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Reliving the Big Bang

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Abstract- Just a few moments after the Big bang, the universe might have found itself in an undiscovered state, today known as Quark-Gluon Plasma(QGP). Quantum Chromo Dynamics and theory of strong interactions predicts a transition of the strongly interacting matter to Quark- Gluon Plasma at high densities and/or temperatures. Several laboratories such as CERN, Geneva can re-create the environment for such transitions to occur. This review article aims to understand Quark-Gluon Plasma, its importance and methods of creating and studying it in a laboratory. We would need new theoretical tools to measure the strength of such interactions. QCD on a space-time lattice is the most reliable tool available to us. Both, the properties of QGP phase and lattice QCD can be predicted using supercomputers. Similar techniques also help in predicting a QCD critical point which experiments have begun actively to look for.

Keywords:- Scissor Jack, Kerb weight, loading, and lead screw etc.

I. INTRODUCTION

1. What is the Big Bang?

All ancient civilizations have gone to great lengths to search for the origin of the universe, which we call home. Several challenging questions such as what are we made of? What does the universe consist of? How did the universe, if it ever, came into existence?

Although almost all civilizations have individually and independently tried answering such questions none has succeeded to satisfy the hungry minds. It was only after superhuman efforts of giants like Galileo and Kepler and the lying of mathematical and theoretical foundations by Newton, Tyco Brahe etc., that modern science gradually began dominating our perspective and understanding about the universe around us.

Truly, as Einstein once remarked," what is incomprehensible is that our universe is so comprehensible to us at all". We, today, are well aware of atoms and molecules as the building block of all that we see around us, including ourselves.

Similarly, we now know the exact reasons why we enjoy different seasons and how the earth revolves around the sun. The constant pressing desire of observing the world around us has played a critical role in building up these concepts. On one side was a telescope that empowered Galileo to marvel through the distant corners of the Milky way while on the other hand, microscopes give us a vision of the otherwise invisible world. And today, with the advanced version of the above two devices, we can delve deeper and further into microscopic and macroscopic worlds. Thus, now it's a well-accepted fact that the sun is just one of the millions of stars that form our milky way galaxy.

The visible universe and beyond contains innumerable stars and other celestial objects. Although it might seem, at first look, an impossible task to measure the dimensions of this seemingly infinite space, one feasible way of measuring it in terms of distance covered by light in one year which comes to be around 5.6*10^13 km, also known as 'Light-Year'.

On similar lines, one 'Light-second' is the distance travelled by light in one second which comes out to be around 3,00,000 Km, and by this definition, our earth is around .043 Light-seconds in dimension. Similarly, one light-minute is the distance covered by light in one minute, and the Sun in this unit is around 8.3 light minutes away from us.

It will take 100,000 years to cross our milky-way galaxy, which proves that the diameter of our universe is around 160 billion light- years. In the same dimension, our entire universe is around 160 billion light-years in dimension.

But, despite its unbelievable size, we claim to be well-aware of most of its properties and functionalities, while the truth remains the fact that the majority of properties of this universe still is well-beyond our mental and technological capacities. But, we hope to know more and more of them as human intelligence and technology develops.

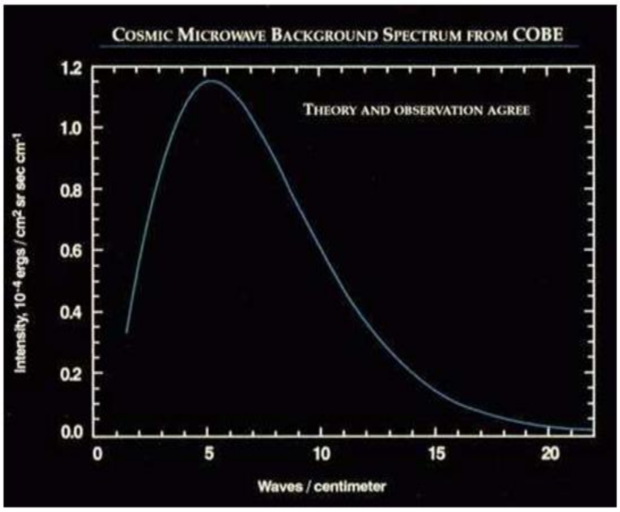

Fig 1. COBE measurement (2) of the cosmic microwave background radiation.

Today, we will try discussing one of the many aspects of the history of the universe which could be re-created in a laboratory environment. On observing stellar objects, Edwin Hubble concluded of the following law: Distant universes move away from us at a rate proportional to their distance. This law leads to a natural conclusion of our universe being much more dense in the past than its current state. We know from the arguments of The Big Bang Theory that the universe began with a giant, hot and violent explosion which cooled up and expanded on gradually (1). These two arguments strongly support others' validity.

