Extended Chandra Multi-Wavelength Project (ChaMPx):

Source Catalog and Applications

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& ChaMP Collaboration**

Abstract

We present new results of the Extended Chandra Multi-wavelength Project (ChaMPx). In addition to our original ChaMP sample where we only used Chandra AO1-2 archival data, we extend to Chandra AO3-6 observations if they are also covered by the SDSS optical images. We cross-correlated Chandra X-ray and SDSS optical sources and visually inspected both X-ray and optical images for each match. Our catalog consists of 13458 X-ray sources of which 6347 sources have optical counterparts and 1347 sources are further identified by optical spectra. We developed sky coverage maps which provide limiting fluxes at every sky location covered in our X-ray dataset. We summarize recent results from ChaMP/SDSS samples of ~1100 QSOs, ~350 stars, ~150 normal galaxies serendipitously detected in ChaMPx.

Extended ChaMP (ChaMPx)

First ChaMP Catalog (M. Kim et al 2007) ➔

149 observations from Chandra observing cycle AO1-2

6600 X-ray sources from ~10 deg^2 of the sky

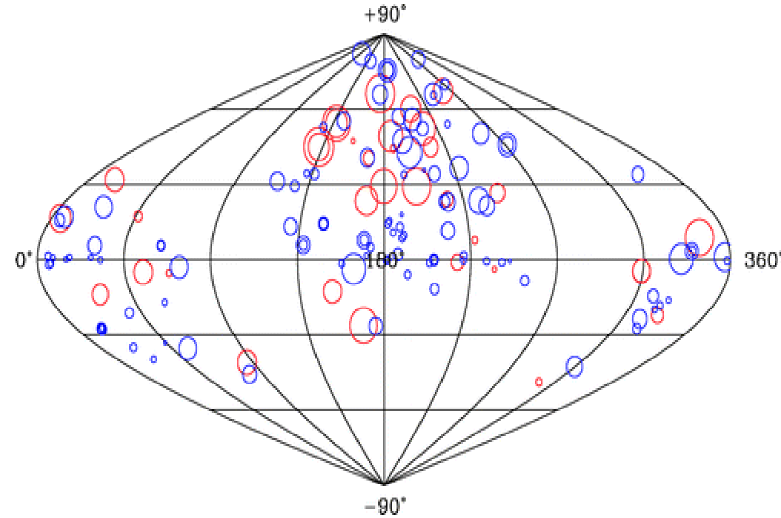
ChaMPx ➔

Additional 258 obs from Chandra observing cycle AO3-6

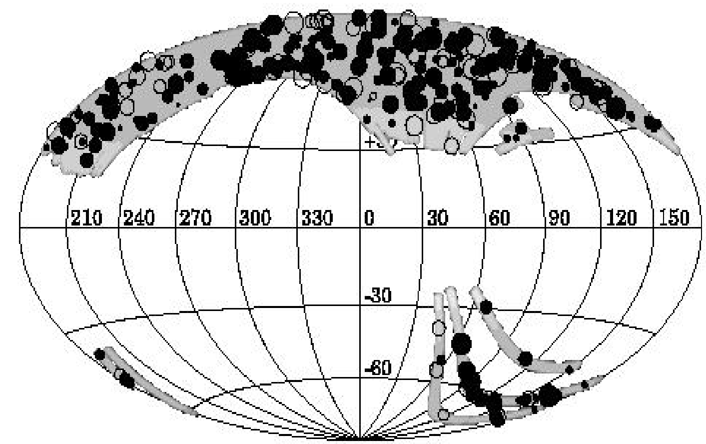
also covered by SDSS DR5 optical images

13458 X-ray sources from ~20 deg^2 of the sky

Equatorial coordinates



Galactic coordinates



ChaMPx Source Catalog

X-ray information for 13458 sources

(select sources detected in I0-3 and S2-3; excluded false sources, e.g., afterglows)

Multi-band X-ray count rate, flux, luminosity (when z is known)

X-ray hardness ratio, colors

Time variability

Position uncertainty (by empirically determined formula)

** **Source detection limits** (for both detected and undetected sources)

Optical match and imaging information for ~50% (6347 sources)

x-o distance

** matching confidence (given by visual inspection)

broad band magnitudes/colors

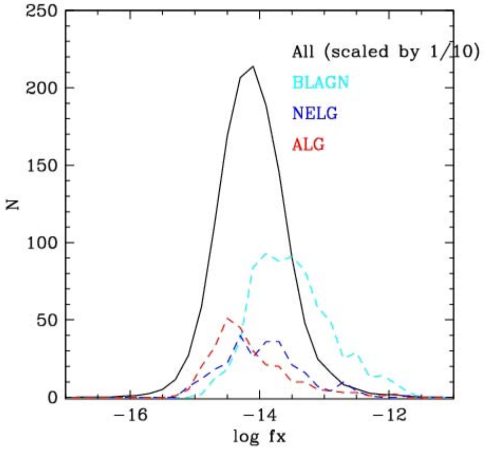
photometric z for 4953 sources (~3000 w/ z=0.01-0.9)

