3rd World Summit on Exploring the Dark Side of the Universe

Dark Gravity confronted to SN, BAO and the CMB

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Dark Gravity theories are extensions of General Relativity aiming at a stable anti-gravitational sector

J.P. Petit, Twin Universe cosmology, Astrophys. Space Sci. Vol. 226, pp 273, 1995. and many other articles

F. Henry-Couannier, Discrete symmetries and General Relativity, the Dark Side of Gravity, Int.J.Mod.Phys, vol. A20, no. NN, pp. 2341-2346, 2004.

F. Henry-Couannier, Dark Gravity, GJSFR A. Vol 13, Issue 3, pp 1-53, 2013.

S. Hossenfelder, Bimetric theory with exchange symmetry Phys. Rev. D 78, 044015, 2008.

M. Milgrom, Matter and twin matter in bimetric MOND, MNRAS 405 (2), pp 1129-1139, 2010.

Laura Bernard, Luc Blanchet, Lavinia Heisenberg Bimetric gravity and dark matter 50th Rencontres de Moriond, ”Gravitation: 100 years after GR”, 2015

From background dependence to Dark Gravity (DG)

How far can we go ?

GR : $g_{\mu\nu}$

DG : $g_{\mu\nu}$ and $\eta_{\mu\nu}$

$$\mathrm{Riemm}(\eta_{\mu\nu}) = 0$$

⇒ $g_{\mu\nu}$ has a twin, « the inverse metric » $\tilde{g}_{\mu\nu}$

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

⇒ $(g_{\mu\nu}, \tilde{g}_{\mu\nu})$

From the Action to DG field equations

The Action must respect the permutation symmetry between $g_{\mu\nu}$ and $\tilde{g}_{\mu\nu}$:

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

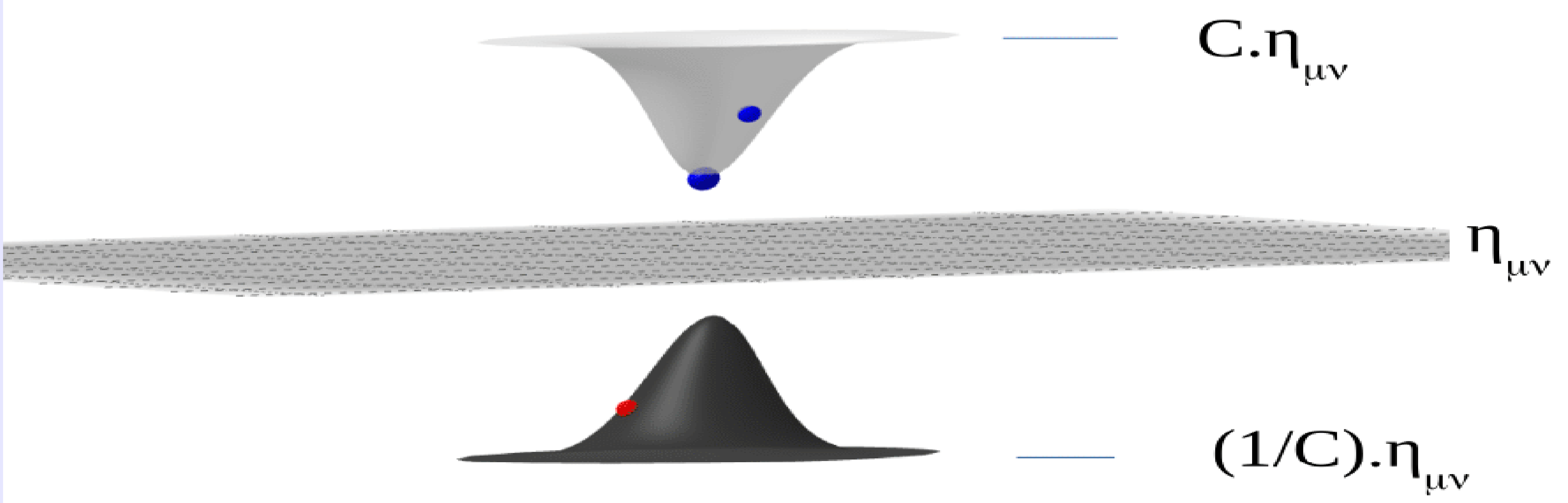
$$\delta g_{\mu\nu} \Rightarrow \delta S = 0$$

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

Contracted form

$$\sqrt{g}R - \sqrt{\tilde{g}}\tilde{R} = 8\pi G(\sqrt{g}T - \sqrt{\tilde{g}}\tilde{T})$$

The static isotropic solution



- Antigravity without run away !
- Asymptotic C matters : GR corresponds to C infinite

Homogeneous flat metrics in privileged coordinate system

2 possible choices

?

$$-d\tau^2 = -dt^2 + a^2(t)\left(dx^2 + dy^2 + dz^2\right)$$

$$-d\tau^2_{Minkowski} = -dt^2 + dx^2 + dy^2 + dz^2$$

$$-d\tilde{\tau}^2 = -dt^2 + \frac{1}{a^2(t)}\left(dx^2 + dy^2 + dz^2\right)$$

Standard metrics

$$-d\tau^2 = a^2(t)\left(-dt^2 + dx^2 + dy^2 + dz^2\right)$$

$$-d\tau^2_{Minkowski} = -dt^2 + dx^2 + dy^2 + dz^2$$

$$-d\tilde{\tau}^2 = \frac{1}{a^2(t)}\left(-dt^2 + dx^2 + dy^2 + dz^2\right)$$

Conformal metrics

Cosmological equations

$g_{\mu\nu} = a^2(t)\eta_{\mu\nu}$ $\quad \tilde{g}_{\mu\nu} = a^{-2}(t)\eta_{\mu\nu}$ $\quad \tilde{a}(t) = \frac{1}{a(t)}$

- Problem : Homogeneous & isotropic Janus solution is flat but static !

$$a^2 H^2 - \tilde{a}^2 \tilde{H}^2 = \frac{8\pi G}{3}\left(a^4 \rho - \tilde{a}^4 \tilde{\rho}\right)$$
$$a^2\left(2\dot{H} + H^2\right) - \tilde{a}^2\left(2\dot{\tilde{H}} + \tilde{H}^2\right) = -8\pi G\left(a^4 p - \tilde{a}^4 \tilde{p}\right)$$

- Solution : Introduce matter-radiation exchange (offshell free Γ(t)) :

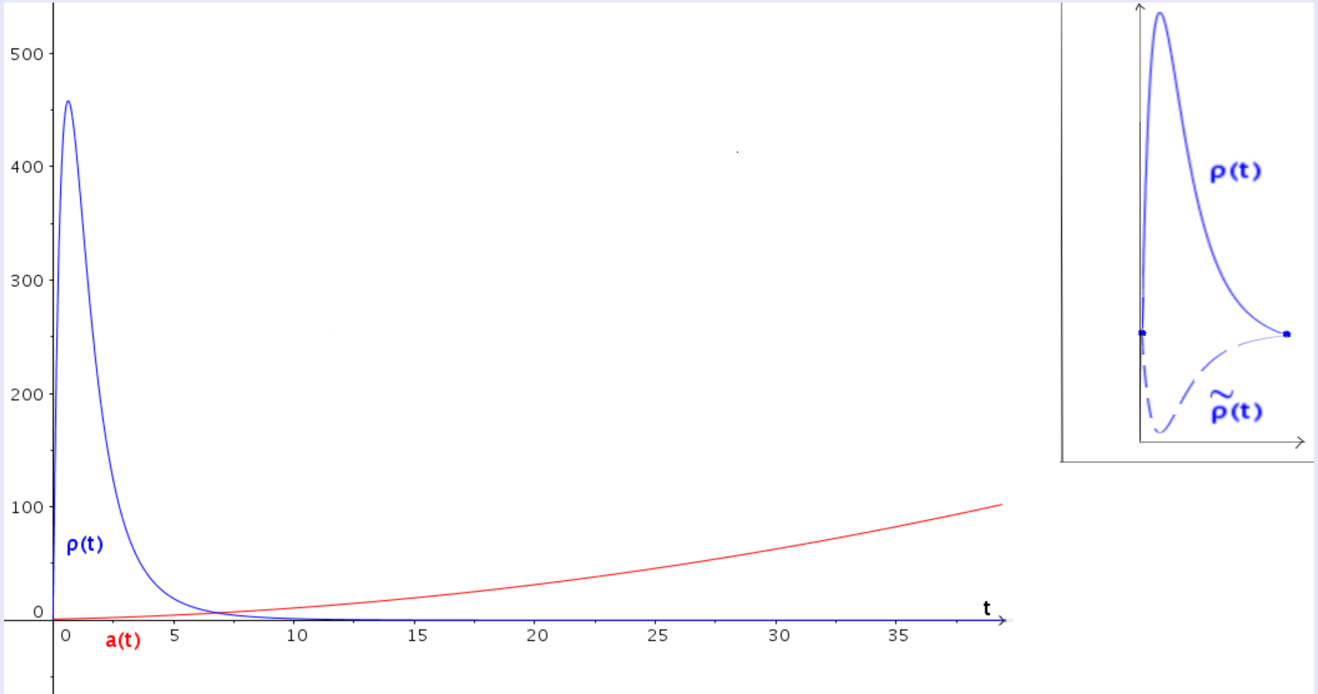
$$\nabla_\nu T^\nu_\mu \neq 0 \implies \frac{\dot{\rho}}{H} = \left(\frac{\Gamma}{H} - 3\right)(\rho + p)$$
$$\tilde{\nabla}_\nu \tilde{T}^\nu_\mu \neq 0 \implies \frac{\dot{\tilde{\rho}}}{\tilde{H}} = \left(\frac{\tilde{\Gamma}}{\tilde{H}} - 3\right)(\tilde{\rho} + \tilde{p})$$
$$\boxed{\tilde{\Gamma} = -\Gamma}, \quad \tilde{H} = -H$$

