Report on 15th Marcel Grossmann Meeting

Koji Nagano

KAGRA Observatory, ICRR, the University of Tokyo

2018/07/20

Outline

1. MG15
2. Report

MG15


Working toward the ideal scenario:
Athena and LISA up together

MG15

Review

1. General report
2. Entanglement of Quantum Clocks Through Gravity

Review

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2. Entanglement of Quantum Clocks Through Gravity

General review

- Schedule
  - 2^{nd}-7^{th} July, 2018
  - Morning: Plenary talks
  - Evening: Parallel session
- There were many theoretical talks. (>2/3?)
  - In plenary talks, more experimental talks.
- Parallel sessions were really parallel.
  - There were about 20 sessions in parallel.
- Many works told in parallel sessions were a kind of review of what has been published in journal paper.

Review

1. General report
2. Entanglement of Quantum Clocks Through Gravity

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PNAS PLUS

Entanglement of quantum clocks through gravity

Esteban Castro Ruiz[a,b,1], Flaminia Giacomini[a,b], and Časlav Brukner[a,b]

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Edited by Abhay V. Ashtekar, The Pennsylvania State University, University Park, PA, and approved January 30, 2017 (received for review October 4, 2016)

In general relativity, the picture of space–time assigns an ideal clock to each world line. Being ideal, gravitational effects due to these clocks are ignored and the flow of time according to one clock is not affected by the presence of clocks along nearby world lines. However, if time is defined operationally, as a pointer position of a physical clock that obeys the principles of general relativity and quantum mechanics, such a picture is, at most, a convenient fiction. Specifically, we show that the general relativistic mass–energy equivalence implies gravitational interaction between the clocks, whereas the quantum mechanical superposition of energy eigenstates leads to a nonfixed metric background. Based only on the assumption that both principles hold in this situation, we show that the clocks necessarily get entangled through time dilation effect, which eventually leads to a loss of coherence of a single clock. Hence, the time as measured by a single clock is not well defined. However, the general relativistic notion of time is recovered in the classical limit of clocks.

how the usual conception is obtained in the limit where quantum mechanical effects can be neglected.

In this work, we show that quantum mechanical and gravitational properties of the clocks put fundamental limits to the joint measurability of time as given by clocks along nearby world lines. As a general feature, a quantum clock is a system in a superposition of energy eigenstates. Its precision, understood as the minimal time in which the state evolves into an orthogonal one, is inversely proportional to the energy difference between the eigenstates (7–11). Due to the mass–energy equivalence, gravitational effects arise from the energies corresponding to the state of the clock. These effects become nonnegligible in the limit of high precision of time measurement. In fact, each energy eigenstate of the clock corresponds to a different gravitational field. Because the clock runs in a superposition of energy eigenstates, the gravitational field in its vicinity, and therefore the space–time metric, is in a superposition. We prove that, as a consequence of this fact, the time dilation of clocks evolving along nearby world

Abstract

- This talk was in Precision Tests session (PT3).

Session: **PT3 - Experimental Gravitation**
Chairperson: Angela di Virgilio Claus Laemmerzahl

Day: **Tuesday, July 3**
Room: FF7 - AULA 7 - CU033

Display record from 1 to 11 of 11 records find

Arrived	Accept	N.	Hour	Time	Talk Type	Speaker	Talk Title	Talk view
√	Yes	**1**	15:15	25'	Oral abstract	Zych, Magdalena	Universal decoherence due to gravitational time dilation	
√	Yes	**2**	15:40	25'	Oral abstract	Bassi, Angelo	Tests of the quantum superposition principle: current experiments on Earth, future experiments in Space	
√	Yes	**3**	16:05	20'	Oral abstract	Haslinger, Philipp	Probing the forces of gravity, blackbody radiation and dark energy with matter waves	
√	Yes	**4**	16:25	20'	Oral abstract	Vitali, David	Testing quantum mechanics and quantum gravity with cavity optomechanics	
					COFFEE BREAK			
√	Yes	**5**	17:15	25'	Oral abstract	Ulbricht, Hendrik	Prospects for using levitated optomechanics to test fundamental physics	
	Yes	**6**	17:40	20'	Oral abstract	Krutzik, Markus	Towards vapor-cell clocks on small satellites	
√	Yes	**7**	18:00	15'	Oral abstract	Salvi, Leonardo	Atom Interferometry With The Sr Optical Clock Transition For Gravity Measurements	
√	Yes	**8**	18:15	15'	Oral abstract	Castro Ruiz, Esteban	Entanglement of Quantum Clocks Through Gravity	
√	Yes	**9**	18:30	20'	Oral abstract	Ruggiero, Matteo Luca	Measuring the effects of the magnetic-like part of gravitational waves on spinning particles	
√	Yes	**10**	18:50	15'	Oral abstract	Raetzel, Dennis	Frequency spectrum of an optical resonator in a curved spacetime	
√	Yes	**11**	19:05	15'	Oral abstract	Van Stephenson, Gary	Proposal for Laboratory Generated Gravitomagnetic Field Measurement	

