anonymous artist, Sesto/Sexten, July 2013

A global view of AGN warm absorbers: WAX

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My proposed questions

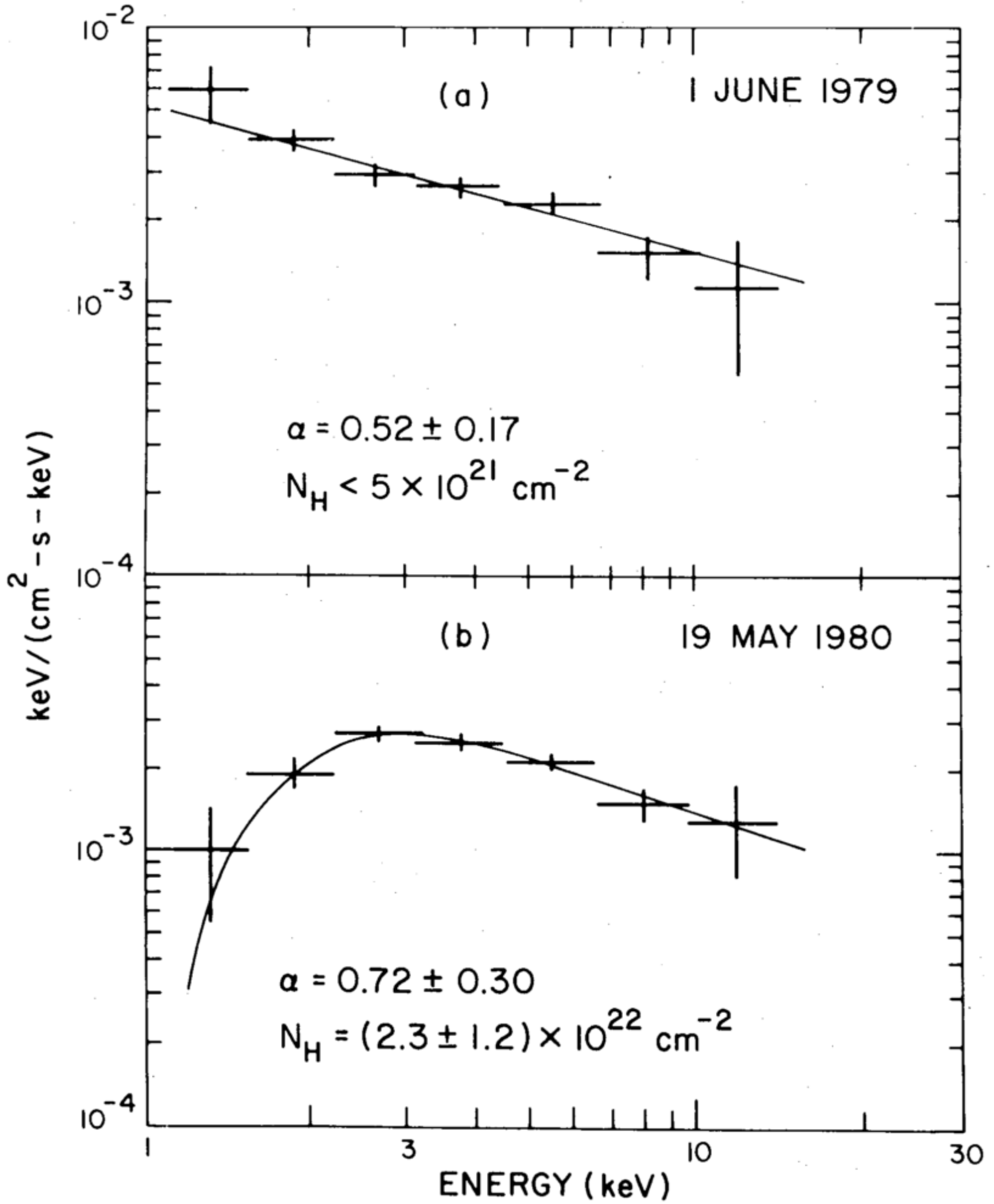
1. Are warm absorbers truly irrelevant for feed-back?

2. Which/where is the reservoir for outflowing gas? Does the "torus" help/is a "torus" required?

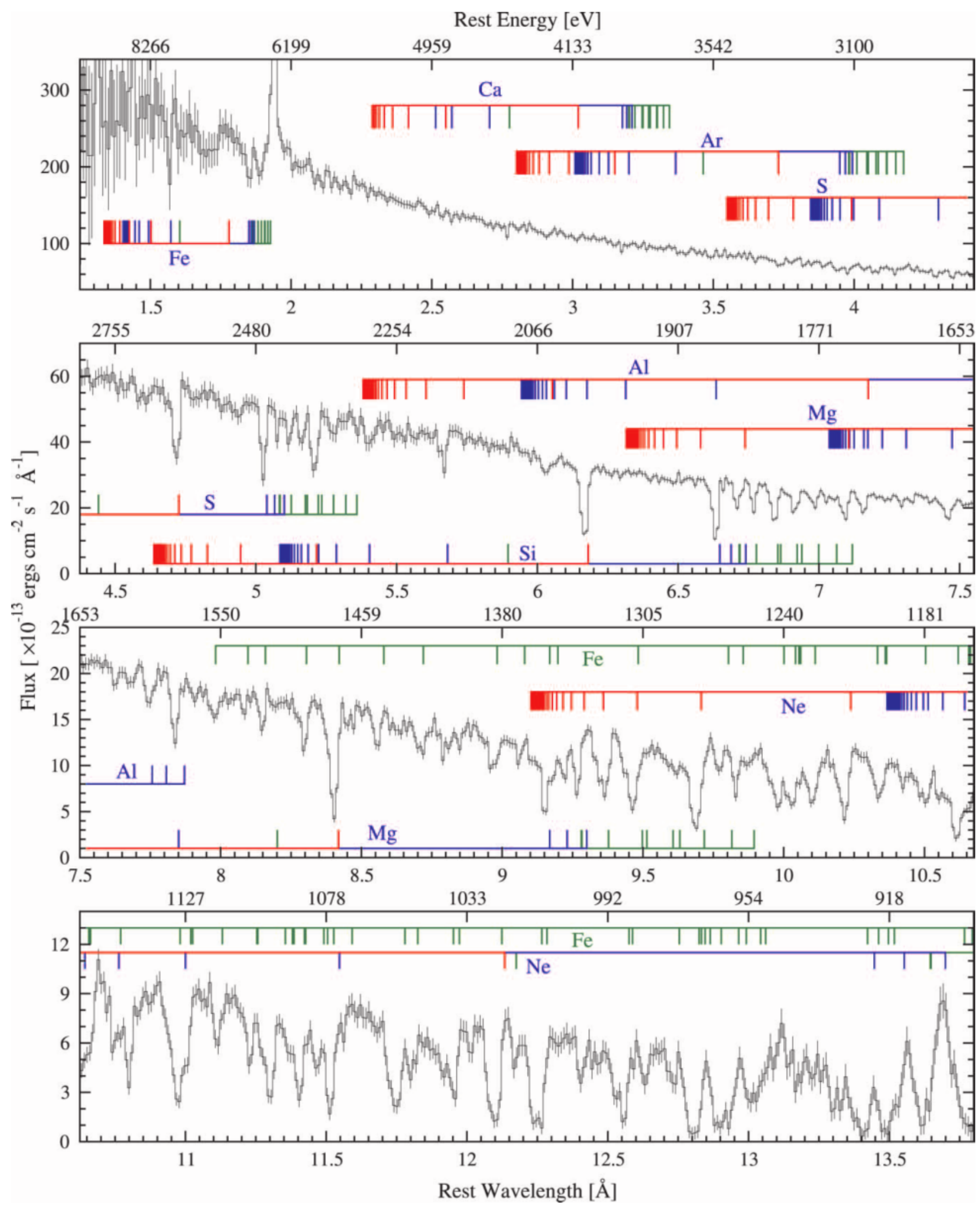
3. Which is the relation (if any) between warm absorbers and X-ray Narrow Line Regions?

A (short) historical prologue

Halpern, 1984, ApJ, 281, 90



Kaspi et al., 2002, ApJ, 574, 643



Scope of this talk

Studies of *homogeneously analysed* Seyfert samples at X-ray *high spectral resolution* to address the following questions:

- incidence of AGN outflows in the local Universe?
- outflow density profile?
- outflows acceleration mechanism?
  - MHD, radiation-driven, thermal winds?
- outflow structure?

Samples, warm absorber (WA)/UFOs incidence

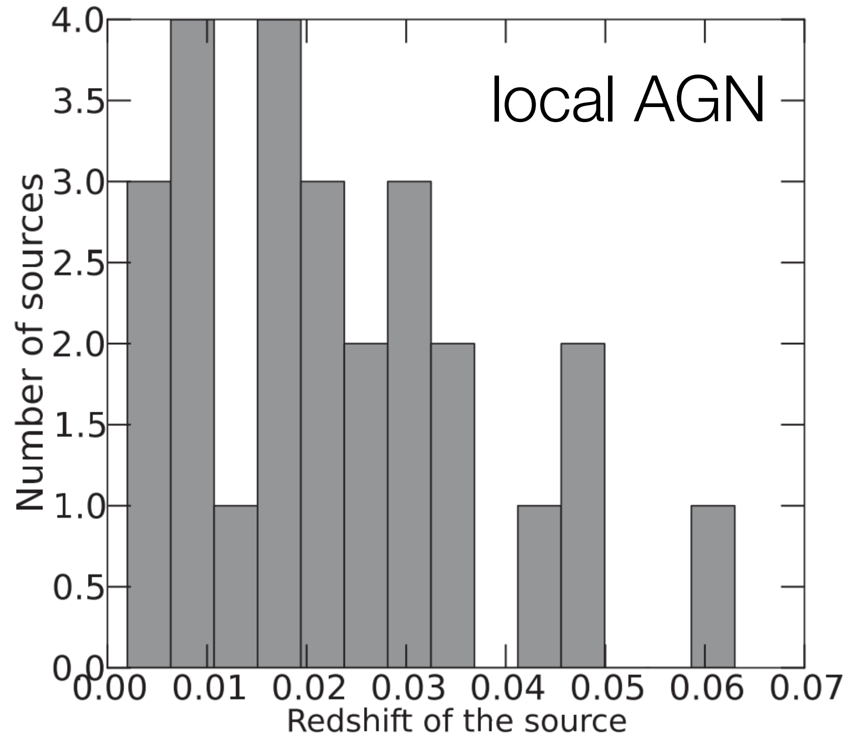
Paper	Instrument	$N_{objects}$	Mimimum incidence
McKernan+07	HETG	15 Type I AGN	WA: ~67%
Tombesi+10	EPIC-pn	42 RQ-AGN	WA: ~60% UFOs: ~34%
Gofford+13	XIS	51 Type 1-1.9 AGN	UFO: ~40%
Laha+14 (WAX)	EPIC-pn+RGS	26 Seyferts 1-1.5 + 1 LINER	WA: $77\pm9^{+3}_{-14}$%
Tombesi+14	EPIC-pn/XIS	26 RL-AGN	UFO: 50±20%

