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RX J0720.4-3125: strong evidence for an isolated pulsating neutron star*

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Abstract. We report the discovery of RX J0720.4-3125, a soft X-ray source showing 8.391 s pulsations, from the ROSAT all-sky survey. The relative constant long-term X-ray intensity, the blackbody-like spectrum with little photo-electric absorption and the limit for f_x/f_v of more than 500 are consistent with an isolated neutron star accreting from the interstellar medium (all very similar to RX J1856.5-3754, so far the best candidate). We estimate the magnetic field strength of the neutron star to be less than 10^{10} G. RX J0720.4-3125 may have emerged from common envelope evolution of a high mass X-ray binary. The final neutron star is expected to be close the galactic plane, have a low space velocity and a low magnetic field, accreting interstellar matter very effectively. In this case RX J0720.4-3125 would not belong to the expected large group of old neutron stars evolved from single stars. The low derived magnetic field strength and the pulse period are however also compatible with an old (10^9 yr) neutron star in which case we see a neutron star from the very low end of the velocity distribution. The low number of isolated neutron star candidates from the ROSAT all-sky survey remains to be explained.

Key words: stars: neutron – stars: individual: RX J0720.4-3125 – X-rays: stars

1. Introduction

The present pulsar birthrate and the number of supernovae required to account for the heavy-element abundance suggest up to 10^9 neutron stars existing in the Milky Way. The young neutron stars are observable as radio pulsars, through their thermal emission from the cooling surface or in X-ray binaries. Recently a group of X-ray pulsars has been suggested as single neutron stars accreting from a disk, the remnant of common-envelope evolution of a high mass X-ray binary (Mereghetti & Stella 1995, van Paradijs et al. 1995).

After about $> 10^7$ yr when the radio emission has faded away and the temperature cooled below 10^5 K, isolated neutron stars become invisible for us. However a fraction of the old neutron stars may be detected in the EUV to soft X-ray energy band when accreting from the interstellar medium (Ostriker et al. 1970). Estimates for the number of old, isolated neutron stars detectable in the ROSAT all-sky survey range from about 2000 to 10000 (Treves & Colpi 1991, Blaes & Madau 1993, Madau & Blaes 1994). However it will be very difficult to prove the nature of the majority of faint sources to confirm these numbers.

Despite of intensive searches however (e.g. Danner 1996, Belloni et al. 1997), evidence for only one candidate for an isolated old neutron star has been found today (RX J1856.5-3754, Walter et al. 1996, Neuhäuser et al. 1997). Walter et al. (1997) identified a blue object of about 26th magnitude as probable optical counterpart to the X-ray source. The ROSAT PSPC spectrum of RX J1856.5-3754 is soft (blackbody temperature kT = 57 eV) and little absorbed (N_H = 1.4 10^{20} cm^{-2}). The distance is limited by a molecular cloud located behind RX J1856.5-3754 to 120 pc, yielding an observed luminosity (5 10^{31} (d/100pc)^2 erg s^{-1}) consistent with that predicted for a slow moving neutron star accreting from the ambient interstellar medium.

The discrepancy between the predicted number of neutron stars to be seen in the ROSAT all-sky survey and the observations is further strengthened by upper limits derived from nearly complete identifications of area-selected survey sources. Motch et al. (1997) found from the small number of unidentified sources in a 65 square degree field in Cygnus a factor of 10 lower limit than most model predictions.

We report here the discovery of RX J0720.4-3125, a likely isolated pulsating neutron star. The X-ray properties (Sect. 2.1) are very similar to those of RX J1856.5-3754. Optical observations, presented in Sect. 2.2, failed so far in finding a counterpart.

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* Partly based on observations collected at the South African Astronomical Observatory and the European Southern Observatory at La Silla

Table 1. Soft X-ray detections of RX J0720.4-3125 (0.1-2.4keV)

Date	Instrument	exposure s	observed counts s^{-1}	predicted[1] counts s^{-1}
March 12, 1984	EXOSAT LE/3Lx	4378	0.105 ±0.007	0.103
March 12, 1984	EXOSAT LE/AlP	1575	0.042 ±0.006	0.042
Oct. 11-13, 1990	ROSAT survey	328	1.69 ±0.07	
Sept. 27, 1993	ROSAT PSPC	3226	1.64 ±0.04	
April 25, 1996	ROSAT HRI	3566	0.36 ±0.01	0.38
May 7, 1996	ROSAT HRI	3145	0.40 ±0.01	0.38
Nov. 3-4, 1996	ROSAT HRI	33660	0.38 ±0.01	0.38

[1] Based on the PSPC spectrum, see end of Sect. 2.1.

Table 2. Bremsstrahlung and blackbody fits to the PSPC spectrum of RX J0720.4-3125. The errors are 90% confidence for two parameters of interest. The observed flux is in the range 0.1-2.4 keV.

