Short PhD project

Unveiling the properties of the first galaxies

Joint supervision of Nicolas Laporte and Roberto Maiolino

Project summary

Understanding the formation and evolution of primeval galaxies is one of the most active topics of modern cosmology. Over the last two decades, many advances have been done on both sides: observations and simulations. The distribution of galaxies emitting light within the first billion years of the Universe is now well understood. Several physical properties, such as their luminosity, stellar mass and star-formation are also well constrained. 8-10m class telescopes have observed the most distant galaxies currently known for hundreds of hours, but the luminosity of those galaxies is too faint to study other physical properties, which remain completely unknown, as for example their metallicity (*amount of metals*), their ionising potential (*amount of UV photons escaping the galaxy*) and their radiation field (*presence of a black hole*). This project aims to take advantage of all observations of bright z>7 galaxies done with NIR spectrographs (X-Shooter and KMOS at the VLT, MOSFIRE at Keck, FLAMINGOS- 2 at Gemini) to obtain a deep stacked spectra (>100 hrs) and to study new physical properties of primeval galaxies.

Background

A fundamental challenge in supporting the now-popular claim that early star-forming galaxies are responsible for cosmic reionization is the nature and strength of the ionizing radiation emerging from a typical source. To account for the optical depth of electron scattering seen by Planck, at least 10%–20% of the radiation produced by hot main sequence stars below the Lyman limit must escape scattering and absorption by clouds of neutral gas in the circumgalactic medium. Direct measures of this "escape fraction" are not yet possible beyond a redshift z~3, and below which, following considerable observational effort, such a high fraction seems to be quite rare. Indirect methods based on tracing the extent of low-ionization gas suggest the escape fraction may increase at higher redshift, but the validity of such methods remains unclear.

The lack of evidence supporting the efficacy of star-forming galaxies as producers of Lyman continuum radiation into the intergalactic medium (IGM) has led some to suggest that a significant contribution of ionizing radiation may emerge from non-thermal sources such as active galactic nuclei (AGNs) in the nuclei of more massive early galaxies. Assuming 100% of such non-thermal radiation can emerge into the IGM, Madau & Haardt (2015) demonstrate that, depending on the uncertain faint end portion of the high-redshift AGN luminosity function, a significant fraction of the late-ionizing contribution may arise in this manner. While it seems unlikely that early AGNs can dominate the reionization process, such a contribution could alleviate the requirement from star-forming galaxies. Of course, given that quasars with supermassive black holes are seen to redshifts of at least z~*7*, it seems reasonable to assume there are earlier galaxies containing nuclear black holes.

Project description

This project will be divided into two parts: (i) data reduction and (ii) data analysis. The first part of this project will consist of reducing homogeneously spectroscopic data of more than 20 bright (and therefore massive) $z>7$ galaxies previously observed with NIR spectrographs installed on 8-10m class telescopes (VLT, Keck, Gemini) and for which the spectroscopic redshift has been measured (either from NIR or FIR). The student will use the new software PypeIt. He/She will then have to identify the best way to stack properly spectra from different instruments. The stacked spectra will be done as a function of the galaxy luminosity (most probably with 2-3 bins in luminosity). The second step will be the analysis of the stacked spectra with the determination of the metallicity and radiation field (detection of UV lines such as CIII, CIV, NV, MgII). The properties will then be analysed as a function of the luminosity of the galaxies sample.

Project Details

The steps of the project are as follow:

- Data reduction of NIR spectra of >20 galaxies at z>7 with PypeIt
- Stack of spectra as a function of luminosity
- Data analysis and search for UV emission lines (NV, HeII, CIV, CIII)
- Determination of the strength of the radiation field and metallicity

Useful references: (List of important papers/review articles relevant to the project)

Stark 2016, ARA&A, 54, 761 : https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-081915-023417

Laporte et al. 2017, ApJ, 851, 40 : https://iopscience.iop.org/article/10.3847/1538-4357/aa96a8/pdf

