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Active Galactic Nuclei as Feedback Source for the Host Galaxy

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Abstract

The Active Galactic Nuclei (AGN), located in the nuclei of several galaxies, generate an extremely large quantity of energy (a factor of 10^{3-4} times the radiation of the rest of the galaxy). The AGN are compact objects condensed in small distances ($\leq 10^{16-18}$cm), their masses range on 10^{6}-10^{10} solar masses. In theory, the AGN central engine is an active Supermassive Black Hole that accretes its nearest material. In some AGN material and energy interaction between the nucleus and the galaxy have been detected. This interaction could change the stellar formation rate of the host galaxy and produce material feedback due to the blend of the AGN material and the galaxy material; those two materials have evolved in two drastic different media, while the AGN material has been processed in hard and high energy circumstances, the galaxy material has evolved mainly due to stellar formation. We present a study of 5 AGN with absorption produced by ionized materials ejected from the AGN. Our goal is to discuss if the AGN material can reach the galaxy and if so, to disturb the galaxy evolution.

Keywords: Active Galactic Nuclei, Astrophysics, Super-Massive Black Holes

Acknowledgments: We thank to María Santos-Lleó who provided the initial sample of 28 type 1 AGN. We thank also to Ehur Behar for the permission to reproduce his Figure as Figure 2 of this paper and to the CONACyT (Science and Technology National Council of Mexico) for funding this project.

Introduction

The active galactic nuclei (AGN) are compact objects located in the nuclei of several galaxies, the most massive AGN detected contains a mass of ~12,000 millions of solar masses (Wu et al., 2014). The AGN are located in spaces smaller than few light days (see as example NGC 4051 by Krongold et al., 2007). In theory, the AGN are active Supermassive Black Holes (SMBH) which accrete their nearest material. The main characteristics of the AGN are: 1) The nucleus integrated luminosity is higher than the host galaxy luminosity –composed by stars, gas and dust–, the AGN luminosities range from 10^{40} to 10^{47} erg s^{-1} (Crenshaw et al., 2003). 2) The AGN luminosities vary significantly in several time scales, since hours to years (see as example NGC 3516 by Huerta et al., 2014). 3) There are different kinds of AGN, their classification depends on the luminosity emitted and their radio emission: The most powerful AGN are the Quasars; the Radio Galaxies are the brightest after the Quasars, often they belong to giant elliptical blue galaxies. With intermediate luminosities there are the Seyfert galaxies, the kind of AGN nearest to the Milky Way. There exist AGN type 1 and 2, the type depends on the broad of the main emission lines in optical wavelengths.

Interestingly, in some AGN direct mass and energy interaction between the nucleus material and the host galaxy has been detected. This interaction was detected by two different ways: 1. By the super-energetic jets emitted in radio and optical frequencies (extended up to galactic distances), located mostly in Radio Galaxies and Quasars; these radio jets eject material from the nucleus to the host galaxy reaching, sometimes, the Intergalactic Medium (IGM), one example is the galaxy Centaurus A. 2. The second possible way to transfer material from the nucleus to the galaxy is through the ionized absorbers (defined as warm absorbers by Harlpen in 1984) detected in the far UV and soft X-ray spectral bands (Mathur et al., 1997). The ionized materials have been detected in ubiquitous out flowing kinematic states with velocities since ~100 km/s to ~50,000 km/s respect to the host galaxy reference system. If the AGN ionized material could reach the escape velocity of the SMBH, then this material could arrive to the host galaxy, and if so, the nucleus material could interact with the host galaxy material. Those two different materials have evolved in completely different circumstances: While in the AGN predominate the high and hard energy processes –due to these materials are located in the zone around the accretion disk of the SMBH–, the galaxy material has evolved mainly by stellar formation. This interaction of energy and mass produce material feedback and then, the stellar formation of the host galaxy and the evolution of the galaxy could change. Along Giga-years the feedback material can reach the Intergalactic Medium (IGM) and possibly, the evolution history of the galaxy cluster varies (Elvis, 2006).

