Older examples :
C IV 1548Å, 1550Å doublet observed with SUMER

Gontikakis, Winebarger, Patsourakos (2013) A&A
Gontikakis, Vial (2016) A&A

**Intensity line ratio map**

Si IV 1393Å/1402Å

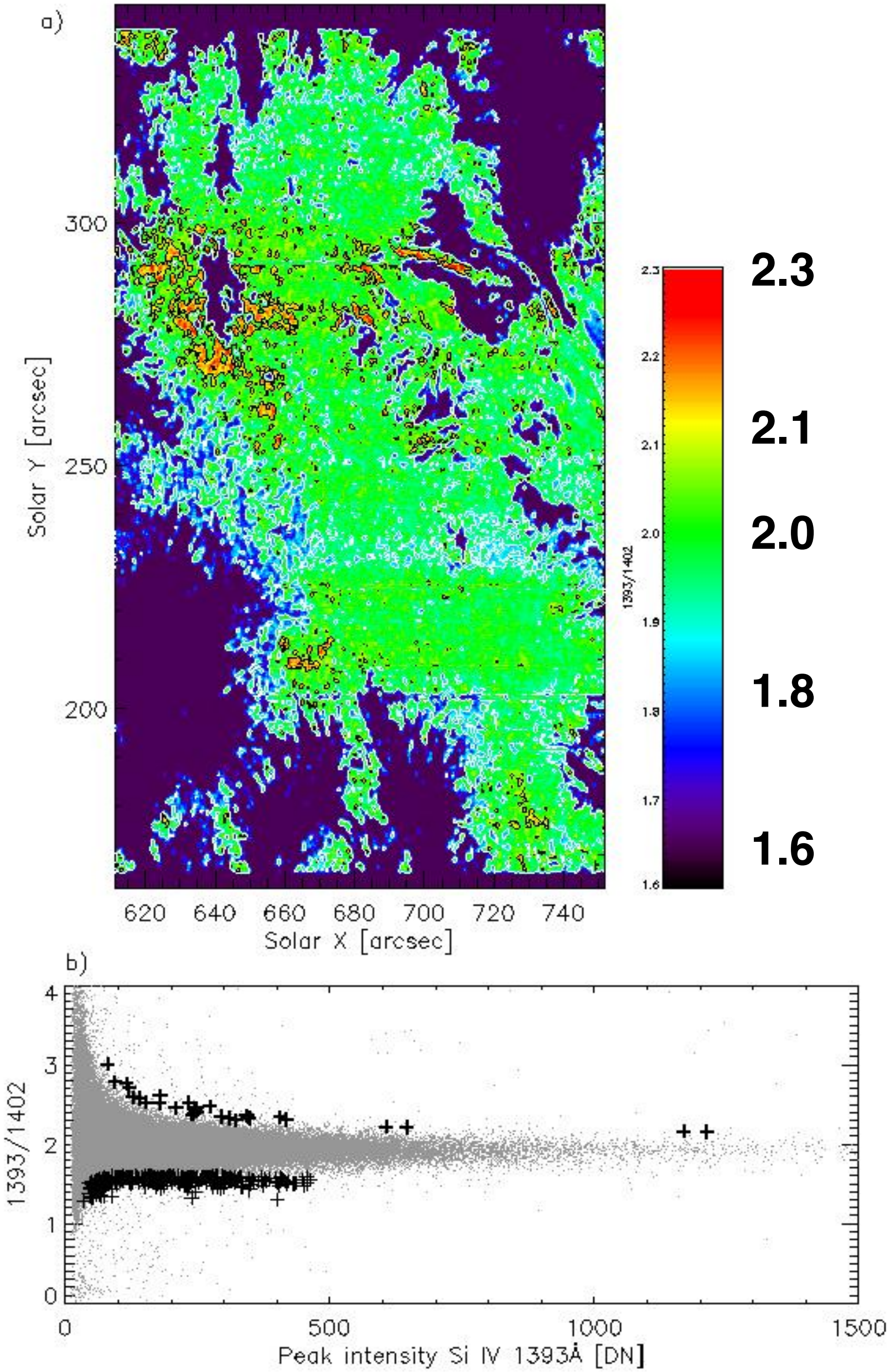
$I_{13}/I_{12}=2$ in most cases

$I_{13}/I_{12}<2$ around quiet areas

$I_{13}/I_{12}=$ versus 1393Å peak intensity

**Only 29** pixels $I_{13}/I_{12}>2$

**However !**
**We re-estimated the error bars**




Peak intensity Si IV 1393Å [DN]

