A new XMM survey to unambiguously determine high-z X-ray AGN Clustering and investigate AGN Bias Evolution, AGN unification paradigm and Cosmological implications (Ω_m, w)

M. Plionis (IAA, Greece) &

O. Garcet (Univ. of Liege, Belgium)

Outline of Talk

- Why study X-ray selected AGN clustering ?
- Review of X-ray AGN clustering results
- The Flux-Dependent -Clustering of X-ray selected AGN (CDFN & CDFS clustering re-visited) and the consequent Luminosity - Dependent Clustering.
- Prerequisites for a consistent comparison of the different clustering results.
- Survey design to unambiguously determine high-z X-ray AGN clustering
- Science cases: (a) Testing the unification paradigm at high-z's, (b) Modelling the AGN bias evolution, (b) Cosmological inference of high-z AGN clustering

Why Study X-ray selected AGN Clustering ?

- X-ray selected AGNs can be detected at very high z´s and thus can provide important clues on $\delta\rho/\rho$ at such z´s. Furthermore their clustering properties can provide important constraints on the relation between AGN activity and DM halo hosts and on Cosmological parameters, while when combined with other LS data (SNIa) on the dark-energy equation of state.

- The relation between local and distant AGN clustering can shed light on the cosmic evolution of the AGN phenomenon.

- Can test unification paradigm since both type I and II's should sample similar environments.

- X-rays have the advantage over optical in that (a) high-z fainter sources are probed and (b) that type II AGNs, largely missed in optical surveys, are included in X-ray surveys.

Pot-pourri of ***high-z*** *AGN Clustering results*

Conflicting Results

1. Vikhlinin & Forman 1995 - ROSAT quite strong clustering
2. Cowie et al 2002; Manners et al 2003 – Chandra strong field-to-field fluctuations, while Kim et al. 2004 weak f-f fluctuations.
3. Carrera et al 1998 – ROSAT spectroscopic data found weak clustering
4. Yang et al 2003 - significant Chandra angular clustering (~0.4 deg^2)
5. Gilli et al. 2005: CDFS – CDFN $\xi(r)$ difference
6. Yang et al. 2006; CLASXS quite strong clustering (~0.4 deg^2)
7. Basilakos et al. 2004; 2005; strong clustering (XMM/2dF ~2 deg^2)
8. Miyaji et al. 2006 weak XMM clustering (COSMOS survey ~2 deg^2)
9. Puccetti et al. 2006 intermediate clustering (ELAIS-S1 survey- ~0.6 deg^2)
10. Ghandi et al. 2006 no HB clustering detection (XMM LSS ~4 deg^2)
11. Carrera et al. 2007 weak XMM clustering in HB and quite strong in SB.

*Comparison of some **X-ray AGN correlation** results*

X-ray study	**Data**	**Method**	**r_0 (h^{-1} Mpc)**	***z***
Vikhlinin & Forman (1995)	Deep ROSAT Pointings	Angular/Limbers	**12**	1.
Basilakos et al. (2005)	XMM/2dF (soft)	Angular/Limbers	**8 – 16**	1.
Gilli et al. (2005)	CDFS CDFN	Redshift	**10.3** **5.5**	1.
Yang et al. (2003)	Chandra Lockman hole (hard)	Angular/count-in-cells	**~20**	1.
Basilakos et al. (2004)	XMM/2dF (hard)	Angular/Limbers	**13 – 19**	0.75
Yang et al. (2006)	Chandra Lockman hole CDFN (hard)	Redshift	**8** **6**	1.
Mullis et al (2004)	ROSAT NEP survey	Redshift	**7.5**	0.22
Grazian et al. (2003)	Asiago-ESO/RASS	Redshift	**8.5**	0.2
Akylas, Georgantopoulos, Plionis (1999)	RASS	Angular/Limbers	**6.5**	0.1

Pot-pourri of ***high-z*** *AGN Clustering results*

The conflicting clustering results could be due to a variety of issues related to:

- Different biases that enter due to different PSFs (***amplification bias***) or different solid angles (***Integral constraint***).
- Different survey ***flux limits*** which imply different z's traced and possibly different populations of sources, which usually have different clustering.
- Possible different input ***logN-logS*** used to determine the random source distribution (even for the same instrument) since it should be clear that this can play an impressively important role in the outcome $\xi(r)$ or $w(\theta)$.
- The ***clustering evolution model*** which should be the same (for example, stable in comoving coordinates or in physical coordinates).
- If results are based on a 2-D analysis then the ***luminosity function*** assumed and the ***cosmology*** used (Ω_m, Ω_Λ, H_o) in Limber's equation should be the same (for example the Vikhlinin & Forman 1995 ROSAT result increases from 8.5 h^{-1} Mpc to 12 h^{-1} Mpc).

*Pot-pourri of **high-z** AGN Clustering results*

The conflicting clustering results could be due to a variety of issues related to:

•Different biases that enter due to different PSFs (***amplification bias***) or different

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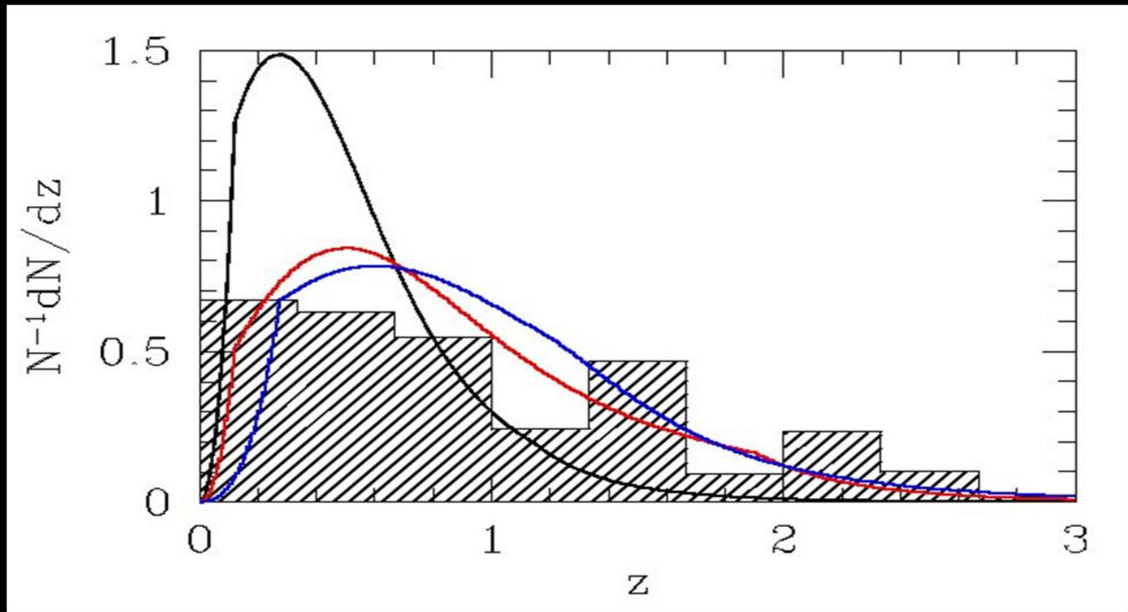
A major source of uncertainty of the recovered r_0 is the luminosity function assumed from which on recovers the z-selection function

