The Accretion History of SMBHs in Massive Galaxies

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Collaborators: M. Brown, A. Dey, B. Jannuzi, and the XBootes and Bootes MIPS teams.

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Questions

- How did the mass of SMBHs grow?
- How is this related to the build-up of the red sequence?
- What is connection between SMBH growth and massive galaxy evolution?
- Have SMBHs accreted a significant fraction of their mass between z=1 and the present?

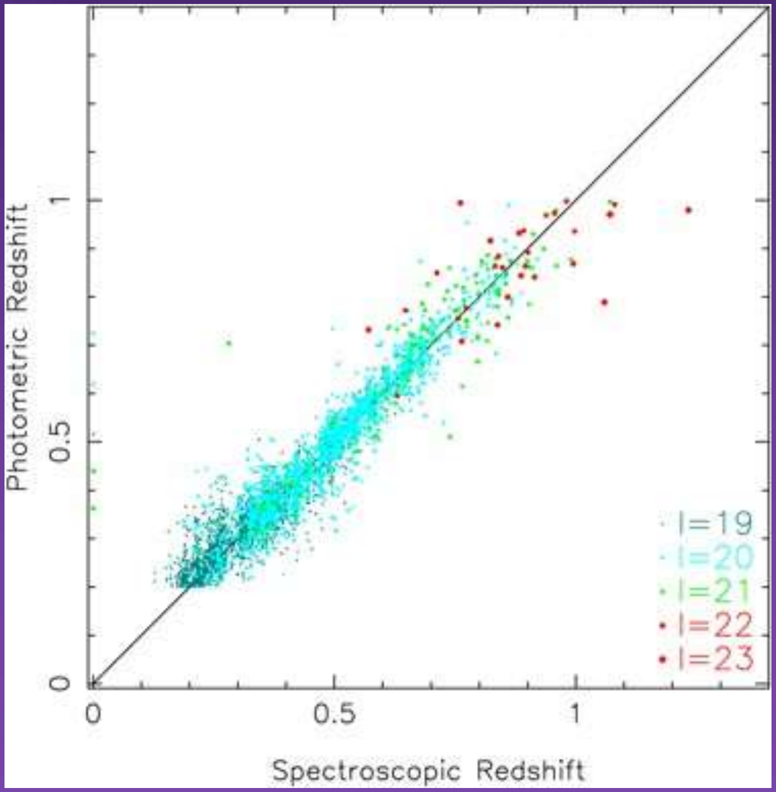
  – An X-ray and Mid-IR stacking analysis of ~30,000 red galaxies from the NDWFS Bootes field.

9 deg^2: Bw, R, I, K ~ 27.1, 26.1, 25.4, 19.0 mag (Vega)

