The role of ionized and molecular outflows in quasar evolution.

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\+ **The BASS team**

Plan of Talk

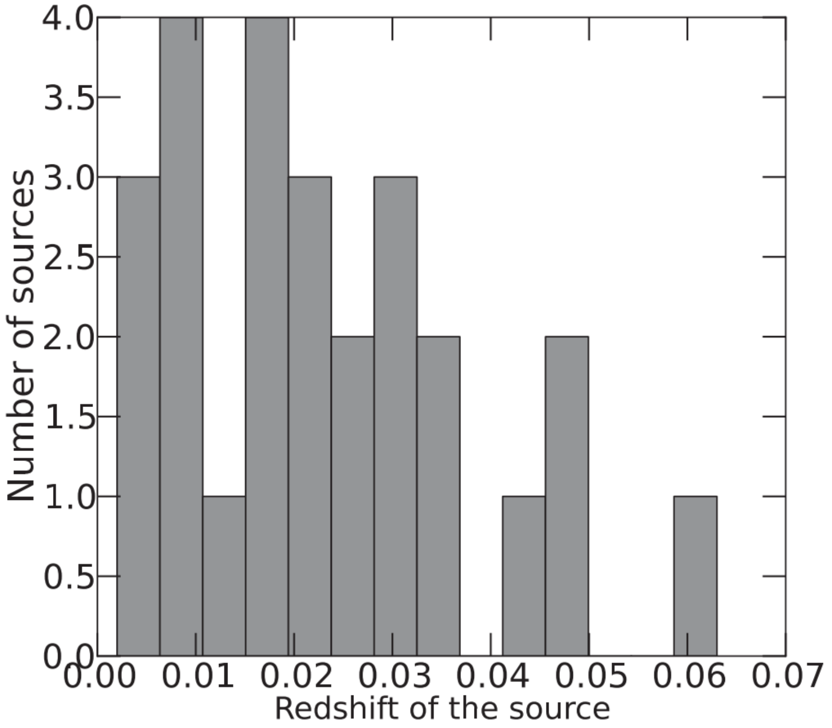
1. The pc scale ionized outflows: Warm absorbers and UFOs, **The WAX project** , (**Laha et al. 2014, 2016**)
2. The kpc scale molecular outflows: **The MOX project** (**Laha et al. 2018**)
3. The central engines of low luminosity local quasars: **The LLQSO project** (**Laha et al. 2018**)
4. The X-ray obscuration in Seyfert galaxies, as a probe for `Torus' morphology?? **(Laha et al. in prep)**

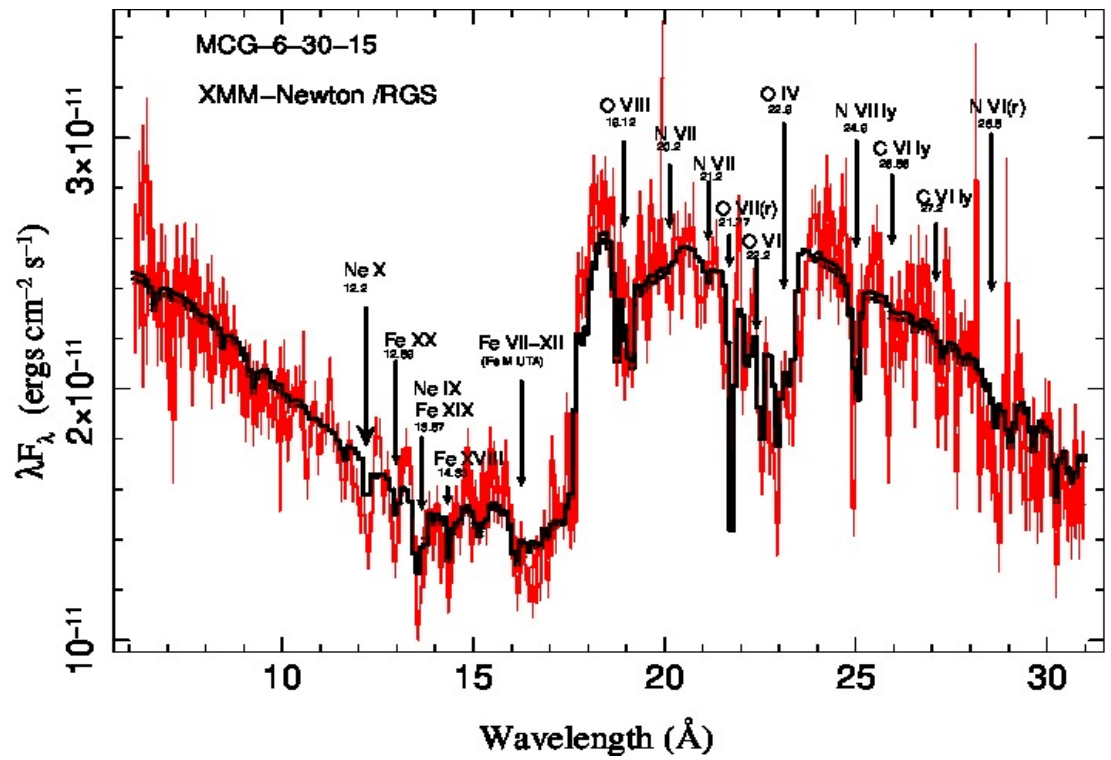
5. Projects with BASS

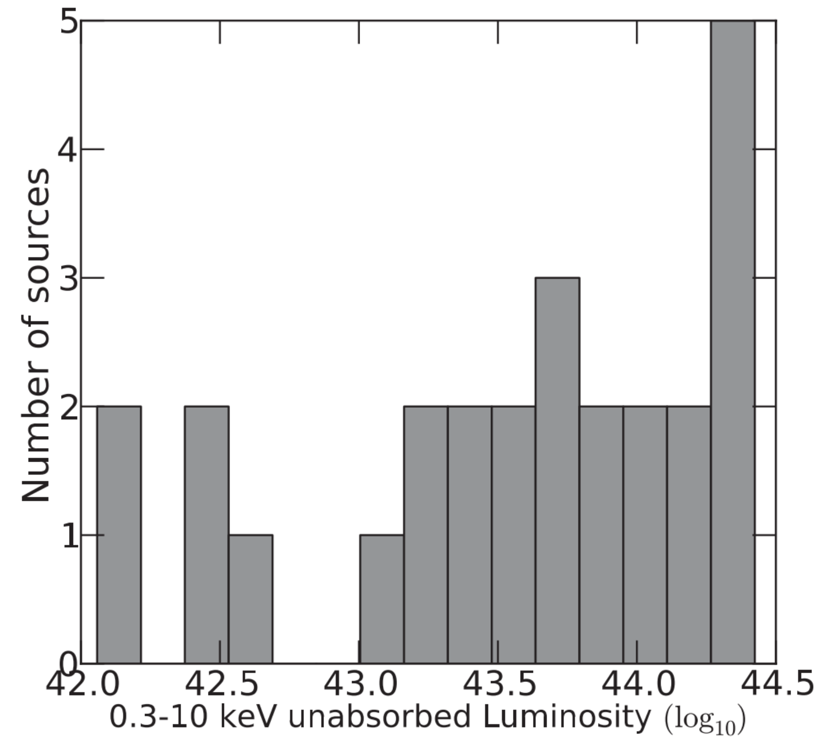
Introduction to WAX

The WAX ("Warm Absorber in X-rays") sample

- *Sample of 26 Seyfert 1 galaxies*
-
- X-ray unobscured , $N_H \leq 10^{22}$ cm^{-2}
-
- High signal-to-noise **XMM-Newton** spectroscopic data, no EPIC pile-up
- Radio-quiet (log R < 2.4; Panessa et al. 2007)



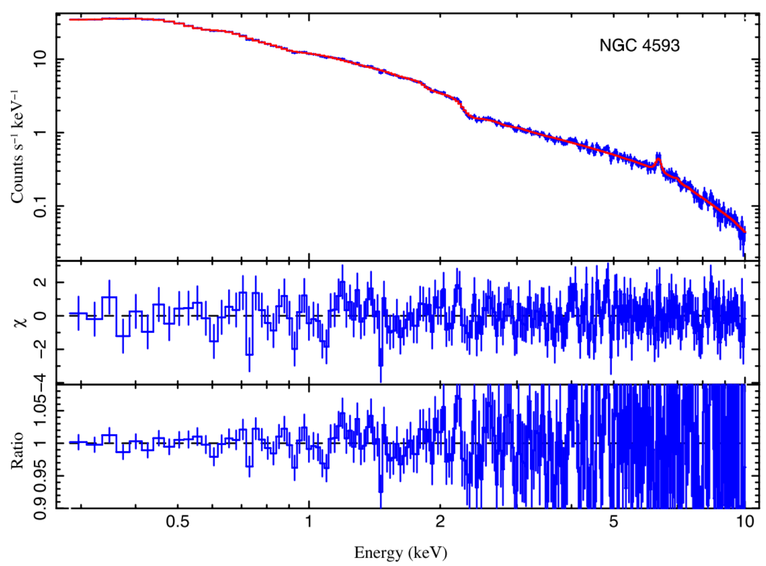


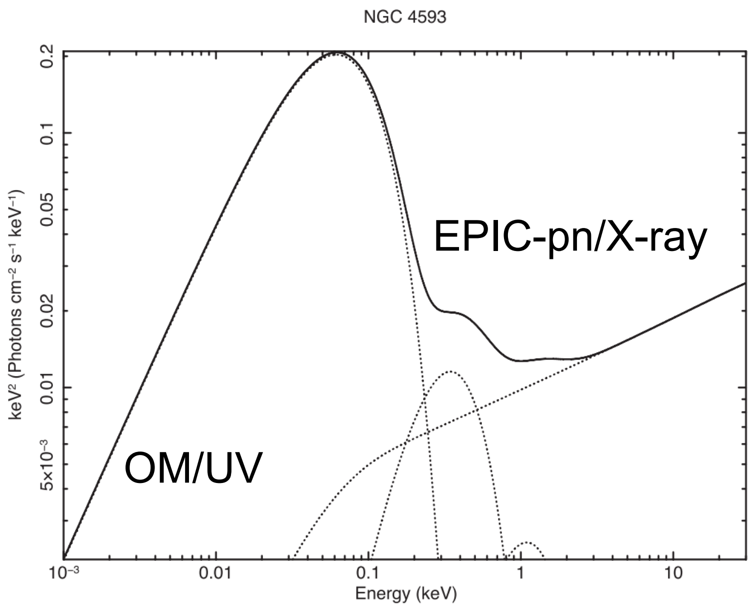


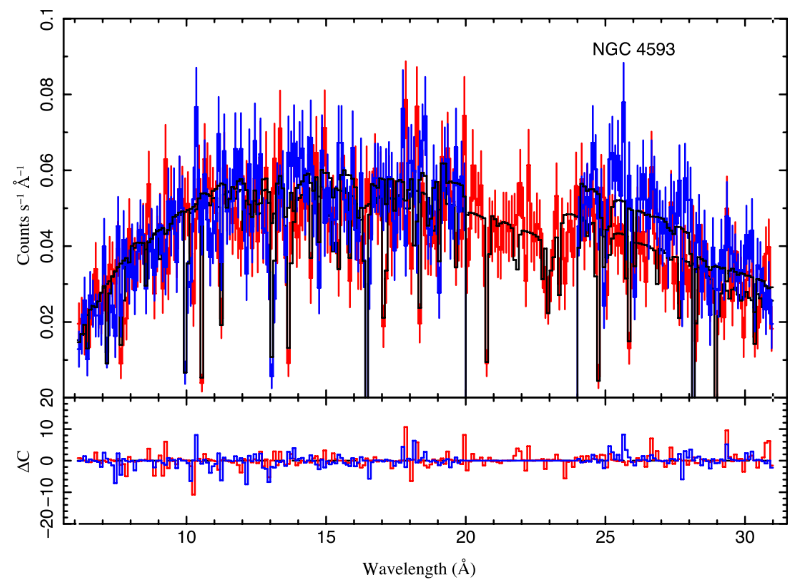
Laha et al. 2014 and 2016

Introduction to WAX

WAX analysis







- Baseline X-ray continuum with EPIC-pn spectrum (0.3-10 keV)
- Optical to X-ray SED with simultaneous OM/EPIC data
- Generation of warm absorber CLOUDY grids
- Self-consistent fit of EPIC-pn and RGS spectra
- A couple of iterations, as required …

Direct derivatives are xi, NH and velocity

Laha et al. 2014 and 2016

WAX result - I

Samples, warm absorber (WA)/UFOs incidence

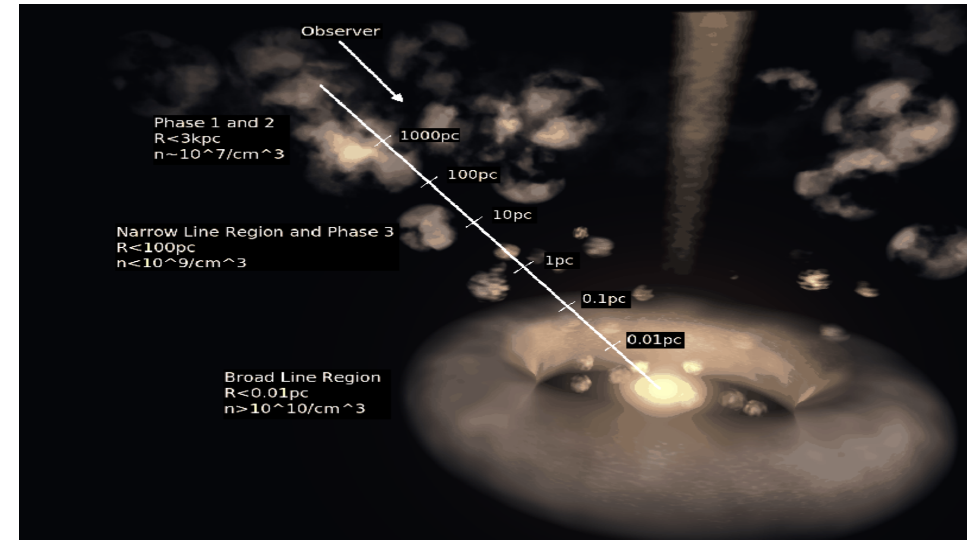
Paper	Instrument	$N_{objects}$	Mimimum incidence
McKernan+07	HETG	15 Type I AGN	WA: ~67%
Tombesi+10	EPIC-pn	42 RQ-AGN	WA: ~60% UFOs: ~34%
Gofford+13	XIS	51 Type 1-1.9 AGN	UFO: ~40%
Laha+14 (WAX)	EPIC-pn+RGS	26 Seyferts 1-1.5 + 1 LINER	WA: 77±9 %
Tombesi+14	EPIC-pn/XIS	26 RL-AGN	UFO: 50±20%

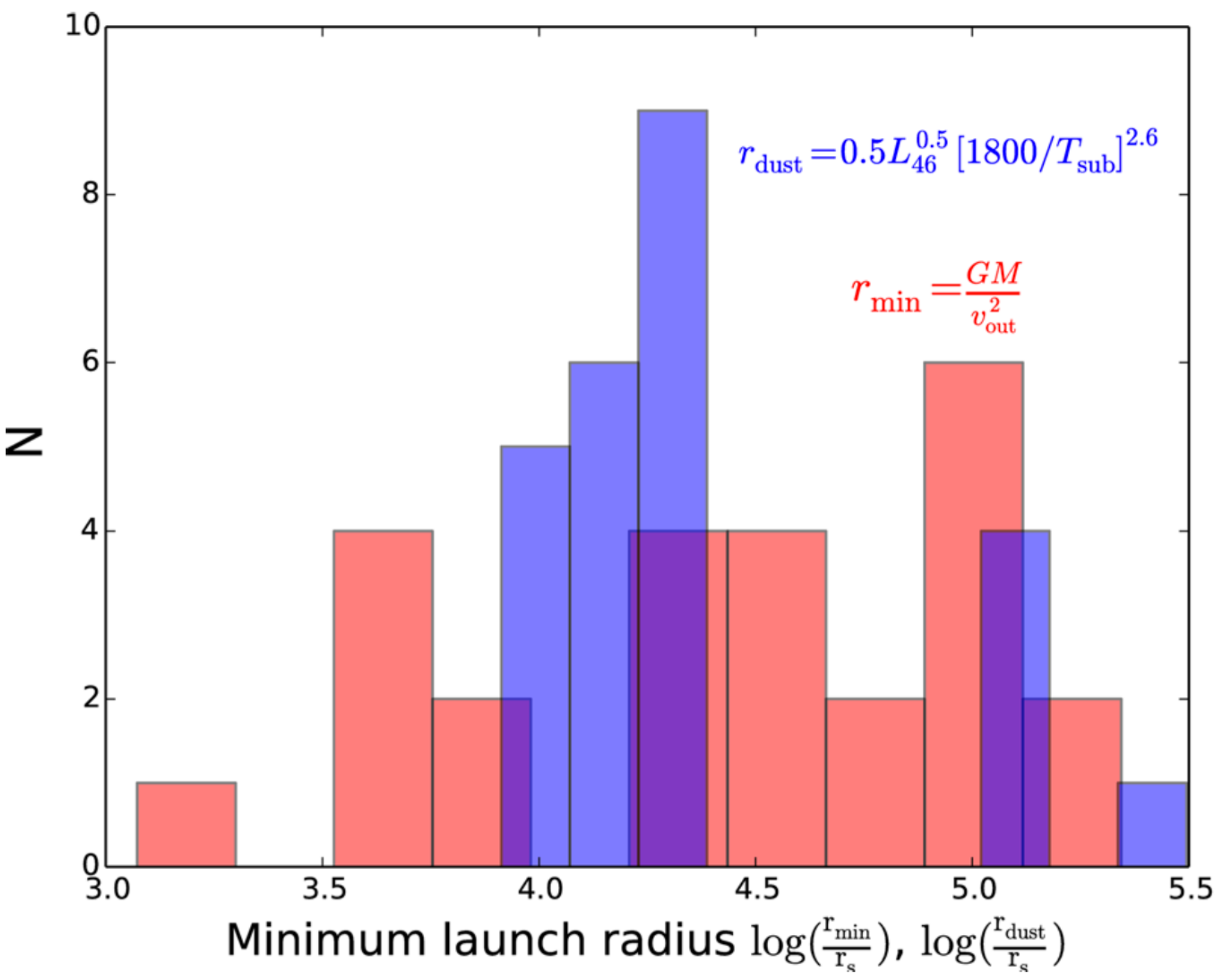
Laha et al. 2014 and 2016

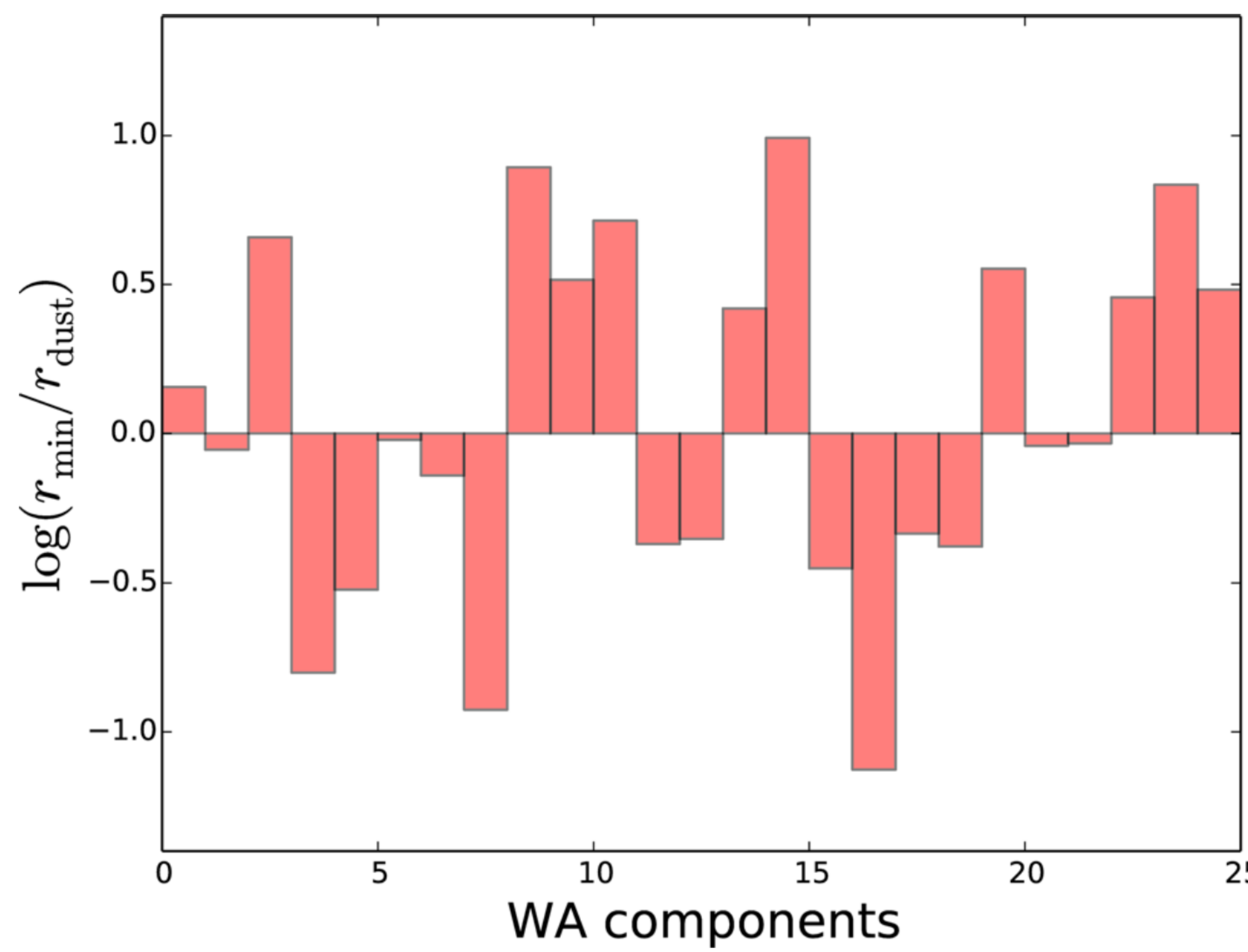
WAX result - II

WA launch radius:

