Relativistic components of the Ultra-Fast Outflow (UFO) in the Quasar PDS 456 from Chandra/HETGS, NuSTAR and XMM-Newton observations

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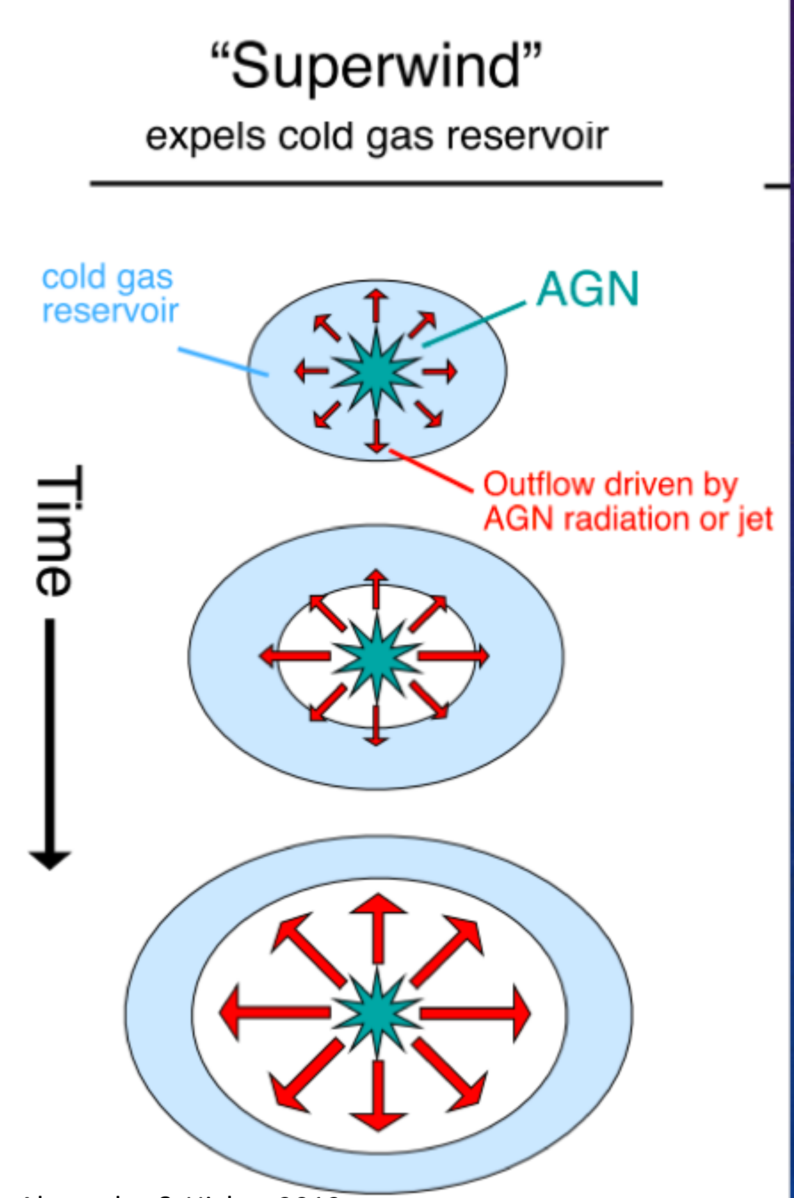
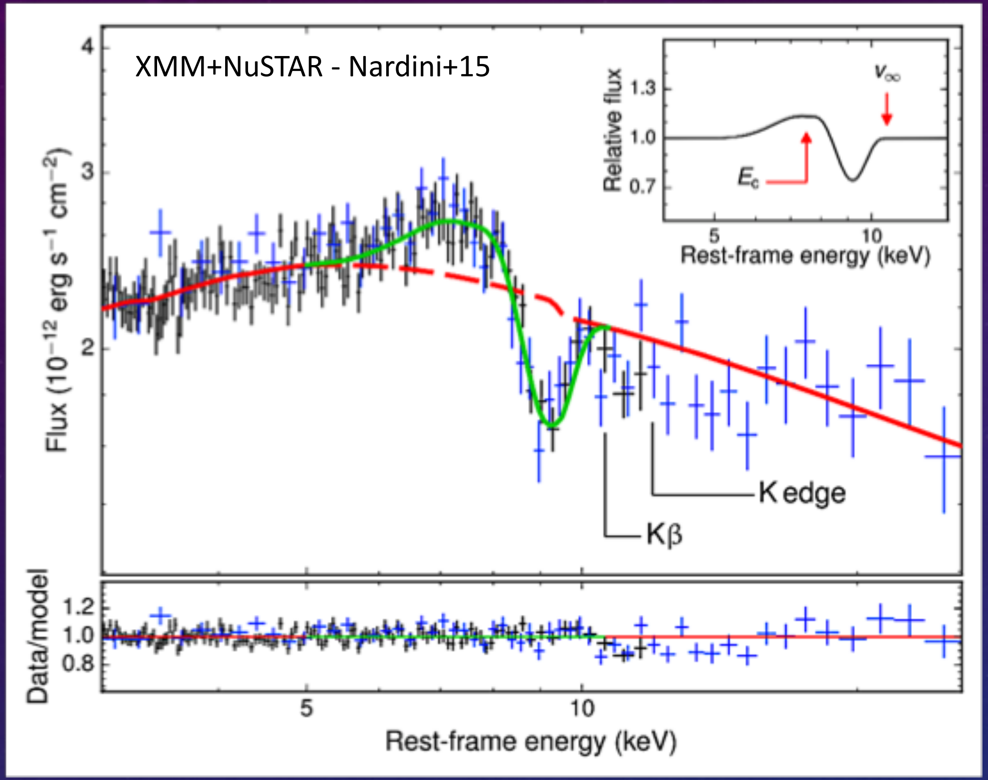
Active Galactic Nuclei (AGN), Ultra-Fast Outflows and Feedback

- **Warm absorbers** (low ξ, v_{out}=100-1000 km/s) detected in >50% AGN
- **UFOs** (v_{out} = −0.1-−0.4c, $N_H \sim 10^{23}\mathrm{cm}^{-2}$) observed through **blueshifted highly ionized iron absorption** lines above 7 keV in ~40% of AGN
- $\dot{M}_{out} \sim 10^3 M_\odot$/yr; $P_{kin} \sim 10^{45} - 10^{46}$ erg s^{-1}; launched from the acc. disk at a few R_g from SMBH
- AGN **feedback**: UFOs with $P_{mechanical}$=0.5-5% L_{bol} => affect the AGN host galaxy, by **sweeping away the galaxy's reservoir of gas and hence quench the star formation**