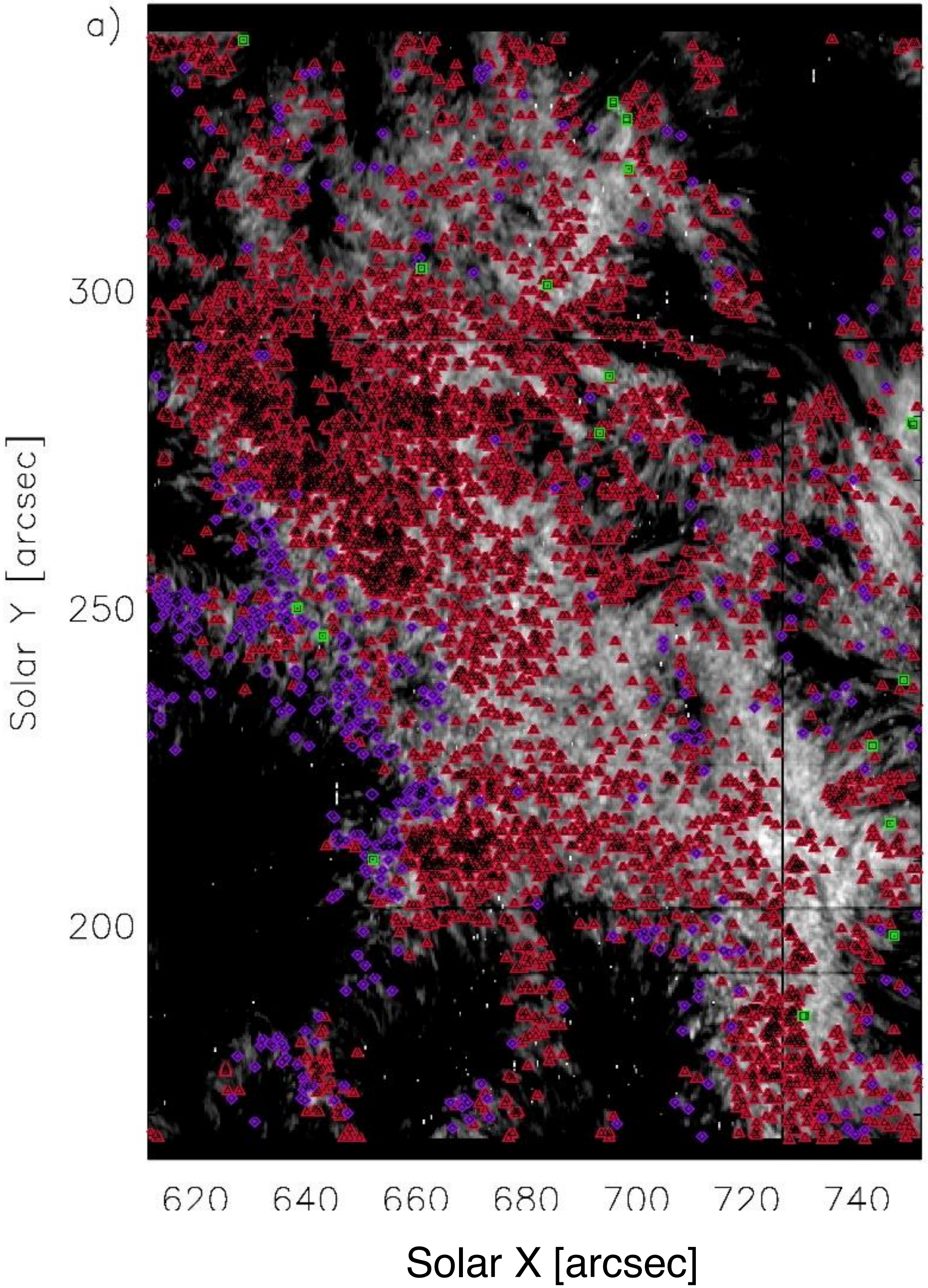
$I_{13}/I_{12}>2$

**~6000 pixels**

**(~3% of FOV)**

$I_{13}/I_{12}<1.6$

**>300 pixels on fibrils**



**443 points**

$n_e$ :