- Then cosmological equations have realistic solutions

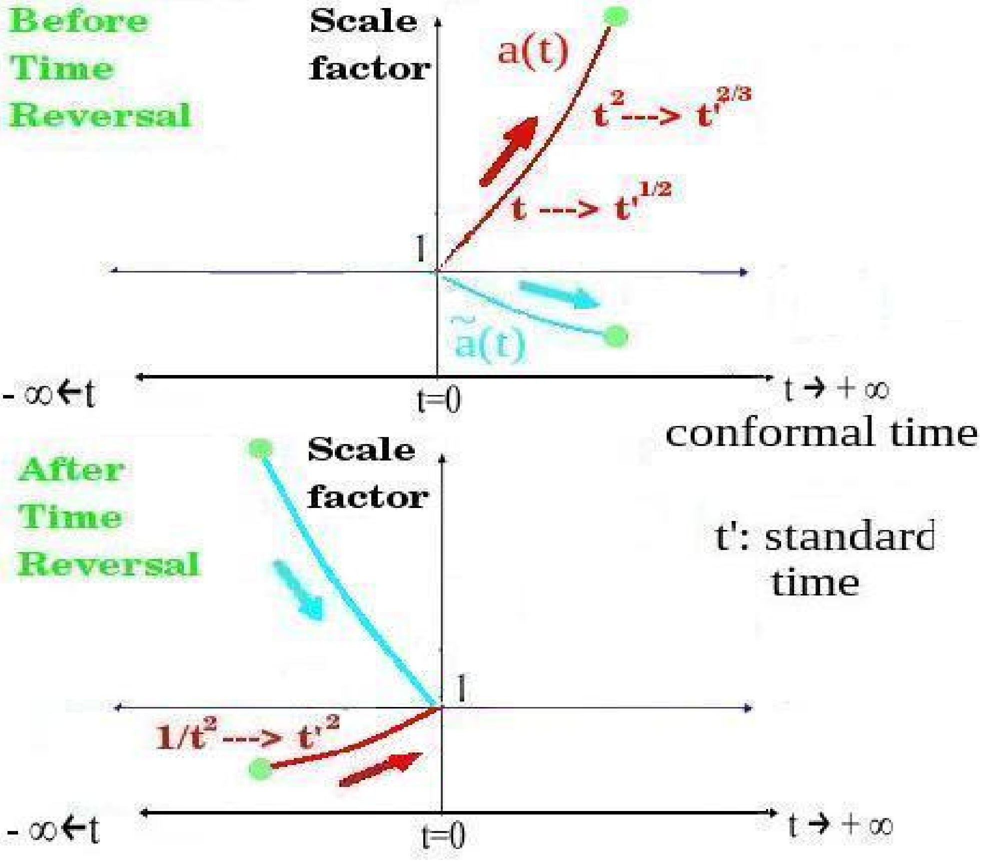
DG with adiabatic exchange of particles

*** adapted from original idea by Prigogin et al**

- Differential equations can be solved numerically :

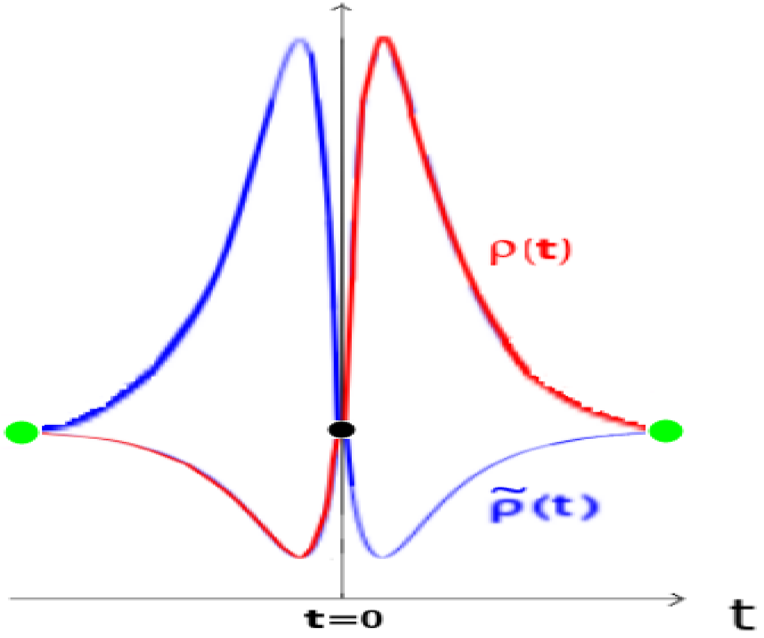


DG Cosmology and exchanges



Exchanges are necessary to:

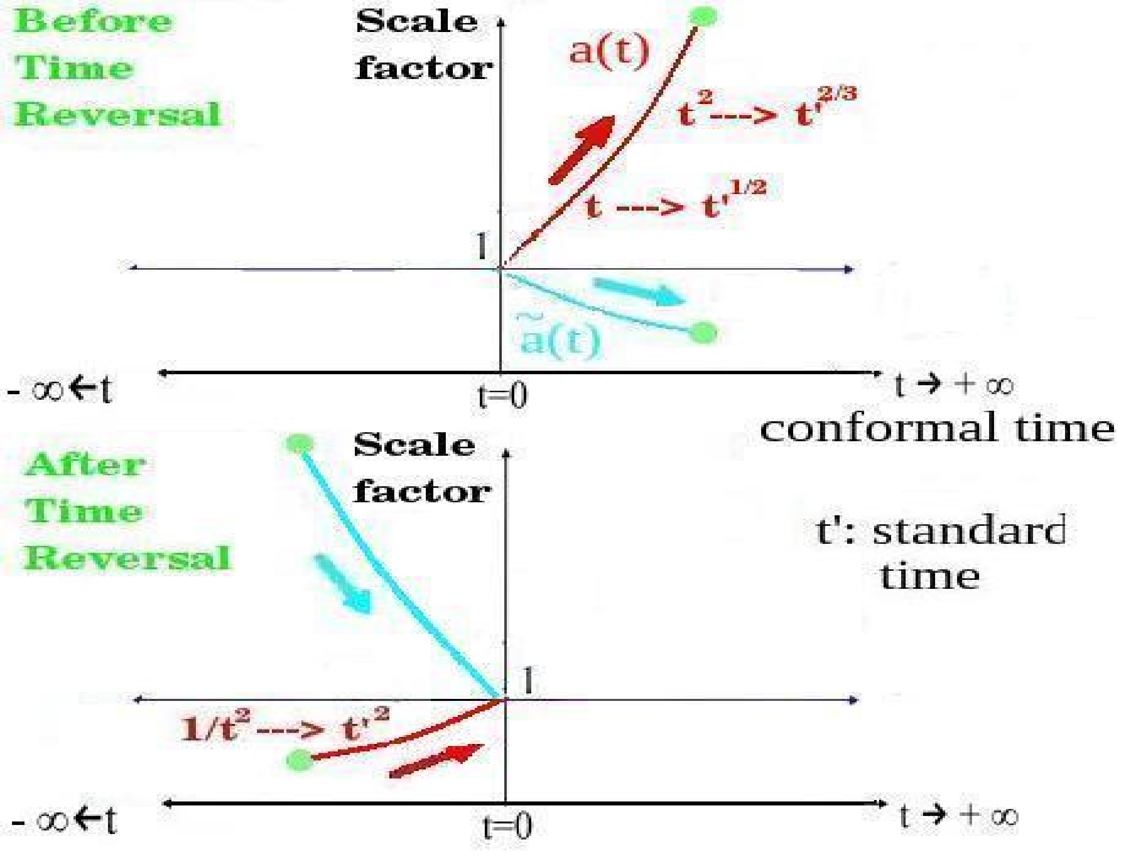
- interpret permutation symmetry as a time reversal symmetry
- get a cyclic universe



$$\Rightarrow \quad \rho(t=0) = \tilde{\rho}(t=0)$$

Cosmological solutions

$$a^2 H^2 - \tilde{a}^2 \tilde{H}^2 = \frac{8\pi G}{3}(\rho \ a^4 - \tilde{\rho} \ \tilde{a}^4)$$



