An exceptionally bright flare from SGR 1806–20 and the origins of short-duration γ-ray bursts

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Soft-γ-ray repeaters (SGRs) are galactic X-ray stars that emit numerous short-duration (about 0.1 s) bursts of hard X-rays during sporadic active periods. They are thought to be magnetars: strongly magnetized neutron stars with emissions powered by the dissipation of magnetic energy. Here we report the detection of a long (380 s) giant flare from SGR 1806–20, which was much more luminous than any previous transient event observed in our Galaxy. (In the first 0.2 s, the flare released as much energy as the Sun radiates in a quarter of a million years.) Its power can be explained by a catastrophic instability involving global crust failure and magnetic reconnection on a magnetar, with possible large-scale untwisting of magnetic field lines outside the star. From a great distance this event would appear to be a short-duration, hard-spectrum cosmic γ-ray burst. At least a significant fraction of the mysterious short-duration γ-ray bursts may therefore come from extragalactic magnetars.

In the magnetar model, SGRs are isolated neutron stars with teragauss exterior magnetic fields[1–4] and even stronger fields within[5,6], making them the most strongly-magnetized objects in the Universe. Four SGRs are known. Three of them have now emitted giant flares[7,8]. These exceptionally energetic outbursts begin with a brief ($\sim$0.2 s) spike of γ-rays with energies up to several MeV, containing most of the flare energy. The spikes are followed by tails lasting minutes, during which hard-X-ray emissions gradually fade while oscillating at the rotation period of the neutron star.

The first-known giant flare, observed on 5 March 1979, came from SGR 0525–66 in the Large Magellanic Cloud. Its fluence implied an energy $\gtrsim 6 \times 10^{44}$ erg (ref. 9). The second-known giant flare came from an SGR in our Galaxy, SGR 1900+14, on 27 August 1998. Its energy, in hard X-rays and γ–rays, was $\sim 2 \times 10^{44}$ erg (refs 8, 10). Here we describe a third giant flare, which came from the galactic SGR 1806–20 on 27 December 2004. Particle and γ-ray detectors onboard the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), and particle detectors aboard the Wind spacecraft, indicate that this event was $\sim$100 times more energetic than the 27 August flare. Its initial γ-ray spike had a quasi-blackbody spectrum, characteristic of a relativistic pair/photon outflow with an energetically small contamination of baryons. This is consistent with the catastrophic release of (nearly) pure magnetic energy from a magnetar[3]. The tremendous luminosity of the initial spike means that similar events could be detected from distant galaxies. This could account for some, and perhaps all, of the mysterious short-duration, hard-spectrum cosmic γ-ray bursts (GRBs).

The giant flare from SGR 1806–20

On 27 December 2004, the International Gamma-Ray Astrophysics Laboratory[11] (INTEGRAL) reported the detection of a spectacular flare. Four other missions in the third interplanetary network of GRB detectors (the High Energy Neutron Detector and Gamma Sensor Head aboard Mars Odyssey[12], the solar-pointing RHESSI[13], particle and γ-ray detectors aboard the Wind spacecraft[14], and NASA's recently launched GRB observatory Swift[15]) also reported this event. The light curve is shown in Fig. 1. Triangulation constrains the flare position to a portion of an annulus consistent with SGR 1806–20's position (annulus centre J2000, right ascension 15 h 56 m 37 s, declination $-20°\,13'\,50''$, annulus radius 30.887 $\pm$ 0.030°). No other known or candidate SGR lies within this area of the sky. SGR 1806–20 was 5.25° from the Sun at the time of these observations.

A $\sim$1-s-long precursor was observed 142 s before the flare, with a roughly flat-topped profile (Fig. 1 inset). Its spectrum can be fitted with an optically thin thermal bremsstrahlung function with $kT \approx 15$ keV. The precursor's >3-keV fluence was 1.8×10^{-4} erg cm^{-2}, implying an energy of $4.8 \times 10^{42} d_{15}^2$ erg, where $d_{15} = (d/15\,\text{kpc})$, and d is the distance to SGR 1806–20. Note that $0.8 < d_{15} < 1$ is likely for SGR 1806–20, owing to the apparent association of the SGR with a compact ($\sim$10 arcsec) stellar cluster[16,17]. The large energy and unusual light curve of the precursor distinguish it from most common SGR bursts. This and its proximity in time to the giant flare suggest that it is causally related.