Warm absorber launch (=escape) radius is commensurable to the dust sublimation radius







Laha et al. 2014 and 2016

WAX result - II

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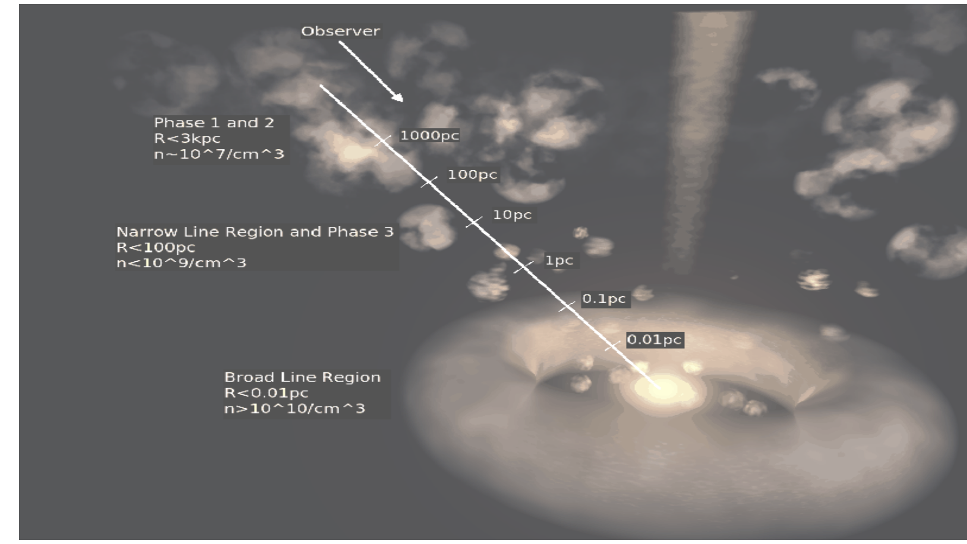
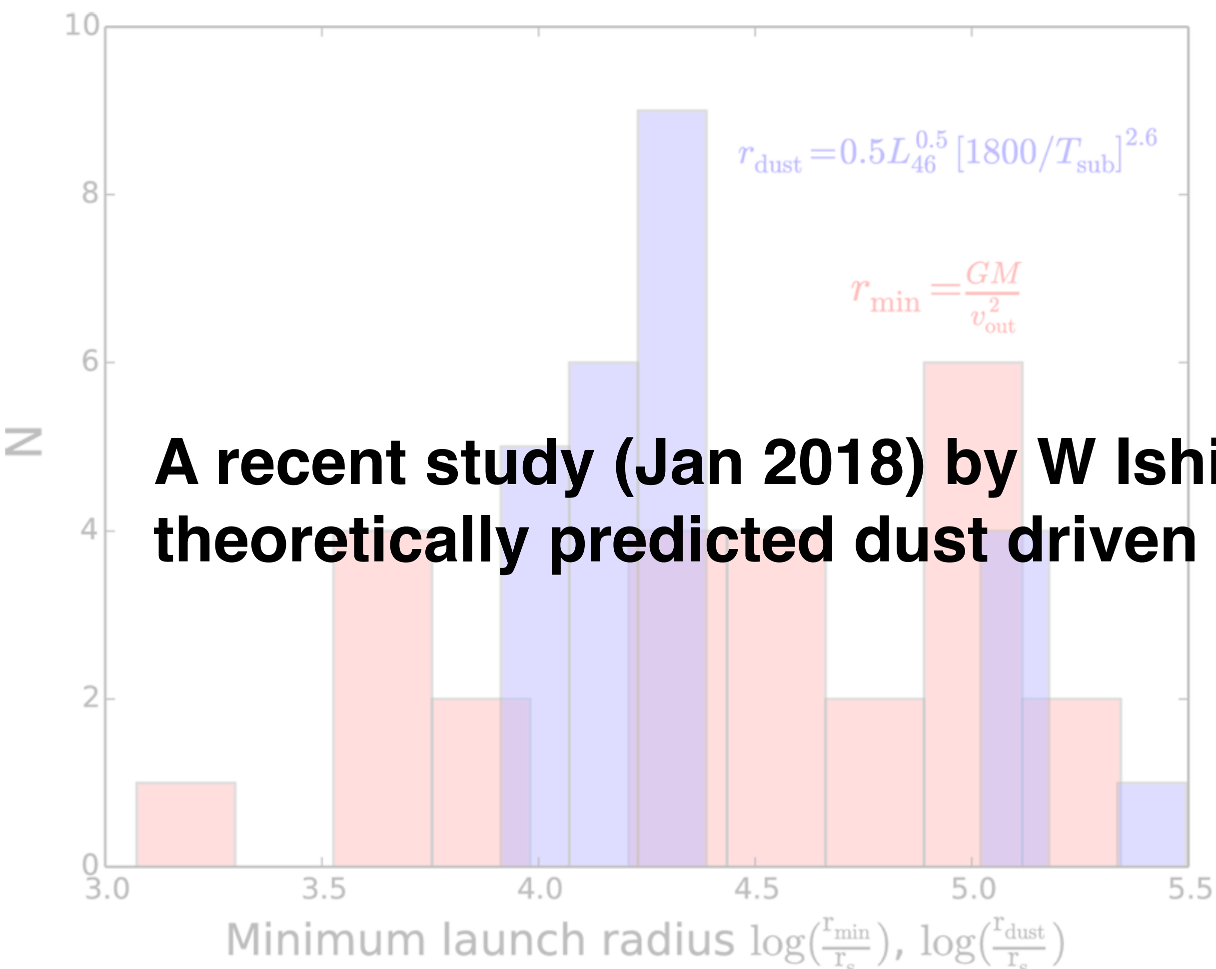
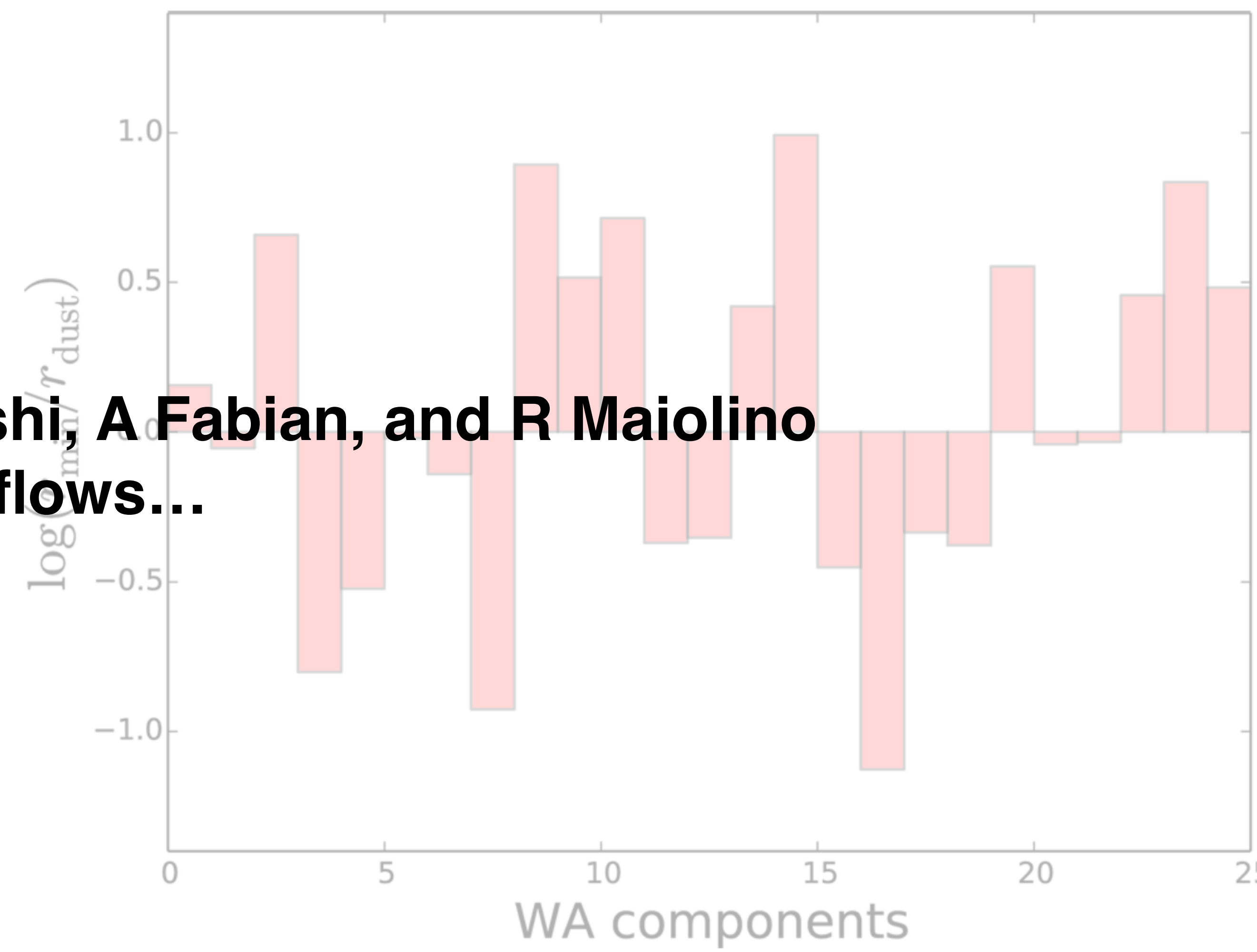






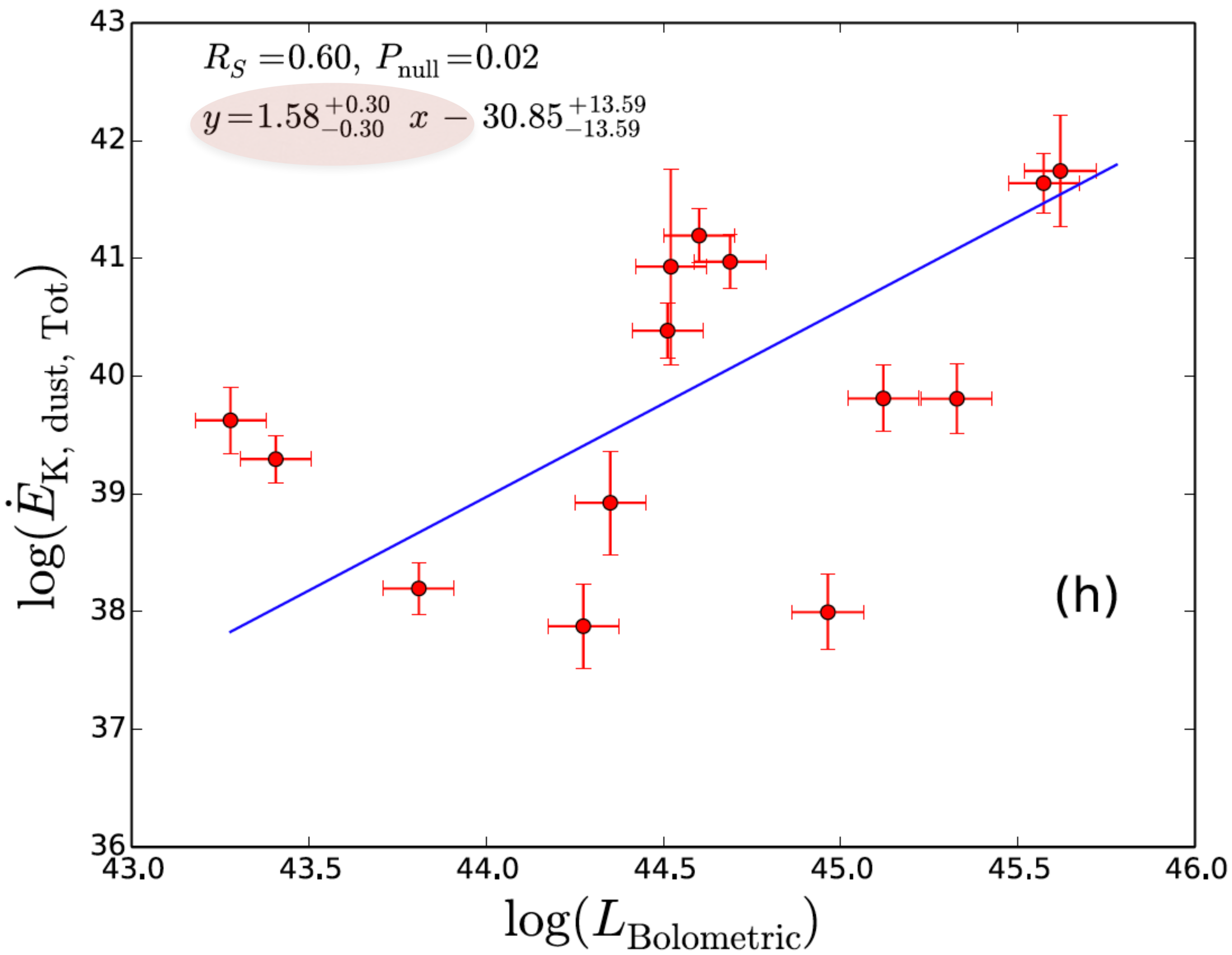
A recent study (Jan 2018) by W Ishibashi, A Fabian, and R Maiolino theoretically predicted dust driven outflows…

Laha et al. 2014 and 2016

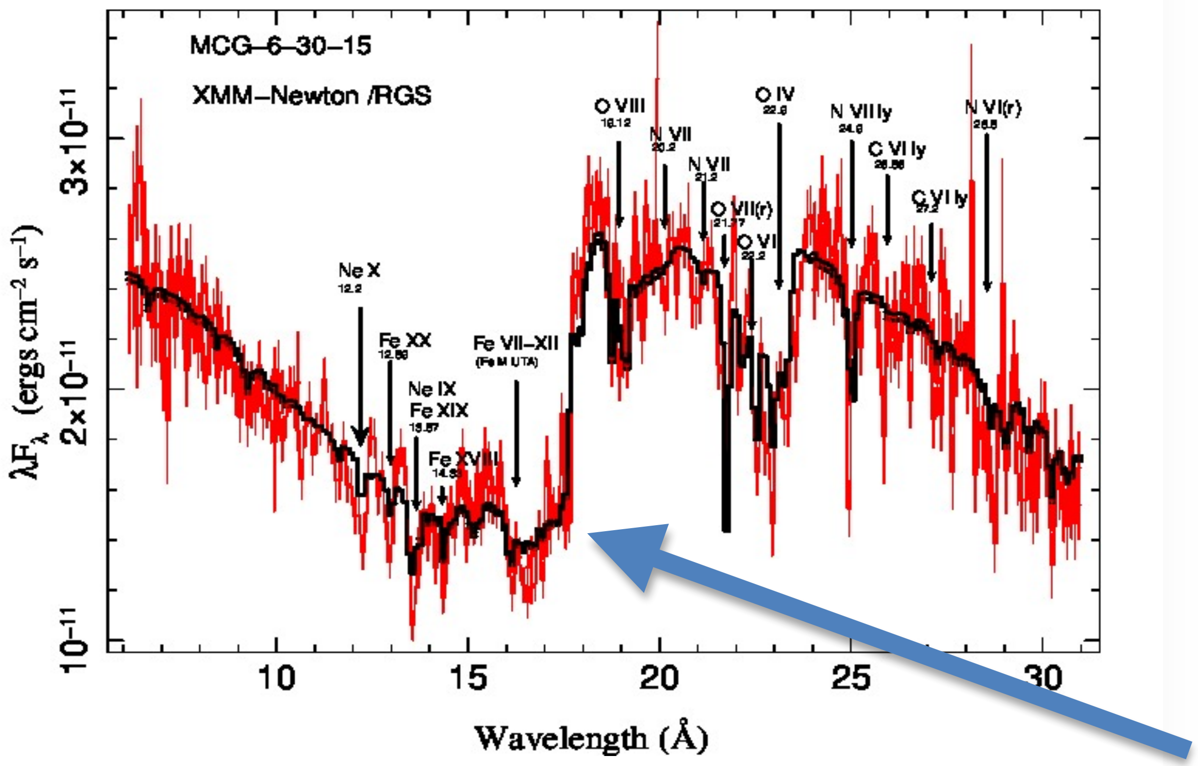
WAX result - II

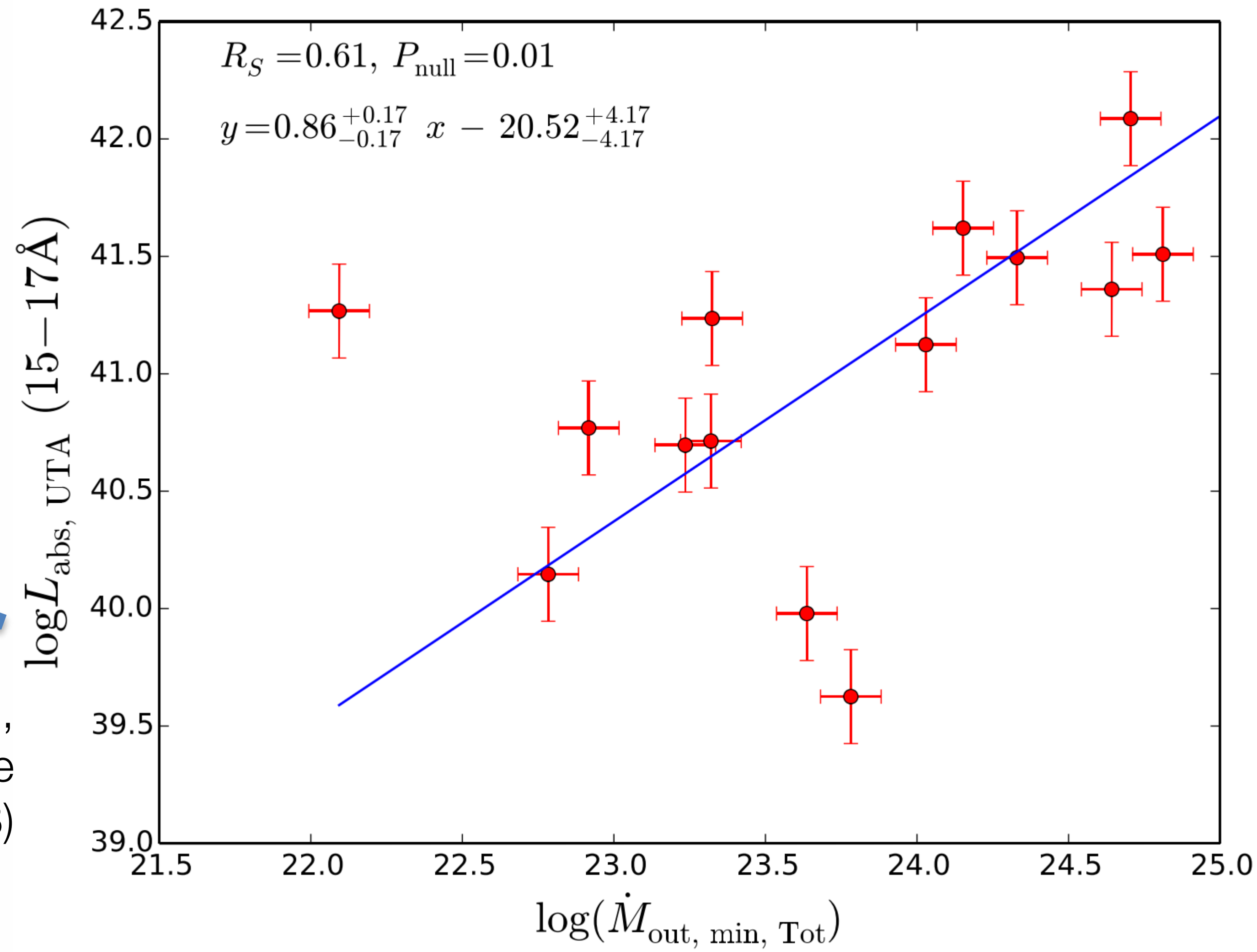
Acceleration in warm absorbers?