The ubiquitous ionized winds of AGN exist in high ionization states at temperatures ~>1000 K. Those winds emerged from the innermost accretion disk zone with outflow velocities ~>|-100| kms^{-1}. The absorption lines produced by these absorbers are mainly due to Oxygen (O^{+6}-O^{+7}), Iron (Fe^{+13}-Fe^{+26}) among others as Ne, S, Mg transitions at a high ionization level[1] (there are around 100 absorption lines observed and identified only in the far UV and soft X-ray energy bands).

One of the absorbers with the highest velocity has been reported by Tombesi et al. (2015), its outflow velocity is given by -0.3c (c: light velocity). It was detected in the Ultra-Luminous InfraRed Galaxy IRAS F11119+3257. The ionized absorbers with relativistic velocities are known as UFO's: Ultra Fast Outflows. UFO's velocities have been detected in the range of -0.1c to -0.7c according to Chartas et al. (2002) and Lanzuisi et al. (2012). The UFO's contain enough velocity for escape from the AGN; however, they are extremely unusual.

It has been suggested that the AGN ionized outflows can play an important role in the galaxy evolution. If the outflowing material is a significant fraction of the mass accreted by the SMBH (according to Crenshaw et al. 2003 the typical SMBH mass accretion rate is given by ~0.1 $M_{\odot}$/year –where $M_{\odot}$ is the solar mass– while the ejected material rate is given by ~0.003-0.06 $M_{\odot}$/year) then, the ionized winds can provide to the IGM the feedback material proposed by the cosmological models (Di Matteo et al., 2005; Hopkins et al., 2006).

In this paper we present the cases of 5 AGN galaxies –selected from a sample of 28 Type 1 AGN. The main goal of this work is to discuss if it is possible for the nucleus galaxy material to escape from the AGN.

Connection between the SMBH and the Host Galaxy

The M-σ Relation

Observationally, there is a correlation which connects the SMBH located in the nucleus of the regular galaxies –according to the Hubble classification of galaxies– with the galaxy stars: The M-σ relation (Ferrarese and Merritt, 2000), the observational correlation between the stellar velocity dispersion of a galaxy bulge σ and the SMBH mass M of the galaxy nucleus. The M-σ relation is considered as the empirical connection between the SMBH evolution and the galaxy stars evolution. An example of this M-σ correlation is reported by Xiao et al., 2011, where 76 Seyfert 1 galaxies were studied, in this analysis the M-σ correlation remains practically linear in logarithmic scales (see Figure 8 of Xiao et al., 2011). On the other hand, Hydro-dynamical computing simulations have modeled the evolution of galaxies and their embedded SMBH evolution during Giga years; it seems pretty possible that the SMBH evolution can disturb the host galaxy evolution (Di Matteo et al., 2008; Hopkins et al., 2006). The AGN can provide us information about this connection because they present direct interaction of material and energy between the nucleus and the

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[1] The ionization level is estimated trough the ionization parameter defined as $U= Q/(4\pi R^2 c n_e)$, where Q is the luminosity of ionizing photons, R the distance from the the radiation source to the ionized material, c the light speed and n_e the numeric density of electrons. U is proportional to the quantity of ionized photons between the number of free electrons.

galaxy. In this research, we selected the ionized absorber out flowing detected in a significant part (~50%) of type 1 AGN (Pichoncelli et al., 2005) in order to discuss if it is possible that the AGN material can reach, at least, the host galaxy.

The Seyfert 1 Galaxies NGC 3516, NGC 4051, MRK 335, NGC 5548 and the Quesar MR 2251-178

We started with a sample of 28 AGN type 1 galaxies provided by María Santos Lleó from *XMM-Newton Science Operation Center* in private communication. With the goal to study the possibility of the AGN ionized absorbers can reach the host galaxy, the first selection was based on their outflowing velocities reported in the literature: These velocities have to be similar to the escape velocities of the SMBH of each AGN. To estimate the escape velocity the distance was selected as 10^{17} cm, due it is a typical distance value between the SMBH and the ionized absorber wind (see Andrade-Velazquez et al., 2010; Krongold et al., 2007; 2009). The galaxies selected to report this work are: The Seyfert 1 galaxies NGC 3516, NGC 4051, Mrk 335, NGC 5548 and the Quasar MR 2251-178.