Alexander & Hickox 2012

Patchwork of previous observations of PDS 456

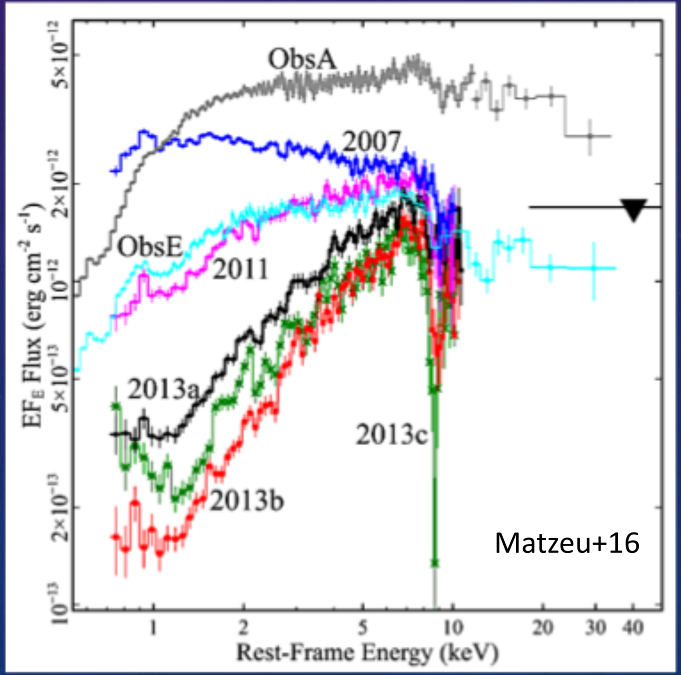


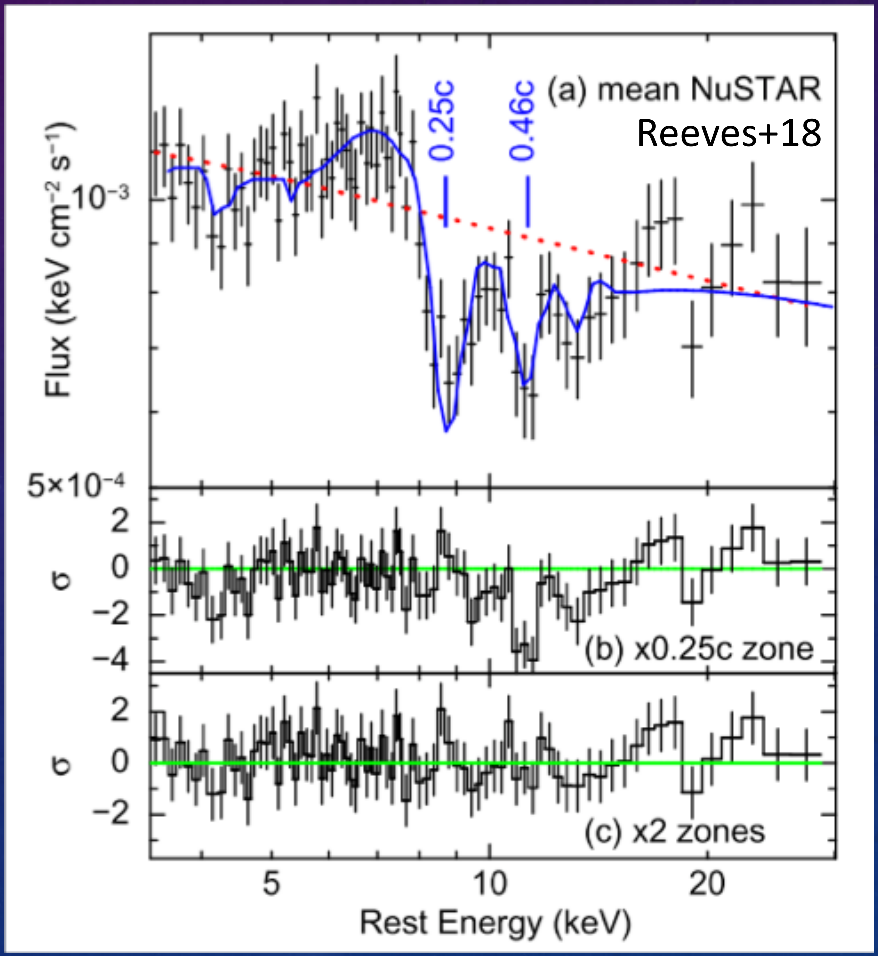
λ_{Edd}~1

$M_{BH}=10^9 M_{sun}$

z=0.184

$L_{Bol}=10^{47}$erg/s





Aim of our work

Is this extreme-velocity Ultra-Fast Outflow never detected in other local AGN persistent in PDS 456?

What are the properties of the UFOs and other winds in this quasar?

I will present:

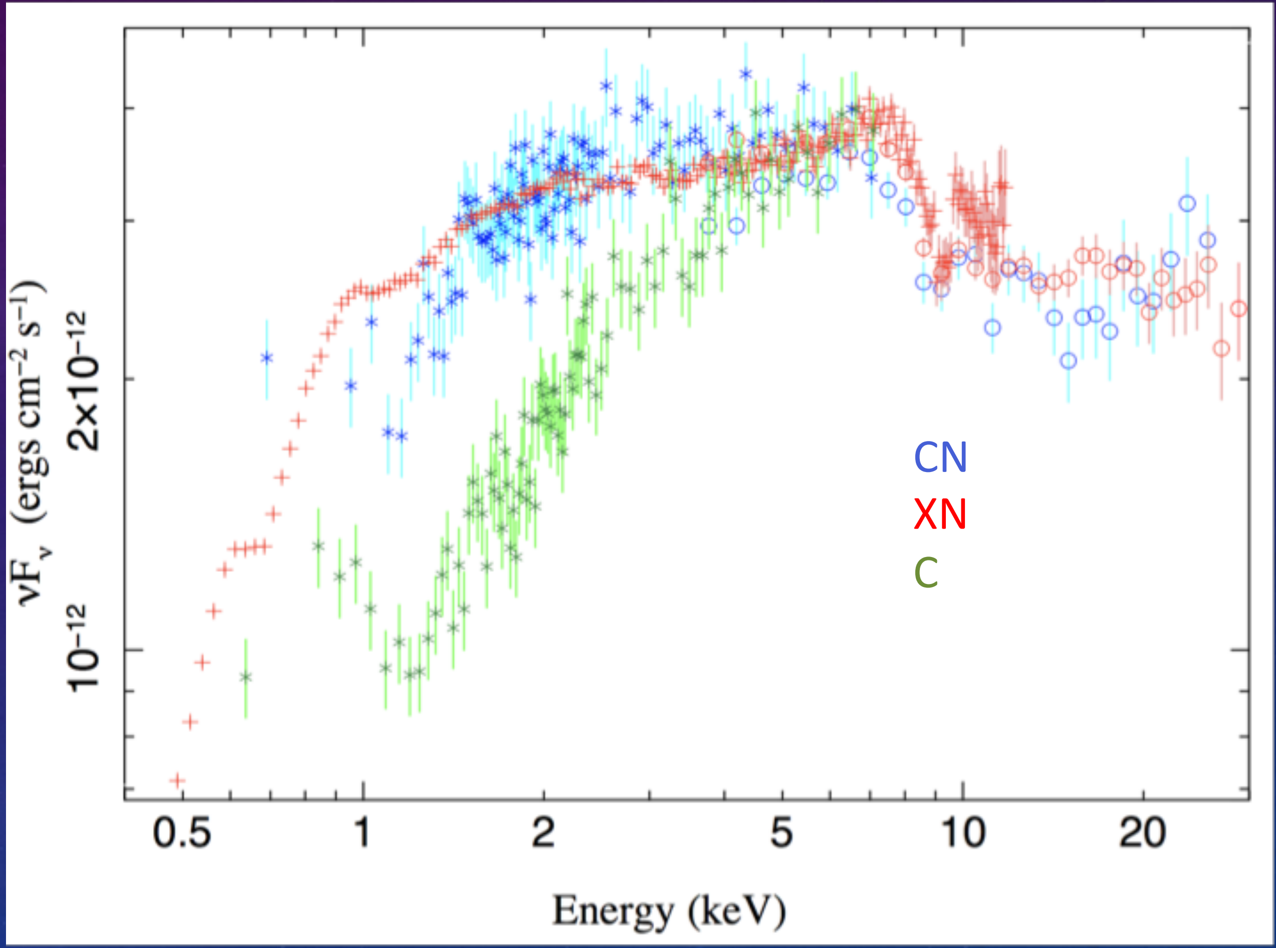
1. The 3 datasets we used for this study
2. Several complementary methods we used to assess the presence of both UFOs and characterize the winds, using a **dual-approach**:

Model-independent methods	**Model-dependent method**
Fit individual lines at high energy with Gaussian lines	Photoionization modeling using XSTAR
Blind line search at lower energy	
(Fit with P Cygni profiles)	
(Additional diagnostic for velocities)	

3. The mass outflow rates, energetics and impact of the UFOs on the host galaxy

Our analysis: three different epochs

Label	Satellite/instrument	Year
CN	Chandra/HETGS + NuSTAR	2015
C	Chandra/HETGS	2003
XN	XMM-Newton/pn + NuSTAR (Combination of 5 observations)	2013- 2014

