Multi-epoch variability of α_{ox} in the CDFS

Fausto Vagnetti

most results by: Marco Antonucci
+ Dario Trevese, Maurizio Paolillo, ...

XMM CDFS Team meeting - Cervia, 2012 May 31- June 1

outline

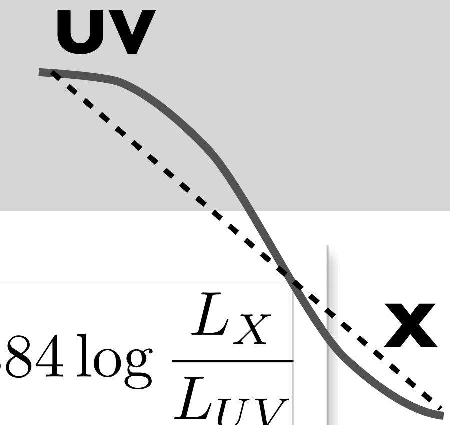
present work on the XMM CDF-S data is part of a research
on the variability of α_{ox} with analyses of more samples

the α_{ox}-L_{UV} relation
dispersion and variability
samples with simultaneous X-UV measurements

→ XMMSSC+XMMOMSUSS
Grupe+ 2010 /Swift
XMM deep survey in the CDF-S

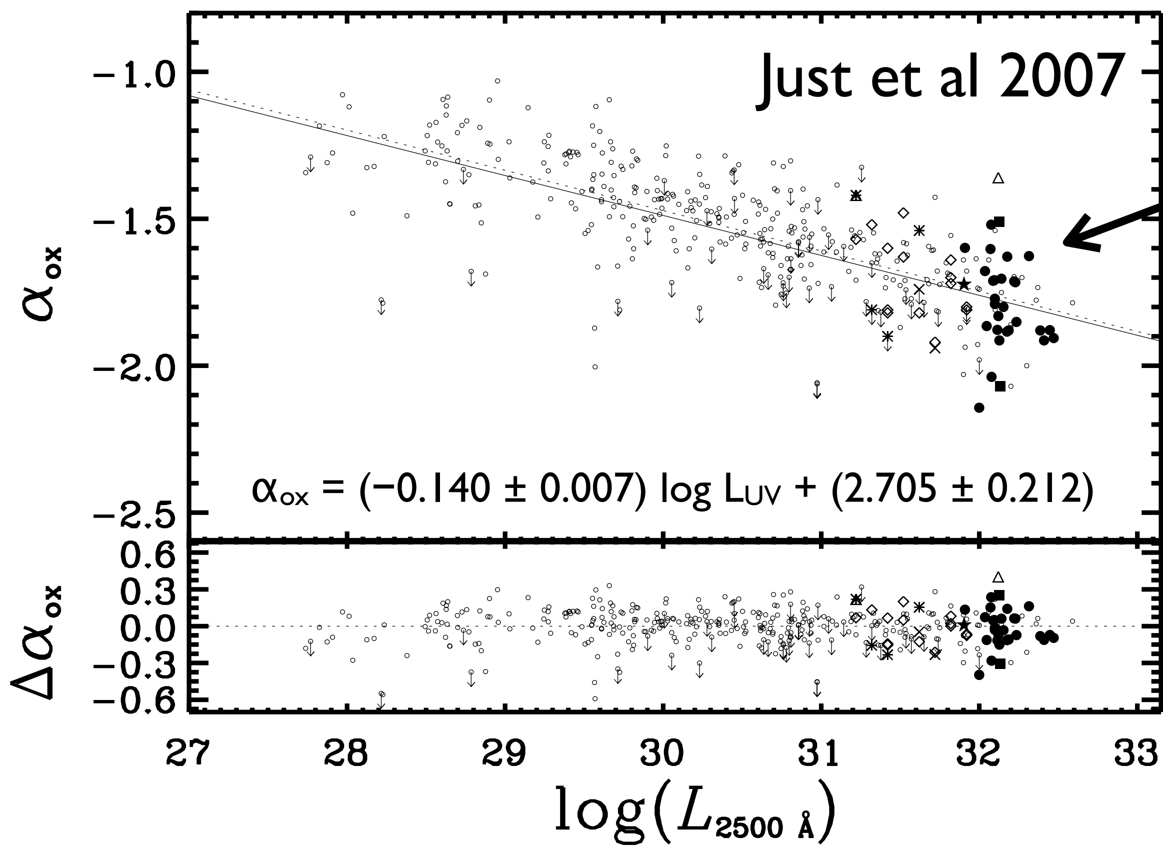
→ archival data - epochs - sources
light-curves
tracks in the α_{ox}-L_{UV} plane
structure functions

the α_{ox}-L_{UV} relation

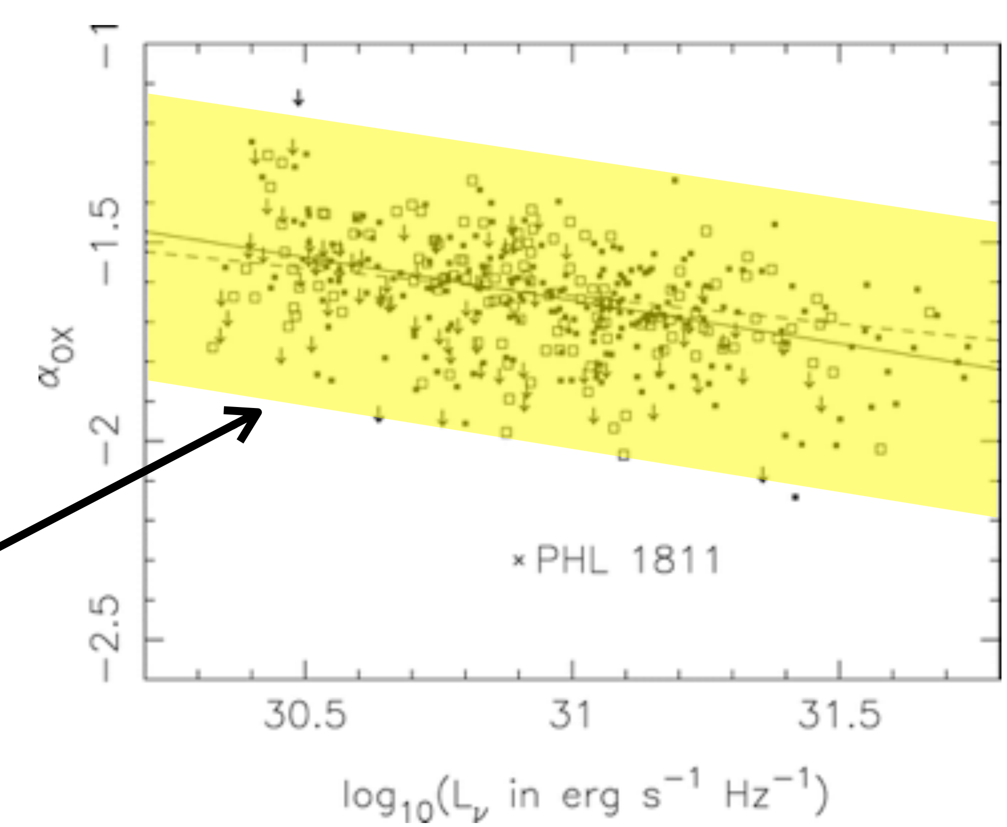


studied by many authors, e.g. Avni & Tananbaum 1986, Vignali et al 2003, Strateva et al 2005, Steffen et al 2006, Just et al 2007, Lusso et al 2010, Young et al 2010, Grupe et al 2010 etc

$$\alpha_{ox} = \frac{\log[L_\nu(2\mathrm{keV})/L_\nu(2500\text{Å})]}{\log[\nu(2\mathrm{keV})/\nu(2500\text{Å})]} = 0.384 \log \frac{L_X}{L_{UV}}$$



more luminous objects are relatively weaker in X-rays



BUT:

Gibson Brandt & Schneider 2008: large **dispersion**, possibly due to **variability** and/or **non-simultaneity** of X and UV

samples

to analyse α_{ox} variability wish to have samples with multi-epoch, simultaneous X/UV measurements

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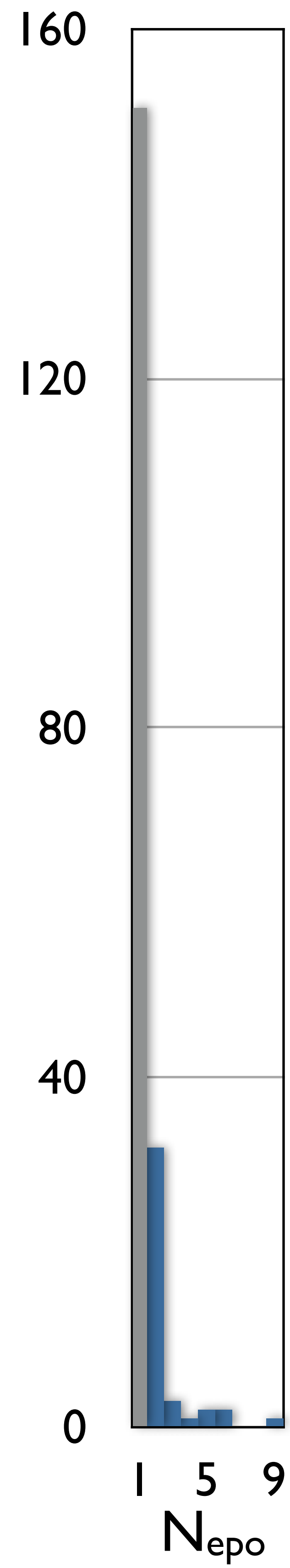
- XMM serendipitous source catalogs
  Vagnetti et al 2010, 192 radio-quiet non-BAL sources, 41 multi-epoch (2-9 epochs)



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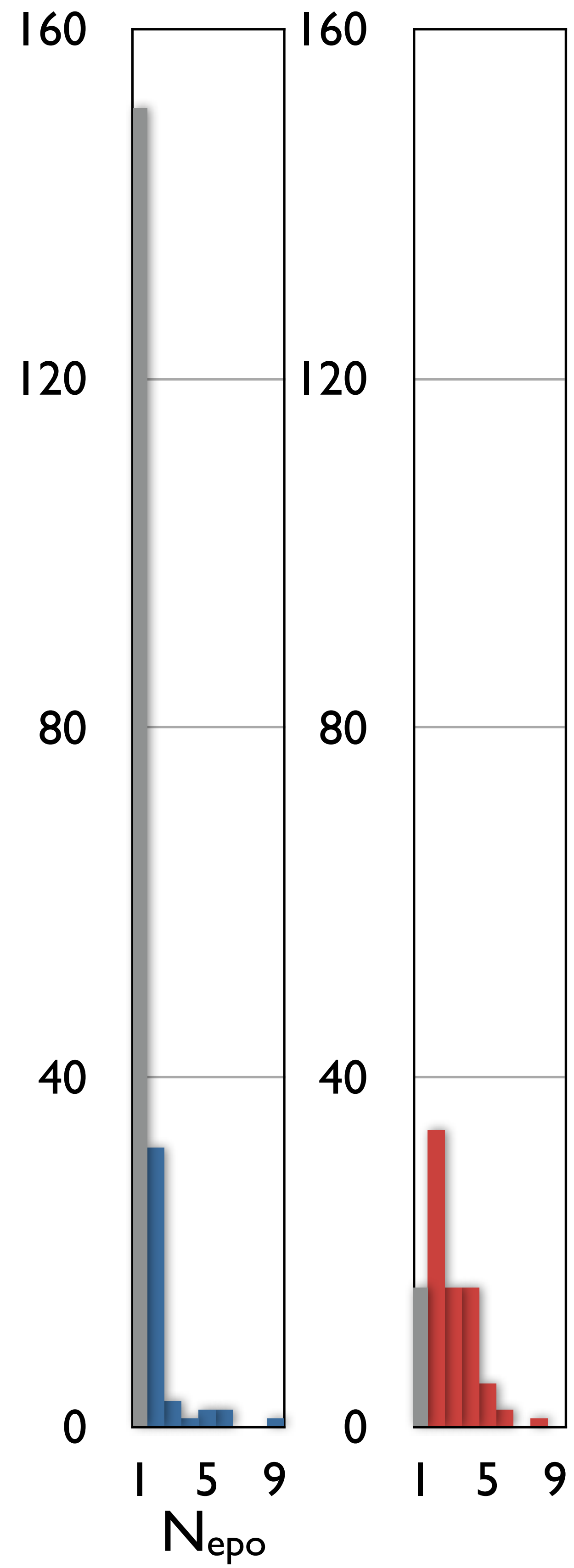
  90 low z sources re-analysed by us, 67 multi-epoch (2-8 epochs), in progress



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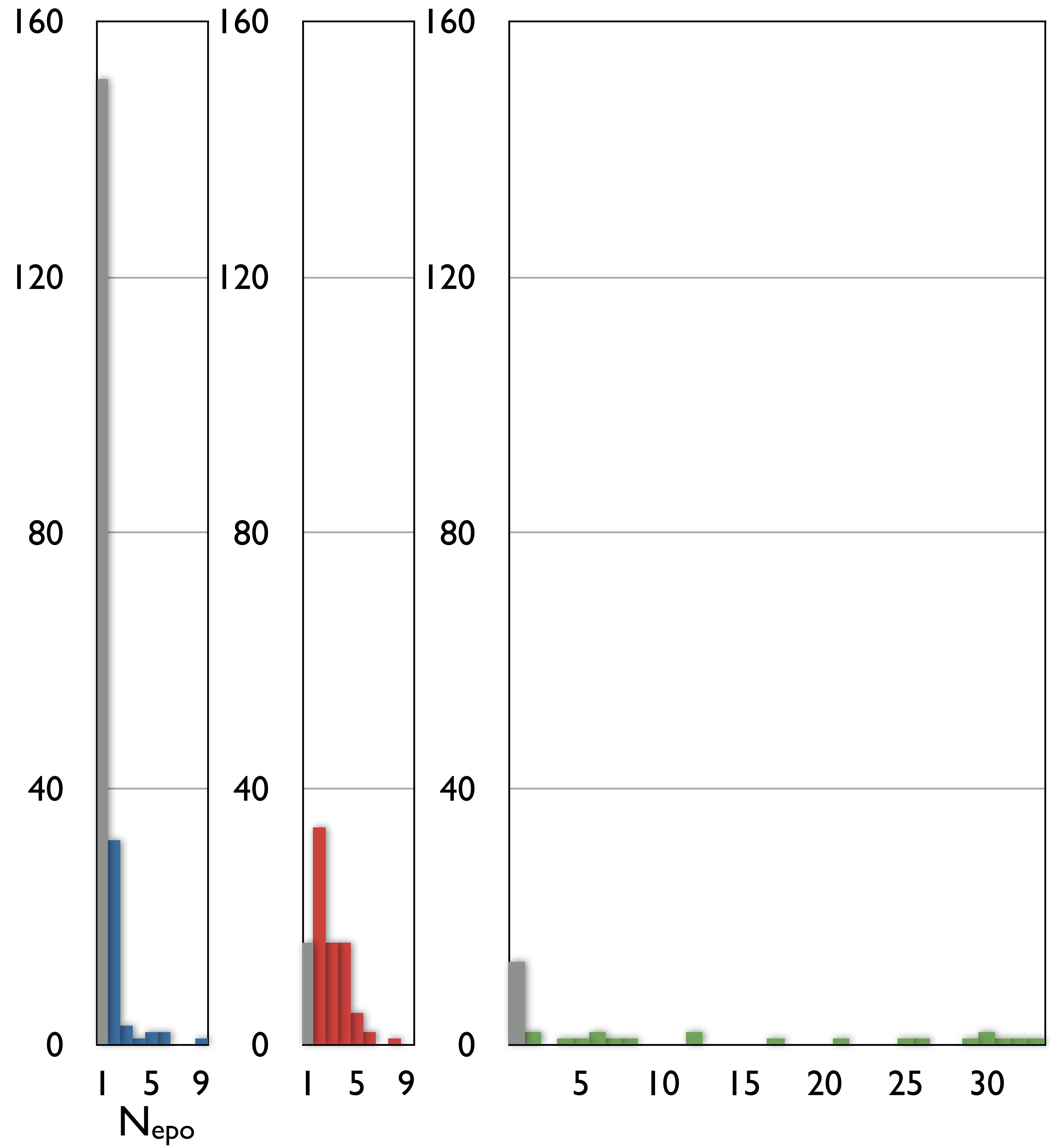
- XMM deep survey in the CDF-S
  20 multi-epoch sources (2-33 epochs), in progress



samples

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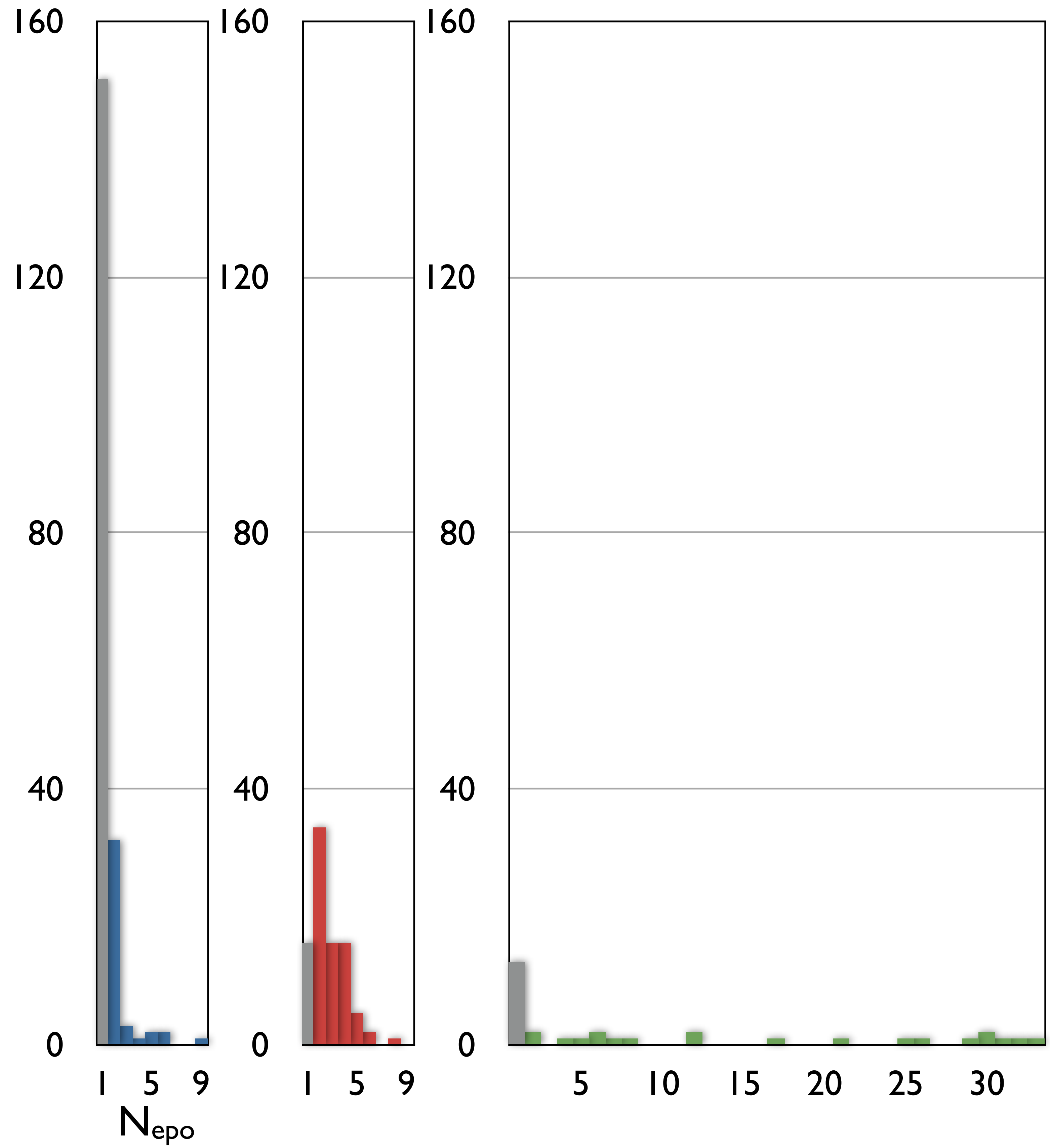
  multi-epoch survey of the same sky area ideal to get detailed information on individual sources



