Three Clocks

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Zusammenfassung

The Scientific Reports paper "A single-clock Ansatz to fundamental metrology" (Sci. Rep. 2024, DOI: 10.1038/s41598-024-71907-0) investigates to was extent a single Zeit Standard is ausreichend as a starting point to define and measure alle physikalisch Größen (Zeit intervals, lengths, masses). A central ingredient is an explicit relativistisch Messung protocol in welche lengths are determined solely from Zeit differences. Zusätzlich, the authors argue, using Standard Quanten Beziehungen (Compton Wellenlänge) and modern metrological techniques (Kibble balance), das masses can auch be traced back to the Zeit Standard.

This document gives a factual summary of the main technical Elemente of the article and relates them to the T0 theory. Insbesondere, it compares the results to jene of the existing T0 documents `T0_SI_De`, `T0_xi_origin_De` and `T0_xi-and-e_De`, wo the reduction of alle Konstanten to the single Parameter ξ and the Zeit–Masse duality have bereits been developed. A short remark on the popular-science video by Hossenfelder places das video as a secondary summary, not as a primary source.

1 Einleitung

The article *A single-clock Ansatz to fundamental metrology* [153] aims at reformulating the foundations of metrology in solch a way das a single Zeit Standard is ausreichend to define alle andere physikalisch Größen. The authors insbesondere consider:

- the definition and Realisierung of Zeit intervals by means of a single, highly stable Zeit Standard (a "clock"),
- the Ableitung of Länge Messungen from purely temporal observational data in a relativistisch setting,
- the reduction of masses to frequencies or Zeit intervals using established Quanten mechanical and metrological Beziehungen.

A popular-science presentation of dies Arbeit appears in a video by Hossenfelder [80]. For the physikalisch argument, jedoch, nur the scientific article is decisive; the video is mentioned hier for orientation nur.

In the T0 theory, `T0_SI_De` develops a comprehensive Ableitung scheme in welche alle fundamental Konstanten and Einheiten are obtained from a single geometrisch Parameter ξ. In `T0_xi_origin_De` and `T0_xi-and-e_De`, the Zeit–Masse duality is analyzed and the internal Struktur of the Masse hierarchy is derived from ξ. The purpose of the present document is to systematically compare diese T0 results with the conclusions of the Scientific Reports article.

2 Time Standard and basic Annahmen of the article

2.1 A single Zeit Standard

In the Scientific Reports paper, the starting point is a single, high-precision Zeit Standard. Operationally, dies means das a reference Frequenz ν_0 is specified, whose period $T_0 = 1/\nu_0$ defines the elementary Einheit of Zeit. All andere Zeit intervals are given as multiples of T_0:

$$\Delta t = n\,T_0\,, \qquad n \in \mathbb{Z}\,. \tag{1}$$

The concrete physikalisch Realisierung (e.g. caesium atomic clock, optical lattice clock) is left open; was matters is the existence of a stable reference Prozess.

This basic Annahme is direkt analogous to the T0 theory, wo the Planck Zeit t_P and the sub-Planck Skala $L_0 = \xi\, l_P$ are introduced as Charakteristik Skalen determined by ξ (`T0_SI_De`). T0 goes further in das it derives the underlying Zeit Struktur itself from ξ, while the Scientific Reports article merely assumes the existence of a Zeit Standard compatible with known physics.

2.2 Relativistic Rahmenwerk

The paper embeds the Messung procedures into speziell Relativität. The key roles are played by:

- proper times of moving clocks along specified worldlines,

- Beziehungen zwischen proper Zeit, coordinate Zeit and spatial Entfernung gemäß the Minkowski metric,
- Invarianz of the Licht cone, welche constrains the Struktur of Raum-Zeit Beziehungen.

Formally, the proper Zeit $d\tau$ of an idealized point Teilchen with four-Geschwindigkeit u^μ in flat Raum-Zeit can be written as

$$d\tau^2 = dt^2 - \frac{1}{c^2}\, d\vec{x}^{\,2} \tag{2}$$

(with a suitable choice of Einheiten). The concrete Messung protocols in the article use dies Struktur to infer spatial separations from gemessen proper times.

