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Negative Energies and a Constantly Accelerating Flat Universe

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It has been shown that in the context of General Relativity (GR) enriched with a new set of discrete symmetry reversal conjugate metrics, negative energy states can be rehabilitated while avoiding the well-known instability issues. We review here some cosmological implications of the model and confront them with the supernovae and CMB data. The predicted flat universe constantly accelerated expansion phase is found to be in rather good agreement with the most recent cosmological data.

I. INTRODUCTION

One of the most challenging tasks in contemporary physics is to understand the observational results indicating that we are living in a flat accelerating universe. The most popular interpretation is that we are dominated by a homogeneous component with negative pressure often called dark energy. The supernovae data from [2] indicate that the equation of state of this dark energy is compatible with the 'concordance model' ($\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, w=p/ρ=-1) but a careful interpretation of the data [3] shows that a component with w < -1 is allowed. Models with very exotic $w(z)$ may come from modified gravity and have very different consequences for the fate of the Universe[4]. Such models are quite unsatisfactory since they inevitably lead to a generic violation of positive energy conditions resulting in vacuum quantum instabilities [12] [13] [14] [15].

However, alternative proposals have been made [10] [17] where the local instability issue can be avoided because the interaction between the positive and negative energy universes is global. The model presented in [10] is particularly attractive since the conjugate universe and its negative energy content are not introduced by hand but emerge as a result of imposing new symmetries on the initial action. It is also very predictive: flatness is mandatory and a constant acceleration phase is one of the very few mathematical possibilities in such a tightly constrained theoretical framework. We confront in this paper its predictions to present observationnal data.

II. MOTIVATIONS FOR A MODIFIED GR

Investigation of negative energies in Relativistic Quantum Field Theory (QFT) indicates that the correct theoretical framework should be found in a modification of General Relativity (GR) [5].

- TheoreticaI motivations

In second quantification, all relativistic field equations admit genuine negative energy field solutions creating and annihilating negative energy quanta. Unitary time reversal links these fields to the positive energy ones. The unitary choice, usual for all other symmetries in physics, also allows us to avoid the well known paradoxes associated with time reversal. Positive and negative energy fields vacuum divergences encountered after second quantization, are unsurprisingly found to be exactly opposite. The negative energy fields action must be maximised. However, there is no way to reach a coherent theory involving negative energies in flat-spacetime. Indeed, if positive and negative energy scalar fields are time reversal conjugate, so must be their Hamiltonian densities and actions. This is only possible in the context of GR thanks to the metric transformation under discrete symmetries.

- Phenomenological motivations

In a mirror negative energy world, whose fields remain non coupled to our world positive energy fields, stability is insured and the behavior of matter and radiation is as usual. Hence, it is just a matter of convention to define each one as a positive or negative energy world. Otherwise, if they interact gravitationally, promising phenomenology is expected. Indeed, many outstanding enigmas indicate that repelling gravity might play an important role in physics: flat galactic rotation curves, the Pioneer effect, the flatness of the universe, acceleration and its voids, etc... But negative energy states never manifested themselves up to now, suggesting that a barrier is at work preventing the two worlds to interact except through gravity.

- A modified GR to circumvent the main issues

A trivial cancellation between vacuum divergences is not acceptable since the Casimir effect shows evidence for vacuum fluctuations. But the positive and negative energy worlds could be maximally gravitationally coupled in such a way as to produce at least exact cancellations of vacuum energies gravitational effects. Also, a generic catastrophic instability issue arises whenever quantum positive and negative energy fields are allowed to interact. If we restrict the stability issue to the modified gravity, this disastrous scenario is avoided. Finally, allowing both positive and negative energy virtual photons to propagate the electromagnetic interaction, simply makes it disappear. The local gravitational interaction is treated very differently in our modified GR .So this unpleasant feature is also avoided.

III. CONJUGATE WORLDS GRAVITATIONAL COUPLING

Ref. [11] shows that time reversal does not affect a scalar action. However, if the inertial coordinates ξ^α are transformed in a non-trivial way:

$$\xi^\alpha \xrightarrow{T} \tilde{\xi}^\alpha_T \tag{1}$$

where $\tilde{\xi}^\alpha \neq \xi_\alpha$, metric terms are affected and the action is not expected to be invariant under T. Having two conjugate inertial coordinate systems, two time reversal conjugate metric tensors can be built:

$$g_{\mu\nu} = \eta_{\alpha\beta} \frac{\partial \xi^\alpha}{\partial x^\mu} \frac{\partial \xi^\beta}{\partial x^\nu}, \quad \tilde{g}_{\mu\nu} = \eta_{\alpha\beta} \frac{\partial \tilde{\xi}^\alpha}{\partial x^\mu} \frac{\partial \tilde{\xi}^\beta}{\partial x^\nu} \tag{2}$$

