Detections of strong UV radiation from distant galaxies - great progress in understanding the end of the cosmic dark age

Abstract

A team including researchers from the National Astronomical Observatory of Japan, Osaka Sangyo University, Tohoku University and France succeeded in the detection of strong ultra-violet (UV) radiation which can ionize hydrogen atom (ionizing radiation) from many galaxies about 12 billon light years away with the observations using the Subaru Telescope. This result is important to clarify the puzzles on the phenomenon so-called "the end of the cosmic dark age" or "the cosmic reionization", which happened about 1 billion years after the beginning of the universe. Although the cosmic reionization is considered to be led by ionizing radiation from first-generation of galaxies, there have been only two cases of detections of ionizing radiation of distant galaxies reported so far, and it has been unclear how much galaxies contributed to the cosmic reionization. Thanks to the unprecedented performance of the prime-focus camera of the Subaru telescope, the team detected ionizing radiation from 17 galaxies at once, and the result indicates that such galaxies with strong ionizing radiation could have played an important role in the cosmic reionization. This result makes a great progress toward the unveiling of the end of the cosmic dark age.

Ionizing Radiation and the End of the Cosmic Dark Age

At one minutes after the Big Bang, there were only protons, neutrons and electrons which flied over quickly in the hot universe. Gradually the temperature of the universe went down as it expanded, and protons and electrons combined to form hydrogen atoms. The universe continued to expand and it cooled down.

At that epoch, there was no astronomical body, and it is called as "the cosmic dark age". This epoch was terminated by the light emitted from the first astronomical objects in the universe. Among the light from such objects, a light which has wavelength shorter than 91.2 nano-meter (*1) has enough strong energy to separate a hydrogen into a proton and an electron (i.e., ionize a hydrogen atom). Such light is called ionizing radiation(*2). Astronomical objects formed one from another, and radiation from them ionized hydrogen in most part of the universe (inter-galactic space) by 1 billion years after the Big Bang (about 12.5 billion years ago). In this phenomenon protons and electrons once combined were again separated, and thus it is named as "the cosmic reionization". After that epoch, the universe has been kept almost ionized (Fig. 1). The formation of the first-generation objects and the cosmic reionization were epoch-making events indeed - they terminated the cosmic dark age and the universe began its first step to form all variety of its contents such as galaxies, stars and planets.

[Figure 1: A brief history of the universe, including the cosmic reionization]

Although astronomers have detected several astronomical objects in the epoch of the cosmic reionization (*3), the process of the cosmic reionization remains as a puzzle. Especially, we don't know what kind of objects are the source of the reionization. One candidate is quasars which are luminous objects hosting super-massive black holes. However, they appear to be too few in the epoch of the reionization to ionize the whole universe. On the other hand, galaxies, which consist of stars and gas, are so numerous that they might have played a primary role in the cosmic reionization, though individual galaxies are much dimmer than quasars. However, there has been a serious problem in the past researches on the process of the cosmic reionization: the amount of ionizing radiation from galaxies has been almost completely unknown. So far there have been only two cases with detections of ionizing radiation from individual galaxies (*4). Thus the galaxies' contribution to the cosmic reionization has remained unclear.

Characteristics and Importance of the Present Research
From September 10th to 14th 2007, the Subaru telescope pointed to distant galaxies to search for ionizing radiation from them. The approach of this observation was different from previous researches on ionizing radiation. In the most of previous researches, spectroscopy (which can separate objects' light with different wavelengths) was adopted. With spectroscopy observers can measure strengths of light in each wavelength, but it is not suited for identifying faint signals. In the observation in September 2007, the team made imaging observations which are much similar to ordinary photographs. The use of a special filter (*5, Fig. 2) designed to collect only ionizing radiation emitted from galaxies at a certain distance from the Earth made it possible to measure the strength of ionizing radiation much efficiently compared to spectroscopic observations. Moreover, the prime-focus camera of the Subaru telescope has the widest field-of-view (about 0.5 degree) among large telescopes in the world, and it enables the observation of large number of galaxies at once. The observed sky area was a field named as SSA22 (*6) where a giant cluster of young galaxies at a distance of about 12 billion light years has been discovered. With a single view of the prime-focus camera of the Subaru telescope, the team was able to examine ionizing radiation from 198 galaxies at 12 billion light years away at once.

