Time and Matter 2007

Sunday 26 August 2007 - Friday 31 August 2007

Bled, Slovenia

Book of Abstracts

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Cold Atom Clocks and Fundamental Tests

We will describe the present status for the realization of the SI unit of time, the second. Microwave frequency standards operating with laser cooled cesium and rubidium atoms have advanced by two orders of magnitude in the last two decades. Cesium fountains currently operate at the fundamental quantum noise limit with 107 detected atoms and display a relative frequency stability of 1.5x10ˆ-16 after 50 000 seconds of averaging time. The SI second is realized with an accuracy of 3x10ˆ-16 implying an error of less than a second over 100 million years.
In a second part, we will describe tests of fundamental physical laws using ultra-stable clocks. By comparing clocks of different nature new limits are obtained for the time variation of the fundamental constants of physics such as the fine structure constant alpha. The ability to compare microwave and optical clocks using the newly developed frequency comb technique opens a wide range of possibilities in clock comparisons.
By installing in space ultra-stable cold atom clocks (PHARAO/ACES project for flight in 2013), improved tests of general relativity will be performed, such as a measurement of Einstein's gravitational red-shift at the one part per million level. A new kind of relativistic geodesy based on the Einstein effect will provide information on the Earth geoid. Finally prospects for laser cooled atomic clocks operating in the optical domain with frequency stability in the 10ˆ-18 range will be outlined.

Measuring Time / 6

Stable and Accurate Single-Ion Optical Clocks

In recent years, several groups throughout the world have initiated research toward the development and systematic evaluation of frequency and time standards based on narrow optical transitions in laser-cooled atomic systems. In this report we present some of the results obtained in comparative studies of the Hg+ single ion optical clock, the Al+ single ion optical clock and the Cs fountain primary frequency standard (NIST-F1) at NIST. The frequencies of the clocks are compared with each other using an octave-spanning optical frequency comb (OFC), which is tightly phase locked to one of the clock lasers. The most recent frequency comparison between the Hg+ optical clock and NIST-F1 shows an uncertainty of ˜9x10ˆ-16 limited by the integration time, and recent measurements of the frequency ratio between the Al+ and Hg+ standards show an overall uncertainty of several parts in 10ˆ-17. The extremely precise measurements of the frequency ratios of these clocks over time have begun to offer more stringent limits on any temporal variation of the fine structure constant alpha as well as other tests of general relativity.

Tests of the temporal stability of the fine structure constant alpha is possible with both the Hg+/Cs and the Hg+/Al+ frequency comparisons. From Hg+/Cs measurements, temporal variation of alpha is estimated to be lower than 1.3 x10ˆ-16 yrˆ-1, assuming stability of the other fundamental constants involved. This limit is determined from the historical series of frequency comparisons of these two standards spanning more than five years. From the measurements of the frequency ratios of various optical clocks it is possible to directly estimate any present-day temporal variation of alpha without constraints on other constants. Preliminary data from the measurements of the Hg+/Al+ frequency ratio spanning a period of several months indicate a more stringent limit on the time variation of alpha is possible.

Results from Hg+/Cs frequency comparisons can also be used to test the postulate of Local Position Invariance (LPI). LPI states that atomic clocks experience the same fractional frequency shift when they move through the same change in gravitational potential. The test presented here uses the natural variation of gravitational potential given by the earth's revolution about the sun to set limits on possible violations of LPI.

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Lunch

Measuring Time / 8

Optical Clocks with Trapped Ions

The techniques of trapping and laser cooling of ions have allowed to perform laser spectroscopy of forbidden transitions with a resolution of a few hertz. These systems will be used as optical atomic clocks that offer higher stability and greater accuracy than the best primary cesium clocks available today. At PTB we have built an optical clock based on a single trapped ytterbium ion and have shown that the frequencies realized in two independent ion traps agree to within a few parts in 10ˆ16 . An interesting question from fundamental physics that can be investigated with optical clocks of this precision is the search for possible temporal variations of fundamental constants, based on comparisons between different transition frequencies over time. Presently, we can infer an upper limit for the relative change of the fine structure constant of 4*10^-16 per year. We are also investigating the concept of a nuclear optical clock that will be based on a low-energy isomeric state in Th-229. Such a system promises further advances in accuracy and may open a new field at the borderline between atomic and nuclear physics.

