THE DYNAMIC BEHAVIOR OF SOFT GAMMA REPEATERS

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ABSTRACT

Soft Gamma Repeaters (SGRs) undergo changes in their pulse properties and persistent emission during episodes of intense burst activity. Both SGR 1900+14 and SGR 1806−20 have shown significant changes in their spin-down rates during the last several years, yet the bulk of this variability is not correlated with burst activity. SGR 1900+14 has undergone large changes in flux and a dramatic pulse profile change following burst activity in 1998. The flux level of SGR 1627−41 has been decreasing since its only recorded burst activity. Here, we review the global properties of SGRs as well as the observed dynamics of the pulsed and persistent emission properties of SGR 1900+14, SGR 1806−20 and SGR 1627−41 during and following burst active episodes and discuss what implications these results have for the burst emission mechanism, the magnetic field dynamics of magnetars, the nature of the torque variability, and SGRs in general.

INTRODUCTION

Soft Gamma Repeaters (SGRs) are a small class (4 confirmed and one candidate) of high-energy transient discovered through their emission of bright X-ray/γ-ray bursts which repeat on timescales of seconds to years. Originally confused with Gamma-Ray Bursts (GRBs see e.g. Fishman and Meegan 1995), SGRs get their name from their burst properties that distinguish them from classical GRBs; namely their softer spectral energy distribution and repetition of bursts. In addition to being prolific burst emitters, SGRs are also persistent X-ray sources. For three objects, the X-ray radiation is modulated by the spin of the underlying neutron star. In each case, the star is spinning down rapidly, indicative of a strong magnetic field (Kouveliotou et al. 1998a). In fact, it was this observation that clinched the now widely accepted magnetar model for SGRs (Thompson and Duncan 1995, 1996). A magnetar is a strongly magnetized neutron star ($B_{\text{dip}} \sim 10^{14} – 10^{15}$ G) where the magnetic energy exceeds all other sources of free energy in the system. Unlike ordinary radio pulsars, the rotational energy loss in SGRs is insignificant compared to their overall energy output. It is the decay of the strong field of the SGR that powers both their burst and persistent emissions.

In addition to the four confirmed SGRs, there is another small class of neutron stars dubbed the Anomalous X-ray Pulsars (AXPs) that were proposed by Thompson and Duncan (1996) as magnetar candidates. The AXPs share a number of characteristics with the SGRs in terms of their persistent X-ray emission properties, and two members were recently discovered to emit SGR-like bursts (Gavriil et al. 2002; Kaspi et al. 2002). The recent burst detection results solidify the common nature of AXPs and SGRs. A review of AXPs will be presented within this volume (Gavriil et al. 2003).

Here, I will review the salient properties of SGRs including burst characteristics, persistent and pulsed X-ray emission, and the effects of burst activity on SGR persistent emission properties. Associations with supernova remnants and massive star clusters will be discussed elsewhere in this volume (Gaensler 2003).
BURST PROPERTIES

The defining behavior of SGRs is their repetitive emission of luminous soft $\gamma$-ray bursts. Typically, the bursts last $\sim 0.1$ sec and have energy spectra ($E > 25$ keV) that can be modeled with an Optically Thin Thermal Bremsstrahlung (OTTB) having temperatures $20$–$40$ keV (e.g. Göğüş et al. 2001, Aptekar et al. 2001). At lower energies, however, this model fails to fit the spectrum (e.g. Olive et al. 2003). The spectral temperatures show little or no variation with intensity, between bursts, at different epochs, or between sources. The burst energies follow a power-law number distribution (dN/dE $\propto E^{-5/3}$ [Cheng et al. 1996, Göğüş et al. 1999]) from $\sim 10^{35}$ ergs up to at least $\sim 10^{42}$ ergs, consistent with a so-called self-organized critical system (e.g. earthquakes, Solar flares, etc.) where the burst energy reservoir greatly exceeds the energy output within any given burst.

Burst active states of SGRs, often referred to as outbursts, range in duration from a few days to several months. During these episodes, they emit anywhere from a handful to several hundred bursts. The burst rate histories of the four SGRs spanning three decades are shown in Figure 1. These lightcurves are comprised of burst detections from several different detectors having different sensitivity limits. The non-uniformity of the burst sampling becomes significant when comparing separate active episodes that were viewed with different detectors. For example, given a stationary burst energy (and peak flux) distribution with a power-law slope of $-5/3$, an increase in the detector sensitivity by a factor 10 yields a factor $\sim 5$ increase in the overall rate.

