WORKING GROUP 2

“Relativistic effects”

“Cosmology and Astrophysics Network for Theoretical Advances and Training Actions (CANTATA)”

1st Grant Period Report

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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1. Overview

CANTATA aims at establishing a network of European experts to construct and develop an effective theory of gravity able to describe our Universe at all scales. The second working group (WG2), “Relativistic effects”, is focused relativistic effects capable of discriminating among different pictures of cosmic dynamics and not only. The final goal is to find out observational "smoking guns" phenomena which pointing out whether the modified gravity picture or a possible geometric picture, or new fundamental field is consistent with universe cosmic dynamics at both theoretical and observational level. The aim is to search for some of these possible relativistic effects in observations ranging from cosmology, particle physics and gravitational waves. Consequently the results of this working group have to be combined with the deliverables of WG1 and WG3 to find viable theories of gravity.

In the “kick-off” meeting Prof. David Mota (University of Oslo, Norway) and Prof. Mariafelicia De Laurentis (Goethe University, Frankfurt, Germany and Tomsk State Pedagogical University, Russian Federation) were appointed leader and co-leader of WG2, respectively. During the 1st grant period both have lead the working group participants to achieve the scientific milestones presented in the memorandum of understanding through the suggestion of some specific tasks and the encouragement of networking activities. Furthermore, according to COST policies and the common objectives of CANTATA, WG1 is engaged in supporting, training and promoting early stage researchers, and empowering female scientists. To this aim two specific tasks have been proposed for the 1st grant period and the co-leader has joined the gender lab of the action to obtain relevant feedback for the working group.

2. Members profile

2.I Academic profile

Our members have interest and/or experience in one or more of the following topics:

- Relativistic astrophysics, with particular devotion to the study of compact objects (neutron stars and black holes)
- Numerical simulations,
- Alternative theories of gravity,
- Cosmology (phenomenology)
- Quantum effects and gravity.
- Quantum Cosmology

2.II Anthropological profile

Since the beginning of the WG2 action, there were not many participants, but now it seems to grow sharply. The percentage of researchers based at ITCs has continued increasing during the grant period.

On the other hand, during the first stage of the first grant period, we have noted a decrease of the percentage of female scientists in our WG at the same time that the percentage of participants from ITC countries increased. In particular, at 5 of July of 2016 there were a 3% of female scientists in WG1 against the 21% in the whole network. After interaction with members of the gender lab (being the co-leader part of this lab), the leader and co-leader of WG2 undertake the measure of contacting renowned female scientists based at CANTATA countries to inform them about the existence of the network and its potential beneficial impact. When the WG meeting took place, WG2 had improved their data to a 13.3% of female researchers against the 23.4% of the whole action. It is clear from the first CANTATA meeting in Lisbon, that the presence of women is under-represented. Therefore, one of the aims in this Work Package is to attract more women researchers into this WP. Some statistical data is presented in the table bellow.

Finally, at a first stage of this grant period the WG2 also had slightly less participation of ECIs than other working groups. This potential imbalance, however, has been adjusted naturally due to the normal growth of the action.

45 members (data at 14 Feb. 17)	#	%	% in CANTATA
Students	8	17.7	
ECIs	6	13.3	
Researchers based at ITCs	6	13.3	
Female researchers	6	13.3	

3. Tasks

3.I Research tasks

The main goal by WG2 will be to select relativistic effects that can confirm or rule out Extended Theories of Gravity (ETG). For this objective to be reached it is necessary a strict collaboration with WG1 and consequently WG3. The goals will be the following:

T1. N-body code that simulates nonlinear structure formation within Alternative theories of gravity
T2. Hydrodynamic code that simulates galaxy and cluster formation taking into account feedback mechanism from baryons (explosions of supernovae, cooling, etc).
T3. Comparing the theoretical results derived from ETG with the rotation curves of both low and high surface brightness galaxies, and with the velocity dispersion profiles in elliptical galaxies.
T4. Testing suitable ETG-models that inducing massive graviton states in the post-Minkowskian limit, and compare GW observations and detection by VIRGO, LIGO detectors, combined with Solar-System tests, extragalactic and cosmological observations to constrain such models (or rule out them in favour of standard GR) [In collaboration WG1]
T5. Testing ETG at the galactic clusters scales, examining the mass profiles reconstructed from the gas component X-ray temperature and the hydrostatic equilibrium hypothesis.
T6. To investigate stellar structure in the framework of ETGs and to derive self-consistent analytical and numerical solutions and build up realistic star models.
T7. To investigate kinetic and diffusion equation models in the context of stellar dynamics (among the many problems: instability issues, critical speed of rotation, symmetry breaking problems)) [In collaboration WG3]

3.II Networking tasks

WG2 have also additional tasks to benefit the participants through networking:

- Within the proposed program, we foresee to strengthen and enlarge the already existing collaborations and to give rise to a pilot project capable of matching theoretical and experimental expertise and competences
- The main goal is to support young researchers partecipating to the research program and any form of synergy able to reinforce an activity that is already qualified and of large international interest.
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4. Scientific topics highlighted in the WG meeting

The WG meeting structure was chosen to strengthen scientific discussion between the participants. After a 5 minutes welcome to the session by the leader and a 10 minutes introduction to the WG presented by the co-leader, there were 3 25 minutes talks where some selected participants introduced some hot topics emphasizing open questions in the field. Later, there was a discussion of 1 hour and 15 minutes in which all the participants were able to ask the speakers, present their opinion on related topics, and/or present additional open question.

