The Lack of Ultraluminous X-ray Sources (ULXs) in Early-type Galaxies

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Ultraluminous X-ray Sources (ULXs)

Discovered in the *Einstein* era (Fabbiano 1989). Have X-ray luminosities of $10^{39} - 10^{41}$ ergs s$^{-1}$. NOT located in the nucleus of the host galaxy. Variability studies have shown that most ULXs are composed of some type of accreting compact object.

$$L_{\text{Eddington}} = \frac{4\pi c G M m_p}{\sigma_T} = 1.3 \times 10^{38} \frac{M}{M_{\odot}} \text{ ergs s}^{-1}$$

For a $1.4 \, M_{\odot}$ neutron star, $L_{\text{Eddington}} = 1.8 \times 10^{38}$ ergs s$^{-1}$
For a $15 \, M_{\odot}$ black hole, $L_{\text{Eddington}} = \sim 2 \times 10^{39}$ ergs s$^{-1}$

*How are X-ray luminosities of up to $10^{41}$ ergs s$^{-1}$ achieved?*
Possible Explanations For ULXs

1) Intermediate mass black holes (IMBHs):
   - a $50-1000 \, M_{\text{sun}}$ black hole accreting near its Eddington limit (Colbert & Mushotzky 1999)
   - would represent the “missing link” between stellar mass black holes and supermassive black holes
   - difficult to create a black hole of this mass

2) Beamed or anisotropic X-ray emission from a stellar mass black hole:
   - thermal-timescale mass transfer onto a stellar mass black hole (King et al. 2001)
   - requires an intermediate-to-high mass donor star
   - difficult to explain ULXs in old stellar populations
The Chandra Sample and Analysis

27 galaxies observed with the Chandra ACIS-S chip (Es and S0s).

Only galaxies within 35 Mpc were considered so that >10^{39} ergs s^{-1} sources contained at least 40 counts to avoid incompleteness.

Γ = 2.0 power law model used to convert counts to energy flux.

All X-ray luminosities computed in the 0.3-10 keV energy range.

The position of each > 10^{39} ergs s^{-1} source was noted (e.g., between 0-1 effective radii, 1-2 effective radii…)
NGC4697 - Chandra ACIS-S
Luminosity Function of $>10^{39}$ ergs s$^{-1}$ Sources For All 27 Galaxies
Expected Number of Unrelated Foreground/Background Sources

Use ROSAT HRI Log $N$ vs. Log $S_X$ from Hasinger et al. (1998):

\[ N(>S_X) = 110.0 \ S_X^{-1.94} \]
\[ = 238.1 \ S_X^{-2.72} \]
\[ = 91.0 \ S_X^{-2.3} \]

$S_X < 2.66 \times 10^{-14}$ ergs s$^{-1}$ cm$^{-2}$

$10^{-13} < S_X < 2.66 \times 10^{-14}$ ergs s$^{-1}$ cm$^{-2}$

$S_X > 10^{-13}$ ergs s$^{-1}$ cm$^{-2}$

Number of Sources

Expected

66.5

23.2

1-2 $\times 10^{39}$ ergs s$^{-1}$

> 2 $\times 10^{39}$ erg s$^{-1}$
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Number of Sources

<table>
<thead>
<tr>
<th>Expected</th>
<th>Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.5</td>
<td>80</td>
</tr>
<tr>
<td>23.2</td>
<td>29</td>
</tr>
</tbody>
</table>

$1-2 \times 10^{39} \text{ ergs s}^{-1} \quad > 2 \times 10^{39} \text{ erg s}^{-1}$
Radial profile of $1 - 2 \times 10^{39}$ ergs s$^{-1}$ sources, normalized by area.
Radial profile of $1-2 \times 10^{39} \text{ ergs s}^{-1}$ sources, normalized by area.

Radial profile of $> 2 \times 10^{39} \text{ ergs s}^{-1}$ sources, normalized by area.
Colbert and Ptak (2002) found 87 ULX candidates within 15 early-type and 39 late-type galaxies with the ROSAT HRI. Some overlap with our sample, and in general extended to larger radii than our sample (out to twice the $R_{25}$ contour).

Assumed a $\Gamma = 1.7$ spectral model, and quoted 2-10 keV X-ray luminosities

$$L_X(2-10 \text{ keV}) = 0.5 \times L_X(0.3-10 \text{ keV})$$

Lower limit of Colbert & Ptak (2002) catalog:

$$L_X(0.3-10 \text{ keV}) = 2 \times 10^{39} \text{ ergs s}^{-1},$$
so we expect their spatial distribution to be consistent with being randomly distributed for ULXs in early-type galaxies.
Spatial Distribution: Early- vs. Late-Type

Colbert & Ptak (2002) ULXs were divided into 4 radial bins:

<table>
<thead>
<tr>
<th>Radial Bin</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>$0.0-0.5 R_{25}$</td>
<td>1</td>
</tr>
<tr>
<td>$0.5-1.0 R_{25}$</td>
<td>3</td>
</tr>
<tr>
<td>$1.0-1.5 R_{25}$</td>
<td>5</td>
</tr>
<tr>
<td>$1.5-2.0 R_{25}$</td>
<td>7</td>
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**Spatial Distribution: Early- vs. Late-Type**

Colbert & Ptak (2002) ULXs were divided into 4 radial bins:

<table>
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<tr>
<th>Radial Bin</th>
<th>Random Distribution</th>
<th>Galaxies with T-type &lt; -2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5 $R_{25}$</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>0.5-1.0 $R_{25}$</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1.0-1.5 $R_{25}$</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>1.5-2.0 $R_{25}$</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>
### Spatial Distribution: Early- vs. Late-Type

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<tr>
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<th>0-0.5 $R_{25}$</th>
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<td>17</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
Two ULXs in Globular Clusters of NGC1399

Two $L_X > 2 \times 10^{39}$ ergs s$^{-1}$ sources were found within globular clusters of NGC1399 (Angelini et al. 2001).

**Source 1:** $L_X = 2.3 \times 10^{39}$ ergs s$^{-1}$ (for $d = 20$ Mpc)

**Source 2:** $L_X = 4.7 \times 10^{39}$ ergs s$^{-1}$

Explanations:

1) Globular cluster is a miss-identified background AGN.
2) Globular clusters are capable of hosting ULXs (although very rarely).
Propose a “Standard” Definition for a ULX

Various studies have defined ULXs differently, using different luminosity thresholds and different energy bands.

X-ray sources that have X-ray luminosities of $1-2 \times 10^{39}$ ergs s$^{-1}$ aren’t really “ultraluminous”, as they can be adequately explained by accretion onto a $\sim 10-20 \ M_{\text{sun}}$ black hole.

$2 \times 10^{39}$ ergs s$^{-1}$ seems to provide a good break between ULXs and normal X-ray binaries:
- more exotic explanation required (IMBH or beaming)
- more luminous sources lacking in old stellar populations

A ULX has $L_X(0.3-10 \text{ keV}) > 2 \times 10^{39}$ ergs s$^{-1}$
Summary

1) A sample of 27 galaxies observed with Chandra has revealed that X-ray sources more luminous than $2 \times 10^{39}$ erg s$^{-1}$ are absent from early-type galaxies, or at least very rare.

2) Both the number and spatial distribution of X-ray sources with X-ray fluxes corresponding to luminosities $> 2 \times 10^{39}$ ergs s$^{-1}$ are consistent with what is expected from a random distribution (not the case for spiral galaxies).

3) Propose that ULXs be defined as non-nuclear X-ray sources having $L_X (0.3-10$ keV) $> 2 \times 10^{39}$ ergs s$^{-1}$.