Those scandalous clocks

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Abstract Both VLBI (Very Long Baseline Interferometry) and GPS (Global Positioning System) indicate that earth-based clocks are biased as a function of their position in the direction of the earth's orbital velocity. The evidence for these biases is discussed, and the result is confirmed by comparison of earth-based clocks with millisecond pulsars. These clock biases are precisely such as to cause the speed of light to appear as "c" in the earth's inertial frame. This shows that the speed of light is not isotropic in the earth's frame and that the Lorentz transformation is only an apparent transformation that results from Selleri's inertial transformations combined with clock biases.

Keywords Relativity · VCBI · GPS · Millisecond pulsars · Clocks · Ether

Background and problem statement

Close to 100 yr ago Einstein (1905) published his revolutionary paper, subsequently referred to as the Special Relativity Theory (SRT). Though it is often claimed (see Will 1986) that the SRT is fact, not theory, a stubborn few have always maintained that the Lorentz Ether Theory (LET) provides a viable alternative. Among the prominent reasons for holding to this alternative is that it gives a mechanism for clock slowing in place of the simple mathematical magic of SRT. But, according to Steven Weinberg (1992), "naïve mechanism seems safely dead." In fact, he says, "The final turn away from mechanism in electromagnetic theory should have come in 1905, when Einstein's special theory of relativity in effect banished the ether and replaced it with empty space as the medium that carries electromagnetic impulses."

Even though regarded as naïve, most physicists will acknowledge that the LET is observationally equivalent to SRT. Mansouri and Sexl (1977) give a thorough derivation of this equivalence. They first discuss different methods of clock synchronization. In the SRT they show that Einstein synchronization (assigning a time based on an isotropic speed of light equal to c) and synchronization by slow clock transport are equivalent. These two methods of clock synchronization are defined as internal methods of clock synchronization because they can be carried out entirely within a single inertial frame. In order to be equivalent to SRT, an ether theory must use an external synchronization procedure. Einstein or slow clock transport synchronization is used to synchronize only those clocks stationary within the ether frame. The clocks in any frame moving with respect to the ether frame are set to the reading of a clock in the ether frame when they are momentarily adjacent to them. An alternate external solution is to assume the speed of light remains isotropic only in the absolute ether frame and to use the ratio of the outbound and inbound speed relative to the moving frame to set the remote clock. (As Mansouri and Sexl (1977) indicate, the most probable absolute frame would be that defined by an isotropic temperature of the cosmic background radiation.) Either of the external synchronization procedures described above leads to the following transformation between the ether frame and any frame moving (in the instantaneous direction X with velocity V) with respect to it.

$$t = \frac{T}{\gamma} \qquad (1)$$

$$x = \gamma(X - VT) \qquad (2)$$

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where: $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$; X, T and V are the direction of the moving frame, the time, and the velocity in the ether frame respectively; and x and t are the direction and time in the moving frame.
Equation (1) shows that the reading of a clock in the moving frame will be smaller because the slower running clock has larger units of time. Equation (2) shows that the reading of a ruler measuring distance will be larger because the units of length in the moving frame are smaller. The reverse of the above transformation is given by:

$$T = \gamma t \tag{3}$$

$$X = \frac{1}{\gamma}(x + vt) \tag{4}$$

Note that the velocity measured in the two frames is different. The larger time unit (slower clock) and the shorter length unit in the moving frame mean that the measured velocity in the ether frame is smaller than it is in the moving frame.

