Jets & outflows in Radio Galaxies: implications for AGN feedback

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ABSTRACT

One of the main debated astrophysical problems is the role of AGN feedback in the formation and evolution of galaxies.
While it is known that supermassive black holes (SMBH) play an important part in this scenario (Silk & Rees 98, A&A, 331, 1; Fabian 99, MNRAS, 308, 39; etc.), as suggested by the correlations between SMBH masses and host galaxy properties (Ferrarese & Merritt 00, ApJ, 539, L9; Gebhardt et al. 00, ApJ, 539, L3), how they communicate with the circumnuclear environment is still an unanswered question. High-resolution hydrodinamical simulations on elliptical galaxies have shown that AGN/environment interaction can be split in two categories: radiative modes (ionization, heating, radiative pressure) and mechanical modes (winds, jets) acting on different radial scales (Ciotti & Ostriker 07, ApJ, 665, 1038; Ciotti, Ostriker & Proga 09; 10, ApJ, 699, 89; ApJ, 717, 708). We explore the interplay between the nuclear engine and the surrounding medium from an observational point of view, through the study of soft X-ray warm absorbers (WA) in Broad Line Radio Galaxies (BLRG) recently detected by the high-resolution grating spectrometers (RGS) onboard XMM-Newton. Radio Galaxies (RG) are indeed fundamental to have a complete view of the feedback since they have accretion flows and winds like Radio-Quiet (RQ) AGNs, but they also produce strong relativistic jets. We present the soft X-ray properties of 3C 390.3 (Torresi et al. 11, submitted) and 3C 382 (Torresi et al. 10, MNRAS, 401, 10; Reeves et al. 09, ApJ, 702, 187), the only BLRGs in which we found evidences of ionized outflows in the soft X-ray band. There is only another Radio-Loud (RL) source, 3C 445, in which Reeves et al. (10, ApJ, 725, 803) found a WA probably related to the accretion disk. A tentative comparison between RL and RQ WAs shows that the properties of the slow outflows are similar: (i) the gas parameters (N_H, ξ) generally span similar range of values; (ii) RL and RQ WAs have to be clumpy (volume filling factor less than 1), otherwise the absorber would carry away more mass than accreted; (iii) the kinetic energy related to these outflows is always a negligible fraction of the bolometric luminosity and, in the case of RGs, also of the jet kinetic power. Thus, slow outflows are not important contributors to the overall energetic budget of the AGN, indipendently of the presence or not of relativistic jets.

SPECTRAL ANALYSIS

Signatures of warm outflowing gas were unambiguously detected in the XMM-Newton/RGS spectra of 3C 382 (Fig.1) and 3C 390.3 (Fig. 2).
Two different photoionization codes have been used throughout the spectral analyses: XSTAR (Bautista & Kallaman 01, ApJS, 134, 139) for 3C 382 and the xabs component in SPEX (Kaastra et al. 96, 'UV and X-ray Spectroscopy of Astrophysical and Laboratory Plasmas' p.411, eds. Yamashita, K., Watanabe, T.) for 3C 390.3. The gas has hydrogen column densities $\mathbf{N_H=10^{20}\text{-}10^{22}\ cm^{-2}}$, ionization parameters **Logξ=2.08-2.69 erg cm/s** and is outflowing at velocities around $\mathbf{10^2\text{-}10^3}$ **km/s** (see Table 1). The possible location of such gas is the Narrow Line Region (NLR).

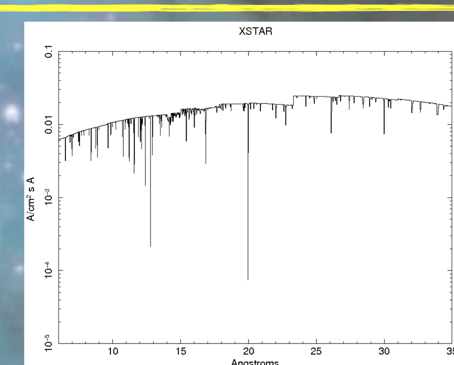

Figure 1 *XSTAR* best-fit model of 3C 382 in the overall RGS band (6-35 Å).