- Janus scale factors are related by a global conformal time reversal symmetry T :

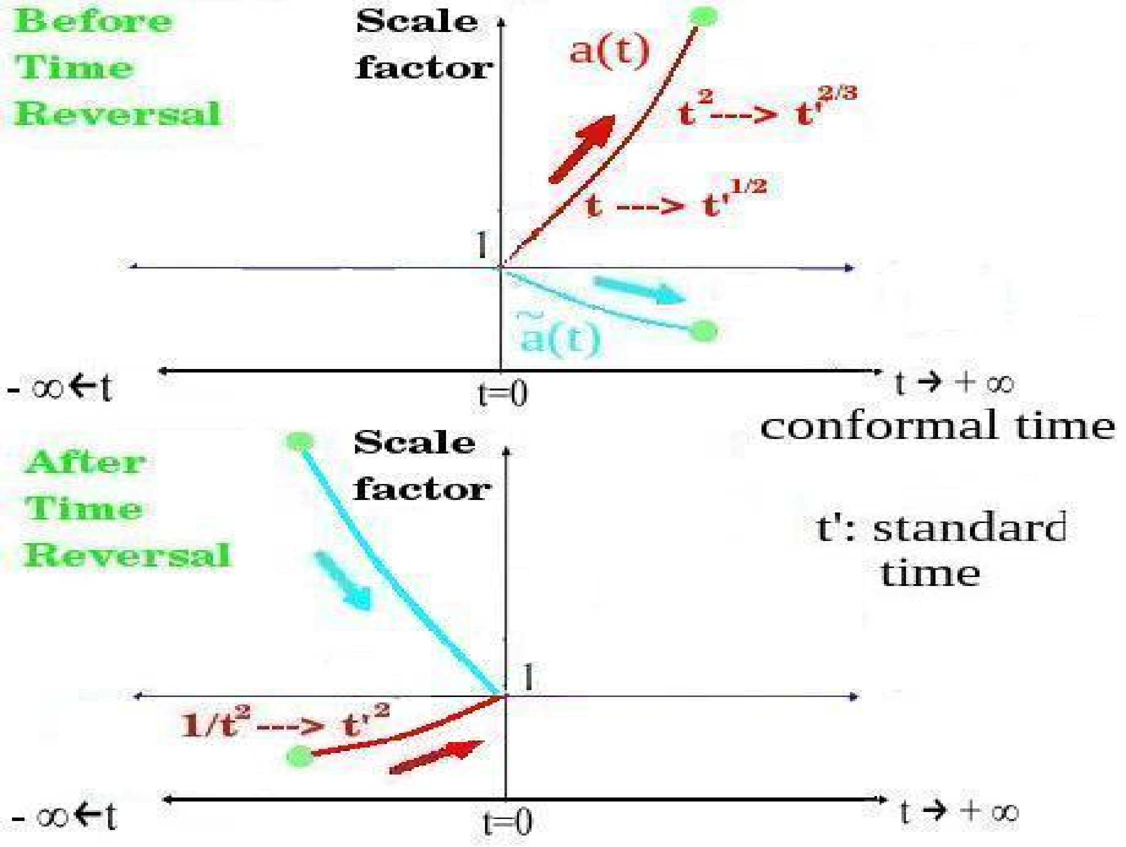
$$\tilde{a}(t) = \frac{1}{a(t)} = a(-t)$$

- Discontinuous permutation T allowed when $\rho = \tilde{\rho}$

Global time reversal : not going backward in time, but jumping to the opposite time !

⇒ A cyclic Universe ?

DG Cosmology



Hyp : $\rho = \tilde{\rho}$ occured at transition redshift triggering T ⇒ $a'(t') \sim t'^2$

With H(t) continuous at the transition and assuming same universe age as in LCDM:

$$a'(t') \sim t'^{\alpha} \Longrightarrow z_{tr} = \left(\frac{2/3 - \alpha}{1-\alpha}\right)^{\alpha} - 1$$

⇒ z_{tr} = 0.78 vs observed z_{tr} =0.67+- 0.1

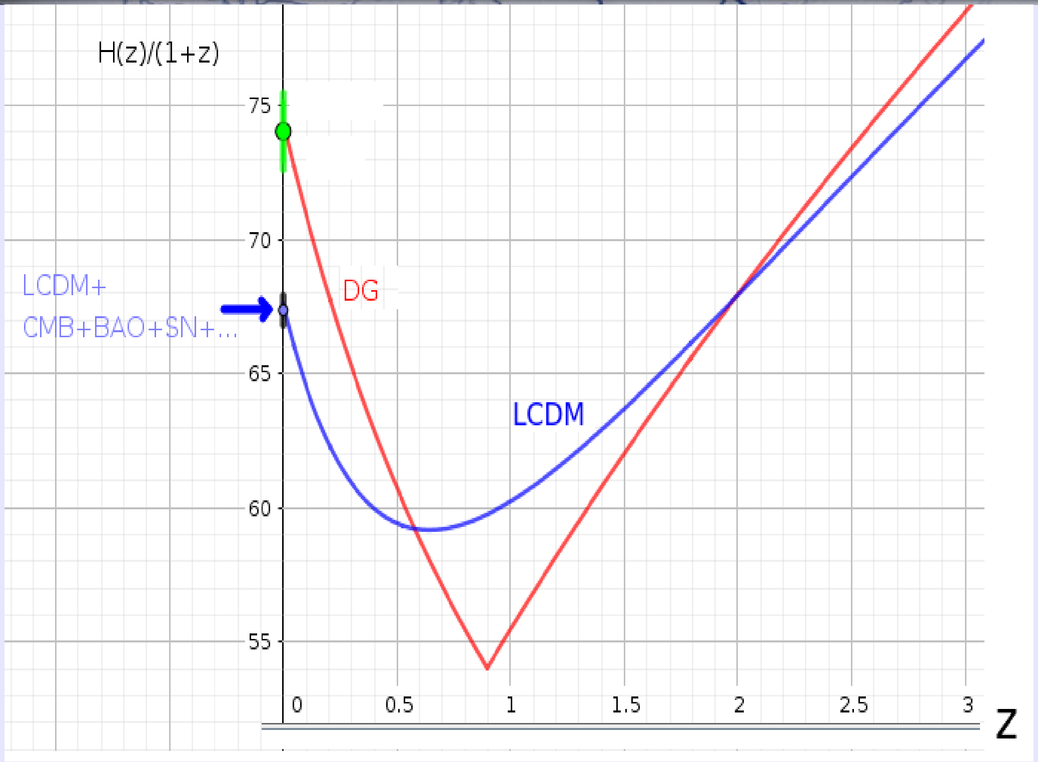
- ~ Same scale factor evolution as in LCDM
- Without DE
- Inflation not needed to get k=0
- Without Big Bang singularity
- Cosmological DM still needed
- Dark side effects only since t_{tr} or near t=0

