# THE DYNAMICS OF THE LOWER TRANSITION REGION AS INFERRED FROM SPECTROSCOPY OF THE HYDROGEN LYMAN-α LINE

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## ABSTRACT

Using the SUMER spectrograph, we have acquired several raster scans and one temporal series in the H I Ly-α 121.6 nm line. In several cases, the optically thin Si III 120.6 nm line ($T \approx 60{,}000$ K) was also recorded simultaneously. The high spectral resolution of SUMER aboard SOHO, orbiting around the first Lagrangian point, allows us to study in detail the H I Ly-α profile without the contamination of geocoronal emission. Quiet-Sun profiles, averaged over areas ranging from cell centres to bright network, show that the relative amplitude of the central reversal becomes smaller with increasing line radiance. High spatial resolution profiles show a high degree of variability, revealing the signature of transition-region explosive events. The H I Ly-α line radiance clearly shows the presence of the 3-min internetwork oscillations, while oscillations with larger periods seem to be present in the network.

## 1. INTRODUCTION

The Lyman-α ($1s\ ^2S_{1/2} - 2p\ ^2P_{3/2,1/2}$) transitions of neutral hydrogen are responsible for the strongest emission line in the solar spectrum and dominate the radiative losses for the temperature regime between 8,000 K and 30,000 K. Hence, H I Ly-α is the most important line formed in the lower transition region (TR) and upper chromosphere.

Although this line is optically thick, it was already shown 25 years ago by the Transition Region Camera (TRC: Bonnet et. al. 1980) Lyman-α imager that structures were still not resolved at 1″ resolution.

More recently, the Very high resolution Advanced Ultraviolet Telescope (VAULT: Korendyke et al. 2001) Lyman-α spectroheliograph has revealed structures as small as its 0.33″ (≈ 240 km) resolution. Such images also show many structures evolving on time scales of few tens of seconds. Thus, the H I Ly-α line can provide a powerful diagnostic for studying the region between the upper chromosphere and the lower TR.

This is the region where the expansion of the photospheric magnetic field takes place, and it is extremely important for studies of the coupling of the solar outer atmosphere with the underlying photosphere. It is through this region that the energy produced in the interior of the Sun must pass to reach and heat the solar corona. Waves and/or magnetic reconnection and currents generated by the motions of the magnetic field at photospheric level are candidates for coronal heating and the study of their signatures in the H I Ly-α profile can help understanding such phenomena. Moreover, being optically thick, the H I Ly-α profile is formed over a wide range of temperatures and is strongly dependent upon the temperature structure of the upper chromosphere and lower TR and on the dynamics of the structures within the resolution element, as discussed by Fontenla et al. (1988). Thus, the modelling of both average and high spatial resolution profiles, characterized by high spectral resolution, may help in understanding the nature of the emitting region.

High spatial and spectral resolution observations in the H I Ly-α line were obtained in the past by instruments in Earth's orbit, where they were affected by strong geocoronal absorption (Fontenla et al. 1988).

The SUMER instrument aboard SOHO (located at the first Lagrangian point) is well outside the hydrogen geocorona. This, together with the precise radiometric calibration of the instrument, permits us to study the morphology and dynamics of the lower TR in its dominant emission line in unprecedented detail and with high accuracy. Furthermore, the high spectral resolution of SUMER allows us to analyse the H I Ly-α profile in different locations of the solar disk.

## 2. OBSERVATIONS AND INSTRUMENTATION

Small raster scans (≈ 80″×58″) of selected quiet Sun areas have been produced with the SUMER spectrograph (Wilhelm et al. 1995) aboard SOHO.

Since May 2004 detector A has been showing a deterioration of the ADC in the time-to-digital

*Table 1: Summary of the quiet Sun H I Ly-α observations used for the present study.*

| Date | Solar coordinates at sequence start[(a)] | Start UTC (duration min) | Exposure time (s) | Type of Sequence | Spectral lines (λ in nm) |
|---|---|---|---|---|---|
| 16 Apr. 2005 | X=0, Y=29 | 22:12:13 (20) | 10 | E-W raster | Ly-α λ 121.567, Si III λ 120.651 |
| 01 June 2005 | X=0, Y=29 | 22:42:17 (15) | 2.0 | Temp. series | Ly-α λ 121.567 |
| 01 June 2005 | X=−43, Y=29 | 22:58:06 (11) | 7.5 | E-W raster | Ly-α λ 121.567, Si III λ 120.651 |

(a) Coordinates refer to the centre of the useable part of the detector covered by the slit.

