AGN winds in PG 1114+445: feedback from nuclear to galaxy scales

R. Serafinelli[1,2,3] F. Tombesi[1,4,5,6], F. Vagnetti[1], E. Piconcelli[6], M. Gaspari[7], F. G. Saturni[6,8]

[1]Università di Roma "Tor Vergata", [2]"Sapienza" Università di Roma [3]INAF – Osservatorio Astronomico di Brera [4]NASA – Goddard Space Flight Center
[5]University of Maryland [6]INAF – Osservatorio Astronomico di Roma [7]Princeton University [8]ASI - Space Science Data Center

ABSTRACT

Extensive evidence in the last few decades suggests that the evolution of supermassive black holes (SMBHs) and that of their host galaxies are tightly related. Powerful winds driven by Active Galactic Nuclei (AGNs) are often invoked as a fundamental mechanism by which the SMBH transfers its energy on the surrounding environment. Here, we present the spectral analysis of 12 XMM-Newton EPIC archival observations of PG 1114+445, a type-1 quasar at $z = 0.144$, showing the presence of three layers of ionized absorbing material with outflow velocities ranging from 500 km s^{-1} up to $0.15c$. Together with a UFO and a slow, moderately ionized warm absorber, we detect the presence of a "low-ionization UFO", that we interpret as the observational evidence of the entraining of the inner UFO on the surrounding ambient medium, represented by the warm absorber. Independently on the assumption of momentum- or energy-driven scenario, we obtain a low value for the clumpiness, $C_v \sim 10^{-3}$, which agrees with a narrow-line region origin at ~ 100 pc.

INTRODUCTION

In the hard ($E \geq 6$ keV) X-rays, mildly relativistic ($v \sim 0.05 - 0.4c$, where c is the speed of light) and high-ionization ($\xi \sim 10^4 - 10^6$ erg cm s^{-1}) winds, known as ultra-fast outflows (UFO), are observed in the spectra of many Seyfert galaxies and quasars (e.g., Tombesi et al. 2010). Slower ($v \sim 100 - 1000$ km s^{-1}) and less ionized ($\xi < 100$ erg cm s^{-1}) outflows, known as warm absorbers (WA), are also commonly observed in the X-ray spectra of many AGN (e.g., Blustin et al. 2005). These two types of outflows have been found to be correlated (Tombesi et al. 2013). However, recent detections of fast outflows also in the soft X-ray band ($E < 2$ keV) (Gupta et al. 2013, 2015, Longinotti et al. 2015, Reeves et al. 2016, Pounds et al. 2016) challenge such initial simple correlations, finding velocities comparable to typical UFOs but with lower ionization states.

DATA ANALYSIS

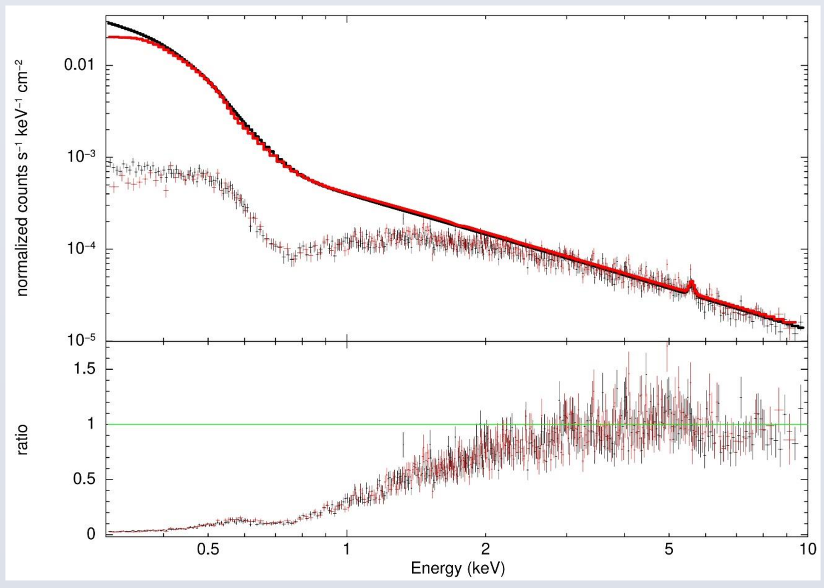

Fig. 1. A simple power law ($\Gamma \sim 1.6$) model, with iron Kα line and soft excess shows significant residuals in the E = $0.3 - 2$ keV band. **An absorber is needed**

