X-RAY SOURCES IN THE DWARF SPHEROIDAL GALAXY DRACO

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Abstract

We present the results of a spectral analysis of a number of X - ray sources in Draco, a nearby dwarf spheroidal galaxy recently observed by XMM-Newton. While most of the sources exhibit properties consistent with AGN, few of them possess characteristics of LMXBs and CVs. We also extract an upper limit for the mass of a putative central BH in Draco.

Observations and Data Analysis

The 87-ks observation of Draco (R.A. = 17h20m12 4 and decl. = +57°54′55 3) was obtained by the European Space Agency's (ESA) X-ray Multi-Mirror Mission—Newton (XMM- Newton) between 2009 August 4 and 28 (PI: K. Dhuga; see Table 1 for details).

We used the 3XMM-DR54 (3XMM) catalog (Rosen et al. 2015) for the automated multiwavelength (MW) classification. For several of the brighter X-ray sources, we performed spectral analyses and extracted spectra from the EPIC data. The observation data files (ODFs) were processed using standard procedures of the XMM-Newton Science Analysis System (XMM-SAS version 13.0.1). We extracted spectra using circular (r = 17′′) regions centered on the X-ray sources for each observation. Background subtraction was performed using source-free apertures located nearby. A standard event screening described in the multixmmselect manual was applied. The spectral analysis of the X-ray data was performed using XSPEC version 12.7. The pn and MOS spectral energy channels were grouped to have at least 10 counts per bin. Each spectrum was fit in the 0.2–10 keV energy range.

Table 1
X-Ray observations of Draco

Date	ObsId	Observatory	Exp[a]
2009 Aug 04	0603190101	*XMM-Newton*	17
2009 Aug 06	0603190201	*XMM-Newton*	18
2009 Aug 08	0603190301	*XMM-Newton*	16
2009 Aug 20	0603190401	*XMM-Newton*	18
2009 Aug 28	0603190501	*XMM-Newton*	18

Note.
[a] Exposure in ks.

Classification

There are over 100 X-ray sources in the 3XMM catalog in the Draco field. We visually inspected all of the sources, and after excluding source duplications (in five separate observations of Draco) and spurious detections (e.g., edge of the chip, bad CCD columns), we selected 35 bright X-ray sources with a signal-to-noise ratio (S/N) > 6 for further investigation (see Figure 1). In Figure 2, we show the hardness ratio diagram for the sources in Draco compared to different classes of literature-verified sources used for automated classification (see Sonbas et al. 2016 for details). The two chosen hardness ratios (HR2 = ($F_{1.2–2}$ - $F_{0.2–1.2}$) / ($F_{1.2–2}$ + $F_{0.2–1.2}$) and HR4 =($F_{2–7}$ - $F_{0.5–2}$) / ($F_{2–7}$ + $F_{0.5–2}$), where $F_{x–y}$ are the observed fluxes in the respective energy bands) allow for some separation between AGNs and the rest of the sources, although there is an expected overlap between the AGNs, CVs, and pulsars.

Results and Discussion

Our goals are to identify and/or set constraints on the number of XRBs that may belong to Draco, to set a limit on the emission from a possible central intermediate-mass BH (IMBH). Here we discuss some individually sources that do not appear to be AGNs or foreground Galactic stars based on our classification. For the brightest of these sources, we performed spectral fits with blackbody radiation (bbodyrad), disk blackbody (diskbb), and power-law (PL) models modified by interstellar absorption (phabs model in XSPEC) (Figure 3). In general, these models provide an adequate description of the thermal and non-thermal components of X-ray spectra typically observed in the 0.2–10 keV range for objects such as CVs, isolated NSs, and LMXBs. The best-fit parameters for these sources are given in Table 2.

Table 2

Best-fit Spectral Results for Selected Point Sources in the Draco Field

Source #	Model	Normalization[a]	n_H[b] (10^{22} cm^{-2})	kT, T_{in}[e] (keV)	Γ	χ^2_ν	ν[f]
#10	PL	$(1.53 \pm 0.48) \times 10^{-5}$	1.35 ± 0.27	···	1.72 ± 0.23	0.85	171
	diskbb	$(1.92 \pm 1.15) \times 10^{-4}$	0.83 ± 0.16	2.09 ± 0.35	···	0.85	171
	bbodyrad	$(3.35 \pm 0.89) \times 10^{-3}$	0.35 ± 0.14	1.11 ± 0.08	···	0.88	171
#11	bbodyrad+PL	$(5.64 \pm 2.94) \times 10^{-3}$[c]	<0.027	0.75 ± 0.11	1.24 ± 0.48	1.05	171
	···	$(2.20 \pm 1.35) \times 10^{-6}$[d]	···	···	···	···	···
#16	PL	$(1.85 \pm 0.50) \times 10^{-5}$	0.92 ± 0.17	···	1.82 ± 0.21	1.16	60
#19	PL	$(1.01 \pm 0.16) \times 10^{-5}$	0.06 ± 0.04	···	2.91 ± 0.38	0.77	43
	bbody	$(3.32 \pm 0.28) \times 10^{-7}$	<0.027	0.18 ± 0.01	···	1.06	43
	bbodyrad	2.21 ± 0.63	<0.027	0.18 ± 0.001	···	1.06	43
#23	PL	$(3.47 \pm 1.98) \times 10^{-6}$	0.23 ± 0.18	···	3.6 ± 1.3	0.89	75
	bremss	$(5.63 \pm 5.56) \times 10^{-6}$	< 0.027	0.83 ± 0.55	···	0.88	75
#25	diskbb	$(2.12 \pm 0.14)\times 10^{-3}$	<0.027	0.64 ± 0.11	···	0.83	197

