Bull. Astr. Soc. India (2005) **33**, 19–26

Period-brightness relationship in chromospheric bright points

R. Kariyappa[1*], A. Satya Narayanan[1], L. Damé[2]
[1] *Indian Institute of Astrophysics, Bangalore 560 034, India*
[2] *Service d'Aéronomie du CNRS, BP 3, 91371 Verrieres-le-Buisson Cedex, France*

Received 29 October 2004; accepted 2 February 2005

Abstract. Chromospheric bright points are sites where intense heating takes place by 3-min period waves. A 35-min-long time series of photographic spectra obtained in CaII H-line on a quiet region at the center of the solar disk under high spatial, spectral, and temporal resolution at the Vacuum Tower Telescope (VTT) of the Sacramento Peak Observatory has been analyzed to show that the period of intensity oscillations associated with bright points in the interior of the supergranular cells is independent of their intensity enhancements. We find evidence for a constant period of oscillations in bright points, independent of their peak brightness, and different from the period of network oscillations. This suggests that the heating mechanism may be identical (by 3-min period waves) in any class of bright points while in the case of network elements it may be an entirely different mechanism (by 5-7 min period waves). In addition, it is shown that the amplitudes of the main and the follower pulses of bright points decay exponentially with time and the decay rate is constant with their brightness in any class of bright points.

Key Words : 3-minute period, Bright points, Chromosphere

1. Introduction

The CaII H and K lines are widely used to study the dynamics of different chromospheric features and their contribution to oscillations and heating of the chromosphere. These lines are very sensitive to variations in temperature and magnetic field strength, therefore they are excellent indicators of chromospheric structural changes related to solar magnetic activity. Two-dimensional images (spectroheliograms) obtained in H and K lines

[*] e-mail : rkari@iiap.res.in , satya@iiap.res.in

demonstrate that the main features which are responsible for chromospheric emission are: (i) internetwork bright points (cell-interior bright points); (ii) network elements, which are co-spatial with the boundaries of supergranular cells in the underlying photospheric levels; and (iii) bright plages. It was shown that network elements and bright points will contribute to the variations in the K-emission flux and UV irradiance (Kariyappa and Sivaraman, 1994; Kariyappa and Pap, 1996; Kariyappa, 1999). Moreover, these chromospheric features will have one-to-one spatial correspondence with regions of enhanced photospheric magnetic fields (Skumanich, Smythe, and Frazier, 1975; Sivaraman and Livingston, 1982; Nindos and Zirin, 1998; Sivaraman et al., 2000). On the other hand, Lites, Rutten, and Berger (1999) have analyzed the observations obtained from Advanced Stokes Polarimeter at NSO/Sac Peak and found no direct correlation between magnetic features and H_{2V} brightenings. This result contradicts one-to-one spatial correspondence claimed by Sivaraman and others for bright points. However, this problem is still an open question.

Since its discovery by Leighton (1961), the 5-min oscillation has been the subject of a large number of observational and theoretical investigations. It is well known from the observations of Jensen and Orrall (1963) that the solar chromosphere oscillates with a period of 180-200 s. Observations of high temporal and long time-sequence spectra of CaII H and K lines show that waves with 3-min period transport, dissipate a large amount of energy, and heat the chromosphere at the sites of bright points (Liu, 1974; Cram and Damé, 1983; Kariyappa, Sivaraman and Anadaram, 1994 henceforth KSA, Kariyappa, 1994, 1996; Damé and Martic, 1987; Martic and Damé, 2003 private communication). Also, according to Kalkofen (1989,1996), bright points are sites where intense heating takes place by 3-min period waves. Kariyappa, Sivaraman and Anadaram (1994, KSA) have classified the bright points into three classes depending on the intensity enhancements during their dynamical evolution. It was shown that bright points in general are associated with 3-minute periodicity while the network elements exhibit 5-7 minute periodicity in their intensity oscillations (Damé, Gouttebroze and Malherbe, 1984; Kariyappa, 1994; Kalkofen, 1999). A peak with frequencies in the range of 2.2 to 2.4 mHz in the network regions, i.e., periods near 7 minutes, from SOHO/SUMER observations of chromospheric Lyman lines is found by Curdt and Heinzel (1998). The strong and weak Fraunhofer lines at the sites of the bright points show that the period of intensity oscillations decreases outward from the lower photosphere (5-min) to the middle chromosphere (3-min) (Kariyappa, 1996). A time series of simultaneously measured velocity (V) and intensity (I) fluctuations of different spectral lines formed in the photosphere and lower chromosphere has been analyzed to show the phase behaviour of 5-min and 3-min oscillations as a function of height (Deubner and Fleck, 1989,1990; Deubner, 1990).

