X-ray emission from star-forming galaxies

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Ultra-Luminous X-ray sources and Middle Weight Black Holes
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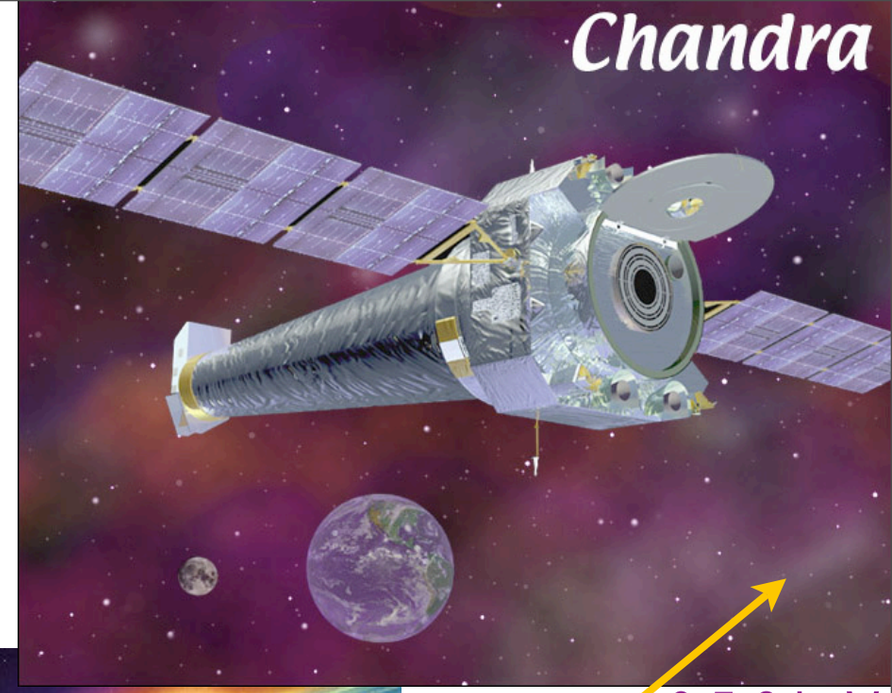
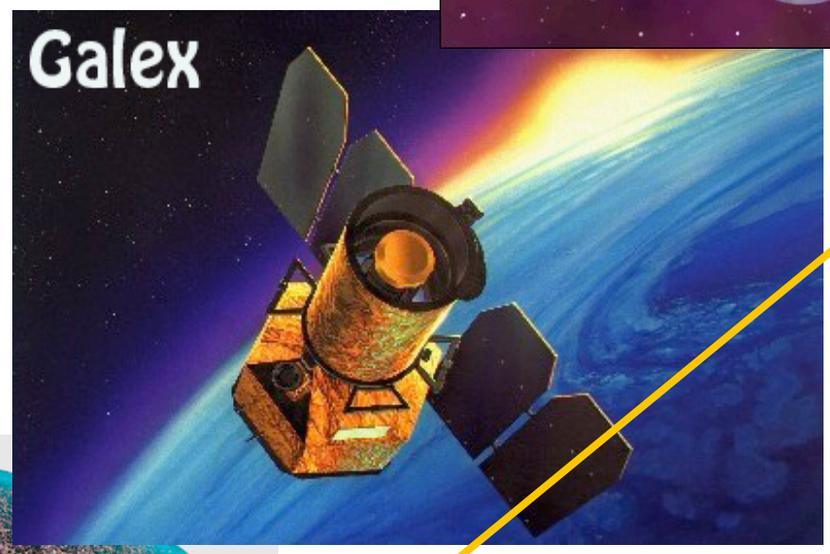
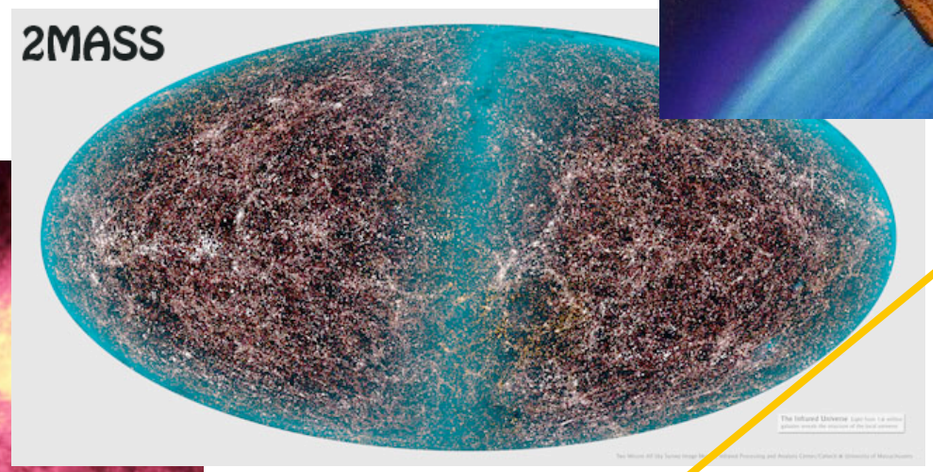
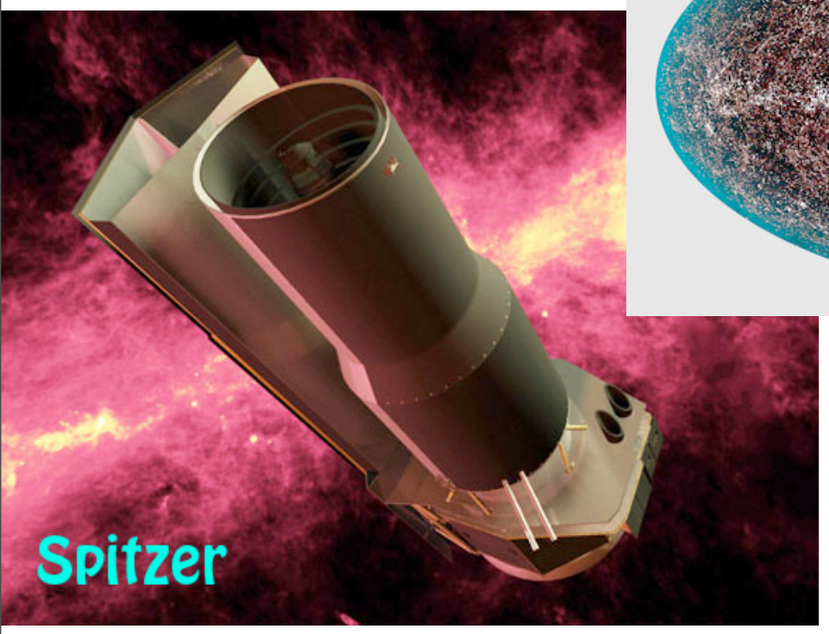
Science goals

- L_X-SFR relation for compact sources and diffuse gas
- luminosity function of high-mass X-ray binaries (HMXBs)
- ultra-luminous X-ray sources (ULXs)









0.5-8 keV

NUV (2312 Å)
FUV (1529 Å)

multiwavelength study of archival data

NIR
2.16μm

FIR
70μm
24μm

Motivation

PREVIOUS WORKS:
Grimm et al. (2003), Ranalli et al. (2003), Gilfanov et al. (2004), Persic et al (2004), Shtykovskiy & Gilfanov (2005), Persic & Rephaeli (2007)

- discrepancy between L_X-SFR calibrations derived by different authors
- presence of dispersion around L_X-SFR relation
- compilation of X-ray data and inhomogeneous SFR estimators

NOWADAYS:
large number of galaxies available in the archives of Chandra, Spitzer and GALEX

⇓

uniform and large sample of star-forming galaxies
significative improvement of statistics
homogeneous SFR estimators

- dispersion around the L_X-SFR relation found in earlier studies
- how many NS and BH end up in a binary system?
- are there features at the L_{Edd} of NS and BH systems?
- constrain the shape of the luminosity distribution of ULXs

Sample selection

Sample selection criteria

- Hubble Type: $T > 0$ (S and Irr) $\Rightarrow$ star-forming
- specific SFR: $\frac{SFR}{M_\star} > 1 \times 10^{-10}\mathrm{yr}^{-1}$ $\Rightarrow$ HMXB dominated

  τ_{HMXB}~10-50 Myr $\Rightarrow$ $N_{HMXB} \propto$ SFR (Grimm, Gilfanov & Sunyaev 2003)

  τ_{LMXB}~1-10 Gyr $\Rightarrow$ $N_{LMXB} \propto M_\star$ (Gilfanov 2004)

- X-ray source detection sensitivity: $L_{lim} < 5\text{x}10^{37}$ erg/s

- distance:

Resolved galaxies: $D < 30$ Mpc, discriminate AGN, low SFR, $L_{TOT}=\Sigma L_i \Rightarrow$ 29 galaxies

Unresolved galaxies: $D > 100$ Mpc, high SFR, spectra $\Rightarrow$ 8 galaxies (5 ULIRGs, 2 LIRGs)

