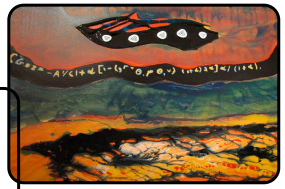
What Mad Pursuit

Orfeu Bertolami

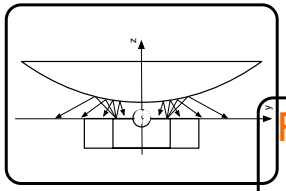
GSAC
Cosmic Vision (2015-2025)
OUSS
Euclid
QUEST - Sat

Noncommutative QM

$$[q_i, q_j] = i\theta_{ij}$$
$$[p_i, p_j] = i\eta_{ij}$$



Unification/
Interaction
Dark Energy -
Dark Matter



Pioneer &
Flyby
Anomalies

U.PORTO
FACULDADE DE CIÊNCIAS
UNIVERSIDADE DO PORTO

CFP-CAUP Workshop
22 March 2013, CAUP

Gravity and Fundamental Physics in Space

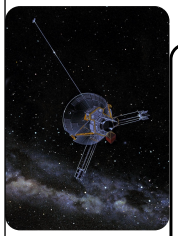
Aim

To create and to test new ideas to understand the universe

esa

Galileo Science Opportunity Document

2010



Interests: the study of unknown forces acting on spacecraft (Pioneer & Flyby anomalies); development of generalizations of quantum mechanics; of models to understand the nature of dark energy and dark matter; of alternative theories of gravity and their implications for astrophysics and cosmology

Collaborators

Giovanni Belletini
Alex Bernardini
Nuno Costa Dias
Paulo Gil
Riccardo March
João Prata

U.PORTO
FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

INFN
Istituto Nazionale di Fisica Nucleare

INSTITUTO SUPERIOR TÉCNICO

UNIVERSIDADE LUSÓFONA de Humanidades e Tecnologias
Humani nihil alienum

Five-year
Jorge Páramos

Post-Docs
Catarina Bastos

Ph.D. Students
Frederico Francisco
Pedro Frazão

M.Sc. Students
Pedro Carrilho
Ricardo Ferreira
André Guerra
António Martins

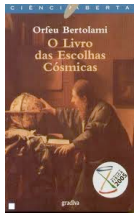
IPFN/IST

Some bench marks

	2009	2010	2011	2012
Peer-reviewed papers	15	9	7	9
Contributions to Conferences	10	11	10	7
Completed Ph. D.	1	2	1	0
Completed M. Sc.	2	1	1	4

Public lectures & Book
Articles (SPF, newspapers)
Painel *SiW*@Príncipe

Public Outreach



OUSS, Euclid & QUEST-Sat mission proposal teams

ESA Cosmic Vision

M. Sc. Theses in 2012

1. Dynamics of perfect fluids in nonminimally coupled gravity
António Martins
O. B., A. Martins, Phys. Rev. D85, 024012 (2012)

2. Wormholes and Time-Machines in Nonminimally Coupled Matter-Curvature Theories of Gravity
Ricardo Zambujal Ferreira
O. B. and R.Z. Ferreira, Phys. Rev. D85, 104050 (2012)

3. A Two-Scalar Field Theory for Dark Matter-Dark Energy Interaction
Pedro Carrilho
O. B., P. Carrilho and J. Páramos, Phys. Rev. D86, 103522 (2012)

4. Comparison of Space Propulsion Methods for a Manned Mission to Mars
André Gomes Guerra
O. B., P. Gil and A.G. Guerra, in preparation

Papers published in 2012

1. Modelling the reflective thermal contribution to the acceleration of the Pioneer spacecraft
F. Francisco, O. B., P. Gil and J. Páramos, Phys. Lett. B711, 337-346 (2012)

2. Testing the interaction of dark energy to dark matter through the analysis of the virial relaxation of Abell Clusters A586 and A1689 using realistic density profiles
O. B., F.G. Pedro and M. Le Delliou, Gen. Rel. Grav. 44, 1073-1088 (2012)

3. OSS (Outer Solar System): A fundamental and planetary physics mission to Neptune, Triton and the Kuiper Belt
B. Christophe, J.D. Anderson, N. Andre, S.W. Amar, J. Aumou, A. Barucci, O. B., et al.
Exp. Astron. 34, 203-242 (2012)

4. On the dynamics of perfect fluids in non-minimally coupled gravity
O. B. and A. Martins, Phys. Rev. D85, 024012 (2012)

