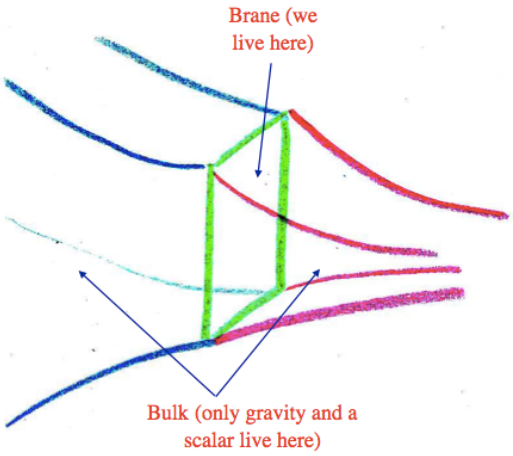
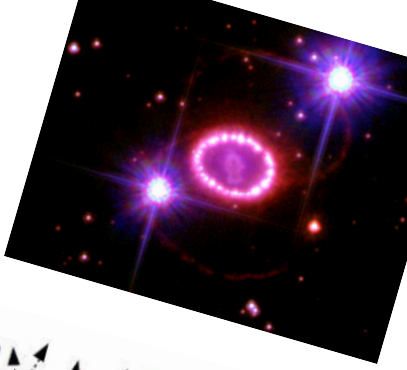
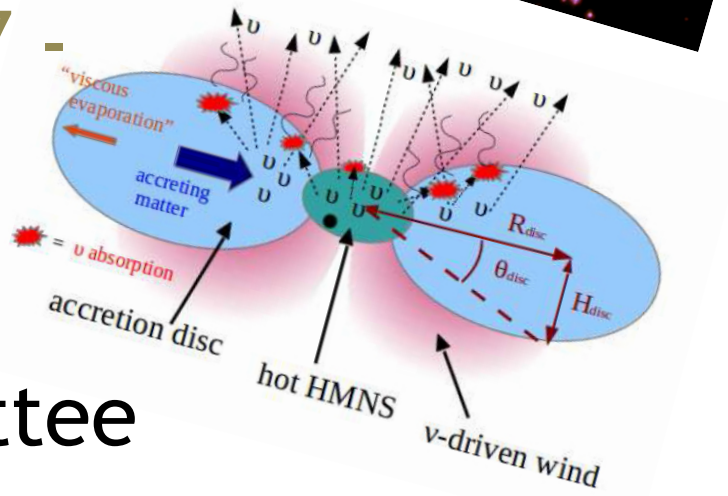
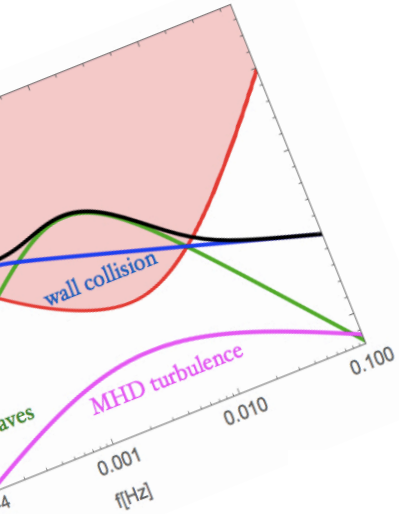


Theory Group

- 2013 to 2017 -



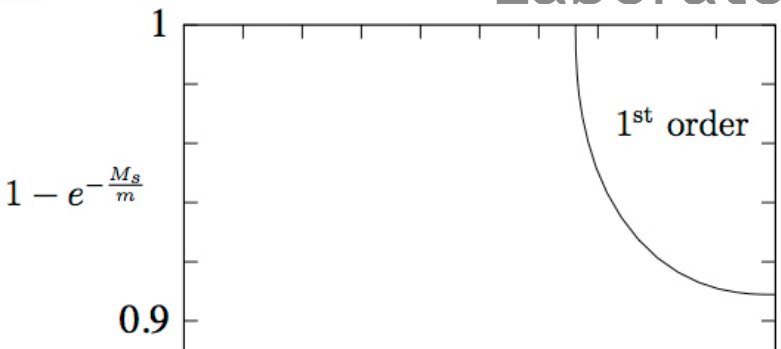




HCERES Committee

Maria Cristina Volpe

Astroparticle and Cosmology Laboratory



- The group composition
- Internal organisation
- Research activity
- Teaching, Supervision, Boards and international visibility
- Public outreach
- The Future

Theory group members

- **15 permanent researchers :**

  P7 University (enseignants-chercheurs) : Eric Huguet (MdC), Jihad Mourad (Pr),Francesco Nitti (MdC), Jacques Renaud (Pr), Julien Serreau (MdC), Danièle Steer (Pr), Jean-Pierre Gazeau (émérite)

  Chercheurs CNRS (02/Theory committee) : Chiara Caprini (CR), Nathalie Deruelle (DR), Elias Kiritsis (DR), Marc Lachièze-Rey (émérite), David Langlois (DR), Dimitry Semikoz (DR), Vincent Vennin (CR), Maria Cristina Volpe (DR)

✓ **HDR :** 11 permanents over 13 have the « Habilitation à Diriger les Recherches » (HDR) - C. Caprini in 2018, V. Vennin just hired.