Model	N_H 10^{20} cm^{-2}	kT eV	χ^2_r	flux erg s^{-1} cm^{-2}
Brems-strahlung	2.6±0.3	148±10	1.07	$1.08^{+0.62}_{-0.21}$ 10^{-11}
blackbody	1.3±0.3	79±4	0.90	$1.15^{+0.30}_{-0.14}$ 10^{-11}

We discuss the properties of RX J0720.4-3125 with respect to its evolutionary status.

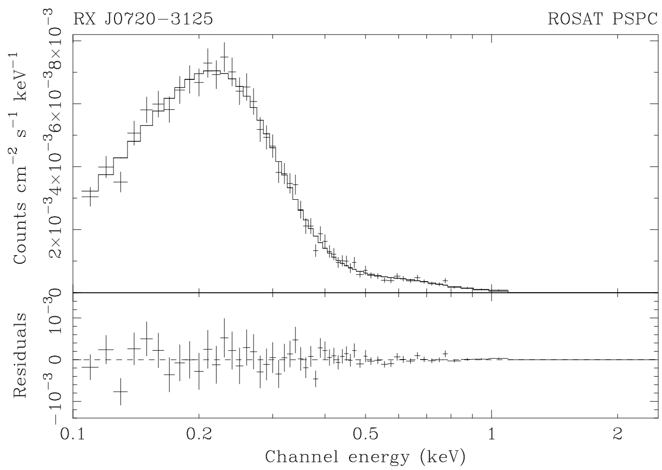

Fig. 1. The PSPC spectrum of RX J0720.4-3125 fitted by a blackbody model. The residuals are shown in the lower panel

2. Observations

2.1. Soft X-rays

RX J0720.4-3125 was discovered as soft X-ray source in the ROSAT all-sky survey data in the course of the Galactic Plane Survey. The aim of this project is to optically identify ROSAT sources in the galactic plane between ±20° galactic latitude (Motch et al. 1991). A description of the satellite and the position sensitive proportional counter (PSPC, 0.1 – 2.4 keV) may be found in Trümper (1983) and Pfeffermann et al. (1986). The high resolution imager, HRI, is described by David et al. (1993).

The source was re-observed in dedicated pointings with the PSPC and HRI detectors. A summary of the observations is presented in Table 1 together with previous soft X-ray detections (see below). The light curve obtained from the PSPC observation is consistent with a constant count rate at a mean compatible to the survey intensity. The average PSPC spectrum (Fig. 1) is very soft with practically no emission above 1 keV. Among single component models thermal bremsstrahlung and blackbody models acceptably fit the spectrum and the derived parameters are summarized in Table 2. Thermal emission from an optically thin plasma with a temperature of 150 eV is however bound to show emission lines, but e.g. a Raymond-Smith type model yields a reduced χ^2 of 1.6 favouring the blackbody model. For the latter a bolometric luminosity of L_{bol} = 2.6 10^{31} (d/100 pc)^2 erg s^{-1} and an emission area of 65 (d/100 pc)^2 km^2 is derived.

A folding analysis of the PSPC data using a Rayleigh Z^2 test (Buccheri et al. 1983) reveals a periodic modulation at 8.3914 s. However the uncertainty in cycle counts between the observation intervals causes several peaks with offsets of multiples of about 0.01 s around this period which can formally not be rejected. The power spectrum is shown in Fig. 2 with a peak near 0.12 Hz. To determine the uncertainty of the pulse period a pulse phase timing analysis was used. The data was divided into five intervals, between 500 s and 800 s long, and for each the phase shift of the folded light curve relative to the total was derived by cross-correlation of the pulse profiles. This yields a formally best period of 8.3914 ± 2 10^{-4} s (90% confidence), but periods offset by multiples of 0.01 s can not be excluded up to ±0.03 s. The light curve folded by the pulse period is plotted in Fig. 3 and shows a sinusoidal semi-amplitude modulation of 11 ± 2%.

In the light curves of the HRI observations no statistically significant variations are seen (an example is shown in Fig. 4) and a Kolmogorov-Smirnov test yields in all cases a probability for variability of below 2.5 sigma.

