MIT HAYSTACK OBSERVATORY

Epoch of Reionization

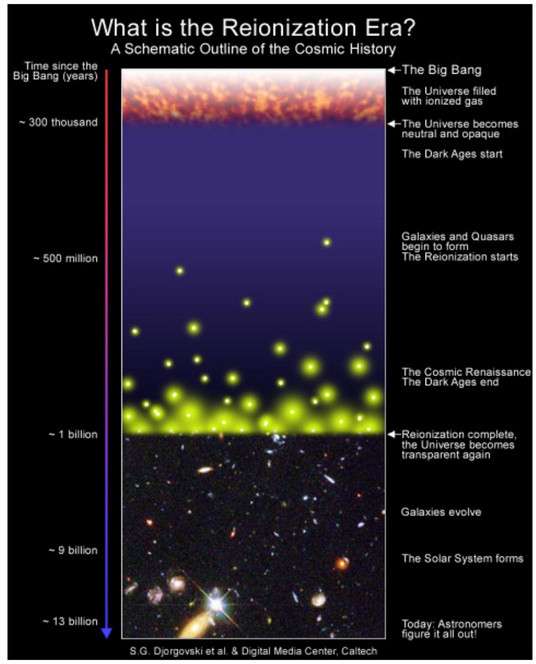
The Epoch of Reionization (EOR) refers to the period in the history of the universe during which the predominantly neutral intergalactic medium was ionized by the emergence of the first luminous sources. These sources may have been stars, galaxies, quasars, or some combination of the above. By studying reionization, we can learn a great deal about the process of structure formation in the universe, and find the evolutionary links between the remarkably smooth matter distribution at early times revealed by CMB studies, and the highly structured universe of galaxies and clusters of galaxies at redshifts of 6 and below. The Low Frequency Demonstrator is designed to provide detailed information on conditions in the intergalactic medium during and immediately preceding the EOR.

The diagram below provides a good graphical representation of the history of the universe, and where the epoch of reionization sits in the overall picture. After the Big Bang, the Universe was a hot, but quickly cooling soup of fundamental particles. After a few hundred thousand years, things cooled enough so that protons and electrons could combine to form neutral hydrogen. This was a rather sudden event, and allowed the thermal glow of the fireball plasma, as it existed immediately before the hydrogen formation event, to radiate throughout the universe unimpeded by constant interactions with the charged particles of the now-absent plasma. This glow, redshifted by a factor of 1100 or so, is what we now observe as the Cosmic Microwave Background (CMB) in all directions. The CMB carries a frozen imprint of the density fluctuations in the early Universe, the study of which, by the observational cosmology community, is intense and sustained.

After the Universe became neutral, it became unobservable across much of the electromagnetic spectrum. Any short wavelength radiation that might have been emitted was quickly absorbed by the atomic gas, and a long interval known as the Dark Ages began. Slowly, gravitational collapse of overdense regions, the same regions we can see in the CMB imprint from earlier times, led to the formation of more and more pronounced structure in the neutral medium, and eventually the first stars, galaxies and quasars started to form. The exact mechanism and nature of this formation, poorly constrained by observation, is a topic of much research and great importance. We know what the Universe looked like at the time of the CMB, and we know what it looks like now, but how did it get from one to the other?

As the collapse of structures proceeded, temperature variations developed. Gradually, energetic radiation emitted by the first sources caused local heating, and then ionization of the hydrogen in the Universe. It will have started with "bubbles" of ionized plasma surrounding the most energetic sources. As the bubbles grew and became more numerous, they started to overlap, and more and more of the neutral medium became exposed to the harsh ionizing radiation, which travels unimpeded through ionized regions. The final phase of reionization of the Universe may have occurred swiftly. As soon as the bulk of the Universe was reionized, light at many wavelengths could escape from the early galaxies and quasars, revealing the distant Universe that we see today with optical and infrared telescopes.

Reionization was complete about 1 billion years after the Big Bang, corresponding to a redshift of about 6.5. Before that time, observations rapidly become more difficult. By and large, one must hope to find isolated, very luminous objects whose radiation in one form or another manages to reach us through the increasingly neutral medium. Perhaps the best hope for a more general and comprehensive probe of these early epochs is the 21cm hyperfine transition line of neutral hydrogen, redshifted to frequencies below 200 MHz. Sensitive observations of emission and absorption in this line can probe deeply into the reheating and reionization epochs, and give us a detailed view of the density, temperature and velocity field of the material. We would get a view, not just of isolated luminous objects and the material which happens to lie in front of them, but of large volumes of the Universe at the target redshifts. Such a view would yield a treasure trove of information from which to deduce the early history of structure formation, and the origin of the stars, galaxies, clusters and quasars that we see today.



Graphical representation of the history of the universe, by Djorgovski et al, (Caltech). <u>**Full Size picture**</u>