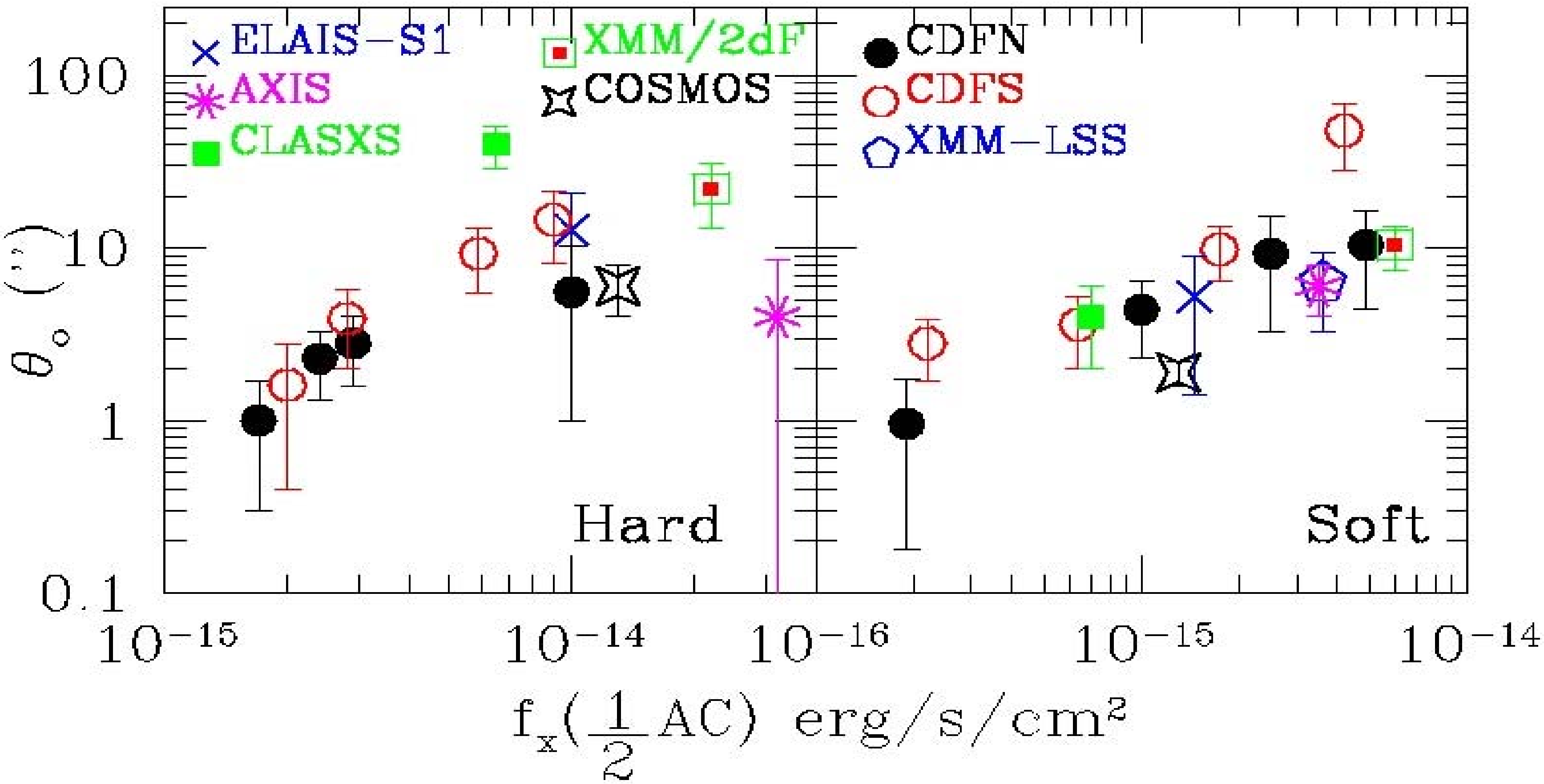


N(z) of hard sources

Ueda et al (2003) LDDE (red)

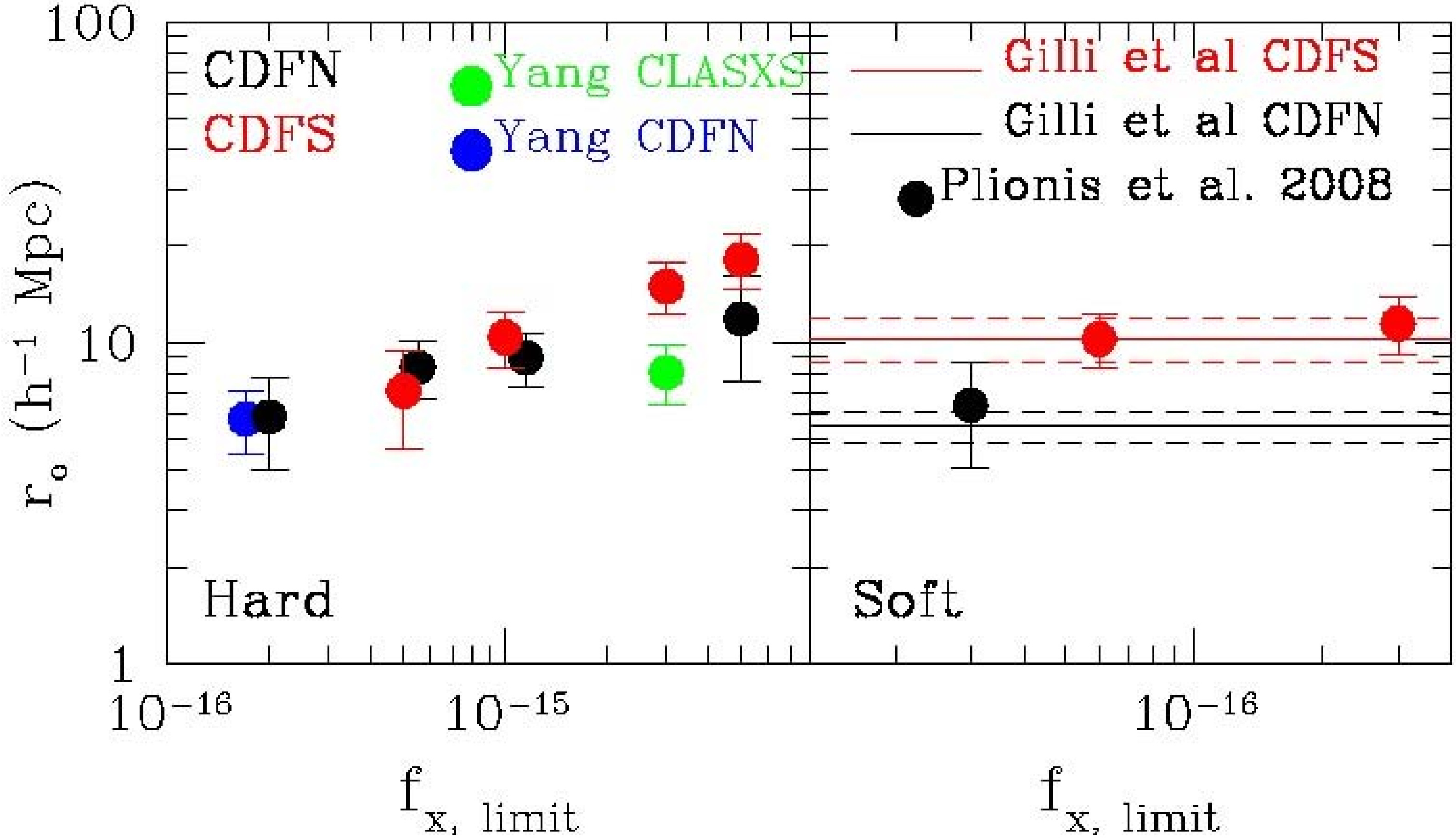
La Franca et al. (2005) LDDE (blue)

Plionis et al. (2008) CDFs re-analysis



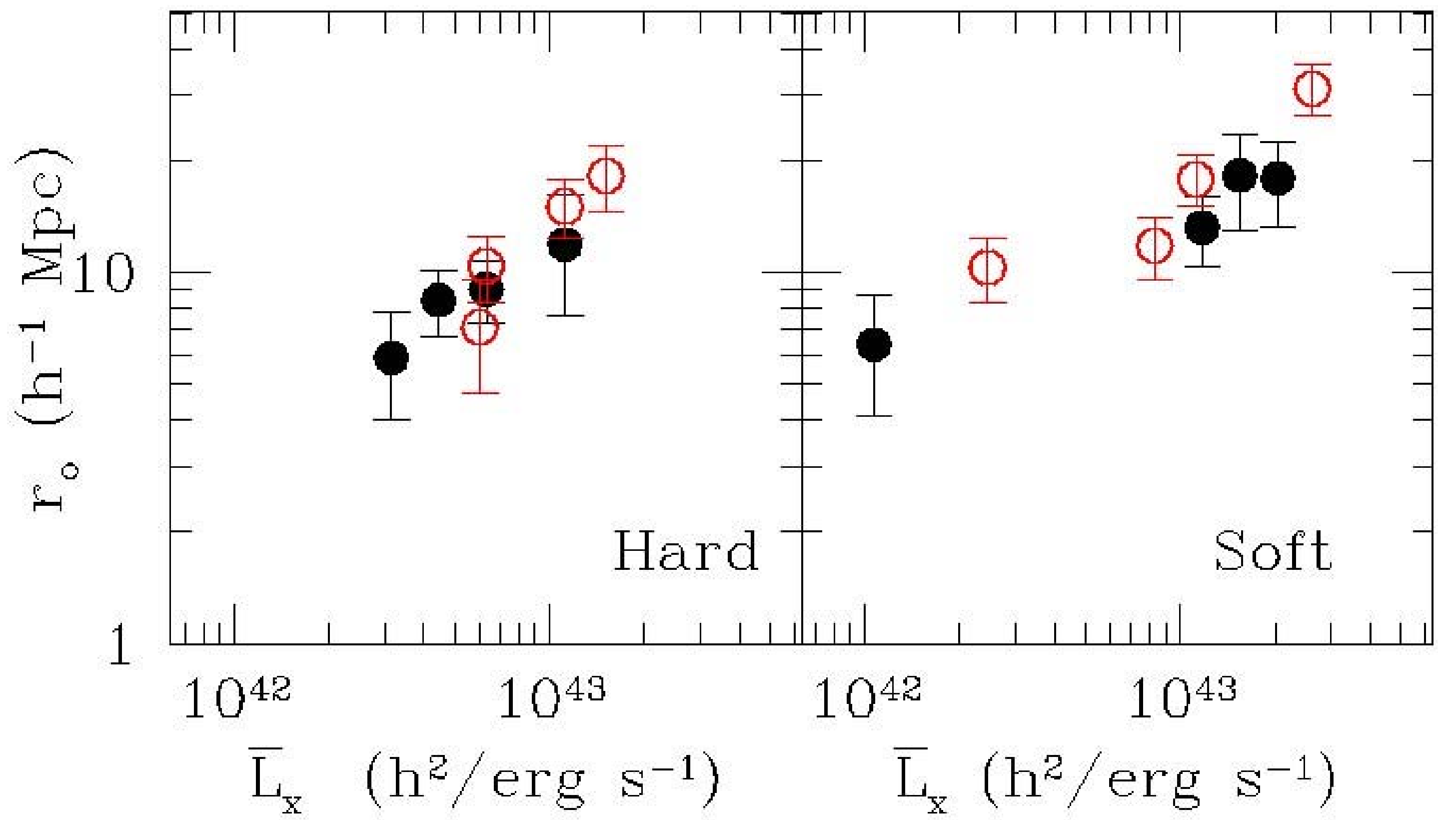
FLUX-LIMIT DEPENDENT CLUSTERING !!

