

## THE 2001 APRIL BURST ACTIVATION OF SGR 1900+14: PULSE PROPERTIES AND TORQUE

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Received 2002 October 14; accepted 2003 May 13

### ABSTRACT

We report on observations of SGR 1900+14 made with the *Rossi X-Ray Timing Explorer (RXTE)* and *BeppoSAX* during the 2001 April burst activation of the source. Using these data, we measure the spin-down torque on the star and confirm earlier findings that the torque and burst activity are not directly correlated. We compare the X-ray pulse profile to the gamma-ray profile during the April 18 intermediate flare and show that (1) their shapes are similar and (1) the gamma-ray profile aligns closely in phase with the X-ray pulsations. The good phase alignment of the gamma-ray and X-ray profiles suggests that there was no rapid spin-down following this flare of the magnitude inferred for the August 27 giant flare. We discuss how these observations further constrain magnetic field reconfiguration models for the large flares of SGRs.

*Subject headings:* pulsars: general — stars: individual (SGR 1900+14) — X-rays: bursts

### 1. INTRODUCTION

Soft gamma repeaters (SGRs) are a small class (four known) of intriguing high-energy transient that emit anywhere from a handful to several hundred brief, intense bursts of soft gamma-rays when active (see Kouveliotou 2003 for a recent review). In quiescence, SGRs have been found to exhibit persistent X-ray luminosities of  $\sim 10^{35}$  ergs  $s^{-1}$ . Three SGRs emit coherent pulsations between 5 and 8 s (Kouveliotou et al. 1998; Hurley et al. 1999a; Kulkarni et al. 2003), and all are spinning down rapidly with time (Kouveliotou et al. 1998, 1999; Kulkarni et al. 2003). The spin-down observed in two of these SGRs (1806–20 and 1900+14) is not constant. Furthermore, most of the spin-down variations do not directly correlate with the bursting activity of the source (Woods et al. 2002).

The rapid spin-down in SGRs has been interpreted (e.g., Kouveliotou et al. 1998) as magnetic braking of a strongly magnetized neutron star with  $B_{\text{dip}} \sim 10^{14} - 10^{15}$  G, or magnetar (Thompson & Duncan 1995, 1996). The magnetar

model postulates that the short duration SGR bursts are triggered by starquakes induced by magnetic stresses in the neutron star crust (Thompson & Duncan 1995) or perhaps magnetic reconnection events in the stellar magnetosphere (Lyutikov 2002). Persistent magnetospheric currents, driven by twists in the evolving magnetic field, and field decay in the stellar interior contribute to the quiescent flux from SGRs (Thompson & Duncan 1996; Thompson, Lyutikov, & Kulkarni 2002).

Burst activity in SGRs occurs sporadically in time, and the separation between successive events can vary from seconds to years. Epochs when SGRs are emitting several bursts or burst active phases vary in both intensity and duration. For example, SGR 1900+14 was discovered in 1979, when it was observed to burst only three times in 3 days (Mazets & Golenetskii 1981). In 1992, the source became active again for a few days and emitted a handful of events (Kouveliotou et al. 1993); it entered an unprecedented level of activity in 1998 (Hurley et al. 1999b), never before observed for any SGR. During the course of 9 months, more than 1000 bursts were recorded from this source with various instruments (Göğüş et al. 1999).