Coherence, Decoherence and Entanglement / 9

The Early History of Quantum Entanglement

This talk traces the history of quantum entanglement from Einstein's earliest worries in 1905-at the time of the photon hypothesis paper-about the failure of the mutual independence of quanta outside of the Wien regime, through his early speculations ca. 1909 about wave-particle duality and his first clear and deep insight into the mutual dependence of systems obeying bosonic statistics in 1924 to the emergence of entanglement as a generic feature of the quantum mechanical formalism as well as the deep physical basis of Bohr's complementarity interpretation ca. 1927 and its eventual baptism, under the name, "entanglement," by Schrödinger in 1935. Discussed along the way will be the early speculations about entanglement's possible role in explaining phenomena such as the Ramsauer effect and its early employment in the late 1920s and early 1930s in quantum chemistry, superconductivity, and quantum field theory. A major thesis of the talk is that by 1927 the central place of entanglement in quantum mechanics was well understood and widely appreciated, Schrödinger's role in naming entanglement in 1935 being, therefore, merely to say more explicitly and for a wider audience what was already by then more or less commonplace physics from the point of view of the mainstream physics community of that era. A major question posed implicitly by the paper is why, in view of this history and in view of continuing work on entanglement by members of the foundations of physics community, it has only been with the recent rise of interest in entanglement among physicists working in quantum information theory, quantum computing, and quantum cryptography that the topic has seemed, finally, to have re-emerged as being of central importance in the eyes of the mainstream contemporary physics community.

Coherence, Decoherence and Entanglement / 10

Decoherence Measurements in Fullerene Interferometry

We use a near field interferometer of Talbot-Lau type to investigate the wave particle duality of large molecules such as C70 fullerenes. This device is also well suited to study the quantum-to-classical transition via decoherence mechanisms that occur quite naturally in such an interferometer. Interactions of the interfering particle with the surrounding environment lead to a collapse of the wave function and to a loss of the observed interference contrast in the following. In particular we study decoherence by collisions with various background gas particles as well as decoherence of very hot molecules by spontaneous emission of thermal photons. We complete our study by measuring the influence of mechanical vibrations on the interference contrast. Our measurements allow us to estimate how large molecules from proteins up to small viruses will be affected by decoherence and make predictions about the experimental requirements to show interference.

Coherence, Decoherence and Entanglement / 11

EPR correlations in Y(4S) -> B0 anti-B0 decays

The neutral B-meson pair produced at the Upsilon(4S) should exhibit a non-local correlation of the type discussed by Einstein, Podolski, and Rosen. The time-dependent flavour asymmetry of the B mesons decaying into flavour eigenstates will be used to test such a correlation.
The asymmetry obtained from semileptonic B0 decays is in agreement with the prediction from quantum mechanics and far away from the predictions of local realism models.
We also test for possible partial decoherence effects.
Our results are consistent with no decoherence.

CP and T Violation / 12

Experimental tests of CPT symmetry and quantum mechanics in the neutral kaon system

The neutral kaon system offers a unique possibility to perform fundamental tests of CPT invariance, as well as of the basic principles of quantum mechanics.
The most recent limits on CPT violation will be reviewed, including the ones based on the Bell-Steinberger relation, related to possible decoherence mechanisms, or Lorentz symmetry breaking.
Quantum coherence and other QM tests performed by studying the time evolution of correlated kaon pairs will also be reviewed.
The results show no deviations from the expectations of quantum mechanics and CPT symmetry, while the accuracy reaches the interesting region of the Planck's scale.
Finally, perspectives on this kind of experimental studies will be presented.

Causality and Signal Propagation / 13

The interaction of gravitational radiation with electron-coated superfluid helium drops: A progress report on experiments at UC Merced

Pairs of Planck-mass–scale drops of superfluid helium coated by electrons, when levitated in the presence of strong magnetic fields and at low temperatures, can be efficient quantum transducers between electromagnetic (EM) and gravitational (GR) radiation. A Hertz-like experiment, in which EM waves (microwaves) are converted at the source into GR waves, and then back-converted at the receiver from GR waves back into EM waves, is being performed at UC Merced. This would open up observations of the gravity-wave analog of the CMB from the extremely early Big Bang, and also communications directly through the interior of the Earth.

CP and T Violation / 14

CP Violation in B Meson Decays

In particle physics, a theory called Standard Model has been established in the last two decades, which successfully describes almost all the known experimental results up to O(100) GeV energy scale. However it is widely believed that the Standard Model is only an approximation of an unrevealed theory that governs physics at O(1000) GeV energy scale, and purposes of the modern high energy physics experiments are to search for and elucidate the new physics. Among several possible approaches to this, flavor physics challenges the new physics through high precision measurements of decays of B mesons, D mesons, tau leptons and so on, which provide complementary informations to the experiments at energy frontier experiments such as the ones at LHC. In this talk, I will describe the quantitative confirmation of Kobayashi-Maskawa scheme of quark mixing and CP violation in B Factory experiments, and describe the upgrade program of the B factory at KEK to challenge the new physics from the studies of flavor physics.

