X-ray timing and spectral properties of the glitching AXP 1RXS J170849.0-400910

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1) Introduction

1RXS J170849.0-400910 (hereafter RXSJ1708) is one of the anomalous X-ray pulsars (AXPs), a small group of peculiar neutron stars that are believed to have super-strong magnetic fields, B $\approx 10^{14}$-10^{15} G, hence dubbed "magnetars" (for a recent review see Wood & Thomson 2006). RXSJ1708 was first discovered by ROSAT (Voges et al. 1996), while ~11s coherent pulsations were detected with ASCA (Sugizaki et al. 1997). Early measurements suggested that it was a fairly stable rotator, with a spin-down rate of ~2×10^{-11} s/s, and a soft spectrum (Israel et al. 1999, 2001). Events of sudden spin-up (glitches) with very different post-glitch recovery were detected by RXTE in 1999 and 2001 (Kaspi et al. 2000, 2003; Dall'Osso et al. 2003). The rather short interglitch time makes this AXP a frequent glitcher among neutron stars.

Rea et al. (2005) analysed over 5 years of data, and noticed that, below ~10 keV, the long term variations in the source X-ray flux and spectral hardness seem to be correlated, with both quantities reaching a maximum close to the epochs of the two glitches in 1999 and 2001. The correlation was not highly statistically significant and it may be due to inter-calibration effects between the various instruments, but, if taken at face value, it led to the tantalizing idea (Zane et al. 2007; Rea et al. 2007) that the long-term variations may have a cyclic behavior with a recurrence time of ≈5-10yrs, possibly due to a periodic twisting/untwisting of the star magnetosphere (Thomson, Lyutikov & Kulkarni 2002). Correspondingly, the source was expected to re-enter into a glitching active phase during 2005-2006, close to the latest maximum in the source flux.

1) Timing Analysis

We analyzed the RXTE archival observations of RXSJ1708 spanning the latest 3.5 years, from 2003 January 5th to 2006 June 3rd. We limited to the PCA, which was operated in good Xenon data mode with a time resolution of 1 μs and 256 energy bins between 2 and 120 keV. For all details, see Israel et al. (2007).

In order to search for new glitches, we first obtained a phase-coherent timing solution using a 29ks archival Chandra observation carried out on 2004 July 3rd (Rea et al. 2005b). This provided a period measure, P=11.00231(3)s, accurate enough that no pulse cycle was missed when extrapolating this value to the epoch of the closest RXTE pointing (2004 July 1st). A phase-coherent timing solution was inferred in the time interval between 2004 May 1st and November 16th: ν=0.090890035(1) Hz, $d\nu/dt$=-1.5884(14) (epoch 53819.0 MJD; 1σ c.l. hereafter). This is coincident with the 2001 post-glitch solution by Dall'Osso et al. (2003).

The inclusion of the 2005 and 2006 datasets showed large disagreement with this timing solution, with two evident "jumps" in phase both marking a decrease in the period (see blue and dark violet filled circles in Figure 1A).
This shows that two new glitches occurred at the end of 2004 / begin 2005 (MJD 53370) and in May 2005 (MJD 53550). No signature for similarly large glitches was instead found in the data taken between Jan. 2003 - June 2004.

Following the scheme outlined in Dall'Osso et al. (2003), we performed a detailed timing analysis to phase residuals and we inferred the main parameters of the two detected glitches (see Table 1). Both glitches reveal large jumps in the spindown rate,
$\Delta d\nu/dt/(d\nu/dt) \sim 7\times10^{-2}$ and ~0.1, among the largest ever observed in glitches that lack a significant short-term exponential recovery. Remarkably, they have opposite signs: the second glitch has cancelled the effect of the previous increase in $d\nu/dt$ and, actually, somewhat overshot it (Fig. 1B).
The jump in spin frequency after the first glitch appears have been recovered in ~120d. The upper limit on $d^2\nu/dt^2$ after the first glitch implies that the jump in $d\nu/dt$ could have been recovered, if at all, only on a much longer timescale and not until the second glitch occurred, ~175d after the first one. At the second glitch, an even larger spin-up occurred, accompanied by a significant flattening of the spindown trend. Thus, the spin up started with a sudden increase and then it slowly continued.

