A Study of Broad-Band Noise Characteristics of AXPs and SGRs

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ABSTRACT

We have analyzed Rossi X-ray Timing Explorer (R-XTE) and Chandra archival data and light curves of several AXPs and SGRs in order to reveal their broad-band noise characteristics. We detect that AXP and SGR sources show band limited noise at low frequencies in the range <0.05 Hz varying from 2.5% to 70% integrated rms in time including quiescence and quiescence data following some burst/outburst. We find that this noise level and its changes is most likely associated with the characteristic of their burst activities. Flares and glitches may also contribute to the changes in the broad band noise levels. We discover band-limited red noise in 1E 2259+586 with R-XTE only for ∼ two years after its outburst and the associated glitch. The system shows no broad-band noise otherwise. We detect a similar rise in the broad-band noise of 1E 1048.1-5937 after a long burst for about 1.95 years revealing a similar origin as the activity in 1E 2259+586. In general sources indicate a persistent band-limited noise at low levels in comparison. We favour that this broad-band noise is related to the Compton scattering of thermal photons in an existing magnetar corona and thus changes reveal coronal time scales and activity in these sources.

1 Introduction

Anomalous X-Ray Pulsars(AXPs) and Soft Gamma Repeaters(SGRs) are part of a new class of neutron stars (NSs), which their emission mechanisms commute with neither accreting X-Ray Pulsars nor radio pulsars (PSRs). Their periods are clustered between 5 - 12 s and they are characterized by their rapid spin down ($\sim 10^{-13} - 10^{-11}$ s s^{-1}) and high quiescent luminosities ($\sim 10^{33} - 5 \times 10^{35}$ erg s^{-1}) that can not be explained by spin down mechanisms. Also their spectra are modeled with a black body (kT≃0.41 - 0.67 keV) plus a power law model (Woods & Thompson 2006, and references therein). These objects are widely accepted as magnetars, neutron stars (NSs) with magnetic fields around 10^{14-15} Gauss powered by the decay of this strong field (Thompson & Duncan 1995). One other explanation for these properties is the existence of a fossil disk and accretion (van Paradijs, Taam, van den Heuvel 1995; Chatterjee et al. 2000; Alpar 2001) which fails to explain the giant flares, repeated bursts or the pulsed optical emission that exists in this class of objects.

SGRs demonstrate gamma ray bursts in various energy ranges in addition to the above AXP properties. This effect is first detected in SGR 0526-66 in March 5 1979 (Ramaty et. al 1980). SGR 1900+14 , SGR 1806-20 and SGR 1627-41 are the other three that belong to this category where former two also exhibit giant bursts in which rapid quasi periodic oscillations (QPOs) are detected after the onset of their flares (Israel et al. 2005; Strohmayer & Watts 2005). The magnetar model for these objects is based mostly on March 5 event (Duncan & Thompson 1992; Thompson & Duncan 1995). It explains the SGR bursts and predicts the AXP bursts which occurred in 1E 1048.1-5937 (Gavriil, Kaspi & Woods 2002) and 1E 2259+586 (Gavriil & Kaspi 2002).

RXTE Observation Log

Object	Obs Id	Ave. Count Rate c/s	Burst†
1E 1048.1-5937	40083-08	3.889	no
1E 1048.1-5937	50082-04	3.771	no
1E 1048.1-5937	60069-03	3.302	yes
1E 1048.1-5937	70094-02	7.030	no
1E 1048.1-5937	80098-02	5.667	no
1E 1048.1-5937	90076-02	3.580	yes
1E 1048.1-5937	91070-02	3.255	no
1E 1048.1-5937	92006-02	3.457	no
1E 2259+586	20145-01	1.799	no
1E 2259+586	20146-01	2.269	no
1E 2259+586	40082-01	1.752	no
1E 2259+586	50082-01	1.167	no
1E 2259+586	60069-01	0.4600	no
1E 2259+586	70094-01	2.695	yes
1E 2259+586	80098-01	1.765	no
1E 2259+586	90076-01	1.673	no
RXS J1708-40	40083-14	13.02	no
RXS J1708-40	50082-07	12.10	no
RXS J1708-40	60069-07	12.37	no
RXS J1708-40	60412-01	12.99	no
RXS J1708-40	70094-04	13.58	no
RXS J1708-40	80098-04	13.38	no
RXS J1708-40	90076-04	13.38	no
1E 1841-045	40083-11	9.521	no
1E 1841-045	50082-05	8.835	no
1E 1841-045	70094-03	9.937	no
1E 1841-045	90076-03	9.013	no
1E 1841-045	91070-03	9.006	no
SGR 1806-20	50142-01	7.626	yes
SGR 1806-20	50142-03	7.607	yes
SGR 1806-20	60121-01	7.053	yes
SGR 1806-20	70136-02	10.69	yes
SGR 1806-20	90073-02	10.93	yes
SGR 1806-20	90074-02	12.70	yes
SGR 1806-20	91062-02	8.721	yes