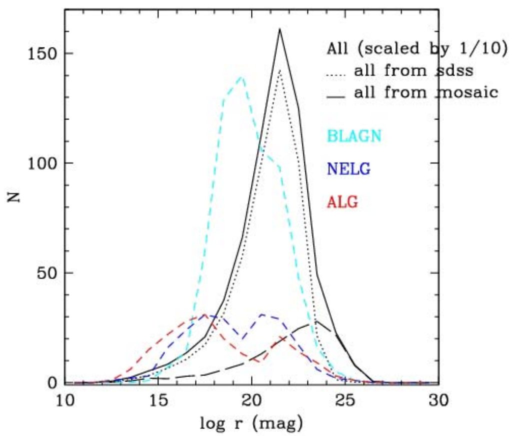
Optical spectroscopic information for ~10% (1347 sources)

spectroscopic identification

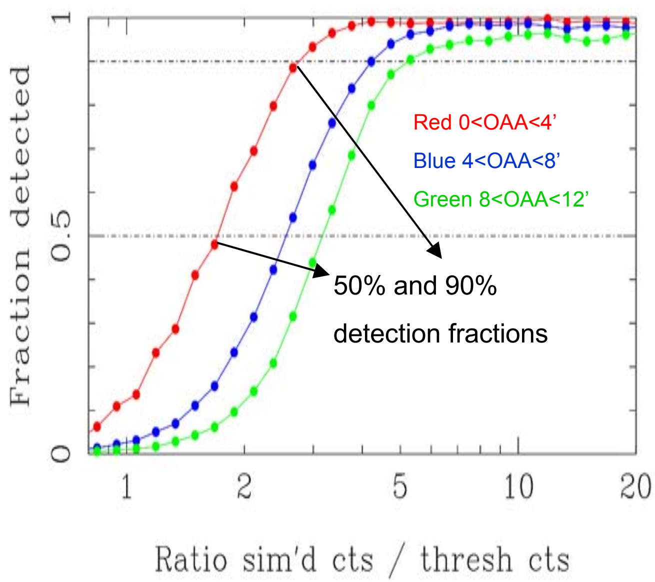
spectroscopic z for 1196 sources

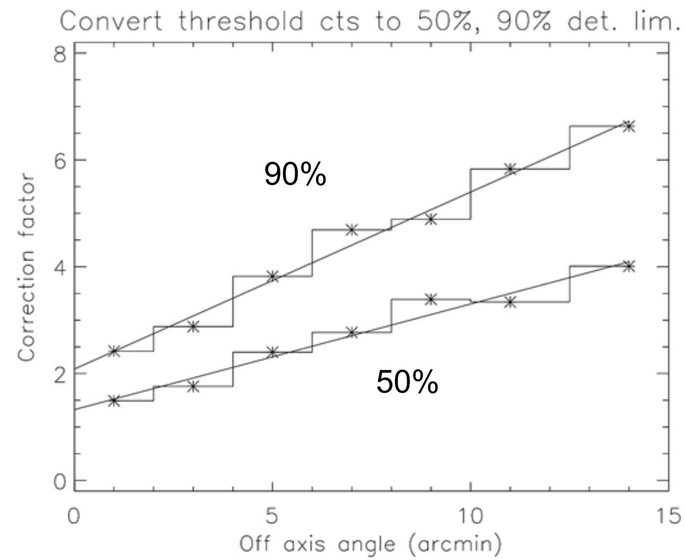
(This catalog will be available in the summer.)





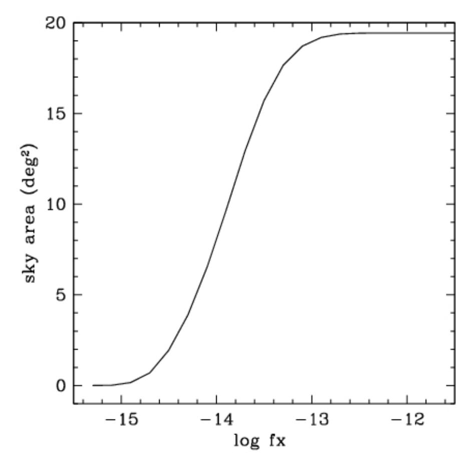
X-ray Source Detection Limits





Threshold map is generated by wtransform (part of wavdetect)
It is then calibrated by simulations to estimate a detection limit in a given confidence.
This procedure also tested and confirmed with 21 CDF-S obsids (1.8 Msec exposure).

