

Review

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Review

Legacy of Galileo (Father of Relativity): Philosophical Transaction of Relativity of Space-Time Symmetry. Relevance to Physical and Biological Frame of Reference

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Abstract

In Greek philosophy, symmetry was closely tied to the concepts of harmony, beauty, and unity of Nature. Modern physics reveals that the integrity of the Universe is intimately linked to concepts of symmetry and relativity. In philosophy, the idea that a single set of laws and principles governs all forms of existence is called monism. In physics, this conjecture was first articulated by Galileo as the relativity principle (RP). Thus, it is fair to say that Galileo is the father of relativity. The historical perspective unveils that the most generalized manifestation of RP is the unity of the Universe. All subsequent evolutions of RP were unfolding of this foundational idea. The evolution of the RP was closely tied to the refinement of the mathematical formulation of space-time geometry and symmetry. Euclidean geometry was gradually displaced from the status of absolute to the role of an initial approximation of physical space determinants. At present, it becomes evident that perceptual indistinguishability of uniform motion, articulated by Galileo, is a consequence of fundamental determinants of existence—space-time symmetry and relativity (STSR). Remarkable, but the nature of elementary (smallest) constituents, the evolution of the largest scales of the Universe, and human behavior follow the same fundamental physical principles. The review is written in a language comprehensible to physicists, mathematicians, biologists, and philosophers (students and teachers). **Prerequisite:** The biologists should be familiar with the fundamental aspects of geometry, and physicist with the origin and evolution of life.

Keywords: bilaterian; bio-chirality; molecular chirality; mirror reflection symmetry; relativity principle; space-time relativity; reference frame

Introduction

The sensitivity of human perception of symmetry is restricted only to a subset of the symmetries realizable in physical space. As a result, the seemingly transparent and easy-to-perceive concept of symmetry becomes one of the most sophisticated, challenging, and fundamental determinants of Nature. Considering space-time symmetry, we will primarily cover space symmetry, as more developed and easier to comprehend intuitively. The Euclidean geometry (EG) was the first draft of the scientific view on the integrity of the Universe, based on self-evident (intuitive) truths or assumptions, called axioms or postulates [1]. Galileo (1564–1642) advanced EG to relativity and equivalence principles (RP and EP) [2], based, as it became evident later, on the principle of space-time symmetry. Kant's declaration that space and time are fundamental and inseparable forms of existence, becomes a prologue to Minkowski's mathematical description of the four-dimensional space-time continuum [3]. Galileo defended the principle of relativity facing opposition from the Holy Office of the Catholic Church (Figure 1. A). Galileo's intuitive insights regarding the RP and equivalence principle (EP) initiates progress in mathematical formalism, from Newton's classical

mechanics to quantum mechanics (QM) contributed by great physicists including Maxwell (1831–1879), Einstein (1879 – 1955), Bohr (1885 -1962), Schrödinger (1887–1961), Pauly (1900–1958), Heisenberg (1901–1976) and many other [4].

The Tails of Galileo Ideas

The unity of the Universe (UU), reflected in the unity of life, science, and art, rests on the idea that a single set of laws and principles governs all forms of existence. In ancient times, Greek philosophers advanced the intuitive idea of UU to the atomic theory of Democritus and the geometry of Epicurus. The spirit of the sane idea was the hidden force of Galilean inspiration in formulating the relativity principle (RP), and Quantum Physics reveals new forms of universal integrity through space-time symmetry and relativity (SPSR) [5]. Galileo's ideas were far ahead of their time, The concerns of motion relativity associated with the RP and EP were behind Einstein's recognition of Galileo as the "father of modern physics-indeed, of modern science altogether" [6]. The hypothesis that "principles of equivalence, invariance, and preservation have an intimate relation to the concept of symmetry" is the most persistent feature of the human mind, from ancient philosophy to modern science. The family of these principles expresses something we believe but do not yet understand the mechanism of action. An illustrative example is the EP, which, as a criterion of identity, has an immediate relation to the space-time symmetry [7–12]. Origin of EP, dating back to Galileo, progresses through general theory of relativity (GTR) [13–15] to quantum physics. Indeed, Galileo's law of free fall, assuming the equivalence of inertial and gravitational mass, known as the equivalence principle (EP), was realized by Einstein as a key tool for expanding RP to systems moving with acceleration. The transfer from SRT to GRT is performed based on two essential principles: -the generalized RP (equating the laws of physics in accelerated reference frames) and-Hilbert principle of least action (PLA) ¹ allow the interpretation of the gravitational force as space-time curvature [16]. Notable that most promising attempts to merge GRT and quantum mechanics (QM) into a unified view of the Universe are made on the grounds of space-time curvature (multidimensional Hilbert geometry [17]) inherently linked to space-time symmetry and relativity (STSR).

