Populations of High Energy Sources in Galaxies
Proceedings IAU Symposium No. 230, 2005
E. J. A. Meurs & G. Fabbiano, eds.

doi:10.1017/S1743921306008222

The trail of discrete X-ray sources in the early-type galaxy NGC 4261: anisotropy in the globular cluster distribution

Ginevra Trinchieri[1], Lea Giordano[2], Luca Cortese[2], Anna Wolter[1], Monica Colpi[2], Giuseppe Gavazzi[2] and Lucio Mayer[3]

[1]INAF-Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milano, Italy
[2]Università degli Studi di Milano Bicocca, Piazza della Scienza 3, 20126 Milano, Italy
[3]Inst. of Theoretical Physics, University of Zürich, Winterurestr. 190, 8057 Zürich, Switzerland

Abstract. The recent evidence of a peculiar distribution of X-ray sources in the elliptical galaxy NGC 4261 reported by Zezas *et al.* has prompted us to study this galaxy combining archive X-ray and optical observations, from Chandra, INT, and HST. We find that a sizable fraction of the X-ray sources has a globular cluster as optical counterpart. This together with the shape of the luminosity function of the X-ray sources suggest that they are accreting low-mass binaries. We further show a remarkable similarity in the anisotropy of the projected spatial distributions of the optical and X-ray sources, which leads us to conclude that the spatial anisotropy of the X-ray sources in NGC 4261 is due to the anisotropy of the globular cluster population.

Keywords. X-rays: galaxies, galaxies: individual (NGC 4261).

1. NGC 4261

NGC 4261 is a massive early-type galaxy in the Virgo W Cloud. The optical spectrum and light distribution indicate an old unperturbed galaxy (Gavazzi *et al.* 2002, Schweizer & Seitzer 1992, Colbert *et al.* 2001), in a group that that does not show prominent signs of gravitational interactions (Garcia 1993, Noltenius 1993). The only evidence of activity is in the nuclear region that hosts a FRI radio source (3C 270).

Chandra observations of NGC4261 have been reported in the literature, mostly for the nuclear region (Chiaberge *et al.* 2003, Sambruna *et al.* 2003, Gliozzi *et al.* 2003). Zezas *et al.* (2003) have concentrated on the galaxy proper and have discovered the presence of about sixty bright off-nuclear X-ray sources in NGC 4261, which stand out for their large-scale spatial anisotropy. Zezas *et al.* (2003) interpret this peculiar distribution as evidence of an association with a young stellar population, possibly formed in a recent episode of star formation dynamically triggered along tidal tails. Since most to all X-ray sources in an early type galaxy are expected to be Low Mass X-ray binaries (LMXB), this association would make NGC 4261 a remarkable exception worth of further study.

2. Our contribution

We have used archival data from *Chandra*, the Isaac Newton Telescope (INT), and the Hubble Space Telescope (*HST*), to better understand the nature of the X-ray sources, to search for their optical counterparts, and to study their relation with the GC population of NGC 4261. XMM-Newton data were also considered but could not add useful information for this project.

The optical data at our disposal is not ideal: the HST dataset does not cover the whole galaxy and is not homogeneous in time and filters (Fig. 1); INT covers the whole optical

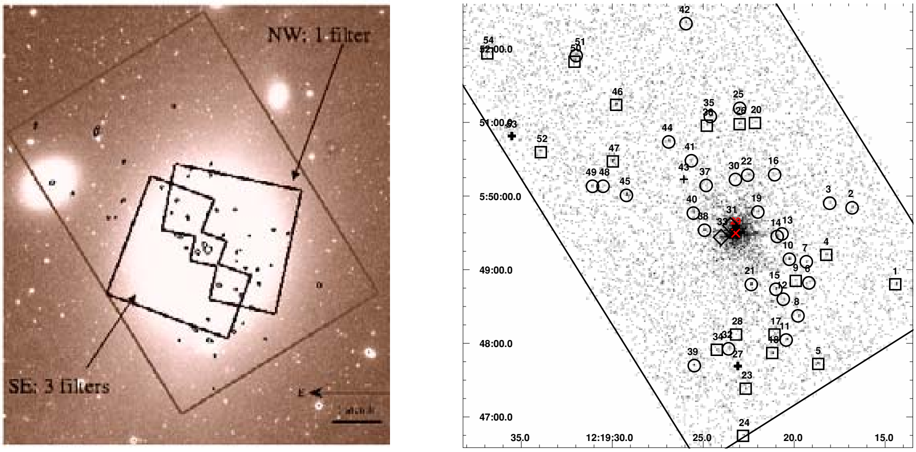


Figure 1. LEFT: R band image of NGC 4261 from the INT. The active field of the *Chandra* ACIS-S3 CCD and *HST* WFPC2 fields are shown. Only the SE field was observed in three filters, allowing us to select GCs on the basis of their colors as well. Ellipses indicate the positions of the X-ray sources. RIGHT: Positions of the X-ray sources identified with GC (open squares); with no id. (open circles); for which no optical counterpart was searched for (model subtraction is too noisy or outside the galaxy radius - diamonds); central AGN (cross); back-/foreground galaxies (+).

