THE VERIFICATION OF CHUNG-CHIEH-CHENG IDEAS ON THE HEATING MECHANISM OF SOLAR FLARES

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Abstract: As demonstrated by Cheng (Solar Physics, *22*, 178) it is possible for some large flares to emit non-thermal, as well as thermal radiation in their initial phases. This radiation must contribute to the soft X-ray region and occur after the hard X-ray burst above 20 keV.

Using our X-ray observations for a number of solar flares, made on Intercosmos satellites, we have checked this hypothesis. We have found soft radiation in evidence a long time before hard X-ray bursts, however, in many cases both types of radiation were observed practically simultaneously. This indicates the existence of a minimum of two different mechanisms during the initial stage of the flare: one which begins to heat the mass of the flare a long time before the acceleration process, emitting non-thermal radiation, and the second beginning practically at a time which agress with Cheng's hypothesis.

Introduction

In the conclusion of his article Cheng (1972) says: "From the preceding discussion we see that it is possible for some large flares in which a substantial number of electrons are accelerated to emit non-thermal, as well as thermal bremsstrahlung in their initial phase. The thermal bremsstrahlung contributes mostly in the soft X-ray region and occurs about 1/2 minute after the hard X-ray burst, seen above 20 keV. These emissions are both product of non-thermal electrons accelerated by the flare. One is due to direct non-thermal bremsstrahlung of the electrons, while the other is an indirect consequence of the heating of the ambient gas. In order to test whether the heating mechanism is operative in solar flares, it is necessary to record the whole range of the X-ray spectrum from a large solar flare. A detailed study of the complete spectrum and its time-characteristics will determine how important the heating of the flare plasma by hard X-ray electrons is at the very early stages of the flare."

Because our observations, made in the Intercosmos programme on board of the Intercosmos 4 and 7 satellites (Valníček et al., 1973), include many solar flares, with the help of this material we have made an attempt to verify the validity of these opinions of Cheng.

For this purpose, we have studied the times of the beginning and of the maximum of the X-radiation of isolated phenomena on separate channels for effective energetic levels of 7, 13, 27, 47, and 72 keV.

Results

We have been able to drawn the following conclusions: In the case of subflares and small flares it was really found that the weak radiation set in later than the hard component (more than 20 keV, see Fig. 1). This is valuble specially for effects in which the high-energy radiation is not present (i.e. unmeasurable values on channels of 47 and 72 keV). This is also in accordance with the results of Drake (1971), who analysed 86 cases, measured by Explorers 33 and 35, and compared with OGO I and III. He came to the conclusion that the radiation in the region of 10—50 keV occurs 2—5 min sooner than the radiation in the region of 1—6 keV. This interval coincides with the values in Figure 1, where the radiation for 3 subflares and 1 Sn-type flare is presented, and the delay of the soft emission is in the time interval of 1—4 minutes. The situation is different for effects a little more important than type 1n and 2b flares. The soft emission sets in simultaneously with or just before the hard emission occurs. The maximum of the soft rays is found sooner than or simultaneously with the hard radiation. The difference is in an interval of 1—2 min (see Fig. 2).

We now come to the third group of effects, to the most energetic effects of proton flares (see Fig. 3). Here we find the soft emission beginning a long time before the hard. The most energetic emission follows about 10 min after the soft emission. This is followed by a series of maxima which all coincide in

