Ultraluminous X-ray Sources in Nearby Galaxies

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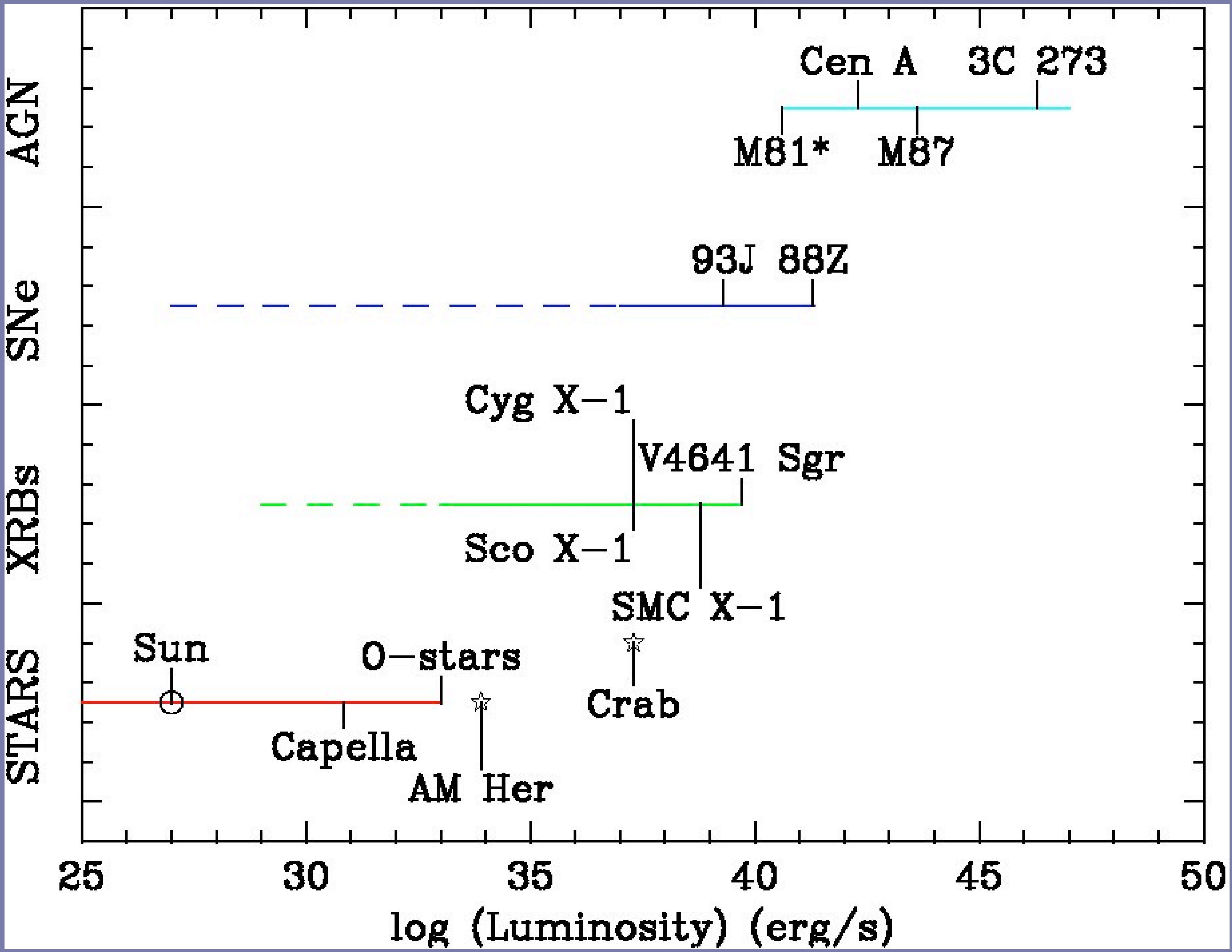
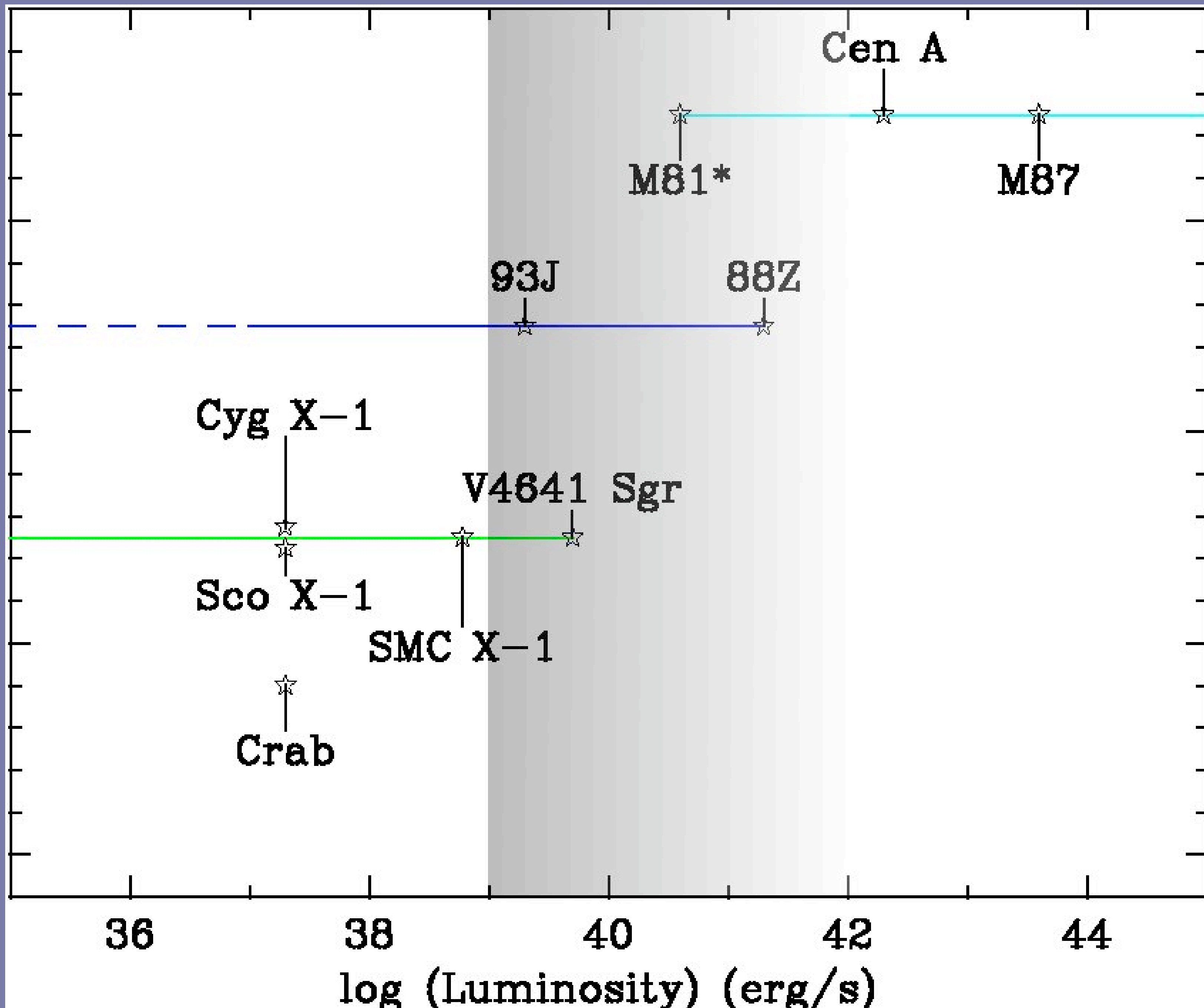
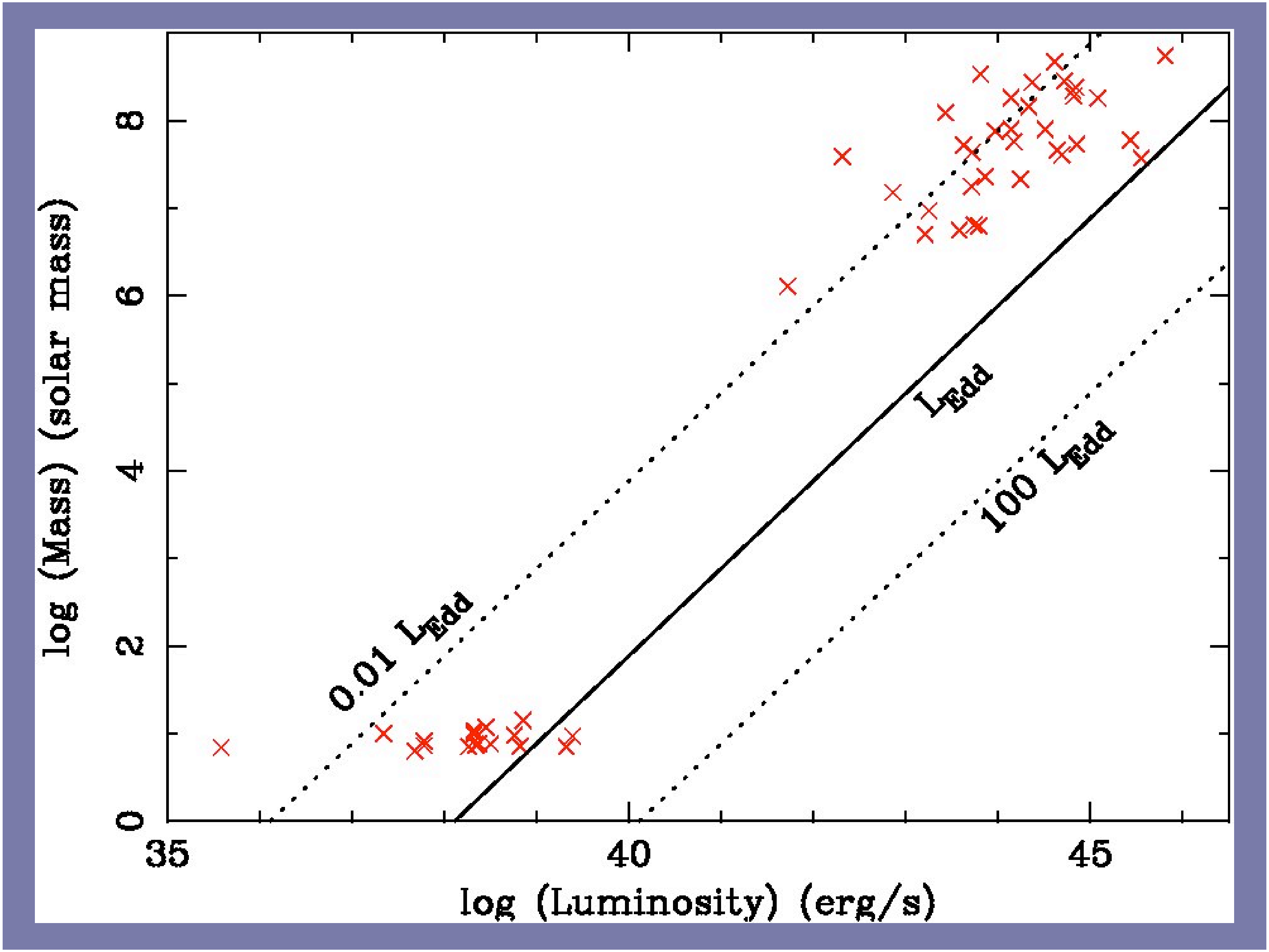
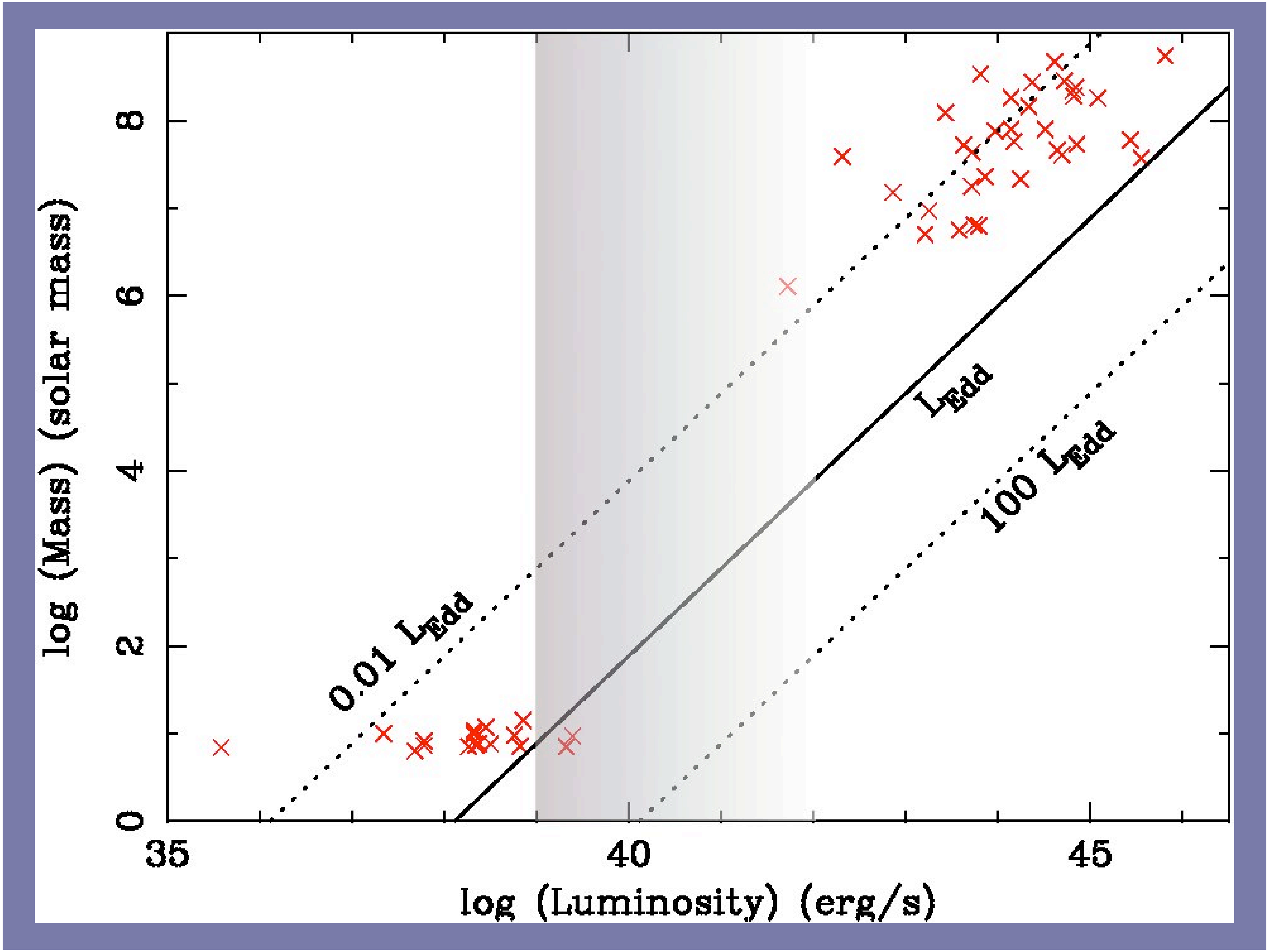