The importance of oscillations in chromospheric bright points has been dealt by Kalkofen (1997). The intensity oscillations observed in the H and K lines of CaII in network regions in the quiet Sun are interpreted in terms of transverse and longitudinal magnetoacoustic waves propagating upward inside magnetic flux tubes. The waves are generated impulsively in the photosphere as transverse waves. As they propagate upward, their velocity increases exponentially until they become nonlinear in the chromosphere, where they transfer power to longitudinal waves. Theoretical studies on flux tube oscillations have been discussed by Roberts and Ulmschneider (1996).

Chromospheric bright points and network regions are known to oscillate with different periodicities, such as 3-min in bright points and 5 - 7 min in network regions. Kalkofen and Ulmschneider (1999) have shown that the solar chromosphere has dynamical signature in the form of oscillations. These oscillations have a period of 3-min in the nonmagnetic chromosphere and a period of 5 - 7 min in the magnetic regions. They have argued that the dynamics of the chromosphere is due to acoustic waves in the magnetic field-free atmosphere which produce bright points, and to kink and longitudinal waves in the magnetic flux tubes which produce network regions. The heating of the chromosphere is caused by acoustic waves whose dissipation makes the kinetic temperature rise in the outward direction, producing the emission spectrum. Carlsson and Stein (1992), Carlsson and Stein (1997, see the references therein) have simulated the generation of Calcium H and K bright grains by acoustic shocks. They have employed a one-dimensional, non-LTE (local thermodynamic equilibrium), and radiative hydrodynamic code. The acoustic waves were induced through a stratified radiative equilibrium atmosphere with a velocity close to the observed Doppler shift in the FeI λ 3966.8 Å line. The simulations matched very well with the observed behaviour of the CaII H_{2V} bright grains down to the individual grain levels. The bright grains are produced primarily by waves from the photosphere that are slightly above the acoustic cut-off frequency.

In this paper, using a 35-min time sequence of spectra in CaII H line we have attempted to provide a quantitative answer to the question: Does the period of oscillations in chromospheric bright points depend on the intensity enhancement during their dynamical evolution ?

2. Observations and data analysis

In this study, we have used a time sequence spectra obtained on a photographic film in CaII H line. The observations have been made by K. R. Sivaraman at the Vacuum Tower Telescope (VTT) with the echelle spectrograph of the Sacramento Peak Observatory, on September 13, 1971 under the Program B of the HIRKHAD mode (Beckers et al. 1972). In all, we have 177 frames for the 35 minute observed data with a repetition rate of 12 sec. We have selected 32 regions for a detailed study and designated them as B_1, B_2, B_3,.......... B_{32}. Out of these, 29 regions correspond to bright points and the remaining 3 (B_4, B_{18}, and B_{25}) belong to network elements (refer Figure 1 of KSA). More details on the observations and data analysis are described in our earlier papers (KSA; Kariyappa, 1994, 1996). We have derived, in all, 5133 photometrically calibrated line profiles for the 29 bright point regions and measured an important line profile parameter, namely, the intensity of the emission peak on the violet side ($I_{H_{2V}}$) for each profile, and plotted $I_{H_{2V}}$

versus time covering the duration of the 35-min sequence. Further the methods of data analysis are also discussed below along with the results.

3. Results and discussion

It was shown in our earlier paper (KSA) that bright points can be grouped into three classes (see KSA, Figures 2 and 3: class I; Figure 4: class II and Figure 5: class III) depending on their intensity enhancements during their dynamical evolution. The Class I bright points show a large enhancement of $I_{H_{2V}}$ at their peak brightness phase, as high as 3 times above the mean ambient level (Refer Figures 2 and 3 of KSA), which correspond to the undisturbed line profile (at time t=0) of Figure 11 of KSA. Class II bright points show moderate intensity enhancement in $I_{H_{2V}}$ (about twice the mean ambient level) at the peak brightness phase. However, Class III bright points show only a marginal increase in I_{H2V} at the brightest phase. The reason for the different classes of bright points may be related to the difference in magnetic field associated with the location of bright points. In the light curves of the bright points, the highest peak in the intensity variation of each bright point is designated as the "main pulse", and marked as P_1 (refer Figures 2 to 5 of KSA). The main pulse is followed by several pulses with smaller amplitudes and they decay exponentially with time. A power spectrum analysis was done for all the three classes of bright points separately by feeding the $I_{H_{2V}}$ digital values (values every 12 sec corresponding to the repetition rate of the frames) to evaluate the period of intensity oscillations. The peak value of $I_{H_{2V}}$ of the main pulses and the follower pulses separately from the plots of $I_{H_{2V}}$ versus time for the three classes of bright points has been obtained. Also, we estimated the average peak intensity value of H_{2V} (average value of $I_{H_{2V}}$) of the main and follower pulses for the three classes of bright points. In addition, we have used the periods of intensity oscillations which are derived from power spectrum analysis for all the three classes of bright points separately.

