Galaxy evolution in the first billion years: plans for JWST/NIRSpec from the Instrument Science Team – Andy Bunker (University of Oxford)

Abstract: Over the past 14 years, we have identified star-forming galaxies at $z > 6$, within the epoch of reionzation, using the Lyman break technique with deep fields from the Hubble Space Telescope and ground-based imaging. From the inferred rest-frame UV luminosity function, we can address the potential role of star formation in the reionization of the Universe, although the escape fraction of ionizing photons remains a large uncertainty at these redshifts. However, spectroscopic follow-up has been challenging, with Lyman-α (the main feature accessible from ground-based observations) often weak or absent. The James Webb Space Telescope (JWST) will revolutionise this – NIRSpec works out to 5 microns with huge multiplex, sampling the rest-frame optical out to $z \sim 7$, and potentially obtaining redshifts from [OII] out to $z \sim 12$ (and much higher with the Lyman break). I will describe the Guaranteed Observing Time programme with my colleagues on the NIRSpec instrument science team. Through emission lines and spectral energy distribution fitting, these observations have the potential to chart the evolution of the star formation rate, dust extinction, metallicity, stellar initial mass function and escape fraction of ionizing photons within the first billion years.

The James Webb Space Telescope is a hugely ambitious space observatory due for launch in 2018. This joint NASA/ESA/CSA mission is far more than simply the successor to the Hubble Space Telescope (HST) – as well as having 7 times the collecting area of HST, JWST operates over a wider range of wavelengths ($0.6 - 25$ microns) in a lower-background environment (at L2), making it orders of magnitude more sensitive than previous observatories, and with new capabilities such as multi-object spectroscopy.

The ESA Near-Infrared Spectrograph (NIRSpec) operates in the range $0.6 - 5$ microns, and has three spectral resolutions: a low-dispersion prism ($R = 100$) which captures all the wavelength range with a single exposure, and medium- and high-resolution grisms ($R = 1000$ and $R = 2700$) which use 3 bands to cover the wavelength range. The unique feature of this spectrograph is its use of micro-shutter arrays, developed specifically for NIRSpec to enable multi-object spectroscopy. Each 100×200 micron micro-shutter subtends 0.2 arcsec $\times$ 0.4 arcsec and can be individually commanded to open, and they are arranged in 4 arrays each containing 171×365 micro-shutters. By opening shutters on targets, we can significantly reduce the background intensity (from zodiacal light and from other astronomical sources in the field), essentially building a slitmask in space and becoming far more sensitive than slitless spectroscopy. The NIRSpec field of view covers over 3 arcmin $\times$ 3 arcmin, well matched to existing deep fields and the JWST NIRCam imager. There is also a 3 arcsec $\times$ 3 arcsec integral field unit (IFU) with 0.1 arcsec sampling for spatially-resolved spectroscopy of individual objects, along with a number of fixed slits for traditional long-slit work.

The NIRSpec Instrument Science Team is closely focussed on galaxy evolution, and we have agreed to pool most of our 900 hours of Guaranteed Time Observations to undertake a comprehensive high-redshift galaxy survey to address two of the main science themes for JWST: (i) The End of the Dark Ages: First Light and Reionization; and (ii) Assembly of Galaxies. We will undertake a cohesive "wedding cake" survey, targeting $z > 7$ galaxies in our deepest fields (potentially out to $z \sim 20 - 30$) and $1 < z < 7$ galaxies in our 'medium' and 'wide' fields. A number of galaxies will be singled out for detailed study with the IFU mode.

The lack of spectroscopic confirmation for most $z > 5$ galaxies is a major issue for the interpretation; while a minority of the $z \sim 6$ candidates have had secure spectroscopic redshifts from Lyman-α, beyond $z \sim 7.5$ the success in confirming the photometric redshifts through spectroscopy is essentially zero. As a consequence, spectroscopy with NIRSpec of longer rest-frame emission lines is crucial to constrain the high redshift population properly at $z > 7$. In addition, NIRSpec will deliver emission line measurements (Lyman-α, Hβ, [O II], [O III], etc.). This will give us the usual characteristics (metallicity, star formation rate, dust extinction), and potentially line widths for dynamical estimates from our R=1000 observations. In principal, Lyman-α and [OII] are accessible over the whole redshift range currently probed by Lyman-break galaxies (up to $z \approx 12$ for [OII], around the reionization epoch, and up to $z \approx 9$ for [OIII] and Hβ).

The highest-redshift galaxies appear to have very blue rest-frame ultraviolet slopes, however, this needs to be explored with NIRSpec spectroscopy to confirm the redshifts and quantify the effects of emission lines and of the nebular recombination continuum which may affect the photometry. We can also search for evidence of Pop III stars, by analyzing in particular the He II 164nm emission line in individual spectra, and by stacking spectra to go deeper.