The timing analysis was performed in the same way as for the PSPC data. The pulse folding reveals two peaks in the Z^2 test of the first HRI observation at periods of 8.3797 s and 8.3917 s

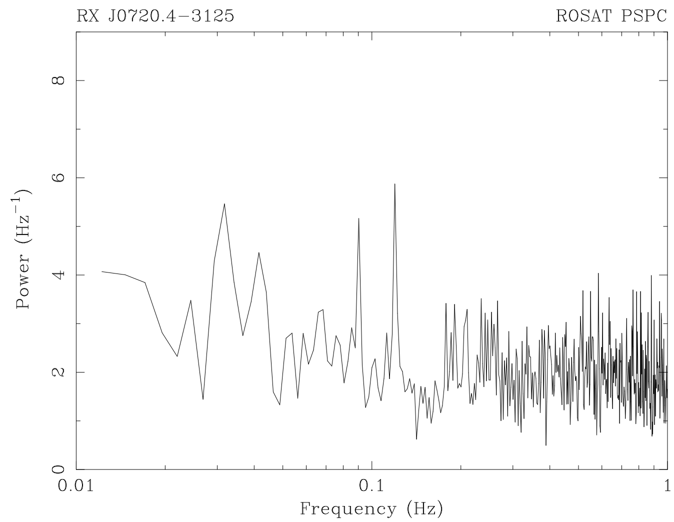

Fig. 2. Power spectrum from the PSPC observation from Sep. 27, 1993. The peak near 0.12 Hz indicates the period of 8.3914 s

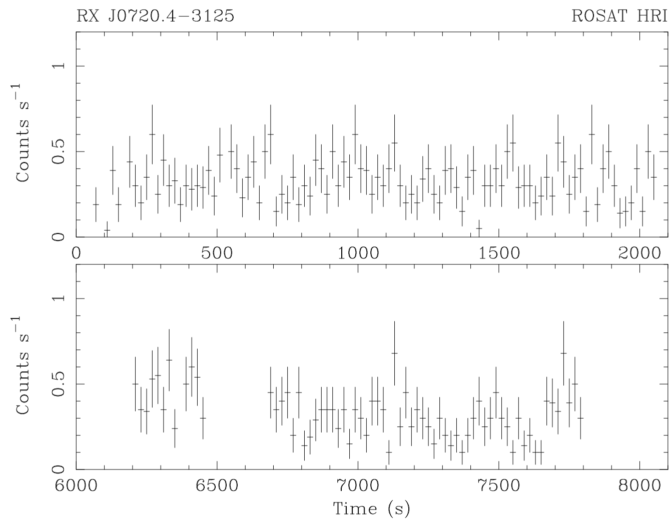

Fig. 4. The HRI light curve of RX J0720.4-3125 on Apr. 25, 1996 (15:19:32 – 17:34:29 UT) with a time resolution of 20 s

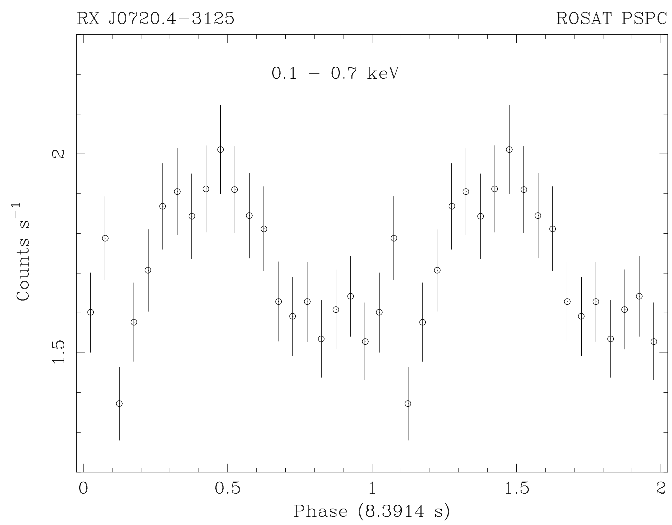

Fig. 3. The light curve from Sep. 27, 1993, folded with a period of 8.3914 s, for clarity data points are repeated for a second period

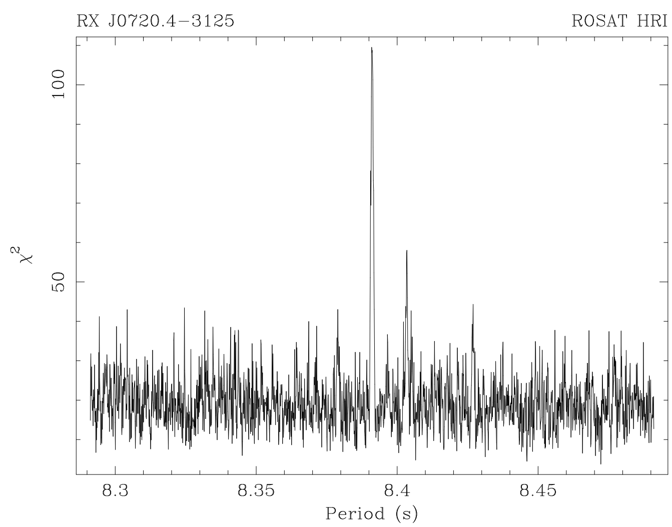

Fig. 5. χ^2 test for the HRI observation from Nov. 3–4, 1996

with the peak at the shorter period only insignificantly higher. From pulse timing analysis of three observation intervals the period is derived to $8.3917 \pm 8\ 10^{-4}$ s (taking the peak which is most significant in the PSPC observation). However, like for the PSPC data, periods away by multiples of 0.01 s can not be excluded and in particular the period of 8.3797 s is equally prominent. During the second HRI observation when the source was 10′ off-axis the statistics was too low to derive useful constraints on the pulse period.