Does Limbers inversion (+ LDDE $\Phi(L)$) give consistent results with direct Chandra $\xi(r)$ analyses ?



Indeed very good consistency of 2D→3D results with direct *ξ(r)* results!

Flux-limit dependence results into a X-ray luminosity dependence of z~1 AGN clustering



Although the flux-limit dependence of the X-ray AGN clustering provides an overall consistency platform of the different survey results, there is still quite a large scatter (mostly due to Cosmic Variance) and an inconsistency of some hard-band results !

THEREFORE, it is essential to address in a conclusive manner the high-z X-ray selected AGN clustering. More so because it has important consequences for a variety of AGN related issues, among which the effects of the local environment to the AGN process, testing the unification paradigm, tracing the evolution of the AGN bias, which can provide important information on the type of DM halos that AGN inhabit and finally it can provide important cosmological constraints

Our Suggestion is to cover 2 areas of the sky with 10ksec

- The **SWIRE area** which covers 6 non-contiguous areas with a total surface of ~ 50 deg^2: ELAIS N1-N2 (14 deg^2), Lochman hole (11 deg^2), south XMM-LSS (9 deg^2), CDF-S (8 deg^2), ELAIS S1 (7 deg^2), which have excellent optical follow-ups (eg., CDF-S, Lochman hole down to r~25). ***The mid-IR data will provide accurate photo-z's and thus enable a 3D analysis !***
- 100 deg^2 on the **SDSS stripe-82** in order to measure large-wavelength contribution to AGN clustrering (BAOs ?). Covered by multiwavelength data (deep SDSS, UKIDSS,… see contribution of Richards et al). → 7 Msec (using 5 pointings/deg^2)

From Kim et al. (2007) logN-logS we expect in total **90000** soft (2 x 10^{-15} ergs/sec cm^2) and **45000** hard-band (10^{-14} ergs/sec cm^2) sources, in fact ~1/2 will probably be detected due to vignetting).

Unprecedented S/N of expected w(θ) measurment.

On the need of a large X-ray survey

✓ The angular correlation function and its estimation

$$\delta P = n^2 \delta\Omega_1 \delta\Omega_2 [1 + \omega(\theta)]$$

The ACF (w) measures the excess probability of finding two sources in the sky at a given angular distance with respect to a random uniform distribution. w=0 when the sample distribution is random and homogeneous.

$$\widetilde{\omega(\theta)}_h = f \frac{DD(\theta)RR(\theta)}{DR(\theta)DR(\theta)} - 1$$

The real value of the angular correlation function is measured with an estimator, mainly the Hamilton and Landy-Szalay estimators (Hamilton 1993; Landy and Szalay 1993).

✓ Its error estimation

$$\sigma_{\widetilde{w}} = \frac{1 + \widetilde{w}}{\sqrt{DD_{ind}}}$$

The error estimation of the measured correlation function is given by this formula, where DD is the number of independant source pairs at a given angular separation

✓The power law fit model

$$w(\theta) = \left(\frac{\theta_0}{\theta}\right)^{\gamma - 1}$$

Most of the angular correlation results in both soft and hard X-ray selected samples can be fitted by a power law.

On the need of a large X-ray survey

- **Angular correlation function:** Basilakos et al. (2004,2005); Carrera et al. (2007); Gandhi et al. (2006), Yang et al. (2003),…

Sky area in the range [0.1-10] deg^2 ➡ Cosmic variance

Comparison of the soft band and the hard band angular correlation functions leads to non significant (2-3 sigma level) and controversial results.

- **Spatial correlation function:** Gilli et al. (2005); Yang et al. (2006),…

Sky area in the range [0.1-1] deg^2 ➡ Cosmic variance !!!

Comparison of the evolution of both the soft and hard X-ray selected AGN clustering properties and of b(z) as a function of the redshift also lead to non significant (2-3 sigma level) results.

➡ X-ray survey both over a much wider sky area and with a large sample size

What is the required size for the large X-ray survey?

✓ The angular correlation function (eg. Gandhi et al. 2006)

The definition of a confidence level of the ACF (x-sigma level) along with the assumption of a power law model lead to the required number of independant source pairs in each bin

$$\frac{\frac{\widetilde{w}}{1+\widetilde{w}}}{\sqrt{DD_{i,ind}}} > x \qquad DD_{i,ind} > \frac{x^2[1+(\frac{\theta_0}{\theta})^{\gamma-1}]^2}{(\frac{\theta_0}{\theta})^{2(\gamma-1)}}$$

1) 1164 sources over 5 deg^2 in the soft X-ray band ([0.5-2] keV band): $(\theta_0, \gamma) = (6'', 2.2)$

230 arcsec at the 4-sigma level requires around 45000 pairs but only 1600 are found

The sky area needs to be increased by 5.3 as N scales as DD$^{0.5}$ and thus around 26 deg^2 need to be covered.

➡

+ photo-z in order to partially remove projection effects: z-distri for soft AGN of Hasinger et al. (2005): around 80 deg^2 for ACF in 3 z bins in the range [0-3.2]

What is the required size for the large X-ray survey?

✓ The angular correlation function (Gandhi et al. 2006)

2) 209 sources over 2 deg^2 in the hard X-ray band ([2-10] keV band) selected in 20 ks pointing

and which have HR>-0.2: $(\theta_0, \gamma) = (42'', 3.1)$

270 arcsec at the 4-sigma level requires around 11000 pairs but only 170 are found
The sky area needs to be increased by 8 as N scales as $DD^{0.5}$ and thus around
16 deg^2 need to be covered.

For 10 ks X-ray pointings, the limiting flux will get around 2 times brighter. However according to their log(N)-log(S), the number of sources is decreased by 2.83.

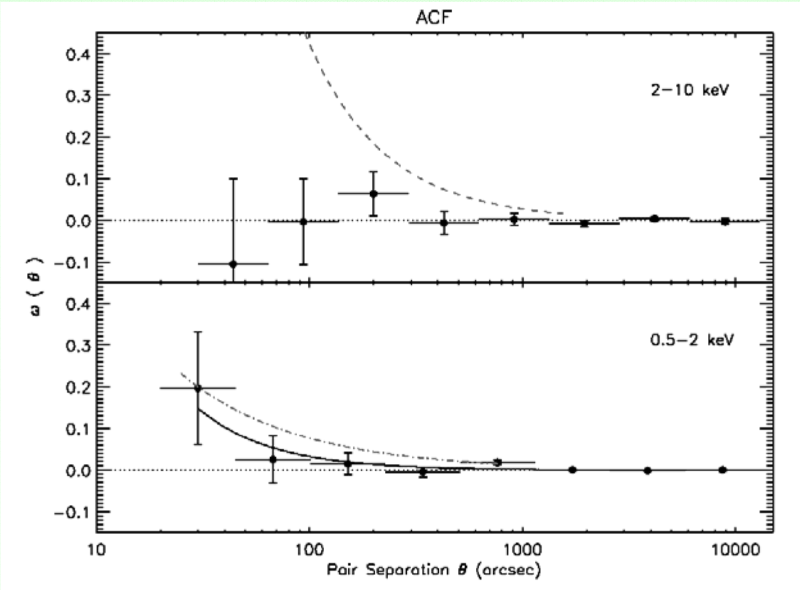
➡ The required size of the X-ray survey is 16*2.83=45 deg^2

Two X-ray surveys 50 deg^2 + 100 deg^2 of 10ks with XMM

Science case 1: *testing the Unification Paradigm at z~1*

According to the unified scheme picture, the spatial distribution of type I and type II AGN should not differ significantly as they are thought to be intrinsically the same objects. Moreover both types should share the same clustering evolution as a function of the redshift.

An alternative model (Fabian et al. 1999) argues that highly obscured AGN represent the initial phase of a black hole. According to this model, the correlation function's amplitude would increase with the redshift since newly formed galaxies and mergers should have been more numerous in the past.



Gandhi et al. (2006)

The angular correlation function of both soft and hard X-ray selected AGN are rather consistent.

Most angular correlation function analysis, even if controversial, yield the same general result : there are no very significant differences between the clustering properties of soft and hard X-ray AGN.
+ HR cut: not consistent (e.g Gandhi et al. 2006; Carrera et al. 2007).

This global trend is also found in spatial correlation function analysis like the one of Yang et al. (2006).

