FURTHER CONSTRAINTS ON THERMAL QUIESCENT X-RAY EMISSION FROM SAX J1808.4-3658

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ABSTRACT

We observed SAX J1808.4-3658 (1808), the first accreting millisecond pulsar, in deep quiescence with XMM-Newton and (near simultaneously) Gemini-South. The X-ray spectrum of 1808 is similar to that observed in quiescence in 2001 and 2006, describable by an absorbed power law with photon index 1.74 ± 0.11 and unabsorbed X-ray luminosity $L_X = 7.9 \pm 0.7 \times 10^{31}$ erg s$^{-1}$, for $N_H = 1.3 \times 10^{21}$ cm$^{-2}$. Fitting all the quiescent XMM-Newton X-ray spectra with a power law, we constrain any thermally emitting neutron star (NS) with a hydrogen atmosphere to have a temperature less than 30 eV and $L_{NS} (0.01-10$ keV) $< 6.2 \times 10^{30}$ ergs s$^{-1}$. A thermal plasma model also gives an acceptable fit to the continuum. Adding an NS component to the plasma model produces less stringent constraints on the NS; a temperature of $35^{+4}_{-5}$ eV and $L_{NS} (0.01-10$ keV) $= 1.3^{+0.6}_{-0.5} \times 10^{31}$ ergs s$^{-1}$.

In the framework of the current theory of NS heating and cooling, the constraints on the thermal luminosity of 1808 and 1H 1905+000 require strongly enhanced cooling in the cores of these NSs. We compile data from the literature on the mass transfer rates and quiescent thermal flux of the largest possible sample of transient NS low-mass X-ray binaries. We identify a thermal component in the quiescent spectrum of the accreting millisecond pulsar IGR J00291+5934, which is consistent with the standard cooling model. The contrast between the cooling rates of IGR J00291+5934 and 1808 suggests that 1808 may have a significantly larger mass. This can be interpreted as arising from differences in the binary evolution history or initial NS mass in these otherwise similar systems.

Key words: dense matter – pulsars: general – stars: neutron – X-rays: binaries

Online-only material: color figures

1. INTRODUCTION

The X-ray transient SAX J1808.4-3658 (hereafter 1808) has provided many fundamental breakthroughs in the study of accreting neutron stars (NSs). It was discovered in 1996 by BeppoSAX’s Wide Field Cameras, and type I X-ray bursts were seen, identifying it as an accreting NS and constraining the distance (in’t Zand et al. 1998; Galloway & Cumming 2006). Coherent millisecond X-ray pulsations, the first discovered in accreting systems, were identified during an outburst using the Rossi X-ray Timing Explorer (RXTE; Wijnands & van der Klis 1998). Burst oscillations have also been seen at 1808’s 401 Hz spin frequency, confirming that thermonuclear burst oscillations in low-mass X-ray binaries (LMXBs) represent the spin period of the NS (in’t Zand et al. 2001; Chakrabarty et al. 2003).

Transiently accreting NSs in quiescence are seen to have a soft, blackbody-like X-ray spectral component, and/or a harder X-ray component generally fit by a power law of photon index of −1 to −2 (Campana et al. 1998). The harder component is of unknown origin; an effect of continued accretion or a shock from a pulsar wind have been suggested (Campana et al. 1998). The blackbody-like component is generally understood as the radiation of heat from the NS surface. This heat is produced by nuclear fusion in the deep crust during accretion, and is radiated from the surface on a timescale of $10^5$ years, producing a steady quiescent thermal NS luminosity (Brown et al. 1998; Campana et al. 1998; Haensel & Zdunik 1990). The deep crustal heating rate can be computed if the mass transfer rate is known (or estimated). Some transiently accreting NSs have been shown to have very low quiescent thermal X-ray luminosities, indicating either enhanced neutrino emission or mass transfer rates much lower than have previously been inferred (e.g., Wijnands et al. 2001; Jonker et al. 2004, 2006; Tomsett et al. 2004). The coolest of these provide the strongest constraints to date on neutrino cooling from NS cores, as a broader range of cooling rates is required from X-ray transients than from young cooling pulsars (see Page et al. 2004; Yakovlev & Pethick 2004).