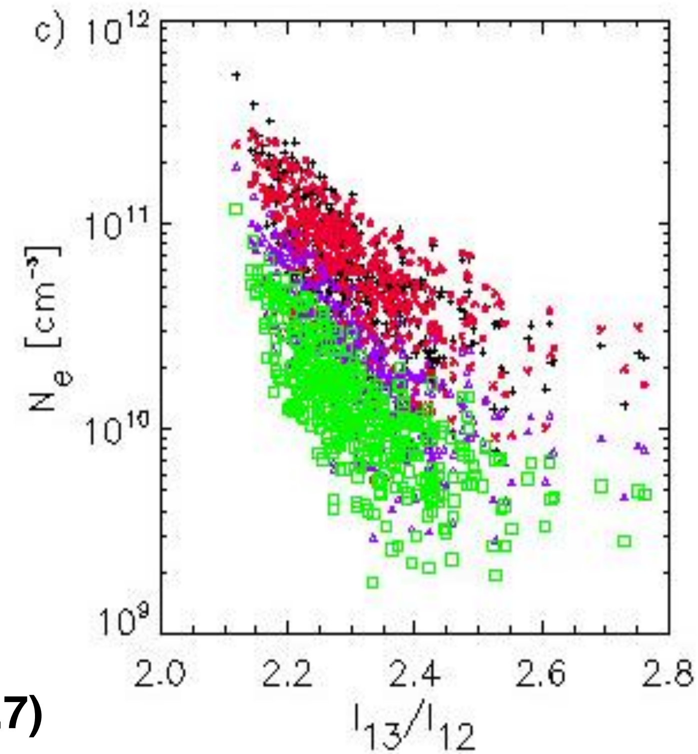
T (4.E4K-2.E5K)

H (1” - 5”)

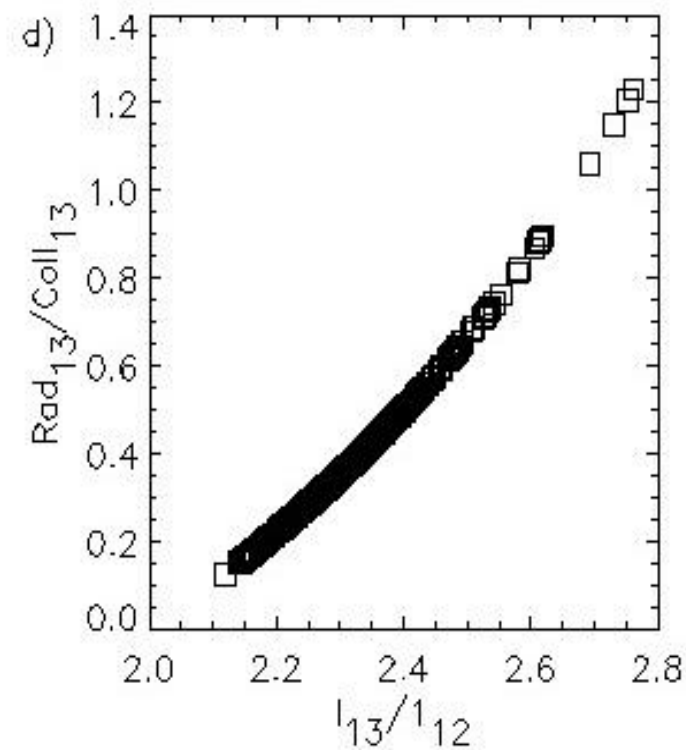
□ H=1” T=2.E5K
▲ H=1” T=8.E4K
* H=5” T=4.E4K
+ H=1” T=4.E4K

