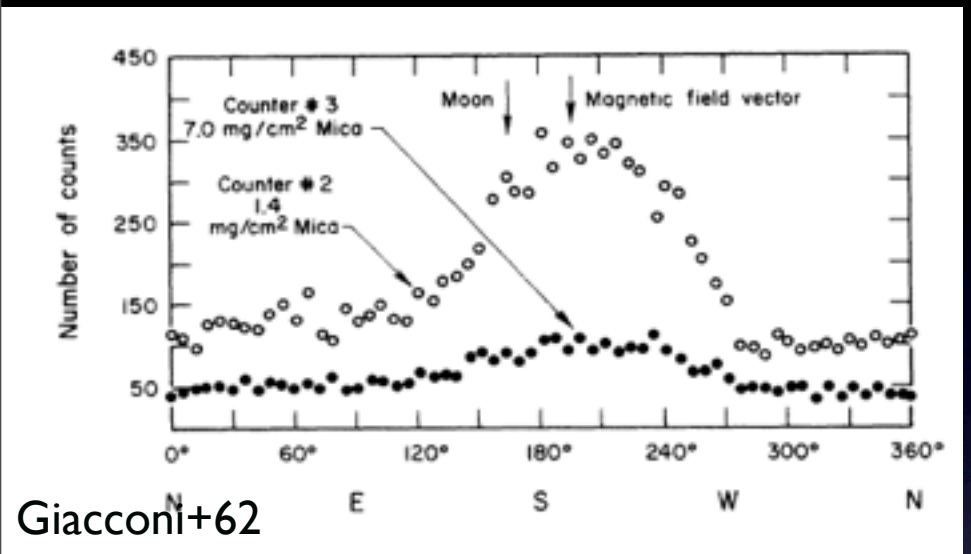
The Nature of the unresolved soft CXB:

a population synthesis model of its fluctuations

Nico Cappelluti
INAF-OABO
UMBC
and the XMM-CDFS team

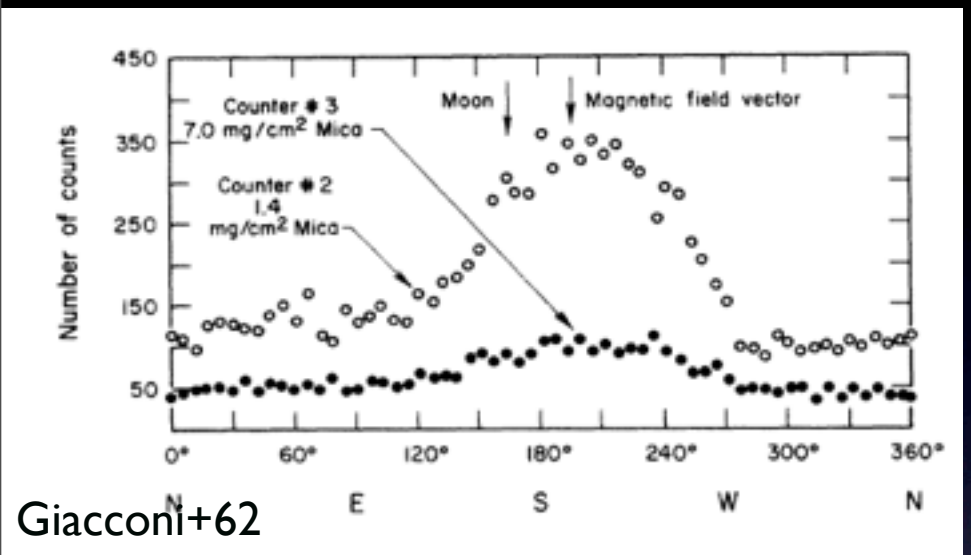
I - Preliminaries

The CXB

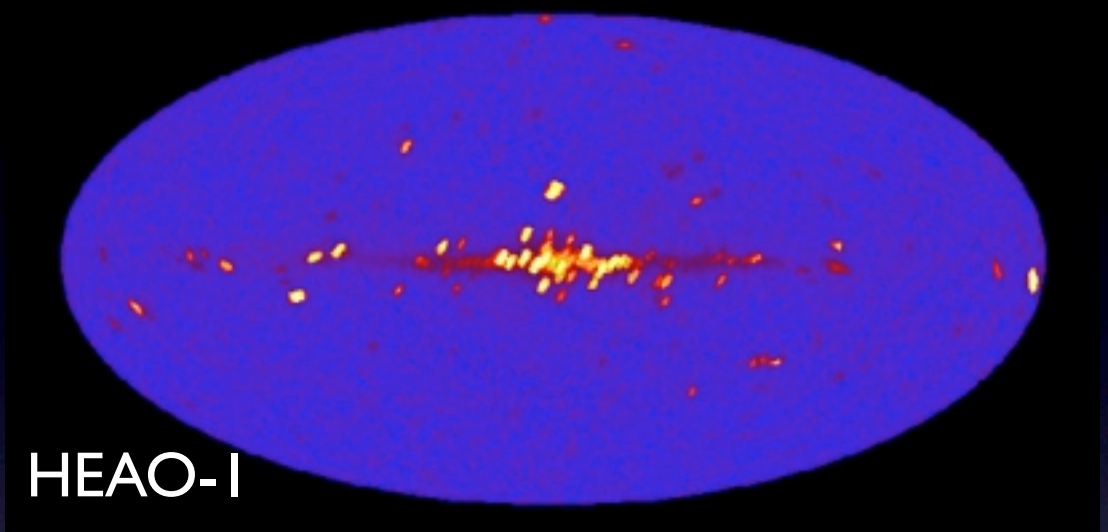


Giacconi+62

The CXB

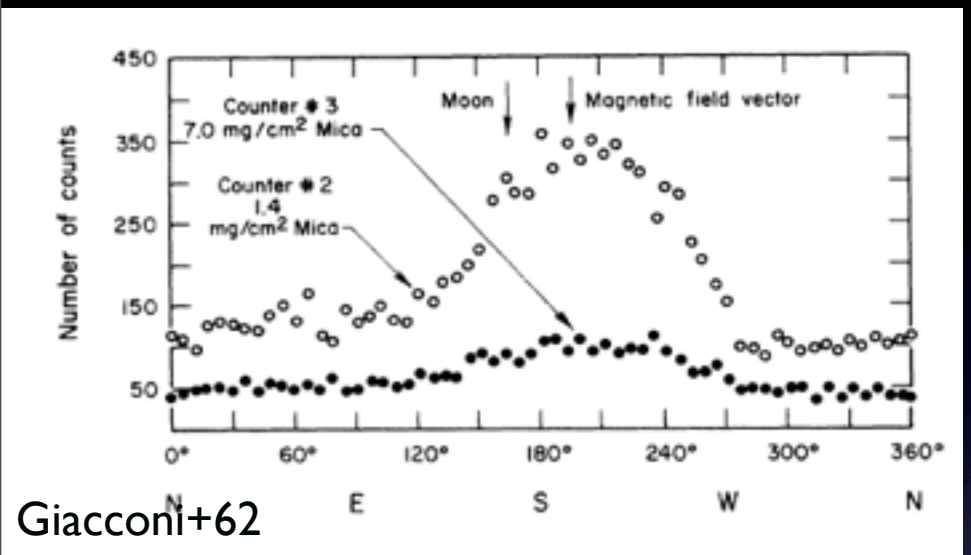


Giacconi+62

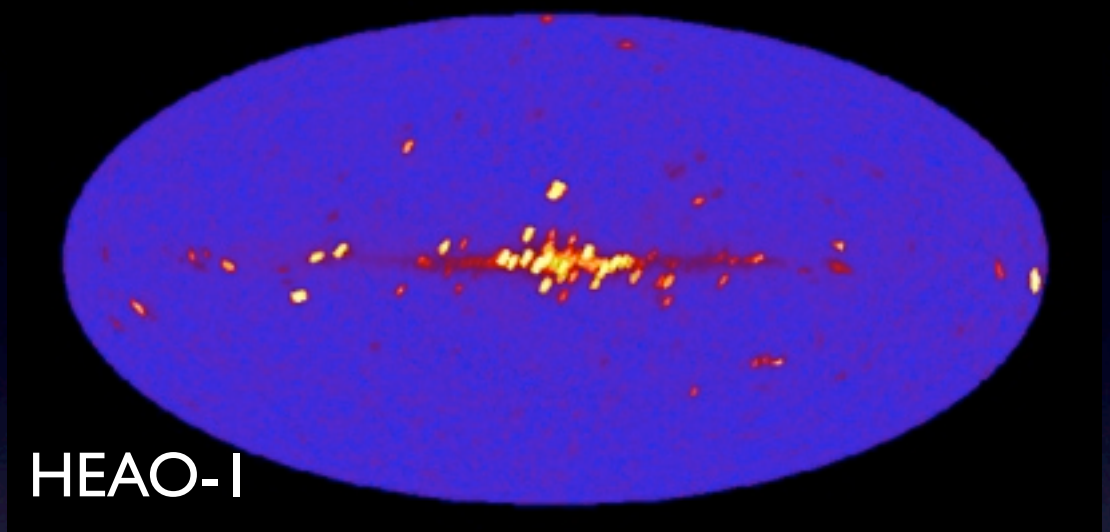


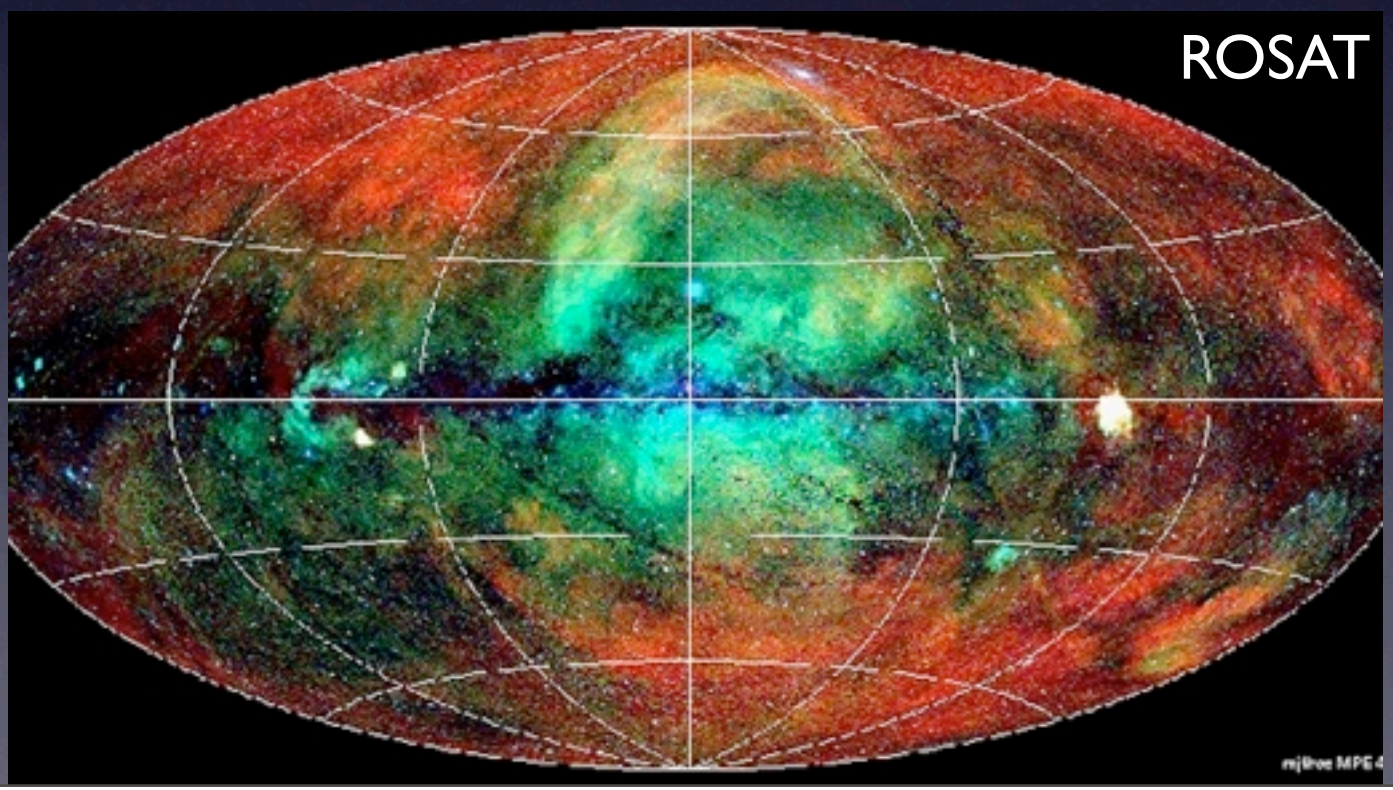
HEAO-1

The CXB



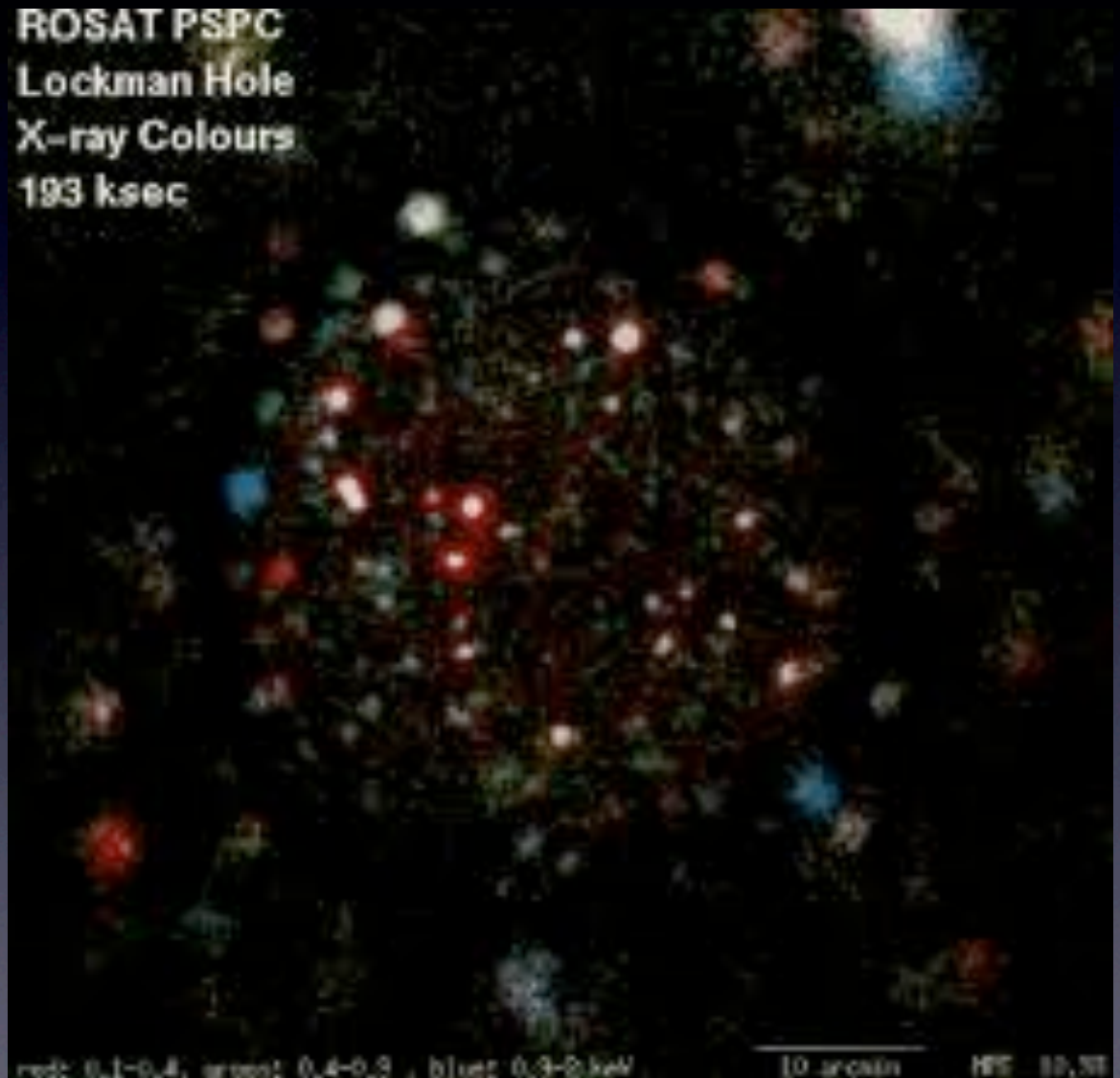
Giacconi+62


HEAO-1

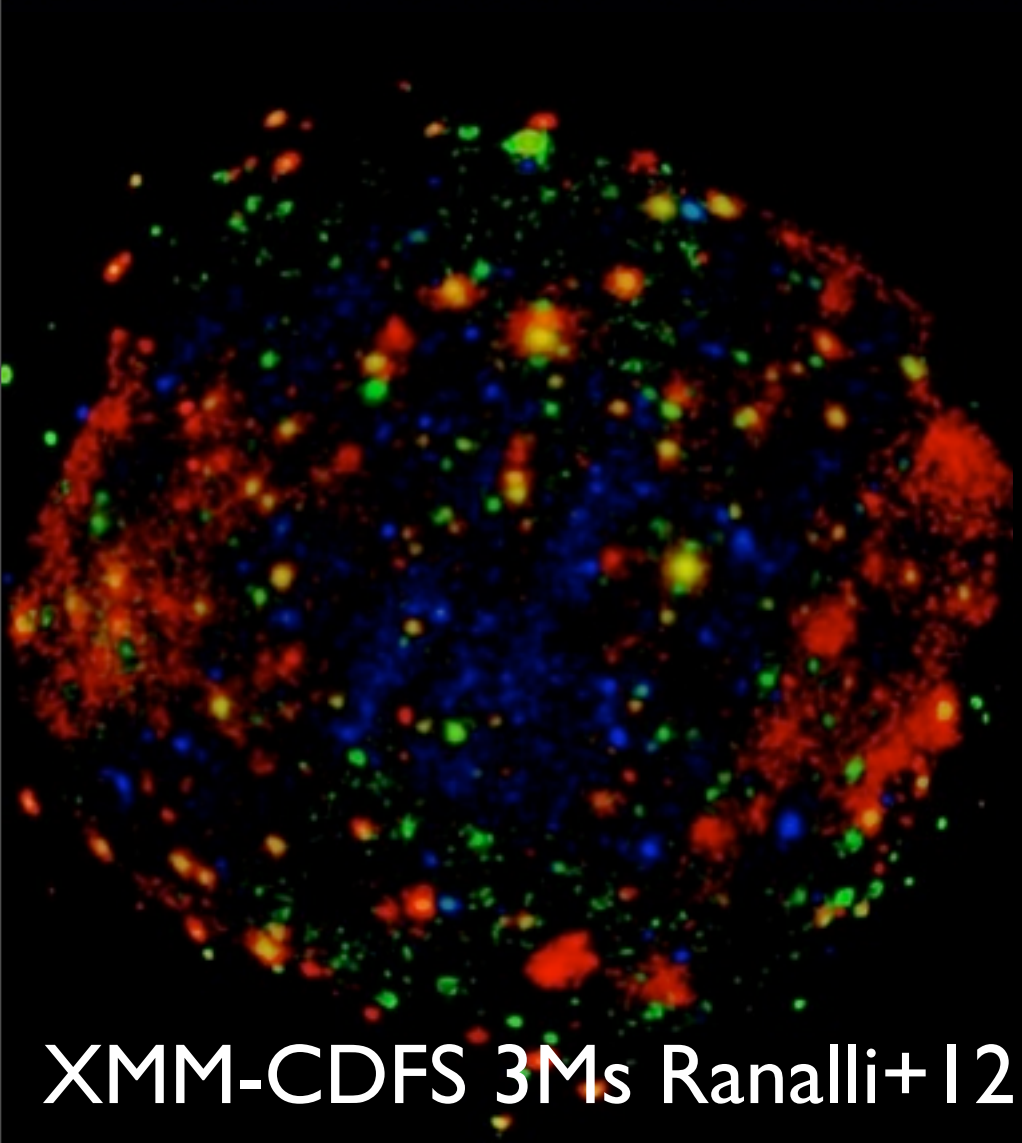

ROSAT

It is made by the contribution of unresolved point and extended sources (e.g. Setti & Woltjer)

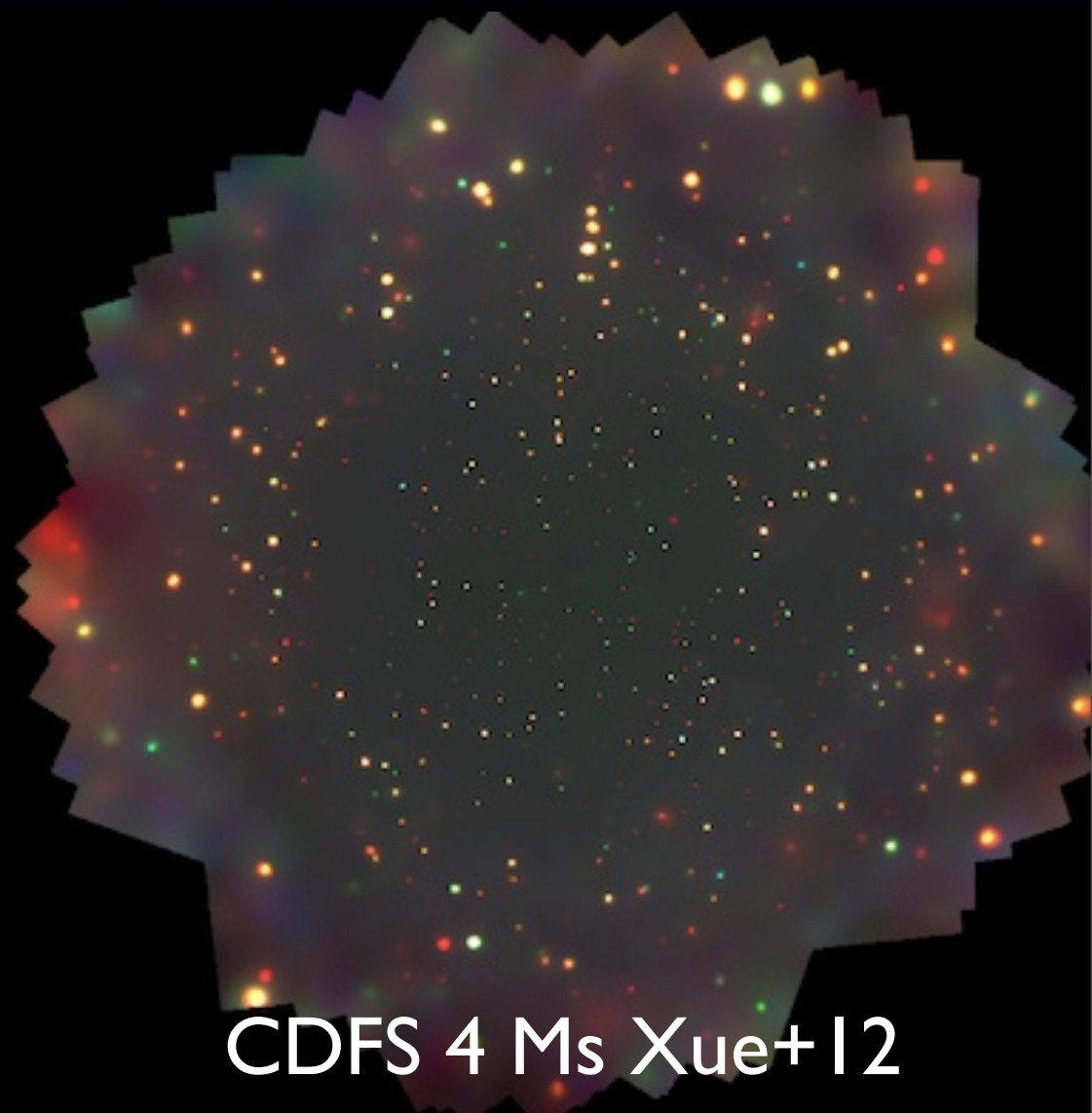
ROSAT, Chandra and XMM-Newton and Swift resolved a large fraction of the CXB in discrete sources AGN, Galaxies and Clusters