Dust driven winds predicted by Ishibashi +18, **E_K = L$^{3/2}$**



Mass loading and UTA



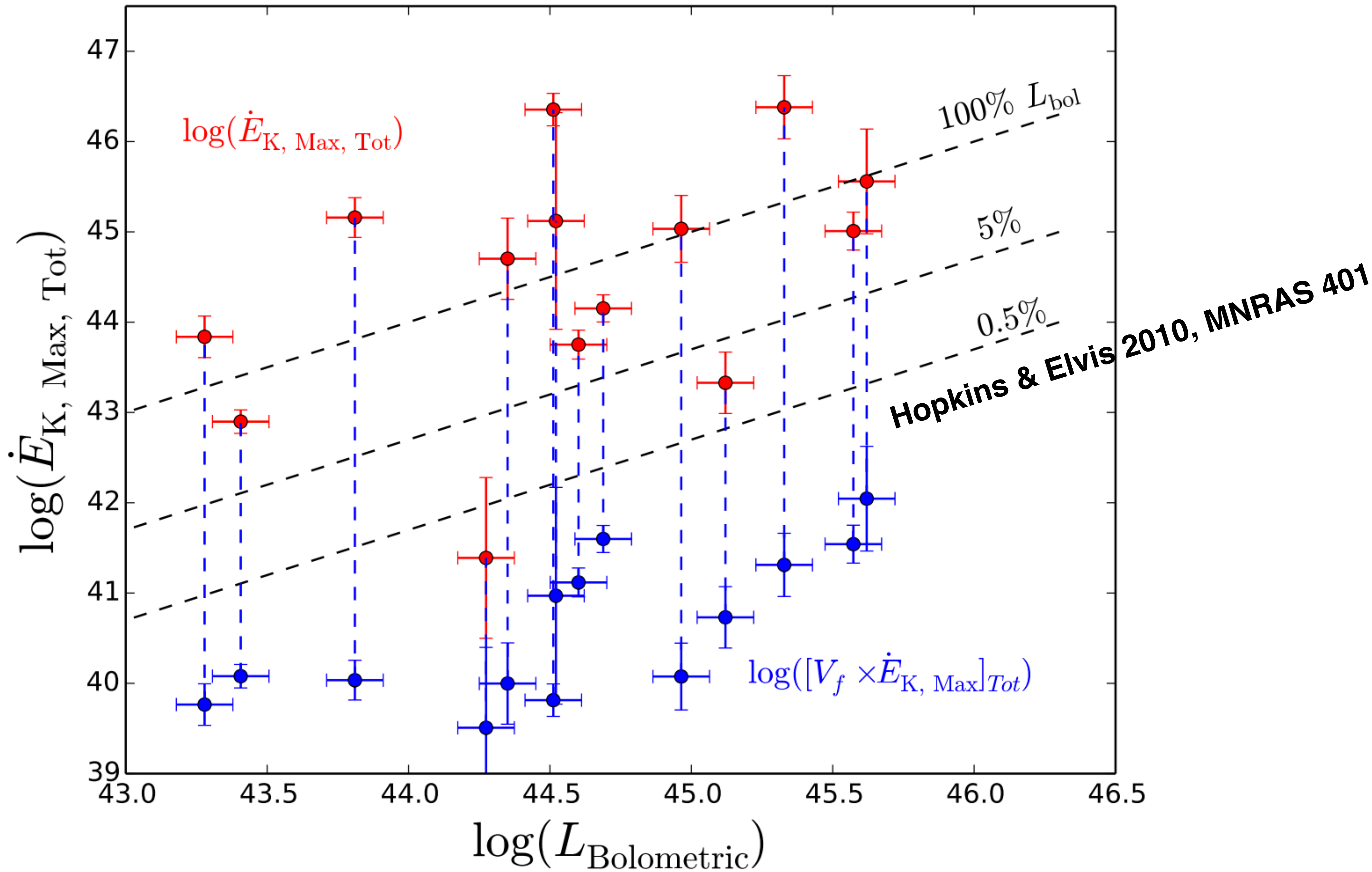


This point was made originally by McKernan+07, who stressed the importance of UTA diagnostics (see also Behar+03)

Laha et al. 2014 and 2016

WAX result - IV

Feedback



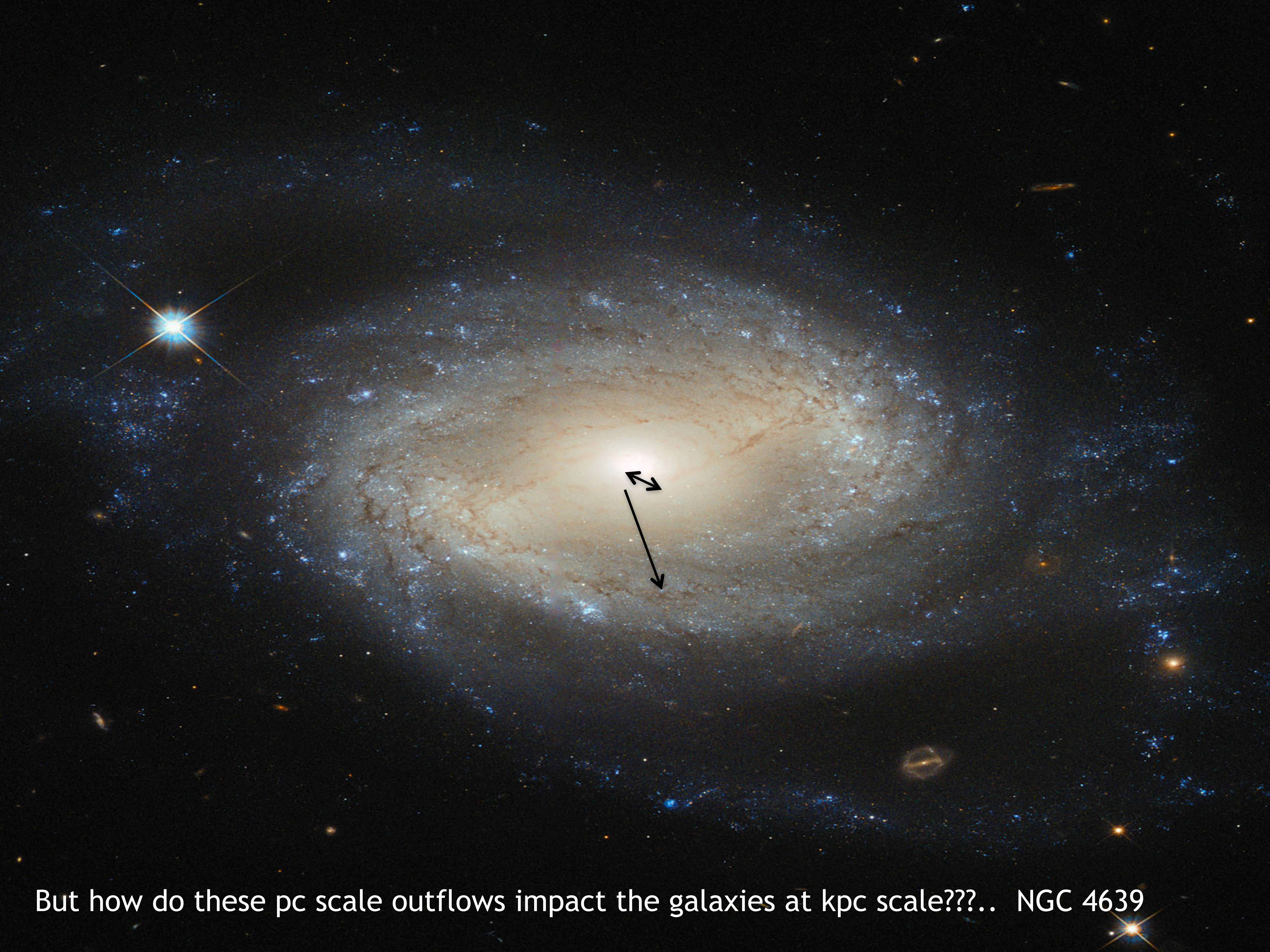
Laha et al. 2014 and 2016

WAX Summary

- N_H=[10^{20},10^{22} cm^{-2}], v_{out}=[$10^{2.5}$,10^4 km/s], log(ξ_{cgs})≤3
- "ionisation (parameter) gap" … **missing ionization states??**
- incidence of AGN outflows in the local Universe: WA≳75%, **others Bonafide NO WA**?
- Acceleration mechanism: **Likely dust driven, radiation coupled in dust!**.
- **Launch radius = Dust sublimation radius… Dusty WA??**
- Outflow structure: **Arguable whether UFO and WA are the same type of outflows**.
- Outflow density profile: $\mathbf{n(r) \propto r^{-1.24}}$

Need to have proper distance estimates!!!

Hopefully NASA/ESA's future missions ARCUS, Lynx and Athena will be able to obtain the distance of the clouds and hence measure accurate feedback rates.



But how do these pc scale outflows impact the galaxies at kpc scale???.. NGC 4639

2. The Molecular outflows and X-ray properties of galaxies
(**MOX project, Laha et al. 2018**)

The MOX sample...

Table 1. The list of sources and their general properties.

Index	Source	Alternative Name	z	R.A.	Dec.	Luminosity [1] class	X-ray [2] classification	References [2]
1	IRAS F08572+3915	-	0.0583	09h00m25.3s	+39d03m54.4s	ULIRG	CT	1
2	IRAS F10565+2448	-	0.0431	10h59m18.1s	+24d32m34s	ULIRG	OA	
3	IRAS 23365+3604	-	0.0645	23h39m01s	+36d21m08s	ULIRG	OA/LINER	
4	Mrk 273	-	0.0377	13h44m42.1s	+55d53m13s	ULIRG	Sy2/CL	
5	Mrk 876	-	0.129	16h13m57.2s	+65d43m10s	-	Sy1	
6	IZw 1	UGC 00545	0.0589	00h53m34.9s	+12d41m36s	Sy1	NLSy1	
7	MrK 231	-	0.0421	12h56m14.2s	+56d52m25s	ULIRG/RL	Sy 1/SB	
8	NGC 1266	-	0.0072	03h16m00.7s	-02d25m38s	Sy	AGN	
9	M 82	-	0.0006	09h55m52.7s	+69d40m46s	-		
10	NGC 1377	-	0.0059	03h36m39.1s	-20d54m08s	-	-	
11	NGC 6240	-	0.0244	16h52m58.9s	+02d24m03s	LIRG	CT/GM	
12	NGC 3256	-	0.0093	10h27m51.3s	-43d54m13s	LIRG	SB	
13	NGC 3628	-	0.0028	11h20m17.0s	+13d35m23s	RL		SB
14	NGC 253	-	0.0008	00h47m33.1s	-25d17m18s	-	Variable SB	
15	NGC 6764	-	0.0081	19h08m16.4s	+50d56m00s	-	AGN+SB	
16	NGC 1068	-	0.0038	02h42m40.7s	-00d00m48s	LIRG	CT/Sy2	
17	IC 5063	-	0.0113	20h52m02.3s	-57d04m08s	Sy1/RL	NLSy2	
18	NGC 2146	-	0.0029	06h18m37.7s	+78d21m25s	LIRG	SB	
19	IRAS 17208-0014	-	0.0428	17h23m21.9s	-00d17m01s	ULIRG/LINER	ULIRG	
20	NGC 1614	-	0.0159	04h33m59.8s	-08d34m44s	LIRG/SB	SB	
21	IRAS 05083+7936	VII Zw 031	0.0536	05h16m46.1s	+79d40m13s	LIRG	OA	
22	Iras 13451+1232	4C +12.50	0.1217	13h47m33.3s	+12d17m24s	ULIRG/RL	Sy2	
23	3C 293	UGC 08782	0.0450	13h52m17.8s	+31d26m46s	Sy/RL		
24	NGC 1433		0.0035	03h42m01.5s	-47d13m19s	SB		
25	IRAS 13120-5453	WKK 2031	0.0308	13h15m06.3s	-55d09m23s	ULIRG		
26	IRAS 14378-3651	-	0.0676	14h40m59s	-37d04m32s	ULIRG		
27	IRAS F11119+3257	B2 1111+32	0.1890	11h14m38.9s	+32d41m33s	ULIRG		
28	IRAS F01572+0009	MRK 1014	0.1631	01h59m50.2s	+00d23m41s	ULIRG/Sy 1.5		
29	IRAS F05024-1941	-	0.1920	05h04m36.5s	-19d37m03s	ULIRG		
30	IRAS F05189-2524	-	0.0425	05h21m45s	-25d21m45s	ULIRG		
31	IRAS 07251-0248	-	0.0875	07h27m37.5s	-02d54m55s	ULIRG		
32	IRAS F07599+6508	-	0.1483	08h04m33.1s	+64d59m49s	ULIRG		
33	IRAS 09022-3615	-	0.0596	09h04m12.7s	-36d27m01s	ULIRG		
34	IRAS F09320+6134	UGC 05101	0.0393	09h35m51.6s	+61d21m11s	ULIRG		
35	IRAS F12072-0444	-	0.1284	12h09m45.1s	-05d01m14s	ULIRG/Sy2		
36	IRAS F12112+0305	-	0.0733	12h13m46.0s	+02d48m38s	ULIRG		
37	IRAS F12243-0036	NGC 4355	0.0072	12h26m54.6s	-00d52m39s	LIRG/Sy2		
38	IRAS F14348-1447	-	0.0830	14h37m38.4s	-15d00m20s	ULIRG		
39	IRAS F14394+5332	-	0.1045	14h41m04.4s	+53d20m09s	ULIRG		
40	IRAS F15250+3608	-	0.0551	15h26m59.4s	+35d58m38s	ULIRG		
41	IRAS F15327+2340	ARP 220	0.0181	15h34m57.2s	+23d30m11s	ULIRG/Sy		
42	IRAS F15462-0450	-	0.0997	15h48m56.8s	-04d59m34s	ULIRG/NLSy1		
43	IRAS F19297-0406	-	0.0857	19h32m21.2s	-03d59m56s	ULIRG		
44	IRAS 19542+1110	-	0.0649	19h56m35.4s	+11d19m03s	ULIRG		
45	IRAS F20551-4250	ESO 286-IG 019	0.0429	20h58m26.8s	-42d39m00s	ULIRG		
46	IRAS F22491-1808	-	0.0777	22h51m49.2s	-17d52m23s	ULIRG		
47	IRAS F23233+2817	-	0.1140	23h25m49.4s	+28d34m21s	ULIRG/Sy2		
48	NGC 5506	-	0.0062	14h13m14.9s	-03d12m27s	Sy		
49	NGC 7479	-	0.0079	23h04m56.6s	+12d19m22s	SB/Sy1.9		
50	NGC 7172		0.0087	22h02m01.9s	-31d52m11s	Sy2		

[1] The Luminosity class as obtained from NED.

[2] CT= Compton thick, CL=Changing Look, OA=Obscured AGN, LINER= Low ionisation nuclear emission line region, Sy2= Seyfert 2, NLSy1= Narrow line Seyfert 1, SB= Star burst, GM=Galaxy mergers. Based on previous X-ray studies of the sources.

Sources with Molecular outflows

Laha et al. 2018. ApJ.

M.O. Reference: Veilleux 2013, Stürm 2011 Cicone et al 2014 etc..

$z<0.13$

The science questions we want to address:

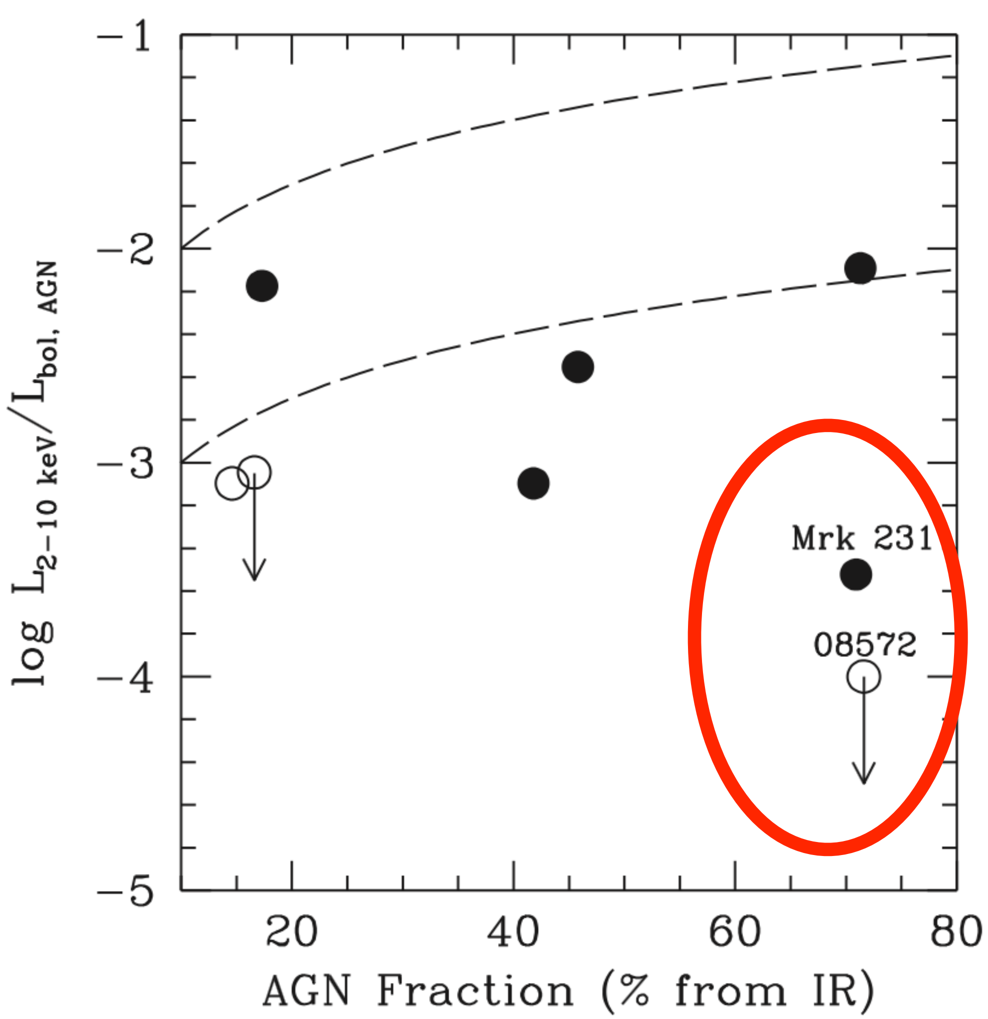
1. Are the AGN in the MOX galaxies X-ray weak or X-ray obscured?

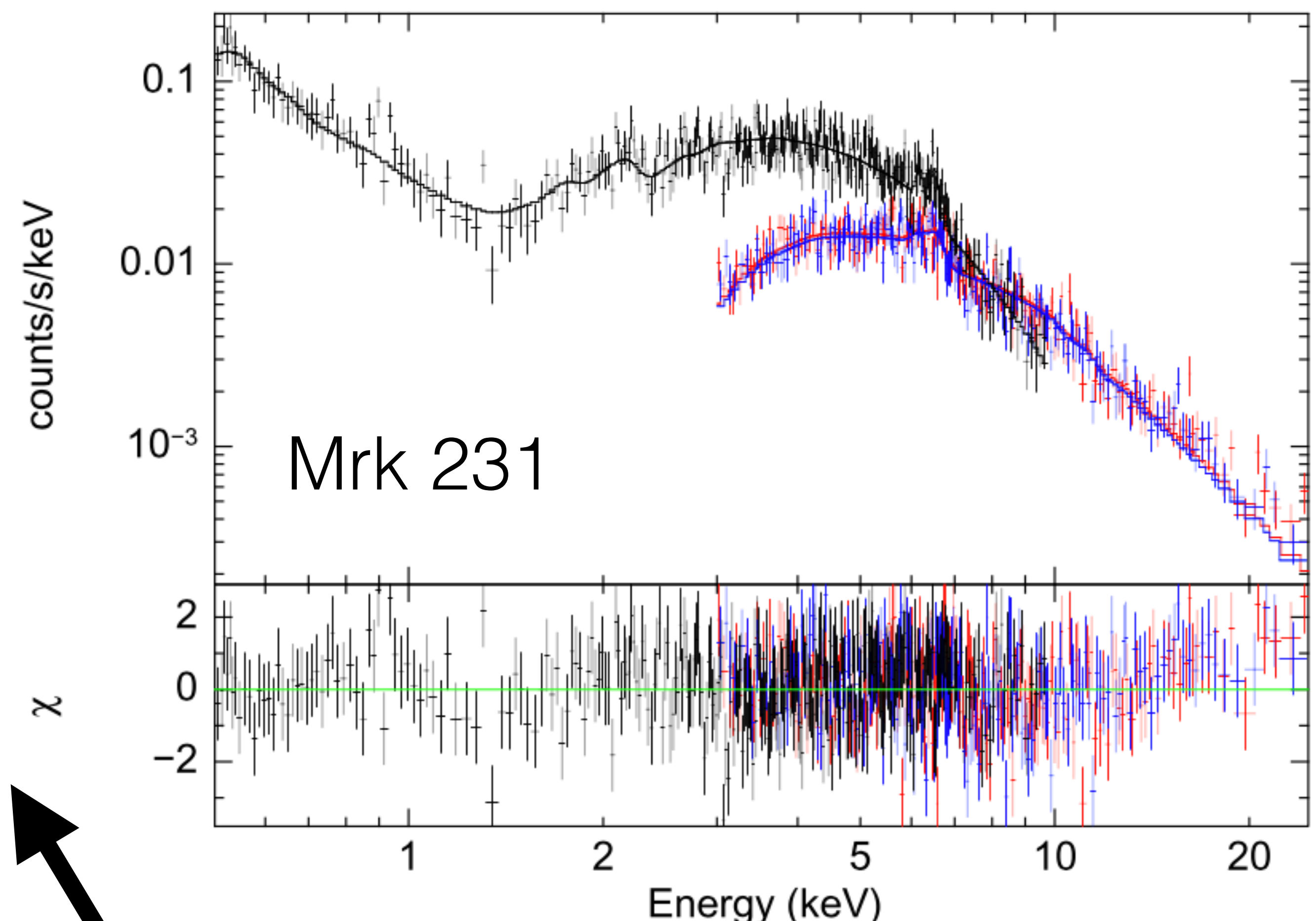
2. Is the AGN the main driver of molecular outflows?

X-ray weak ULIRGs…

Teng et al. 2015 (with <u>NuSTAR</u>) concluded that the weakness in X-rays may be a manifestation of large scale outflows in other wave bands… but how??

