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Holographic Cosmology and Experimental Observations from MoEDAL and LIGO Detections

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Abstract – One of the theoretical models for finding the beginning of Universe is based on Holographic Cosmology which presents a scenario of dense sea of black holes from which the observable universe would have originated. Proposed by Thomas Banks and Willy Fischer, this model needs further experimental evidence. This paper presents the cosmological model and some of the experimental observations of Monopole and Exotics Detector at the LHC (MoEDAL) collaboration and Laser Interferometer Gravitational Wave Observatory (LIGO) and Virgo collaboration with reference to the model.

Keywords: Holographic Principle, Big Bang Scenario, Inflation, Monopoles, Cosmic Microwave Background, Binary Black holes, Gravitational Waves.

I. INTRODUCTION

Thomas Banks of University of California, Santa Cruz and Willy Fischer of the University of Texas at Austin proposed a model to conclude that the Universe in its earliest moments i.e. when less than 10-35 seconds old, was a dense sea of black holes. The idea is based on the holographic principle, which says the entropy in a given volume is limited by its surface area and maximised in the case of a black hole, proposed in 1993 by Gerard't Hooft of Utrecht University in the Netherlands and developed by Leonard Susskind of Stanford University in California.

In order to explain the birth of the universe in low entropy state astrophysicists have taken the help of the second law of thermodynamics [4]. Considering the second law of thermodynamics, the entropy of the universe – a measure of its disorder – increases with time. So the universe should have begun in the most orderly state and has been getting messier since then. But the observable universe suggests that the universe would have been more chaotic and disordered. Banks and Fischer's model present an answer to this low entropy problem while explaining the sea of black holes scenario.

II. THE COSMOLOGICAL MODEL

Banks and Fischer's cosmological model says that the universe began as a black hole fluid, with maximum entropy or disorder. Our observable universe then emerged as a low-entropy bubble of ordinary space that underwent the conventional model of inflation. The conventional model of inflation as proposed by Alan Guth of MIT along with others explains that the expansion of early universe happened exponentially from a patch that was extremely small to start with.

In the initial condition of the black hole fluid was said to be in a stable state consisting of a homogeneous gas with equation of the state as $p = \rho$ which saturates the entropy bound. Apart from the quantum and statistical fluctuations the $p = \rho$ state is stable. The black holes would fill the space around with a fluctuation towards lower density as per the principle of quantum mechanics. This fluctuation towards lower density would mean that in the region the black hole does not fill the volume there would be space filled with radiation. This creates the conditions for our observable universe to come into existence [1] [2].

After some time the universe consists of large $p = \rho/3$ regions with larger primordial black holes and smaller primordial black holes caught in the interstices between the large regions. While the larger black holes merge to form single horizon sized black holes the smaller black holes decay rapidly via hawking radiation and evolve as $p = 0$ gas and thus produce small radiation dominated regions. These regions grow in physical volume more rapidly than the $p = \rho$ background. The universe in this phase is described by a non relativistic gas of large black holes. The $p = \rho$ phase was of dense black hole fluid and the $p = \rho/3$ phase is of dilute black hole gas [1] [2].

The large black holes which comprise of the non relativistic gas are unstable to decay and dominate the energy density until the time they decay after which universe becomes radiation dominated further increasing the dilute black hole gas regions. The dilute black hole gas regions give rise to conditions for formation of conventional matter in these regions while radiation causes expansion of space in these regions. The expansion of space causes the black holes to move further apart and decrease the possibility for their mergers [1] [2].

Holographic cosmological model thus explains the low entropy of early universe saying that many bubbles of ordinary space could have emerged from black hole fluid with low entropy because higher entropy corresponds to faster moving black holes that are prone to colliding and merging. If the black holes in the region where ordinary space opens up are densely packed and moving fast, their collisions and mergers make them grow until they fill the space. But if the black holes are far enough apart and moving slowly, mergers won't happen fast enough and the space between the black holes filled with hot radiation would quickly expand, pushing the black holes further apart [4].

While space is expanding, the conventional matter is forming in these radiation regions of dilute black hole gas regions. The fluctuations in the distribution of matter in these regions are quantum fluctuations that convert into classical matter density fluctuations. The initial density of dilute black hole gas regions is small and the fluctuations of this distribution around its average are even smaller causing the dense black hole fluid to persist for a considerable time. The fluctuations in the distribution of matter in the dense $p = \rho/3$ regions are the fluctuations in the distribution of the larger black holes and can be determined at very large scales by the quantum fluctuations in the original distribution of $p = \rho/3$ regions. Once these quantum fluctuations convert to classical matter density fluctuations the scale invariance will persist and will show up in the Cosmic Microwave spectrum [1] [2] [3] [4].

Since the dense black hole fluid persists for longer time when the black holes are growing via mergers forming large black holes in the $p = \rho/3$ regions they become quite massive by the time the universe becomes matter dominated and also develop a very large charge. The magnetically charged black holes will remain as remnants and will evolve into massive magnetic black holes with huge charge which can be called as black monopoles. The decay of both charged and neutral black holes via Hawking radiation produces a large number of photons per monopole.

