# The quantum theory of time: Emergence of Lorentz invariance

Aida Sadeghi, Fatema Tanjia, and Joan Alfina Vaccaro

*QUATRI, Griffith University, 170 Kessels Road, Nathan, Australia*

The violation of the discrete symmetries of charge conjugation (C), parity inversion (P), and time reversal (T) observed in high energy physics are fundamental aspects of nature. A new quantum theory [1,2] has been introduced to explore the possibility of their large-scale physical consequences. The new theory does not assume any conservation laws or equations of motion at the outset. In particular, if T violation is turned off, matter is represented in terms of virtual particles that exist momentarily only. However, with T violation turned on, what was the mathematical structure of a virtual particle now traces out an unbounded world line that satisfies conservation laws and an equation of motion. The important point here is that time evolution and conservation laws are shown to emerge phenomenologically from T violation.

A key point of the theory is that the effective strength $\lambda = \mathrm{i}\langle[\hat{H}_F, \hat{H}_B]\rangle$ of the T violation, where $[\hat{H}_F, \hat{H}_B]$ is the commutator of the Hamiltonians for forward $\hat{H}_F$ and backward $\hat{H}_B$ directions of time, determines a relative scale for clock time. (Here $\hat{H}_B = \hat{T}^{-1}\hat{H}_F\hat{T}$ and $\hat{T}$ is Wigner's time reversal operator.) Consequently, the time shown by an accurate clock depends on the value of $\lambda$ in its local region. In fact, the theory predicts that two identical clocks will loose synchronicity if they are in spatial regions with differing values of $\lambda$ [3]. Importantly, this effect is manifested as differences in the quantum states of the clocks (rather than differences in coordinate times). The T violation exhibited by neutrinos emitted by nuclear reactors offers an opportunity for testing this prediction experimentally [4].

It follows that a velocity-dependent $\lambda$ would induce a corresponding velocity-dependent variation in clock time. Indeed, under a Galilean transformation, interacting scalar fields with vacuum expectation values exhibit an effective T violation that changes in a velocity-dependent way to give precisely the time dilation of the Lorentz transformation, but associated with the relative quantum states of the clocks rather than their coordinates. In other words, quantum clocks are found to undergo time dilation. The speed of propagation of the scalar fields is found to be a limiting speed for all dynamics deduced from quantum states, and an operationally-derived length contraction is found to operate in the relative description of the quantum states. Hence, without being directly introduced, Lorentz invariance is found to *emerge phenomenologically* in the relative quantum description as a consequence of what is essentially a Doppler shift of the effective T violation. This remarkable result suggests that Lorentz symmetry is not an elemental one, as usually assumed, and it illustrates how the new theory offers fresh insight into the quantum nature of time.

[1] J.A. Vaccaro, Quantum asymmetry between time and space, Proc. R. Soc. A (2016) 472 20150670. https://dx.doi.org/10.1098/rspa.2015.0670

[2] J.A. Vaccaro, The quantum theory of time, the block universe, and human experience, Phil. Trans. R. Soc. Lond. A 376 (2018) 20170316. https://dx.doi.org/10.1098/rsta.2017.0316

[3] J.A. Vaccaro, in preparation.

[4] E. Streed, M. Wouters, J.A. Vaccaro, in preparation.