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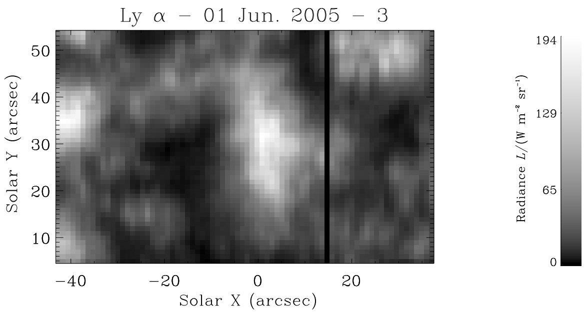


*Figure 1. Square-root line radiance images of a quiet region near Sun centre. The dark vertical line is due to telemetry drop-outs.*

converter box. As a consequence, large portions of the detector can only be used binned over 64 spatial pixels. This defect concerns only the *y*–ADC, affecting the pixel rows, while the *x*–ADC is still properly working, leading to correct spectral information. Presently, only the 58 rows at the bottom of the detector still retain their full spatial resolution (≈1″) and were used for the present study. The defect appears to progress also when the detector is turned off. This has led to the decision of allowing, for the first time since the beginning of the mission, on-disk observations of the H I Ly-α line to be made outside of the attenuator areas. A summary of all the data used in this paper is given in Table 1.

Due to the continuously changing detector conditions, special attention needs to be paid to the data reduction process. The flat-fields, in particular, have been obtained by averaging and median filtering large amounts of data. All data were acquired using the narrow 0.3″×120″ slit on the bottom part of detector A.

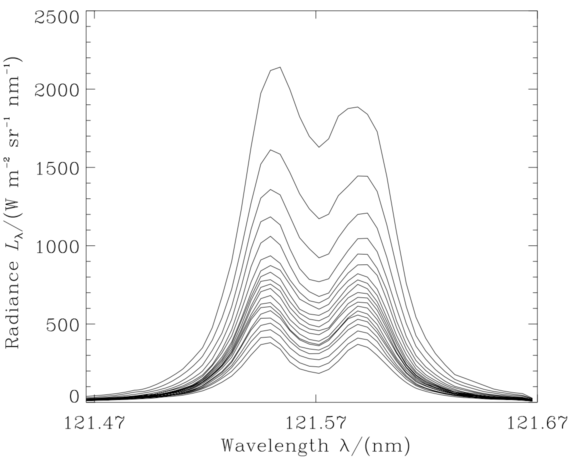


*Figure 2. H I Ly-α spectral profiles obtained by dividing the H I Ly-α raster scan shown in Fig. 1 into 20 intensity bins, each containing the same number of spectra (i.e., each arising from the 5% of the total observed area).*

## 3. NETWORK AND INTERNETWORK AVERAGE SPECTRAL LINE PROFILES

Figure 1 shows a quiet Sun network cell as seen in the H I Ly-α line. The individual spectra forming the image are characterized by a high degree of variability and can only be studied individually. Figure 2 shows the H I Ly-α profiles obtained by dividing the raster scan into 20 radiance bins, each containing the same number of spectra. Thus, the weakest profile arises from the faintest 5% of the observed area, and so on for the other profiles. The averaging process smoothes out solar variability, highlighting differences that may be due to the different (on average) magnetic structures of the emitting regions, going from the darker cell centres to the brighter network. The profiles clearly show a decrease of the relative amplitude of the central reversal with increasing radiance.

Recently, Emerich et al. (2005) found that the central spectral irradiance ($E_{\lambda 0}$) and the total line photon irradiance ($E$) of the H I Ly-α line were related as: $E_{\lambda 0}/(10^{12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{nm}^{-1}) = 0.64\times(E/10^{11}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1})^{1.21}$. In the above cases the irradiance variations are largely due to the varying number of active regions across the solar cycle. Optically thick lines (Wilhelm et al. 1998) show no relevant limb brightening and, hence, average quiet Sun profiles can be considered as representative of irradiance profiles for a disk without active regions. The spectral radiances of Fig. 2 have been transformed into irradiances to verify whether the same relationship also holds for the quieter areas of the Sun.

Our results, shown in Fig. 3, prove this to be the case. The small difference with respect to the Emerich et al. (2005) result is possibly due to some small limb brightening of H I Ly-α and/or to the effect of coronal holes on the real irradiance profiles.

