The 2009 Outburst of Magnetar 1E 1547-5408

Paul Scholz and Victoria M. Kaspi
McGill University
Montreal, Canada

Abstract

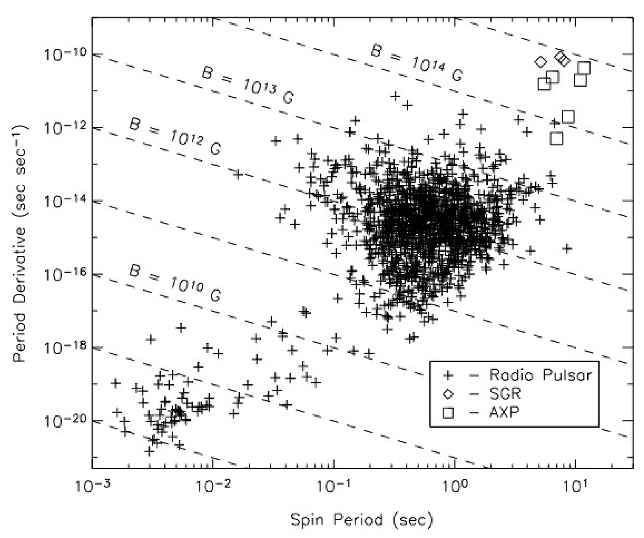
The magnetar 1E 1547−5408 exhibited a period of outburst, beginning on 2009 January 22. Here we present an analysis of the persistent radiative evolution and burst properties during the outburst using the *Swift* X-ray Telescope (XRT). We find that the 1–10 keV flux increased by a factor of ~ 500 and hardened significantly, peaking ~ 6 hours after the onset of the outburst. The pulsed fraction exhibited an anti-correlation with phase-averaged flux. We find that the peaks of the bursts occur randomly in phase but that the folded counts that compose the bursts exhibit a pulse. We compare the hardness-flux evolution of the persistent emission of the outburst to those from other magnetars and find that although there does exist an overall trend, the degree of hardening for a given increase in flux is not uniform from source to source.

Magnetars: AXPs and SGRs

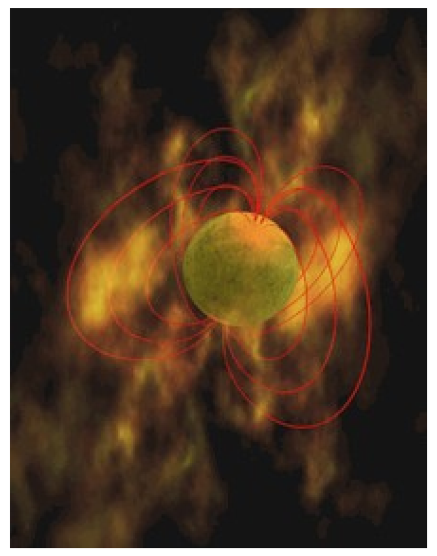
Magnetars:
- Highly magnetized neutron stars
- B ~ $10^{14\text{-}15}$ G
- Long periods (2-12s)
- We know of 21 magnetar candidates[a]
- X-ray luminosities exceed their spin-down energies
- Exhibit episodes of violent bursting activity (outbursts)
- Outbursts caused by magnetospheric twists following an internal energy or stress release [1]

AXPs and SGRs:
- Magnetar candidates
- Historical observational classification
  - Anomalous X-ray Pulsars
    - X-ray luminosity higher than spin-down energy
    - Later found to exhibit high energy bursts
  - Soft Gamma Repeaters
    - High energy transient burst sources
    - Later found to exhibit persistent pulsed emission
- **AXPs and SGRs increasingly appear to be subclasses of the same object, the magnetar**

[a]see McGill SGR/AXP Catalog at http://www.physics.mcgill.ca/~pulsar/magnetar/main.html



