Title: Weak measurements, decoherence and cosmology

Date: Jun 01, 2017 04:50 PM

URL: http://pirsa.org/17060029

Abstract: In this work we consider a recent proposal in which gravitational interactions are mediated via the exchange of classical information and apply it to a quantized Friedman-Robertson-Walker (FRW) universe with the assumption that any test particles must feel a classical metric. We show that such a model results in decoherence in the FRW state that manifests itself as a dark energy fluid that fills the spacetime. Motivated by quantum-classical interactions this model is yet another example of theories with violation of energy-momentum conservation whose signature could have significant consequences for the observable universe.

Weak measurements, decoherence and cosmology

(CQG-34,11 (2017) — arXiv:1605.05980)

Natacha Altamirano

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PI Day
June 2017

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Sunyaev-Zeldovich effect

With Chiamaka Okoli and Niayesh Afshordi

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Sunyaev-Zeldovich effect

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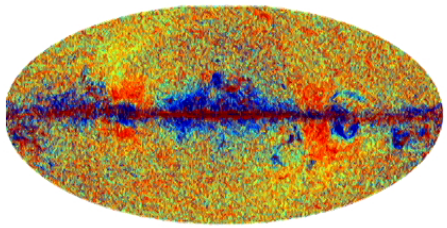
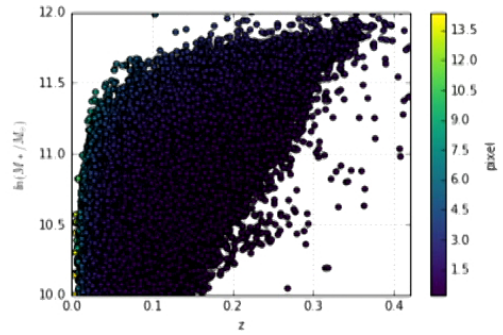
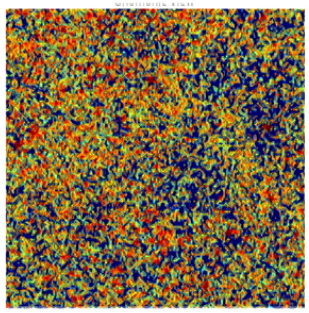
y-maps ⟷ Galaxy based y-templates







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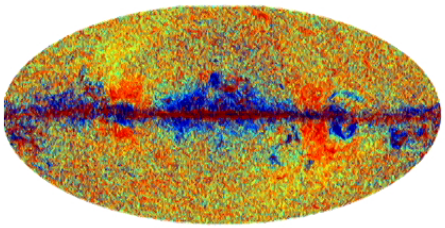

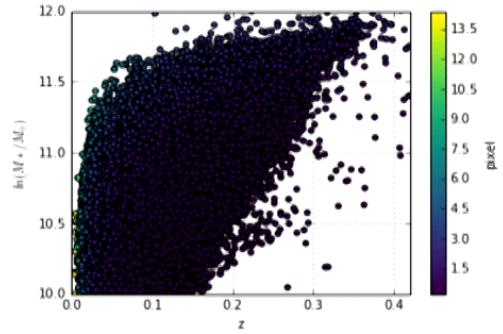

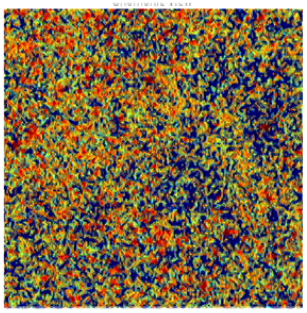

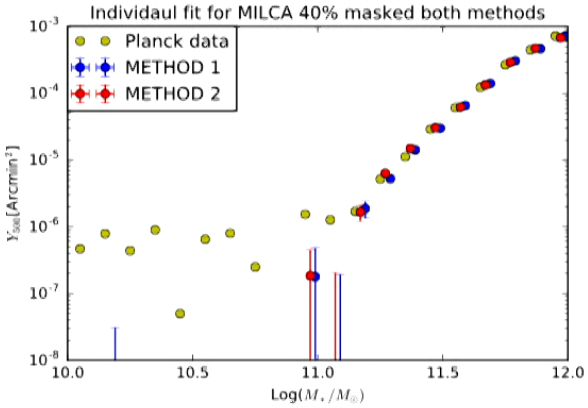

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INTRODUCTION

- **QUANTUM INTERACTIONS**
  - → Mediated by virtual particles
  - → Produce entanglement
- **CLASSICAL INTERACTIONS**
  - → Ehrenfest theorem
  - → Do not produce entanglement

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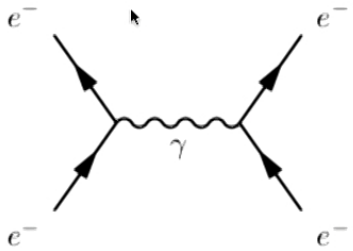
INTRODUCTION



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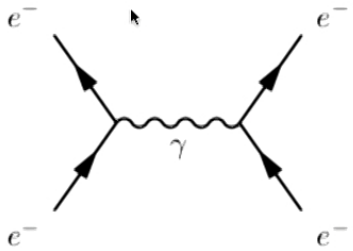

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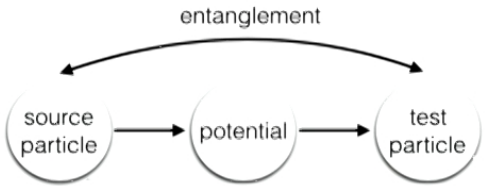

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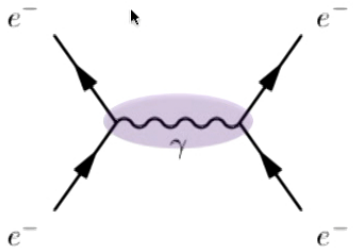

