A global view of AGN warm absorbers: WAX

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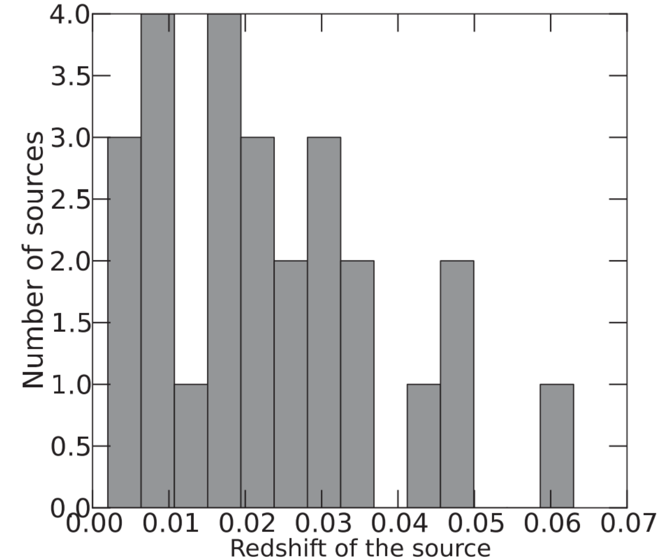
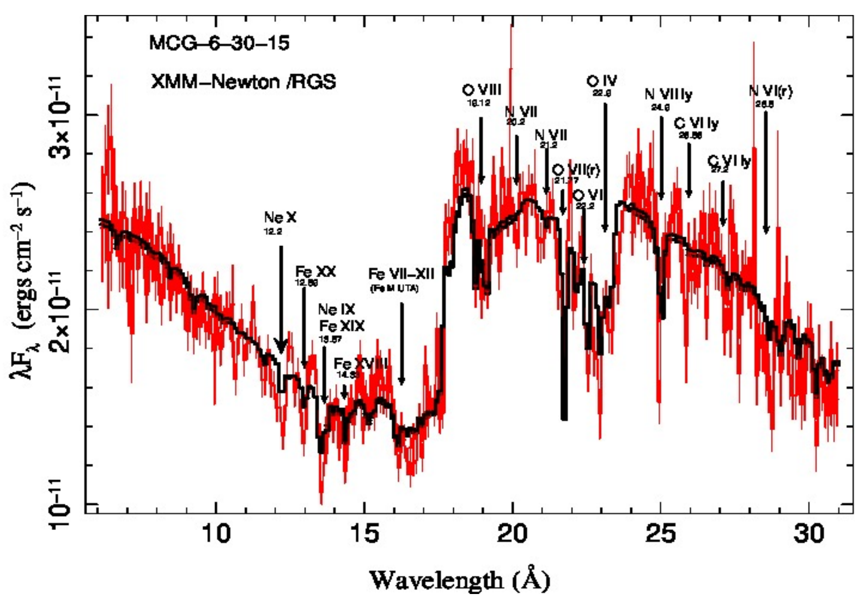
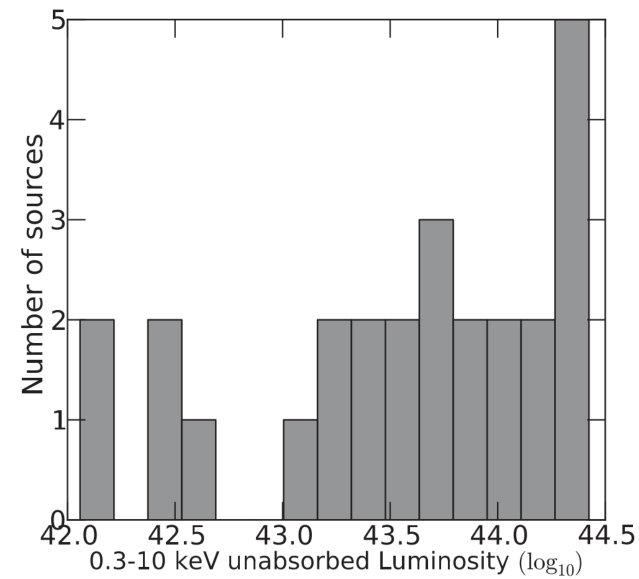
Introduction to WAX

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)