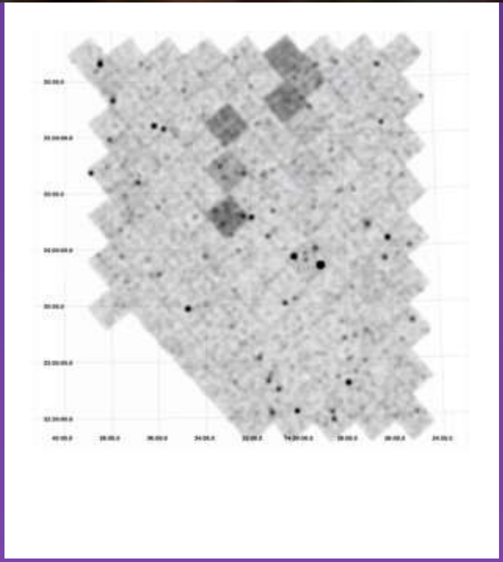
PI's: A. Dey, B. Jannuzi

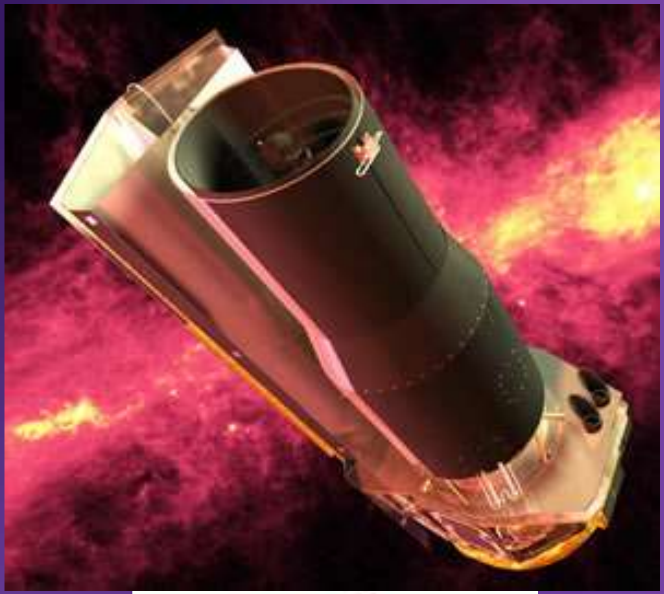
The Red Galaxy Survey

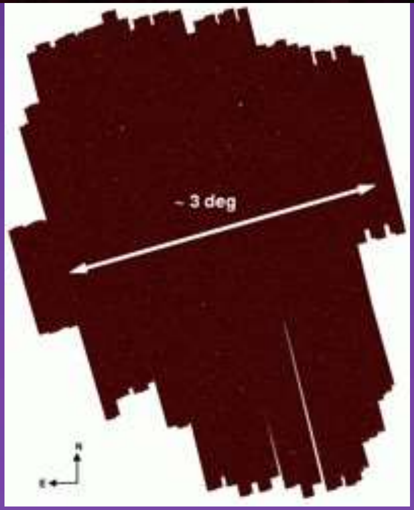
- ~ 30,000 red galaxies selected from NDWFS to be on red sequence (see Brown et al. 2006)



Chandra and Spitzer imaging



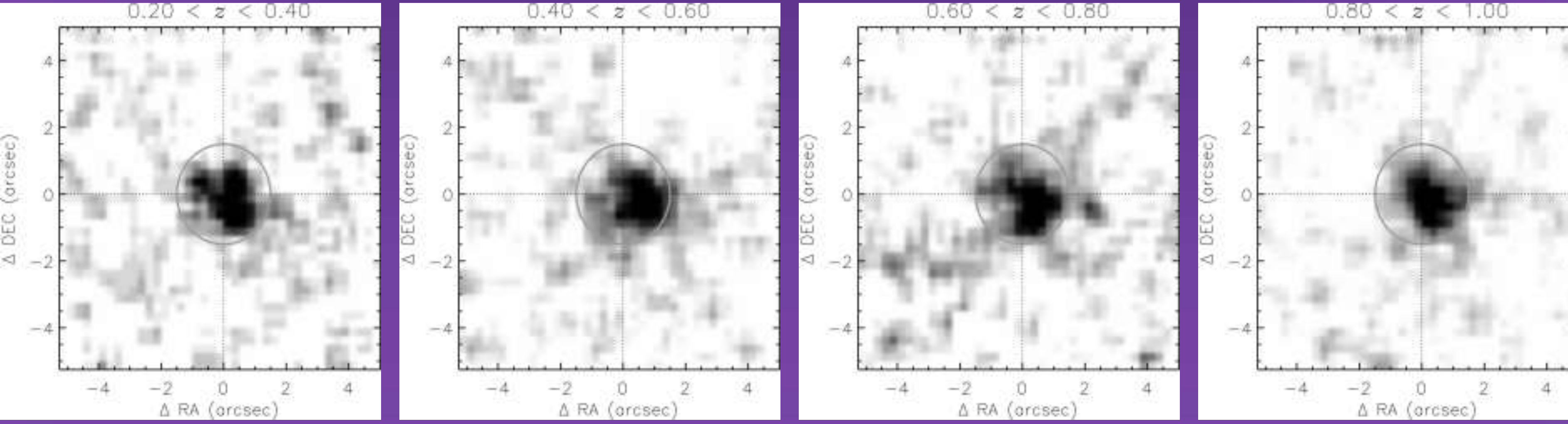




Stacking the X-ray images gives a highly significant signal

- Stacked up the X-ray images in different subsets of the data to obtain a mean X-ray luminosity as a function of galaxy properties.
- 5-ks on a single object but for 1000 galaxies, equivalent to a 5-Ms observation on the mean object.