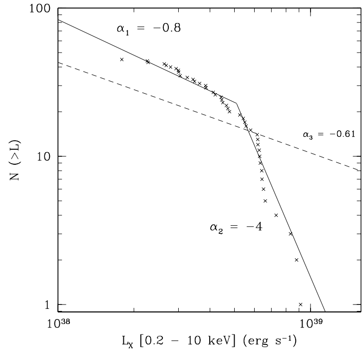
galaxy but in a single filter and at a lower (~1″) resolution (see details in Giordano *et al.* 2005). Nonetheless we have combined all information and produced a valid list of candidate globular clusters (GC) in NGC 4261. We have first selected GCs in the SE HST field, using the color information. The 325 objects selected span a V-I range from ~0.5 to ~2, typical of the globular cluster populations observed in other massive early-type galaxies, and indicative that both "red" and "blue" GCs are represented. We have then used this list to "calibrate" the results from the NE HST field and INT data, for which we have no color information. The cross-correlation between the three lists indicates that ~97% (37/38) and ~83% (49/59) of the sources in the common area between *HST*-SE and *HST*-NW and INT field, respectively, coincide with a GC in the *HST*-SE field. We have then used the INT "GC candidate" list, that provides an homogeneous set of optical sources over the whole galaxy, to determine the optical identification of X-ray sources obtained from the *Chandra* data.

We find that 50% of the X-ray sources can be associated with a GC cluster, preferentially belonging to the "metal rich" bright population (when the color information is available). Therefore it appears that the properties of the sources in NGC 4621 are like those in other early type galaxies (see for example Kundu *et al.* 2002, Maccarone *et al.* 2003), except for their spatial distribution (a rather big "except"!).

This is also confirmed by the shape of the luminosity distribution in the X-ray sources (Fig. 2): unquestionably the functional form appropriate for low mass X-ray binaries is a significantly better representation than that for High Mass systems.

We therefore conclude that NGC 4621 has a population of LMXB associated with GCs, like other early type galaxies studied. But unlike any other, the spatial distribution of these sources is peculiar, and totally at odds with the distribution of the optical light.

https://doi.org/10.1017/S1743921306008222 Published online by Cambridge University Press



The integral luminosity function in the 0.2-10 keV band of the X-ray sources in NGC 4261. The solid line gives a broken power-law with fixed slopes, from Gilfanov (2004), renormalized to our data. We overlay the single power-law (dashed line) with a slope $\alpha_3 = -0.61$ as suggested by Grimm *et al.* (2003) to describe a population of HMXBs.

Figure 2.

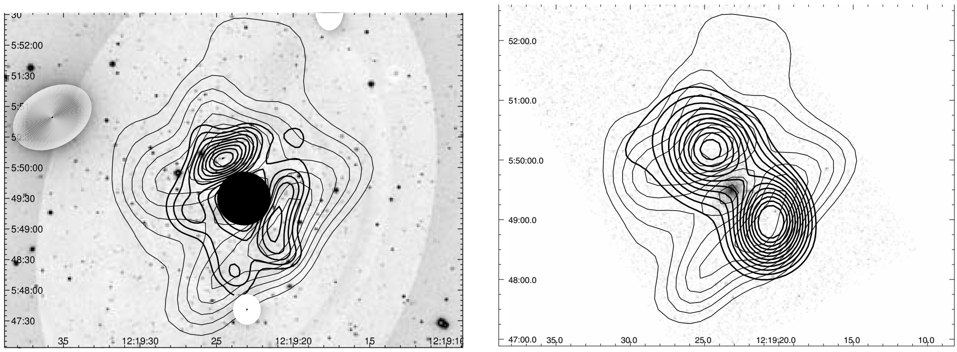


Figure 3. Iso-Density contours from the kernel density analysis. Left: comparison between the distributions of GCs in the INT (thin line) and HST (thick line). Right: comparison between the distributions of GCs in the INT (thin line) and of the *Chandra* X-ray sources (thick line).

3. Why is the X-ray source distribution so peculiar?

Since the spatial distribution of the sources is not that of the stellar light, we have looked at a correlation with the distribution of the GCs to which they are associated. The comparison between the sky projected distributions of the INT and *HST* GC candidates, estimated with the aid of an adaptive kernel density analysis (Silverman 1986) indicates a peculiar distribution of the GC population, with two main concentrations NE and SW of the nuclear region (Fig. 3-left). The same analysis applied to the distribution of the X-ray sources (Fig. 3-right) also shows two peaks. We have also simply computed the surface number density of sources for both GCs and X-ray sources in several regions, chosen to maximize the differences in the X-ray source population. The plots in Fig. 3 and Fig. 4 (left panel) show a remarkable similarity between the two distributions. We have also looked at the surface brightness distribution of hard photons (expected from individual sources of all luminosities) and found that the anisotropy might not be confined to the brightest sources (Fig. 4-center), since it is visible also when the detected sources are removed. This suggestion is also intriguing and worth of further investigation.