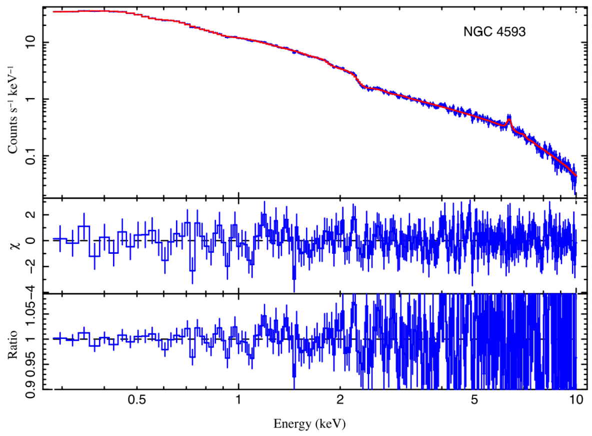


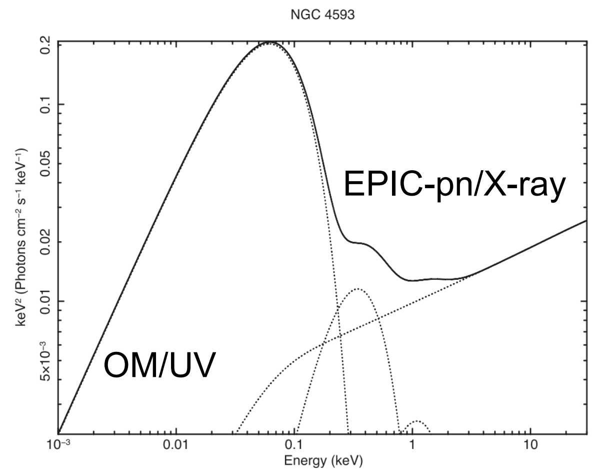


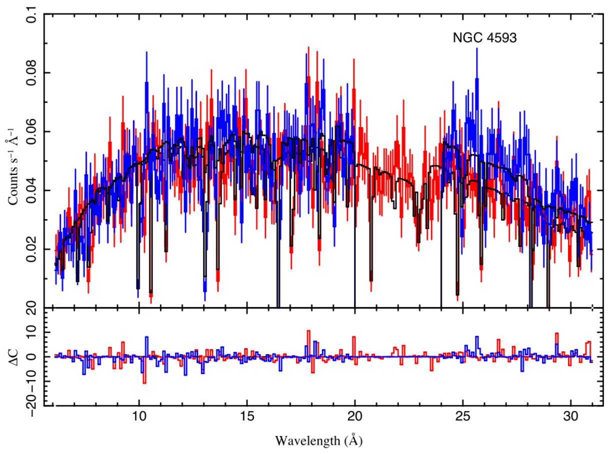
Laha et al. 2014 and 2016

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

We will present the most important results from WAX

Laha et al. 2014 and 2016

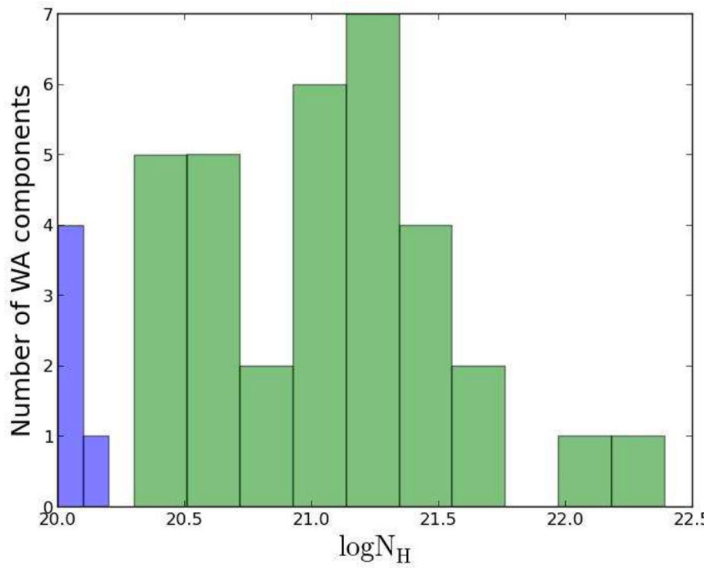
WAX result - I

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%

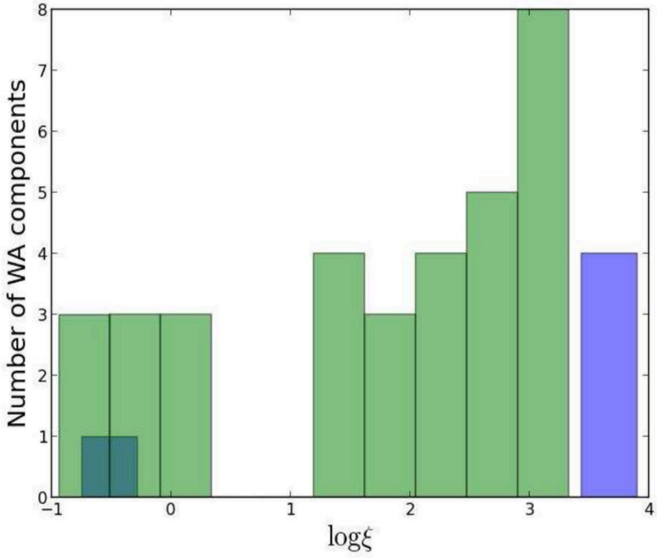
Laha et al. 2014 and 2016

WAX result - II



Column densities

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

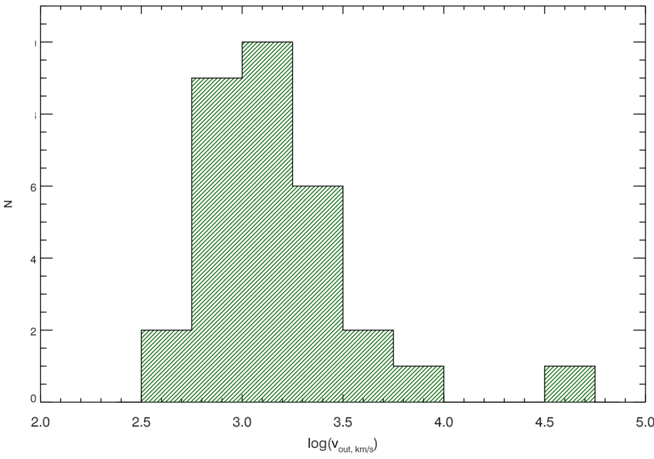


Ionisation parameter

-1< log(xi) <3.2

Outflow velocity

V_{out} ~300-6000 km/s

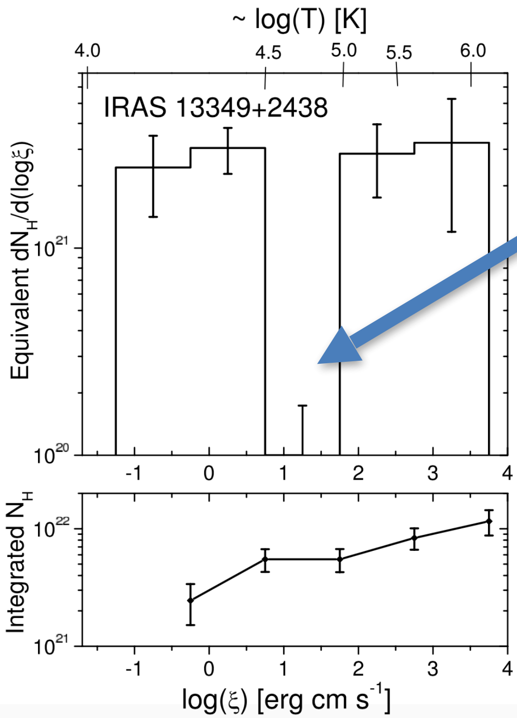


Laha et al. 2014 and 2016

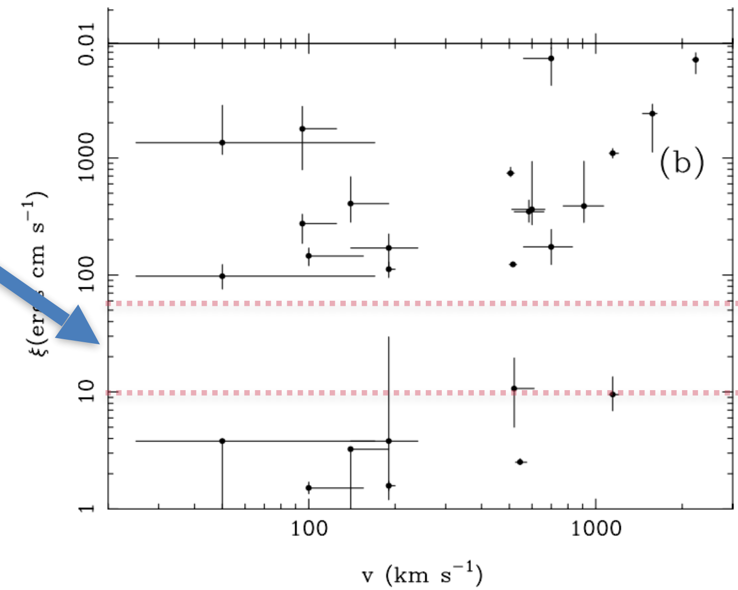
WAX result - II

Ionisation structure: the "ionisation gap"

