First Light: Physical Characterization of Early Star Formation in the Universe

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The discovery and characterization of the earliest stars are key to understanding the seeding of galaxies in the universe. Reaching the most distant and faintest objects will push available technology to its absolute limits. In particular, finding galaxies whose redshifts place them well before the reionization of the universe, and uncovering the physical properties of their stars themselves and of the surrounding intergalactic medium (IGM), will require the combination of both JWST and GSMT. The necessary capabilities include (1) sensitive broad-band imaging in the near infrared – for which JWST is ideal – to measure the continuum flux in the rest-frame ultraviolet of massive stars at z > 7, (2) sensitive narrow-band imaging and spectroscopy at similar wavelengths available with both telescopes in different regimes, to detect emission-line flux from these galaxies, and (3) high-resolution spectroscopy unique to GSMT to measure the detailed Lyman-alpha emission-line profiles needed to characterize the IGM while it is being reionized.

1. The nature of early star formation in the universe

To date, we have few clues to the nature of the earliest star formation in the universe. Results from the WMAP satellite\(^1\,^2\) and Gunn-Peterson troughs in the spectra of high-redshift quasars\(^3\,^4\) point to an epoch of reionization at redshifts \(6 < z < 20\). However, extrapolating the number counts of high-redshift quasars indicates that they have not emitted enough energetic radiation to reionize the universe\(^5\); thus, star-forming galaxies must be responsible. These galaxies lie at the next frontier in the study of the early universe. The highest-redshift galaxies with certain redshifts are found at about \(z=7\)\(^6\). The spectra of these extremely faint galaxies have no light in the optical at all, and their other properties, for example, chemical abundance, are beyond present-day technology. Theoretical models yield only uncertain predictions for the expected properties of gas and galaxies at such early times.

2. Discovering galaxies at redshifts \(z > 7\)

The next generation samples of the earliest-known galaxies will likely be found via their rest-frame ultraviolet emission, which is strong in galaxies with ongoing star formation. In general terms, JWST is more sensitive to their continuum flux in the (observed-frame) near infrared through broad-band imaging, and GSMT is more sensitive to flux from their emission lines through narrow-band imaging or spectroscopy. Because major uncertainties in the properties of the intergalactic and interstellar medium hamper our ability to calculate the emergent flux from the strongest line, Lyman-alpha, JWST’s continuum-flux searches will be the key capability. However, those galaxies that have the highest ongoing star formation rates will ionize local bubbles in the IGM, possibly resulting in strong emission-line flux\(^7\,^8\). Therefore, in its complementary role, GSMT will make large field maps of the early universe in these strong Lyman-alpha emitters.
3. Uncovering the physics of early star formation

Many compelling scientific questions surround the earliest star formation in the universe. When did metal enrichment and dust formation begin? How rapidly did the heavier elements made in supernovae disperse throughout the universe? Were the first stars extremely massive, as predicted by hydrodynamic simulations of star formation in pristine gas? Measurements of emission and absorption lines in the spectra of extremely high-redshift galaxies will answer these questions. In this, JWST and GSMT have complementary spectroscopic capabilities. JWST will fly above the atmosphere, providing uninterrupted wavelength coverage in the near-infrared – this is crucial for measuring multiple line strengths in the same galaxy. GSMT will provide higher spectral resolution measurements of the lines and more sensitive measurements of weaker lines. Both capabilities are required for diagnosing the properties of the first galaxies.

4. Observing the reionization of the intergalactic medium

Recent measurements from the Wilkinson Microwave Anisotropy Probe suggest that reionization began very early in the history of the universe – this is not easy to explain with current theory. For this reason, direct measurements of the state of the IGM during the reionization process are essential. If, as expected, high-redshift galaxies are the cause of reionization, these objects will ionize local bubbles in their environs that will eventually grow together. High-resolution spectroscopy of the Lyman-alpha emission profiles of high-redshift galaxies will yield information about their bubbles. In addition, other luminous high-redshift sources, such as gamma ray bursts and supernovae, may also yield constraints on the state of the intervening IGM. Because GSMT will provide higher signal-to-noise spectroscopy at higher spectral resolutions, it is crucial to the study of the process of reionization.

REFERENCES