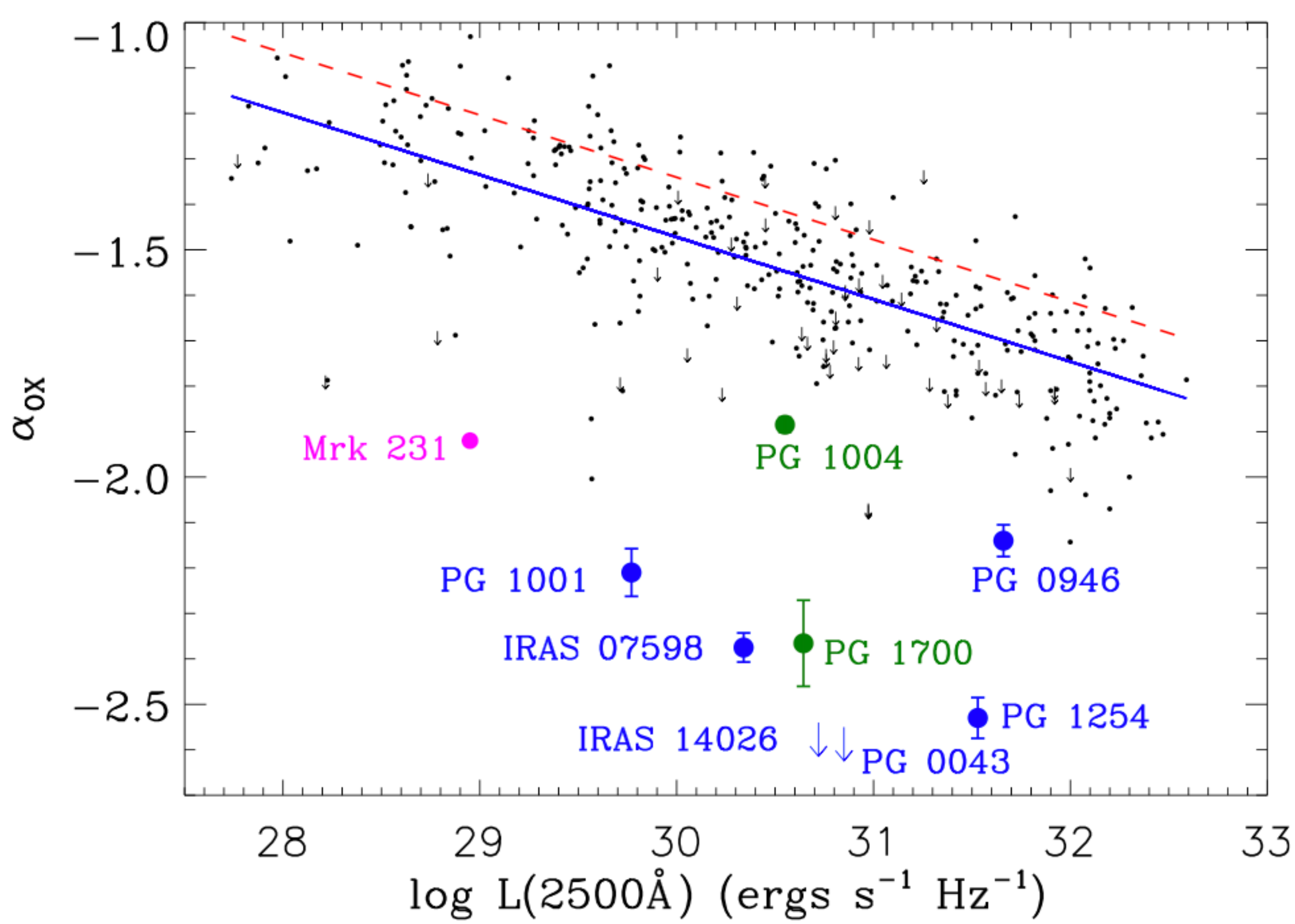
THE ASTROPHYSICAL JOURNAL, 814:56 (16pp), 2015 November 20

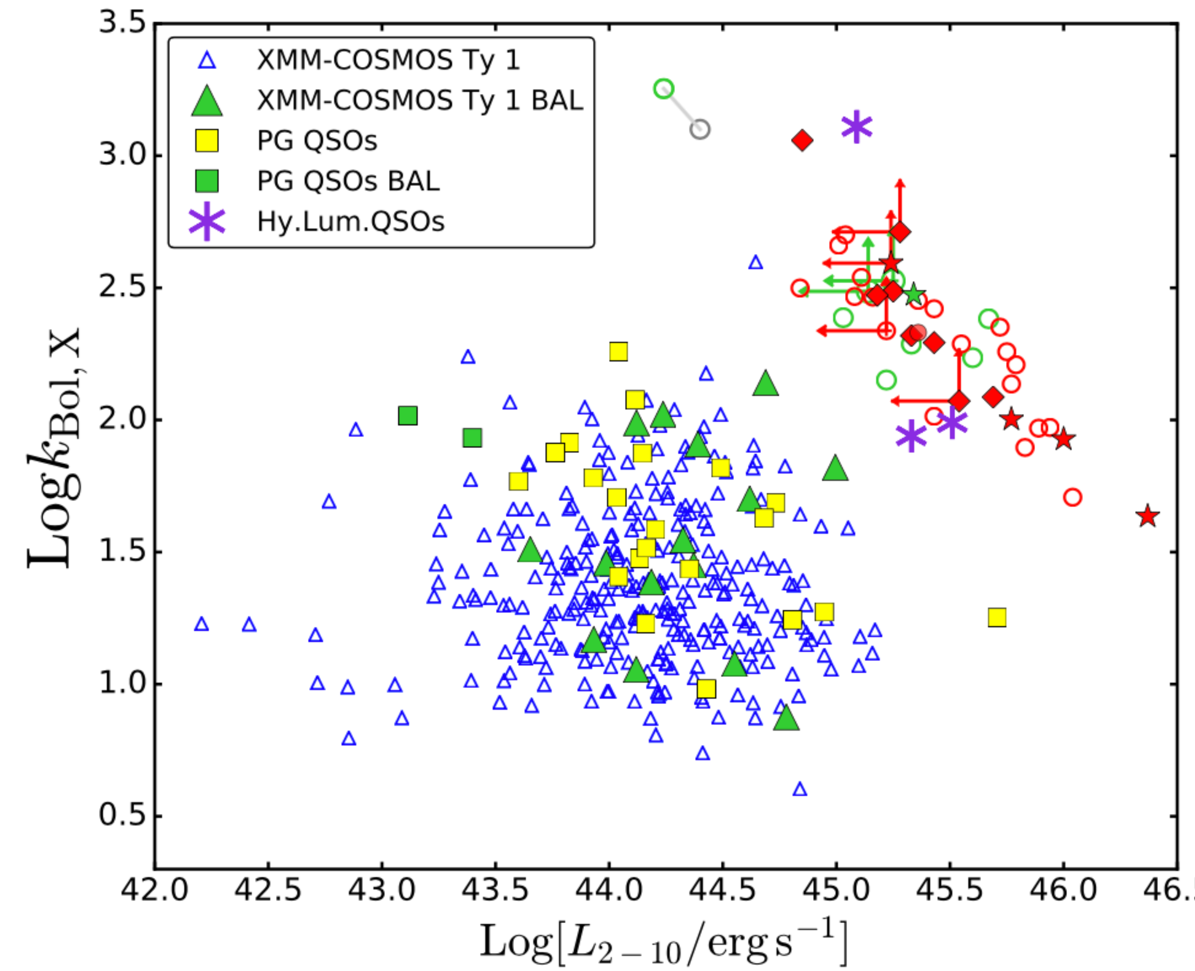




<u>Particularly under-luminous in X-rays</u>

Physics behind X-ray weak BALs…





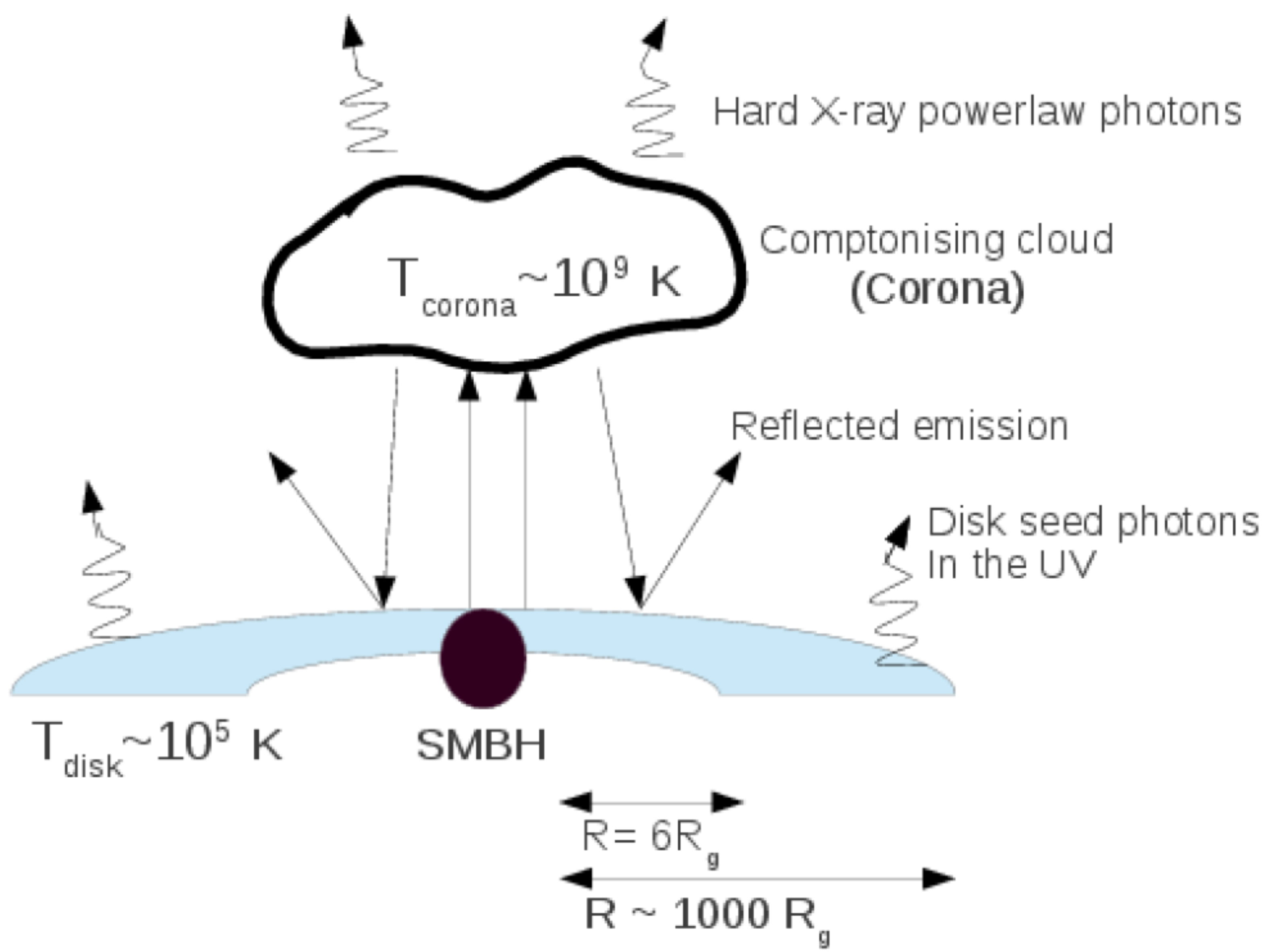
BAL quasar study with Nustar
Luo et al. 2014, ApJ 794

z=2-4 bright quasar study
Exhibiting UV outflows
Martocchia et al. 2017, A&A 608

Can something similar happen to molecular outflows

Now, the question is…

Why should the corona be selectively quenched for MOX sources?
While the AGN bol-luminosity is of standard value compared to normal AGN?



The X-ray spectral analysis of the MOX

We should note that the **best way** to obtain un-obscured 2-10 keV luminosity is using **NuSTAR 3-79 keV spectra**…

However, only 23 out of 47 have been observed by NuSTAR

And out of 23 only 10 were detected and analyzed

How did we obtain L_AGN

$$L_{\rm AGN} = \alpha_{\rm AGN} \times L_{\rm bol}$$

$$L_{\rm bol} = 1.12 L_{\rm IR\,(8-1000 \mu m)}$$

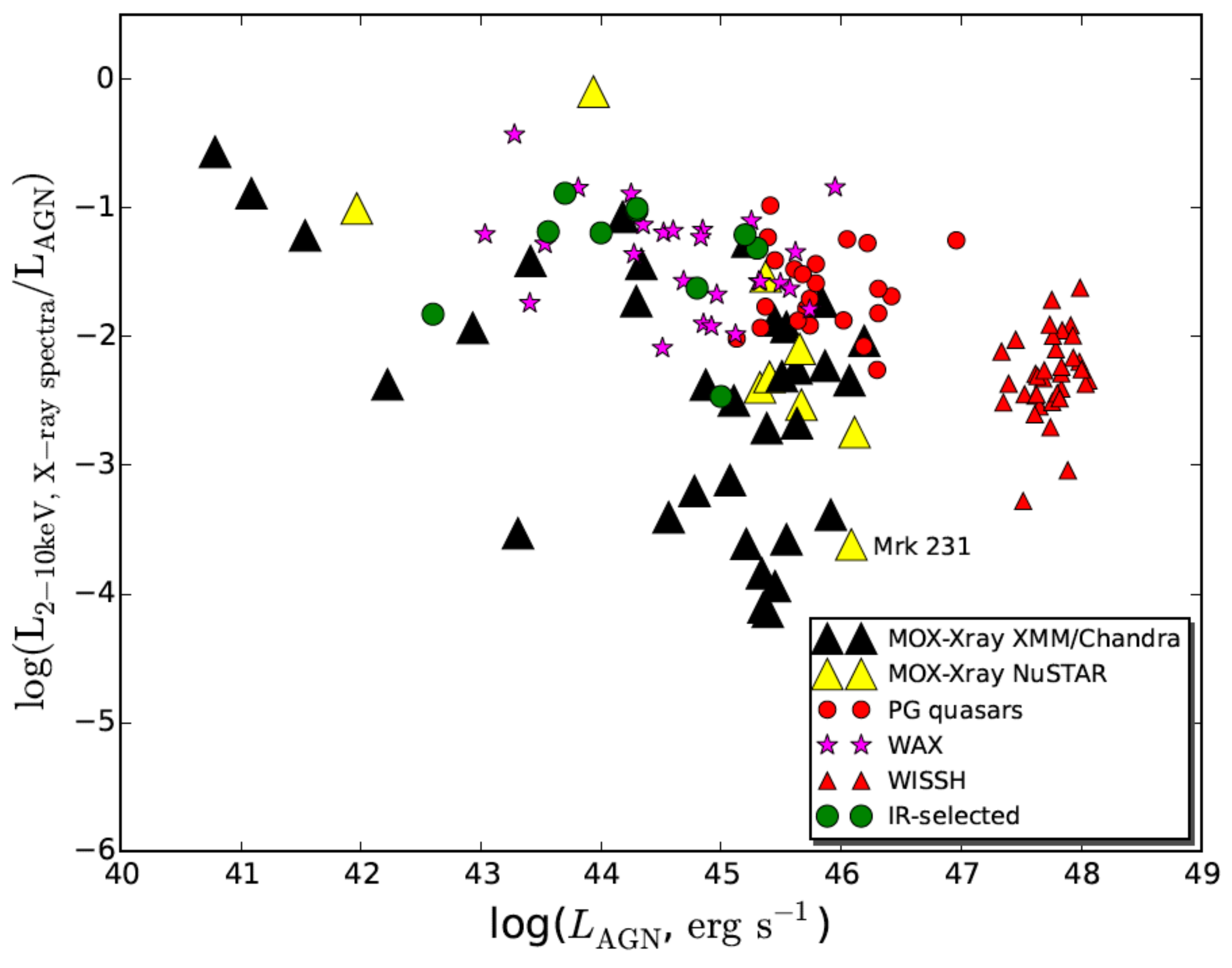
$$\alpha_{\rm AGN} = f(f_{15\mu{\rm m}}/f_{30\mu{\rm m}})$$

Veilleux et al. 2013

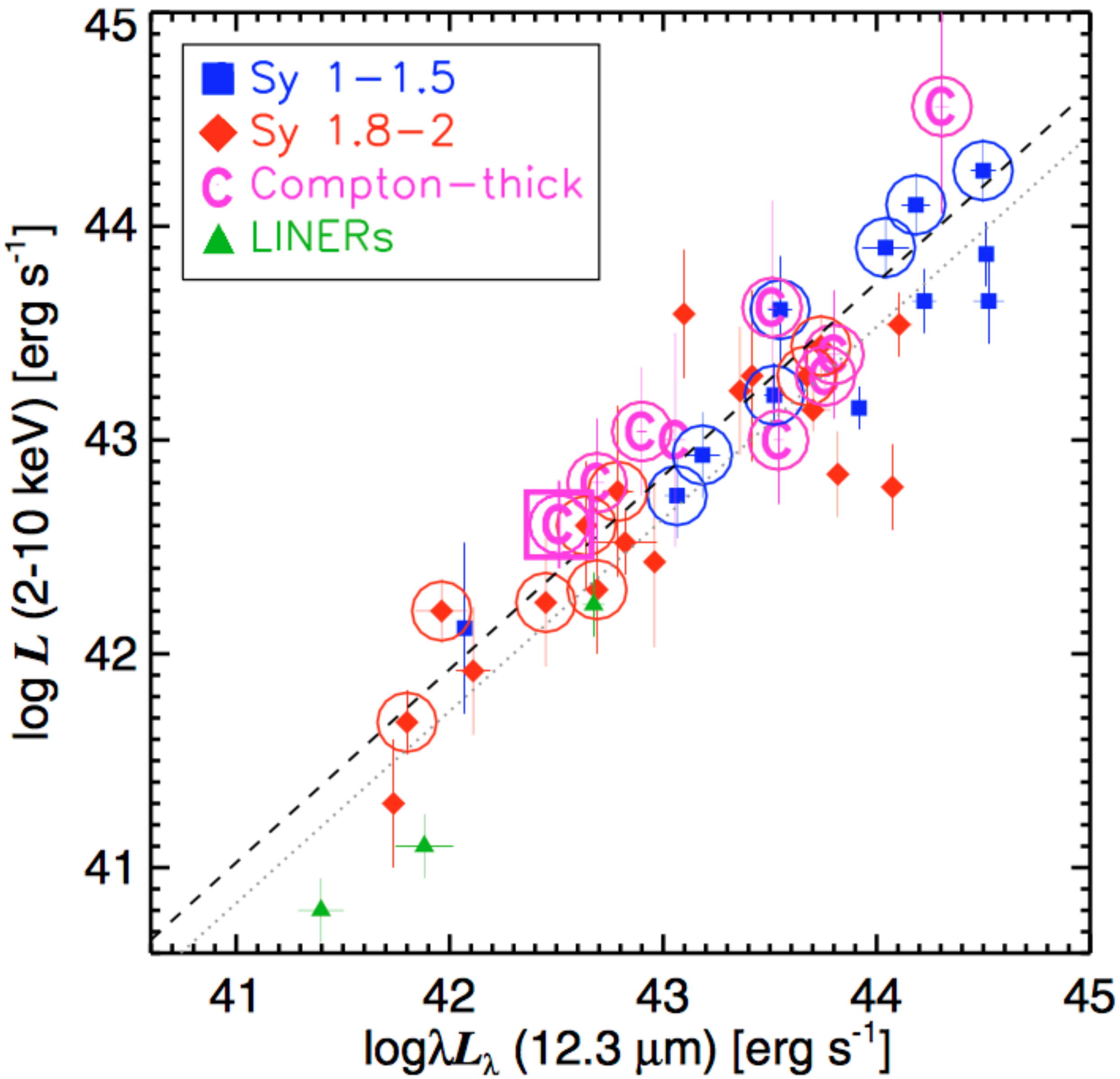
The X-ray bolometric correction for MOX sources

