Recent Discoveries of Ultraluminous X-ray Sources in M31

-Data suggest LMXBs as the underlying source population-

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ULXs in general

- Off nuclear X-ray transients.
- Luminosity greater than 10^{39} erg/s Eddington luminosity of 10 $M_{\odot}$ black hole.
- Occurrence rate ~ "one" per galaxy
- Star forming host galaxies.

Nature of underlying sources not clear

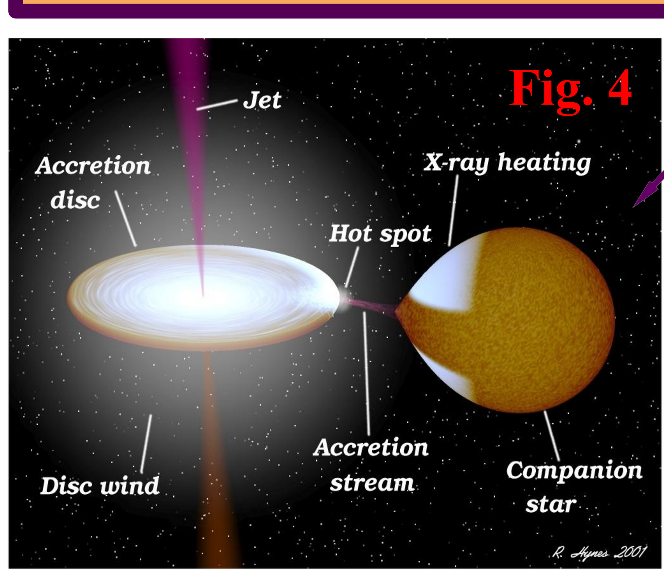
Possible scenarios

- Powered by an intermediate mass black hole (10^2 – 10^4 $M_{\odot}$) (IMBH) accreting at sub-Eddington rate. (Fabian, A.C. et al.1993, MNRAS, 263, L51)

•*But few likely candidates, e.g. ESO 243-49, M82-X1 , Cartwheel N10 (L_X > 10^{41} erg/s), (Sutton, A.D. et al. 2012, arxiv-1203-4100v1).*

- Powered by a stellar mass black hole (StMBH), accreting at super-Eddington rate. (Begelman, M.C. 2002, ApJ, 568, L97)

•*The donor mostly identified as blue optical counterpart, suggestive of ULXs association with the young, high-mass stellar population i.e. HMXBs (High Mass X-ray binaries), **but recent observation of a ULX in M83 and statistical study suggests an alternative.***



A schematic representation of an X-ray binary system

ULXs association with Low Mass X-ray Binaries

Observational evidence

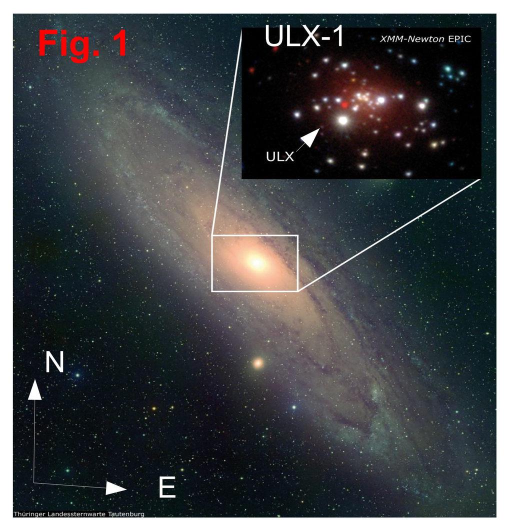
(Soria, R et al. 2012, ApJ, 750, 152S)

- Recently discovered ULX , Lx ~10^{39} erg/s in M83.
- Blue counterpart identified with HST in 2011, but no such object was present in 2009, prior to outburst.
  =>Donor star is not a massive star.
- Blue color of the donor due to optical emission or reprocessed radiation from the X-ray source.

