Discovery of a 26.2 day period in the long-term X-ray light curve of SXP 1323: a very short orbital period for a long spin period pulsar

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\begin{abstract}
\textbf{Context.} About 120 Be/X-ray binaries (BeXBs) are known in the Small Magellanic Cloud (SMC); about half of them are pulsating with periods from a few to hundreds of seconds. SXP 1323 is one of the longest-period pulsars known in this galaxy.

\textbf{Aims.} SXP 1323 is in the field of view of a large set of calibration observations that we analyse systematically, focusing on the time analysis, in search of periodic signals.

\textbf{Methods.} We analyse all available X-ray observations of SXP 1323 from Suzaku, XMM-Newton, and Chandra, in the time range from 1999 to the end of 2016. We perform a Lomb-Scargle periodogram search in the band 2.5-10 keV on all observations to detect the neutron star spin period and constrain its long-term evolution. We also perform an orbital period search on the long-term light curve, merging all datasets.

\textbf{Results.} We report the discovery of a 26.188±0.045 d period analysing data from Suzaku, XMM-Newton, and Chandra, which confirms the optical period derived from the Optical Gravitational Lensing Experiment (OGLE) data. If this corresponds to the orbital period, this would be very short with respect to what is expected from the spin/orbital period relationship. We furthermore report on the spin period evolution in the last years. The source is spinning-up with an average rate of $\dot{P}/|P|$ of 0.018 yr\textsuperscript{−1}, decreasing from ~1340 to ~1100 s, in the period from 2006 to the end of 2016, which is also extreme with respect to the other Be/X-ray pulsars. From 2010 to the end of 2014, the pulse period is not clearly detectable, although the source was still bright.

\textbf{Conclusions.} SXP 1323 is a peculiar BeXB due to its long pulse period, rapid spin-up for several years, and short orbital period. A continuous monitoring of the source in the next years is necessary to establish the long-term behaviour of the spin period.

\textbf{Key words.} galaxies: individual: Small Magellanic Could – stars: neutron – X-rays: binaries – X-rays: individual: SXP 1323 – stars: emission-line, Be
\end{abstract}

1. Introduction

Be/X-ray binaries (BeXBs) belonging to the class of High-Mass X-ray binaries (HMXBs) are composed of a Be star and a compact object, generally a neutron star. In those systems, it is believed that mass transfer occurs from the equatorial decretion disc around the donor star, onto the compact object during the periastron passage of the neutron star in an eccentric orbit, either via an accretion disc or via wind capture. In this class of object, the pulse period is generally well correlated to the orbital period as reported initially by Corbet [1984, 1986], although with large scatter. The second group of HMXBs are the supergiant X-ray binaries, where the massive companion is an evolved star in which matter is transferred to the compact object via a strong wind.

A large number of BeXBs have been reported so far in the Small Magellanic Cloud (SMC) [Coe & Kirk 2015, Haberl & Sturm 2016, Galache et al. 2008] monitored 41 BeXB systems in the SMC over nine years using RXTE Proportional Counter Array (PCA) data in search of orbital modulations. They confirmed and refined ten known orbital ephemerides and determined ten new ones. More recently, Klus et al. [2014] reported the long-term average spin period of 42 BeXB systems, using RXTE data, claiming they all contain a neutron star accreting via a disc rather than a wind.

SXP 1323 is a pulsar discovered by Haberl & Pietsch [2005], and it shows one of the longest pulse periods known in the SMC.

Schmidtke & Cowley [2006a,b] reported the discovery of several strong periodic signals in the optical light curve of SXP 1323, using Optical Gravitational Lensing Experiment (OGLE) data. The optical light is coming from the Be star itself, the decretion disk and transient accretion disk around the neutron star. Three strong peaks were discovered at periods of 0.41 d, 0.88 d, and 26.16 d, all showing approximatively sinusoidal light curves. The first two are believed to come from non-radial pulsations of the Be star. Later, Bird et al. [2012], analysed the OGLE light curves of 49 SMC BeXBs, and confirmed the period at 26.17 d. Authors of both papers conclude that the short periods and sinusoidal shapes are not characteristic of an orbital modulation of a decretion disc, and explain the 26.2 d period with the aliasing of non-radial pulsations at a period of 0.96 d.

