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?

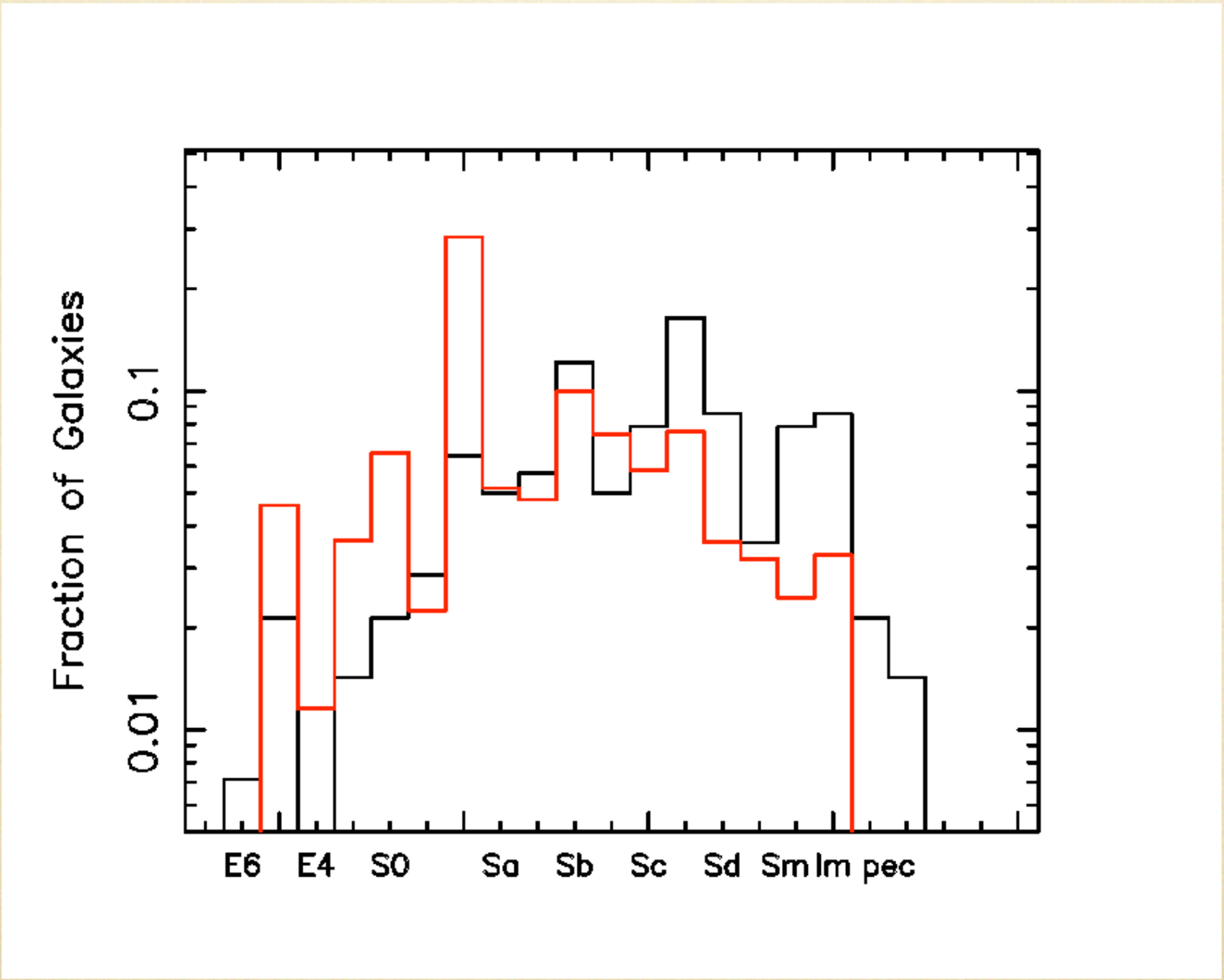
A Complete Sample of ULX Host Galaxies

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

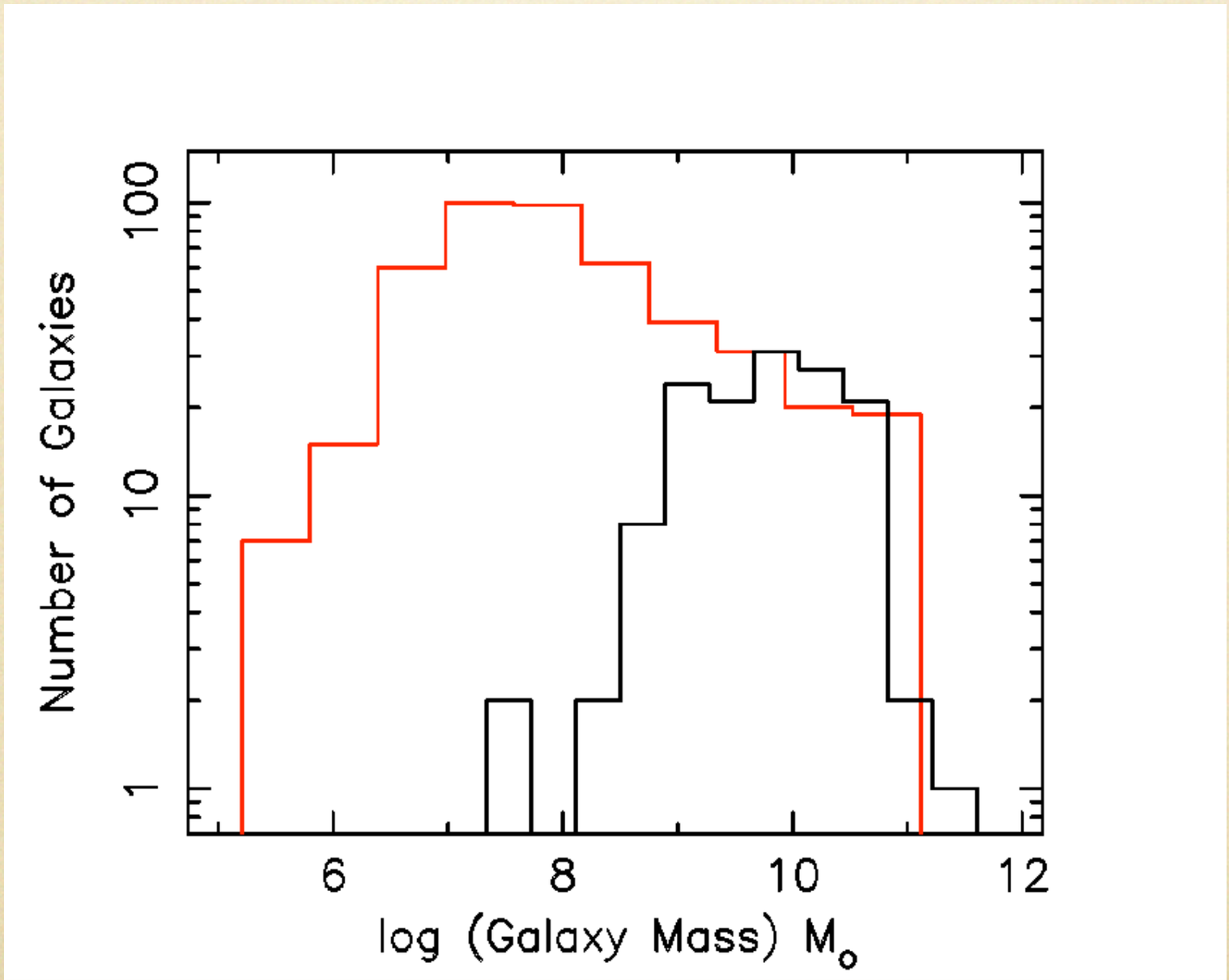
A Complete Sample of ULX Host Galaxies



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>20$M_{\odot}$
- Dense young clusters (sites of massive star mergers; **Portegies Zwart+2004)**

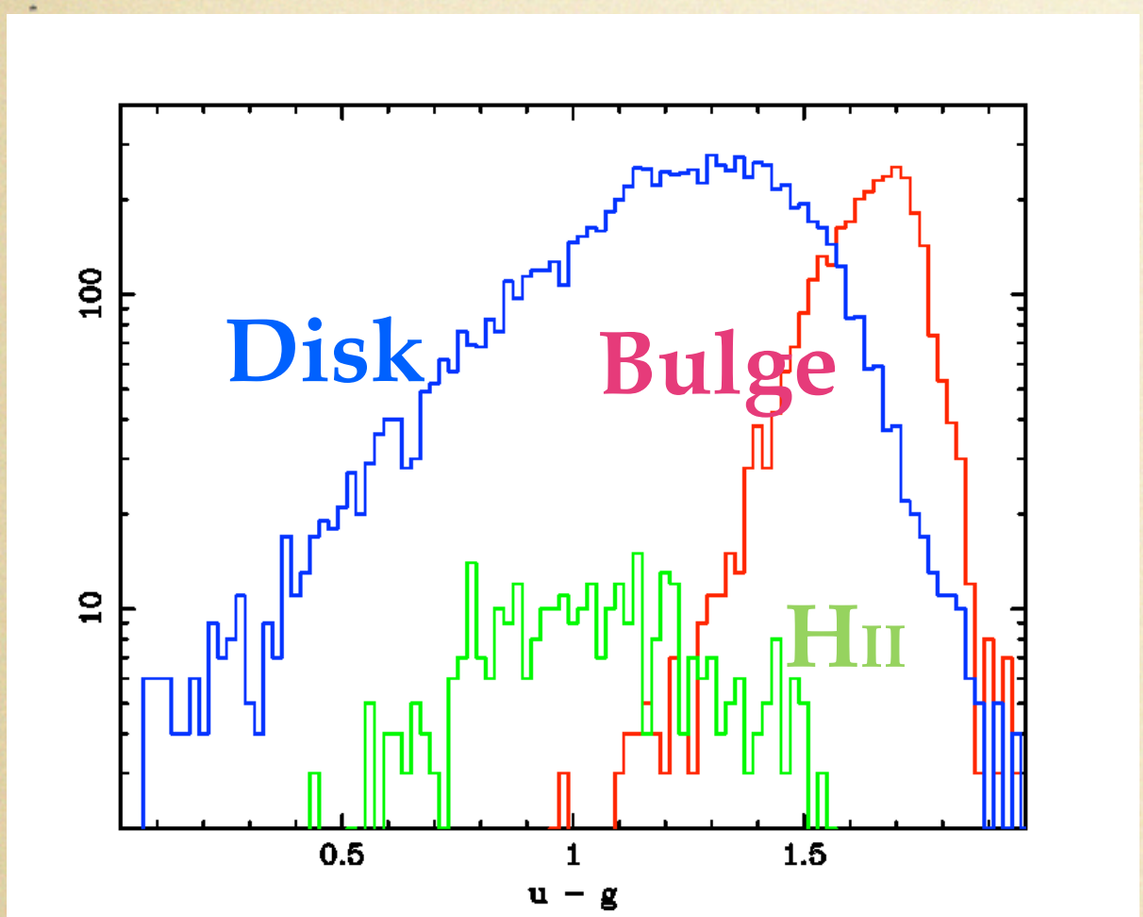
Are ULXs within Star-forming Regions?

SDSS g,r,i composites 58/140 galaxies in DR6 footprint & $i<65^{o}$

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?



