Pulsed X-ray emission from the young, high magnetic field radio pulsar PSR J1119–6127

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We report the first detection of pulsed X-ray emission from the radio pulsar PSR J1119-6127 using XMM-Newton. The pulsar has a characteristic age of 1,700 yrs and inferred surface dipole magnetic field strength of 4.1×10^{13} G. In the 0.5–2.0 keV range, the emission shows a single, narrow pulse with a very high pulsed fraction of ~70%. No pulsations are detected in the 2.0–10.0 keV range, where we derive an upper limit for the pulsed fraction of 28%. The pulsed emission is well described by a thermal blackbody model with a high temperature of ~2.4×10^{6} K. Atmospheric models result in problematic estimates for the distance/emitting area. PSR J1119–6127 is now the radio pulsar with smallest characteristic age from which thermal X-ray emission has been detected. The observed combination of temporal and spectral characteristics provide an excellent test site for current models of thermal emission from neutron stars.

INTRODUCTION

- PSR J1119-6127 was discovered with Parkes (Camilo et al. 2000, ApJ, 541, 367). It has one of the smallest characteristic ages and largest infe-rred magnetic field strengths in the radio pulsar population (see Table 1).

Table 1. Spin Characteristics of PSR J1119-6127

Period, P	408 ms
Period derivative, $\dot{P}$	4.1×10^{-12}
Spin-down luminosity, $\dot{E}$	2.3×10^{36} ergs s^{-1}
Magnetic field, B	4.1×10^{13} G
Characteristic age, ?	1,700 yr

- It powers a small (~3" x6") X-ray pulsar wind nebula (PWN) previously resolved with *Chandra* (Gonzalez & Safi-Harb 2003, ApJ, 591, L143). No radio PWN has been detected.
- It lies close to the center of a 15'-diameter X-ray and radio supernova remnant, G292.2-0.5 (Crawford et al. 2001, ApJ, 554, 152; Pivovaroff et al. 2001, ApJ, 554, 161).
- A lower limit for the distance of 8.5 kpc has been established from HI absorption measurements (Caswell et al. 2004, MNRAS, 352, 1405).

OBSERVATION AND IMAGING ANALYSIS

- PSR J1119-6127 was observed with *XMM-Newton* on June 26 2003.
- The MOS and PN instruments were operated at temporal resolutions of 2.6 sec and 48 ms, respectively.
- Total observing time was 48 ks for MOS and 43 ks for PN.
- Figure 1 shows the MOS1/MOS2 image of the pulsar and its SNR.

