PDS 456

Chandra/HETGS and NuSTAR observations of its Ultra-Fast Outflows (UFOs)

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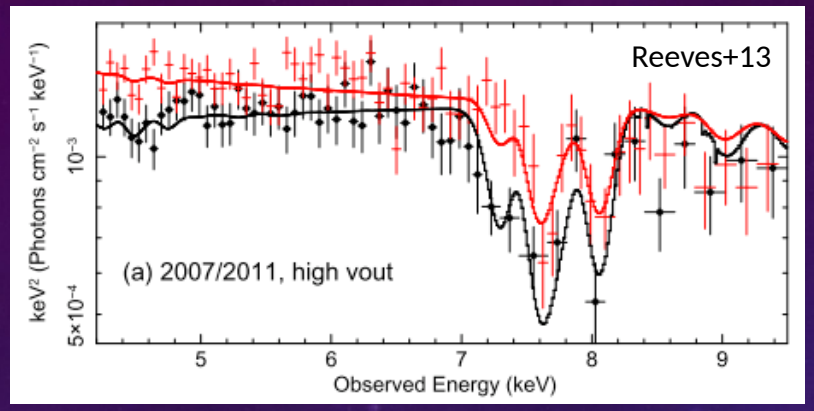
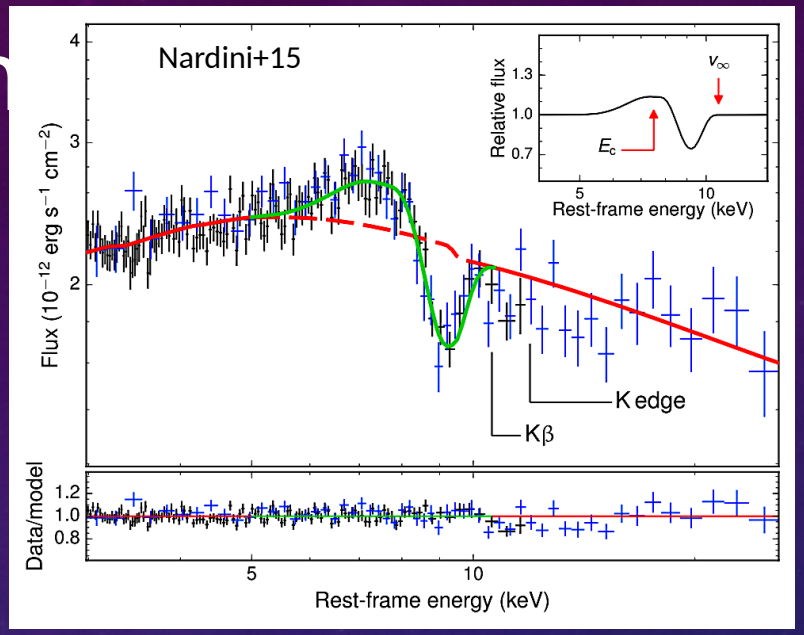
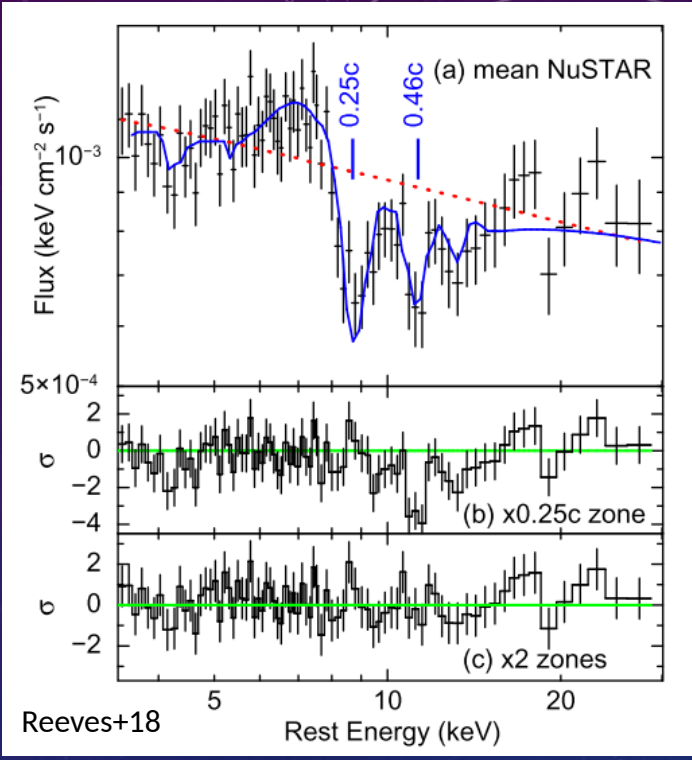
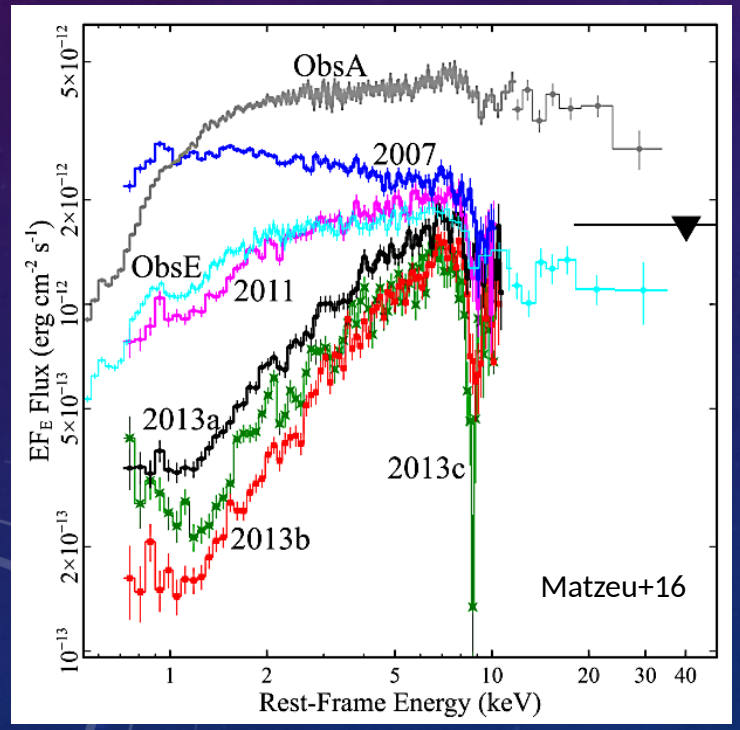
Previous observation

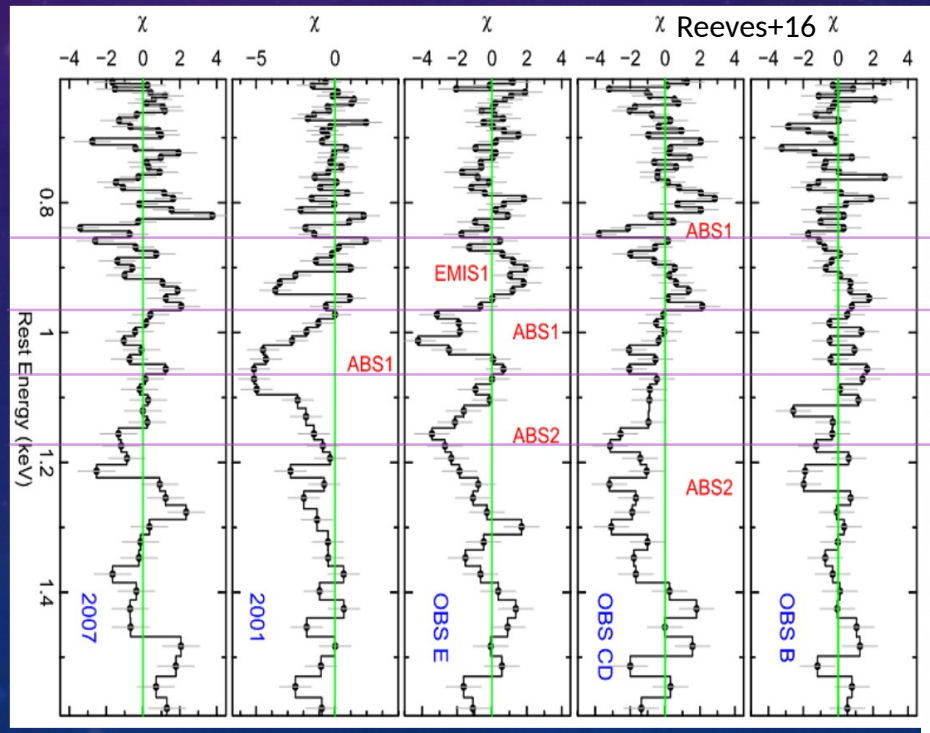
λ_{Edd}~1, $M_{BH}=10^9 M_{sun}$, z=0.184

