X-ray emissivity from old stellar populations: a Local Group census

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Abstract We study the unresolved X-ray emission from old stellar population in three Local Group dwarf elliptical (dE) galaxies (NGC 147, NGC 185 and NGC 205) using XMM-Newton observations. This emission originates from a collection of weak X-ray sources belonging to the old stellar population, mainly cataclysmic variables (CVs) and coronally active binaries (ABs). Precise knowledge of this emission is crucial not only for understanding the relevant stellar astrophysics but also for disentangling and quantifying the thermal emission from diffuse hot gas in nearby galaxies. We measure the 0.5-2 keV stellar emissivity of the dEs to be $L_X/M_* = (6.0 \pm 3.1) \times 10^{27}\ \mathrm{erg\ s^{-1}\ M_\odot^{-1}}$ in the $0.5-2$ keV band, and compare this value to the cumulative X-ray emission from four Galactic globular clusters (ω Cen, 47 Tuc, NGC 6266 and NGC 6397) using *Chandra*, as well as to the X-ray emissivities of other stellar systems from the literature. We find that average X-ray emissivity of dEs are consistent with that measured in the Solar vicinity, but are sandwiched between the emissivities of globular clusters and old open clusters. We discuss the role of dynamical effects in regulating the stellar X-ray emissivity.

1. Introduction

The diffuse X-ray emission from hot gas in galaxies traces the feedback from both young and old stellar populations, and activity of the central super massive black hole, which are believed to play a critical role in regulating the energy, mass, and metal transport, as well as the dynamics of the ISM. However, studies of hot gas in most nearby galaxies have been challenging even with the bright sources detected and removed, because the apparently diffuse X-ray emission must contain, and in some cases be dominated by, unresolved emission from faint stellar sources, whose contribution has not been carefully quantified until recently. Previous studies from the vicinity of the Sun (Sazonov et al. 2006); dwarf elliptical galaxy M32 (Revnivtsev et al. 2007); the intermediate-mass, gas-poor elliptical galaxy NGC 3379 (Revnivtsev et al. 2008); and the outer bulge of M31 (Li & Wang 2007) showed that the cumulative X-ray emissivities from these galactic environments agree within a factor of 2 with each other. In this work we study three nearby dEs (NGC 147, NGC 185 and NGC 205) in order to advance the calibration to the low galaxy stellar mass end. These dEs provide the best places in the Local Group to measure the cumulative X-ray emissivity of old stellar populations, since i) they are not expected to confine a significant amount of hot gas, given their shallow gravitational potential; ii) they are not expected to have recent star-formation and are hence free of relevant activities, e.g., HMXBs, SNRs, pre-main sequence stellar objects, that might contribute to X-ray emission; iii) they are however among the most massive dwarf galaxies in the Local Group and are located at appropriate distances so that the contribution of possible LMXBs can be resolved and subtracted. For comparison, we also study four Galactic globular clusters (GCs): ω Cen, 47 Tuc, NGC 6266 and NGC 6397. They contain large numbers of weak X-ray sources and are at different dynamical states. Highlights of our sample are: (1) a low mass sample, (2) in different dynamical environments.

2. Properties of the unresolved X-ray emission

Fig. 1 shows the unresolved X-ray emission from NGC185, for which we have the deepest exposure (100 ks) among the three dEs The similarities of the morphology and radial surface brightness distribution between the X-rays and the near-infrared starlight prove the stellar origin of this unresolved emission.

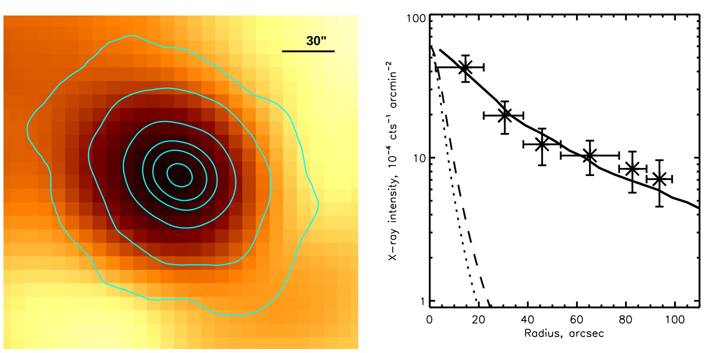

Figure 1: (a) Image of the $0.5-2$ keV unresolved emission in NGC 185, overlaid by 2MASS K-band intensity contours. (b) $0.5-2$ keV radial surface brightness profile of NGC 185, the solid line is the 2MASS K-band surface brightness distribution. The dotted and dashed lines are the MOS1 and pn PSF, respectively.

We implemented in Xspec a single log-normal plasma temperature distribution model to fit the unresolved emission spectrum.

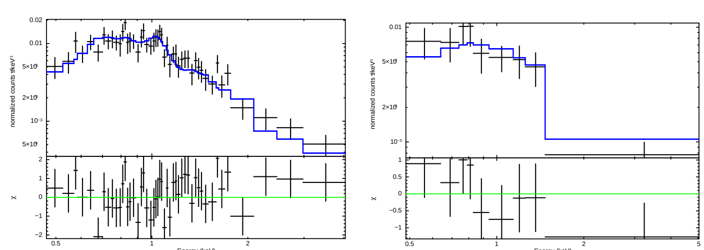

Figure 2: (a) *Chandra* unresolved emission spectrum of M32 and its best fit model with $\chi^2_{\mathrm{red}}/\mathrm{dof}$ = 0.91/45, peak temperature $kT = 1.3 \pm 0.2$ keV and dispersion σ = 3.0 $\pm$ 0.3. (b) XMM-Newton spectrum of NGC185 with $\chi^2_{\mathrm{red}}/\mathrm{dof}$ = 1.03/6, peak temperature $kT = 0.9 \pm 0.6$ keV and dispersion σ = 3.0 $\pm$ 1.0.

