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LASER CLOCKS AND NEAR FIELD GRAVITY OF ROTATING OBJECTS

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This work explores the feasibility of using high performance laser clocks to detect effects of rotation in the near field region of the Earth's gravitational field. According to general relativity, the time recorded by an independent clock is the proper time of the space-time metric that applies to the system under consideration. If the gravitational source is stationary (nonrotating), proper time involves only the speed of the clocks and the scalar gravitational potential at the position of the clocks. However, if the source is rotating, the motion of the source could have an effect on the metric. Previous attempts to calculate the relativistic timekeeping for terrestrial clocks have used the metric for a nonrotating system, primarily because metrics for a rotating system were not available. This work investigates the specific effects of rotation on the Earth's gravitational field and the corresponding effect on timekeeping of laser clocks in the near field environment.

An important application of high performance laser clocks, those that are expected from the Stanford University - NASA Laser In Space Technology Experiment (SUNLITE), is shown in Fig. 1, which illustrates a technique that might be used to measure the gradient in the Earth's gravitational field near the surface. The probe clocks would be linked to the surface reference clock by a flexible fiber optic cable, and the difference in clock frequencies would be observed by detecting the interference beat frequency at the reference clock. The gravitational potential difference would be measured by intercomparing the clocks via the fiber optic link when they are located at different altitudes and depths.

The classical "Universal Law of Gravity", first postulated by Isaac Newton more than 300 years ago, states that all matter in the universe exerts a force of attraction on all other elements of matter according to an inverse square law. However, Newton's theory falls silent on effects of rotation of a centrally located extended source of gravity because of an implicit assumption that gravity propagates *instantaneously*, that is, that the speed of gravity is infinite. This assumption is no longer tenable. If gravity is assumed to propagate with Nature's own speed limit, the speed of light, it turns out that significant effects of rotation are predicted in the near field region of a rotating sphere, particularly on or near the surface of the sphere. The finite speed theory predicts a sensible peaking at the surface in the acceleration of gravity.

A recent report in Physics Today ("From Mine Shafts to Cliffs - The 'Fifth Force' Remains Elusive", July, 1988, p. 21) provides observational support for a peak near the surface. The "Fifth Force" may actually be a manifestation of the finite speed of gravity. The surface peaking effect has previously been considered "anomalous" because it is not predicted by the standard stationary-source theory. It now appears that a peak at the surface is a natural consequence of finite speed gravity, and may not be an "anomaly" in the inverse square law. In fact, it may be possible to use the available gravity data to infer the speed of the gravitational interaction.

If gravity propagates with the speed of light, there should be two components in the gravitational

