# A *XMM*-NEWTON SEARCH FOR X-RAY SOURCES IN THE FORNAX DWARF GALAXY: HINTS FOR AN IMBH?

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Diffuse dwarf galaxies (DDGs) are low luminosity galaxies which seem to be characterized by structural parameters (luminosity, stellar scale length) fundamentally different with respect to those found in spiral and elliptical galaxies (Kormendy 1985) with the dwarf spheroidal galaxies (dSphs) at the extreme end of this sequence. In particular, dSphs are thought to be satellite galaxies in the Local Group (see e.g., Mashchenko et al. 2006), have approximately spheroidal shapes (sometimes typical of irregular and late-type spiral galaxies) and are, typically, at least two orders of magnitude less luminous than the faintest known spiral galaxies. These systems have typical stellar contents in the range $3 \times 10^3$ $M_\odot$ to $2 \times 10^7$ $M_\odot$ on length scales of the order of a few kpc or less. Additionally, they show evidence of being dark matter dominated at all radii (for a review see Mateo 1997) as demonstrated by the measurements of the central velocity dispersion, which allows the mass-to-light ratios to be estimated, resulting to be much larger than typical values (see Kleyna et al. 2002 and references therein). The distinctions between the normal galaxies and the dSphs families probably come from a different formation history with the most favored theory being that dSphs have low mass density since past supernova winds removed large amounts of gas. Despite being very distinct in their physical properties from spirals and ellipticals, dSphs show kinematical properties that can be modeled using dark matter (DM) halos with the same mass profiles as those which reproduce the rotation curves of spirals (Salucci et al. 2012). Thus, the derived central densities and core radii for dSphs are consistent with the values obtained by extrapolation of the relevant quantities from spiral galaxies. dSphs are also interesting since they provide an optimal laboratory to study the evolution of a particular stellar population (of known metallicity and age) without suffering of extreme crowding conditions as often happens in globular clusters. In this respect, the high energy view of these galaxies -as that offered by deep *XMM*-Newton observations- allows one to study the faint end of the X-ray luminosity function of an old stellar population and, by comparing the low mass luminosity X-ray binary (LMXB) population characteristics in dSphs and globular clusters, to understand its formation history which is still challenging (see e.g. Maccarone et al. 2005). In fact, since any persistently bright LMXB would entirely consume via accretion the mass of the companion in a few hundreds million years (see e.g. the discussion on the LMXB formation history in Maccarone et al. 2005), the presence of bright X-ray binaries in old stellar systems represents a problem that is yet to be solved. An example of these challenging targets is the Sculptor dSph galaxy. When studying a deep Chandra survey of this dwarf galaxy, Maccarone et al. (2005) found at least five X-ray sources with optical counterparts hence pushing towards alternative formation theories of the local LMXB population. A push in this direction would be the observation of targets with no globular cluster contamination (as the Sculptor galaxy) and, possibly, with a short epoch of star formation. Apart from the dark matter and stellar population issues, dSphs are intriguing objects to search for intermediate mass black holes (hereafter IMBHs), i.e. collapsed objects in the mass range $10^2$-$10^5$ $M_\odot$ which are considered to be the missing link between the observed stellar mass black holes (of a few tens of solar masses) and the super massive ones ($10^6-10^8$ $M_\odot$) residing at the center of most, if not all, galaxies. One of the reasons why one expects the existence of such objects is that they might play a crucial role in the formation of the super massive objects which are thought to grow from a population of seed objects with masses right in the IMBH range. Obviously, those seeds that did not accrete a substantial amount of matter and/or did not merge to form a central supermassive black hole remain as IMBHs. Based on the extrapolation to globular clusters of the fundamental $M_{BH} - M_{Bulge}$ relation derived from the study of super massive black holes in galactic nuclei (see e.g. Magorrian et al. 1998), one expects to find IMBHs in globular clusters, i.e. spherical systems of stars which survived the interactions with the surrounding and now orbit the center of the hosting galaxy. Since it is commonly accepted that the galaxies and associated globular clusters formed at the same time, it is natural to expect that at least some of these spherical systems may host an IMBH. IMBHs are expected to be hosted in spheroidal dwarf galaxies as well. For example, the nearby dwarf starburst galaxy Henize2-10 possibly harbors at its dynamical center a compact radio source spatially coincident with a hard X-ray source (possibly an $\simeq 10^6$ M$_\odot$ accreting black hole). Or again, in the halo of the edge-on S0a galaxy ESO 243-49, the brightest known ultra-luminous X-ray source HLX-1 is possibly associated with a IMBH whose with mass initially evaluated to be $\gtrsim 900$ M$_\odot$ and then better constrained to the range $9 \times 10^3$-$9 \times 10^4$ M$_\odot$: a further analysis allowed to identify a young ($<$ 200 Myr) stellar cluster of total mass $\sim 10^6$ M$_\odot$ around the putative black hole and concluded that HLX-1 is likely to be the stripped remnant of a nucleated dwarf galaxy. In the case of the Fornax dSph, van Wassenhove et al. (2010) assumed that an IMBH of mass $M_{BH} \simeq 10^5$ M$_\odot$ is hosted in the galactic core and suggested that measuring the dispersion velocity of the stars within 30 pc from the center would allow that hypothesis to be tested. Jardel & Gebhardt (2012) recently constructed axisymmetric Schwarzschild models in order to estimate the mass profile of the Fornax dSph and, once these models were tested versus the available kinematic data, it has been possible to put a 1-$\sigma$ upper limit of $M_{BH} = 3.2 \times 10^4$ M$_\odot$ on the IMBH mass. Nucita et al. (2012) concentrate on the Fornax dSph re-analyzing a set of *XMM*-Newton data already studied by Orio et al. (2010) who searched for the X-ray population in the Leo I and Fornax dSphs. Here, we took the opportunity to re-analyze the data with the most recent calibration files. Apart from the characterization of the high energy population detected towards the galaxy and the cross correlation with the available databases, we discuss the possible identification of a few genuine X-ray sources belonging to the Fornax dSph. We also considered the possible existence of an IMBH in the galaxy core as suggested by van Wassenhove et al. (2010) and Jardel & Gebhardt (2012) and show that one of the detected X-ray sources coincides with one of the possible Fornax dSph centers of gravity. We then constrained the black hole (if any) accretion parameters and noted that further important information may be obtained by moderately deep radio observations and high angular resolution X-ray data. The X-ray emission from the putative IMBH at the center of the Fornax dSph may be due to Bondi accretion onto the black hole, either from the cluster gas or from stellar winds. Thus, assuming that low-angular momentum gas close to the compact object accretes spherically, for a black hole of mass $M_{BH}$ moving with velocity $v$ through a gaseous medium with hydrogen number density $n$, the expected X-ray luminosity is

