Einstein And The Evolving Universe

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Abstract

A panoramic view, preceded by a short background of Newtonian mechanics and Maxwellian electrodynamics, is offered on the extent of how Einstein’s space-time geometry, believed to be central to an understanding of the structure of the universe, is overshadowed by several hitherto unheard of features like dark matter and dark energy, that seem to be necessary, but by no means sufficient, for a more complete picture.

1 Newtonian Mechanics

Once upon a time there was only Newton with his 3 Laws of Motion. Space and time were two distinct and independent entities, each absolute in its own right, which provided a joint playfield for the activities of Matter, (yet another distinct entity) in accordance with his 3 Laws of Motion. Gravitation was a universal force, again governed by Newton’s diktat, which pulled everything far and near, according to the inverse square law. To manage this huge investment, Newton had to take recourse to the tools of Mathematics for which his own resources proved inadequate however. The most important tool in this regard turned out to be Differential Calculus which he promptly borrowed from a fellow mathematician Leibnitz. The resulting structure was a beautiful piece of physics clothed in elegant mathematics which was Newton’s legacy to the world under the name of Classical Mechanics. It was

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a most formidable instrument, capable of predicting the outcome of every
type of motion under the Sun in a fully deterministic manner, provided only
the initial condition was known! Relativity as known today was a far cry
at that time, yet the equations of motion incorporated Galilean invariance
(which stemmed from Newton’s first law).

This powerful machinery was to rule the world, from terrestrial to the
celestial, for the next 150 years. It proved so self-sufficient that God had
apparently decided not to have an explicit role in driving it, except perhaps
watch it from a distance, as a detached observer! Indeed this deterministic
scenario for purely physical systems led DeCartes to enunciate his celebrated
law of Cartesian Partition according to which all physical phenomena were
to be totally separated from anything which had to do with the psychic, or
the mystical. God was however not totally banished from this scenario, for
Newton had thoughtfully provided for an implicate order for the universe
as a whole, whose logic was best left ”unanswered”. During this period,
mathematical thinkers, and there was a whole galaxy of them

[Laplace, Lagrange, Hamilton, Poisson, Fourier; Gauss, Euler, Riemann]

had a field day in shaping and re-shaping this wonderful machinery to their
taste, and in the process, giving newer and newer meanings to its physical
content. In particular, the ”canonical” Hamiltonian equations of motion for
the time evolution of dynamical entities in terms of Poisson brackets, was
a most profound structure which (though identical in physical content to
the original form of Newton’s laws ) was later to prove the ”golden road to
quantization” at the hands of Dirac.

2 Maxwell, Lorentz & Einstein’s Relativity

In a totally different sector of physics, the piecemeal laws of electricity and
magnetism which had been building up under different heads (Gauss, Faraday,
Biot-Savert) were brought together by James Clerk Maxwell under a
single umbrella of four interlinked differential equations in which his own
contribution of Displacement Current proved seminal for a profound unifica-
tion process giving rise to a consistent wave theory wherein the wave velocity
turned out to be precisely the velocity of light! This was another masterpiece
of effort to demonstrate the underlying unity of the basic laws of physics despite their outward appearance of disjointed entities. As if to drive home the true significance of this great result, H.A. Lorentz showed that the Maxwell Equations were not invariant under the simple Galilean transformations (the hallmark of the limited relativity principle for Newtonian mechanics), but rather under a new set of linear transformations in which time and space appeared more symmetrically connected than seen from the equations of Newtonian Mechanics. Thus was born the precursor of the special theory of relativity several decades ahead of its formal inauguration by Einstein.

