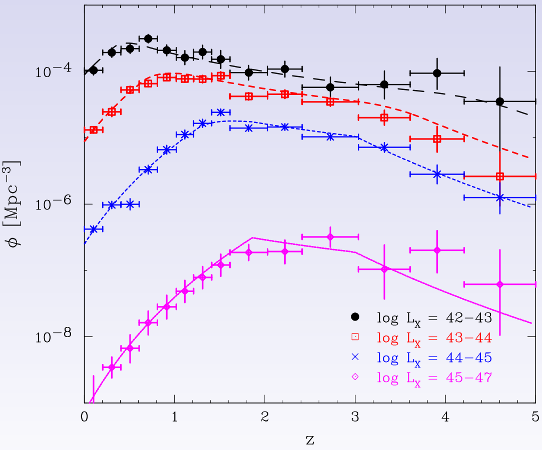
The Hard X-Ray Luminosity Function of High-Redshift ($z > 3$) AGN

Fabio Vito
Dipartimento di Fisica e Astronomia - Università di Bologna
INAF-OABo

F. Vito, R.Gilli, C. Vignali, A. Comastri, M. Brusa, N. Cappelluti, K. Iwasawa; MNRAS
accepted yesterday! (on astro-ph today)

AGN Population Evolution



Ueda+14

$z < 3$:
AGN "downsizing" (LDDE; e.g. Miyaji+00, Ueda+03, Hasinger+05, La Franca+05, Silverman+08, Ebrero+09, Yencho+09, Ueda+14)

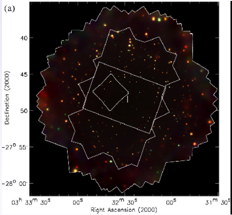
$z > 3$:
not well assessed.

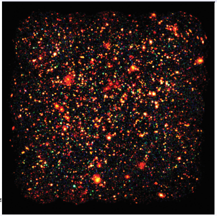
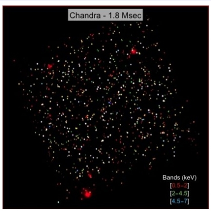
High-Redshift AGN Population Evolution

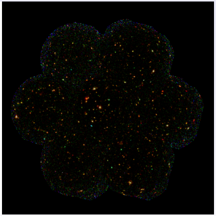
Need for large, complete and reliable samples

$\Downarrow$

- Deep (4 Ms CDF-S) and wide (XMM-COSMOS, Chandra-COSMOS, SXDS) X-ray surveys
- Multi-wavelength coverage.



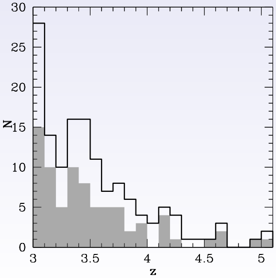


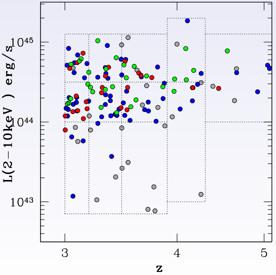
AGN sample

141 X-ray ($0.5 - 2\,\mathrm{keV}$) detected AGN at $3 \leq z < 5.1$

- $\sim$ 5 x Hiroi+12 sample
- $\sim$ 2 x Civano+11 sample

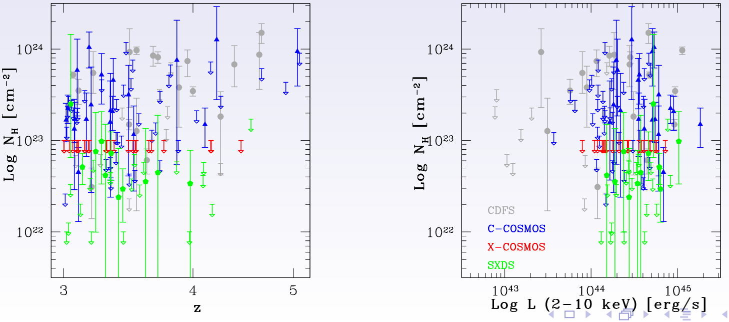
using the most up-to-date redshift information and a careful and clean (e.g. no strong radio-loud AGN) selection in the 4 Ms CDFS (Vito+13), XMM-COSMOS (Brusa+10, Salvato+11, Civano+12), Chandra-COSMOS (Civano+12, Lilly+ in prep.) and SXDS (Hiroi+12) fields. Redshift completeness > 95%.