Laha et al. 2018, arXiv:1809.07906

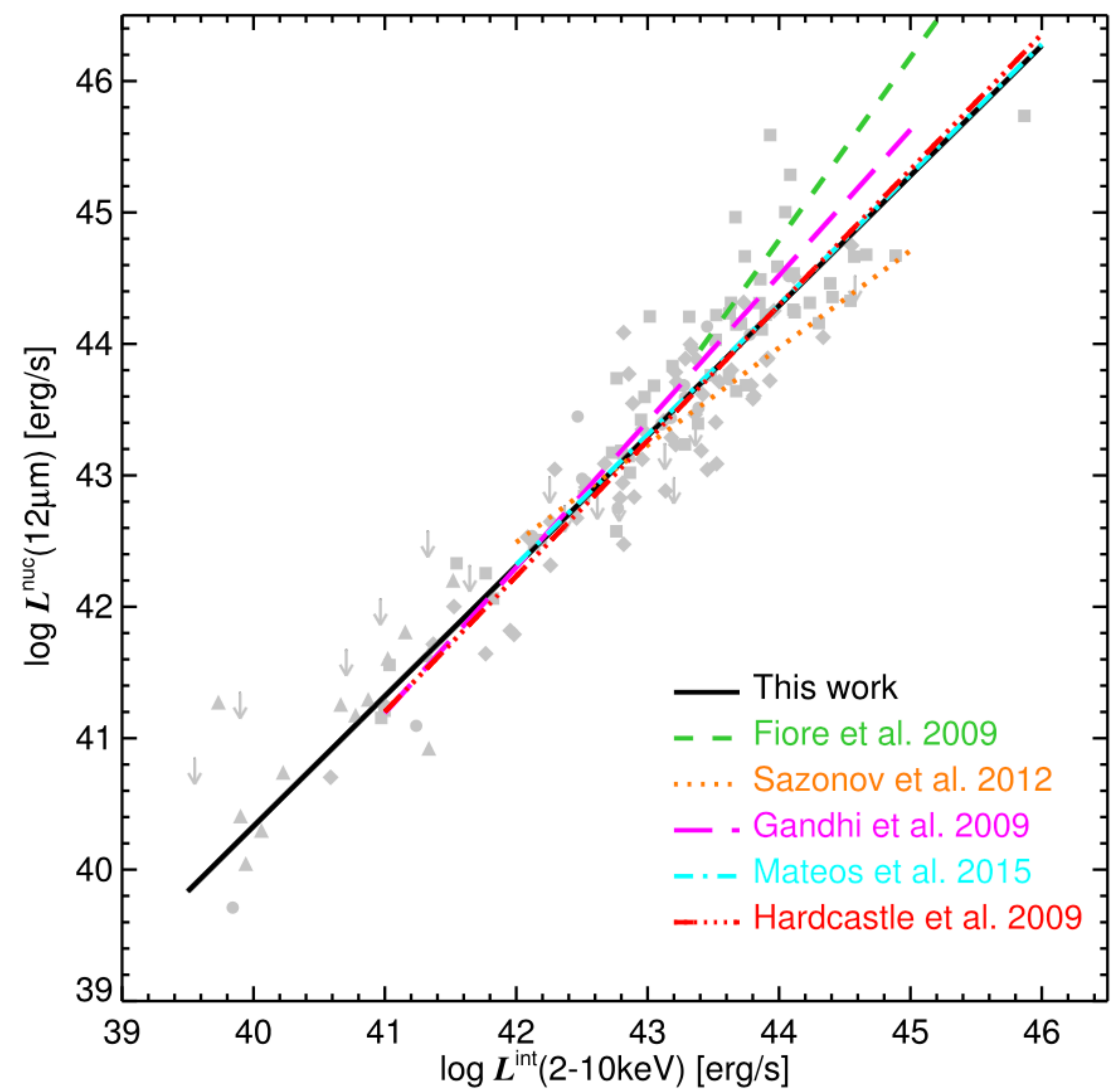
The MOX bolometric corrections are weak…



An alternate way of calculating L2-10keV…
using**12 micron** flux



Gandhi et al. 2009



Asmus et al. 2015

The relation used to calculate L2-10 keV

$$\log\left(\frac{L_{2-10\ \mathrm{keV}}}{10^{43}\,\mathrm{erg\,s^{-1}}}\right) = -0.32 + 0.95 \times \log\left(\frac{L_{12\,\mu m} \times \alpha_{\mathrm{AGN}}}{10^{43}\,\mathrm{erg\,s^{-1}}}\right).$$

Asmus et al. 2015

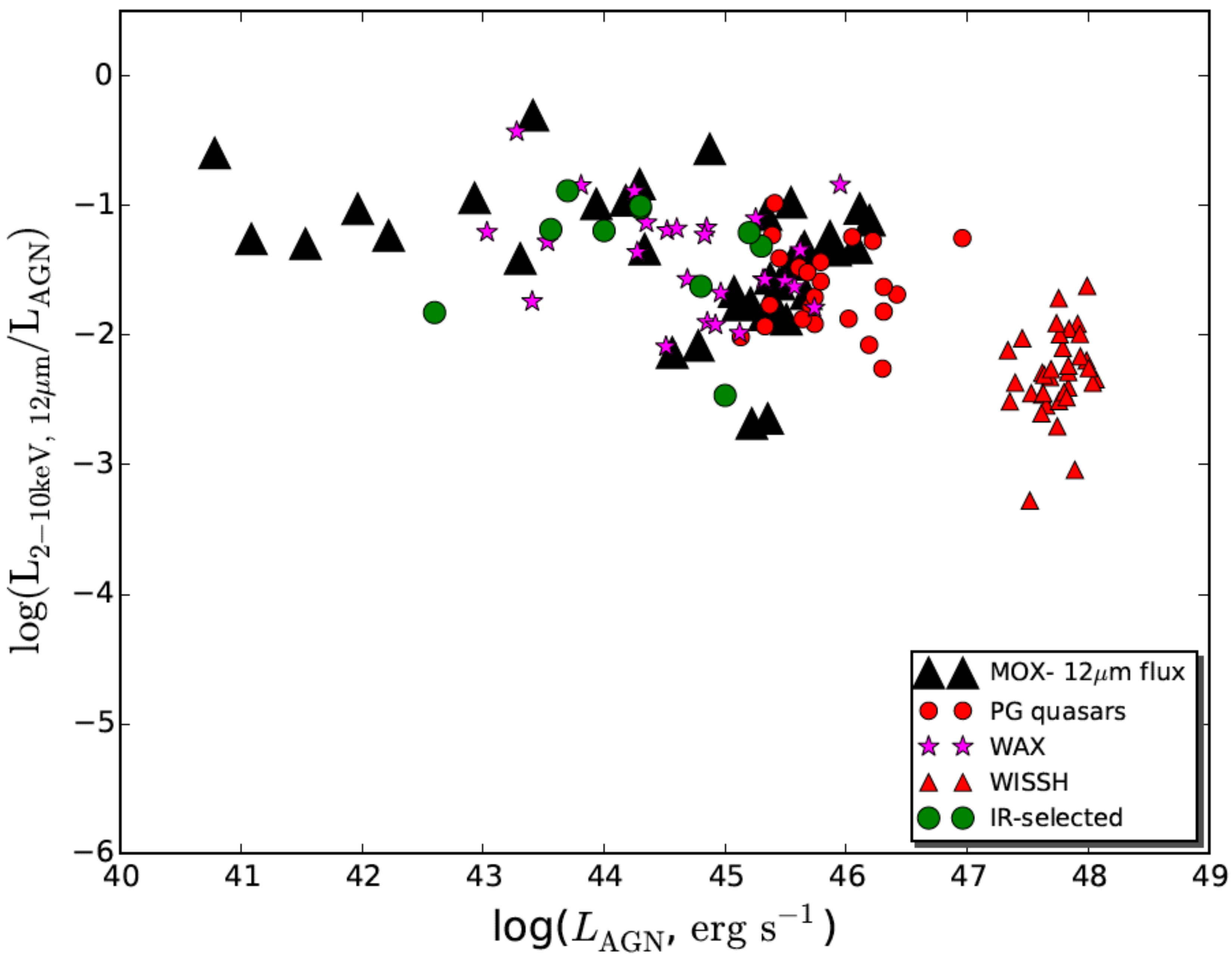
This is an *upper limit* on 2-10 keV luminosity

Caveats: the 12 micron luminosity from the galaxy
may be contaminated by PAH emission, hence we call
this 2-10keV luminosity value an ***upper limit***

The X-ray bolometric correction using 12 micron

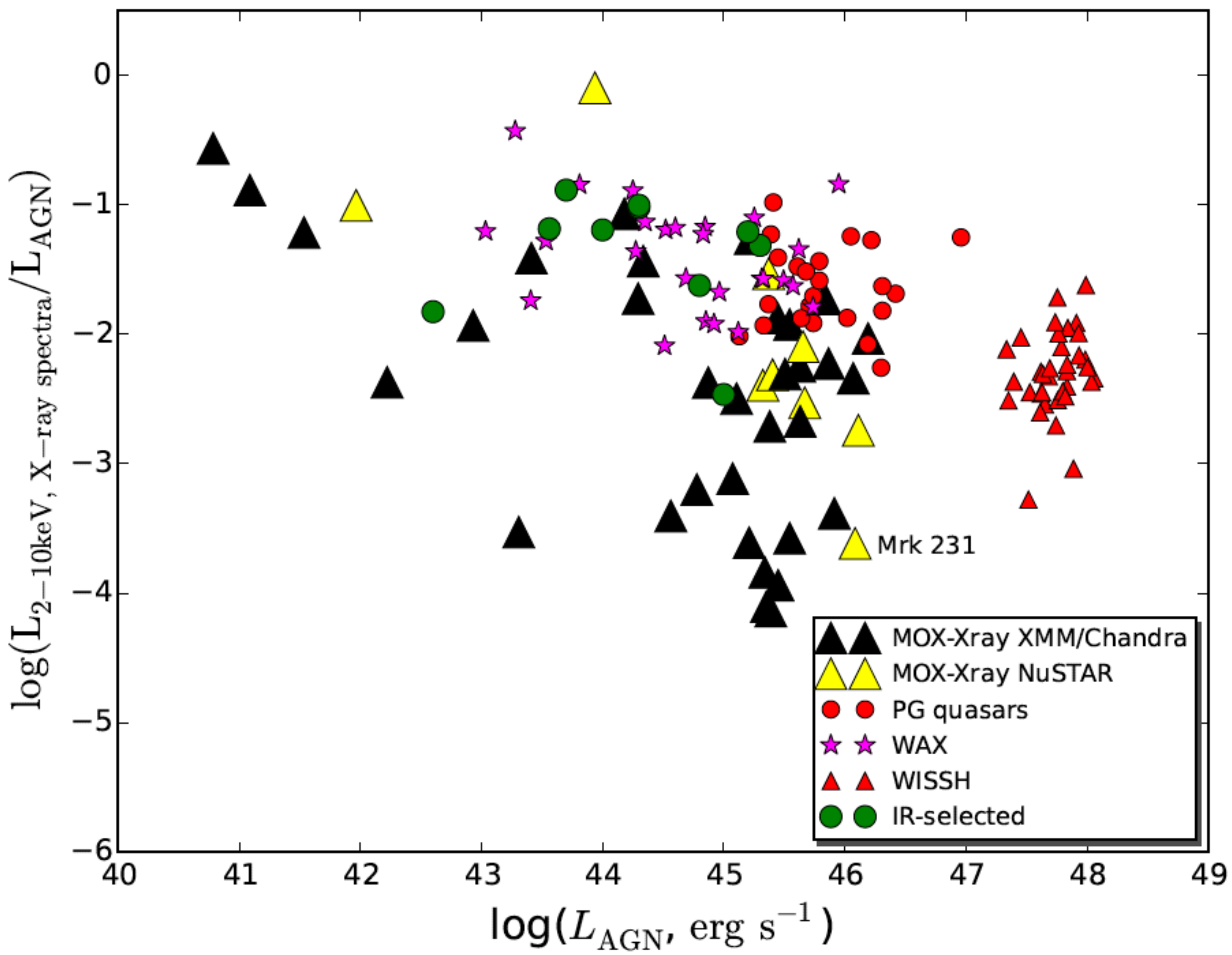
Laha et al. 2018, ApJ

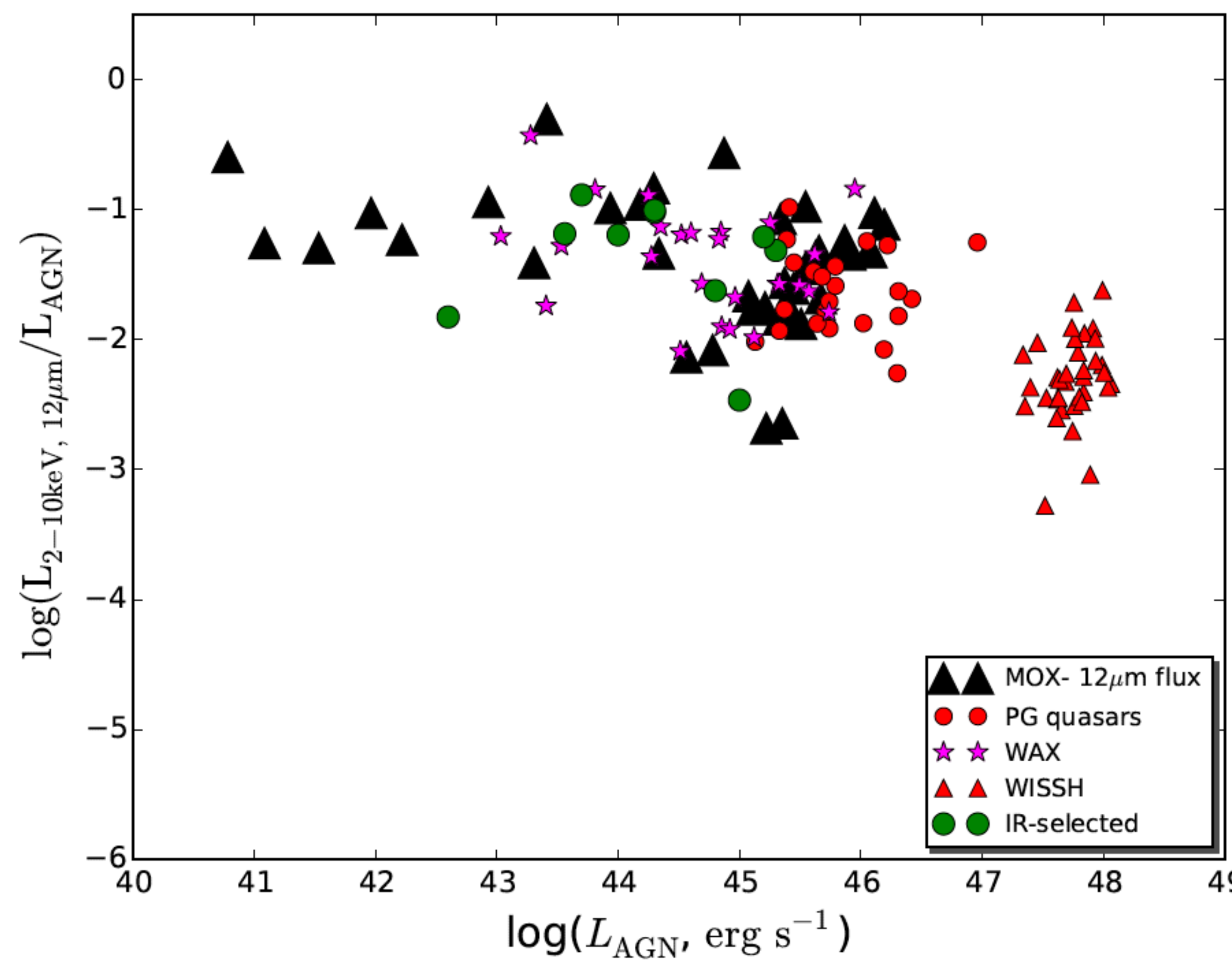
The MOX data points all line up with ‘normal AGN’



A comparison…

Laha et al. 2018, ApJ





Conclusion: Possibly these sources are X-ray bright, they are just extremely obscured… need further probes…

II. Impact of AGN on the Mol outflows

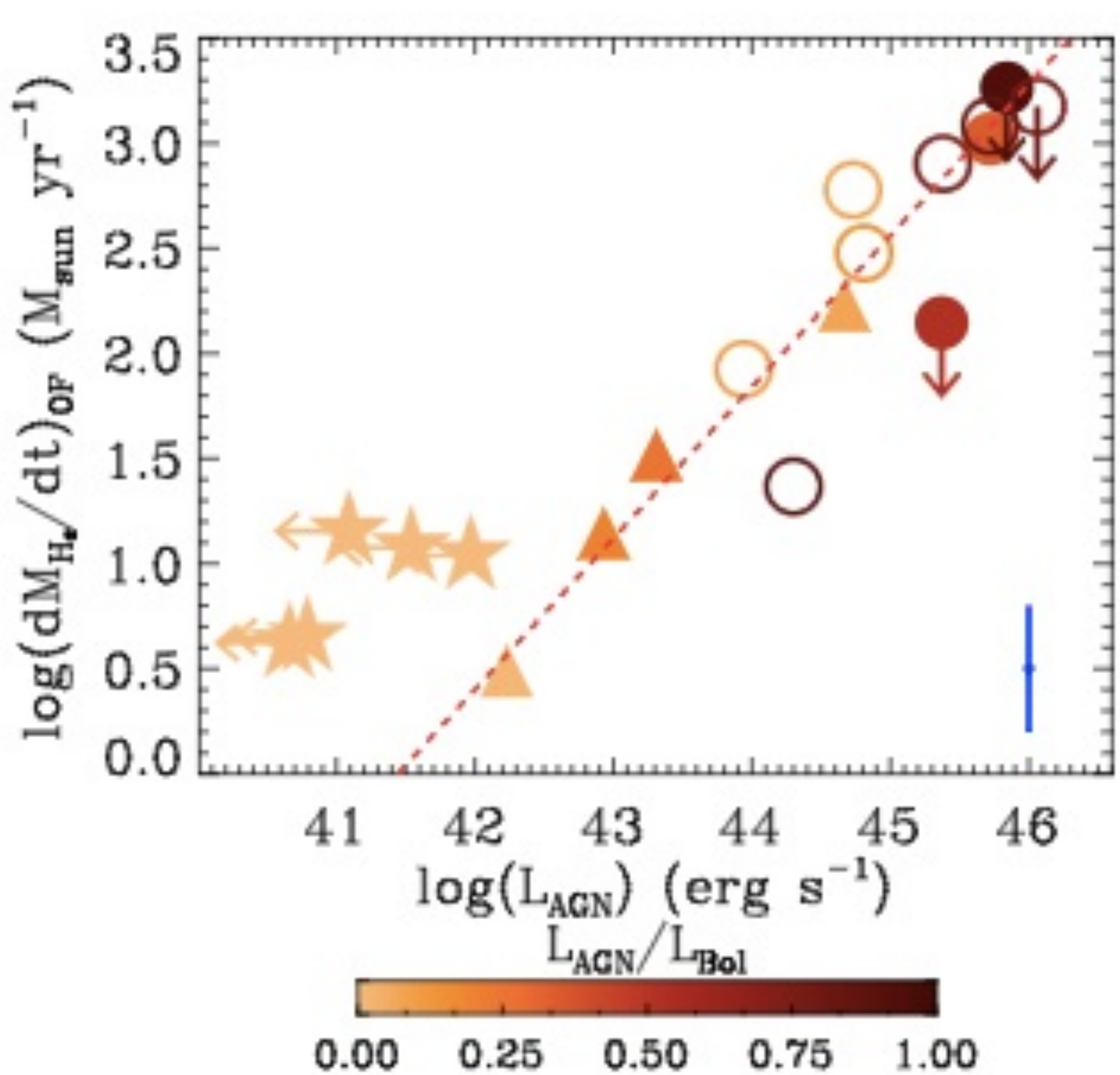
But how do these pc scale outflows impact the galaxies at kpc scale???.. NGC 4639

Are the AGN the primary driver of MO?

#Molecular mass outflow rate is proportional to AGN strength.

