X-ray emission from early type galaxies

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- Current status at z=0, and first/few results at z>~0
- A few science goals for WFXT

working definition for **NORMAL early type galaxies** (ETG):

X-ray emission not dominated by AGN
L_X <= 10^{42} erg/s

z=0

detailed studies with Einstein/ROSAT/XMM/Chandra:
~200 ETG more or less well known, at d<100 Mpc

L_X powered by:

stellar sources (LMXBs)

low luminosity AGN

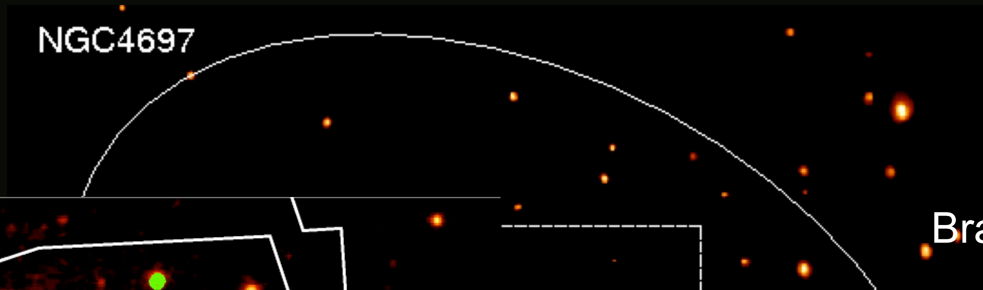
hot gaseous halo (kT<~1 keV)

Stellar sources

Major advances from *Chandra*

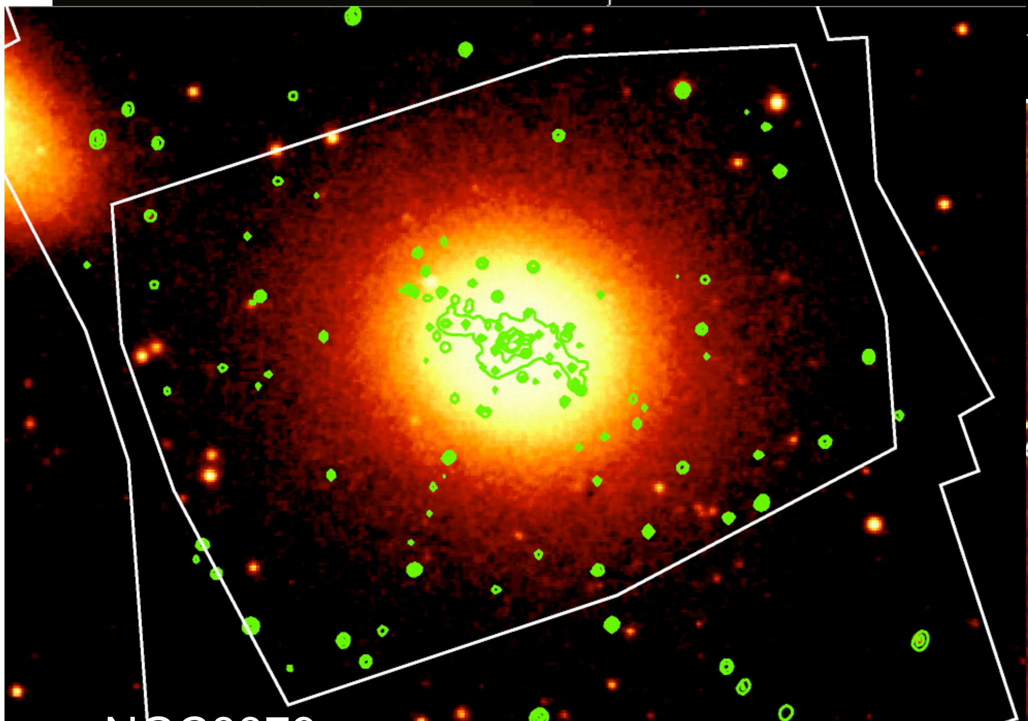
Deep pointings (few 10^2 ksec) for few nearby ETG with **low hot gas contents**