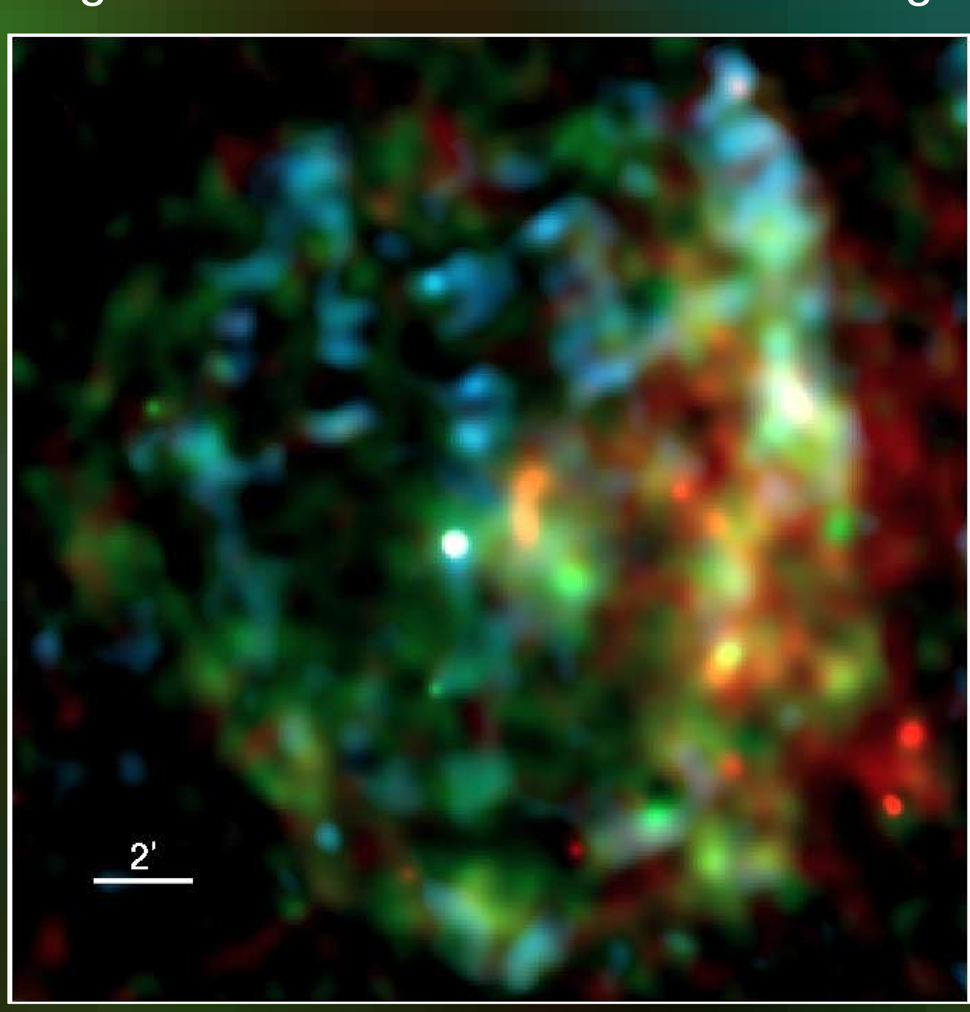

Figure 1. MOS1/MOS2 image of G292.2-0.6 and PSR J1119-6127. Images in the 0.5-1.5 keV (red), 1.5-3.0 keV (green) and 3.0-10.0 keV (blue) were combined. The bright source at the centre is the pulsar.

TIMING ANALYSIS

- The PN data were used to search for a signal at the radio period.
- The Z_n^2 test (Buccheri et al. 1983, A&A, 128, 245) shows a signal in the 0.5-2.0 keV band (340±25 cts) with significance of 6.6 σ. The profile shows a single, narrow peak with a high pulsed fraction of (74±14)%.
- No pulsations are seen in the 2.0-10.0 keV range (275±22 cts) and we derive an upper limit for the pulsed fraction of 28% (see Vaughan et al. 1994, ApJ, 544, 390).