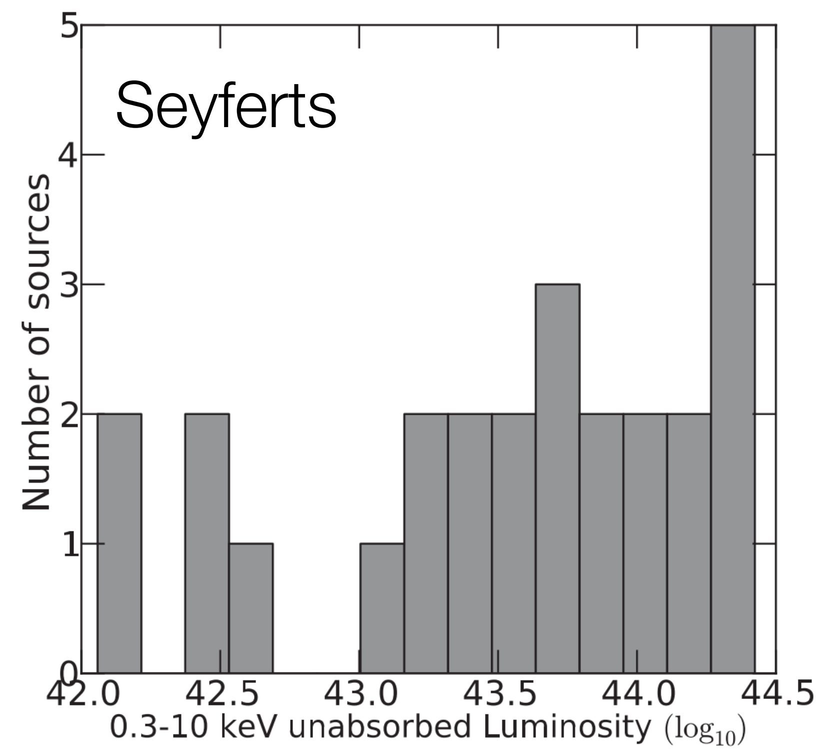
"RQ"=Radio-Quiet; "RL"=Radio-Loud

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

Laha et al., 2014, MNRAS, 441, 2613

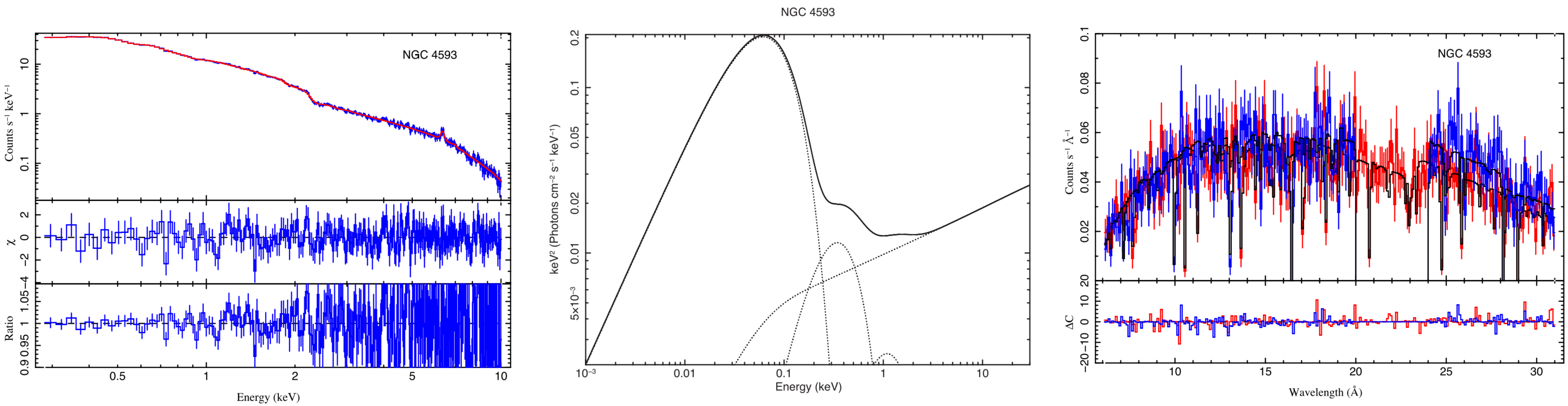
- *Parent sample*: RXTE X-ray Survey, 3-8 keV rate ≥1 s^{-1} [Revnivtsev et al. 2004]
- X-ray unobscured ($N_H \leq 10^{22}$ cm^{-2})
- High signal-to-noise XMM-Newton spectroscopic data, no EPIC pile-up
- Radio-quiet (log R < 2.4; Panessa et al. 2007)
- Final sample: 26 sources (76% completeness)





WAX analysis

Laha et al., 2014, MNRAS, 441, 2613



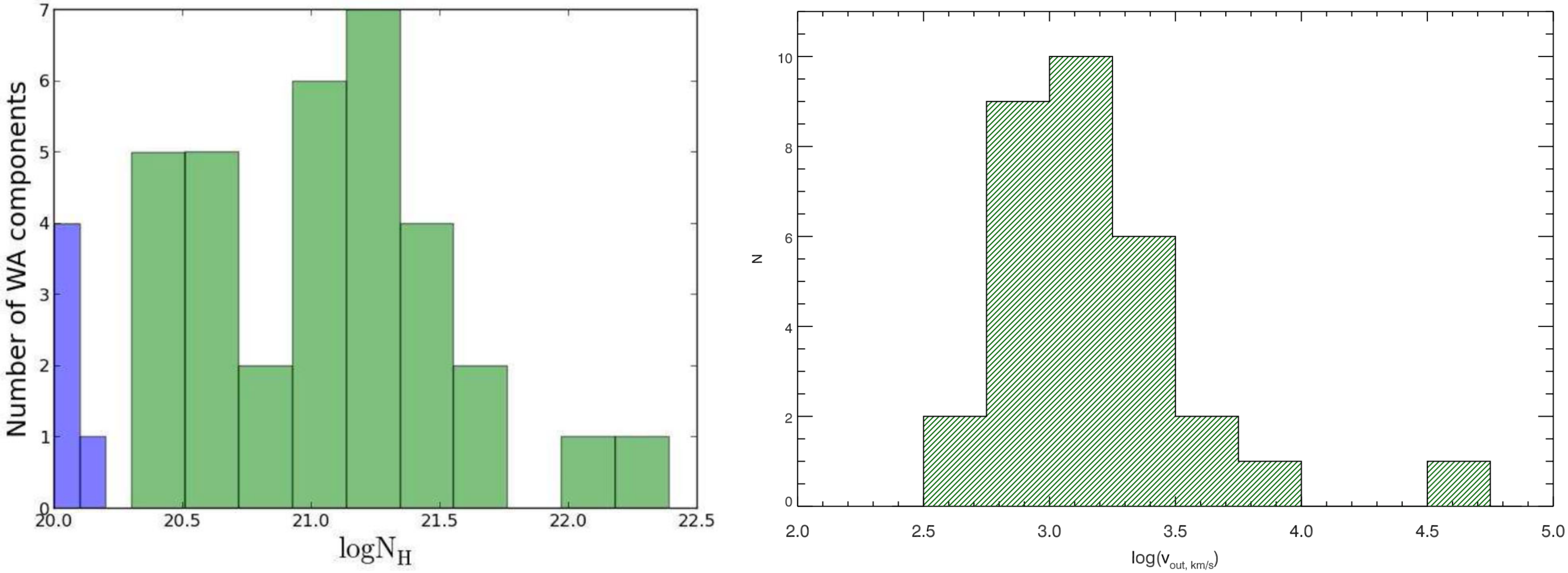
- Baseline X-ray continuum with EPIC-pn spectrum (0.3-10 keV)
- Optical to X-ray SED with simultaneous OM/EPIC data
- Generation of warm absorber CLOUDY grids
- Self-consistent fit of EPIC-pn and RGS spectra
- A couple of iterations, as required …

N_H and v_{out} distributions

Laha et al., 2014, MNRAS, 441, 2613

Column densities
$N_H \leq 10^{22.5}$ cm^{-2}

Outflow velocity
$<v_{out}> \sim 10^3$ km/s

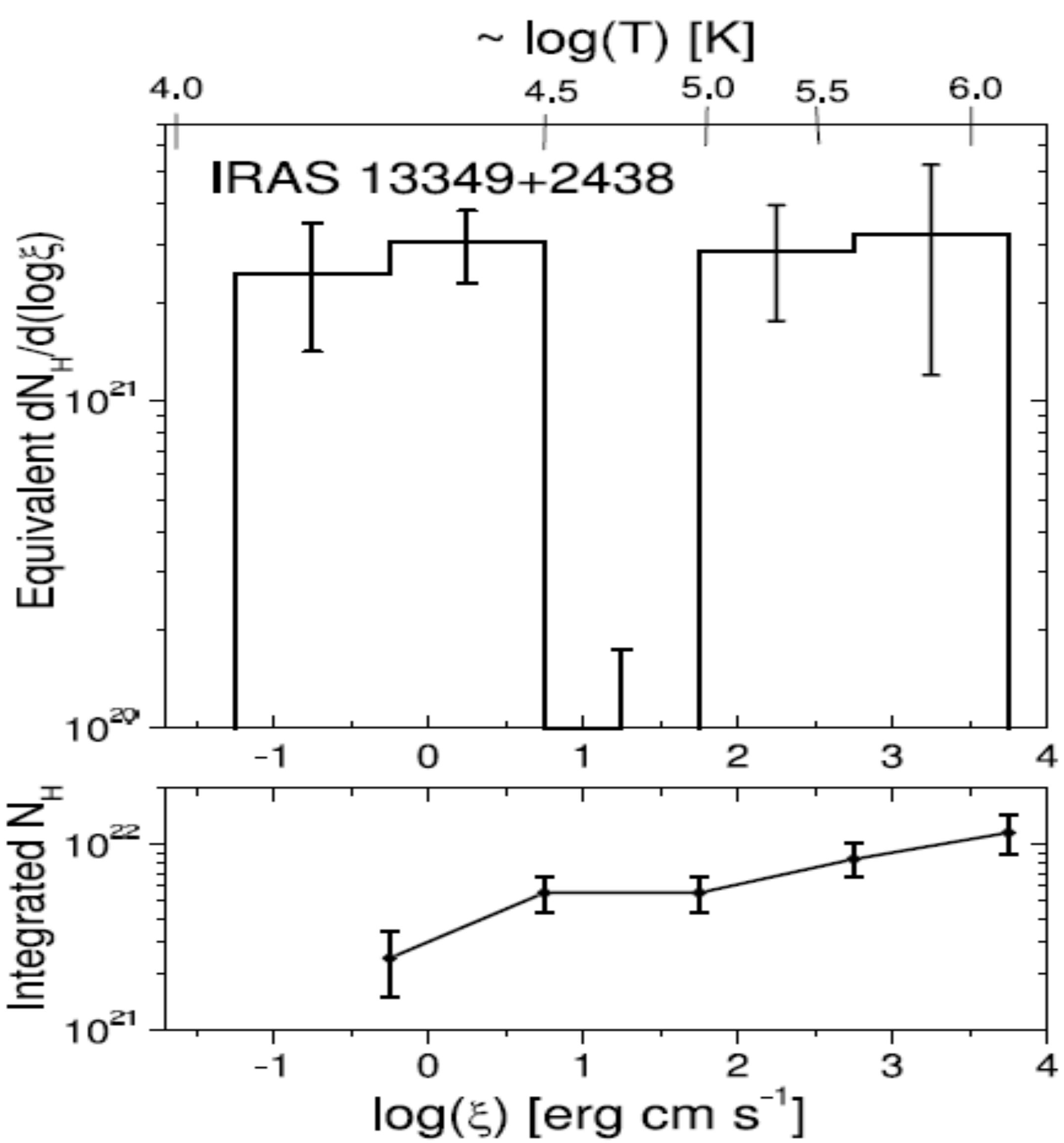


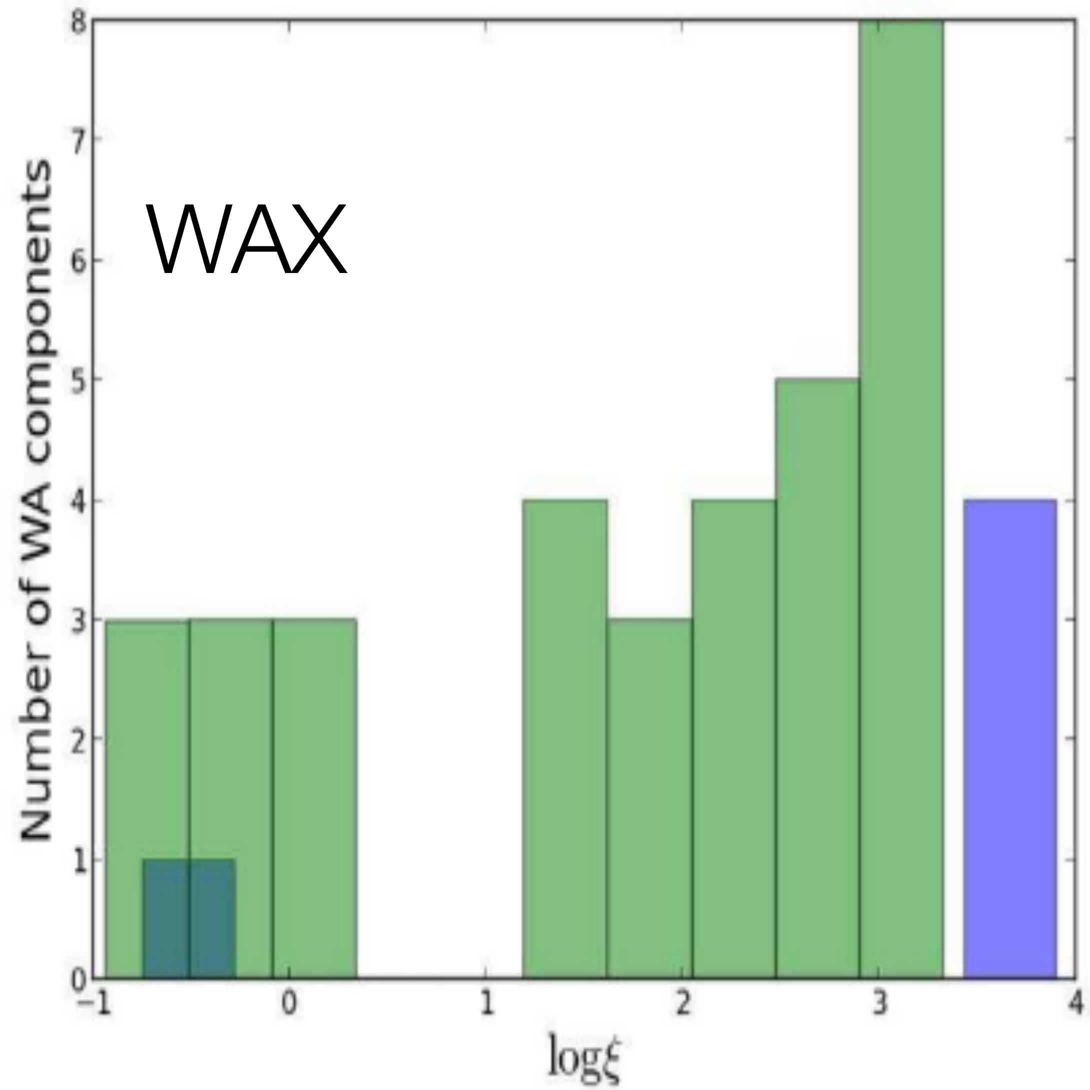
"Classical" warm absorber components

Ionisation structure: the "ionisation gap"