samples in the L-z plane

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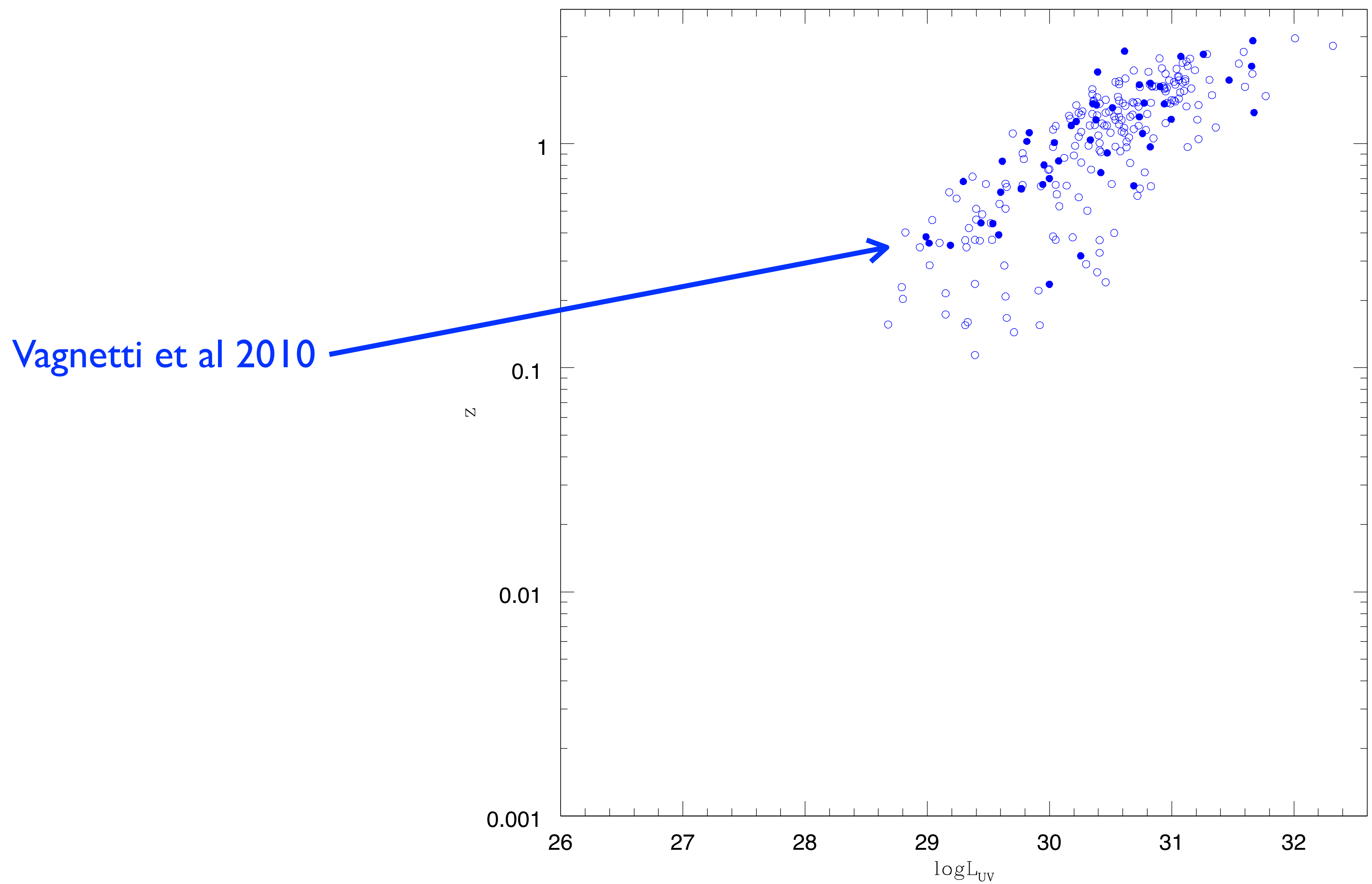
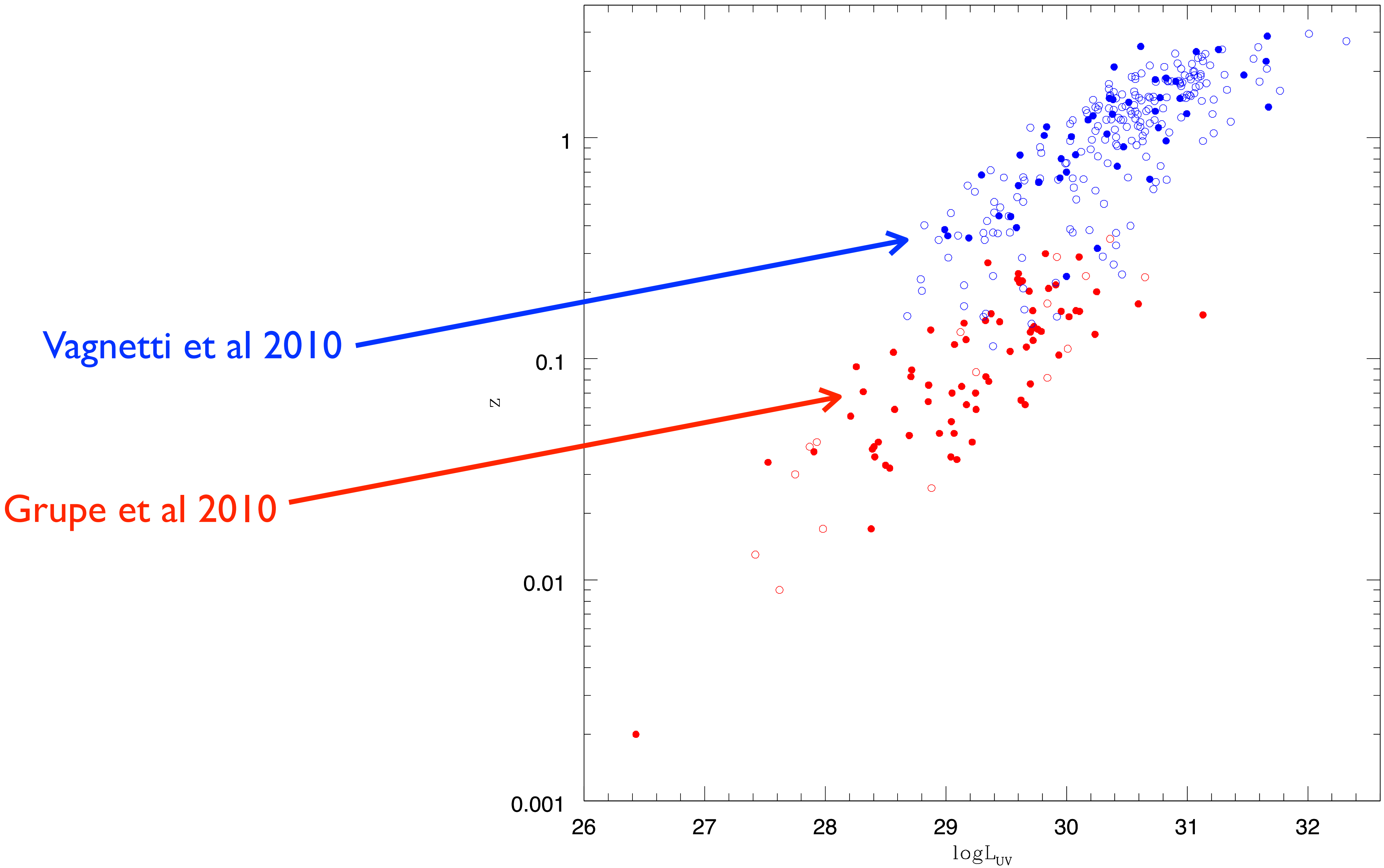


samples in the L-z plane



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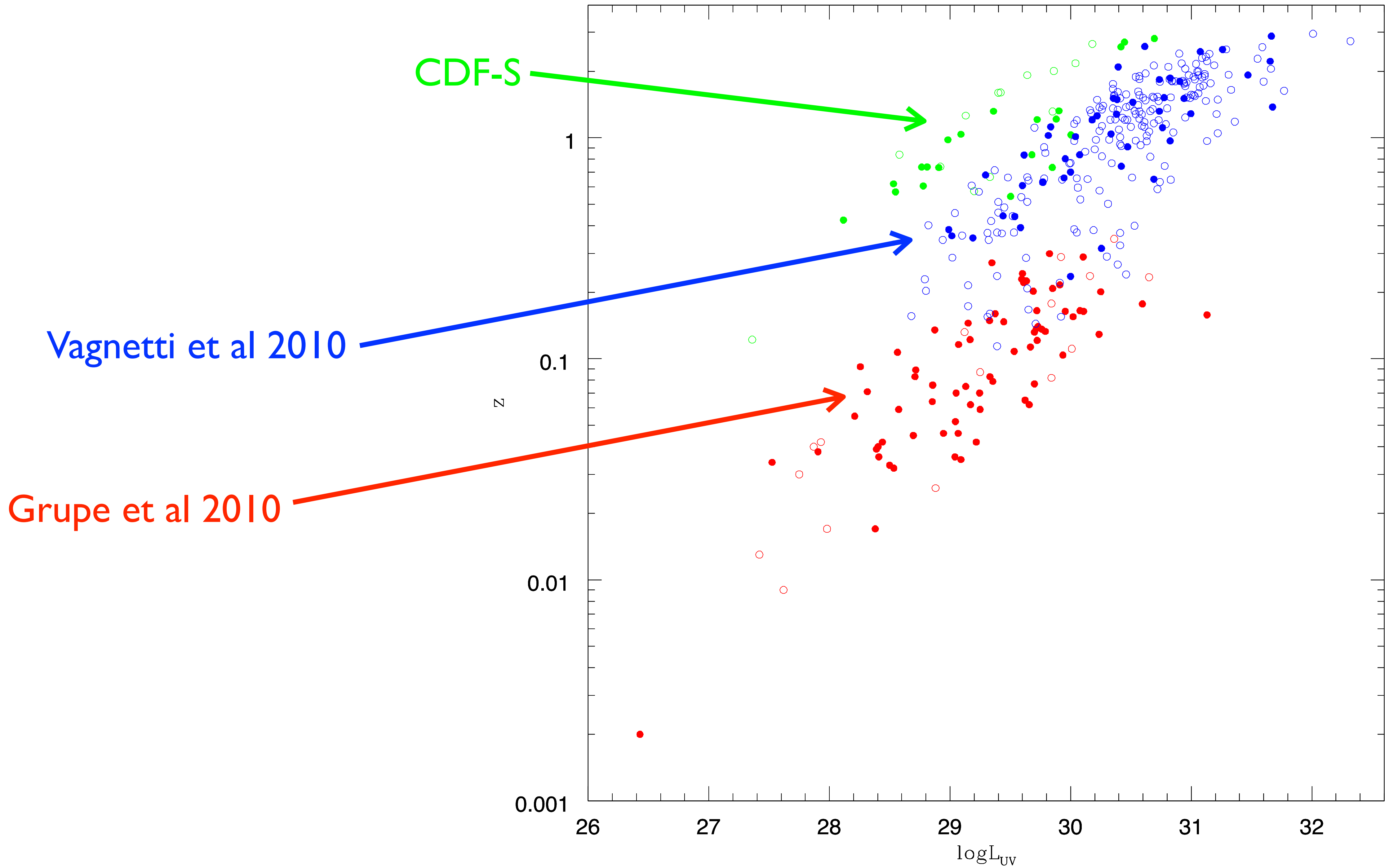
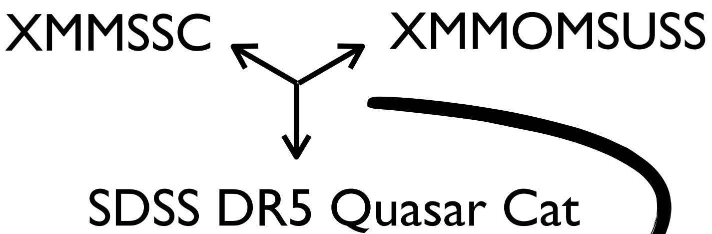


XMM serendipitous source catalogs

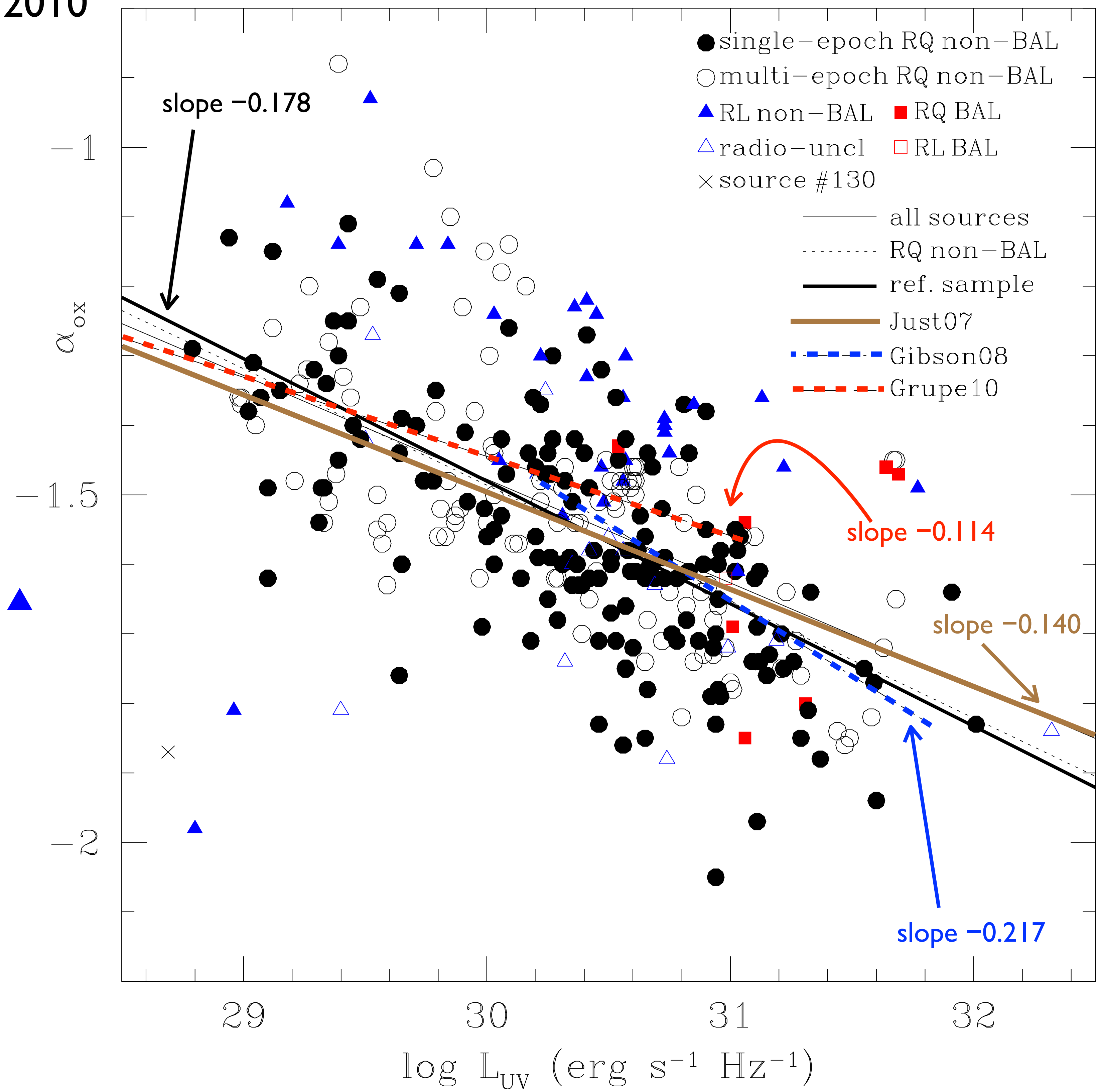
Vagnetti Turriziani Trevese Antonucci 2010



241 sources
315 observations in total
192 radio-quiet non-BAL sources
41 with multiple epochs

radio loud AGNS ▲
and BAL QSOs ■
are removed

- the slope of the correlation can be compared with other authors
- we are more interested in the dispersion



dispersion and variability of α_{ox}

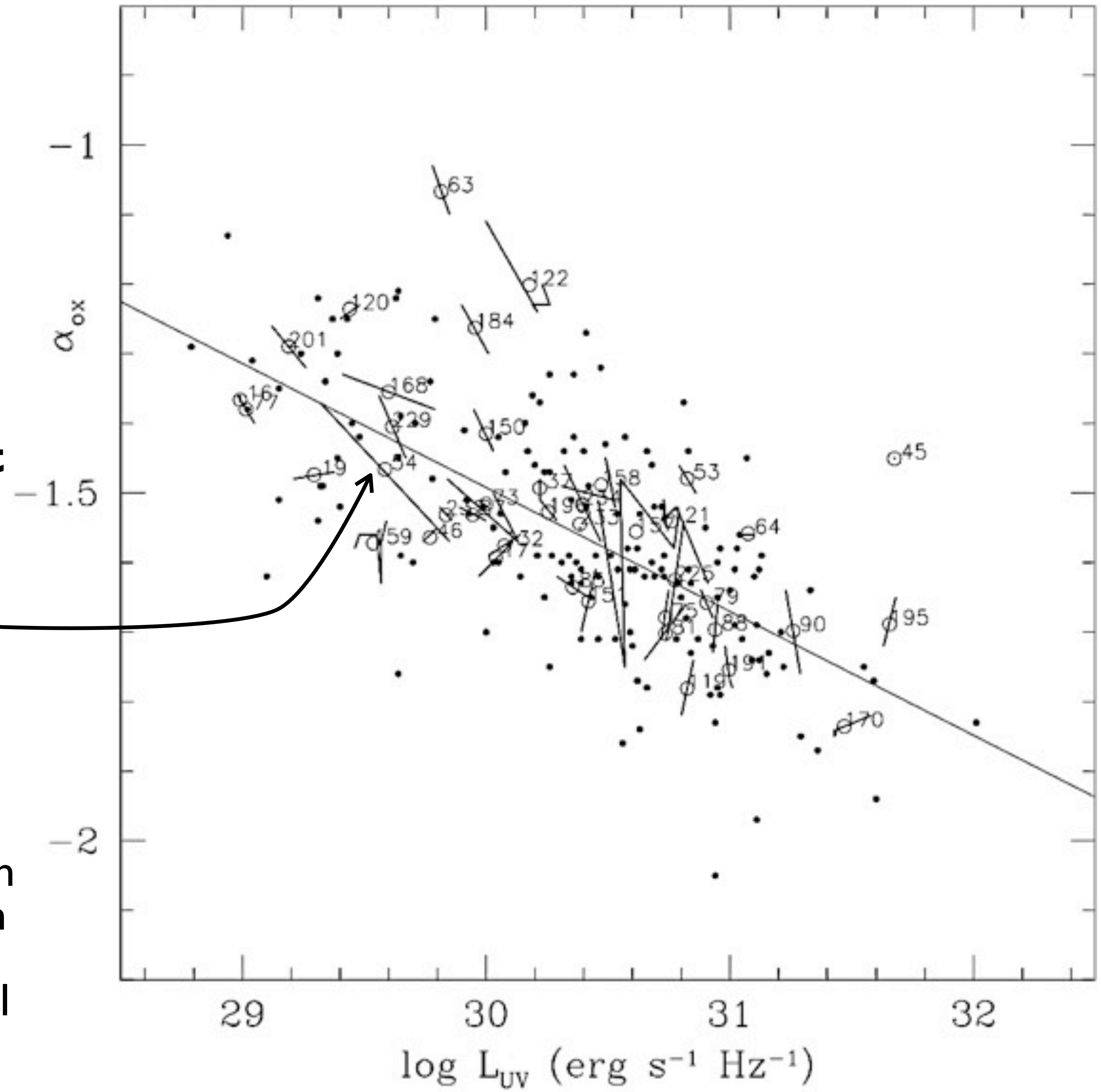
dispersion σ=0.12: similar to previous non-simultaneous analyses

artificial α_{ox} variability
(non-simultaneity): **not important**

intrinsic α_{ox} variability
(true change of α_{ox}): **important**

its contribution can be called **intra-source dispersion**

another important contribution is due to intrinsic differences in the average α_{ox} values from source to source, which we call **inter-source dispersion**

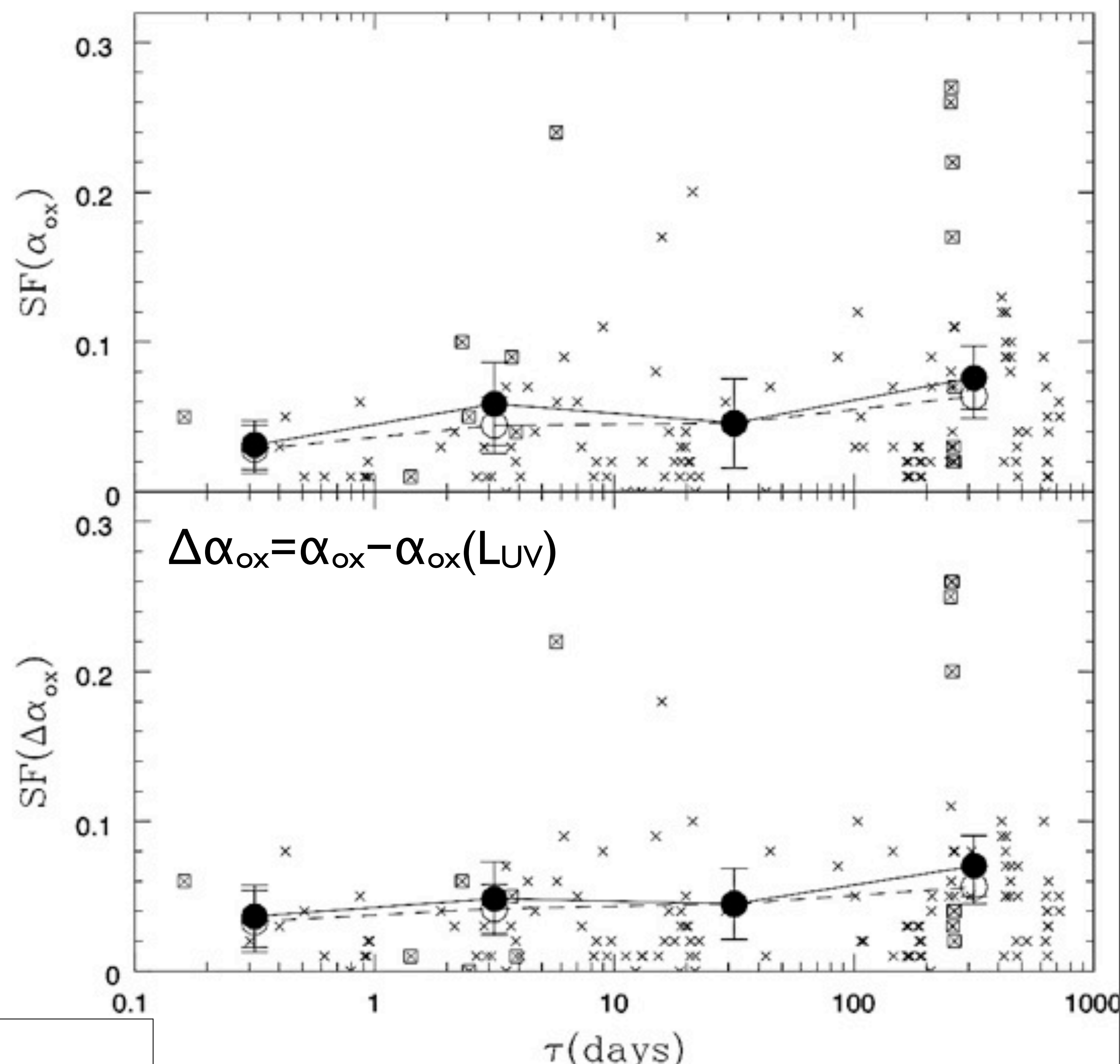


how much intra-source and how much inter-source?

intra-source and inter-source dispersion

variations are on different time scales, to compare use **Structure Function :**

$$SF(\tau) = \sqrt{\frac{\pi}{2}}\langle|\alpha_{ox}(t+\tau) - \alpha_{ox}(t)|\rangle$$



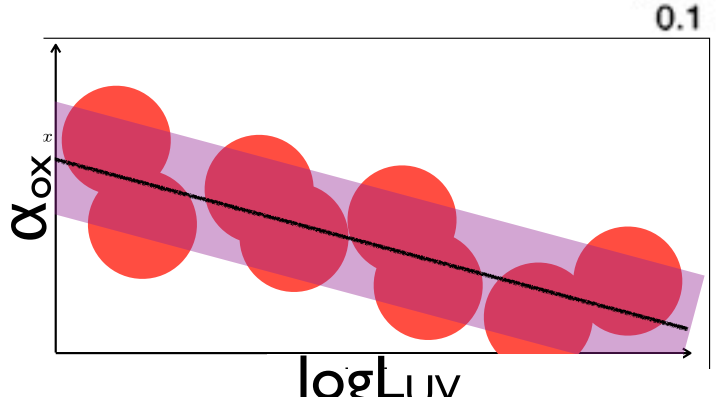
SF is increasing, both for α_{ox} and for the residuals $\Delta\alpha_{ox}$

greatest change at 1 yr, $\sigma_{intra\text{-}source} \sim 0.07$

$\sigma^2_{tot} = \sigma^2_{intra\text{-}source} + \sigma^2_{inter\text{-}source}$