X-ray observations in quiescence have shown 1808 to have one of the lowest quiescent thermal luminosities yet measured from any accreting NS (Campana et al. 2002; Heinke et al. 2007; Jonker et al. 2007b). 1808 is of particular importance because of its well-known distance (Galloway & Cumming 2006) and relatively stable (within a factor of 2) time-averaged mass transfer rate onto the NS measured over multiple outbursts. 1808’s low quiescent thermal luminosity indicates that most of the heat absorbed by the NS core during accretion is reradiated not as thermal X-ray emission, but through neutrino cooling processes (Yakovlev & Pethick 2004).

We have obtained a third XMM-Newton observation of 1808 in quiescence in 2007, in conjunction with near-simultaneous (separated by 6.5 hr) Gemini optical ($g'$ and $i'$) imaging. The science goals included further constraining the thermal component of the X-ray emission, constraining X-ray variability in quiescence, and measuring the sinusoidal orbital optical
modulation nearly simultaneously with an X-ray observation to determine the origin of the optical modulation. One key finding is that 1808 provides one of the two most constraining upper limits on the thermal component for any accreting NS. Accordingly, we report on the X-ray analysis here, along with comparison to other X-ray transients in quiescence, while the optical analysis and comparison of the X-ray and optical results is presented in a companion paper (Deloye et al. 2008).

2. DATA REDUCTION

We observed 1808 on 2007 March 10–11 (ObsID 0400230501; starting at 16:24 UT) for 49 ks with XMM-Newton’s EPIC camera, using two MOS CCD detectors (Turner et al. 2001) with medium filters and one pn CCD detector (Strüder et al. 2001) with a thin filter. All data were reduced using FTOOLS and SAS version 7.0.0. Soft proton flares were excluded by excluding times when the total MOS count rate exceeded 4 0.2–12 keV counts s\(^{-1}\), and times when the total pn count rate exceeded 20 0.2–12 keV counts s\(^{-1}\). This left 36.9, 49.7, and 49.8 ks in the 2007 pn, MOS1, and MOS2 data sets. Event grades higher than 12 were also excluded. We extracted spectra from a 10‘ circle around the position of 1808, and combined the pair of simultaneous MOS spectra and responses using FTOOLS. We generated response and effective area files using the SAS tasks rmfgen and arfgen, and produced background spectra from 90‘ circular source-free regions on the same CCD. The spectra were grouped to > 15 counts per bin for the MOS data, and > 30 counts per bin for the pn data (other choices gave similar results).

2.1. X-ray Variability

We produced background-subtracted light curves of the 2007 pn data within SAS, and analyzed them using HEASARC’s XRONOS software. The Kolmogorov–Smirnov and \(\chi^2\) tests on the first 37 ks of 0.2–12 keV pn data (mostly unaffected by background flaring) revealed mild evidence of variability, as the probability of a constant flux is 3 \(\times\) 10\(^{-2}\) and 3 \(\times\) 10\(^{-3}\) for the two tests, respectively.

3. X-RAY SPECTRAL ANALYSIS

Our X-ray spectral analysis includes photoelectric absorption (XSPEC model \(phabs\)), with a hydrogen column density, \(N_H\), fixed at the interstellar value of 1.3 \(\times\) 10\(^{21}\) cm\(^{-2}\) (Dickey & Lockman 1990). We checked this \(N_H\) value by analyzing a series of Swift observations taken during the tail of 1808’s 2005 outburst (Kong 2005; Campana et al. 2005b). We used window timing data from June 17, 23, and 29, and July 7 and 13, and photon-counting data from June 17 and 23. The June 17 observation suffered from pileup in the photon-counting mode. We addressed this by excluding the central 18‘ of the point-spread function (chosen by fitting a King model to the radial profile). An absorbed power-law model (with only \(N_H\) fixed between observations) gave a nearly reasonable fit to the seven Swift spectra (\(\chi^2 = 1.19\), null hypothesis probability (nhp) = 1.4 \(\times\) 10\(^{-4}\)), while an absorbed power-law plus blackbody model gave a slightly better fit (\(\chi^2 = 1.15\), nhp = 1.8 \(\times\) 10\(^{-3}\)). Photon indices ranged from 1.8 to 2.3 for the simple power-law fits, or 2.2 to 2.4 for the power-law plus blackbody fits, while the blackbody temperatures ranged from 0.7 to 1.2 keV.