=> ULXs might be associated with low mass stellar population or Low Mass X-ray Binaries (LXMBs). See Fig. 4

Abstract

The presence of members of the very rare class of ultraluminous X-ray sources (ULXs) was only recently established for M31 with CXO M31 J004253.1+411422 and XMMU J004243.6+412519, discovered by Chandra-HRC-I on December 17, 2009 and XMM-Newton on January 26, 2012, respectively. Both sources exhibit similar luminosities (> 10^{39} erg/s) and spectra that are best fit by a combination of a thermal (kT ~ 1keV) and a non-thermal powerlaw component (photon index in the range 2-3). Modeling indicates that this emission originates predominantly from the inner disk of a stellar mass black hole. We discuss these recent discoveries, and consider their implications in the context of the global X-ray source populations of M31.



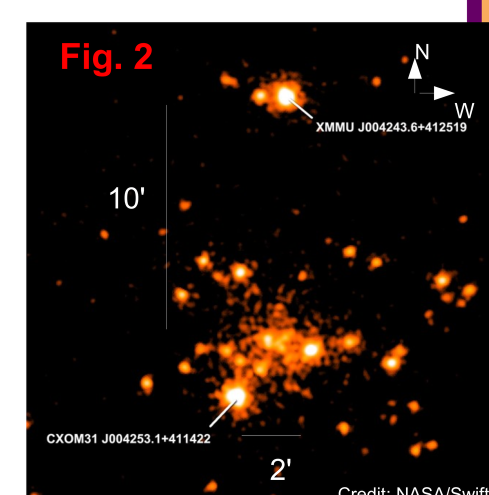
Our M31 Model

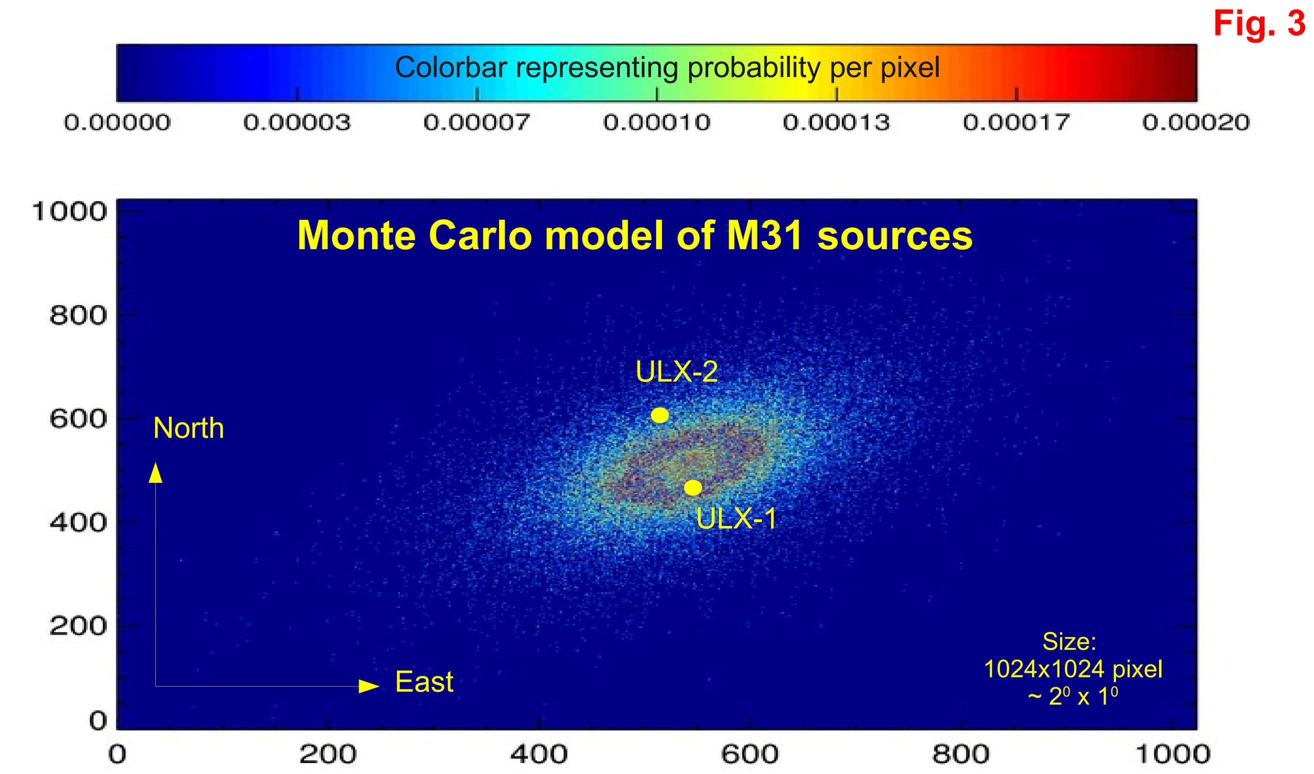
- To place the recent ULX discoveries in the context of their underlying source population, we generate a Monte Carlo model of a single source population following a double exponential profile as shown below:

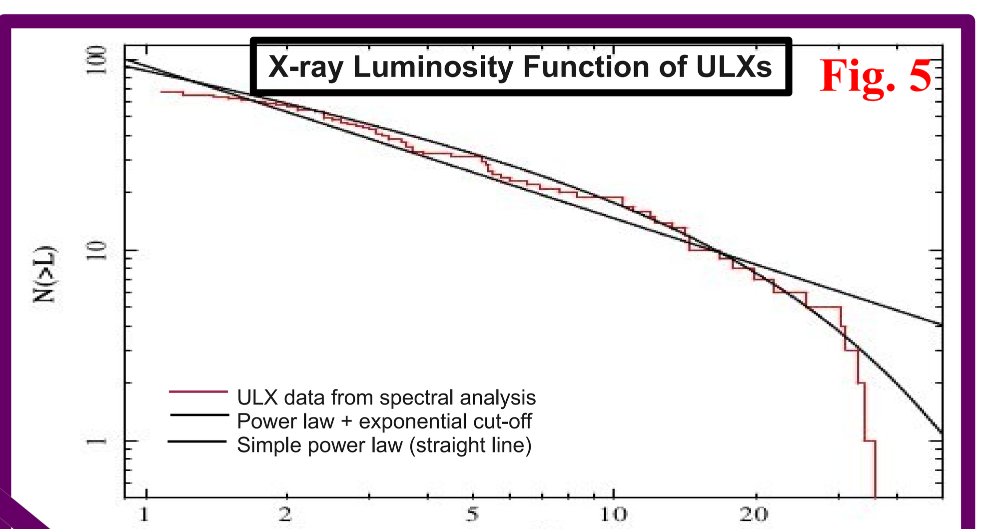
$$\exp(-r/R_h)\exp(-z/H),$$

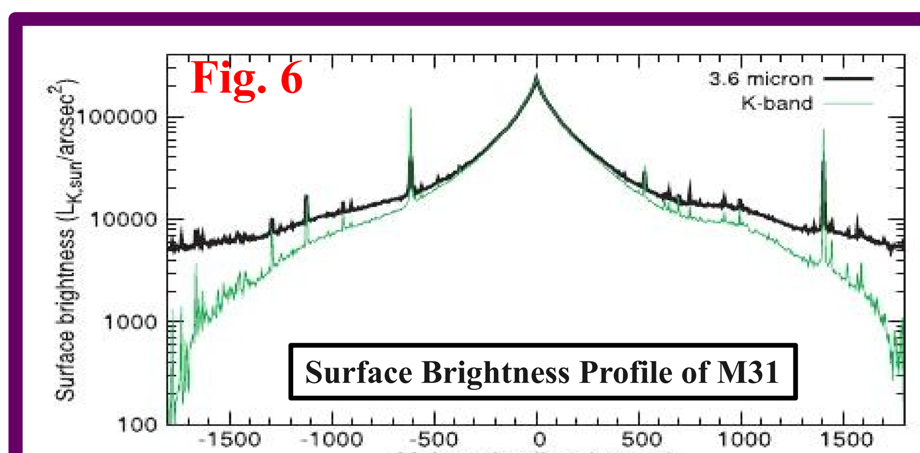
R_h =2kpc and H=100pc are scale length and scale height, respectively.