37 star-forming galaxies

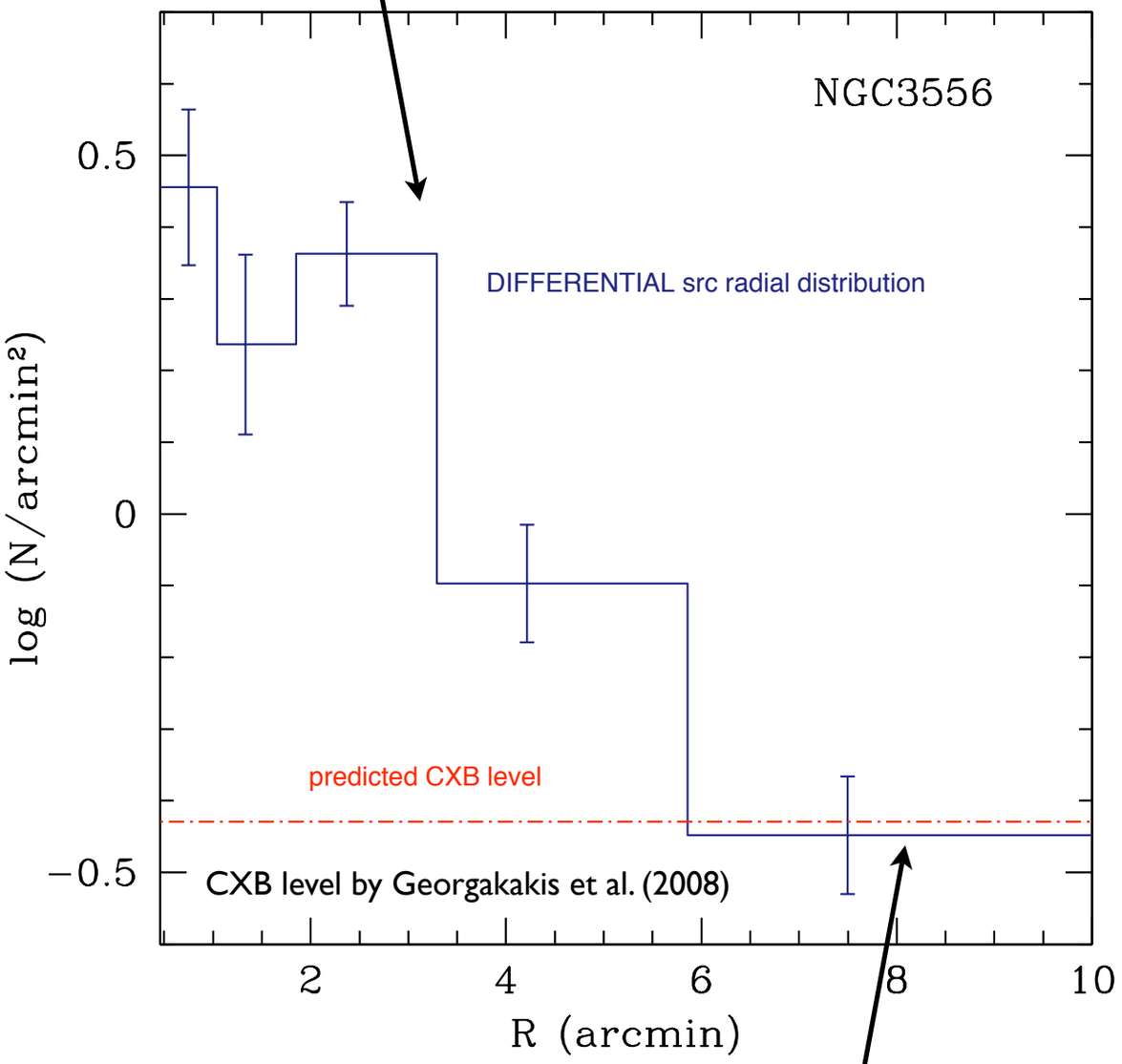
0.1 < SFR < 400 M_{sun}/yr

~700 resolved HMXBs

Spatial analysis: minimizing the CXB contribution

central regions

- high surface density of XRBs
- negligible contribution of CXB sources



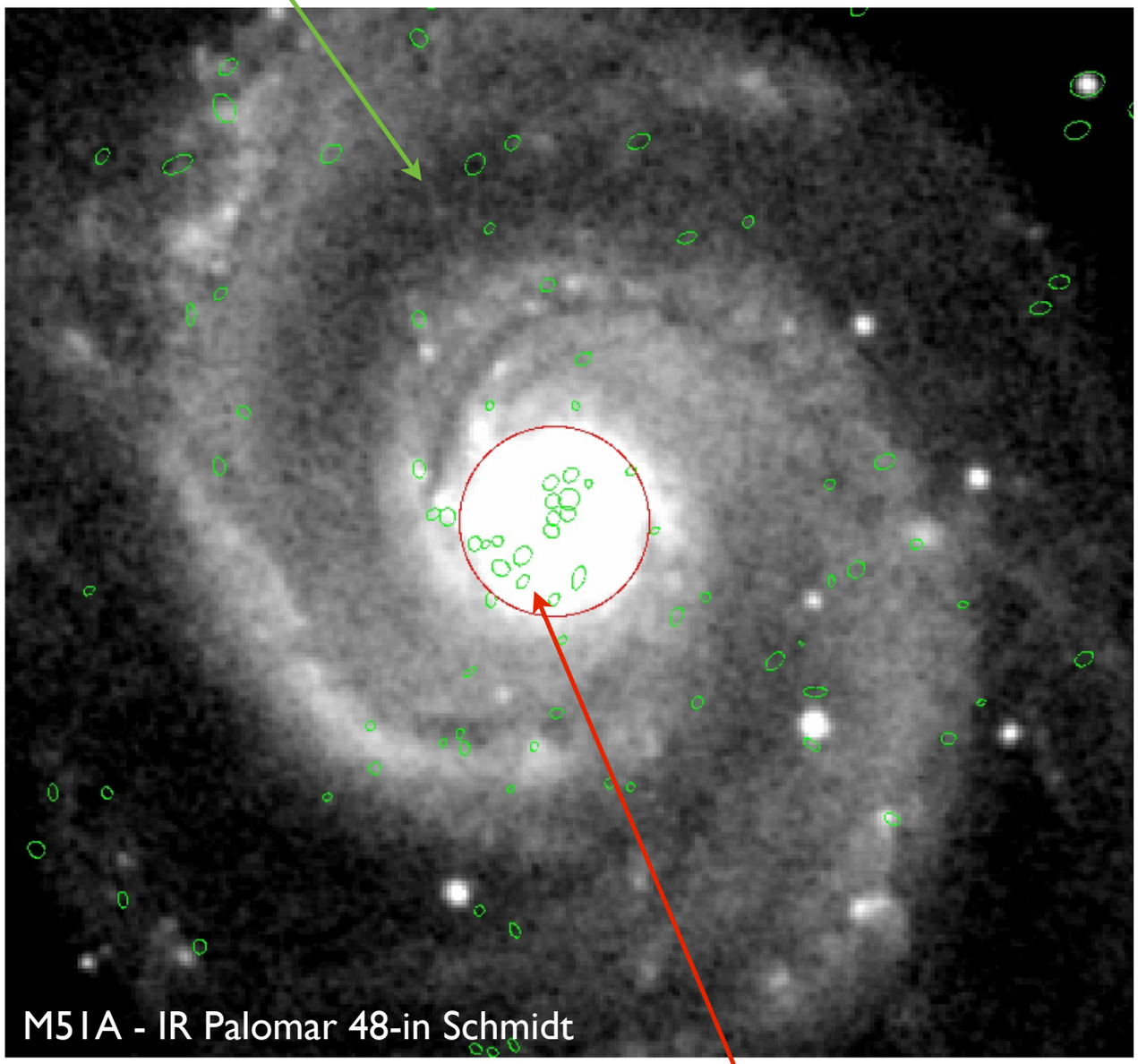
outer regions

surface density of XRBs ~ average density of CXB sources

Bulge exclusion: minimizing the LMXB contribution

disk population

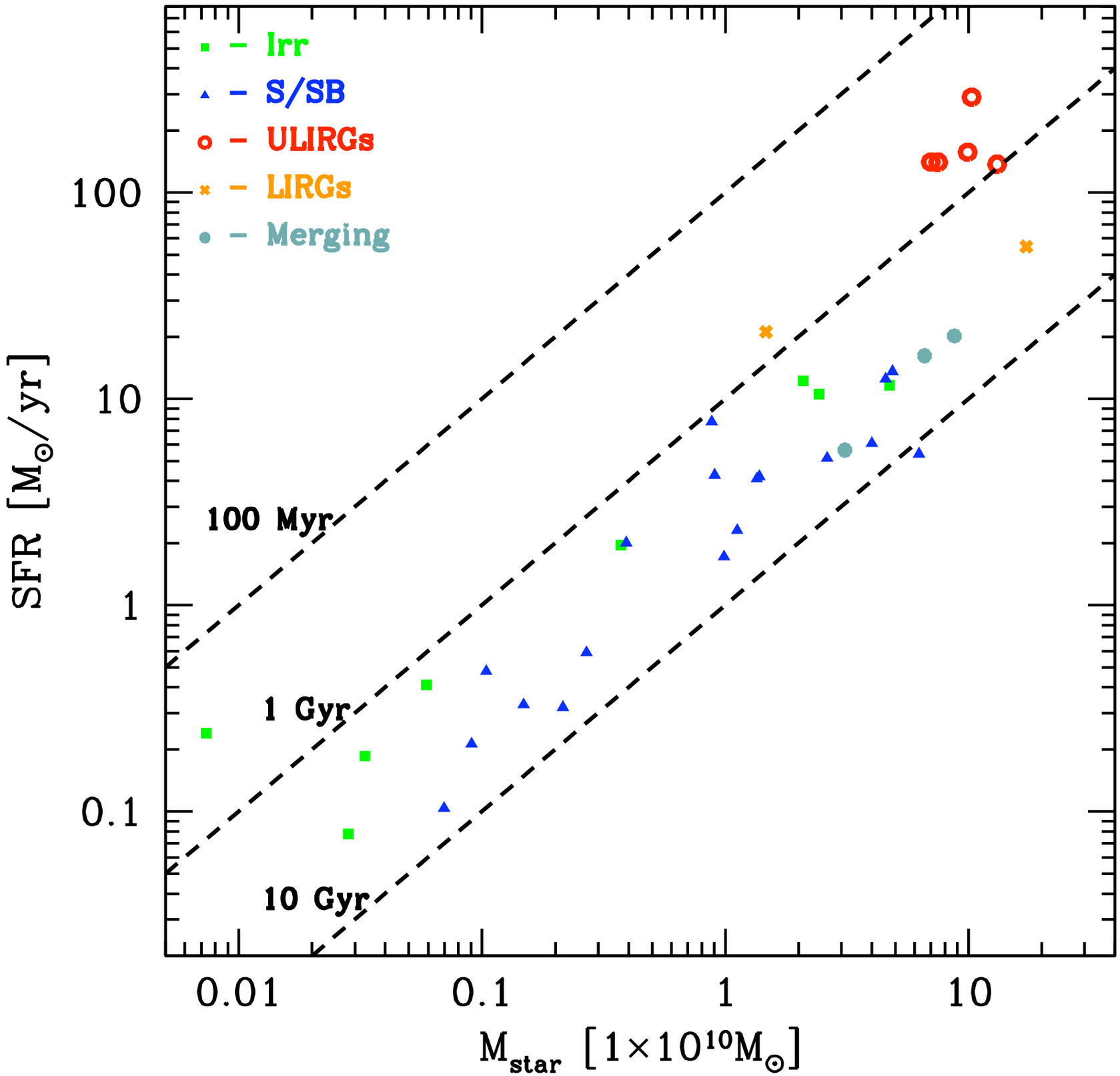
XRBs of a wide range of age



bulge population

dominated by LMXB

SFR - M★ plane


Irr
S/SB
ULIRGs
LIRGs
Merging
100 Myr
1 Gyr
10 Gyr
SFR [M⊙/yr]
100
10
1
0.1
0.01
0.1
1
10
M_star [1×10^10 M⊙]