- **Permanent :**

  Arrivals : - Vincent Vennin (CR), CNRS section 02, arrived in 2017
  - Chiara Caprini (CR), from IPhT Saclay, arrived in 2016
  -Maria Cristina Volpe (DR), from IPN Orsay, arrived in 2012

  Departures : - Pierre Binetruy (DR), died in 2017
  - J.P. Gazeau (Pr) et M. Lachièze-Rey (DR), retired

Theory group members

- **10 PhD students :**

  Amélie Chatelain (2015-18, C. Volpe, ENS)
  Jewel Ghosh (2016-19, F. Nitti- E. Kiritsis, ERC)
  Felix Julié (2015-18, STEP-UP, N. Deruelle)
  Fréderic Lamy (2015-18, STEP-UP, P. Binetruy-D. Langlois)
  Gabriel Moreau (2016-2019, Polytechnique, J. Serreau)
  Jan Maelger (2016-19, co-direction J. Serreau, Polytechnique)
  Tanguy Marchand (2015-18, co-direction D. Langlois, IAP)
  Andrea Gallo Rosso (2015-18, co-direction C. Volpe, GSSI L'Aquila U.)
  Leandro Silva Pimenta (2015-18, E. Kiritsis-F. Nitti, STEP-UP)
  Hongoung Li (2016-19, K. Noui-délégation CNRS, U. Tours)

- **6 postdocs :**

  Sajad Abbar (CDD IN2P3), Davide Forcella (ERC), Andrei Belokogne (U. Corse), Marcela Cardenas (Chile), Nelson Merino (Chile), Lukas Witkowski (ERC)

- **Associates :** H. Bergeron (ISMO Orsay), K. Noui (Tours U.), U. Reinosa (Polytechnique), B. Van Tent (LPT Orsay), F. Vernizzi (IPhT Saclay).

Internal organisation

Theory group leader from 2014 to 2017

M. C. Volpe (head of the group), D. Steer (deputy)

D. Semikoz since 1/11/2017 and E. Huguet (deputy), D. Langlois in 2013 with Steer (deputy)

Group scientific life :

- Seminars every Tuesday at 14:00 – organizer : J. Serreau
  planning on the group and APC web sites, coffee and cookies
- Theory Journal Club every Friday between 12:30 and 13:30, organized by the postdocs and N. Deruelle

Several meetings per year , depending on the information to give (budget, changes at the laboratory/IN2P3 or CNRS, calls, arrivals….), decisions to take collectively (CNRS candidats, invited professors, positions at CNRS/University, organisation, …)

Common lunches on Tuesdays (hall de convivialité)

Research activity

We work on key open questions at the forefront of research in

- **fundamental interactions :** gravity, strong and weak interactions
- **cosmology**
- **quantum field theory and string theory**
- **astro-particles : cosmis rays, photons and neutrinos**

As theoreticians our research is focused on fundamental questions, development of computational tools,model building, understanding experimental observations, up to proposing new experiments…

Tight links with the experimental groups of high energy astrophysics, neutrino, cosmology and gravitation : i) strong implication of some of the members in/for experiments - Planck, LSST, EUCLID, LISA, CTA, JEM-EUSO, Virgo, JUNO ; ii) common PhD thesis; iii) common meetings at APC, or elsewhere (ex. GDR).

Highlights : Gravitation

- Deruelle, Kiritsis, Langlois, Lachièze-Rey, Mourad, Steer

Our goals :

To conceive theories of modified gravity, that are mathematically consistent (ex. free of instabilities) and in agreement with tests of general relativity, in order to explain the current accelerated expansion of the Universe.

