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Faculty of Sciences of the University of Lisbon

Department of Physics

Geometrical methods in electromagnetism and gravitation.

Gravitoelectromagnetism and gravity with torsion

(with cosmological applications)

Francisco Tenreiro Oliveira Cabral

Master Dissertation on Physics

(Field of Astrophysics and Cosmology)

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Departamento de Física

Métodos geométricos em electromagnetismo e gravitação. Gravitoelectromagnetismo e gravidade com torsão (com aplicações cosmológicas)

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Dissertação de Mestrado em Física

(Especialização em Astrofísica e Cosmologia)

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Resumo

Principais motivações que orientam a linha de investigação na qual a tese se insere

- Aprofundar o estudo da relação íntima entre *geometria* e *física*;

- Estudar as *analogias* e o *acoplamento* entre *gravidade* e *electromagnetismo* usando *métodos geométricos*, compreendendo a possibilidade de importantes aplicações teóricas e tecnológicas, podendo mesmo ser relevante para a astrofísica, a cosmologia e, eventualmente, no caminho para uma teoria consistente da gravidade quântica;

- Estudar o *gravitoelectromagnetismo* e suas aplicações astrofísicas e eventualmente tecnológicas;

- Explorar a noção de *torsão* em geometria diferencial e sua importância em física, nomeadamente no âmbito das *teorias de gravitação*.

Enquadramento geral e tópicos principais da dissertação.

Relação entre geometria e Natureza - relação entre geometria e física.

• Importância dos *métodos geométricos* no estudo do *campo eletromagnético* e da *gravidade* e na exploração das *analogias* e *acoplamento* entre estas duas interações:

- Axiomática do electromagnetismo;
- Gravitoelectromagnetismo;
- Acoplamento entre gravidade e electromagnetismo;
- Gravidade com torsão:

  - Relevância teórica. Diferentes modelos;
  - Alguns modelos cosmológicos;
  - Exploração das analogias entre gravidade e electromagnetismo;
  - Testes experimentais.

- A questão da interpretação do papel das estruturas geométricas do espaço-tempo em física é abordada, realçando algumas reflexões relacionadas com a geometrização da física, motivadas pelo estudo das analogias e acoplamento entre gravidade e electromagnetismo. Neste âmbito a noção da ontologia física do espaço-tempo é brevemente abordada na sua conexão com as teorias unificadas.

Author's note

Although this work contains many personal investigations, interpretations and ideas, it was mainly constructed as a review compilation on several selected topics concerning the electromagnetic and gravitational studies using geometrical methods. The selected topics and their sources reflect the author's interests and were compiled together and organized into a single framework in order to construct a meaningful and solid line of research on the related topics of gravitation and electromagnetism. One could say that this project fits within the wider scientific arena for research on the relation between geometry and physics and the nature of space and time. Some of the topics addressed, such as the coupling of gravity and electromagnetism, gravitoelectromagnetism and gravity with torsion, are areas of active research from the theoretical side but it's the author's conviction that these studies will eventually reveal many astonishing practical (technological) applications.

Main motivations and research lines:

- To deepen the study on the profound relation between *geometry* and *physics* and the nature of *space* and *time*;

- To study the *analogies* and *physical coupling* between *gravity* and *electromagnetism* using *geometrical methods*, considering the possibility of important theoretical (and technological) applications, being relevant for astrophysics, cosmology and, eventually, for the search of a consistent theory of quantum gravity;

- To study *gravitoelectromagnetism* from a theoretical point of view as well as its astrophysical and technological applications;

- To explore the notion of *torsion* in differential geometry and its importance in physics, namely in classical and quantum gravitation, unified theories of interactions and cosmology;

- To explore, using the already mentioned analogies, to which extent is it possible to have a *geometrical explanation of "inertial forces"* (compatible with the equivalence principle), seen as *geometrical deformations of space-time*, such as curvature and torsion.

(Not all of these topics are covered in the present work but these are the main research lines that motivate this and future projects)

General conceptual framework and main topics present in this thesis

Relation between geometry and physics:

- Importance of *geometrical methods* in the study of the *electromagnetic* and *gravitational fields* and in the exploration of the *analogies* and *coupling* between these physical interactions:

  - Axiomatic of the electromagnetism;
  - Coupling between gravity and electromagnetism;
  - Gravitoelectromagnetism and GP-B experiment;
  - Gravity with torsion:

    - Theoretical relevance of extended theories of gravity. Different models with torsion and interpretations;
    - Some cosmological applications;
    - Exploration of the analogies and coupling between gravity and electromagnetism.
    - Testing space-time torsion

  - The work suggests the idea that the *electromagnetic properties* of "empty space" might be interpreted as *geometrical properties of the space-time continuum* and that electromagnetic and gravitational waves should be fundamentally connected and be mutually generated. In this sense, it also reinforces the need to rethink the concept of "vacuum" in physics. It is also briefly explored the possibility of a *geometrical description of the electromagnetic field*..

  - Being essentially devoted to *geometrical methods* in the study of the *electromagnetic* and *gravitational fields* and to the role of space-time (geometrical) structures in these field theories, this work enhances the philosophical debate on the nature of space and time inspired by ideas coming from physics. On the last part it discusses some relevant open questions such as the possibility of a *coherent physicalism of space-time* and the geometrization of fundamental structures such as Higgs fields.