

X-ray selected normal galaxies at low redshift



Antonis Georgakakis

National Observatory of Athens
Institute of Astronomy & Astrophysics

Outline

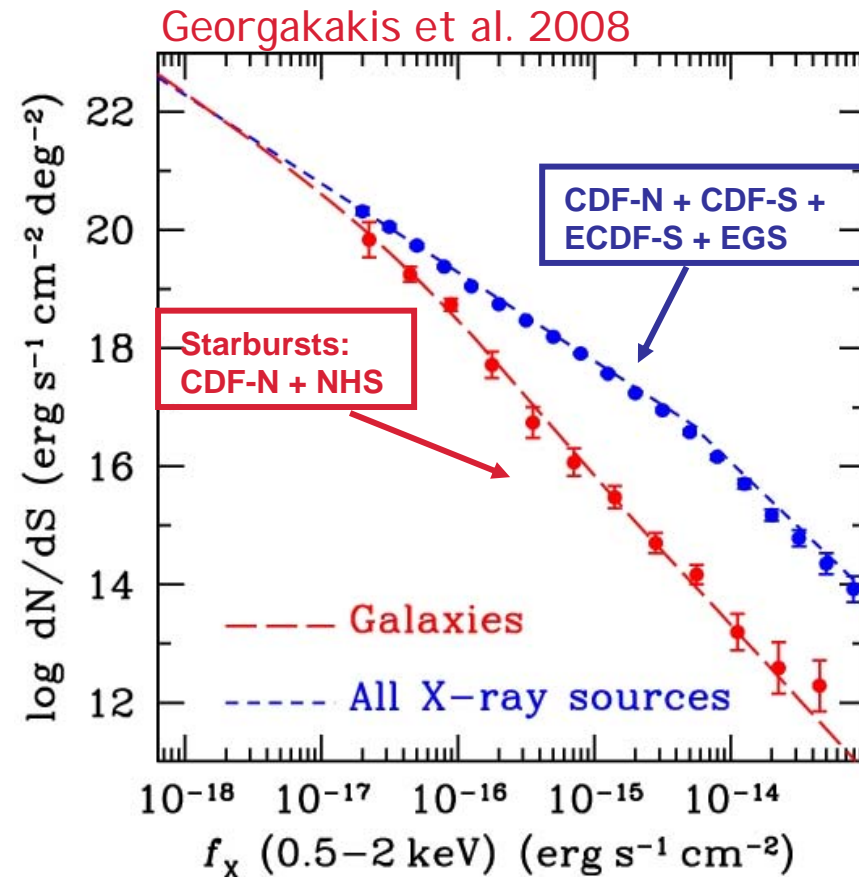
- Study of galaxies at X-ray wavelengths important
- State of the game + problems/issues
- Further progress requires wide area X-ray survey in the SDSS

Galaxies at X-rays

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

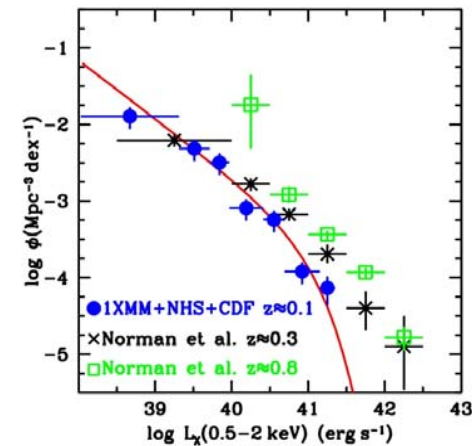
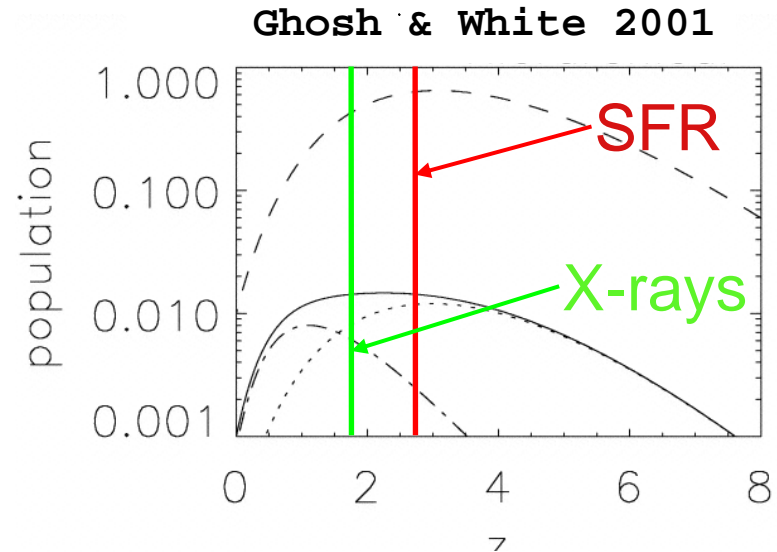
Why study galaxies