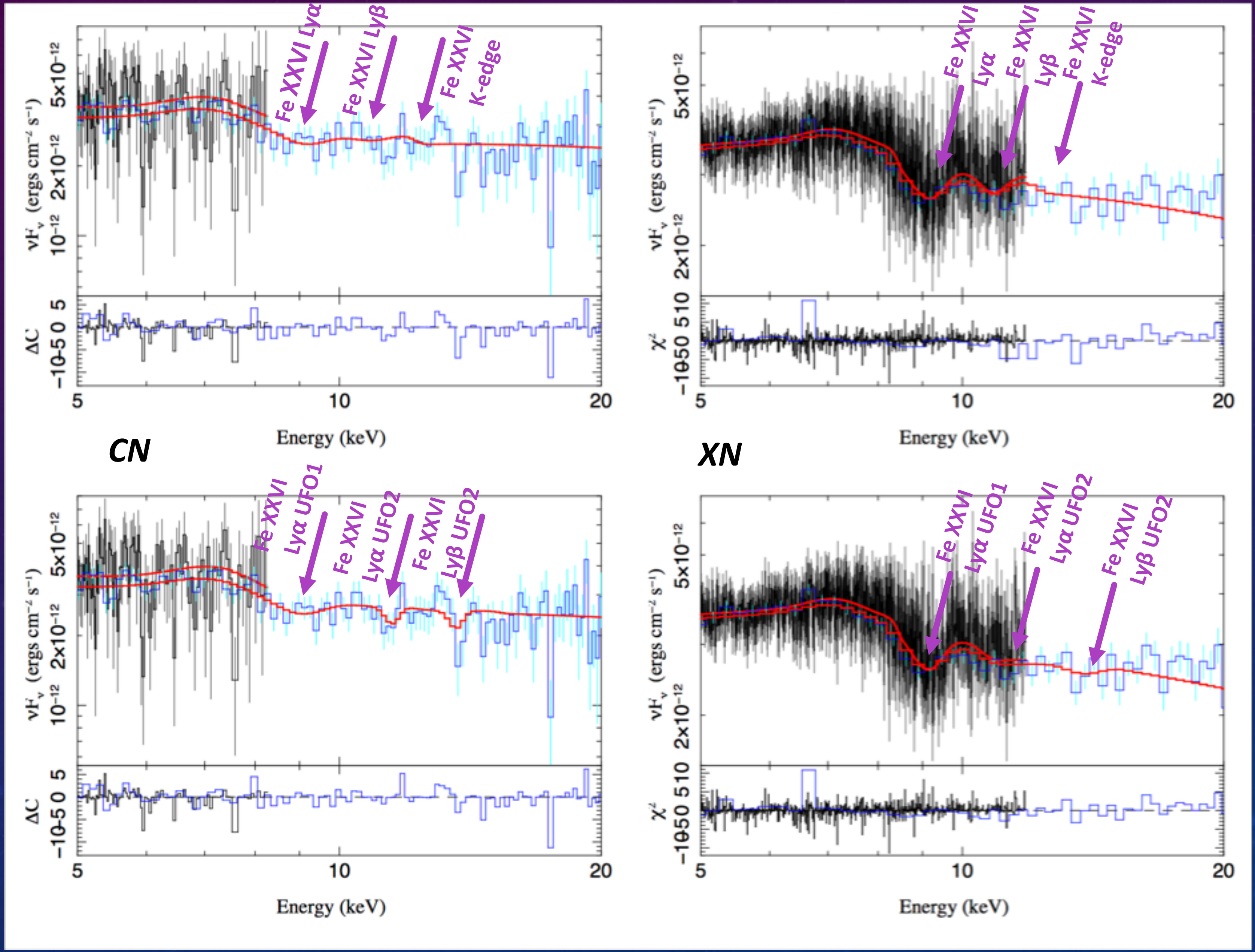


Continuum: constant*tbabs*zpcfabs*(powerlaw+zgauss)

Absorption features above 9 keV – fit with Gaussian lines

1 UFO

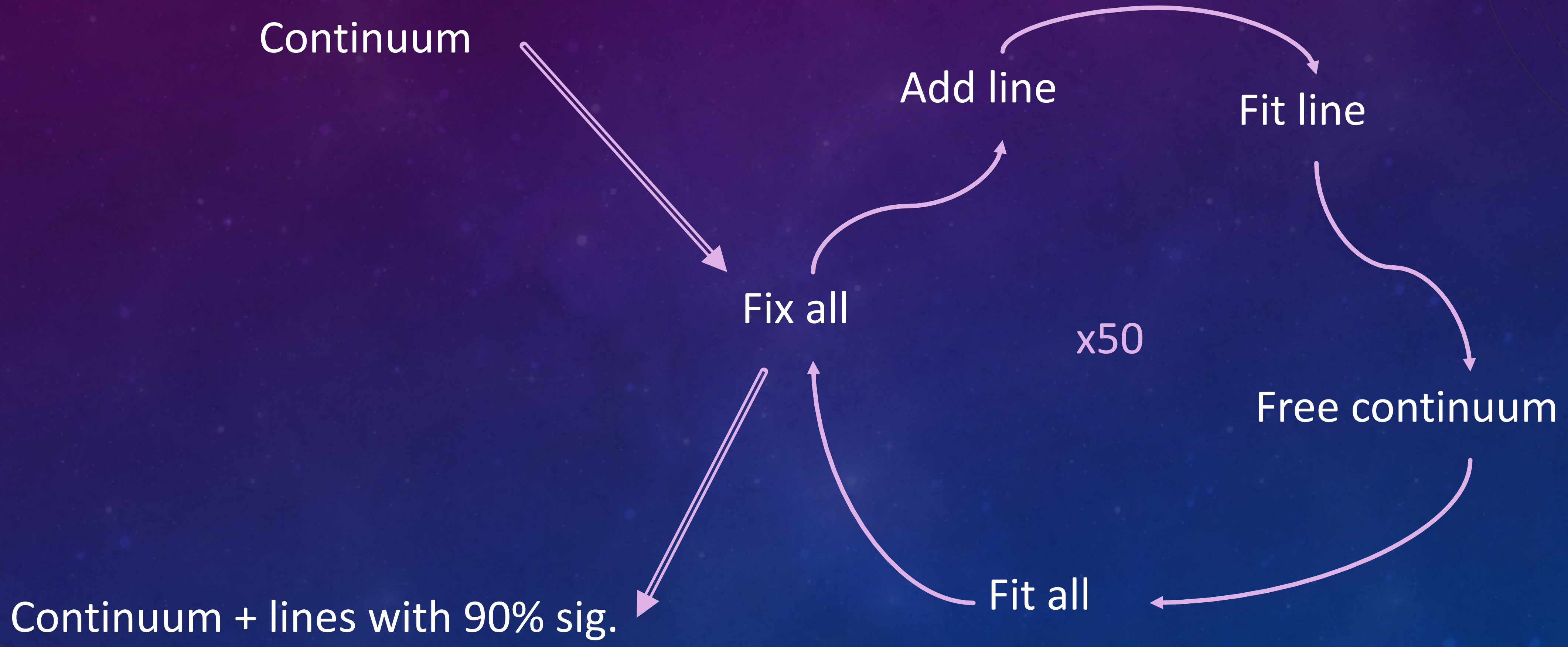
2 UFOs



v_{out}=-0.27c

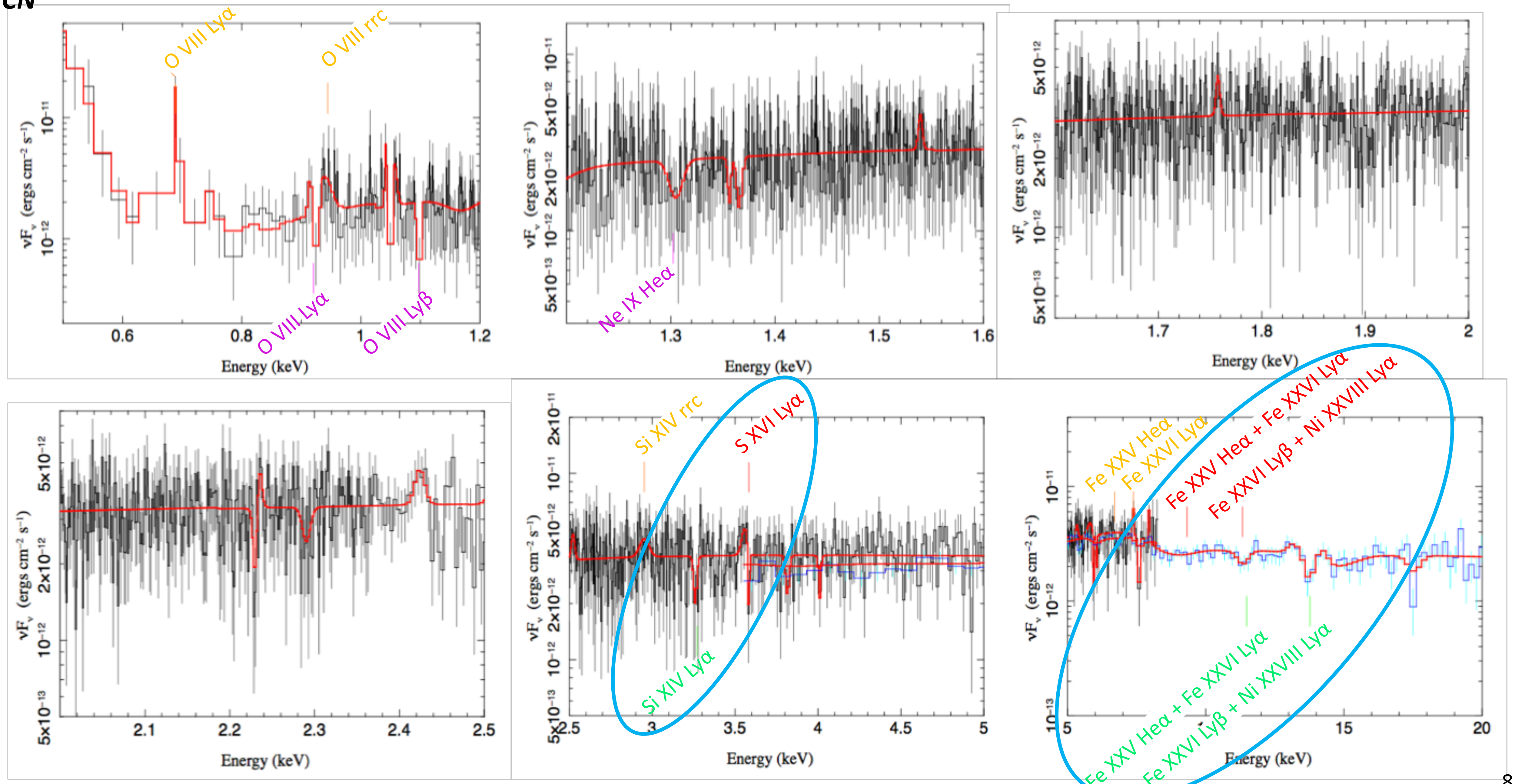
$v_{out\ 1}$ =-0.26c
$v_{out\ 2}$ =-0.47c

Blind line search



Legend: Photoemission; PC absorber; Slowest UFO; Fastest UFO.

