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ON A NON-THERMAL VELOCITIES IN THE SOLAR CORONA

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Abstract. The paper considers the change in the width of the coronal spectral lines along the solar disk. The change in the width of the coronal lines along the solar disk is sometimes contradictory. Often, the widths of the lines are changed little along the solar disk. We explain such cases by joint motion on slow magneto-sound and Alfven waves.

It is shown that the relation between the motion velocities on the Alfven wave δv and the phase velocity v_a is $\delta v \sim v_a$ meaning that with an increasing (decreasing) phase velocity δv, the motions increase (decrease). Since with the height above the limb, the phase velocity of the Alfven waves are increased due to the decreased density, the phase velocity is increased, therefore the motions velocities are increased as well. This explains the increasing widths of lines above the limb.

Keywords: Solar corona, MHD waves, non-thermal velocities.

1. Introduction

According to the studies of many authors, the width of the coronal lines above the solar disk is almost unchanged. The width of the coronal lines is determined by two motions: thermal motions of ions and non-thermal motions caused by slow magneto-acoustic waves propagating in the corona and mostly by Alfven waves and turbulent motions [5, 7, 11, 10, 1 and references of these works].

Turbulent motions broaden the spectral lines most likely the equally across the solar disk. If non-thermal motions in the corona were caused only by turbulent motions and motions on Alfven waves, then the values of non-thermal velocities would increase from the center of the disc to the limb. But, as we will see below, in many cases, there is an isotropy of non-thermal velocities along the solar disk.

We assume that the isotropy of non-thermal movements is caused by the motions on slow magneto-sound waves and on Alfven waves. In the given paper, we consider the isotropic case of broadening of the coronal lines of MHD waves, without involving turbulent motions.

Note that since at all coronal points a given coronal line is radiated at the same temperature, we must say that the changes in the width of the coronal line are caused by non-thermal motions on MHD waves.

The given paper considers the possible role of MHD waves in the isotropic broadening of coronal lines, as well as the change of velocities on Alfven waves with height.

2. Isotropy of the widths of the coronal lines along the Solar disk

During the observations, the authors obtain a spectrum from a large disk area (1″⋅120″, for example, see [4]). Clearly, there are numerous Alfven and slow magneto-sound waves in this area. Therefore, the observed coronal spectral line broadens simultaneously by motions on both Alfven and slow magneto-sound waves.

In other words, the non-thermal velocity found on the Doppler width of the line is the square of the sum of the squares of the most probable velocities of the motions on Alfven and slow magneto-sound waves:

$$V_{nt}^2 = \upsilon_{nt}^2(s) + \upsilon_{nt}^2(a). \quad (1)$$

Here: $\upsilon_{nt}(a)$ and $\upsilon_{nt}(s)$ nt (s) are non-thermal velocities of Alfven and slow magneto-sound waves, respectively.

The question is how to find the values of $\upsilon_{nt}(a)$ and $\upsilon_{nt}(s)$. We will calculate the values of these quantities based on the following consideration, bearing in mind that the waves in question propagate in magnetic tubes that are perpendicular to the surface of the Sun.

Further, the motions of the slow magneto-sound waves occur along the magnetic tube, and the motions on the Alfven wave occur perpendicularly to the magnetic tube.Then, during the observations in the center of the Solar disk, the line of sight is perpendicular to the motions on the Alfven wave and therefore in the center of the disk $\upsilon_{nt}(a)=0$, while the value of $\upsilon_{nt}(s)$ is maximum; near the limb, on the contrary: $\upsilon_{nt}(a)$ is maximum, and $\upsilon_{nt}(s)=0$. Obviously, the non-thermal velocities observed on the centre of the disk are the velocities of motions on slow magneto-sound waves, and the non-thermal velocities observed closer to the limb are the velocities of motions on the Alfven wave. As an example, we can show coronal line λ1037 OVI from Table 1 [5]: in the centre of the solar disk, the value of non-thermal velocities is υ_{nt}=32km/s, and closer to the limb υ_{nt}=34km/s.

Thus:

$$\upsilon_{nt}(s)= 32 \text{ km / s}, \upsilon_{nt}(a)=34 \text{ km / s}.$$

Obviously, depending on angle θ on the surface of the Sun, the total velocity will change as follows:

$$V_{nt}^2(\theta)= (32 \cos\theta)^2 +(34 \sin\theta)^2 \quad (2)$$

The values of $V_{nt}(\theta)$ are calculated for values θ=0, 10, 20,….90° .

θ, (°)	0	10	20	30	40	50	60	70	80	90
V_{nt}, (km/s)	32,00	32,06	32,23	32,51	32,85	33,18	33,51	33,78	33,94	34,00

As it can be seen from the table above, in this example, the values of non-thermal velocities are almost constant throughout the Sun disk.

In [7], coronal lines MgX 609 and Mg X 625 were observed near the limb on the disk and above the limb. A portion of r/R was observed in the interval 0.7-1 on the disc. The values of non-thermal velocities, determined by the observed Doppler widths of the indicated lines in the indicated interval turned out υ_{nt}=26 km/sec. Besides, it turned out that this value is constant in the whole indicated interval.

The authors believe that the observed non-thermal velocities are motions on the Alfven wave.

In this case, expression (1) takes the form:

$$V_{nt}(\theta) =\upsilon_{nt}(\theta)= 26\sin\theta \quad (3)$$

In the given paper, the values of non-thermal velocities are given for the following values sinθ= 0.7, 0.8, 0.9, 1.0.

Using expression (3), we find:$V_{nt}(45^\circ)$=18.2; $V_{nt}(54^\circ)$=21.8; $V_{nt}(65^\circ)$=23.4; $V_{nt}(90^\circ)$=26 km/sec.As it can be seen, if non-thermal velocities were the velocities of motions only on the Alfven wave, the values of these velocities would decrease toward the centre of the disk.