Abstract

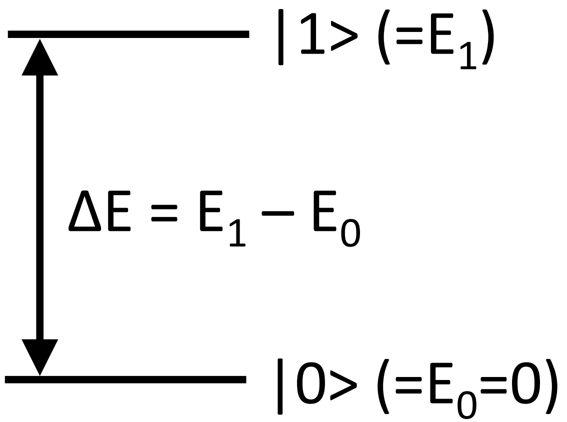
- In general relativity, the picture of space–time assigns an ideal clock to each world line. Being ideal, gravitational effects due to these clocks are ignored and the flow of time according to one clock is not affected by the presence of clocks along nearby world lines.
- However, if time is defined operationally, as a pointer position of a physical clock that obeys the principles of general relativity and quantum mechanics, such a picture is, at most, a convenient fiction.

Abstract

- Specifically, we show that the general relativistic mass–energy equivalence implies gravitational interaction between the clocks, whereas the quantum mechanical superposition of energy eigenstates leads to a nonfixed metric background.
- Based only on the assumption that both principles hold in this situation, we show that the clocks necessarily get entangled through time dilation effect, which eventually leads to a loss of coherence of a single clock.
- Hence, the time as measured by a single clock is not well defined. However, the general relativistic notion of time is recovered in the classical limit of clocks.

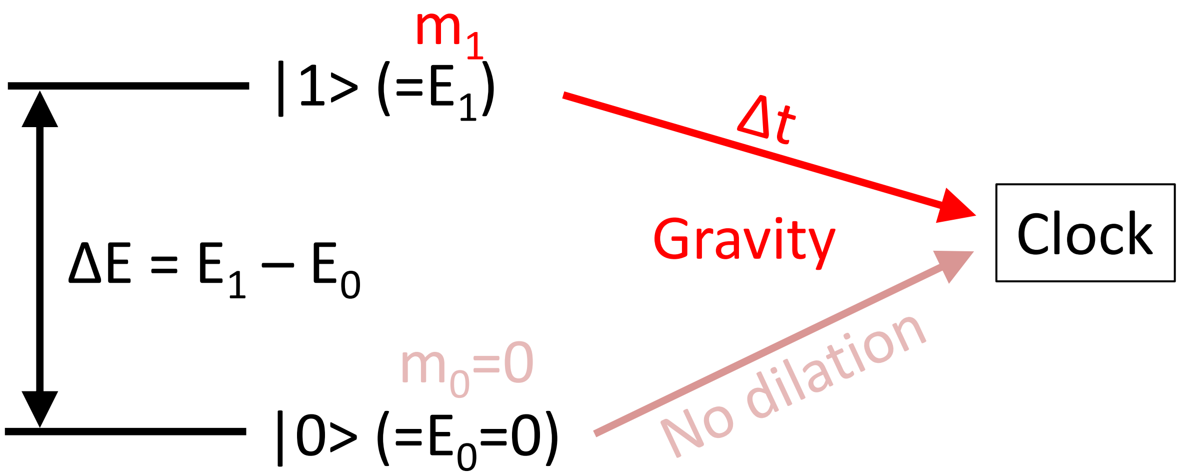
Clock

- In this paper, two-level systems are used as clocks.
- The systems are initially in superposition. Then, it will be orthogonalized in $t_\perp = \hbar\pi/\Delta E$.
- $t_\perp$ quantifies the precision of the clock, and it is, in this sense, a measure of time uncertainty.



