amodio carleo

Postdoktor i evolutionen av primordiala magnetfält

Ref nr: SU FV-4638-25-19
Datum för ansökan: 2026-01-17 12:09

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E-post	amodiocarleo.alt@gmail.com
Kön	Annat

Frågor

1. *Nuvarande sysselsättning (ange huvudsaklig sysselsättning)*
Anställd vid lärosäte utanför Sverige

2. *Högsta examen*
Doktors-/licentiatsexamen

3. *Från vilket land har du din högsta examen?*
Italien

4. *Har du din högsta examen från Stockholms universitet?*
Nej

5. *Ange datum när du tog din doktorsexamen*
2024-03-07

6. *NUVARANDE ANSTÄLLNING. Ange arbetsplats och jobbtitel samt när anställningen påbörjades..*
Postdoctoral Fellow at the National Institute for Astrophysics in Italy (INAF) - Observatory of Cagliari (CA) - Full Time Employment

7. *REFERENSER. Ange namn, telefon och e-post för 2–3 referenspersoner som kan komma att kontaktas.*
Andrea Possenti - andrea.possenti@inaf.it
Delphine Perrodin - delphine.perrodin@inaf.it

8. *SPRÅKKUNSKAPER. Beskriv kort dina språkkunskaper.*
Italian - Mother Tongue
English - B2/C1
French - A2

9. *FORSKNINGSPLAN/PROJEKTPLAN. Bifoga din plan som beskriver det tilltänkta projektet.*
Research_Statement_Nordita_PMF.pdf

10. *DOKTORSEXAMEN ELLER MOTSVARANDE. Ange doktorsexamen med ämne och lärosäte.*
PhD in Astrophysics - University of Salerno & INFN (IT)
Title: Tests of General Relativity from Astrophysical to Cosmological Scales

11. *EXAMENSBEVIS ELLER MOTSVARANDE. Bifoga examensbevis.*
Certificate_PhD_EU_with_Reports.pdf

Eget uppladdat CV

Cover Letter

Amodio Carleo
2025

To Whom It May Concern,

I am writing to apply for a postdoctoral position at Nordita within the COSMOMAG project. I am currently a second-year postdoctoral researcher at the National Institute for Astrophysics (INAF) in Italy, Observatory of Cagliari, where my recent work has focused on pulsar timing and tests of gravity using relativistic binary pulsars. Alongside this activity, my broader research background includes theoretical studies of primordial magnetic fields, early-Universe dynamics, and their cosmological and observational implications, which I am now keen to further develop within the COSMOMAG framework.

My scientific background is particularly well aligned with the end-to-end philosophy of COSMOMAG. During my Master's thesis, completed at the MITP in Mainz (Germany) under the supervision of Prof. Pedro Schwaller, I worked on cosmological first-order phase transitions in a gauge extension of the Standard Model, modeling the resulting stochastic gravitational wave background using CosmoTransitions. Throughout my university years, I was a student at Collegio Ghislieri and IUSS, one of the four Italy's excellence institutes for advanced studies. This afforded me the opportunity to broaden my knowledge and obtain a second level Master in Science and Technology. Among my research activities, I must also highlight a pre-Ph.D. Fellowship at SISSA in Trieste (Italy), during which I focused on computational fluid dynamics and advanced reduced-order methods, under the supervision of Prof. G. Rozza.

During my PhD, in addition to testing gravity models with pulsars, I dealt with primordial magnetic fields from a theoretical perspective, authoring two first-author papers on the survival and amplification of PMFs via conformal-symmetry breaking in extended gravity and electrodynamics frameworks. Through this work, I developed a detailed understanding of PMF generation during inflation and reheating, as well as the role of helicity, spectral constraints, and the physical consistency conditions required for viable magnetogenesis scenarios. These studies naturally motivate the need for controlled numerical experiments to test theoretical assumptions. Therefore, I have gained hands-on experience with some relevant numerical tools, such as Pencil Code, CosmoGW and RM-Tools. Moreover, I am also an active member of the European Pulsar Timing Array (EPTA), SKA and LISA, which places me in a strong position to explore synergies between primordial magnetic fields and stochastic gravitational-wave backgrounds.

A central aspect of my planned contribution to COSMOMAG is the characterization of physically admissible initial conditions for primordial magnetic fields sourced at the end of inflation or during cosmological phase transitions. Treating these early-Universe processes as a "fluid box" problem, I aim to connect microscopic magnetogenesis mechanisms to macroscopic MHD initial conditions, carefully tracking helicity, spectral slopes, and coherence-length evolution. In particular, using Pencil Code, I plan to test the robustness of theoretical decay laws, inverse-transfer mechanisms, and the impact of expansion and dissipation. By combining analytical modeling, controlled numerical simulations, and eventually observational insight, I aim to contribute to COSMOMAG's goal of establishing a coherent and physically grounded picture of cosmic magnetism from first principles to observables.

Given that my primary interest is in analytical modeling and numerical simulations, I consider Nordita a particularly suitable environment to pursue this research within the COSMOMAG collaboration. I am confident that my interdisciplinary background makes me an ideal candidate to advance the core objectives of the project. I am eager to apply my skills to help uncover the origins and evolution of the first magnetic fields in our universe.

Thank you for considering my application !