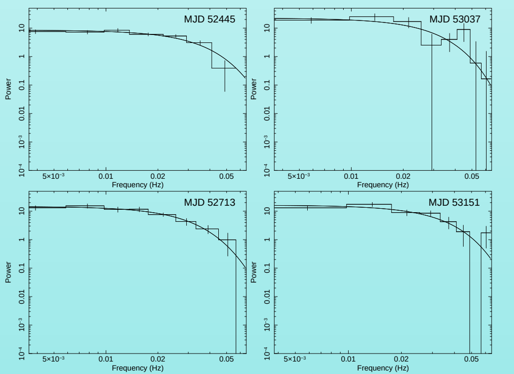
† Observation dates have been correlated with the GCN (http://gcn.gsfc.nasa.gov/gcn3_archive.html) burst data and relevant papers (see captions of Fig. 5).

2 RXTE Observations and Results

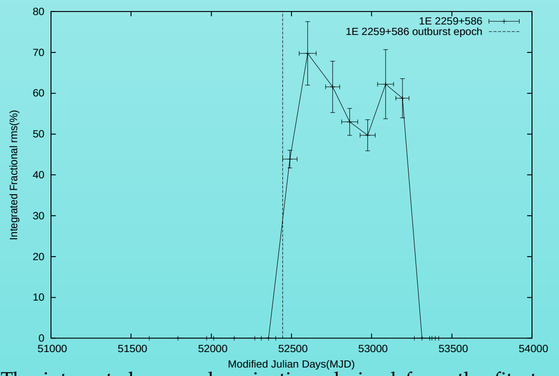
To calculate the band limited noise of these objects we used the 2 - 60 keV archived public light curves of Rossi X-Ray Timing Explorer (R-XTE). The R-XTE archive has a total of 10 sources that are either AXP or SGR. We used only appropriate sets of data, eliminating sources depending on epochs, exposures, burst dates and strong variable sources in the field of view (FOV). The data were obtained by the Proportional Counter Array (PCA; Jahoda et al. 1996) instrument aboard R-XTE. We obtained 125 ms resolution background subtracted light curves from archived standard products (StdProds) of R-XTE. The manipulation of the data was made with the FTOOLS v5.21 software. In order to measure the broad-band noise, we derived and averaged several power spectra for each source. The power spectral densities (PDS) expressed were calculated in terms of the fractional rms amplitude squared following from Miyamoto et al. (1991), and the expected white noise levels were subtracted hence leaving us with the rms fractional variability of the time series in units of $(\mathrm{rms}/\mathrm{mean})^2/\mathrm{Hz}$.

Figures show the averaged PDS fitted with a broken power law model ($\gamma\left[1. + (x/\nu)^2\right]^{-\alpha}$). Then, fitted PDS are integrated over $5 \times 10^{-3} - 5 \times 10^{-2}$ Hz interval. Each consecutive spectra in the panels of the integrated rms plots is averaged over three-month intervals and are separated by 5–900 days. In all sources, we find red noise with a break in the averaged PDS which may be considered as band limited noise (BLN).

1E 2259+586

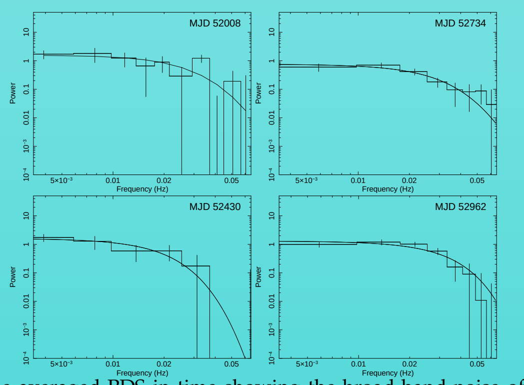


The averaged PDS in time showing the broad-band noise in AXP 1E 2259+586 with MJD 52443 as the burst epoch (Kaspi et al. 2003). The time line increases top to bottom first, then from left to right.

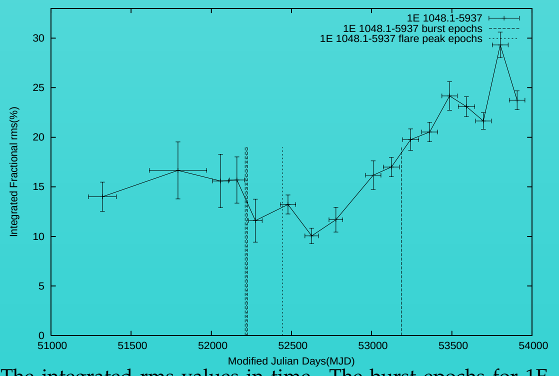


The integrated rms values in time derived from the fits to the PDS. The outburst epoch for 1E 2259+586 is from Kaspi, Gavriil & Woods 2002.

