IS NI I 676.8 NM LINE AFFECTED BY ELECTRON BEAMS IN FLARING ATMOSPHERES?

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ABSTRACT

Non-LTE simulations for a model Ni I atom in the ambient plasma with solar element abundances are carried out in order to investigate the effects of electron beams on the resulting Ni I 676.8 nm emission during solar flares. The Ni I 676.8 nm line profiles, source functions and departure coefficients were calculated for a period of 10 s after an injection of beams with a variety of their initial parameters. The Ni I 676.8 nm line was found to decrease its depth in the core by about 30% in response to the increase of hydrodynamic heating of the atmosphere during the electron beam precipitation. At the maximum electron flux (6 s in our models), the line profile changes to emissive and stays as such for several seconds returning to the normal absorption profile after the beam is switched off (10 s). Therefore, the line measurements within a timescale of 1 min or longer are more likely not to be strongly affected by the line inversion while more precise (within seconds) temporal measurements on Ni 676.8 nm line profiles of the impulsive phase of flares have to be carefully investigated.

Key words: Sun, solar flares, electron beam, radiative transfer, non-thermal ionization.

1. INTRODUCTION

Transient magnetic field changes associated with solar flares, called magnetic transients, were often observed from the ground in Fe lines (Patterson and Zirin, 1981; Patterson, 1984). Recently, the fast magnetic field variations also associated with solar flares were observed from SOHO/MDI (Kosovichev and Zharkova, 1999, 2001). While the ground-based observations in iron by Patterson and Zirin (1981) have revealed a magnetic field sign reversal around a flare location those from MDI in the Ni I 676.8 nm line by Kosovichev and Zharkova (2001) has demonstrated a substantial decrease in magnetic energy in the unipolar regions (likely footpoints of flaring loops) during the 14\(^{th}\) July 2000 flare while the sign of magnetic field was not affected.

They found two types of variations in the MDI line-of-sight magnetic field signal. The variations of the first type are permanent irreversible changes that are observed as increases and decreases of the line-of-sight component. These variations reflect changes in the magnetic structure of flaring active regions associated with the magnetic energy release. Obviously, the observations of the permanent changes are not affected by temporal variations of the line profile. The variations of the second type are observed as impulses in the MDI line-of-sight magnetic signal. These variations that last from 1 to 5 min occur during the impulsive phase of solar flares and strongly correlate with hard X-ray impulses and continuum emission. Clearly, the magnetic transients are caused by the interaction of high-energy particles with the photosphere. However, the precise nature of these variations is not understood. These variations may represent electromagnetic response to beams of charged particles, or just be caused by variations in the line profile due to the impulsive heating. The impulsive heating can result in rapid changes and even inversion of the line profile, and thus cause spurious variations in the MDI signal which is obtained from a series of filtergrams taken with 3-sec cadence over a 30-sec period. Therefore, a detailed investigation of the effects of electron beams on the line profile are of significant interest for the correct interpretation of the magnetic transient and understanding the physics of interaction of high-energy particles with the photosphere.

The SOHO/MDI observations based on the detailed non-LTE investigation of the Ni I 676.8 nm line formation in a quite atmosphere and in supergranulation sells with a much higher temperature (Bruls, 1993). The intercombination Ni I 676.8 nm line was shown to be rather insensitive to temperature and density variations that confirmed its choice for measurements of Doppler velocities and magnetic field (Scherrer et al., 1995).

Recently, the Ni line non-LTE simulations were fulfilled by Ding et al (2002) in semi-empiric flaring atmospheres affected by electron beam. In a presence of beam electrons the Ni line profile was concluded to reverse to the emission one owing to a super-ionisation of the ambient plasma by these electrons. In some cases their Ni I 676.8 profiles in flares have a decrease in wings by the order of magnitude that leads to an increase in the line core above the absorption level. However, this behaviour (decrease in wings in comparison with the quiet atmosphere) of the

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Ni line profiles never has been observed from MDI instrument, at least within often observed timescales.