Sincerely,
Amodio Carleo

Amodio Carleo

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Current position

- **Research Fellow in Astrophysics** — **Cagliari - Trieste (IT)**
  INAF - SISSA — *March 2024–Today*

Education

- **PhD in Astrophysics** — **Naples (IT)**
  University of Salerno & Scuola Superiore Meridionale of Naples & INFN — *November 2020–February 2024*
  Tests of General Relativity from Astrophysical to Cosmological Scales
  Supervisors: G. Lambiase, S. Capozziello

- **II Level Master in Sciences and Technologies** — **Pavia (IT)**
  IUSS — *October 2017-May 2020*
  Mark: 100/100 cum laude

- **Master's Degree in Physics** — **Pavia (IT), Mainz (DE)**
  J. Gutenberg University & University of Pavia — *September 2017–October 2019*
  Gravitational Wave Background from Cosmological Phase Transitions in a Gauge Extension of the Standard Model
  Supervisors: P. Schwaller, E. Madge, C. Dappiaggi
  Mark: 110/110 cum laude

- **Bachelor's Degree in Physics** — **Pavia (IT)**
  University of Pavia — *October 2014–September 2017*
  Gravity & Antigravity
  Supervisor: A. Rotondi
  Mark: 110/110 cum laude

Teaching experience

- **University of Pavia – Physics Department** — **Pavia (IT)**
  Linear Algebra (undergraduate) — *October 2017 – June 2018*
- **University of Salerno – Physics Department** — **Salerno (IT)**
  Mathematical Analysis II (undergraduate) — *February - March 2021*
- **University of Naples Federico II – Physics Department** — **Naples (IT)**
  Celestial Mechanics (PhD level) — *November - December 2022*
- **Supervisor for Master students:**
  - *Matteo Pili* (University of Cagliari, IT)
  - *Even Coquery* (Ecole Normale de Lyon, FR)
- **Referee for Master Thesis:**
  - *Jyotijwal Debnath* (Institute of Mathematical Sciences, Chennai, IN)

Awards

- **Researcher Mobility Grant**, CNR-IRET (Cagliari-Bonn, 2025), 3000 €
- **GSSI Grant**, High Energy Polarimetry Academy (L'Aquila, 2025), 1200 €
- **Italian Space Agency (ASI) Scholarship**. IXPE Data Analysis (Rome, 2024), 800 €
- **Ghislieri College Scholarship**. Selected with admission test; 5 years full maintenance,
- **IUSS Scholarship**. Selected with admission test; 5 years full maintenance, 10000 €
- **SISSA Pre-PhD Fellowship**, Computational mechanics by reduced order methdos (Trieste, 2019/20), 2000 €
- **Prize "S. Giuliano Martire"**. For distinguished students (Naples, 2013)

Academic Experiences

- **J. Gutenberg University (MITP)**, Erasmus Scholarship, Mainz (DE), 2019 - 6 months
- **Bicocca University**, Milano (IT): visiting in Prof. *Alberto Sesana*'s group, 2022 - 3 months
- **INAF**, Cagliari (IT), LOFAR Tutorial by *Caterina Tiburzi*, 2022
- **SISSA**, Trieste (IT): visiting in Prof. *Enrico Barausse*'s group, 2025 - 3 weeks
- **Rossi Lectures**, Arcetri (IT): The Gravitational Universe (by *Monica Colpi*), 2025
- **VLBI Training Day (EVN)**, JIVE, 2025
- **GW Open Data Workshop**, Trieste (2023) and online (2025)
- **Majorana Lectures**, University of Naples (IT): Gravitational Waves and Binary System (by *Thibault Damour*), 2025
- **ACME**, Training Workshop on Swift and XMM-Newton data analysis, 2025
- **ACME**, Training Workshop on `LISAbeta`, 2025
- **MPIfR**, Bonn (DE): visiting in M. Kramer's group, 2025 - 5 weeks

Conferences (main)

- **Bonn-Cologne Summer School**, Bad Honnef (DE), 2016
- **Cabibbo Memorial Symposium**, online INFN, 2020
- **Q-GRAV**, online, 2021
- **SIGRAV**: online 2021 & Vietri (IT) 2023
- **SIF-Italian Physical Society**, Salerno (IT), 09/2023
- **QGSKY**, University of Genova (IT), 2023
- **IPTA-International Meeting**, Sexten (IT), 2024
- **CNOC XIII**, Alghero (IT), 2024
- **Dynamical Tracers of the Nature of Dark Matter**, online workshop, 2025
- **Frontiers in X-ray Polarimetry**, GSSI, L'Aquila (IT), 2025
- **EPTA Meetings**, 2025
- **Bonn Neutron Star Workshop**, Bonn (DE), 2025
- **Multiverse From Home**, 2025
- **Cosmology From Home**, 2025
- **IPTA-International Meeting**, CALTECH, (online) 2025
- **SKAO**, Science Meeting, Gorlitz (DE), 2025
- **Pulsar Conference**, INAF, Geremeas (IT), 2025
- **The Fifth National Workshop on the SKA Project**, INAF, Bologna (IT), 2025
- **LISA AstroWG Meeting**, University of Geneva (CH), 2025
- **Nordita Winter School 2026**, Cosmological Magnetic Fields (online), 2025

Languages

- **Italian**: Mother tongue.
- **English**: B2 CEFR (Certified)
- **French**: A2 CEFR

Professional Experience

- Assistant at Political Science Library, University of Pavia, IT (2017-2019)
- Conference Planner at Collegio Ghislieri in Pavia, IT (2017-2019)

