Resolving the Rise and Fall of Star Formation in Galaxies
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The JWST/NIRSpec GTO programme "The Physics of Galaxy Assembly: IFS observations of high-z galaxies"

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Abstract. We present an overview of the project "The Physics of Galaxy Assembly: IFS observations of high-z galaxies", a Guaranteed Time Observations (GTO) programme of the James Webb Space Telescope (JWST). It an ambitious project aimed at investigating the internal structure of distant galaxies with the NIRSpec integral field spectrograph (IFS), having allocated 273 hours of JWST prime time. The NIRSpec capability will provide us with spatially resolved spectroscopy in the 1-5 μm range of a sample of over forty galaxies and Active Galactic Nuclei in the redshift range $3 < z < 9$. IFS observations of individual galaxies will enable us to investigate in detail the most important physical processes driving galaxy evolution across the cosmic epoch. More in detail, the main specific objectives are: to trace the distribution of star formation, to map the resolved properties of the stellar populations, to trace the gas kinematics (i.e. velocity fields, velocity dispersion) and, hence, determine dynamical masses and also identify non-virial motions (outflow and inflows), and to map metallicity gradients and dust attenuation.

Keywords. James Webb Space Telescope – galaxies: formation – galaxies: evolution – galaxies: high-redshift – galaxies: star formation

1. Introduction

The James Webb Space Telescope (JWST) promises to reveal a new view of galaxy formation in the early Universe. Thanks to its unprecedented sensitivity and spectroscopic capability in the near/mid-infrared (NIR/MIR) wavelengths, for the very first time, the rest-frame optical nebular emission lines (e.g., Hβ, [O III]$\lambda\lambda$4959,5007, Hα and [N II]$\lambda\lambda$6549,6585) of star-forming galaxies (SFGs) and active Galactic Nuclei (AGN) can be directly detected and resolved across the cosmic epoch, from the cosmic noon ($z \sim 2-3$; e.g. Förster Schreiber & Wuyts 2020) to the Epoch of Reionization (EoR, $z \lesssim 15$; e.g. Robertson 2022). Early Release Observations (EROs; Pontoppidan et al. 2022) results have clearly demonstrated the power of JWST's spectroscopic observations (e.g. Brinchmann 2022; Curti et al. 2022; Tacchella et al. 2022), promising many exciting discoveries to be made over the coming years.

The focus of this paper is to present an overview of the project "The Physics of Galaxy Assembly: IFS observations of high-z galaxies" (Leads: Santiago Arribas and Roberto Maiolino), a Guaranteed Time Observations (GTO) programme for the JWST NIRSpec instrument (Jakobsen et al. 2022; Ferruit et al. 2022). We will describe the sample, the observational design, and the general goals of the project.

2. Programme overview

The project "The Physics of Galaxy Assembly: IFS observations of high-z galaxies" (GA-IFS hereinafter) is based on the use of the NIRSpec's Integral Field Spectroscopy (IFS) mode (Böker et al. 2022). It allows to cover the wavelength range $0.6-5.3\mu$m at spectral resolutions of R$\approx$100, 1000, and 2700; more in detail, low resolution (R100) observations cover the full wavelength range, while for R1000 and R2700 multiple exposures with different bands are required to cover the entire range (see Table 3 in Böker et al. 2022). The field of view (FOV) of the IFS aperture is a contiguous $3.1'' \times 3.2''$ sky area, with a sampling of $0.1''$/spaxel and a spatial resolution even lower than $0.1''$ at shortest wavelengths (Böker et al. 2022).

