GTC DATA EXPLOITATION IN THE SEARCH FOR THE FIRST GALAXIES

C. Cabello[1,2,★], J. Gallego[1,2], N. Cardiel[1,2], S. Pascual[1,2], R. Guzmán[3], A. Herrero[4,5], A. Manrique[6], A. Marín-Franch[7], J.M. Mas-Hesse[8], J.M. Rodríguez-Espinosa[4,5], E. Salvador-Solé[6] and S. Eikenberry[9]

[1] Universidad Complutense de Madrid, [2] Instituto de Física de Particulas y del Cosmos (UCM-IPARCOS), [3] University of Florida, [4] Instituto de Astrofísica de Canarias, [5] Universidad de La Laguna, [6] Institut de Ciències del Cosmos (UB-IEEC), [7] Centro de Estudios de Física del Cosmos de Aragón (CEFCA), [8] Centro de Astrobiología (CSIC-INTA), [9] The College of Optics and Photonics (CREOL)

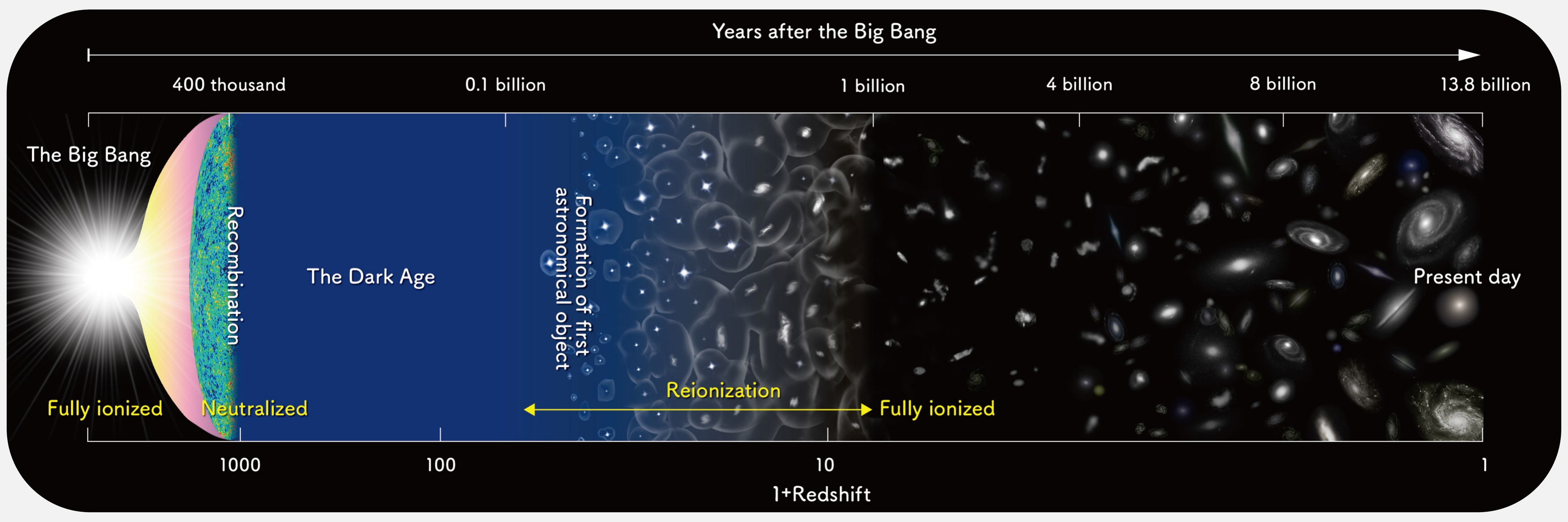
★criscabe@ucm.es

ABSTRACT

Detecting the first galaxies of the Universe has always been a goal in extragalactic astronomy because the study of these sources provides important constraints on cosmic reionization. In **Cabello et al. 2022**, we exploited the capabilities of the 10.4 m Gran Telescopio Canarias (GTC) to carry out the narrow-band (NB) Lyα survey at the highest redshift ever. The NB filter (FWHM = 11nm, λc = 1257 nm) targets the Lyα line of z = 9.34 galaxies and it was specially designed by the ALBA team to be used on the near-IR camera CIRCE@GTC for this work. After 18.3 hours of exposure time, we obtained an NB image of ~ 6.7 arcmin^2 within the Extended Groth Strip (EGS) field. No robust LAE candidates were found down to an emission-line flux of 2.9×10^{-16} erg s^{-1} cm^{-2}, which allowed us to derive an exclusion zone of the Lyα luminosity function that agrees well with the previous observational constraints at z ~ 9. The current NB surveys at very high redshift probe only the most luminous rare sources, but wider and deeper observations are needed to address the scientific challenge of detecting galaxies at the cosmic dawn. In this context, the study of the early Universe is one of the main scientific cases of the upcoming facilities such as the JWST or the ELT, which will allow us to reach fainter magnitudes and detections at higher redshifts.

