WHITE LIGHT FLARES AND ATMOSPHERIC MODELING

(Working Group Report)

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ABSTRACT

We give a short summary of our discussions, and a set of recommendations which may help in the study of white light flare emission processes.

1. INTRODUCTION

Within the limited time period available for detailed discussions, the group was only able to define a few topics of common interest and provide a series of guidelines for future research to be carried out in order to try and understand the emission mechanisms at work and the energetics of the continuum emission region.

Questions addressed during the discussion were:

(1) What is the range of observed parameters in terms of spectra, temporal development, and spatial development?

(2) Which is (are) the emission mechanism(s) favored by observations?

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(3) Can we establish a "working" model (semi-empirical type) to try and see which are the possibilities to produce continuum emission by different radiative processes?

(4) Which are the causes of white light flare (WLF) emission?

(5) What do we need from the observational and theoretical sides to improve our knowledge on white light flares?

2. DISCUSSION

With respect to the first question, a wide range of observations is now available in the current literature, showing that the characteristics of the continuum spectrum are extremely varied (see e.g., Canfield et al., 1986). Still, there seem to be two distinct classes within which most spectra can be fitted. The first class, which we shall call Type I, generally corresponds to the brightest events, shows an increase in contrast towards the blue, with a Balmer jump probably masked by the merging of the highest members of the Balmer lines series (Donati-Falchi et al., 1985), and the probable presence of a Paschen discontinuity which has only recently been observed (Neidig and Wiborg, 1984; see also Neidig in these proceedings). On the other hand, several white light spectra show rather flat wavelength dependence, absence of Balmer discontinuity and rather narrow Balmer lines, as compared with the previous class, which indicate electron densities not higher than $10^{13}$ cm$^{-3}$. We call this kind of emission as Type II. Examples of these two classes of events can be found in papers by Neidig and Wiborg (1984, Type I), Boyer et al. (1985, Type II), and Hiei (1981, both types). The overall consensus is that the extremes of these two kinds of observed spectra are well enough defined so as to warrant separate detailed study and modelling efforts, even though it is clear that many (if not most) WLF's could be a combination of both.

With regard to the second question, the classical possibilities of hydrogen free-bound (Balmer and Paschen transitions) and $H^-$ continuum emission were considered, although it was also mentioned that other, more exotic, processes that have been rejected in the past (see Svestka, 1966) could be reconsidered. An important aspect which should be recognized is that the continuum spectrum by itself does not generally carry enough information to allow us to discriminate between emission processes. An example showing these problems is given by Boyer et al. (1985), who were able to fit the wavelength dependence of the observed continuum contrast by either free-bound or $H^-$ emission processes originating, presumably, at different depths and temperatures within the solar chromosphere/photosphere.

The actual problem with the varied interpretation that the continuum spectrum is amenable to, refers to the fact that the observed absolute intensity, as well as its wavelength dependence, is related to (in the optically thin approximation)
\[ I_f - I_0 (1 - \Delta \tau_\lambda) = (\beta_\lambda(T)/b) \Delta \tau_\lambda \]  

where we have replaced the continuum source function \( S_\lambda \) by \( \beta_\lambda(T)/b \), where \( b \) is the NLTE departure coefficient (= \( b_3 \) for Paschen transitions), and \( \Delta \tau_\lambda \) is the continuum optical thickness of the emitting layer which has different wavelength dependence when either \( H_f \) or \( H^- \) opacity are considered. Thus, except for very extreme cases, one can find a reasonable combination of \( \beta(T) \) and \( \Delta \tau \) which can fit the observed spectrum by either process. On the other hand, the absolute intensity in the optically thin case is directly related to the value of \( \Delta \tau_\lambda \) (in the optically thick case, the observed contrast simply reflects the temperature increase, \( \Delta T \), at the \( \tau(5000 \text{A}) = 1 \) level), so that once the \( \beta(T) \) and \( \Delta \tau_\lambda \) combination has been fixed, one has to look for the possibility of having a large enough optical thickness to match the observed contrast. This information can only be provided by the study of other spectral features, spectral lines of hydrogen and HeI in particular, as well as weak metallic lines (see below).

In terms of the additional constraints imposed by the spectral lines, the association of the Type I WLF events with extremely broad Balmer lines suggests the possibility that the emission can be due to hydrogen free-bound processes in an optically thin layer. The high densities deduced from the Stark broadened lines make it possible to obtain a reasonably large optical thickness within a not too large geometrical scale, at a temperature \( T = 10^4 \) K (see Neidig, these proceedings and references therein). On the other hand, spectra with relatively narrow hydrogen lines make it extremely difficult to postulate that a Paschen contribution could be substantial enough so as to produce enhanced continuum emission in the visible spectrum, even in cases where \( \Delta I/I_0 = 0.1 \) (Hiei, 1982; Boyer et al., 1985; see also Mauias and Machado in these proceedings). Therefore, in these particular cases it is likely that the main contribution to the WL emission originates from deep atmospheric layers, where the hydrogen density largely exceeds \( n_H = 10^{15} \text{ cm}^{-3} \), and where \( H^- \) is the main contributor to the continuum emission, although very deep seated Paschen contribution regions could also increase the overall output (Aboudarham and Henoux, 1985).