Figure 1(a) presents the scatter plot-diagram for the period of intensity oscillations with a peak value of $I_{H_{2V}}$ for the main pulses, while Figure 1(b) depicts the period of intensity oscillations as a function of an average peak value of $I_{H_{2V}}$ of main and follower pulses for the three classes of bright points. It is clearly seen from Figures 1(a) and (b) that the period of intensity oscillations does not vary significantly for different intensity enhancements at the sites of a large variety of bright points. This indicates the existence of the constant period of intensity oscillations (around 3-min) with different brightness of the bright points. It is known from the earlier work of Damé, Gouttebroze, and Malherbe (1984), Kariyappa (1994) that the network elements show 5-7 min periodicity in their intensity oscillations. Combining these two studies, we infer that the period of intensity oscillations in any class of bright points is 3-min while it is 5-7 min in the network oscillations. Hence, we suggest that the heating mechanism may be identical in any class of bright points and they are heated by 3-min period waves. In the case of network elements, the heating mechanism may be different from bright points and are heated by 5-7 min period waves. This result may answer the question raised by Kalkofen (1989) that it is

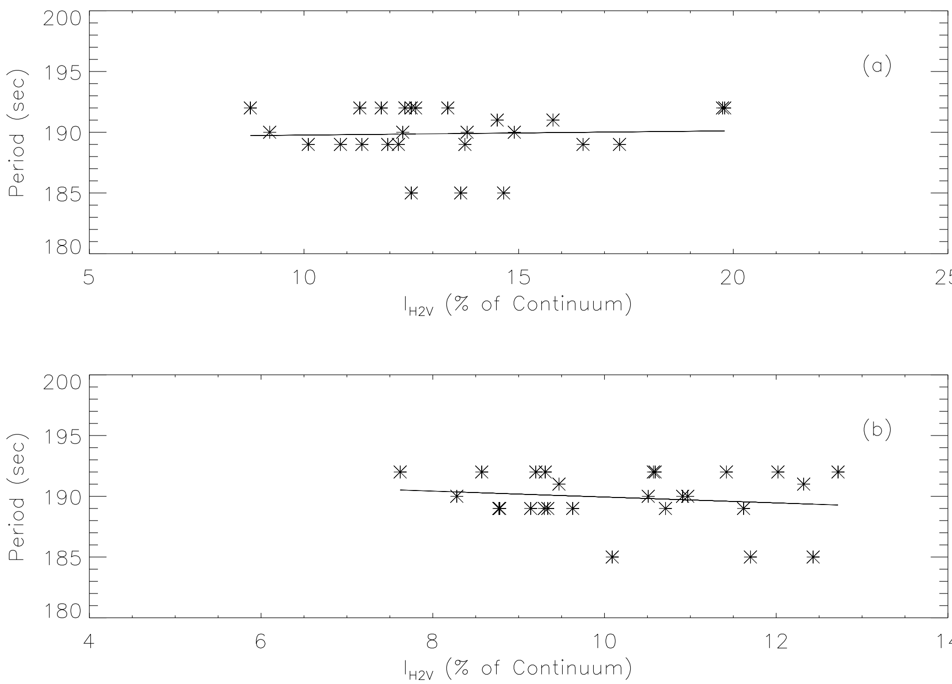

Figure 1. (a) Variation of the period of intensity oscillations with the peak value of I_{H_2V} of the main pulse of all the three classes of bright points. The solid curve represents the linear regression equation fitted to the data. (b) Variation of the period of intensity oscillations with the average peak value of I_{H_2V} of the main and follower pulses of all the three classes of bright points. The solid curve represents the linear regression equation fitted to the data.

not known whether the layers in the network elements and bright points are heated in the same way. Chromospheric waves that are visible in emission features of the CaII H and K lines arise in two different regions, namely the bright points and network elements of the quiet Sun and show different radiative signatures as well as different temporal behaviour (but found an identical temporal behaviour among the different classes of bright points); they are therefore, presumably different in nature, although perhaps not in the manner of excitation.