$0.2 < z < 0.4$ | $0.4 < z < 0.6$ | $0.6 < z < 0.8$ | $0.8 < z < 1.0$



1692 | 4778 | 8647 | 11250

(X-ray detected sources not included)

Basic X-ray Stacking Results

- $\langle L_X \rangle \sim 10^{41}$ ergs s^{-1} is at least 10x too high to be due to stellar sources.

→ **The X-ray emission is dominated by accretion onto a SMBH**

- $\langle L_X \rangle$ is ~10-100x fainter than typical Seyferts

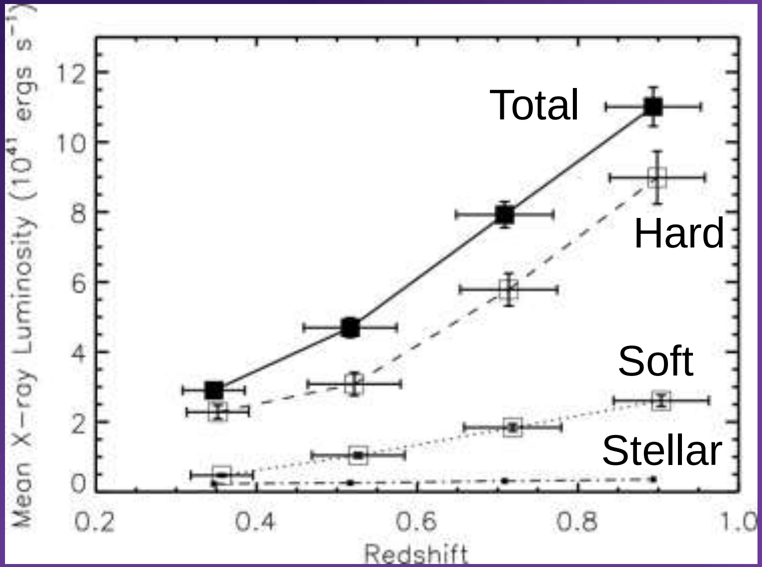
→ **The accretion rate is very low and/or radiatively inefficient**

- The X-ray spectrum is hard and can be explained by:
  - Absorbed ($N_H = 2 \times 10^{22}$ cm^{-2}) $\Gamma=1.7$ power-law
  - Unabsorbed $\Gamma=0.7$ power-law (e.g. ADAF)

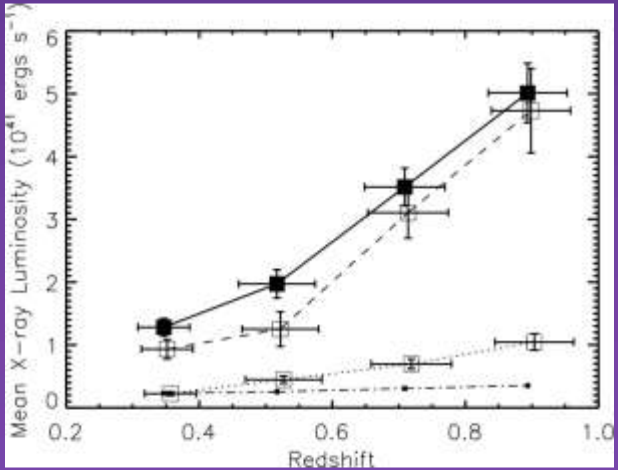
→ **The AGN must be obscured or radiatively inefficient**

