Observational searches for g-mode oscillations in the quiet solar atmosphere from TRACE 1600 Å Continuum Observations

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powerful tool for the investigation of the solar core, and a way to solve, for instance, the neutrino problem. It has been suggested that the turbulent convection below the photosphere will generate the high order, non-radial g-mode oscillations (internal gravity waves) (Meyer and Schmidt, 1967; Stix, 1970). There are theoretical studies earlier on solar-atmospheric gravity waves by various groups (Whitaker, 1963, Lighthill, 1967, Stein, 1967 and Schmieder, 1977). In Frazier’s (1968) $k - \omega$ diagrams, the traces of internal gravity waves may be present. Deubner (1974) observed the generation of internal gravity waves by individual granules. Cram (1978) has investigated the evidence of low, but significant, power at frequencies relevant to internal gravity waves. He had also concluded from the studies of the phase lag between successive layers, that there was an upward energy flux. In addition, Brown and Harrison (1980) have observed the indications of the possible existence of trapped gravity waves by analyzing the brightness fluctuations of the visible continuum. These internal gravity waves, by-products of the granulation, are expected to be fairly common and may not be negligible in the energy balance of the lower chromosphere. Pallé (1991) had discussed in great detail on various methods to search for solar gravity modes.

In recent years, an increasing amount of attention has been given to the possible effects of internal gravity waves in the interiors of the Sun and stars. Such waves are likely to be excited when convective down-flows in Sun’s outer envelope penetrate into the underlying stably stratified, radiative layers. The internal gravity waves were not observed with that much evidence earlier and they can be attributed to several reasons. As a result of strong radiative damping, the gravity waves cannot propagate in the photosphere (Souffrin, 1966), and thus may not be observed in lines formed in this region. As pointed out by Deubner (1981), the gravity waves were expected to be extremely difficult to observe because there are local, small-scale features requiring very high spatial resolution observations. High temporal & spatial resolution data will reveal that these gravity waves are small-scale phenomena. Many authors have claimed, in the past 22 years, to detect g-modes in the Sun, but, so far, there is no observational evidence. Using wavenumber and frequency-resolved $(k,f)$ phase-difference spectra and horizontal propagation diagram, Straus and Bonaccini (1997) have presented observationally, the strongest evidence of gravity wave presence in the middle photosphere. There are some observational investigations to show that there is a signature of atmospheric gravity waves at the chromospheric level using the time sequence of filtergrams and spectra obtained in CaII H & K and Mg b2 lines (Damé et al. 1984, Kneer and von Uexkull, 1993, Kariyappa, et al. 2006). Recently, Rutten and Krijger (2003) have analysed the ultraviolet (1700 Å) and white-light image sequences of internetwork regions from TRACE and shown that there is a signature of atmospheric gravity waves.

In the present paper, we made an attempt in search of atmospheric g-modes in the lower chromosphere using the long time sequence of intensity oscillations in a quiet region at the sites of the uv bright points, uv network elements and uv background regions observed under a high spatial, spectral and temporal resolution in 1600 Å from TRACE Space Mission. We will be presenting the first results of these analysis.

2. Observations and Data Analysis

We obtained a coordinated and simultaneous observations during May 18-24, 2003 with TRACE, SOHO/MDI and SOHO/CDS experiments. A high spatial and temporal resolution of images have
been obtained almost at the center of the solar disk covering both active and quiet regions. The solar rotation correction has been taken care during the observations. The TRACE observations are obtained in three wavelength regions: 1550 Å, 1600 Å and 1700 Å. In this paper, we have used the observations obtained with TRACE on May 24, 2003 in 1600 Å UV continuum and it is a 6-hour long time sequence of uv images. These images have been analysed in IDL using SolarSoftWare (SSW). For the preliminary study, we have chosen 15 uv bright points (UVBP), 15 uv network elements (UVNW), and 15 uv background regions (UVBG) in a quiet region. We have used the square/rectangular boxes covering the selected features for the study. Then we have summed up all the pixel intensity values covered by the box and extracted the cumulative intensity of a chosen feature for the entire 6-hours duration of observations. The light curves of all the UVBPs, UVNWs, and UVBGs have been derived and plotted them as a function of time. We have done a power spectrum analysis on the time series data to determine the period of intensity oscillations associated with these features.

