A deep Chandra look at the nearby, low L_B elliptical galaxy NGC821

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Abstract

NGC821, known to host a central massive black hole, has been observed with *Chandra* for 230 ksec, detecting 41 X-ray sources. For the low mass X-ray binaries (LMXBs), the fractions in the field and in globular clusters were determined, together with the X-ray luminosity function down to L(0.3-8 keV)~2x10^{37} erg s^{-1}. At the galactic center a weak source was detected for the first time; it is surrounded by three other sources, two of which are extended. Diffuse emission is detected out to a radius of 30", however there is no evidence for hot gas, and this emission comes mostly from unresolved LMXBs, with a possible minor contribution from other types of stellar sources. Hydrodynamical simulations specific for NGC821 show that the hot gas is driven out of the galaxy in a wind sustained by type Ia supernovae, but also that it is accreting towards the center from within a very small inner region.

NGC821: main properties

d=24.1 Mpc, E6, L_B=2 x 10^{10} $L_{B\odot}$

Isolated. Very regular optical isophotes (Bender et al. 1994).

Old (~12 Gyrs) and metal rich stellar population (Proctor et al. 2005).

Resolved (HST based) dynamical studies give M_{BH}= 8.5 x10^7 $M_\odot$ (Gebhardt et al. 2004).

No cold ISM or dust detected (Sarzi et al. 2006)

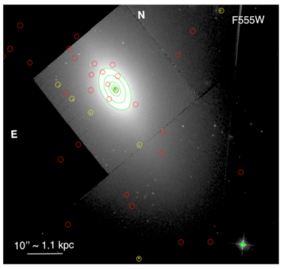


Figure 1:
***HST* WFPC2** image of NGC821, with the positions of the ***Chandra* ACIS-S** sources detected by *wavdetect* marked with red circles.
The six yellow circles show the **optical/X-ray coincidences** falling within the D25 ellipse (not including the nuclear source). *HST* isophotes for the central galactic region are also overlaid.

With the deep (230 ks) pointing at the sub-arcsecond resolution of ***Chandra* ACIS-S** we could establish the contribution of the different components of the X-ray emission:

- the population of low mass X-ray binaries (LMXBs)
- the hot gas
- the nucleus

The central galactic region in the X-rays

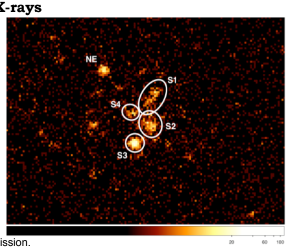


Figure 2:
0.3-6 keV image of central 40" x 25" [1"=117 pc].
S1-S4 detected for the first time (Pellegrini et al. 2007a, ApJ in press, astro-ph/0701639).
S2 is coincident with the optical **galactic center.**
No optical or IR source detected at the center; a 1.4 GHz source detected by the VLA (Pellegrini et al. 2007b, ApJ in press, astro-ph/0701642).

S3 is consistent with being pointlike, and is likely a LMXB.
S1, S2 and S4 are extended (e.g., semimajor x semiminor axes of S2 in Fig. 2 = 1.7"x1.5") :
WHAT ARE THEY ?
Their spectral shape is typical of LMXBs and their luminosities [L_X=(2-9)x10^{38} erg s^{-1}] are on the brightest end of the XLF of LMXBs (see Fig. 6).
They could be the superposition of few unresolved LMXBs, and possibly also of truly diffuse emission.
S1 resembles a jet-like feature (see also Pellegrini et al. 2007b).

X-ray properties of the nuclear source **S2** : Net counts: 246±16
Spectral model wabs(**pow**):
N_H < 0.5 10^{21} cm^{-2}
Γ = 1.49 $^{+0.14}_{-0.13}$
χ^2/dof = 11.5/9
L(0.3–8 keV) = **6.0 10^{38}** erg s^{-1}
L(2–10 keV) = 3.8 10^{38} erg s^{-1}

Pointlike emission within S2 (3σ upper limits):
L(0.3–8 keV) < 2.8 10^{38} erg s^{-1}

Pellegrini et al. 2007b study the nuclear emission properties and its possible origin.

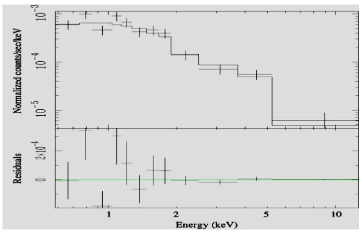


Figure 3: ACIS-S spectrum of S2

The point source population

We detected a significant portion of the LMXB population (see Pellegrini et al. 2007a).

