Joachim Herrmann

E: jherrmann-berlin@web.de **E:** jherrman@mbi-berlin.de
W: mbi-berlin.de/p/joachimherrmann

Creating a unified theory for the fundamental physical interactions

Research Objectives

Joachim Herrmann's tangent bundle quantum field theory provides a fresh perspective on the search of a unified theory beyond the standard model of elementary particles and solves some up to now unexplained problems in the standard model, such as the family problem and the fractionalisation of quark charges.

Detail

Bio
Dr Herrmann completed his PhD in 1971 and became an associate professor in Jena in 1980. He has worked at the Max Born Institute in Berlin since 1989. His research activities include the theory of ultrafast lasers and nonlinear optics, nanooptics and elementary particle theory. He is author or co-author of 135 scientific publications and co-author of one book.

References

Herrmann, J, (2023) Origin of internal symmetries of the fundamental interactions, the family problem, fractional quark charges and unification in the tangent bundle geometry, *Letters of High Energy Physics*, 427/2023.

Herrmann, J, (2022) Towards a unified theory of the fundamental physical interactions based on the underlying geometric structure of the tangent bundle, *The European Physical Journal C*, 82(10), 947. doi.org/10.1140/epjc/s10052-022-10781-4

Herrmann, J, (2019) Extension of the standard model of electroweak interaction and Dark Matter in the tangent bundle geometry, *The European Physical Journal C*, 79(9), 779. doi.org/10.1140/epjc/s10052-019-7260-z

Personal Response

What is next for your research?

" Leading on from this discovery, in future work I will apply the theory for the determination of a new possible mass generation mechanism with the calculation of the masses of charged leptons and quarks. "

Creating a unified theory for the fundamental physical interactions

The search for a theory which unifies the Universe's four known fundamental forces has now endured for over a century. Recently, Dr Joachim Herrmann at the Max-Born Institute, Germany, revisited the geometrisation programme of unified field theory from the 20th century, in combination with the modern theory of elementary particles. He has shown that a possible solution may be found based on the hypothesis that all fundamental physical interactions have a joint geometrical origin in the frame of the mathematical structure of tangent bundles. His approach delivers an extension of the Standard Model including dark matter particles, a possible solution of the so-called family problem, and also explains the existence of fractional quark charges. Herrmann's work may finally lead to a long-awaited unification of the strong, electroweak, and gravitational interactions.

When Einstein presented his general theory of relativity in 1915, it turned our understanding of gravity on its head. For over 200 years, since the discoveries of Newton, physicists had described gravity as a force, which causes a mutual attraction between two or more massive objects. Einstein proved that gravity isn't really a force at all: instead, it is a geometric phenomenon that arises from the curvature of spacetime, and the spacetime metric determines both metric relations as well as the gravitational interaction.

For many physicists at the time, the next logical step to this work would be an even more fundamental theory which unifies gravity and electromagnetism. The programme of unified field theories then aimed to find a joint underlying geometric structure of the world spacetime for the unification of gravity with electromagnetism. Yet despite inspiring new results, this theory never materialised.

THE STANDARD MODEL OF ELEMENTARY PARTICLE PHYSICS

Over the coming decades, advances in nuclear physics led to the discovery of two new forces: the strong interaction – which binds together the quarks that form protons and neutrons; and the weak interaction – responsible for radioactive decay. Together with gravity and electromagnetism, these now make up the Universe's four known fundamental forces.

According to the general principle of relativity in Einstein´s theory of gravity, general spacetime transformations play a central role that determine the form of the laws of nature. However, the discovery of the existence of non-geometrical symmetries (denoted as gauge symmetries) in contrast to geometrical spacetime symmetries was a cornerstone in the development of modern particle physics and led to a new unified theory of electromagnetic and weak interaction. On the other hand, the gauge theory for strong interaction (so-called quantum chromodynamics) was since developed, which is also based on the existence of an (internal) non-geometrical gauge symmetry. In comparison to quantum electrodynamics, which describes interaction by exchanging photons, in strong interaction quarks carry an additional charge named 'colour charge' and interact via the exchange of another type of massless particle, named 'gluon'. Gauge symmetries are linked to the existence of discrete conserved internal quantum numbers such as charge, isospin, hypercharge, and colour, which characterise different types of leptons and quarks. Both gauge theories constitute the so-called Standard Model of elementary particles representing one of the greatest success in modern physics. But even though it proved to be extremely successful in the description of a large number of experiments, physicists now widely believe that the Standard Model in its current form is incomplete.

