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Star-formation history, globular clusters and XRBs in early-type galaxies

L. A. Nolan[1]†, R. Kraft[2], T. Ponman[1], C. Jones[2] and S. Raychaudhury[1]

[1]School of Physics and Astronomy, University of Birmingham, Birmingham, B15 2TT, UK
[2]Harvard/Smithsonian Center for Astrophysics, 60, Garden St., MS-67, Cambridge, MA, 02138

Abstract. NGC 5102 has an unusually low number of XRBs. The deficit of LMXBs is even more striking because some of these sources may in fact be HMXBs, produced in one of the two recent bursts of star formation ∼15 and ∼300 Myr ago. Our UV-optical spectral synthesis analysis demonstrates that a significant fraction (>50%) of the stars in this galaxy are comparatively young (<3 Gyr). NGC 5102 also has an usually low number of globular clusters for its mass, luminosity and environment.

We discuss the relationship between the XRB population, the globular cluster population and the relative youth of the majority of the stars in this galaxy. We intend to extend our investigation of the relationship between XRB populations, star-formation history and globular clusters to a sample of ten early-type galaxies with a range of star-formation histories and investigate the implications for models of LMXB formation and evolution.

Keywords. X-rays: binaries, galaxies; galaxies: stellar content.

1. Introduction

The X-ray binary (XRB) populations of galaxies with a range of masses and morphological types have now been studied in detail, and it is clear that the variance in the number of XRBs per unit optical luminosity in early-type galaxies is greater than that expected based on counting statistics alone. This variance is likely to be related to the much-debated origin and evolution of XRBs.

Some have argued that most or all of the XRBS in early-type galaxies originate in globular clusters (GCs), where the stellar densities are sufficient for neutron stars to be captured in N-body interactions. Recent Chandra observations show that a significant fraction (40–60%) of the XRBs are spatially coincident with GCs, supporting this idea. Others have argued that that XRBs are related to the bulk of the stars in the galaxy, and that the variance in XRB populations is therefore related to the star-formation history (sfh) of the galaxy (White & Ghosh 1998, Wu 2001). The fact that the majority of LMXBs in the Galactic and M31 bulges do not appear to be associated with GCs supports this argument. However, recent analysis suggests both mechanisms may be important (Irwin & Bregman 2003).

We present the results of a 34ks Chandra/ACIS-S observation of the small ($M_B = -17.45$), blue, nearby (d = 3.1 ± 0.015 Mpc (McMillan, Ciardullo, & Jacoby 1994)), lenticular galaxy, NGC 5102. ROSAT and Einstein observations suggest it is under-X-ray luminous for its mass (Forman, Jones, & Tucker 1985, Irwin & Sarazin 1998, O'Sullivan, Forbes, & Ponman 2001). It is also unusually blue, with one or more recent (<0.1 Gyr ago) bursts of star-formation, which could have resulted in a high-mass X-ray binary (HMXB) population as well as the low-mass XRB (LMXB) population expected in early-types.

† email: lan@star.sr.bham.ac.uk

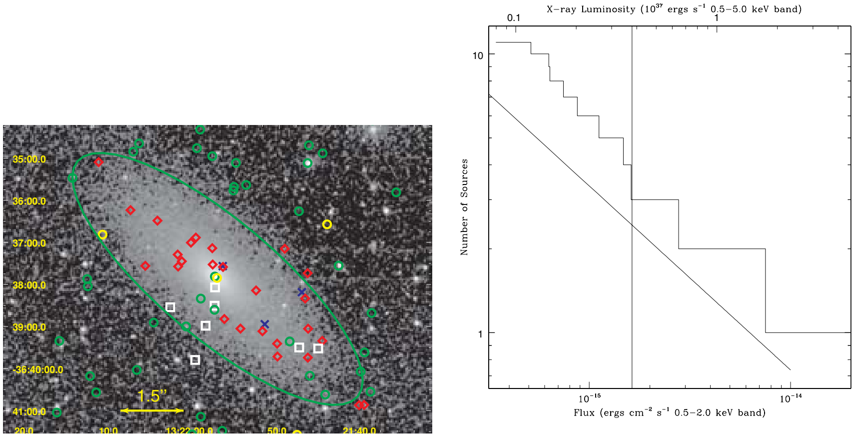

Figure 1. LHS: Positions of the X-ray point sources overlaid onto a 2MASS J band image of NGC 5102. The large green ellipse denotes the optical boundary (D_{25}) of the galaxy; the yellow and green circles the XPSs with $L_X \geqslant 10^{37}$ ergs^{-1} and $L_X < 10^{37}$ ergs^{-1} respectively. The red diamonds are planetary nebulae, and the white boxes are HII regions (both from McMillan, Ciardullo, & Jacoby 1994). The blue Xs represent GC candidates. RHS: Cumulative luminosity function (histogram) of X-ray point sources detected within the D_{25} ellipse. The log(N)-log(S) of the background AGN is plotted as the continuous curve (Tozzi *et al.* 2001). The corresponding X-ray luminosity of the sources in the 0.5-5.0 keV band (assuming the source to be at a distance of 3.1 Mpc) is shown across the top. The solid vertical line denotes the flux corresponding to 16 counts in our observation. Above this line, we are complete and unbiased.

