GEOTAIL observation of SGR 1900+14 giant flare on 27 August 1998

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1. Introduction

Soft gamma repeaters (SGRs) are young neutron stars emitting short and energetic bursts of photons in soft gamma ray energies. In addition, SGRs occasionally provide giant flares, whose energy amounts to $10^3$-$10^5$ times of those of repeated bursts. The first giant flare was discovered on 5 March 1979 as a sudden increase of soft gamma ray photon fluxes from SGR 0525-66 in the Large Magellanic Clouds, a galaxy neighboring to our Galaxy (Mazets et al. 1979). Since then two giant flares occurred within our Galaxy on 27 August 1998 and 27 December 2004, the latest of which was stronger by a factor of hundreds than preceding ones. While practically all gamma-ray detectors on any satellites were saturated during the first ~500 ms interval after the onset of the 2004 giant flare (e.g., Hurley et al. 2005, Palmer et al. 2005, Mazets et al. 2005, Mereghetti et al. 2005), a few particle detectors were not saturated and provided important information on the initial very intense spike (Terasawa et al. 2005, Schwartz et al. 2005). From the plasma particle detectors on the GEOTAIL spacecraft the peak photon energy flux (integrated above 50 keV) was estimated to be the order of $10^7$ photons sec$^{-1}$ cm$^{-2}$, the peak energy flux $\sim$20 erg sec$^{-1}$ cm$^{-2}$ (Terasawa et al. 2005). That this energy flux was by a factor $>$1000 stronger than those from largest solar flares is surprising if we notice that the estimated distance to the source of this giant flare (SGR1806-20) is 15 kpc, namely $3\times10^9$ times farther than the sun.

The “magnetar” model (Duncan and Thompson 1992, Thompson and Duncan 1995) is generally accepted to explain the nature of SGRs, where neutron stars having ultrathick magnetic field of the order of $10^{14}$–$10^{15}$ G eventually release the magnetic energy to keep repeating soft gamma activity as well as to cause giant flares. It is noted that in spite of its success in SGR energetics the magnetar model still includes hypothetical parts: For example, the magnetic reconnection process in magnetars’ magnetospheres is invoked to explain the energy conversion from magnetic fields to relativistic pair plasmas at the onset of bursts/giant flares. Where and how such reconnection process occurs is yet to be studied both theoretically and observationally. We expect the data of the initial phase of giant flares should play an essential role in such studies.

2. Instrumentation and Calibration

The Low Energy Particle (LEP) experiment (Mukai et al. 1994) onboard GEOTAIL consists of two nested sets of quadspherical electrostatic analyzers with seven microchannel plates (MCPs) installed as ion detectors and seven channel electron multipliers (CEMs) as electron detectors. We can perform gamma-ray observation using the MCPs.

Because the MCPs onboard GEOTAIL are not designed to perform gamma-ray observations, we must calibrate them as the gamma-ray detectors. First we have to conduct Monte Carlo simulations in order to examine the contaminations of photo-electrons, compton-electrons, and characteristic X-rays as well as the effect of the scattering with the satellite body. Next, we have to measure the detection efficiency of the MCP for gamma-rays in the laboratory.

We have constructed the mass model of GEOTAIL based on the Geant4 (Agostinelli et al. 2003). The validity of this mass model is confirmed as follows. When X-class large solar flares occurred, the background noise counts of the MCPs increased predominantly. These were due to the gamma-rays which were emitted from the solar flares and came into the detectors directly. Because GEOTAIL is a spin-stabilized satellite, the detected gamma-rays were...
modulated as the quantity of material along the path to the detector differed. The modulation profile of gamma-rays during the peak time of the X5.3 solar flare occurred on 25 August 2001 are shown in Fig. 1 with red line. The blue line in Fig. 1 shows the simulation results. This is obtained by irradiating gamma-rays to the mass model from various azimuthal angles (the incident polar angle is fixed as 90 degree because the orbit of GEOTAIL is almost in the ecliptic plane). Note that the spectrum of the solar flare was observed by YOHKOH satellite so that we can use it as the incident gamma-ray spectrum. We can well reproduce the modulation so that we can confirm the validity of the mass model.

We irradiated the numerous gamma-rays whose spectrum was $kT=240$ keV optically thin thermal bremsstrahlung (Hurley et al. 1999) to the mass model of GEOTAIL. Because we know both the spin axis of GEOTAIL and the spin phase, we can exactly determine the direction of gamma-rays. From the simulation results we found that the contaminations of photo-electrons, compton-electrons, and characteristic X-rays are less than 1% compared to the primary gamma-rays.