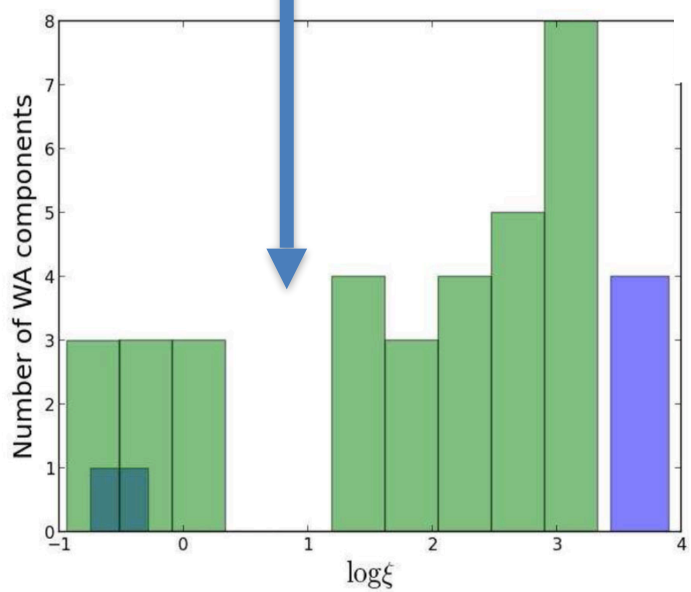
The Gap



Holczer et al. 2007



McKernan et al. 2007

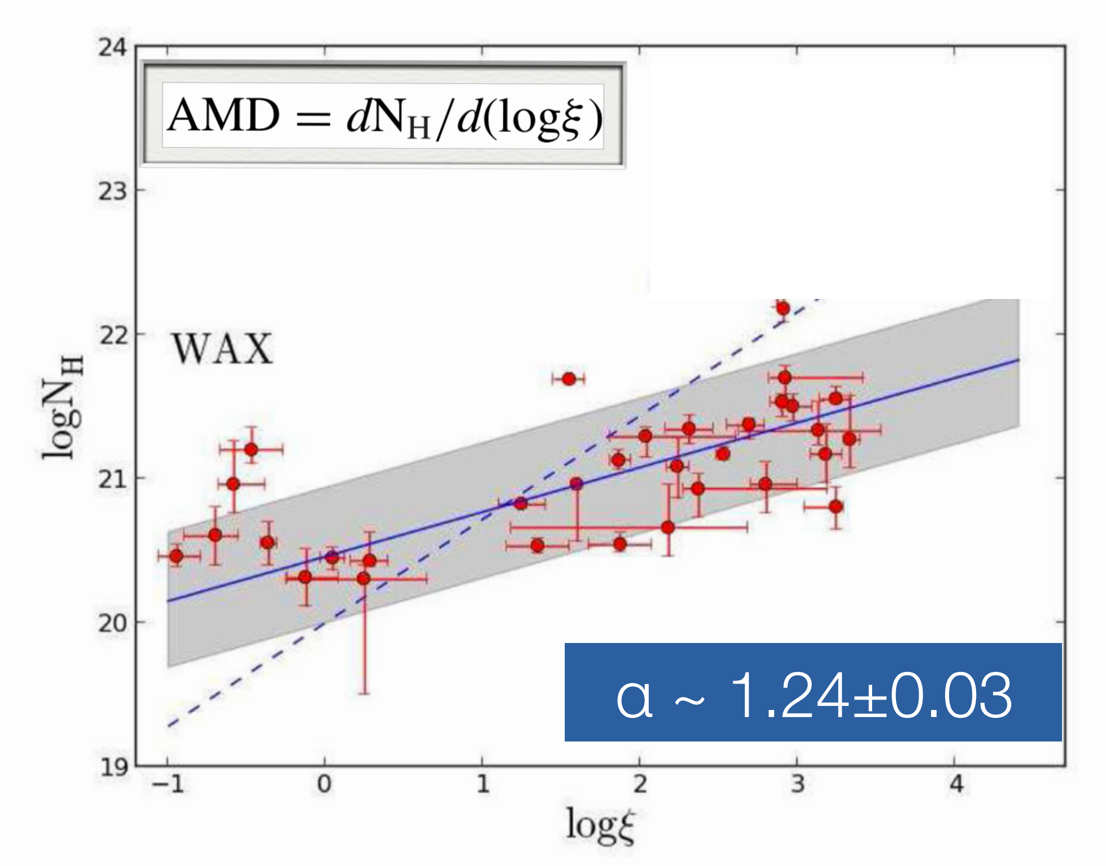


WAX, Laha et al. 2014

Laha et al. 2014 and 2016

WAX result - III

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

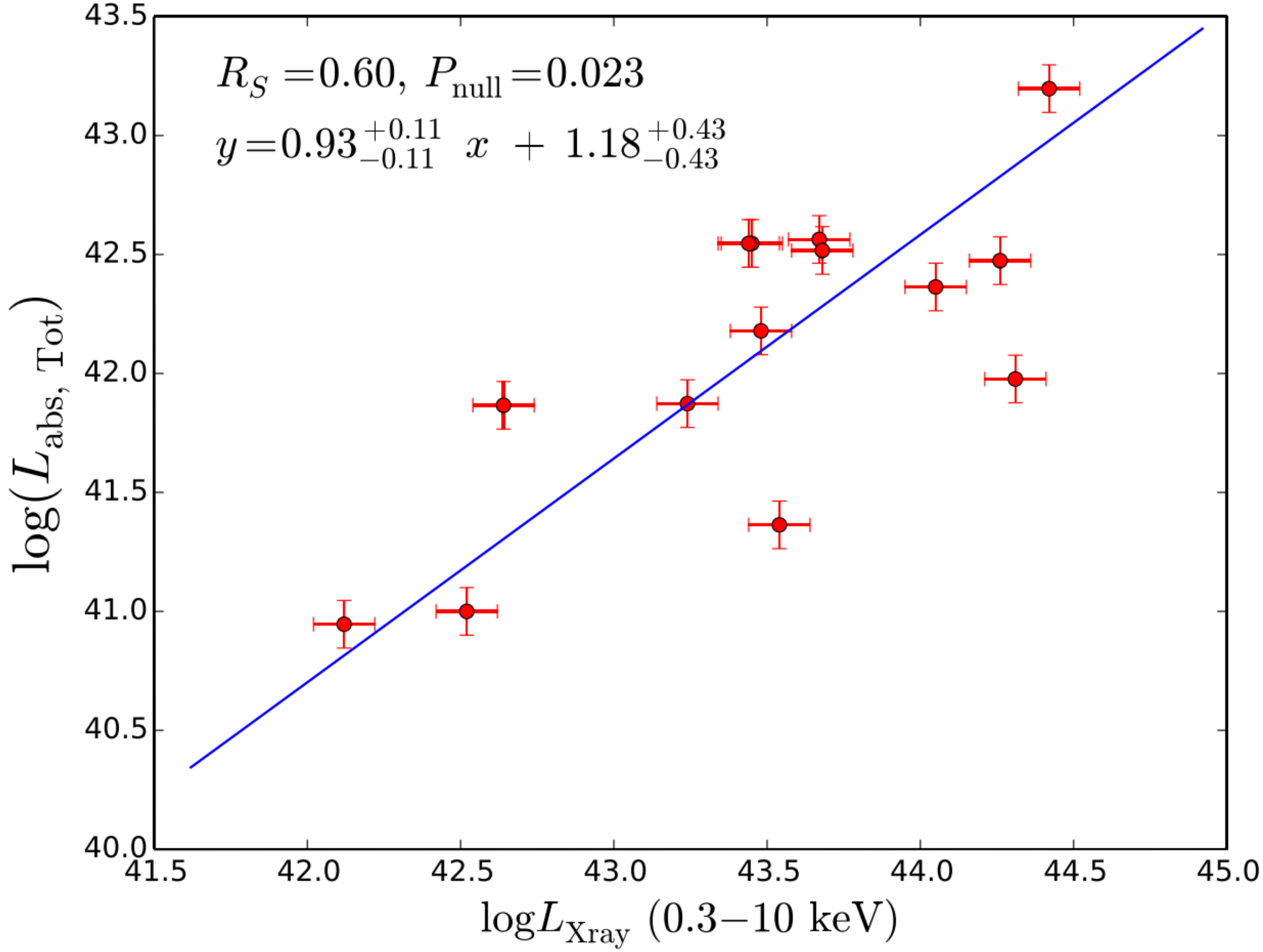


Consistent with the a small but well studied sample of Seyfert galaxies (Behar 2009; 1<α<1.3). And has implications in Mass outflow rate calculations.

Laha et al. 2014 and 2016

WAX result - IV

L_{abs} vs L_X: Slope =1…

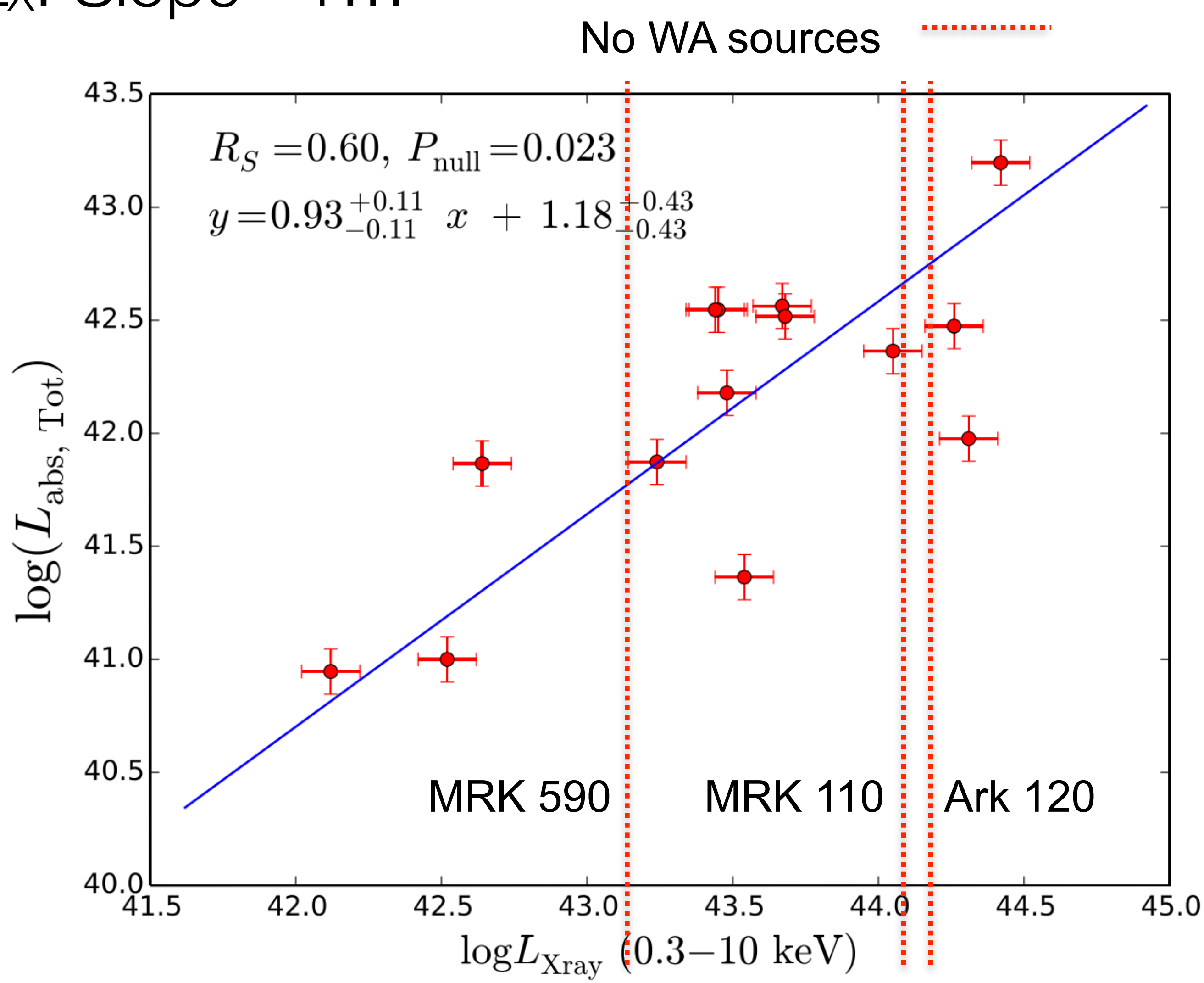


How to interpret this result in terms of brighter sources without WA?

Laha et al. 2014 and 2016

WAX result - IV

L_{abs} vs L_X: Slope =1…



Laha et al. 2014 and 2016

Bonafide NO outflows??

WAX result - V

The most important yet, most uncertain quantity…

…. **the radial distance of WA**

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

⇐ outflow escape velocity

⇓ dust sublimation radius

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

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

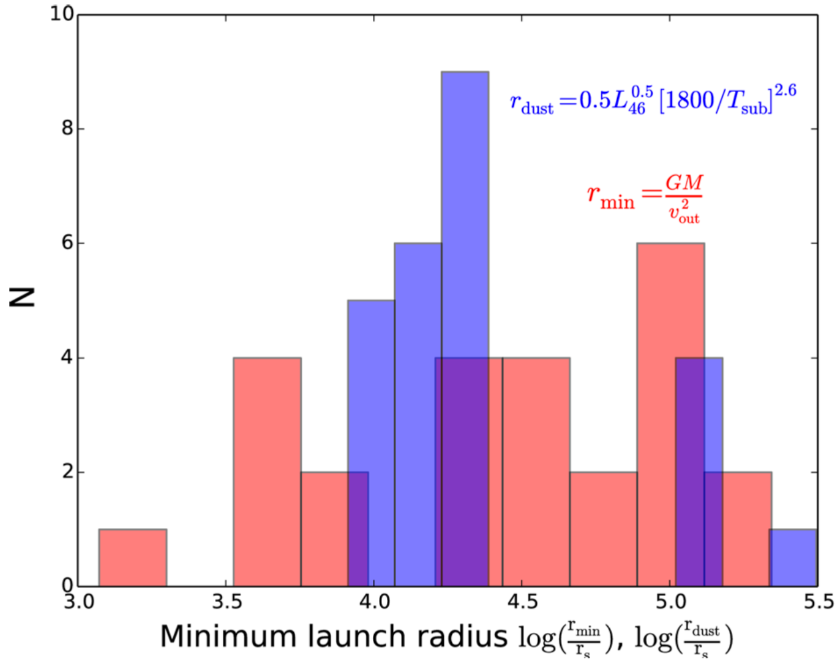
⇐ $\Delta r/r \leq 1$. **??**

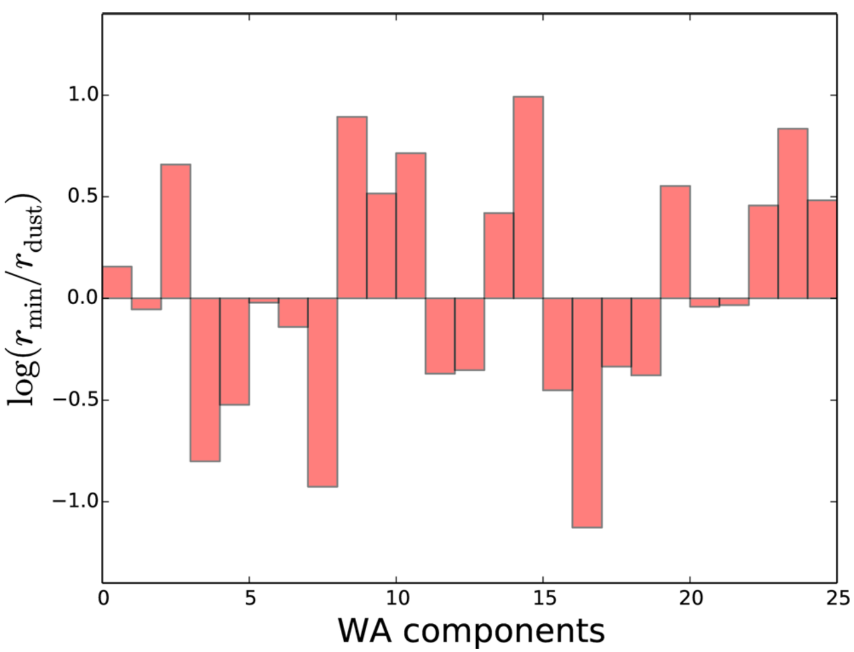
Laha et al. 2014 and 2016

WAX result - V

WA launch radius:

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





Laha et al. 2014 and 2016

WAX result - VI

Diagnostics on acceleration mechanisms

Compton scattering

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

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

MHD

Fukumura et al. 2010, ApJ 715

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

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

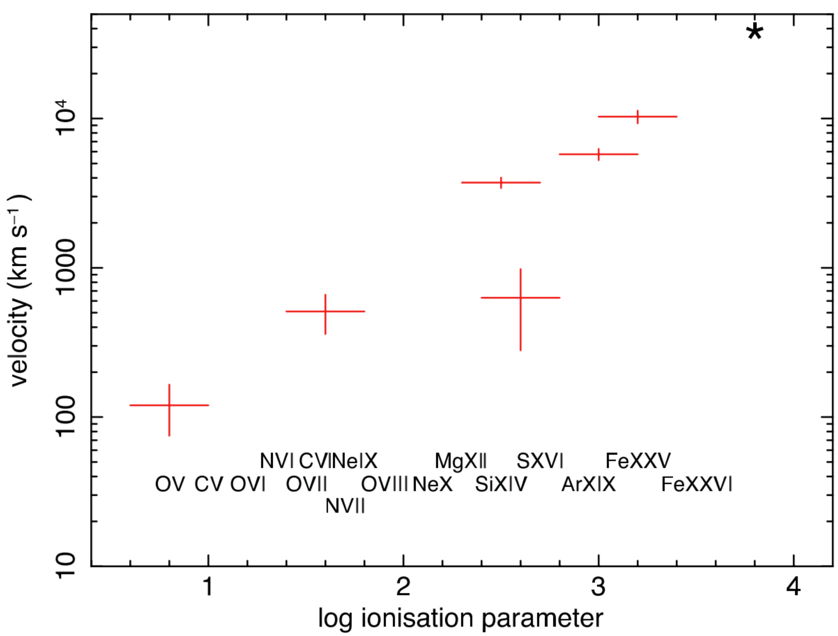
Laha et al. 2014 and 2016

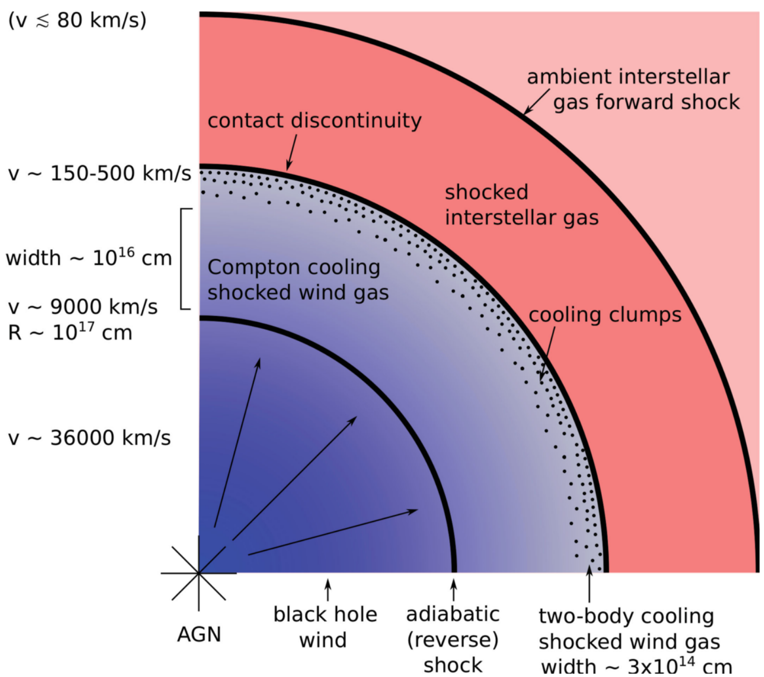
WAX result - VI

Warm absorbers as shock cooling front

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

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





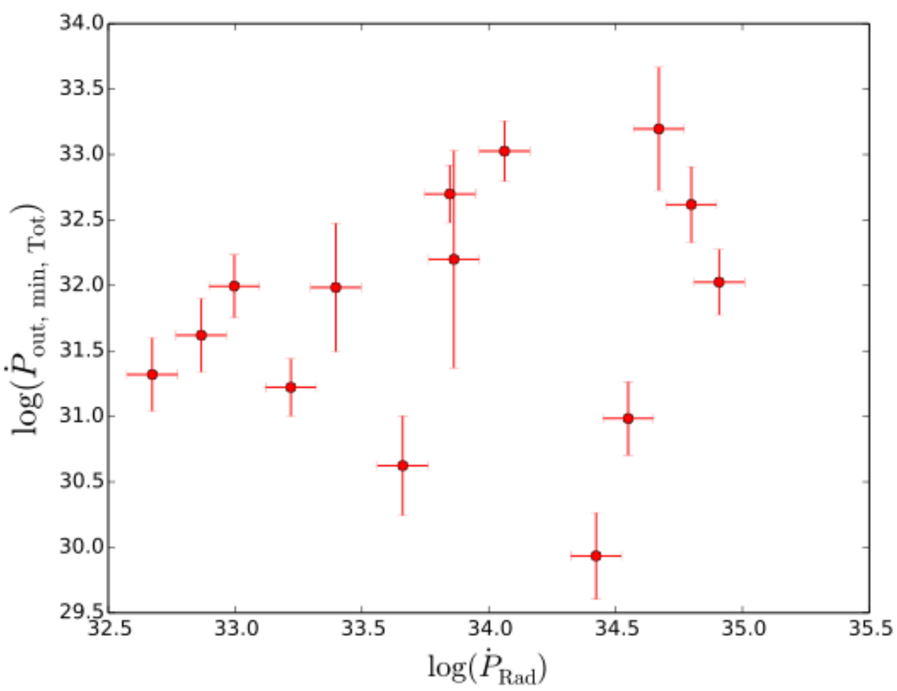
Pounds and king 2013, MNRAS 433

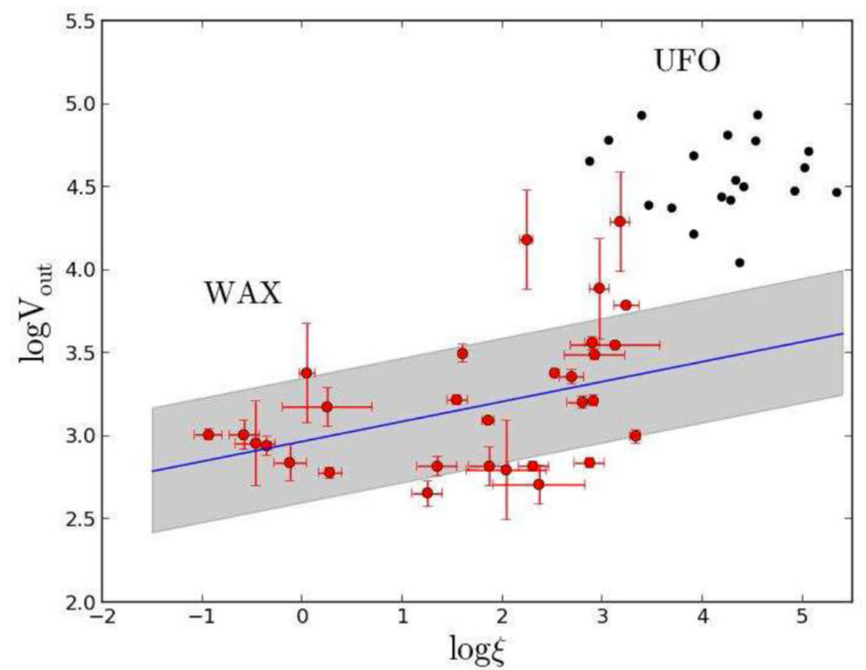
WAX result - VI

Acceleration in warm absorbers?