LMXBs resolved down to ~5 10^{36} erg s^{-1}

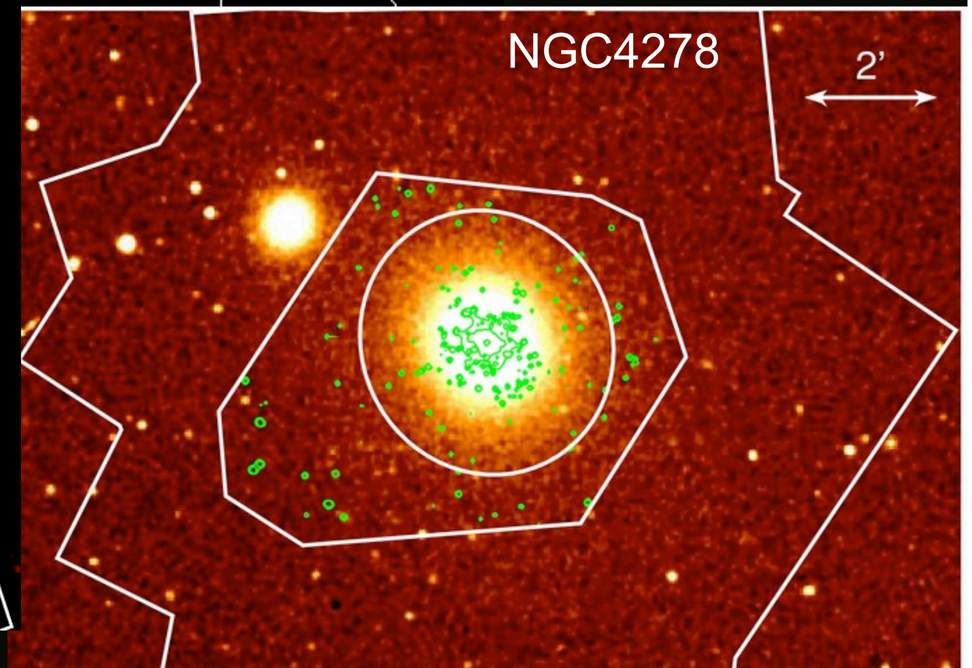


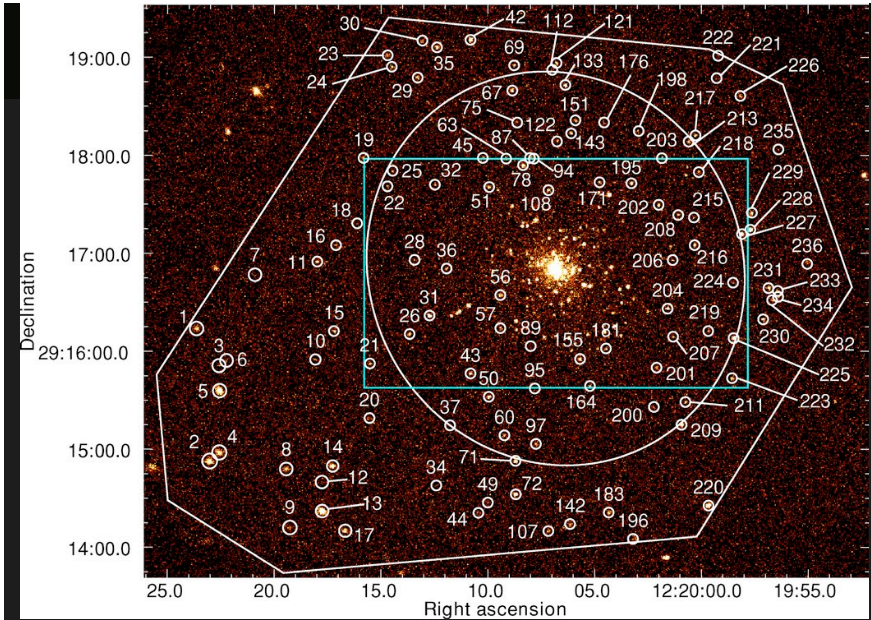
Soria+ 06

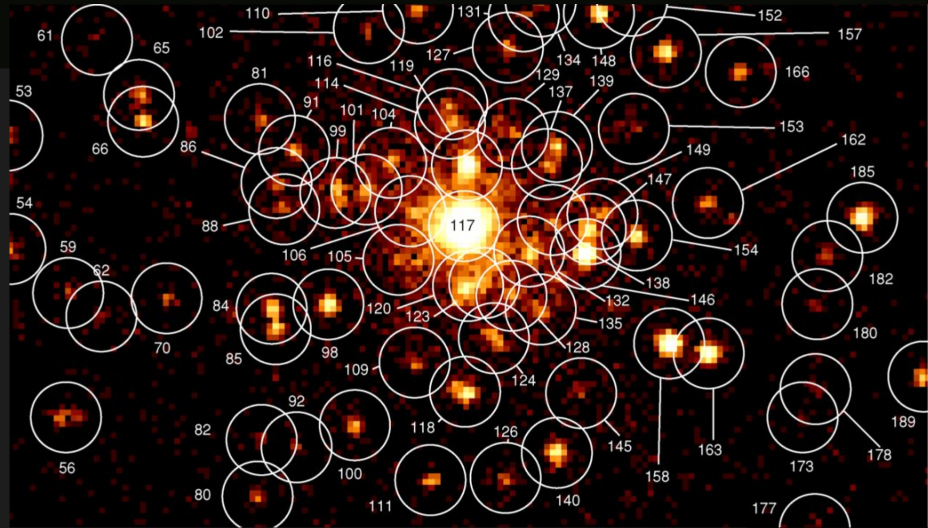
Brassington+ 08, 09



NGC3379

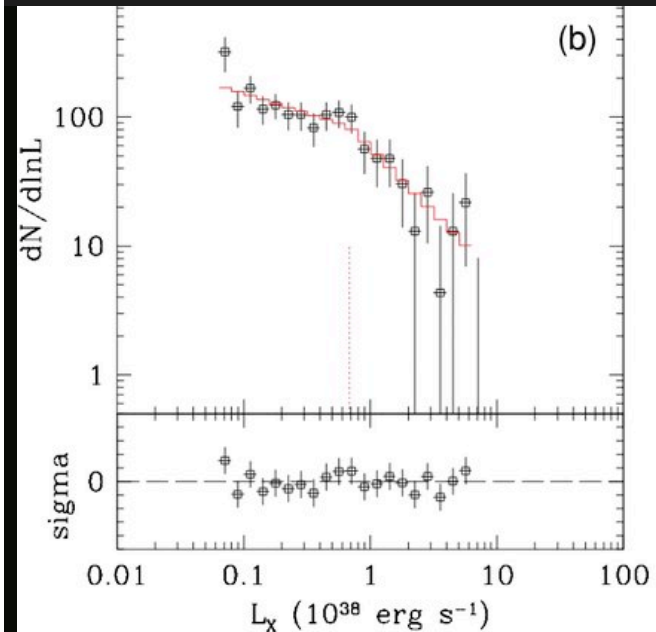


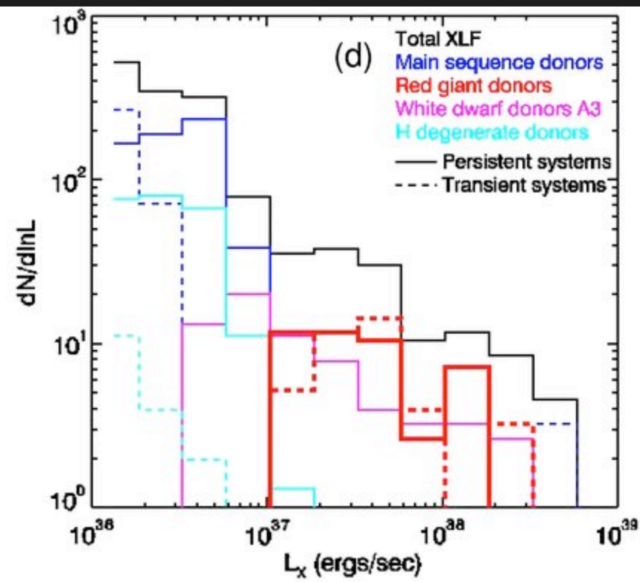




NGC4278, Brassington+ 09

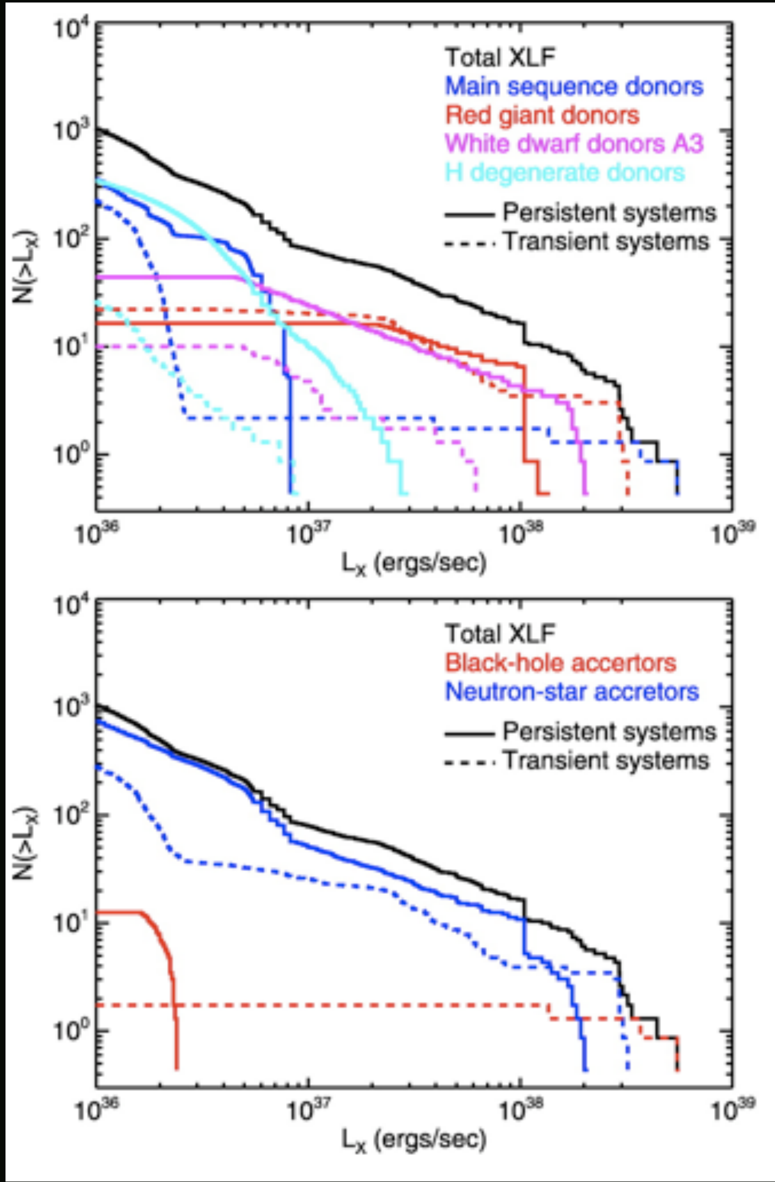
NGC3379, NGC4278, NGC4697: combined XLF (Kim+ 06, 09)





LMXB's synthesis models

evolution of primordial field LMXB population with *StarTrack* code (Belczynski+ 07) and predictions for XLF (Fragos+ 08, 09)

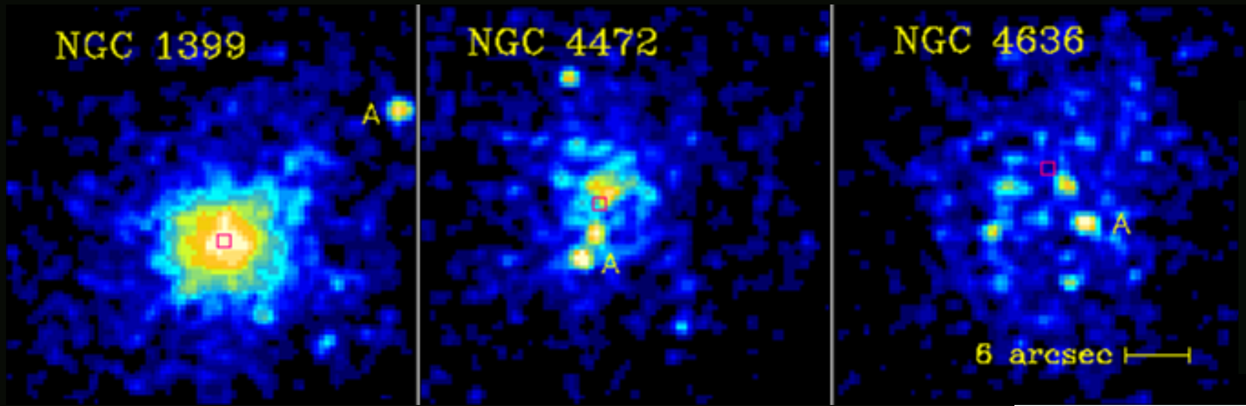


main contributors to XLF:
NS accretors with RG donors

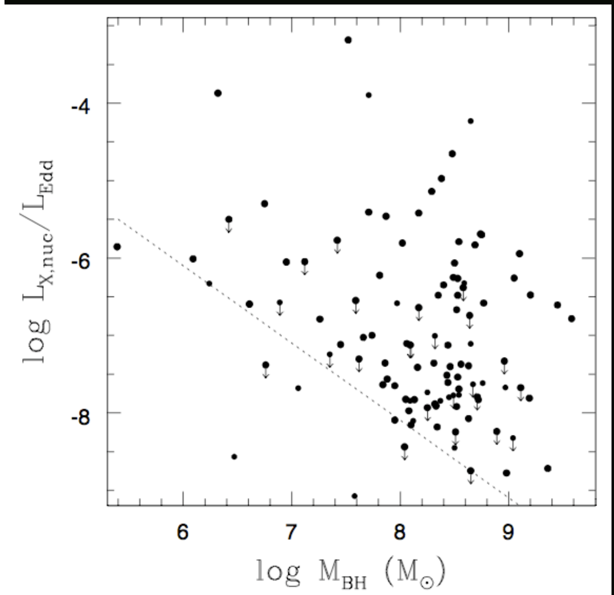
GOAL: calibrate collective L_X(LMXBs) on galaxy stellar mass, age, GC S_N, …

Low luminosity nuclei

weak central sources down to ~10^{38} erg s^{-1} (Virgo or closer)



Loewenstein+ 01



nuclei at d<60 Mpc

$L_{X,nuc} << 0.1 \dot{M}_{in} c^2$

⬇

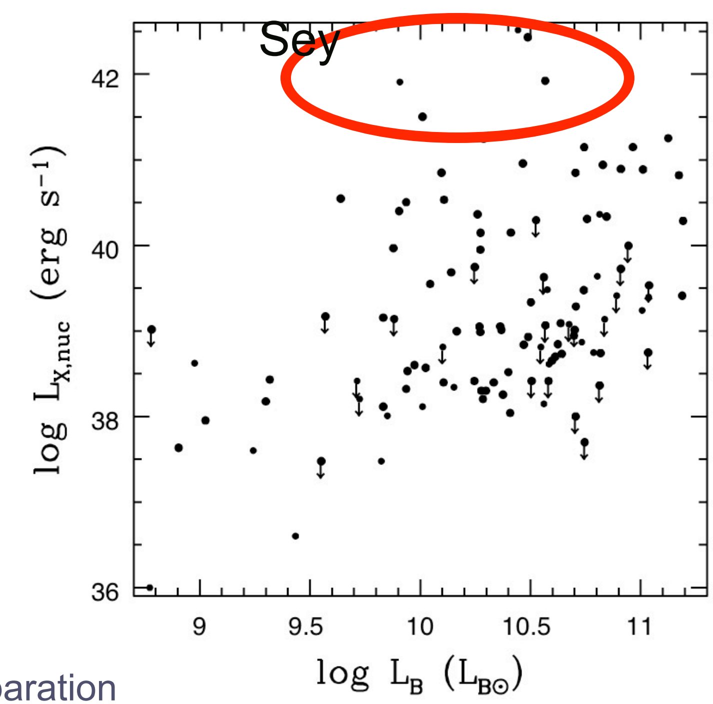
low radiative efficiency

intermittent accretion

dispersion?