CN



CN

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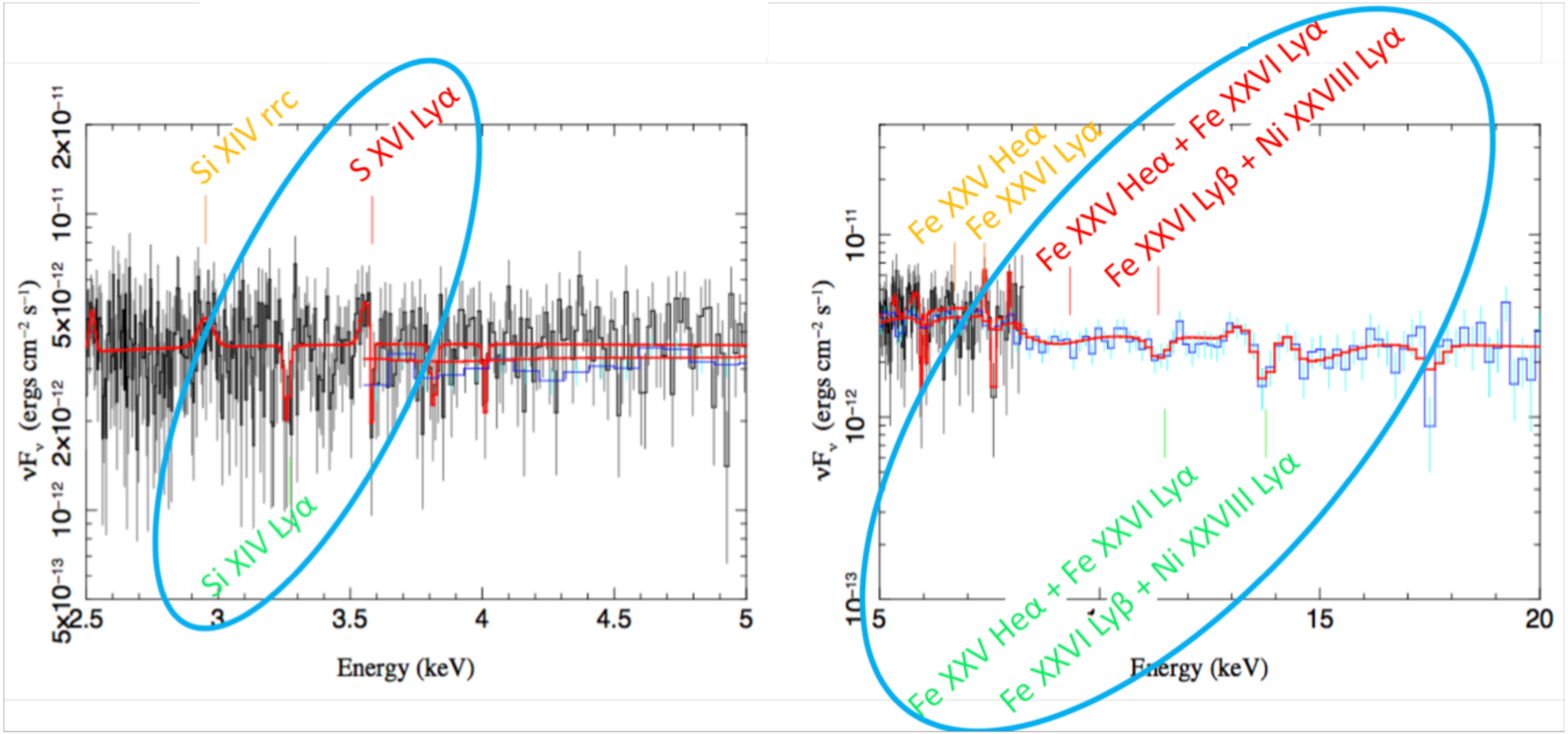
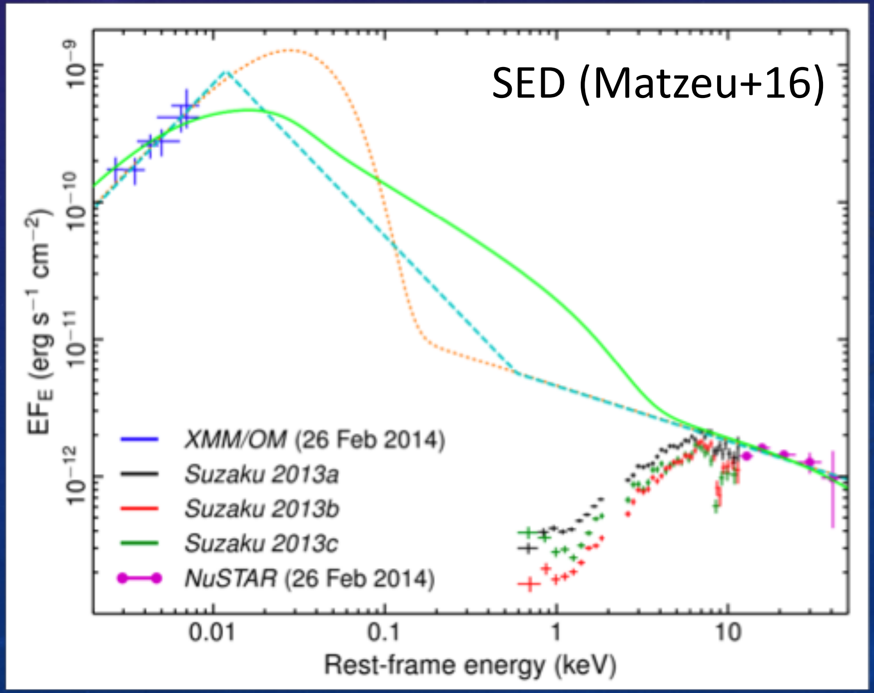


Photoionization modeling

	Component	Outflowing velocity	Ionization	Datasets
Absorption	Partial covering	V_1 high	ξ_1 medium	CN, XN, C
	UFO 1 (slowest)		ξ_2 high	CN, XN, C
	UFO 2 (fastest)	V_2 very high		CN, XN
	Warm absorber	V_3 null	ξ_3 small	XN
Emission	Photoemission	V_4 small	$= \xi_2$	CN, XN, C

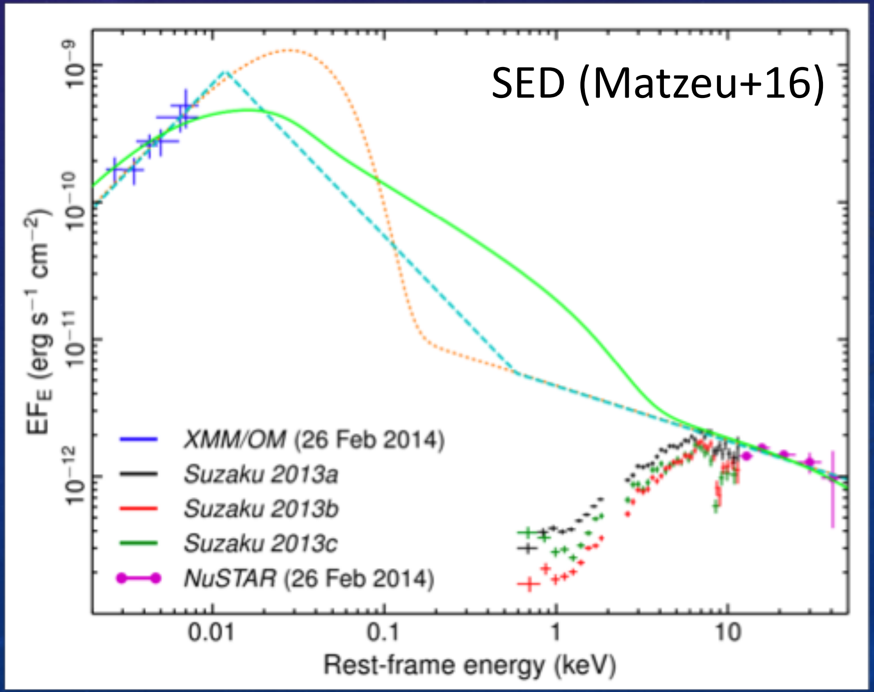
- Analytic model warmabs, instead of XSTAR grids
- MCMC in ISIS



