Zero Kelvin Big Bang, an Alternative Paradigm:

II. Bose-Einstein Condensation and the Primeval Atom

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Abstract

In the first paper in this series, we described the logic suggesting a "cosmic fabric", which served as the birthplace of our universe: a sparse distribution of spin-oriented hydrogen atoms at zero Kelvin, perhaps infinite and (almost) eternal. This second paper describes how a portion of this cosmic fabric could have condensed into a Bose-Einstein condensate (BEC). This cold ball of highly concentrated matter may be the "primeval atom", proposed by Georges Lemaître in 1931, as the starting point for our universe.

Keywords: Bose-Einstein Condensation, Zero Kelvin Big Bang, Atomic Hydrogen, Primeval Atom

Introduction

In the first paper in this series, we introduced an alternative paradigm for the history of the universe, the Zero Kelvin Big Bang (ZKBB), a rational and comprehensive alternative to the widely-accepted Standard Big Bang (SBB). The ZKBB model hypothesizes a pre-Big Bang "cosmic fabric" of spin-oriented hydrogen atoms at a temperature of zero Kelvin, and a density of , at most, only a few atoms per cubic meter of space. Thus, both matter and space existed prior to the Big Bang. In this second paper we will look at the transition which must have taken place to get from such a sparse matter distribution to a state of concentrated mass which was capable of supporting an explosive Big Bang event.

Bose-Einstein Condensation

Any Big Bang theory requires a starting point of unusually high density: high energy density in SBB, or high matter density in ZKBB. If one tentatively accepts the premise of the ZKBB theory, a Big Bang preceded by a state of extremely low matter density, then the question becomes, how does one get from that low density to a density high enough for a Big Bang to take place? How and why did diffuse atomic hydrogen at zero Kelvin transition into the "primeval atom", the entity proposed by Georges Lemaître as precursor to the universe? Here again we encounter the almost uncanny serendipity of Einstein's insights, and their close relationship to modern cosmology.

It was about seventy years ago that an obscure Indian physicist, Satyendra Nath Bose, sent a manuscript and letter to Albert Einstein asking him to translate Bose's paper into German, and help him to get it published in a leading German physics journal. As mentioned previously (Paper I), the manuscript concerned Bose statistics and the behavior of bosons. The paper predicted that at a low enough energy, photons of light (which are bosons) would all enter the same energy state and act as one. This phenomenon would later manifest itself as the laser. Einstein did as he was requested, but also added to the idea by suggesting that particles of matter might also do the same thing, if they were also bosons. There the matter stood for decades, a theoretical scientific oddity, since no one believed that a sufficiently low temperature could ever be achieved at which one might be able to test this hypothesis. However, as with many of Einstein's bizarre predictions, it was eventually tested and found to be correct.

It was not until 1995 that two groups of incredibly smart, persistent, and technically brilliant physicists were able to demonstrate this feat, creation of the first man-made Bose-Einstein condensates [1, 2]. This work was rightfully rewarded with Nobel Prizes for Eric Cornell, Carl Wieman, and Wolfgang Ketterle in 2001. For those not very familiar with Bose-Einstein condensation, a brief review is in order here.