$$V = \frac{v}{\gamma^2} \tag{5}$$

In a footnote, Mansouri and Sexl (1977) acknowledge that Tangherlini had previously considered the transformation given in Eqs. (1) and (2). The most complete discussion of the transformation, its inverse and successive applications of it, is found in Selleri (2001), who calls it an inertial transformation. I will subsequently refer to it as the Selleri transformation.
When the Selleri transformation, above, is compared to the Lorentz transformation used in SRT, it is found that the position transformation is identical. Only the time transformation differs in the two theories. Specifically, the Lorentz time transformation is given by:

$$t = \gamma T - \gamma \frac{VX}{c^2} \tag{6}$$

Taking the difference between Eqs. (3) and (6) reveals that the only difference between the Selleri and Lorentz transformations is a bias or clock offset given by:

$$\Delta t = (\gamma - \frac{1}{\gamma})T - \gamma \frac{VX}{c^2} \tag{7}$$

But when this bias is expressed in the units of position, time and velocity of the moving frame, using Eqs. (3), (4), and (5), it becomes:

$$\Delta t = -\frac{vx}{c^2} \tag{8}$$

Thus, a simple clock bias as a function of position converts the Selleri transformation into an apparent Lorentz transformation. Furthermore, by using either Einstein or slow clock transport to synchronize the clocks in the moving frame (in place of the absolute external synchronization), the clocks are automatically biased by the precise amount required to convert the Selleri transformation into the Lorentz transformation. Biasing the clocks by the amount given in Eq. (8) causes the nonisotropic speed of light in the earth's frame to appear as if it is isotropic.
So what is the problem? Setting a clock with or without a bias presents no apparent problem. It would seem that SRT and LET are completely equivalent. Indeed, Mansouri and Sexl (1977) reach that conclusion and state, "We arrive at a remarkable result that *a theory maintaining absolute synchronization is equivalent to special relativity.*" (Italics were present in the original.) Of course, Mansouri and Sexl (1977) go on record as preferring the SRT because the alternative "destroys the equivalence of all inertial frames." So is it a matter of preference? Are those of us who prefer the LET simply naïve? A careful analysis of clock behavior near the earth provides a scandalous answer to these questions.
Specific experimental evidence is cited from VLBI (Very Long Baseline Interferometry), from GPS (Global Positioning System) and from millisecond pulsars which demonstrate significant problems with the SRT. VLBI data show that even biasing a clock in the direction of the velocity vector can lead to problems when the direction of that velocity vector changes. GPS and millisecond pulsar data show that, unlike LET, the SRT requires that the "proper frequency," i.e. clock rate, in the earth's frame differ from the "proper frequency" in the sun's frame. However, while setting a clock with or without a bias may not be a problem, a physical clock cannot simultaneously run at two different rates. One can imagine that a constant rate difference might simply be a matter of definition; but, clearly, a cyclical rate difference is a physical impossibility. A common solution to the clock bias and clock rate problems will be offered—but it is a scandalous solution.

The VLBI aberration problem

To illustrate the VLBI problem, an idealized experimental setup is postulated. One VLBI receiver is located on the equator precisely at a longitude such that it is 6:00 AM at a time when the earth is at the winter solstice. This means that the direction of this VLBI station from the center of the earth is in the same direction as the earth's orbital velocity vector. Our second VLBI station is also located on the equator but 180° of longitude away, i.e., at 6:00 PM. Both are observing a quasar in a direction opposite to that of the sun, i.e., it is orthogonal to the velocity vector. In this geometry, the two stations are thus separated in distance by the earth's diameter. The fact that extended common observation of the quasar is impossible because of the earth's rotation is part of the idealization—it is assumed that common observation is possible for this geometry.
The VLBI experiments (when adjusted for our idealization) agree well with the results predicted by Einstein (1905) in section 7 of his classical paper, "On the electrodynamics of moving bodies." Specifically, the Lorentz transformation leaves the ray direction and the wave front direction orthogonal for an observer stationary in the

moving frame. This is verified by the fact that the observations can be used to solve for quasar direction using either the earth's inertial frame or the sun's inertial frame. The two frames are linked by the Lorentz transformation of the coordinates and time and by the electromagnetic transformation for the received light. The result is that in the earth's frame the expected aberration of the wave front is detected, i.e., the light arrives at the forward (6:00 AM) receiver about 4 μs sooner than at the aft (6:00 PM) receiver. The 4 μs arise from a minus 2-μs bias at the forward location and a plus 2-μs bias at the aft VLBI position. These biases are a result of the clock bias term of Eq. (8) when internal synchronization is used. However, when the results are processed using the sun's barycentric frame, there is no wave front aberration; and the time of arrival is measured as simultaneous. (While it is impossible to identify particular waves in the incoming radiation, the correlation of the noise amplitude is the fundamental measurement and is sufficient to determine the direction of arrival.)