The pinnacle of the 1998 activity of SGR 1900+14 was realized on August 27, when a giant flare was recorded from this source (Hurley et al. 1999c; Mazets et al. 1999; Feroci et al. 1999, 2001). The event reached a peak luminosity of  $\sim 4 \times 10^{44}$  ergs  $s^{-1}$  and persisted for over  $\sim 6$  minutes, releasing a total of  $\sim 10^{44}$  ergs in gamma-rays above 15 keV. The flare started with a spectrally hard, nonthermal initial spike that was followed by a softer tail which decayed in a quasi-exponential manner. Superimposed on the decaying tail were coherent 5.16 s pulsations whose shape evolved with time. Eighteen minutes after the termination of the gamma-ray emission, a bright X-ray tail from SGR 1900+14 was detected that decayed in time as a power law (Woods et al. 2001). The change in pulse profile observed during the August 27 flare at gamma-ray energies was also evident in the persistent X-ray emission pulse profile seen before and after the flare (Woods et al. 2001; Göğüş et al. 2002). In addition, a transient radio outburst was seen for the first and only time from an SGR source, due to a sudden outflow of material associated with this flare (Frail, Kulkarni, & Bloom 1999). Finally, there is strong circumstantial

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evidence indicating that there was a brief, albeit substantial, spin-down event [ $\Delta P = 5.72(14) \times 10^{-4}$  s; Woods et al. 1999b] within the hours following the flare (Palmer et al. 2002), due perhaps to this large outflow of material (Thompson et al. 2000).

On 2001 April 18, a burst was detected from SGR 1900+14 with a high energy ( $\sim 10^{43}$  ergs) and long duration ( $\sim 40$  s; Guidorzi et al. 2001). Unlike the August 27 flare, there was no intense, nonthermal emission episode at the onset of this event (C. Guidorzi et al., in preparation). The energy released by this flare was less than the giant flare of August 27, yet much larger than a typical SGR event, and was consequently dubbed an “intermediate flare” (Kouveliotou et al. 2001). Several, more common SGR bursts were detected during the following weeks. We triggered a sequence of target-of-opportunity (ToO) observations of the source with the *Rossi X-Ray Timing Explorer* (*RXTE*) and *BeppoSAX* over the 2 weeks following the April 18 event. Here we present pulse timing and profile results from these observations. The flux history during this epoch is discussed in the accompanying paper (Feroci et al. 2003).

## 2. OBSERVATIONS

The ToO observations of SGR 1900+14 with the *RXTE* Proportional Counter Array (PCA) began  $\sim 34$  hr after the intermediate flare and continued for the next 2 weeks. A total of 128 ks of data were collected during 13 pointings. A single monitoring observation (10 ks exposure time) of SGR 1900+14 was serendipitously performed on 2001 April 14, just 4 days prior to the flare.

We find no burst activity during the preflare observation on 2001 April 14. We performed a search through the data following the flare and found a total of 32 bursts that exceeded  $5.5 \sigma$  above background (using a running mean) on the 0.125 s timescale. The last burst from SGR 1900+14 detected in the PCA data was recorded on 2001 May 1 at 04:00:22 UT. On 2001 April 28, we noted a sudden increase in the intensity of SGR 1900+14 between consecutive *RXTE* orbits. We determined that this flux increase was associated with another high-fluence burst from SGR 1900+14 recorded by instruments aboard *Ulysses* and *Konus* while the source was Earth-occulted for *RXTE*. A detailed analysis of this event is presented elsewhere (Lenters et al. 2003).

Two observations of SGR 1900+14 were performed with the *BeppoSAX* Narrow Field Instruments (NFI) during the 2001 April activation of the source. The first commenced  $\sim 8$  hr after the intermediate flare, and the second observation took place  $\sim 12$  days later. The source exposure times for the two Medium Energy Concentrator Spectrometer (MECS) units were 34.8 and 57.3 ks, respectively. A more detailed account of the NFI observations are presented in Feroci et al. (2003).

## 3. PULSE TIMING ANALYSIS

The PCA data from each observation were first filtered to remove the 32 detected bursts by eliminating all data prior to and following each burst by 1 s. The data were then energy selected (2–5 keV) to maximize the signal-to-noise ratio and allow for a comparison to the *BeppoSAX* NFI data. The data were binned to 0.125 s time resolution and transformed to the solar system barycenter using the

FTOOL *faxbary*. Next, we generated Lomb-Scargle power spectra (Lomb 1976) to determine coarse frequencies for each set of observations.