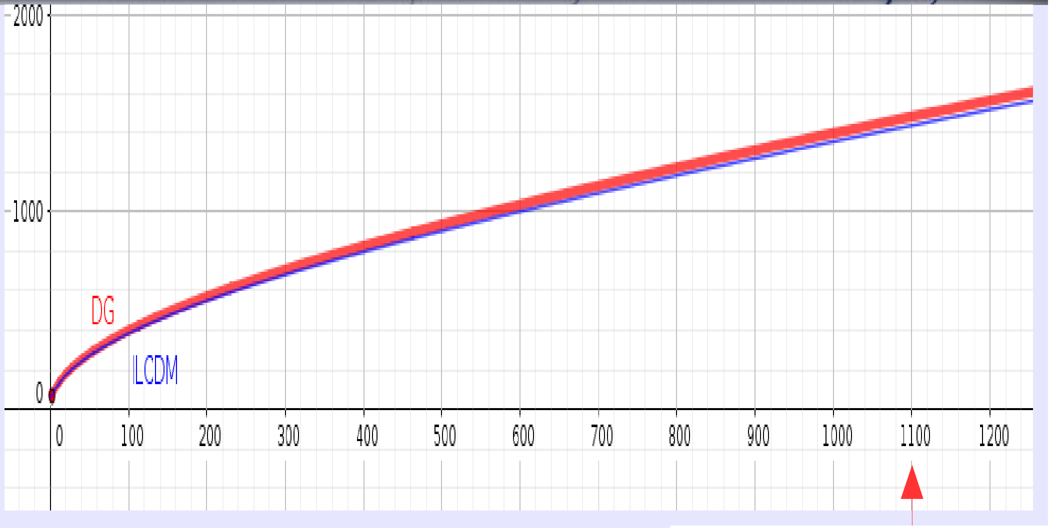
Testing Dark Gravity

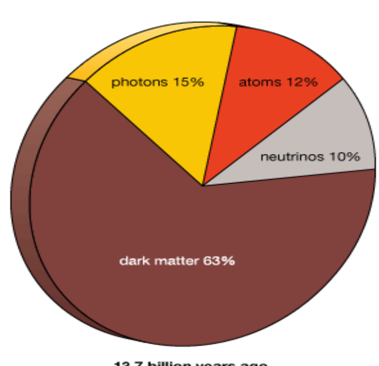
Assume a flat cosmological model with:

- Radiation ($\sim t^{1/2}$) then matter ($\sim t^{2/3}$) dominated era (nothing else !)
- Instantaneous transition @ z_{tr}
- Constantly accelerated era ($\sim t^2$)

H(z) /(1+z) :
Dark Gravity vs LCDM







A single free parameter : z_{tr}

A single fit parameter z_{tr} vs 2 parameters in LCDM (Ω_M,Ω_Λ)

$$\Omega_M(z_{tr}) = \frac{8\pi G \rho_M(z_{tr})}{3H_{tr}^2} = 1 - \Omega_{rad}(z_{tr}) \approx 1$$

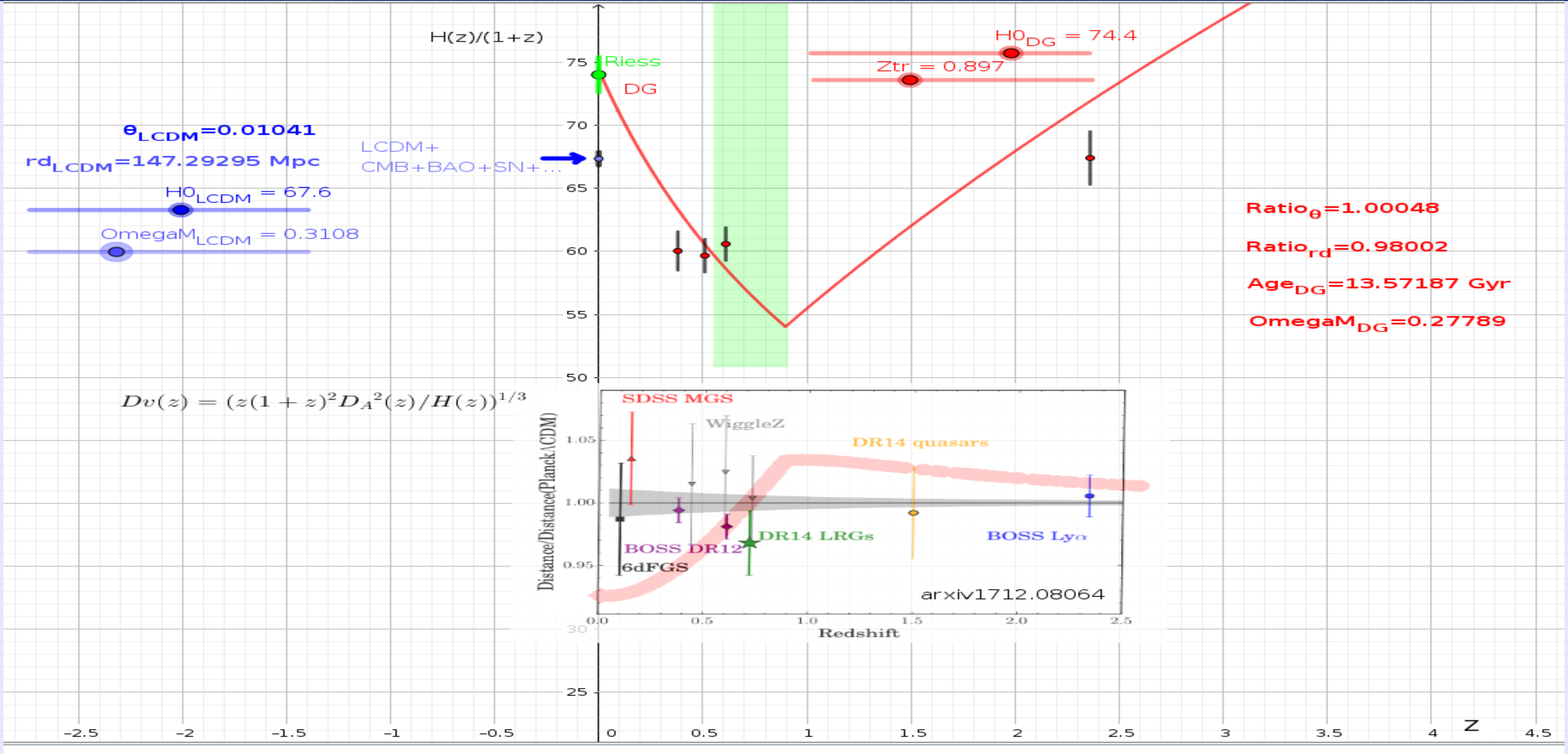
$$\rho_M(z_{tr}) = \rho_M(0).(1+z_{tr})^3 ; H_{tr} = H_0(1+z_{tr})^{0.5}$$

$$\Downarrow$$

$$\Omega_M = \frac{8\pi G \rho_M(0)}{3H_0^2} \approx 1/(1+z_{tr})^2$$

BAO, SN & CMB test of DG

BOSS RD12 arxiv:1607.03155
Planck arxiv:1807.06209



Conclusion and outlooks

- DG avoids Big-Bang singularity (and BH horizon!) very naturally
- Acceleration, k=0, large scale homogeneity, matter/antimatter asym
- Likely to cancel the gravity of vacuum energy
- Outlook :

New rich and effective phenomenology
(DM candidate, …)

www.darksideofgravity.com/DG.pdf

Adiabatic creation of particles

arXiv:1601.03955 , ...