Others

- Founder member of **Indiscienza** 🌐, a yearly scientific exhibition at Collegio Ghislieri in Pavia, IT
- Science Communicator at 'European Research Night' (SHARPER)
- Member of the CUG (unified committee for equal opportunities, the wellbeing of the personnel, and against discriminations)
- Member of the **Italian Physical Society** (SIF)
- Member (support) of the **New Athena Science Community** (NASC)
- Member of the **Sardinian Gravitational Wave Science Community** (SGWSC)
- Member of the **GRAWITA Collaboration** 🌐
- Member (associate) of **EPTA**
- Member (associate) of **LISA**

- Member (associate) of **SKA**
- Member of the **Journal Club** 'Gravitation and Cosmology' at Scuola Superiore Meridionale of Naples (SSM)
- Partecipation to **Astronomy Journal Meetings** (SAIt)
- Partecipation to **Radioastronomy and Emerging Challenges**
- Partecipation to "APRE Conferenza annuale 2025"
- Co-PI Parkes proposal for PSR J1757-1854
- Certificate in Public Engagement, *APEnet* 2025
- Active member of **Skype a Scientist** to divulgate science to worldwide classrooms

Programming Skills & Softwares

High Performance Computing (HPC), Mathematica, Matlab, Maple, C++, Fortran, Pencil-Code, FreeFem, Python, TEMPO2, PRESTO, TempoNest, DS9, HEASoft, IXPEOBSSIM, CASA, CosmoTransitions, RM-Tools, CosmoGW, SciServer, Stimela2

Technical professional with experience in distributed computing and secure remote workflows. Proficient in managing complex data pipelines using Workflow Management Systems (Stimela2) within high-performance computing (HPC) environments. Skilled in maintaining secure connectivity to remote clusters via OpenVPN and SSH, with a strong command of Linux/Unix environments and containerized software deployment (Docker/Singularity). Familiar with data discovery via SQL/ADQL queries in astronomical archives.

Scientific Interests

Gravitation, Alternative Theories of Gravity, General Relativity, Pulsars, Binary Systems, Primordial Magnetic Fields, Compact Objects, Dark Matter, Dark Energy, Bayesian Analysis

Contact Information

- Email: amodio.carleo@inaf.it
- Website: https://sites.google.com/view/amodio-carleo
- GitHub: https://github.com/amodiocarleo

Amodio Carleo
Dec. 2025

Master Thesis: link

Publications (First Author)

- A.Carleo, L.Mastrototaro, G.Lambiase
  Energy extraction via magnetic reconnection in Lorentz breaking Kerr-Sen and Kiselev black holes, Eur. Phys. J.C 82 9, 776 (2022) link

- A.Carleo, S.Capozziello, G.Lambiase
  The amplification of cosmological magnetic fields in extended f(T,B) teleparallel gravity, JCAP 10, 020 (2022) link

- A.Carleo, A.Ovgun, G.Lambiase
  Non-Linear Electrodynamics in Blandford-Znajek energy extraction, Ann. Phys. (Berlin), 535, 2200635 (2023) link

- A.Carleo, B.Ben-Salem
  The effect of environment on pulsar timing around SgrA* ,
  Phys. Rev. D 108, 124027 (2023) link

- A. Carleo
  Constraints on non-local gravity from binary pulsars
  Phys.Lett.B 848 138410 (2024) link

- A. Carleo, M. Capriolo, S. Capozziello, G. Lambiase
  Non-locality in quadrupolar gravitational radiation, JCAP02 049 (2025) link

- A.Carleo, P.Esposito, **Shock conditions in a binary system consisting in a WR star and black hole in NGC4490** (in preparation) link

- A. Carleo, D. Perrodin, A. Possenti
  Towards an exact approach to pulsar timing, Phys. Rev. D 111, 083055 (2025) link

- A. Carleo, A. Corongiu, D. Perrodin, A. Possenti, F. Abbate, M. B. Colom
  Pulsar emission analysis, timing update and mass measurements for PSR J1807-2459 (in preparation)

- A. Carleo, E. Barausse, M. Vaglio, A. Corongiu, D. Perrodin, A. Kuntz
  New contraints on Einstein-Aether theory from GWs emitted by binary pulsars (in preparation)

Publications (Co-Author)

- V. De Falco, A. Carleo, A. Corongiu, A. Ridolfi
  Reconstruction of spider system's observables from orbital period modulations via the Applegate mechanism, A&A (2025) link

- A. Sacchi et al.
  A soft and transient ultraluminous X-ray source with 6-h modulation in the NGC 300 galaxy, A&A 682, A151 (2024) link

- F. Abbate, A. Carleo, et al.
  Galactic center pulsars with the SKAO, OJA 8 1, 2025 link

- V.K.Vivek et al.
  Testing Gravity with binary pulsars in the SKA era, OJA 8 1, 2025 link

- X. Hu et al.
  Constraints on Ultralight Scalar and Dark Photon Dark Matter from PPTA-DR3 and EPTA-DR2 (in preparation)