Now, let us consider the assumption that thermal motions are created by both Alfven waves and slow magneto-sound waves. Obviously, in the center of the disk, the velocity of motions on Alfven waves is equal to zero, since these motions are perpendicular to the line of sight. The authors believe that the values of non-thermal motions are uniform throughout the disk. In this case, these motions should satisfy expression (1). This means that in the center of the disk $\upsilon_{nt}(s)$=26 km/sec. The observed value of non-thermal velocities on the limb is the velocities of motions on Alfven waves. So, according to expression (1) for a given case, we can write down:

$$V_{nt}^2(\theta)=(26\cos\theta)^2 +(26\sin\theta)^2=26^2.$$

Hence: $V_{nt}(\theta)$=26 km/sec. In other words, if non-thermal velocities are "created" by the combined action of slow magneto-sound and Alfven waves, then non-thermal velocities will be uniform throughout the disk. Therefore, we can conclude that the observed isotropic distribution of non-thermal velocities on the Sun disk is explained simultaneously by motions on Alfven and slow magneto-sound waves.

The determination of non-thermal velocities on the lines λ195,12 FeXII and λ 202,94 FeII showed [11] that the values of these velocities from the center of the disk to the limb are constant and equal to 36 km/sec (Fig. 7). This interesting result can only be explained by the fact that these velocities are the motions on Alfven and magneto-sound waves, and the amplitude of the velocities of the motions on both waves is the same. We emphasize that the authors explain this fact that the source of non-thermal motions are turbulent motions in the corona. The observed values of non-thermal velocities in line λ624.94 MgX are almost constant on all disk of the Sun ([10] Fig. 6).

According to observations [9], the widths of the line λ625 MgX on the disk closer to the limb significantly differ with various data and have a somewhat complex appearance with a tendency to grow to the limb. Unfortunately, the authors do not explain this observational fact.

Based on the observations of some spectral lines arising in the upper atmosphere and in the corona, the authors concluded that non-thermal velocities change slightly along the solar disk, i.e. they are isotropic.

According to the observations [8], the width of line Fe X 6374 (red line) above the solar limb increases with height, while the width of line FeXIV 5303 (green line) decreases.

The authors (et al., see references in the present work) explain this by the fact that, according to the line of sight, there are many undisturbed structural elements with different temperatures in the corona. As a result, the velocity of the Alfven wave decreases and therefore the width of the blue line decreases with height. But we must indicate that the velocity of the Alfven wave is independent from temperature. Most likely, unresolved structures with different densities are found along the line of sight.

3. On change in non-thermal velocities over the solar limb

The results of determining changes of the non-thermal velocities value with a height above the limb are very contradictory.

In [2], the results of measurement of the values of non-thermal velocities in the corona, depending on the height above the limb, are shown from observations in the line λ 5303 Fe XIV at the coronagraph of the Sacramento Peak Observatory. Figure 8 shows that the values of non-thermal velocities decrease with increasing height.

According to the observations on the SUMER / SOHO spectrograph in ultraviolet lines, the authors of [3] found that the velocities of non-thermal motions increase with height (Fig. 4).

It is of interest to look at the theoretical dependence of the velocities of motions on the Alfven wave (which lead to the broadening of the coronal emission lines observed on the limb) with the phase propagation velocity of this wave and compare it with the observations. Mean square value of the velocities on the Alfven wave is proportional to $\rho^{-1/4}$ [4]:

$$(\delta v^2)^{1/2} \sim \rho^{-1/4}$$

The phase velocity of the Alfven wave is proportional $\rho^{-1/2}$:

$$v_a \sim \rho^{-1/2}$$

Consequently:

$$\delta v \sim v_a^{1/2} \quad (4)$$

Since the density decreases with the height in the corona, the velocities at the Alfven wave should increase with the height. The comparison between the calculated values of non-thermal velocities on the Alfven wave and the observed values along the SiVIII line 1445.75 made by the authors shows a good agreement between these values: both velocities (the calculated and the observed) increase with the height (Fig. 4). This suggests that the observed non-thermal motions are motions on Alfven waves. The phase velocity of the Alfven wave increases with the height in the corona due to a decrease in density.

Expression (4) shows that with the height in the corona, the amplitude of the velocities of motions on the Alfven wave increases as well.

The conflicting results of measuring the width of the lines in the height above the limb remains unexplained so far. If the widths of the coronal lines were expanded only by motions on Alfven waves, then they would show the growth with height above the limb. The contradictory results of the measurement of the widths of the lines in height above the limb remain unexplained.

Thus, we conclude that if non-terminal motions are motions on Alfven waves, the non-terminal motions must grow with the height on the limb.

4. Conclusion

The study of changes of coronal lines along the solar disk is of interest from the point of view of revealing the mechanism used by non-thermal motions to create broadening spectral lines. The broadening of coronal lines is caused by MHD waves: slow magneto-sound and Alfven waves, as well as turbulent motions. The observational data are contradictory, but mostly, the widths of the spectral lines are almost constant across the solar disk. In the present paper, we investigate the cases of almost constant (isotropic) line widths over the solar disk. We conclude that in this case, the motions on slow magneto-acoustic and Alfven waves can be the mechanisms for broadening coronal lines without involving turbulent motions.

We find that there is a relation $\delta v \sim v_a$ between the phase velocity of the Alfven wave and the motion velocities on this wave, showing that with increasing (decreasing) of the phase velocity of the Alfven wave, the motions velocities increase (decrease) on that wave. This effect can explain the increasing of the line widths over the solar limb. This effect can explain the increase in line widths above the solar limb.

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