

plasma cools is less clear than it was before. In reality, our knowledge of the microphysics of plasmas is so poor that we must consider a large number of possible models before making any positive conclusions.

### 5.3.6 Summary of Conclusions

Let us address the five conclusions of Moore *et al.* (1980) and suggest how future theoretical efforts could clarify them further.

(1) We find that, under the assumption of filling factors equal to one, the densities obtained in these five flares are consistent with those of Moore *et al.* However, the SMM results suggest that the particles are contained within filamentary structures occupying no more than 1% of the observed volume (de Jager *et al.*, 1983; Wolfson *et al.*, 1983). Thus the densities quoted from the Skylab results are too small by at least an order of magnitude. The large uncertainties in the density and possibility of fine structure dictate our response to the remaining four questions.

(2) Depending upon the flare parameters, either conduction or radiation can dominate the cooling process. Mass motions may also play a role in energy transport, a point not considered by Moore *et al.* We therefore disagree with their conclusion that conduction and radiation are generally equally important. For small filling factors, radiative cooling will dominate.

(3) In the May 21 flare, continued heating is needed, confirming the conclusions of Moore *et al.* The understanding of how this heating can occur has improved on the basis of the work by Forbes and Priest (1982, 1983a, b) and Cargill and Priest (1982, 1983), which is discussed in Chapter 1 of this report.

(4) The question of whether compact flares need long-term heating is now open again as a result of the filling factor problem. We do not know what type of filamentary structure exists in such flares. One possible way of heating such flares is via turbulence (Bornmann, 1985c).

(5) The chromospheric evaporation scenario proposed by Moore *et al.* seems to be confirmed by our work on these five flares.

Thus, two of the original conclusions of Moore *et al.* have been unambiguously confirmed by our work. Unfortunately, the SMM data have confused the other three; but they still could be true. A crucial issue for theorists and observers is to determine the nature of the fine structure in flares. This would appear to hold the key to our understanding of the decay phase.

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## 5.4. RELATIONSHIPS AMONG THE PHASES

C.J. Crannell and H.S. Hudson

### 5.4.1 Introduction

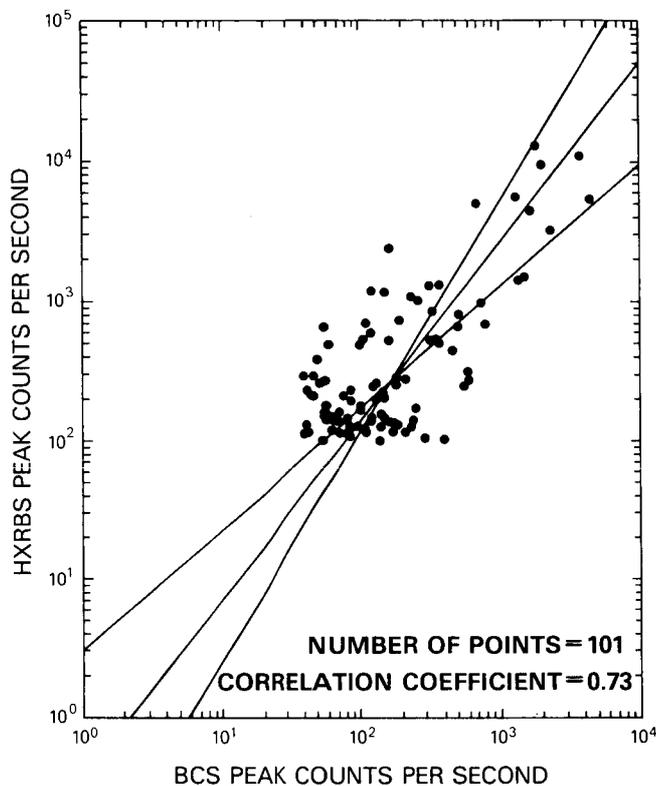
The overall flare process involves phenomena we have characterized as the "impulsive" and "gradual" phases, following the X-ray signature first recognized by Kane (1969). In addition, evidence exists for a pre-flare phase in some flares, and recent SMM data have shown that a post-flare phase, in which extensive and energetically important coronal activity occurs, may also exist. The data to describe the pre-flare and post-flare phases are insufficient to place them properly into an overall picture of the energetics, aside from noting that these phases may indeed be significant from the energetics point of view. In this section, therefore, we review what is presently known and comment about the possible interactions among the flare structures involved.

### 5.4.2 Relationship Between Impulsive and Gradual Phases

The distinction between the impulsive and gradual phases of a flare was originally made by Kane (1969). The energetics relationship between these phases has been controversial from the beginning, when Kane and Donnelly (1971) showed that the large energy in 10-1030 Å bursts correlated well with the energy inferred for 10 to 100 keV electrons, assuming non-thermal bremsstrahlung as an explanation of the hard X-ray bursts. This was the first real evidence that particle acceleration during the impulsive phase could have energetically significant consequences in the chromosphere, the source of the EUV flashes. We now have far better data with which to examine this question quantitatively, and this subsection deals with the investigation of the energetic relationship between the impulsive and gradual phases.