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

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



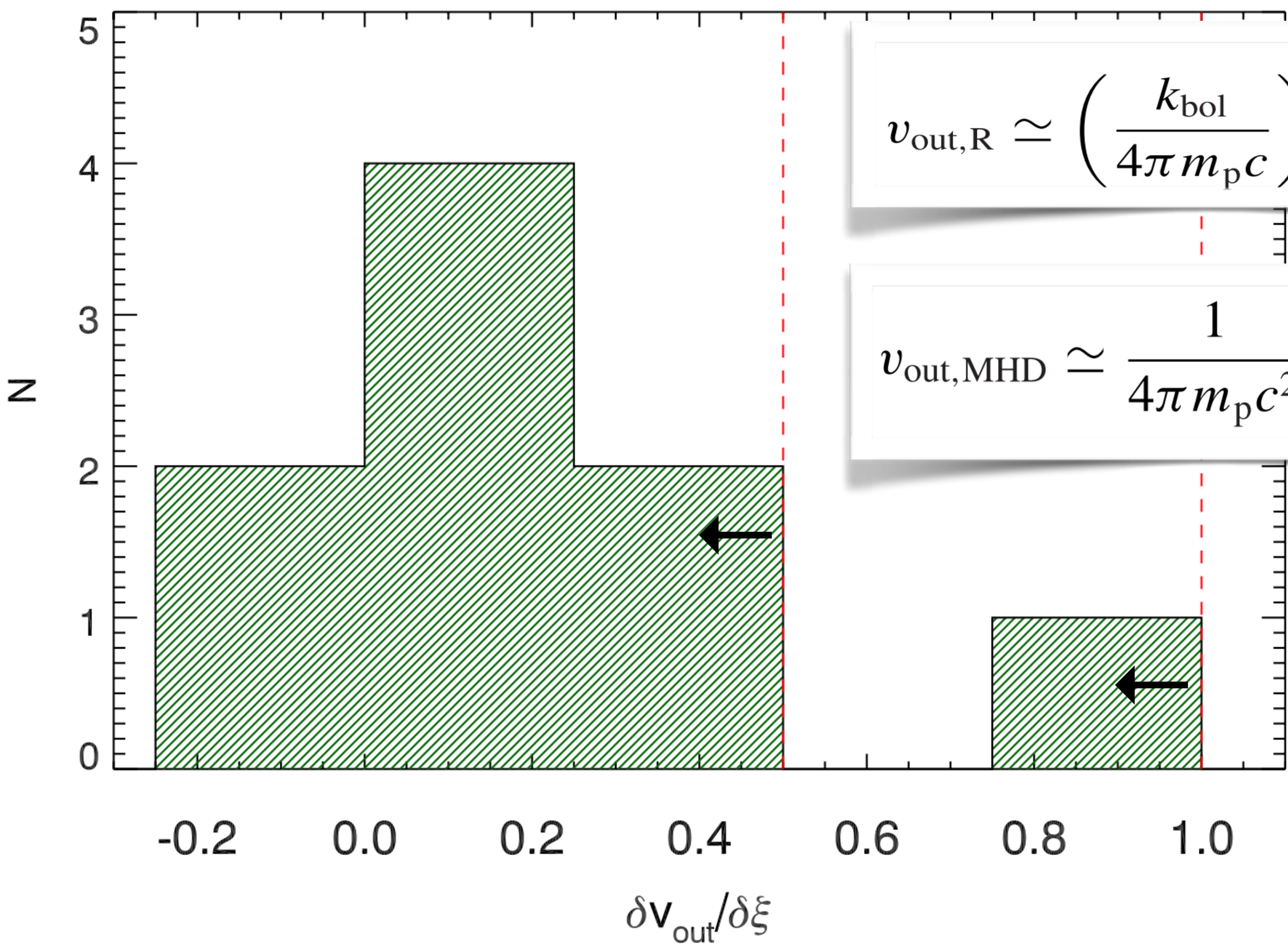


$\log(\xi)$ vs. $\log(v_{out})$:
<slope> = <a> = 0.12
σ_{slope} = 0.03

Laha et al. 2014 and 2016

WAX result - VI

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



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

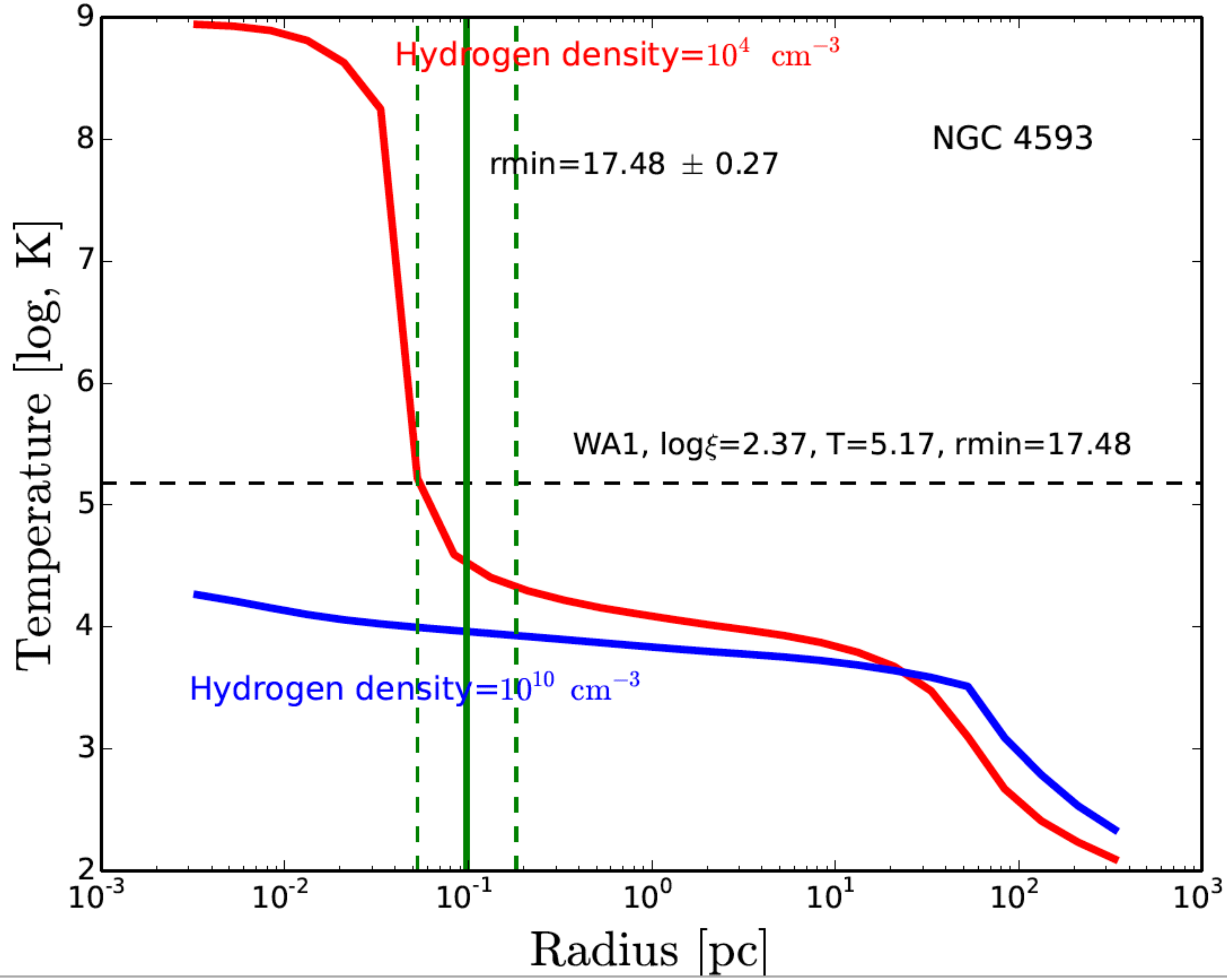
$$v_{\mathrm{out,MHD}} \simeq \frac{1}{4\pi m_{\mathrm{p}} c^2} \left(\frac{k_{\mathrm{bol}}}{\eta \omega^2 C_{\mathrm{f}}}\right) \xi$$