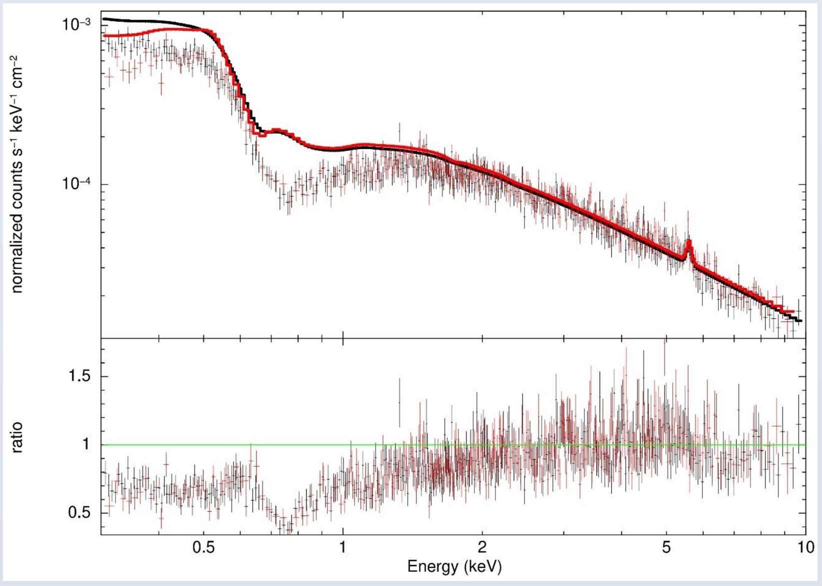

Fig. 2. A warm absorber with $v \simeq 500$ km s^{-1} (Mathur et al. 1998), significantly reduced data residuals. **A second absorber is also needed.**

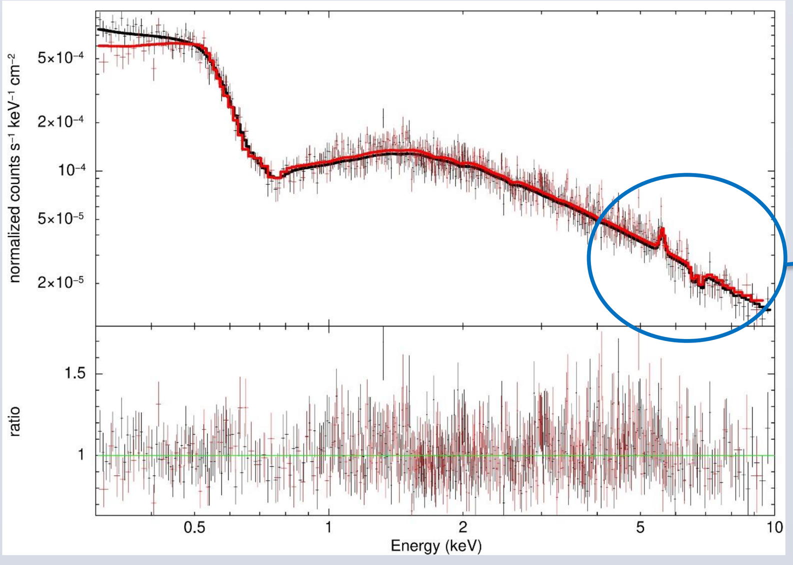

Fig. 3 A second absorber with v=(0.120 ± 0.029)c further reduced data residuals.