**Teq=8.E4K (CHIANTI v.7)**

electron densities




Scatterings/Collisions




$$I_{13}(\nu) = h\nu_{13}(n_i\, n_e C_{13}\, \psi_\nu \;\; + \; n_i B_{13} \bar{J}_{13}(\nu)) \frac{L}{4\pi}, \quad 1393Å$$

$$I_{12}(\nu) = h\nu_{12}(n_i\, n_e C_{12}\, \psi_\nu \;\; + \; n_i B_{12} \bar{J}_{12}(\nu)) \frac{L}{4\pi}. \quad 1402Å$$

Kohl & Withbroe1982 ApJ
Noci etal 1987 ApJ
Gontikakis etal 2013 A&A

**$n_e$ decreases as a function of $I_{13}/I_{12}$.**

**$I_{13}/I_{12}$ >2.4 Scatterings/Collisions> 0.5**

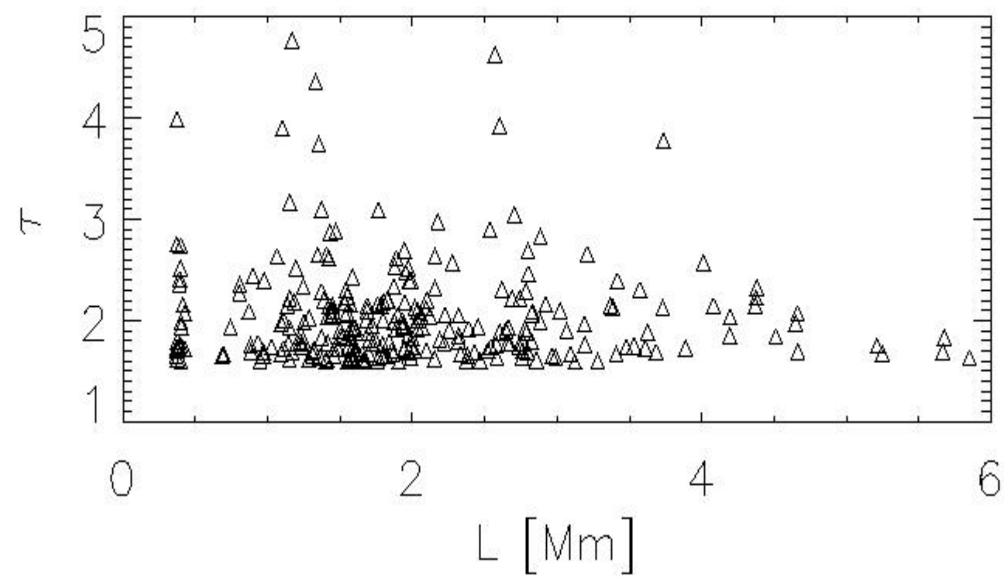
<u>Calculation of the optical thickness τ</u>

1) **τ** computed as a function of $I_{13}/I_{12}$.

$$\frac{I_{13}}{I_{12}} = \frac{\int (1 - e^{-\tau_{130} e^{-0.5y^2}})dy}{\int (1 - e^{-\frac{\tau_{130}}{2} e^{-0.5y^2}})dy},$$

Buchlin & Vial 2009 A&A
Dere & Mason 1993 Sol. Phys.

