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Accreting SMBH in the COSMOS field: the connection to their host galaxies

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Abstract. Using the rich multi-band photometry in the COSMOS field we explore the host galaxy properties of a large, complete, sample of X-ray and spectroscopically selected AGN. Based on a two-components fit to their Spectral Energy Distribution (SED) we derive rest-frame magnitudes, colours, stellar masses and star formation rates up to $z \sim 3$. The probability for a galaxy to host a black hole growing at any given specific accretion rate (the ratio of X-ray luminosity to the host stellar mass) is independent of the galaxy mass and follows a power-law distribution in L_X/M. By looking at the normalisation of such a probability distribution, we show how the incidence of AGN increases with redshift as rapidly as $(1+z)^{4.2}$, in close resemblance with the overall evolution of the specific star formation rate. Although AGN activity and star formation appear to have a common triggering mechanism, we do not find any 'smoking gun' signalling powerful AGN influence on the global properties of their host galaxies.

Key words. Surveys, Catalogues, Galaxies:active, Galaxies: fundamental parameters, Galaxies: evolution

1. Introduction

To study growing supermassive black hole (SMBHs) and their influence on the host galaxies over different periods of their cosmic evolution, one needs to compile a sample of AGN (both unobscured and obscured) as complete as possible, spanning a wide range in luminosity and redshift.

The major observational challenge is the accurate separation of the AGN and galaxy emission components, at all optical-IR wavelengths. This is a crucial step for a number of reasons: depending on the intrinsic spectral energy distribution of the nuclear (AGN) and of the stellar light, and of their respective level of extinction, inaccurate de-blending might not only hamper any precise determination of the galaxies' physical properties, but also mask AGN signatures and bias our view of the SMBH growth.

This is by no means a trivial task. Distinguishing nuclear AGN emission from the surrounding galactic one requires high spatial resolution observations, but these are challenging, particularly because the resolving power of telescopes varies widely across the electromagnetic spectrum. Indeed, for more distant AGN, combining observations at the highest

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possible resolution at different wavelength on large, statistically significant samples, is nearly impossible, and one often resorts to less direct means of separating nuclear from galactic light.

Optical (and, in fact, NIR) surveys easily pick up AGN at high Eddington ratio, and thus, potentially, all members of a relatively homogeneous class of accretors. The "galaxy dilution bias", i.e. the inefficiency of selecting accreting black holes because of the "contamination" from (stellar) galaxy light in distant systems is linearly correlated to the Eddington ratio (see e.g. Merloni & Heinz 2013, and references therein). On the other hand, deep X-ray and radio surveys, for which stellar light contamination is minimal, can easily circumvent such biases. Indeed, large multi-wavelength galaxy survey and extensive follow-up campaigns of medium-wide and deep X-ray surveys (such as the Chandra Deep Field, Giacconi et al. 2002; the COSMOS field, Hasinger et al. 2007; or the X-Bootes field, Hickox et al. 2009) have allowed to extend AGN SED systematic studies to a wide variety of Eddington ratios and AGN-galaxy relative contributions. Here we report on the results of a systematic analysis of the SED of an almost complete X-ray selected sample of AGN observed in the COSMOS field. We focus our attention on the stellar mass of the AGN host galaxies, and derive robust statistical properties of the accreting black holes population in terms of "AGN occupation fraction", i.e. absolute probability distribution for galaxies of different masses to host X-ray active nuclei (see Bongiorno et al. 2012 for details).

2. XMM-COSMOS AGN sample and data analysis

We studied a sample of ~ 1550 obscured and unobscured AGN, selected in the COSMOS field using X-ray and optical (spectroscopic) criteria. Of these, 602 are unobscured type–1 AGN (430 with spectra) and 953 obscured type–2 AGN (402 with spectra) with $L_{\rm bol}$ ranging from 10^{43} to 10^{47} erg s^{-1}.