The *BeppoSAX* MECS data were filtered for bursts by first binning the source region event times into a histogram having 0.5 s time resolution and calculating the normalized Poisson probabilities for each bin. Bins having probabilities less than  $1 \times 10^{-3}$  ( $\sim 7$  counts) were identified as bursts, and events recorded during those times ( $\pm 1$  s) were removed from the subsequent analysis. As with the PCA data, we energy-selected our event list to only include photons with energies 2–5 keV. The event times were transformed to the solar system barycenter using the SAXDAS tool *baryconv*.

All data following the flare were folded on a single frequency determined by the highest peak in the Lomb-Scargle power spectrum, and a phase was calculated for each set relative to a template profile (generated from a subset of PCA observations when the source was brightest). We found significant curvature in the phase residuals, indicative of spin-down. The phases were fitted to a second-order polynomial, and a new template was generated from the full data set. This procedure was iterated, and the final second-order polynomial fit yielded a  $\chi^2 = 20.8$  for 26 degrees of freedom. Using the combined *RXTE* and *BeppoSAX* data sets, we measure a frequency and frequency derivative of 0.193317095(15) Hz and  $-6.56(9) \times 10^{-12}$  Hz s $^{-1}$ , respectively (epoch = 52,023.0 MJD TDB). The combined data set spans the time range MJD 52,017.68–52,034.01 (Fig. 1). The spin-down rate measured here is more rapid than the spin-down observed following the giant flare of 1998 August 27 (Woods et al. 1999b) by a factor of  $\sim 2.9$ .

We next extrapolated our fit to the time of the PCA observation that preceded the April 18 flare by 4 days. Using the full covariance matrix from our fit to the postflare phases, the model uncertainty in the predicted phase at the time of

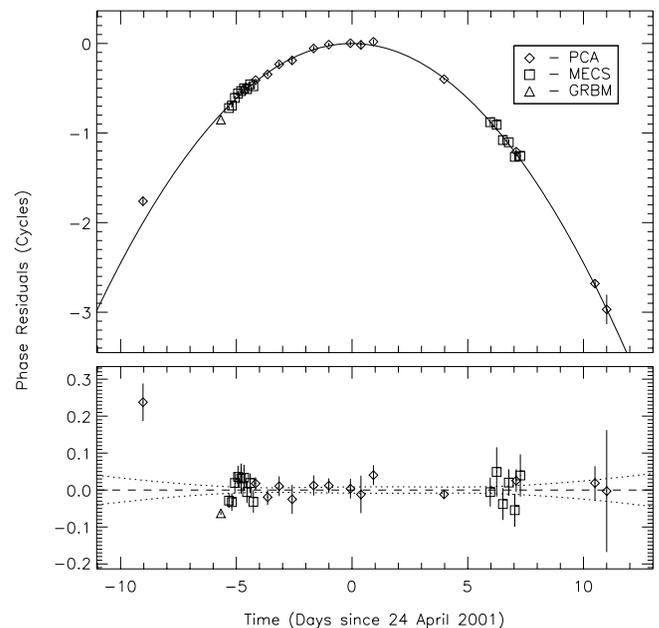


FIG. 1.—*Top*: Pulse phases (PCA, MECS, and GRBM) during the April activation of SGR 1900+14 minus a linear trend. *Bottom*: The same phases minus a second-order polynomial fit to the PCA and MECS phases after April 18. The dotted lines represent the  $\pm 1 \sigma$  errors to this fit. Note the outlier at  $\sim -9$  days preceding the April 18 flare (triangle).

the preflare observation is  $\pm 0.027$  cycles. We find that the relative phase measured for this observation is discrepant from the model ephemeris by  $\sim 0.24$  cycles or  $4.1\sigma$ . The frequency during this brief observation, however, is poorly determined, so we cannot rule out the existence of cycle slips between April 14 and April 18 which would only increase the phase discrepancy (e.g., the phase difference could be  $-1.76, -0.76, 0.24, 1.24$ , cycles, etc.). The disagreement of our phase measurement on April 14 suggests that the source suffered a timing anomaly; however, the absence of a precise frequency measurement on April 14 precludes us from determining the manner in which the spin evolution deviated. Therefore, it is not possible to place a meaningful quantitative limit on any hypothetical glitch coincident with or following the April 18 flare.

