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The dark side of gravity and the acceleration of the universe

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The Dark Gravity theory allows to understand the observed recent acceleration of the universe in a very original way which was presented at the "2nd world submit on exploring the dark side of the universe" along with one of the main predictions of the theory : the avoidance of a true Black Hole Horizon. A complete, regularly updated, review of the theory and full references can be found in [1].

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1. Introduction

In the seventies, theories with a flat non dynamical background metric and/or implying many kinds of preferred frame effects became momentarily fashionable and Clifford Will has reviewed some of them (Rosen theory, Rastall theory, BSLL theory ...) in his book. Because those attempts were generically roughly conflicting with accurate tests of various versions of the equivalence principle, the flat non dynamical background metric was progressively given up. The Dark Gravity (DG) theory we support here is a remarkable exception as it can easily reproduce most predictions of GR up to Post Newtonian order (as we shall remind in the two following sections) and for this reason deserves much attention since it might call into question the assumption behind most modern theoretical avenues: background independence. DG follows from a crucial observation: in the presence of a flat non dynamical background $\eta_{\mu\nu}$, it turns out that the usual gravitational field $g_{\mu\nu}$ has a twin, the "inverse" metric $\tilde{g}_{\mu\nu}$. The two being linked by :

$$\tilde{g}_{\mu\nu} = \eta_{\mu\rho}\eta_{\nu\sigma}\left[g^{-1}\right]^{\rho\sigma} = \left[\eta^{\mu\rho}\eta^{\nu\sigma}g_{\rho\sigma}\right]^{-1} \tag{1.1}$$

are just the two faces of a single field (no new degrees of freedom) that we called a Janus field.

The action treating our two faces of the Janus field on the same footing is achieved by simply adding to the usual action, the similar action with $\tilde{g}_{\mu\nu}$ in place of $g_{\mu\nu}$ everywhere.

$$\int d^4x(\sqrt{g}R + \sqrt{\tilde{g}}\tilde{R}) + \int d^4x(\sqrt{g}L + \sqrt{\tilde{g}}\tilde{L}) \tag{1.2}$$

where R and $\tilde{R}$ are the familiar Ricci scalars respectively built from $g_{\mu\nu}$ and $\tilde{g}_{\mu\nu}$ as usual and L and $\tilde{L}$ the Lagrangians for respectively SM F type fields propagating along $g_{\mu\nu}$ geodesics and $\tilde{F}$ fields propagating along $\tilde{g}_{\mu\nu}$ geodesics. This theory symmetrizing the roles of $g_{\mu\nu}$ and $\tilde{g}_{\mu\nu}$ is Dark Gravity (DG) and the field equation satisfied by the Janus field derived from the minimization of the action is:

$$\sqrt{g}\eta^{\mu\sigma}g_{\sigma\rho}G^{\rho\nu} - \sqrt{\tilde{g}}\eta^{\nu\sigma}\tilde{g}_{\sigma\rho}\tilde{G}^{\rho\mu} + \mu \leftrightarrow \nu = -8\pi G(\sqrt{g}\eta^{\mu\sigma}g_{\sigma\rho}T^{\rho\nu} - \sqrt{\tilde{g}}\eta^{\nu\sigma}\tilde{g}_{\sigma\rho}\tilde{T}^{\rho\mu} + \mu \leftrightarrow \nu) \tag{1.3}$$

with $T^{\mu\nu}$ and $\tilde{T}^{\mu\nu}$ the energy momentum tensors for F and $\tilde{F}$ fields respectively and $G^{\mu\nu}$ and $\tilde{G}^{\mu\nu}$ the Einstein tensors (e.g. $G^{\mu\nu} = R^{\mu\nu} - 1/2g^{\mu\nu}R$). We find that, at least about a Minkowskian background common to the two faces of the Janus field, instabilities are trivially avoided because:

- Fields minimally coupled to the two different sides of the Janus field never meet each other from the point of view of the other interactions (EM, weak, strong) so stability issues could only arise in the purely gravitational sector.
- The run away issue is avoided between two masses propagating on $g_{\mu\nu}$ and $\tilde{g}_{\mu\nu}$ respectively, because those just repel each other, anti-gravitationally as in all other versions of DG theories rather than one chasing the other ad infinitum.
- The energy of DG gravitational waves vanishes about a common Minkowski background (DG has a vanishing energy momentum pseudo tensor $t_{\mu\nu} - \tilde{t}_{\mu\nu}$ in this case) avoiding for instance the instability of positive energy matter fields through the emission of negative energy gravitational waves.