The VLBI measurements are routinely processed using the sun's barycentric frame. This avoids the aberration problem because the bias term given by Eq. (8) is removed in the process of mapping time from the earth's frame back to the sun's barycentric frame. Of course, there are other terms in the clock mapping which account for the geometric path differences and the gravitational potential differences. A description of the mapping from earth coordinate time to the sun's barycentric frame can be found in many places. Thomas (1974 and 1971) provides some of the clearest descriptions. In the first of these references, Eq. (10) on page 429 gives the two clock adjustment terms required to map to the sun's barycentric frame that are due to the clock's position and velocity relative to the center of the earth. Specifically,

$$\Delta t = \frac{1}{2c^2}\int [2\phi_e(\vec{x}) - v^2]dt - \frac{\vec{v}_e \bullet \vec{x}}{c^2} \tag{9}$$

The first term is simply the clock adjustment needed to account for the effects of the earth's gravitational potential and velocity relative to the center of the earth. The second term is precisely equal to the bias given in Eq. (8). On page 431, Thomas (1971 and 1974) claims that the second periodic term is never greater than about 2 μs and is essentially diurnal, since the earth's velocity vector changes very little over one day. He further states, "This term corresponds to the special relativity clock synchronization correction that accounts for the fact that simultaneous events in one frame (a "solar system frame") are not necessarily simultaneous in a frame (a "geocentric frame") passing by with velocity $\vec{v}_e$." Thus, this second term would not be present if the external synchronization of the LET were used in place of the internal synchronization of the SRT when synchronizing clocks on the earth.

In the context of VLBI, Thomas (1971 and 1974) identifies the difference in the second term at two sites as the clock synchronization term or the aberration term. In Eq. (17) on page 434, he indicates that it has a maximum value of about 4 μs. Clearly, the tilting of a telescope on the earth for the aberration of an incoming ray is required no matter which frame is used. However, in the earth's frame, the wave front and the incoming ray are orthogonal to one another when the SRT synchronization is used to set the clocks. In the sun's frame, the wave front as observed by the VLBI stations is not orthogonal to the incoming ray and it does not see any aberration of the incoming wave front. In the sun's frame, the aberration effect is clearly analogous to the classical falling raindrop description. The ray bending is caused by the composition of the velocities. Just as rain falling in layers, no bending of the layers would occur for a moving observer. The wave fronts, in this case, are not orthogonal to the direction of fall that a moving observer would see.

If wave-front aberration in the earth's frame were real, as indicated by Einstein's special relativity theory (SRT), another problem would arise that seems to suggest an inconsistency in the theory. From the observations over a one-year interval, we know that the real direction of the quasar is exactly orthogonal to the earth's velocity vector at the winter solstice. If the light in the wave front travels at the speed of light, how can part of the wave front arrive early and part of the wave front arrive late? This contradicts the SRT claim that the speed of light is always given by the constant, c. The only solution to this problem that even appears to be consistent with SRT is to call upon Minkowski's claim that time and position in the direction of the velocity has been interchanged. However, such a claim clearly relies upon magic. While it was indicated above that there is no apparent problem in setting a clock with any arbitrary bias, it does create a problem if that bias undergoes a cyclic variation as a function of a changing velocity vector.

The alternative explanation is that wave-front bending is not real and that clocks on the earth simply have a bias as a function of their position relative to the along-track velocity vector of the earth. This bias results from using Einstein or slow clock transport to synchronize the clocks rather than the external synchronization consistent with LET. So, is wave front aberration in the earth's frame real or are our clocks biased? Do we have magic (SRT) or mechanism (LET)?