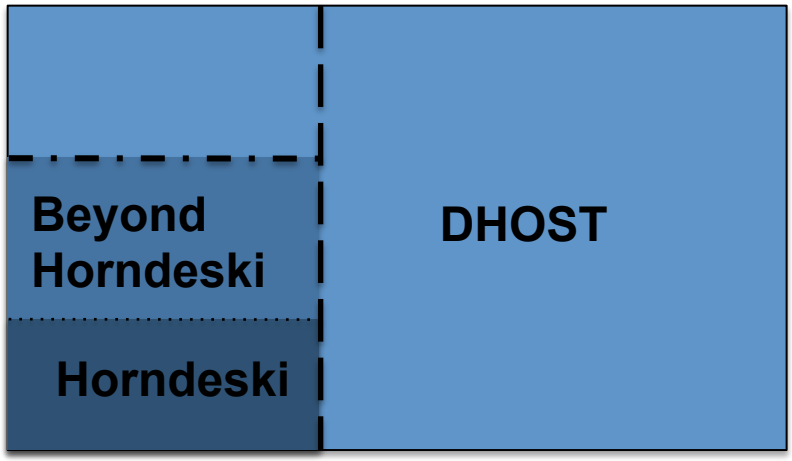
The group investigates gravity models with higher derivatives (f(R), «Galileon» and «generalised Galileon » models), massive gravity.

« Two-body problem in scalar-tensor theories as a deformation of General Relativity : an effective two-body problem. »

- Felix Julié et Nathalie Deruelle, arXiv :1703.05360

Highlights : Gravitation

"DHOST (Degenerate Higher-Order Scalar-Tensor) theories: a new class of scalar-tensor theories, which contain a single scalar degree of freedom and avoid the Ostrogradsky instability."



Langlois et Noui, JCAP 1602 (2016) 034, 1510.06930

see also C.Deffayet, G.Esposito-Farese, D. Steer, Phys.Rev. D92 (2015) 084013.

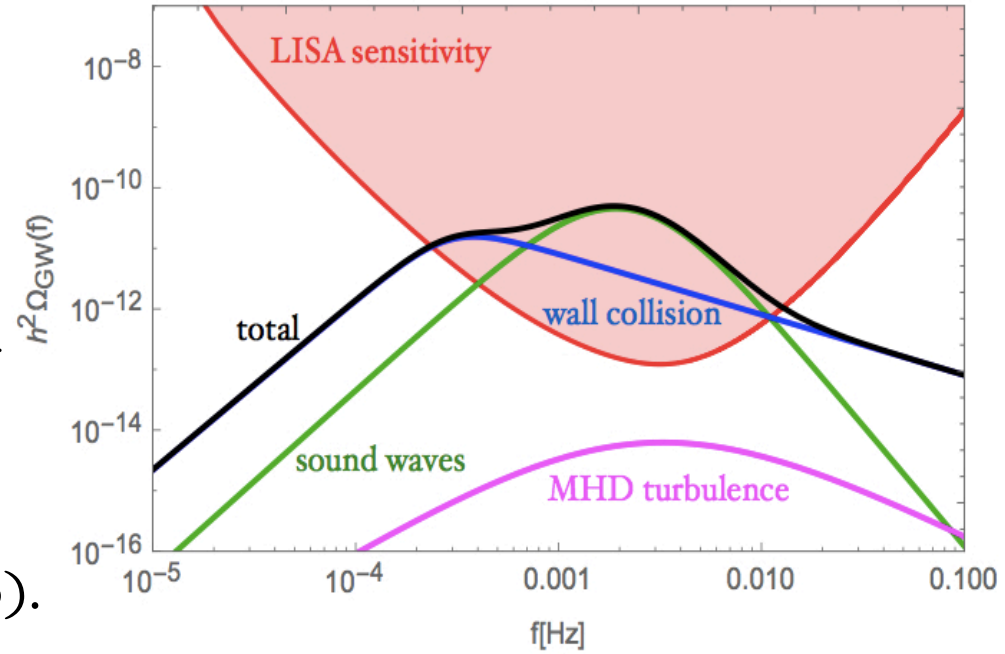
Highlights : Gravitation

- **Gravitational waves,** with LIGO/VIRGO and with LISA.

We investigate how gravitational waves can be used to test cosmology : Primordial Universe (phase transitions) and late time Universe (cosmological parameters).

«Physics potential of LISA interferometer to detect the signal from a first-order phase transition in the early Universe and to test beyond the Standard Model physics.»

- Caprini et al, JCAP 1604 (2016).



Highlights : Cosmology

- (Binétruy), Deruelle, Kiritsis, Langlois, Steer

Our goals :
We work on key open questions in cosmology, including inflation and cosmological perturbations, dark energy, topological defects.

- **Inflation :** « Introduction of a new framework useful to classify models of inflation based on universality classes (gauge/gravity duality) »
  - Binétruy, Kiritsis, Pieroni, al, JCAP 1504 (2015) 03.

- **Dark energy :**
  « New approach to dark energy, that includes the majority of existing models and allows to explore systematically new regions of the parameters' space describing models of dark energy. »
  - Gleyzes, Langlois, Piazza, Vernizzi, JCAP 1308 (2013) 025.

