Transient magnetars
And their implications

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JILA: R. Perna GSFC: J. Cummings Saclay: D. Gotz …and many others

Paris, 13th Jul 2009
Why Magnetars?

Loss of rotational energy is orders of magnitudes too small ($10^{30}$ erg/s) with respect to the observed persistent $L_x$.

No accretion from a (massive) companion.

No Doppler modulation/shift in the spin pulses.

In analogy with isolated rotation-powered NS:

$$B = 3.2 \times 10^{19} \sqrt{P \dot{P}} \text{ G}$$

$10^{14-15}$ Gauss $\rightarrow$ MAGnetic sTARS

Magnetars are rare objects which might allow us to test the physics under extreme conditions (grav. field, B, etc.).

Several indirect evidences (for high B) collected through years!

Paris, 13th Jul 2009
The sample

**Common properties:**
- Spin periods: 2 - 12 s
- Period derivatives: $10^{-10}$-$10^{-13}$ s s$^{-1}$
- Young objects ($b<0.5$): $\sim 10^4$-$10^5$ yr
- Inferred dipole $B \sim 10^{14}$-$10^{15}$ Gauss

- Isolated objects (NS)
- Soft X-ray spectra + a steep PL tail
- Short ($\sim 100$ ms) X/$\gamma$ bursts / Glitches
- Rare Giant Flares ($>10^{47}$ ergs; minutes)
- Associated with SNRs (2) and massive open clusters (3) with $M$ turn-off of 30-40$M_{\odot}$ $\rightarrow$ young ($\sim 10^5$)

**Served in two flavors:**

**Soft Gamma-ray Repeaters**
Bursting $\gamma$-ray sources

**Anomalous X-ray Pulsars**
Persistent X-ray sources
**AXP census: 9 confirmed + 1 candidates**

**SGRs census: 5 confirmed + 1 candidate**

<table>
<thead>
<tr>
<th>Source</th>
<th>P (s)</th>
<th>dP/dt (10^{-11} s/s)</th>
<th>dipolar B (10^{14} Gauss)</th>
<th>Spin-down age (kyr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4U 0142+61</td>
<td>8.7</td>
<td>0.2</td>
<td>1.3</td>
<td>70</td>
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<tr>
<td>1E 2259+586 (CTB 109)</td>
<td>7.0</td>
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<td>1E 1048-5937</td>
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<td>2-3</td>
<td>3.9</td>
<td>4.3</td>
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<tr>
<td>1E 1841-045 (Kes 73)</td>
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<td>4.0</td>
<td>7.1</td>
<td>4.5</td>
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<tr>
<td>XTE J1810-197</td>
<td>5.5</td>
<td>1.8</td>
<td>2.9</td>
<td>5.7</td>
</tr>
<tr>
<td>RXS J1708-4009</td>
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<td>2.0</td>
<td>4.7</td>
<td>9.0</td>
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<td>AX J1845-03 (G296+0.1)</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>CXO J0110-72 (in SMC)</td>
<td>8.0</td>
<td>2.1</td>
<td>3.5</td>
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<tr>
<td>CXO J1647-45 (op. clus.)</td>
<td>10.6</td>
<td>0.09</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>1E1547.0-5408</td>
<td>2.1</td>
<td>2.3</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>SGR 1900+14 (op. clus.)</td>
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<td>6.1-20.0</td>
<td>5.7</td>
<td>1.3</td>
</tr>
<tr>
<td>SGR 1806-20 (op. clus.)</td>
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<td>8.3-47.0</td>
<td>7.8</td>
<td>1.4</td>
</tr>
<tr>
<td>SGR 0526-66 (N49/LMC)</td>
<td>8.0</td>
<td>6.6</td>
<td>7.4</td>
<td>1.9</td>
</tr>
<tr>
<td>SGR 1627-41</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>SGR 0501+4516</td>
<td>5.8</td>
<td>0.7</td>
<td>1.0</td>
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<tr>
<td>SGR 1801-23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(For a review see Mereghetti 2008)
AXPs ≈ SGRs ?