Fig. 1. Burst activity lightcurve of the four confirmed SGRs. The bursts identified here were detected with various detectors having different sensitivities. The shaded regions indicate epochs where there were no active detectors in flight to detect SGR bursts. IPN data courtesy of Kevin Hurley.

On two occasions, more energetic bursts or giant flares were recorded one each from SGR 0526$-$66 on 1979 March 5 (Mazets et al. 1979) and SGR 1900$+$14 on 1998 August 27 (Hurley et al. 1999a). The lightcurve of the August 27 flare is shown in Figure 2. Each of these extraordinary events had a bright ($\sim 10^{44}$ ergs s$^{-1}$), spectrally hard initial spike followed by a softer, several minute long tail showing coherent pulsations at 8 and 5 s, respectively. More recently, an intermediate flare ($\sim 10^{43}$ ergs) lasting 40 s was recorded from SGR 1900$+$14 on 2001 April 18 (Guidorzi et al. 2001), suggesting a continuum of bursts energies rather than a dichotomy of bursts and flares (Kouveliotou et al. 2001).
Recently, discrete features in the spectra of bursts from two SGRs, 1900+14 and 1806–20 have been reported. In the case of SGR 1900+14, an emission line at $\sim 6.5$ keV was discovered (Strohmayer and Ibrahim 2000) during the onset of a single, bright burst. No candidate line features in other bursts have been reported from this source since. For SGR 1806–20, an absorption line feature was found near $\sim 5$ keV in a small subset of spectra taken from selected bursts (Ibrahim et al. 2002). The presence of less significant features at higher energies consistent with a harmonic relationship is intriguing, but their significance (for individual bursts) is not convincing.

**PERSISTENT EMISSION**

All SGRs are associated with persistent X-ray counterparts; three of them have quiescent luminosities $\sim 10^{35}$ ergs s$^{-1}$ (Murakami et al. 1994; Rothschild et al. 1993; Hurley et al. 1999b), while the quiescent flux level of SGR 1627–41 has not yet been reached (C. Kouveliotou, private communication). The spectra of SGR 1627–41 and SGR 1806–20 can be modeled with a power-law (Woods et al. 1999a; Mereghetti et al. 2000) while SGR 1900+14 requires an additional blackbody component ($kT \sim 0.5$ keV [Woods et al. 1999b; Kouveliotou et al. 2001]). The presence of a blackbody component in SGR 0526–66 is marginal (Kulkarni et al. 2003). Currently, we are investigating the stability of the power-law photon index in SGR 1900+14. Our preliminary finding is that the photon index evolves from $\sim 1.0$ to $\sim 2.2$ within a few years.

<table>
<thead>
<tr>
<th></th>
<th>SGR 0526–66</th>
<th>SGR 1627–41</th>
<th>SGR 1806–20</th>
<th>SGR 1900+14</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_X$ (ergs)</td>
<td>$1 \times 10^{36}$</td>
<td>$\lesssim 3 \times 10^{34}$</td>
<td>$4 \times 10^{35}$</td>
<td>$2 \times 10^{35}$</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>3.1</td>
<td>2.5</td>
<td>2.0–2.2</td>
<td>1.0–2.2</td>
</tr>
<tr>
<td>$kT$ (keV)</td>
<td>0.5</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$N_H$ ($10^{22}$ cm$^{-2}$)</td>
<td>0.54</td>
<td>7.7</td>
<td>6.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Period (s)</td>
<td>8.0</td>
<td>...</td>
<td>7.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Pdot ($10^{-11}$ s s$^{-1}$)</td>
<td>6.5</td>
<td>...</td>
<td>8–30</td>
<td>6–35</td>
</tr>
</tbody>
</table>
Three SGRs show low-amplitude pulsations in their persistent emission within a narrow period range (Kouveliotou et al. 1998a; Hurley et al. 1999b; Kulkarni et al. 2003). The frequency of these pulsations is increasing rapidly (Kouveliotou et al. 1998a, 1999; Kulkarni et al. 2003), consistent with the interpretation of an underlying strongly magnetized neutron star. Due to the strong timing noise present in both SGR 1806–20 and SGR 1900+14 (Woods et al. 2002), it is best to give ranges for their measured period derivatives (Table 1).

