Magnetars: explosive neutron stars with extreme magnetic fields

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No more distinction between Anomalous X-ray Pulsars, Soft Gamma Repeaters, and transient magnetars: all showing all kind of magnetars-like activity.
Magnetars general properties

- X-ray pulsars $L_x \sim 10^{33}-10^{36}$ erg/s
- strong soft and hard X-ray emission
- short X/gamma-ray flares and long outbursts
- pulsed fractions ranging from $\sim2$-80 \%
- rotating with periods of $\sim0.3$-12s
- period derivatives of $\sim10^{-14}$-$10^{-11}$ s/s
- magnetic fields of $\sim10^{13}$-$10^{15}$ Gauss
- glitches and timing noise
- faint infrared/optical emission ($K\sim20$; sometimes pulsed and transient)
- transient radio pulsed emission

(see Woods & Thompson 2006, Mereghetti 2008, Rea & Esposito 2011 for a review)

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How magnetar persistent emission is believed to work?

- Magnetars have magnetic fields twisted up, inside and outside the star.

- The surface of a young magnetar is so hot that it glows brightly in X-rays.

- Magnetar magnetospheres are filled by charged particles trapped in the twisted field lines, interacting with the surface thermal emission through resonant cyclotron scattering.

(Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b; Rea et al. 2008; Zane et al. 2009)

Where do we see the twisted magnetic fields?

In their X-ray spectral shape....

In their transient outbursts....

In their X-ray/gamma-ray flares...
Spectral shape: Resonant Cyclotron Scattering

Magnetars’ magnetospheric density is \(~10^3\) times the normal radio pulsar density!

(Thompson, Lyutikov & Kulkarni 2002; Fernandez & Thompson 2008; Nobili, Turolla & Zane 2008a,b)

see A. Beloborodov and R. Hascoet's talk!

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Magnetar Outbursts

see G. Rodriguez-Castillo, L. Lin and A. Tiengo's talk!

(updated from Rea & Esposito 2011)
Magnetar outbursts

August 23

August 29

August 31

September 02

September 30

Energy

Total Flux

PL Flux

BB Flux

Phase

Phase

Phase

Phase

Phase

Phase

Phase

Phase

Phase

Phase

Phase

How magnetar outbursts and flares are believed to work?

- Varying injected energy:
  - \( \approx 10^{44} \) erg
  - \( \approx 10^{43} \) erg
  - \( \approx 10^{42} \) erg
  - \( \approx 10^{41} \) erg

- Varying initial quiescent luminosity:
  - \( \approx 10^{44} \) erg

Magnetar flaring activity

**Short bursts**
- the most common
- they last ~0.1s
- peak ~$10^{41}$ ergs/s
- soft $\gamma$-rays thermal spectra

**Intermediate bursts**
- they last 1-40 s
- peak ~$10^{41}$-~$10^{43}$ ergs/s
- abrupt on-set
- usually soft $\gamma$-rays thermal spectra

**Giant Flares**
- their output of high energy is exceeded only by blazars and GRBs
- peak energy > $3 \times 10^{44}$ ergs/s
- <1 s initial peak with a hard spectrum which rapidly become softer in the burst tail that can last > 500s, showing the NS spin pulsations, and quasi periodic oscillations (QPOs)

see E. Gogus and C. D'Angelo's talk!

(Nanda Rea CSIC-IEEC)
Other evidence of magnetic instability

- star-quakes on a neutron star!

(Israel et al. 2005; Stromayer & Watts 2006)

see M. Gabler and R. Ciolfi’s talk!
1. Magnetars can be radio pulsar during outbursts.
   (Camilo et al. 2006, Nature 442, 892)

2. A “normal” X-ray pulsar showed magnetar activity.

3. A magnetar was discovered having a low B-field.
   (Rea et al. 2010, Science, 330, 944)
For a long time we believed that magnetars have X-ray luminosity exceeding their rotational power.

All radio magnetars have quiescent luminosities lower than their rotational power. Can their radio emission be powered by rotation?
Magnetar radio emission might be powered by rotation

Large twisted field. High density and strong currents. Pair cascades inhibited in the magnetosphere.

Low twists. Low density, weak currents. Enough $E_\text{dot}$, hence pair cascade can proceed. Flat spectra because of high magnetospheric densities.

We know now of two low field magnetars: SGR 0418+5729, and Swift 1822.3-1606

Low magnetic field magnetars: SGR 0418+5729

Magnetic field is: $B = 6 \times 10^{12} \text{ G}$ (3.5 sigma)

$P = 9.07838822(5) \text{s}$ and $P_{\text{dot}} = 4(1) \times 10^{-15} \text{ s/s}$

NASA Press Release today at 16:00!

Low magnetic field magnetars: SGR 0418+5729


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We know now of at least two low field magnetars: SGR 0418+5729, and Swift 1822.3-1606. Are low field magnetars in line with the magnetar model?

Can a neutron star with $6 \times 10^{12}$ Gauss dipolar field, as SGR 0418+5729, show magnetar-like outburst and flares?

See J. Pons and D. Vigano' talks!

(Rea et al. 2013 in press; Vigano', et al. 2013, submitted)
Magnetic evolution of neutron stars: toward a unification

See J. Pons and D. Vigano' talks!

(Vigano', Rea, Pons, Perna, Aguilera & Miralles 2013, MNRAS submitted)
A magnetar is a neutron star which showed magnetic-powered emission!

- Regardless of the measured surface dipolar field (SGR0418)
- Regardless of being in part powered by rotation (Kes75)