Spectral synthesis modelling suggests that most or all of the stars are relatively young (<5 Gyr) (Pritchet 1979, Rocca-Volmerange & Guiderdoni 1987, Deharveng *et al.* 1997). Here, we study the sfh (via long-baseline spectral decomposition) and the GC population (using archival HST data) of NGC 5102, to investigate their relationship with the XRB population detected in the Chandra observation.

2. The X-ray point sources

The point sources in NGC 5102 were detected using the CIAO programme *wavdetect* in the 0.5–5.0 keV band. Here, we will consider only the X-ray point sources detected within the D_{25} ellipse which is shown on the left-hand side of Figure 1. The right-hand side of Figure 1 plots the cumulative X-ray luminosity function in this region. We find only 11 XRBs within the D_{25} ellipse, and only 2 with $L_X > 10^{37}$ ergs^{-1}. One of these sources is likely to be a background AGN (see Figure 1), so we are left with only 1 XRB in NGC 5102 which has $L_X > 10^{37}$ ergs^{-1}. We restrict ourselves to this energy range as we know that we are complete and unbiased here, and for ease of comparison to other galaxies. By comparison with other early-types, scaling with the B band luminosity, we predict that NGC 5102 should contain 6 LMXBs (5, if scaled with the J band luminosity). NGC 5102 clearly has a dearth of LMXBs, which is exacerbated by the possibility that this single source could be an HMXB associated with the recent star-formation.

3. The globular clusters

The archival HST/WFPC2 data, observed with the F569W filter, was searched for GCs using the image-finding algorithm SEXTRACTOR on the unsharp masked image. The positions of the detected GCs are shown in Figure 1. As the HST data only cover

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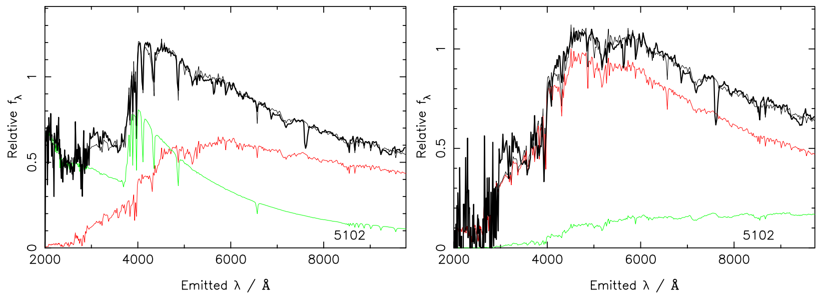

Figure 2. Left: The best-fitting two-component model (thin black line) superimposed over the spectrum of NGC 5102 (thick black line). The two component populations are also shown: the dominant population (3 Gyr, Z = 1.5 $Z_\odot$) is in red, and the lesser population (0.3 Gyr, Z = 0.2 $Z_\odot$) is in green. Right: The best-fitting two-component model (thin black line) superimposed over the residual of the spectrum of NGC 5102 following the subtraction of the 0.3 Gyr population (thick black line). The two component populations are also shown: the dominant population is in red (2 Gyr, Z = $Z_\odot$), and the lesser population (10 Gyr, Z = 2.5 $Z_\odot$), is in green. A faint population of older (10 Gyr) stars is not rejected by the fitting statistics.

∼46% of the total light of the galaxy, the number of GCs was scaled by the galactic light fraction. We estimate that there are 7 GCs in NGC 5102. This gives a globular cluster specific frequency (GCSF) of 0.4, which is atypically low for a galaxy of this luminosity, morphology and environment. A more typical GCSF for an NGC 5102-like galaxy would be ∼1.5. However, if the number of GCs scales with the GCSF, then, by comparison with Cen A and NGC 4472, we would expect 1 XRB in NGC 5102 given 7 GCs.

4. The star-formation history

We have estimated the ages of the stellar populations in NGC 5102 by fitting a two-component stellar population evolutionary synthesis model to its UV-optical spectrum. We use the stellar population models of Jimenez *et al.* (2004). The age, metallicity and relative mass fraction of each single stellar population component is allowed to vary freely, and the best-fitting two-component model is found via χ^2 minimisation. The results are shown on the left-hand side of Figure 2. The dominant (93%) population has an age of 3 Gyr, and Z = 1.5 $Z_\odot$. The smaller population has age = 0.3 Gyr and Z = 0.2 $Z_\odot$. This is consistent with the results of other authors (Pritchet 1979, Rocca-Volmerange & Guiderdoni 1987, Bica 1988). The age of the dominant population is remarkably young, so, to check for the presence of an sub-population we subtracted the 0.3 Gyr model population from the observed spectrum, and apply the two-component model-fitting technique to the residual spectrum. The results are shown on the right-hand side of Figure 2. The addition of a third, older (10 Gyr) population is not ruled out by the fitting statistics. Even with the addition of this third population, the majority (>55% by mass) of the population is still young (2 Gyr). If the XRB population is directly linked to the stellar population, this would suggest that NGC 5102 has not had sufficient time to develop an XRB population appropriate to its stellar mass.

