N66 37954

SOLAR X-RAYS: A COMPARISON WITH MICROWAVE RADIATION

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Analysis of data from the OSO–1 satellite shows that solar X-rays shortward of 10 Angstroms exhibit a violent dynamic behavior which however contains within counterparts of the somewhat less dramtic behavior of the solar microwave flux. Specifically, the solar X-ray flux contains: (1) a slowly-varying component, (2) "gradual rise and fall" bursts, and (3) impulsive bursts. The OSO–1 data shows the first two to be related to their microwave counterparts, and the emperical relations are given in this paper. Observations at 10 Angstroms of the third component (impulsive bursts) could not be associated directly with microwave observations owing to the extreme disparity in sensitivities of the two methods of observation of this phenomenon. However, observations by Frost (reported at this Symposium) of solar X-rays in the 20 Kev—100 Kev region do show a direct counterpart of the microwave impulsive burst.

1. INTRODUCTION

With the launching of the OSO–1 on March 7, 1962, it became possible for the first time to point instruments at the sun accurately and continuously for entire daylight portions of a satellite orbit; for the 550-Km orbit of OSO–1 these observing time intervals were the order of one hour each, separated by darkness intervals of about two-thirds of an hour. The observing periods were long enough to disclose some interesting dynamic effects which would be difficult to study otherwise.

2. SENSOR CHARACTERISTICS

OSO–1 provided coverage of the solar X-ray radiation near a wavelength of 10 Angstroms by means of an ion chamber whose characteristics are given in Table 1.

TABLE 1

Window Material	Beryllium
Window Thickness	0.005 inch
Total Window Area (Two chambers in parallel)	3.38 cm^2
Absorbing Gas	Xenon
Gas Pressure	780 mm
Ion Chamber Dept at Normal Incidence	2.19 cm
Ion Pairs per erg	$2.8\,(10)^{10}$

The conversion efficiency as a function of wavelength is shown in Fig. 1.

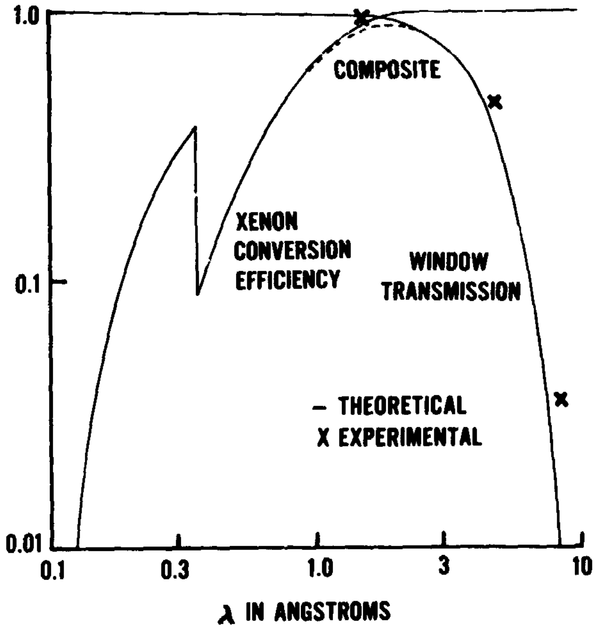

FIGURE 1.—OSO–1 ion chamber conversion efficiency as function of wavelength.

Amplified ion-chamber current was sampled for 2 seconds every 20 seconds by the telemetry.

The full-scale sensitivity of such a broad-band sensor is, of course, dependent upon the shape of the input spectrum. It has been shown[1] that

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*Published as *Goddard Space Flight Center Document X-610-64-42*, February 1964.

for non-flare periods it is reasonable to assume a spectral shape consistent with a $2.8(10)^{6\circ}K$ plasma composed of ionized hydrogen and helium in the ratio of their solar abundances. Over the frequently used band limits of 2–8Å, the full-scale sensitivity is then $3.6(10)^{-4}$ ergs cm^{-2} sec^{-1}.

3. COMPONENTS OF THE SOLAR X-RAY FLUX

Changes in the solar X-ray flux as observed by OSO-1 occurred over a broad range of time scales; from fractions of a second to many weeks. In particular, counterparts to the microwave slowly-varying component and to the microwave "gradual rise and fall" burst are clearly seen.

The markedly dynamic character of the solar X-ray flux as contrasted with the 2800–Mc radiation should be emphasized; for instance, on only 3 occasions out of 70 days (7 March through 15 May, 1962) was the X-ray flux "quiet") i.e., free from bursts) for an interval of as much as 8 hours.