Dr. Amodio Carleo

Research Statement

Past Scientific Results

A) Phenomenology of Black Holes

Despite the no-hair theorem, according to which a black hole (BH) cannot have its own magnetic field, astrophysical black holes are typically immersed in an external magnetic field generated by the accretion disk. The latter is involved in numerous phenomena, including relativistic jets and gamma-ray bursts (GRBs). I have dealt with this topic in two different ways: in [**CLM22**] I investigated the very recent model of magnetic reconnection by trying to modify the geometry of the space-time around the black hole, while in [**CLO22**] I assumed the Blandford-Znajek (B-Z) mechanism as valid while modifying the electromagnetic interaction. In particular, in [**CLM22**] I evaluated whether energy extraction via **magnetic reconnection** could be achievable in an extended Kerr solution, namely a Kerr-Sen BH (which is a solution of heterotic string theory) with a bumblebee background, which differs from the standard Kerr solution via a Lorentz symmetry breaking parameter ℓ and an electric charge b. After a parametric space analysis, it became clear that small charge b and positive ℓ values are optimal for energy extraction. In [**CLO22**], instead, I analyzed the established **Blandford-Znajek** mechanism in light of a new promising theoretical context, namely **non-linear electrodynamics** (NLED), a generalization of Maxwell's theory for strong fields, providing the general form of the extracted power up to second order in the spin parameter a. By analytically solving the magnetohydrodynamical problem, I found that the energy flux depends not only on the radial magnetic field B_r, but also on the other two components, namely B_θ and B_ϕ, and that, after a perturbative expansion in powers of a, no monopole solutions exist for power-law models $L_{NLED} = -CX - \gamma X^\delta$ (where $X := (1/4)F_{\mu\nu}F^{\mu\nu}$), while paraboloidal solutions seem to be possible, although they differ significantly compared to linear theory, especially in the radial part, as shown in Fig. (1). It also became evident that the NLED power-law model with $\delta = 2$ can in principle extract much more energy compared to classical Maxwell theory while ensuring, at the same time, the collimation of the jet.

B) Primordial Magnetic Fields

Strong-field scenarios can accommodate changes not only in the electromagnetic sector, but also in the gravitational field. In this sense, an ideal setting for probing deviations from GR is offered by **primordial magnetic fields** (PMFs). Observations indicate that intergalactic magnetic fields have amplitudes of the order of $\sim 10^{-6}$ G and are uniform on scales of $\sim$10 kpc. Despite their wide presence in the Universe, their origin remains an open issue. Even by invoking a dynamo mechanism or a compression effect for magnetic field amplification, the existence of seed fields before galaxy formation is still problematic. General Relativity predicts an adiabatic decrease of the magnetic field evolving as $|\mathbf{B}| \propto 1/a^2$, where a is the scale factor of the Universe, and thus it predicts only for very small primordial fields, unless the conformal symmetry of the electromagnetic sector is broken. Since the scale factor tends to infinity during inflation, this type of decay involves too many weak or practically absent magnetic fields at the end of the inflation period. This scaling is the same for every cosmic energy density present in the Universe. In particular, the Universe is filled with a cosmic microwave background radiation (CMB), a relic of the hot big bang, with a thermal spectrum at the (current) temperature of $T = 2.725$ K. The energy density of this radiation, $\rho_\gamma = \pi^2 T^4/25$, which formed a dominant component of the energy density of the early Universe, corresponded to the energy of the void and was almost constant during inflation. Immediately afterwards, it began to dilute as the Universe expands as $\rho_\gamma \sim 1/a^4$ (the extra factor $1/a$ w.r.t to matter, which decays as $\sim 1/a^3$, comes from energy redshift); therefore, the ratio $r \doteq \rho_B/\rho_\gamma$ remained constant until today, with a current value of $r \approx 1$. It is then standard practice to characterize the primordial field with either this ratio r, or the present day value $\mathbf{B}_0$ as a function of its coherence scale L. Precisely, a present day magnetic field strength of 3.2 μG has an energy density equal to the present day CMB energy density, i.e. $r = 1$. In order to explain this value, one needs a pregalactic seed field with a ratio $r \simeq 10^{-34}$ if dynamo amplification is assumed, and $r \simeq 10^{-8}$ if compression occurred in the collapse of protogalactic cloud. An adiabatic decay-law on all length scales, moreover, implicitly assumes the existence of electric currents with super-horizon correlations, thus violating causality [Tsa14]. One way to overcome these critical points is to assume that the flux is not conserved and therefore that the electromagnetic sector is no longer conformally invariant, i.e. $\int d^4x F^{\mu\nu} F_{\mu\nu} \neq \int d^4x F^{\mu\nu} F_{\mu\nu}$, where $F^{\mu\nu}$ is written in terms of the new metric $g_{\mu\nu} = \Omega^{-2} g_{\mu\nu}$, with Ω the conformal factor. This would imply a non-adiabatic decay of the primordial magnetic field $\mathbf{B}$, ensuring its survival even after inflation, in the form of current large-scale fields. On the other hand, post-inflationary scenarios consider PMFs created after inflation via either cosmological phase transitions or during the recombination era [Sub16], even if, in this case, the role of helicity is fundamental to transfer energy from small to large scales [DN13]. It has also been pointed out that a FRW negative curvature ($K = -1$) allows a super-adiabatic decay, i.e. in this case the magnetic field would have had a relative amplification w.r.t. the radiation.