The mean X-ray luminosity increases with redshift

$L_X \propto (1+z)^{4.0 \pm 0.5}$

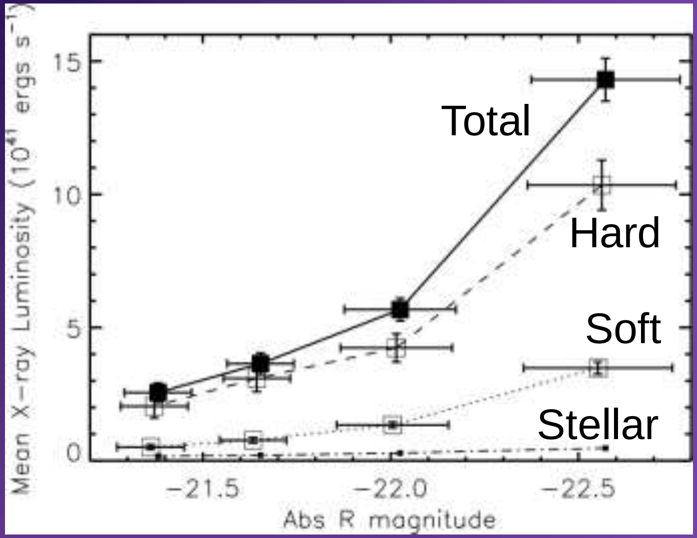


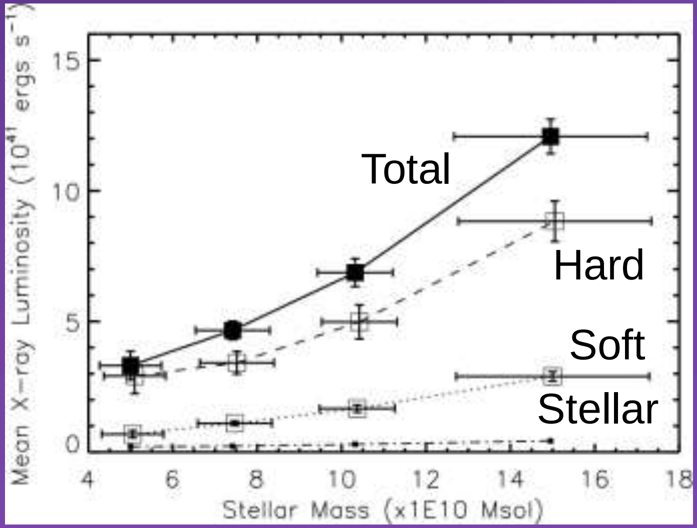
[excluding X-ray detected sources: $L_X \propto (1+z)^{4.1 \pm 0.7}$]



More massive galaxies are more X-ray luminous

The mean X-ray luminosity increases as a function of optical luminosity and stellar mass.





Converting X-ray luminosity to a nuclear accretion rate

$\varepsilon \dot{M} = L_{bol}/c^2$

$\dot{M} = 1.76 \times 10^{-5}\, M_{\odot}/yr\ (0.1/\varepsilon)\ (Lx/10^{41})\ x\ C_B$