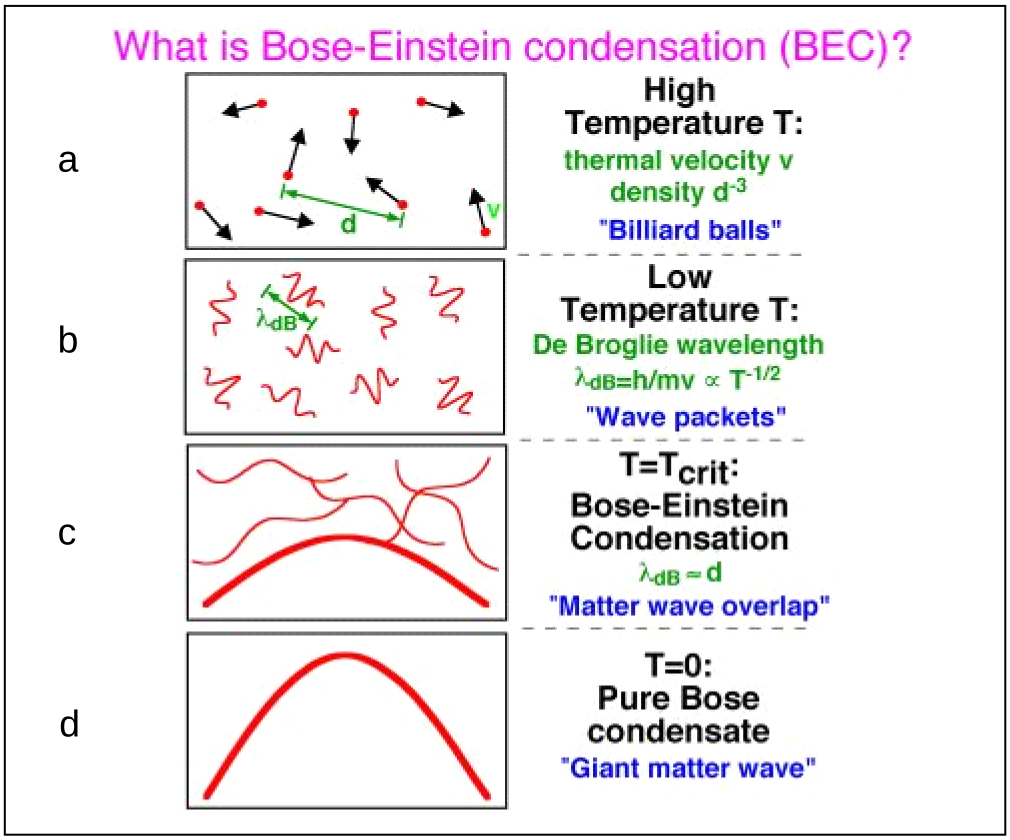

Figure 1: What is Bose-Einstein condensation (BEC)? *Reprinted by permission.* http://cua.mit.edu/ketterle_group/intro/what%20is%20BEC_150.jpg

One usually thinks of only things like light and electricity as having a wave-like property, but particles of matter do also. This property of matter-waves was predicted in 1924 by Louis de Broglie, the first scientist to receive a Nobel Prize (Physics 1929) for a Ph.D thesis. As shown in Figure 1, particles of matter have a certain wavelength, but at normal temperatures that wavelength is extremely small (Figure 1a); so much so that they appear as point particles. As temperature is decreased, and the energy of the particles decreases, their wavelength increases (Figure 1b). At a very low temperature, the wavelengths of individual particles begin to overlap (Figure 1c), until at a low enough temperature the waves overlap completely (Figure 1d). In this state the particles lose their individual identity, and act as if they were a single particle, with a single, very large matter wave; they become what is known as a Bose-Einstein condensate (BEC).

One can think of a BEC as the fifth state of matter. In our everyday lives we are all familiar with the three most common states: gas, liquid and solid. However, at the extremes of temperature there are two other states. At a high enough temperature, electrons can be stripped completely from atomic nuclei. The resulting mixture of atomic nuclei and free electrons is called plasma. We rarely see plasma directly, but we do see its effect in fluorescent lights, plasma TV screens, and the aurora borealis. The importance of plasma and its effect in the universe was heavily promoted by Nobel laureate Hannes Alfven. The cause of "The Plasma Universe" has more recently been championed by Eric Lerner and Anthony Peratt.

At the other end of the temperature scale, as matter approaches zero Kelvin or absolute zero, all of the particles enter their lowest energy state, the ground state. If the particles have certain properties e.g. bosons or fermion pairs, they all act as one and condense into a dense BEC.