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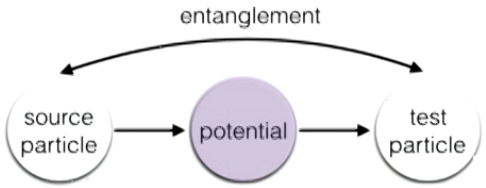

The quantum interactions described by quantum field theory are governed by **unitary evolution**

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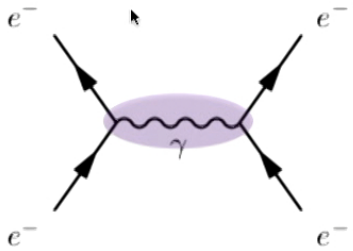

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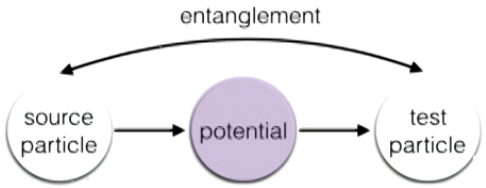

The quantum interactions described by quantum field theory are governed by **unitary evolution**

Gravitation remains stubbornly resistant to quantization

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INTRODUCTION

General Relativity and Gravitation, Vol. 28, No. 5, 1996

On Gravity's Role in Quantum State Reduction

Roger Penrose[1,2]

Received August 22, 1995. Rev. version December 12, 1995

The stability of a quantum superposition of two different stationary mass distributions is examined, where the perturbing effect of each distribution on the space-time structure is taken into account, in accordance with the principles of general relativity. It is argued that the definition of the time-translation operator for the superposed space-times involves an inherent ill-definedness, leading to an essential uncertainty in the energy of the superposed state which, in the Newtonian limit, is proportional to the gravitational self-energy E_Δ of the difference between the two mass distributions. This is consistent with a suggested finite lifetime of the order of $\hbar/E_\Delta$ for the superposed state, in agreement with a certain proposal made by the author for a gravitationally induced spontaneous quantum state reduction, and with closely related earlier suggestions by Diósi and by Ghirardi *et al.*

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Models for universal reduction of macroscopic quantum fluctuations

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(Received 17 October 1988; revised manuscript received 21 March 1989)

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use principles of relativity to **limit the lifetime of spatial quantum superpositions** and, as a result, **breaking the unitary evolution of the wavefunction**

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INTRODUCTION

(Classical channel model for Gravitational decoherence)

(Kafri *et.al.* arXiv:1401.0946 NJP - 2013)

A classical channel model for gravitational decoherence.

D. Kafri, J.M. Taylor[1] and G. J. Milburn[2]

Abstract

We show that, by treating the gravitational interaction between two mechanical resonators as a classical measurement channel, a gravitational decoherence model results that is equivalent to a model first proposed by Diosi. The resulting decoherence model implies that the classically mediated gravitational interaction between two gravitationally coupled resonators cannot create entanglement. The gravitational decoherence rate (and the complementary heating rate) is of the order of the gravitationally induced normal mode splitting of the two resonators.

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This approach is motivated by the fact that **gravity cannot be shielded** and therefore any observer can in principle **gain information about the quantum state sourcing gravity**

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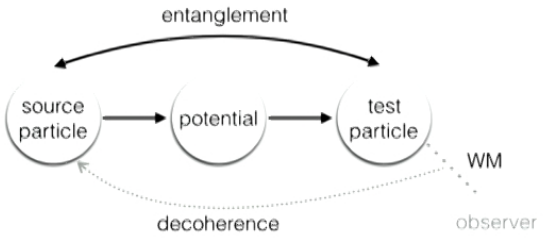

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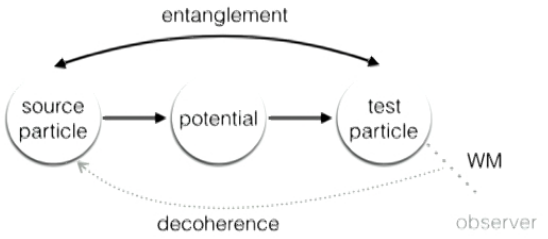

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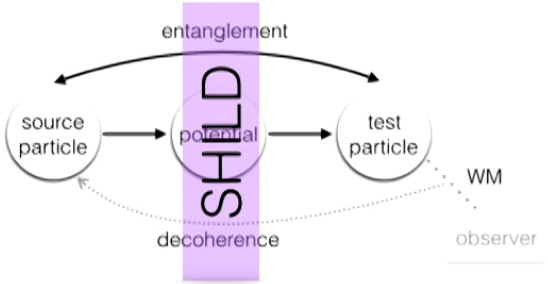

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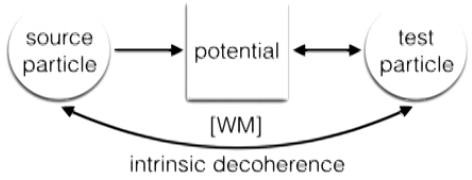
Gravity can not be shielded



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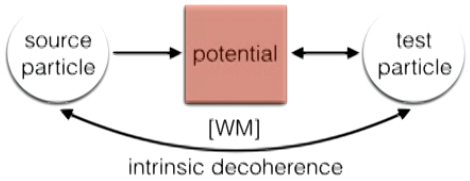