2. Observations and data reduction

SXP 1323 is very close to the bright supernova remnant (SNR) 1E 0102-72.3, which is often observed for calibration purposes (see e.g. Plucinsky et al. 2008, 2017). A large number of observations of the source are therefore available from several X-ray observatories.

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2.2. XMM-Newton observations

Currently, 48 XMM-Newton (Jansen et al. 2001) observations are available for SNR 1E 0102-72.3. For two of them no European Photon Imaging Camera (EPIC) data are available, leaving 46 datasets with exposures from \( \sim 14 \) to 69 ks performed between April 2000 and December 2016. Only exposures recorded in imaging mode and with the source in the field of view are analysed. Table [A.2] reports a summary of all observations used in this work.

For the event filtering, single to double and single to quadruple events are used for pn (Strüder et al. 2001) and Metal-Oxide-Silicon (MOS) (Turner et al. 2001) cameras respectively, all with FLAG=0.

2.3. Chandra observations

The pulsar is visible in 201 observations performed with Chandra’s Advanced CCD Imaging Spectrometer (ACIS) instrument (Garmire et al. 2003), on the SNR. Those data were recorded from August 1999 to March 2016 and the datasets used in this paper are listed in Table [A.3]. Events from observations performed on the same day or on two consecutive days were merged together, leaving 66 independent datasets (see column 1 of Table [A.3]). Columns 2 and 3 give the observation ID, the operating ACIS CCDs (0-3 are I0-I3 and 4-9 are S0-S5). From 2008, the source is not in the field-of-view for most observations since only one detector was used to observe 1E 0102-72.3.

3. Analyses and results

The source extraction region is centred on coordinates RA, DEC= 01:03:37.8, -72:01:33, extracted from the Two Micron All Sky Survey (2MASS) catalogue (Cutri et al. 2003), with a radius of 62.5\'' for Suzaku and 30\'' for XMM-Newton. For Chandra the radius was 7.4\'', 12.3\'', 24.6\'' depending on the off-axis angle of the source. For the background region, for XMM-Newton and Chandra, we use an annulus centred on the source, both with an inner and outer radius of, for XMM-Newton, \( r_{in}=25\''\), \( r_{out}=40\''\) and for Chandra, depending on the position of the source in the field of view: \( r_{in}, r_{out}=7.4\'', 14.8\'', 12.3\'', 24.6\''\) or \( r_{in}, r_{out}=24.6\'', 39.6\''\). On the other hand, in the case of Suzaku, the background region was not centred around the pulsar coordinates because of a potential contamination from the nearby SNR due to the large extraction region. Instead it is centred for most of the observations around coordinates RA, DEC= 01:02:56, -72:00:57, with a radius of 62.5\'' (another region is chosen when this one is out of the field of view).

3.1. Pulse period search

The pulse period search was performed using Lomb-Scargle periodogram analysis (Lomb 1976; Scargle 1982), in the energy band 2.5–10 keV where the signal-to-noise ratio for the emission of the pulsar is maximised, and in the period range 900–1600 s. The light curves are barycenter-corrected, background-subtracted and binned to 50 s. In the case of XMM-Newton and Suzaku, events recorded by the different instruments are merged together. However, when one or more instrument is not operating for some time interval discontinuities appear in the light
Fig. 2: Long-term spin period evolution observed with Suzaku (green), XMM-Newton (blue) and Chandra (red) data. The dotted black line is the result of a linear fit performed on data from 2006 to 2017.

curves. We correct for those effects by multiplying the portions of the light curves not covered by all cameras, by some factor, assuming that, in the 2.5–10.0 keV band, the effective area of the XMM-Newton pn camera is about 3.2 times larger than the MOS ones, and that the effective area of Suzaku’s front illuminated cameras (XIS0, XIS2 and XIS3) is about 1.1 times larger than the back illuminated one (XIS1). The uncertainties on the period are measured by fitting a Gaussian function with the Python module astropy.modeling.Gaussian1D. The error bars correspond to the 1-σ standard deviation of the Gaussian.