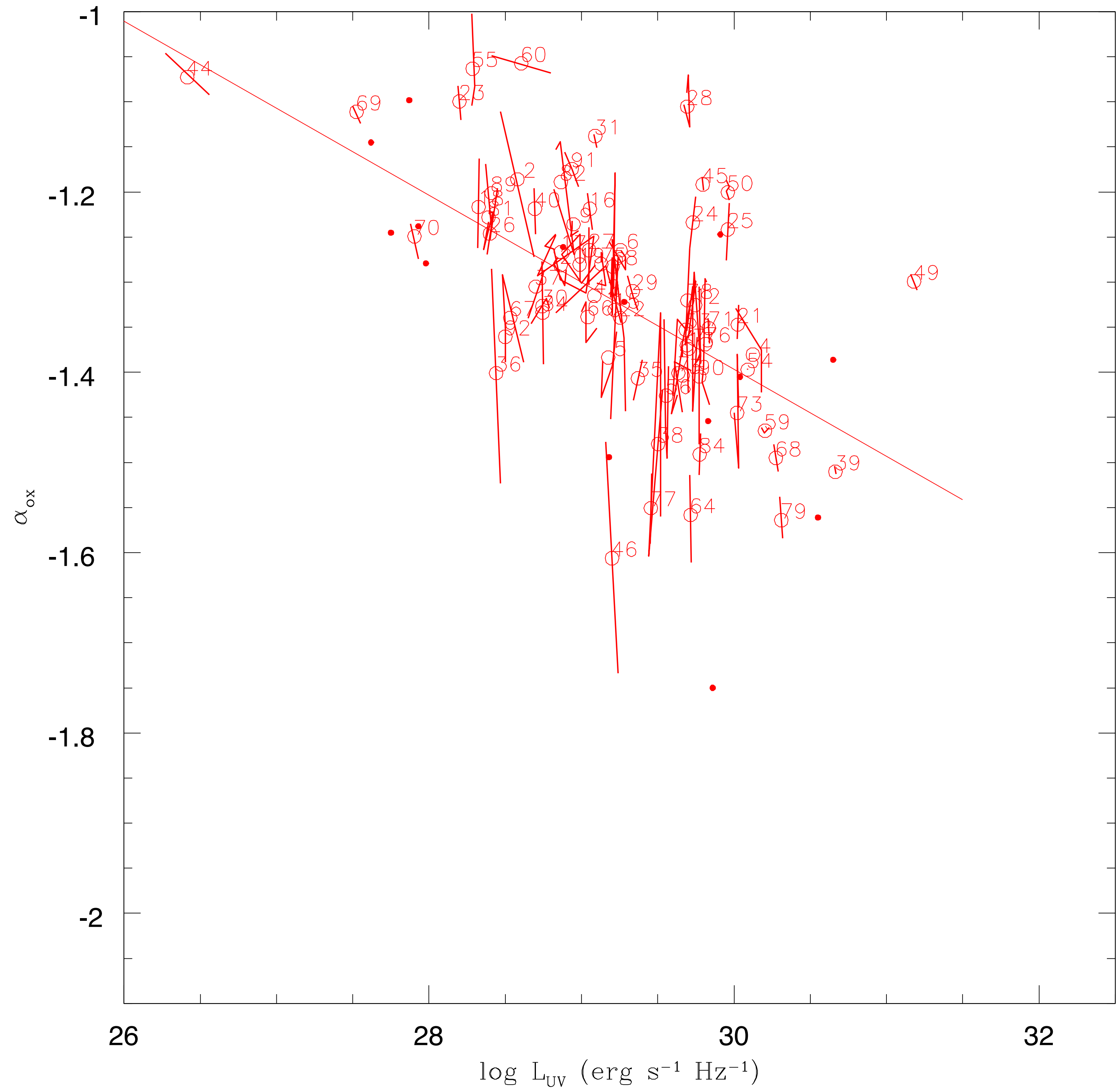
$\sigma^2_{intra\text{-}source} \sim 30\% \ \sigma^2_{tot}$

comparable contributions:



Swift sample by Grupe et al 2010

90 low redshift sources (z<0.35)
74 multi-epoch, 67 radio-quiet
analysis in progress



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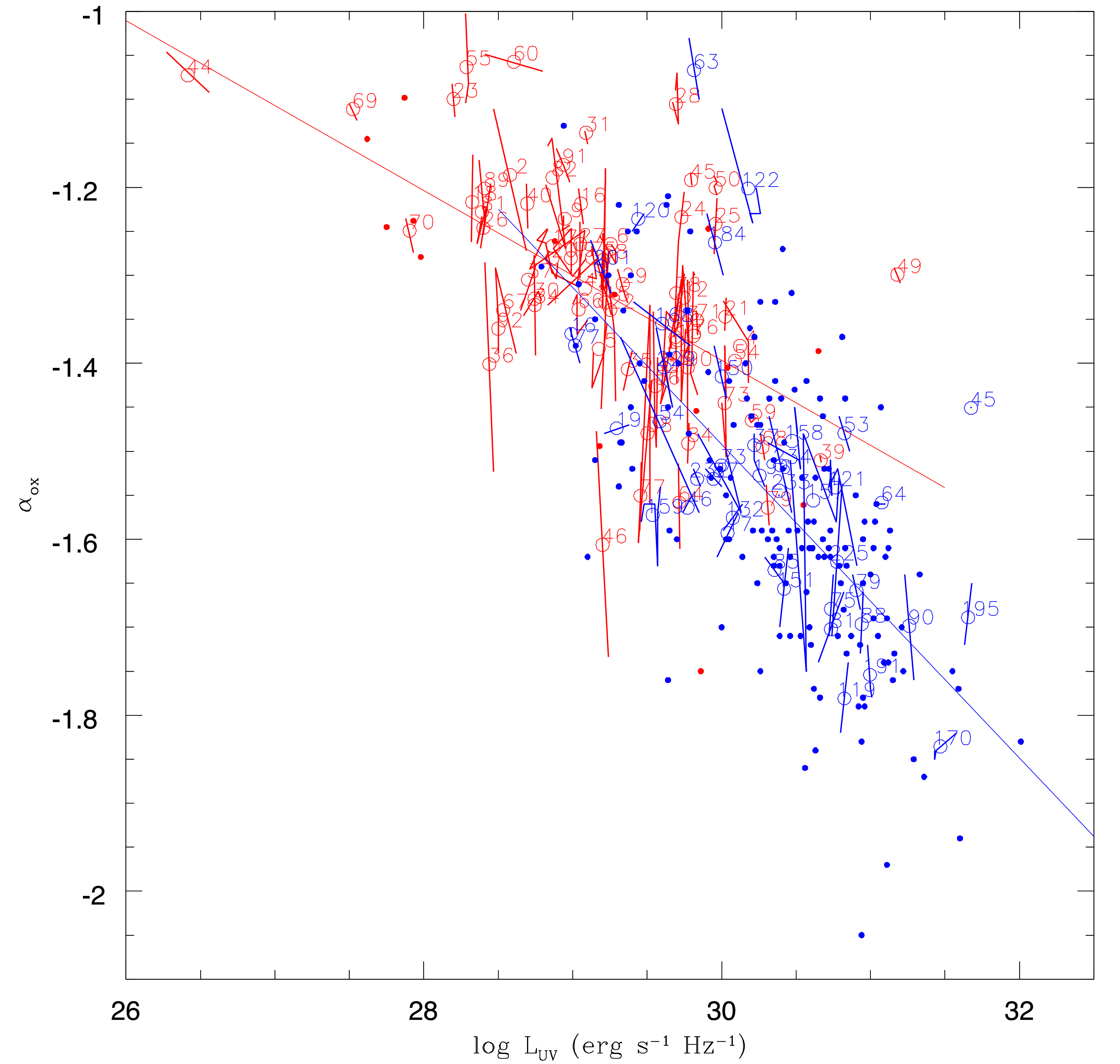
tracks in the α_{ox}-L_{UV} plane are not much different from serendipitous sample



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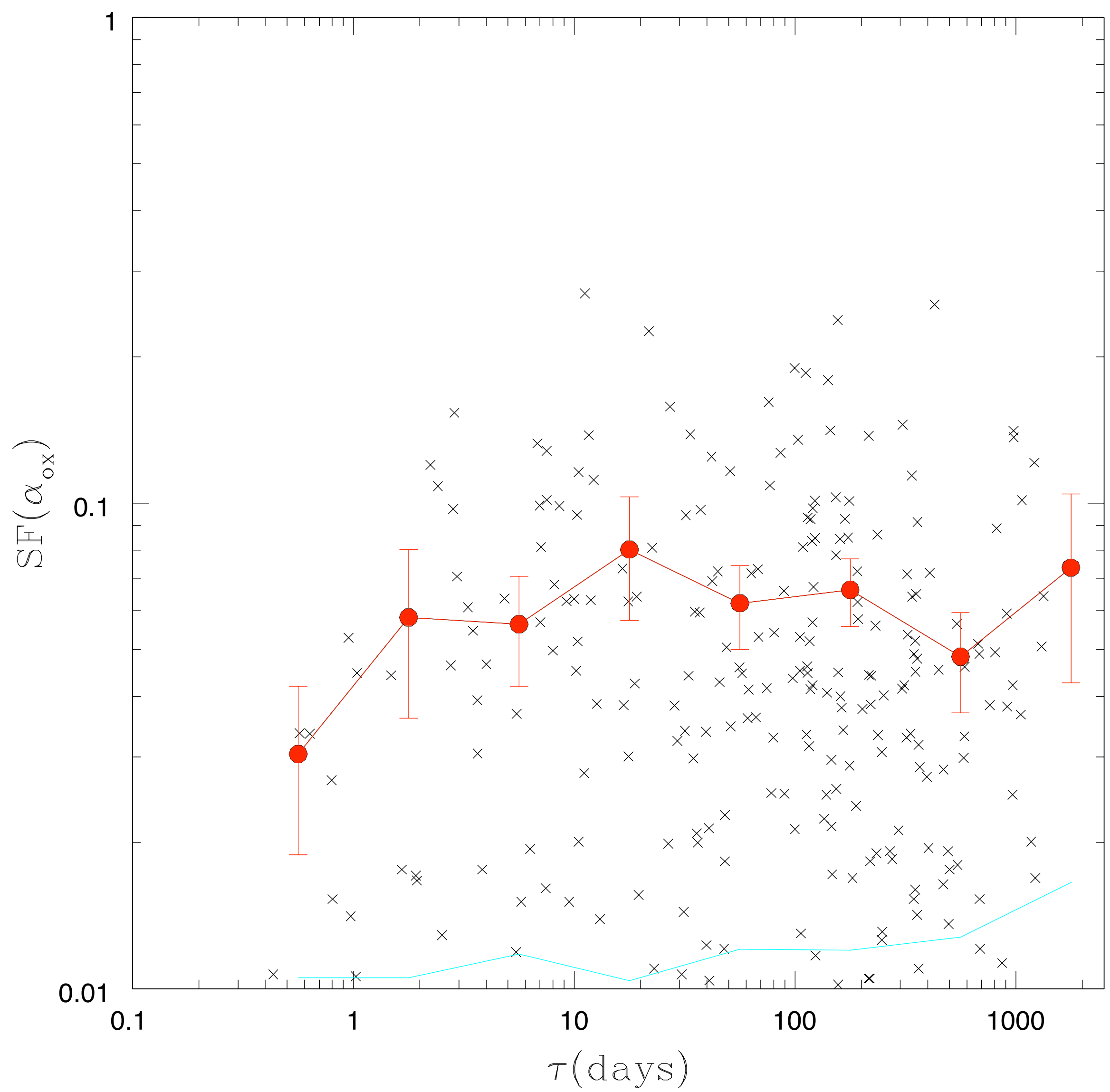
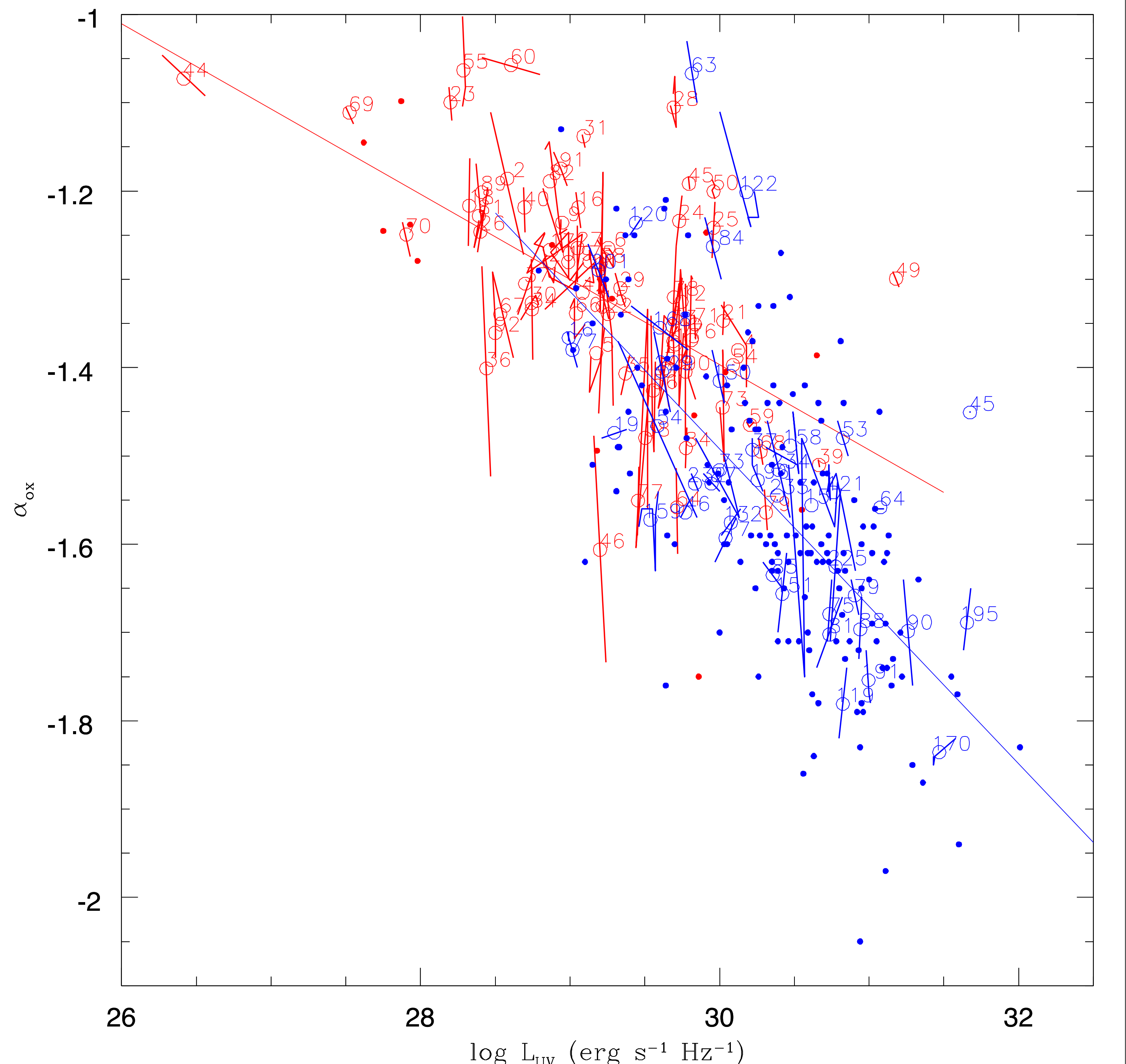
tracks in the α_{ox}-L_{UV} plane are not much different from serendipitous sample

the SF of α_{ox} is also consistent with the serendipitous sample, with $\sigma_{intra\text{-}source}$ ~ 0.07





XMM-Newton deep survey in the CDFS

preliminary analysis of XMM-Newton archive on HEASARC

also in the same field
8 epochs PI Bergeron
2001-2002

25 epochs PI Comastri
2008-2010

great advantage:
many epochs
8+25=**33**

XMM-Newton Master Log & Public Archive

	obsid	status	name	ra	dec	time	duration	pi lname	pi fname	public date	data in heasarc	Search Offset
☐	0108061601	archived	AXAF Ultra Deep F	03 32 28.00	-27 48 30.0	2001-07-27 02:03:20	9797	Jacqueline	Bergeron	2003-05-17	Y	0.000 (CDFS)
☐	0108061701	archived	AXAF Ultra Deep F	03 32 26.70	-27 48 40.0	2002-01-14 16:48:09	4221	Jacqueline	Bergeron	2003-05-17	Y	0.332 (CDFS)
☐	0108062201	archived	AXAF Ultra Deep F	03 32 26.48	-27 48 33.1	2002-01-20 16:14:36	3118	Jacqueline	Bergeron	2003-05-17	Y	0.339 (CDFS)
☑	0108062101	archived	AXAF Ultra Deep F	03 32 26.45	-27 49 15.3	2002-01-20 17:08:24	62119	Jacqueline	Bergeron	2003-05-17	Y	0.829 (CDFS)
☑	0108061901	archived	AXAF Ultra Deep F	03 32 25.15	-27 49 03.8	2002-01-17 16:38:43	54218	Jacqueline	Bergeron	2003-05-17	Y	0.845 (CDFS)
☑	0108062301	archived	AXAF Ultra Deep F	03 32 25.37	-27 49 08.9	2002-01-23 00:23:50	88620	Jacqueline	Bergeron	2003-05-17	Y	0.871 (CDFS)
☐	0108062001	archived	AXAF Ultra Deep F	03 32 25.04	-27 49 25.3	2002-01-16 16:26:50	3321	Jacqueline	Bergeron	2003-05-17	Y	1.130 (CDFS)
☑	0108061801	archived	AXAF Ultra Deep F	03 32 25.01	-27 49 25.2	2002-01-16 17:24:02	63018	Jacqueline	Bergeron	2003-05-17	Y	1.133 (CDFS)
☑	0108060401	archived	AXAF Ultra Deep F	03 32 29.08	-27 47 21.1	2001-07-27 09:03:09	49906	Jacqueline	Bergeron	2003-05-17	Y	1.172 (CDFS)
☑	0108060501	archived	AXAF Ultra Deep F	03 32 31.70	-27 47 39.4	2001-07-27 23:42:55	64267	Jacqueline	Bergeron	2003-05-17	Y	1.175 (CDFS)
☑	0108060701	archived	AXAF Ultra Deep F	03 32 23.93	-27 49 33.7	2002-01-14 17:47:17	94021	Jacqueline	Bergeron	2003-05-17	Y	1.392 (CDFS)
☑	0108060601	archived	AXAF Ultra Deep F	03 32 25.19	-27 49 45.7	2002-01-13 13:48:44	65318	Jacqueline	Bergeron	2003-05-17	Y	1.406 (CDFS)
☐	0555781801	archived	CDFS	03 32 25.00	-27 49 55.0	2009-01-10 16:27:51		Comastri	Andrea	2009-01-26	Y	1.564 (CDFS)
☑	0604961101	archived	CDFS	03 32 21.70	-27 49 44.9	2010-01-04 18:54:02	120817	Comastri	Andrea	2011-01-28	Y	1.871 (CDFS)
☑	0604961301	archived	CDFS	03 32 21.73	-27 50 15.1	2010-01-19 22:44:43	21920	Comastri	Andrea	2011-03-22	Y	2.234 (CDFS)
☐	0555781701	archived	CDFS	03 32 22.13	-27 50 19.8	2009-01-06 17:02:58	6911	Comastri	Andrea	2009-01-26	Y	2.243 (CDFS)
☑	0604960501	archived	CDFS	03 32 21.66	-27 50 17.1	2010-01-18 18:13:38	46983	Comastri	Andrea	2011-03-22	Y	2.269 (CDFS)
☑	0555780501	archived	CDFS	03 32 21.95	-27 50 20.4	2009-01-06 20:57:27	113004	Comastri	Andrea	2009-01-26	Y	2.276 (CDFS)
☑	0604961201	archived	CDFS	03 32 18.92	-27 49 44.8	2010-01-08 18:45:45	120718	Comastri	Andrea	2011-02-23	Y	2.363 (CDFS)
☑	0555780801	archived	CDFS	03 32 19.79	-27 50 16.8	2009-01-16 18:24:02	120919	Comastri	Andrea	2009-01-26	Y	2.542 (CDFS)
☐	0555782001	archived	CDFS	03 32 19.79	-27 50 16.8	2009-01-16 16:21:14	6237	Comastri	Andrea	2009-01-26	Y	2.543 (CDFS)
☑	0555780601	archived	CDFS	03 32 22.42	-27 50 45.7	2009-01-10 19:11:41	118413	Comastri	Andrea	2009-01-26	Y	2.576 (CDFS)
☑	0604960701	archived	CDFS	03 32 19.57	-27 50 19.1	2010-01-12 18:39:40	120819	Comastri	Andrea	2011-02-04	Y	2.604 (CDFS)
☑	0604960601	archived	CDFS	03 32 21.73	-27 50 46.3	2010-01-26 17:48:13	125212	Comastri	Andrea	2011-03-01	Y	2.661 (CDFS)
☐	0555782101	archived	CDFS	03 32 19.82	-27 50 48.9	2009-01-18 16:13:20	6237	Comastri	Andrea	2009-01-26	Y	2.938 (CDFS)
☑	0555780901	archived	CDFS	03 32 19.75	-27 50 49.1	2009-01-18 18:16:08	121518	Comastri	Andrea	2009-01-26	Y	2.949 (CDFS)
☑	0604961801	archived	CDFS	03 32 19.46	-27 50 48.7	2010-02-17 15:59:48	125042	Comastri	Andrea	2011-03-22	Y	2.984 (CDFS)
☑	0604961001	archived	CDFS	03 32 19.39	-27 50 48.8	2010-02-13 16:27:56	122515	Comastri	Andrea	2011-03-22	Y	2.996 (CDFS)
☐	0555781901	archived	CDFS	03 32 22.09	-27 51 24.9	2009-01-12 16:37:31	7025	Comastri	Andrea	2009-01-26	Y	3.194 (CDFS)
☑	0604960801	archived	CDFS	03 32 21.77	-27 51 23.6	2010-02-05 17:12:18	121087	Comastri	Andrea	2011-03-05	Y	3.204 (CDFS)
☑	0555780701	archived	CDFS	03 32 21.95	-27 51 25.2	2009-01-12 18:59:31	118415	Comastri	Andrea	2009-01-26	Y	3.212 (CDFS)
☐	0555782401	archived	CDFS	03 32 19.82	-27 51 18.9	2009-01-24 15:50:13	8529	Comastri	Andrea	2009-01-26	Y	3.346 (CDFS)
☑	0555781001	archived	CDFS	03 32 19.72	-27 51 18.1	2009-01-22 18:39:27	125813	Comastri	Andrea	2009-01-26	Y	3.347 (CDFS)
☐	0555782201	archived	CDFS	03 32 19.72	-27 51 18.1	2009-01-22 15:58:10	8430	Comastri	Andrea	2009-01-26	Y	3.347 (CDFS)
☑	0555782301	archived	CDFS	03 32 19.75	-27 51 19.2	2009-01-24 18:34:13	125714	Comastri	Andrea	2009-01-26	Y	3.358 (CDFS)
☑	0604960901	archived	CDFS	03 32 19.54	-27 51 24.2	2010-02-11 16:36:42	125344	Comastri	Andrea	2011-03-09	Y	3.454 (CDFS)
☑	0604960401	archived	CDFS	03 32 43.08	-27 45 11.6	2009-07-29 04:07:27	133915	Comastri	Andrea	2010-08-19	Y	4.697 (CDFS)
☑	0604960301	archived	CDFS	03 32 45.42	-27 45 14.9	2009-07-05 08:07:59	122302	Comastri	Andrea	2010-08-17	Y	5.042 (CDFS)
☐	0555781501	archived	CDFS	03 32 42.76	-27 44 36.3	2008-07-10 18:36:43	2371	Comastri	Andrea	2008-07-12	Y	5.081 (CDFS)
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☐	0555781201	archived	CDFS	03 32 45.02	-27 44 40.8	2008-07-08 18:44:02	2618	Comastri	Andrea	2008-07-12	Y	5.364 (CDFS)
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☐	0555781601	archived	CDFS	03 32 42.72	-27 44 09.2	2008-07-12 18:29:12	2333	Comastri	Andrea	2008-07-12	Y	5.431 (CDFS)
☑	0604960101	archived	CDFS	03 32 45.35	-27 44 37.1	2009-07-27 04:00:26	129439	Comastri	Andrea	2010-08-17	Y	5.458 (CDFS)
☐	0555781101	archived	CDFS	03 32 44.81	-27 44 08.1	2008-07-06 18:40:00	2532	Comastri	Andrea	2008-07-12	Y	5.734 (CDFS)
☑	0555780101	archived	CDFS	03 32 44.88	-27 44 07.8	2008-07-05 05:22:38	133118	Comastri	Andrea	2008-07-12	Y	5.747 (CDFS)

exposure times

most epochs have X-ray exposures above 100 ks
but the O/UV exposures are shorter, divided among the 6 OM filters
and the adopted filters vary from epoch to epoch
UVW1 and U have most often the longest exposures

n	obsid	time	Xray,ks	UVW2	UVM2	UVW1	U	B	V
1	108060401	2001.5681	49	+	.				
2	108060501	2001.5698	64	+	.	.	.	.	
3	108060601	2002.0344	65	+	.	.	.	.	
4	108060701	2002.0376	94	+	+	.	.	.	
5	108061801	2002.043	63	+	.	.	.	.	
6	108061901	2002.0457	54	+	.	.	.	.	
7	108062101	2002.054	62	.	.	.	.	.	
8	108062301	2002.0603	88	.	.	.	.	.	
9	555780101	2008.5088	133		+	+	+		
10	555780201	2008.5142	133		+	+	+		
11	555780301	2008.52	123		+	+	+		
12	555780401	2008.5255	122		+	+	+		
13	555780501	2009.016	113	+	+	.	.	.	.
14	555780601	2009.0268	118	+	+	.	.	.	.
15	555780701	2009.0323	118	+	+	.	.	.	.
16	555780801	2009.0431	120	+	+	.	.	.	.
17	555780901	2009.0486	121	+	+	.	.	.	.
18	555781001	2009.0596	125	+	+	.	.	.	.
19	555782301	2009.0651	125	+	+	.	.	.	.
20	604960301	2009.5077	122	+		+	+		
21	604960201	2009.5406	121	+		+	+		
22	604960101	2009.5675	129	+		+	+		
23	604960401	2009.573	133	+		+	+		
24	604961101	2010.0103	120	.		+	+		
25	604961201	2010.0213	120	+		+	+		
26	604960701	2010.0322	120	.		+	+		
27	604960501	2010.0486	46				+		
28	604961301	2010.0519	21			+	.		
29	604960601	2010.0705	125	+		+	+		
30	604960801	2010.0978	121	+		+	+		
31	604960901	2010.1142	125			.	+		
32	604961001	2010.1196	122	+		+	+		
33	604961801	2010.1305	125	+		+	+		