AGN
SNe
XRBs
STARS
Cen A
3C 273
M81*
M87
93J
88Z
Cyg X-1
V4641 Sgr
Sco X-1
SMC X-1
Sun
O-stars
Crab
Capella
AM Her
25
30
35
40
45
50
log (Luminosity) (erg/s)

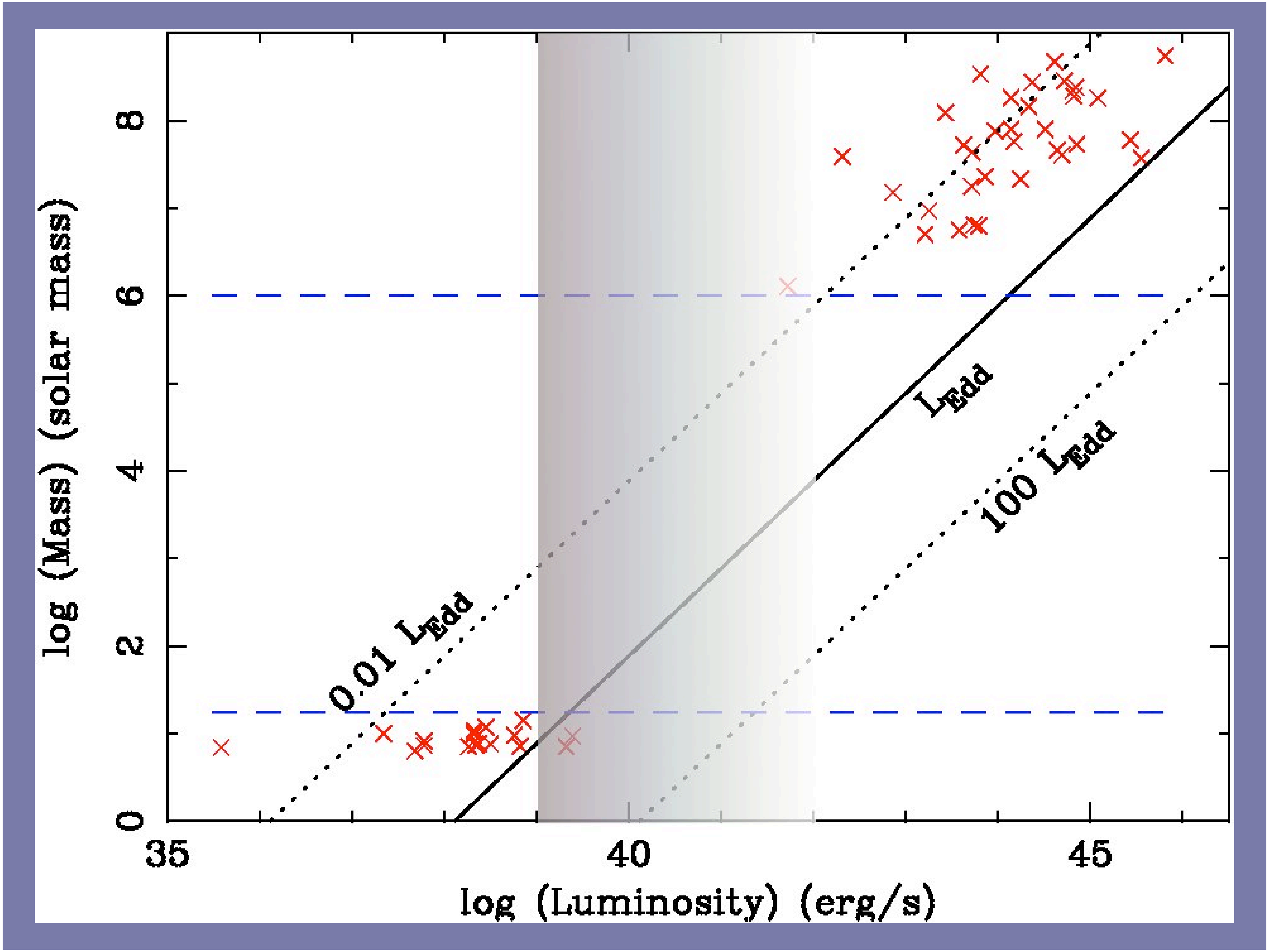


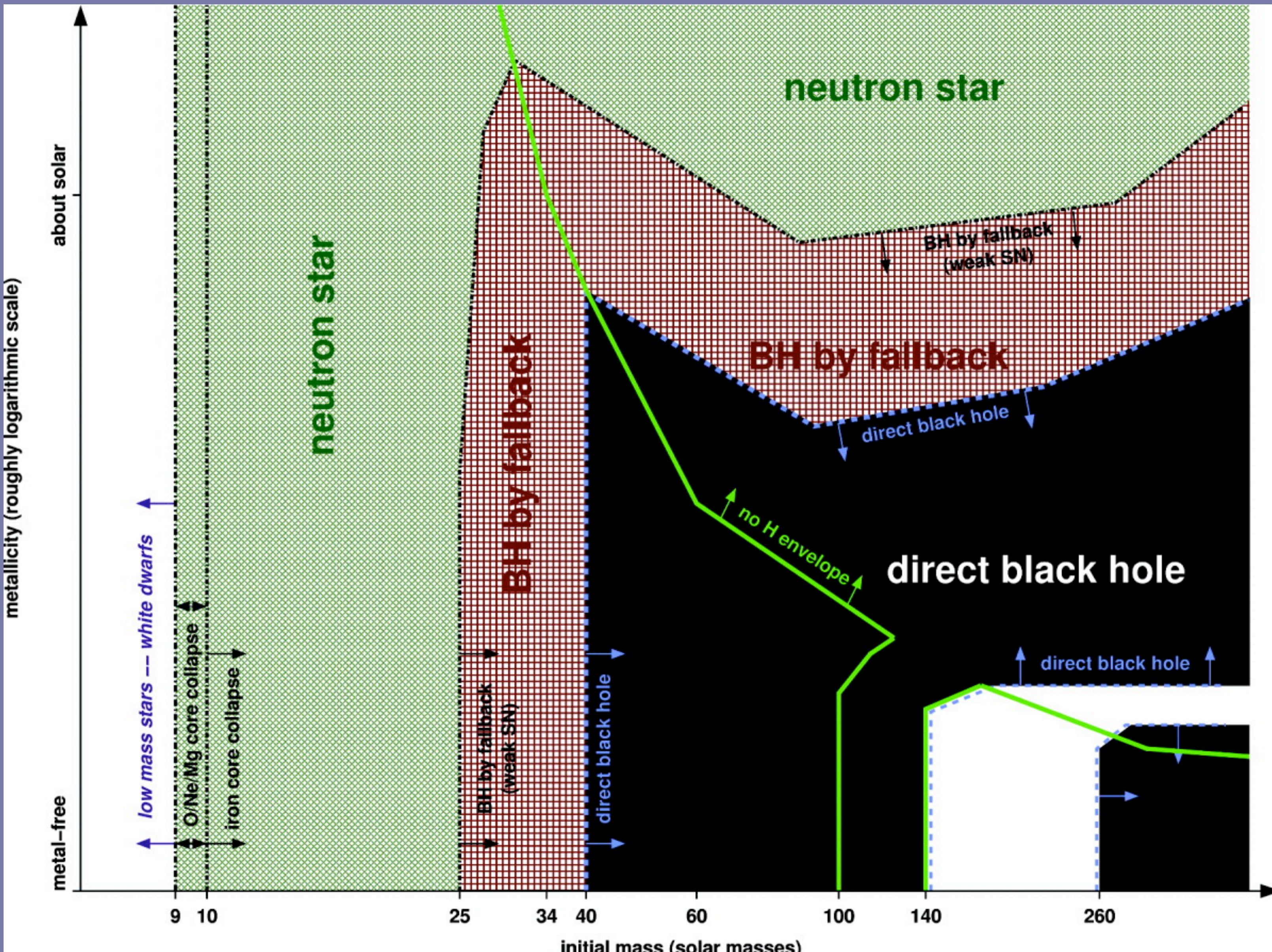
Cen A
M81*
M87
93J
88Z
Cyg X−1
V4641 Sgr
Sco X−1
SMC X−1
Crab
36
38
40
42
44
log (Luminosity) (erg/s)


log (Mass) (solar mass)
log (Luminosity) (erg/s)
0
2
4
6
8
35
40
45
0.01 L_Edd
L_Edd
100 L_Edd

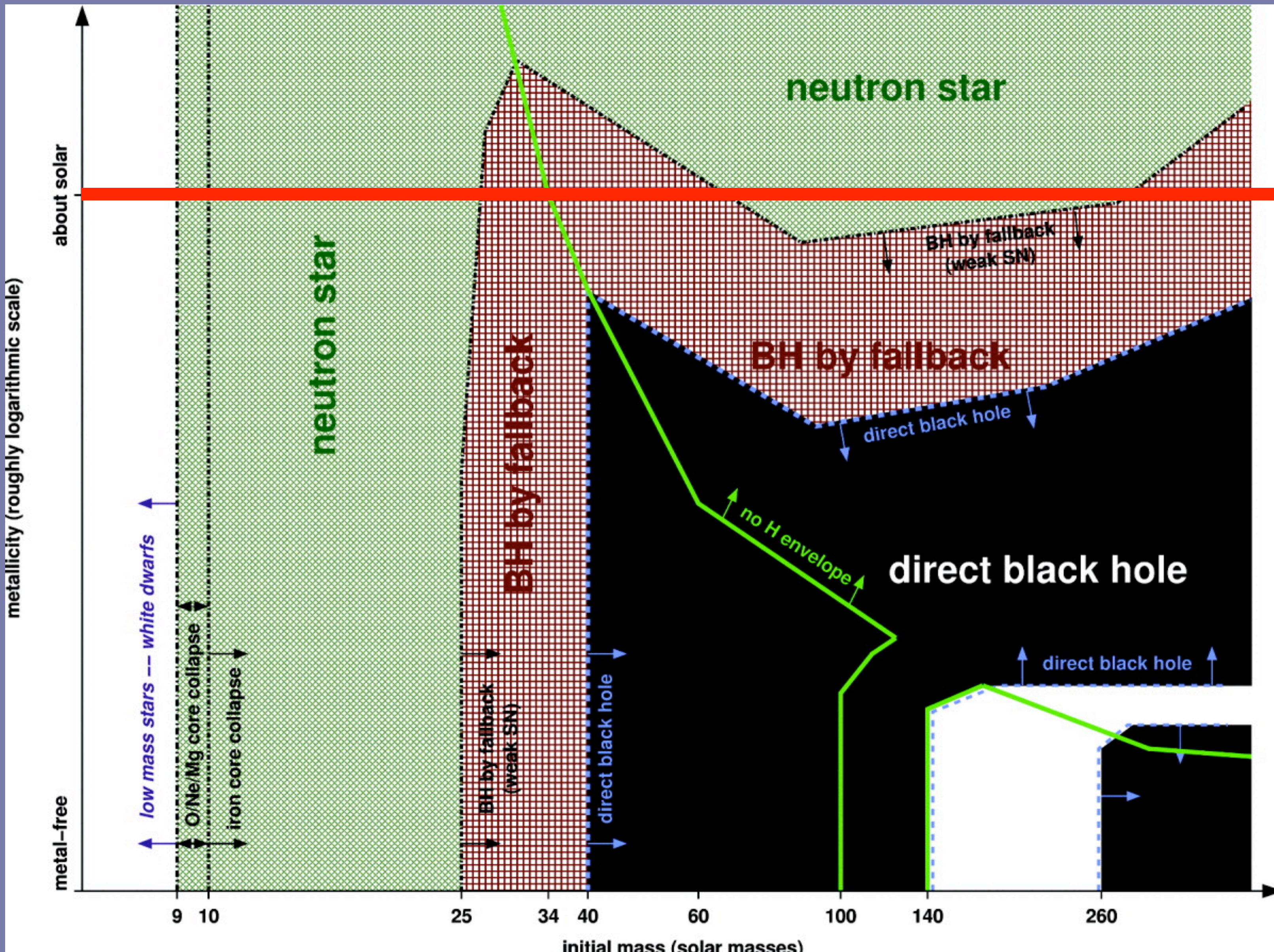


log (Mass) (solar mass)
0
2
4
6
8
35
40
45
log (Luminosity) (erg/s)
0.01 L_Edd
L_Edd
100 L_Edd


log (Mass) (solar mass)
log (Luminosity) (erg/s)
0
2
4
6
8
35
40
45
0.01 L_Edd
L_Edd
100 L_Edd



Heger et al. 2003



neutron star
neutron star
BH by fallback
BH by fallback
BH by fallback (weak SN)
BH by fallback (weak SN)
direct black hole
direct black hole
direct black hole
direct black hole
no H envelope
low mass stars -- white dwarfs
O/Ne/Mg core collapse
iron core collapse
metallicity (roughly logarithmic scale)
about solar
metal-free
9
10
25
34
40
60
100
140
260
initial mass (solar masses)

ULX accreting source models:

-massive population III progenitors

Madau & Rees 2001

-super-Eddington stellar mass BHs

Begelman 2002

-beamed smBH systems

King et al. 2001; Kording et al. 2002

- coalescence of protostars in young cluster

Freitag et al. 2004, 2005

- coalescence of smBH in evolved clusters

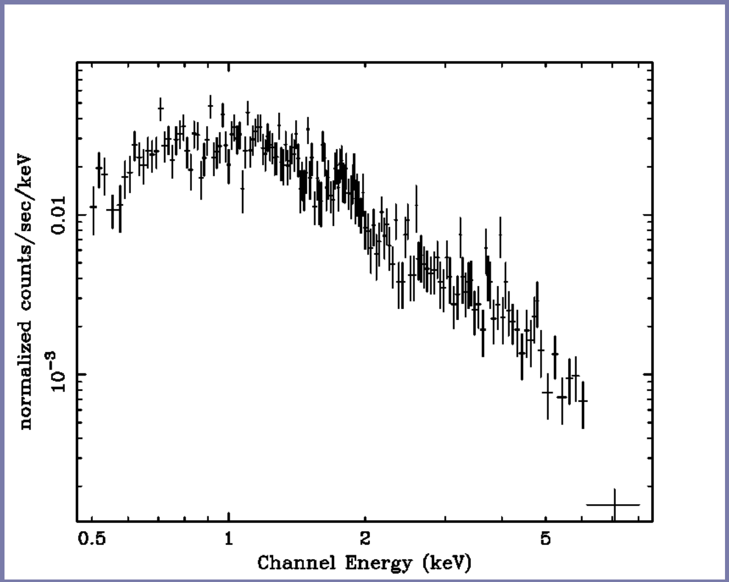
Miller & Hamilton 2002

....also need to form a binary and feed at a high rate

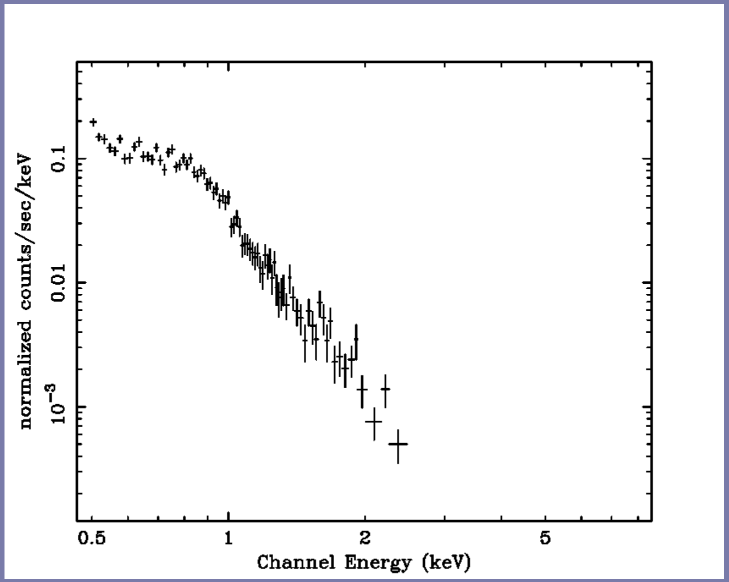
Chandra Archive ULX Survey

Swartz et al. 2004 ApJS 154, 519

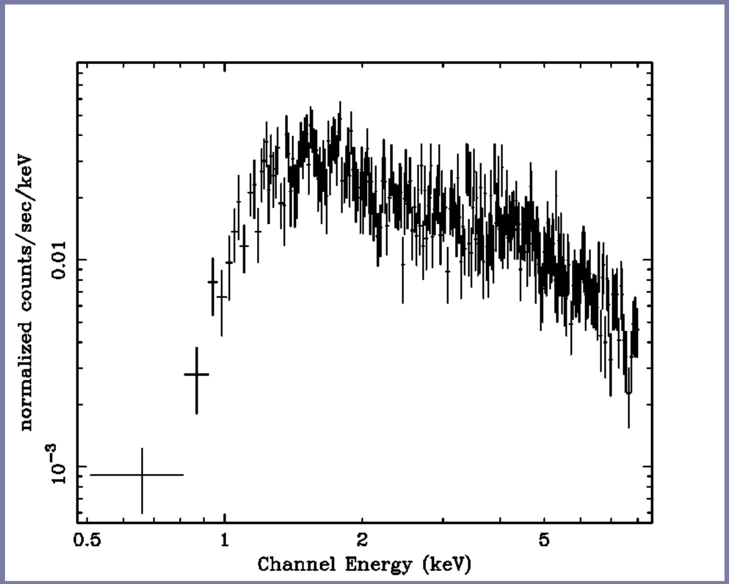
82 Galaxies surveyed, 0.9 – 29 Mpc
3500 X-ray sources detected
1900 estimated with Lx > 10^{38} erg/s
357 with spectral fits
154 ULX candidates



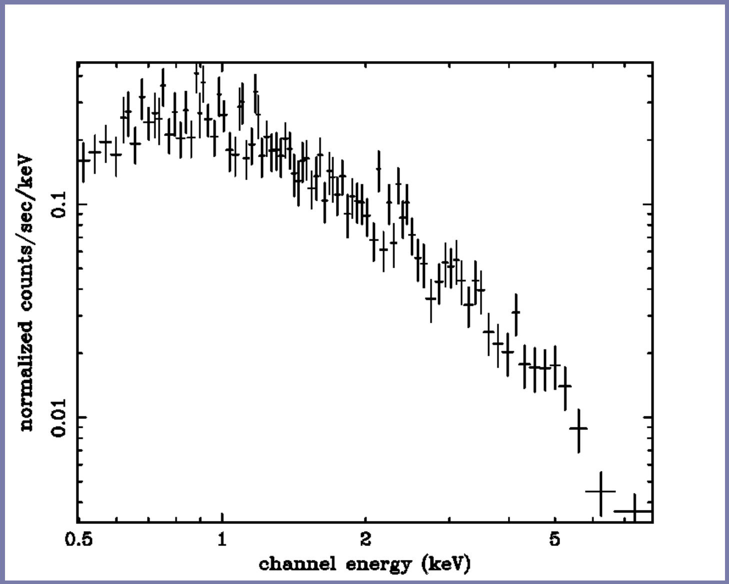
normalized counts/sec/keV
0.01
10^{-3}
0.5
1
2
5
Channel Energy (keV)



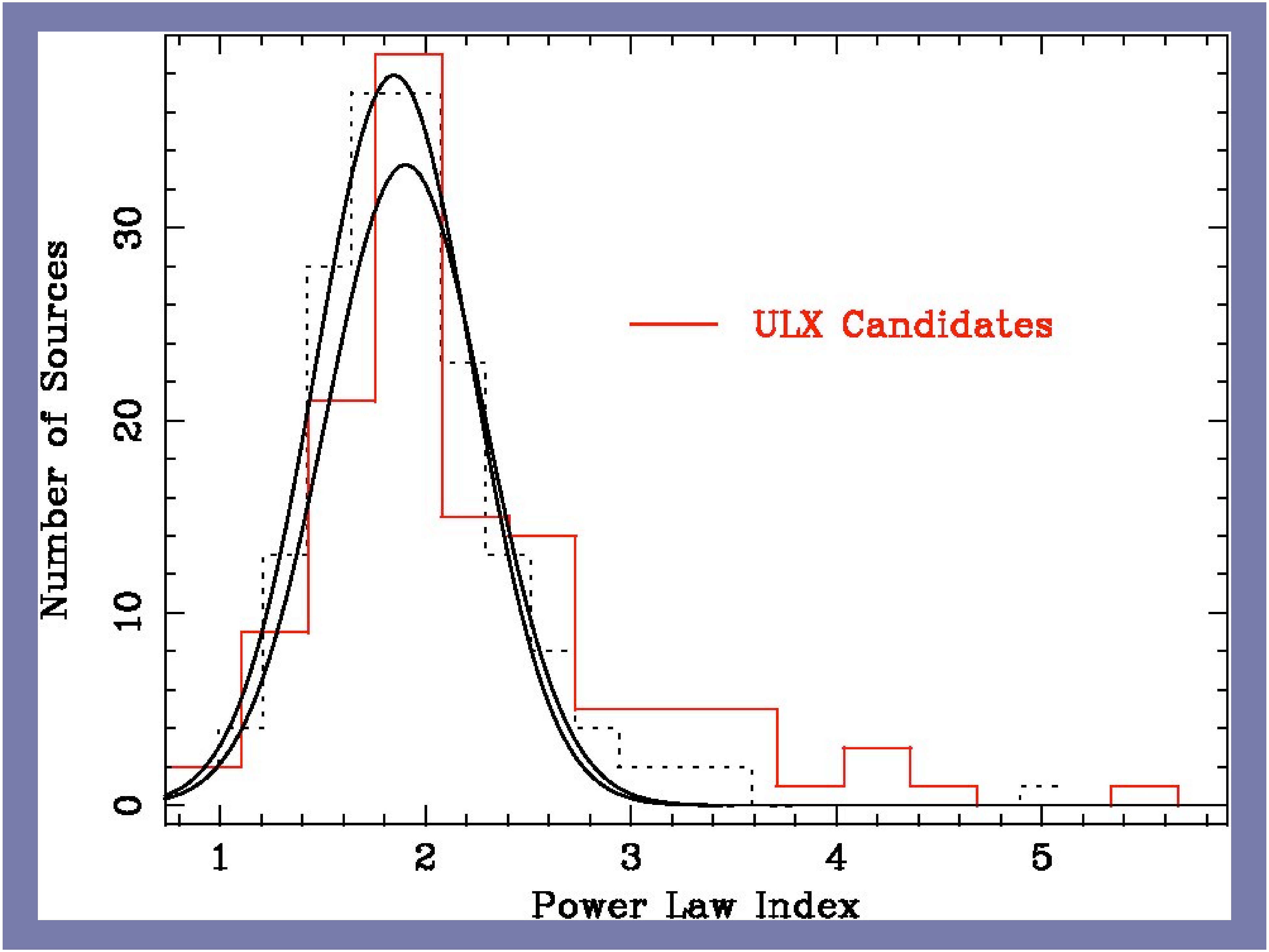
normalized counts/sec/keV
0.1
0.01
10^{-3}
0.5
1
2
5
Channel Energy (keV)



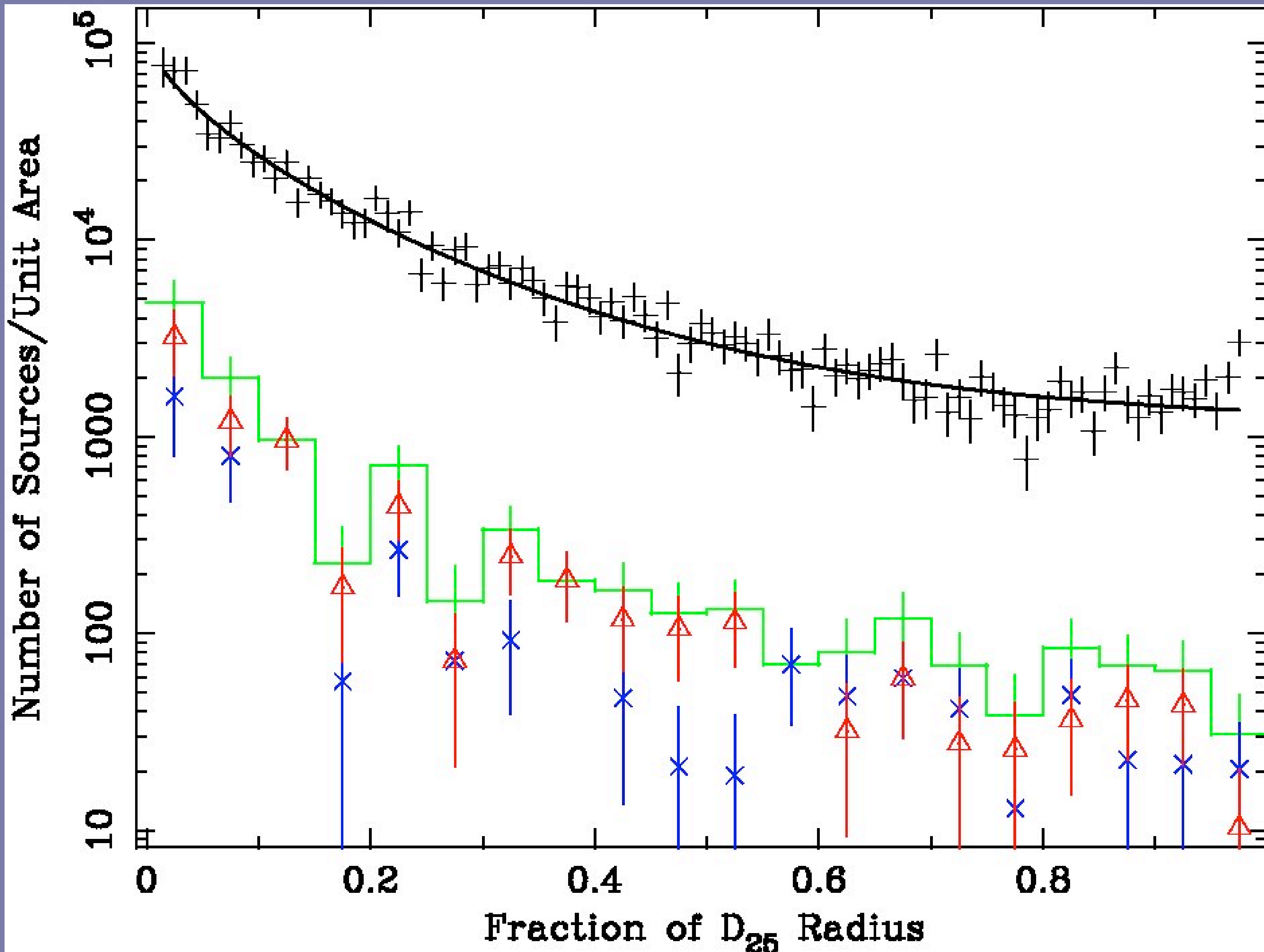
normalized counts/sec/keV
0.01
10^{-3}
0.5
1
2
5
Channel Energy (keV)