The theoretical motivations for studying as far as possible a theory such as DG are three-fold:

- Challenge the idea of background independence because DG is the straightforward generalization of GR in presence of a background non dynamical metric so either there is no such background and GR is most likely the fundamental theory of gravity or there is one and DG is the most obvious candidate for it.
- Bridge the gap between the discrete and the continuous because we here have both the usual continuous symmetries of GR but also a permutation symmetry which is a discrete symmetry between the two faces of the Janus field.
- Challenge the standard understanding of time reversal because as we shall see the two faces of the Janus field are related by a global time reversal symmetry.

2. Global gravity

2.1 The scalar-η cosmological field

We found that an homogeneous and isotropic solution is necessarily spatially flat because the two sides of the Janus field about our flat Minkowski non dynamical metric are required to satisfy the same isometries. However, it is also static so that the only way to save cosmology in the DG framework is to introduce a η-scalar Janus field built from our non dynamical background and a scalar Φ such that $g_{\mu\nu} = \Phi\eta_{\mu\nu}$ and $\tilde{g}_{\mu\nu} = \frac{1}{\Phi}\eta_{\mu\nu}$. Then our fundamental cosmological single equation obtained by requiring the action to be extremal under any variation of $\Phi(t) = a^2(t)$ is:

$$a\ddot{a} - \tilde{a}\ddot{\tilde{a}} = \frac{4\pi G}{3}(a^4(\rho - 3p) - \tilde{a}^4(\tilde{\rho} - 3\tilde{p})) \tag{2.1}$$

where $\tilde{a}(t) = \frac{1}{a(t)}$. With this scalar cosmology we avoid all the normal degrees of freedom of a metric and corresponding two Friedmann type equations which for a spatial curvature k=0, could only be satisfied all together by a static solution for any equations of state. An independent other Janus field is then of course required to describe all other (other than cosmological) aspects of gravity with all it's usual degrees of freedom, but then a field forced to remain asymptotically static to satisfy all the equations. Discussion of the implications and how to unify the two sectors in order to correctly reproduce results of GR theory of small fluctuations in DG, can be found in [1].

2.2 Cosmology

2.2.1 Continuous evolution and discontinuous permutation

The expansion of our side implies that the dark side of the universe is in contraction. Provided dark side terms can be neglected, our cosmological equation reduces to a cosmological equation known to be also valid within GR. For this reason it is straightforward for DG to reproduce the same scale factor expansion evolution as obtained within the standard LCDM Model at least up to the redshift of the LCDM Lambda dominated era when something new must have started to drive the evolution in case we want to avoid a cosmological constant term. The evolution of our side scale factor before the transition to the accelerated regime is depicted on the left of Figure 1 as a function of the conformal time t and the corresponding evolution laws as a function of standard time t' are also given in the radiative and cold era. Notice however the new behaviour about t=0 meaning that the Big-Bang singularity is avoided.

A discontinuous transition is a natural possibility within a theory involving truly dynamical discrete symmetries as is our permutation symmetry in DG. The basic idea is that some of our beloved differential equations might only be valid piecewise, only valid in the bulk of space-time domains at the frontier of which new discrete rules apply implying genuine field discontinuities. Given that our cosmological equation (2.1) is actually invariant under the combined permutations of densities and scale factors rather than permutation of scale factors alone, we can even specify two kinds of triggering conditions for a permutation to occur: either (A) a scale factor permutation can occur at the crossing when we have equal density source terms; or similarly when the scale factors cross each other (which defines the origin of time), it is the permutation of the densities (B) which is allowed corresponding to the two metrics exchanging their matter and radiation content.

We thus postulated that a transition (A) occurred billion years ago as a genuine permutation of the conjugate scale factors, understood to be a discrete transition in time modifying all terms explicitly depending on $a(t)$ but not the densities and pressures themselves in our cosmological equation (2.1). This permutation (at the green point depicted on figure 1) could produce the subsequent recent acceleration of the universe. This was demonstrated assuming our side source $a^4(\rho-3p)$ term has been dominant and therefore has driven the evolution up to the transition to acceleration triggered when $\rho-3p=\tilde{\rho}-3\tilde{p}$. Then, following the transition, the dark side source term have started to drive the evolution: $a^4(\rho-3p) << \tilde{a}^4(\tilde{\rho}-3\tilde{p})$ resulting from $a(t) << \tilde{a}(t)$.

If the two kind of transitions (A and B) are actually occurring, the solutions then turn out to satisfy the fundamental relation $\tilde{a}(t)=\frac{1}{a(t)}=a(-t)$ and for this reason, we could interpret our permutation symmetry as a global time reversal symmetry about privileged origin of conformal time t=0. Moreover B results in the inversion of densities evolution laws i.e from decreasing to increasing or vice versa, so that the evolution of both densities and scale factors are cyclic as explained in more details in [1]. For the scale factors to exchange their respective values (A) at the equality of densities, we just need to jump from t to -t as illustrated in fig 1.

