ON THE MEASUREMENT OF ABSOLUTE TIME.

By

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Abstract: If ‘absolute time’ is to be a meaningful concept, it must be measurable. Here, we set out to show how it may be measured, using both cosmic black hole thermodynamics and the Solar System’s absolute motion relative to the CMB.
Keywords: Cosmology: theory; cosmological parameters.

Section 1: Introduction.

Let it be first understood that what is meant here by ‘absolute time’ is ‘absolute *cosmic* time’. The present author has argued in an earlier paper (Blaber, 2020) that, although Einstein (1905) had apparently abolished absolute time and space by means of his Special Theory of Relativity (SR), replacing them with relative space-time (Minkowski, 1909), this was by no means the last word on the subject.

The Lorentz-Poincaré transformations (Lorentz, 1904; Poincaré, 1905), used by Einstein (op. cit.) in SR, do not require his principle of relativity to work, and are consistent with an aether, a preferred reference-frame, and thus absolute time and space, as was pointed out by Lorentz (1910). Furthermore, Larmor continued to argue that absolute, Newtonian time was essential to astronomy (Larmor, 1927a & b).

The implications for absolute time of Einstein’s *General* Theory of Relativity (GR, Einstein, 1914) were first pointed out by Gödel (1949), who argued (as this author, op. cit., has noted) that the cosmological models ensuing from GR, and incorporating expansion, all required an absolute time-coordinate. This was the only way they could also conform to the requirement of homogeneity and isotropy in cosmic models. Gödel introduced a static model whose metric was an exact solution of the field equations of GR, but was homogeneous and *anisotropic*, with an absolute rotation about a ‘compass of inertia’. It incorporated CTCs – ‘closed time-like curves’ – allowing time-travel into the past, resulting in catastrophic causal paradoxes. Raychaudhuri (1955) showed that a CTC-including model could be constructed that allowed for cosmic expansion.

One of the cosmological models that included an absolute cosmic time coordinate is that of Einstein and de Sitter (1932), the line-element of the metric of which reads (in Cartesian coordinates):

$$ds^2 = c^2dt^2 - R^2(dx^2 + dy^2 + dz^2)\,. \tag{1a}$$

Here, R, the scale-factor, is a function of t, and c is the speed of light (electromagnetic radiation) in vacuum = 2.99792548×10^8 m s^{-1}. If $dx^2 + dy^2 + dz^2 = 1$, R has the dimension of length, and equation (1a) reduces to:

$$ds = |cdt - R|\,, \tag{1b}$$

and at the present epoch, where cosmic time $t = t_C$ = the present age of the universe, t_0 = the present value of the Hubble time, τ_0 (the reciprocal of the Hubble parameter at the current epoch, H_0, see Hubble, 1929), given that the density parameter, $\Omega = 1$ and the curvature parameter, $k = 0$, which is consistent with the empirical findings of Hinshaw, *et al* (2013), and Aghanim, *et al* (2019), this further reduces to:

$$s = c(t_0 - \tau_0) = 0\,. \tag{1c}$$

It is, in any event, the in-built assumption of the Einstein-de Sitter model that space has zero curvature at cosmic scale, and cosmological constant $\Lambda = 0$, the latter in contrast to the Gödel metric.

Section 2: Calculating Cosmic Time.

We shall examine the implications of the zero length in equation (1c) in just a moment – but first, let us see how cosmic time may be calculated. In Blaber (2020, op. cit.) the present author argued that $R = ct_0 = c\tau_0$ was equal to $2GM/c^2$, the Schwarzschild radius of the universe (Schwarzschild, 1916), and that therefore the universe was an enormous black hole. This implies that the mass of the universe, M, is given by:

$$M = \frac{M_P^4}{m_p^2 m_e} = \frac{M_P^2}{\alpha_G m_e} = 8.804353 \times 10^{52}\ \mathrm{kg}\,. \tag{2a}$$