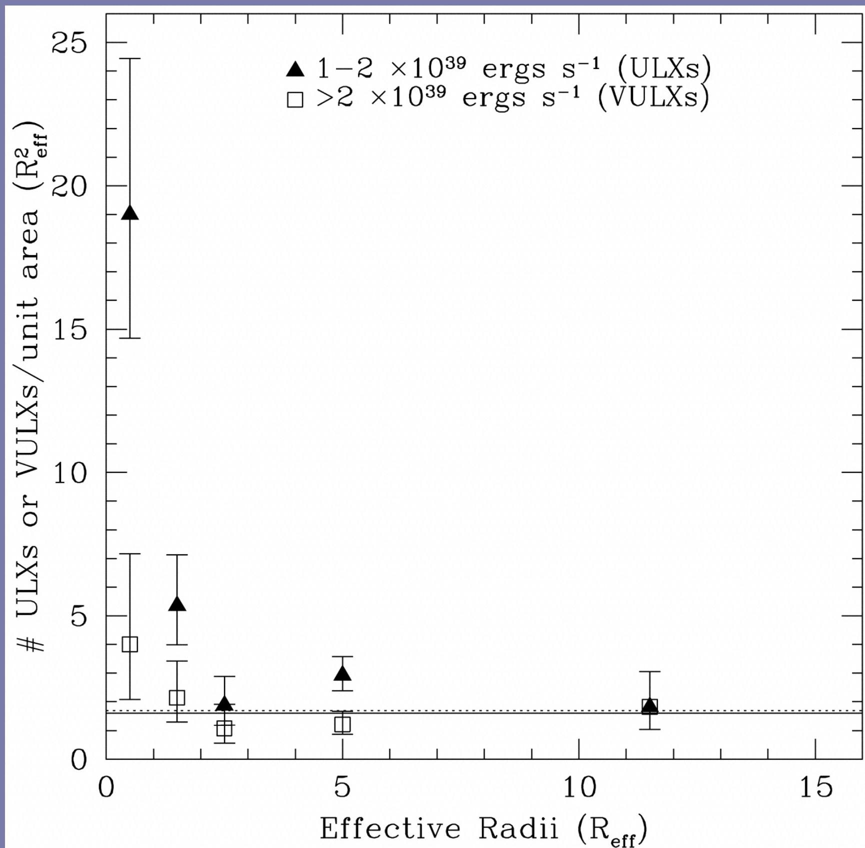
normalized counts/sec/keV
0.1
0.01
0.5
1
2
5
channel energy (keV)

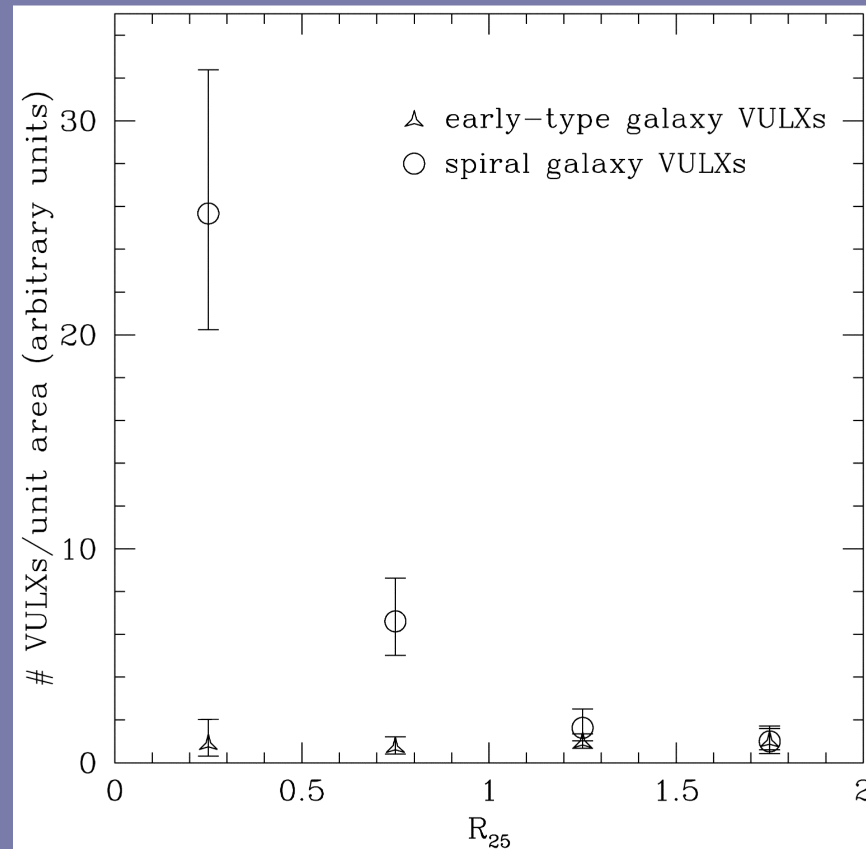


ULX Candidates
Number of Sources
0
10
20
30
1
2
3
4
5
Power Law Index

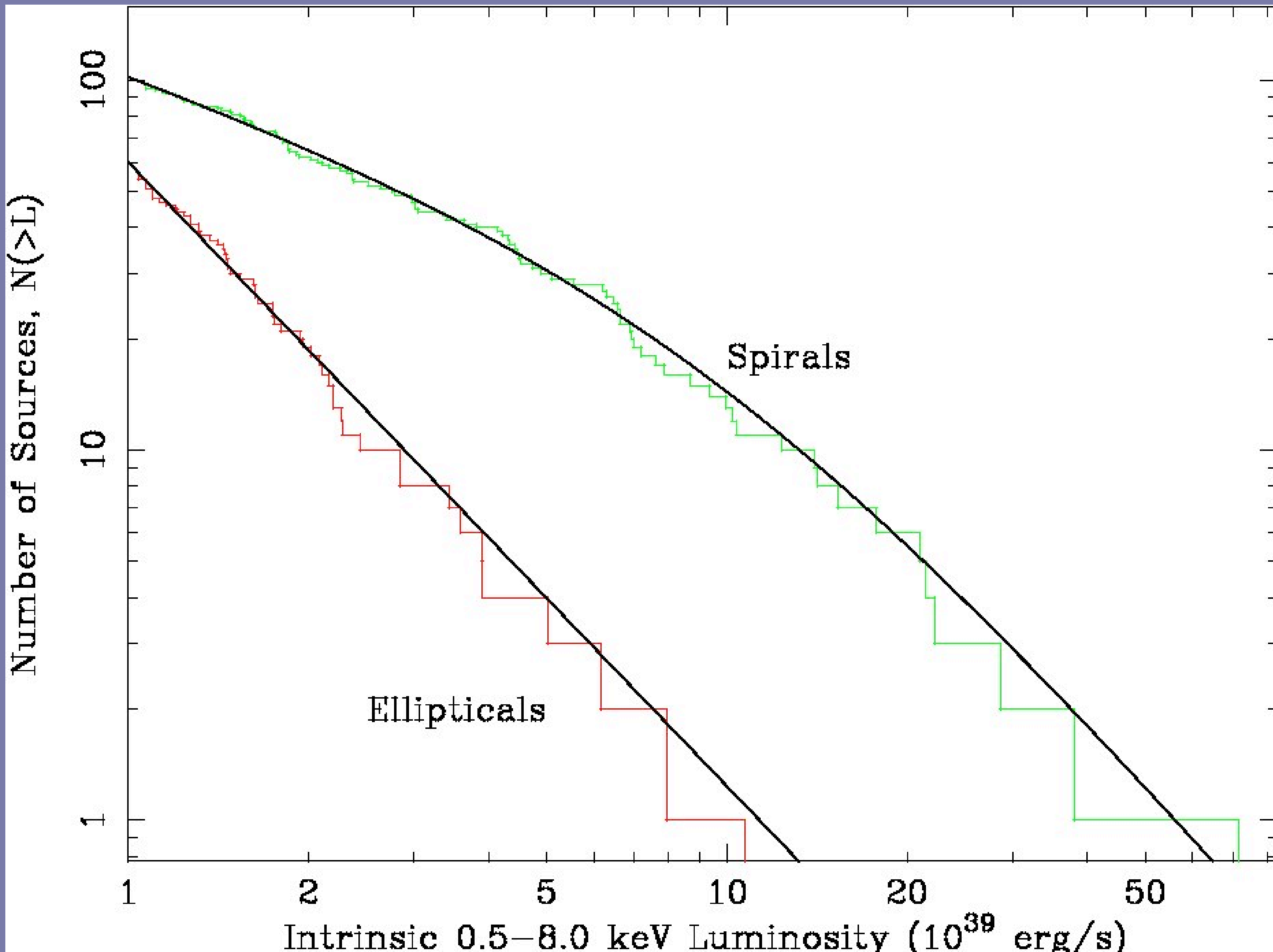


Number of Sources/Unit Area
Fraction of D25 Radius
0
0.2
0.4
0.6
0.8
10
100
1000
10^4
10^5

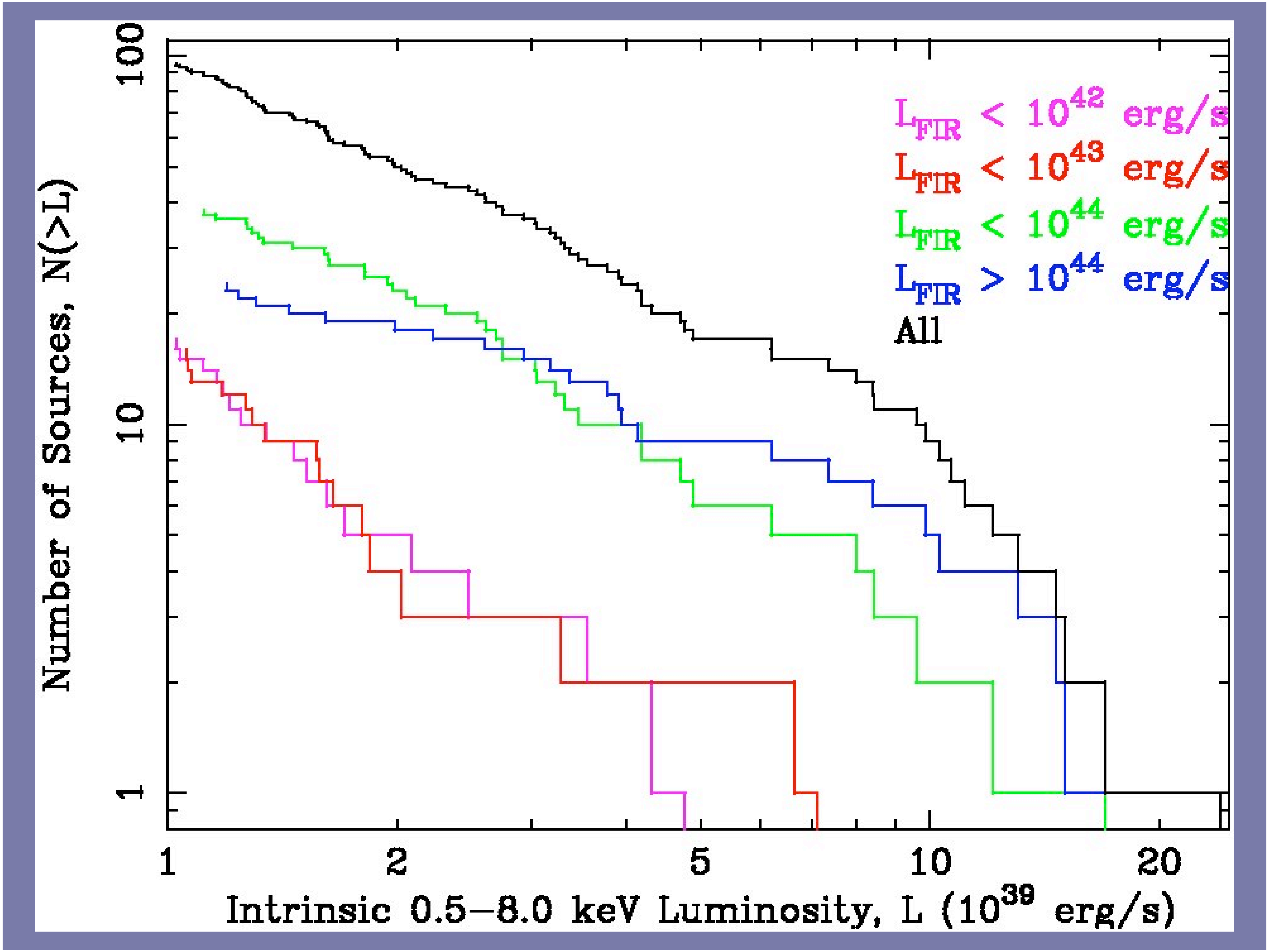




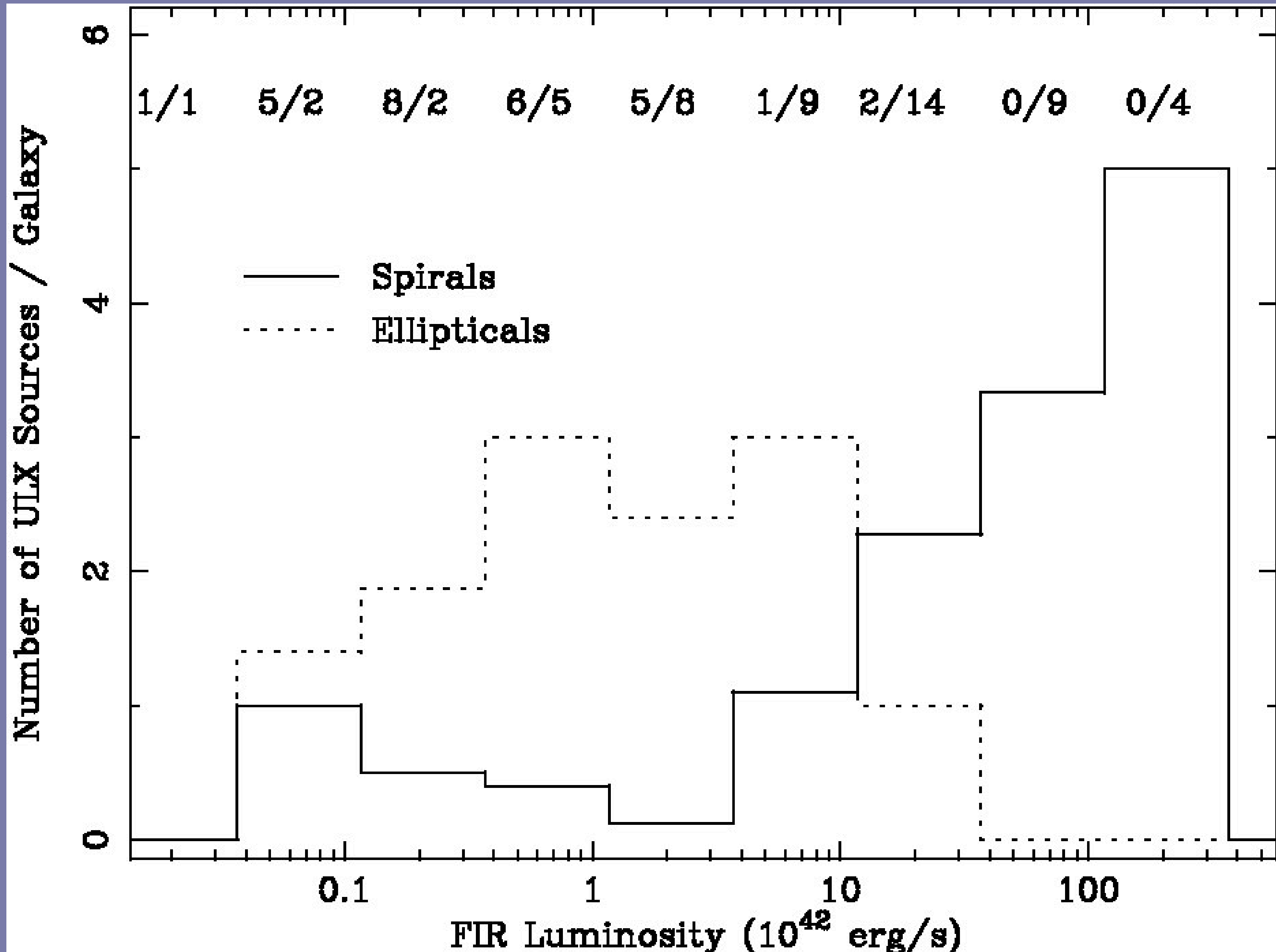
Irwin et al. 2004



Number of Sources, N(>L)
100
10
1
Spirals
Ellipticals
1
2
5
10
20
50
Intrinsic 0.5–8.0 keV Luminosity (10^{39} erg/s)