5. Mimicking dark matter in galaxy clusters through a non-minimal gravitational coupling with matter
O. B., P. Frazão and J. Páramos, Phys. Rev. D86, 044034 (2012)

6. Testing the Flyby Anomaly with the GNSS Constellation
O. B., F, Francisco, P. Gil and J. Páramos, Int. J. Mod. Phys. D21, 1250035 (2012)

7. Traversable Wormholes and Time Machines in non-minimally coupled curvature-matter f(R) theories
O. B. and R. Z. Ferreira, Phys. Rev. D 85, 104050 (2012)

8. Two-scalar-field model for the interaction of dark energy and dark matter
O. B., P. Carrilho and J. Páramos, Phys. Rev. D 86,103522 (2012)

9. Violation of the Roberstson-Schroedinger uncertainty principle and non-commutative QM
C. Bastos, O.B., N. C. Dias and J. N. Prata, Phys. Rev. D86, 105030 (2012)

Other papers 2011-2012-2013

1. What if ... General Relativity is not the theory?
O. B., arXiv:1112.2048 [gr-qc]

QSO Astrophysics, Fundamental Physics and Astrometry Cosmology in the Gaia era, 6-9 June 2011, Departamento de Física e Astronomia, Faculdade de Ciências, Universidade Porto.

2. Digging Down the Past
O. B., arXiv:1110.4428 [physics.hist-ph], J. Iberian Archeology 14, 89-96 (2011)

3. Noncommutative Graphene
C. Bastos, O. B., N.C. Dias and J. Prata, arXiv:1207.5829 [hep-th]

4. Non-Linearities in the Quantum Multiverse
O. B. and V. Herdeiro, arXiv:1208.0236 [gr-qc]

5. Interacting universes and the cosmological constant
A. Alonso-Serrano, C. Bastos, O. B. and S. Robles-Perez, Phys. Lett. B719, 200-2005 (2013)

6. The Hamiltonian formalism for scalar fields coupled to gravity in a cosmological backeground
A.E. Bernardini and O. B., arXiv:1212.0341 [gr-qc]

7. Probing phase-space noncommutativity through quantum beating, mising information and the thermodynamic limit
A.E. Bernardini and O. B., arXiv:1303.0685 [quant-ph]

8. Zen and the Art of Space-Time Manufacturing
O. B., arXiv:1303.2381 [qr-qc]

The Time Machine Factory, 14-19 October, Turin, Italy

Highlights

- First fully consistent mathematical proof that black hole singularities can be solved by quantum effects in the context of a space with some noncommutative properties, believed to present in unification models of all interactions of Nature. More specifically, it has been shown that the Schwarzschild black hole quantum problem in a space with non-canonical phase-space noncommutative features admits wave functions that are square integrable and whose probability vanishes at the black hole singularity.

The singularity problem and phase-space noncanonical noncommutativity.
Catarina Bastos, O. B., Nuno Costa Dias and João Nuno Prata,
Rapid Comms. Phys. Rev. D82 (2010) 041502

- Rather remarkable proofs that dark matter can be mimicked by an alternative theory of gravity where matter and curvature are coupled non-minimally and that dark energy can be accounted.

Mimicking dark matter through a non-minimal gravitational coupling with matter.
O. B. and Jorge Páramos, JCAP 1003, 009 (2010)

Accelerated expansion from a non-minimal gravitational coupling to matter.
O. B., Pedro Frazão and Jorge Páramos, Phys. Rev. D81, 104046 (2010)

- The solution to the Pioneer Anomaly Problem!
  F. Francisco, O. Bertolami, P. Gil and J. Páramos, Phys. Lett. B711, 337-347 (2012)

Some Activities

Determination of scientific objectives and design of space missions

- Opportunities for fundamental physics research through space missions (ESA)
- Galileo Science Advisory Committee (2008-2012)
- Advanced Gravity Package (Jupiter Ganymede Explorer) Scientific Advisory Group
- OUTSS & Euclid & QUEST-Satellite international teams
- Scientific objectives: Solar system gravitational map, Kuiper belt mass profile, scale dependent gravity and measure of the Eddington parameter γ

Thermal analysis of spacecraft

- Development of a general methodology to analyse thermal effects in spacecraft:
  - simplicity, full analytical computation and straightforward sensitivity analysis
  - refining of geometrical and material modelling
  - inclusion of reflections using analytical methods (*e.g.* Phong shading)
- Application to the Pioneer (Phys. Rev. D 2008, Space Sci. Rev. 2010, Phys. Lett. 2012)
- Modelling of the Cassini spacecraft and analysis of the Flyby Anomaly