Holczer et al., 2007, ApJ, 663, 799

Laha et al., 2014, MNRAS, 441, 2613

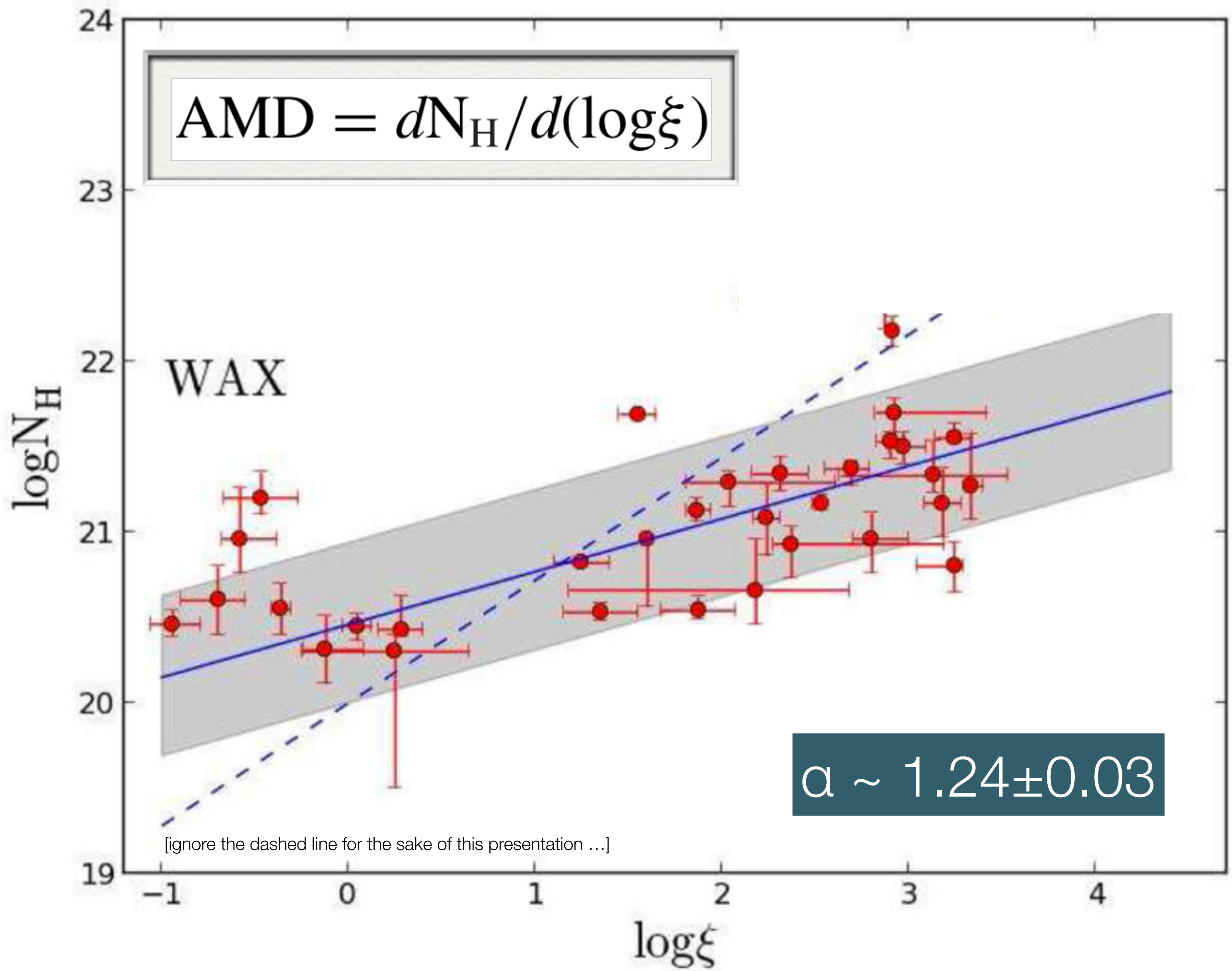




Hypothesis: thermal instabilities [Goosmann et al., 2016, and many, many others]

Density profiles $n(r) \propto r^{-\alpha}$

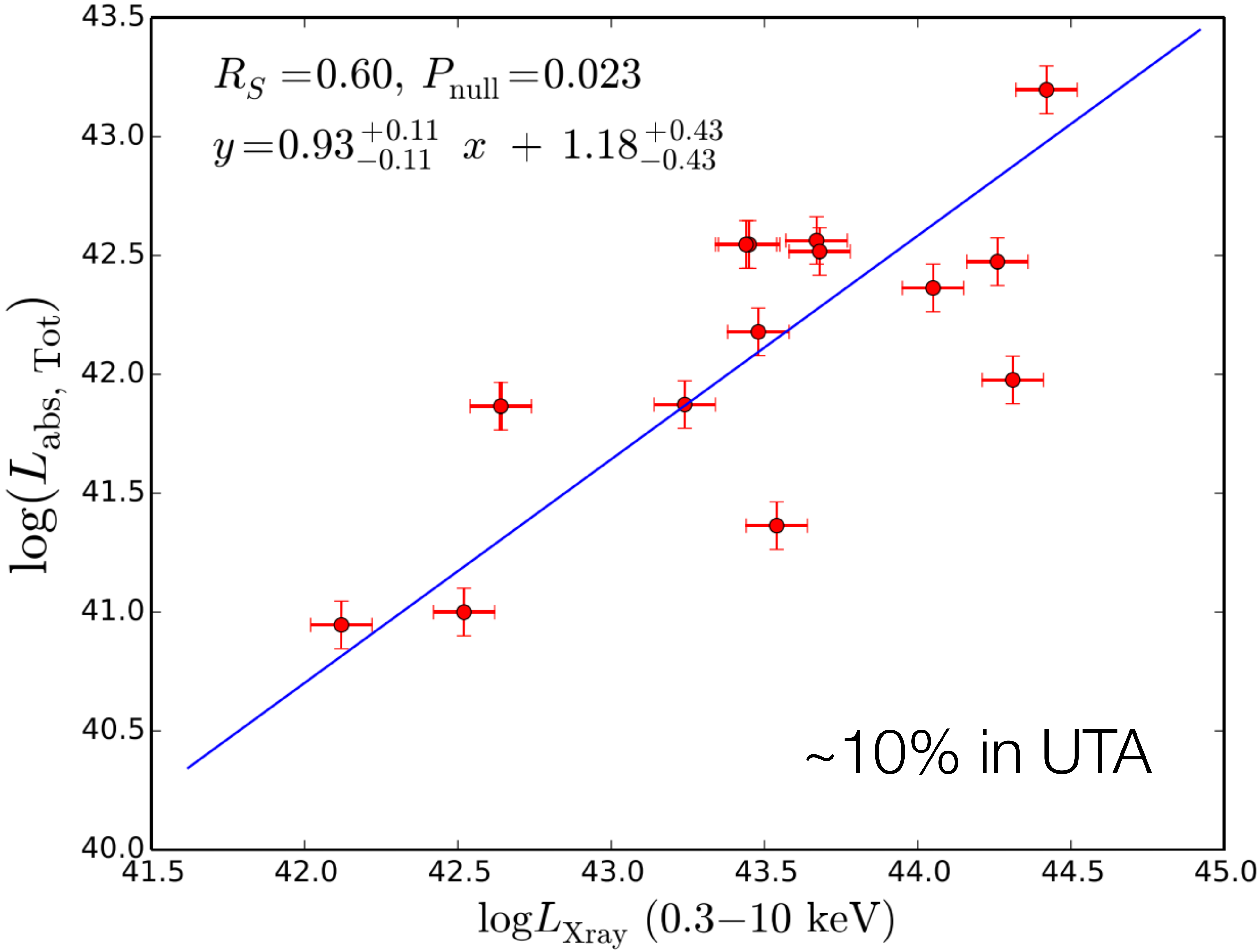
Laha et al., 2014, MNRAS, 441, 2613



Consistent with the a small but well studied sample of Seyfert galaxies (Behar 2009; $1<\alpha<1.3$)

L_{abs} vs L_X: a (WAX) constant of nature?

Laha et al., 2016, MNRAS, 457, 3896



Lack of global correlations with continuum/source

Laha et al., 2014, MNRAS, 441, 2613; Mc Kernan et al., 2007, ApJ, 379, 1359

Quantity	MBH	L_{X-ray}	L_{ion}	Γ	α_{OX}
WA-highest log ξ	(0.05,0.84)	(0.40,0.11)	(0.23,0.37)	(0.04,0.87)	(−0.01,0.97)
WA-lowest log ξ	(−0.34,0.174)	(−0.35,0.15)	(−0.48,0.05)	(0.10,0.68)	(0.11,0.66)
WA-highestlog N_H	(0.10,0.68)	(0.40,0.10)	(0.43,0.08)	(0.16,0.53)	(0.018,0.94)
WA-lowest log N_H	(−0.03,0.89)	(−0.19,0.45)	(−0.32,0.19)	(0.09,0.71)	(−0.11,0.65)
WA-highest velocity	(0.25,0.33)	(0.23,0.36)	(0.16,0.53)	(−0.14,0.56)	(0.14,0.58)
WA-lowest velocity	(0.29,0.25)	(0.036,0.88)	(−0.08,0.75)	(−0.29,0.24)	(−0.04,0.87)

Warm absorber observables do not correlate with continuum or source properties

Chandra/HETG: lower outflow rate and higher velocity outflows could be associated with lower Eddington ratio accreting sources

Derived WA quantities: launch radius

$$r_{\rm min} = \frac{GM}{v_{\rm out}^2}$$

⇐ outflow escape velocity

⇓ dust sublimation radius

$$r_{\rm dust} = R_{\rm Sub,graphite} \sim 0.5 * L_{46}^{0.5}(1800/T_{\rm sub})^{2.6} f(\theta)$$

[Barvanis et al. 1987]

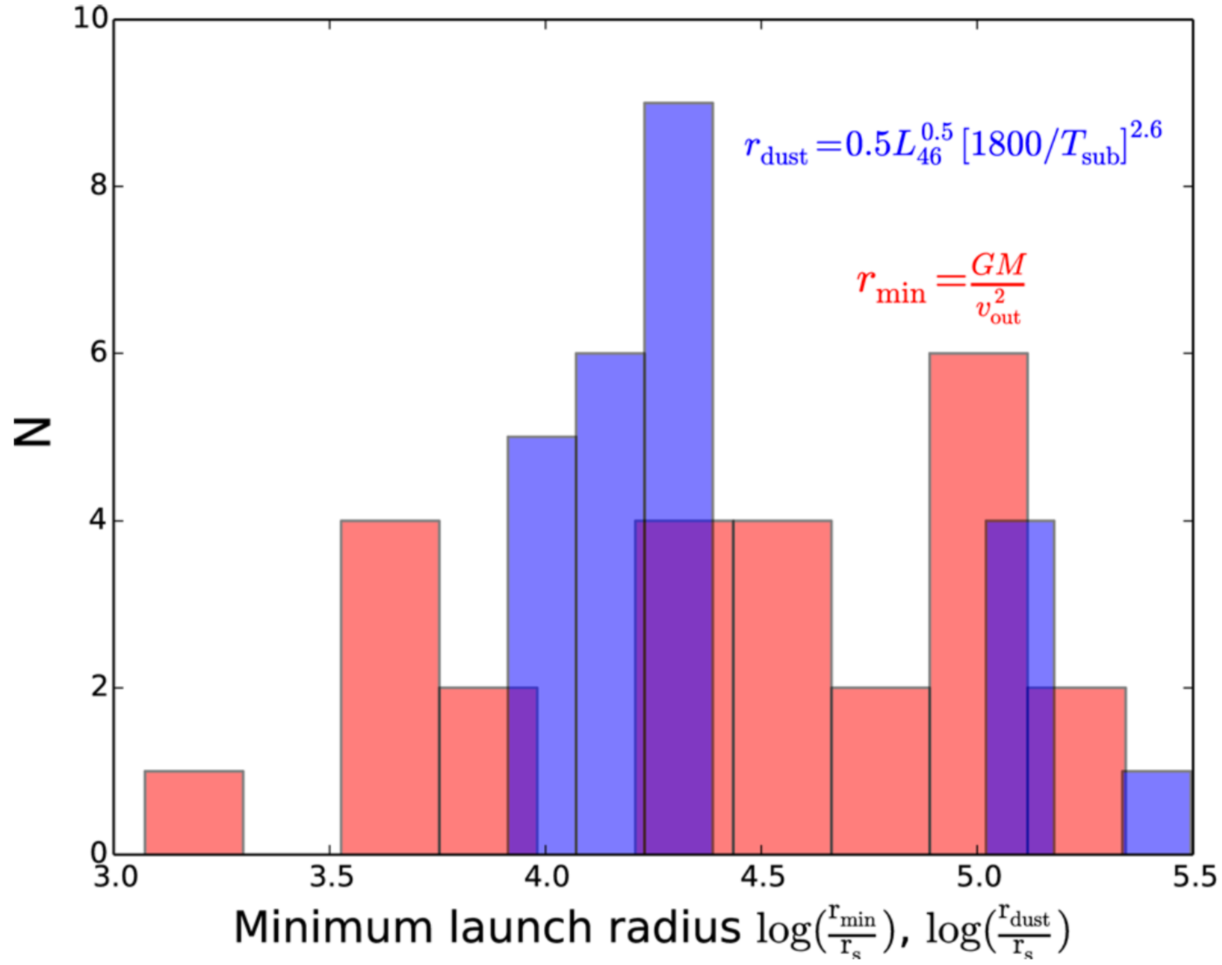
$$r_{\rm max} = \frac{L_{\rm ion} V_f}{\xi N_{\rm H}}$$

