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The study of the nature of sources AX J1749.1−2733 and AX J1749.2−2725

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Two faint X-ray pulsars, AX J1749.1−2733 and AX J1749.2−2725, located in the direction to the Galactic Center, were studied using data of INTEGRAL, XMM-*Newton* and CHANDRA observatories, in X-rays and SOFI/NTT in the infrared band. Combining data from X-ray observatories positions of both sources were determined with the uncertainty better than $\sim 1''$ that allowed us to identify unambiguously their optical counterparts. The following analysis of the photometry data leads us to the conclusion that the AX J1749.2−2725 optical counterpart is a massive star of the B3 class and the system is located behind of the Galactic Center at a distance of ~ 14.4 kpc from us. The lack of statistics of the measurements in the K-band and a data shortage in other wavebands prevents firm conclusions about the spectral class of the AX J1749.1−2733 counterpart. However, taking into account the similarity of properties of both pulsars we suppose that AX J1749.1−2733 should have an optical companion of the similar class and that both sources are located behind of the Galactic Center, probably in the Perseus arm.

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1. Introduction

The source AX J1749.1−2733 was discovered on Sept 19, 1996 by the ASCA observatory; its position was measured as RA=17^h 49^m 10^s, Dec=-27$^\circ\!\!.$33′14″(J2000) with the uncertainty of $\sim 55''$[1]. For a long time the source nature was unknown, but observations with INTEGRAL [2] and XMM-*Newton* observatories allowed us to detect pulsations from the source and establish its X-ray pulsar nature [3, 4].

Another X-ray pulsar AX J1749.2−2725 with a period of ~ 220 s, located just a few minutes from AX J1749.1−2733, was discovered by the ASCA observatory in March 1995 and localized with the coordinates of RA=$17^h 49^m 10.^s1$, Dec=-27$^\circ\!\!.$25′16″and an uncertainty about 50″[5]. Combining the presence of coherent pulsations with results of the spectral analysis which revealed a strong absorption of $\sim 10^{23}$ cm^{-2} for both sources, it was proposed that they belong to the class of the high mass X-ray binary (HMXB) systems.

It is worthy to know, that no reliable optical identifications have been obtained to date for both sources. Here we briefly present results of this searching; details can be found in the recent paper of Karasev et al. (submitted).

2. AX J1749.1−2733 in X-rays with XMM-*Newton* and INTEGRAL

As mentioned in the previous section, the timing analysis of XMM-*Newton* data revealed pulsations of the 2-10 keV X-ray flux from AX J1749.1−2733 with period of ~ 132 s [3]. An analysis of INTEGRAL public data confirms this result also in the hard X-ray band (20-60 keV). The source pulse profile has a double-peaked structure, that leads to the appearance of several other peaks of a slightly lower intensity at both periodograms, mostly prominent at the period of ∼66 s. Due to the source faintness it was really difficult to make a final conclusion about true value of the pulse period, but our analysis showed that the value of ~ 132 s is more preferable (see [4] for details). The list of possible pulse periods near 66 and 132 s measured with different instruments is presented in Table 1. Errors (corresponding to 1σ) were determined by the bootstrap method (see e.g. [6] for details). A comparison of INTEGRAL and XMM-*Newton* measurements gives us an estimation of the deceleration rate of the neutron star rotation $\dot{P}/P \simeq 10^{-3}$ yr^{-1}.

Note that the INTEGRAL and XMM-*Newton* data were obtained not only in different epochs but also in different source states: INTEGRAL observed the source during the outburst and XMM-*Newton* observed the source most likely in a quiescent state. Despite of a certain casuality of such a combination of the XMM-*Newton* and INTEGRAL data obtained parameters and the spectrum shape are typical for X-ray pulsars (see e.g. [8]).

The formal approximation of the XMM-*Newton* and INTEGRAL data simultaneously (combined using relative normalization) with the model of White et al. [7] modified by the photoelectric absorption gives the photon index of $\Gamma = 1.03^{+0.18}_{-0.24}$, the cutoff energy $E_{cut} = 7.1^{+0.6}_{-0.9}$ keV, the folding energy $E_{cut} = 19.8^{+1.9}_{-2.6}$ keV, the absorption column $N_H = (20.2^{+1.0}_{-1.9}) \times 10^{22}$ cm^{-2}.