3 Length Messung from Zeit: three-clock construction

3.1 Principle of the procedure

The Nature article analyzes a type of Experiment das is conceptually equivalent to the three-clock set-up described by Hossenfelder. The central idea is as follows:

- Two spatially separated events (the ends of a rigid rod) are separated by an unknown Entfernung L.
- Clocks are transported along known worldlines zwischen diese points.
- The proper times accumulated by the transported clocks are schließlich compared at one location.

The authors show das from the proper times of the transported clocks and the known kinematic Bedingungen (e.g. Konstante Geschwindigkeit) one can obtain an Gleichung of the form

$$L = F\left(\{\Delta\tau_i\}\right), \tag{3}$$

wo $\{\Delta\tau_i\}$ denotes a endlich set of gemessen proper Zeit differences and F is a Funktion determined by speziell Relativität. The crucial point is das F does not require irgendein independently gemessen Länge Einheit.

3.2 Operational Interpretation

Operationally, dies implies das a spatial Entfernung L can in Prinzip be fully determined from times:

$$L = n_L\, T_0\, c_{\text{eff}}\,. \tag{4}$$

Here T_0 is the elementary Zeit Standard, n_L is a dimensionless Zahl obtained from the proper-Zeit Messungen and knowledge of the Dynamik, and c_{eff} is an effektiv Geschwindigkeit Parameter welche, while formally being the Geschwindigkeit of Licht, is not introduced as a separate base Größe. The article emphasizes das no zweit, independent Dimension (a separate meter Standard) is needed; the Länge Skala follows from the Zeit Struktur and the Dynamik.

This is consistent with the Ableitung given in `T0_SI_De`, wo the meter in SI is defined via c and the zweit, and wo c itself is derived from ξ and Planck Skalen. In T0, daher, the Länge Einheit is bereits reduced to the Zeit Struktur vor the metrological construction begins.

4 Mass determination from frequencies and Zeit

4.1 Elementary Teilchen: Compton Beziehung

For elementary Teilchen, the article uses the well-known Compton Beziehung

$$\lambda_{\mathrm{C}} = \frac{\hbar}{mc}\,, \tag{5}$$

and the corresponding Compton Frequenz

$$\omega_{\mathrm{C}} = \frac{mc^2}{\hbar}\,. \tag{6}$$

If lengths have bereits been defined by Zeit Messungen (as in the vorherig section), es folgt das the Compton wavelengths and the masses are auch fixed by the Zeit Standard. In natural Einheiten ($\hbar = c = 1$) dies reduces to

$$\lambda_{\mathrm{C}} = \frac{1}{m}\,, \qquad \omega_{\mathrm{C}} = m\,. \tag{7}$$

Thus Masse is a Frequenz Größe, i.e. an inverse Zeit.

In the T0 theory, dies Beobachtung appears explizit in `T0_xi-and-e_De` in the form

$$T \cdot m = 1\,. \tag{8}$$

There es wird gezeigt das the Charakteristik Zeit Skalen of unstable Leptonen are consistent with their masses once T is taken as a Charakteristik Zeit and m as Masse in natural Einheiten. The argument of the Nature article regarding Masse determination via Frequenz Messungen daher finds, innerhalb T0, a pre-existing formal elaboration.

4.2 Macroscopic masses: Kibble balance

For macroscopic masses, the Nature paper refers to the Kibble balance. This device wesentlich operates in two modes:

- a static mode, in welche the weight Kraft mg of a Masse in the gravitativ Feld is balanced by an elektromagnetisch Kraft,
- a dynamic mode, in welche induced voltages and currents are related to quantized elektrisch Effekte and, schließlich, to frequencies.

By exploiting quantized electrical Effekte (Josephson Spannung standards, Quanten Hall resistances), one obtains a chain

$$m \longrightarrow F_{\mathrm{weight}} \longrightarrow U, I \longrightarrow \text{frequencies, counting} \longrightarrow T_0\,. \tag{9}$$

Formally, the Masse m is thereby reduced to a Funktion of frequencies (Zeit standards) and diskret Ladung counts. Again, no new kontinuierlich base Größen appear; electrical and thermal Konstanten are coupled to the Zeit norm via defining Beziehungen.

In T0, `T0_SI_De` derives the corresponding Beziehungen for e, α, k_B and further Konstanten from ξ, so das the Kibble balance can be interpreted as an experimentell Realisierung of an bereits geometrically fixed Konstanten network.