BURST-INDUCED EFFECTS ON THE PERSISTENT EMISSION

During the last few years, we have noted changes in the X-ray emission properties of SGRs during episodes of burst activity (Woods et al. 2001). Through studying the transient effects imparted upon SGRs (or the lack thereof) during times of burst activity, we have gained deeper insight into the nature of the burst mechanism and the SGR systems in general. The changes in SGR pulsed properties and persistent X-ray emission and their relationship to burst activity are presented below.

Torque Changes

Coherent pulsations from the persistent emission of SGR 1806–20 were discovered within an RXTE PCA observation from 1996 November (Kouveliotou et al. 1998a). Including both archival and subsequent monitoring observations, the spin frequency history of SGR 1806–20 has now been extended from 1993 through 2001 (Figure 3, from Woods et al. 2002). We have found that at all times, the SGR has been spinning down, but the rate of spindown shows substantial variability. In fact, the measured spin-down torque on this SGR has been found to vary by up to a factor \( \sim 6 \). The torque variations seen in SGR 1806–20 do not correlate directly with the burst activity (Woods et al. 2002).

![Fig. 3. Top – Burst rate history of SGR 1806–20 as observed with BATSE. The hashed region starts at the end of the CGRO mission. Middle – The frequency history of SGR 1806–20 covering 8 years. Plotting symbols mark individual frequency measurements and solid lines denote phase-connected timing solutions. The dashed line marks the average spin-down rate prior to burst activation in 1998. Bottom – The frequency derivative history over the same timespan. Dotted lines denote average frequency derivative levels between widely spaced frequency measurements. Solid lines mark phase-coherent timing solutions and triangles mark instantaneous torque measurements, both using RXTE PCA data.](image-url)
Pulsations from the X-ray counterpart of SGR 1900+14 were discovered during an ASCA observation in 1998 April (Hurley et al. 1999b), shortly before the SGR entered an intense, sustained burst active interval (Figure 1). Similar to SGR 1806−20, a compilation of data preceding and following the discovery observation showed that this SGR was spinning down rapidly and irregularly (Kouveliotou et al. 1999; Woods et al. 2002). As with SGR 1806−20, the variations in torque do not directly correlate with the burst activity from this SGR with one notable exception, the giant flare of August 27 (Woods et al. 1999c; Palmer 2002).

We note that although a rapid spin-down event most likely occurred within the hours following the August 27 flare, its impact on the overall spin history of the SGR was very small relative to the much larger variations observed during ∼5 years of monitoring. So, in general, the direct effects of burst activity are insignificant to the overall torque noise in each of these SGRs. For a more complete discussion of the torque variability in these two SGRs, as well as a quantitative analysis of the torque noise, see Woods et al. (2002).

Recently, the 8 sec pulsations observed in the tail of the March 5th flare from SGR 0526−66 (Mazets et al. 1979) were confirmed in the persistent X-ray emission of the source (Kulkarni et al. 2003). As of yet, there are only two period measurements which provides a measure of the spindown. Further data are required to determine if the torque varies in this system as well.

**Pulse Profiles**

Currently, the pulse profiles of both SGR 1900+14 and SGR 1806−20 are very nearly sinusoidal (i.e. they show very little power at the higher harmonics). This has not always been the case, however, as both SGRs have shown significant changes in their pulse profiles during the last several years. The most notable of these changes occurred in the pulse profile of SGR 1900+14 during the tail of the giant flare of August 27 (e.g., Feroci et al. 2001).

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![Fig. 4. Evolution of the pulse profile of SGR 1900+14 over the last 3.8 years. All panels display two pulse cycles and the vertical axes are count rates with arbitrary units. The two middle panels were selected from Ulysses data (25−150 keV) of the August 27th flare. Times over which the Ulysses data were folded are given relative to the onset of the flare (T_o). See text for further details. The top and bottom rows are integrated over the energy range 2−10 keV. From top-to-bottom, left-to-right, the data were recorded with the RXTE, BeppoSAX, ASCA, RXTE, RXTE, RXTE, BeppoSAX, and RXTE.](image-url)
Forty seconds after the onset of the August 27 flare, 5.16 s coherent gamma-ray pulsations at high amplitude emerged. Initially, the pulse profile was complex, having four distinct maxima per rotation cycle. A few minutes later toward the end of the flare, the pulse profile was significantly more sinusoidal (Figure 4 – middle row). The same qualitative behavior was observed in the persistent X-ray pulse profile of SGR 1900+14. In all observations prior to the August 27th flare, the pulse profile was complex having significant power at higher harmonics (Figure 4 – top row). For all observations after 1998 August 27 through the present, the pulse profile remained relatively simple (Figure 4 – bottom row). Hence, the pulse profile change observed at gamma-ray energies during the tail of the August 27th flare translated to the persistent emission pulse profile of this SGR in a sustained manner (i.e. for years after the August 27 X-ray tail had disappeared [Woods et al. 2001]).