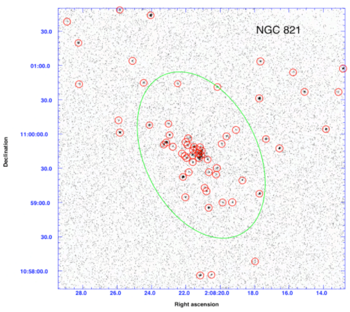


Figure 4:
ACIS-S field with detected sources and optical D25 ellipse overlayed.

104 sources detected within the ACIS-S3 CCD, 41 lie inside the D25 ellipse. Except for very minor contamination from interlopers and the sources in the central region discussed above, these sources are all pointlike and represent the LMXBs population (see Fabbiano 2006 for a review on X-ray binary populations of galaxies).

In agreement with previous spectral studies of LMXB populations (e.g., Kim et al. 1992; Irwin, Athey & Bregman 2003, Fabbiano 2006), most well-defined colors fall near a typical Γ=1.5-2.0 spectrum, with no intrinsic absorption.

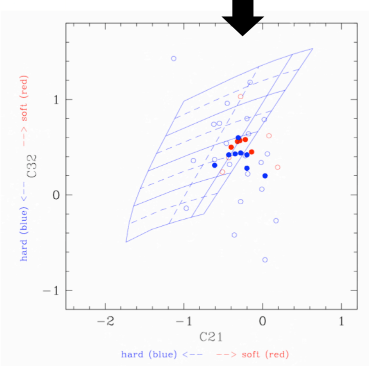


Figure 5:
X-ray colors of point sources (see Pellegrini et al. 2007a for the C32 and C21 definition).

The grid refers to power law spectra: from bottom to top, photon index Γ values are 0, 1, 2, 3, 4 ; from right to left, intrinsic N_H values are 10^{20}, 10^{21}, 5x10^{21} (dashed line), and 10^{22} cm^{-2}.

Red circles correspond to sources at R< 10",
blue circles to sources between R=10" and the D25 ellipse.

Filled circles are sources with net counts > 30,
open circles with net counts <30.

There is no clear evidence for supersoft sources.

Connection with Globular Clusters

With *HST* WFPC2 images, we investigated **possible associations of detected point sources with LMXBs belonging to the galactic field or to globular clusters** (GC).

The optical images cover a large fraction (~ 60%) of the D25 ellipse, and here Kundu & Whitmore (2001) identified 105 GC candidates at a 50% completeness limit of 24.1 V-mags. This list of GCs (kindly provided by A. Kundu) was cross-correlated with the X-ray source list: ***6 matches*** were found well within the 95% uncertainty radius of the X-ray position (see also Fig.1).

LMXBs are ***preferentially found in the brightest clusters*** (4 matches reside in the 5 brightest GCs), following a general trend already reported (e.g., Sarazin et al. 2003, Kim E. et al. 2006). The LMXBs of NGC821 also tend to be ***associated with the redder GCs***, in agreement with previous works (e.g., Kundu et al. 2007).

~ 30% of the LMXBs lie in GCs. From *Chandra* studies this fraction is known to increase with the GC specific frequency, or the morphological type (e.g., Sarazin et al. 2003), and goes from ~20% in S0s to 30-50% in Es (e.g., Fabbiano 2006 and refs. therein). The fraction estimated here for NGC821 is therefore close to what expected, given also its morphological type (E6).

The ***fraction of GCs that host a LMXB is ~ 6.6%,*** a value broadly consistent with what typically observed previously from Chandra studies (3-5%, Sarazin et al. 2003, Kim, E. et al. 2006), but somewhat higher, likely because of the larger depth of our X-ray observation compared to the previous analyses.

The X-ray Luminosity Function (XLF) of LMXBs

Figure 6: Cumulative **XLF** of LMXBs.
Black squares with error bar show the bias-corrected function; green circles are the uncorrected function.

The red histogram gives the best fit single power-law.

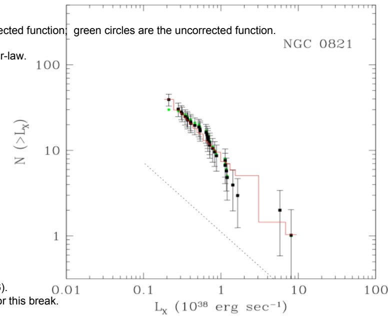
The dotted line shows the expected number of Cosmic X-ray background sources from the logN-logS relation of ChaMP plus CDF data (Kim et al. 2007).