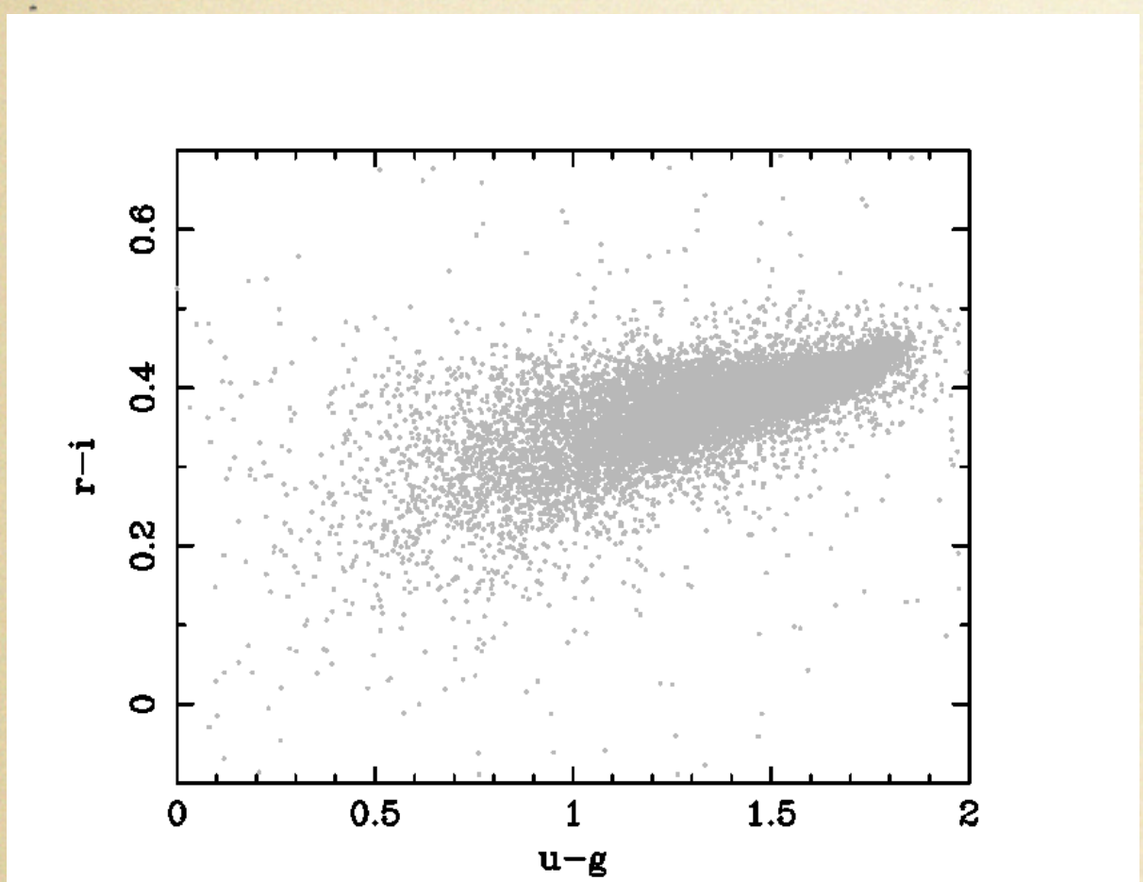
SDSS u-g

492 HII regions

(Petit+ 1988)

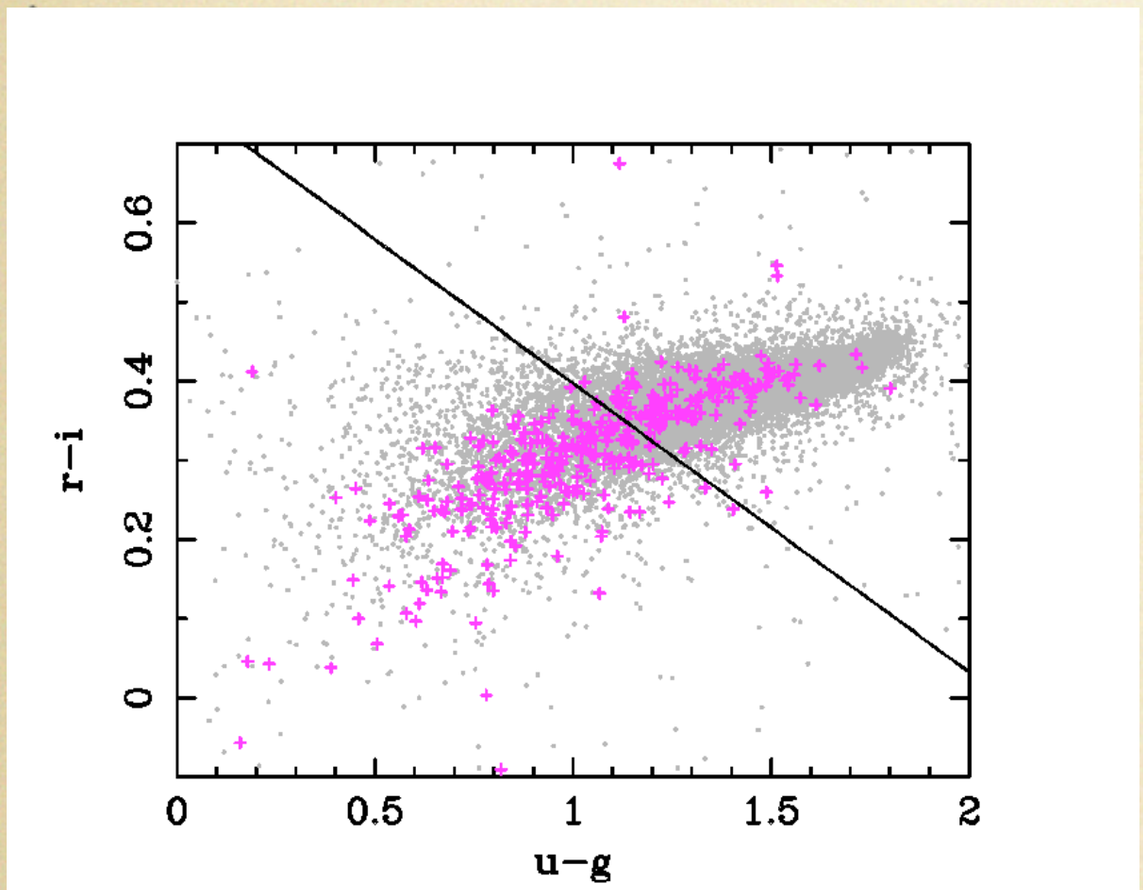
(~12000 regions total)

Are ULXs within Star-forming Regions?



Fisher's Discriminant:

Are ULXs within Star-forming Regions?



Fisher's Discriminant:

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

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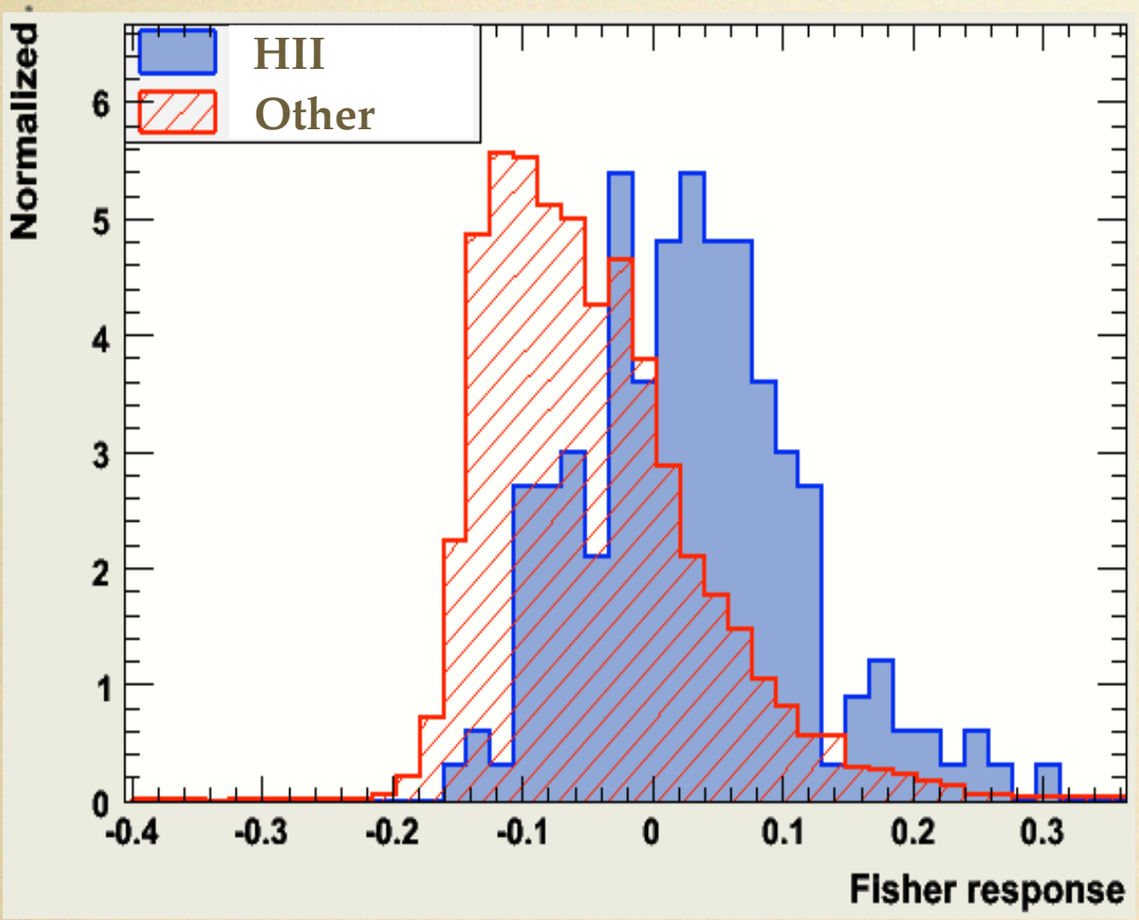

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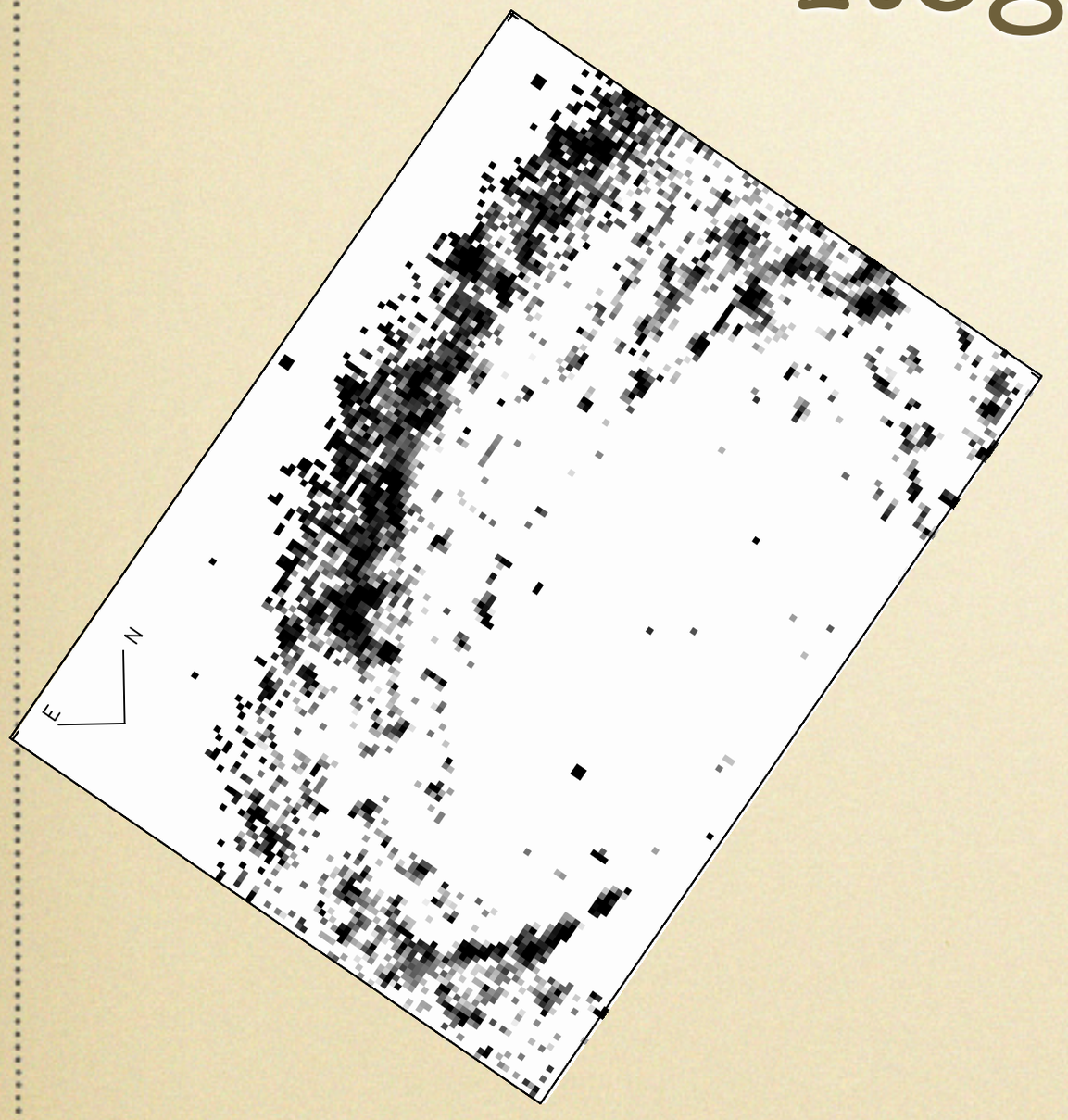

