QUASARS AND JETS IN THE EARLY UNIVERSE: UNDERSTANDING THE FORMATION AND EVOLUTION OF SUPERMASSIVE BLACK-HOLES

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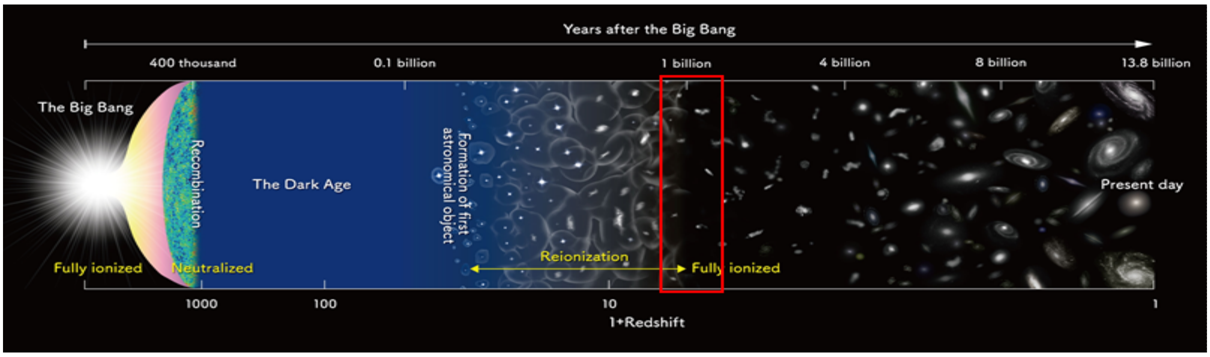
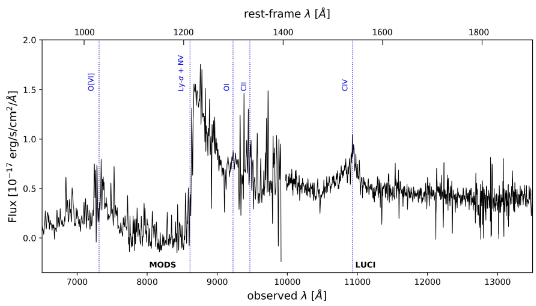


Universe timeline, since the big-bang to present days. The red box indicates the range of redshift we are exploring in the project discussed here

Supermassive black holes (SMBH), with masses reaching several billions of solar masses (Msun), are present in the center of nearly all galaxies. Current theoretical models assume that they formed relatively "light" (10^{2}-10^{4} M_{sun}) when the Universe was ~300-500 Myr old and then rapidly accreted matter to reach the huge masses observed today. However, the observation of galaxies in the early Universe (less than 1 Gyr old) hosting already massive SMBH (~10^{8-9} Msun) is a challenge for current models, since the time available for the black-hole growth was very short. For this reason, searching and studying SMBH in the early Universe, in particular those actively accreting matter (the so-called quasars), is a lively and hot topic in current astrophysical research. A general review on this topic can be found here:
https://arxiv.org/abs/2110.10175v1
Our research group, currently including 4 staff researchers and 1 PhD student, has been actively working in this important research field in the last ~5 years. In particular we have been focused on the enigmatic sub-set of **quasars that are able to produce powerful relativistic jets** (the so-called "radio-loud quasars") in order to establish their actual role in the overall picture. The list of publications of our group on this research field in the last 4 years can be found here:
http://www.brera.mi.astro.it/~alessandro.caccianiga/highz_pub.html

In all the PhD theses we are offering the student will have the possibility of taking a leading role on some specific aspects of this stimulating field either by exploiting the large amount of data we have collected so far and/or obtaining new data set by writing specific proposals. The PhD student will also have the possibility of spending one or more periods abroad to gain expertise and foster external collaborations. The (non-exhaustive) list of possible lines of research to be carried out includes:

- **The search and multiwavelength follow-up of new radio-loud QSO at high redshifts** by exploiting both the existing and the new generation of radio/optical/infrared surveys. Our group has a very good expertise in this field as demonstrated by the fact that **more than half of the radio-loud quasar at redshift above 6 has been discovered by two PhD students in our group**. We expect that, with the existing surveys, it will be possible to discover several z>5.5/6 radio-loud quasars in the next couple of years. In addition, this work will soon benefit of the new data-sets produced by the new generation of radio and optical+near/IR (LSST) surveys which will be available in a 2 years time-frame and for which our group has a privileged access. Thanks to these new data it will be possible to push the discovery limit up to z~7, a currently unexplored territory for radio-loud quasars.



