OBSERVATIONAL PROPERTIES OF THE
SOFT GAMMA REPEATERS

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A FEW SGR FACTS

• SGRs are sources of short (~100 ms), repeating bursts of soft $\gamma$-radiation (<100 keV)

• They often exhibit intense, sporadic bursting periods, but may be dormant for years

• Bursts have super-Eddington luminosities

• 4 are known
  – 3 in our Galaxy (SGR1806-20, 1900+14, 1627-41)
  – 1 in the direction of the LMC (SGR0525-66)
• Rarely (~every 50 y?) they emit hard-spectrum (~MeV energy) giant flares, producing the most intense cosmic gamma-ray fluxes at Earth

• The SGRs are quiescent soft X-ray sources (2-10 keV)

• They have rotation periods in the 5-8 s range

• Many of their properties can be explained by the magnetar model; that is, the SGRs are neutron stars with magnetic fields B~10^{15} G
THE BURSTS
BURST ACTIVITY CYCLES OF TWO SGRS

SOURCE: BURSTS DETECTED BY THE 3RD INTERPLANETARY NETWORK
SHORT, SINGLE PULSE (MOST COMMON)

ULYSSES
SGR1900+14
25-150 keV
980530A
Alfvén excitation frequency

$$\nu \sim \frac{(\mu/\rho)^{1/2}}{\Delta l}$$

Minimum excitation radius

$$R_\nu \sim c/\nu$$

Displacement of magnetic footpoints

Thompson & Duncan 1995
ULYSSES
SGR1900+14
25-150 keV
980530D
SEVERAL SECOND LONG “INTERMEDIATE” BURST (RARE)

ULYSSES
SGR1627-41
JULY 2, 2001
25-150 keV
HARD SPECTRUM GIANT FLARE (EVERY ~50 YEARS?)

SGR1900+14
AUGUST 27 1998
ULYSSES
25-150 keV

5.16 s period
MAGNETAR MODEL OF A GIANT FLARE

- Global crustal fracture
- B field annihilation
- Magnetosphere fills with hot e⁻e⁺ plasma
NUMBER-INTENSITY RELATION FOR SHORT BURSTS
(Gogus et al. 1999)

- BATSE and RXTE number-intensity relations for SGR1900 and SGR1806 follow power laws with indices $\approx 1.7$
SGR BURST DURATIONS FOLLOW A LOGNORMAL DISTRIBUTION (Gogus et al. 2001)
WAITING TIME DISTRIBUTION (TIME BETWEEN BURSTS FROM A GIVEN SGR) IS LOGNORMAL

RXTE
SGR1900
Gogus et al. 1999
DISTRIBUTIONS OF SGR PROPERTIES

• Number-intensity relation: power law

• Burst durations: lognormal

• Waiting times between bursts: lognormal

• Consistent with self-organized criticality (Gogus et al. 2000)
  – system (neutron star crust) evolves to a critical state due to a driving force (magnetic stress)
  – slight perturbation can cause a chain reaction of any size (leading to a burst of arbitrary size)
BURST ENERGY SPECTRA
THE OLD VIEW: SPECTRA OF SHORT SGR BURSTS ARE OTTB

Histogram from the data of Aptekar et al. 2001

1/E \exp(-E/kT)

BATSE
SGR1900+14
kT=39 keV

Kouveliotou et al. 1993

Histogram from the data of Aptekar et al. 2001
THE NEW VIEW FROM HETE: BROADBAND SPECTRA ARE THE SUM OF TWO BLACKBODIES (Olive et al. 2004)

• HETE FREGATE & WXM are the first experiments to measure SGR spectra over a broad range (6-400 keV) which includes both soft X-rays and gamma-rays with excellent energy resolution

• OTTB does not provide an acceptable fit over a wide energy range

• Two blackbody fit is much better, with kT≈4 and 10 keV

• This is probably an approximation to a multi-temperature spectrum expected on theoretical grounds when opacities in strong B fields are taken into account
ABSORPTION LINES IN BURST SPECTRA

- RXTE spectrum of a burst from SGR1806-20
- 3 cyclotron features (~5, 11, and 17 keV)
- If electron cyclotron features, $B \sim 6 \times 10^{11}$ G (significant thermal broadening expected, but not observed)
- If proton cyclotron features, $B \sim 8 \times 10^{14}$ G
SPECTRAL EVOLUTION OF SHORT BURSTS OBSERVED BY INTEGRAL-IBIS (Götz et al. 2004)