*** Prigogin et al**

- Non conservation of matter and radiation fields through gravitationnally induced adiabatic* (Γ) creation of particles
- But total tensor including a « pressure creation » is conserved and can source the Einstein equation

$$\frac{\dot{\rho}}{H} = (\frac{\Gamma}{H} - 3)(\rho + p) \Leftrightarrow \nabla_\nu T_\mu^{\nu(\gamma)} \neq 0$$

$$p = (\gamma - 1)\,\rho$$

$$G_{\mu\nu} = 8\pi G\,(T_{\mu\nu}^{(\gamma)} + T_{\mu\nu}^{(c)})$$

- It can then mimick the effects of a cosmological constant term

DG with adiabatic exchange of particles

*** adapted from original idea by Prigogin et al**

- Matter and radiation fields conservation equations including adiabatic gravitationnally induced* transfers occuring between the two metrics :

$$\nabla_\nu T^\nu_\mu \neq 0 \implies \frac{\dot\rho}{H} = (\frac{\Gamma}{H} - 3)(\rho + p)$$

$$\tilde\nabla_\nu \tilde T^\nu_\mu \neq 0 \implies \frac{\dot{\tilde\rho}}{\tilde H} = (\frac{\tilde\Gamma}{\tilde H} - 3)(\tilde\rho + \tilde p)$$

$$\tilde\Gamma = -\Gamma, \quad \tilde H = -H$$

- Replacing in DG_Friedmann equations

$$a\ddot a - \tilde a\ddot{\tilde a} = K(a^4(\rho - 3p) - \tilde a^4(\tilde\rho - 3\tilde p))$$
$$\dot a^2 - \dot{\tilde a}^2 = 2K(a^4\rho - \tilde a^4\tilde\rho)$$

$\Rightarrow$

$$a\ddot a = K(a^4(\rho - 3p) + \frac{1}{2}(C + \tilde C))$$
$$\tilde a\ddot{\tilde a} = K(\tilde a^4(\tilde\rho - 3\tilde p) + \frac{1}{2}(C + \tilde C))$$

$$C = a^4\frac{\Gamma}{H}(\rho + p)$$
$$\tilde C = \tilde a^4\frac{\Gamma}{H}(\tilde\rho + \tilde p)$$

⇒ ~ usual solutions valid provided $\Gamma \approx 2H\frac{a\ddot a}{\tilde a\ddot{\tilde a}}$ $(\ a \ll \tilde a\ )$

SN test of a DG transition

(JLA : 740 SN)

- $a(t) \sim t^2$ ($q0 \sim -0.5$) now : meaningless within LCDM but expected in DG

- Fit between 0 and zmax with free power law t^α

  - zmax=0.6 ⇒ $\alpha = 1.85 \pm 0.15$ (1σ from $\alpha = 2.$)

  - zmax=0.8 ⇒ $\alpha = 1.78 \pm 0.11$ (2σ from $\alpha = 2.$)

- DG transition from $t^{2/3}$ to t^2 at z_{tr} :

  Good χ^2 (742.7) fit with SN ⇒ $z_{tr} = 0.64 \pm 0.15$

  BTW : Improved χ^2 (734.1) with 2 normalisation constants (1σ appart)

BAO,SN & CMB test of DG

How far could we go ?

Background dependent ⇒ EP violating

+ Ghost ⇒ OK* ⇒ Quantum unstable

+ Semiclassical ⇒ OK ⇒ OK** ⇒ Static

+ Exchanges ⇒ OK ⇒ OK ⇒ OK ⇒ unbounded

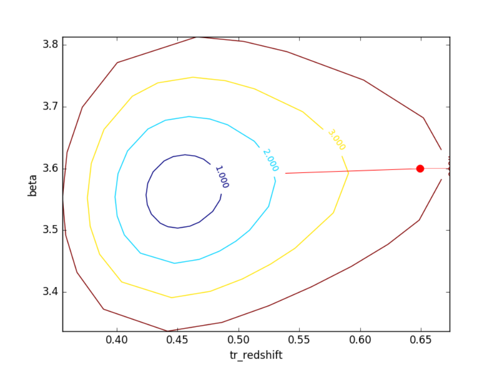
+ Discontinuous ⇒ OK ⇒ OK ⇒ OK ⇒ OK

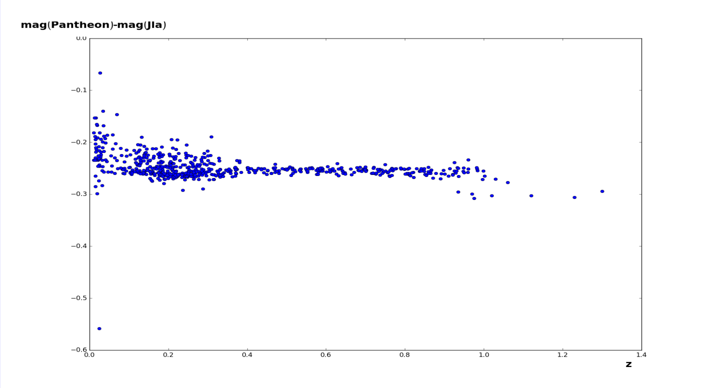
* EP violations (η effects) usually small, **harmless classical instabilities

⇒ Fascinating phenomenological and theoretical implications !

DG vs Pantheon sample

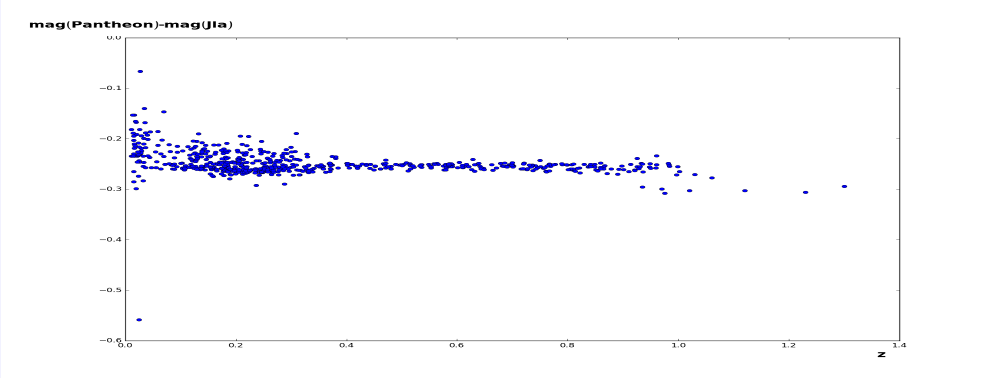
- Pantheon : 1048 Sns (+50 % @lowz, +40%@ mid and high z)
- ⇒ dramatic change in z_tr
- Even with JLA only SNs (~ 630 SNs in common)
- mag(Pantheon)-mag(Jla) different from new calibration effect (?!)





DG vs Pantheon sample

- mag(Pantheon)-mag(JLA) different from new calibration effect (?!)



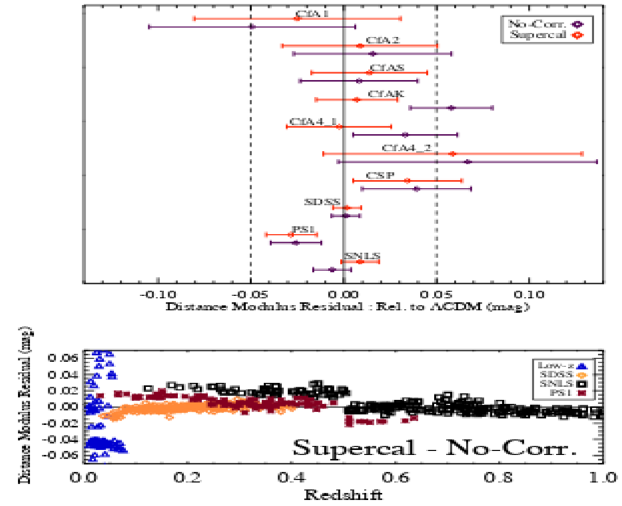
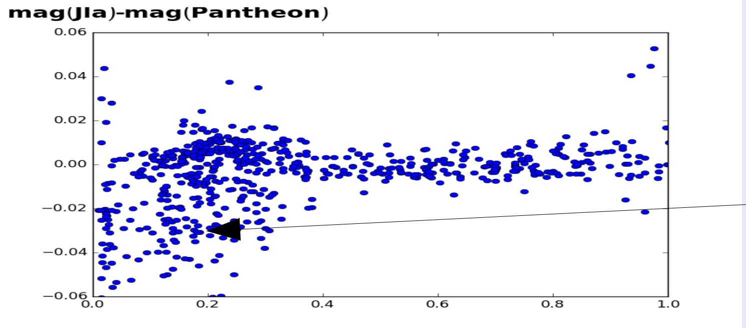
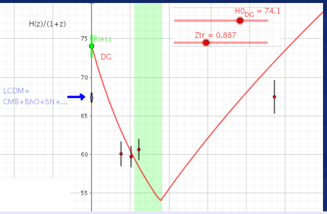


FIG. 7.— (Top) Mean relative Hubble residual offsets to the ΛCDM model for SN observed by each system analyzed. The points in black represent the residuals when no change to the calibration systems are made, and in red, they represent the offsets after we apply the average Supercal correction. (Bottom) The change in distances due to forcing all calibration to agree to the average Supercal solution. The values are such that $\Delta\mu = \mu_{\rm Supercal} - \mu_{\rm NoCorr.}$. SN from different samples are represented by different symbols and colors as indicated in the legend.

- 

SDSS SNs !?