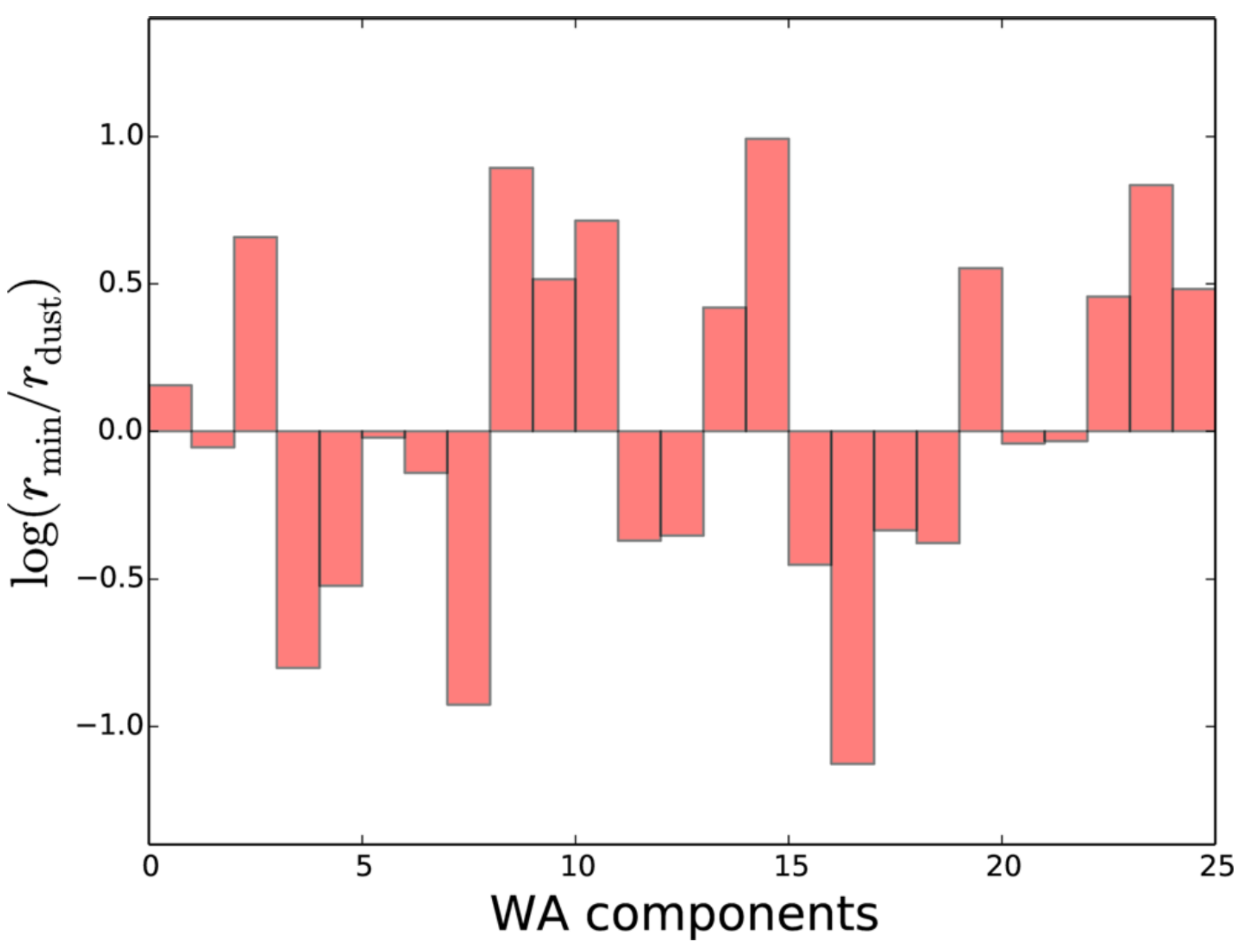
⇐ $\Delta r/r \leq 1$

WA launch radius

Laha et al., 2016, MNRAS, 457, 3896

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





Diagnostics on acceleration mechanisms

King & Pounds, 2003, MNRAS, 345, 657

Fukumura et al., 2010, ApJ, 715, 636

Compton scattering

$$\dot{P}_{\mathrm{out,R}} \simeq C_{\mathrm{f}} \tau_{\mathrm{e}} \dot{P}_{\mathrm{rad}}$$

$$v_{\mathrm{out,R}} \simeq \left(\frac{k_{\mathrm{bol}}}{4\pi m_{\mathrm{p}} c} \right)^{1/2} \tau_{\mathrm{e}}^{1/2} \xi^{1/2}$$

MHD

$$\dot{P}_{\mathrm{out,MHD}} \simeq \frac{\beta}{\omega^2 \eta} \dot{P}_{\mathrm{rad}}$$

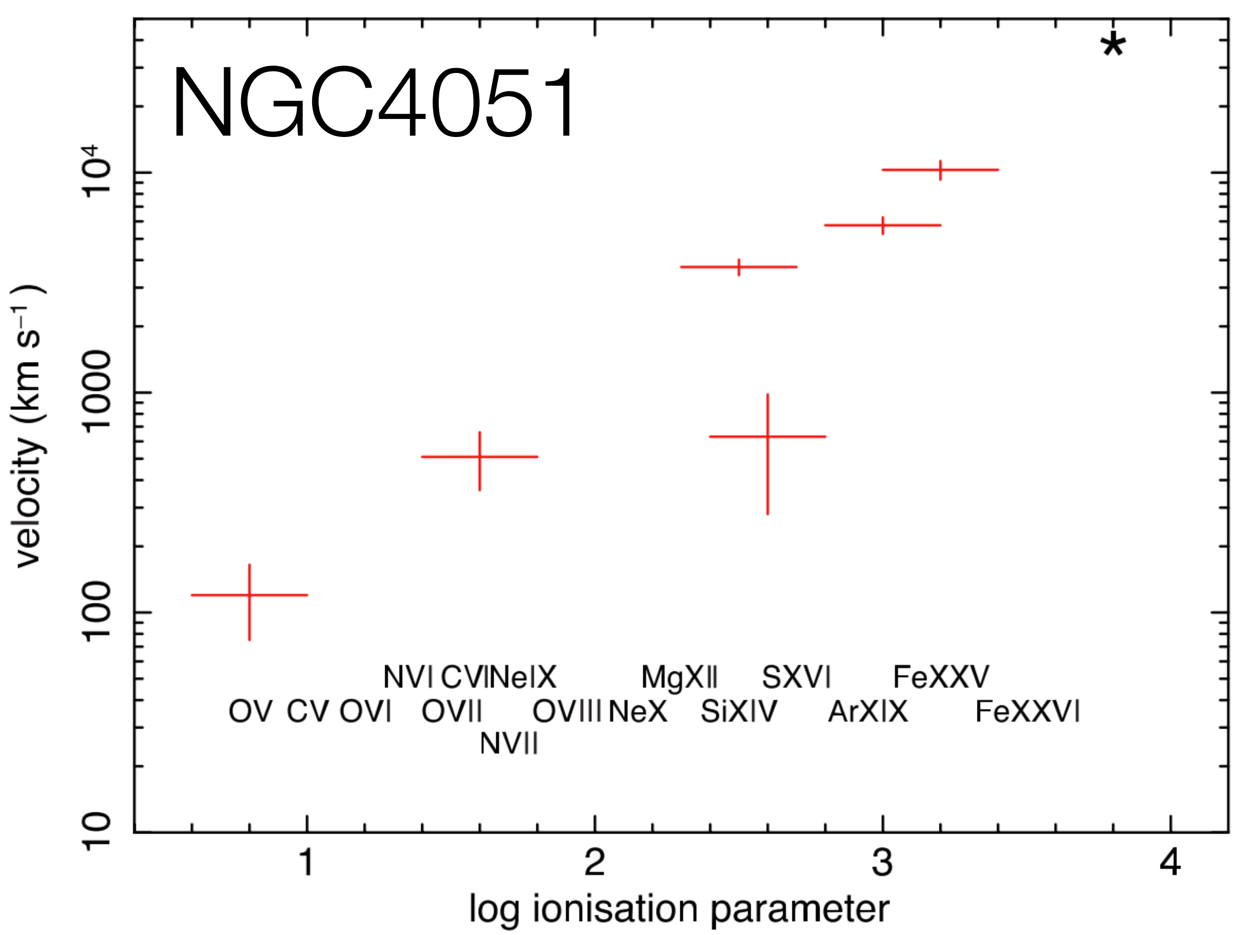
$$v_{\mathrm{out,MHD}} \simeq \frac{1}{4\pi m_{\mathrm{p}} c^2} \left(\frac{k_{\mathrm{bol}}}{\eta \omega^2 C_{\mathrm{f}}} \right) \xi$$

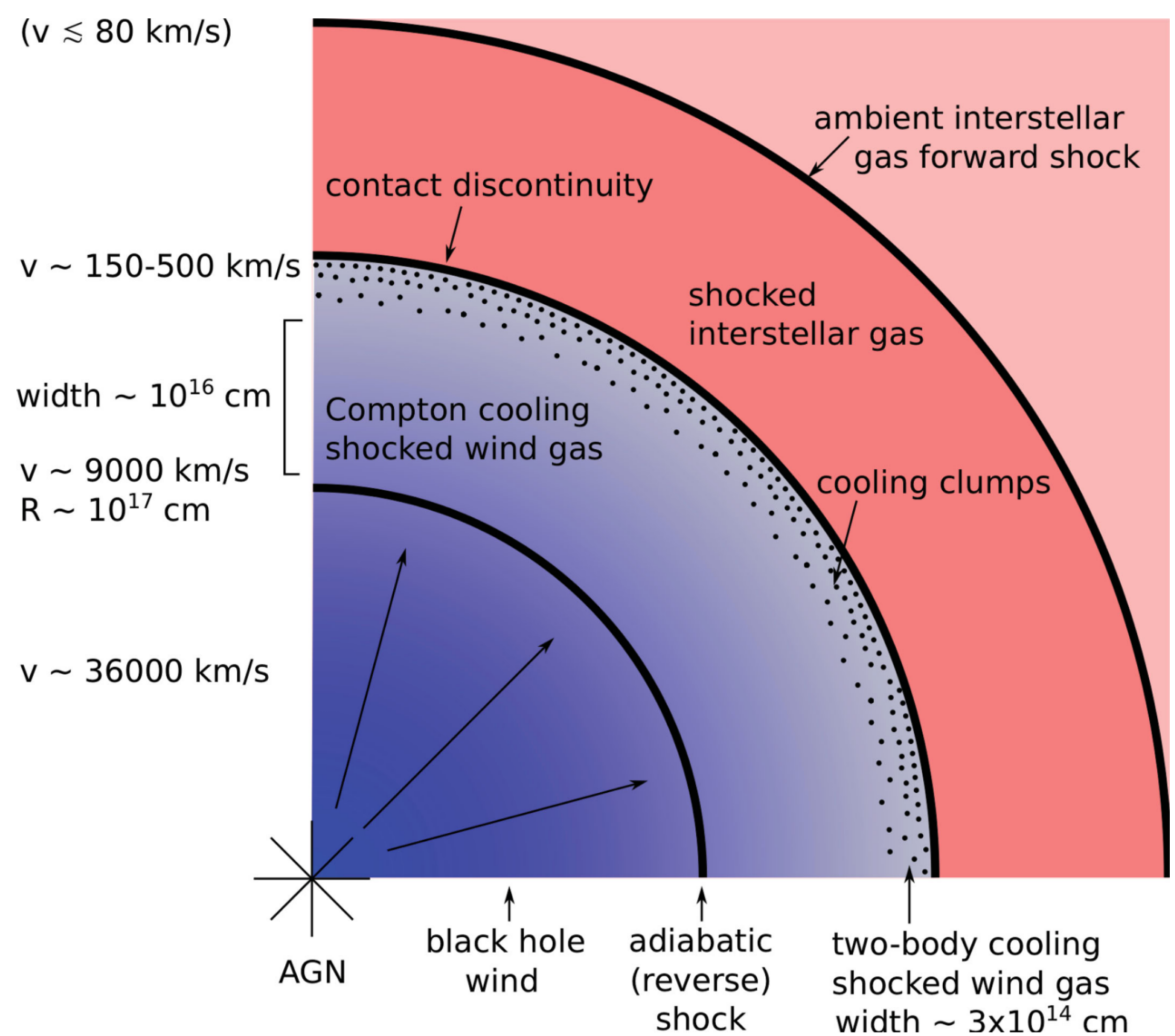
Warm absorbers as shock cooling front

Pounds & King, 2013, MNRAS, 433, 1369

$d(M_{out})/dt = 4\pi b m_p n r^2 v$ mass conservation $\Rightarrow$ nr^2v constant