In [**CCL22**], we discovered that the amplification of PMFs can be naturally achieved in the context of extended teleparallel theories of gravity (with torsion), i.e. $f(T, B)$ gravity, which recently has proven extremely useful to address several cosmological issues. First, we computed and solved the exact cosmological equations in a spatially flat FRW metric, distinguishing between inflationary and reheating eras. We used two different models, namely $f(T, B) = -T + \lambda B^n$ and $f(T, B) = -\lambda T B^n$. Here, we found important deviations from GR, both in inflation and in the reheating era. Then, we adopted a non-minimal gravity-photon coupling in order to generate primordial magnetic fields with a non-adiabatic behaviour, exploiting the breaking of conformal symmetry (which naturally arises from such non-minimal couplings). These couplings are well motivated, since according to the QED on curved space-time, one-loop vacuum-polarization effects can lead to non-minimal gravitational couplings between the curvature and the electromagnetic field. After obtaining the corresponding Maxwell equations, we studied the evolution of magnetic field $\mathbf{B}$ in the two epochs, finding that an amplification is always possible. Interestingly, we found that imposing a zero electric field automatically leads to the super-horizon approximation, $k\eta \leq 1$ (where η is the conformal time), while the inverse is guaranteed (approximately) only for inflation phase. Addionally, we also estimated amplification of the magnetic field assuming its manifestation during ***inflation***, i.e. turning on the non-minimal coupling in this epoch, rather than in the reheating one, constraining compatibility regions for the model power n and the ratio r during inflation ($r = 10^\chi$), as shown in Fig. (2).

In [**CLO22**], instead, we tried to find constrains on some NLED models, exploiting existence and survival of PMFs and the astrophysical observation $r \simeq 1$. Indeed, when coupled to a gravitational field, NLED theories can give the necessary negative pressure and enhance cosmic inflation, as well as avoid the Big Bang singularity. This time, instead of non-minimal coupling, a minimal one is allowed. In particular, we found that only in one case it is possible to constrain the model.

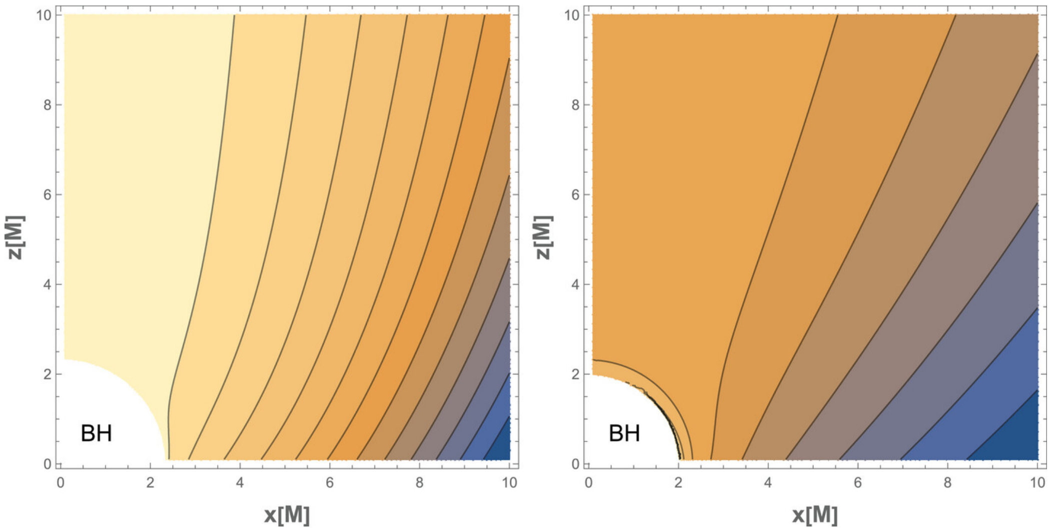

*Figure 1: (LEFT) Contour-plot representing paraboloidal solution (or stream function) (**??**), i.e. in a power-law NLED model $L_{NLED} = -\gamma X^2$, where $X = (1/4)F_{\mu\nu}F^{\mu\nu}$, as function of Cartesian coordinate $x = r\sin\theta$ and $z = r\cos\theta$. The lines shown corresponds to poloidal magnetic field lines around a static ($a = 0$, $M = 1$) black hole. Colors are purely indicative, since the exact values depend on the integration constants, here assumed to be ideally 1. Any accretion disk (not shown) would 'lie' along the x axis. (RIGHT) Same as before, but in the conventional linear theory (Maxwell). Notice the more pronounced 'verticality' of the non-linear case. Having set $M = 1$, all distances are actually dimensionless.*

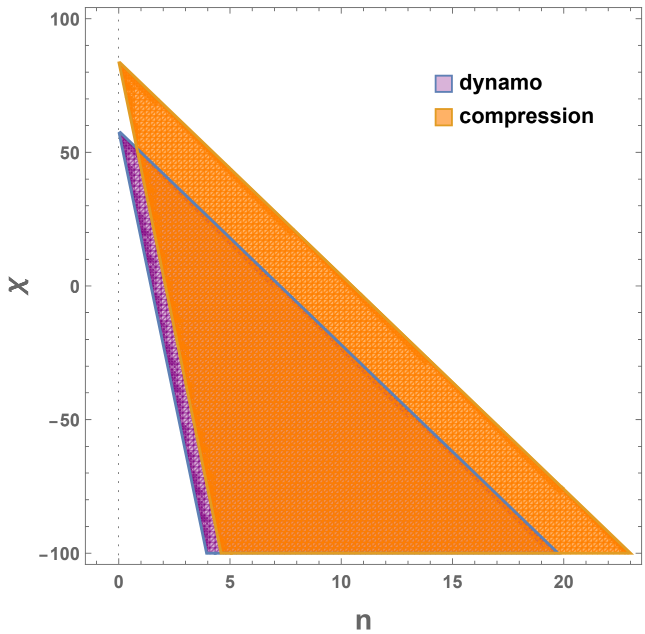

Figure 2: Compatibility regions for the model power n and the inflation exponent χ assuming a dynamo mechanism (purple) or a compression effect (orange) on the galactic seed fields. Notice that, at a fixed power n, wide intervals are allowed to χ, which becomes less restrictive as n increases.