ROSAT, Chandra and XMM-Newton and Swift resolved a large fraction of the CXB in discrete sources AGN, Galaxies and Clusters

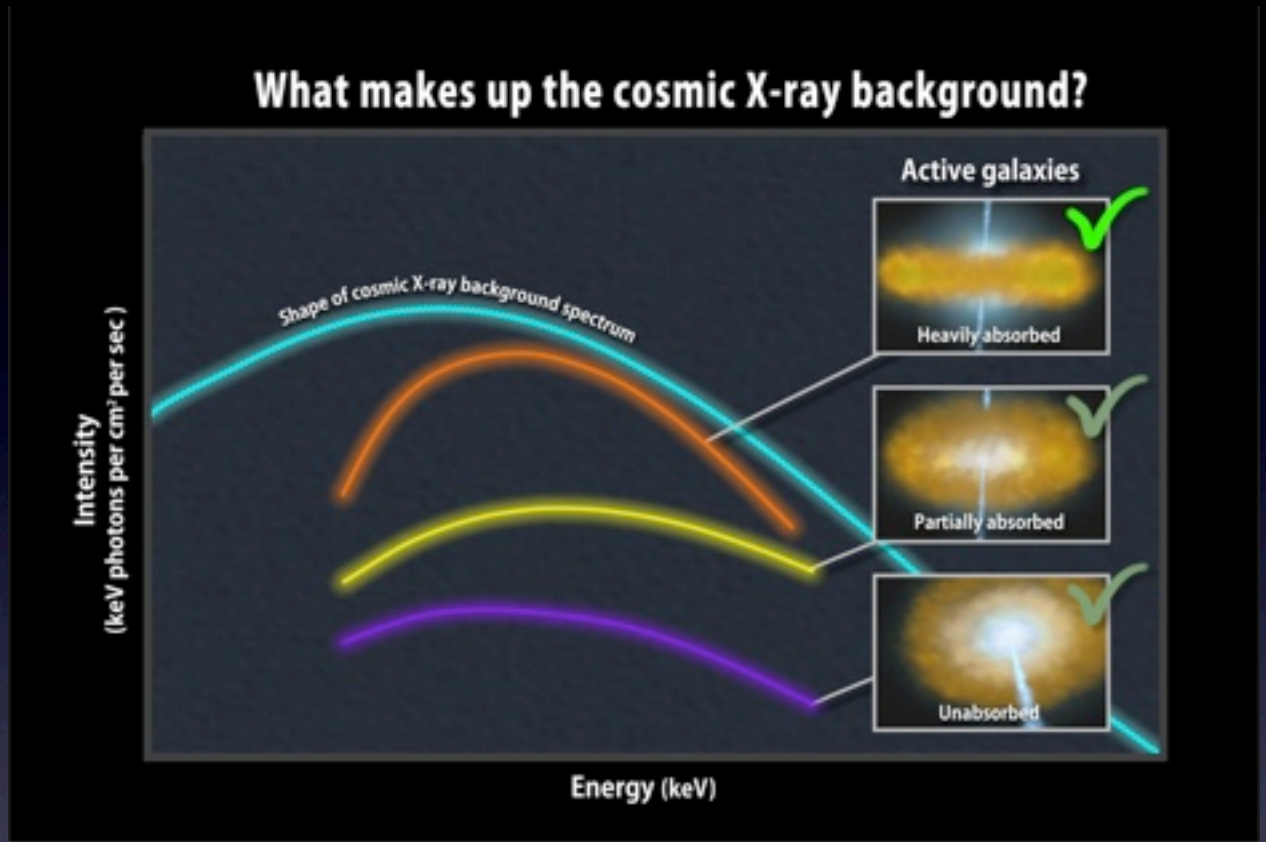


XMM-CDFS 3Ms Ranalli+12



CDFS 4 Ms Xue+12

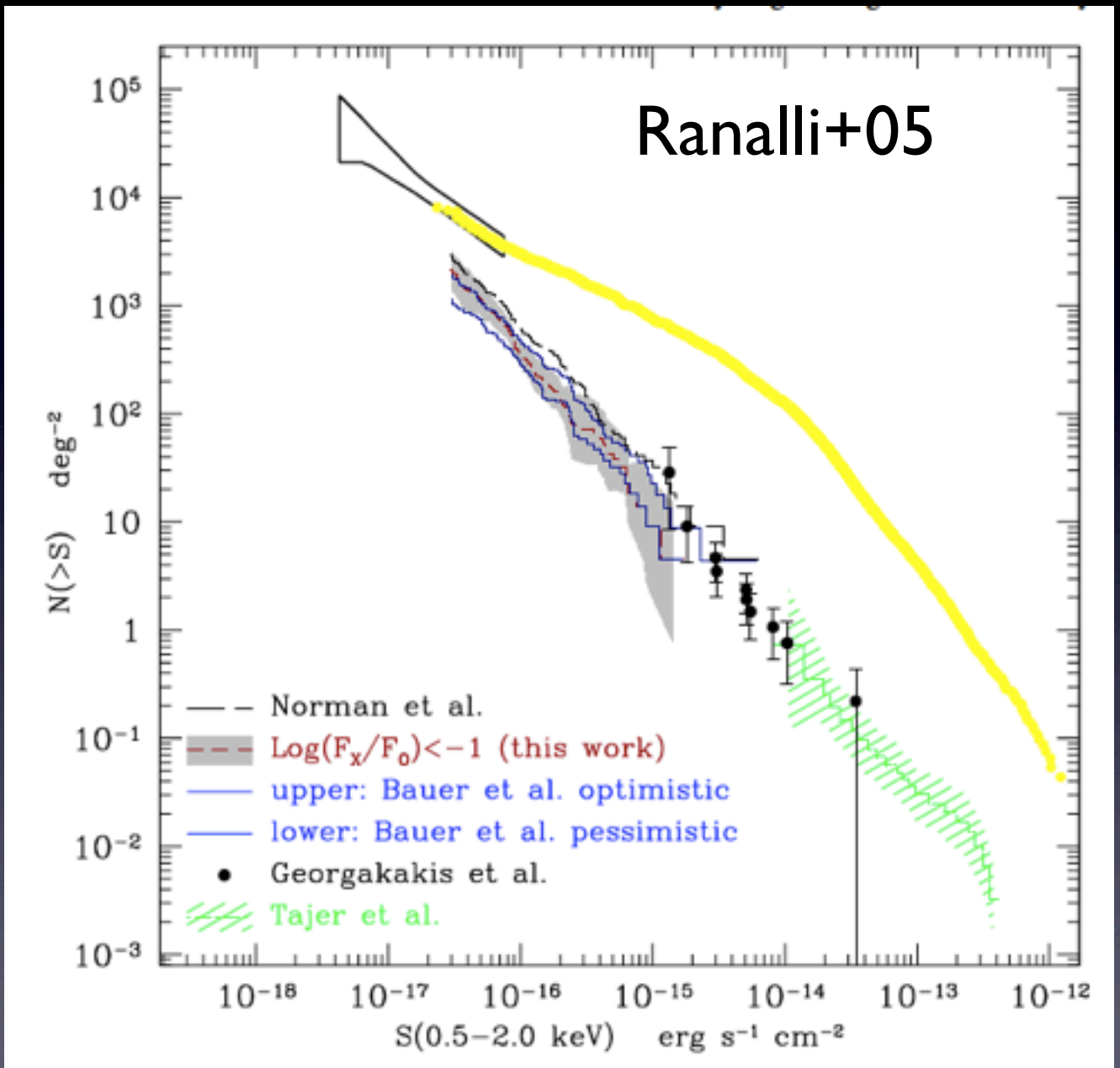
Sources producing the CXB



Most of the CXB is produced by a combination of absorbed and unabsorbed AGN Gilli+07, Treister+08, Ajello +08

10% is made by clusters

Sources producing the CXB



Most of the CXB is produced by a combination of absorbed and unabsorbed AGN Gilli+07, Treister+08, Ajello +08

10% is made by clusters

At faint fluxes galaxies become the dominant class of sources but they produce a small fraction of the CXB

2- Open questions on the sources of the unresolved CXB

2- Open questions on the sources of the unresolved CXB

Unresolved CXB actually contains all those sources that we haven't seen,... yet!

How many AGN at high-z?

AGN Number Density
at high-z

How many AGN at high-z?

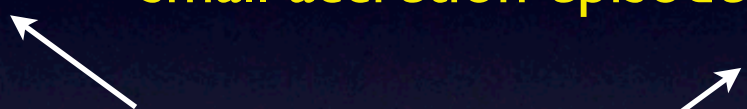
Formation of the black hole seeds that form SMBHs

AGN Number Density at high-z

How many AGN at high-z?

Formation of the black hole seeds that form SMBHs

Physics of accretion at high-z:
1-few accretion episodes
2-chaotic accretion (hundreds to thousands of small accretion episodes)



AGN Number Density at high-z

How many AGN at high-z?

Formation of the black hole seeds that form SMBHs

Physics of accretion at high-z:
1-few accretion episodes
2-chaotic accretion (hundreds to thousands of small accretion episodes)

AGN Number Density at high-z

Duty Cycle with SMBH Mass Function + Faint End LF

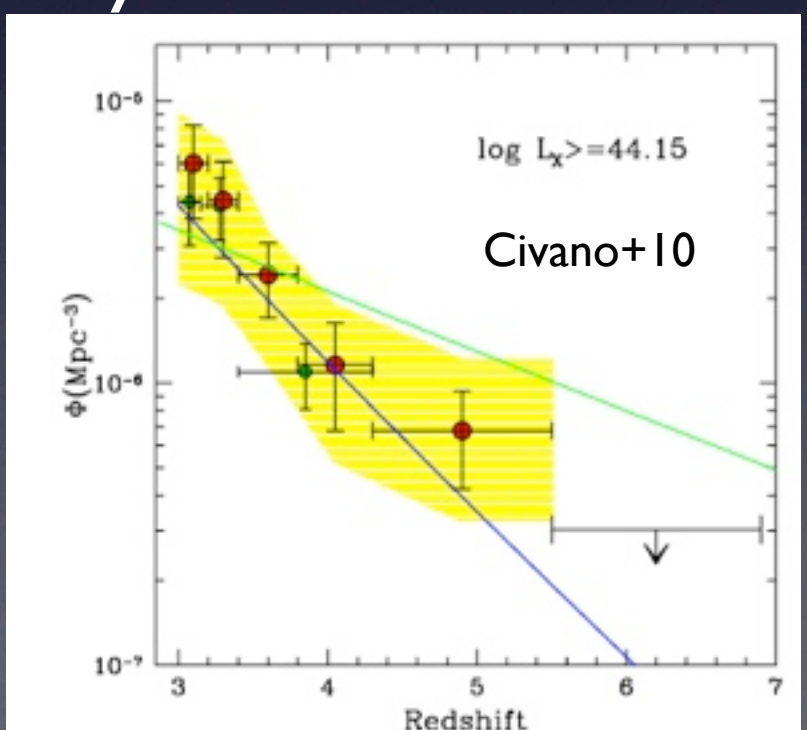
How many AGN at high-z?

Formation of the black hole seeds that form SMBHs

Physics of accretion at high-z:
1-few accretion episodes
2-chaotic accretion (hundreds to thousands of small accretion episodes)

AGN Number Density at high-z

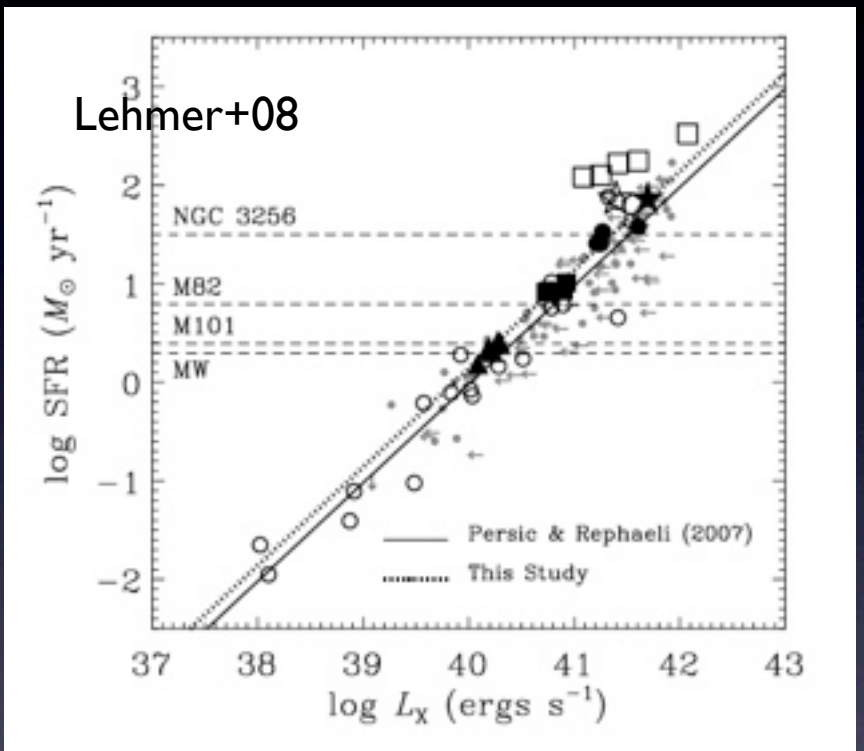
Duty Cycle with SMBH Mass Function + Faint End LF



What is the X-ray emission of normal galaxies at high-z?

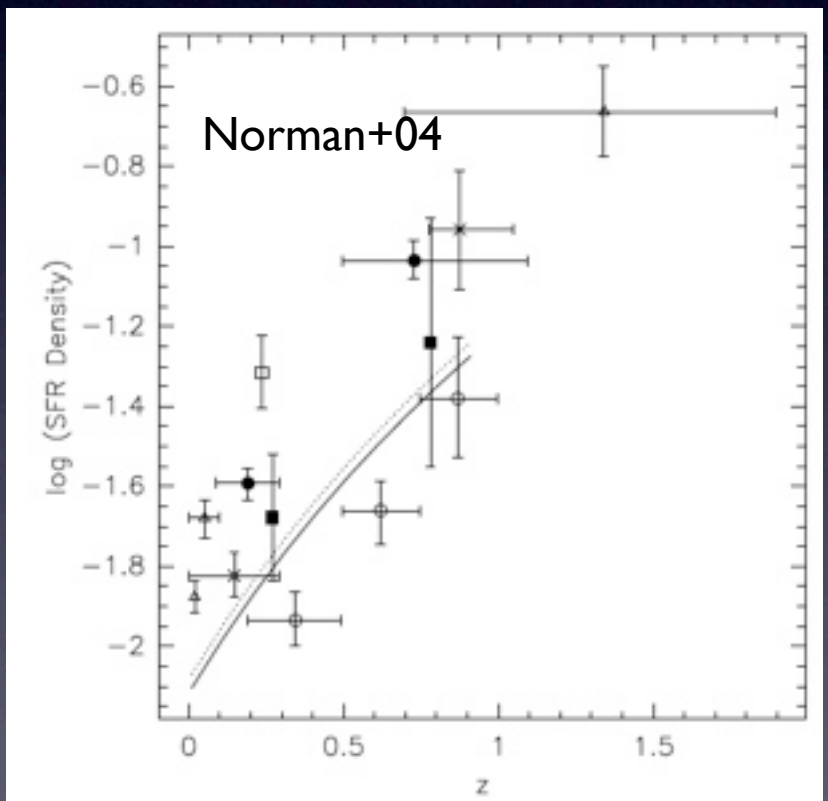
What is the X-ray emission of normal galaxies at high-z?

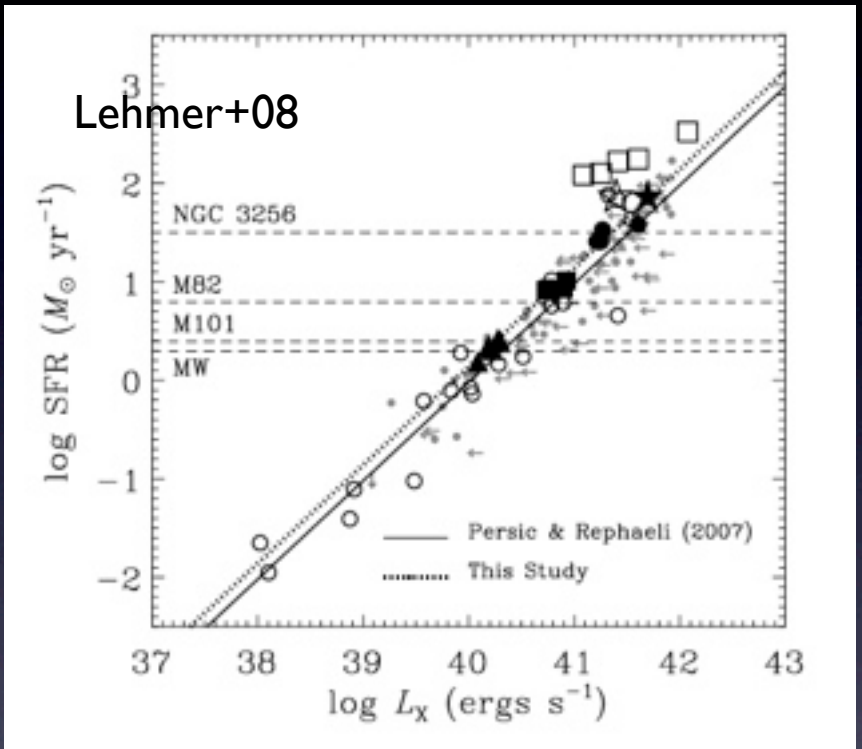
X-ray are diagnostics of SFR through X-ray: Binaries, SNr



What is the X-ray emission of normal galaxies at high-z?

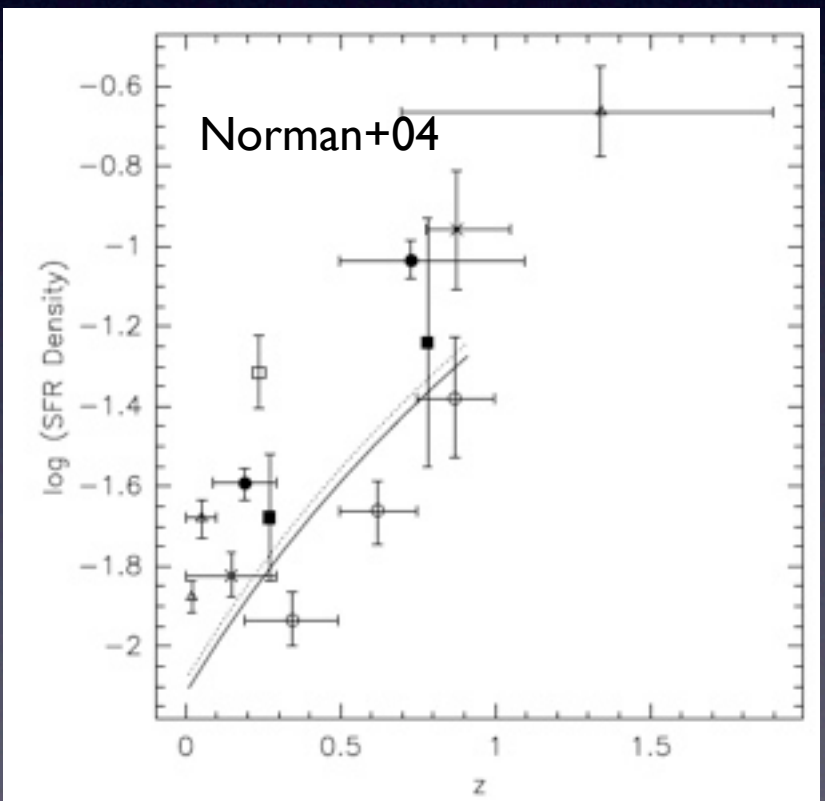
X-ray are diagnostics of SFR through X-ray: Binaries, SNr





Local XLF is known, but evolution has been detected only to z~1

What is the X-ray emission of normal galaxies at high-z?

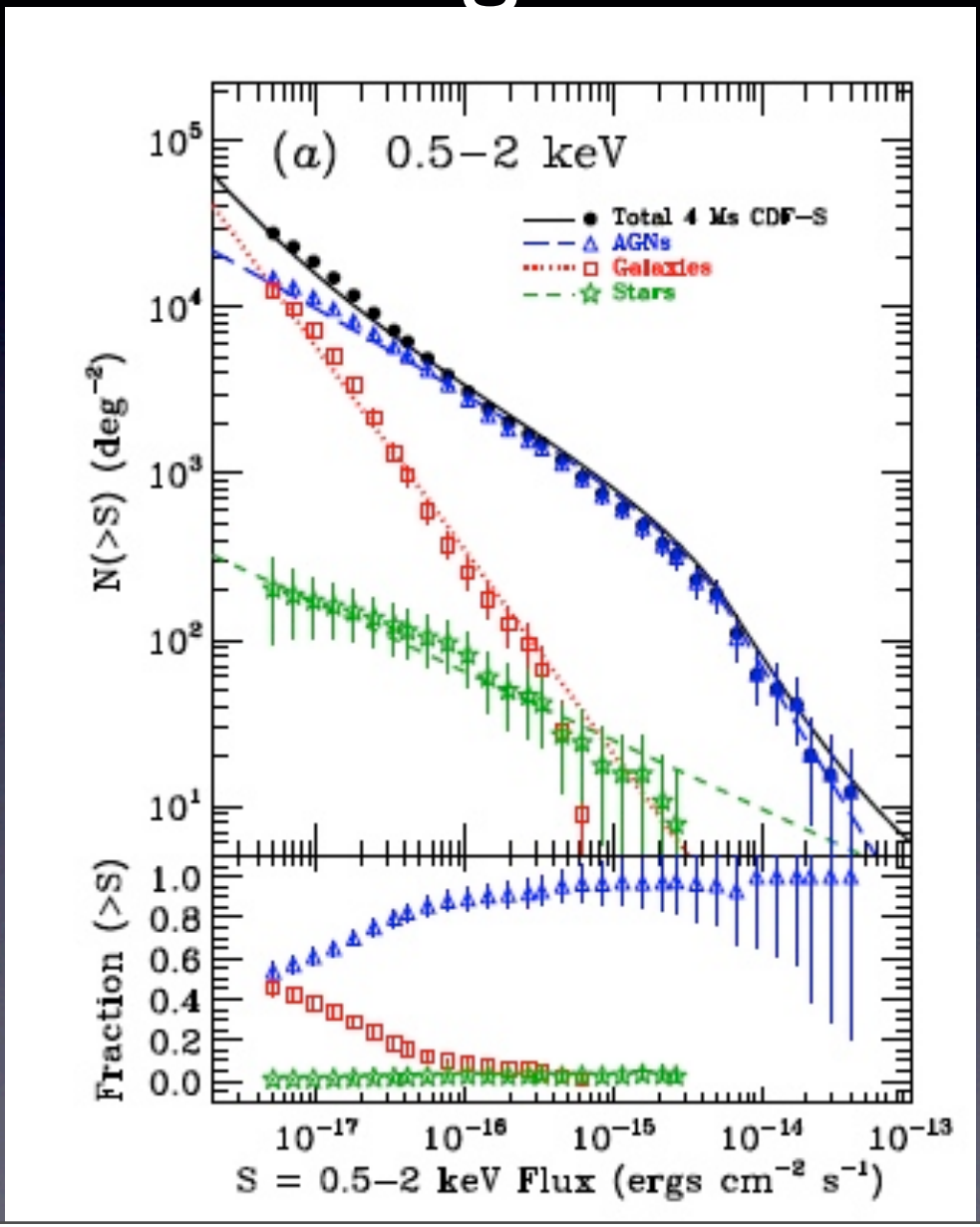


Local XLF is known, but evolution has been detected only to z~1

What is the X-ray emission of normal galaxies at high-z?