Part I

L_X-SFR relation for HMXBs

SFR estimators

(see Kennicutt 1998 for a review):
UV continuum, recombination lines (H_α), forbidden lines ([OII]), IR continuum, thermal radio emission (Condon 1992)

$$\mathrm{SFR_{TOT}} = \mathrm{SFR^0_{UV}} + (1-\eta) \times \mathrm{SFR_{IR}}$$

$$\eta = \begin{cases} 0 & \text{for Starburst galaxies} \\ 0.4 & \text{for normal disk galaxies} \end{cases}$$

Hirashita et al. (2003), Bell (2003), Iglesias-Paramo et al. (2006) [Salpeter IMF, 0.1-100 Msun]

- **UV** $\Rightarrow \mathrm{SFR_{UV}}(M_\odot \mathrm{yr}^{-1}) = 1.4 \times 10^{-28} L_\nu(\mathrm{erg/s/Hz})$

+ originates in the atmospheres of stars younger than 10^7 - 10^8 yr
- attenuated by dust surrounding the young stars

- **IR** $\Rightarrow \mathrm{SFR_{IR}}(M_\odot \mathrm{yr}^{-1}) = 4.5 \times 10^{-44} L(8-1000\mu m)(\mathrm{erg/s})$

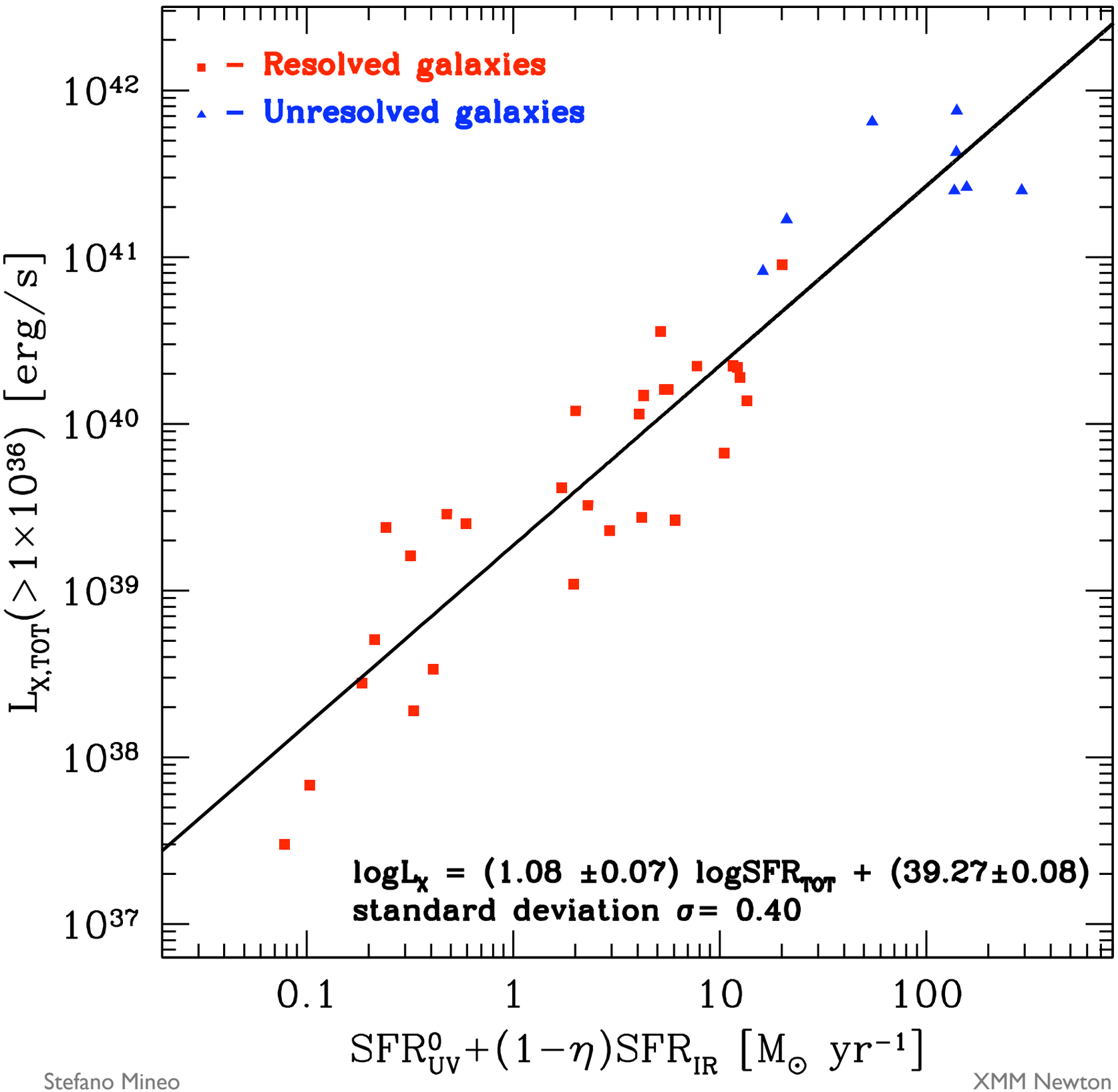
+ absorbs most of the UV photons and reemits them at IR wavelength
- unknown fraction of escaping UV photons

- **X-ray:**

+ not affected by absorption
+ independent estimator
- AGN, gas and LMXB contribution to X-ray luminosity

The L_X-SFR relation

$$L_{0.5-8\mathrm{keV}}(\mathrm{erg/s}) = 2.0 \times 10^{39} \mathrm{SFR}_{\mathrm{TOT}}(M_\odot \mathrm{yr}^{-1})$$



fit with a power-law:

$$L_X = A \cdot \mathrm{SFR}^{\alpha}$$
$$\alpha \sim 1 \rightarrow \mathrm{linear}$$

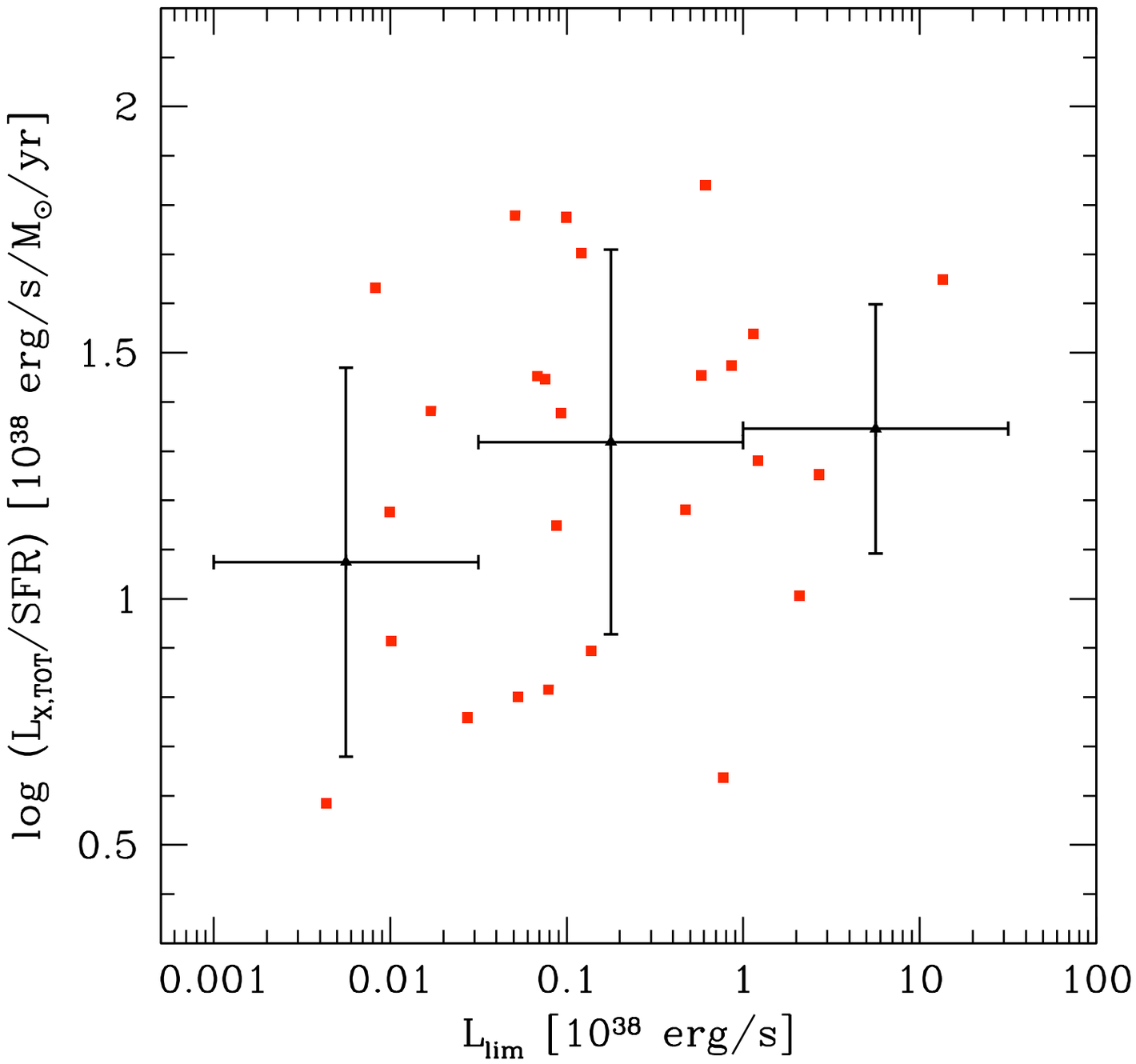
consistent with L_X-SFR relation of:
Grimm et al. (2003)
Ranalli et al. (2003)

we also see the dispersion around the L_X-SFR relation found in earlier studies

Dispersion: data reduction?

