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A study of unknown X-ray sources

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We analyze the X-ray spectra and light curves of five unknown X-ray sources found in the observations obtained by the *XMM-Newton* satellite. For two objects we have found X-ray flares. Three other objects have X-ray spectra similar to those of enigmatic γ Cas analogs and may be new candidates for such stars. All the considered sources are faintly visible in the DSS optical images. We suggest that all the studied objects can be either very distant stars or transient sources.

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1. Introduction

Sometimes, during observation of any astronomical objects other sources can be seen in the field of view. Usually, when analyzing observed data such sources are ignored. Many of them are not catalogued. In the fields of the X-ray observations of selected stars obtained by the *XMM-Newton* space observatory, we find many bright X-ray sources in the images obtained by the EPIC camera on the satellite. All these objects in most cases are not investigated. In this paper we present the most interesting results for the sources that we detected.

2. Observations and data reduction

We reanalyzed the archival X-ray observation of 4 stars obtained by the *XMM-Newton* space observatory and found unknown X-ray sources in the frames centered to these objects. The log of observation is given in Table 1.

Data reduction was implemented using the SAS 19.0 software, following a recommendation of the SAS team.[1] We extracted and analyzed low-resolution spectra and light curves of unknown sources from the images obtained by the European Photon Imaging Camera (EPIC) on the satellite. The detailed procedure of observed data reduction are described, for example, in [1].

2.1 Spectral analysis

The EPIC spectra of the studied objects in the 0.2–8 keV energy band were fitted by different models in the XSPEC 12.0 package.[2] The EPIC-PN, EPIC-MOS1, and EPIC-MOS2 spectra were fitted simultaneously. We applied the following fitting models. The APEC (Astrophysical Plasma Emission Code, [2]) and MEKAL [3–5][3] models describe the stationary X-ray emission from the collisionally ionised diffuse gas, where atoms are ionised by electron impacts. The model of shocked plasma emission PSHOCK [6] describes the non-stationary thermal X-rays. BBODYRAD is a simple model of a black body X-ray spectrum, the PL (Power Law) model describes a power component contribution corresponding to the nonthermal X-rays. To take into account the interstellar absorption of X-rays, we used the TBABS model [7]. It presents the cross section for X-ray absorption by the interstellar medium (ISM) as the sum of the cross sections for X-ray absorption due to the ISM gas, grain, and molecular components. We fitted the spectra by the following model combinations.

TBABS·(APEC+APEC), TBABS·(MEKAL+MEKAL): this model can describe X-ray spectra of normal stars.

TBABS·(APEC+PSHOCK), TBABS·(MEKAL+PSHOCK): X-ray spectra of some massive stars, stars with strong winds, supernova remnants can be fitted by such models.

TBABS·(APEC+PL), TBABS·(MEKAL+PL), TBABS·(PSHOCK+PL): such models can describe spectra of stars with a nonthermal contribution to their X-ray spectra.

TBABS·(APEC+BBODYRAD), TBABS·(MEKAL+BBODYRAD): X-ray spectra of double or multiple systems with a compact companion can be fitted by such models.

[1]www.cosmos.esa.int/web/xmm-newton
[2]https://heasarc.gsfc.nasa.gov/xanadu/xspec/
[3]Hereafter "thermal models"

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Table 1: Log of observations.

Target name	ObsID	Data	Exposition, s
HD 100546	761790101	2015-07-10	68000
HD 101088	672080101	2011-08-14	61399
HD 152404	651870201	2011-03-15	23000
	651870301	2011-03-18	23000
	651870401	2011-03-22	23000
HD 283571	722320101	2013-08-21	109000

TBABS·(BBODYRAD+PL), this model can describe X-ray spectra of neutron stars or white dwarfs surrounded by nebulae.