Bose-Einstein Condensate of Atomic Hydrogen

It was while reading about BECs that I encountered my second "Eureka" moment, when I read that a group at MIT headed by Thomas J. Greytak and Daniel Kleppner had succeeded in forming a BEC of atomic hydrogen, after a twenty year quest [3,4]. Even though, according to theory, hydrogen should have been one of the easiest atoms to condense, in practice it turned out to be one of the most difficult. The reason for the problem was the spin of hydrogen's electron, as described earlier in Paper I. Hydrogen atoms with opposite electron spins react very rapidly, releasing energy, while forming molecular hydrogen, H_2. This energy causes other hydrogen electrons to "spin-flip", accelerating the process, almost like a chain reaction. This made it almost impossible to maintain the extremely low temperatures necessary to facilitate condensation.

Due to technical difficulties, Greytack and Kleppner et.al. were only able to form a BEC with the doubly polarized, "d" (up-up) form of atomic hydrogen (see Figure 3, Paper I), but it was a BEC of hydrogen nonetheless. If my speculation is correct, a cosmic fabric consisting exclusively of atomic hydrogen "a", at its lowest energy (proton and electron spins anti-parallel), and possibly mutually repulsive, could only have existed prior to the Big Bang, at zero Kelvin when there was zero energy. The electron spin-flip of atomic hydrogen requires only 5.9×10^{-6} eV of energy (equivalent to 0.07 degrees K), but at zero Kelvin even this miniscule amount of energy is lacking. Based on Greytack and Kleppner's work it may be technically impossible to replicate the conditions prior to the Big Bang in our energetic universe, because zero Kelvin is theoretically unattainable, and we always have to start with a mixture of spin states.

Cosmic Fabric to BEC

If a BEC forming somewhere within the cosmic fabric is theoretically possible, how might it have happened? One possibility is a quantum event or fluctuation, as claimed for the appearance of the entire universe in SBB theory. At a density of, at most, only a few atoms per cubic meter of space, with atoms possessing only zero point energy, the chance of two atoms even encountering each other is essentially zero; it could never happen. However, one must remember that in quantum theory there is never a “never”, especially during eternity. The fact that there is, as far as we know, only a single universe, might attest to the incredibly low probability of whatever events happened prior to the Big Bang.

Figure 2 shows a representation of the original cosmic fabric, with hydrogen atoms at equilibrium and distributed uniformly throughout space.

