New scenario for the early cosmology

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We need a unified theoretical framework that predicts a sharp transition between:

- Primordial cosmology with quantum gravity :

$$t \leq 10^{-32}s - \epsilon$$

- (Our) Cosmology phase with effective classical gravity everywhere :

$$t \geq 10^{-32}s + \epsilon$$

$\epsilon \sim 10^{-36}s$. **I call the epoch made of the last moments of this transition the exit of inflation, after which we can describe the evolution of the Universe by a standard 4d QFT's with a Lorentz time, a non zero cosmological constant and some (phenomenological) slowly disappearing inflaton field(s).**

Getting an initial condition as near as possible to $10^{-32}s + \epsilon$ is a fascinating problem, both experimentally as well as theoretically.

But both phases must be also described by the same microscopic theory (based on the Einstein equations).

Ordinary quantisation cannot define a Lorentz time evolution for gravity, so any attempt for a QFT for gravity must be computed as an Euclidean one. (Schwinger introduced Euclidean field theory in ∼1948, where $t \to x^4 = i\tau$).

The Lorentz time will emerge by the inverse Wick rotation as a possible parameter to order phenomena, if suitable conditions are gathered .

It won't emerge before the exit of inflation. Before, there is an interesting new Physics, with neither clocks nor particles. which I will explain.

The reason why one cannot describe quantum gravity as one does for the standard gauge theories.

- Standard quantisation of Quantum Gravity tells us that one cannot handle the Lorentz time consistently : In the canonical quantisation of gravity, the Wheeler–deWitt equation implies that the action of the Hamiltonian on physical states is zero, as a consequence of the invariance under reparametrisation.

Thus, no quantum gravity evolution in the Lorentz time can occur beyond perturbation theory !

- The standard and well-grounded QFT methodology is by defining first the Euclidean theory, then computing all Euclidean correlators of fields and proving eventually that they can be analytically continued in e.g. $x^4 \to it$, the so-called inverse Wick rotation. Then one tentatively computes S-matrix elements and decay probabilities of particles and understand what is a physical clock. In this way some $t \equiv ix^4$ can be used as an ordering parameter to describe the evolution of possible experiments for standard theories coupled to classical gravity. Causality follows.

But in Euclidean quantum gravity, the Euclidean weight $\int d^4x R\sqrt{g}$ is not positive and the Euclidean path integral of gravity is meaningless beyond perturbation theory.

Thus, there is nothing to Wick rotate from the beginning !

Warning : I will use the word : "stochastic quantisation".

Nothing to be worried : it's a great and physical way to understand the standard quantisation by path integral from a deeper point of view. It is swell under control. (A missing chapter in all elementary books).

Stochastic quantisation was introduced in the 60' by Kadanov and others to describe standard quantum mechanics, and generalised beautifully in 1981 for ordinary QFT's such as QCD by G. Parisi and Y.S. Wu.

The Langevin equation of stochastic quantisation is a key to understand/define the QFT path integral formula, and all its applications like perturbation theory, etc..., as the Langevin equation is a key to understand/define the Boltzmann thermal equilibrium formula.

Quantum gravity will be seen as an out of equilibrium statistical system, something we cannot be afraid of, because we can arrange gas systems that exist and don't thermalise.

The rules of the game:

For the evolution of the correlators of the 4d metrics and other fields that describe the whole physics, the Lorentz time is replaced by the so-called stochastic time in the primordial phase of the Universe.

The stochastic time is the exact analogous of the microscopic Langevin time in the Brownian motion, when one studies the approach to a thermal equilibrium. In the later case, one can clearly substitute the microscopic time to the macroscopic time to describe the physics. (Not easy experimentally, although possible in principle). The Lorentz time is a bit like the thermodynamic adiabatic time and there is no reason to assume that the stochastic time is unphysical.

The stochastic time has a scale $\Delta T \sim 10^{-70}s << \tau_{Planck}$. "Our" Lorentz time is an effective variable to describe the evolution that may or may not exist, depending on the phase of gravity that may occur. (Sorry, but quantum gravity is complicated ! Here I quote Polyakov.)

The primordial cosmology is made of oscillations in function of the stochastic time of the vacuum at the rate ΔT, counterbalanced by the emission of pairs of gravitational bound states. (This will define initial conditions in any inflation model as a distribution of primordial blackholes).

What may happen to end the metastable quantum regime ?

At a given value of the stochastic time, one given fluctuation can and will expand the 4d space so drastically that the quantum regime of oscillations will stop irreversibly.

Then a Universe where gravity is effectively classical will emerge, where the Lorentz time can be defined by the possibility of analytical continuations of all field correlator .