$nr^2 = L/\xi \Rightarrow \xi \propto v$ (if L does not vary too much over r)



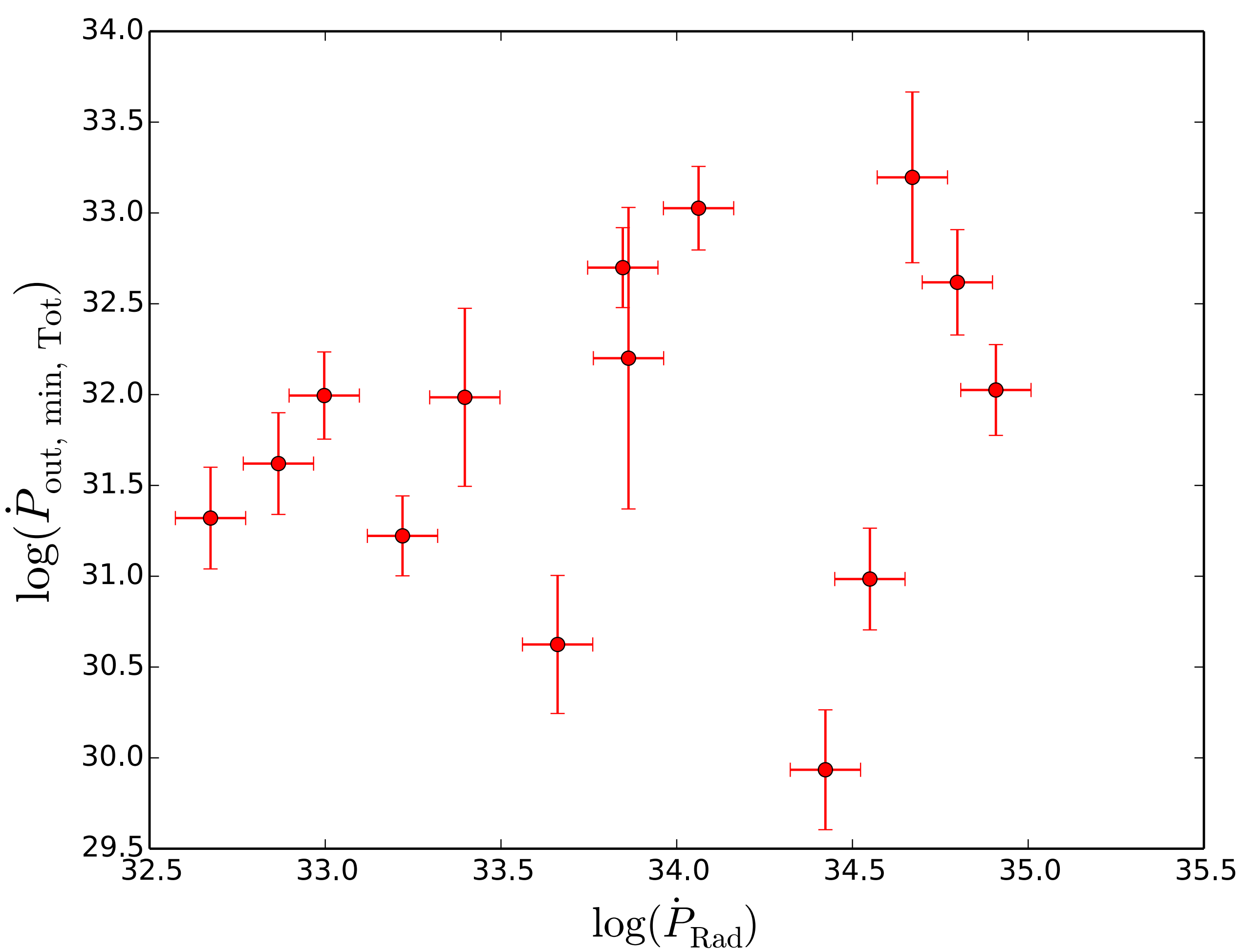


Acceleration in warm absorbers?

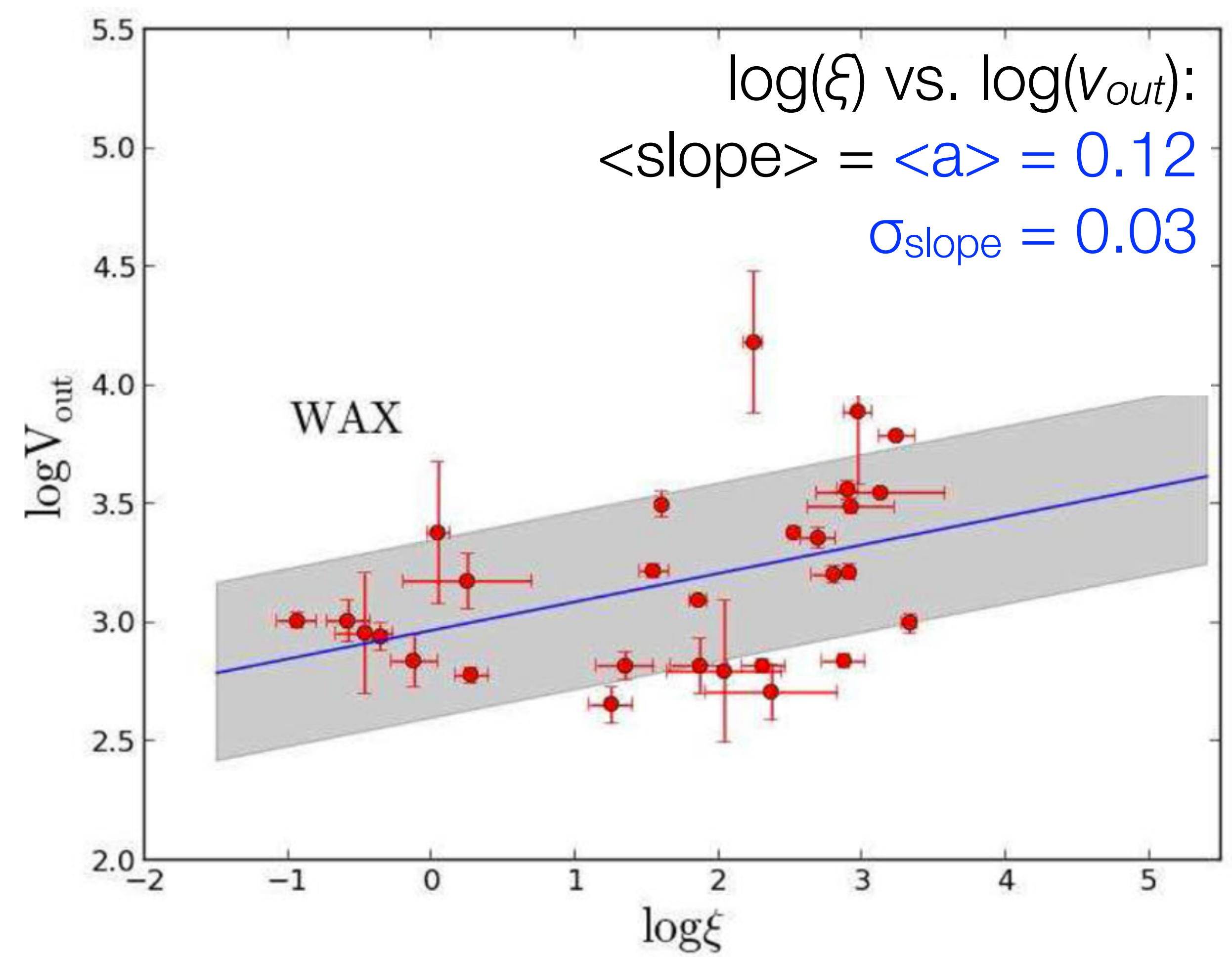
Laha et al., 2016, MNRAS, 457, 3896

Laha et al., 2014, MNRAS, 441, 2613

Weak correlation $\dot{P}_{out}$ vs. $\dot{P}_{rad}$



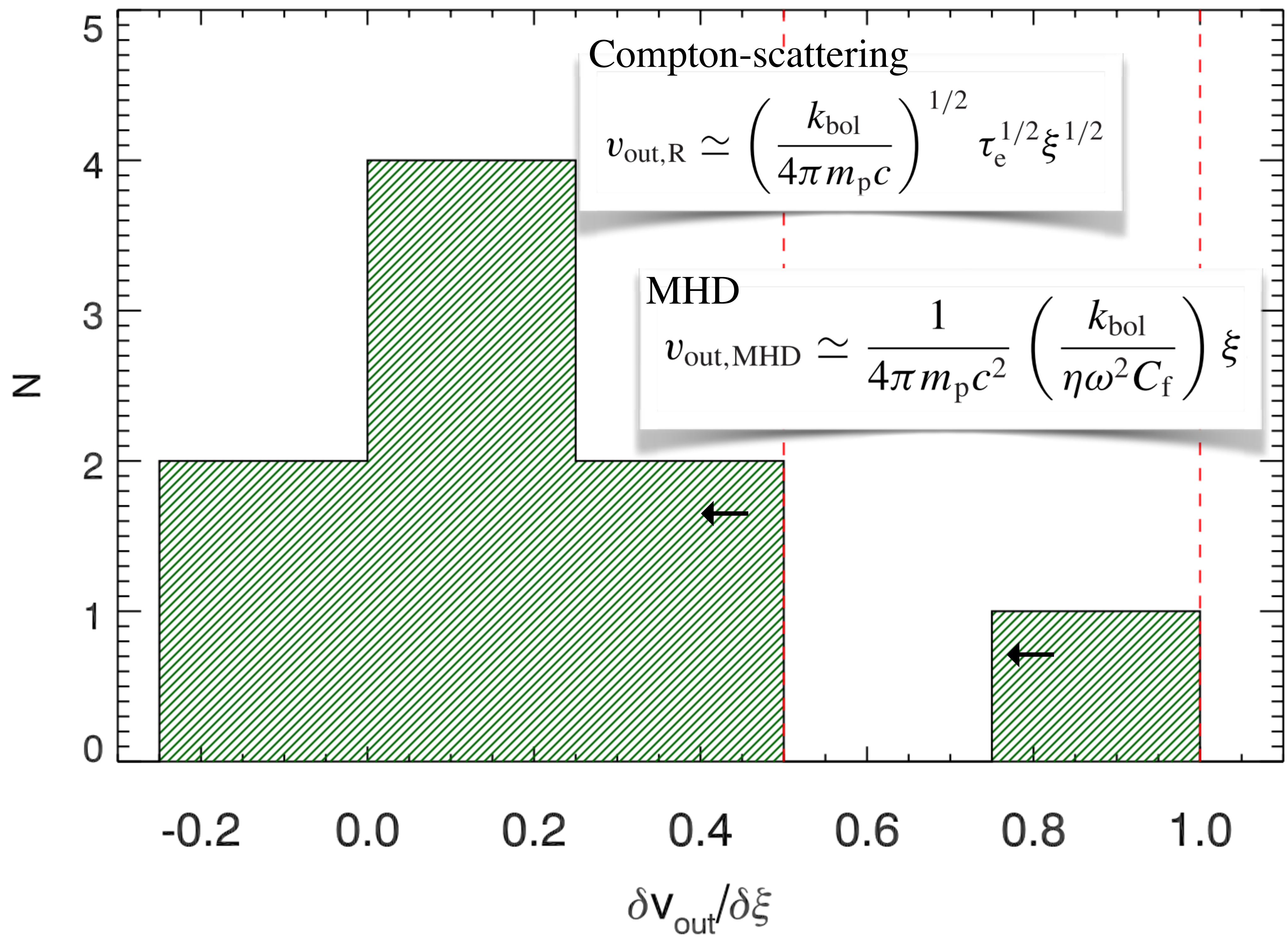
Flat relation $\log(v_{out})$ vs. $\log(\xi)$



[similar results in Crenshaw & Kraemer, 2012]

$\partial\xi/\partial v_{out}$ in WAX (source-by-source)