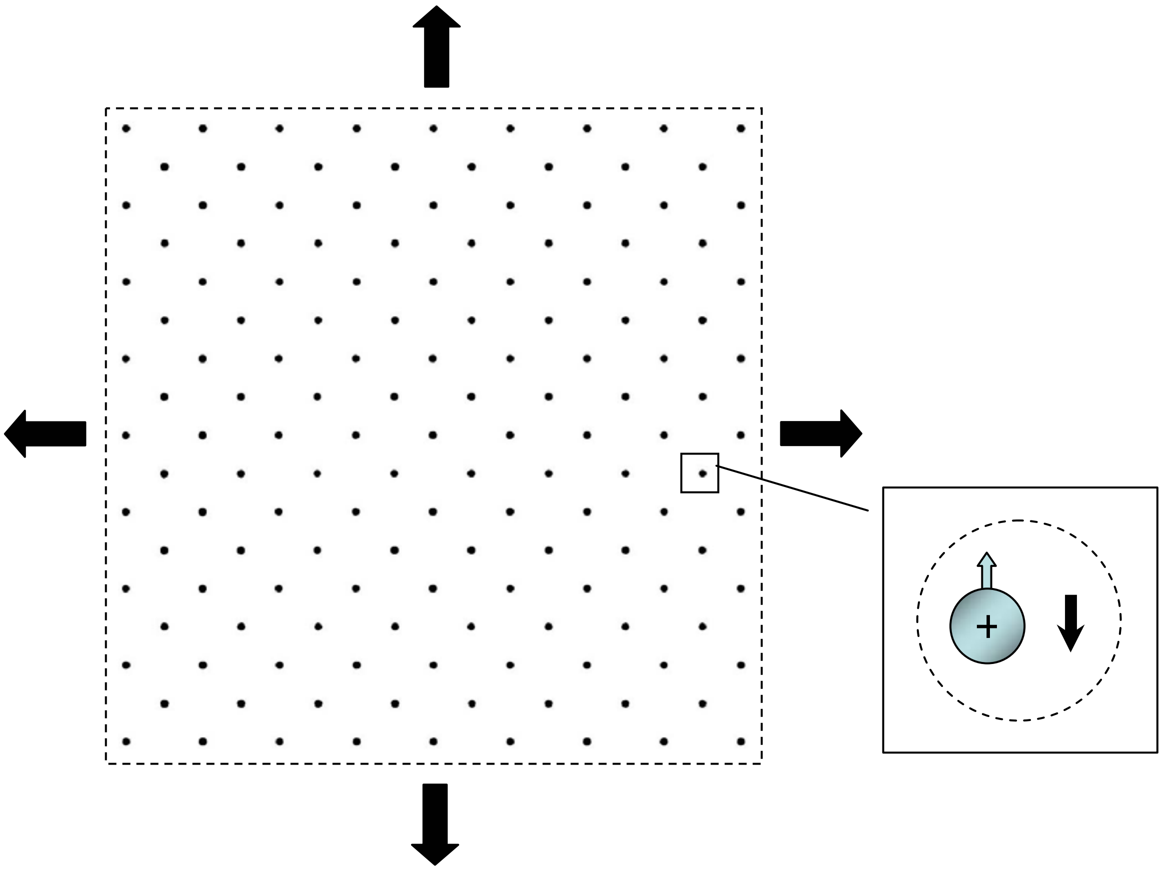

Figure 2: The Cosmic Fabric. Singlet state hydrogen atoms, the lowest energy state (proton and electron anti-parallel), at equilibrium.

If two hydrogen atoms did manage to overlap, that would have created an infinitesimally small gravitational dimple in space, towards which other hydrogen atoms might move. This could have been the first gravity, the first directional motion of matter in space, and the beginning of time. The theory behind Bose-Einstein condensation shows that it is a self-reinforcing process; bosons are very gregarious, and as more atoms participate in the BEC, the chance of other atoms joining in is dramatically increased. So it is like a snowball effect, with the BEC growing larger and faster with time. If this did occur, the growing BEC would suck in hydrogen atoms from farther and farther out. Concomitantly, a larger volume of the cosmic fabric would become depleted of hydrogen atoms, creating what I call a “matter-depletion zone”, around the growing BEC. This process is represented in Figure 3.

