Normal galaxies outside the local Universe

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Outline

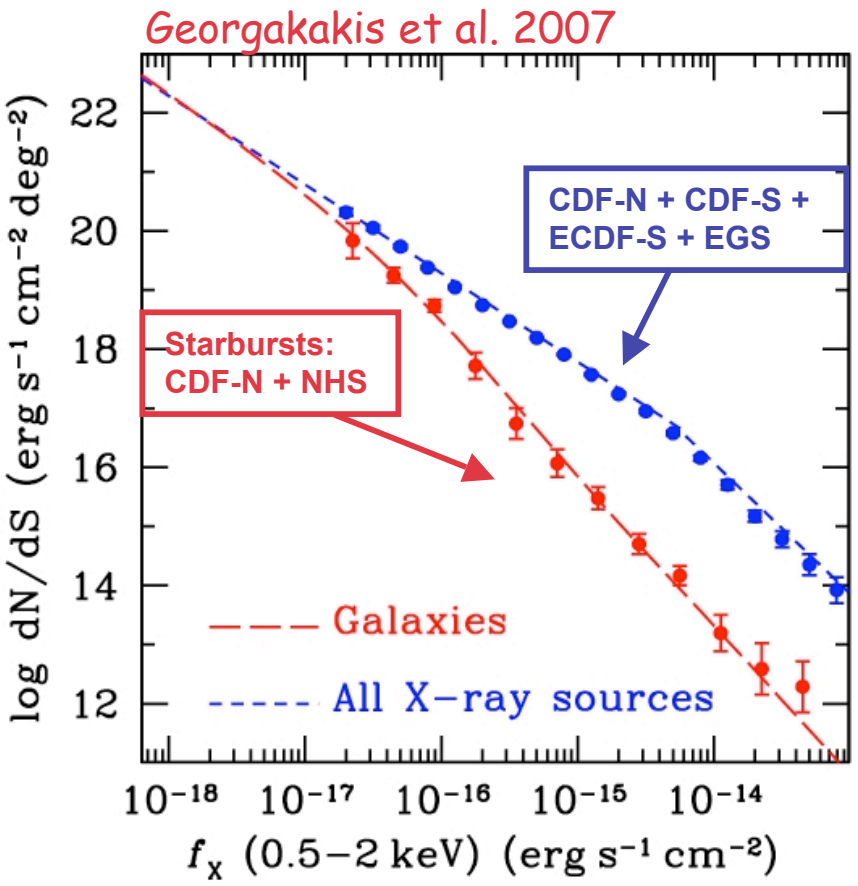
- Study of galaxies at X-ray wavelengths important
- State of the game + problems/issues
- Further progress requires wide area X-ray survey (Sloan Digital Sky Survey)
- Science demonstration using 2XMMp and SDSS

Galaxies at X-rays: it does worth it!

- Dominant population in future X-ray surveys (e.g. XEUS)
- Star-formation indicator (dust-free)
- X-ray binaries and evolution
- Hot gas and metal enrichment

Why study galaxies

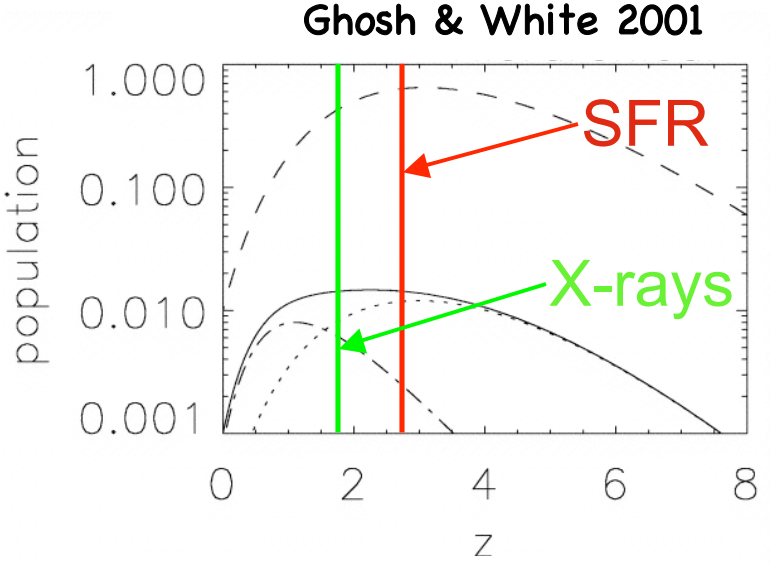
- Dominant population below the limit of current surveys (e.g. XEUS)
- At f_X~10^{-18}erg/s/cm^2
  - 30,000 galaxies/deg^2
  - Mean redshift <z>~1.5

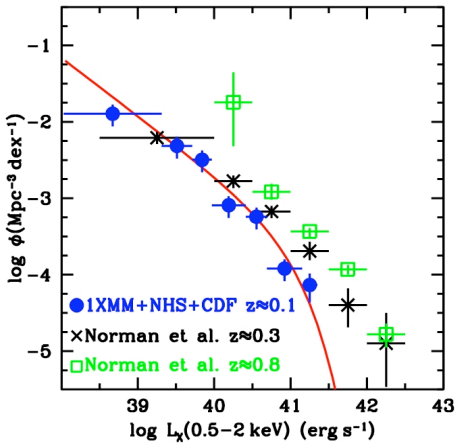


X-ray evolution of star-forming galaxies

- X-ray binaries:
  - low mass: long timescales
  - high mass: fast evolution
- X-ray evolution of starbursts different compared to other wavebands
  - time lag between the peaks of SF and X-ray luminosity
- Attempts to constrain galaxy XLF as a function of redshift
  - *Chandra* Deep Fields identify galaxies to *z*~1
  - *Chandra* & *XMM* wide-angle shallow surveys find galaxies at *z*~0.1

