Dr. Cecilio **García Quirós**

PHYSICS DOCTOR

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Profile

Physics PhD with 4+ years of experience solving complex challenges in Gravitational Waves Astronomy. Developer of the most computationally efficient waveform models including subdominant modes used in the data analysis infrastructure of the LIGO-Virgo detectors. Skilled in data collection, cleaning, analysis, modelling, visualization, statistics and communicating insights to both technical and non-technical audiences. Passionate about software development, computing technologies and open science.

Skills

Programming	C/C++; Python; Mathematica; CUDA; Bash; Fortran; SQL
Operating Systems	Linux; macOS; Microsoft Windows
Software	Gravitational Waves software (LALSuite, Bilby, PyCBC, GWpy, PESummary);
	Particle Physics software (ROOT); Version Control (Git, GitHub, Gitlab, svn);
	Project Jupyter; Conda environments; Markdown; Microsoft Office; LaTex;
	HPC software (HTCondor, Slurm)
Communication	Presented research insights at 8 international conferences and to non-technical audiences through public outreach (science fairs, meetups, etc.).
	Published 2 first-author articles in high-impact, internationally peer-reviewed journals and co-authored other 7.
	Worked independently, on small teams and within large international collaborations.
Languages	Spanish (native), English (C1 level), French (beginner)

Education

University of Balearic Islands — *Palma, Spain*

PH.D. IN GRAVITATIONAL WAVES ASTRONOMY — *2016 - 2020*

- Thesis: *Waveform Modelling of Binary Black Holes in the Advanced LIGO Era*
- *Viva voice*: July 2020 – Awarded: July 2020 – Honours: *cum laude*
- Supervisors: Prof. Sascha Husa, Prof. Alicia Sintes Olives

University of Granada — *Granada, Spain*

M.S. IN PHYSICS: RADIATION, NANOTECHNOLOGY, PARTICLES AND ASTROPHYSICS — *2015*

- Average mark: 9.2/10
- Specialized in Particles and Astrophysics.
- Master thesis: *Formulations of General Relativity as Gauge Theory*. Extensive manual tensorial calculations in curve geometries, including (Anti-)de Sitter spaces and different kinds of local transformations. Study if they allow the quantization of gravity.
- Supervisor: Prof. Bert Jansen

University of Granada — *Granada, Spain*

B.Sc. IN PHYSICS — *2010 - 2014*

- Average mark: 9.1/10
- Bachelor thesis: *Uncertainty Relations in Quantum Information*. Extensive review of the different existing formulations of the Heisenber principle by using other uncertainty measurements like the Shannon or Renyi entropies.
- Supervisor: Prof. Jesús Sánchez-Dehesa

Experience

University of Balearic Islands | LIGO Scientific Collaboration | LISA Consortium *Palma, Spain*

POSTDOCTORAL RESEARCHER *October 2020 - March 2021*

- Led the design, development and review of a new infrastructure within the LIGO Software Library (LALSuite) to obtain individual subdominant modes from waveform models of gravitational waves (GW) in the frequency domain.
- Contributed to the parameter estimation reanalysis of the public GWTC-1 and O3a catalogues of GW events with the waveform models developed during the Ph.D. Extensive use of HPC resources and generation of results web pages with the PEsummary package.
- Contributed to the analysis of the LIGO-Virgo Collaboration (LVC) and performed parameter estimation runs used for the study of the first detection of a black-hole neutron-star merger: `https://doi.org/10.3847/2041-8213/ac082e`.
- Developed an implementation of our waveform models in LALSuite capable of running on GPUs by using the CUDA language.
- Contributed to the development and review of the first phenomenological time domain models to be used in the LVC data analysis infrastructure.

