Fine structure and Alfven string-mode oscillations of a quiescent prominence

Nicola Petrov[1], Peter Duchlev[1], Bogdan Rompolt[2], Pawel Rudawy[2]
[1] Institute of Astronomy, Bulgarian Academy of Sciences
[2] Astronomical Institute of the Wroclaw University, Poland
duchlev@astro.bas.bg
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Abstract. Series of Hα spectra and slit-jaw Hα filtergrams of a quiescent prominence taken at Pic du Midi Observatory on November 7, 1977, are studied. The image processing of the Hα filtergrams reveals an internal structure of the prominence consisting of several arches. Series of high-resolution Hα spectra obtained with the slit position located on a selected part of one of the prominence arches have been chosen for Doppler shift analysis. We got a good correspondence between the prominence structural elements identified in the Hα filtergrams and the corresponding spectral cuts. The prominence arch shows cyclic displacement along the line-of-sight direction implying Alfvén string-mode oscillations.
Key words: prominences, fine structure, oscillations

Фина структура и осцилации от типа Алфвен стринг-мода при един спокоен протуберанс

Никола Петров, Петър Духлев, Богдан Ромполт, Павел Рудави

Изследвана е серия от Hα спектри и филтрограми на спокоен протуберанс, получена в обсерваторията Пик дю Миди на 7 ноември 1977 г. Обработката на Hα филтрограмите разкрива вътрешна структура на протуберанса, съставена от няколко арки. За анализ на доплеровите скорости е използвана серия от Hα спектри с висока разделителна способност, получена за позиция на слита в избрана част на една от арките на протуберанса. Получено е добро съответствие между структурните елементи на протуберанса, установени по Hα филтрограмите и съответните спектрални профили. Изследваната арка на протуберанса показва циклично изместване по лъча на зрение, загатвайки за осцилации от типа Алфвен стринг-мода.

Introduction

It is well known (Tandberg-Hanssen, 1995) that the high-resolution limb observations of quiescent prominences (QPs) often reveal fine scale filamentary structure exhibiting systematic, transverse directed to the line of sight, downward motion in short time scales. When such prominences are observed on the disk as filaments the Doppler shift measurements indicate both upward and downward line of sight directed plasma motion, the average velocities being mainly upward. Internal motions in QPs have been long time under study but there is still little knowledge about their origin, behaviour, and range of velocities. Pettit (1932) has found, from time sequences of filtergrams, velocities of 5 to 10 kms^{-1}. Newton (1934) studied the radial velocities of some dark disk filaments and obtained velocities smaller than 4 kms^{-1}. Using Hα high-resolution emission line in QPs single knots, Ten Bruggencate and Elste (1958), obtained internal motion with velocities up to 10 kms^{-1}; in fainter QP microstructures, velocities up to 40 kms^{-1} were observed (Severny and Khokhlova, 1953).

Extensive measurements of line-of-sight (l.o.s.) velocities in prominence have been carried by Liszka (1970), Giogolashvili and Zhugzhda (1982), Engvold (1972), Engvold, Wiehr and Wittman (1980), Yi, Engvold and Keil (1991), Yi and Engvold (1991). The $H\alpha$ high-resolution observations of Yi (1992) have given velocities of about ± 1 kms^{-1}. Recently the re-examination of some earlier high-resolution observations of limb prominences by means of Local Cross-Correlation Techniques (Zirker, Engvold and Yi, 1994) and with a method for calculating the geometric distortion between subsequent images (Pojoga and Molowny-Horas, 1999) reveals flow velocities and directions that are in good agreement with those obtained by Doppler measurements of disk filaments. The impression is (Zirker, Engvold and Yi, 1994) that the matter in the fine structure of prominences flows both upwards and downwards under forces other than the gravitational one.

There is a big amount of observations implying oscillations in QPs, and cyclic velocity and intensity changes are to be a commonplace there (Tandberg-Hanssen, 1995). The oscillations have a large range of periods, of the order of an hour to 3 - 5 min. High-resolution observations of quiescent filaments (QFs) show oscillations that are strongly tied to their fine threads (Yi, Engvold and Keil, 1991). Recent studies have detected pronounced oscillatory variation in the Doppler velocities of QFs (Yi, Engvold and Keil, 1991; Yi and Engvold, 1991; Tomson and Schmieder, 1991). The oscillations with periods between 12 and 16 minutes have been found (Yi, 1992) to be much stronger in QFs than in the nearby chromosphere.