C) Binary Pulsars

A very promising alternative theory of gravity is the so-called 'non-local gravity', which attempts to combine General Relativity and Quantum Mechanics by introducing non-local terms at the action level. In this framework, referred to as 'non-local gravity' [CB21], it is important to study the linearized version of the theory and to derive the **gravitational radiation** (GWs), since this allows detection of possible effects of non-locality as well as classification of the degrees of freedom of a given theory. A feature of this class of theories (but not only) is the emergence of a scalar mode. The detectability of this scalar mode was considered in [**CCCL25**], where it is shown that, although generally extremely weak, near the model divergence its amplitude could fall within the low-frequency sensitivity of the Einstein Telescope. An application to real sources was the subject of a parallel paper [**Car24**], in which the strong dependence of the GWs instantaneous flux on the non-local contribution appeared evident. By exploiting the predicted gravitational wave emission in the three binary pulsars PSR J1012+5307, PSR J0348+0432, and PSR J1738+0333, I derived, for the first time, constraints on the non-local coupling constant. For more complicated theories of gravity, such as Einstein-Aether (E-A) theory, inference from a single PK parameter is no longer sufficient, or it is still limited to a few parameters at a time. To overcome this and constrain the twelve free parameters of E-A theory (some of which related to a preferred time direction associated with a dynamical vector field), I developed a Bayesian inference tool called `TempoGravity` [1], enabling precise (and robust) estimation of the parameters, with posterior distributions derived from a full analysis involving both the timing model and the theory of gravity. The results are currently under investigation.

Testing GR is one of the primary applications of **pulsar timing** technique, which involves measuring the precise times of arrival (ToAs) of the pulsar's radio signal and comparing them with a theoretical model. This technique has become a standard and indispensable method in modern radio astronomy, allowing researchers to detect minute deviations from expected arrival times and infer physical properties of the pulsar, its binary companion, and the intervening medium. This enables the detection of possible deviations from Einstein's theory, providing insights into alternative gravitational models. One of the best-measured quantities from pulsar timing is the **propagation delay**, which is caused by the motion of photons in the companion's gravitational field. This effect is usually computed using formulas based on a post-Newtonian approach, for both the light trajectory and the orbital motion. Recently, however, evidence has emerged suggesting that this approximation may be insufficient when the companion is a supermassive black hole, with deviations from a full GR computation potentially reaching several seconds—a dramatically large discrepancy, potentially capable of thwarting any effort to infer relevant information about the black hole. Employing a **full GR approach**, my findings in [**CBS23**] indicate that while the spin solely induces a phase shift in the maximum delay without affecting its amplitude, the presence of matter surrounding the black hole leads to a noticeable modification of the delay, further complicating the scenario but at the same time offering a new avenue of investigation to explore the environment surrounding black holes. In particular, in the presence of dark energy (the type of matter exerting the strongest influence), the latter should potentially be detectable by the timing of SGR J1745-2900, the closest magnetar orbiting Sgr A*. Even moving towards less extreme systems, namely binary pulsars with stellar-mass or intermediate-mass black hole companions, the inaccuracy of PN formulas still appears to be a serious problem, as found in [**CPP25**]. Most importantly, despite their relative mildness, these systems are projected to be significantly more abundant, which of course promises richer statistical insights but at the same time requires a rigorous and very accurate model. To better understand their timing properties, I have developed a numerical algorithm that allows for a full GR treatment of the propagation delay. My findings indicate that for a pulsar orbiting a $10M_\odot$ black hole in a circular, edge-on orbit with radius $a_R = 10^6 M$, the maximum discrepancy at superior conjunction is $\Delta_{DIF} \sim 10^{-7}$ s, exceeding the predicted timing precision of SKA (~50 ns). This discrepancy decreases

1. https://github.com/amodiocarleo

with increasing orbital separation, reaching $\Delta_{DIF} \sim 10^{-8}$ s for $a_R = 10^7 M$ and $\Delta_{DIF} \sim 10^{-9}$ s for $a_R = 10^8 M$. In general, Δ_{DIF} increases by an order of magnitude for each tenfold decrease in a_R. Furthermore, relativistic corrections to orbital motion introduce additional timing errors, reaching $\sim 3.2 \times 10^{-4}$ s for a $10 M_\odot$ black hole at $a_R = 10^5 M$. These results underscore the necessity of more precise pulsar timing methodologies, especially in light of upcoming discoveries with the SKA, whose two major scientific goals are: (a) detecting and timing pulsars in the Galactic Center; (b) identifying and timing pulsars in orbit around stellar-mass black holes [**A+25, VK+25**].

From a data-analysis point of view, of all the pulsars used to test gravity, two that deserves close attention, in my opinion, are **PSR J1757−1854** and **PSR J1807−2459B**. Regarding the first, I collaborated in submitting a proposal for Parkes observations to track the time evolution of the pulse profile of this pulsar. We plan to use the large bandwidth of the UWL receiver to derive a fully polarised profile every two months in order to continue tracking the effect of the GP. These observations will be conducted in conjunction with Green Bank Telescope observations, which regularly observe this pulsar in the 1.15–1.73 GHz and 1.73–2.60 GHz bands. While the timing sensitivity of the Parkes UWL receiver will not be as high as that of the GBT receivers, the wide frequency coverage of the UWL will provide a comprehensive view of all the features of the profile, and with enough time integration it will even be a superior machine than the GBT in this regard. This will contribute to the measurement of PK parameters (like $\dot{P}_{\mathrm{B}}$), which will enable an accurate distance estimation of PSR J1757−1854 by disentangling the GR-predicted value from the excess value derived from a combined Shklovskii and Galactic acceleration field effect. Regarding PSR J1807-2459B, a binary system in the globular cluster NGC 6544, I aim to analyze new radio data in order to find an updated timing solution, with a particular focus on the Einstein delay. Since the eccentricity is very high (e=0.78) this binary system could be a powerful testbed for gravity tests. Most importantly, a previous work (2012) showed that there appear to be no tidal effects or mass exchanges in this system, so gravity is solely responsible for the dynamics, a unique opportunity to test gravity theories. Therefore, together with the Double Pulsar, it could be one of the most constraining systems from this point of view. I used the **Bayesian** inference tool `TempoGravity` to obtain a stringent GR test from this source.