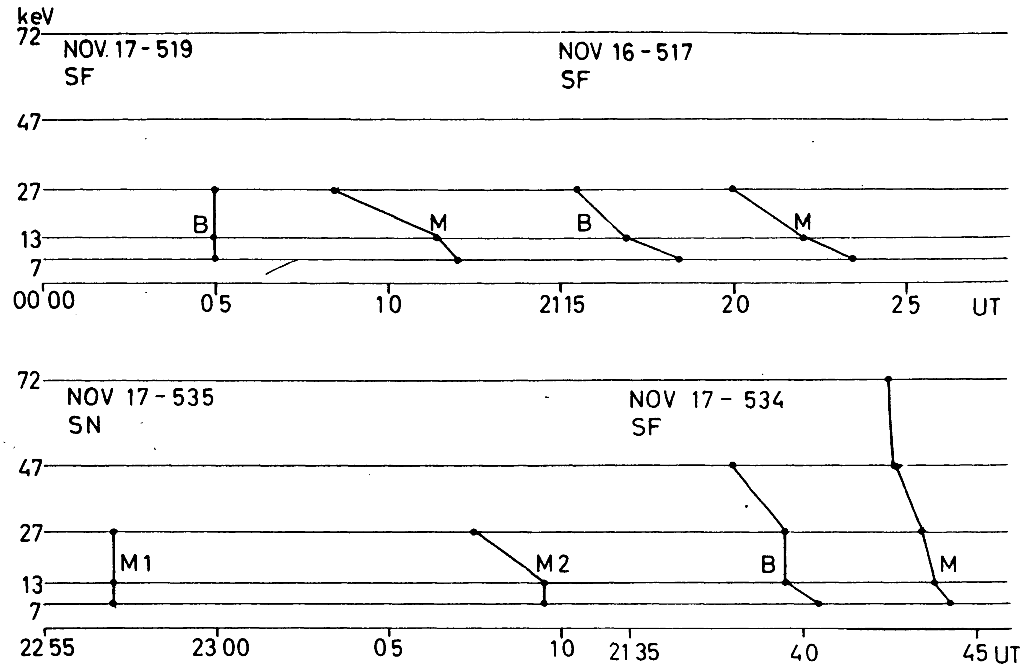

Fig. 1. Time energy diagram for 4 effects in 1970 (measured by Intercosmos 4). Vertically — energy in keV, horizontally — universal time. B — beginning of radiation, M — maximum of radiation. In the caption: the date and number of orbit, below: the type of flare.

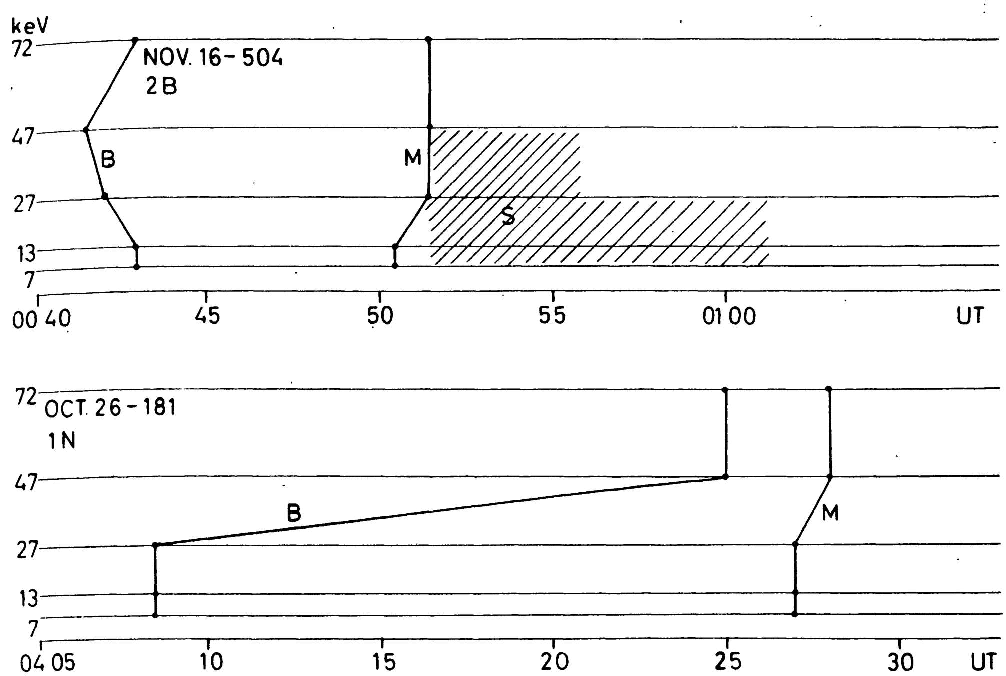

Fig. 2. Time energy diagram for 2 effects in 1970. See text to Figure 1. S — saturation of channels.

time with, or the hardest are 1—2 min delayed relative to the soft-maxima. In all cases the level of the soft radiation is so high that these channels become saturated.

The impression for big flares is different. The occurrence of different components of radiation, starting with the softest, seems be the manifestation of some preparatory process in the active region,