SCIENTIFIC MOTIVATION

Finding very high redshift galaxies would help to constrain the ionization state of the IGM and to discern how the reionization took place. The AMIGA model (Salvador-Solé et al. 2017, 2022 in press.) predicts a double reionization scenario based on two stages: a first peak of ionization at redshift 10 due to the first population of stars, and a second and definitive one at redshift 6, due to young galaxies.

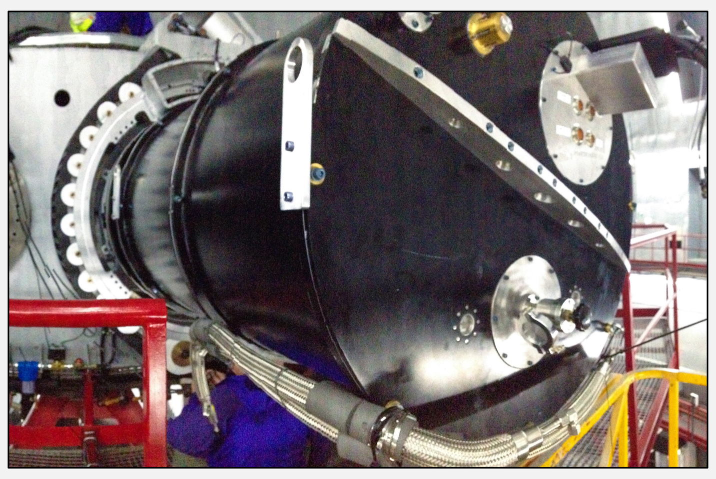


The EGS is a particular cosmological field
- Is the IGM more transparent in this sky region?
- Higher detectability of z > 7 galaxies?
- Are there overdensities powering large ionized bubbles?

INSTRUMENTAL SETUP

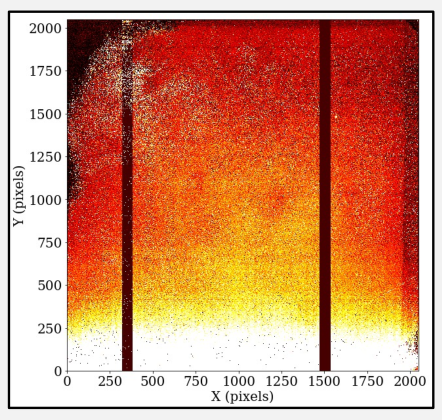
CIRCE@GTC

Canarias **I**nfra**R**ed **C**amera **E**xperimen (**CIRCE**)



CIRCE DETECTOR

Teledyne HAWAII-2RG
2048 x 2048 pixels
FoV 3.4’ x 3.4’
Plate scale: 0.1"/pix
Readout noise: 30-45 e- RMS
Gain: 5.3 ± 0.5 e-/ADU



CIRCE is a near-infrared camera designed and constructed by the University of Florida to be used as a visitor instrument at the **10.4m Gran Telescopio Canarias (GTC)**. It is comprised of a single large Liquid Nitrogen-cooled Dewar, designed to be mounted to the GTC Folded Cassegrain Rotator

The detector is optimized to work on the 1 – 2.5 micron wavelength range. It is subdivided into 32 independent channels, although 2 channels are inactive. The CIRCE near-IR detector exhibits more cosmetic defects than typical optical CCD counterparts. This makes the dithering technique necessary during the observations. Currently, the CIRCE instrument is decommissioned.

