An Observer's view of Magnetars

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Magnetars are magnetically powered NS

- ~29 sources to date: 23 confirmed, 5 candidates, 1 RPP; 11 in 2008-2014
- All but two (LMC, SMC) are MW sources
- Discovered in X/γ-rays/radio; radio, optical and IR observations - Short, soft repeated bursts
  - \( P = [2-11] \text{s}, P \sim [10^{-11} - 10^{-13}] \text{s/s} \)
  - \( \tau_{\text{spindown}}(P/2 P) = 2-220 \text{ kyrs} \)
- \( B \sim [1-10] \times 10^{14} \text{ G} \) (mean surface dipole field: \(3.2 \times 10^{19} \sqrt{PP} \)) - **BUT**: SGRs J185246.6+003317, \( B < 4.1 \times 10^{13} \text{ G} \); 0418+5729, \( B = 6.2 \times 10^{12} \text{ G} \); 1822.3-1606, \( B \sim 2.0 \times 10^{13} \text{ G} \)

- Luminosities range from \( L \sim 10^{32-36} \text{ erg/s} \)
- No evidence for binarity
The neutron star is powered by its super strong B-field = $10^{14-15}$ G. To create such fields requires the collapse of a fast rotating star (1-3 ms) with very high convection rates (magnetic Reynolds number $\sim 10^{17}$). Ideal efficiency can generate $\sim 10^{16}$ G (Duncan and Thompson 1992, 1993).

However: The magnetic energy has to be less than the gravitational binding energy of the neutron star (Lai 2001) providing an upper limit of:

$$\frac{4\pi R^3}{3} \left( \frac{B^2}{8\pi} \right) \leq \frac{GM^2}{R}.$$

$$B \lesssim 10^{18} \left( \frac{M}{1.4 M_{\odot}} \right) \left( \frac{R}{10 \text{ km}} \right)^{-2} \text{ G}.$$
NS populations comprising Magnetars

Soft Gamma Repeaters (SGRs)

Anomalous X-ray Pulsars (AXPs)

Dim Isolated Neutron Stars (DINs)

Compact Central X-ray Objects (CCOs)

Rotation Powered Pulsars (PSRs J1846-0258 & J1622-4950)

IDEALLY we should call them all MGC XXXX±YYYY as in MaGnetar Candidate followed by coordinates in RA, Dec
Magnetar detection missions

**IPN**: WIND, 2001 Mars Odyssey, INTEGRAL, RHESSI, Swift, MESSENGER, Suzaku, AGILE, and Fermi
Magnetar detection rates

Magnetar Distribution in our Galaxy

NEW: GBM
Bursts detected since Fermi launch
SYNERGY: Swift-Fermi-RXTE-IPN
Old source reactivation

SGRs

AXPs

CRADLE

Kouveliotou et al. 2011
Magnetar States

- **Quiescent**
- **Active**
  - Several 100s of bursts (storms) - 4 sources
  - Giant Flares (3 sources one each)
  - Few 10s of bursts (3 sources)
  - <10 bursts (10 sources)
  - No bursts (4 sources)
Quiescent Emission Properties
Magnetar Timing Properties

From the quiescent pulsed X-ray emission we can calculate:

The minimum surface dipole field in vacuum:

\[ B = 3.2 \times 10^{19} \left( \frac{P}{P'} \right)^{1/2} \text{G} \] (minimum magnetic field strength in vacuum);

The spindown luminosity:

\[ \dot{E} = 4\pi I P P'^3 \] (I = 10^{45} g cm^2);

The characteristic age:

\[ \tau_c = \frac{P}{2P} \]
p-pdot Diagram

Burst effects - or not...

SGR 1806-20

Woods et al. 2002

SGR J1745-2900

Kaspi et al. 2014
Outburst effect in the persistent flux

SGR 1900+14

Woods et al. 2002
Outburst effect in the pulse profile

Gogus et al. 2002
Spectral Properties

Most spectra are best fit with an absorbed PL + BB

Active Emission
Properties: BURSTS
<table>
<thead>
<tr>
<th>Magnetar</th>
<th>Active Period</th>
<th>Triggers</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR J0501+4516</td>
<td>Aug/Sep 2008</td>
<td>26</td>
<td>New source at Perseus arm</td>
</tr>
<tr>
<td>SGR J1550-5418</td>
<td>Oct 2008, Jan/Feb 2009, Mar/Apr 2009, June 2013</td>
<td>7, 117/331+, 14, 1</td>
<td>Known source - first burst active episodes</td>
</tr>
<tr>
<td>SGR J0418+5729</td>
<td>June 2009</td>
<td>2</td>
<td>New source at Perseus arm</td>
</tr>
<tr>
<td>SGR 1806-20</td>
<td>Mar 2010</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>AXP 1841-045</td>
<td>Feb 2011, June/July 2011</td>
<td>3, 4</td>
<td>Known source - first burst active episodes</td>
</tr>
<tr>
<td>SGR 1822-1606</td>
<td>July 2011</td>
<td>1</td>
<td>New source in galactic center region</td>
</tr>
<tr>
<td>AXP 4U0142+61</td>
<td>July 2011</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>1E 2259+586</td>
<td>April 2012</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>Unconfirmed Origin</td>
<td>2008-2013</td>
<td>21</td>
<td>Multiple error boxes include new source 3XMM J185246.6+003317</td>
</tr>
</tbody>
</table>
Unknown source locations