Spectral parameters

- $\Gamma = 1.8$ fixed
- N_H from uniform spectral analysis (CDFS, C-COSMOS) or HR (SXDS, Hiroi+12). Objects from X-COSMOS assumed unobscured.
- Intrinsic $L_{2-10\,\mathrm{keV}}$ from spectral analysis (CDFS, C-COSMOS), literature (SXDS, Hiroi+12), or extrapolated from soft-band flux from catalogue (X-COSMOS, Cappelluti+09)

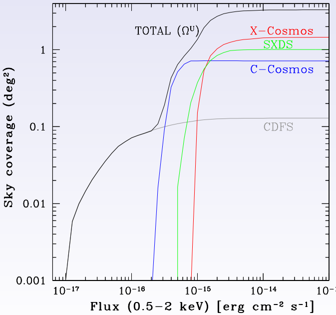


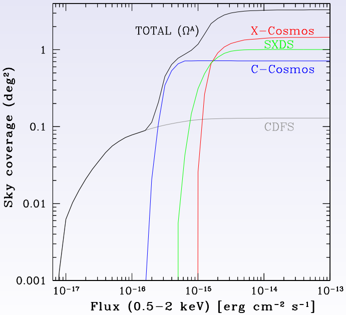
$$\phi = \phi^U + \phi^A$$

ϕ as in Page&Carrera 2000

$\log N_H < 23$ ↓ UNABSORBED (105 objects) ↓ Ω^U

$\log N_H > 23$ ↓ ABSORBED (36 objects) ↓ Ω^A

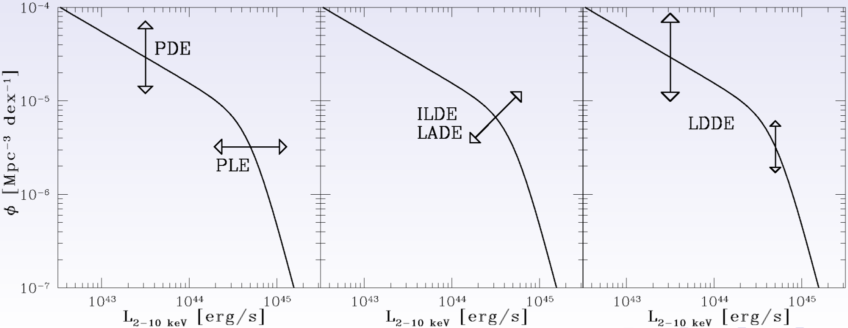




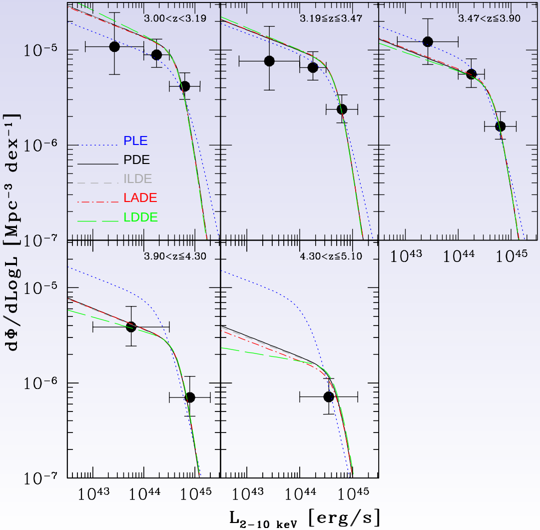
Evolutionary models

$$\Phi(L,z) = \frac{A(z)}{\left[\left(\frac{L}{L_*(z)}\right)^{\gamma_1} + \left(\frac{L}{L_*(z)}\right)^{\gamma_2}\right]}$$

