Geotail observation of soft gamma repeater giant flares

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Abstract. Soft gamma repeaters (SGRs) occasionally provide extremely strong hard-X and gamma ray photon fluxes, known as giant flares. In this paper, we report the Geotail observation of the initial phase of two giant flares, one at SGR1806-20 on 27 December 2004, and one at SGR1900+14 on 27 August 1998, and show that there is an intrinsic time scale of several tens of ms in the energy release phase of these giant flares.

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 May 1979 as a sudden increase of soft gamma ray photon fluxes from SGR0525-66 in the Large Magnetic Cloud, a galaxy neighboring to our Galaxy. 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 \(\sim 500\) ms interval after the onset of the 2004 giant flare (e.g., [1, 2, 3, 4]), a few particle detectors were not saturated and provided important information on the initial very intense spike [5, 6]. From the LEP particle detectors on the Geotail spacecraft the peak photon energy flux (integrated above 50 keV) was estimated to be \(\sim 20\) erg sec\(^{-1}\)cm\(^{-2}\) [5]. That this energy flux was by a factor \(\sim 1000\) 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 \(3 \times 10^9\) times farther than the sun.

The “magnetar” model [7, 8] is generally accepted to explain the nature of SGRs, where neutron stars having ultrastrong 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. The initial 600 ms of the SGR1806-20 giant flare

Figure 1 shows the initial light curve of the giant flare of SGR1806-20 on 27 December 2004 observed by Geotail. The data are from the LEP/CEM sensors ($t=0-170$ ms) as well as from the LEP/MCP sensors ($t=176-600$ ms). Note that the former sensor has a geometrical factor $G$ smaller than the latter by a factor of $1/280$. Because of this smallness of $G$ the unsaturated observation of the initial phase of this giant flare was possible [5]. (In Figure 1 counts of CEM are multiplied by a factor of 280 so as to compensate this sensitivity difference.) A quasi-periodic modulation of the time scale of several tens of ms was seen during the interval of $t=22.7-170$ ms, suggesting repeated energy injections. The light curve showed more or less smooth decay after 176 ms till $\sim 400$ ms, but had small humps between 400 and 500 ms (see an enlarged plot in Figure 2). The physical significance of these small humps are confirmed as they were seen in three independent satellite observations, Geotail [5], Swift [2], and Double Star [6].

![Figure 1](image1.png)

**Figure 1.** The initial light curve (0–600 ms) of the giant flare of SGR1806-20 obtained by Geotail.

![Figure 2](image2.png)

**Figure 2.** The light curve enlarged for the interval $t=300–580$ ms. Humps of the time scale of several tens of ms are seen.

![Figure 3](image3.png)

**Figure 3.** The power spectral density calculated for the interval of $t=45–175$ ms with the maximum entropy method.

![Figure 4](image4.png)

**Figure 4.** Similar to Figure 3, but for the interval of $t=430–567$ ms.
To derive characteristic time scales of these humps, if any, we have attempted to make power spectral analyses for two intervals, 45–175 ms and 430–567 ms, separately. However, since the numbers of data points are limited (<32), it is found that the usual Fourier analysis does not give any meaningful results. Instead, we have utilized the maximum entropy method, and the results are shown in Figure 3 and Figure 4. In Figure 3, the leftmost peak is sensitive to the choice of the model parameters of the method, and not considered further. On the other hand, the peak at the frequency of 50 Hz (or the period of 20 ms) is found robust against the changes of the model parameters. In Figure 4, the peak at the frequency of 48 Hz (or the period of 21 ms) is found also robust against the changes of the model parameters. If, therefore, we assume that these spectral peaks are physically significant, the period similarity between the earlier and later humps would argue to support that they are of internal origin of the magnetar rather than of external magnetospheric origin. (If the latter is the case, it is difficult to understand why the period is kept constant during the giant flare by which the structure of the magnetosphere should be modified substantially.) It is noted further that this period, ∼20 ms, is close to what was observed for the initial phase of the 1979 giant flare (∼23 ms obtained for t=0–200 ms) [9].

