Spectrum of Gamma-Ray Burst's Afterglow Indicates the Beginning of the Reionization Process

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The intergalactic gas became neutral by the cosmic recombination. On the other hand, the intergalactic gas is ionized in the present Universe. To account for this difference between the past and present, there must have been a transition era of re-ionization after the dark age of the Universe, which was filled with neutral gas. However, scientists do not yet know when this transition occurred or understand how the process took place. One strong possibility is that the ultraviolet (UV) radiation from the first-generation galaxies in the one-billion-year-old Universe ionized the hydrogen gas in the intergalactic space. Therefore, it is very important to identify when the re-ionization occurred relative to the formation of the first generation of light-emitting objects.

Previous studies of the re-ionization have focused on galaxies or quasars. Observations of galaxies are indirect in that a number-count decreases when neutral hydrogen gas obscures their light. Observations of quasars directly measure the absorption features in their spectra caused by neutral hydrogen. However quasars occur in the most developed regions of galaxy evolution, and their own radiation ionizes the surrounding material. These factors make it difficult to estimate the neutral gas in this environment. In contrast, GRBs allow the direct measurement of neutral hydrogen and also overcome the drawbacks of the quasar approach.Although studies based on GRBs are highly desirable, the rare occurrence of GRBs bright enough to enable detailed analysis has been a challenge. The only previously available data about re-ionization was the current team's 2006 report of data from observations of GRB 050904 from the Subaru Telescope. This past data proved that the ionization rate was already high in that era, without any sign of intergalactic neutral hydrogen [1].

A research team composed of scientists from the University of Tokyo, the National Astronomical Observatory of Japan, the Tokyo Institute of Technology and others observed the afterglow of GRB 130606A on June 6, 2013 and studied its spectrum in great detail [2]. Its afterglow was bright enough in the visible wavelength to allow for analysis, despite its great distance at a redshift of 5.913. Its distance situates the object at a time close to the presumed re-ionization era. The data from Subaru Telescope clearly show that intergalactic, neutral hydrogen gas accounts for the observed absorption feature (Figure 1). Further analysis led the team to conclude that more than 10 % of the hydrogen gas was neutral relative to the total amount of hydrogen. This means that the Universe still had a high proportion of neutral hydrogen gas when it was one billion years old. This is the first time that a research team has made a quantitative measurement of such a high proportion of neutral gas during this era.

This finding marks a significant beginning for scientists to understand the era that preceded re-ionization. Next generation telescopes, whether in space or ground-based, such as the future Thirty-Meter-Telescope (TMT), will definitely show how the first generation galaxies formed in the primordial Universe and more clearly define the process of transition from an opaque, neutral-hydrogen-filled Universe to a transparent, re-ionized one.

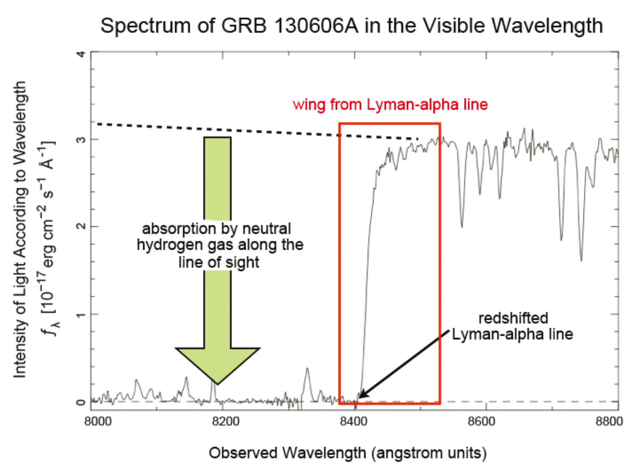

Figure 1: Visible wavelength spectrum of the afterglow of GRB 130606A at redshift of $z=5.913$, when the Universe was a mere one billion years old. Due to its redshift, the Lyman-alpha line (originally 1215 Å) is at 8400 Å. The analysis of a distinctive feature (i.e., the wing feature) between 8000–8400 Å contributed to the estimate of the ratio of neutral hydrogen relative to the entire amount of hydrogen.

References

[1] Totani, T., et al.: 2006, *PASJ*, **58**, 485.
[2] Totani, T., et al.: 2014, *PASJ*, **66**, 63.