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Big Crunch Where It Started and Where It End?

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***Abstract*—In present paper the review of theory of big crunch based on various models and analytical methods is presented. We focus our work on major breakthrough of the very important field of astronomy. An approach using computational algorithm is also presented in this work.**

***Index Terms*—Big-Bang, Big-Crunch, Milne Space, M Theory, Quantum Loop Cosmology, Black Hole.**

I. INTRODUCTION

The idea of big crunch was not developed in a day or two, its roots are very deeply seeded in the era of seventeenth century. As we know that Isaac Newton (1643-1727) was pioneer in the field of cosmology who proposed systematic mathematical analysis of the outer world. Though the work was also done by Nicolaus Copernicus (1473-1543) in sixteenth century in the same direction but he faces lots of criticism from conservative protestants however after his death his data was used by many workers in the field. Copernicus was the first person who strongly believe that our solar system is Heliocentric. Netherland based spectacle makers Hans Lippershey & Zacharias Janssen and Jacob Metius invented telescope in 1608 but Galileo Galilei (1564-1642) has also credited to customized the telescope with better resolution to observe outer space, his research in the field of astronomy helps to the mankind to see very outer space with a different approach. Johannes Kepler (1571-1630) was the premier in the field who channelize the motion of planets and other objects around the sun.

As the most trusted and systematic literature in the field of mechanics is developed by Newton hence his work has wide range of expectation also. When Newton's law of gravitation is applied to the scale of our universe, certain problems arise. This was pointed first time by Richard Bentley in a communication with Newton. He said that if law of gravitation applied at cosmological scale in finite universe, then every star of universe will collapse with each other at a single point, on the other hand if universe is infinite then due to forces from all directions every star will be pull apart. This is also known as Bentley's paradox or cosmological paradox. However, Newton in his reply to Bentley said that he agreed with the point of Bentley that if universe is finite then every star will collapse at a single point. Newton further stated in his communication with Bentley that universe is infinite and have infinite stars. Each star will exert force in all direction and at the same time feel forces of other stars from all directions. These forces cancelled effect of each other and hence no collapse takes place [1]. In this whole discussion Newton and Bentley both consider that stars are stationary, factually finite number of stars which are in motion will also never collapse with each other, for example there are approximately 10^{16} stars on an average account of a galaxy, though they are in motion but never collapse with each other. As we know that concept of stationary universe is not correct and Newton's explanation is not satisfactory at cosmological scale the Bentley's Paradox may be the reason behind the origination of concept of Big Crunch [2]. Hence one can say that idea of big crunch has its roots in the seventeenth century.

II. BIG CRUNCH IN LITERATURE

K C K Chan and R B Mann investigated various cosmological models in 1+1 dimensions and suggested how hot big bang or hot big crunch takes place. They also found that 1+1dimension cosmologies have good resemblance with 3+1dimension cosmologies, most significant resemblance is that cosmic singularity occurs in almost all models except for model of radiation dominating scenario [3].

E Calzetta and C E Hasi presented analytical and numerical evidence of chaotic behavior in a cosmological model, consisting of a spatially closed, Friedmann - Robertson - Walker (FRW) Universe, filled with a conformally coupled but massive real scalar field. In their computational work they present how to predict the time of big crunch if time of big bang is known [4]. V. Alan Kosteleck´y and Malcolm J. Perry in their work on string theory are seeking simple closed-string analogs of the usual de Sitter, Minkowski, and anti-de Sitter solutions arising in a particle field theory when a scalar form a Higgs condensate.

These solutions are dynamical, i.e., they represent evolving universes, in which both the metric and the dilaton fields change with time [5]. T. Aida, Y. Kitazawa, H. Kawai, M. Ninomiya in their work found that the spacetime singularity at the big bang is resolved by the renormalization effect and universes are found to bounce back from the big crunch [6]. Finn Larsen and Frank Wilczek present a solution of Friedmann-Robertson-Walker cosmology in 3+1 dimensions they find singularity for big bang/ big crunch at non-singular horizon of higher dimension [7]. Vladimir S. Mashkevich comes with an idea for incorporation of local singularity (like of black hole) with global singularity (like of big bang or big crunch). He comes with the idea of Big Cram (Big Bang followed by Big Crunch) [8]. In a study of 1987A supernova, S Perlmutter and his team reveal that ultimate fate of the universe, infinite expansion or a big crunch, can be determined by measuring the redshifts, apparent brightnesses, and intrinsic luminosities of very distant supernovae [9]. In year of 2000 Vladimir S. Mashkevich comes with the idea that in singularity state no laws are applicable he proves it by taking example of black hole, white hole, big bang and big crunch [10]. Donald Marolf, Mark Trodden comes with a concept that when a black hole and a negative tension brane collide the horizon area shrink this shows violation of second law of thermodynamics. This give growth to catastrophic space-time singularity which is similar to the big crunch [11].