Laha et al. 2014 and 2016

WAX result - VI

Future work ….WA as thermal winds

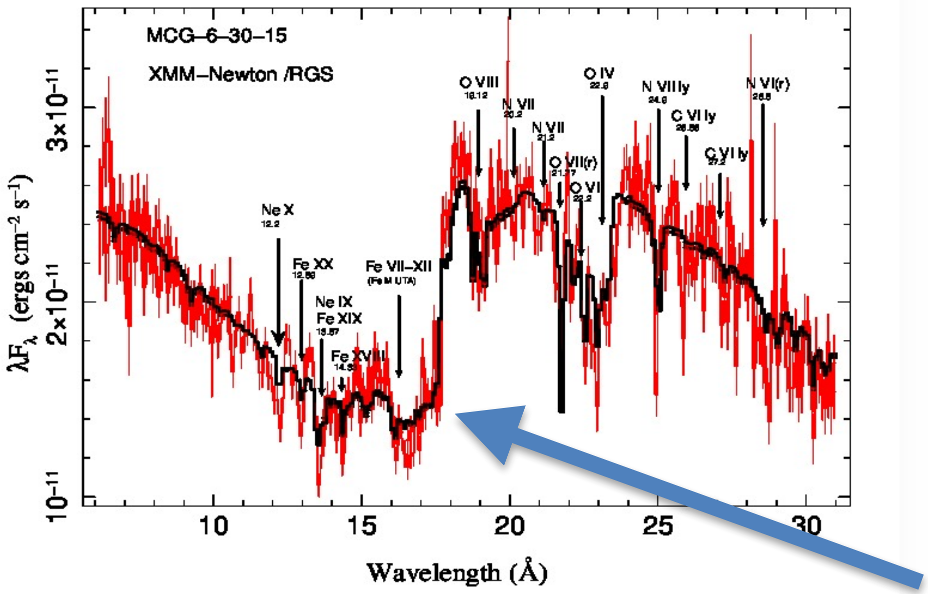
Guainazzi and Laha in preparation…

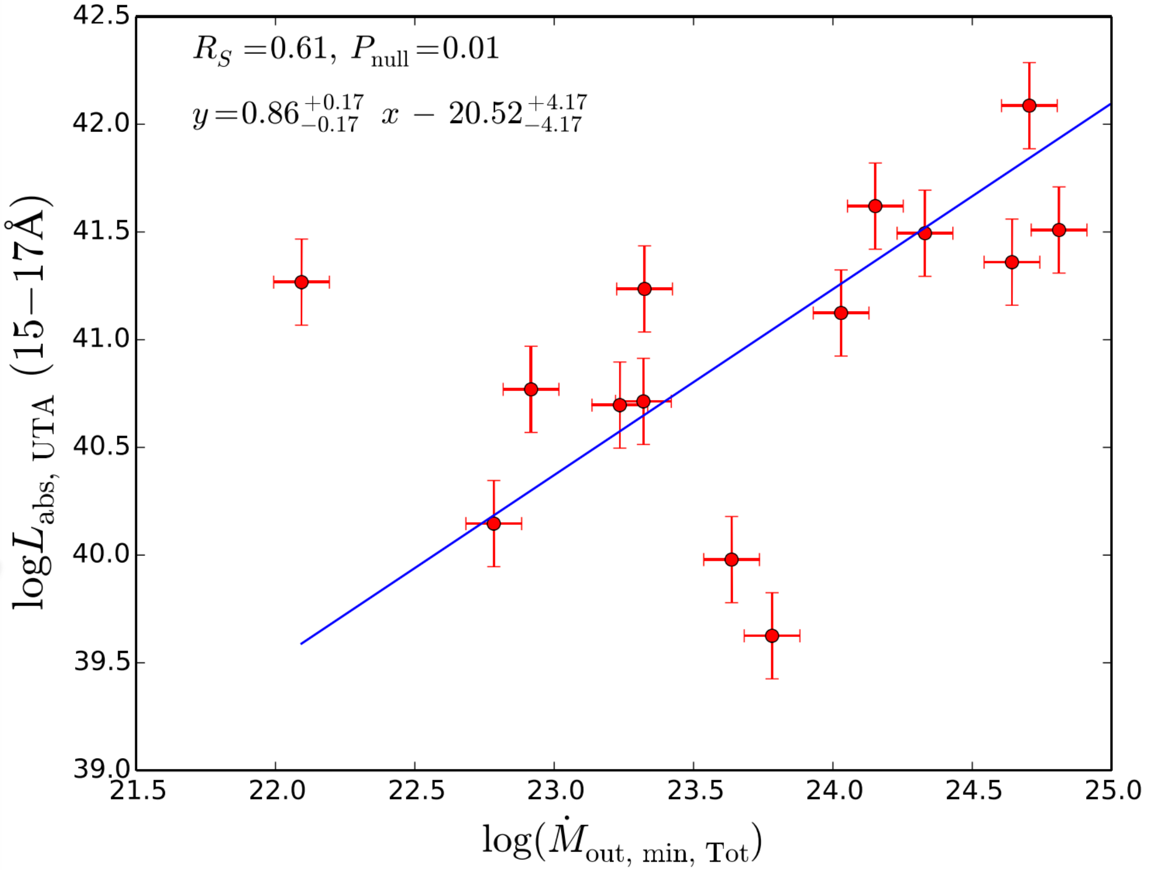


Parker winds: Everett & Murray 2007

WAX result - VII

Mass loading and UTA



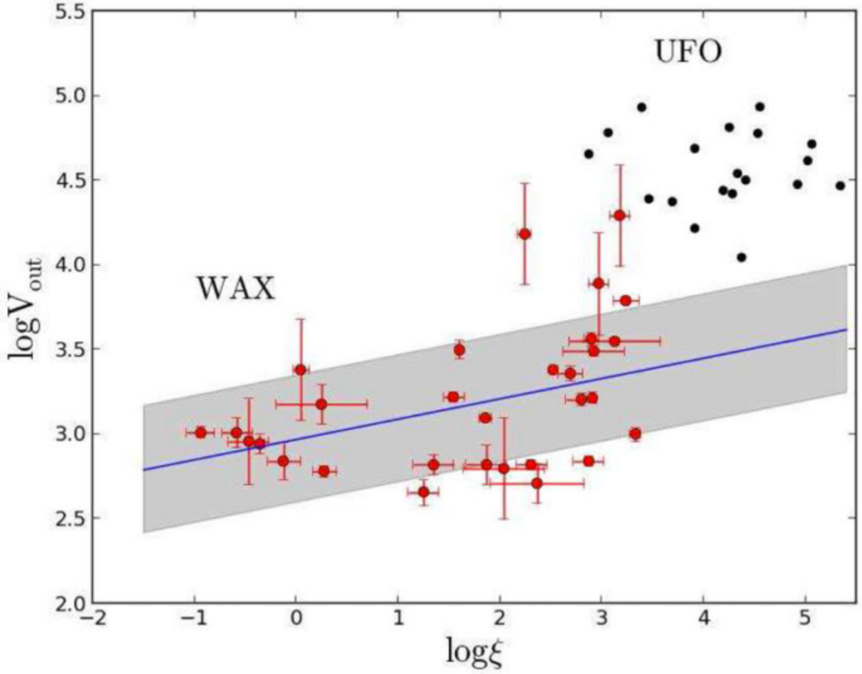


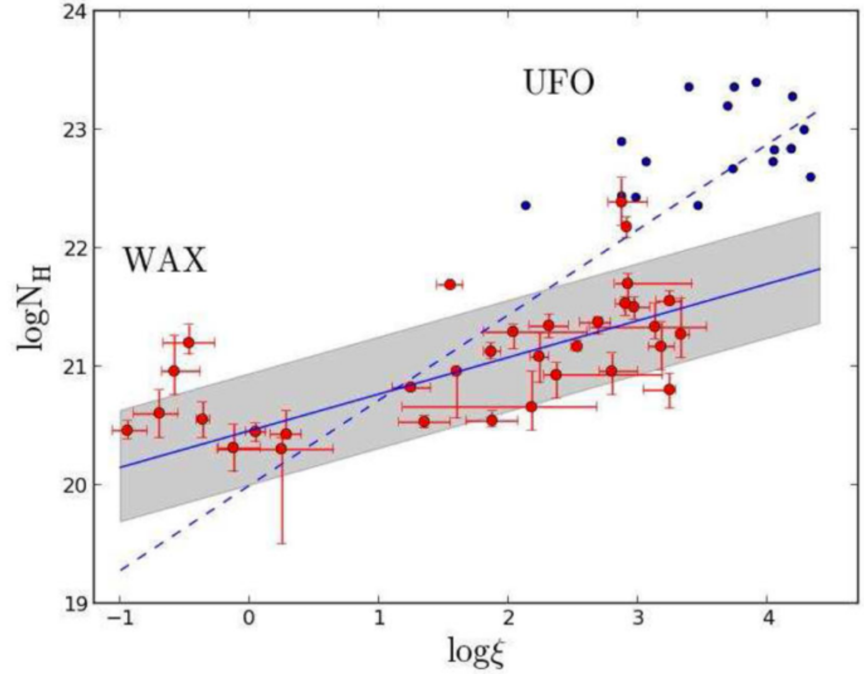
This point was made originally by McKernan+07, who stressed the importance of UTA diagnostics (see also Behar+03)

Laha et al. 2014 and 2016

WA vs. UFO.