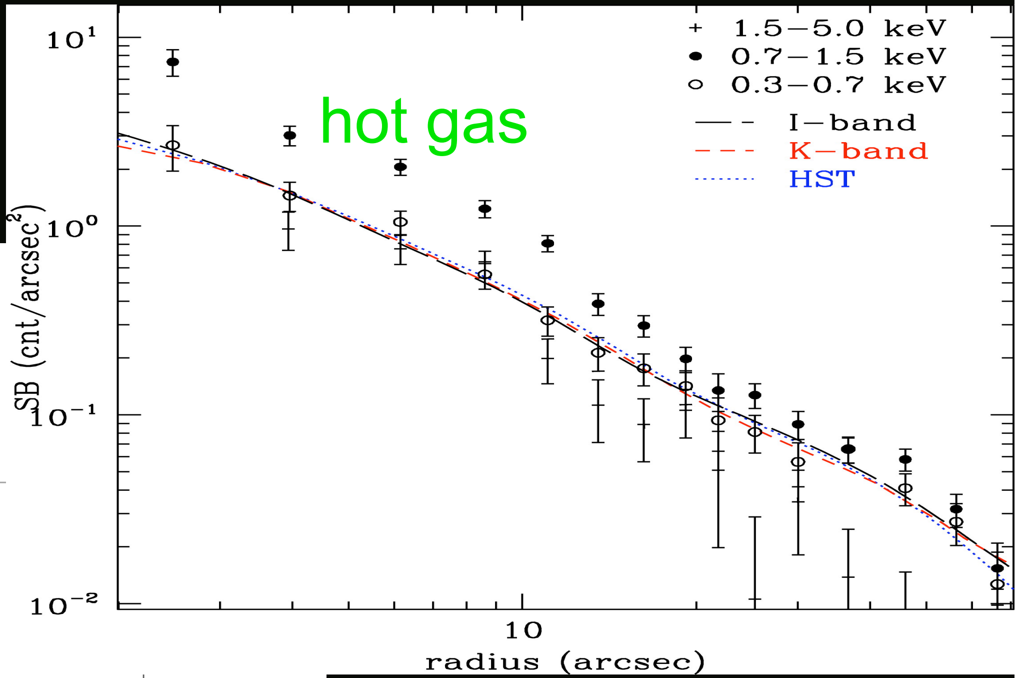
Pellegrini 2005, and in preparation

2-10 keV

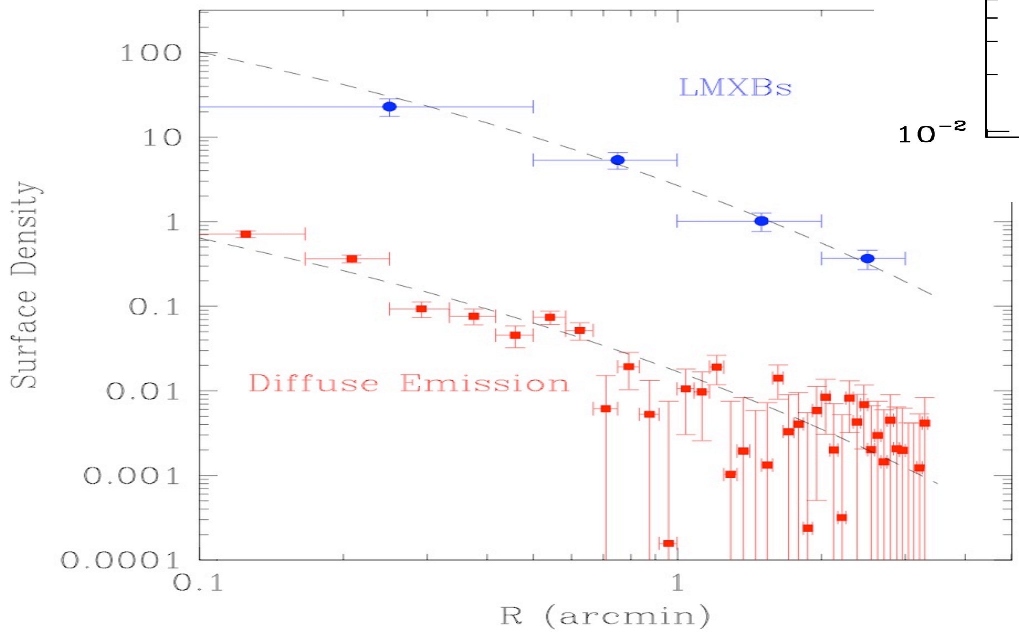


Hot gas

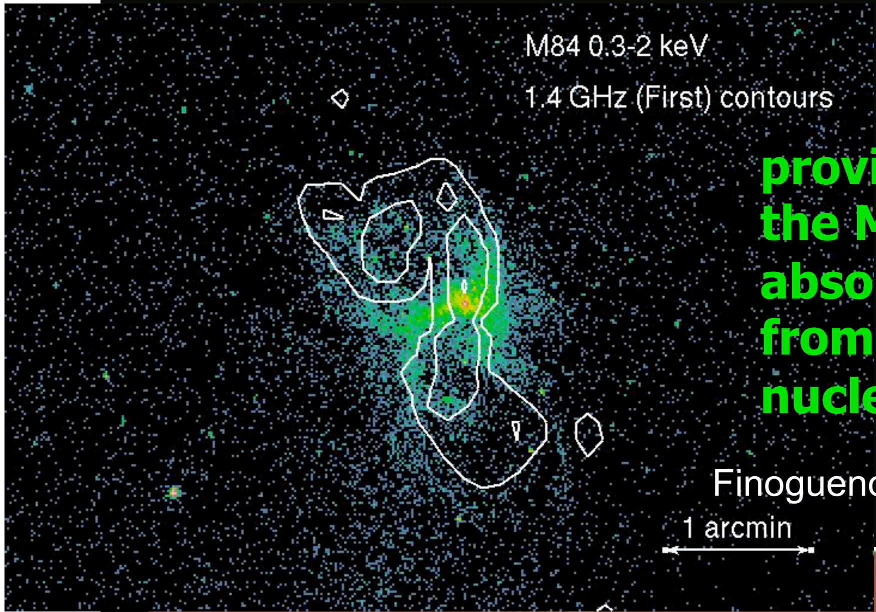
Stellar **point sources** can be subtracted (resolved and not) to obtain best estimates ever of ρ(r), T(r), L_X for the hot gas



NGC821, limits on hot gas content
Pellegrini+ 07

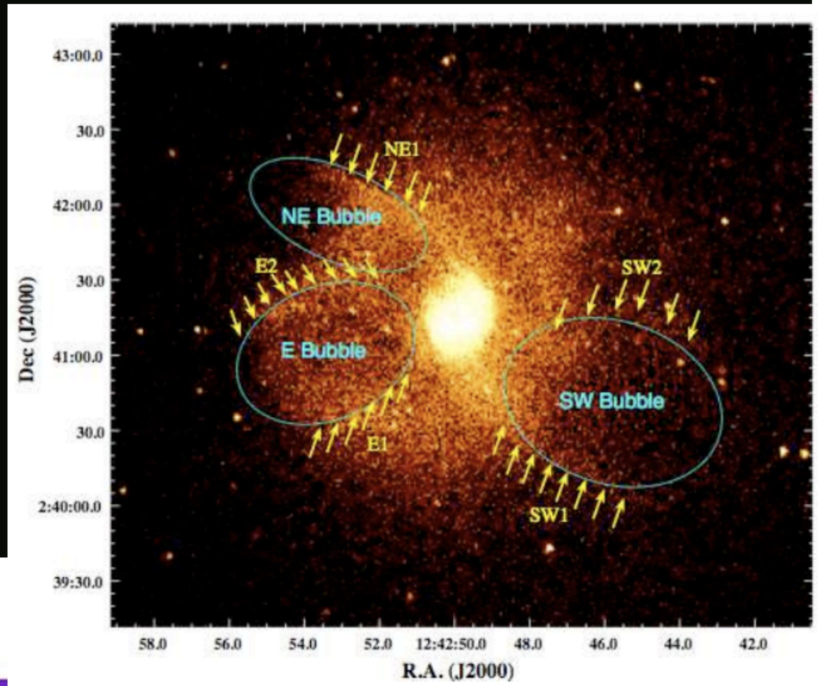


detection of an outflow in NGC3379
Trinchieri+ 08

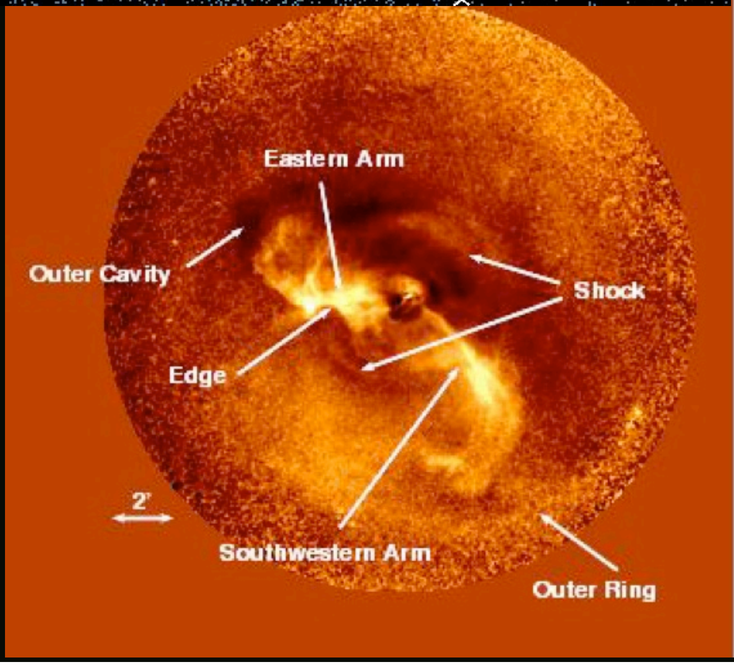


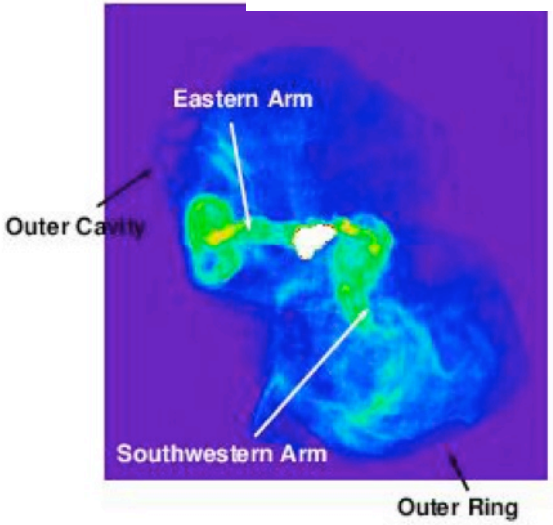
provides fuel for the MBH and absorbs energy from nuclear outbursts

