Recent Suzaku View of Magnetar and Magnetar-related Objects

Teruaki Enoto (RIKEN, NASA/GSFC), Kazuo Makishima (Univ. Tokyo), Shinpei Shibata (Yamagata Univ.),
Yujin Nakagawa (JAXA/ISAS), Takanori Sakamoto (Aoyama Gakuin Univ.) and Suzaku Magnetar team

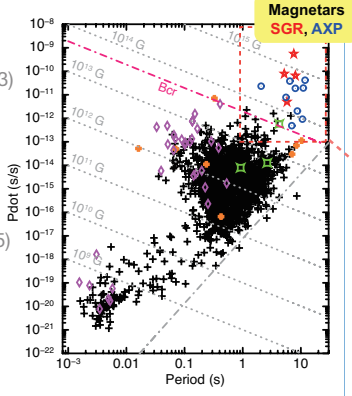
- *Suzaku* X-ray satellite observed 11 magnetars. Some objects were observed during burst-active outbursts.
- Quasi-thermal soft X-rays (<10 keV) and hard power-law (>10 keV) components were simultaneously observed in the 0.5-70 keV energy band.
- Hard X-ray luminosity relative to that of soft X-rays correlates with the characteristic age and magnetic field evaluated from P and Pdot (spectral evolution?)
- Accumulation of weak short bursts during the outbursts resemble the persistent X-ray spectrum.

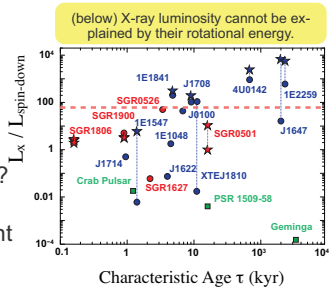
1. Magnetar Class

☑ **Two Historical Subclass** (Ref 1-3)
- **Soft Gamma Repeater (SGR)**
  - discovered by giant flare, bursts
- **Anomalous X-ray Pulsar (AXP)**
  - discovered by persistent X-rays

☑ **Observational Features** (Ref 4, 5)
- ~20 sources in Our Galaxy
- X-ray bright (Lx~10^{35} erg/s), few reports on their radio emission
- Slow spin period (P~2-12 sec) & large derivative ($P_{dot} > 10^{-12}$ s/s)
- Strong magnetic field $B \propto \mathrm{sqrt}(P\,P_{dot}) > 10^{14\text{-}15}$ G
- Young system; $\tau \sim P/2P_{dot}$ <100 kyr
- Hard X-rays were discovered (Ref 6)

☑ **Questions on Magnetars**
- Energy source of X-ray emission? Magnetically-powered pulsar?
- Emission Mechanism of persistent and burst X-ray emissions?
- Birth environment and evolution?



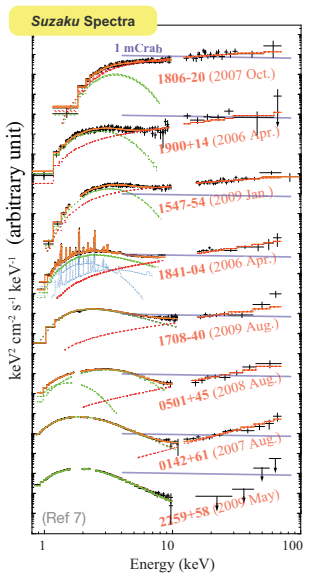


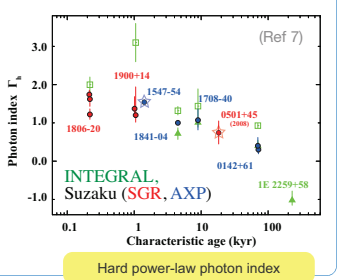
2. *Suzaku* View (Ref 7)

☑ **Suzaku X-ray Satellite**
- Japan/US, launched in 2005
- Broadband Energy Coverage
  - X-ray Imaging Spectrometer (XIS, 0.2-10 keV) and Hard X-ray Detector (HXD, 10-600 keV)
- 11 magnetars were observed in AOs, Key Project, and ToOs.

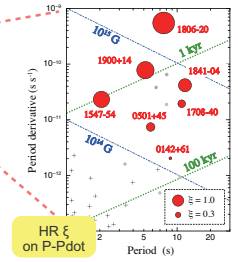
☑ **Two-Component X-ray Spectra**
- Quasi-thermal soft component from all sources (kT~0.5 keV)
- Hard power-law component was confirmed from 7 sources (Γ~1)

☑ **Broadband Spectral Evolution**
- **Hard X-ray component becomes harder towards sources with older characteristic age**
- Hardness ratio (HR), defined as $\xi = F_{hard}/F_{soft}$ in 1-60 keV, is tightly correlated with their age, $\xi = (3.3\pm0.3) \times (\tau / 1\ \mathrm{kyr})^{-0.67\pm0.04}$ with a correlation coeff. -0.989, and with their magnetic field, $\xi = (0.09\pm0.07) \times (B / B_{QED})^{1.2\pm0.2}$ with a coeff. 0.871.