What is the X-ray emission of normal galaxies at high-z?

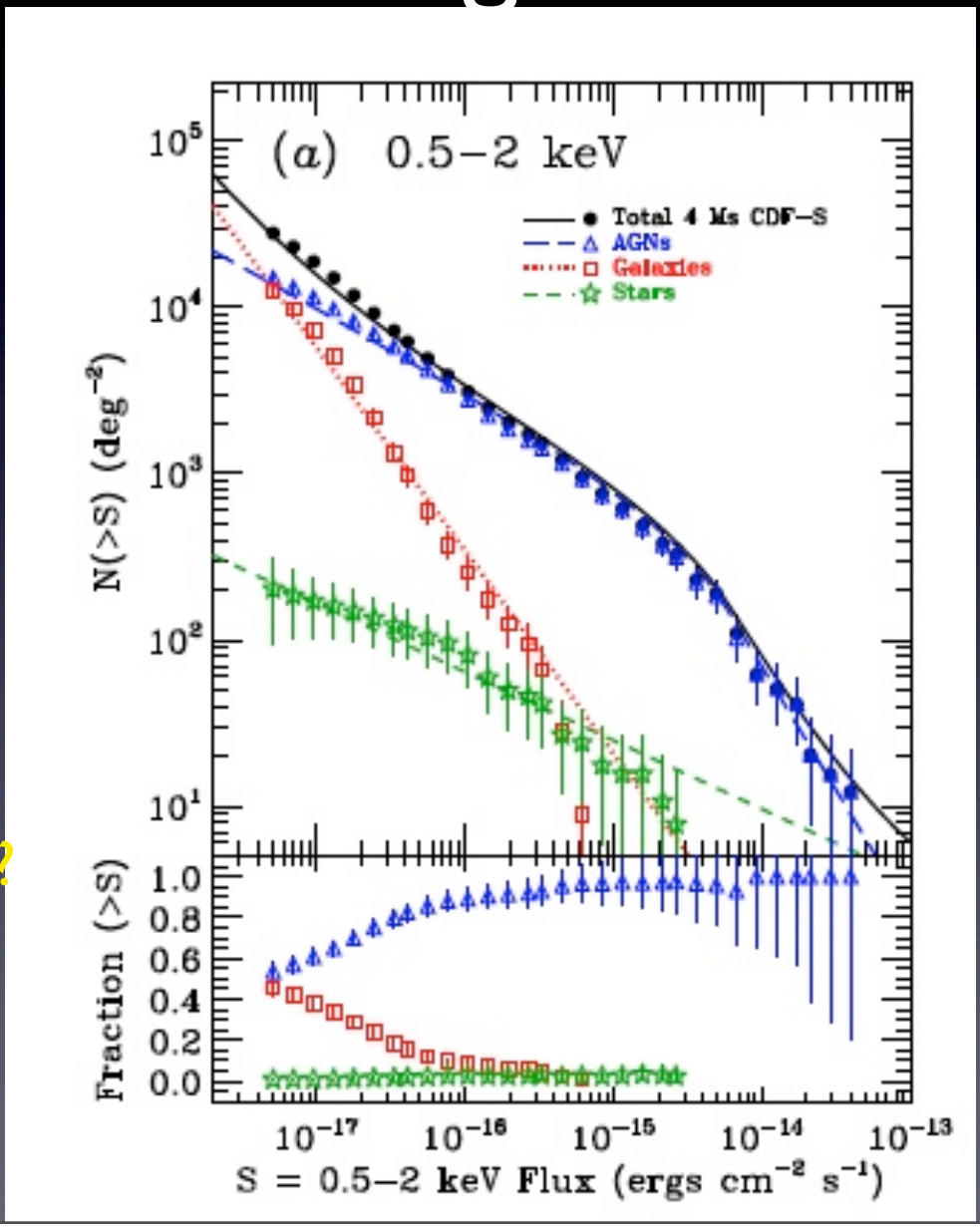
At current X-ray flux limit galaxies are as numerous as AGN
Lehmer+12



What is the X-ray emission of normal galaxies at high-z?

At current X-ray flux limit galaxies are as numerous as AGN
Lehmer+12

How does the X-ray emission evolve?



How many high-z clusters?

Number density of Galaxy cluster

How many high-z clusters?

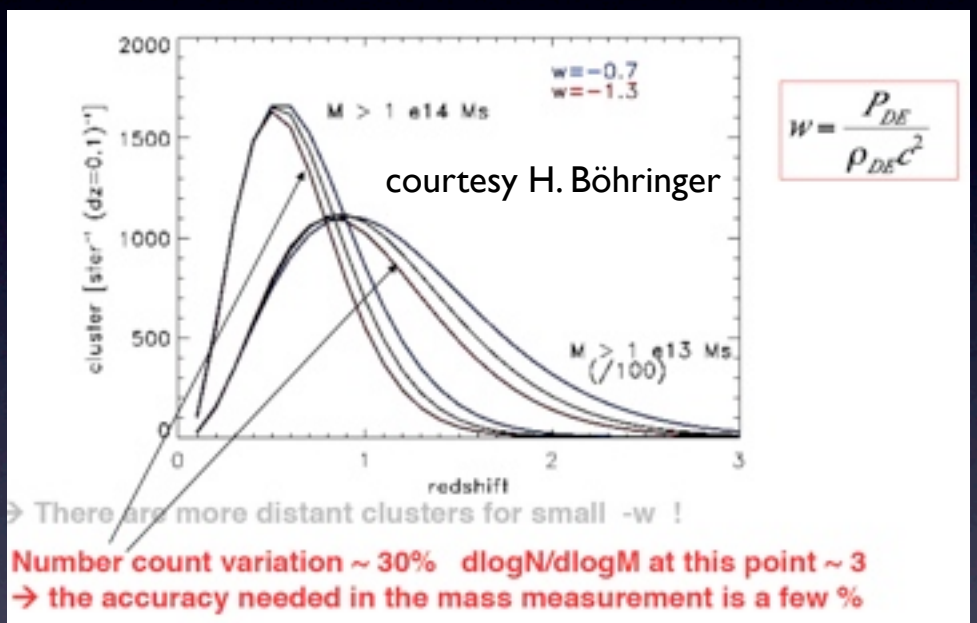
Is a probe of structure growth: Dark Energy

Number density of Galaxy cluster

How many high-z clusters?

Is a probe of structure growth: Dark Energy

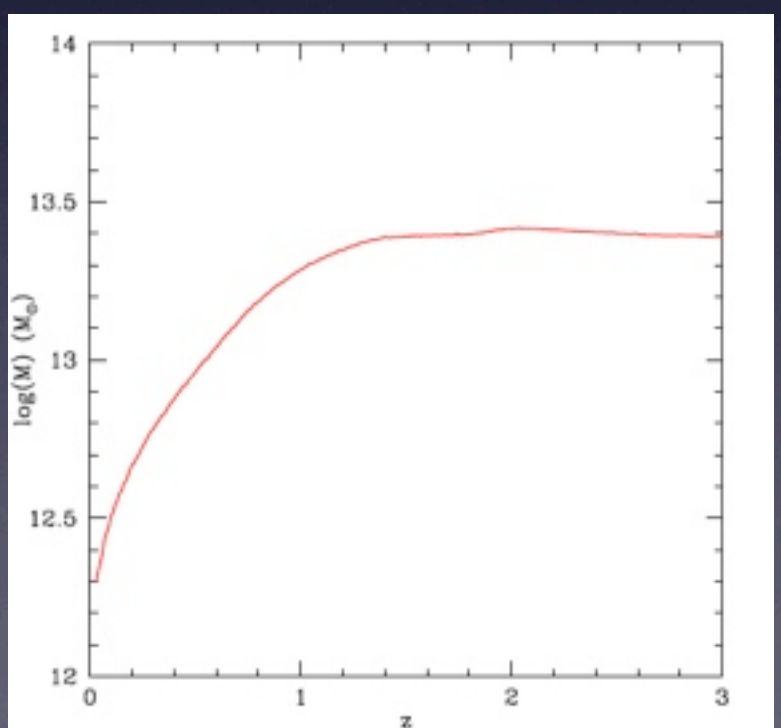
Number density of Galaxy cluster

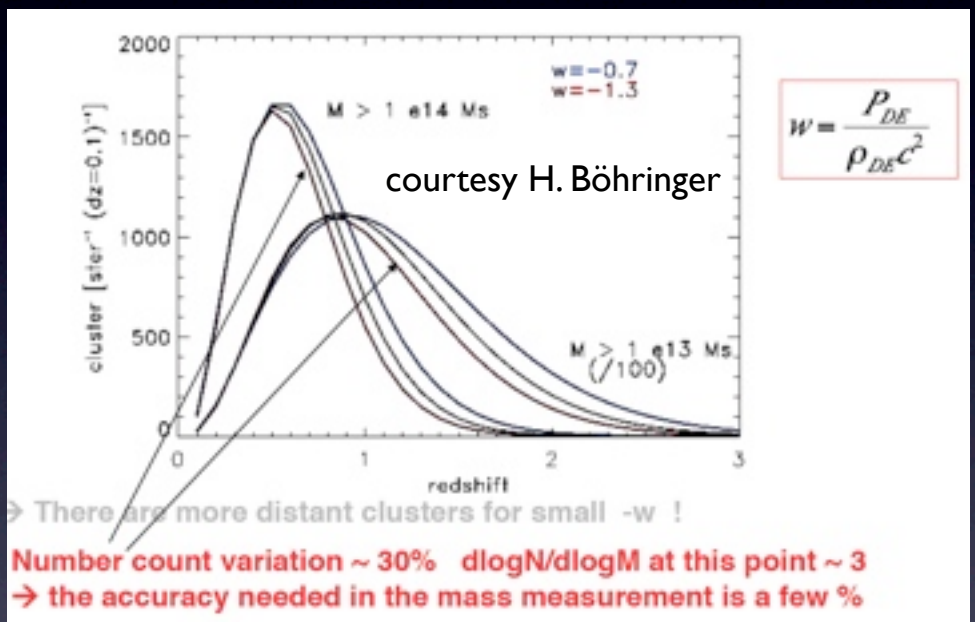


How many high-z clusters?

Is a probe of structure growth: Dark Energy

Number density of Galaxy cluster





Limits of 4 Ms CDFS

How do SMBH form?

We need to explain how to make
a 10^9 $M_\odot$ SMBH @z~7

How do SMBH form?

We need to explain how to make
a 10^9 $M_\odot$ SMBH @z~7

How do SMBH form?

Massive Progenitors

We need to explain how to make
a 10^9 $M_\odot$ SMBH @z~7

How do SMBH form?

Massive Progenitors

QUASI STARS
$M_{BH}=10^4$-$10^5 M_\odot$
Begelman+08

We need to explain how to make
a 10^9 $M_\odot$ SMBH @z~7

How do SMBH form?

Massive Progenitors

QUASI STARS
$M_{BH}=10^4$-$10^5 M_\odot$
Begelman+08

We need to explain how to make a 10^9 $M_\odot$ SMBH @z~7

POPIII, Metal free massive stars
$M_{BH}=10^3$-$10^4 M_\odot$

How do SMBH form?

Massive Progenitors

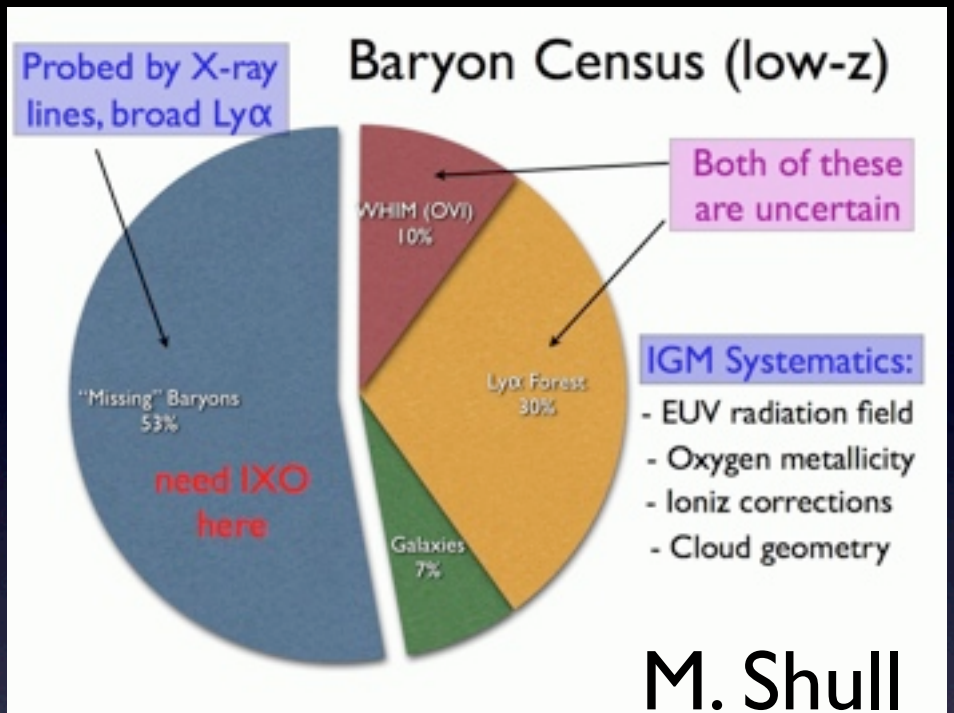
QUASI STARS
$M_{BH}=10^4$-$10^5 M_\odot$
Begelman+08

We need to explain how to make a 10^9 $M_\odot$ SMBH @z~7

POPIII, Metal free massive stars
$M_{BH}=10^3$-$10^4 M_\odot$

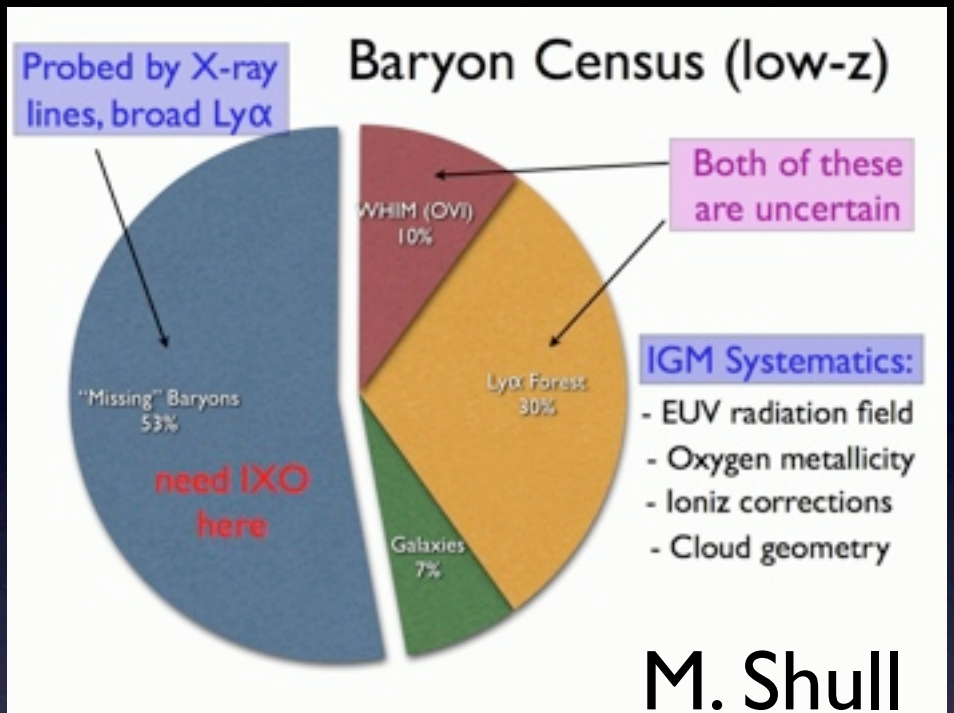
These sources should leave their signature in the anisotropies of Cosmic backgrounds
Kashlinsky+05,07,12

Missing Baryons (WHIM)

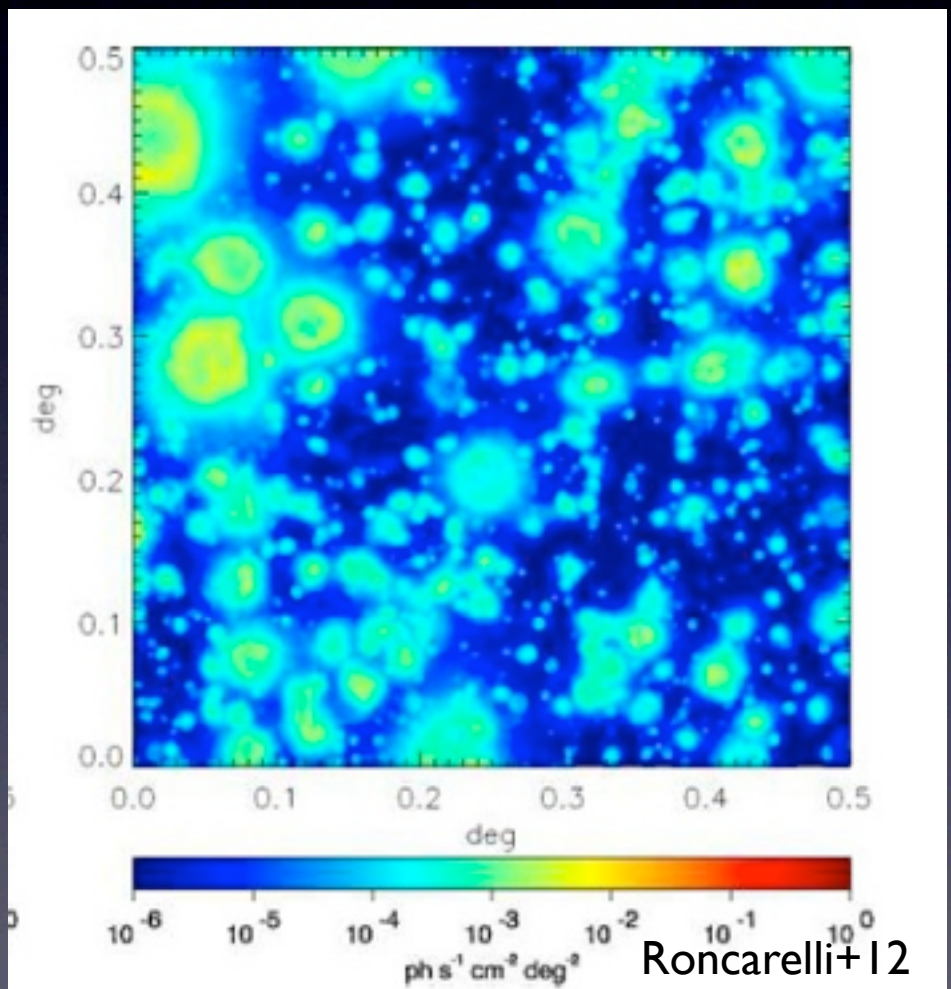


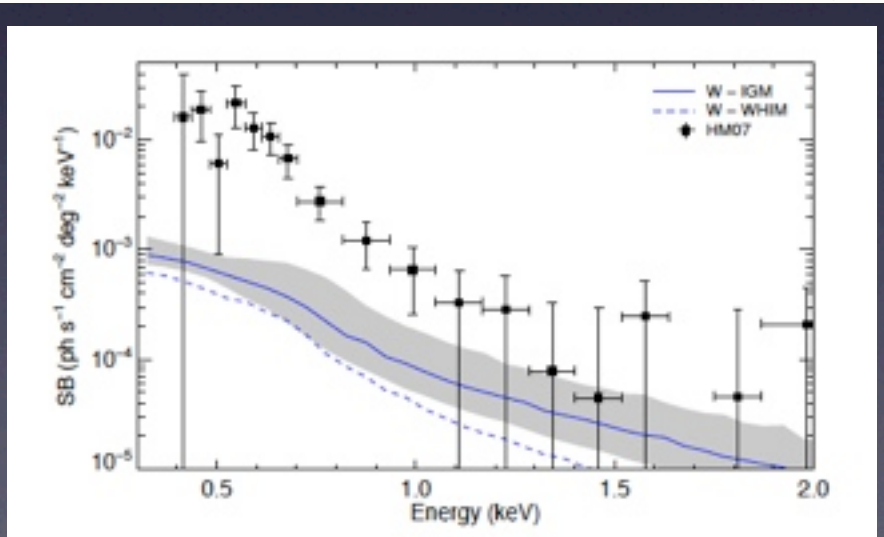
Half of the baryons are missing in the Local Universe wrt to z~3 and are supposed to lie in the WHIM

Missing Baryons (WHIM)



Half of the baryons are missing in the Local Universe wrt to z~3 and are supposed to lie in the WHIM