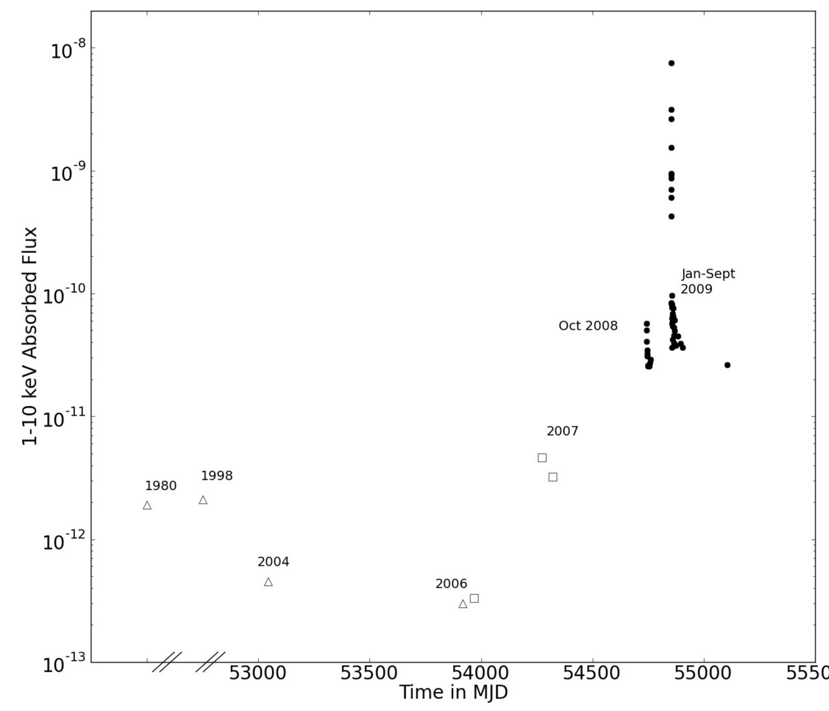
Period – Period derivative plane showing the location of the magnetars. Figure from [2]



NASA

1E 1547-5408

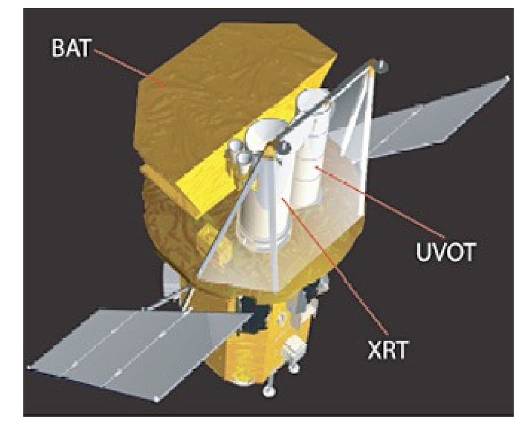
- Discovered as an X-ray source by the *Einstein* satellite in 1980 [3]
- Identified as an anomalous X-ray pulsar (AXP) in 2006 based on its X-ray spectrum, infrared flux and possible association with SNR G327.24-0.13 [4]
- One of three magnetars that have detectable radio emission [5]
- Outbursts in October 2008 and January 2009 quickly observed by the *Swift* satellite.



Flux history of 1E 1547-5408. Triangles indicate flux values are from [4]. Squares indicate flux values are from [6]. Shows evidence for at least 3 outbursts.