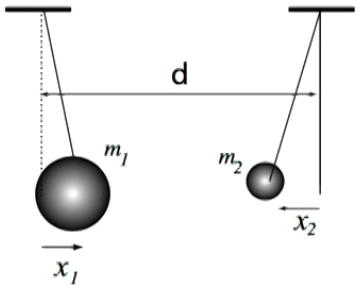

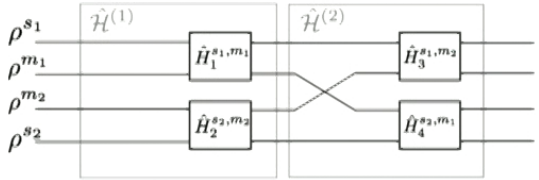

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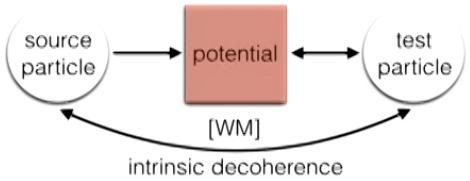

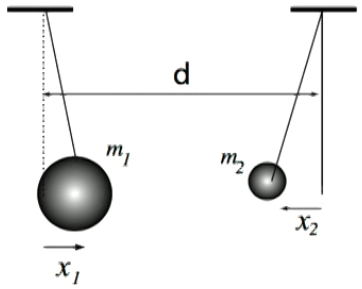

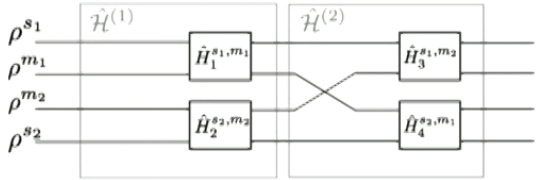

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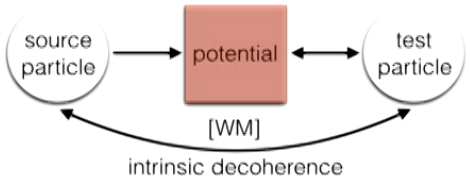

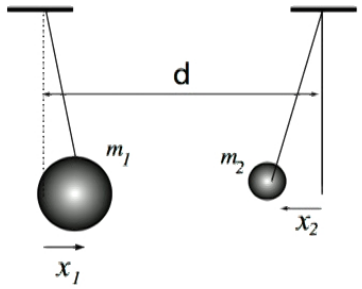

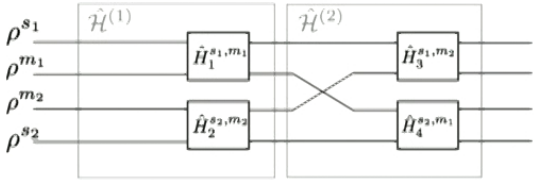

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UNITARY **DECOHERENCE**

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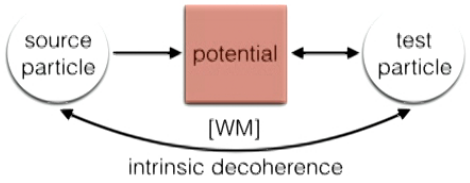

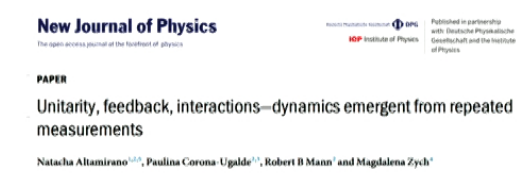

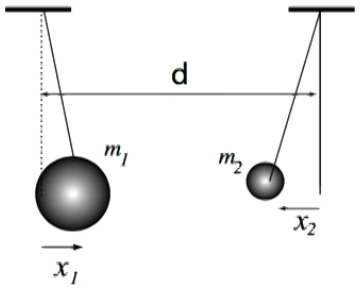

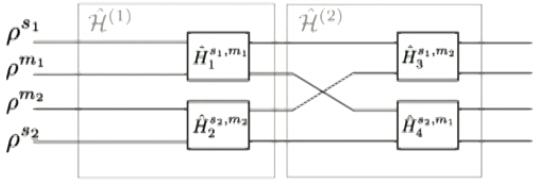

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UNITARY **DECOHERENCE**

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COSMOLOGY [Review]

- **EINSTEIN EQUATIONS** $R_{ab} - \frac{1}{2} R g_{ab} = 8\pi G T_{ab}$
- **METRIC** $ds^2 = -dt^2 + a^2(t)\left(\frac{1}{1-kr^2}dr^2 + r^2 d\Omega^2\right)$
- **ENERGY-MOMENTUM TENSOR** $T_{ab} = (\rho + P)u_a u_b + P g_{ab}$

$$H^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho \qquad \frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P) \qquad H = \frac{\dot{a}}{a}$$

- **EQUATION OF STATE** $w(t) \longrightarrow P = w(t)\rho$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho(1 + 3w(t))$$

$w > -1/3 \longrightarrow$ **decelerating**

$w < -1/3 \longrightarrow$ **accelerating**

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MODEL

Class. Quantum Grav. **34** (2017) 115007 (19pp)

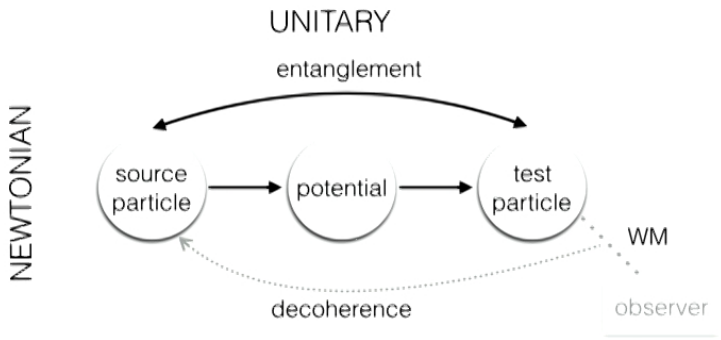
Emergent dark energy via decoherence in quantum interactions

Natacha Altamirano[1,2], Paulina Corona-Ugalde[2,3], Kiran E Khosla[4,5], Gerard J Milburn[4,5] and Robert B Mann[1,2]

