ON THE PRESENCE OF HIGH-FREQUENCY TURBULENT ELECTRIC FIELDS IN THE AUGUST 7, 1960 FLARE

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Received 21 March 1989

In the presence of high-frequency turbulent electric fields (Langmuir turbulence), a non-equilibrium hydrogen plasma emits Balmer lines with typical dip-like features in their wings. Such dips have been predicted theoretically and observed under special laboratory conditions. They are also expected to be present in the spectra of solar flares, where the plasma instability can be generated by fast electron beams entering the chromosphere. According to Oks (1978), the wings of some hydrogen Balmer lines observed in the spectrum of the moustache-like flare of August 7, 1960 do exhibit theoretically predicted dips, which should indicate the presence of Langmuir turbulence. However, these features are rather subtle and thus several difficulties arise if one tries to identify them in the noisy spectra with typically many blends. Moreover, the Balmer profiles used for Oks' analysis were already "filtered" in a special manner described here, which also strongly affects the results. In view of these problems, we decided to re-investigate whether these dips in this particular flare were real, starting with newly obtained microphotometric records. Using the same lines as Oks (i.e. H\textsubscript{7}, H\textsubscript{8}, H\textsubscript{11}–13), together with H\textsubscript{14}, we were unable to identify any expected dips in the line wings. We discuss in detail all observational aspects of this analysis and propose new special observations. The role of electron density variations within the flare volume is also briefly discussed.

\textbf{Key words:} Solar flares: turbulent electric fields

1. Introduction

An important problem of current flare research is that of energy release and its transport to lower parts of the solar atmosphere. In order to explain the heating of chromospheric and upper photospheric layers during the flare, one class of flare models assumes that electrons are accelerated at the site of primary energy release and, subsequently, running down as fast particle beams, they transport the flare energy into the lower, denser atmospheric regions (e.g. Neidig 1986). Simultaneously, these electron beams are supposed to generate the Langmuir plasma turbulence, i.e. high-frequency (HF) oscillations of collective electric fields. According to the important theoretical results of Oks and Sholkin (1975) and Zhuzhunashvili and Oks (1977), HF stochastic modes should be detectable as plasma satellites (absorption dips) in the wings of various hydrogen lines. It is clear that an identification of such dip-like features

in the flare spectra would provide us with an independent justification of the existence of particle beams or other plasma instabilities related to the energy transport from the hot coronal loops. The first attempt to search for dips in hydrogen spectra of chromospheric flares was made by Oks (1978) and Banin et al. (1979). Oks' (1978) paper is sometimes referred to as the first direct confirmation of the existence of HF — Langmuir oscillations in chromospheric flares. To reach this conclusion, Oks analyzed the Balmer line profiles in the August 7, 1960 flare observed with the multichannel flare spectrograph at the Ondřejov Observatory and published by Švestka (1963) (for observational details see Švestka's paper). In these data, Oks identified several dip-like features which, according to him, were produced by HF — turbulent electric fields. In view of the principal importance of these diagnostics for our understanding of basic flare mechanisms and since Oks' conclusions have evoked rather controversial responses, we have decided to re-investigate this problem. To do this, we have used — in contrast to Oks — the original spectra deposited at the Ondřejov Observatory and, moreover, we have carefully examined the procedure used by Švestka (1963) to obtain his line profiles which served as basic observational data for Oks' work. The results of Banin et al. (1979) have a preliminary character with no definite conclusions concerning the actual existence of dips in the seventh levels, i.e. the Balmer-\(e\) line).

2. Newly obtained photometric records of the same spectra of H7 and H11 lines, together with additional tracings of H8, H12, H13 and H14. We have measured the flare spectrum \(I_F\), as well as the background radiation \(I_0\) of nearby regions for all these lines. From the reduced data we were able to determine the so-called pure emission profiles (or contrast profiles) of the flare itself, defined as

\[ I = I_F - I_0 \]  

(1)

To estimate the unambiguity of our conclusions, we have made some special measurements with different sizes of the microphotometer slit (for smoothing) and we also obtained two profiles for the H7 line, corresponding to two very closely spaced flare regions — this is to avoid the effect of the noise which is supposed to be different at different positions of the photographic plate. All measurements and data reductions were performed by using a modified Zeiss-Jena microdensitometer, connected to EMG-666 computer (Tomsa 1989).