To calculate the confidence levels, since the noise is not purely white photon noise, but also contains some red/correlated component, we proceed in the following way:

1. We divide light curves into blocks of maximum 1000 s for Chandra and XMM-Newton, and of 4000 s for Suzaku (for which observations are lasting much longer), ensuring that at least ten blocks are present per light curve.
2. We shuffle the different blocks randomly, perform a Lomb-Scargle period search and determine the maximal power of the corresponding periodogram.
3. We repeat the 2nd step 1000 times and, by collecting the maxima of all periodograms, we derive the confidence levels.

Results of the spin period search are shown in Fig. 2 for Suzaku (green), XMM-Newton (blue), and Chandra (red) data. Only periods with significance above 99% are shown. From 2002 to 2006 the pulse period seems to have increased slightly, although error bars are relatively large. This spin-down trend is in contradiction with the slow spin-up trend reported by Klus et al. (2014) who analysed RXTE data in roughly the same time interval.

From 2006 to end 2016, the source is rapidly spinning up at a rate of $P = -2.165 \pm 0.0178 \text{s yr}^{-1}$. This value was calculated by fitting a line using the numpy.polyfit function in Python (shown as a black dotted line in Fig. 2). Using the mean value of 1216 s in the 2005–end 2016 time interval, the relative spin period change becomes: $P/P_0 = 0.045 \pm 0.0178 \text{s yr}^{-1}$. Alternatively, we tried to fit a 3rd degree polynomial (in purple) that takes into account the data before 2005 as well, while a 2nd degree polynomial alone would not fit the data well. From 2010 to the end of 2014, the pulse period is only occasionally detected, but at a lower confidence level.

3.2. The orbital period search

The search for the orbital period was made using all available observations from Suzaku, XMM-Newton and Chandra merged together and a period search was performed in the range from 10 to 50 d. Differences in the effective area from the various instruments and vignetting issues had to be taken into account. We therefore created a simulated spectrum for the source in every observation, using XSPEC and the fakeit command and using the relevant response files. The model spectrum is the one described in Section 3.3 with $N_H$ value of $0.5 \times 10^{22} \text{ cm}^{-2}$ and $\Gamma = 0.7$. The count rate extracted in the 2.5–10 keV band, from all spectra, is recorded and then used to scale the different light curve segments, since these represent the values expected for a constant source. We note that, for every observation, we extract and scale the expected count rates as if all instruments were always operating (pn, MOS1 and MOS2 for XMM-Newton, and XIS0, XIS1, XIS2 and XIS3 for Suzaku). We then divide, for each observation, the measured count rate by its theoretical counterpart and multiply by a single factor to get values expected for XMM-Newton (pn+MOS1+MOS2). The results are shown in Fig. 3 where the total background-subtracted and barycenter-corrected light curve is shown at the top, the Lomb-Scargle periodogram in the middle and the folded light curve with sinusoidal correction at the bottom. A clear peak is found at a period of 26.188 d and a 1-σ uncertainty of 0.045 d is determined from the width of the Gaussian fit on the peak. Phase 0 of the sine function is at MJD = 51417.1695288±0.0026188±0.045, where N is an integer (maximum is at phase 0.75). To calculate the significance levels we again use the bootstrap method but this time we randomly shuffle the whole light curves of all observations, again 1000 times.

3.3. Spectral changes with orbital period

Because of its higher sensitivity, XMM-Newton data are analysed to search for any change in the X-ray spectra with the orbital modulation. We extracted a source and background spectrum for each observation and exposure separately using standard SAS tasks. We fit the data, in the 0.3-10 keV energy band, with XSPEC using a power-law emission component and two absorption components (phabs*vphabs*power). The first absorption component has a fixed Galactic $N_H$ value of 5.36×10$^{20} \text{ cm}^{-2}$ (Dickey & Lockman 1990) and the second $N_H$ is left free, while the abundance is fixed to 1.0 for He and 0.2 for Z (Russell & Dopita 1992). Sometimes a faint soft excess (<1 keV) is observed but because this component is not well constrained, we use only the power-law component to model the spectrum.