5 Relation to the T0 documents

5.1 T0_SI_En: From ξ to SI Konstanten

`T0_SI_De` presents in detail wie, starting from the single Parameter ξ, one can derive the gravitativ Konstante G, Planck Länge l_P, Planck Zeit t_P and schließlich the SI Wert of the Geschwindigkeit of Licht c. The central Beziehung

$$\xi = 2\sqrt{G\, m_{\text{char}}} \tag{10}$$

and its variants ensure consistency with CODATA Werte and with the SI 2019 reform.

Against dies background, the single-clock metrology of the Scientific Reports paper can be interpreted as follows:

- The claim das a single Zeit Standard suffices is consistent with the T0 statement das ξ as a single fundamental Parameter suffices.
- The reduction of SI Einheiten to Zeit and counting Einheiten mirrors the T0 Beschreibung of reducing alle Konstanten to ξ.

5.2 T0_xi_origin_En: Mass scaling and ξ

`T0_xi_origin_De` addresses wie the concrete numerisch Wert $\xi = 4/30000$ emerges from the Struktur of the e–p–μ System, the fractal Raum-Zeit Dimension and related considerations. This internal justification Ebene is absent from the Scientific Reports article: dort, one simply assumes das a Zeit Standard exists and can be reconciled with known physics.

From the T0 Perspektive, the Masse–Frequenz Beziehung used in the article is daher not nur accepted, but traced back to a deeper geometrisch Ebene in welche Masse Verhältnisse appear as Konsequenzen of ξ. The metrological statement of the paper is thereby supported and at the gleich Zeit embedded into a broader theoretisch Rahmenwerk.

5.3 T0_xi-and-e_En: Time–Masse duality

In `T0_xi-and-e_De`, the Beziehung $T \cdot m = 1$ is highlighted as an Ausdruck of a fundamental Zeit–Masse duality. The Scientific Reports article uses dies duality in the form of established Beziehungen (Compton Wellenlänge, Masse–Frequenz Beziehung) without explizit formulating it as a duality.

The Vergleich shows:

- The article uses the duality operationally to argue das masses can be fixed by a Zeit Standard.

- The T0 theory formulates the duality explizit and anchors it in the geometrisch Struktur (Parameter ξ) and in the Masse hierarchy of the Teilchen.

6 Quantum Gravitation and range of validity

The Nature article formulates its claims innerhalb the Rahmenwerk of established physics, i.e. basierend auf speziell Relativität, Quanten Mechanik and the Strom metrological Standard Modell. Hossenfelder points out das the argument implizit assumes das clocks can, in Prinzip, be used with arbitrarily high precision. In the regime of Planck Skalen dies expectation will wahrscheinlich fail, since Quanten-gravitativ Effekte should lead to fundamental uncertainties.

The T0 theory addresses dies issue by introducing Planck Länge, Planck Zeit and the sub-Planck Skala as Größen determined by ξ. In `T0_SI_De`, $L_0 = \xi\, l_P$ is discussed as an absolute lower bound of Raum-Zeit granulation. Planck Skalen thereby appear in T0 not as additional Parameter independent of ξ, but as derived Größen.

In dies sense, the domain of validity of the single-clock metrology argument can be characterized as follows:

- Within the T0-described range (oben L_0 and t_P), the reduction to a single Zeit Standard is consistent with the geometrisch Struktur.
- Below diese Skalen, a modification of the Messung concept is to be erwartet; single-clock metrology does not provide a complete answer in dies regime, and T0 proposes a concrete Struktur of diese sub-Planck Skalen.

7 Concluding remarks

The Scientific Reports article on single-clock metrology shows das a consistent use of speziell Relativität, Quanten Mechanik and modern metrology leads to the result das a single Zeit Standard is, in Prinzip, ausreichend to define and measure alle physikalisch Größen. Length Messung from Zeit differences (three-clock construction) and Masse determination via frequencies and Kibble balances are the central technical building blocks.

The T0 theory, insbesondere in `T0_SI_De`, `T0_xi_origin_De` and `T0_xi-and-e_De`, provides a complementary Standpunkt in welche diese operational facts are traced back to a single geometrisch Parameter ξ. Time is the primary Größe; Masse appears as inverse Zeit, and alle SI Konstanten are derived from ξ or interpreted as conventions. The single-clock metrology of the article can somit be viewed as a metrological Bestätigung of the Zeit–Masse duality and single-Parameter Struktur postulated in T0.