ε= radiative efficiency of accretion energy

C_B=bolometric correction

e.g. Armitage in “SMBHs in the Distant Universe”, A. Barger

The Build-up in the mass of the SMBHs

$M_{BH} \sim 0.002\ M_{bulge} \rightarrow M_{BH} \sim 2 \times 10^8\ M_\odot$

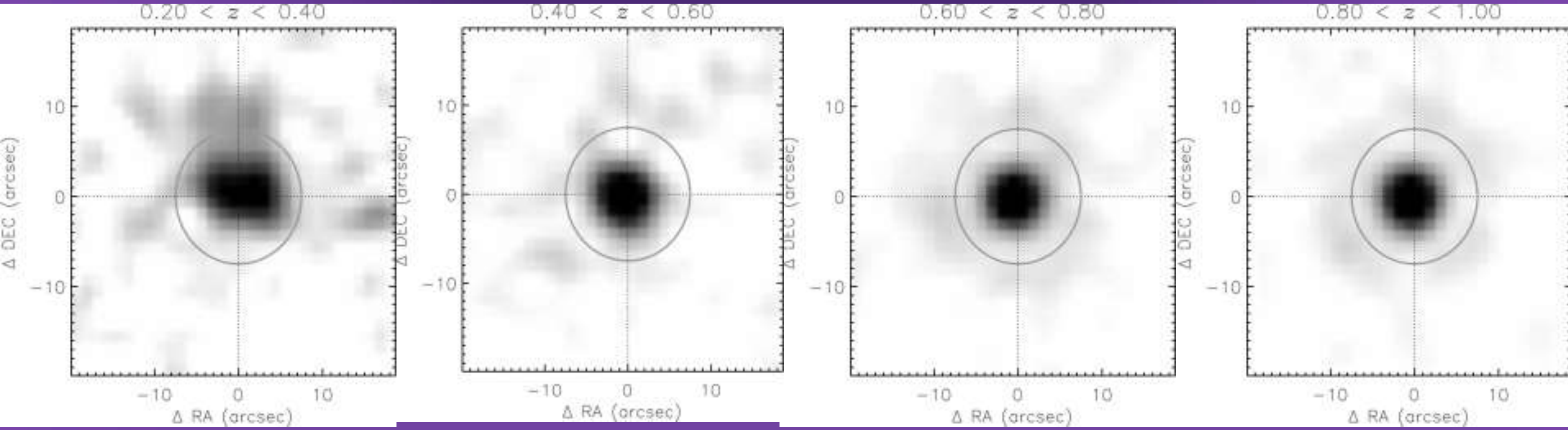
Integrating accretion rate from z=1 to present ->
Assuming $\varepsilon = 0.1$ - increase in BH mass ~ $9 \times 10^7\ M_\odot$ (~50%)
~half of build-up due to ~1% of population.

- What population are we tracing?
- may be accreting at lower efficiencies:
  $\varepsilon = 0.001$ (ADAF) - increase in BH mass ~ $9 \times 10^9\ M_\odot$

- Mid-IR properties can help determine whether the hard X-ray spectrum is due to obscuration or low efficiency accretion flow.

Stacking the 24μm images gives a highly significant signal

0.2 < z < 0.4 | 0.4 < z < 0.6 | 0.6 < z < 0.8 | 0.8 < z < 1.0



(24μm detected sources not included)

Basic L_{IR} properties of red galaxies

- 20% of red galaxies have f_{24}>0.3 mJy
- Mean flux ~ 0.3 mJy (~0.04 for f_{24}<0.3 mJy sources)

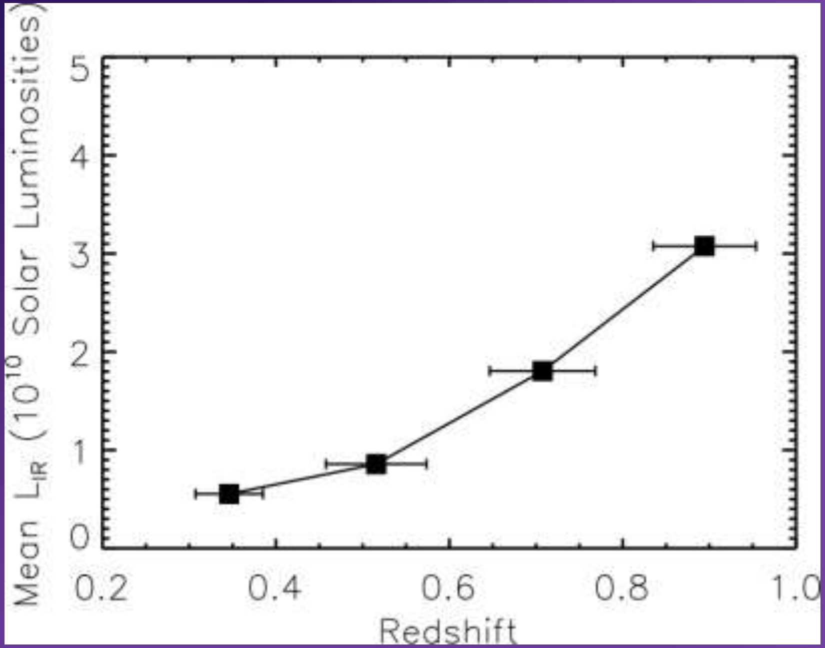
  → red galaxies go through 'active' phases.

