XMM-NEWTON SETS THE RECORD STRAIGHT: NO X-RAY EMISSION DETECTED FROM PSR J0631+1036

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**Abstract**

The pulsar PSR J0631+1036 was discovered during a radio search of *Einstein* X-ray source error circles. A detection of a 288ms sinusoidal modulation in the *ASCA* lightcurve, the same period as the radio pulsar, appeared to confirm the association of the X-ray source and the pulsar. Its X-ray spectrum was said to be similar to that of middle aged γ-ray pulsars such as Geminga. However, an *XMM-Newton* observation of the PSR J0631+1035 field, along with a re-analysis of VLA data confirming the timing position of the pulsar, show a 75′′ discrepancy in location of the X-ray source and the pulsar, and therefore these cannot be the same object. The X-ray source appears to be the counterpart of an A0 star, detected by the *XMM-Newton* Optical Monitor. No 288ms period was detected from either the area around the pulsar or the bright X-ray source. The upper limit on the X-ray luminosity with relation to the empirically observed correlation between radio measured dE/dt and X-ray luminosity is discussed.

**Key words**: pulsars: PSR J0631+1036 – X-rays – stars: neutron

1. **Introduction**

PSR J0631+1036 is a young (\(\tau=43,000\) yr), 288ms pulsar in the direction of the Galactic anticentre. First reported by Zepka et al. (1996), it was discovered in a radio search of the error circle of 2E 0628.7+1037, an *Einstein* X-ray source. PSR J0631+1036 has an unusually high dispersion measure (DM) of 125 pc cm\(^{-3}\), which corresponds to a distance of 6.5 kpc (using the model of Taylor & Cordes 1993). This distance is the largest of the Galactic anticentre pulsars. The association of this source with the dark cloud LDN 1605 (Lynds 1962) however, suggests that this high DM is due to ionised gas in or near the cloud. The actual distance to PSR J0631+1036 is suggested to be \(\sim 1\) kpc (Zepka et al. 1996).

Although the radio pulsar lies 75′′ from the centre of the *Einstein* X-ray error circle, which makes the position outside of the nominal 90% confidence area, Zepka et al. (1996) argued that the error circle was most likely underestimated due to it being partially occulted by an IPC support strut. Zepka et al. (1996) argue that the *ROSAT* source is also partially occulted by the PSPC support strut, and use the same argument to explain the difference between the X-ray and radio positions. Ignoring this argument, Becker & Trümper (1997) report the source as not being detected, and give an upper limit of \(L_X = 1.7 \times 10^{33}\) erg/s (0.1-2.4 keV).

It is clear from *ROSAT* and *Einstein* data that it is not possible, using positional arguments alone, to determine whether PSR J0631+1036 and 2E 0636.7+1037 are the same object, or whether the discovery of the radio pulsar near the X-ray source was coincidental. The apparently final piece of evidence needed to show that the X-ray source and radio pulsar are related was given by the recently published work by Torii et al. (2001), in which analysis of an *ASCA* observation of the PSR J0631+1036 field was presented. Torii et al. (2001) report a detection of the 288ms period in the *ASCA* data to within \(10^{-7}\) of the radio period. In the paper they make no comment about the discrepancy between the radio position and the X-ray position, but Torii (2001, private communication) does not consider a 75′′ discrepancy to be particularly significant given the positional accuracy of *ASCA*. Spectral fitting of the X-ray source lead Torii et al. (2001) to report that PSR J0631+1036 has X-ray properties similar to γ-ray pulsars such as Geminga.

In this paper we present analysis of an *XMM-Newton* observation of PSR J0631+1036 utilising the EPIC-pn cameras.

2. **Observations**

The data presented are 14000s of *XMM-Newton* EPIC-pn data of which 8000 were good (4000 lost due to high background), taken as part of the guaranteed time program (PI: Fred Jansen). No MOS data were obtained due to an unusually high background level, and the RGS data were not useful due to source brightness. The *XMM-Newton* Optical Monitor obtained 3000s of simultaneous data with the UVW2 filter.

3. **Analysis of the PSR J0631+1036 Field**

Figure 1 shows the *XMM-Newton* EPIC-pn image of the region around PSR J0631+1036. The image has been annotated with positions of Simbad catalogue objects. The
Figure 1. Annotated EPIC-pn image of the region around PSR J0631+1036. The Einstein error circle of 2E0628.7+1037 clearly contains a bright X-ray source. However the radio position of PSR J0631+1036 does not contain any detectable X-ray emission. Foreground stars are labeled to show correctness of the astrometry.

Astrometry of the pn data has been confirmed by comparing with that of the Optical Monitor data, and has been found to be consistent with foreground star positions to ~1 arcsecond. From Figure 1 we see that 2E 0628.7+1037 is detected within the Einstein error circle, however with XMM-Newton’s improved spatial resolution it is now clear that the radio position of PSR J0631+1036 is not consistent with the X-ray position of 2E 0628.7+1037, but in fact lies 75″ north. Analysis of the region around PSR J0631+1036 shows that there is no X-ray source detected, and the 3σ upper limit on X-ray luminosity is: \( L_x < 5.0 \times 10^{33} \text{ erg/s, (0.5–2.0 keV)} \) assuming a distance of 6.56 kpc, or \( L_x < 1.1 \times 10^{30} \text{ erg/s, (0.5–2.0 keV)} \), assuming a 1 kpc distance. These upper limits are shown in Figure 2 along with fluxes and ROSAT upper limits for other pulsars (from Becker & Trümper 1997). For a more detailed discussion of the upper limits on X-ray emission from PSR J0631+1036 see Oosterbroek et al. (2002).