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and the adopted filters vary from epoch to epoch
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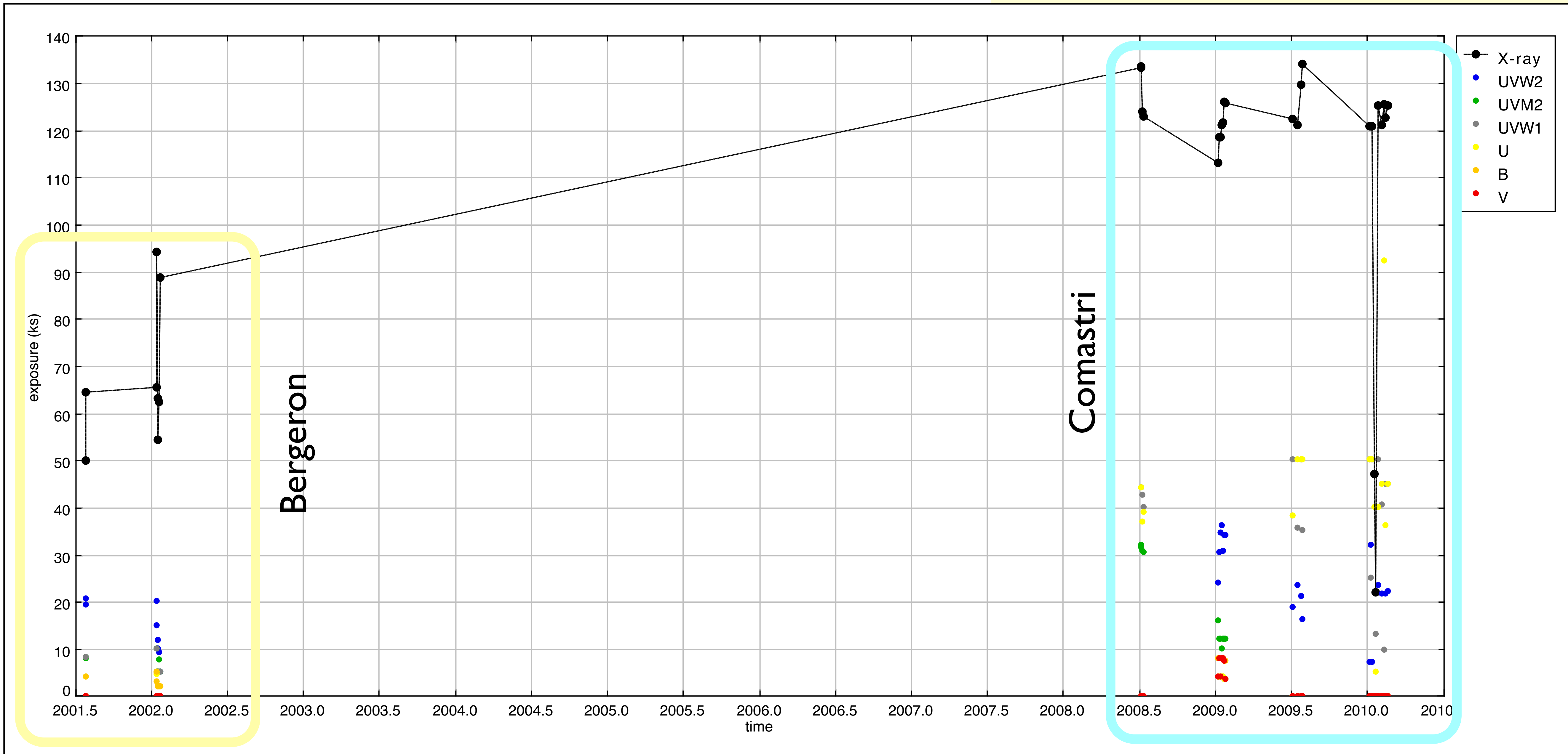
n	obsid	time	Xray,ks	UVW2 UVM2 UVW1 U B V
1	108060401	2001.5681	49	+.
2	108060501	2001.5698	64	+....
3	108060601	2002.0344	65	+....
4	108060701	2002.0376	94	++...
5	108061801	2002.043	63	+....
6	108061901	2002.0457	54	+....
7	108062101	2002.054	62	.....
8	108062301	2002.0603	88	.....
33	604961801	2010.1305	125	+ ++

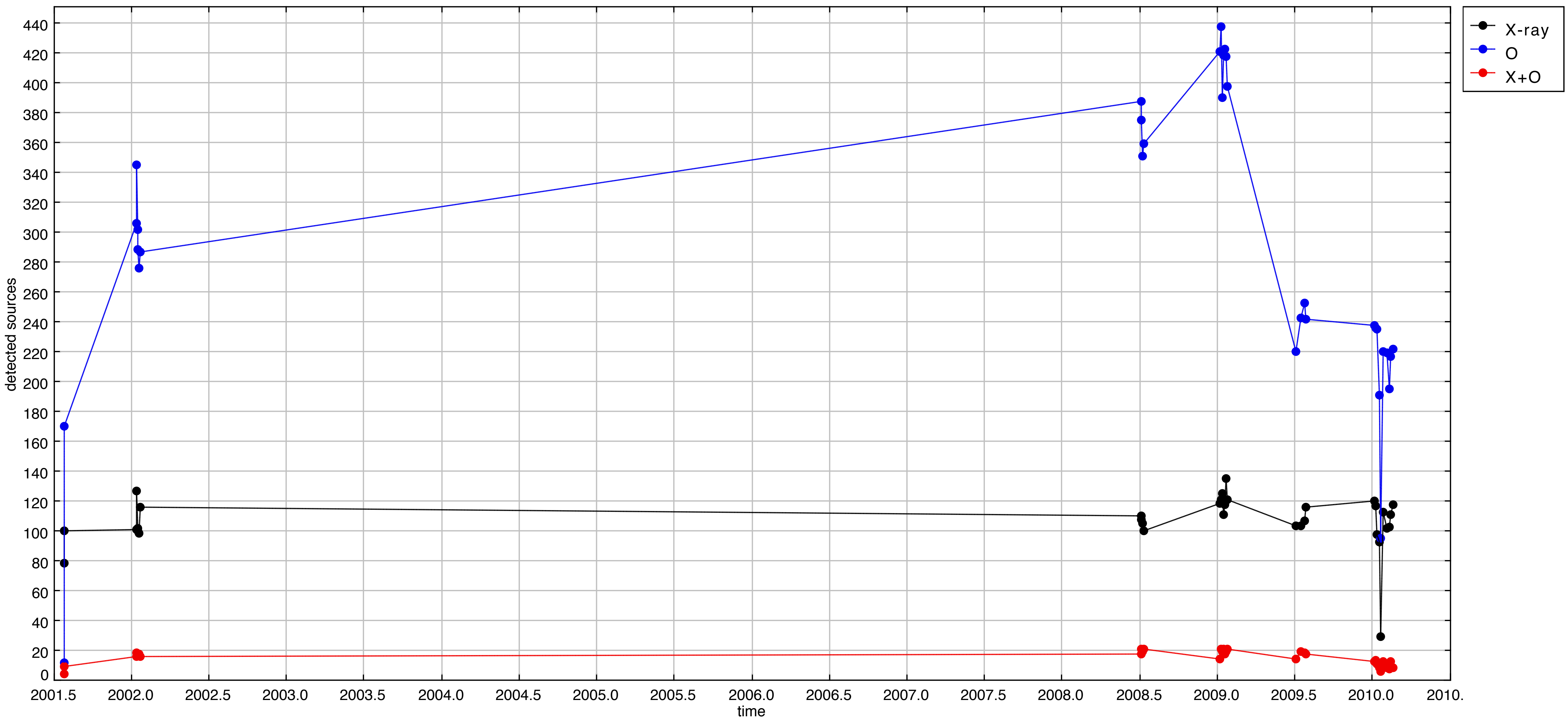


source numbers

as a result, the number of detected sources varies from epoch to epoch, both in X-ray and O/UV

we compare source coordinates with tables of known redshifts, and search for sources with simultaneous X-ray/UV detections

hundreds of sources are detected in UV and not in X-rays, mostly galaxies
several tens of sources are detected in X-rays and not in UV, mostly AGNs
few sources, up to 20, are detected at each epoch in both X-ray and UV

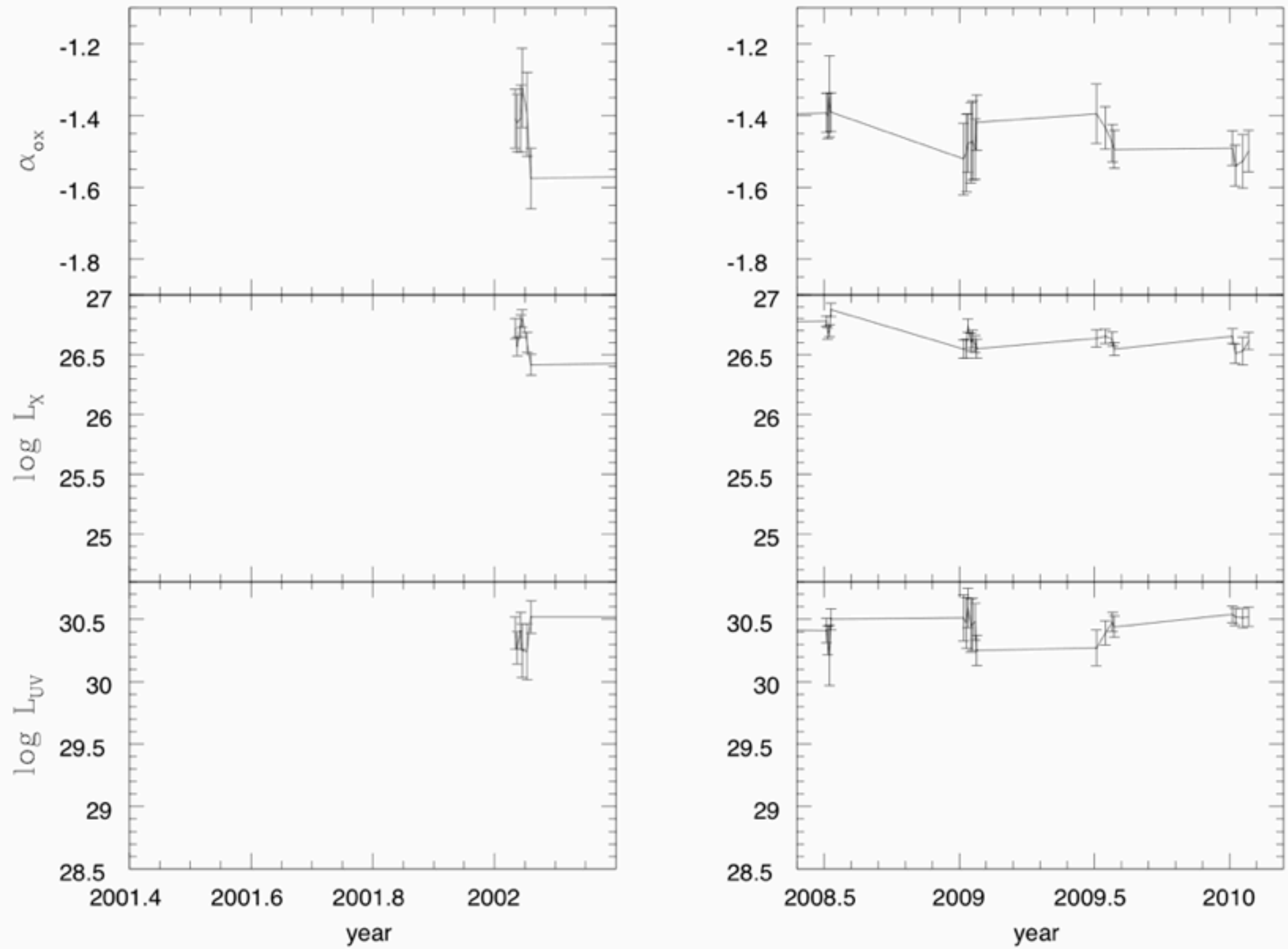


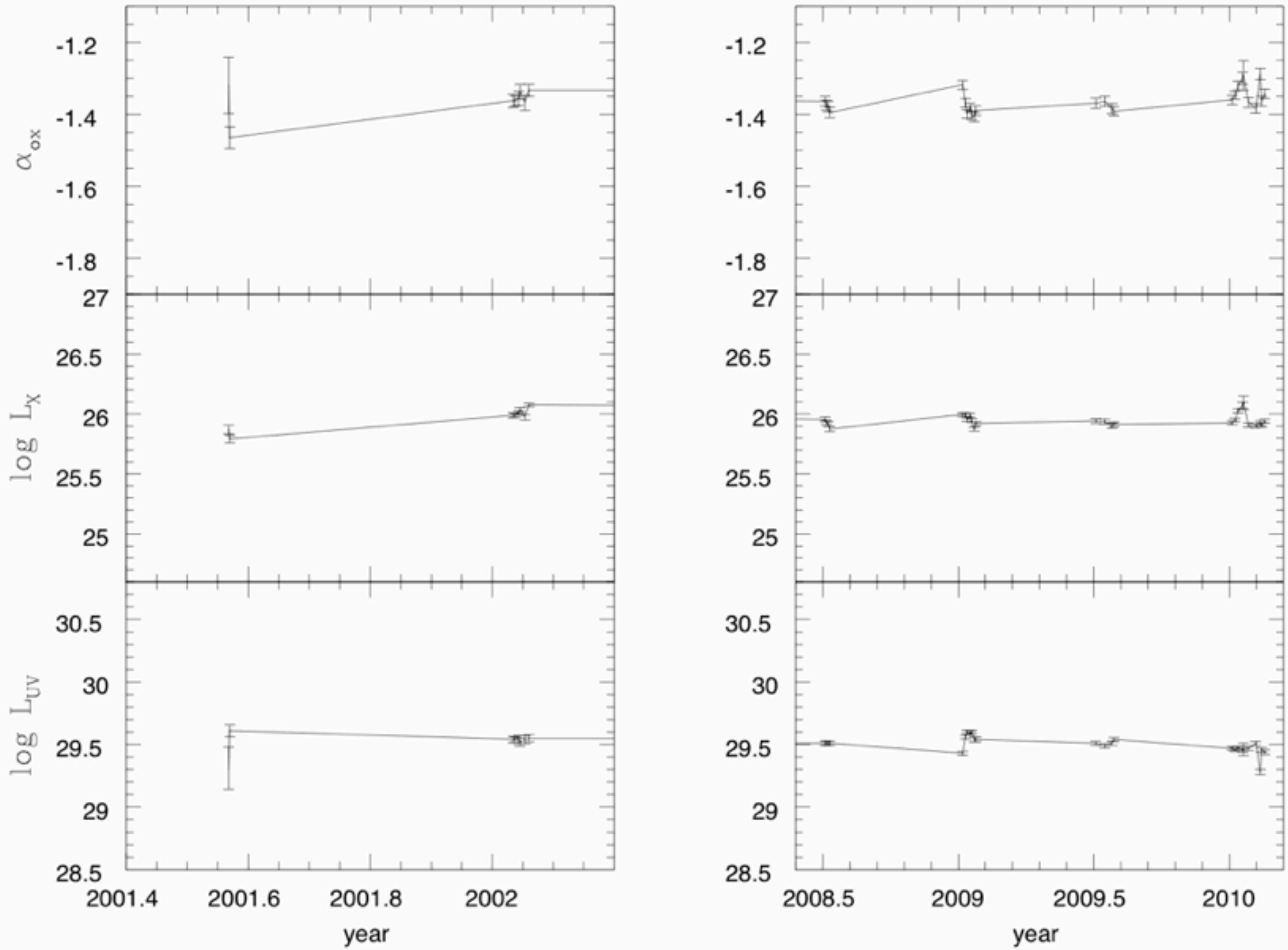
sources

this corresponds to 65 source with simultaneous X-ray/UV measurements for a number of epochs between 1 and 33

27 unclassified sources
5 possible/uncertain AGNs
13 single-epoch AGNs
20 multi-epoch AGNs

# i	z	Nepo	class	X-class	RAJ2000	DEJ2000	RA	DEC	Src_num
50	0.737	2	HEX	AGN-2	52.98075	-27.91344	52.980656	-27.913761	78
42	2.81	7	BLAGN	QSO-2	53.03942	-27.80189	53.039474	-27.802145	194
5	2.579	25	BLAGN	QSO-1	53.24929	-27.79672	53.249493	-27.796642	200
222	2.709	6	UAGN		52.91729	-27.79619	52.916367	-27.795929	201
43	0.543	33	BLAGN	QSO-1	53.03617	-27.79289	53.035942	-27.79297	203
4	0.424	5	LEX	AGN-2	53.24904	-27.774	53.248558	-27.774008	222
17	1.216	21	BLAGN	AGN-1	53.16287	-27.76722	53.163383	-27.767927	228
52	0.619	6	BLAGN	AGN-1	53.25642	-27.76183	53.256733	-27.762136	237
24	1.209	29	BLAGN	QSO-1	53.12525	-27.75853	53.124786	-27.758322	241
23	0.738	26	BLAGN	AGN-1	53.12625	-27.7515	53.125504	-27.751036	249
7	0.733	12	BLAGN	AGN-1	53.24621	-27.72764	53.245953	-27.727787	273
47	1.037	17	BLAGN	AGN-1	53.00146	-27.72211	53.002476	-27.722862	276
218	1.318	2	UAGN		52.95637	-27.72203	52.956177	-27.721489	277
35	0.569	8	BLAGN	AGN-1	53.07146	-27.71761	53.071262	-27.717728	284
39	0.605	30	HEX	AGN-2	53.05517	-27.71142	53.05594	-27.711884	289
9	0.979	12	LEX	QSO-1	53.19958	-27.70911	53.20021	-27.709154	292
26	0.734	32	BLAGN	QSO-1	53.1125	-27.68475	53.112335	-27.684969	319
28	1.031	30	BLAGN	QSO-1	53.11037	-27.67658	53.11019	-27.676619	328
18	0.837	31	BLAGN	QSO-1	53.15888	-27.6625	53.15889	-27.662363	337
95	1.324	4	BLAGN	QSO-1	53.0675	-27.6585	53.067577	-27.658184	341


-1.2
-1.4
-1.6
-1.8
α_{ox}
27
26.5
26
25.5
25
log L_X
30.5
30
29.5
29
28.5
log L_{UV}
2001.4
2001.6
2001.8
2002
2008.5
2009
2009.5
2010
year
year



α_{ox}
log L_X
log L_{UV}
-1.2
-1.4
-1.6
-1.8
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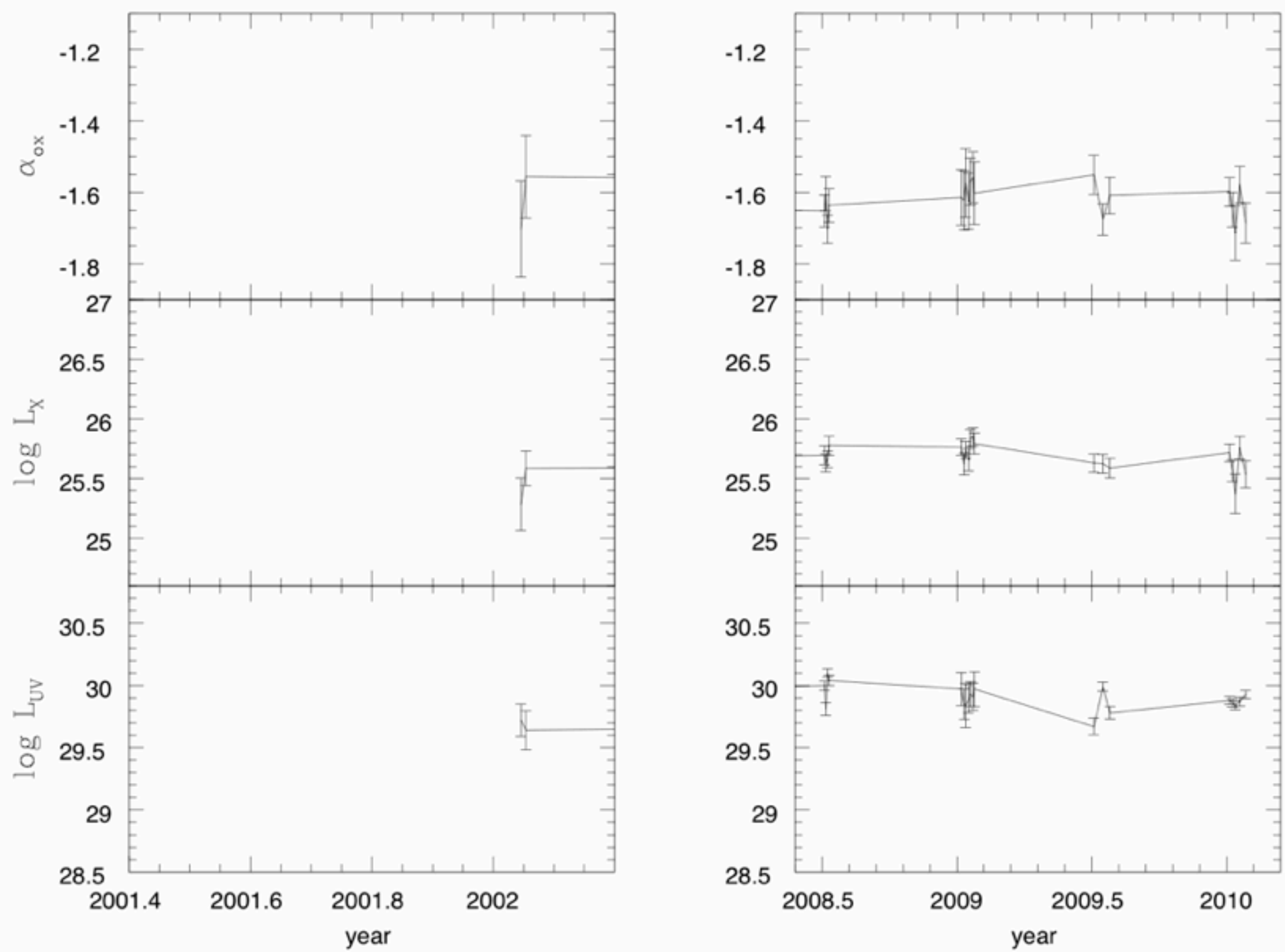
year