- **PLE** : $L_*(z) \propto L_*(3) \cdot (1+z)^{p_{lum}}$
- **PDE** : $A(z) \propto A(3) \cdot (1+z)^{p_{den}}$
- **ILDE** : PLE + PDE
- **LADE** : PLE + $A(z) \propto A(3) \cdot 10^{p_{den}(1+z)}$
- **LDDE** : $A(z) \propto A(3) \cdot (1+z)^{p_{den}+\beta(logL-44)}$



Fit to unbinned data through a Maximum Likelihood procedure



MODEL	2DKS
PLE	0.05
PDE	0.38
ILDE	0.38
LADE	0.46
LDDE	0.42

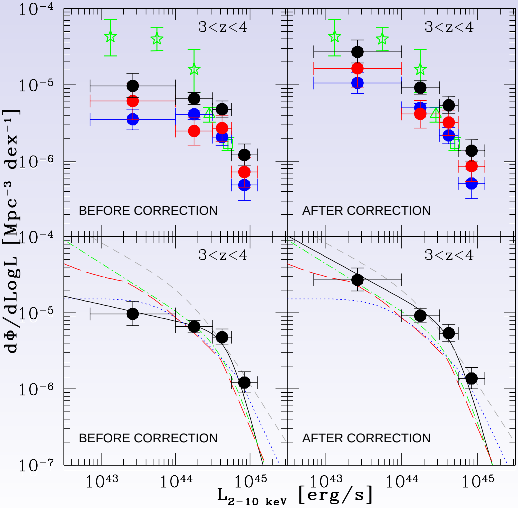
$2\text{DKS} \gtrsim 0.20$

$\downarrow$

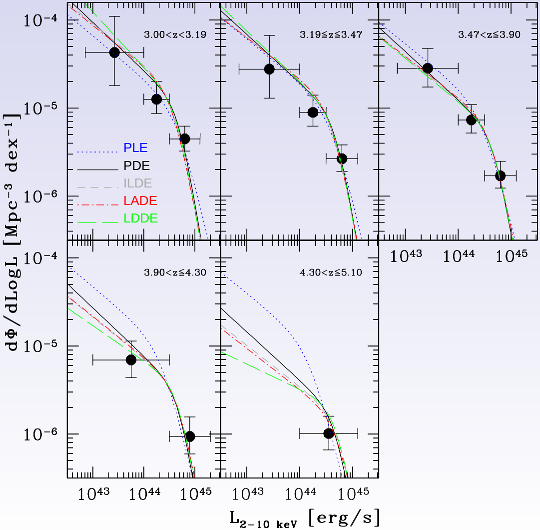
model and data not significantly different

Correction for redshift incompleteness: $\Theta = \Theta(z, L_X, N_H)$

- 65 sources with no redshift information (but flux known)
- All of them assumed to be at $3 < z < 5.1$
- Assumed same fraction of absorbed sources (at similar fluxes) and same redshift distribution of the sources with redshift