Palmer (2002) noted that the gamma-ray pulsations (15–150 keV) during the 1998 August 27 flare were  $\sim 150^\circ$  out of phase with the postflare X-ray pulse ephemeris (2–10 keV) measured 1 day after the flare. He noted that this misalignment could be either due to a strong energy dependence of the pulse profile or the consequence of rapid spin-down during the minutes or hours following the flare, as was deduced earlier from the spin history of the source (Woods et al. 1999b). Using Gamma-Ray Burst Monitor (GRBM) data from *BeppoSAX*, we performed a similar analysis for the April 18 flare. The GRBM bin times were converted to the solar system barycenter to within the absolute time accuracy of the GRBM clock ( $\sim 10$  ms or 0.002 cycles). Using the spin ephemeris determined above, we calculated the phase of each GRBM time bin. The model uncertainty in the phase at the time of the flare is 0.001 cycles. The detrended flare data are plotted along with the folded (2–5 keV) PCA X-ray profile (Fig. 2). Unlike the August 27 flare, we find good agreement in the occurrence in phase of the peak in the pulse profile between the X-ray and gamma-ray bands.

We next quantified the alignment of the gamma-ray to X-ray pulsations. We chose not to cross-correlate the profiles as was done for the X-ray data alone because of the modest, yet significant differences in pulse shapes between the X-ray and gamma-ray bands. Instead, we chose to fit the peak of each pulse profile to a quadratic and compare the centroids of the gamma-ray pulsations to the X-ray pulse train. We fitted the peak of the X-ray profile to the quadratic and measured its phase. Before centroid fitting the gamma-ray pulsations, we removed the burst envelope using a low-pass digital filter. We identified eight local maxima in the filtered gamma-ray light curve (labeled above and to the left of each maximum in Fig. 2). We fitted pulses 1–7 to the quadratic function and measured their phases relative to the X-ray profile. To check the validity of our filtering procedure, we fitted the unfiltered pulse maxima and found that only peak 1 changed significantly. Peak 1 is found during the rapid and jagged rise of the flare, where our filter could not reliably subtract the burst envelope from the pulse. We therefore omitted the phase measurement of pulse 1. The local maximum 8 occurs after the primary burst envelope (encompassing pulses 1–7) returns to background. We interpret this as a separate burst event, and not a pulse. The distinction between this event and the other pulses is more apparent when viewing the unfiltered light curve (C. Guidorzi et al., in preparation). We find that the six remaining gamma-ray pulsations arrive systematically earlier in phase between 0.041 and 0.093 cycles. The average phase lag is  $\sim 0.063$  cycles or  $23^\circ$  (denoted by the triangle in