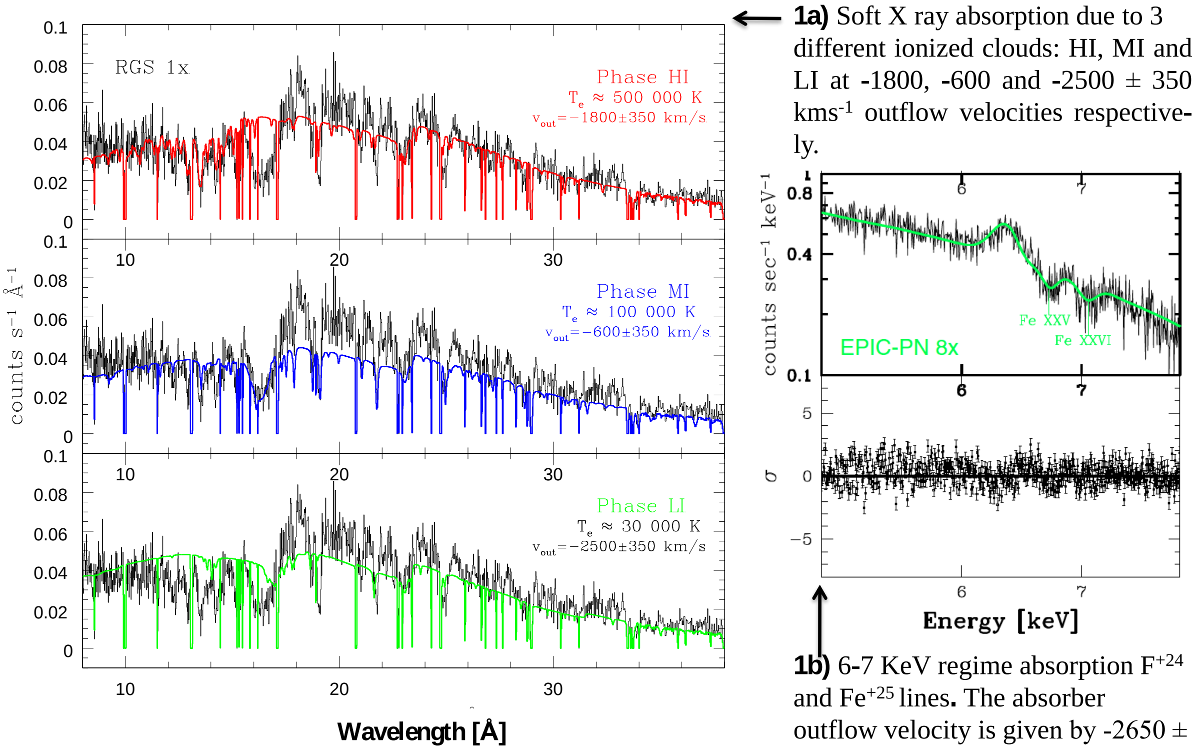
NGC 3516

NGC 3516 is classified as Seyfert 1.5 galaxy at z=0.0088 (Local Universe). The SMBH mass was estimated as $M_{BH}=(42.7\pm14.6)\times10^6\ M_\odot$ (Peterson et al., 2004). At a distance of 10^{17}cm from the central SMBH the escape velocity is given by $v_{esc}=3365^{+533}_{-636}$ kms^{-1}.

In NGC 3516 four different ionized clouds which absorb the extremely variable luminosity emerged from the nucleus have been detected. Those four ionized clouds coexist with different ionization levels and their outflow velocities range on ~-350 km/s to ~-4000 km/s. It seems that two of those four ionized clouds are responding to the flux variation through their ionization level, indicating that those two ionized clouds are near the photoionization equilibrium with the central source emission (Huerta et al., 2014).