➔applicable to (1) estimate detection upper limit for a given undetected object
(2) determine sky area (as a function of fx) for a given sample



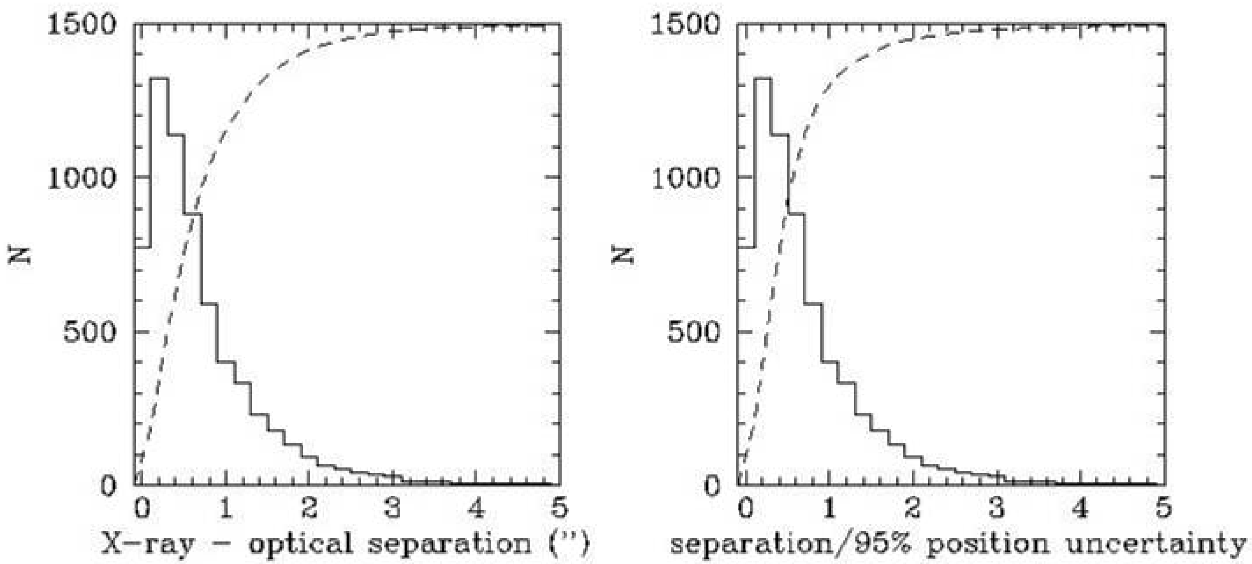
X-ray-Optical Source Match

Visual inspection

Every source was visually inspected and the match confidence was assigned
We use only reliable matches with a high confidence

X-ray – optical source position offset

80% of matches within 1 arcsec
85% of matches within 95% X-ray position uncertainties
which was empirically determined by simulations



(dashed lines for the cumulative fraction)

Source Types

Comparison of ID/types: spec_type, photoz_type, ext_type (optical extendedness)

Types determined by optical spectra:

659 BLAGN
245 NELG
247 ALG
190 stars

comparison between spec_type and photoz_type

photoz_type		total	BLAGN	NELG	ALG	STAR
-0.1	0.0	583	35+	22	72	15
0.0	0.1	293	1	16	23	21
0.1	0.2	221*	2	13	12	5
0.2	0.3	215*	2	15	5	4
0.3	0.4	200*	6	10	6	1
0.4	0.5	181*	7	15	5	0
0.5	0.6	203*	5	5	4	1
0.6	0.7	167*	5	14	1	0
0.7	0.8	202	11	12	1	3
0.8	0.9	204	11	8	0	1
0.9	1.0	247	19	6	0	0
1.0	1.1	2241**	357	9	1	3

+ Wrong photoz_type
  (photometric z is way off from spec z)

** 2241 objects (identified as photoz_type>1) are likely BLAGNs with a very small (~3%) contamination

* 73% of 1187 objects (photoz_type = 0.1-0.7) are NELG + ALG.

comparison between spec_type and ext_type

spec_type	ext_type=3 (extended)	ext_type=6 (point-like)
BLAGN	80	397
NELG	138	9
ALG	126	6
contin	2	5
STAR	5	49
unclass	0	1
NULL	2136+	2003++

+ 75% of 2136 optically extended objects are likely galaxies (NELG+ALG).