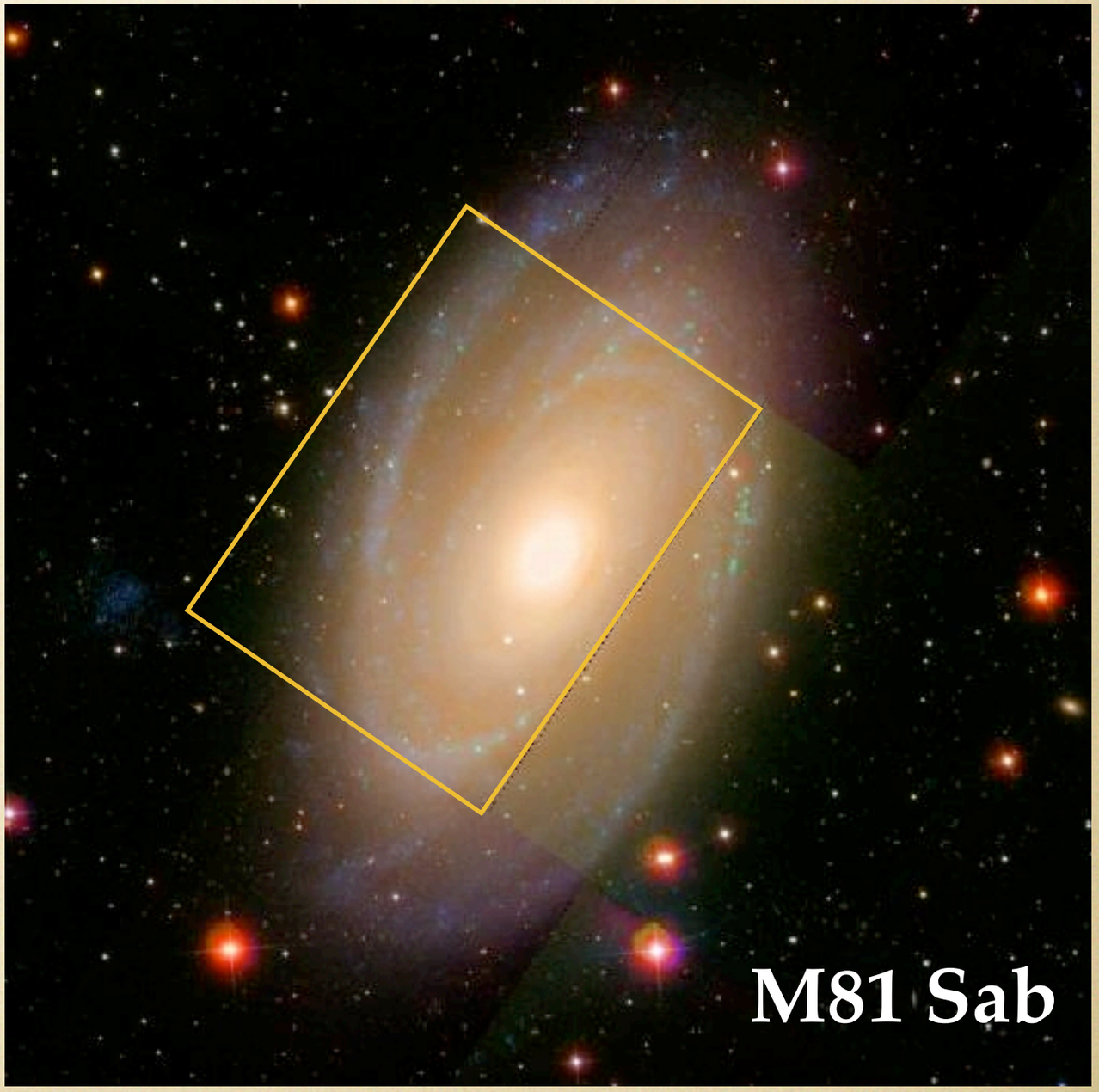

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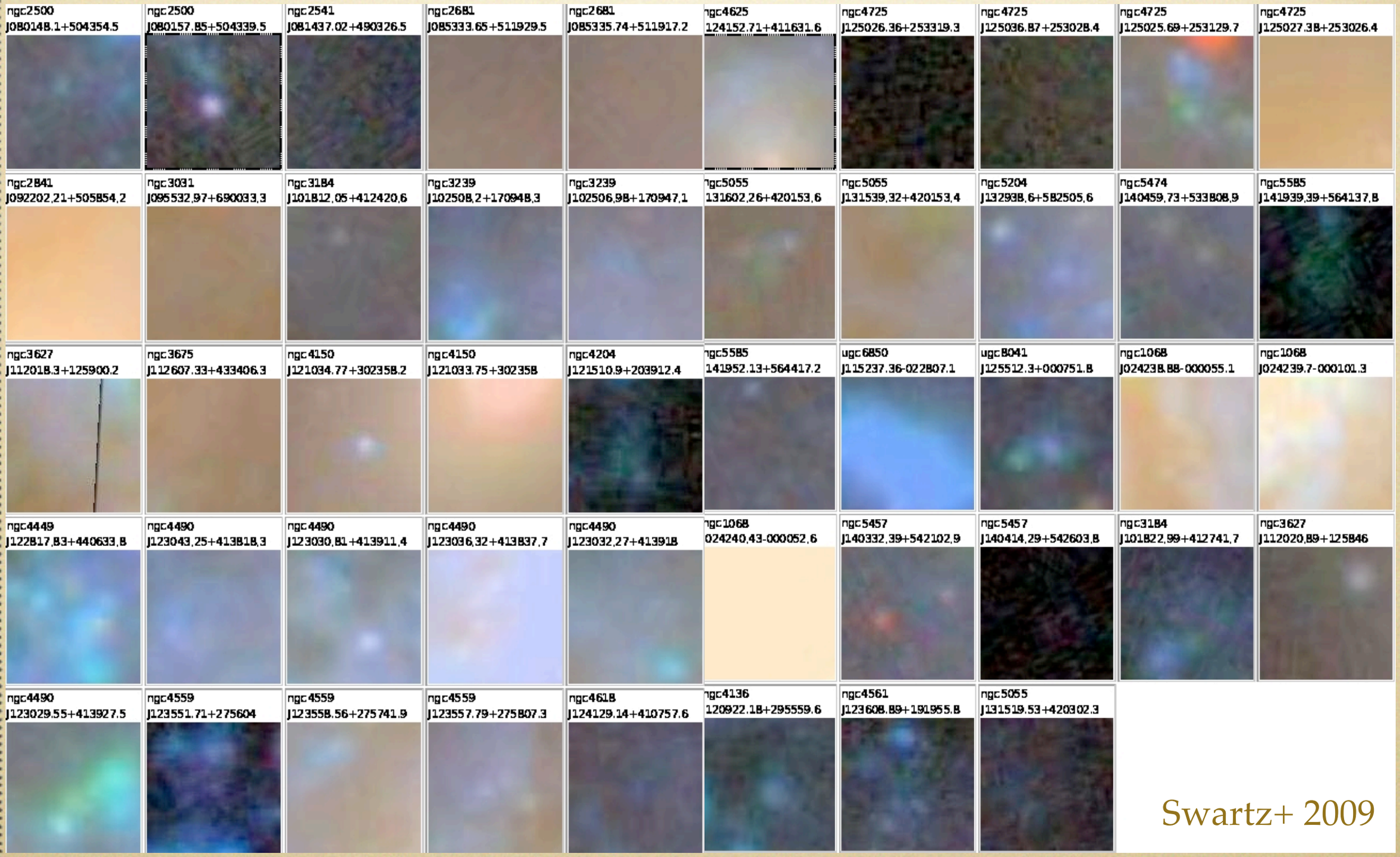


Swartz+ 2009

Are ULXs within Star-forming Regions?

YES

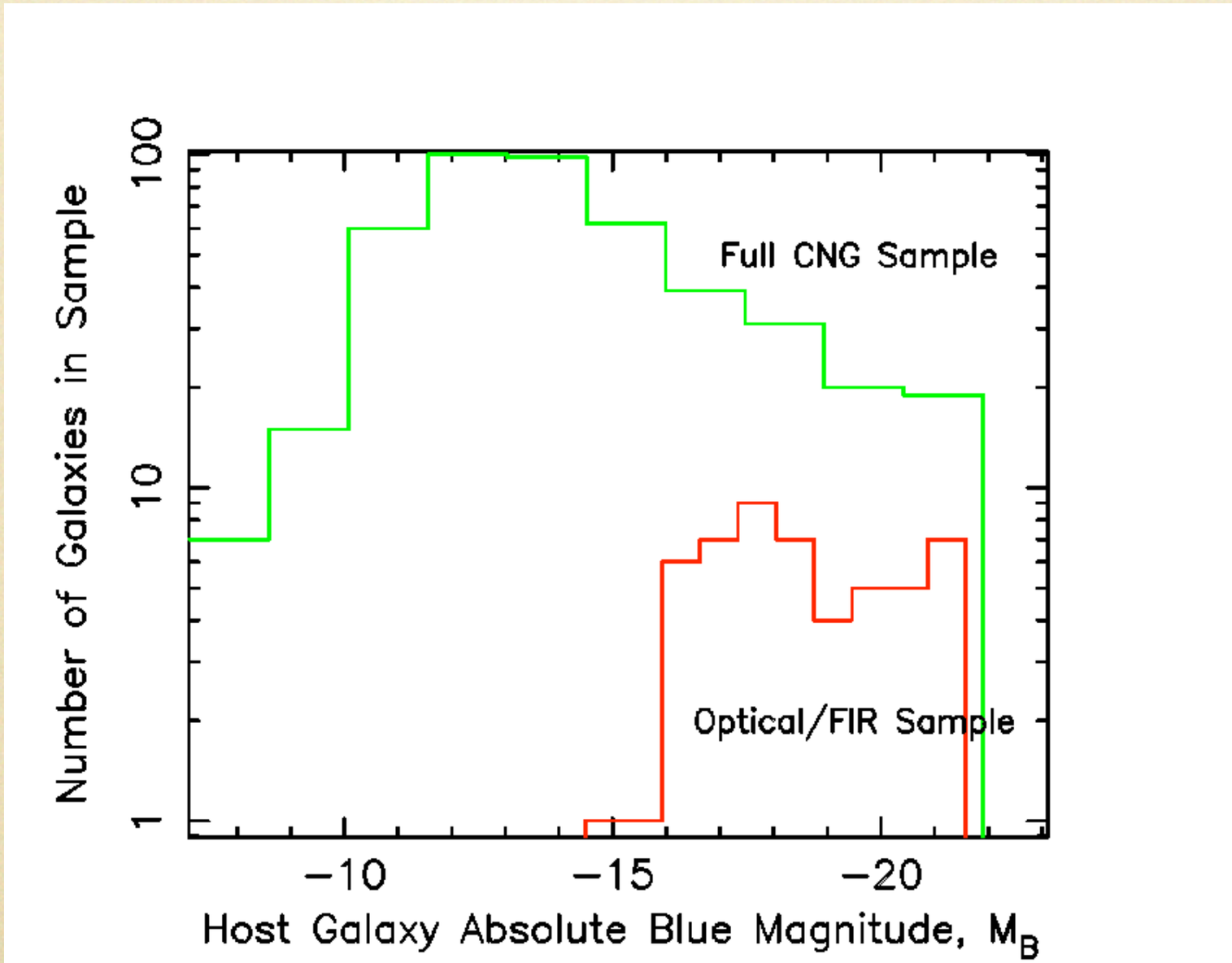
- 60% (21/35) of ULXs in optically-bright regions are in regions blueward of typical HII regions;
  - companion star ages <10 Myr, 15-20 $M_\odot$ OB stars
  - (only 32% of all regions are star-forming; 3σ)
- Many in crowded SFRs but no ULXs found in SSCs
- 80% (8/10) of ULXs with Lx>3×10^{39} erg/s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

Swartz+ 2009

Are there ULXs in dwarf galaxies?

- Low ϕ_g, high f_{gas} **(Geha+2006)**, low Z **(Lee+2006)**, low $\dot{M}_{wind}$, high M_{BH} **(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)**

Are there ULXs in dwarf galaxies?



