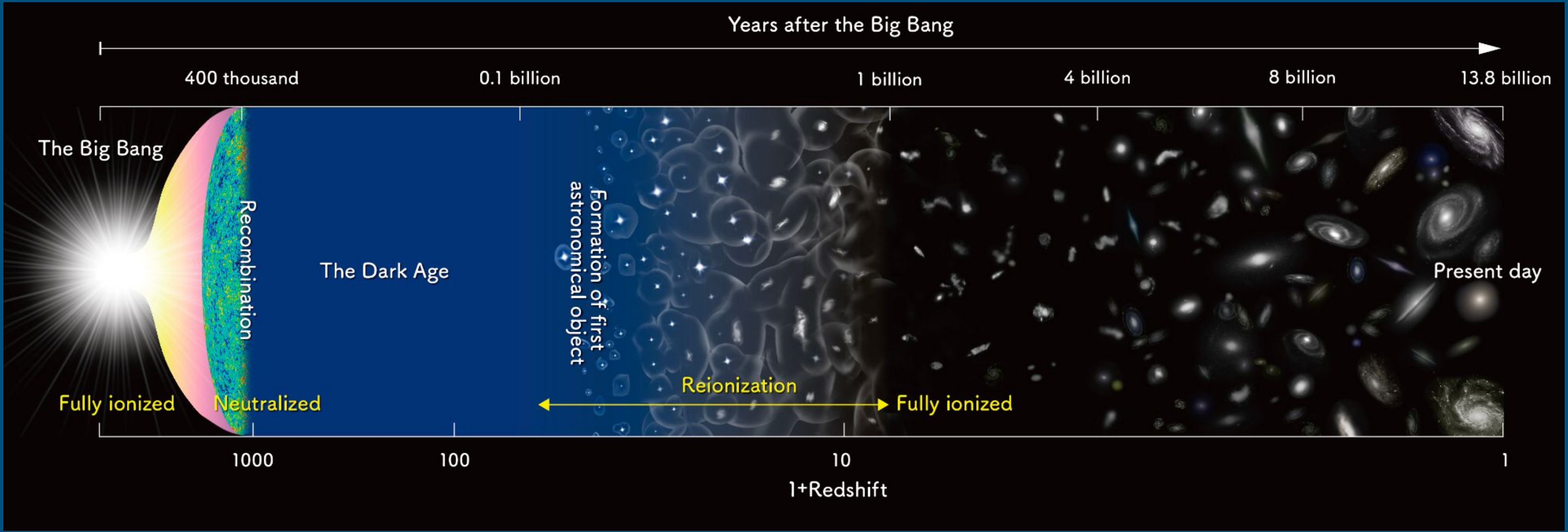
First stars and reionization

Barbara, Avery & Harshill

Preview

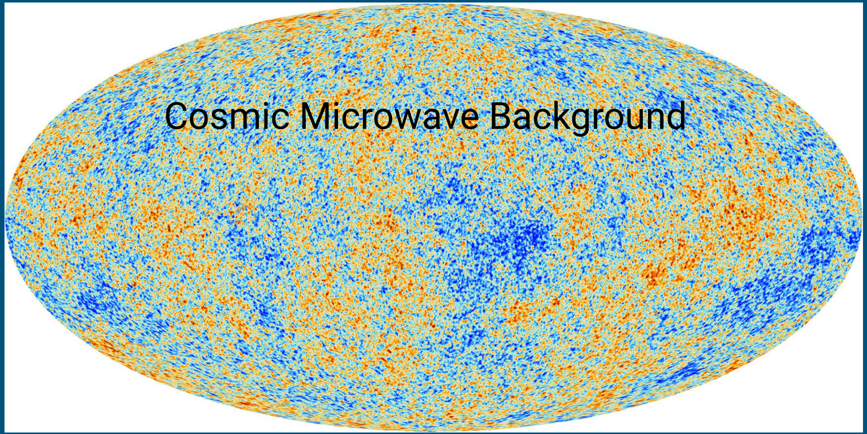


https://astrobites.org/2018/03/29/the-imprint-of-cosmic-reionization-on-dwarf-galaxies/

After the Big Bang

Hot, dense fog of ionized gas -> 370,000 years of cooling -> electrons and protons were able to combine to form the first neutral atoms.

