Geometric optical knots as sources of topological gravitation

Miftachul Hadi[1, 2, 3]
[1)] *Badan Riset dan Inovasi Nasional (BRIN), KST Habibie (Puspiptek) Gd 442, Serpong, Tangerang Selatan 15314, Banten, Indonesia.*
[2)] *Institute of Mathematical Sciences, Kb Kopi, Jalan Nuri I, No.68, Pengasinan, Gn Sindur 16340, Bogor, Indonesia. E-mail: instmathsci.id@gmail.com*
[3)] *Institute of Natural Sciences, Krajan, Jalan Imam Bonjol, Klagenserut, Jiwan 63161, Madiun, Jawa Timur, Indonesia.*

We propose a novel viewpoint in which gravitational fields emerge not from conventional matter-energy sources, but from topological configurations of light encoded in twistor space. This preliminary study proposes that geometric optical knots—nontrivial configurations of light rays forming closed or linked loops—can act as sources of topological gravitation, where space-time is emergent. These knots naturally reside in twistor space, where null structures are fundamental.

Keywords: *geometrical optic, knot, gravitational field, twistor space.*

It is widely recognized that one of the major goals of theoretical physics is the unification of general relativity and quantum field theory. The unification of general relativity and quantum field theory remains a central challenge in theoretical physics, due in large part to their fundamentally different conceptions of space-time. While general relativity describes gravity as the curvature of a dynamical space-time shaped by matter and energy, quantum field theory operates on a fixed, background geometry where fields propagate. This conceptual gap becomes particularly severe at regimes where both quantum effects and space-time curvature are significant—such as near singularities or at the Planck scale. To overcome this, various approaches have sought to replace the notion of space-time itself with more fundamental structures.

Twistor theory, introduced by Penrose, reformulates the geometry of space-time in terms of complex structures where massless fields — particularly light — are fundamental. In this framework, the topological structure of light fields in twistor space encodes information about the space-time geometry.

Motivated by this, we propose a novel viewpoint: gravitational fields may originate not from conventional matter-energy distributions but from the topological structures of light i.e. geometric optical knots encoded in twistor space. This perspective opens a path toward understanding gravitation as an emergent phenomenon rooted in the geometry and topology of null fields, with potential implications for quantum gravity and unification. Here, null fields are fields—like light or electromagnetic waves—that travel at the speed of light and have zero rest mass.

Among these, twistor theory offers a compelling alternative. Originally introduced by Penrose, twistor space is a complex manifold in which null rays—lightlike trajectories—are the fundamental entities. In this framework, space-time is not taken as primary, but instead emerges from the algebraic and geometric relationships among twistors. This perspective is particularly well-suited to exploring light-based structures, such as knotted configurations of rays.

This approach suggests that topological gravitation may arise from purely topological data encoded in light-like congruences, independent of conventional mass-energy sources.

Our goal in this preliminary work is to develop the foundations of this idea by drawing analogies to Einstein's field equations and investigating how geometric optical knots structures in twistor space might serve as sources of the topological gravitation in the emergent space-time picture.

Knotted configurations of electromagnetic fields, such as those described by Hopfions or Ranada's solutions, exhibit non-trivial topological structure even in vacuum. These topological field configurations carry quantized helicity and momentum density, despite having no mass source. This indicates that light itself can possess rich geometrical and dynamical content capable of influencing the surrounding geometry.

The classical theory of gravitation, as encoded in Einstein's general relativity, describes gravitation as the curvature of space-time induced by the presence of mass and energy. In this framework, light rays follow null geodesics shaped by the geometry of space-time. However, the theory itself does not explain the origin of this curvature — it assumes the geometry is shaped by matter fields through the Einstein field equations. General relativity explains how space-time curvature arises when energy and momentum are present, but it does not explain why energy and momentum should produce curvature in the first place.

In contrast, recent developments in topological field theory and knot theory suggest that topological structures in field configurations may play a more fundamental role in shaping physical phenomena. For instance, in electromagnetic theory, Ranada and others have constructed stable, finite-energy solutions in vacuum — such as Hopfions — whose field lines are knotted and linked, yet free of sources. The phrase "free of sources" means that the field solution does not originate from external charges or currents — in other words: the field arises not from conventional sources such as electric charge, mass, or current, but purely from the internal structure of the field itself. This raises a provocative question: could spacetime curvature, and therefore gravitation itself, emerge from the topological properties of light rather than from mass-energy?

In this preliminary work, we explore the idea that geometric optical knots — that is, ray trajectories in the eikonal approximation that form closed, topologically nontrivial structures — may act as effective sources of topological gravitation. Unlike standard matter fields, these knots do not require mass but instead carry energy and topological invariants, potentially enough to influence or define curvature.

The guiding insight is to reinterpret gravitational interaction not as a fundamental force, but as a manifestation of complex topological configurations in the underlying field content, specifically light. From this viewpoint, the bending of light is not caused by gravity — it is gravity. In other words, topological behaviour of light — especially in the form of knotted, self-entangled rays — is not the consequence of gravity, but the very mechanism that gives rise to what we perceive as gravitational interaction. The bending of light is not merely an effect of gravity — rather, it is the very manifestation of gravity itself.

This inversion of perspective motivates an inquiry into the role of light's geometry, not just as a probe of spacetime, but as a generator of its structure. Though speculative at this stage, this viewpoint suggests an intriguing path toward unifying optics, topology, and geometry in a new gravitational paradigm.

Taking inspiration from knotted electromagnetic fields such as Hopfions, and guided by insights from Abelian Chern–Simons theory in (2+1) dimensions, we outline a research program aimed at understanding whether geometric optical knot may serve as effective sources of topological gravitation. While no detailed model is presented here, we motivate the idea that the gravitational field might not be fundamental but a topological byproduct of self-organized light configurations.

We would like to thank ChatGPT for fruitful discussions. We would like to thank also to Juwita Armilia and Aliya Syauqina Hadi for much love and patience. Al Fatihah for his Ibunda and Ayahanda. May Allah bless them Jannatul Firdaus. This research is supported fully by self-funding.

[1]Roger Penrose, *Fashion Faith and Fantasy in the New Physics of the Universe*, Princeton University Press, 2016.

[2]Roger Penrose, *A Brief Outline of Twistor Theory*, in *Cosmology and Gravitation: Spin, Torsion, Rotation, and Supergravity*. Edited by Peter G. Bergmann and Venzo De Sabbata, Plenum Press, 1980.

[3]Carlo Rovelli, *Reality Is Not What It Seems: The Journey to Quantum Gravity*, Penguin Publishing Group, 2018.

[4]Miftachul Hadi, *Weak geometric optical knot in vacuum (2+1)-dimensional space-time* and all references therein, OSF Preprint, https://osf.io/preprints/osf/e7afj_v1, 2025.

[5]Miftachul Hadi, *On Newtonian knot in empty (2+1)-dimensional de Sitter space-time*, and all references therein, OSF Preprint, https://osf.io/preprints/osf/su3dp_v2, 2025.