- **Dominant** population below the limit of current surveys (e.g. XEUS)
- At $f_x \sim 10^{-18}$ erg/s/cm²
 - **30,000** galaxies/deg²
 - Mean redshift $\langle z \rangle \sim 1.5$



X-ray evolution of star-forming galaxies

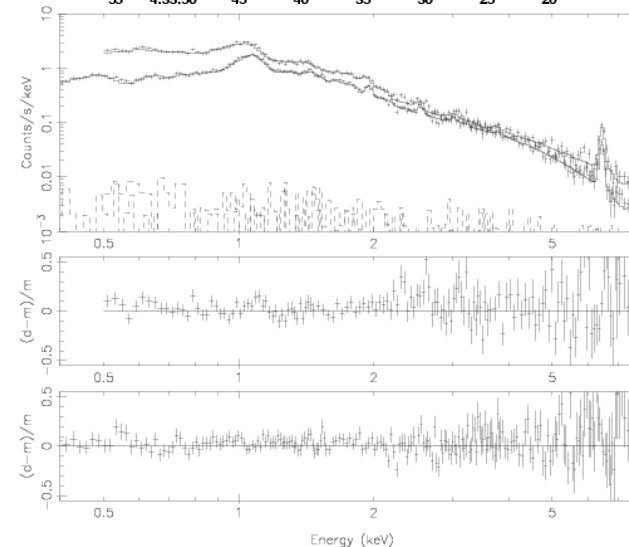
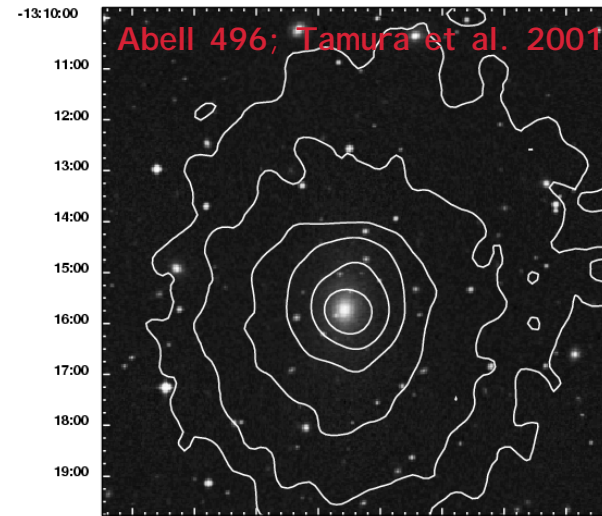
- X-ray binaries:
 - low mass: long timescales
 - high mass: fast evolution
- X-ray evolution of starbursts different compared to other wavebands
 - time lag between the peaks of SF and X-ray luminosity
- Attempts to constrain galaxy XLF as a function of redshift
 - *Chandra* Deep Fields identify galaxies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