Literatur

[1] J. Pascher, *T0 Theory: Time-Mass Duality*, 2024. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_unified_report.pdf

[2] J. Pascher, *T0 Theory: Fundamentals*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Grundlagen_En.pdf

[3] J. Pascher, *T0 Theory: Quantum Mechanics*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/QM_En.pdf

[4] J. Pascher, *T0 Theory: SI Units*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_SI_En.pdf

[5] J. Pascher, *T0 Theory: The g-2 Anomaly*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Anomale-g2-9_En.pdf

[6] J. Pascher, *T0 Theory: CMB Analysis*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zwei-Dipole-CMB_En.pdf

[7] A. Einstein, *On the Electrodynamics of Moving Bodies*, Annalen der Physik, 1905. https://doi.org/10.1002/andp.19053221004

[8] P.A.M. Dirac, *The Quantum Theory of the Electron*, Proc. Roy. Soc. A, 1928. https://doi.org/10.1098/rspa.1928.0023

[9] M. Planck, *On the Theory of the Energy Distribution Law*, 1900. https://doi.org/10.1002/andp.19013090310

[10] E. Mach, *Die Mechanik in ihrer Entwicklung*, 1883.

[11] Various Authors, *100 Authors Against Einstein*, 1931.

[12] H. Dingle, *Science at the Crossroads*, 1972.

[13] J. Terrell, *Invisibility of the Lorentz Contraction*, Phys. Rev., 1959. https://doi.org/10.1103/PhysRev.116.1041

[14] R. Penrose, *The Apparent Shape of a Relativistically Moving Sphere*, Proc. Cambridge Phil. Soc., 1959. https://doi.org/10.1017/S0305004100033776

[15] R. Penrose, *Twistor Algebra*, J. Math. Phys., 1967. https://doi.org/10.1063/1.1705200

[16] R. Penrose, *The Road to Reality*, 2004.

[17] J. Terrell et al., *Modern Terrell-Penrose Visualization*, 2025.

[18] D. Weiskopf, *Visualization of Four-dimensional Spacetimes*, 2000.

[19] T. Müller, *Visual Appearance of Relativistically Moving Objects*, 2014.

[20] S. Hossenfelder, *YouTube: The Terrell Effect*, 2025.

[21] C. Rovelli, *Quantum Gravity*, Cambridge University Press, 2004.

[22] T. Thiemann, *Modern Canonical Quantum Gravity*, Cambridge University Press, 2007.

[23] A. Ashtekar, J. Lewandowski, *Background Independent Quantum Gravity*, Class. Quant. Grav., 2004. https://doi.org/10.1088/0264-9381/21/15/R01

[24] T. Jacobson, *Thermodynamics of Spacetime*, Phys. Rev. Lett., 1995. https://doi.org/10.1103/PhysRevLett.75.1260

[25] J. Maldacena, *The Large N Limit of Superconformal Field Theories*, Adv. Theor. Math. Phys., 1998. https://doi.org/10.4310/ATMP.1998.v2.n2.a1

[26] J. Polchinski, *String Theory*, Cambridge University Press, 1998.

[27] L. Susskind, *The World as a Hologram*, J. Math. Phys., 1995. https://doi.org/10.1063/1.531249

[28] E. Verlinde, *On the Origin of Gravity*, JHEP, 2011. https://doi.org/10.1007/JHEP04(2011)029

[29] F. Hoyle, *A New Model for the Expanding Universe*, MNRAS, 1948. https://doi.org/10.1093/mnras/108.5.372

[30] H. Bondi, T. Gold, *The Steady-State Theory*, MNRAS, 1948. https://doi.org/10.1093/mnras/108.3.252

[31] F. Zwicky, *On the Redshift of Spectral Lines*, Proc. Nat. Acad. Sci., 1929. https://doi.org/10.1073/pnas.15.10.773

[32] C. Lopez-Corredoira, *Tests of Cosmological Models*, Int. J. Mod. Phys. D, 2010.

[33] E. Lerner, *Evidence for a Non-Expanding Universe*, 2014.