To fit the spectra by models with an additional PL component, we calculated the fraction of the power component $F_{\rm PL}$:

$$F_{\rm PL} = \frac{H_{\rm PL}[2-8{\rm keV}]}{H_{\rm FIT}[0.2-2{\rm keV}]}. \tag{1}$$

Stellar spectra unabsorbed by the ISM were calculated according to the approximation formulas from [8]. Two characteristics of unabsorbed spectra of the studied objects were estimated: the X-ray luminosity in the 0.2-8 keV energy interval

$$L_{\rm X} = 4\pi d^2 H[0.2-8{\rm keV}], \quad [{\rm erg\,s^{-1}}], \tag{2}$$

and the hardness ratio (i.e., [9])

$$HR = \frac{H[2-8{\rm keV}]}{H[0.2-2{\rm keV}]}. \tag{3}$$

Here H is the X-ray flux in the energy bands indicated in the brackets.

3. The list of the sources

The list of detected sources is given in Table 2. The coordinates of the objects were determined from the EPIC images using the ds9 sofware. Only one source belongs to The XMM-Newton Extended Survey of the Taurus Molecular Cloud (XEST) [10]. The source UXS 2 is located near an object from the GAIA EDR3 catalog and could be identified with it in the future. Other three sources have not been found in known catalogues. Figure 1 demonstrates the EPIC camera X-ray frames with the obtained sources and the same regions on the DSS maps.

4. X-ray spectra of studied sources

4.1 Possible γ Cas analogs

Enigmatic γ Cas analogs [11] are Be stars that display thermal spectra of extremely high plasma temperatures $kT \sim$ 5–20 keV and even more. X-ray luminosities of γ Cas-type stars are intermediate between those of "normal" massive stars and X-ray binaries, $L_{\rm X}[0.5\text{–}10{\rm keV}] \sim 10^{31}\text{–}10^{33}$ erg s^{-1}.

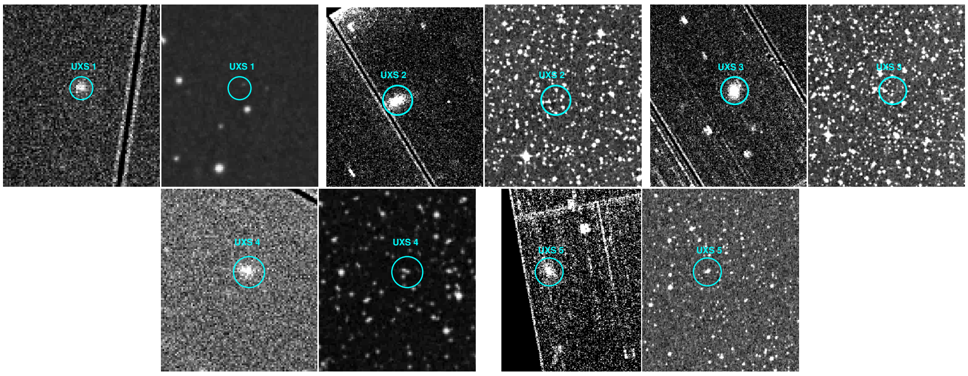

Figure 1: The EPIC-PN X-ray frames with the studied sources (*left panels*) and the same regions on the DSS maps (*darker right panels*), the sources are shown by blue circles.

Table 2: The list of detected sources. Column 1 contains the source names introduced in this paper, the equatorial coordinates are given in Column 2, possible counterparts of the objects and their angular distances from the sources are presented in Columns 3 and 4 respectively. The sources are sorted by equatorial coordinates.

Source ID	Equatorial coordinates	Possible identification	Offset (″)
UXS 1	4:22:10.408,+28:30:28.718	XEST 21-048	1.81
UXS 2	11:33:57.792,-70:01:16.279	Gaia EDR3 5233701397197179776	5.79
UXS 3	11:34:31.169,-70:09:45.316		
UXS 4	11:37:22.085,-69:49:18.594		
UXS 5	16:55:35.115,-36:57:51.380		

Note. The abbreviation “UXS” in the object names means an “unstudied X-ray source.”