This therefore indicates that the anisotropy in the LMXBs is but a reflection of the peculiar spatial distribution of the GCs. It has been instrumental in discovering the large scale anisotropy of the globular cluster distribution as well, which to our knowledge is not observed in other systems.

Unfortunately this only implies that we have moved the focus onto the GC system, without uncovering the reason for this anisotropy. While we would like a confirmation of our GC list with better optical data, these results are already important for several reasons:

https://doi.org/10.1017/S1743921306008222 Published online by Cambridge University Press

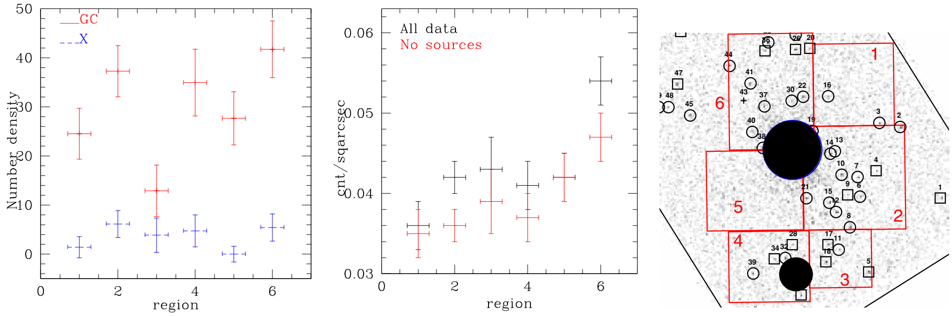


Figure 4. Distribution of the surface number density of GC candidates and of X-ray sources (Left) in the regions (shown on the Right) chosen to maximize the contrast in the X-ray sources. Central: photon surface brightness in 2-5 keV in the same area. Symbols indicate all data (black) and contribution of the (brighter) detected sources excluded (red: the lower symbol in each bin).

• The spatial correlation between the LMXB and the GC must be taken into account when studying the LMXB formation: all X-ray sources are concentrated in the same peculiar region of the galaxy, suggesting a strong link between the formations of "all" LMXB in GC.

• The spatial anisotropy of GC system of NGC 4261 may reflect a peculiar history of formation of this galaxy. Major mergers are thought to redistribute the original GC systems of the progenitor galaxies and trigger the formation of new ones in the center as well as along the tidal tails of the object arising from the merger. Whether this structure is the signature of such a phenomenon is unclear, given that all other optical parameters suggest a relaxed system. However, NGC 4261 could be an excellent target for further investigations, and in fact we are planning to follow this up with both improved data and a theoretical study with high-resolution simulations of galaxy mergers.

• Whether this is a unique system or whether this is the first discovered thanks to the X-ray image remains to be seen. Detailed X-ray data are available for only a limited number of nearby early type galaxies, so we could yet discover more examples of peculiar distributions of LMXB/GC in other, perhaps more distant systems.

References

Chiaberge, M., Gilli, R., Macchetto, F. D., Sparks, W. B., & Capetti, A., 2003, Ap.J. 582, 645

Colbert, J. W., Mulchaey, J. S., & Zabludoff, A. I., 2001, A.J. 121, 808

Garcia, A. M., 1993, A&A Suppl. 100, 47

Gavazzi, G., Bonfanti, C., Sanvito, G., Boselli, A., & Scodeggio, M., 2002, Ap.J. 576, 135

Gilfanov, M., 2004, MNRAS 349, 146

Giordano, L., Cortese, L., Trinchieri, G., Wolter, A., Colpi, M., Gavazzi, G., & Mayer, L. 2005 ApJ, in press (astro-ph/0508189)

Gliozzi, M., Sambruna, R. M., & Brandt, W. N., 2003, A&A 408, 949

Grimm, H. J., Gilfanov, M., & Sunyaev, R., 2003, MNRAS 339, 793

Kundu, A., Maccarone, T. J., & Zepf, S. E., 2002, Ap.J. 574, L5

Maccarone, T. J., Kundu, A., & Zepf, S. E., 2003, Ap.J. 586, 814

Nolthenius, R., 1993, Ap.J.Suppl. 85, 1

Sambruna, R. M., Gliozzi, M., Eracleous, M., Brandt, W. N., & Mushotzky, R., 2003, Ap. J. 586, L37

Schweizer, F. & Seitzer, P., 1992, A.J., 104, 1039

Silverman, B. W., 1986, Density estimation for statistics and data analysis, Monographs on Statistics and Applied Probability, London: Chapman and Hall, 1986

Zezas, A., Hernquist, L., Fabbiano, G., & Miller, J., 2003, Ap.J. 599, L73

https://doi.org/10.1017/S1743921306008222 Published online by Cambridge University Press

Discussion

KIM: Are GCs bimodal in their optical colours? If so, is there any difference between blue & red GCs in their spatial distributions?

TRINCHIERI: The colour distribution is such that both red and blue globular clusters are included, although they don't seem to show a clear bimodal distribution as other galaxies. Unfortunately colours are available for the HST field only (where there are few X-ray sources!) and the blending between the two populations does not allow us a clear cut between red and blue to do a very good comparison of the spatial distributions. But we will look again.