Highlights : Quantum field theory

- Huguet, Kiritsis, Mourad, Nitti, Renaud, Serreau

We work at different aspects of quantum field theory -- curved space-time, conformal methods, higher spin theories, quantization methods, strong interaction and confinement.

- « FLRW subspaces as manifolds of R^6 : restriction to the Klein-Gordon operator »
  - Arias Zapata, Belokogne, Huguet, Queva, Renaud, JMP 58 (2017) 113503.

- **Quantization methods**

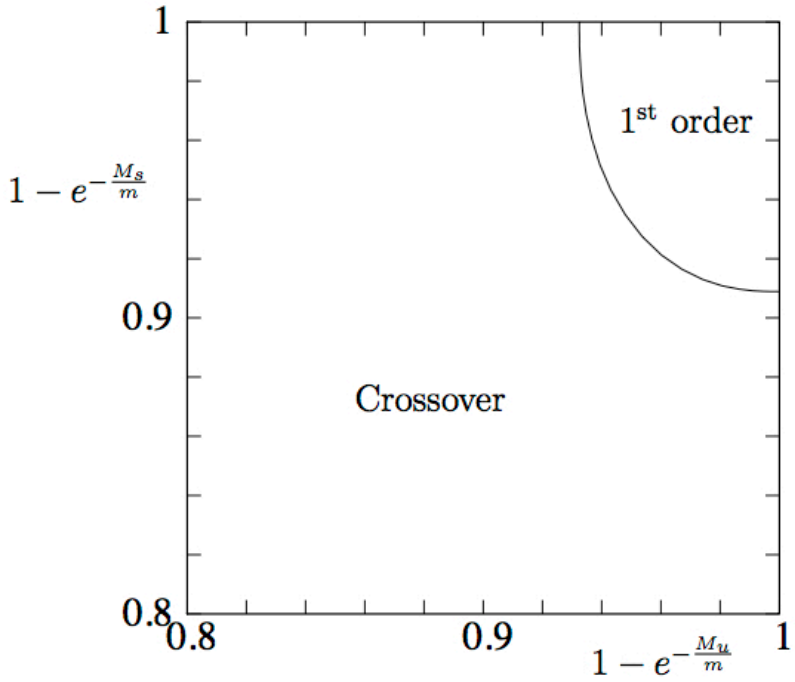
We propose a new approach to the vacuum Bianchi IX model in analogy with molecular physics. The quantization method generates a repulsive potential that resolves the classical singularity.

- Bergeron, Czuchry, Gazeau, Małkiewicz, Piechocki, PRD,92, 061302(R).

Highlights : Quantum field theory

Strong interaction and confinement

« Perturbative description of the phase diagram of QCD with heavy quarks a nonzero temperature and chemical potential in the context of a massive gluon approach. We obtain a qualitative (and, for some quantities, even quantitative) agreement with known lattice results for the deconfinement phase transition. »



Columbia plot

$M_C/T_C = 8.07$

$(M_C/T_C)_{lattice} = 8.32(5)$

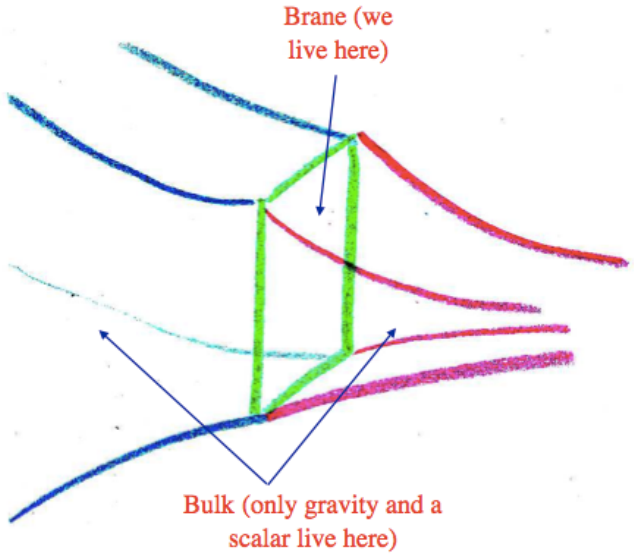
- Reinosa, Serreau, Tissier, PRD92 (2015) 0250.

Highlights : Quantum field theory

Our goals :

The duality or « holography » is the conjecture of the equivalence between quantum field theory (QFT) on one hand and a theory of gravitation in more than 4 dimensions on the other. It furnishes a computational method that allows to replace a strong correlated QFT with a classical gravity theory.