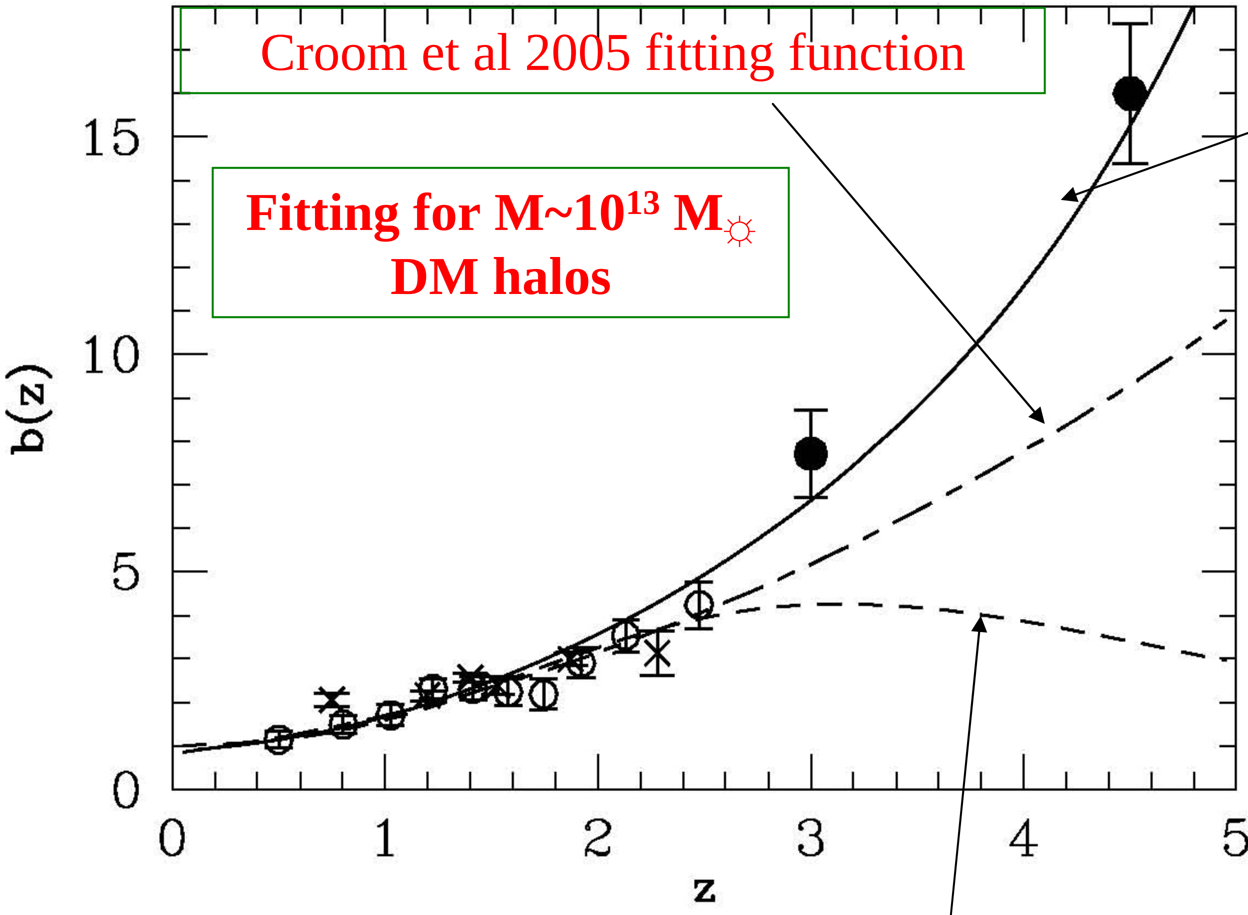
Large X-ray survey badly needed to conclusively test these two pictures

Science case 2: *X-ray AGN Bias Evolution*

The extragalactic mass tracer fluctuation field is related proportionally to that of the underlying mass:

$$\delta_{\rm tracer} = b\delta_{\rm matter}$$

$$\xi_{\rm tracer} = \langle \delta_{\rm tracer}(\vec{r}), \delta_{\rm tracer}(\vec{r} + {\rm d}\vec{r}) \rangle = b^2 \langle \delta_{\rm matter}(\vec{r}), \delta_{\rm matter}(\vec{r} + {\rm d}\vec{r}) \rangle = b^2 \xi_{\rm matter}$$



Basilakos, Plionis & Ragone-Figueroa 2008

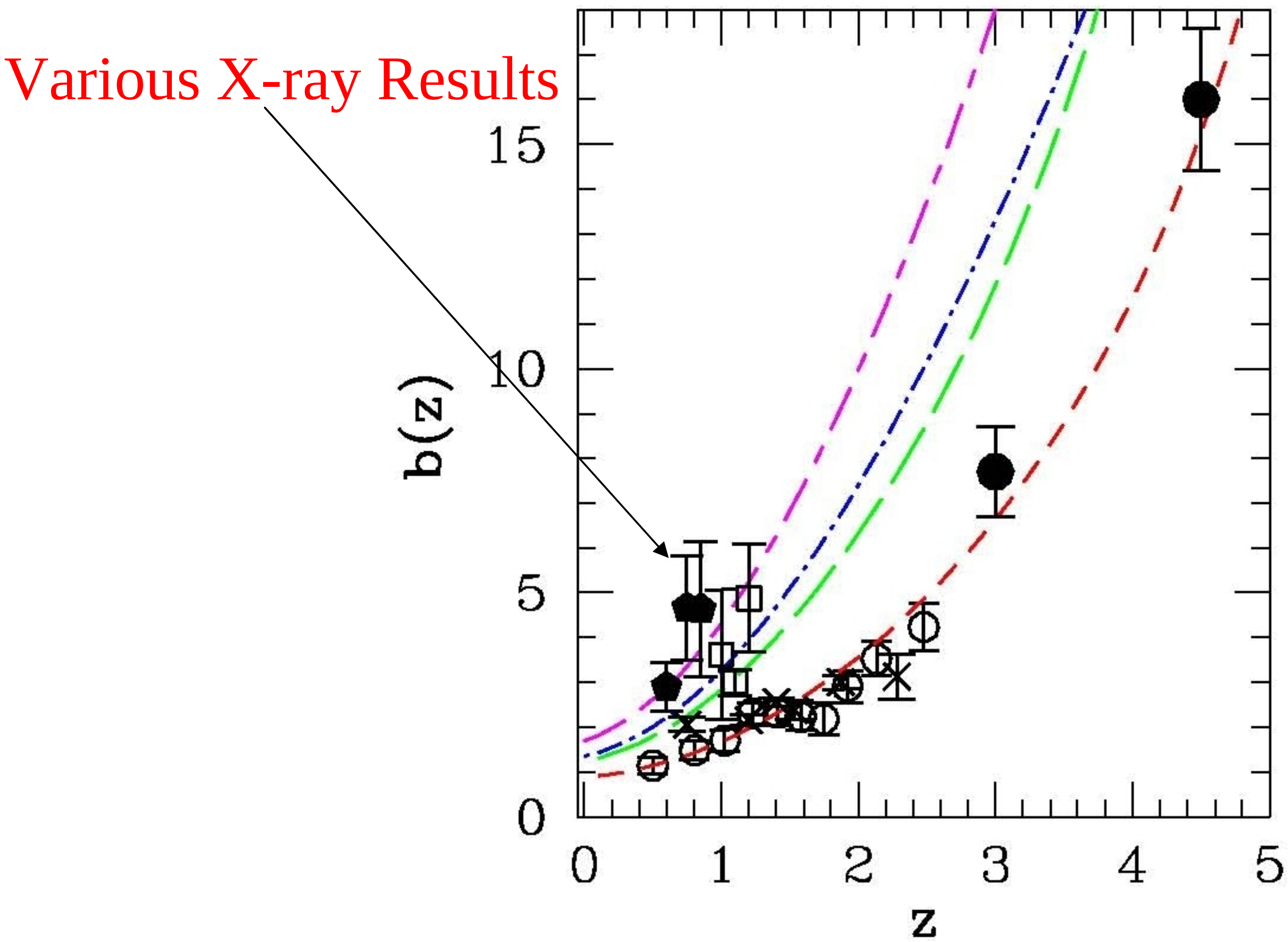
Data: SDSS DR5 (Shen et al. 2007)

SDSS DR4 (Maiers et al. 2006)

2QZ (Croom et al. 2005)

Hopkins et al. 2007

Bias Evolution of X-ray AGNs



Implication:

Xray selected AGN's at z~1 should reside today in overdensities related to poor clusters and groups of galaxies

Science case 3: *Cosmological Inference from modeling AGN correlations*

Model AGN Correlations

$$\xi_{th}(r,z) = b^2(z) D^2(z) \frac{1}{2\pi^2} \int_0^\infty k^2 P(k) \frac{\sin(kr)}{kr} \mathrm{d}k$$

P(k) is the Cold Dark Matter power spectrum.
• **b(z)** and **D(z)** is the evolution of bias and linear growing fluctuation mode respectively.

Linear Perturbation Theory

- (Peebles 1993) for w=-1 and w=-1/3

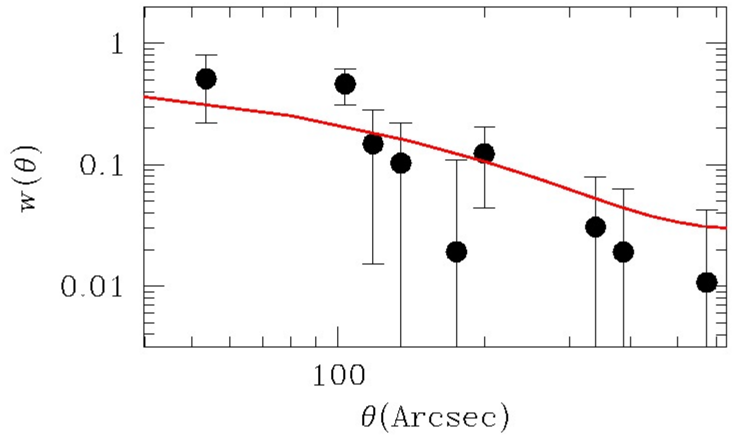
$$D(z) = \frac{5\Omega_m E(z)}{2} \int_z^\infty \frac{(1+x)}{E^3(x)}$$

- (Basilakos & Plionis 2003) w=-2/3

$$D(z) = (1+z)^{3/2} \int_z^\infty \frac{\mathrm{d}x}{(1+x)^2 E(x)}$$

$$E(z) = \left[\Omega_m (1+z)^3 + \Omega_\Lambda (1+z)^{3(1+w)}\right]^{1/2}$$

Comparing the measured ξ(r) with that expected from the models we can estimate different sets of Cosmological parameters.



