# THE FORMATION OF THE FIRST STARS IN THE UNIVERSE

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"The good thing about science is that it's true whether or not you believe in it." ― Neil deGrasse Tyson

what are stars? Why do they exist? where do they come from? Many questions like these have been asked. As technology becomes better we learn more and more about them. Something that we learned is how they are born.

One of the biggest challenge in modern Astrophysics is to understand the formation of the first stars at the end of the cosmic 'dark ages'. The first star didn't appear until perhaps 100 million years after the big bang, and nearly a billion years passed before galaxies flourished across the cosmos. Astronomers have long wondered: How did this dramatic transition from darkness to light come about?Their appearance signaled the end of the cosmic dark ages,through the production of ionizing photonsand the initial augmentation with heavy chemical elements leading to a fundamental transformation of the early Universe.It is thought that during this period the Universe was transformed from its simple initial state into a complex, hierarchical system, by the input of heavy elements from the first stars, and by energy injection from these stars and from the first black holes.

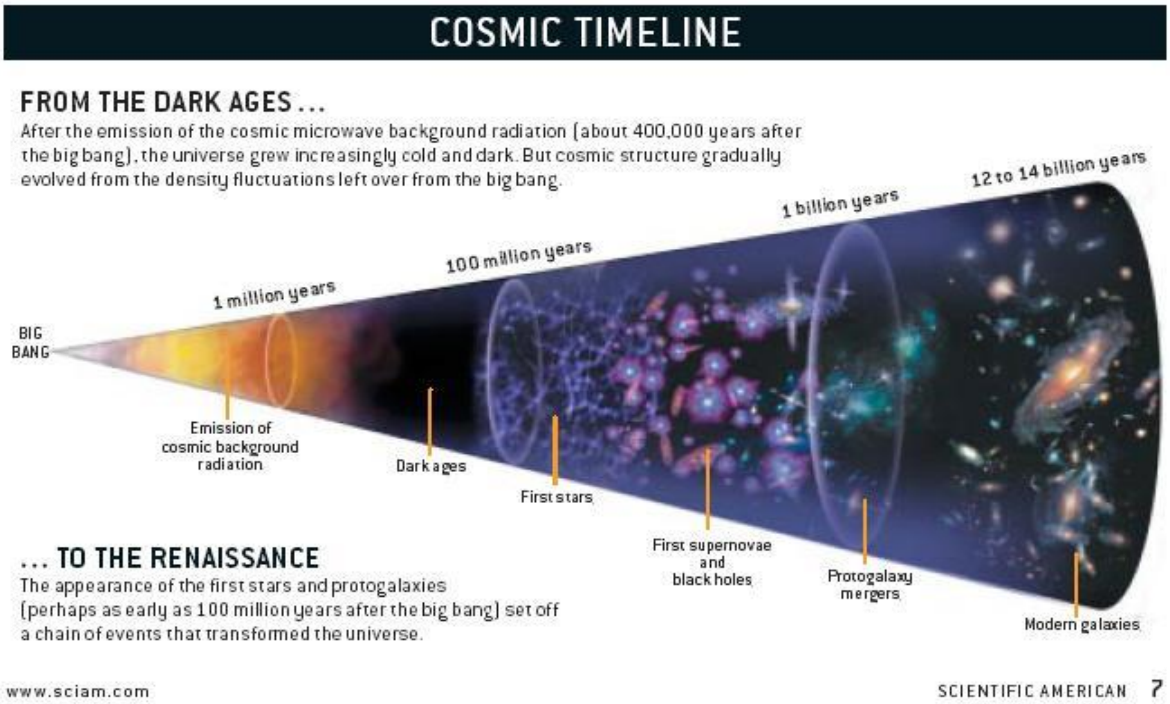
Using computer simulation techniques, cosmologists have devised models that shows how the density fluctuations left over from the big bang could have evolved into the first stars. The Standard star-formation theory predicts that at first a tiny protostar forms and subsequently by accreting the surrounding gas it become massive star. Nevertheless, the ultimate mass of the star is determined by the mass of the cloud out of which the star forms and by the number of feedback processes. The radiative forces on the gasses are much weaker because the primordial gas does not contain dust grains. Also in the primordial star-forming gas the amplitudes of the magnitude fields generated in the early universe are so small that they never become dynamically significant. In short, the earliest stars made possible the emergence of the universe, everything from galaxies and quasars to planet and people.

**The Dark Ages**

By a billion years after the big bang, some bright galaxies and quasars had already appeared, so the first stars must have formed sometime before. When did these first luminous objects arise, and how might they have formed?

To begin the star formation, anadequate amount of cold dense gas must amass in a dark halo. In the early Universe, the primordial gas could not efficiently cool radiatively because atoms have excitation energies that are too high, and molecules, which have accessible rotational energies, are very rare.