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

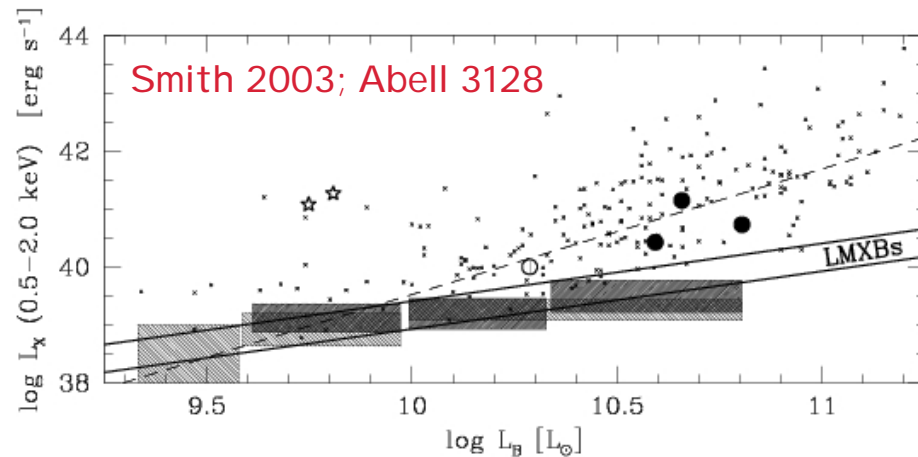
Metal enrichment

- 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)

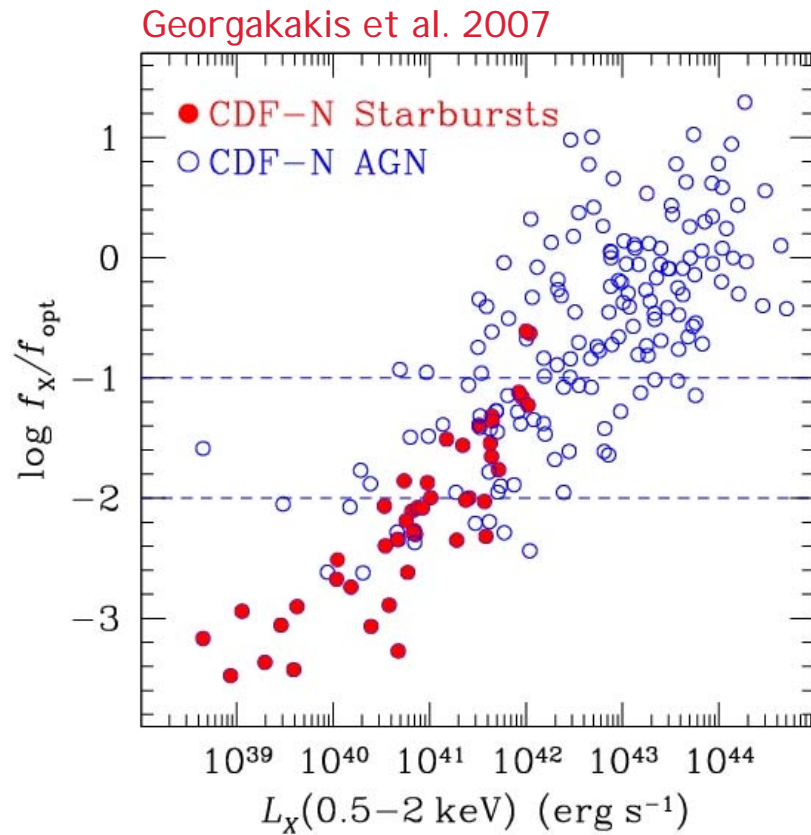
Stacking signal consistent with low-mass X-ray binary expectation (no hot gas)

See also Hornschemeier et al. 2006

Problems

- Selection of galaxies
 - Contamination from AGN
 - Incompleteness
- Galaxy samples are still small (~ 100)
 - Luminosity function: uncertainties in the determination of the faint-end slope and L_*