++ 85% of 2003 optically point-like objects are likely BLAGNs

X-ray to optical flux ratio, F_{XO}

[$\log f_{XO} = \log f_X + r/2.5 + 5.36$ (f_X = X-ray flux in 0.5-8 keV)]

spec type vs fxo

spec type	log fxo<-2	-2:-1	>-1
BLAGN	0	38	587
NELG	39	49	124
ALG	79	42	72
conti	1	1	6
star	57	61	15
unclass	0	0	1
NULL	97	364	4710
	273	555	5515

ext type vs fxo

ext type	log fxo<-2	-2:-1	>-1
extended	128	293	2057
point-like	62	159	2246
NULL	83	103	1212
	273	555	5515

photoz type vs fxo

photoz type		log fxo<-2	-2:-1	>-1
-0.1	0.0	76	100	405
0.0	0.1	41	86	166
0.1	0.2	18	42	160
0.2	0.3	8	40	167
0.3	0.4	7	25	167
0.4	0.5	6	25	150
0.5	0.6	6	23	170
0.6	0.7	4	18	145
0.7	0.8	8	22	171
0.8	0.9	4	8	192
0.9	1.0	6	4	236
1.0	1.1	6	59	2174
		190	452	4303

Object types and f_{XO} can be used to distinguish different samples.
e.g., *normal galaxies* can be selected by the following criteria (to effectively exclude AGNs):

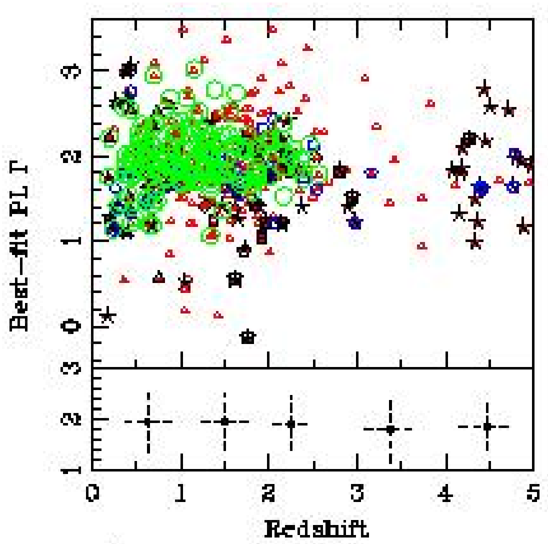
(log f_{XO} < -2) & (spec type = NELG or ALG)

or (log f_{XO} < -2) & (ext type = extended) & (photoz type < 1.0)

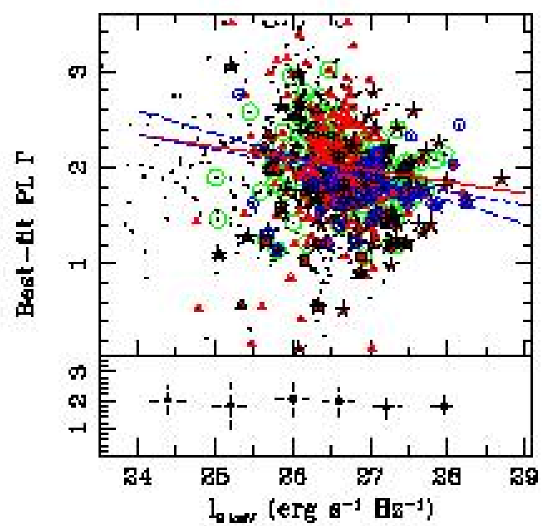
ChaMPx Quasars

P. Green et al. 2008 submitted to ApJ

1135 X-ray detected quasars in z = 0.2 - 5.4, representing 36 Msec of eff. exposure (57 QSOs at z > 3)



No evidence of evolution out to z=5 for either spectral index (Γ) or α_{ox}



Significant hardening toward higher Lx (and smaller α_{ox})

ChaMPx Stars

(ChESS = ChaMP Exended Stellar Survey)

K. R. Covey et al. 2008 submitted to ApJ

348 X-ray emitting stars

(see poster by Argueros et al. in this meeting)

ChaMPx Normal Galaxies

D.-W. Kim et al. 2008 in prep.

(preliminary results presented

in 2007 Vulcano meeting)

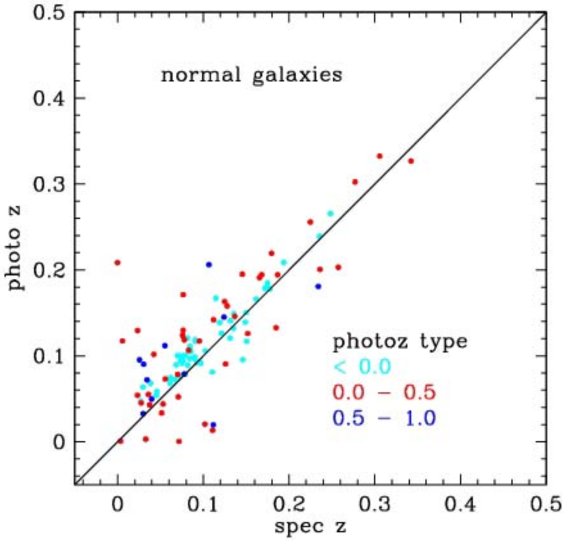
- 147 Normal galaxies selected by Fxo, spec type, extendedness, photoz type with spec z (125) and/or photo z