Photoionization modeling

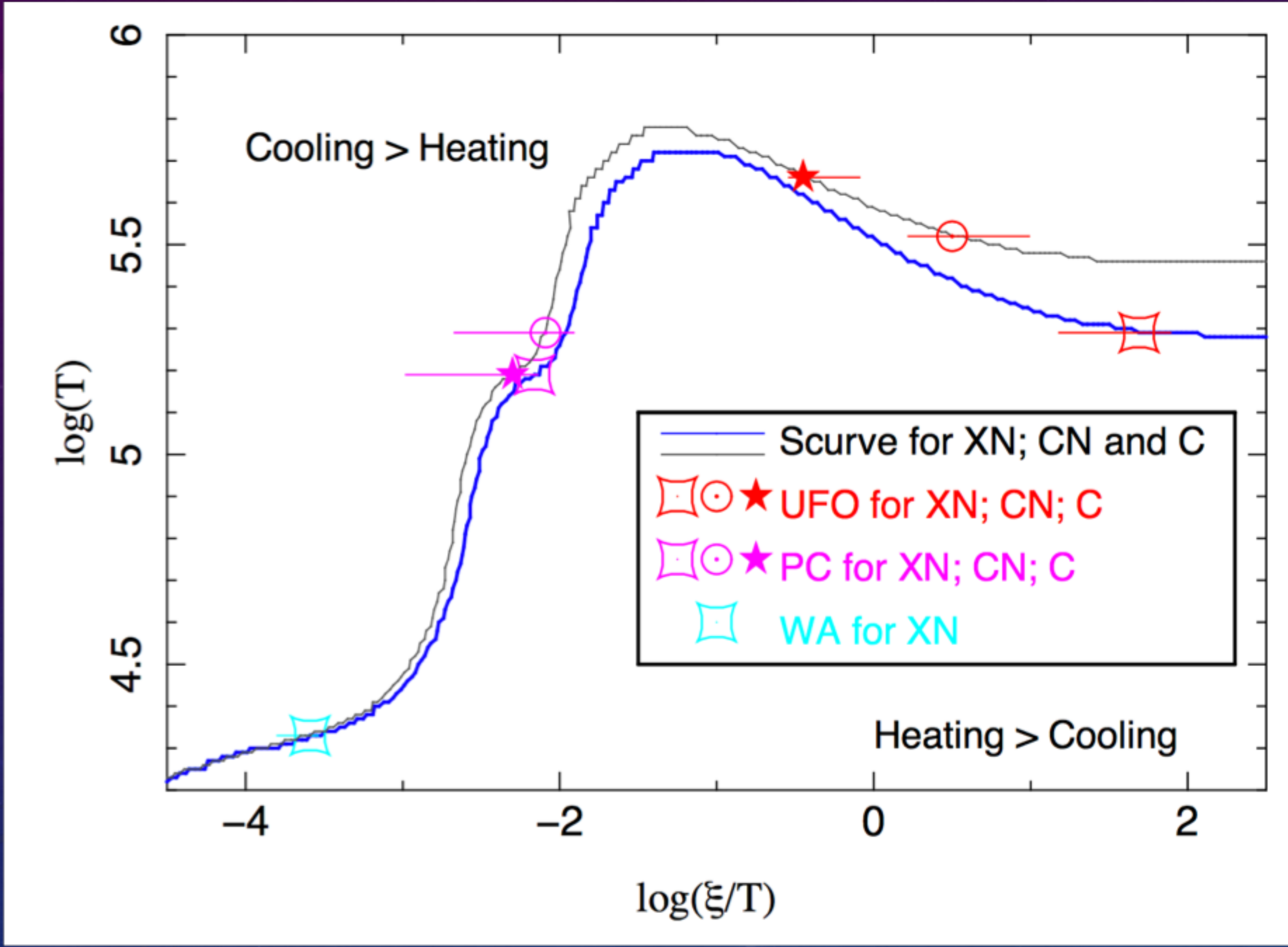
	Component	Outflowing velocity	Ionization	Datasets
Absorption	Partial covering	**0.24-0.29c**	**~3**	CN, XN, C
	UFO 1 (slowest)		**~6-7**	CN, XN, C
	UFO 2 (fastest)	**0.48c**		CN, XN
	Warm absorber	0	0.7	XN
Emission	Photoemission	0.03-0.09c	~6-7	CN, XN, C

- Analytic model warmabs, instead of XSTAR grids
- MCMC in ISIS



Thermal stability

(see Youtube video: https://www.youtube.com/watch?v=UKSVT_Fbwuw)



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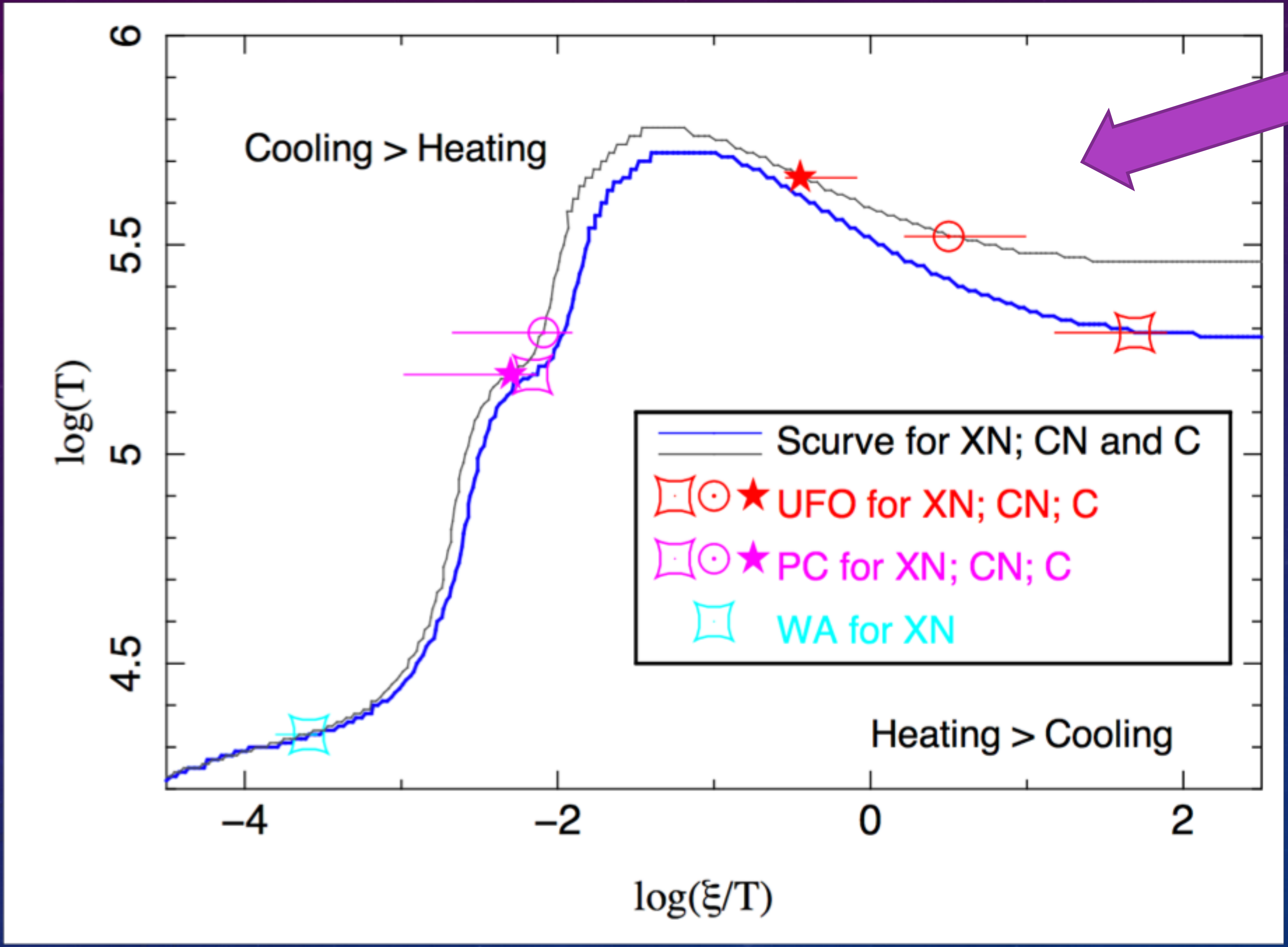
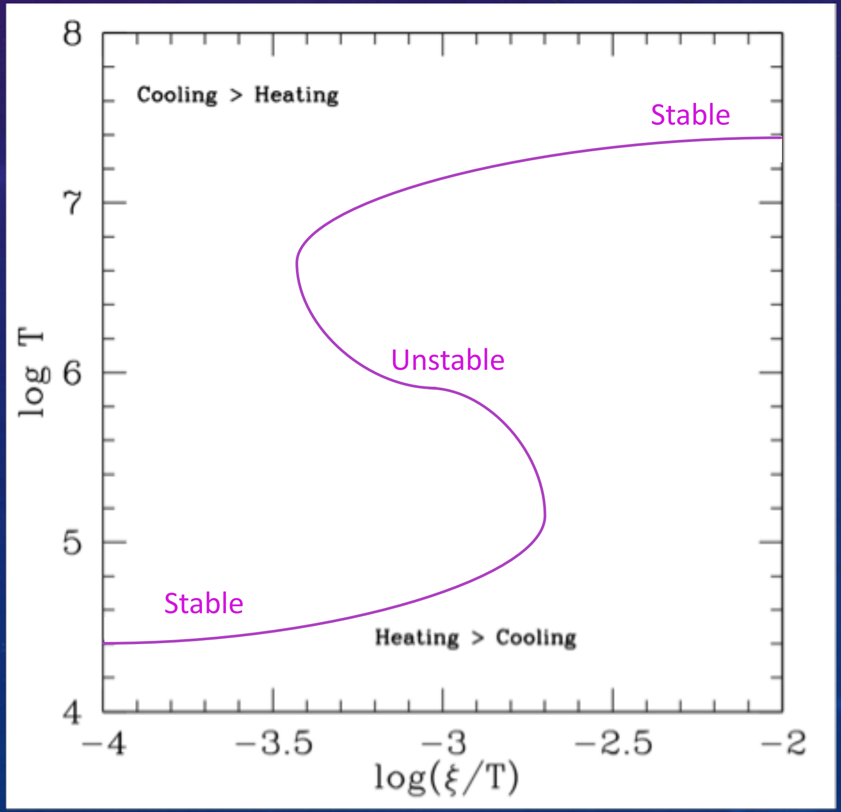


