JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, NO. A3, PAGES 3473–3477, MARCH 1, 1995

Comment on "The solar flare myth" by J. T. Gosling

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Introduction

In a recent paper *Gosling* [1993] claims that solar flares are relatively unimportant for understanding the terrestrial consequences of solar activity. This opinion conflicts with observations and could have the unfortunate consequence of discouraging research in an area of fundamental significance. In this brief response we present new Yohkoh data and discuss older results that demonstrate the close relationships among coronal mass ejections (CMEs), flares, filament eruptions, and other forms of energy release such as nonthermal particle acceleration. We point out that even high-latitude events, such as those in the polar crown filament zone, have similar morphology and physics to CME-associated flares occurring in active regions. The X ray emission from such events cannot easily be seen in whole-Sun observations, such as GOES photometry, but appear very clearly in the spatially resolved Yohkoh data.

In essence the Gosling paper argues that the solar phenomena we term coronal mass ejections produce the most powerful terrestrial disturbances. This statement is not particularly controversial, since CMEs surely drive magnetic storms on the Earth. However it is also well known that CMEs and flares are closely associated (e.g., *Haisch et al.* [1991], section 5.2). We disagree with Gosling's insistence on a simplistic cause-and-effect description of the interrelated phenomena of a solar flare. Neither observation nor theory comes close to explaining these phenomena quantitatively.

A solar flare consists of a broad range of associated phenomena. The expulsion of solar atmospheric material into the interplanetary medium is a frequent but not universal occurrence, and type III bursts show that open field lines often connect flares directly into the interplanetary medium. Historically speaking, Hale in fact preferred the term "eruption" to "flare," but there were subsequent dark ages in flare research where the ease of Hα observations made a flare seem like a creature of the chromosphere only rather than (as we now know) a perturbation of all levels of the solar atmosphere and often the interplanetary medium as well. It is a mistake to identify a flare with only its soft X ray light curve, as recorded by GOES, for example, or with its Hα structures. These do not tell the whole story, because soft X rays and Hα each contain only 5–10% of the total radiated energy. There are other major energetic components, but our knowledge is incomplete and we currently cannot establish causal links.

We present below some Yohkoh observations of a high-latitude event typical of the ones considered to be not associated with flares, and show on this basis that a considerable part of the morphology of these events matches that of flare events associated with CMEs arising in active regions. On this basis we can only conclude that the physical explanations need to be similar as well.

High-Latitude Solar Event on April 14, 1994

A typical high-latitude coronal disturbance was recently observed by Yohkoh on April 14, 1994 (Figure 1). This event could be seen in near real-time data from Yohkoh, and its occurrence was immediately relayed on the Yohkoh reporting system. Because the event was in the southern hemisphere, the notification was also provided directly to Ulysses investigators. Subsequently Ulysses did indeed detect a related interplanetary event (A. McAllister, personal communication, 1994), and a large magnetic storm occurred. There was almost nothing visible in the GOES data at this time (Figure 2), and this event would therefore have been incorrectly classified as a CME without a flare according to Gosling's ideas.

The Yohkoh prototype for this kind of observation was presented by *Tsuneta et al.* [1992] as a "global restructuring" of the corona, and it seems clear that events of this type can be identified with Skylab filament-cavity events and with coronagraph "bugles" [e.g., *Kahler*, 1991]. Such an event has the appearance (in soft X rays) of an arcade of loops. The structure of such an event may be enormously extended. Observations of only the limb projection, as with a coronagraph, do not show the three-dimensional structure so completely. At the limb, such an event sometimes shows a helmet-streamer configuration, before or after the restructuring. Although we have no coronagraph data in this case, we believe that this event resembles the Yohkoh/Mauna Loa event of January 24, 1992, studied by *Hiei et al.* [1993].