• Hardness-intensity *anticorrelation* – the opposite of GRBs
• Explanation not clear
SPECTRA OF SHORT BURSTs AND GIANT FLAREs

GIANT FLARE

SHORT BURST
PERSISTENT X-RAY EMISSION
INTEGRAL-IBIS OBSERVATIONS OF THE REGION AROUND SGR1806-20
(Mereghetti et al. 2004)

4.5º

BEFORE

AFTER
P and P FROM QUIESCENT SOFT X-RAYS (2-10 keV)

SGR1900+14 (P=5.16 s)

SGR1806-20 (P=7.48 s)

SPINDOWN PROVIDES GOOD EVIDENCE FOR MAGNETAR-STRENGTH MAGNETIC FIELDS

Hurley et al. 1999

Kouveliotou et al. 1998

Woods et al. 1999

Woods et al. 2000
DISCOVERY OF HARD X-RAY PERSISTENT EMISSION FROM SGR1806-20 BY INTEGRAL-IBIS
(Mereghetti et al. 2004, Molkov et al. 2004)

- Extends up to ~120 keV
- Emission is variable
- Power law spectrum is distinct from burst spectra
- Similar to what has been observed in AXPs
TWO POSSIBLE EXPLANATIONS
(Thompson and Beloborodov 2004)

• Luminosity exceeds spin-down power by orders of magnitude

1. Surface of neutron star is heated by a downward beam of particles

2. Runaway pair creation in magnetosphere
SGR LOCATIONS
LOCATIONS OF THE FOUR KNOWN MAGNETARS

SGR 1627-41
SGR 1806-20
SGR 1900+14
SGR 0525-66

N49 LMC
SGR1806-20

- Lies along the line of sight towards G10.0-0.3, a possible radio SNR
- Fuchs et al. (1999) showed that the SGR may be associated with a massive star cluster (separation 0.5 pc)
- Eikenberry (2001) may have identified the IR counterpart to the SGR
SGR1900+14

- SGR1900+14 lies near the line of sight towards the radio SNR G42.8+0.6 (Vasisht et al. 1994)

- Distance between the two is ~20 pc. If the SGR was born in the SNR, it must have a very large proper motion, >1000 km/s (Chandra measurements in progress)

- This SGR is also near a massive star cluster (separation 0.8 pc; Vrba et al. 2000)
SGR0525-66

- SGR0525-66 lies in the direction of the optical SNR N49 in the LMC – the only unobscured SGR

- If the two are associated, this is the only SGR with a known distance and age (~50 kpc, ~5 kyr)

- *Chandra* measurements indicate that the quiescent X-ray spectrum resembles that of an AXP, suggesting that the neutron star may be intermediate between a SGR and an AXP

- Recent evidence of a nearby (30 pc) massive star cluster has been presented by Klose et al. (2004)
• SGRs might be expected to be associated with SNRs, if they are young objects
  – Radio SNRs are observable for \(~20\) kyr
  – Spindown age of SGR \(~1.5\) kyr

• However, the possible associations found so far are very uncertain

• Gaensler (2001) has pointed out that associations between radio pulsars and SNRs are based on three criteria:
  – common age
  – common distance
  – either a statistically significant positional coincidence, or if not, “reasonable” implied transverse velocity

• Most SGR/SNR associations do not satisfy at least one of these

• Massive star cluster associations are about equally compelling from a statistical point of view – but clusters tend to be much older objects
### APPROXIMATE DISTANCES AND TYPICAL LUMINOSITIES

<table>
<thead>
<tr>
<th>Source</th>
<th>Distance (kpc)</th>
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<tr>
<td>SGR1900+14</td>
<td>10</td>
</tr>
<tr>
<td>SGR1627-41</td>
<td>11</td>
</tr>
<tr>
<td>SGR1806-20</td>
<td>14</td>
</tr>
<tr>
<td>SGR0525-66</td>
<td>50</td>
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</table>

<table>
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<tr>
<th>Type</th>
<th>Duration (s)</th>
<th>Luminosity (erg)</th>
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<tbody>
<tr>
<td>Short burst</td>
<td>0.1</td>
<td>$10^{40}$</td>
</tr>
<tr>
<td>Intermediate burst</td>
<td>7</td>
<td>$5 \times 10^{41}$</td>
</tr>
<tr>
<td>Giant flare</td>
<td>300</td>
<td>$10^{43}$</td>
</tr>
<tr>
<td>Persistent X-rays</td>
<td></td>
<td>$10^{36}$ erg s$^{-1}$</td>
</tr>
</tbody>
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SUMMARY

