The Cosmic history of accreting Supermassive Black Holes in Galactici nuclei : a high energy perspective

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Foreword

No hair Theorem:

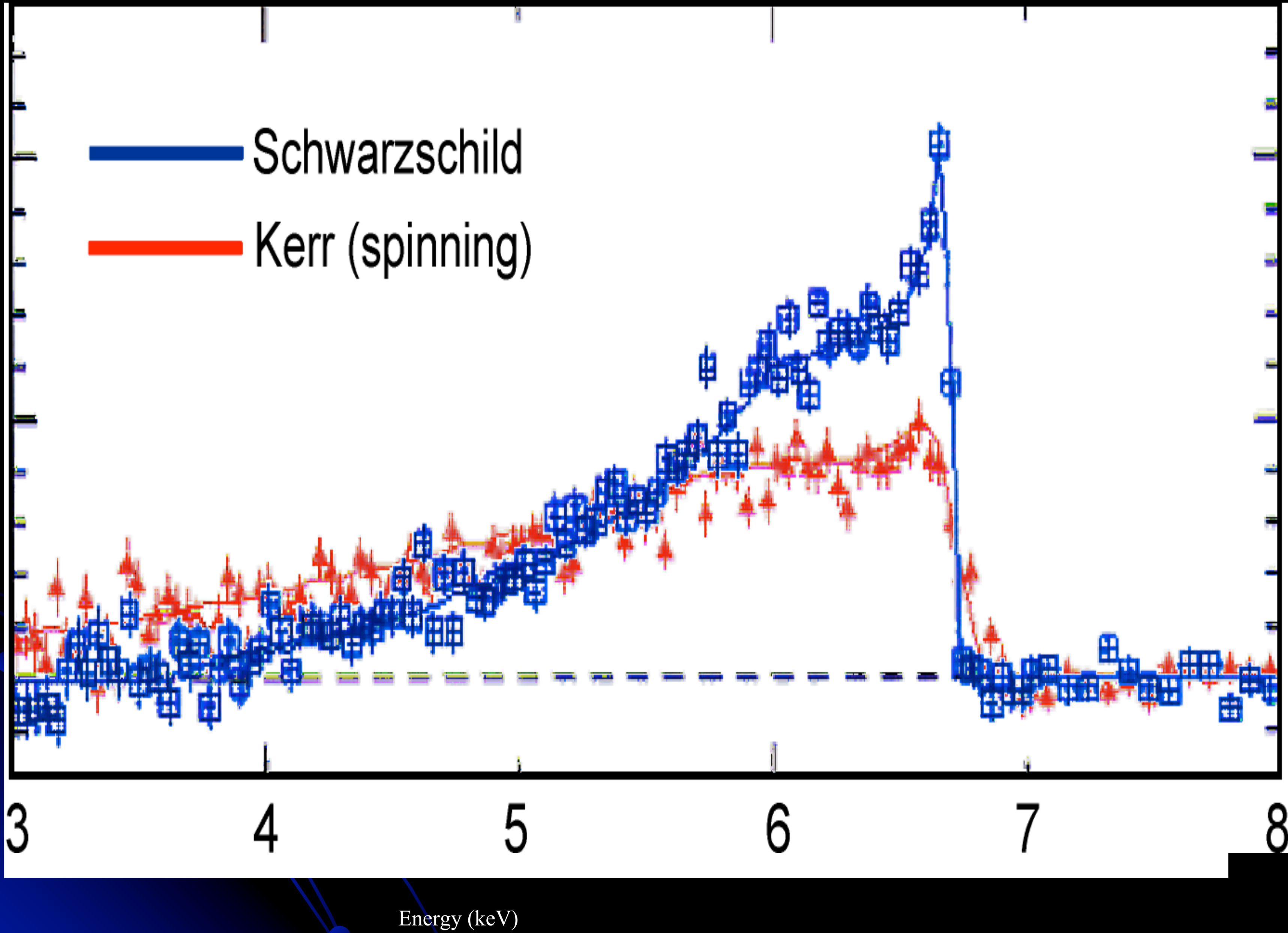
All Black Hole solutions of the Einstein-Maxwell equations of gravitation and electromagnetism in General Relativity can be completely characterized by only 3 externally observable parameters : Mass (M), Charge (Q) and Angular Momentum (J)

M and J are expected to be astrophysically relevant

Astrophysics is "hairy"

Black Holes are accreting matter, which most likely form a disk and emitX-rays, the shape of the iron emission line at 6-7 keV traces the metric

High energy observations offer a powerful tool to probe GR !



Schwarzschild
Kerr (spinning)
3
4
5
6
7
8
Energy (keV)

Motivations

- SMBH are powering high z quasars and reside (ubiquitous) in nearby inactive galaxies [Mbh - sigma - Mbulge relations]
- SMBH keep the ICM hot (no stationary cooling flows)
- SMBH and galaxy self-regulate growth
  (key ingredient in galaxy evolution -> explain high z red passive galaxies)
- AGN trace SMBH and show the same "downsizing" seen for starforming galaxies (Ueda+03, La Franca+05, Hasinger+05, …
- AGN trace the LSS and reside in densest environments (?)
- …

→ AGN play a <u>key role</u> in galaxy evolution

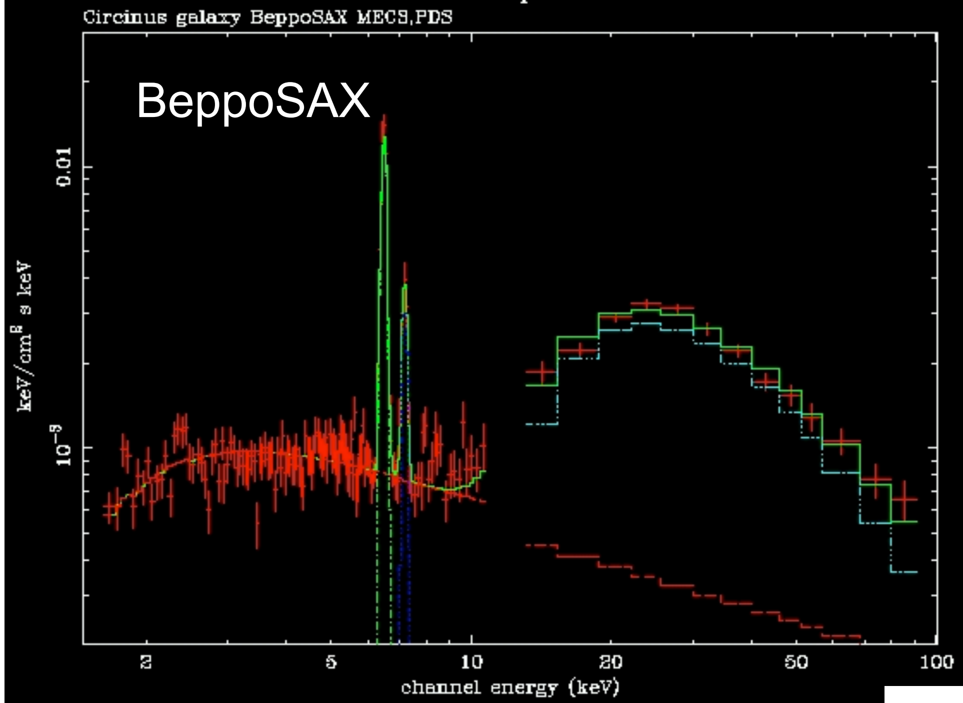
SMBH (> 10^6 M_{sun})

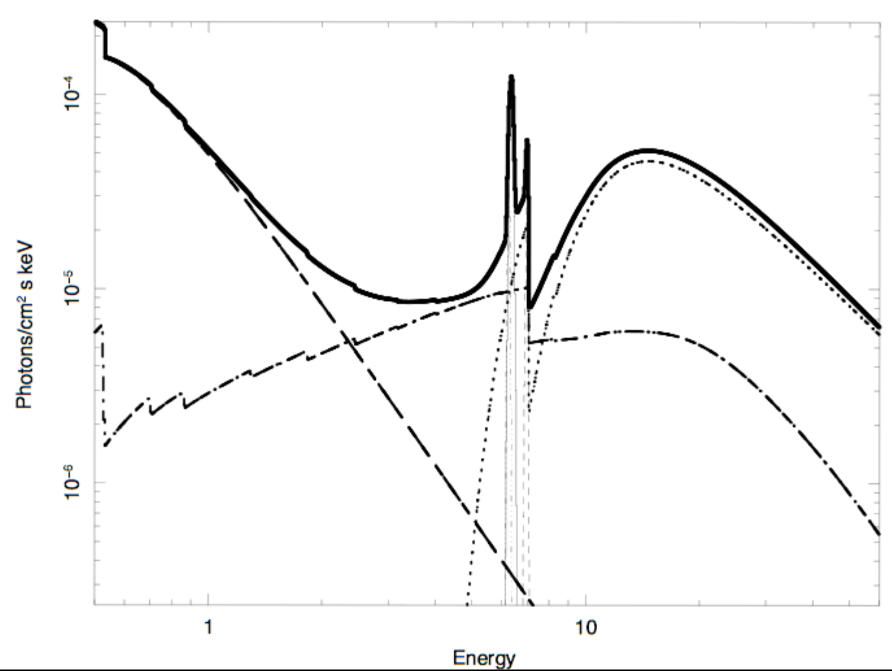
- SMBH are powering AGN over a wide range of Luminosities and redshifts; most of them (70-80%) are obscured by large amounts of gas and dust

- SMBH reside (ubiquitous) in nearby inactive galaxies [M_{BH} - σ - M_{bulge} relations]

- SMBH and galaxy self-regulate growth (key ingredient in galaxy evolution -> explain high z red passive galaxies)

Highly obscured ($N_H \geq 10^{24}$ cm^{-2}) AGN are common in the local Universe…





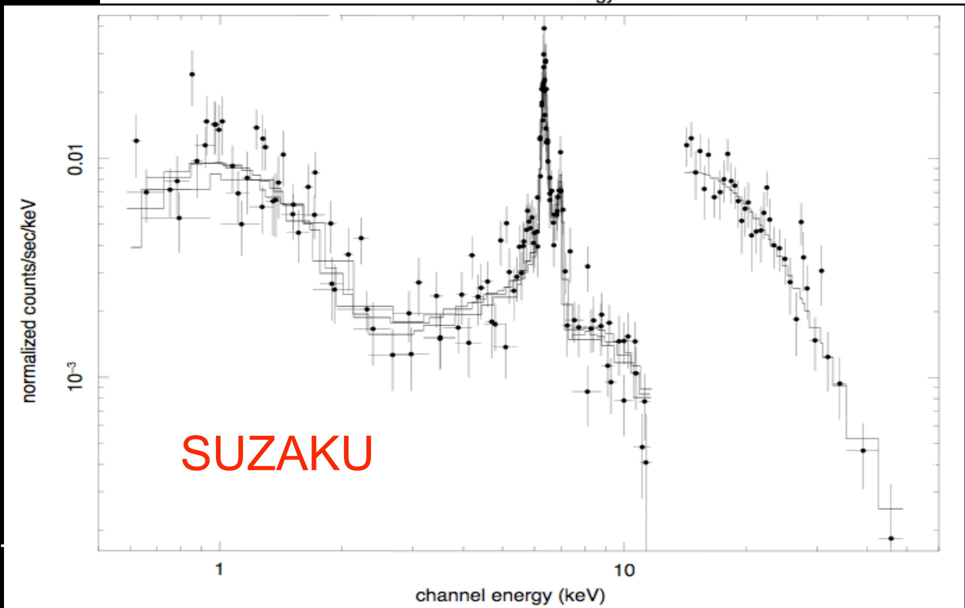
Compton Thick AGN

log N_H > 24 (cm^{-2})

(τ ~ 1 -3)

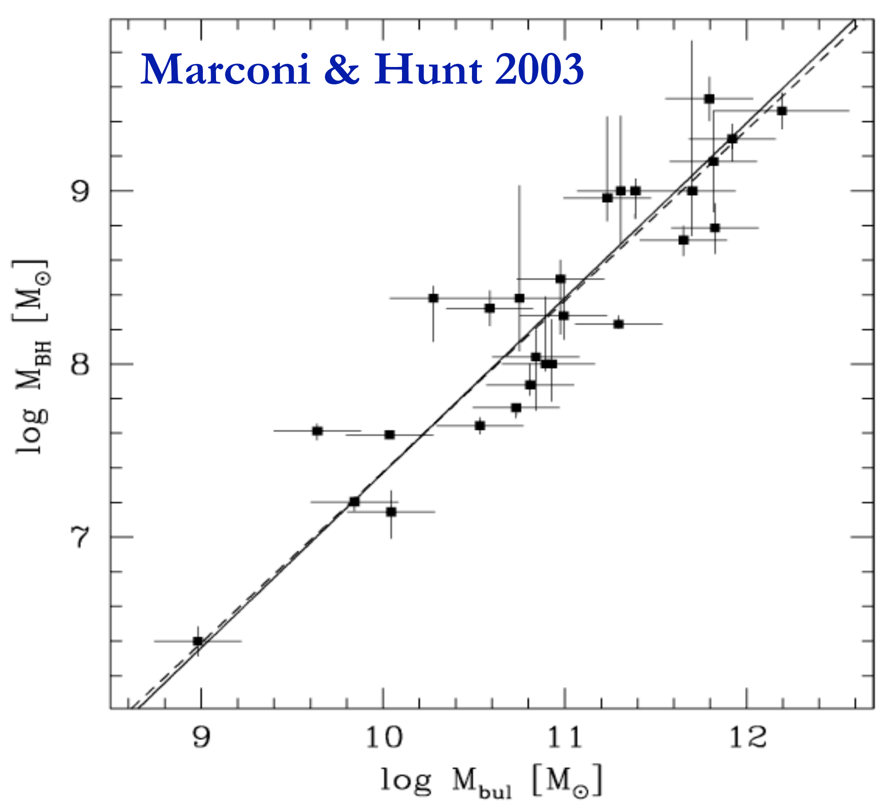
Log N_H >~ 25 (cm^{-2})