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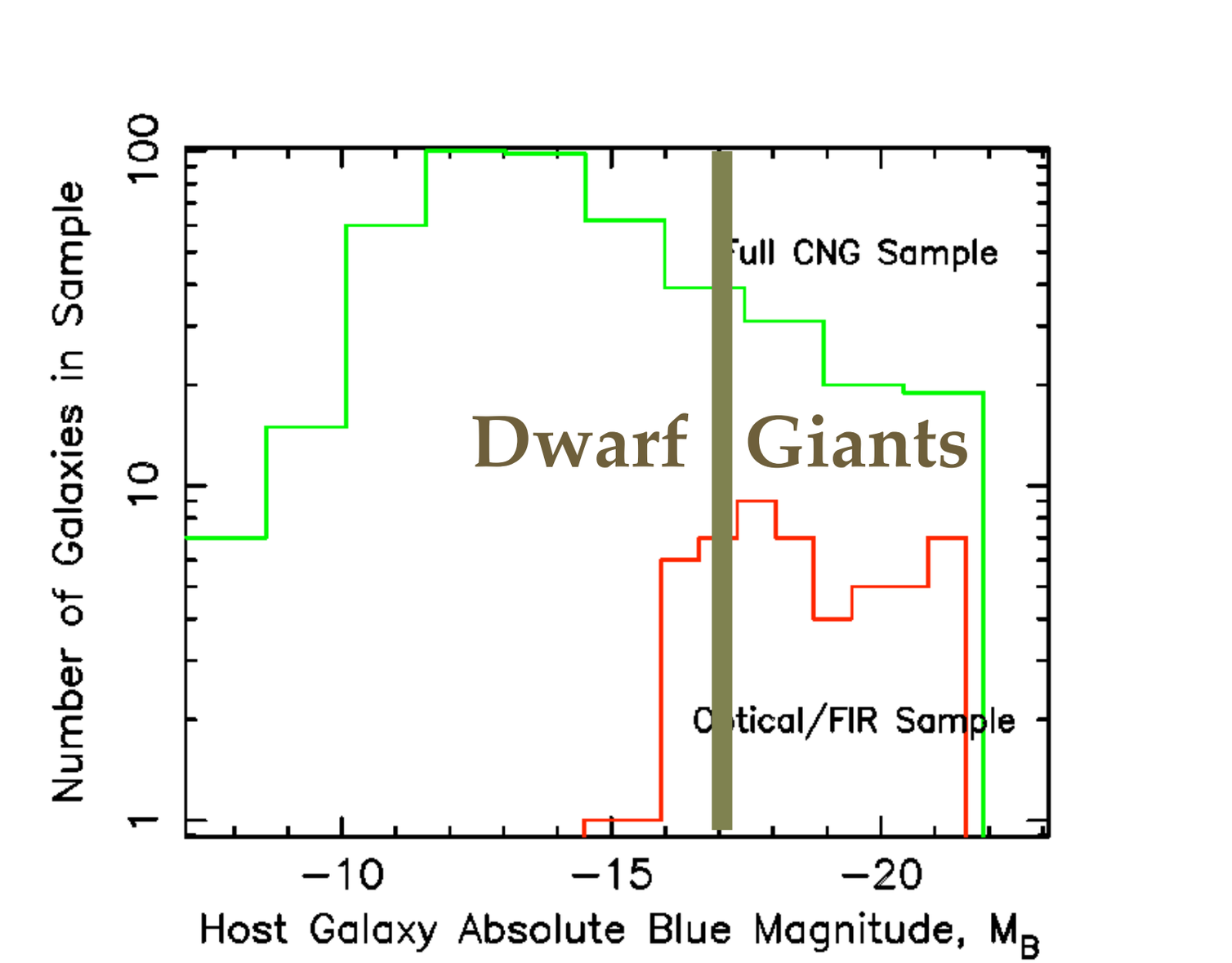

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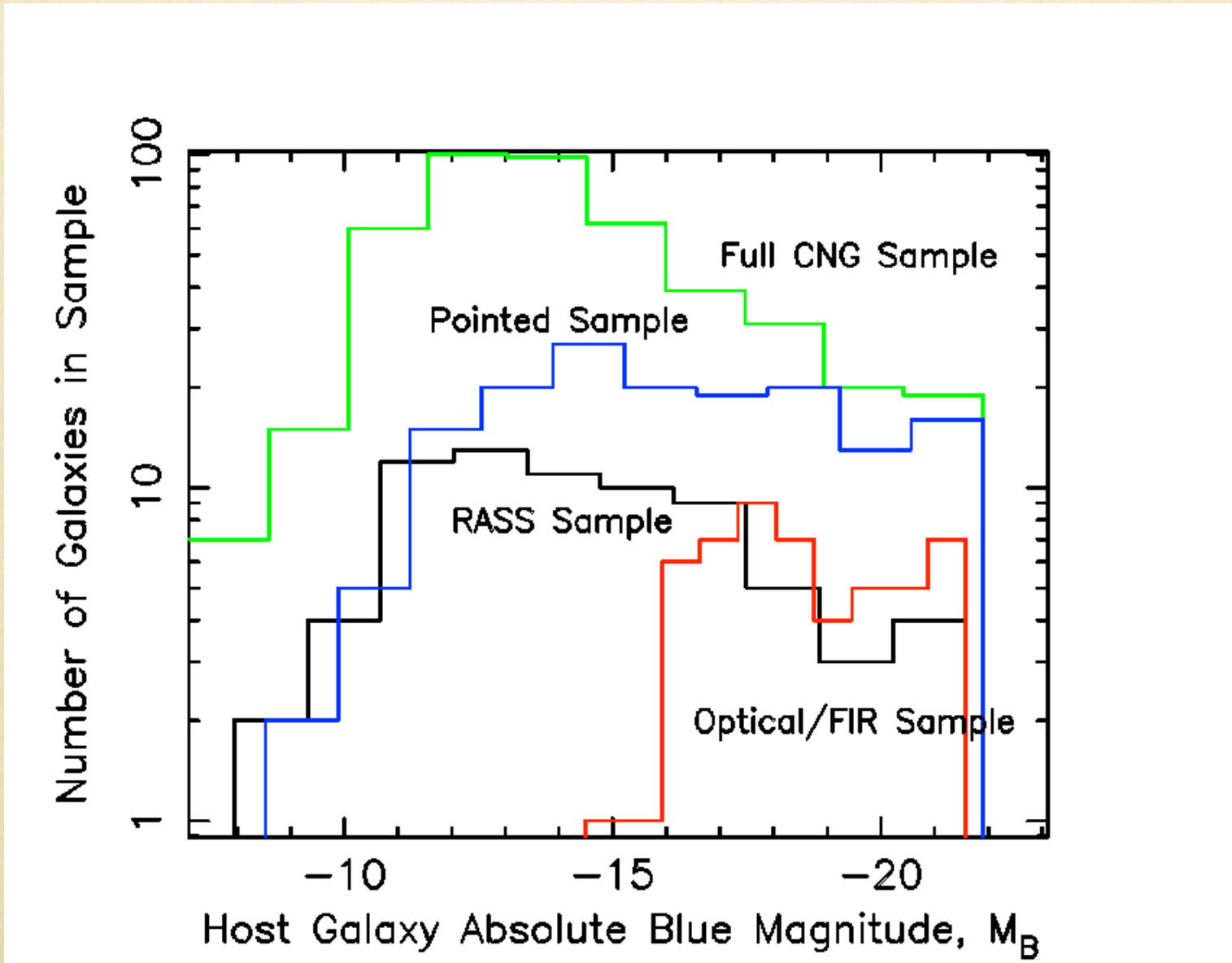

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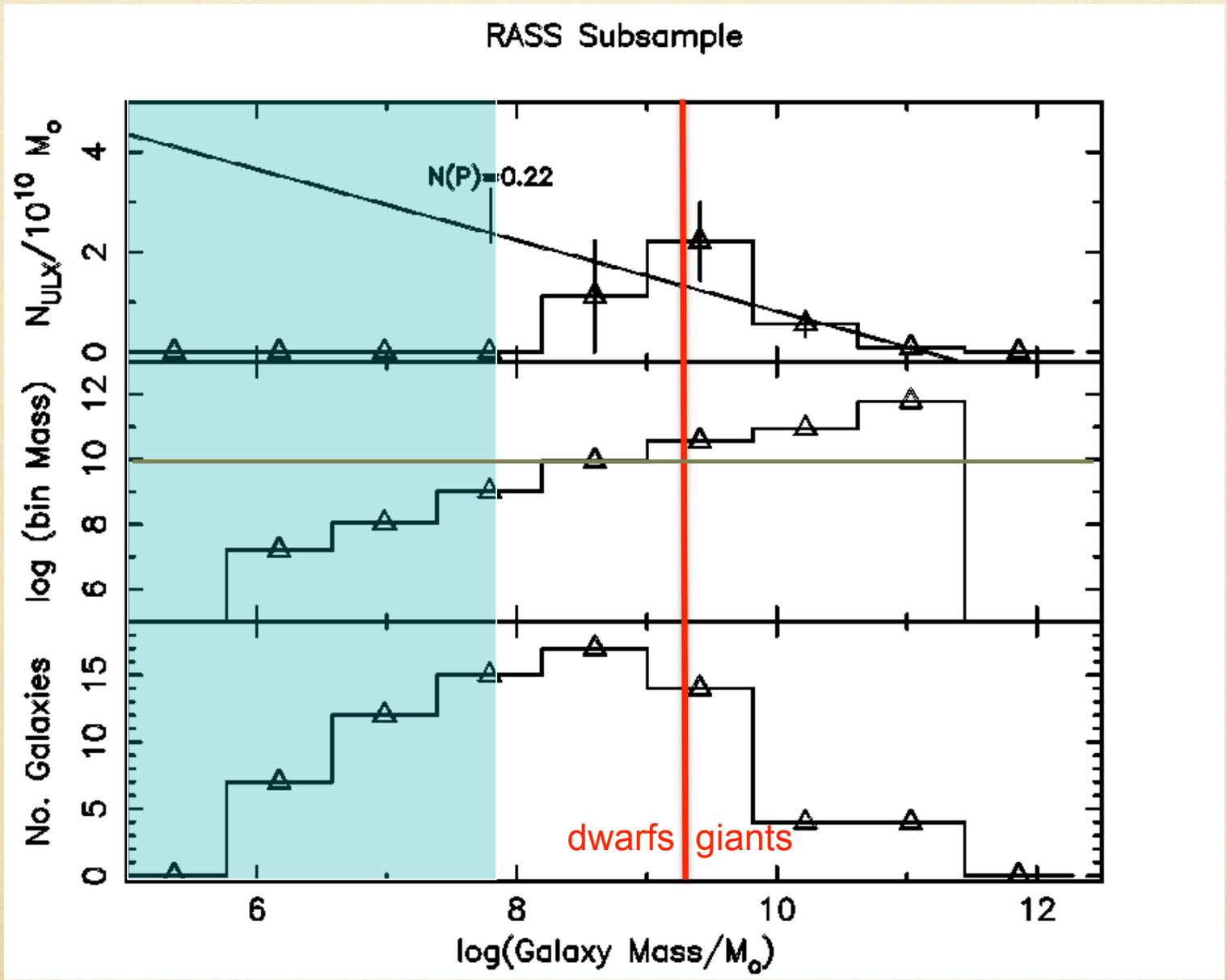