Unusual shape of the S-curve:
Strong soft component of the SED, so low Compton temperature; gas partially ionized can reach higher temperatures

Positive gradient: thermal stability
Negative gradient: unstable



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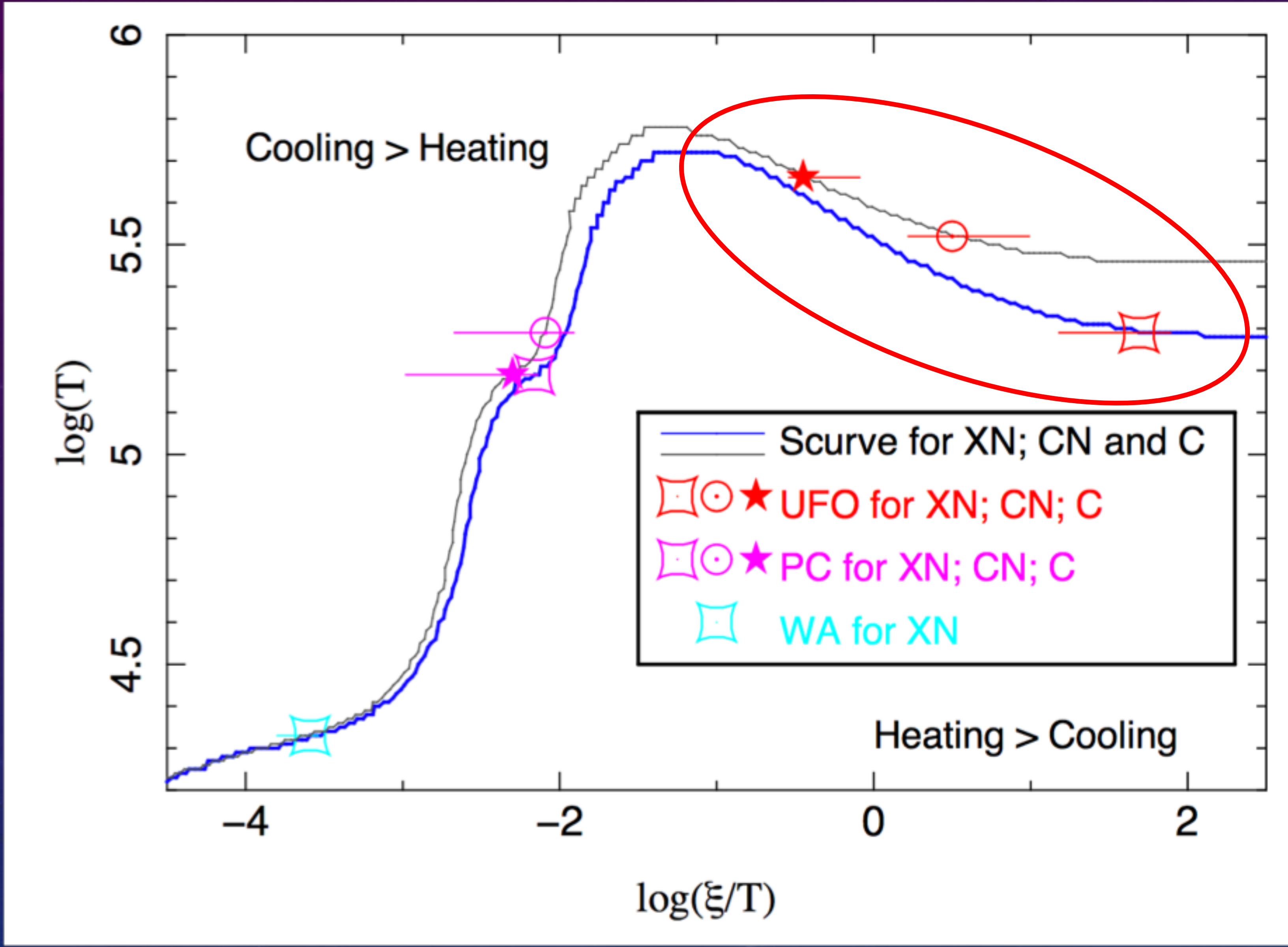

UFOs persistent, but…
Negative gradient => unstable?

Thermal stability

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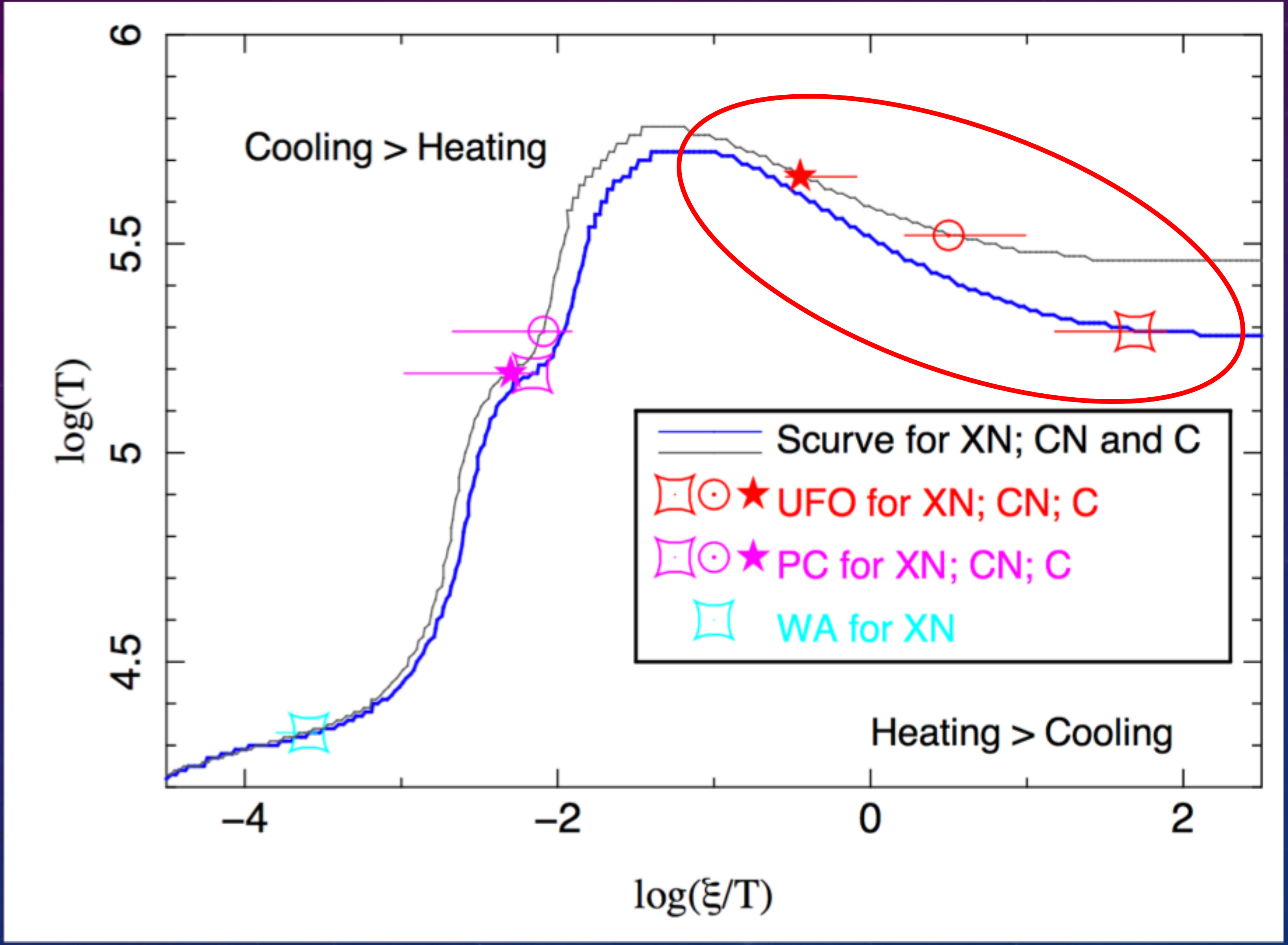