In order to investigate the conditions for possible Ni I 676.8 nm line inversion the line profiles were calculated in flaring dynamic atmospheres using the RH radiative including the transitions from as many elements as possible with the coronal abundances (for details see Uitenbroek, 2001). This allows taking into account some overlapping effects from other elements reducing the effect of hydrogen Paschen continuum.

2. DESCRIPTION OF THE MODELS

2.1. THE ATMOSPHERIC MODELS

The atmospheric models were calculated as a hydrodynamic response of a flaring atmosphere to electron beam injection (Zharkova, Brown & Syntayvski, 1995). The electron beam heating functions were computed from the continuity equation with velocity with partial ionisation. The calculations were performed for the following beam parameters: an initial energy flux on the top boundary in the corona: \( F_0 = 10^{10} - 10^{12} \text{erg cm}^{-2} \text{s}^{-1} \), and the beam spectral index \( \delta = 4 \) and 6. The lower \( E_1 \) and upper \( E_2 \) cut-off energies on the top boundary for beam electrons were accepted to be equal 10 and 300 keV, respectively. As we are interested in comparison of thermal and non-thermal effects on the Ni line formation, the calculations were carried only for the times from 1 to 10 sec when electron beam being injected. The resulting distributions of temperature, density and macro-velocity for model 410 (\( \delta = 4 \), \( F_0 = 10^{10} \text{erg cm}^{-2} \text{s}^{-1} \)) are plotted in Figure 1.

2.2. THE ATOMIC MODEL

The atomic models taken into consideration included 14 atoms (H, He, Ni, C, O, S, and other metals) distributed with the coronal abundances and some molecules with respect to the RH-radiative code by Uitenbroek (2001). Ni was considered as an active atom while all others including hydrogen were assumed to produce the background radiation.

2.2.1. The Ni I atomic model

For the Ni I atomic model we have used the comprehensive model proposed by Bruls (1993) and kindly offered by the author for our calculations. It includes 83 spectral lines (see in Figure 1 in Bruls, 1993) while the redundancy has been minimized by replacing groups with similar terms and lines by single representatives. In the line profile computation, the radiative damping and Van der Waals damping were taken into account. Micro-turbulence and macro-velocity effects of the ambient plasma motions were also included.

A multi-level accelerated lambda iteration (MALI) method for radiative transfer calculation in one-

![Figure 1. The hydrodynamic models of flaring atmospheres affected by the injection of electron beams with the parameters: the initial energy flux on the top boundary in the corona: \( F_0 = 10^{10} \text{erg cm}^{-2} \text{s}^{-1} \); and the beam spectral index \( \delta = 4 \) (model 410).](image)

...dimension flaring atmospheres (Uitenbroek, 2001). The method, based on Rybicki and Hummer's complete frequency redistribution formalism with full preconditioning, consistently accounts for overlapping radiative transitions.

2.2.2. The hydrogen atomic model

The hydrogen atom was considered to govern the flaring atmosphere ionisation via radiative transfer in the continua with the effects of non-thermal ionisation and excitation by electron beams following the method by Zharkova and Kobylynsky (1991). The full non-LTE calculations were performed for 5-level plus continuum model hydrogen atom with the Voigt absorption coefficients in lines. Because the flaring atmospheres are very dynamic ones with steep depth variations of temperature, density and macrovelocity, the Doppler half-widths, Voigt parameters, excitation and ionisation rates were recalculated for each depth step while the effective parameters were used for a line profile calculation with...
2.3. Ni I 676.8 nm line

The Ni I 676.8 nm corresponds to a transition between levels 3P^0 and 1S. The lower level 1S is metastable being populated by collisions from the lower and upper levels while for the upper level 3P^0 most important are photo-ionisation by the external and diffusive radiation

2.3.1. Source functions and departure coefficients

The source functions of Ni line, continuum background and Plank functions are calculated for the atmospheric model 411 and presented in Figure 3 for 6 seconds after a beam injection with the beam electron ionisation. The upper level abundances and departure coefficients calculated for the same HD model are presented in Figure 4, without the beam ionisation at 1 s after the beam onset (upper panel), and 6 s after the beam onset (lower panel).