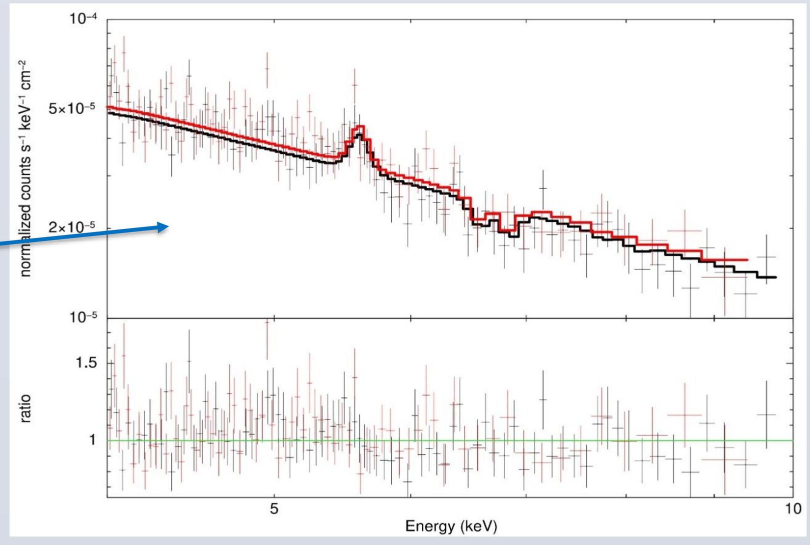

Fig. 4 An ultra-fast outflows (UFO) with $v = (0.145 \pm 0.035)c$ in the hard X-ray band is also needed

Parameter	Median	Units
$\log N_{H,1}$	21.88 ± 0.05	cm^{-2}
$\log \xi_1$	0.35 ± 0.04	erg cm s^{-1}
$v_{1,out}$*	~ 530	km s^{-1}
$\log N_{H,2}$	21.5 ± 0.2	cm^{-2}
$\log \xi_2$	0.50 ± 0.36	erg cm s^{-1}
$v_{2,out}$	0.120 ± 0.029	c
$\log N_{H,3}$**	22.9 ± 0.3	cm^{-2}
$\log \xi_3$	4.04 ± 0.29	erg cm s^{-1}
$v_{3,out}$	0.145 ± 0.035	c

Table 1. Median values and median absolute deviations of velocity, ionization and column density of the three absorbers.

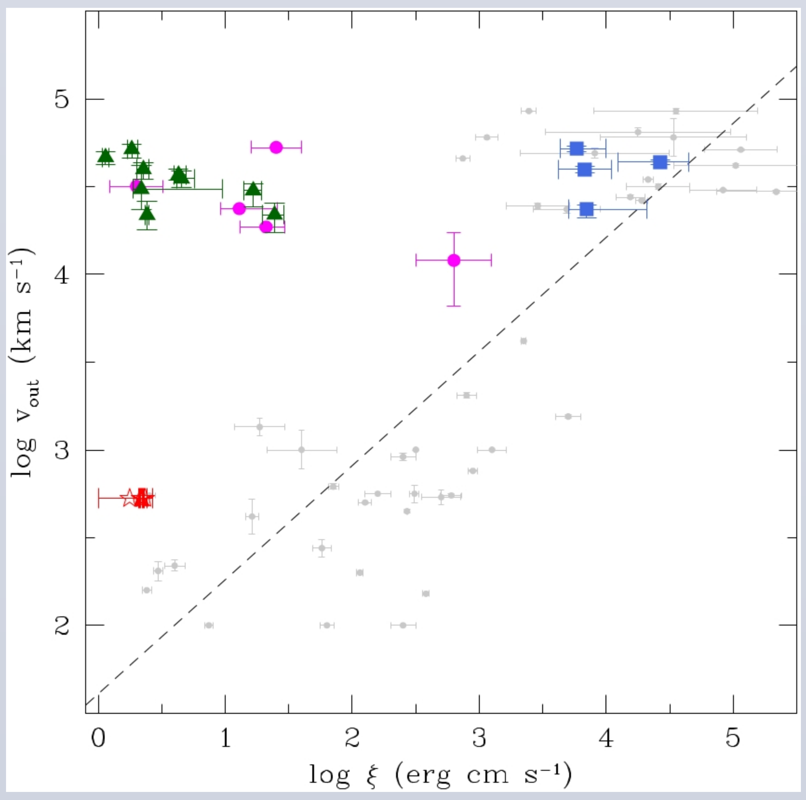

Fig. 5. Outflow velocity v_{out} versus ionization state ξ. The grey points represent literature values from Tombesi et al. (2013). Both high-ξ (blue squares) and low-ξ UFO (green triangles), together with the WA (red stars) of PG 1114+445 are shown. Magenta points represent past detection of moderately ionized UFOs.