3. Results and Discussion

There was an indication of the existence of longer-period of oscillations in chromospheric bright points and network elements from CaII H-line observations. Since it was only a 35-minute duration of time sequence of observations, it was difficult to investigate on the longer period of oscillations (Kariyappa, et al. 2006). In order to confirm on the existence of longer period of oscillations, in this paper, we have analyzed a long time sequence of uv images (6 hours of observations) obtained on May 24, 2003 with TRACE in 1600 Å UV continuum. We identified and chosen 15 uv bright points (UVBPs), 15 uv network elements (UVNWs), and 15 uv background regions (UVBGs) from the time sequence of uv images. We derived the cumulative intensity values of the UVBPs, UVNWs, and UVBGs using SSW in IDL. To calculate the intensity we have put the rectangular or square boxes covering the selected features. We derived the intensity time series of all the ultraviolet bright points (UVBPs), uv network (UVNWs) and uv background regions (UVBGs). As an example we have shown the time series of the two UVBPs (UVBP1 and UVBP2) from our selection in the upper panel of Fig.1. The time series of UVBPs show a small fluctuations in their intensity values. In addition there is an indication of longer period. To determine the period of intensity oscillations, we have done the power spectrum analysis using their time series data. The power spectra for UVBP1 and UVBP2 are shown in the lower panel of Fig.1. It is clearly seen from the power spectra the existence of significant & prominent peak around 5.5 hours in both the cases. Similarly, we have shown the time series and power spectra for two uv network elements (UVNW1 and UVNW2) respectively in the upper and lower panels of Fig.2. As we could see from the power spectrum plots that the uv network elements exhibit around 4.6 hours of period of intensity oscillations. In the upper and lower panels of Fig.3, we have presented the time series and power spectra for two background regions (UVBG1 and UVBG2). The background regions will be associated with around 3.4 hours of period of intensity oscillations. We have performed the cross spectrum analysis on the uv bright points and uv network elements of May 22, 2003 to compare with May 24, 2003 observations. We found that both the data sets show a coherent in phase & there is a single dominate period associated with uv bright points (around 5.5 hours) and uv network elements (4.6 hours). It has high coherence between May 22 and 24 uv bright point and uv network modulation. This
suggests strongly for high-order atmospheric gravity waves and they can be excited by turbulent stresses in the convection zone.

We can summarize the main results derived from the analysis of 1600 Å continuum observations as follows: (i) The uv bright points, uv network elements and uv background regions will exhibit a fluctuations with a smaller period in their intensity oscillations. (ii) We find evidence from the power spectrum analysis for a longer period of oscillations: the uv bright points are associated with around 5.5 hours, the uv network elements exhibit around 4.6 hours and whereas the background regions show around 3.4 hours. (iii) It is noted that the different features will have different period of intensity oscillations and the reason for the existence of different periods is still to be investigated. (iv) But, we can argue that the longer period of oscillations associated with all
these three features may be related to g-mode oscillations of the lower chromosphere. These results confirm the earlier findings that there is a signature of gravity waves in the chromosphere and transition region derived from the analysis of time sequence of filtergrams and spectra obtained in CaII H & K, Mg b2 lines and from TRACE observations (Damé et al. 1984 and Kneer and von Uexkull, 1993, Rutten, and Krijger, 2003, Kariyappa, et al. 2006). We expect that the atmospheric gravity waves can exist in the stably stratified photosphere and chromosphere, where convective overshoot is a natural mechanism to excite them. For these atmospheric gravity waves no model has been proposed yet that is supported by all the available observational constraints.

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Fig. 2. **Left upper box:** An example of the light curve of a uv network element (UVNW1) observed on May 24, 2003 (6 hours) with TRACE in 1600 Å UV continuum. **Left lower box:** The power spectra taken for the light curve of the uv network (UVNW1). **Right upper box:** The light curve of another uv network element (UVNW2). **Right lower box:** The power spectra taken for the light curve of the uv network (UVNW2).
Fig. 3. **Left upper box:** An example of the light curve of a background region (UVBG1) observed on May 24, 2003 (6 hours) with TRACE in 1600 Å UV continuum. **Left lower box:** The power spectra taken for the light curve of the background region (UVBG1). **Right upper box:** The light curve of another background region (UVBG2). **Right lower box:** The power spectra taken for the light curve of the background region (UVBG2).

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