Unify through symmetries

DG: Discrete and continuous symmetries unified:

Hidden Global Lorentz Invariance of background metric : structure of spacetime

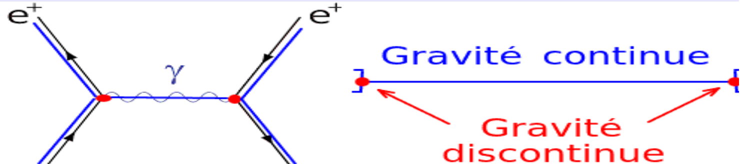
⇒ Induced manifest symmetries (local or Gauge ~ RG) are degraded

⇒ Induced permutation symmetry X

⇒ X:= induced discrete symmetry T with privileged frame (origin of time)

⇒ Discontinuous (non local) and continuous processes unified

Most natural way toward a more fundamental understanding (more unified) of QM discontinuities and non locality : allow discontinuous fields !...



Field Discontinuities

- a(t) discontinuities in time

  T
  - Different domains for the continuous and discontinuous :] … , T - [,] T+ , … [
  - Impossible discontinuity in GR, possible in DG thanks to permutation symmetry

- a(t) discontinuities in space

  - Save gravity of stars
  - Allow exchanges between 2 sides (crossing metrics)
  - If necessary, allow simultaneous crossing of densities and pressures
  - Avoid classical instability issues

  ⇒ Dark side voids can mimick dark matter

a(t) discontinuous : GR

a²(t)(dt²-dx²-dy²-dz²)

GR

$$H_-^2 = \frac{8\pi G}{3}\rho_- a_-^2 \qquad H_+^2 = \frac{8\pi G}{3}\rho_+ a_+^2 \qquad (1)$$

$$\frac{\dot\rho_-}{\rho_-} = -3H_- \qquad \frac{\dot\rho_+}{\rho_+} = -3H_+ \qquad (2)$$

T_- T_+ t

$$a_+(T_+) = C a_-(T_-)$$

$$H_+(T_+) = H_-(T_-)$$

$$\frac{c_+}{a_+^3(T_+)} = \rho_+(T_+) = \rho_-(T_-) = \frac{c_-}{a_-^3(T_-)}$$

(1) ~~OK~~
(2) OK

A piecewise GR ?
(the flat homogeneous case)

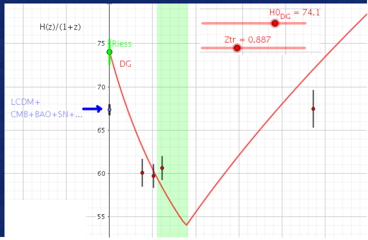
$$d\tau^2 = a^2(t)\left(-dt^2 + \left(dx^2 + dy^2 + dz^2\right)\right)$$

Discontinuous scale factor and derivatives with continuous densities and Hubble rates ?

⇒ Not possible !

a(t) discontinuous : DG

$a^2(t)(dt^2-dx^2-dy^2-dz^2)$



DG

$$a_-^2 H_-^2 - \tilde{a}_-^2 \tilde{H}_-^2 = \frac{8\pi G}{3}(\rho_- a_-^4 - \tilde{\rho}_- \tilde{a}_-^4) \quad \Big| \quad a_+^2 H_+^2 - \tilde{a}_+^2 \tilde{H}_+^2 = \frac{8\pi G}{3}(\rho_+ a_+^4 - \tilde{\rho}_+ \tilde{a}_+^4) \qquad (1)$$

$$\frac{\dot{\rho}_-}{\rho_-} = -3H_- \quad \frac{\dot{\tilde{\rho}}_-}{\tilde{\rho}_-} = -3\tilde{H}_- \quad \Big| \quad \frac{\dot{\rho}_+}{\rho_+} = -3H_+ \quad \frac{\dot{\tilde{\rho}}_+}{\tilde{\rho}_+} = -3\tilde{H}_+ \qquad (2)$$

T₋ T₊ t

$$\begin{aligned} a_+(T_+) &= C a_-(T_-) \\ \tilde{a}_+(T_+) &= C^{-1}\tilde{a}_-(T_-) \\ H_+(T_+) &= H_-(T_-) \\ \tilde{H}_+(T_+) &= \tilde{H}_-(T_-) \\ \rho_+(T_+) &= \rho_-(T_-) \\ \tilde{\rho}_+(T_+) &= \tilde{\rho}_-(T_-) \end{aligned}$$

(2) OK

$$\begin{aligned} a_+(T_+) &= \tilde{a}_-(T_-) \\ \tilde{a}_+(T_+) &= a_-(T_-) \end{aligned} \Rightarrow C = \frac{a_+(T_+)}{\tilde{a}_+(T_+)} = \frac{\tilde{a}_-(T_-)}{a_-(T_-)}$$

(1) OK

A piecewise DG ?
(the flat homogeneous case)

$$d\tau^2 = a^2(t)\left(-dt^2 + \left(dx^2 + dy^2 + dz^2\right)\right)$$

- Discontinuous scale factor with continuous Hubble rates ?

  Possible thanks to permutation <u>and</u> H ⇒ -H symmetry !

- Discontinuous scale factor with continuous Hubble rates and densities ?

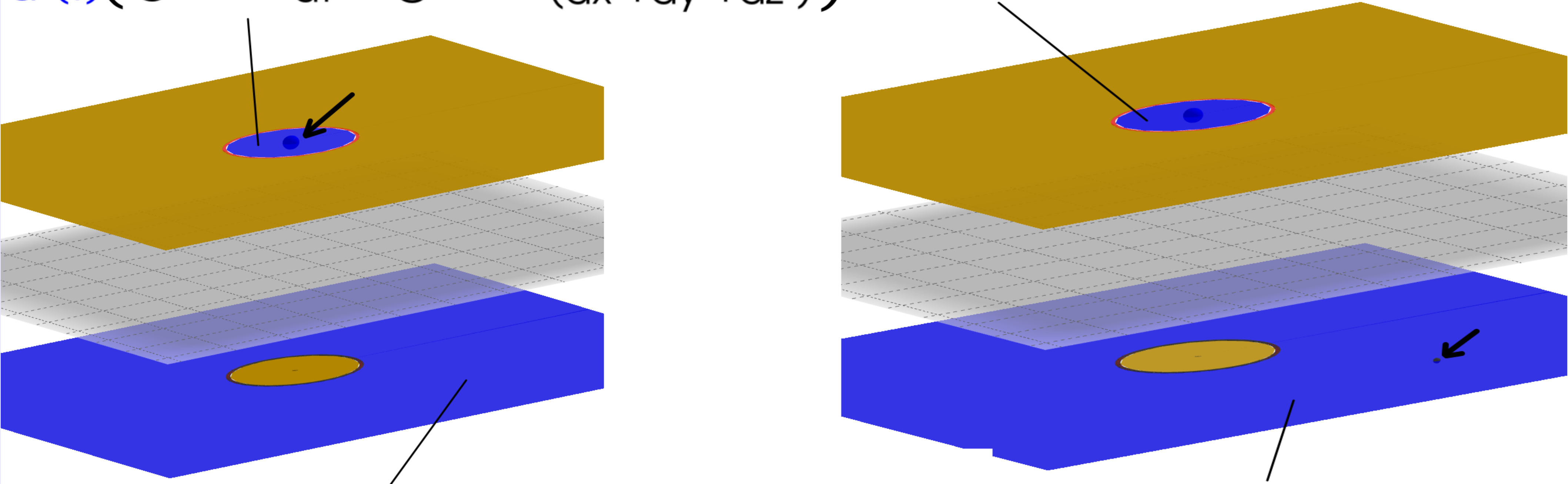
  – Still possible but only when conjugate densities are equal : the seeked discontinuity triggering criterion !