N.B., this is a constant. Here, M_P = Planck mass = $(\hbar c/G)^{½}$ = 2.176434×10^{-8} kg; $\hbar = h/2\pi = 1.054571817 \times 10^{-34}$ J s (Dirac constant); G = Newtonian constant of gravitation = 6.6743×10^{-11} m^3 kg^{-1} s^{-2}; m_p = proton mass = $1.67262192369 \times 10^{-27}$ kg; m_e = $9.1093837015 \times 10^{-31}$ kg (source: NIST); and $\alpha_G = Gm_p^2/\hbar c$ = $5.9061494 \times 10^{-39}$ = gravitational fine-structure constant (α_G^{-1} = 1.6931505×10^{38}). The total rest-energy of the universe is then given by:

$$E = Mc^2 = 7.912958\ \times 10^{69}\ \mathrm{J}\,. \tag{2b}$$

It follows that the total span of cosmic time is given by:

$$\frac{R_S}{c} = t_0 = \tau_0 = t_S = \frac{2GM}{c^3} = \frac{2}{\alpha_G \omega_e} = 4.36185 \times 10^{17}\ \mathrm{s}\,. \tag{3}$$

This is ~13.822 billion years, the age of the present cosmic epoch. Here, ω_e = the angular Compton frequency of the electron = $m_e c^2/\hbar$ = $7.76344071 \times 10^{20}$ rad s^{-1}.

It would seem, then, that the present age of the universe is also the end-point of cosmic time, and that – to quote Harry Hotspur in Henry IV, Part I, Act V, Sc. IV, ll.82-3 – ‘And time, that makes survey of all the world,/Must have a stop.’

Section 3: The Hubble Sphere and its 'Cosmic Horizon'.

The inner surface-area of the 4-ball that constitutes our universe – the surface-area of the Hubble sphere (the radius of which is now determined by c/H_0, see Hubble, op. cit.) – is what Melia (2007), terms a 'cosmic horizon', and constitutes, in Rindler's (1956, p.663) terminology, an event horizon. (Strictly speaking, in mathematical terms, what is usually called the 'Hubble sphere' should be called the 'Hubble hyperball', and its horizon the 'Hubble hypersphere', the former being four-dimensional, the latter three-dimensional.)

The 4-volume of this hyperball is given by $V_4 = \pi^2(ct_0 - c\tau_0)^4/2 = 0$, which contrasts with its 3-volume = $4\pi(ct_0)^3/3 \simeq 9.3662 \times 10^{78}$ m^3. Likewise, the three-dimensional inner surface area of the hypersphere, $S_3 = 2\pi^2(ct_0 - c\tau_0)^3 = 0$, whereas the two-dimensional surface area of the Hubble 3-sphere, $S_2 = 2\pi(ct_0)^2 = 1.0743919 \times 10^{53}$ m^2. We can understand this if we look at the implications of Hubble's Law (Hubble, op. cit.):

$$v_r = H_0 d \; ; \; v_r = c \text{ when } d = ct_0 \, . \tag{4}$$

Furthermore, when $v_r = c$, the redshift, z, is given by:

$$z = \sqrt{\left[\frac{(1+\beta)}{(1-\beta)}\right]} - 1 = \infty \, , \tag{5}$$

where $\beta = v/c$. (The redshift formula is not that for GR but is the same as for SR – in other words, Minkowski 'flat' space.)

This horizon coincides with the *fons et origo* of our universe – the so-called 'Big Bang', which was not 'big' but extremely small, and has now swelled to occupy the vast area of S_2. Not only, then, is it an event horizon (Rindler, op. cit.), but it is a one-way street to a space-time singularity (Penrose in Lebovitz, Reid and Vandervoot, 1978; Penrose in Hawking and Israel, 1979).

A space-time singularity, of the kind from which our universe emerged at cosmic time $t_C = 0$, had zero volume, infinite density and pressure, infinite temperature, and zero entropy, as we shall show.

Section 4: Cosmic Thermodynamic History.

