Scientific curriculum

ALESSANDRO ZUCCOTTI

1. Personal info

- I was born in Messina (Me), Italy, on January 05, 1994
- Nationality: Italian
- Currently living in Pisa (Pi), Italy
- Institutional e-mail: a.zuccotti@studenti.unipi.it
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- Languages: Italian (native), English (Independent level - CEFR level B1 intermediate)
- Available for transfer

2. Qualifications

- **Master degree in Theoretical Physics**
  E. Fermi physics department, University of Pisa
  Final grade: 110/110 **cum Laude**
  Thesis title: "Wormhole solutions in Einstein-Weyl gravity".

- **Bachelor degree in Physics**
  E. Fermi physics department, University of Pisa
  Final grade: 107/110
  Thesis argument: Aharonov-Bohm effect and experimental observation.

- **Scientific high school diploma**
  Liceo Scientifico Archimede, Messina
  Final grade: 97/100

3. Master's degree exams

This is the list of MSc exams included in my study plan, with the respective grade, reported in chronological order. The official exams list provided by University of Pisa is reported in the attached certificates.

- General Relativity | 9 credits | grade: **27/30**
- Theoretical physics 1 | 9 credits | grade: **28/30**
- Quantum chromodynamics | 9 credits | grade: **28/30**

- Structure of matter 2 | 9 credits | grade**: 26/30**
- Statistical analysis of data | 9 credits | grade: **29/30**
- Theoretical physics 2 | 9 credits | grade: **28/30**
- Cosmology A | 6 credits | grade: **27/30**
- Theory of gravitation A | 6 credits | grade: **30 cum Laude**
- Statistical physics | 9 credits | grade: **30/30**
- Final thesis | 45 credits | final grade: **110 cum Laude**

4. Scientific activities

Study interests

My master studies allowed me to explore and got interested in the following topics, which I wish to continue as future research work:

- Quantum field theory and high energy physics
- Standard model
- Quantum chromodynamics
- General relativity
- Extension of general relativity
- Modern cosmology

I focused on some topics related to gravitational theories which converged to my final master thesis publication, whose abstract is reported in the last section.

Description of research activity

My research activity up to now has been focused on modifications of general relativity. In particular, my works deal with **static spherically symmetric solutions** that emerge taking into account **quadratic terms in the curvature**, in the action of gravity.

As shown in previous works, when considering quadratic corrections, various classes of solution appear in addition to the Schwarzschild metric. A new family of black holes, together with other solutions appearing as black holes mimickers for a distant observer, exist. This makes the quadratic theory relevant for research topics like information paradox, black holes thermodynamics and other phenomenological aspects of solutions with high density source.

Moreover, the quadratic action has been largely studied since it appears in many attempts to build a consistent theory of quantum gravity, and quadratic terms are expected to become relevant at high-energy scales.

Nevertheless, even in the case of static spherically symmetric metric, the equations of motion of the theory have not exact solutions, and this makes difficult to extract physical information from the theory.

My work consisted in connecting different regimes of solution in which analytical approximations are known, thanks to powerful **numerical techniques** implemented with Wolfram Mathematica. In this way it is possible to determine the geometric properties of the high curvature regime in function of the gravitational parameters of the low curvature regime (for example, the gravitational potential at large distance).

In my master thesis I studied a particular family of solutions that covers a relevant region of the solution space with positive mass: the **non-symmetric wormhole** family.

The **numerical code** I built allowed me to:

- completely characterize these interesting objects
- show that such solutions could seem similar to Schwarzschild black holes with the same mass
- discover an asymptotic non-flat behaviour of the theory, not present in previous works, that determines peculiar geometrical properties of these wormholes.

My future research studies will continue this work on modifications of general relativity. Together with this I would like to investigate related topics like blackhole thermodynamics, cosmology and quantum gravity, but I am also very interested in any topic concerning quantum field theory and high energy physics.

5. Projects

As part of my Master's thesis work, I implemented a programme with Wolfram Mathematica to **find numerical solutions of non-linear differential equations**. The code allows to:

- integrate a standard Cauchy problem
- give analytical approximation of the solution in certain regimes
- connect the different regimes by solving a "boundary value problem" with the implementation of a shooting method
- find classes of solutions that cannot be studied with a simple numerical integration.

6. Publications and future articles

Ongoing papers

Two papers have been agreed with my supervisor, professor Alfio Bonanno, and the PhD student Samuele Silveravalle, and we are currently working on them.

1. A first article concerning the publication of the static spherically symmetric solution space of the Einstein-Weyl gravity, in which we present an original phase diagram of the theory, in both the case of vacuum solutions and solutions coupled with matter source.
2. A second paper with a further analysis of the original results found in my thesis work, about the non-symmetric wormholes found in Einstein-Weyl gravity.

Master thesis

A. Zuccotti. "Wormhole solutions in Einstein-Weyl gravity". Master thesis. University of Pisa. Published by ETD. (2021)

Abstract:

In this work we are going to study the wormhole solutions of Einstein-Weyl gravity. Such solutions emerge when looking for a static spherically symmetric metric in the vacuum, in the more general context of classical quadratic gravity. Classical quadratic gravity is the theory of gravitation that comes out when including quadratic terms in the curvature in the Einstein-Hilbert action of general relativity. The study of such theory is motivated by the presence of quadratic corrections in almost all the attempts to find a consistent description of quantum gravity. Indeed, it is well known that general relativity can be consistent as a quantum field theory only as a low-energy effective theory. We are not going to discuss the quantum aspects of the quadratic action: instead, we consider what happens to the classical description of the space-time when quadratic corrections are taken into account. In order to do that, we restrict to the simple case of static spherically symmetric space-time in the vacuum. Given these restrictions in general relativity, we have the well-known Schwarzschild solution, i.e. black hole solution. In classical quadratic gravity the Schwarzschild solution is still present, but we can also find many different classes of solutions:
the aim of this thesis is to classify the various solutions families, as well as to characterize a specific family that covers a large part of the solution space, i.e. the wormhole solutions.
We solve the geodesic equation in such solutions which shows the reason why we call them traversable wormholes.
We report all the solution families found in previous works while adding a new subfamily of the generic wormhole solutions.
By numerically solving the equations of motion, we classify the various solution families in a phase diagram of the theory. By using the shooting method for the boundary value problem between spatial infinity and the radius of the wormholes, we find the geometric properties of the wormhole solutions, and in particular we characterize the behaviour of these solutions in function of their gravitational properties at the spatial infinity. Then we use the numerical results to explore the new "copy" of $r > r_0$ that emerges in such wormholes. We report a qualitative analysis of the behavior of the metric in this new patch $r > r_0$, discovering that it has a finite proper volume for $r \to +\infty$ for almost all solutions, due to a strongly non-flat behaviour of the metric that, among the other things, brings a singularity for $r \to +\infty$.
We conclude with a physical discussion about the case of a massive observer that falls into these solutions.

Reference letter are available on request

January 17, 2022