Comparing this to the previously obtained upper limit from ROSAT of \( 1.7 \times 10^{33} \text{ erg/s} \), shows that XMM-Newton allows us to improve the upper limit on X-ray emission from PSR J0631+1036 by a factor of 30 over the upper limit deduced by Becker & Trümper (1997).

Catalogue searches show that the X-ray source previously thought to be X-ray emission from PSR J0631+1036 is consistent with a catalogued V=10.4 A0 spectral classification. Further analysis of the XMM-Newton optical monitor UVW2 data confirms the A0 spectral type of this star. This star is present in the Tycho catalogue and has a parallax of 53.9+/−26.4 mas, corresponding to a distance of 12–36 parsecs. The estimated luminosity of 2E 0628.7+1037 is consistent with that of X-ray emission from an A0 star (e.g. Panzera et al. 1999), however the errors on the luminosity are large due to the uncertainty of the distance to the A0 star.

Spectral fitting of this source with the blackbody plus power-law model used by Torii et al. (2001) shows that the spectral parameters of 2E 0628.7+1037 are consistent with those derived from the ASCA data. However the XMM-Newton data shows an improved spectral fit utilising an absorbed MEKAL model (e.g. Mewe et al. 1985) with a fit-
Figure 2. The Becker and Trümper (1997) empirical relationship between the radio measured $dE/dt$ and 0.1-2.4 keV X-ray flux, plotting both X-ray detections of pulsars and $3\sigma$ upper limits derived from ROSAT. The upper limits for PSR J0631+1036 from the XMM-Newton data are marked for distances of 6.56kpc (upper arrow) and 1kpc (lower arrow).

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The predicted temperature of $kT=0.9\pm0.1$ keV and an abundance of $\sim0.15$ of solar.

We have also performed temporal analysis of the area around PSR J0631+1036 and from the detected X-rays from 2E 0628.7+1037. In both cases there is no significant detection of the 288ms pulsar period. Simulations show that if the periodicity was present in 2E 0628.7+1037 at the level reported by Torii et al. (2001), it would have been detected with high significance by XMM-Newton.

4. Discussion

Our results show that the association of PSR J0631+1036 and the Einstein source, 2E 0628.7+1037, is not real despite the claimed detection of the pulsar period in the ASCA data.

Although the position of the radio and X-ray source are offset by 75", a 3' extraction radius was used in the ASCA analysis, and in principle the signal from the pulsar could be included in the total signal. However, given that the suggested ASCA modulation had a 45% pulse fraction, we would expect that if PSR J0631+1036 were contributing this modulation, it would be detected by XMM-Newton. It is therefore likely that the period detected by Torii et al. (2001) is a statistical artifact rather than a real modulation.

Another possibility is that the radio timing position of pulsar is incorrect. To rule this out we analysed a previously unpublished VLA observation of PSR J0631+1036. Figure 3 shows VLA images of the pulsar which confirm its position at RA = 06h31m27.5s, Dec = +10°37'01.6" (J2000) with a position error $<1''$, which is consistent with the originally reported radio timing position Zupko et al. (1996).

Proper motion of the pulsar is not a likely explanation of any differences in position; if the pulsar were at 1kpc this would imply a proper motion of 60,000 km/s (and much higher if at 6.5kpc). Also the X-ray positions of 2E 0628.7+1037 measured in ROSAT and XMM-Newton data are consistent within 10" despite the observations having been taken $\sim9$ years apart. Therefore we conclude that
Figure 3. VLA image of PSR J0631+1036, clearly showing a detection of the pulsar. The coordinates of PSR J0631+1036 derived from these data are consistent with that of the originally published timing position in Zepka et al. (1996) and not consistent with any X-ray emission detected by the EPIC-pn.

the results published by Torii et al. (2001) must be incorrect.

Given this we need to re-examine the X-ray properties of PSR J0631+1036, as at present the literature is misleading. If we assume that PSR J0631+1036’s X-ray emission follows the empirical relationship of Becker & Trümper (1997) $L_x = 10^{-3} \dot{E}$ erg/s, then the expected X-ray luminosity from this source will be: $L_x = 1.7 \times 10^{32}$ erg/s, which is close to our upper limit of $5.0 \times 10^{31}$ erg/s (for 6.56kpc). This upper limit lies 1σ below the Becker & Trümper (1997) relationship line shown in Figure 2. We therefore conclude that the non-detection of the pulsar by XMM-Newton is consistent with the Becker & Trümper (1997) relationship if the distance to the pulsar is 6.56kpc.

If the distance to pulsar is 1kpc as suggested by Zepka et al. (1996), the X-ray upper limit is now $\sim 2$ orders of magnitude lower than estimated $10^{-3} \dot{E}$ value, suggesting that the emission is not following the Becker & Trümper (1997) relationship. However without an accurate measurement of the distance to PSR J0631+1036 this cannot be considered firm evidence. Therefore further X-ray observations are encouraged to further constrain the distance and X-ray luminosity of this pulsar.

5. Conclusions

X-rays from PSR J0631+1036 have not been detected by XMM-Newton. Therefore the detection of the 288ms pulsar period in ASCA data by Torii et al. (2001) is not likely to be correct due to the 75″ discrepancy between the position of the X-ray source and the radio position of the pulsar. It is therefore considered very unlikely that the object 2E 0628.7+1037 is related to PSR J0631+1036.

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