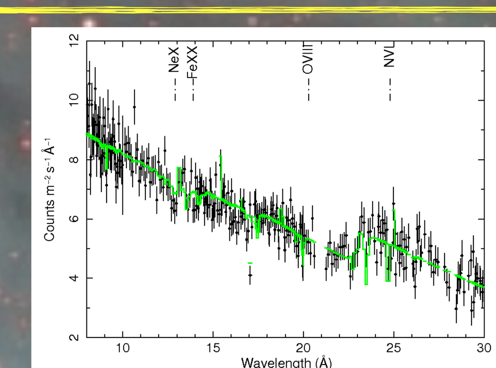

Figure 2 *SPEX xabs* best-fit model for the RGS spectrum of 3C 390.3.

WARM ABSORBER PHYSICAL PROPERTIES & ENERGETICS

Physical parameters	$\log N_H$ (cm^{-2})	$\log \xi$ (erg cm s^{-1})	v_{out} (km s^{-1})	r_{min} (pc)	r_{max} (pc)	r_{BLR} (pc)	r_{torus} (pc)
3C 390.3	20. 7	2. 08	<600	≥9	≤450	0. 03	0. 7
3C 382	22. 5	2. 69	1000	≥10	≤60	0. 05	1. 5

TABLE 1 WA physical parameters together with the minimum and maximum distance of the outflow are reported for the two BLRGs analyzed (see above). In order to establish the location of the absorbing region the BLR and the torus distances are also listed.

Energetics	$\log \dot{M}_{out}$ ($M_\odot\ yr^{-1}$)	$\log \dot{E}_{out}$ (erg s^{-1})	$\log L_{acc}$ (erg s^{-1})	$\dot{M}_{acc}$ ($M_\odot\ yr^{-1}$)	$\log P_{jet}$ (erg s^{-1})	η_{jet}
3C 390. 3	1. 40	41. 66	45. 65	0. 2	45. 12	0. 03
3C 382	1. 41	41. 91	45. 84	0. 77	44. 81	0. 01

TABLE 2 For each BLRG we give the mass outflow rate estimated as (1), the kinetic energy related to the outflow estimated as (2), the accretion luminosity, the mass accretion rate, the jet kinetic power obtained from (3) and the jet extraction efficiency (defined as $\eta_{jet}=P_{jet}/L_{acc}\ \eta$).

$$\dot{M}_{out} \sim \frac{1.23 m_p L_{ion} v C_v \Omega}{\xi} \qquad (1)$$

The solid angle of the outflow is set to **Ω=2.1,** as deduced considering that ~33% of the Radio Galaxies belonging to the 3CR sample are BLRGs (Buttiglione et al. 09, A&A, 495, 1033) and assuming that at least 50% of the objects possesses an outflow as in Seyfert 1s. The volume filling factor $\mathbf{C_v}$ is unknown and therefore it was kept **equal to 1.**

$$\dot{E}_{out} = \frac{\dot{M}_{out} v_{out}^2}{2} \qquad (2)$$

$$P_{jet} = 3 \times 10^{45} f^{3/2} L_{151}^{6/7}\ \mathrm{erg\ s^{-1}} \qquad (3)$$

From Shankar et al. 08, ApJ, 676, 131

RADIO-LOUD/RADIO-QUIET WA COMPARISON

As an exercise, we compare the X-ray properties of our BLRGs (3C 382 and 3C 390.3) plus 3C 445, the only other BLRG showing absorbing gas, with a sample of 13 type 1 RQ AGNs from Blustin et al. (05, A&A, 431, 111). In order to match our assumptions, the mass outflow rates and related kinetic powers of RQ sources are rescaled to C_v=1. As shown in Fig. 3, assuming a volume filling factor of the order of the unity, the mass outflow rates are implausibly higher, for both RQ and RL sources, much higher than the mass accretion rates. Therefore the gas is probably clumped also in BLRGs.
Even considering upper limits on the mass accretion rates, the kinetic luminosity related to the outflow is always a negligible fraction (<1%) of the bolometric luminosity (Fig. 4) and, for RL sources, also of jet kinetic power (Table 2).
The three sources (2 type 1 QSO and 1 BLRG) showing accretion disk winds (v_{out}≥10^4 km/s) have $\dot{E}_{out}$≥L_{acc}. For radio sources, similar fast outflows could compete with the jet in transferring momentum to the circumnuclear environment, unless these events are transients and/or the winds have small covering factors.