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

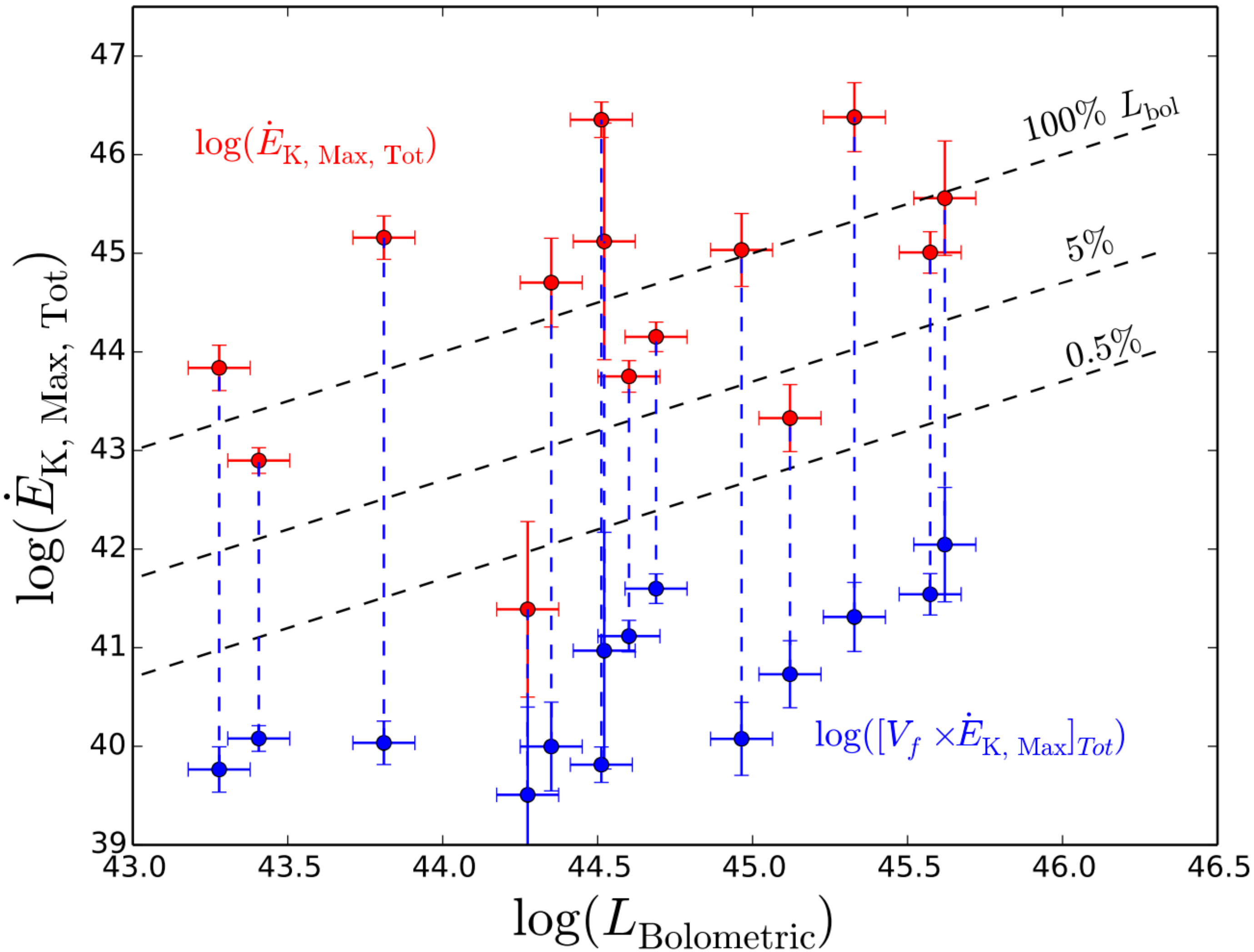




Laha et al. 2014 and 2016

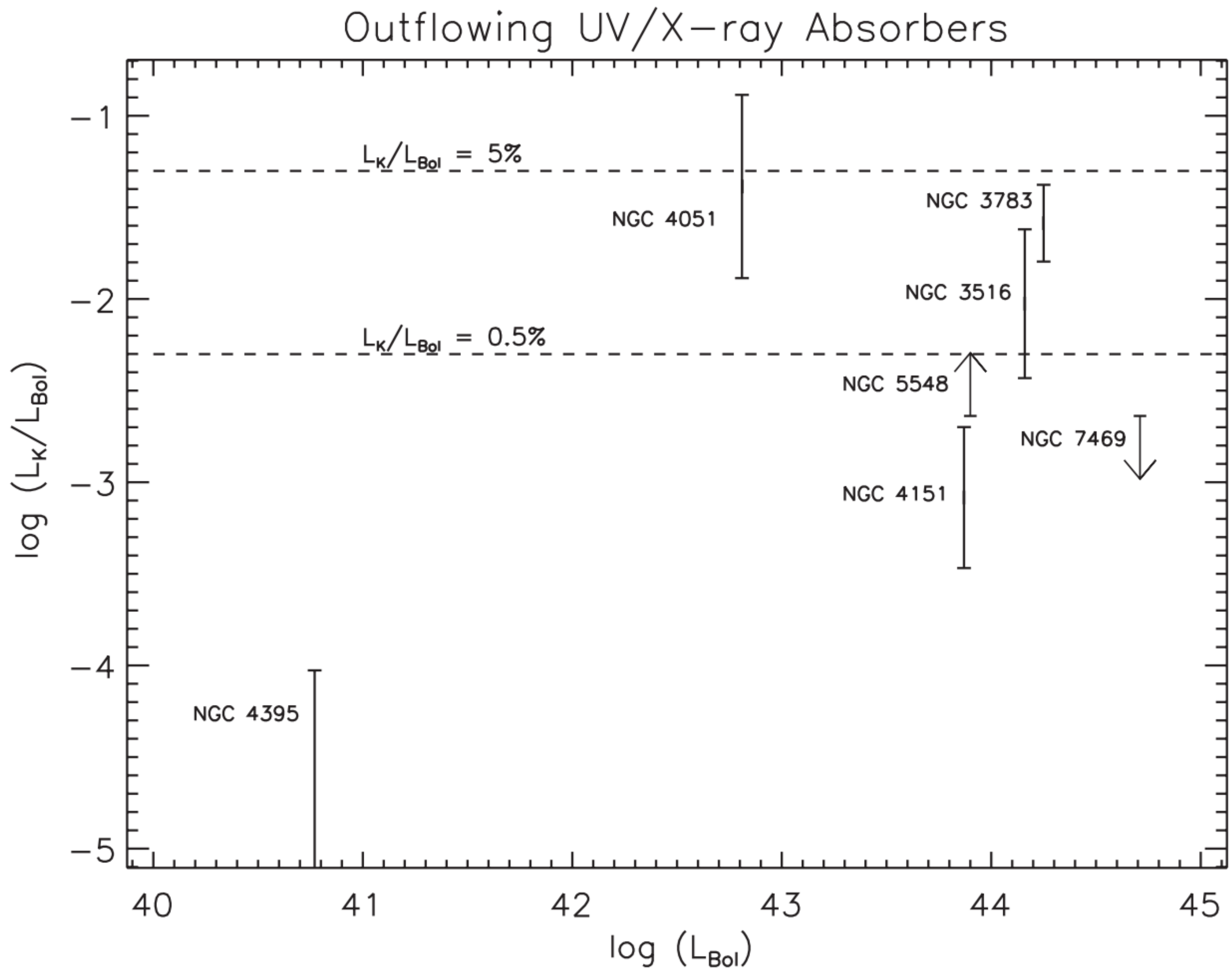
WAX result - IX

Feedback



Laha et al. 2014 and 2016

X-ray+UV WA feed-back

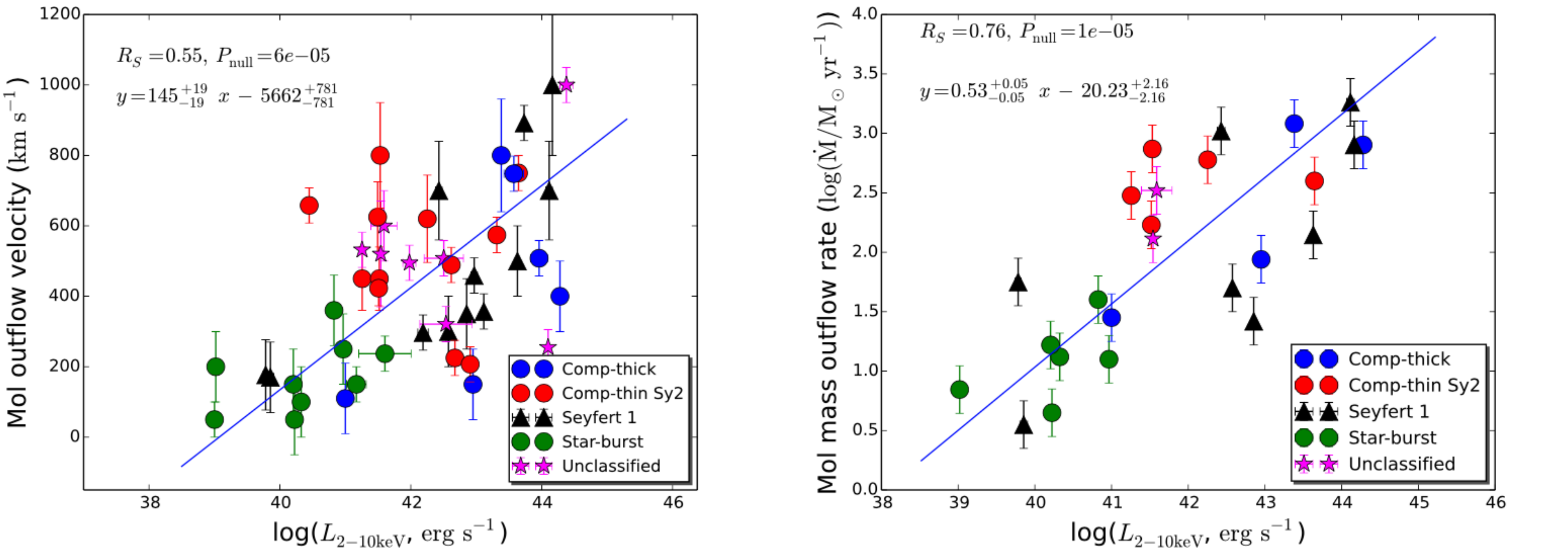


Crenshaw & Kraemer 2012, ApJ…753

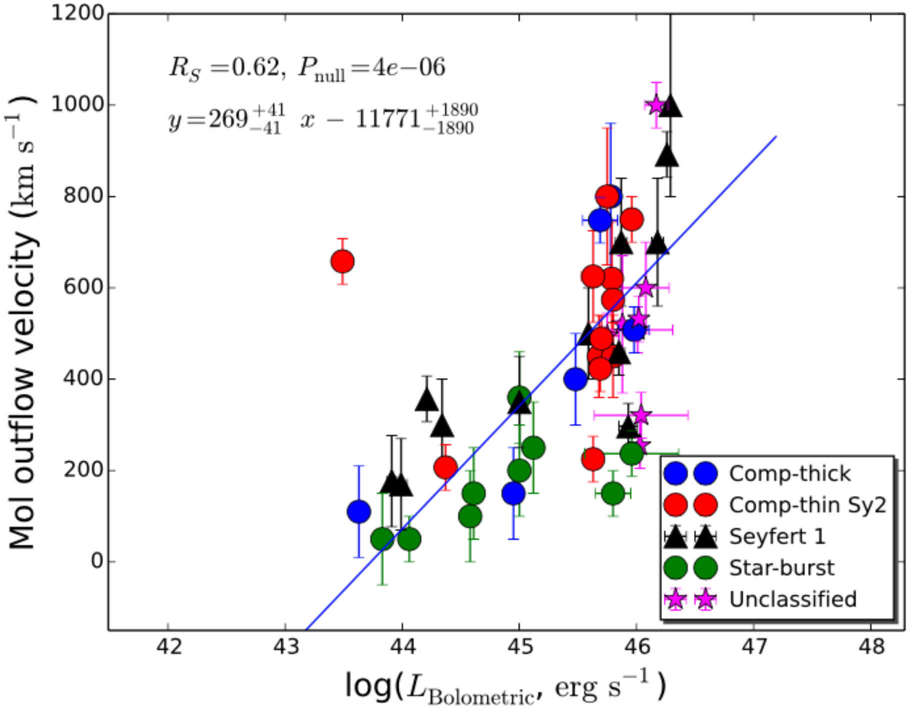
WAX Summary

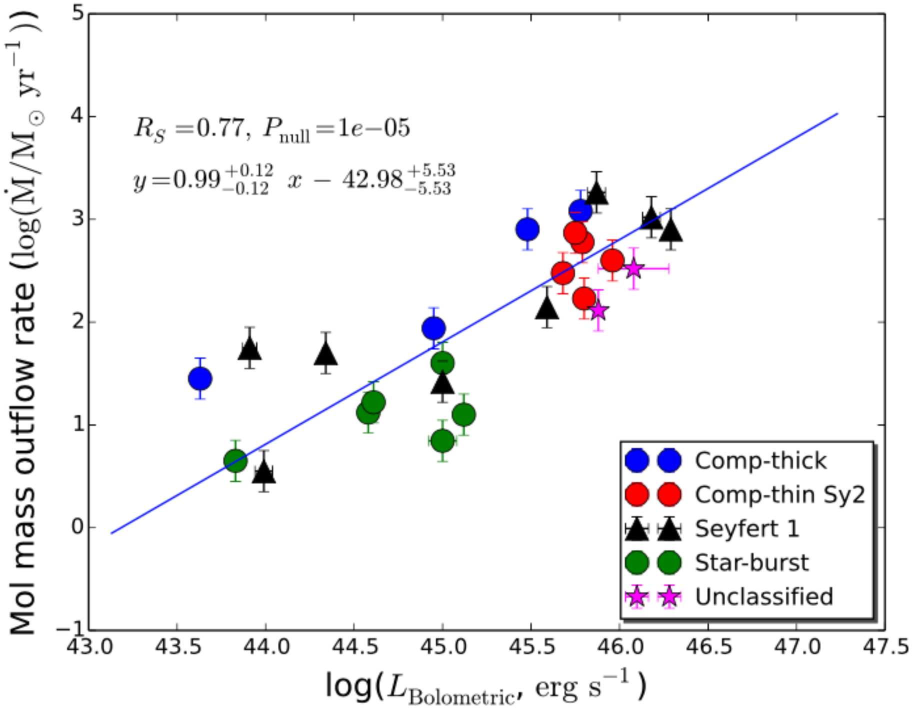
- N_H=[10^{20},10^{22} cm^{-2}], v_{out}=[$10^{2.5}$,10^4 km/s], $\log(\xi_{cgs}) \leq 3$
- "ionisation (parameter) gap" … **missing ionization states??**
- incidence of AGN outflows in the local Universe: WA≳75%, **others Bonafide NO WA**?
- Acceleration mechanism: **Likely Thermal winds and radiation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

Thanks for your attention…



$R_S = 0.55,\ P_{\rm null} = 6e{-}05$
$y = 145^{+19}_{-19}\ x\ -\ 5662^{+781}_{-781}$
Mol outflow velocity ($\rm km\ s^{-1}$)
log($L_{\rm 2-10keV}$, erg s^{-1})
Comp-thick
Comp-thin Sy2
Seyfert 1
Star-burst
Unclassified