Swartz+ 2008

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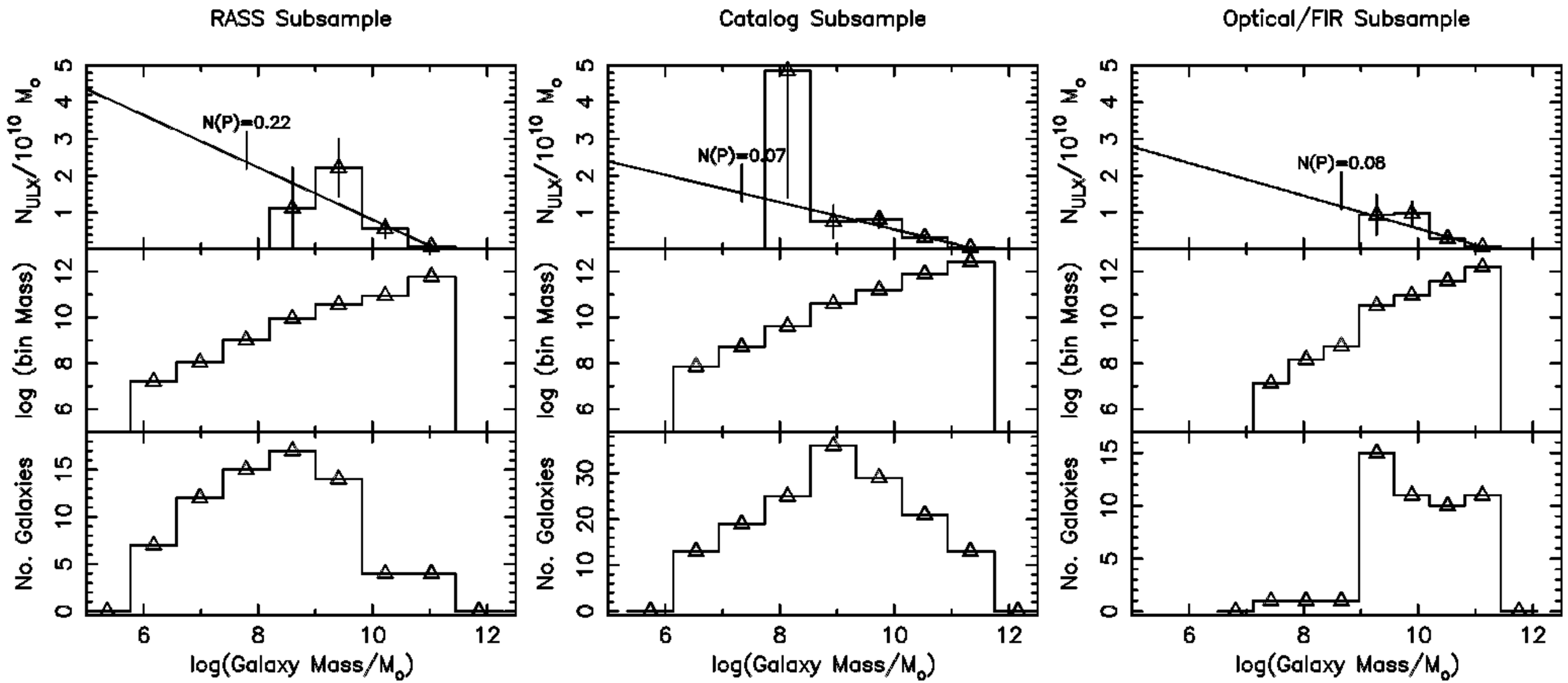


Swartz+ 2008

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

N_{ULX}/SFR independent of galaxy mass

- Still rare: only 5 ULXs in 118 dwarfs
- None in galaxies <3x10^8 $M_\odot$
- Of order 1 ULX per 10^{10} $M_\odot$

Are there ULXs in galaxy halos?

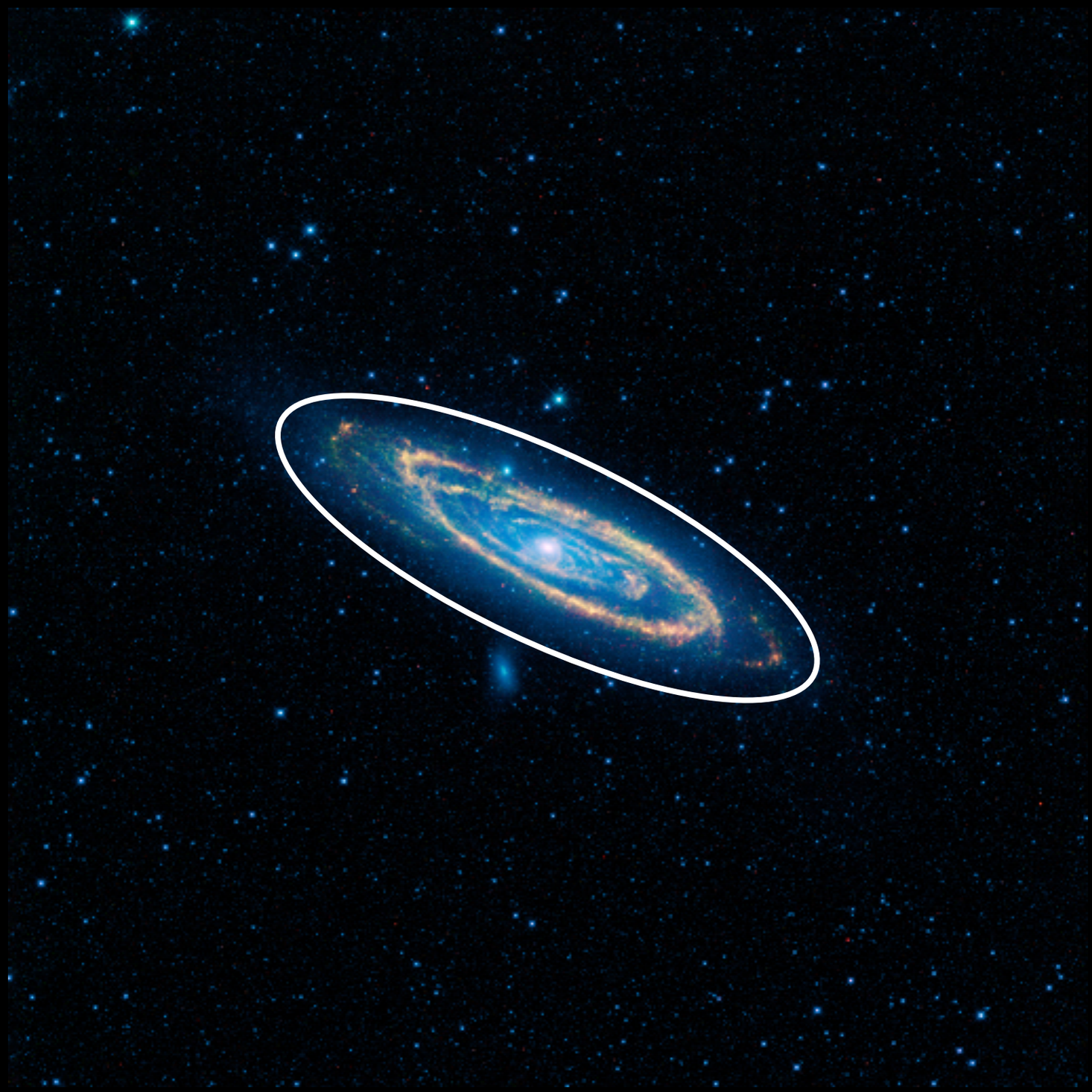
Among the promising IMBH candidates:

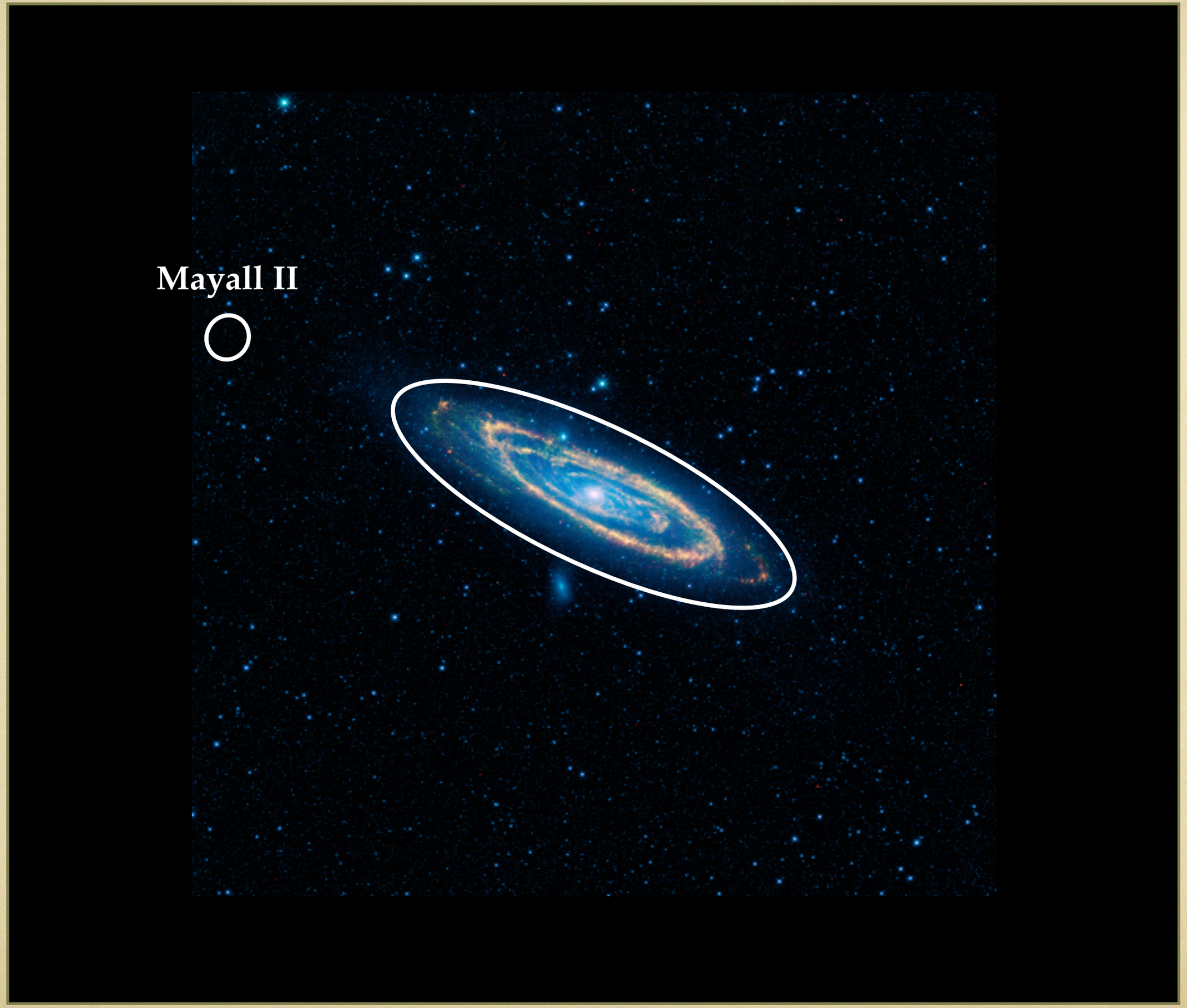
- Pop III stars leave massive remnants and are distributed throughout halo **(Madau&Rees 2001, Islam+ 2004ab)**

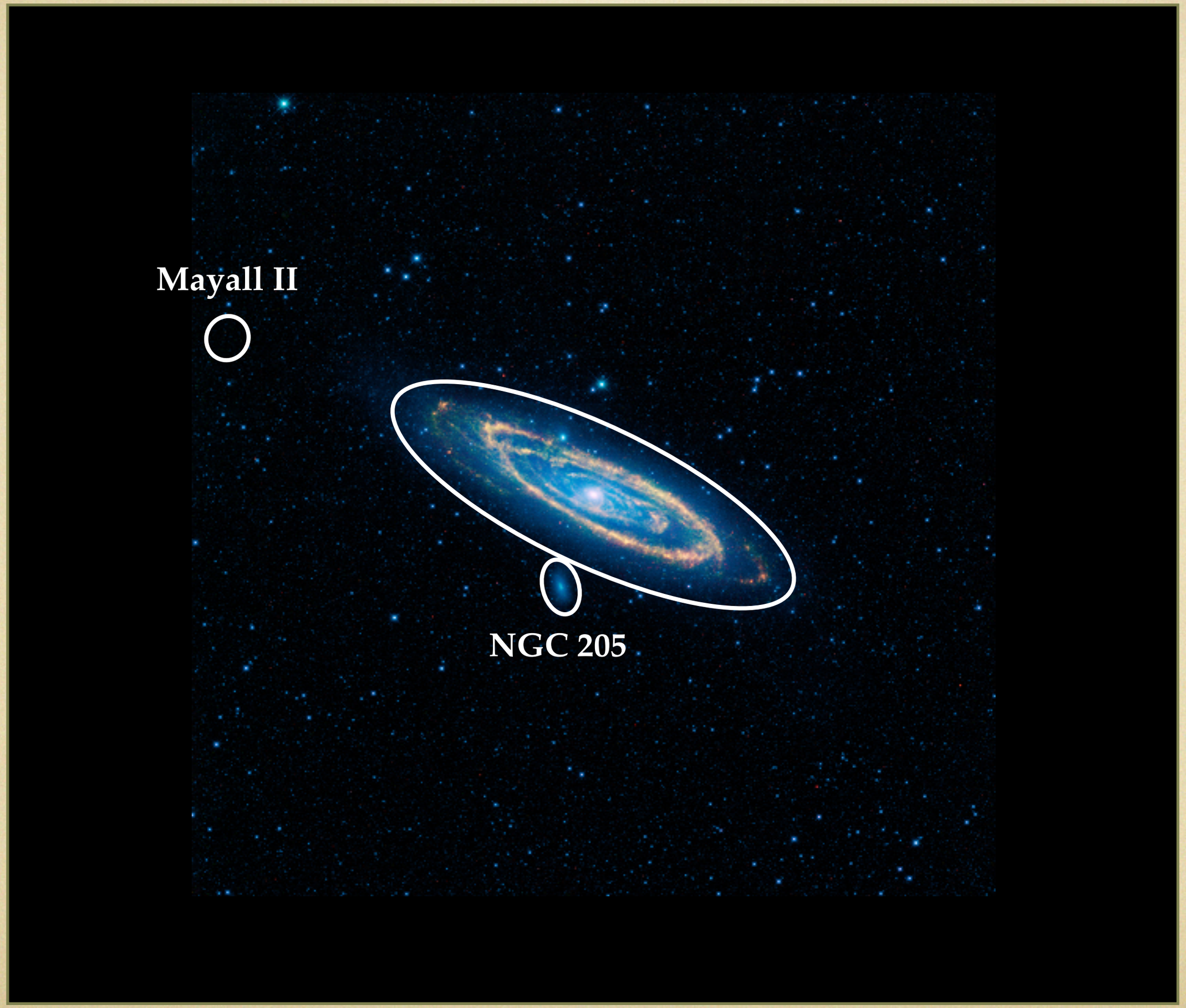
- BH coalescence in massive star clusters including Globulars **(Miller&Hamilton 2002, Kawakatu&Umemura 2005, Portegies Zwart+2004)**