Finoguenov+ 08



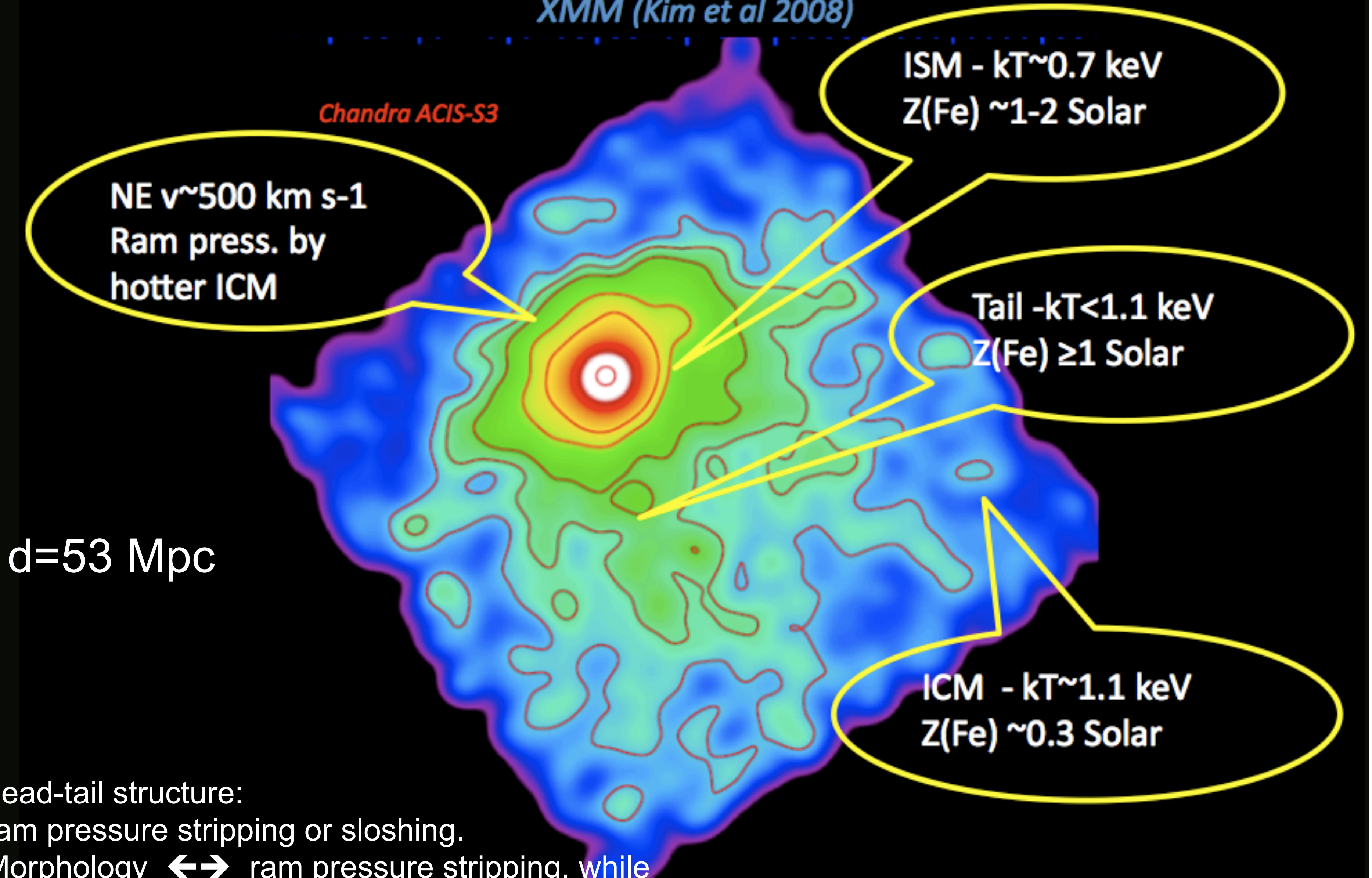
NGC4636
Baldi+ 09





M87
Forman+ 06

ICM and element dispersion - NGC 7619 in the Pegasus Group *Chandra/ XMM* (Kim et al 2008)



head-tail structure:
ram pressure stripping or sloshing.
Morphology ←→ ram pressure stripping, while
central position in the Pegasus I group ←→ sloshing (Markevitch & Vikhlinin 07)

0<z<1

Mostly XLF and logN-logS

A few surveys have separated ETG…
for samples with small numbers (<~few tens) →

NB: normal galaxies divided from AGN via X-ray/optical flux ratios,
optical spectroscopic identification, hardness ratio, and X- ray luminosity.

Previous surveys with results at z>0 **for ETGs**:

Chandra:

Survey	# ETGs	ref.
CDF-N : deepest	<10	Hornschemeier+ 03
CDF-S : deepest	101	Tzanavaris & Georgantopoulos 08
ECDF-S	13+stacking	Lehmer+ 07
XBoötes : widest	stacking	Watson+ 09
ChaMP (Green+ 09)	36 (110)	Kim+ 06
GOODS fields	40	Ptak+ 07

XMM:

Survey	# ETGs	ref.
NHS (70 fields, 11 deg^2, z<0.2)	27*	Georgantopoulos+ 05
1XMM catalog (6 deg^2, f(0.5-2 keV)>10^{-15}erg/cm^2/s, z<0.2)	34**	Georgakakis+ 06

[`2XMM` catalog cross-correlated with SDSS DR6 (Watson M.)]

** including 22 from NHS and CDFs

* including 15 from CDFs

The deepest 0.1<z<1.0

z<~1 probes lookback times of <~7.7 Gyrs

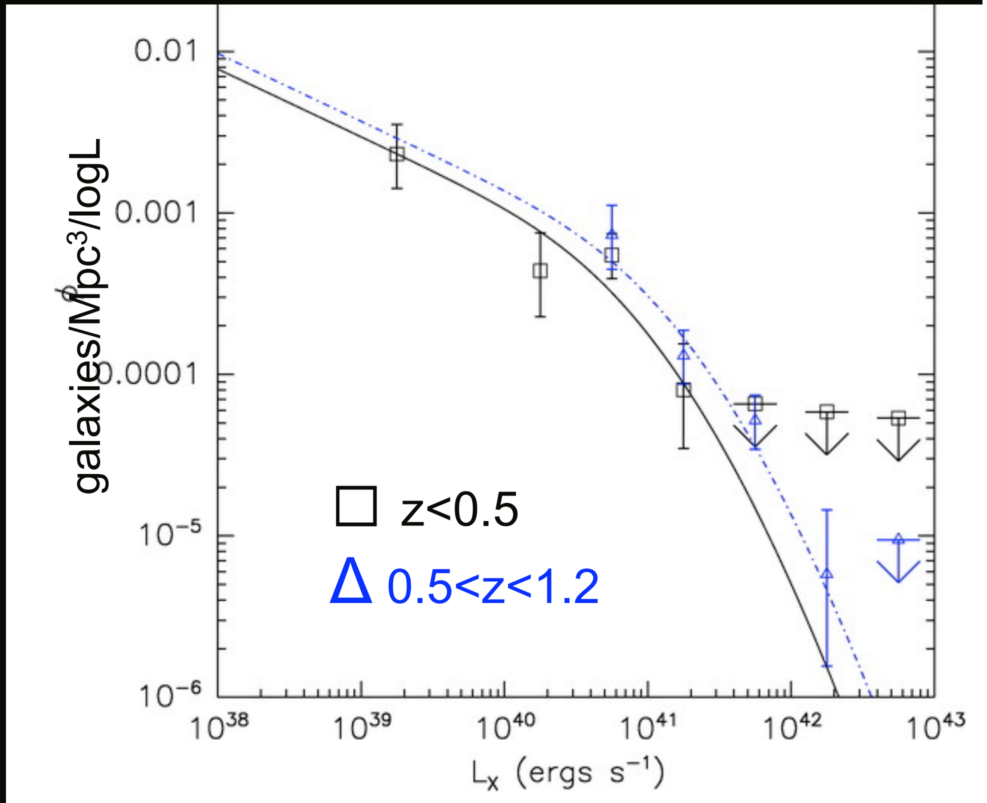
Galaxies rival AGN as the most numerous point source population at f_X(0.5-2 keV)<10^{-17} cgs

1. **CDF-N** : 36 X-ray selected galaxies, f_X/f_O<0.01 (Hornschemeier+ 03),
   median z~0.3, 0.1<z<0.845
   179 arcmin^2 area, exposure>1500 ks, F(0.5-2 keV)>2.3 10^{-17} erg/cm^2/s
   mainly spiral/irregular morphology

2. **GOODS** fields (multi-λ survey of a subarea of the CDFs)

Ptak+ 07: galaxies classified by spectral type
k-corrections to both X/O and X/NIR
L(0.5-2 keV)<10^{42} erg/s
40 ETGs

Lognormal fits
luminosity evolution assumed,
found significant at >99% confidence:
ETGs brighter by 1.7 between z~0.25 and 0.75:
passive evol of LMXBs?



The intermediate z

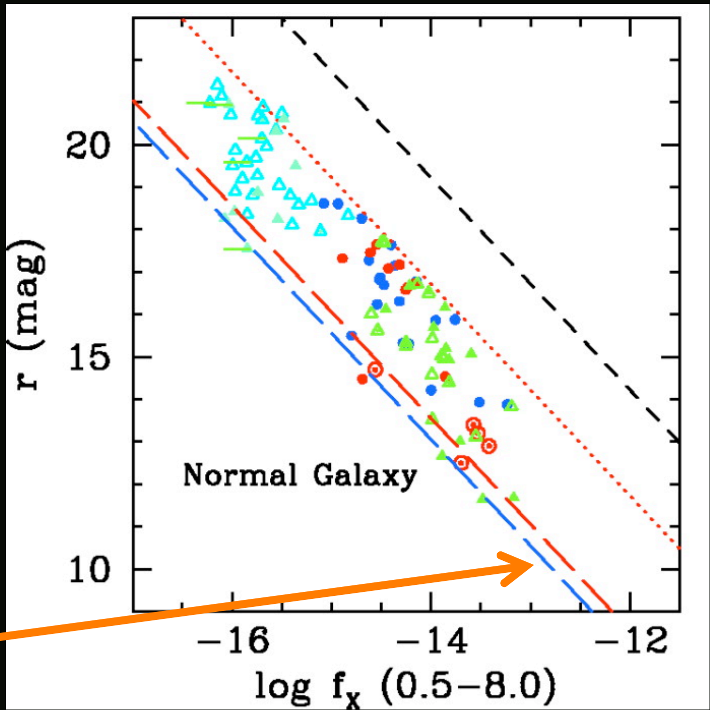
1. **ChaMP** : wide area ~30 deg^2, 392 archival fields (through AO6), SDSS coverage
36 (will be ~110) normal galaxies at **0.01<z<0.3**

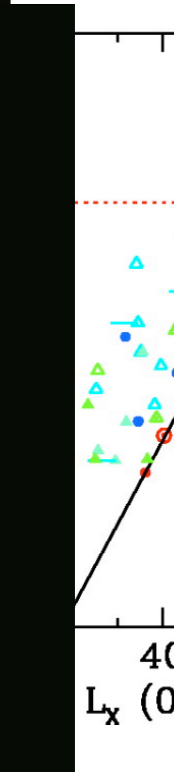
f_X/f_O <0.01 most efficient to distinguish AGN and ETG
when 0.01< f_X/f_O <0.1 spectral hardness and optical line ratio also needed

from deeper surveys:
Δ = CDF-N (Hornschemeier+ 03)
Δ = NHS (Georgantopoulos+ 05)

Filled circles: ChaMP galaxies
ETG in red, spirals in blue

(Kim+ 06)





The minimum f_X/f_O is constant with *z*

[minimum f_X/f_O from local ETG (Kim & Fabbiano 04) and spiral galaxies (Colbert et al. 04)]

