The Time Machine Factory Conference
25-28 October 2015
Turin, Italy

INTERNATIONAL YEAR OF LIGHT 2015

October 26, Monday

Session [II–A] Teleportation, entanglement and CTCs

Chair Lev Vaidman

14:15 **Title** (*TBA*) *A. C. Elitzur* *[key-speaker]*

Abstract
TBA

15:00 **Signal causality in closed timelike curves** *L. Maccone* *[invited]*

Abstract
Closed timelike curves (CTC) describe paths in spacetime that allow one to travel, along a locally-timelike trajectory, to a past instant. It seems obvious that a CTC should not permit to communicate to earlier instants, a condition named "signal causality". Here we show that this intuition is false: classical general relativity augmented by the Novikov principle (the minimal requirement to enforce its logical consistency) implies violations of signal causality. We prove this by presenting a simple thought experiment that entails no quantum effects. Nonetheless, signal causality is a desirable property and we present a quantum mechanism based on post-selected teleportation (P-CTCs) that can restore signal causality to the theory.

15.30 **Visualising the Page-Wootters scheme of time emerging from quantum entanglement** *M. Genovese* *[invited]*

Abstract
Quid est ergo tempus? si nemo ex me quaerat, scio; si quaerenti explicare velim, nescio *

As Aurelius Augustinus everybody has a clear perception of what time is, but a clear physical definition of what it is still remains a debated task.

The "problem of time" in present physics substantially consists in the fact that a straightforward quantization of the general relativistic evolution equation and constraints generates for the Universe wave function the Wheeler-De Witt equation [1], which describes a static Universe.

Page and Wootters [2] considered the fact that there exist states of a system composed by entangled subsystems that are stationary, but one can interpret the component subsystems as evolving: this leads them to suppose that the global state of the universe can be envisaged as

one of this static entangled state, whereas the state of the subsystems (us, for example) can evolve.

Here I present an experiment, based on PDC polarisation entangled photons, that allows showing with a practical example a situation where this idea works, i.e. a subsystem of an entangled state works as a "clock" of another subsystem [3]

[1] C.Rovelli, quant-gr0006061
[2] D.N. Page and W.K. Wootters, Phys. Rev. D 27, 2885 (1983); W.K. Wootters, Int. J. Theor. Phys. 23, 701 (1984).
[3] E. Moreva, G. Brida, M. Gramegna, V. Giovannetti, L. Maccone, M. Genovese; Phys. Rev. A 89(2014) 052122.

* *What is the time? If nobody ask me, I know; whether I want to explain it to somebody, I do not know.*

16:00 COFFE BREAK

Session [II–B] Teleportation, entanglement and CTCs

Chair Avshalom C. Elitzur

16:30 **How to build a quantum time translation machine and can we affect the past?** *L. Vaidman [key-speaker]*

Abstract

A design of a time machine which can move objects to their past or future states using quantum measurements will be presented. To which extent these and other quantum measurements can affect the past will be discussed.

17:15 **Making sense of a time symmetric universe: time travelling in both directions** *J. Vaccaro [invited]*

Abstract

Time evolution appears to be elemental. It is presumed at an axiomatic level in conventional theories and it manifests the underlying order represented by conservations laws. Yet it represents a fundamental asymmetry between space and time because there is no spatial counterpart to the way time evolution and conservation laws operate over time. For example, time evolution and mass conservation forbid matter from being localised in time as a "lump" that exists only at a certain time, whereas nothings forbids a lump of matter existing only at a particular location in space. However, despite its apparently elemental character, I will show that this asymmetry between time and space may actually be phenomenological in origin and due a deeper cause. A crucial point is that the violation of the discrete symmetries of charge conjugation (C), parity inversion (P) and time reversal (T) are properties of the Hamiltonian which is the generator of translations in time. They are not directly associated with the generator of translations in space, the momentum operator, and this sets time and space apart phenomenologically. To illustrate how the asymmetry arises, I use a quantum sum-over-paths formalism to contrast two specific cases: one where the Hamiltonian obeys T symmetry and the other where it violates T symmetry. The paths include every possible path in space and in time, including closed time paths. In the T symmetry case the sum-over-paths allows states of matter to be localised both in space and in time. This ensures a symmetry between space and time, but the price paid is the absence of an equation of motion, conservation laws and time evolution in the formalism. In stark contrast, in the second case, where the Hamiltonian violates T symmetry, quantum interference between different paths gives a very different situation. In that case, the same sum-over-paths yields states of matter that are localised in space and distributed over an unbounded region of time. The distribution of states over time allows an equation of motion (the Schrodinger equation) to be formulated and conservation laws to operate. Conventional quantum mechanics is then recovered and, along with it, the asymmetry between time and space. It seems, therefore, that the violation of T symmetry may have a deep connection with time evolution.
But there is a twist. By construction, the formalism is symmetric with respect to the direction of time regardless of whether T symmetry is obeyed or violated. The time evolution that emerges in the T violation case is actually in both directions of time: the universe is in a superposition of a state corresponding to time t and evolving to the "future", and a state corresponding to time -t and evolving to the "past". An observer in the universe would not be able to distinguish between these two states. Although effectively travelling to the past, the situation would not help the

observer travel back to a previously visited state in time. The only allowed translations in time are further to the future and further to the past, despite the fact that paths representing closed time loops are included in the formalism.

