Tracing Supermassive Black Hole Feedback, from the Event Horizon up to Cluster Scales

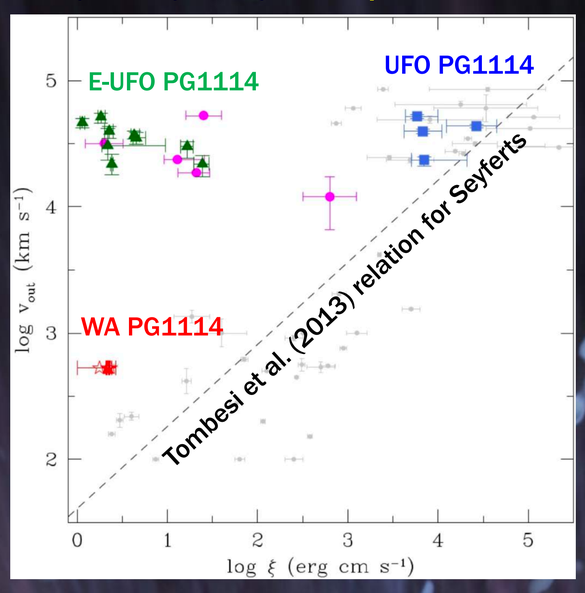
F. Tombesi, A. Luminari, R. Serafinelli, R. Smith, A. Tumer, H. Bourdin, E. Piconcelli, S. Veilleux, F. Vagnetti, M. Gaspari

Observations performed in the last decades have shown that supermassive black holes (SMBHs) and cosmic structures are not separate elements of the Universe. While galaxies have sizes roughly ten orders of magnitude larger than SMBHs, black holes would not exist without matter feeding them, and cosmic structures would not be the same without feedback from SMBHs. Powerful winds/jets in active galactic nuclei (AGN) may be the basis of this co-evolution. Synergistic observations in the X-rays and other wavebands has been proven to be fundamental to map AGN winds from the event horizon up to galaxy scales, providing a promising avenue to study the multi-phase SMBH feeding and feedback processes. The combination of X-ray, optical/UV, IR, and mm observations of ULIRGs and quasars provide a very promising avenue to link the SMBH activity to molecular outflows that may be able to quench star formation. Moreover, spatially resolved, spectroscopic analysis of AGN in clusters will allow to probe the multiphase medium ranging from galactic to up cluster scales. Revolutionary improvements are expected from upcoming observatories, such as XARM and Athena, in synergy with JWST, ALMA, E-ELT, SKA.

Entrained Ultra-Fast Outflows in PG 1114+445

(Serafinelli, Tombesi et al. 2019, A&A, 627, A121)

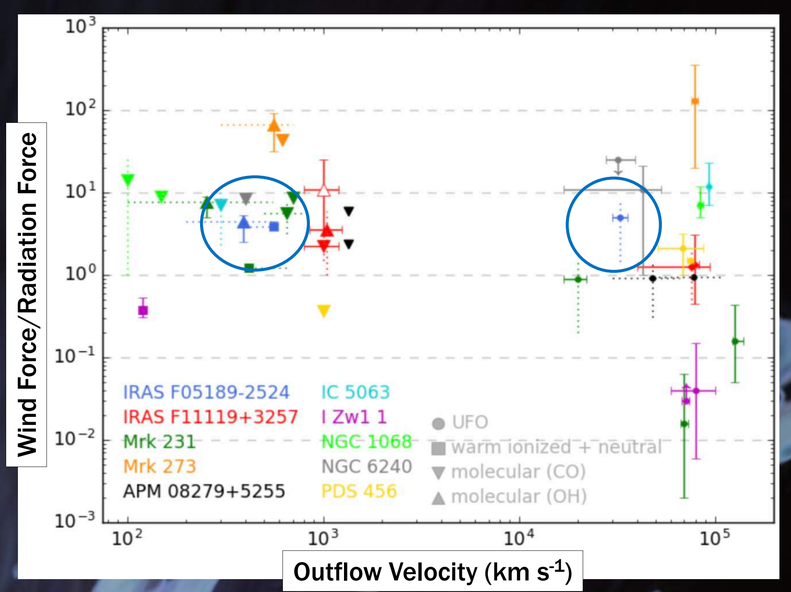
	Parameter	Median	Units
Abs. 1 (WA)	$\log N_{H,1}$	21.88 ± 0.05	cm^{-2}
	$\log \xi_1$	0.35 ± 0.04	erg cm s^{-1}
	$v_{1,out}$*	~ 530	km s^{-1}
Abs. 2 (E-UFO)	$\log N_{H,2}$	21.5 ± 0.2	cm^{-2}
	$\log \xi_2$	0.50 ± 0.36	erg cm s^{-1}
	$v_{2,out}$	0.120 ± 0.029	c
Abs. 3 (UFO)	$\log N_{H,3}$**	22.9 ± 0.3	cm^{-2}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