[Figure 2: the filter used in the present research. Because this filter does not transmit light visible to humans, it reflects an image of the ceiling.]

With this observation, ionizing radiations from 17 galaxies among 198 observed were detected. This number largely exceeds the number of previous detections (only two). It is indicated that the wide-field imaging observation with the Subaru telescope is extremely powerful in searching for ionizing radiation from galaxies.
Interestingly, some of those detected galaxies show ionizing radiation much more than theoretical expectations. This indicates that young galaxies in the distant universe, at least some of them, emit ionizing radiation much more than previously considered, and such galaxies with strong ionizing radiation may have played an important role in the cosmic reionization. In addition, for some galaxies spatial positions of ionizing radiation appear to have offsets from brightest part of the galaxies (Fig. 3). This finding can be a clue to understand how ionizing radiation escapes from galaxies.
These new discoveries should also have a large impact upon "the theory of galaxy evolution", which describes how stars have been formed in the galaxies and how galaxies formed their beautiful shapes we observe in the current universe.

[Figure 3: Galaxies in the universe about 12 billion light years away, as seen in ionizing and non-ionizing radiations. Strengths of ionizing radiation are indicated as contours over images in non-ionizing radiation. For some galaxies there appears some offsets between ionizing and non-ionizing radiations. At the distance of the observed galaxies, five arcseconds correspond to 120 thousand light years.]

Prospects for Further Developments
This observation made advantage of the unique capability of the Subaru telescope and achieved a significant progress on the research of the ionizing radiation from galaxies in the early universe. The results would provide important clues to understand what kind of objects is responsible for the cosmic reionization and how they made it. It is expected that with the follow-up observations including new observing facilities astronomers will clarify what actually happened at the epoch of the cosmic reionization (i.e., the end of the cosmic dark age) - which is the epoch human beings have not fully understood yet.

These results will be published in the February 2009 issue of the Astrophysical Journal.

Title: "Detections of Lyman Continuum from Star-forming Galaxies at z~3 Through Subaru/Suprime-Cam Narrow-band Imaging", I. Iwata, A. K. Inoue, Y. Matsuda, H. Furusawa, T. Hayashino, K. Kousai, M. Akiyama, T. Yamada, D. Burgarella, and J.-M. Deharveng, 2009, The Astrophysical Journal, Volume 692, Issue 1

Notes

(1) 1 nano-meter (nm) is 0.000000001 meter or 0.000001 cm. Visible lights have wavelengths between 380 nm and 780 nm.

(2) In standard astronomical observations (using optical telescopes) we observe non-ionizing photons which have wavelengths longer than 91.2 nm and their energy is lower than ionizing radiation.

(3) E.g., "Cosmic Archeology Uncovers the Universe's Dark Ages", Subaru Press Release on Sep. 13, 2006 (http://www.subarutelescope.org/Pressrelease/2006/09/13/index.html); "Universe Re-ionized 900 Million Years After Birth", Subaru Press Release on May 25, 2006(http://www.subarutelescope.org/Pressrelease/2006/05/25/index.html)

(4) Shapley, A. E. 2006, Astrophysical Journal 651, 688. In addition, there is a report of a detection of ionizing radiation by combining spectral data from many galaxies into one to amplify signal (Steidel, C. C., 2001, Astrophysical Journal 546, 665). These are on galaxies at about 12 billion light years away. For galaxies closer to the Earth, their redshifts (see note 5) are smaller and ionizing radiation from them cannot be observed from the ground due to atmospheric absorption, and space-borne observation is required. Although there is one report of the detection of ionizing radiation from such a nearby galaxy, there are arguments on its reality and no conclusion has been drawn.

(5) The expansion of the universe makes a wavelength of light from distant objects to the Earth longer (i.e., "redder"). Redshift is a factor of this extension, and it is also an indicator of the distance of astronomical objects. Ionizing radiation is originally a UV radiation with wavelength shorter than 91.2 nm, but the observed wavelength is longer than that due to redshift. For ionizing radiation with a wavelength of 90 nm from galaxies at 12 billion light years away is observed at about 360 nm.