Cosmological Inference

X-ray Likelihoods

$$\mathcal{L}^{\rm AGN}(\mathbf{c}) \propto \exp[-\chi^2_{\rm AGN}(\mathbf{c})/2]$$

with:

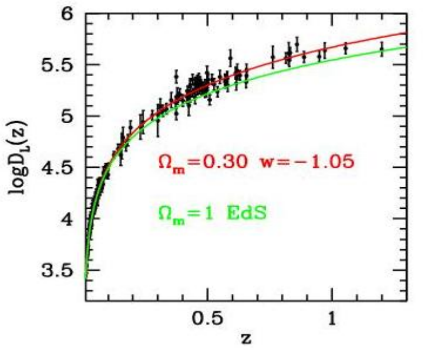
$$\chi^2_{\rm AGN}(\mathbf{c}) = \sum_{i=1}^{n} \left[\frac{w_{\rm th}(\theta_i, \mathbf{c}) - w_{\rm obs}(\theta_i)}{\sigma_i}\right]^2$$

432 X-ray sources in the soft energy band (0.2-2)keV found in the XMM data

+

SNIa Likelihhods

- 172 SNIa, Tonry et al. (2003)
- 0.1<z<1.4



$$\mathcal{L}^{\rm SNIa}(\mathbf{c}) \propto \exp[-\chi^2_{\rm SNIa}(\mathbf{c})/2]$$

with:

$$\chi^2_{\rm SNIa}(\mathbf{c}) = \sum_{i=1}^{172} \left[\frac{\log D_{\rm L}^{\rm th}(z_i, \mathbf{c}) - \log D_{\rm L}^{\rm obs}(z_i)}{\sigma_i}\right]^2$$

where $D_{\rm L}(z)$ is the dimensionless luminosity distance

$$D_{\rm L}(z) = H_{\circ} d_{\rm L} = H_{\circ}(1+z)x(z)$$

In order to to combine the X-ray clustering properties with the SNIa data we have to perform a joined likelihood:

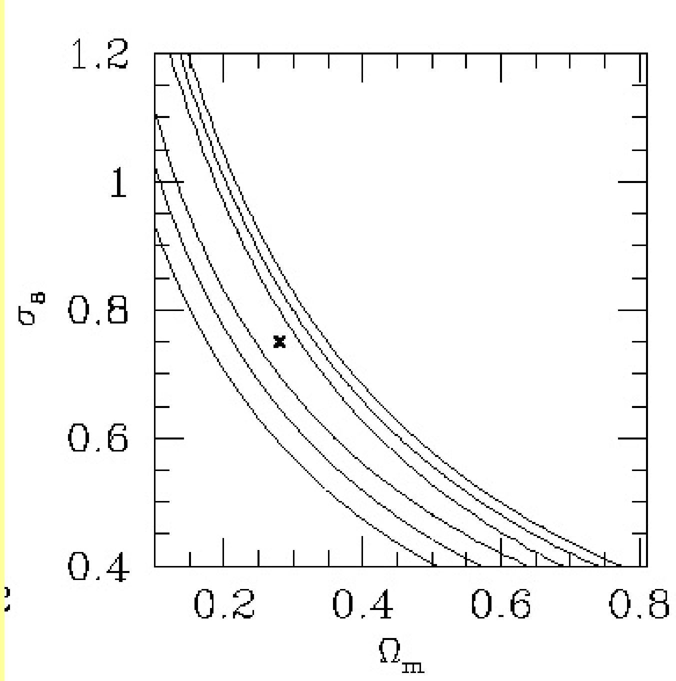
$$\mathcal{L}^{\rm joint}(\Omega_{\rm m}, w) = \mathcal{L}^{\rm AGN} \times \mathcal{L}^{\rm SNIa}$$

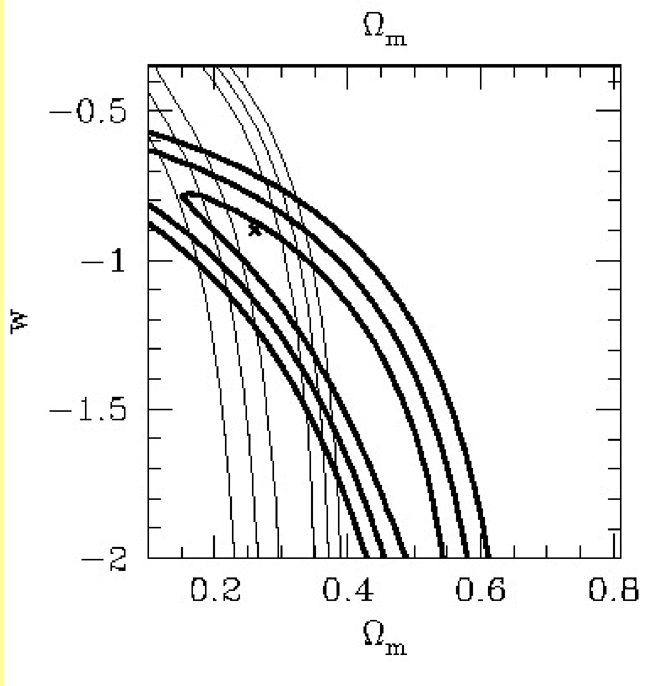
Note that c= c (Ω_m ,w, H_o) , We use further results from **Observational Cosmology:** the age of the Universe should be greater than the age of the globular clusters should be greater than T_o>12.7 Gyr.

We can obtain exactly:

Ω_m ,w, H_o

Preliminary Cosmological Results





Hubble Constant sensitive to AGN clustering but insensitive to bias: **H_o=72 km/sec Mpc**

TABLE 1

COSMOLOGICAL PARAMETERS FROM THE LIKELIHOOD ANALYSIS: THE 1^{st} COLUMN INDICATES THE DATA USED (THE LAST ROW CORRESPONDS TO THE JOINT LIKELIHOOD ANALYSIS). ERRORS OF THE FITTED PARAMETERS REPRESENT 1σ UNCERTAINTIES. NOTE THAT FOR THE JOINED ANALYSIS THE CORRESPONDING RESULTS ARE MARGINALIZED OVER THE σ_8 AND THE BIAS FACTOR AT THE PRESENT TIME, FOR WHICH WE USE THE VALUES INDICATED.

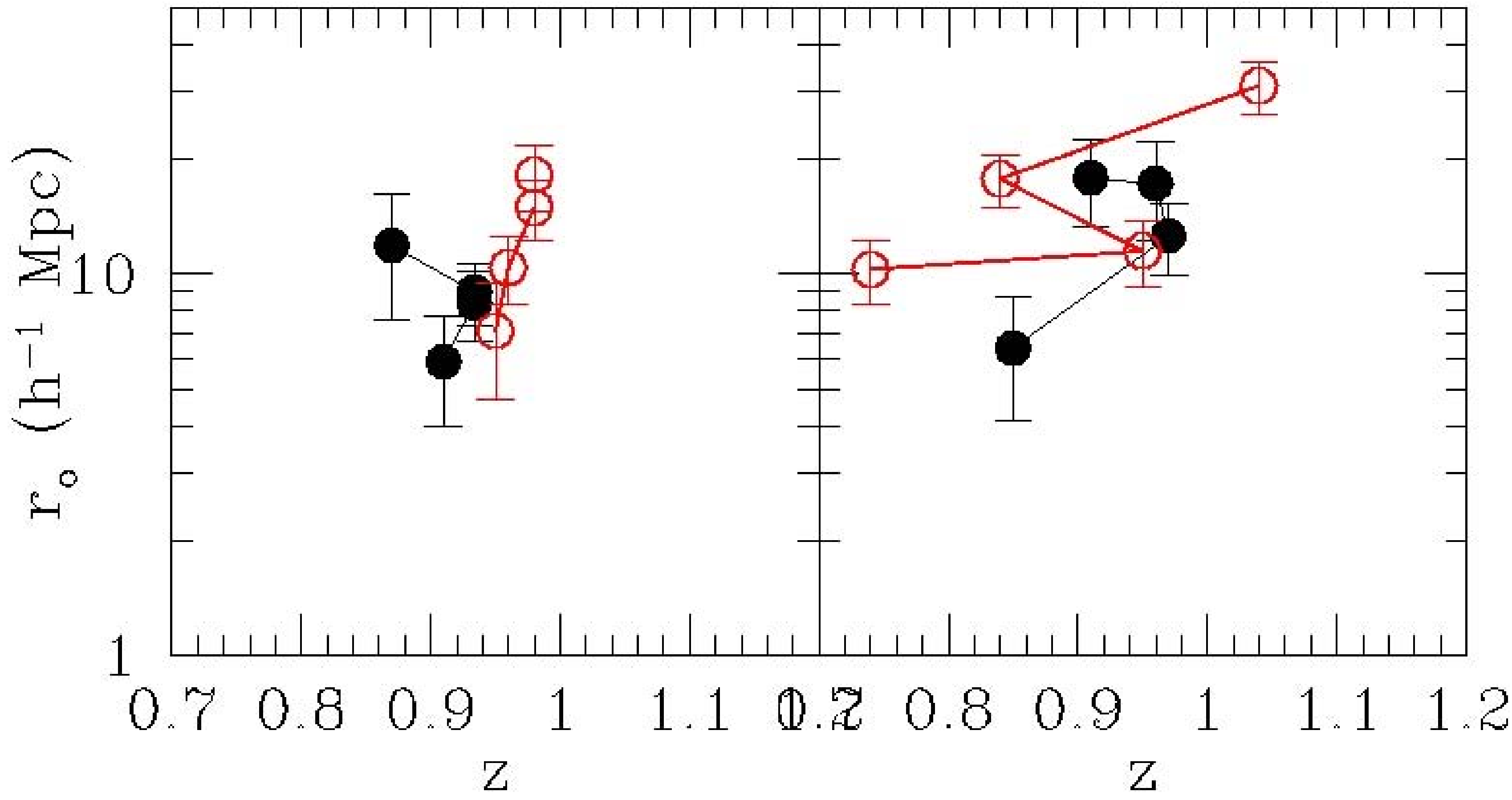
Data	Ω_m	w	σ_8	b_0	χ^2/dof
XMM	0.28 ± 0.03	uncons. ($w = -1$)	0.75 ± 0.03	$2.0^{+0.20}_{-0.28}$	0.90
XMM/SNIa	0.26 ± 0.04	$-0.90^{+0.10}_{-0.08}$	0.75	2.0	0.87