3. Search for Dips

In this section we describe several approaches which we have used to find the expected plasma satellites (dips).
Fig. 1. Relative intensities of the H7-line. Plot a — data obtained by Švestka (1963) and used by Oks (1978). Our new measurements: b — pure flare emission, c — flare spectrum $I_F$, d — spectrum of the neighbouring chromosphere ($I_B$). Note that H7 line is strongly blended by the very near CaII H line. CaII H emission cores are shown as hatched areas. Three arrows indicate a flare emission in the metallic lines, some other significant blends are also indicated (see the text). The thin vertical lines indicate theoretical positions of dips computed from Eqs (2) for $n_e = 2 \times 10^{19}$ m$^{-3}$ (the labels correspond to $\Delta \lambda/\lambda_p$).
plasma satellites with $\Delta \lambda = X_{\alpha 2} \lambda_{\beta} / \alpha$, but only the set corresponding to Eqs (2) is expected for higher Balmer lines (Oks 1978). In the present paper, we use Oks' notation, while in Firstova et al. (1988) we denoted the upper level as $\beta$ [in Eq. (2) of Firstova et al., $\Delta \lambda$ should appear instead of $\Delta \lambda_{\beta}$]. Of course, both formulations lead to the same results because of the symmetry of dips around the line center. According to Oks (1978) in the following discussion we have used the ratio $\Delta \lambda / \lambda_{\beta}$ as a measure of the satellite positions (see Figs 1–6). For all theoretical details concerning the satellite positions, their widths and expected visibility in hydrogen Balmer lines see Oks (1978) and references cited therein.

All expected positions of plasma satellites have subsequently been compared with the observed positions of dip-like features in our tracings of H7 to H14 — this is displayed in Figs 1–6, where the positions of dips are denoted by thin vertical lines. In contrast to Oks (1978), we have found no unique correlation between these two sets of data. In fact, the computed separations between dips are relatively small in most cases, especially for H7 and H8 lines, and usually comparable with mutual distances and widths of numerous blending lines and noise features (see also the discussion below). Under such circumstances, any identification of plasma satellites is rather questionable.
3.2. Line Symmetry

Since the contrast profiles $I$ (Eq. 1) are more or less symmetrical (see also lower Balmer lines in Švestka’s paper), we can superimpose both the wings and look at mutual correlations between the profile variations (except of H7, which is strongly blended by the broad CaII emission). Again, no definite conclusions can be drawn regarding the satellites. For example, H11 was measured by Švestka in both more or less symmetrical wings, but Oks has used only one wing exhibiting more pronounced dips — we have found a quite different fine structure in the opposite wing (see our Fig. 3). This is particularly clear for the feature at position 4.5. Due to the procedure used by Švestka (see below), the Oks’ plot for H11 (our Fig. 3a) is relatively very smooth as compared to our detailed measurements presented in Fig. 3b — it only exhibits a few “satellites”. The same also applies to H7 in Fig. 1.

3.3. Effect of Noise

For H7, we have compared two tracings which are pertinent to two closely spaced flare regions. While some dips seem to be real in the first tracing, they are missing in the second. Of course, we cannot discuss the possible spatial variations of turbulent processes here as this is far beyond the scope of this paper. However, we know that our spatial resolution is of the same order as the distance of tracings (due to both instrumental and seeing conditions), so that we can eliminate the effect of the noise in the wings while real features should be similar in both tracings.