The most confident and valid proof to support the above-presented argument by Hubble has been made available by very precise measurements of the CBMR data [Fig. (1)]. Despite several error bars on observed data, it clearly resembles the spectrum emitted from a black body.

In Fact, this is the most perfectly observed blackbody spectrum ever. Due to its perfection, we can measure the extremely low temperature of our universe to great precision.(2)

The temperature thus measured is of the epoch of the universe at which the electromagnetic radiation decoupled the matter: T= 300 degK, red-shifted due to the expansion of our universe to T= 2.727 degK. Astronomers, by using fluctuations in the background radiation from the WMAP satellite experiment, have constructed the earliest picture of the universe around 380,000 years of its age.

Universe was much hotter at earlier times due to the explosive expansion. If we understand the dynamics of nature’s laws at high temperatures or of those early times, then we will be able to glance into even earlier times in the history of the universe.

It's confirmed by observations hwo universe behaved in its first three minutes, but the new landmark in Physics would be 10-20 secs or more as we move closer and closer to Big Bang, when protons and neutrons came into existence from a hitherto unobserved and unknown state of Quark-Gluon plasma.[3]this introductory review aims of explaining Quark-Gluon plasma, its importance and methods of creating and studying it in laboratory.

2. Why re-create the Big-Bang?

Around a century ago, only known interactions were electricity and Gravity and particles were electrons and atoms. Starting from the Rutherford model of atoms and it’s further sophisticated versions explained in detail to us about the nature of the fundamental block of the Universe.

We now know that the number of electrons and protons decide the nature and property of material such as conductors and insulators.The nucleus itself contains newtons, protons and pions. And, in turn, these sub-nuclear particles are made of even tinier quarks and gluons. Quarks and leptons are today accepted as the fundamental particles which make up the entire universe.

Protons and Neutrons make up the nuclei, while they themselves are made up of Quarks. Proton (Neutron) consists of two u(d) quarks and one d(u) quark while a pion, regarded as the key behind the nuclear force, is made of a u-quark and d-antiquark.

As technology advanced, strong and weak nuclear forces also got added to the list of forces. A variety of vector bosons act as the carriers of these forces. The strengths of these forces are substantially different. As technology advanced, strong and weak nuclear forces also got added to the list of forces. A variety of vector bosons act as the carriers of these forces. The strengths of these forces are substantially different.

The electromagnetic force, although stronger than weak nuclear forces, are weaker than strong nuclear forces by the magnitude of two, which are in turn is responsible for holding quarks together as sub-nucleic particles namely protons and neutrons. The W and Z-bosons are responsible for weak-nuclear forces while vector particles such as massless gluons do the task of strong interaction among particles.

The weak nuclear forces played a major role in shaping the fate of our universe a few moments after the big bang, other fundamental forces of nature were prominant at the instant of the big bang and just after it. we, due to several limitations, aren't yet able to study and predict must about those early instants of the universe. But, as a ray of hope, we now have the experimental setup needed to produce particles that appeared just after the big bang.

We have been successful in studying their nature closely for some time recently, by studying these particles, we can to a great precision know about the nature, behaviour and structure of our universe in those early moments. We also have suffiv=ceinet information about strong nuclear force, and its computation method, which will, in turn, help us derive the nature of particles at that time.

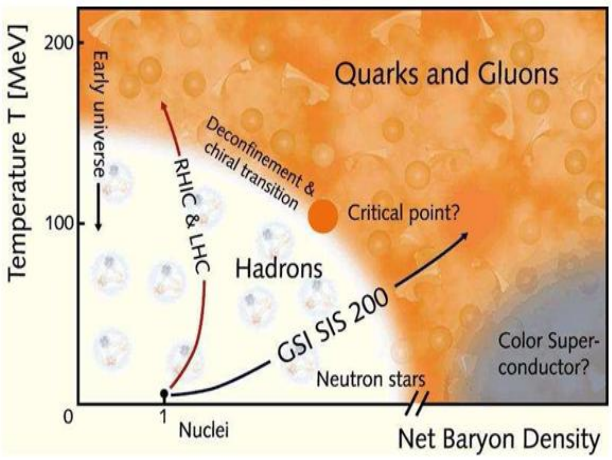

Fig 2. Expected QCD phase diagram.