Finally, it should also be noted (Falciani, workshop discussion) that in the most complete lists of emission lines in WLF spectra (see Svestka, 1976; Machado and Rust, 1974; Donati-Falchi et al., 1983) there are many lines which do not show any flare response at all, i.e. that their intensity does not change in any appreciable way in the spectrum, as compared to the quiet Sun or preflare profiles. These observations may set a limit to the maximum depth at which the atmosphere shows associated temperature increases. The depths at which the cores of these lines are formed usually correspond (see papers cited above) to 300 km > \( h > 200 \) km above \( \tau(5000 \text{A}) = 1 \). If one assumes that the central intensity of these lines reflects local temperature at these depths and their possible variation, given a 5 to 10% photometric accuracy to the spectra, the absence of changes in their residual intensity implies that temperature changes should not exceed 80 K at these depths. It is, however, not completely clear that these lines are formed in LTE and, thus, how sensitive they are to changes in local
conditions (see e.g., Caccin et al., 1976). Hiei, however, reported that his 1982 study supports the idea of such a correlation.

Referring now to the third question addressed in Section 1, it was felt that a set of computations was needed to provide a "benchmark" type of working model based on detailed radiative transfer calculations of atmospheric models (see e.g., Machado et al., 1980), which would give more accurate physical parameters than the commonly used plane-parallel-constant-temperature slab approximation. The purpose of these calculations, which would be undertaken by Avrett and Machado using the PANDORA program, is not to provide model atmospheres that reproduce the observations of a given event, but rather to explore the range and location of physical parameters changes (as compared with the undisturbed atmosphere) that can lead to enhanced continuum emission. The atmospheric modelling approach also enables us to attain a self-consistent physical picture of internal radiative processes which affect the atmospheric energy balance and, thus, plausible temperature distributions and net radiative losses at each given height. A preliminary report of these computations is given separately in these proceedings (Avrett et al.), and the results, which should be analyzed in detail, are very encouraging in the sense that they give support to the Type I, II distinction as due to different emission processes originating at distinct depths in the solar atmosphere, as postulated in the purely empirical analyses.

The last two questions could not be addressed in great detail during the meeting, but relate strongly to the non-spectral characteristics to which the first question refers. It is recognized that although many WLF's show emission kernels which brighten in good temporal correlation with hard X-ray emission (Rust and Hegwer, 1975), others do not (Rust, these proceedings and references therein). The absence of a strict correlation with hard X-rays as well as γ-ray emission (Ryan et al., 1983) reveals that energetic particles (electrons and protons) are not, in many instances, the cause of the heating leading to WL emission (note, however, that many events show good correlation with low energy, deka-keV, hard X-rays; Kane et al., 1985). Similar conclusions can be reached from the analysis of WLF's showing narrow line spectra and continuum emission lasting for several minutes (Mauas and Machado, these proceedings). Irradiation by XUV photons was a topic discussed during the meeting (see Emslie's and Rust's contributions), but the implications of the proposed mechanisms on other observables should be worked out in some detail before being accepted.

An additional aspect of WLF emission which may pose rather stringent conditions for energy transfer processes, is the report of very large, about 200% according to Zirin and Neidig (1981) and up to 500% in another case (Neidig, these proceedings), increases in the Balmer continuum brightness. If due to true continuum, they imply extremely large energy deposition rates at the level where they originate (likely within the upper chromosphere, see model F3 in Avrett et al., these proceedings). It is also clear that this emission must originate from over-dense atmospheric regions, as estimated by Neidig et al. (1986), where a theoretical treatment of combined energy input and radiative processes becomes extremely involved.
3. CONCLUSIONS AND RECOMMENDATIONS

Except for the last nagging aspect of the observations, which may perhaps be explained by the combined effect of line and continuum emission, we concur with the statement of Donati-Falchi et al. (1984) that WLF's are not a peculiar class among flares as it was thought before (McIntosh and Donnelly, 1972; Svestka, 1976). With improved observational capabilities, particularly in terms of sensitivity as well as temporal and spatial coverage, the statistics of WLF's has increased dramatically during the last few years (Neidig and Cliver, 1983), indicating that many flares, not even the most energetic ones, produce continuum enhancements. On the other hand, as noted by Neidig and Wihorg (1984), the continuum radiative output may be quite substantial, with cases in which it exceeds by a factor of 100 the Hα intensity (Slonim and Korobova, 1978; Neidig, 1983), so that the preceding discussion on the identification of the emission mechanism and layer where the continuum originates becomes extremely important in the overall energy balance and the identification of the heating mechanism(s).

In conclusion, we would like to list a set of recommendations for anyone who has the chance of analyzing white light flare spectra:

1. Give spectral intensity distribution in erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) A\(^{-1}\), or \(\Delta I/I_0\) referring to which (listed) values of \(I_0\) they correspond.

2. Estimate, as accurately as possible, the WL power (erg s\(^{-1}\)), brightness (erg cm\(^{-2}\) s\(^{-1}\)) and total energy (erg).

3. Whenever possible, give additional information as deduced from other spectral features, like electron density and/or Balmer line widths, energy output and power (to be compared with WL values, see e.g., Donati-Falchi et al., 1984), identification of spectral lines and molecular bands that are not flare sensitive, i.e., that do not show any detectable intensity variation (filling in of absorption core) during the flare.

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REFERENCES