From Galileo to Quantum Physics

Most publications devoted to Galilei's contribution to modern physics are suffering from the lack of generalized view reflecting the demand of philosophical transaction [2, 18 -20]. This review aims to fill this gap can be considered complementary to the book "Galileo Unbound" [21]. Galilean RP was grounded on EG created by a distinctive faculty of sensory perception and human imagination as a pragmatics approximation of reality. The most fundamental Euclidean assumption was absolute space characterized by attributes of homogeneity and isotropy. The visual foundations of EG link its axioms and postulates to the primary cognitive ability and psychological function of the organism [19,22]. From the platform of currently accumulated knowledge, concepts of space isotropy and homogeneity have become unconvincing. It isn't easy to imagine the spiral structure of our galaxy (background spacetime structure) does not contribute to the reference frames (RFs) geometrical properties (such as symmetry) (Figure . 2). Euclidian axioms, postulates, and theorems were under permanent attack by mathematical genius, including Lobachevsky (1772–1856), Reimann, (1826–1866), Hilbert (1862 – 1943) and Noether (1888 – 1935)}. Symmetry preservations and symmetry breaking are experimentally observed in the various condensed matter, molecular, atomic, and elementary particle physics quantum effects [23–25], suggesting the relative nature of symmetry determinants. In the post Newton time, a pleades of talented physicists initiated the penetration of new geometric ideas in theoretical and experimental physics. Among them are *Maxwell (1831 – 1879), Michelson (1852 – 1931), Lorentz (1853 – 1928), Curie (1859 – 1906), Minkowski (1864 – 1909), Rutherford (1871 – 1937); Einstein (1879 – 1955), Schrödinger (1887–1961), Pauly (1900 1958), Heisenberg (1901 – 1976), and Dirac (1902 – 1984)*. Galilei's work on RP accompanied by unsuccessful attempt to measure the speed of light brings Galileo to conclusion that it is limited but too fast for available measured

tools. In 1676 Rømer (1644 – 1710) experimentally confirm assumptions of Galilei. Analyzing the conclusions of Aristotle and Copernicus, Galileo generated several hypotheses, many of which he evaluated experimentally. Among them are the principle of inertia and law of constant acceleration induced by constant force (independent of the body mass) finalized by the RP. His *objective was to formulate the laws of movement in the most general form, resulting in the first RP potentially covering relations between space, time, and the concept of symmetry*. Galileo, his contemporaries, and several generations of scientists did not realize that they had caught the tail of the most powerful law of Nature. Galileo transformed ancient intuitions regarding space, time, and symmetry into the principle of equivalence of all inertial RFs. Notably, Galileo (as well as Newton and Einstein) did not explicitly comment on the fundamental association of relativity-symmetry. However, in a broad sense, Galileo's Relativity principle means that the equivalence of all inertial systems indicates their equal relation to something fundamentally common, i.e., to the rest of the world. It is the reason why the question of how relativity, equivalence, Le Shatelier's (1850-1936), and Curie's principles, underlying a relativistic understanding of the Universe, are related to space-time symmetry has increasingly attracted attention in physics and philosophy [26, 27]. In the development of Galilean intuition, classical mechanics held two competing views on space and time. One is based on the distinctive faculty of sensory perception (evolutionary first), and the second—is on the synthetic judgment of higher cognitive functions. Galilean the fundamental determinants of physical objects, space, time, symmetry, and relativity constantly acquire a broader spectrum of meaning. The historical examples include adaptation of the Galilean RP to Newton's mechanics. An essential break-through in the natural evolution of ideas belongs to Minkowski, who replaced the sensory-perception-based view on space and time relations as absolute and separated forms of existence by the mathematical formulation of a four-dimensional (3+1) continuum [28]. A new interpretation of space-time geometry (Minkowski's space-time diagrams) provides an opportunity to visually represent the claims of the special theory of relativity (STR), substituted by the general theory of relativity (GTR), following the branching network of specifications and generalizations. The parade of Galilean, Newtonian, STR, and GTR evolution of RP gained new direction of development after formulation of Noether's theorems pointing to the link between symmetry transformations and preservation of distinct physical parameters [29, 30]. Inspired by Hilbert's application of the last action principle (LAP) to GRT and the challenges of energy conservation in GRT, explore the Klein theoretical framework of (invariance under a group of transformations) Noether contracted famous theorems, providing a broader (not only for GRT but also for quantum systems) underlying mathematical basis applicable to any theory formulated with the LAP [31]. The contribution of Noether was signified by the consecutive transfer of some specific symmetry transformation from the category of absolute to a relative. The breaking of Galilean invariance disregards/dismisses the concept of absolute symmetry for many physical appearances, including mirror symmetry associated with the effect of chirality (handedness or lack of mirror symmetry) [32]. Hand chirality (asymmetry), depicted by the curiosity of ancient Greeks as a specific form of spatial asymmetry, does not influence the formulation of Galileo's and Newton's relativity principle. Until Pasteur (1822–1895) discovered molecular chirality (1848), physical science did not pay much attention to this curious phenomenon. However, now it becomes a common-sense axiom that chirality pervades the natural world (including physical and biological matter), reviling enigmatic preferences of fundamental forces [33, 34], the helices traced out by the arms of galaxies [35], and all hierarchal levels of biological chirality [34, 35]. Chirality and handedness, viewed from the general sense, have different relations to the object/observer dimensionality and the object's physical nature (electron, photon, or mechanical structure) [36]. The most intriguing scientific discovery reveals that any form of RP, beginning from Galileo, is associated with the concept of symmetry. The discovery of the violation of parity in 1956 [33] became the basis for the final rejection of the Galilei-Newtonian time regarding the abstract ideas of homogeneity and isotropy of physical space. Relativity of Space-Time Symmetry (R-STs) has become the driving force in the development of physical and, consequently, in biological sciences.