Meanwhile Tom Banks*, Michael Dine comes with solutions of Fischler-Susskind equations which have Big Bang and Big Crunch singularity [12]. In year 2002 P J Steinhardt, Niel Turok and their team comes with an idea where they show contraction of the universe at a point and from there only, big bang occurs soon after the big crunch. For the same model they consider conditions under which a universe contracting towards a big crunch, can make a transition to an expanding big bang universe. A promising example is eleven-dimensional M-theory in which the eleventh-dimension collapses, bounces, and re-expands [13]. At the same time Jnanadeva Maharana solved Wheeler-De Witt equation which combine quantum mechanics with theory of relativity, his quantum cosmological approach gives another idea to show transition from big crunch to big bang [14].

*(Tom Banks, Willy Fischler, Stephen Shenker, and Leonard Susskind presented famous BFSS matrix theory, it is a quantum mechanical model which is used in many applications to simplify M-Theory which is also called string theory.)

An approach of non-singular big bounce is presented in the work of J Hwang and H Noh. It states that in the spherical geometry with a pressureless medium, there exists a special gauge-invariant combination Φ. Special gauge invariant stays constant throughout the evolution from the big-bang to the big-crunch with the same value even after the bounce: it characterizes the coefficient of the C-mode, which is called conserved amplitude [15]. Using Brane cosmology and model of tachyon S Mukohyama concludes that the tachyon never settles down to its potential minimum and the universe eventually hits a big-crunch singularity [16].

Entropy bounds and Cardy-Verlinde formula is applied on Yang-Mills theory by S Nojiri and S D Odinstov. Gauge formulation of gravity the three-dimensional SU (2) YM theory equations of motion were presented which are in equivalent form as FRW cosmological equations in their work. With the radiation, the particular (periodic, big bang-big crunch) three-dimensional universe is constructed [17].

A scalar field approach with negative potential to explain big crunch is given by A. de la Macorra, G. German in 2004. They show that the existence of a negative potential leads, inevitable, to a collapsing universe, i.e. to a would-be big crunch [18].

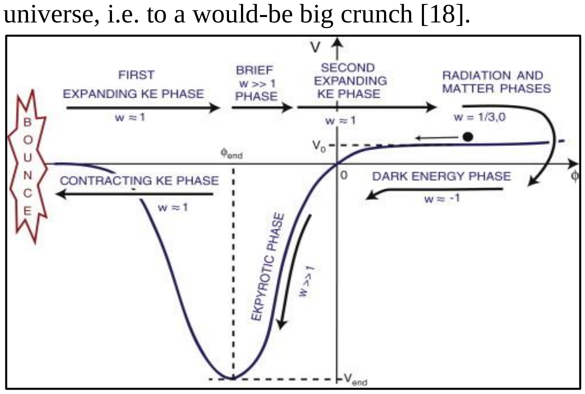

Fig:1 Scalar potentials suitable for a cyclic universe model. Running forward in cosmic time, dark energy phase governs the decay of the vacuum energy, leading to the end of the slow acceleration epoch.

Ekpyrotic phase is the region where scale invariant perturbations are generated. Contracting kinetic energy phase is one approaches to the big crunch ($\phi \rightarrow -\infty$), where the kinetic energy dominates [18].