The results of the spectral fits are shown in Fig. 4. The plot at the top shows the observed 0.3-10 keV flux as a function of the orbital phase; errors are given at 68% confidence level. From these plots we can observe a variation of the flux with the orbital phase (phase 0 is the same as for the merged data in Fig. 3 that is, MJD=51417.1695288). In the second and third plots, values of $\Gamma$ for the power-law component and $N_H$ for the absorption component are shown, as a function of the flux.

Fitting a linear relation between the parameters and the flux, gives slopes of $-0.11 \times 10^{34} \text{ erg}^{-1} \text{ cm}^2$ for the $\Gamma$ and $-0.30 \times 10^{34} \text{ erg}^{-1} \text{ cm}^2$ for the $N_H$ although there is a larger scatter in the latter plot, indicating that there is an anti-correlation between the flux and $\Gamma$.
4. Discussion

From the analysis of XMM-Newton, Suzaku, and Chandra data it appears that SXP 1323 is a quite atypical BeXB. First, it has a long pulse period, with a very high derivative, and as described in Sec 3.1, from 2006 to the end of 2016, the neutron star is spinning up at a very rapid average rate: \( |\dot{P}/P| = 0.018 \text{ s yr}^{-1} \). This is much higher than for any other SMC BeXB reported by Klus et al. (2014) in their Table 4. From 2010 to the end of 2014, the pulse period is no longer clearly detected. Such rapid spin-up and temporary apparent pulsation disappearance for several years has also been reported by Townsend et al. (2013) on SXP 91.1 using RXTE data. In their Fig. 6, they report a spin period changing linearly from 91.1 s to 85.4 s in approximately 13.5 yrs. A linear fit provided a spin-up rate of \( P = 1.442 \times 10^{-8} \text{ s}^{-1} \). Dividing by the average period (88.45 s), and changing units leads to \( |\dot{P}/P| = 0.005 \text{ s yr}^{-1} \), which is still smaller than what we derived for SXP 1323. From MJD 52500 to 55200, that is, for about 8 yrs, no pulse period could be found for SXP 91.1. The authors suggest that the source is continuously accreting matter, and that it is unlikely that the source stopped to pulse for many years. Instead there might be nearby absorbing material preventing the pulsed X-ray emission from reaching the observer, or there might be a change in the geometry. This could easily be concluded for SXP 1323 as well.

A second peculiarity of the pulsar reported here, SXP 1323, is the very short 26.2 d period detected in X-rays and optical wavelengths compared to the long pulse period. While the 26.2 d optical period has been explained so far by aliases of non-radial pulsations of the Be star, this is no longer possible due to the detection of the same period in X-rays. Although we cannot exclude other possibilities for the X-ray variability, we don’t know of any plausible explanation which is not related to the orbital period. Such a short orbital period does not follow the spin-orbit period relationship reported by Corbet (1984, 1986), although there is a large scatter of the observed systems for this relation. From Eq. 1, in Corbet (1986), a pulse period of 1323 s would lead to an orbital period of 364 d for circular orbit, and higher for an eccentric orbit. This relationship assumes that the neutron star is in a state of quasi-equilibrium in which the Alfvén and corotation radii are equal on average. Other exceptions to this rule are observed for BeXBs in the SMC, although these are
less extreme cases than SXP 1323. Some examples with $P_{\text{spin}} > 100$ s and $P_{\text{orb}} < 50$ d are SXP 264 (Haberl & Pietsch 2004) with an orbital period of 49.1 d (Schmidtke & Cowley 2005), SXP 325 (Haberl et al. 2008) with an orbital period of 45.995 d (Coe et al. 2008); SXP 214 (Coe et al. 2011) with an orbital period of 29.91 d (Schmidtke et al. 2013); and SXP 101 (Yokogawa et al. 2009) with an orbital period of 21.94 (McGowan et al. 2007). All orbital periods were derived using optical data from OGLE and in some cases from the Massive Astrophysical Compact Halo Object (MACHO) project as well. In our Galaxy, some other comparable systems are: 1A 1118-616, with a pulse period of 405 s and an orbital period of 24.0 d (Staubert et al. 2011) determined using RXTE data, and, SAX J2103.5+5455 with a pulse period of 358.6 s, which is the BeXB with the shortest known orbital period of 12.7 d (Reig et al. 2005) determined using RXTE data as well. They occupy the region of the wind-fed supergiant binaries in the $P_{\text{spin}} - P_{\text{orb}}$ diagram. Reig et al. (2010) suggest that the X-rays observed during the quiescence of SAX J2103.5+5455 are more likely the result of wind accretion. The dominant accretion wind is likely coming from a more stable equatorial low-velocity high-density wind from the Be star, since, in contrast to wind-fed systems with supergiants, which show erratic and flaring X-ray variability, the X-ray flux in quiescence is stable. In this scenario, the neutron star orbit is coplanar to the plane of the circumstellar disk.