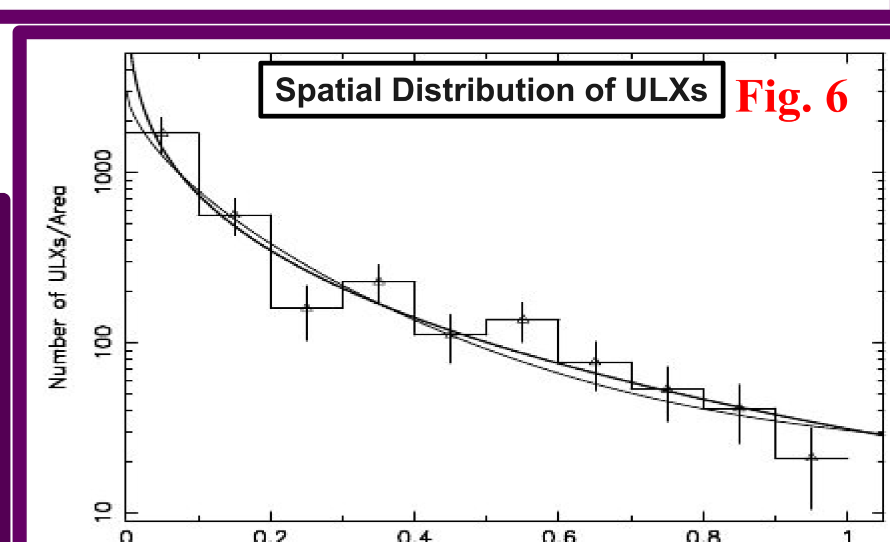
- This spatial source distribution, when projected on the sky at a distance of 770 kpc yields the probability (per pixel) shown in Fig. 3. The observed positions of the two ULXs are consistent with this probability map.











Statistical arguments

(Swartz et al. 2011, ApJ, 741, 49S)

- ULXs with Lx <10^{41} erg/s can be explained by extrapolation of X-ray luminosity function of LMXBs. See Fig. 5
- The ULX spatial distribution, as shown in Fig. 6, resembles the *De Vaucouleurs law* => ULXs trace star light
- Fig. 7 represents that K-band surface brightness profile of M31 which in turn, traces the unresolved X-ray emission.
  => We model the LMXB X-ray source population analog to the stellar population.

(Bodgán et al.,2010, MNRAS.408.218)

Recent ULX discoveries in M31

- **ULX-1 : CXOM31 J004253.1+411422 (Fig. 1 and 2)**
- Discovered by *Chandra* on 12/17/2009 in a monitoring program to resolve super-soft sources in M31. (Kaur et al. 2012, A&A, 538A, 49K ; Middleton, M.J. , 2012MNRAS.420.2969M)
- Follow up X-ray observations using *Swift* and XMM-Newton.
- **Detailed spectral analysis and results below.**

ULX-2 : XMMU J004243.6+412519 (Fig. 2)

- Discovered by XMM-Newton on 01/15/2012 in the above mentioned monitoring program. (M. Henze et al., Atel # 3890)

Spectral fitting using XSPEC

- **Model** : Powerlaw + Multicolored blackbody disk
- **Absorption model** : Tuebingen-Boulder ISM model (TBABS) for M31 and Milky Way.

