

## Far-Infrared Spectral Line Studies of the Epoch of Reionization

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Existing cosmological observations show that the reionization history of the universe at  $z > 6$  is both complex and inhomogeneous. All-sky CMB polarization measurements provide the integrated optical depth to reionization. A detailed measurement of the reionization history may come over the next decade with 21-cm HI radio interferometers, provided that they are able to remove the foregrounds down to a sub-hundredth percent level. Deep sky surveys, especially those that employ gravitational lensing as a tool, are now efficient at finding Lyman drop-out galaxies at  $z > 7$ , though with a large systematic uncertainty on the redshift due to degeneracies between Lyman drop-out and dusty galaxy SED templates. During the next decade the study of reionization will likely move from studying galaxies during reionization from  $z = 6$  to 9 to understanding primeval stars and galaxies at  $z > 10$ .

In the JWST era current studies that focus on the rest-frame UV and optical lines to study the ISM and gas-phase metallicities of galaxies at  $z \sim 1$  to 2 will quickly extend to  $z$  of 6. In the post-JWST era a far-infrared space telescope with a factor of 10 sensitivity improvement over SPICA will enable studies on the gas properties, AGN activity and star-formation within galaxies at  $z = 6$  to 15, in addition to a large list of sciences at  $z < 6$ . This redshift range is especially important for our understanding of the cosmic origins, formation of first stars, galaxies and blackholes, and the onset of large-scale structure we see today. The community is already struggling with many scientific issues during this epoch. For example, an outstanding problem involves the growth of supermassive blackholes and the presence of billion to ten billion solar masses backholes at  $z > 6$  at an age of 600-800 Myr after the Big Bang. One possibility to grow such high masses is seed blackholes associated with massive PopIII stars. Could we directly observe the formation of such massive stars at  $z \sim 12$  to 15? And could we study the blackhole activity in galaxies at  $z \sim 7$  to 10 as these blackholes grow in mass rapidly to values measured at  $z \sim 6$ ?

To aid study of reionization 20 to 600  $\mu\text{m}$  spectroscopic observations can: (a) disentangle the complex conditions in the ISM of  $z = 6$  to 15 galaxies by measuring the gas densities and excitation, and the prevalence of shock heating; (b) compare the conditions of the ISM in high-redshift galaxies with local galaxies to address whether faint dwarf galaxies found at low-redshifts are analogues of galaxies during reionization; (c) use spectral line diagnostics to study AGN or star-formation regulated actively within first galaxies, including the formation of first massive blackholes; and (d) detect, measure, and map out molecular hydrogen rotational line emission from primordial cooling halos that are the formation sites of first stars and galaxies at  $z > 10$ .

The role of far-infrared spectral capabilities will allow diagnostic studies and ways to establish the role of feedback, radiation, and AGNs, among many others, in regulating star-formation in reionization era galaxies. For example, [OIV]26 and Ne[V]14.3 are high-ionization lines that are enhanced in AGN environments and far-IR diagnostics such as [OIV]26/[SIII]33 or [NeV]14.3/[NeIII]15.6 ratios provide a direct measure of the AGN fraction to galaxy luminosity, even when there is significant dust extinction. Such diagnostics then allow a way to distinguish galaxies at  $z > 8$  that harbor AGNs and are likely to grow