Number of Sources, N(>L)
100
10
1
1
2
5
10
20
Intrinsic 0.5−8.0 keV Luminosity, L (10^{39} erg/s)
$L_{FIR} < 10^{42}$ erg/s
$L_{FIR} < 10^{43}$ erg/s
$L_{FIR} < 10^{44}$ erg/s
$L_{FIR} > 10^{44}$ erg/s
All


1/1
5/2
8/2
6/5
5/8
1/9
2/14
0/9
0/4
Spirals
Ellipticals
Number of ULX Sources / Galaxy
0
2
4
6
0.1
1
10
100
FIR Luminosity (10^42 erg/s)

LINEAR CORRELATION COEFFICIENTS

	All	Ellip.	Spiral
$N_{\rm ULX}$,$L_{\rm B}$	0.74	0.89	—
$N_{\rm ULX}$,$L_{\rm FIR}$	0.63	—	0.88
$N_{\rm ULX}$,θ_p	—	—	(-.54)
$L_{\rm ULX}$,$L_{\rm B}$	—	0.82	—
$L_{\rm ULX}$,$L_{\rm FIR}$	0.57	—	0.88
$L_{\rm ULX}$,θ_p	—	—	(-.54)
$L_{\rm ULX}/N_{\rm ULX}$,$L_{\rm B}$	—	0.86	—
$L_{\rm ULX}/N_{\rm ULX}$,$L_{\rm FIR}$	—	—	0.82
$L_{\rm ULX}/L_{\rm B}$,$L_{\rm FIR}/L_{\rm B}$	0.80	—	0.99
$N_{\rm ULX}/L_{\rm B}$,$L_{\rm FIR}/L_{\rm B}$	0.56	—	0.97
$(L_{\rm ULX}/N_{\rm ULX})/L_{\rm B}$,$L_{\rm FIR}/L_{\rm B}$	—	—	0.90

NOTE.–Parentheses denote marginally significant correlation, dash denotes no correlation

Survey Conclusions:

- ULXs are similar to lower-luminosity sources

- ULXs in spiral galaxies
  are luminous (up to $6x10^{40}$)
  correlate with high star-formation rates (HMXB)
  ....beaming, coalescence in protostar clusters

- ULXs in elliptical galaxies
  are about 1/2 background AGN
  remainder are under luminous (<few 10^{39})
  correlate with galaxy mass (LMXB)
  ....SXT, microquasars, BH coalescence in GCs

Survey Limitations:

- **X-ray selected sample based on Chandra archive**

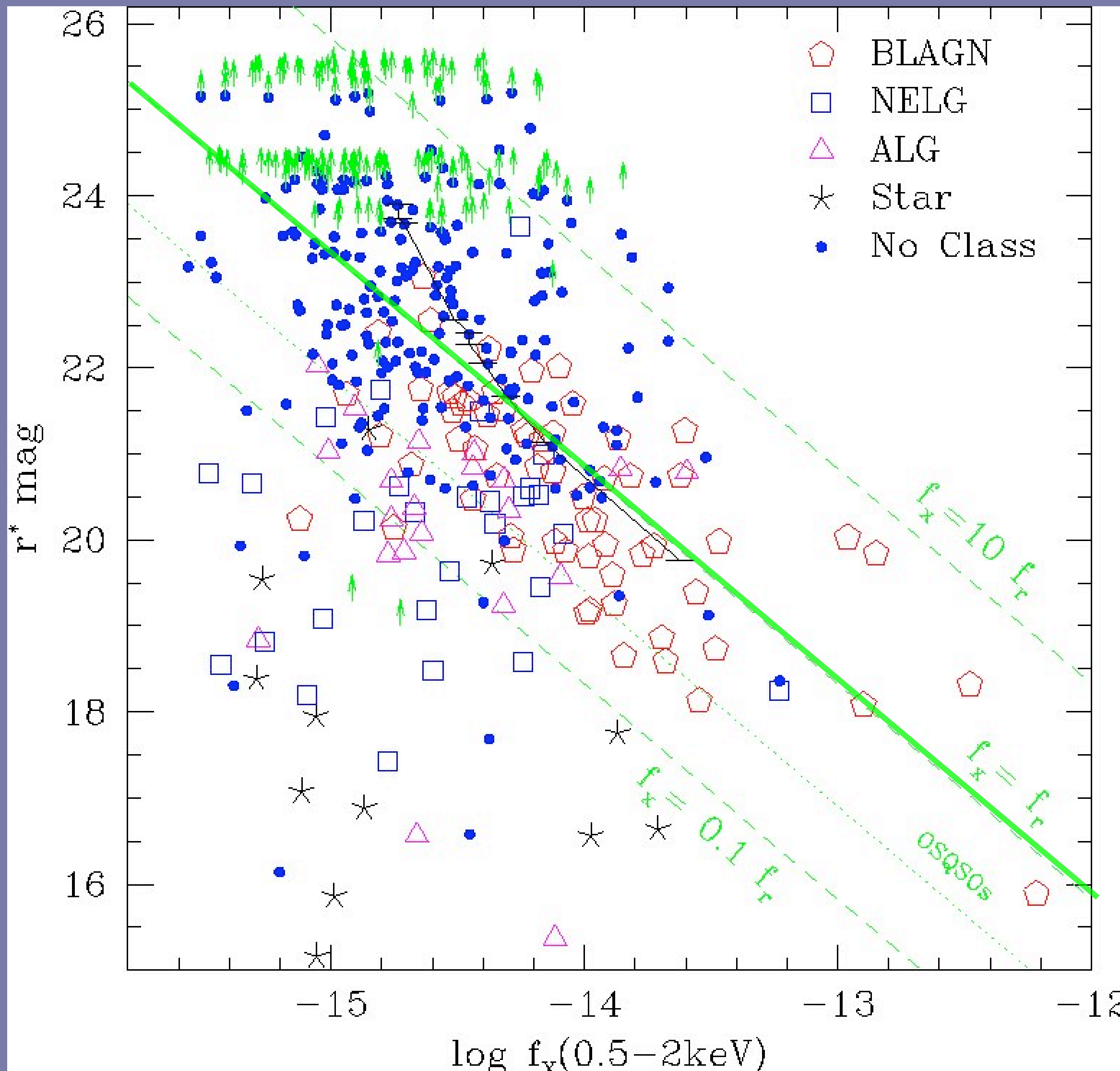
  ...favors large, nearby, optically-bright, massive galaxies

- **Lacks long-term temporal information**

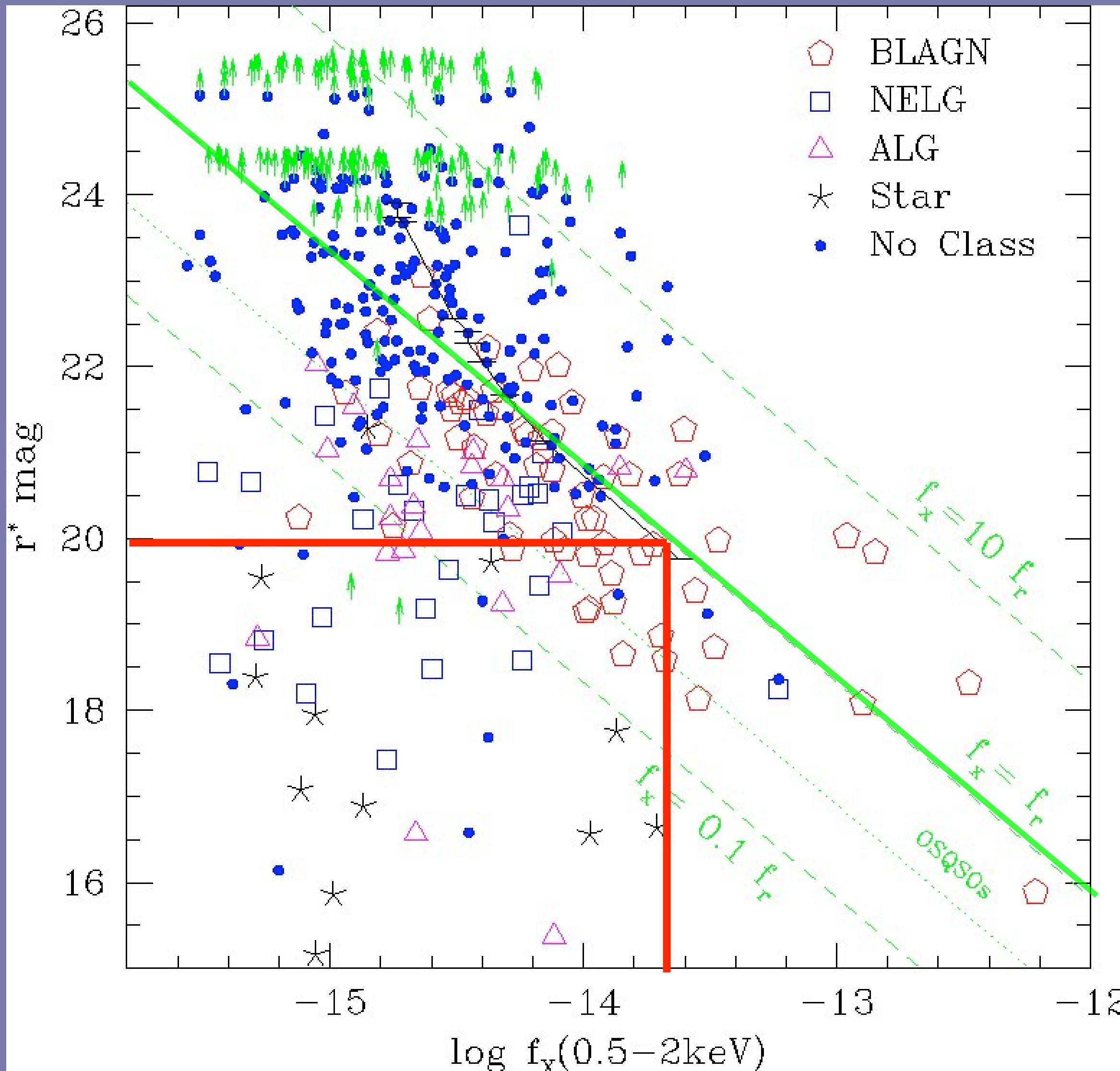
  ...insensitive to state transitions seen in Galactic XRBs

- **Lacks supplemental broad-band coverage**

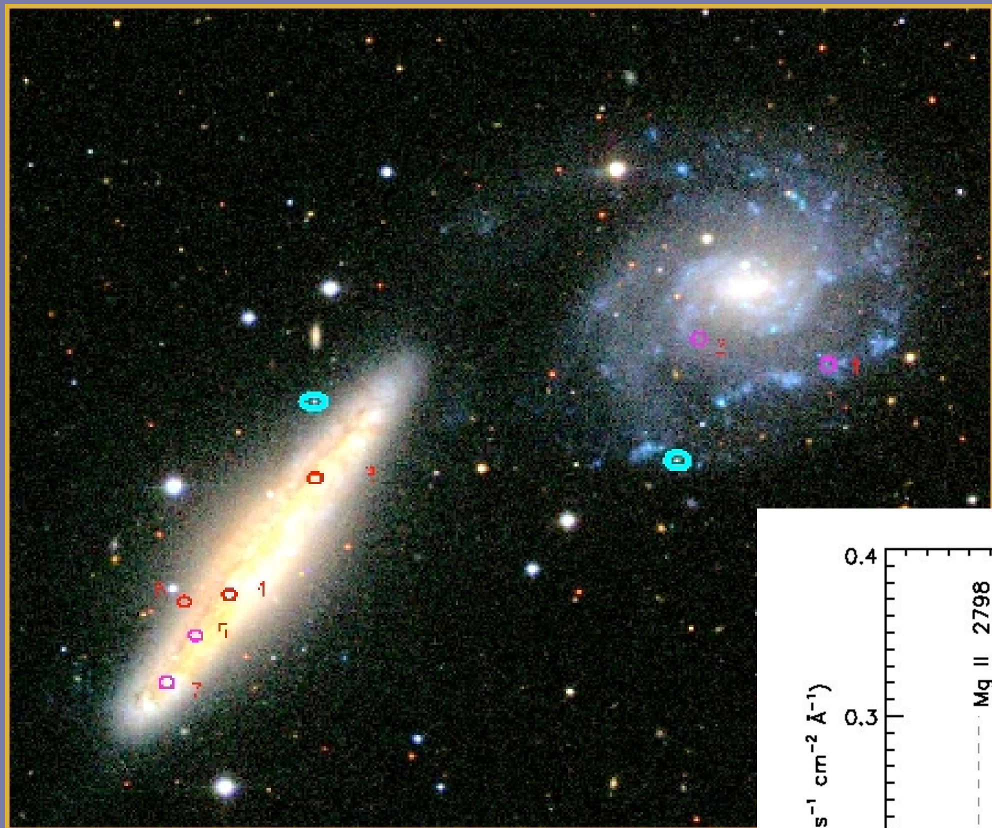
  ...source classes cannot easily be distinguished by X-rays alone