3.4. Blending Lines

In the background radiation $I_0$ we can identify a large number of Fraunhofer lines of different intensities, belonging to several species. In interpreting pure-emission profiles, one has to consider two limiting cases. Firstly in the near wings, the line opacity is non-negligible and thus $I$ itself will also be partly affected by the variations of $I_0$. This situation can be demonstrated in Fig. 1. Close to position 7, we can resolve a dip-like structure (identified by Oks as a plasma satellite), which seems to originate as the difference between the two absorption features in Figs 1c and 1d, denoted as the FeI blend. Secondly,
in the optically thin limit, \( I \) is practically unaffected by \( I_0 \), but since the flare emission is very weak at these wavelengths, the difference \( I_F - I_0 \) is determined with a rather low accuracy (ten or even more percents) — see the large negative values of \( I \) in the far wings. Therefore, for higher Balmer lines we can hardly distinguish between the mutual effects of the background radiation, the noise and some additional dip-like features. All these can easily be misinterpreted as plasma satellites — see also the discussion by Banin et al. (1979). Note also that some blending lines are visible in the emission in the \( I \)-profile because they are indeed an emission within the flare region as mentioned by Švestka (1963).

3.5. Švestka's Mean Profiles

For H7 and H11 lines, we display four plots in both Figs 1 and 3:

a) \( I \) as obtained by Švestka (1963) and used by Oks (1978)
b) Our determination of pure emission \( I \)
c) Original flare spectrum \( I_F \)
d) Background spectrum \( I_0 \).

According to Švestka (1987), the non-equidistant points in his plots are due to the sophisticated selection of those regions in the wings of lines which are not affected by the flare emission of other species (see the previous item) — such emissions would change the "mean" level of the contrast in the wings, i.e. the shape of the hydrogen line profile itself. Therefore, Švestka simply omitted such parts of the spectrum and used only specifically selected intensities. These intensities have been connected by abscissas in Oks' figures (see also our Figs 1a and 3a). In this way, the resulting pure-emission profiles, reproduced in Švestka's paper, represent more or less the average emission in the wings of the hydrogen lines and the scattering of the individual points is partly due to measurement errors (noise) and partly due to the non-ideal removal of blends (both in emission and in absorption). Knowing these facts, one can use Švestka's mean profiles for modelling purposes (as Švestka indeed did), but we cannot rely on any feature in the wings as far as plasma satellites or other fine structures are concerned. For example, feature 16-5 is
very probably the flare emission in some of the lines indicated in Fig. 1d, which is clearly seen in Fig. 1b (an emission peak). Therefore, there is definitely no dip at this position. However, Švestka has a dip-shaped feature at position 16-5 because he tried a priori to remove all emission peaks in the wings and thus, as he desired, his minimum at 16-5 roughly follows the global behaviour of the line profile. This example clearly shows that such plots cannot be used in any search for plasma satellites (dips). On the other hand, we have also identified a dip-like feature at position 20 in our data, but this is much narrower than Oks’ one. This discrepancy follows from the fact that Švestka avoided (or suppressed) the emission peaks, denoted in Fig. 1 by three arrows, which seem to correspond to the flare emission in some FeI lines. Consequently, if the feature at position 20 would really represent a satellite, then the level of HF-turbulence $E_0 \approx 3 \times 10^5$ V/m, derived by Oks (1978), would be overestimated (the same is also valid for the feature at position 16-5). However, for lower $E_0$, the theoretical widths of the other “satellites” at positions 7 and 9-5 would be comparable or less than the actual resolution of our spectrograph, which is of the order of 0.01 nm in this wavelength region (Valněček et al. 1959, Kotrč 1988). Therefore, only dip 20 could eventually be interpreted as a plasma satellite, providing $n_e$ is exactly equal to $2 \times 10^{19}$ m$^{-3}$. Given a somewhat different electron density, several other absorption features in our data could be identified as plasma satellites.

