

Ultra fast outflows, and their connection to accretion and ejection processes in AGNs

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Abstract. The growing evidence for energy-conserving outflows in powerful and luminous AGN supports the idea that high-velocity winds launched from the accretion disc evolve systematically after undergoing a shock with the ambient medium and that they are capable to expel enough mass and energy so as to produce feedback. This talk will give an overview of recent results on AGN ultra fast outflows, with focus on grating X-ray spectra of bright sources. I will review how UFO work, their observational properties and their relation with AGN outflows in other bands, what is their impact on the host galaxies and their role in feedback processes.

Keywords. galaxies: active, hydrodynamics, atomic processes

1. Introduction

Feedback from Active Galactic Nuclei (AGN) is generally thought to be an important ingredient for galaxies evolution. After large amount of gas is accreted during the earliest stage of a quasar life time, the accumulated energy can be released via ejection of powerful outflows driven by the AGN. If the outflow is as strong as 0.5–5% of the Eddington luminosity of the AGN, it has a profound impact on the development of the host galaxy itself. The effect of these winds is to eventually expel the gas that would otherwise be available for forming new stars in the host galaxy therefore providing an effective mechanism of quenching star formation. It is in this sense that we refer to AGN feedback as a mechanism able to regulate the growth of the galaxy and the growth of the central black hole as well (Di Matteo *et al.* 2005, Hopkins *et al.* 2010).

A widely accepted scenario for explaining AGN feedback postulates that a fast wind observable in the X-ray band is launched at accretion disk scale (Faucher-Giguère & Quataert 2012). This highly ionized X-ray gas is currently observed in the form of Ultra Fast Outflows in some AGN spectra (Tombesi *et al.* 2012, Gofford *et al.* 2013). While traveling outward, the impact of the wind with the ISM (inter-stellar medium) gives rise to shock processes (King 2010). After shocking with the gas, deceleration and cooling processes lead to the production of a slower outflow with less ionized lines observable in the optical band and to the formation of a bubble of hot, tenuous gas (e.g. Zubovas & King 2012). As a result of the cooling, the presence of molecular gas outflowing at a much lower velocity is expected. This latest phase is frequently observed in several ULIRGS and Quasars (Cicone *et al.* 2014, Feruglio *et al.* 2010, 2015).

To date, only two cases of ULIRGS are reported where the observed X-ray and molecular phases of the outflow are physically related, IRAS F11119+3257 (Tombesi *et al.* 2015) and Mrk 231 (Feruglio *et al.* 2015). Both results remarkably fit in with the prediction of the energy-conserving outflow model outlined above.

This fascinating picture, among several other variables, relies on the existence and the properties of the nuclear wind, the so-called “Ultra Fast Outflow”. The X-ray spectra