The Yohkoh/SXT (soft X ray telescope) imaging data allow us to study the X ray behavior of such an event, which is normally considerably weaker than the X ray event associated with a long-duration event (LDE) flare in an active region. The time profile of the event has a slow rise, slow decay character much like any slow LDE flare in an active region, however (Figure 2). Events such as this also produce two-ribbon chromospheric effects, as seen in the HeI λ10830 Å line [*Harvey et al.*, 1986] (see Figure 3 for a view of the ribbons in the April 14 event). The main differences between this and an active region flare are the slowness of the evolution and the largeness of the scale. We note from Figure 2 that only the other activity present on the Sun at the same time makes this particular event undetectable in the GOES time profile. The SXT photometry (also

Paper number 94JA02710.
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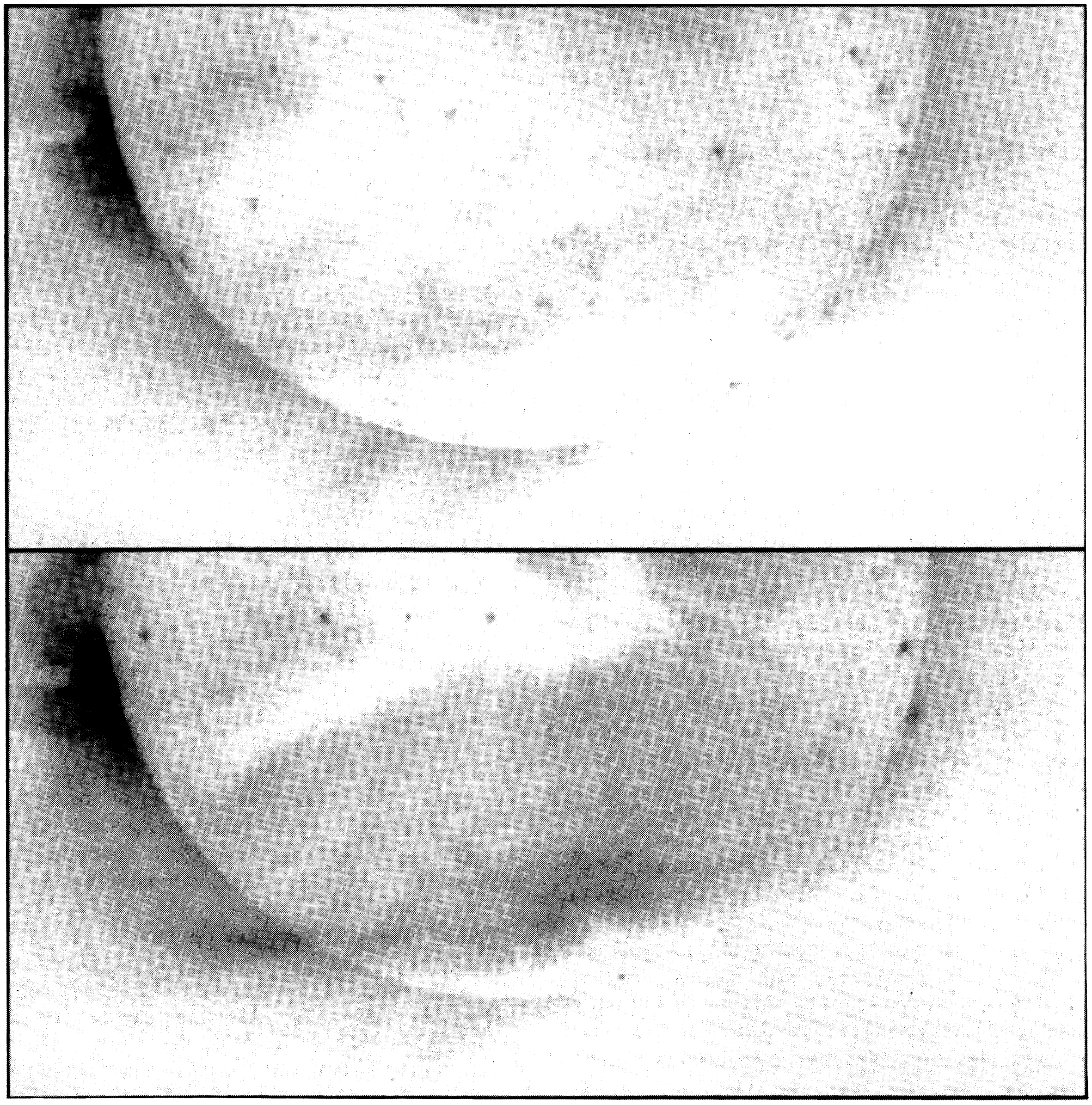