  – Should both ρ and p cross at transition ? ⇒ If yes it's unlikely for the whole universe but likely for a part of the universe

Spatial domains and discontinuities

$$a^2(t)\left(e^{\frac{-2Gm}{a(t)rc^2}}\, dt^2 - e^{\frac{2Gm}{a(t)rc^2}}\,(dx^2+dy^2+dz^2) \right)$$

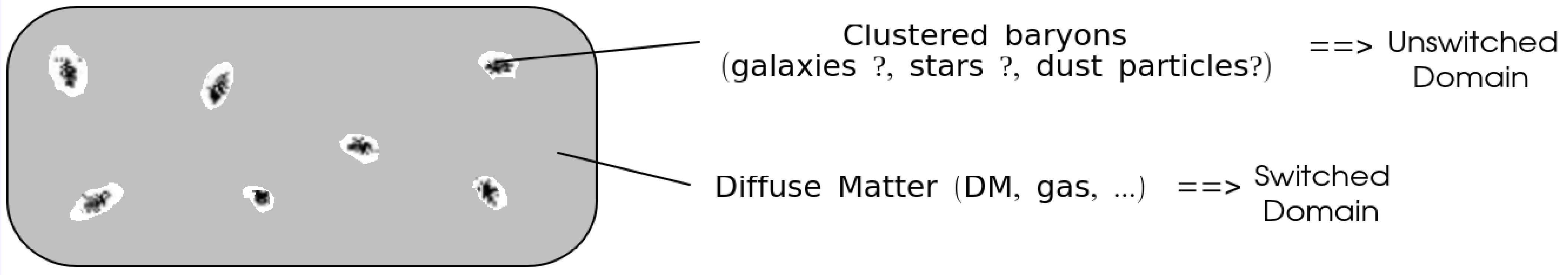
$$\sim a^2(t)\,(dt^2-(dx^2+dy^2+dz^2))$$



$$\frac{a^2(t)}{a^4(T)}\left(e^{\frac{-2Gm}{a(t)rc^2}}\, dt^2 - e^{\frac{2Gm}{a(t)rc^2}}\,(dx^2+dy^2+dz^2) \right)$$

$$\sim \frac{a^2(t)}{a^4(T)}\,(dt^2-(dx^2+dy^2+dz^2))$$

Static bounded domains needed



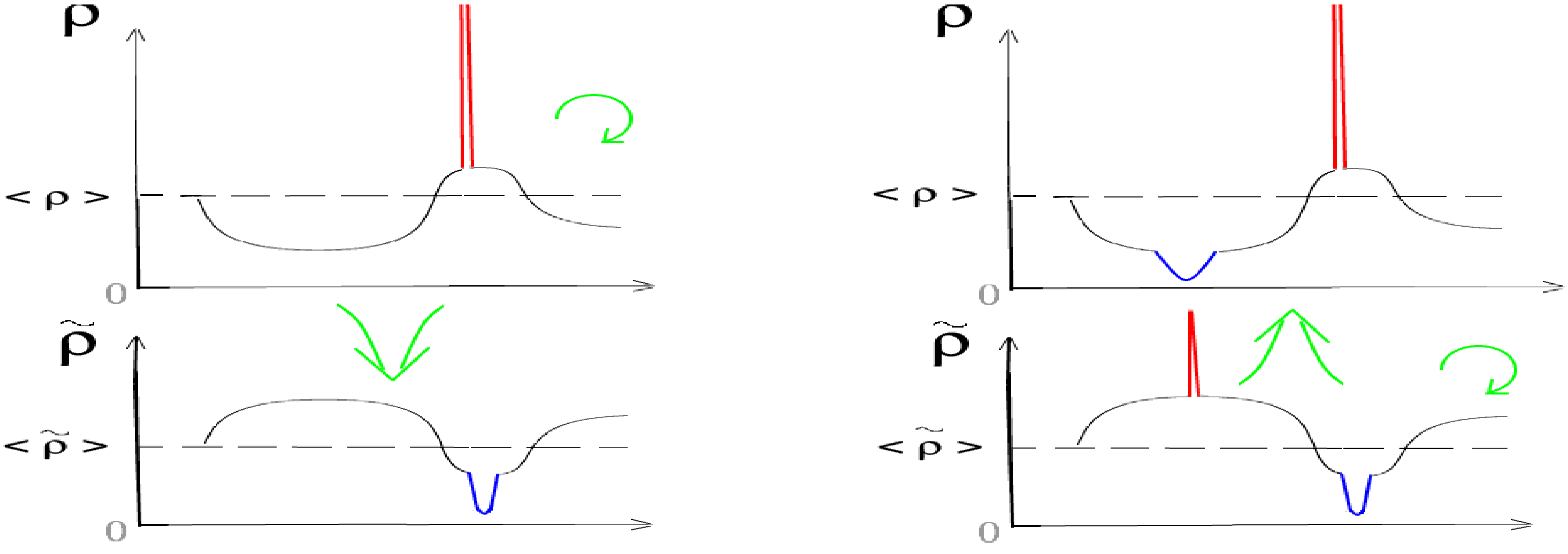
- To avoid transition switching off gravity of clustered baryonic matter

- To better understand Matter-Radiation exchange (crossing metrics)
  ⇒ avoid BH central singularities

- Might help simultaneous crossing of densities and pressures

Phenomenology of conjugate perturbations

Densities for DM and diffuse gas only

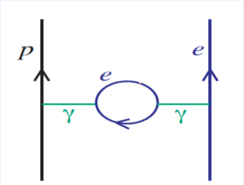


Before transition

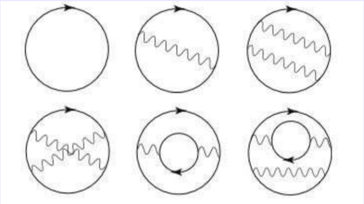
After transition

Vacuum energy terms if gravity is classical

- Evidence for Vacuum energy Feynman graphs through Casimir and Lambshift effects : actually these graphs have quanta external legs.

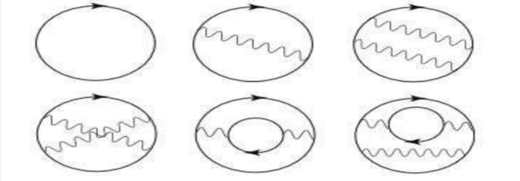


- In Quantum Gravity a cosmological constant is expected from the same kind of graphs in which the external legs are replaced by gravitons.
- If gravity is classical the true vacuum graphs (without quanta but rather external legs from classical external field) matter. But we have no evidence for the existence of such graphs so far !



Vacuum energy in DG equations

For a graph with quanta external legs, these correspond to particles coupled (classically) to one side of Janus field hence internal propagators must also be coupled to the same metric but such constraint no longer applies for a graph without quanta external legs !



⇒ Instead, it might be that the above true vacuum graphs belong to the background metric $\eta_{\mu\nu}$ and in this case :

a) No effect on Janus field as long as $g_{\mu\nu} = \tilde{g}_{\mu\nu} \neq \eta_{\mu\nu}$

b) $g_{\mu\nu} = \tilde{g}_{\mu\nu} = \eta_{\mu\nu}$ ⇒ DG vacuum source term is :

$$\left(\sqrt{g}\Lambda - \sqrt{\tilde{g}}\tilde{\Lambda}\right) g^{\mu\nu}$$ vanishes because $\Lambda = \tilde{\Lambda}$

SR vs QM

- Requirements for a « good » theory :
  - Self consistent — SR : OK QM : OK
  - Agrees with observations — SR : OK QM : OK
  - Economic = unifying = predictive — SR : OK* QM : ??!!**

* : SR unifies space and time, no other fundamental speed than c

**: QM has arbitrary weird postulates i.e. not based on symmetry principles, QM constant h defines an additional energy scale (others already exist !)

⇒ unification required ! Would explain $\frac{e^2}{c}=\frac{\hbar}{137,\ldots}$

Dynamical discrete symmetries

- Standard view :

Symmetries (cont & disc) ⇒ Action

Extreme action principle ⇒ Eoms & conservation equations

No dynamical processes associate with discrete symmetries

- Extended view :

Symmetries (cont & disc) ⇒ Action

Extreme action principle ⇒ Eoms & conservation equations

Discrete symmetries ⇒ Discontinuous processes

Dynamical discrete symmetries

1) Discrete (permutation) symmmetry and continuous symmetries already unified in DG framework
2) Just as discrete (T&P) and continuous spacetime symmetries already unified in the Lorentz group

1) and 2) turn out to be related : global T symmetry is permutation symmetry !

Dynamical discrete symmetries ⇒ discontinuous transitions in addition to usual continuous evolution processes deduced from differential eoms.

⇒ Fills the gap between the discrete and the continuous

⇒ Hopefully opens the way to a genuine unification (understanding) of QM discrete and non local laws to the rest of physics !