**τ (1.5 - 2.6)**

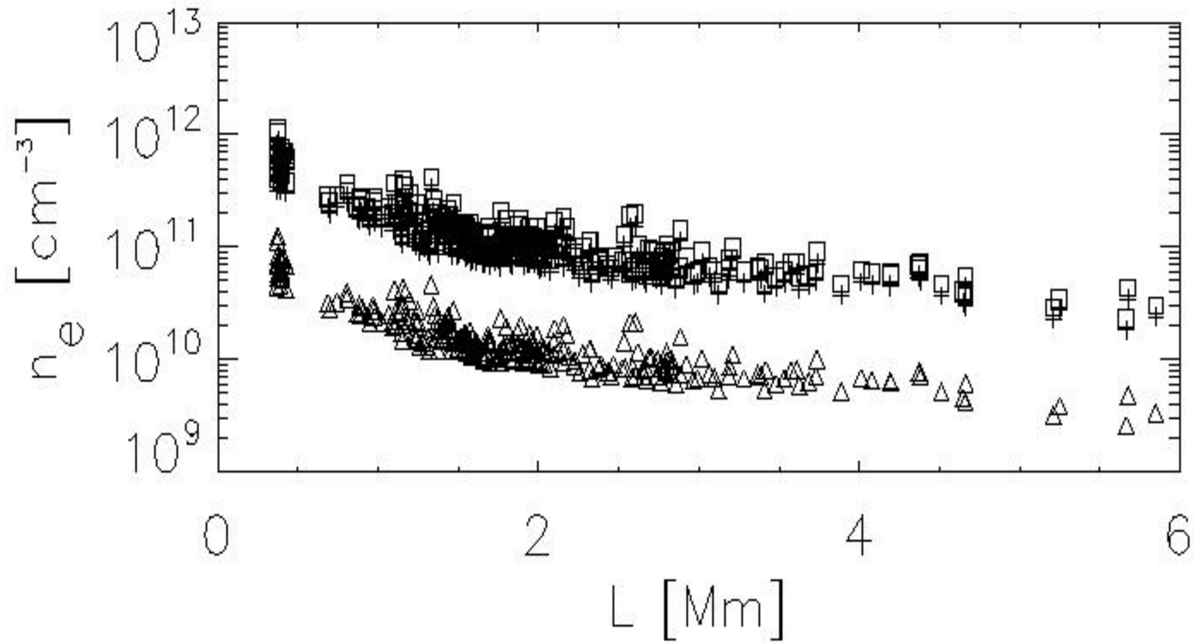



L structure size along LOS [Mm]

2) Measurement of fibril size **L,** using Gaussian fits along the slit across the fibrils.

Electron density $n_e$ calculated as a function of $\tau$ and **L**

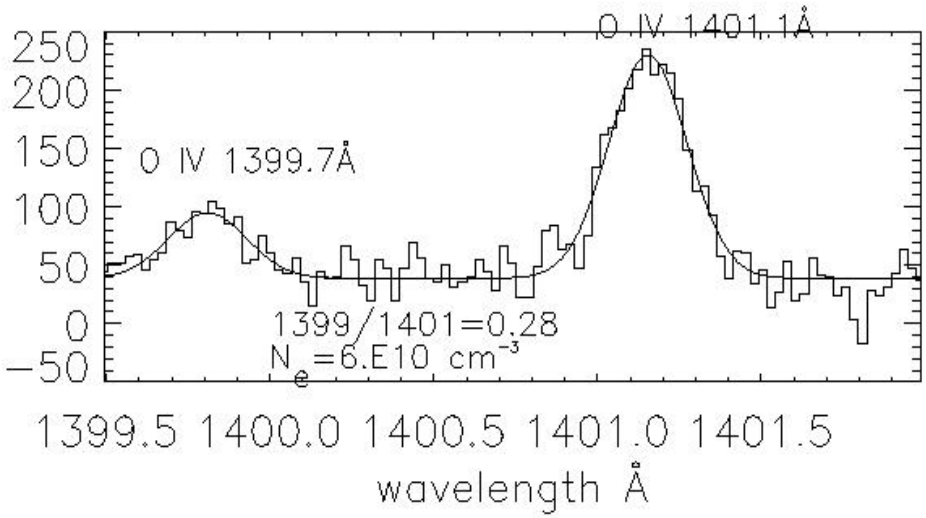
$\tau = n_e \, 0.8 \, Ab \, l_0 \, f(T) \, \mathbf{L}$