The standard cosmological model describes the evolution of the universe following big bang. The age of an object in the universe can be determined through the redshift its light which shows the expansion of universe since the light was produced. About 400,000 years after the big bang the Cosmic Microwave Background Radiation was emitted and its uniformity indicates that matter was distributed very smoothly at that time. As the cosmos expanded the background radiation redshifted to longer wavelengths and the universe grew increasingly cold and dark. Astronomers have no observations of this dark era.




The source of the most of the heavier element is thermonuclear fusion reactions in stars, whereas the big bang produced hydrogen and helium. So, the heavier elements(metals) would not have been present before the first star had formed. The young metal-reach stars in the Milky Way are called Population I stars and the old metal-poor stars are known as Population II stars. The stars with no metal at all are called Population III stars. The evolution of the Population III stars is based on the assumptions that the stars are not rotating. The Population III stars whose initial masses belongs in the range $25M_\odot \leq M_* \leq 140M_\odot$ and $M_* \geq 260M_\odot$, ends their lives by collapsing into black holes with relatively little ejection of elements.

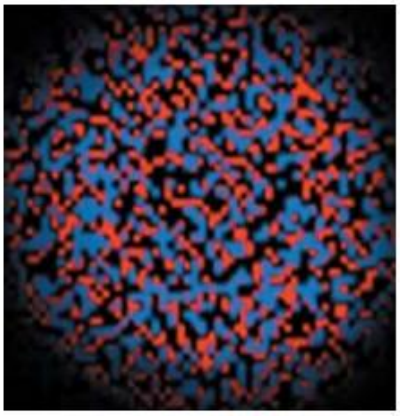
## Let There Be Light!

How relevant is the Jeans mass in determining typical stellar masses?

The primordial gas clouds contracts because of their gravity. The compression due to gravity increases the temperature of the gas above 1,000K.The density also starts increasing at the centre of the minihalo.Some hydrogen atoms would pair up in the dense, hot gas, creating trace amount of molecular hydrogen. By emitting infrared radiation,the densest parts of the gas start to cool after they collide with hydrogen atom.

Due to this the temperature drop to about 200-300K reducing the gas pressure and allowing them to gravitationally bound clumps. The cooling of the hydrogen allowed the matter to contract, whereas the dark matter remained dispersed. The hydrogen settled into a disk at the center of the protogalaxy.

The protogalaxies would have consisted mostly of dark matter, the elementary particles that consists of 90% of the universe's mass. Typically, ordinary matter concentrates in the galaxy's inner region and the dark matter remains scattered throughout an enormous outer halo. But in the protogalaxies, the ordinary matter would still have been mixed with the dark matter.



**PRIMEVAL TURMOIL**

**The process that led to the creation of the first stars was very different from present-day star formation. But the violent deaths of some of these stars paved the way for the emergence of the universe that we see today.**

**1** The first star-forming systems—small protogalaxies—consisted mostly of the elementary particles known as dark matter (*shown in red*). Ordinary matter—mainly hydrogen gas (*blue*)—was initially mixed with the dark matter.

The molecular gas cloud in which most stars currently form is much cooler than the first star-forming clumps. The minimum mass that a clump of gas must have to collapse under its gravity is called the Jeans mass, which is proportional to the square of the gas temperature and inversely proportional to the square root of the gas pressure.

Though the first star-forming systems would have had similar pressure to those of present-day molecular cloud but the temperatures of the first collapsing gas clumps were almost 30 times higher and also their Jeans mass would have been 1,000 times larger.