If our universe is a black hole, then its entropy at the present epoch, given that the temperature of the CMB (cosmic microwave background) is ~2.27548 K (Fixsen, 2009, pp.916, 920), is given by:

$$S_{now} = \frac{8\pi^2 GM^2 kc}{h} = 2.5517511 \times 10^{116}\ \mathrm{JK}^{-1}\ . \tag{6}$$

Equation (6) is the Bekenstein-Hawking formula for black hole entropy (Bekenstein, 1973, 2008; Hawking, 1974). Here k is the Boltzmann constant (Boltzmann, 1877) = 1.380649×10^{-23} J K^{-1}, and h = Planck's constant = $6.62607015 \times 10^{-34}$ J s (source: NIST, as above, p.3).

The Second Law of Thermodynamics – the idea that the entropy (a word meaning 'transformation of content', from Greek, *en*, 'in', *tropē*, 'turning') of a closed thermodynamic system always increases over time – was worked out in the 19th Century by Carnot (1824), William Thomson (Lord Kelvin) (1852), Clausius (1865), and Boltzmann (op. cit.), and with it the concomitant notion of the 'heat death' of the universe. Physicists have been premature in their rejection of this idea, as is clear from what follows.

At the beginning of cosmic time, when $t_C = 0$, $S = 0$; then, at $t_C = t_P$, the Planck time = $(G\hbar/c^5)^{½} = 5.391247 \times 10^{-44}$ s, when the temperature would have been:

$$T = \frac{E}{k} = 5.73133 \times 10^{92}\ \mathrm{K}\,, \tag{7}$$

the entropy then would have been:

$$S_{Planck} = \frac{2\pi l_p^2 kc}{h} = 1.96245 \times 10^{19}\ \mathrm{JK}^{-1}\ . \tag{8}$$

Here, l_p = the Planck length = $(G\hbar/c^3)^{½}$ = 1.616255×10^{-35} m. Entropy then grows in increments, given in part by the number of Planck time units, and there are:

$$N_p = \frac{t_0}{t_p} = 8.090614 \times 10^{60} \tag{9}$$

such units in the total cosmic time, t_0. We find that the rate of increase is:

$$\frac{S_{now}}{S_{Planck} N_p} = 1.6071567 \times 10^{36} \tag{10}$$

units of entropy per Planck time unit.

What this entails is that the volume of the Gibbs phase space (Gibbs, 1902), which appears in the modern version of the Boltzmann equation, $S = k \log_e V$ (Boltzmann, op. cit.), now, given by:

$$\log_e V = \frac{8\pi^2 GM^2 c}{h} = 1.8482258 \times 10^{139}\ , \therefore$$

$$V = e^{1.8482258 \times 10^{139}} = 5.214709 \times 10^{1115} \tag{11}$$

is truly enormous, and consequently, so is the probability of the universe falling into an irretrievable state of thermodynamic equilibrium. Eddington (in Čapek, 1976) was clearly right to speak of the Second Law of Thermodynamics providing a unidirectional 'arrow of time', distinguishing time from the spatial dimensions, and to link it with the ‘expansion’ of space (in reality, as Milne, 1933, pointed out, the expansion of matter *in* space).

Section 5: Local, Relative Time *versus* Absolute Cosmic Time.

The experiments of Kennedy and Thorndike (1932) and Ives and Stilwell (1938) appear to uphold the relativity of time, and the findings of SR, as opposed to the Lorentz aether theory (Lorentz, 1904, op. cit.). This is, however, not the case, for these experiments were conducted at a local level, and their results only apply at a local level.

The metre is now defined internationally, in the S.I. system of units, as the distance travelled by light in vacuum in 1/299,792,458th of a second (BIPM), and the second is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the unperturbed ground state of an atom of caesium-133 (BIPM2). Light thus travels one metre in ~30.66332 of those periods.

Caesium atomic clocks are highly accurate. The one at the National Physical Laboratory, Teddington, Middlesex, UK, is accurate to 1 second in every 158 million years (NPL, 2014).

Wolf and Petit (1995) give a set of equations enabling such clocks to be synchronised and ‘syntonised’ (i.e., coordinated), in spite of travelling at different speeds and at different heights relative to each other and to a geocentric system of coordinates, given the effect of the Earth’s gravitational field. Again, this in no way invalidates the concept of absolute time, or that of the preferred frame of reference, as these are valid at a local level only.