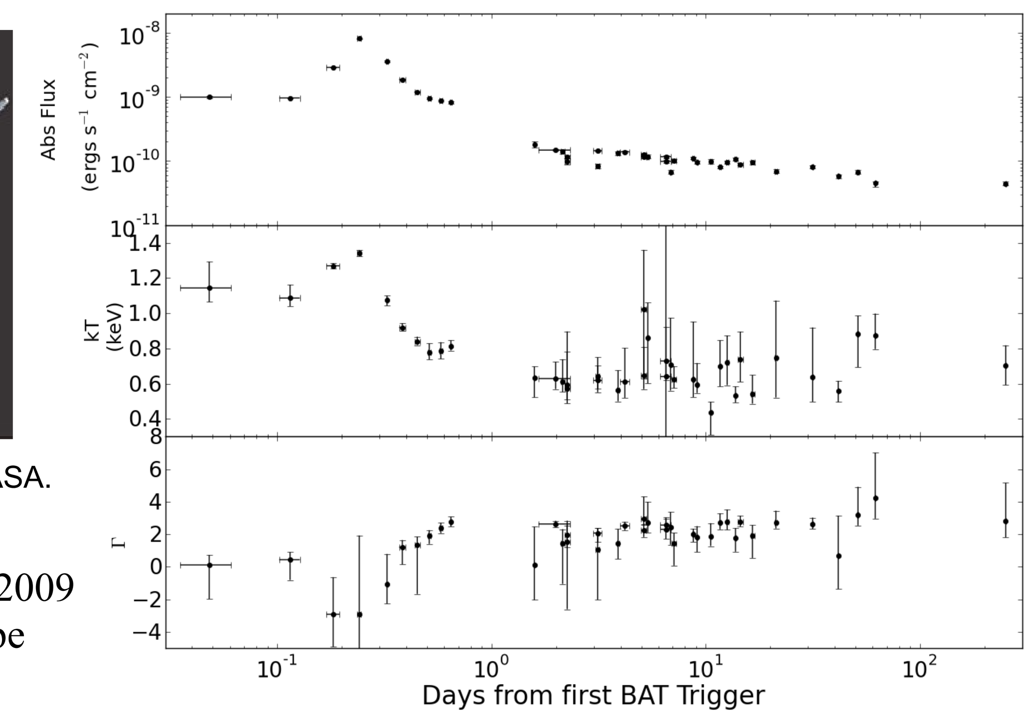
A prolific burster:
- During the 2009 outburst 424 bursts were observed by the *Swift* XRT.
- Classified as an soft gamma repeater (SGR), namely SGR 1550-5418, because of its extreme bursting behaviour
- The high number of bursts from the 2009 outburst allowed a detailed statistical burst study of 1E 1547-5408 [7], something that has only been done for three other magnetar outbursts.

2009 Outburst



Swift Satellite. Image courtesy of NASA.

Observations:
- 34 observations in Jan-Sept 2009 with the *Swift* X-Ray Telescope (XRT)[8]



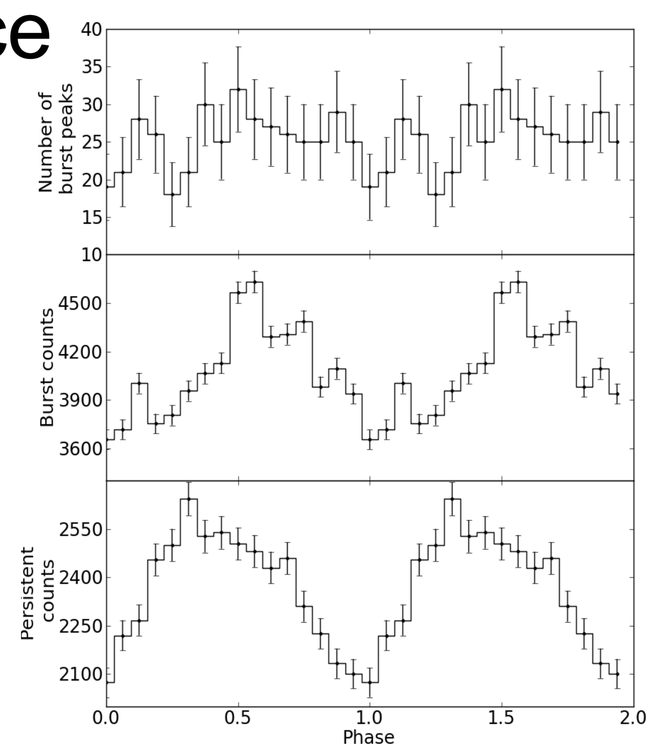
1-10 keV spectral evolution of 1E 1547-5408 during the 2009 outburst as observed by the *Swift* XRT. The flux decreased from a peak ~6 hr after the onset of the outburst. After ~1 day kT and Γ returned to their pre-outburst values.