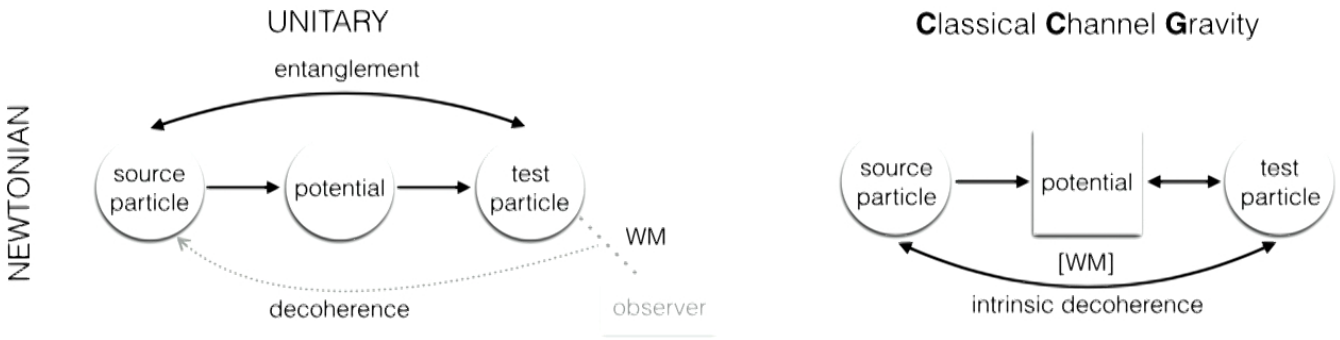
Abstract

In this work we consider a recent proposal that gravitational interactions are mediated via classical information and apply it to a relativistic context. We study a toy model of a quantized Friedman–Robertson–Walker (FRW) universe with the assumption that any test particles must feel a classical metric. We show that such a model results in decoherence in the FRW state that manifests itself as a dark energy fluid that fills the spacetime. Analysis of the resulting fluid, shows the equation of state asymptotically oscillates around the value $w = -1/3$, regardless of the spatial curvature, which provides the bound between accelerating and decelerating expanding FRW cosmologies. Motivated with quantum-classical interactions this model is yet another example of theories with violation of energy-momentum conservation whose signature could have significant consequences for the observable universe.

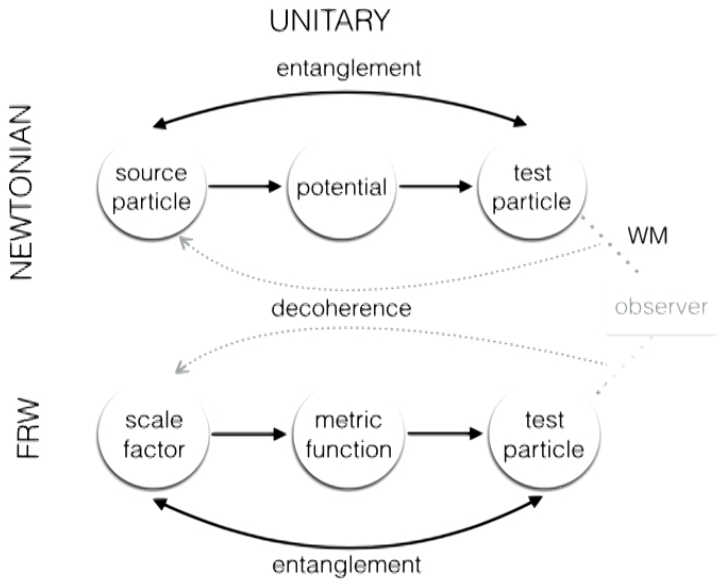
MODEL

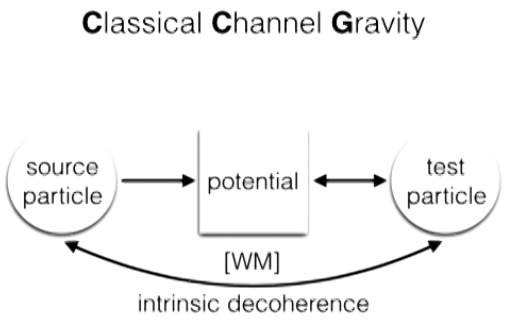

UNITARY
entanglement
NEWTONIAN
source particle
potential
test particle
WM
observer
decoherence

MODEL


UNITARY
Classical Channel Gravity
NEWTONIAN
entanglement
source particle
potential
test particle
WM
observer
decoherence
source particle
potential
test particle
[WM]
intrinsic decoherence