Such a model could be applied to SXP 1323 as well, to explain on one hand the presence of a short orbital period and on the other hand the sinuosoidal shapes of the folded X-ray and the optical light curves, as shown in this work by Schmidtke & Cowley (2006a) and Bird et al. (2012). This rather sinuosoidal shape would mean that the system is not undergoing regular outbursts as commonly observed in BeXBs, but the neutron star seems to accrete continuously during its orbit around the Be star companion. Accretion from an equatorial low-velocity high-density wind could provide an explanation. Some of the SMC BeXBs with known X-ray orbital periods presented by Schmidtke et al. (2008) also have sinuosoidal shape, similar to, for example, SXP 138 ($P_{\text{orb}} = 103.6$ d) and SXP 280 ($P_{\text{orb}} = 64.8$ d) and could also be explained by this model.

5. Conclusions

From this work, it appears that SXP 1323 is a peculiar BeXB due to its long pulse period, rapid spin-up for several years, and short orbital period. Thanks to the nearby SNR 1E 0102-72.3, which is used as a calibration target for most CCD detectors, a large number of observations are already available for this source allowing a study of the long-term behaviour of the pulse period and the detection of long periodicities in X-rays. A continuous monitoring of the source in the future is necessary to determine how the pulse period will evolve in the near future.

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Appendix A: Summary of the XMM-Newton, Chandra and Suzaku observations


Table A.1: Summary of the Suzaku observations used in this work (see text for more details).

| Obs ID | Instr | Mode | Date start | Telapse | Ontime |
|--------|-------|------|------------|---------|--------|
| 100044010 | XIS0 | 3x3 | 2005-12-16T01:43:08 | 289212 46991 | |
| 100044020 | XIS0 | 3x3 | 2006-01-17T22:22:57 | 12142 69194 | |
| 100044030 | XIS0 | 3x3 | 2006-02-02T20:19:20 | 198072 18726 | |
| 100105010 | XIS0 | 3x3 | 2006-04-16T09:42:04 | 43672 21340 | |
| 100105020 | XIS0 | 3x3 | 2006-05-21T17:16:07 | 36774 17238 | |
| 100105030 | XIS0 | 3x3 | 2006-06-26T20:47:26 | 18818 4410 | |
| 100105040 | XIS0 | 3x3 | 2006-07-17T06:22:33 | 54584 12813 | |
| 100105050 | XIS0 | 3x3 | 2006-08-25T04:55:35 | 74046 33157 | |