Philosophy and intuition are necessary instruments of comprehension Nature. It is way physics has been an evolving narrative. This is relevant to evolution of Galileo's relativity principle in contemporary physics. The generalization of RP to the Quantum Principle of Relativity (QPR) is

currently running a streamlined process. In short, QPR postulates (suggests) statistical nature predictions of quantum systems' evolution associated with the structure (symmetry) of space-time itself [37–40]. Space-time structure mediates the interaction of the system of interest with the rest of the world [40]. In other words, if the equation describing a quantum system does not contain the time-dependent impact of the external world on the system of interest, then the price is the randomness of the theory's prediction.

I. The principle of least action (PLA) states that a physical system's path through space and time minimizes a quantity called "action". The implementation of this philosophical principle in mathematics enables Hilbert to derive a system's equations of motion (field equations) without requiring any additional postulates. The field equation (in the language of geometry) describes how matter (mass or gravity) and energy warp space-time. Geometric properties of space-time may include parameters such as distance, volume, dimensionality, curvature, and symmetry. The Hilbert field equation (HFE) serves as a mathematical prototype of the Eastmain field equation (EFE) in GRT.



Figure 1. (A, B, C). A. Painting depicts Galileo during his trial for blasphemy by the Holy Office of the Catholic Church. B. Chiral-centric view on biological evolution. B. The integrity of the universe thesis is the most generalized form of RP. C. Biological relativity [41]. Chiral-centric view on biological evolution and biological

relativity [42, 43]. A *phylogenetic tree* (Tree of Life) represents a scientific hypothesis about the congruence (correspondence, relevancy, relativity) between the diversity of organisms. Biological relativity (bio-chirality) is evident in chirality transfer between all levels of biological organization. Chain of chirality transfer (simplified version) reflecting 5 distinct hierarchical stages: prevalent molecular chirality (I), bilateral motor skills and sensory perception (II), vertebrate's laterality (III), mammals' pyramidal neurons (IV), and human brain /mind handedness (V) are present on the ground of phylogenetic tree.