5. Discussion

We have demonstrated that NGC 5102 has a deficit of XRBs. We have also shown that more than half the stars in this unusually blue lenticular galaxy are less than 3 Gyr old, and that it has an atypically small number of GCs. Is the lack of XRBs related to the relative youth of the stellar population, to the lack of GCs, or to both? There seems

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little doubt that GCs play an important role in the formation of XRBs in early-types, so the question is, what role does the stellar population play? It is probable that both the sfh and the deficit of GCs play a role in the lack of XRBs in NGC 5102.

Even if 30−60% of the XRBs in all early-type galaxies are contained within GCs, the other 40−60% remains unaccounted for. It is possible that all XRBS in early types were formed in GCs and some have been ejected, although there is little evidence either way. On the other hand, the non-GC XRBs may be an entirely distinct population. Studies of the LMXB populations in the Galactic and M31 bulges suggest that these sources were likely formed via a stellar evolution scenario, where the LMXB begins life as a wide binary with a large mass ratio. The more massive star evolves rapidly, and explodes as a supernova. The binary orbit then decays, possibly through magnetic breaking, until Roche lobe overflow occurs, and the LMXB is born. If this is the case, our results suggest that there is a minimum timescale of a few Gyr for XRB populations to form. This timescale is roughly consistent with estimates of the timescale required for rotational breaking of the magnetic winds of companion stars sufficient to reduce the binary separation to the point where Roche lobe overflow occurs (Verbunt & Zwaan 1981). There would also be a minimum timescale for LMXBs to evolve if their companion stars were red giants, which have a characteristic timescale to evolve off the main sequence depending on their mass and metallicity.

There is clearly an important relationship between LMXBs and GC populations in massive ellipticals in rich environments with large GCSFs. However, sfh and binary evolution must also play an important part in the formation of LMXBs. We are currently investigating the relationship between XRBs, sfh and GCs in a sample of early-types.

These results are presented and discussed in detail in Kraft *et al.* (2005).

Acknowledgements

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References

Bica, E., 1988, A&A, 195, 76

Deharveng, J.-M., Jedrzejewski, R., Crane, P., Disney, M. J., & Rocca-Volmerange, B., 1997, A&A, 326, 528

Forman, W., Jones, C., & Tucker, W., 1985, ApJ, 293, 102

Irwin, J. A. & Bregman, J. N., 2003, AAS, 203,

Irwin, J. A. & Sarazin, C. L., 1998, ApJ, 499, 650

Jimenez, R., MacDonald, J., Dunlop, J. S., Padoan, P., & Peacock, J. A., 2004, MNRAS, 349, 240

Kraft, R. P., Nolan, L. A., Ponman, T. J., Jones, C., & Raychaudhury, S., 2005, ApJ, 625, 785

McMillan, R., Ciardullo, R., & Jacoby, G. H., 1994, AJ, 108, 1610

Pritchet, C., 1979, BAAS, 11, 429

O'Sullivan, E., Forbes, D. A., & Ponman, T. J., 2001, MNRAS, 328, 461

Rocca-Volmerange, B., & Guiderdoni, B., 1987, A&A, 175, 15

Tozzi, P., *et al.*, 2001, ApJ, 562, 42

Verbunt, F. & Zwaan, C., 1981, A&A, 100, L7

White, N. E. & Ghosh P., 1998, ApJ, 504, L31

Wu, K., 2001, PASA, 18, 443

Discussion

Sarazin: I just wanted to suggest that E + A elliptical galaxies are particularly good objects for studying the relation of LMXBs with star formation history.

Nolan: Yes, that would be a good way to probe younger stellar populations, although care may have to be taken to avoid contamination of the population with HMXBs. I believe one of the galaxies in our sample B is in fact an E + A galaxy.

Ghosh: We're so used to thinking of early-type galaxies not having young, massive stars that NGC 5102 seems a remarkable case indeed. What's special about this lenticular galaxy that it had such recent bouts of star formation?

Nolan: Early type galaxies are not the simple, mature stellar systems that they were once declared to be! They suffer from mergers (many are probably formed from major, recent ($z < 1$) mergers) both major & minor (e.g. capture of dwarfs) & interactions, which are likely to induce bursts of star formation. So we do expect to find a range of ages of the stellar populations in early-type galaxies. NGC 5102 is in a poor environment, and its recent star formation was probably as a result of the capture of a dwarf galaxy. It's unusual for its large mass fraction of young stars, but not for having a young stellar population.