Astron. Astrophys. 318, 490–494 (1997)

ASTRONOMY
AND
ASTROPHYSICS

RX J0529.8-6556: a new pulsating Be/X-ray transient in the LMC

F. Haberl[1], **K. Dennerl**[1], **W. Pietsch**[1], **and K. Reinsch**[2]

[1] Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße, D-85748 Garching, Germany
[2] Sternwarte, Geismarlandstraße 11, D-37083 Göttingen, Germany

Received 16 April 1996 / Accepted 11 July 1996

Abstract. We report the discovery of RX J0529.8-6556, a new transient X-ray source in the direction of the Large Magellanic Cloud. From 32 pointed ROSAT observations distributed over 3.5 years one single outburst with 0.25 cts s^{-1} was detected while from most observations only upper limits could be derived. During the outburst periodic modulation of the X-ray flux with a period of 69.5 s is seen. Optical spectra taken from the B = 14.5 mag star closest to the X-ray position, reveal the presence of an Hα emission line and yield a spectral type of B2e. The radial velocities derived from the Balmer absorption lines are consistent with that of the Large Magellanic Cloud. Thus RX J0529.8-6556 is the fifth accretion powered X-ray binary pulsar, the fourth with a Be star companion, known in this nearby galaxy.

Key words: stars: binaries – stars: neutron – stars: emission-line, Be – stars: individual: RX J0529.8-6556 – X-rays: stars

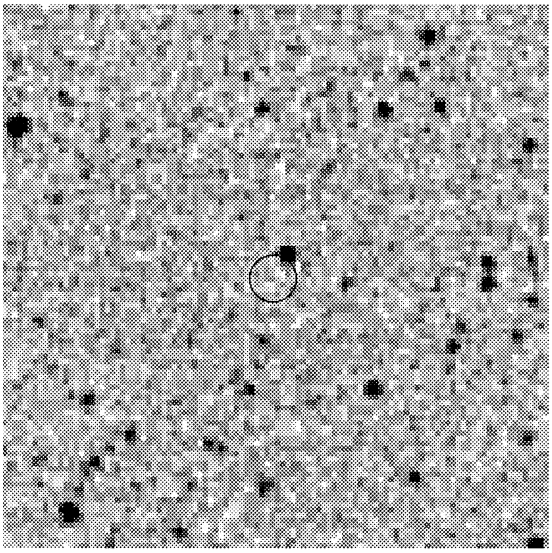

Fig. 1. Finding chart for RX J0529.8-6556 with a field size of 3′ by 3′ produced from the digitized UK Schmidt plate 06B0. East is to the left and north is up. The proposed counterpart is the R $\sim$ 13.3 mag object on the error circle with radius 8″

1. Introduction

The recent ROSAT discoveries of pulsations in the soft X-ray flux from EXO 053109-6609.2 (13.7 s, Dennerl et al. 1995) and RX J0502.9-6626 (4.06 s, Schmidtke et al. 1995) have increased the number of accretion powered X-ray binary pulsars in the Large Magellanic Cloud (LMC) to four. All belong to the class of high mass X-ray binaries with a massive companion star.

The bright X-ray source LMC X-4 (13.5 s) was identified with an O8III star in a 1.4 day binary orbit with a neutron star. The X-ray luminosity of more than 10^{38} erg s^{-1} is powered by material lost from the Roche lobe filling star and accreted via a disk around the compact object.

The two new pulsars belong together with A0538−66 (0.069 s) to the subclass of high mass X-ray binaries with a Be companion star. In these systems a neutron star is in a moderately eccentric orbit around the early type star accreting matter from the high-density, low-velocity wind in the equatorial plane of the Be star (for a recent review see Apparao (1994)). Be/X-ray binaries are often transients showing two types of outbursts, one associated with the periastron passage of the neutron star and the other occurring irregularly when the Be star enters a phase of increased mass loss. Outbursts of the latter type can last of the order of weeks and hence longer than the binary orbit. Moreover outbursts near periastron are not always present indicating changes in the circumstellar disk structure.