[34] A. Albrecht, J. Magueijo, *Variable Speed of Light*, Phys. Rev. D, 1999. https://doi.org/10.1103/PhysRevD.59.043516

[35] J. Barrow, *Cosmologies with Varying Light Speed*, Phys. Rev. D, 1999. https://doi.org/10.1103/PhysRevD.59.043515

[36] A. Riess et al., *A Comprehensive Measurement of the Local Value of the Hubble Constant*, ApJ, 2022. https://doi.org/10.3847/2041-8213/ac5c5b

[37] DESI Collaboration, *DESI Year 1 Results*, 2025. https://arxiv.org/abs/2404.03002

[38] E. Di Valentino et al., *Planck Evidence for a Closed Universe*, Nat. Astron., 2021. https://doi.org/10.1038/s41550-019-0906-9

[39] P. Di Francesco et al., *Conformal Field Theory*, Springer, 1997.

[40] Particle Data Group, *Review of Particle Physics*, 2024. https://pdg.lbl.gov/

[41] CODATA, *Recommended Values of Fundamental Constants*, 2019. https://physics.nist.gov/cuu/Constants/

[42] D. Newell et al., *The CODATA 2017 Values of h, e, k, and N_A*, Metrologia, 2018. https://doi.org/10.1088/1681-7575/aa950a

[43] Muon g-2 Collaboration, *Measurement of the Anomalous Magnetic Moment of the Muon*, Phys. Rev. Lett., 2023. https://doi.org/10.1103/PhysRevLett.131.161802

[44] Fermilab, *Muon g-2 Results*, 2023. https://muon-g-2.fnal.gov/

[45] ATLAS Collaboration, *Measurements at the LHC*, 2023. https://atlas.cern/

[46] ATLAS Collaboration, *Higgs Boson Properties*, 2023. https://atlas.cern/

[47] CMS Collaboration, *Top Quark Measurements*, 2023. https://cms.cern/

[48] CMS Collaboration, *Heavy Ion Collisions*, 2024. https://cms.cern/

[49] ALICE Collaboration, *Quark-Gluon Plasma Studies*, 2023. https://alice-collaboration.web.cern.ch/

[50] M. Kasevich et al., *Atom Interferometry*, 2023.

[51] A. Ludlow et al., *Optical Atomic Clocks*, Rev. Mod. Phys., 2015. https://doi.org/10.1103/RevModPhys.87.637

[52] S. Brewer et al., Al^+ *Optical Clock*, Phys. Rev. Lett., 2019. https://doi.org/10.1103/PhysRevLett.123.033201

[53] LISA Collaboration, *LISA Mission*, 2017. https://www.lisamission.org/

[54] L. Nottale, *Fractal Space-Time and Microphysics*, World Scientific, 1993.

[55] M.S. El Naschie, *E-Infinity Theory*, Chaos Solitons Fractals, 2004.

[56] J.A. Wheeler, *Information, Physics, Quantum*, 1990.

[57] J. Barbour, *The End of Time*, Oxford University Press, 1999.

[58] D. Sciama, *On the Origin of Inertia*, MNRAS, 1953. https://doi.org/10.1093/mnras/113.1.34

[59] K. Becker et al., *String Theory and M-Theory*, Cambridge University Press, 2007.

[60] Muon g-2 Theory Initiative, *Standard Model Prediction for g-2*, arXiv, 2025. https://arxiv.org/abs/2006.04822

[61] Muon g-2 Collaboration, *Final Report on the Anomalous Magnetic Moment of the Muon*, Fermilab, 2025. https://muon-g-2.fnal.gov/

[62] J. Pascher, *T0 Theory: Complete Framework*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/systemEn.pdf

[63] M.E. Peskin and D.V. Schroeder, *An Introduction to Quantum Field Theory*, Westview Press, 1995.

[64] R.H. Parker et al., *Measurement of the Fine-Structure Constant*, Science, 2018. https://doi.org/10.1126/science.aap7706

[65] L. Morel et al., *Determination of α from Rubidium Atom Recoil*, Nature, 2020. https://doi.org/10.1038/s41586-020-2964-7

[66] T. Aoyama et al., *Theory of the Electron Anomalous Magnetic Moment*, Phys. Rep., 2020. https://doi.org/10.1016/j.physrep.2020.07.006

[67] X. Fan et al., *Hadronic Contributions from Lattice QCD*, Phys. Rev. D, 2023.