4.I Constraining the spatial variations of the fine structure constant using clusters of galaxies.

[*Presented by Dr Ivan De Martino*]

We propose an improved methodology to constrain spatial variations of the fine structure constant using clusters of galaxies. We use the *Planck* 2013 data to measure the thermal Sunyaev-Zeldovich effect at the location of 618 X-ray selected clusters. We then use a Monte Carlo Markov Chain algorithm to obtain the temperature of the Cosmic Microwave Background at the location of each galaxy cluster. When fitting three different phenomenological parameterizations allowing for monopole and dipole amplitudes in the value of the fine structure constant we improve the results of earlier analysis involving clusters and the CMB power spectrum, and we also found that the best-fit direction of a hypothetical dipole is compatible with the direction of other known anomalies. Although the constraining power of our current datasets do not allow us to test the indications of a fine-structure constant dipole obtained though high-resolution optical/UV spectroscopy, our results do highlight that clusters of galaxies will be a very powerful tool to probe fundamental physics at low redshift.

4.II Fundamental Fields in Cosmology

[*Presented by Dr. Lavinia Heisenberg*]

After summarising the theoretical and observational challenges that we are facing in the standard model of cosmology, I will then introduce different ideas proposed in the literature to tackle these problems within modified gravity theories, among which I will pay special attention to massive gravity, scalar-tensor theories and generalised Proca theories on curved space-time.

4.III Domain Walls and Dark Energy

[*Presented by Dr Lara Sousa*]
In this talk, I review and rule out the possible connections between domain walls and dark energy. Domain wall networks may provide a negative average pressure --- and thus accelerate the expansion of the universe --- provided that they are frozen by cosmological expansion (or frustrated). Here, I show that the frustration of the network is not the natural endpoint of the cosmological evolution of a

domain wall network and that it would require the existence of an additional cosmological component to deccelerate the walls. However, since the energy necessary to decelerate the walls is very large, such a domain wall network would have an energy density that is several orders of magnitude smaller than the critical density and cannot, thus, contribute significantly contribute to dark energy. I further review the devaluation scenario that was proposed as a possible solution to the Cosmological Constant Problem. In this scenario, the universe would be separated into different domains with different values of vacuum energy density, separated by a biased domain wall network. As the universe expands, the regions with higher energy density would progressively be suppressed and the universe would end up with a small value of ρ_{vac}. Here, I show that this scenario is also plagued by finetuning problems and, thus, cannot be considered a solution the Cosmological Constant Problem.

4.IV Discussion

The discussion session was particularly prolific and many participants of different institutions took part of the discussion actively. In this report we include some topics of discussion, related with different tasks.

T1:

- How can we differentiate MG from dark energy models?
- Are different gravitational modifications with the same number of (extra) degrees of freedom equivalent?
- What is the proper formulation of varying c theories from the action principle (Lorentz symmetry violation)? In which MG framework can this work most natural?

T2:

- Can we discriminate hybrid metric-Palatini gravity from other MG theories?
- What new tests/telescopes can do to measure dynamical constants/MG effects more precisely?

T3:

- Can MG be a viable alternative to the dark matter problem? (e. g. explaining the bullet cluster)?

T5:

- What are the massive and massless modes of gravitational waves in hybrid metric-Palatini gravity?
- Can we measure the signal from other universes (e.g. through the wormhole) which may show different dynamics of constants than in our universe? How could we measure this (entanglement temperature influencing the cosmic microwave background)?

T5:

- Can MG give some insight into parallel universes evolution? Can this be explored in the LHC for the micro black hole and other particle states (e.g. separate universe problem)?

T6:

- There are self-consistent quantum cosmology scenarios related to MG? In particular, what is the role of the Wheeler–De Witt equation in MG?

5. Deliverables

CANTATA has encouraged scientific discussions leading to new research ideas. Apart of these important contributions, which are not measureable in a direct way, the interaction of members of WG2 and of theses members with those of other WGs has lead to more tangible deliverables that are detailed in this section. It should be noted that, in some cases, the classification of one deliverable as belonging only to one WG would be artificial; therefore, overlapping with the reports of other WGs should be expected in this regards.

5.I Publications

A CANTATA publication is a paper that it is co-authored by at least two authors based at two different CANTATA countries and acknowledges CANTATA for support. In this section, we include CANTATA publications that are oriented towards the accomplishment of the objectives of WG2, although overlapping with other WGs is in some cases completely necessary.

