

THE DYNAMIC NATURE OF THE LOWER TRANSITION REGION AS REVEALED BY SPECTROSCOPY OF THE HYDROGEN LYMAN- α LINE

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ABSTRACT

Taking advantage of the spectral capabilities of the SUMER spectrograph aboard SOHO, we have acquired several temporal sequences comprising simultaneously both the H I Lyman- α 121.567 nm and the optically thin Si III 120.651 nm line ($T \approx 20,000$ K) on both Sun centre and the north limb. The temporal evolution of the integrated radiances looks very similar at the 1.5" SUMER spatial resolution, showing the H I Lyman- α radiance to be a good diagnostic of the dynamics of the lower transition region. At disk centre the 3 min oscillations are sporadically observed in bursts of short duration (≈ 15 minutes) in the inter-network but also in locations at the edges of network lanes. Longer bursts of 5 minutes oscillations are also sometimes observed in the inter-network, while they clearly dominate in the network. Si III data yield the same picture, although the lower S/N limits the analysis mostly to the network. Above the limb, the variability is dominated by spicules and macrospicules. Some of them show a quick (≈ 100 s) rise up to around 15" to 30", followed by a slower fall back (200 to 300 s). An indication of a periodicity of about 10 min in their appearance is also present. At the base of spicules (1" to 2" above limb), we find evidence of 3 to 5 min oscillations.

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 energy losses of the plasma at temperatures between 8,000 K and 30,000 K.

Past spectroscopic observations of the Lyman- α line have often been characterised by a compromise between spatial and spectral resolution and, even more often, by the lack of adequate temporal resolution and coverage.

However, they have shown the extreme variability of the Lyman profiles in different solar features.

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.

In this region most of the expansion of the photospheric magnetic field has already taken place (especially in active regions and the network, but also in the internetwork), and it is 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 (e.g., Fontenla et al., 1988).

High spatial and spectral resolution observations in the H I Ly- α line were obtained so far 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.

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)
1	01 June 2005	X=0, Y=29	22:42:17 (15)	2.0	Temp. series	Ly- α λ 121.567
2	06 Oct. 2005	X=0, Y=-88	15:12:01 (91)	7.5	Temp. series	Ly- α λ 121.567, Si III λ 120.651
3	07 Oct. 2005	X=0, Y=-88	15:12:09 (91)	7.5	Temp. series	Ly- α λ 121.567, Si III λ 120.651
4	12 Oct. 2005	X=0, Y=980	16:10:52 (91)	7.5	Temp. series	Ly- α λ 121.567, Si III λ 120.651
5	13 Oct. 2005	X=0, Y=991	15:13:58 (91)	7.5	Temp. series	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.