RESULTS AND INTERPRETATION

The low-ionization UFO is somehow puzzling: it shares the same ionization and column density values with the warm absorber, but it is as fast as the ultra-fast outflow (see Table 1 and Fig. 5).

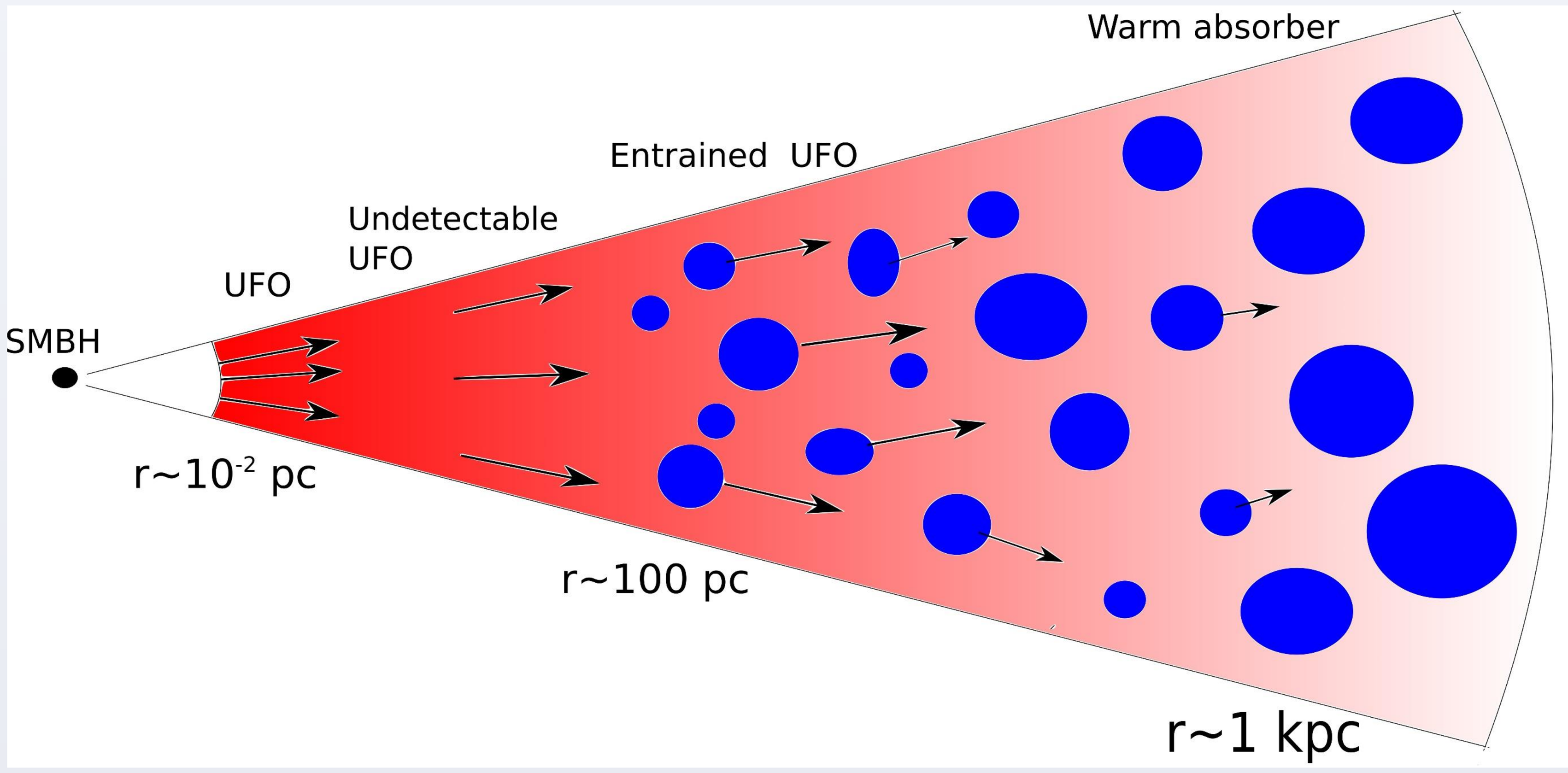

Fig. 6. Diagram of the multi-phase structure of the outflows in PG 1114+445. A UFO is present in the inner part of the AGN, with decreasing density (represented by shades of red). At larger distances from the SMBH, the density of the UFO is so low that it becomes undetectable, until it interacts with the clumpy ambient gas (blue clouds) at $r \simeq 100$ pc, entraining it via Rayleigh-Taylor and Kelvin-Helmholtz instabilities. This gas is pushed at velocities comparable with the UFO, resulting in an Entrained Ultra-Fast Outflow, that is observable in the soft X-ray since the gas retains its ionization state and column density. The farther ambient gas remains unaffected by the UFO and therefore moves at significantly lower line-of-sight velocities, being hence observable as a warm absorber. Figure not on scale.

The low-ionization UFO must be produced by the **interaction between the inner disk wind with the unperturbed ambient medium**, identified with the warm absorber. The UFO entrains the warm absorber via hydrodynamical instabilities, such as Rayleigh-Taylor and Kelvin-Helmholtz, **pushing the ambient medium to comparable velocities** (see Fig. 6). For this reason we name this absorber the **ENTRAINED ULTRA-FAST OUTFLOW (E-UFO).**

	r/r_s	r (pc)	n (cm^{-3})	$\dot{M}_{out}$ ($M_\odot$/yr)	$\dot{P}_{out}/\dot{P}_{rad}$	$\dot{E}_K/L_{bol}$
Warm Absorber						
r_{min}	3.2×10^5	18	3.6×10^5	$2.63C_v$	$0.05C_v$	$4.2 \times 10^{-5}\,C_v$
r_{max}	8.6×10^8	4.9×10^4	0.05	$7.1 \times 10^3\,C_v$	$130C_v$	$0.11C_v$
Entrained UFO						
r_{var}	1.7×10^6	109	7.5×10^3	$401C_v$	$495C_v$	$29C_v$
Ultra-Fast Outflow						