II. PHASE DIAGRAM OF STRONG MATTER

1. Some results:

Quantum Chromo Dynamics (QCD) is the (gauge) theory of (strong) interactions of quarks and gluons. The strength of this force as well as its complexity leads to a much richer structure: Quarks are permanently confined to hadrons like proton and neutrons; a dynamical symmetry breaking ensures that the quarks become massive due to interactions although free quarks are rather light etc. These and many more such properties need to be obtained from QCD. It was only possible after around half a century, using lattice field theory techniques, that we could find the mass and structure of protons and neutrons.

As is shown in figure 2, these similar lattice techniques, and some other methods that we estimate the nature of matter at high temperatures and densities. One such newly discovered phase is quark-gluon plasma. It is also expected to be produced in relativistic heavy-ion collisions as is also discussed in further sections.

The experimental confirmation of these tests will test the estimations of the theory of strong interaction QCD in a completely new scenario. Also, as it is well known that such high temperatures were existent in the early moments of our universe, these collisions will empower us to study those times. Like the high densities present in very dense cosmic bodies like stars, we can see the manifestation of the novel phase of colour conductivity. Now, it is to be noted that whether or not this would have any significant consequences is a matter of active research.

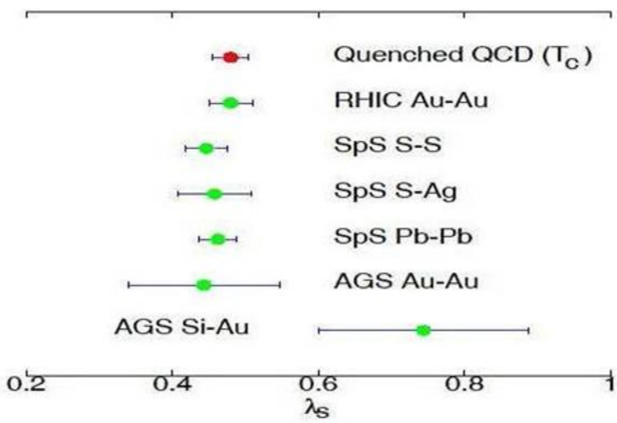

Fig 3. Experimental results for the excess strangeness produces in the nucleus-nucleus collisions compared to lattice QCD outcomes.

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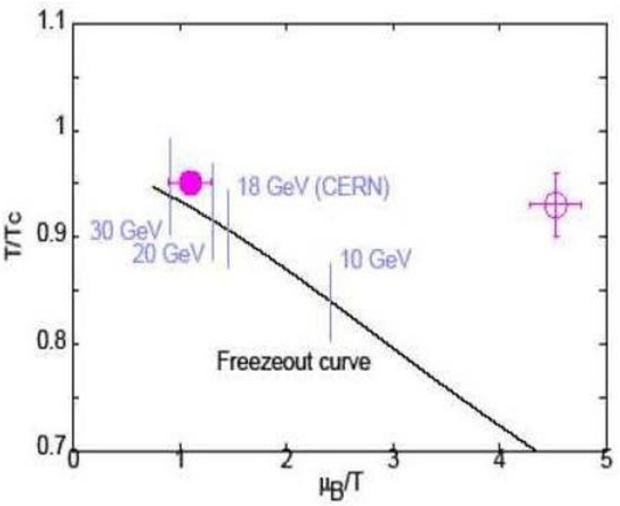

Fig 4. QCD critical point determination from two computations with different spatial volumes.

Using the newly found lattice-technique method, we can now confidently predict that usual nuclear matter such as neutrons, protons, pions etc. at temperatures around 2 trillion degrees Kelvin, undergo a transition to Quark-Gluon plasma phase.

Using the Wroblewski parameter has also resulted in the equation of state along with many other properties. It is a measure of the production of strange quark-antiquark pairs. For the theoretical new state estimates, experiments agree on the observations. Using the method, several other correlations have been predicted for heavy-ion physics.

Several theoretical physicists have tried to search for the critical point in the artistic sketch. They were located at lower densities than expected. If RHIC is run at 20-40 GeV of lower colliding energy, then it can potentially discover it. There exists one more challenge to this. The collision exists for a negligible time, and it is almost impossible to look for any leftovers of the QCD critical point in their end products.

The fundamental concept for finding QCD critical points is the same as that for what we find in liquid-gas phase diagrams, but here we will discuss in detail only the experimental aspect of the collisions. Any physical quantity displays physical fluctuations.

In reality, we have to perform several experiments at very low temperatures to minimize these thermal fluctuations. And when phase transitions or critical points come into the picture, the fluctuations become infinitely large. One, therefore, tries to find a critical point due to these extreme observations.