1E 1048.1-5937



The averaged PDS in time showing the broad-band noise of AXP 1E 1048.1-5937. MJD 52211 and 52227 are burst epochs (Gavriil & Kaspi 2004). The time line increases top to bottom first, then from left to right.



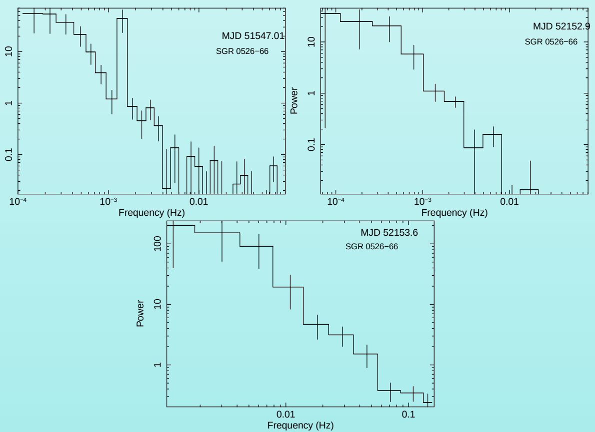
The integrated rms values in time. The burst epochs for 1E 1048.1-5937 are from Gavriil, Kaspi & Woods 2002 and Gavriil, Kaspi & Woods 2006, flare epochs are from Gavriil & Kaspi 2004.

The other two AXPs 1E 1841-045 and RXS J1708-40 maintain a persistent broad-band noise level compared with the two AXPs discussed in the above paragraph. Sources show around $\sim 11\%$ rms $\sim 7\%$ rms level noise, respectively with a slight increase in these levels in time. The total time span of the detected broad-band noise for the two different epochs for RXS J1708-40 are 2.3 years (51215-52053 MJD) and 2.6 years (52366-53325 MJD) . Also for 1E 1841-045 the time spans for two separate time epochs are 2 years (51977-51260 MJD) and 3.5 years (53635-52349 MJD). 1E 1841-045 also stands out as the noisier of the two.

We had difficulty relating the burst activity and the PDS for SGR 1806-20 due to the existence of excessive number of bursts. Overall this source exhibits broad-band noise at slightly variable but persistent level of about $\sim 10\%$ rms.

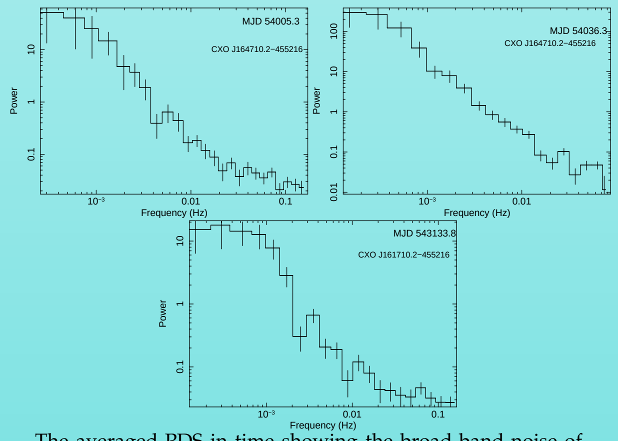
3 Preliminary Chandra PDS Analysis

SGR 0526-66



The averaged PDS in time showing the broad-band noise of SGR 0526-66. The source has been burst-inactive since 1983. The time line increases from top left to right.

CXO J164710.2-455216



The averaged PDS in time showing the broad-band noise of CXO J164710.2-455216. The data mode is obtained in continuous clocking mode. MJD 53999 is the burst epoch (Krimm et al. 2006) . The time line increases from top left to right.

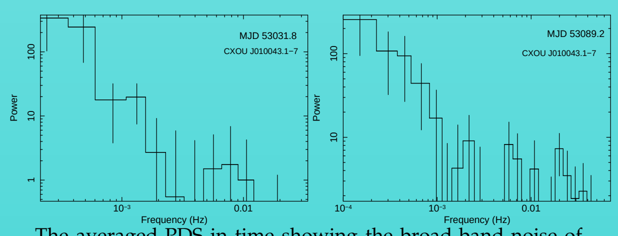
SGR 1627-41

This source does not show any broad-band noise in the time series derived from archival Chandra data between MJD 52182.2- MJD 53668.5

