

# Photon Chip Introduction

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## **Abstract**

Photonic integrated circuits (PICs) are revolutionizing communication engineering: From low-latency RF filters for 6G networks to parallel AI operations in data centers. \*\*6G standardization begins in 2025, with photonic components being the key to unlocking the terahertz (THz) frequency range for extremely high data rates [?].\*\* This introduction is based on current literature (2024–2025) and highlights analog realization principles (e.g., interference via MZI), preferred operations (matrix multiplication, signal filtering), and relevance for real-time communication. Practical: Table of techniques, outlook on hybrid systems. Sources: Reviews from Nature, SPIE, and ScienceDirect. \*\*Current research (EPFL/Harvard) has introduced a revolutionary optoelectronic chip that processes THz and optical signals on a single processor [?].\*\*

# 1 Basics: Photonic Chips in Communication Engineering

Photonic quantum chips use light waves for highly parallel, energy-efficient processing – essential for 6G (bandwidths  $> 100$  GHz, latency  $< 1$  ms). \*\*The European Commission has announced the start of 6G standardization for 2025, with a focus on sovereignty and a leading technology position [?]. Additionally, 2025 has been declared by the United Nations as the International Year of Quantum Science and Technology (IYQ), underscoring the strategic importance of photonics [?].\*\* In contrast to electronic CMOS chips (heat limits at high frequencies), PICs enable analog signal processing through optical interference and modulation, drawing on classical analog optics (e.g., from 1980s RF technology). Important Note: The technology is strongly analog: Continuous wave transformations (phase shifts, diffraction) dominate, as photons are intrinsically parallel (wavelength multiplexing) and low-latency. Hybrid systems (photonics + electronics) complement for control.

Current trends (2025): Scalable wafers (e.g., 6-inch TFLN) for industrial deployments in data centers, with  $1000\times$  speedup for AI workloads [?, ?].

## 2 Realization of Operations: Analog Principles

Operations are primarily realized through optical components that prioritize analog processing. Core components:

- **Mach-Zehnder Interferometer (MZI):** For phase modulation and linear transformations; analog addition/multiplication via interference.
- **Waveguides and Modulators:** Electro-optical (e.g., LiNbO<sub>3</sub>) or thermal control for continuous signals.
- **Monolithic Integration:** Co-packaging on Si or TFLN platforms minimizes losses ( $< 1$  dB), enables dynamic reconfiguration.

The technology draws on analog RF systems: Instead of discrete bits, continuous wave fields for real-time filtering (e.g., demodulation in 6G) [?]. Example: Linear transformation (matrix-vector multiplication) via MZI mesh:  $y = M \cdot x$ , where  $M$  is programmed by phases  $\phi_i$ :  $\phi_i = \arg(M_{ij})$ .

## 3 Preferred Operations for Photonic Components

Photonic chips are suited for linear, frequency-dependent, and parallel operations, as analog continuity saves energy (pJ/bit) and maximizes bandwidth. Based on 2025 reviews:

Not preferred: Non-linear logic (e.g., AND/OR), as photons are linear; hybrids required here.

## 4 Literature Review: Current Developments (2024–2025)

Based on the latest reviews (open access) and current projects:

Operation	Realization (analog)	Relevance for Communication Engineering
Matrix Multiplication (GEMM)	MZI arrays for interference-based addition/multiplication	AI training in edge networks (e.g., Transformers for 6G routing) [?]
RF Signal Filtering	Optical diffraction/FFT via waveguides	Demodulation, BSS in 5G/6G (bandwidth > 100 GHz) [?]
Recurrent Processing	Programmed photonic circuits (PPCs) for sequential transformations	Real-time monitoring in networks (e.g., RNNs for anomaly detection) [?]
Differential Operations	Meta-optics for gradients (e.g., edge detection)	Image/signal enhancement in optical networks [?]
Parallel Optimization	Correlation via coherent PICs	Gradient descent for routing optimization [?]

Table 1: Preferred Operations on Photonic Chips – Focus on Analog Techniques

- **Analog optical computing: principles, progress, and prospects (2025):** Overview of analog PICs; advances in reconfigurable designs for real-time signals [?].
- **Integrated Terahertz Communication:** A revolutionary optoelectronic processor (EPFL/Harvard, 2025) integrates the processing of **terahertz waves** and optical signals on a chip. This breakthrough is crucial for 6G, as it enables high performance without significant energy loss and is compatible with existing photonic technologies [?].
- **Integrated Photonics for 6G Research:** Projects like **6G-ADLANTIK** and **6G-RIC** (Fraunhofer HHI) develop photonic-electronic integration components to unlock the THz frequency range for 6G and improve network resilience (SUSTAINET) [?].
- **Integrated photonic recurrent processors (2025):** Recurrent operations via PPCs; applications in sequential processing (e.g., network monitoring) [?].
- **Photonics for sustainable AI (2025):** GEMM as core for AI; photonic advantages for energy-poor 6G inference [?].
- **All-optical analog differential operation... (2025):** Meta-optics for differential computing; ideal for signal enhancement [?].
- **Harnessing optical advantages in computing: a review (2024):** Parallel advantages; focus on FFT and correlation for RF [?].

These sources emphasize the shift to analog hybrids for 6G: From prototypes to scalable wafers.

## 5 Outlook: Photonics in 6G Networks

Photonic chips enable low-latency, scalable communication: E.g., optical BSS for multi-user MIMO in 6G. Challenges: Minimize losses (via InAs QDs). Future: Fully integrated PICs for edge computing in base stations. \*\*Fraunhofer HHI already offers application-specific PICs on the silicon nitride (SiN) platform, which are also used in biosciences and sensing [?].\*\*

## References

- [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](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](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](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](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](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](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](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>

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- [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  $\alpha$  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](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](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](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](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](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](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](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](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](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](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](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](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  $\alpha$* , 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](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](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](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](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](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](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](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](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/LagrangianVergleichEn.pdf>

- 
- [143] J. Pascher, *Extended Lagrangian Formalism*, 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0\\_lagrndian\\_En.pdf](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](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](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](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](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](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](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](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](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](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](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](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](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](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Ho_En.pdf)

- 
- [162] J. Pascher, *Markov Processes in  $T_0$* , 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Markov\\_En.pdf](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](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](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/neutrino-Formel_En.pdf)
- [167] J. Pascher, *Neutrinos in  $T_0$* , 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0\\_Neutrinos\\_En.pdf](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Neutrinos_En.pdf)
- [168] J. Pascher, *Koide Formula in  $T_0$* , 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0\\_koide-formel-3\\_En.pdf](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](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Teilchenmassen_En.pdf)
- [170] J. Pascher,  *$T_0$  Particle Masses*, 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0\\_Teilchenmassen\\_En.pdf](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_Teilchenmassen_En.pdf)
- [171] J. Pascher, *Penrose Analysis in  $T_0$* , 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0\\_penrose\\_En.pdf](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](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](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](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](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](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](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](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0_xi_ursprung_En.pdf)
- [179] J. Pascher, *Time in  $T_0$  Theory*, 2025. [https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/Zeit\\_En.pdf](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](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](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](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](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](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](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](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](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](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](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](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](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/detaillierte\\_formel\\_leptonen\\_anemal\\_En.pdf](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/detaillierte_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](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](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](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](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](https://github.com/jpascher/T0-Time-Mass-Duality/blob/main/2/pdf/T0vsESM_ConceptualAnalysis_En.pdf)