2.1 Special Theory Of Relativity

Einstein thus had a two-fold legacy to build on, viz., i) Newtonian mechanics and ii) Maxwell’s electrodynamics, flanked by two crucial ”data”, one on the structure of space-time, and the other on the possibility of a discrete (quantum) structure of matter. The first emanated from the Michelson-Morley experiment pointing to the absence of any ether-like substance constituting the vacuum, while the other stemmed from Max Planck’s revolutionary explanation of the black-body spectrum in terms of a hitherto unknown constant $h$. He took up both challenges in two outstanding papers in a single year—1905—, and confirmed both: A) a unified structure of space-time (hitherto thought as two disjointed entities); B) corpuscular nature of light (hitherto thought of only as wave). His Special Theory of Relativity gave a new meaning to the Lorentz transformations not only through the kinematical invariance of a flat space-time entity, but also a more profound result at the dynamical level, viz., the formal equivalence of mass and energy ($E = mc^2$) which was to find dramatic manifestations throughout the Twentieth Century in more ways than one. Einstein’s active love affairs with Quantum Theory however ended with his single, but seminal, paper on the photo-electric effect (which fetched him the Nobel Prize), while the quantum banner was left to be taken up by other stalwarts (de Broglie, Bose, Heisenberg, Schroedinger, Dirac, Pauli, Wigner). For Einstein, his success with special relativity was only a beginning—a sort of appetizer for more exciting things in relativity. It was another matter that despite being the progenitor of quantum theory, Einstein had profound reservations on its completeness, as evidenced by his dispute with Niels Bohr on the subject. But except for the Einstein-Fock-Podolsky paper, he had little else to offer on the completeness issue.
3 General Relativity : Equivalence Principle

The year 1905 was truly a landmark year which saw the unification of space-time into a single entity at the kinematical level, and a corresponding unification of mass and energy at the dynamical level of matter, both within the framework of Special Relativity. Not content with this big achievement, Einstein embarked on the next stage of unification (this time of matter with space-time) by appealing to the universality of gravitation. This took him a full decade of mathematical gymnastics, at the end of which he came up with a generalized version of relativity, one in which space-time is no longer flat but gets curved whenever it encounters the gravitational attraction of a lump of matter, the bigger the lump the greater the curvature! This had some remarkable logical consequences. First, the special status of ‘inertial’ frames, viz., ones that move with uniform velocities wrt one another in flat space-time (characteristics of special relativity), gave way to a more generalized Equivalence Principle wherein all frames, including accelerated ones, are deemed equivalent to all others. To see the physical significance of this apparently innocuous statement, consider the famous example of a lift undergoing downward acceleration equal to that of gravity. A man sitting in such a lift will not feel the effect of gravity at all! Another way to express this result is to assert that the gravitational and inertial masses are identical. This imbedding of gravitation into a curved space-time geometry has both conceptual and observable ramifications. Conceptual because in a curved space-time, the line of shortest distance (a geodesic) is no longer straight, but curved, the curvature being the greater the bigger the local mass that causes the bending. Observable because of the possibility of bending of light in the vicinity of a large mass (such as the Sun), which was dramatically confirmed during the solar eclipse of 1918 by an expedition led by Arthur Eddington. [It was another matter that Eddington had apparently ‘doctored’ some data to suit the theory, as revealed in a recent book by J. Waller( Fabulous Science, Oxford, 2002), yet it was perhaps an irony of fate that such ‘doctoring’ gave a much needed boost to the Theory (GTR) at its nascent stage of evolution, since similar subsequent observations amply bore out its basic strength]. Two other observable consequences that have become text-book material are i) the advance of the perihelion of mercury, and ii) the gravitational red-shift of light when it is emitted from a massive body like the Sun. [None of these phenomena could however be explained by Newtonian mechanics]. An important lesson from these early studies was
that GTR once for all transformed space-time from its backdrop status in Newtonian mechanics, to the centre-stage as an active dynamical entity on par with other material objects.

4 GTR And Cosmology

A dynamical status of space-time conferred by the new geometry proved the right incentive for addressing the most important question concerning Cosmology itself, viz., its connection with the structure of the Universe. To unravel this mystery needed a continuous feedback between theory and observation, of which only one component (theory) was forthcoming in abundance, while the other (observation) was to wait for several decades before materializing. In the theory sector, the rich structure of the new geometry, with its Riemannian metric, gave rise to a set of tensor equations which characterized Einstein’s equations, and proved a field day for mathematicians all over the world – Friedman, Schwarzschild, de Sitter Robertson-Walker, and later Ray Chaudhury and Vaidya – to discover newer and newer facets of these tensor equations emanating from diverse types of metrics, employing the most intricate techniques of differential geometry.