- Log(N)-log(S) and X-ray luminosity function of normal galaxies

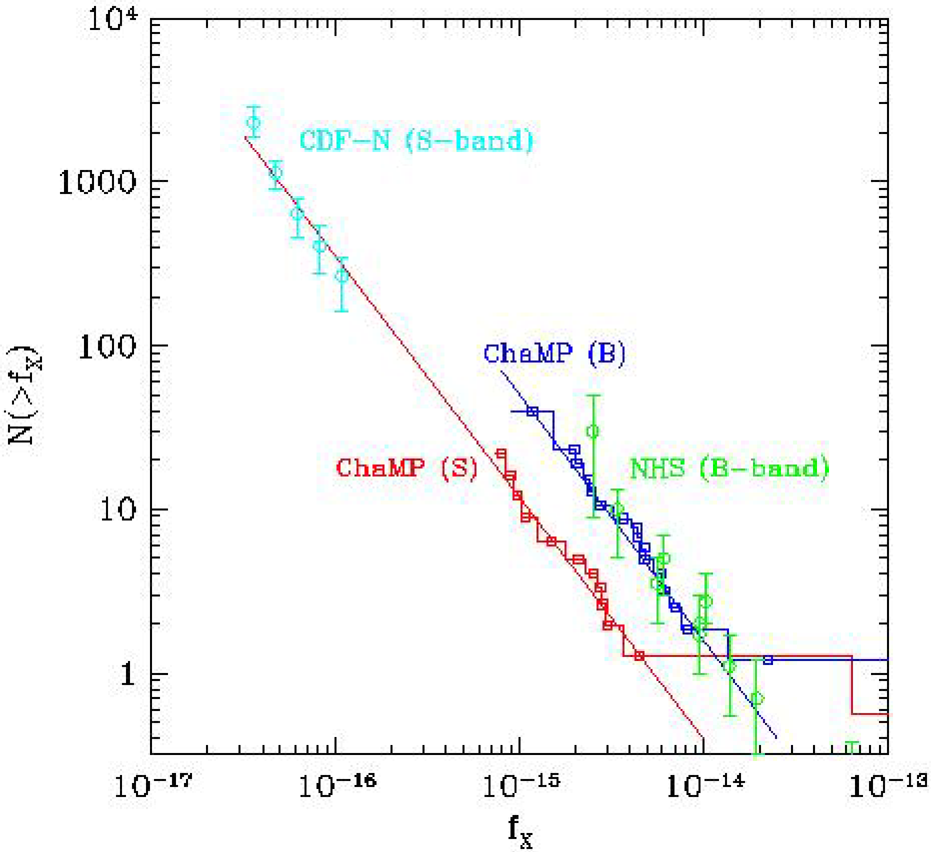
- ULX (off-nuclear luminous X-ray sources): found in ~10% of normal galaxies

- E+A galaxy: 3 candidates with no intrinsic absorption (against dusty starbursts)

- Additionally, 66 XBONG candidates: heavily obscured in the high luminosity end



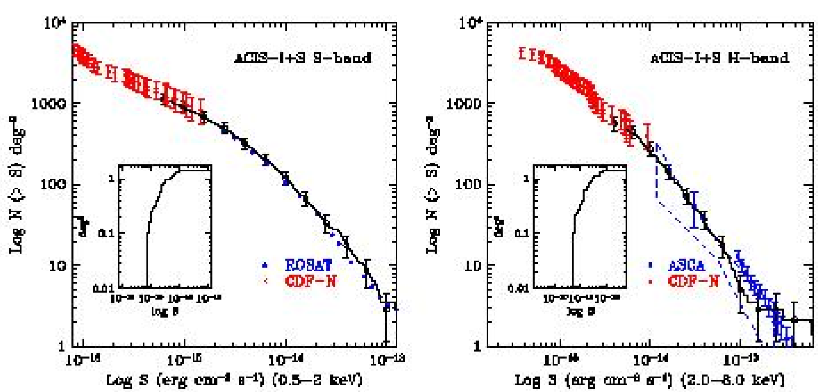
Log N-Log S for Normal Galaxies



For completeness, we further limit our sample to 24 obsids with full optical imaging spectroscopic obs.