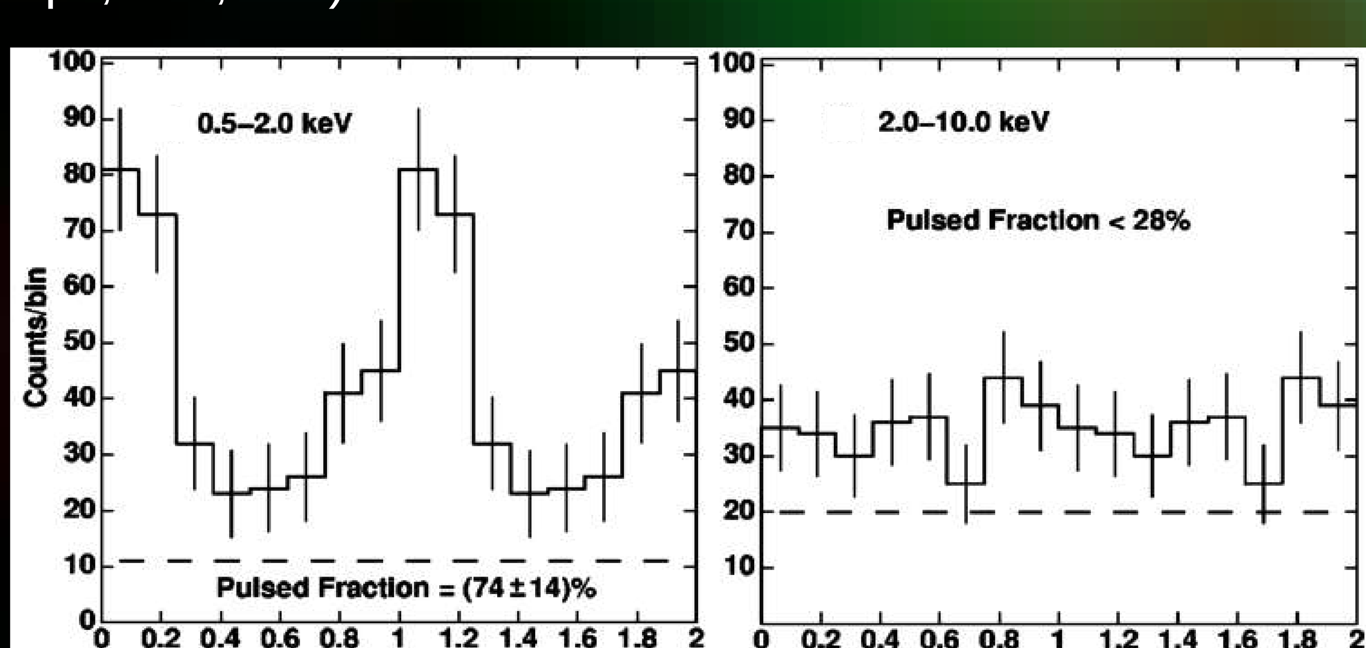

Figure 2. X-ray pulse profiles for PSR J1119-6127 in the 0.5-2.0 keV (left) and 2.0-10.0 keV (right) bands.

SPECTRAL ANALYSIS

- Two-component models were needed to fit the extracted spectrum within a 25" radius of the pulsar (see Table 2).
- The soft component requires a steep power law (Γ~5) or a high-temperature blackbody model ($T^{?}$ ~ 2.4 x10^{6} K).
- The hard component is well fit by a power law with Γ~1.3.
- The pulsed component (phases 0.7-1.3) is dominated by soft emission (see Figure 3) and originates from the pulsar.
- The unpulsed, hard component originates from the unresolved PWN and the surrounding diffuse emission (see Fig 1).

Table 2. Spectral fits to PSR J1119-6127

Parameter	PL + PL ($\pm 1\sigma$)	BB + PL ($\pm 1\sigma$)	Atm[a] + PL ($\pm 1\sigma$)
N_H (10^{22} cm^{-2})	$2.3^{+0.4}_{-0.3}$	$1.6^{+0.4}_{-0.3}$	$1.9^{+0.5}_{-0.3}$
χ^2(dof)	79(66)	78(66)	78(66)
	Soft component characteristics		
Γ or T^{∞}	6.5±0.9	$2.4^{+0.3}_{-0.2}$ MK	0.9±0.2 MK
R^{∞} (km)	...	$3.4^{+1.8}_{-0.3}$	12 (fixed)
d (kpc)	8.4 (fixed)	8.4 (fixed)	$1.6^{+0.2}_{-0.9}$
f_{abs} [b] (10^{-14})	$2.1^{+2.3}_{-0.9}$	$1.5^{+1.8}_{-0.2}$	$1.7^{+7.0}_{-0.4}$
f_{unabs} [b] (10^{-13})	63^{+57}_{-32}	$2.4^{+3.0}_{-0.5}$	$7.2^{+31}_{-1.6}$
L_X [b] (10^{33})	53^{+50}_{-27}	$2.0^{+2.5}_{-0.4}$	$0.22^{+0.88}_{-0.05}$
	Hard component characteristics		
Γ	$1.3^{+0.5}_{-0.2}$	$1.5^{+0.3}_{-0.2}$	$1.5^{+0.2}_{-0.3}$
f_{abs} [b] (10^{-14})	$7.1^{+10}_{-1.5}$	$7.4^{+3.6}_{-1.0}$	$7.3^{+4.7}_{-2.7}$
f_{unabs} [b] (10^{-13})	$1.0^{+1.6}_{-0.2}$	$1.1^{+0.6}_{-0.2}$	$1.1^{+0.8}_{-0.3}$
L_X [b] (10^{33})	$0.8^{+1.3}_{-0.2}$	$0.9^{+0.5}_{-0.1}$	0.04±0.02

[a]Atmospheric model with hydrogen composition.
[b]Fluxes and luminosity in the 0.5-10.0 keV range.