Times Arrow and the Early Universe / 15

Holography and Chronology Protection

We study in detail the solution space for a class of sypersymmetric solutions to supergravity. The solutions fall into three classes, non-singular, null-singular and time machines with a time-like naked singularity. We study the general features of these metrics and prove that there are actually just two generic classes of space-times - those with null singularities are in the same class as the non-singular metrics. Holography seems to provide a dual description only for the first of these two types of space-time in terms of a unitary CFT indicating the possible existence of a chronology protection mechanism for this class of geometries.

CP and T Violation / 16

CP violation and Flavour Physics experiments in the LHC era

Study of Flavour quantum numbers in elementary particle physics had successfully revealed the structure of the Standard Model indirectly, before the direct discoveries were made; such as charm, beauty and top quarks and GIM mechanism and Kobayashi-Masukawa phase and CP violation. At LHC, physics beyond the Standard Model will be studied directly by searching for new particles produced at the highest energy machine. Flavour physics will also enter a new phase to look for evidence of physics beyond the Standard Model through precision studies of rare phenomena. The latter will give complimentary information necessary to obtain the complete picture of new physics which we all hope to see very soon. In this talk, after reviewing historical development, we explore the role of Flavour Physics experiment in this LHC era.

Times Arrow and the Early Universe / 17

Challenging the Cosmological Constant

We outline a dynamical dark energy scenario whose signatures may be simultaneously tested by astronomical observations and laboratory experiments. The dark energy is a field with slightly sub-gravitational couplings to matter, a logarithmic self-interaction potential with a scale tuned to $\sim 10^{-3}\mathrm{eV}$, as is usual in quintessence models, and an effective mass m_ϕ influenced by the environmental energy density. Its forces may be suppressed just below the current bounds by the chameleon-like mimicry, whereby only outer layers of mass distributions, of thickness $1/m_\phi$, give off appreciable long range forces. We discuss its cosmological evolution and consequences. Among the signatures of this scenario may be dark energy equation of state $w \neq -1$, stronger gravity in dilute mediums, that may influence BBN and appear as an excess of dark matter, and sub-millimeter corrections to Newton's law, close to the present laboratory limits.

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Neutrino Oscillations

Quantum Gravity / 20

Conceptual Problems in Canonical Quantum Gravity and Cosmology

Canonical quantization is among the main approaches to quantum gravity. Its main conceptual problems are reviewed in my talk.
Most of them are centred around the problem of time: a time parameter is absent in the fundamental equations. I discuss the meaning of time in full quantum gravity and the recovery of semiclassical time as an approximation. This also includes the Hilbert-space problem.
I conclude with a discussion of the arrow of time and the quantum-to-classical transition.

Ref.: C. Kiefer, Quantum Gravity, second edition
(Oxford University Press 2007).

Quantum Gravity / 21

Investigation of Frame-Dragging-Like Signals Close to Rotating Superconductors

The search for frame dragging around massive rotating objects such as the Earth is an important test for general relativity and is actively pursued with the LAGEOS and Gravity Probe-B satellites. Within the classical framework, frame dragging is independent of the state (normal or coherent) of the test mass. This was recently challenged by proposing that a large frame-dragging field could be responsible for a reported anomaly of the Cooper-pair mass found in Niobium superconductors. In 2003, a test program was initiated at the Austrian Research Centers to investigate this conjecture using sensitive accelerometers and fiber optic gyroscopes in the close vicinity of fast spinning superconducting rings. The sensors are mounted in close proximity to the superconductor in a separate evacuated, mechanically and thermally de-coupled chamber. Recently obtained high-precision data show that the angular velocity and acceleration applied to the superconductor can indeed be seen on the sensors. The signal amplitude is about 8 orders of magnitude below the values applied to the ring for the case of Niobium at 4 Kelvin. The origin of the observed signals so far is not clear. Our measurements and analysis suggest that the signal can not be explained by mechanical influence or by carefully monitored magnetic fields surrounding the sensors. If the frame dragging-like signals are confirmed, their explanation must be sought outside of general relativity. This talk will give an overview of the initial motivations and the experimental program and discuss in particular the latest measurements using fiber optic gyroscopes. Possible error sources as well as the experimental difficulties are reviewed and discussed.

Quantum Gravity / 22

Gravitational Limitations on space and time measurements and fundamental loss of coherence in General Relativity

There are gravitational limitations on how accurately one can measure space and time. As a consequence of these limitations, when one formulates quantum mechanics and quantum field theory in terms of real measuring rods and clocks the resulting theory is not unitary. This has implications for the black hole information puzzle and may in a not too distant future lead to testable experiments.