Calculate X-ray sky coverage as a function of S_X by extensive simulations (Kim, M. et al. 07) A similar method as applied for LMXB's XLF (Kim & Fabbiano 03, 04)

- same shape in S-band and B-band
- our slope = 1.5
  steeper than CXB (0.7 below the break)
  less steep than CDF-N (1.74± 0.3)
- normal galaxies will exceed in number over the AGN population (Bauer et al. 05) at faint F_X ~10^{-18} erg s^{-1} cm^{-2}
  (lower than the previous estimate)



← ChaMP logN-logS (Kim et al. 2004)

from E-ChaMP

out of 6553 x-ray sources with optical ID

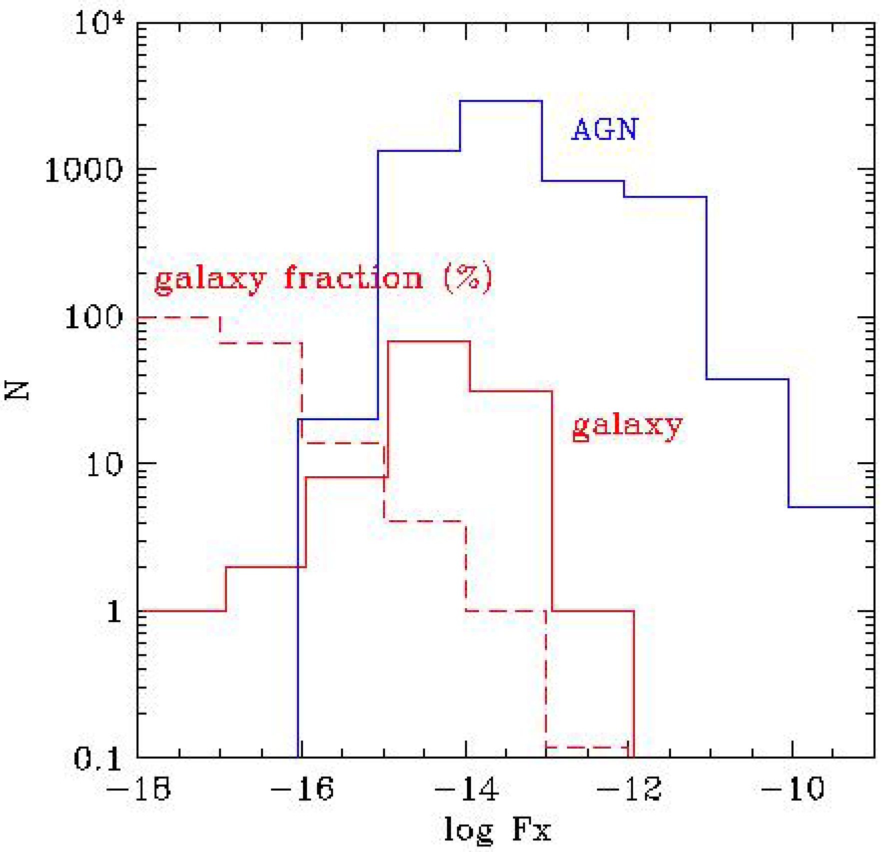
	fxo<0.01	(0.01:0.1)	fxo>0.1
extended	111*	260	2750*
point src	88	145	3005*

Cosmic X-ray background **(Hickox and Markevitch 2007)**

80% of the total extragalactic CXRB resolved at 1-2 keV, but the remaining CXRB requires logN-logS steeper than that of AGNs

➔subpopulation of normal galaxies

(the best fit slope of 1.3)



Off-nuclear ULXs

(Ultra-Luminous X-ray Sources)

ULX with $L_X > 10^{39}$ erg s^{-1} (exceed Eddington L_X of stellar mass BH) often found in star burst galaxies in the local universe and known to be **correlated with SFR (e.g. Gilfanov et al 2004; Swartz et al 2004)**
➔ ULX can be used to probe SFR and its increase with z

Ptak and Colbert (2004) found
12% of RC3 spiral and Irr galaxies with 1 or more ULX (10^{39} erg s^{-1})

Lehmer et al. (2006) found 24 ULX candidates from CDFs at z=0.05 – 0.3
Fraction **elevated** (~80% confidence) by a factor of 1.9 (+1.4 -1.3) from the local value

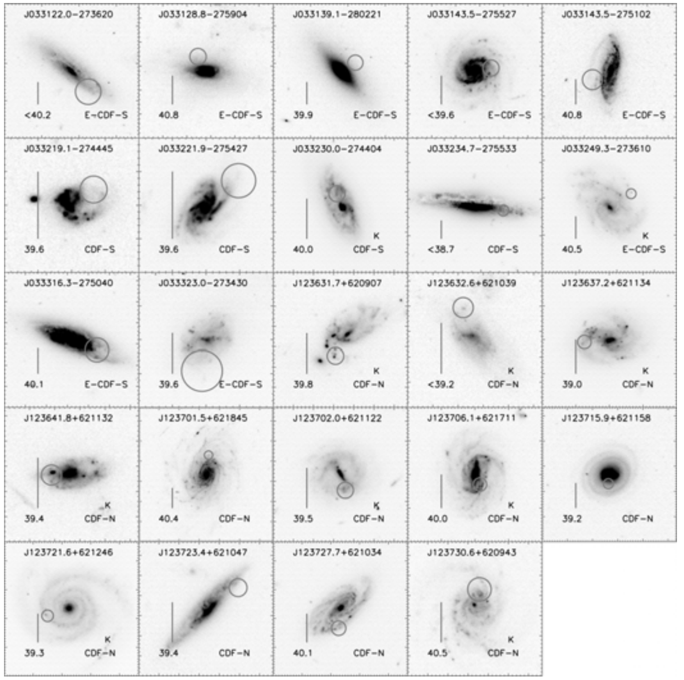
from E-ChaMP (z = 0.01 - 0.13)