Among the various solutions, a scenario of great historical interest, and one which has come into prominence in the modern era, concerns the role of the Cosmological term Λ which Einstein had introduced by hand in his equations for the sake of mathematical consistency. For, in his attempts to solve these equations for an idealized static 3-sphere universe filled with matter at uniform density, he realized that the radius of such a universe could not be viewed as "static" (independent of time) unless there was a counter-term to balance the effect of time evolution. But he later abandoned this term as the "biggest blunder in his life". de Sitter (1917) on the other hand, picked up this item where Einstein had left it, by recognizing, a la Einstein, its need for balancing the gravitational attraction of matter, so as to produce a static universe where the mean density of matter, and the mean curvature of space would stay constant. de Sitter then observed that he could obtain another static model by removing all the matter from the original Einstein model, but now the (repulsive) Λ-term would cause test particles to accelerate away from each other. The rate of this separation was predicted by H. Weyl (1923) to follow the simple law $v = H.(\text{distance})$. Similar derivations of an evolving universe with the same law of separation
were also given by A. Friedmann (1922) and G. Lemaitre (1927), which was experimentally confirmed by Hubble (1929).

In a landmark theoretical development, George Gamow (1946) proposed that matter in the early universe was dense enough to undergo rapid thermonuclear reaction, and that energy densities were radiation-dominated. Soon afterwards, R. Alpher, H. Bethe and G. Gamow (1948) predicted that the black-body radiation that originally filled the universe, should have a Planck spectrum corresponding to a temperature of about $250^\circ K$. [This was the famous “$\alpha\beta\gamma$ paper” put in without Bethe’s formal consent (!); so when the theory was later in (temporary) trouble, Bethe had allegedly wished his name were Zacharias!]. The eventual observation by A. Penzias and R. Wilson (1964) of an unexpected background radiation of 7 cm, with a temperature of about $3.5^0 K$, and its immediate identification by Dicke-Peebles-Roll-Wilkinson as the expected relic radiation (à la the $\alpha\beta\gamma$ paper), was the first major experimental confirmation of the “Big-Bang” scenario. [A parallel proposal by Bondi-Gold-Hoyle (1948), later to be known as the Hoyle-Narlikar Steady State Theory, had to be abandoned in response to the Penzias-Wilson discovery].

An important prediction by the Indian astrophysicist Subramaniam Chandrasekhar, of the existence of a critical mass – the Chandrasekhar limit – beyond which the star collapses under its weight, met with stiff resistance from Eddington, but the profound nature of the discovery eventually fetched him the Nobel Prize. Other outstanding predictions of these investigations included i) gravitational radiation, ii) the expanding universe, and iii) black holes as the final stage of dense neutron stars. This is about as far as Einstein’s GTR machinery could go towards unravelling the mysteries of Cosmology, taking into account the severe experimental limitations of the time, but more tests were in the offing.

4.1 Experimental Discoveries: Pulsars; GPS

Towards the end of the last century, great strides in high precision instrumentation, and in the observational techniques of astronomy, have led to new precision tests of GTR predictions. Over a thousand neutron stars have been found in the form of pulsars (fast rotating stars) whose gravitational fields can be adequately described in terms of GTR only. Another important discovery was a binary pulsar [R. Hulse and J. Taylor, 1976] whose orbital motion measurement with great accuracy, led to a precision test of GTR. Still
another important observation was that as a result of the emission of energy into gravitational radiation, the total energy of the orbital motion decreases with time at a rate predicted by GTR to within a third of a percent. This has led to a standard GTR correction to the flow of time on orbiting satellites, as compared to the corresponding rate on earth, as an essential part of the Global Positioning System (GPS), which allows various users (commercial, military, etc) to calculate a precise location on the surface of the earth, and to transfer accurate time readings using triangulation with satellite signals.

4.1.1 Black Holes; Quasars

In the views of S. Chandrasekhar (as elaborated by the famous GTR specialist Abhay Ashtekar in the Indian Acad Sci publication Patrika, March 2005), "black holes of nature are the most perfect macroscopic objects in the universe, the only elements in their construction being concepts of space and time." Black holes have also proved a gold-mine for generating ideas on fundamental physics. Indeed their amazing variety of properties have intrigued quantum field theorists and relativists alike, and provided insights into the inter-connection between general relativity, quantum theory and statistical physics, which constitute the three pillars of modern physics.

Many black hole candidates have been identified via astronomical observations. They can be broadly classified under two heads: i) those arising from the collapse of stars, having masses of the order of $1 - 10$ times that of the Sun, and radii of a few kilometers; ii) those found at the centres of galaxies, having masses of the order of millions to billions of times that of the Sun, and radii comparable to that of the solar system. Our own galaxy may well contain such a black hole! Not only that, the most violently energetic objects in the universe—the quasars—are thought to be powered by accretion of matter onto such huge spinning black holes.