As Gift (2007) has argued, the principle of relativity in SR depends on the postulate of the constancy of the *one-way* speed of light, and it is that, and only that, that differentiates SR from the Lorentz aether theory, and allows the proponents of SR to deny the existence of absolute time and space, and of a preferred reference-frame (p.2). He offers evidence that, whereas the two-way speed is constant, relative to the preferred frame, its one-way speed for an observer changes according to that observer’s motion relative to the preferred frame (p.4).

Gift (2016) followed this up with an experiment to measure the one-way speed of light using the Global Positioning System (GPS), and obtained a result showing that it was, as the Lorentz aether theory predicted, a variable, with the one-way speed different for light travelling east between two points fixed on the surface of the (rotating) Earth at the same latitude (= $c - v$), and for light travelling west between two such points (= $c + v$), as predicted also by GR (Gift, 2016, op. cit., pp.4-6; see Alley, *et al*, 1983, pp.245, 257; Alley, *et al*, 1988, 1992). Here v is the surface speed of the Earth at the latitude of the points (Gift, op. cit., p.6).

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Section 6: Conclusion.

Szostek and Szostek (op. cit.), using their equations (67), and assuming the CMB is homogeneous in the system of the aether, with the temperature of a black body (see Fixsen, op. cit.), obtain a velocity of the Solar System relative to the CMB preferred reference-frame of 369.3 ± 3.3 km s^{-1}, in the direction Right Ascension 11h 13m 58.8s; Declination: –6° 57′ 24″ (2020), in the constellation Leo.

This implies a very small Lorentz-Poincaré transformation correction to the measurement of Earth time of:

$$t' = t(1 - \beta^2)^{½}\ ;\ \beta = \frac{v}{c} \simeq 1.2318522 \times 10^{-6}\ . \tag{12}$$

This amounts to 0.99999999999848254 s for every 1 s that passes – in other words, the duration of 1 s on Earth is reduced to 0.99999999999848254 s by the Solar System's motion relative to the CMB. Given the S.I. definition of the metre (see above, p.7), the Solar System's velocity can be expressed as ~369,300 × 1/299,792,458 × 0.99999999999848254 = 0.0012318522 s = 1,000βs.

This can then be used as a basic time unit (t_{btu}) for measuring cosmic time. We find that, using this measure, the universe is 3.54088745 × 10^{20} t_{btu} old, and – for reasons we have adumbrated – has now reached its senescence, where it may, at any moment, and with a very high degree of probability, enter a state of thermal equilibrium.

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References[1].

Aghanim, N., *et al* (2019), 'Planck 2018 Results. VI. Cosmological Parameters,' *Astronomy & Astrophysics* **MS no. ms**, 24th September 2019,
https://arxiv.org/pdf/1807.06209.pdf, Table 2, p.15.

Alley, C.O., *et al* (1983), 'Time Transfer Between the Goddard Optical Research Facility and the US Naval Observatory Using 100 Picosecond Laser Pulses,'
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19830027092.pdf

Alley, C.O., *et al* (1988), 'Differential Comparison of the One-Way Speed of Light in the East-West and West-East Directions on the Rotating Earth,' https://apps.dtic.mil/dtic/tr/fulltext/u2/a519904.pdf.

Alley, C.O., *et al* (1992), 'Plans to Improve the Experimental Limit in the Comparison of the East-West and West-East One-Way Light Propagation Times on The Rotating Earth,' December 1992,
https://apps.dtic.mil/dtic/tr/fulltext/u2/a500933.pdf.

Bekenstein, J. (1973), 'Black Holes and Entropy,' *Physical Review D* **7:2333**, 15th April 1973, DOI: 10.1103/PhysRevD.7.2333.

Bekenstein, J. (2008), 'Bekenstein-Hawking entropy,' *Scholarpedia* **3(10):7375**, most recent rev., 25th April 2017, DOI: 10.4249/scholarpedia.7375,
http://www.scholarpedia.org/article/Bekenstein-Hawking_entropy.

Blaber, R.M. (2020), 'On Absolute Space and Time and Neo-Ptolemaic Cosmology,' v.2, 6th May, 2020, https://vixra.org/pdf/2005.0067v2.pdf.