3. AX J1749.2−2725 in X-rays with XMM-*Newton*

During observations of AX J1749.1−2733 by XMM-*Newton* on March 2007 another X-ray pulsar AX J1749.1−2725 was in the same field of view of the MOS2 camera. X-ray pulsations

Table 1: List of AX J1749.1-2733 pulse periods

Date	Observatory	Pulse Periods
Sept 9, 2003	INTEGRAL	131.54 ± 0.02, 65.77 ± 0.01
March 31, 2007	XMM-*Newton*	131.95 ± 0.24, 66.05 ± 0.15

with a period of 216.86±0.14 s were found. This value is very close to the earlier measured pulse period for this source [5].

The source spectrum can be well approximated by a power law model with the photon index of $\Gamma = 1.41^{+0.75}_{-1.06}$, modified by the photoelectric absorption of $N_H = 14.1^{+6.13}_{-7.96} \times 10^{22}$ cm^{-2}. The source flux in the $2-10$ keV energy band during XMM-*Newton* observations was about $\sim 2.6 \times 10^{-12}$ ergs cm^{-2} s^{-1}, that is about one order of magnitude lower than one registered by the ASCA observatory in 1995 [5]. Nevertheless, the spectrum shape and parameters for both observations are in a good agreement. The measured value of N_H is significantly higher than the interstellar absorption in the direction to the source, that is connected with the strong intrinsic absorption in the binary system, that is typical for HMXBs.

4. Identification of IR counterparts for AX J1749.1−2725 and AX J1749.1−2733

Using SOFI/NTT archive data (http://archive.eso.org) we have found IR counterparts for both pulsars (see. Fig. 1; Table 2). It is clearly seen that only one relatively faint star is detected inside of the AX J1749.2−2725 error circle of XMM-*Newton* (Fig. 1, left panel). In the field of AX J1749.1-2733 (Fig. 1, right panel) at least two very faint IR stars are also visible, one of them was proposed earlier as a possible optical counterpart of AX J1749.1-2733 [9]. A combination of

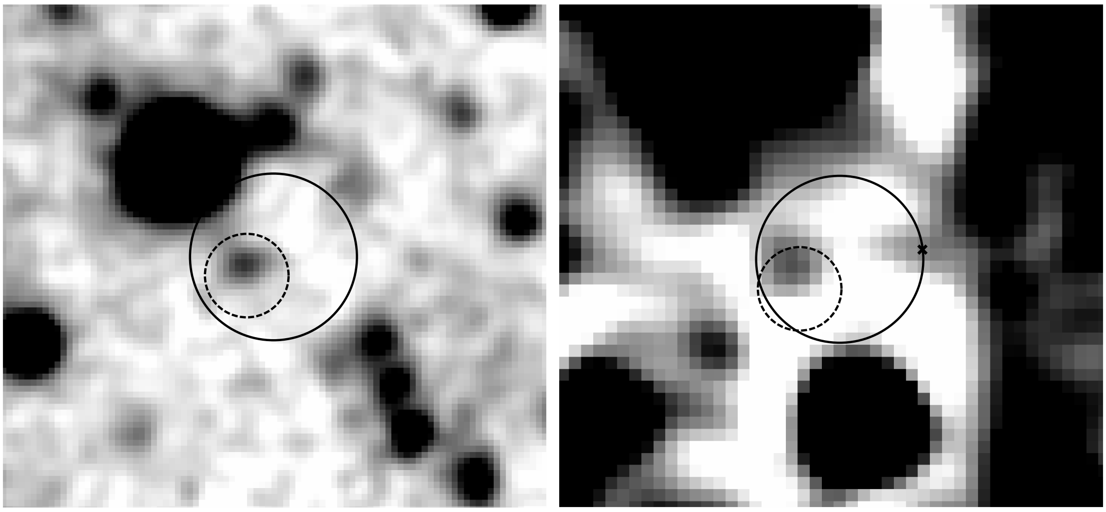

Figure 1: SOFI/NTT *K*-band images of sky fields near X-ray pulsars AX J1749.1−2725 (left) and AX J1749.1−2733 (right). Large circles show the standard (statistical plus systematic) positional uncertainty from XMM-*Newton*/MOS2 measurements. Dashed circles show CHANDRA astrometric uncertainty in the sources position ($\sim 1''$). The position of the star proposed by [9] as a counterpart for AX J1749.1−2733 is marked by the cross.