α_ox
log L_X
log L_UV
-1.2
-1.4
-1.6
-1.8
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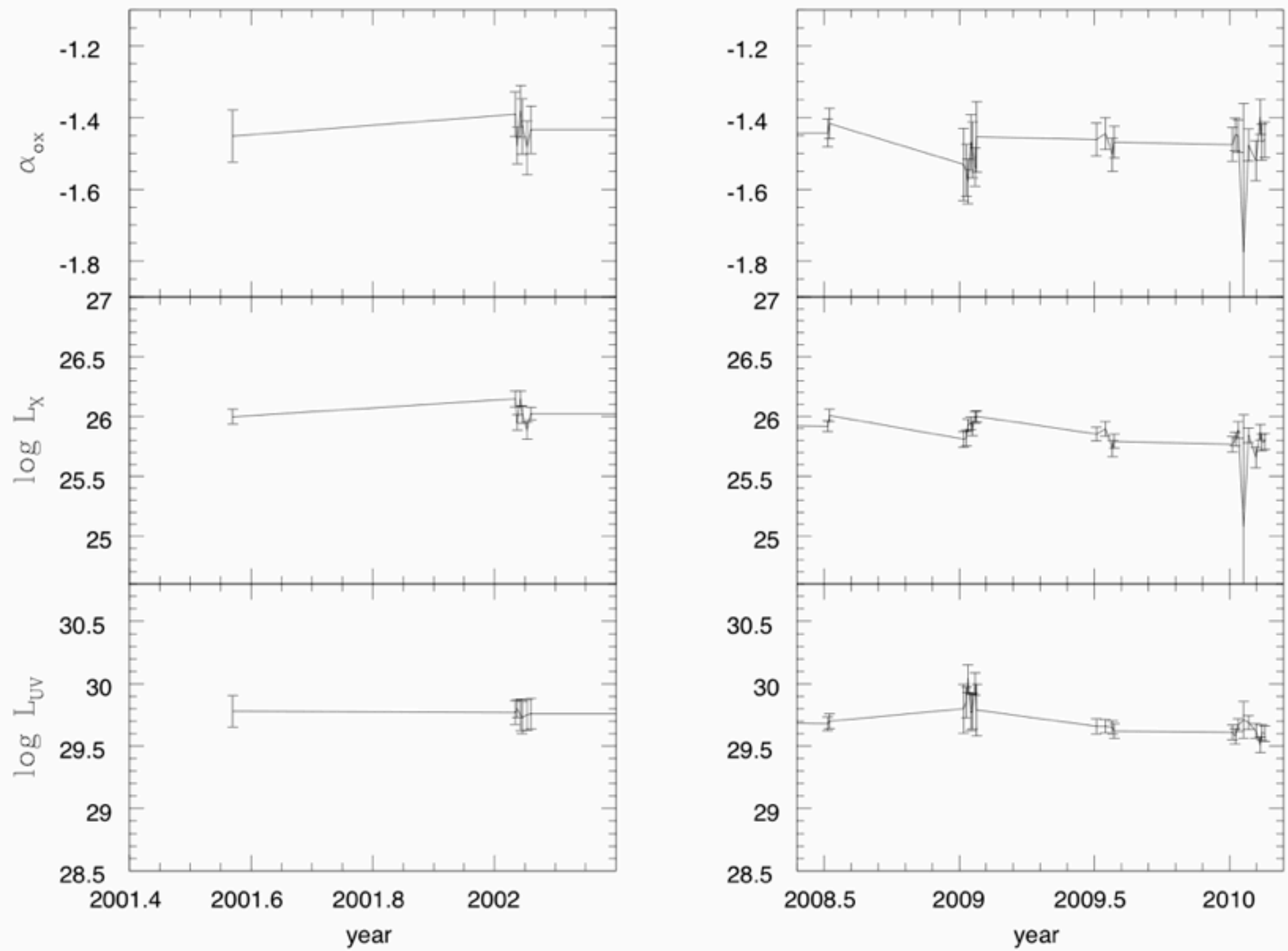

α_{ox}
log L_X
log L_{UV}
-1.2
-1.4
-1.6
-1.8
27
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year
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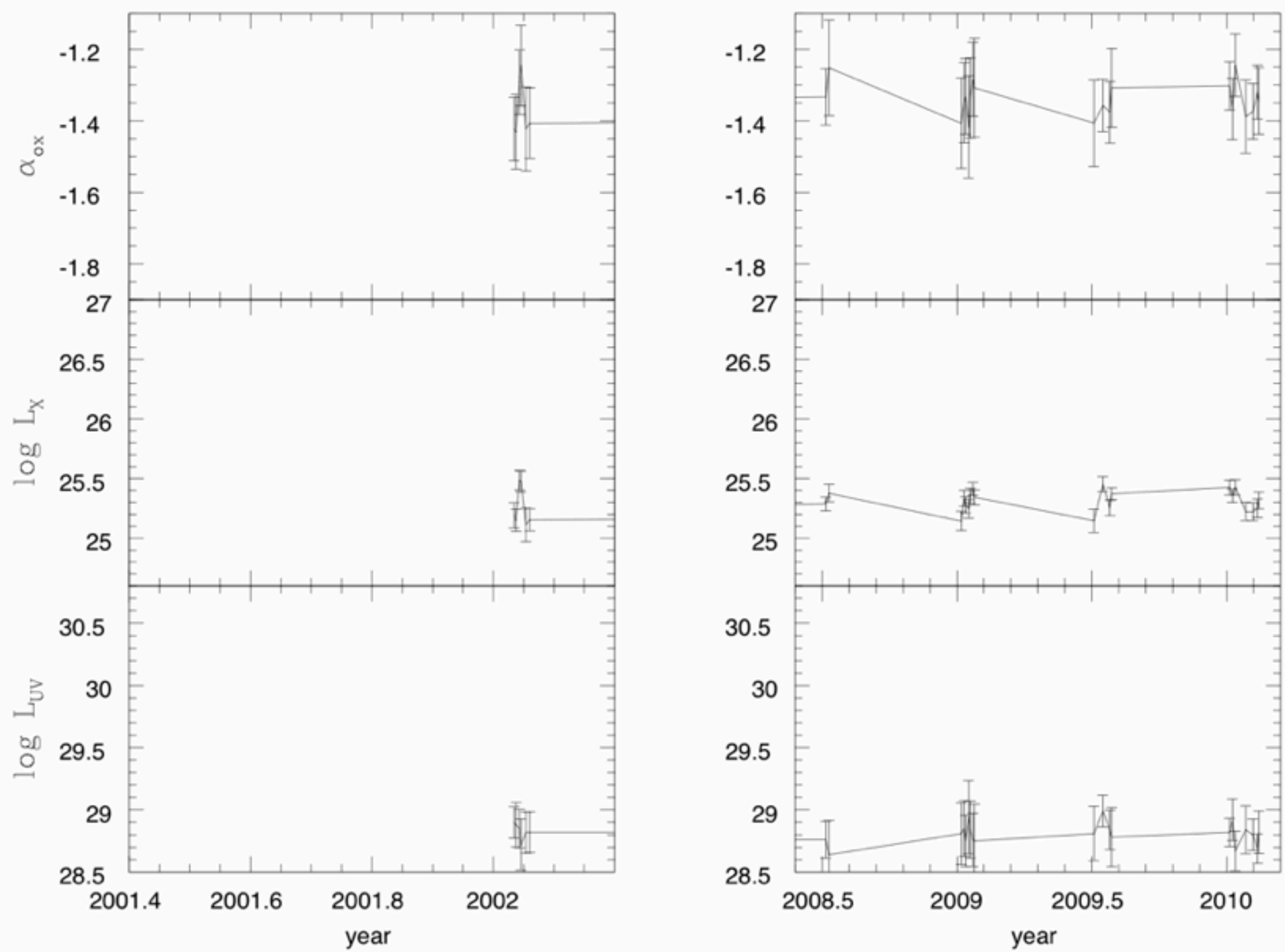
2010
year


-1.2
-1.4
-1.6
-1.8
α_{ox}
27
26.5
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log L_X
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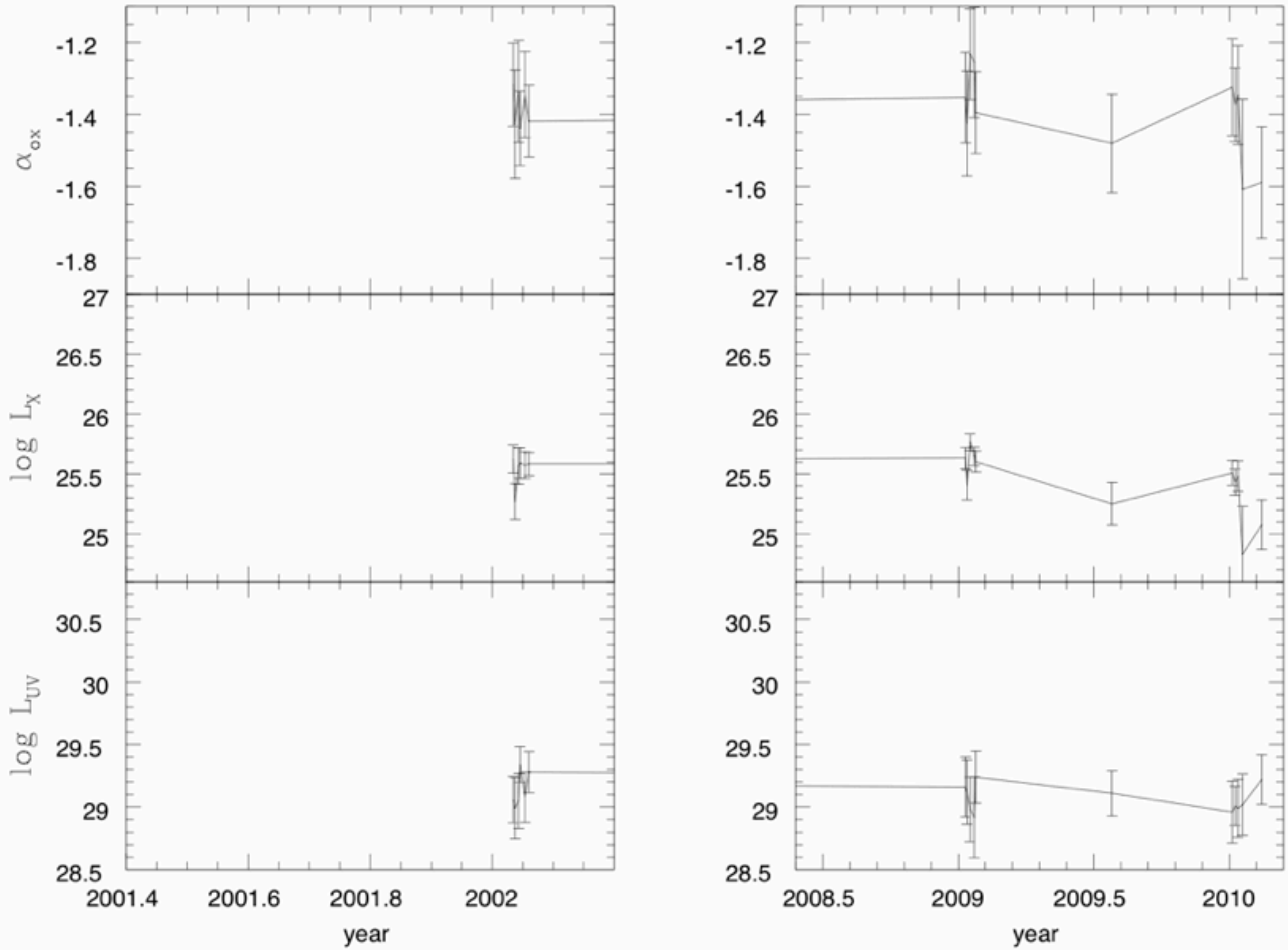
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-1.8
α_{ox}
27
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log L_X
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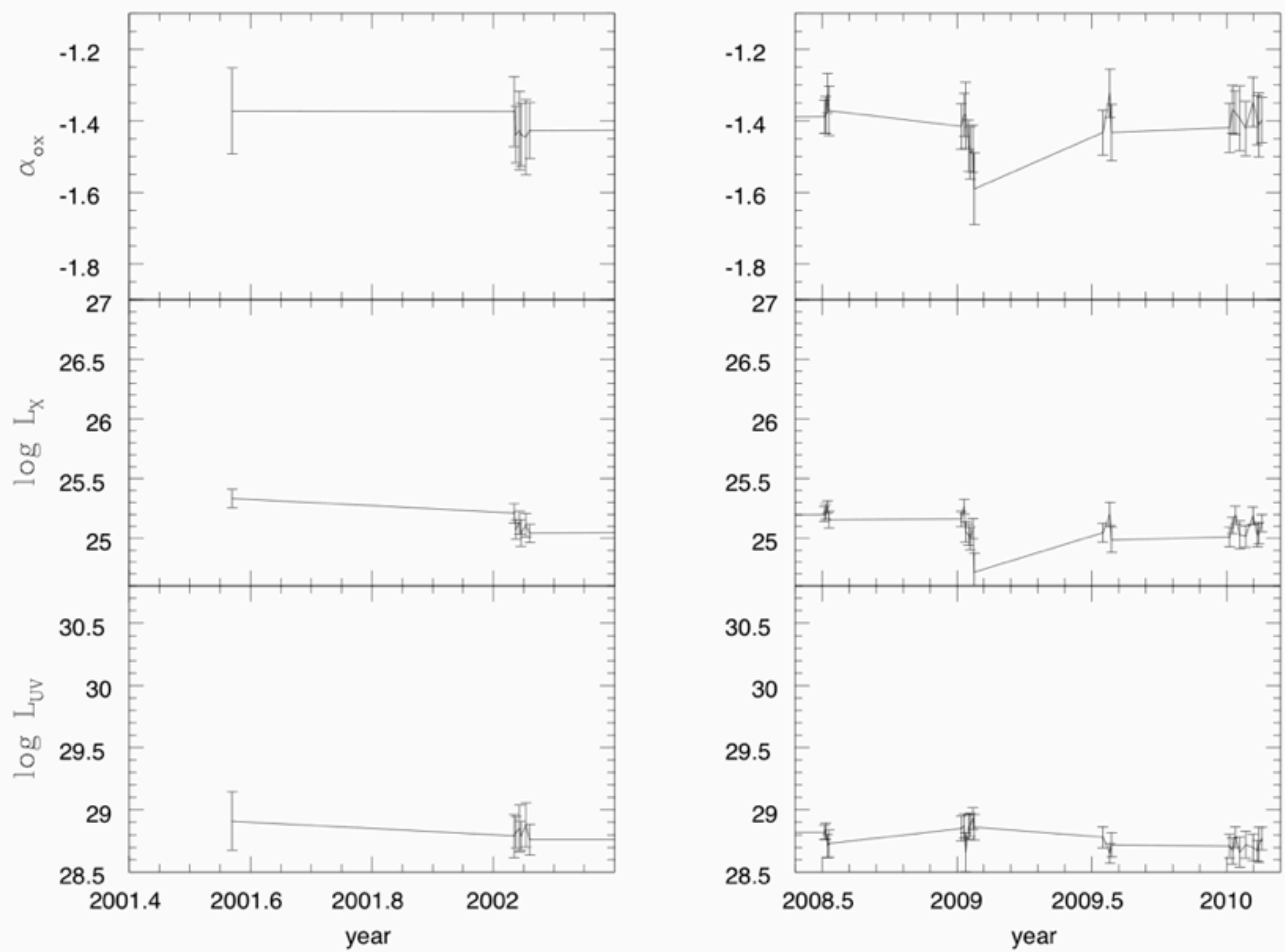

-1.2
-1.4
-1.6
-1.8
α_{ox}
27
26.5
26
25.5
25
log L_X
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29.5
29
28.5
log L_{UV}
2001.4
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year
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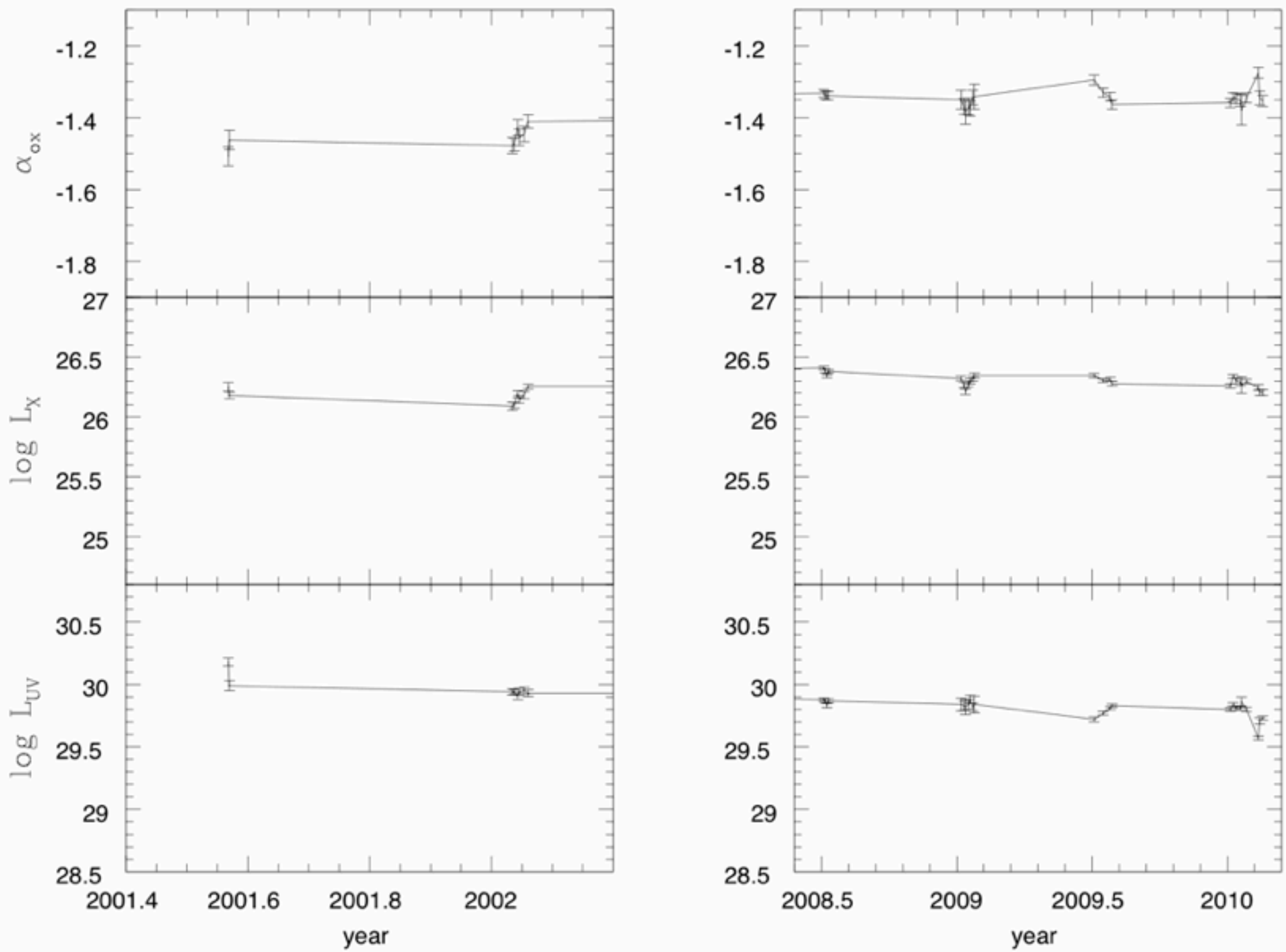
2009
2009.5
2010
year

319



-1.2
-1.4
-1.6
-1.8
α_{ox}
27
26.5
26
25.5
25
log L_X
30.5
30
29.5
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log L_{UV}
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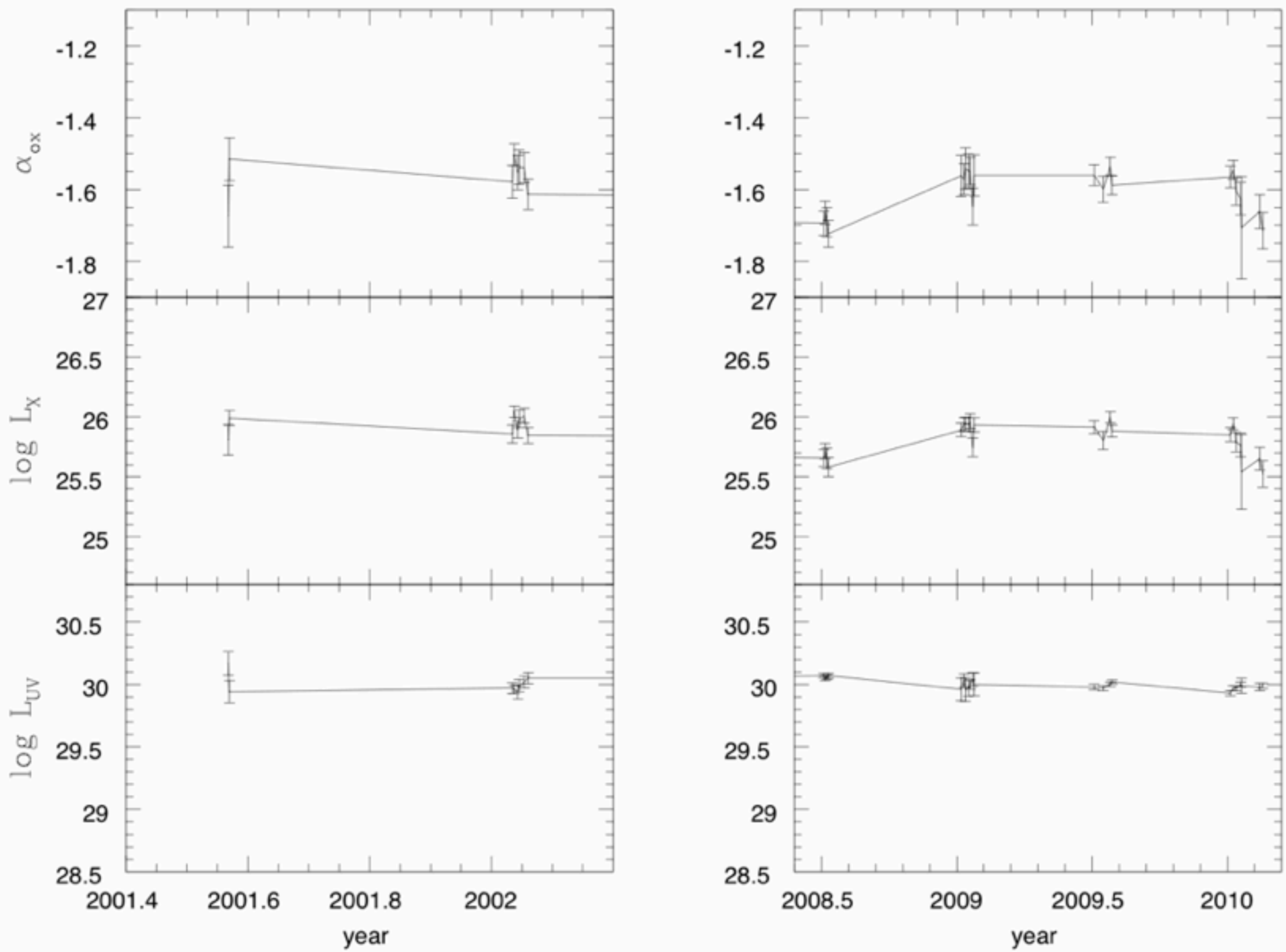
2009
2009.5
2010
year