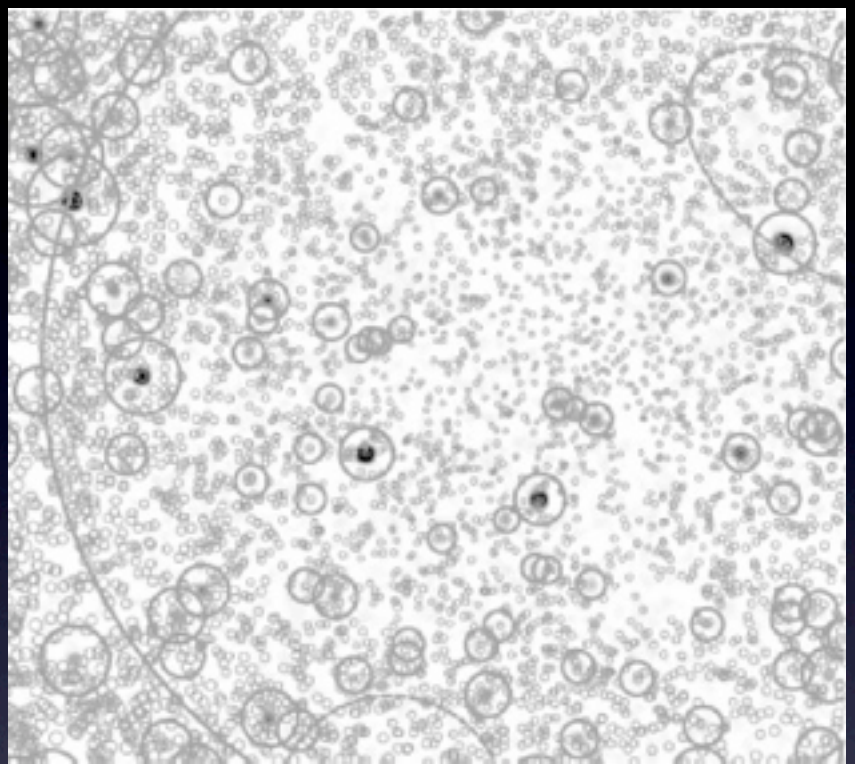


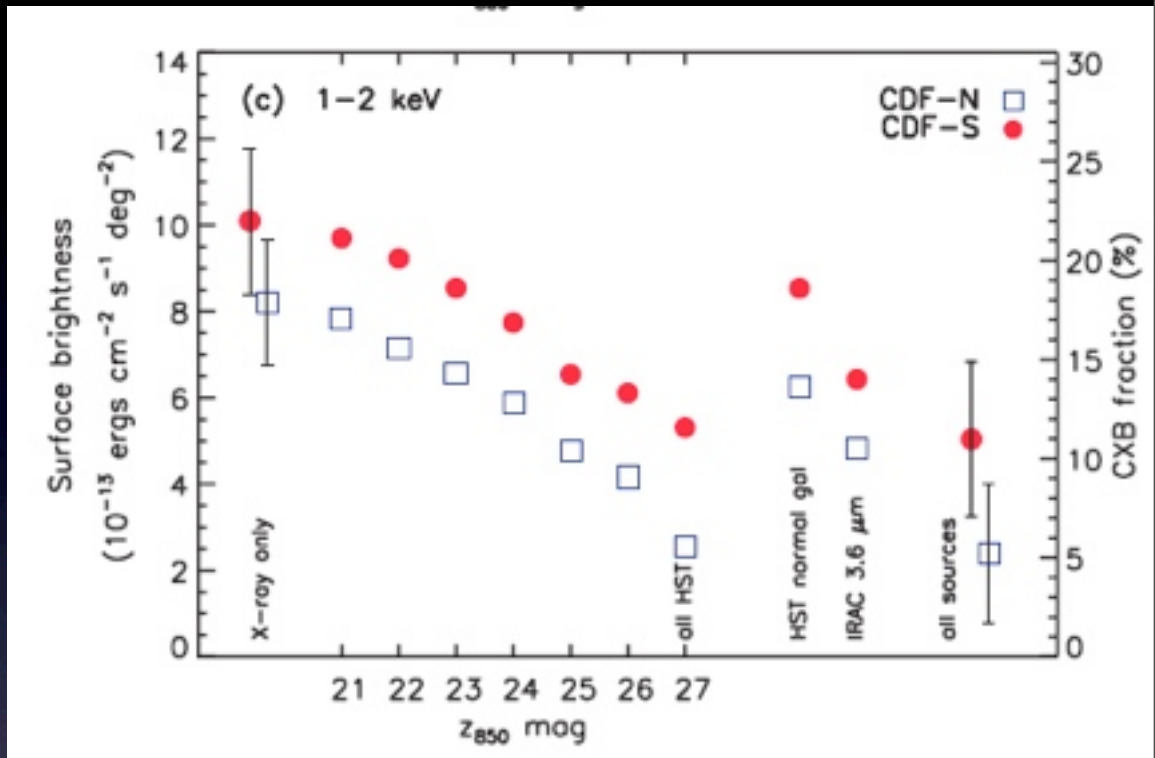


Significant contribution to the soft CXB

3-The unresolved CXB

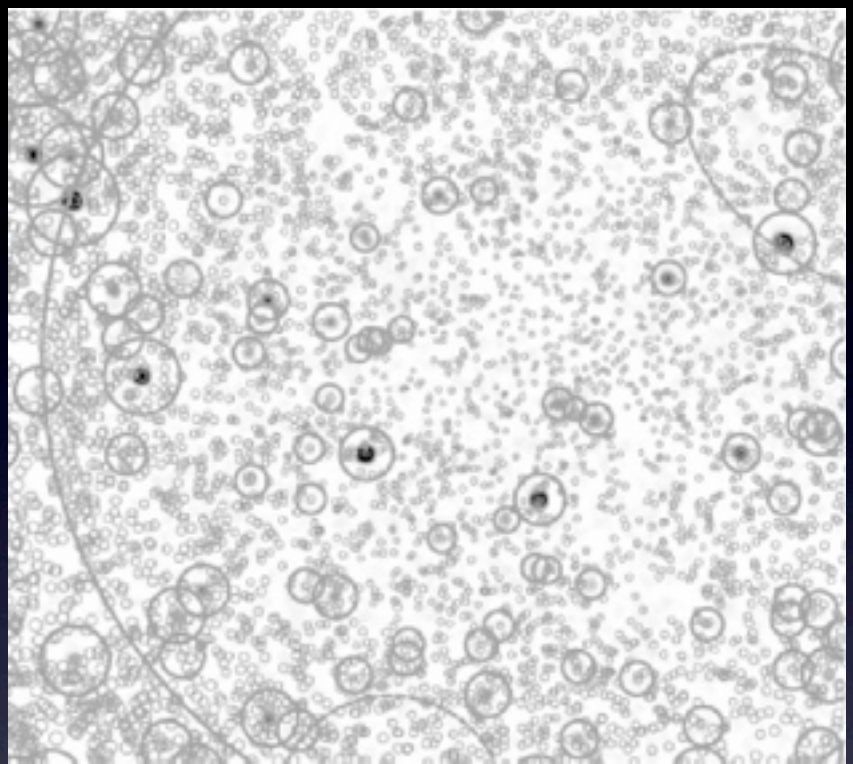
Previous studies

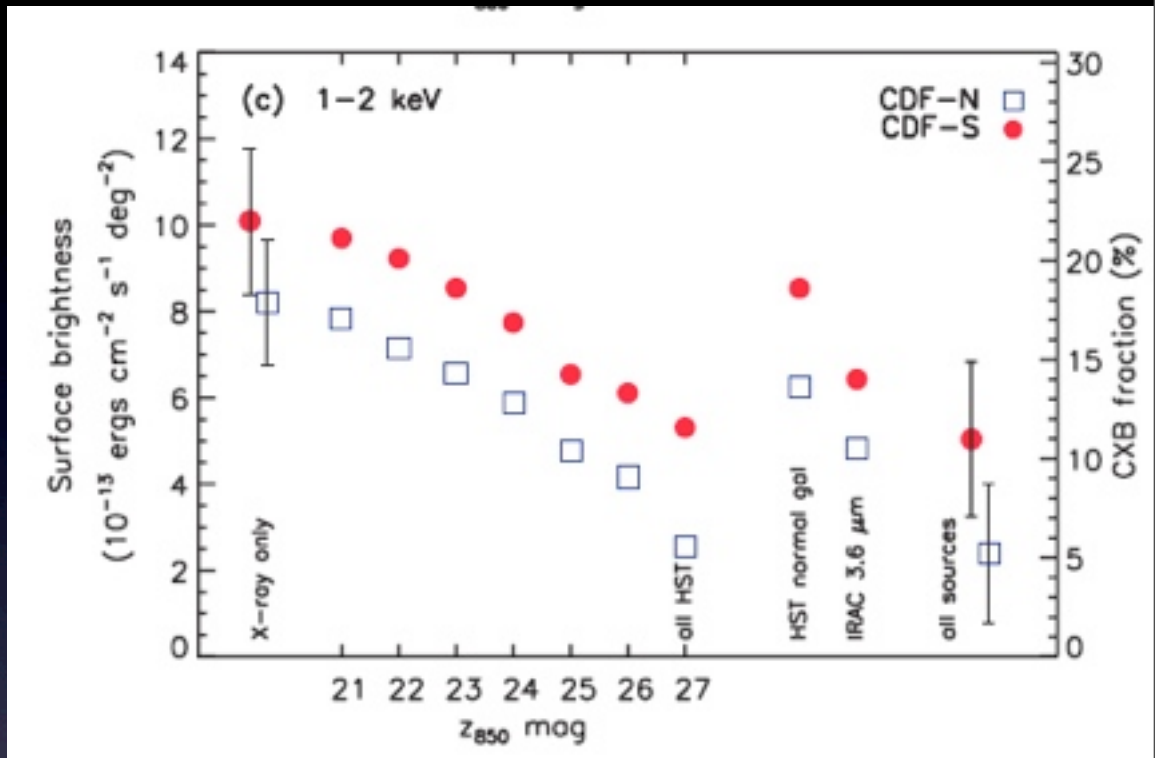




Removal of HST Galaxies down to z_{850}=27 and X-ray sources in CDFS, only 50% of the soft unresolved 1-2 keV CXB is explained

Previous studies





Removal of HST Galaxies down to z_{850}=27 and X-ray sources in CDFS, only 50% of the soft unresolved 1-2 keV CXB is explained

Faint or diffuse sources should produce the remainder CXB

The Power Spectrum of fluctuations in the CDFS

- The PS contains information on both clustering and emissivity evolution of a given source population

$$P_{2,AGN}(q) = \int_0^z \left(\frac{dS}{dz}\right)^2_{AGN} \frac{P_{3,AGN}(qd_A^{-1}, z)}{c\ dt/dz\ d_A(z)^2}\ dz$$

The Power Spectrum of fluctuations in the CDFS

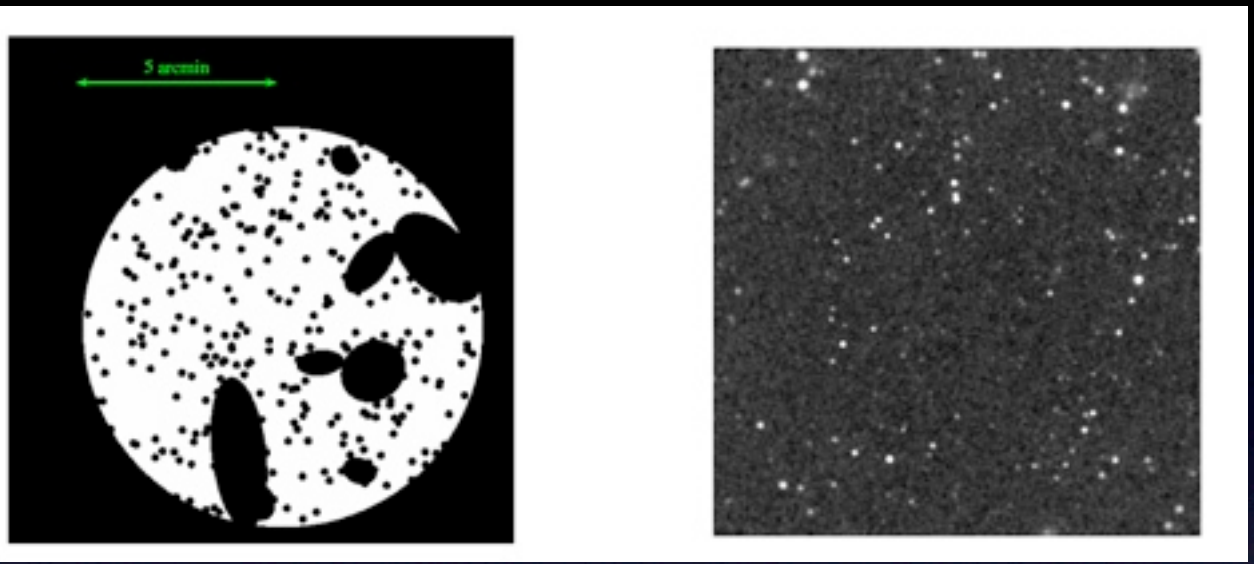
- The PS contains information on both clustering and emissivity evolution of a given source population

$$P_{2,AGN}(q) = \int_0^z \left(\frac{dS}{dz}\right)^2_{AGN} \frac{P_{3,AGN}(qd_A^{-1}, z)}{c\ dt/dz\ d_A(z)^2}\ dz$$

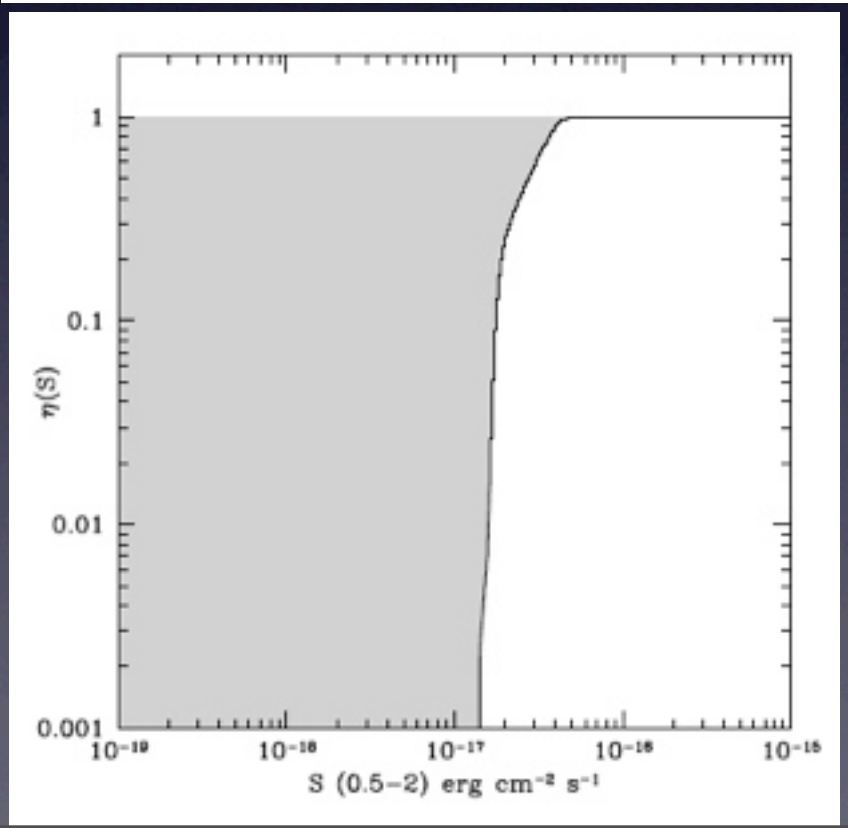
- PS can be decomposed in additive components

$$P_{2,CXB}(q) = P_{2,SN}(q) + P_{2,AGN}(q) + P_{2,GAL}(q) + P_{2,IGM}(q)$$

Dataset

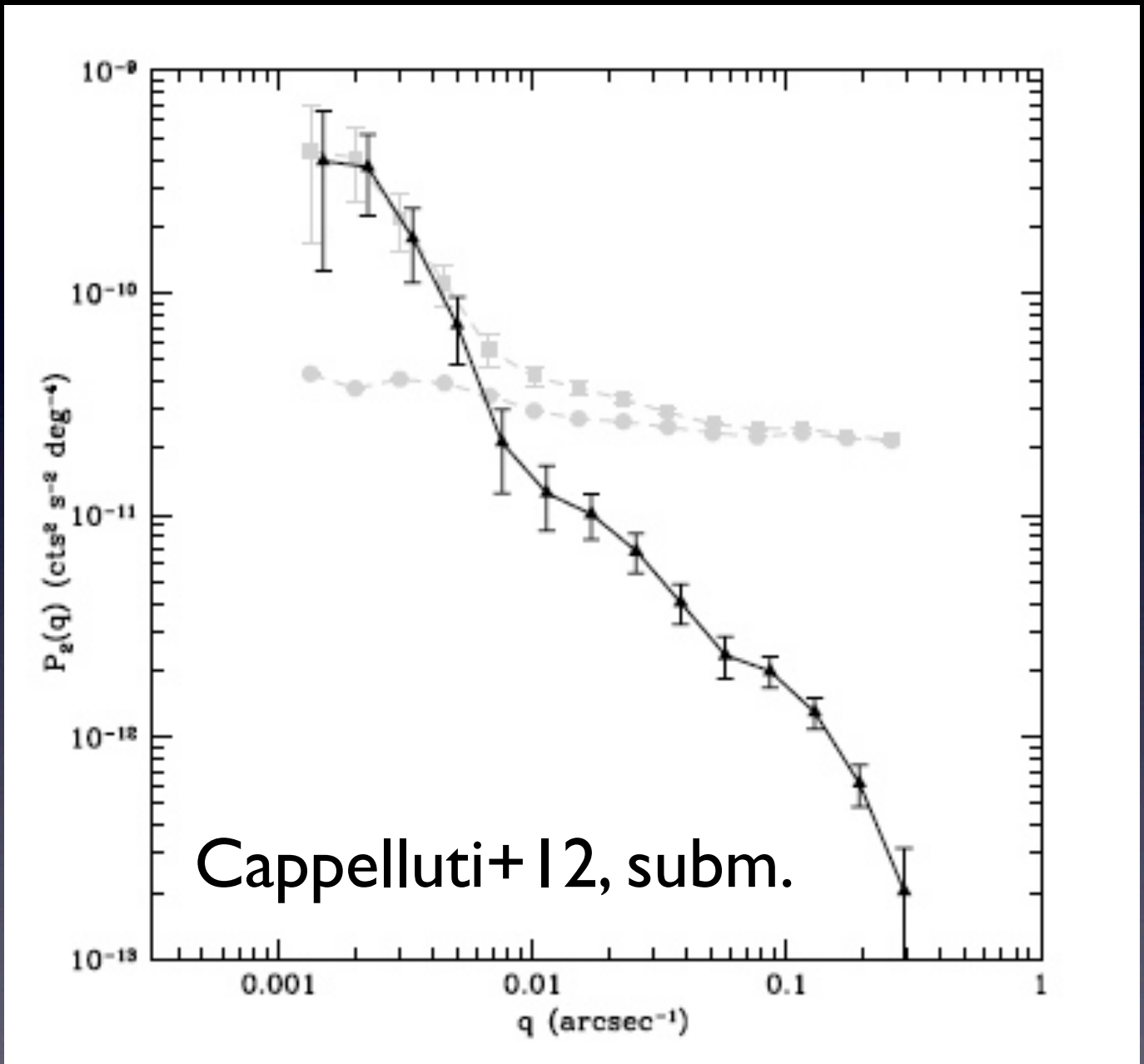


4 Ms 0.5-2 keV
CDFS survey
Xue+11



Dataset

Dataset



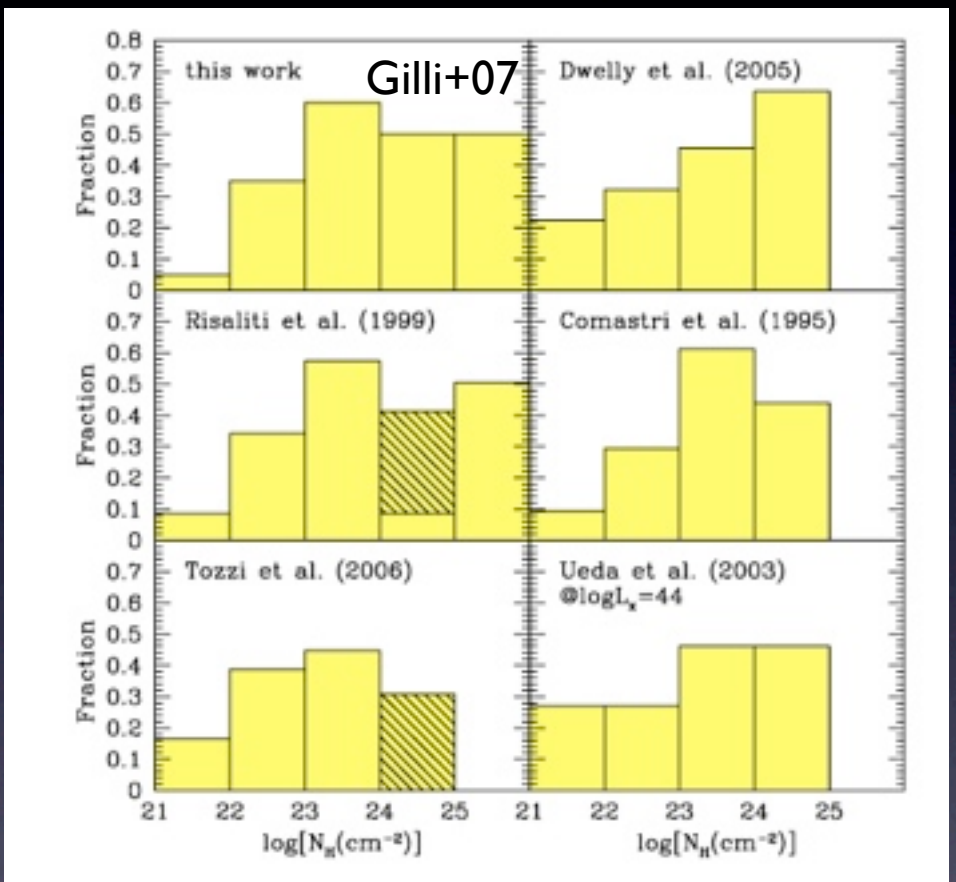
Power Spectrum of the 0.5-2 unresolved CXB after removal of background

How do we explain these fluctuations?