Laha et al., 2016, MNRAS, 457, 3896



Compton-scattering

$$v_{\rm out,R} \simeq \left(\frac{k_{\rm bol}}{4\pi m_{\rm p} c}\right)^{1/2} \tau_{\rm e}^{1/2}\xi^{1/2}$$

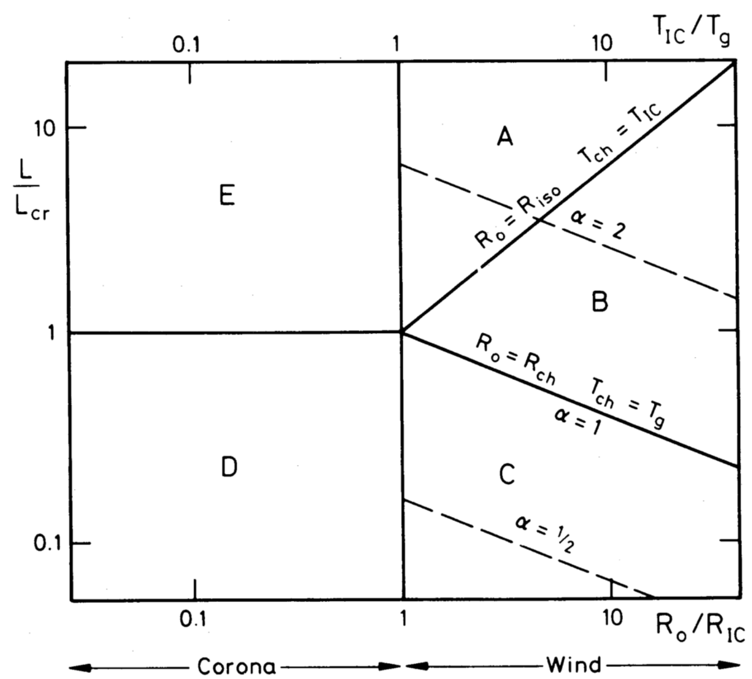
MHD

$$v_{\rm out,MHD} \simeq \frac{1}{4\pi m_{\rm p} c^2}\left(\frac{k_{\rm bol}}{\eta\omega^2 C_{\rm f}}\right)\xi$$

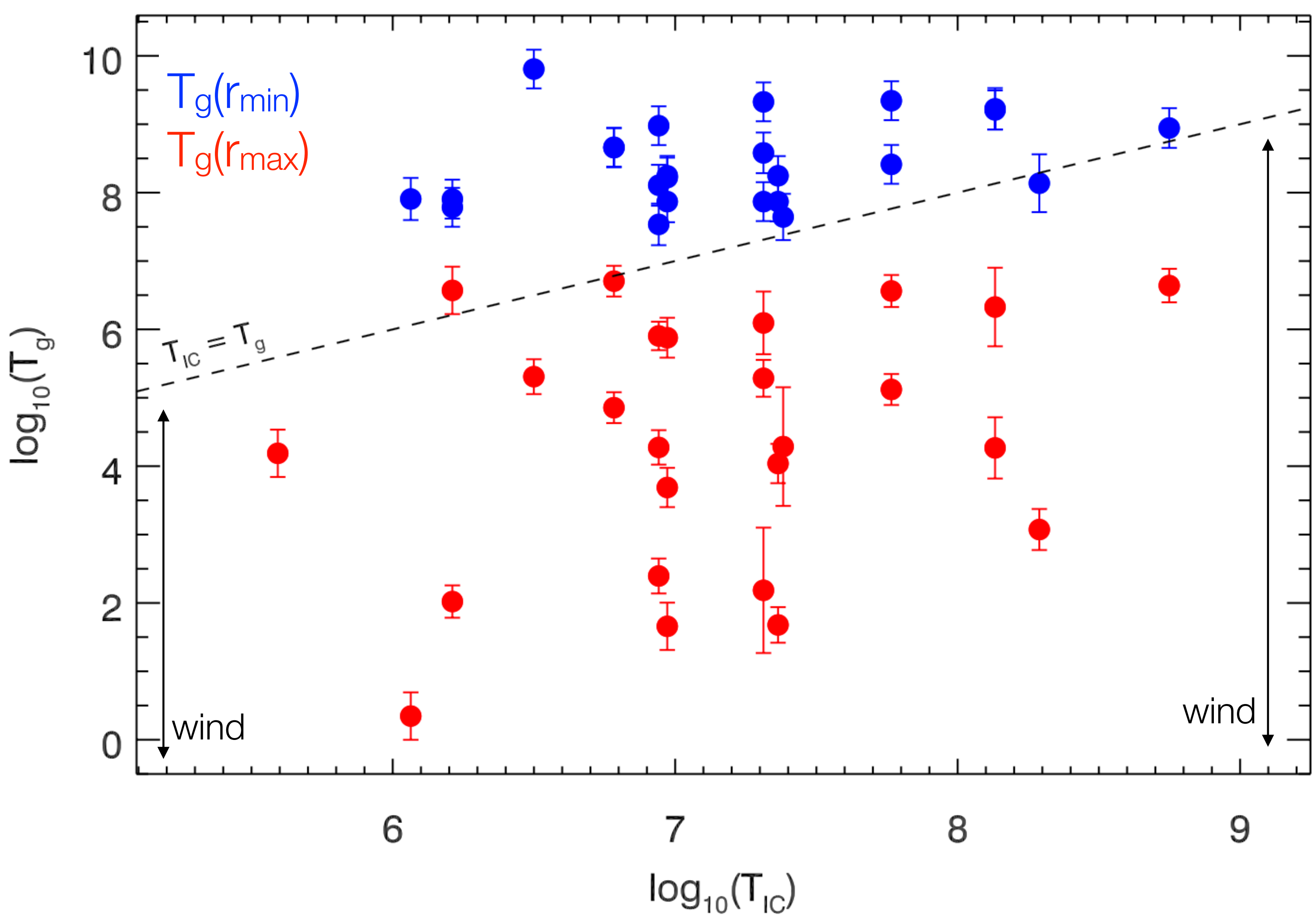
WA as thermal winds: supersonic condition

Begelman et al., 1983, ApJ, 271, 70

Guainazzi & Laha, in prep.

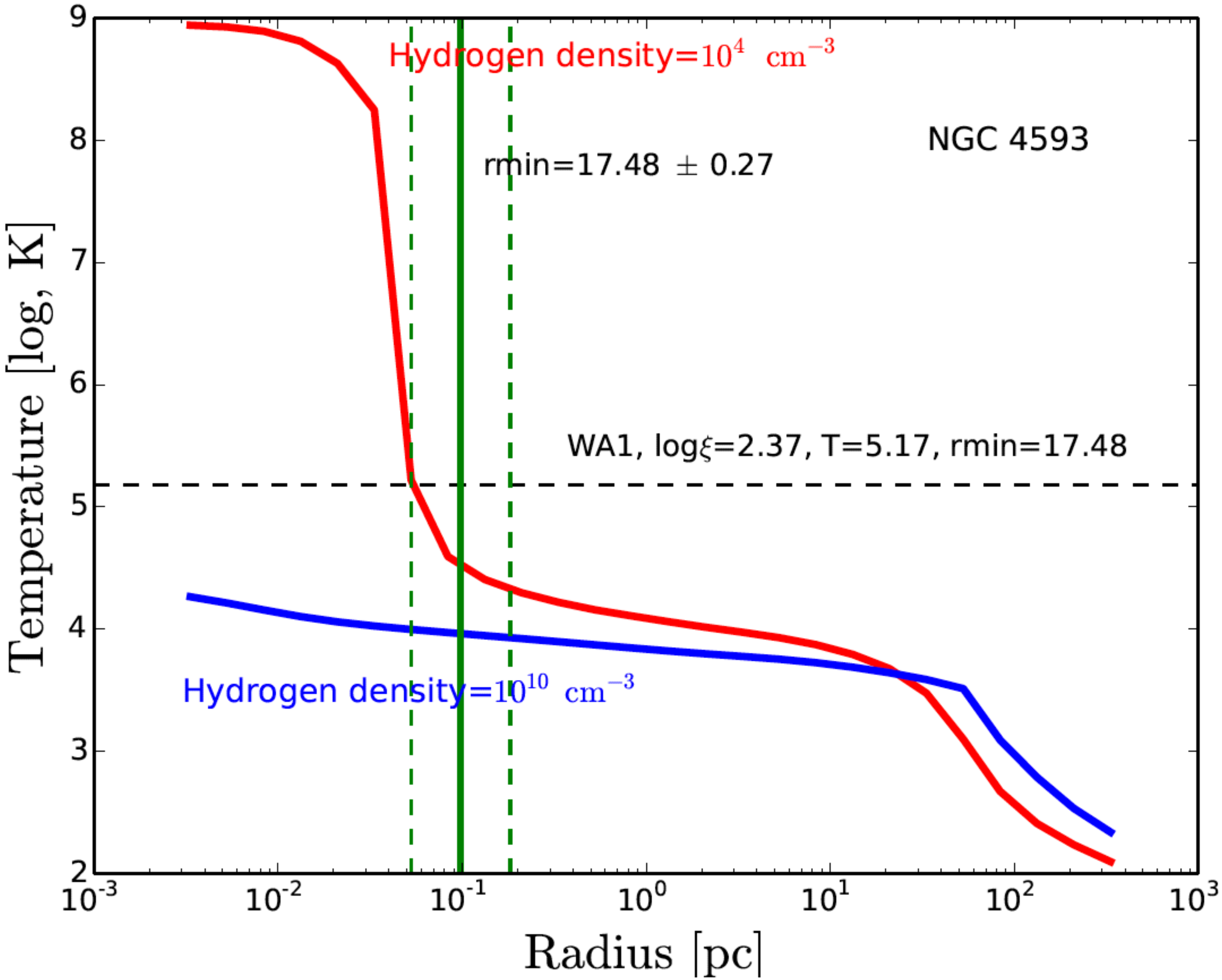


"Escape Temperature" $T_g = GM\mu/rk$
vs. Inverse Compton Temperature T_{IC}



Future homework …

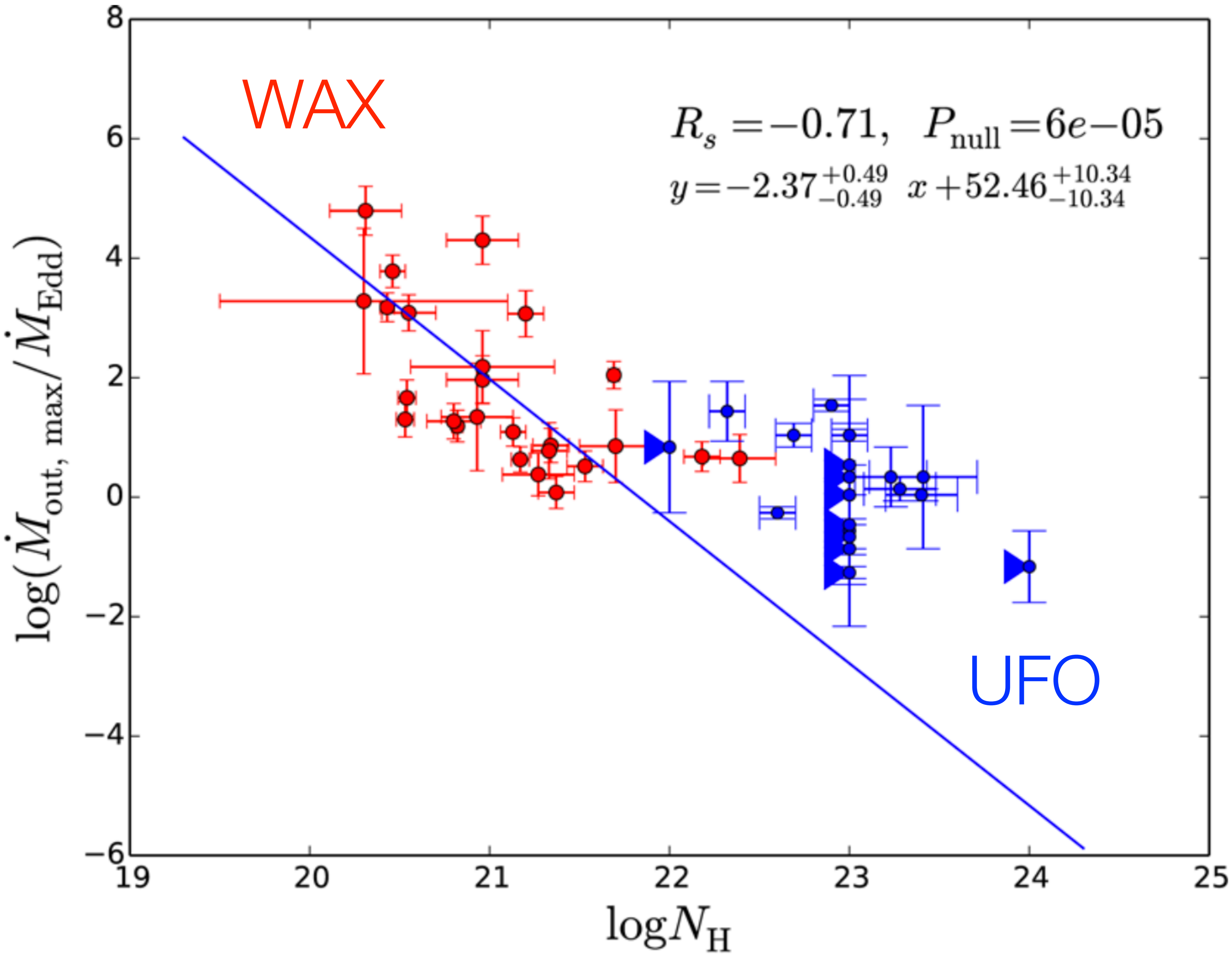
Guainazzi & Laha, in prep.