4.2 Expanding Universe

One of the most dramatic predictions of GTR is the theory of the expanding universe which has been convincingly confirmed by observation of the velocities of distant objects. The gravitational red shift of spectral lines, which was initially a most difficult test of GTR, has now become a standard tool of astronomy. In the same way, the bending of light by the Sun, is now a routine technique to map dark matter using gravitational lensing. Indeed the
mass of intervening galaxies is often observed to distort the light from more distant sources quite significantly, resulting in the production of multiple images. This provides a method for searching massive objects that produce no detectable radiation. All this is in complete accord with the predictions of GTR.

5 GTR-QFT Unification Issues

All this constitutes very impressive confirmation of the basic tenets of GTR, yet there are compelling reasons to believe that there are still unknown facets to gravity than are contained in these results. The biggest goal is now the need for a consistent theory that comprises both GTR and quantum theory (QFT). Now the degree of unification achieved within GTR has been outlined in Sects 3-4. And in the QFT sector, the unification achieved so far is equally impressive. This last is symbolized by Dirac’s synthesis of quantum mechanics and special relativity which together have resulted in the prediction of antimatter. Indeed quantum theory has even covered the problem of interaction of radiation with matter – QED that is– by addressing the problem virtual processes (the problem of emission and subsequent absorption of radiation) which was fraught with dangerous infinities that would not make sense for physical processes! The solution lay in the absorption of infinities through a redefinition of physical entities like mass and charge (in terms of ‘bare’ charge and mass), a process termed Renormalization, so that physical process could be expressed entirely in terms of the ‘renormalized’ quantities only. A consistent treatment further required that the operation be independent of the inertial frame under consideration. This was eventually achieved by the Covariant QED Formalism of Tomonaga-Schwinger-Feynman-Dyson, a truly great theory which achieved experimental confirmation to within one part in a trillion!

5.1 Hawking Paradox

A far bigger challenge at this stage is the unification of GTR and quantum theory as this goal is fraught with major conceptual problems. The nature of such conceptual problems is best illustrated by Stephen Hawking’s discovery that when the effects of quantum mechanics are included, black holes start emitting radiation, i.e., they are no longer black! Of course this ra-
diation is too small to be detectable, but it is conceptually very important. In Hawking’s approximate calculation, however, this radiation is randomly distributed, i.e., in a \textit{thermal} manner. It is not apriori clear whether this is an exact result or not, but if so, then the causal connection between the past and the future— an essential characteristic of quantum mechanics—gets lost. In other words, a black hole which, in principle, carries quantum information from the past emanating from the objects it has swallowed in the past, can evaporate by radiating in a random fashion, thus apparently violating the law of causality. This is the famous Hawking paradox whose ultimate resolution may well be a key to the understanding of the quantum nature of space-time.

5.2 Initial Conditions, Etc

Then comes the question of initial conditions which are left unanswered in the essential framework that GTR provides for the understanding of Big Bang Cosmology. To give a simple analogy, Newton’s theory describes the motion of planets to be sure, but does \textit{not} determine the size and shape of the solar system, which in turn would have needed the specific details of its history. Again, other sectors of the universe have different features from ours. Yet the universe as a whole has some strikingly simple features like \textit{approximate homogeneity} and \textit{spatial flatness}, which a fuller theory is expected to explain. Homogeneity means basically that any large region of the universe of a given age looks much like any other region of the same age. Spatial flatness means that \textit{space} by itself (not space-time !) is \textit{flat} on large scales. Both these properties have been observed and measured with considerable precision, through studies of the micro-wave background radiation. Note that neither homogeneity nor spatial flatness are required by by classical GTR but are at least allowed by it. Now questions like ”Why is our universe so homogeneous and flat ? ”, call for some extra ingredient beyond the premises of GTR, ingredients which are no less concerned with the ramifications of quantum theory (QFT) down to the earliest moments of the Big Bang. This in turn would require the calculation of the behaviour of quantum gravity at high energies, something which is not known at the moment. Stated differently, a synthesis of GTR (the theory of space-time) with QFT requires the introduction of ideas which impinge on both sectors in a highly interlinked manner, consistently with the new observational features of Cosmology.
5.3 Unification Candidates: Inflation

One such idea, which has been highly successful, is inflation first proposed by A. Guth. He assumed that the universe, early in its history underwent a period of exceptionally rapid expansion. Now expansion tends to decrease spatial curvature, just as the blowing up of a balloon makes its surface appear flatter. The enormous expansion associated with inflation means that the universe we see today began from a very tiny region of space that could have been smooth before inflation. While inflation cannot fully eliminate the dependence of the state of the universe today upon its initial state, it can at least considerably reduce that effect. A great advantage of the inflation theory is that it is rooted in concepts associated with the particle physics scenario, thus fulfilling the condition of synthesis of GTR with QFT.