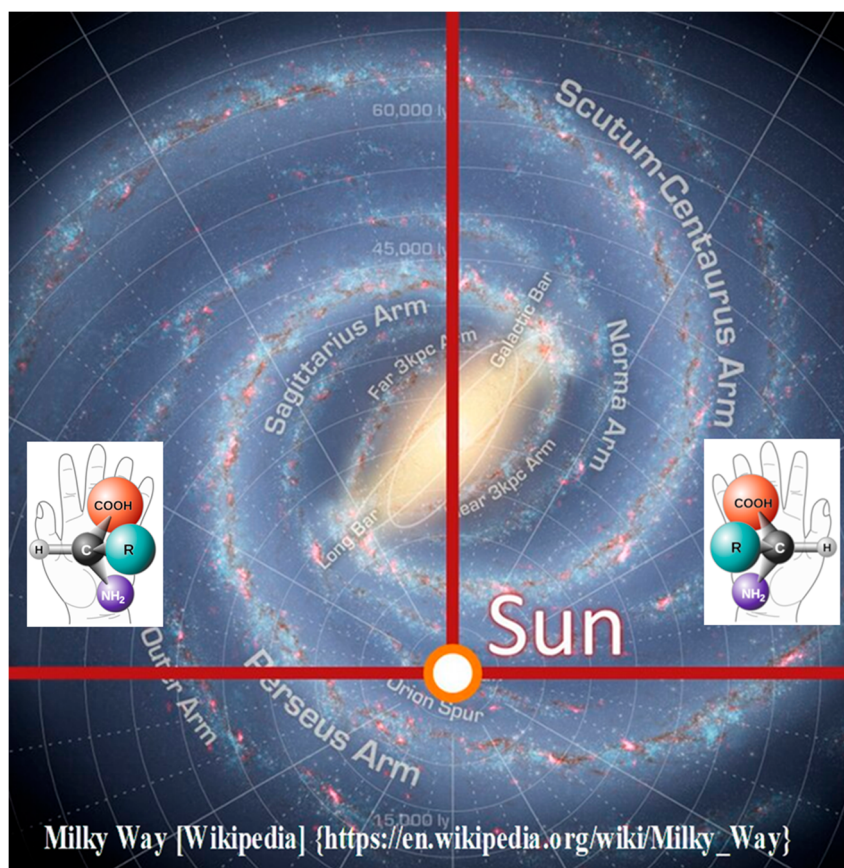


Figure . 2. *Spiral structure of our galaxy.*

Biological Relativity

RP is associated with movement. The movement permeates the features of the universe, and therefore, the attributes of life. Consequently, spatial and temporal scales of movement, in all levels of biological organization, from the molecular, cellular [44, 45] to cognitive and psychological [46–48]. suggest a crucial role of fundamental space-time parameters – symmetry and relativity.

Indeed, life is compatible with two basic principles, which are the non-equilibrium state and breaking the mirror symmetry (biological chirality and handedness) [37, 43, 49]. Mental space gradually acquires functional structure from perceptual space of infancy. Filled during a life-time by the experience of gratifying and adverse events of the physical environment, self, and social domain, it holds relations to physical space, movement, and symmetry. The essential structural elements of mental space are perceptual [50], cognitive [51], and psychological [52] space. Left–right asymmetry is a phenomenon having broad manifestation in biology, including, anatomy, development, evolution, and psychology because it is a morphological feature of organisms that spans scales of size and levels

of an organization [53, 54]. Bohr [1885 – 1962] pays attention to the fact that we are spectators and actors in the great drama of existence [55]. This notion of duality brings us to understanding the psychological domain of our experience. The physics arrow of time (and space-time symmetry in

general), directed by the expanded universe (higher levels of cosmological structures), propagates impact on lower-level structures, including planetary systems, geology, and biology [56–63]. *Biological relativity is grounded on three interlinked domains of sciences: phase transition PhTr; scale relativity, and FR relativity. Let's briefly consider each of them.*

Phase Transition (Physics and Biology)

The early evolution of universe and biological evolution are described in the PhTr accompanied by breaking and restoration of phase symmetry [64–70]. Spontaneous PhTrs are the key elements of fundamentals of physics underlying understanding all (without exception) aspects of biology. Non-equilibrium PhTr play a critical role in maintaining this dynamic condition. STR distinguishing two meanings for the concept of mass, rest mass and relativistic mass (declaration of mass relativity) (see Appendix IV). Theoretical prediction of mass relativity in spontaneous symmetry breaking (SSB) open aspect of mass relativity linked to the geometry of interaction of physical objects with the external environment [67, 71]. The phenomenological core of the theory of PhTs chiefly concerned with the symmetry of the system, link non-equilibrium physics (from solid matter to cosmic scale events) [72–74] with biology (biological aging) [75–77]. The symmetry bridge GRT, quantum field theory and bio-chirality [78, 79].

Scale Relativity (Physics and Biology)

The comparison of spatial and temporal scales of Life and the Universe serves as helpful introduction and background [41]. The origin, evolution, and maintenance of bio-specific effects, including biochirality, follow nature's fundamental laws [80]. The illustrative examples are the theory of scale relativity (TSR) [81–83] and Gestalt psychology [84]. The transformation of entropy has a non-trivial association with the symmetry of the system [83, 84]. Notably, that specific form of global STS, characterized by scale-invariance, reflects the dynamics of energy/matter at all levels of the organizational hierarchy, from elementary particles through cells and organisms to the Universe as a whole [85, 86].