The initial spike of the giant flare lasted for $\sim$0.2 s. Its rise and fall times were $\tau_{\text{rise}} \leq 1$ ms and $\tau_{\text{decay}} \approx 65$ ms, similar to those of the other giant flares[8,18]. The spike's intensity drove all X- and γ-ray detectors into saturation, but particle detectors aboard RHESSI and Wind made reliable measurements. (The Supplementary Information describes our extensive Monte Carlo simulations of these particle detectors and has a full discussion of systematic uncertainties.) The RHESSI particle detector data imply a spike fluence in photons >30 keV of (1.36 ± 0.35) erg cm^{-2}, making this the most intense cosmic or solar transient ever observed (in terms of photon energy flux at Earth). The time-resolved energy spectrum, as measured by the Wind particle detectors, is consistent with a cooling blackbody (Fig. 2) with average temperature $T_{\mathrm{spike}} = (175 \pm 25)$ keV. The spike energy is thus $E_{\mathrm{spike}} = (3.7 \pm 0.9) \times 10^{46} d_{15}^2$ erg, assuming isotropic emission. The peak flux in the first 0.125 s was $L_{\mathrm{spike}} = 2 \times 10^{47} d_{15}^2$ erg s^{-1}. Evidently, this event briefly outshone all the stars in the Galaxy put together by a factor of ~10^3.

The spike was followed by a hard-X-ray tail modulated with a period of 7.56 s, detected by the RHESSI γ-ray detectors, which were by this time unsaturated, for 380 s. This period agrees with the neutron star rotation period as inferred from cyclic modulations of its quiescent soft-X-ray counterpart[2]. The fluence in 3–100-keV photons during the tail phase is 4.6×10^{-3} erg cm^{-2} or $E_{\mathrm{tail}} \approx 1.2 \times 10^{44} d_{15}^2$ erg.

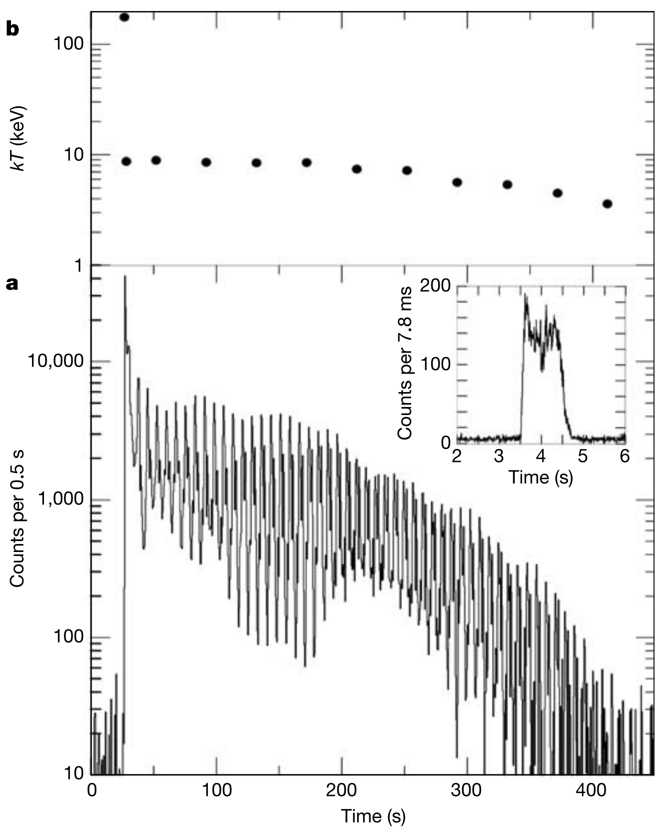

Figure 1 Profiles of the 27 December 2004 giant flare. **a**, 20–100-keV time history plotted with 0.5-s resolution, from the RHESSI γ-ray detectors. Zero seconds corresponds to 77,400 s Universal Time (UT). In this plot, the flare began with the spike at 26.64 s and saturated the detectors within 1 ms. The detectors emerged from saturation on the falling edge 200 ms later and remained unsaturated after that. Photons with energies ≳ 20 keV are unattenuated; thus the amplitude variations in the oscillatory phase are real, and are not caused by any known instrumental effect (Supplementary Information). Inset, time history of the precursor with 8-ms resolution. Zero corresponds to 77,280 s UT. **b**, Spectral temperature versus time. The temperature of the spike was determined by the RHESSI and Wind particle detectors; the temperatures of the oscillatory phase were measured by the RHESSI γ-ray detectors. Although RHESSI measured time- and energy-tagged photons >3 keV continuously, unattenuated spectra were measured for short 'snapshot' intervals only twice in each 4.06-s spacecraft spin period during the oscillatory phase (Supplementary Information). Preliminary spectral analysis (3–100 keV), using the RHESSI on-axis response matrices, are generally consistent with a single-temperature blackbody or optically thin thermal bremsstrahlung model; the blackbody temperatures have been plotted. The formal uncertainties in the oscillatory phase are smaller than the data points and are not shown.