The best-fit \(N_H\) for either fit was 1.2 \(\pm\) 0.1 \(\times\) 10\(^{21}\) cm\(^{-2}\), consistent with the Dickey & Lockman value.\(^{10}\) We also tested models with photoelectric absorption as a free parameter, finding \(N_H\) consistent with the outburst value. Quoted errors are at 90% confidence.

We simultaneously fit our pn and MOS spectra along with spectra from the two previous XMM-Newton observations from 2001 March 24 and 2006 September 14 (see Heinke et al. 2007, for details of these observations). The X-ray characteristics are similar to those observed in the prior observations (Campana et al. 2002); the spectrum can be well fit with a power law of photon index 1.74 \(\pm\) 0.11, while a hydrogen-atmosphere model (the NSATMOS\(^{11}\) model of Heinke et al. 2006, or the similar NSA model of Zavlin et al. 1996) gives very poor fits.

Although each of the spectra are well fit by an absorbed power law with the \(N_H\) observed in the outburst, requiring all spectral parameters to be identical across observations produces somewhat poor fits (\(\chi^2 = 1.09\), nhp = 0.03). Allowing a constant normalization to vary between the observations, we find that the 2001 flux is 1.29\(^{+0.23}_{-0.21}\) of the 2006 flux, and the 2007 flux is 1.46\(^{+0.20}_{-0.17}\) of the 2006 flux. This suggests that at its lowest flux levels 1808 remains X-ray variable in quiescence (see also Campana et al. 2008). Such variability could indicate that the X-ray emitting process is powered by time-variable accretion, either onto the NS or in the interaction of a disk and the NS magnetosphere.

Allowing only the \(N_H\) to vary improves the fit only slightly (nhp = 0.04), and we note that a different \(N_H\) in the outburst than quiescence is rarely seen in quiescent LMXBs, especially those like 1808 at relatively low inclination (Jonker & Nelemans 2004). We fix the \(N_H\) at 1.3 \(\times\) 10\(^{21}\) cm\(^{-2}\) and free the power-law photon index and normalizations, including also a NSATMOS component with NS mass = 1.4 \(M_\odot\) and radius 10 km, with the same temperature between observations. We freeze the distance to 1808 at 3.5 kpc, as measured by Galloway & Cumming (2006). The parameters of this fit are listed in Table 1, and it is shown in Figure 1. No thermal component is required, but a thermal component with \(kT < 30\) eV (90% confidence) is permitted, thus placing a limit on the NSs thermal bolometric (0.01–10 keV) luminosity \(L_{NS,bol} < 6.2 \times 10^{30}\) erg s\(^{-1}\). This is a substantially tighter constraint on the NS’s quiescent thermal luminosity than that of Heinke et al. (2007), and may be the tightest constraint on the thermal bolometric luminosity of an NS in an X-ray transient (note that I1H1905+000 has a much lower total X-ray luminosity than 1808; see Jonker et al. 2007b). This tighter constraint is produced by doubling the XMM-Newton pn exposure, and thus nearly doubling our sensitivity.

The rather tight distance limits of Galloway & Cumming (2006; 3.5 \(\pm\) 0.1) kpc produce only a 6% uncertainty in our upper limit. Increasing the assumed \(N_H\) by 10\(^{22}\) cm\(^{-2}\) increases this limit by \(\sim 20\%\); decreasing the \(N_H\) decreases the limit similarly. Changing the assumed NS mass to 2 \(M_\odot\) (as suggested by the results of Deloye et al. 2008) increases the upper limit by 10%, as does altering the assumed NS radius to 13 km.

The nature of the high-energy spectral component in qLMXBs is unclear, and thus other continuum models are possible. One possibility for the emission is a hot plasma, possibly a shock between an infalling accretion stream and a pulsar wind (e.g., Campana et al. 2002; Bogdanov et al. 2005). Such a model

\(^{10}\) After this paper was submitted, an independent analysis of the Swift data found \(N_H = 1.3 \pm 0.1 \times 10^{21}\) cm\(^{-2}\) (Campana et al. 2008).

\(^{11}\) http://xspec.gsfc.nasa.gov/docs/xanadu/xspec/models/nsatmos.html
is not ruled out by the spectral fits, which allow \( \chi^2 = 0.95 \) for 84 degrees of freedom) a hot plasma MEKAL model with \( kT = 4-8 \) keV instead of a power-law spectrum. Adding a faint NSATMOS component is modestly preferred in this spectral fit; the best fit has \( kT = 36^{+4}_{-8} \) eV, for a bolometric NS luminosity of \( L_X = 1.3^{+0.6}_{-0.8} \times 10^{31} \) erg s\(^{-1}\) (Table 1). This model allows a larger NS component due to the flatter shape of the model at low energies, and demonstrates the dependence of our constraints on the continuum model. The nature of the hard spectral component, and thus choice of the MEKAL versus power-law model, could be tested by a sensitive search for line emission, or by measuring the hard tail out to higher X-ray energies, with next-generation X-ray instruments.