[68] D. Hanneke et al., *New Measurement of the Electron g-2*, Phys. Rev. Lett., 2008. https://doi.org/10.1103/PhysRevLett.100.120801

[69] J. Pascher, *Higgs Connection in T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Energie_En.pdf

[70] J. Pascher, *T0 Theory and SI Units*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_SI_En.pdf

[71] J. Pascher, *Gravitational Constant in T0 Framework*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Gravitationskonstante_En.pdf

[72] J. Pascher, *Fine Structure Constant Analysis*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Feinstruktur_En.pdf

[73] J.S. Bell, *Muon Studies*, 1966.

[74] J. Pascher, *Quantum Field Theory in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/QFT_En.pdf

[75] Planck Collaboration, *Planck 2018 Results*, A&A, 2018. https://doi.org/10.1051/0004-6361/201833910

[76] J. Pascher, *T0 Theory Foundations*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Grundlagen_En.pdf

[77] J. Pascher, *Geometric Formalism in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Geometrische_Kosmologie_En.pdf

[78] A. Riess et al., *Hubble Constant Measurements*, ApJ, 2019. https://doi.org/10.3847/1538-4357/ab1422

[79] J. Pascher, *T0 Kosmologie*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Kosmologie_En.pdf

[80] S. Hossenfelder, *Single Clock Video*, YouTube, 2025. https://www.youtube.com/c/SabineHossenfelder

[81] Various, *Video References*, 2025.

[82] C.S. Unnikrishnan, *Gravity Studies*, 2004.

[83] A. Peratt, *Plasma Cosmology*, 1992. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_peratt_En.pdf

[84] J. Pascher, *T0 Time-Mass Extension*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_tm-erweiterung-x6_En.pdf

[85] J. Pascher, *T0 g-2 Extension*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_g2-erweiterung-4_En.pdf

[86] J. Pascher, *T0 Networks*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_netze_En.pdf

[87] W. Adams, *Gravitational Redshift*, 1925. https://doi.org/10.1073/pnas.11.7.382

[88] N. Ashby, *Relativity in GPS*, Living Rev. Rel., 2003. https://doi.org/10.12942/lrr-2003-1

[89] B. Bertotti et al., *Cassini Doppler Test*, Nature, 2003. https://doi.org/10.1038/nature01997

[90] A. Bolton et al., *Gravitational Lensing*, 2008.

[91] M. Born, *Einstein's Theory of Relativity*, Dover, 2013.

[92] C. Brans and R.H. Dicke, *Mach's Principle*, Phys. Rev., 1961. https://doi.org/10.1103/PhysRev.124.925

[93] P.A.M. Dirac, *Quantum Mechanics*, Proc. Roy. Soc., 1927. https://doi.org/10.1098/rspa.1927.0039

[94] P. Duhem, *Theory of Physics*, 1906.

[95] A. Einstein, *Special Relativity*, Ann. Phys., 1905. https://doi.org/10.1002/andp.19053221004

[96] R. Feynman, *QED: The Strange Theory of Light and Matter*, 2006.

[97] D. Griffiths, *Introduction to Quantum Mechanics*, 2017.

[98] J.D. Jackson, *Classical Electrodynamics*, 1999.

[99] T. Kaluza, *Five-Dimensional Theory*, 1921.

[100] O. Klein, *Quantum Theory and Relativity*, 1926.

[101] T. Kuhn, *Structure of Scientific Revolutions*, 1962.

[102] T. Kuhn, *Essential Tension*, 1977.

[103] A. Ludlow et al., *Optical Atomic Clocks*, Rev. Mod. Phys., 2015. https://doi.org/10.1103/RevModPhys.87.637

[104] J.C. Maxwell, *Treatise on Electricity and Magnetism*, 1873.

[105] S. McGaugh et al., *Radial Acceleration Relation*, Phys. Rev. Lett., 2016. https://doi.org/10.1103/PhysRevLett.117.201101

[106] P. Mohr et al., *CODATA Values*, Rev. Mod. Phys., 2016. https://doi.org/10.1103/RevModPhys.88.035009

[107] Particle Data Group, *Review of Particle Physics*, Prog. Theor. Exp. Phys., 2020. https://pdg.lbl.gov/

[108] R. Parker et al., *Measurement of α*, Science, 2018. https://doi.org/10.1126/science.aap7706

[109] M. Peskin and D. Schroeder, *QFT*, 1995.

[110] M. Planck, *Quantum Theory*, 1900.