5.4 Condensates In QFT: Dark Matter

Now unified theories of particle physics, in turn, require the existence of condensates which are the relics of "symmetry breaking" (spontaneous or otherwise) in the theoretical framework. Even without going into the details of the symmetry-breaking mechanism, the immediate consequence of the existence of these condensates is that their very presence indicates that the symmetry of the fundamental equations are "broken", as demanded from observation. Now since these condensates belong to the "matter part" of the GTR equations, they must be compatible with the observation that visible matter is only about 5 percent of the total amount of matter needed to account for the consistency of these equations. Therefore the rest must be invisible or dark matter, whose identity is thus one of the key questions of GTR cosmology today. While the weakly interacting neutrinos by virtue of their neutral charge, are an ideal candidate for dark matter, their negligible masses and light-like velocities are impediments in the way of accounting for the (95 percent) dark matter, as is is hard to see how they would be gravitationally trapped in density fluctuations in the early universe. A more promising candidate which is compatible with this cosmological requirement, is the (heavy) neutralino which is a new electrically neutral stable particle arising from the breaking of supersymmetry, but which interacts very weakly with matter. [It is yet to be experimentally identified, despite several ideas for its detection in high energy accelerator based experiments]. Another hypothetical candidate – the axion – was introduced by Weinberg in the strong
interaction (QCD) sector of the Standard Model to compensate for the observed lack of CP (charge-parity or matter-antimatter symmetry) violation, since unfortunately QCD would otherwise predict a small CP-violating phase ($\theta$) in its structure. The axion is thus predicted as an additional low mass weakly interacting particle which would have been produced abundantly during the Big Bang and thus could easily account for the needed amount of dark matter. Other dark matter candidates have also been suggested, but no final solution has yet been found. Understanding the nature of dark matter is today one of the most challenging problems for the unification of matter with space-time.

5.5 Temperature Dependence of Condensates

Now to see how the behaviour of condensates with increase in temperature holds the key to an understanding of inflation, we need to go through a twin logic: i) standard phase transition associated with a condensate when a ‘broken symmetry’ is restored; ii) the gravitational behaviour of the energy when it is trapped in the condensate, versus when it was ‘free’ at the higher temperature. (i) In a standard phase transition, when the temperature is raised sufficiently, the condensate just evaporates away, (like the melting of ice into water). Stated differently, the broken symmetries associated with the condensates are sort of “restored”. This may be seen by analogy with the behaviour of an ordinary magnet where, at low temperatures, the spins are aligned in some preferred direction, since such a configuration is energetically favourable. However, as the temperature is increased, such an alignment is no longer energetically favourable, and the configuration tends to be ‘isotropic’ (more symmetrical), with the spin directions getting more randomly oriented. (ii) The second part of the logic concerns the rather different behaviour of the vacuum-energy as it undergoes a transition from the higher (no condensate) to the lower (condensate) temperature state. Now the lower temperature corresponds to the situation where the condensate contains an enormous amount of vacuum-energy in a “trapped ” form, obeying the ‘normal’ laws of gravitation. On the other hand, at the higher temperature, the same vacuum-energy has entirely different gravitational properties from its (more conventional) ”trapped form”. Namely, if the vacuum energy is dissipated ”slowly”, it causes an exponentially rapid expansion of the universe, giving rise to a period of inflation.
5.6 Baryon Asymmetry: CP Violation

Another observational aspect of the universe is the preponderance of matter over antimatter. Now in the Standard Model, this preponderance is totally absent, i.e., the number of baryons minus the number of anti-baryons is strictly conserved. Now if this principle is accepted for all time, then the observed baryon asymmetry would be merely an initial condition, a legacy of the original big bang. On the other hand, in unified theories, the baryon number evolves with time (since quarks can change to anti-quarks and / or other particles), leading to exotic phenomena like proton decay! If such processes do indeed occur, then (as explained in the preceding paragraph), the symmetry would be valid at sufficiently high temperatures, down to the moment of the big bang. In this alternative scenario, the present preponderance of matter over anti-matter must be regarded as the result of cosmological evolution of the equations of motion.