Physical interpretation

This event can be understood as a result of a catastrophic instability in a magnetar. Strong shearing of the neutron star's magnetic field, combined with growing thermal pressure, appears to have forced an opening of the field outward, launching a hot fireball. The release of energy above a rate of ~10^{42} erg s^{-1} (less than one part in 10^4 of the peak flare luminosity) into the magnetosphere leads to the formation of a hot, thermal pair plasma ($kT \approx 0.1$–1 MeV)[19]. The fast initial rise $\tau_{\mathrm{rise}} \lesssim 1$ ms is consistent with a magnetospheric instability with characteristic time $\tau_{\mathrm{mag}} \approx (R/0.1V_{\mathrm{A}}) \approx 0.3$ ms, where $R \approx 10$ km and $V_{\mathrm{A}} \approx c$ is the Alfvén velocity in the magnetosphere, and c is the speed of light[3]. This process must have occurred repeatedly, given that the hard initial spike persisted for a duration ~$10^3 \tau_{\mathrm{mag}}$. Indeed, there is evidence for spike variability in this and other giant flares[8,20,21]. The resulting outflow emitted a quasi-blackbody spectrum as it became optically thin, with spectral temperature comparable to the temperature at its base, because declining temperature in the outflow is compensated by the relativistic blueshift[22]. For luminosity $L_{\mathrm{spike}} = 10^{47} L_{47}$ erg s^{-1}, where $L_{47} = L/10^{47}$ erg s^{-1} and L is the luminosity emerging from a zone with radius $R \approx 10$ km, the expected spectral temperature is $T_{\mathrm{spike}} = (L_{\mathrm{spike}}/4\pi acR^2)^{0.25} = 200 L_{47}^{0.25}$ keV, neglecting complications of magnetospheric stresses and intermittency. Almost all the pairs annihilated, and the outflow was only weakly polluted by baryons, as is clear from the extended, weak radio afterglow that followed the flare[23,53]. Note that we do not expect strong beaming of such powerful emissions from such a slowly rotating star.

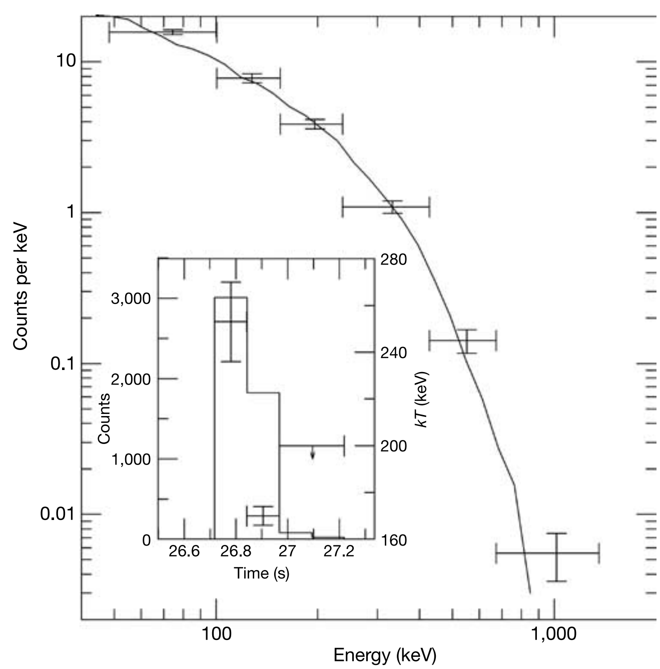

Figure 2 Spectrum and time history of the initial spike, from the RHESSI and Wind particle detectors. The crosses show the spectrum measured by the Wind 3D O detector[52] with coarse time resolution that averages over the peak. The error bars are 1σ, plus 10% systematic errors. The line is the best-fitting blackbody convolved with the detector response function; its temperature is 175 ± 25 keV (Supplementary Information). Inset, the time history of the peak (histogram, left-hand scale) and of the blackbody temperature (error bars, right-hand scale) with 0.125-s resolution, from the RHESSI particle detector (ref. 35 and Supplementary Information). The error bars are 1σ, plus 25% systematic errors.