- Stripped cores of satellite galaxies might contain IMBHs **(King&Dehnen 2005)**

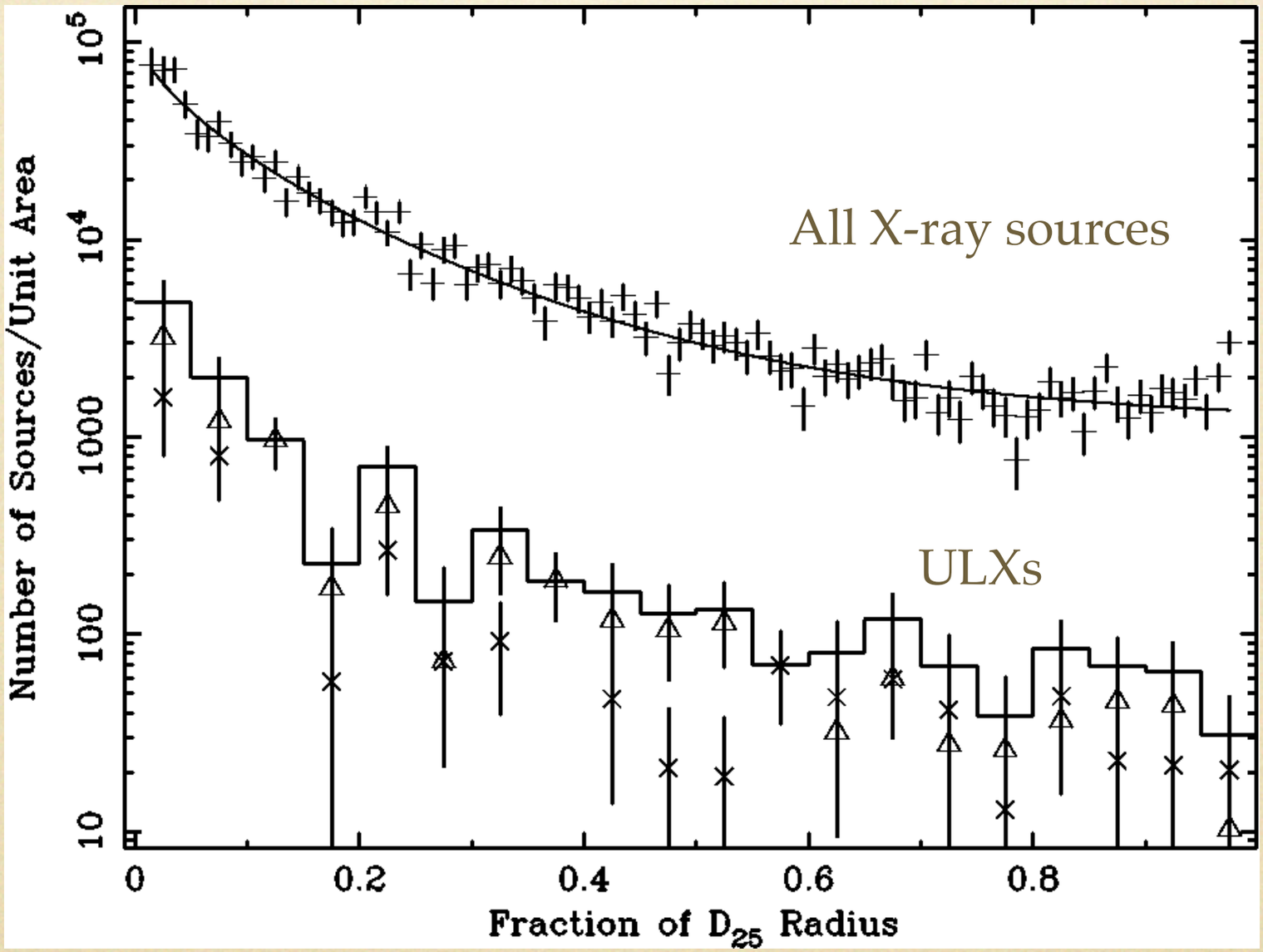
Wide-field Infrared Survey Explorer




Mayall II


Mayall II
NGC 205

Are there ULXs in galaxy halos?



Swartz+ 2004

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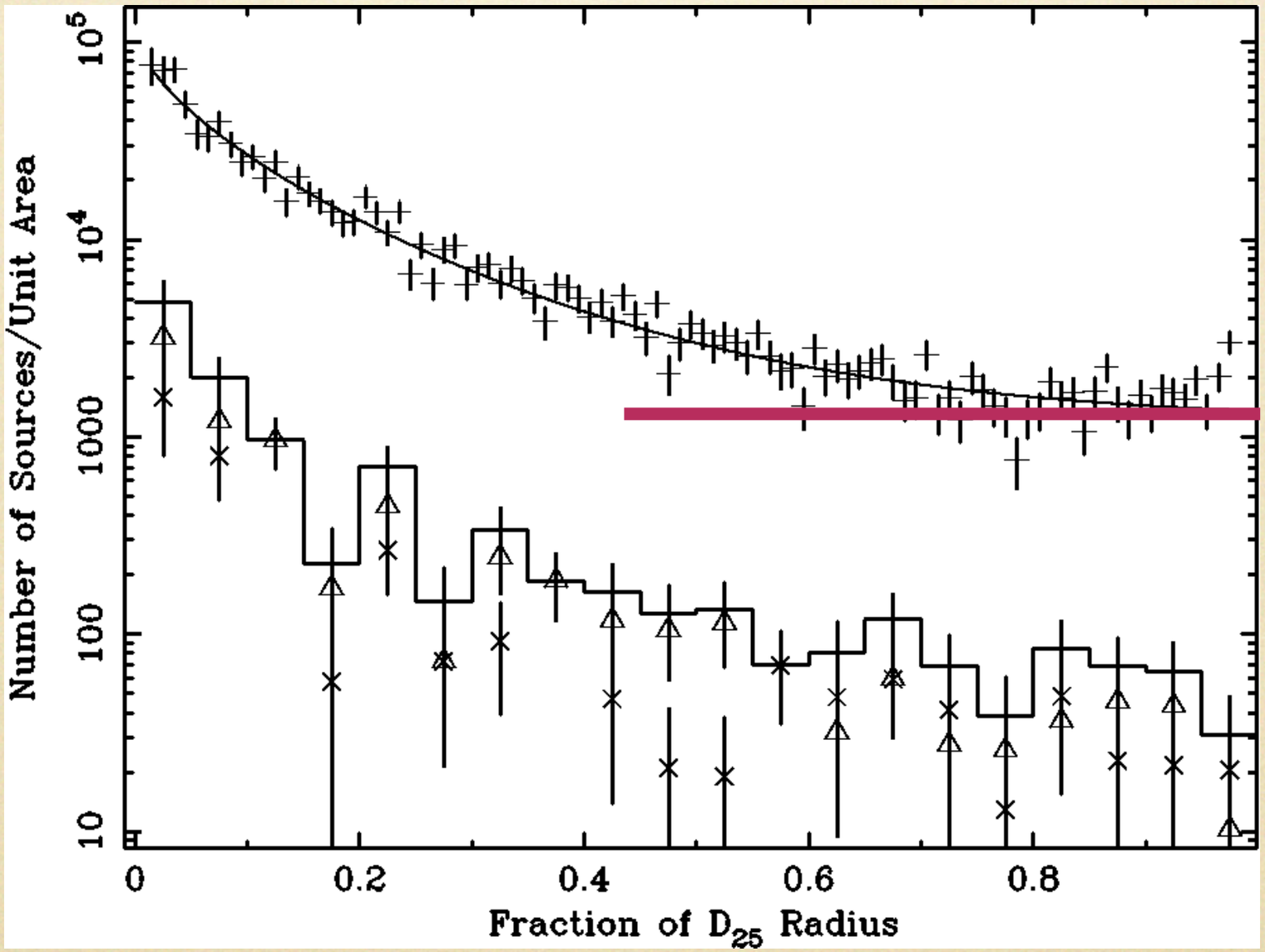
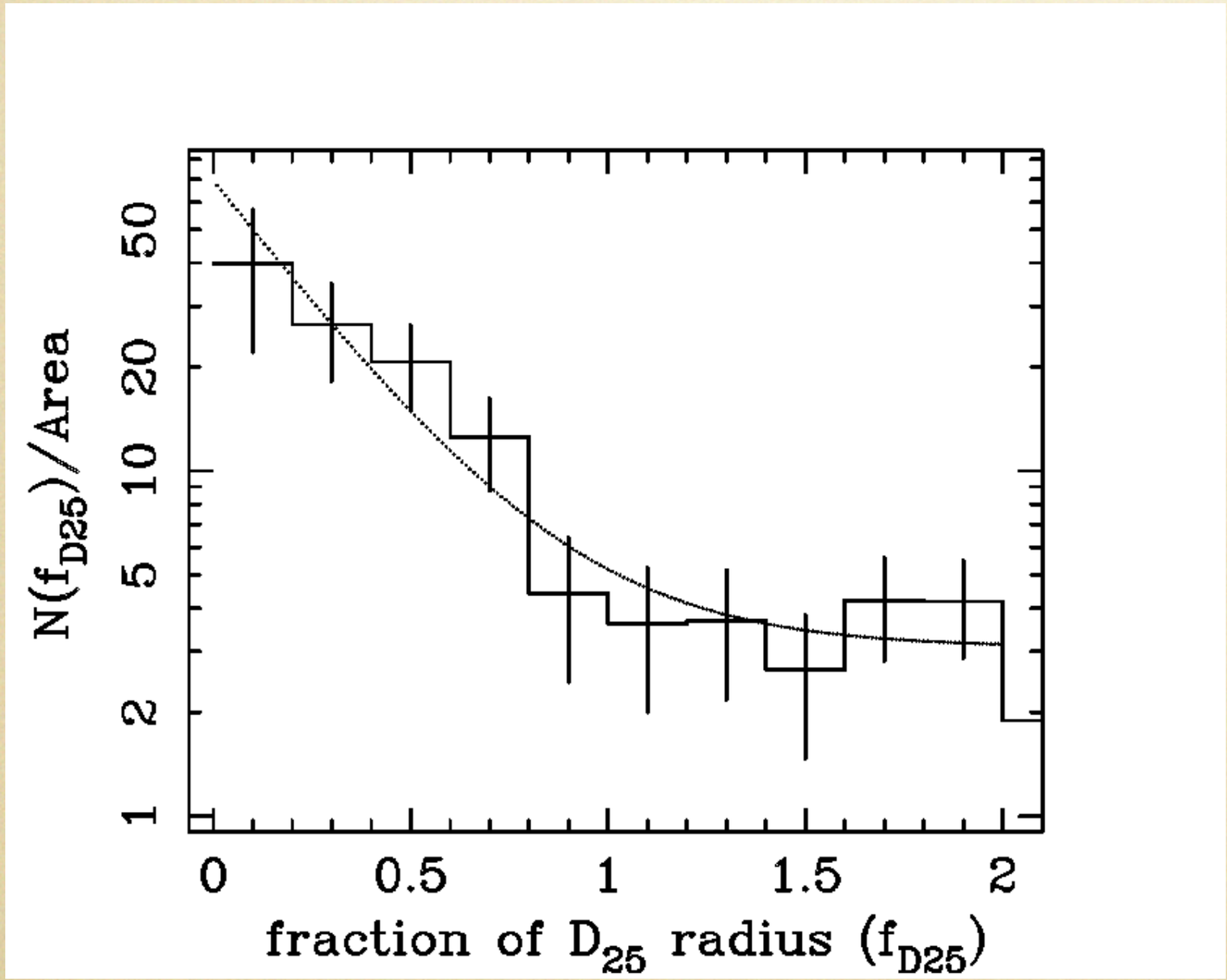


CDF bg prediction
(Rosati+ 2004)

Swartz+ 2004

Are there ULXs in galaxy halos?