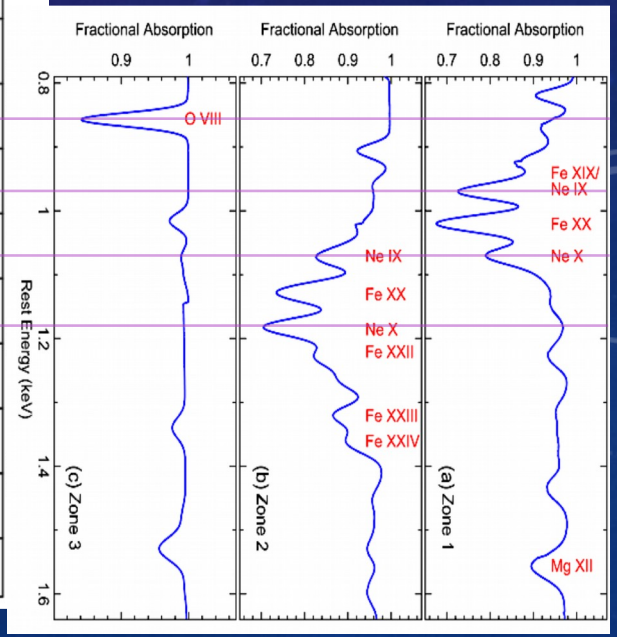












Our analysis: three Datasets

Combined in ”XN”

Obs.	Satellite	Obs. ID	Obs. Start	Obs. End	T_{tot}	T_{net}	Detector	Flux
CN	Chandra/HETGS	17452	2015-07-21, 12:52	2015-07-23, 03:48	138	136	heg meg	5.16 ± 0.07 6.00 ± 0.12
	NuSTAR	90101008002	2015-07-21, 11:01	2015-07-23, 07:46	160	74	FPMA FPMB	4.63 ± 0.14 4.51 ± 0.16
		90101008004	2015-07-24, 11:36	2015-07-25, 10:51	83	38	FPMA FPMB	4.75 ± 0.81 4.47 ± 0.20
C	Chandra/HETGS	4063	2003-05-07, 03:29	2003-05-08, 20:08	145	143	heg meg	3.85 ± 0.06 4.23 ± 0.07
XN1	XMM-Newton	0721010201	2013-08-27, 04:41	2013-08-28, 11:13	110	85.5	EPIC/pn	10.87 ± 0.04
	NuSTAR	60002032002	2013-08-27, 03:41	2013-08-28, 11:41	114	44	FPMA FPMB	9.70 ± 0.22 9.50 ± 0.23
XN2	XMM-Newton	0721010301	2013-09-06, 03:24	2013-09-07, 10:36	112	92.1	EPIC/pn	5.63 ± 1.39
	NuSTAR	60002032004	2013-09-06, 02:56	2013-09-07, 10:51	114	43	FPMA FPMB	3.56 ± 0.38 3.61 ± 0.17
XN3	XMM-Newton	0721010401	2013-09-15, 18:47	2013-09-17, 03:57	119	102.0	EPIC/pn	6.08 ± 0.02
	NuSTAR	60002032006	2013-09-15, 17:56	2013-09-17, 04:01	119	44	FPMA FPMB	5.20 ± 0.18 4.59 ± 0.18
XN4	XMM-Newton	0721010501	2013-09-20, 02:47	2013-09-21, 09:37	111	92.9	EPIC/pn	6.35 ± 0.03
	NuSTAR	60002032008	2013-09-20, 03:06	2013-09-21, 11:11	119	44	FPMA FPMB	5.18 ± 0.16 5.38 ± 0.17
XN5	XMM-Newton	0721010601	2014-02-26, 08:03	2014-02-27, 22:51	140	103.9	EPIC/pn	4.47 ± 1.38
	NuSTAR	60002032010	2014-02-26, 08:16	2014-02-28, 22:56	224	110	FPMA FPMB	3.01 ± 0.53 3.00 ± 0.58

Analysis with ISIS. Combining instruments of each satellite. Binning: min 1 channel per bin and min sn of 2 for “CN” and “C” (Cash statistics); min 2 chan per bin and min sn of 2 (NuSTAR), min 1 chan per bin and min sn of 5 (XMM) for “XN” (Chi^2 stats)