α_{ox}
log L_X
log L_{UV}
-1.2
-1.4
-1.6
-1.8
27
26.5
26
25.5
25
30.5
30
29.5
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2001.4
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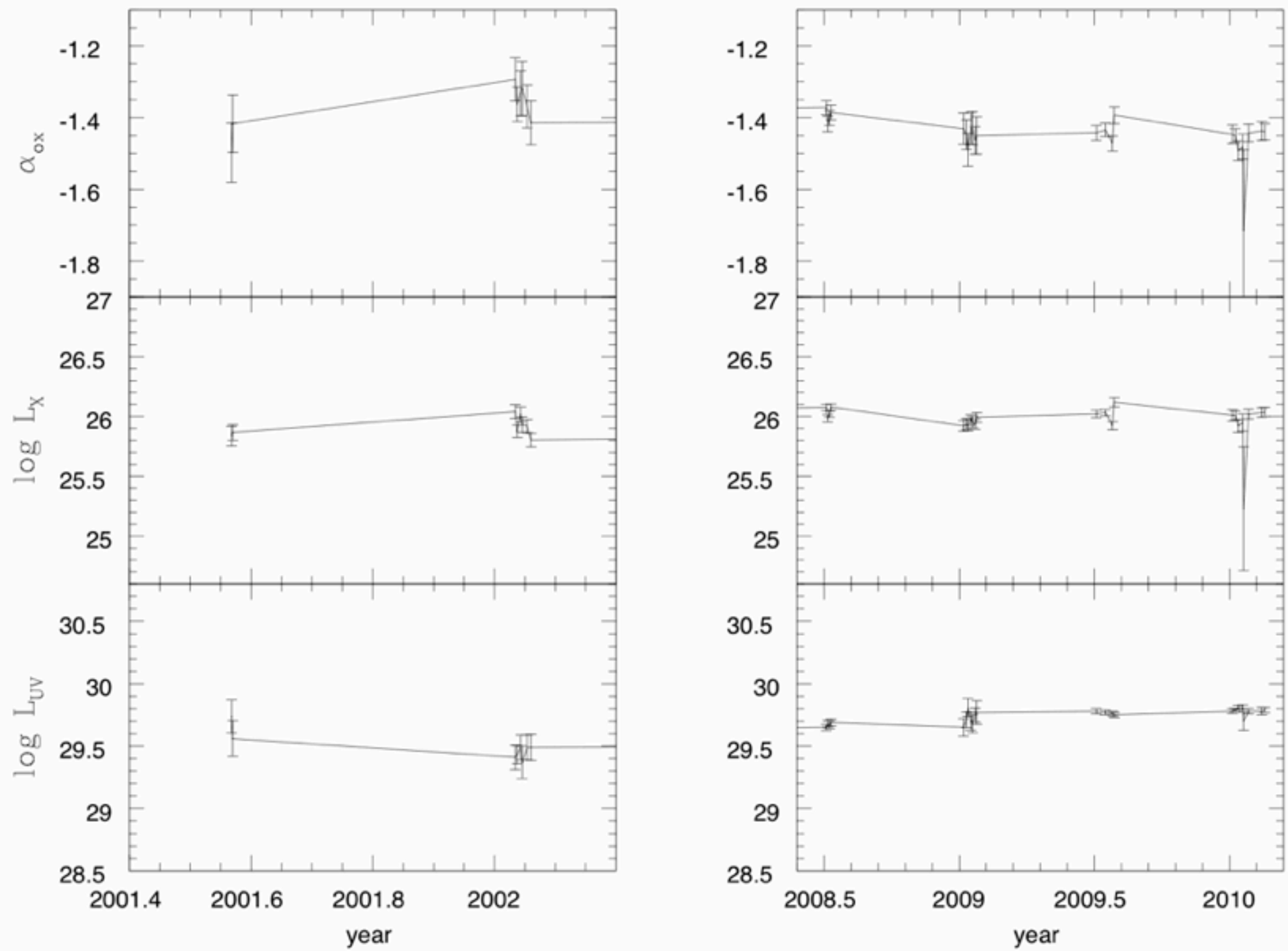
2009
2009.5
2010
year
year

337



-1.2
-1.4
-1.6
-1.8
α_{ox}
27
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log L_X
30.5
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28.5
log L_{UV}
2001.4
2001.6
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2008.5
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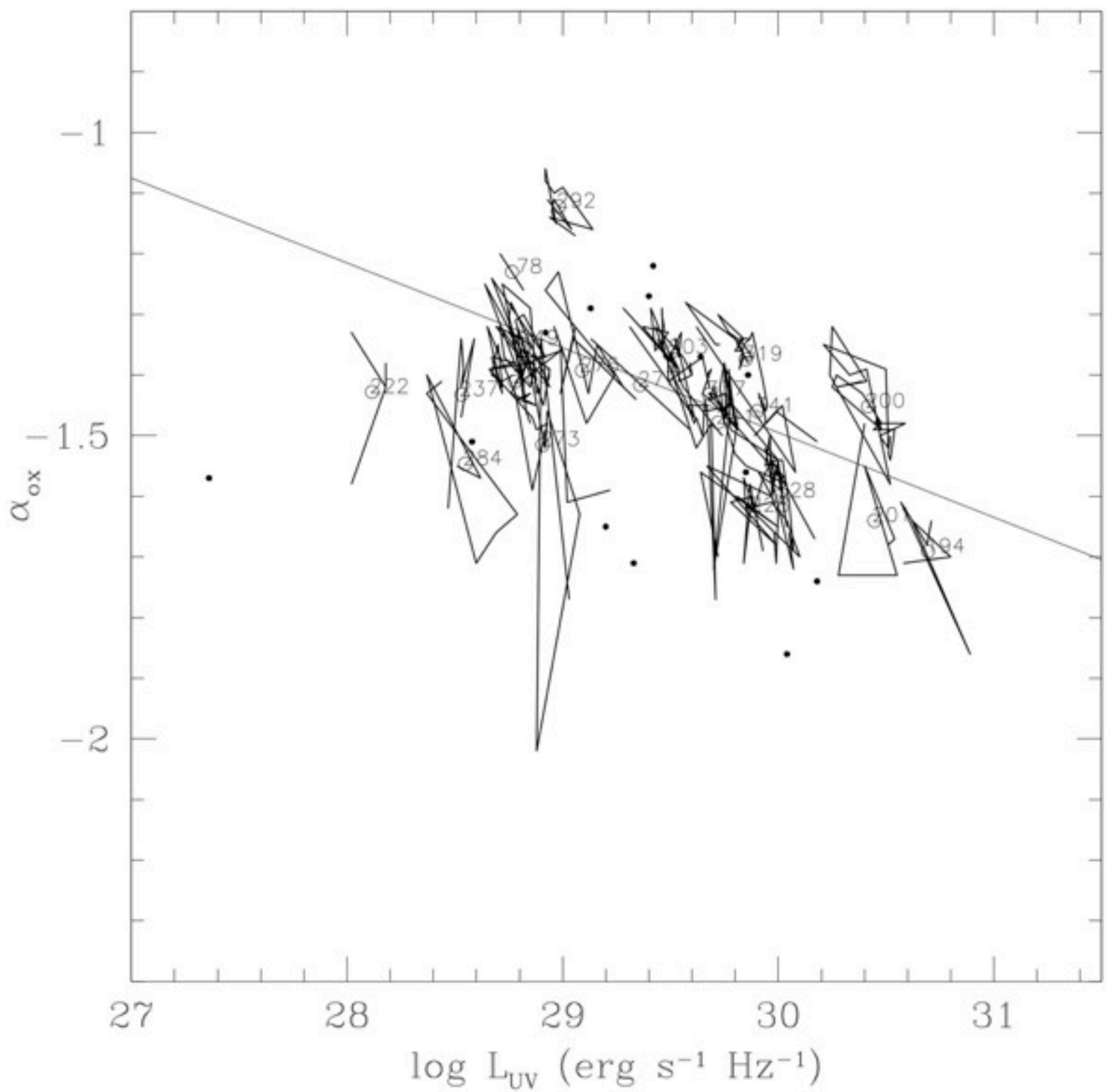
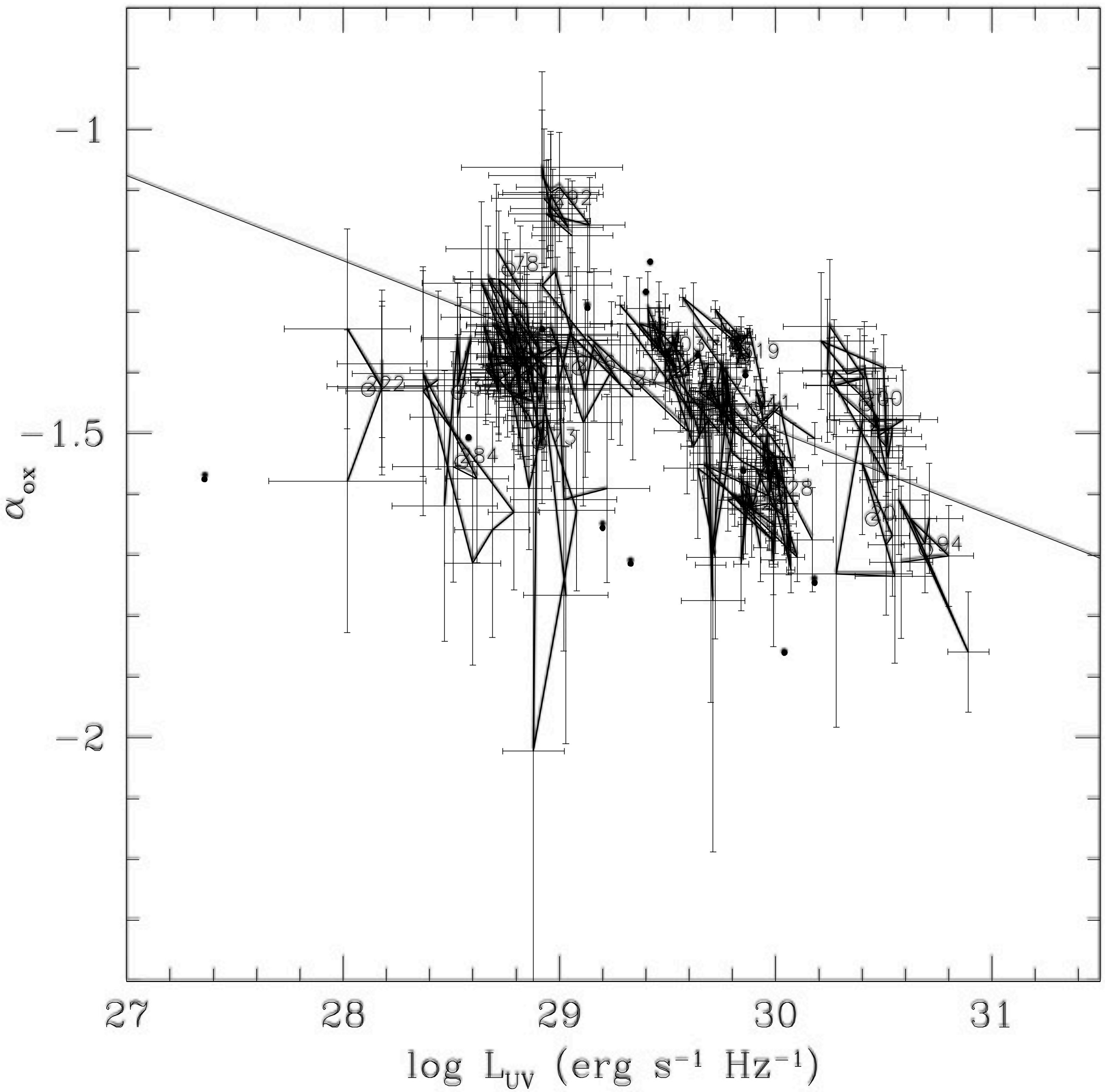
2009.5
2010
year

tracks in the plane α_{ox}-L_{UV}



detailed information on individual variability

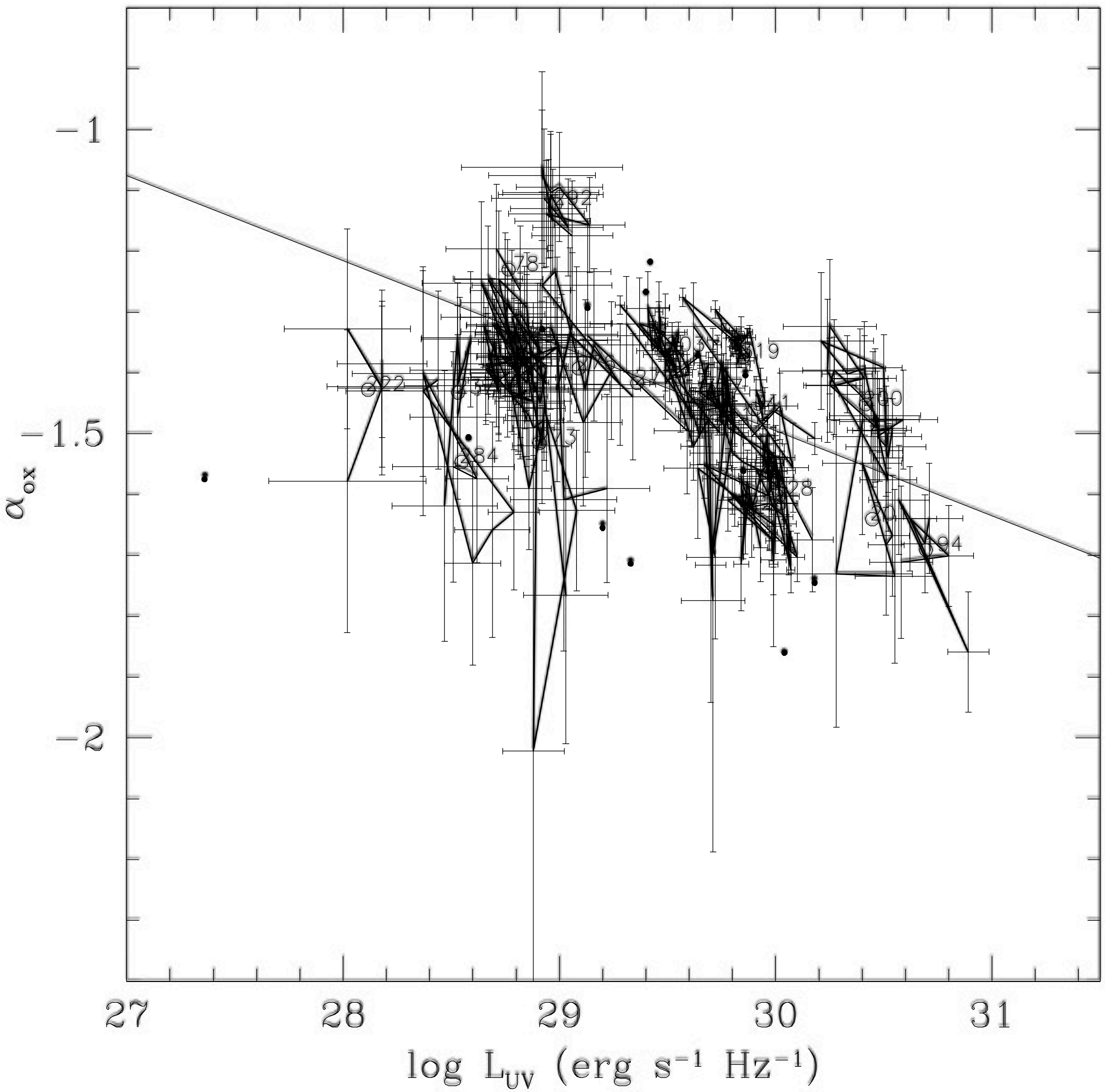
tracks in the plane α_{ox}-L_{UV}



detailed information on individual variability

but with large errors

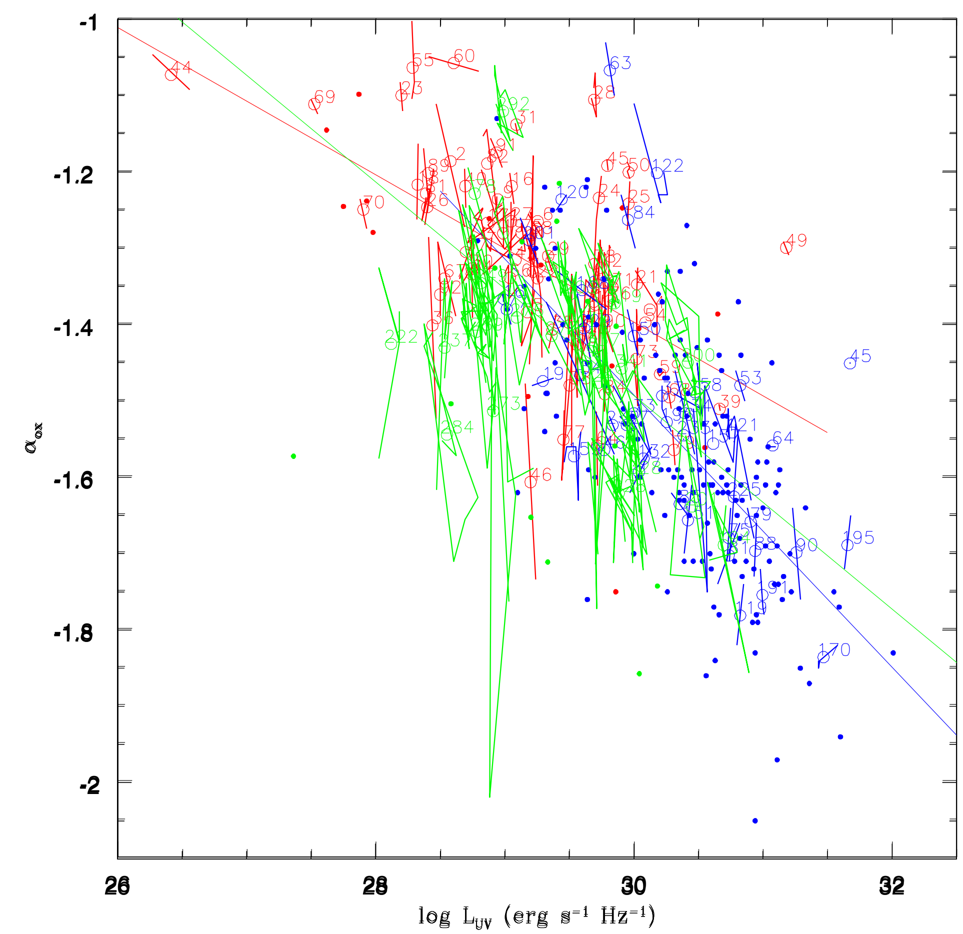
tracks in the plane α_{ox}-L_{UV}



detailed information on individual variability

but with large errors

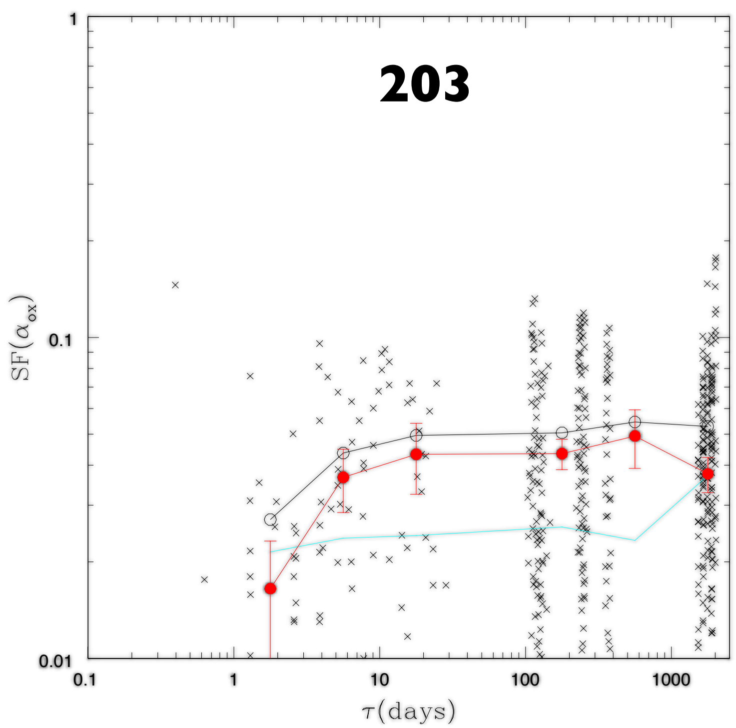
comparison with previous samples

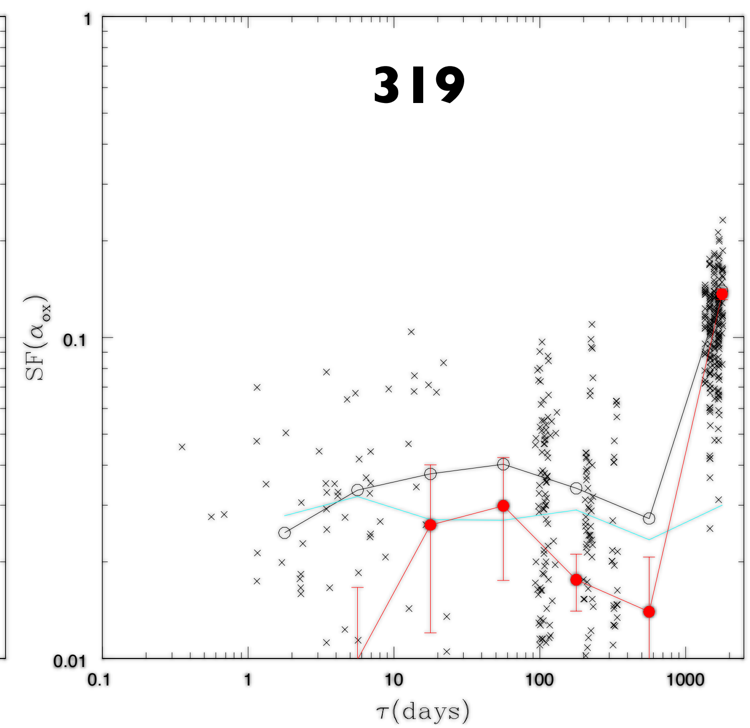


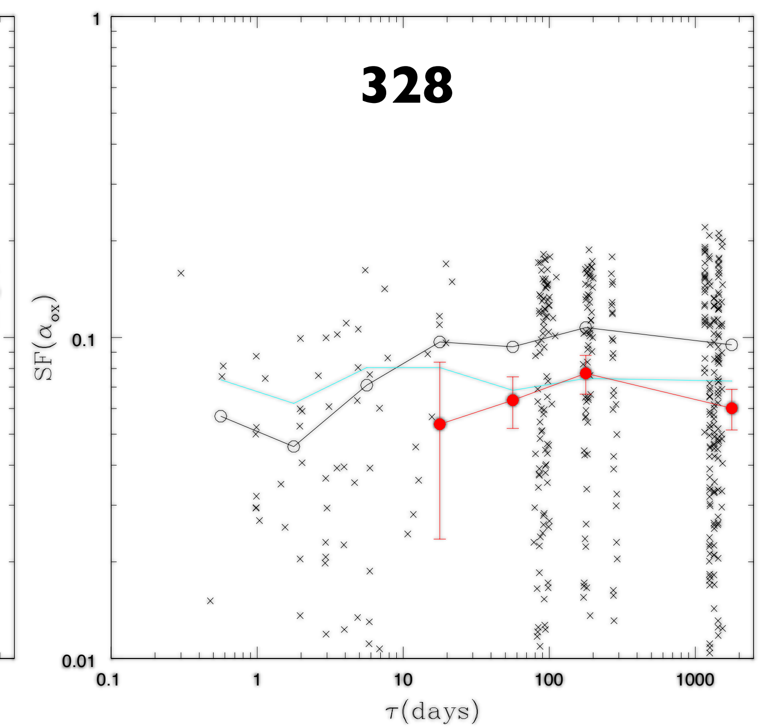
structure functions

individual SF: a few cases where we are able to subtract variability due to photometric errors (brightest sources)