4. COMPARISON TO OTHER RESULTS

Heinke et al. (2007) noted a possible trend of NSs with low mass transfer rates having faster cooling. To test this, we have increased our sample of LMXBs with useful constraints on their mass transfer rates and quiescent thermal luminosities (Table 2). For several systems, we take both values from the recent literature. For some, we compute the quiescent 0.01–10 keV thermal NS luminosity given the 0.5–10 keV fluxes in the literature and NS atmosphere models, or by reanalyzing Chandra or XMM-Newton data on quiescent NSs. For several systems, we estimate the time-averaged mass transfer rate (or an upper limit) from X-ray flux histories in the literature, since the RXTE all-sky monitor (ASM) light curves (used in Heinke et al. 2007) generally do not cover their full outbursts. Distance estimates are often rather poorly quantified. We take best estimates of these distances from the quoted references, noting that an uncertainty of 50% in distance is a reasonable upper bound. Changes in distance at this level will not greatly affect our (broad) conclusions. We also list orbital periods where known. We discuss a few systems in detail below.

4.1. Comparison to Other LMXBs in Quiescence

Jonker et al. (2007b) obtained a long observation of the quiescent NS LMXB 1H1905+000, deriving a very tight limit on the quiescent bolometric NS flux of \(< 1 \times 10^{31} \) erg s\(^{-1}\) (for a 0.1 keV blackbody). The mass transfer rate of
1H1905+000 is not known; but for any mass transfer rate greater than $10^{-12}\ M_\odot\ yr^{-1}$, the quiescent luminosity limit is below the fiducial pion cooling curve of Yakovlev & Pethick (2004). On the other hand, the mass transfer rate for 1808 is rather well constrained by the Eddington limit for hydrogen-rich material. Allowing for a factor of 40 reduction in our observed flux, we estimate a (conservative) upper limit of $L_\times < 1.6 \times 10^{38} \ ergs \ s^{-1}$, and $M < 5.2 \times 10^{-9} \ M_\odot \ yr^{-1}$.

### 4.2. Comparison to Other Accreting MSPs in Quiescence

Of the other accreting millisecond X-ray pulsars, deep quiescent studies have not been performed for Swift J1756.9-2508 and HETE J1900.1-2455. For most of the remainder, we compute mass transfer rates using the distance estimates, time-averaged bolometric fluxes, and recurrence time limits in Galloway (2006). For XTE J1814-338, we assume a recurrence time of 19 years (Wijnands & Reynolds 2003). For XTE J1751-305, the discovery outburst seems to have been much brighter than the other three recorded outbursts (Markwardt et al. 2002; Linares et al. 2007), so we add the estimated outburst fluxes and average over the past 12 years.

XTE J1814-338 (1814) does not have a published quiescent flux measurement, but one archival (2005 September 6) XMM-Newton observation exists. We have analyzed this data set to search for 1814 in quiescence. We excise periods of high background, > 30 (> 6) counts s$^{-1}$ in the 0.2–10 keV pn (MOS) data, giving 22.9, 30.9, and 29.5 ks of pn, MOS1, and MOS2 data, respectively. A slight flux enhancement may be seen in the 0.2–4 keV images, although it is not highly significant. We estimate the flux of 1814 by computing the counts within 15′′ of 1814’s nominal position, and subtracting background estimated from an annulus from 20′′ to 40′′ away. Calculating the fluxes for an absorbed power law of photon index 2 using PINMS gives an (averaged) $F_X (0.5–10) \ ergs \ cm^{-2} \ s^{-1}$. Using a blackbody of temperature 0.2 keV gives $F_X = 3.9 \pm 1.6 \times 10^{-15} \ ergs \ cm^{-2} \ s^{-1}$. We therefore identify $F_X < 9 \times 10^{-15} \ ergs \ cm^{-2} \ s^{-1}$ as a 3σ upper limit on the blackbody-like flux from a NS in 1814, and for an assumed distance of 8 kpc, $L_\times (0.01–10 \ keV) < 1.7 \times 10^{32} \ ergs \ s^{-1}$.