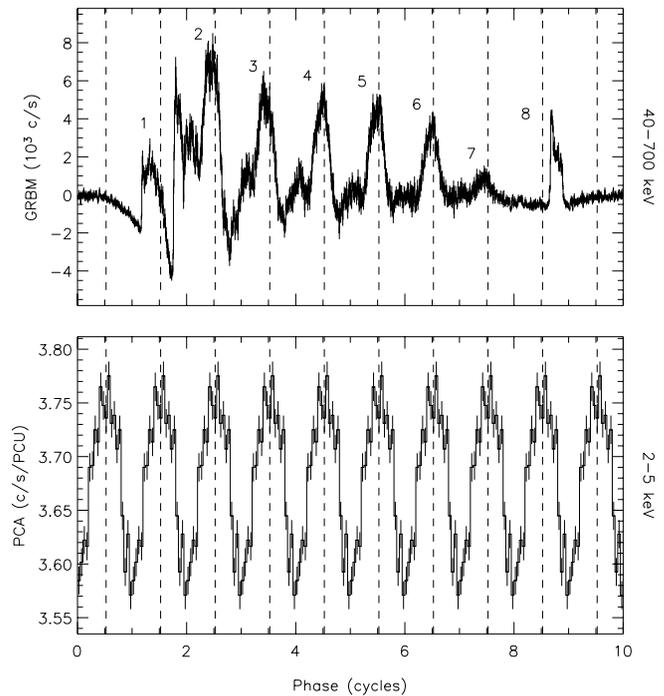


FIG. 2.—*Top*: Detrended GRBM light curve of the April 18 flare from SGR 1900+14 (40–700 keV) transformed from time to rotational phase of the star. *Bottom*: 2–5 keV pulse profile from PCA data acquired during the 2 weeks following this flare folded on the same ephemeris and repeated here 10 times. Note the good agreement in the phase of the peak between X-rays and gamma-rays. The vertical dotted lines denote the centroid of the pulse peak in X-rays.

Fig. 1). We conclude that there are only minor changes in the pulse profile with both energy (2 to  $\sim 100$  keV) and luminosity ( $10^{35}$ – $10^{42}$  ergs  $s^{-1}$ ). Another consequence of the relatively good agreement between the X-ray ephemeris and the gamma-ray pulsations implies that there was no sudden spin-down following the April 18 flare of the magnitude and type inferred for the August 27 flare.

#### 4. PULSE PROFILE AND FRACTION

The X-ray pulse profile (2–5 keV) is quite simple, showing a single nearly sinusoidal peak. We investigated the evolution of the pulse shape with energy by extracting profiles in different energy bands. To expand the range to lower photon energies, we also included data from *Chandra* Advanced CCD Imaging Spectrometer (ACIS) observations (Kouveliotou et al. 2001) performed during this epoch. We find no significant energy dependence within the X-ray band (0.5–20 keV). Comparison of the X-ray profile with the gamma-ray profile seen during the burst shows that the pulse shapes are similar, but not identical. The primary gamma-ray peak is narrower than the X-ray pulse peak, and a secondary maximum is seen at gamma-ray energies between peaks.

It has been previously shown (Woods et al. 2001) that the dramatic change in pulse profile found within the gamma-ray tail of the August 27 flare manifested itself within the persistent X-ray pulse profile as well. We searched for changes in the X-ray pulse profile by comparing with observations from the PCA in the year 2000. The folded pulse profiles for the year 2000 and the April 2001 activation are shown in Figure 3. Comparing the two pulse shapes using a

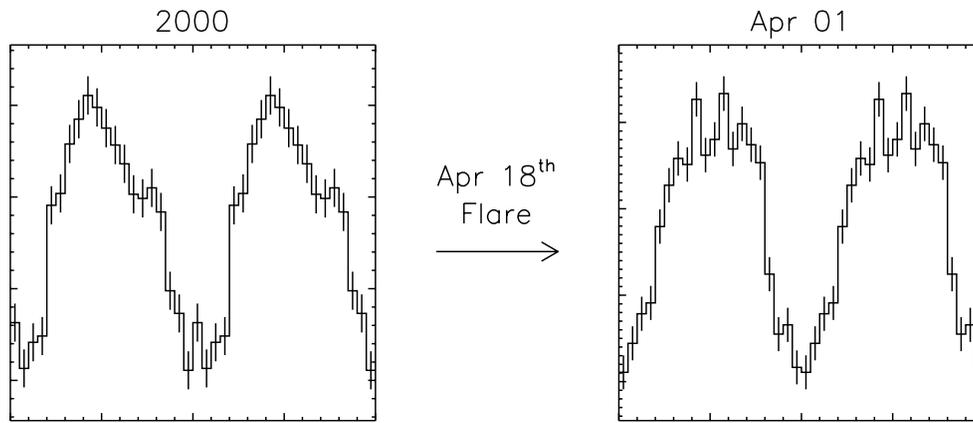


FIG. 3.—Folded pulse profile of SGR 1900+14 in 2–10 keV X-rays as seen with the PCA during the year 2000 (*left*) and during the 2 weeks following the April 18 flare (*right*).