The GPS clock problem

GPS presents us with a different problem. As is reasonably well known, GPS, a navigation satellite system developed by the U.S. Department of Defense, provides a highly accurate means for determining both position and time anywhere on the earth and its vicinity. But GPS clocks (and even earth-bound clocks) present us with a problem that is not well known—and the proposed solutions to that problem are clearly incorrect.

The GPS clocks do show, as expected, that moving clocks run slower and that clocks also run slower with lower gravitational potential. The GPS clocks are adjusted to run slow before launch into orbit to account for the fact that the earth's gravitational potential at the nominal orbital height makes them run faster. This faster clock rate is partially offset by the effect of the nominal circular orbital speed of the satellites.

There are two interesting interactions between the effects of gravitational potential and the effects of speed on the clock rate. First, at mean sea level, all clocks on the earth run at the same rate. It turns out that the spin of the earth causes it to bulge out at the equator such that the gravitational potential is greater. (Clocks at the equator are farther from the center of the earth.) The effect upon clock rate of this greater potential at the equator and the effect upon the clock rate of the spin velocity at the equator cancel each other exactly. So, the clock rate is the same as the clock rate at the poles.

The second interaction of gravitational potential and speed upon clock rate occurs due to the eccentricity of the GPS orbits. At perigee, the lower gravitational potential causes the GPS clocks to run slower than nominal. Also, at perigee the satellites are moving faster than nominal and this also causes the GPS clocks to run slower—by exactly the same amount. It seems that energy is what causes the clocks to run at different rates. Increased gravitational potential energy causes clocks to run faster. Increased kinetic energy (speed) causes clocks to run slower.

So what is the clock problem? The problem is, contrary to expectations, clocks on the earth do not seem to be affected by the sun's gravitational potential. Why not? For earth-bound clocks, the problem has been described as the "noon-midnight" problem. Clocks at noon are closer to the sun by the diameter of the earth than clocks at midnight. Thus, one would expect that the noon clocks would run slower than the midnight clocks due to the sun's gravitational potential; yet this is not observed.

Banesh Hoffmann (1961) suggested a solution to the noon-midnight problem in an article titled "Noon-Midnight Red Shift." The article claims the gravitational potential effect is missing because a relativistic Doppler effect cancels it. Thus, Hoffmann (1961) says that, like the clocks at sea level, there is a cancellation of velocity and potential effects. In a nutshell, he claims that, because the point on the earth closest to the sun and the point on the earth farthest from the sun move around the sun at different velocities, they will get different clock effects from their orbital speed around the sun.

It is true that a clock which orbited the sun once per year at the radius of earth's noon would have the same clock rate as a clock which orbited the sun once per year at the radius of earth's midnight, i.e., the gravitational potential difference would be canceled by the speed difference. However, Hoffmann's explanation cannot be valid. It is contradicted by the behavior of the GPS clocks. The difference in the sun's gravitational potential upon the GPS clocks at their point closest to the sun and farthest from the sun (a difference in distance of approximately four times the earth's diameter) seems to have no effect upon the GPS clocks. Clearly, the satellite orbital points closest and farthest from the sun do not orbit about the sun at different speeds. The planes of the GPS satellite orbits do not rotate as the earth orbits the sun. Thus, all points in the satellite orbit travel around the sun at the same velocity (absent precession effects). The fact that the spin axis of the earth does not change as the earth orbits the sun should have been sufficient to negate Hoffmann's explanation. The rotation of the noon-midnight point on the earth does not imply that the earth's inertial frame undergoes an annual rotation. Some other explanation for the missing effect is needed.

An alternative attempt at an explanation can be found in the literature. A paper by Ashby and Bertotti (1986) titled, "Relativistic effects in local inertial frames," claims that the acceleration of free-fall induces a fictitious gravitational field that cancels out the real field. An easier to read version of the same argument by Ashby and Spilker (1996) is found in a comprehensive GPS book.