The Figures 1a and 1b show the spectra of XMM-Newton X-ray from NGC 3516 modeled by an emission source absorbed by four different ionized winds. The ionized absorption detected in the soft X-ray band [8-38 Å] is shown in Figure 1a, with three different ionized clouds; the fourth ionized wind –the highest one in ionization level and temperature– has an outflow velocity of 2650±350 kms^{-1}; this highly ionized cloud imprints absorption lines in the 6-7 keV regime due to Fe^{+24}Hα and Fe^{+25}Lyα resonant transitions shown in Figure 1b (Huerta et al., 2014).

Figure 1. *NGC 3516 X-Ray Spectra of High and Low Resolution Obtained from XMM-Newton X-Ray Observatory on October of 2006.* ***1a)*** *Soft X-Ray High Resolution Spectrum in the Range of 8-38 Å or 0.33-1.55 keV Modeled by Three Ionized Clouds: HI (Red), MI (Blue) and LI (Green) –from Top to Bottom Respectively. The Outflow Velocities are Given by: HI -1800±350 kms^{-1}, MI -600±350 kms^{-1} and LI -2500±-350 kms^{-1} and their Temperatures were Estimated as T_{HI}=500,000 K, T_{MI}=100,000 K, T_{LI}=30,000 K.* ***1b)*** *6-7 keV X-ray Spectrum from the Low Resolution XMM-Newton Detector. The Absorption Features are due to the Fe^{+24}Hα and Fe^{+25}Lyα Resonant Transitions, the Outflowing Velocity is Given by 2600±350 kms^{-1} (Huerta et al., 2014)*

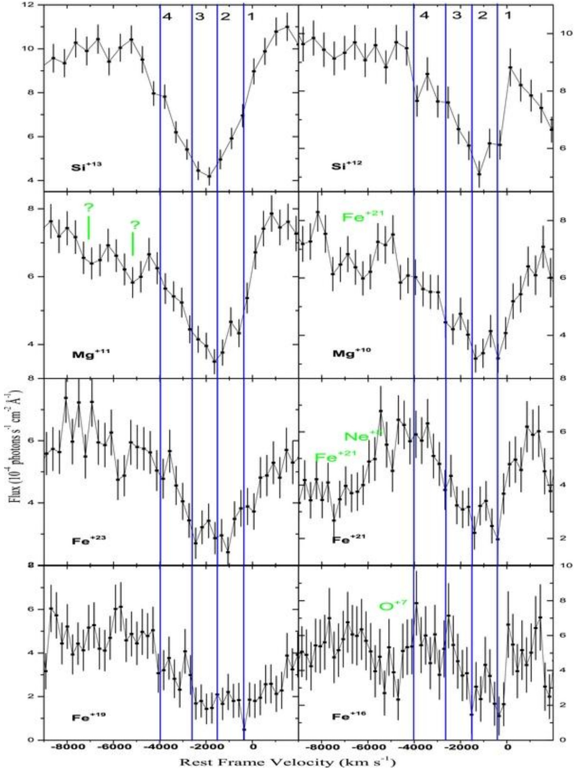


1a) Soft X ray absorption due to 3 different ionized clouds: HI, MI and LI at -1800, -600 and -2500 ± 350 kms^{-1} outflow velocities respectively.

1b) 6-7 KeV regime absorption F^{+24} and Fe^{+25} lines**.** The absorber outflow velocity is given by -2650 ± 350 kms^{-1}.

Hoczer and Behar (2012) reported the highest velocity outflow detected in the highest resolution spectrum of NGC 3516 taken by Chandra X-ray observatory on October of 2006. Hoczer and Behar (2012) found the Mg^{+11} and Fe^{+19} absorption transitions blue-shifted from the galaxy reference system, this implies an outflow velocity corresponding to -4000±400 kms^{-1}. Figure 2 was taken from Hoczer and Behar (2012) paper in order to show the highest outflowing wind (with v_{out}=-4000±400 kms^{-1}). In the Figure 2 there \the four different kinematic outflow systems of NGC 3516 at -350±100 kms^{-1}, -1500±150 kms^{-1}, -2600±200 kms^{-1} and -4000±400 kms^{-1} velocities found in NGC 3516 Chandra high resolution spectrum, are plotted.