Ghosh & White 2001

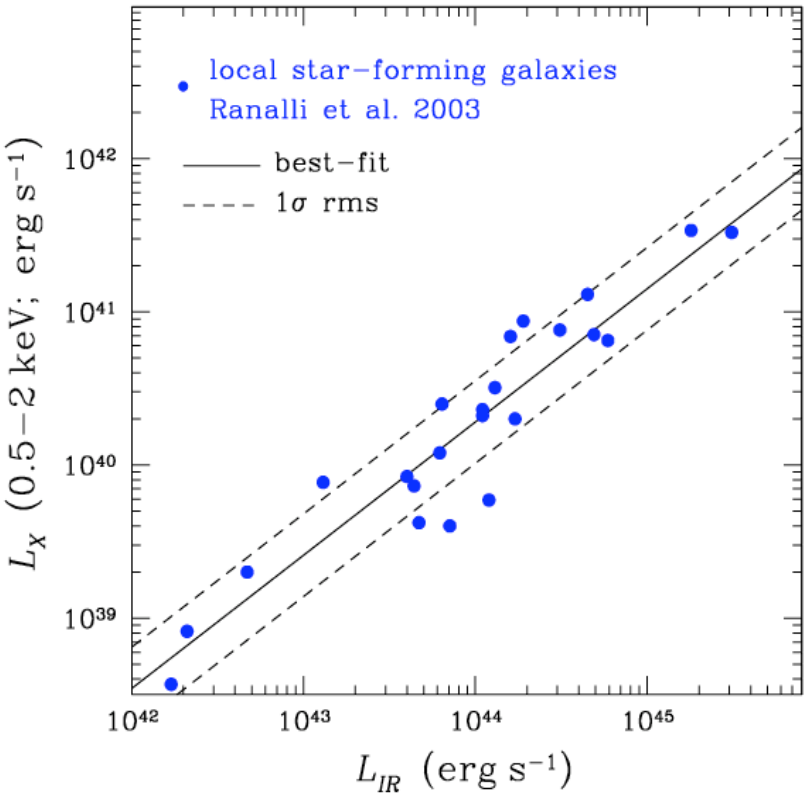




Norman et al. 2005; Georgantopoulos et al. 2005; Georgakakis et al. 2006

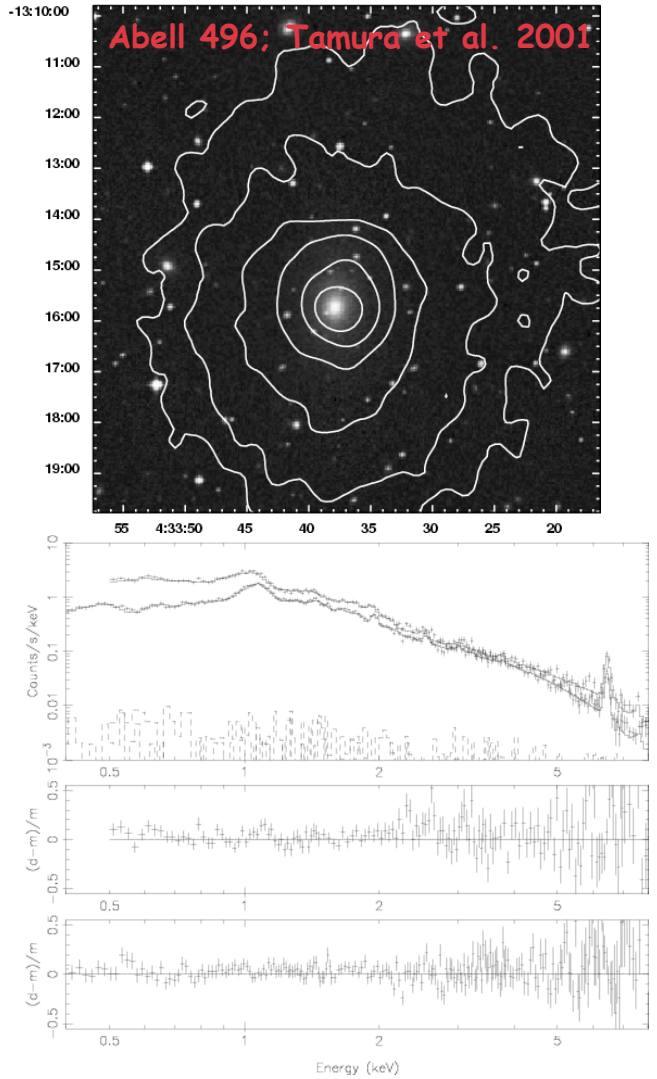
X-ray emission as star-formation indicator

- Late type galaxies: X-ray emission SFR indicator.
- Almost independent of dust extinction (>2keV)
- Ranalli et al. 2003: $L_X \propto L_{IR}$ over 4dex in L_{IR}
- Problems:
  - relatively small number of galaxies
  - Does the relation remain linear at low SFRs?



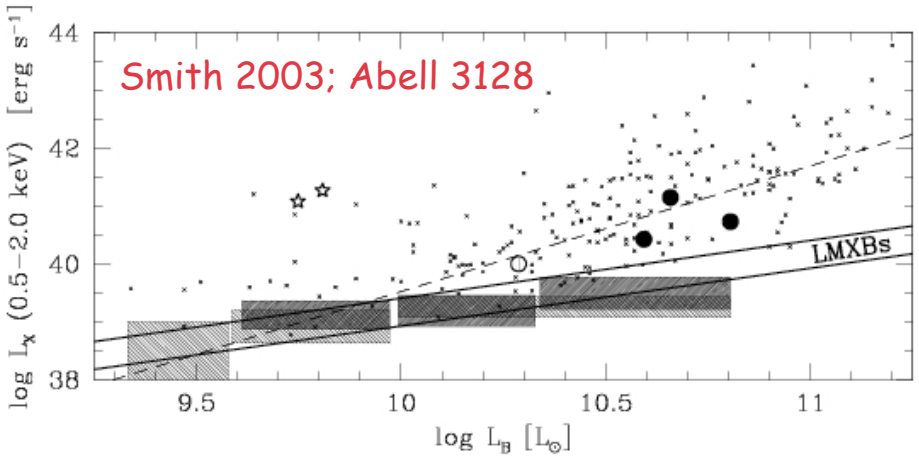
Metal enrichment

- Hot gas of clusters/groups rich in metals, i.e. not primordial
- Gas is processed in galaxies before transported to the inter-galactic medium:
  - SN explosions
  - Gas stripping
  - AGN jets
  - Galaxy interactions



Metal enrichment via gas stripping

- Early-type galaxies in clusters are X-ray faint for their L_B.
- X-ray emission dominated by binary stars
- Galaxy hot gas is stripped to the intergalactic medium
- We need to study of the X-ray properties of galaxies in a range of environments.



X-ray stacking of Abell 3128 cluster members (not individually detected)

Stacking signal consistent with low-mass X-ray binary expectation (no hot gas)