At the same time γ Cas analogs display flare-like variations of their X-ray emission on timescales from a few minutes to several years [12].

The origin of X-rays from γ Cas-type stars remains debated. There are three main scenarios of their formation. First, the interaction between localized small-scaled magnetic fields and the decretion disks of the stars, leading to flaring X-ray emission [11, 13]. The second scenario involves accretion onto a compact companion: a white dwarf [14] or a neutron star in the propeller stage [15]. Finally, Ryspaeva & Kholtygin [1, 16] proposed the nonthermal origin of X-rays from γ Cas analogs as a result of inverse Compton scattering of UV photons on relativistic electrons in the framework of the Chen & White [17] hypothesis.

Our sample contains three sources, UXS 1, UXS 2, and UXS 3, with X-ray spectra similar to those of the γ Cas-type stars. We could fit the EPIC spectra of the sources by a two-temperature thermal model and by a thermal model with an additional power component. The model spectra parameters are given in Tables 3 and 4, and Figs. 2–4 demonstrate the fits. As it follows from the tables, the spectra of the three sources can be described by the APEC/MEKAL models with extremally high plasma temperatures up to 36 keV. These temperatures essentially decrease if we add a power component to the model spectra. The fraction of the power component appears to

Table 3: Best fit parameters of the UXS 1, UXS 2, and UXS 3 spectra by thermal models.

Source	N_H, 10^{22} cm^{-2}	kT_1, keV	norm$_1$ 10^{-4}	kT_2, keV	norm$_2$ 10^{-4}	χ^2 (d.o.f.)	HR, rel. un.
UXS 1	0.66±0.40	0.48±0.29	2.85±2.84	3.86±1.34	0.26±0.07	1.02 (106)	0.68±0.67
UXS 2	0.26±0.03	1.43±0.46	0.46±0.34	17.08±8.28	3.37±0.25	1.16 (281)	1.77±0.78
UXS 3	0.18±0.02	2.85±0.34	0.81±0.18	24.40±12.19	1.56±0.17	1.27 (424)	1.37±0.43

Note. Parameter of metallicity Abundance= 0.63 ± 0.33 in solar units by Anders & Grevesse [18] is calculated for UXS 2. For UXS 1 and UXS 3 we used the fixed value of Abundance=1.0.

Table 4: Best fit parameters of the UXS 1, UXS 2, UXS 3 spectra by a thermal model with an additional power component, the "abundance" parameter is fixed at 1.0 solar unit.

Source	N_H, 10^{22} cm^{-2}	kT_1, keV	norm$_1$ 10^{-4}	Γ	norm$_{PL}$ 10^{-4}	F_{PL}	χ^2 (d.o.f.)	HR, rel. un.
UXS 1	0.72±0.29	0.40±0.25	3.08±3.07	2.49±0.34	0.17±0.06	0.82	0.91 (106)	0.41±0.38
UXS 2	0.27±0.04	3.71±2.48	0.96±0.81	1.37±0.21	0.64±0.30	0.88	1.17 (282)	1.65±0.86
UXS 3	1.00±0.34	0.50±0.10	1.48±0.79	1.99±0.06	1.04±0.08	0.74	1.43 (424)	0.64±0.43

be large, F_{PL} ~0.7–0.8. A similar conclusions for known γ Cas analogs was made by Ryspaeva & Kholtygin [1, 16]. The hardness ratios of the three mentioned objects are also similar to those of the γ Cas analogs. In the case of identification of UXS 2 with the object from Gaia EDR3 (see Table 2), which is possibly a star of the RR Lyr type at a distance d ~3.02 kpc, the X-ray luminosity of UXS 2 should be $L_X[0.2\text{–}8\text{keV}] = 9.92 \pm 1.57 \cdot 10^{32}$ erg s^{-1} (APEC/MEKAL fit) or $L_X[0.2\text{–}8\text{keV}] = 1.02 \pm 0.17 \cdot 10^{32}$ erg s^{-1} (APEC/MEKAL+PL fit). Such values match with those for γ Cas-type stars. For the X-ray luminosities to be typical of γ Cas analogs, UXS 3 and UXS 1 should be at distances of 1.1–4.2 kpc and 0.6–12 kpc respectively. Finally, we have not revealed X-ray flares or periodicity of X-ray fluxes on short timescales.