PHENOMENA BEYOND THE STANDARD MODEL

In the Standard Model, the specific gauge symmetries are assumed by phenomenological reasons arising from experimental observations, but the physical origin of these symmetries remains unknown. There are several other problems. The existence of dark matter and dark energy are the most well-known examples of this. Another gap in the theory lies in the mysterious existence of lepton and quark families with identical properties except for their masses. A lepton family, for example, consists of electrons, muons, and tauons, but in the Standard Model they have the same internal quantum numbers and identical properties, and the origin of their significant different masses is not known. Another problem is the missing explanation of quark charges of a fraction of the electron charge. Despite many attempts to solve these problems, none of them are generally accepted.

THE GEOMETRICAL ORIGIN OF ALL FUNDAMENTAL PHYSICAL INTERACTIONS

In the current state of physical theories, gravity has a geometrical origin, whereas the other three interactions do not. In the 1960s, the formal identity between gauge theories (in particular the standard model) with the mathematical structure of geometrical fibre bundles was discovered. However, because the specific fibre bundle was not known, this important discovery could not be used as a bridge to a new physical theory beyond the Standard Model.

In his research, Herrmann pursued the hypothesis that the most fundamental fibre bundle – the tangent bundle – is the underlying geometrical structure for a unified theory of all fundamental interactions. Widely used in mathematics, in these structures all tangent vectors at every point x in spacetime are placed in their own space (the tangent space at the point x) and the union of all tangent spaces are denotes as the tangent bundle. In a first step, he presented a generalised theory of electroweak interaction (Herrmann, 2019). In this theory, besides the particles known in the Standard Model, new particles are predicted which can be interpreted as hypothetical dark matter particles arising on a common root without additional a priori phenomenological model assumptions.

STRONG INTERACTION IN THE TANGENT BUNDLE GEOMETRY

A next step in this research programme is the problem how strong interaction could arise in the tangent bundle geometry. Recently he found a possible solution of this problem (Herrmann 2022; Herrmann, 2023). In the tangent bundle approach, the gauge symmetry for strong interaction arises as an emergent symmetry similar to certain semiconductors (denoted as Quantum Hall systems). Here, thin layers of electrons in a semiconductor are subjected to a strong, perpendicular magnetic field which causes them to move in circular motions. Surprisingly, in the ground state – as a result of the collective interaction – the charge of the electrons becomes a fraction of its value in the vacuum and results to a specific voltage across the system. Fractional charge quantisation of quarks can be understood in analogy to this effect. Based on this new theory, central problems beyond the Standard Model can be explained. In the underlying geometric structure of the tangent bundle, two additional internal quantum numbers arise which explain the existence of three families of leptons and quarks, and the two additional internal quantum numbers provide an underlying explanation for the existence of families of quarks and leptons.

This approach led to an important discovery: that the strong interaction can emerge in the geometry of tangent bundles.

Leading on from this discovery, Herrmann has now used his tangent bundle geometry to shed new light on the origin of strong interaction and delivered an explanation why quarks carry an electrical charge of 1/3 and 2/3 of an electron charge. The analogy with the anomalous Quantum Hall effect could hint to the possible existence of other types of exotic particles formed from exotic quark states with hypercharges of e/5.

UNIFYING ALL FOUR FORCES

The Standard Model of particle physics does not include gravity and there currently is no quantum theory of gravitation. Because all the other fundamental interactions are described successfully by gauge theories of internal symmetries, several attempts have been made to develop a gauge theory of gravity. A specific class of a gauge gravity theory (denoted as teleparallel gravity theory) has been developed which has found much attention by considering the translation symmetry in the tangent bundle as gauge symmetry. In this theory, gravity is described in terms of torsion instead of the curvature, but nevertheless teleparallel gravity theory and Einstein's theory of gravity are classical equivalents. In Herrmann's tangent bundle quantum field theory, all the other fundamental symmetries arise as rotational gauge transformations of tangent fibres in the tangent bundle. This offers the possibility to identify the tangent bundle as the underlying geometrical structure for a new type of unified geometrised theory for all fundamental interactions. However, the quantisation of gravity remains an unsolved problem in the unification.

Herrmann's tangent bundle quantum field theory provides a fresh perspective on a search which began over a century ago. In his work, he explored how strong interactions dynamically emerge from a unified geometrical framework of tangent bundles with the result of the unification of electroweak and strong interaction (denoted often as grant unification). This theory could deliver a significant missing link to the hidden structure of a consistent unification of all the fundamental interactions including gravity not only at the classical but also at the quantum level.

researchoutreach.org

research OUTREACH

The public outreach magazine for the research community

researchoutreach.org

Partnership enquiries: simon@researchoutreach.org