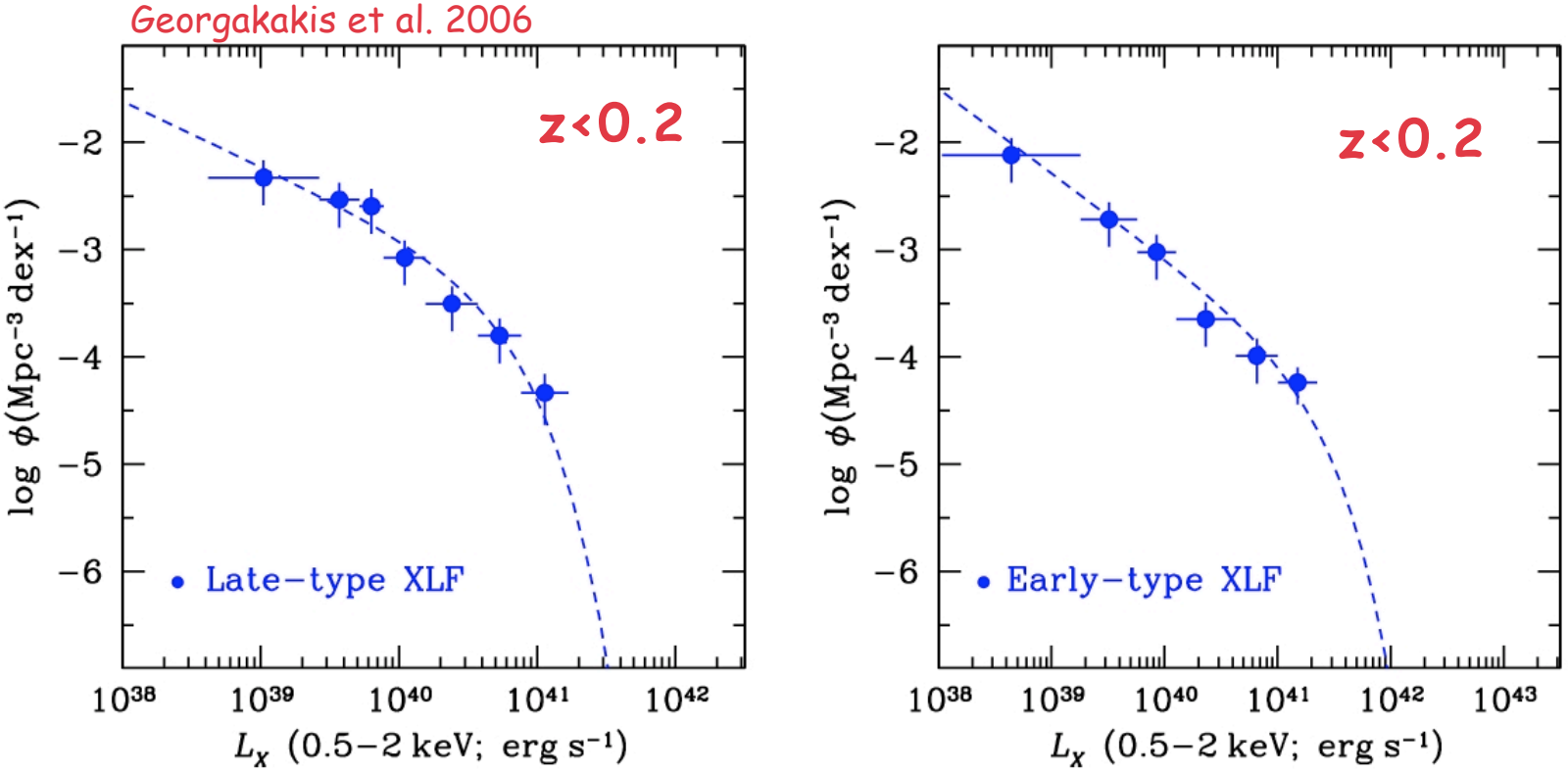
See also Hornschemeier et al. 2006

Problems

- Selection of galaxies
  - Contamination from AGN
  - Requires good spectroscopy and/or multi-wavelength data
- Galaxy samples are still small (~100)
  - Luminosity function
  - Environmental studies

Galaxy X-ray Luminosity Function

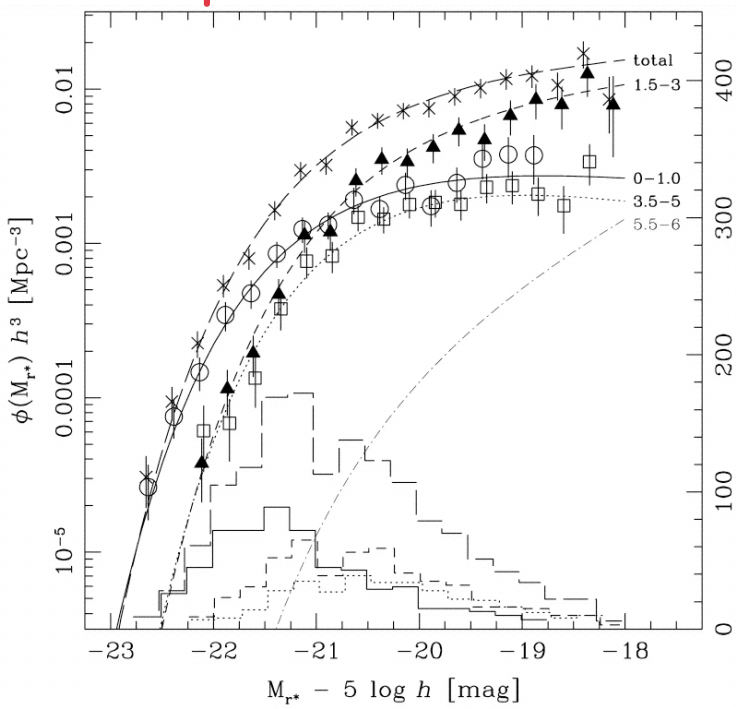
Georgakakis et al. 2006



- Local X-ray Luminosity Function, <z>~0.1
- Data: Needles in Haystack Survey + 1XMM + Chandra Deep Fields (~15deg^2)