In parallel with the gravity tests, I also used pulsar data to test one of the most widely accepted models for describing a subclass of eclipsing binary systems, known as **spider pulsars**, namely redback and black widow pulsars [**DFCRC25**]. They are characterized by very short orbital periods, very low-mass companions, and, in several cases, regular eclipses in their pulsed radio signal. Long-term timing revealed systematic but unpredictable variations in the orbital period, which can most likely be explained by the so-called Applegate mechanism. This relies on the magnetic dynamo activity generated inside the companion star and triggered by the pulsar wind, which induces a modification of the star's oblateness (or quadrupole variation). This, in turn, couples with the orbit via gravity, causing a consequent change in the orbital period. The Applegate description is limited to providing estimates of physical quantities by highlighting their orders of magnitude. In particular, we developed the **first dynamical model for these systems** , by deriving the time-evolution differential equations underlying the Applegate model and tracking such physical quantities as functions of time. Our strategy was to employ the orbital period modulations, measured by fitting the observational data, and implement a highly accurate approximation scheme to finally reconstruct the dynamics of the spider system under study and the related observables. Among the latter is the magnetic field activity inside the companion star, which remains a matter of debate due to its complex theoretical modeling and the ensuing expensive numerical simulations. As an application, we examined two real sources, namely 47 Tuc W (redback) and 47 Tuc O (black widow).

Future Directions

Understanding the origin and evolution of cosmic magnetic fields remains one of the central open problems in modern cosmology. Primordial magnetic fields generated in the early Universe—during inflation, reheating, or cosmological phase transitions—offer a compelling explanation for large-scale magnetization, but their viability depends on both physically consistent generation mechanisms and a realistic description of their subsequent evolution through recombination and into the late Universe. The COSMOMAG Synergy Grant provides a unique framework to address this challenge through an end-to-end approach that links early-Universe physics, nonlinear magnetohydrodynamics, and observational signatures. My research aims to contribute to this effort by combining experience in early-Universe phase transitions, primordial magnetogenesis, and radio and multi-messenger observations to develop and test robust models of primordial magnetic fields from their origin to measurable signals.

A primary focus of my work will be characterizing the hydrodynamic and magnetic initial conditions sourced at the end of inflation and during cosmological phase transitions. During my previous research, I used tools such as CosmoTransitions to model the stochastic gravitational wave background (SGWB) from first-order phase transitions. Building on this background, I will treat these early-universe events as a "fluid box" problem, focusing on the anisotropic stress produced by the primordial plasma. I will investigate magnetogenesis scenarios with particular attention to how the breaking of conformal invariance ensures the survival and amplification of magnetic fields. Drawing on my experience with the theoretical survival of PMFs, I will produce physically admissible magnetic field spectra, carefully tracking helicity, large-scale spectral slopes, and the evolution of the coherence length, using Pencil Code to test my assumptions. By quantifying the joint generation of magnetic fields and gravitational waves, I will also provide predictions for the correlated spectral features of the SGWB and PMFs, which can be compared with pulsar timing array observations to help distinguish primordial magnetic contributions from astrophysical backgrounds.

Even if primordial magnetic fields are efficiently generated, their relevance for cosmology depends critically on their nonlinear evolution and survival during the radiation-dominated era and through recombination. My previous research has given me a solid command of the magnetohydrodynamic equations governing primordial plasmas and of the mechanisms responsible for magnetic field amplification and decay. In COSMOMAG, I will build on this foundation to study the evolution of primordial magnetic fields under realistic conditions, focusing on decaying MHD turbulence, helicity conservation, inverse transfer, and the role of dissipative processes. I will make use of state-of-the-art numerical tools, including the Pencil Code, to characterize the evolution of magnetic energy spectra and correlation lengths and to assess how changes in plasma properties across recombination affect magnetic field survival. The outcome will be a statistically robust description of the magnetic field at recombination, suitable for forward modeling toward observable signatures.

Another likely central goal of COSMOMAG will be to establish firm connections between primordial magnetic fields and measurable observables. In this context, my experience with radio data analysis and large collaborations will play an important role. I have hands-on experience with LOFAR data and am familiar with rotation-measure analyses relevant for constraining intergalactic magnetic fields. I will use this expertise to connect recombination-era magnetic field predictions to radio observables, while carefully accounting for contamination from astrophysical magnetic fields. In parallel, as a member of the EPTA and of the SKA communities, I am well positioned to explore synergies between primordial magnetic fields and stochastic gravitational wave backgrounds probed by pulsar timing experiments. In particular, I will investigate how magnetic fields and gravitational waves sourced by the same early-Universe processes, such as first-order phase transitions, can be jointly constrained, and whether distinctive signatures such as helicity-induced parity-odd correlations can be identified. In addition, I am very interested in the role of cosmic voids as clean environments for probing primordial magnetic fields, where astrophysical contamination is minimal. Building on recent work on PMFs in voids [GBC+25], I would like to explore whether specific magnetogenesis scenarios and helicity properties leave distinguishable signatures in void magnetization and related radio observables.