The pulse periods of the LMC binary pulsars are at the lower end of the period distribution found from high mass X-ray binary pulsars known so far in the Milky Way and the Magellanic Clouds. This has probably two reasons; the longer period Be/X-ray pulsars are persistent low-luminosity systems and longer periods are more difficult to detect in general. The pulse profiles of high mass X-ray binaries show a variety of shapes and different energy dependence. A complex multi-peak profile is observed e.g. from the supergiant X-ray binary Vela X-1 between 2 – 6 keV while it is more double sinusoidal above

Send offprint requests to: F. Haberl

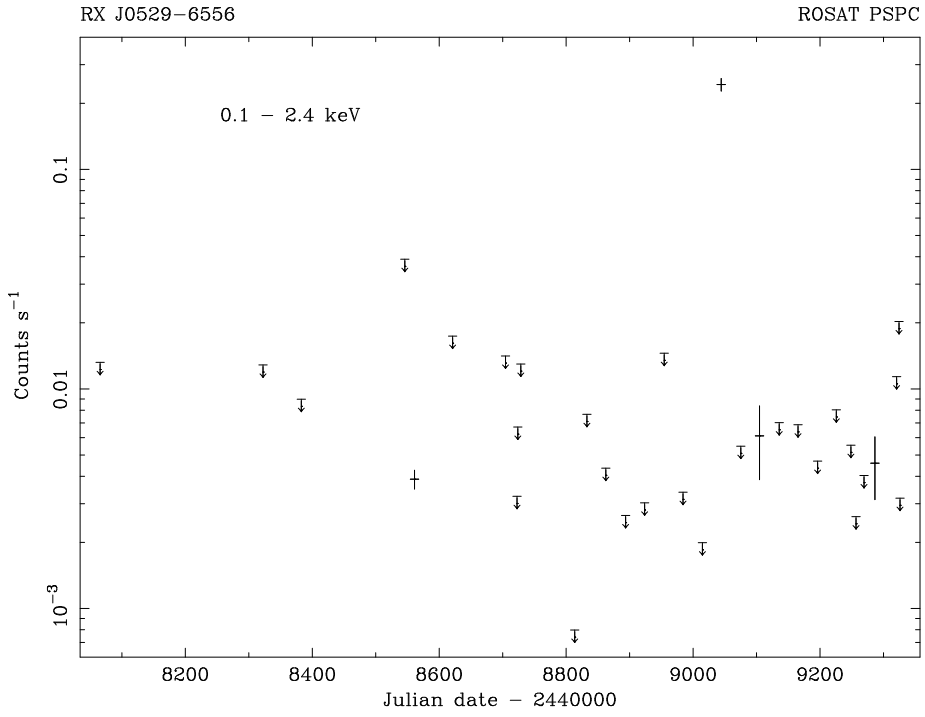

Fig. 2. The long term soft X-ray light curve of RX J0529.8-6556. Upper limits are marked with an arrow (at center of the symbol), while crosses show the detections from the pointed observations

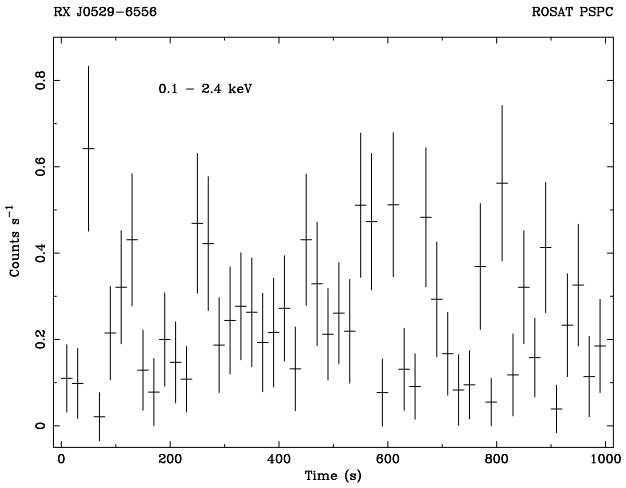

Fig. 3. Background subtracted X-ray light curve of RX J0529.8-6556 from the observation performed on Feb. 25, 1993. The time binning is 20 s