3.1 Slowly-Varying Component

Solar rotation markedly affects the X-ray flux. In fact, if one defines the non-burst X-ray flux background as the minimum flux reached in a 6-hour interval and evaluates this for a succession of such intervals, one finds that for the spring of 1962 the OSO–1 data empirically fits the relation

$$\Phi_{2-8A}=k_1\quad(\Phi-\Phi_0)_{2800Mc}\text{ erg cm}^{-2}\text{ sec}^{-1}\qquad(1)$$

That is, the daily mean non-burst X-ray flux is proportional to the difference between the daily mean of the 2800–Mc flux and a value of 2800–Mc flux which is presumably a "quiet sun" asymptote for the appropriate phase of the solar cycle.[2] Note that any such quiet sun asymptote in the X-ray flux is *zero*, at least to the sensitivity and accuracy of this empirical fit. Apparently a truly quiet sun, stripped of plage, would be dark in X-rays while still emitting an appreciable 2800–Mc flux. Fig. 2 shows the measured mean non-burst X-ray flux and the index values calculated from Eqn. (1) with $K_1=1.4(10)^{-5}$, $(\Phi)_{2800\ Mc}$ in units of $10^{-22}Wm^{-2}(c/s)^{-1}$, and $(\Phi_0)_{2800Mc}=73$ such units.

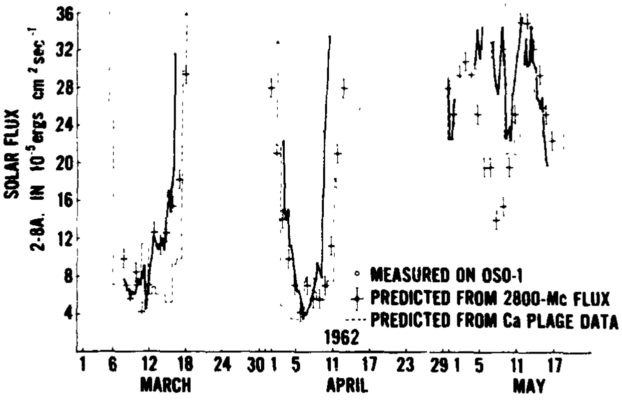

FIGURE 2.—Slowly-varying component of solar x-ray flux

It is fruitful to look in more detail at the relationship between the calcium plages and the X-ray flux. For example, is the brightness of a plage in Ca emission a measure of its brightness in X-rays? If so, we might expect a relationship somewhat as follows:

The brightness of a plage in Ca *K* emission is expressed by an Intensity Number assigned by the McMath-Hulburt Observatory apparently on the basis of a subjective estimate of relative densities on a patrol photograph; as such, it is likely to be approximately logarithmic.

The other routinely reported parameter characterizing a Ca plage is its area. Since we are dealing at X-ray wavelengths with a volume source, an assumption has to be made regarding the dependence of the X-ray source volume upon the area of the plage. It is found from the OSO–1 data that it is much better to assume that the thickness of the X-ray source is proportional to the mean plage diameter, than to assume a constant thickness. The volume of the i^{th} plage is then given by

$$(dV)_i\propto(A_i)^{3/2}$$

where A_i is the reported area.

The hypothesis that the X-ray flux arises from such a plage-associated volume sources with X-ray brightness proportional to Ca *K* brightness can be written as

$$\Phi_{2-8A}=K_2\ \sum_i(A_i)^{3/2}(b)I_i\text{ erg cm}^{-2}\text{ sec}^{-1}\quad(2)$$

where A_i is the volume of the i^{th} plage in thousandths, I is the McMath Ca *K* intensity number, and k_2 and b are constants to be empirically determined from the OSO–1 data.

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[1] White, W. A., "Solar X-rays·Slow Variations and Transient Events" —COSPAR IV, Warsaw, June 1963. NASA GSFC Document X-614-63-195.

[2] A. E. Covington and G. A. Harvey, Astrophys. Jour. *132* (1960) 435.

The best fit to date is plotted in Fig. 2, for plages of area $\geq$ 1 thousandth, for

$$k_2 = 0.134\ (10)^{-5},$$

and for

$$b = 2.$$

Plage data reported by the McMath-Hulburt Observatory and published in the CRPL Bulletin was used, with times of rising and setting of the X-ray sources calculated from plage Central Meridian Passage minus and plus 7.8 days respectively. This corresponds to an assumed source height extending to some 21,000 Km above the photosphere.

Two types of gross discrepancy can be seen between the X-ray flux and the hypothetical indices derived from plage and 2800–Mc data. The first type, exemplified by the periods March 12–14, April 10–14, and May 1–2, show too low a value for the plage-derived index. Each of these periods saw the birth of one or more small plages upon the disc which were not included in the index computation of Fig. 2. The second type of discrepancy is seen during the period May 3–7 for which the index derived from the 2800–Mc flux is low. This period included a large plage (McMath 6412) which was reported to be declining in Ca *K* intensity; this plage contained a single sunspot which was seen to die on the disc.