Quantum Gravity / 23

Timeless Records Approach to the Problem of Time in Quantum Gravity

The problem of time is a major conceptual stumbling block in attempting to quantize gravity. For, time is conceptually different in general relativity and in conventional quantum theory, which are the two structures that one would seek to combine in forming a theory of quantum gravity. I consider the timeless records approach to this in this seminar. Records are localized, information-containing subconfigurations of a single instant. Records theory is the study of these and of how science (or history) is to be abstracted from correlations between them. I critically evaluate motivations for this approach that have previously appeared in the literature. I provide a ground-level structure for records theory and discuss what kind of further tools are needed, illustrated in some classical toy models: ordinary mechanics, the 2-d dynamics of pure shapes and (perturbations about) minisuperspace.

CP and T Violation / 24

CP and T violation measurements with K mesons

A review is provided of the measurements and investigations of direct and indirect CP violation, and the related T violation, within the neutral and charged kaon systems, discussing the evolution of the field, the most relevant and recent experimental results. An overview of ongoing activities and new projects being prepared is also presented.

Times Arrow and the Early Universe / 25

Expectations and challenges from future CMB science

We review the physics of the cosmic microwave background anisotropies and how the early universe and cosmological structure formation imprint their records into it.
We describe the status of the CMB experiments, pointing out the CMB observables which are still beyond reach of the operating detectors.
Finally, we focus on the the expectations from Planck and future probes.

Times Arrow and the Early Universe / 26

A Discrete Space and Time before the Big Bang

A discrete structure of space and time is often expected to result from a quantum theory of gravity. Loop quantum gravity realizes this clearly at least for space while time, in such a canonical quantization, is handled more indirectly. Cosmological scenarios show how the discreteness of time, unnoticeable at current scales, becomes an important feature in the early universe. It plays a crucial role in resolving the classical big bang singularity and in opening the door to a universe before the big bang. While this happens independently of what matter is prevalent at the big bang, parity violating effects do have a bearing on the relation between pre- and post-big bang branches. They may be important to discern the origin of the universe.

Times Arrow and the Early Universe / 27

Physics in 6-Dimensions

We review the physics in space times of higher than 4-dimensions with particular emphasis on two extra dimensions. Some recent results about the spectrum of 3-brane with positive and negative tensions in gauged supergravities in 6 dimensions will be discussed. In these theories it is possible to be obtain large mass gaps even in the large volume limit.

Times Arrow and the Early Universe / 28

New Matter at the LHC

The LHC will begin data taking in the Summer of 2008.
We review the physics potential of the ATLAS and CMS experiments with an emphasis on the new types of particles which might be produced in the Proton-Proton collisions at 14 TeV.

Quantum Gravity / 30

Emergent spacetime

There is a possibility that spacetime itself is ultimately an emergent phenomenon, a "low-energy long-distance approximation", similar to the way in which fluid mechanics is the near-universal low-energy long-distance approximation to quantum molecular dynamics. If so, then direct attempts to quantize spacetime are misguided — at least as far as fundamental physics is concerned.

Quantum Gravity / 32

Towards a New Paradigm: Relativity in Configuration Space

A generalization of the theory of relativity is considered in which spacetime M_4 is replaced by the configuration space $calC$ associated with a given physical system. In particular, for a system of point particles we assume that its dynamical behavior is determined by the minimal length action in $calC$. In other words, the system is considered as a point that traces a geodetic line in configuration space. The theory thus predicts in general a different dynamical behavior for a many particle system than does the ordinary theory. But in particular, for a suitable metric of $calC$, we obtain the ordinary many particle action in the presence of gravitational field. In general, the configuration space can have non vanishing curvature. From the point of view of 4-dimensional spacetime, which is a subspace of $calC$, there exist extra

forces that act on a particle, besides the ordinary gravity.
Observations suggest that the ordinary theory cannot be straightforwardly applied to the large scale system such as galaxies, clusters of galaxies and the universe. Instead one has to introduce the concept of dark matter and dark energy, or alternatively, to consider suitable modifications of the theory of gravity (MOND). We propose to explore the possibility that general relativity, not in spacetime M_4, but in multidimensional configuration space $calC$ might solve such astrophysical puzzles.
The theory can also be applied to other sorts of configuration spaces, e.g., those associated with extended objects such as strings and branes.
This enables a deeper understanding of the geometric principle behind the string theory, and the insight on the occurrence of the Yang-Mills and gravitational fields.

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Time and Matter - The Future

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