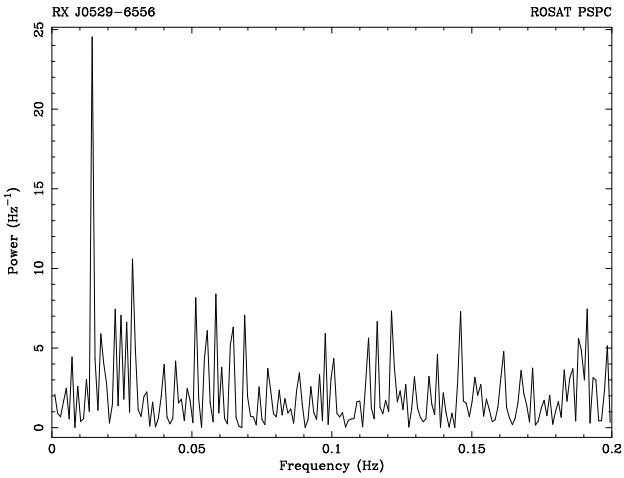

Fig. 4. Power spectrum of RX J0529.8-6556. The period of 69.3 s (0.014 Hz) and its first harmonic is clearly visible

10 keV. Scattering of the X-rays in the dense stellar wind of the supergiant and the existence of an un-pulsed soft spectral component in the ROSAT energy band result in only little modulation below 2.4 keV (Haberl 1994). This makes the detection of periodic modulation in the soft X-ray flux, in particular for wind-accretion powered supergiant X-ray binaries, difficult and not surprisingly the new ROSAT discovered pulsations were found only from Be/X-ray transients.

We report the discovery of periodic pulsations during an X-ray outburst from a previously unknown X-ray source in the direction of the LMC. We present data from ROSAT observations distributed over 3.5 years and optical spectra of the likely optical counterpart. X-ray and optical data are consistent with a Be/X-ray pulsar in the LMC.

2. ROSAT observations

ROSAT observations in the direction of the LMC provide an overwhelming amount of soft X-ray data from this nearby galaxy. In particular certain regions were observed quite regularly due to monitoring programs of known X-ray sources. In this respect the long term behaviour of the two high mass X-ray binaries EXO 053109-6609.2 (Haberl et al. 1995a) and

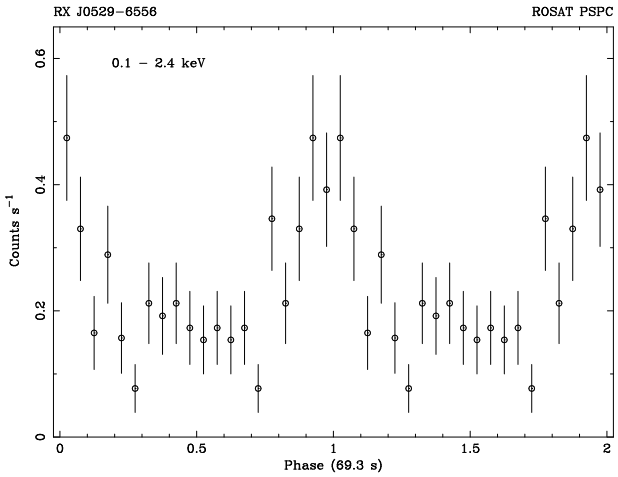

Fig. 5. The soft X-ray pulse profile of RX J0529.8-6556 from Feb. 25, 1993

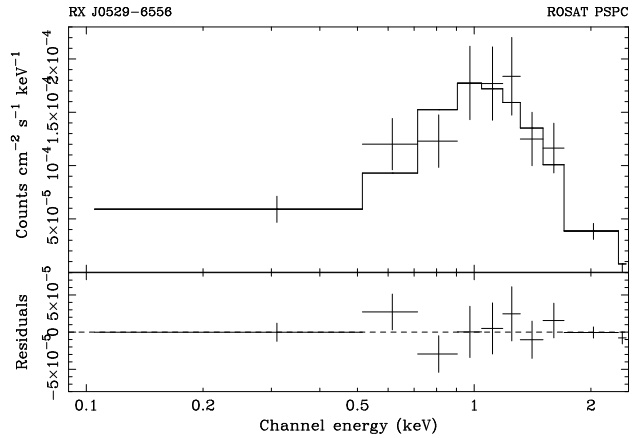

Fig. 6. The average PSPC spectrum of RX J0529.8-6556 from Feb. 25, 1993. The histogram represents the best fit power law with photo-electric absorption