- Of the X-ray detected sources, 50% have f_{24}>0.3 mJy

  → link between X-ray and mid-IR activity.

The mean L_{IR} increases with redshift

$Lx \propto (1+z)^{4.8 \pm 0.6}$



- Assuming IR SED of APM 08279+5255
  $\rightarrow L_{IR}$ (8-1000 μm)

But what is contribution of AGN / SF?

- Do appear to contain large amounts of dust

Conclusions - Red Galaxies

- X-ray luminosities imply weak AGN activity.
- Hard X-ray spectra imply obscured or radiatively inefficient AGNs.
- $L_X \propto (1+z)^{4.0 \pm 0.5}$
- If $\varepsilon = 0.1$, SMBHs increase in mass by order 50%.
- Large mid-IR luminosities suggest large amounts of warm dust.
- Much of the X-ray & 24µm luminosity is from a small fraction of sources, consistent with short bursts of activity.

- SMBHs in red galaxies could be growing by ~50% between z=1 and the present in bursty but optically obscured phases.

Extra Slides

Multiwavelength Observations of the Bootes Field

VLA P-band	90 cm	7 sq.deg.	100μJy	100% complete; van Breugel, PI
VLA L-band	21 cm	1 sq.deg.	15μJy	100% complete; Higdon, PI
VLA (FIRST)	21 cm	9 sq.deg.	1mJy	100% complete; public
Westerbork	21 cm	7 sq.deg.	8μJy	100% complete; Rottgering, PI
Spitzer/MIPS	24,70,160μm	9 sq.deg.	3.0, 30, 100mJy	100% complete; Jan 2004 GTO
Spitzer/IRAC	3.6,4.5,5.8,8μm	9 sq.deg.	6.4, 8.8, 51, 50μJy	100% complete; Eisenhardt et al.
NOAO	J, Ks	5 sq.deg.	23 mag	100% complete; Elston et al. (2005)
NOAO	K, Ks	9 sq.deg.	19.2 mag	100% complete
NOAO	J, H	9 sq.deg.	21 mag	40% complete
NOAO	B_W, R, I	9 sq.deg.	25.5-26.6 mag	100% complete
NOAO	U	9 sq.deg.	25 AB mag	100% complete
NOAO	U	1 sq.deg.	26 AB mag	100% complete
GALEX	FUV, NUV	1 sq.deg.	26 AB mag	100% complete, GTO
GALEX	FUV, NUV	9 sq.deg.	25 AB mag	in progress, GTO
Chandra	0.5-2 keV	9 sq.deg.	4.7e-15 erg/s/cm^2	100% complete
Chandra	2-7 keV	9 sq.deg.	1.5e-14 erg/s/cm^2	100% complete
NOAO/Keck	spectroscopy	sparse	24 mag	in progress (400 so far)
MMT/Hectosp	spectroscopy	9 sq.deg.	R~20.5 mag	completed
Spitzer/IRS	spectroscopy	sparse		in progress