Outburst:
- 1-10 keV flux increased by a factor of ~500.
- Flux increase was accompanied by significant spectral hardening
- Hundreds of bursts were detected by *Swift*, *INTEGRAL*, and *Fermi*.
- Most radiative changes occurred in the first day, and so were captured uniquely by *Swift* [7].
- Following the first day 1E 1547-5408 was observed with Chandra [9], Suzaku [10], Fermi [11], RXTE [12], INTEGRAL [13], and Parkes [14].
- The emission during the first day was heavily contaminated by dust scattering emission which complicates the spectral properties during that time [26]

Burst Phase Occurance

Bursts from other AXPs, as defined by their peak, are observed to arrive in phase [15,16] . SGR bursts, on the other hand, arrive randomly in phase [17,18].

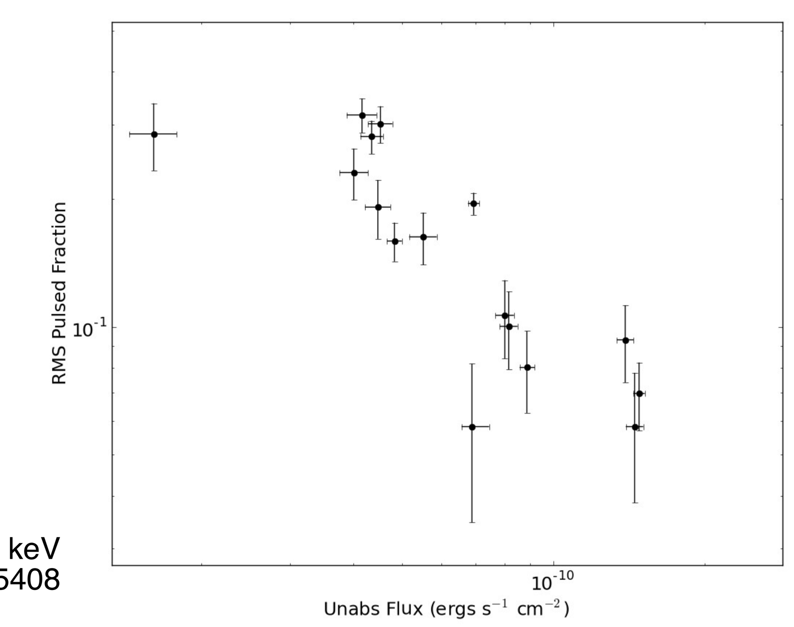
For the 2009 outburst of 1E 1547-5408:
- Times of the burst peaks seem to be distributed randomly in phase (top panel)
- The folded individual burst photons show a clear pulse(middle panel)
- Pulse is slightly offset from the persistent emission (bottom panel)
- Indicates burst origin distinct but similar from that of persistent emission



Folded profiles of burst peaks (top), individual burst photons (middle), and the persistent emission(bottom) for 2009 outburst.

Pulsed Fraction

- Figure shows anti-correlation between pulsed fraction and persistent flux during the 2008 and 2009 outbursts, possibly caused by an increase in emitting area as the flux of the source increases [9].
- Correlations [22,23] and anti-correlations [21,24] have been observed in other outbursts; must depend on viewing geometry [25].