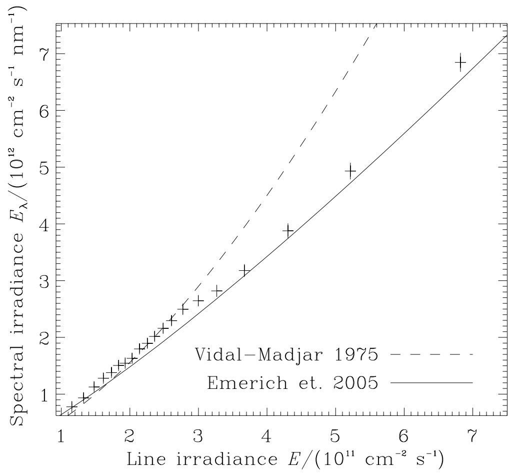


*Figure 3. Total versus central spectral irradiances for the 20 profiles of Fig. 2 (converted into irradiances, see text). The relationships found by Emerich et al. (2005) and Vidal-Madjar (1975) from irradiance data are also shown.*

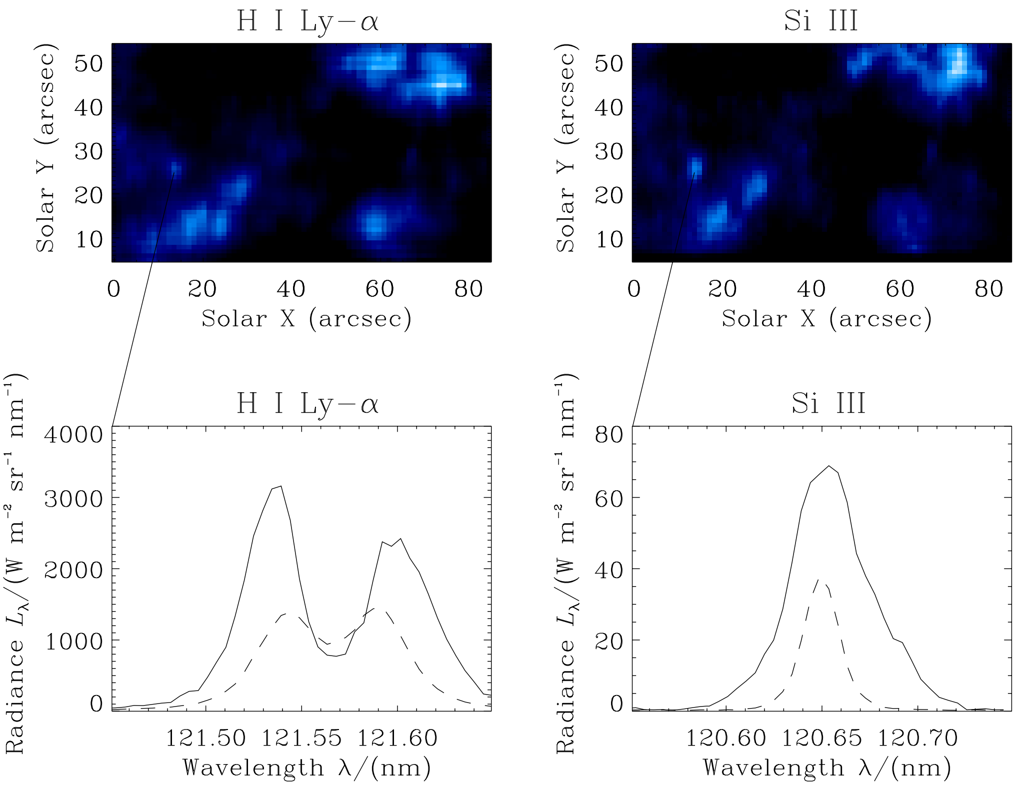


*Figure 4. Example of the signature of transition region EEs (identified in Si III spectra) in the H I Ly-α line. Radiance maps (top) and spectral profiles (bottom) from 16 April 2005 are plotted. The dashed lines refer to the profiles obtained by averaging along the slit, above and below the EE location. The H I Ly-α profile seems to be characterized by strongly enhanced wings in EEs with respect to the quiet profile*

## 4. EXPLOSIVE EVENTS

When observed at high spatial resolution (≤1″), the solar TR reveals the existence of dynamic transient events such as explosive events (EEs), jets and spicules. EEs, in particular, are characterized by strongly non-Gaussian line profiles due to velocities up to 200 km $s^{-1}$, and are generally believed to be the result of magnetic reconnection (Innes et al. 1997). They are usually observed in optically thin emission lines formed between $5\times10^4$ K and $7\times10^5$ K. Figure 4 (right column) shows such an event as identified from the Si III spectral profile. The corresponding H I Ly-α profiles also show enhanced wings with respect to quiet-Sun profiles. A comparison with Fig. 1 shows that the H I Ly-α enhancement in an EE cannot be mistaken with the enhanced brightness in regions of strong field. This is the first time that such events are observed in H I Ly-α.