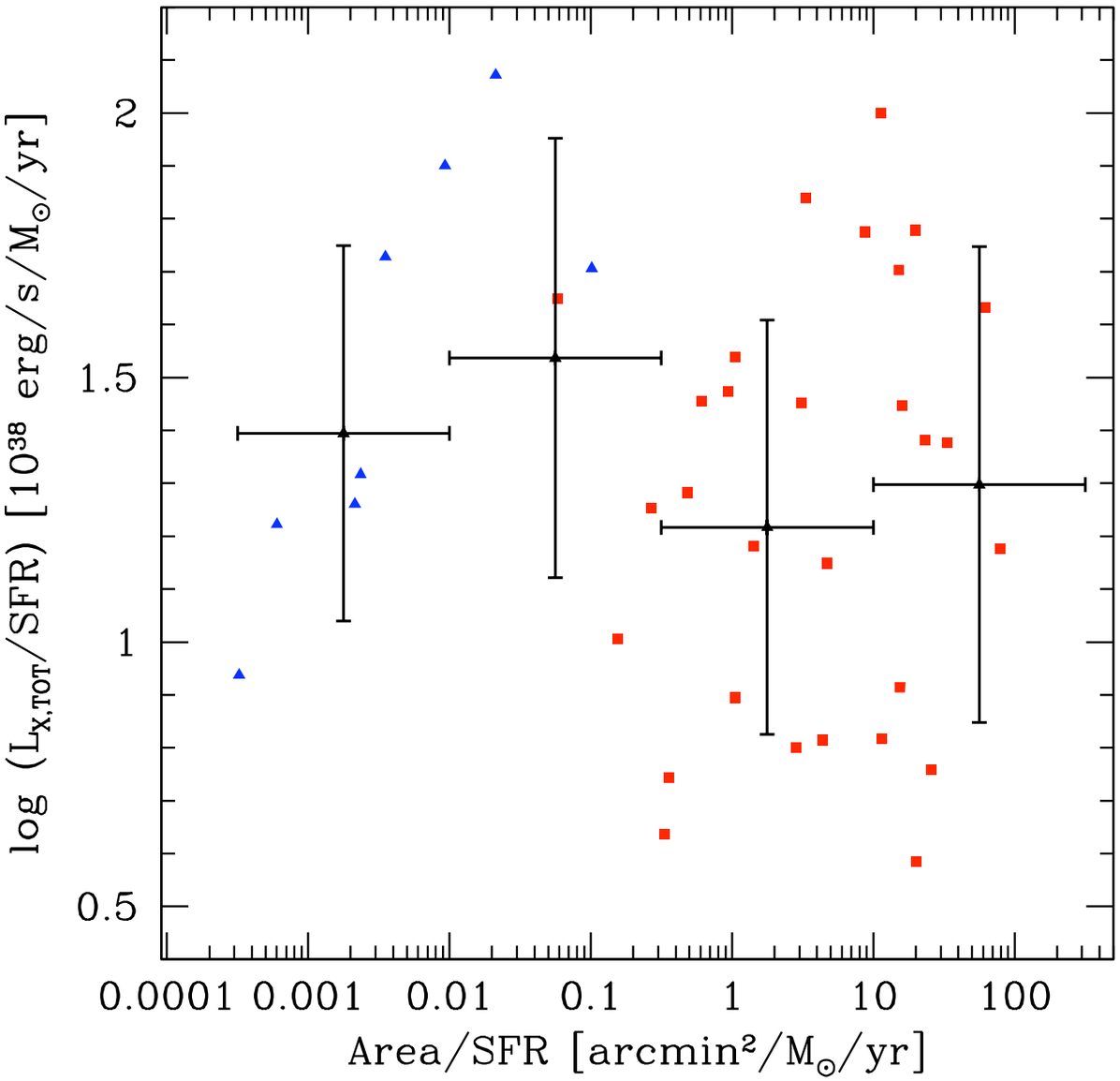
sensitivity limit

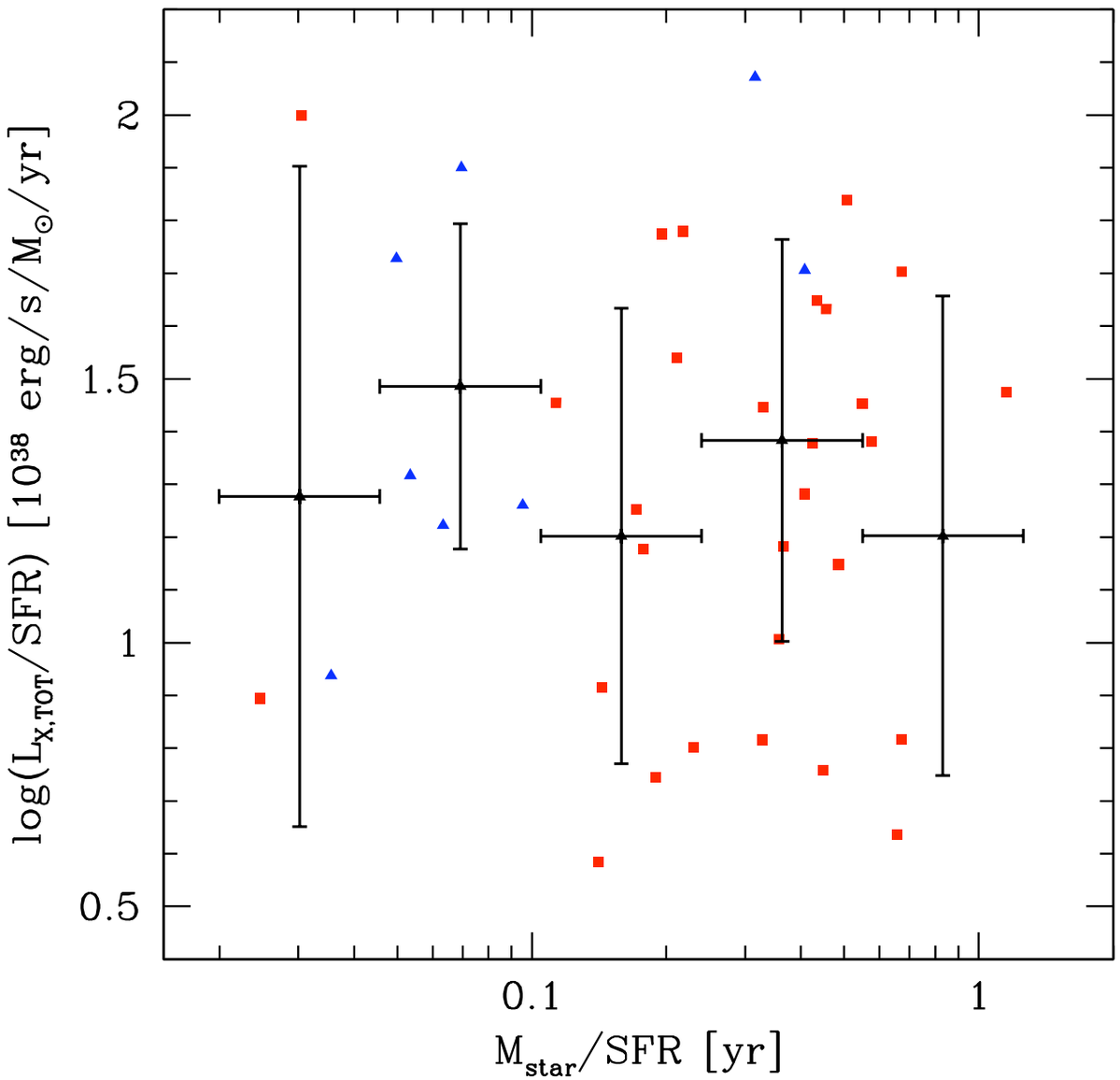
L_X-SFR relation: $L_X = L_{0.5\text{-}8keV}(>10^{36}$ erg/s)



L_{lim} = point source detection limit

Dispersion: CXB/LMXB contamination?