$$L_X \simeq \epsilon\eta 8.8 \times 10^{36} \left(\frac{M_{BH}}{10^3 \text{ M}_\odot}\right)^2 \left(\frac{V}{15 \text{ km s}^{-1}}\right)^{-3} \left(\frac{n}{0.1 \text{ cm}^{-3}}\right) \quad (1)$$

(in GCS units) where $V = (v^2 + c_s^2)^{1/2}$, $\epsilon$ is the efficiency in converting mass to radiant energy and $\eta$ is the fraction of the Bondi-Hoyle accretion rate onto the black hole. The hydrogen number density of the mass feeding the black hole can be estimated by using the structural parameters of the Fornax dSph. In particular, it was found that the galaxy hosts at least $M_{HI} \simeq 0.17 \times 10^6$ M$_\odot$ of gas within the observed half-light radius of $r_h \simeq 710$ pc. Thus, a lower limit to the gas density can be evaluated as

$$n \simeq \frac{3M_{HI}}{4\pi r_h^3 m_p} \simeq 5 \times 10^{-3} \text{ cm}^{-3} \ . \quad (2)$$

Assuming that $v \simeq c_s \simeq 10$ km s$^{-1}$, one has $V \simeq 14-15$ km s$^{-1}$. Thus, using the IMBH upper limit of $M_{BH} = 3.2 \times 10^4$ M$_\odot$ quoted above, eq. 1 finally gives the expected X-ray luminosity, i.e.

$$L_X \simeq \epsilon\eta 4.50 \times 10^{38} \text{ erg s}^{-1} \ . \quad (3)$$

For an estimated distance of 0.138 Mpc to the Fornax dSph, the expected IMBH luminosity $L_X$ corresponds to an observable flux of $F_X \simeq \epsilon\eta 1.98 \times 10^{-10}$ erg s$^{-1}$ cm$^{-2}$.

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