[111] Planck Collaboration, *Planck 2020 Results*, 2020. https://doi.org/10.1051/0004-6361/201833910

[112] H. Poincaré, *Dynamics of the Electron*, 1905.

[113] R.V. Pound and G.A. Rebka, *Gravitational Redshift*, Phys. Rev. Lett., 1960. https://doi.org/10.1103/PhysRevLett.4.337

[114] W.V. Quine, *Two Dogmas of Empiricism*, 1951.

[115] T. Quinn et al., *Gravitational Constant*, 2013. https://doi.org/10.1103/PhysRevLett.111.101102

[116] L. Randall and R. Sundrum, *Extra Dimensions*, Phys. Rev. Lett., 1999. https://doi.org/10.1103/PhysRevLett.83.3370

[117] A. Riess et al., *Type Ia Supernovae*, AJ, 1998. https://doi.org/10.1086/300499

[118] I. Shapiro et al., *Time Delay Test*, Phys. Rev. Lett., 1971. https://doi.org/10.1103/PhysRevLett.26.1132

[119] A. Sommerfeld, *Fine Structure*, 1916.

[120] S. Suyu et al., *Time Delay Cosmography*, MNRAS, 2017. https://doi.org/10.1093/mnras/stx483

[121] J. Pascher, *T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/systemEn.pdf

[122] J. Pascher, *Fine Structure in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Feinstruktur_En.pdf

[123] J.-P. Uzan, *Constants Variation*, Rev. Mod. Phys., 2003. https://doi.org/10.1103/RevModPhys.75.403

[124] J.K. Webb et al., *Fine Structure Constant*, Phys. Rev. Lett., 2001. https://doi.org/10.1103/PhysRevLett.87.091301

[125] S. Weinberg, *Cosmological Constant*, Rev. Mod. Phys., 1979.

[126] S. Weinberg, *Cosmological Constant Problem*, 1989. https://doi.org/10.1103/RevModPhys.61.1

[127] S. Weinberg, *Quantum Theory of Fields*, 1995.

[128] C. Will, *Theory and Experiment in Gravitational Physics*, 2014. https://doi.org/10.12942/lrr-2014-4

[129] P.A.M. Dirac, *Principles of Quantum Mechanics*, 1930.

[130] A. Einstein, *Cosmological Considerations*, 1917.

[131] JWST Collaboration, *Early Universe Observations*, 2023. https://www.jwst.nasa.gov/

[132] KATRIN Collaboration, *Neutrino Mass*, 2022. https://doi.org/10.1038/s41567-021-01463-1

[133] J. Pascher, *T0 Fundamentals*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Grundlagen_En.pdf

[134] J. Pascher, *g-2 Analysis Rev9*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Anomale-g2-9_En.pdf

[135] J. Pascher, *ML Addendum*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0-QFT-ML_Addendum_En.pdf

[136] J. Pascher, *Beta Derivation*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/DerivationVonBetaEn.pdf

[137] J. Pascher, *CMB Analysis in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zwei-Dipole-CMB_En.pdf

[138] J. Pascher, *Cosmos in T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/cosmic_En.pdf

[139] J. Pascher, *Derivation of Beta*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/DerivationVonBetaEn.pdf

[140] J. Pascher, *Gravitation in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/gravitationskonstante_En.pdf

[141] J. Pascher, *Lagrangian in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_lagrndian_En.pdf

[142] J. Pascher, *Lagrangian Framework*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/LagrandianVergleichEn.pdf

[143] J. Pascher, *Extended Lagrangian Formalism*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_lagrndian_En.pdf

[144] J. Pascher, *Mathematical Structure of T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Mathematische_struktur_En.pdf

[145] J. Pascher, *Muon g-2 in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Anomale-g2-9_En.pdf

[146] J. Pascher, *Pragmatic Approach*, 2025.

[147] J. Pascher, *T0 Energy Formalism*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0-Energie_En.pdf

[148] J. Pascher, *Unified T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_unified_report.pdf

[149] Science Daily, *Physics News*, 2025. https://www.sciencedaily.com/

[150] S. Weinberg, *The Cosmological Constant Problem*, Rev. Mod. Phys., 1989. https://doi.org/10.1103/RevModPhys.61.1

[151] Wikipedia, *Bell's Theorem*, 2025. https://en.wikipedia.org/wiki/Bell%27s_theorem

[152] B. van Fraassen, *The Scientific Image*, Oxford University Press, 1980.