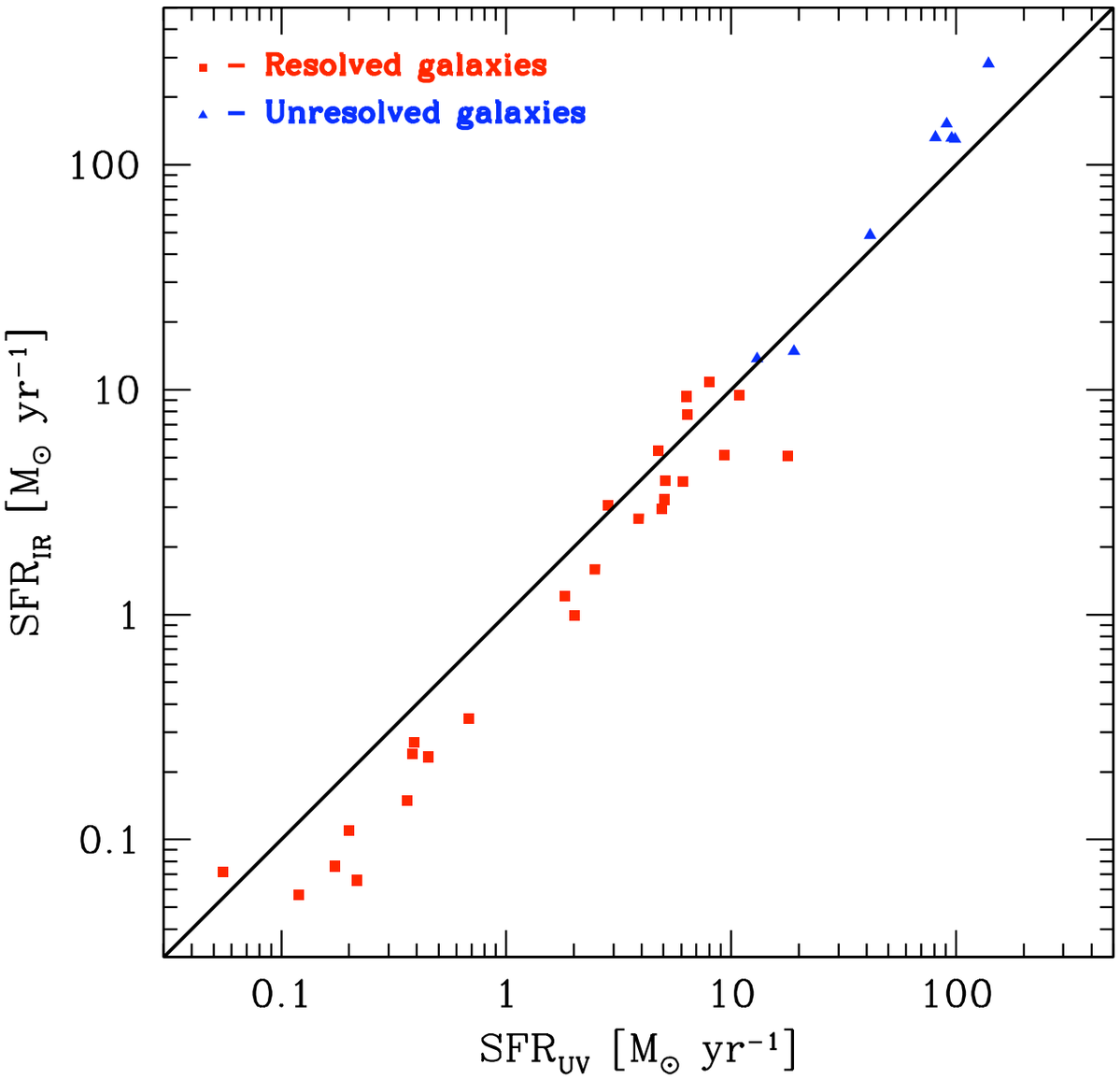
Area/SFR ~ N_{CXB}/N_{HMXB}

$M_\star$/SFR ~ N_{LMXB}/N_{HMXB}

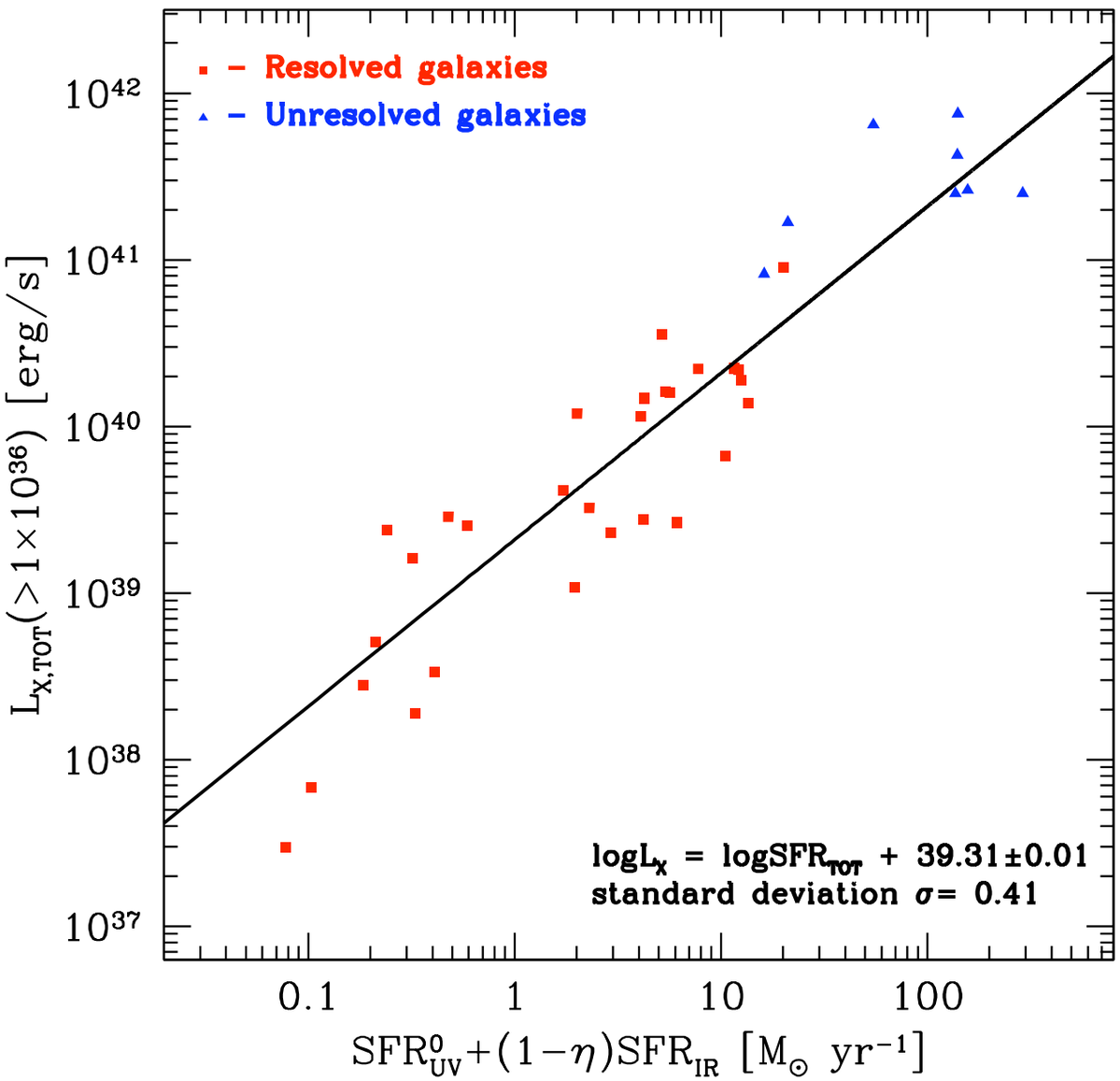
sample galaxies free of CXB and LMXB contamination

Dispersion: accuracy of SFR estimators?

relation between SFR_{IR} and SFR_{UV}



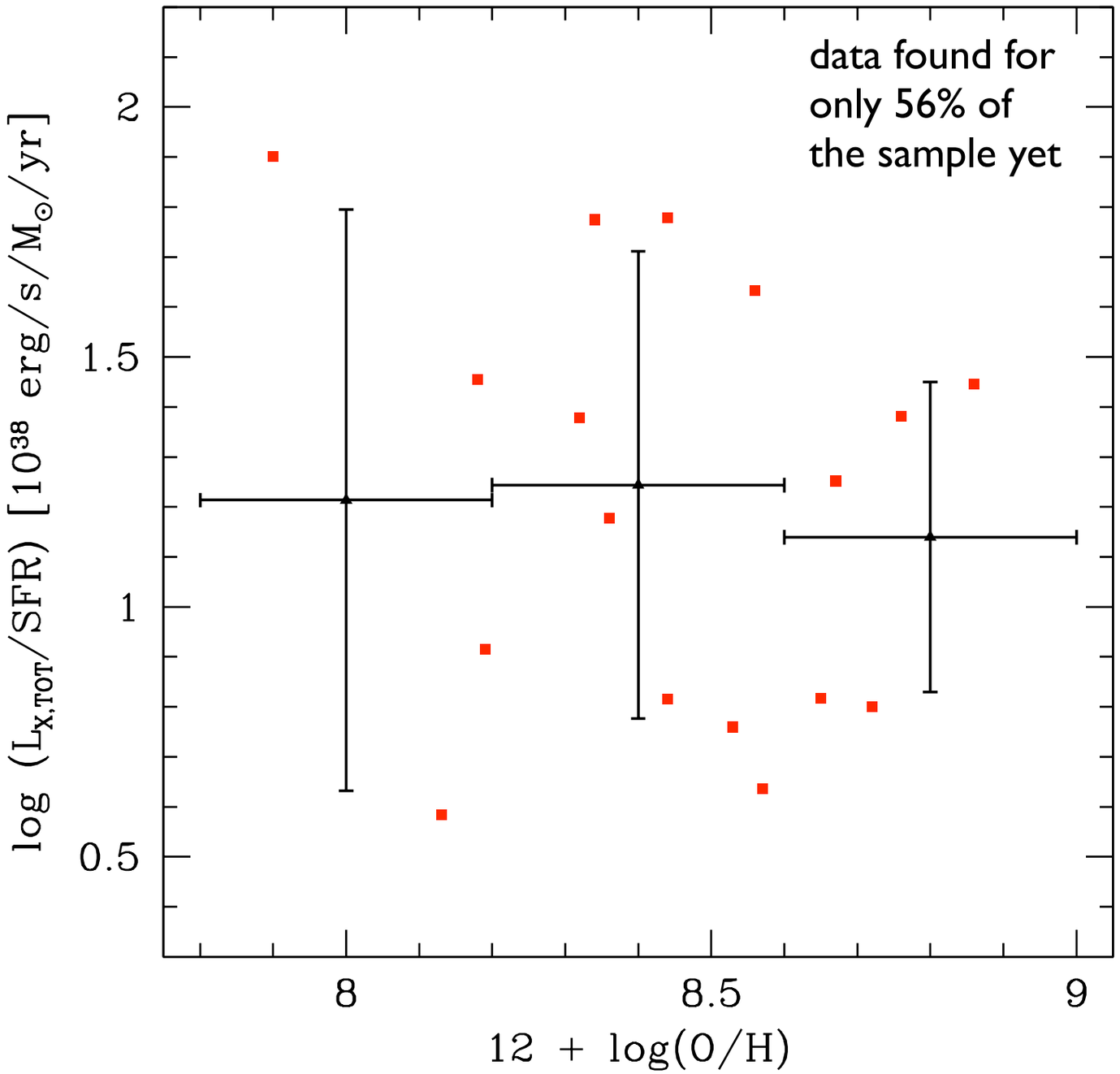
Lx-SFR relation



scatter lower than that observed in the Lx-SFR relation

Dispersion: physical?