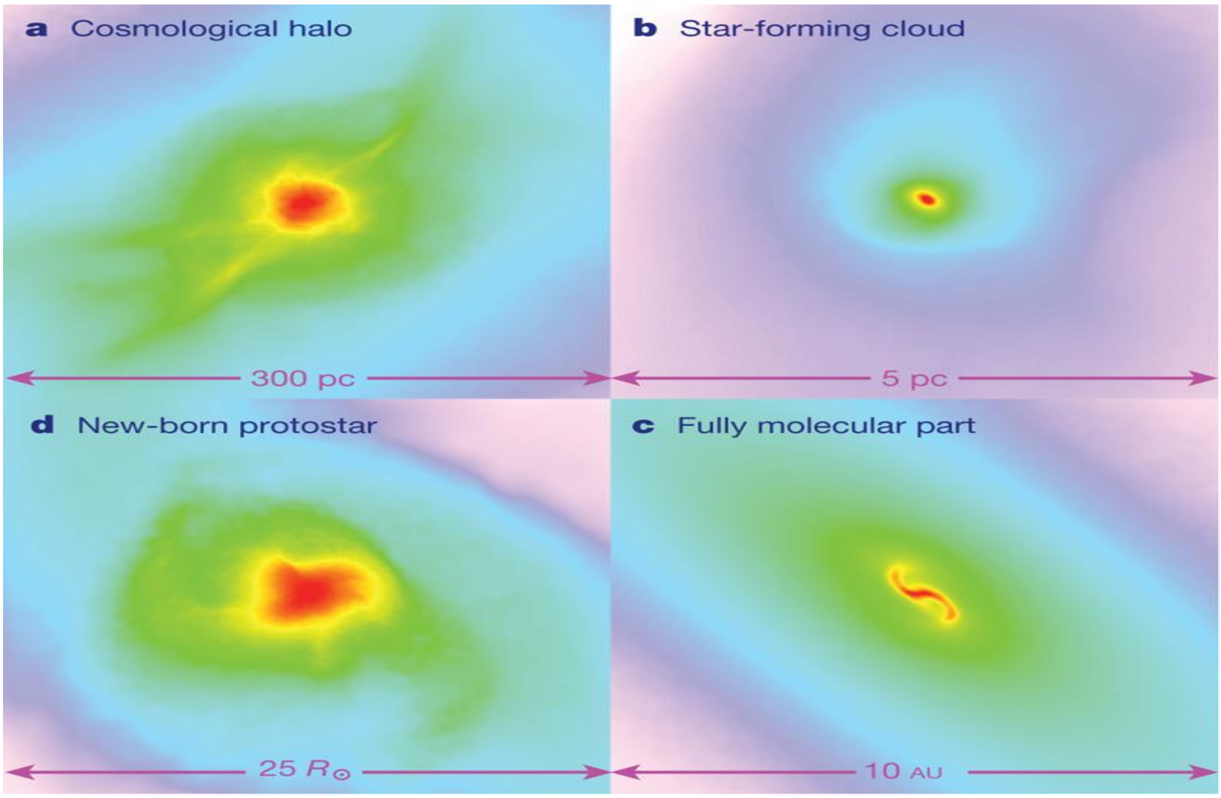
The first star-forming systems would have had pressures similar to those of present-day molecular clouds. But because the temperatures of the first collapsing gas clumps were almost 30 times higher, their Jeans mass would have been almost 1,000 times larger. One of the reason behind this is that molecular hydrogen cannot cool the gas below 200K. cannot cool makes a lower limit to the temperature of the first forming stars. Also at the higher densities when the clumps begin to collapse the cooling from molecular hydrogen becomes inefficient. The hydrogen molecules at higher densities collide with other atoms which increases the temperature and slows down contraction until clumps have built up to at least a few hundred solar mass.

What happened with the first collapsing clumps? Did they form the large masses stars or did they form many smaller stars due to fragmentation? The inefficiency of molecular hydrogen cooling keep Jeans mass high so fragmentation seems less likely to occur in the primordial clumps. Because of the feedback effects it's difficult to estimate how massive the first star might have been. There are some predictions that might be valid in different circumstances. For the very first star to form the masses might have had no longer less than 300 solar masses whereas the stars that formed from the collapse of larger protogalaxies might have had masses as high as 1000 solar masses. Because of the feedback effect the quantitative predictions are difficult. But these effects strongly depend on the presence of heavy element in the gas. Thus, the first stars in the universe were much more massive and luminous than the sun.

## Cosmic Renaissance

To counteract the gravity the star have to be more compact and hotter. And because of the compact structure, the surface layer of the star would also be hotter. Theoritical model showed that the star with masses 100 and 1,000 solar masses had surface temperature 100,000K which is about 17 times higher than the surface temperature of the sun. Thus the first starlight in the universe would have been mainly ultraviolate radiation which would have ionized the neutral hydrogen and helium gas soon after they formed. This event is known as cosmic renaissance.

The ionization energy of heliunm is higher than hydrogen but if the first star were as massive as predicted, they would have ionized helium at the same time. Also they would have had relatively short lifetimes- only a few million years. Some of the stars woould have exploded as supernova and much much more massive star would have formed black holes- through which light even couldn't escape. If the first stars were not so massive,the helium must have been ionized later by energetic radiation from sources such as quasars. The abundance of metals in star-forming clouds rises above one thousandth of the metal abundance in the sun, the metals rapidly cool the gas to the temperature of the cosmic background radiation. This efficient cooling allows the formation of stars with smaller masses and may also considerably boost the rate at which stars are born.




## Future Empirical Probes

If we put the timelines of the universe in a photo-album, the first image that we will find is the Cosmic Microwave Background that is an image of the universe when it first became transparent, 400,000 years before big bang. It was sufficient cold for all the free electrons to combine with protons make H atom and allow the universe to be transparent. And the next picture will be the images of galaxies. If we go little farther away and find the galaxies when the universe was a billion years old. But there is a gap in our understanding, there are some missing pages in the photo album. And the next decade will be dedicated to obtaining these missing pages of the photo-album of the universe. The instrument such as The James Webb Space Telescope - the planned successor of Hubble Space Telescope will perform number of observations and might detect some of those ancient bodies.

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