The demographics of ultraluminous X-ray sources

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Are ULXs in star-forming regions?
Are there ULXs in dwarf galaxies?
Are there ULXs in galaxy halos?
Is there an upper limit to ULX luminosity?
A Complete Sample of ULX Host Galaxies

- $D < 15$ Mpc
- All UGC galaxies with $m_p < 14.5$
  - $>1'$ on first POSS plates
  - North of B1950 $\delta = -2.5$
- And above IRAS completeness limit: $f_{\text{FIR}} > 1.5$ Jy

Result is a volume-limited sample of 140 galaxies:

- 85 Archival: 8 XMM-Newton, 8 ROSAT, rest CXO
- 55 “new” Chandra snapshots (c. 2006)
- 112 ULX candidates (45 new) in 56 (26) galaxies
A Complete Sample of ULX Host Galaxies

RC3 (deVaucouleurs+ 1991) Complete Sample
A Complete Sample of ULX Host Galaxies

Catalog of Nearby Galaxies (Karachentsev+ 2004)

Complete Sample
Are ULXs within Star-forming Regions?

- ULXs correlate with galaxy-wide (global) star-formation rate (Grimm+2003, Swartz+2004, Liu+2006)
- What is the association to the local stellar populations?
  - In particular, HII regions powered by young, $t<10$ Myr, stars with M>$20M_\odot$
  - Dense young clusters (sites of massive star mergers; Portegies Zwart+2004)
Are ULXs within Star-forming Regions?

M101 Scd  
M81 Sab

SDSS g,r,i composites  
58/140 galaxies in DR6 footprint & \(i < 65^\circ\)
Are ULXs within Star-forming Regions?

- Divide galaxies into 100x100 pc$^2$ regions
- Determine SDSS colors of each region
- Compare to colors of known HII regions
- Which regions are younger (bluer) than HII regions?
- Are ULX regions bluer than HII regions?
Are ULXs within Star-forming Regions?

SDSS $u$-$g$

492 HII regions
(Petit+ 1988)

(~12000 regions total)

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Are ULXs within Star-forming Regions?

Fisher’s Discriminant:

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\[ F > 0.37 - 0.18(u-g) - 0.49(r-i) \]

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Swartz+ 2009
Are ULXs within Star-forming Regions?

YES

- 60% (21/35) of ULXs in optically-bright regions are in regions blueward of typical HII regions;
- companion star ages <10 Myr, 15-20 $M_\odot$ OB stars
- (only 32% of all regions are star-forming; 3$\sigma$)
- Many in crowded SFRs but no ULXs found in SSCs
- 80% (8/10) of ULXs with $L_x > 3 \times 10^{39}$ erg/s are in faint or red regions
- (suggests brighter ULXs are 10-20 Myr old systems)

Swartz+ 2009
Are there ULXs in dwarf galaxies?

- Low $\phi_g$, high $f_{\text{gas}}$ (Geha+2006), low Z (Lee+2006),
  low $M_{\text{wind}}$, high MBH (Heger+2003)

- Low shear, high mass molecular clouds, samples high end of IMF (Billet+2002)

- Cold massive clusters, protostar mergers, top-heavy IMF (Peretto+2007)
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Swartz+ 2008
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Swartz+ 2008
Are there ULXs in dwarf galaxies?

YES

Number of ULXs/mass increases with decreasing galaxy mass

But the dwarfs have higher SFR/mass than the giants

\( \frac{N_{ULX}}{SFR} \) independent of galaxy mass

- Still rare: only 5 ULXs in 118 dwarfs
- None in galaxies \(<3 \times 10^8 \, M_\odot\)
- Of order 1 ULX per \(10^{10} \, M_\odot\)
Are there ULXs in galaxy halos?

Among the promising IMBH candidates:

- Pop III stars leave massive remnants and are distributed throughout halo \( (\text{Madau}&\text{Rees 2001, Islam+ 2004ab}) \)

- BH coalescence in massive star clusters including Globulars \( (\text{Miller}&\text{Hamilton 2002, Kawakatu}&\text{Umemura 2005, Portegies Zwart+2004}) \)

- Stripped cores of satellite galaxies might contain IMBHs \( (\text{King}&\text{Dehnen 2005}) \)
Wide-field Infrared Survey Explorer
Are there ULXs in galaxy halos?

All X-ray sources

ULXs

Swartz+ 2004
Are there ULXs in galaxy halos?

CDF bg prediction (Rosati+ 2004)

Swartz+ 2004
Are there ULXs in galaxy halos?

larger FOV with ROSAT

• 87 ULX candidates
• 41 beyond D$_{25}$

(Colbert & Ptak 2002)
Are there ULXs in galaxy halos?

Swartz 2006
Are there ULXs in galaxy halos?

All 21 with spectroscopic redshifts are background

(Lopez-Corredoira & Gutierrez 2006)
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\[(F_x/F_0) \sim 1\]
Are there ULXs in galaxy halos?

- log(Fx/Fo) ~ 0+/−1 (AGN-like)
- 21 of 21 w/ redshift are background ⇒ 95% probability that >90% of all 41 are background (for bimodal distribution of backgrounds+ULXs)
- uniform spatial distribution like background sources

NO ULXs (or, rarely) beyond D_{25}

- Pop III remnants are not accreting; if so, then would also be UV & optically bright
- Globular Cluster sources are consistent with high Lx end of LMXB
- Stripped cores of satellite galaxies are rare
Is there an Upper Limit to ULX Luminosity?

- Eddington Limit is still a good first estimate of $M_{\text{BH}}$
Is there an Upper Limit to ULX Luminosity?

Luminosity Function normalized to unit SFR

(Grimm+ 2003)
Is there an Upper Limit to ULX Luminosity?

Swartz+ 2004
Is there an Upper Limit to ULX Luminosity?

Complete sample of ULX host galaxies:

Power law & exponential cut-off power law acceptable:

\[ \text{slope} = 1.89^{+0.21}_{-0.17} \]

cutoff $\approx 65 \times 10^{39}$
Is there an Upper Limit to ULX Luminosity?

YES

or, maybe, NO