## 5. RADIANCE OSCILLATIONS

The observation of periodic or quasi-periodic variability of the radiances of lines formed in the upper chromosphere and low TR is of particular interest for the understanding of the so-called non-magnetic chromosphere in internetwork areas as well as the magnetic network.
The top left panel of Fig. 5 shows the time behaviour of the H I Ly-α line radiance at each position along the slit. The top right panel was obtained by normalising each row of the data on the left panel to its second order polynomial fit, and clearly shows the variable nature of the quiet-Sun lower TR. Figure 5 also shows that H I Ly-α line radiance oscillations with a period of ≈ 3 min are visible in the internetwork (green and blue panels). In the network (red and black panels), periods longer than 3-4 min seem to be present together with periods shorter than 2 min. However, the short duration of our observations prevents us from making a conclusive statement, especially regarding the network.

## 6. CONCLUSIONS

We have acquired and analysed high spectral and spatial resolution profiles of the H I Ly-α line at 121.567 nm in quiet-Sun regions using the SUMER spectrograph aboard SOHO. Data cover both network and internetwork lanes.

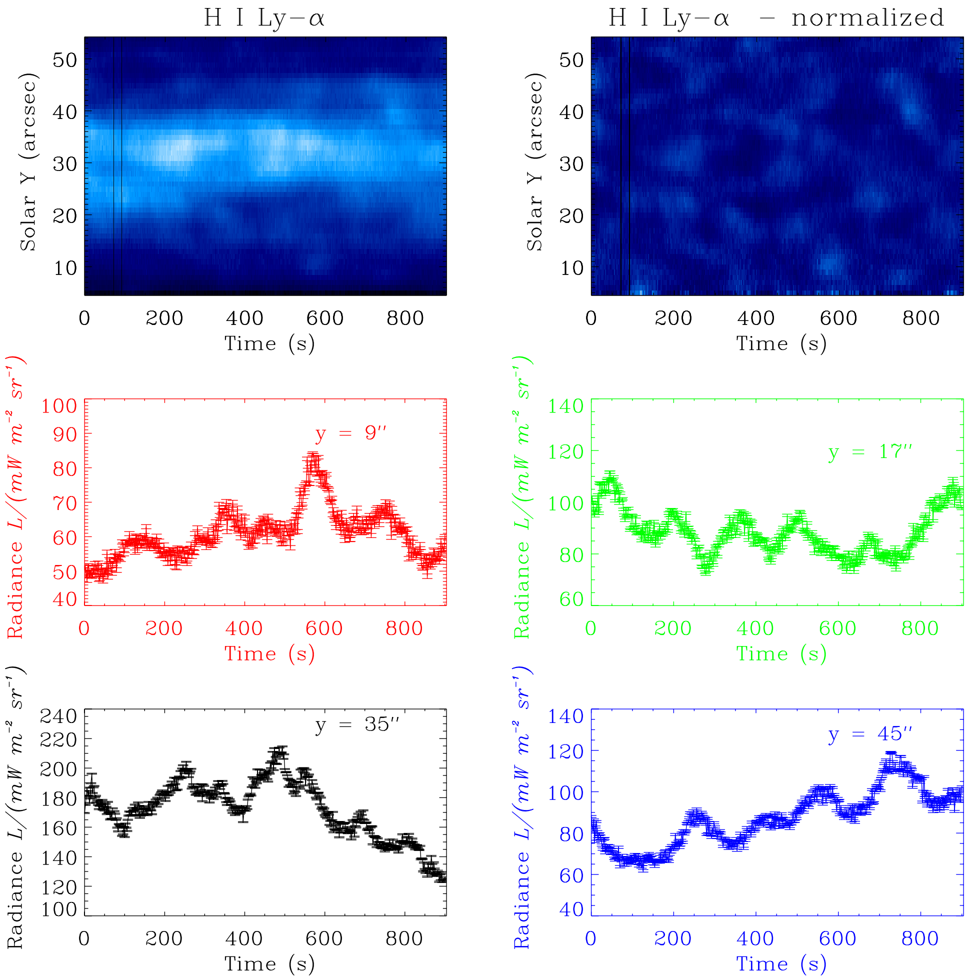


*Figure 5. The top left panel shows the time behaviour of the H I Ly-α line radiance at all locations along the slit. Tthe top right panel shows the same image is plotted after dividing the temporal evolution at each position along the slit by a second order polynomial fit. The two dark vertical lines are due to telemetry drop-outs. Oscillations are evident almost everywhere. At internetwork locations (y=17 and y=45) the well known 3-min oscillations are clearly seen.*

The relative amplitude of the central reversal of the H I Ly-α averaged line profiles becomes progressively smaller in increasingly brighter areas, and the relation between the line radiance and central spectral radiance appears to follow the same functional relationship found for the variation of disk-integrated line profiles along the solar cycle.

Transition-region explosive events are visible in H I Ly-α line radiances and spectral profiles.

Internetwork 3-min oscillations are clearly seen in the H I Ly-α line radiance, while longer periods seem to be present in the network lanes.

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