Figure 1. Yohkoh/SXT soft X ray images from the April 14, 1994, event at (upper) 0116:56 UT and (lower) 1612:52 UT. This is a negative representation for better clarity. Yohkoh/SXT has observed many similar events during its first 3 years of observation. This event is larger than most and occurred well away from active regions. Note the complexity of the structure apparently lying at the tops of the loop arcade.

shown in Figure 2) clearly shows the flarelike time evolution of the source. Here we have summed the signal from a 1024-×-128-pixel east-west (EW) strip, thereby eliminating the confusing sources in the GOES time series. This shows that soft X ray imaging observations are essential in identifying the solar counterparts of interplanetary events, and that GOES (or Hα) alone may often be deceptive. The soft X ray observations view the entire visible hemisphere plus parts of the corona above the limb and therefore offer a uniquely unbiased view of coronal dynamics.

The SXT images allow us to follow the temperature development of the source by using the filter-ratio technique. For the April 14 event we have whole-Sun images in two broad passbands sensitive in the 1–2 keV range (see work by *Tsuneta et al.* [1991] for technical details). As with an active region flare, the temperature increases to a maximum and then decays, with the peak temperature preceding the peak emission measure [e.g., *Horan*, 1971]. There is a difference here in that the peak temperature does not exceed about 3×10^6 K. We are aware of no study that characterizes flare temperatures as functions of size, location, or surface brightness; only the spatially resolved SXT data would allow this. However in terms of bulk parameters (unresolved measurements of temperature and emission measure) the event discussed here resembles a flare. This relatively low peak temperature is roughly consistent with the weak correlation between peak flare temperature and event magnitude: the brightest GOES events tend to show the highest temperatures [e.g., *Garcia*, 1994]. We conclude that the temperature evolution of this event, within present knowledge, does not distinguish it from an extrapolation of ordinary flare behavior.