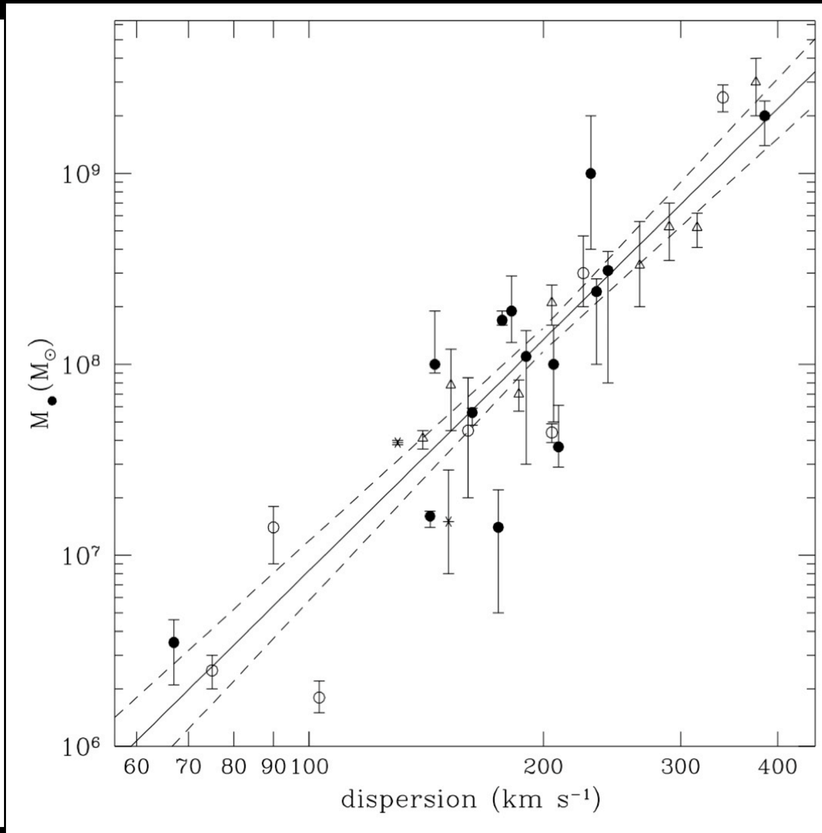
(τ >> 1)



Estrela -

M_{BH} vs M_{bul}

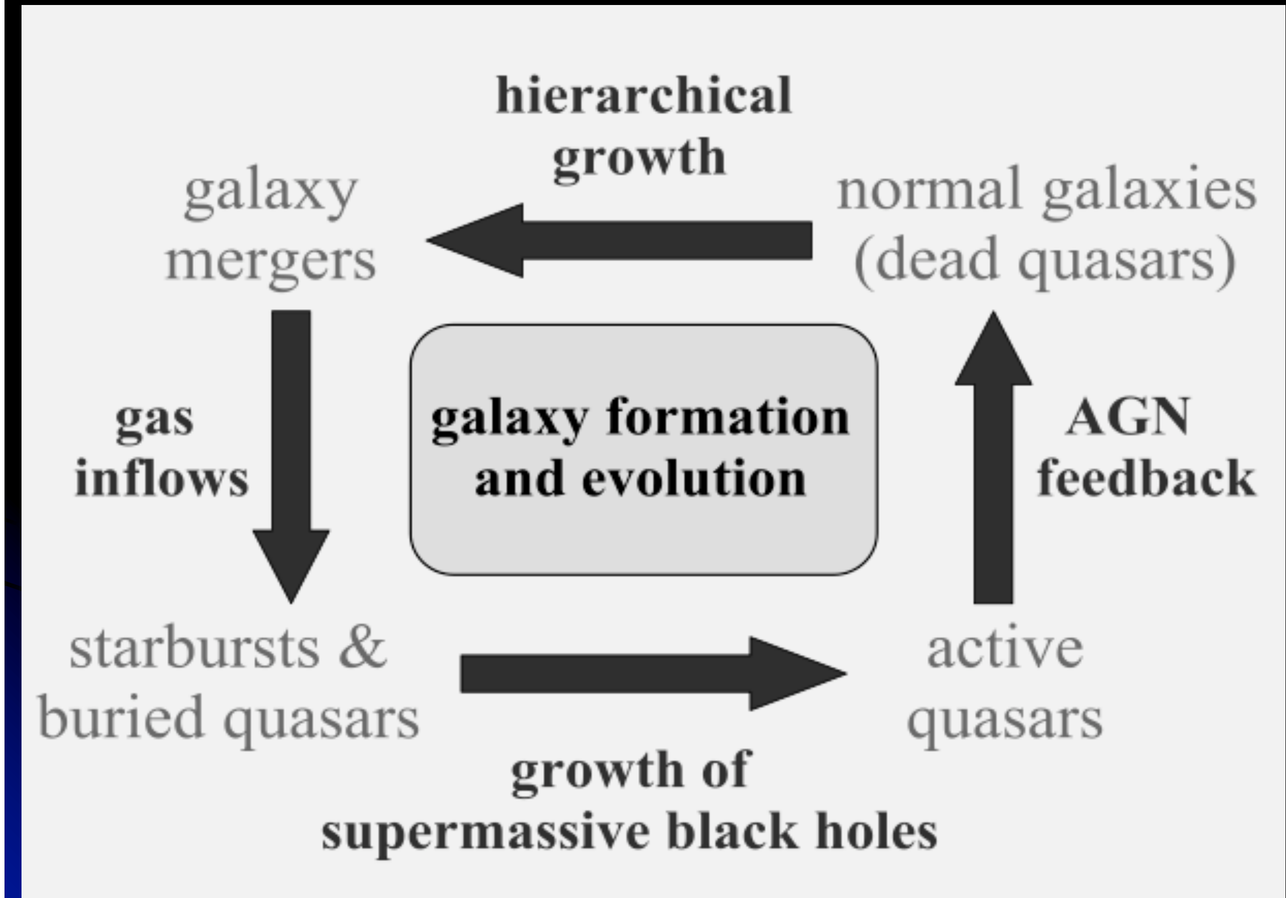




- Tight correlation between M_{BH} and virial bulge mass ($\approx R_e\, \sigma_e^2$) with *rms* 0.25 (all 0.5).
- Linear slope (0.96+/-0.07), average ratio $M_{BH}/M_{bul} \simeq 0.002$.

The Cosmic Cycle of Galaxy and AGN evolution

(Hopkins+2005)



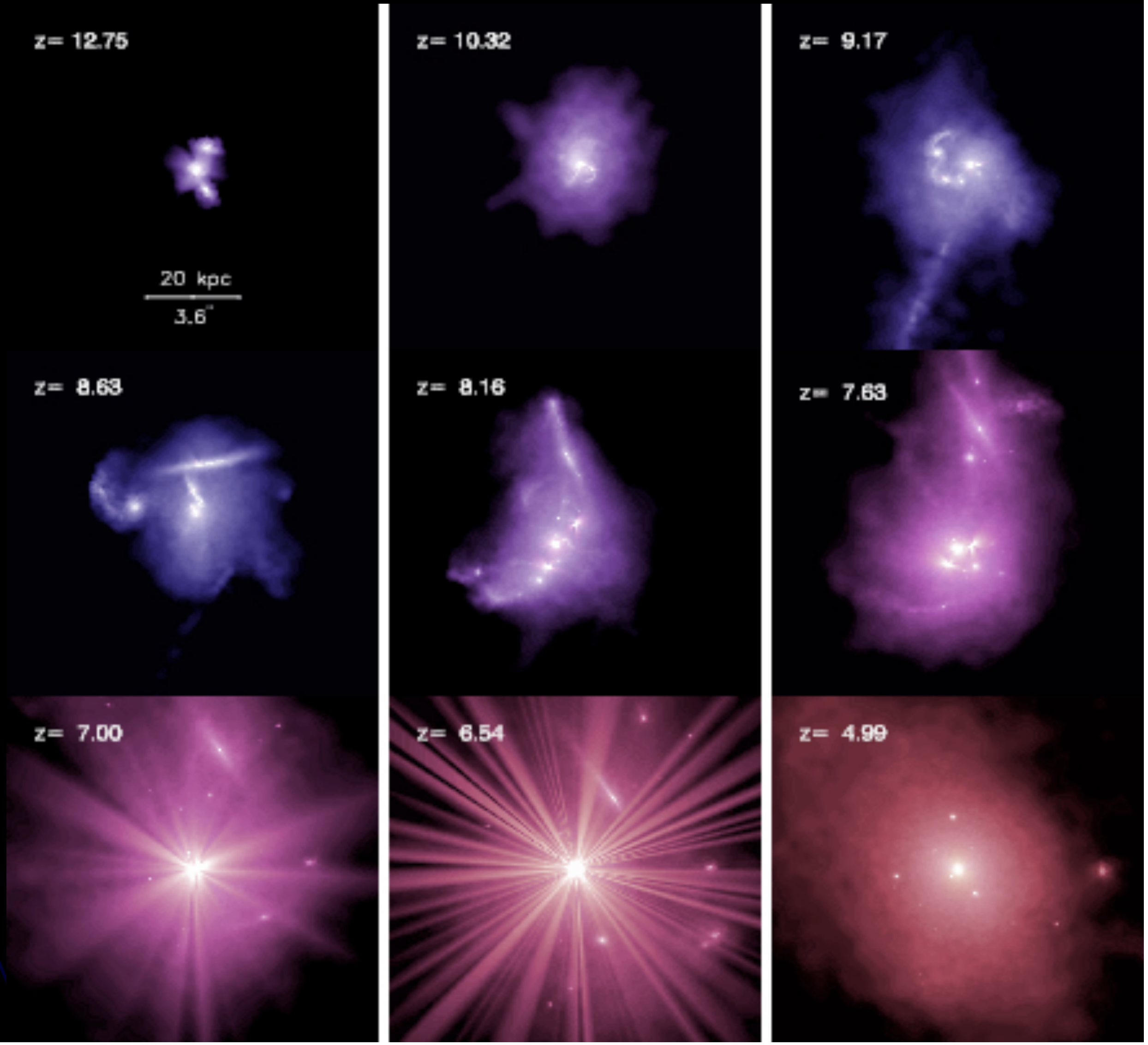
Mergers between gas rich galaxies drive gas which fuel both SF and QSO activity (QSO mode)
Obscured growth (ULIRG, SCUBA phase, 4pi Covering ?)