Continuum

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constant*tbabs*zpcfabs*(powerlaw+zgauss)
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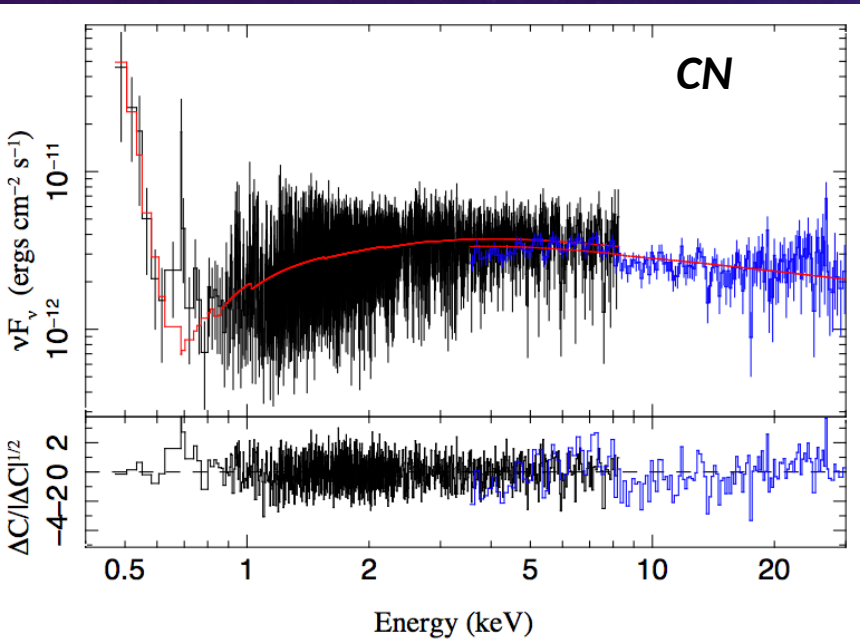
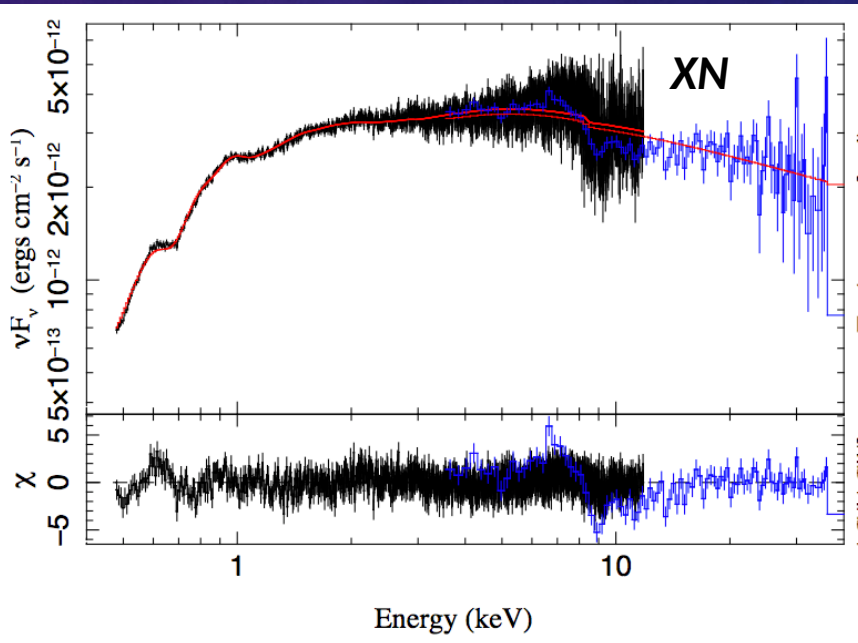
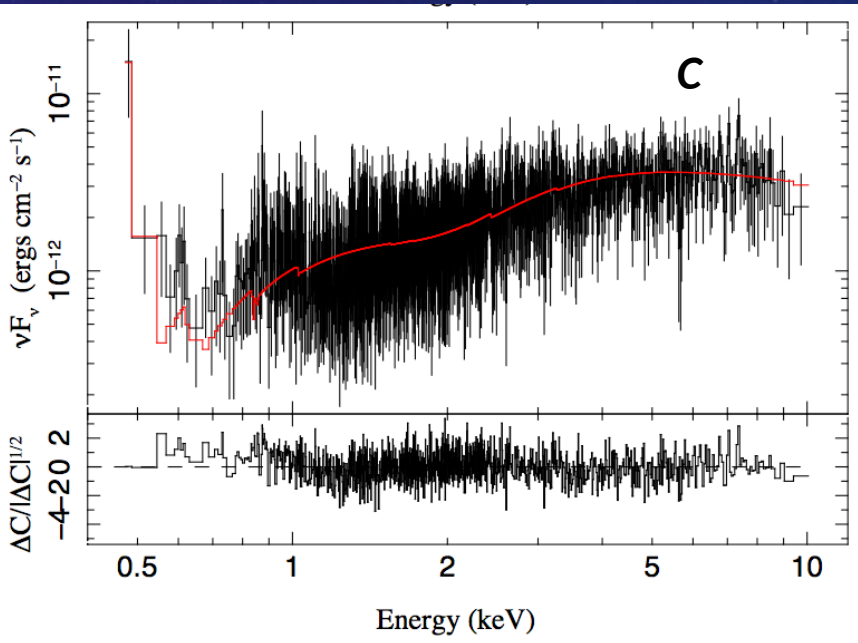
Parameters		Obs. CN	Obs. XN	Obs. C
Powerlaw	Photon Index	$2.30^{+0.0048}_{-0.012}$	$2.33^{+0.009}_{-0.008}$	$2.47^{+0.01}_{-0.01}$
	$F_{7-30keV}$	$1.28^{+0.011}_{-0.011}$	$1.24^{+0.001}_{-0.001}$	$1.27^{+0.013}_{-0.013}$
	$F_{0.4-30keV}$	$12.27^{+0.10}_{-0.10}$	$13.31^{+0.0015}_{-0.0015}$	$16.49^{+0.16}_{-0.16}$
Partial covering	N_H	$3.03^{+0.46}_{-0.53}$	$8.46^{+0.49}_{-0.42}$	$3.42^{+0.14}_{-0.11}$
	Covering factor	$0.32^{+0.009}_{-0.006}$	$0.33^{+0.009}_{-0.009}$	$0.75^{+0.004}_{-0.004}$
Soft-excess	E	$0.060^{+0.008}_{-0.01}$	$0.69^{+0.007}_{-0.007}$	$0.14^{+0.05}_{-0.03}$
	σ	$0.10^{+0.0017}_{-0.0017}$	$0.19^{+0.004}_{-0.004}$	$0.06^{+0.003}_{-0.006}$
	$F_{0.4-30keV}$	$65.59^{+13.67}_{-15.45}$	$0.97^{+0.007}_{0.007}$	$9.43^{+3.44}_{-2.87}$
Cross-calibration		$0.90^{+0.005}_{-0}$	$0.97^{+0.007}_{-0.007}$	-
C or Chi /dof		1693.48 / 1608	2240.58 /1703	1409.60 / 1345







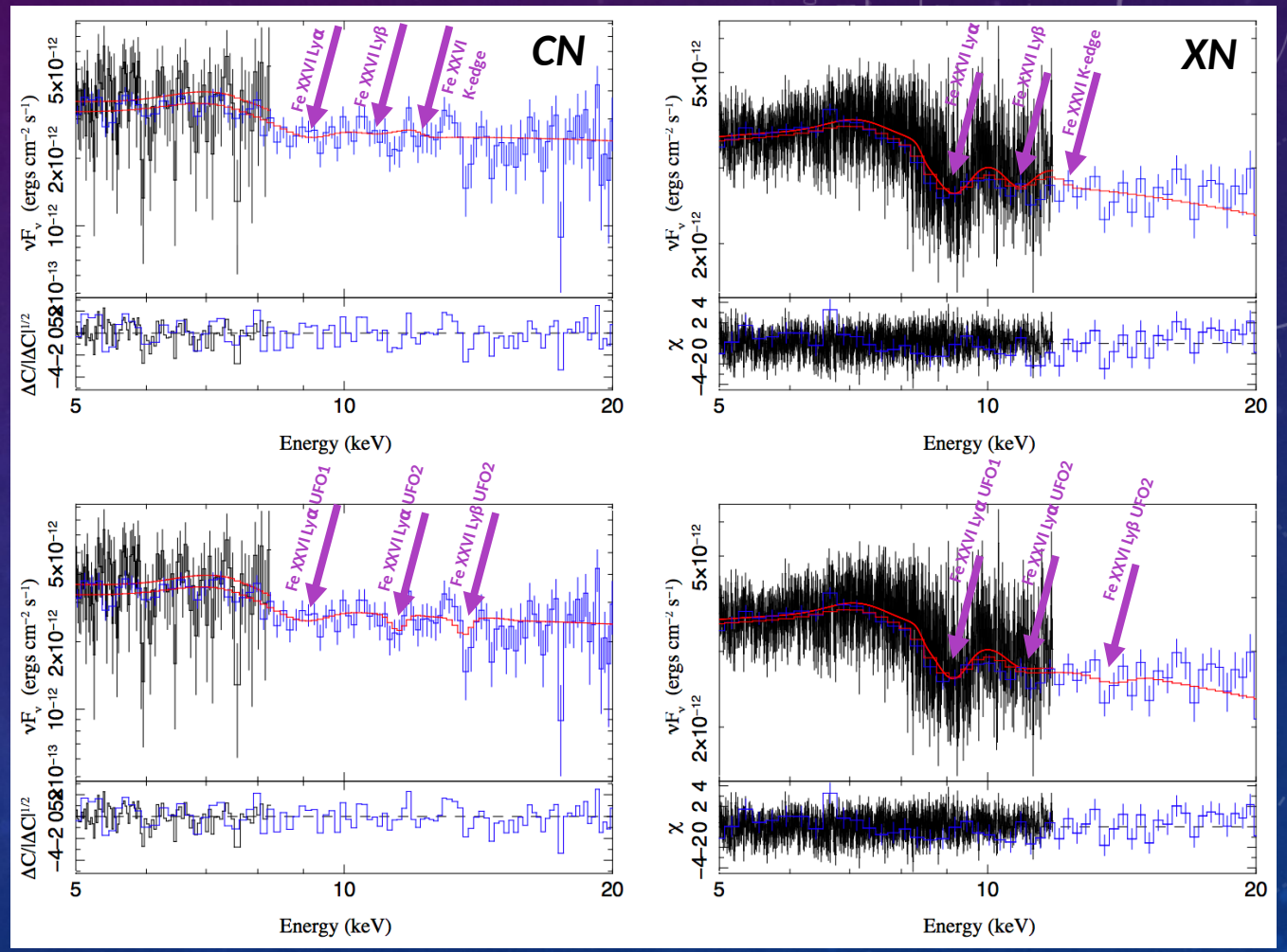
Absorption features above 9 keV – fit with Gaussian lines