When the outflow ceased, a trapped fireball was evidently left behind: an optically thick photon-pair plasma confined by closed field lines near the star[3,17]. The luminosity and lifetime of the tail (see the fitted curve in Fig. 3) are consistent with a fireball cooling rate that is limited by the transparency of the surface layers, where the temperature is $\sim$10 keV and the plasma is dominated by ions and electrons[3,19,24]. The condition that the magnetic field must be strong enough to confine energy $E_{\rm tail}$ within a distance $\Delta R \approx 10$ km of the star yields a rough bound on the dipole field, $B_{\rm dipole} > 2\times10^{14}(\Delta R/10\,{\rm km})^{-3/2}[(1+\Delta R/R)/2]^3$ G, similar to bounds implied by the previous giant flares[3,8].

A clue to the nature of the instability comes from the spike's $\sim$0.2-s duration, which is similar to the durations of other giant flare spikes[7,8,18] and of most other SGR bursts[25]. In the magnetar model, SGR activity results from the unwinding of a strong, toroidal magnetic field inside the star, and the transfer of magnetic helicity across the surface[19,26]. Such a twist propagates along the poloidal magnetic field $B_{\rm p} = 10^{15}B_{\rm p_{15}}$ G with a speed $V_{\rm A} \approx B_{\rm p}/(4\pi\rho)^{-0.5}$ that is weakly dependent on the twist amplitude. The time to cross the neutron star interior (density $\rho 10^{15}\rho_{15}\,{\rm g\,cm^{-3}}$) is $\Delta t \approx 2R/V_{\rm A} \approx 0.2B_{\rm p_{15}}^{-1}$ s.

Thus the 27 December event could have been a crustal instability that drove helicity from the star[19,26]. The unwinding of a toroidal magnetic field embedded in the crust is strongly impeded by the stable stratification and near-incompressibility of the crust[19]. Because of the energetic cost of forming isolated dislocation surfaces that cross the magnetic flux surfaces, the crust must undergo smooth and vertically differential torsional motion when it fails, which requires a fundamental breakdown of its solid structure. The maximum field energy which can be released is estimated by balancing elastic and magnetic stresses in the crust: $E_{\rm max} \approx 1\times10^{46}(\theta_{\rm max}/10^{-2})^2B_{P_{15}}^{-2}$ erg, where $\theta_{\rm max}$ is the yield strain. Supplying the energy of the 27 December flare thus requires a relatively large yield strain, as well as a large twist of the crust with angular displacement approaching $\sim 0.5B_{P_{15}}^{-1}$ radian.

Since March 2004, SGR 1806–20 has been very burst-active[27], while its quiescent X-ray brightness has increased by a factor of 2 to 3, and its spectrum has hardened dramatically[28]. Evidently, crust failure has enhanced the twist in the external magnetic field, with growing magnetospheric currents[26]. The free energy of such an exterior magnetic twist can reach a modest fraction ($\sim 10^{-1}$) of the untwisted exterior dipole field energy, $E_{\rm twist} \approx 10^{-2}B_{\rm dip}^2R^3 \approx 10^{46}B_{\rm p_{15}}^2$ erg, with more energy in the non-potential components of higher multipoles. Some of this energy could be catastrophically released via reconnective simplification of the magnetosphere[26,29]. An extreme possibility, consistent with the flare energy, is a global magnetospheric untwisting. This would predict a dramatic post-flare drop in the stellar spin-down rate, as well as greatly diminished, softened and less strongly pulsed X-ray emissions. However, a pure magnetospheric instability would proceed much faster than $\sim$0.2 s. Note also that the detection of accelerated spin-down[30] several months after previous active periods of SGRs 1806–20 and 1900+14 betrays a net increase in the magnetospheric twist during the X-ray bursts, and in the 27 August 1998 giant flare. Observations of SGR 1806-20's spin-down over the coming year will provide important constraints on the location of the non-potential magnetic field that was dissipated during the flare.