BH feedback expels Gas --> BL QSO

Shut down of BH activity dead quasars (or slowly accreting BH) in red galaxies (radio mode)

AGN and galaxy co-evolution

- Early on
  - Strong galaxy interactions= violent star-bursts
  - Heavily obscured QSOs
- When galaxies coalesce
  - accretion peaks
  - QSO becomes optically visible as AGN winds blow out gas.
- Later times
  - SF & accretion quenched
  - red spheroid, passive evolution



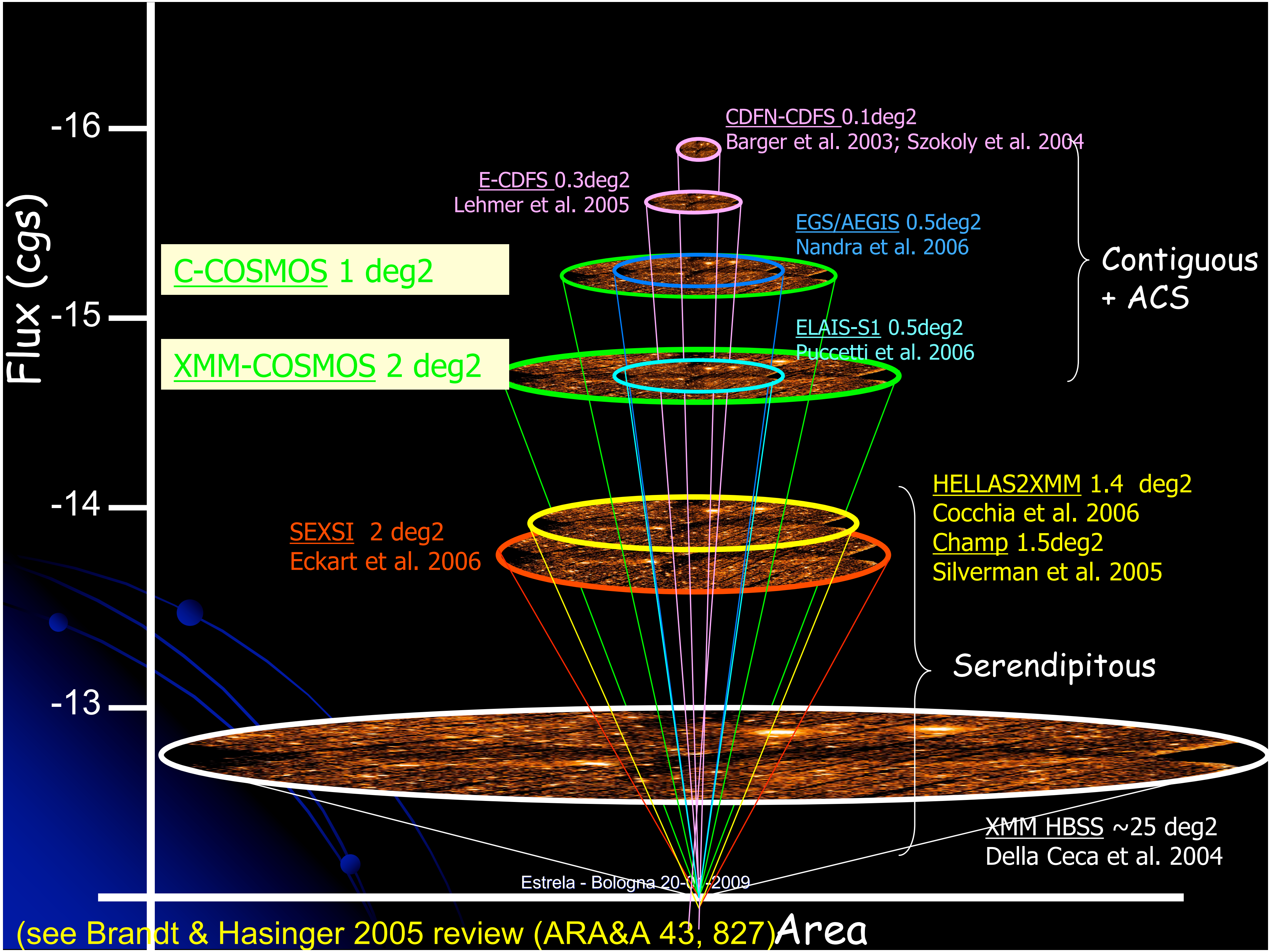
AGN census

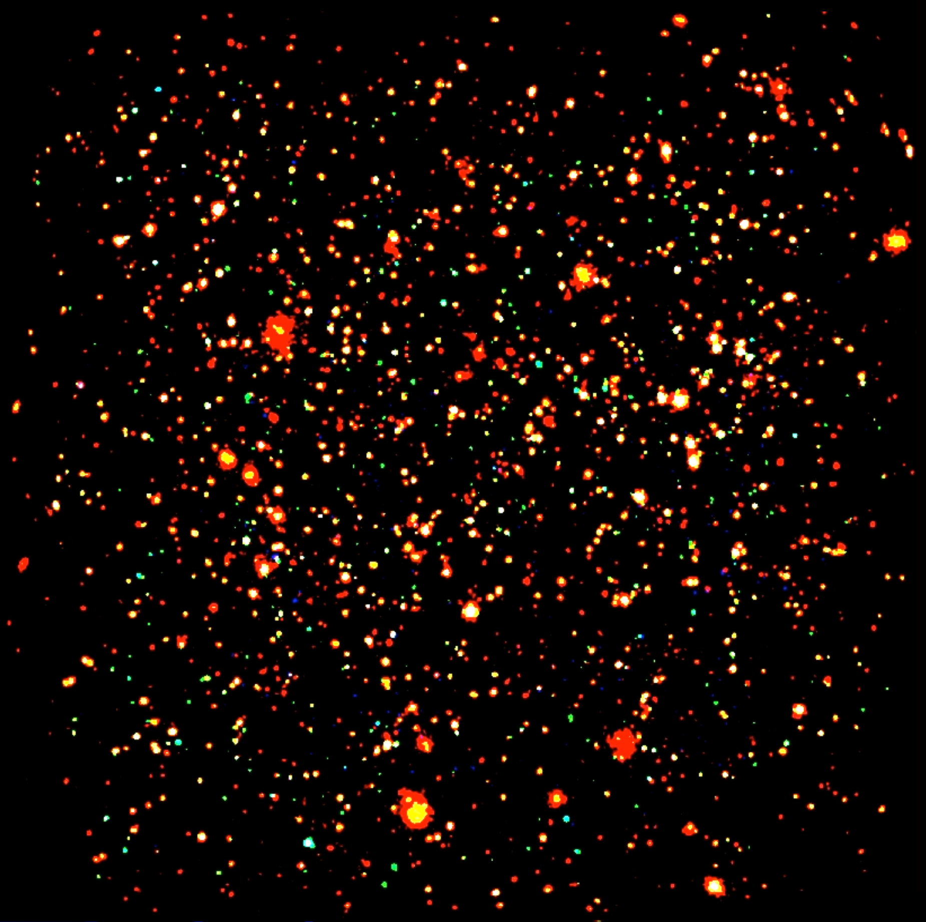
- Hard X-ray selection provide an **almost** unbiased view of obscured AGN

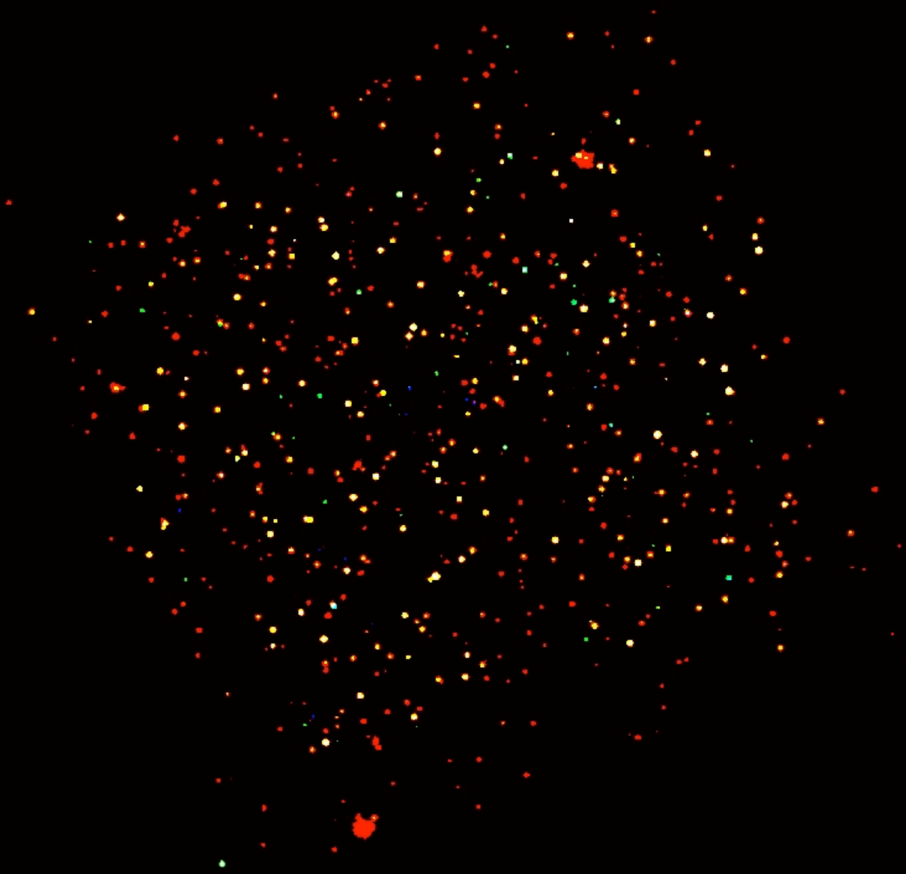
- AGN activity is a **broad band phenomenon**

(flat SED almost equal power per unit frequency)

- Models predict **bolometric luminosity/properties** → bolometric approach is needed for a proper census of SMBH (most of them are obscured or elusive) **Bolometric LF and evolution is a key parameter**


Flux (cgs)
-16
-15
-14
-13
CDFN-CDFS 0.1deg2
Barger et al. 2003; Szokoly et al. 2004
E-CDFS 0.3deg2
Lehmer et al. 2005
EGS/AEGIS 0.5deg2
Nandra et al. 2006
C-COSMOS 1 deg2
XMM-COSMOS 2 deg2
ELAIS-S1 0.5deg2
Puccetti et al. 2006
Contiguous
+ ACS
HELLAS2XMM 1.4 deg2
Cocchia et al. 2006
Champ 1.5deg2
Silverman et al. 2005
SEXSI 2 deg2
Eckart et al. 2006
Serendipitous
XMM HBSS ~25 deg2
Della Ceca et al. 2004
Estrela - Bologna 20-01-2009
(see Brandt & Hasinger 2005 review (ARA&A 43, 827)
Area