Conclusions

1. Limiting flux (ie., luminosity & z) dependence of high-z X-ray selected AGN clustering explains disparate results but still large scatter due to Cosmic Variance and ?
2. Need large XMM survey: We propose 50 deg^2 in SWIRE region (to take advantage of mid-IR for good photo-z's) and 100 deg^2 in SDSS stripe-82 (due to multi-λ & spectroscopic coverage) in order to measure large wavelength range of correlation function and possibly BAOs.

Important **science cases** include:

1. Test the unification paradigm by investigating the clustering evolution of types I and II AGN.
2. Bias evolution of X-ray selected AGNs at z~1. Preliminary results show a present bias of b_o~2 (ie., X-ray z~1 AGNs live today in moderate overdensities… eg. poor clusters and groups of galaxies).
3. Cosmological inference: Preliminary results show that high-z X-ray AGN clustering is consistent with Ω_m=0.26-0.28 (flat universe is assumed), h=0.7, σ_8 =0.75 consistent with WMAP 3y. Joint likelihood with SNIa can be used to constraint Dark Energy equation of state: -0.9<w<-1.05



r_o (h^{-1} Mpc)
10
1
0.7 0.8 0.9 1 1.1
0.7 0.8 0.9 1 1.1 1.2
z
z

Science case 2: *X-ray AGN Bias Evolution*

The extragalactic mass tracer fluctuation field is related proportionally to that of the underlying mass: $\delta_{\rm tracer} = b\delta_{\rm matter}$

$$\xi_{\rm tracer} = \langle \delta_{\rm tracer}(\vec{r}), \delta_{\rm tracer}(\vec{r} + {\rm d}\vec{r}) \rangle = b^2 \langle \delta_{\rm matter}(\vec{r}), \delta_{\rm matter}(\vec{r} + {\rm d}\vec{r}) \rangle = b^2 \xi_{\rm matter}$$

Evolution of Bias Parameter

From Continuity, Euler's, Poisson's equations & L.P.T. we derive the evolution equation of δ:

$$\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G \rho_m \delta \ , \quad \delta_g = b\delta$$

we seek the time evolution equation for b:

From continuity equation and if gals and DM share the same v-field:

$$\dot{\delta} + \nabla u \approx 0 \ , \dot{\delta}_g + \nabla u \approx 0 \Longrightarrow \quad \dot{\delta}_g - \dot{\delta} = 0$$

From $\delta_g = b\delta$ and $y = b - 1 \quad \Longrightarrow$

$$\frac{d}{dt}(y\delta) = 0 \Longrightarrow \frac{d^2}{dt^2}(y\delta) = \ddot{y}\delta + 2\dot{y}\dot{\delta} + y\ddot{\delta} = 0$$

$$y\ddot{\delta} = -2H\dot{\delta}y + 4\pi G\rho_m \delta y$$

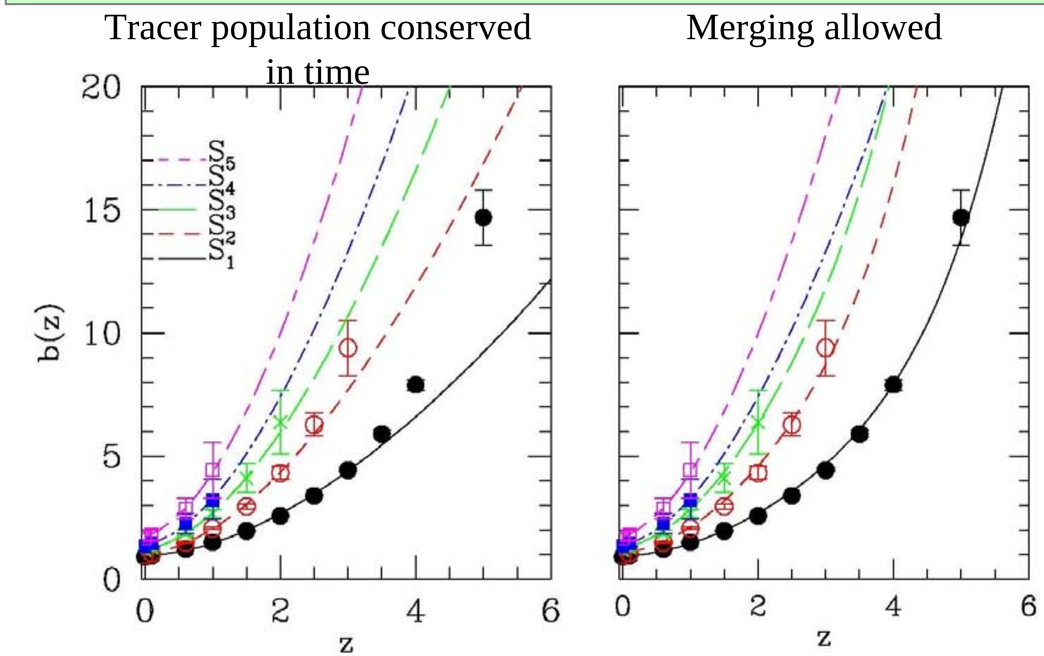
and together with $y\dot{\delta} = -\dot{y}\delta \quad \Longrightarrow$

$$\boxed{\ddot{y}\delta + 2(\dot{\delta} + H\delta)\dot{y} + 4\pi G\rho_m \delta y = 0}$$

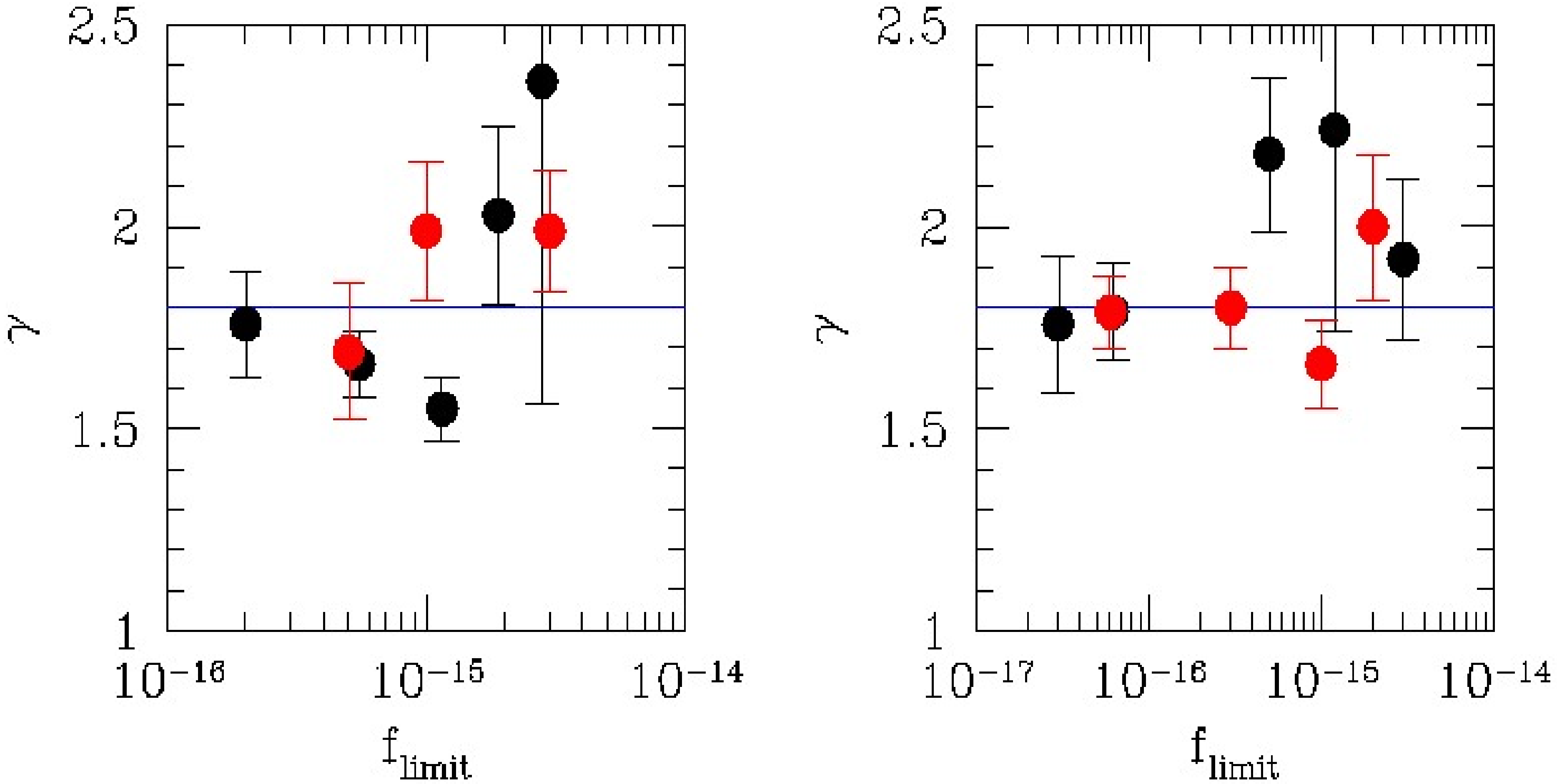
$$\Longrightarrow \ b(t) - 1 = At^{-2/3} + Bt^{-1} \qquad \text{for} \quad \Omega_o = 1$$