#Possibly AGN drives Molecular outflows

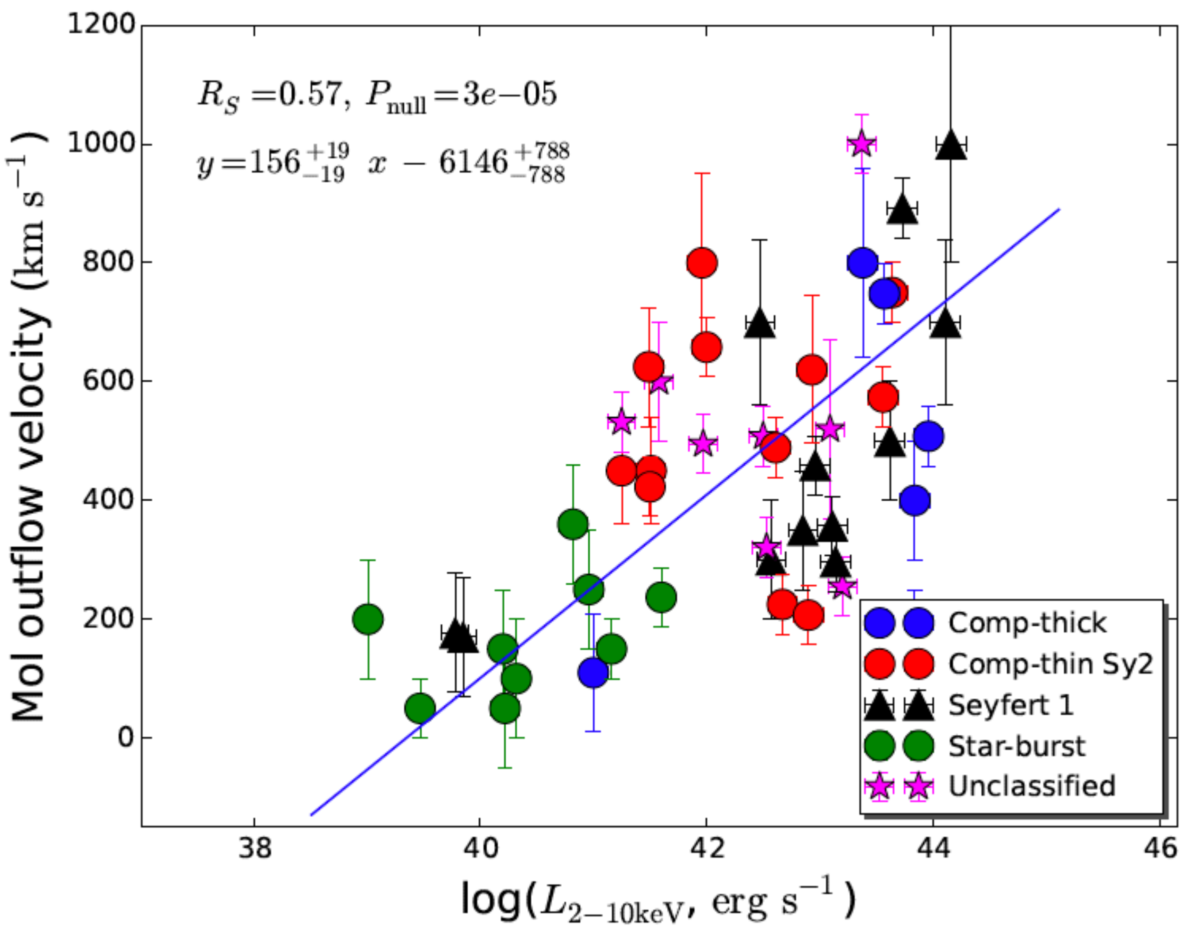
Cicone et al. 2014

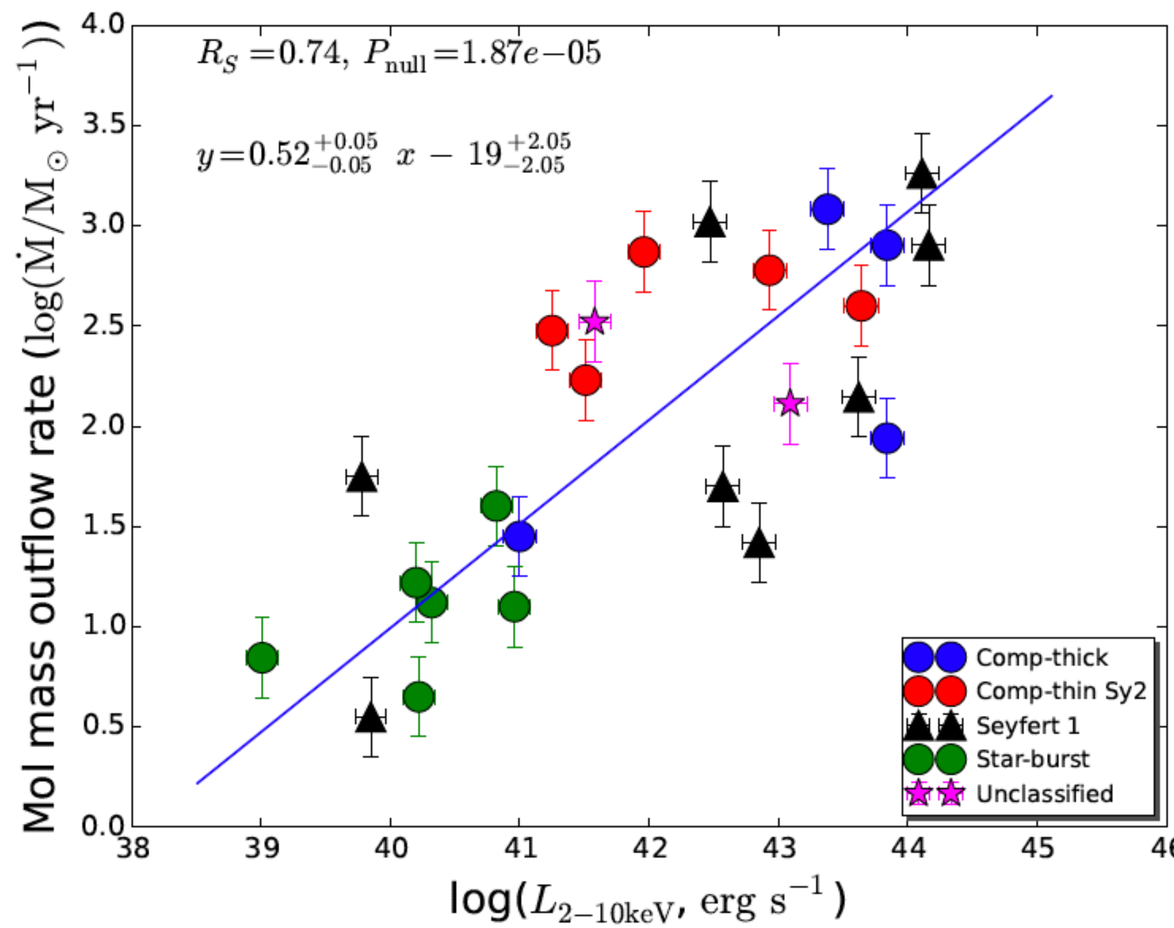


MOX results….

Laha et al. 2018, ApJ

2-10 keV Luminosity as a proxy for AGN luminosity

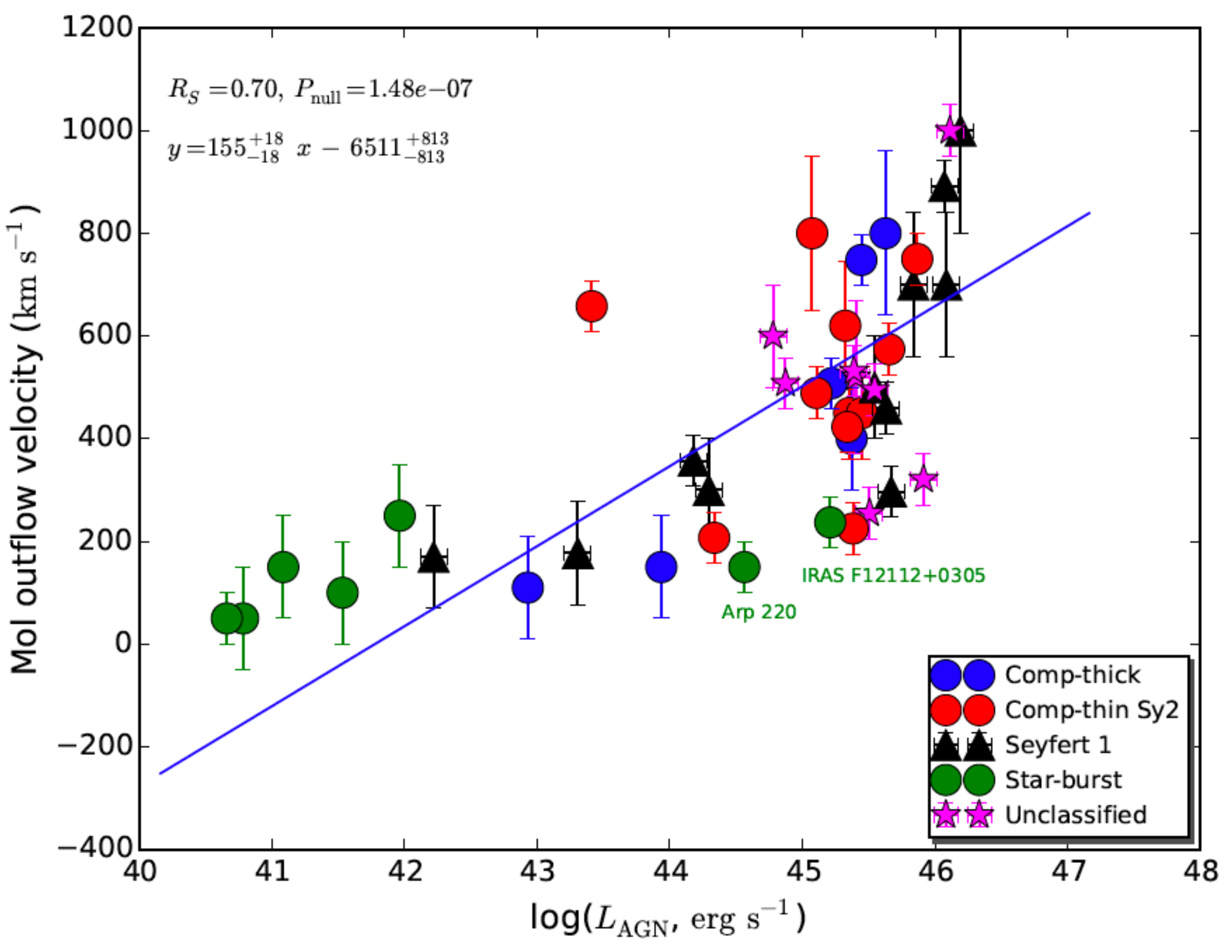


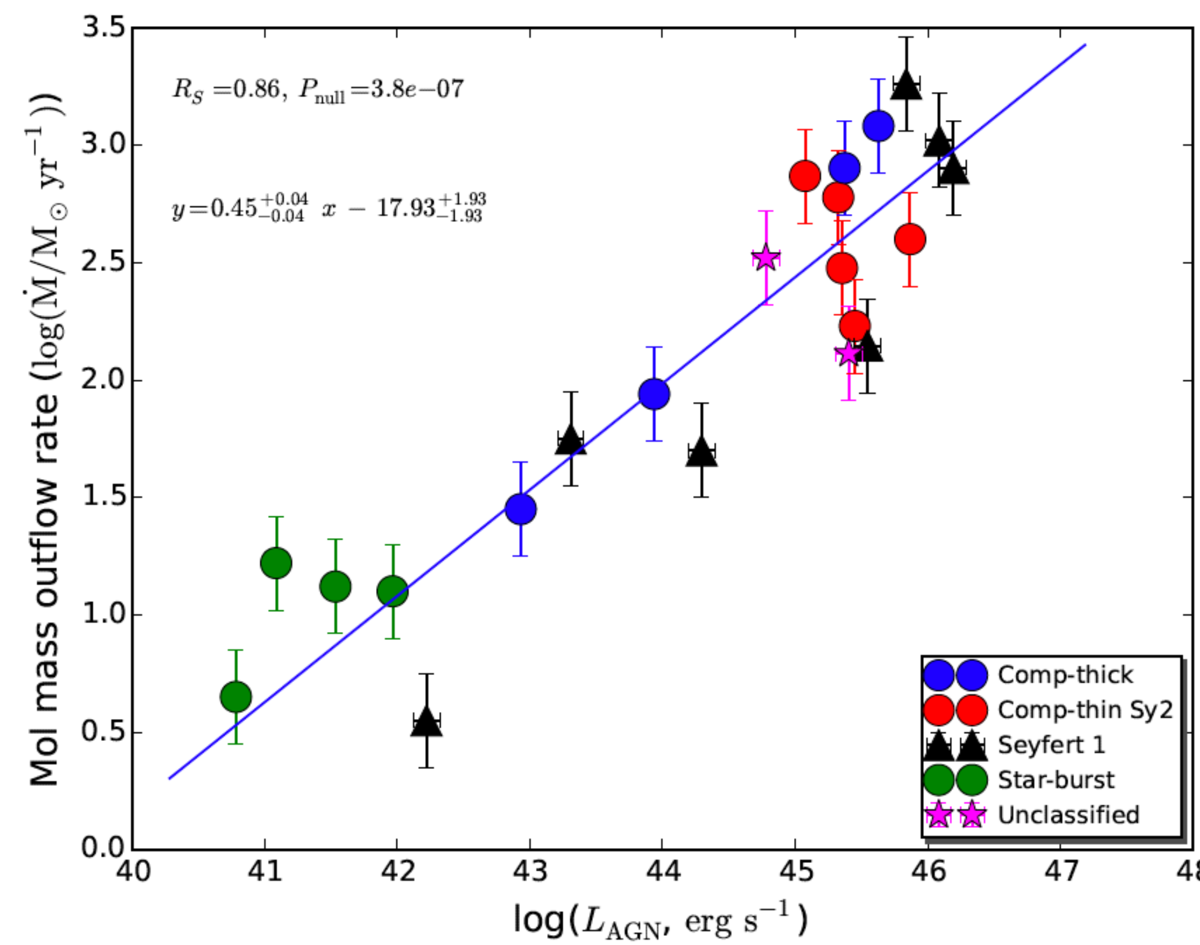


MOX results….

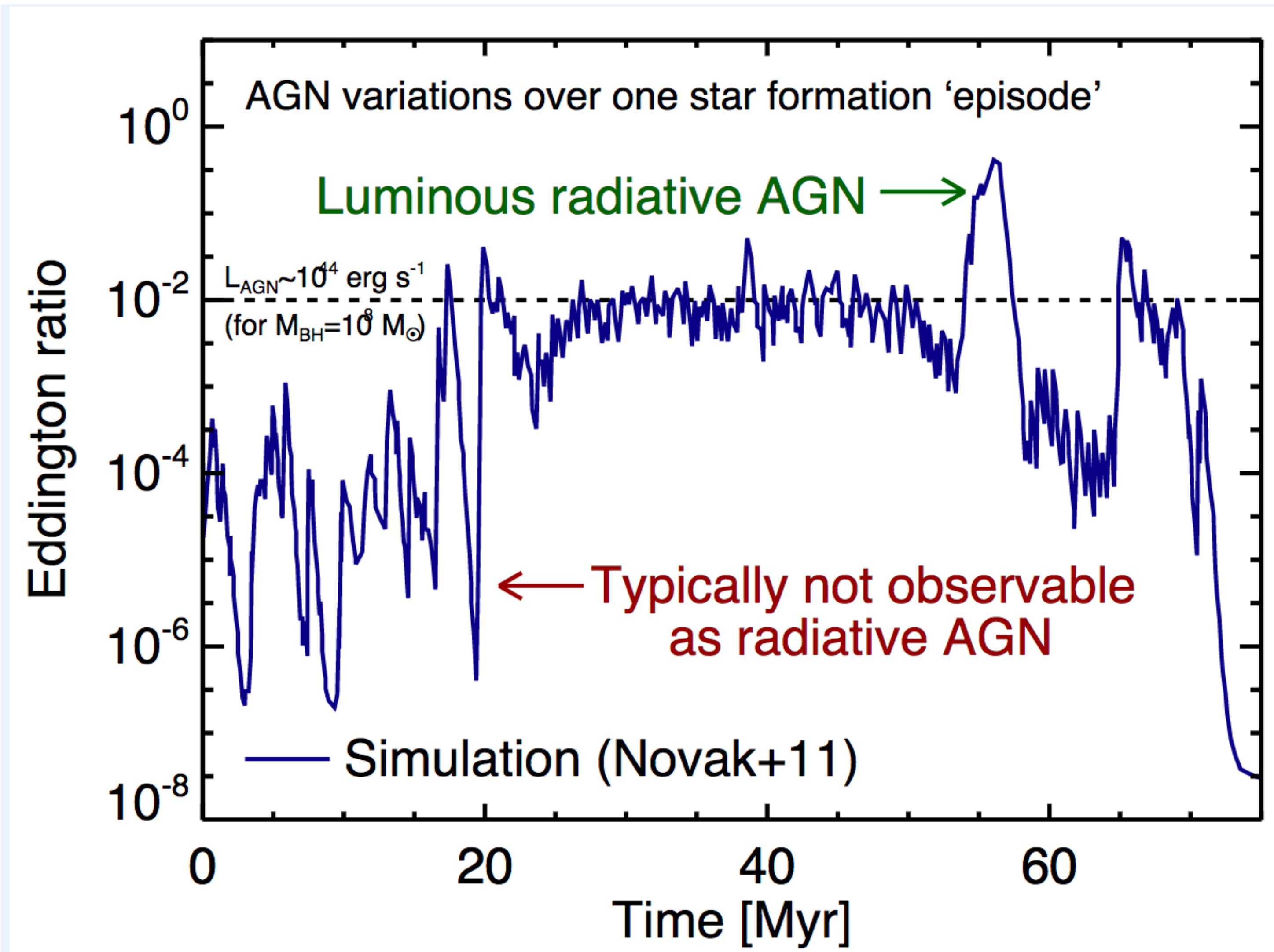
Laha et al. 2018, arXiv:1809.07906

Strong correlations between L_AGN and MO properties





AGN and SFR lifecycles….



C.M. Harrison et al. 2017

\# **Outflows at distances >0.1 kpc are unlikely to be inflated by the current AGN episode!!   Zubovas et al. 2018, MNRAS**.

Summary on the MOX study… main results

1. The MOX sources (LIRGs/ULIRGs) **may not be X-ray weak**. Instead it is highly probable that they are very obscured.

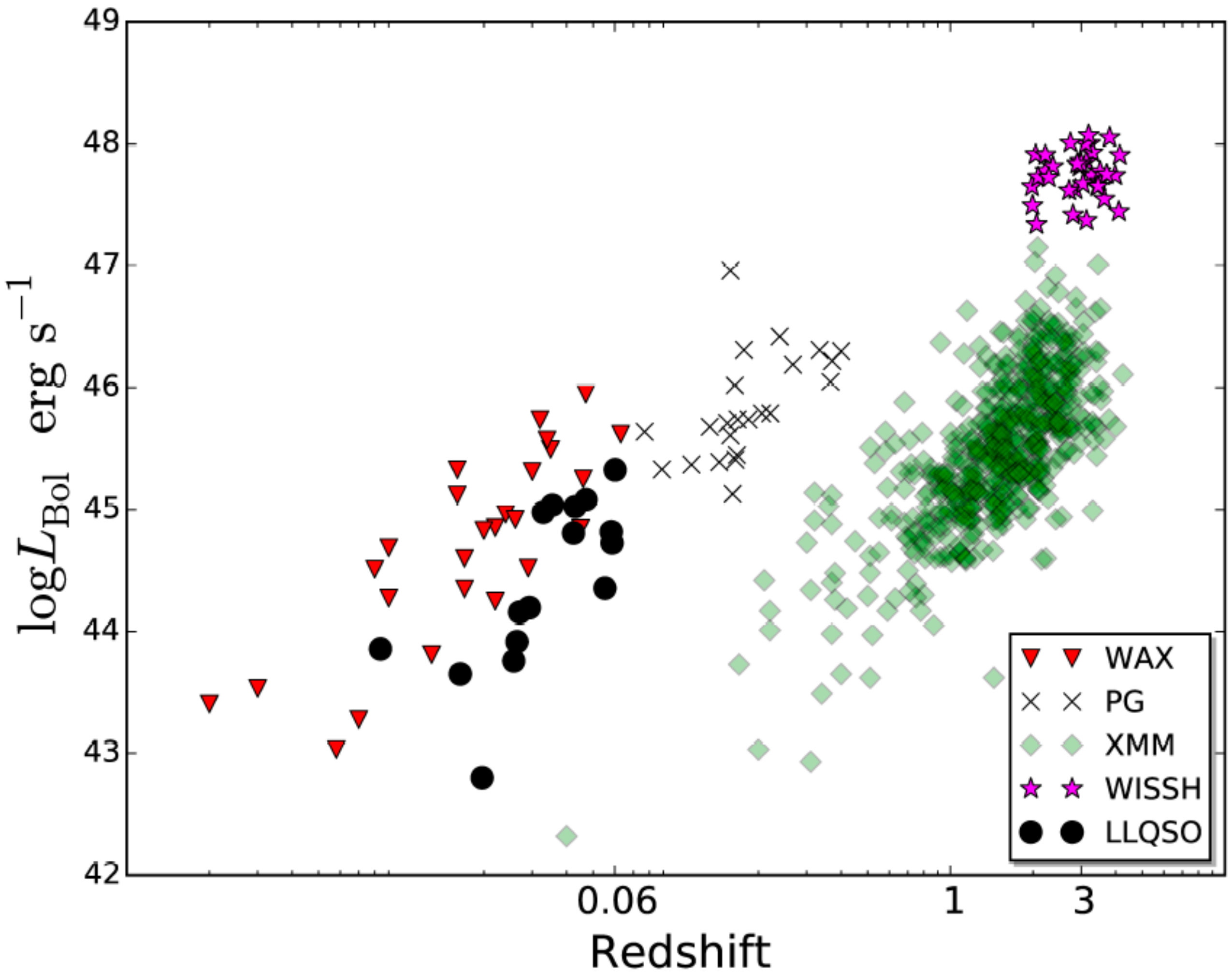
2. **AGN plays a very dominant role** in driving the Molecular outflows, showing tight correlations. **But still we are uncertain how**?

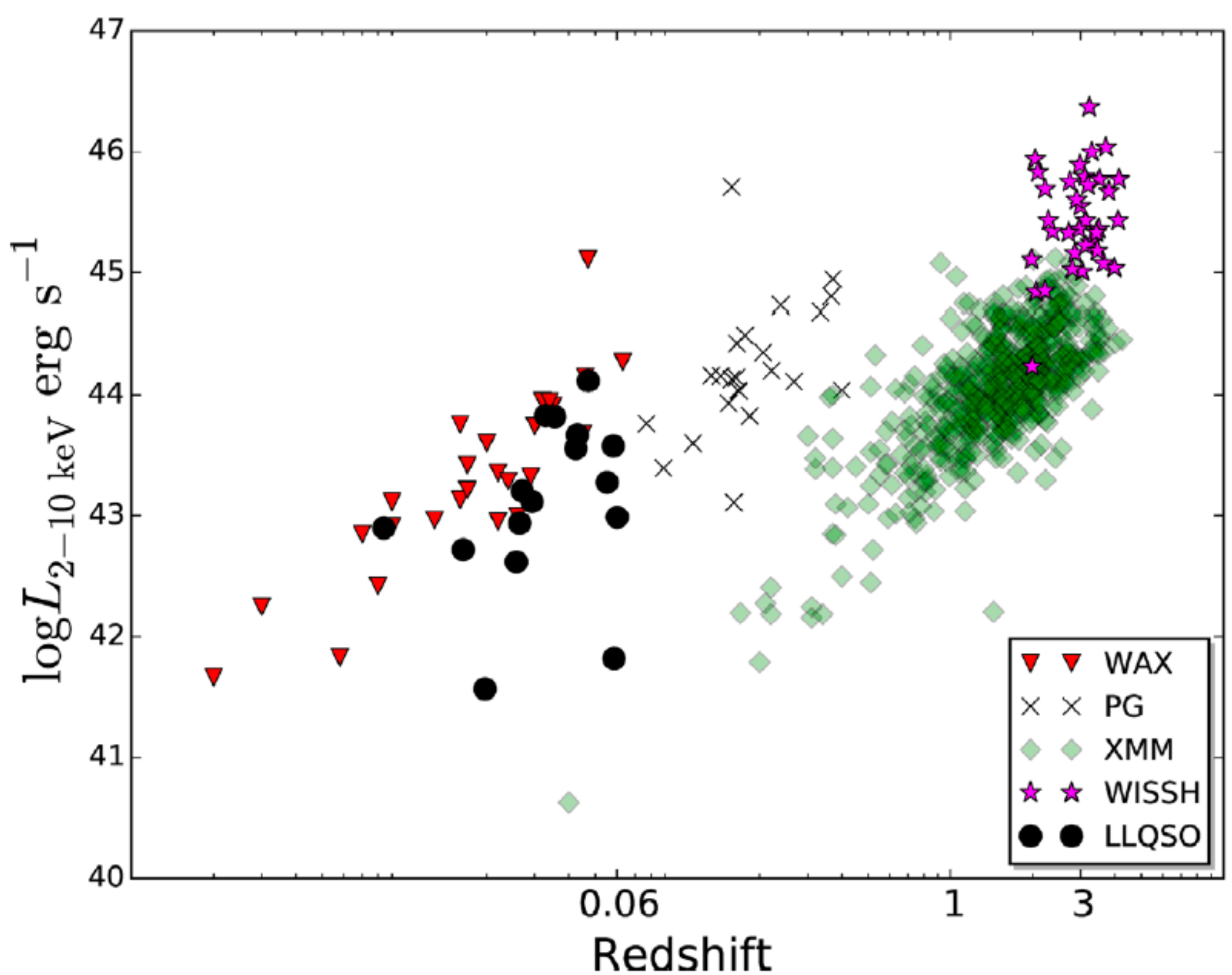
3. **Starbursts also play significant role** in driving the Mol outflows. What is their share of driving a Mol outflow compared to the AGN?