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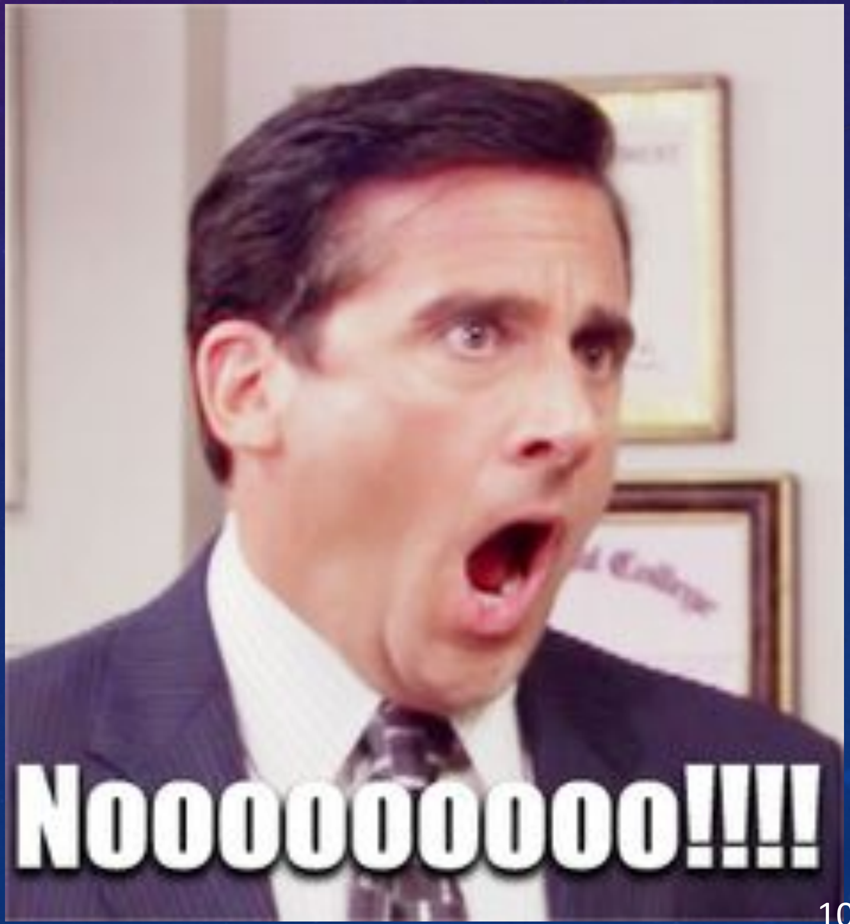

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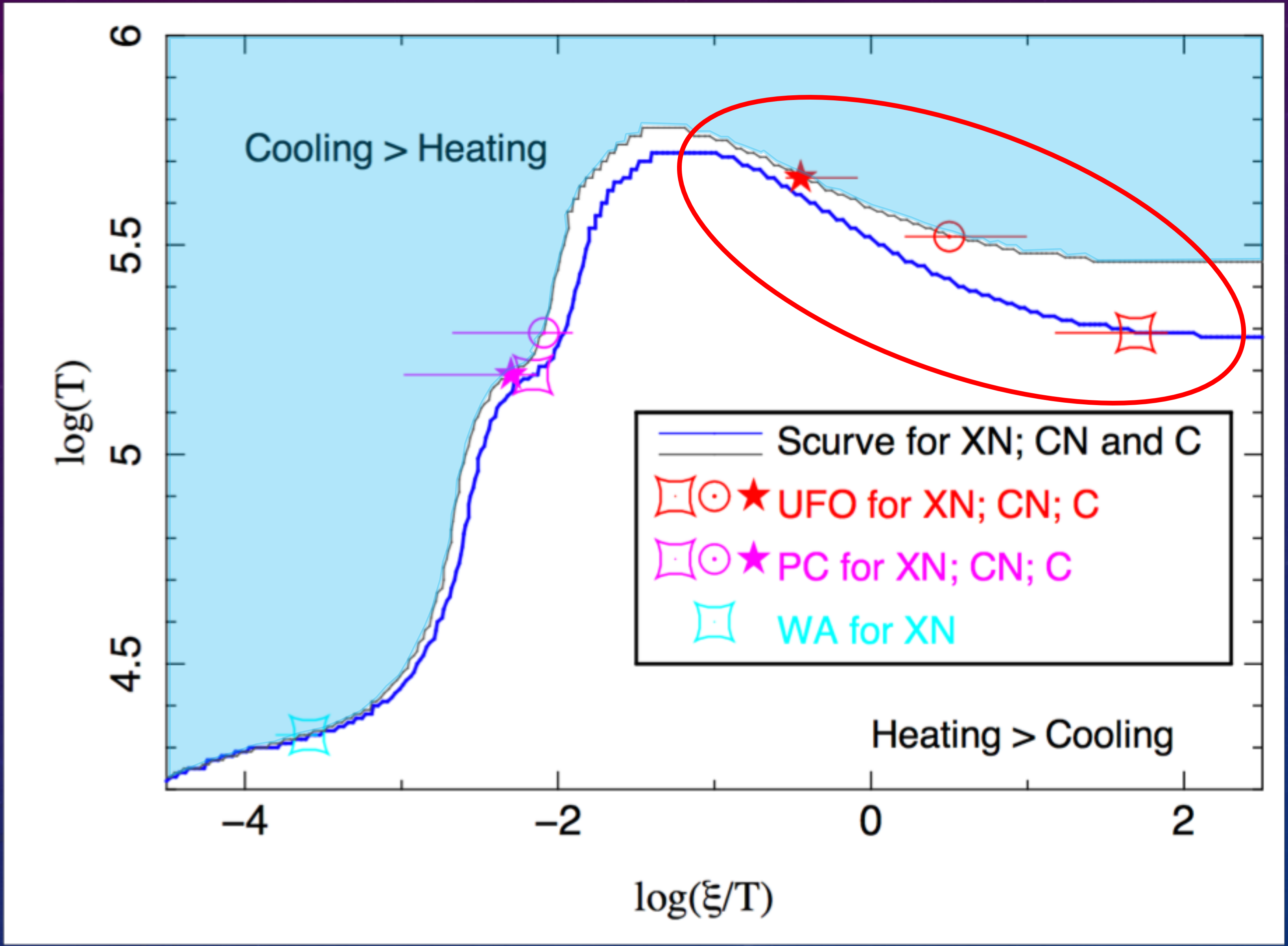

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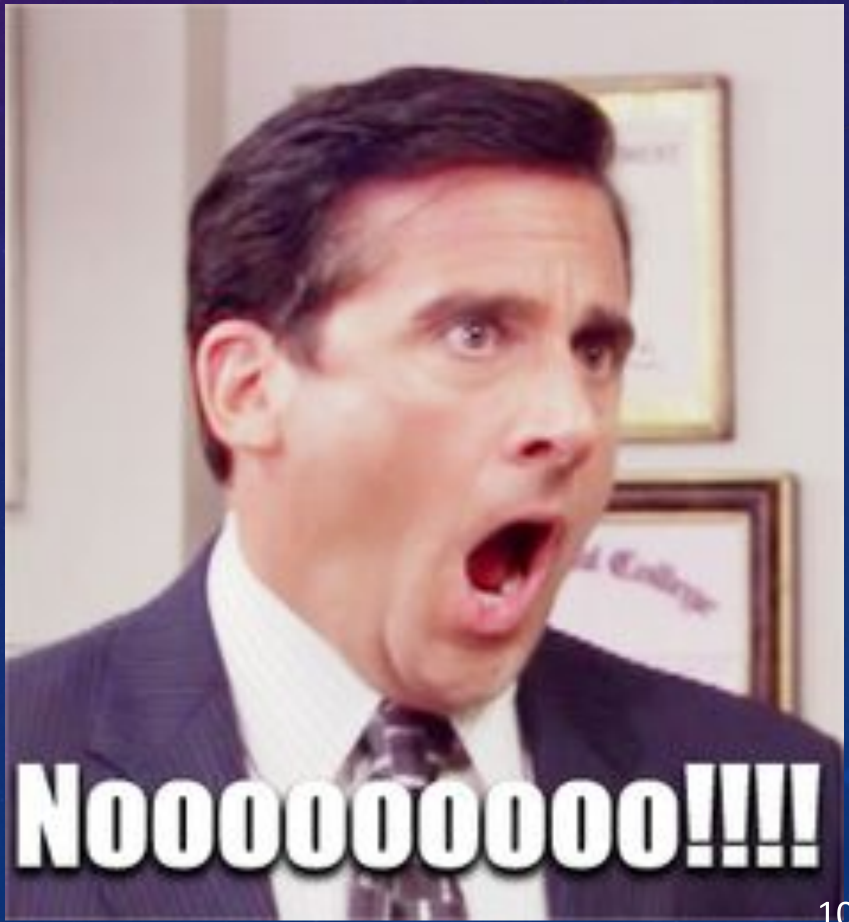