5.7 Accelerated Expansion: Dark Energy

Finally, any theory of space-time-matter must address the most mysterious question in physical science: the nature of the vacuum which is believed to be populated with the virtual particles on the one hand, and the symmetry-breaking condensates on the other. The definition of zero energy can be arbitrarily adjusted in many theories, but once adjusted in one epoch, it cannot be altered, and the effect of quantum corrections must then give the vacuum energy in all epochs. To set the question of vacuum energy in the GTR language of Sect.4, it is tempting to identify this quantity with the energy of a de Sitter universe with positive cosmological constant $\Lambda$. [A negative $\Lambda$ would correspond to an anti-de Sitter or "AdS" vacuum]. A quantitative connection is however fraught with danger, since the quantum corrections give values of the expected scale of energies far in excess of what is allowed experimentally! Indeed, the discrepancy is so large ($\sim 10^{55}$) that it indicates a big gap in the understanding of vacuum in terms of gravity!

Now the most intriguing hint of a new physics from cosmology is the observation that the expansion of the universe is speeding up, rather than slowing down, thus implying the presence of a mysterious form of energy, termed dark-energy, that pervades the universe with a gravitational effect that is repulsive rather than attractive. Indeed the latest observation suggests that this energy which corresponds to negative pressure, constitutes
about 70 percent of the energy density of the universe, the other 30 percent being shared between visible matter (5) and dark matter (25). The observational basis for such a composition of the universe comes from the study of temperature anisotropies in the cosmic background temperature radiation (CMBR), which (as noted in Sect. 4), is a relic from the hotter phase of the universe when it was about a thousand times smaller in size!

We have by now encountered three kinds of energy: i) the (observed) dark energy; ii) the (quantum) energy of the vacuum; and iii) the (GTR) motivated cosmological constant of the de Sitter universe. They are presumably interconnected, but so far there is no deeper theory for a natural understanding of these apparently disparate items, taking account of the ubiquitous role of gravitation.

6 Strings To The Rescue?

In the quest for a unified quantum theory which includes gravitation, a natural direction to look for is the only available candidate on the horizon, viz., the 3 decade old String Theory which was motivated by precisely such a need, and has undergone several stages of sophistication, from string theory to superstring theory, and now to $M$-theory. Unfortunately no specifically testable prediction of this grand theory has emerged so far, yet many believe that the theory is probably on the right track. As to its main features, string theory is concerned with the problem of constructing a consistent quantum theory of "extended particles" or strings, and not point particles to start with. Its most startling consequence is the prediction of the existence of gravity within its basic framework, with the added advantage that (unlike conventional GTR), it does not suffer from the problem of infinite quantum corrections. [This is not as mysterious as might appear on first sight, since a certain length dimension associated with this extended object is available for "toning" down the effect of an otherwise naked infinity associated with point structures and their interactions]. Unfortunately a consistent string theory does not work in 4 dimensions, the minimum number of dimensions needed for a consistent description being eleven. Therefore it is necessary to assume that these additional (7) dimensions get curled up, leaving the usual 4 (extended) dimensions to play with. The new theory yields many solutions, some with the known features of the existing theories (unification of couplings, supersymmetry, and axions), but there are other equally con-
istent solutions that lack these features. So far there is no reason to prefer one solution to another, nor has a unique solution emerged which accounts for all observations. Supersymmetry which is a key feature of String Theory, predicts a doubling of the number of known particles, and although this prediction has not yet been fulfilled, the predicted particles are believed to be well within the range of the next generation of particle accelerators.

A key question now concerns the possibility to understand the twin features of inflation and an accelerating universe (de Sitter universe with positive $\Lambda$) within the ambit of string theory. Recent progress in this direction [see for a review: S.P. Trivedi, Curr. Sci. vol 88, p 1125 (2005)] seems to suggest that, despite the existence of various no-go theorems in the way of such pursuits, alternative scenarios are available within the broad framework of string theory for the construction of de Sitter universes with the desired properties which may be able to circumvent the no-go theorems. Similar possibilities also seem to exist for the understanding of inflation within the same broad framework. The details are however too technical to warrant elaboration.

Although no explicit references are given, I wish to acknowledge that I have greatly benefitted from two key references: i) Gravitation by Meissner et al, considered as the "Bible"; ii) Connecting Quarks with the Cosmos, National Academies Press, Washington, D.C., 2003. From both these classics, I have frequently drawn ideas in sequence (albeit in my own language), but without explicit reference in context.