(This moment occurred at $t \sim 10^{-32}s$, from what we measure, and the transition may have last maybe for $t \sim 10^{-36}s$).

In this (our) classical gravity phase, only a deep inelastic scattering of "point like" particles, with $q^2 \sim 2pq \sim 1/\Delta T$, could reveal the quantum gravity regime. In such a deep inelastic scattering, each particle sees the other one as a cloud of microscopic black holes in the (5d) condition of the primordial cosmology for the very brief time of the collision. During the process the notion of Lorentz time disappears, but reappear asymptotically (as in a parton model).

This last remark is quite interesting.

In fact, the use of stochastic time to define and compute all Euclidean quantum field theory correlators of gauge theories was proposed in 1981 by Parisi and Wu (somehow inspired by Monte Carlo simulations).

It is a deeper approach to QFT, exactly as the Langevin approach to the thermal equilibrium of a gaz is a deeper approach to the Boltzmann approach.

$$\text{Brownian motion}: \ \Delta \mathrm{T}\frac{\partial^2}{\partial^2_\tau}\tilde{\mathrm{v}}(\tau)+\frac{\partial}{\partial_\tau}\tilde{\mathrm{v}}(\tau) = -\tilde{\mathrm{v}}(\tau)+\sqrt{\mathrm{kT}}\,\tilde{\eta}(\tau) \quad ; << \eta(\tau_1), ..., \eta(\tau_\mathrm{n} >> \equiv \int [\mathrm{d}\eta]\eta(\tau_1)....\eta(\tau_\mathrm{n}) \exp - \int \frac{1}{2}\eta^2$$

$$\text{Langevin proved}: \quad \boxed{\lim_{\tau\to\infty} << v(\tau), ..., v(\tau) >> = \int [dv] v^n \exp - \int \frac{\frac{1}{2}v^2}{kT}}$$

$$\text{Stochastic quantisation}: \ \Delta \mathrm{T}\frac{\partial^2}{\partial^2_\tau}\phi(\mathrm{x},\tau)+\frac{\partial}{\partial_\tau}\phi(\mathrm{x},\tau) = \frac{\delta \mathrm{S}}{\delta\phi(\mathrm{x},\tau)}+\sqrt{\hbar}\,\eta(\mathrm{x},\tau) \quad ; << \eta....\eta >> \equiv \int [\mathrm{d}\eta]_{\tau,\mathrm{x}}\eta, ..., \eta \exp - \int \frac{1}{2}\eta^2$$

$$\text{Parisi} - \text{Wu et al proved}: \quad \boxed{\lim_{\tau=\infty} << \phi(x_1,\tau), ..., \phi(x_n,\tau) >> = \int [d\phi]\phi(x_1)....\phi(x_n) \exp - \frac{1}{\hbar}S[\phi]}$$

Lorentz time becomes a secondary entity, as well as the the standard quantization pattern. One thus can check its possible emergence instead of postulating its existence.

The details of the gravity Langevin equation valid in both classical and quantum phases of gravity:

Some work is needed to enforce general 4d covariance at each value of the stochastic time (with Luca Ciambelli and Siye Wu, https://arxiv.org/pdf/1909.11478.pdf).

The covariant Langevin equation or the unimodular part $\hat{g}_{\mu\nu}(\tau, x^\mu)$ of the metrics is :

$$\Delta T\left(\hat{\gamma}^T_{\mu\nu} + 4\tilde{\partial}_\tau\phi\hat{D}^T_\tau\hat{g}_{\mu\nu}\right) + \hat{D}^T_\tau\hat{g}_{\mu\nu} = -\hat{\mathcal{N}}(\hat{E}^T_{\mu\nu} - (d-2)(\hat{\nabla}_\mu\partial_\nu\phi - \partial_\mu\phi\partial_\nu\phi)^T) + \sqrt{\hbar}\ \hat{\eta}^T_{\mu\nu}.$$

For the conformal factor $\phi(\tau, x^\mu)$of the metrics, it is:

$$\Delta T(\hat{\gamma} + 2d\tilde{\partial}^2_\tau\phi + 4d(\tilde{\partial}_\tau\phi)^2 - 8\tilde{\partial}_\tau\phi\hat{\nabla}_\mu\hat{N}^\mu) + 2(d\tilde{\partial}_\tau\phi - \hat{\nabla}_\mu\hat{N}^\mu)$$
$$= \frac{\hat{\mathcal{N}}}{2}(1 - d\lambda)(d-2)\left(\hat{R} - 2(d-1)\hat{g}^{\mu\nu}\left(\hat{\nabla}_\mu\partial_\nu\phi + \frac{d-2}{2}\partial_\mu\phi\partial_\nu\phi\right)\right) + 2d\exp(\phi)\hat{N} + \sqrt{\hbar}\ \hat{\eta}.$$

(These Langevin equations have a very interesting geometrical interpretation in the mathematical language of foliations.)