The problem with the Ashby and Spilker (1996) and the Ashby and Bertotti (1986) argument is with their use of the equivalence principle. Note the quotation from page 686 of Ashby and Spilker (1996).

> The principle of equivalence implies that an observer in free fall in the gravitational field of the solar system cannot sense the presence of external gravitational fields. Although at the instantaneous location of the freely falling observer there is a gravitational field of strength $-\nabla\Phi$ (force per unit mass), this field produces an acceleration $A = -\nabla\Phi$ of the falling observer. Because of this acceleration, an additional fictitious gravitational field –A is induced in the observer's reference frame. The two fields—the real one and the induced one—cancel each other; the net field strength at the observer's location is zero. This implies that the gravitational potential in the neighborhood of the freely falling observer cannot have any terms linear in the spatial coordinates. Only quadratic terms can survive—these are tidal terms. The tidal terms associated with these residual's effects are negligible in the GPS.

It is the last two sentences of this quote, which are at issue. Both Michael Friedman (1963) in "Foundations of space-time theories" and Ciufolini and Wheeler (1995) in "Gravitation and inertia" tell us that the equivalence principle specifically holds not over a local region but rather over an infinitesimal region. Let me quote from Friedman (1963; p. 202) at some length.

> Standard formulations of the principle of equivalence characteristically obscure this crucial distinction between first-order laws and second-order laws by blurring the distinction between "infinitesimal" laws, holding at a single point, and local laws, holding on a neighborhood of a point. They lose the distinction between the structure of the tangent space T_p and the configuration of the tangent spaces T_q for q in a neighborhood of p. (This is one place where the physicist's casual attitude toward the "infinitesimal" gets him into real trouble!) What the principle of equivalence clearly says, then, is that special relativity and general

relativity have the same "infinitesimal" structure, not that they have the same local structure.

Clearly over an extended region (neighborhood), the gradient of the potential cannot be cancelled precisely simply by using the equivalence principle. On page 14 of Ciufolini and Wheeler (1995) they say of the weak equivalence principle, "The principle can be reformulated by saying that in every local, nonrotating, freely falling frame, the line followed by a freely falling test particle is a straight line." To clarify this point further, another quote from Friedman (1963; p. 199) is given.

> Freely falling, nonrotating, normal reference frames (that is, local inertial frames) look just like special relativistic inertial frames along the trajectory σ to which they are adapted... Freely falling frames follow geodesics of the unique connection *D,* the very same connection that figures in the laws of motion and the electrodynamic field equations. The vanishing of the components of this connection along σ yields the special relativistic equations for an inertial frame.
> It must be emphasized that this equivalence holds only on a single trajectory σ. At finite distances from σ nonvanishing Γ^i_{jk}'s appear. Thus, although physics texts often claim that freely falling frames are "locally" equivalent to inertial frames, this assertion is strictly false if "local" has its usual mathematical meaning: local = *on some neighborhood...* Freely falling frames are only "infinitesimally" equivalent to inertial frames: only at a single point or on a single trajectory.

Ashby and Bertotti (1986) and Ashby and Spilker (1996) have explained the absence of differential clock effects upon the GPS satellites from the sun's gravitational potential as due to the equivalence principle. Nevertheless, they err by applying a result that is valid only over an infinitesimal area to a large region. So Ashby and Bertotti (1986) and Ashby and Spilker (1996) have failed, like Hoffmann (1961), in providing an explanation for the missing differential effect of the sun's gravitational potential upon clocks in the vicinity of the earth. Some other explanation for the missing effect is still needed.
There is another way to see that the argument by Ashby and Bertotti (1986), and Ashby and Spilker (1996) cannot be correct. Specifically, they claim that in the earth's frame, the sun's gravitational potential does not contribute any clock terms linear in the spatial coordinates. However, this is equivalent to the claim that the clocks run at a different rate when expressed in the earth's frame than the rate at which they run when expressed in the sun's frame. Clearly in the sun's frame, the clocks located at different distances from the sun run at different rates as a function of the sun's gravitational potential, which does have a linear dependence on the spatial coordinates. If clocks actually could run at different rates in the two frames, the clock readings in the two frames would suffer either a secular or periodic divergence. Now the mapping from the earth's frame to the sun's frame as shown above in Eq. (9) does, in fact, show that a periodic divergence between the clocks exists. Nevertheless, such a divergence cannot be due to a real clock-rate difference since clocks are physical objects that cannot simultaneously run at two different rates—especially at cyclically different rates. The cyclical mapping term in Eq. (9) must then be due to ascribing an improper rate to the clocks in the earth's frame.