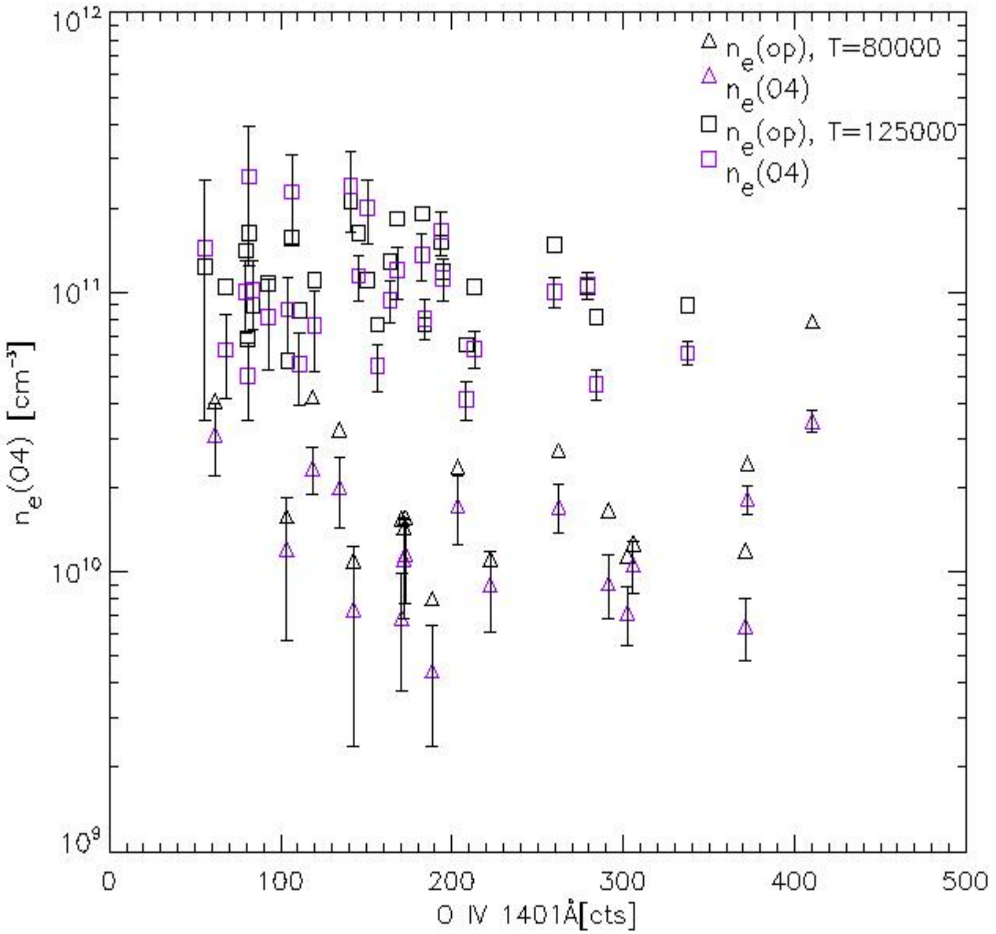



L structure size along LOS [Mm]

Ab, f(T) from CHIANTI v.7
filling factor =1

$n_e$ from O IV 1399Å/1401.Å compared with $n_e$ from opacity profiles (fibrils)




**$n_e$** from O IV 1399Å/1401Å

and **$n_e$** from optically thick profiles :

Both measurements agree for **27%** of pixels
for T=80000 and T=125000K
T(OIV)=140000K

Pressure equilibrium:
$n_e$(OIV) T(OIV) = $n_e$(op)T(op)

# Conclusions

Doublets used to measure resonant scattering and opacity

3% individual profiles affected by resonant scattering

Resonant scattering when $n_e$ low
Resonant scattering important in and around many active regions ?

~300 Optically thick profiles over fibrils

Measured $\tau$ : 1.5 – 2.6

Two tools to measure electron densities

$n_e$ (O IV), $n_e$(optically thick)

Measurements agree for 27% of cases
For Temperatures 80000K and 125000K

C. Gontikakis thanks Université Paris-Sud France
Many thanks to B. De Pontieu, W. Liu, J.-P. Wuelser for their comments

**Collision term and radiative scattering term**

$$I_{13}(\nu) = h\nu_{13}(n_i\, n_e C_{13}\,\psi_\nu \;\; + \; n_i B_{13}\bar{J}_{13}(\nu))\frac{L}{4\,\pi},$$

$$I_{12}(\nu) = h\nu_{12}(n_i\, n_e C_{12}\,\psi_\nu \;\; + \; n_i B_{12}\bar{J}_{12}(\nu))\frac{L}{4\,\pi}.$$

Incident intensities J13, J12
The diffusion region is at altitude **h** above the disk and is illuminated 'from below'