The observed SED of our sources was fitted with a large grid of models based on a

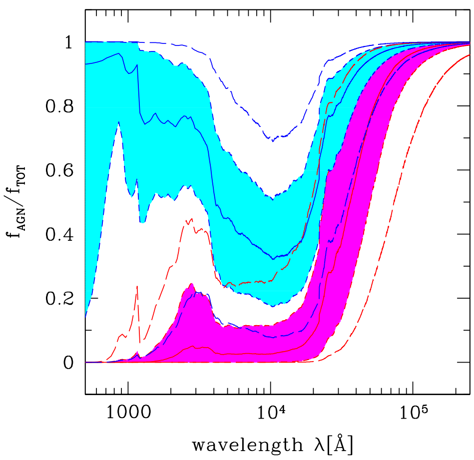

Fig. 1. Median AGN contribution to the total SED at different wavelengths for unobscured (blue continuum line/light grey shaded) and obscured (red continuum line/dark grey shaded) AGN. Shaded areas correspond to the range within the 25th and 75th percentiles, while long dashed lines that within the 10th and 90th percentiles.

combination of the Richards et al. (2006) AGN template and several host-galaxy models (i.e. synthetic spectra created from the stellar population synthesis models of Bruzual & Charlot 2003). Given the wide multi-wavelength coverage available in the COSMOS field, this fitting technique allows to decompose, typically with a high level of confidence, the entire SED into nuclear AGN and host galaxy components and to derive robust measurements of the host galaxy physical properties, e.g. restframe colours, stellar mass, K-band luminosity and star formation rate. The strength of the SED fitting method is that, given sufficiently wide photometric coverage, it is applicable to all AGN, obscured and unobscured, independent of their luminosity. In particular, once a comprehensive set of templates for the SED components is chosen, the method can be applied (almost) blindly to any detected object in a multi-wavelength survey, irrespective of the specific selection criteria, reaching an accuracy that depends crucially on the number of bands and depth of the available photometric catalogs. In this respect, COSMOS is a uniquely suited field for our investigation.

Figure 1 shows the median AGN contribution to the global SED at different wavelengths for unobscured (blue continuum line/light grey shaded) and obscured (red continuum line/dark grey shaded) AGN. The shaded area and the long dashed lines mark the 10th, 25th, 75th and 90th percentiles of the samples. From this figure, we see that, for obscured AGN, three quarters of the objects have AGN contribution in the optical bands smaller than 20%. Thus, any residual AGN contamination (or AGN over-subtraction), should not affect the determination of the rest-frame optical colours of the host by more than about 0.1 magnitude. On the other hand, at rest-frame wavelengths of about 1μm, three quarters of type–1 AGN have AGN fraction smaller than about 50%, implying that, even for unobscured objects, our method allows a robust determination of the host total stellar masses.

3. Main results and Conclusions

The XMM-COSMOS AGN host galaxy masses range from $10^{10}M_{\odot}$ to $10^{11.5}M_{\odot}$ with a peak at $\approx 10^{10.9}M_{\odot}$. No significant difference is found in the stellar mass distributions of X-ray obscured and unobscured AGN hosts. We have then compared the AGN hosts to a complete parent sample of galaxies from the Spitzer IR selected sample (Ilbert et al. 2010). For a galaxy of any given mass above the stellar mass completeness limit of the COSMOS survey, the probability to host an AGN of a given X-ray luminosity increases with stellar mass, and this holds true for any value of the X-ray luminosity we are sensitive to. In fact, against the naive expectation that more luminous AGN should be found in more massive galaxies and less luminous ones in lower mass galaxies, we find that AGN *of any intrinsic luminosity* are more common the more massive the galaxy is.

Having measured the host stellar mass for all AGN in the sample, we have then used the observable "specific accretion rate", i.e. the ratio between X-ray luminosity and host galaxy stellar mass as a proxy for the Eddington ratio of the growing black hole. By doing so we find that the probability for a galaxy to host an AGN *of any given Eddington ratio* (or specific accretion rate) is roughly independent of the host galaxy stellar mass, but strongly decreases with increasing L_X/M_* (see figure 2). This implies that the higher incidence of AGN observed in massive galaxies by essentially all multi-wavelength surveys is just a consequence of the fact that low specific accretion rate objects are more common than high specific accretion rate ones, and, at the same time, low L_X/M_* objects in low mass galaxies drop out of flux-limited AGN samples. This effect, closely associated to the broad Eddington ratio distribution of AGN was anticipated in Merloni & Heinz (2008) and has been confirmed observationally by Aird et al. (2012). Figure 2 also shows that the probability for a galaxy to host an AGN *of any given specific accretion rate* strongly increases with redshift, approximately as $(1+z)^4$ for SMBH accreting at about 10% of the Eddington limit, where most of the SMBH mass assembly is supposed to take place. Such a very strong evolutionary trend follows closely the overall evolution of the specific star formation rate of the galaxy population (Karim et al. 2011). This is yet another strong indication that AGN activity and star formation are globally correlated. In addition, the colours and star-formation properties of obscured AGN hosts (where they can be measured reliably), do not appear to deviate strongly from those of the overall parent galaxy population (see Bongiorno et al. 2012 for details).