Topping et al. 2021, arXiv:2107.06295 , https://arxiv.org/pdf/2107.06295.pdf

PypeIt : https://github.com/pypeit/PypeIt

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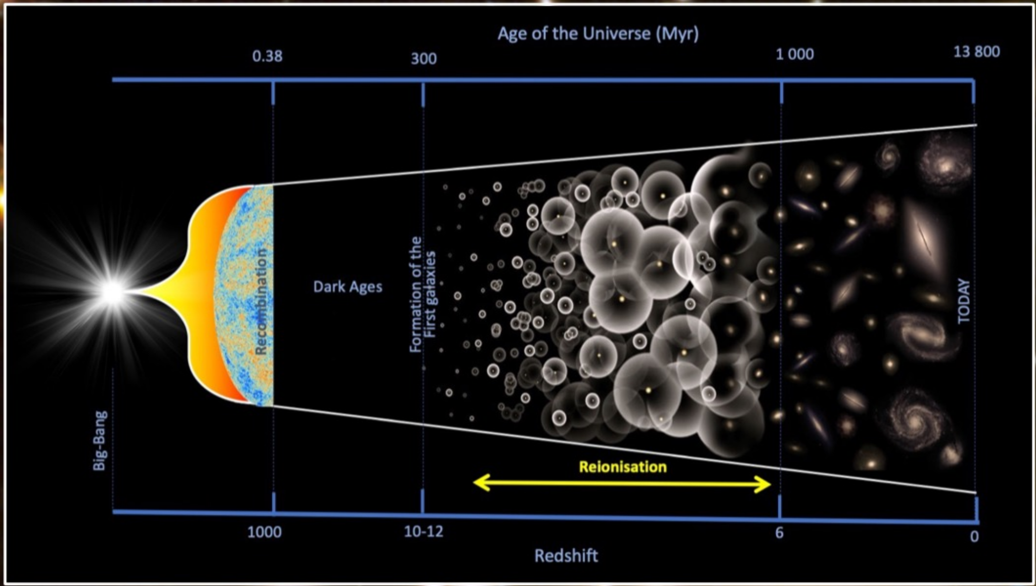

KEY POINTS

- 1 billion years after the Big-Bang, the hydrogen in the Universe is mainly ionized (epoch of reionisation)
- However, the UV photons produced by the first galaxies are not sufficient to explain the ionization of the neutral hydrogen formed after the Big-Bang (*assuming they have similar properties as local galaxies*)

The physical properties of the first galaxies are not similar to local galaxies

UNANSWERED QUESTIONS

- What are the physical properties of the first galaxies (Star Formation Rate, Stellar Mass, Escape Fraction, ...)
- When did the first black hole form in the early Universe ?
- How the physical properties evolve with the UV luminosity ? With the redshift ?

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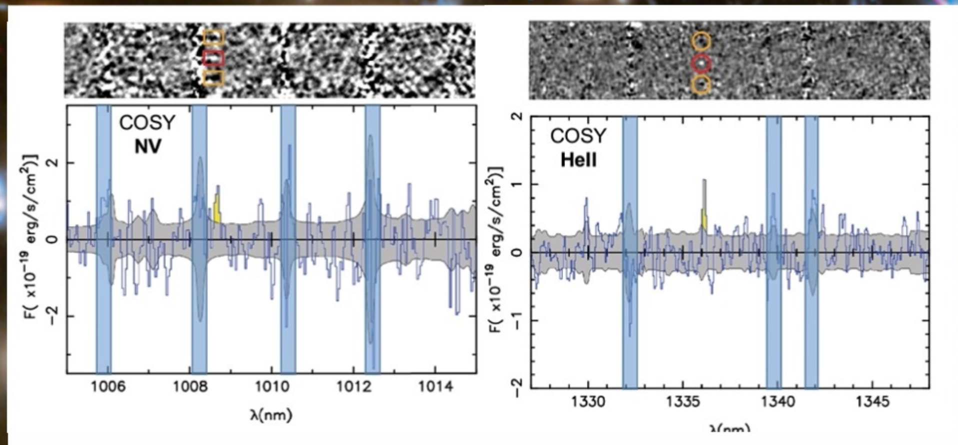
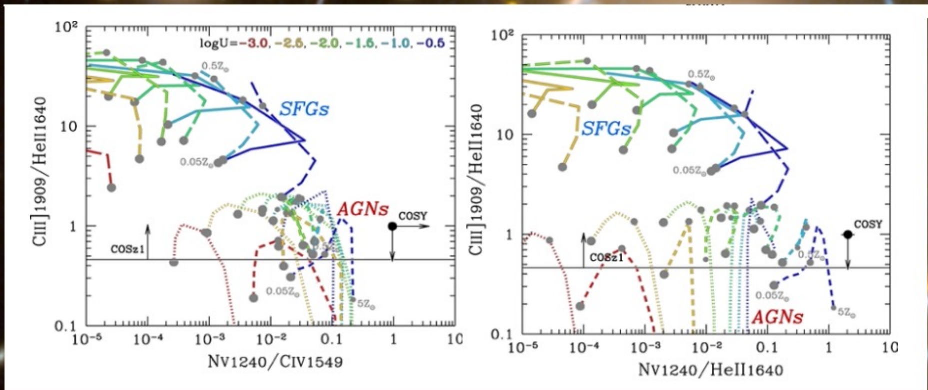
MAIN GOALS OF THIS PROJECT

1. Identify all z>7 galaxies which have been spectroscopically observed with 8-10m class telescopes
2. Reduce and combine all spectra to obtain the deepest stacked spectrum so far of primeval galaxies
3. Analyze the stacked spectrum to identify UV emission lines and to study several physical properties (AGN activity, metallicity)
4. If time permit, study how these properties evolve with UV luminosity.



Example of UV emission lines at z>7



Emission lines ratio used to study the strength of a z>7 galaxy radiation field

SKILLS REQUIRED

- Programming in Python

References :

- Stark 2016, ARA&A, 54, 761
- Laporte et al. 2017, ApJ, 851, 40
- Topping et al. 2021, arXiv:2107. 06295