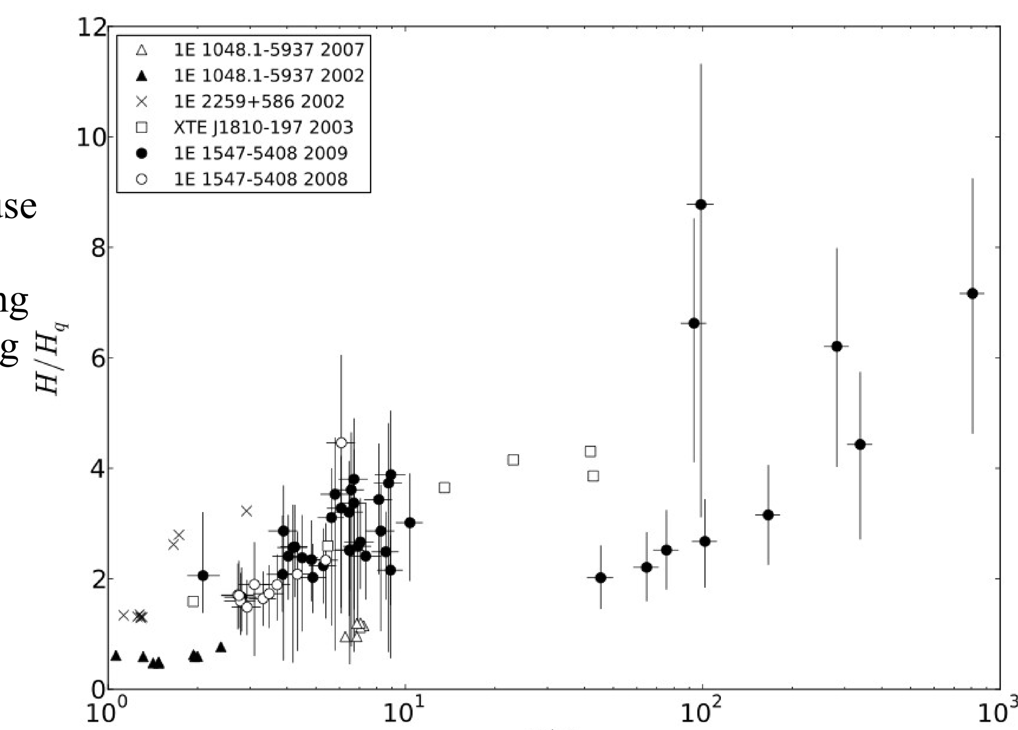


1-10 keV RMS pulsed fraction as a function of 1-10 keV unabsorbed flux for *Swift* observations of 1E 1547-5408 during the 2008 and 2009 outbursts.

Hardness-Flux Relation

Twisted magnetosphere model:
- The thermal emission of magnetars is caused by internal heating due to the decay of the strong magnetic fields [1]
- Twists in the magnetic field cause currents in the magnetosphere
- Currents cause additional heating of the surface as well as scattering in the magnetosphere

During Outburst:
- Increase of flux during an outburst is caused by an internal heat-releasing event
  - Increases the temperature of the surface
  - Increases the magnitude of the twists in the magnetosphere and thus the magnetospheric currents
- The increase in temperature and scattering leads to a hardening of the spectrum



4–10 keV/2–4 keV flux hardness, H, as a function of 2–10 keV flux, F for magnetar outbursts. Both are normalized to their quiescent values, Hq, Fq. For 1E1547−5408, the spectral fits used to determine the hardnesses and fluxes were from this work. For XTE J1810−197 the spectral parameters were taken from [20]. For 1E1048.1−5937 they were taken from [21]. For 1E 2259+586 they were taken from [22].

- A correlation between hardness and flux is thus expected [19].

In order to test this prediction, and to see if the amount of hardening is uniform among magnetars, the hardness increase for several magnetar outbursts is plotted against flux increase. A general correlation is observed, but there does not appear to be a uniform relation that holds among all magnetar outbursts [7].

Summary & Conclusions

On January 22, 2009, 1E 1547−5408 went into outburst. Its flux increased by a factor of ~500 and hundreds of bursts were detected. An analysis of the bursts and the persistent emission based on *Swift* XRT observations was performed [7]. The major results were:

- There was significant spectral hardening at the peak of the outburst, which occured ~6 hrs after the initial burst trigger; the emission then softened as the flux relaxed
- Though the burst peaks occurred randomly in phase, the folded burst counts showed a preferential phase that was distinct from that of the persistent emission
- The pulsed fraction was anti-correlated with persistent flux, consistent with an expanding hotspot on the neutron star surface
- Hardness – Flux correlation of magnetar outbursts holds in general, but there is no uniform relation that holds from magnetar to magnetar or outburst to outburst

The fast response of telescopes like *Swift* is crucial to understanding magnetars and their outbursts. For 1E 1547−5408, it allowed an analysis of the first day of the 2009 event. This is important as both the most significant spectral changes and the majority of the bursts occurred within this period. This highlights the necessity of prompt response to magnetar outbursts in understanding their nature.

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