We work both on formal aspects of gauge/gravity duality and on applications to QCD, condensed matter and cosmology.



« A mechanism is proposed that can hide the cosmological constant in the holographic/ braneworld context. »

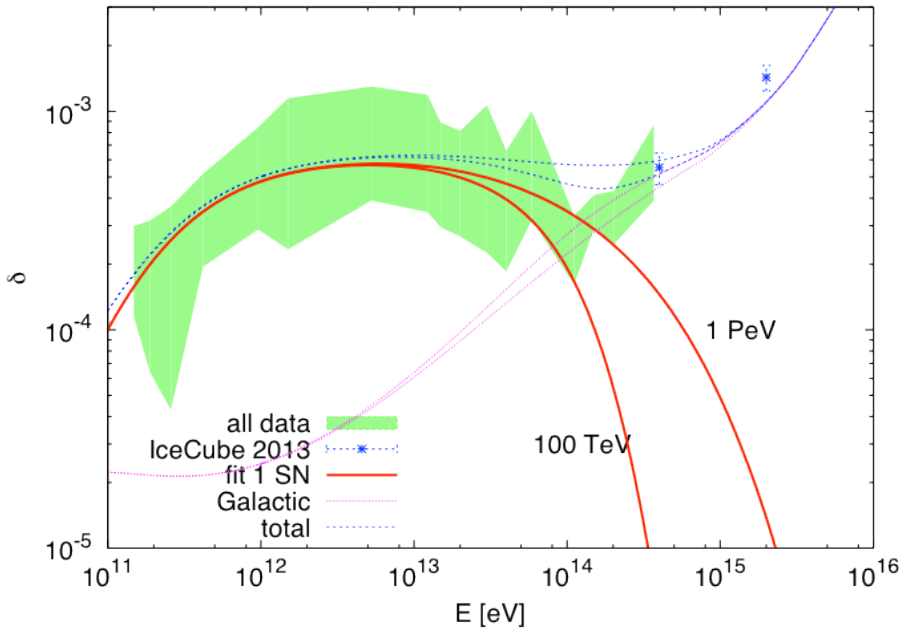
- Charmousis, Kiritsis, Nitti,1704.05075 .

Highlights : Astro-particle physics

- Semikoz

Our goals :

We develop theoretical models to explain the spectra, the composition and the source of cosmic rays, as well as their propagation in the intergalactic medium. We work at the explanation of the origin of neutrinos observed in IceCube.



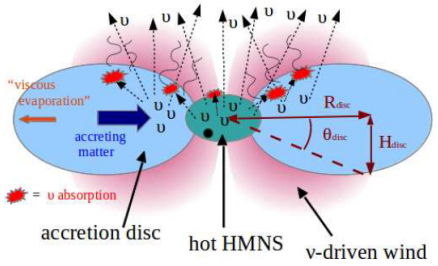
❑ Cosmic rays :

« A two million year old supernova can explain the spectra of cosmic ray protons, antiprotons and positrons as well as the dipole asymmetry in the cosmic rays spectra, unexplained since the '80s. »

Kachelriess, Neronov and Semikoz, PRL 115, 181103 (2015), Astrophys. J. 809 (2015) L23.

Highlights : Neutrino physics

- Volpe

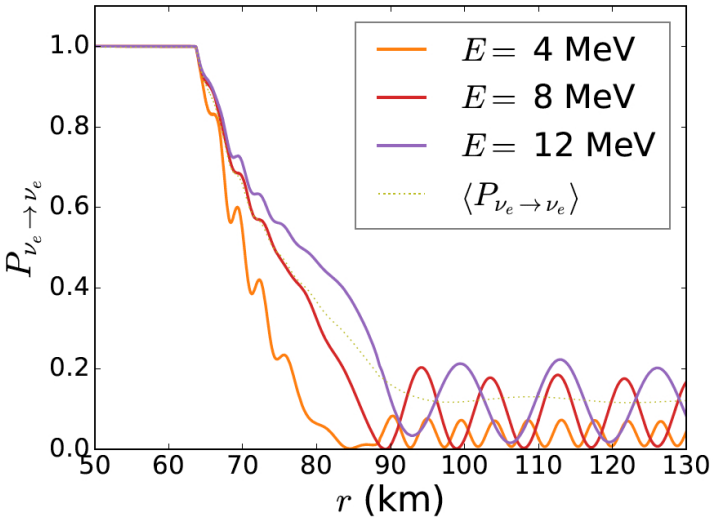


Our goals :

We contribute: - to the understanding of novel neutrino conversion phenomena in astrophysical environments -supernovae, binary neutron star mergers (BNS)-, thei impact on the SN dynamcs and r-process nucleosynthesis ; - to exploring the links between neutrinos and many-body systems such as condensed matter and nuclei ; -to making predictions for experiments.

