Uncovering Early Galaxy Evolution in the ALMA and JWST Era
Proceedings IAU Symposium No. 352, 2019
E. da Cunha, J. Hodge, J. Afonso, L. Pentericci & D. Sobral, eds.

doi:10.1017/S1743921319008950

JWST advanced deep extragalactic survey: NIRCam imaging to $z > 10$

Marcia Rieke on behalf of JADES Collaboration

Steward Observatory, University of Arizona, 933 N. Cherry, Tucson, AZ 85721 USA
email: mrieke@as.arizona.edu

Abstract. The JWST Advanced Deep Extragalactic Survey (JADES) is a joint program of the JWST NIRCam and NIRSpec Guaranteed Time Observation (GTO) teams involving over 800 hours of observation. This paper describes the imaging portion of the program which covers nearly 200 square arc minutes divided between two well-studied fields with excellent supporting data (e.g. from Chandra, ALMA, and HST-CANDELS): GOODS North and South, including the Ultra Deep Field. NIRCam imaging will enable the study of galaxy evolution to $z \sim 10$ and higher using multi-color imaging with 9 filters covering 0.9 to 5 microns. Such data will provide photometric redshifts and a wealth of data for constructing luminosity and mass functions. A key component of the program is rapid turn around of imaging into NIRSpec target lists. Preparing for this program has benefited from the development of a mock catalog and simulated imaging to test these processes.

Keywords. galaxies: evolution, galaxies: high-redshift, surveys

1. Introduction

The original justification for the construction of the James Webb Space Telescope (JWST) was based on detecting the first light to be produced by stars and black holes in the Universe (Dressler 1996). This led to the nickname "First Light Machine" for JWST, but this appellation can be misleading as JWST cannot detect the first star. It will be able to detect the first galaxies and possibly structures as small as the precursors to current day globular clusters as described by Renzini at this conference. Many of JWST Guaranteed Time Observers (GTOs) have formed a collaboration to produce a legacy-scale deep survey to address the questions that underlie the questions presented at this conference. This paper describes the observing strategy adopted for the near-infrared imaging portion of the survey with the NIRSpec portion described in more detail by Bunker at this conference. In addition to providing results and insights relevant to the galaxy evolution questions posed at this conference, the JADES collaboration also hopes that this deep survey will lead to some surprises and guide new directions for study in the future. Two fields, GOODS North and GOODS South, have been chosen for observation due to the wealth of ancillary data available. The deepest observations will be centered on the UDF in GOODS South with GOODS North receiving only medium depth exposure, a level which is still sufficiently deep to detect luminous $z \sim 10$ galaxies.

This JADES program evolved from considering the need for NIRCam imaging to select targets for the NIRSpec microshutter array which provides the ability to observe 100s of objects at once. The NIRCam - NIRSpec synergy is deeper than just using NIRCam to produce finding charts for NIRSpec, however. NIRCam will detect many more sources than can be observed with NIRSpec in a program of the scale of JADES. NIRSpec data can be used to anchor relations found in the imaging data with NIRCam's larger source numbers providing improved statistics, for example. NIRCam imaging will be needed for ensuring accurate spectral energy distributions because the broad wavelength range of NIRSpec (1 - 5 microns) and fixed slit width means that wavelength dependent corrections will be needed to avoid biases introduced by diffraction. The combined NIRSpec-NIRCam data set will be more valuable than either one alone.

2. NIRCam Overview

NIRCam has been designed expressly to be efficient at executing surveys. Because NIRCam is the wavefront sensor for JWST, it must be fully redundant, and so NIRCam is comprised of two identical cameras mounted back-to-back. In survey mode, both modules can be used at the same time thus doubling the area covered. Each module has a dichroic beamsplitter which divides the incoming radiation at 2.35 microns and sends each the light into short wavelength (0.7 to 2.3 microns) and long wavelength (2.4 to 5 microns) arms that view the same area on the sky The overlap of the short and long wavelength arms is $>96\%$. A module will always be capable of observing at two wavelengths simultaneously which further improves survey efficiency. The JDOX pages at STScI (http://www.stsci.edu/jwst/) illustrate the NIRCam field of view in detail with its $\sim 43''$ separation between modules and $\sim 4''$ gaps between the four detectors that comprise the short wavelength arms.

3. Observing Plan

Central to the JADES survey plan is observing with NIRCam and NIRSpec operated in parallel (eg. what Space Telescope Science Institute calls a coordinated parallel). This effectively doubles the amount of observing time available for the program. Figure 1 shows the layout for GOODS South. Mid-infrared imaging using MIRI will also be acquired both in prime mode on the UDF and in parallel with some of the NIRCam imaging. These data will be collected by various parts of the MIRI GTO teams. One nuance of the parallel usage of NIRCam and NIRSpec stems from the requirement that NIRSpec must formally be designated as the prime instrument because of how the microshutter array in NIRSpec is configured to match targets. This issue has been handled in our program by specifying NIRSpec as prime with central pointing coordinates chosen to yield a fully sampled NIRCam region. Additionally dither patterns suitable for both instruments also had to be selected. Last, the layouts shown in Figure 1 are for an observation date in October, and will be different if the program is executed at another time of year because of the fixed relationship between the NIRCam and NIRSpec fields of view, and the modest amount of roll control available with JWST.