We have an available record of those predictions from such fluctuations made by lattice techniques. It will be interesting to analyse them with respect to the experimental data coming from RHIC and look for QCD critical point

III. HEAVY ION COLLISIONS

Now, we will be dealing with the question as to where one would be getting these new phases and how they can be produced in a laboratory. As we have already discussed in the beginning, our universe was full of QGP until around 30 secs after the big bang. However, we can best study Quark-Gluon plasma by recreating that instant of our history in laboratory conditions. The setup that we necessarily need for the setup are large system size, high energy density and production of many particles.

We need particles colliding at 99.5%-99.995% of that of the speed of light, which is currently only possible at CERN and BNL, New York. The entire systematic steps of this are explained in Fig(5). In a very small duration of almost an instant, the fireball of Quark-

Gluon plasma gets condensed into hadrons. We can carry the task of looking for a new phase QGP by observing the similarity of the cooling of the QGP fireball produced in heavy-ion collisions with the early universe as is shown on the right side of Fig(5).

One such method of achieving this is jet quenching. It is clearly known to scientists that when quark and gluons are scattered at high energy in the colliding hadrons, it produces jets of particles. Such jets have been vividly studied under the same particle or antiparticle collision. If we make QGP interact with such a jet, it will cause energy loss due to multiple scatterings. Due to momentum conservation, such jets emerge, again and again, and we would be able to observe only one of them with the other missing due to QGP. We have very extensive observations about such jet quenching.

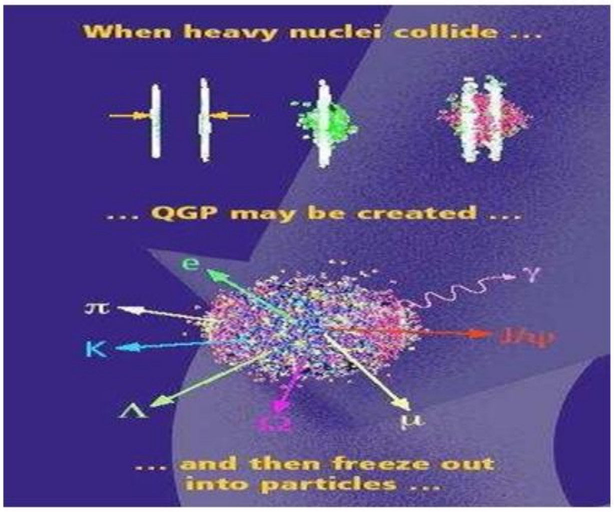

Fig 5. Pictorial presentation of heavy ion collisions explaining plasma formation and evaporation.

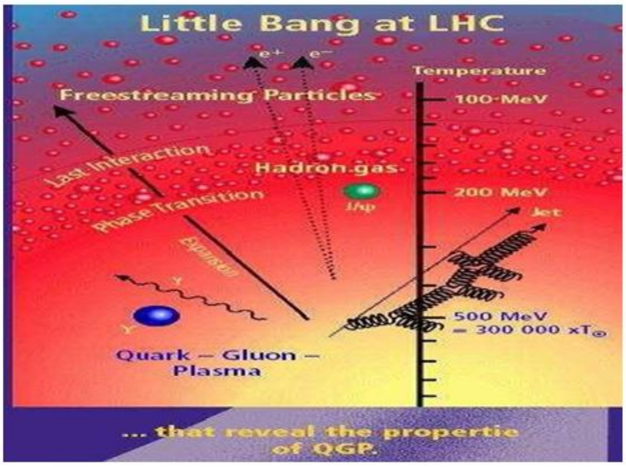

Fig 6. Pictorial representation of possible signatures of plasma.

While looking for flow in the horizontal direction, we have found additional evidence for QGp, which concludes that QGP behaves like a non-viscous ideal liquid. Using techniques like characteristics of plasma, debye screening etc. we can stop quarks from binding into hadrons. Anomalous suppression of heavy particles has shown that in the aftermath of heavy ions collisions, Debye scattering may have been present. Thus, we have strong and significant signs of new phase QGD having been produced in these collisions.

IV. SUMMARY

We have been able to predict the properties of Quark-Gluon plasma and new states of strongly interacting matter using Lattice QGP. The achieved results are coherent with the chances of QGP formation in experiments.

We have found out that QGP has quark-like excitations due to co-relations in quantum numbers. This fact has been well-confirmed by experiments in CERN and BNL, New York. Mork excitement and expectations are on the way due to the upcoming LHC in CERN, geneva.

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