A systematic study of the temporal and spectral evolution of the pulse profiles of SGR 1900+14 and SGR 1806−20 is presented in Göğüş et al. (2002). This study confirms the temporal evolution of the pulse profile of SGR 1900+14 mentioned above and shows that there is a similar time-dependence in the pulse profile of SGR 1806−20. From 1996 November to 1999 January, the pulse profile of SGR 1806−20 becomes more sinusoidal. Due to the sparseness of the observations, however, we cannot determine the exact time of this change, nor the timescale over which it progressed to better than 2.3 years.

Fig. 5. Top panel – Burst rate history of SGR 1900+14 as observed with BATSE. Bottom panel – Persistent/Pulsed flux history of SGR 1900+14 covering 5.5 years. The vertical scale is unabsorbed 2−10 keV flux. The pulsed fraction is assumed constant to convert pulsed flux to phase-averaged flux (see text for details). The dotted line marks the nominal quiescent flux level of this SGR. Note the drop in flux below the quiescent level during the latest observation in 2002.

**Flux Changes**

Changes in the flux of SGRs were first noted in SGR 1900+14 following the giant flare of August 27 (Remillard et al. 1998; Kouveliotou et al. 1999; Murakami et al. 1999; Woods et al. 1999b). Following this discovery, a compilation of persistent and pulsed flux measurements over several years (Figure 5 [Woods et al. 2001]) revealed that, in general, there is an excellent correlation between burst activity (top) and enhancements in the persistent/pulsed flux from this SGR (middle). We have found that the pulse fraction is consistent with remaining constant at most epochs.
despite changes in the persistent flux. It is by assuming that this fraction remains constant at all times that we can plot both the pulsed flux (RXTE PCA) and the persistent flux (BeppoSAX and ASCA) on the same scale. We note, however, that there are exceptions to this rule when the pulse fraction has increased for short periods of time (see below).

Four Bursts from SGR 1900+14

The brightest pulsed/persistent flux excess seen in Figure 5 is directly linked with the August 27 flare. The flux decays approximately as a power-law in time \((F \propto t^{-0.7})\) following the giant flare (Figure 6 [Woods et al. 2001]). The X-ray spectrum as measured with the PCA one day after the flare can be fit with the sum of a blackbody and a power-law. The blackbody temperature is hotter \((kT = 0.94 \pm 0.03)\) than the quiescent level and the power-law photon index is steeper \((\Gamma = 2.76 \pm 0.07)\). The spectrum \((0.1-10 \text{ keV})\) of the X-ray tail at \(\sim19\) days after the flare was found to be exclusively non-thermal (Woods et al. 1999b). These observations are consistent with the thermal excess fading more rapidly to its quiescent value than the power-law component.

![Fig. 6. The flux decay following the 1998 August 27 flare from SGR 1900+14. The reference time is the beginning of the flare as observed in soft \(\gamma\)-rays. The dotted line is a fit to the RXTE/PCA, BeppoSAX, and ASCA data only (i.e. the ASM data are not included in the fit). The slope of this line is \(-0.713 \pm 0.025\).](image)

For SGR 1900+14, there are now four X-ray tails that can be linked with specific bursts or flares. The second of these events was recorded on 1998 August 29 (Ibrahim et al. 2001; Lenters et al. 2003), just two days after the flare. This burst had a high gamma-ray fluence and an X-ray tail whose flux decayed more rapidly than a power-law in time (Lenters et al. 2003). We define the onset of the tail emission when the intensity quickly drops by \(\sim4\) orders of magnitude within a few tens of milliseconds. Simultaneously, the X-ray spectrum suddenly hardens. Over the next several minutes as the flux decays through the tail, the energy spectrum softens. Formally, the energy spectrum of the tail is equally well fit by a power-law plus a blackbody or an optically thin thermal bremsstrahlung, each with interstellar attenuation (Ibrahim et al. 2001). However, the bremsstrahlung model yields a column density \(\sim5\) times larger than the measured column from the persistent emission whereas the two component model fit yields a column consistent with the persistent emission value. The pulsed fraction increases above the quiescent level (11\% RMS) up to \(\sim20\%\) during this tail (Lenters et al. 2003), and the phase of the pulsations does not shift during the tail relative to the pre-burst pulse phase.