« We unravel conversion mechanisms that can influence heavy elements nucleosynthesis in neutrino-driven winds in binary neutron star mergers. »

- Chatelain, Volpe, arXiv : 1710.11518



Teaching and supervision

- **Strong involvement in teaching – almost half of the group is University personnel (enseignants-chercheurs) and CNRS researchers also teach – all levels as well as international schools**

- **17 PhD Thesis supervised during 2012-2017 :**

  A. Chatelain (Neutrinos), J. Ben Achour (Gravitation, QFT), F. Julié (Gravitation), F. Gautier (QFT), J. Ghosh (Holographie), M. Guilleux (QFT), A. Helou (Gravitation), J. Maelger (QFT), F. Lamy (Gravitation), W. Li (Holographie), T. Marchand (Gravitation), M. Pieroni (Cosmologie), L. Silva Pimenta (Holographie), A. Gallo Rosso (Neutrinos), D. Väänänen (Neutrinos), A. Tresmontant (QFT), Georges Zahariade (Gravitation).

- **13 postdocs supervised during 2012-2017 :** S. Abbar, A. Belokogne, M. Cardenas, V. Domcke, D.H. Kumar, E. Joung, M. Lilley, P. Malkiewicz, S. Mizuno, A. Naruko, N. Merino, R. Saito, L. Witkowski.

- Many students for training periods (L3, M1, M2) of 2-6 months every year.

Publications (2012-2017)

- **Number of publications in refereed journals : 169**
- **Proceedings : 39**
- **Books : 3**

  N. Deruelle et J.P. Uzan, “Théories de la Relativité”, Belin (2014)

  S.T. Ali, J.P. Antoine and J.P. Gazeau, "Coherent states, wavelets and their generalizations", Springer (2013)

  D. Langlois, “Relativité générale: des fondements géométriques aux applications astrophysiques”, Vuibert (2013)

- **Lecture notes : 11**
- **Editors of Proceedings' books : 2**
- **Editors of Focus Issues : 2** - Journ. of Phys. G (2014), (2017)

International visibility

- **Invited talks at international conferences and workshops: 123**
- **Organisations of conferences, workshops : 22**

  8 at APC, 5 in Greece, 1 in Italy, 1 in Iceland, 1 in Japan, 1 in Korea, 1 in Cyprus, 1 in Belgium, 1 in Bresil, 1 in the US and 2 EPS conferences.

- **Distinctions :**

  International committee of the Marcel Grossmann meetings, 'nominating committee' of the Scie GRG, chairman (2008-2014) and Honorary member (2015-) of the Standing Committee of the International Colloquium on Group Theoretical Methods in Physics (ICGTMP)

Scientific responsibilities

- **Boards, convenerships**

  Conveners du GDR «Neutrinos», President of «Gravitational waves»

  Committees : GRAM National Program, Labex P2IO, CNRS section 02 (2011-2012), CNU (2012-), nominated members of the CNRS Scientific Council (P. Binetruy, N. Deruelle)

  International committees : European Physical Society High Energy Physics Board (since 2011). Deputy Chair of EPS HEPP (2015-2017), coordinator of the LISA cosmology working grou

  "Sociétés savantes" : International committee of the Marcel Grossmann meetings, 'nominating committee' of the Scie GRG, chairman (2008-2014) and Honorary member (2015-) of the Standing Committee of the International Colloquium on Group Theoretical Methods in Physics(ICGTMP)

- **Grants**

  CT IN2P3 (2012-2016), PICS Paris-Kyoto (2013-2016), PEPS Physique Théorique et Interface (2013), Défi InPhyNiTi (2014), GPhys (2014-2016), PICS Uruguay (2017-2020), ERC Advanced Grant (2016-2020).