(6) SSA22 is located in Aquarius (Fig. 4). The results on the cluster of galaxies in SSA22 using the Subaru telescope include Matsuda, Y. et al. 2004, Astronomical Journal 128, 569 and Hayashino, T. et al. 2004, Astronomical Journal 128, 2073. Also, there was a Subaru web-release on the results for the field (26th July, 2006; http://www.subarutelescope.org/Pressrelease/2006/07/26/index.html).

[Figure 4: the position of SSA22. Created with the StellaNavigator by AstroArts Inc.]

Supplemental Note: the Relationship between the Present Observation and the Cosmic Reionization

The galaxies observed in this study are about 12 billion light years away from the Earth, and it means the universe was about 2 billion years after its beginning. On the other hand, the cosmic reionization is considered to be completed by about 1 billion years after the beginning of the universe. So the galaxies observed in this study are those at the epoch after the completion of the cosmic reionization. It would be direct and desirable if we were able to observe ionizing radiation from galaxies in the epoch of the cosmic reionization. Unfortunately, it is impossible; hydrogen atoms between us and distant galaxies absorb ionizing radiation emitted during the cosmic reionization and it is invisible for us. It has been found that we can observe ionizing radiation only from galaxies in the universe more than 2 billion years after the Big Bang (Inoue, A. K. and Iwata, I. 2008, Monthly Notice of Royal Astronomical Society 387, 1681).

It is known that the properties of galaxies at the epoch of 2 billion years after the beginning of the universe (e.g., they form stars more actively than galaxies in the current universe) are similar to those of galaxies in the epoch of the cosmic reionization. Thus it is quite important to study many young galaxies at the epoch of 2 billion years and to know the relationship between the strength of ionizing radiation and other properties of galaxies such as their sizes, mass and age. With such correlations and observations of the properties of galaxies at the epoch of the cosmic reionization, it would be possible to estimate the amount of ionizing radiation from galaxies at the epoch and to clarify how important the galaxies was to the cosmic reionization.