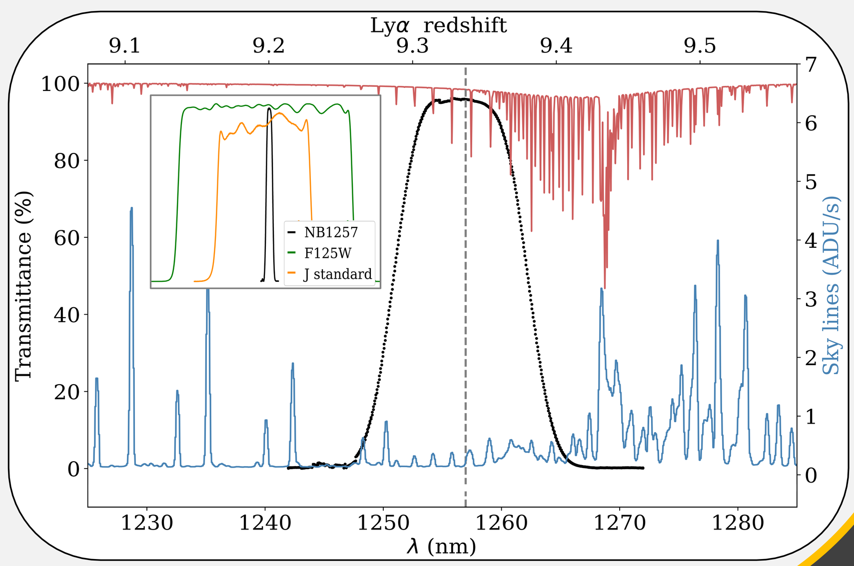
NB1257 FILTER

The NB157 filter is a steep near-IR interference bandpass filter with FWHM of 11nm and a central wavelength of 1257 nm at cryogenic temperature (see more details in Brauneck et al. 2018 and Hull et al. 2019). It was produced by Schott Suisse S.A. and designed by the ALBA team specifically for this project with the aim of detecting LAEs at z = 9.3