In this scenario relic density of monopoles would have been produced and the relic black monopoles are exotic and have extremely large charge [1] [2].

This model does not refer to big bang explosion. So how did big bang explosion happen?

III. BIG BANG SCENARIO AND THE INFLATION THEORY

As per the explanation of the cosmological model the Big Bang can be thought of as the simultaneous appearance of many bubbles of ordinary space everywhere in the universe and not as an exposition at a point of time. After 10-35 seconds after the beginning of time, this ordinary space joins up with the conventional picture of universe in which the inflation expands our universe exponentially. This Cosmic Inflation theory was developed by Alan Guth, Andrei Linde, Paul Steinhardt, and Andy Albrecht.

Big Bang cosmology predicts that a very large number of magnetic monopoles should have been produced in the early universe. Inflation theory reasons that these magnetic monopoles exist if they were produced before the period of cosmic inflation since during inflation, the density of monopoles drops exponentially, so their numbers drop to undetectable levels.

IV. EXPERIMENTAL TESTS FOR HOLOGRAPHIC COSMOLOGICAL MODEL

The largest black holes from holographic cosmology, might survive to the present day as magnetic monopoles. Astrophysicists believe that these monopoles produced in the early universe would have been sucked into these relic black holes. So it is expected that some black holes would retain their contents and might still exist but their small size suggests it is difficult to detect them. To search these particles MoEDAL collaboration is conducting experiments at the CERN laboratory near Geneva, Switzerland.

Another way to detect these black holes is by detecting the gravitational waves generated during inflation from collisions of clumps of matter. Some of these waves are expected to be detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors or by the imprint they would leave on the cosmic microwave background [6][7].

Cosmic microwave temperature fluctuations are expected to trace fluctuations in the density of matter in the early universe, as they were imprinted shortly after the Big Bang [1][2].

V. EXPERIMENTAL OBSERVATIONS

Quantum Physics Experiments

In 2010 the Large Hardon Collider (LHC) approved the Monopole and Exotics Detector at the LHC (MoEDAL) experiment. The prime motivation of MoEDAL is to search directly for the magnetic monopole – a hypothetical particle with a magnetic charge [5].

The MoEDAL collaboration has built a detector to search for this particle which is an array of 400 modules, each consisting of a stack of 10 sheets of plastic nuclear-track detectors. If magnetic monopoles do exist, they could be formed in collisions in the LHC. These monopoles would rip through the MoEDAL detector, breaking long-chain molecules in the plastic nuclear-track detectors and creating a minute trail of damage through all 10 sheets. A clear indication of the path of a monopole would be an aligned set of holes with the trajectory pointing back to the collision point [5].

Gravitational Wave discovery

The prediction of Einstein's theory was that everything came out of a single event – the big bang singularity. The early universe was opaque to light it is transparent to gravitational waves. So, by gathering gravitational waves it is expected to find out exactly what happened at the initial singularity.

On 14 September 2015, scientists from Laser Interferometer Gravitational Wave Observatory (LIGO) and Virgo collaboration detected the gravitational waves using an instrument so sensitive that it could detect a change in the distance between the solar system and the nearest star four light years away to the thickness of a human hair. The phenomenon detected was the collision of two black holes the scientists listened for 20 thousandths of a second as the two giant black holes one 36 times the mass of the sun and the other 29 times the mass of the sun, circled around each other. The event took place 1.3 billion years ago. The merger produced a black hole with mass 62 times the mass of the sun that spins at the rate of 67% of the maximum possible spin of the black holes. About 3 times the mass of sun was converted into gravitational waves in a fraction of a second with a peak power output about 50 times that of the whole visible universe [6].

On 26 December 2015, another collision of two black holes was detected. The black holes of masses 14 and 8 times the mass of sun merged into a more massive, rapidly rotating black hole 21 times the mass of sun. The event happened 1.4 billion years ago. About approximately the mass of sun was radiated as gravitational waves in a fraction of a second [7].

The cosmological Gravitational Wave background is expected to be produced by processes in the very early Universe during the period of inflation and the observation of this background can provide a picture of the Universe very shortly after the big bang.

However the expected strength of the Gravitational Wave background from inflation is too low to detect by the ground based detectors but these detectors can put interesting upper limits on the strength of other sources of Cosmic Gravitational Wave backgrounds arising in high-energy physics scenarios [6][7].

VI. CONCLUSION

This research paper presents the Holographic cosmology model of origin of universe and relates the model with the recent experimental observations from Monopole and Exotics Detector at the LHC (MoEDAL) collaboration and Laser Interferometer Gravitational Wave Observatory (LIGO) and Virgo collaboration which are intended to test the model for experimental validity. Magnetic monopoles are yet to be detected and experiments are in progress at the CERN laboratory. Gravitational Wave observations of binary black holes at LIGO could give valuable insights about black hole formation scenarios and will be able to provide a measure of their luminosity distance to the source. Cosmological Gravitational Wave background can provide a picture of the Universe very shortly after the big bang.

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