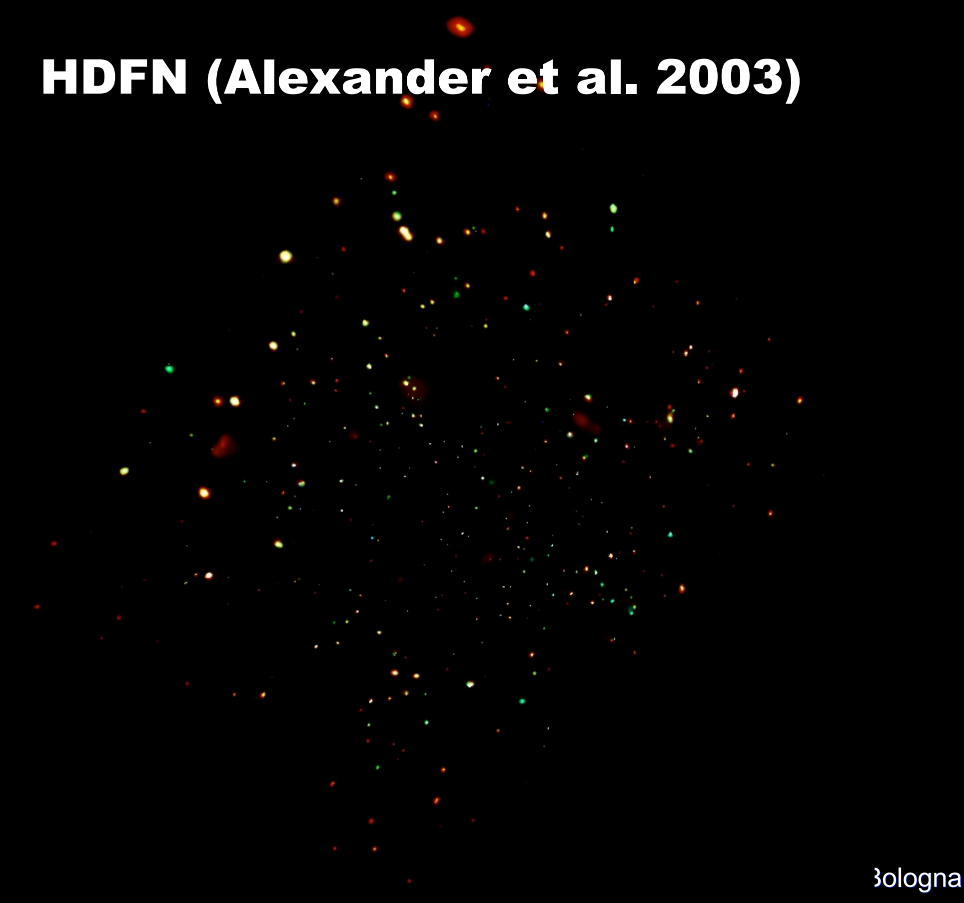


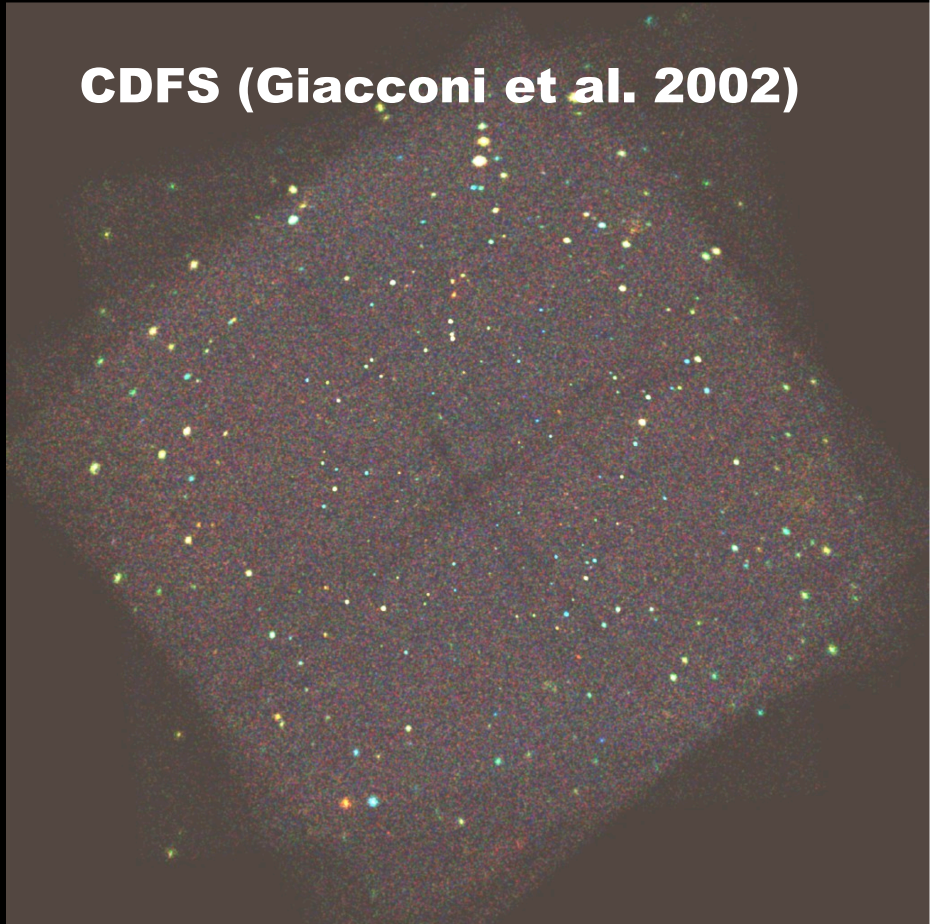
COSMOS

2 deg^2 XMM
0.9 deg^2 Chandra

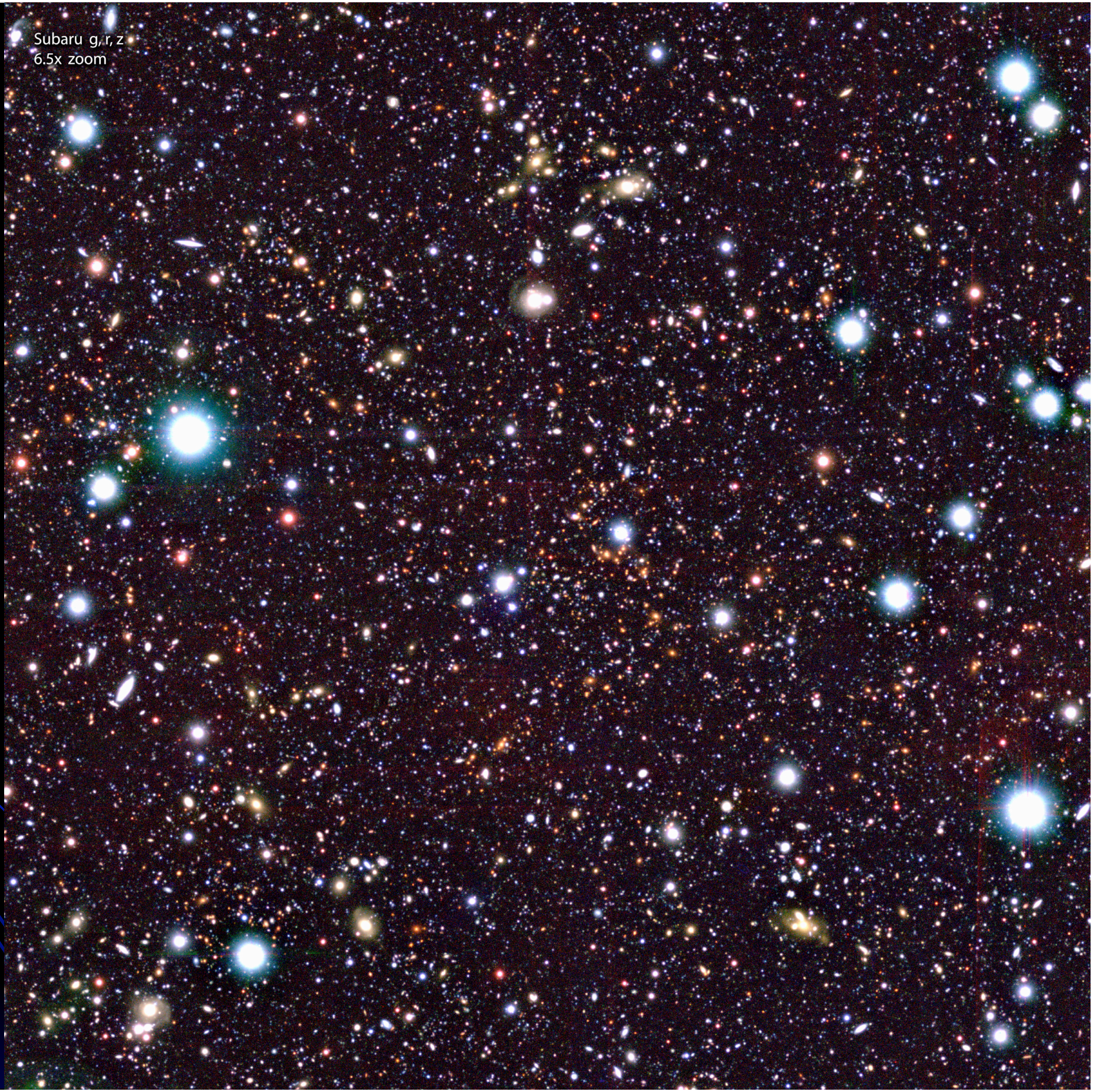
The deepest X-ray sky

Chandra Deep Field Surveys →
Megaseconds exposures

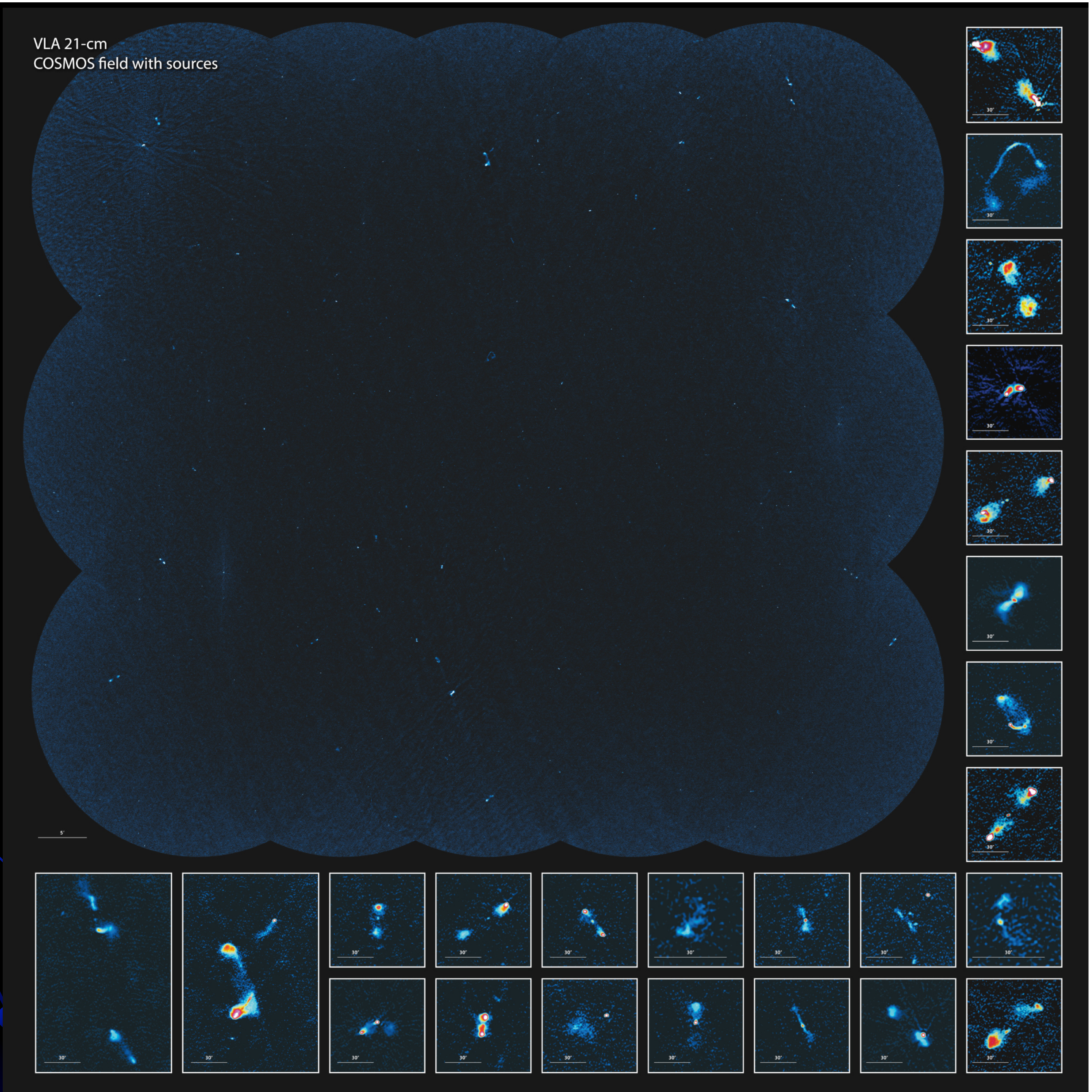




Subaru SCAM
PI : Taniguchi
25 nights
26 - 28 mag 5σ



VLA
PI : Schinnerer
300 hrs
7-10 μJy



Identification of faint AGN
need for multi-λ (near-IR) data

Optically faint (I>24) objects

candidate high-z (z>1) obscured QSO, z>4 QSO...

→ difficult to identify using optical bands only

"too" deep wrt XMM-Newton PSF

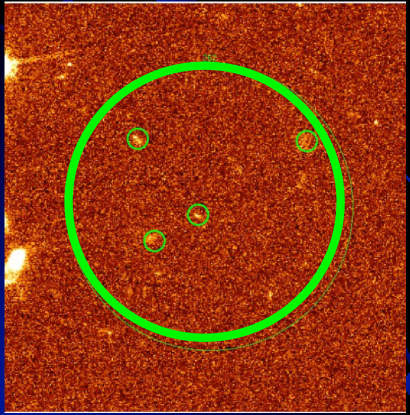
optical data

Obscured AGN are red [Mignoli et al. 2004, Koekemoer et al. 2004, Brusa et al. 2005, Mainieri et al. 2005, Maiolino et al. 2006 etc.]

→ use IR bands

ACS band:

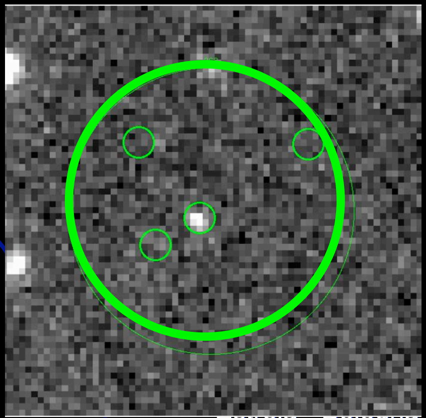
>4 optical sources (marked i<25 objects)

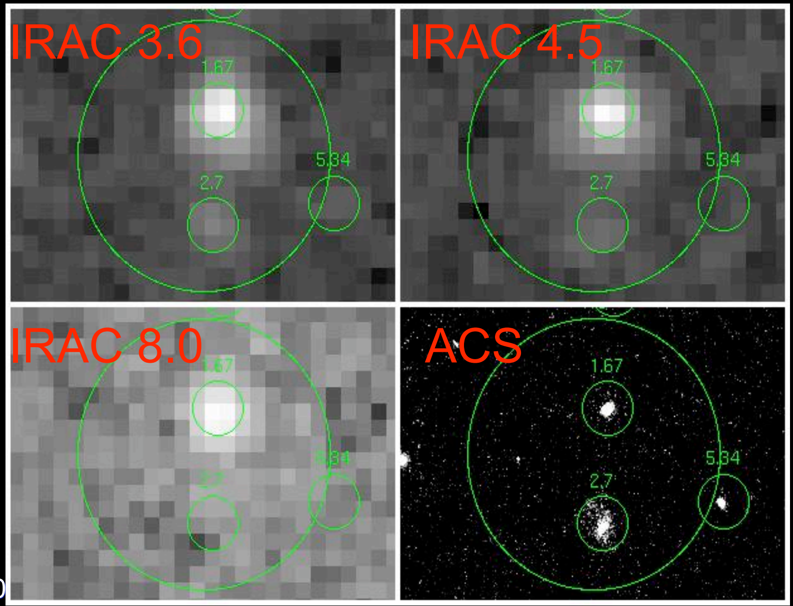


XMM 7" radius error circle

K-band:

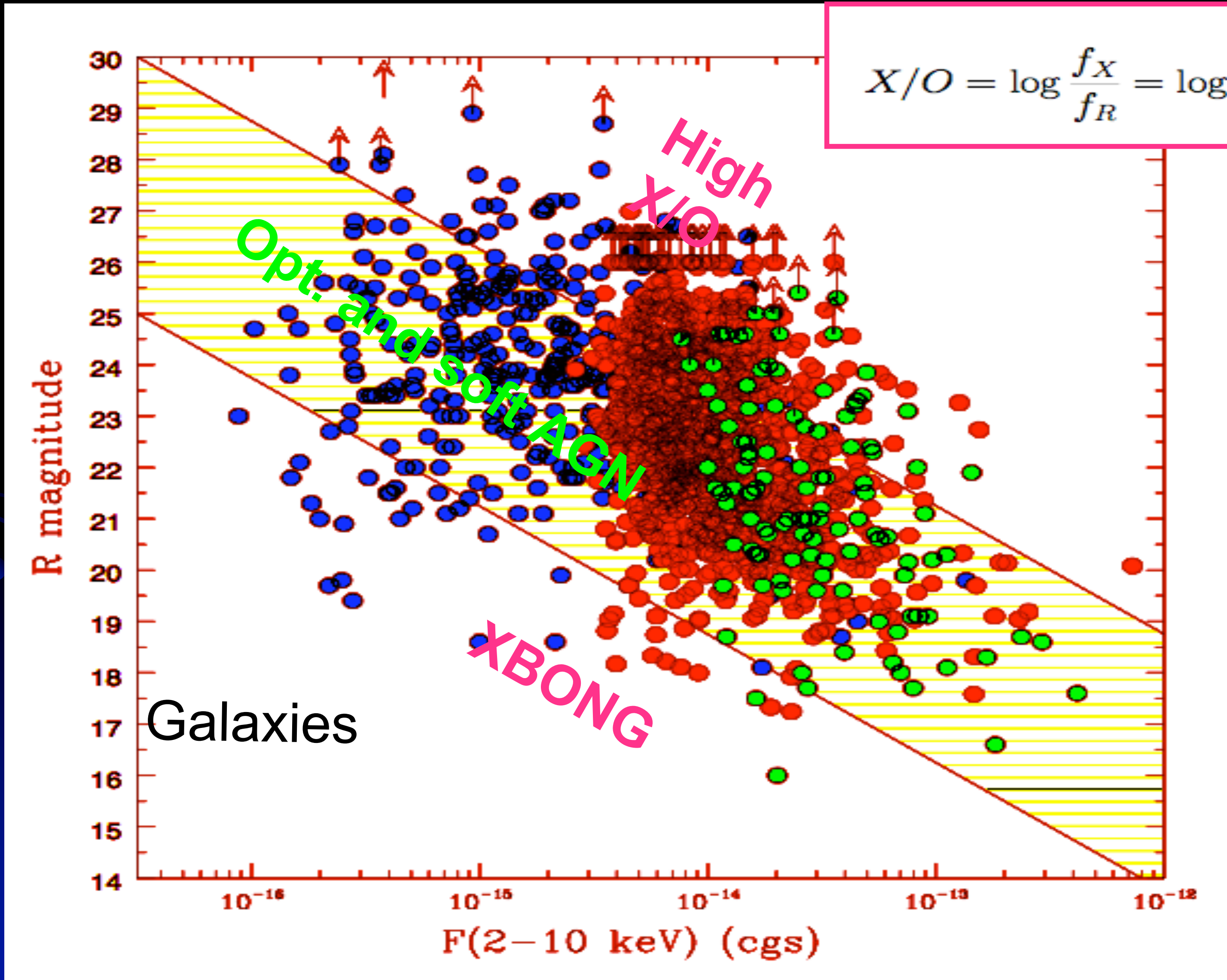
only one source, cleaner error-box!

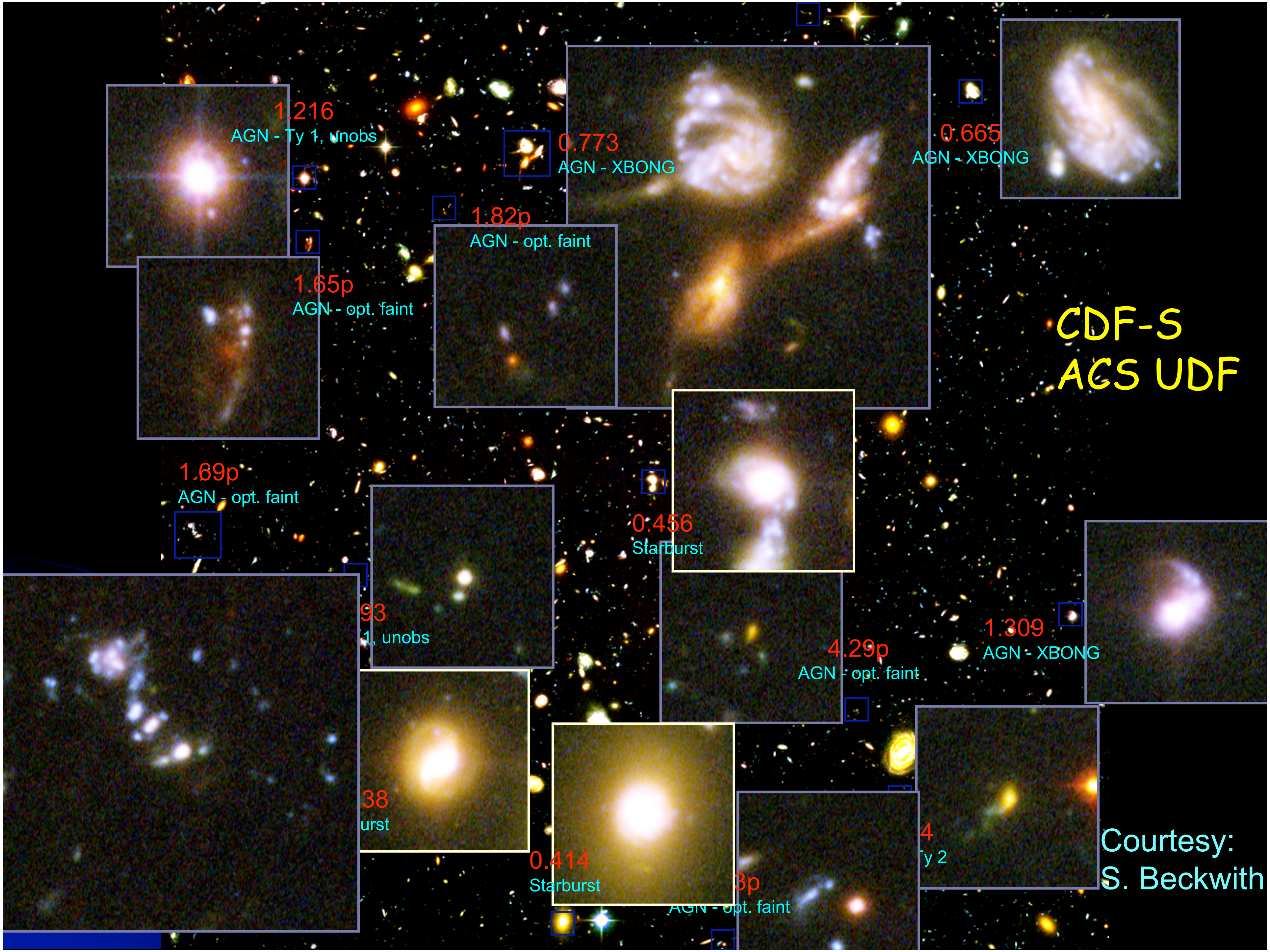




X-ray vs Optical

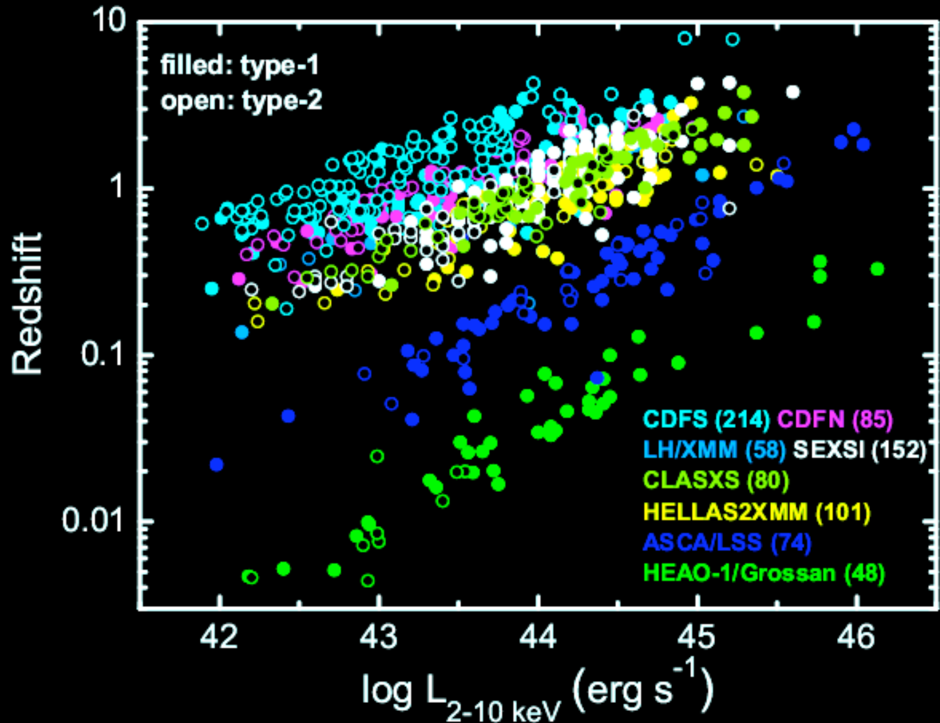
$$X/O = \log \frac{f_X}{f_R} = \log f_X + C + \frac{R}{2.5}$$




1.216
AGN - Ty 1, unobs
0.773
AGN - XBONG
0.665
AGN - XBONG
1.82p
AGN - opt. faint
1.65p
AGN - opt. faint
CDF-S
ACS UDF
1.69p
AGN - opt. faint
0.456
Starburst
93
1, unobs
1.309
AGN - XBONG
4.29p
AGN - opt. faint
38
urst
0.414
Starburst
4
y 2
3p
AGN - opt. faint
Courtesy:
S. Beckwith

Optically identified hard samples

type-1: optical BLAGN, or galaxy with $L_X>10^{42}$, HR<-0.2
type-2: optical NLAGN, or galaxy with $L_X>10^{42}$, HR>-0.2



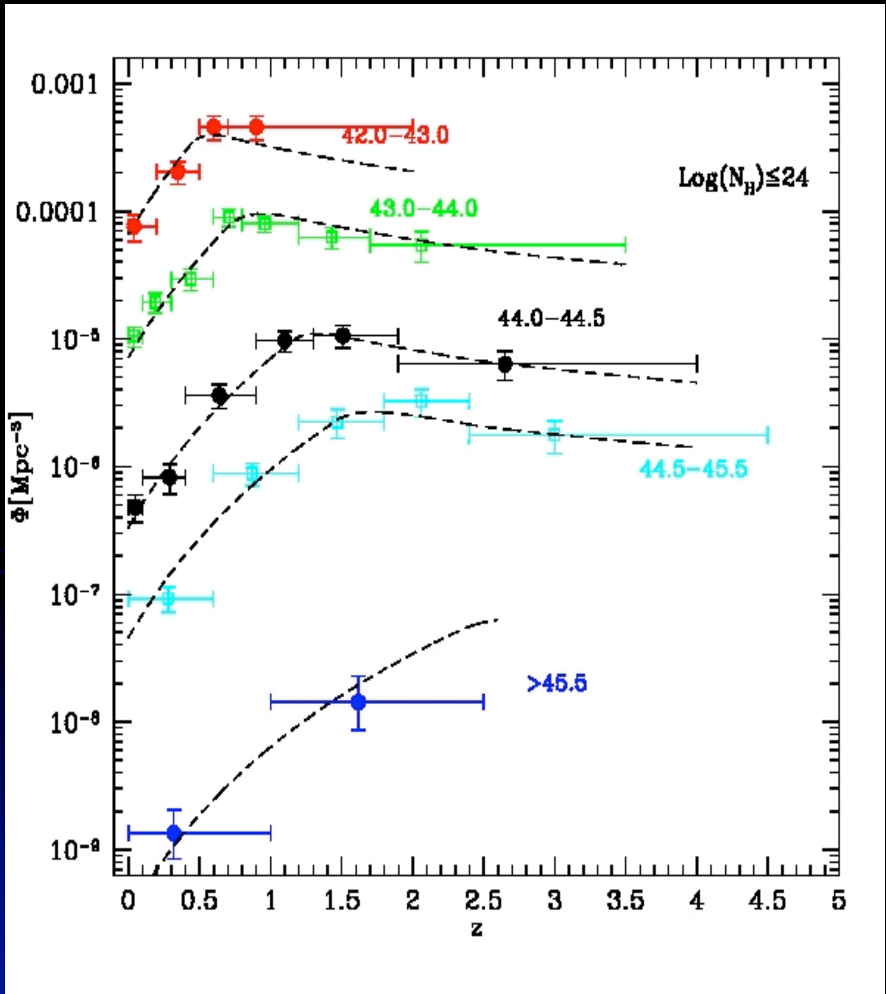
< 1000 AGN selected in the 2-10 keV band,
optical/NIR completeness ~< 80-90%