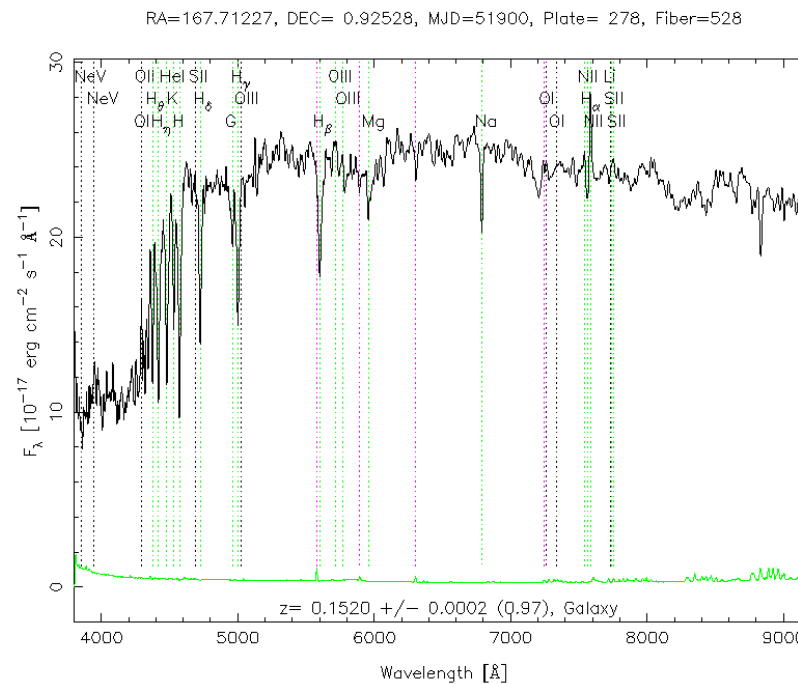
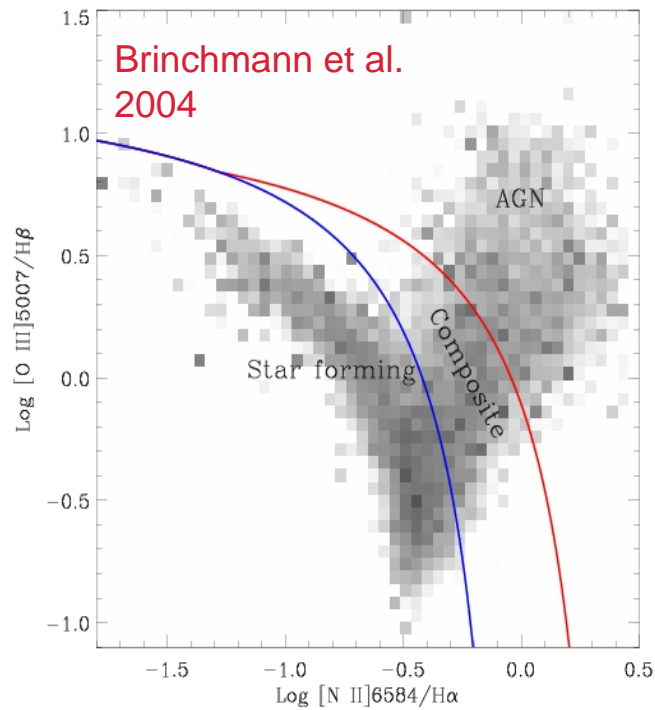
Galaxy X-ray Luminosity Function: selection effects