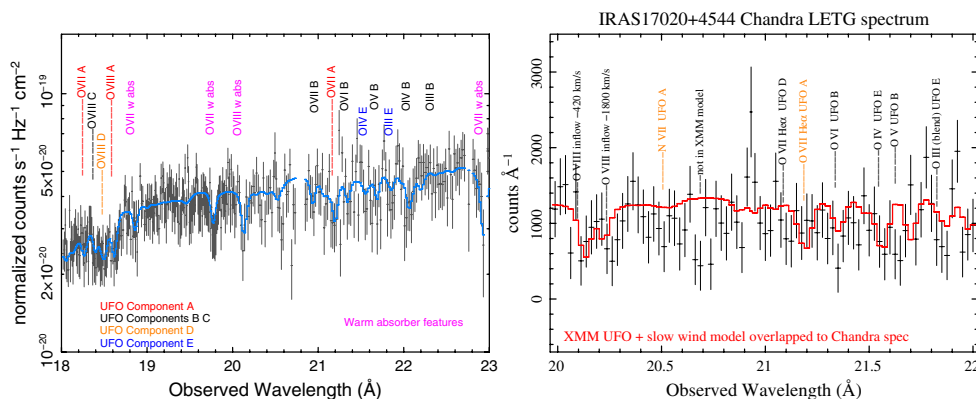


Figure 2. The system of outflowing and inflowing gas in the NLSy1 Galaxy IRAS17020+4544. *Left:* Portion of the *XMM-Newton*-RGS spectrum (observed in 2014) mostly affected by the fast wind absorption. Letters indicate the velocity component of the outflow as described in L15. The label “Warm absorber” marks lines that are part of the slow ionized outflow. *Right:* Close-up of the *Chandra*-LETG spectrum of the source (observed in 2017) with the XMM model overlapped (without fitting) in the spectral region where “slow” inflow and fast outflow are visible (Longinotti *et al.* in prep.). Labels refer to absorption features identified in the *XMM-Newton*-RGS spectrum (L15 and Sanfrutos *et al.* submitted).

of AGN fast winds. Compared to the results based on CCD spectra, the higher detail provided by grating spectroscopy has revealed that soft X-ray fast winds can be made by multiple components of distinct outflowing velocity, ionization state and column density and that they can be massive enough to produce feedback in the host galaxy, e.g. IRAS 17020+4544 (Longinotti *et al.* 2015, L15 throughout) and Mrk 1044 (see Fig 1, Krongold *et al.* submitted). When luminosity variations takes place, the combination of timing and spectroscopy techniques shows that fast X-ray winds respond to flux variations revealing a tight connection between continuum photons emitted in the very inner accretion disc with highly ionized outflowing gas (IRAS 13224-3809 Parker *et al.* 2017; PDS 456 Matzeu *et al.* 2017). With the exception of the luminous QSO PDS 456 (Reeves *et al.* 2016), if we consider the other few cases of fast winds observed in gratings spectra (PG1211+143, Reeves *et al.* 2018; Akn 564, Gupta *et al.* 2013), it is clear that the sources where this phenomenon is detected share the same classification: they are all Narrow Line Seyfert 1 (NLSy1).

This AGN class represents an extreme form of Seyfert activity that is manifested in their peculiar continuum and emission-line properties in almost all bands (see Gallo 2006), their small black hole masses ($M_{BH} \sim 10^{6-7} M_{\odot}$), high Eddington ratios and often, high degree of X-ray variability (Komossa & Xu 2007).

The recent findings of fast X-ray winds in an increasing number of NLSy1 seem to hint to a common behavior of these sources with objects of much higher luminosity (e.g. Chartas *et al.* 2002, Tombesi *et al.* 2015, Nardini *et al.* 2015). Increasing evidence that the velocity of the wind correlates with the source luminosity (i.e. winds are faster at higher luminosities, Pinto *et al.* 2018) strongly favours radiation driving as the launching mechanism for the outflows, leading therefore to the hypothesis that a high accretion rate is the likely driver of fast winds (Matzeu *et al.* 2017).

3. Stratification of the fast outflow: a shocked outflow origin?

We now focus on the peculiar case of the NLSy1 IRAS17020+4544. This source presents the simultaneous presence of a stratified fast outflow (L15) and a multi-layered slower

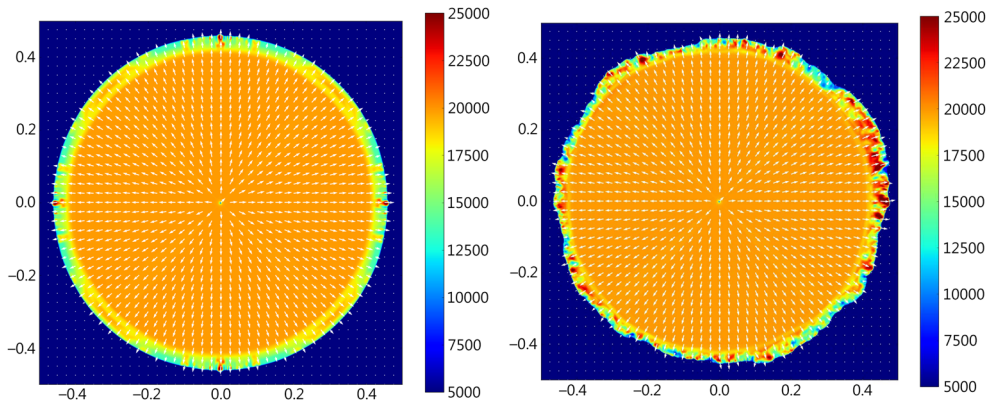


Figure 3. Toy model showing the appearance of a shocked outflow affected by instabilities. The color scale maps the velocity of the ultra fast outflow ejected at $20,000 \text{ km s}^{-1}$ that is pushing the shock outward (*Left*). When instabilities are introduced (*Right*), sections of gas with higher velocities start to appear at the border of the shock (simulations to be included in Longinotti *et al.* in prep.)