RX J0532.5-6551 (Haberl et al. 1995b) could be investigated in detail over four years. The inspection of the PSPC images which contain this pair of close sources revealed another nearby X-ray source which was bright during only one single observation. The transient source, RX J0529.8-6556, is 14′ away from EXO 053109-6609.2 and 17′ from RX J0532.5-6551 and was located 10′ from the detector center during the outburst observation. The position of RX J0529.8-6556 is RA (2000) = 05 29 48.4, DEC = -65 56 51 with a 90% confidence radius of 8″ which is shown in the finding chart in Fig. 1. This chart was produced from the digitized UK Schmidt plates which yield a R $\sim$ 13.3 mag object as brightest candidate in the error circle. This star is also contained in the HST guide star catalogue (entry 8891.0213, Lasker et al. 1990) with B = 14.5 mag. The chance coincidence estimated from the X-ray positional error radius and the density of stars brighter than the proposed counterpart 5′ around RX J0529.8-6556 is 8 10^{-3}.

A total of 32 observations from the ROSAT pointed observation phase contain RX J0529.8-6556 in the PSPC field of view. So far no HRI observation covered the source. The observations used for the present analysis have partly been extracted from the ROSAT public archive and are a subset of those described in Haberl et al. (1995a). 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). In 4 PSPC observations RX J0529.8-6556 was detected with a likelihood exceeding 8 (corresponding to about 2 Gaussian sigma) using the EXSAS maximum likelihood source detection method (Zimmermann et al. 1994). The derived average count rates for each observation are plotted in Fig. 2. Upper limits (2 σ) derived from the pointed observations with no positive detection are also shown. A strong outburst with an average PSPC count rate of 0.25 cts s^{-1} was detected in a short 1 ksec observation on February 25, 1993. The lowest upper limit of 7.4 10^{-4} cts s^{-1} results from a 14.5 ksec observation on July 9, 1992, yielding a ratio of at least 300 between maximum and minimum observed source intensity.

Fig. 3 presents the PSPC light curve of the outburst observation. The intensity varies by at least a factor of 5 with a maximum of $\sim$0.6 cts s^{-1}. A temporal analysis of the soft X-ray flux using the folding technique revealed peaks in the χ^2 test at a modulation period of 69.3 s and multiples thereof. A power spectrum analysis yields a pulse period of 69.5 $\pm$ 2.5 s with a significance of 98.7%. The basic frequency at 0.014 Hz and the first harmonic at 0.028 Hz are seen in the power spectrum (Fig. 4). The folded light curve which exhibits a pulsed fraction of about 45% for sinusoidal variation is plotted in Fig. 5.

Because of shadowing effects of detector anode wires and the satellite wobble of 402 s we investigated if the detected period could be caused by these effects. Detector images of the source with selected pulse phase intervals around pulse minimum and maximum show in both cases a smooth and uniform distribution of the photons along the path of the source on the detector. The source moves over two crossings of thick wires splitting the wobble period evenly into 4 parts which leads to an artificial modulation of the X-ray flux with a period of 100.5 s. Folding analysis with high resolution around integer fractions of the wobble period confirm this. Folding 500 s intervals of data with the period determined from the whole observation and folding data excluding the innermost peak of the point spread function (which is mostly affected by the shadowing effects of the detector wires) yields very similar pulse profiles, providing further confidence for a periodic modulation of the X-ray flux. The peak at 69.3 s in the χ^2 test is the strongest, while from the peaks caused by the wobble the one at 402 s is expected to be most prominent (see e.g. the case of the constant source HZ 43 in Haberl et al. (1994)). We are therefore confident that the period of 69.5 s is unlikely being caused by instrumental effects.

