A study of four Milky Way dSph satellites observed by *XMM*-Newton.

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Dwarf spheroidal galaxies (dSphs) represent a peculiar and intriguing class of star systems characterized by masses in the range 10^3 - 10^7 $M_\odot$ [1] and relatively poor contents of old and intemediate-age stars. Therefore, they turn out to be very faint and difficult to be detected and studied in details. Nevertheless, McConnachie [2] listed over 100 nearby galaxies, in and around the Local Group, along with their relevant properties.

If dSphs orbit close enough to the center of a normal galaxy, with mass in the range 10^9 - 10^{11} $M_\odot$ such as the Milky Way (MW) or the Andromeda Galaxy (M31), they may lose mass and be disrupted by the tidal forces due to the galactic gravitational potential. Such tidal effects can be easily revealed in the Sagittarius , Carina and Ursa Minor dSphs.

The large mass-to-light ratio of dSps leads scientists to infer that they are the smallest stellar systems dominated by dark matter [3] which may have played a fundamental role in their formation process [4]. This approach is not universally approved, indeed it was also argued that a merger in M31 had caused a mass ejection and the following formation of MW dwarf satellites [5]. Furthermore, dSphs may be either remnants of bigger systems, affected by tidal forces or supernova winds taking out the majority of gas, or small mass systems since their origin. DSphs may have led to normal galaxies by interacting among themselves, on the contrary if they have remained isolated dSphs can have been doomed to be fossils of the galactic formation.

This kind of galaxies are believed to host intermediate mass black holes (IMBHs) in their cores because of the extrapolation from the $M_{BH} - M_{Bulge}$ relation in the dSphs mass range. It is likely that IMBHs are the missing link between stellar mass BHs and supermassive ones that inhabit the gravitational center of the aforementioned normal galaxies and could have been arisen from a IMBHs merger. Therefore, it is useful to inspect dSphs central regions in order to detect radio or X-ray emissions of putative accreting IMBHs.

X-ray signatures can be due to the foreground or background sources, as well as to IMBHs and low mass X-ray binary (LMXB) in dSphs. Since LMXBs are expected to turn off in a few hundred million years, their presence in systems characterized by old stellar population and lack of recent stars formation processes is an unfixed problem.

Having previously studied the high-energy sources population of two MW dSph companions, via the analysis of *XMM*-Newton (an ESA satellite) [7] and Chandra (a NASA space-based mission) [8] observations, we stretch out the dSphs sample. We re-analyze deep archive *XMM*-Newton data concerning Draco, Leo I, UMa II and UMi revealing 96, 116, 49 and 54 X-ray sources, respectively.

In order to understand the correct position of those sources along the line of sight, we evaluate the theoretical number of background AGN in our field of view using the lonN-logS relation. Although the observed occurrences are statistically consistent with the expected ones, we cannot rule out that some high-energy emitting objects reside in the researched dSphs.

To attempt a classification of the detected sources we calculate the hardness ratios (HR) and produce a color-color diagram following the method used by Ramsay & Wu [9]. The association of sources with two spectral model (bremmsstrahlung and power-law) turns out to be vain due to the large HR error bars. For that reason we resort to another color-color diagram, based on the ratio between $0.2 - 2.4$ keV X-ray and J band NIR fluxes versus the J-K color. We note that some X-ray sources, correlating with 2MASS catalogue counterparts, seem to have stellar origin. This tool is useful to determine the real nature of some controversial sources having counterparts both in AGN and stellar catalogues we consulted. Moreover we perform a source sorting using only high-energy data. Starting from the literature [10,11] we set up our own criteria that could distinguish among foreground stars, supernova remnants, active galactive nuclei, galaxies, super soft sources, hard and local sources. This further statistical method leaves us with a wider and more complete classification of the X-ray sources in the dSphs field of view.