2. XBoötes (Murray+ 05): ACIS-I 5ks mosaic (126 pointings) of 9.3 deg^2 of the Bootes field

+

IR, optical from NOAO Deep Wide-Feld Survey (NDWFS) and Galaxy Evolution Survey (AGES)
Jannuzi+ 09 Kochanek+ 09

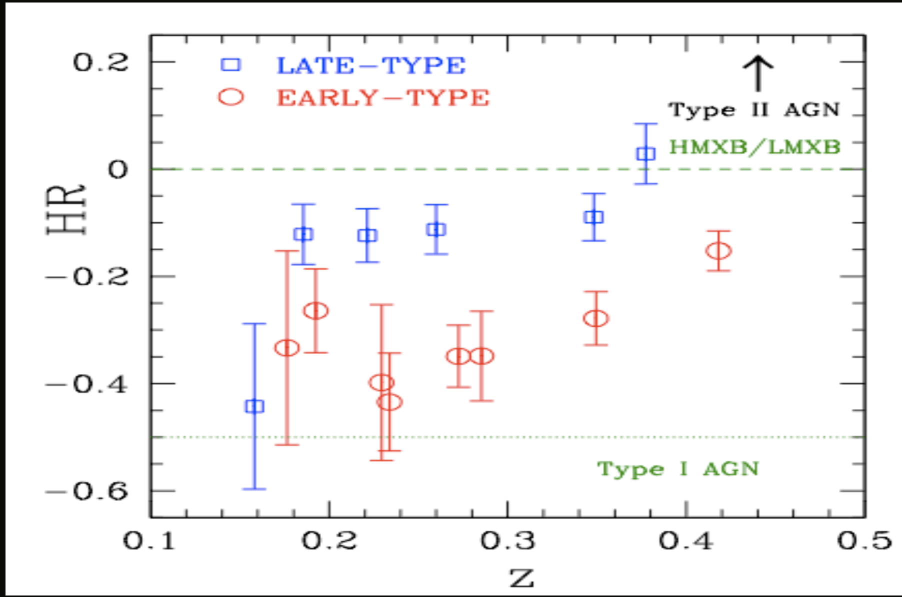
↓

evolution over **$0.1 \leq z \leq 0.5$** of mean X-ray properties from stacking,
as a function of absolute R (<20) and spectral type (Watson+ 09)

2968 ETGs – when stacked – produce 246/342 hard/soft net counts

Excluded: spectroscopically identified AGNs
and $L_X > 6.6\ 10^{42}$ erg/s

ETGs : dominated by AGN+hot gas
spectra become harder with z
(increasing AGN contribution?)



HR=H-S/(H+S)=
>~0 for XRBs (Muno+ 04)
-0.5 Type 1 AGN (Rosati+ 02)
0<HR<1 Type 2 AGN (“)
-1 for hot gas with kT<~1 keV

Watson+ 09

Luminosity evolution:

$$L_{\rm x40,hard}^{\rm EARLY}(L_*) = (3.6 \pm 1.5)(1+z)^{4.5\pm1.7}$$

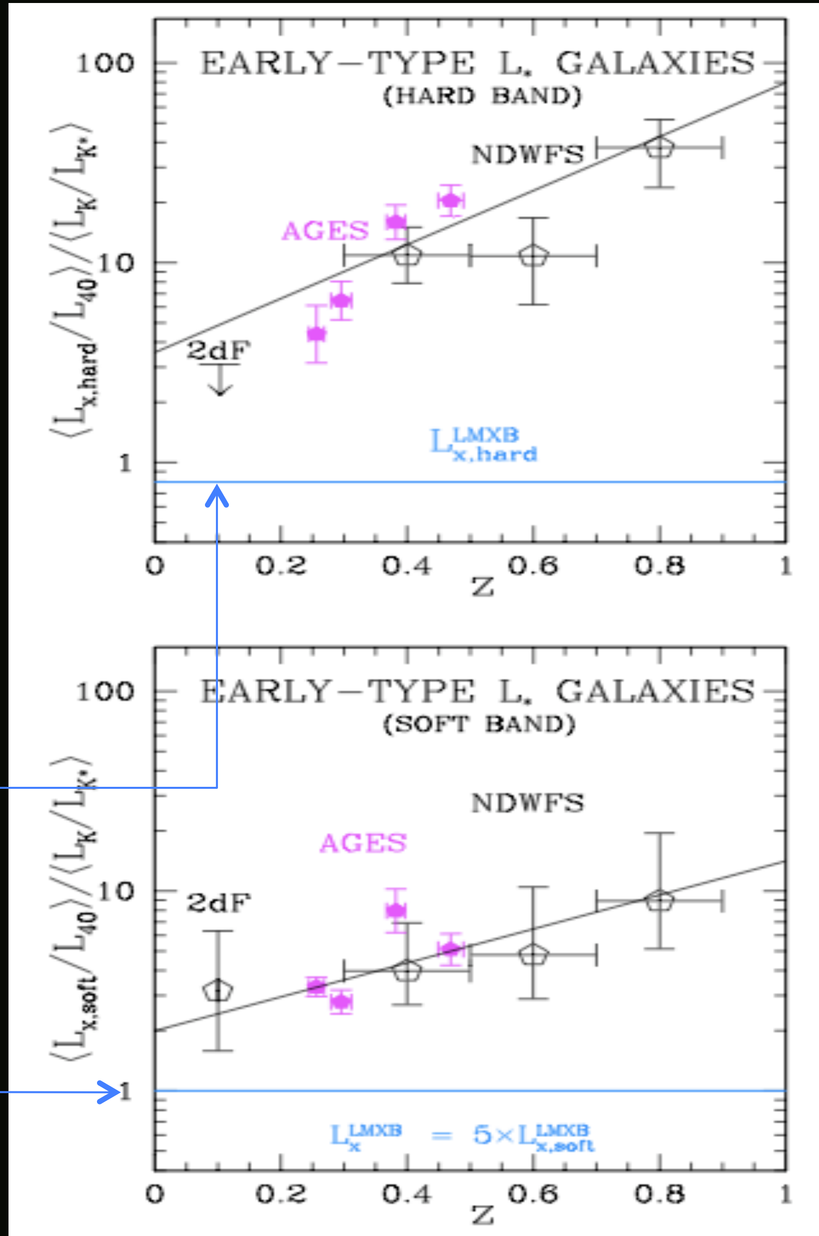
and

$$L_{\rm x40,soft}^{\rm EARLY}(L_*) = (2.0 \pm 0.8)(1+z)^{2.8\pm1.1}$$

More evolution in hard than in soft :
LMXBs and hot gas ~ constant for z≤0.5
while AGN evolving

stellar mass density evolves slowly between z=0 and z=0.5 (Bell+04) ➔ little change in number of LMXBs ➔$L_X=10^{40}\, L_K/L_{K^*}$ erg/s for them out to z=0.5, as locally (Kim & Fabbiano 04).

$L_{X,hard}$ is ~10x brighter than this estimate

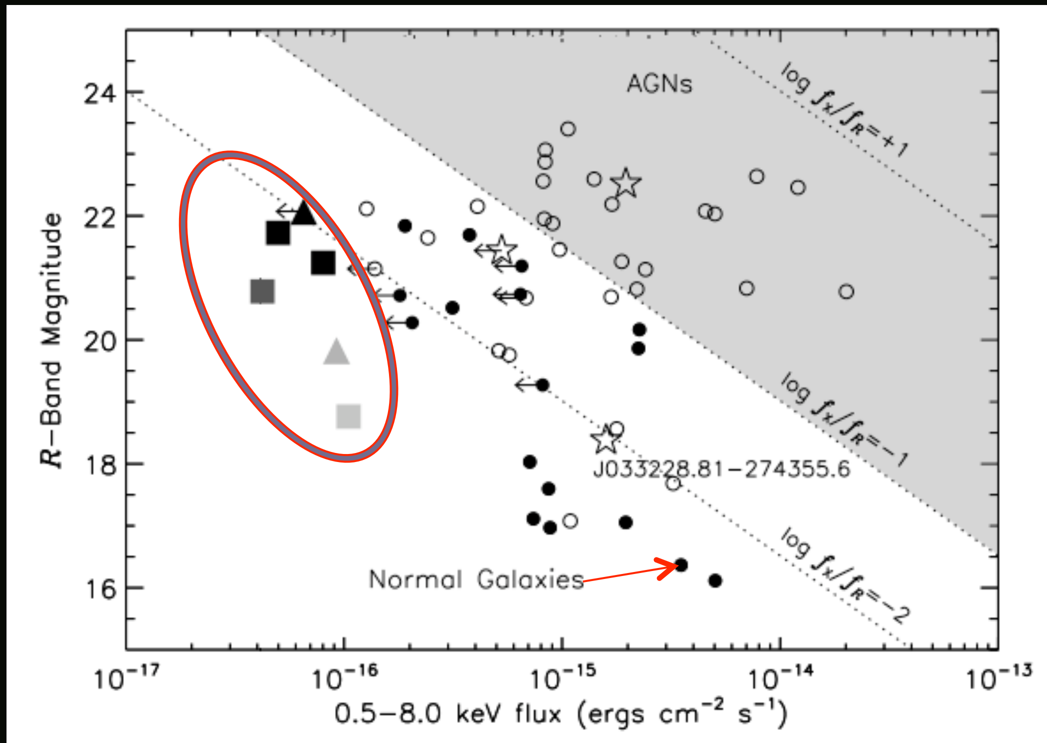


Watson+ 09

3. **E-CDF-S** (Lehmer+ 07): 0.3 deg^2 = CDF-S + 4 contiguous 250 ks Chandra pointings
F(0.5-2 keV)>5 10^{-17} cgs and 3 10^{-16} cgs over most of the field (L>3 10^{41} erg/s at z=0.7)

Start from optically selected 539 ETG with **0.1<z<0.7**, R<24
13 normal + 32 AGN detected, the other stacked in z-bins