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[1] Abbreviations used: BibCode = Bibliographic Code; DOI = Digital Object Identifier; hdbk. = hardback; pbk. = paperback; ISBN = International Standard Book Number; ISSN = International Standard Serial Number.

Boltzmann, L. (1877), 'On the Relationship between the Second Fundamental Theorem of the Mechanical Theory of Heat and Probability Calculations Regarding the Conditions for Thermal Equilibrium,' *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse (Reports of the Meetings of the Imperial Academy of Sciences, Mathematical-Natural Scientific Class)* **Abteilung (Section) II, LXXVI:373-435**, trans. by Sharp, K. & Matschinsky, F. (2015), in *Entropy* **17:1971-2009**, DOI: 10.3390/e17041971, ISSN: 1099-4300, http://crystal.med.upenn.edu/sharp-lab-pdfs/2015SharpMatschinsky_Boltz1877_Entropy17.pdf.

Carnot, N.-L.-S. (1824), 'Réflexions sur la Puissance Motrice du Feu (lit., Reflections on the Motive Power of Fire),' trans. as 'Reflections on the Motive Power of Heat,' 2nd rev. ed. by Thurston, R.H., 1897, New York: John Wiley, https://www3.nd.edu/~powers/ame.20231/carnot1897.pdf.

Clausius, R. (1865), 'I. On the Determination of the Energy and Entropy of a Body,' *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* **S.4, 32(213):1-17**, July 1866, trans. from & orig. pub. in the *Zeitschrift für Mathematik und Physik* **xi, Part I:31**, DOI: 10.1080/14786446608644119.

Eddington, A.S., 'The Arrow of Time, Entropy and the Expansion of the Universe,' in Čapek, M., ed. (1976), *The Concepts of Space and Time. Their Structure and Their Development*, Boston Studies in the Philosophy of Science, Volume XXII, ed. Cohen, R.S. & Wartofsky, M.W., Dordrecht: Springer Science+Business Media, hdbk., ISBN: 978-90-277-0375-0, pp.463-470.

Einstein, A. (1905), 'Zur Electrodynamik bewegter Körper,' *Annalen der Physik* **17:891-921/322(10):891-921**, June 1905, DOI: 10.1002/andp.19053221004,
Eng. trans., 'On the Electrodynamics of Moving Bodies,' https://einsteinpapers.press.princeton.edu/vol2-trans/154#, pp.140-171.

Einstein, A. (1914), 'Die formale Grundlage der allgemeinen Relativitätstheorie,' *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften zu Berlin (Reports of the Royal Prussian Academy of Sciences of Berlin)* **S:1030-1085**, 19th

November 1914, English trans., 'The Formal Foundation of the General Theory of Relativity,' https://einsteinpapers.press.princeton.edu/vol6-trans/42#, pp.30-83.
Einstein, A. & de Sitter, W. (1932), 'On the Relation between the Expansion and the Mean Density of the Universe,' *Proceedings of the National Academy of Sciences of the United States of America* **18(3):213-214**, March 1932, DOI: 10.1073/pnas.18.3.213, https://www.pnas.org/content/pnas/18/3/213.full.pdf.
Fixen, D.J. (2009), 'The Temperature of the Cosmic Microwave Background,' *Astrophys. J.* **707(2):916-920**, 30th November 2009, DOI: 10.1088/0004-637X/707/2/916, https://iopscience.iop.org/article/10.1088/0004-637X/707/2/916/pdf.
Gibbs, J.W. (1902), *Elementary Principles in Statistical Mechanics. Developed with Especial Reference to the Rational Foundation of Thermodynamics*, New York: Charles Scribner's Sons; London: Edward Arnold, https://www-liphy.univ-grenoble-alpes.fr/pagesperso/bahram/Phys_Stat/Biblio/gibbs_1902.pdf.
Gift, S.J.G. (2007), 'Light Speed Invariance is a Remarkable Illusion (On Einstein's Light Speed Invariance Postulate),' https://arxiv.org/ftp/arxiv/papers/0708/0708.2687.pdf.
Gift, S.J.G. (2016), 'One-way Speed of Light Using the Global Positioning System,' https://www.researchgate.net/profile/Stephan_Gift/publication/317771597_One-way_speed_of_light_using_the_global_positioning_system/links/5afd76fc0f7e9b98e06cdf8b/One-way-speed-of-light-using-the-global-positioning-system.pdf.
Gödel, K. (1949), 'An Example of a New Type of Cosmological Solutions of Einstein's Field Equations of Gravitation,' *Reviews of Modern Physics* **21(3):447-450**, July 1949, DOI: 10.1103/RevModPhys.21.447, https://journals.aps.org/rmp/pdf/10.1103/RevModPhys.21.447.
Hawking, S.W. (1974), 'Black hole explosions?', *Nature* **248(5443):30-31**, March 1974, DOI: 10.1038/248030a0.
Hubble, E.P. (1929), 'A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae,' *Proceedings of the National*

