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Searching for "First Light" with the Gemini telescopes

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Abstract

Astronomers from across the Gemini partnership have embarked on an ambitious mission to discover the first stars and forming galaxies during the epoch of reionization ($6 < z < 15$). Observers are using new techniques and technologies to make this dream a reality. In this article I provide an overview of a few of these programs, focusing primarily on experiments searching for objects with redshifts $z > 7$, which must be observed and studied at near-IR wavelengths (1–2.5 μm). Programs currently in progress include searches for high-redshift galaxies lensed by foreground galaxy clusters, the use of narrow-band filters to improve the signal-to-noise ratio by reducing the background, and near-IR spectroscopic follow-up of optical drop-out high-redshift candidates. Other programs seek to identify and observe high-redshift gamma-ray bursts. Finally, I describe Gemini's plans for the future, and ways that objects with $z > 7$ may be identified in the next few years.

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Keywords: Cosmology: observations; Infrared: galaxies; Early universe; Galaxies: formation; Gravitational lensing; Gamma rays: bursts

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1. Background

In June of 2003, approximately 100 representatives from the Gemini partner countries assembled in Aspen, Colorado, to discuss the most compelling questions in astronomy today, and suggest observations and experiments that could answer them in the coming decade. The Aspen science goals included answering fundamental questions about the nature of matter, energy, and life in the Universe. What is the nature of dark matter and dark energy? How do galaxies (and their central black holes) form? How did the cosmic "dark ages" end? How common are planets, and what are their characteristics? How do stars process elements into the chemical building blocks of life? Among the Aspen science goals was the desire to learn how the first luminous sources formed, reionized the neutral hydrogen in the Universe, and formed the first galaxies. The participants in Aspen suggested observations that could help answer these questions by taking advantage of Gemini's excellent IR performance to find very faint objects over a relatively large field of view. The Gemini community is not waiting for revolutionary new instrumentation to begin the search for "First Light" objects in the Universe. Observers are leveraging existing instruments and new technologies to take advantage of new opportunities to find high-redshift $z > 7$ objects, if possible (Simons et al., 2004).

In the sections that follow, I describe some of the observing programs that are either in the planning stages or are currently under way, programs that attempt to find ever-more-distant galaxies and probe into the era of reionization. More information on particular programs can be obtained directly from the researchers involved, since many of the programs have not yet been completed and results are not yet published.

2. Observational limitations and strategies

Study of the Universe beyond $z \gtrsim 7$ is largely limited by the fact that Lyman α is redshifted to wavelengths longward of 1 μm, where the atmosphere becomes much brighter due to OH emission (Fig. 1). Different detectors are also needed at these wavelengths. OH emission from the atmosphere is particularly bright in the near-IR J and H bands (1–1.6 μm). Ly α is redshifted into the J-band for $z \sim 7$ to 10, and into the H-band for $z \sim 10$ to 15. Understanding reionization will require working in these near-IR windows. If one can overcome the effects of the OH airglow, which arises from a large number of discrete, narrow lines, achieving a sensitivity similar to that in the optical is possible.

There are a number of strategies currently being employed at Gemini to increase the detectability of faint, compact objects in the presence of the bright OH background:

(1) Lower the background to increase the signal-to-noise ratio using narrow-band filters. Narrow-band filters can be difficult to design to fit between OH lines. They necessarily sample only a small range in redshift, so large fields must be sampled to have a reasonable chance of success. Working between OH airglow lines to reduce the background is a matter of spectral resolution. The atmospheric OH lines are very narrow, but ubiquitous. At a resolution $R = 300$ (where $R = \Delta\lambda/\lambda$), less than 10% of the J-band is free of OH. By increasing the resolution to $R = 1000$, the fraction increases to more than 25%.

(2) Look between OH lines using high-resolution spectroscopy. Because long-slit or integral field spectroscopy only cover a small area on the sky, it is only

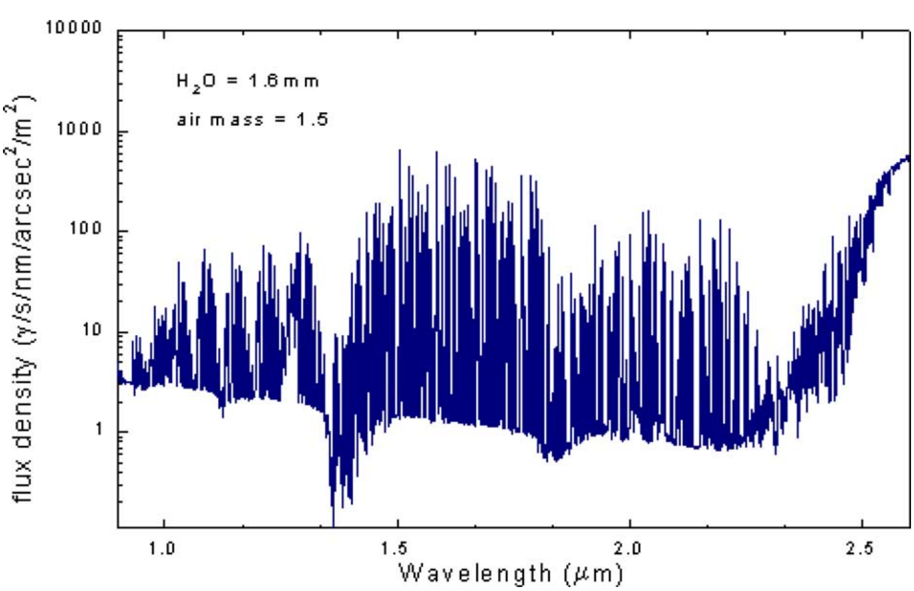

Fig. 1. The near-IR atmospheric emission line spectrum.