Are the observational differences only introduced by observational selection effects? In this case these sources belong to the same class of objects:
in AXPs the quiescent, pulsating emission was discovered first in the X-ray band.
SGRs were discovered through their bursts in γ-ray

Temporal evolution? However P and Pdot similar

TWELVE POSSIBLE magnetars have been detected in or near our Milky Way galaxy.
1E2259 +586: the first case

~ 80 short bursts \((L_x \sim 10^{36}-10^{38}\) erg/s) detected in June 2002 (RXTE). Enhanced persistent emission (1-yr long). A large glitch was detected too.

Apart from this event, discovered by chance, no or very few real-time info on bursts/outbursts from AXP were obtained in many years.

\(L_{\text{peak}}: 10^{36}-4 \times 10^{38}\) erg/s

(Kaspi et al. 2003, Woods et al. 2004)
1E2259+586: 2002 bursting activity

Pulse shape and pulse fraction variability after the glitch

(Woods et al. 2004)

Sharp and quick change in PF at the decay law transition

Large T/S changes occur during the first outburst phases!
Why transient and outbursts?

In analogy with studies done in the past on transient X-ray pulsars in binary systems the (identification and) study of transient AXPs might give insights on:

• the emission mechanisms (mainly unknown) as a function of flux (continuously changing main parameters) for a constant distance, geometry and magnetic field B. Outburst timescales (years) are such that monitoring observations are easy to set.

• a large variety of spectral and timing variations (at all wavelengths) are present during the first days/week since the outburst onset.

• timing and spectral burst properties on short timescales

All this need of a new and *ad hoc* observational strategy: rapid response multiwavelength ToO (to detect new objects/outbursts/flare) AND long-term monitoring. Swift have changed the observational strategy [BAT large FOV (15-150keV); XRT small FOV (0.1-10keV); ~4" spatial res.]. Follow-up obs. in less of 100s (in the best cases)

**SOME EXEMPLES IN THE FOLLOWING SLIDES**
From outburst to quiescence: XTEJ1810-197

A 5.5s transient ($\Delta L_X \sim 100$) X-ray pulsar was discovered in 2003.

Timing and spectral properties consistent with those of AXPs.

$N_H = 1.05(5) \times 10^{22} \text{ cm}^{-2}$

$kT = 0.67 \pm 0.01 \text{ keV}$

$\Gamma = 3.7 \pm 0.2 \ (kT=0.3\text{keV})$

$P=5.5s$

$P_{\text{dot}}=2 \times 10^{-11} \text{ s/s}$

$B = 2.4 \times 10^{14} \text{ G}$

$PF=46(3)\%$

$F_X \sim 5 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$

BB with $kT=0.18(2) \text{ keV}$ and $R \sim 10\text{km}$

No pulsations with $PF>20-25\%$

$L_X \sim 10^{33} \text{ erg/s @ 4kpc}$ not distinguishable from hundreds of unidentified ROSAT sources.

$F(2-10 \text{ keV}) \propto \exp\left(-\left(t[MJD]-52672\right)/233.5\right)$
The SPECTRAL evolution – 3BBs

Tail component present between 03-04 possibly related to a HE PL observed in other AXPs (3σ c.l.)

Hard BB disappeared between MAR and SEP 06 -> PF flattens (Bernardini [Ph.D Student] et al. 2009)

2BB → 3BB Ftest gives p~10^{-12}
The coldest one from the whole NS sur.
constraints from XTEJ1810-197 mw obs.

No significant X-ray variability during the radio transitions. \( \text{Flux} \sim \text{const} \) however \( \text{Fr} \sim 0.01 \text{Fx} \)

Radio variability not correlated to X-rays - no significant flux variations

In agreement with the idea that most of the X-rays originated deep in the crust after thermalization.
Constraints from XTEJ1810-197 MW obs.