- PG 1114+445 is a quasar at z=0.144 hosting a SMBH with mass $\log(M_{BH}/M_\odot)$=8.77.
- 13 X-ray spectra (1 ASCA, 12 XMM-Newton) from 1996 to 2010.
- Detection of three distinct X-ray absorbers, variable but persistent over ~15 years!
- Abs. 1 is consistent with typical Warm Absorbers (WAs), Abs. 3 with Ultra-fast Outflows (UFOs) and a newly discovered absorbing phase, Abs. 2, is intermediate.
- The low ionization/column but high velocity (v_{out}=0.12c) Abs. 2 is interpreted as an Entrained Ultra-fast Outflow (E-UFO) at ~100pc from the SMBH, representing the interaction of the UFO with the host galaxy environment, which is affected by Rayleigh-Taylor and Kelvin-Helmholtz instabilities.
- The E-UFO expands the parameter space for X-ray absorbers compared to WAs and UFOs and it may be relatively common, as being reported in five other quasars.

X-ray Outflows Driving Galaxy-Scale Winds

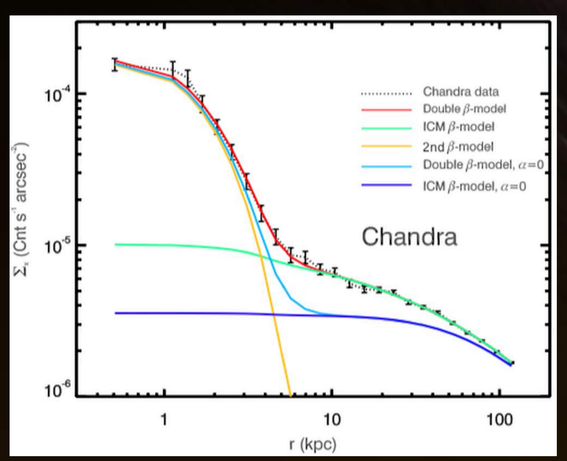
(Smith, Tombesi et al. ApJ submitted)

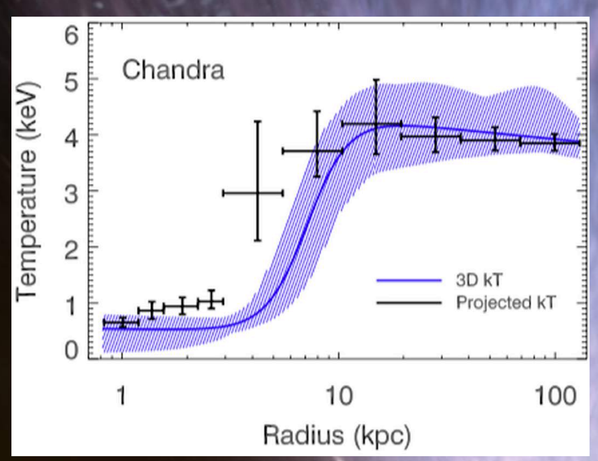


- The quasar/ULIRG IRAS F05189-2524 (z=0.0426) has a SMBH of $\log(M_{BH}/M_\odot)$=8.3.
- An X-ray analysis of the XMM-Newton spectrum show a UFO with column density $\log N_H$=23.5±0.2 cm^{-2}, $\log\xi$=4.0±0.3 erg s^{-1} cm and outflow velocity v_{out} = 0.11±0.01c
- The UFO mass outflow rate of > 1$M_\odot/yr^{-1}$, the kinetic power of >8% L_{AGN} and the momentum rate of >1.4 L_{AGN}/c, indicate that it is powerful enough for AGN feedback.
- Comparing the UFO with the multi-phase (neutral, warm ionized, molecular) outflows in this source show that an efficiency of ~0.05 is enough for the UFO to drive the galaxy-scale winds, possibly as a momentum-driven outflow in this case.
- An increasing number of Seyferts/quasar/ULIRGs show X-ray and multi-phase outflows, with a range of momentum/energy driving and efficiency f~0.001-1, which may depend on the ISM distribution, in-situ formation of molecular gas, instabilities.