Contribution of Stellar Sources - HMXBs

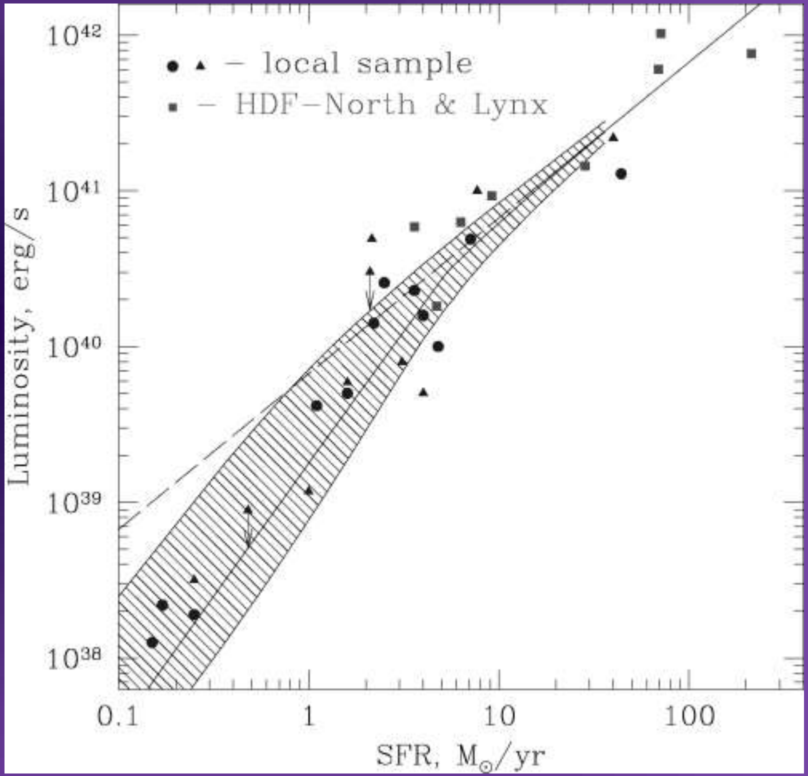
Short lifetime -> SFR

Population Synthesis fits to optical photometry

-> SFR

Grimm et al.2003

-> Expected luminosity



8 % of total Luminosity in each redshift bin

Contribution of Stellar Sources - LMXBs

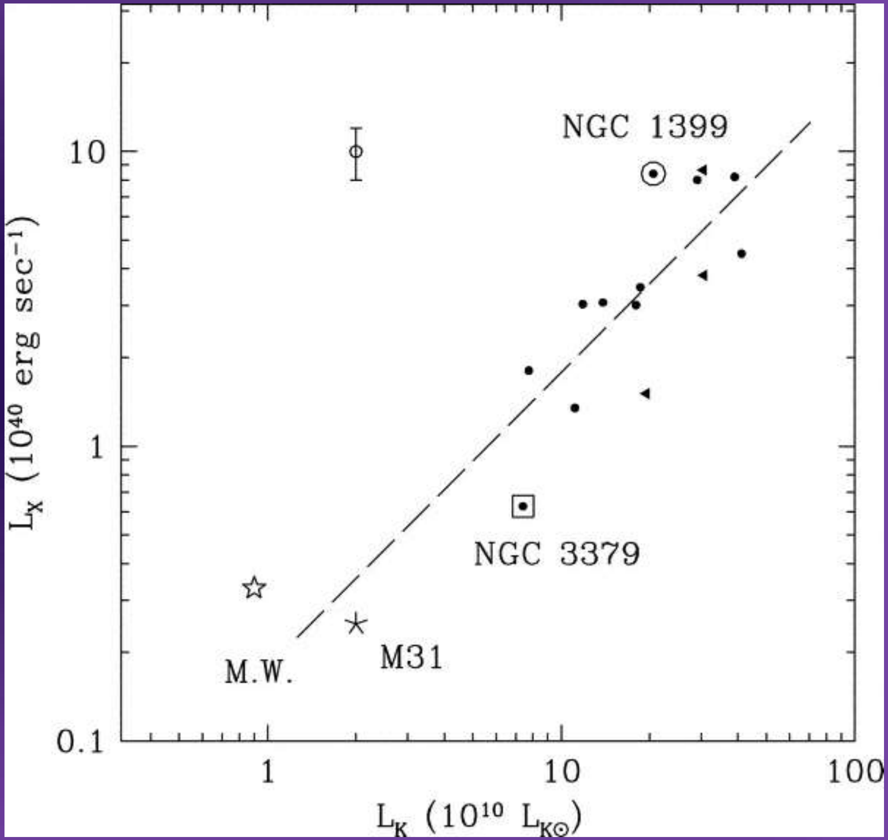
Long lifetime

-> stellar mass

-> absolute K mag

Kim et al.2004

-> Expected luminosity



~10 % of total Luminosity in each redshift bin