Mass outflow rates, energetics

	Inner radius	Mass outflow rate	Kinetic power
	$R_{in} \sim 2(\alpha \frac{L}{L_{Edd}} - 1)(\frac{v_\infty}{c})^{-2}$ (for radiatively accelerated winds, Reeves+18)	$\dot{M}_{out} \sim \Omega N_H m_p v_{out} R_{in}$ ($\Omega=2\pi$, Nardini+15)	$P_{kin} = 0.5 \dot{M} v_{out}^2$
UFO 1 (slowest)	R_{in}= 30 R_g = 5 x 10^{15} cm	$\dot{M}_{out}$= 3-20% $\dot{M}_{Edd}$	P_{kin}= 0.8-8% L_{Edd}
UFO 2 (fastest)	R_{in}= 9 R_g = 1 x 10^{15} cm	$\dot{M}_{out}$= 2-7% $\dot{M}_{Edd}$	P_{kin}= 0.8-8% L_{Edd}

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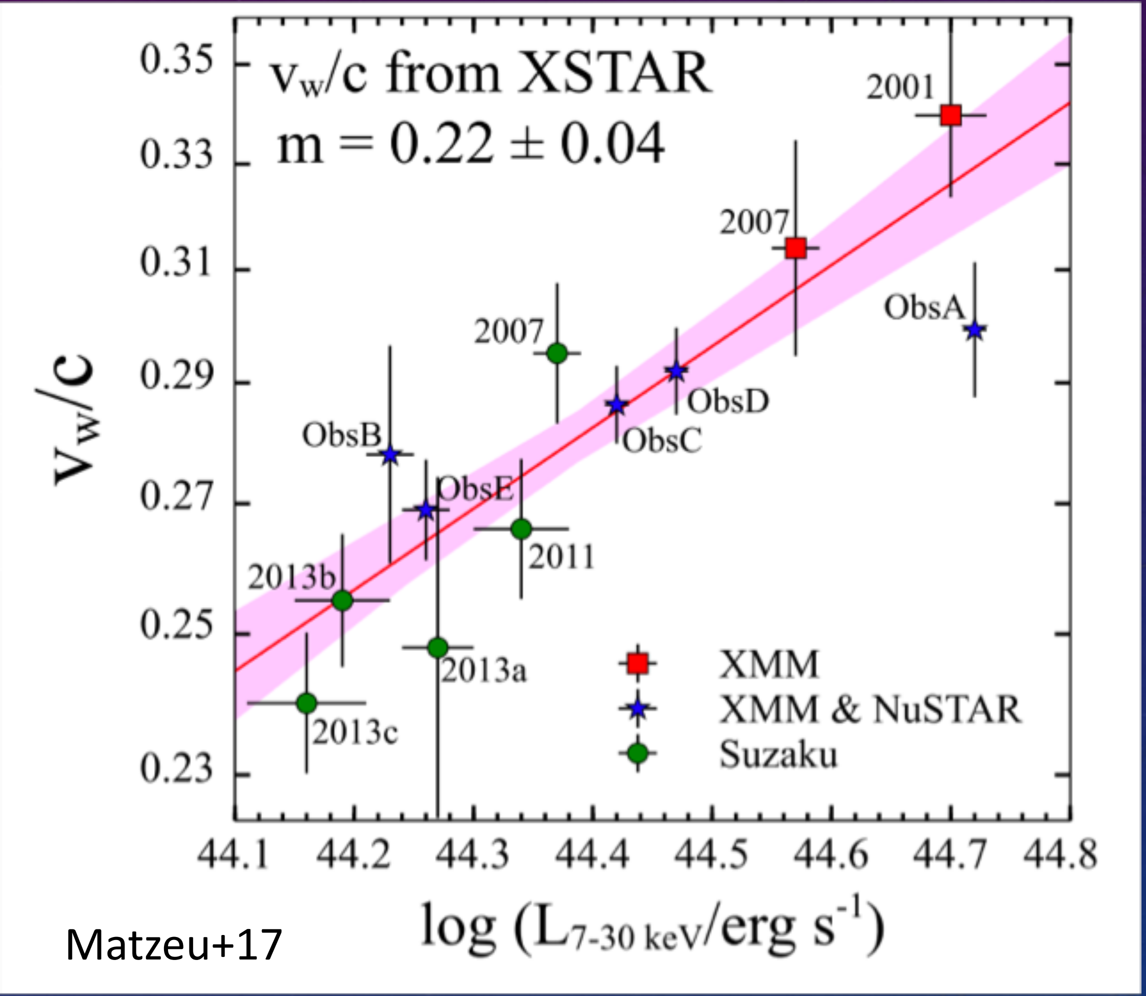

Possible correlation between outflow velocity and intrinsic flux (see Matzeu+17) => **radiatively driven wind** (and λ_{Edd}~1)

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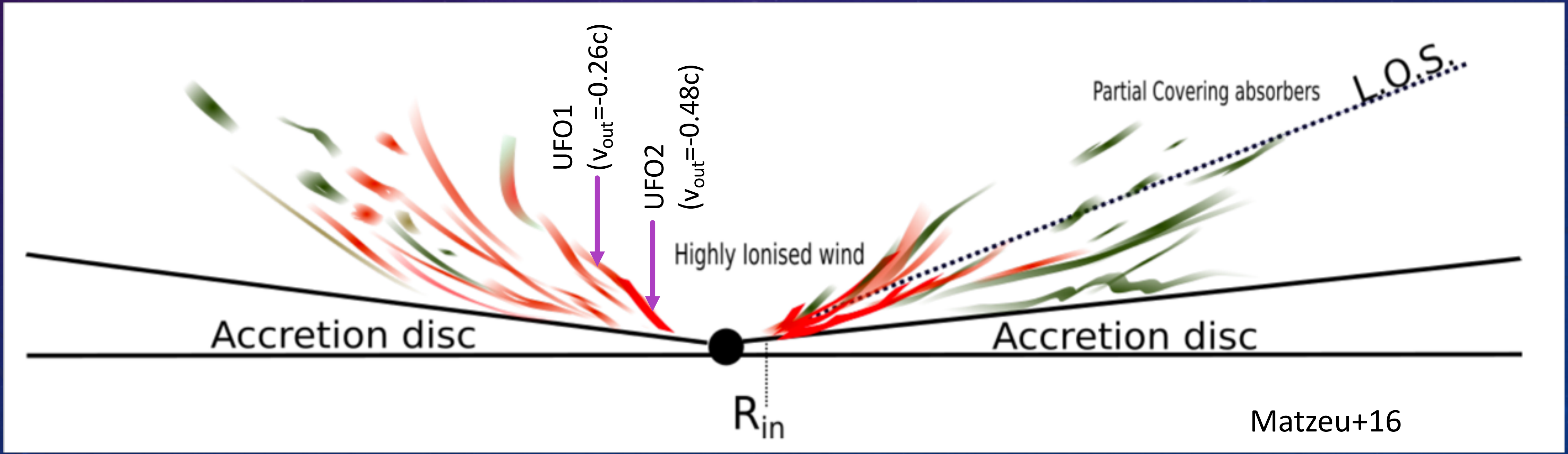
=> Clumpy wind with different components, with a kinetic power of about 0.8-8% of the bolometric luminosity that is sufficient to induce significant AGN feedback



Conclusion

- 3 datasets: Chandra/HETGS + NuSTAR (2015), Chandra/HETGS (2003), XMM-Newton + NuSTAR (2013-2014)
- Confirmation of the presence of the UFO with v_{out}=-0.24-0.29c
- Significant detection of a **faster UFO** with **v_{out}=-0.48c** (HETGS+NuSTAR 2015; XMM+NuSTAR 2013; 2017): **persistent UFO with an extreme velocity never found before in other local AGN!**
- Use of several methods in a **dual-approach** :
  - Modeling of Fe K lines around 9 and 11 keV
  - Blind line search: identification of **blueshifted high spectral resolution lines in HETGS**
  - Photoionization modeling
- UFO (**log(ξ)~6–7**, N_H ~1–8×10^{23} cm^{-2}); PC (log(ξ)~3, N_H ~ 3-20×$10^{22}$$cm^{-2}$, C_f ~ 0.3–0.8); **thermally stable**
- UFOs powerful enough to impact **the evolution of the host galaxy**: $\dot{M}_{out}$=2-20% $\dot{M}_{Edd}$, **P_{kin} = 0.8-8%** L_{Edd}
- Results published in **2019, Astrophysical Journal, 873, 29**
- Great target for XRISM, Athena, Arcus, and Lynx!