Academy of Sciences of the United States of America **15(3):168-173**, March 1929, DOI: 10.1073/pnas.15.3.168.
Ives, H.E. & Stilwell, G.R. (1938), 'An Experimental Study of the Rate of a Moving Atomic Clock,' *Journal of the Optical Society of America* **28(2):215-226**, DOI: 10.1364/JOSA.28.000215.
Hinshaw, G., *et al* (2013), 'Nine-Year Wilkinson Anisotropy Probe (*WMAP*) Observations: Cosmological Parameter Results,' 4th June 2013, https://lambda.gsfc.nasa.gov/product/map/dr5/pub_papers/nineyear/cosmology/wmap_9yr_cosmology_results.pdf, Table 2, p.6.
Kennedy, R.J. & Thorndike, E.M. (1932), 'Experimental Establishment of the Relativity of Time,' *Physical Review* **42(3):400-418**, 1st November 1932, DOI: 10.1103/PhysRev.42.400, https://paulba.no/paper/Kennedy_Thorndike.pdf.
Kühne, R.W. (2002), 'General Relativity Requires Absolute Space and Time,' https://cds.cern.ch/record/583737/files/0209107.pdf.
Larmor, J. (1927a), 'Newtonian Time Essential to Astronomy,' *Nature* **119(2997):49-60**, 9th April 1927, DOI: 10.1038/119049a0x, https://www.nature.com/articles/119049a0x.pdf.
Larmor, J. (1927b), 'Newtonian Time Essential to Astronomy: A Correction,' *Nature* **120(3018):333**, 3rd September 1927, DOI: 10.1038/120333a0, https://www.nature.com/articles/120333a0.pdf.
Levy, J. (1996a), 'Relativity and Aether Theory: a Crucial Distinction,' https://arxiv.org/ftp/physics/papers/0610/0610067.pdf.
Levy, J. (1996b), 'Aether Theory and the Principle of Relativity,' https://arxiv.org/ftp/physics/papers/0607/0607067.pdf.
Lorentz, H.A. (1904), 'Electromagnetic phenomena in a system moving with any velocity smaller than that of light,' *Proceedings of the Royal Netherlands Academy of Arts and Sciences* **6:809-831**, Amsterdam, 1904, https://www.dwc.knaw.nl/DL/publications/PU00014148.pdf.
Lorentz, H.A. (1910), 'The Principle of Relativity and its Application to some Special Physical Phenomena (Das Relativitätsprinzip und seine Anwendung auf einige besondere physikalische Erscheinungen),' in *Alte und neue Fragen der Physik (Old and New Questions in Physics)*; Lectures held in Göttingen from 24th – 29th Oct 1910,

