

Cosmic Archeology Uncovers the Universe's Dark Ages (Forwarded)

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Cosmic Archeology Uncovers the Universe's Dark Ages

Astronomers using the Subaru telescope in Hawai'i have looked 60 million years further back in time than any other astronomers, to find the most distant known galaxy in the universe. In doing so, they are upholding Subaru's record for finding the most distant and earliest galaxies known. Their most recent discovery is of a galaxy called IOK-1 that lies so far away that astronomers are seeing it as it appeared 12.88 billion years ago.

This discovery, based on observations made by Masanori Iye of the National Astronomical Observatory of Japan (NAOJ), Kazuaki Ota of the University of Tokyo, Nobunari Kashikawa of NAOJ, and others indicates that galaxies existed only 780 million years after the universe came into existence about 13.66 billion years ago as a hot soup of elementary particles.

To detect the light from this galaxy, the astronomers used Subaru telescope's Suprime-Cam camera outfitted with a special filter to look for candidate distant galaxies. They found 41,533 objects, and from those identified two candidate galaxies for further study using the Faint Object Camera and Spectrograph (FOCAS) on Subaru. They found that IOK-1, the brighter of the two, has a redshift of 6.964, confirming its 12.88 billion-light-year distance.

The discovery challenges astronomers to determine exactly what happened between 780 and 840 million years after the Big Bang. IOK-1 is one of only two galaxies in the new study that could belong to this distant epoch. Given the number of galaxies that have been discovered from 840 million years after the Big Bang, the research team had expected to find as many as six galaxies at this distance. The comparative rarity of objects like IOK-1 means that the universe must have changed over the 60 million years that separate the two epochs.

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The most exciting interpretation of what happened is that we are seeing an event known to astronomers as the reionization of the universe. In this case, 780 million years after the Big Bang, the universe still had enough neutral hydrogen to block our view of young galaxies by absorbing the light produced by their hot young stars. Sixty million years later, there were enough hot young stars to ionize the remaining neutral hydrogen, making the universe transparent and allowing us to see their stars.

Another interpretation of the results says that there were fewer big and bright young galaxies 780 million years after the Big Bang than 60 million years later. In this case, most of the reionization would have taken place earlier than 12.88 billion years ago.

No matter which interpretation finally prevails, the discovery signals that astronomers are now excavating light from the "Dark Ages" of the universe. This is the epoch when the first generations of stars and galaxies came into existence, and an epoch which astronomers have not been able to observe until now.

BACKGROUND INFORMATION:

Archeology of the Early Universe Using Special Filters

Newborn galaxies contain stars with a wide range of masses. Heavier stars have higher temperatures, and emit ultraviolet radiation that heats and ionizes nearby gas. As the gas cools it radiates away excess energy so that it can return to a neutral state. In this process, hydrogen will always emit light at 121.6 nanometers, called the Lyman-alpha line. Any galaxy with many hot stars should shine brightly at this wavelength. If stars form all at once, the brightest stars could produce Lyman-alpha emission for 10 to 100 million years.

In order to study galaxies like IOK-1 that exist at early times in the universe, astronomers must search out Lyman-alpha light that is stretched and redshifted to longer wavelengths as the universe expanded. However, at wavelengths longer than 700 nanometers, astronomers have to deal with foreground emissions from OH molecules in Earth's own atmosphere that interfere with faint emissions from distant objects.

To detect the faint light from distant galaxies, the research team had been observing at wavelengths where Earth's atmosphere doesn't glow much, through windows at 711, 816, and 921 nanometers. These windows correspond to the redshifted Lyman-alpha emission from galaxies with redshifts of 4.8, 5.7, and 6.6, respectively. These numbers indicate how much smaller the universe was compared to now, and correspond to 1.26 billion years, 1.01 billion years, and 840 million years after the Big Bang. This is like doing archaeology of the early universe with particular filters allowing scientists to see into different layers of an excavation.

To obtain their spectacular new results, the team had to develop a filter sensitive to light with wavelengths only around 973 nanometers, which

corresponds to Lyman alpha emission at a redshift of 7.0. This wavelength is at the limit of modern CCDs, which lose sensitivity at wavelengths longer than 1000 nanometers. This one of its kind filter, called the NB973, uses multilayer coating technology, and took more than two years to develop. Not only did the filter have to pass light with wavelengths only around 973 nanometers, but it also had to cover uniformly the entire field of view of the telescope's prime focus. The team worked with a company, Asahi Spectra Co.Ltd, to design a prototype filter to use with Subaru's Faint Object Camera, and then applied that experience to making the filter for Suprime-Cam.