Table 2: Magnitudes of the proposed counterparts

band	AX J1749.1−2733	AX J1749.2−2725
J	> 18.7	> 20.3
H	> 18.4	16.67 ± 0.08
K	15.23 ± 0.07	15.62 ± 0.17

these XMM-*Newton* observations with results of the Chandra observatory (dashed circles) allowed us to establish unambiguously optical counterparts for both pulsars (note that the counterpart for AX J1749.1−2733 is different from the source proposed by [9], see Fig. 1).

To identify the nature of these optical stars we firstly need to estimate the interstellar extinction $E(B-V)$ to the Galactic bulge or Center in the direction to sources. Using the SOFI/NTT H and K images we plotted the color-magnitude diagram (CMD) for all stars in the $2'$ fields around sources. Assuming the distance to the Galactic Center as 8.5 kpc [10] and using the reddening of the red giant branch as a measure of the interstellar absorption towards the Galactic bulge [11, 12] we obtained $E(B-V) \approx 4$.

In order to constrain the spectral type of the optical star in studied systems we compared their measured magnitudes and colors with those of various suggested types of stars at a range of distances. Thus varying the distance and absorption to AX J1749.2−2725 we can estimate a possibility of different types of stars being the counterpart of this source. As shown in Fig. 2 the most reliable counterpart is a B3 star, located at the distance of $D \approx 14.4 \pm 3.1$ kpc. The corresponding X-ray luminosity of the pulsar in the 2-10 keV energy band would be about $L_x \approx 6.1 \times 10^{34}$ erg/s.

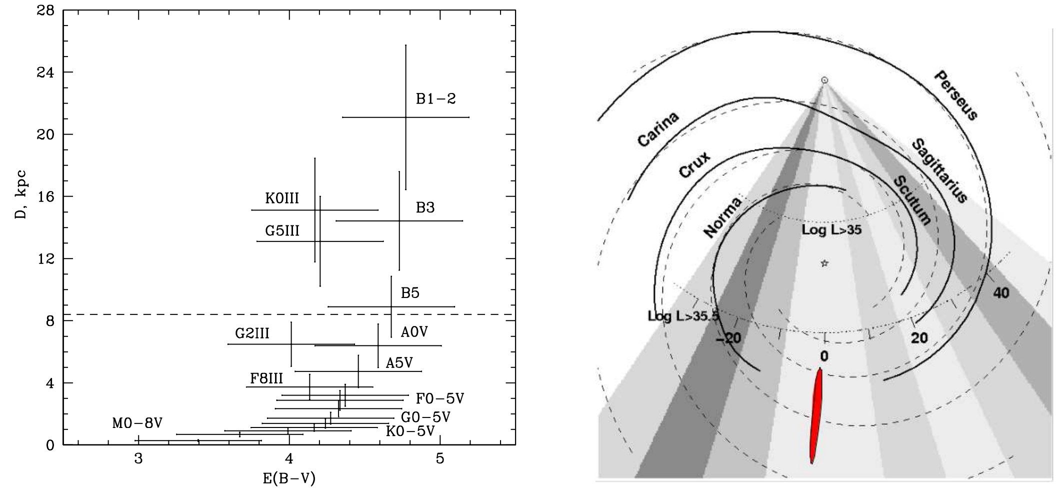

Figure 2: *Left panel:* Extinction – distance diagram for the stars which would be observed with the magnitudes and colors similar to that of AX J1749.2−2725 IR counterpart assuming a standard law of interstellar absorption [13]. Dashed line shows the distance to the Galactic Bulge, where we estimated $E(B-V) \simeq 4.0$. *Right panel:* Face-on view of the inner part of the Galaxy with overlayed densities of HMXBs shown in gray scale [14]. Red region shows AX J1749.2-2725 location.

The lack of H band of the AX J1749.1−2733 counterpart didn't allow us to make any reliable conclusions about the class of the optical star. However, X-ray properties and estimations of its magnitudes (see Table 2) are similar to AX J1749.2−2725 ones. This is consistent with the suggestion that this system is located at a distance higher than 8.5 kpc and that it has the extinction higher than $E(B-V) \approx 4.0$.

Summarizing all above, we can conclude that the method of the estimation of the interstellar absorption based on the study of the color-magnitude diagram of stars in the region around X-ray source can be very useful for the optical counterpart identification of sources located in the direction to the Galactic Bulge, in particular for those behind the Galactic Center. Moreover, the combination of this method with results of deep observations of the Galactic Center field by the INTEGRAL observatory and the capabilities of grazing-incidence X-ray telescopes for the localization of faint X-ray sources provide us the possibility to indentify and localize these sources at the further end of the Galaxy, thus reconstructing its structure (see Fig. 2).

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