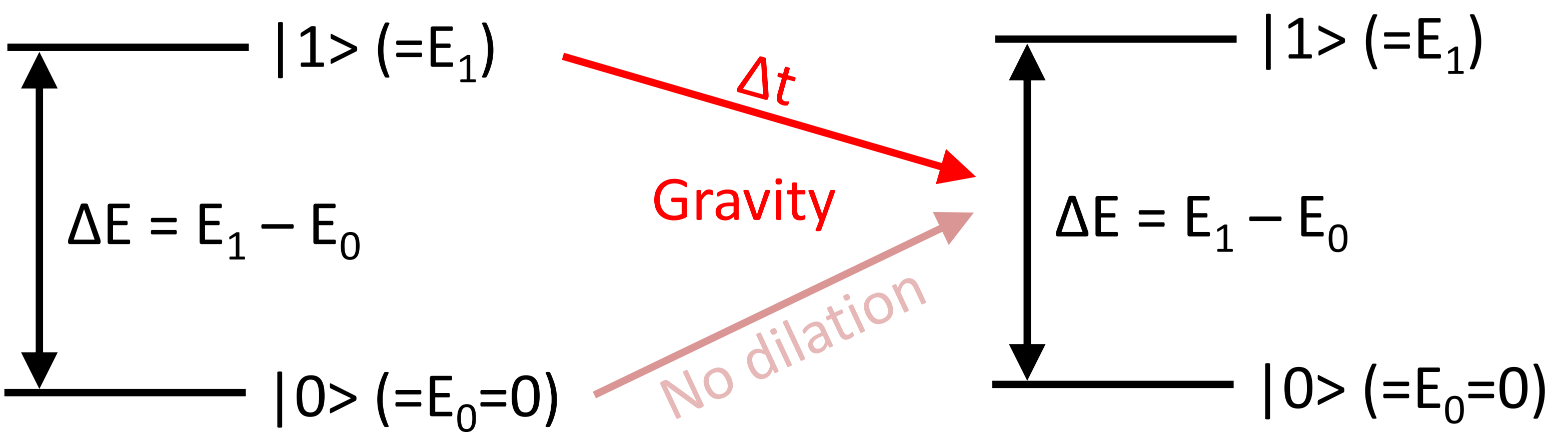
Time dilation

- In general relativity, energy is equivalent to mass, $E = mc^2$.
- Thus, the different energy level has the different mass.
- When we consider general relativity, the clock close to the two-level system is affected differently according to its energy level.