1 UFO

Parameters		Obs. CN				Obs. XN			
Line		E_{rest}	E_{obs}	EW (or τ)	sig.	E_{rest}	E_{obs}	EW (or τ)	sig.
Fe XXVI Lyα	em.	7.04	$5.95^{+0.446}_{-1.554}$	233^{+46}_{-46}	28.28	7.13	$6.02^{+0.519}_{-1.481}$	91^{+16}_{-16}	96.50
	abs.	9.16	$7.74^{+0.267}_{-0.188}$	259^{+71}_{-71}	15.55	9.15	$7.73^{+0.043}_{-0.043}$	212^{+23}_{-23}	134.18
Fe XXVI Lyβ abs.		10.84	$9.16^{+0.316}_{-0.223}$	142^{+88}_{-88}	3.09	10.83	$9.15^{+0.051}_{-0.051}$	132^{+29}_{-29}	23.58
Fe XXVI K-edge		12.20	$10.30^{+0.355}_{-0.250}$	$0.10^{+0.05}_{-0.05}$	4.31	12.18	$10.29^{+0.057}_{-0.058}$	$0.06^{+0.03}_{-0.03}$	5.06
v_{out}	em.	$-0.010^{+0.02}_{-0}$				$-0.022^{+0.012}_{-0.012}$			
	abs.	$-0.267^{+0.0312}_{-0.023}$				$-0.266^{+0.0051}_{-0.0052}$			
σ	em.	$0.600^{+0}_{-0.0791}$				$0.442^{+0.0874}_{-0.0769}$			
	abs.	$0.457^{+0.1432}_{-0.1568}$				$0.319^{+0.0423}_{-0.0390}$			
C or Chi / dof		376.94 / 356 =1.059				1133.66 / 1177 =0.9632			

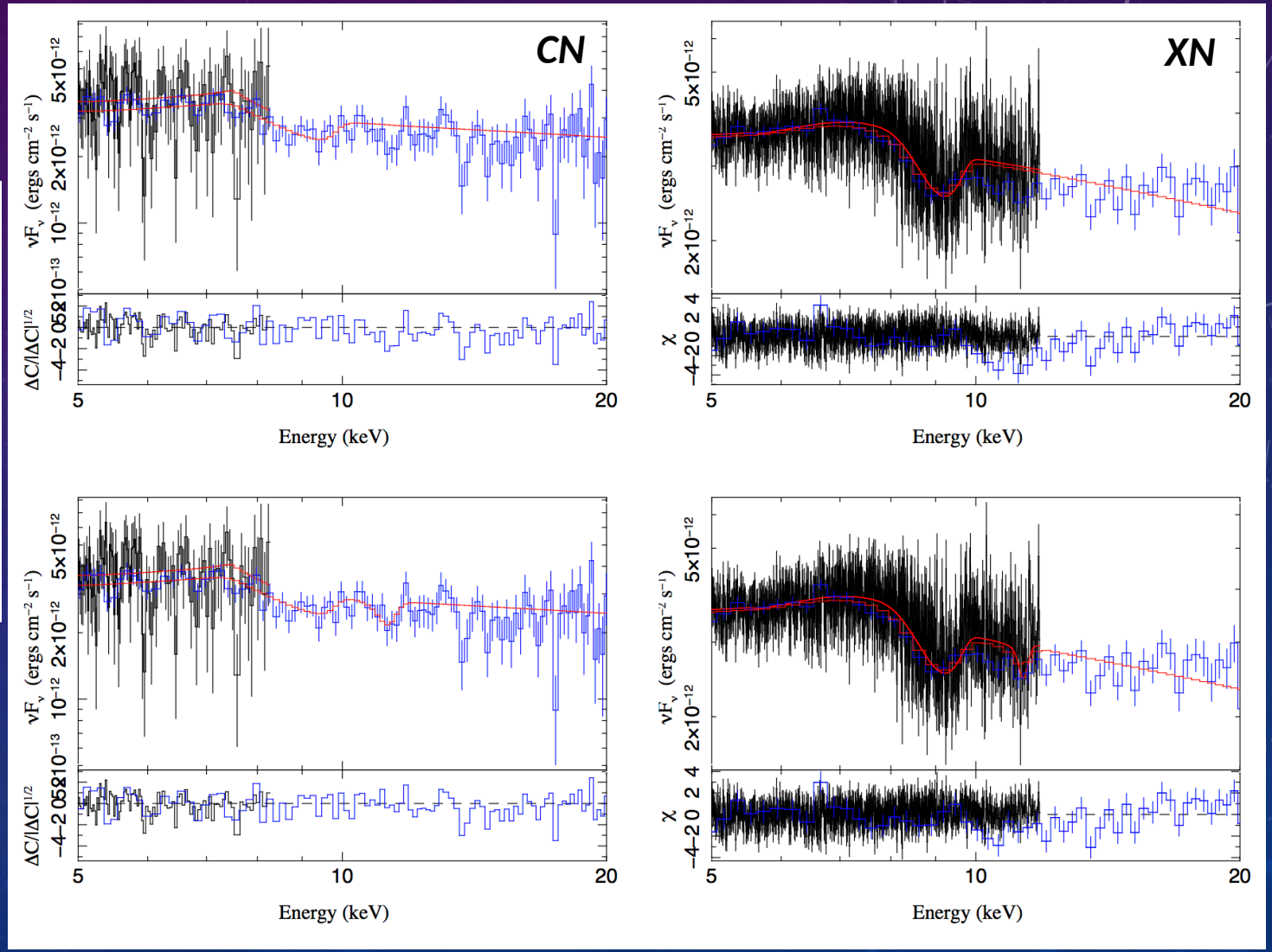
2 UFOs

Parameters		Obs. CN				Obs. XN			
	Line	E_{rest}	E_{obs}	EW (or τ)	sig.	E_{rest}	E_{obs}	EW (or τ)	sig.
UFO 1&2	Fe XXVI Lyα em.	7.11	$6.01^{+0.446}_{-1.554}$	231^{+46}_{-46}	27.05	7.13	$6.03^{+0.519}_{-1.481}$	97^{+15}_{-15}	104.29
UFO 1	Fe XXVI Lyα abs.	9.08	$7.67^{+0.177}_{-0.168}$	231^{+56}_{-56}	16.39	9.13	$7.71^{+0.041}_{-0.042}$	159^{+18}_{-18}	126.36
	Fe XXVI Lyβ abs.	10.74	$9.07^{+0.210}_{-0.199}$	462^{+0}_{-0}	-1.73	10.80	$9.13^{+0.048}_{-0.049}$	432^{+11}_{-11}	1.89
	Fe XXVI K-edge	12.09	$10.21^{+0.236}_{-0.224}$	$0.042^{+0.032}_{-0.058}$	0.21	12.15	$10.26^{+0.054}_{-0.055}$	$0.010^{+0}_{-0.012}$	-0.71
UFO 2	Fe XXVI Lyα abs.	11.63	$9.82^{+0.658}_{-0.378}$	184^{+134}_{-134}	7.55	11.59	$9.79^{+0.420}_{-0.338}$	161^{+57}_{-57}	28.68
	Fe XXVI Lyβ abs.	13.77	$11.63^{+0.779}_{-0.447}$	184^{+147}_{-147}	4.88	13.72	$11.59^{+0.497}_{-0.400}$	161^{+77}_{-77}	5.18
	Fe XXVI K-edge	15.49	$13.08^{+0.877}_{-0.503}$	$0.010^{+0}_{-0.076}$	0.02	15.43	$13.03^{+0.539}_{-0.450}$	$0.010^{+0}_{-0.005}$	-1.78
UFO 1&2	v_{out} em.	$-0.020^{+0.0212}_{-0}$				$-0.023^{+0.0114}_{-0.0033}$			
UFO 1	v_{out} abs.	$-0.258^{+0.0212}_{-0.0208}$				$-0.263^{+0.0049}_{-0.0050}$			
UFO 2	v_{out} abs.	$-0.472^{+0.0489}_{-0.0311}$				$-0.469^{+0.0321}_{-0.0279}$			
UFO 1&2	σ em.	$0.600^{+0}_{-0.077}$				$0.449^{+0.0808}_{-0.0710}$			
UFO 1	σ abs.	$0.474^{+0.1256}_{-0.1262}$				$0.282^{+0.0462}_{-0.0438}$			
UFO 2	σ abs.	$0.3^{+0.3}_{-0}$				$0.560^{+0.0400}_{-0.2465}$			
C or Chi / dof		374.38 / 357=1.049				1136.31 / 1178=0.9646			