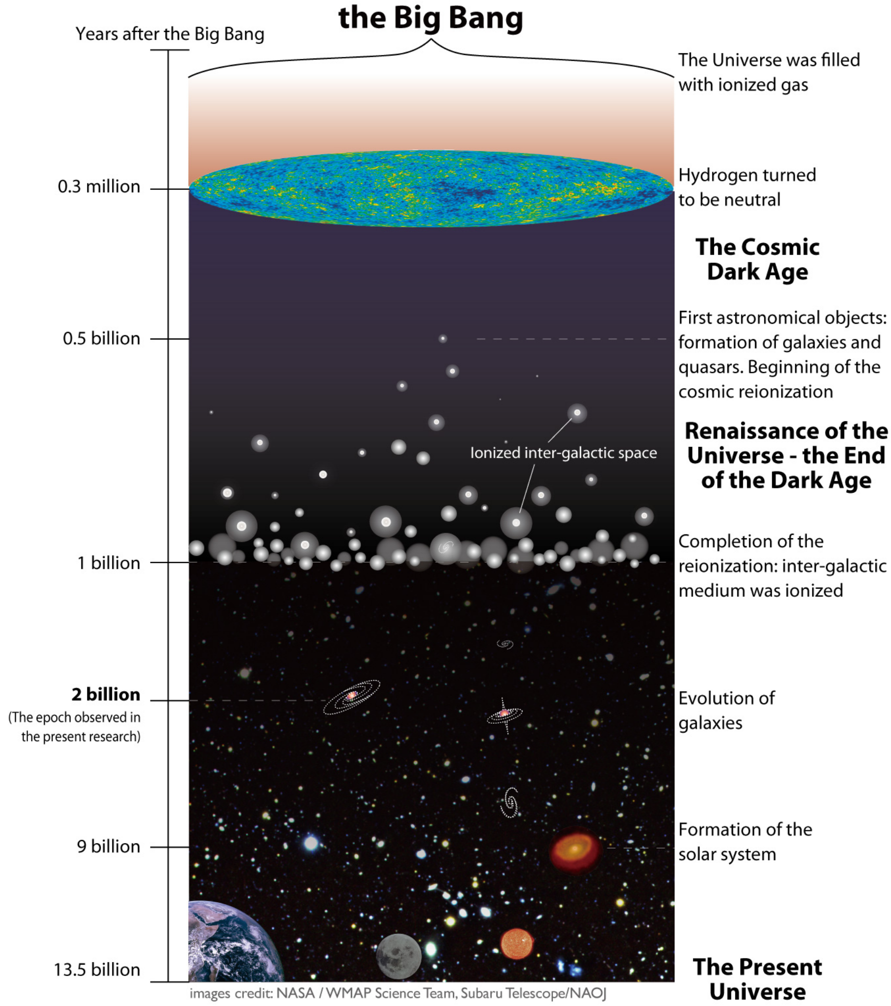

Figure 1

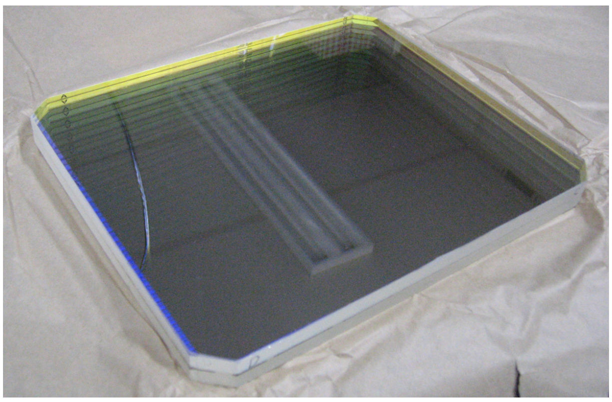

Figure 2

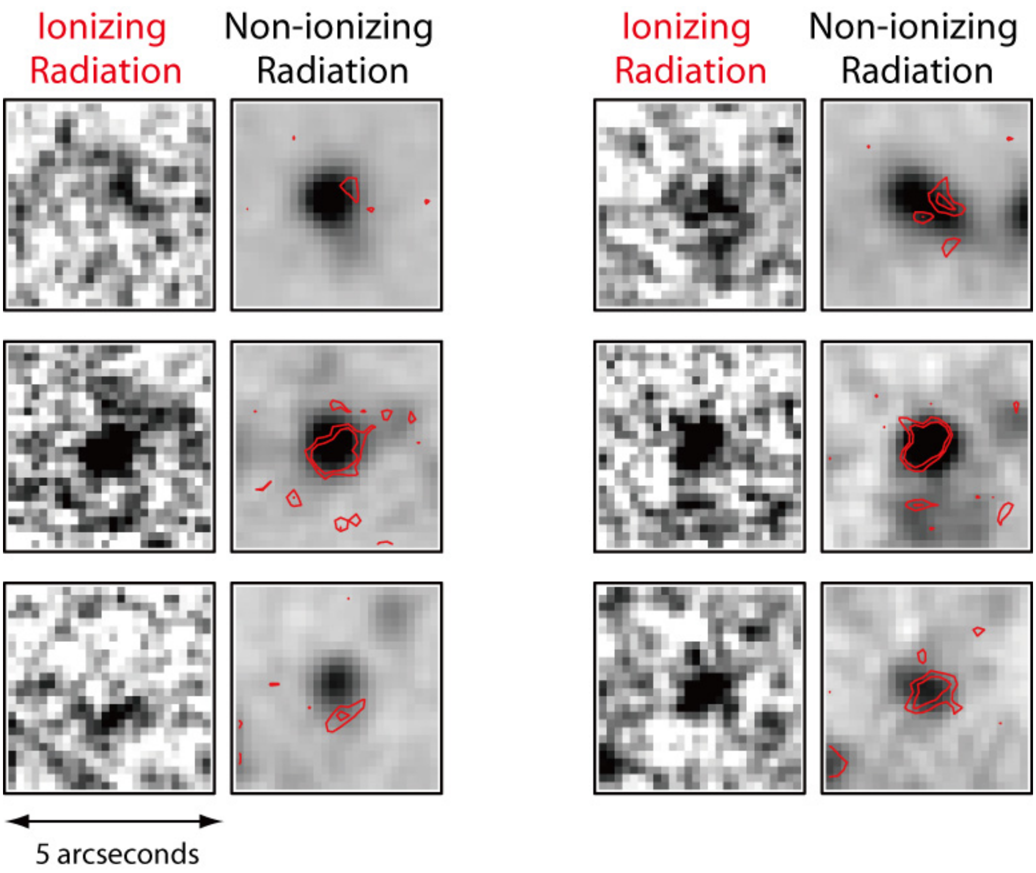

Figure 3

Figure 4