PROPER TIME EXPERIMENTS IN GRAVITATIONAL FIELDS WITH ATOMIC CLOCKS, AIRCRAFT, AND LASER LIGHT PULSES

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INTRODUCTION

Quantum Optics is a part of the more general subject of Quantum Electronics which includes atomic clocks as well as lasers. By utilizing our understanding of the quantum mechanical properties of ground state hyperfine transitions at microwave frequencies in certain atoms, very stable clocks have been made which allow highly accurate time measurements. Similar knowledge of optical transitions between electronic energy states in atoms allows lasers to be made with their many marvelous properties. These include the ability to produce very, very short pulses of light which can be used for optical radar and remote time comparison.

By combining these techniques, we have the capability of making direct measurements of distance and time of sufficient accuracy to measure the predicted effects of General Relativity in "human scale" situations on the earth.

In this talk, three different types of proper time experiments on the earth, which colleagues and I have recently carried out,[1] will be discussed:

1) local experiments in which clocks are raised to a higher gravitational potential by an aircraft and compared with clocks on the ground by short pulses of laser light;

2) global transport of clocks over a large latitude difference to study the combined effects on time of rotational velocity and gravitational potential on the rotating oblate earth;

P. Meystre et al. (eds.), *Quantum Optics, Experimental Gravity, and Measurement Theory*

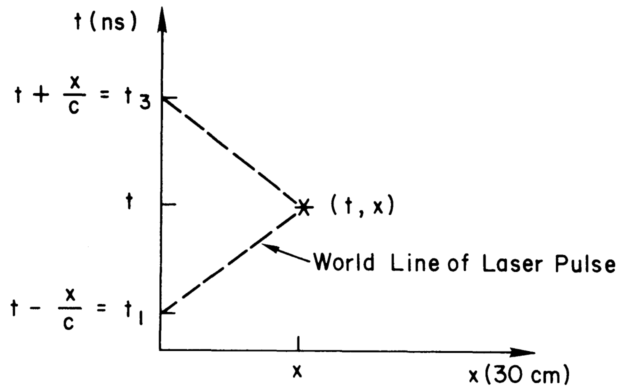

Fig. 1. Minkowski space-time diagram showing Einstein's prescription for comparing separated clocks.

and,

3) global transport of clocks between northern and southern hemispheres at the time of the summer solstice, using the earth to represent "Einstein's Elevator" falling freely in the gravitational field of the sun.

To set the experiments in context and to acquaint members of the Quantum Optics community with some of the fundamental concepts of General Relativity, these will be presented in the historical way, as I understand it, in which Einstein arrived at them.[2]

EINSTEIN'S LIGHT PULSE PRESCRIPTION FOR COMPARING SEPARATED CLOCKS

In Einstein's 1905 paper on "The Electrodynamics of Moving Bodies", he stated the ideas now known as "special" relativity -- the observers being restricted to the class of inertial observers, with gravity being ignored. Central to these ideas was his realization that time is not absolute and that the simultaneity of separated events is relative to the inertial observer. Acceptance of the physical reality of this was the key to the puzzles of light propagation and electrodynamics on which he had pondered since the age of sixteen, ten years earlier. Let us review the prescription he gave for comparing the readings of clocks separated from one another. This is most readily done with a space-time diagram as shown in Figure 1. (Einstein himself did not use such diagrams; they were first introduced by Hermann Minkowski in 1907). If one plots time in units of nanoseconds and distance in units of 30 centimeters, then the world line of a light pulse plots as a line with a slope of 45 degrees. The