Characteristics of NB1257 filter

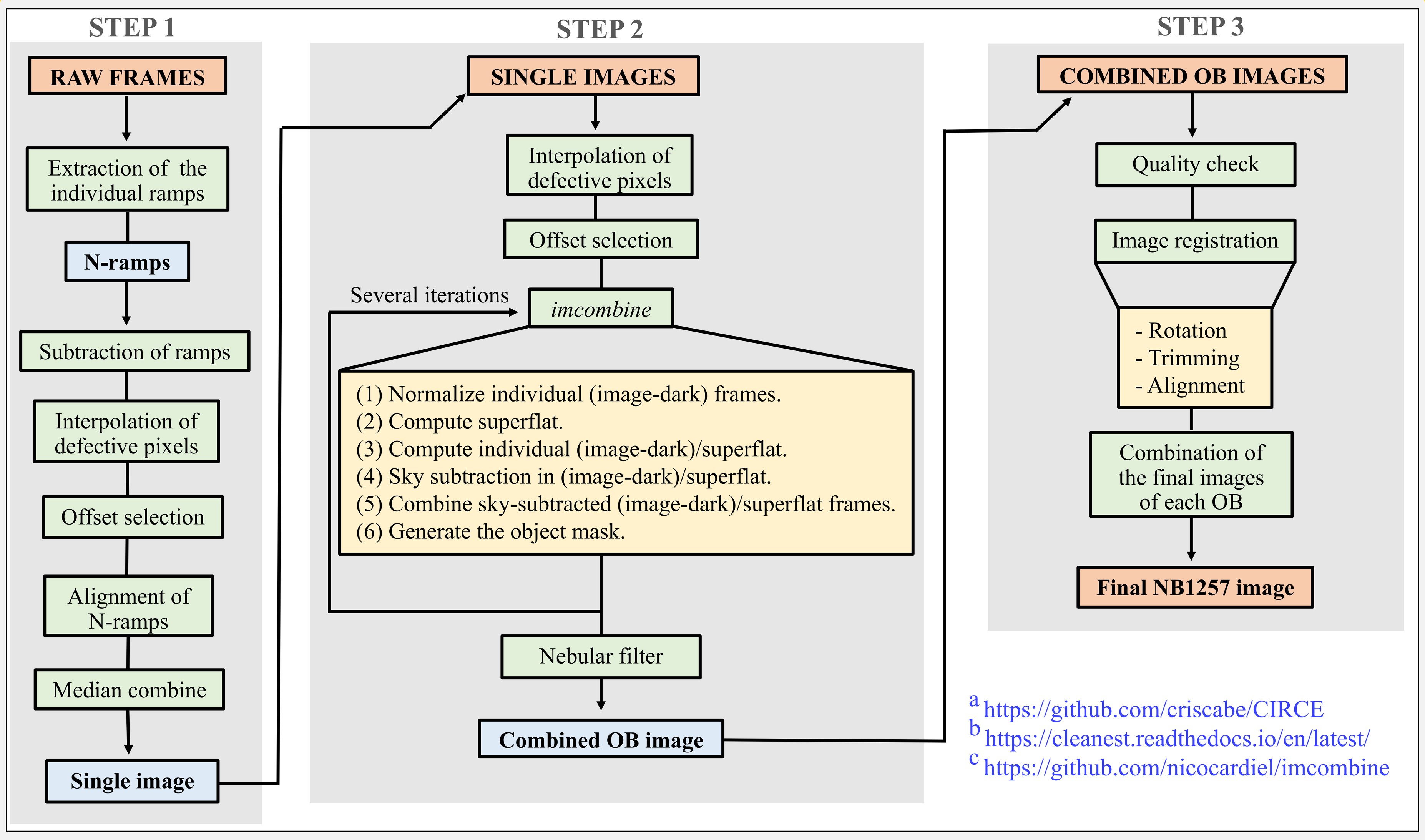
FWHM = 11 ± 0.5 nm
λ_c = 1257 ± 2 nm
Diameter = 68.0 ± 0.1 mm
Thickness = 6.0 ± 0.1 mm
Bandpass transmission > 90%

Transmission curve. The black dots show the empirical profile measured in the laboratory. The NB1257 filter lies in a wavelength range with minimum sky continuum emission (blue line) and avoids the atmosphere absorptions (red line).



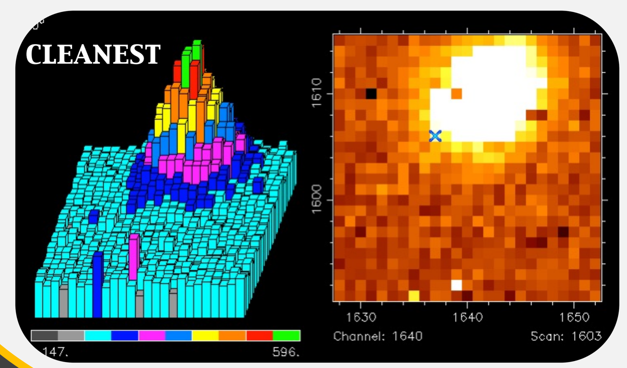
DATA REDUCTION

We describe in **Cabello et al. 2022** the details about the data reduction procedure that was especially optimized to minimize instrumental effects. We used different tools and routines to reduce the CIRCE narrow-band data: Python codes[a], tasks of IRAF, the **CLEANEST**[b] software, and the **IMCOMBINE**[c] software.