Millisecond pulsars as clocks

It turns out that the relationship between clocks on the earth and clocks in the sun's frame are needed for many different reasons. Distant pulsars, which have pulse rates of hundreds of pulses per second, act as extremely stable clocks with a slow but very precise change in frequency as they loose energy. These clocks, external to the solar system, can be compared to clocks on the earth. Their stability rivals the very best clocks on the earth. Charles M. Hill (1995) has reported results comparing the clocks on the earth to millisecond pulsars. This comparison clearly reveals the source for the cyclic clock biases described above. Specifically, in the sun's frame, the vector sum of the earth's orbital velocity and the earth's spin velocity causes a cyclic clock rate term which integrates into a cyclic clock bias as a function of the along track distance from the earth's center. (Though not addressed here, the clocks in the GPS satellites would also suffer cyclic clock-rate terms as a result of the vector sum of the satellite orbit velocity with the earth's orbit velocity.) Note that in the sun's frame these cyclic clock disturbances are properly recognized and removed in the process of determining a correct time within the sun's barycentric frame. Like the cyclic clock-rate error, which occurs as a result of ignoring the sun's gravitational potential, this velocity product (in the sun's frame) gives a clock rate error that is ignored in the earth's frame.
As Hill (1995) describes, the pulsar data reveals a diurnal variation in the clock rate of about 300 ps s peak-to-peak. The noon second is about 300 ps shorter (frequency higher at noon) than the midnight second because of the product of the earth's orbital and spin velocities at the equator. The term causing this clock rate variation comes from the squaring of the vector addition of the two velocities. It is given by:

$$\Delta f = \frac{v_e v_s}{c^2} \cos\theta \qquad (10)$$

where the "*e*" subscript designates the orbital velocity, the "*s*" subscript the spin velocity, and θ is the angle between the earth's orbital velocity and the earth spin velocity at the clock. Plugging in the values gives a clock rate peak magnitude of 153 ps s or 2.1 μs per radian of the earth rotation rate. Clearly, the cosine term integrates to a value of one for a single quadrant of rotation. The result directly corresponds to the bias term given in Eq. (8) above.
The difference in sun's gravitational potential causes a clock rate term given by:

$$\Delta f = \sqrt{1 - \frac{2GM}{(r_a - r_e\cos\phi)c^2}} - \sqrt{1 - \frac{2GM}{r_a c^2}} \cong -\frac{GM}{r_a c^2}\frac{r_e}{r_a}\cos\phi \quad (11)$$

where the “a“ subscript designates the orbital radius, the “e“ subscript the earth radius and ϕ is the angle between the earth radius to the clock and the orbital radius of the earth. Plugging in the values gives a clock rate peak magnitude of 0.42 ps s (365 times smaller than the velocity cross product term) or 2.1 µs per radian of the earth orbital rate. The sign of this gravitational term is opposite to that of the diurnal term. (The frequency is lower at noon.) It causes the diurnal period of one sidereal day, which results from Eq. (10) to become a period of one solar day. Again, the result clearly corresponds to the bias given in Eq. (8) above. In the earth’s frame, both clock rate terms are ignored. It is by ignoring these cyclic rate terms in the earth’s frame that the clock biases are generated, which cause the speed of light to appear as isotropic.