Figure 2. *Reproduction of the Figure of Holczer and Behar, 2012 (taken from Holczer and Behar ApJ, 747, 71 under the Author Permission). The Figure Shows the Average High Resolution Spectrum from Chandra X-Ray Observatory in the Velocity Space from NGC 3516. The Transitions* Si^{+13}, Si^{+12}, Mg^{+11}, Mg^{+10}, Fe^{+23}, Fe^{+21}, Fe^{+19} *and* Fe^{+16} *were Plotted on Velocity Space. There are Detected Four Different Kinematic Ionization Systems with Velocities of 1: -350±100 kms*$^{-1}$, *2: -1500±150 kms*$^{-1}$, *3: -2600±200 kms*$^{-1}$ *and 4: -4000±400 kms*$^{-1}$ *Identified with the Four Numbered Vertical Blue Lines.*



NGC 4051

The NGC 4051 type 1 Seyfert galaxy (z=0.0023) presents an extreme luminosity variation along different time scales (see Krongold et al. 2007 and Pounds et al., 2013). The central SMBH detected in NGC 4051 contains ~1.73×10^{6} $M_{\odot}$ (Denney et al., 2009). At a distance of 10^{17} cm from the central engine, the escape velocity is given by ~680 kms^{-1}.

NGC 4051 is an interest case: Krongold et al. (2007) reported two different ionized wind systems with outflow velocities from -500 kms^{-1} to -600 kms^{-1}. Using a novel technique to estimate the mass ejection rate of the two ionized outflows –those reported by Krongold et al. 2007–, Mathur et al. (2009) estimated the mass and energy outflow rates. The mass outflow rates are 4 or 5 orders of magnitude bellow of those required for efficient galactic feedback.

Recently, Pounds et al. (2013), based on XMM-Newton high resolution spectra taken on 2009, reported highly outflow velocity systems: The highest velocity is given by -0.12c; this absorber is reported as an UFO (Ultra-fast outflow system) which is produced by N^{+6}Lyα as an absorption component. Pounds et al. (2013) reported seven kinematic outflow systems with velocities range from -120±45 kms^{-1} to -10290±1000 kms^{-1} with different ionization levels. These results would change the mass and energy rates estimated by Mathur et al. (2009) for NGC 4051; it is important to estimate those two rates in order to know if this ionized material could cause, at least, the NGC 4051 feedback.

Mrk 335

Mrk 335 is classified as Seyfert 1 galaxy (z=0.0258). Mrk 335 central black hole contains a mass of $\sim 31.6\times10^{6}\ M_{\odot}$ (Brenneman 2013). At a distance of 10^{17} cm the escape velocity is given by ~2900 kms^{-1}. In Mrk 335 extreme flux variation and spectral variability have also been detected.

The ionized absorption of the galaxy Mrk 335 was recently discovered in the high resolution XMM-Newton spectra taken on 2009 in combination with the *Swift* monitoring program. Longinotti et al. (2013) has reported three ionized winds which imprint some absorption lines in the soft X-ray band [0.3-2.5 KeV]. Those absorption features were confirmed by Mrk 335 UV spectra taken from the Hubble Space Telescope. The three ionized clouds were found in an outflowing kinematic state with a velocity of ~-5000 kms^{-1}. It is important to mention that this ionized wind is only revealed when the source shows an intermediate flux emission ($2\text{-}5\times10^{-12}$ erg $cm^{-2}\ s^{-1}$). This fact allows us to suppose that some ionized winds that emerged from the AGN can appear and disappear depending on the luminosity emitted by the source, or maybe they can be hidden by another obscure component.

NGC 5548

The SMBH mass of the AGN Seyfert 1 galaxy NGC 5548 (z=0.0172) is estimated as $6.7\pm2.6\times10^{7}\ M_{\odot}$ (Peterson 2004). Situated at a distance of 10^{17} cm from the central engine of NGC 5548, the escape velocity is given by $v_{esc}=4216^{+751}_{-919}$ kms^{-1}.