Model of AGN

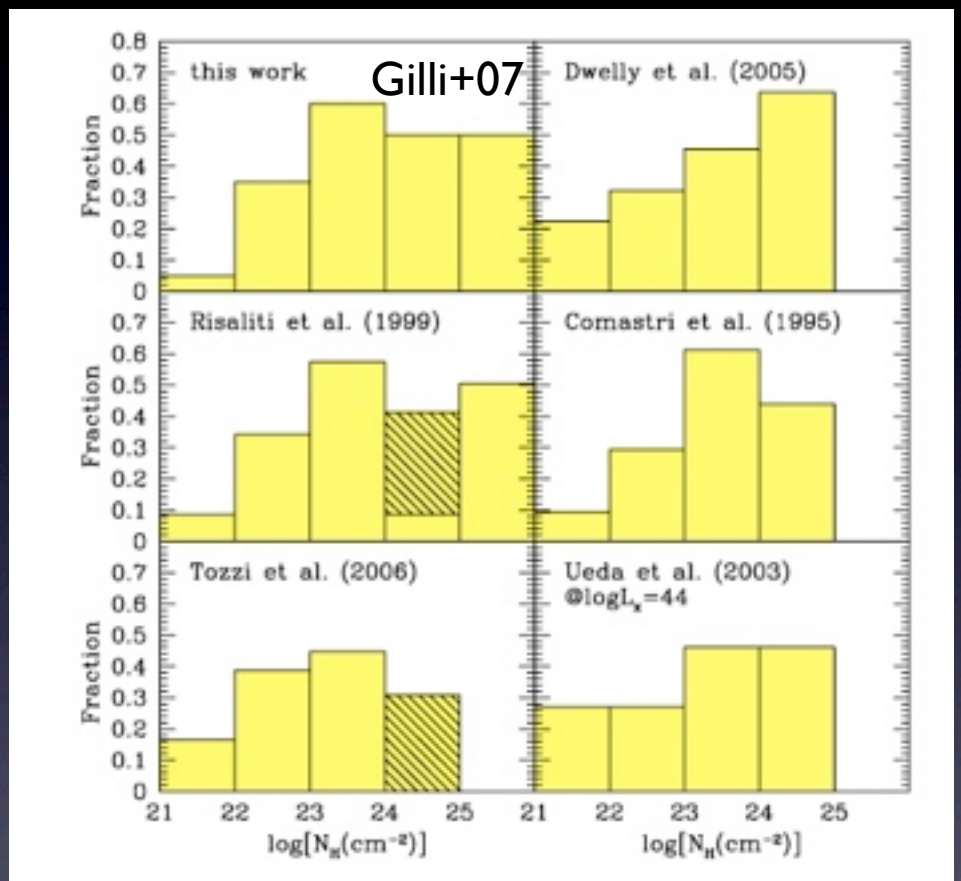
- We need to feed into the model a recipe for
- XLF evolution, absorption distribution
- Bias evolution
- Cosmology... (we believe in ΛCDM)

AGN population synthesis model

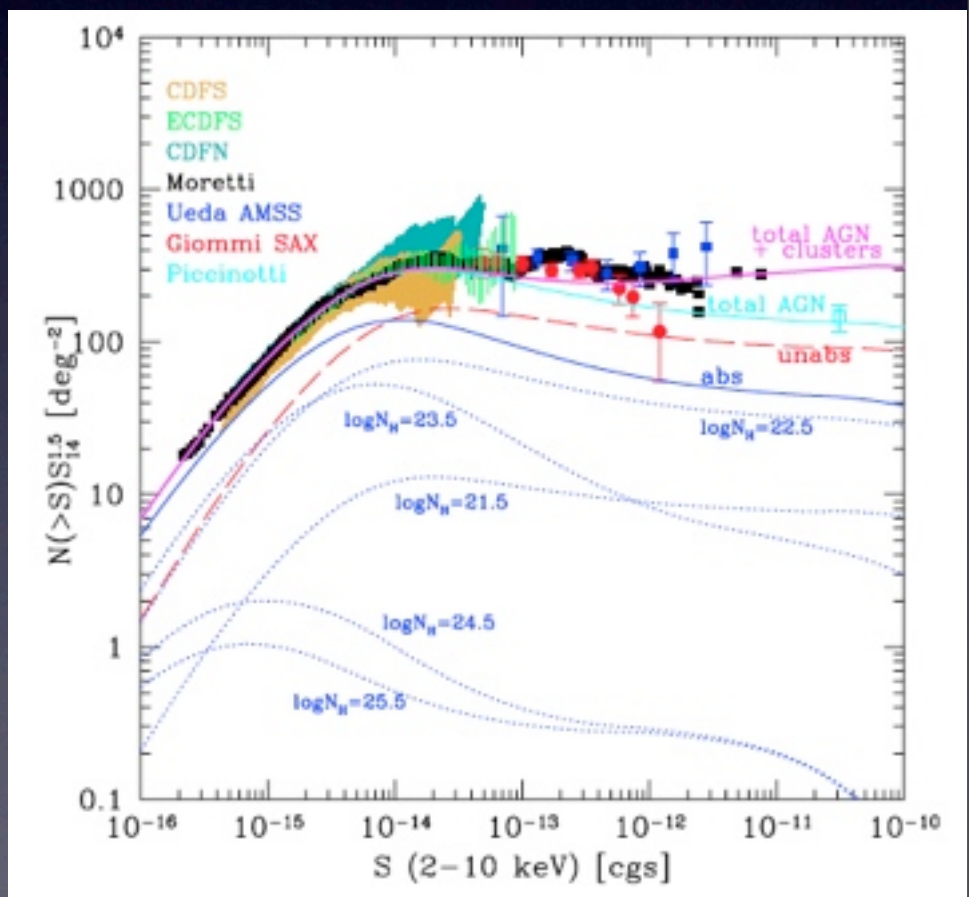


Large fraction of obscured sources

AGN population synthesis model

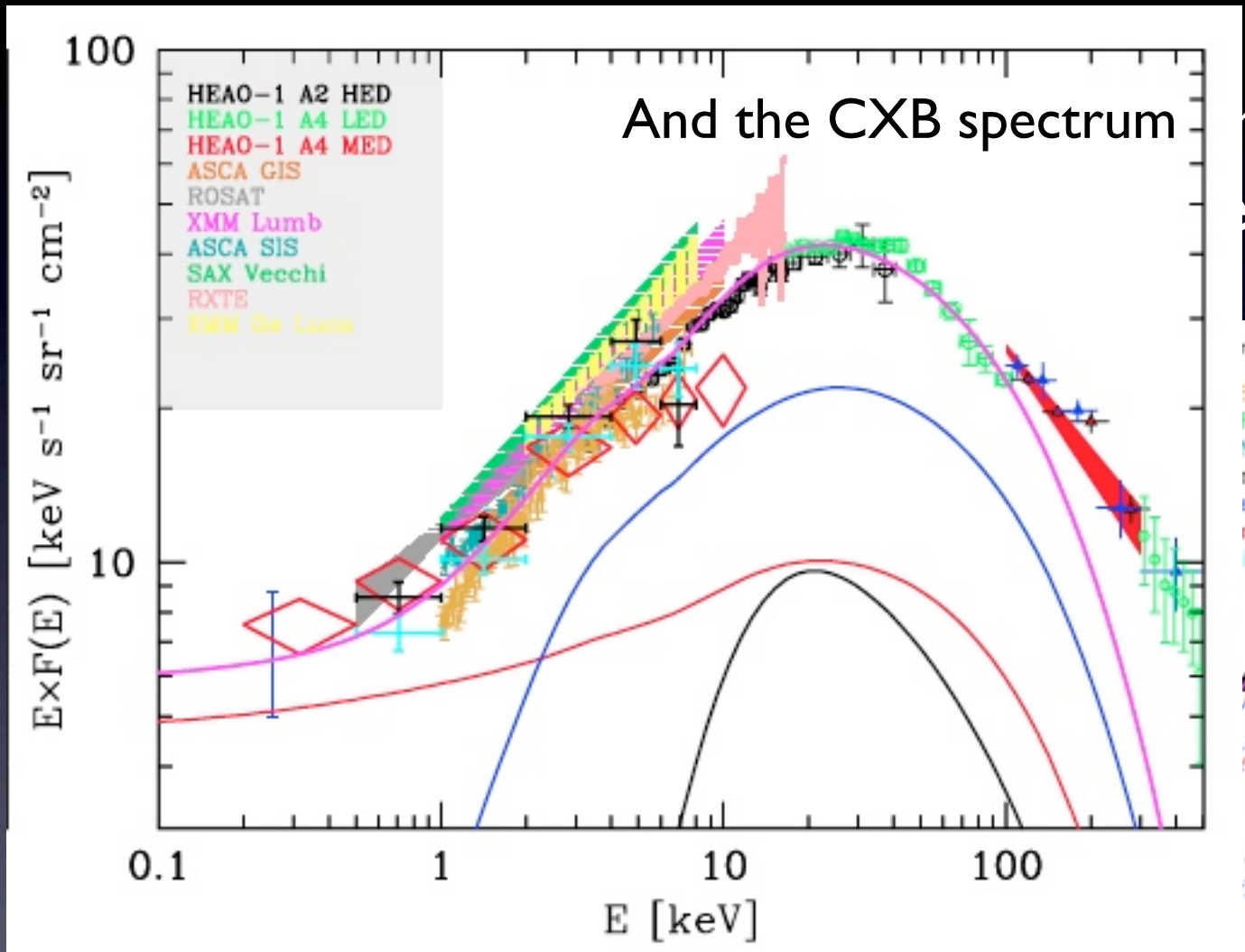


Large fraction of obscured sources



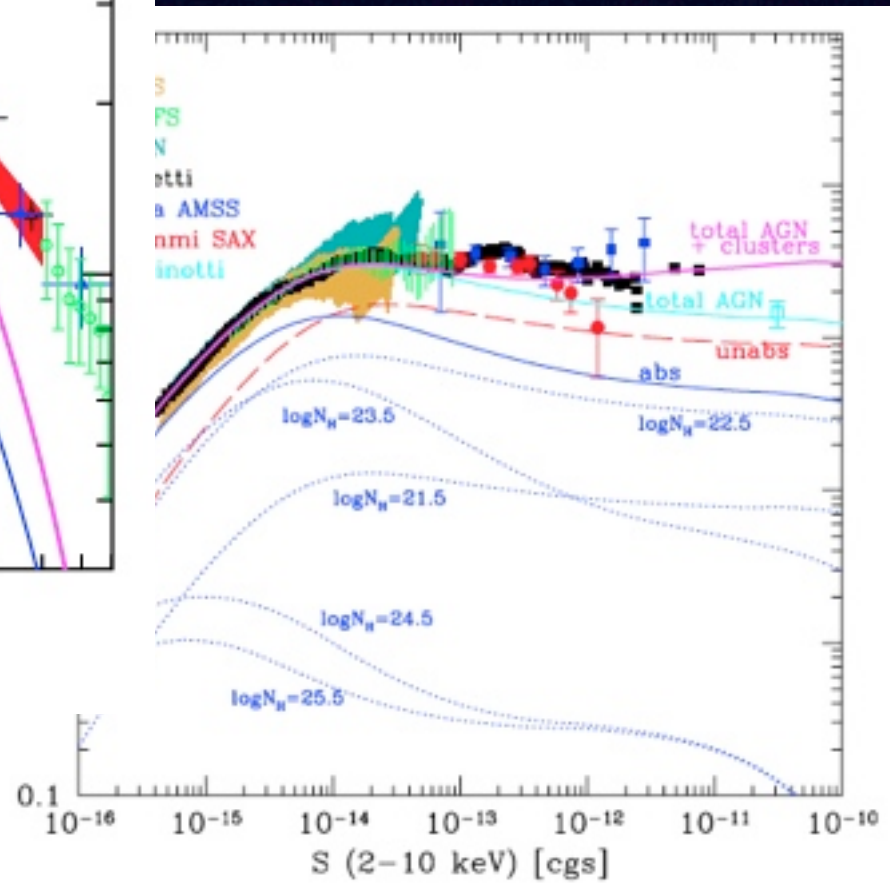
The model reproduces well the observed source counts

AGN population synthesis model



And the CXB spectrum

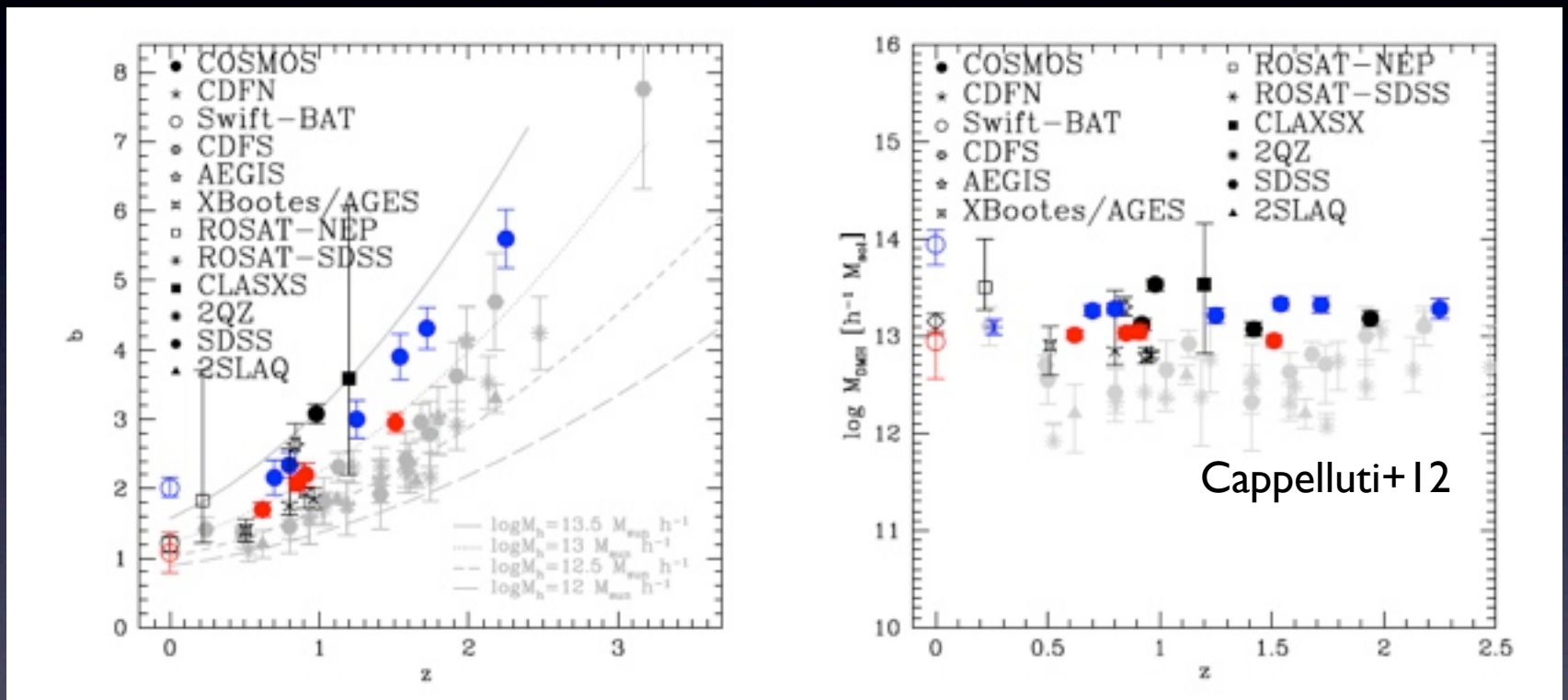
raction of
d sources



The model reproduces well the observed source counts

AGN clustering

$$P_{3,AGN}(k,z) = b(z)^2 P_{3,M}(k,z),$$



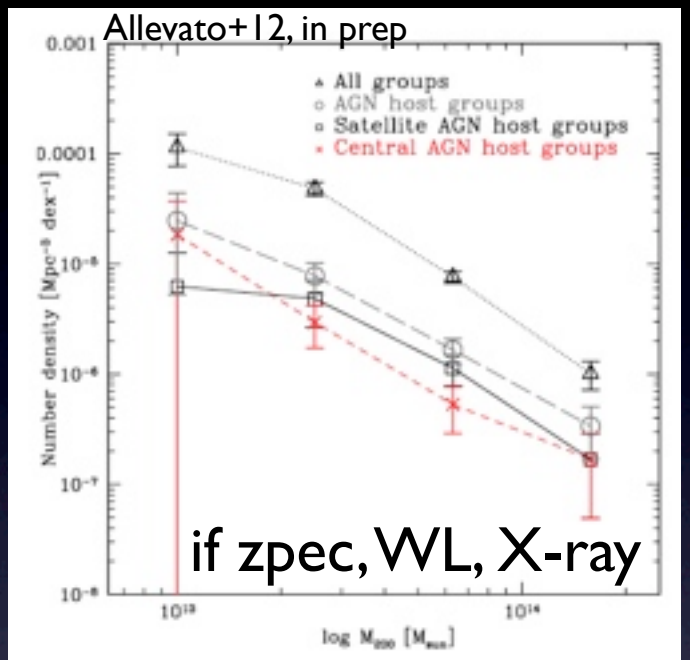
AGN follows logM~13 at all z!

AGN biasing evolution is strictly related with the AGN activation mechanisms!

Halo Occupation of AGN

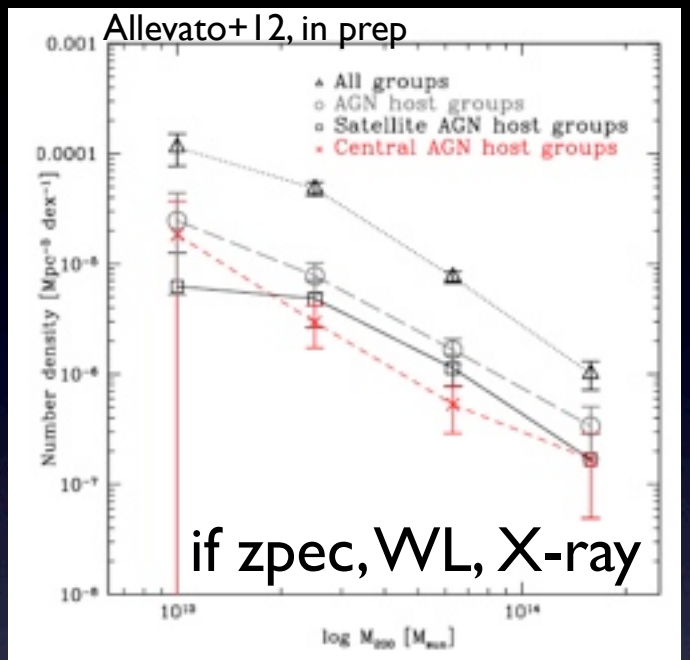
Fraction of
DMH hosting
an AGN as f(M)

Halo Occupation of AGN

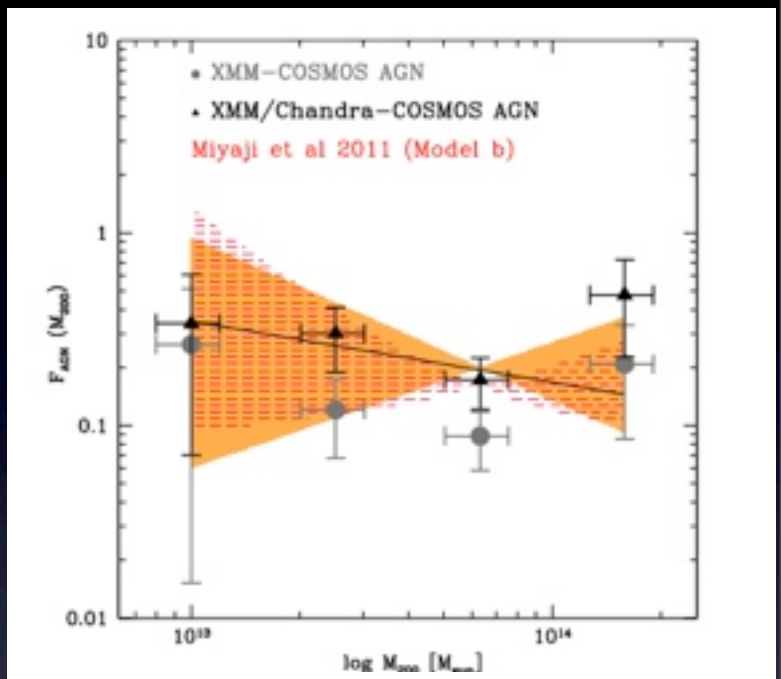


Fraction of
DMH hosting
an AGN as f(M)

Halo Occupation of AGN

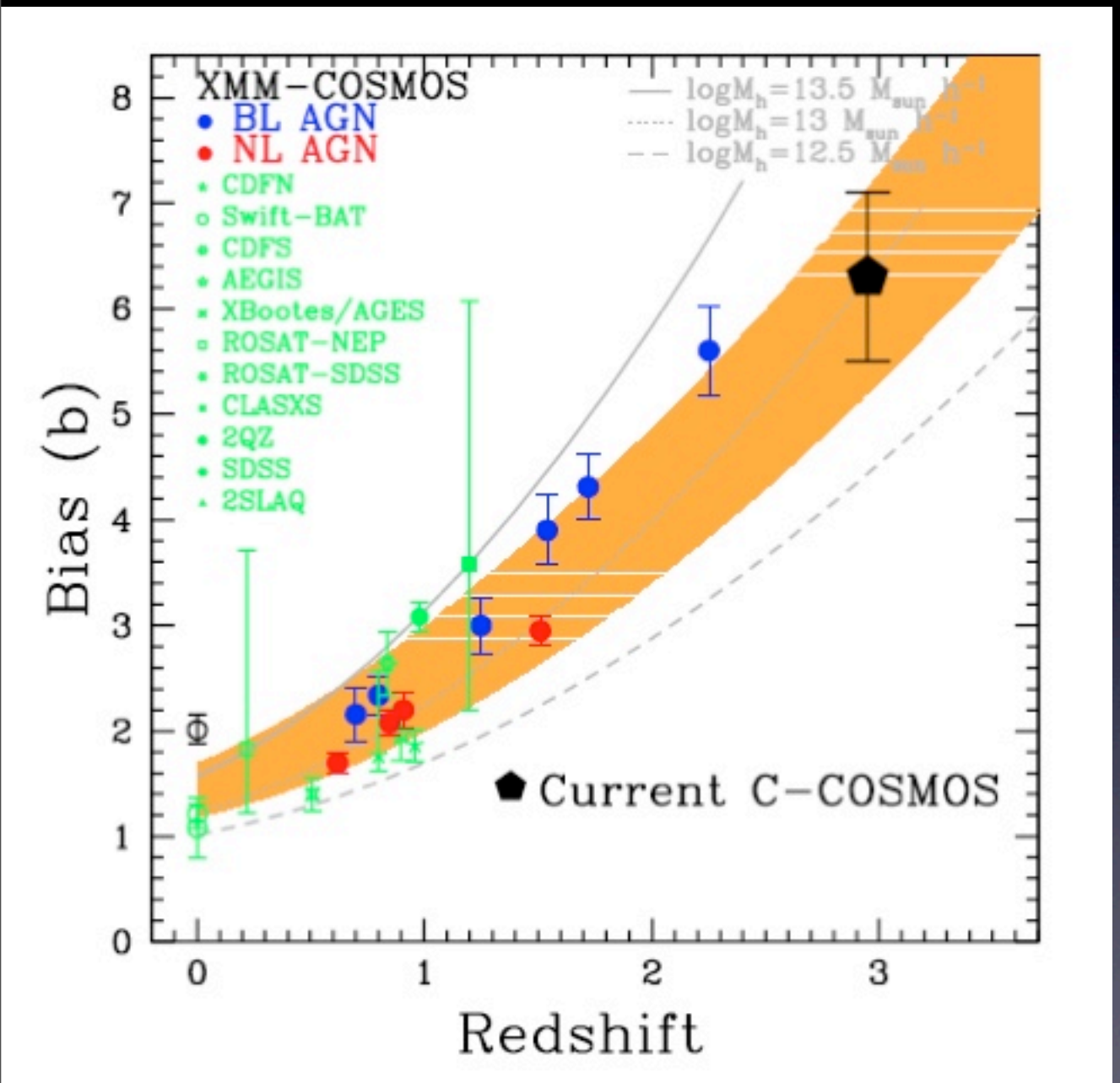


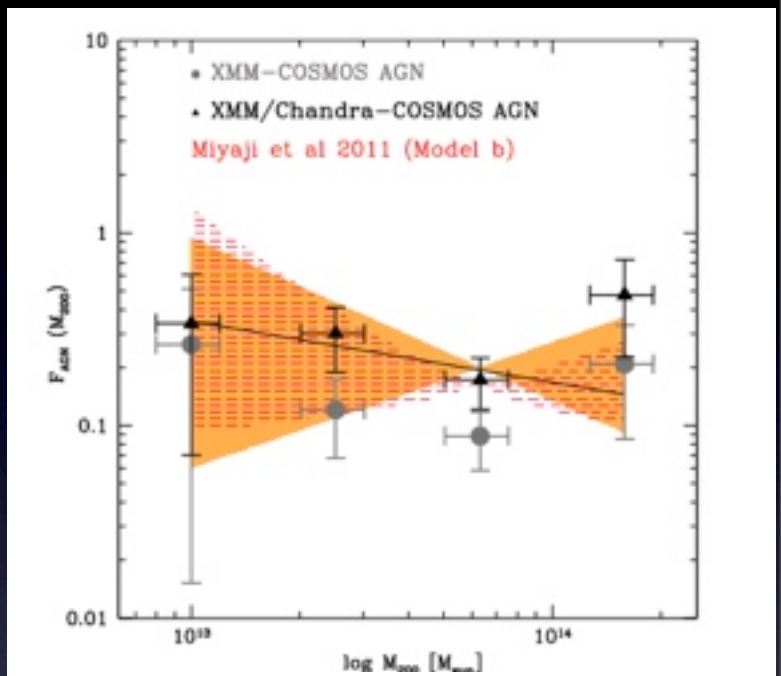
Fraction of DMH hosting an AGN as f(M)