Notes.
[a] Normalization of the bbodyrad model is R^2_{km}/D^2_{10}, where R_{km} is the source radius in km, D_{10} is the distance to the source in units of 10 kpc and the normalization of the diskbb model given as $((R_{in}/km)/(D/10\,kpc))^2 \cos\theta$, where R_{in} is the is "an apparent" inner disk radius.
[b] Galactic extinction is assumed as 2.7×10^{20} cm^{-2} for each source.
[c] Normalization of the bbody component.
[d] Normalization of the PL component.
[e] kT; temperature keV from bbody and bbodyrad models. T_{in}; temperature at inner disk radius (keV) from diskbb model.
[f] Number of degrees of freedom.

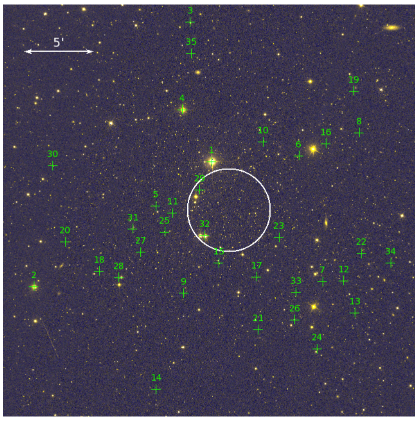

Figure 1. Color-coded (Blue: u, Green: g, and Red: r) SDSS image of Draco. The X-ray sources are shown with green crosses and numbered according to S/N ratios. Both images show the same region of the sky (north is up, east is to the left). 3′ of the center of Draco is shown with white circle.

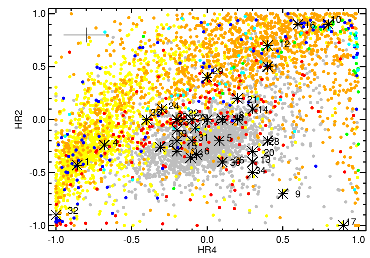

Figure 2. HR diagram where sources from the Draco field are shown by asterisks with numbers. The population of AGNs from our training data set are shown in gray, stars in yellow, YSOs in orange, LMXBs in cyan, HMXBs in green, CVs in red, and pulsars in blue. The average uncertainty of the sources is shown in the top left corner.

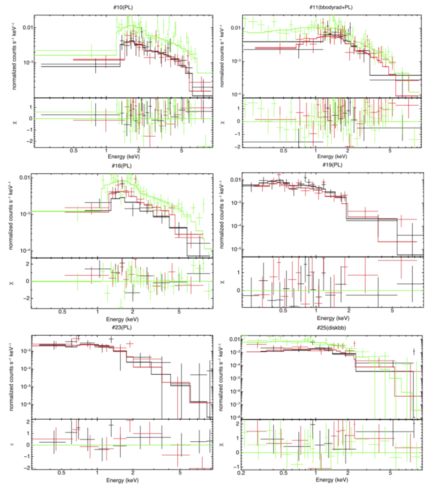

Figure 3. Best-fit model spectra and their residuals for sources #10, #11, #16, #19, #23, and #25 which are not classified as AGNs or foreground galactic stars by our automated classification pipeline. MOS1, MOS2, and EPIN-PN data points and their respective best model fits are shown in black, red, and green.

References

Aaronson, M., Liebert, J., & Stocke, J. 1982, ApJ, 254, 507
Beskin, G. M., & Karpov, S. V. 2005, A&A, 440, 223
Rosen, S. R., Webb, N. A., Watson, M. G., et al. 2015, arXiv:1504.07051
Sonbas, E. Rangelov, B., Kargaltsev, O. et al. 2016, ApJ, 821, 54
Stappers, B. W., Archibald, A. M., Hessels, J. W. T., et al. 2014, ApJ, 790, 39
Walker, M. G., Olszewski, E. W., & Mateo, M. 2015, MNRAS, 448, 2717

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X-Ray Sources

In the following, we highlight the spectral properties of a select number of sources. For a full list of sources the reader is referred to Sonbas et al 2016.