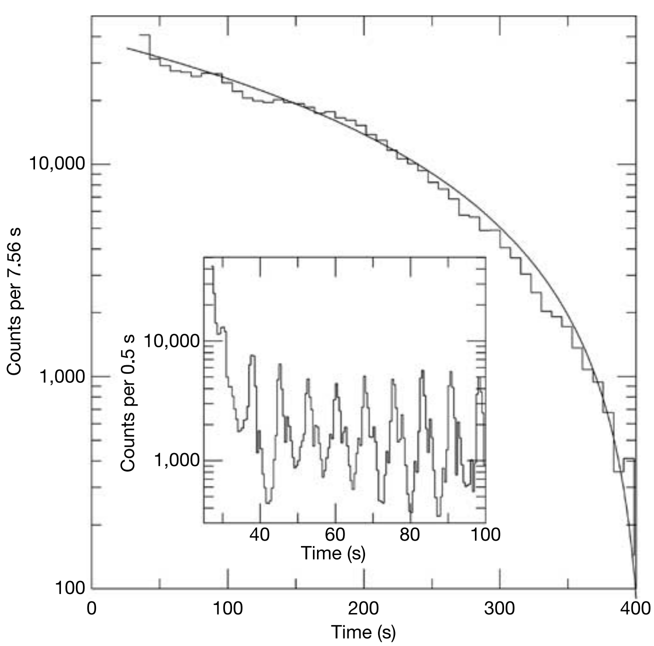

Figure 3 Time-averaged counts in the tail phase of the giant flare, compared with the 'trapped fireball' model. Zero corresponds to 77,280 s UT. The step plot shows the RHESSI γ-ray detector data averaged over the 7.56-s rotation period of the neutron star. It is fitted by a simple model (smooth curve) that describes the emission from the cool surface of a magnetically confined plasma as it contracts and evaporates in a finite time: $L_X(t) = L_0[1-(t/t_{\rm evap})]^{a/(1-a)}$ (ref. 49). We find $t_{\rm evap} = 382 \pm 3$ s, and the index $a = 0.606 \pm 0.003$ is near the value $a = 2/3$ expected for a homogeneous, spherical trapped fireball[19,49]. Inset, RHESSI γ-ray detector light curve for the first ten cycles of the flare tail. The energy range is 20–100 keV. The first peak of the trapped fireball emission is evident on the falling edge of the hard spike at $t = 30$ s. A changing two-peaked pulse–interpulse structure is present.

Short-duration GRBs and magnetars

If observed from a great distance, only the brief, initial hard spike of the 27 December flare would be evident. Thus distant extragalactic magnetar flares (MFs) would resemble the mysterious short-duration GRBs[31,32]. These hard-spectrum events have long been recognized as a separate class of GRBs[33–37] but have never been identified with any counterparts[38].

The Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory was a landmark experiment of the 1990s that produced a catalogue[39] of more than 2,000 GRBs. How many of these bursts were MFs? Taking the 27 December event as our prototype and adopting the 50% trigger-efficiency flux[40] of 0.5 photons $\rm cm^{-2}\,s^{-1}$ for the 256-ms timescale yields a BATSE sampling depth of $D_{\rm BATSE} = 30d_{15}$ Mpc. If such events generally happen once every $\tau = 30$ yr in galaxies like the Milky Way (such as has now occurred in the Milky Way itself) then the BATSE detection rate of MFs is $\dot N_{\rm BATSE} = 19d_{15}^3(\tau/30\,{\rm yr})^{-1}\,{\rm yr}^{-1}$. Here we have estimated the effective number of galaxies like the Milky Way within $D_{\rm BATSE}$ of Earth by multiplying the local blue luminosity density[41] $j_{\rm b} = 5.8\times10^{41}h_{70}\,{\rm erg\,Mpc^{-3}}$ by the sampling volume $(4\pi/3)D_{\rm BATSE}^3$, and dividing by the blue luminosity of the Milky Way as estimated in the Supplementary Information. We use blue emissions as a benchmark because SGRs are Population I objects, the post-supernova remnants of massive, short-lived, blue stars. Thus, over 9.5 yr of operation with half-sky coverage, BATSE probably detected $180d_{15}^3(\tau/30\,{\rm yr})^{-1}$ MFs, representing $0.4d_{15}^3(\tau/30\,{\rm yr})^{-1}$ of all BATSE short-duration bursts. There is evidence of 100-s-long soft tails in the co-added time histories of many short-duration BATSE GRBs[42,43]; but not in any single event. For the brightest observed BATSE short-duration, hard-spectrum GRB (trigger number 6293), we find that the ratio of the tail-to-peak fluence is <0.5%, compared to our measured ratio for the 27 December event of 0.34%. Thus BATSE was not sensitive enough to have detected MF tails in single bursts.