oxygen abund./metallicity

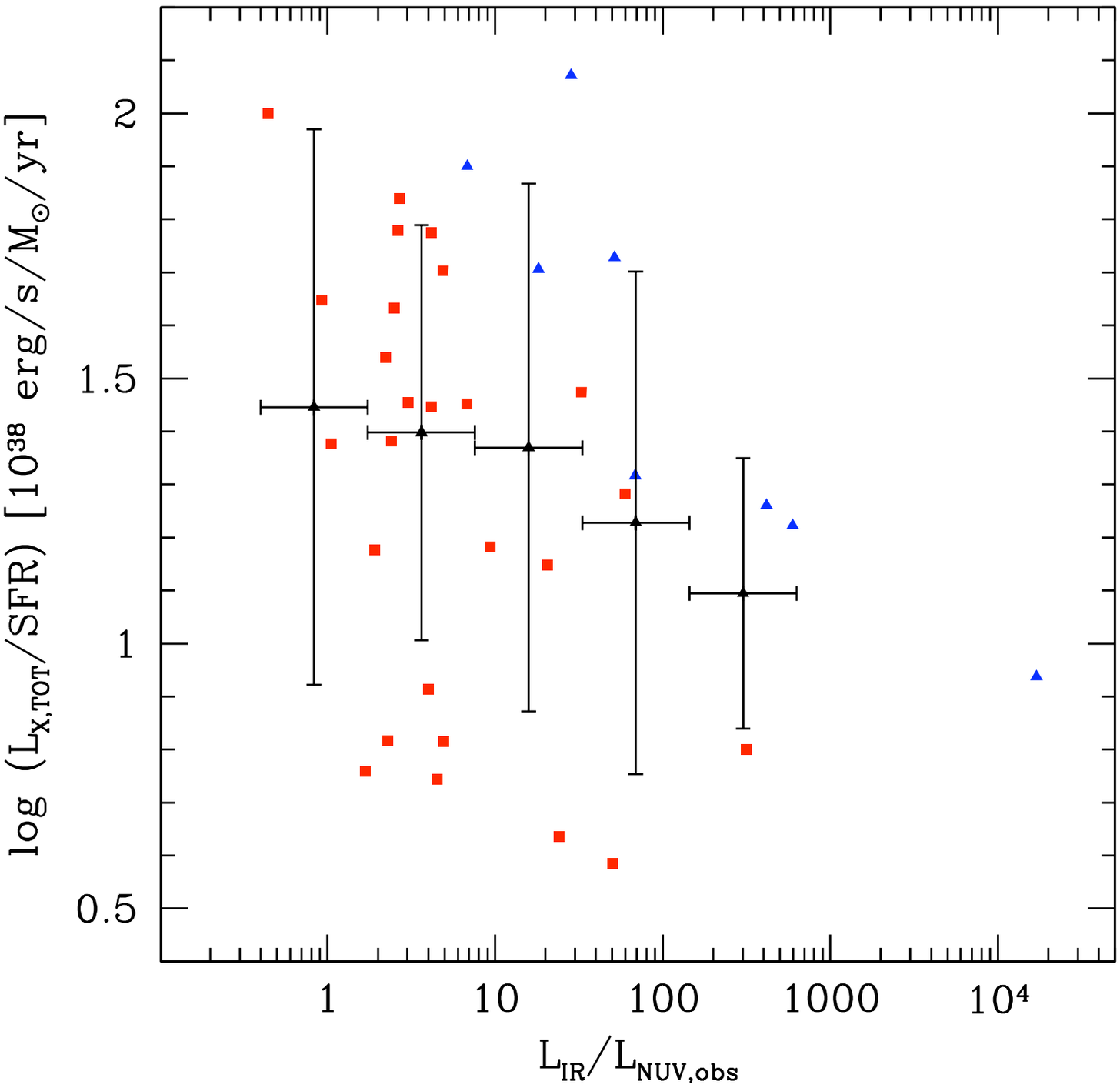


Oxygen abundances from:
Storchi-Bergmann et al. (1994)
Garnett (2002)
Pilyugin & Thuan (2007)
Calzetti et al. (2010)

also we will search for stellar age/colors effects

Dispersion: physical?

dust attenuation effects ?



Spearman's rank correlation test

total sample:
Rs = -0.31 (weak anti-correlation)
probability = 10%

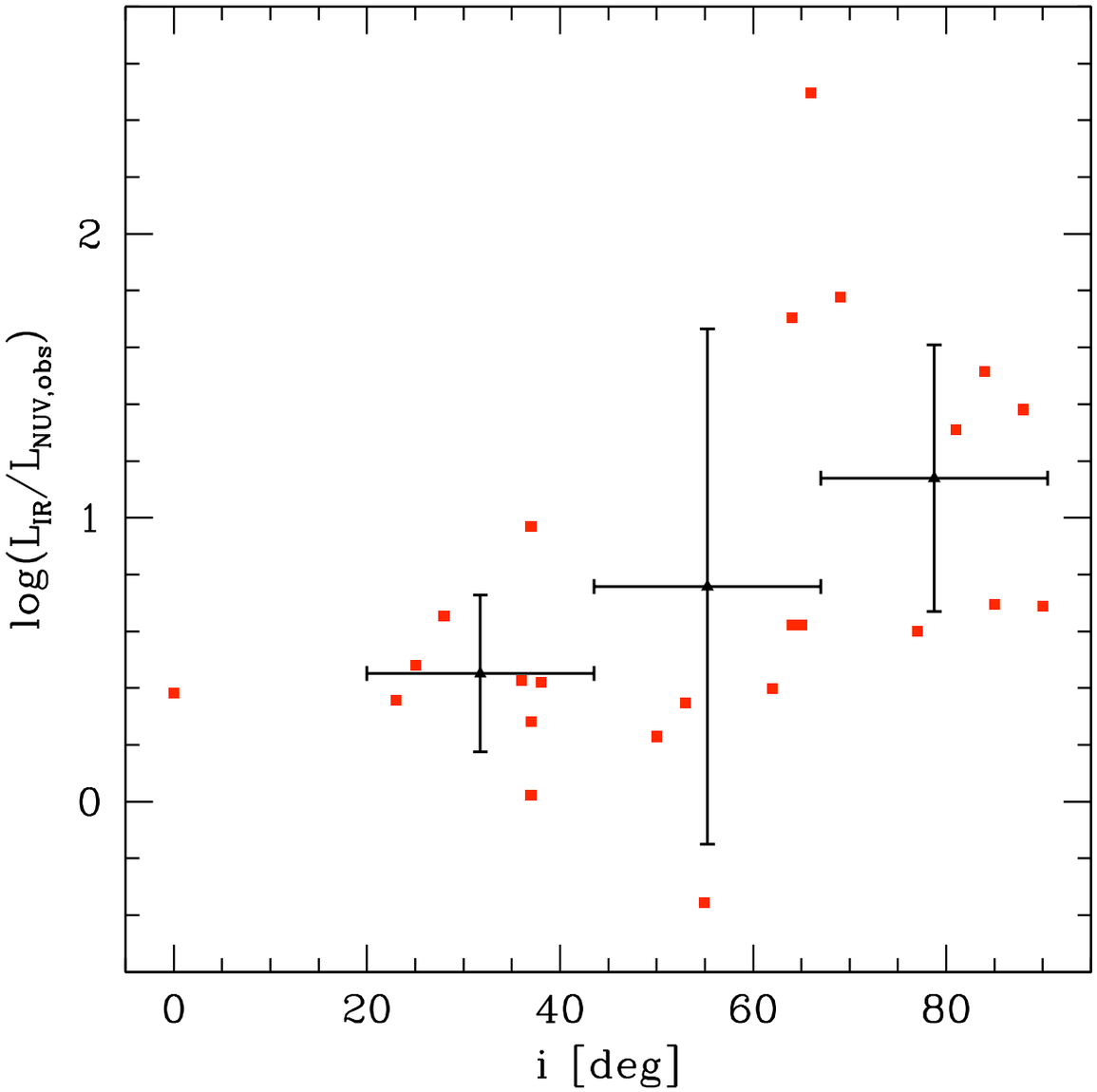
only nearby galaxies:
Rs = -0.37 (weak anti-correlation)
probability = 5%