MODEL

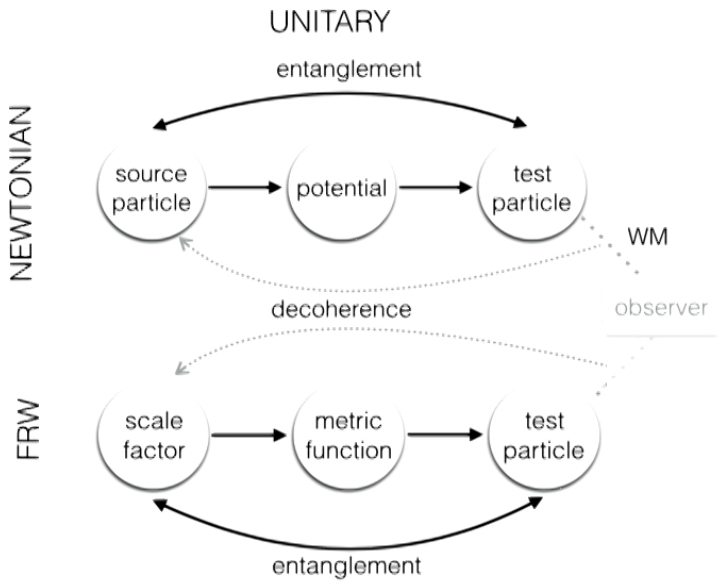


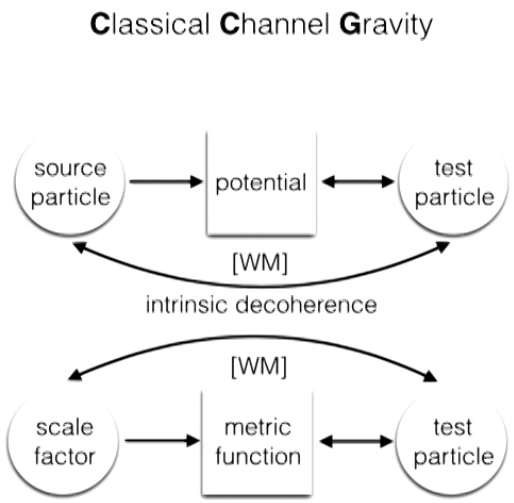


- Wheeler De-Witt equation

$$\hat{H}|\psi>=0$$

MODEL





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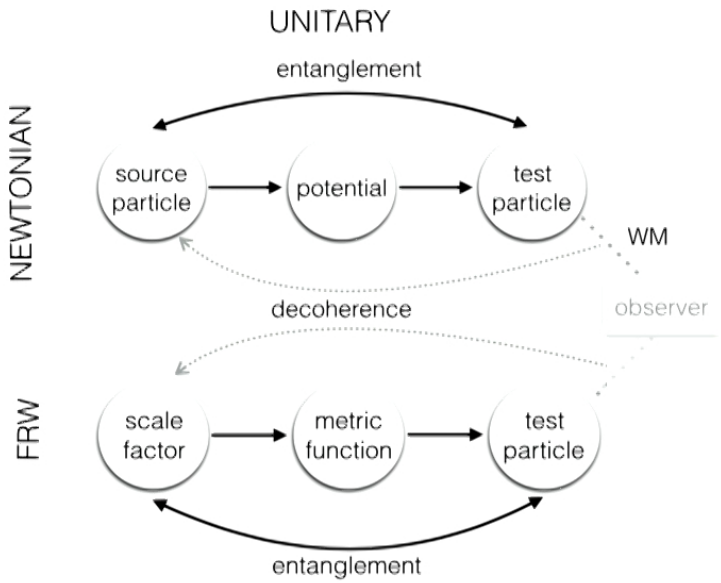

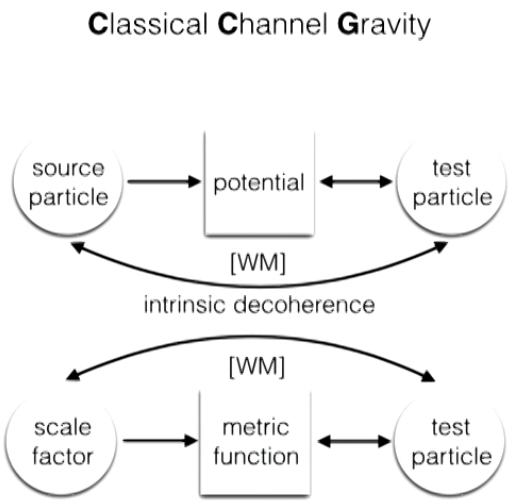

- Wheeler De-Witt equation

$$\hat{H}|\psi>=0$$

- Master equation

$$d\hat{\rho} = -\frac{i}{\hbar}[\hat{H},\hat{\rho}] - \frac{\gamma}{8\hbar}[\hat{a}^2,[\hat{a}^2,\hat{\rho}]]$$

COSMOLOGY

Emergent dark energy fluid from quantum decoherence

(Altamirano *et.al.* arXiv:1605.05980 CQG-34,11 (2017))

Hilbert Space

CCG

$$d\hat{\rho} = -\frac{i}{\hbar}[\hat{H}, \hat{\rho}] - \frac{\gamma}{8\hbar}[\hat{a}^2, [\hat{a}^2, \hat{\rho}]]$$

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HAMILTONIAN:

- If no interaction is performed then we have an empty FRW

$$\hat{H} = -\frac{\hat{\pi}^2}{4} - k\hat{a}^2$$

CLASSICAL METRIC:

$$ds^2 = <\hat{a}^2> [d\tau^2 + \frac{1}{1-kr^2}dr^2 + r^2 d\Omega^2]$$

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DYNAMICS

$$\frac{d<\hat{a}^2>}{d\tau} = \mathrm{Tr}[\dot{\hat{\rho}}\hat{a}^2]$$

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DYNAMICS

$$\frac{d<\hat{a}^2>}{d\tau} = -<\hat{a}\hat{\pi}+\hat{\pi}\hat{a}>/2\,,$$
$$\frac{d<\hat{\pi}^2>}{d\tau} = 2k<\hat{a}\hat{\pi}+\hat{\pi}\hat{a}> + \gamma<\hat{a}^2>\,,$$
$$\frac{d<\hat{a}\hat{\pi}+\hat{\pi}\hat{a}>}{d\tau} = -<\hat{\pi}^2> + 4k<\hat{a}^2>\,.$$