The GRB observatory Swift[44] was designed, in part, to unravel the short-duration GRB mystery. How many MFs will Swift spot? The Swift Burst Alert Telescope has a photon flux sensitivity (50–300 keV) that is $\sim$5 times better than BATSE[45], corresponding to a trigger threshold of ~ 0.10 photons $cm^{-2} s^{-1}$. Thus for our prototype MF, $D_{Swift} = 70 d_{15}$ Mpc. The expected rate of MF detections, given Swift's sky coverage of 1.4 steradians, is then $\dot{N}_{Swift} = 53 d_{15}^3 (\tau/30\,yr)^{-1}\,yr^{-1}$, or about one MF per week. Of course, the galactic rate of MFs, $\Gamma = \tau^{-1}$, is very uncertain. Given that there has occurred one MF with peak luminosity in the range 10^{47} erg s^{-1} in our Galaxy during $t_0 = 30$ yr of observations, the bayesian probability distribution for the underlying galactic rate Γ of such bright MFs is $(dP/d\Gamma) = t_0 \exp(-\Gamma t_0)$, with expected value $\langle \Gamma \rangle = t_0^{-1}$. This implies that the probability that Swift will detect one or more MF per month is 80% for $d_{15} = 1$. The probabilities of detecting one or more event per {3, 6, 12, 24} months are {93, 96, 98, 99}%, respectively. Even if $d = 10$ kpc, the probabilities would be {78, 88, 94, 97}%. The prospects for observing MFs during Swift's 24-month prime mission are excellent.

Of course, all of the above estimates idealize MFs as 'standard candles' defined by the 27 December prototype. The actual luminosity function of MFs is unknown. It is possible that some MFs are significantly brighter than the 27 December event. For example, a magnetic instability on a rare magnetar with $B_{dipole} \approx 10^{16}$ G could release 10^{48} erg, and be detected by Swift out to ~ 1 Gpc. Nevertheless, we suspect that MFs constitute only a substantial subset of BATSE Class II GRBs, not all of them. The 175-keV blackbody spectrum would probably result in a significantly higher hardness ratio than that of the average short-duration burst[37]. The fact that Class II GRBs have $\langle V/V_{max} \rangle < 0.5$ does not seem consistent with all these events being local. Moreover, no galaxies at $D < 100$ Mpc were found for the Interplanetary Network positions of four short-duration GRBs[38].

Studying extragalactic magnetars

Swift can identify MFs via their positional correlations with galaxies, allowing the source distances from Earth to be inferred. A spiral galaxy of size ~ 30 kpc at distance D_{Swift} spans ~ 3.4 arcmin, comparable to the Swift BAT location accuracy of $\Delta\theta_{BAT} \approx 1$–4 arcmin. This localization can be greatly improved, to an accuracy of $\lesssim 10$ arcsec, if the oscillating tail of the flare is detected by Swift's X-ray Telescope (XRT) when it slews to observe the burst site within about 1 min. Our measurements of soft X-ray emissions in the giant flare tail (Fig. 4) make it possible to assess the prospects of XRT acquisition for the first time. Extrapolating our X-ray spectral fits down to 0.3 keV, we find that the 27 December pulsating tail produced a 0.3–10-keV incident fluence of $(0.18–1.6) \times 10^{-3}$ erg cm^{-2}. The threshold fluence for XRT detection[44] is 2×10^{-10} erg cm^{-2}, so that the 27 December flare tail could be marginally detected to a distance of $D_{tail} = (10–40) d_{15}$ Mpc. Thus only the nearest fraction $(D_{tail}/D_{Swift})^3 \approx 0.2$ of all MFs spotted by Swift will have detectable tails. We have verified that the soft X-rays are strongly pulsed (Fig. 5). For events within about 8 Mpc, simulations indicate that the magnetar's rotation period can be reliably determined. For more distant sources, the spectrum and the rapid flux decay will distinguish magnetar tail emissions from cosmic GRB afterglows.