| Obs ID | Instr | Mode | Date start | Telapse | Ontime |
|--------|-------|------|------------|---------|--------|
| 101005070 | XIS0 | 3x3 | 2006-01-11T15:36:54 | 13564 72435 | |
| 101005090 | XIS0 | 3x3 | 2006-12-13T18:53:16 | 29180 28226 | |
| 101005100 | XIS0 | 3x3 | 2007-01-15T03:20:53 | 44089 22614 | |
| 101005110 | XIS0 | 3x3 | 2007-02-10T22:13:47 | 75499 36102 | |
| 101005120 | XIS0 | 3x3 | 2007-03-18T21:11:19 | 31388 18242 | |
| 101005130 | XIS0 | 3x3 | 2007-07-20T10:14:24 | 48686 26801 | |
| 101005140 | XIS0 | 3x3 | 2007-10-25T12:24:45 | 78017 20679 | |
| 101005150 | XIS0 | 3x3 | 2007-12-01T19:25:40 | 51709 24767 | |
| 101005160 | XIS0 | 3x3 | 2008-03-15T05:43:27 | 48686 26801 | |
| 101005170 | XIS0 | 3x3 | 2008-07-09T20:13:48 | 32517 24915 | |
| 101005180 | XIS0 | 3x3 | 2008-08-14T16:57:28 | 37839 29970 | |
| 101005190 | XIS0 | 3x3 | 2008-06-25T03:30:53 | 80875 13483 | |
| 101005200 | XIS0 | 3x3 | 2008-07-17T06:22:33 | 54584 12813 | |

A&A proofs: manuscript no. scarpano
| Obs ID | Instr | Mode | Date start | Telapse | Ontime |
|--------|-------|------|------------|---------|--------|
| 102010220 | XIS0 | 3x3 | 2009-04-30T10:57:50 | 47627 | 18578 |
| 102010230 | XIS0 | 3x3 | 2009-10-11T03:54:56 | 56278 | 20109 |
| 102010240 | XIS0 | 3x3 | 2010-01-01T02:59:33 | 54867 | 20201 |
| 102010250 | XIS0 | 3x3 | 2010-11-24T01:42:32 | 54109 | 20159 |
| 102010260 | XIS0 | 3x3 | 2011-02-28T00:42:56 | 53519 | 20190 |
| 102010270 | XIS0 | 3x3 | 2011-04-05T01:39:13 | 52833 | 20122 |
| 102010280 | XIS0 | 3x3 | 2011-05-17T03:12:35 | 52174 | 20104 |
| 102010290 | XIS0 | 3x3 | 2011-06-25T02:11:23 | 51509 | 20106 |
| 102010300 | XIS0 | 3x3 | 2011-07-20T01:01:53 | 50949 | 20107 |

Table A.1 (continued)
### Table A.1: (continued)

| Obs ID         | Instr | Mode | Date start | Telapse   | Ontime  |
|---------------|-------|------|------------|-----------|---------|
| 100003020     | XIS0  | 3x3  | 2012-10-27T12:40:18 | 54329     | 29143   |
| 100003010     | XIS0  | 5x5  | 2012-10-27T12:40:18 | 60336     | 2108    |
| 100003020     | XIS0  | 3x3  | 2012-10-27T12:40:18 | 54329     | 29143   |
| 100003010     | XIS0  | 5x5  | 2012-10-27T12:40:18 | 60336     | 2108    |
| 100003020     | XIS0  | 3x3  | 2012-10-27T12:40:18 | 54329     | 29143   |
| 100003010     | XIS0  | 5x5  | 2012-10-27T12:40:18 | 60336     | 2108    |

### Table A.2: Summary of the XMM-Newton observations used in this work (see text for more details).

| Obs ID         | ExpID  | Date start | Telapse   | Ontime  | Filter |
|---------------|--------|------------|-----------|---------|--------|
| 012310201     | PNS001 | 2000-04-16T19:55:28.094 | 01930     | Thin1   |
| 013131001     | PNS002 | 2000-04-16T19:55:28.094 | 01930     | Thin1   |
| 013130200     | PNS001 | 2001-04-16T19:55:28.094 | 01930     | Thin1   |
| 013130201     | PNS002 | 2001-04-16T19:55:28.094 | 01930     | Thin1   |
| 013130202     | PNS003 | 2001-04-16T19:55:28.094 | 01930     | Thin1   |