$R_S = 0.76,\ P_{\rm null} = 1e{-}05$
$y = 0.53^{+0.05}_{-0.05}\ x\ -\ 20.23^{+2.16}_{-2.16}$
Mol mass outflow rate ($\log(\dot{\rm M}/{\rm M_\odot\ yr^{-1}})$)
log($L_{\rm 2-10keV}$, erg s^{-1})
Comp-thick
Comp-thin Sy2
Seyfert 1
Star-burst
Unclassified

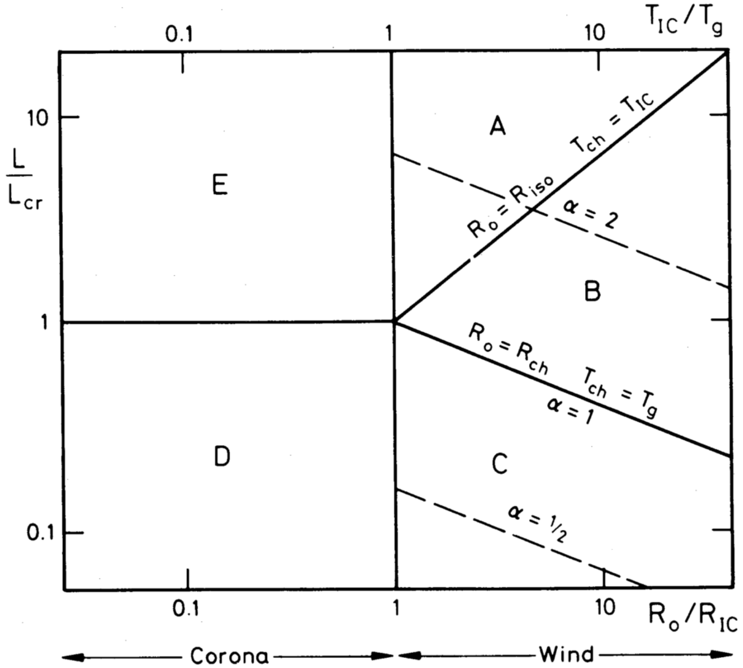

$R_S = 0.62,\ P_{\rm null} = 4e{-}06$
$y = 269^{+41}_{-41}\ x\ -\ 11771^{+1890}_{-1890}$
Mol outflow velocity (km s^{-1})
log($L_{\rm Bolometric}$, erg s^{-1})
Comp-thick
Comp-thin Sy2
Seyfert 1
Star-burst
Unclassified


$R_S = 0.77,\ P_{\rm null} = 1e{-}05$
$y = 0.99^{+0.12}_{-0.12}\ x\ -\ 42.98^{+5.53}_{-5.53}$
Mol mass outflow rate (log($\dot{\rm M}$/M$_\odot$ yr^{-1}))
log($L_{\rm Bolometric}$, erg s^{-1})
Comp-thick
Comp-thin Sy2
Seyfert 1
Star-burst
Unclassified

WAX result - VI

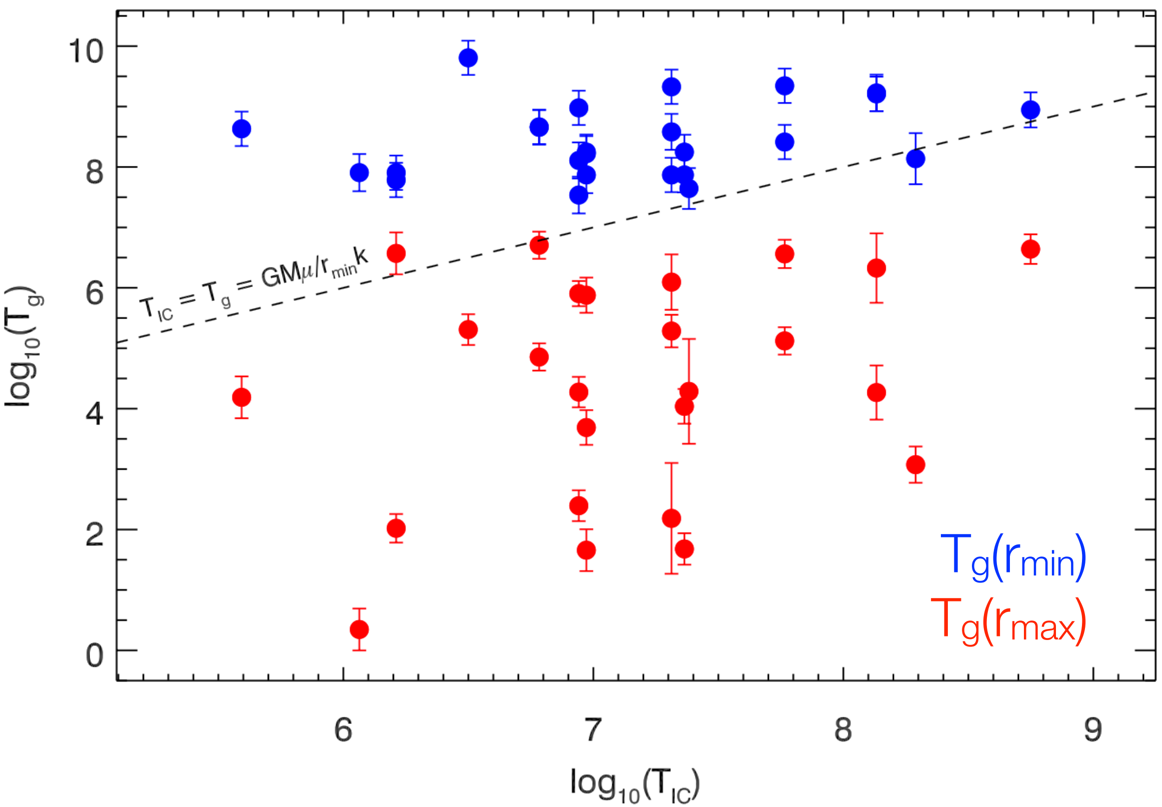
WA as thermal winds: supersonic condition

Guainazzi and Laha in preparation…



Begelman 1983, ApJ 271

"Escape Temperature" T_g vs.
Inverse Compton Temperature T_{IC}



Laha et al. 2014 and 2016