$$F_{AGN}(M_h) = f_a \left(\frac{M_h}{M_1}\right)^{\alpha}$$

Halo Occupation of AGN

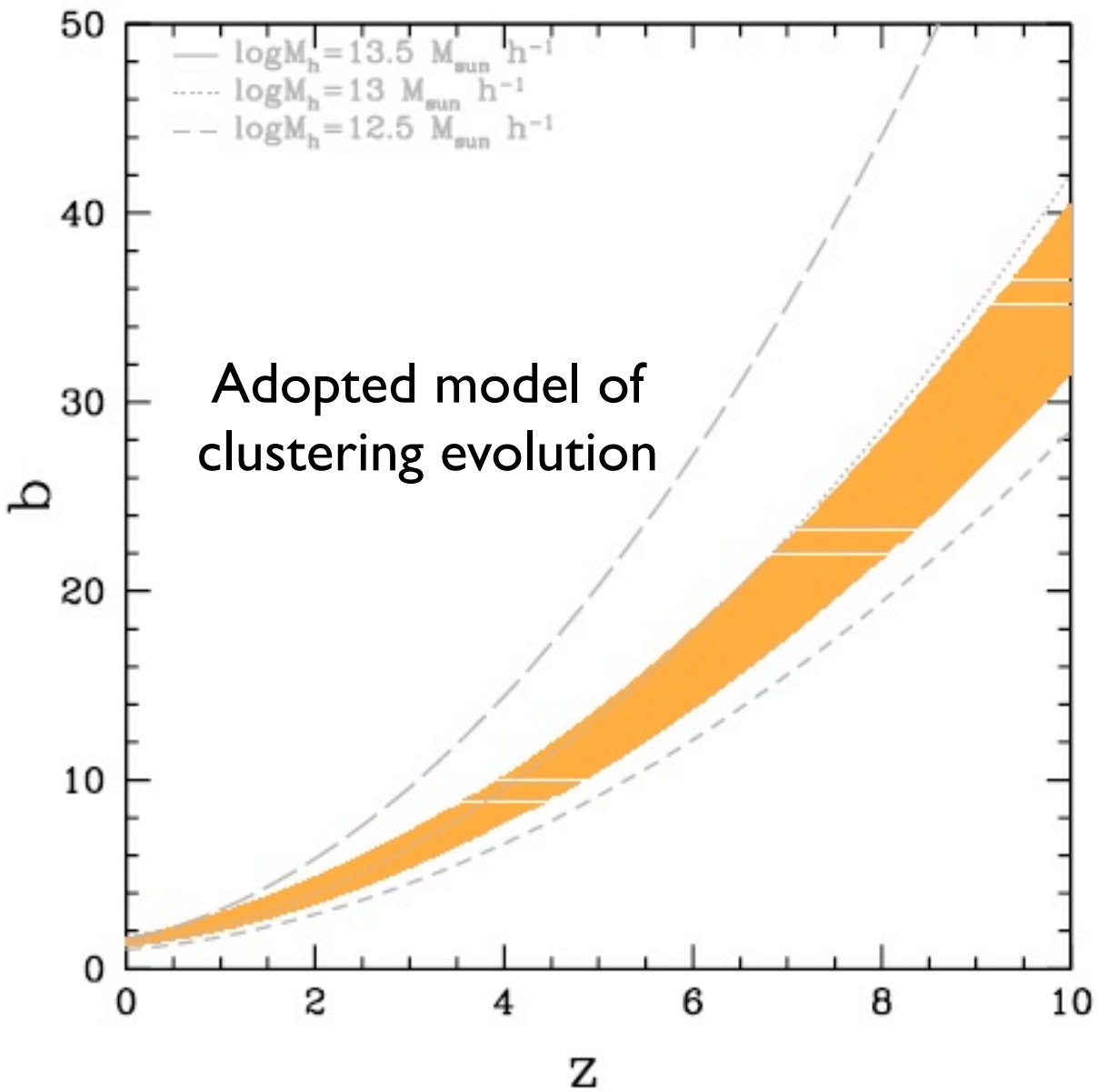




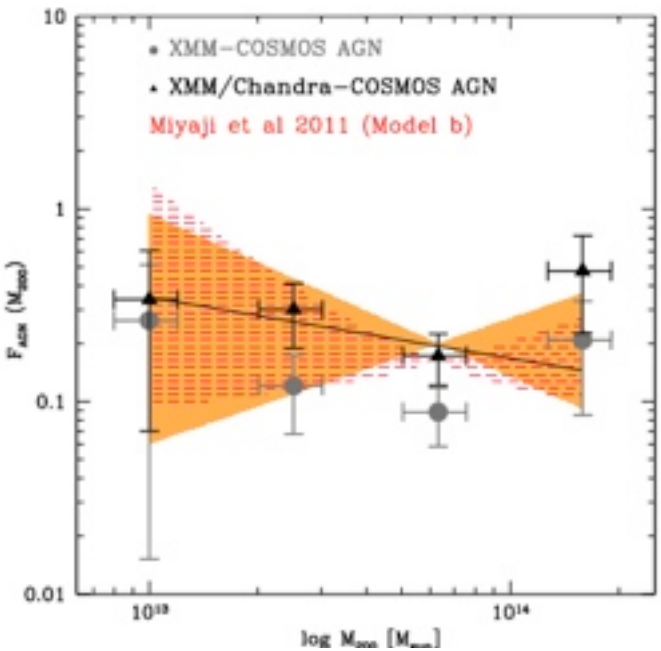
$$F_{AGN}(M_h) = f_a \left(\frac{M_h}{M_1}\right)^{\alpha}$$

If HOD=const
not only mergers should
trigger AGN

Halo Occupation of AGN



Adopted model of clustering evolution

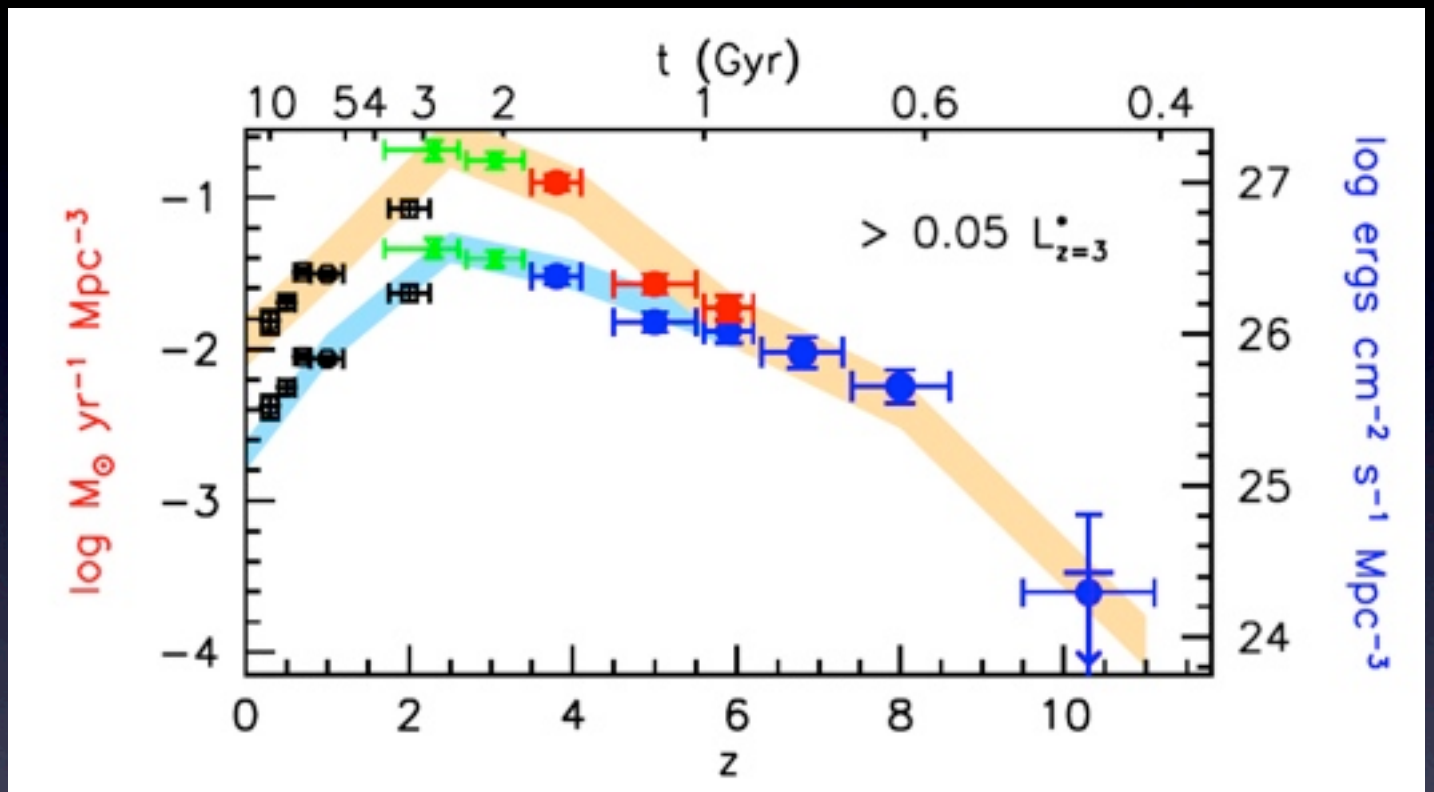


$$F_{AGN}(M_h) = f_a \left(\frac{M_h}{M_1}\right)^{\alpha}$$

If HOD=const
not only mergers should trigger AGN

Model of Galaxies

Assumption:
X-ray galaxies evolve like SFR (Bouwens+10) starting from z~0 XLF (Ranalli+06)



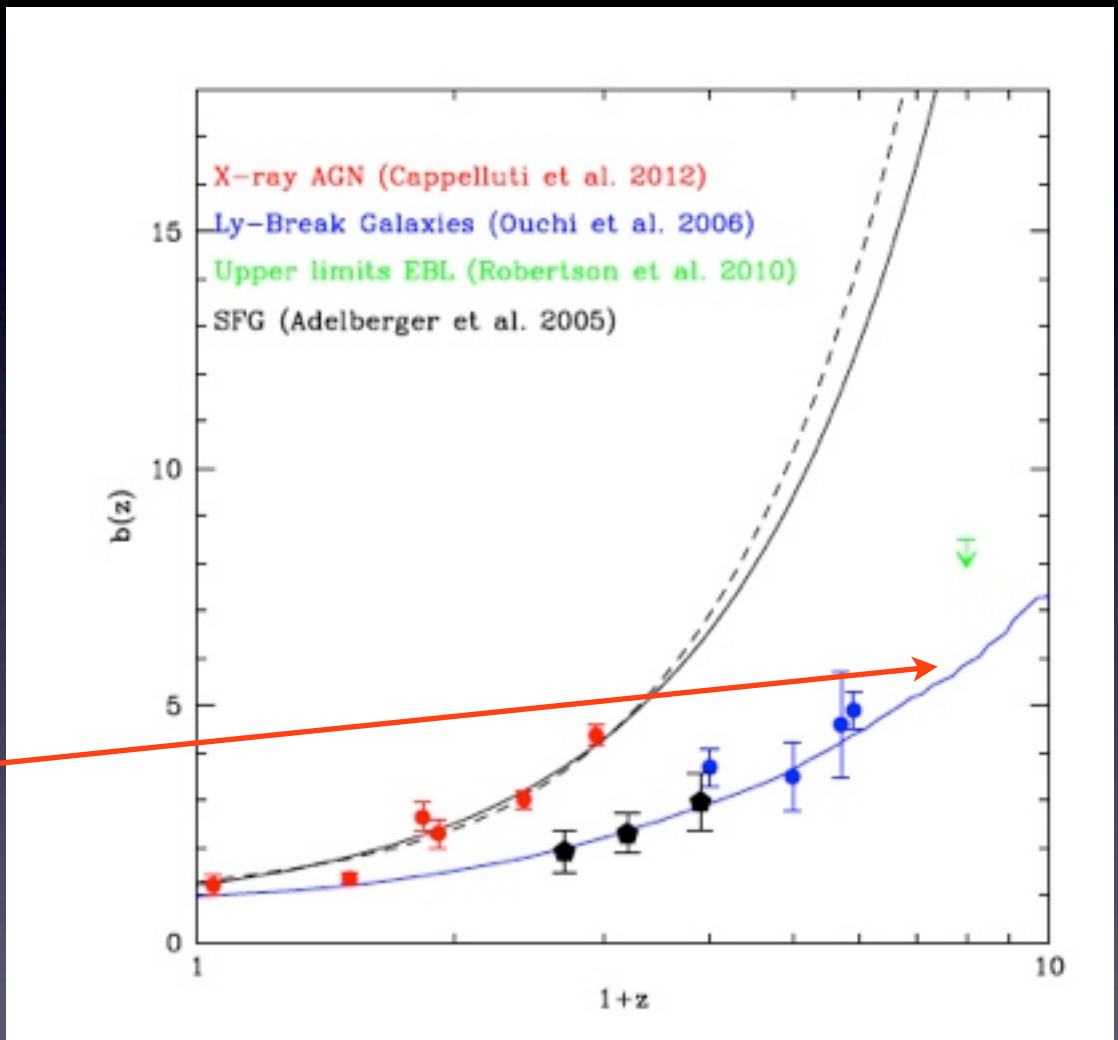
X-ray galaxies evolution is not known above z~1

Galaxies Bias

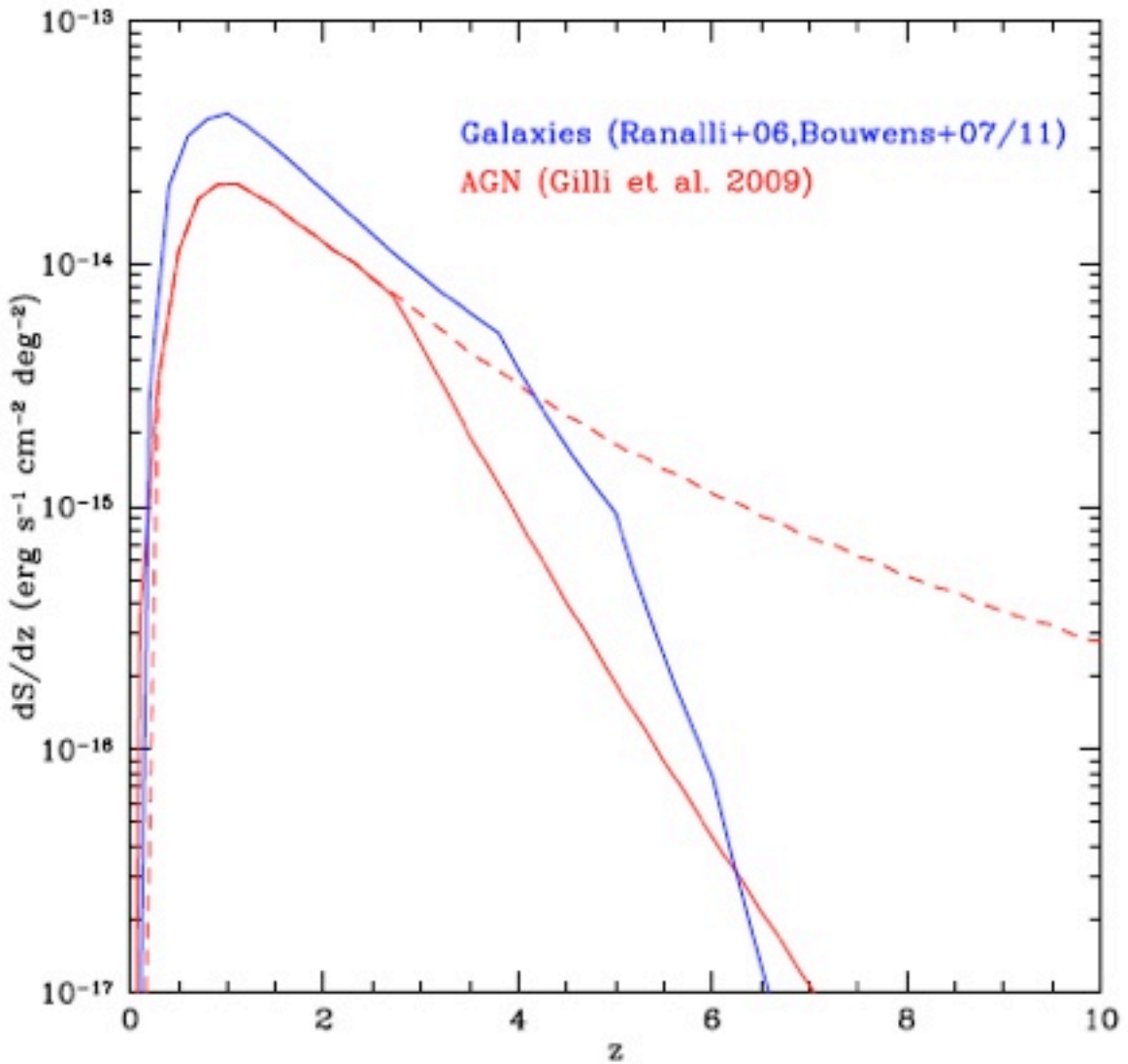
Assuming r_0=4.5 Mpc/h, γ=1.6 like for SFG

$$(\sigma_{8,G})^2 = J_2(\gamma)\left(\frac{r_0}{8Mpc/h}\right)^{\gamma}$$

$$b(z) = \sigma_{8,G}(z)/\sigma_{8,DM}(z),$$

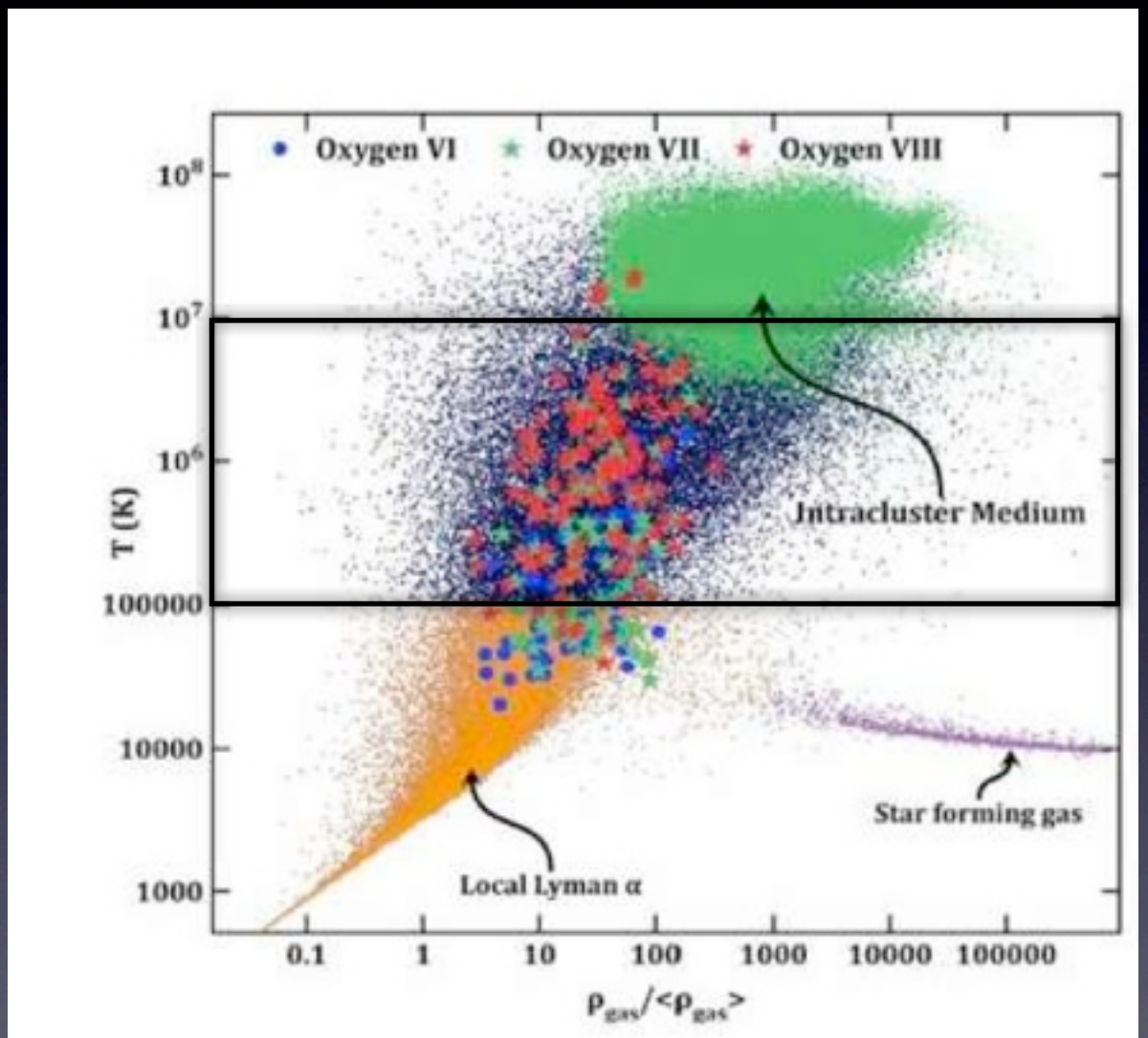


Contribution of undetected point sources to the CXB



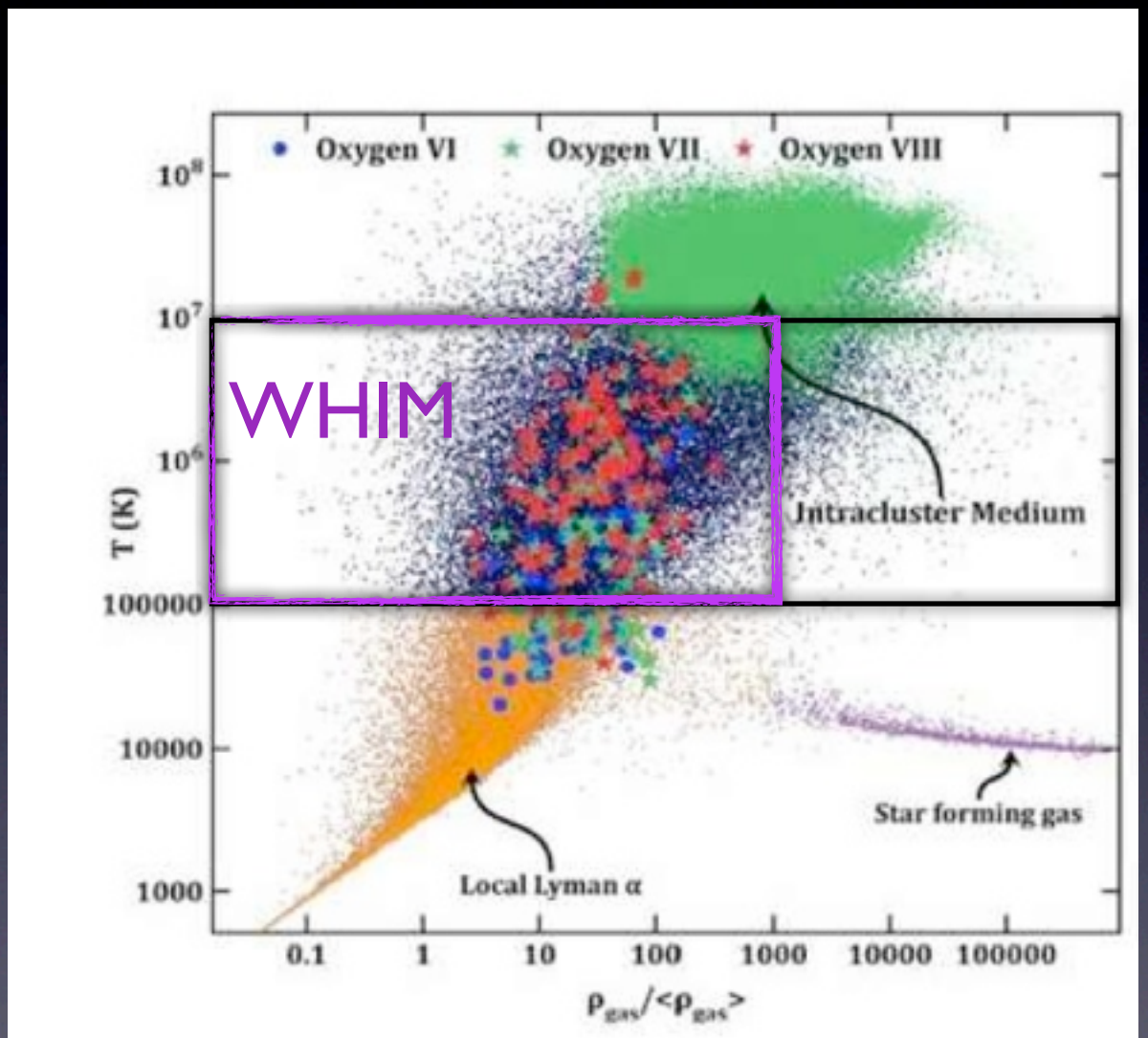
Galaxies are the main contributors in flux and like AGN peak at z~1

