Classification of X-ray sources in the direction of M 31

Vasilopoulos, G.[1] ; Hatzidimitriou, D.[1] ; Pietsch, W.[2] ; Stiele, H.[3] ;Williams B.[4] ; XMM-Newton, M 31 Large Program Collaboration

[1]Department of Physics, University of Athens, Athens, Greece ; [2]Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany ; [3]INAF Osservatorio Astronomico di Brera, Milano, Italy ; [4]Department of Astronomy, University of Washington, Seattle, USA

Introduction

✓M 31 is the nearest spiral galaxy to our own (780 kpc), and thanks to its moderate galactic foreground absorption and favorable inclination (78°), it is an ideal target for a detailed X-ray inventory of an archetypal low-star formation rate galaxy.

✓The XMM-Newton Large Project for M 31 gave us an abundant sample of X-ray sources (1897)(1). Hardness ratios, X-ray variability and correlations with catalogs in other wavelengths (optical, radio) have been used in an attempt to classify them. However, about 65% are only identified as hard sources, that could be X-ray binaries(XRBs), Crab-like supernovae (SN) & active galactic nuclei (AGN).

✓The high mass XRB (HMXB) population in M 31 remains largely elusive, with only a small number of supergiant HMXBs identified with optical spectroscopy(2). The occurrence of HMXBs, of the Be type in particular, is a sensitive star-formation indicator. No Be-XRB has been discovered in M 31 to date.

✓Low mass XRBs (LMXBs) are associated with old populations, including globular clusters (GIC).

Our goal is to refine the classification criteria using results from optical spectroscopy in order to construct lists of candidate HMXBs, LMXBs and AGN.

The XMM-Newton M 31 Large Project

XMM-Newton EPIC observations of the largest Local Group spiral galaxy **M 31**, taken between June 2006 and February 2008, together with archival observations(3) from June 2000 to July 2004 yielded a total of **1897 X-ray sources** (0.2-12.0 keV) covering (for the first time) the entire D25 ellipse of M 31, down to a limiting luminosity of ~10^{35} erg/s in the 0.2-4.5 keV band(1).

HMXBs

- **High Mass X-ray binaries** are expected to be classified as **hard** sources.
- **Be-XRBs** are expected to have early B spectral types (**blue stars**) and H-alpha emission.
- No **HMXB** has been confirmed optically yet in **M 31.**
- In the SMC ~100 HMXBs have been found, most of them of Be type. A combination of optical colors and X-ray hardness ratios (HR) are used to identify candidate Be-XRBs in M 31. Fig. 1 & 2

AGN

Candidates based on optical and X-ray criteria derived from a sample of spectroscopically confirmed AGN in our field (*9 Seyfert 1 galaxies* with redshifts z~0.7-1.6, and V<21)(2).

Classification Criteria

HMXBs / Be-XRBs
- •X-ray: HR3>-0.1, HR4>-0.7 Fig. 1
- •Optical: V=[20,22], (B-V)=[-0.25,0.2](4) Fig.2

AGN
- •X-ray: HR3<-0.1, HR4<-0.2 Fig. 1
- •Optical: V<21, (B-V)>0.25 Fig. 2

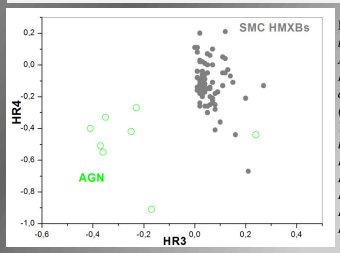

Fig. 1: *X-Ray criteria used for distinguishing AGN and HMXBs . Hardness ration HR_i is defined as $(R_{i+1} - R_i)/(R_{i+1} + R_i)$ Where R_i are count rates in energy bands 1 to 5 Band 1 = 0.2 − 0.5keV, Band 2 = 0.5 − 1.0keV, Band 3 = 1.0 − 2.0keV, Band 4 = 2.0 − 4.5keV, Band 5 = 4.5 − 12keV*

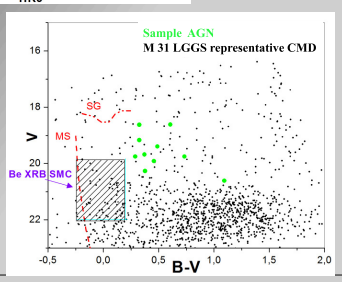

Fig. 2: *Optical criteria used for distinguishing AGN and HMXBs. Black points represent M 31 colour magnitude diagram (CMD)*

Results

~20 BeXRB Candidates with some showing enhanced H-alpha emission(5),(6) (example shown in figures 4)