Bias using Linear Perturbation Theory: Basilakos & Plionis ApJ 2001, 2003. Note that β=3(1+w)

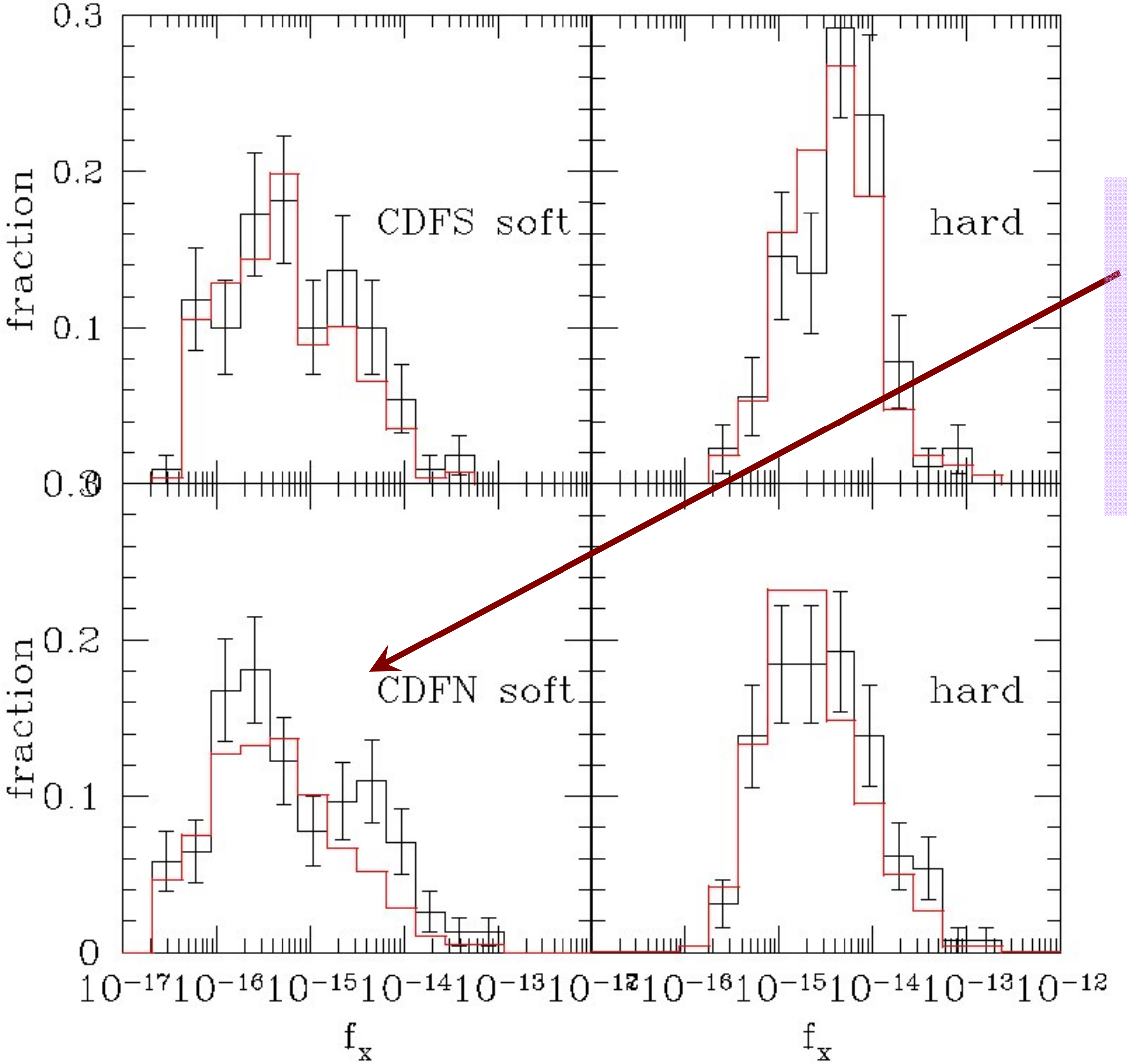
$$b(z) - 1 = \mathcal{A}E(z) + \frac{2\mathcal{C}}{\Omega_m^{3/2}} E(z)(1+z)^{\frac{\beta-3}{6-2\beta}} F\left[\frac{1}{6-2\beta}, \frac{3}{2}, \frac{7-2\beta}{6-2\beta}, -\frac{\Omega_x}{\Omega_m (1+z)^{3-\beta}}\right]$$



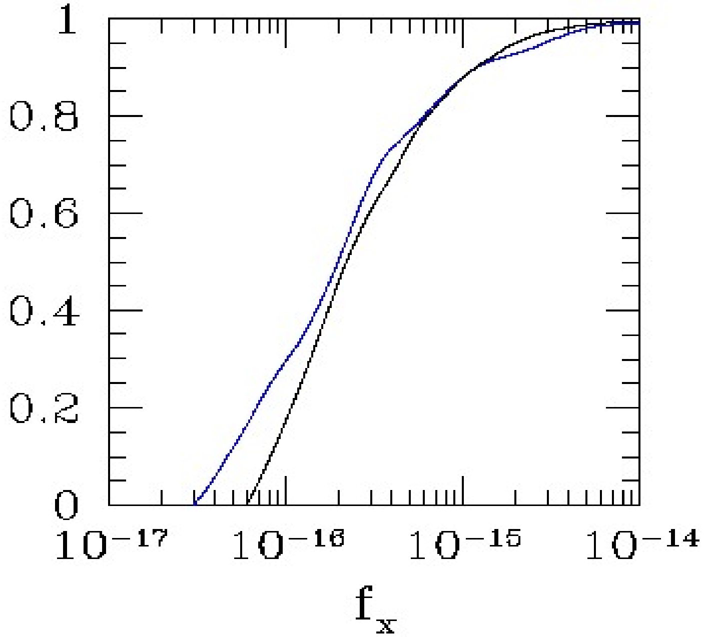
Exponent γ -- flux-limit dependence

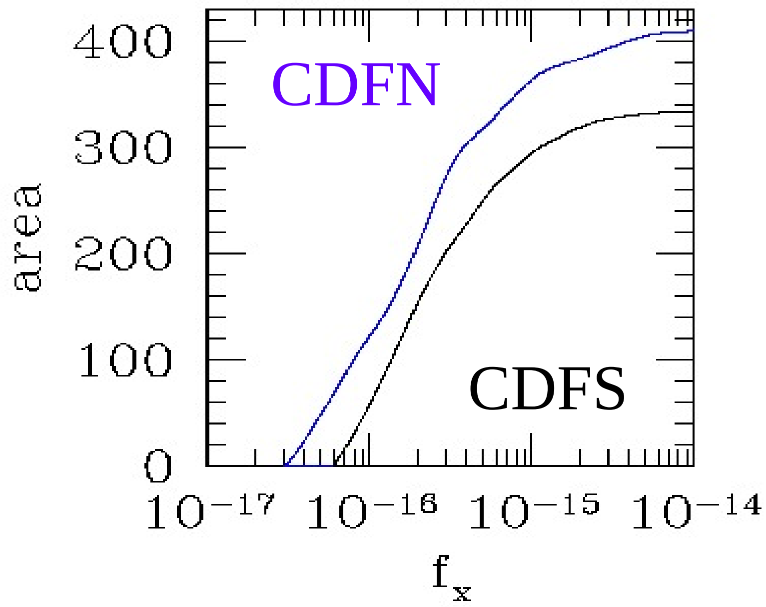


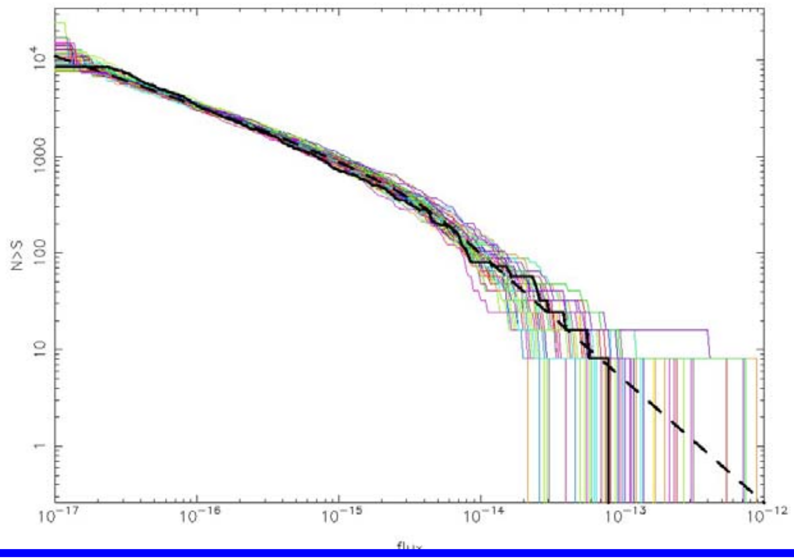
Note that our 2D→3D CDFN & CDFS results can be directly compared with the direct ξ(r) results of Gilli et al (2005) because their analysed *z* based subsample is a random realization of the whole source catalogue (no flux-dependence) – verified by KS tests

