Intermittent accreting millisecond pulsars: Light houses with broken lamps?

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A Decade of Accreting Millisecond X-ray Pulsars

Intermittent accreting millisecond pulsars: light houses with broken lamps?

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Abstract. Intermittent accreting millisecond X-ray pulsars are an exciting new type of sources. Their pulsations appear and disappear either on timescales of hundreds of seconds or on timescales of days. The study of these sources add new observational constraints to present models that explain the presence or not of pulsations in neutron star LMXBs. In this paper we present preliminary results on spectral and aperiodic variability studies of all intermittent AMSPs, with a particular focus on the comparison between pulsating and non pulsating periods.

Keywords: binaries: general, stars: neutron, stars: rotation, intermittent pulsars, accreting millisecond X-ray pulsars
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INTRODUCTION

Already in the early 1980s it was predicted [1, 2] that the progenitors of millisecond radio pulsars should be accretion-powered millisecond X-ray pulsars (AMSPs) in neutron-star low-mass X-ray binaries (LMXBs). However, it was not until 1998 that the first AMSP was discovered [3]. Since then, a total of seven AMSPs have been found but still for most neutron-star LMXBs no coherent millisecond X-ray pulsations are detected. Recently three sources were found which showed characteristics connecting these two types of behavior.

HETE J1900.1-2455 [4] is a transient source which has remained active for $\sim$ 3 years[1] but (intermittent) pulsations were detected during only the first $\sim$ 70 days of activity [see 5]. On three occasions during this period, it was observed an abrupt increase in the pulse amplitude, approximately coincident with the time of a thermonuclear burst, followed by a steady decrease on a timescale of 10 days. Although there seems to be a relation between between occurrence of X-ray burst and onset of pulsations, only 1 X-ray burst was observed with PCA, while the other 7 were observed with Swift or HETE-II. Therefore, the delay between the burst and the onset of pulsations is not always known. No burst oscillations have been detected yet.

Aql X-1 is a $\sim$ 550 Hz burst oscillation transient source from which pulsations were detected [6] only for $\sim$ 150 sec out of the $\sim$ 1.5 Msec the source has so far been observed with RXTE. The pulsations were discovered at the end of a one-orbit $\sim$ 1500-seconds observation. Given the data structure, we cannot exclude the occurrence of an

[1] At the time of submitting this contribution, the source is still active – see also Duncan Galloway's contribution.

X-ray burst $\sim$ 1400 seconds before the pulsations or immediately after the pulsations disappeared [see Figure 2 in 6].

SAX J1748-2021 is a transient source from which intermittent pulsations were detected during the 2001 and 2005 outbursts [7][2]. The pulsations appeared and disappeared on timescales of hundreds of seconds. A suggestive relation between the occurrence of type-I X-ray bursts and the appearance of the pulsations was found, but the relation is not strict [7, 8]. Similarly to HETE J1900.1-2455, no burst oscillations have been detected.

It is unclear if the intermittence of the pulsations in these three sources are caused by the same mechanism and if they are unique among the neutron-star LMXBs. In this paper, we present preliminary results on our effort to further explore on the differences and similarities between AMSPs, intermittent AMSPs and non-pulsating neutron star systems.

SOURCE STATES AND PULSATIONS

Hasinger and van der Klis [9] classified the NS LMXBs based on the correlated variations of the X-ray spectral and rapid X-ray variability properties. They distinguished two sub-types of NS LMXBs, the Z sources and the atoll sources, whose names were inspired by the shapes of the tracks they trace out in an X-ray color-color diagram on time scales of hours to days. The Z sources are the most luminous while the atoll sources cover a much wider range in luminosities [e.g. , 10, and references therein]. For each type of source, several spectral/timing states are identified which are thought to arise from qualitatively different inner flow configurations. In the case of atoll sources, the main three states are the extreme island state (EIS), the island state (IS) and the banana branch (BB). Each state is characterized by a unique combination of spectral and timing behavior.

Interestingly, all AMSPs with persistent pulsations have been observed **only** during their island or extreme island state [11]. The 3 intermittent AMSPs are the only pulsating sources that have been observed not only in their island states, but also in their (soft) banana states. In Figure 1 we show the color-color diagrams for these three sources. For Aql X-1 and SAX J1748–2021 we also mark where the pulsations were found. For HETE J1900.1-2455, the pulsations are only present in the EIS/IS.