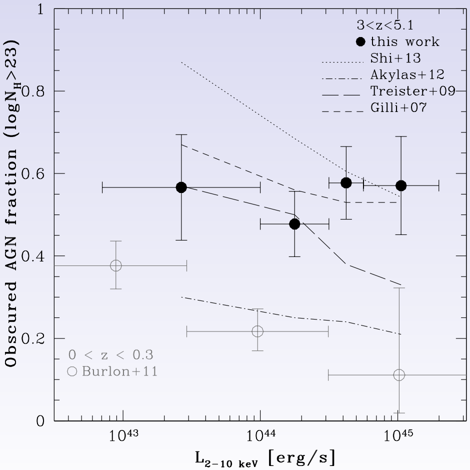


Fit to unbinned data after completeness correction

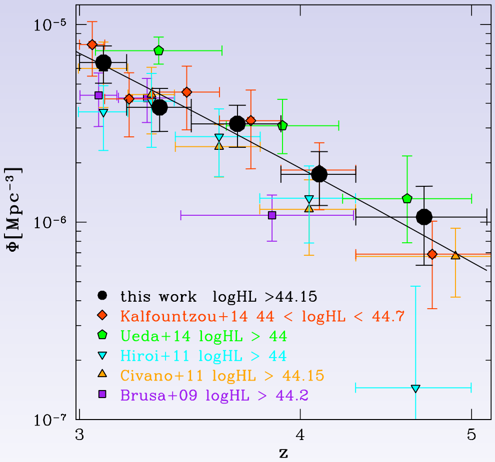


MODEL	2DKS
PLE	0.20
PDE	0.44
ILDE	0.20
LADE	0.23
LDDE	0.27

$$F_{(\log N_H > 23)} = \phi^A / (\phi^A + \phi^U)$$

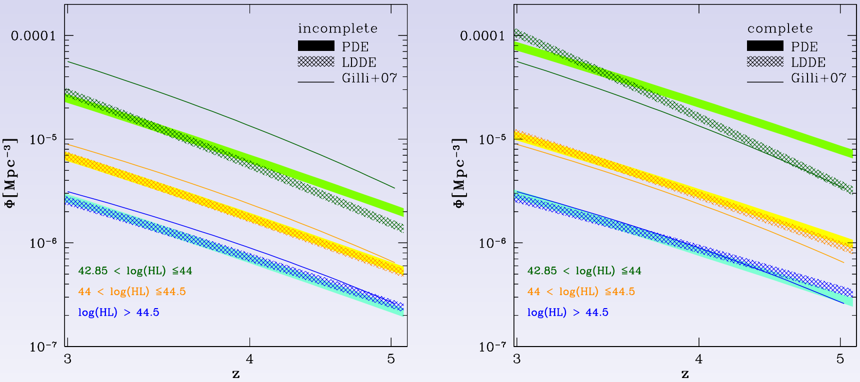


- Constant with luminosity (χ^2 fit returns $F_{23} = 0.54 \pm 0.05$)
- ...but the most obscured sources at low-L are probably missing!
- Evolution from $z = 0$ to $z > 3$



$$\Phi = \frac{dN}{dV} = \sum_{i=1}^{N} \frac{1}{V_{max,i}}$$

- $\Phi \propto (1+z)^p$ with $p = -6.00^{+0.84}_{-0.87}$, in agreement with Hiroi+12, but larger dataset and different method (Maximum Likelihood fit on unbinned data vs. χ^2 minimization)
- We confirm the decline in the space density of luminous high-redshift AGN (factor of ~ 10 from z=3 to 5)



- No evidence for the "up-sizing" (i.e. flatter space density for less luminous AGN at $z > 3$) suggested by Ueda+14
- Larger sample of $L_X < 10^{44}$ AGN needed to discriminate between PDE and LDDE

Conclusions

- Evolution of the HXLF at $z > 3$ dominated by a negative density term (PDE). More complex models mimic the behaviour of the PDE model. Larger samples of low-luminosity ($L_X < 10^{44}$) AGN needed to constrain a possible luminosity-dependent density evolution at high-z.
- Obscured ($logN_H > 23$) AGN fraction is 0.54 ± 0.05. No evidence for an anti-correlation with luminosity, but evolution from $z = 0$!
- The space density of luminous AGN declines by a factor of ~ 10 from z=3 to 5
- No evident dependency of the decline slope on luminosity, but larger low-L samples are required

Future perspective

Larger samples of (low-luminosity) AGN thanks to the 7 Ms in CDFS
(+ deep follow-up and/or proper photo-z)