Mass loading?

Laha et al., 2016, MNRAS, 457, 3896

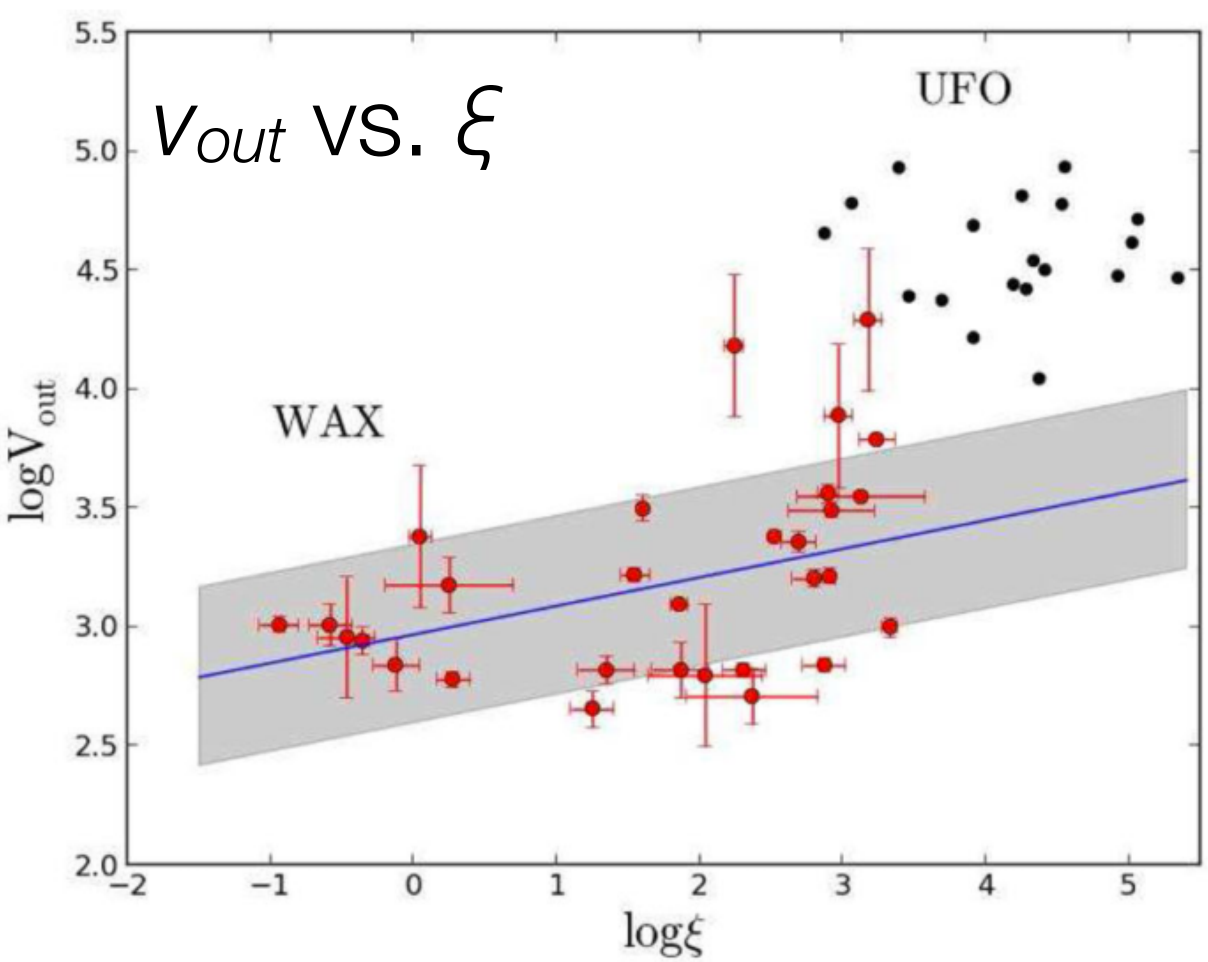
The mass outflow rates are 1-10[4] the accretion rate
Higher for lower column density components

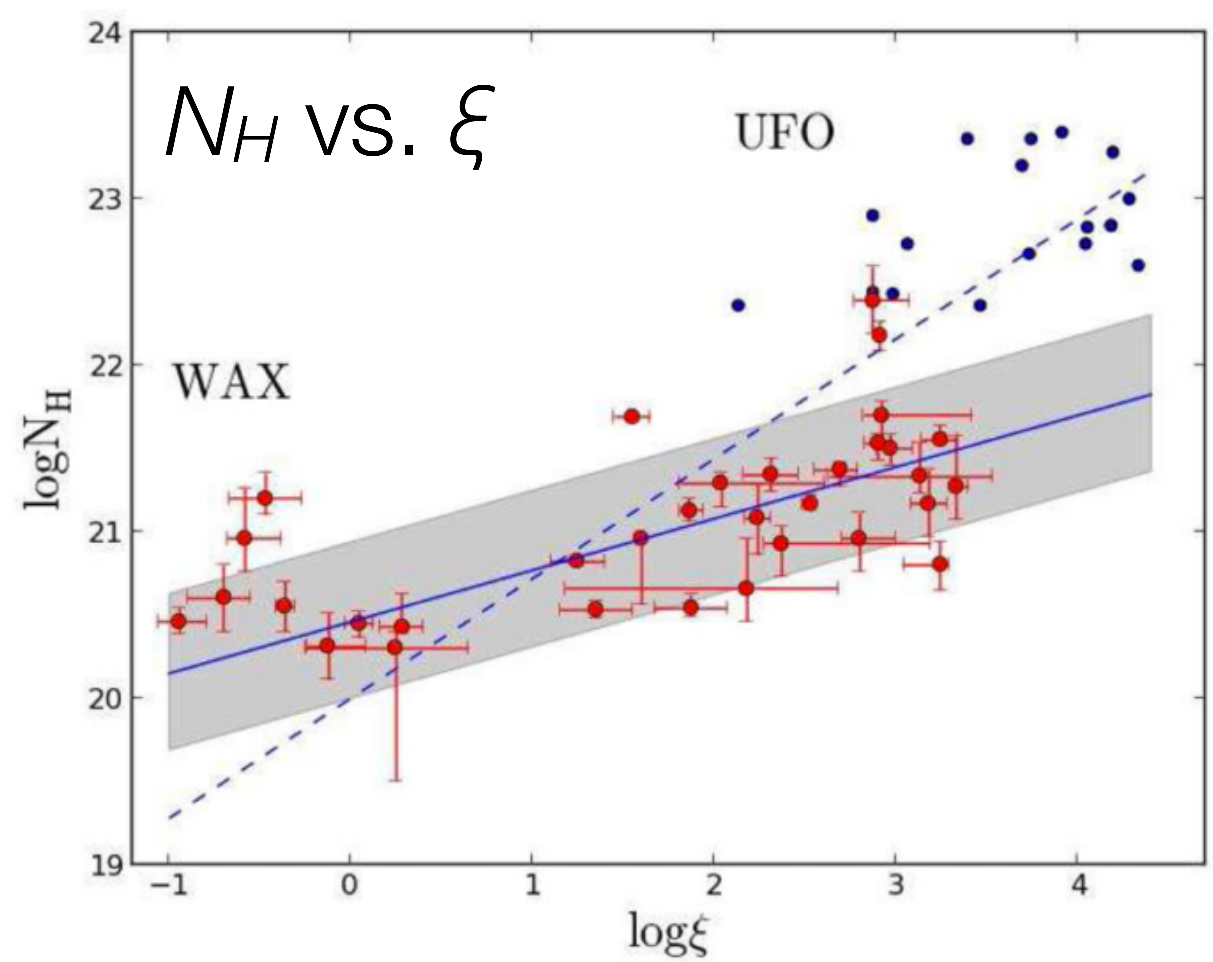


WA vs. UFO.

Laha et al., 2014, MNRAS, 441, 2613

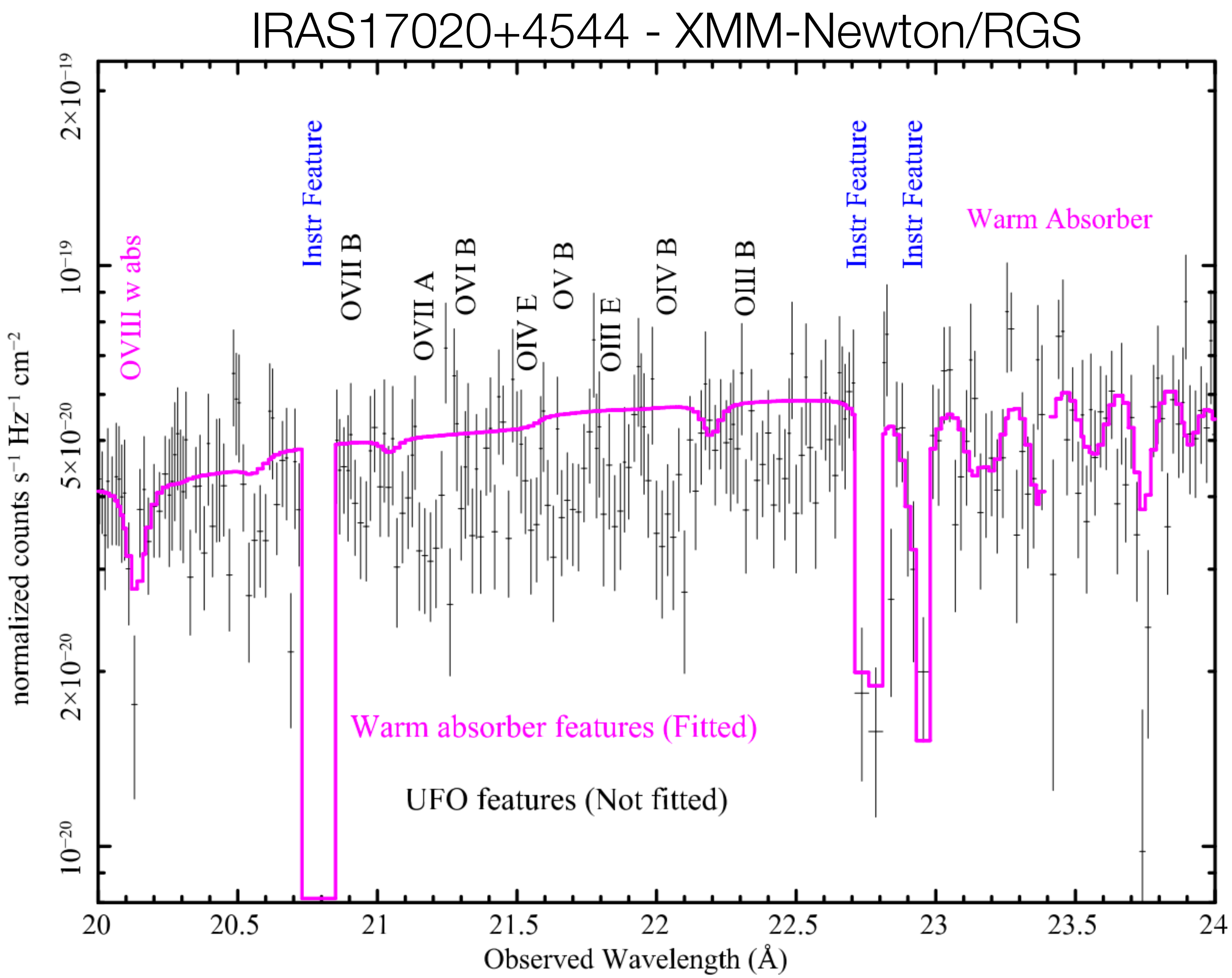
WA and UFO basic observables do not follow the same scaling laws