Some of the NIRSpec slit assignments will be generated based on HST data. Other pointings will observe galaxies either detected only by NIRCam or shown to be particularly interesting using NIRCam data. The JADES team would like to observe NIRCam-selected objects with NIRSpec during the same four-month visibility period as when the NIRCam imaging is obtained. To fit all the imaging in the beginning of the visibility period and allow time for STScI to prepare and upload observing sequences implies that the NIRCam imaging must be processed and converted into NIRSpec target selections in at most 45 days. Williams *et al.* (2018) have created a mock catalog, JAGUAR, to simulate what the survey may see, and to provide a tool for testing analysis techniques to ensure that this rapid time scale can be met.

The NIRCam portion of the JADES survey uses seven wide ($R \sim 4$) filters supplemented with two medium width filters. Figure 2 shows the filter transmission functions overlaid on a $z \sim 5$ galaxy spectral energy distribution. Only a limited area will be observed using NIRCam's shortest W filter, F070W (0.7 microns), as JWST has the smallest advantage over HST at this wavelength, and much of the area has deep HST

https://doi.org/10.1017/S1743921319008950 Published online by Cambridge University Press

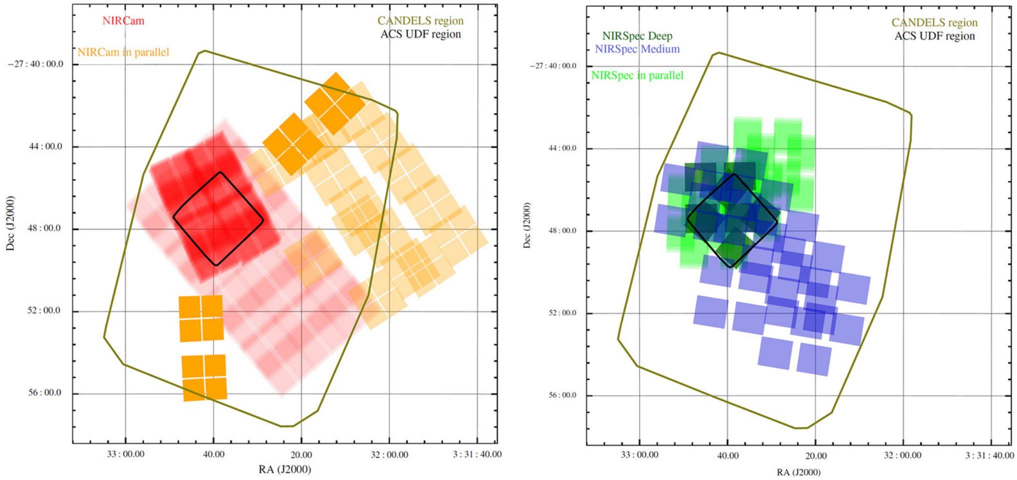

Figure 1. Footprints for the NIRCam (left), and NIRSpec (right) observations in GOODS South. The heavy outline shows the area covered by CANDELS, Grogin *et al.* (2011). The NIRCam lighter-toned areas constitute the medium survey while the deeper tones are the deep survey. The exact areas to be covered will depend on when the observations are scheduled.

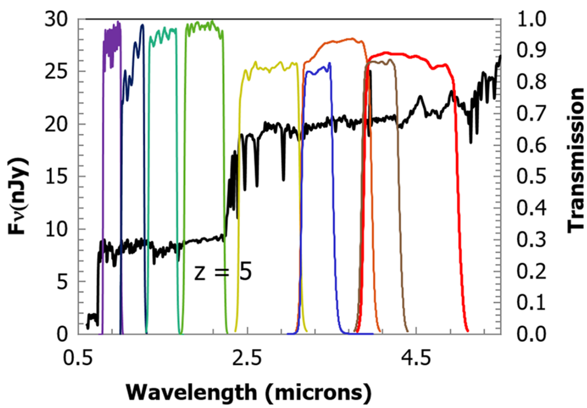

Figure 2. NIRCam filter transmission functions overlaid on a $z \sim 5$ galaxy spectral energy distribution.

imaging in similar filters. Figure 2 shows that the two medium filters that will be used subdivide nearly in half the two longest wavelength filters. By comparing fluxes in the corresponding medium and wide filters, an estimate of possible emission lines can be made. F410M (4.1 microns) will be observed on all areas because its sensitivity is nearly the same as the wider filter because the dominant zodiacal background is concentrated in the long wavelength half of F444W. The other medium filter, F335M (3.35 microns), will be used over a portion of the survey to provide additional constraints on emission lines and photometric redshifts. See Rasappu *et al.* (2016) and references therein for a discussion of how IRAC photometry has revealed strong $H\alpha$ and other emission lines in some galaxies in the range $3.5 < z < 6.0$.