On 2001 April 18, a burst was detected from SGR 1900+14 with a high fluence \((\sim10^{43} \text{ ergs})\) and long duration \(\sim40\) s (Guidorzi et al. 2001). The burst energy of April 18 was intermediate between the giant flare of 1998 August 27 and typical SGR events. Like the August 27 flare, this event showed an extended X-ray tail following the burst which lasted for several days (Kouveliotou et al. 2001; Feroci et al. 2003). The properties of this burst tail (Table 2)

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are similar in many respects to the two previously mentioned.

A second burst from SGR 1900+14 also recorded during the 2001 April activation also possessed an X-ray tail. This event was detected on April 28 and like previous tails, showed a transient increase in pulse fraction and a cooling blackbody spectral component (Lenters et al. 2003). In fact, this is the only tail thus far to show an exclusively thermal X-ray tail.

Table 2. Spectral and pulsed properties of the four X-ray tails following bright bursts from SGR 1900+14. The burst energy of the events decreases from left to right. See text for references.

<table>
<thead>
<tr>
<th>Time</th>
<th>Spectral Structure</th>
<th>$kT$ Change</th>
<th>$\Gamma$ Change</th>
<th>$E_{\text{tail}}/E_{\text{burst}}$</th>
<th>Pulse Profile Change</th>
<th>Pulse Timing Change</th>
<th>Pulse Fraction at Late Times</th>
<th>Timing Spindown Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>980827</td>
<td>BB+PL early</td>
<td>Increase</td>
<td>Steeper</td>
<td>0.021</td>
<td>Dramatic</td>
<td>Sudden</td>
<td>~18%</td>
<td>measured</td>
</tr>
<tr>
<td>020418</td>
<td>BB+PL early</td>
<td>Increase</td>
<td>Nothing</td>
<td>0.021</td>
<td>Slight</td>
<td>Some</td>
<td>~20%</td>
<td>measured</td>
</tr>
<tr>
<td>980829</td>
<td>BB+PL late</td>
<td>Increase</td>
<td>Steeper</td>
<td>0.024</td>
<td>Early</td>
<td>Nothing</td>
<td>~32%</td>
<td>measured</td>
</tr>
<tr>
<td>020428</td>
<td>BB only</td>
<td>Increase</td>
<td>N/A</td>
<td>0.024</td>
<td>Nothing</td>
<td>Nothing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Within the group of four X-ray tails following bright bursts detected from SGR 1900+14 (Table 2), we find a number of similarities and some slight differences indicating possible trends (within the restrictions of small number statistics). In all cases, the thermal component becomes hotter while the power-law component brightens following three of the four bursts. The ratio of tail energy to burst energy is consistent with being constant among the group (Figure 7 [Lenters et al. 2003]). Timing anomalies and pulse profile changes are seen following the two most energetic bursts and the pulse fraction increases for the three weakest. An interesting trend which arises from this small set of X-ray tails is that the pulse fraction enhancement in the separate X-ray tails appears to correlate with the magnitude of the thermal contribution to the X-ray flux. That is, tails with the highest relative blackbody flux show the largest increase in pulse fraction. Given the small numbers, however, more examples are required to establish this trend.

Fig. 7. Tail energy versus burst energy output of four separate bursts from SGR 1900+14. An assumed distance of 14 kpc is used.
SGR 1627−41 was discovered in 1998 June when it was observed to burst more than 100 times in a short span of about a month (Kouveliotou et al. 1998b; Woods et al. 1999a). No bursts from this SGR have been seen since 1998 August. Shortly after the onset of burst activity in this SGR, an X-ray counterpart was identified and observed to fade in brightness over the next two years. Dissimilar to the observed flux variations in SGR 1900+14, the decay in the lightcurve of SGR 1627−41 proceeds on a much longer timescale of order years and has yet to “bottom out” at a baseline flux level. This object shows that the response of SGRs to burst activity varies between sources.

**DISCUSSION**

We have summarized the recent observations of dynamic behavior in the persistent and pulsed emission from SGR 1900+14, SGR 1806−20 and SGR 1627−41. Now, we will discuss what constraints these observations place on the models for the SGRs, in particular the magnetar model.