Both the two new glitches have a large fractional amplitude, $\Delta\nu/\nu \sim 1.2\times10^{-6}$ and 2.1×10^{-6} respectively, comparable to the so-called giant glitches observed from Vela and to those previously detected from this source in 2001 (Dall'Osso et al., 2003; Kaspi et al. 2003). Therefore, giant glitches seem to be the rule for this source. Based on conservative assumptions, and considering all X-ray flux measurements taken until the first Swift set of observations in 2005, we estimated the false alarm probability that the observed glitches occur by chances close to the flux maxima displayed by the observations to be 3%.

Rib et al (2008) reported on an independent discover of glitches from RXSJ1708, based on the same datasets, and considered our glitch N.1 as a candidate rather than a true event. Although a detailed comparison is beyond our scope, we note that a source of discrepancy is due to their use of high order frequency derivatives (used to identify glitches), in the presence of gaps in the phase-series. Indeed, two out of the three candidate glitches reported by these authors are found when data gaps are also present.

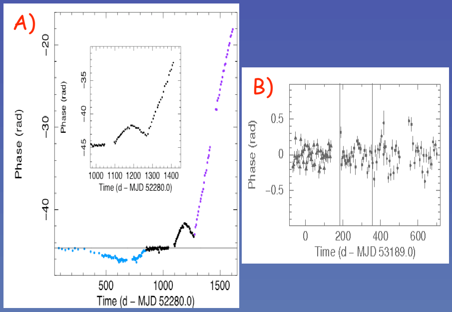

Fig.1. A) RXTE time residuals for the time interval January 2003- June 2006 after subtraction of the phase-coherent P-dP/dt solution by Dall'Osso (2003). The inset shows the time interval over which we detected the two glitches.
B) Time residuals of RXTE observations from June 2004 to June 2006 after subtraction of pre-and post-glitch model N.1 and the polynomial post-glitch model N.2 (Table 1). Vertical lines indicate the inferred epochs of the glitches. Both Figures are taken from Israel et al. (2007).

Table 1. Measured parameters for the two glitches. 1σ errors in the last digit are quoted in parenthesis. From Israel et al. (2007).

pin Parameter	Post glitch N.1	Post glitch N.2
poch (MJD)	53372(2)	53546.0(8)
(Hz)	0.090887638(16)	0.09088525(20)
ν/dt (10^{-13} s^{-2})	-1700(4)	-1.536(7)
$^2\nu/dt^2$ (10^{-22} s^{-3})	<4.7	-3.78(34)
MJD range	53372-53545	53546-53889
. datapoints	29	45
.m.s. (s)	0.26	0.39
ν/ν (x 10^{-6})	1.18(3)	2.08(5)
dν/dt /(dν/dt) (x 10^{-2})	7.0(3)	-10.35(34)

2) Spectral Analysis

In order to investigate the spectral properties of RXSJ1708 over a broader energy range and to further assess the validity of the flux/hardening correlation below 10keV, we are performing a multi-wavelength observation campaign with Integral (ISGRI data, 15keV-1MeV energy range, taken as a part of the Key Programme observation of the Galactic Centre, 622 pointings performed in Fall 2006, and Spring 2007) and Swift. Here we report a preliminary update of our results. In addition:

- we selected and analyzed all publicly available IBIS INTEGRAL coded mask imager pointings within 12 degrees from the direction of the source, for a total of 2550 pointings of 2-3 ks each.
- re-analysed, using the latest s/w releases, all the public available recent data of RXSJ1708 taken with X-ray imaging telescopes in the soft X-rays (i.e. below ~10 keV). This encompasses data taken with SAX, Chandra, XMM-Newton and Swift.

All details of this work, and a complete observations log, are reported in Gotz et al. (2007). Since that paper, we obtained 3 new Swift observations, further INTEGRAL data became public, and we obtained INTEGRAL data from the KP observations of the Galactic Centre in Fall 2007 and Spring 2008. We also added an INTEGRAL point non-simultaneous with Swift data (third pointa from the right in the top panel of Fig.2), for a a total of 1479 more pointings than in Gotz 2007). The preliminary analysis of all these new datasets is reported here.

In the 1-10 keV energy range, the spectral analysis has been performed by fitting all the datasets simultaneously (except for Chandra data which were limited to 8 keV), and by using an absorbed black body plus power law model. While the parameters of the power law have been left free to vary, the absorption column density and the black body temperature have been forced to be the same for all instruments. We found a good fit (χ^2/d.o.f. = 1.02 for 1986 d.o.f.), with $N_H=1.36(5)\times10^{22}$ cm^{-2} , and kT=0.42(1) keV; we verified that, if leaving these parameters free to vary, they do not change significantly among all the observations. The fluxes and photon indices are reported in Fig.2.