https://en.wikisource.org/wiki/Translation:The_Principle_of_Relativity_and_its_Application_to_some_Special_Physical_Phenomena.
Melia, F. (2007), 'The cosmic horizon,' *Monthly Notices of the Royal Astronomical Society* **382(4):1917-1921**, December 2007, DOI: 10.1111/j.1365-2966.2007.12499.x, https://academic.oup.com/mnras/article/382/4/1917/1152726.
Milne, E.A. (1933), 'World-Structure and the Expansion of the Universe,' *Zeitschrift für Astrophysik* **6:1-95**, BibCode: 1933ZA……6….1M, http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1933ZA......6....1M&defaultprint=YES&filetype=.pdf.
Minkowski, H. (1909), 'Raum und Zeit (Space and Time),' A Lecture delivered before the Congress of Natural Philosophers at Cologne, 21st September 1908, *Jahresberichte der Deutschen Mathematiker-Vereinigung (Annual Report of the German Mathematical Association)* **18:1-14**, https://www.minkowskiinstitute.org/mip/MinkowskiFreemiumMIP2012.pdf, pp.39-53.
National Physical Laboratory (NPL) (2014), 'Accuracy of NPL caesium fountain clock further improved,' 19th February 2014, https://phys.org/news/2014-02-accuracy-npl-caesium-fountain-clock.html.
Penrose, R., 'Singularities of spacetime,' in Lebovitz, N.R., Reid, W.H. & Vandervoort, P.O., eds. (1978), *Theoretical principles in astrophysics and relativity*, Chicago: University of Chicago Press, pbk., ISBN: 978-0-226-46990-4, pp.217-243.
Penrose, R., 'Singularities and Time-Asymmetry,' in Hawking, S.W. & Israel, W. eds. (1979), *General Relativity, an Einstein Centenary Survey*, Cambridge: Cambridge University Press, hdbk., ISBN: 0-521-22285-0, Ch.12, pp.581-638.
Poincaré, H. (1905), 'Sur la dynamique de l'électron (On the dynamics of the electron),' *Rendiconti del Circolo matematico di Palermo (Reports of the Mathematical Circle of Palermo)* **21:129-176**, report of meeting of 23rd July 1905, publ. January 1906, https://en.wikisource.org/wiki/Translation:On_the_Dynamics_of_the_Electron_(July).

Raychaudhuri, A. (1955), 'Relativistic Cosmology. I,' *Physical Review* **98(4):1123-1126**, 15th May 1955, DOI: 10.1103/PhysRev.98.1123.
Rindler, W. (1956), 'Visual horizons in world models,' *Monthly Notices of the Royal Astronomical Society* **6(6):662-677**, 1st December 1956, DOI: 10.1093/mnras/116.6.662, http://articles.adsabs.harvard.edu/pdf/1956MNRAS.116..662R.
Schwarzschild, K. (1916), 'Über das Gravitationsfeld einer Kugel aus inkompressibler Flüssigkeit nach der Einsteinschen Theorie (On the gravitational field of a sphere of [an] incompressible fluid according to Einstein's theory),' *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften zu Berlin* Physikalisch-Mathematische Klasse **S:424-434**,
English trans. by S. Antoci (1999), https://arxiv.org/pdf/physics/9912033.pdf.
Selleri, F. (1996), 'Noninvariant one-way velocity of light,' *Foundations of Physics* **26:641-664**, May 1996, DOI: 10.1007/BF02058237, abstract & refs. at:
https://link.springer.com/article/10.1007/BF02058237.
Selleri, F. (1997), 'Non-invariant Speed of Light and Locally Equivalent Reference Frames,' *Foundations of Physics Letters* **73-83**, http://www.anti-relativity.com/Selleri_Sagnac_Paradox.pdf.
Szostek, K. & Szostek, R. (2018), 'The derivation of the general form of kinematics with the universal reference system,' *Results in Physics* **8:429-437**, March 2018, published online 23rd December 2017, DOI: 10.1016/j.rinp.2017.12.053,
https://www.sciencedirect.com/science/article/pii/S221137971732329X.
Thomson, W. (Lord Kelvin) (1852), 'XLVII. On a universal tendency in nature to the dissipation of mechanical energy,' *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* **Ser. 4, 4(25):304-306**, DOI: 10.1080/14786445208647126.
Wolf, P. & Petit, G. (1995), 'Relativistic theory for clock syntonisation [coordination] and the realisation of geocentric coordinate times,' *Astronomy and Astrophysics* **304:653-661**, December 1995, BibCode: 1995A&A…304..653W, http://articles.adsabs.harvard.edu/pdf/1995A%26A...304..653W.