Fit parameters

MOD.	A	L_*	γ_1	γ_2	p_{lum}	p_{den}	β	2DKS
PLE	$0.65^{+0.06}_{-0.06}$	$6.56^{+2.38}_{-2.22}$	$0.21^{+0.16}_{-0.20}$	$2.58^{+0.75}_{-0.60}$	$-3.73^{+0.77}_{-0.92}$	—	—	0.05
PDE	$1.10^{+0.11}_{-0.11}$	$5.26^{+1.06}_{-1.20}$	$0.22^{+0.13}_{-0.16}$	$3.79^{+1.08}_{-0.87}$	—	$-6.00^{+0.84}_{-0.87}$	—	0.38
ILDE	$1.13^{+0.11}_{-0.11}$	$5.13^{+1.32}_{-1.53}$	$0.21^{+0.13}_{-0.17}$	$3.75^{+1.10}_{-0.91}$	$0.13^{+0.94}_{-0.81}$	$-6.13^{+1.17}_{-1.23}$	—	0.38
LADE	$1.08^{+0.11}_{-0.11}$	$5.10^{+1.33}_{-1.54}$	$0.21^{+0.13}_{-0.18}$	$3.74^{+1.11}_{-0.91}$	$0.16^{+0.95}_{-0.82}$	$-0.57^{+0.11}_{-0.11}$	—	0.46
LDDE	$1.05^{+0.10}_{-0.10}$	$5.24^{+1.05}_{-1.19}$	$0.28^{+0.16}_{-0.19}$	$3.87^{+1.08}_{-0.88}$	—	$-6.43^{+1.12}_{-1.17}$	$1.18^{+2.06}_{-2.00}$	0.42

Binned HXLF

$$\phi = \frac{\Phi}{\mathrm{dlogL}} = \frac{\mathrm{d^2N}}{\mathrm{dV\,dlogL}}$$

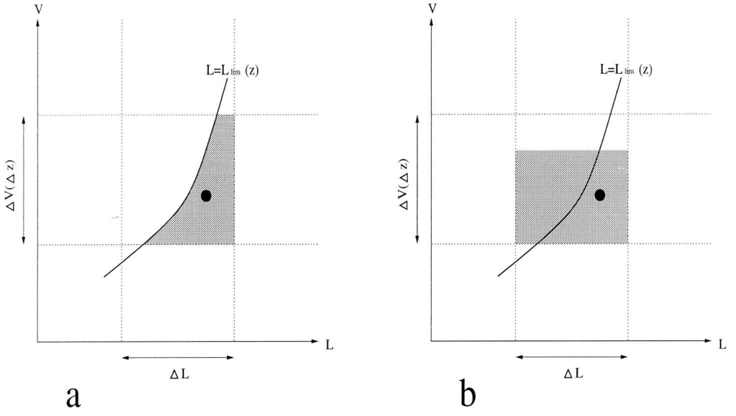
$$\Downarrow$$

Assuming ϕ does not vary in the $\Delta\mathrm{z}$–$\Delta\mathrm{LogL}$ bin
(i.e. narrow $\Delta\mathrm{z}$–$\Delta\mathrm{LogL}$ bin)

$$\Downarrow$$

$$\phi\Big|_{(\Delta\mathrm{z},\Delta\mathrm{LogL})} = \frac{N(\Delta z,\Delta LogL)}{V(\Delta z,\Delta LogL)} = \frac{N(\Delta z,\Delta LogL)}{\int_{\Delta\mathrm{logL}}\int_{\Delta\mathrm{z}} \Omega\Theta\frac{\mathrm{dV}}{\mathrm{dz}}\mathrm{dz\,dlogL}}$$

Binned HXLF: Page&Carrera2000 vs V_{MAX}



(Page&Carrera, 2000)

Likelihood estimator

$$\mathcal{L} = -2 \sum_{i=1}^{N} \ln[\phi(z_i, L_i)] + 2 \iint \phi(z, L) \Omega \Theta \frac{\mathrm{d}V}{\mathrm{d}z} \mathrm{d}z \mathrm{d}L$$

(Marshall+1983)