Optical spectrum of PSOJ0309+27, one of the most distant jetted Quasar discovered so-far at z=6.1 (adapted from Belladitta et al.2020)

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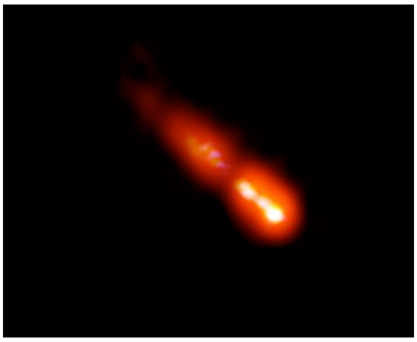
- **Studying the innermost part of the relativistic jets of high-z QSO using the Very Long Baseline Interferometry (VLBI) technique**. This special technique, that has been recently used to directly image the SMBH shadow in M87 and CenA*, is based on the combination of the simultaneous observation of different radio telescopes distributed worldwide and it permits to obtain the sharpest view of the innermost part (within a few parsecs) of a jet. **We have already obtained VLBI data on about 20 high redshift QSO**, using the European VLBI Network (EVN) and this unique data set can be the starting point for a very interesting PhD thesis work.



High resolution (VLBI) radio map of the innermost region of PSOJ0309+27 at z=6.1

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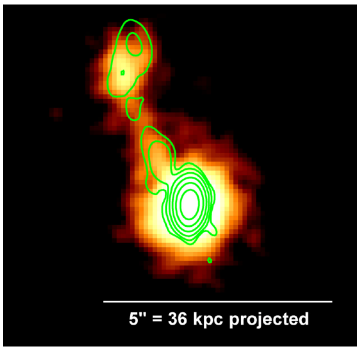
- **Extended X-ray jets**: the relativistic jets departing from radio-loud Quasars, in some cases extend over tens of kpc and are directly observable as resolved structures at different wavelengths. In particular, the X-ray emission of these objects is particular intriguing for, at least, two reasons. First, the physical mechanism responsible for this emission is unclear and has been debated for over two decades. Second, current observations show that their properties evolve with redshift. Starting from the observation of the most distant extended object ever observed (at redshift z=6.1), **in a recent work conducted by a PhD student of our group, we interpreted these phenomena as due to the interaction of the jet electrons with the CMB radiation which is much denser in the early Universe**. However, since this explanation is contentious, an extensive comparison of the model predictions with larger datasets would be very useful for testing the presented model. This is a suitable PhD thesis in a forefront research field for a student who would like to complement the analysis of observational data with a more theoretical approach.



Example of extended jet observed in the X-rays with Chandra telescope

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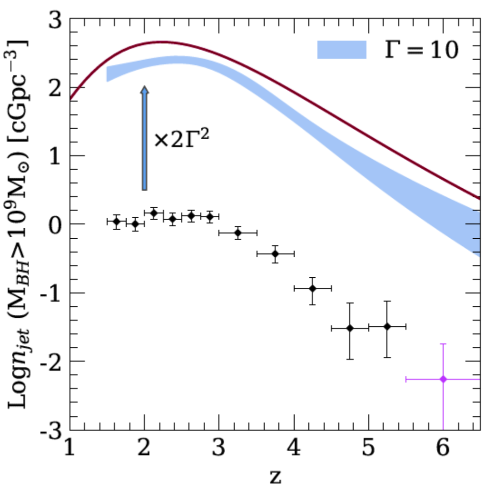
https://iopscience.iop.org/article/10.3847/1538-4357/aa907a/pdf

- Studying the cosmological evolution of SMBH hosting relativistic jets.
Understanding how SMBH evolved since their formation and the role of the relativistic jets is a key issue which requires a careful study of well-defined and statistically complete samples of jetted Quasars at high redshifts. Appropriate statistical analyses, taking into account all the possible selection effects, allow us to derive important quantities like **Luminosity Function**, **Cosmological Evolution** and **SMBH mass function.** Thanks to the availability of large spectroscopic data sets (in addition to the results of our own searches discussed in the first item) it is now possible to build sizable (hundreds objects) samples of z>4 jetted Quasars with a reliable SMBH mass estimate. This unprecedented situation makes it possible to accurately estimate the cosmological properties mentioned above and to compare them with those of non-jetted Quasars. This comparison will allow us to derive important conclusions about the relevance of the relativistic jets on the SMBH evolution.



Evolution of the most massive SMBH hosting a relativistic jet (blue area) compared to those hosted by all Quasars (red line), including those not hosting jets). Adapted from Diana et al. (2022)

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https://ui.adsabs.harvard.edu/abs/2016LNP...905..101M/abstract
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