The prospects of detecting extragalactic MFs with the Swift Ultra-Violet and Optical Telescope (UVOT) or ground-based optical telescopes are not wholly bleak. The trapped fireball is too tiny to

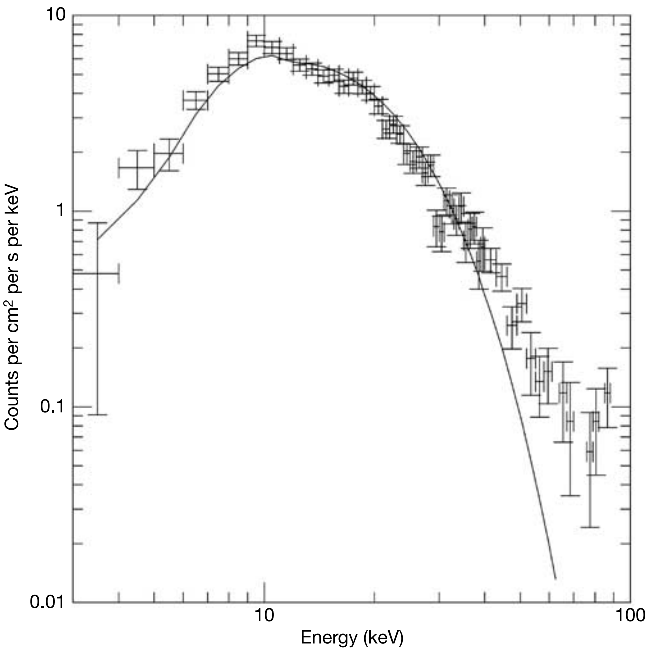

Figure 4 3–100-keV phase-averaged energy spectrum of the pulsed tail, from the RHESSI γ-ray detectors. The crosses show the measured spectrum with 1σ statistical error bars; the solid line represents a fit to a blackbody function $E^2(\exp(E/kT) - 1)^{-1}$, where E is the energy and $kT = 5.1 \pm 1.0$ keV. This spectrum is averaged over various phases between 272 and 400 s in Fig. 1, corresponding to intervals where the photons could reach the detectors passing through a minimum amount of intervening materials (Supplementary Information). An optically thin thermal bremsstrahlung function with $kT \approx 22$ keV also provides a reasonable fit. The spectra show evidence of deviations from both models, probably due to the use of an approximate response matrix[24].

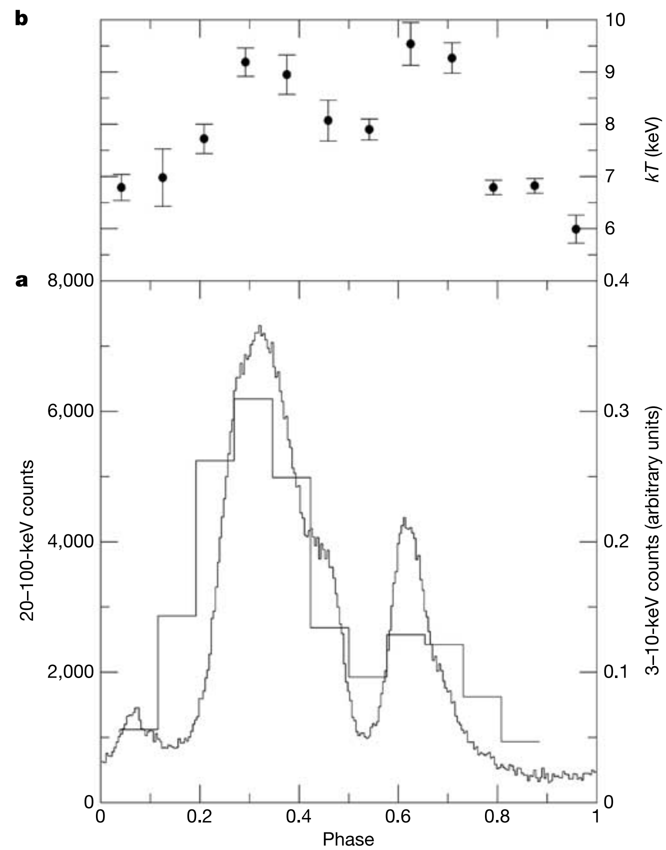

Figure 5 Detailed profiles of the oscillations, from the RHESSI γ-ray detectors. **a**, RHESSI light curve for the oscillatory portion of the giant flare, folded modulo the 7.56-s neutron star rotation period (20–100 keV, fine resolution curve, and 3–10 keV, coarse resolution curve). **b**, The blackbody spectral temperature kT. The radius of the emitting surface varies between ~ 18 and 40 km at 15 kpc. The error bars represent 1σ statistical uncertainties.