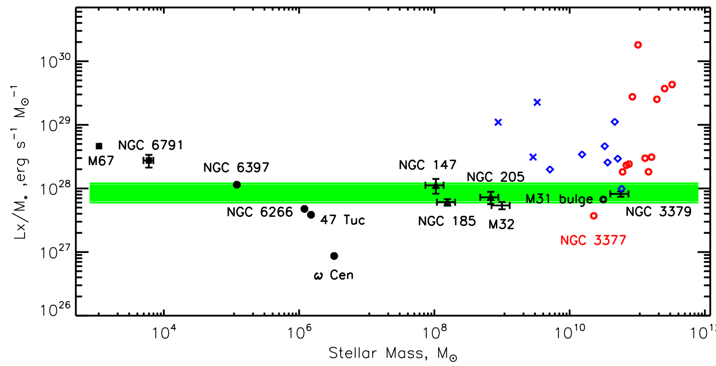

Figure 3: $0.5-2$ keV emissivities of galaxies and star clusters: M32 (Revnivtsev et al. 2007) and NGC 3379 (Revnivtsev et al. 2008) are in black pluses; 12 early-type galaxies (red circles), the bulge of M31 (black circle), 7 spiral galaxies (diamonds) and 3 irregular galaxies (crosses) from Bogdan & Gilfanov (2011); the black triangles are the three dEs (NGC 147, NGC 185 and NGC 205); the black dots are the four GCs (ω Cen, 47 Tuc, NGC 6266 and NGC 6397); the boxes are 2 old open clusters M67 (4Gyr) and NGC 6791 (8Gyr) (van den Berg et al. 2013); and the green strip is the value and uncertainty ($9 \pm 3 \times 10^{27}\ \mathrm{erg\ s^{-1}\ M_\odot^{-1}}$) of the cumulative emissivity of ABs and CVs with luminosities between $\sim 10^{27}$ to $\sim 10^{34}\ \mathrm{erg\ s^{-1}}$ measured in the Solar vicinity (Sazonov et al. 2006).

3. The quasi-universality of stellar X-ray emissivity

The unresolved emissivities of most gas poor early-type galaxies, especially the dEs, are consistent with the cumulative emissivity of CVs and ABs in the Solar vicinity, which suggests a quasi-universality of stellar X-ray emissivity (Fig. 3). This emission should be prevalent in all galaxies and scaled with their stellar masses. We calibrate this average stellar X-ray emissivity with the four Local Group dEs (NGC 147, NGC 185, NGC 205 and M32) in the soft (0.5-2 keV) band,

$$L_{0.5-2\ \mathrm{keV}}/L_K = (4.7 \pm 2.5) \times 10^{27}\ \mathrm{erg\ s^{-1}\ L_{\odot,K}^{-1}}, \quad (1)$$
$$L_{0.5-2\ \mathrm{keV}}/M_* = (6.0 \pm 3.1) \times 10^{27}\ \mathrm{erg\ s^{-1}\ M_\odot^{-1}}, \quad (2)$$
$$L_{2-8\ \mathrm{keV}}/L_K = (4.7 \pm 3.7) \times 10^{27}\ \mathrm{erg\ s^{-1}\ L_{\odot,K}^{-1}}, \quad (3)$$
$$L_{2-8\ \mathrm{keV}}/M_* = (5.9 \pm 4.5) \times 10^{27}\ \mathrm{erg\ s^{-1}\ M_\odot^{-1}}. \quad (4)$$

4. Discussion

Three GCs have lower emissivities than the Solar vicinity, and ω Cen exhibits the lowest emissivity. Most of the least luminous X-ray sources in GCs are CVs and ABs. Unlike their counterparts in normal galactic environments, binaries are continuously formed and destroyed in GCs through interactions between binaries and single stars. Observations found that the binary fraction in GCs is lower than in the field (Sollima et al. 2010). Meanwhile, theoretical simulations also found a depletion of the binary population in GCs (Ivanova et al 2005). Moreover, Milone et al. (2008) discovered an anti-correlation between binary fraction and GC mass, and the trend of GC emissivity decrease with their mass in Fig. 3 is consistent with these studies.

The old open clusters have higher emissivities than dEs/Galactic field, which could be explained by the cluster dynamical effects: mass segregation and evaporation (Portegies Zwart et al. 2001). Mass segregation cause the heavier binaries congregate at the cluster center, while lighter single stars are expelled toward the periphery. Evaporation causes high velocity stars escape from the cluster, losing a significant fraction of its mass. The net result is the high emissivity showed in Fig. 3. The GCs also have those dynamics as in the open clusters, which may causes its anti-correlation between binary fraction and GC mass, but the relaxation time of GCs is much longer than open clusters and these effects are weaker, and the observational result of their lower emissivities suggests that the dominate process in GCs is binary destruction. The binary fraction or X-ray emissivity depends on the dynamical environment or evolution history of the stellar population. It can be expected that similiar effects apply to the Galactic center.

References

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