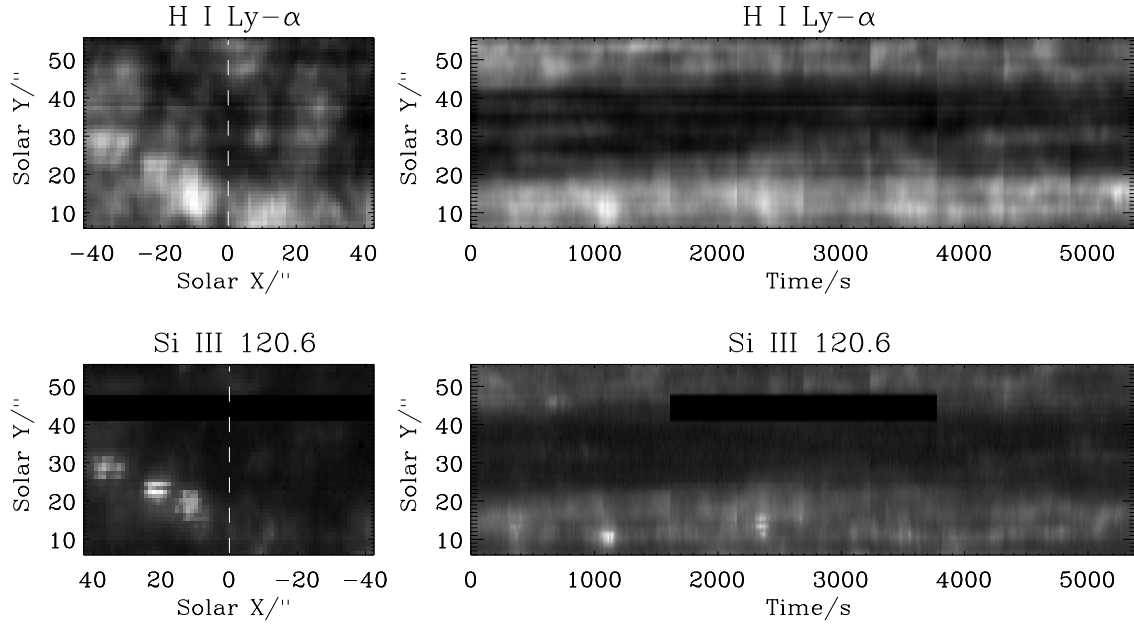


Figure 1: Square-root radiance images (left panels) observed on 6th October (# 2 in Table 1). The vertical dashed lines indicate the position of the slit at the start of the temporal series shown on the right panels. Black areas are unusable data due to the presence of dead pores in the micro-channel plates.

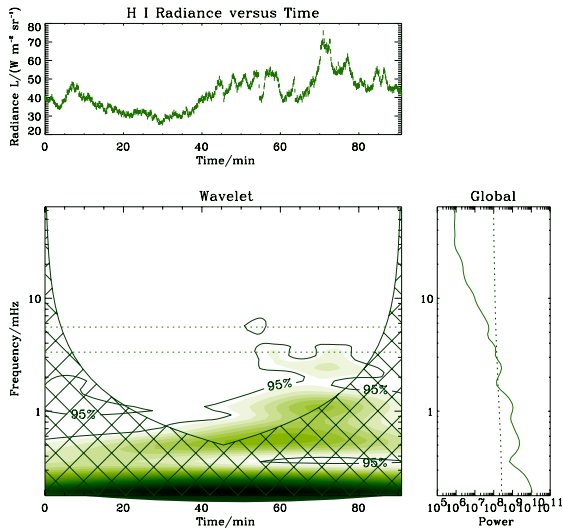


Figure 2: Wavelet analysis of the H I Ly- α radiance in the inter-network ($Y=29''$, # 2). Top panel: radiance time series. Data points are represented by vertical bars whose lengths indicate the uncertainties. The large panel shows the wavelet power spectrum of the shown light curve. The regions enclosed by the thick solid lines have confidence above 95%. Edge effects become important in the cross-hatched regions. The horizontal dotted lines indicate frequencies of 3.3 mHz (5 min) and 5.5 mHz (3 min). Bottom right panel: average over time of the wavelet power spectra. Power around 5.5 mHz can be seen only for very short time (10 to 15 min). Power around 3.3 mHz can also be seen towards the end of the series.

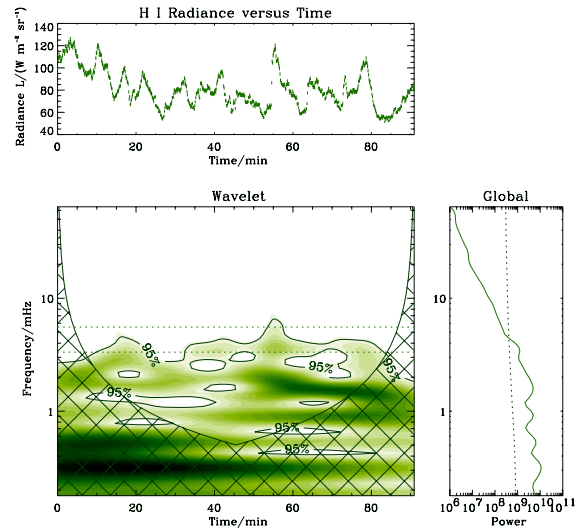


Figure 3: Same as Fig. 2 but showing the wavelet analysis of the H I Ly- α radiance in a network region ($Y=51''$, # 2). Power around 5.5 mHz can be seen only for very short time (10 to 15 min). Power around 3.3 mHz (5 min) can be seen during most of the time series.

2. OBSERVATION AND INSTRUMENTATION

The observations here discussed were obtained with the SUMER spectrometer (Wilhelm et al. 1995) aboard SOHO using the A detector.