No significant X-ray variability during the radio transitions. Flux~const however Fr~0.01Fx

Simultaneous detection of radio and X-ray pulsations is one of the strongest evidence against accretion being at work!

X-ray/radio alignment → X-rays and radio are coming from the same portion of the NS. A larger X-ray duty cycle indicates a larger emitting area for X-rays.
The 2006 burst Forest

More than 100 single bursts were detected in 20min, with 40 in less than 30s. Few of them have intermediate duration (200ms-2s).

Total Energy: few \( \times 10^{42} \) ergs (one of the more energetic events recorded ever after the 1998 giant flare)

Time resolved spectroscopy Resulted in 729 spectra with an average # of photons of 4000 and \( \Delta t \) in the 8ms-400ms range
the ‘06 burst forest: spectroscopy

Different simple models considered in analogy with previous work done by Feroci et al. (2004), Olive et al. (2004) and Nakagawa et al. (2007). [Brems not able to fit the low energy part; 2BB better choice]

Fits carried out on BAT (on short timescales; 729 spectra; 10-150keV) and BAT+XRT (burst average; 8 spectra; 2-150keV) data.

2BB and CompTT are, by far, the models which give the smallest reduced $\chi^2$

<table>
<thead>
<tr>
<th>Spectral Model</th>
<th>$\langle \chi^2_{\nu} \rangle_{\text{BAT+XRT}}$</th>
<th>$\sigma_{\text{BAT+XRT}}$</th>
<th>$\langle \chi^2_{\nu} \rangle_{\text{BAT}}$</th>
<th>$\sigma_{\text{BAT}}$</th>
<th>Parameters (#)</th>
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</thead>
<tbody>
<tr>
<td>Bremss</td>
<td>4.84 1.17</td>
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<td>1.71 1.95</td>
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<td>2</td>
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<tr>
<td>DiskBB</td>
<td>2.91 0.84</td>
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<td>1.17 0.51</td>
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<td>CompST</td>
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<td>1.08 0.42</td>
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<tr>
<td>CutoffPL</td>
<td>1.36 0.07</td>
<td></td>
<td>1.07 0.23</td>
<td></td>
<td>3</td>
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<tr>
<td>Bremss+BB</td>
<td>1.33 0.25</td>
<td></td>
<td>1.06 0.23</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>CompTT</td>
<td>0.88 0.07</td>
<td></td>
<td>0.99 0.17</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>BB+BB</td>
<td>0.88 0.08</td>
<td></td>
<td>1.01 0.16</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
The KT - $R^2$ plane

Sharp edge / saturation present for the brightest part of the bursts

The 2BB distributions identify a natural separation surface at 20-25km

A sort of turn/cut-off is present for the BBh around 10-13keV and 5-15km

The locus identified by the relation $R^2kT^3=c$ can be regarded as constant number of emitted $\gamma$ per unit time ($R^2kT^4=c$ identifies a constant $L$)

(Israel et al. 2008)

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2BB: $L_{\text{soft}}$ vs $L_{\text{hard}}$

BBs and BBh Luminosities correlate below $3 \times 10^{41}$ erg/s (iso-L). Above such value only LBBh evolves.

Max LBBh is $\sim 3 \times 10^{41}$ erg/s at 10keV and 15km = magnetic Eddington luminosity (Paczynsky 1992) for B of $8 \times 10^{14}$ G [similar to that inferred from P and Pdot].

$$L_{\text{Edd},B}(r) \approx 2 L_{\text{Edd}} \left(\frac{B(r)}{10^{12}}\right)^{4/3}$$

Max LBBs $\sim 10^{41}$ erg/s at 100km hints to the maximum efficiency of the MF to sustain the radiation pressure.
The proposed/qualitative scenario

A possible interpretation: different way with which E- and O-mode polarised photons propagate into the magnetosphere; scattering cross section of E-mode may be reduced by $B$ and the scattering photosphere is smaller ($\sim R_{NS}$).