Galaxies are often
selected to have
 $\log(f_X/f_{opt}) < -2$

incompleteness

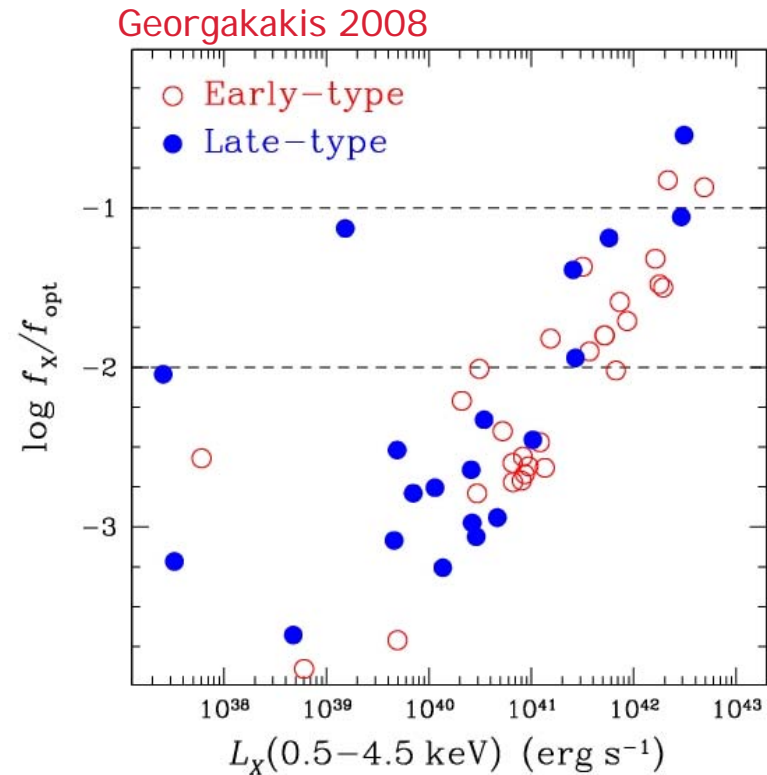
Optical spectroscopy



High quality optical spectra (e.g. SDSS):
Unbiased galaxy selection

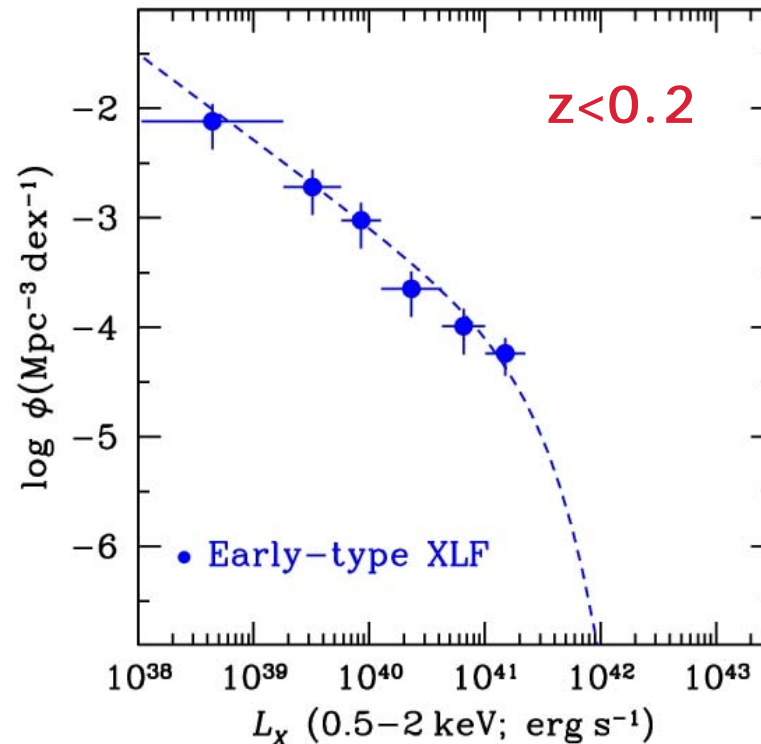
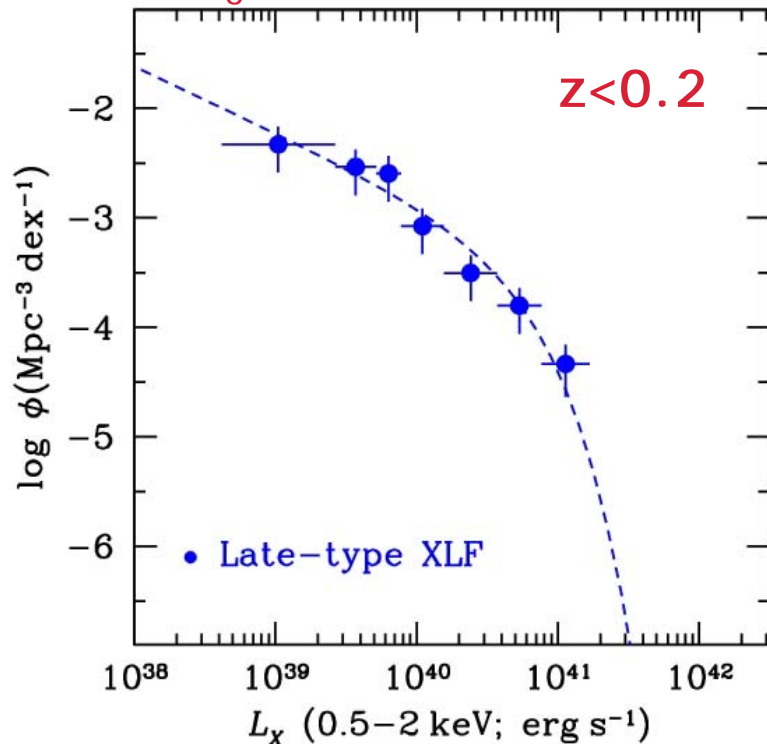
X-rays + SDSS spectra