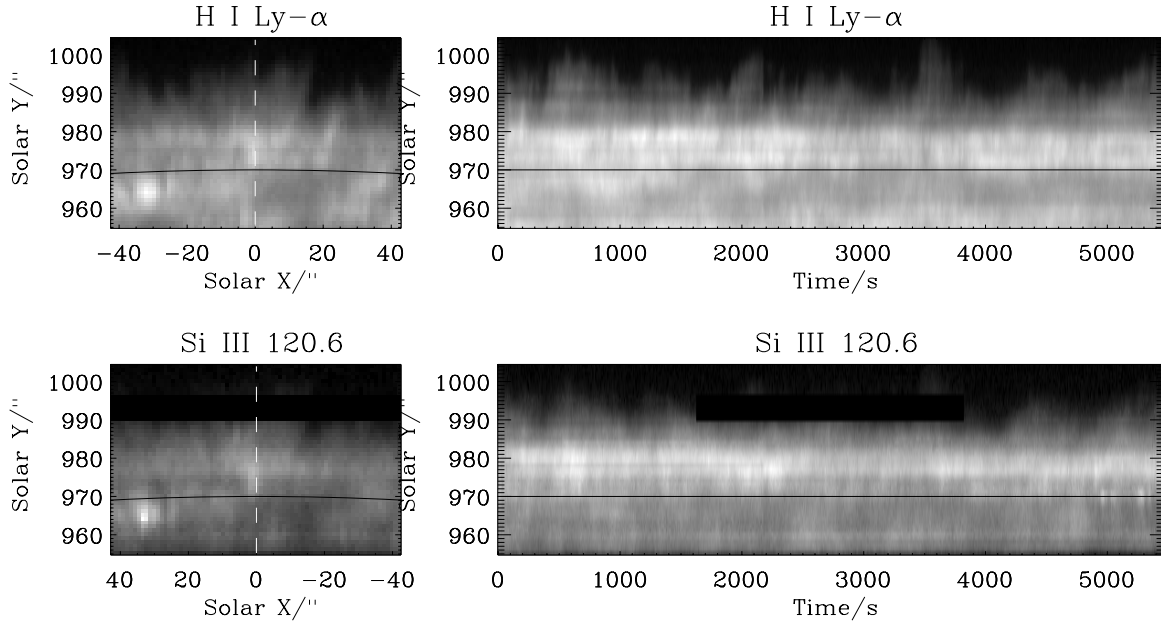


Figure 4: Same as Fig. 1 but at the solar limb. Square-root radiance images (left panels) observed on 12th October (# 4 in Table 1) at the north limb. In this dataset spicules show a periodicity of about 10 min in their appearance. Some of them (at $t=400$ s, 1200 s and 3400 s) show a quick rise (≈ 100 s) and a slower fall back (≈ 300)

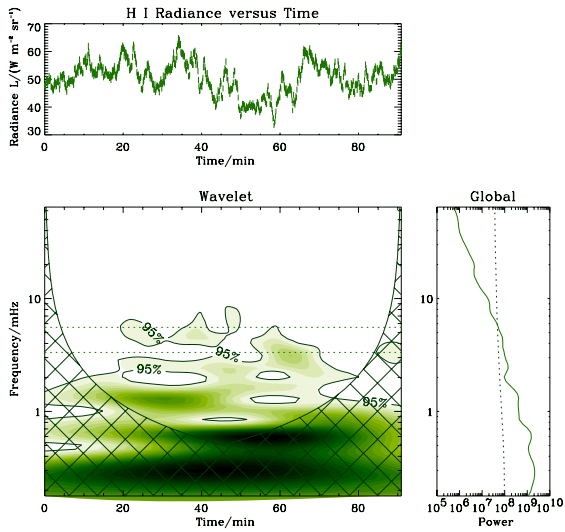


Figure 5: Same as Fig. 2 but showing the wavelet analysis of the H I Ly- α radiances in a region $1''$ to $2''$ above the limb (defined from the position of the radiance peak in the continuum near the Si III line). Power up to 6 mHz can be seen in the central part of the time series.

The very high radiances of the H I Lyman- α 121.567 and Si III 120.651 lines would allow very high observing cadences. On the other hand SUMER/SOHO has a limited telemetry rate. Nevertheless, by transmitting only the spectral windows centred on the lines of interest and by using the on-board memory, we achieved cadences of 2 s (only H I Ly- α for 15 min) and 7.5 s (both lines for 91 min).