Collazzi et al. 2014
SGR J1550-5418 (AXP 1E1547.0-5408)

- $P = 2.069\,\text{s}$
- $P = 2.318 \times 10^{-11}\,\text{s/s}$ and $B = 2.2 \times 10^{14}\,\text{G}$
- Near IR detection, $K_s = 18.5\pm0.3$
- Only three other sources have exhibited in the past such "burst storms": SGR 1806-20, SGR 1900+14, SGR 1627-41
- $T_{90}$ burst duration = 155 (10) ms for 353 (unsaturated) bursts
SGR J1550 - 5418: Spectral
SGR J1550 - 5418: Spectral
All triggers: temporal properties

Unknown event avg $T_{90} = 61$ ms (known avg $\sim 100$ ms)
All triggers: comparative properties
BURST ENERGETICS

1550−5418
Fluence: $7 \times 10^{-9} − 1 \times 10^{-5} \text{ erg/cm}^2$
$E = (2 \times 10^{37} − 3 \times 10^{40}) \ d_5 \text{ erg}$
Flux: $8 \times 10^{-7} − 2 \times 10^{-4} \text{ erg/cm}^2 \text{s}$
$L: 5 \times 10^{38} − 1 \times 10^{41} \text{ erg/s}$
*Total Energy Release: $6.6 \times 10^{41} d_5 \text{ erg (8-200 keV)}$

1806−20: $3.0 \times 10^{36} − 4.9 \times 10^{39} \text{ erg}$
1900+14: $7 \times 10^{35} − 2 \times 10^{39} \text{ erg}$
1627−41: $10^{38} − 10^{41} \text{ erg}$
0501+4516: $2 \times 10^{37} − 1 \times 10^{40} \text{ erg}$
1E2259+586: $5 \times 10^{34} − 7 \times 10^{36} \text{ erg}$
Time resolved spectroscopy of the 50 brightest bursts from SGR J1550-5418

Younes et al. 2014
Selection Criteria for the initial sample of 63 bursts:

Fluence (8-200 keV) \ (>10^{-6} \ \text{erg/cm}^2\)
Average flux (8-200 keV) \ (>10^{-5} \ \text{erg/cm}^2 \, \text{s}\)
Two thermally emitting regions during bursts
  · Highly coupled with energy equipartition between the two
  · \( kT_{\text{high}} \): Could be thought of as the footprints of the plasma fireball.
  · \( kT_{\text{low}} \): more complicated to interpret! — Representing the outer surface layer of the plasma?

\( R^2 - kT^4 \) relation places the plasma close to the surface of the NS.
New trends - conclusions

- COMPT:
  - $E_{\text{peak}}$ - flux correlation: break at $10^{-5}$ erg cm$^{-2}$ s$^{-1}$
  - index - flux correlation break at same flux

- 2BB:
  - high-$kT$: $R^2$ increases & $kT$ decreases with flux
    $\rightarrow$ adiabatic cooling of fireball
  - low-$kT$:
    - $< 10^{-5.5}$ erg cm$^{-2}$ s$^{-1}$: $R^2$ increases & $kT$ constant with flux
    - $> 10^{-5.5}$ erg cm$^{-2}$ s$^{-1}$: $R^2$ saturates & $kT$ increases with flux
  - saturation $R = 30$ km $\rightarrow$ maximum fireball $R$ $\rightarrow$ internal magnetic field $> 4.5 \times 10^{15}$ G
  - flux dependence of $R^2 - kT$ correlation
1. Since the Fermi launch, GBM has detected bursts from 8 sources: one third of the total population in five years!
2. The GBM magnetar burst spectra provide the first evidence for an unusual hardness $E_{\text{peak}}$ - flux relationship.
3. Evidence for higher energetic content in SGR bursts than in AXP bursts.
4. Power of high-time resolution spectral studies of magnetar bursts:
   - Track the evolution of the emitting regions
   - Put to test the emission from a photon-pair plasma fireball
   - Prediction of intrinsic parameters of the system
What Next?

The next five years of Magnetar observations:
• Population studies of magnetars
• Understand the links between PSRs - Magnetars - DINS
• Systematic searches for seismic vibrations in magnetar bursts-independent B-field measurement
• Giant flare detection becomes a strong possibility (for a rate of 1/source/10yrs, we expect one in the next three years - last was in 2004)
• Confirm pulsed emission breaks >100 keV will constrain $E_{\text{max}}$ of particles and localization of emission

Overarching theoretical issues:
• Localize the burst energy injection possibly on or near the NS surface to determine the injection mechanism
• Detection of gravitational waves from magnetar Giant Flares
• Determination of the magnetic Eddington limit

Synergy with new observatories:
NuSTAR, LIGO, LOFAR, AstroSAT, SVOM, GEMS

Serendipitous Discoveries:
Always welcome!
The GBM Magnetar Team

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