Spectrum of gamma-ray burst's afterglow indicates beginning of re-ionization process

April 30 2014

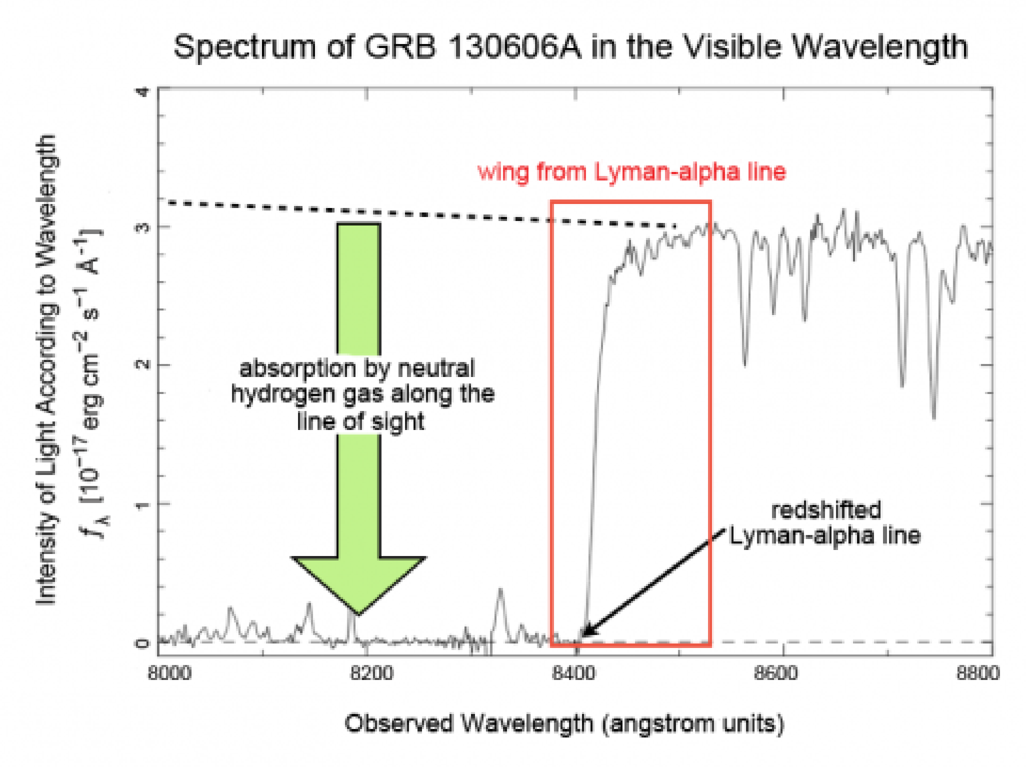

Figure 1: Visible wavelength spectrum of the afterglow of GRB 130606A at redshift of z=5.913, when the Universe was a mere one billion years old. Due to its redshift, the Lyman-alpha line (originally 1215 Å) is at 8400 Å. The analysis of a distinctive feature (i.e., the wing feature) between 8000-8400 Å (in the vicinity of this Lyman-alpha line near GRB) contributed to the estimate of the ratio of neutral hydrogen relative to the entire amount of hydrogen. Left: Absorption by neutral hydrogen gas along the line of sight Middle (within the red outline): Wing feature from the Lyman-alpha line Right: Redshifted Lyman-alpha line at z=5.913

A research team, led by Professor Tomonori Totani (School of Science, the University of Tokyo) and composed of scientists from the National Astronomical Observatory of Japan, the Tokyo Institute of Technology and others, has discovered an indicator of when re-ionization of the primordial Universe began. The team used the Faint Object Camera and Spectrograph (FOCAS) mounted on the Subaru Telescope to thoroughly study the visible wavelength spectrum of the afterglow of a gamma-ray burst, which is a violent explosion of a massive star. Direct measurement of the absorption features in the spectrum of the afterglow toward GRB 130606A, located at a great distance, revealed the proportion of neutral hydrogen gas absorbing the light in its vicinity. This finding provides the best estimate of the amount of such neutral gas in the early Universe. The team's research means that scientists can now narrow down the time when the Universe was beginning to re-ionize after its dark age.

Hydrogen is the main element of ordinary matter (5%) in the Universe, which is primarily composed of more abundant dark matter (27%) and dominant dark energy (68%). During a stage of high temperature right after the Universe's birth about 14 billion years ago, the hydrogen atom was ionized, i.e., split into a nucleon and electron. When the temperature dropped about 400,000 years after the Universe's birth, the nucleon and electron combined to make neutral hydrogen atoms. At that time, the Universe became transparent to radiation, and light-emitting objects became visible. In the present Universe, most hydrogen exists as diffuse, ionized intergalactic gas. 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. Therefore, it is very important to identify when the re-ionization occurred relative to the formation of the first generation of light-emitting objects.

When astronomical objects are far-distant, it means that they are also from the far-distant past. Recent observations from large, ground-based telescopes have enabled astronomers to study galaxies, quasars, and GRBs during an era one billion years after the birth of the Universe. If an object already existed at a time re-ionization was occurring, it must have had some neutral hydrogen gas surrounding it. Although there have been many attempts to detect such neutral gas, no clear proof of it has emerged.

Previous observational approaches to discovering it have focused on galaxies or quasars. Observations of the 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.

The current research team used Subaru Telescope's FOCAS to detect the afterglow of GRB 130606A on June 6, 2013 and studied its spectrum in great detail. 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. 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.

More information: "Probing Intergalactic Neutral Hydrogen by the Lyman Alpha Red Damping Wing of Gamma-Ray Burst 130606A Afterglow Spectrum at z = 5.913." Tomonori Totani, Kentaro Aoki, Takashi Hattori, George Kosugi, Yuu Niino, Tetsuya Hashimoto, Nobuyuki Kawai, Kouji Ohta, Takanori Sakamoto, Toru Yamada. arXiv:1312.3934v3 [astro-ph.HE] arxiv.org/abs/1312.3934

Provided by Subaru Telescope