2.2.2 An acceleration scenario

Let's assume the dark side is also in a cold era at the transition and satisfies $\tilde{\rho}-3\tilde{p}\approx\tilde{\rho}=\rho-3p\approx\rho$. Then the continuity of the Hubble rate is automatically satisfied. This leads to a constantly accelerated universe $a(t')\approx t'^2$ in standard coordinate following the transition redshift.

Constraining the age of the universe to be the same as within LCDM the transition redshift can be predicted and confronted to the measured value $z_{tr}=0.67\pm0.1$. The prediction is $z_{tr}=0.78$ in very good agreement with the measured transition redshift. Another scenario leading to an exponential acceleration is discussed in [1]. Eventually our framework has a single parameter replacing the cosmological constant: the redshift of densities equality i.e. the transition redshift z_{tr}.

3. Local gravity: the isotropic case about Minkowski

The isotropic solution in vacuum of the form $g_{\mu\nu}=(-B,A,A,A)$ in e.g. $d\tau^2=-Bdt^2+$

$A(dx^2+dy^2+dz^2)$ and $\tilde{g}_{\mu\nu} = (-1/B, 1/A, 1/A, 1/A)$.

$$A = e^{\frac{2MG}{r}} \approx 1+2\frac{MG}{r}+2\frac{M^2G^2}{r^2} \qquad B = \frac{1}{A} = -e^{\frac{-2MG}{r}} \approx -1+2\frac{MG}{r}-2\frac{M^2G^2}{r^2}+\frac{4}{3}\frac{M^3G^3}{r^3} \quad (3.1)$$

is perfectly suited to represent the field generated outside an isotropic source mass M. This solution is different from the GR one, though in good agreement up to Post-Newtonian order and it involves no horizon. It also confirms that a positive mass M in the conjugate metric is seen as a negative mass -M from its gravitational effect felt on our side. The linearized equations about a common Minkowskian background allow to define the pseudo energy-momentum tensor of the gravitational field itself which vanishes. However with differing asymptotic values we shall show that DG approximately reproduces most GR predictions.

4. Differing asymptotic values

Due to expansion on our side and contraction on the dark side the common Minkowskian asymptotic value of our previous section is actually not a natural assumption. At the contrary a field assumed to be asymptotically $C^2\eta_{\mu\nu}$ with C constant has its conjugate asymptotically $1/C^2\eta_{\mu\nu}$ so their asymptotic values should differ by many orders of magnitude.

Given that $g^{C^2\eta}_{\mu\nu} = C^2 g^{\eta}_{\mu\nu}$ and $\tilde{g}^{\eta/C^2}_{\mu\nu} = \frac{1}{C^2}\tilde{g}^{\eta}_{\mu\nu}$, where the $< g^\eta, \tilde{g}^\eta >$ Janus field is asymptotically η, it is straightforward to rewrite the local DG Janus Field equation now satisfied by this asymptotically Minkowskian Janus field after those replacements (here only the time-time equation):

$$C^2\sqrt{g}\frac{G_{tt}}{g_{tt}} - \frac{1}{C^2}\sqrt{\tilde{g}}\frac{\tilde{G_{tt}}}{\tilde{g}_{tt}} = -8\pi G(C^4\sqrt{g}\delta\rho - \frac{1}{C^4}\sqrt{\tilde{g}}\tilde{\delta\rho}) \quad (4.1)$$

where $G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$ and $\delta\rho$ is as usual the energy density for matter and radiation density fluctuations. Notice that for no fluctuations, the solutions are Minkowskian as needed. Then for $C >> 1$ we are back to $G_{tt} = -8\pi GC^2 g_{tt}\delta\rho$, a GR like equation for local gravity from sources on our side because all terms depending on the conjugate field become negligible on the left hand side of the equation while the local gravity from sources on the dark side is attenuated by the huge $1/C^8$ factor (in the weak field approximation, $G_{tt} = 8\pi G\frac{\delta\tilde{\rho}}{C^6}$). So for $C >> 1$ we expect the same gravitational waves emission rate as within GR and the same weak gravitational field. However on the dark side everything will feel the effect of the anti-gravitational field from bodies on our side amplified by the same huge factor relative to the gravity produced by bodies on their own side. Of course the roles are exchanged in case $C << 1$. Only in case C=1 would we recover our exponential dark gravity, with no significant GW radiations and also a strength of gravity ($G_{tt} = -4\pi G\delta\rho$) reduced by a factor $2C^2$ relative to the above approximately GR gravity.