In primordial cosmology, there are only oscillations of the Euclidian correlators of all fields (metrics and YM fields) in function of the stochastic time. Their rate is as fast as the microscopic frequency $1/\Delta T$:

$$\Delta T << \tau_{Planck}$$

implying some new early Physics. No smooth infinite stochastic time limit of the field correllators can occur toward an equilibrium distribution.

The four coordinates x^μ of $\phi(\tau) \equiv g_{\mu\nu}(\tau, x^\mu)$ remain Euclidean, because there is no way to do the Wick rotation at finite τ.

In fact, having no Lorentz time is physically consistent because no particles can emerge when the space is so small that there is no room to contain them and thus no clock can exist.

Before the exit of inflation : no clock $< - - -- >$ no Lorentz time

We have a 5d-QFT, which is the quantum phase of quantum gravity. This phase of the primordial Universe is as much different from that of the post-inflation Universe where we live, as iced water is different from steamed water !

The definition of our phase is that it has a Lorentz time to order phemomena, as demonstrated by the far than obvious possibility of building synchronised clocks.

Then we have a phase transition just due to a single fluctuation after which the metrics will becomes very diluted. It must occur because the primordial violent fluctuations of the gravity vacuum counter-balanced by emissions and absorptions of 4d Euclidean gravitational states (sorts of e.g. black holes with 4d wave functions) can strongly change the size of the Universe.

In a picturesque way, we can see that the primordial Universe functions as a resonant cavity where the vacuum oscillations go together with counterbalancing Schwinger effects.

The details and the duration ($10^{-36}s$?) of the sharp transition itself are rather irrelevant but certainly beautiful to observe, were it possible.

The relevant prediction is that gravity can and will brutally become classical after wild oscillations in the stochastic time.

Once gravity becomes classical, the effective thermalisation in function of the stochastic time evolution for computing quantum matter amplitudes is almost instantaneous as compared to the time scales of our most advanced standard clocks. Everything can be effectively described most precisely by the equilibrium distribution

$$\exp -\frac{1}{\hbar} S[g^{cl}_{\mu\nu}, A, .., \varphi^{inflaton}]$$

$\rightarrow$ all our standard computations of field correlators for CMB, etc...

In this phase where gravity has become effectively classical everywhere, the analyticity properties of all correlators allow the Wick rotation and the use of a Lorentz time to describe the evolution of Physics.

The standard QFT methods are then sufficient to compute the decay rate of particles (that can be proven to exist as poles in the 2-point functions), as well as their scattering processes. Moreover one use them to build clocks and check the effective existence of the Lorentz time. it's a matter of experimental physics to build more and more accurate clocks in atomic physics (up to a precision $10^{-18}s$ and accelerator physics (up to $10^{-27}s$) from the measured form-factors of LHC.

To summarise :

Before the exit of inflation, gravity is in its quantum phase, with Euclidean correlations functions that cannot be Wick rotated, so there is no Lorentz time in its 5-dimensional physics.

There is only the stochastic time to order the phenomena in this primordial phase that contains no particles, with no scattering and no clock that can possibly exist.

The primordial Physics looks thus not the same as the one after the exit of the inflation, but the fields are identical with the same microscopic interactions, albeit they are organised in a different phase,

What is truly relevant is that the same theory describes both the classical and quantum phases of gravity.

Conclusion Stochastic quantisation is a way to work out gravity, because it goes deeper in the formalism of classical and quantum field theory, using the robust notion of a quantum noise.

It's predictions when gravity is very strong are heuristically described by saying that the quantum gravity regime is a gravitational coherent state oscillating in a very small early 5d universe with creations and absorptions of 4d bound states by generalised Schwinger effect. Such fluctuations with no smooth thermalisation have stochastic time dependent correlators that define the quantum gravity phase. This metastable phase must end with probability one by the exit of the inflation, leaving us with an initial condition for the inflation model(s), which is a quite diluted classical universe filled with a given distribution of scattered primordial classical blackholes (to be fitted).

After the exit of inflation, gravity becomes effectively classical with a possible Wick rotation. Then the space is big enough to contain particles, allowing the existence of clocks, created by standard cosmology mechanisms and decays of primordial lightest blackholes. The heaviest ones are still around... There are (will be) multiple ways to observe the last moments of the exit of inflation and the disappearance of inflaton fields, using the effective Lorentz time to parametrise the propagation of signals. But no instruments can be build at the right scale to detect the 5d phase predicted by stochastic quantisation.