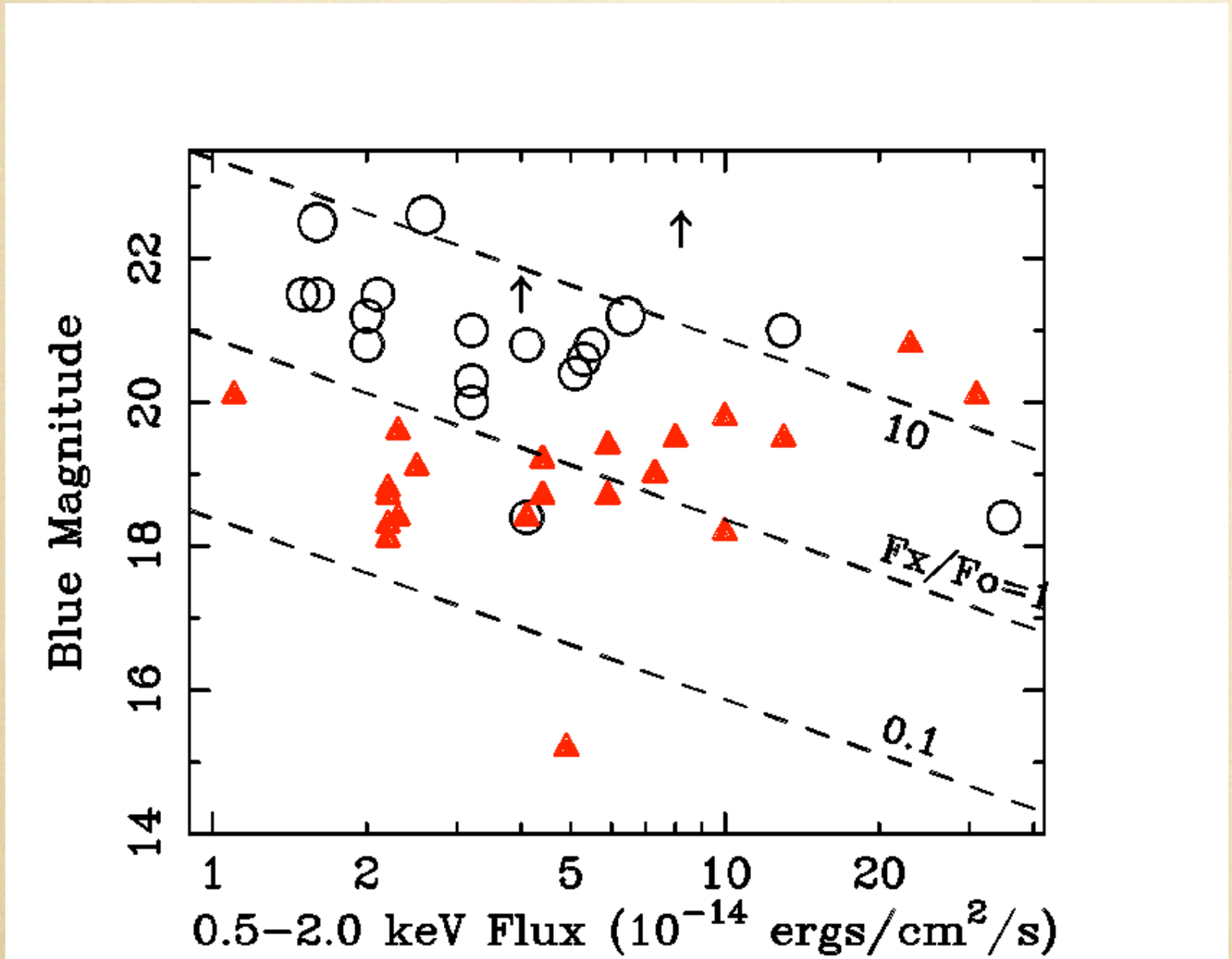
larger FOV with ROSAT

- 87 ULX candidates
- 41 beyond D_{25}

(Colbert & Ptak 2002)

Swartz 2006

Are there ULXs in galaxy halos?



Swartz 2006

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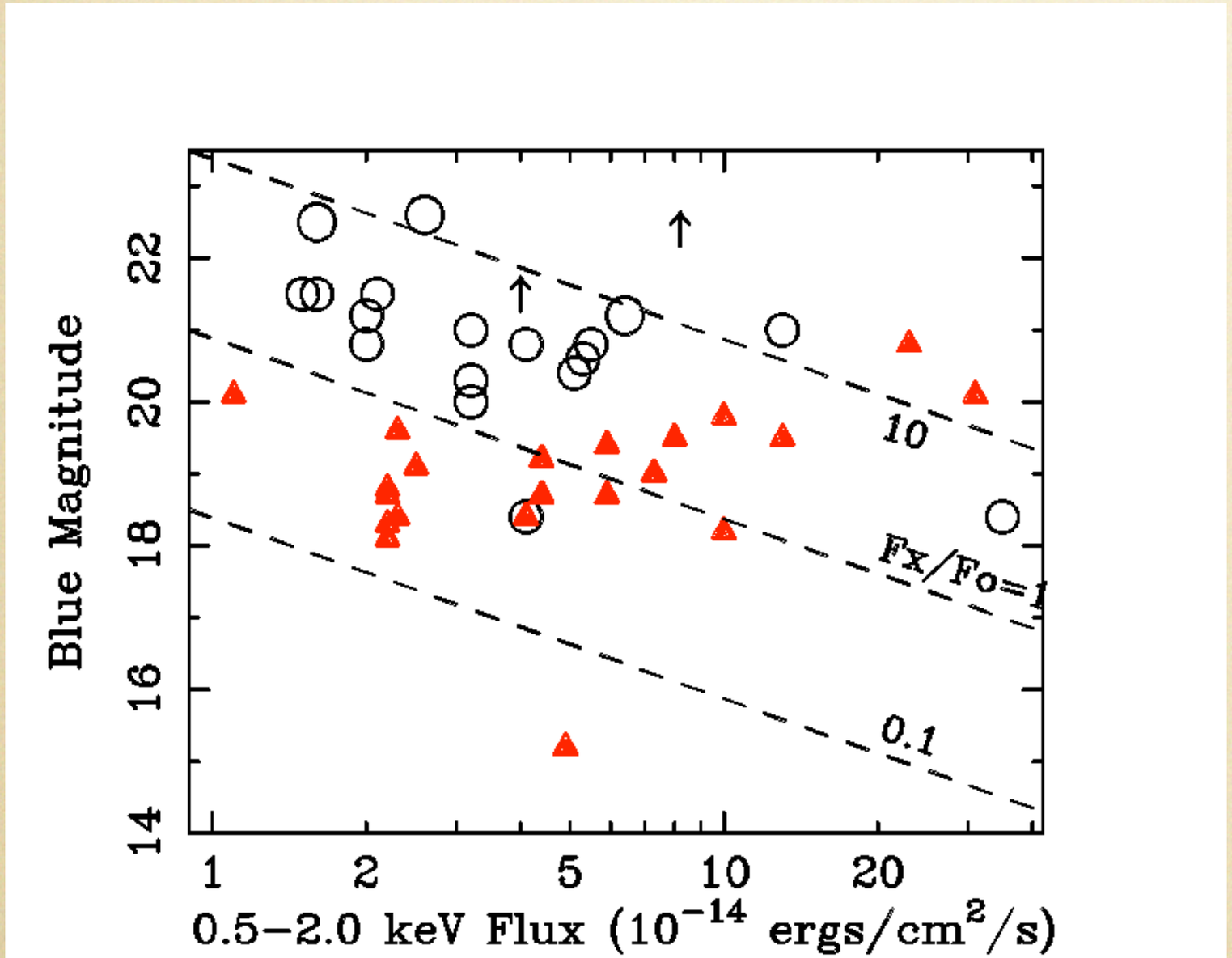

<u>all</u> 21 with spectroscopic redshifts are background

(Lopez-Corredoira & Gutierrez 2006)

Swartz 2006

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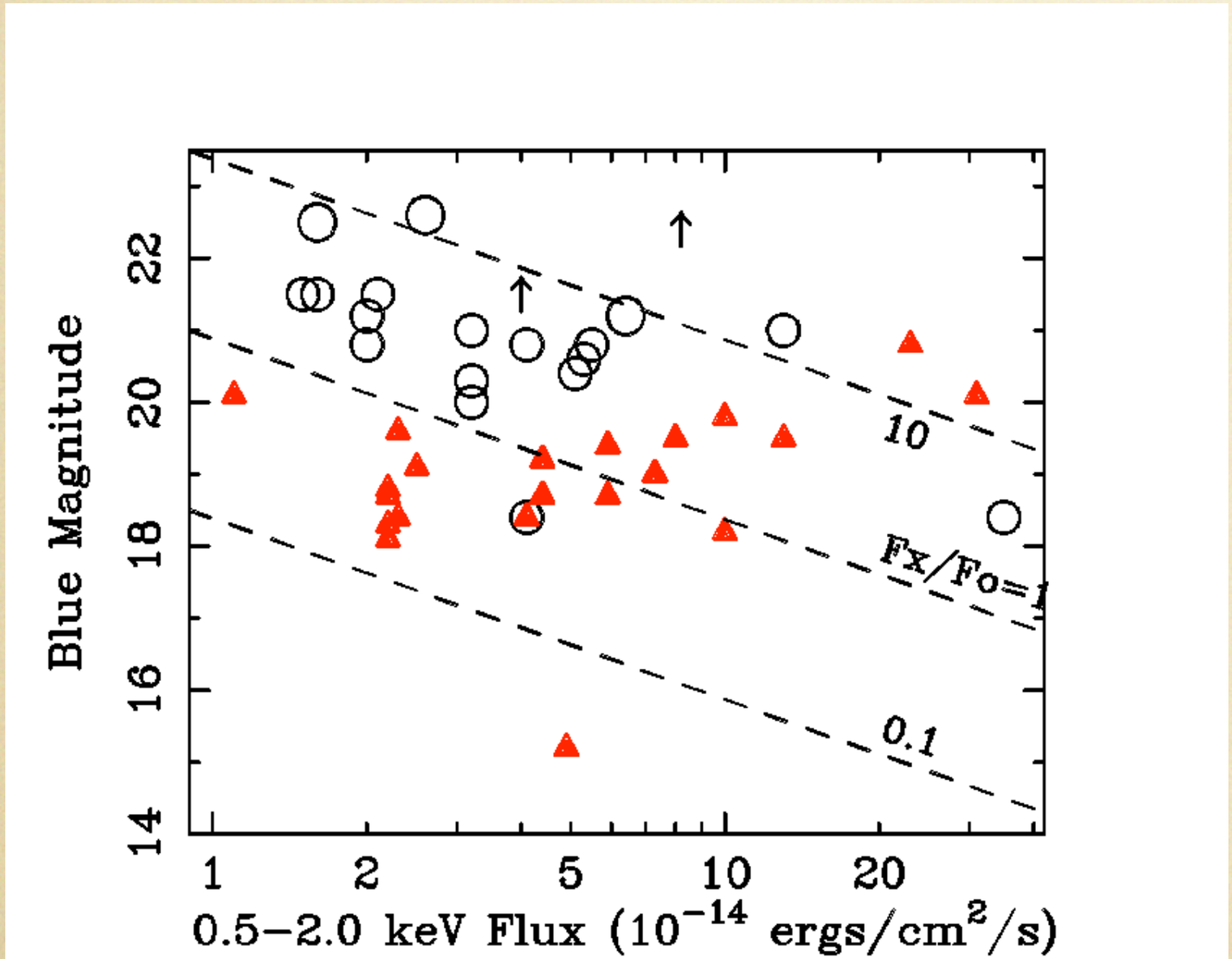


<u>all</u> 21 with spectroscopic redshifts are background

(Lopez-Corredoira & Gutierrez 2006)

(Fx/Fo) ~ 1

Swartz 2006

Are there ULXs in galaxy halos?