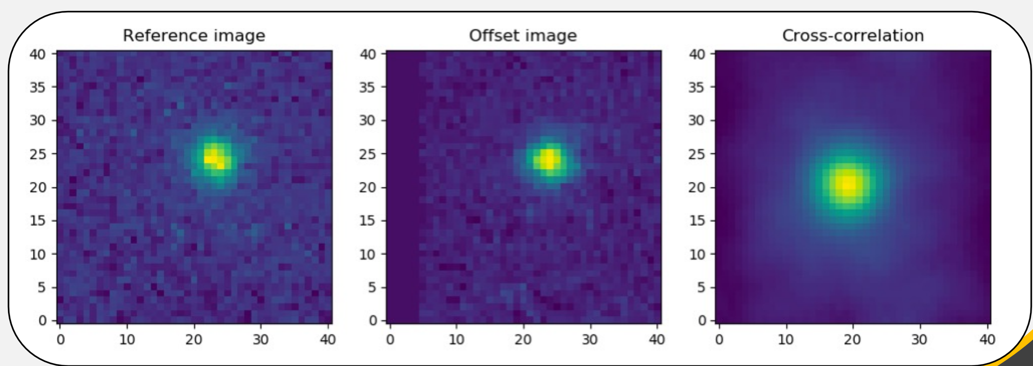


[a] https://github.com/criscabe/CIRCE
[b] https://cleanest.readthedocs.io/en/latest/
[c] https://github.com/nicocardiel/imcombine