Galaxy X-ray Luminosity Function: indirect estimation

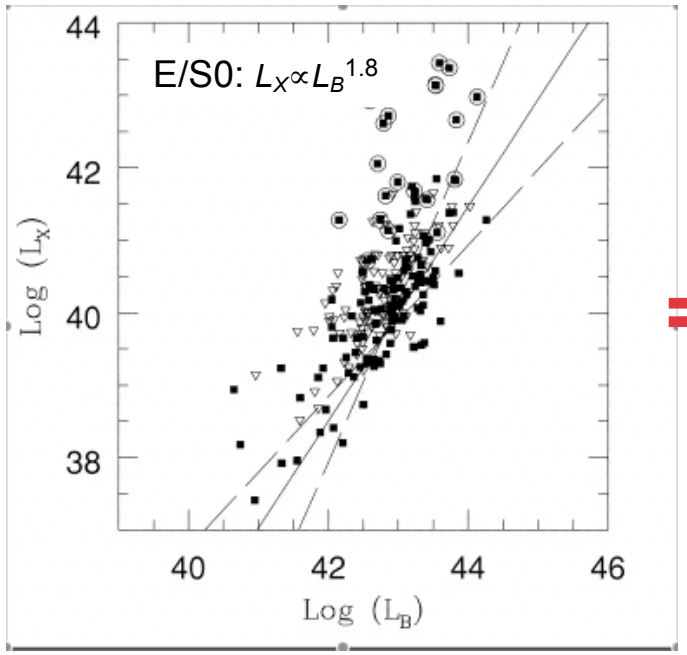
Optical LF



SDSS, Nakamura et al. 2003

+

L_X-L_B relation



Shapley et al. 2001

= **XLF**

Georgantopoulos et al. 1999

Galaxy X-ray Luminosity Function

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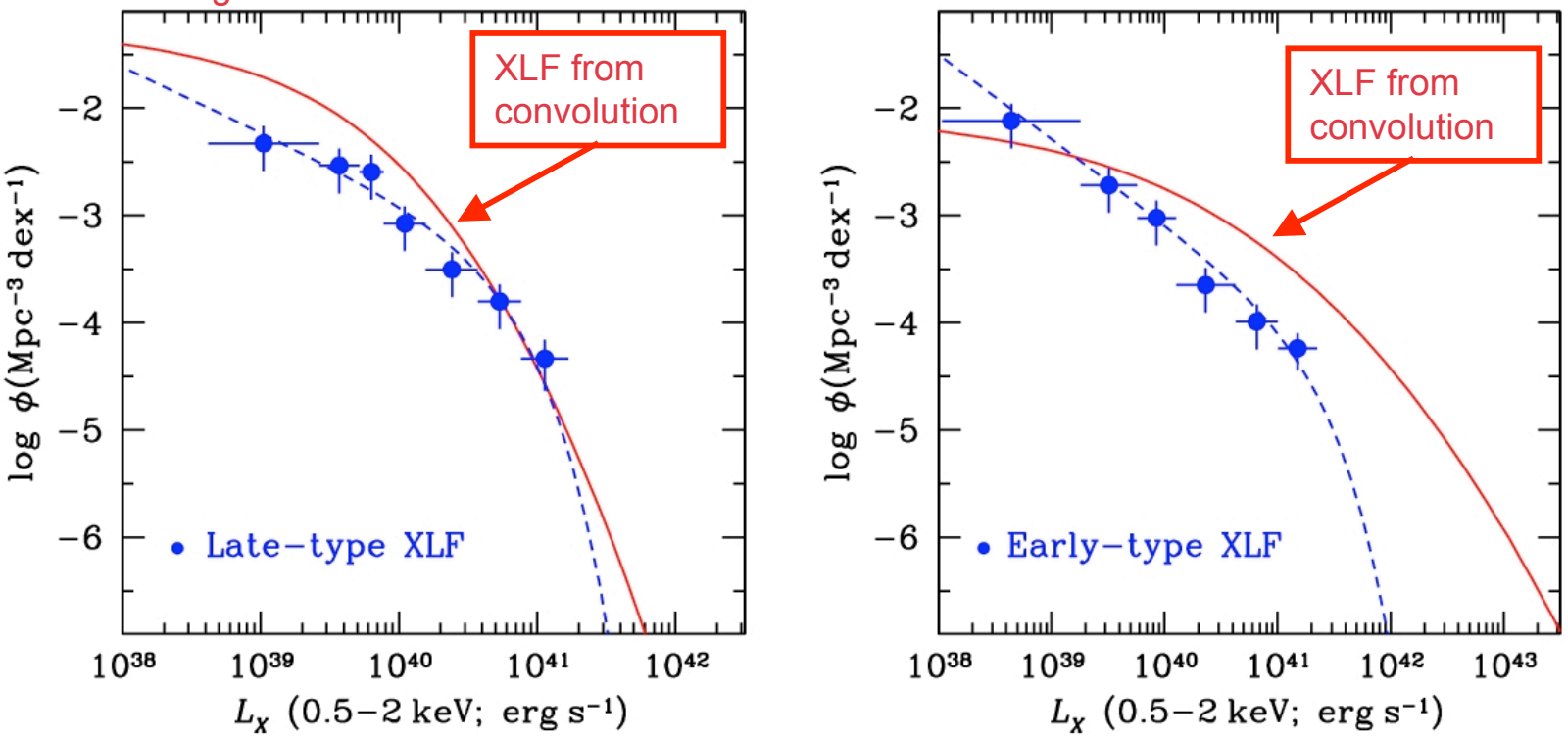

- Local X-ray Luminosity Function, <z>~0.1
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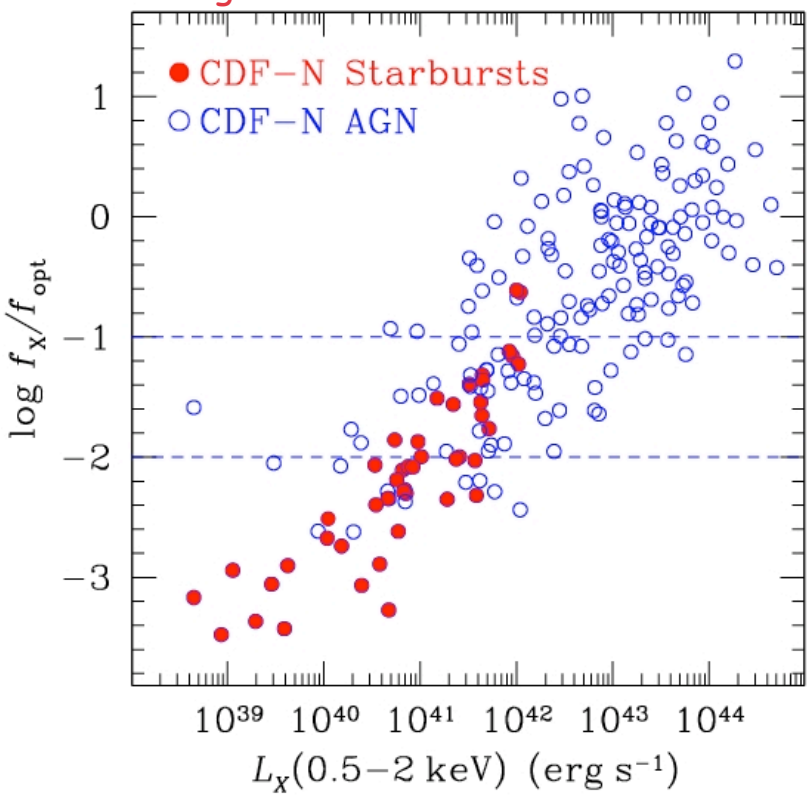
Galaxy X-ray Luminosity Function: selection effects