Multi-phase Medium, from AGN up to Cluster Scales

(Tumer, Tombesi et al. 2019, A&A accepted, arXiv:1908.08560)

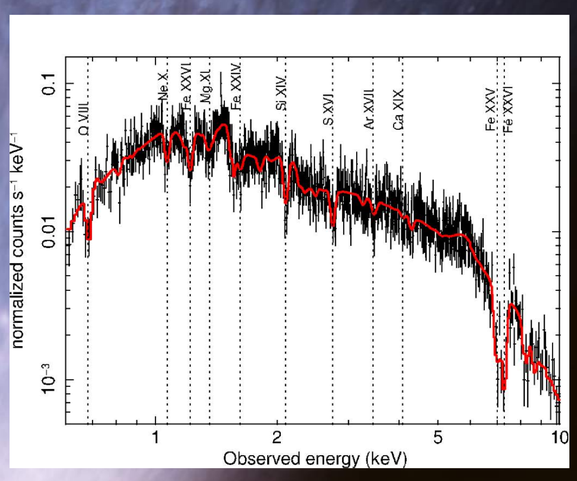




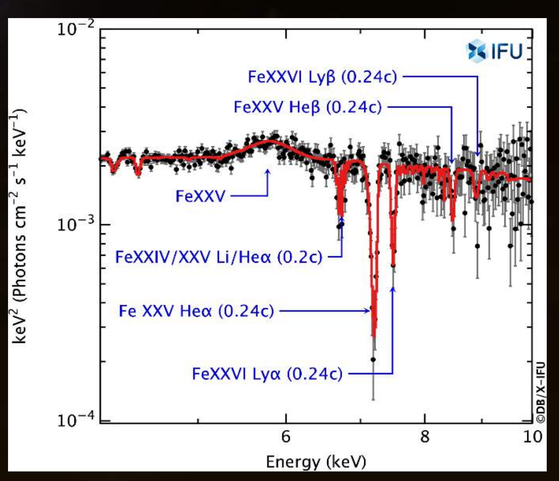
- The study of the brightest cluster galaxy (BCG) coronae is crucial to understand the BCG's role in galaxy cluster evolution as well as the activation of the self-regulated cooling and heating mechanism in the central regions of galaxy clusters.
- We explore the X-ray properties of the ICM of the NCC cluster MKW 08 and the corona of its BCG (namely NGC 5718), along with their interface region, through an XMM-Newton and Chandra spectral/imaging analysis.
- Centered on the BCG, we clearly find an AGN and a mini cool core, the latter characterized by a cooling time of only 65 Myr at ~ 3 kpc. The isothermal BCG corona favors mechanical feedback from the AGN as the major source of heating. The coronal gas reaches pressure equilibrium with the hotter and less dense ICM at an interface within 4 < r < 10 kpc.
- A metal enriched tail is found extending up to 40 kpc, suggesting ram-pressure stripping by the surrounding ICM and/or interaction with a nearby galaxy, IC 1042.

Breakthroughs from XRISM and Athena calorimeters

(Cappi et al. 2013, arXiv:1306.2330; Tombesi et al. 2019, BAAS, 51, 103)



Broadband XRISM spectrum of PDS 456



Athena Fe K spectrum of PDS 456

Fundamental open questions on SMBH winds will be answered thanks to the X-ray calorimeters onboard XRISM and Athena:

- Microphysics? Density, turbulence, ionization gradients, ...
- How are winds accelerated? Radiation and/or MHD driven?
- Which are the launching region and geometry?
- How much power can be delivered to the host galaxy?

(Image credit: ESA/ATG medialab; Serafinelli, Tombesi et al. 2019)