$\chi^2$  test, we find that the profiles are different at a confidence level of 99.7%. Specifically, the rise to pulse maximum is faster in the year 2000 profile, and the decline is faster in the April 2001 profile. We note that the phase discrepancy of April 14 ( $\gtrsim 0.24$  cycles) cannot be accounted for by the difference in shape between these pulse profiles. A more detailed investigation of the energy and temporal dependence of SGR pulse profiles is presented in Göğüş et al. (2002).

We next measured the pulse fraction following the April 18 flare using the data from the two imaging telescopes, the *BeppoSAX* (SAX) MECS and *Chandra* (CXO) ACIS detectors. We measure 2–10 keV rms pulse fractions of 18.1(10)%, 16.3(11)%, 13.6(15)%, and 12.9(12)% for the respective epochs of MJD TDB 52,018.113 (SAX), 52,021.324 (CXO), 52,029.591 (SAX), and 52,030.092 (CXO). Note that the measured CXO pulse fractions differ slightly from those reported in Kouveliotou et al. (2001), who reported the pulse fractions in the 0.5–7.0 keV energy range. The pulse fraction of SGR 1900+14 increases significantly following the April 18 flare, and during the subsequent 11 days slowly declines, approaching its quiescent value.

We have also studied the pulse fraction evolution with energy. The known *temporal* evolution of the pulse fraction restricted our study to contemporaneous observations (i.e., we could only search for changes within individual observations). We find no significant evolution of the pulse fraction with energy (0.5–10 keV) within the individual *BeppoSAX* and *Chandra* observations, although our limits are not very strong ( $\lesssim 25\%$  at 95% confidence).

## 5. DISCUSSION

We have observed a good phase alignment, and similar pulse morphology, between the bright gamma-ray emission ( $>15$  keV) during the April 18 flare, and the much fainter X-ray emission (0.5–10 keV) following the flare. These observations have interesting implications for the source of the dissipation and the mechanism that shapes the pulse profile in these two very different states of SGR 1900+14, which differ by more than a factor of  $10^6$  in luminosity.

The pulse maximum in these two states is apparently produced at the same geometric location on (or above) the surface of the neutron star. In the magnetar model, this

means either that the bursting and persistent emission are emanating from the same region close to the star, or that the angular pattern of the X-ray/gamma-ray emission is being modified in a similar way by resonant (electron) cyclotron scattering high in the magnetosphere. By themselves, the observations of the 2001 April flare and postflare pulsations cannot distinguish between these two models. However, the pulse profile of SGR 1900+14 showed significant changes during the 1998 burst activation. Combining these earlier observations with the measurements of the 2001 April activity, we can begin to constrain the underlying physics.

There were gross changes both in the gamma-ray pulse morphology at high luminosity during the 1998 August 27 flare, and in the much fainter X-ray pulsations observed before and after this flare. On that basis, we argue that the magnetic field of SGR 1900+14 was reconfigured during the August 27 flare (Woods et al. 2001). During the tail of that flare, the luminosity exceeded the Eddington luminosity by as much as a factor of 10,000, which allows a substantial optical depth to accumulate in material blown off the surface of the star (Thompson & Duncan 1995). It has been argued that the outburst was driven by the relaxation of a nonaxisymmetric magnetic field close to the star, which channeled the outflow of material and created anisotropies in the opacity high in the magnetosphere (Feroci et al. 2001; Thompson & Duncan 2001). The change in pulse profile during the flare was proposed to be due to the contraction and simplification in topology of a hot fireball powering the gamma-ray emission during the tail.