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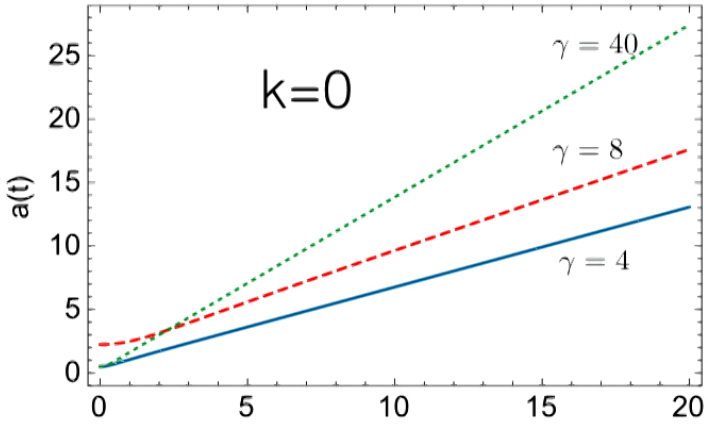

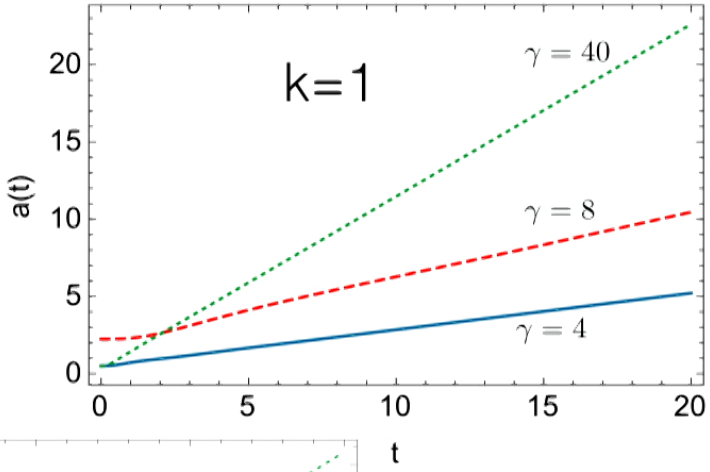

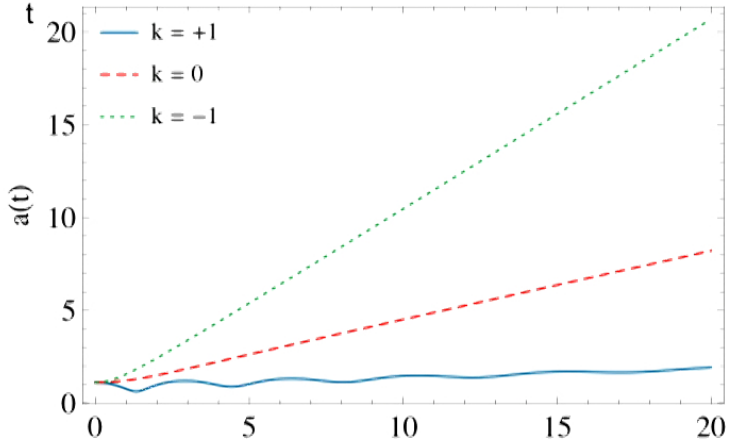

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$$\hat{H} = -\frac{\hat{\pi}^2}{4} - k\hat{a}^2$$

$$ds^2 = <\hat{a}^2>\left[d\tau^2 + \frac{1}{1-kr^2}dr^2 + r^2 d\Omega^2\right]$$

DYNAMICS

$$\frac{d<\hat{a}^2>}{d\tau} = \mathrm{Tr}[\dot{\hat{\rho}}\hat{a}^2]$$

$$\frac{d\hat{H}}{d\tau} = -\frac{\gamma}{4}<\hat{a}^2>$$

$$G_{ab}(<\hat{a}^2>) = 8\pi T_{ab}$$

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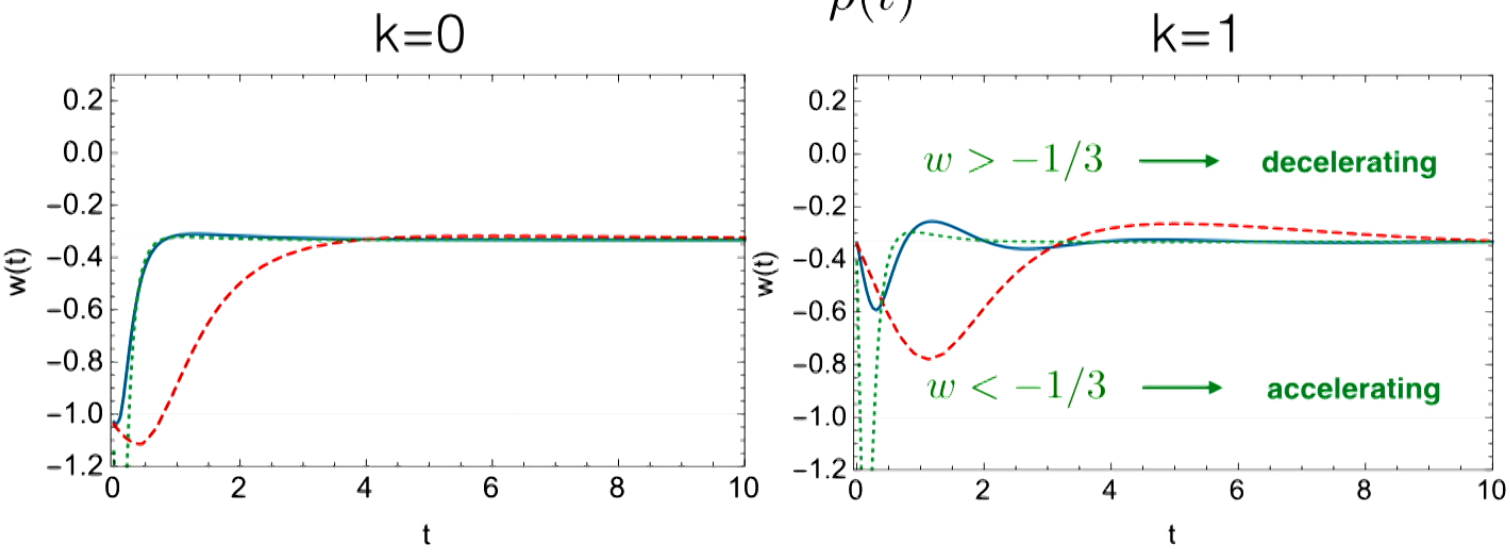
$$w(t) = \frac{P(t)}{\rho(t)}$$