Biological Frame of Reference

According to Schopenhauer, we experience the world through hierarchical levels of cognitive power, Sensation (S), Understanding (U), and Reason (R) evoked to action by the Will (W) (of action) – the concepts paving the way to modern psychology and idea of psychological RF [87–121]. The origin, continuation, and consequences of stereospecificity in biological systems are under the long-term attention of biologists [87]. In all animals, the ability and necessity of efficient movement relies on the prevalent molecular chirality (1), which, in the higher animals, shapes the stem cell differentiation, morphology of neuronal cells, bilateral geometry (2) of the body, and handedness of sensory perception (2) and higher cognitive functions (3) [88–91]. In humans, all three elements shaping space perception are involved in evolutionary selected cognitive and psychological adaptation. From this point, animal physiology, ameliorated by life-time experience, James (1842 – 1910), and Freud (1856–1939) and Pavlov (among many others) began trying to explain the link between physiology, perception, cognition, and action, which constitute the body of psychological functions [92–121]. –

Conclusion

The observer-dependent interaction of light and matter quantum subsystems means that the correlation of two parts behaviors can be perceived differently from different RF [121]. However, some families of RF exhibit consistency in the perception of light-matter interaction – the feature

interpreted as symmetry [122] Unfortunately, this apparent link is frequently overlooked (with rare exceptions [123, 124]. Philosophy of symmetry demands attention. The significance of Galileo's RP in his association with the integrity of the Universe. An idea supported by the commonly accepted paradigm that quantum fluctuations in chiral elementary particles (the smallest structures in the

Universe) cause handedness in clusters of galaxies (the largest structures in the Universe) [125–129]. The well-known prevalent chirality in elementary particles (e.g., L-neutrinos), organic molecules (e.g., L-amino acids and D-sugars), and galaxy rotation suggests the existence of an unknown (yet) not-trivial mechanism of symmetrical transfer consistent with the idea of universal integrity. The elucidation of causal relations within the range of hierarchical events remains one of the challenging questions in modern physics. The significance of the subject matter: “SPACE-TIME-SYMMETRY-RELATIVITY (STSR)” is reflected in several high-quality publications (such as [130, 131]). STSR projects its power far forward by interpreting the space-time structure through spinor geometry and algebra. Prior to Dirac, it was a common assumption that scalars, vectors, and tensors provide a mathematical description of reality. Nevertheless, the Dirac equation reveals that the particles with spin $1/2$ (fermions) are described by mathematical objects called spinors, which are neither scalars, vectors, nor tensors [132–134]. The study of STSR points to possible connection between the quantum property of electron spin and macroscopic rotation at the galaxy scale. Despite the apparent challenges, the human mind assumes the existence of such a link [135, 136]. See Appendix I.

Appendix I.

Proposed by Maxwell, a fundamental physical theory of electromagnetism, revealed that the speed of light is a constant value, and was the first call for the generalization of Galilean transformations and the initial variant of the relativity principle (RP). The laws of electromagnetism obey new forms of symmetry that are not consistent with Galilean transformations. Lorentz (1853–1928) formulated new transformations required by Maxwell's theory, showing that the velocity of light is the same with respect to all inertial frames of reference. The Lorentz transformation, interpreted as a "rotation" in Minkowski's four-dimensional continuum, was the first attempt to reconsider the structure of space-time associated with symmetry and left-right discrimination. The invariance of the speed of light under Lorentz transformations breaks the invariance (absolute meaning) of time-space intervals/distance, compromising the concept of event simultaneity. Notably, in the interaction of massless and massive elementary particles and light-matter effects, Lorentz transformations allow distinguishing chirality and helicity parameters and discriminating left and right sides (in the space-time continuum) [137]. Einstein, recognizing the significance of emerging developments, integrated them under the umbrella of the set of axiomatic principles (postulates) in his special theory of relativity (SRT), which has received numerous experimental confirmations. However, Einstein concluded that SRT could not be applied to gravity or to an object undergoing acceleration [138, 139]. The project to overcome these limitations is known as the general theory of relativity (GRT), which fundamentally redefined gravity not as a force but as the curvature of spacetime caused by mass and energy. Notably, GRT incorporates the results of mathematical brain-storm re-initiated by the Maxwell field equations.

Abbreviations

Euclid geometry (EG); Eastmain field equation (EFE); Hilbert field equation (HFE); Phase transition (PhTrs); Principle of least action (PLA); Quantum mechanics (QM); Quantum principle of relativity (QPR); Relativity principle (RP); Relativity of space-time symmetry (R-STs); Special theory of relativity (STR); General theory of relativity (GTR); Space-time symmetry and relativity (STSR); Reference frame (RF); Spontaneous symmetry breaking (SSB); Sensation (S); Understanding (U); and Reason (R); Unity of Universe (UU).

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