[153] J. Terrell, *Single Clock Nature*, Nature, 2024.

[154] J. Pascher, *The Number 137 in T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/137_En.pdf

[155] J. Pascher, *Ampere's Law in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Amper_Low_En.pdf

[156] J. Pascher, *Bell's Theorem in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Bell_En.pdf

[157] J. Pascher, *Kinetic Energy in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Bewegungsenergie_En.pdf

[158] J. Pascher, *$E=mc^2$ in T0 Framework*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/E-mc2_En.pdf

[159] J. Pascher, *Energy-Based Formulas*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Formeln_Energiebasiert_En.pdf

[160] J. Pascher, *Hannah Document*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Hannah_En.pdf

[161] J. Pascher, *H0 Analysis*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Ho_En.pdf

[162] J. Pascher, *Markov Processes in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Markov_En.pdf

[163] J. Pascher, *Elimination of Mass*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/EliminationOfMassEn.pdf

[164] J. Pascher, *Dirac Equation Mass Elimination*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Elimination_Of_Mass_Dirac_TabelleEn.pdf

[165] J. Pascher, *Fine Structure Constant*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/FeinstrukturkonstanteEn.pdf

[166] J. Pascher, *Neutrino Formula*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/neutrino-Formel_En.pdf

[167] J. Pascher, *Neutrinos in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Neutrinos_En.pdf

[168] J. Pascher, *Koide Formula in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_koide-formel-3_En.pdf

[169] J. Pascher, *Particle Masses*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Teilchenmassen_En.pdf

[170] J. Pascher, *T0 Particle Masses*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Teilchenmassen_En.pdf

[171] J. Pascher, *Penrose Analysis in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_penrose_En.pdf

[172] J. Pascher, *Photon Chip Implementation*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_photonenchip-china_En.pdf

[173] J. Pascher, *Three Clock Experiment*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_threeclock_En.pdf

[174] J. Pascher, *Redshift and Deflection*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/redshift_deflection_En.pdf

[175] J. Pascher, *Apparent Instantaneity*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/scheinbar_instantan_En.pdf

[176] J. Pascher, *Universal Derivation*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/universale-ableitung_En.pdf

[177] J. Pascher, *Xi Parameter for Particles*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/xi_parmater_partikel_En.pdf

[178] J. Pascher, *Origin of Xi*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_xi_ursprung_En.pdf

[179] J. Pascher, *Time in T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zeit_En.pdf

[180] J. Pascher, *Time Constant*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zeit-konstant_En.pdf

[181] J. Pascher, *Summary of T0 Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zusammenfassung_En.pdf

[182] J. Pascher, *RSA in T0 Framework*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/RSA_En.pdf

[183] J. Pascher, *Quantum Atomic Theory*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_QAT_En.pdf

[184] J. Pascher, *QM, QFT and RT Unification*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_QM-QFT-RT_En.pdf

[185] J. Pascher, *QM Optimization*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_QM-optimierung_En.pdf

[186] J. Pascher, *Complete Calculations*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Vollstaendige_Berchnungen_En.pdf

[187] J. Pascher, *T0 Theory vs Synergetics*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0-Theory-vs-Synergetics_En.pdf

[188] J. Pascher, *T0 Model Overview*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Modell_Uebersicht_En.pdf

[189] J. Pascher, *MNRAS Analysis*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Analyse_MNRAS_Widerlegung_En.pdf

[190] J. Pascher, *Anomalous Magnetic Moments*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Anomale_Magnetische_Momente_En.pdf

[191] J. Pascher, *Seven Questions in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_7-fragen-3_En.pdf

[192] J. Pascher, *Detailed Lepton Anomaly*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/detailierte_formel_leptonen_anemal_En.pdf

[193] J. Pascher, *Parameter Derivation*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/parameterherleitung_En.pdf

[194] J. Pascher, *Absolute Ratios in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_verhaeltnis-absolut_En.pdf

[195] J. Pascher, *Xi and Energy*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_xi-und-e_En.pdf

[196] J. Pascher, *Inversion in T0*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_umkehrung_En.pdf

[197] J. Pascher, *T0 vs ESM Conceptual Analysis*, 2025. https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0vsESM_ConceptualAnalysis_En.pdf