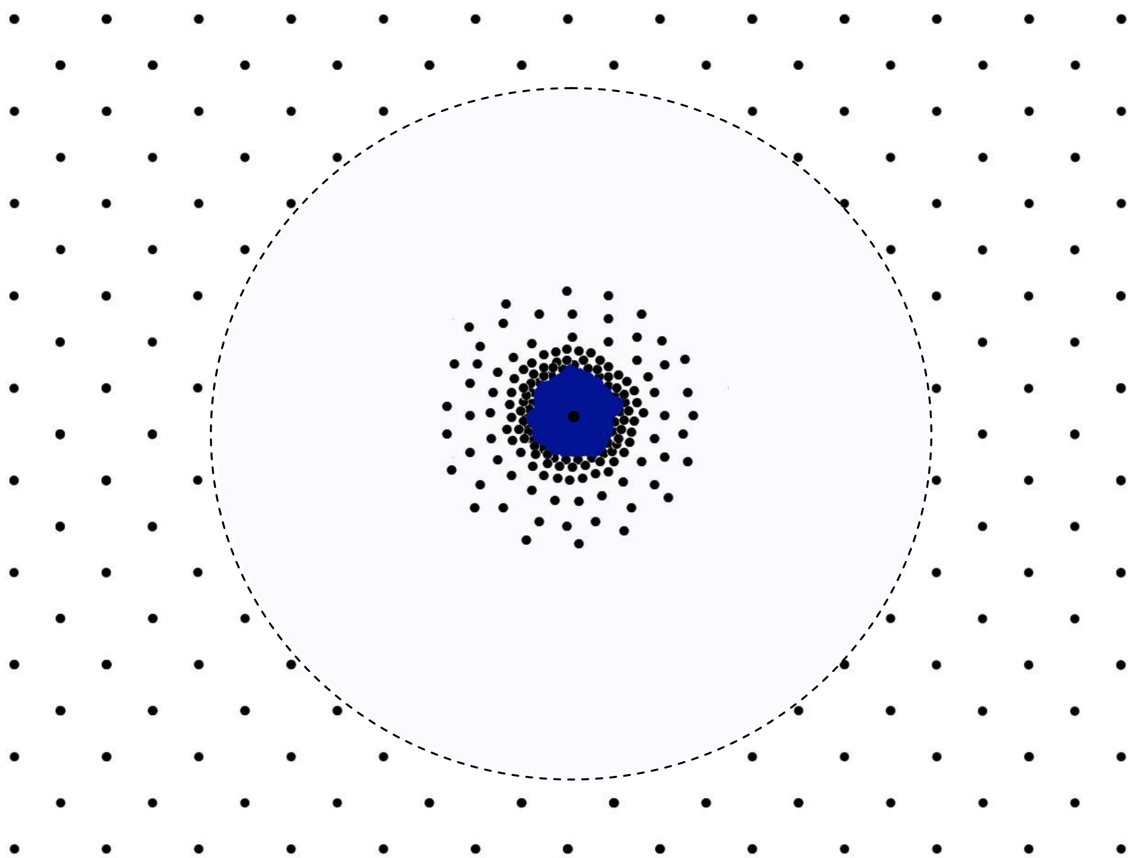

Figure 3: Bose-Einstein condensate (BEC) formation, creating surrounding matter-depletion zone.

Three questions might arise here:

Q. If the hydrogen atoms were mutually repulsive, how or why would they aggregate?

A. Laboratory studies of BECs have shown that even atoms which are mutually repulsive can, and will, form BECs. In fact, it is only mutually repulsive atoms which can form very large, stable BECs.

Q. An even more serious question is: if the system was already at zero entropy, as claimed, would not the formation of a BEC (a phase change) imply a decrease in entropy, and therefore perhaps negative entropy?

A. The key here is that, theoretically, any reaction at zero Kelvin involves no change in entropy, because any reaction at zero K is completely reversible. So, even though it seems like entropy should decrease, it does not.

Q. A third question might be: why didn't the pressure of the concentrated atomic hydrogen gas cause it to re-expand?

A. At zero Kelvin a gas has zero pressure, so that concentrating a gas with zero pressure results in concentrated gas, still with zero pressure; there was no impetus for the growing primeval atom to re-expand. That is until energy was released in the Big Bang event.

Primeval Atom as Bose-Einstein Condensate (BEC)

At first I had difficulty in imagining what a BEC actually was, and then I found out that even physicists studying them had the same problem. As stated above, one way of looking at it is that, as their energy is decreased by cooling, the wavelengths of elementary particles become so long that their wavelengths eventually superimpose, and they all act as one single wave (Figure 1). Another way that I have visualized it may not be technically correct but it works for me, so here it is as applied to atomic hydrogen.

