# The role of quasars during Reionization

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Following the so-called Dark Ages, the Universe experienced a crucial transition called Reionization. During the first hundred million years, the first sources of light produced enough UV photons to ionize cosmic hydrogen. Reionization sets up a network of ionized bubbles that eventually overlap: the transition yields a fully ionized intergalactic medium (IGM) by redshift z~6, i.e. ~1 billion years after the Big-Bang with only a few remaining neutral regions detected in the absorption features of the Lyman-alpha forest. A wide range of experiments such as ALMA, EELT, JWST (for high-z galaxies), SKA (for the neutral IGM 21 cm radio signal) or ATHENA (for the first super massive black holes, SMBHs) are being set up in the next decade to investigate these early times.

Until now, models focused on the role of star-forming galaxies as the most important drivers of the Reionization. However, it is becoming increasingly clear that quasars, i.e. active supermassive black holes, played a significant role in these early epochs, as supported by a number of probes:

- SMBHs, the central engines of quasars, have masses as large as $10^9$ solar masses at high z. This raises questions about their origin, their growth and feedback on their host galaxies or their environment.
- Some published luminosity functions at z=5.5 even predict a contribution of quasars as important as of the galaxies for $M_{UV}$<-20 to the UV photon budget. The plausibility of a quasar-driven reionization must therefore be assessed.
- Predictions on the 21 cm signal require accurate predictions on the gas temperature: in that respect the role of quasars, as IGM heaters through X-rays emission, is crucial. The recent results obtained by the EDGES experiment illustrate the need for a proper description of the reionization radio signal.

The aim of this thesis is to include and investigate the effects of quasars during Reionization using state-of-the-art cosmological simulations. The student will participate in :

- expanding the Strasbourg simulation code EMMA by coupling the physics of radiative hydrodynamics to the processes at play in SMBHs,
- exploring the impact of SMBHs from the galactic to the cosmological scales at z>6 by producing the appropriate set of simulations
- predicting observational signatures of the physics of quasars during Reionization, in the properties of galaxies and the 21 cm radio signal of the IGM

The candidate will work within at the Observatoire de Strasbourg, under the supervision of D. Aubert and P. Ocvirk. The project will involve state-of-the art numerical tools to assess galaxy formation in a radiative environment such as EMMA [1], a homebrew AMR code driven by GPUs, or RAMSES-CUDATON [2]. Access to important computing resources, locally in Strasbourg and on Tier-0 international facilities will also be granted. Recently the team has produced CoDa I, CoDa I-AMR and CoDa II, the largest hydro-radiative simulations of the reionization ever performed [2, 3], on the Titan supercomputer using up to 16384 GPUs, adding up to more than 100 million core hours and producing 2 PB of data. The proponents are also members of the SKA and ATHENA working groups as well as participants to a Key Science program dedicated to Reionization using the Nenufar radio observatory.

[1] Aubert D, Deparis N and Ocvirk P 2015, *MNRAS*, **454**, 1012
[2] Ocvirk, P., Gillet, N., Shapiro, P. R. et al. 2016, *MNRAS*, 463, 1462

[3] Aubert D., Deparis N. et al. 2018, *ApJL*, 856, 2