Scientific responsibilities

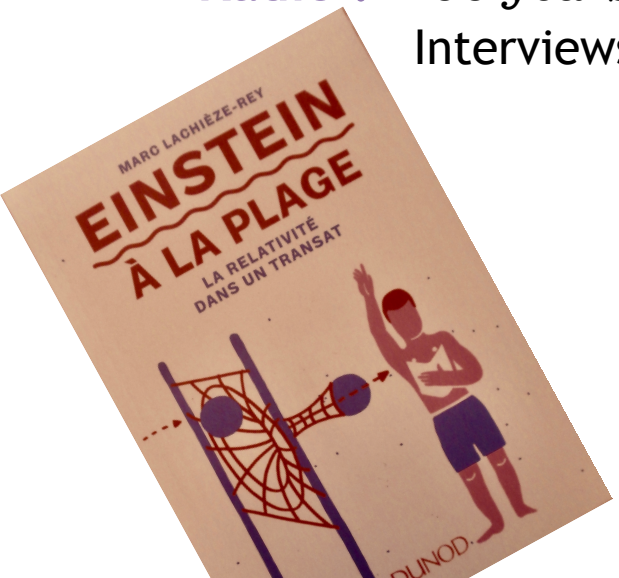
- **Referees for funding agencies and grants:** Italian Ministry for Education University and Research (2012, 2013, 2014) and Roumanian Ministry (2012), FNRS (2012-2017), COFUND Marie Curie Fellowships (2012-2014), Marie Curie pannels (2012-2017), ERC grants (2014, 2016), Fondo Nacional de Desarrollo Científico y Tecnológico (Fondecyt, Chili, since 2009), European Science Foundation College of Expert Reviewers, Natural Sciences and Engineering Research Council of Canada (NSERC), Austrian Science Fund, Czech Science Foundation, ERC committee ``Sciences de l'Univers" for the ERC Consolidator Grants (2012, 2014, 2016), INFN Theory commitee for Astroparticle (CSN4, 2013), National Science Foundation (NSF, USA), Department Of Energy (DOE, USA), Research Foundation Flanders (FWO), Research Council of KU Leuven (Leuven U.), Russian Science Foundation, Russian Foundation for Research, Netherlands Organisation for Scientific Research, Royal Society (UK), STFC (UK), COST (EU), Cyprus Institute, Polish National Science Center, Levehume trust (UK), American-Israeli binational Foundation, Institut Universitaire de France, Israel Science Foundation.
- **Editorial Boards :** JCAP (since 2009), EPL (since 2016), Journ. Phys. G (2008-2017), Journal of Physics A: Math. and Theoretical, Classical and Quantum Gravity (since 2011), International Journal of Modern Physics (since 2010), European Physical Journal C (since 2014).

Public outreach

Actions

- ✓ MOOC Gravity and MOOC "Histoire des sciences »
- ✓ **Articles : 21, Conferences : 14**
- ✓ **Multimedia lectures :** Lectures in Astroparticle physics for Master-2 students with APC virtual Institute of Astroparticle Physics (2015, 2016)
- ✓ **Primary schools :**

  «*Comment "meurent" les supernovae ?*», (CM2, 2017); «*Comment vivent les étoiles ?*», (CM1, 2016) ; «*La petite énigme des ν solaires*», (CE2, 2015).
- ✓ **Radio :** "100 years of General Relativity".
  Interviews at RFI, France Culture, France Inter.



The future

In the coming years we will follow axes that we have identified or that have emerged from our works, or stimulated by observations.

- **Astro-particle :** galactic/extra-galactic transition, cosmic rays anisotropies, origin(s) of neutrinos seen in IceCube, ν in supernovae and binary neutron star mergers, flavor evolution mechanisms, impact on observations

- **Cosmology :** effective theories for dark energy, inflation

- **Gravitation : :** Horndeski et beyond, DHOST theories, quantum gravity, gravitational waves

- **Quantum field theory :** renormalisation in de Sitter space, confinement, gauge/gravity duality and strong interactions, conformal methods

AFOM analysis

- **Weaknesses** (aka SWOT = Strengths, Weaknesses, Opportunities, Threats)

❖ the very small number of young researchers (1 is less than 40)

- **Threats**

❖ The age pyramid : Researchers around 40/above 47 = 0.38.

❖ The allocated budget (SBNA) for about 30 researchers

40850 euros (2014), 43300 euros (2015), 41250 (2016), 40850 (2017)

About 1000-1500 euros per person/year is too low !

❖ Too many administrative tasks (data bases, complicated procedures to hire students and postdocs) : need for more administrative support, and a simplification/(automatic when possible) of procedures.