Georgakakis et al. 2007

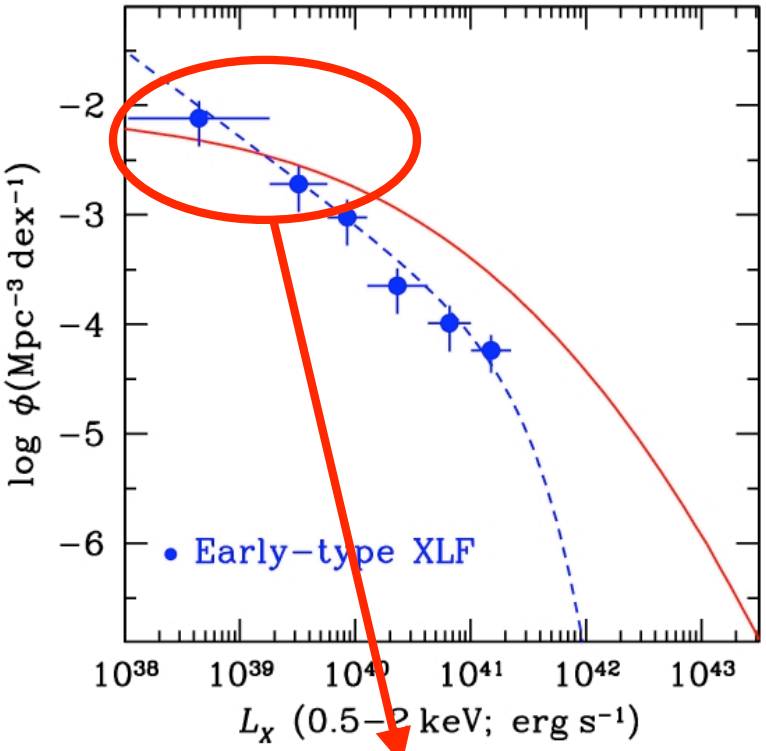


Galaxies are often selected to have $\log(f_X/f_R) < -2$

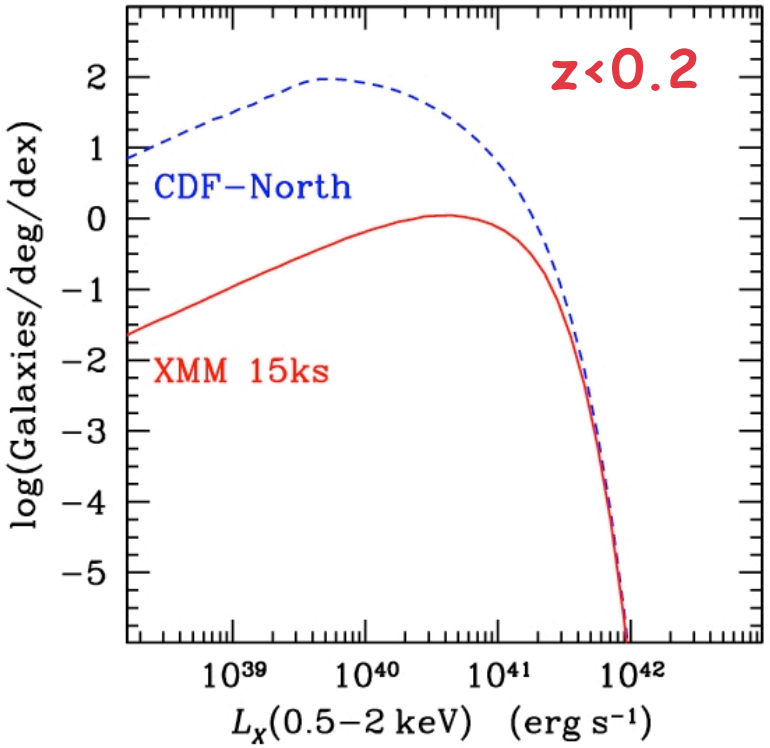
incompleteness

See also Tzanavaris et al. 2006

Galaxy X-ray Luminosity Function: faint-end slope



Faint-end (L_X~10^{39}erg/s) mainly from CDF-North



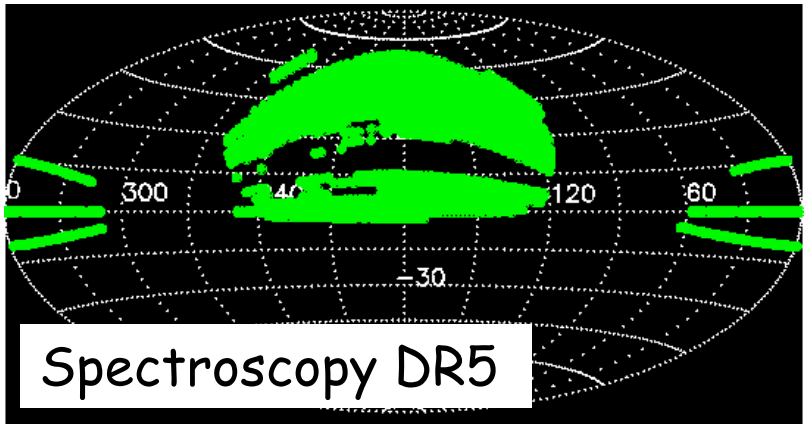
CDF-N efficient at the faint-end

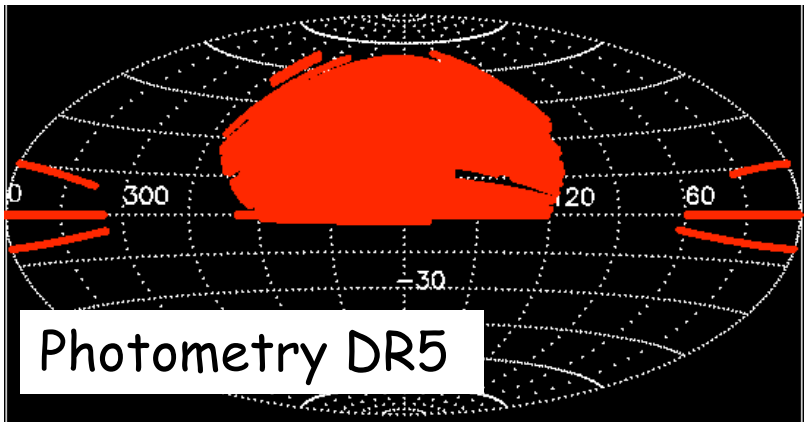
BUT

XMM wide survey (~100deg^2): larger sample (×5) at L_X~10^{39}erg/s

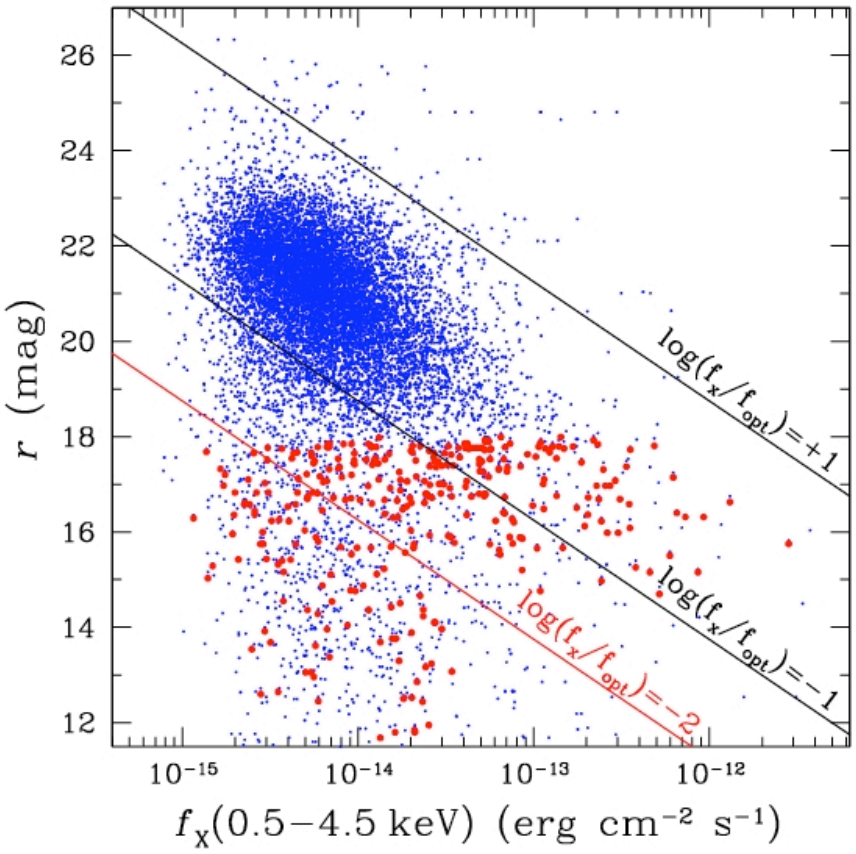
Sloan Digital Sky Survey

- DR5: 8000deg^2
  - spectroscopy
  - photometry
- Multi-wavelength data
  - FIRST (1.4GHz)
  - UKIDSS (YJHK)
  - AKARI (1.7-180μm)
  - X-rays missing!
- Advanced products
  - star-formation rates
  - AGN/star-formation diagnostic diagrams
  - local density measures