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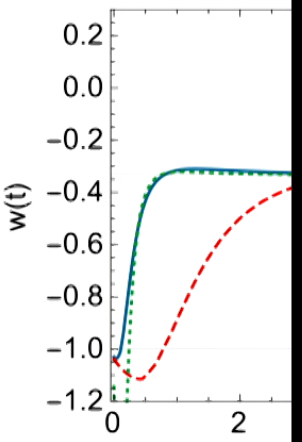
cos



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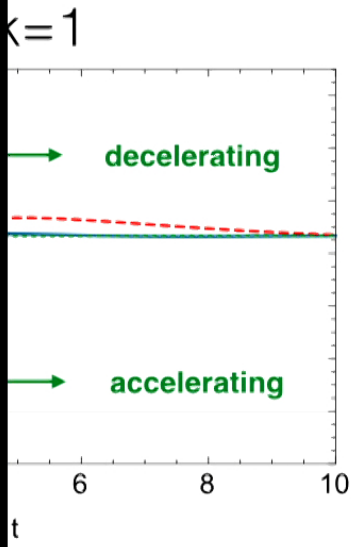
k energy fluid from

decoherence

t.al. CQG-34,11 (2017)
:1605.05980)



cos

k energy fluid from

decoherence

t.al. CQG-34,11 (2017)
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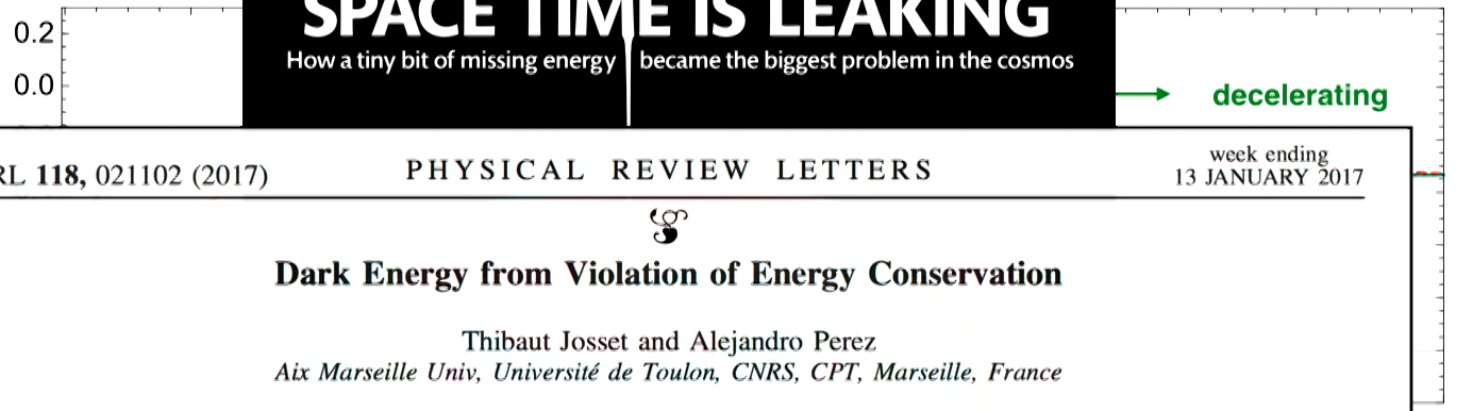
k=1



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Dark Energy from Violation of Energy Conservation

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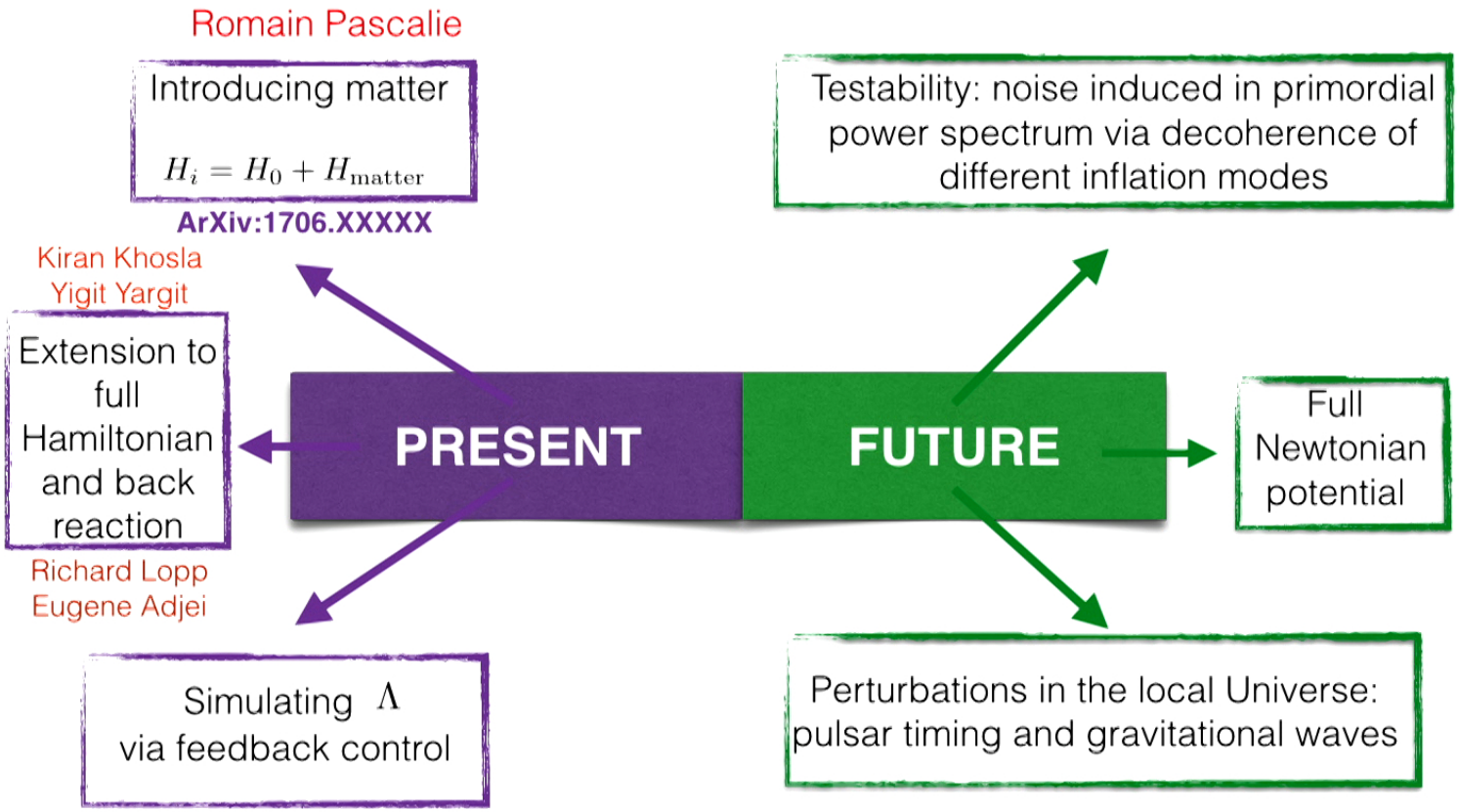