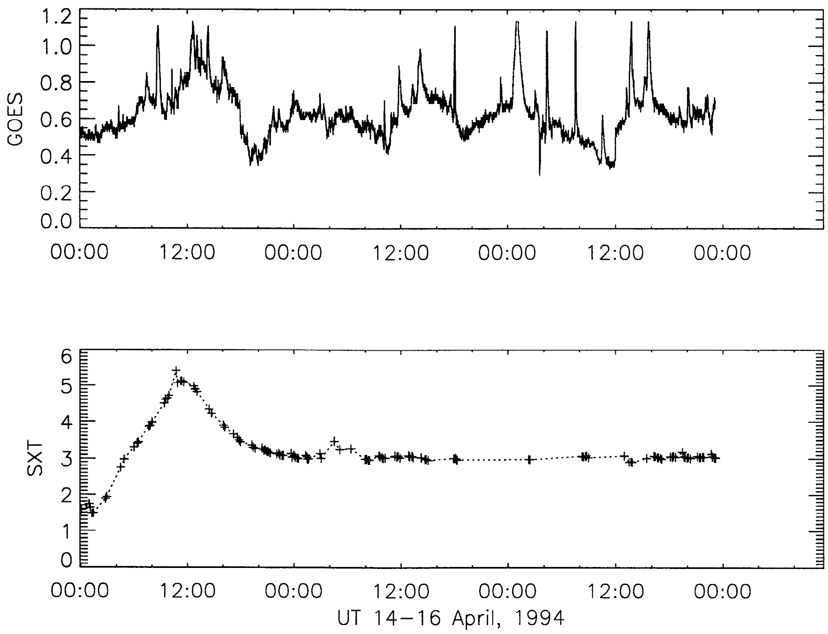

Figure 2. Time histories of flux of the April 14 event on linear scales as observed (upper) by GOES and (lower) by Yohkoh/SXT. The SXT photometry is the sum of the counts from the pixels participating in the event, 1/8 of the total pixel area. The event left an enormous arcade structure (see Figure 1) that did not decay appreciably after April 14 for several days. GOES cannot see this event but SXT detects an X ray burst strongly resembling that from an LDE flare.

Recent work [e.g., *Hundhausen*, 1993] has shown that many CMEs arise in filament eruptions outside active regions. On the basis of the Yohkoh soft X ray images, we have shown that these quiet-Sun and high-latitude events strongly resemble flares in active regions. We do not know of any physical parameter showing a bimodal distribution that can distinctly divide the events arising outside active regions from those (''flares'' by any definition) that occur inside active regions. The quiet-Sun events tend to be larger, slower, weaker, and cooler, but in a manner consistent with the normal progression of flare parameters. It is certainly premature to claim that there is a clear difference in the physics of flares and CME launching events.

Flares on the Sun and Other Stars

Gosling [1993, p. 18,947] states that ''research on solar flares should not be justified, as it often is [e.g., *Haisch et al.*, 1991], on the basis of the solar flare myth''. *Haisch et al.*'s [1991] review (''Flares on the Sun and other stars,'' hereinafter referred to as HSR) makes note of the March 10, 1989, flare associated with the CME that damaged the Hydro-Quebec distribution network and blacked out large parts of North America. The review goes on to make it quite clear that flare/CME causation remains unknown. Indeed, the unknown but important mechanisms that link CMEs (when they occur) and flares provide a major motivation for flare research, in our opinion. The occurrence of the CME in conjunction with such a flare is probably due to the origin of flare energy in the destabilization of the coronal magnetic structures that had stored sufficient energy, according to the conventional picture [e.g., *Low*, 1993]. Gosling thus singled out the HSR review for criticism in the context of his ''new paradigm,'' but in fact the relevant HSR (pp. 289–290) text already includes the physics point of view that Gosling claims to be new:

> CMEs are associated with flares and prominence eruptions (Munro et al. 1979, Webb and Hundhausen 1987, Gopalswamy and Kundu 1987, Harrison and Sime 1989); at issue is which causes which. (Note that estimated CME energies often exceed that of the associated flare.) To address this question systematically, a CME Onset Program was initiated in 1985 by using the Coronagraph/Polarimeter (C/P) and the X-ray Polychromator on *SMM*. On the basis of 16 data sets, Harrison et al. (1990) found that CME launches precede major X-ray flares by tens of minutes, and that a majority of CMEs are associated with eruptive prominences. The picture they paint is the following: a weak soft X-ray burst signals the onset of the rising of a large-scale magnetic structure; some tens of minutes later a region of magnetic complexity at one of the CME footpoints destabilizes as a result of stresses from the field line stretching above, and this results in particle acceleration, reconnection, and heating, i.e., a flare underneath and off to one side (footpoint) of the CME. An erupting prominence may also occur underneath the rising CME, but it is unaffected by the flare activity below. The CME continues to rise as a result of magnetic buoyancy of the disconnecting bubble following the ''melon seed mechanism'' model of Pneuman (1984). The frequent occurrence of preimpulsive microwave emission is evidence for such a model, since that emission signals the presence of energetic electrons in the corona up to several minutes before the impulsive phase (Pick, Klein and Trottet 1990).
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> Clearly CMEs, prominence eruptions, and flares are intimately related.