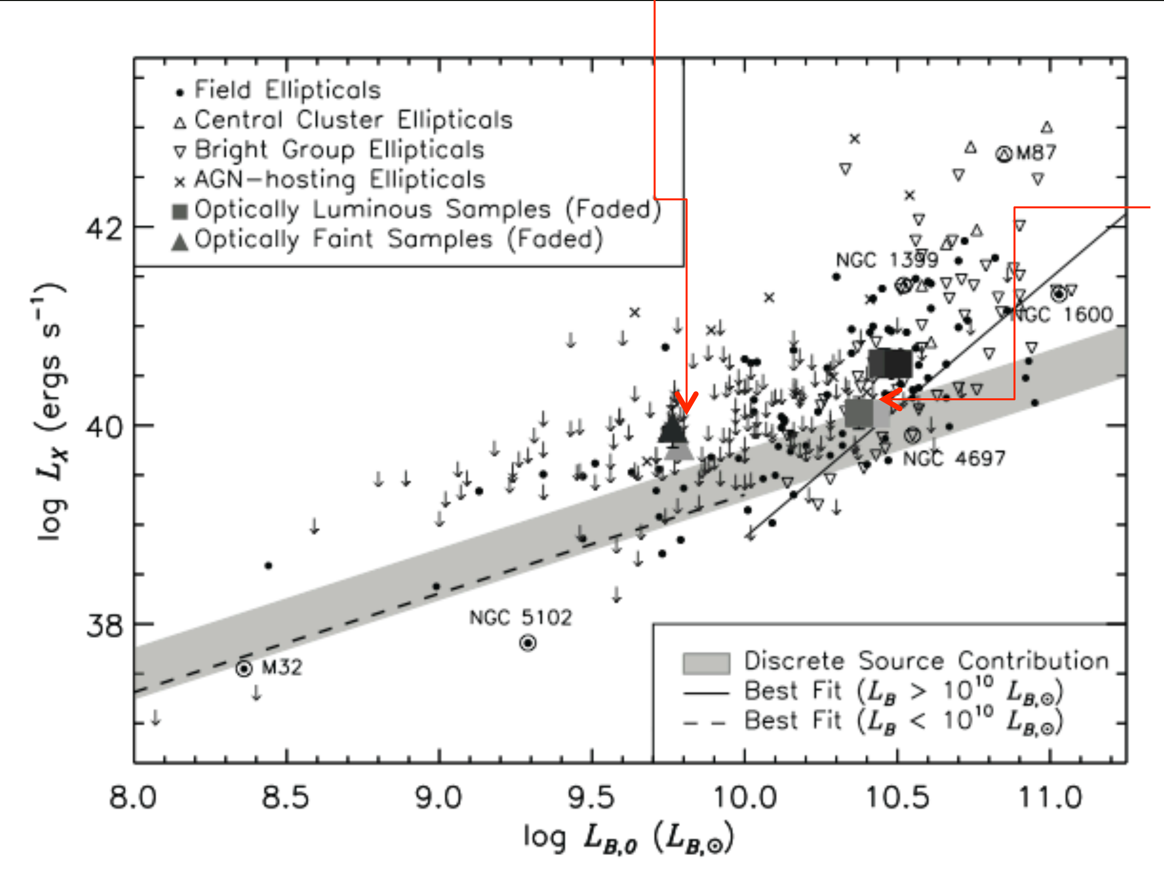
stacked ETGs



Lehmer+ 07

2 luminosity bins:
$L_B \sim 10^{10} L_{B,sun}$ critical luminosity to separate hot ISM dominated from LMXB dominated

Optically faint samples at z=0.22, 046 are brighter than locally
➔increased AGN level?
➔younger st. pop. and larger LMXB contribution?



Optically luminous samples at z=0.25, 0.47, 0.58, 0.66 follow local relation

⬇

long-lasting (~6 Gyr) balance between heating and cooling of gas

darker symbol=higher z

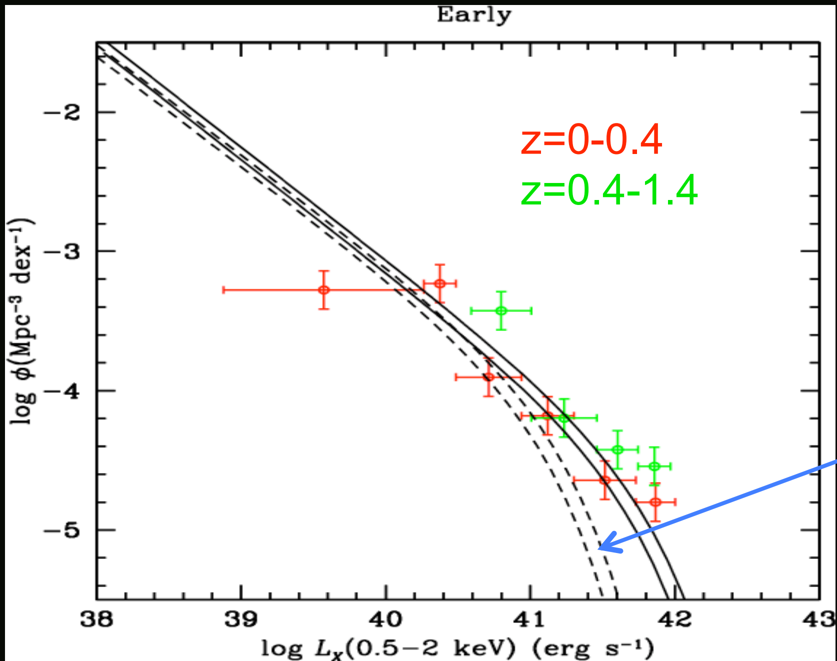
Lehmer+ 07

The latest

Tzanavaris & Georgantopoulos 08

101 ETG up to z~1.4
Data from *Chandra* deep fields (north, south and extended) and XBootes
Optical counterparts in Barger+ 03 (CDF-N), Szokoly+ 04 (CDF-S),
cross-corr with the COMBO-17 survey (ECDF-S), with SDSS DR5 (XBoötes).

X-ray selection criteria: (after accounting for k-correction)
$L_X<10^{42}$ erg s^{-1}; HR=(H-S)/(H+S)≤ 0 (soft sources) ; $f_X/f_O<0.1$ + visual checks of optical surveys



no significant evolution for ETGs

XLF from Georgakakis+ 06 based on 34 ETGs at z<0.2, shifted to the median redshifts of the two z-bins (0.17 and 0.67)
(steep cutoff due to their taking $f_X/f_O<0.01$?)

Important questions for WFXT

i.e., to be solved with large samples

few ″ angular resolution

good spectral resolution

Locally:

measure LMXBs + LLAGN + hot gas (L_X, …) for a **large**, complete sample,
for different environments

➔ baseline for low/medium-z studies

largest catalog (401 ETG with B_T<13.5), ROSAT

all contributions (stars+LLAGN+ISM) included in the (soft) X-ray emission

(O' Sullivan et al. 2001)

- ✓ larger sample
- ✓ less upper limits (at low L_B)
- ✓ for hard and soft bands

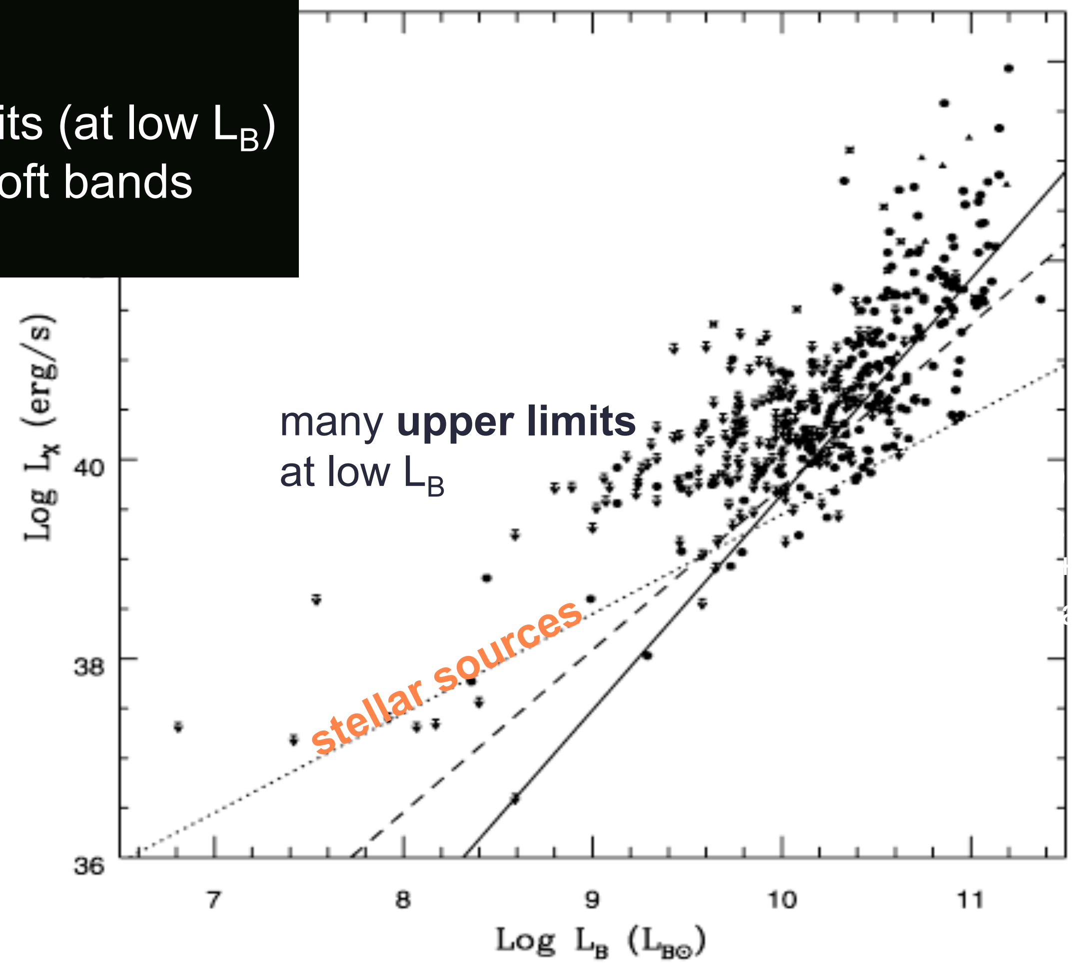
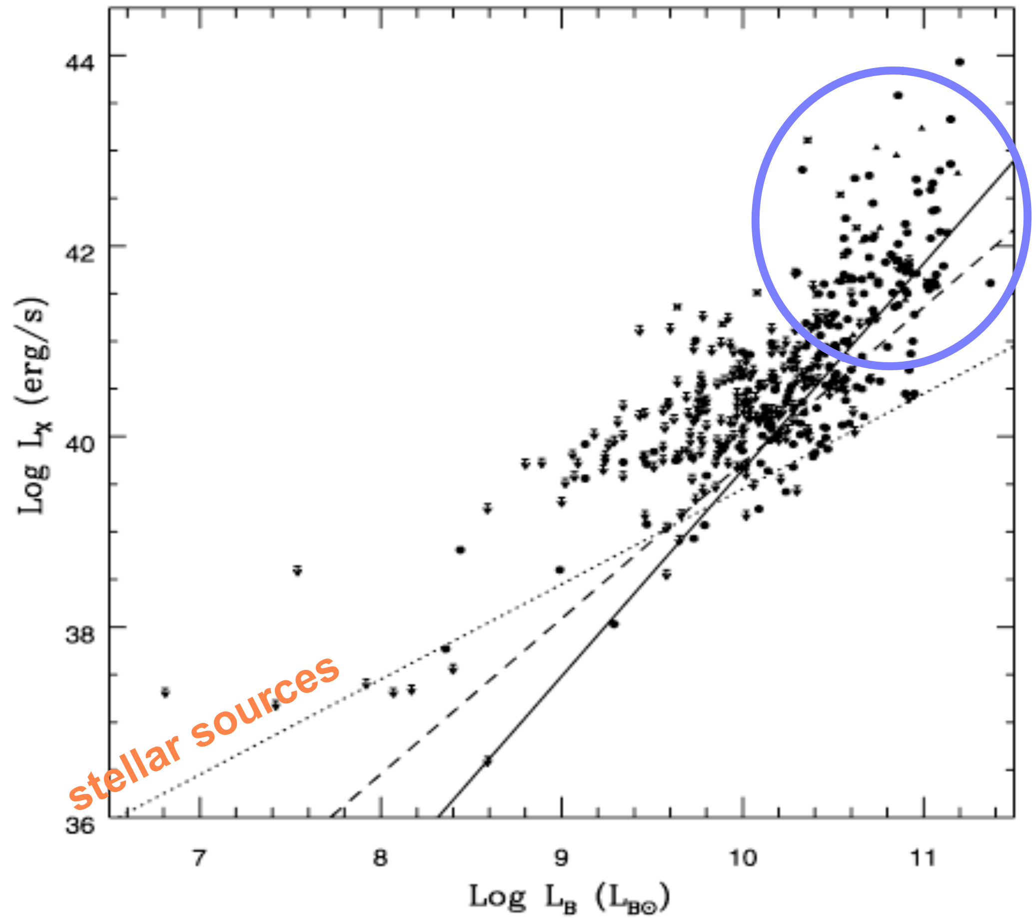