17:45 **CTCs, Retrocausality and Free-Will** *E. Cohen [invited]*

Abstract

We discuss the construction and implications of having a universe with two opposing time arrows. Surprisingly, this can be achieved quite easily by employing a time-dependent four-partite quantum entanglement. We then analyse the possibility of communication between two such systems with opposite time directions. Several causal paradoxes naturally ensue, whose resolution sheds light on classical stability and quantum uncertainty. Finally, the notion of free-will in this hypothetical universe is briefly discussed.

18:15 **Poster Session**

Boson as a Time Machine with Varying Time Rate *Yau Hou*

Abstract

We show that a quantized oscillator with vibrations in time can have the same properties of a free zero-spin boson in quantum theory. Taking the amplitude of matter wave as a 4-vector with vibrations in space and time, the formulation of a bosonic field (e.g., Schrödinger's equation, Klein-Gordon equation, probability density etc.) can be derived. The quantized oscillator can be considered as a time machine that travels with varying time rate. It is this varying time rate that leads to quantization of the field.

18:20 END SESSIONS

October 27, Tuesday

Session [II–C] Teleportation, entanglement and CTCs

Chair Joan Vaccaro

16:00 **Bizarre monogamy of entanglement in time** *Marcin Nowakowski*

Abstract

In this presentation we state a fundamental question about the structure of correlations in time and analyze temporal monogamy relations. We show that the nature of temporal correlations is inherently different from the spatial ones and prove new monogamy relations for temporal correlations. We perform this task applying entangled histories framework and show the difference between spatial and temporal correlations in case of Legget-Garg inequalities and entropic time inequalities. Finally, we point out that in a context of the tensor algebra used for linking states in different times further studies on mathematical structure of the state representing evolving systems are needed. These considerations are supported by introduction of necessary tools specific for the tensor algebra used for representation of spatial correlations.

16:20 **(Quantum?) Processes and Correlations with no definite causal order** *Cyril Branciard*

Abstract

The framework of process matrices introduced by Oreshkov et al. [Nat. Commun. 3, 1092 (2012)] allows for so-called causally non separable processes that are "locally compatible" with quantum theory, but are incompatible with a definite causal order. Such processes may (or may not) generate correlations that are themselves incompatible with a definite causal order, and violate so-called causal inequalities. I will clarify in this talk the link between the causal nonseparability of process matrices and their ability to violate causal inequalities, highlighting the rich analogy with entanglement and Bell nonlocality.

16:40 **Title T.B.A.** *(Remote Talk - to be confirmed)*

Seth Lloyd

Abstract

T.B.A.

17:20 **Poster Session**

Time emerging from quantum correlations: an experimental illustration *E. Moreva*

Abstract

Page and Wootters' mechanism of "static" time is experimentally realized using a static, entangled state of the polarization of two photons, one of which serves as a clock to gauge the evolution of the second.

Testing Quantum Gravity by Quantum Light *I. Ruo Berchera, I. P. Degiovanni, S. Olivares, N. Samantaray, P. Traina, and M. Genovese*

Abstract

Several quantum gravity theories (string theories, holographic theory, heuristic arguments from black holes,...) predict or conjectured non commutativity of position variables along perpendicular directions at Planck scale. This would imply a sort of space-time uncertainty principle determining slight random wandering of transverse position, called "holographic noise" (HN).

Indeed, in Michelson interferometer the estimation of the phase shift among the arms can be seen as a simultaneous measurement of the positon of the beam splitter along perpendicular direction and therefore should be affected by HN, which will accumulates in a random walk-like behavior during a round trip of light propagation.
Albeit still too faint to be measured even with the most sensitive interferometers available nowadays, this effect could be measurable by correlating the output ports of two independent interferometers, provided they share the same space-time volume. In that case other sources of noise limiting the sensitivity (mainly shot noise) will vanish since they are independent, while HN, the same in both the devices, should emerge in the correlation measurement. In particular, this last idea led to the planning of a double 40 m interferometers at Fermilab, dabbed as "Holometer" [1].

We show how the use of quantum correlation and entanglement lead to a significant improvements of the sensitivity to the HN of the double interferometric scheme, up to a noise-free scenario for the ideal lossless case [2,3]. This finding prompts the possibility of testing QG in experimental conjuration affordable in a traditional quantum optics laboratory with current technology.

[1] https://holometer.fnal.gov/
[2] Quantum light in coupled interferometers for quantum gravity tests, IR Berchera, IP Degiovanni, S Olivares, M Genovese, Phys. Rev. Letters 110, 213601(2013).
[3] One- and two-mode squeezed light in correlated interferometry, I. Ruo Berchera, I. P. Degiovanni, S. Olivares, N. Samantaray, P. Traina, and M. Genovese, Phys.Rev. A, Accepted.

17:25 **END SESSIONs**