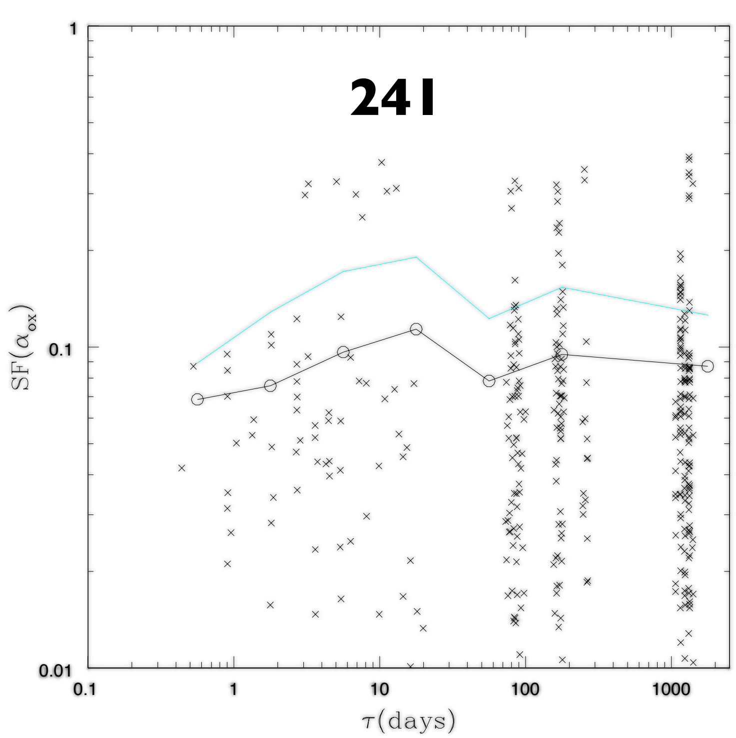
$$SF(\tau) = \sqrt{\frac{\pi}{2}\langle|\alpha_{ox}(t+\tau) - \alpha_{ox}(t)|\rangle^2 - \sigma_n^2}$$



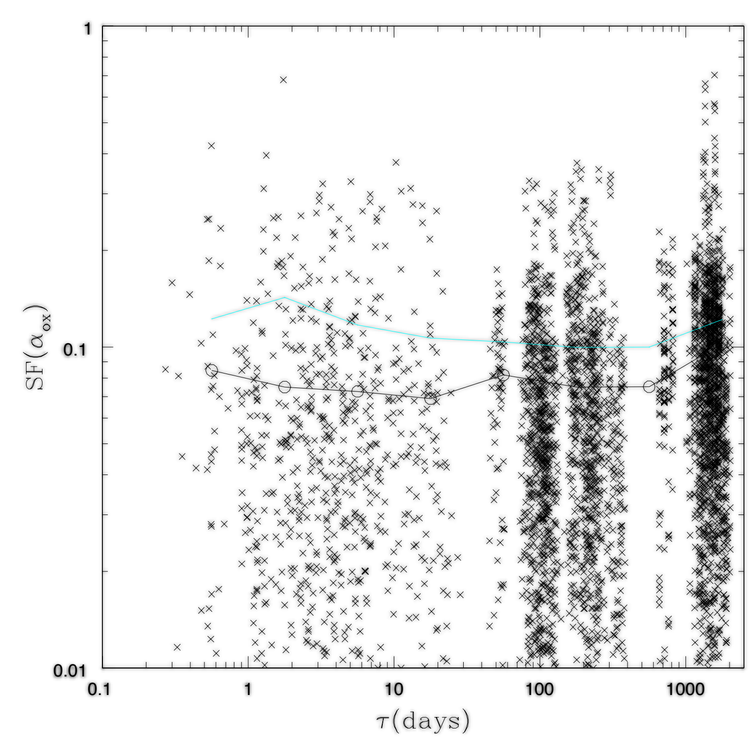




in most cases the error is larger than the measure



the same occurs for the ensemble SF



spectral variability parameter

describes changes of spectral index divided by changes of luminosity

introduced by Trevese & Vagnetti 2002 in the optical

$$\beta(\tau) = \frac{\alpha(t+\tau) - \alpha(t)}{\log L(t+\tau) - \log L(t)}$$

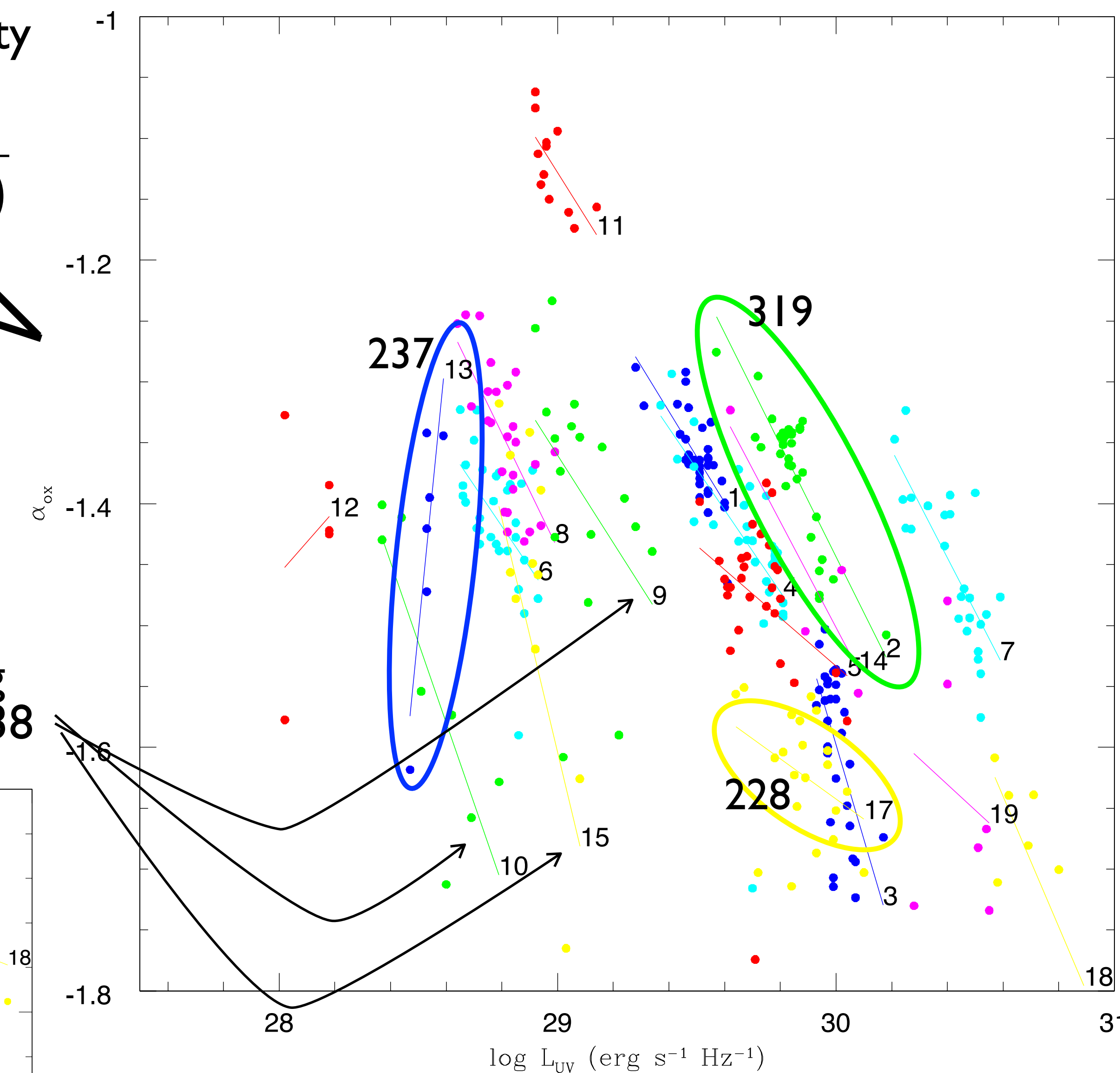
$\beta>0$: harder when brighter

$\beta<0$: softer when brighter

can be used also in α_{ox}-L_{UV} relation: can be estimated by average slope of α_{ox}-L_{UV} relation for individual source

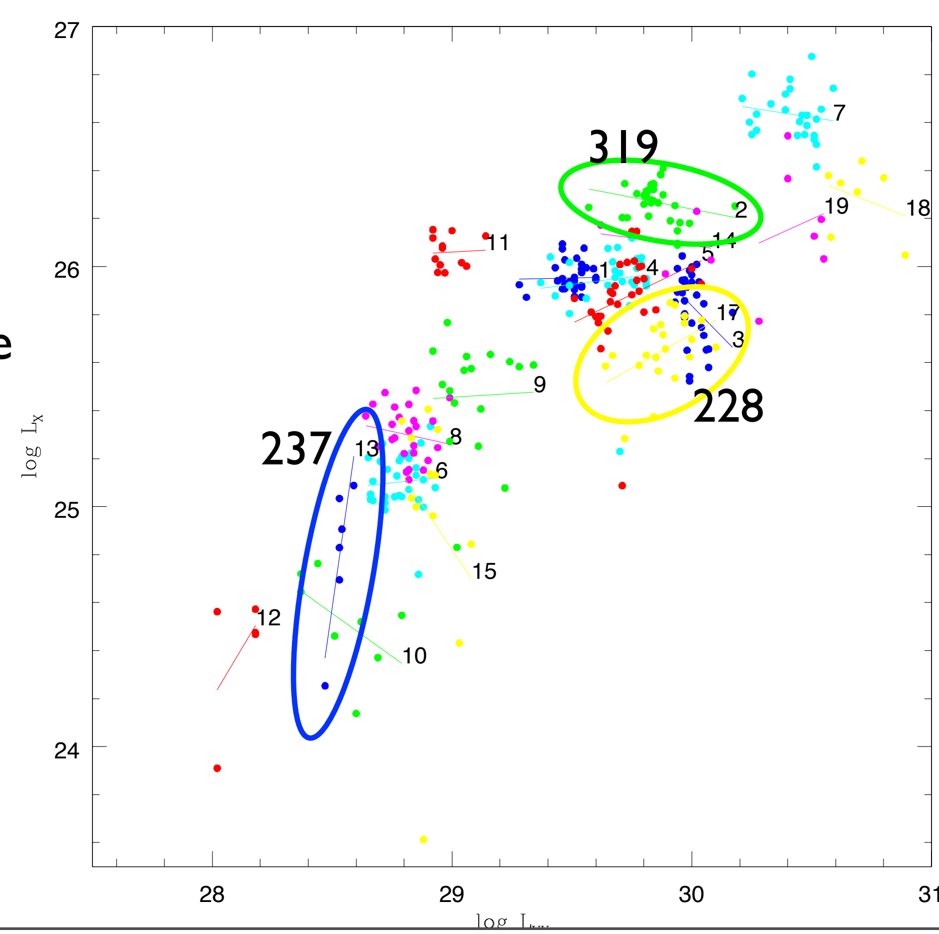
$$\beta_{ox} = \frac{\Delta \alpha_{ox}}{\Delta \log L_{UV}}$$

however, many correlations have slopes approaching -0.38, because α_{ox} is intrinsically correlated with L_{UV} by the definition α_{ox}=0.38log (L_X/L_{UV}). if L_X stays constant and only L_{UV} changes, slope will be -0.38



better evaluate L_X-L_{UV} correlations

best cases (P_{null}<0.03) are the sources:
237 (β_{ox}= 2.3±0.7)
228 (β_{ox}=-0.16±0.09)
319 (β_{ox}=-0.46±0.05)



most sources have negative β_{ox} . softer when brighter means that optical varies more than X-ray

source 237 shows an opposite behavior

next steps

- try to decrease the errors → get optimised X-ray fluxes from the collaboration; → check OM images
- improve ensemble and individual structure functions
- improve evaluation of β_{ox} with errors
- try X-ray/UV cross correlations to determine lags

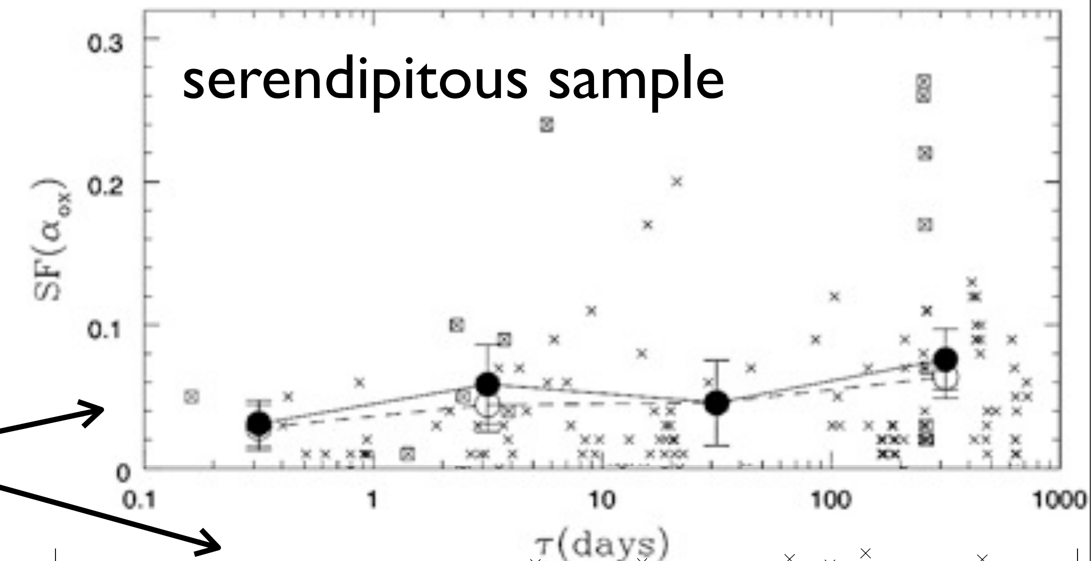
backup slides

disk-corona relation
CIV blueshift
3 bright sources in L-z plane
N_{epo} histograms
cross-correlations
optical and X-ray images

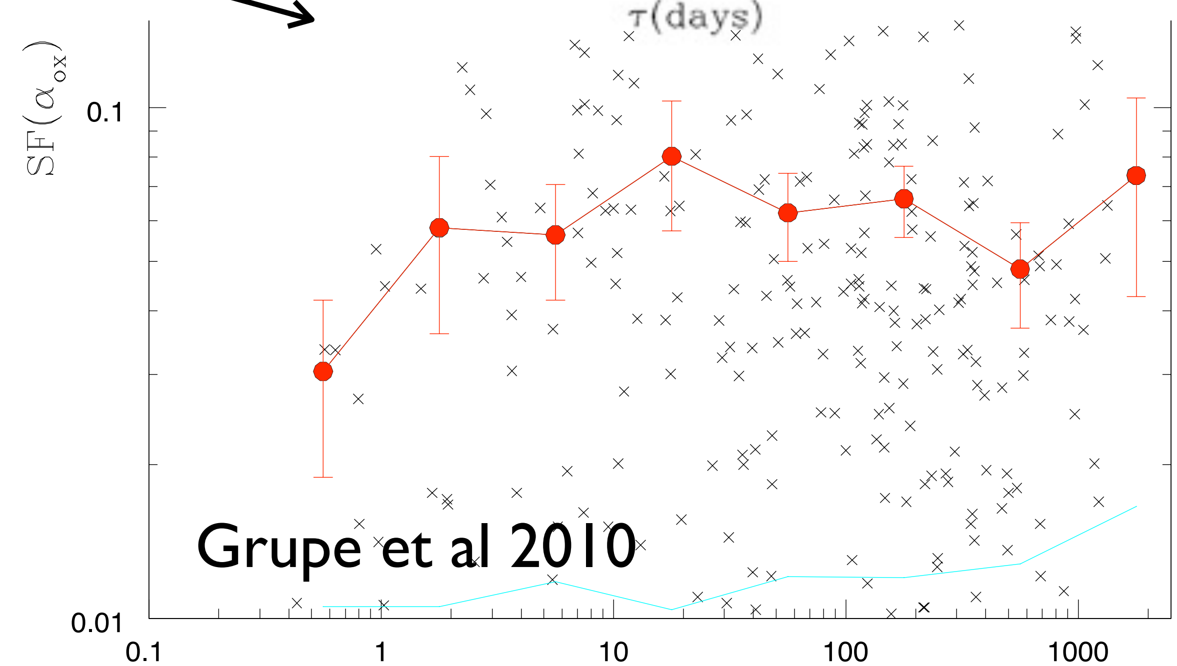
X-ray/optical interplay

$$\alpha_{ox} \equiv 0.38 \log \frac{L_X}{L_{UV}}$$

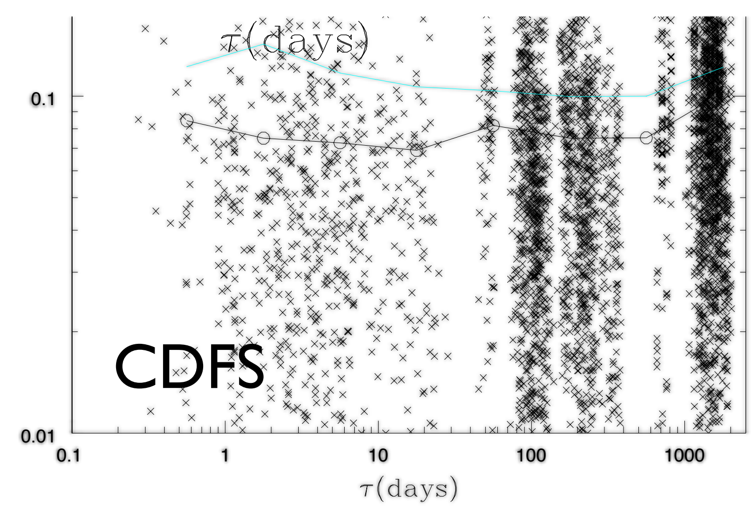
if α_{ox} changes, then X and UV must vary differently, one more than the other