PH.D. STUDENT; SUPERVISORS: PROF. SASCHA HUSA, PROF. ALICIA SINTES OLIVES *September 2016 - July 2020*

- Development of two new frequency domain waveform models to be used in the data analysis infrastructure of the LVC detectors.
- The models describe the subdominant mode content of both aligned-spin and precessing binary black holes systems.
- Production of numerical relativity (NR) simulations with the BAM code.
- Calibration of the model to NR simulations by producing data-driven non-linear fits across parameter space using Mathematica.
- Pionereed the description of mode-mixing in phenomenological waveform models, their extension to the extreme-mass-ratio-inspiral regime and the inclusion of the Multibanding technique to significantly reduce the computational cost of the models. Both are key features for the expected longer signals that will be detected by the LISA mission.
- Implementation and review of both models for production level in LALSuite. Extensive use of C debuggers, Python, Bash and distributed computing.
- Both models are now the preferred ones used by the LVC to analyze events from the O3b period, having particularly contributed to the analysis of the first detection of a black-hole neutron-star merger.
- The three papers related to the models (I led two of them) have achieved 68 citations and have provided me with an h-index of 3 in less than a year. With the rest of short author list papers I accumulate 252 citations and an h-index of 7.

University of Cardiff *Cardiff, United Kingdom*

PH.D. RESEARCH STAY; SUPERVISOR: PROF. VIVIEN RAYMOND *October 2019 - December 2019*

- Work in gravitational waves data analysis within the LVC.
- Parameter estimation studies of exceptional events detected in the O3a period with the new waveform model developed in the thesis.
- Use of the LALInference library and the Bilby Python package to perform Bayesian Inference runs on computer clusters. New features were added to these packages to handle the extra freedom of subdominant modes waveform models.
- Results showed that the new aligned-spin model developed in the thesis produced better constrained results in a much shorter timescale than previous models.
- Use of the Reduced-Order-Quadrature (ROQ) algorithm and the PyROQ package to produce for the first time a prototype for the ROQ basis of a waveform model with subdominant modes.

Institute of Materials Science of Seville | Spanish National Research Council *Seville, Spain*

LAB TECHNICIAN, RESEARCH FELLOW; SUPERVISOR: PROF. ASUNCIÓN FERNÁNDEZ CAMACHO *May 2016 - July 2016*

- Study of porous silicon through the electron microscope.
- Manufacture porous silicon through the spark plasma sintering method.
- Prepare samples of material to be analyzed in the transmission and scanning electron microscopes.
- Use the transmission electron microscope to produce high quality pictures of the resulting structure of the material.
- Use specialized software to analyze the pictures, study the structure and composition of the material and seek its best properties.

Corpuscular Physics Institute (IFIC) | University of Valencia *Valencia, Spain*

RESEARCH FELLOW; SUPERVISOR: PROF. JUAN DE DIOS ZORNOZA *October 2015 - November 2015*

- Search of dark matter with the neutrinos telescopes Antares and KM3NeT.
- Production of simulated skies of the background neutrino flux through Montecarlo simulations run on the Lyon's computer cluster.
- Calculation of the dark matter halo profile with the program CLUMPY for different channels of formation and theoretical profiles.
- Use of data analysis and statistics techniques to determine the expected number of signals and their likelihood.
- Analysis and visualizations performed using the ROOT data analysis framework developed at CERN.
- Results showed that a new theoretical profile led to a consistently lower upper limit for the number of events required to achieve a real observation.

University of Granada *Granada, Spain*

SUMMER RESEARCH FELLOW; SUPERVISOR: PROF. ANTONIO BUENO VILLAR *July 2014 - October 2014*

- Research activity within the Ultra High Energy Particles group.
- Studies by computer simulations for the improvement in the measurement of cosmic rays detected by the Pierre Auger Observatory.
- Analysis and visualizations performed using the ROOT data analysis framework developed at CERN.
- Results showed the current analysis for the time of arrival was not robust enough and neglected some important factors.
- Contributed talk for the Pierre Auger collaboration in Malargüe, Argentina.