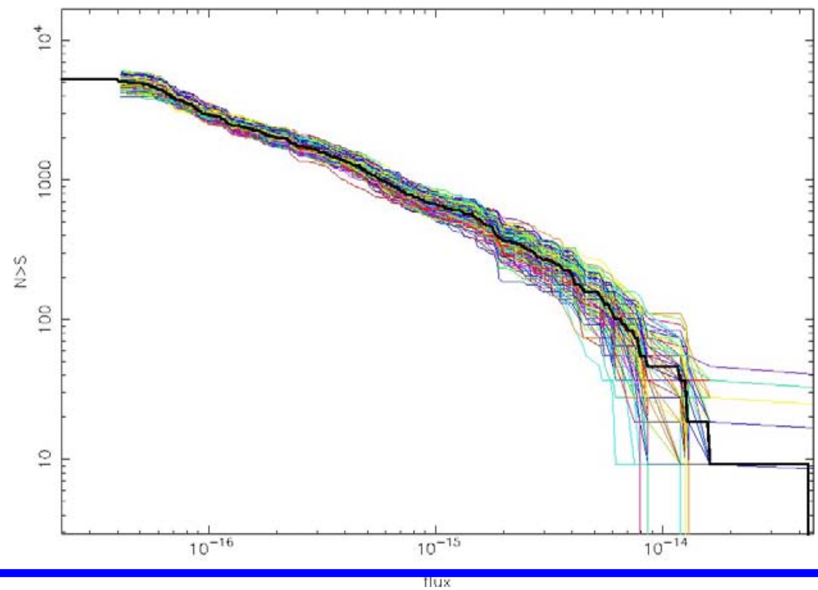


Only CDFN (soft) shows different distribution but not systematically brighter fluxes…



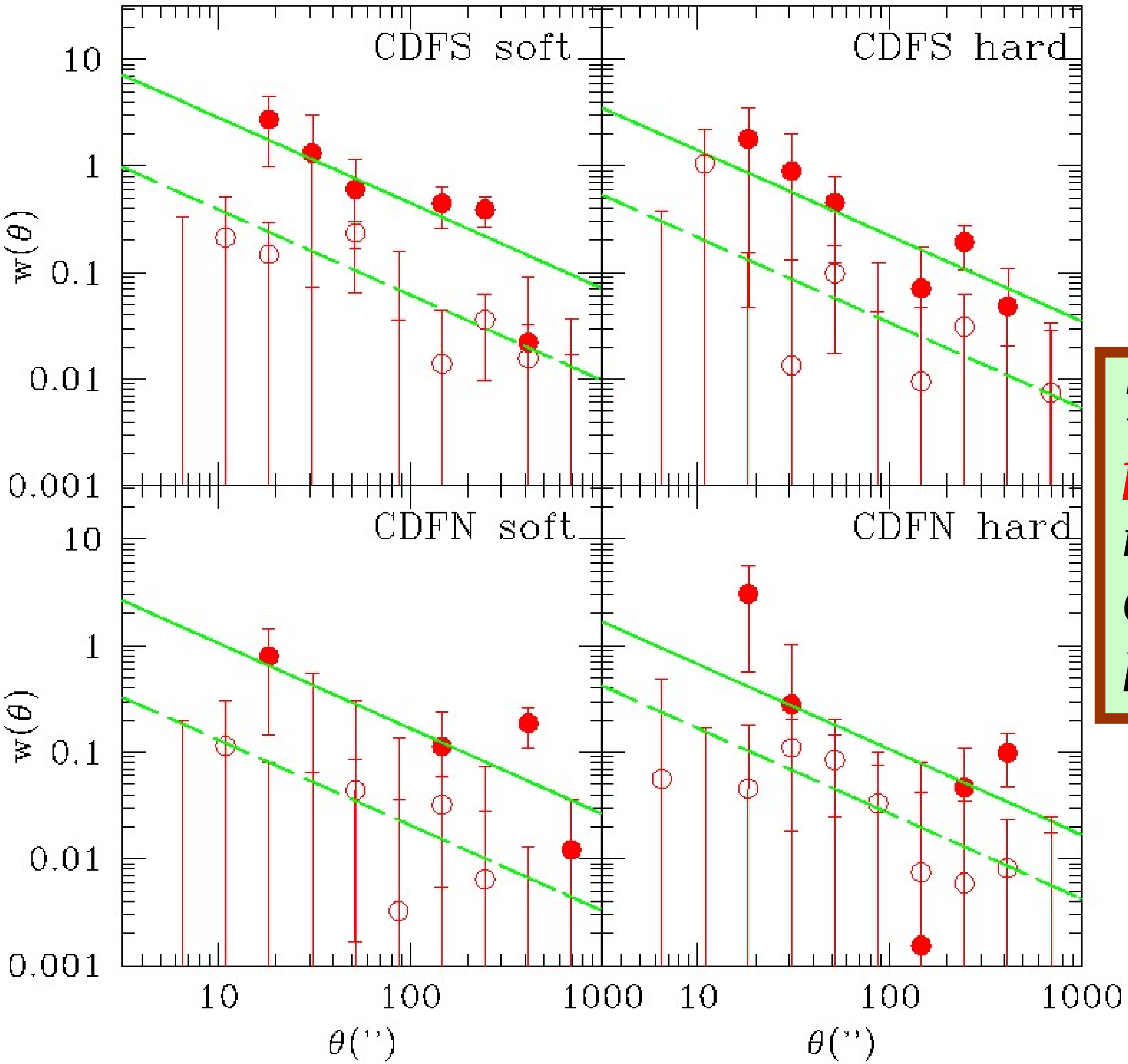






Random catalogues reproduce logN-logS in 2 ways: (a) using as input the theoretical curve (left panel) or (b) directly the one recovered by the X-ray sources themselves (right panel).

***RESULTS: The CDFN and CDFS** angular clustering properties*



There is a strong w(θ) flux limit dependence in both CDFN & CDFS (for the soft & hard bands)

To investigate issue of clustering differences we have ***re-analysed the CDFN and CDFS*** *clustering properties*

- *We use newly determined sensitivity maps (F.Bauer), which reduce by ~10% the Alexander et al. (2003) number of X-ray sources.*

- *We use the Bauer et al. (2004) classification and select only the AGNs in the 0.5-2 and 2-8 keV bands*

- *In order to use all the available sources and to avoid possible problems with misidentified optical counterparts, we work in angular space and then invert using Limbers equation and the LDDE luminosity functions of Hasinger et al 2006 (soft-band) and La Franca et al 2005 or Ueda et al. 2003 (hard-band).*

- *We verify that the logN-logS reproduces the Kim et al. (2007) and we take great care to reproduce it in the random-catalogues [used for the w(θ) analysis] by using also the same sensitivity maps used to find the sources.*

Inverting from projected to 3D correlations

Limber's Integral equation relates angular and spatial correlations under the assumption of power law correlations !

$$\xi(r) = (r_\circ/r)^\gamma$$

Modelling the evolution of the spatial correlation function by:

$$\xi(r,z) = (r/r_\circ)^{-\gamma}\,(1+z)^{-p}$$

Where *p* determines type of evolution (eg. *p=(3+ε)=1.8*→ constant clustering in comoving coordinates)

$$\theta_\circ^{\gamma-1} = r_\circ^\gamma H_\gamma \left(\frac{H_\circ}{c}\right)^\gamma \frac{\int_0^\infty dy\phi(y)^2[1+z(y)]^{-p}y^{5-\gamma}/F(y)}{[\int_0^\infty y^2 dy\phi(y)/F(y)]^2}$$

$$H_\gamma = \Gamma(\tfrac{1}{2})\Gamma(\tfrac{\gamma-1}{2})/\Gamma(\tfrac{\gamma}{2})$$

$$y = 2\frac{(\Omega-2)(1+\Omega z)^{1/2}+2-\Omega+\Omega z}{\Omega^2(1+z)}$$

$$F(y) = [1-y^2(\Omega-1)]^{1/2}$$

$$\phi(y) = \int_{L_{min}}^\infty \Phi(L_x,z)\,dL$$