Interpolation of defective pixels



Offset selection by the 2D cross-correlation technique



SCIENTIFIC ANALYSIS AND RESULTS

GTC/CIRCE - 18.3 h **HST/WFC3- 25.9 h**

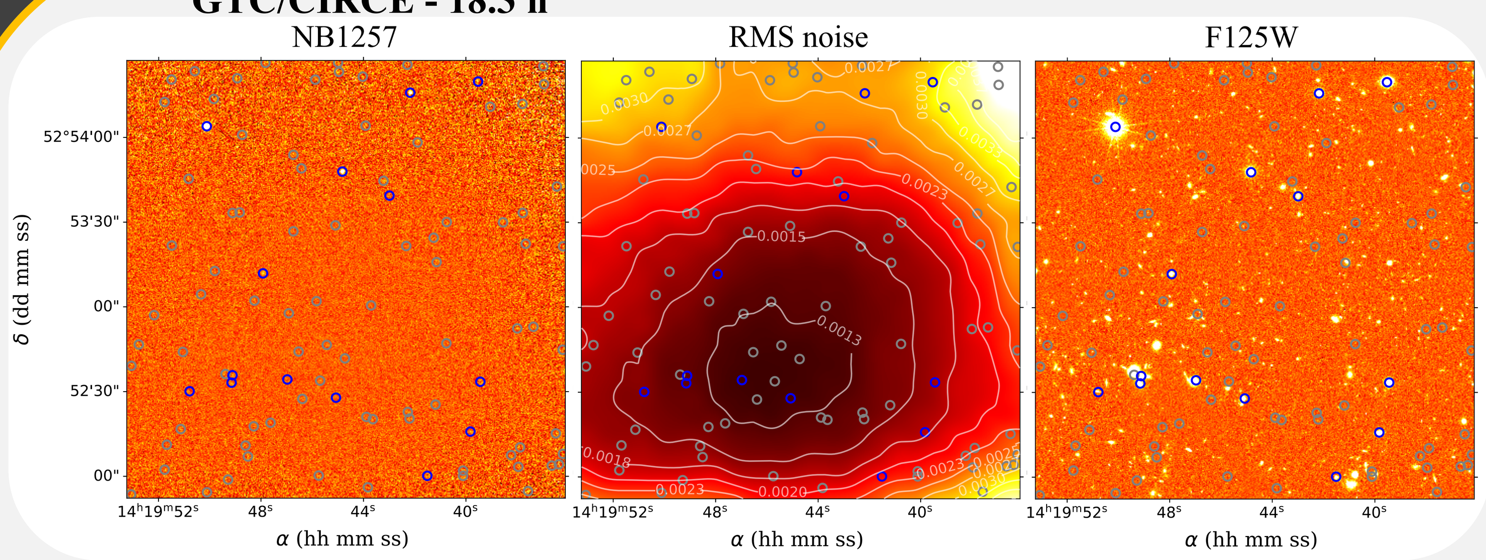


Image characterization and source detection

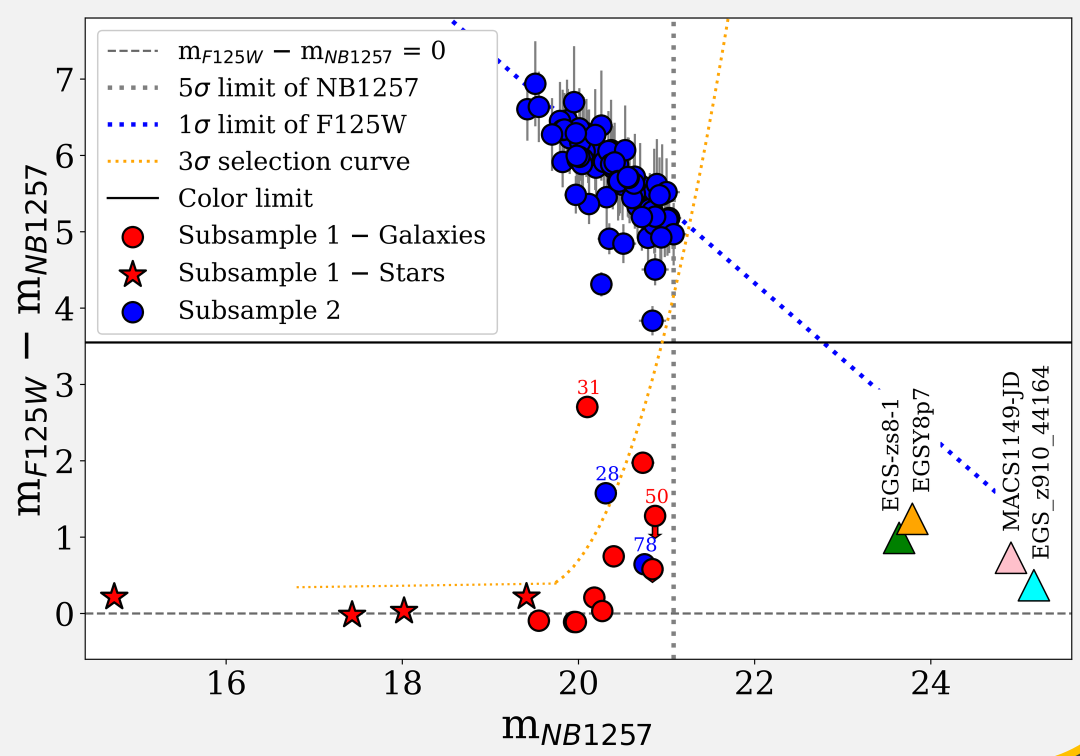
1) PSF matching and flux calibration.
2) Source detection.
3) Detection completeness and contamination.
4) Astrometric calibration.