4. Conclusions

Thanks to the wide COSMOS multi-wavelength coverage we were able to study in detail the source SEDs and to fit the observed fluxes with a two component model based on a combination of AGN and host-galaxy templates, accounting for dust extinction in both components independently. This method allowed us to decompose the entire spectral energy distribution into a nuclear AGN and a host galaxy component for almost all the sources and to derive robust

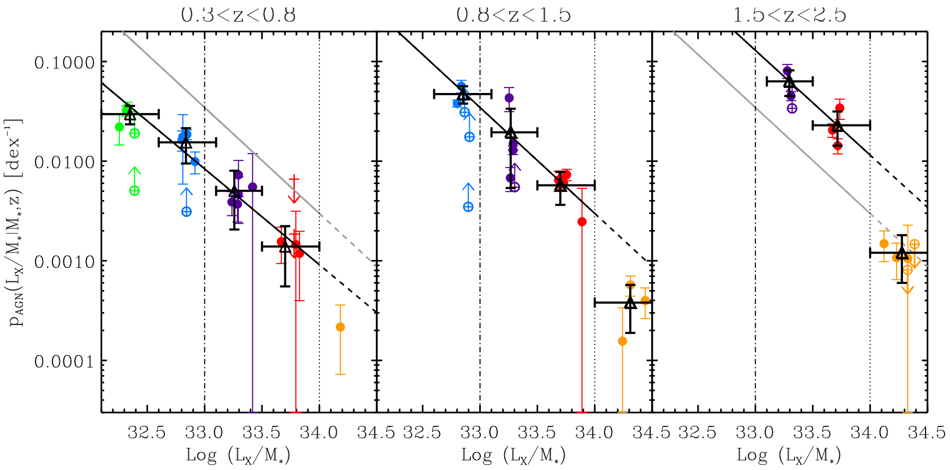

Fig. 2. The probability of a galaxy to host an AGN of a given specific accretion rate (per decade L_X/M_* ratio) is plotted as a function of L_X/M_* for three redshift intervals. Different colors show different L_X/M_* intervals, while black thick triangles are the mean values. The thick black line in each panel is a power-law fit to all the mean points obeying Log(L_X/M_*) < 34. For ease of comparison, in each panel we also show the best fit to the central redshift interval. The vertical dotted (dot-dashed) lines mark the approximate location of objects at the Eddington limit (or ten per cent of it) calculated assuming a constant bolometric correction k_{bol} = 25 and a constant host stellar to black hole mass ratio of $\mathcal{A}$ = 500.

measurements of both the AGN and the host galaxy properties (i.e. rest-frame colours, masses and SFRs). The most striking piece of evidence that emerges from our study is the fact that AGN hosts do follow quite closely the overall evolution of the stellar build-up of the parent galaxy population. However, on the basis of the evidence accumulated from the AGN COSMOS sample, it is hard to find very strong indication that AGN play a direct role in shaping the global properties of their host galaxies or their evolution. Instead, it appears that the same, probably stochastic, process of AGN activation and triggering seems to be in place in galaxies of all masses all the time, with just an higher incidence the higher the star-formation rate is. Because of the robustness of this picture across the wide redshift range probed, we believe that whatever physical process is responsible for triggering and fueling AGN activity, it must be the same between z ∼2.5 and z ∼0.3, but must decrease in frequency or shift towards lower accretion rates. Although AGN activity and star formation appear to have a common triggering mechanism, we do not find strong evidence of any 'smoking gun' signalling powerful AGN influence on star forming galaxies SFR. The extent to which this lack of evidence can be meaningfully used to constrain and/or rule out theoretical models of AGN feedback, remains to be investigated.

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