Model of WHIM



WHIM is by definition whatever has $10^5 < kT < 10^7$ K

Model of WHIM



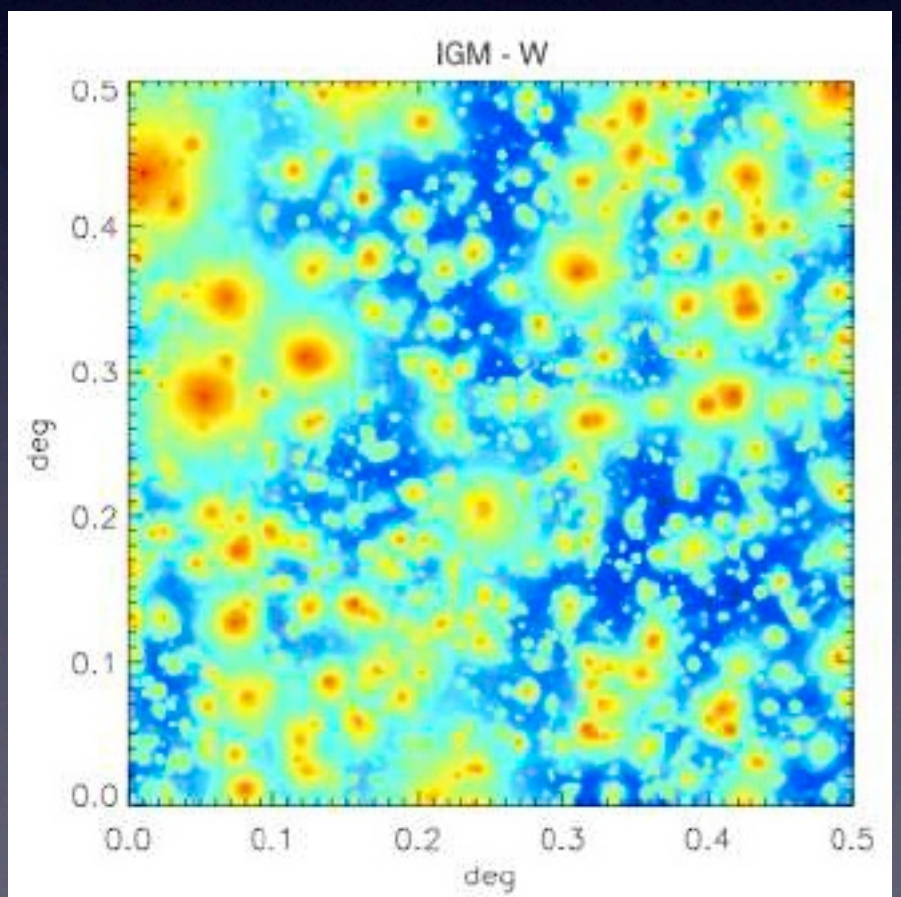
WHIM is by definition whatever has $10^5<kT<10^7$ K

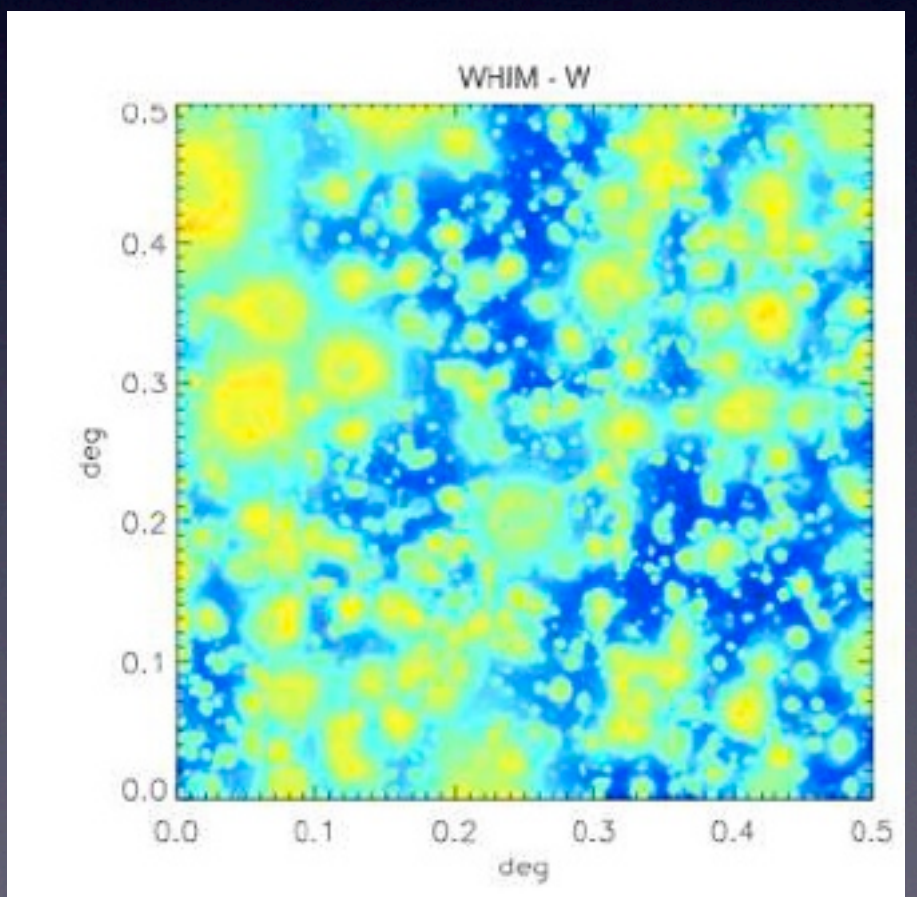
30-40% of Missing baryonsare expected to lie in a medium with $10^5<kT<10^7$ K and $\delta<1000$

Needs simulations to define diffuse emission

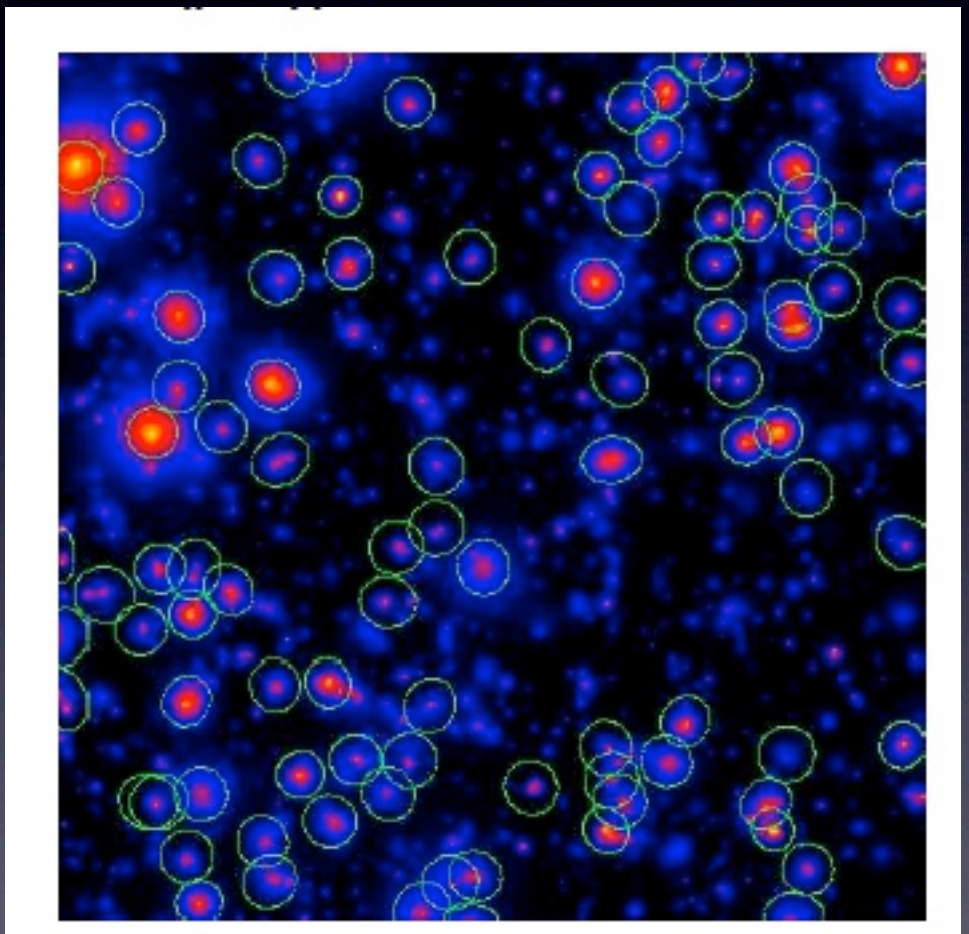
The WHIM emissivity depends the metallicity
on how the IGM is enriched of Metals

Wind Driven
feedback (Roncarelli+2012, for details)
20 simulations of 1deg2 each and averaged