That the impulsive and gradual emissions are related can be seen in Figures 5.4.1 and 5.4.2, in which the peak counting rates of hard X-ray bursts (Figure 5.4.1) and the total hard X-ray counts (Figure 5.4.2) are plotted versus the peak Ca XIX soft X-ray counting rate. These scatter plots include all events observed with HXRBS and BCS which have both a peak hard X-ray counting rate greater than 100 counts s<sup>-1</sup> and a peak soft X-ray counting rate greater than 40 counts s<sup>-1</sup>. The total hard X-ray counts (TOTAL) are better correlated with the peak Ca XIX counting rate (BCS) than is the peak hard X-ray counting rate. This result supports the conclusion of Neupert (1968) that the gradual soft X-ray emission resembles an integral of the impulsive hard X-ray emission.

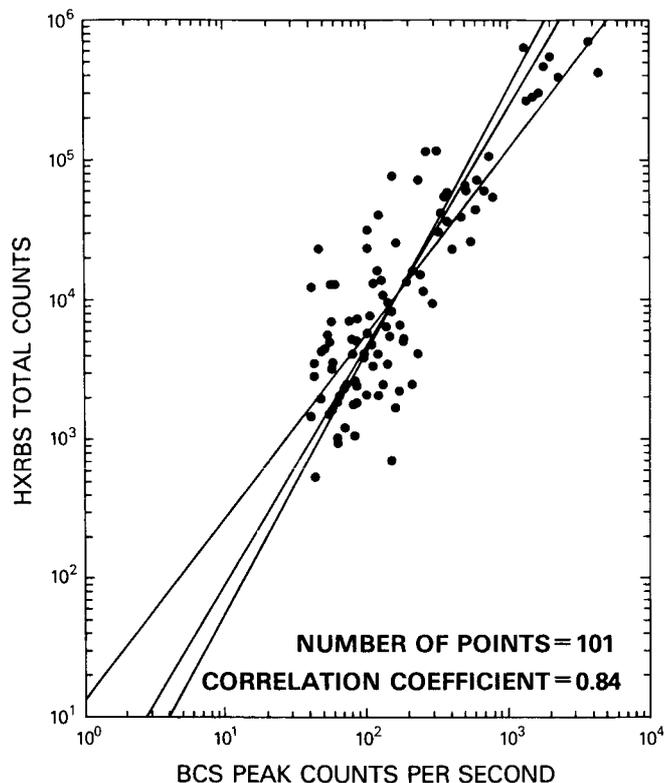
The significance of these results must be evaluated in view of the Big Flare Syndrome (BFS) identified by Kahler (1982). He found, quite simply, that bigger flares are bigger at all wavelengths. Quantitatively, the BFS is manifest as correlation coefficients of approximately 0.48, with a range of 0.3 to 0.65, between widely diverse parameters. The correlations shown in Figures 5.4.1 and 5.4.2 clearly indicate a closer relationship than would be expected from the BFS.



**Figure 5.4.1** Scatter plot of the peak HXRBS counting rate versus the peak BCS counting rate in the Ca XIX channel for all flares recorded jointly by these two instruments in 1980 with  $>100$  counts  $s^{-1}$  in HXRBS and  $>40$  counts  $s^{-1}$  in BCS. The three lines were obtained from least-squares fits to the points minimizing the vertical, horizontal, or perpendicular distances of the points from the line.

In an earlier investigation of the relationships between the energetics of the gradual and impulsive emissions, Cranell *et al.* (1982) found a good correlation between the energy in the energetic electrons, estimated from hard X-ray and microwave observations analyzed with a thermal model, and the energy in the soft X-ray emitting plasma estimated from SOLRAD observations. The value of the correlation coefficient determined in that work lies in the range 0.8 to 0.9, comparable to that found here for TOTAL versus BCS. In Section 5.2 a similar comparison based on a non-thermal, thick-target loop model of the impulsive emissions is presented. The correlation found there also is comparable to that for TOTAL versus BCS.

From these results, we conclude that the energetics of the gradual and impulsive emissions are more closely related than are parameters which characterize the BFS. On the other hand, we note with disappointment that the data we have considered are not sufficient to distinguish between the thermal and the non-thermal model of the impulsive emissions and,



**Figure 5.4.2** Same as Figure 5.4.1 but with the HXRBS total number of counts integrated over the duration of the flare (with a 40 counts  $s^{-1}$  background subtracted) substituted for the HXRBS peak rate.

in fact, do not enable us to distinguish between the models and a non-model, i.e. TOTAL versus BCS.