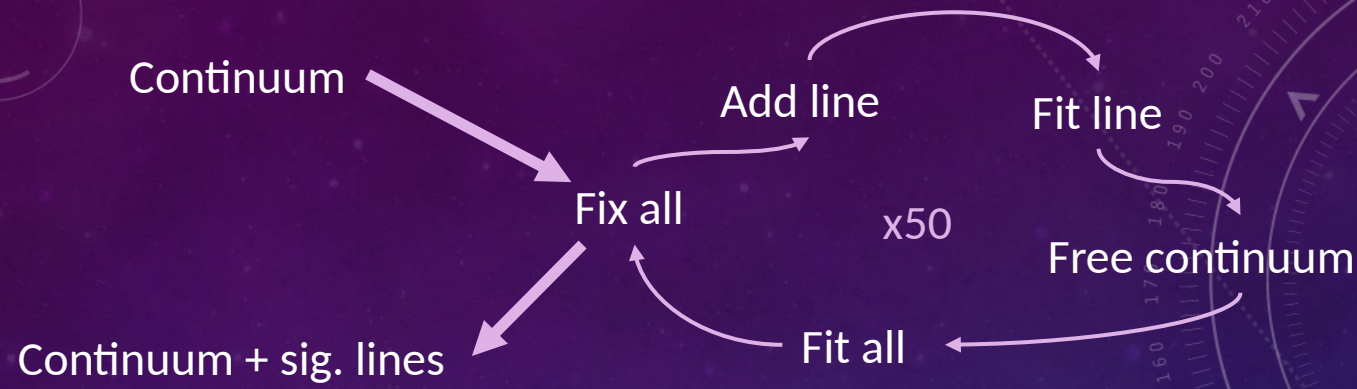
Absorption features above 9 keV – fit with P-Cygni profiles

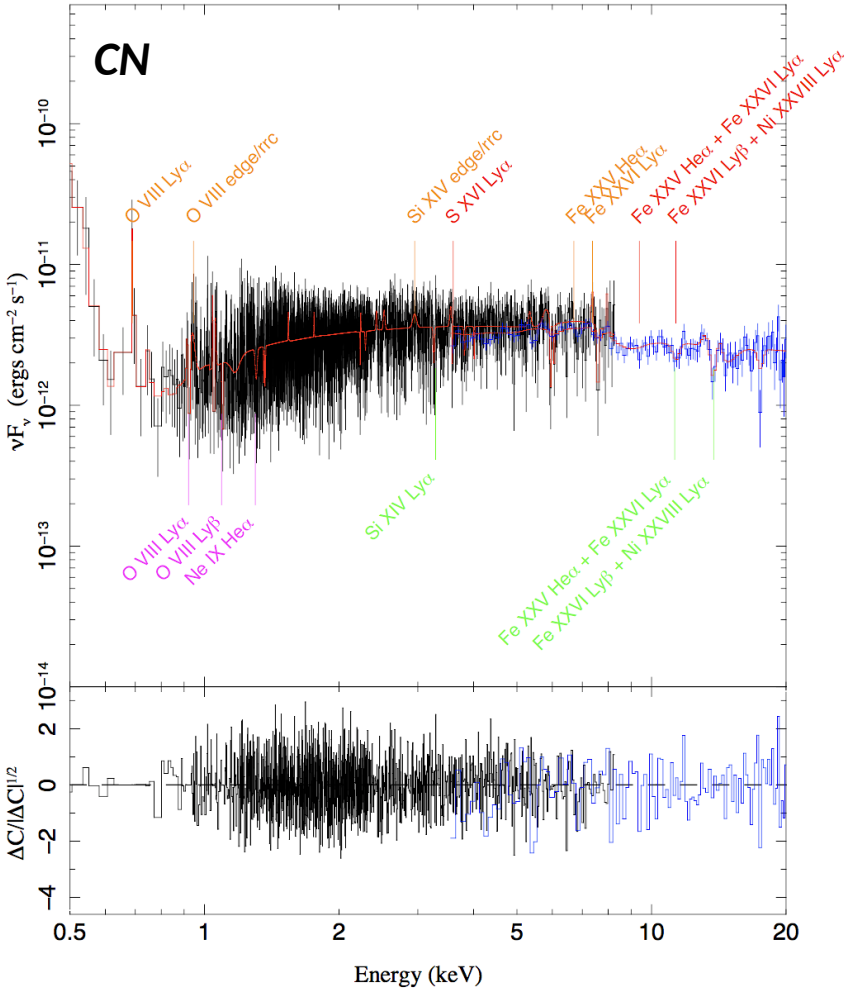
Parameters		Obs. CN	Obs. XN
P-Cygni 1&2	E0	$6.32^{+0.05}_{-0.05}$	$6.35^{0.04}_{-0.04}$
P-Cygni 1	v_{inf}	$-0.32c^{+0.012}_{-0.027}$	$-0.32c^{+0.049}_{-0.012}$
	τ_{tot}	$0.17^{+0.02}_{-0.03}$	$0.13^{+0.001}_{-0.016}$
	α_1	$0.93^{+1.33}_{-0.84}$	$3.60^{+1.38}_{-0.37}$
	α_2	$0.17^{+0.77}_{-0.42}$	$1.58^{+0.91}_{-0.91}$
	C or Chi / dof	389.6/364=1.07	1187.5/1181=1.005
P-Cygni 2	v_{inf}	$-0.52c^{+0.024}_{-0.015}$	$-0.53c^{+0.034}_{-0.022}$
	τ_{tot}	$0.04^{+0.004}_{-0.004}$	$0.02^{+0.003}_{-0.005}$
	α_1	$6.17^{+3.28}_{-7.18}$	$4.13^{+1.87}_{-3.22}$
	α_2	$-0.42^{+0.68}_{-0.63}$	$-0.68^{+0.22}_{-0.17}$
	C or Chi / dof	376.6/365=1.03	1162.5/1182=0.98
ΔC or $\Delta\chi^2$		13.0	25.0