Publications

Refereed

10. H. Estellés, A. Ramos-Buades, S. Husa, **C. García-Quirós**, M. Colleoni, L. Haegel, and R. Jaume. "Phenomenological time domain model for dominant quadrupole gravitational wave signal of coalescing binary black holes". *Physical Review D* 103, 124060, 2021. `https://doi.org/10.1103/PhysRevD.103.124060`

9. G. Pratten, **C. García-Quirós**, M. Colleoni, A. Ramos-Buades, H. Estellés, M. Mateu-Lucena, R. Jaume, M. Haney, D. Keitel, J. E.Thompson, and S. Husa. "Computationally efficient models for the dominant and subdominant harmonic modes of precessing binary black holes". *Physical Review D*, 103, 104056, 2021. `https://doi.org/10.1103/PhysRevD.103.104056`

8. M. Colleoni, M. Mateu-Lucena, H. Estellés, **C. García-Quirós**, D. Keitel, G. Pratten, A. Ramos-Buades, and S. Husa. "Towards the routine use of subdominant harmonics in gravitational-wave inference: Reanalysis of GW190412 with generation X waveform models". *Physical Review D* 103, 024029, 2021. `https://doi.org/10.1103/physrevd.103.024029`

7. **C. García-Quirós**, S. Husa, M. Mateu-Lucena, and A. Borchers. "Accelerating the evaluation of inspiral–merger–ringdown waveforms with adapted grids". *Classical and Quantum Gravity*, 38(1):015006, 2020. `https://doi.org/10.1088/1361-6382/abc36e`

6. **C. García-Quirós**, M. Colleoni, S. Husa, H. Estellés, G. Pratten, A. Ramos-Buades, M. Mateu-Lucena, and R. Jaume. "Multimode frequency-domain model for the gravitational wave signal from nonprecessing black-hole binaries." *Physical Review D* 102 064002, 2020. `https://doi.org/10.1103/PhysRevD.102.064002`

5. G. Pratten, S. Husa, **C. García-Quirós**, M. Colleoni, A. Ramos-Buades, H. Estellés, and R. Jaume. "Setting the cornerstone for a family of models for gravitational waves from compact binaries: The dominant harmonic for nonprecessing quasicircular black holes". *Physical Review D* 102, 064001, 2020. `https://doi.org/10.1103/physrevd.102.064001`

4. I. M. Romero-Shaw, et al. (**C. García-Quirós** position 29 of 59 authors). "Bayesian inference for compact binary coalescences with bilby: validation and application to the first LIGO–Virgo gravitational-wave transient catalogue". *Monthly Notices of the Royal Astronomical Society*, Volume 499, Issue 3, Pages 3295–3319, 2020. `https://doi.org/10.1093/mnras/staa2850`

3. A. Ramos-Buades, S. Husa, G. Pratten, H. Estellés, **C. García-Quirós**, M. Mateu-Lucena, M. Colleoni, and R. Jaume. "First survey of spinning eccentric black hole mergers: Numerical relativity simulations, hybrid waveforms, and parameter estimation". *Physical Review D* 101, 083015, 2020. `https://doi.org/10.1103/PhysRevD.101.083015`

2. L. London, S. Khan, E. Fauchon-Jones, **C. García**, M. Hannam, S. Husa, X. Jiménez-Forteza, C. Kalaghatgi, F. Ohme, and F. Pannarale. "First Higher-Multipole Model of Gravitational Waves from Spinning and Coalescing Black-Hole Binaries". *Physical Review Letters* 120, 161102, 2018. `https://doi.org/10.1103/physrevlett.120.161102`

1. As a member of the LIGO-Virgo collaboration I have been coauthor of more than 50 articles. A full list of refereed papers can be found at `https://www.scopus.com/authid/detail.uri?authorId=57196021724`

Unrefereed

4. H. Estellés, S. Husa, M. Colleoni, M. Mateu-Lucena, M. de Lluc Planas, **C. García-Quirós**, D. Keitel, A. Ramos-Buades, A. K. Mehta, A. Buonanno, S. Ossokine. "A detailed analysis of GW190521 with phenomenological waveform models", 2021. `https://arxiv.org/abs/2105.06360`

