# INFLATIONARY COSMOGONY, COPERNICAN RELEVELLING AND EXTENDED REALITY

YUVAL NE'EMAN
*Wolfson Distinguished Chair of Theoretical Physics*
*Raymond and Beverly Sackler Faculty of Exact Sciences*
*Tel-Aviv University, Tel-Aviv, Israel 69978*

and

*Center for Particle Theory, Physics Department*
*University of Texas, Austin, Texas 78712*

ABSTRACT. "Eternal" Inflation has relevelled the creation of universes, making it a "routine" physical occurence. The mechanism of the Big Bang, from the conditions triggering it, to the eventual creation of the entire matter content of the resulting universe, involves no singular physical processes. However, causal horizons, due to General Relativity, separate the newborn universe from the parent universe in which it was seeded as a localized vacuum energy. The new universe's expansion only occurs "after" infinite time, i.e. "never", in the parents frame. This forces a reassessment of "reality". The two universes are connected by the world line of the initial localized vacuum energy, originating in the parent universe. Assuming that the parent universe itself was generated in a similar fashion, etc., an infinite sequence of previous universes is thus connected by one world-line, like a string of beads.

## 1. Copernican relevellings in Inflationary Cosmogony

Inflation [1-3] was conceived as the solution to paradoxes within conventional Friedmann cosmology and in the interface with Standard-Model inspired unified gauge (or string) theories. As spin-off, it yields in addition a mechanism for the Big-Bang, in the form of a "de Sitter model" exponential expansion, locally triggered by a large vacuum-energy in a microscopic region. This is the quantum field theory version of the "cosmological constant", in which the latter represents a quantum vacuum energy density (localized), e.g. a fluctuation of the Higgs field responsible for spontaneous symmetry breakdown of the GUT (at $10^{16} GeV$, in the presently experimentally favoured "minimal supersymmetric" version), i.e. of an *inflaton* field. Another unexpected bonus consists in the energy-conserving features of that same mechanism, in creating the full particle content of the universe (a null total energy throughout the process, with the gravitational binding energy cancelling the mass).

Several aspects of Inflation represent a Copernican relevelling. First, the Big-Bang-originated universe is very much larger (beyond the observational horizon at $1.5 \times 10^{10}$ light-years) than the observable "village". Secondly, it is *eternal* [2]: (a) our Big-Bang was born in an existing universe and (b) flatness ensures a quasi-eternal expansion. Thirdly, the "Big Bangs" are "normal" phenomena and occur stochastically, provided the conditions

*M. Kafatos and Y. Kondo (eds.), Examining the Big Bang and Diffuse Background Radiations,* 559–562.

we described (large vacuum energies) happen to materialize. There are thus infinitely many "universes" – using the term to imply something like our observable universe plus its unobservable embedding (resulting from the same Big Bang). Very roughly, this is a return to the Bondi-Gold-Hoyle (1948) Steady-State universe, yet on an infinitely grander scale – and with continuous creation replaced by creation of spacetime and matter in discrete "bursts".

## 2. Classical General Relativity Horizons Stretch the Twin Paradox

In this presentation, however, I shall discuss yet another revolutionary feature, which I recently pointed out [4]. This is *a new conceptual watershed in our understanding of time, and even more so of "reality".* We shall see that even though the "parent" and "offspring" universes are not disconnected (the offspring being the outcome of a "vacuum fluctuation" in a tiny region of the parent), *the newborn will never develop and never 'exist' – within the eternal time frame of the parent!* And yet it will exist in its own time frame, an existence with a time-stretch spreading over billions of years – years that will *never* "come" for the parent's clocks. This leads to surprising metaphysical conclusions about our idea of *reality*, which has to be replaced by a new *"surreality".* We develop these points in the next sections. Before this, however, we review in this section the seeds of this conceptual revolution, as they already appear in the simplest problems in classical GR.