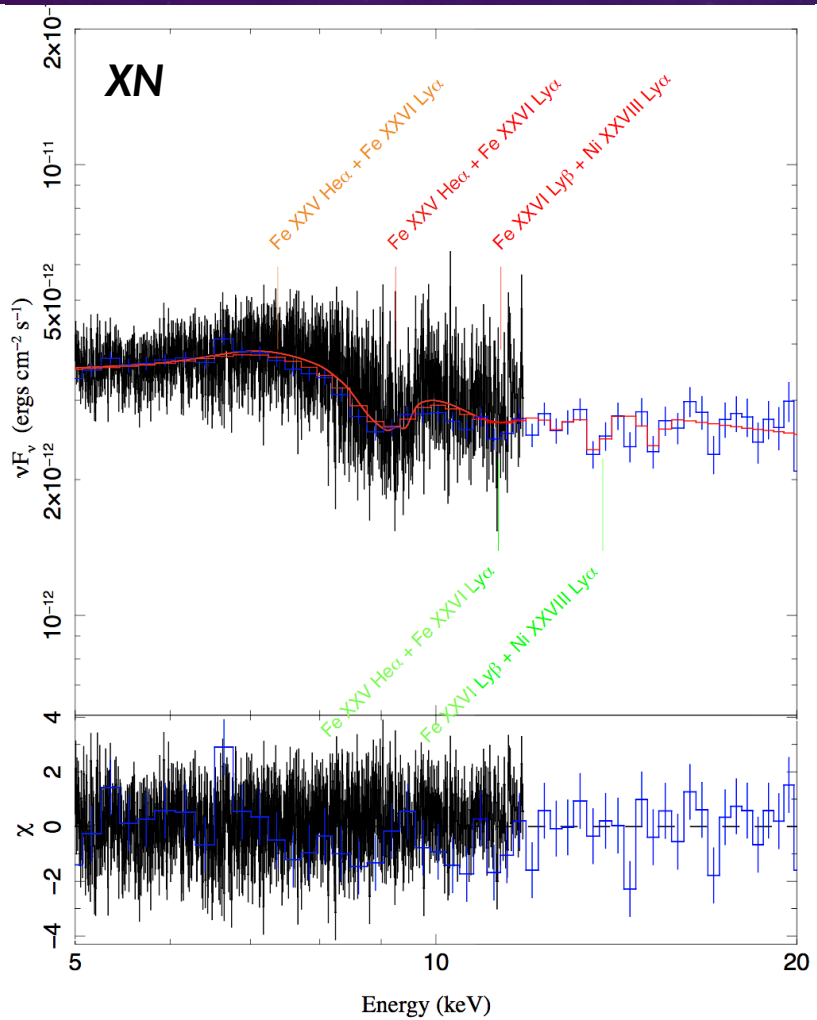


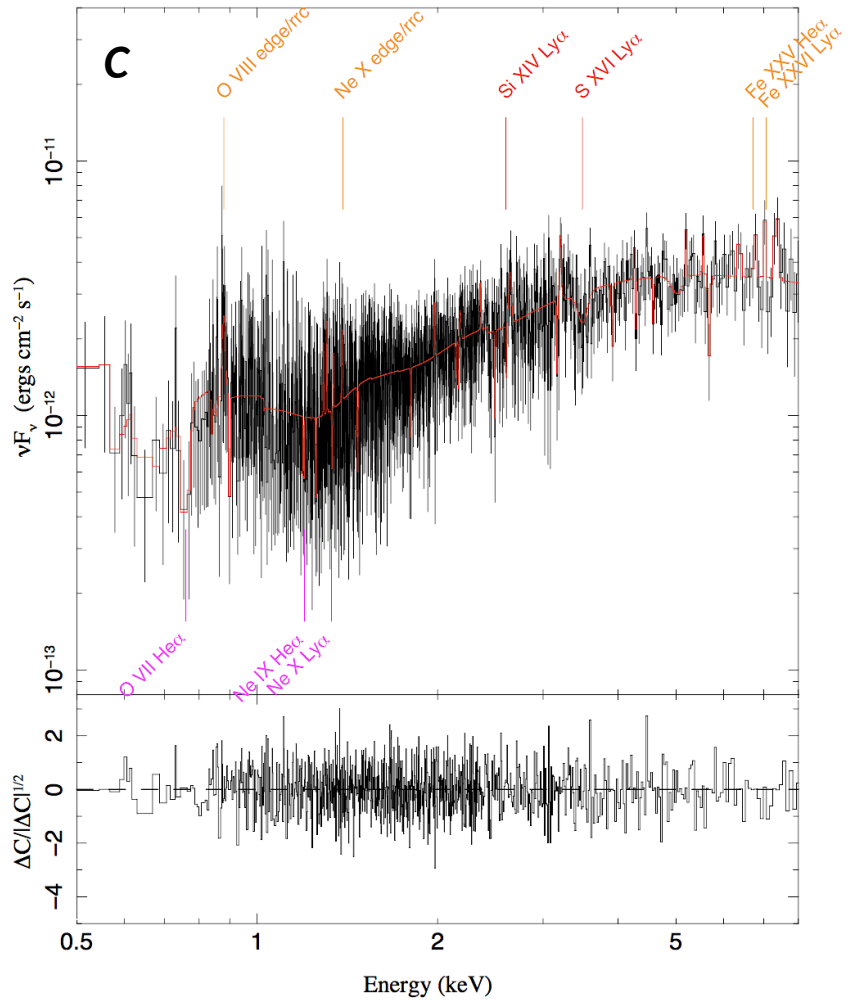
Expansion of spherically symmetric stellar winds (Done+07)

Blind line search





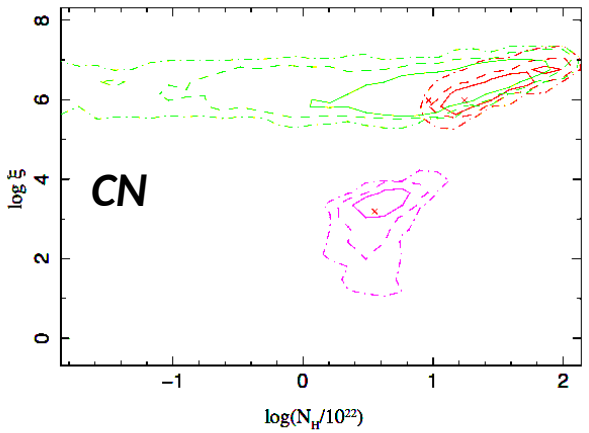


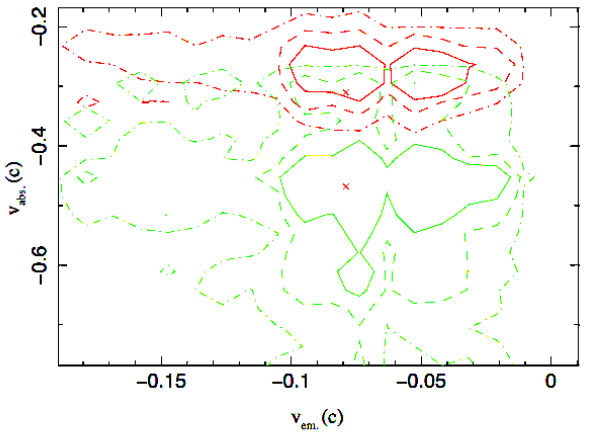


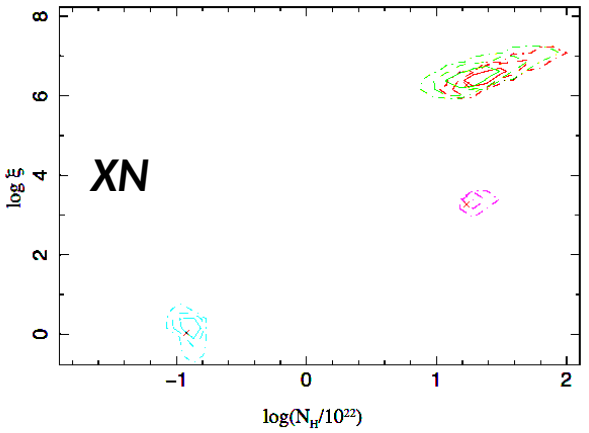
Photoionization modeling

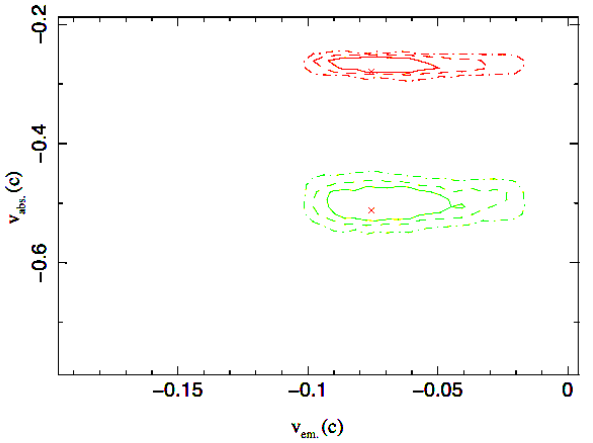
cst*gal*(wa)*ufo1*(ufo2)*[photemis+pc*pow+se]