- Match 2XMM with the SDSS-DR4 spectroscopy
- Total of 48 galaxies
 - $L_X \sim 10^{40} - 10^{43} \text{ erg/s}$
 - 50% $\log(f_X/f_{opt}) > -2$



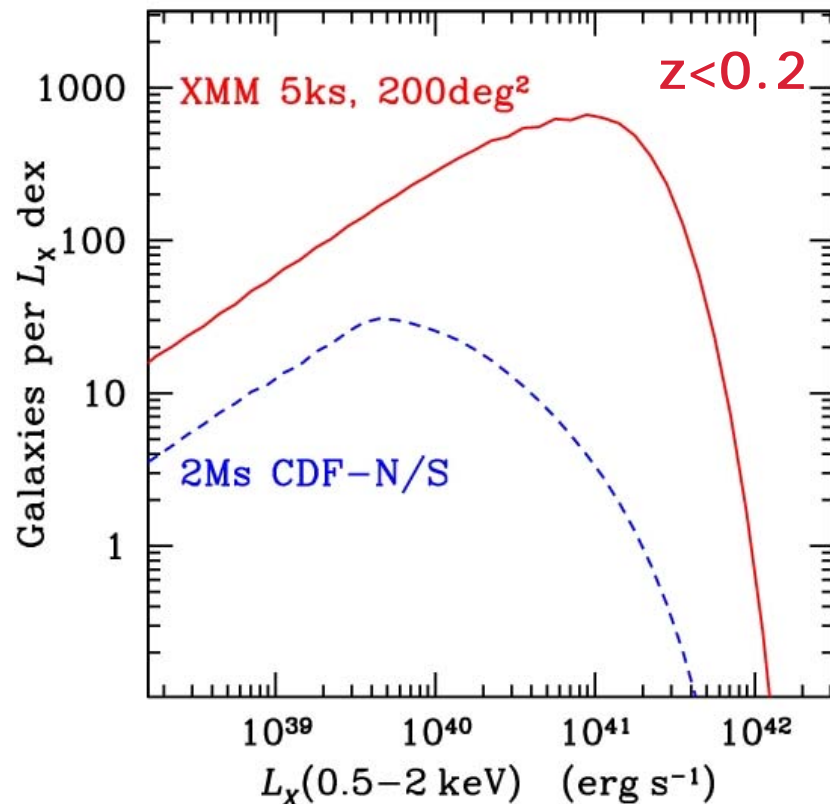
Galaxy X-ray Luminosity Function: small number statistics