There are two main points of view concerning the nature of the QP internal motion. The first one, suggested by Malvile (1968), supposes a flux of mechanical energy entering the prominence in the form of Alfvén waves. This supposition stimulated many observational studies for detection of pronounced oscillatory variations in the l.o.s. velocity of QFs (Yi, Engvold and Keil, 1991; Yi and Engvold, 1991; Tomson and Schmieder, 1991) and QPs (Gigolashvili and Zhugzhda, 1982; Bashkirtsev, Kobanov and Mashnich, 1983; Wiehr, Stellmacher and Balthasar, 1984; Balthasar, Stellmacher and Wiehr, 1988; Molowny-Horas et all., 1997; Petrov, Dermendjiev and Rompolt, 1998). The observational results stimulated, on the other hand, theoretical attempts aiming to explain the reported quasi periodical oscillations in the Doppler shift time series in terms of propagating megnetohydrodynamic (MHD) waves (Olivier et al., 1993; Olivier and Ballester, 1996), and Alfvén waves (Solov'ev, 1985; Tomson and Schmieder, 1991; Jensen, Yi and Engvold, 1994). According to a second point of view, proposed by Jensen (1982), the observed l.o.s. velocity distribution functions imply MHD-turbulence, as it is described by Krai-chnan (1965), and that a characteristic relationship should exist between velocities and eddies size.

1 Observations, method of processing

We examine the structure and the l.o.s velocity variations of a QP on the base of high-resolution Hα spectra and filtergrams obtained by one of the authors (BR) on November 7, 1977 at Pic du Midi Observatory. The prominence was located at the northeastern (N45-E) limb, according to Meudon synoptic map for rotation N1681. The filament lasted for two solar rotations and during the observations it was on its first rotation.

The series of high-resolution Hα spectra have been recorded on photographic film using the 11-m solar horizontal telescope equipped with a 9-m spectrograph (Mouradian and Leroy, 1977) and a spectrohelioscan developed at the Astronomical Institute of the Wroclaw University. A slit-jaw unit coupled with an Hα camera have provided Hα filtergrams together with the actual slit position against the prominence body. The spectra from the QP have been taken with an exposure time of 5 s and 0.75 mm slit width.

The Hα filtergrams have revealed that the QP consists of several arches. For the purpose of this study we took seventeen Hα spectra obtained at a slit position located on one of the arches, marked by line 12 in Figure 1. The spectra have been obtained in a time interval of about 57 min (from 10:07:48 to 11:04:35 UT) with a nearly equal time step of 3.5 min between the consecutive scans.

The selected spectra and filtergrams have been digitized by an automated microdensitometer Joyce Loebl at the National Astronomical Observatory "Rozhen". Using computer facilities the position of the centre of gravity of each Hα profile has been determined with respect to the mean Hα profile of the studied volume of the arch. The deviation of the determined wavelength in respect to the mean Hα position has been interpreted in terms of microscopic l.o.s. velocity fluctuation; the velocity has been defined

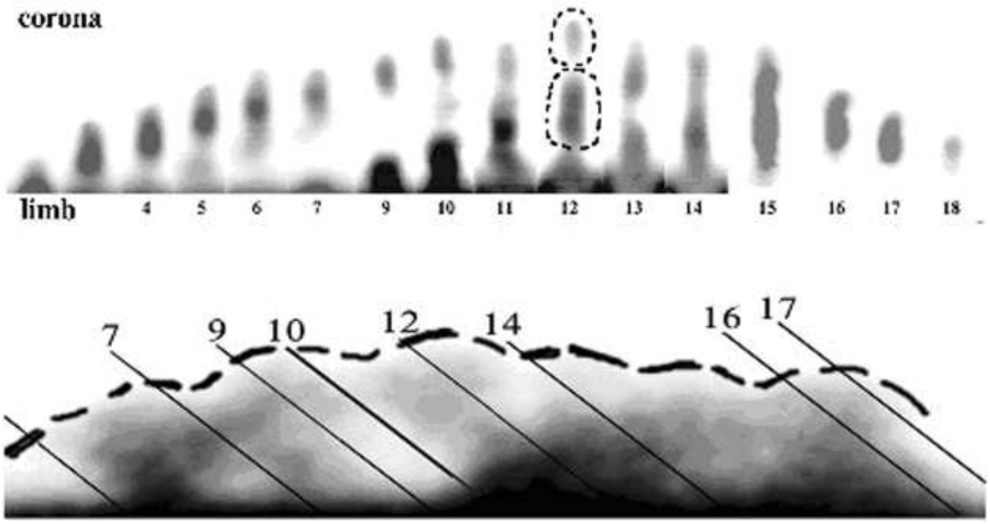

Fig. 1. One of the series of Hα spectra used for Doppler shift measurements (upper part) on the prominence body. Hα filtergram of the prominence (lower part). The line points to the selected arch and the position of the slit. The position along the slit is given in 50μ (one pixel) step equal to 343 km.

as positive for red shifted Hα features. The Hα profiles have been plotted by means of a computer-operated curve in order to eliminate noisy and erroneous microdensitometer tracing.