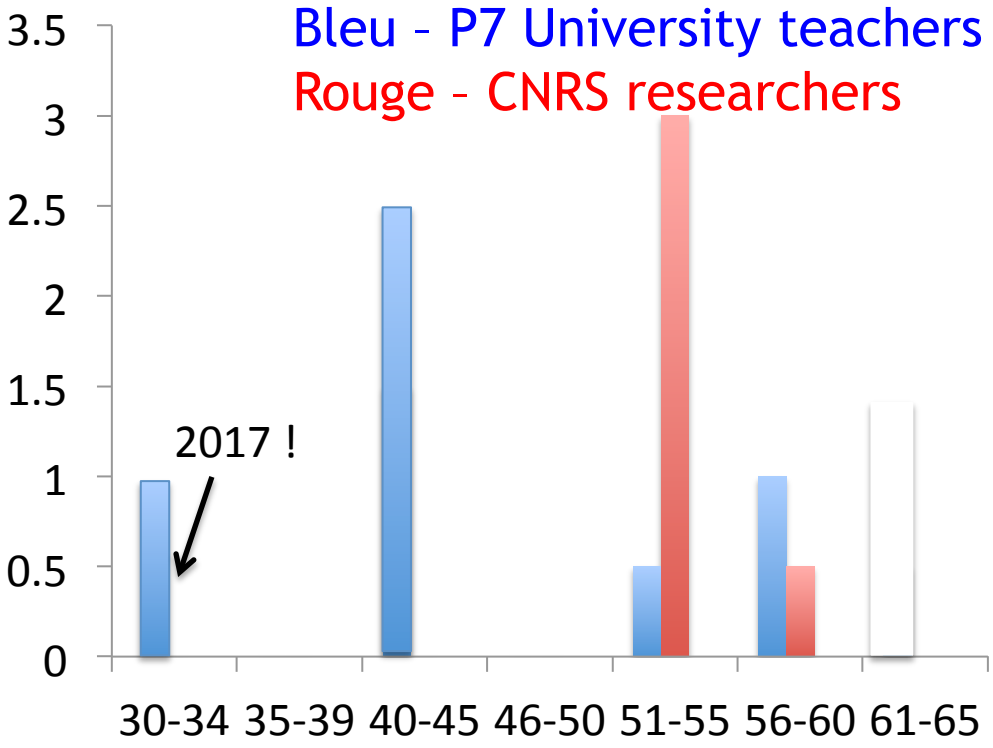
- **Strengths**

❖ internationally reknown experts in these fields and high international visibility

❖ heavily involved in teaching and the supervision of students/postdocs strong connections with the 4 experimental groups in the laboratory

Future of the group

- Departures for retirement: N. Deruelle (DR, 2018), J. Renaud (Pr)



Todayi : Ratio below-and-around «40 »/ »over 47» = 0.54 .
In 3 years, the group will consist of 2.5 University teachers (50% ETP) and 6 CNRS researchers.

Future of the group

There is a real need to hire new people to keep the critical size of the theory group and maintain its international visibility, its role at different levels, i.e. research, teaching, surpervision, and committees.

Our priorities for the near future :

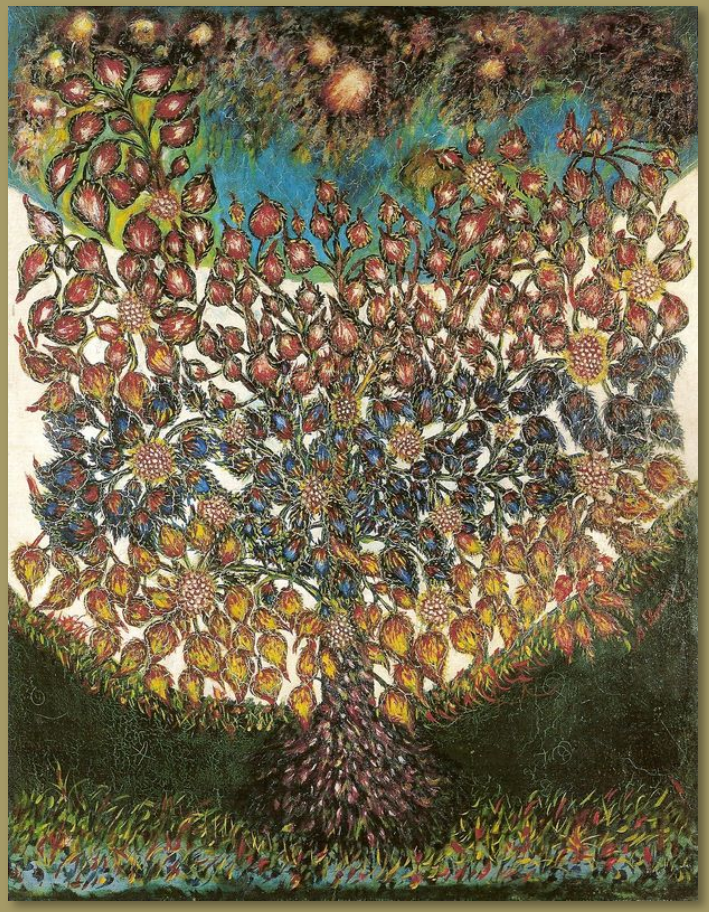
CNRS position :

- CR section 01 : «Theoretical aspects of astroparticles – cosmic rays, neutrinos, gravitational waves »

- University position :

Opening of a Professor position in 2018 (29-34) :

«Theory of fundamental interactions and astroparticles »



Life tree