The amplitude of the main pulse is far higher than the amplitudes of the follower pulses in all the three classes. An examination of the amplitudes of the follower pulses suggests an exponential decay. The exponential functions have been fitted for all the bright points and they are presented for a few bright points in Table I of KSA. We have shown the scatter plot diagram of decay rate (slope of the exponential function) with the peak value I_{H_2V} for the main pulses in Figure 2(a) and the average peak value of main and follower

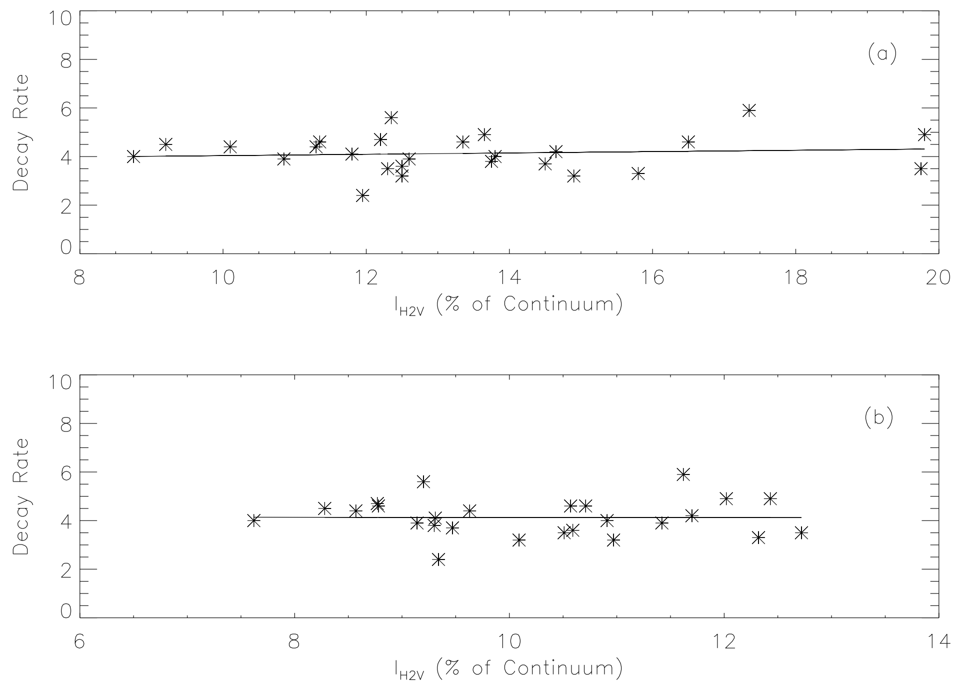

Figure 2. Variation of the decay rate in amplitudes of the pulses with the peak value of $I_{H_{2V}}$ (a) for the main pulses and (b) for the average peak value of $I_{H_{2V}}$ of the main and follower pulses of all the three classes of bright points. The y-axis values will be multiple of 10^{-4} (in seconds).

pulses in Figure 2(b) for all the three classes of bright points. It is interesting to note that their slopes (decay rates) are nearly the same for the bright points in the 3 classes and it is possible to represent the exponential decay in the amplitudes reasonably well for the 3 classes by one parameter which clustered around $4.14 \mathrm{x} 10^{-4}$ (in seconds). This implies that the amplitudes of the main and follower pulses decay exponentially with time in all the three classes of bright points and it is clearly seen from Figure 2 that the decay rate is also constant, like period, with their brightness in any class of bright points.

To conclude, the evidence of constant period (3-min) with brightness of the bright points and different period from network oscillations (5-7 min) may seem to support that the heating mechanism may be identical in any class of bright points, whereas there may be a different heating mechanism at the sites of the network elements. In addition, it has been shown that the amplitudes of the main and follower pulses of the bright points decay exponentially with time and the decay rate is constant, as in the case of period, with their brightness in any class of bright points. It has been observed earlier (Sivaraman and Livingston, 1982; Nindos and Zirin, 1998; Sivaraman et al. 2000) that there is a one-to-one spatial correspondence between the chromospheric bright points and the underlying photospheric magnetic elements. This suggests that reasons for the existence of different classes of bright points depending on their brightness enhancement may be related to the difference in magnetic field with which they have been associated. It will be interesting to know if small period of oscillations exist in the magnetic field variations from the observations of a high spatial and temporal resolution of Full-disk magnetograms obtained with the SOHO/MDI experiment. In addition, it is not known whether the network elements fall into different classes, as in the case of bright points, during their dynamical evolution, and show a constant or different period of intensity oscillations with their brightness variation.

Acknowledgments

We wish to thank Profs K. R. Sivaraman, J. M. Beckers, and Raymond Smartt for use of the HIRKHAD data and for their valuable advice on this research. We also thank Dr. M. Martic for useful discussions. We are extremely thankful to the referee for constructive comments.

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