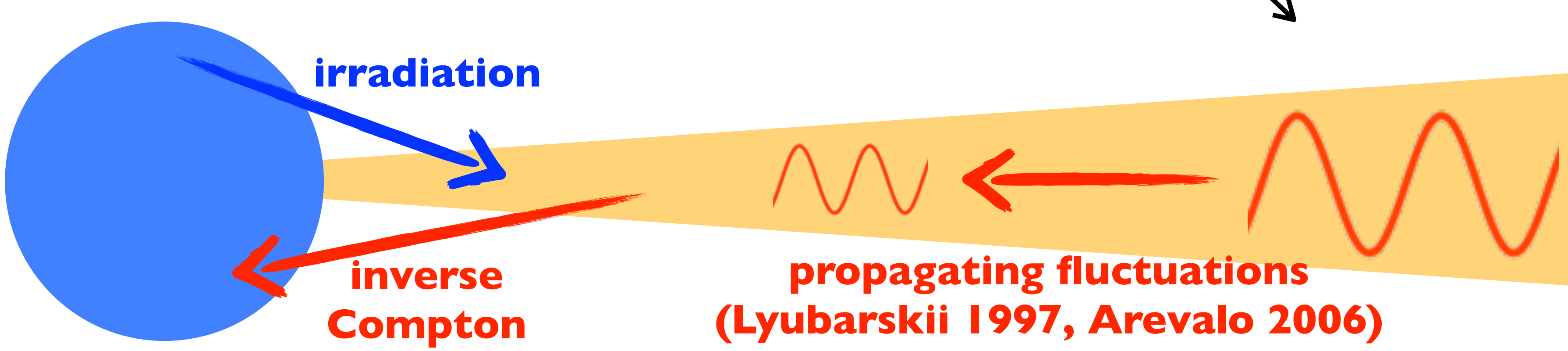


larger variations at **long time scales**, according to SF

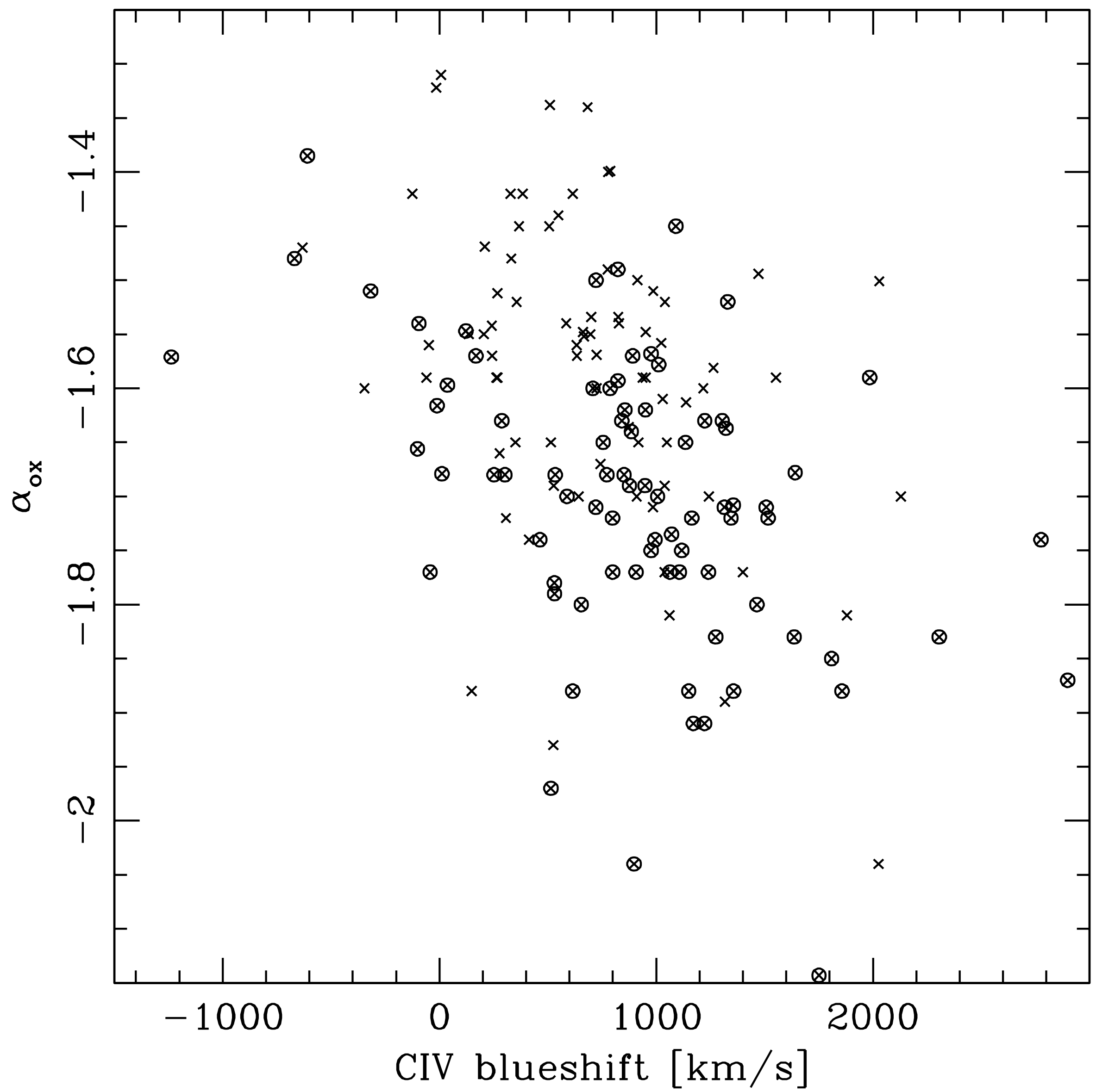


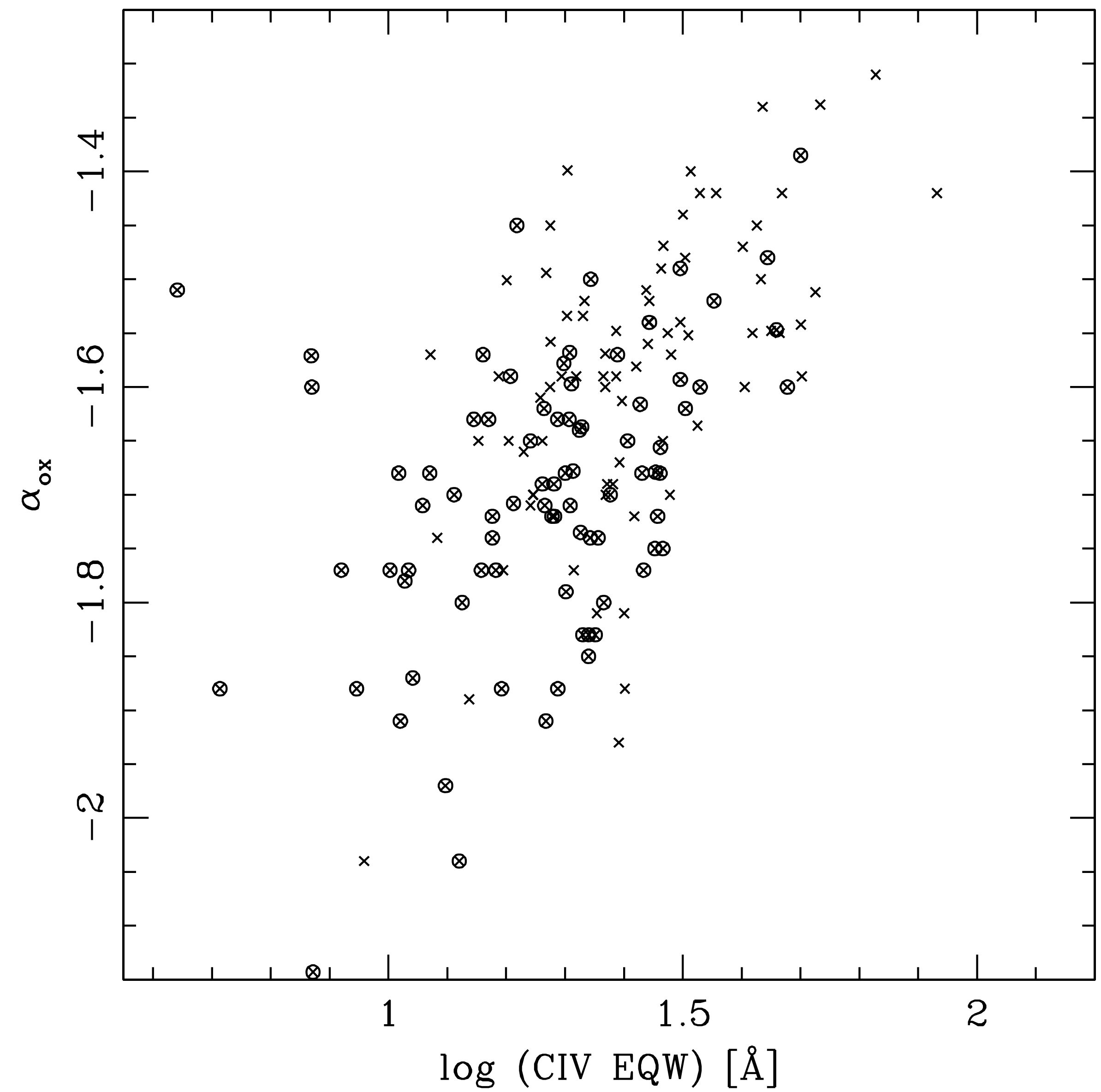
expected to be driven by **optical** fluctuations





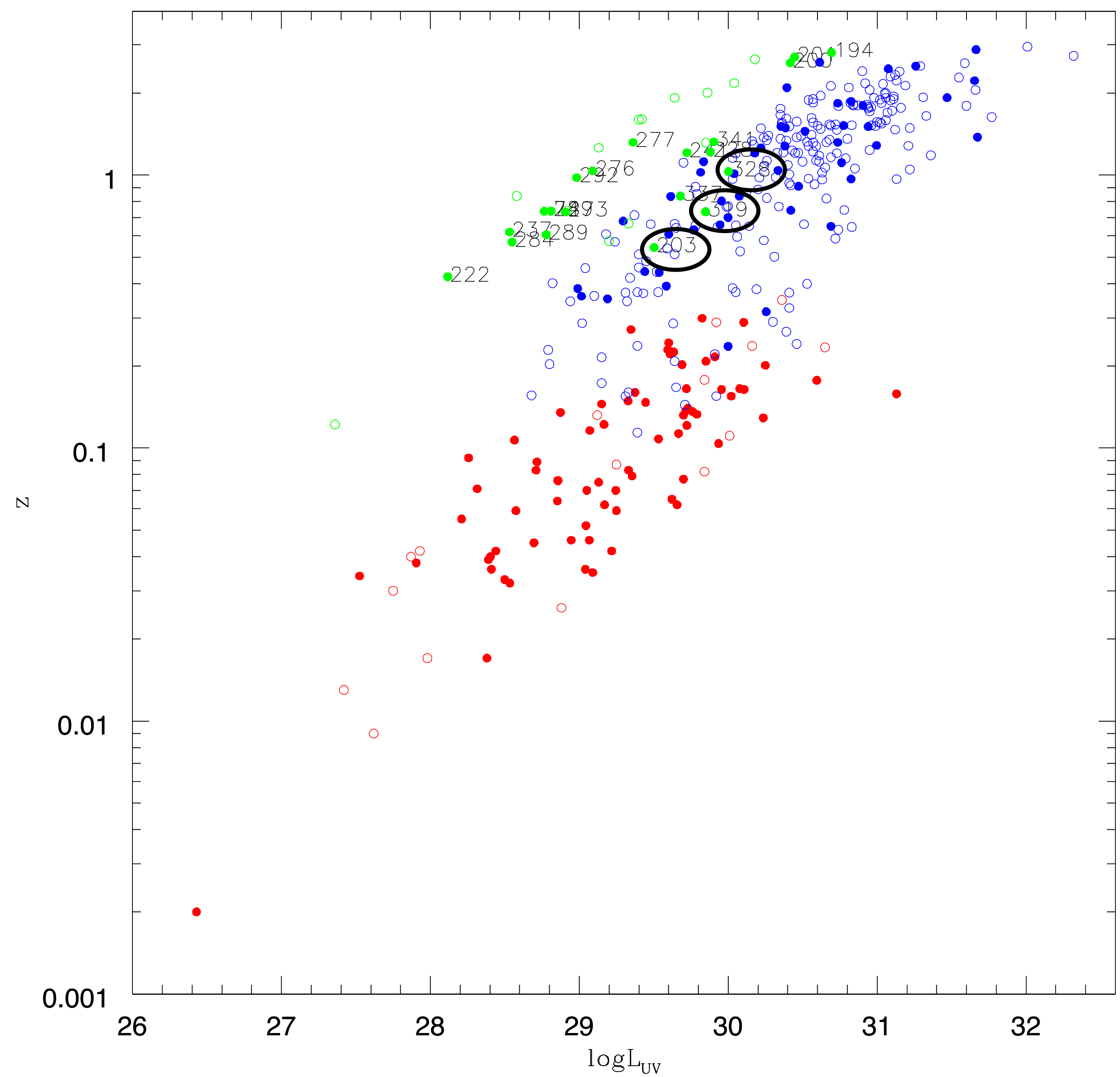
CIV Equivalent Width and blueshift





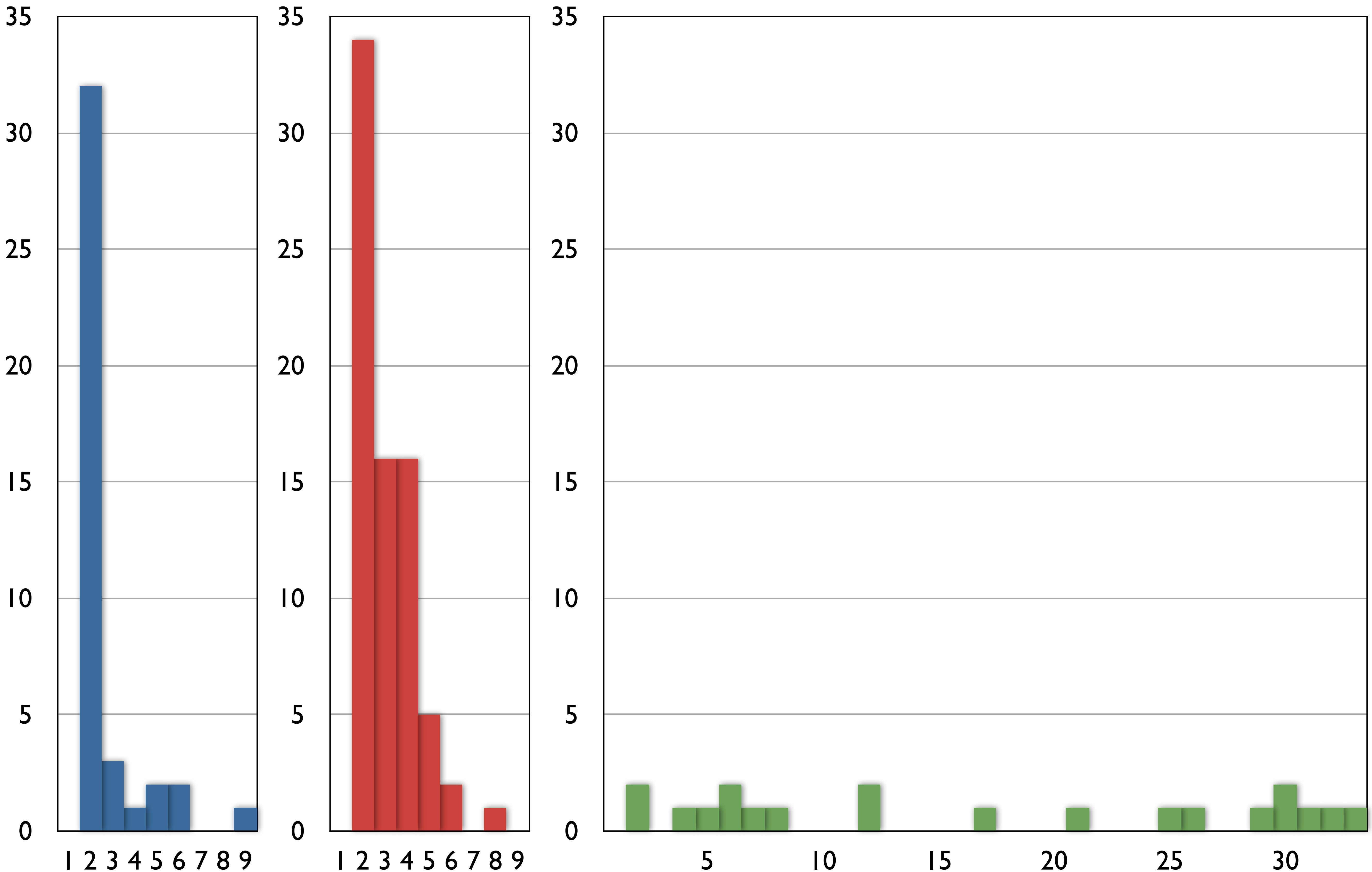
α_{ox} is anti-correlated with CIV blueshift and correlated with CIV Equivalent Width (Richards et al 2011, Kruczek et al 2011)

L-z plane

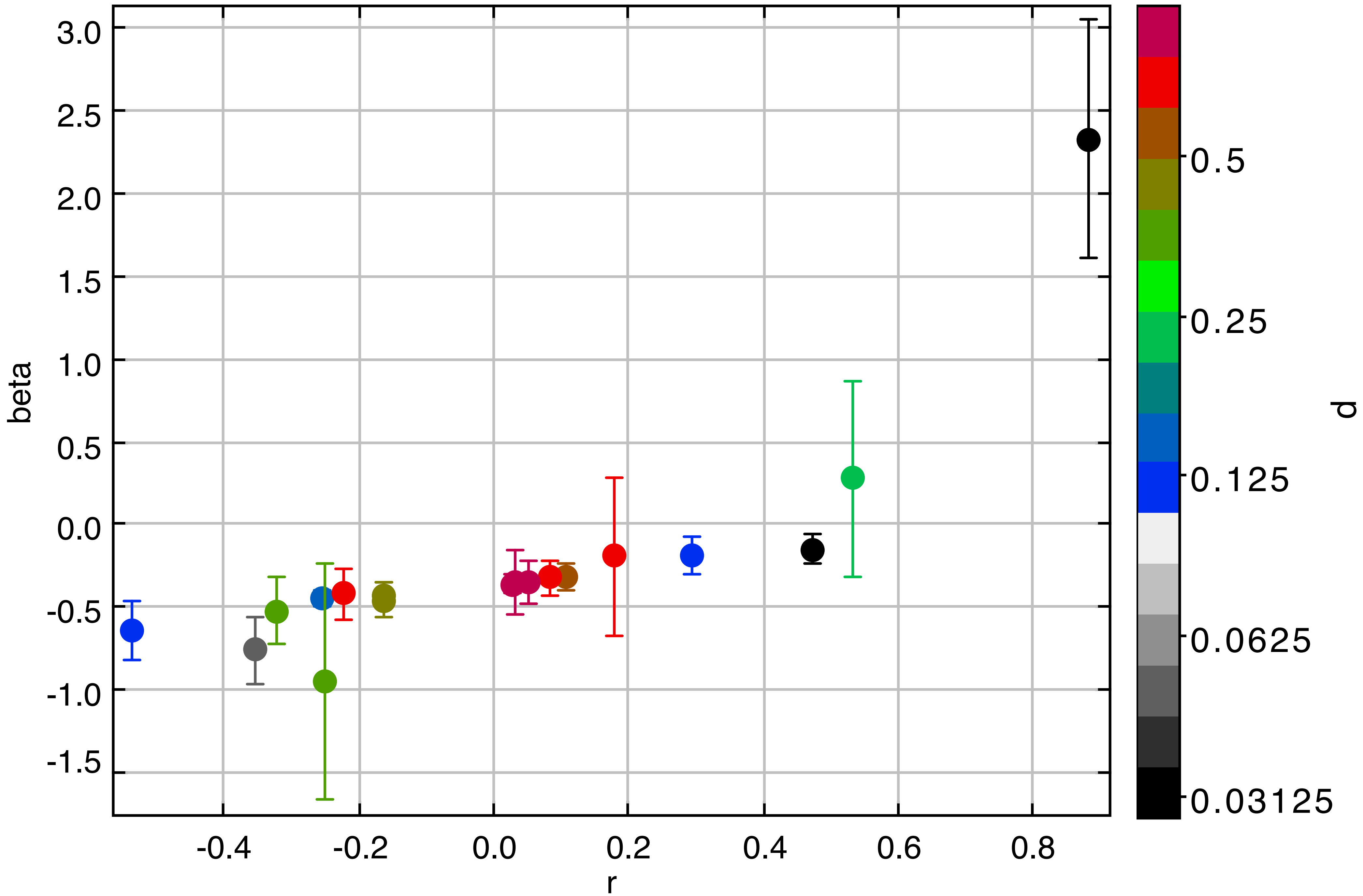


z
logL_UV
1
0.1
0.01
0.001
26
27
28
29
30
31
32
194
277
276
292
273
237
289
284
222
341
328
203

N_{epo} histograms



β, r and P(>r)

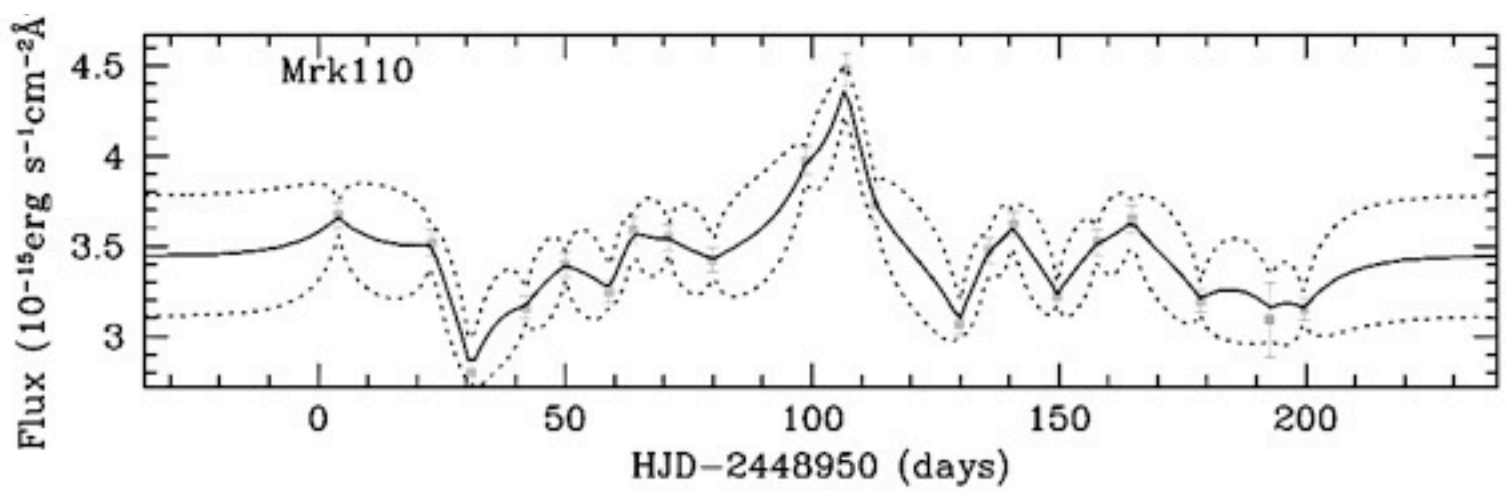


3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
beta
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
r
0.5
0.25
0.125
0.0625
0.03125
d

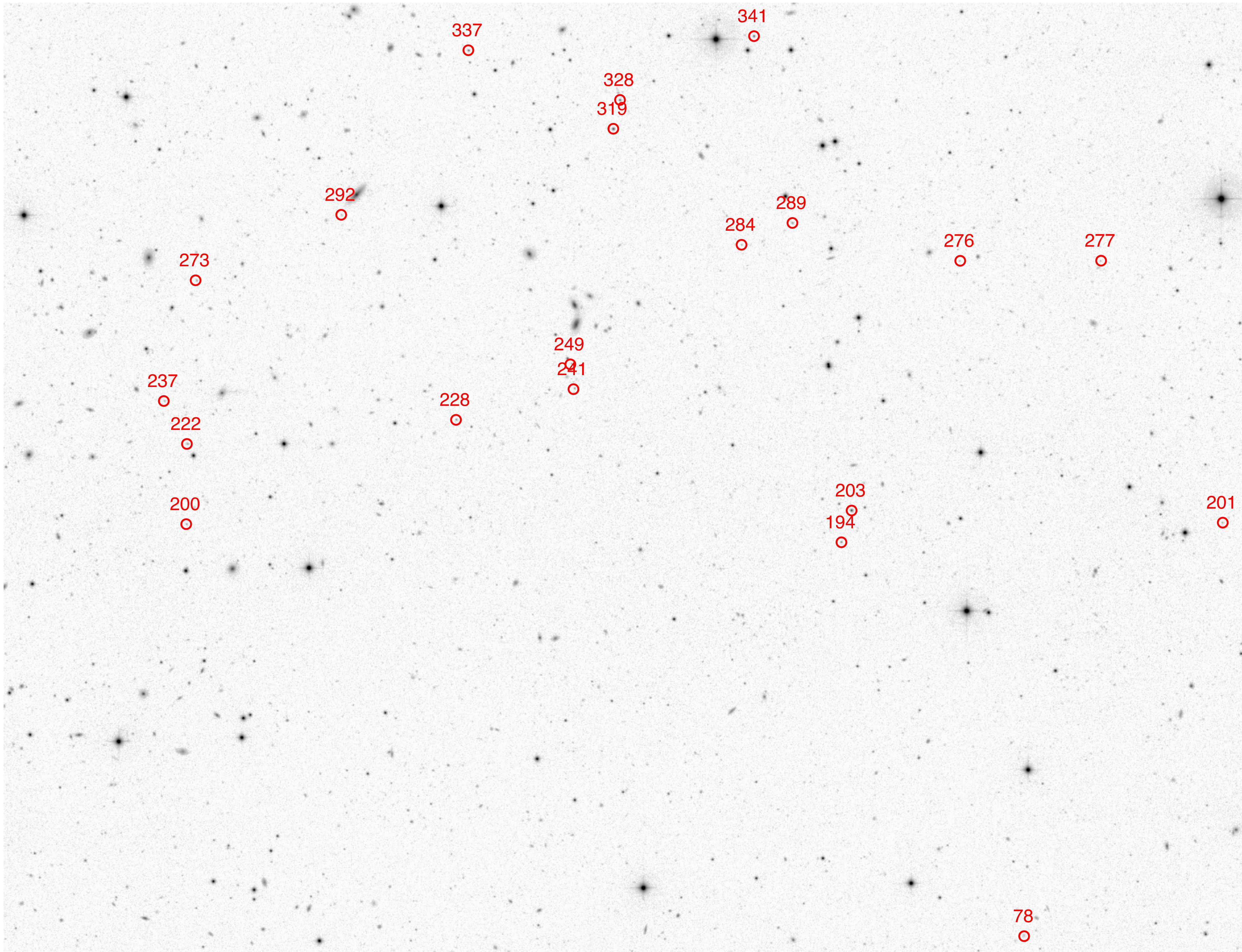
cross-correlation

with quite large number of epochs, it could be possible to try **cross-correlations** to determine time-lags between X-ray and optical

methods to estimate probabilities within the gaps could be applied (Zu et al 2011)



optical image, V_{EIS}



X-ray image, 4Ms Chandra