Free parameters : Altitude h, Temperature T

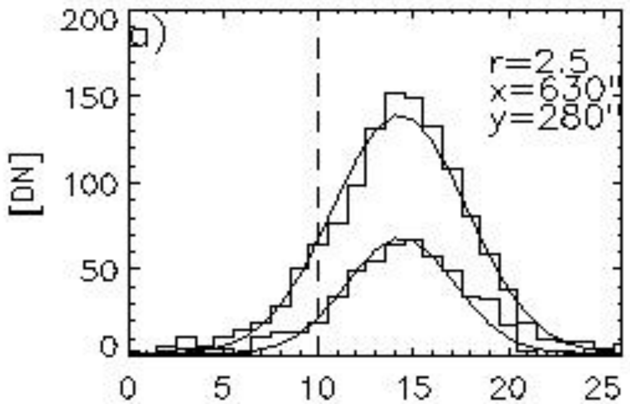
$n_i$ $n_e$ density of ion, electrons
$C_{13}$(T) collision frequency (CHIANTI v.7)
$\Psi_v$ , $\Phi_v$ emission,absorption profiles
$B_{13}$,$B_{12}$ Einstein coefficiens
L line of sight length

Examples of individual profiles

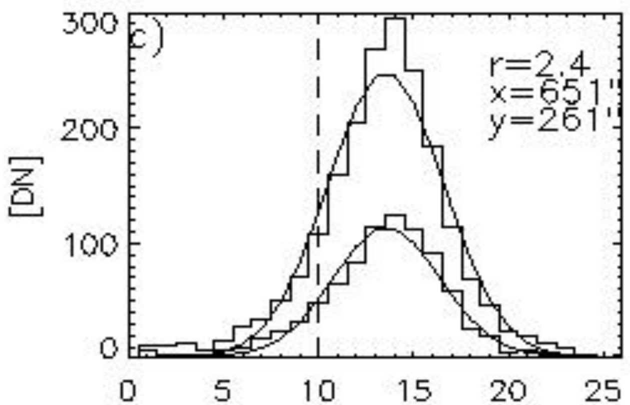
Resonant scattering profiles

Optically thick profiles

$I_{13}/I_{12}$=2.5

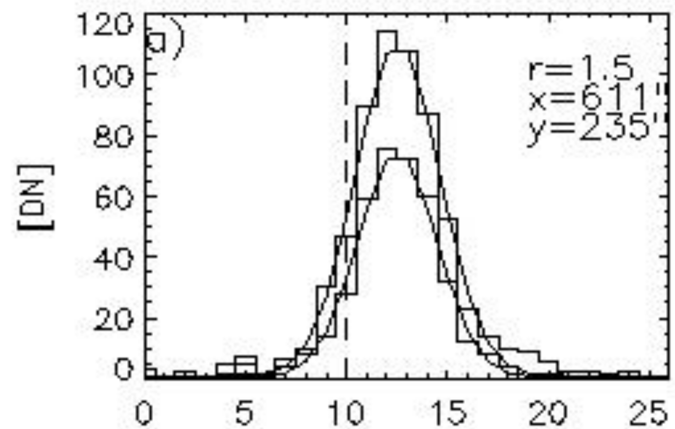



$I_{13}/I_{12}$=2.4

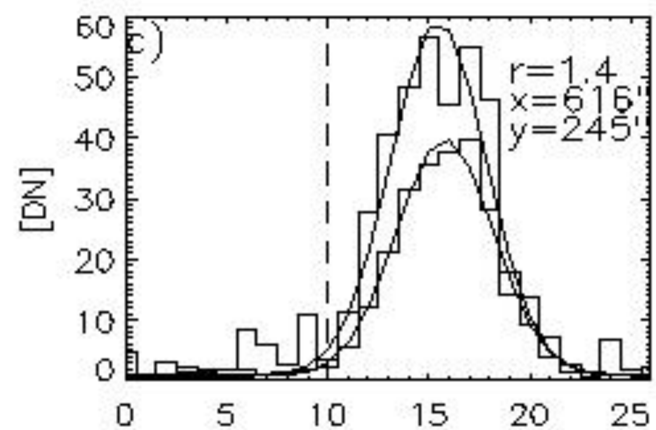



Spectral pixels

$I_{13}/I_{12}$=1.5




$I_{13}/I_{12}$=1.4




Spectral pixels