UFO in IRAS17020+4544: AGN feedback in a normal spiral galaxy

Longinotti et al., 2015, ApJ, 813, L39

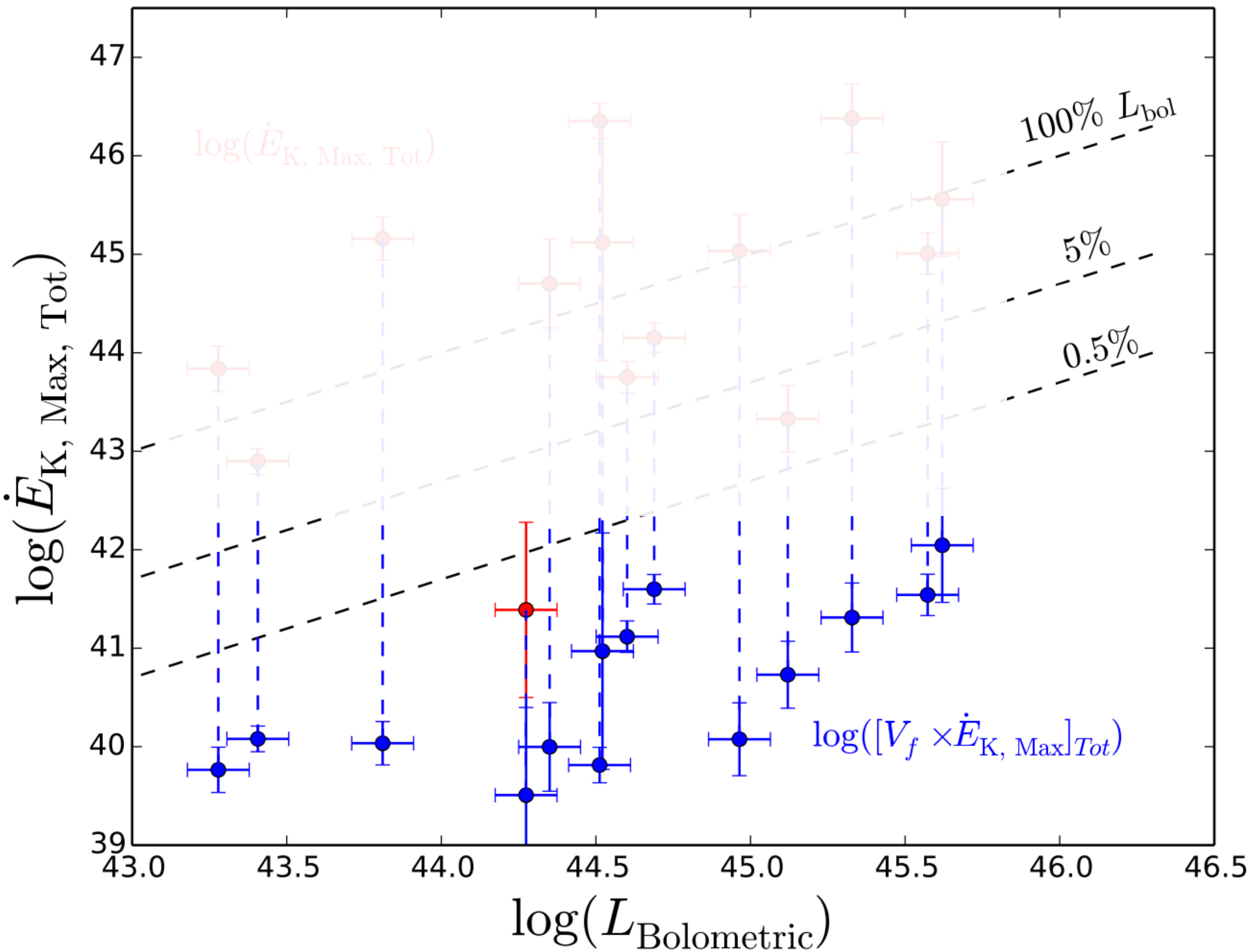


UFO Component Index	log U (erg cm s^{-1})	Log N_H (cm^{-2})	v_{out} (km s^{-1})
Comp (A)	$-0.39^{+0.30}_{-0.15}$	$21.47^{+0.18}_{-0.21}$	23640^{+150}_{-60}
Comp (B)	$-1.99^{+0.33}_{-0.26}$	$20.42^{+0.21}_{-0.58}$	27200^{+240}_{-240}
Comp (C)	$2.58^{+0.17}_{-0.85}$	$23.99^{+0}_{-1.86}$	27200^{+300}_{-270}
Comp (D)	$0.33^{+1.79}_{-0.40}$	$21.42^{+0.84}_{-1.28}$	25300^{+210}_{-180}
Comp (E)	$-2.92^{+0.51}_{-0.14}$	$19.67^{+0.34}_{-0.36}$	33900^{+360}_{-270}

- UFO with a complex velocity and ionisation structure
- v~20-30,000 km s^{-1}
- *L_{KE}~11%L_{bol} x C_f*
- Seyfert AGN: *L_{bol}~5x10^{44} erg/s*
- Host galaxy: spiral
- Surprise: feedback expected to occur in brighter AGN, hosted in post-merger spheroidals

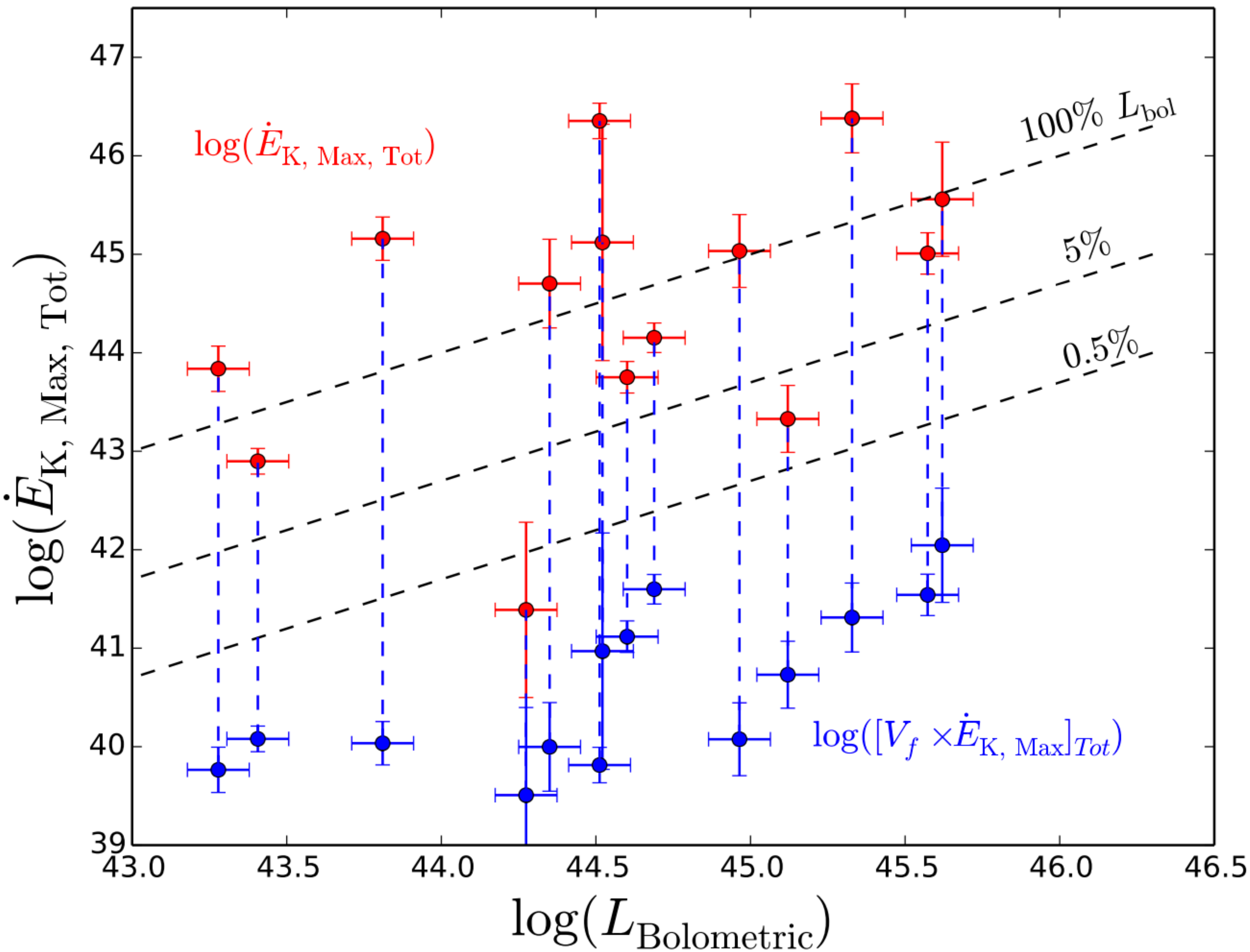
Are WA truly irrelevant for feedback? - I.

Laha et al., 2016, MNRAS, 457, 3896



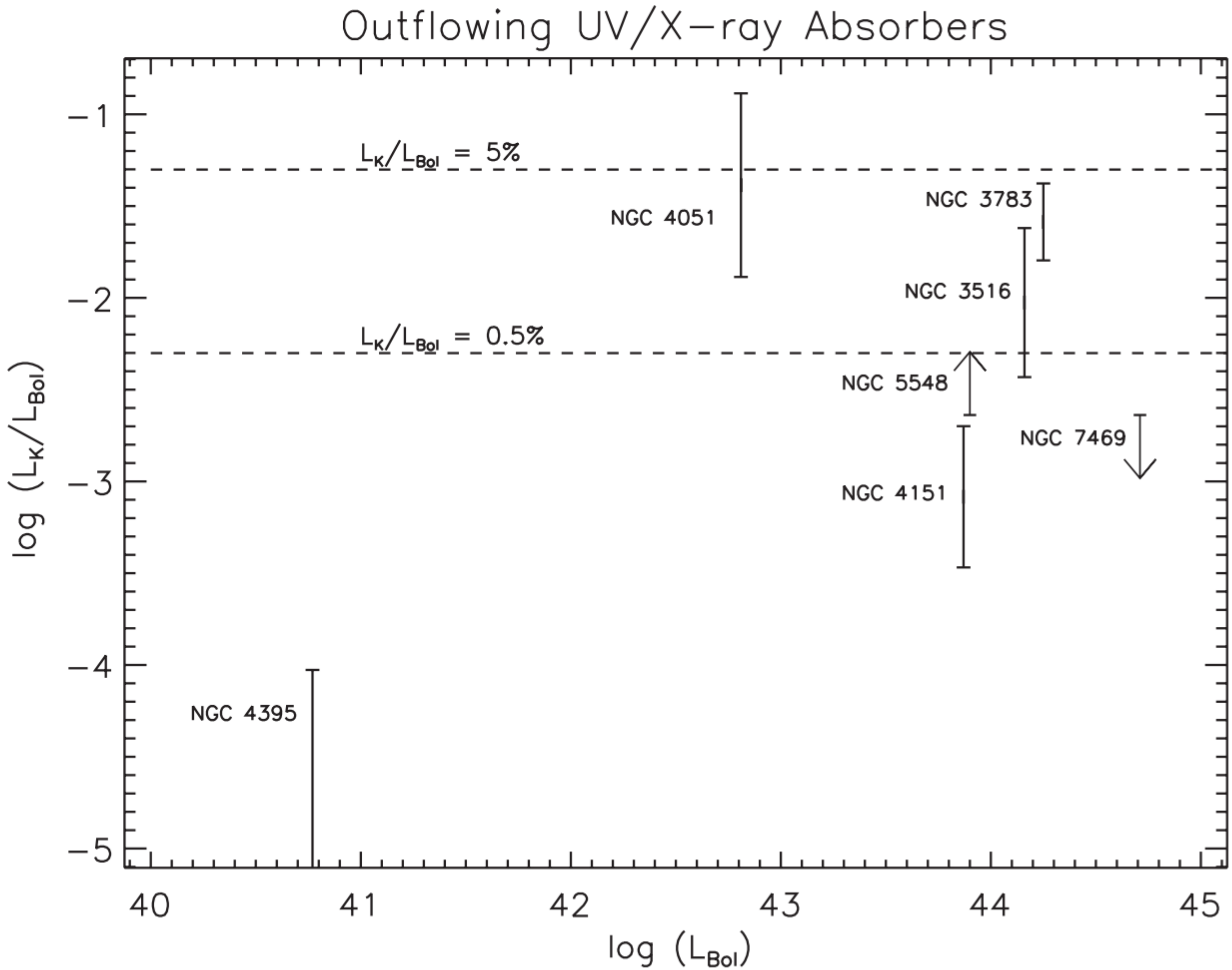
Are WA truly irrelevant for feedback? - I.

Laha et al., 2016, MNRAS, 457, 3896



Are WA truly irrelevant for feedback? - II.

Crenshaw & Kraemer, 2012, ApJ, 753, 75



WAX Summary

- WA observational properties:
  - N_H=[10^{20},10^{22} cm^{-2}], v_{out}=[$10^{2.5}$,10^4 km/s], log(ξ_{cgs})≤3
  - "ionisation (parameter) gap"
- incidence of AGN outflows in the local Universe
  - UFO≳40%, WA≳75%
- outflow density profiles
  - $n(r) \propto r^{-1.3-1.4}$
- outflows acceleration mechanism. Most likely hypothesis:
  - WA: thermal/thrust on dust
- outflow structure
  - Arguable that UFO and WA belong to a single stratified flow. So?