absorber. Fine quality multi-epoch spectroscopic information available from two *XMM-Newton* observations (obtained in the years 2004 and 2014) and a long look with *Chandra* LETG (obtained in 2017) confirm a surprisingly steady continuum flux and a complex pattern of absorption features (see Fig. 2). While no significant variations are observed in the properties of the fast wind along the 10 years elapsed in between the two *XMM-Newton* observations, the peculiar evolution of the 4 components of the slow absorber (Sanfrutos *et al.* submitted) reveals gas flowing inward ($v_{inflow} \sim 1800\text{--}3000 \text{ km s}^{-1}$) and outward ($v_{outflow} \sim 2000\text{--}3400 \text{ km s}^{-1}$), thus suggesting a different nature of this wind compared to “standard” warm absorber.

To explain this complex pattern of absorbers we postulate that the coincidence of the fast outflow with slower winds moving in opposite directions may be explained in terms of a “shocked outflow”. This model predicts that an initial fast outflow radiatively launched at accretion disc scale with outflow velocity $v_{out} \geq 10^4 \text{ km s}^{-1}$ shocks with the ambient medium (see King & Pounds 2015 for a review). The two shock fronts (reverse and forward) produced by the impact of the wind with gas at an escape velocity lower than the outflow velocity, are separated by a contact discontinuity and whereas the shocked ambient gas could decelerate to velocity of the order of 10^2 km s^{-1} , the wind shock (forward) maintains its high velocity while entraining the ambient gas and pushing it further out (Faucher-Giguère & Quataert 2012).

Analogously to Supernova Remnants (Velazquez *et al.* 1998), fluid instabilities (e.g. Rayleigh-Taylor) are likely to develop at the discontinuity between the two shock fronts due to the difference between the densities of the impacting wind and of the impacted medium. A condition for the Rayleigh-Taylor instability to grow is that the mass of the ISM that is pushed by the discontinuity is higher than the mass of the ejecta (Velazquez *et al.* 1998), which undergoes to a deceleration process that is able to trigger instabilities in the fluid (see Fig. 3). Such instabilities would easily alter the dynamics of the shocked outflow and they may give rise to a re-distribution of the overall velocity field in which slower (and faster) components of the wind may simultaneously cross our line of sight. The effect of the turbulence would then provide a replenishment mechanism that continuously supply new sections/blobs of gas that might as well fall backwards with an opposite direction with respect to the bulk of the outflow.