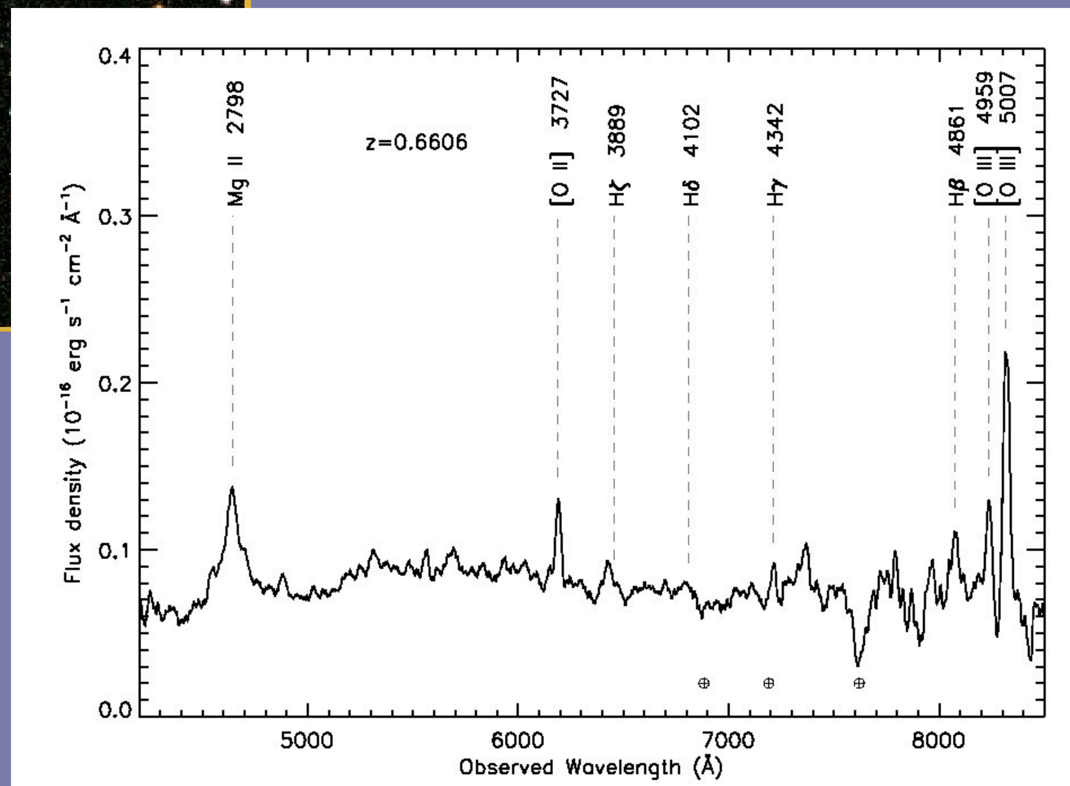


Green et al. 2004



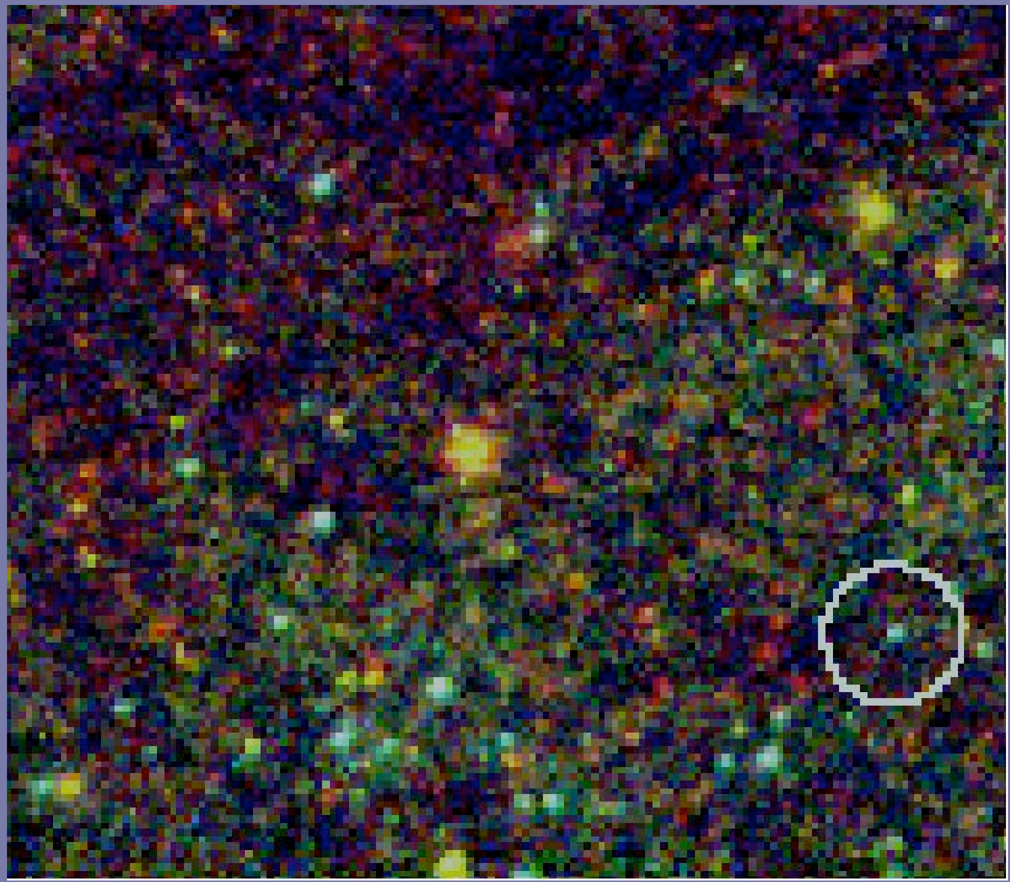
$\uparrow$ 10^{39} erg/s source at 20 Mpc





NGC 5774/5

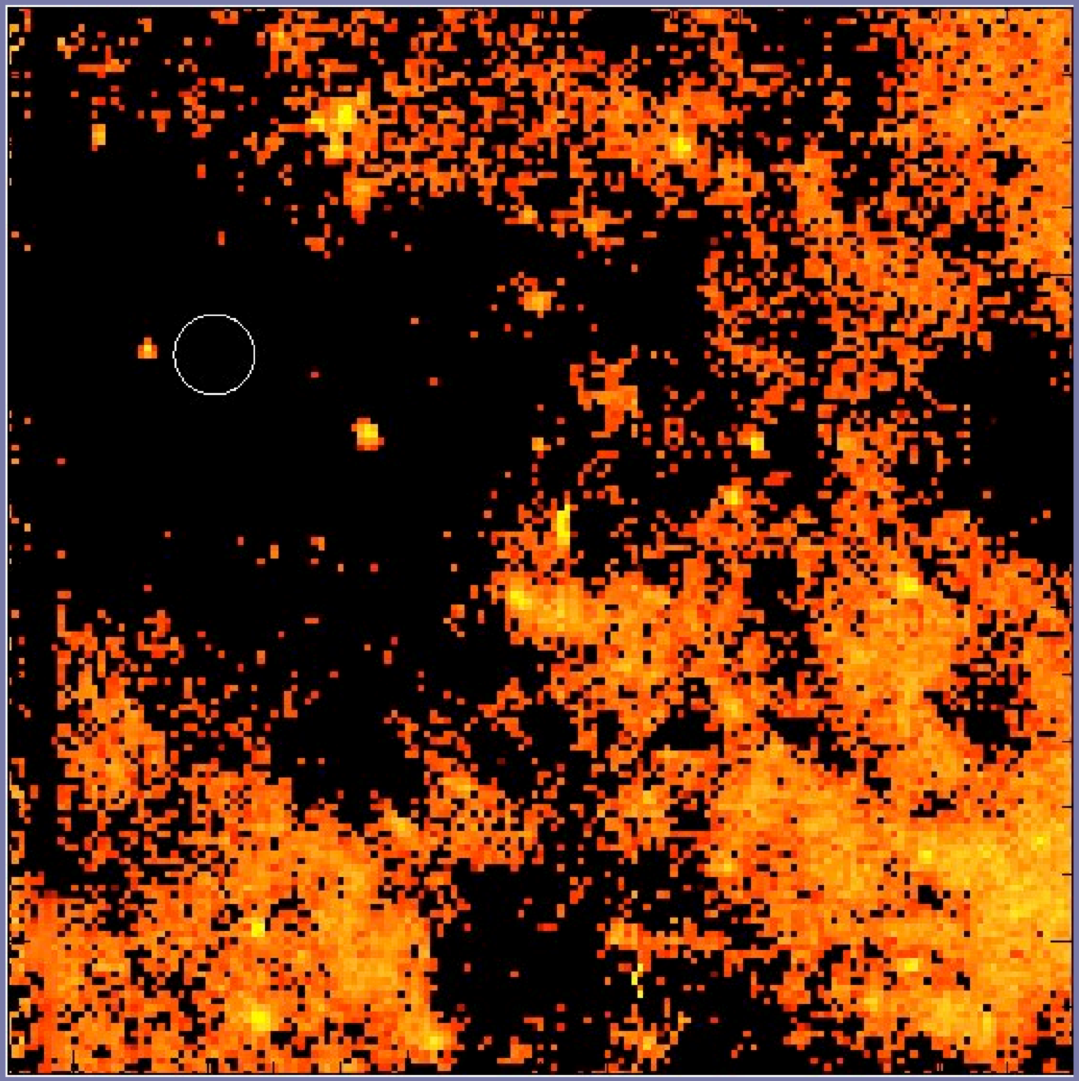
Ghosh et al. in prep.



Swartz et al. 2003

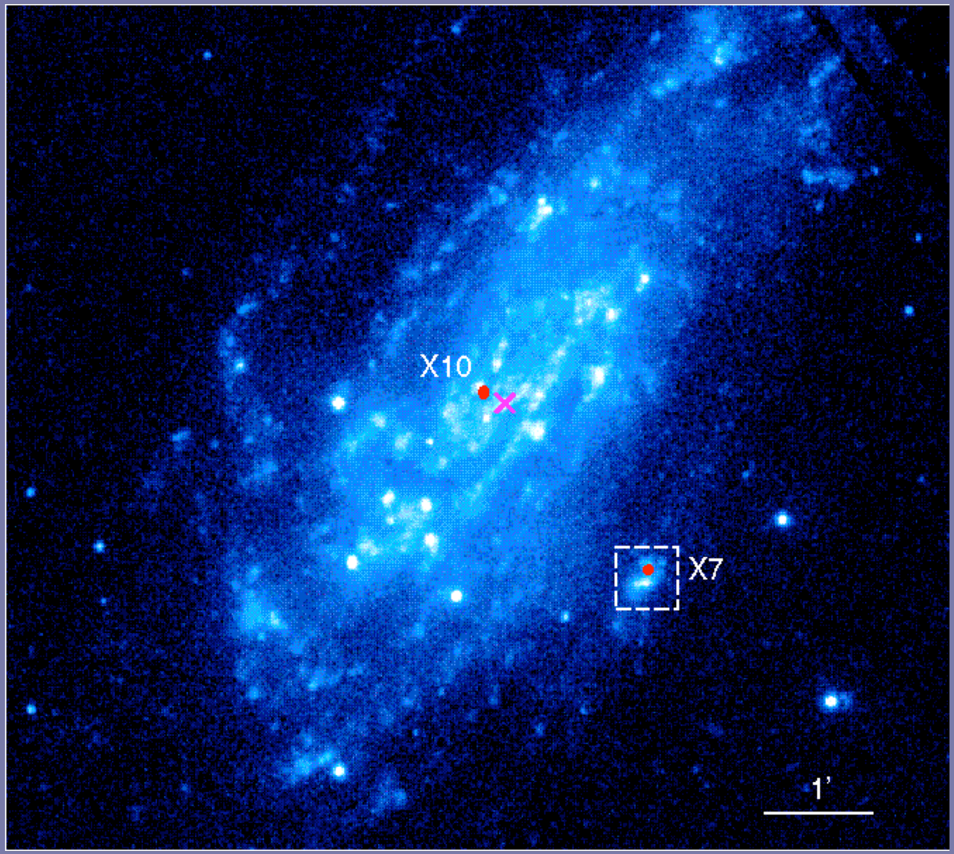
M81 X-6

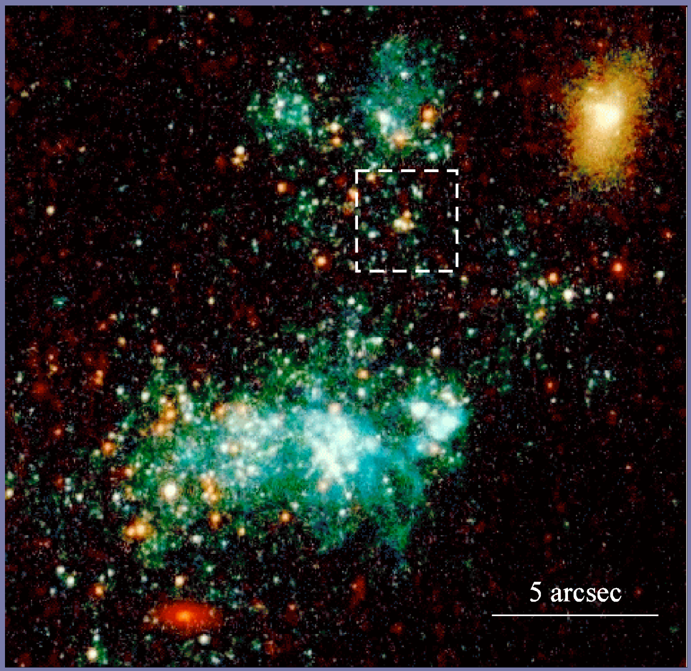
N5204	B0 Ib	Goad 2002, Liu 2004
M81 X-6	O8V,O9 - B1V	Liu 2002, Swartz 2003
Ho II	O4V - B3 Ib	Kaaret 2004
M101 X-1	mid B Iab	Kuntz 2005