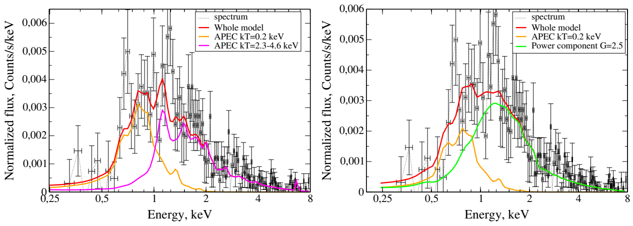

Figure 2: Two model spectra of UXS 1 with component resolution. *Left panel:* spectral fit by two-temperature thermal models, *right panel:* spectral fit by a thermal model with an additional power component.

Thus, we suppose that UXS 1, UXS 2, and UXS 3 can be new candidates for γ Cas analogs. But this conclusion have to be independently confirmed, because these three sources are weak on the DSS optical maps, as it is seen in Figure 1. They could be very distant single stars or transient X-ray sources in binary systems with compact components. If, as indicated above, UXS 2 is indeed a star of the RR Lyr type, then it should be a unique object.

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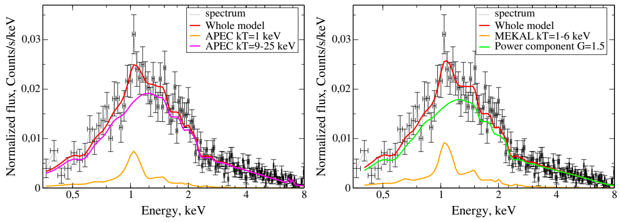

Figure 3: The same as in Fig. 2 for UXS 2.

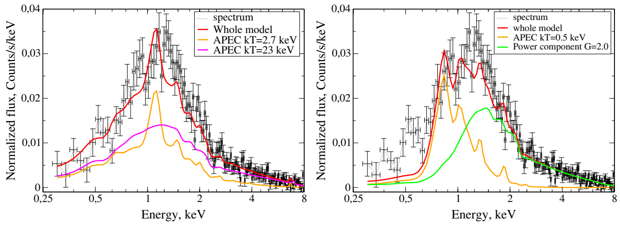

Figure 4: The same as in Fig. 2 for UXS 3.

Table 5: The best fit parameters for the UXS 4 and UXS 5 spectra by thermal models with solar abundances.

Source	State	$N_{\rm H}$, 10^{22} cm^{-2}	kT_1, keV	norm$_1$ 10^{-5}	kT_2, keV	norm$_2$ 10^{-5}	χ^2 (d.o.f.)	HR, rel. un.
UXS 4	whole	0.63±0.18	0.08±0.03	2532±2305	0.68±0.12	7.11±2.89	0.92 (258)	-
UXS 5	flare	≤0.102	0.80±0.13	6.08±2.35	7.04±4.37	24.02±5.17	0.8 (155)	0.64±0.32
UXS 5	quiet	≤0.014	0.31±0.02	1.35±0.17	1.1±0.12	1.9±0.15	1.07 (279)	0.78±0.50

4.2 Flaring X-ray sources

Bright X-ray flares with duration about 5 ks are detected for UXS 4 and UXS 5. Figure 5 demonstrates corresponding light curves. We extracted and fitted the spectra of the objects both during flares and in their quiet states. The best spectral fit parameters are given in Table 5. Figure 6 shows the spectral fits.