emit detectably in this waveband. However, we can scale directly from the observed radio afterglow[23], which had spectral index $\alpha = -0.7$ and time decay $t^{-1.5}$ in the optically thin regime. Extrapolating to $10^{14.5}$ Hz gives $L_{\rm opt} \approx 4\times10^{37} t_3^{-1.5}\,{\rm erg\,s^{-1}}$ at a time $10^3 t_3$ s post-flare. Such a source would have a brightness of 22nd magnitude at 1 Mpc for $t_3 \approx 1$.

Prospects are even better for the detection of X-ray afterglows[32]. SGR 1900+14 emitted strong nonthermal X-rays in the aftermath of the 27 August 1998 event[46], thought to be due to a heated magnetar crust[47]. If afterglow energy scales linearly with flare energy, as found in less energetic events[48], then a MF like the 27 December event would glow brighter by a factor of $f \approx 100$, suggesting $L_{\rm X} \approx 2\times10^{39}(f/100)(t/1\,{\rm h})^{-0.7}\,{\rm erg\,s^{-1}}$. This could be detected by the Chandra X-ray Telescope within $D_{\rm Chandra} \approx 30(f/100)^{0.5}(\Delta t_{\rm obs}/10^4\,{\rm s})^{0.5}(t/10\,{\rm h})^{-0.35}$ Mpc in an observation of duration $\Delta t_{\rm obs} \ll t$.

New horizons and speculations

The detection of extragalactic magnetars, if achieved by Swift, will open up a new field of astronomy. A catalogue of giant flare spikes, once assembled, will contain a wealth of information about magnetic instabilities in neutron stars. Information about the luminosity function of MFs, their range of durations, and possible spectral diversity (suggested by measurements of the 27 August event[8,49]; note that less compact flows than that of the 27 December event could show nonthermal spectra) will constrain magnetar physics and population diversity. Unusually bright flares may be detected from very young magnetars with shorter rotation periods and stronger fields than are observed in galactic SGRs. (The birthrate of SGRs is evidently low enough that no stars younger than $\sim 10^3 - 10^4$ yr are observed in our galaxy.) MFs from very young magnetars may be disproportionately common in extragalactic studies because of their greater brightness and higher flare rate. More frequent cataclysms are expected in younger magnetars because magnetic diffusion slows down as stars age and cool[6].

We emphasize that most SGR activity is ultimately powered by the strong toroidal interior field of a magnetar, B_ϕ, which is the remnant of the rapid differential rotation which the neutron star experienced at birth[1,5]. The energy of this field, $E_\phi \approx (1/6)B_\phi^2 R^3 \approx 2\times10^{49} B_{\phi_{16}}^2$ erg, where $B_{\phi_{16}} = (B_\phi/10^{16}\,{\rm G})$, can power many flares of $\sim10^{46}$ erg over a star's lifetime. Magnetic helicity is gradually transported outward via ambipolar diffusion and Hall drift[6], winding up the field within the crust and outside the star, and leading to catastrophic instabilitities[19,26]. (Note, however, that the strong, internal toroidal field stabilizes a magnetar against catastrophic decay of the exterior dipole field; compare with refs 5 and 32.) Measurements of SGR 1806–20's spin-down over the coming year will reveal whether the exterior magnetic helicity increased or decreased during the 27 December event. SGR 1806–20 may come to resemble an anomalous X-ray pulsar, with a diminished spin-down rate and a softer X-ray spectrum. SGR 0526–66 developed these characteristics, indicating weakened magnetospheric currents, after the giant flare of 5 March 1979 (ref. 50). Sporadic, short bursts were observed from SGR 0525–66 until 1983 (ref. 51), but the source has not been observed to burst since then, suggesting that sub-crust stresses were (at least temporarily) relieved in the giant flare. We speculate that SGR 0526–66 and now SGR 1806–20 may have entered the 'low' phase in a magnetar activity cycle that involves changes in the rate of expulsion of magnetic helicity out of the star. □

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