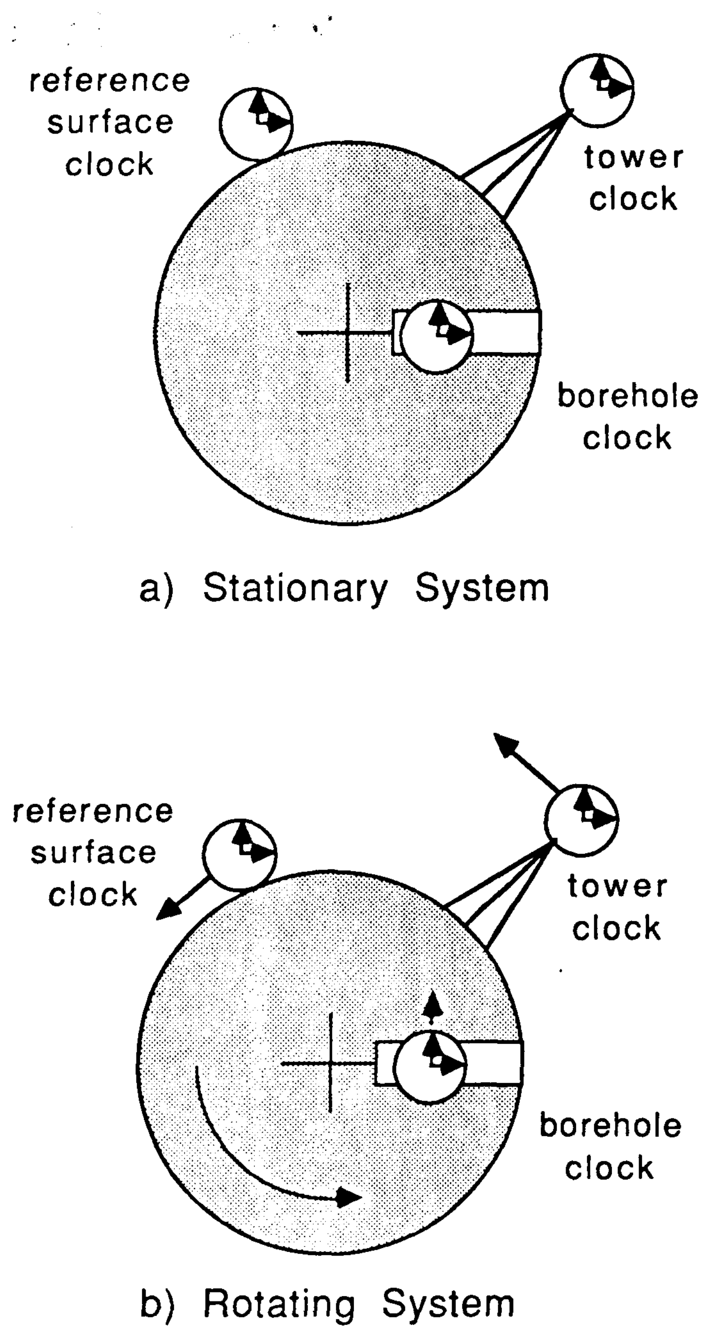

Fig. 1. Physical arrangement to use clocks as gravity meters. Standard clocks above and below the surface record time relative to the surface reference clock according to the difference in the gravitational field above and below the surface. Effects of rotation on the gravitational field in b) compared with the stationary field in a) can be detected with high performance laser clocks.

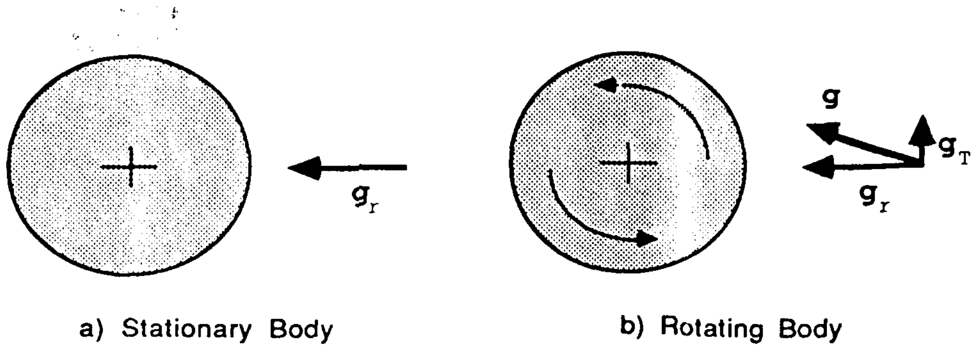

Fig. 2. Components of the gravitational field for a) a nonrotating spherical body and b) a rotating spherical body. The transverse component g_T lies in the plane of rotation and is perpendicular to the radial component g_r.

field, the standard radial component for a stationary body, and an additional transverse component that is caused by the motion of the body, as illustrated in Fig. 2. For a uniform rotating sphere, the radial component would obey the standard inverse square law, but the transverse component would follow an inverse cube law. A highly sloped inverse cube dependence would cause the transverse component to rise more quickly than the radial component. Therefore, the gravitational field of a rotating body should exhibit a rise above the inverse square force as the surface is approached, in a manner not unlike the peak that has been observed in the gravity data.

Figure 3 graphs the strength of the radial component, which follows the standard inverse square law, and the strength for the new transverse component, which follows an inverse cube law.

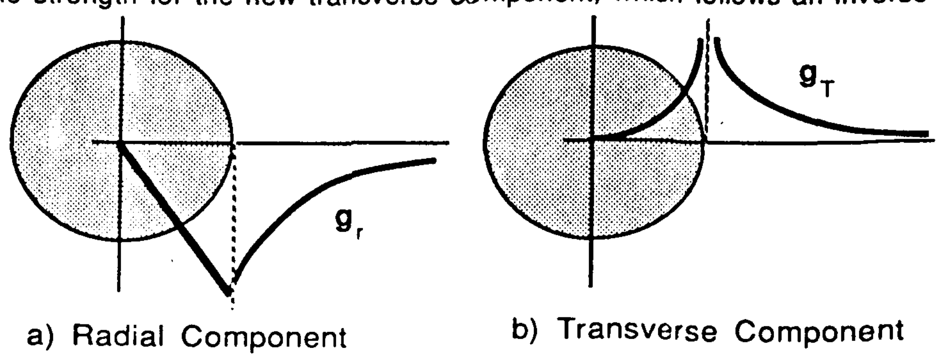

Fig. 3. Components of the gravitational field of a rotating body: a) standard radial component and b) transverse component.

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