A corresponding simplification was observed in the persistent X-ray pulse profile, from a multi-peaked shape preflare to a nearly sinusoidal profile postflare (Woods et al. 2001). In this much lower luminosity state, it was hypothesized that the external magnetic field of the star retains a significant nonpotential component, and that the associated electrical currents power the continuing nonthermal X-ray emission (Thompson, Lyutikov, & Kulkarni 2002). This model implies a significant optical depth to resonant cyclotron scattering, which is independent of frequency in the simplest case of a self-similar and axisymmetric magnetosphere. The optical depth to scattering has a maximum at the magnetic equator, and drops smoothly toward the magnetic pole. Resonant scattering of X-rays (2–10 keV) by electrons would take place far enough from the surface of a magnetar ( $\sim 5\text{--}10R_*$ ) that the poloidal magnetic field would

be almost dipolar; hence the simplified X-ray pulse shape observed in all observations of the persistent emission since the August 27 flare. In the simplest case, this “scattering screen” was activated at the onset of the giant flare when most of the energy was deposited into the magnetosphere. Because the quiescent X-ray spectrum was nonthermal even before the flare, it was suggested that the outer magnetosphere of SGR 1900+14 was already twisted, and made a transition from a nonaxisymmetric to an axisymmetric configuration during the flare (Thompson et al. 2002). It should be emphasized that, in this model, the mechanism for supplying the scattering screen is different in the high and low luminosity states. Moreover, the field geometry close to the star can remain quite complicated even after the flare.

We now consider the observations of the 2001 April activation of SGR 1900+14 within the framework of the model outlined above for the August 27 flare. The presence of a scattering screen in the outer magnetosphere provides a possible explanation for the phase alignment of the pulse maxima between outburst and quiescence. (The optical depth in the screen is smallest along the magnetic pole, which can be assumed to have a fixed orientation with respect to the body of the star.) However, the pulse profiles in the April 18 and August 27 flares are grossly different in the same energy band, in spite of having similar luminosities. During an outburst, the optical depth in the screen can be temporarily augmented by ionized matter blown off the surface of the star and channeled along the magnetic field.<sup>13</sup> As a result, one must postulate that the flux of material reaching a distance of 50–100 km was much more irregular during the August 27 flare than it was during the April 18 flare (whose energy was an order of magnitude lower). Matter and radiation interact in a complicated way in the part of the magnetosphere where electrons and X-rays are resonantly coupled (Thompson et al. 2002), and more detailed work is required to determine if this supposition is reasonable.

An unattractive feature of this model is that the simplification in the pulse profile observed *both* during the August 27 flare and in the persistent emission following the flare is ascribed to two separate physical mechanisms. The electrical current flowing along extended field lines is hypothesized to have changed at the beginning of the flare, giving rise to the change in the persistent emission pulse shape. The pulse morphology evolution during the flare itself is ascribed to the passive cooling of a confined fireball, with the distribution of suspended matter undergoing a gradual simplification in response to the changing pattern of radiative intensity emerging from the contracting fireball. In addition, the persistent X-ray pulse profile observed before the flare had a similar morphology to the complicated four-peaked pulse shape observed during the intermediate stages of the August 27 flare (Woods et al. 2001)—and yet the mechanism for supplying the anisotropic scattering screen is different in the two cases. One requires a correlation between the variations in current flowing across the surface of the star in the preflare state, and the energy release within the flare itself.