r_{min}	57	3.2×10^{-3}	2.3×10^9	0.41	0.62	0.04

Table 2. Distance and energetics of the three absorbers. Values of the distance in both units of Schwarzschild radius and parsec are reported, with the estimated density n at such distance, the mass outflow rate in units of solar masses per year, the momentum rate in units of the radiation momentum rate $\dot{P}_{rad} = L_{bol}/c$ and the kinetic power in units of L_{bol}. C_v is the filling factor, assumed to be unitary for the UFO and parametric for the E-UFO and WA

Independently of the assumption of momentum- or energy-conserving impact between the UFO and the E-UFO (see Costa et al. 2014) we obtain a **clumpiness of $C_v \simeq 1.3 \times 10^{-3}$**, which is supported by various models (e.g. Zubovas & Nayakshin 2014, Gaspari & Sadowski 2017). The mass outflow rate of the E-UFO is slightly larger than the UFO, implying a snowplow-like effect on the ambient medium.

CONCLUSIONS

- **We found three absorbers in the X-ray spectra of PG 1114+445: a warm absorber (WA), an ultra-fast outflow (UFO) and a UFO with low ionization.**
- **Ultra-fast outflows entrain the host galaxy ambient medium, pushing it to comparable velocities. This produces the observational absorption features of the low-ionization UFO, that we call Entrained UFO (E-UFO).**
- **We find that the ambient medium is very clumpy, with clumpiness $C_v \sim 10^{-3}$ comparable with a narrow-line region origin.**

References

● Blustin et al. 2005, A&A, 431, 111 ● Gaspari & Sadowski 2017, ApJ, 837, 159 ● Gupta et al. 2013, ApJ, 772, 66 ● Gupta et al. 2015, ApJ, 798, 4 ● Longinotti et al. 2015, ApJL, 813, L39 ● Pounds et al. 2016, MNRAS, 459, 4389 ● Reeves et al. 2016, ApJ, 824, 20 ● Tombesi et al. 2010, A&A, 521, A57 ● Tombesi et al. 2013, MNRAS, 430, 1102 ● Zubovas & Nayakshin, 2014, MNRAS, 440, 2625

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