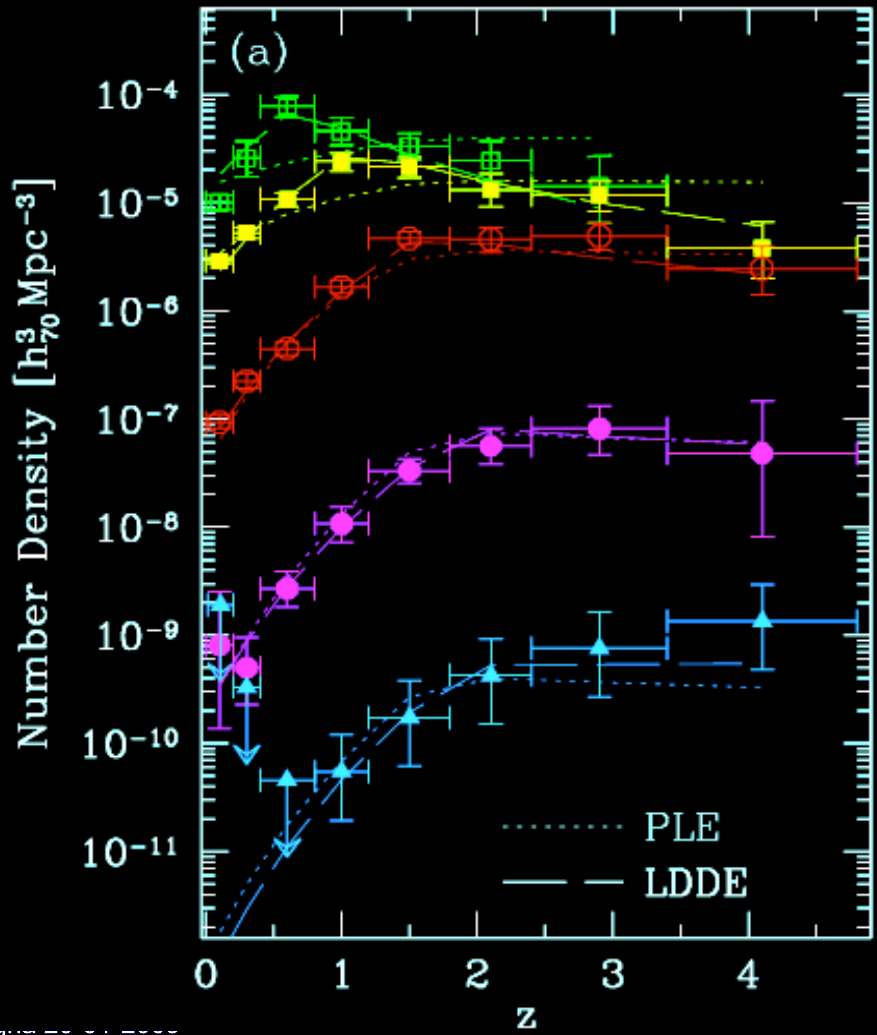
DOWNSIZING

La Franca+05 ; Ueda+03
2-10 keV surveys

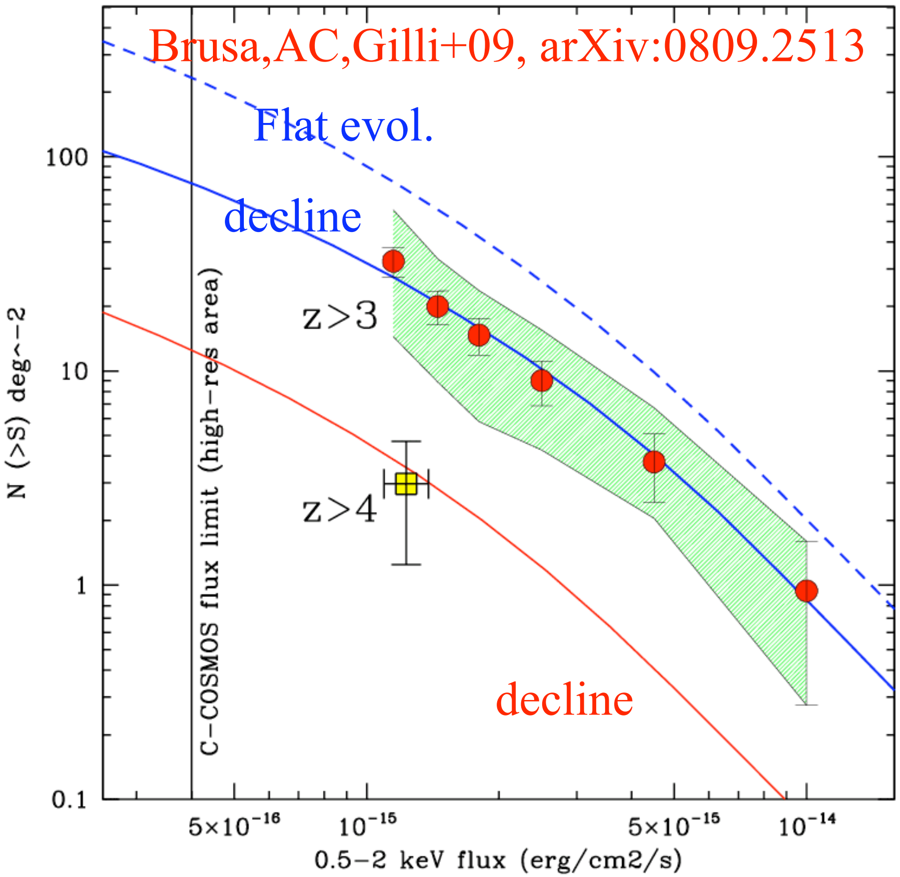
~ 1000 sources

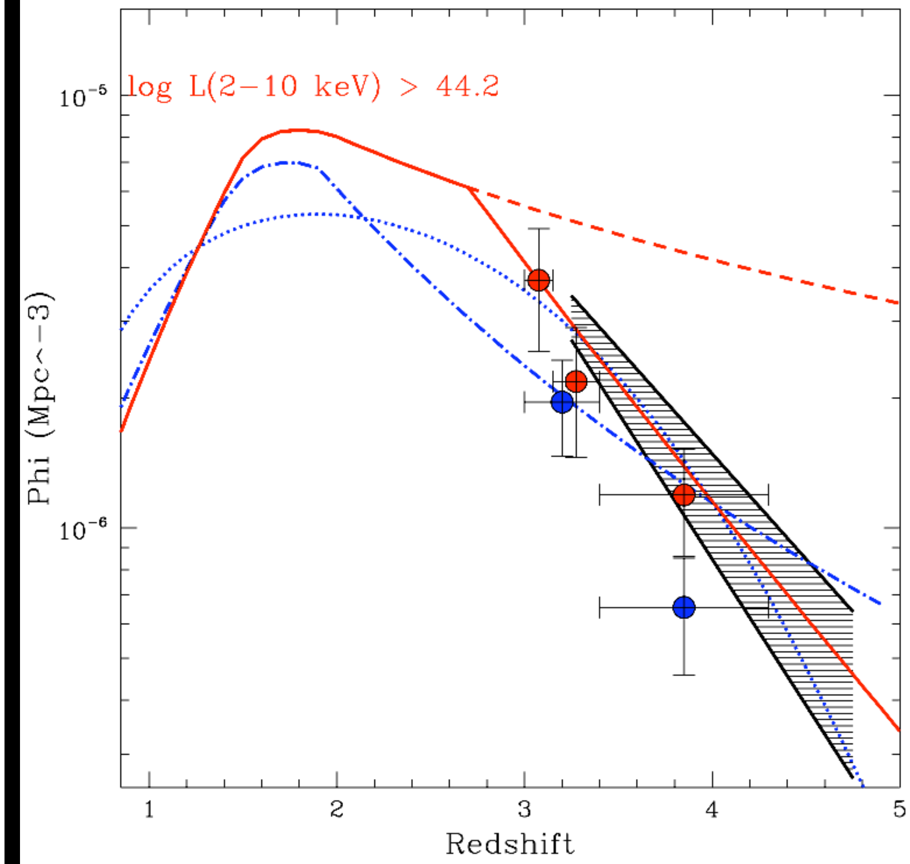
Hasinger+05
0.5-2 keV surveys





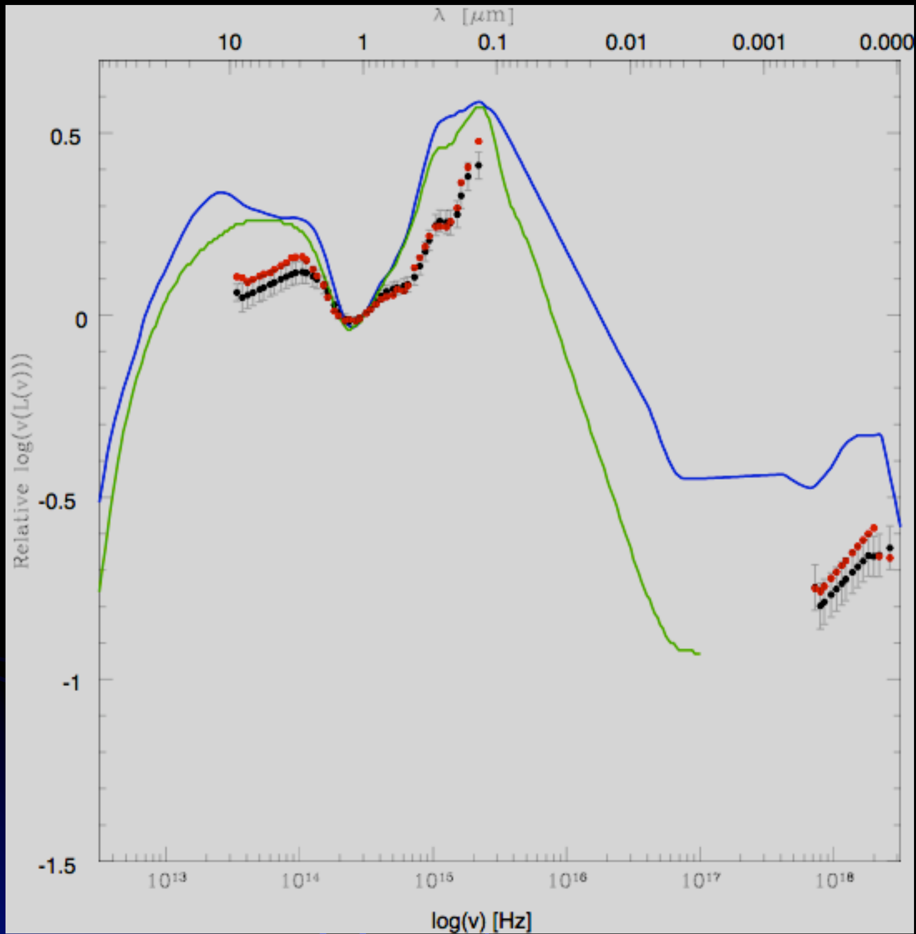
Luminous QSOs (L_X> 10^{44} erg/s): decline goes up to z~4

