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"Understanding the evolution of Active Galactic Nuclei"
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FINAL REPORT

Active Galactic Nuclei (AGN), powered by accretion of material onto super-massive black holes (SMBHs), have experienced dramatic evolution in the last 7×10^9yrs of the lifetime of the Universe. A number of observations have established that the space density of these systems has dropped by almost 2 orders of magnitude during that period, from redshift z=1 to the present day. The goal of the proposed ERG program was to shed light on the physical processes responsible for this rapid decline of AGN activity in the Universe.

The approached adopted to tackle this problem was the study of the properties of the galaxies that host an active SMBH. Numerical simulations show that the physical conditions under which SMBH grow (e.g. fueling mode, triggering mechanism) should imprint on properties such as the star-formation history, stellar mass, large scale environment and morphology of AGN hosts. By studying how these properties change with cosmic time, from z=1 to z=0, one could infer the key physical processes at play and how they affect the accretion history of the Universe.

Observations at X-ray wavelengths are arguably the most direct and efficient way of selecting AGN at any redshift. Until recently however, most X-ray surveys were optimised for AGN studies at moderate and high redshifts, z~1. The main goal of the ERG proposal was to complement these surveys with a low redshift sample of X-ray selected AGN. We proposed to use these data to constrain the evolution with redshift of the (a) star-formation history, (b) stellar mass and (c) large scale environment of AGN hosts.

We used archival data from the XMM-Newton X-ray satellite to perform a serendipitous X-ray survey in the footprint of Sloan Digital Sky Survey (SDSS). This is the largest optical program to date and is designed to study galaxies at z~0.1. The SDSS covers 10,000deg^2 and provides high quality optical photometry in 5 broad bands (*ugriz*) and extensive optical spectroscopy for galaxies at z~0.1.

An automated pipeline was developed to reduce and analyse the large volume of archival XMM data that overlapped with the SDSS. This included the reduction of the raw data, the detection of sources, the estimation of their properties (e.g. flux, X-ray spectrum), the identification of X-ray sources with optical galaxies from the SDSS. This effort resulted in an X-ray source catalogue that was presented in the refereed publication "A serendipitous XMM survey of the SDSS: the evolution of the colour-magnitude diagram of X-ray AGN from z= 0.8 to 0.1", 2011, MNRAS, 414, 992, by A. Georgakakis & K. Nandra. The X-ray catalogue has been made available to the astronomy community at http://www.astro.noa.gr/~age/xmmsdss.html.

Novel features of the pipeline developed as part of the ERG program include a simple but efficient source detection method, a new realistic parameterization of the XMM-Newton Point Spread Function, a Bayesian approach for the estimation of X-ray source fluxes and an accurate description of the X-ray survey sensitivity using Bayesian statistics.

Using the serendipitous X-ray source catalogue of the SDSS footprint we then compiled a sample of ~400 X-ray selected AGN at z~0.1. This was combined with deep X-ray surveys targeting AGN at z~1

to explore possible evolution of host galaxy properties.

The evolution from z=0.1 to z=1 of the AGN host galaxy colours (a proxy to star-formation history) and the AGN host stellar mass has been presented in the refereed scientific publication “Observational constraints on the physics behind the evolution of active galactic nuclei since z˜~1”, 2011, MNRAS, 418, 2590, by Georgakakis et al. We find no evidence for evolution of the colours or the typical stellar mass of AGN host galaxies since z=1. This suggest that the conditions under which SMBH grow has not changed with time, i.e. the same fueling mode or combination of fuelling modes are in operation at all epochs since z=1. Our findings support a picture in which the rapid evolution of the AGN population with redshift is related to the depletion of gas reservoirs of galaxies (the fuel of SMBHs) with cosmic time, rather than a change of accretion mode.

The large scale environment of X-ray AGN from z=1 to z=0 has been presented in the refereed scientific publication “The clustering of X-ray-selected active galactic nuclei at z= 0.1”, 2012, MNRAS, 420, 514, Mountrichas G. & Georgakakis A. We find that the typical environments of X-ray AGN at both z=1 and z=0.1 are small groups, i.e. concentrations of few to few tens of gravitationally bound galaxies. The lack of evolution in the large scale environment of AGN further suggests that the fueling mode of SMBH has not changed dramatically with cosmic time since z=1.

Work is also currently in progress to follow X-ray sources in our serendipitous X-ray survey with optical spectroscopy to expand our z=0.1 results to z~0.6 and therefore bridge the time gap between z=0.1 (our serendipitous X-ray survey) and z=1 (deep X-ray surveys).

Also during the ERG a novel method has been developed for the determination of the large scale environment of AGN. This methodology is now been applied to deep X-ray surveys to improve constraints on the large scale structure of X-ray AGN at z~1. A refereed publication presenting the method and results is in preparation.

During the ERG funding period, in addition to the core scientific activities related to the ERG proposal, research has also been carried out in the broad area of SMBH fueling physics. This work has resulted in three refereed publications:

“The radio spectra of reddened Two Micron All Sky Survey quasi-stellar objects: evidence for young radio jets”, 2012, MNRAS, in press, by Georgakakis et al.,

“Searching for an intermediate-mass black hole in the blue compact dwarf galaxy MRK 996”, 2011, MNRAS, 413, 1729, by Georgakakis et al.,

“Infrared Excess sources: Compton thick QSOs, low-luminosity Seyferts or starbursts?”, 2010, MNRAS, 406, 420, Georgakakis et al.

In summary, we believe that all the goals set out in the ERG proposal (performing a serendipitous X-ray AGN survey, studying the evolution since z=1 of AGN hosts' star-formation, stellar mass and environment) have been achieved, and the results have already been presented in refereed publications to high impact factor journals (Monthly Notices of the Royal Astronomical Society, impact factor 5.1).

The Researcher

Antonis Georgakakis

The Scientist in charge

Ioannis Georgantopoulos