The $R\sim 25\text{km}$ corresponding to max radius of the BBh and the min of the BBs identify a critical surface at which $B=B_{\text{crit}}$ (QED).

$B < B_{\text{QED}} = 4.4 \times 10^{13} \text{ G}$
SGR1627-41’s return

(Tens of short burst detected in the BAT.)

Persistent flux a factor 200 above quiescence

Burst properties similar to those of SGR1900 (but not that extreme).

A 120ks XMM pointing was carried out three months later at a flux level 5 times above quiescence.
SGR1627-41’s spin period

6σ detection of pulsations at $P=2.6s$

Pulsed fraction of 19% and 24% for the fundamental and the harmonic

Recently confirmed through archival Chandra data (Esposito et al. 2009b)

\[
P = 2.594578(6) \text{ s}
\]

\[
\dot{P} \gtrsim 1.2 \times 10^{-11} \text{ s s}^{-1}
\]

\[
\dot{E} \gtrsim 8 \times 10^{33} \text{ erg s}^{-1}
\]

\[
\tau_C = P/(2\dot{P}) \lesssim 3.4 \text{ kyr}
\]
1E1547.0-5408 outbursts

2 outbursts in less than 4 months (Oct 08 / Jan 09)

Oct 08
$\Delta L \sim 50$
ToO:
Swift
INTEGRAL

Jan 09
$\Delta L > 1000$ !
ToO:
Chandra
XMM
Parkes
VLT-IR
Swift

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1E1547.0-5408 ‘08 P – P – \( \dot{P} \) solution

\[ P = 2.0713410(7) \, s, \]
\[ \dot{P} = 2.9(2) \times 10^{-11} \, s \, s^{-1} \]
\[ \ddot{P} = 2.4(4) \times 10^{-17} \, s \, s^{-2} \rightarrow \text{inc. spin-down} \]

Oct. 2008

Implications (preliminary):

- standard scenario (radio pulsarlike) \( P > 0 \) or \( < 0 \) depending on whether \( P_{\text{post}} / P_{\text{sec}} < 0 \) or \( > 1 \)
- magnetar/twist scenario in disagreement unless the twist is implanted locally and it have not yet reached its maximum value (after that it decreases)

\[ \ldots \] to be confirmed in the future

For a review on glitches and \( P_{\text{dot}} \) see Dib et al. 2008

(Israel et al. 2009)
**1E1547.0-5408: the ‘09 radio Switch**

Not detected on 22\textsuperscript{nd} (Camilo et al. 09) and 23\textsuperscript{rd} (Burgay et al. 09) Jan 09 – weak radio pulsations detected on 25\textsuperscript{th} from Parkes in simultaneity with Chandra.

(Burgay et al. 2009)

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2007 observations
1E1547.0-5408 ’09 broad band spectrum

Properties are in between those of SGRs and AXPs:
Same PL at Low and High energies BUT BB dominates at Low energies

Chandra + INTEGRAL (simultaneous)

\[ \Gamma \sim 1.5 \]

(Israel et al. 2009b, Bernardini et al. 09)
Conclusions.... Not that conclusive

TAXP studies seems to be a very powerful tool to study the emission mechanism(s) from AXPs/SGRs and their evolution.
Almost all AXPs/SGRs are Transient !! At all wavelengths !!
The difference between AXPs and SGRs is small ... if any.

The greatest part of these results obtained thanks to Swift BAT burst detection and quick follow-up with the XRT.
ToO and Multi-Wavelengths obs strategy has revealed to be fundamental
However relatively quick follow-up obs. with larger area instruments is vital.

Open questions to be addressed in the near future:
- Are the outbursts permanently modifying the timing/spectral parameters of the source ? Observations are not yet conclusive
- Are different outbursts behaving similarly ? NO !
- Which is the (causal) connection between glitches/bursts/outbursts ?

New, more physical spectral fits (to be) used (but model-dependent)......
Simultaneous timing and spectral fits are a powerful tool.

More in general... we need more models and details from theoreticians ...
... next talk ?!