In conclusion, by combining expertise in early-Universe phase transitions, magnetohydrodynamics, numerical modeling, and observational analysis, my work will support COSMOMAG's end-to-end strategy and help determine whether and how primordial magnetic fields can account for the magnetic properties of the Universe observed today. In particular, my background positions me as a **bridge** between magnetic field generation in the early Universe and their subsequent evolution through recombination, as well as their observable signatures at late times, thereby contributing to a coherent interface between early-Universe dynamics and recombination-era and post-recombination studies within COSMOMAG.

January 2025

Dr. Amodio Carleo

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UNIVERSITÀ DEGLI STUDI DI SALERNO

Translation on request of the person concerned
Should any discrepancies exist between the Italian version and the English version of this certificate, the Italian version shall take precedence.

On request, we confirm that, on the basis of documents in possession of this Office, Mr **CARLEO Amodio** born in VILLARICCA (NA) on June, 03rd, 1994, Italian citizen, has attended the PhD Course in MATHEMATICS, PHYSICS AND APPLICATIONS, *Curriculum Physics* at the University of Salerno from November, 1st, 2020 to Ocotber 31st, 2023.

He, successfully, obtained the PhD Degree (3°cycle QF-EHEA /8° Level EQF) with the evaluation of GOOD by submitting a dissertation entitled: TESTS OF GENERAL RELATIVITY FROM ASTROPHYSICAL TO COSMOLOGICAL SCALES (SSD FIS/05 - ASTRONOMY E ASTROPHYSICS).
on February 29th 2024.

To achieve the aforementioned Degree, Mr. **CARLEO Amodio** passed the following exams :

Year	Course/Activity Name	CFU	Date	Judgment
1	AUTOFORMAZIONE CURRICULUM FISICA	24	31/10/2021	SUPERATO
1	GRAVITATIONAL LENSING: FROM MATHEMATICAL THEORY TO ASTROPHYSICAL APPLICATIONS	4	30/09/2021	OTTIMO
1	INGLESE	20	24/02/2022	SUPERATO
1	INTRODUZIONE ALLA TEORIA DELL'ELASTICITÀ	4	19/10/2021	OTTIMO
1	PROBLEMI AL BORDO PER EQUAZIONI DIFFERENZIALI LINEARI E APPLICAZIONI	4	29/10/2021	OTTIMO
1	PROCESSI DI PUNTO STAZIONARI: ASPETTI PROBABILISTICI E STATISTICI	2	25/10/2021	OTTIMO
1	QFT AT FINITE TEMPERATURE AND APPLICATIONS TO PARTICLE PHYSICS	2	30/09/2021	OTTIMO
2	RICERCA SUPERVISIONATA 1 - FISICA	60	25/10/2022	SUPERATO
3	RICERCA SUPERVISIONATA 2 - FISICA	50	26/10/2023	SUPERATO
3	TESI CURRICULUM FISICA	10	07/03/2024	SUPERATO

For any clarifications and / or explanations, you can send a request to the e-mail address: ufforpla@unisa.it.

IL CAPO UFFICIO
Dott. Giovanni SALZANO
Firmato digitalmente ai sensi del Dlgs 82/2005

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Report for PhD thesis by Amodio Carleo,
Tests of General Relativity from Astrophysical to cosmological scales.

Torino January 9, 2024

The thesis focuses on effects of modified gravity in strong regimes.
The issue is very important since it deals with observability of modified gravity models which is always hard to tackle.

The candidate investigates different situations, from black holes to binary systems, to cosmology. He discusses the issue of magnetic fields and astrophysical mechanisms to produce them as well as gravitational waves, as well as inflation and reheat era in cosmology.
As for modified gravity, non-local gravity, non-minimally coupled models and *f(T,B)* are considered.

The thesis is well written, the review parts are very clear and contributions are well described.

The thesis overall is an excellent work. It also guarantees perfect perspectives for future research programs.

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Thessaloniki, 10th January, 2024

The thesis of Amodio Carleo is an excellent and timely piece of work. It is focused on mainstream theories in cosmology and astrophysics, with emphasis on major contemporary science issues, such as the gravitational waves from astrophysical and cosmological sources.

The thesis is based on 11 research articles which have been published on pending publication in mainstream journals in the field.

The thesis is pedagogically written, starting with an informative introduction in each scenario developed. It starts with a general and informative introduction in GR and beyond and gradually presents several aspects of the mainstream research topics that were developed in the thesis, namely black holes and related advanced topics, binary systems and gravitational waves, emphasizing on non-local theories, cosmology emphasizing on the inflationary phase and the subsequent reheating era. The thesis is professionally written and I have no further comments or suggestions for its presentation. Hence I believe that the PhD candidate can defend the thesis as it is. I think it is overall in an excellent level and I am happy to approve it. I also believe that the PhD candidate is in an excellent research path, which is related to mainstream and timely physical problems, strongly related to gravitational wave physics coming from both astrophysical and cosmological sources.

Sincerely,

Dr. Vasilis K. Oikonomou
Lecturer-Teaching Fellow
Physics Department Aristotle University of Thessaloniki

Δρ. Βασίλης Οικονόμου