The Observations

The observations with the NB973 filter took place during the spring of 2005. After more than 15 hours of exposure time, the data obtained reached a limiting magnitude of 24.9. There were 41,533 objects in this image, but a comparison with images taken at other wavelengths showed that only two of the objects were bright only in the NB973 image. The team concluded that only those two objects could be galaxies at a redshift of 7.0. The next step was to confirm the identity of the two objects, IOK-1 and IOK-2, and the team observed them with the Faint Object Camera and Spectrograph (FOCAS) on the Subaru telescope. After 8.5 hours of exposure time, the team was able to obtain a spectrum of an emission line from the brighter of the two objects, IOK-1. Its spectrum showed an asymmetrical profile that is characteristic of Lyman-alpha emission from a distant galaxy. The emission line was centered at a wavelength of 968.2 nanometers (redshift 6.964), corresponding to a distance of 12.88 billion light years and time of 780 million years after the Big Bang.

The Identity of the Second Candidate Galaxy

Three hours of observation time did not yield any conclusive results to determine the nature of IOK-2. The research team has since obtained more data that is now being analyzed. It is possible that IOK-2 may be another distant galaxy, or it could be an object with variable brightness. For example, a galaxy with a supernova or a black hole actively swallowing material that just happened to appear bright during the observations with the NB973 filter. (Observations in the other filters were made one to two years earlier.)

The Subaru Deep Field

The Subaru telescope is particularly well suited for the search of the most distant galaxies. Of all the 8- to 10-meter-class telescopes in the world, it is the only one with the ability to mount a camera at prime focus. The prime focus, at the top of the telescope tube, has the advantage of a wide field of view. As a result, Subaru currently dominates the list of the most distant known galaxies. Many of these are in a region of the sky in the direction of the constellation Coma Berenices called the Subaru Deep Field that the research team selected for intense study at many wavelengths.

The Early History of the Universe and the Formation of the First Galaxies

To put this Subaru accomplishment into context, it is important to review what we know about the history of the early universe. The universe began with the Big Bang, which occurred about 13.66 billion years ago in a fiery chaos of extreme temperature and pressure. Within its first three minutes, the infant universe rapidly expanded and cooled, producing the nuclei of light elements such as hydrogen and helium but very few nuclei of heavier elements. In 380,000 years, things had cooled to a temperature of around 3,000 degrees. At that point, electrons and protons could combine to form neutral hydrogen.

With electrons now bound to atomic nuclei, light could travel through space without being scattered by electrons. We can actually detect the light that permeated the universe back then. However, due to time and distance, it has been stretched by a factor of 1,000, filling the universe with radiation we detect as microwaves (called the Cosmic Microwave Background). The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft studied this radiation and its data allowed astronomers to calculate the age of the universe at about 13.66 billion years. In addition, these data imply the existence of such things as dark matter and the even more enigmatic dark energy.

Astronomers think that over the first few hundred million years after the Big Bang, the universe continued to cool and that the first generation of stars and galaxies formed in the densest regions of matter and dark matter. This period is known as the "Dark Ages" of the universe. There are no direct observations of these events yet, so astronomers are using computer simulations to tie together theoretical predictions and existing observational evidence to understand the formation of the first stars and galaxies.

Once bright stars are born, their ultraviolet radiation can ionize nearby hydrogen atoms by splitting them back into separate electrons and protons. At some point, there were enough bright stars to ionize almost all the neutral hydrogen in the universe. This process is called the reionization of the universe. The epoch of reionization signals the end of the Dark Ages of the universe. Today most of the hydrogen in the space between galaxies is ionized.

Pinpointing the Epoch of Reionization

Astronomers have estimated that reionization occurred sometime between 290 to 910 million years after the birth of the universe. Pinpointing the beginning and end of the epoch of reionization is one of the important stepping stones to understanding how the universe evolves, and is an area of intense study in cosmology and astrophysics.

It appears that as we look farther back in time, galaxies get rarer and rarer. The number of galaxies with a redshift of 7.0 (which corresponds to

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a time about 780 million years after the Big Bang) seems smaller than what astronomers see at a redshift of 6.6 (which corresponds to a time about 840 million years after the Big Bang). Since the number of known galaxies at a redshift of 7.0 is still small (only one!) it is difficult to make robust statistical comparisons. However, it is possible that the decrease in number of galaxies at higher redshift is due to the presence of neutral hydrogen absorbing the Lyman-alpha emission from galaxies at higher redshift. If further research can confirm that the number density of similar galaxies decreases between a redshift of 6.6 and 7.0, it could mean that IOK-1 existed during the epoch of the universe's reionization.

These results will be published in the September 14, 2006, edition of Nature.

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Note: Throughout this article redshifts were converted to distances and ages using cosmological parameters of $H_0=71\text{km/s/Mpc}$, $(\Omega)=0.27$, and $(\Lambda)=0.73$ to maintain consistency with previous releases. The research paper submitted to Nature reports slightly different numbers based on cosmological parameters of $H_0=70\text{km/s/Mpc}$, $(\Omega)=0.3$, and $(\Lambda)=0.7$.

[NOTE: Images supporting this release are available at <http://www.subarutelescope.org/Pressrelease/2006/09/13/index.html>]