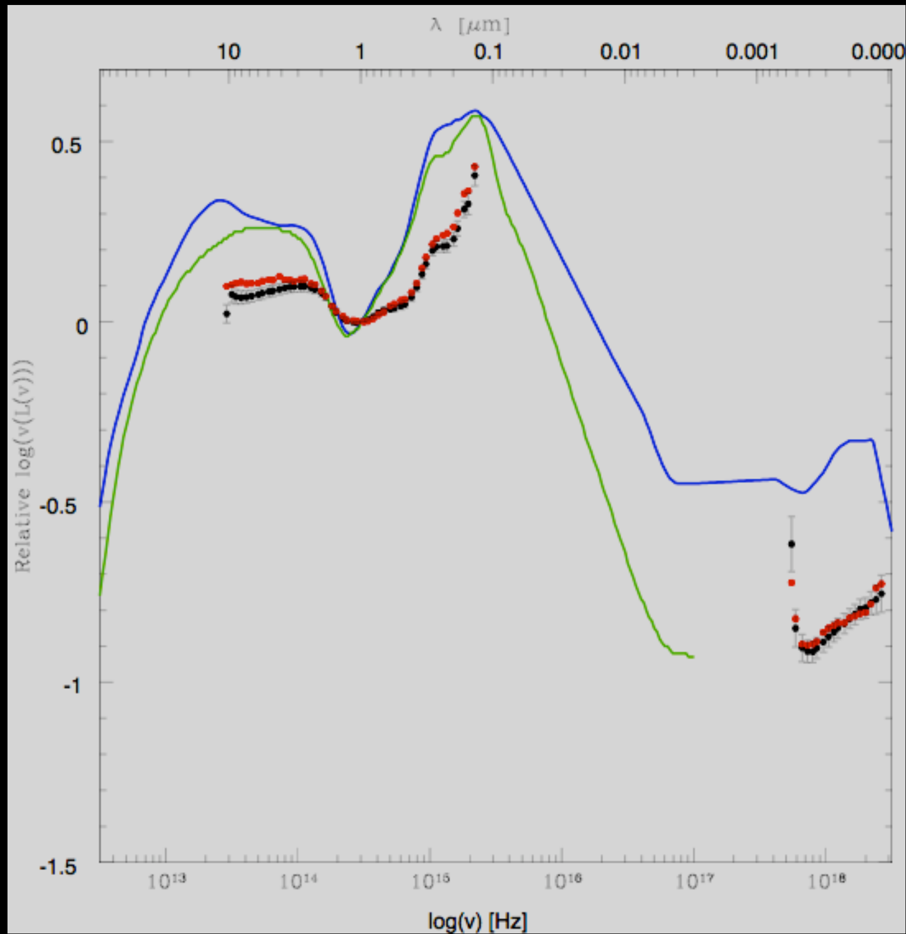




XMM-COSMOS: the largest sample of X-ray selected AGN at z>3

COSMOS Broad band SED

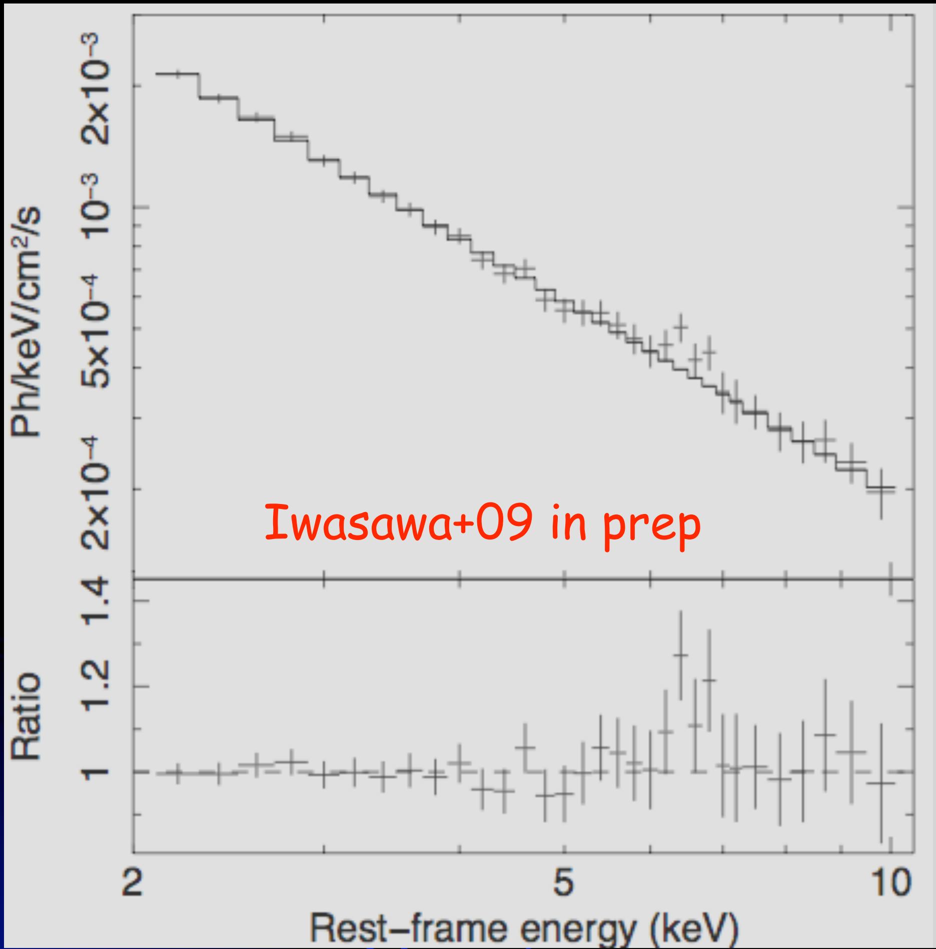


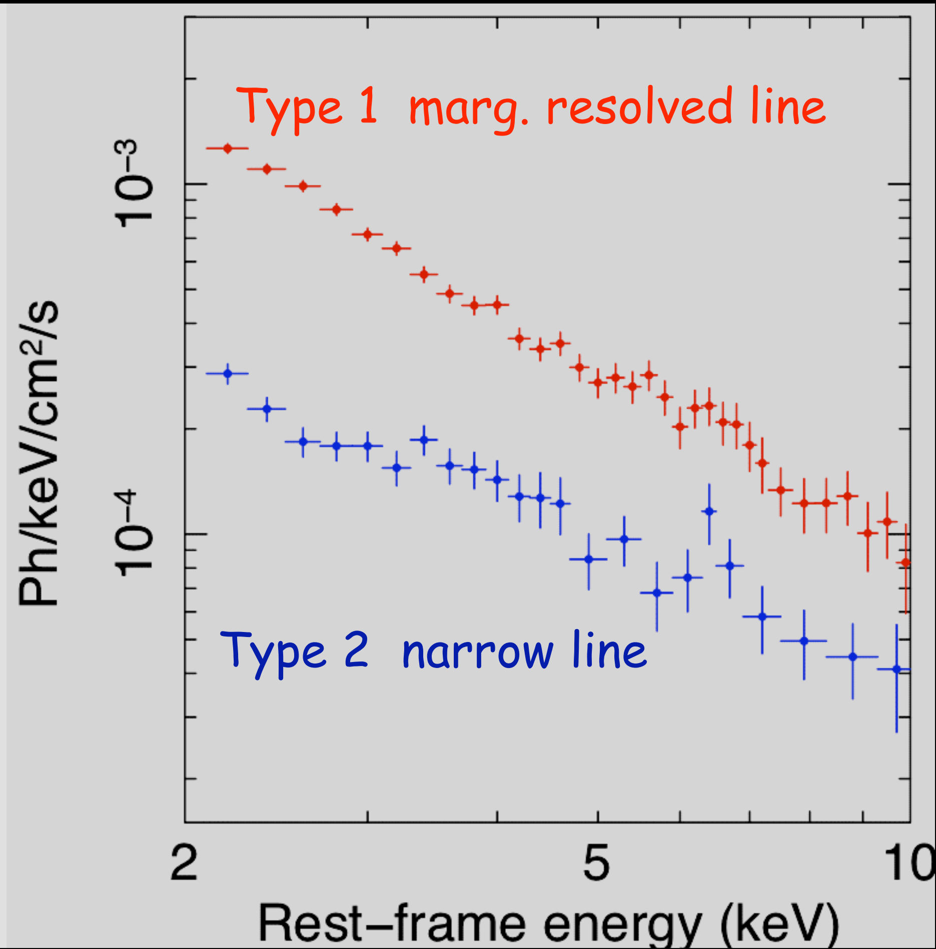


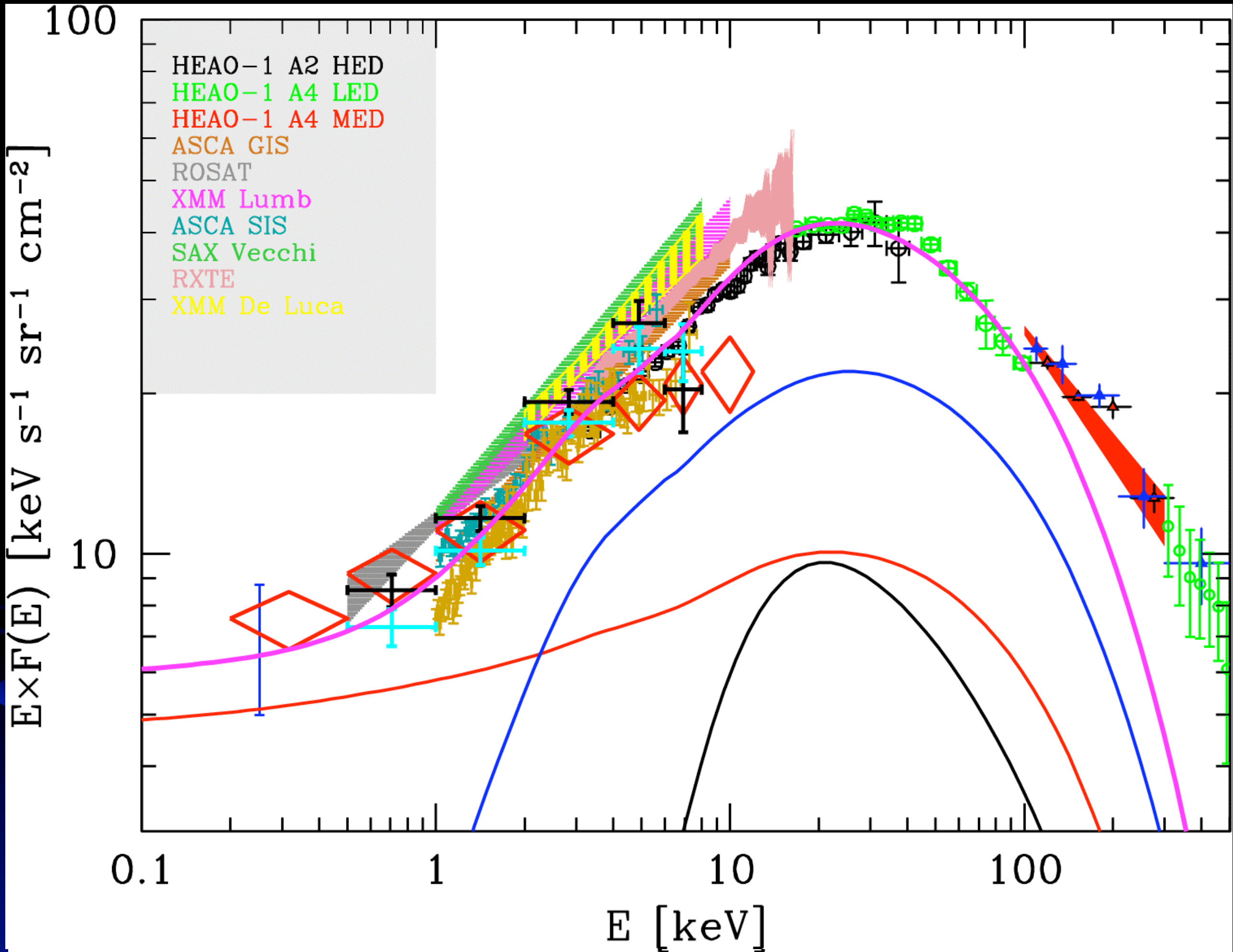
Luminosity dependent KBOL
α_{OX} is luminosity dependent
Vignali+03; Steffen+06

Lusso, AC, et al. 09
in preparation

ε < 0.1 -> Slowly rotating BH ?







The XRB synthesis provides an integral constraint (Gilli, Comastri, Hasinger 2007)

Red -> unobscured

Blue -> Compton Thin

Black -> Compton Thick

The evolution is folded in the adopted XLF

Black Hole Mass Density

Soltan (1982) argument: the BH mass density due to growth by accretion

$$\varepsilon_{\rm rad}(1+\langle z\rangle) = \eta\rho_\bullet c^2 \qquad (1)$$

$\varepsilon_{\rm rad}$ can be obtained by integrating the sources luminosity function (2) or from the background radiation they produce (3)

$$\rho_\bullet = \frac{k_{bol}}{\eta c^2}\int \frac{dt}{dz}dz \int L\phi(L)dL \qquad (2)$$

η accretion efficiency, k_{bol} Bolometric correction

Using bright quasars optical counts, $\eta = 0.1$ and $k^B_{bol} \simeq 15$

$2.2\times10^5\ M_\odot\ Mpc^{-3}$ (Yu & Tremaine 2002)

$2\times10^5\ M_\odot\ Mpc^{-3}$ (Salucci et al. 1998)

$$\rho_\bullet = \frac{k_{bol}}{\eta c^2}(1+\langle z\rangle)\frac{4\pi I_0}{c} \qquad (3)$$

I_0 Background Intensity

Using the XRB spectrum, $\eta = 0.1$ and $k^X_{bol} \simeq 30$

$6-9\times10^5\ M_\odot\ Mpc^{-3}$ (Fabian & Iwasawa 1999)

$7.5-17\times10^5\ M_\odot\ Mpc^{-3}$ (Elvis, Risaliti, Zamorani 2002)

Optical counts and pre Chandra/XMM estimates of the BH mass density

Lower limit = only UNOBSCURED objects

All hard X-ray sources (accretion dominated)

Main assumptions in estimate from the XRB intensity:
- Redshift distribution (<z>)
- Efficiency (η)
- Bolometric correction (k_{bol})

BH mass density from "new" luminosity function and z distribution (Fiore+03; Marconi+04; …)

$$\rho_{\bullet} \sim 4\text{-}5 \times 10^{5}\ M_{\odot}\ \mathrm{Mpc}^{-3}$$

The local BH mass density

$\rho^{direct} \rightarrow$ Using the $M_\bullet - M_{bulge}$

$\sim 10 \times 10^5\ M_\odot\ Mpc^{-3}$ (Magorrian et al. 1998)