5. Back to Black-Holes and gravitational waves

For C-asymptotic isotropic static metrics of the form $g_{\mu\nu} = (-B, A, A, A)$ in e.g. $d\tau^2 = -Bdt^2 + A(dx^2+dy^2+dz^2)$ and $\tilde{g}_{\mu\nu} = (-1/B, 1/A, 1/A, 1/A)$. With $A = C^2e^a$ and $B = C^2e^b$, we get the differential equations satisfied by a(r) and b(r):

$$a'' + 2a' + \frac{a'^2}{p} = 0 \qquad b' = -a'\frac{1+a'r/p}{1+2a'r/p} \quad (5.1)$$

where $p = 4\frac{e^{a+b}C^4+1}{e^{a+b}C^4-1}$. The integration is not easy when p can't be assumed constant so in the strong field regime we need to rely on numerical approximation methods to understand what's going on near the Schwarzschild radius. The numerical integration in Geogebra (using NResolEquaDiff) was carried on and the resulting b(r) are shown on the right of Figure 1 for various C values. It is found that as C increases b(r) will closely follow the GR solution near the Schwarzschild radius over an increasing range of b(r) and perfectly mimic the GR black hole horizon, however at some point the solution deviates from GR and crosses the Schwarzschild radius without singularity. This pseudo-BH solution and other more speculative related ideas are discussed at length in [1].

6. Conclusion

New developments of DG solve the tension between the theory and gravitational waves observations. The most important theoretical result remains the avoidance of both the Big-Bang singularity and Black Hole horizon. It also turns out that a discontinuous transition very natural within the DG framework, could have triggered the recent acceleration of the Universe. Stability issues are discussed in great details in [1] leading to the conclusion that the theory is viable and natural as a semiclassical theory of gravity. Unifying the global and local sectors of DG leads to a new rich MOND like phenomenology and Dark Matter candidates.

References

[1] www.darksideofgravity.com/DG.pdf

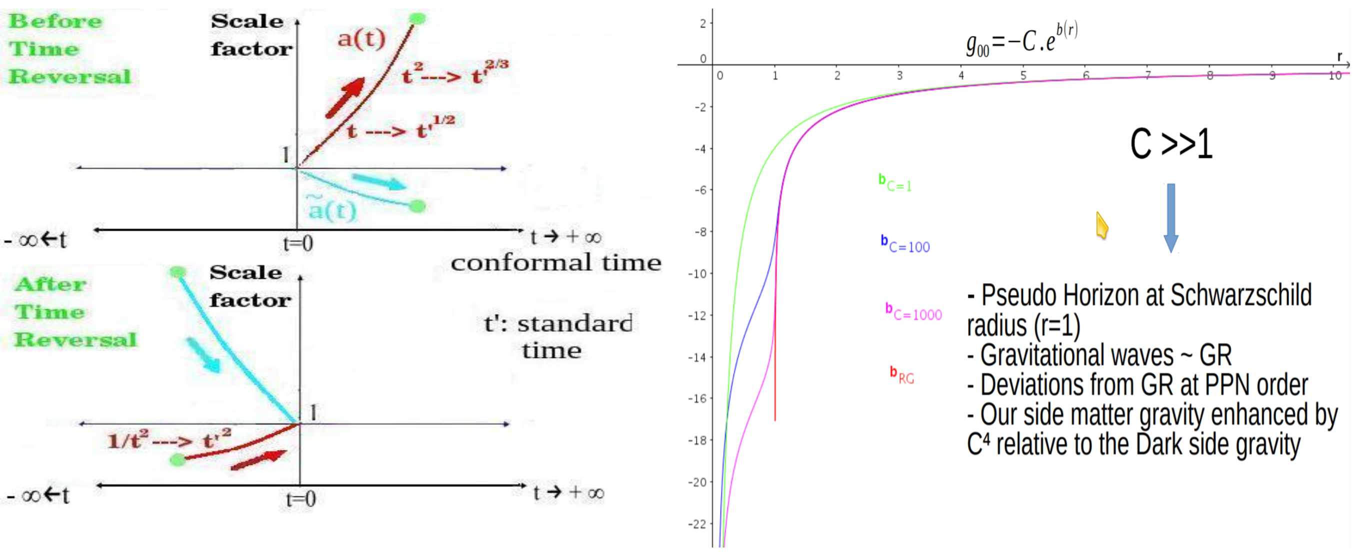

Figure 1: Left: Evolution laws and time reversal of the conjugate universes, our side in red. Right: b(r) near the Schwarzschild radius (r=1) for various C values.