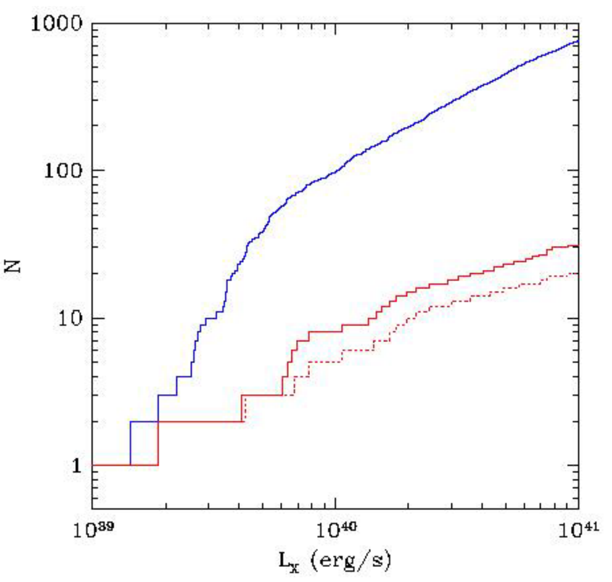
Out of 2740 galaxies (Chandra fov, R_{25} > 20" and r =15-19 mag and z>0.01), 835 galaxies have the limiting luminosity ($L_X = 10^{41}$ erg s^{-1})

Fraction of galaxies with ULX candidate (Lx > 2 x 10^39 erg/s) = 10%
after removing 20% bkg src within 1/2 D25.
assuming that all the src in 1/2 x D25 < r < D25 are bkg src

the fraction depends on galaxy size
50% increase in bigger galaxies (R < -20 mag) than in smaller (R > -20)

Lehmer et al. (2006)





XBONG

X-ray **B**right **O**ptically **N**ormal **G**alaxies = ALG with $L_X > 10^{42}$ erg s^{-1}
known to exist since Einstein (Elvis et al. 1981)

• Could be intrinsically luminous, but obscured AGN, where the obscuration must be extreme and cover all direction to hide both BL and NL.

Out of **21** candidates, **2 heavily obscured**.

Name	net counts S	net counts H	r (mag)	z	log fx/fo	log Lx (erg s^{-1})	HR	1σ limit (lower upper)
CXOMP J105626.8-033721	14.46	86.04	21.26	0.643	-0.08	43.36	0.72	(0.63 0.81)
CXOMP J205601.2-042955	0.68	9.18	21.33	0.370	-0.74	42.09	1.00	(0.68 1.00)

• Dilution of nuclear emission lines (from type 2) by the stellar light of the host galaxy
But no significant distinction between AGN2 and XBONG candidates in Fx, Fo, Lx, Lo

• Inner radiatively inefficient accretion flow which could in turn produce strong IC X-ray emission (Yuan and Narayan 05)