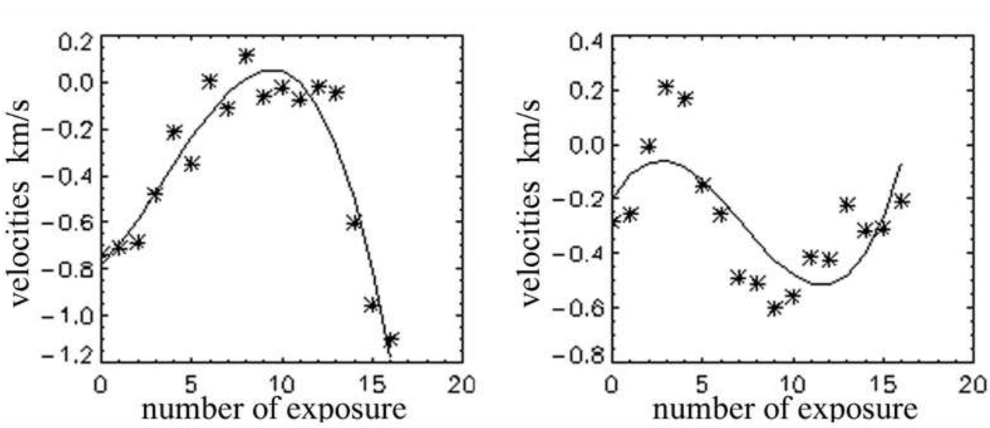

Fig. 2. Time-dependence of the average V (points) of the l.o.s. velocity distribution along the slit and a polynomial fit, respectively. The observed volume of the arch shakes first in opposite direction to the observer (left part on the Figure), then reverses in direction to the observer with a tendency to reverse again. The right part of the Figure shows us the behaviour of the average l.o.s. velocities of the second (lower) separated volume on the same slit position.

2 Results and discussions

As it can be traced in Figure 2, the sign and the magnitude of the l.o.s. velocity are changing along the slit, and with the time, especially near the periphery of the arch. The maximum magnitude of the velocity is about $\pm 1.5\ km/s$. In order to trace cyclic displacement or shaking of the prominence arch along the l.o.s. direction, which could be accepted as parallel to the solar surface, we compute, for the selected prominence volumes, the position of the centre of gravity of each Hα profile, with respect to the corresponding chromosphere Hα. As a representative statistical quantity for such a displacement we take the average of the velocity distribution along the slit. We calculated these values for two separated volumes on the slit position 12 shown in Figure 1. For the upper part of the prominence we calculated the l.o.s. velocities as one separated volume and for the lower part as another volume, each one forms different arches. The time-dependence of the average of the l.o.s. velocity (V) distribution along the slit is shown in Figure 2 (left), where the polynomial fit is shown as well. It is well seen that the observed volume of the arch shakes first in opposite direction from the observer (positive values of V), then in direction to the observer (negative values) and later it seems to show again a tendency to reverse. This tendency implies for oscillation of the prominence arch with a frequency $\omega \approx 3.10^{-4} s^{-1}$. Results were presented by Petrov, Dermendjiev, Rompolt (1998) and Detchev et al. (1999) and V. N. Dermendjiev et al. (1998, 2001).

The average l.o.s. velocities of the second elementary volume close to the limb show a different tendency to reverse (Figure 2 right). This tendency implies for oscillation of a different prominence arch with a frequency $2/3\omega \approx 2.10^{-4} s^{-1}$. To keep long time the structure of a prominence body we need a state of a stable equilibrium (Chandrasekhar, 1961). In this case to have a QP we execute the equation:

$$p = const - \frac{1}{2}\rho V_a^2, \quad and \quad \frac{\delta V_a^2}{\delta t} = 0,$$

where p is plasma pressure, ρ – density, and V_a is Alfvén speed. The Alfvén speed V_a is corresponding to the magnetic field B: $V_a \sim B$ (Parker, 1979). The period of plasma oscillations in a magnetic tube is:

$$T = L/Va,$$

where L is the length of the magnetic tube. Let us use one typical value of $B = 8G$ and $Va = 55kms^{-1}$ (Tandberg-Hanssen, 1995); for the two period of oscillations that we calculated we have: $L_{upper} \approx 200000km$ and $L_{lower} \approx 130000km$.

These are two lengths of two different arches as a fine structure in the QP. The Doppler shift measured with respect to the averaged Hα profile of the chromosphere, indicates cyclic displacement or vibration of the arches that could be referred to Alfvén string modes. Using the average of the consecutive in time l.o.s velocities along the slit as a representative estimate for tracing cyclic displacement, we find frequencies $\omega_1 = 3.10^{-4} s^{-1}$ and $\omega_2 = 2.10^{-4} s^{-1}$ respectively.

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