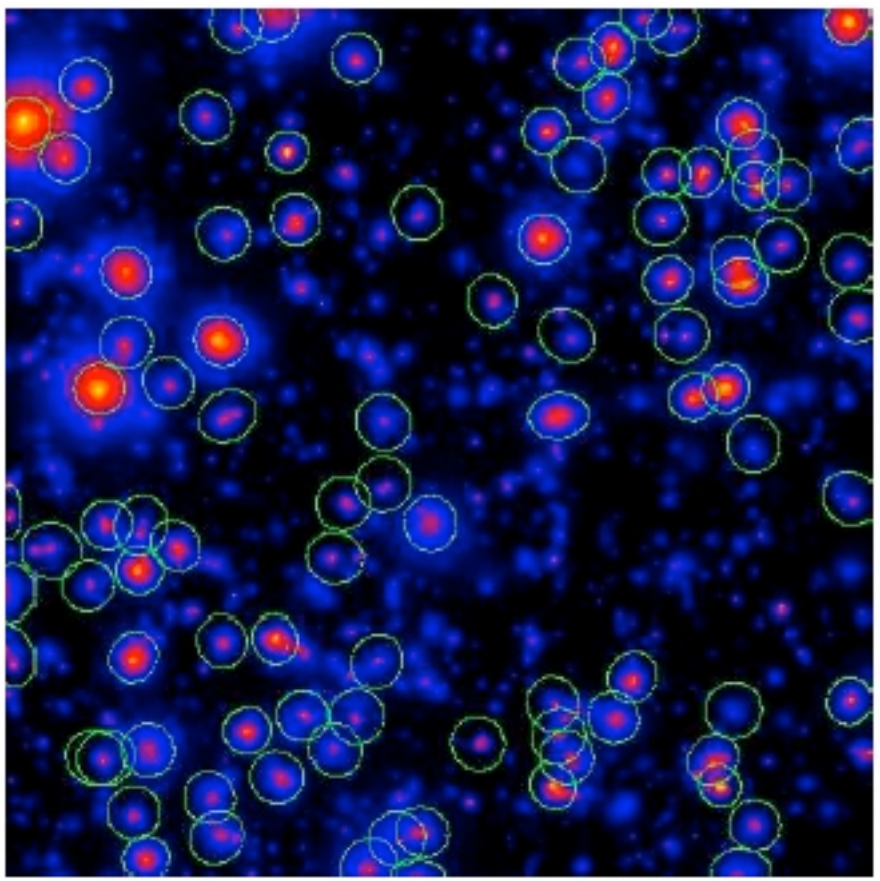




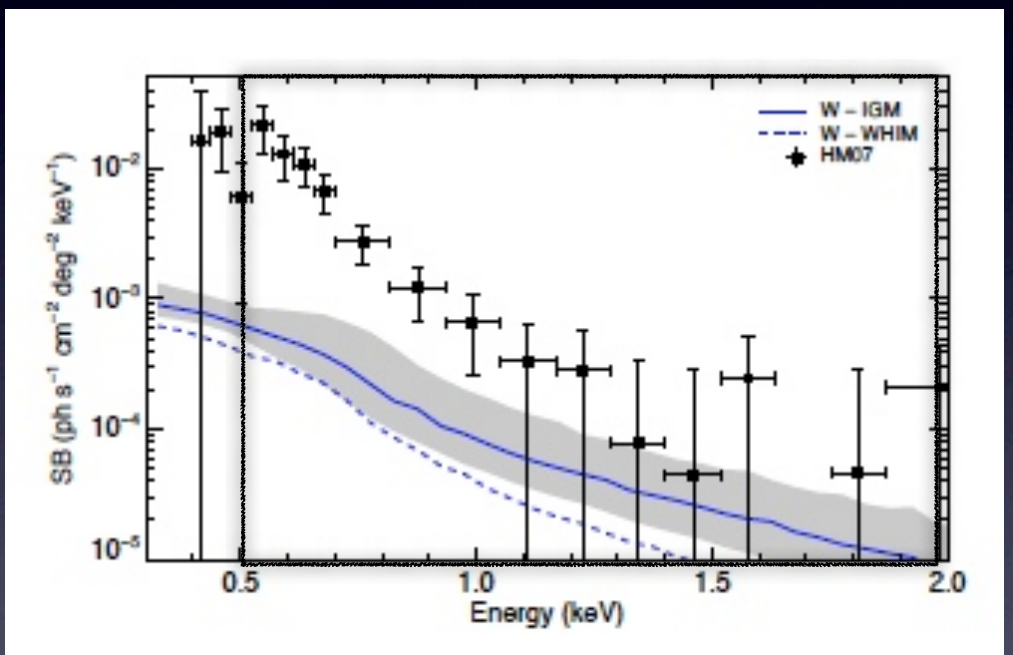
4 Ms CDFS observable sources



4 Ms CDFS observable sources

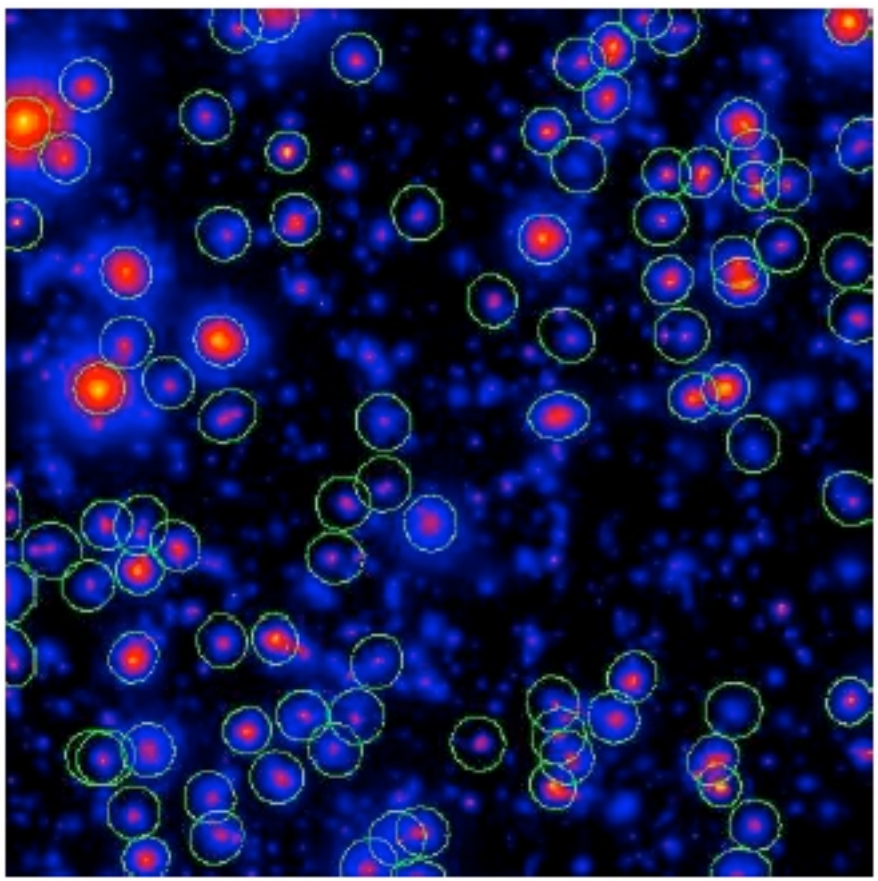


Comparison with unresolved CXB spectrum

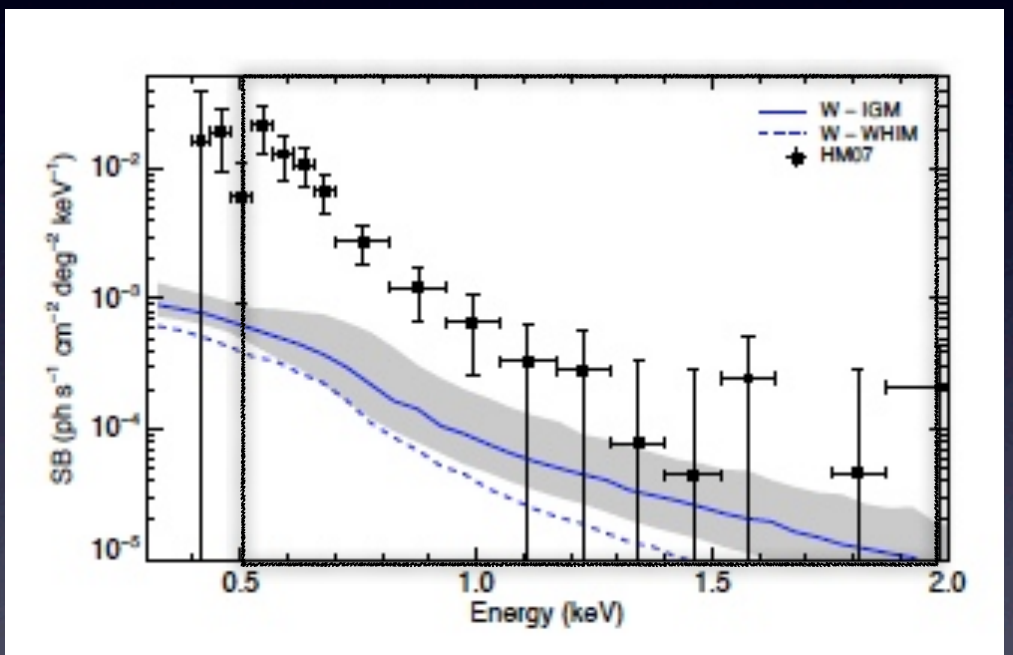


50% of the unresolved CXB made by IGM

4 Ms CDFS observable sources



Comparison with unresolved CXB spectrum

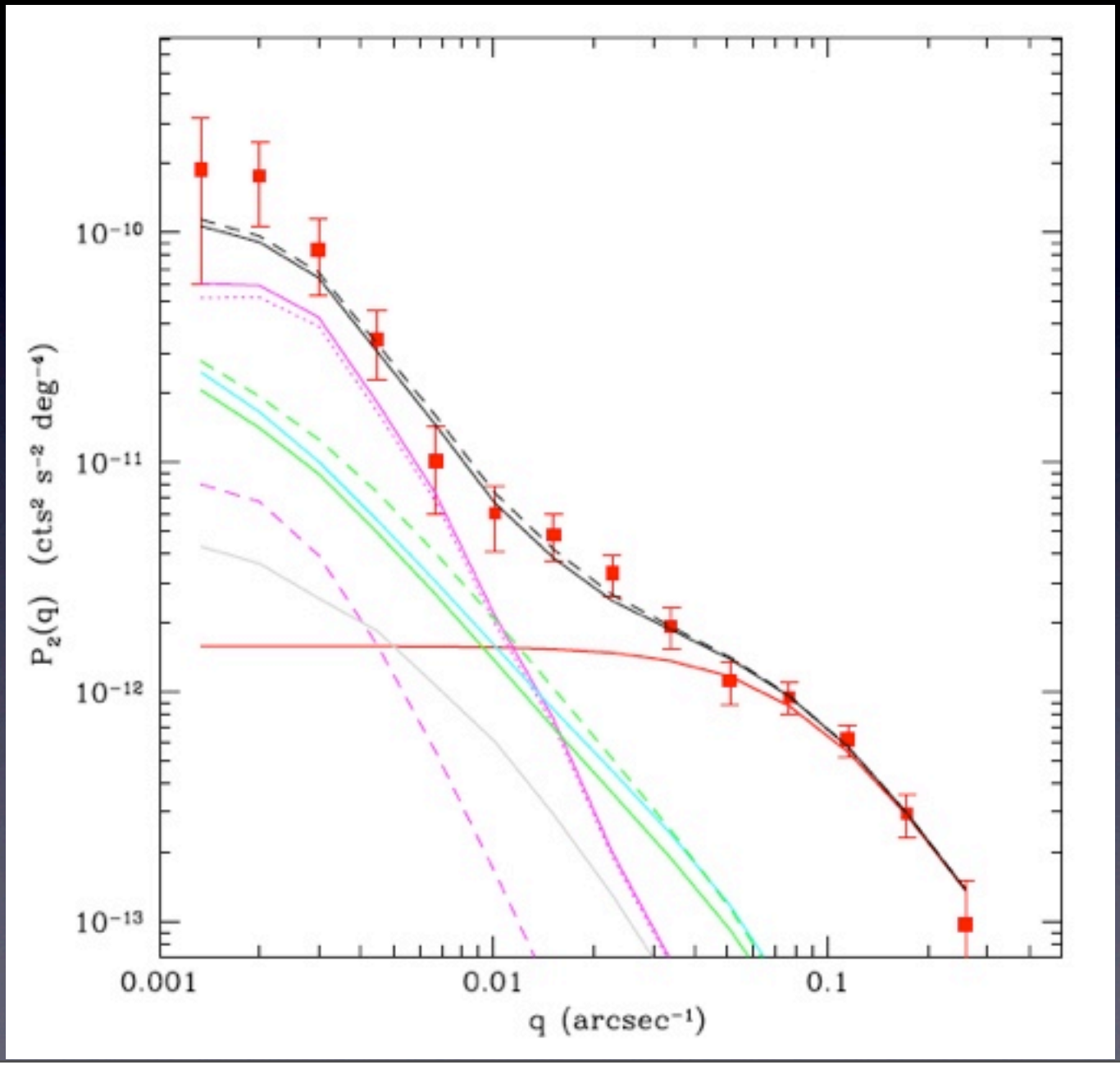


50% of the unresolved CXB made by IGM

Taking the PS of the remaining area

4-Results

PS of CXB fluctuations



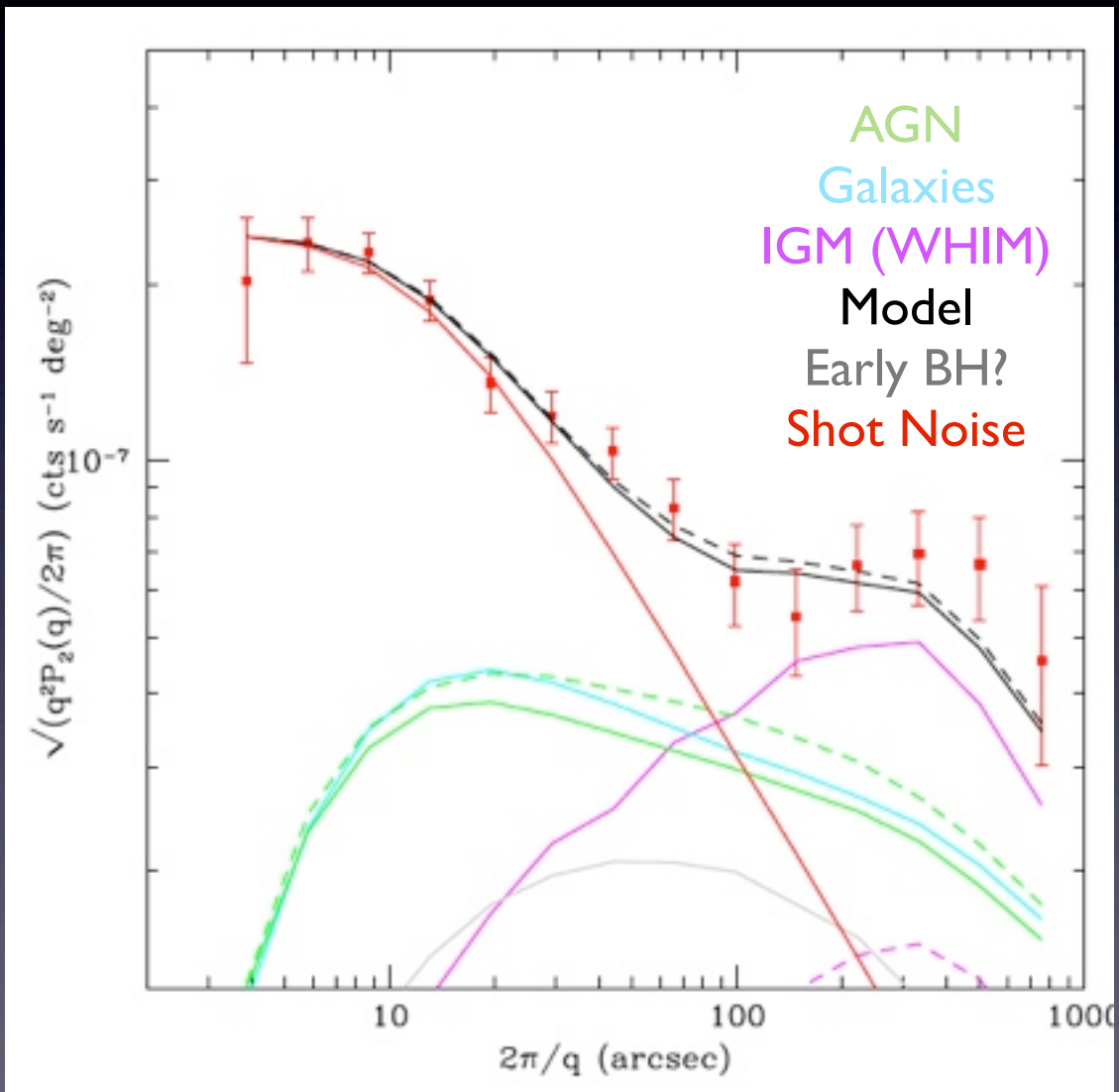
AGN+IGM+Gal required >4σ

High-z BH not necessary but not excluded

Model 1
AGN with High-z decline

Model 2 without

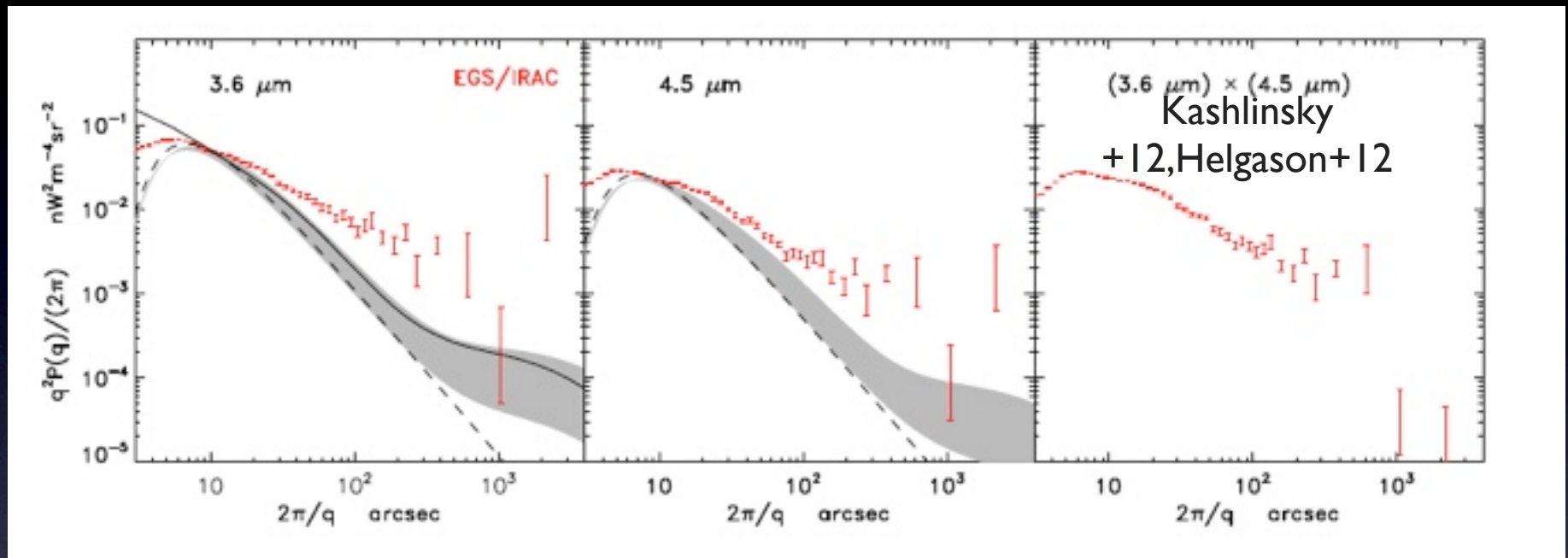
RMS fluctuations



$$C(0) = \langle \delta S^2 \rangle_\theta = \frac{1}{2\pi} \int_0^\infty P_2(q) W_{TH}(q\theta) q dq \sim \frac{1}{2\pi} q^2 P_2(q) \Big|_{q \sim \pi/\theta}$$

Estimate of <δS> at any scale

Signatures of z>7.5 sources



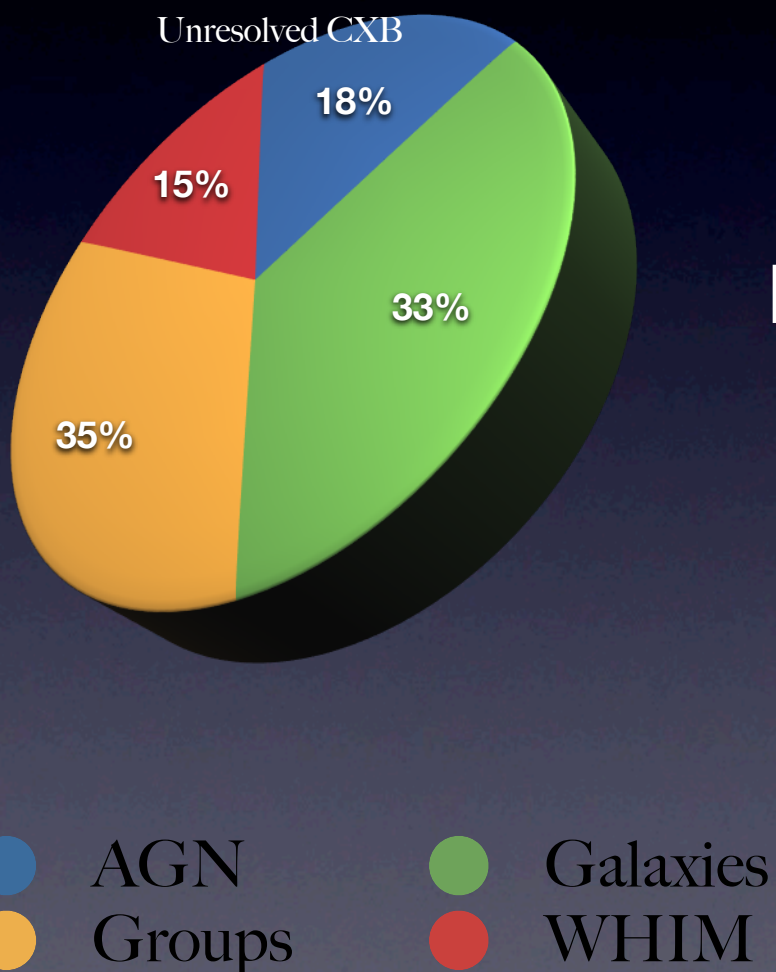
Excess power wrt to galaxies
No correlation with HST sources
z>7.5

Fluctuations from first stars/BH era

Very high-z sources

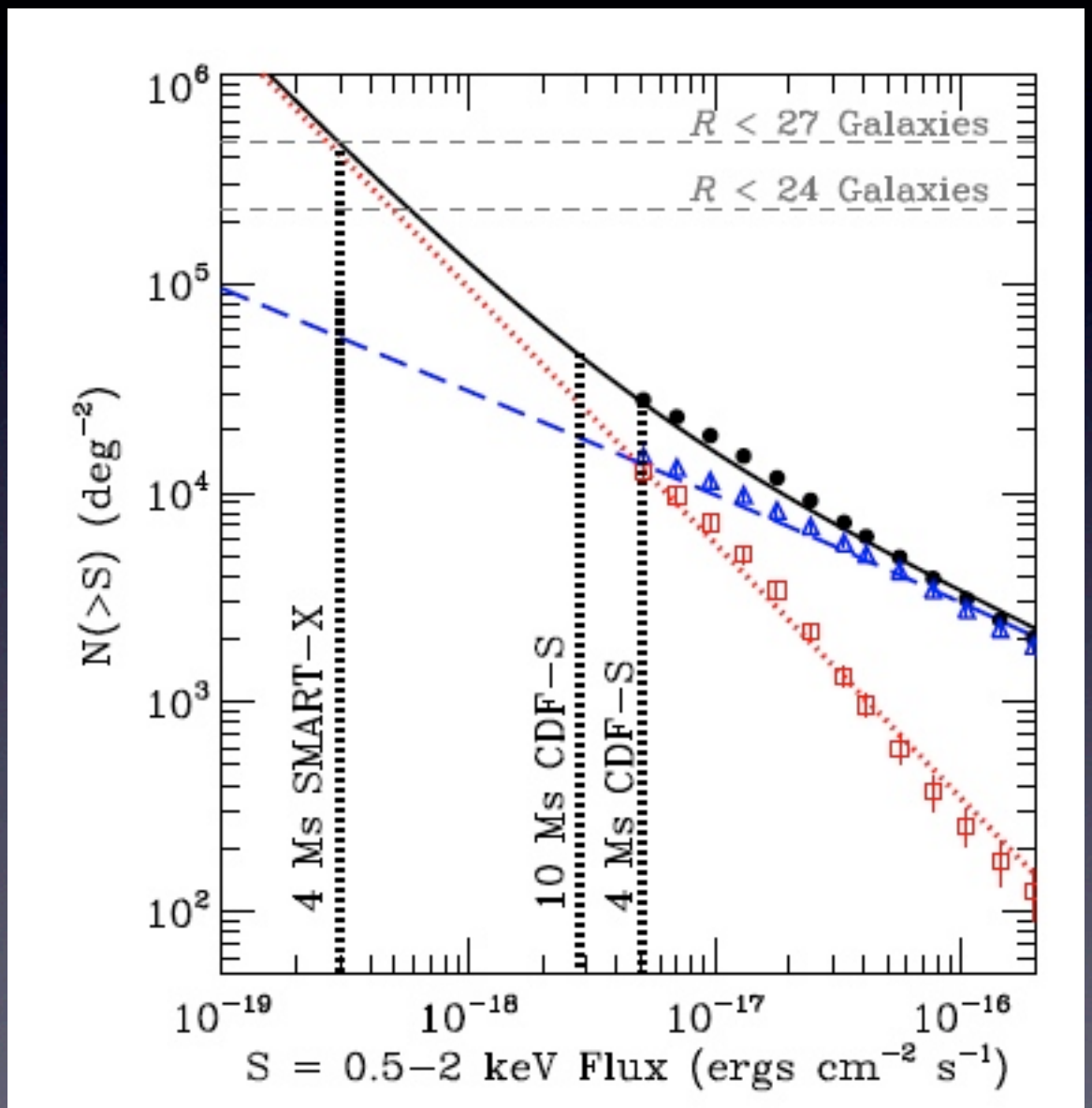
- Source of the CIB make early BH
- $P_{BH,CXB}(q) \sim (SCXB/SCIB)^2 * P_{HZ,CIB}(q, z=9)$
- Basic assumption CIB fluctuations come from first stars era
- This would make <8% of the unresolved CXB

The nature of the unresolved CXB



14% of the overall CXB
MUST NOT BE CONFUSED
WITH THE QUOTED ~5%
Lehmer+12, Moretti+04

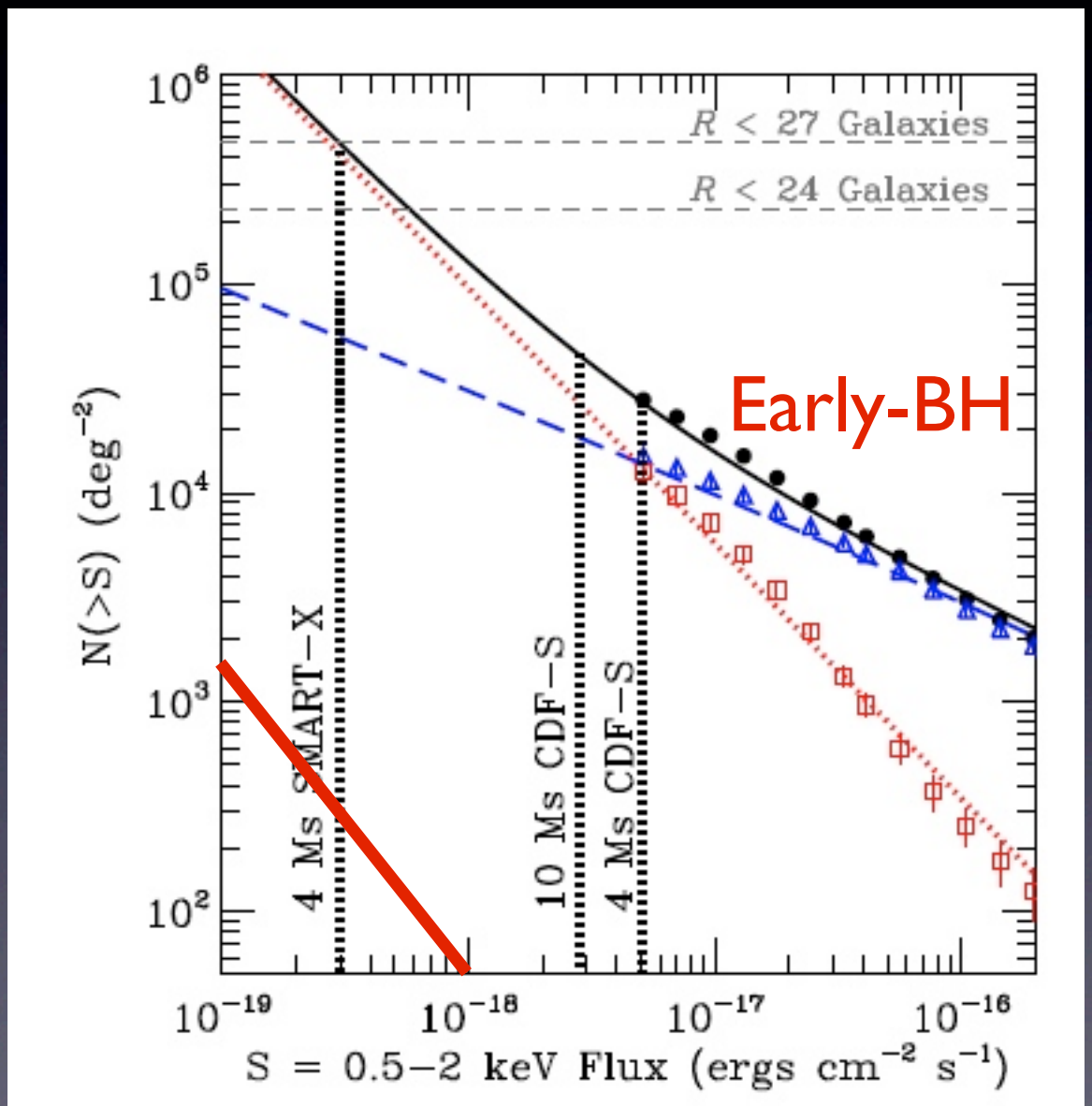
Source counts of undetected sources



Galaxies are the larger population

AGN almost "finished"

Source counts of undetected sources



Galaxies are the larger population

AGN almost "finished"

At the flux limit of future X-ray observatories possible detection of early BH

current upper limit in agreement with declining QSO

What's next?

Constrain faint end high-z AGN evolution → Deeper survey

10 Ms CDFS

Athena :(

Smart-X

What's next?

Constrain faint end high-z AGN evolution → Deeper survey

10 Ms CDFS

Athena :(Smart-X

WHIM emissivity (metallicity) → Wide field survey Calorimeter

What's next?

10 Ms CDFS

Constrain faint end high-z AGN evolution → Deeper survey

Athena :(Smart-X

WHIM emissivity (metallicity) → Wide field survey Calorimeter

Athena :(WFXT

What's next?

Constrain faint end high-z AGN evolution → Deeper survey

10 Ms CDFS

Athena :(Smart-X

WHIM emissivity (metallicity) → Wide field survey Calorimeter

Athena :(WFXT

High-z sources (BH) →

What's next?

Constrain faint end high-z AGN evolution → Deeper survey

10 Ms CDFS

Athena :(
Smart-X

WHIM emissivity (metallicity) → Wide field survey Calorimeter

Athena :(
WFXT

High-z sources (BH) → WFXT COSMOS-like Athena survey :(

What's next?

Constrain faint end high-z AGN evolution → Deeper survey

10 Ms CDFS

Athena :(
Smart-X

WHIM emissivity (metallicity) → Wide field survey Calorimeter

Athena :(
WFXT

High-z sources (BH) → WFXT COSMOS-like Athena survey :(

CXB-CIB correlations?... work in progress

Conclusions

- Nature of the unresolved soft CXB via PS
- 50% IGM, 14% WHIM, however WHIM is whatever is Warm....
- AGN make 20% of the unresolved CXB, hint of shallower decline wrt to high-L AGN
- 30% Galaxies
- This technique will likely help us to find signature of SMBH seeds

Soon on MNRAS..

Mon. Not. R. Astron. Soc. **000**, 1–14 (2002) Printed 13 April 2012 (MN LATEX style file v2.2)

The nature of the unresolved soft CXB

N. Cappelluti[1,2⋆] , P. Ranalli[3,9,1], M. Roncarelli[3], P. Arevalo[4], G. Zamorani[1]
A. Comastri[1], R. Gilli[1], E. Rovilos[1], C. Vignali[3,1], V. Allevato[5], A. Finoguenov[2,6],
T. Miyaji[7], F. Nicastro[8] and I. Georgantopoulos[1,9]
[1] *INAF-Osservatorio Astronomico di Bologna, Via Ranzani 1, 40127 Bologna, Italy*
[2] *University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA*
[3] *Università di Bologna, Dipartimento di Astronomia, via Ranzani 1, 40127 Bologna, Italy*
[4] *Departamento de Ciencias Fisicas, Universidad Andres Bello, Av. Republica 252, Santiago, Chile*
[5] *Max-Planck-Institut für Plasmaphysik and Excellence Cluster Universe, Boltzmannstrasse 2, D-85748 Garching, Germany*
[6] *Max-Planck-Institute für Extraterrestrische Physik, Giessenbachstrasse 1, D-85748 Garching, Germany*
[7] *Instituto de Astronoma, Universidad Nacional Autnoma de Mxico, Ensenada, Baja California, Mexico (mailing address: P.O. Box 439027, San*
[8] *Osservatorio Astronomico di Roma (INAF), Via Frascati 33, I-00040 Monte Porzio Catone, Italy*
[9] *Institute of Astronomy and Astrophysics, National Observatory of Athens, Lofos Nymfon, Thisio, PO Box 20048, 11810 Athens, Greece*

ABSTRACT

In this paper we investigate the power spectrum of the unresolved 0.5-2 keV CXB with deep *Chandra* 4 Ms observations in the CDFS. We measured a signal which, on scales $>30''$, is significantly higher than the Shot-Noise and is increasing with the angular scale. We interpreted this signal as the joint contribution of clustered undetected sources like AGN, Galaxies and IGM. The power of cosmic sources fluctuations is consistent with a flux of the order of ∼14% the 0.5-2 keV extragalactic CXB. We developed a model which satisfactorily explains all the observed power from fluctuation by taking into account AGN and Galaxy X-ray evolution and biasing. Overall, our modeling predicts that ∼20% of the unresolved CXB flux is made by low luminosity AGN, ∼30% by galaxies and ∼50% by the IGM. We do not find any direct evidence of the so called Warm Hot Intergalactic Medium (i.e. matter with 10^5K<T<10^7K and density contrast δ <1000), but we estimated that it produces ∼1/7 of the unresolved CXB. We also speculated the presence of a population of high redshift sources which may result from the collapse of early massive stars or gas clouds. Although we did not detect their signature, our data are still well fitted by a model that includes such a component. We placed upper limits to space density of z>7.5 X-ray sources.

This paper therefore snapshots the population of sources that will be sampled by next generation X-ray telescopes.

Key words: (cosmology:) dark matter, (cosmology:) large-scale structure of universe, X-rays: galaxies, galaxies: active, (cosmology:) diffuse radiation