The deep 33 ksec HRI observation performed in Nov. 1996 was distributed over more than 18 hours and allows to uniquely determine the pulse period to $8.39115 \pm 2\ 10^{-5}$ s with a probability for chance detection of 4 10^{-9} derived from the χ^2 test (Fig. 5). The folded light curve with a sinusoidal modulation of $12 \pm 2\%$ is plotted in Fig. 6 and is consistent with that from the PSPC observation. A linear fit to the 3 measured periods yields a $\dot{P}$ of -2.6 10^{-12} with a 90% confidence range of -6.0 10^{-12} to 0.8 10^{-12}, compatible with no period change.

The best determined PSPC position was derived from the survey data utilizing the X-ray detection of the nearby, optically identified source EUVE0720-317, for bore-sight correction (only about 2″ were required). The remaining 90% confidence error of 9.6″ is mainly determined by the statistical uncertainties in the survey data. Unfortunately the EUVE source is partly hidden by the detector window support structure in the pointed PSPC observation, resulting in a 15″ error, dominated by bore-sight uncertainties. To derive the most accurate position of RX J0720.4-3125 the two HRI observations from May and Nov. 1996 can be used. The first of the two pointings was directed to include both RX J0720.4-3125 and EUVE0720-317 at an off-axis angle of 10′, while six other faint objects were detected in the HRI image of the latter observation. In the first case an interactive analysis using the maximum likelihood tech-

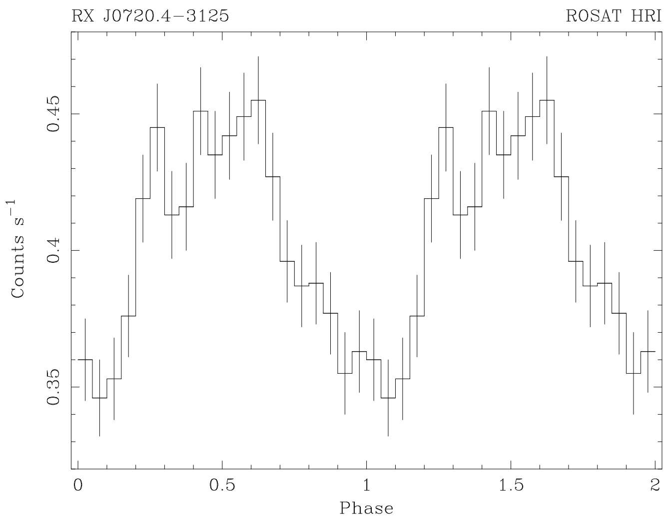

Fig. 6. The HRI light curve from Nov. 3–4, 1996, folded with a period of 8.39115 s and repeated for two cycles

nique of EXSAS (Zimmermann et al. 1994) gives RA (2000) = $07^h\ 20^m\ 25^s.00$ Dec = -31° 25′ 46″.3 with a 90% confidence error of 3″ (statistical errors of the X-ray positions and 2″ error for the optical position of EUVE0720-317). The HRI pixel size has recently been determined to 99.57% of the originally assumed value (see discussion in Neuhäuser et al. 1997) which shifts the HRI position by about 5″ towards EUVE0720-317 to RA (2000) = $07^h\ 20^m\ 25^s.09$ Dec = -31° 25′ 51″.8.

During the deep HRI observation from Nov. 1996 EUVE0720-317 was outside the field of view of the detector, but six other X-ray sources were detected with likelihoods exceeding 10. For five of the X-ray sources close objects can be found in the Digitized Sky Survey (Laidler et al. 1996) with distances between 0.7″ and 7.4″ (for only one object the distance exceeds 3.1″) and R magnitudes between 9.4 and 16.0. The HRI positions of the five X-ray sources were again corrected for the HRI pixel size which improved the coincidence with the optical positions by 1″ on average. A firm identification of the X-ray sources requires detailed optical observations, but on a statistical basis they can be used to reduce the systematic bore-sight uncertainty. A correction of only -0.8″ was found by minimizing the distances between X-ray and optical position. Taking into account the statistical errors on the X-ray positions and 2″ uncertainty for the optical positions an uncertainty of 3″ remains. The position of RX J0720.4-3125 was determined to RA (2000) = $07^h\ 20^m\ 24^s.90$ Dec = -31° 25′ 51″.3. The two obtained confidence circles for the position of RX J0720.4-3125 overlap and are shown in Fig. 7 (see below).