Generalized *f(R)* theories

$$S = \int \left[\frac{1}{2k} f_1(R) + (1 + \lambda f_2(R)) \mathcal{L}_{\mathcal{M}} \right] \sqrt{-g} d^4x$$

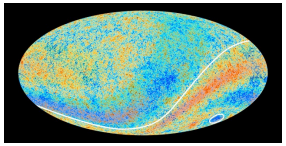
- Non-minimal coupling curvature/matter (O.B. *et al.*, Phys. Rev. D 2007)
- Breaking of the Equivalence Principle
- Equivalence with multi-scalar-tensor theories
- Astrophysical constraints and PPN parameters
- Dynamic mimicking of "dark matter","dark energy" and a cosmological constant
- Early universe cosmology: inflation and reheating

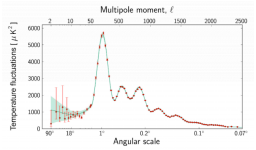
Dark Matter and Dark Energy

- Effects due to dark components at astrophysical scales (O.B. *et al.*, Phy. Lett. B. 2007)
- Interaction between dark matter/energy and Standard Model fields
- Interaction between Dark Matter and Dark Energy
- Alternative models to explain Dark Matter and Dark Energy
- The Generalized Chaplygin Gas model

Generalized Chaplygin Gas model

- Unified model for Dark Matter and Dark Energy
- 12 peer-reviewed publications, 1400+ citations (inc. TopCite700+ Bento, O.B., Sen, 2002)





Generalized d-brane

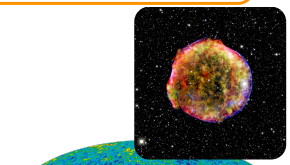
$$\mathcal{L} = -A^{\frac{1}{1+\alpha}}\left(1-(g^{\mu\nu}\Theta_{,\mu}\Theta_{,\nu})^{\frac{\alpha+1}{2\alpha}}\right)^{\frac{\alpha}{\alpha+1}}$$

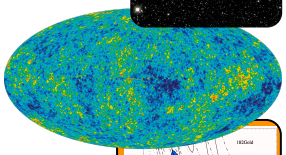
$\alpha = 1$: d-brane

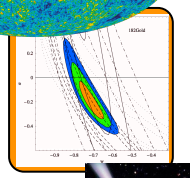
Generalized Chaplygin gas

$$p = -\frac{A}{\rho^{\alpha}}$$

$\alpha = 1$: Chaplygin gas







$p \ll \rho$ Dust

$p = \alpha\rho$ $\alpha = 1$ stiff matter

$p = -\rho$ De Sitter

- SNe, CMBR, BAO, Structure Formation: $\alpha \leq 0.2$

Phase Space Noncommutativity

- NC Phase-Space Extension of Quantum Mechanics (configuration&momentum space)
- Quantitative/qualitative effects in Quantum Mechanics (quantum beat, entanglement, ...)
- Implications for Quantum Cosmology and black hole physics (singularity)*
- Implications on astrophysical scales

Gravitational Quantum Well (ultra-cold neutrons bound states)

- Implications for the Equivalence Principle
- Generic noncommutative phase space effects
- Unparticle and ungravity type corrections

Further Objectives

- Multiverse (classical and quantum) effects on our universe
- Breaking of symmetries and of the underlying principles of General Relativity
- Astrophysical & cosmological implications of alternative gravity theories

2013 and beyond

Research

- Focus on issues relevant for the Euclid & GAIA missions
- Spacecraft thermal modelling and Flyby anomalies
- Phase Space Noncommutative Geometry: quantum mechanics, quantum cosmology, black hole physics & field theory
- Cosmology: dark energy, dark matter and their interaction (gamma-ray bursts, cosmic shear, ...)
- Alternative theories of gravity with non-minimal coupling between curvature and matter: disks of accretion, dynamics of clusters, PPN parameters, ...

Books

- Handbook of Space-Time (Springer Verlag 2013)
  The Experimental Status of Special and General Relativity
  O. B. & Jorge Páramos arXiv:1212.2177

- Extensions to General Relativity (Springer Verlag 2014)
  O. B. & Jorge Páramos

Funding

Ph. D grants, *Post-Docs* and a 5-year position

FCT

Fundação para a Ciência e a Tecnologia

Research

- Funding of several research projects till 2009
- No funding at all in 2010!
- Funded project* (April 2011- April 2014)
- New evaluation rules for research centers require new strategies and a new organizational approaches

*Towards a unified cosmological description 67.4 KEuros