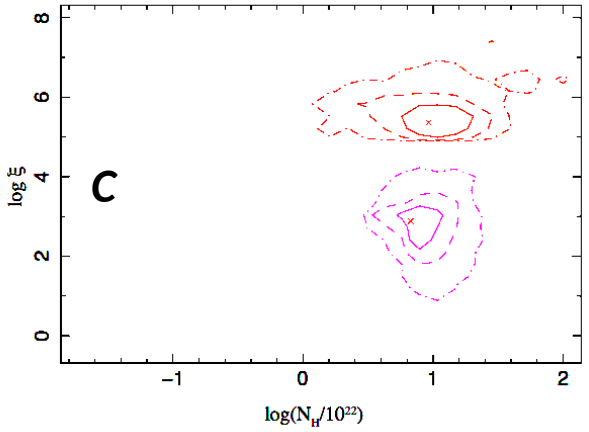
Parameters		"CN"	"XN"	"C"
Galactic absorption	N_H^{gal} (10^{22} cm^{-2})	0.24 (f)	(f)	(f)
Continuum	Γ	$2.21^{+0.012}_{-0.008}$	$2.37^{+0.003}_{-0.003}$	$2.5^{+0.001}_{-0.004}$
	$F_{0.4-30\ \mathrm{keV}}$ (10^{-12} erg s^{-1} cm^{-2})	$11.30^{+0.10}_{-0.10}$	$15.33^{+0.018}_{-0.018}$	$17.10^{+0.17}_{-0.17}$
Wind emission	log(ξ/erg cm s^{-1})	$6.03^{+0.49}_{-0.28}$	$6.97^{+0.20}_{-0.51}$	$5.19^{+0.36}_{-0.09}$
	norm ($\times 10^{-2}$)	$8.5^{+5.2}_{-4.2}$	$5.8^{+0.1}_{-2.2}$	$5.3^{+0.092}_{-0.028}$
	v_{turb} (km s^{-1})	20000 (f)	(t)	(t)
	v_{out} (c)	$-0.056^{+0.006}_{-0.042}$	$-0.089^{+0.020}_{-0.001}$	$-0.026^{+0.002}_{-0.021}$
Partial covering	log(N_H/10^{22} cm^{-2})	$0.52^{+0.12}_{-0.13}$	$1.22^{+0.01}_{-0.04}$	$0.83^{+0.13}_{-0.08}$
	log(ξ/erg cm s^{-1})	$3.20^{+0.18}_{-0.58}$	$3.04^{+0.02}_{-0.21}$	$2.89^{+0.08}_{-0.68}$
	c_f	$0.33^{+0.046}_{-0.054}$	$0.40^{+0.001}_{-0.003}$	$0.77^{+0.03}_{-0.04}$
	v_{turb} (km s^{-1})	20000 (t)	(t)	(t)
	v_{out} (c)	$-0.289^{+0.025}_{-0.030}$	$-0.268^{+0.007}_{-0.004}$	$-0.236^{+0.025}_{-0.064}$
Wind absorption 1	log(N_H/10^{22} cm^{-2})	$1.32^{+0.39}_{-0.22}$	$1.90^{+0.05}_{-0.46}$	$0.99^{+0.12}_{-0.24}$
	log(ξ/erg cm s^{-1})	$6.03^{+0.49}_{-0.28}$ (t)	$6.97^{+0.20}_{-0.51}$(t)	$5.19^{+0.36}_{-0.09}$ (t)
	v_{turb} (km s^{-1})	20000 (t)	(t)	(t)
	v_{out} (c)	$-0.289^{+0.025}_{-0.030}$ (t)	$-0.268^{+0.007}_{-0.004}$ (t)	$-0.236^{+0.025}_{-0.064}$ (t)
Wind absorption 2	log(N_H/10^{22} cm^{-2})	$1.13^{+0.21}_{-1.31}$	$1.71^{+0.09}_{-0.38}$	-
	log(ξ/erg cm s^{-1})	$6.03^{+0.49}_{-0.28}$ (t)	$6.97^{+0.20}_{-0.51}$(t)	-
	v_{turb} (km s^{-1})	20000 (t)	(t)	-
	v_{out} (c)	$-0.478^{+0.031}_{-0.094}$	$-0.483^{+0.001}_{-0.033}$	-
Warm absorption	log(N_H/10^{22} cm^{-2})	-	$-0.99^{+0.009}_{-0.002}$	-
	log(ξ/erg cm s^{-1})	-	$0.73^{+0.05}_{-0.21}$	-
	v_{turb} (km s^{-1})	-	100 (f)	-
	v_{out} (c)	-	0 (f)	-
Soft-excess	E (keV)	$0.40^{+0.07}_{-0.02}$	$0.55^{+0.008}_{-0.007}$	$0.087^{+0.041}_{-0.010}$
	σ (keV)	$0.05^{+0.008}_{-0.014}$	$0.24^{+0.003}_{-0.003}$	$0.057^{+0.0007}_{-0.0002}$
	$F_{0.4-30\ \mathrm{keV}}$ (10^{-12} erg s^{-1} cm^{-2})	$62.9^{+13.8}_{-15.8}$	$2.27^{+0.011}_{-0.011}$	$9.14^{+2.98}_{-3.60}$
Cross-calibration		$0.90^{+0.014}_{-0}$	$0.98^{+0.006}_{-0.007}$	
C or χ^2 / dof		1652.2 / 1611	1811.3 / 1706	1384.2/1325
ΔC or $\Delta\chi^2$ for 2nd UFO		5.4	49.7	-

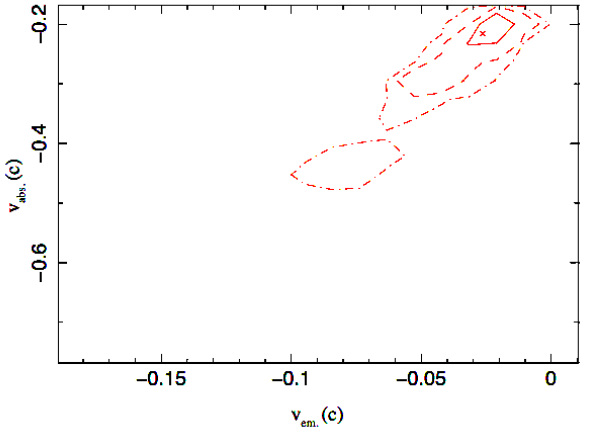












UFOs parameters

See Matzeu+16

See Danehkar+17

$$\dot{M}_{out} \sim \Omega N_H m_p v_{out} R_{in}$$

UFO 1: $\dot{M}_{out}$= 3-20% $\dot{M}_{Edd}$

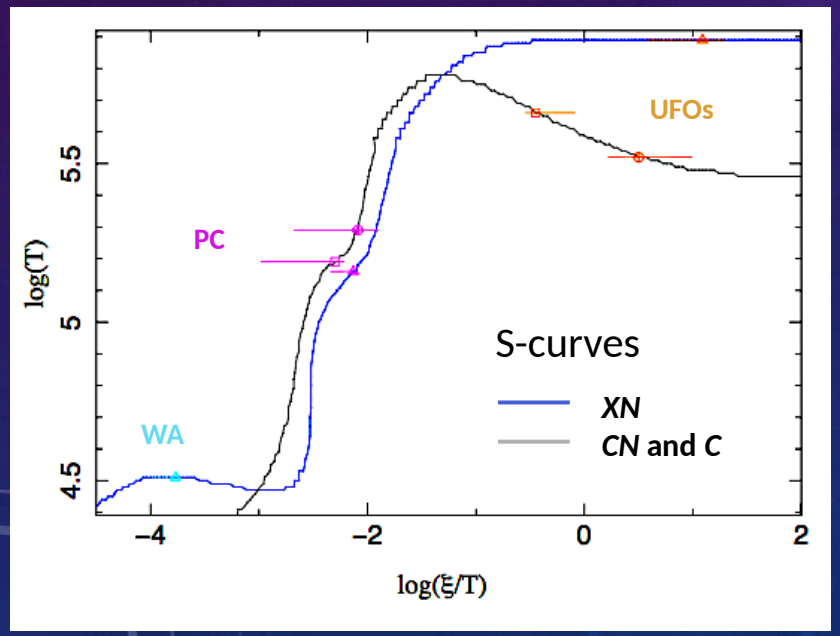
UFO 2: $\dot{M}_{out}$= 7-40% $\dot{M}_{Edd}$