### Notes

1. Jonker & van der Klis (2001) estimate that the luminosity of the accretion disk corona source 2A 1822-371 is reduced by a factor of 40 due to its high inclination.

12 Jonker & van der Klis (2001) estimate that the luminosity of the accretion disk corona source 2A 1822-371 is reduced by a factor of 40 due to its high inclination.

13 Since a harder spectrum gives a higher upper limit, the total luminosity could be slightly higher.
IGR J00291+5734’s (hereafter 00291) quiescent X-ray flux has been observed with Chandra on five occasions, reported by Jonker et al. (2005), Torres et al. (2008), and Jonker et al. (2008). The third observation found 00291 to be significantly brighter (a factor of 2), with a softer spectrum, than the first two or the latter observations (Jonker et al. 2005). This observation can be fit with an NS atmospheric model alone, but the implied radius is rather small (only $3.5_{-1.5}^{+2.5}$ km for a distance estimate of 4 kpc; see Galloway et al. 2005; Torres et al. 2008; Jonker et al. 2005). However, the addition of a power-law component, dominant at high energies, allows a reasonable NS radius. The temperature of the NS appears higher in this observation than in the other observations. Exploring the nature of this variation lies outside the scope of this work. Since only the faintest blackbody-like flux measurement can represent the emission from a slowly cooling NS heated by multiple outbursts, this observation is in any case not relevant to our purpose.

The other four observations of 00291 show a similar spectrum and X-ray flux (of $7 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$, 0.5–10 keV, for a power-law fit). We analyze the longest observation, from 2005 November (it has 143 counts versus 36, 63, and 22 from the others), with slightly different methods than those used by Torres et al. (2008). We fit a model consisting of an absorbed power law, with an optional NS atmosphere, with $N_H$ fixed to $4.6 \times 10^{21}$ (the average value from several methods summarized by Torres et al. 2008). We binned the source spectrum so that each bin contains at least 10 counts (using 15 or 20 counts per bin yields similar results). We set the NS distance to 4 kpc (Galloway et al. 2005), radius to 10 km, and mass to 1.4 $M_\odot$. We find that the power-law component is absolutely required, but that the NS component significantly improves the fit (see Table 3, Figures 2 and 3). The fraction of the 0.5–10 keV flux attributable to the NS component is $44_{-27}^{+22}$%.

The reduced $\chi^2$ is reduced by half with the addition of the NS component, and the temperature of the NS component is inconsistent with the model minimum (effectively zero) at the $> 99\%$ level ($\Delta \chi^2 = 7.0$). An F-test indicates that the probability of attaining an equivalent fit improvement by adding one model parameter is only 0.4%. Protassov et al. (2002) showed that the F-test is often inaccurate for testing the necessity of adding an additional spectral component. We therefore simulated 100 data sets using the best-fit absorbed power-law model, and fit them with this model and with the absorbed NS plus power-law model. None of our simulations gave a $\Delta \chi^2$ or F-statistic larger than that produced by our model, allowing us to conclude that the probability of incorrectly concluding that an NS component is required for 00291 is less than 1%.

The difference between our results and those of Torres et al. (2008) (which found an upper limit of 19% to a thermal component for 00291) may be attributed to four factors: our inclusion of the lowest energy bin in our fit (this bin is dominated by data above 0.5 keV), our use of a fixed distance (which imposes a relation between NS temperature and NS flux), Torres et al.’s use of a fixed NS temperature, and, perhaps most importantly, Torres et al.’s method of first fitting an absorbed power law, and then fixing the best-fit power-law parameters before adding and constraining a blackbody component. This method is likely to underestimate the flux that may be present in a second component, since the parameters of the first component are not allowed to vary from those of the best one-component fit. We have replicated the spectral fit of Torres et al., with similar results (the NS is $< 19\%$ of the 0.5–10 keV unabsorbed flux), but when we free the power-law component parameters the NS component then makes up $56_{-35}^{+23}$% of that flux. Torres et al.’s method is common in the literature (e.g., Campana et al. 2002, 2005a), but we do not feel it is the most

![Figure 2](image-url)
Figure 3. X-ray spectrum of IGR J00291+5934, fitted with a power law and an NS atmosphere model. The NS atmosphere component is shown by the dashed line, and the power-law component by the dotted line, in the upper panel, while residuals are shown in the lower panel. Note the improvement in the fit compared to Figure 2.