*Horizons*, as produced by GR, have been thoroughly studied by Penrose and described in the literature [5,6]. The conceptual issue we discuss here is present *classically* in the simplest Schwarzschild horizons. After the discovery of the quasars, Hoyle et al.[7] suggested that their energy originate in the gravitational collapse of very massive stars. It was then realized that in the formation of a black hole, the collapsing matter never really reaches its Schwarzschild radius, in the reference frame of a distant outside observer A. For a quasar this is of the order of $10^{16} cm$, thus yielding a density of $10^{-4} g/cm^3$ with very little chance for nuclear reactions to be initiated. This led to the suggestion that quasars are (extremely dense)*white holes*, rather than such rarefied *black holes* [8]. Returning to the collapsing star case, its matter accumulates as a shell close to the Schwarzschild radius, gradually becoming infinitely red-shifted, with time-dilation causing it to emit less and less all the time. The whole of A's 'eternity' then corresponds to one hour, in the reference frame of an observer B in the collapsing star, falling into the black hole. This is a common GR extension of the *twin paradox* of Special Relativity. In B's frame, however, things happen very fast: the Schwarzschild radius is reached and crossed within that hour and after another comparable stretch of B's time, he (or she) disappears in the $r = 0$ (classical) singularity. A metaphysical problem then arises – namely 'when' does this last half-hour of the collapsing star occur? Clearly, *half an hour after the end of (our) time!* The issue disappeared, however, when, as a result of the work of J. Bekenstein [9] and of S. Hawking [10], it was realized that quantum black holes, unlike the classical ones, evaporate away through quantum tunneling and through pair creation at the microscopic level. This causes a gradual shrinkage of the Schwarzschild radius and the vanishing of the horizon. Thus, the issue is only marginally present in black hole physics.

The constraints fixing the size of this contribution do not allow us to go into the actual formalism and we refer the reader to the publications listed in ref. [4]. We also recommend gaining insights through the study of the Schwarzschild solution in Kruskal-Szekeres coordinates [11] and through the latter's adaptation to de Sitter geometry by Gibbons and Hawking [12].

## 3. Non-overlapping Time-Extensions in "Eternal" Inflation

We now come to the related conceptual revolution with respect to time, in the context of Eternal Inflationary Cosmology [2]. The model assumes that the first stage (lasting some $10^{-35}$ sec) of a Big Bang follows a de Sitter Model (i.e. an exponential expansion), triggered by a large quantum vacuum energy-density $\lambda =< 0|V(\Phi)|0 >$; $V$ is the potential of the *inflaton*, e.g. the 'upper' Higgs at $E_{GUT} = 10^{16} GeV$. The scale function $S(t)$ is then given by $S(t) = exp(Ht)$, with Hubble constant $H = (8\pi G\lambda/3c^2)^{1/2}$. For this stage to last for a brief instant only and then to transit into the Friedmann model we observe, the vacuum energy 'trigger' has to correspond to a 'false' vacuum (e.g. the symmetric $\Phi = 0, V = 0$ solution for the quartic potential of the Higgs field), reached through a supercooling-like unstable procedure and easily replaced (through tunneling) by the true vacuum and Friedmann's slowed expansion. The 'falseness' of that vacuum is a necessary but not a sufficient condition as a 'gracious exit' from the inflationary regime proceeds through the merger of 'bubbles' of 'true' vacuum, forming inside the prevailing 'false' vacuum – a merger which has to overcome the exponential growth of the interbubble intervals. In the latest version [13] this is achieved by assuming Einsteinian gravity to represent the low-energy (long-range) regime of an Affine [14,15] or Conformal quantum gravity. Newton's "constant" is then $G = (16\pi < 0|\sigma|0 >)^{-1/2}$, $\sigma(t)$ the (Brans-Dicke like) dilaton field. In the Planck-energy regime of the de Sitter stage, $G$ isn't yet 'frozen' at this present value; the increasing $\sigma$ and decreasing $G$ then decrease $S(t)$, letting the bubble-merger process catch up.

Let us follow the birth of a new universe [16,17]. A vacuum fluctuation occurs (e.g. as the energy concentration in a topological defect, such as a cosmic string). The dimensions of this trigger could be as small as $10^3 - 10^9$ Planck lengths. At the end of the inflationary stage it will have reached the size of an orange – and $10^{10}$ years later (in its own frame B) it will look like our observable universe.

Outside observers A *will just note the creation of a tiny black-hole like object*, with only the very beginnings of an expansion, lasting in this state "forever", i.e. while $t \to \infty$ – very much like the case of the Schwarzschild horizon above. Our entire universe is an A frame and will *never* see the transformation of that tiny false vacuum region into anything else. However, for an inside frame of reference B, we have the birth of a de Sitter universe, a Big Bang, followed by the exit phase, then evolving into a new Friedmann (flat) universe – and perhaps, some $10^{10}$ years later, astronomers discussing horizons and concepts of reality. Note that classically, the new universe would have involved a singularity (a time-like half-line) due to the Penrose theorem – except that quantum tunneling makes it now possible for that budding 'world' to escape the theorem. In one such solution [16], the new universe starts with a configuration which, classically, would make it recollapse without inflation, a true black hole; *would thus have reached its ordained singularity in the future*. Instead, however, it quantum-tunnels into an exponentially inflating solution *whose classical singularity would have lain in the past*, thus avoiding the singularities altogether. It then goes on to make a universe, with the latter carrying no singularity 'blemish' and being in no way different from its parent, "our" present universe. Presumably, this is also how the universe we live in came into being, with an *eternal* lifetime and with no singularities. We should thus extend the Principle of Covariance to all such universes. They are all eternal - except that this is meaningless within our present conceptual framework: the new universe *will never exist, in our frame A, in all our time;* and yet it is as good as our own universe, will have (in its B frame) galaxies, suns, astronomers and physicists. So where and when does it exist? Note that the time variables in the two frames overlap before the "happy event" which triggers the birth of a universe. They then separate, B going it by itself, observing A fading away, flashing out its eternity in the infinitely red-shifted environment of the new Big Bang..