### 5.4.3 The Pre-Flare Phase

The pre-flare conditions are the subject of an entire chapter of this workshop. As far as this chapter is concerned, it is important for a given flare theory that the energy source in the pre-flare state is adequate to supply the flare energy release. Most modern flare theories derive the energy input from the energy stored in stressed magnetic fields. The magnitude of the stresses can be estimated from the photospheric magnetic field distribution, with a model of the coronal field that permits field-aligned currents to maintain the stress (Tanaka and Nakagawa 1973). The amount of stored energy then follows from the model, which can derive the energy build-up rate from the photospheric boundary conditions. Such models of magnetic storage and free energy generation in general contain adequate energy for flares. This consistency of observations with models is mainly a result of inadequate data upon which to determine exact model parameters.

#### 5.4.4 The Post-Flare Phase

A new phase of flare activity, namely a late, high-altitude, coronal phase, was first identified in SMM data for May 21/22 by Svestka *et al.* (1982a). Other similar events from SMM were reported by Lantos *et al.* (1982) and Svestka *et al.* (1982b and c), and in retrospect some of the large-scale structures observed by Webb and Kundu (1978) probably fall in this category.

Based upon HXIS observations, Svestka (private communication) has estimated that the total energy content of the post-flare arch structures in the 21 May event was between  $1.5 \times 10^{29}$  and  $4.7 \times 10^{30}$  ergs; the total energy in the analogous structure of the November 6 event was  $1.2 \times 10^{31}$  ergs. In both cases, the estimated energies are comparable to the energies of other major flare components. It is necessary in a complete picture of flare energetics to understand the relationship between these manifestations and those of the more well-known flare phases. It is premature, based upon the limited number of events — not all of which may be of the same type — to draw general conclusions yet.

#### 5.4.5 Phenomena in the Distant Corona

Coronal transients, coronal mass ejections, interplanetary shock waves, and the like have an uncertain but important place in flare energetics. These phenomena can be observed by coronagraphs and by meter-wave radio telescopes, as well as by *in situ* techniques at larger distances from the Sun. The Skylab coronagraph observations provided the earliest comprehensive views of coronal transients (Rust *et al.*, 1980), and observations have continued both in space (SMM and P78-1) and on the ground (notably with the Mauna Loa K-coronameter).

The relationship of these coronal phenomena with classical H $\alpha$  “chromospheric flares,” or with the high-energy flare events, remains problematical. There is no doubt that major flares often produce major coronal transients, but we have to guard against inferring a causal relationship: the BFS may confuse the picture (Kahler 1982). Indeed the suggested existence of “forerunner” coronal transients (Jackson and Hildner 1978) could imply that the coronal phenomena cause the flare rather than the other way round, and this is consistent with some theoretical views. The relationships are obscured by two major factors: there are only limited quantitative observations in the key inner corona, and in the outer corona there is confusion and uncertainty in the assignment of a given event to a given flare because of overlapping in time. Finally, it is known that coronal transients, especially with low speeds, may arise without the occurrence of a flare (Wagner, 1984). These events tend to fall in the “eruptive prominence” classification.

The energetics analysis of coronal phenomena has not advanced appreciably since the Skylab Workshop treatment

(Webb *et al.*, 1980). Among the prime flares studied by the energetics team in this chapter, only one (June 29) had C/P observations. However, even this limb flare was not satisfactory for quantitative energetics analysis because it could not properly be compared with the disk flares in the remainder of our list.

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### 5.5 CHARACTERIZATION OF TOTAL FLARE ENERGY

H.S. Hudson

#### 5.5.1 Statement of the Problem

##### 5.5.1.1 Introduction

The total energy released by a solar flare has a certain distribution in form as well as a certain pattern of flow among the several forms, as described above. As data have grown more comprehensive, the definition of this distribution has improved; classical assessments are found in the works of Ellison (1963), Bruzek (1967), Smith and Smith (1963), and Smith and Gottlieb (1975). Most recently the Skylab flare workshop (Sturrock 1980) addressed this question in two surveys of a single well-observed flare on 1973 September 5. These surveys dealt with the radiant energy (Canfield *et al.*, 1980) and the mechanical energy (Webb *et al.*, 1980), and their results have become the definitive data on flare energetics despite acknowledged gaps in coverage and in theoretical understanding.

This section aims at updating our knowledge of this fundamental matter. Unfortunately, there are still limitations in data coverage, as described in detail below. In some areas, notably the X-ray and gamma-ray ranges, there have been striking improvements, as reported above. We summarize the improvements here and take the further step of attempting to fill in the gaps in coverage to estimate the total radiant energy. One purpose for doing this is to permit a comparison of the observed or estimated total with the upper limits derived from the precise total-irradiance monitor (the Active Cavity Radiometer Irradiance Monitor-ACRIM) on SMM.

##### 5.5.1.2 Availability of Data

What are the key limitations in the data set available to us? The foregoing discussions have naturally emphasized the observed forms and have relied on theoretical considerations to bridge the gaps. Where are the largest gaps? We discuss these items briefly here and present recommendations for future observations in Section 5.6.

The most important omissions from the data set fall into two major areas: the radiant energy in optical and EUV wavelengths, and coronal observations of all types. The brightness of the quiet Sun makes the optical wavelengths