$\rho^{direct} \rightarrow$ Using the $M_\bullet - \sigma$

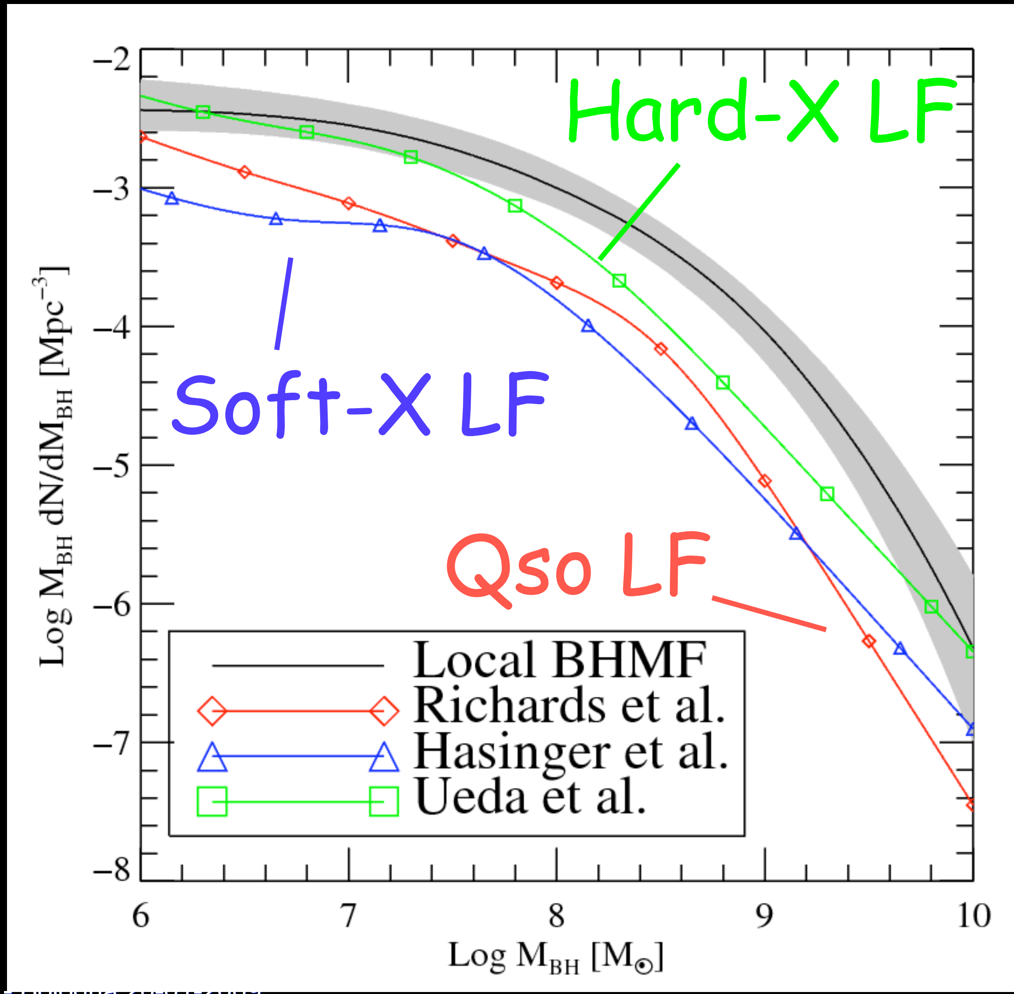
$2.5 - 3.5 \times 10^5\ M_\odot\ Mpc^{-3}$ (Yu & Tremaine 2002)

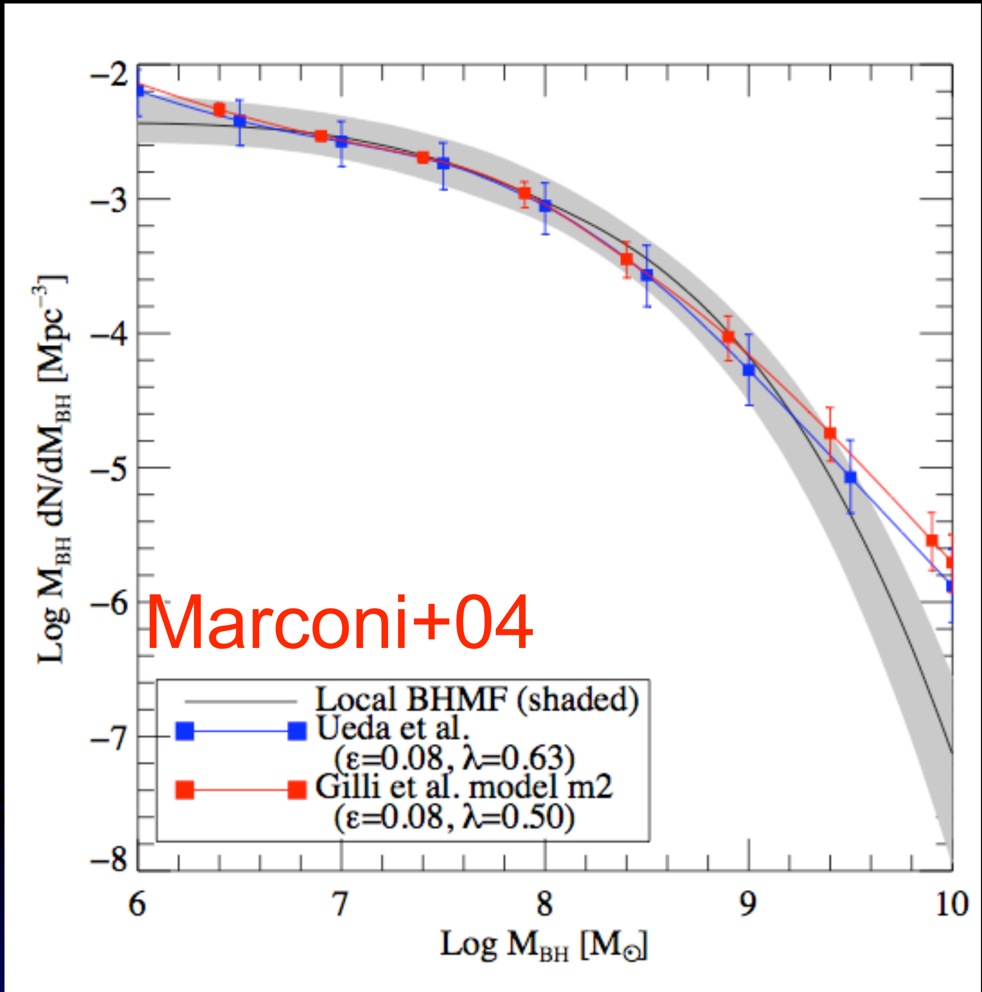
$4 - 5 \times 10^5\ M_\odot\ Mpc^{-3}$ (Ferrarese 2002)

Good agreement between local BH mass density
and AGN BH mass density (Fabian 03; Marconi+04, …)
Little room for inefficient accretion …

Local Black Holes and AGN relics

- Marconi et al. 2004 have shown that local BHs are relics of AGN activity by comparing:
  - the local BH mass function (from galaxy L/σ functions and M_{BH}-L_{bul}/M_{BH}-σ_e)
  - the relic BHMF (from AGN luminosity function and continuity equation)
- Importance of AGN LF: even the hard (2-10 keV) XLF does not sample the whole AGN population.
- Heavily obscured Compton-thick AGN are missing ...



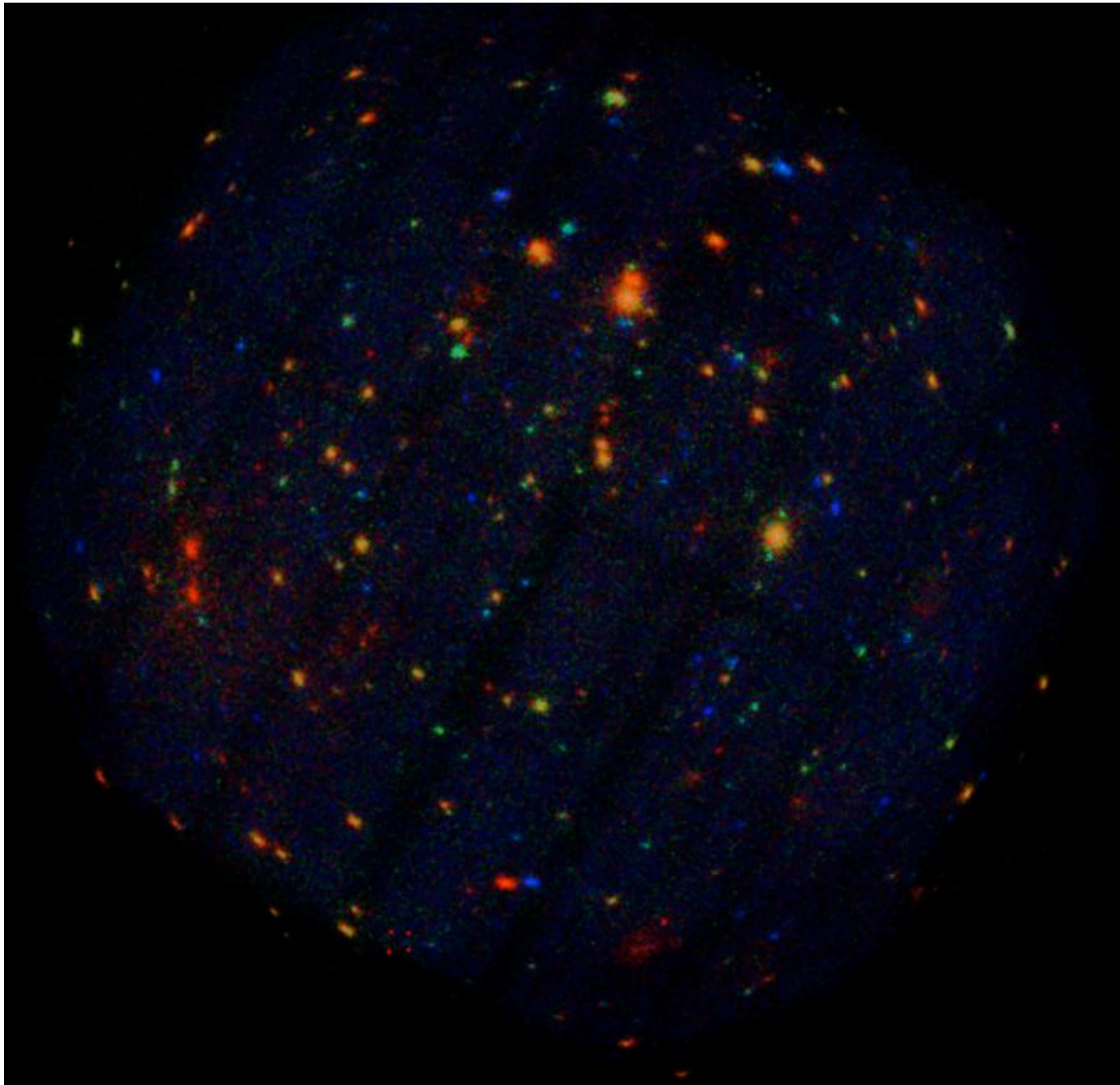


- Correction for Compton-Thick sources from XRB models ➔ whole AGN pop considered
- The only free parameters are the accretion efficiency and Eddington ratio

$$L = \epsilon \, dM/dt \, c^2$$
$$L = \lambda L_{Edd}$$

Determine locus in ϵ-λ plane where there is the best match between local and relic BHMF!

ϵ=0.04-0.10 λ=0.08-0.5



Chandra 2 Ms

10^{-17} cgs over
50 arcmin^2

XMM ~ 0.7 Ms
will reach
~ 3 Ms

the deepest X-ray
survey …
… ever …

THE FUTURE IS "HARD" AND DEEP

Simbol X French-Italian+Other collaboration
formation flight experiment
imaging survey in the 10 - 70 keV energy range
Goals : resolve the sources of the hard X-ray background

XEUS
ESA
European-Japanese proposal to ESA CV 2015-2025
Large collecting area (5 m^2), deep imaging (good PSF)
high resolution spectroscopy, variability, polarimetry
OBSERVATORY

Con-X
NASA
High throughput, spectroscopic mission, grating spectra
25-100 more sensitive than present mission (i.e. XMM)
"The physics is in the spectra"

esa JAXA NASA

3 m @ 1 keV + good PSF + high resolution spectra
+ polarimeter + HTRS + HXRT (> 10 keV) + ...

International X-ray Observatory (IXO)

Summary

A proper census of SMBH demography and evolution (especially for the most obscured sources) cannot rely only on multi-λ follow-ups of X-ray selected sources

A full bolometric approach is needed :
in particular IR (Spitzer + Herschel) , future sensitive surveys in the hard (> 10 keV) band would provide a major step forward

Fit the data (XRB, counts, …) with a time dependent model for the AGN activity able to account for Redshift and Luminosity dependence as well as mass density/function arguments