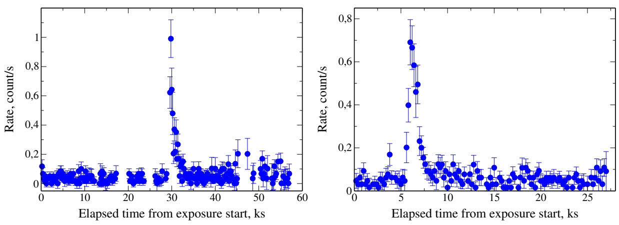

Figure 5: The light curves of UXS 4 (*left panel*) and UXS 5 (*right panel*) with a step of 200 s.

The X-ray spectra of UXS 4 and UXS 5 can be described by thermal models. We could not fit the spectrum of UXS 4 during the flare because this spectrum was rather noisy. We fitted the full spectrum of the object and estimated the hardness ratio during the flare HR=0.88±0.76 and in the quiet state HR=0.57±0.47. Assuming the distance to both sources $d = 1$ kpc, the X-ray luminosity of UXS 4 in the quiet state is $L_{\rm X}[0.2\text{–}8{\rm keV}] = 1.26 \pm 0.99 \cdot 10^{30}$ erg s^{-1}, and

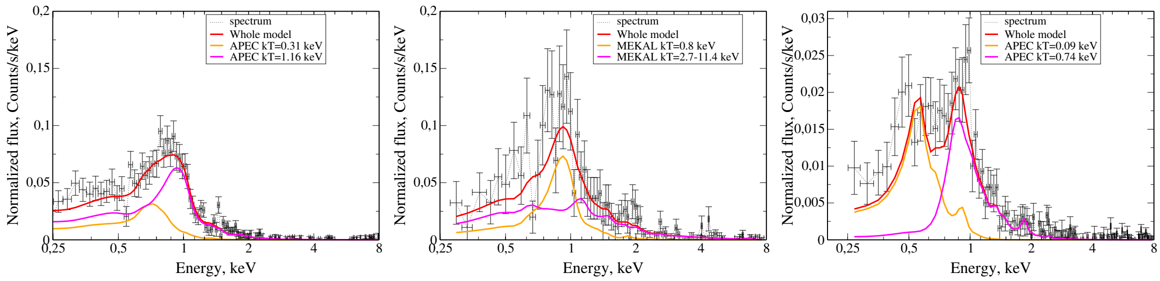

Figure 6: The model spectra with component resolutions. *Left panel:* spectra of UXS 5 during the quiet state. *Center panel:* spectrum of UXS 5 during the flare. *Right panel:* spectrum of UXS 4.

during the flare $L_X[0.2\text{–}8\text{keV}] = 2.03 \pm 1.24 \cdot 10^{30}$ erg s^{-1}. The analogous values for UXS 5 are $3.35{\pm}1.39{\cdot}10^{31}$ erg s^{-1} and $1.36{\pm}0.30{\cdot}10^{32}$ erg s^{-1} respectively.

Additionally we looked for the periodicity of X-ray emission from the flared sources in their quiet state and did not find evidence for such periodicity for both objects.

Our analysis of the X-ray spectra and light curves of UXS 4 and UXS 5 reveals that flares of the objects are short. During the flare of UXS 4, X-ray luminosity increased two times, and during the UXS 5 flare it increased one order. The hardness ratios for both sources did not vary significantly at the time of the flares. The plasma temperature of UXS 5 increased during the flare. We can propose that the origin of the flares on the above-mentioned sources could be associated with magnetic reconnection or with flares of a low-mass component in a binary system. UXS 5 was detected in the DSS maps, and UXS 4 is seen in the DSS images as a weak optical source. Both objects can be either transient X-ray binaries with a compact component or normal stars with a complex magnetosphere.

5. Conclusion

All five X-ray sources studied in the present paper are bright in X-rays and faint in the optical range. Their X-ray spectra can be described by thermal models as well as by those with an additional power component. The spectra of all considered sources can not be fitted by models with the BBODYRAD component. So we can conclude that the studied sources could be distant stars or X-ray transients in double systems with a compact component. They can not be single compact objects.

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