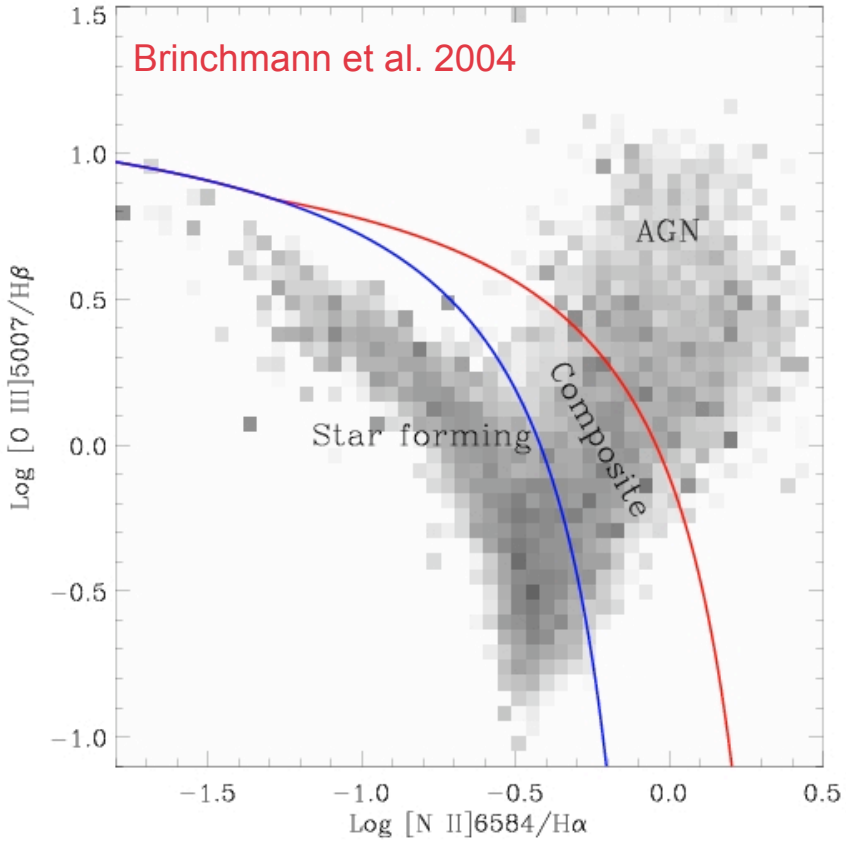
2XMM–SDSS cross-matching



Match 2XMMp with the SDSS:

- 0.5-4.5keV (*LH*>20)
- 1.3×10^4 sources over ~50deg^2
- 0.9×10^4 optical IDs
- 200 SDSS spectra (~9deg^2)

2XMM–SDSS cross-matching



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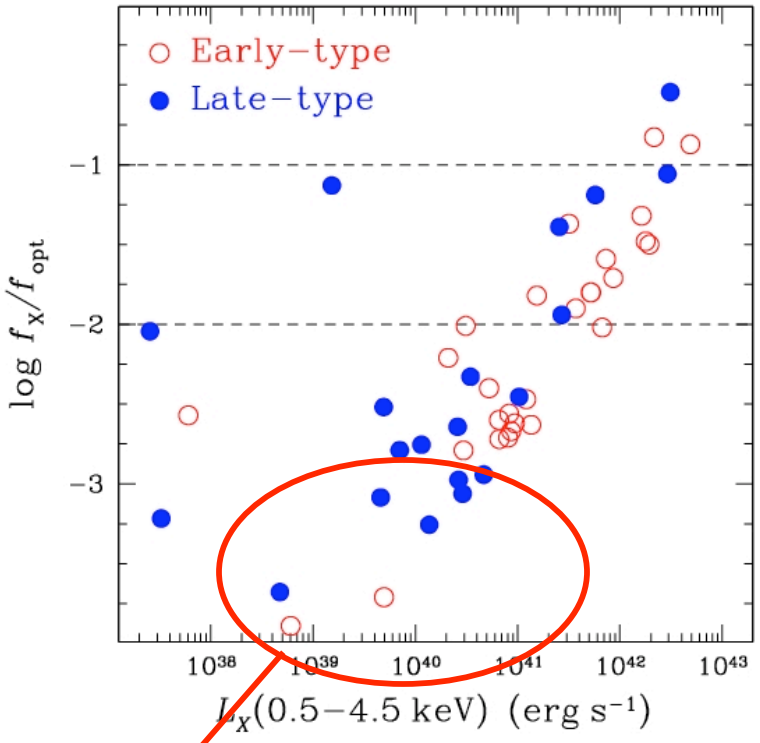
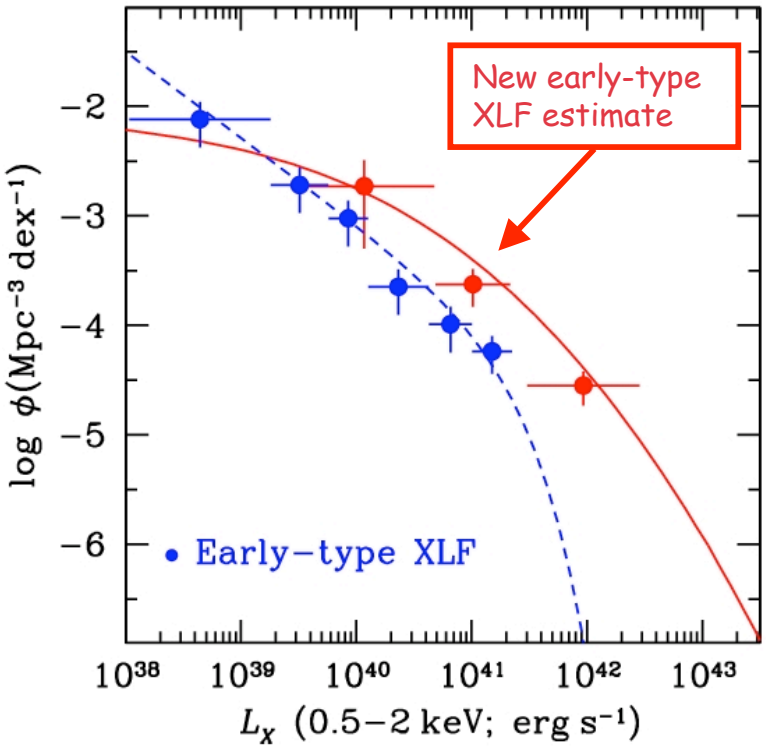
2XMM–SDSS cross-matching

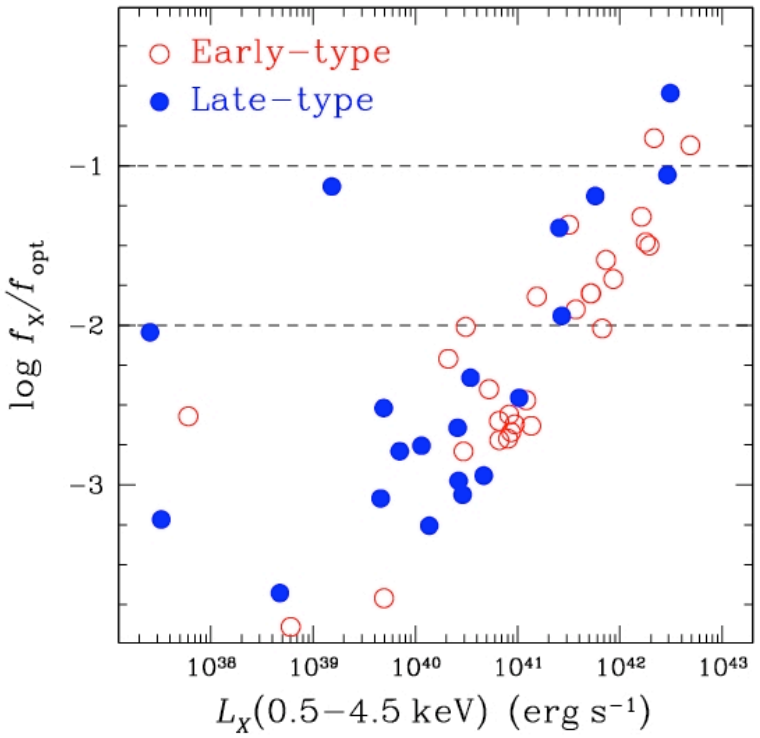
- Total of 48 galaxies
- 20 star-forming
  - mostly $\log(f_X/f_R)<-2$
- 28 early-type
  - $L_X \sim 10^{40}$–10^{43}erg/s
  - 50% $\log(f_X/f_R)>-2$