An extreme alternative to this model is that the *entire* external magnetic field of SGR 1900+14 was reconfigured

into a simpler geometry over the duration of the August 27 flare (Woods et al. 2001). In this model, the magnetosphere is assumed to remain optically thin postflare (i.e., no scattering screen). The similar morphology and good phase alignment of the burst and postburst pulsations during the 2001 April 18 flare follow naturally if there is a common dissipative region. However, the reconfiguration of the field would have to progress on a timescale  $\sim 10^7$  times longer than the Alfvén crossing time of the magnetosphere ( $\sim 30 \mu\text{s}$ ), and  $\sim 10^4$  times longer than the corresponding timescale in the deep interior of the star (Thompson & Duncan 1995). Recently, Lyutikov (2003) argued that reconnection in the magnetosphere driven by a tearing-mode instability would proceed on a longer timescale of the order of  $\sim 10$  ms. This timescale is consistent with the rise time of the more common SGR bursts (Göğüş et al. 2001), but still many orders of magnitude shorter than the timescale of the pulse profile change observed during the August 27 flare ( $\sim 5$  minutes).

A global magnetospheric reconfiguration during the August 27 flare has the advantage of providing the most straightforward explanation of the pulse morphology changes seen in SGR 1900+14, in both 1998 and 2001. However, there is still the challenge of explaining how the field would continue to reconfigure itself over a duration of  $\sim 400$  s in a very smooth manner, without inducing secondary instabilities and reconnection events that would manifest themselves as sudden changes in the X-ray flux. A compromise between these models would involve a gradual simplification of the most extended magnetic field lines (those that extend out to the electron cyclotron resonance for soft gamma-rays up to  $\sim 100$  keV).

We have shown that the torque in the aftermath of the 2001 April 18 flare was a factor of  $\sim 3$  larger than the torque measured immediately following the 1998 August 27 flare. In contrast, the burst activity following the August 27 flare was more intense and persisted longer than the activity following April 18. The torque measured following this intermediate flare is large compared to the post-August 27 torque, but is not the largest measured for SGR 1900+14. Comparison of the burst activity and spin-down in April 2001 with previous epochs in SGR 1900+14 strengthens our earlier conclusion (Woods et al. 1999b, 2002) that there exists no *direct* correlation between burst activity and torque in this system.

Our comparison of the gamma-ray pulse profile with the X-ray ephemeris has shown that there is no evidence for transient postflare spin-down of the magnitude and type inferred for the August 27 flare. This observation also lends credence to the interpretation of the phase misalignment in the August 27 flare as being due to a sudden spin-down event (Palmer 2002; Woods et al. 1999b) rather than a strong energy dependence in the pulse profile. Although we can exclude a sudden spin-down like that inferred for the August 27 flare, the fortuitous observation preceding the April 18 flare indicates that there was some timing anomaly near the epoch of the flare. Unfortunately, the *exact* manner in which the spin frequency of the star evolved leading up to and through both flares is not certain because of uncertainty in the preflare spin ephemerides. The value of precise preflare spin ephemerides is best illustrated in the recent SGR-like outburst from the anomalous X-ray pulsar 1E 2259+586 (Kaspi et al. 2003). In this case, the continuous monitoring of 1E 2259+586 leading up to this outburst allowed

<sup>13</sup> Only one part in  $10^{10}$  of the energy of the August 27 flare need be expended to lift a scattering cloud that is optically thick at 10 keV at the electron cyclotron resonance. Similarly, one part in a million is enough to create a large optical depth to Thomson scattering at a similar radius.

Kaspi et al. (2003) to detect a sudden spin-up or glitch that coincided with the burst activation. Since the onset of burst activity in SGRs is unpredictable, continuous monitoring of their spin ephemerides is required to quantify timing events such as the glitch detected in 1E 2259+586 coincident with bursts, and hence constrain the underlying physical mechanism responsible for the bursts.

We thank the *RXTE* SDC and the *SAX* SDC for pre-processing the *RXTE* PCA and *BeppoSAX* data, respectively. This work was funded through a NASA ADP grant (NAG5-11608) for P. M. W. and a Long Term Space Astrophysics program (NAG5-9350) for both P. M. W. and C. K. In addition, M. H. F. and E. G. acknowledge support from the cooperative agreement NCC 8-200.

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