High-energy radiation cooled and has been red-shifted by a factor of over 1,000 due to the expansion of the universe. We see this today as the CMB.



https://en.wikipedia.org/wiki/Reionization

The Dark Ages

After the CMB became imprinted on the universe, the cosmos became opaque at shorter wavelengths due to the absorbing effects of atomic hydrogen.

The Dark Ages: time period of low light and high density of neutral gas

https://www.khanacademy.org/humanities/whp-origins/era-4-regional/43-a-dark-age-betaa/a/read-the-dark-ages-debate-beta

Birth

These regions cooled and collapsed, allowing nuclear fusion in their cores to begin, leading to the first stars.

The first stars reionized the hydrogen in the surrounding medium, as their energy heated the local area.

areas formed bubbles that grew until large enough to overlap with each other, allowing ionizing radition to travel further through space.

https://www.physics.uu.se/research/astronomy-and-space-physics/research/galaxies/first-stars-galaxies/

Post-Birth

Through nucleosynthesis in these short-lived stars and supernovae, a fraction of the universe’s initial hydrogen and helium were converted into elements, significantly altering the chemical makeup of the cosmos.

after reionization, about one billion years after the Big Bang, light was able to travel uninterrupted through the cosmos, revealing the universe as we see it today.

Reionization

Electrons and protons combined to form neutral hydrogen gas after cooling from the big bang, approximately 13.7 billion years ago

This is known as the dark age due to there being few luminous objects.

The dark age ended when the first stars formed and their ultraviolet radiation split hydrogen atoms into electrons and protons, a process called ionization.

This period of time last from about 150 million to 800 million years.

Calculations

$$\frac{N_{II}}{N_I} = \frac{2Z_{II}}{n_e Z_I} \left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi/kT}$$

Assume NII/NI > 1 for ionization of H

For early universe, T = 10^9 K radiation

n_e = 7.63516E28

For late universe, T = 10^4 K radiation

n_e = 1.74358E15

Reionization Video Link

https://www.youtube.com/watch?v=dgXfTx2e2MA

This simulation shows the progress of reionization. Ionized regions are blue and translucent, ionization fronts are red and white, and neutral regions are dark and opaque. See Alvarez et al. (2009) for more details on the simulations.

https://www.eso.org/public/videos/eso1041d/

Observations

Quasars

CMB anisotropy and polarization

21 cm line

Quasars

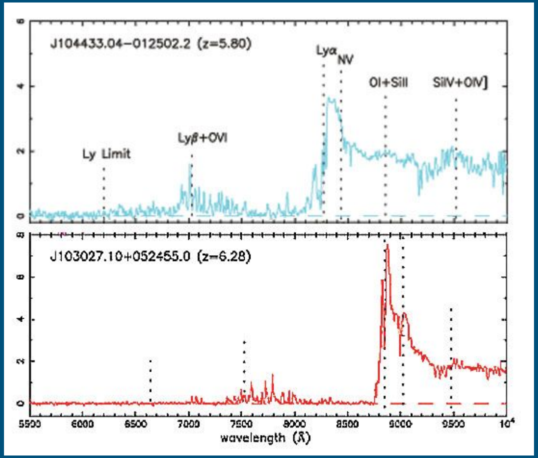
-extremely bright objects, fairly uniform spectral features

-visible out to the early universe

-so only difference in spectra should occur due to interaction of the emission line with material in the line of sight (IGM)

-light traveling from a quasar through neutral hydrogen will show a gunn-peterson trough

-this trough has been detected at z>6 via SDSS



Becker et al. 2001

CMB anisotropy and polarization

-CMB undergoes observable thompson scattering as the universe expands, which is visible on a CMB anisotropy map and secondary ones are introduced by reionization

-comparing to electron column densities, age of reionization can be calculated

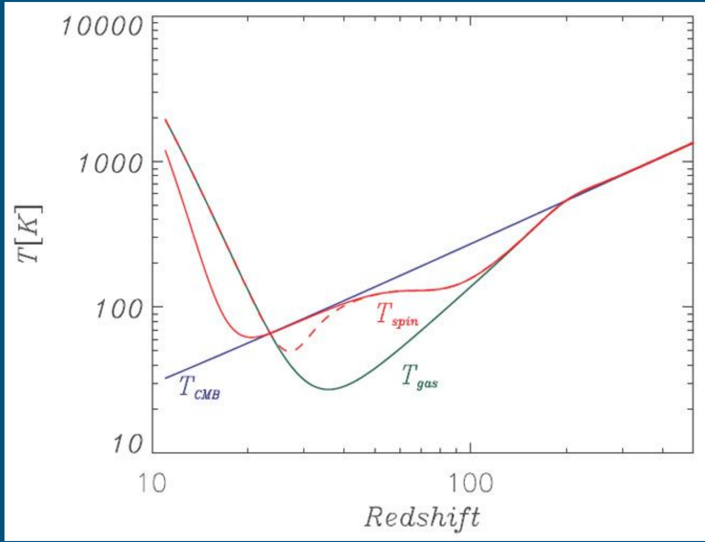
- Wilkinson Microwave Anisotropy Probe studied this and yielded $11<z<30$ but year 3 data is consistent with quasar data of reionization beginning at $z = 11$ and the universe ionized by $z = 6$

