DETERMINATION OF THE SOURCE HEIGHT AND ANISOTROPY OF SOLAR HARD X-RAYS BY MEASUREMENTS WITH GOOD TIME RESOLUTION

(Research Note)

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Abstract. When emitted at the same time, solar hard X-rays reflected by the photosphere arrive at an observer at later times than primary hard X-rays coming directly from the source. This time lag of albedo photons, therefore, should be taken into account in interpreting fine-scale hard X-ray time profiles. If hard X-ray bursts consist of succession of short-lived 'elementary bursts', under favorable conditions reflected hard X-rays can be resolved from primary hard X-rays with good time resolution. If so, from the time lag and the ratio of the albedo flux to the primary flux, one can determine the source height and anisotropy of solar hard X-rays.

Time resolutions of solar hard X-ray detectors so far flown on various satellites are longer than 1 s (Kane and Anderson, 1970; Frost, 1969; Darlowe et al., 1974; Hoyng et al., 1976). Viewed on these time scales, hard X-ray emissions from solar flares are continuous. However, on much shorter time scales, solar hard X-ray emissions may consist of discrete, impulsive flashes, reflecting discrete, impulsive productions of accelerated electrons. Van Beek et al. (1973) called such hypothetical impulsive flashes 'elementary bursts'. It is very important for the understanding of electron acceleration processes in flares to determine the existence of such elementary bursts and to know their characters if they exist. A solar hard X-ray detector to be flown on the Solar Maximum Mission will have time resolution as short as $10^{-3}$ s (depending on the operation mode) and thus will be able to provide such information (Frost, 1976).

The purpose of this Research Note is to point out that under favorable conditions one could also get information on the source height and anisotropy of solar hard X-rays from measurements with good time resolution, and to examine the effect of the albedo on fine structures of hard X-ray time profiles. A large fraction of hard X-rays emitted toward the photosphere are reflected due to Compton scatterings (Bai and Ramaty, 1978a and references in it). Photons arriving at an observer after the Compton scatterings have path lengths longer by $\sim 2h$ than primary photons coming directly from the source, where $h$ is the height of the hard X-ray source. Thus, albedo photons arrive at the observer at later times ($\Delta t \approx 2h/c$) than primary photons. Therefore, if the solar hard X-ray emission consists of a succession of short lived elementary bursts, under favorable conditions, hard X-ray measurements with very good time resolution not only could resolve these elementary...
bursts but also could resolve albedo photons from primary photons. When such a resolution is possible, we can determine the height $h$ from the delay of albedo photons, and can determine the anisotropy of the hard X-ray emission by comparing the number of primary photons with that of albedo photons.

As examples, let us consider idealized cases in the following. For simplicity, first consider a point source at a height $h$ above the photosphere, at the center of the solar disk. In general, the reflection probability depends on the incident and outgoing angles, but for 15 keV photons reflected along the vertical to the photosphere, the reflectivity can be approximated to be constant (0.5), regardless of the incident direction (Bai and Ramaty, 1978a). Thus, if photons are instantaneously emitted isotropically from a point source above the disk center, the time profile of the albedo photons (~15 keV) can be easily found from the geometry; i.e.,

$$I(t) dt \sim \begin{cases} 
0 & \text{for } t \leq 2h/c \\
(t-h/c)^{-2} dt & \text{for } t > 2h/c,
\end{cases}$$

where $c$ is the speed of light and the time $t = 0$ is the arrival time of primary photons. For vertically extended sources, we can find the time profiles by integrating over $h$. In Figure 1 we plot the time profiles of the albedo photons for three cases: for two point sources with $h = h_0$ and $h = 2h_0$; and for a vertically extended linear source of uniform brightness with $h_0 < h < 2h_0$. For sources not at the disk center, the exact time profile of the albedo photons becomes complicated, but the general characters will be similar to those shown in Figure 1.

![Fig. 1](image)

As can be seen in this figure, for a point source the duration of the albedo photon time profile is $\sim h/c$, and for a vertically extended source it becomes longer. From this figure we can derive the conditions for successful temporal resolution of albedo...