RX J0720.4-3125 was also in the field of view of EXOSAT LE observations on March 12, 1984, using the 3000 Lexan and the Aluminum-Parylene filters. The observed intensities are consistent with the ROSAT values. All the soft X-ray observations are summarized in Table 1. Assuming the blackbody model derived from the PSPC spectrum of the pointed observation, the expected intensities for the other detectors are calculated. The count rates differ by less than 5% from the expected count rates calculated for the assumed spectral model. The EXOSAT position derived from the observation using the 3000 Lexan filter is 10″ away from the best HRI positions but has a large error radius of 15″.

2.2. Optical

CCD images of the RX J0720.4-3125 field were obtained using the South African Astronomical Observatory's 1.0-m telescope in November 1995. The Tek4 camera, utilizing a Tektronics 512 x 512 CCD, was used to obtain B, V, R, I and H-alpha images. The CCD frames were cleaned, bias subtracted, and analyzed using the DoPHOT analysis program (Mateo & Schechter 1989) to derive PSF and aperture magnitudes of all stars. Colour-colour and colour-magnitude plots were produced (e.g. U-B vs V) to identify unusual objects in the frame. No such object, nor indeed any stellar image, was found in or near the X-ray error circles. All stars in the vicinity had colours consistent with normal field stars. Only one unusual object, exhibiting possible H-alpha emission (from a comparison of H-alpha versus R magnitudes), was seen in the entire 9′ x 9′ field. However it was 5′ from the X-ray position, clearly unassociated with the X-ray source. In Fig. 7 the R-band image around the position of RX J0720.4-3125 is shown together with the positional error circles from the ROSAT HRI observations.

No objects fainter than B = 21.0, V = 20.7 and R = 21.4 magnitudes are seen in the images. The limiting V magnitude yields a $f_x/f_v > 510$ for RX J0720.4-3125 (using $\log(f_x/f_v) = \log(f_x) + (m_v/2.5) + 5.37$ (Maccacaro et al. 1988)).

In March 1996 we observed the three faint objects about 6–10″ away from the best HRI position (Fig. 7) spectroscopically at the ESO/MPIA 2.2 m telescope. Their V magnitudes range between 19.9 and 20.1. The observations were obtained with the *EFOSC2* spectrometer which was equipped with a Thomson 1024×1024 pixel CCD chip (ESO CCD #19). The spectral resolution obtained with grism #1 and the 1″ slit (cf. ESO Users Manual) was ∼ 24 Å. The spectra are displayed in Fig. 8. They are consistent with those of normal stars.

3. Discussion

We have discovered the soft X-ray source RX J0720.4-3125 in the ROSAT all-sky survey. From optical observations we found no counterpart down to a limiting B magnitude of 21.0. The source neither appears in the ROSAT WFC 2RE catalogue (Pye et al. 1995), as EUVE source (Malina et al. 1994), in radio catalogues, as IRAS nor as EGRET source. RX J0720.4-3125 is probably identical with the Einstein IPC slew source 1ES0718-313, only 11″ away from the best ROSAT position. The IPC count rate was 0.39 ± 0.16 counts s^{-1}, compatible with the ROSAT fluxes, although with a large error and from a different energy band. The lower limit for f_x/f_v of 500 would still be compatible with a low mass X-ray binary nature as these systems have typical ratios of 100-1000 (White et al. 1993). The EXOSAT LE fluxes together with the ROSAT measurements