Next, we prepared the MCP of the same geometrical size and constituents as was equipped on GEOTAIL and measured the quantum detection efficiency for gamma-rays. In order to examine the energy dependency of the efficiency, we used two gamma sources: Cs137 (662 keV) and Am241 (60 keV). Furthermore, in order to examine the angular dependency, we irradiated the gamma-rays whose incident angle to the detector is 0 degree or 180 degree. Preliminary results show that the efficiency is about 1% and depends to some extent on the energy and the incident angle of gamma-rays. Note that fine tunings of this experiment is now under way, and the details of this experiment will be reported elsewhere (Tanaka et al. in preparation).

It should be noted that the time resolution of this observation is 5.577 ms, which is a little different compared to that of the observation of SGR 1806-20 giant flare in 2004 (Terasawa et al. 2005). This is because the time resolution is determined by dividing the spin period and the spin period changes slightly year by year.

3. The initial spike of the SGR 1900+14 giant flare on 27 August 1998

SGR 1900+14 giant flare occurred at 10:22 UT on 27 August 1998. Fig. 2 shows the orbit of GEOTAIL around 27 August 1998. The position of GEOTAIL at the time when the giant flare occurred is shown with the blue star and the plasma particle detectors onboard GEOTAIL was observing the magnetospheric plasmas.

The flux of SGR 1900+14 giant flare was so intense that most of the gamma-ray detectors could not observe the peak profile of the giant flare because of the saturation effects or pulse pile-up problems: in fact, the gamma-ray detectors onboard Ulysses and Konus-Wind saturated during the initial spike and could determine only the lower limits of the peak flux intensity and fluence (Hurley et al. 1999, Mazets et al. 1999). On the other hand, we have found that the initial time profile was obtained by the plasma particle detector onboard GEOTAIL. This is because the effective area of the detector is very small and the detection efficiency is very low compared to the common gamma-ray detectors on any satellites.

Fig. 3 shows the first 300 ms profile of the giant flare with the time resolution of 5.577 ms after the dead time correction. Note that the time profile is preliminary. The energy range of the time profile is above $\sim 50$ keV, which is confirmed from the Monte Carlo simulations. The shaded
bars indicate the operational data gaps. The onset time \( t=0 \) corresponded to 10 h 22 min 15.47 s UT. After the onset the photon counts reached a very sharp peak at \( t=5.58 \) ms. Following the peak, there was a dip during the interval of \( t=15-45 \) ms. After the dip, the photon counts again increased and reached the flat-top second peak during 60–120 ms. Then the counts decayed exponentially and the decay time was calculated as \( \sim 22 \) ms using the time profile during the \( t=120-240 \) ms. Around 310 ms, the small hump was seen in GEOTAIL data and this was also observed with Konus-Wind (see Fig.6 of Mazets et al. 1999).

The exponential decay and the small hump may be the common features of the time profiles of the initial spikes. These structures were also observed in the time profile of SGR 1806-20 giant flare: the decay time was \( \sim 66 \) ms and the small hump was observed for \( t=402-451 \) ms (Terasawa et al. 2005). These timescales are a little different from those observed during the SGR 1900+14 giant flare in 1998. The physical meanings of this difference are unknown so far.

Because the particle detectors onboard GEOTAIL cannot observe the spectrum, we have to assume the spectrum of the initial spike in order to estimate the total energy of the giant flare. We took the \( kT=240 \) keV optically thin thermal spectrum from Hurley et al. (1999) and from the preliminary analyses found that the total emitted energy was the order of the \( 10^{44} \) erg. Here we assumed that the distance to SGR 1900+14 is 10 kpc. More detailed analyses are now under way.

4. Conclusions

In this report we present the GEOTAIL observation of SGR 1900+14 giant flare on 27 August 1998. The initial spike of the giant flare was first resolved and the profile consisted of five segments: the main spike, the deep dip, the flat-top second peak, the exponential decay and the small hump. The similar exponential decay and the small hump was also observed in the SGR 1806-20 giant flare in 2004 (Terasawa et al. 2005, Palmer et al. 2005). Now the experiments which measure the detection efficiency of the plasma particle detector equipped with GEOTAIL for gamma-rays are under way. More detailed results of our analyses of the SGR 1900+14 giant flare in 1998 will be reported elsewhere (Tanaka et al. in preparation).

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