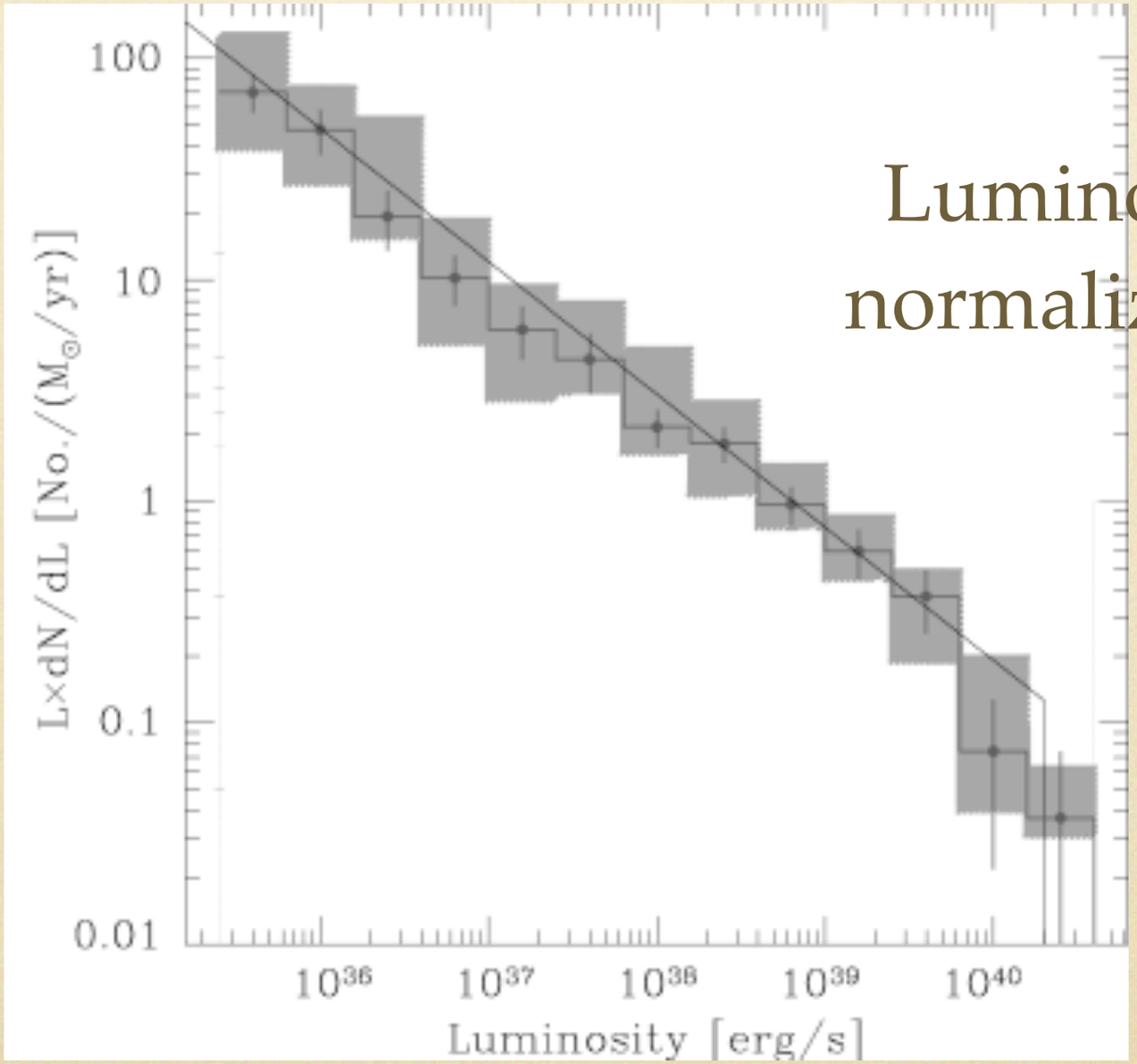
- log(Fx/Fo) ~ 0+/−1 (AGN-like)
- 21 of 21 w/redshift are background => 95% probability that >90% of all 41 are background (for bimodal distribution of backgrounds+ULXs)
- uniform spatial distribution like background sources

  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_{BH}

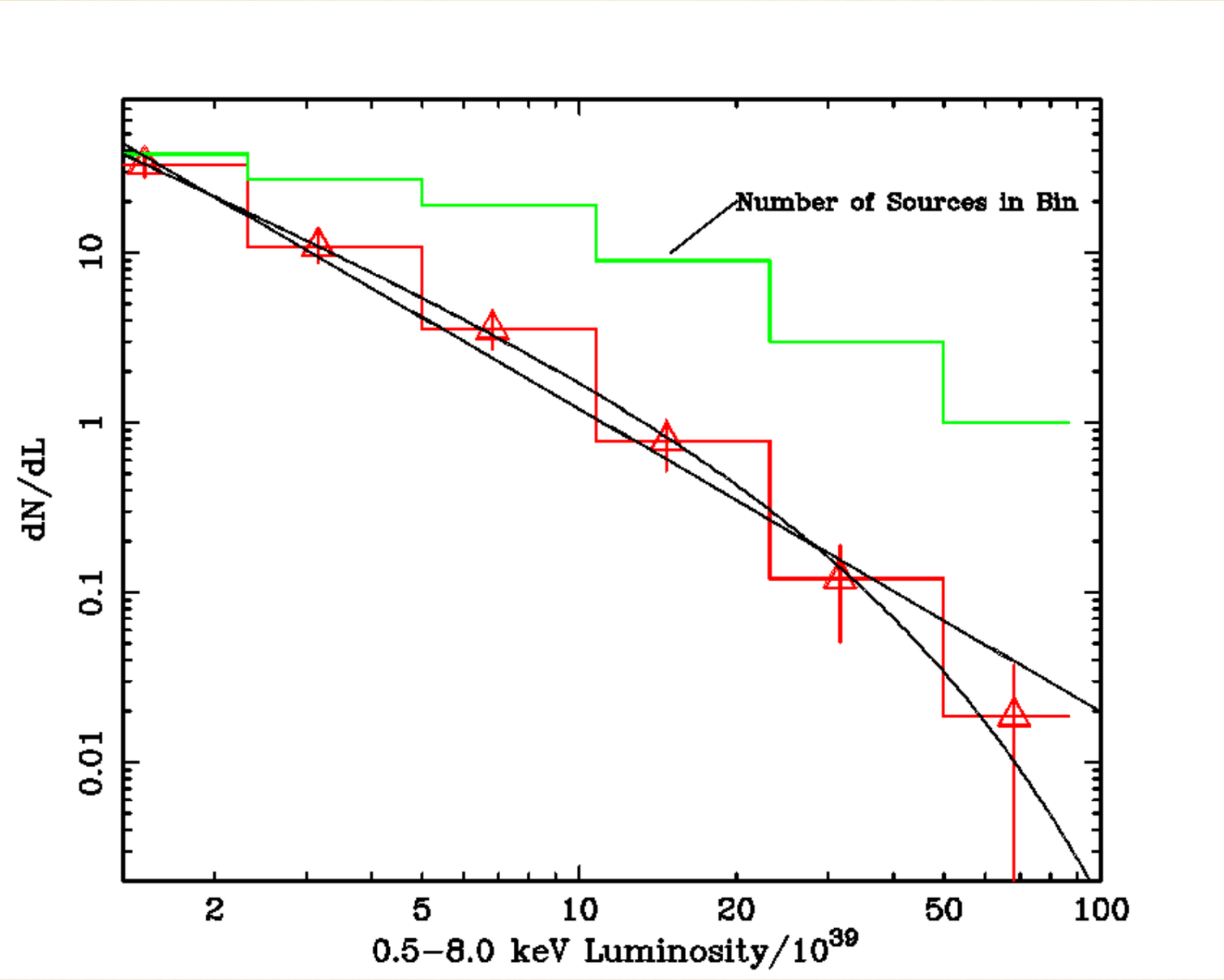
Is there an Upper Limit to ULX Luminosity?



Luminosity Function normalized to unit SFR

(Grimm+ 2003)

Is there an Upper Limit to ULX Luminosity?



Swartz+ 2004

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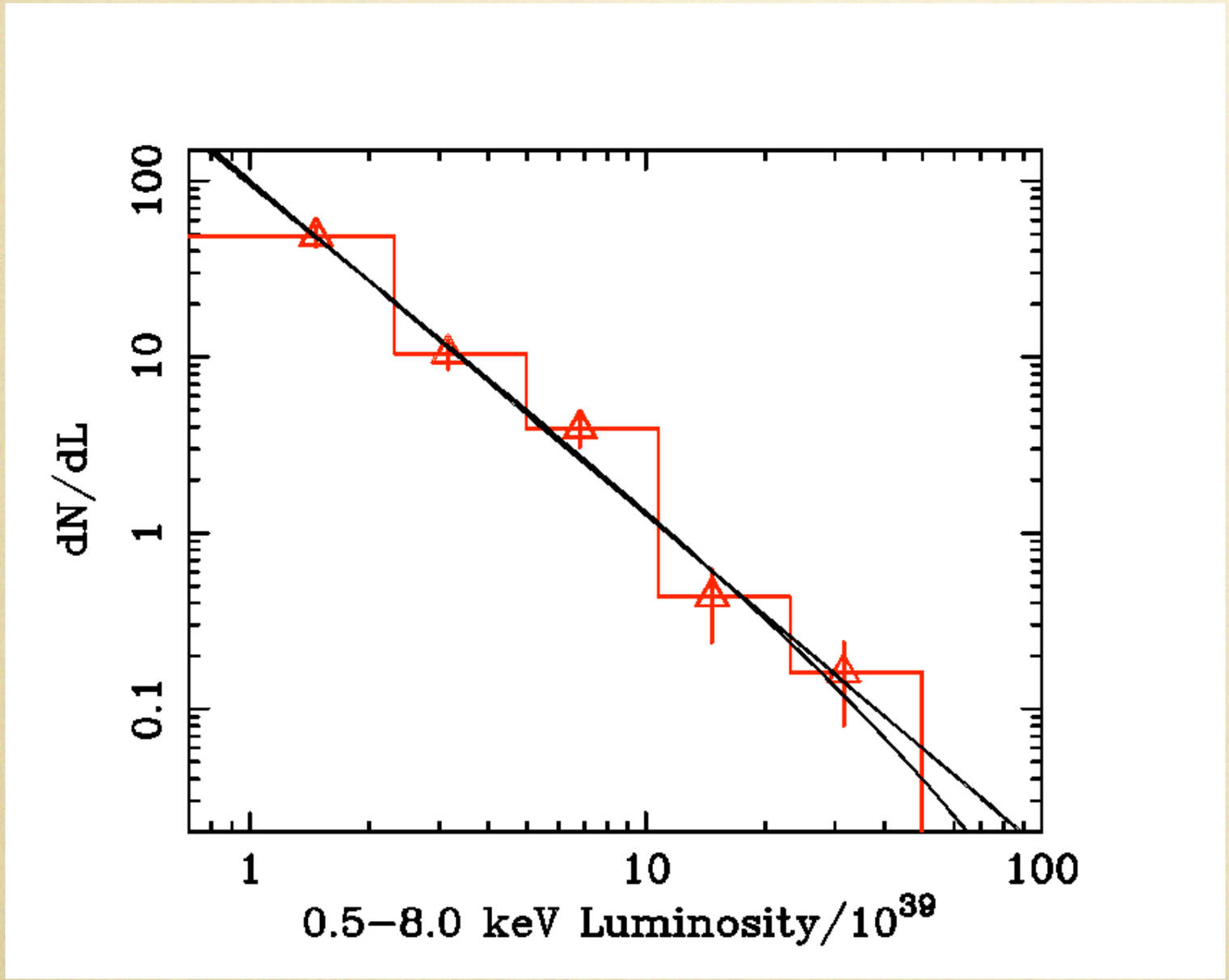

Complete sample of ULX host galaxies:

Power law & exponential cut-off power law acceptable:

slope=$1.89^{+0.21}_{-0.17}$

cutoff~65x10^{39}

Is there an Upper Limit to ULX Luminosity?

YES

or, maybe, NO