To sum up, according to the framework we developed, we reveal two high-energy sources (among which a carbon star) belonging to Draco, one to UMa II and none to Leo I, indead fourteen high energy emitting objects remain at the candidate stage. For these three galaxies we do not identify any high-energy (and radio) sources nearby the galactic centers, therefore we use the energy flux of the faintest detected source to obtain an upper limit to the luminosity of the putative central object. Assuming a Bondi accretion of a low-angular momentum gas onto the BH, we get an upper limit for the amount of mass of about $10^2 M_\odot$.

The 2005 UMi dSph observation is more profitable as for the IMBH quest rather than the detection of local sources. Actually, the possibility that this galaxy hosts a BH has been studied quite intensily and mass estimate of few 10^4 and 10^5 $M_\odot$ have been performed by the use of N-body simulation [12] and radio observations [13], respectively. As for our analysis, we pinpoint an inspiring source close to the gravitational center and only sexteen local candidates. The central object we detected is characterized by an absorbed 0.2-12.0 keV flux of 7.3±2.9)$\times 10^{-15}$ erg s^{-1} cm^{-2} which corresponds to an unabsorbed flux $F^{Unabs}_{2-10\ keV}=(4.05\pm1.61)\times10^{-15}$ erg s^{-1} cm^{-2}. Using the distance of 73±10 kpc provided by NED, we determine the relevant 2-10 keV luminosity of $(2.50\pm1.21)\times10^{33}$ erg s^{-1}.

The source also correlates in position with 150914+671258 radio source, detected by Maccarone et al. [13], therefore we can estimate the putative central BH mass using the fundamental plane relation [14]

$$logL_R = \xi_{RX} log(L_X) + \xi_{RM} log(M_{BH}) + b_R \ ,$$

where the mass and the luminosities are in units of solar masses $M_\odot$ and erg s^{-1}, respectively, $\xi_{R_X}=\ 0.60^{+0.11}_{-0.11}$, $\xi_{R_M}=0.78^{+0.11}_{-0.09}$ and $b_R=7.33^{+4.05}_{-4.07}$.

Solving for the BH mass and using the X-ray 2-10 keV luminosity and the $(2.19\pm0.62)\times10^{32}$ erg s^{-1} radio one (obtained from the 1.4 GHz radio flux density of the source 150914+671258 assuming a flat source spectrum), we estimate a mass of $\left(2.76^{+32.00}_{-2.54}\right)\times10^6$ $M_\odot$ for the putative IMBH. It is consistent with that estimated by Nucita et al. [8] when analyzing an independent 2011 Chandra observation, i.e. $\left(2.9^{+33.6}_{-2.7}\right)\times10^6 M_\odot$. Scaling the 0.2-12 keV source flux (as detected by the *XMM*-Newton satellite) to the range 0.5-7 keV, we get a flux consistent (within the errors) to the Chandra one, therefore we are well confident that this X-ray emission is not related to a background fluctuation.

By comparing the bolometric luminosity, calculated from the X-ray luminosity as $L_B \simeq 16 L_X$, with the expected Eddington one $L_{Edd} \simeq 1.3 \times 10^{38}\,(M_{BH}/M_\odot)$ erg s^{-1}, we obtain $L_B/L_{Edd} \simeq 1.43\times10^{-10}$. This clearly shows that the UMi putative BH is radiatively inefficient.

Indeed, assuming the simplified Bondi accretion scenario, the product between the efficiency in converting mass to radiant energy (ϵ) and the fraction of the Bondi-Hoyle accretion rate onto the BH (η) is

$$\epsilon\eta \simeq 7.3\times10^{-11}\ -\ 7.3\times10^{-9}\ ,$$

that confirms the expected low IMBH accretion efficiency, previously highlighted.

Finally, we rule out the possibility that our source is due to an object standing behind UMi dSph evaluating the expected number of background objects which is very low ($N \simeq 0.07$ within 25″ from the center).

This report is based on the paper by Manni et al. [15] to which we refer for more details.

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