



AFRL-AFOSR-JP-TR-2024-0008

Relativistic quantum metrology: polarization effects

Terno, Daniel
MACQUARIE UNIVERSITY
BALACLAVA ROAD
NORTH RYDE, , 2109
AUS

11/26/2023
Final Technical Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
Air Force Office of Scientific Research
Asian Office of Aerospace Research and Development
Unit 45002, APO AP 96338-5002

REPORT DOCUMENTATION PAGE

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE 20231126	2. REPORT TYPE Final	3. DATES COVERED	
		START DATE 20200821	END DATE 20230820
4. TITLE AND SUBTITLE Relativistic quantum metrology: polarization effects			
5a. CONTRACT NUMBER	5b. GRANT NUMBER FA2386-20-1-4016	5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER	5e. TASK NUMBER	5f. WORK UNIT NUMBER	
6. AUTHOR(S) Daniel Terno			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) MACQUARIE UNIVERSITY BALACLAVA ROAD NORTH RYDE 2109 AUS			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AOARD UNIT 45002 APO AP 96338-5002		10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/AFOSR IOA	11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-AFOSR-JP-TR-2024-0008
12. DISTRIBUTION/AVAILABILITY STATEMENT A Distribution Unlimited: PB Public Release			
13. SUPPLEMENTARY NOTES			
14. ABSTRACT The research addressed two related problems: 1. Unambiguous determination of polarization rotation in the near-Earth environment due to post Newtonian gravitational effects in the geometric optics approximation and beyond. 2. Evaluation of gravitational effects beyond the geometric optics approximation. There is a well-developed theory, but its applications are controversial. Its specific goals were to 1. Evaluate the effect of polarization rotation, particularly the still controversial gravity-induced polarization, and their impact on quantum communications. 2. Propose a scheme to counter the deleterious effects, once the performance requirements make it necessary 3. Evaluate the effects of polarization on light propagation and consider their potential effects on the proposed solar-system experiments.			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:		17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3
a. REPORT U	b. ABSTRACT U		
19a. NAME OF RESPONSIBLE PERSON MICHAEL RICHARDS			19b. PHONE NUMBER (Include area code) 3152277000

Standard Form 298 (Rev. 5/2020)
Prescribed by ANSI Std. Z39.18

Polarization rotation in gravitational field

Final Report

FA2386-20-1-4016

PI: Associate Professor Daniel Terno (sole investigator)

School of Mathematical and Physical Sciences, Macquarie University, Sydney NSW 2109, Australia

Total funding: \$39,194

Period: 20.08.20 -20.08.23 (extended due to COVID19)

Brief summary of the scientific problem and the goals of the project

The research addressed two related problems:

1. Unambiguous determination of polarization rotation in the near-Earth environment due to post-Newtonian gravitational effects in the geometric optics approximation and beyond.
2. Evaluation of gravitational effects beyond the geometric optics approximation. There is a well-developed theory, but its applications are controversial.

Its specific goals were to

1. Evaluate the effect of polarization rotation, particularly the still controversial gravity-induced polarization, and their impact on quantum communications.
2. Propose a scheme to counter the deleterious effects, once the performance requirements make it necessary
3. Evaluate the effects of polarization on light propagation and consider their potential effects on the proposed solar-system experiments.

Annotated list of papers

1. P. K. Dahal and D. R. Terno, *Polarization rotation and near-Earth quantum communications*, Physical Review A **104**, 042610 (2021). [available at <https://arxiv.org/abs/2106.13426> and <https://journals.aps.org/pr/abstract/10.1103/PhysRevA.104.042610>]

We investigated the effects of gravitational field on light polarization in the near-Earth environment, focusing on the consequences of the realistic schemes of establishing common reference frames for quantum communications. The errors due to this effect are negligible, but together with much more significant Doppler-like errors they can be efficiently countered by a fully reference frame independent scheme that also handles arbitrary misalignments between the reference frames of sender and receiver. Fully achieved goals 1 and 2.

2. P. K. Dahal and D. R. Terno, *Light rays in the Solar system experiments: phases and displacements*, in Proceedings of the Sixteenth Marcel Grossmann Meeting, World Scientific, Singapore, 2023) p. 3942

[available at <https://arxiv.org/abs/2111.03849> and https://www.worldscientific.com/doi/10.1142/9789811269776_0328]

We adapted the covariant formulation of geometric optic correction up to the leading post-geometric order approximation, to the post-Newtonian expansion. We use this formalism to obtain a closed form of the polarization dependent correction of the light ray trajectory in the leading order in a weak spherically symmetric gravitational field. Provides the framework to apply the general theory to analytical study of specific set-ups, goal 3. (The implementation of the scheme had drawback rectified in the subsequent work)

3. S. Murk, D. R. Terno, and R. V. Vadapalli, *Gravitational spin –Hall effect in Schwarzschild spacetimes* (in writing)

We developed an efficient scheme to perturbatively evaluate the effect of polarisation on the propagation of electromagnetic radiation on spherically-symmetric background that is based on the system of equations of Frolov. The scheme allows calculation both in strong and weak regimes. Several potentially observationally relevant set-ups very evaluated. Resolves goal 3 for the Solar system experiments and for general spherically-symmetric spacetimes.

Academia/Industry Relationship or Collaboration

Evaluation of the effect for several classes of astrophysical objects show that the polarization dependence of the trajectory in sum-cm band may be observable. This recent development initiated the discussions with radio astronomers at Macquarie and the CSIRO [the Commonwealth Science and Engineering Research Organisation] unit.

Follow-on awards

Daniel Terno was promoted to (full) professorship (2023). The case for promotion is based in part on the research achievements (the interdisciplinary aspect of this program have been highlighted) and the partnerships, including external grants.

Students involved

Pravin K Dahal, research assistant between completion of his MRes and commencement of the PhD program, part-time assistant [Jan-April 2021, July-December 2021]

Sebastian Murk, research assistant after completion of his PhD [June-July 2022]

Rama V. Vadapalli, Master of Research student [January – November 2023], thesis title: *Polarization effects on light propagation in gravitational fields*.