4. Conclusions

In the present analysis, we have tried to check Oks’ (1978) conclusions rather than to identify other sets of possible plasma dips corresponding to different electron densities. We conclude that the dips found by Oks are very probably unrealistic and do not represent the expected plasma satellites in hydrogen Balmer lines observed in this particular flare. Further, as stated by Oks (1978), his electron density is in agreement with that obtained from the analysis of the
Stark wings in the same flare by Kurochka (1970). However, if the flare plasma is in a non-equilibrium state (as expected by Oks), \( n_e \) derived from a pure particle broadening of the wings is overestimated because of the additional broadening caused by collective processes. A lower \( n_e \) would subsequently lead to a quite different set of plasma satellites. Moreover, the assumption of a unique electron density within the emitting plasma volume is also very crude, leading to a great oversimplification of the problem. Different sets of satellites will arise from different atmospheric depths as a result of electron-density variations. Therefore, the resulting widths of dips will depend on the run of the electron density with depth and on the contribution functions for particular lines (note that the widths of the individual dips depend primarily on \( E_0 \)). From preliminary estimates, we expect broad and shallow features rather than the individual resolved dips indicated in our figures. In the case of many closely spaced satellites, this should lead to a nearly continuous change of the absorption profile, which would have the same effect on line formation as the usual line broadening mechanisms. On the other hand, as can be seen from Figs 3—6, the satellites pertinent to higher Balmer lines form rather well-defined and separated groups of 2 or 3 dips, which could, under favourable conditions, be identified as shallow and broad (due to variable electron density) gaps. However, the wings of these higher Balmer members are probably optically thin which leads to a higher noise level in the contrast profiles. Therefore, we propose new observations of high-resolution spectra with a sufficiently improved signal-to-noise ratio (photoelectric data). Also the time resolution can play an important role since the corresponding plasma instabilities are supposed to vary on short-time scales. Theoretical modelling of Balmer line wings in the presence of turbulent electric fields is now in progress, using actual flare models with depth-dependent electron densities.

Acknowledgements

The authors are deeply indebted to Drs Z. Švestka and V. P. Maksimov for useful discussions which have led to the clarification of several important points. We also appreciate the technical help provided by Dr. J. Tomsa, L. Žďárská and M. Tesaříková. One of the authors (N. M. F.) thanks the Astronomical
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GRAVITY FIELD OF SATELLITES DISINTEGRATING AT THE ROCHE LIMIT

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Received 27 April 1989

ПОЛЕ СИЛЫ ТЯЖЕСТИ СПУТНИКОВ, РАЗРУШАЕМЫХ БЛИЗ ПРЕДЕЛА РОША

Предполагается, что процесс разрушения спутников начинается, когда сила притяжения уравновешена суммой приливных и центробежных сил. В таком положении могут оказать три спутника солнечной системы: Фобос, Адрареста и Метис. Процесс разрушения начинается в экваториальной области, однако, состояние нулевой силы тяжести никогда не будет иметь место в полярных областях. Гана оценка параметров фигуры Метис для равновесной модели: а' = 36,5 км, б' = 24,1 км, если принять наблюдаемое значение с' = 20 км.

The disintegrating process of satellites is assumed to start when the gravitation is balanced by the sum of the tidal and centrifugal forces. Three satellites in the solar system can reach such a state: Phobos, Astrarastea, and Metis. The disintegrating process should start at the equatorial zone of the satellite, however, zero-gravity cannot occur at the polar region. The figure parameters of Metis have been estimated for an equilibrium model: а' = 36.5 km, b' = 24.1 km if the observed value in situ c' = 20 km is adopted.

Key words: Solar system, satellites Phobos, Astrarastea, Metis, tidal distortion, disintegration

1. Introduction

There are three satellites in the solar system orbiting under the synchronous zone. This means their mean motions \( n_s \) are greater than the angular velocities \( \omega_p \) of rotation of the planets: \( n_s > \omega_p \). These are: Phobos, Astrarastea and Metis (Table 1). All three rotate synchronously (Davies 1988), i.e. their angular velocities \( \omega_p \) of rotation are equal to their mean motions: \( \omega_p = n_s \). That is why their tidal-rotational dynamics and the evolution of the satellite-planet system can be treated and described using a simplified model. We assume the disintegration starts when gravity on the surface of the satellite becomes zero.