Je-A Gu, W-Y. P. Hwang conceptually proved that the negative cosmological constant indicates ultimate fate of universe that is big crunch [19]. In year 2006 Przemyslaw Malkiewicz and Wlodzimierz Piechocki presents classical and quantum dynamics of a test particle in the compactified Milne space. Background spacetime includes one compact space dimension undergoing contraction to a point followed by expansion this shows clearly big crunch /big bang transition [20]. The AdS/CFT correspondence is used to describe five-dimensional cosmology with a big crunch singularity in terms of super-Yang-Mills theory by Neil Turok and his coworkers in 2007. The bulk interpretation of their result is a quantum transition from a big crunch to a big bang [21]. E G Dellavalle and his coworkers found that Contrary to the common belief that inflation arises independently of the initial curvature. They show that in the positive curvature case the universe collapses again into a Big Crunch without allowing the cosmological constant term to dominate and to produce inflation [22]. A quantum geometrical approach to understand cosmic singularity to understand big bang and big crunch is investigated by A Ashtekar [23]. Pouria Pedram presented a new initial condition for the homogeneous and isotropic quantum cosmology, where the source of the gravitational field is a conformally coupled scalar field, and the maximally symmetric hypersurfaces have positive curvature. After solving corresponding Wheeler-DeWitt equation, he obtains exact solutions in both classical and quantum levels. In short, we can say he get singularity at both classical and quantum level [24]. In January 2009 edition of Physics Today Igor R Klebanov and Juan M Maldacena published an article titled “Solving quantum field theories via curved spacetimes.” In this article an approach of Anti de Sitter blended with Conformal Field Theory is presented. This AdS/CFT correspondence later used to describe 5-D cosmology with Big Crunch singularity by using Yang Mills theory [25].

Te Ha et al comes with the idea of super fluid for classification of the FRW universe coupled with a cosmological constant **Λ** and describe an equation of state p = ωρ. Here p is pressure ω is arbitrary real constant and ρ is energy density of fluid. With the specific values of above-mentioned parameters in 3-D space they studied singularity for big bang, big crunch and big rip [26].

By using Ofer Aharony, Oren Bergman, Daniel Jafferis, and Juan Maldacena theory popularly known as ABJM theory, Neil Turok and his team consider marginal triple face deformation and established perturbative UV fixed point and also shows that big crunch singularities may extended to orbifold model coupled with ABJM theory [27].

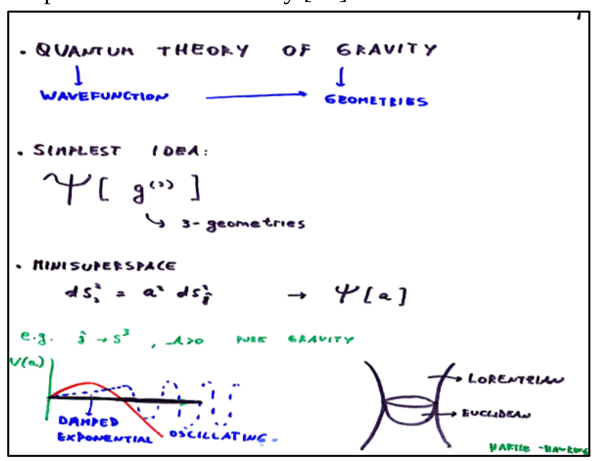

Fig: 2 The hand-written notes by Juan M Maldacena used to explain theory of quantum gravity. Courtesy Juan M Maldacena Princeton. See https://online.kitp.ucsb.edu/online/strings_c03/maldacena/oh/02.html

A work by A Yu Kamenshchik on Belinski–Khalatnikov–Lifshitz (BKL) singularity model of the dynamic evolution of the universe near the initial gravitational singularity, suggested about the past and the future of the Universe in the light of the oscillatory approach to the Big Bang and the Big Crunch cosmological singularities [28]. For vibrating string in Hilbert space, M Znojil studied quantum big bang and big crunch time dependent singularity [29]. In his work, question of possible physics before Big Bang (or after Big Crunch) is addressed via a schematic non-covariant simulation of the loss of observability of the Universe. In the year of 2012 the team of P J Steinhardt and Neil Turok headed by Itzhak Bars comes with a new approach using antigravity to show big crunch/ big bang transition which is very useful in construction of bouncing cyclic model of the universe [30]. A. Chaney, Lei Lu and A. Stern proposed tachyonic toy model of fuzzy sphere which is solution of Lorentzian IKKT matrix. In this model it is derived that computed curvature is negative in nature, not constant and have singularities at fixed latitudes [31]. Loop Quantum Cosmology (LQC) is another popular approach to form a bridge between contracting and expanding cosmological branches at Plank regime, Parampreet Singh of Louisiana State University presented his work in which cosmological singularity is discussed by using LQC. He discussed various types of singularities and stress on the point that in isotropic cosmological model the big bang/big crunch singularity is point like on the other hand in anisotropic model it will be of shape of cigar, barrel or pancake shape depending on behavior of directional scale factor [32].