very low fx/fopt sources:
70% in dense regions

2XMM–SDSS cross-matching





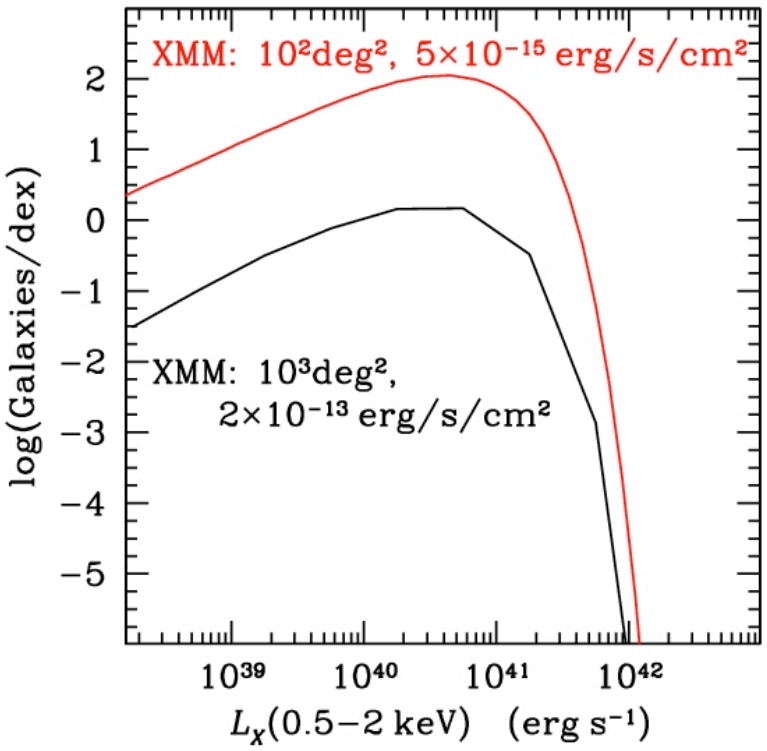
Future

Important science to be done with galaxies

- X-ray luminosity function at z~0.1
  - interpretation of deeper surveys
  - evolution studies
- X-ray properties as a function of environment
  - Use SDSS local galaxy density measure
  - X-ray detections + stacking
- L_X/SFR relation calibration
  - Use SFR of individual galaxies from the SDSS

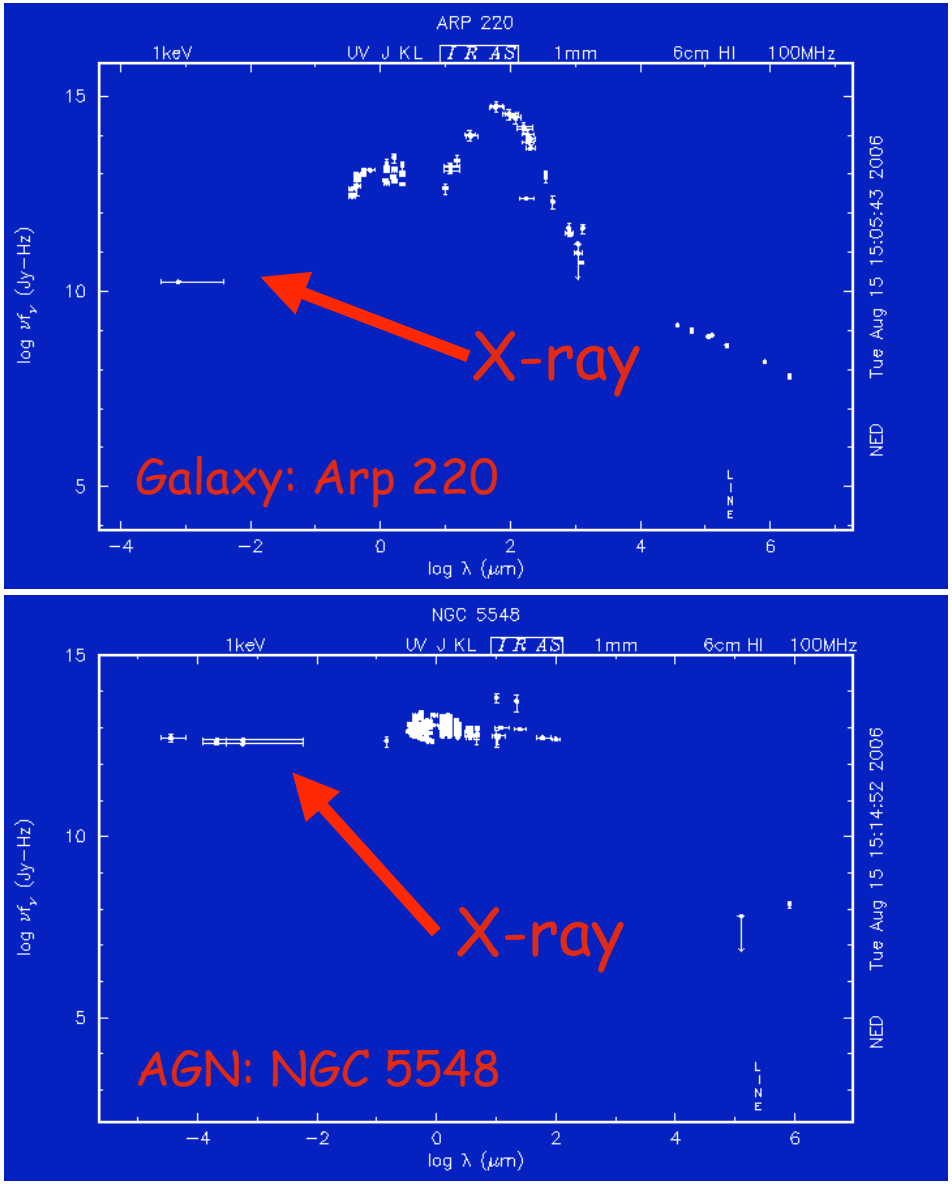
Future

- Important science to be done with galaxies
- Wide medium-deep XMM survey:
  - 15ks, f_X~5×10^{-15}erg/s/cm^2
  - ~100deg^2
- NOT very-wide shallow:
  - ~1000deg^2
  - f_X~10^{-13}erg/s/cm^2

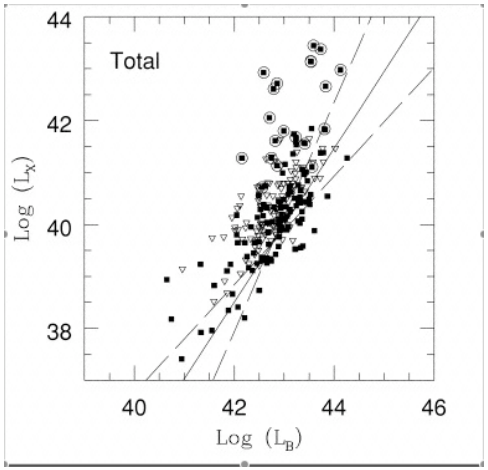


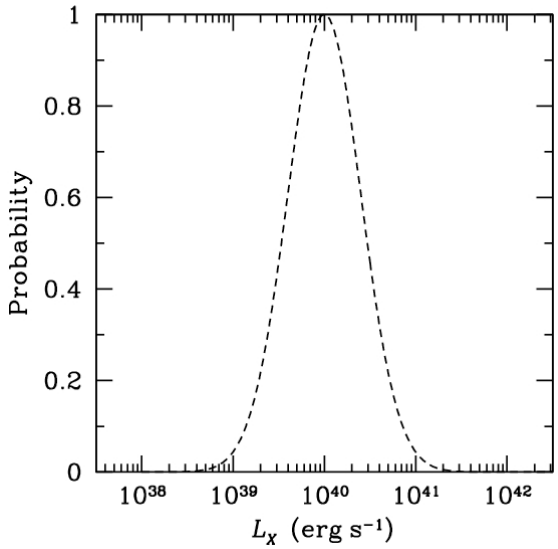
Galaxies at X-rays: does it worth it?