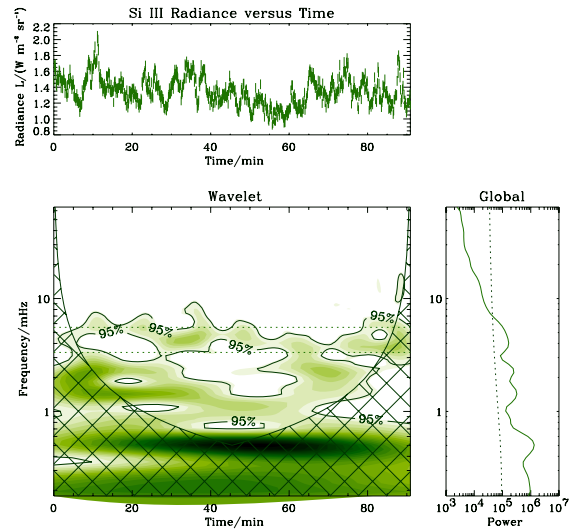


Figure 6: Same as Fig. 2 but showing the wavelet analysis of the Si III radiances in a region $1''$ to $2''$ above the limb (defined from the position of the radiance peak in the continuum near the Si III line). Power up to 6 mHz can be seen for the entire time series.

Since May 2004 detector A has started showing a deterioration of the ADC such that only the first 58 rows were still useable at the time of observations. All data were acquired using the narrow $0.3'' \times 120''$ slit on the bottom part of detector A. Table 1 summarizes the studied datasets. Each temporal series is preceded and followed by a $\approx 80'' \times 50''$ context raster image.

3. TIME VARIABILITY OF THE QUIET SUN

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. Teriaca et al. (2005) reported the observation of clear 3 min (5.5 mHz) oscillations of the H I Ly- α radiance in inter-network areas. However, the observations consisted of a short time series (15 min, dataset 1) that prevented a study of their duration and occurrence. On October 2005 we have acquired two new datasets each lasting 91 min. In both datasets, the H I Ly- α and Si III observations are simultaneous in time and space and appear similar despite the large optical thickness of H I Ly- α . These datasets (2 and 3) allow a detailed study of the quiet Sun temporal behaviour.

Figure 1 shows the time variability of the H I Ly- α and Si III radiances and clearly underline the variable nature of the quiet Sun lower TR.

Figures 2 and 3 show the wavelet analysis of the H I Ly- α line radiance at selected positions along the slit. Oscillations with a period around 3 min are sporadically observed in bursts of short duration (\approx 15 minutes) in the inter-network (see Fig. 3) but also in locations at the edges of network lanes. Longer bursts of 5 minutes oscillations are also sometimes observed in the inter-network, while they clearly dominate in the network (see Fig. 4). Si III data yield the same picture, although the lower S/N limits the analysis mostly to the network.

4. TIME VARIABILITY ABOVE THE LIMB

Time variability at the limb is dominated by spicules and macrospicules that appear to rise to heights of 15" to 30" above the limb. Figure 4 shows the temporal evolution of the north limb in both H I Ly- α and Si III lines. Some spicules show a quick (\approx 100 s) rise up to around 15" to 30", followed by a slower fall back (200 to 300 s). An indication of a periodicity of about 10 min in their appearance is also present. Figures 5 and 6 show the wavelet analysis of the H I Ly- α and Si III radiances at a position 1" to 2" above the limb (defined from the maximum along the slit of the radiance of the continuum near the Si III line). At this location we find clear signature of oscillations with periods between 3 and 5 minutes, particularly well visible in the Si III line.

On inclined magnetic flux tubes, photospheric p-modes (5 min) may leak sufficient energy into the chromosphere to generate shocks driving upward motions leading to the formation of spicules (De Pontieu et al. 2004).

5. 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 the disk centre and the north limb.

Despite the large opacity characterizing the H I Ly- α , images and temporal series in this line look similar to those obtained in the optically thin Si III 120.6 nm line. In the inter-network, short (10 to 15 min) bursts of oscillations with a period around 3 min are sometimes observed. Five minutes oscillations are more frequently seen and appear to last longer.

In the network, 5 min oscillations appear to be present very often during large fractions of the observed time series.

At the limb, variability is dominated by the raising and falling of spicules and macrospicules. Some spicules show a quick (\approx 100 s) rise up to around 15" to 30" above the limb, sometimes followed by a slower fall back (\approx 300 s). A periodicity in their appearance of about 10 min seems also present.

An indication of 3 to 5 min oscillations is found at the base of spicules (1" to 2" above limb).

ACKNOWLEDGEMENTS: The SUMER instrument and its operation are financed by the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the Centre National d'Études Spatiales (CNES), the National Aeronautics and Space Administration (NASA), and the European Space Agency's (ESA) PRODEX programme (Swiss contribution). The instrument is part of ESA's and NASA's Solar and Heliospheric Observatory (SOHO).

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