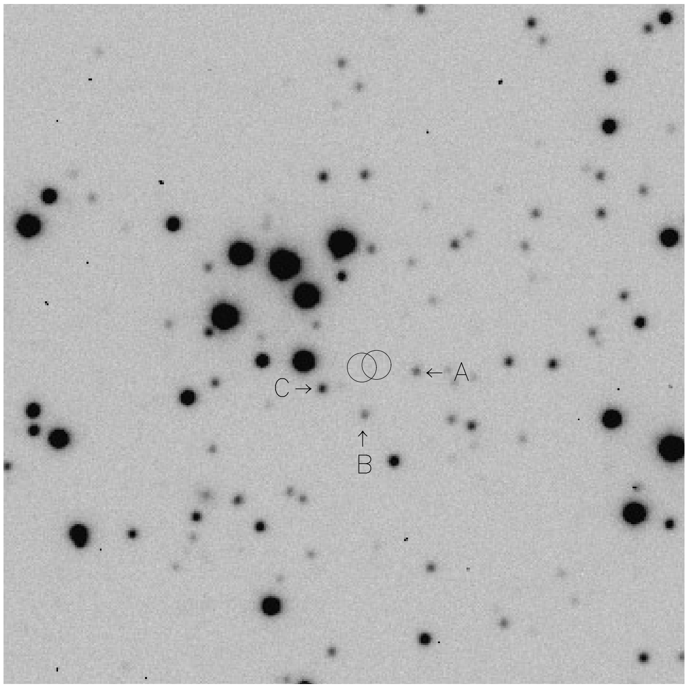

Fig. 7. CCD R-band image with 300 s exposure around the X-ray position of RX J0720.4-3125. The circles represent the 90% confidence regions from the X-ray positions of the HRI observations with available bore-sight correction. From the three faint objects A, B, and C optical spectra were taken. The size of the image is about 2.2′ x 2.2′, north is to the top and east to the left

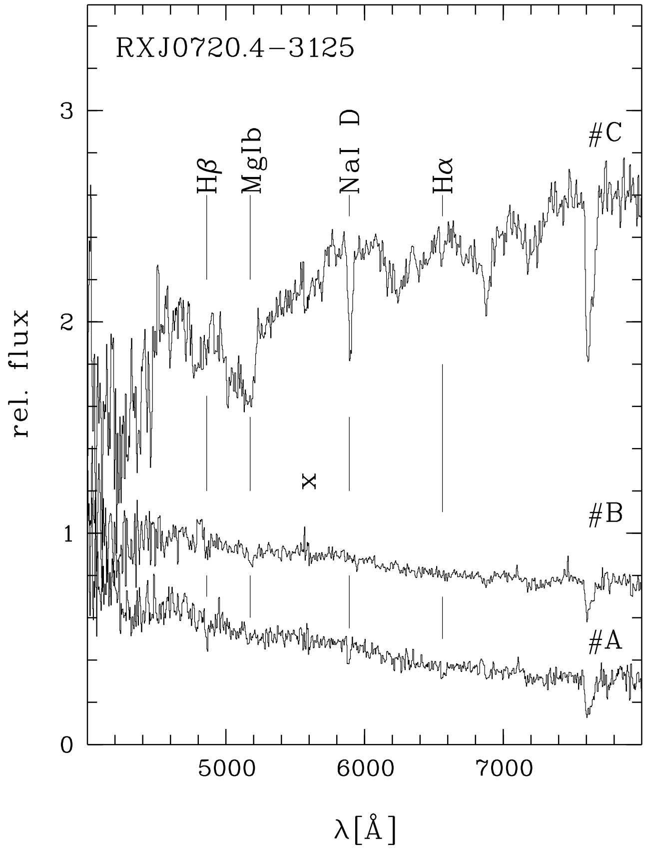

Fig. 8. Spectra of the three objects marked in Fig. 9. Spectra #B and #C are vertically shifted by 0.5 units in order to avoid overlap. "x"denotes residuals of a night sky line. Some characteristic spectral features are indicated. The spectra of objects #A and #B are consistent with ∼ F-G type stars, although in #B the absorption features are relatively faint. Object #C is an M-type dwarf

indicate no large changes of the X-ray intensity (±5%) on time scales of years, in contrast to the highly variable X-ray binaries. Also the derived X-ray luminosity using distance estimates (see below) is orders of magnitudes lower than for typical low mass X-ray binaries.

The 8.391 s pulse period, if interpreted as spin period, makes it unlikely to come from a white dwarf. A massive white dwarf with this rotation period is still stable (e.g. Chanmugam et al. 1987) but would be expected in a binary system, spun up by accretion, and optically visible as cataclysmic variable. An isolated white dwarf which has fully accreted or evaporated its low-mass companion and is accreting from the interstellar medium would need to be about 30 times closer than a corresponding neutron star (see discussion below), to account for the observed X-ray flux. Also in this case it should be seen in the optical.

The similarities in the X-ray properties of RX J0720.4-3125 compared to RX J1856.5-3754 and the high limit of the f_x/f_v ratio suggest it as very likely candidate for an isolated neutron star. If the bolometric luminosity of RX J0720.4-3125 and RX J1856.5-3754 is comparable then the distance to RX J0720.4-3125 can not be far in excess of 100 pc. In this case the derived emission area is only a fraction of the neutron star surface, compatible with the observation of pulsed 8.391 s modulation of the soft X-ray flux from RX J0720.4-3125. In fact to keep the emission area smaller than the surface of a neutron star, the distance must be less than about 440 pc for a standard neutron star with 10 km radius.

