Science topic: looking for accreting super-massive black holes during the re-ionisation epoch

Abstract

The study of the accreting super-massive black holes (SMBHs) population in the first Gyr of the Universe is a crucial topic in the context of the present-day astrophysics and is part of the science goals of the most relevant project of the next decade (LSST, Euclid, SKA, WFIRST, Athena). In our proposed PhD thesis, in particular, the student will be part of the project "*High-z AGN and galaxies into the Re-ionization Epoch with LSST*", supported by INAF, which is expected to provide a significant transformation in this field, allowing for the first time statistical studies on the high redshift (z$\sim$7) QSO population, on a few-year time scale since now. The aim of the proposed thesis is to develop a new selection method, based on a multi-wavelength approach which will allow, for the first time, the detection of high-z (moderately) absorbed QSOs. The work will be accomplished in the three-year time scale using the currently public surveys as first tests, the LSST simulated datasets and, finally, the very first data releases. Eventually the student will be provided with the skills to appropriately exploit the unprecedented LSST database and, in the post-doc years, its synergies with Euclid and SKA.

Context

One of the most intriguing issues in astrophysics is to understand when and how the first super massive black holes (SMBHs) formed in the Universe, how they are related to the early galaxy formation and what is their role in driving the re-ionisation process in the early Universe.

Finding accreting SMBH, i.e. QSOs at high redshift is not an easy task: at the moment we know only 8 QSOs at $z > 6.5$ (Bañados et al. 2016, ApJS, in press), with the highest redshift being 7.08 (Mortlock et al. 2011, Nature, 474, 616). The reason is that these are very rare objects, usually confused in a multitude of apparently similar objects, in huge photometric catalogs produced by multi-wavelength surveys of several hundreds of sky square degrees. A great leap forward is expected in the near future thanks to the LSST project, in the optical/near-IR, and to EUCLID, in the near-IR. LSST, in particular, is a 6.5 m effective primary mirror telescope, with 9.6 deg^2 field of view. It is in the construction phase and will begin regular survey operations by 2020. In a one (ten) -year time scale, the survey will cover 18,000 deg^2 in six bands (ugrizy), covering the wavelength range $0.32 - 1.05$ μm, yielding a co-added map to r $\sim$ 25.5 (27.5). For what concerns the early accreting SMBH, we estimate that in the first year LSST catalog, 600 unabsorbed QSOs in the 6.5 -7.5 redshift bin will be easily detectable using the standard color selection, down to $M_{AB}(1450)$=-24.5 corresponding to a bolometric luminosity of $\sim 5\times10^{46}$ erg/s. At the end of the survey the detectable high z QSOs will be $\sim$ 2000 with a limit of $M_{AB}(1450)\leq$-23 corresponding to a bolometric luminosity of $\geq 10^{45}$ erg/s. Two INAF institutes (OA Brera and OA Roma) are involved in this science topic through the approved project "*High-z AGN and galaxies into the Re-ionization Epoch with LSST*".

The project

A critical problem in the selection of high-z QSO is that most of the accretion on early SMBH is expected to be hidden by a wide range of dust and gas column densities. The standard selection methods which have been used so far in literature can only detect objects with fully transmitted spectra without any absorption (except for the cosmological HI). The point is that even a small amount of dust in the host galaxy can alter the QSO spectrum in such a way that optical and near IR colors become photometrically indistinguishable from cool dwarf stars.

A possible way out, which has not yet been completely exploited, comes from the synergy with the radio (at $\sim$GHz frequencies) surveys. The combination of optical-IR data sets with radio maps is able to produce lists of high-z QSOs candidates free from any stellar contamination. This allows

us to expand the quest for high-z QSOs allowing a moderate spectral reddening. Indeed the few AGNs, discovered so far by combining a radio (FIRST) and an IR surveys, present a light level of absorption (E(B-V)$\sim$0.1) that would have left them undetected in a "standard" optical/IR selection (McGreer et al. 2006). This suggests that current densities of high-z AGN based on optical/IR surveys may be significantly underestimated due to the presence of dust along the line of sight.
The great advantage of the radio band is the availability of relatively deep all-sky surveys (or covering large fraction of sky), like FIRST, NVSS and CLASS, an essential requirement for an efficient selection of rare sources like high-z QSO. In the next few years a great improvement in this field is expected from the SKA precursor radio all sky surveys, like ASKAP EMU (Norris et al. 2011) and SKA1 (Norris et al. 2014), that are expected to improve the sensitivity of 1-3 orders of magnitude with respect to current surveys.
In addition, radio-loud sources are extremely valuable probes of the physical state of the very early inter-galactic medium (IGM) up to very high redshift. In fact, the study of the IGM through GunnPeterson effect is limited at z <6.5 beyond which the neutral hydrogen density is so high that it cannot be probed using continuum Lyα absorption (e.g. Furlanetto 2006). On the other hand radio-loud quasars will be used by the coming generation of radio telescopes (EVLA, ALMA, SKA, LOFAR, etc.) to measure the properties of neutral hydrogen through 21 cm absorption studies (e.g. Carilli et al. 2004).
In conclusion, our plan is to combine LSST data with the radio catalogues that will become available during the next 10 years (mostly from SKA precursors or SKA1) to exclude most of the sources that usually contaminate the selection of high-z QSO. At the same time, we want to develop new selection methods, based on the SED of the sources, to allow the inclusion of moderately reddened high-z QSO. The proposed thesis represents a fundamental part of this project, as detailed below.