As it was expected the Ni 676.8 nm line source function with electron beam reveal a substantial deviation from the Plank function (Figure 3). The increase of a hydrogen non-thermal ionisation by electron beam decreases dramatically the upper level source function for the cooler hydrodynamic model 411 while it increases for the hotter HD model 312 (δ = 3, F_0 = 10^{12} erg cm^{-2} s^{-1}).

2.3.2. Ni 676.8 nm line profiles

The Ni I 676 nm line profiles calculated for the maximum flux of electron beam precipitation (6s) are presented for the HD model 411 in Figure 5. For the hydrodynamic model 411 with the beam heating not reaching the deeper atmospheric levels in an absence of a non-thermal hydrogen ionisation the Ni line profile remains the absorptive one without any substantial changes during the first 10 seconds.

The inclusion of the non-thermal ionisation does not affect the profile in the first second or two then reversing the profile into emission at the maximum of the beam flux (6 seconds after its onset, see Figure 6). After the 10 s when the beam is switched off, the emission disappears, and
the line profile returns to the absorption one for the rest of the hydrodynamic response time (up to 300 seconds in our simulations).

It is caused by the hydrogen ionisation increase owing to an impact ionisation by beam electrons leading to an increase of opacities in the hydrogen Paschen continuum (see Figure 2). It decreases the total intensity in the Ni line (see Figure 6) and particularly, the wing intensity affected by collisional effects. The core intensity remains decreased by the order of magnitude with respect to the case without electron beam ionisation. However, it becomes much higher than beam electrons can reverse the Ni line profile the intensity in the line wings reversing into the weak emission profile. It is not clear yet how it would be reflected in the Stokes parameters that is a subject of the future investigation.

Without a non-thermal ionisation by electron beam the upper level abundances are steady growing with depth (Figure 4, upper panel) while the departure coefficients are nearly constant over the depth being slightly lower than the LTE values. With the hydrogen non-thermal ionisation the upper level abundances on the Ni I 676.8 nm line still steady increase with depth becoming by an order of magnitude lower than those without a non-thermal ionisation.

Figure 4. The population of the upper level in the Ni I 676.8 nm line in a flaring atmosphere 411 at 1 s (upper panel) and 6 s (lower panel) after the beam onset with a non-thermal hydrogen ionisation.

Figure 5. The emerging line profile of the Ni I 676.8 nm line in a flaring atmosphere 411 at 6 s after the beam onset with a non-thermal hydrogen ionisation. The lowest black line corresponds to a viewing angle 0°, the gray lines correspond to the 4 other viewing angles equally increasing up to 90°.

3. CONCLUSIONS

The initial results of the non-LTE simulations of flare electron beams on the variations of the line profile of the photospheric line Ni I 676.8 nm, which is used in the MDI magnetic field measurements, indicate that the impulsive heating of the photosphere can cause significant changes and even inversion of the line profile. However, in terms of the observable values this line profile inversion is a very weak and short-lived (a few seconds) one. It can affect the MDI measurements accumulated over the timescale of 30 sec, and contribute to the observed magnetic transient signal. However, these line profile variations last only for few seconds during the beam impulses. Therefore, they cannot affect the long-term flare-related magnetic field changes observed with MDI. Clearly, the physics of the interaction of the high-energy particles with the photosphere is quite complicated and deserves further careful investigation.

REFERENCES

Zharkova, V.V., Kobylynsky, V.A: 1989, SvA Let., 15, 366
Zharkova, V.V., Kobylynsky, V.A: 1991, SvA Let., 17, 34

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