Classical stability issues

- Background remains bounded thanks to global time reversal
- Linear inhomogeneous perturbations unstable in contracting phase

  but gravity from these is negligible : suppressed by C^4 factor (~scale_factor^8) before transition to acceleration.
- Linear inhomogeneous perturbations from the dark sector can start to grow under their own gravity after transition
- Strong gravity inhomogeneous pertubations presumably always stable on both sides thanks to C >1 at our side structures while C<1 at dark side structures

Problems with semiclassical Gravity

- Case I : Classical gravity triggers quantum collapses ⇒ no Energy-momentum conservation violation, nor violation of uncertainty relations contrary to popular argument by Eppley & Hannah ...

  https://arxiv.org/pdf/0802.1978.pdf

  otherwise :

- Case 2A : No collapse interpretation of QM (MWI, decoherence …) ruled out because classical gravity would see the uncollapsed superpositions
- Case 2B : Realistic collapse interpretation of QM leads to possible faster than light signaling. Either specific more local model of quantum collapse can solve this or … DG : instantaneous signaling is not anymore a menace to causality as soon as there exists a unic privileged instantaneity frame for any collapse !

Implications of DG equations

- DG is background dependent yet deviations from GR can remain arbitrarily small provided one side of the Janus Field dominates the other
- Ghost interaction between Janus and source fields but Janus field not understood to be a quantum field !
  - DG more natural than GR as a semiclassical* theory of gravity
  - Semiclassical DG stability : OK**
- New discrete (permutation) symmetry is very fundamental : will be interpreted as a global time reversal symmetry.

* https://arxiv.org/abs/0802.1978 Mark Albers, Claus Kiefer, Marcel Reginatto, Measurement Analysis and Quantum Gravity : « Despite the many physical arguments which speak in favor of a quantum theory of gravity, it appears that the justification for such a theory must be based on empirical tests and does not follow from logical arguments alone »

** https://arxiv.org/pdf/1401.4024.pdf V. A. Rubakov, page 8 : Gradient, tachyonic and ghost instabilities in scalar-tensor theories : « for ghosts, background is QM unstable but classically stable »

The static isotropic solution

C=1

DG:

$$g_{ii}(r) = A = e^{2MG/r} \approx 1 + 2\frac{MG}{r} + 2\frac{M^2G^2}{r^2}$$

$$-g_{00}(r) = \frac{1}{A} = e^{-2MG/r} \approx 1 - 2\frac{MG}{r} + 2\frac{M^2G^2}{r^2} - \frac{4}{3}\frac{M^3G^3}{r^3}$$

C=∞

RG (Schwarzschild) :

$$g_{ii}(r) = \left(1 + \frac{MG}{2r}\right)^4 \approx 1 + 2\frac{MG}{r} + \frac{3}{2}\frac{M^2G^2}{r^2}$$

$$g_{00}(r) = \frac{\left(1 - \frac{MG}{2r}\right)^2}{\left(1 + \frac{MG}{2r}\right)^2} \approx 1 - 2\frac{MG}{r} + 2\frac{M^2G^2}{r^2} - \frac{3}{2}\frac{M^3G^3}{r^3}$$

- No Horizon
- Zero Gravitational Waves

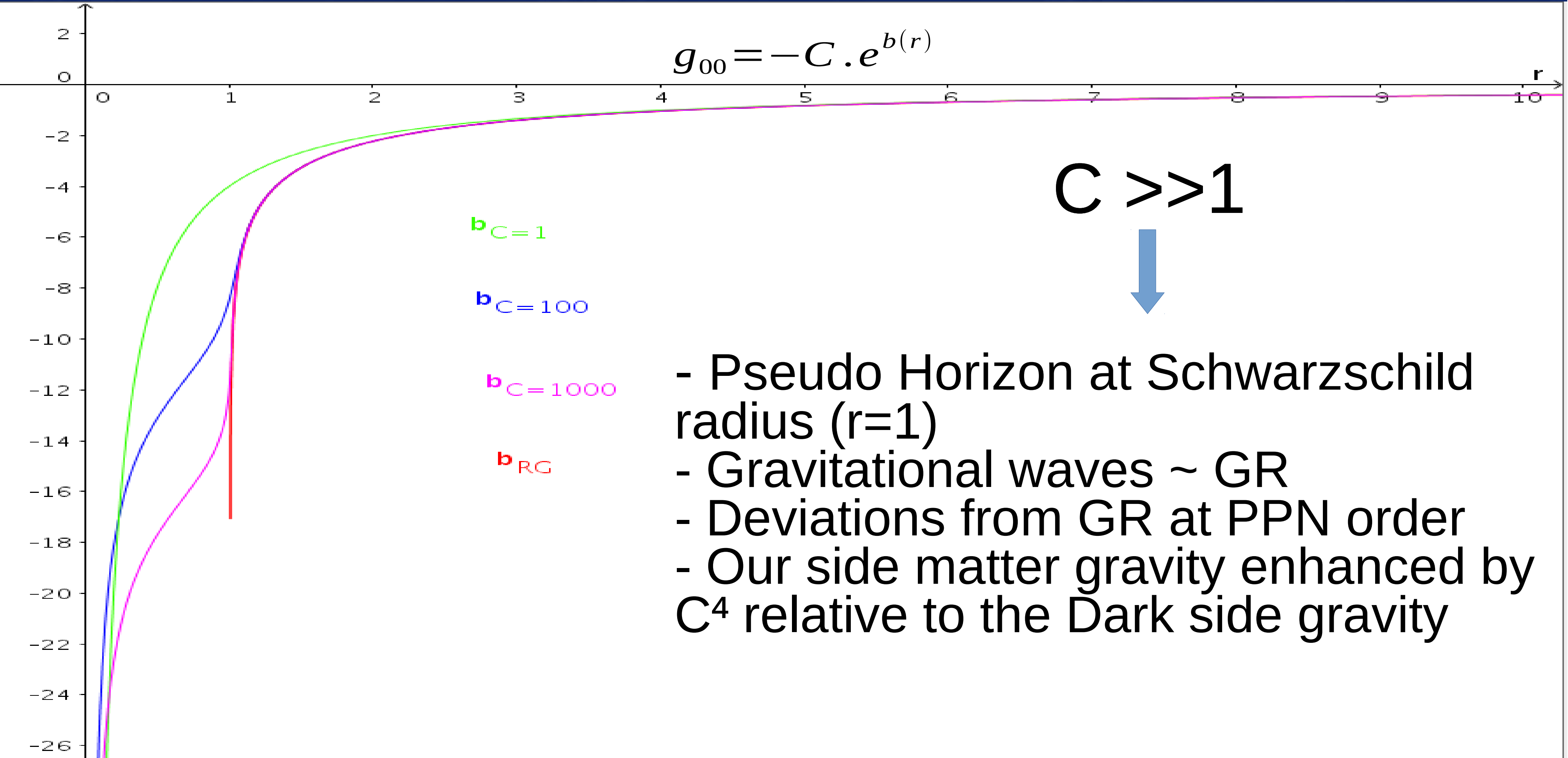
$$\tilde{h}_{\mu\nu} = -h_{\mu\nu} + O(h^2)$$

$$2(R^{(1)}_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}R^{(1)\lambda}_{\lambda}) = -8\pi G(T_{\mu\nu} - \tilde{T}_{\mu\nu} + t_{\mu\nu} - \tilde{t}_{\mu\nu})$$

$t_{\mu\nu} - \tilde{t}_{\mu\nu} \to 0$

- Deviations from GR at PPN order only

The static isotropic solution



C >>1

- Pseudo Horizon at Schwarzschild radius (r=1)
- Gravitational waves ~ GR
- Deviations from GR at PPN order
- Our side matter gravity enhanced by C^4 relative to the Dark side gravity

Tension on H0

- Tension (4.4 σ) between H0 low z (SN + cepheids) and H0 (CMB, BAO, SN, lensing)

- Reminder: Planck measures first peak angle ~ 0.001041 @ 0.03 %

⇒ constraint on $f(\Omega_M , \Omega_b , \Omega_r , H0)$ @ 0.03 %

⇒ constraint on $F(\Omega_M , H0)$ @ 0.3 % and highly degenerate

⇒ + low z constraints (SN,BAO, ...) ⇒ Omega_M & H0 @ %

Does the H0 tension call for new physics ?

- Introduce new kind of DE with $w < -1$ (ghostfree bimetric, ...) at low z ?

  - $z < 1 \Rightarrow$ hardly possible because constrained by SN, BAO ...
  - $z > 1 \Rightarrow$ does not work

  – https://arxiv.org/pdf/1801.07260.pdf (Does the Hubble constant tension call for new physics)
  – https://arxiv.org/pdf/1811.00537.pdf (Sounds discordant)

- Add Dark Radiation in radiative era ? Works but very exotic DR : $w \ll 1/3$!

- Dark Gravity theory (discrete transitions at low z) ?