AX J1845-0258

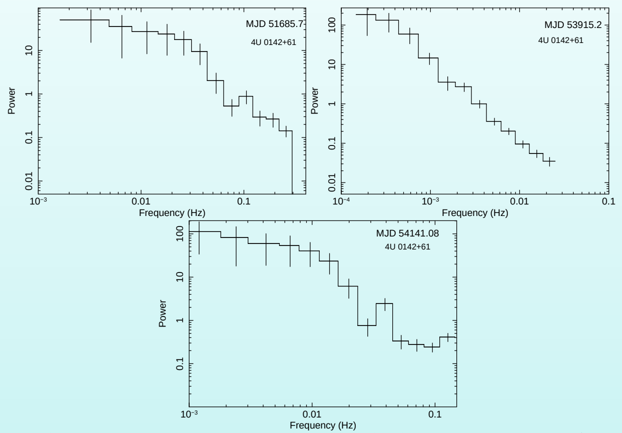
This source does not show any broad-band noise in the time series derived from archival Chandra data between MJD 52816.3 - MJD 54150.4

CXOU J010043.1-7



The averaged PDS in time showing the broad-band noise of CXOU J010043.1-7. The source have not shown any burst activity up until now. The time line increases from left to right.

4U 0142+61



The averaged PDS in time showing the broad-band noise of 4U 0142+61. The data is obtained in continuous clocking mode. The source has shown burst active period between burst epochs MJD 53831 and MJD 54138. It has shown 6 bursts with long durations of 3-8×10^3 sec. The time line increases from top left to right.

4 Discussion and Conclusions

- We find broad-band noise in the AXPs (1E 1048.1-5937, 1RXS 1708-40, 1E 1841-045 and 1E 2259+586, CXO J164710.2-455216, 4U 0142+61, CXOU J010043.1-7) and SGRs (SGR 1806-20, SGR 0526-66) mainly over the <0.05 Hz frequency band.
- The integrated rms values for the RXTE obseravtions are in a range 2.5-15% for four sources and 0% rms for 1E 2259+586 in quiescence. After bursts (our data do not include burst/outburst epochs) we have 20-70% integrated rms noise in two cases 1E 2259+586 and 1E 1048.1-5937, respectively.
- We detect flattening of the PDS in the lower frequencies with sharp cut-offs after 0.05 Hz; break frequencies in a range 0.05-0.7 Hz, and power-law indices varying between (-)4.8-375.8 (general best fit value range with a few exceptions) in time.
- Chandra PDS analysis indicates existence of broad-band noise for CXO J164710.2-455216, 4U 0142+61, CXOU J010043.1-7 and SGR 0526-66. We detect NO broad-band noise for SGR 1627-41 and AX J1845-0258 for a period of 3.5–4.0 years. CXO J164710.2-455216 shows increase in this noise after the burst at MJD 53999 for 4 months only. 4U 0142+61 shows a similar increase after the burst active state of 6 long burts after MJD 54138. This lasts at least a year. CXOU J010043.1-7 show some broad-band noise and no variation on this noise, but this source has no burst activity.
- The broad-band noise characteristics do not resemble either the accreting X-ray binaries or the isolated pulsars completely. In general, we find that they indicate a persistent level of integrated rms in time over a long base line of 3.5–5.5 years which may be a result of frequency fluctuations and variability due to Compton-up scattering in a magnetar coronae.
- The transition layer between the atmosphere and the corona is the location where up-scattered bremsstrahlung photons are emitted and they are converted to pairs in the ultra strong magnetic field (Thompson & Beloborodov 2005). The observed soft X-ray tail (2-10 keV) in AXPs and SGRs can be related to the resonant upscattering of the keV photons in the corona. We suggest that this scattering can produce or contribute to the noise we detect and its changes. The duration of this noise may be persistent or transient depending if the corona is in some sort of dynamic equilibrium where it is lost to the stellar surface and replenished with new particles.
- We calculate that 1E 2259+586 displays high level of broad-band noise lasting for a timescale of 2 years and no broad band noise other wise following its outburst and glitch. In addition, we find significant rise of the rms broad-band noise level in 1E 1048.1-5937 after the burst epoch at 53185 MJD which lasts at least for about 1.95 years as we have detected in our study. The change seen in 4U 0142+61 lasts over a year given the scarce amount of data. The increase in the broad-band noise level in CXO J164710.2-455216 is only for 4 months consistent with the short nature of the burst. There is similarity in the nature of the change in 4U 0142+61 and 1E 2259+586 after a collection of long bursts.
- There is a small class amoung AXPs and SGRs where no broad-band noise is deteceted. These sources are 1E 2259+586, SGR 1627-41 and AX J1845-0258. Amoung these only 1E 2259+586 shows a long noisy state after a period of burst activity and no noise once the long term effect subsides. In contrast to these three the rest of the sources indicates persistent level of noise at all times.

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