The ionized winds detected in NGC 5548 have been found in two different ionized phases with two different outflowing kinematic states (Andrade-Velazquez et al., 2010). These two outflow velocities are reported as $v_{out}\approx$-590 kms^{-1} and $v_{out}\approx$-1040 kms^{-1}, even if these velocities are lower than the escape velocity, Krongold et al. (2010) estimated the ionized wind ejection rate given by $\dot{M}_{w}>0.04\ M_{\odot}yr^{-1}$, while the accretion rate of the material falling into the SMBH is estimated as $\dot{M}_{accr}\approx0.1\ M_{\odot}yr^{-1}$ (Mathur et al., 1995); therefore, the wind ejected rate is given by $\dot{M}_{w}>0.4\dot{M}_{accr}$ which is a significant fraction of the accreted mass. Krongold et al. (2010) calculated the total kinetic energy deployed by the ionized wind in the host galaxy ($>1.2\times10^{56}$ erg), this energy can be enough to disrupt the interstellar medium, possibly regulating and quenching large-scale star formation; but the mass and energy ejected by the wind may still be lower than the one required for cosmic feedback. If the AGN material reach the IGM it is necessary that the wind before is fully accelerated (see details in Krongold et al., 2010).

The Quasar MR 2251–178

MR 2251–178 is a very nearby Quasar at $z=0.064$; it was the first Quasar discovered only by X-ray observations (Ricket et al., 1978) and the first quasar where the warm absorption was detected (Halpern, 1984). The MR 2251–178 SMBH contains a mass of $M_{BH}=2\times10^{8}\ M_{\odot}$(Wang et al., 2009), located at a distance of 10^{17} cm the escape velocity is estimated as $v_{esc}=7300\ kms^{-1}$.

Based on high resolution, the Chandra X-ray telescope spectra Ramírez et al. (2008) reported three different warm absorbers with outflow velocities given by: ~ -600, -2000, and -3000 kms^{-1}. Even if the ionized wind velocities are lower than the escape velocity, it is important to mention the existence of giant ionization cones at a distance of 140 Kpc [Kiloparsecs] (1 parsec=3.08×10^{18} cm) around the galaxy nucleus –a galactic distance scale–; those cones are aligned with the weak double-lobed radio source detected in a scale <30 Kpc as Kreimeyer and Veilleux (2013) reported. The bicone has an opening angle ~80^{o}-130^{o} and the geometry produces that the ionizing radiation emerged from the Quasar is collimated along the bicone. Kreimeyer and Veilleux (2013) proposed that this collimated radiation could contribute to ionize the MR 2251–178 interstellar medium. This fact could imply energy interaction between the AGN and the host galaxy.

AGN Feedback Implications Discussion

Theoretical studies have proposed that if the AGN carry enough mass and kinetic energy, they can produce a significant interstellar feedback. Even more, theoretical models propose that the AGN could be the mass and energy providers to produce the cosmic feedback necessary to explain the presence of the over-abundance of cooling flows in the galaxy clusters which regulate black hole growth in the dominant galaxies (Mathur et al., 2009). The radio and the optical super-energetic jets of AGN are commonly invoked to explain those cooling flows; however, the powerful jets are no generic, only 10% of all Quasars have these powerful lobed-jets. Potentially, the ionized outflows could be a more common way to produce the galaxy and cosmic feedback: ~50% of type 1 AGN show ionized absorption in UV and X-ray bands (Pichoncelli et al., 2005).

To start a reasonable discussion about the possibility of the AGN material and kinetic energy can reach the IGM, it is necessary to analyze if it is possible that the AGN innermost material can reach the host galaxy interstellar medium. The first criterion in this work to study this possibility was to find ionized winds with outflow velocities with the same order of magnitude with the AGN escape velocity. On the other hand, X-ray variability analyses of ionized absorbers have estimated the distance between them and the SMBH (see as examples Krongold et al., 2007; Huerta et al., 2014): A typical value of that distance is given by 10^{17}cm. Supposing a particle located at this typical distance, the AGN escape velocity was estimated and then, a comparison with the outflow ionized winds velocities –detected in 5 type 1 AGN galaxies– was done in order to determinate if the arrival of AGN material and kinetic energy to the outer regions is possible, at least to the host galaxy interstellar medium.