Georgakakis et al. 2006



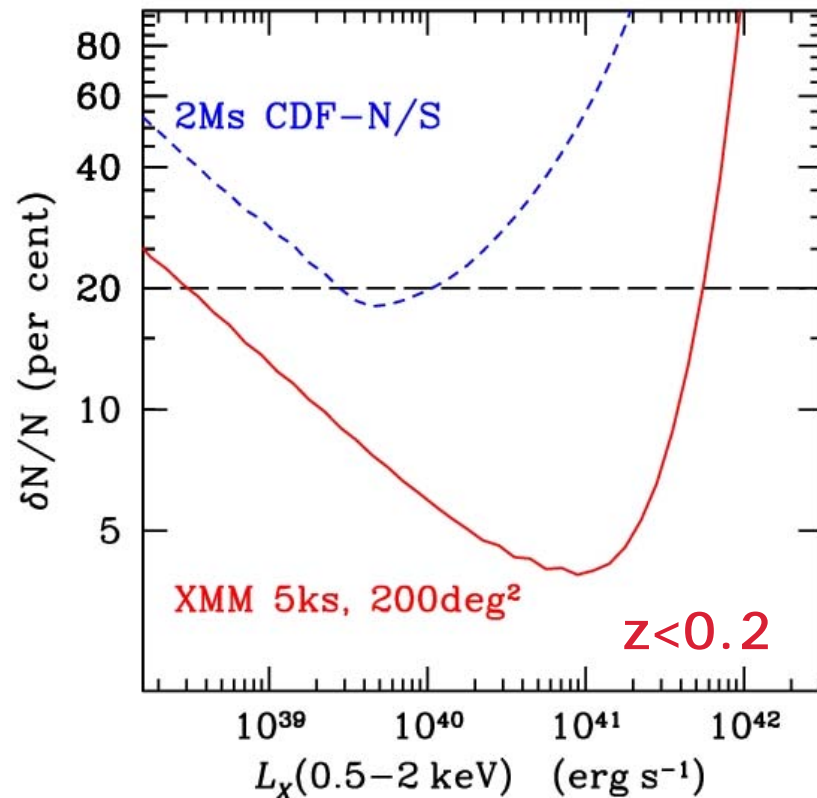
- Local X-ray Luminosity Function, $\langle z \rangle \sim 0.1$
- Data: Needles in Haystack Survey + 1XMM + Chandra Deep Fields ($\sim 15 \text{ deg}^2$)

Wide-area & shallow X-ray survey in the SDSS



- Many $z < 0.2$ galaxies over wide L_x -range
- Accurate XLF determination (e.g. faint-end slope, L_*)
- $< 20\%$ uncertainty in individual L_x -bins

Wide-area & shallow X-ray survey in the SDSS

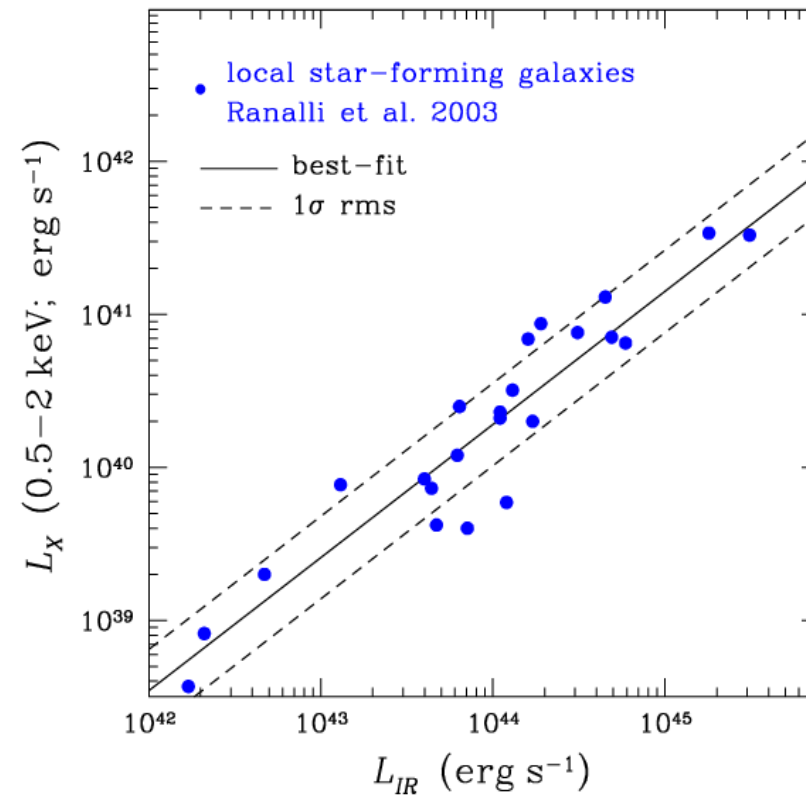


- Many $z < 0.2$ galaxies over wide L_x -range
- Accurate XLF determination (e.g. faint-end slope, L_*)
- $< 20\%$ uncertainty in individual L_x -bins