from E-ChaMP

66 XBONG Candidates

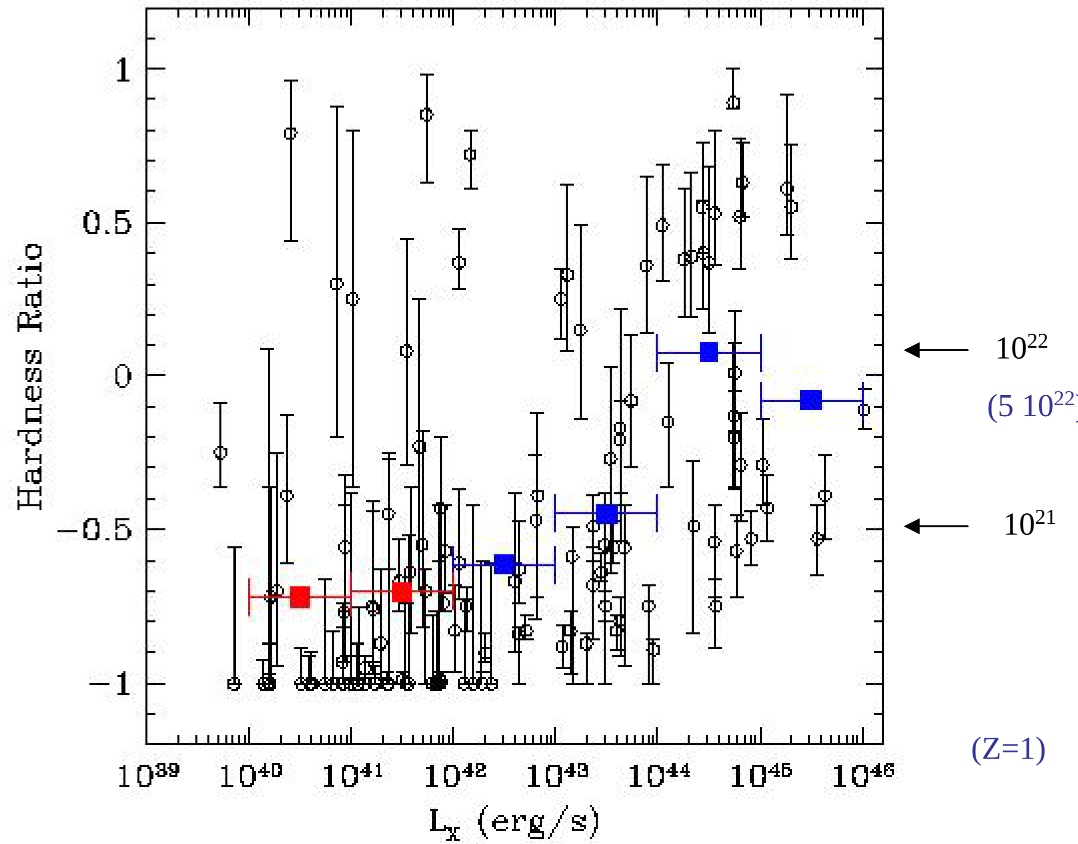
($L_X > 10^{42}$ and ALG)

Lx	#	<HR>	#(HR>0)*		
40-41	18	-0.721506	2	11%	
41-42	30	-0.703647	3	10%	
42-43	16	-0.614662	2	13%	
43-44	23	-0.448117	4	17%	
44-45	20	0.075500	11	55%	←
45-46	6	-0.080000	2	33%	←

(HR > 0 == $N_H > 10^{22}$ cm^{-2} at z=0)

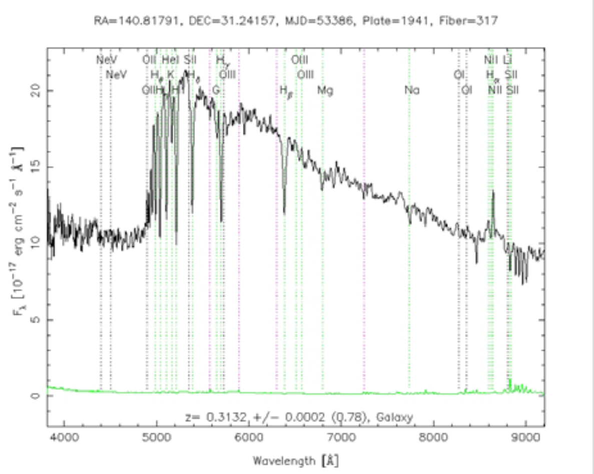
➔heavily obscured populations

in the luminous end!



E+A Galaxies

E+A galaxies – strong Balmer absorption lines + no emission in [OII]
== Post starbursts with a recent star burst in ~1 Gyr ago, but no sign of current SF



What truncates the star formation abruptly?
Link to other types of galaxies in their evolutionary path?
(blue galaxies at high z, S0 progenitors?)

- cluster-related mechanism
- merger/interaction origin 🡐 (Goto 05: excess local density)
- dusty starbursts (with current, but hidden star formation)

We identified 3 E+A candidates (2 from ChaMP sp + 3rd one from E-ChaMP, also in Goto 07 sample):

name	net counts S	net counts H	r (mag)	z	log fx/fo	log Lx (erg s^{-1})	HR	1σ limit (lower upper)
CXOMP J113956.1+660553	17.5	0.0	18.90	0.376	-1.96	42.25	-1.00	(-1.00 -0.82)
CXOMP J230243.1+083945	136.5	53.5	19.26	0.438	-0.69	43.14	-0.44	(-0.53 -0.34)
092316.3+311431	8.1	3.6	17.58	0.313	-1.11	43.05	-0.67	(-0.92 -0.36)

All candidates have soft X-ray emission ➔ ***can not be dusty starbursts***
1 (+1) has a close companion in ~50 kpc ➔ consistent with ***merger/interaction scenario*** (Goto 05)
X-ray bright ➔ E+A phenomenon somehow ***enhances X-ray*** emission (?)