•**Powerlaw (PO)** : "*Non-thermal*"

$$F(E) = KE^{-\beta}$$

K = normalization constant (photons keV^{-1} cm^{-2} s^{-1}) at 1keV
β = dimensionless photon index

•**Multicolored disk (DISKBB)** : "*Thermal*"
The bolometric luminosity, (Lbol), innermost disk temperature (Tin), mass of black hole (M), and innermostdisk radius (Rin) are related by equations provided below assuming flat and optically thick disk:

$$L_{bol} = 7.2\times10^{38}\left(\frac{\xi}{0.41}\right)^{-2}\left(\frac{\kappa}{1.7}\right)^{-4}\alpha^2\left(\frac{M}{10M_{\Theta}}\right)^2\left(\frac{T_{in}}{keV}\right)^4 erg/s$$

Mass determination of the underlying source in ULX

$$R_{in} = 8.86\alpha\left(\frac{M}{M_{\Theta}}\right)km$$

All parameters as defined in thepaper given below: $\alpha=1$, $\xi=0.41$, $\kappa=1.7$,

(Makishima, K. et al. 2000, ApJ, 535, 632)

Results from spectral fitting XMM data

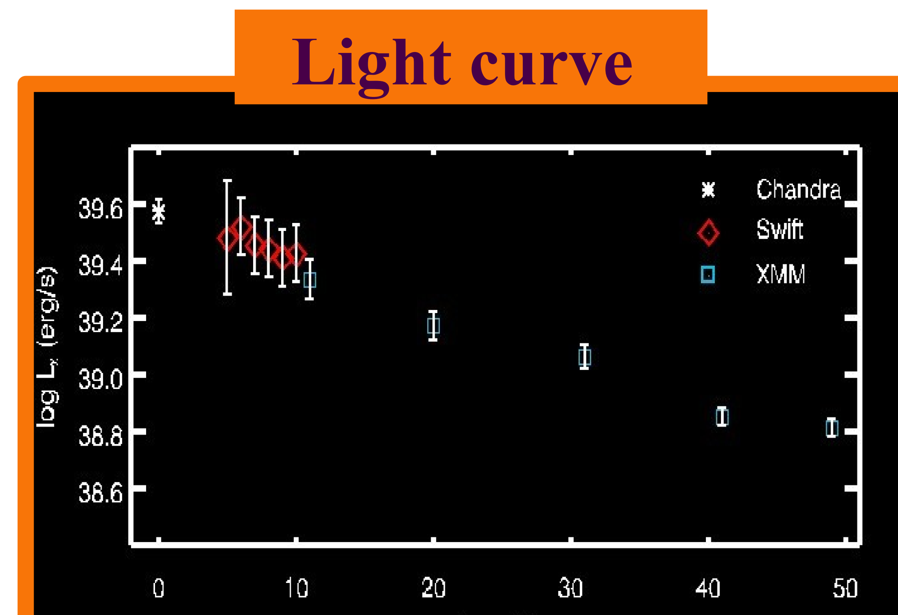
Obs ID	NH[a] (10 20 cm-3)	kT[b] (keV)	Γ[c]	R_{in}[d]√cos(i) (km)	χ2 /d.o.f
0600660201	5.1±1.1	1.070±0.010	2.59±0.16	52.90±0.01	1318.87/1165
0600660301	7.1±1.2	0.993±0.016	2.58±0.13	58.89±0.02	963.62/991
0600660401	9.1±1.2	0.913±0.013	2.81±0.14	57.32±0.02	1046.74/953
0600660501	5.3±1.0	0.815±0.014	2.51±0.12	61.57±0.02	962.61/938
0600660601	6.5±1.6	0.769±0.013	2.70±0.13	64.18±0.03	830.66/821

[a]Absorption column density from M 31. [b]Temperature of inner disc from DISKBB. [c]The photon index from POWERLAW. [d]The innermost radius of multicolored blackbody disk and i is the inclination angle.

Conclusions

- Our Analysis of ULX-1 implies:
  (assuming the case of a non-spinning black hole) a black hole of mass ~ 13 M_{Θ}.
- The observed exponential decline of ULX-1 (~ 34 days timescale) is consistent with galactic X-ray novae (Chen, W. et al. 1997, ApJ, 491, 312) i.e. XRBs.
- The positions of both ULXs are consistent with the hypothesis of an underlying LMXB population.

Light curve



Temporal evolution of ULX in M31 with decay timescale of ~ 34 days resembling exponential decay timescale of galactic X-ray novae