Calibrate infrared methods for selecting normal galaxies

- Mid/far-IR: alternative to optical spectroscopy for selecting galaxies
- Useful at high z , where high S/N spectra difficult
- IR selection methods not yet calibrated
 - contamination rate
 - incompleteness

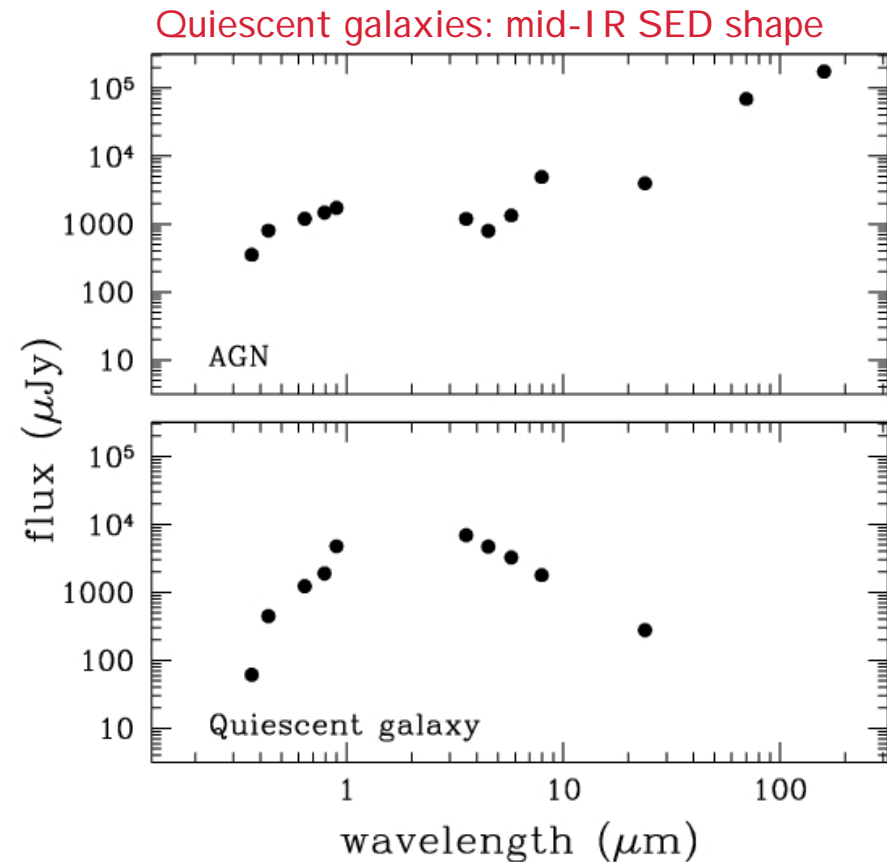
Star-forming galaxies: L_X - L_{IR} correlation



e.g. Georgakakis et al. 2008; Lehmer et al. 2008

Calibrate infrared methods for selecting normal galaxies

- Mid/far-IR: alternative to optical spectroscopy for selecting galaxies
- Useful at high z , where high S/N spectra difficult
- IR selection methods not yet calibrated
 - contamination rate
 - incompleteness



e.g. Georgakakis et al. 2008

Summary

- A wide-area ($\sim 200\text{deg}^2$) shallow (5ks) X-ray survey is needed for normal galaxy studies:
 - Unbiased & complete sample
- Important science:
 - X-ray luminosity function at $z\sim 0.1$
 - evolution studies
 - interpretation of deeper surveys
 - Calibrate IR methods for selecting X-ray galaxies
 - Star-forming galaxies: L_X - L_{IR} correlation
 - Early-type galaxies: mid-IR SED