The proposed thesis

The goal of the PhD thesis proposed here is **the development of a method to efficiently select and study (slightly) absorbed high-z QSOs using the combination of optical, IR and radio surveys.** This will represent a significant improvement of the standard procedures for the high-z QSO detection and will allow to probe a population which is almost completely unknown. The work, that will be mostly based on existing optical/IR and radio surveys, is an important step for a full exploitation of the LSST data.
During the **first year**, the student will investigate the effect of moderate reddening (E(B-V)$\leq$0.1) on the broad band colours of high-z QSO. Indeed, in order to include moderately reddened objects, the standard color constraints which have been used so far in literature to select high-z QSO must be significantly modified. It will be particularly important to establish the best photometric bands (optical/near and mid-IR) that maximize the differences between high-z QSO and other classes of sources. SED-fitting procedures will be also developed to automatically pre-select promising list of candidates. The new selection methods will then be tested on the existing radio (FIRST), optical (PanStarrs, KIDS) and infrared (VIKING, UKIDSS) public surveys. The application of these new color filtering and SED-fitting procedures is expected to produce a list of high-z QSO candidates that will be then proposed for spectroscopic follow-up at 8-10 meter class telescopes (VLT, LBT, GTC). We stress that these public surveys have been almost fully exploited for what concerns the unabsorbed high-z QSO but they are still largely unexplored for moderately reddened objects. For this reason we expect that some new high-z QSO will be found after the spectroscopic follow-up. In any case, these data will be important to quantify the actual type of contaminants and, hence, to refine the selection methods. This part of the work will be carried out mostly during the **second year**. We also expect that new deep radio data (down to $\sim$50 micro-Jy) will be soon available thanks to the first SKA precursor surveys (like ASKAP EMU) on a large fraction of the sky. These new data will allow to further extend the selection to less radio-loud objects. During the first two years it will be possible to apply the new selection methods also to the simulated LSST data, that

will be produced before the LSST observations, in order to optimize the procedures on the real data. During the **third year** (2020) the first data release of LSST is expected. Since the student will be officially part of the LSST collaboration, he/she will have full and immediate access to all the products that will be available right after the verification phase. These data will allow us to expand the search to higher redshift ($6.5<z<7.5$) and lower luminosities. Notably, some of the QSOs with $z>6.5$ in the sample are expected to be *blazars* and they will be by far the highest redshift objects of this type ever selected (to date the highest-z blazar has z=5.47, Romani et al. 2006, AJ, 610, L9). The study of sizable samples of blazars at these redshifts will offer an independent method to quantify the space density of the radio-loud QSO (see e.g. Volonteri 2011; Sbarrato et al. 2015).
Although the main goal of the thesis is the development of new selection method, the discovery of new high-z QSO will surely represent an important and exciting part of the work. During the third year the student is expected to carry out the analysis of the high-z QSO discovered during his/her work. The analysis of the optical/IR spectra, in particular, will provide important information on the SMBH masses powering the QSOs and on the accretion rate. Follow-up proposals (X-rays, VLBI) on the selected high-z QSO will be also possible.

After the PHD

Working on the LSST preparatory science will put the student at the end of its PhD thesis in a favoured position to fully exploit the LSST data-base. A very promising build-out in this filed, expected for the first part of the next decade, will be the synergy between LSST and EUCLID which is an ESA mission, with a strong INAF involvement. As a by product of its main science goal, the EUCLID satellite will produce an near-IR survey of 15,000 deg^2, among which 50% will be in common with LSST, with the unprecedented depth of 24.5 (AB mag.). The combination of the LSST and EUCLID databases will allow to expand the quest for accreting primordial SMBH up to higher redshift and higher levels of absorption.