3.2 Gradual Rise and Fall Bursts

Superimposed upon the X-ray slowly-varying component and occurring so frequently as to make difficult the finding of intervals completely free from their effects, are X-ray bursts analogous to the "gradual rise and fall" bursts seen in solar microwave radiation. A complete statistical analysis of the X-ray bursts observed by OSO–1 has not yet been made, but typical on-scale bursts (see Fig. 3) have rise times of 2 to 4 minutes and fall times of 10–20 minutes. However, many bursts carry the experiment output offscale; for these, the duration of the event can be as long as 6 hours. A comparison of the X-ray data with 2800–Mc records (kindly made available by A. E. Covington) taken at Ottawa shows that all 2800–Mc gradual bursts had a time-coincident counterpart in the X-ray data. A peak amplitude on only 1 or 2 units of 10^{-22} $W\ m^{-2}$ sec^{-1} at 2800-Mc was in all cases accompanied by an off-scale X-ray burst; larger bursts at 2800–Mc were of course also off-scale in X-rays, but again times of onset and recovery were found to agree with the corresponding times for the accompanying X-ray burst.

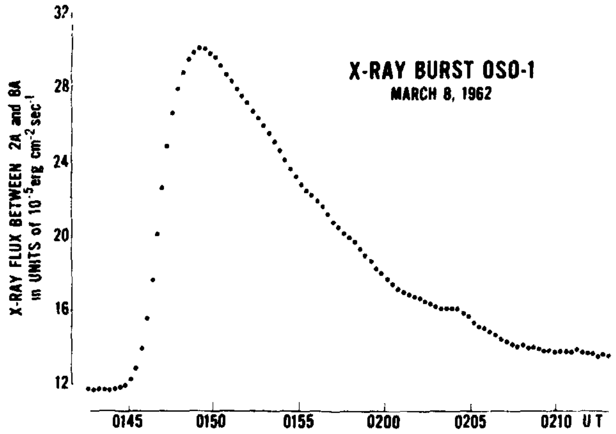

Figure 3.—X-ray burst OSO–1 March 8, 1962

It is important to note that the relationship between burst flux at 2800–Mc and at 2–8 A is different from the relationship between the slowly-varying component at 2800–Mc and at 2–8 A. As has been shown (Eqn. 1), a change in 2800–Mc slowly-varying component of 1 flux unit is accompanied by a change in 2–8 A flux of about 1.4 $(10)^{-5}$ erg cm^{-2} sec^{-1}; whereas a burst type change at 2800–Mc of 1 flux unit is accompanied by a change in 2–8 A flux of at least 30.$(10)^{-5}$ erg cm^{-2} sec^{-1}. This increase in the X-ray/microwave ratio of more than 20 times is suggestive of a different physical process being responsible for the two phenomena.

Several apparent associations of certain X-ray bursts into groups displaying a definite pattern were observed; Fig. 4 shows such grouping. Similar groupings are present in the data for the first week in April 1962; in fact, the one-particular March group shown in Fig. 4 appears to have an exact April counterpart 27.1 days later with identical time-separations between events and with identical peak excursions above mean background level. In addition to these two groups, two others each having 4 members and one other having 3 members were found. For all five groups, the envelope joining the peaks of the bursts within a group is a straight line of slope $\pm 1.51 (10)^{-9}$ erg cm^{-2} sec^{-2} for wavelengths be-

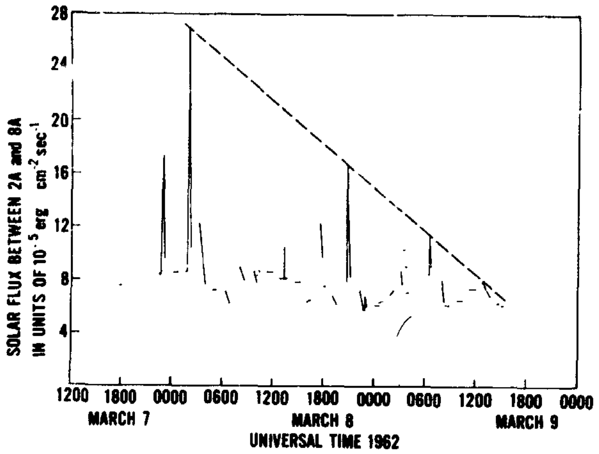

FIGURE 4.—Solar x-rays (2–8A) showing grouping of x-ray bursts.

tween 2 and 8A; three groups displayed positive slopes, two groups negative.

3.3 Impulsive Bursts

Several instances of very fast bursts (entire duration less than 2 minutes) were seen by Frost (reported at this Symposium) from an OSO–1 sensor responsive to photons of energy greater than 20 Kev. For every one of these instances the lower-energy ion-chamber channel was off-scale prior to and during the time interval of the impulsive burst. It is indeed unfortunate that we are thus unable to obtain an X-ray/microwave ratio for an impulsive burst to compare with the values obtained for gradual bursts and for the slowly-varying component.