Reports in progress to be published in "General Relativity and Gravitation"

1. M. De Laurentis, I. De Martino, V. Salzano "*Overview on Yukawa potential in alternative theories of gravity*".

Articles

1. I De Martino, M. De Laurentis, *"On the universality of MOG weak field approximation at galaxy cluster scale"* PLB, 770, (2017), 440D

2. S. Capozziello, M. De Laurentis S. Nojiri, S. D. Odintsov, " *Evolution of gravitons in accelerating cosmologies: The case of extended gravity",* Physical Review D 95, (2017) 083524
3. I. de Martino, C. J. A. P. Martins, H. Ebeling, D. Kocevski "*Constraining spatial variations of the fine structure constant using clusters of galaxies and Planck data*", Phys. Rev. D 94 (2016) 083008.
4. R. Garattini, M. De Laurentis, *"The Cosmological Constant as an Eigenvalue of the Hamiltonian constraint in a Varying Speed of Light theory"* , Fortschr. Phys. 65, (2017) 13
5. M. De Laurentis, O. Porth, L. Bovard, B. Ahmedov, A. Abdujabbarov "*Constraining alternative theories of gravity using GW150914 and GW151226*", Phys. Rev. D 94 (2016) 124038
6. C. Goddi, H. Falcke, M. Kramer, L. Rezzolla, C. Brinkerink, T. Bronzwaer, R. Deane, M. De Laurentis et al. *"BlackHoleCam: fundamental physics of the Galactic center"*, Int. J. Mod. Phys. D 26, (2017) 1730001
7. S. Capozziello, M. De Laurentis, K. F. Dialektopoulos, "*Noether Symmetries in Gauss-Bonnet-teleparallel cosmology*", The European Physical Journal C 76, (2016) 629
8. Y.F. Cai, S. Capozziello, M. De Laurentis, M. Saridakis *"f(T) teleparallel gravity and cosmology"*, Reports on Progress in Physics 79, (2016), 10, 106901
9. G. Basini,S. Capoziello, M. De Laurentis, *"Gravitational Massive Modes from Extended Gravity"*, Journal of Geometric Methods in Modern Physics, 13, (2016), 03, 1650034

10. S. Capozziello, M. De Laurentis, R. Farinelli, S.D. Odintsov, *"Mass-Radius relation for neutron stars in f(R) gravity"*, Physical Review D 93, (2016), 2, 023501

11. S. Capozziello, M. De Laurentis, *"Stellar structures in Extended Gravity"*, Nuovo Cim. C38, (2016), 5, 156
12. S. Capozziello, M. De Laurentis, "*Metric and connections in theories of gravity. The role of equivalence principle"*, Int.J.Geom.Meth.Mod.Phys. 13, (2016), 08, 1640007

Preprints

1. F. Tamburini, M. De Laurentis, I. Licata "*Radiation from charged particles due to explicit symmetry breaking in a gravitational field*", arXiv:1702.04096 [gr-qc].
2. F. Tamburini, M. De Laurentis, I. Licata, B. Thide *"Twisted soft photon hair implants on Black Holes"* arXiv:1702.04094

5.III Short term scientific missions (STSMs)

5.IV Outreach

- CANTATA video, http://cantata-cost.eu/multimedia/ by Prado Martin-Moruno, Diego Saez-Goméz, José Alberto Cembranos, Lavinia Heisenberg, Matteo Martinelli, Bridget Falck, Jackson Levi Said, Thomas Tram, Mariafelicia De Laurentis, Vincenzo Salzano. Promotional CANTATA video emphasizing the interconnection of different nodes and the influential role of ECIs within the action.

6. Overview and comments for the next grant period

In summary, during the 1st grant period WG1 has growth rapidly by the addition of new participants from countries that were already included in the initial proposal and participants based at new countries that have joined CANTATA. During this growth, we have actively implemented measures according to COST strategy of promoting excellence and inclusiveness, encouraging the participation of researchers of different genders and affiliations at different stages of their careers. As a result, scientific interactions between researchers interested in formulating an effective theory of gravity able to describe our Universe at different scales have been established and strengthened.

The following concrete deliverables produced during the first grant period have to be emphasized: the beginning of collaborations oriented to produce reports that will be published in General Relativity and Gravitation; the publication of CANTATA papers in international journals, which are papers co-authored by researchers based at two (or more) CANTATA countries acknowledging CANTATA support; CANTATA preprints, which are available online but are not yet published in international journals; short term scientific missions funded by CANTATA to create new collaborations focused on particular hot topics; and, outreach activities acknowledging the network.

In order to improve our results for the next grant period we plan to implement concrete measures to continue encouraging the collaboration between the participants of the WG1 and of these researchers and those from other WGs within the action. Moreover, we plan to strengthen the outreach activity of WG1 to increment the impact of our results in the society.