POWER SPECTRA IN THE INTERMITTENT AMSPS

It has been shown that the frequencies of all the components (except for those of the so-called hectoHertz QPOs) found in the power spectra of non-AMSPs are correlated in a similar way between sources [see, e.g., 12, 13, 14]. It has also been shown that the shape of the power spectra between AMSPs and non-AMSPs are very similar. However, the frequency correlations for AMSPs and non-AMSPs are found to be shifted in frequency

[2] We emphasize that this is the third AMSPs showing more than a single outburst; the other two are SAX J1808-.4-3658 and IGR J00291+5934.

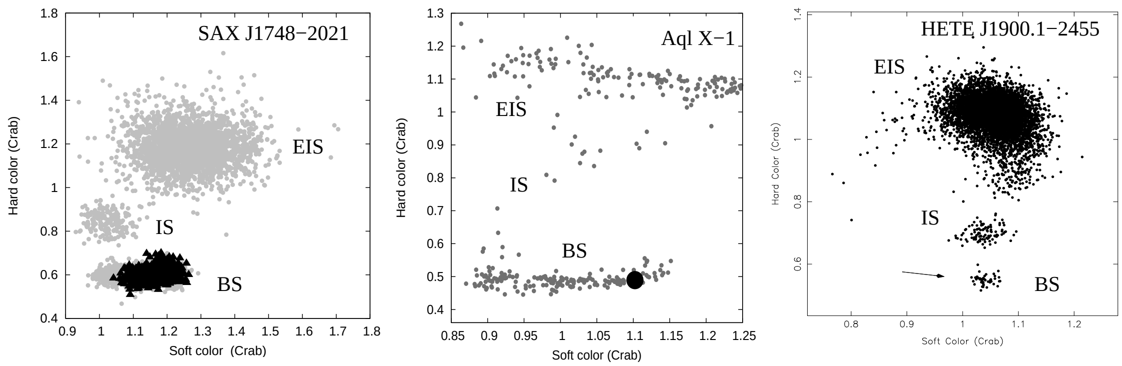

FIGURE 1. Color Color diagrams for SAX J1748–2021 (16s averages), Aql X-1 (average per observation) and HETE J1900.1-2455 (16s averages). The black triangles and the circle show the source state when pulsations in SAX J1748–2021 and Aql X-1 were present. The arrow marks the detection of kHz QPOs in HETE J1900.1-2455. This detection plus the colors confirm that this source was in its soft state.

[15, 16] and only one non-AMSP (4U 1820–30) might show frequency shifts as those seen in AMSPs [17]. Confirming whether the pulse mechanism in AMSPs is related or not with these frequency shifts might give important clues that help us understand the differences between AMSPs and non-AMSPs.

The intermittent AMSPs now allow us to further investigate differences in the aperiodic variability during pulsating and non-pulsating intervals. As a first step, we analyzed all public observations of these three sources, and compare power spectra within each source. We find that (i) for SAX J1748–2021 most of the power spectra are typically of the (upper) banana state, during both pulsating and non-pulsating periods; the low-frequency noise seems to be weaker when pulsations are present; (ii) the average power spectrum of the observation of Aql X-1 in which pulsations were detected is typical of the upper banana state; the statistics is not enough to allow any detailed study of the shape of the PDS during the 150 seconds in which pulsations were detected; (iii) most of the power spectra of HETE J1900.1-2455 are like those typically seen during the EIS and IS. We found identical (within errors) power spectra during the pulsating and the non-pulsating periods. In Figure 2 we show representative power spectra. Our results suggest that frequency correlations within a given intermittent source will not differ between pulsating and non-pulsating periods.

QUESTIONS AND ANSWERS

Only 10 out of more than 100 neutron stars LMXBs have shown millisecond pulsations associated with the spin frequency. Why these sources are different has been the subject of many discussions during the last decade. Now, the recent discovery of the 3 intermittent AMSPs allow us to better study differences between sources, as well as to conclude that irrespective of the mechanisms behind the pulsations in these three sources, it is now clear that there is not a strict division between pulsating and non-pulsating sources. It is possible that all sources pulsate occasionally although the recurrence times could be very long.