The GA-IFS sample consists of 42 individual systems to be observed in Cycle 1 (230 hours of JWST time), plus a number of additional targets to be selected for Cycles 2 and 3 (43 hours). The sample contains a good representation of the most massive and extended SFGs in the redshift range $3 < z < 9$, selected to increase the leverage of IFS capabilities. For instance, at $z \sim 6$, the NIRSpec IFS FOV corresponds to a physical area of $\sim 20 \times 20$ kpc, hence large enough to cover the entire galaxy emission with a sub-kpc sampling. The GA-IFS sample also comprises AGN and quasars (QSOs) in the redshift range $3 < z < 7.5$, to test the IFS capabilities in detecting extended emission associated to their host galaxy component, and map virial and non-virial motions (e.g. kpc-scale outflows and inflows). A plethora of selection criteria have been used to identify these systems: for instance, most SFGs and AGN have been selected from the COSMOS and GOODS-S fields, on the basis of their available multi-wavelength information; the sample also contains Ly-α and [O III]88μm emitters, submillimeter-bright galaxies, and the brightest and most distant QSOs (up to z$\sim$7.5).

For the SFGs sub-samples, we request observations at low (R100) and high (R2700) spectral resolution, to better study the continuum and line emission, respectively. For AGN and QSOs, only R2700 observations are requested, as we are interested in studying only their emission lines properties (but see Sect. 3). The specific band for the high-resolution observations mainly depends on the redshift of the individual galaxies, and it is aimed at including in a single band the most important rest-frame emission lines (e.g. covering the H$\beta-$ Hα range, redshifted in the NIR). The exposure time for each target is settled to map all prominent rest-frame optical lines, according to flux predictions obtained from different diagnostics (taking advantage of available multi-wavelength information). No extra background exposures are requested: for R100 observations, we expect to have a relatively large number of spaxels free from galaxy emission, useful to estimate the background level. High resolution observations are instead dedicated to the study of emission line features, less affected by background emission.

In Table 1 we summarise the general properties of the selected targets, as well as the observational design for each class of sources in our sample. For more details, we refer to the APT of each program of the GTO: PID 1215, 1216, 1217, 1218, 1219, 1220, 1222, 1262, 1263, 1264. The GTO project has allocated 273 hours of JWST prime time; most of the program will be executed during the first three JWST cycles (2022-2024).

3. Addressing the study of galaxy formation and assembly with NIRSpec IFS

GA-IFS high resolution (R2700) observations, with a spectral range encompassing the main rest-frame optical emission lines, allows a plethora of diagnostic tools to study the structural, chemical, and dynamical properties of the ionised gas with a sub-kpc sampling. More in detail, we will:

• trace the gas kinematics (i.e. velocity fields, velocity dispersion) and, hence, determine dynamical masses and also identify non-virial motions (outflow and inflows);

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Table 1. Observations and targets.

#	Class and type of selection criteria	redshift range	Average exp. time and configuration(s) per target
14	SFGs: mainly optical and UV-selected; a few objects are IR-selected	$3 < z < 6.3$	$\sim 4-5$ hr (R2700) ~ 1 hr (R100)
9	SFGs at the EoR: Ly-α, [O III]88μm emitters	$6.5 < z < 9.1$	$\sim 3-5$ hr (R2700) ~ 1 hr (R100)
13	AGN: X-ray, optical and/or MIR selected	$3 < z < 5$	~ 1 hr (R2700)
6	type 1 AGN/QSOs	$6.3 < z < 7.5$	~ 3 hr (R2700, all targets) ~ 1 hr (R100, two targets*)

Notes: Column (1): Number of targets; (2): Class of targets and selection criteria; (3): redshift range; (4): average exposure time and spectral configuration per individual target.
*dedicated PSF star observations will be acquired, and used to model and subtract the QSO component and reveal the stellar emission.

- map metallicity gradients (e.g. using strong-line diagnostics) and dust attenuation (using the Balmer decrement);
- map the distribution of star formation traced by the Balmer emission.

Moreover, the R100 continuum emission (complemented with available R2700 emission line fluxes) will allow us a full characterisation of the SFGs in our sample, for instance tracing the distribution of dust, and mapping the resolved properties of the stellar populations (e.g. star formation history, stellar mass, age, and metallicity). R100 observations will be also obtained for two QSOs at $z > 6$: dedicated PSF star observations will be used to model and subtract the nuclear component and reveal the stellar emission.

To summarise, the GA-IFS sample has been chosen to maximize the novelty and the impact of the very first NIRSpec IFS outcomes; our project will also pave the way for more efficient observational strategies in future NIRSpec IFS programs.

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