Figure 2. Log L_X versus Log L_B for our full catalogue of 401 early-type galaxies. Triangles are cluster central galaxies; asterisks are AGNs; circles are all other detections; arrows are upper limits. The lines shown are: the best-fit line to the early-type galaxies excluding AGNs, BCGs and dwarfs (solid line); the best fit to the galaxies excluding all questionable objects (dashed line); and an estimate of the discrete-source contribution taken from Ciotti et al. (1991).

<~200 ETGs with Chandra, **only a minority (gas rich) shows**
AGN outburst / jets inflating radio lobes / hot gas displacement & heating
(Forman+ 05, McNamara & Nulsen 2007)

- ✓ **how is feedback working IN GENERAL?** **(impact, duty cycle, nuclear luminosities…)**

- ✓ **is the large dispersion in L_X/L_B due to nuclear activity? environment?**



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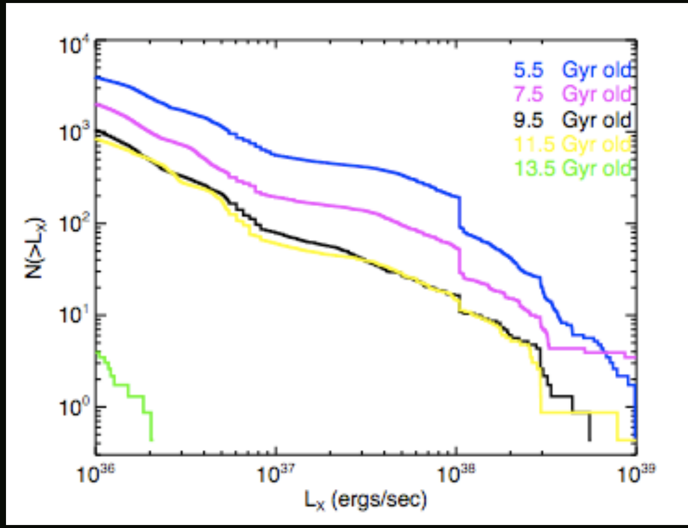
At z>0, evolution of:

- **LMXBs**

fossil record of past star formation : their collective L_X could be higher than that in the local galaxies depending on epoch of major SF
(e.g., Ghosh and White 2001, Fragos+ 08)



Fragos+ 08

The total number of (luminous) sources decreases steadily with time

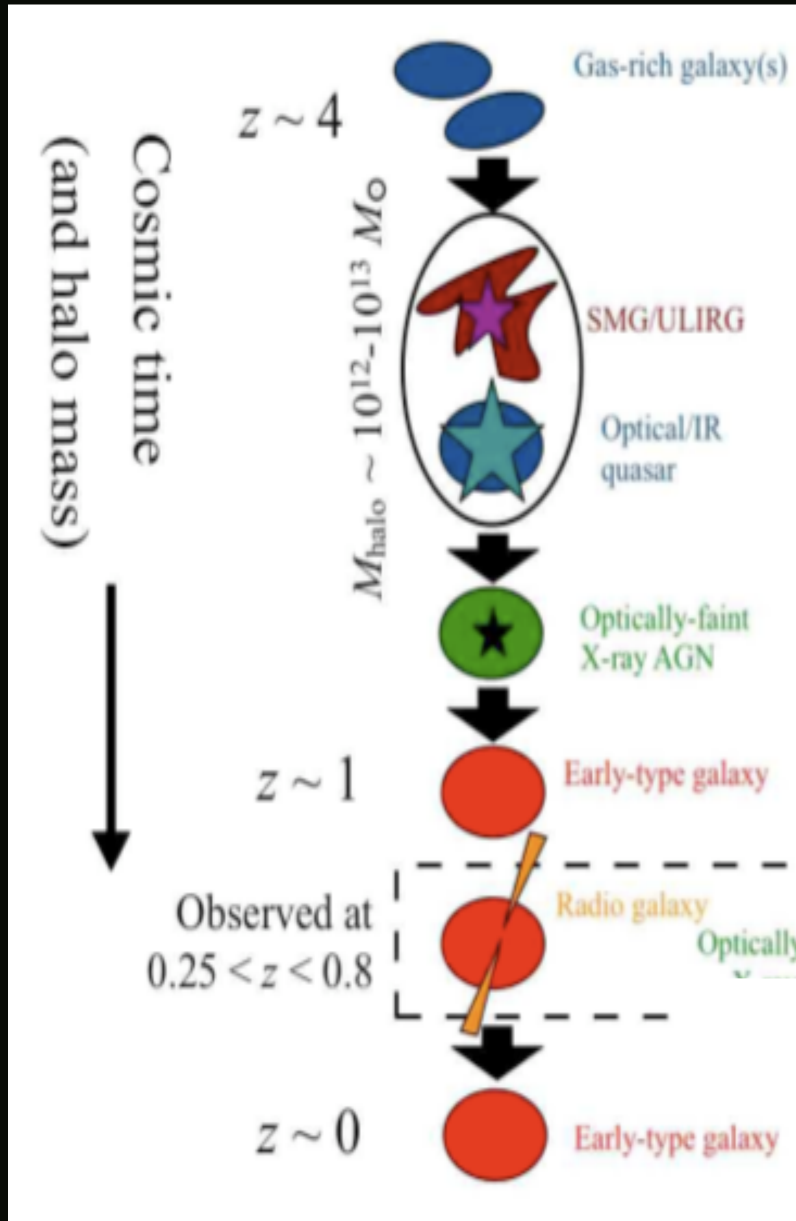
- **hot gas**
- low/moderate **nuclear activity** :

} feedback

ETGs are the typical hosts of quasars at high z>~2, tracking the decay of nucler activity to lower z important to understand the whole MBH accretion history

accretion rate declines on τ ~1 Gyr
reaching $L_{BH} / L_{Edd} \sim 10^{-2}$ (Hopkins+ 05)
SED becomes increasingly dominated by X-rays
(Steffen+ 06, Vasudevan& Fabian 07)

As $L_{BH} / L_{Edd} \sim 10^{-3}$ accretion shifts to radio-bright mode:
radiatively inefficient, jet-dominated outbursts fueled by accretion directly from the hot gas (e.g., Croton+ 06)



Hickox+ 09

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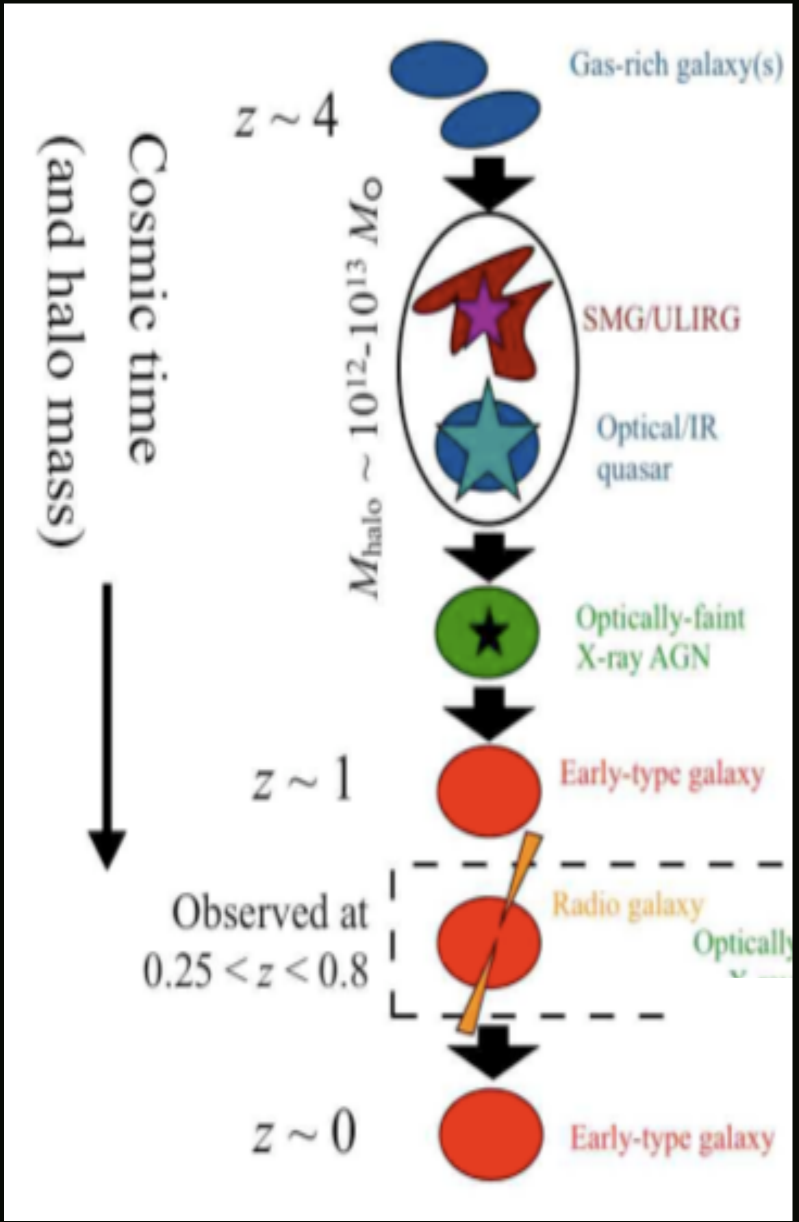