The average PSPC spectrum from the outburst observation of RX J0529.8-6556 is consistent with a power law with photon index 0.64 modified by photo-electric absorption with a column density of 2.1 10^{20} H cm^{-2}. The power law model formally yields the best fit with a reduced χ^2 of 0.7 with 7 degrees

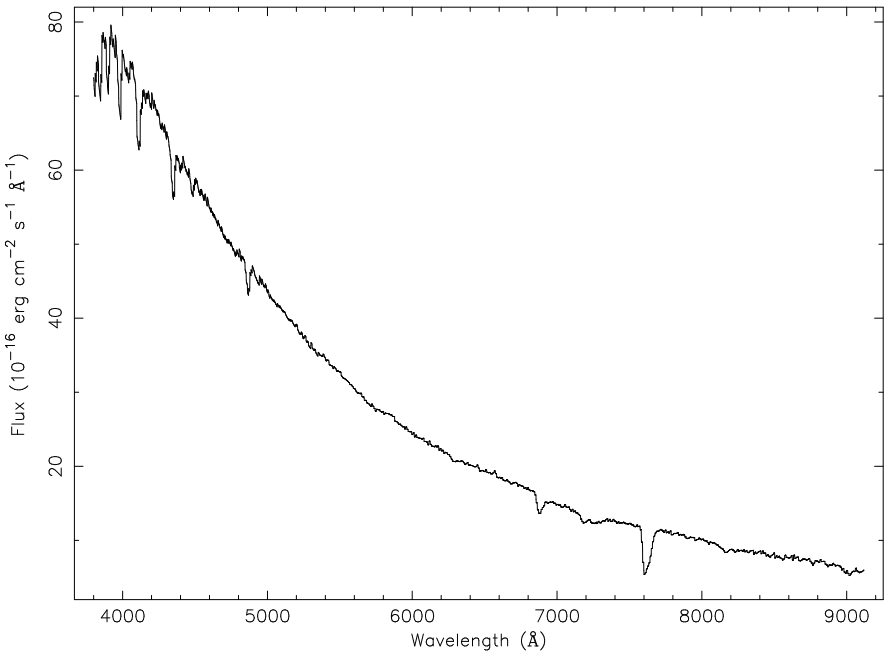

Fig. 7. Low-resolution (∼25ÅFWHM) spectrum of RX J0529.8-6556. Apart from Hα, the Balmer lines are seen in absorption. The exposure time was 30 min

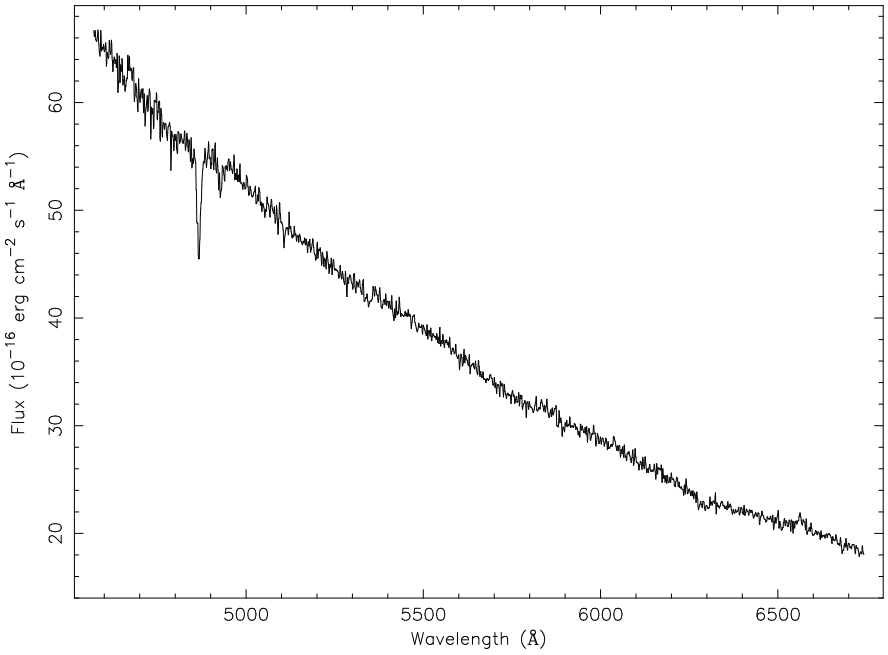

Fig. 8. Medium-resolution (∼10ÅFWHM) spectrum of RX J0529.8-6556. The Hα line (near 6560Å) is in emission with an equivalent width of 0.9 Å. The exposure time was 15 min

of freedom for single component spectral models (Fig. 6). The derived N_H is however smaller than the galactic absorption to the LMC. Fixing the N_H at 6 10^{20} H cm^{-2} one obtains a photon index of 1.16 with a still acceptable reduced χ^2 of 1.2. A thermal bremsstrahlung model with kT larger than 10 keV and N_H = 4.2 10^{20} H cm^{-2} is with a reduced χ^2 of 1.1 also acceptable. The observed 0.1 – 2.4 keV flux is 3.8 10^{-12} erg cm^{-2} s^{-1} for the best fit power law model.