Then, a new set of fields couples to the new $\tilde{g}_{\mu\nu}$ metric field. The total action is the sum of I_M, the usual action for matter and radiation in the external gravitational field $g_{\mu\nu}$, $\tilde{I}_M$ the action for matter and radiation in the external gravitational field $\tilde{g}_{\mu\nu}$ and the actions $I_G + \tilde{I}_G$ for the gravitational fields alone. The conjugate actions are separately general coordinate scalars and adding the two pieces is necessary to obtain a discrete symmetry reversal invariant total action. $g_{\mu\nu}$ and $\tilde{g}_{\mu\nu}$ are linked since these are symmetry reversal conjugate objects, explicitly built out of space-time coordinates. We postulate that there exists a privileged general coordinate system such that $\tilde{g}_{\mu\nu}$ identifies with $g^{\mu\nu}$, where for instance a discrete time reversal transformation applies as $x^0 \rightarrow -x^0$. In this system, varying the action, applying the extremum action principle and making use of the relation $\delta g^{\rho\kappa}(x) = -g^{\rho\mu}(x)\, g^{\nu\kappa}(x)\, \delta g_{\mu\nu}(x)$ leads to a modified Einstein equation only valid in the privileged coordinate system. This equation is not general covariant and not intended to be so.

IV. MODIFIED COSMOLOGY

Following the method outlined in the previous section, local solutions satisfying the symmetry invariance requirements under Parity or space/time exchange transformations have been found and interpreted in [10]. In the case of cosmology and time reversal, there exists one global privileged coordinate system where a couple of purely time dependent time reversal conjugate solutions can be derived from the couple of conjugate actions. The existence of a time reversal conjugate universe was also suggested a long time ago in Ref. [16]. The only possible privileged coordinate system where both metrics are spatially homogeneous and isotropic is the flat Cartesian one:

$$d\tau^2 = B(t)dt^2 - A(t)dx^2 \tag{3}$$

The privileged coordinate system is the conformal time system where $B = A$. Expressing in the polar coordinate system, the modified cosmological Einstein equations are:

$$3A\left(-\frac{\ddot{A}}{A} + \frac{1}{2}\left(\frac{\dot{A}}{A}\right)^2\right) - \frac{3}{A}\left(\frac{\ddot{A}}{A} - \frac{3}{2}\left(\frac{\dot{A}}{A}\right)^2\right) = 0 \tag{4}$$

The purely time dependent scale factor evolution is then driven (a nondimensional time unit is used) by the following differential equations in the three particular domains:

$$a << 1 \Rightarrow \ddot{a} \propto \frac{3}{2}\frac{\dot{a}^2}{a} \Rightarrow a \propto 1/t^2 \text{ where } t < 0, \tag{5}$$

$$a \approx 1 \Rightarrow \ddot{a} \propto \frac{\dot{a}^2}{a} \Rightarrow a \propto e^t, \tag{6}$$

$$a >> 1 \Rightarrow \ddot{a} \propto \frac{1}{2}\frac{\dot{a}^2}{a} \Rightarrow a \propto t^2 \text{ where } t > 0. \tag{7}$$

We check that $t \rightarrow -t$ implies $1/t^2 \rightarrow t^2$ but also $e^t \rightarrow e^{-t}$, as required. Flatness is the main prediction of this model. A striking and very uncommon feature is that the evolution of the scale factor is completely independent of the matter and radiation content in the two universes. In particular, the observed flatness can no longer be translated into the usual estimation of $\Omega_m = 1$ from the WMAP data [6]. According the t^2 evolution, we are most probably living in a constantly accelerating universe. Our and the conjugate universe either have crossed in the past or will cross each other and time reversal will occur in the future. Our universe is accelerated without any need for a cosmological constant or dark energy component No source enters our cosmological equation except at the crossing time where a small perturbation is needed to start the non stationary cosmological solutions.

V. APPLICATION TO SUPERNOVAE DATA

We have confronted this model with the existing supernovae data published by [2]. The luminosity distance, for a flat constantly accelerated (t^2 evolution) universe is:

$$d_L = a_0 r_l (1+z) = \frac{2}{H_0}(\sqrt{1+z}-1)(1+z) \qquad (8)$$

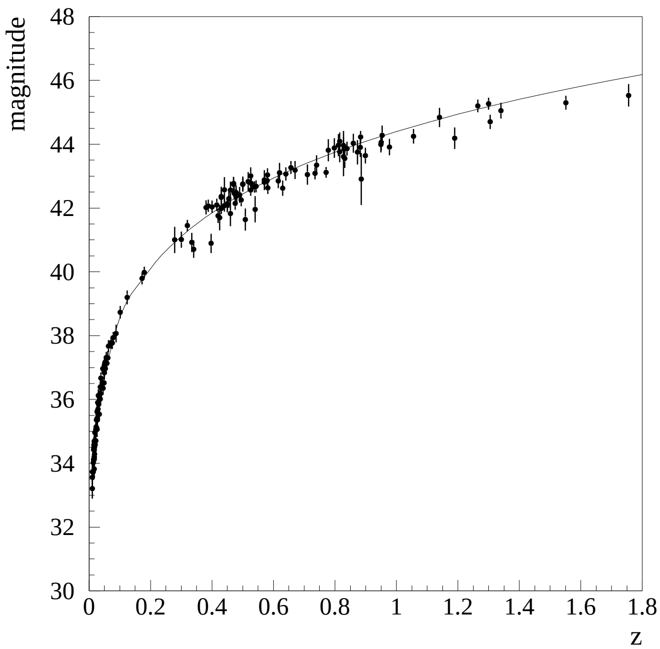

FIG. 1: The distance luminosity prediction of this model compared to the present supernovae data