The low value of photo-electric absorption derived from the PSPC spectrum ($1.3\ 10^{20}$ cm^{-2} compared to the integrated galactic absorption in this direction of $1.89\ 10^{21}$ cm^{-2}, Dickey & Lockman 1990) also excludes an extragalactic origin. The absorption may further provide an estimate for the distance of RX J0720.4-3125. Studies of the local interstellar medium conclude that in the direction to RX J0720.4-3125 the density is very low (Paresce 1984). No absorbing interstellar clouds are visible in CO-maps (Dame et al. 1987) and dark cloud maps (Feitzinger & Stüwe 1986). Welsh (1991) finds a 'tunnel' with $n < 0.1$ cm^{-3}, 300 pc long, about 5° away from RX J0720.4-3125. The nearby (1°) open cluster Collinder 140 shows an E(B-V) of 0.05, corresponding to an N_H of $2.8\ 10^{20}$ cm^{-2}, and is located at a distance of 400pc. Hence the distance may well be up to around 300 pc, limiting the X-ray luminosity to about $2.3\ 10^{32}$ erg s^{-1}.

An isolated neutron star may be visible in X-rays for a relatively short period as young cooling object or when it is accreting matter from the interstellar medium. For the latter case, assuming blackbody-like emission, Blaes & Madau (1993) predict neutron star surface temperatures of kT = 20 $(\dot{M}_{10}/f)^{1/4}$ eV, where $\dot{M}_{10}$ is the mass accretion rate in units of 10^{10} g s^{-1} and f is the fraction of the neutron star surface covered by accretion. Using the observed kT of 80 eV one derives $\dot{M}_{10}$ = 250f. For the bolometric luminosity Blaes & Madau (1993) give $L_{bol} = 2\ 10^{30}$ $\dot{M}_{10}$ erg s^{-1} for a standard 1.4 $M_{\odot}$, 10 km radius neutron star, i.e. for RX J0720.4-3125 a luminosity L_{bol} of 5 10^{32} f erg s^{-1}. Observed and modeled luminosity are consistent for $(d/100pc)^2$ = 20f, e.g. for a distance of 100 pc yielding f = 0.05, L_{bol} = 2.6 10^{31} erg s^{-1} and $\dot{M}$ = 1.2 10^{11} g s^{-1}. For this distance the derived luminosity yields a lower limit for the ambient interstellar gas density (assuming spherical accretion with a relative neutron star velocity of 0, see Eq. 21 in Blaes & Madau 1993) of about 0.05 cm^{-3}. For a typical gas density of 1 cm^{-3} a relative velocity of around 15 km s^{-1} is expected. Because the density rises steeply with the relative neutron star velocity, unrealistic high densities are derived for velocities in excess of 100 km s^{-1}. The only solution would be a lower luminosity and hence a lower distance which is probably in contradiction to the values derived from the absorption, if it is mainly of interstellar origin. However the emitted spectrum might deviate from a blackbody (Zampieri et al. 1995, Zavlin et al. 1996) and the parameters derived above should be treated critically.

Isolated neutron stars with internal frictional heating only are expected to cool to the observed temperature of 8 10^5 K within about 4 10^5 yr (Umeda et al. 1993, Becker 1996). This is a lower limit for the age of a neutron star in RX J0720.4-3125 and the real age is depending on how much the accretion onto the magnetic poles re-heats the star. The case of a purely cooling neutron star is improbable for RX J0720.4-3125. Unlike young cooling neutron stars RX J0720.4-3125 has no radio or gamma-ray counterpart or association with a supernova remnant and the spin period would be exceptionally long.

An estimate of the age of the neutron star may come from the group of 5–9 s X-ray pulsars which has been suggested as the result of common envelope evolution of a high mass X-ray binary (van Paradijs et al. 1995). In this picture a neutron star is accreting from a massive disk, the remnant of the companion star. These pulsars show apart from their very narrow period distribution other similarities: their X-ray spectra are much softer than those of 'normal' pulsars, their pulse period increases with time, their locations are well confined to the galactic plane (within $\sim$ 100 pc) like for high mass X-ray binaries and their X-ray luminosities are in the range of 10^{35} to 10^{36} erg s^{-1} and relatively constant on time scales of days to about 10 years. The fact that the pulse period of RX J0720.4-3125 fits into the period distribution of the 5–9 s pulsars is conspicuous and could indicate a relation between the objects, but we stress that it may be purely accidential as the relation between the 5–9 s pulsars is not proven yet. However if there is a relation, and the required low space velocity of RX J0720.4-3125 and its low distance to the galactic plane may be arguments for an evolution from a high mass X-ray binary, RX J0720.4-3125 could be the finally evolved single neutron star having lost the disk or at most have only a tenuous remainder as the much lower X-ray luminosity of RX J0720.4-3125 indicates. In the latter case RX J0720.4-3125 might be relatively young ($\lesssim 10^7$ yr), but modeling the spin evolution of the neutron star through the disk accretion phase and beyond is required to yield better age estimates. The evolutionary scenario outlined above could even hold if the 5–9 s pulsars turn out to be a group of unrelated objects with a different evolution. Isolated neutron stars which were going through a common envelope evolution in a high mass X-ray binary, perhaps via a Thorne-Zytkow object (the neutron star spirals into the center of the massive star) are expected to have a relatively low space velocity of around 50 km s^{-1} (Podsiadlowski 1995). They can accrete more efficiently from the interstellar medium than high velocity neutron stars and are therefore brighter and more easily to detect.