The best fit of the differential XLF is:

$$\frac{dN}{dL_X} = k\left(\frac{L_X}{10^{38}\ \mathrm{erg/s}}\right)^{-\beta}$$

with β=2.0± 0.3, compatible with other power law fits of XLFs (e.g., Kim et al. 2006), and k=8.4$^{+3.1}_{-2.5}$

A low luminosity break was suggested to be a feature of LMXB populations (Gilfanov 2004), but is not observed in all cases (Kim et al. 2006).
For NGC821 there is no compelling evidence for this break.



Is there hot gas?

Estimating the amount of gaseous emission in NGC821 is important, because this hot gas could be a source of fuel for the nuclear MBH; also, the properties of the hot ISM give clues on the way the ISM evolves in this galaxy, and more in general in galaxies of similar optical luminosity (e.g., Pellegrini & Ciotti 1998, Sansom et al. 2006).

The adaptively smoothed image (Fig. 7) shows diffuse emission, roughly aligned with the galaxy major axis. However, this emission is not proof of the presence of a hot ISM, since an important contaminant in a low L_X/L_B galaxy like NGC821 is the undetected fraction of the LMXB population. Another contaminant is the collective emission of stellar sources such as coronae of late type main sequence stars, RS CVn systems and supersoft sources (first discussed for this type of galaxies in Pellegrini & Fabbiano 1994).

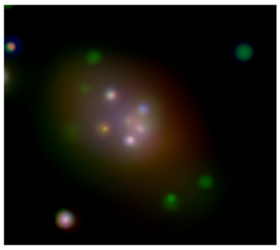


Figure 7:
Co-added smoothed "true-color" image of a central 55"x55" field.
The red, green and blue colors correspond to the 0.3-1 keV, 1-2 keV and 2-4 keV bands.
The diffuse emission follows the optical shape of the galaxy.

To **evaluate the possible presence of hot gas** we determined the spatial and spectral properties of the diffuse emission; then we compared:

1) the shape of the radial profiles observed for the diffuse emission, the resolved point sources and the stellar optical light (Figure 8);

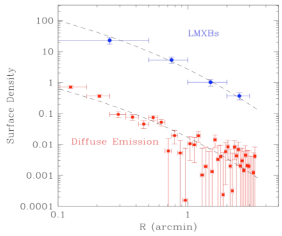
2) the radial profile of the soft emission contributed by LMXBs and the total observed soft profile (Figure 9);

3) the total luminosity of the diffuse emission and that expected from unresolved LMXBs, using the XLF derived for NGC821.

The expected cumulative contribution from other types of stellar sources to the diffuse emission (Pellegrini et al. 2007a) turned out to be very small (<~10%).

Figure 8:
Detected point sources in #/sq. arcmin
Diffuse emission in cnt/pix
Dashed line: R-band galactic profile

All three profiles are consistent with having the **same shape.**



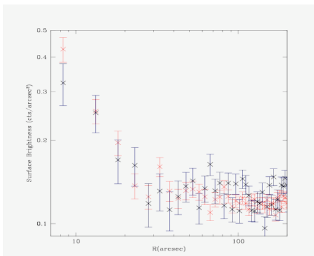


Figure 9:
Radial distribution of the diffuse 0.3-1.5 keV emission (black crosses) that is **implied** by the observed 1.5-6 keV emission, when assuming for it the spectral model of LMXBs.
Red crosses show the **observed** profile in the same 0.3-1.5 keV band. The flattening at large radii is due to field bkgd.

The observed 0.3-15 keV profile is consistent with coming from LMXBs.

In conclusion :

- the spectral analysis of projected and deprojected annuli does not require a soft thermal component at a statistically significant level.
- the similarity of the profiles in Figs. 8 and 9 provides support to (or at least is consistent with) the idea that also the diffuse emission mostly comes from undetected LMXBs.
- the spectral luminosity of the diffuse emission and the luminosity of unresolved LMXBs, derived integrating their XLF down to L(0.3-8 keV)=10^{37} erg/s, agree within the uncertainties.

The possible presence of **hot gas is severely constrained** [L(0.3-8 keV)<1.3x10^{38} erg/s from the spectral analysis].

However, an aging stellar population continuously returns gas to the hot ISM, via stellar mass losses (e.g., Ciotti et al. 1991). Numerical simulations of the ISM evolution for a galaxy model tailored on NGC821 show that the bulk of the gas is driven out in a wind for the whole galaxy lifetime, due to the heating provided by type Ia supernovae. The simulations also show that the gas is **accreting towards the center from within a very small inner region** (of few tens of pc radius), with a density below the detection limit.

This gas flow pattern is expected to be common in low L_B ellipticals, due to their cuspy central mass distribution.

Gaseous accretion alone at the rates given by the simulations cannot have formed the central MBH of NGC821.

see Pellegrini et al. 2007a (astro-ph/0701639) for more details and full references.