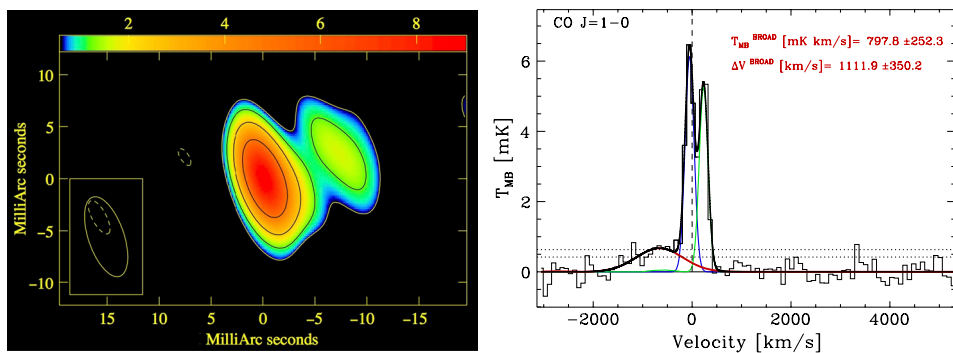


Figure 4. *Left:* Simultaneous 5-8 GHz spectral index VLBA image of IRAS17020+4544 observed in 2014. Contours show total intensity at 8 GHz and colours show the spectral index values (Giroletti *et al.* 2017). *Right:* Spectrum of the CO(1-0) line in IRAS17020+4544 obtained with the LMT telescope in 2017. The double peaked structure is fitted by two narrow Gaussian components (blue and green), and the line wings are fitted by broad Gaussian line (red line). The molecular gas mass is estimated assuming a CO-to-H₂ conversion factor appropriate for ULIRGs (Solomon *et al.* 1997). The molecular gas masses estimated in each narrow component are very similar, which is compatible with the presence of a ring of molecular material in the galaxy, while the blue wing of the line is consistent with the presence of molecular gas outflowing at $\sim 660 \text{ km s}^{-1}$ (Longinotti *et al.* submitted).

We have developed a toy model for simulating this behavior and testing the viability of this idea. The simulation is based on the GUACHO code (Esquivel & Raga 2013) and a preliminary output is displayed in Fig. 3. An expanding shock is pushed within a turbulent medium by an inner wind with $v_{out}=20,000 \text{ km s}^{-1}$. The expansion time is set to 20 yr, the mass of the central object is $10^6 M_{\odot}$ (i.e. the mass of IRAS17020+4544 and in general of the order of black hole masses in NLSy1 galaxies).

Fig. 3 shows the pattern of velocities developed at the shock front with and without instability. The right panel shows that “plumes” or “fingers” of gas with different velocities are formed as a result of the introduction of instabilities process in the expansion of the shocked outflow. Depending on which “fingers” are intercepted by our line of sight, it is evident that the resulting absorption line spectrum is likely to show a stratified wind consistent with the spectrum observed in IRAS17020+4544 (see Fig. 2). This scenario can easily apply to other NLSy1 sources with the same observational properties.

4. A truly multi-phase outflow in IRAS17020+4544?

Further hints to the presence of a shocked outflow in this source come from radio observations (see Fig. 4) that have revealed an elongated structure on a scale of 10 pc in VLBI images (Giroletti *et al.* 2017). The appealing possibility that such compact jet, which is produced by synchrotron emission, may represent the signature left by the shock of the inner X-ray outflow with the ambient gas has been postulated by several models of galactic outflows (e.g. Zakamska & Greene 2014; Nims *et al.* 2015) in an attempt to link synchrotron emission in radio-quiet sources with galaxy scale molecular outflows.

IRAS17020+4544 is hosted by a barred spiral galaxy with IR luminosity typical of LIRG ($L_{FIR} = 1.05 \times 10^{11} L_{\odot}$) therefore likely to be rich in molecular gas. We have obtained millimetric observations with the Large Millimetric Telescope (LMT, Hughes *et al.* 2010) and found tentative evidence for a galaxy scale outflow traced by CO gas (Fig. 4, Longinotti *et al.* submitted).

Assuming a dynamical timescale of $\text{few} \times 10^6$ years for the outflow to propagate out of the nucleus at the observed bulk velocity of $\sim 600 \text{ km s}^{-1}$, the spatial scale of the

wind is approximately $\sim 0.5\text{--}3$ kpc. The CO mass in the wind is of the order of $10^8 M_{\odot}$ and following [Feruglio et al. 2015](#), we find an approximate estimate of the molecular outflow rate of $\sim 100 M_{\odot}\text{yr}^{-1}$, which is consistent with recent findings reported for Active Galaxies with comparable CO properties ([Cicone et al. 2014](#))

The relative proportion of momentum load for the X-ray and molecular outflows in IRAS17020+4544 would provide an additional evidence for the existence of energy conserving winds that propagate through the galaxy after undergoing a momentum boost, supporting the feedback scenario as proposed in earlier works ([Feruglio et al. 2015](#)).

Admittedly, these numbers suffer from the large uncertainties in the estimates of the mass outflow rate and of the wind spatial extent, therefore we are currently awaiting the outcome of an already performed interferometry observation to constrain the size of the molecular outflow region and its physical properties.

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