Timing analysis of solar flares in hard X-ray and soft γ-ray bands measured by the Suzaku Wide-band All-sky Monitor

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Hard X-ray and γ-ray observations have proved to be a powerful tool to for studying the physics of particle acceleration and transfer in solar flares. These high-energy photons are often observed in X class flares defined by the GOES satellite. The origin of emission is thought to be the thick-target bremsstrahlung of high energy particles accelerated by magnetic reconnection. Previous observations have revealed that the arrival times of hard X-ray photons (20 - 200 keV) depend on their energy[1]. The energy-dependent time delays can be explained through the trap plus precipitation model[1]. First, the model suggests that electrons accelerated by magnetic reconnection are injected into a magnetic loop and trapped (magnetic mirror trap). Next, the trapped electrons escape the loop by pitch-angle scattering and precipitate to the chromosphere. As a result, hard X-ray photons are produced by thick-target bremsstrahlung. If Coulomb collisions represent the dominant pitch angle scattering for trapped electrons, the collisional deflection time τ can be represented as[2]

$$\tau(E) \propto E^{1.5}. \tag{1}$$

In this progress report, we performed a timing analysis of the Sept 24 2011 solar flare observed by the Wide-band All-sky Monitor (WAM)[3] onboard Japanese fifth X-ray satellite *Suzaku* from 80 keV to 7 MeV.

The WAM consists of four lateral walls composed of bismuth germanium oxide $Bi_4Ge_3O_{12}$ (BGO) crystals. The event data are recorded with a 1-s time resolution in the 55 energy band. The WAM has a large effective area that reaches 400 cm^2 at 1 MeV. This is the largest area in among currently working γ-ray spectrometers on-board astronomical satellites. Therefore, WAM is suitable for hard X-ray and soft γ-ray observation of solar flares[4]. Figure 1 shows the energy-resolved time profiles of the solar flare on Sept 24 2011 observed by WAM. The lightcurves show that the main peak has shifted progressively later at the higher energy band.

In order to evaluate the time lag quantitatively, we measured the delay using a cross correlation technique between the 80 - 130 keV lightcurve and the other eight energy-resolved lightcurves (130 - 7000 keV band). Before the analysis, we used a low-pass filter for each lightcurve by running an average of 10 bins (the time bin size is 1 s) to exclude the higher frequency component, because the observed fast structures are caused by the difference of electron time-of-flight from directly precipitating electrons[1]. The derived time delays as a function of energy are shown in Fig.2. The results show the energy dependence of the time delays are clearly changed around 1000 keV. In the lower energy band, the relation is roughly consistent with $E^{1.5}$, which is predicted by the pitch angle scattering of Coulomb collision[2]. On the other hand, above 1000 keV, the relation becomes more flat. If we fit the results using the broken power-law model and the power-law index of the lower energy is fixed at 1.5, the derived index of the higher energy band is 0.253 ± 0.008 with a cutoff energy of 598 ± 9 keV (the errors are 90% confidence). The estimation of systematic errors caused by a pile up effect is currently in progress.

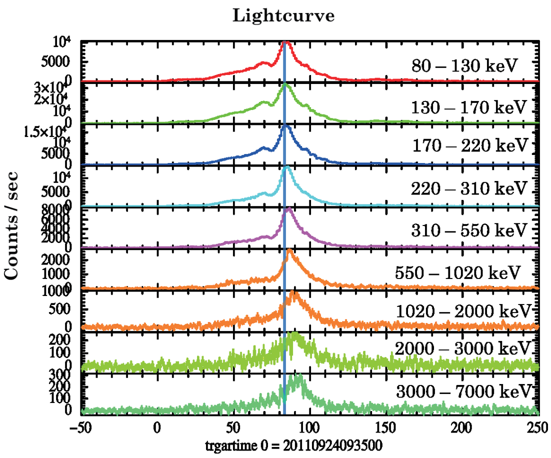

Fig. 1. Background-subtracted lightcurves of solar flare triggered on Sept 24 2011 09:35:00 UT observed by Suzaku-WAM in nine energy bands.

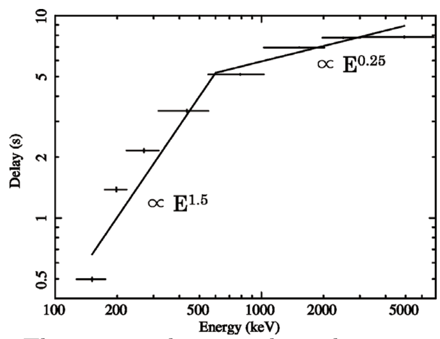

Fig. 2. The measured energy-dependent time delay of the Sept 24 2011 flare using the cross correlation method.

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References

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