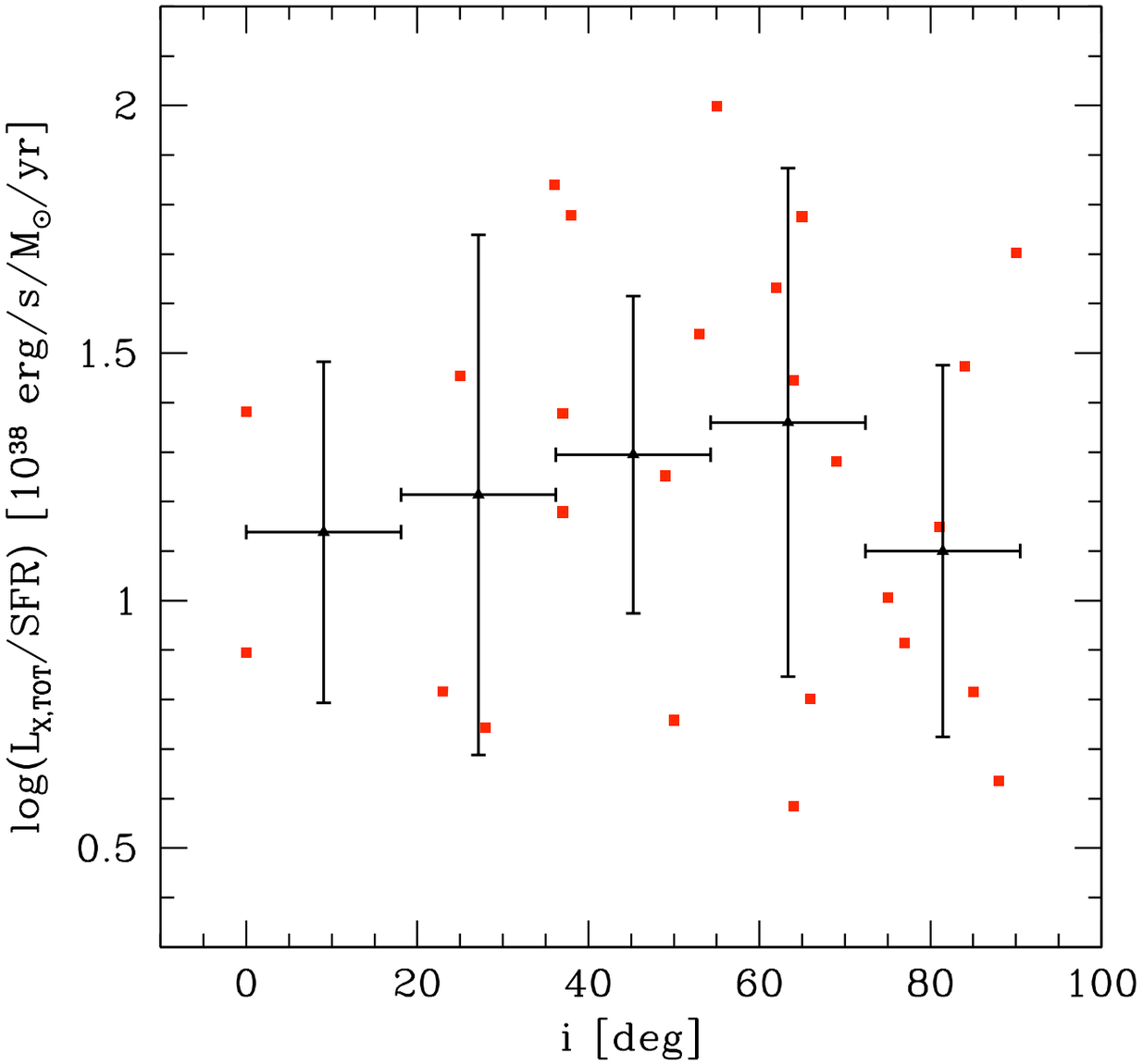
only unresolved galaxies:
Rs = -0.90 (strong anti-correlation)
probability = 1%

in order to attenuate the L(0.5-8 keV) by one order of magnitude
a $n_H \sim 10^{23}$ cm^{-2} is needed!

Dispersion: physical?

galaxy inclination





dust attenuation correlates with the inclination of galaxies:
Rs = 0.6
probability = 0.1%