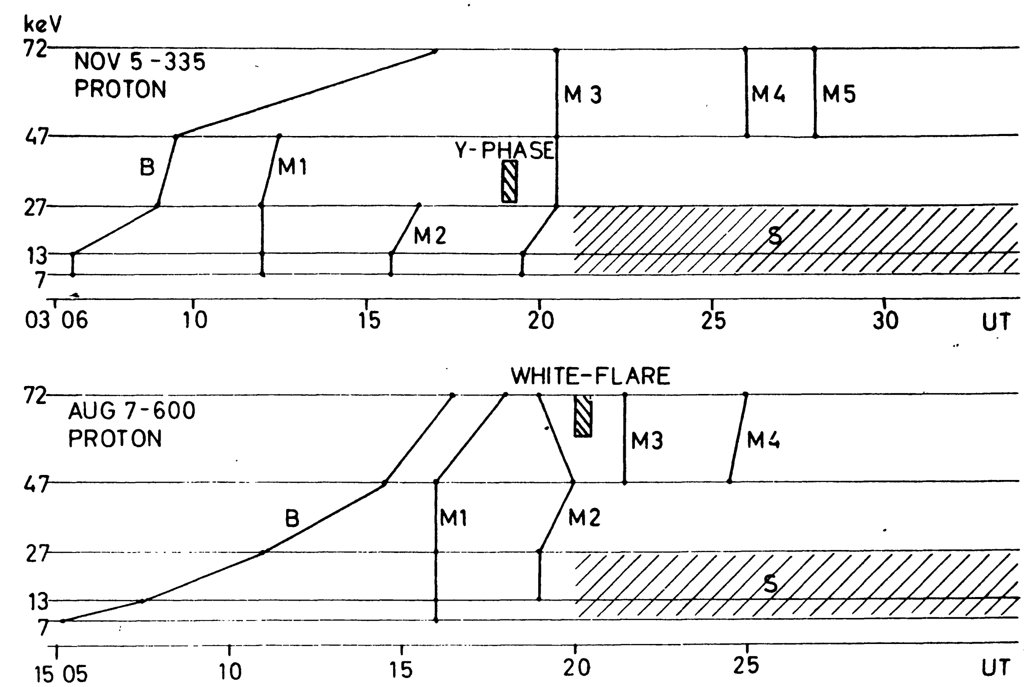

Fig. 3. Time-energy diagram for the large flares of Nov. 5, 1970 and Aug. 7, 1972. See text to Figures 1 and 2.

The same effect was found for the two big flares studied of November 5, 1970 and August 8, 1972. For the flare of Nov. 5 the occurrence of the hardest radiation coincides with the maximum of the Y-splitting of the flare ribbons (Fárník et al., 1973). For the flare of Aug. 8 this phase coincides with the white-flare phenomenon (Rust, 1972). Similar trends of energetic levels can also be found for the big flare of March 22, 1967 (Hudson, 1969).

Conclusion

It is a matter for discussion, if the soft-radiation delay, we found for the small effects, is identical with the delay of 1/2 minute, given by Cheng to support his conclusion, i.e., if this delay can be caused by the thermal bremsstrahlung, as suggested by Cheng.

The fact that at the beginning of these small effects we have seen the hard component beginning sooner than the soft, and that in few cases both components are in coincidence, could be important.

which can be of thermal character. This process is changed suddenly and at this moment a great quantity of energy accompanied by hard X-radiation, is delivered within a short time interval. During this short time interval, limited to a few minutes only, the most important phase of the flare is concluded. This is identical with the explosive phase (Křivský et al., 1973).

This flare pattern, derived from X-ray observations, seems to agree with the point of view of Takakura (1971) which is starting of the growth of electric field gradient in the lower corona more as 10 V/km, where the acceleration of electrons to higher energies can "be a critical condition for the triggering of flares". According to Takakura this electric field is sufficient to accelerate electrons up to relativistic energies in 1 sec and sufficient to create a layer of sufficient depth in 10^2 sec.

In this connection the fact that both big flares discussed here have different degrees of polarization of the X-radiation can be important for solving the mechanism problems in big flares. The flare of Nov. 5 gives a high degree of polarization, 21%, for an energy of about 10 keV (Tindo et al., 1972). The following flare of Aug. 8, on the contrary, only yields a polarization of a few per cent (Tindo et al., 1973). The maximum of polarization in both cases is in coincidence with the maximum phase, as discussed above.

This short review of the time development of the X-emission in flares demonstrates that it is impossible to agree without exception to Cheng's idea of the production of X-radiation in flares. The possibility of two different mechanisms in the active region, accompanying or preparing the flare, is demonstrated.

In small effects the soft radiation can be generated after the thermal bremsstrahlung. For large effects a long preparatory process can be present. This is characterized by the growth of the soft radiation and the sudden change to a very energetic process for which bursts of hard radiation of a few minutes duration are characteristic.

As regards the technical part of the experiments we have come to the conclusion that the soft radiation needs a more involved explanation, particularly in the maximum phase of the effect, where saturation occurs. Also high time resolution is important.

Both will be respected in the new X-ray photometer now being prepared for the Intercosmos satellite to be launched in 1974.

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