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XMM-Newton Spectral and Timing Observations of Three Millisecond Pulsars

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Abstract. We present *XMM-Newton* MOS imaging and pn timing data of the millisecond pulsar (MSP) PSR J0218+4232 and the two faint MSPs PSR J0751+1807 and PSR J1012+5307. We confirm the previously detected pulsations of PSR J0218+4232 and we show that its folded lightcurve is strongly dependent on energy. We present evidence to suggest that the broad band X-ray spectrum for this MSP may not be a simple power law, but that there is some evidence for an excess of soft thermal emission, in particular from the strongest pulse, in support of a heated polar cap model for this pulsar. We present, for the first time, the X-ray spectra of the two faint MSPs. We find that a power law model best fits the spectrum of PSR J0751+1807, Γ=1.59±0.20. A power law is also a good description of the spectrum of PSR J1012+5307, Γ=1.78±0.36, however, a blackbody model can not be excluded as the best fit to this data. We also present some evidence to suggest that both of these MSPs show pulsations in this X-ray band.

Key words. X-rays: stars – pulsars: individual: PSR J0218+4232 – Radiation mechanisms: non-thermal – Radiation mechanisms: thermal

1. Introduction

MSPs show two types of X-ray pulsations: soft pulsed emission with blackbody spectra, due to a heated region of the neutron star surface, i.e. the polar cap; or pulsed emission with narrow pulses, characterised by hard power law spectra, thought to arise from the magnetosphere, see e.g. Saito et al. (1997).

Therefore detecting the pulsation and its form, should help to identify the X-ray emission mechanism. In many cases, X-ray pulsations and spectra have not been observable for faint MSPs e.g. PSR J0751+1807 (Becker & Trümper 1993) and PSR J1012+5307 (Halpern & Wang 1997). However, taking advantage of the sensitivity of *XMM-Newton* (Jansen et al. 2001), it is becoming possible to observe both the X-ray spectrum and detect the X-ray pulsations of these faint MSPs.

In other cases, X-ray MSPs i.e. PSR B1821-24, see Saito et al. (1997), like many ordinary pulsars, have been observed to emit X-ray spectra that are well fitted by hard power laws. In contrast, it has been proposed that PSR J0437-4715 emits thermal radiation Zavlin & Pavlov (1998); Zavlin et al. (2002).

Detection of the polar cap thermal emission allows us to discriminate between pulsar models and study the properties of neutron star surface layers e.g. Zavlin et al. (2002); Zavlin & Pavlov (1998).

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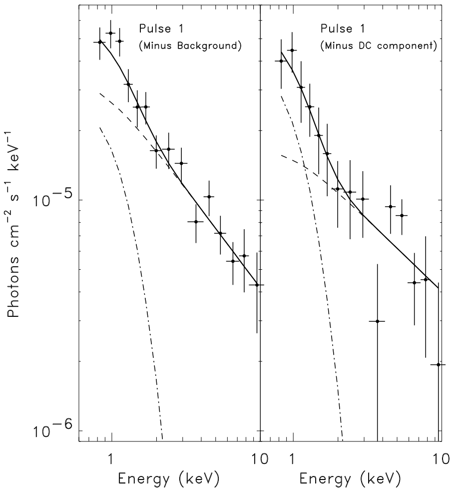

Fig. 1. Blackbody plus power law fit (solid line) and the components (dotted line = power law, dashed-dotted line = blackbody) to pulse 1 of PSR J0218+4232. Left: pulse 1 minus background (χ^2_ν=0.85, 30 dof). Right: pulse 1 minus DC and background contributions (χ^2_ν=1.07, 30 dof).

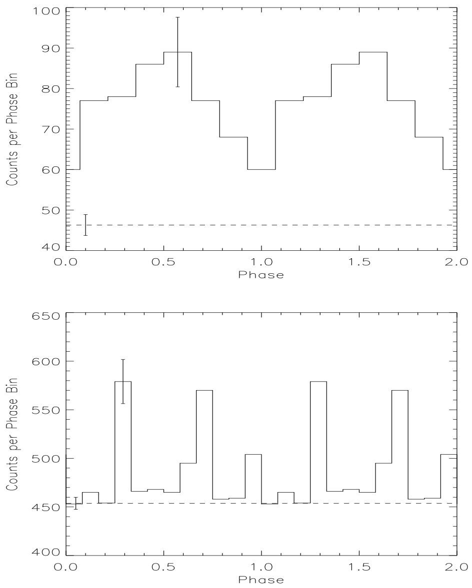

Fig. 2. Lightcurves, folded on the radio ephemerides: Top: PSR J0751+1807 (7×0.5 ms bins). Bottom: PSR J1012+5307 (12×0.44 ms bins). Two cycles are shown in each case and a typical $\pm1\sigma$ error bar. Dashed line = background level. The pulse-phase distribution deviates from a statistically flat one at 2 and 5 σ respectively.

2. The millisecond pulsars

We observed all three MSPs with the *XMM-Newton* MOS (imaging) and pn (timing) cameras (Webb et al. 2003a,b).

The pulsed spectra of PSR J0218+4232 are well fitted by single powerlaws, but the photon indices determined with the *XMM-Newton* data (0.6-10.0 keV) are softer than those found by Mineo et al. (2000) using the *BeppoSAX* MECS (2-10 keV). Fitting the *XMM-Newton* spectra with a blackbody and a power law, as for PSR J0437-4715 (Zavlin et al. 2002), we recover the same photon indices found by Mineo et al. (2000), which could indicate that there may be excess soft emission, not observable by *BeppoSAX*. Taking the blackbody temperature ((2.9±0.7)×10^6 K) from the two component fit to pulse 1, we find an emission radius of 0.37±0.33 km (90% confidence), consistent with the polar cap temperature and radius (10^6-10^7 K, ~1 km e.g. Zavlin & Pavlov 1998,and references therein).

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