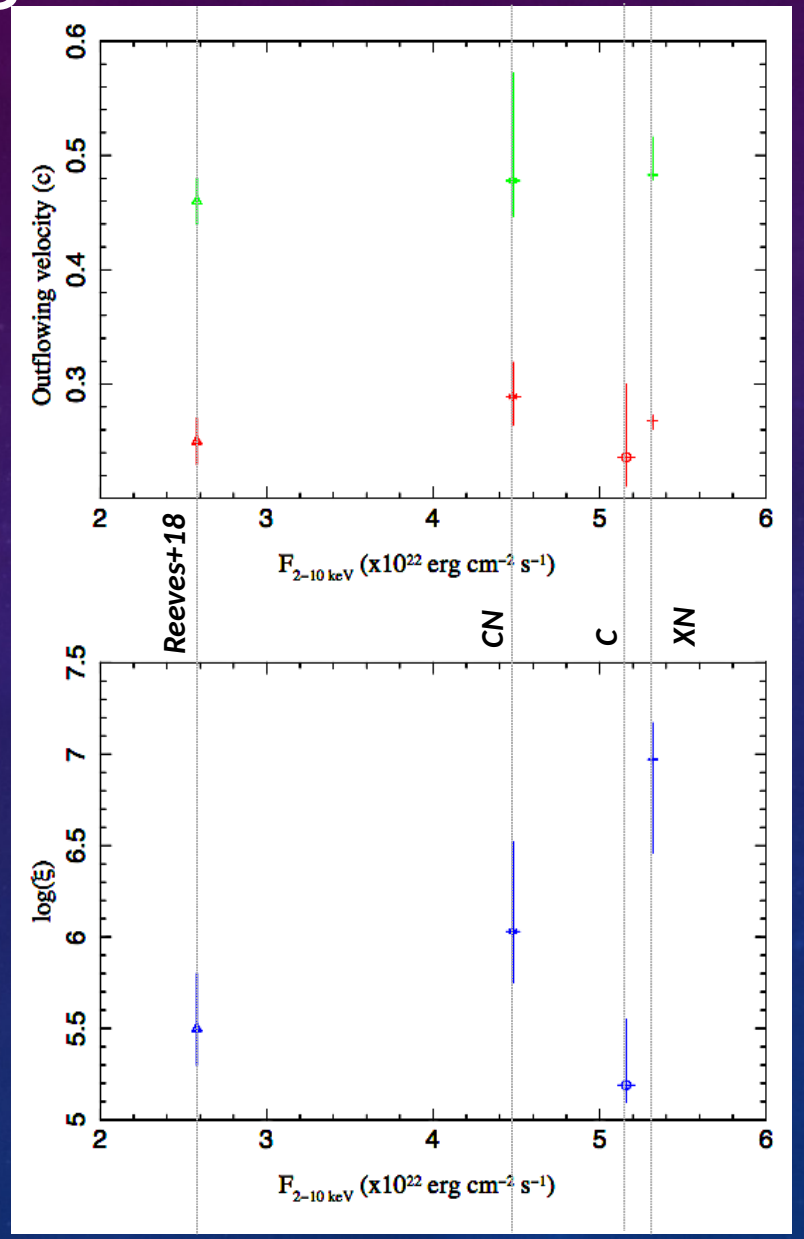
$$P_{kin} = 0.5 \dot{M} v_{out}^2$$

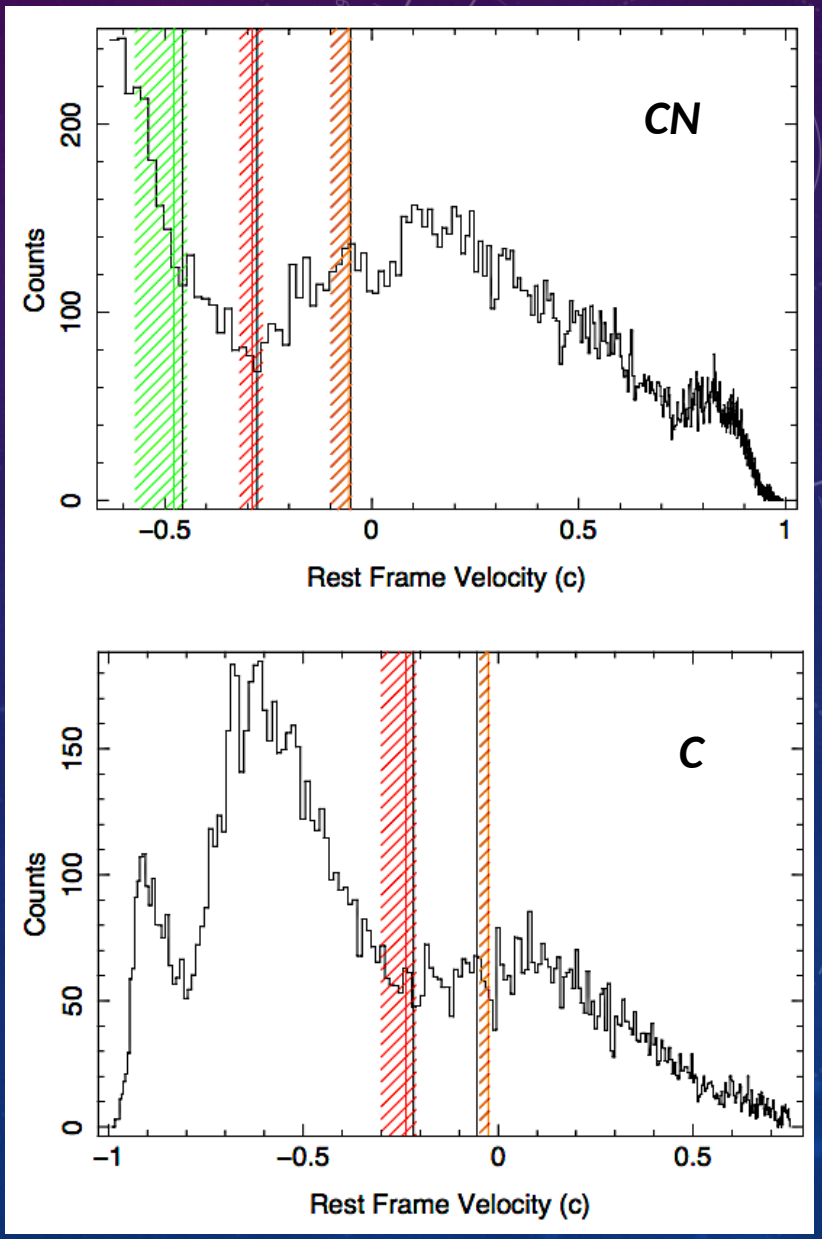
CN: P_{kin}= 2% L_{Edd}

XN: P_{kin}= 7-8% L_{Edd}

C: P_{kin}= 0.8% L_{Edd}







Conclusion

- Study of simultaneous Chandra/HETGS + NuSTAR data (2015), plus analysis of Chandra/HETGS observation from 2003, plus re-analysis of observations XMM-Newton + NuSTAR (2013-2014)
- Confirmation of the presence of the UFO as found in previous works (e.g. Nardini+15) with v_{out}=-0.24-0.29c
- Confirmation of the presence of a faster UFO as found by Reeves+18 with v_{out}=-0.48c, even in XMM+NuSTAR!
- Use of several methods that lead to the same results: fits with sets of Gaussians, P-Cygni profiles, Blind line search, Photoionization modeling, Velocity spectrum

Thanks !