~49 AGN Candidates Fig. 3

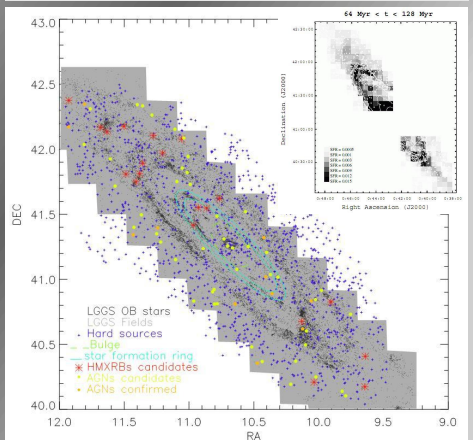

Fig. 3: Distribution of BeXRB and AGN candidates overlaid on map of OB stars from LGGS(4) . On the top right corner we show the locus of populations with ages 64 to 128 Myr(7), which is close to the period of expected maximum BeXRBs occurrence(8)(9)

A Be-XRB candidate (source 235) with enhanced H-alpha

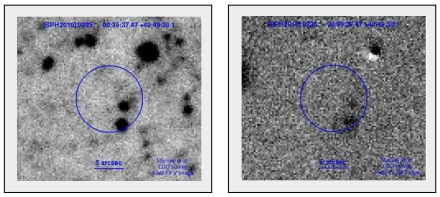

Fig. 4: (left)LGGS V image(6). (right) LGGS H-alpha image(6). Both objects within the XMM error circle satisfy the Be-XRB classification criteria and show enhanced H-alpha emission

LMXBs

- **XRBs detection based on variability**(1). Method requires multiple observations and it cannot be used in the entire field of the galaxy. Analysis resulted in 10 confirmed XRBs and 26 candidates. Their distribution is shown in Fig. 5. Most of these are likely LMXBs as they are not associated with young stars
- **Association of X-ray sources with globular clusters** (GICs) using the revised Bologna Catalog (V.4 December 2009)(10). We found 42 confirmed old globular clusters correlated with X-ray sources i.e. about 11.5% of the old clusters, and 6.4% of all the confirmed clusters in M 31.
- Inspection of the dynamical characteristics(11) of the clusters confirmed(12) that LMXBs are preferentially formed within more massive clusters or with higher collision rates. Kolmogorov-Smirnov tests confirm this hypothesis with probability over 99.9%.

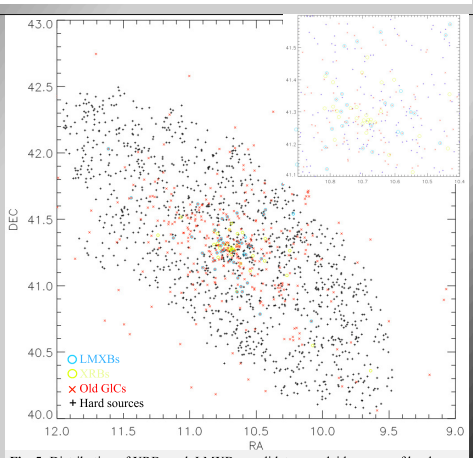

Fig. 5: Distribution of XRBs and LMXBs candidates overlaid on map of hard sources and old globular clusters

X-ray cumulative luminosity functions

- •Sources associated with GICs show a characteristic break at log(L_x)~37.2 Fig. 6
- •X-ray cumulative luminosity functions (XLF) of XRBs and GIC sources are similar in higher fluxes suggesting that most XRBs* should be LMXBs
- •Similar XLF of hard sources with no optical counterparts within the bulge indicates that several of these sources may also be LMXBs.
- •Incompleteness and different observing times prevent us from comparing XLFs using sources from the entire M 31 field.

*different completeness at low fluxes due to difficulty in identifying faint variable sources

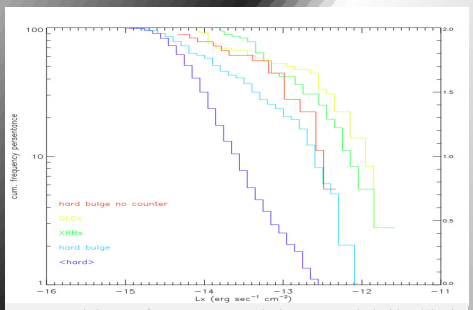

Fig. 6: Cumulative XLF for XRBs & LMXBs in the M 31. Marked with red line is the population within the bulge with no optical counterpart

References

(1) Stiele et al. 2011, A&A submitted
(2) Hatzidimitriou et al. 2011, in preparation
(3) Pietsch et al.2005, A&A, 434, 483
(4) Massey et al. 2006, AJ, 131, 2478
(5) Massey et al. 2007 AJ,134, 2474
(6) ftp://ftp.lowell.edu/pub/massey/lgsurvey/datarelease/M31/
(7) Williams, 2003, AJ, 126, 1312
(8) McSwain & Gies ,2005, ApJS, 161, 118
(9) Antoniou et al., 2010, ApJ Let, 716, L140
(10) http://www.bo.astro.it/M31/
(11) Barmby et al. 2007, AJ, 133, 2764
(12) Peacock et al. 2010 MNRAS, 407,2611

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