Source #10: The optical-IR properties of this source exhibit characteristics of an old (few Gyr), evolved star. The X-ray spectrum is well fit with the bbodyrad model with a temperature of 1.11 ± 0.08 keV. If the source is in Draco, then the normalization of the diskbb model, ((R_{in} km) (D 10 kpc))^2 cosθ, where θ is the angle of the disk (assumed face-on), corresponds to r_{in} = 0.11 km, which seems to be too small for an accretion disk in an XRB. The X-ray luminosity, L_X ; 8 × 10^{34} erg s^{-1}, is too high for a redback or black widow type binary unless it goes through an outburst episode and switches to an accretion state (see e.g., Stappers et al. 2014). However, the X-ray light curve does not show any significant variability during any of the five XMM-Newton observations.

Source #11: The X-ray spectrum requires two components, bbody (BB)+PL, as PL or BB models alone do not provide acceptable fits to the data. Both the temperature (kT = 0.7 ± 0.1 keV) and the photon index (Γ = 1.2 ± 0.5) are not uncommon for several object types (e.g., AGN and CV), but even for the two-component model the data show systematic excess below 0.4 keV over the best fit, suggesting that an even softer component is needed. We found no variability between five XMM-Newton exposures.

Source #16: This source is strongly (intrinsically) absorbed with an odd jump >8 keV in the X-ray spectrum. The source's optical/NIR properties are consistent with those of an evolved low-mass single star, but the apparently high absorption in X-rays rules out an active corona in a nearby star as a source of X-rays. It is possible that this source is a symbiotic star or CV in Draco. The X-ray light curve does not exhibit any significant variability.

Source #17: This source has been reported as a candidate symbiotic star (Belczyński et al. 2000). Aaronson et al. (1982) identified this source as a carbon star with an unusual SED showing strong emission lines. The authors suggest that the optical colors can be explained by a symbiotic binary (a red giant with a hot main-sequence companion). Aaronson et al. (1982) also claim that #17 is in Draco based on radial velocity measurements. However, the observed X-ray flux implies a high X-ray luminosity of L_X = 1.2 × 10^{33} erg s^{-1} at the distance of Draco, which can hardly be produced in a non-degenerate binary with a red giant and a late-type main- sequence star. Therefore, we consider this source to be a good candidate for a quiescent XRB in Draco.

Source #19: Given its X-ray flux and the lack of an optical counterpart (arguing against binary nature), it is unlikely that this source would belong to Draco (X-ray luminosity, L_X = 4.6 x 10^{35} erg s^{-1}, for d = 80 kpc, is too high for isolated NSs), and so it could be an old recycled or non- recycled pulsar in a non-accreting binary in our Galaxy. The lack of optical/IR data prevents our algorithm from confidently classifying this source.

Source #23: This source is faint with a soft X-ray spectrum, too soft for a typical AGN. There is some evidence of even further hardening beyond 5–6 keV in pn. PL and bremss provide a reasonable fit to the data. Our automated algorithm does not provide a confident classification, likely due to incomplete MW parameters (a very faint counterpart found in SDSS, but not in 2MASS).

Central IMBH

According to the 3XMM catalog, there are four X-ray sources with S/N ≈ 3–5 within ~3′ of the center of Draco (R.A. = $17^h20^m13^s.2$ and decl. = +57°54′55 3; Rave et al. 2003). The measured flux for the source nearest the center (not shown) is F_X = 4.5 x 10^{-15} erg s^{-1} cm^{-2} (the other three sources, also not shown, have similar fluxes and S/N). By assuming luminosity due to Bondi-Hoyle accretion, the measured flux, and the radiative efficiency (a somewhat optimistic value of ε ~ 10^{-5}) for synchrotron radiation (Beskin & Karpov (2005)), we can then obtain an upper limit for the mass of the putative IMBH as the following:

$$M_{\rm BH}\left(\frac{n}{0.02\ {\rm cm^{-3}}}\right)^{1/2} < 3.4\times10^{3}\left(\frac{F_X}{10^{-15}\ {\rm cgs}}\right)^{1/2} \times \left(\frac{\epsilon}{10^{-5}}\right)^{-1/2}\left(\frac{c_s}{10\ {\rm km\ s^{-1}}}\right)^{3/2} M_{\odot}.$$

Summary

Our main results are as follow:

- The classification of X-ray sources in Draco resulted in 12 AGNs and 3 foreground stars. We also identified 4 X-ray sources (#10, #16, #17, #25, potential quiescent LMXBs or CVs) that could belong to Draco. For two of them (#16 and #17) the associations are supported by the line-of-sight velocity measurements reported in Walker et al. (2015).

- The upper limit on the mass of the IMBH that we obtained from the X-ray data analysis is similar to the predictions based on the velocity dispersion correlation. Although not definitively ruled out, our current data are consistent with the non-existence of a central IMBH.