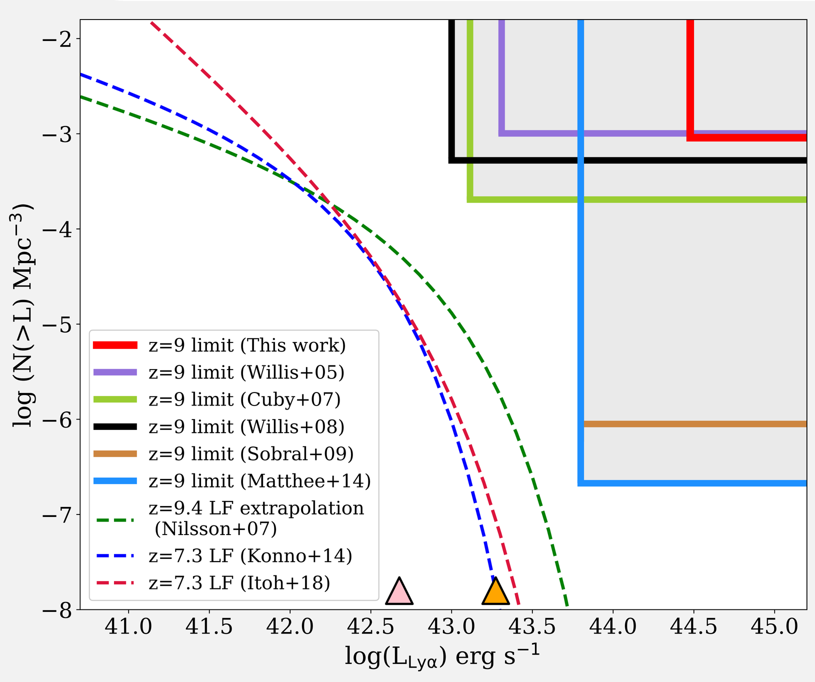
Final sample and candidate analysis

Ten galaxies in the range z = [0.34 – 1.53]

Two emission-line sources at z ~ 1.5

Wide range of observed equivalents widths: EW_{obs} ~ [23 – 797] Å (except object 31).





Lyα luminosity function (LF) at z = 9.3

The cumulative Lyα LFs at the highest redshifts and the observational constraints derived from the non-detections of the NB surveys at z ~ 9 reveal the scarcity of high redshift sources.

The NB Lyα survey at the highest redshift: no robust LAE candidates were found down to an emission-line flux of 2.9×10^{-16} erg s^{-1} cm^{-2},

This work:
- Lyα luminosity limit of 3×10^{44} erg s^{-1}
- Volume of 1.1 Mpc^3

Currently, the Comic Evolution Early Release Science (CEERS) project is surveying the EGS field and discovering new high-z galaxies thanks to the JWST (see Finkelstein et al. 2022).

SUMMARY AND CONCLUSIONS

- One of the main techniques for detecting distant galaxies is measuring flux excesses in an NB filter due to the Lyα emission. For this purpose, we built a near-IR image of 18.3 hours of exposure time using the NB1257 filter and CIRCE@GTC (see more details in **Cabello et al. 2022**).
- We derived an upper limit on the Lyα luminosity function at z ~ 9 that agrees well with previous constraints but both wider and deeper observations are needed for detecting the first galaxies.
- Our short-term purpose is to mount the NB1257 filter on a future near-IR camera, which will allow us to carry out a wider and deeper survey to continue searching for very high-z galaxies. This study will provide important insight into the early Universe and the reionization process.

References

(1) Cabello, C. – 2023 – *PhD thesis* – Universidad Complutense de Madrid.
(2) Cabello et al. 2022 – *“Near-IR narrow-band imaging with CIRCE at the Gran Telescopio Canarias: Searching for Lya-emitters at z ~ 9.3”*
(3) Salvador-Solé et al. 2017 – “Constraining the Epoch of Reionization from the Observed Properties of the High-z Universe”
(4) Salvador-Solé et al. 2022 in press. – “LAEs at Cosmic Dawn: Implications and Predictions”
(5) Brauneck et al. 2018 – *“First results using a new near-infrared 1% narrow-band filter in the GTC 10.4m telescope to detect galaxies at the dawn of the universe”*
(6) Hull et al. 2019 – *“A steep bandpass interference filter with FWHM 11nm centered at 1254nm for studying Lyman Alpha signatures of highly redshifted galaxies”*
(7) Finkelstein et al. 2022 – *“A Long Time Ago in a Galaxy Far Away: A Candidate z ~ 14 Galaxy in Early JWST CEERS imaging”*

See more details → SCAN ME

Acknowledgments

This research was supported by the Spanish Ministry of Science and Innovation (MCIN) under the grants AYA2016-75808-R and RTI2018-096188-B-I00. C.C. acknowledges the Universidad Complutense de Madrid and the MCIN for the grant PRE2019-087503. The authors thank the help given by Dr. Antonio Cabrera during the preparation and execution of the observations at the GTC.