Figure 4. Measurements of, or limits on, the quiescent thermal luminosity of various NS transients, compared to estimates of, or upper limits on, their time-averaged mass transfer rates. Data from the compilations of Heinke et al. (2007) and Table 3. The predictions of standard NS cooling and various enhanced cooling mechanisms are plotted, following Yakovlev & Pethick (2004). The accreting millisecond pulsars (including the intermittent ones) are labeled separately (in red). The effect of using a MEKAL rather than a power-law continuum for 1808, allowing a higher upper limit on the NS component, is indicated with the dotted line. The effect of increasing the distance by a factor of 1.5 for any system is indicated with an arrow (labeled D × 1.5).

(A color version of this figure is available in the online journal.)

appropriate when constraining the contributions of broadband components.

The best estimates of the mass transfer rates and quiescent X-ray luminosities in Table 2 are plotted in Figure 4. These estimates suffer uncertainties in distances and recurrence times (where appropriate, we plot upper limits, in some cases upper limits in both mass transfer rate and $L_{\text{NS}}$). However, there is clearly a large variation in cooling behavior exhibited by these accreting NSs, with quiescent thermal luminosities ranging by several orders of magnitude. Heinke et al. (2007) suggested that NSs with lower mass transfer rates, which are generally older systems, have experienced significant mass transfer over their lives and are now more massive, and inclined to faster cooling. The larger data set collected here argues against this idea. In addition to the two systems with high mass transfer rates, 4U 1730-22 and 00291 lie near the predictions of standard cooling. We note the contrast between the bright thermal component of 00291 and the faint thermal component of 1808. These two systems have similar periods (2.46 and 2.01 hr, respectively) and heated low-mass (brown dwarf) companions (Bildsten & Chakrabarty 2001; Galloway et al. 2005). One might expect similar evolutionary histories, similar amounts of accreted mass, and thus similar cooling rates from these two systems. The observed difference in cooling requires different neutrino emission mechanisms, suggesting that 1808’s NS may be significantly more massive than that in IGR J00291+5934. This might be interpreted as due to differences in their mass transfer histories, or by the NS in 1808 being born with a higher mass.

There are a few caveats to consider. The evidence for the thermal component in 00291 is only at the 3σ level. It is not absolutely certain that the thermal component in 00291 is produced from deep crustal heating, especially considering the odd quiescent X-ray behavior seen by Jonker et al. (2005). The distance and mass transfer rate of 00291 are not known to high accuracy. However, changes in 00291’s distance by a factor of 2, or mass transfer rate by a factor of 10 or more, would not eliminate the contrast between 1808 and 00291 (see Figure 4).

5. CONCLUSIONS

The three combined XMM-Newton observations of 1808 in quiescence provide one of the most stringent constraints on the thermal component of any transiently accreting NSs observed so far, with the thermal $L_{\text{NS, bol}} < 6 \times 10^{30}$ ergs s$^{-1}$ (for a power-law continuum model) or $< 1.9 \times 10^{31}$ ergs s$^{-1}$ (for a MEKAL
thermal plasma model). Combined with 1808’s well constrained mass transfer rate and distance, this constraint strongly requires enhanced neutrino cooling from the NS in 1808. The models of kaon and pion cooling presented by Yakovlev & Pethick (2004) are excluded by this constraint, favoring direct Urca neutrino emission processes involving protons, hyperons, or deconfined quarks, depending on the constituents of matter at supranuclear densities.

We have compiled literature estimates of the mass transfer rates and quiescent thermal luminosities of a large number of transient NS LMXBs. Uncertainties in transient outburst histories and the lack of detections of thermal components limit the number of useful data points. Although many of the measurements are upper limits, there is strong evidence for a range of NS neutrino cooling rates. Uncertainties in the measurements are upper limits, there is strong evidence for a useful report. C.O.H. acknowledges support from NASA Chandra grant NNX06AE78G and NNX06AH62G. C.J.D. acknowledges support from NASA grant TM7-007-PAE.

Facilities: XMM-Newton (EPIC), Swift (XRT), CXO (ACIS). Note added in proof: Campagna et al. (2008b) have independently found evidence for a thermal component in 00291 from XMM data, confirming our detection of such a component.

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