**Notes.** Columns 1 to 5 show the observation ID, the exposure ID, the start of the observation, the exposure time (in seconds), taken from the \texttt{O}ntime keyword, and the filter used.
Table A.2: (continued)

| Obs ID | ExpID | Date start | Ontime | Mode |
|--------|-------|------------|--------|------|
| 0412981001| PNS001 | 2008-04-23 22:52:44 | 29872 | Thin1 |
| M1S002 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| M2S003 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| 0412981002| M1S002 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| M2S003 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| 0412981003| M2S003 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| 0412981004| M2S003 | 2008-04-23 22:52:44 | 29567 | Thin1 |
| 0412981005| PNS010 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| M1S002 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| M2S003 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| 0412981006| M2S003 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| 0412981007| PNS010 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| M1S002 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |
| M2S003 | 2010-10-18T21:42:28.952 | 7048 | Thin1 |

Table A.3: Summary of the Chandra observations used in this work (see text for more details).

| Set | Obs ID | DetNam | Date start | Ontime | Mode |
|-----|-------|--------|------------|--------|------|
| 1   | ACIS-235678 | 1999-08-23T16:04:07 | 9575 | FAINT |
| 2   | ACIS-235678 | 1999-08-23T18:41 | 9760 | FAINT |
| 3   | ACIS-235678 | 1999-08-23T19:51:54 | 9760 | FAINT |
| 4   | ACIS-235678 | 1999-08-23T11:59:32 | 9759 | FAINT |
| 5   | ACIS-235678 | 1999-09-23T22:35:42 | 88208 | FAINT |
| 6   | ACIS-235678 | 1999-09-23T22:35:42 | 88208 | FAINT |
| 7   | ACIS-235678 | 2000-01-17T21:31:53 | 9270 | FAINT |
| 8   | ACIS-235678 | 2000-01-17T21:31:53 | 9270 | FAINT |
| 9   | ACIS-235678 | 2000-01-17T21:31:53 | 9270 | FAINT |
| 10  | ACIS-235678 | 2000-01-17T21:31:53 | 9270 | FAINT |

Notes: Columns 3 to 5 list the time of the start of the observation, the exposure time (in seconds), taken from the ONTIME keyword, and the observing Mode (Faint and Very Faint format, where pixel values are read out from a 3x3, and 5x5 region surrounding the event, respectively).
| Set | Obs ID | DetNam | Date start | Ontime | DataMode |
|-----|--------|--------|------------|--------|----------|
| 39  | 2857   | ACIS-012367 | 2002-06-21T02:11:35 | 7601   | FAINT    |
| 38  | 2858   | ACIS-012367 | 2002-06-21T04:39:09 | 7654   | FAINT    |
| 37  | 2859   | ACIS-012367 | 2002-06-21T06:59:19 | 7658   | FAINT    |
| 36  | 2860   | ACIS-012367 | 2002-06-21T09:19:30 | 7654   | FAINT    |
| 35  | 2861   | ACIS-012367 | 2002-06-21T13:59:50 | 7658   | FAINT    |
| 34  | 2862   | ACIS-012367 | 2002-06-21T16:20:00 | 7658   | FAINT    |
| 33  | 2863   | ACIS-012367 | 2002-06-21T18:40:10 | 7658   | FAINT    |
| 32  | 2864   | ACIS-012367 | 2002-06-22T00:20:31 | 7856   | FAINT    |
| 31  | 2865   | ACIS-012367 | 2002-06-22T02:58:42 | 7654   | FAINT    |
| 30  | 2866   | ACIS-012367 | 2002-06-22T11:12:52 | 7658   | FAINT    |
| 29  | 2867   | ACIS-012367 | 2002-06-22T13:34:30 | 7660   | FAINT    |
| 28  | 3828   | ACIS-012367 | 2002-12-07T14:48:39 | 137658 | FAINT    |
| 27  | 3829   | ACIS-012367 | 2002-12-07T17:07:47 | 7254   | FAINT    |
| 26  | 3830   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |
| 25  | 3831   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |
| 24  | 3832   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |
| 23  | 3833   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |
| 22  | 3834   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |
| 21  | 3835   | ACIS-012367 | 2002-12-07T23:28:20 | 7254   | FAINT    |

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Table A.3: (continued)