3. The initial 200 ms of the SGR1900+14 giant flare

As seen in the previous section, the initial time profiles of the light curve of the SGR giant flares in 1979 and 2004 seem to include important information for energy release process. It is, therefore, desirable to investigate the initial time profile for another giant flare of SGR1900+14 on 27 August 1998. However, this had been prevented by the detector saturation effect: For example, the gamma ray detector aboard of Konus-Wind was saturated during the first ∼200 ms again because of the strong photon flux [10]. Hurley et al. [11] corrected all available information for the 1998 giant flare, but could determine only the lower limit of the peak flux intensity and fluence. On the other hand, we have found that the initial time profile was obtained by the LEP/MCP sensor, which is shown in Figure 5.

As seen in Figure 5, there was a very sharp peak 5 ms after the onset. The duration of the peak was not resolved since it was shorter than time resolution (∼5 ms). Following the peak, there was a flat-top peak extending from t=60–120 ms. Following the dip, there was a dip of the photon counts during the interval of t=20–45 ms. Following the dip, there was a flat-top peak extending from t=60–120 ms. Some remarks should be given for the observation of the 1998 giant flare: Firstly, while the dataset for the 2004 giant flare shown in Figure 1 and Figure 2 was free from the plasma counts, there were contaminations of plasma counts (up to ∼300) in the dataset for the 1998 giant flare. This difference between 2004 and 1998 datasets are due to the different satellite positions. Geotail was in the cold plasma region in the solar wind on 27 December 2004 so that the plasma counts existed only in a limited range of the satellite spin phase angle, and had little overlap with SGR photons. On the other hand, Geotail was in the hot plasma region of the earth’s magnetotail, so that the plasma counts spreaded over the wide range.
spin phase, and the overlap with SGR photons was unavoidable. Fortunately, the SGR photon counts at the initial peak as well as at the flat-top peak far exceeded the plasma count level so that their significance was not affected by the existence of plasma counts. We are now carefully removing the plasma counts from the raw counts and trying to extend the time coverage of the reliable estimation of photon counts. Secondly, the geometrical configuration of the LEP detectors against the SGR1900+14 in 1998 was different from that against SGR1806-20 in 2004. The incoming direction of photons from SGR1806-20 was close to the direction of the sun (\(\sim 5^\circ\)), so that the results of the calibrations of the detector sensitivity with solar hard-X and gamma ray photons from solar flares in 1997-2003 were directly applicable to the SGR analysis [5]. On the other hand, the incoming direction of photons from SGR1900+14 significantly differed from the solar direction, so that the detector sensitivity for SGR1900+14 photons was not previously known. We are conducting the computer simulation (Geant4) as well as laboratory experiment to obtain the detector sensitivity (namely, the combined effect of photon absorption/scattering along the propagation path within the spacecraft body and the counter angular response). The preliminary results show the detector sensitivity along the direction to SGR1900+14 does not significantly differ from that to SGR1806-20. If we tentatively apply the detector sensitivity same as the 2004 giant flare to the analysis of the 1998 giant flare, we see that the peak photon intensity was \(\sim 1/10\) of the former, and that the fluence was two order of magnitude smaller than the former. More reliable estimations of the flux and fluence are now under way.

4. Concluding remarks

In this report we suggest that there is a quasi-periodic oscillation with a period of \(\sim 20\) ms during the initial strong peak of SGR giant flares in 2004, which is similar to \(\sim 23\) ms quasi periodicity in 1979 [9]. In another giant flare in 1998 no quasi-periodic behavior similar to the 1979 and 2004 giant flares was found. However, if we measure the the duration of the initial spike, we obtain 15-20 ms (Figure 5). Thus there is a time scale of \(\sim 20\) ms common to all three giant flares. It is noted that quasi-periodicities of 84 Hz (period 11.9 ms) [13] and 92.5Hz (period 10.8 ms) [14] was recently reported for the late phase of 1998 and 2004 giant flares, respectively. While Duncan [12] interpreted 23 ms quasi periodicity of the 1979 giant flare in terms of torsional vibrations of neutron star crust, whether the torsional vibration model explain varieties of these time scales in the 10-23 ms range (depending on the phase of giant flares?) is an interesting theoretical problem.

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