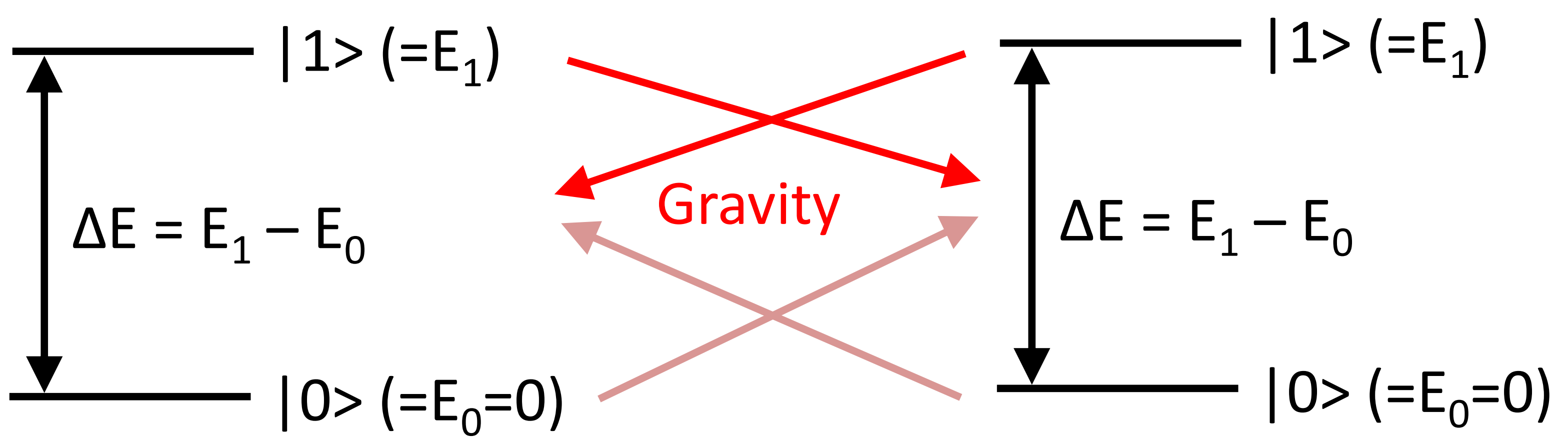
Time dilation

- The other clock is also the two-level system.



Time dilation

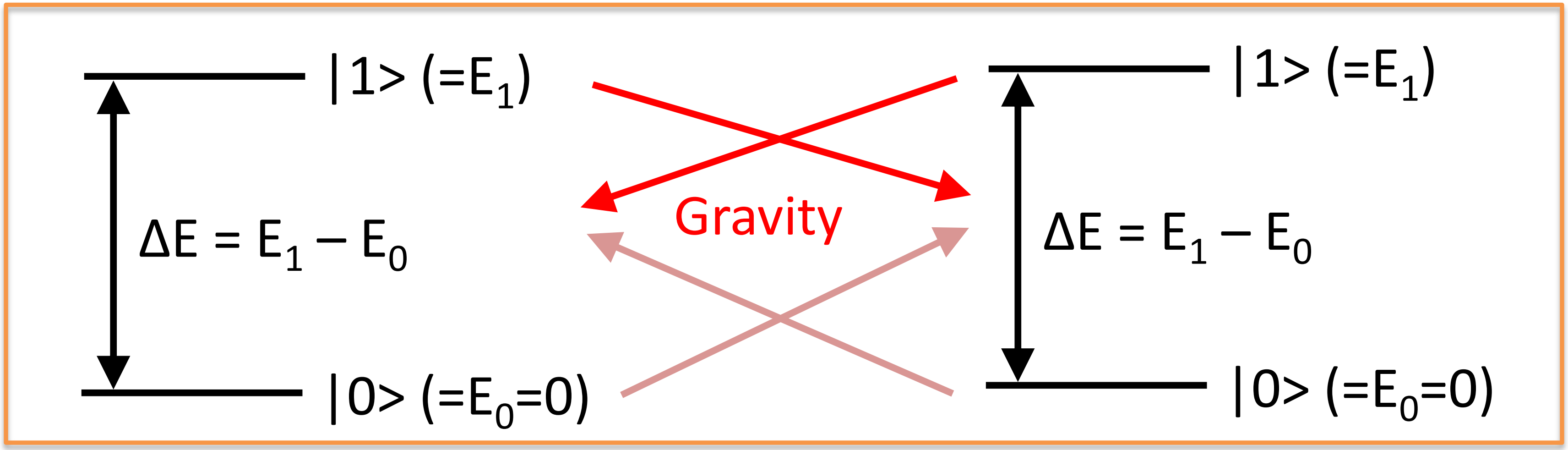
- The other clock is also the two-level system.
- In this situation, the clocks affect each other.



Time dilation

- The other clock is also the two-level system.
- In this situation, the clocks affect each other.
- As a result, the two clocks gets to be ***entangled via gravity.***

Entangle



Time uncertainty

- As a consequence of these considerations, there is a fundamental trade-off between the accuracy of measuring time at the location of the clock and the uncertainty of time dilation at nearby points.

$$t_{\perp}\Delta t = \frac{\pi\hbar G t}{c^4 x}$$

- This uncertainty relation that arises due to both ***quantum mechanical and general relativistic effects***.