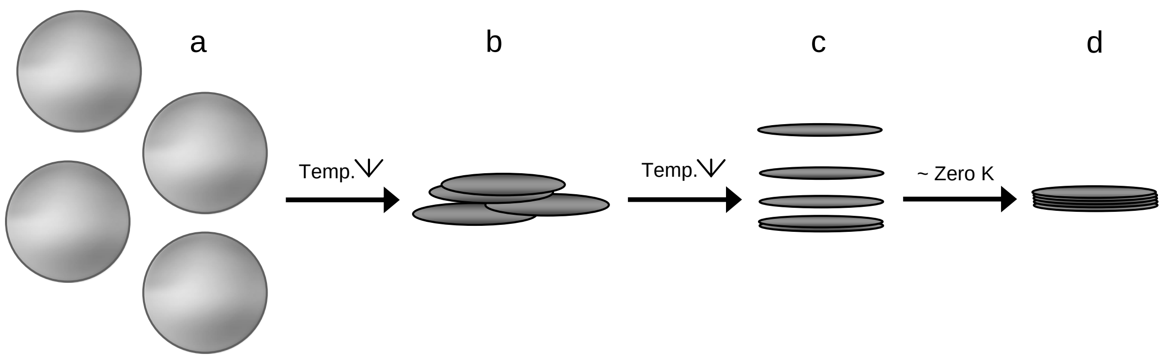

Figure 4: (a) Spin-oriented hydrogen atoms in ground state. (b) atom waves begin to overlap. (c) atom waves completely superimpose. (d) Bose-Einstein condensate, all atoms occupy same phase space.

Imagine that each hydrogen atom is a big fuzzy ball with a tiny speck of dust in the center. The dust speck represents the proton of the nucleus, and the fuzzy ball represents the probability of the electron's position. One can see here the similarity to the 1s shell in atomic physics. When the atom is cooled down to a sufficiently low energy, the electron effectively stops. This I visualize as the electron probability function losing one dimension, and going from three dimensions (fuzzy ball) to two dimensions (an infinitely thin disk). Now voluminous balls cannot pack very tightly, but if reduced to disks, they can pack themselves on top of each other very tightly. In physics parlance, the atoms all occupy the same phase space, and behave as if they were a single atom. One can now perhaps imagine how almost the entire mass of the universe, as spin-oriented hydrogen, could realistically be compressed into a super-dense entity, an actual primeval atom.

Vital Statistics

Then the question becomes: is it possible to estimate the density and size of this entity? At one extreme, the density of the whole could theoretically approach the density of an atomic nucleus; this is not the "infinite" density of the singularity as in SBB theory, but is extremely dense nonetheless. Based on the density of the proton, this would be about 230,000,000,000,000 grams per cubic centimeter, where the density of water is 1. Based on an estimate of 1 x 10^{80} atoms in the universe, this would make the primeval atom smaller than the solar system, equal to a sphere out to about halfway between Jupiter and Saturn.

At the other extreme, some physicists have estimated a pre-Big Bang density of not much greater than that of water, 1 gram per cubic centimeter. This would translate into a sphere encompassing from the sun out to the nearest star, Alpha Centauri.

I suspected that it was probably somewhere between these extremes. Using a somewhat unconventional approach, I used logic and actual data from a Bose-Einstein condensate to take a stab at estimating a density and size. Dr. Lene Vestergaard Hau at Harvard found that light was slowed down to 17 meters per second (m/s) in a BEC of sodium atoms, versus 299,792,458 m/s in a vacuum [5]. Since refractive index (RI) is the light speed in a vacuum divided by light speed in the medium, this equates to an effective RI of 17,634,850. Differences in the RI of similar states is proportional to atomic weight, so one might expect the RI of the lighter hydrogen atom BEC to be lower than that of sodium (atomic weight 23). I estimated the RI of a hydrogen BEC to be about 1,322,614. If one uses water as a reference (1 g/cc has a RI of 1.3334), this RI for hydrogen would equate to a density of 991,911 g/cc, or about 1 million g/cc. This translates into a sphere about 57 times as big as our solar system.

Whatever the actual density, a super-dense state of atomic hydrogen BEC would then set the stage for a Big Bang explosion. In the third paper of this series, we will look at the Big Bang explosion itself; how it might have been initiated, how it propagated, its approximate temperature, and its impact on the BEC.

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