Figure 1 shows the fitted magnitude versus redshift curve from the model, where the only free parameter is the normalisation parameter $\mathrm{m_s}$, compared to the observational data derived from the gold sample of [2]. The quality of the fit is estimated with the computed χ^2 to be at a 2% confidence level (CL). This should be compared to the 11% confidence level found by using the standard ΛCDM model with no prior. Fitting our model on the SCP data [1] leads to a 59% confidence level compatibility, to be compared with a 56% confidence level using the ΛCDM model.

To go further in this analysis, we parametrise the scale factor evolution as a simple power low $\mathrm{a} \propto \mathrm{t}^\alpha$. The luminosity distance reads:

$$d_L = \frac{1}{H_0}\frac{\alpha}{\alpha-1}((1+z)^{1-1/\alpha}-1)(1+z) \qquad (9)$$

Fitting simultaniously $\mathrm{m_s}$ and α on the Riess gold data sample gives $\alpha = 1.41 \pm 0.13$ which is 4.5σ away from the predicted value. Assuming a simple variation of the intrinsic supernovae magnitude versus the redshift $\partial \mathrm{m_s}/\partial \mathrm{z} = 0.15$ which is below the current statistical error, leads to a systematical error : $+0.5-0.3(syst.)$ for this model, both for Riess [2] and SCP [1] data. This shows that the power law parametrisation is much more sensitive to systematical errors than the standard fitting procedure including evolution of the equation of state [2]. In conclusion, the current precision is not sufficient to discriminate between the ΛCDM model and the model presented here.

We have then investigated the expected sensitivity with future SN projects. We simulate the SNLS [8] [9] experiment expecting about 700 SNIa with redshifts up to about 1, adding 300 simulated nearby SNIa from the future SN factory project and using ΛCDM as fiducial model. We get $\alpha = 1.26 \pm 0.04(\mathrm{stat.}) \pm 0.3(\mathrm{syst.})$, where the systematical error has been evaluated using a 10% evolution on the intrinsic magnitude with redshift. Thus the SNLS experiment will be able to distinguish between the ΛCDM model and this one at a 3 sigma level.

The SNAP/JDEM [7] mission will observe about 2000 SNIa with redshifts up to 1.7. The intrinsic evolution of SNIa magnitudes is expected to be controlled at the percent level. Again, using ΛCDM as a fiducial model and 300 SNIa from the SN factory model gives:$\alpha = 1.24 \pm 0.02(\mathrm{stat.}) \pm 0.04(\mathrm{syst.})$, where the systematical error is coming from a 2% remaining possible evolution of the intrinsic magnitude. The SNAP/JDEM mission will thus definitely answer the question of the compatibility of this new model with supernovae observations.

Finally, as explained in [10], the constantly accelerated evolution could be affected by Pioneer like effets (as it is indeed in our neighborhood) resulting in locally inverted evolutions of space-space metric elements. This should result in a systematical drift proportional to the relative photons time of flight accross the regions with inverted cosmological regime along their path. The effect predominantly affects the higher redshift part of the path, when the matter structure (living in the inverted regime) occupied a relatively more important fraction of space, so a jerk behaviour is a natural outcome of the model. This could account for the difference between the constantly accelerated regime prediction of this model and the current data favoring a recent transition from a decelerating to an accelerating universe.

VI. CONCLUSION

Introducing discrete symmetries in the context of General Relativity not only allows to solve many long lasting theoretical issues such as negative energies and stability, QFT vacuum divergences and the cosmological constant but also leads to very remarkable phenomenological predictions. A constantly accelerating necessarily flat universe is a natural outcome of the model and cannot be excluded by present data The large scale structure formation and evolution need to be completely revisited in the new context where the rules of the game are significantly modified due to the interactions between conjugate density fluctuations. Last, as shown in [10], the space/time exchange symmetry allows the derivation of a propagating solution and the clarification of the status of tachyonic representations. The published supernovae data are not in disagreement with this model. The one is very sensitive to systematical effects. Therefore, only the SNAP/JDEM mission should be able to distinguish without ambiguity between standard cosmology and a constantly accelerated regime as predicted by the new model in the case where no pioneer-like theoretical systematical effect is to be expected.

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