## 4. Transcendant time and Surreality

There is, presumably a countable infinity of such "eternities", branching out from each other, then separating, with the offspring, eternally "incubating" – without ever being born – in the parent universe's *reality.* [Semantically, *real* as against *abstract* implies *existence in spacetime as perceived in the user's frame*, which justifies our discussion of the effects of the above de Sitter horizons on *reality.*] And yet, beyond the parent's eternity, there is another full-fledged universe, the offspring, flourishing and "realizing itself".

This new picture calls for our conceptual framework to admit "surrealism", *i.e. "existence" beyond our subjective space and time [4].* Note that in the direction of the past, there is one world-line tying together all past eternities. (This construction misses 'brother' or 'cousin' universes, selecting only the line of direct descendance). We may use a "transcendant- time variable" $\tau$ ($A$ refers here to a frame in the $n-th$ universe, distant from the point where the $n+1-th$ universe will be born), $\tau = \sum^{\oplus}_{A^n, n\in Z(n)"} arctan[tanh(t_{A^n})]$ for a linear sequence. $Z(n)$" denotes all integer values between 0 and $n$. This time-resembling variable spans surreality; the genealogy of universes can be represented by $(\tau, \sum^{\oplus} t_n)$.

## References.

1. A.H. Guth, *Phys. Rev.* **D23** (1981), 347; A. Linde, *Phys. Lett.* **B108** (1982) 389; A. Albrecht, and P.J. Steinhardt, *Phys. Rev. Lett.*, **48** (1982) 1220.
2. A. Linde, *Phys. Lett.***B175** (1986) 395.
3. Recent reviews of Inflationary Cosmology: A.H. Guth, *Proc. Nat. Acad. Sci. USA*, **90** (1993) 4871; A. Linde, in *Gravitation and Modern Cosmology* 1991, A. Zichichi, ed., (New York: Plenum Press); P.J. Steinhardt P.J., *Class. Quantum Grav.*, **10** (1993) S33.
4. Y. Ne'eman, *Found. of Phys. Lett.*, to be pub. ; also "Inflation, the Top and all that" (Erice lectures, May 1994) to be pub. ; "Time after Time in Eternal Inflation" PASCOS 94 contribution, to be pub.
5. R. Penrose, *Phys. Rev. Lett.* **14** (1965) 57.
6. S.W. Hawking and G.F.R. Ellis, *The Large-Scale Structure of Spacetime*, Cambridge Un. Press, Cambridge (1973).
7. F. Hoyle, W.A. Fowler, G.R. Burbidge and E.M. Burbidge E.M., *Ap. J.* **139** (1964) 909.
8. I.D. Novikov I.D. *Astr. Zh.* **41** (1964) 1075; Y. Ne'eman *Ap. J.***141** (1965) 1303; Y. Ne'eman and G. Tauber *Ap. J.* **150** (1967) 755.
9. J.D. Bekenstein, *Lett. Nuovo Cim.* **4** (1972) 737; *Phys. Rev.* **D7** (1973) 2333.
10. S.W. Hawking, *Comm. Math. Phys.*4 (1975) 199; *Phys. Rev.* **D14** (1976) 2460.
11. M.D. Kruskal M.D., *Phys. Rev.* **119** (1960) 1743; G. Szekeres, *Pub. Math. Debrecen* **7** (1960) 285.
12. G.W. Gibbons and S.W. Hawking, *Phys. Rev¿***D15** (1977) 2738.
13. D. La and P.J. Steinhardt *Phys. Rev. Lett.* (1989) **62** 376.
14. Y. Ne'eman and Dj. Sijacki, *Phys. Lett.***B200** (1988) 286.
15. F.W. Hehl, J. Dermott McCrea, E. Mielke and Y. Ne'eman, "Metric Affine Gravity", to be pub. in *Physics Reports.*
16. E. Farhi, A.H. Guth and J. Guven, *Nucl. Phys.***B339** (1990) 417.
17. W. Fischler, D. Morgan and J. Polchinski, *Phys. Rev.* **D42** (1990) 4042.