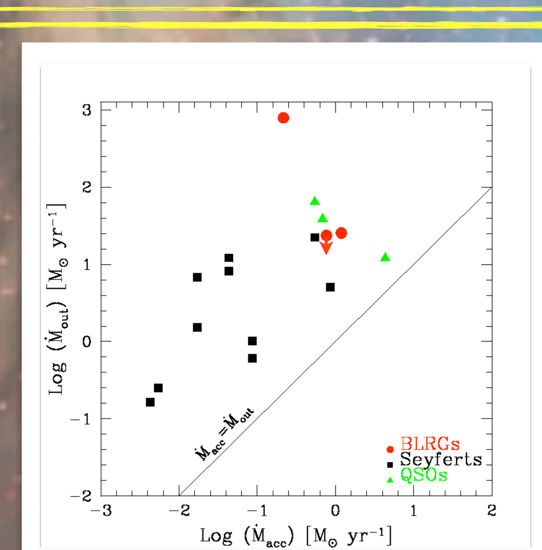

Figure 3 Mass outflow rate plotted against the mass accretion rate.
It is evident that assuming a volume filling factor C_v=1 the mass outflow rates of both BLRGs and type 1 RQ AGNs are higher than the mass accretion rates. This implies that the distribution of photoionized gas is not uniform. This was already ascertained for Seyferts (Blustin et al. 05), now it is evident also for radio sources. Indeed assuming that the same amount of matter is accreted and ejected in the form of a wind the BLRG volume filling factor should be as small as ~0.01.

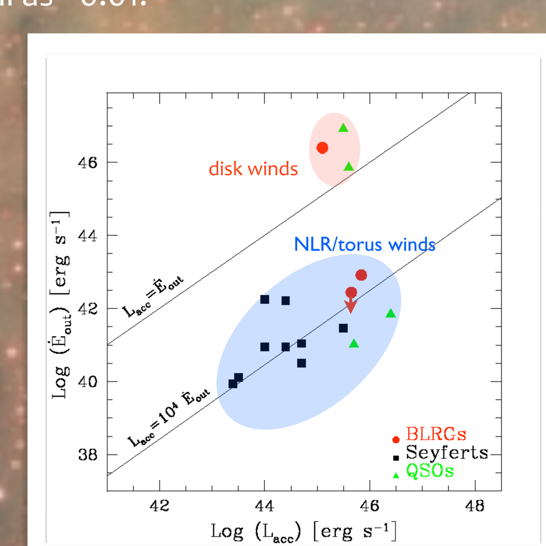

Figure 4 Kinetic luminosity associated with the outflow plotted against the accretion luminosity (L_{acc}≡L_{bol}). Even considering upper limits on $\dot{M}_{out}$ (since C_v=1) $\dot{E}_{out}$ is always negligible with respect to the accretion luminosity for both BLRGs and Seyferts, and moreover, for RL objects, it is negligible also with respect to the jet kinetic power. This is true when slow winds, probably located in the NLR/torus region are considered. Differently, for accretion disk winds the kinetic luminosities can be comparable, or even higher, than the accretion luminosity.

★High-resolution X-ray spectroscopy has shown that warm absorbers exist also in unobscured RL sources at different scales (NLR/torus, accretion disk) and with different outflow velocities.
★The absorbing gas has to be clumpy (C_v<1) otherwise implausible high mass outflow rates are obtained. The kinetic luminosity related to slow outflows (v=10^2-10^3 km/s) is always a negligible fraction (<1%) of the accretion luminosity and the jet kinetic power (for RL AGNs), except for accretion disk winds. Therefore these slow and far outflows seem to be important in the overall mass budget but are less important energetically (Kurosawa et al. 09, ApJ, 707, 823).
★The number of RL sources with detected WAs is still too small to draw firm conclusions. Longer high-resolution observations are fundamental to enlarge the sample and to deeply investigate the physical state, geometry and energetics of these outflows and their role on AGN feedback.

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