The point of the above is worth emphasizing again. Clocks external to the solar system (millisecond pulsars) can be compared to clocks on the earth. Since clocks run at a unique rate, the difference in the external clocks and the earth-bound clocks can provide us with the unique knowledge of the true clock rate of clocks on the earth. The values obtained show that a cyclic clock rate occurs which integrates into a cyclic clock bias. The cyclic clock rate arises from two sources including (1) the product term of the spin velocity combined with the orbital velocity, and (2) the differences in the gravitational potential of the sun at the clocks’ position compared to that at the center of the earth. When the earth’s frame is used, it is easy to ignore the composite velocity term because the orbital velocity is removed. (But even though it is easy to ignore, removing it assigns an erroneous cyclic clock rate to the clocks according to the millisecond pulsars.) However, the absence of the second cyclic term, due to the gradient of the sun’s gravitational potential, cannot be explained by SRT when the earth’s frame is used. As we saw above, two faulty attempts have been made to explain its absence. The millisecond pulsars testify to its presence, and it causes the clock bias value to have a cyclic period of one year such that the bias always remains a function of the distance in the direction of the changing orbital velocity vector.

Conclusion

When the various clock measurements taken in the vicinity of the earth are processed in the sun’s frame, it becomes apparent that the composite velocity and the sun’s gravitational potential combine to generate a diurnal variation in the clock rate which results in diurnal clock biases.

Clearly, these cyclic clock biases must be removed before a common time is obtained in the sun’s frame or before an isotropic light speed in the sun’s frame is obtained. Interestingly, if these biases were not removed, the speed of light in the vicinity of the earth, even in the sun’s frame, would appear to be isotropic relative to the earth rather than the sun. If the LET synchronization procedure were used on the earth, the biases would be removed and the speed of light in the vicinity of the earth would remain isotropic relative to the sun. However, the SRT synchronization process assumes the speed of light is isotropic relative to the earth. As a result, it ignores the physical processes which give rise to the cyclic clock biases, assigns an improper rate to the clocks, and as a result retains the clock biases—but does not recognize them as such. Nevertheless, the clocks cannot run at a different cyclical rate just because we have chosen arbitrarily to process the data in a different frame.

At least one other point needs to be made regarding the rate at which clocks run. Specifically, the definition of “proper time” and “proper frequency” versus “coordinate time” and “coordinate frequency.” One critic claims that the clock problems discussed above do not arise if we use coordinate frequency rather than proper frequency. However, according to Ciufolini and Wheeler (1995), p. 100, the mapping from proper time to coordinate time is simply the adjustment of the clock to account for the difference in the gravitational potential. Clearly, moving from the proper time to the coordinate time is simply a mathematical adjustment to the clocks and has no impact on the physics of the clock comparisons described above. Using the SRT, no proper explanation for the apparently missing effect of the sun’s gravitational potential upon the clocks in the earth’s frame can be found. However, LET shows us that the same gradient of the potential (force), which causes the velocity vector of the earth to change direction, also causes the direction of the clock biases in the vicinity of the earth to be changed so as to remain aligned with the velocity vector. This effect is undoubtedly common to all gravitational potentials, i.e., it also applies to the effect of the moon’s potential upon the earth and to the galactic potential upon the sun.

The importance of the above results is not that clocks on the earth should be treated in a different manner. It is in fact very convenient (and even amazing) that by ignoring the effect of the sun’s gravitational potential (and the composite velocity in the sun’s frame) we can cause the apparent speed of light to remain isotropic on the earth even as its velocity changes direction. The importance of the result is that the clock behavior in the sun’s frame reveals the mechanism underlying the effect. This allows us to distinguish between the magic of SRT and the mechanism of LET. The two are not equivalent. LET can correctly explain the effect of the sun’s gravitational potential and allow the clocks to run at a single unique rate. SRT cannot explain the missing effect from the sun’s gravitational potential and incorrectly assigns multiple rates to the same clock in the same identical environment. SRT is clearly incorrect. Such a conclusion is, of course, scandalous.

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