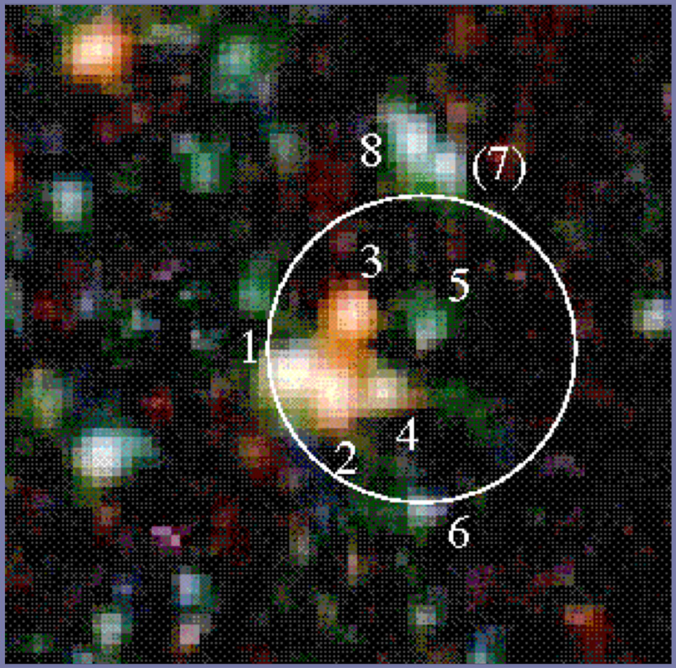


NGC 3628

V > 26 mag

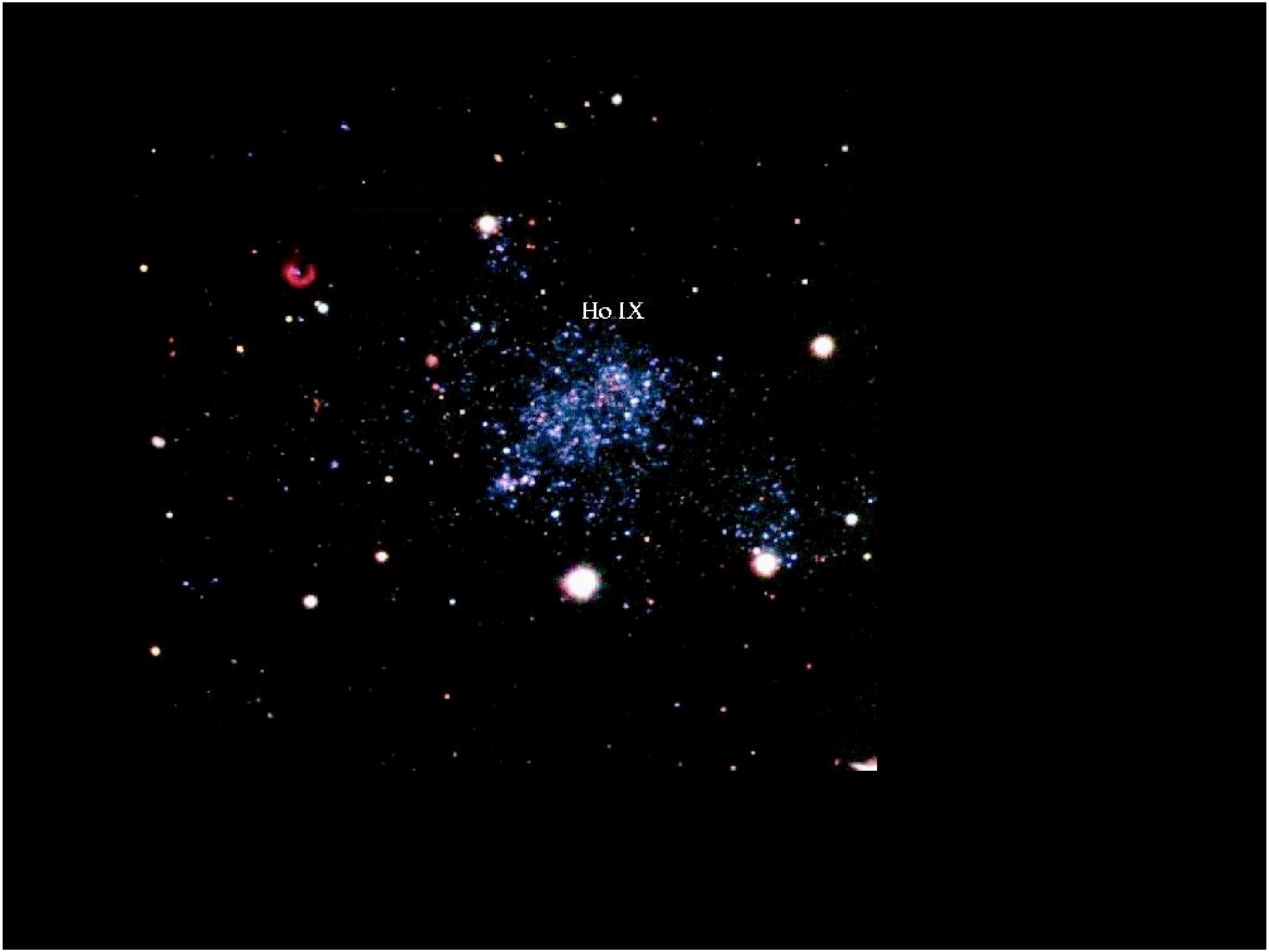


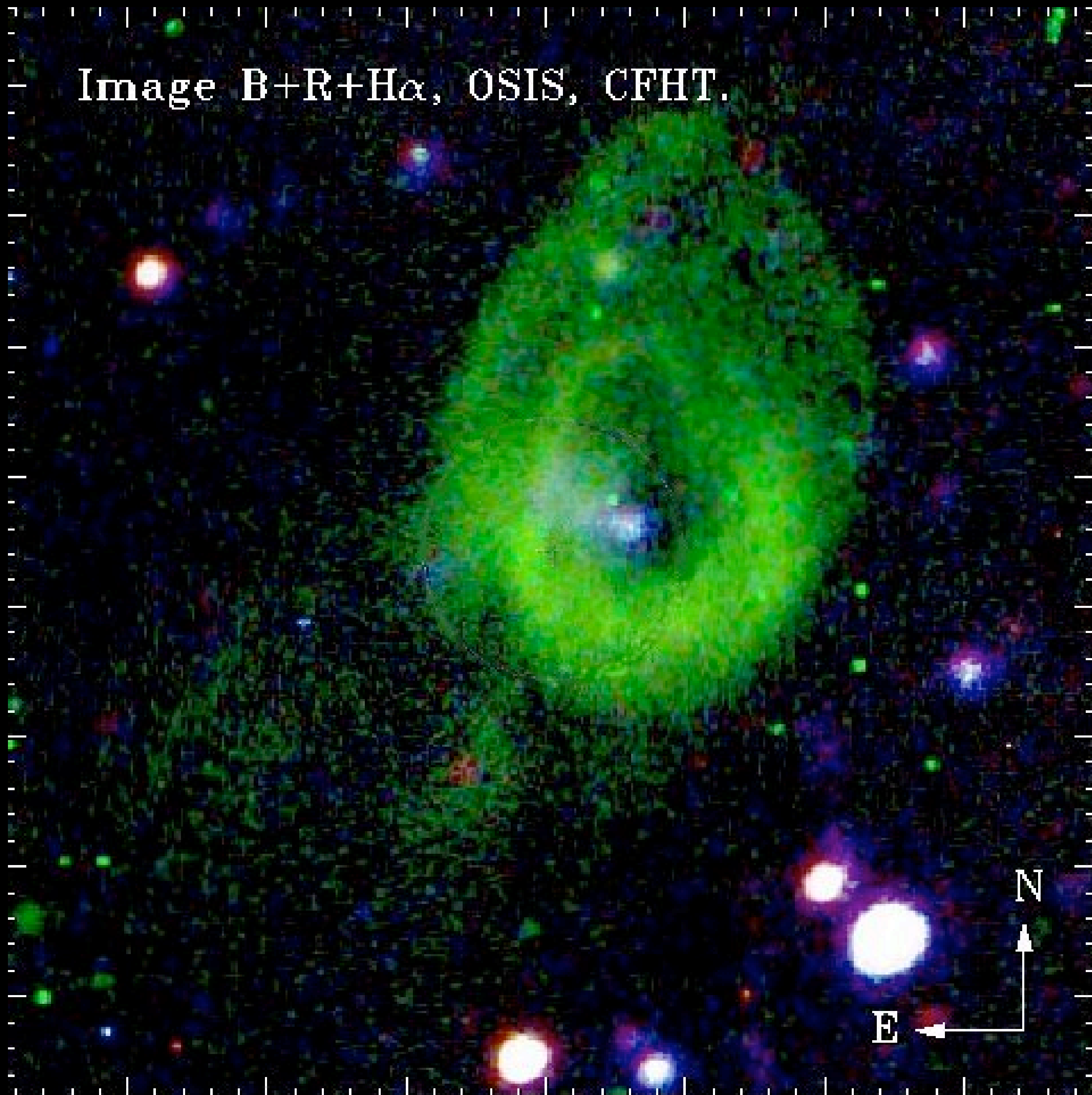




NGC 4559 X-7

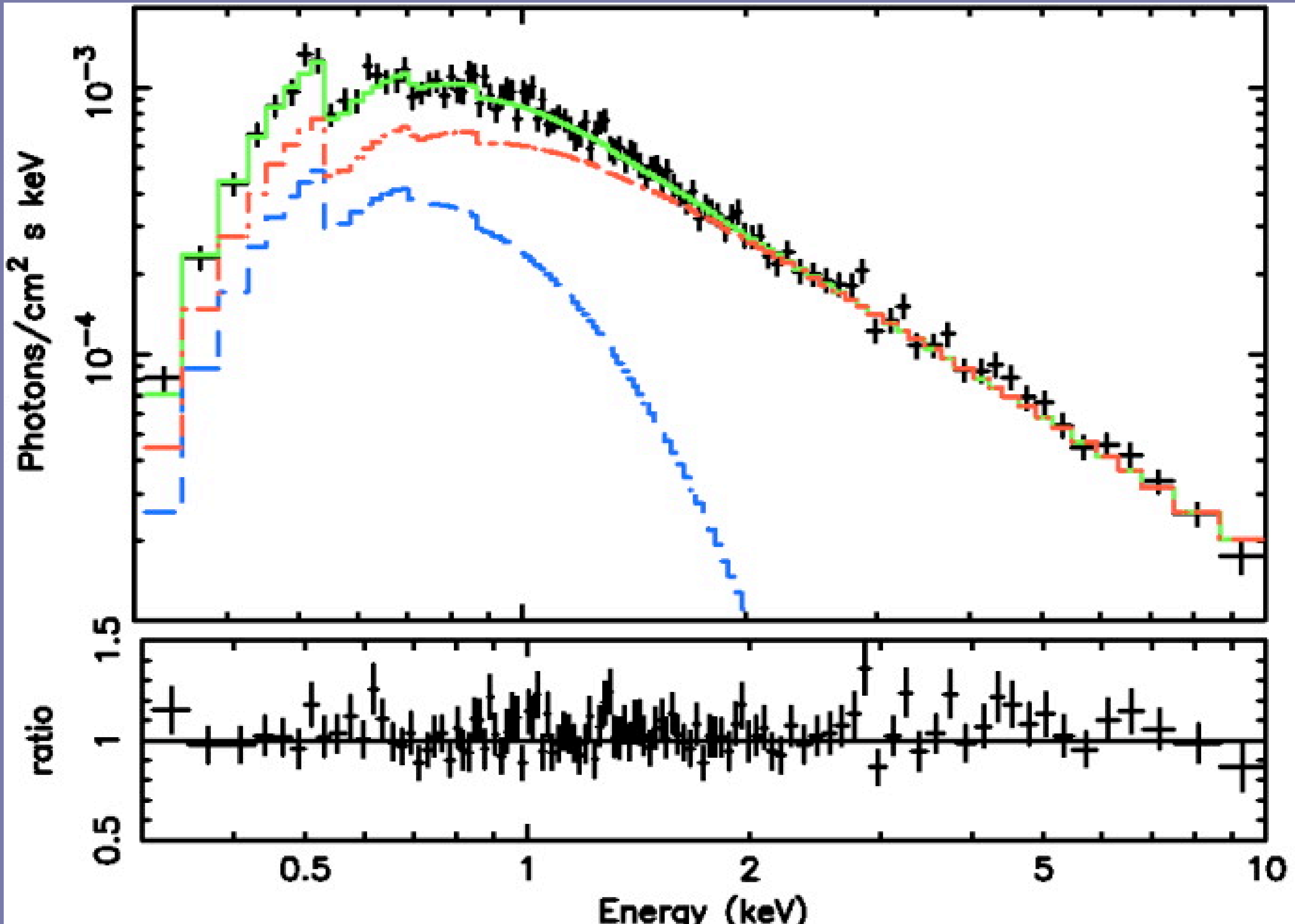
Soria et al. 2004


Ho IX

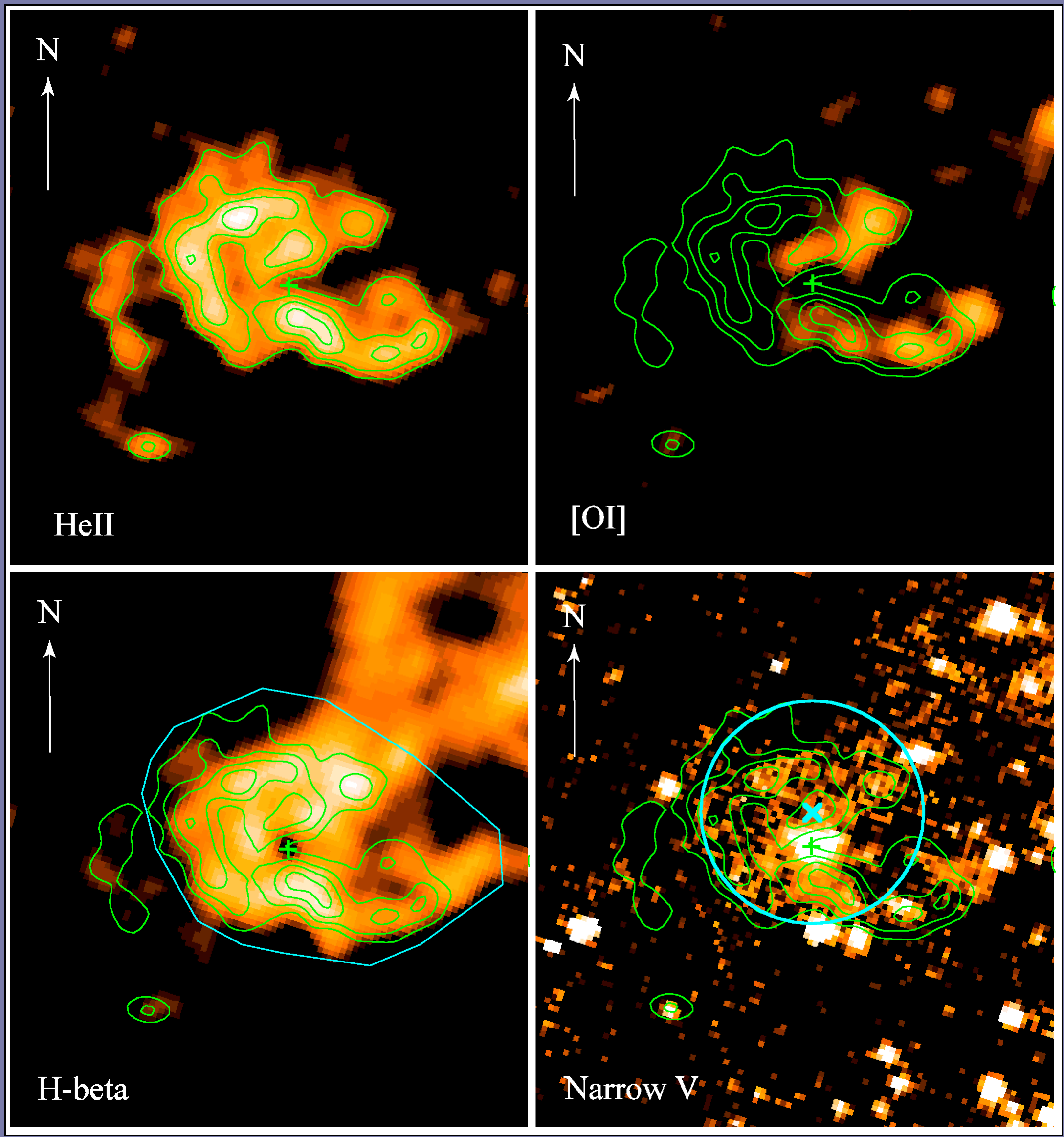


Mirioni Thesis (2002)

HoIX X-1

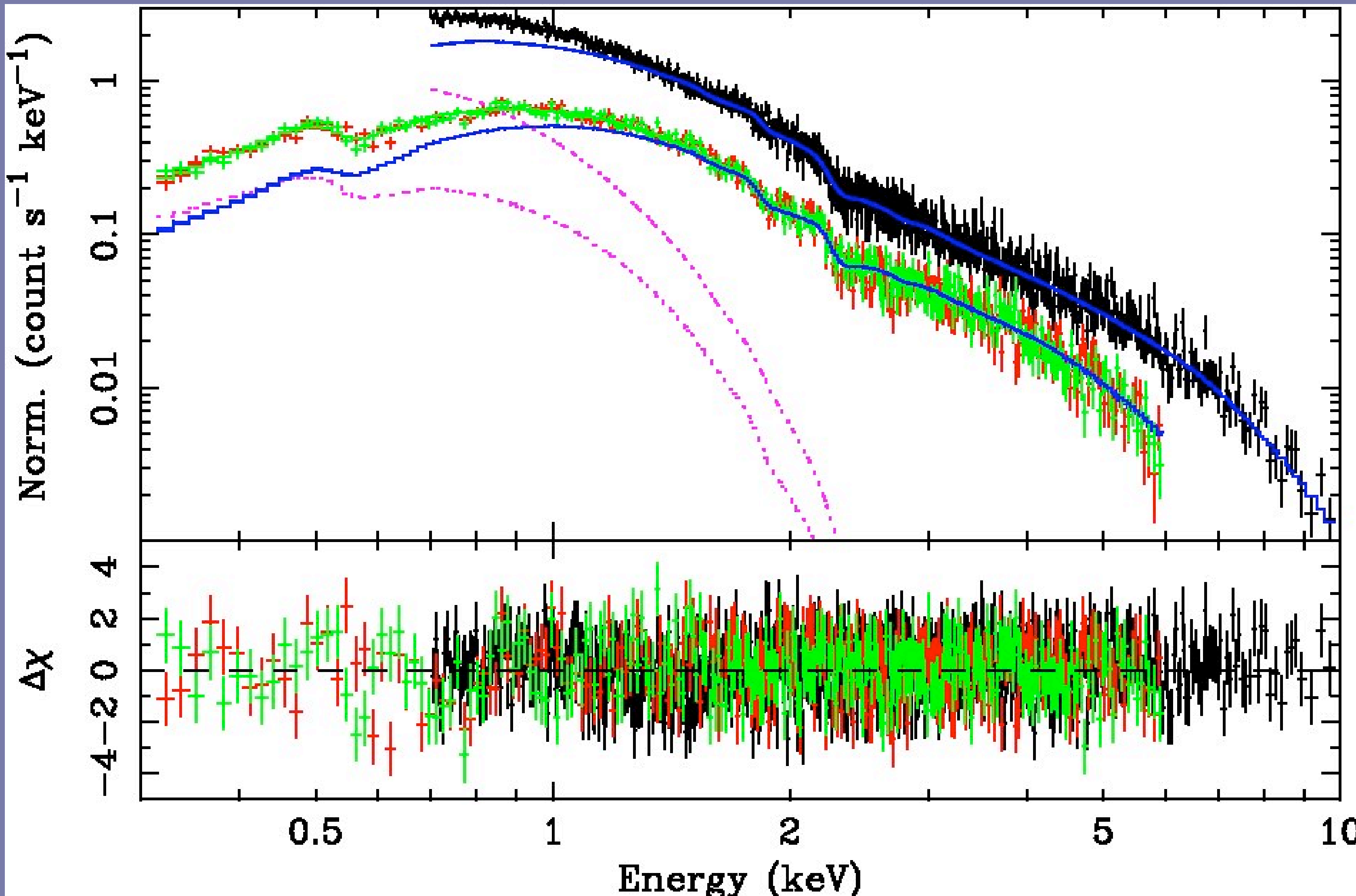


Miller, Fabian & Miller 2004



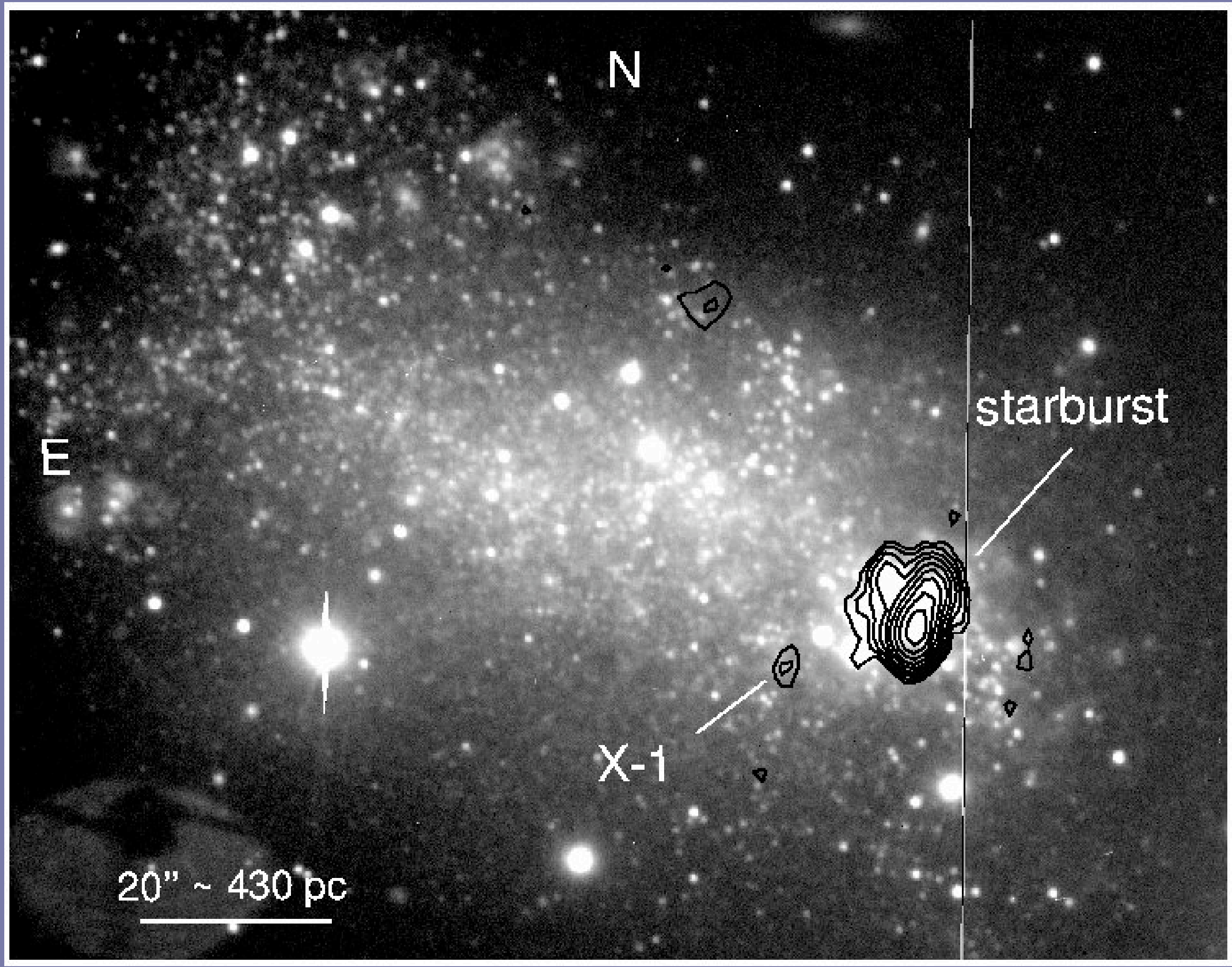
Kaaret, Ward & Zezas 2004

Ho II



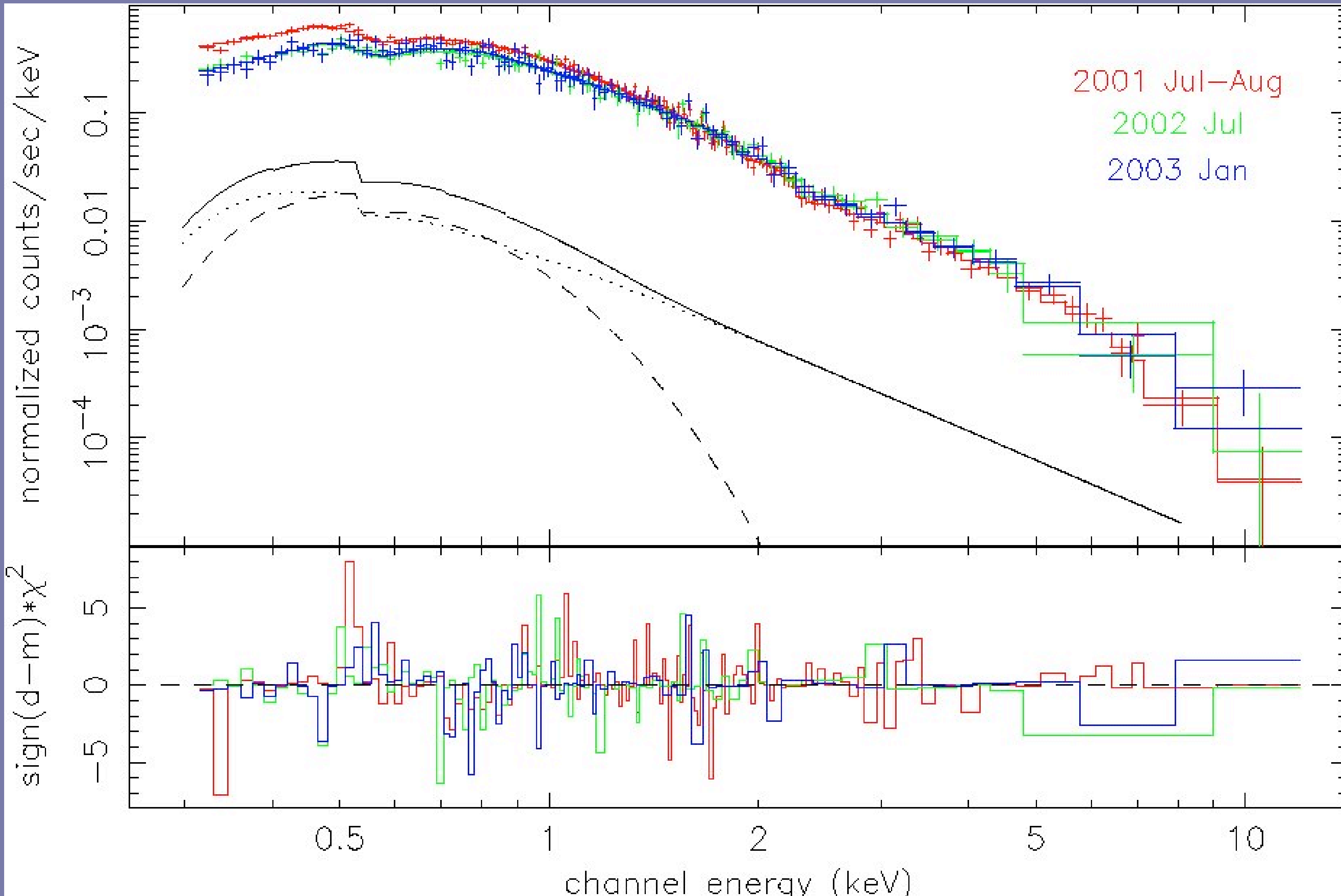
Goad et al. 2005

Ho II



Soria et al 2005

NGC 5408



Soria et al. 2004

NGC 5408

Outlook

- Build a cleaner sample
  cull the AGNs, ‘normal’ XRBs, and SNe

- Constrain masses and emission mechanisms
  using X-ray timing/spectra and broadband data

- Understand how ULXs affect and are affected by
  local environment

Luminous X-ray sources are not common objects. Consequently, it is useful to study these objects to improve statistical estimates, to better define the extremes of the phenomenon, to determine the dependence of the probability of X-ray source formation upon the stellar population and galactic morphology, and possibly to discover new classes of these rare objects...

Long & Van Speybroeck, 1983