3. Optical observations

Optical spectra were obtained from the likely counterpart GSC 8891.0213 at ESO with the ESO-MPI 2.2 m + EFOSC2 telescope (Buzzoni et al. 1984). Spectra were obtained using grisms #1 ($\lambda\lambda$ 3800 – 9100 Å, see Fig. 7) and #4 ($\lambda\lambda$ 4600 – 6700 Å, see Fig. 8) on Nov. 11, 1995, 03:15 – 03:45 and Nov. 27, 1995, 06:55 – 07:10, respectively. The medium resolution spectrum clearly shows Hα in emission with an equivalent width of 0.9±0.2 Å. From the red-shifted Hβ absorption line the radial velocity was determined to 345±15 km s^{-1}. By comparison of

our spectra with stellar spectra in Jacoby et al. (1984) we obtain a spectral type B2e with an uncertainty of about one sub-class.

4. Discussion

We have discovered the new X-ray source RX J0529.8-6556 in a high intensity state during a single ROSAT observation with about 0.25 PSPC cts s^{-1}. The source is strongly variable on time scales of months as shown by three detections at a level about 50 times fainter and upper limits a factor of 300 below the maximum. The X-ray properties of RX J0529.8-6556 and the available optical magnitudes of the proposed counterpart suggest that the source is a Be/X-ray binary transient in the LMC. The ROSAT PSPC spectrum is compatible with a power law model as observed from such X-ray sources, but the low statistical quality does not allow to determine power law index and photo-electric absorption independently. The average X-ray flux during the outburst observation corresponds to a luminosity of 1.1 10^{36} erg s^{-1} for a distance of 50 kpc (not corrected for absorption), typical for Be/X-ray binaries. The optical magnitudes of the counterpart star given in the HST guide star catalogue (blue) and derived from the UK Schmidt plates (red) indicate a somewhat (0.5 mag) fainter object compared to the nearby Be/X-ray transient EXO 053109-6609.2 and yield a similar B-R colour index. The optical brightness (blue) of 14.5 mag implies $M_B \lesssim -4$ at the distance of the LMC, compatible with a typical Be star of luminosity class III-V.

Our optical spectra of GSC 8891.0213, the only bright object close to RX J0529.8-6556, yield a spectral type B2e, and the radial velocity derived from the Hβ line of 345 km s^{-1} is compatible with the radial velocity of the LMC. This confirms the Be/X-ray transient nature of RX J0529.8-6556.

During the outburst we found a periodic modulation of the X-ray flux with a period of 69.5 s, the longest period found from an LMC pulsar so far. If the neutron star rotates with the equilibrium period where the co-rotation velocity at the magnetospheric radius equals the Keplerian velocity of the matter in the inner accretion disk an orbital period of about 60 days is expected for RX J0529.8-6556 from the spin to orbital period relation found by Corbet (1984, 1986) with a typical magnetic field strength of 10^{12} G. Given the high number of ROSAT observations spread over more than 3 years it seems unlikely that the single observed outburst is related to the regular periastron passage of the neutron star in an eccentric orbit, but rather is caused by an episode of increased matter ejection of the Be star which can last several tens of days. The two upper limits derived from the observations before and after the outburst limit the duration of the outburst from RX J0529.8-6556 to about 60 days.

The observed X-ray and optical properties of RX J0529.8-6556/GSC 8891.0213 strongly suggest a new pulsating Be/X-ray transient in the LMC. It becomes the fourth in this sub-class of high mass X-ray binaries.

Acknowledgements. The ROSAT project is supported by the German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF/DARA) and the Max-Planck-Gesellschaft. The finding chart is based on photographic data obtained using the UK Schmidt Telescope and digitized by the Space Telescope Science Institute under US Government grant NAG W-2166.

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