NGC 3516 and Quasar MR 2251–178

To estimate the AGN ejection rate mass is not an easy task, first, the geometrical structure of the material ejected from the AGN has to be defined. There is important evidence to suppose that the ionized winds with ubiquitous geometry emerging from the accretion disk of the SMBH, particularly a bi-conical structure has been invoked to explain all the AGN frequencies observations, since radio to hard X-ray and γ frequencies (Elvis, 2006). To know the geometrical structure of the AGN some X-ray variability studies have been done; however if the information is not sufficient to determinate the characteristics of the bi-conical structure, its opening angle or the particle number density, it is not possible to estimate the ejected mass rate, only in a rough approximation. It is the case of NGC 3516 and the Quasar MR 2251–178. In those two cases we only can compare the ionized outflow velocities with their escape velocities at a distance of 10^{17} cm from the galaxy nucleus.

The highest ionized outflow velocity of NGC 3516 reaches the escape velocity of the SMBH, so the arrival of this material to the host galaxy is possible.

The Quasar MR 2251–178 presents ionized outflow velocities smaller than its escape velocity, however, the existence of giant ionization cones supports that AGN wind could reach the host galaxy interstellar medium. It is possible that the innermost ionized winds can drive on the larger bi-conical ionized winds reported by Kreimeyer and Veilleux (2013) and if so, the AGN winds can reach the interstellar medium. MR 2251–178 could present a similar behavior to the Ultra-Luminous InfraRed Galaxy IRAS F11119+3257, analyzed by Tombesi et al. (2015); they reported the existence of a large-scale molecular outflow that can be connected with the UFO detected. Tombesi et al. (2015) propose a scenario where the AGN ionized winds can ride on the larger scale molecular outflows to reach the outer AGN regions.

NGC 4051 and NGC 5548

NGC 4051 is an interesting case since its escape velocity at 10^{17} cm is given by $\approx$680 kms^{-1}. The ionized AGN winds reported can reach and exceed this velocity. However, the estimation of the mass ejection rate from the AGN done by Mathur et al. (2009) determined that the mass outflow rates are not sufficient for efficient feedback, those rates are bellow of those required (4 or 5 orders of magnitude bellow); however new results have been reported by Pounds et al. (2013): Seven kinematic outflow components with velocities from ~-100 kms^{-1} to ~-10300 kms^{-1} with different ionization levels. Those high velocities could imply mass and energy outflow rates larger than the estimated by Mathur et al. (2010). It is necessary to reproduce Pounds et al. 2013 results and to estimate the mass and energy rates emerged from the AGN. It seems possible that NGC 4051 AGN material can escape from the SMBH due to the v_{esc}<-1000 kms^{-1}.

NGC 5548 shows a scenario where it is possible that the AGN innermost material can reach the galaxy interstellar medium –even if the AGN ionized winds do not reach the escape velocity. However, to reach the IGM the estimate mass and energy emerged rates are not enough for an efficient feedback as Krongold et al. (2010) proposed.

Time Variability of the Ionized Absorbers: Mrk 335 and NGC 3516

Mrk 335 galaxy has shown ionized absorbers variations over time. The ionized wind of Mrk 335 appeared in X-ray spectra until 2009, when the emitted galaxy flux has an intermediate level. It is important to notice that the ionized winds of Mrk 335 could exist before but maybe they were not detected, even more, if the mechanism that pushes the AGN winds is the pressure radiation of the central source, then it is possible that when the source radiation grows up, the material is being pushing out from the central engine.

Another case of ionized absorber variation is NGC 3516, it presents absorption features which vary over short time scales (hours). It seems that this variation was produced because some ionized winds were responding directly to the ionizing flux variations; this kind of information allows us to constrain the distance where the ionized winds are located, through a reverberation mapping (Huerta et al., 2014).