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REMARKS

Introducing matter

$H_i = H_0 + H_{\text{matter}}$

$$\dot{\rho} = \frac{i}{\hbar}[H_0 + \frac{\Lambda}{3}a^4, \rho] + \left(\frac{1}{4D} + \frac{D\Lambda^2}{9\hbar^2}\right)[a^2, [a^2, \rho]]$$

Romain Pascalie

Kiran Khosla

PRESENT

$$H_\Lambda = -ka^2 - \frac{p^2}{4} + \frac{1}{3}\Lambda a^4$$

$$\dot{\rho}(t) = -\frac{i}{\hbar}[\hat{S}_0, \rho(t)] - \frac{i}{\hbar}\frac{\bar{g}_2}{4}[\hat{S}_2, \hat{S}_1\rho(t) + \rho(t)\hat{S}_1] - \frac{1}{8D}[\hat{S}_1, [\hat{S}_1, \rho(t)]] - \frac{D}{\hbar^2}\frac{\bar{g}_2^2}{8}[\hat{S}_2, [\hat{S}_2, \rho(t)]]\,.$$

Simulating Λ via feedback control

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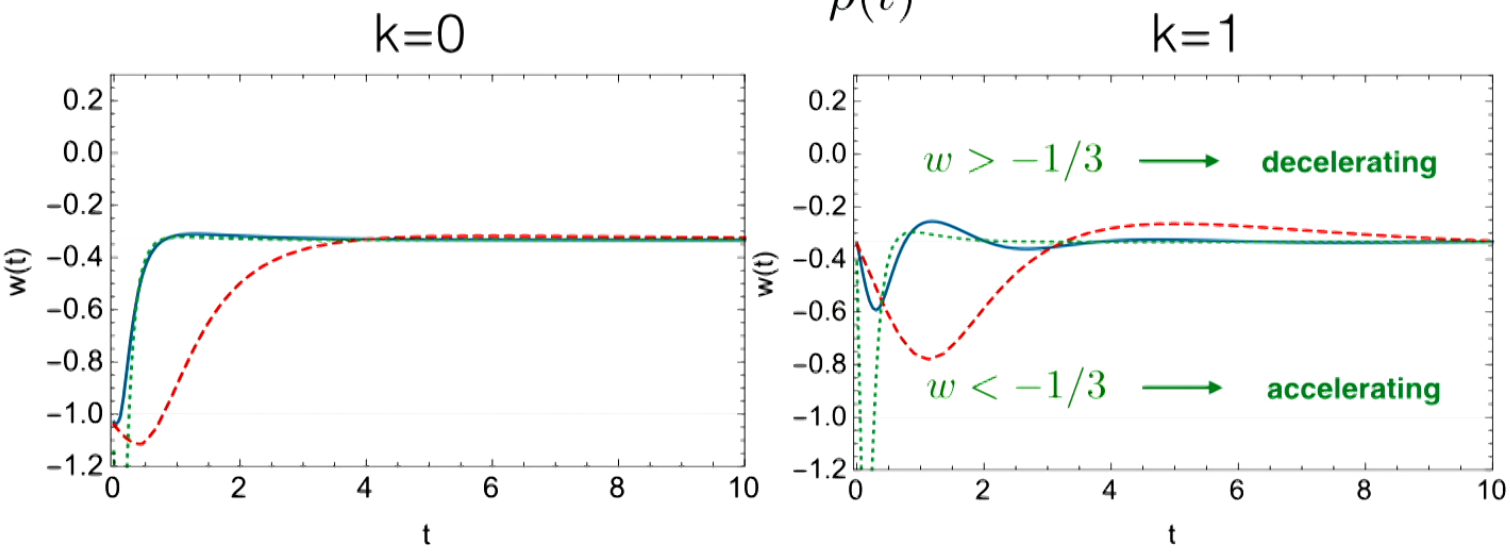

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