The view of flares and CMEs expounded here does not differ appreciably from that of Gosling from the point of view of the observations, but does not seek to draw sweeping and unwarranted conclusions from them. This was prudent in light of the observational difficulties (see the next section) and the lack of theoretical work of sufficient depth to predict the important elements of flares.

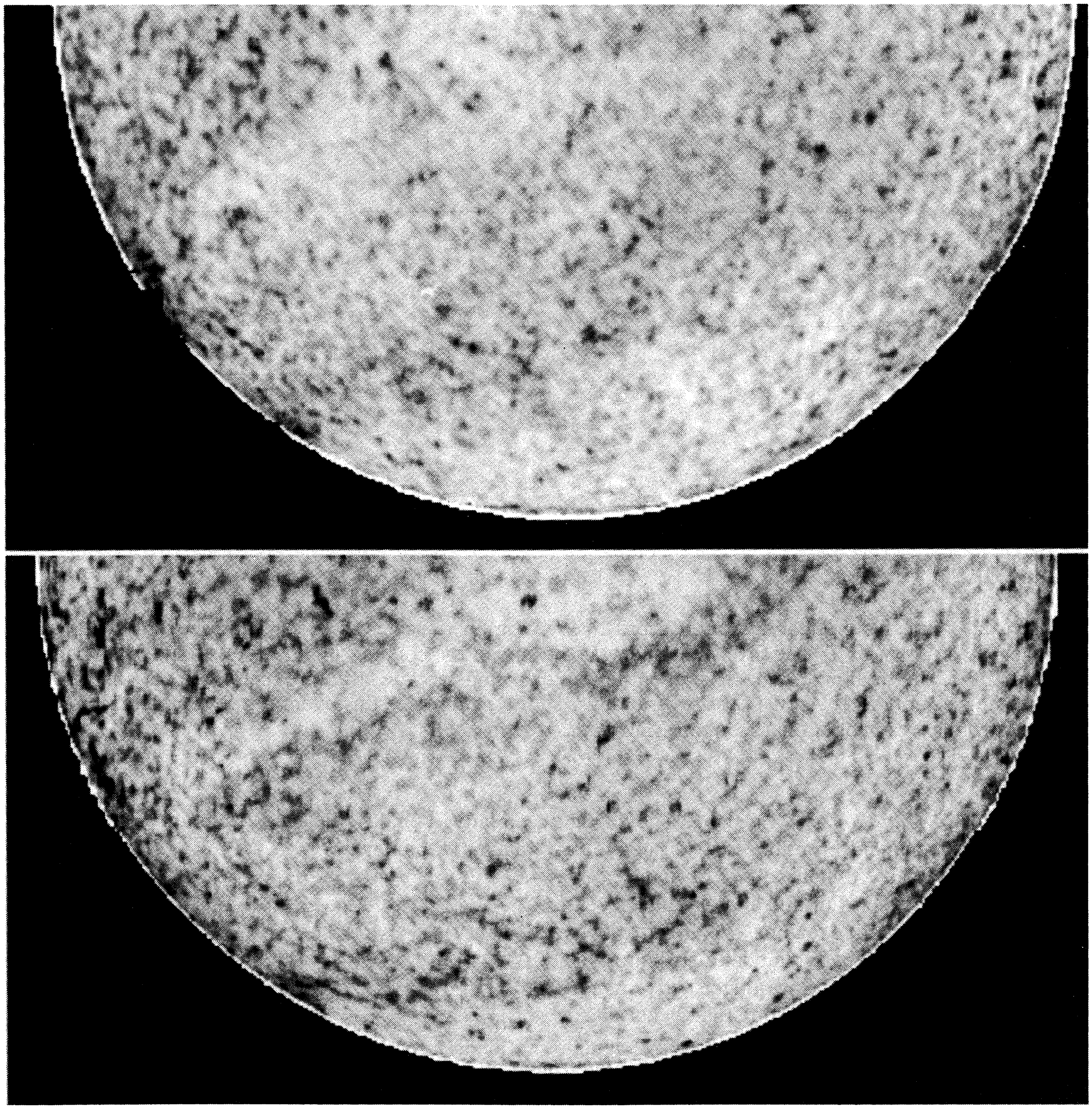

Figure 3. Images from April 13–14 in He I λ10830 Å from NSO/Kitt Peak on (upper) April 13, 2142:39–2222:59 UT, and (lower) April 14, 1833:10–1913:35 UT. The structure (excess darkness) is weak and hard to recognize in this representation, partly because the "after" image came some 16 hours after the event began, but it is unmistakeably present (K. Harvey, personal communication, 1994). The excess darkness generally matches the location of the X ray brightness seen in Figure 1. As noted by *Harvey et al.* [1986], such events appear to be the same as flares in the chromosphere, except that they are larger, slower, and weaker.

Cause and Effect

We believe that too little is known observationally or theoretically of the solar flare process to be comfortable with ideas about cause and effect in relating CME energetics with (say) nonthermal energy release in a flare.

Harrison [1994, p. 23] remarks that "the onset of a CME-onset associated flare can occur at any time before, during, or after the CME onset" and that "a CME-onset related flare can occur anywhere under the CME span—there is no preferential site with respect to the CME."

Gosling cites earlier results that were misleading regarding cause and effect, but it is quite clear from these quotes that the processes involved are complex and that simple cause-and-effect arguments (such as those presented by *Lin and Hudson* [1976]) still cannot be reliably established. In a recent study *Feynman and Hundhausen* [1994, p. 8451] suggested that "CMEs. . .are neither the direct cause nor the direct effect of flares. . . ." To simplify this complexity with a naive paradigm emphasizing cause and effect is premature and tendentious.

Conclusion: What is a Solar Flare?