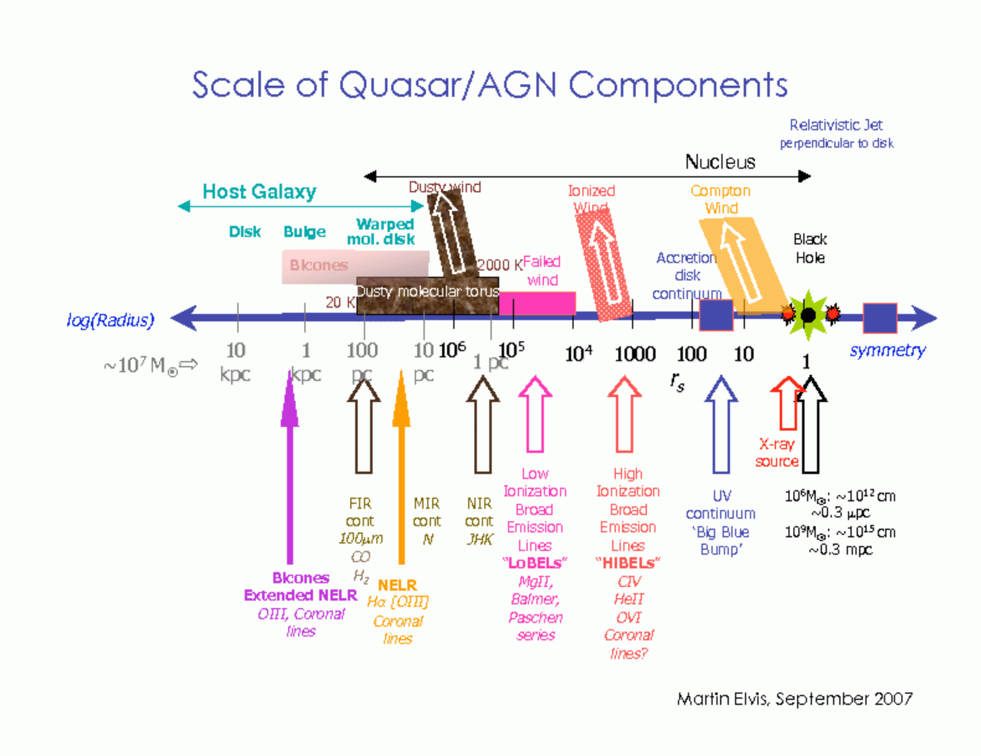
Conclusions

The most generic conclusion is that the theoretical scenarios which propose the AGN ionized winds can arrive to the interstellar medium of the host galaxy, is plausible, but only in some AGN which present ionized absorption with high velocity outflows (~>1000 kms^{-1}), in this study only 5 of 28 AGN contain high velocity outflows. However, it is necessary to do more studies to test the possibility of the AGN ionized winds arriving to the IGM (Inter-Galactic Medium). The galaxies with UFO's (Ultra-Fast Outflows) have more possibilities to expulse to the intergalactic medium the AGN material as the theoretical models proposed (see as example Di Matteo et al., 2005). It is important to mention that the galaxies with UFO's are very few so their contribution would not be significative and sufficient to explain the IGM cooling winds observed.

To verify the theoretical scenarios it is necessary to obtain more X-ray high resolution information with the most advanced observatories: The next generation of X-ray telescope is projected as the ATHENA (The Astrophysics of the Hot and Energetic Universe) mission, the Europe Space Agency's next generation X-ray observatory. The ATHENA mission will have the best detectors with the highest X-ray resolution spectra and the highest signal to noise to identify more atomic transitions and to identify more AGN objects.

To conclude this work, we present the Figure 3 from Martin Elvis. It is the Quasar structure proposed by Elvis (2006) based on all the frequency observations –since radio to hard X-ray and γ rays. As Figure 3 shows, the AGN ionized winds located until 1 Kpc.

Figure 3. *Quasar Structure/AGN Components Proposed by Elvis (2007). The Figure Shows All the Known Components Found in All Frequency Observations of AGN in a Geometrical Structure from the Central SMBH. This Figure was Taken from the Public Martin Elvis Site: http://bit.ly/1mCJHsf*



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