3. The low luminosity quasars in the local Universe. (**LLQSO project**, Laha et al. 2018)

An X-ray view of the central engines of the Low Luminosity Quasars (**LLQSO**) sample…

Laha et al. 2018 MNRAS.





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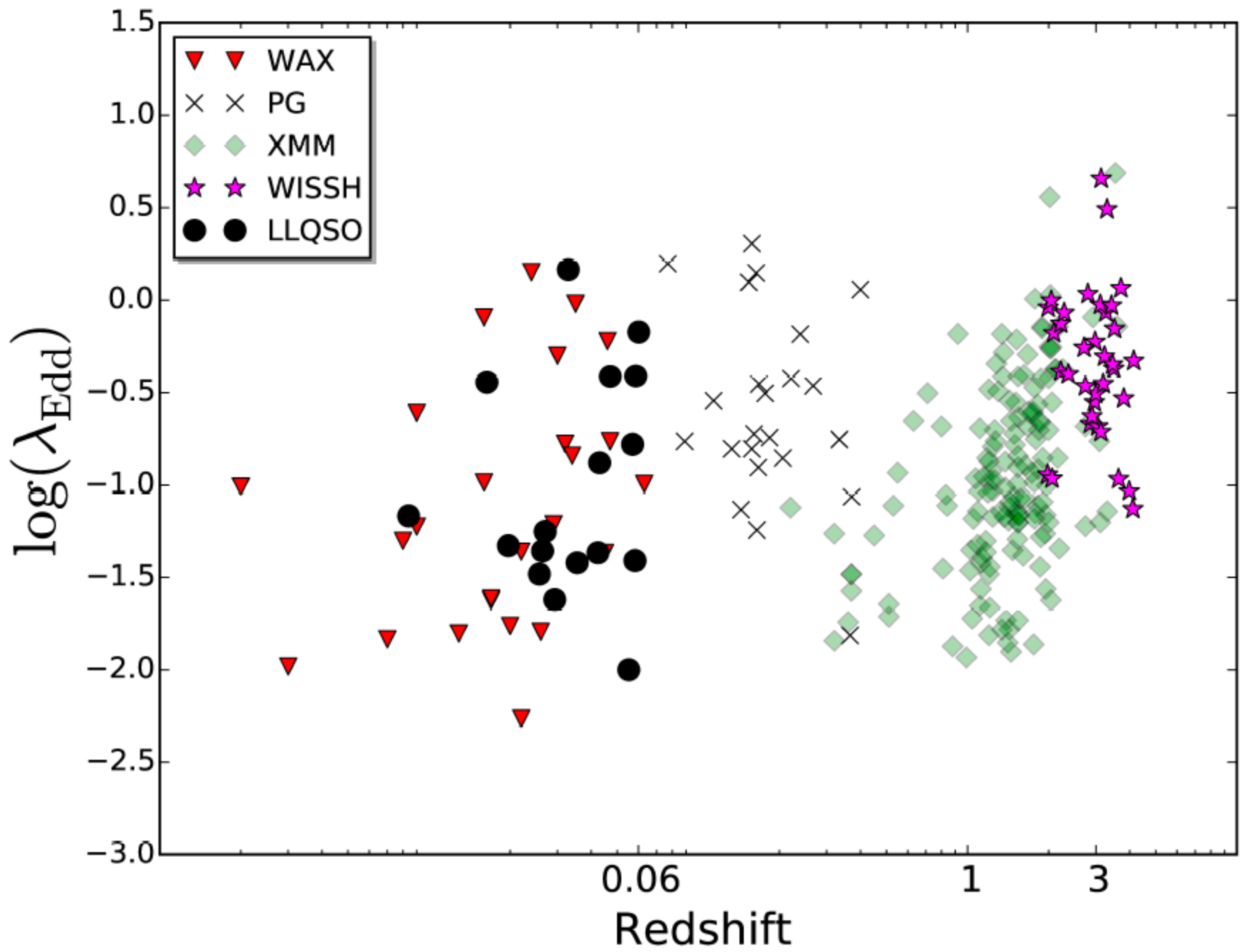

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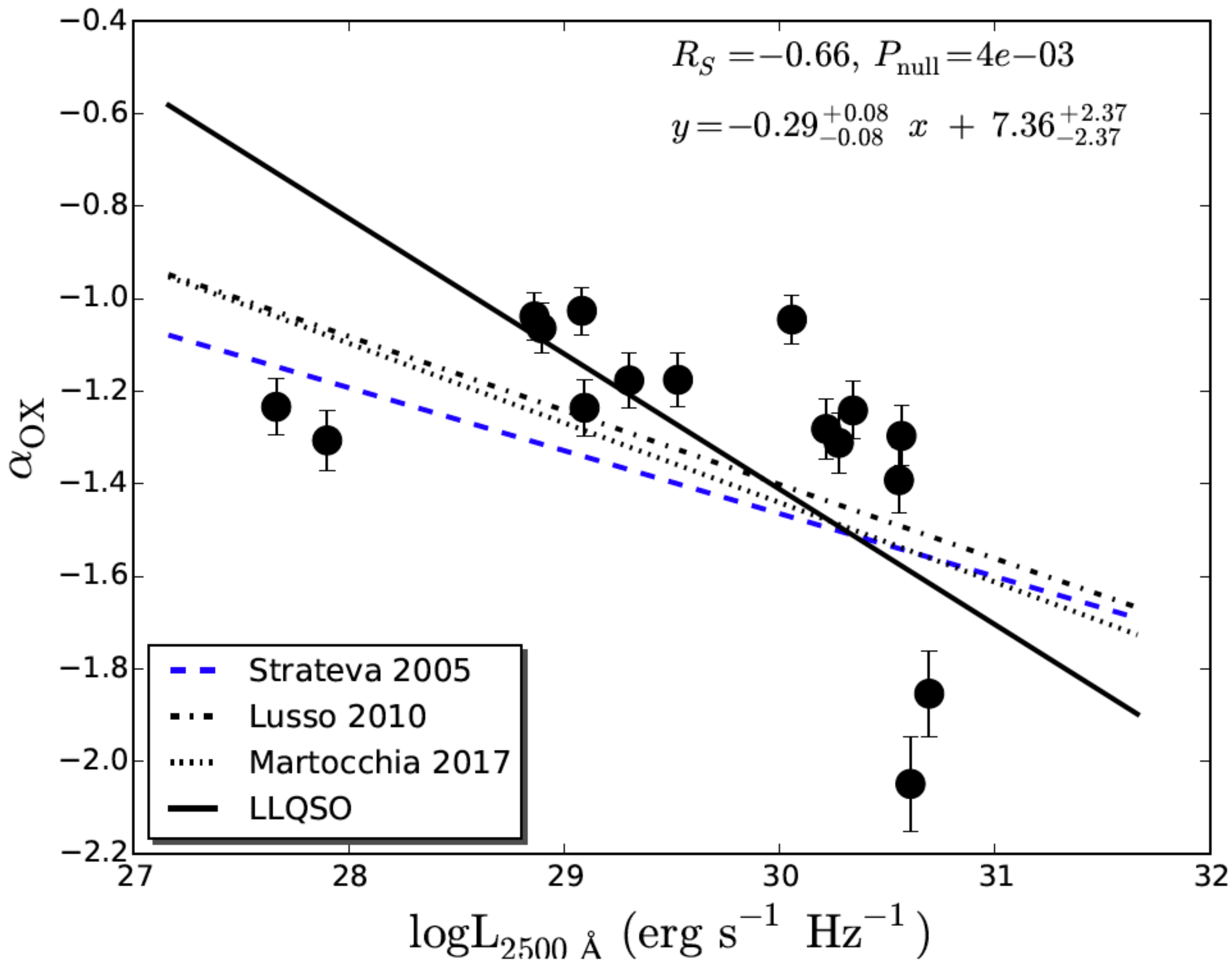


The central engines of the LLQSOs function similarly as that of the higher redshift brighter quasars.

An X-ray view of the central engines of the Low Luminosity Quasars (**LLQSO**) sample…

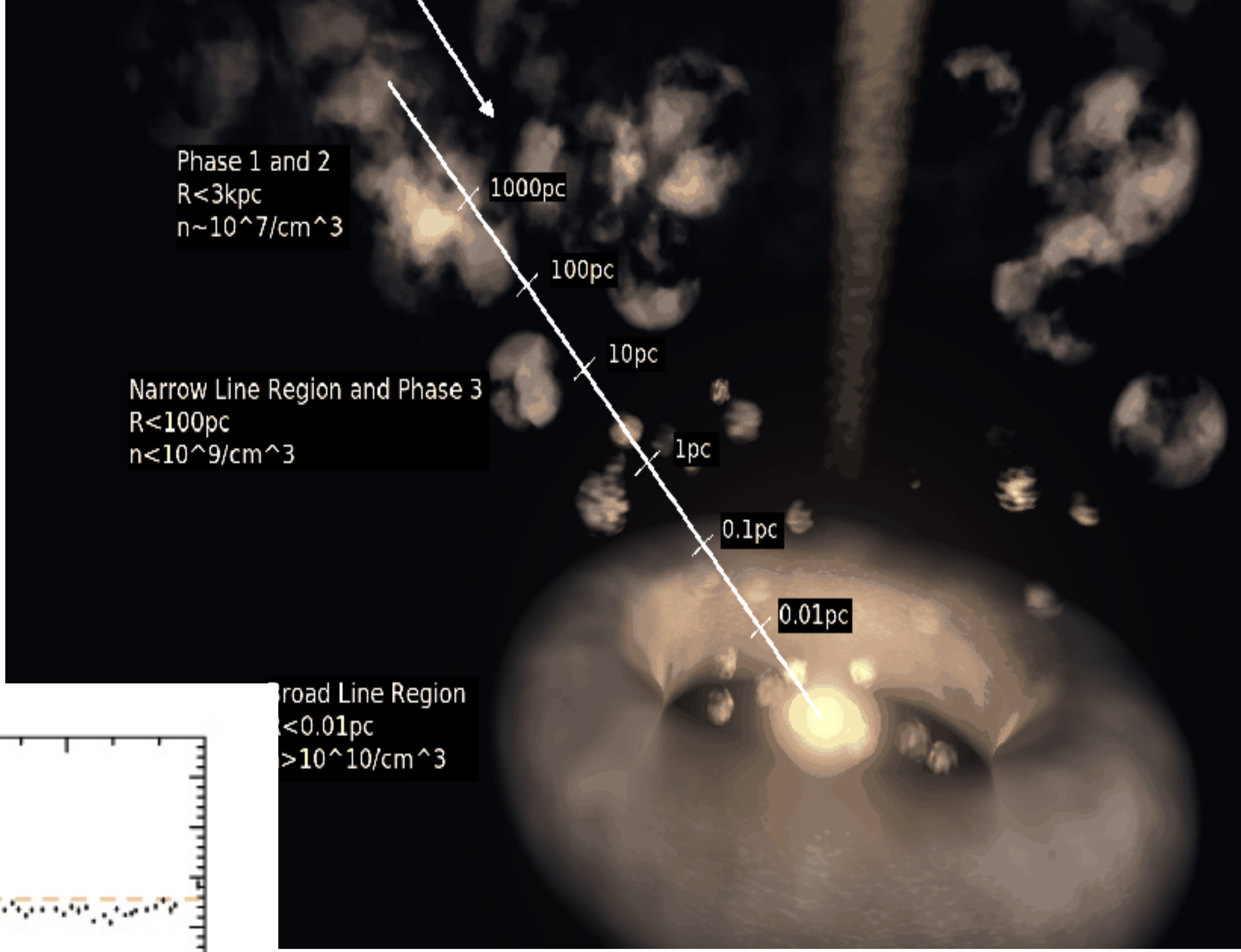
Laha et al. 2018 MNRAS.

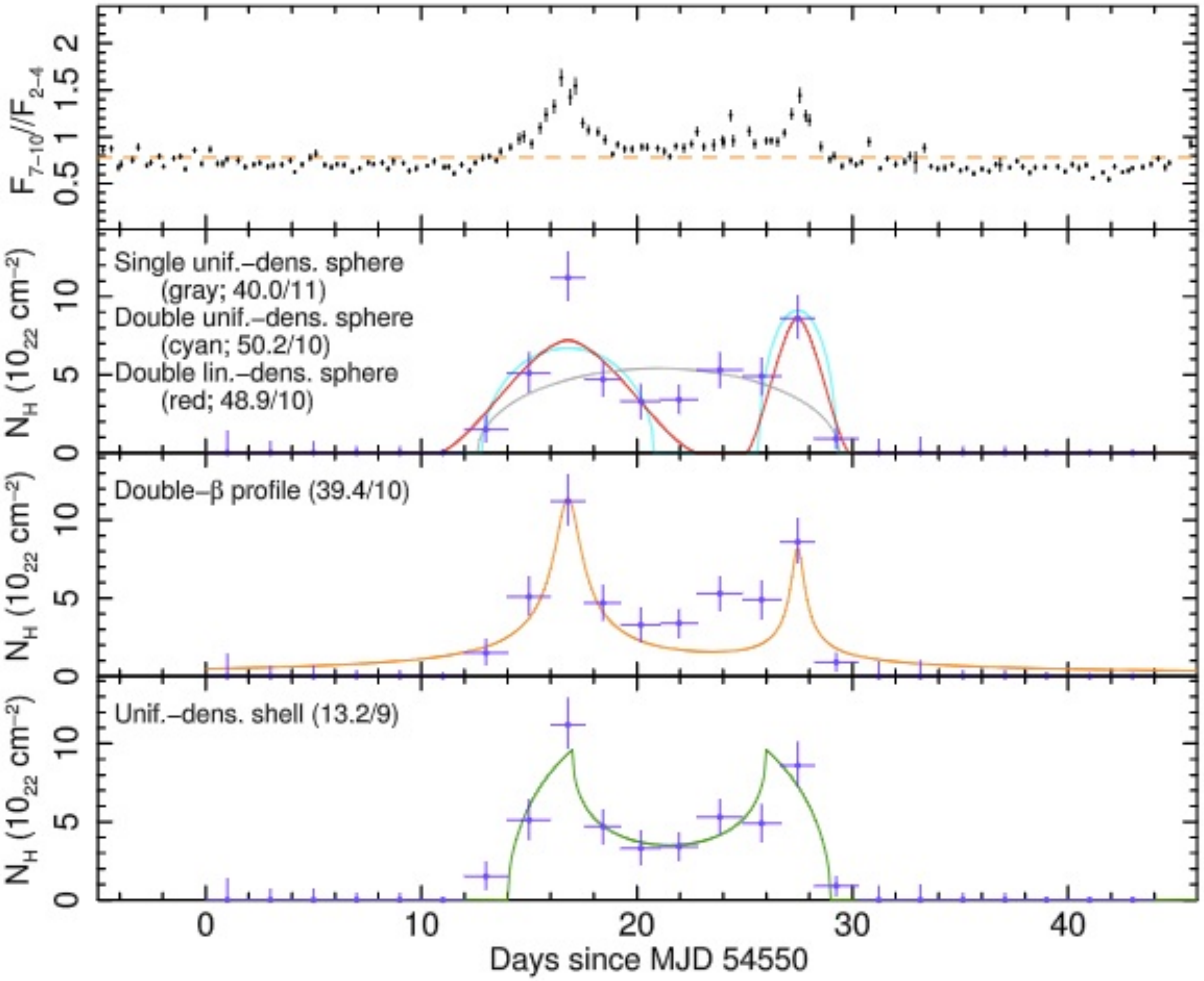
Summary:

1. The central engines of the LLQSOs function similarly as that of the higher redshift high luminosity quasars.

2. The presence of large amounts of molecular gas does not have any effect on the instantaneous accretion rates.

Finding Eclipsing events





Sy 1.5 < Range of candidates < C-Thin Sy2

NGC 3783.. Markowitz et al. 2014
(RXTE , PCA)

Quantifying variability/non-variability in a sample of 20 Compton thin Sy-2 galaxies using archival XMM, Chandra and Suzaku monitoring.

(Laha et al. in prep)

#250 separate observations

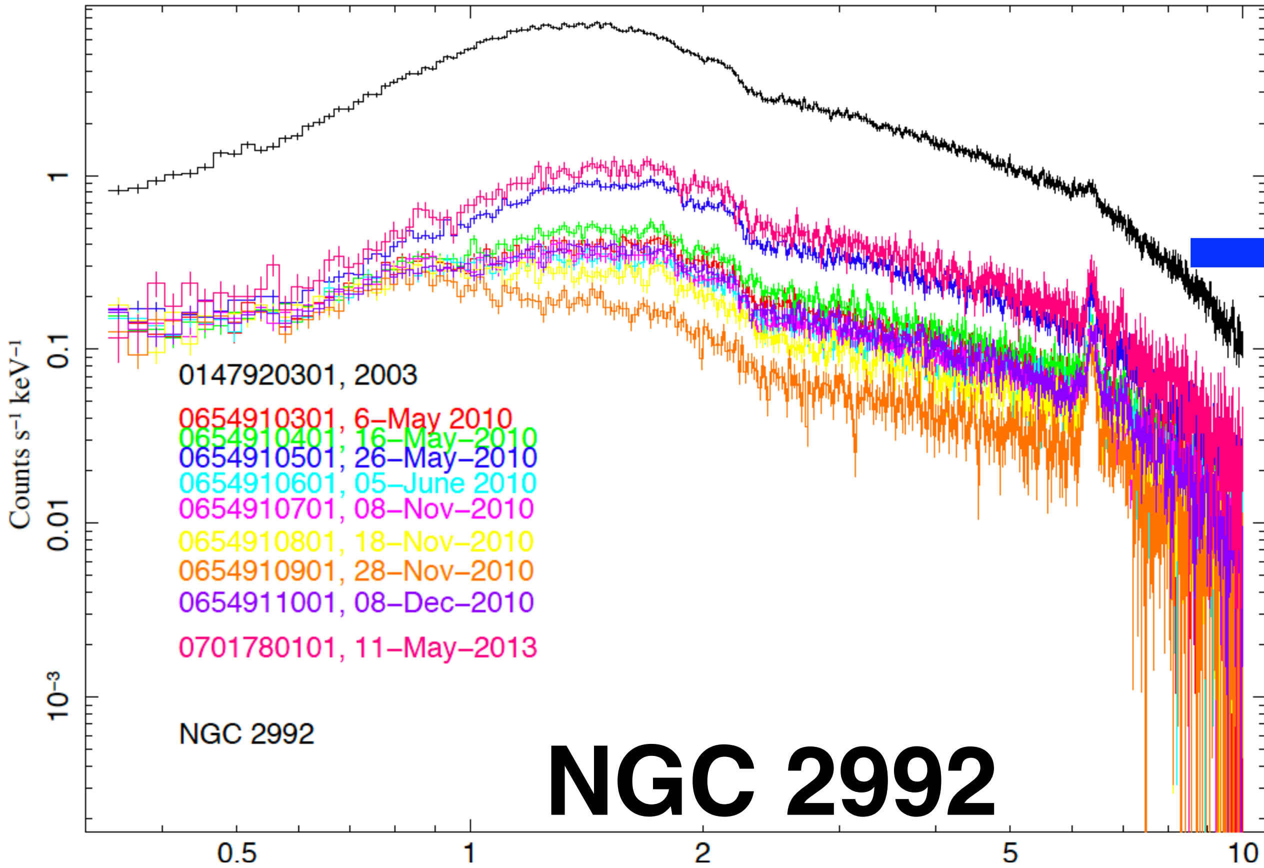
#Systematically derive NH light-curves for every source,
…probe log NH~ 20.5-23.5