4. Expected Results

JWST will of course provide the deepest view of the near- to mid-infrared universe yet and likely for the forseeable future. Current space telescopes have no observing capability

https://doi.org/10.1017/S1743921319008950 Published online by Cambridge University Press

Table 1. NIRCam Imaging Sensitivity. The 10-σ depth for a point source corresponding to the average exposure times (60 ksecs for deep, 12 ksecs for medium) is tabulated.

Subsurvey	Area □′	10σ Point Source Magnitude (AB)									
		F070W	F090W	F115W	F150W	F200W	F277W	F335M	F356W	F410M	F444W
Deep	46	—	29.5	29.8	29.9	29.9	29.5	28.8	29.4	29.0	29.1
Medium	190	28.0[a]	28.6	28.8	28.9	29.0	28.6	28.0[a]	28.6	28.1	28.3

[a] The F070W and F335M areas of the Medium survey are only 93 square arcminutes.

between HST's long wavelength end of WC3IR at 1.6 microns and IRAC on Spitzer with its 3.6 micron filter. No current facility operates beyond IRAC's 4.5 micron channel. Current groundbased telescopes lack the sensitivity needed for detecting high redshift galaxies in the near- and mid-infrared. JWST will for the first time supply data with space based sensitivities in the near-infrared. Depth is only part of the strength of JADES and related surveys. Neither IRAC nor WFC3IR have adequate spatial resolution for discerning shapes and structures in distant galaxies. NIRCam with a diffraction-limited imaging resolution of $0.12''$ at 4 microns will be able to discern kiloparsec scale structure at the highest redshifts.

Table 1 presents predicted detection limits for the JADES survey. The JAGUAR mock catalog mentioned above has been constructed to match HST results as far as they go with particular attention paid to matching the redshift evolution of sizes, colors, star formation, and chemical properties based on what is known from observed galaxy populations. Williams *et al.* (2018) estimate that 1000s of galaxies at $z \sim 6$, and 10s at $z \sim 10$ will be detected at a level of 3.6 nJy (5σ). The exact numbers of galaxies at higher redshifts depend on what star formation histories and feedback processes are correct. Cowley *et al.* (2018) predicted numbers of high redshift galaxies to be detected at several levels of NIRCam survey depth. They also ensured that their nominal model reproduces HST UV luminosity function results. The Cowley *et al.* (2018) nominal predictions using a semi-analytical model of galaxy formation and evolution in a ΛCDM framework imply that there would be only one galaxy per NIRCam field of view at $z \sim 12$ detected at 2 microns in 100,000 seconds (slightly longer than the deep JADES exposures). Adjusting the model to reproduce also the reionization redshift implied by Planck data increases the galaxy detection rate by a factor of 5. Clearly the JADES survey will provide crucial inputs to constraining what processes are at work in the early universe.

5. Summary

The JADES survey will provide a rich data set for addressing galaxy evolution questions. Depending on the exact launch data of JWST which dictates when the survey can be executed, the JADES collaboration hopes to have public releases of portions of the survey as early as consistent with ensuring that performance questions and systematics are understood adequately. These releases will include both the raw and processed data along with lessons learned. Astronomer's Proposal Tool (APT) files for the survey are already available on the STScI web site and can serve as guides to others wanting to design their own surveys.

Acknowledgements

Development of NIRCam has been supported by NASA Contract NAS5-02015 which also supports the NIRCam portion of the JADES team.

References

Cowley, W., Baugh, C. M. Cole, S., Frenk, C. S., & Lacey, C. G. 2018, *MNRAS*, 474, 2352

Dressler, A. 1996, *HST and Beyond* (Washington: Association of Universities for Research in Astronomy)

https://doi.org/10.1017/S1743921319008950 Published online by Cambridge University Press

Grogin, N. A, Kocevski, D. D., Faber, S. M., Ferguson, H. C., Koekemoer, A. M., *et al.* 2011, *ApJS*, 207, 24

Rasappu, N., Smit, R., Labbe, I., Stark, D. P. Ellis, R. S., & Oesch, P. A. 2016, *MNRAS*, 461, 3886

Williams, C. C., Curtis-Lake, E., Hainline, K. N., Chevallard, J., Robertson, B. E., Charlot, S., Endsley, R., Stark, D. P., Willmer, C. N. A., Alberts, S., Amorin, R., Arribas, S., Baum, S., Bunker, A., Carniani, S., Crandall, S., Egami, E., Eisenstein, D. J., Ferruit, P., Husemann, B., Maseda, M., Maiolino, R., Rawle, T. D., Rieke, M., Smit, R., Tacchella, S., & Willott C. J. 2018, *ApJS*, 236, 33

https://doi.org/10.1017/S1743921319008950 Published online by Cambridge University Press