On the X-ray Emission Mechanisms of the Persistent Source and Very Low Fluence Bursts of SGR J0501+4516

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Persistent Emission v.s. Short Bursts

- Focus on very low fluence bursts
X-ray emission from Magnetar

- Persistent Emission
  - $10^{33} \sim 10^{35}$ erg s$^{-1}$

- Short Bursts
  - $~10^{37}$ erg s$^{-1}$
  - $~10^{41}$ erg s$^{-1}$
  - $~10^{45}$ erg s$^{-1}$
  - ~0.1 s
  - Up to 200 keV
  - Unpredictable from SGRs and AXPs (18/23 magnetars*)

- Intermediate Flare

- Giant Flare
  - Short hard spike + long soft periodic tail
  - Only 3 : SGRs 0526-66, 1900+14, 1806-20

* From McGill SGR/AXP Online Catalog
Persistant Emission v.s. Short Bursts

- Focus on very low fluence bursts
- Idealized physical models for both persistent emission and bursts spectra
Phenomenological models

- **Persistent**: \((BB+BB\) or \(BB+PL\)) + PL hard band
- **Bursts**: \(BB+BB\)
- **Low fluence bursts**: \(BB+BB\) (+ PL hard band)

Nakagawa et al. (2011)

Enoto et al. (2010)

Lin et al. (2012)
Idealized physical models

**Surface emission**
- transport through atmosphere: harder than Planck shape

**Magnetosphere**
- Resonant cyclotron scattering (RCS) by a non-relativistic warm plasma in an inhomogeneous magnetic field
  - Lyutikov & Gavriil (2006)

**Persistent emission**: STEMS
- Guver et al. (2007, 2008)

** Burst emission**: MBB + RCS

**The sudden magnetic energy release → hot pair plasma → trapped by magnetosphere formed a bubble: modified BB (MBB)**
Persistent Emission v.s. Short Bursts

- Focus on very low fluence bursts
- Idealized physical models for both persistent emission and bursts spectra
- Proper source to study both spectra together
SGR J0501+4516

- $P = 5.762\text{s}$, $\dot{P} = 5.8 \times 10^{-12} \text{s/s}$, $B_{\text{dipol}} = 2 \times 10^{14} \text{G}$
- Anti-Galaxy center direction, most likely at the Perseus arm (~2 kpc)
  \[ \text{R.A.} = 05^\text{h}01^\text{m}06^\text{s}.76 \quad \text{decl.} = +45^\circ16'33''.92 \]
- Burst active period
  ~ 2 weeks after 2008 August 22
- XMM-Newton observation: 0560191501
  - 2008 August 23 (the most burst active day)
  - Exposure 48.9 ks
  - Study the spectra of burst and underlying persistent emission at the same time
Persistent and bursts selection

- 100 ms binned lightcurve

- Persistent emission: ~5.5 counts per bin; total exposure of 32.7 ks

- Bursts: 2σ over persistent level, ~10 counts per bin, 129 burst bins with total exposure of 8.7 s
Persistent emission spectrum

- Galactic $N_H$ towards the direction of the source
  $(0.62 \text{ or } 0.52) \times 10^{22} \text{ cm}^{-2}$
- Unabsorbed flux (0.5-6.5 keV)
  $(5.88 \pm 0.02) \times 10^{-11} \text{ erg/s/cm}^2$
- Hot-spot surface area
  $131 \pm 27 \text{ km}^2$
**B-field**

For SGR J0501+4516

\[ B_{\text{stem}} \sim B_{\text{dipo}} \]

Its surface magnetic field is close to a dipole

Guver et al. 2011
Weak bursts stacked spectrum

- combine 129 burst bins into one stack spectrum
- Adopt $N_H$, $\beta$ & $\tau$ from the persistent spectrum fit with STEM
  - MBB+RCS
    - $kT_b = 1.16 \pm 0.04$ keV
  - The emission area
    - $93 \pm 10$ km$^2$,
    - ~7.4% of magnetar surface
  - Average unabsorbed flux
    - $(1.8 \pm 0.05) \times 10^{-9}$ erg/s/cm$^2$
    - over 30 times of the persistent flux level
  - Average luminosity
    - $\sim 10^{36}$ erg/s
Time resolved burst stacked spectra

- Select 47 relatively stronger bursts, and separate each one into three parts:
  - rise
  - 25 ms peak
  - decay
- Fit 3 stacked spectra with MBB+RCS model
Time resolved burst stacked spectra

Emission areas for rise, peak and decay parts are:

\[58 \pm 19, 160 \pm 41, 118 \pm 29 \text{ km}^2\]
Summary

- Study X-ray spectra from magnetar with idealized physical models
  
  Persistent - STEMS
  Bursts - MBB+RCS

- Any the connection between the persistent emission and bursts?
  
  Persistent emission and weak bursts (~2σ) have different spectral shape, hence different origin