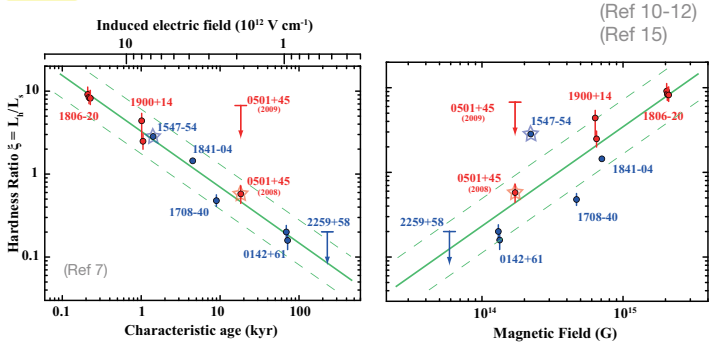


Hard power-law photon index



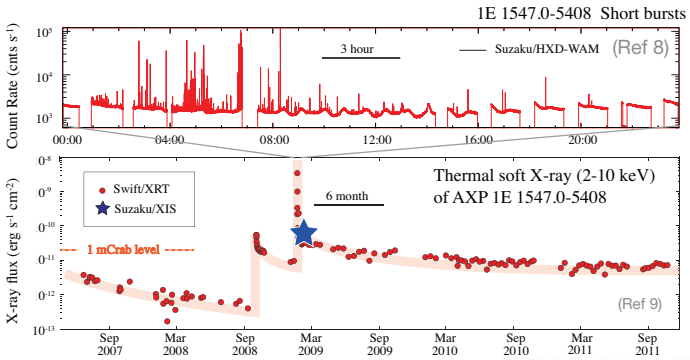
☑ **To summarize ξ-τ, ξ-B correlations,**
- Hard X-ray component becomes weaker relative to the soft component towards sources with older age and higher magnetic field.

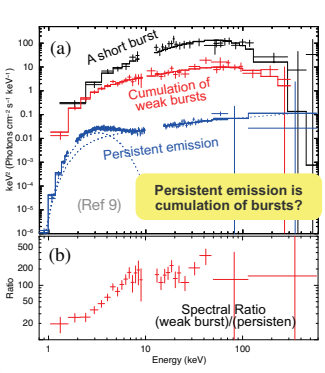
☑ **Suzaku ToOs of Transient sources**
- also detected the hard X-rays from SGR 0501+4516 and 1E 1547.0-5408. (Ref 10-12) (Ref 15)



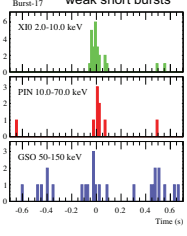
3. Bursts vs. Persistent Emissions

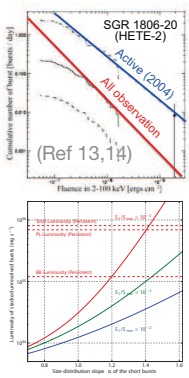
☑ **Suzaku ToO pointing observation of 1E 1547.0-5408**
- was performed ~7 days after the outburst onset in 2009.
- and detected weak 18 short bursts (fluence < 2x10^{-7} erg/cm^2).
- Cumulation of weak burst spectra resembles the persistent emission spectrum (e.g., the slope in the hard band). (Ref 9)





Gutenberg-richter law of short bursts (solar flare, earthquake)
$N(>S) \propto S^{-\alpha}$
α = 0.7 -- 1.1 of magnetars





Teruaki Enoto
RIKEN (The Institute of Physics and Chemical Research)
teru.enoto@riken.jp
NASA Goddard Space Flight Center
teruaki.enoto@nasa.gov

(1) Duncan C., Thompson C., 1992, ApJL, 392, L9
(2) Thompson C., Duncan C., 1995, MNRAS 275
(3) Thompson C., Duncan C., 1996, ApJ 473
(4) Merethetti S., 2008, A&AR 15, 225
(5) Kaspi V. M., 2007, Ap&SS 308, 1
(6) Kuiper L., et al., 2006, ApJ 645, 556
(7) Enoto T., et al., 2010, ApJL722, L162
(8) Yasuda T., et al., 2010, MAXI conf., 31p
(9) Enoto T., et al., 2012, MNRAS (arXiv:1209.1714)
(10) Enoto T., et al., 2009, ApJL, 2009
(11) Enoto T., et al., 2010, PASJ 62, 475
(12) Enoto T., et al., 2010, ApJ 715, 665
(13) Nakagawa et al., 2007, PASJ, 59, 653
(14) Nakagawa et al., 2011, PASJ, 63, 813
(15) Rea N. & Esposito P., 2011, High-Energy Emission from Pulsars and their Systems, 247