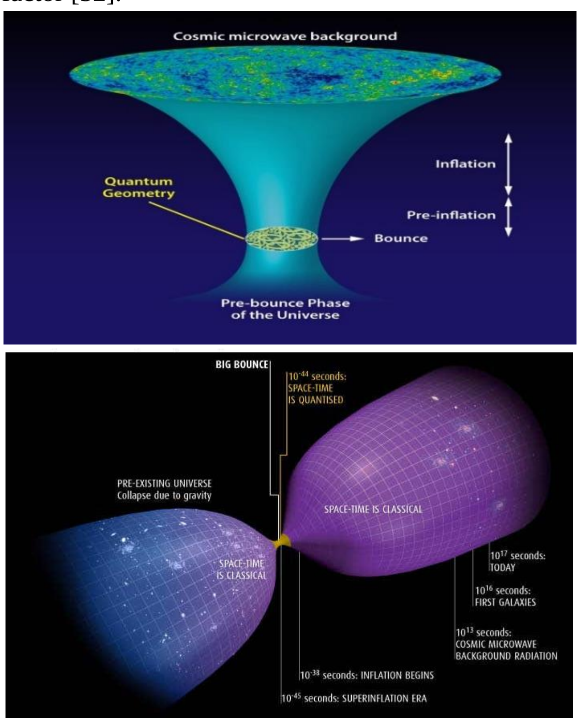

Fig:3 Diagram showing the evolution of the Universe according to the paradigm of Loop Quantum Origins, developed by scientists at Pennsylvania State University. Credit: Alan Stonebraker. P. Singh, Physics 5, 142 (2012); APS/A. Stonebraker.

Computational techniques are used to analyze large data sets in various field like economics, market segments and also in the field of astronomy. BB-BC algorithm using k-means clustering is studied by Kayvan Bijari et al in their work. They compare memory enriched BB-BC algorithm with other similar heuristic techniques [33]. Jared Speck in his work using spatial topology found, the maximal development of near-FLRW data for the Einstein-scalar field system and suggested more stability in big bang and big crunch at spacelike hyper surfaces [34]. A two boundary quantum mechanics which is applied on big bang/ big crunch, is proposed by F W Bopp in his work [35]. Recently Sushovan Mondal and his coworkers studied behavior of gravitational waves in various cosmological backgrounds in the study when they evaluate gravitational wave with time in a radiation dominated spatially closed universe the results are significantly indicating towards collapsing nature of the universe [36]. Cosmological (AdS Kasner) singularity was studied in recent work of R Bhattacharya, K Narayan and P Paul's work for 2-d dilaton gravity-scalar theory. In this work they concluded that how cosmological singularity is obtain even if we study bouncing behavior of universe. The dilaton potential encodes information about the asymptotic data defining the theories, and encompasses various families such as flat space, AdS, conformally AdS as arising from nonconformal branes, and more general nonrelativistic theories. [37]. In the study of spherically symmetric metric in 5D setting within the framework of Lyra manifold by P S Singh and K P Singh a Dark Energy (DE) model is proposed, it is a cyclic model in which, each cycle starts with big bang and end at big crunch [38]. In the recent study at North American Nanohertz Observatory for Gravitational Waves (NANOGrav) detected gravitational waves via regular observations of an ensemble of millisecond pulsars using the Green Bank Telescope, Arecibo Observatory, the Very Large Array, and the Canadian Hydrogen Intensity Mapping Experiment (CHIME). This project is being carried out in collaboration with international partners in the Parkes Pulsar Timing Array in Australia, the European Pulsar Timing Array, and the Indian Pulsar Timing Array. In the work they studied Gravitational Waves Background (GWB). In this work they analyze data of LIGO (Laser Interferometer Gravitational-Wave Observatory) experiment, and discovered isotropic gravitational waves background (GWB) with frequency f^{-8} Hz which ultimately support the idea of cyclic universe [39]. Recently work of Fabio Stroppa and Ahmet Astar on big bang- big crunch algorithm proposes the Multiple Global Peaks Big Bang-Big