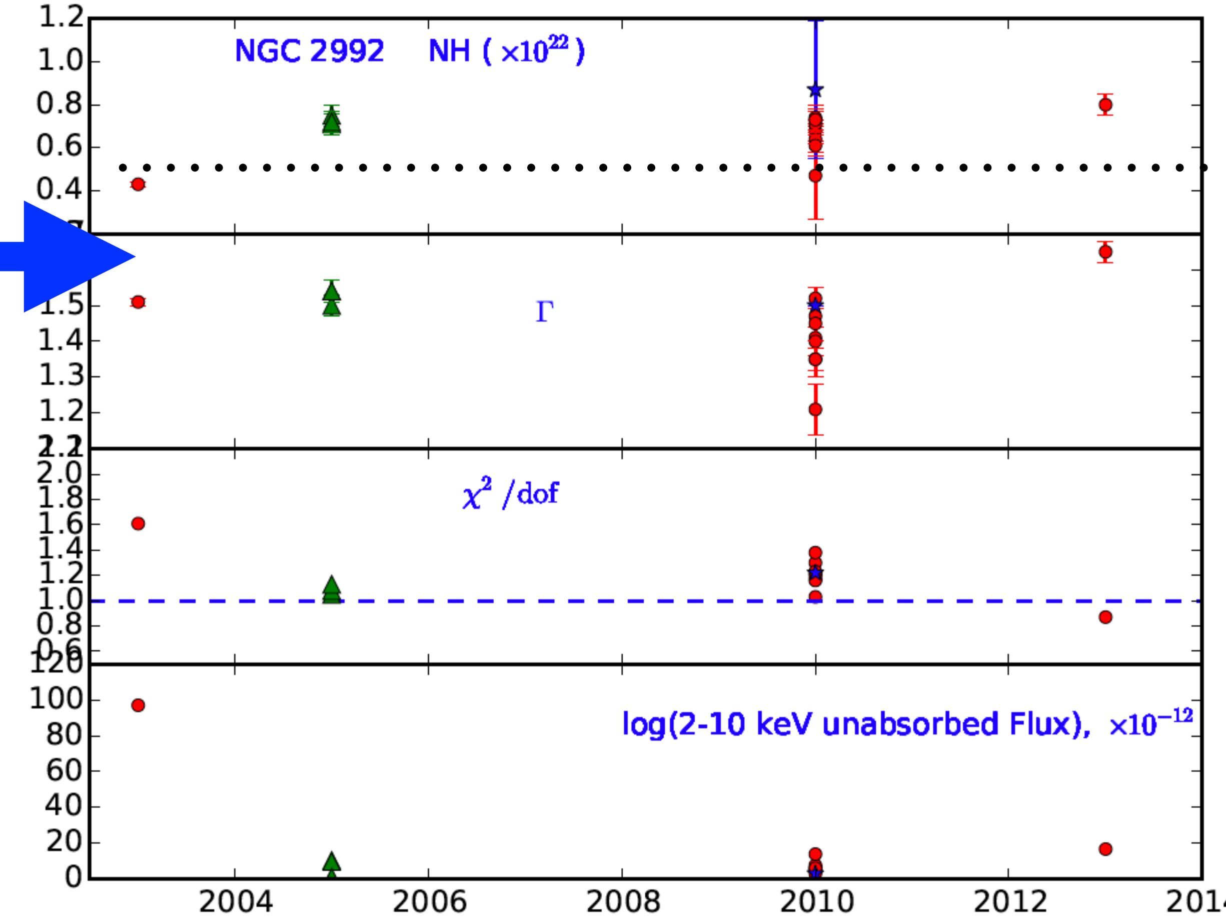
#Variability timescale ~days to > a decade

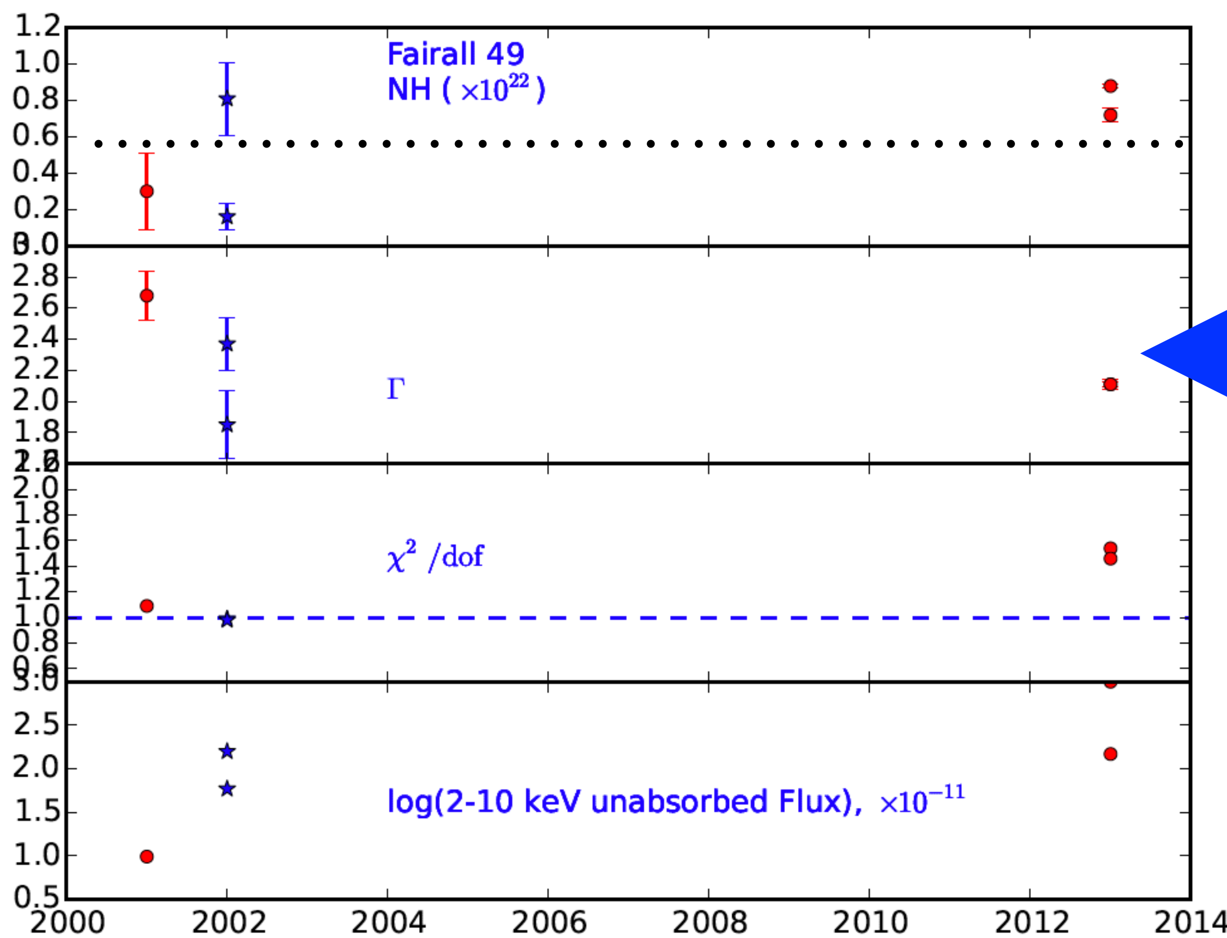
#Distance scale probed: pc- kpc

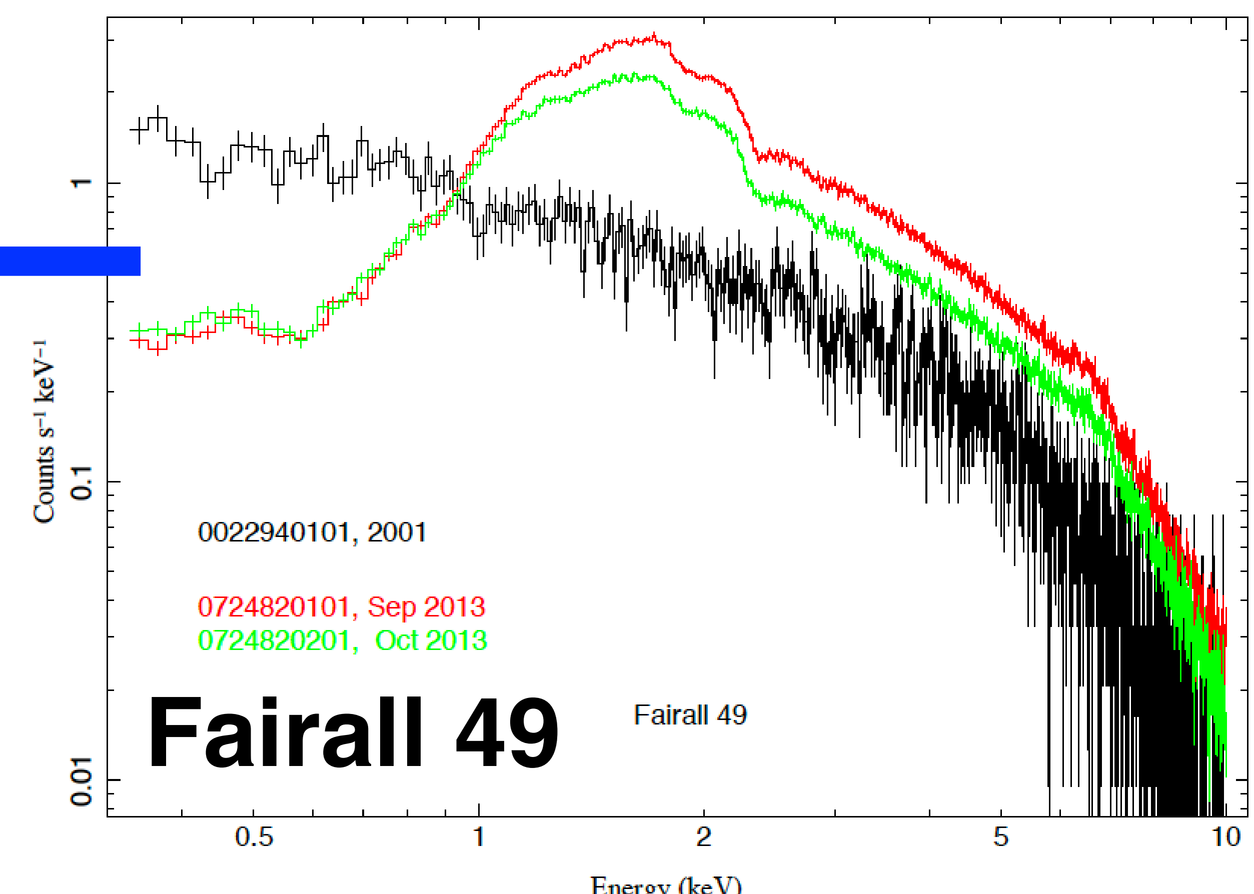
I will be happy to talk in details about spectral modeling and other details after my talk.

Possible NH varied sources









Possible NH constant source

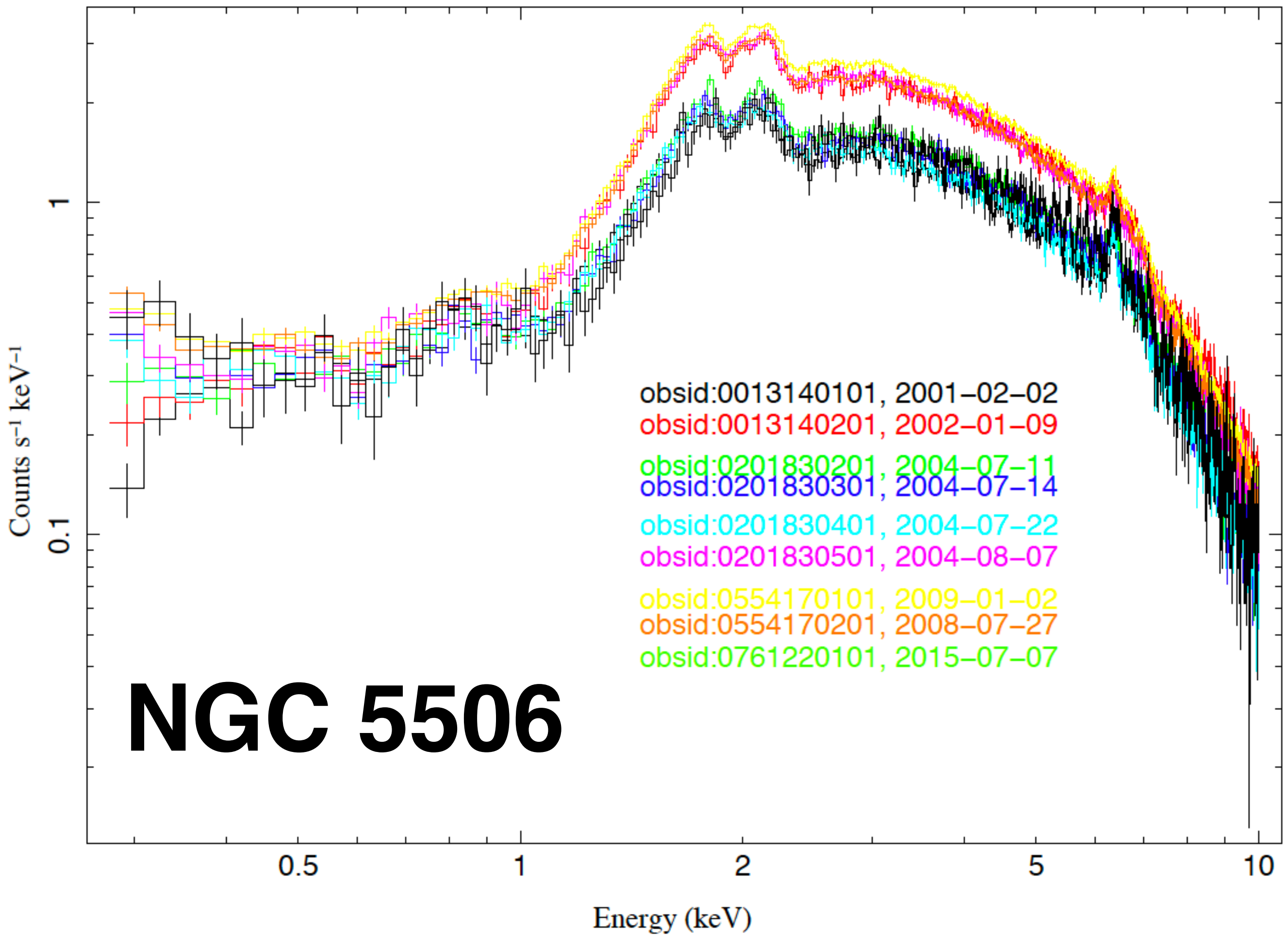
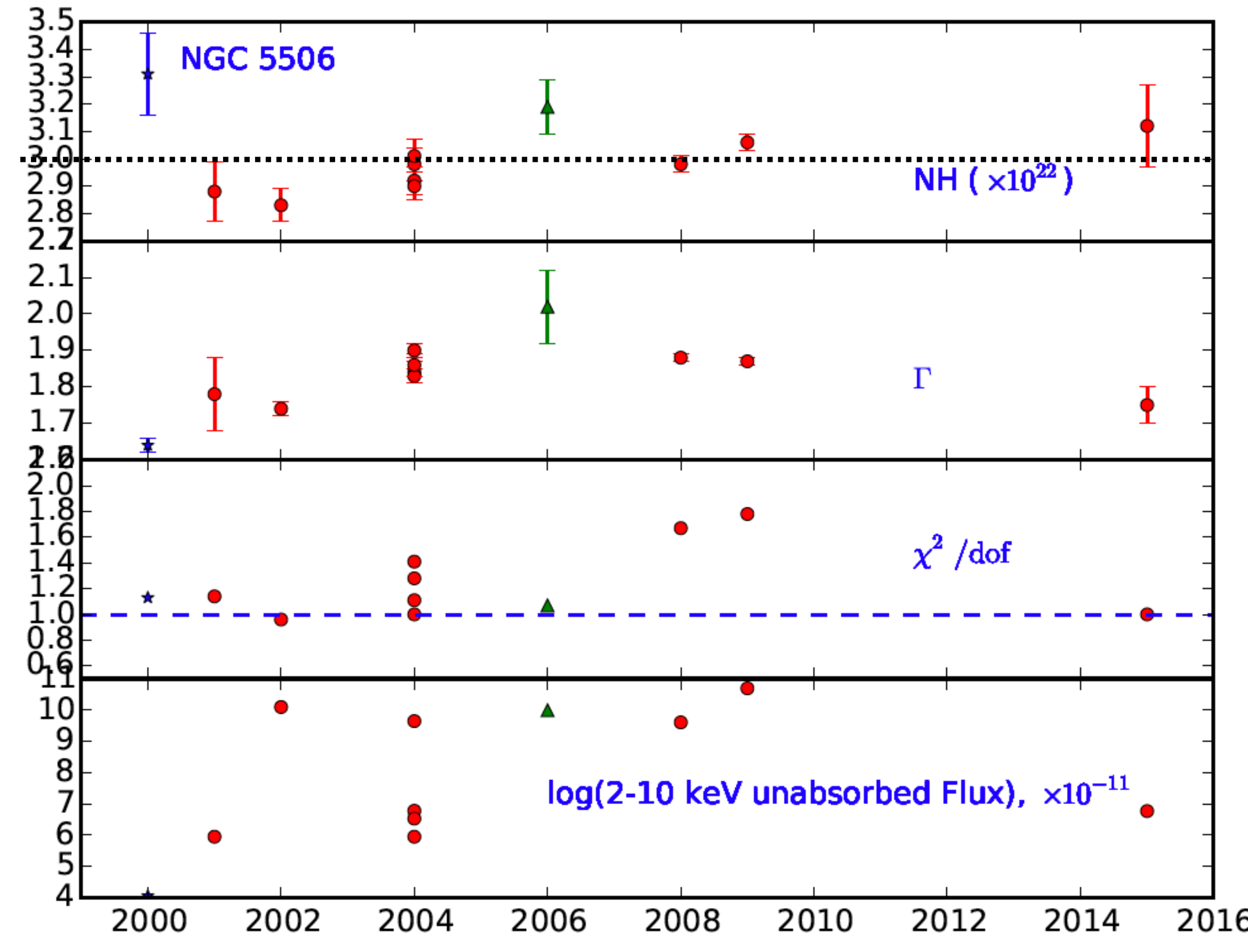


Figure B10. The Overplot of the different XMM observations of NGC 5506.

logNH~ 22.4



Main Results:

(Laha et al. in prep.)

1. Only 4 sources out of 20 show bonafide full covering NH variability between observations at days-years timescale, **implying clumpy non-homogeneous structures**.

2. For 12 sources, the X-ray absorption NH is consistent with host galaxy dust lanes.. **implying kpc scale structures responsible for absorption**.

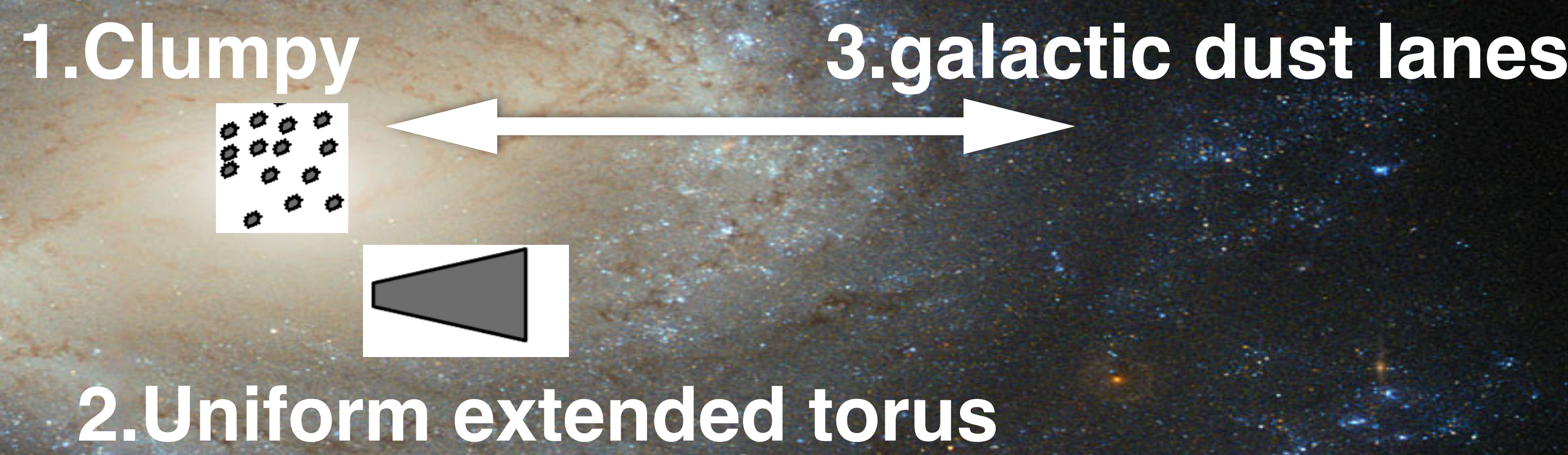
>>> For 7 sources, X-ray absorption is constant at logNH~23, in excess of host galaxy absorption…
implying compact smooth torus

3. For 9 sources there is a presence of partially covering absorption with logNH ~ 23, in addition to fully covered absorbers, **implying <<pc scale absorbing structures, which are clumpy! Thus we confirm presence of clumpy torus.**

Take home points:

Laha et al. in prep..

1.We **confirm the presence of clumpy logNH~23 `torus'** in the near vicinity of the AGN in some of the sources… however…



2. We **may not assign a common definition of torus to all the absorbed Seyfert candidates.** Torus may take up different features for different types of sources.

AGN Feedback… warm absorbers and molecular outflows…

Please take a look at the papers from our group:

1. **MOX**, **Laha et al. ApJ, 2018**,

2. **LLQSO**, **Laha et al. MNRAS, 2018**.

3. **WAX- I and II** , **Laha et al. MNRAS, 2014, 2016**

Thank you…