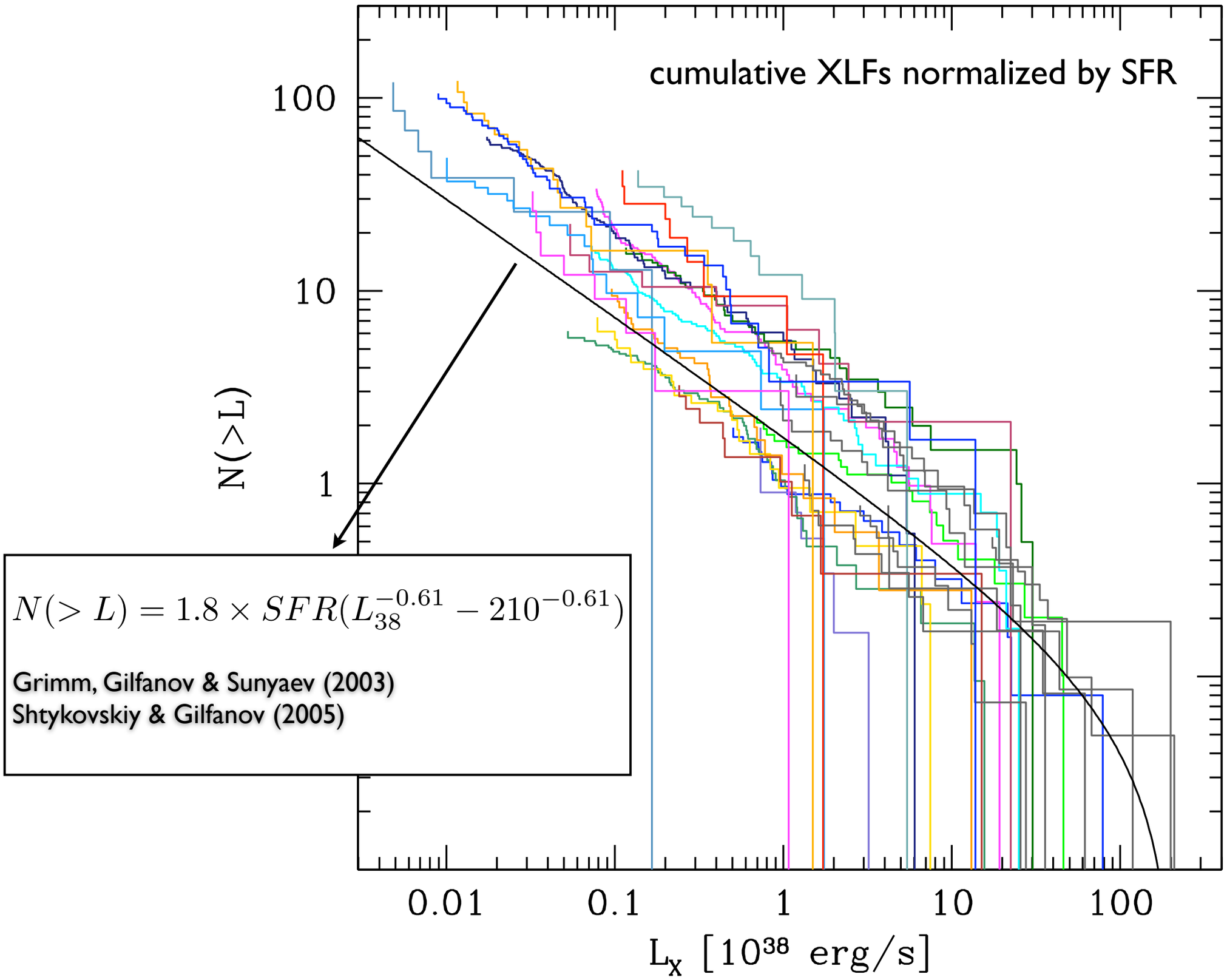
BUT

Lx-SFR ratio does not correlate with the inclination of galaxies

Part II

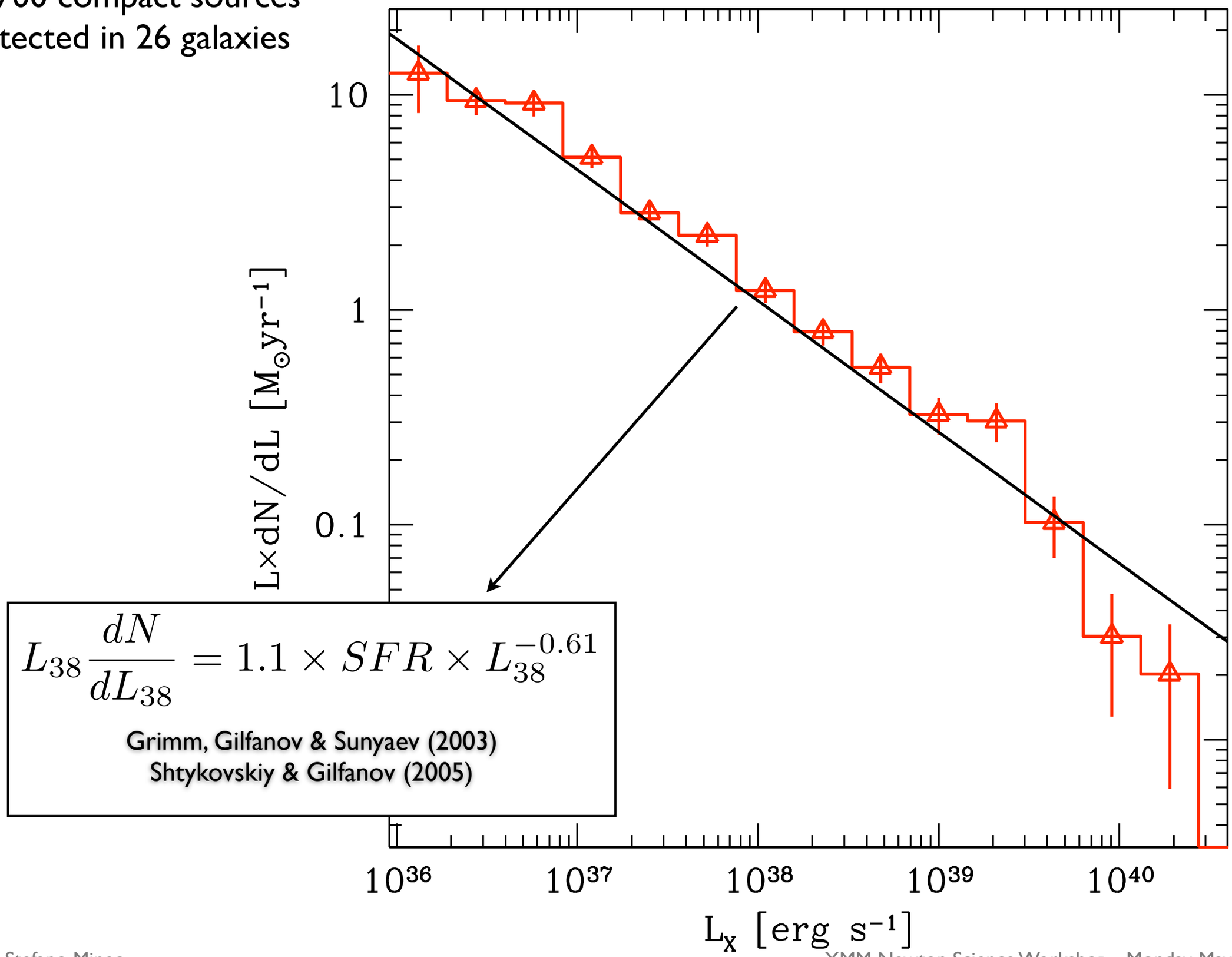
Luminosity function of HMXBs

X-ray point source luminosity function

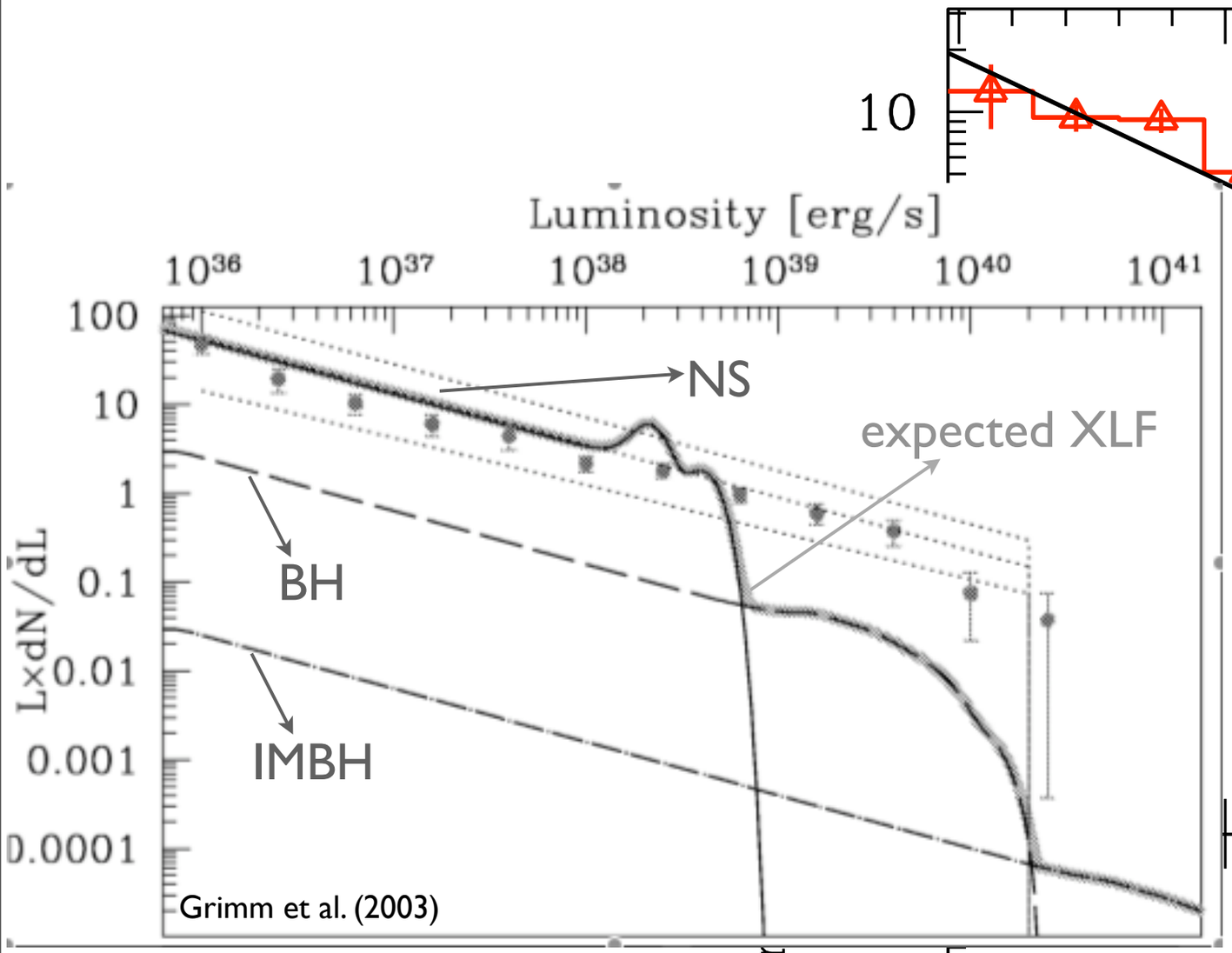


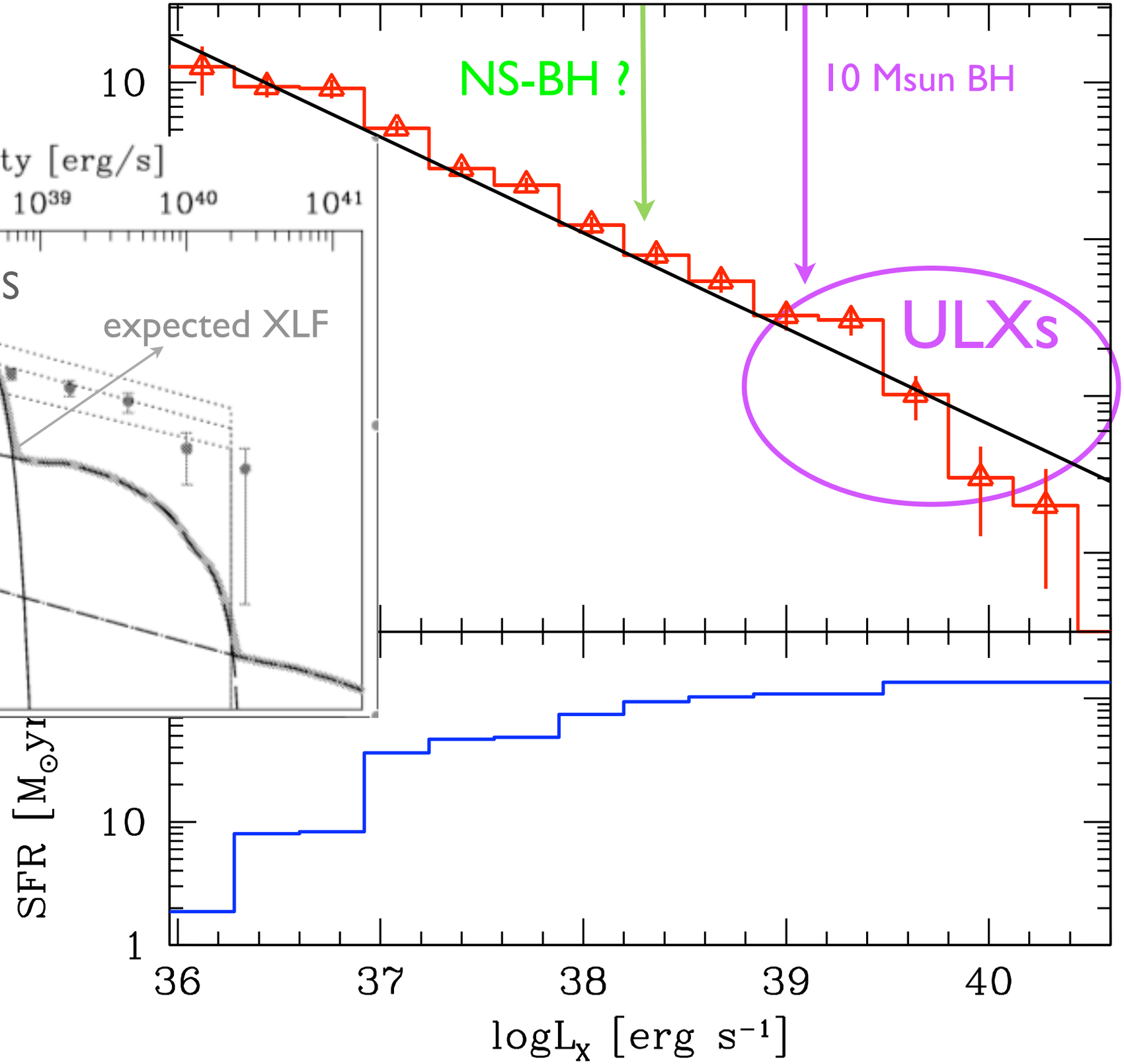
Combined luminosity function

~ 700 compact sources
detected in 26 galaxies



Combined luminosity function and SFR





Conclusions

- L_X-SFR relation in agreement with previous results
  Grimm et a. (2003), Ranalli et al. (2003)

- confirmed presence of the dispersion around L_X-SFR relation seen in previous works ⇒ must be physical

- first evidence of a change of the slope of the HMXB luminosity function near to L_{Edd} of a 10 Msun BH

Future work

- L_X-SFR relation for high-redshift galaxies (using Chandra deep fields)

- extending the sample to include spatially resolved high-SFR galaxies that potentially host ULXs

- relation between SFR and X-ray luminosity of diffuse gas

Thank you for your attention!