• Evidence for the magnetar model continues to build

• Evidence for an SGR/SNR association is debatable

• Evidence for an SGR/massive star cluster association is intriguing
  – lack of a radio or optical SNR may be due to rapid dissipation
  – SGRs could still be young neutron stars

• Similarities between SGRs and AXPs continue to be found

• IPN, RXTE, HETE, INTEGRAL, and Swift will continue to monitor SGR activity for the next several years

• Discovery of extragalactic magnetars would be possible with missions on the drawing board (CASTER, EXIST)
  – would allow a better census of magnetar populations, birthrates, lifetimes
R. Mallozzi, 1998
IRREGULAR SPINDOWN OF SGRs  
(Woods et al. 2002)

- Frequency derivatives for this SGR and SGR1900 are erratic, but unrelated to bursting activity
- Analogous to timing noise in radio pulsars
- Argues against accretion models for SGR bursts
GIANT FLARES TURN NIGHT INTO DAY

Effect of the giant flare of 1998 August 27 from SGR1900+14

Inan et al. 1999

Level of the ionosphere as measured by propagation of VLF signal from Hawaii (21.4 kHz) descends to daytime value, due to ionization by 3-10 keV X-rays at 30-90 km
Toward an Astrology of Magnetars
©1998-1999 by Richard Nolle

Earth - or half of it, any rate - got blasted at 10:22 UT on August 27, 1998. During the following five minutes, our home planet was on the receiving end of a cosmic ray barrage (of gamma-rays, X-rays and radio waves) so intense that it ionized Earth's upper atmosphere to levels normally seen only during the daytime. Researchers at Stanford University who measured the ionization described it as "the first direct evidence of a physical effect on the Earth's environment by a distant star, or by any star other than our own Sun."

The blast came from SGR 1900+14, a newly recognized type of star called a magnetar, in the constellation Aquila (the Eagle). At its source, the phenomenal five-minute cosmic ray surge was the energy equivalent of our Sun's entire output for the next 360 years, according to UC Berkeley physicist Kevin Hurley.

Fortunately for us, SGR 1900+14 is so far away that it took the surge of cosmic radiation over 20,000 years just to reach us. Our distance from the source of the blast was one major protective factor. Another is that Earth's upper atmosphere absorbed the lion's share of the interstellar burst. By the time it reached ground level, the intensity of that flare had been reduced to the point that anyone on the receiving end only got the equivalent of a normal dental X-ray. (Two satellites in Earth orbit, outside the protective blanket of our atmosphere, were overwhelmed by the blast. They went into automatic shutdown to preserve their shielded electronics from destruction by the onslaught of cosmic radiation.)
## ESSENTIAL SGR PROPERTIES

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<tbody>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>$2 \times 10^{35}$</td>
<td>7.47 s</td>
<td>$\sim 10^{-10}$</td>
<td>Yes</td>
<td>8x10^{14}</td>
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<tr>
<td>SGR1900+14</td>
<td>$10^6 x$</td>
<td>Aug 27 1998</td>
<td>5.16 s</td>
<td>$3 \times 10^{34}$</td>
<td>5.16 s</td>
<td>$\sim 10^{-10}$</td>
<td>No</td>
<td>2-8x10^{14}</td>
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<td>SGR0525-66</td>
<td>$10^6 x$</td>
<td>Mar 5 1979</td>
<td>8 s</td>
<td>$10^{36}$</td>
<td>8.04 s</td>
<td>$\sim 7 \times 10^{-11}$</td>
<td>No</td>
<td>7x10^{14}</td>
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<tr>
<td>SGR1627-41</td>
<td>$4 \times 10^5 x$</td>
<td>No</td>
<td>No</td>
<td>$10^{35}$</td>
<td>6.4 s (?)</td>
<td>No</td>
<td>No</td>
<td>?</td>
</tr>
</tbody>
</table>
EMISSION LINE IN THE SPECTRUM OF SGR1900+14  
(Strohmayer & Ibrahim 2000)

• 6.4 keV line is present over OTTB continuum; weaker line at 13 keV
• Chance probability \( \sim 2 \times 10^{-4} \)
• Fe fluorescence from ablated material after giant flare?
• Proton cyclotron?