Kauffmann & Heckman 09: the MBH grows at a rate indep of the ISM characteristics, as long as gas is plentiful; **when the gas runs out**, growth is regulated by rate of mass loss from evolved stars

Hickox+ 09

Simulations with central MBH

high resolution hydrodynamical code, with detailed treatment of
radiative + mechanical energy input from the MBH & transfer to the ISM
(Ciotti & Ostriker 97, 01, 07; Ciotti, Ostriker & Proga 09)

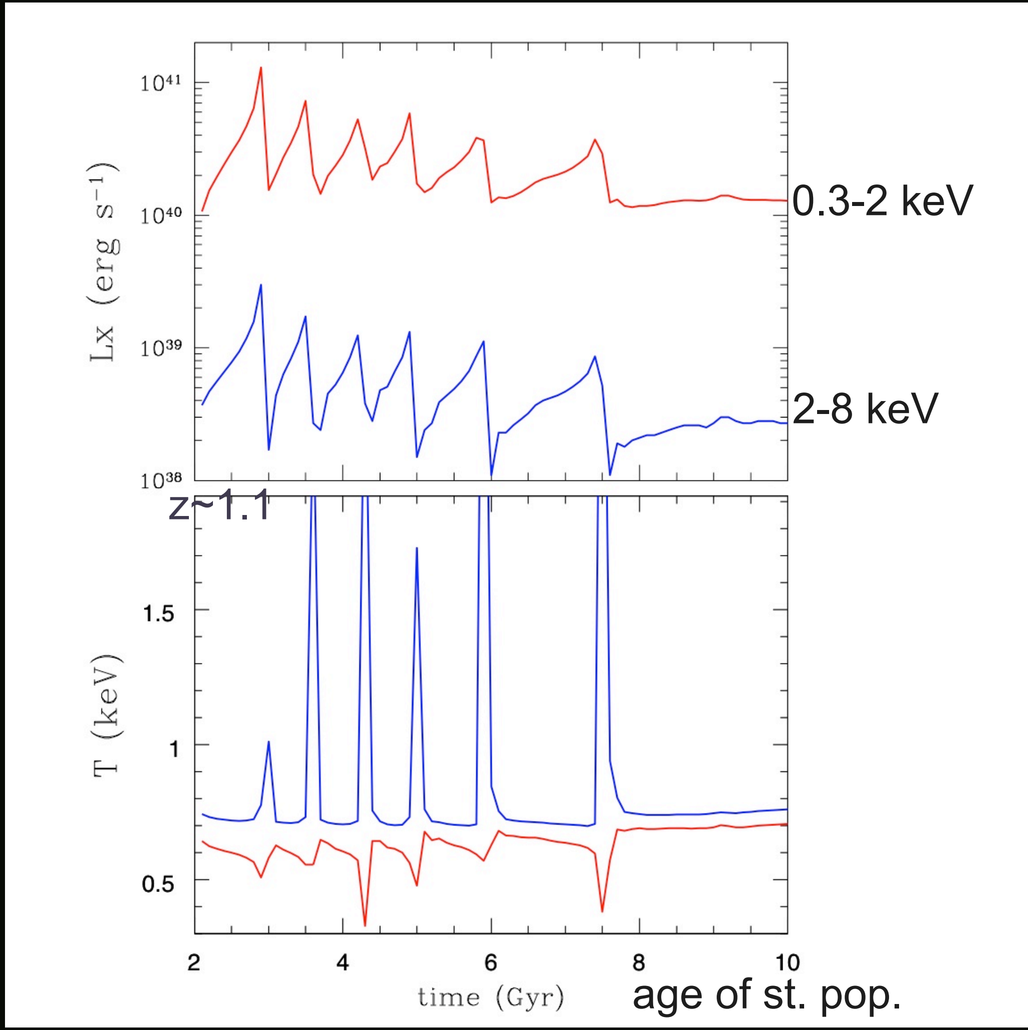
- ✓ **mass model**: stars + dark halo + MBH ; **internal dynamics**: from Jeans eqs
- ✓ gas evolution with **heating** and **cooling**

SUMMARIZING:

For $l \sim 1$ ➔ high $\varepsilon \sim 0.1$,
high $\varepsilon_W \sim \varepsilon_W^{max}$,
low ε_{jet} "radiative mode"

For $l < 0.01$ ➔ low $\varepsilon < 0.1$,
$\varepsilon_W \sim 0$,
high $\varepsilon_{jet} \sim 0.01$ "kinetic mode"
(Allen+ 06, Merloni & Heinz 08)

Time evolution: hot gas



gas luminosity

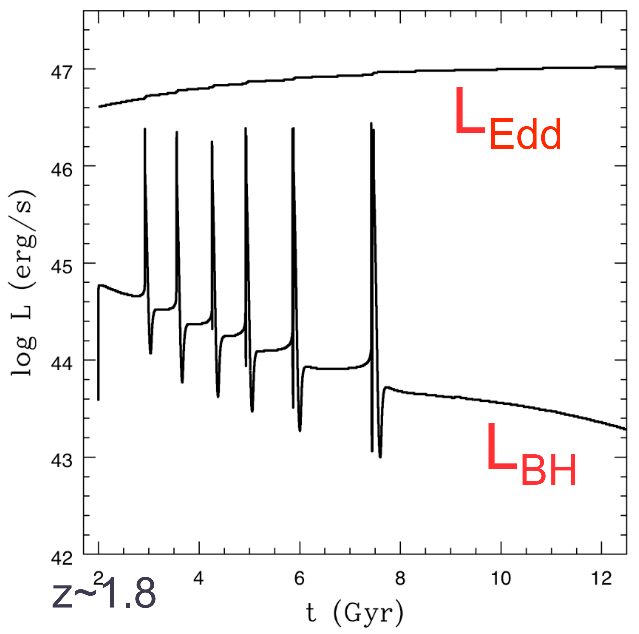
On average,
slow decrease
in hot gas content
($\dot{M}_* \propto t^{-1.3}$)

emission weighted T
within the optical Re

Pellegrini+ 09, and in preparation

large variations up to ~8 Gyrs (=last major nuclear outburst), **then hot accretion**

Time evolution: nuclear luminosities



Ciotti+ 07, 09

Strong intermittencies at early times,
L_{BH} close to L_{Edd}

Smooth, very sub-Eddington accretion at low redshift

At the present epoch:

$l = L_{BH} / L_{Edd} \sim 10^{-4}$

$\dot{m}=0.001$

➔ RIAF radiative regime ($\varepsilon \sim 0.02$)

WFXT

0.1 or 0.4 - 7 keV: ok

PSF=5”

0.5-2 keV flux limits and area:

	Wide	Medium	Deep
Area (deg^2)	~20,000	~3,000	~100
$F_{lim,ext}$ (cgs)	5×10^{-15}	1×10^{-15}	1×10^{-16}
$F_{lim,pt}$ (cgs)	3×10^{-15}	5×10^{-16}	3×10^{-17}

WFXT could drastically increase the number of detected ETGs ➔ revolutionize the field:

>~few x10^3 ETGs in the local universe (d<100 Mpc) with good image/spectra

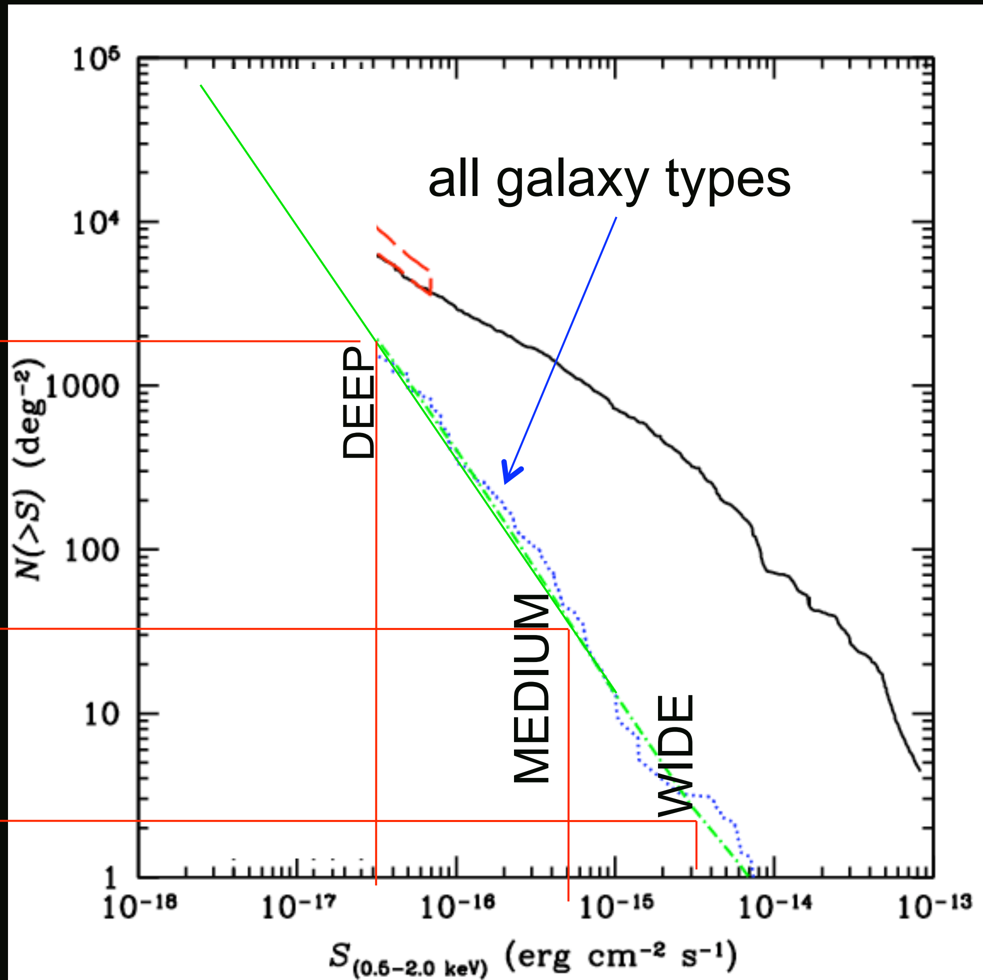
[F(0.4-7 keV)>1e-14 cgs and d<100 Mpc]

Tzanavaris+ 08

2000x100=2 10^5

30x3000=90000

2x20000=40000



For a size~20 kpc, the angular dimensions are :

10” at z=0.1 ---> distinguish nucleus/halo

5” at z=0.3
3” at z=0.5
2.4” at z=1

} --> point sources for WFXT

Using flux limits for point sources, 1e41 erg/s will be detected

out to z=1 in the DEEP
out to z=0.3 in the MEDIUM
out to z=0.1 in the WIDE (for the extended sources flux limit)

Distances and galactic parameters from
matches with surveys as 2MASS, SDSS, Galex, LSST, SDSS III/BOSS…