For the INTEGRAL data, we produced the images of each pointing in ten energy bands between 20 and 300 keV. We then added up the images in order to detect the source in the 20-70 keV energy range. To investigate the broad-band temporal X-ray variability, the observations were ganged-up to overlap available soft X-ray data sets. The resulting fluxes (20-70 keV) are shown in Fig.2.

As for the soft X-rays we found that, when using the latest s/w releases, the hardening/flux correlation is still present in data taken until 2005, although at a slightly lower level of significance. Furthermore, the new XRT campaign undertaken after 2006 (last 3 points in Fig.2) shows that the source entered a state of nearly constant flux (both, the 1-10keV flux and photon index are consistent with being constant within 2σ). This is somewhat disappointing since, in order to assess the flux-hardness correlation proposed by Rea et al. (2005), having a complete set of data taken with the same instrument and therefore not affected by cross-calibration unceratainaties is particularly compelling. At present, due to the almost nil flux variations experienced in the last period, no firm conclusion can be reached.

Similarly goes for the new hard-X data. As we can see from Fig.2,the hard X-ray count rates measured before 2005 follow well the variations measured in the soft X-ray range, showing that before the new glitching period the long term variation in flux was correlated over more than two orders of magnitude in energy. However, after 2006 the IBIS fluxes show a more erratic behaviour, apparently uncorrelated with that of the soft X-rays (see also den Hartog 2007). Unfortunately, due to the faintness of the source we could not statistically prove spectral changes at high energies, by comparing different Integral observations. In order to obtain a statistically significant high energy spectrum, we co-added the IBIS data. The resulting 20-200 keV spectrum is well fitted by a single power law, without the need for a cutoff, with photon index Γ=1.46 ± 0.21. The 20-100 keV flux is $(3.6 \pm 0.5)\times10^{-11}$ ergs cm^{-2} s^{-1}.

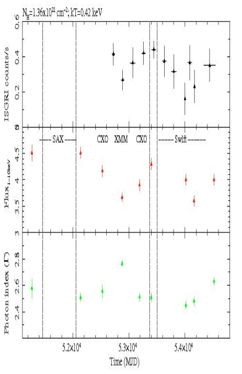

Fig.2.

Upper Panel: INTEGRAL/IBIS count rate (20-70 keV).
Middle Panel: absorbed 1-10 keV fluxes (in units of 10^{-11} erg cm^{-2}s^{-1}) derived from recent observations of X-ray imaging telescopes as a function of time.
Lower Panel: photon indices measured in the 1-10 keV energy band. Vertical dashed lines mark the times of four observed glitches.

Updated from Gotz et al. (2007).

3) Summary

In Rea et al. (2005), we noticed a possible correlation between the X-ray flux and the spectral hardness and proposed that, if real, it may be explained if the evolution is regulated by the change of a "twist" in the magnetosphere (see also Thompson et al. 2002). The evolving magnetic field is expected to fracture the crust at intervals, eventually causing an increased activity and large amplitude glitches. At that time, we found that observations collected until 2003 were consistent with a scenario in which the twist angle was steadily increasing before the glitch epochs, culminating with glitches and a period of increased timing noise, and then decreasing, leading to a smaller flux and a softer spectrum.

Interestingly, the evolving twist model provides a natural explanation for the new period of glitching activity, that was foreseen in our previous papers.
We emphasise that while we do expect glitching activity corresponding to an increasing stress of the crust caused by a growing twist, glitches might also occur outside these epochs, in particular if glitches with different properties (such as amplitude and recovery) reflect a difference in triggering mechanism.

In order to assess more robustly the flux/hardening correlation, and eventually to investigate its extrapolation in a broader energy range, we are now continuing to monitor the long term behaviour of RXJ1708 in the soft X-ray range (<10 keV) with Swift and in the hard X-rays (20-70keV) with INTEGRAL. We have now analysed all the currently available high energy data (1-200 keV) of the source showing that, before 2005, there may be a hint for a correlation between the hard X-ray long term flux changes and the flux variations detected at lower energies. However, after 2005 the source entered a phase of nearly constant flux, and the link between the various quantities become more erratic. Therefore, at present no robust conclusion can be drawn and we cannot yet exclude the variability being due to a fluctuation or inter-calibration issues. Further Swift and INTEGRAL observations, expected in the near future, will shed light on this issue.