A great deal of the confusion on this subject may originate from uncertainty about the definition of the word "flare." The most common modern definition of a flare is that it is a sudden energy release in the solar atmosphere, that is, a general and physically based definition rather than the traditional view of a chromospheric flare, based upon Hα alone. Some definers restrict the use of the term to a sudden energy release in an active region, but this would be physically unreasonable in view of the similarities pointed out here between an active region flare and a filament event outside an active region. *Low* [1993] suggests another type of definition, one that would make a CME the result of a global MHD instability in the corona; this implies that the "flare" is the part of the process that cannot be described by MHD theory. This seems reasonable since flares involve strong particle acceleration and other evidence of non-MHD behavior. On the other hand, we do not know that MHD theory is always adequate to describe the conditions for CME launching. *Hudson et al.* [1994] have recently shown that even slowly rising LDE flares invariably involve strong acceleration of nonthermal electrons detectable via hard X ray bremsstrahlung.

We have argued in this paper that it is shortsighted to distinguish CMEs and flares, except in the sense that the CME symptoms certainly seem to be present if strong terrestrial effects are to result. To imply, as Gosling does, that flare physics does not deserve intense study for the sake of solar-terrestrial effects is to argue that the symptoms are more important than the disease. We believe that the occurrence of a solar eruption event demands a full understanding of the entire process. At least the data from Yohkoh and SOHO will need to be analyzed before we can even be certain which are the most important questions to ask, and it certainly would be premature to close off research efforts devoted to understanding solar flares in their full complexity.

Acknowledgments. We thank the National Solar Observatory (NSO) and Karen Harvey for the use of the λ10830 Å observations for the event we have discussed. The NSO/Kitt Peak data used here are produced cooperatively by NSF/NOAO, NASA/GSFC, and NOAA/SEL. Yohkoh is a project of the Institute of Space and Astronautical Sciences, Japan. NASA supported this work under contract NAS 8-37334. We thank Alan McAllister for bringing the Ulysses observations of the April 14 event to our attention.

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(Received August 8, 1994; revised October 11, 1994;
accepted October 12, 1994.)