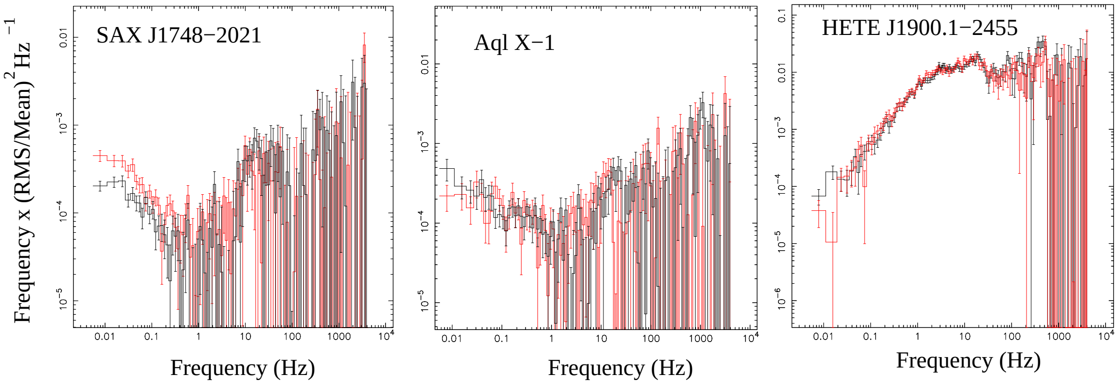

FIGURE 2. Representative power spectra during periods with and without pulsations (black and gray, respectively) for SAX J1748–2021 (left), Aql X-1 (middle) and HETE J1900.1-2455 (right).

Although the intermittent AMSPs might give us new clues to understand these systems, they also raise new questions: can a unique scenario explain all the intermittency observed (HETE J1900.1-2455 shows a decrease in pulse amplitude in timescales of days or weeks, while Aql X-1 and SAX J1748–2021 in timescales of hundreds of seconds)? Is there a relation between the pulse mechanism and the thermonuclear burning on the neutron star surface? What is the relation between the pulse mechanism and the burst oscillation mechanism? Interestingly, bursts and burst oscillations have been detected in the AMSPs SAX J1808.4-3658 and XTE J1814-338, and bursts without burst oscillations in the two intermittent AMSPs SAX J1748-2021 and HETE J1900.1-2455. The only connecting system might be Aql X-1, since no X-ray bursts have been detected in the other AMSPs. Does the pulse mechanism affect in any way the observed aperiodic variability? Some of these questions are discussed in this volume.

REFERENCES

1. M. A. Alpar, A. F. Cheng, M. A. Ruderman, and J. Shaham, *Nature* **300**, 728–730 (1982).
2. D. C. Backer, S. R. Kulkarni, C. Heiles, M. M. Davis, and W. M. Goss, *Nature* **300**, 615–618 (1982).
3. R. Wijnands, and M. van der Klis, *Nature* **394**, 344–346 (1998).
4. P. Kaaret, E. H. Morgan, R. Vanderspek, and J. A. Tomsick, *ApJ* **638**, 963–967 (2006).
5. D.Galloway, E.Morgan, M. Krauss, P. Kaaret, and D. Chakrabarty, *ApJ* **654**, L73–L76 (2007).
6. P. Casella, D. Altamirano, A. Patruno, R. Wijnands, and M. van der Klis, *ApJ* **674**, L41–L44 (2008).
7. D. Altamirano, P. Casella, A. Patruno, R. Wijnands, and M. van der Klis, *ApJ* **674**, L45–L48 (2008).
8. A. Patruno, D. Altamirano, J. W. T. Hessels, P. Casella, R. Wijnands, and M. van der Klis, *ArXiv e-prints* **801** (2008), `0801.1031`.
9. G. Hasinger, and M. van der Klis, *A&A* **225**, 79–96 (1989).
10. E. C. Ford, M. van der Klis, M. Méndez, R. Wijnands, et al. , *ApJ* **537**, 368–373 (2000).
11. R. Wijnands, *ArXiv Astrophysics, astro-ph/0501264* (2005), `arXiv:astro-ph/0501264`.
12. S. van Straaten, M. van der Klis, T. di Salvo, and T. Belloni, *ApJ* **568**, 912–930 (2002).
13. S. van Straaten, M. van der Klis, and M. Méndez, *ApJ* **596**, 1155–1176 (2003).
14. D. Altamirano, M. van der Klis, M. Méndez, P. G. Jonker, et al. , *ApJ in press* (2008)
15. S. van Straaten, M. van der Klis, and R. Wijnands, *ApJ* **619**, 455–482 (2005).
16. M. Linares, M. van der Klis, D. Altamirano, and C. B. Markwardt, *ApJ* **634**, 1250–1260 (2005).
17. D. Altamirano, M. van der Klis, M. Méndez, S. Migliari, P. G. Jonker, A. Tiengo, and W. Zhang, *ApJ* **633**, 358–366 (2005).