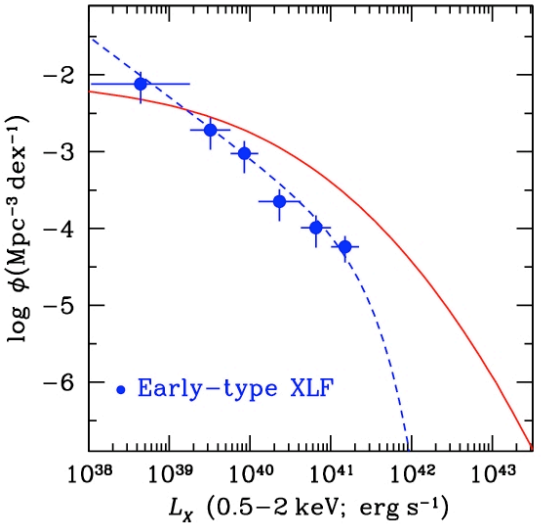
- X-rays only a small fraction of the energy output of galaxies
- e.g. Arp 220:
  - most of the energy at the infrared
  - X-rays: 5dex lower flux!
- Unlike AGN where X-rays are a major component



Galaxy X-ray Luminosity Function







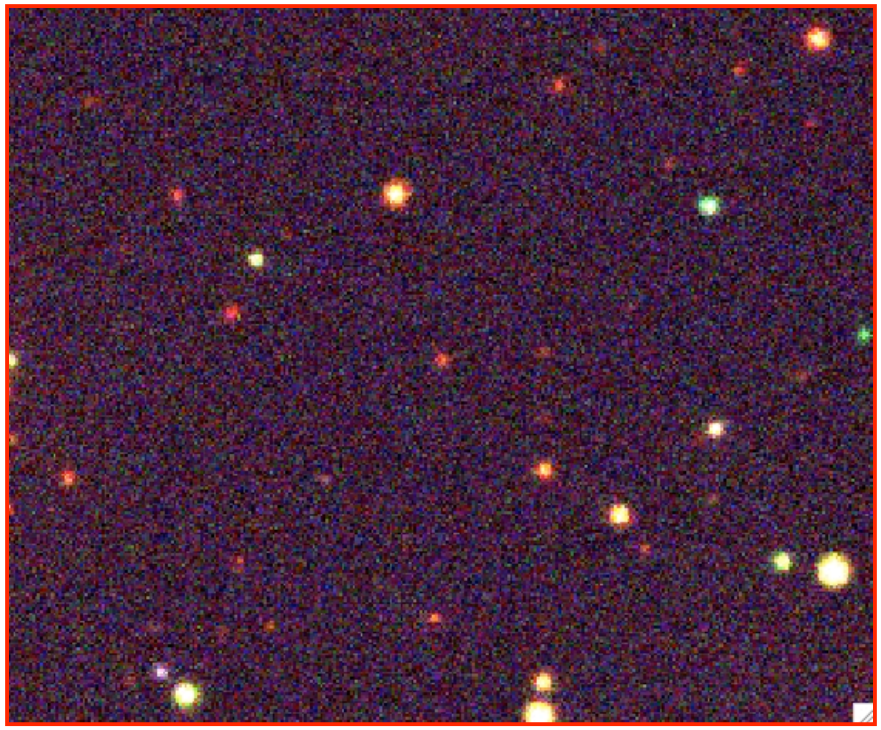
Difference between the two XLF estimates:

- L_X/L_B relation more complex than power-law
- At a given L_B the distribution of L_X not Normal (e.g. low-L_X tail).

Why study galaxies

- Dominant population below the limit of current surveys
- At f_X~10^{-18}erg/s/cm^2
  - 30,000 galaxies/deg^2
  - Mean redshift <z>~1.5

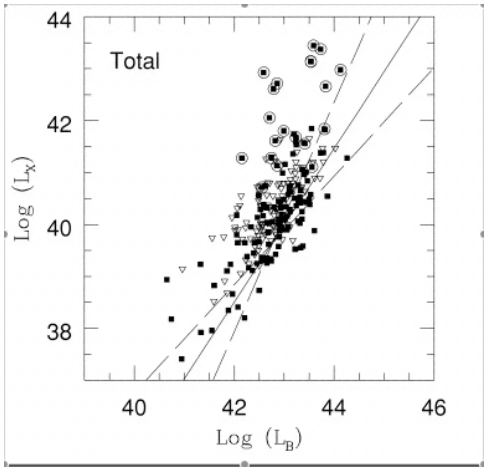
1Ms XEUS simulation of the UDF (T. Dwelly)

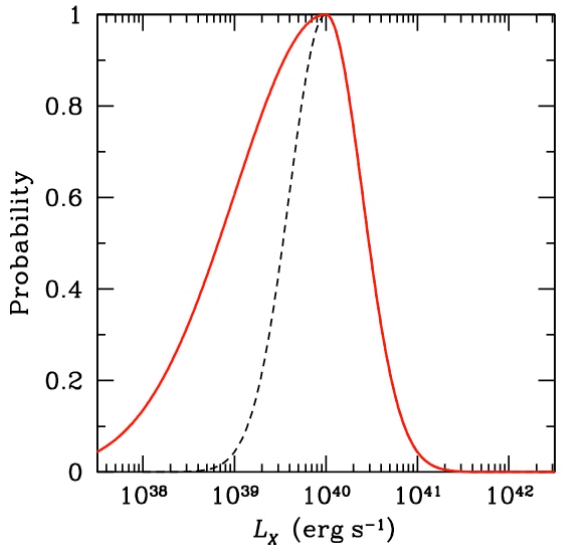


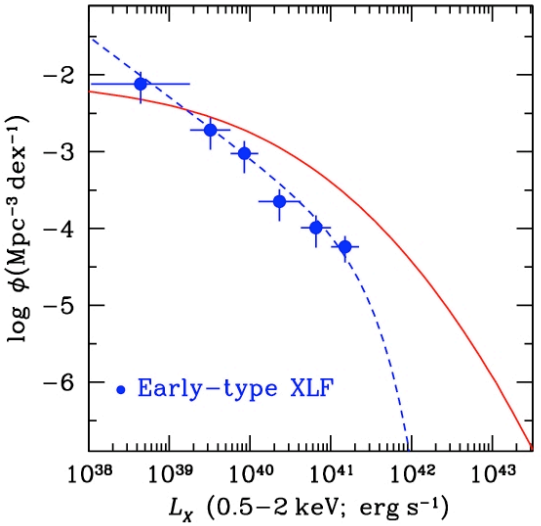
Galaxies: Imperial College

AGN: Bologna

Galaxy X-ray Luminosity Function







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