21 cm

-this line can potentially study energy sources of reionization and the effects on, and role of, structure formation during reionization

-its a forbidden line occurring in neutral hydrogen, due to differences in energy between the spin triplet and spin singlet states of the electron and proton

-many projects studying this: Precision Array for Probing the Epoch of Reionization (PAPER), Low Frequency Array (LOFAR), Murchison Widefield Array (MWA)



https://ned.ipac.caltech.edu/level5/March14/Zaroubi/Zaroubi4.html

https://www.science.org/doi/10.1126/science.1125644

Energy sources for reionization

Dwarf galaxies

Quasars

Population III stars

Dwarf galaxies

-dwarf galaxies are currently the primary source of ionizing photons

-a larger fraction of ionizing photons can escape a dwarf galaxy (50%) than in larger galaxies (5%)

-they quickly expel all of their gas

Quasars

-are a very nice candidate because they are very effective at turning mass into energy

-but were there enough of them? We can only see the brightest ones

-studying nearby quasars and assuming a constant luminosity function across time predicts that quasars do not exist in high enough numbers to reionize the IGM alone

Shapiro and Giroux 1987

Population III Stars

-hypothetical star

-massive and comprised of mostly hydrogen and helium

Very short lifespans 2-5 mil years

-quasars spectra show heavy elements which would come from supernovas of these stars

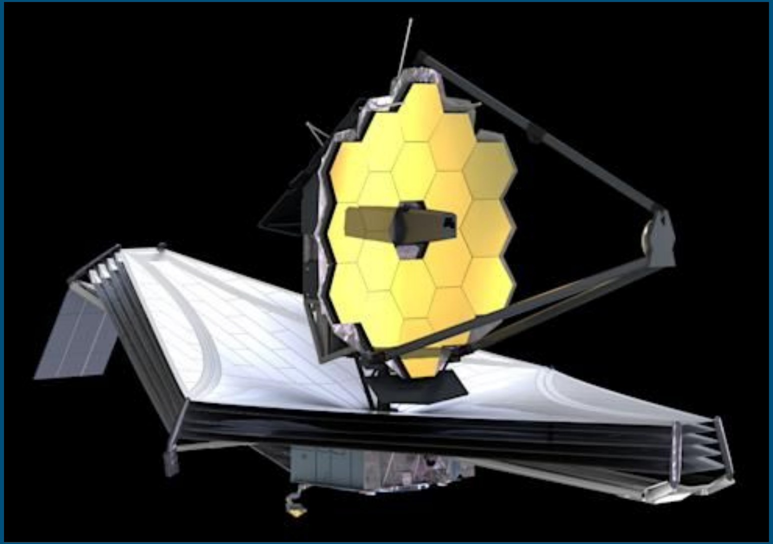
-evidence for them in Cosmos Redshift 7 galaxy at z = 6.60 but haven't been directly detected yet

-detecting them is one of JWST's main goals

https://arxiv.org/abs/2107.09324

Present day connection

The James Webb Space Telescope missions goal is to get a look back in time to the birth of the cosmos, as we see it today.



Questions Remain

What is the processes that drove galaxy formation?

Galaxies in the early universe were relatively small, thus studying their shape and movement is difficult.

Use of higher-resolution images and Doppler studies of their internal velocities, to better understand how these galaxies emerged from the primordial gas, and evolved into the large galaxies.

Questions Remain

What is the process of early star formation?

The process of star formation is difficult to unravel, even in nearby star forming regions today.

Current conditions: cooling of superheated gas, feedback from supernovae, and supermassive black holes

In the very early universe, these complex conditions become even more challenging to comprehend.

These early galaxies would have contained massive stars formed from primordial gas unlike any stars in the universe today and would likely have formed and evolved under radically different conditions.