The torque enhancements in SGR 1806−20 and SGR 1900+14 do not directly correlate with the burst activity. In the context of the magnetar model, the absence of a direct correlation between these two parameters has strong implications for the underlying physics behind each phenomenon. The magnetar model postulates that the bursting activity in SGRs is a result of fracturing of the outer crust of a highly magnetized neutron star. Furthermore, the majority of models proposed to explain the torque variability in magnetars invoke crustal motion and/or low-level seismic activity (Thompson and Blaes 1998; Harding et al. 1999; Thompson et al. 2000). Since there is no direct correlation between the burst activity and torque variability, then either (i) the seismic activities leading to each observable are decoupled from one another, or (ii) at least one of these phenomena is not related to seismic activity (Woods et al. 2002).

The dramatic change in the pulse profile of SGR 1900+14 in conjunction with the giant flare requires a substantial change in the magnetic field of the neutron star (Woods et al. 2001; Thompson et al. 2002). In the magnetar model, there are at least two possible ways that this can happen. One possibility proposed by Thompson et al. (2002) is that a twist in the magnetosphere is generated following the flare, driving a persistent current which produces an observable change in the magnetic field of the neutron star (Woods et al. 2001; Thompson et al. 2002). The decay of this magnetospheric twist is believed to be several years. An alternative scenario involves restructuring of the surface magnetic field geometry. In this picture, the field geometry is complex prior to the flare and relaxes to a more dipolar structure following the event giving rise to the observed change in pulse profile.

Thompson et al. (2002) recently investigated each of these scenarios in detail, noting advantages and disadvantages for each model. In this work, they have identified further observational tests involving the energy spectrum of the emission before and after the flare. Simulations of the expected behavior and an analysis of the spectral evolution of SGR 1900+14 are currently underway.

Currently, only four clear X-ray tails have been detected from SGR 1900+14. As mentioned earlier, there is a potential correlation between the relative abundance of thermal emission in the tail and the enhancement of the pulse fraction. This correlation, if proven correct with the detection and analysis of several more SGR tails, would provide a strong argument for heating of a localized region on the neutron star during bursts (Thompson et al. 2000; Lyubarsky et al. 2002).

Since the pulse fraction increases during three of the four X-ray tails detected from SGR 1900+14, the flux enhancement must be anisotropic about the star in these cases. For the August 29 and April 28 burst tails, the location of the heating is also constrained (Lenters et al. 2003). In each of these events, we have precise pulse phase information prior to, during, and after the tail. For both bursts, the phase of the pulsations during the tail does not shift relative to the pulse phase prior to the burst. This requires that the localized region on the neutron star with the largest relative flux enhancement is within or nearby the region giving rise to the persistent X-ray pulse peak (e.g. the polar cap). In the magnetar model, the burst emission is due to the build up of stress in the stellar crust from the evolving magnetic field and the eventual release of this stress when the crust fractures (Thompson and Duncan 1995). Localized heating of the polar cap requires that the fracture site of the burst be at the same location. Since these two events do not occur at all near the same pulse phase (Lenters et al. 2003), the burst emission arising from near the surface must
be significantly scattered. An alternative model (Lyutikov 2002) invokes a magnetospheric rather than crustal origin for the bursts. This model is attractive in that it negates the need for large angle scattering of the burst emission and provides a natural explanation for the preferential brightening of the polar cap regions.

Contrary to the short-lived X-ray tails seen following SGR 1900+14 bursts, the much longer timescale flux decay in SGR 1627−41 following its 1998 outburst shows that the effects of burst activity on the persistent emission of SGRs is not uniform among the class. As another example, the recent outburst of the AXP 1E 2259+586 (Kaspi et al. 2002) shows several source parameters that changed as a result. Some of the observed changes (e.g. persistent and pulsed X-ray flux increases) are similar to those seen in SGR 1900+14 whereas others are not. As discussed above, episodes where the properties of these objects are rapidly evolving are paramount in determining the nature of these sources and the physical mechanism driving the dynamics of the source spectral and temporal properties. The diversity in SGR/AXP outbursts observed thus far necessitates detailed study of each outburst in order to obtain a comprehensive picture of the class as a whole. This in turn requires diligent monitoring and prompt follow-up of each source when they become active.

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REFERENCES


Gaensler, B.M., Anomalous x-ray pulsars and soft gamma-ray repeaters – the connection with supernova remnants, these proceedings, 2003.


Hurley, K., Li, P., Kouveliotou, C., Murakami, T., Ando, M., Strohmayer, T., van Paradijs, J., Vrba, F., Luginbuhl, C.,


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