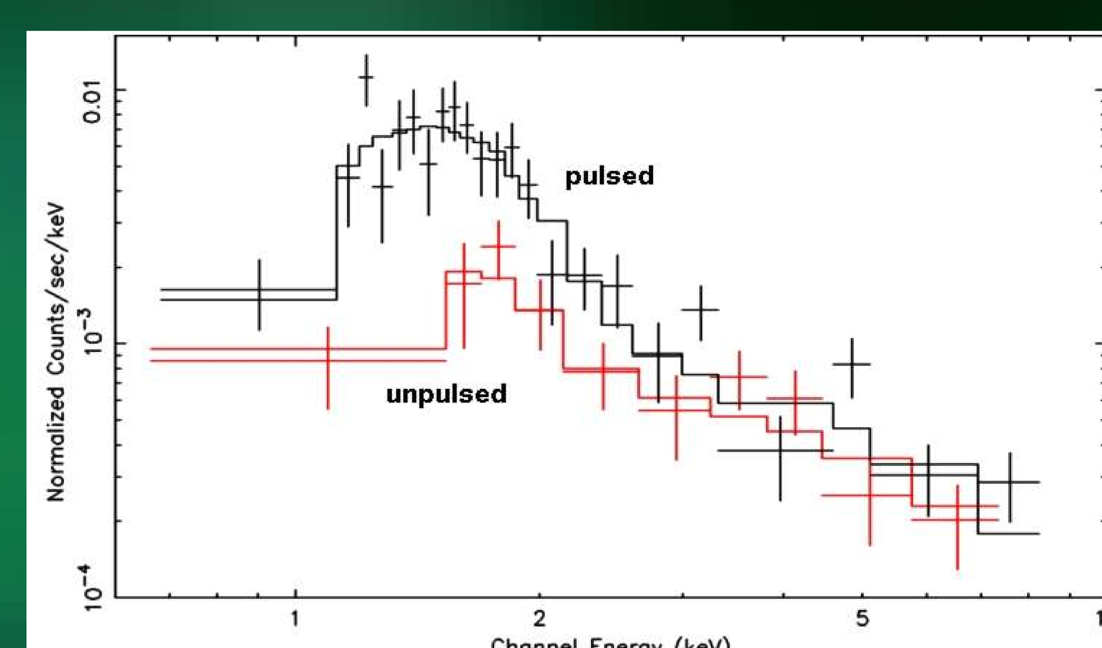

Figure 3. Phase-resolved spectra with best-fit blackbody plus power-law model.

DISCUSSION

- PSR J1119-6127 is now the radio pulsar with smallest characteristic age and detectable thermal (pulsed) emission.
- The emission has a higher temperature and larger pulsed fraction than is commonly seen for radio pulsars at low X-ray energies (e.g., Pavlov et al. 2002, MPE Report 278, 273; Becker & Aschenbach 2002, MPE Report 278, 64).
- A blackbody model is favored over atmospheric models, as the latter result in problematic estimates for the distance (<2 kpc, ruled out from HI absorption measurements) or problematic estimates for the emitting area (~50 km radius at 8.5 kpc).
- If the emission arises from the entire surface of the star due to initial cooling, the blackbody temperature is slightly higher than predicted (<1.8x10^{6} K, e.g. Yakovlev et al. 2004, AdSpR, 33, 523) and the blackbody radius of ~2.5-8 km (at 8.5 kpc) is smaller than allowed from equations of state (Lattimer & Prakash 2000, Phys. Rep., 333, 121). The high pulsed fraction is also problematic, as the maximum expected in this case is 40% (Psaltis et al. 2000, ApJ, 544, 390).
- Thermal emission from localized hot spots would be able to generate larger pulsed fractions. Preliminary results suggest that very small hot spot sizes (<20º) are required to reproduce the observed pulsed fractions.
- The mechanism for generating such spots has been physically uncertain, with metallicity gradients (Pavlov et al. 2000, ApJ, 531, L53) or non-uniform heating due to magnetic field decay (Thompson & Duncan 1996, ApJ, 473, 322) being proposed candidates. Recent work also suggests that significant surface anisotropies are possible for neutron stars with high dipolar magnetic fields restricted to the stellar crust (Geppert et al. 2004, A&A, 426, 267).

The X-ray emission characteristics of PSR J1119-6127 provide an excellent testing site for models of thermal emission from neutron stars. Further work is needed to compare model predictions to these observations. Additional observations are also needed to further constrain the observed characteristics.

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