Crunch (MGP-BBBC) algorithm, which addresses the challenge of multimodal optimization problems by introducing a specialized mechanism for each operator. The algorithm is state-of-the-art metaheuristic, inspired by the universe's evolution [40]. Very recently Abhishek Sahu and his coworker Mark Van Raamsdonk had studied lattice black hole to understand big bang-big crunch transition. In their paper, they described a microscopic construction of a big-bang / big-crunch cosmological spacetime using the tools of holography. They used a Euclidean CFT path integral to define a particular entangled state of a collection of uncoupled CFTs; in some cases, the dual spacetime has an interior region that is a state of cosmology where the matter is a lattice of black holes [41].

In this paper we review the development of the field of study about big crunch. The roots of the idea of big crunch seeded long back when Richard Bentley correspond with Newton on his work on gravity. We went through the basic approaches used to describe big crunch-big bang transition by various ways. Some worker used Friedmann equations to show the big crunch-big bang transition, some used cosmological constant to explain the same. Here some researchers used cosmological singularity to prove ultimate fate of universe and on the other hand concept of cyclic universe fascinate others to prove bc-bb transition. M theory is most promising to show the ultimate fate of universe as it used Kaluza Klein particles to explain behavior of contracting universe in its dooms era. A very promising way of using dark energy to show big crunch is used recently. The review is not completed without talking about AdS/CFT approach and dilaton model or tachyon to explain the big crunch. In recent findings workers used Gravitational Wave Background and Lattice Black holes to explain ultimate fate of our universe that is big crunch. In the recent work (see fig:4 and reference there in) Enrique Gaztanaga reviewed the idea given by R K Pathria and I J Good, that the observable universe is the interior of a black hole. In his work he suggested that instead of emerging from a singular Big Bang (a global solution), origin of universe could result from the cold collapse of a large and low-density (local) cloud into a black hole. Such a collapse originates from a small initial over-density within a flat background, which can be modeled as a local FLRW closed curvature. The idea is fascinating but need more study in future. Many computational methodologies which are used to create simulation of BC-BB transition are also used in the field of other statistical analysis and in research area of industrial production.

III. CONCLUSION

In this paper we gave in depth review of literature related to the idea of ultimate fate of our universe, which is known as big crunch. All approaches to explained the idea of big crunch are discussed in chronological order.

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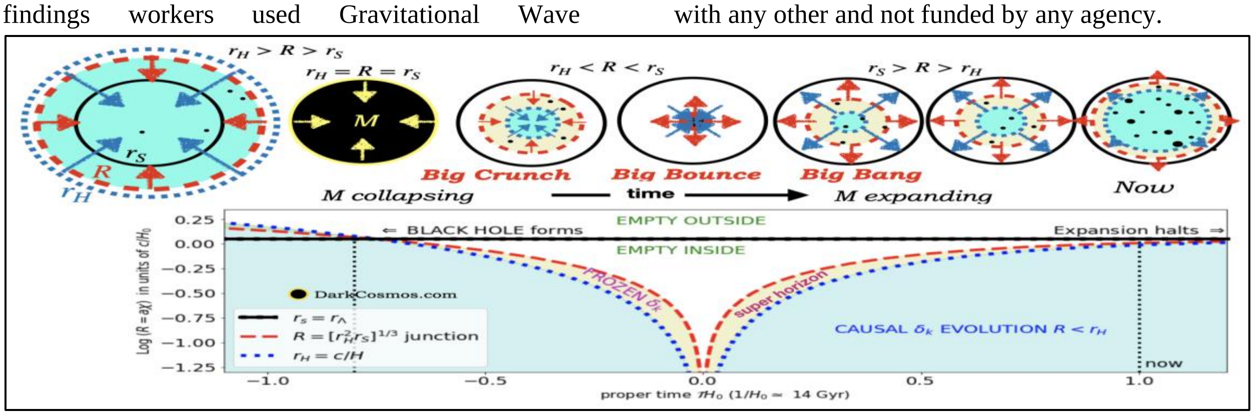

Fig 4: Illustration on formation of Blck Hole Universe (BHU), Courtesy: Enrique Gaztanaga in his work "On the interpretation of Cosmic Acceleration". Available at preprint.org, doi: 10.20944/preprints202309. 0873.v8, (2024)

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