The estimate of the X-ray luminosity and the pulse period allow to constrain the magnetic field strength of the neutron star in RX J0720.4-3125, if the X-ray emission is powered by accretion. For accretion to significantly occur, the Kepler co-rotation radius should be larger than the Alfven radius, which implies for an X-ray luminosity of around 10^{32} erg s^{-1} a magnetic field strength of less than 10^{10} G. According to current ideas the decay of neutron star magnetic fields is strongly related with the accretion of matter. Observations of binary radio pulsars with low-mass companions are consistent with increasing field decay with increasing amount of matter accreted (van den Heuvel & Bitzaraki 1995). Evolution via a Thorne-Zytkow object could easily provide the required mass for accretion to explain the systematically low magnetic fields in the 5-9 s X-ray pulsars of the order of 10^{11} G (van Paradijs et al. 1995, White et al. 1996) and the even lower field required for RX J0720.4-3125. A similar evolutionary scenario was proposed by Lorimer et al. (1995) for low-velocity radio pulsars with low magnetic field. On the other hand an old isolated neutron star evolved from a single star can not be ruled out from the magnetic field strength arguments. Lyne et al. (1985) present field decay time scales of $\sim 10^7$ yr from observations of pulsars, but Bhattacharya et al. (1992) argue for no significant decay in single radio pulsars over 10^8 yr and Kulkarni (1986) derives evidence for a long-lived component of $\lesssim 10^{10}$ G at least for neutron stars in binaries. It is therefore not clear how the magnetic field of an isolated neutron star decays with time, but 10^9 yr may be sufficient for the field to decay from typical 10^{12} G to 10^9 G and also spin down a fast rotating neutron star to the observed spin period of RX J0720.4-3125.

RX J0720.4-3125 and RX J1856.5-3754 are both close to the galactic plane and have a low space velocity, if our picture of accreting neutron stars is correct. These facts however do neither favour the evolution from a high mass X-ray binary nor from a star which left a single low-velocity neutron star. The derived low magnetic field strength in the case of RX J0720.4-3125 may suggest that it has undergone periods of large matter accretion in favour of a high mass X-ray binary evolution. The temporal evolution of neutron star magnetic fields however needs to be better understood before a definite statement can be made. The low magnetic field in RX J0720.4-3125 may be in turn the reason for the still relatively short spin period as the propeller mechanism which can slow down the rotation becomes inefficient. This may suggest that at least RX J0720.4-3125 is not belonging to the expected large class of isolated old neutron stars. The latter may have larger space velocities, closer to that of radio pulsars which are distributed around 450 km s^{-1} (Lyne & Lorimer 1994) or low mass X-ray binaries (van Paradijs & White 1995), as assumed in the estimates for the number of old neutron stars detectable in the ROSAT survey (e.g. Blaes & Madau 1993). Faster neutron stars are expected to be fainter because spherical accretion (Bondi & Hoyle 1944) strongly depends on the relative velocity of the matter to the neutron star ($\propto (v_{rel}^2+c_s^2)^{-3/2}$). In this case even nearby (a few 100 pc) old isolated neutron stars would be very faint in the ROSAT survey data (e.g. for only a factor 2 higher space velocity, the count rate of RX J0720.4-3125 would decrease to 0.2 counts s^{-1}). However, it can again not be excluded that we see old objects (evolved from a single star) from the very low end of their velocity distribution. In particular at low velocities this distribution is not certain and the number of isolated neutron stars detected in the ROSAT all-sky survey may help to constrain it. Further observations to determine the pulse frequency change and proper motion of RX J0720.4-3125 will gain further insight into this object. The upper limits derived from optical identifications of ROSAT survey sources in selected fields (Motch et al. 1997) on the number of isolated neutron star observed by ROSAT however still needs to be explained by the models.

4. Conclusions

The discovery of RX J0720.4-3125 and its pulse period of 8.391 s indicates that we found an isolated neutron star which probably accretes matter from the ambient interstellar medium. A possible scenario including common envelope evolution of a high mass X-ray binary is consistent with the required low space velocity, the low distance to the galactic plane and the low magnetic field strength of less than 10^{10} G and could mean that isolated neutron stars have larger velocities and are more difficult to detect in the ROSAT all-sky survey than expected. The negative results for identifications of old isolated neutron stars in sample areas from the ROSAT all-sky support this picture.

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