3. M. Mateu-Lucena, S. Husa, M. Colleoni, H. Estellés, **C. García-Quirós**, David Keitel, M. de Lluc Planas, A. Ramos-Buades. "Adding harmonics to the interpretation of the black hole mergers of GWTC-1", 2021. `https://arxiv.org/abs/2105.05960`

2. H. Estellés, M. Colleoni, **C. García-Quirós**, S. Husa, D. Keitel, M. Mateu-Lucena, M. de Lluc Planas, A. Ramos-Buades. "New twists in compact binary waveform modelling: a fast time domain model for precession", 2021. `https://arxiv.org/abs/2105.05872`

1. H. Estellés, S. Husa, M. Colleoni, D. Keitel, M. Mateu-Lucena, **C. García-Quirós**, A. Ramos-Buades, A. Borchers. "Time domain phenomenological model of gravitational wave subdominant harmonics for quasi-circular non-precessing binary black hole coalescences", 2021. `https://arxiv.org/abs/2012.11923`

Membership of scientific collaborations and societies

LIGO Scientific Collaboration, International	2016 - 2021
LISA Consortium, International	2018 -
Spanish Society of Astronomy, Spain	2018 -

Teaching

University of Balearic Islands

Teaching Assistant

- 30 hours of Electromagnetism and Waves in first year of Industrial and Automatic Engineering, 2020
- 54 hours of Partial Differential Equations I in second year of Physics degree, 2017 - 2019
- 5 hours of Tensorial Calculus and Groups in third year of Physics degree, 2018 - 2019
- 1 hour of Tensorial Calculus and Groups in third year of Physics degree, 2017

Outreach

Jury in the First LEGO League, University of Balearic Islands, Palma, Spain	2019
'Ciència per a tothom', Local science faire, Palma, Spain	2017 - 2019
'Fira de la ciència i la Tecnologia d'Inca', Local science faire, Inca, Spain	2016 - 2018
Gravitational Waves, how universe sounds, Talk at Placa Base, Palma, Spain	2017

Honours & Awards

Best poster presentation in the Theory and Data Analysis category, LIGO-Virgo meeting Warsaw	2019
Princess of Asturias Award for Technical and Scientific Research, I was co-awarded as a member of the LIGO Scientific Collaboration	2017
Premi Jaume II, I was co-awarded as a member of the General Relativity Group of the University of Balearic Islands. This award is one of the major distinctions of the Mallorca Government for Science and Research	2016
Ph.D. grant (FPU), University of Balearic Islands, financed by Spanish Ministry of Education, Culture and Sport	2016 - 2020
Youth Guarantee Program from the Spanish National Research Council, Institute of Materials Science of Seville, financed by Spanish Ministry of Economy and Competitiveness	2016
Introduction to Research Fellowship (JAE Intro), Corpuscular Physics Institute (IFIC), financed by Spanish Ministry of Economy and Competitiveness	2015
Summer Research Fellowship, University of Granada	2014

Presentations and Congresses

(Poster) IMRPhenomXHM: Waveform model calibrated to multimode Hybrids and accelerated evaluation, LIGO-Virgo Meeting, Warsaw, Poland	2019
(Poster) PhenomXHM: A Modular, Accurate and Computationally Efficient Waveform model including subdominant spherical harmonics and mode mixing effects, 22nd International Conference on General Relativity and Gravitation 13th Edoardo Amaldi Conference on Gravitational Waves, Valencia, Spain	2019
(Oral) IMRPhenomXHM: waveform model calibrated to multimode hybrids with accelerated evaluation, 9th Iberain Gravitational Waves Meeting, Santiago de Compostela, Spain	2019
(Poster) IMRPhenomXHM: Waveform model calibrated to multimode hybrids and accelerated evaluation, LISA Consortium Waveform Working Group, Albert Einstein Institute, Potsdam, Germay	2019
(Poster) Modelling gravitational waves subdominant modes and its astrophysical implications, 'XIII Reunión científica de la Sociedad Española de Astronomía', Salamanca, Spain	2018
(Oral) Multi-mode frequency-domain gravitational waves model for non- precessing black-hole binaries, 8th Iberian Gravitational Waves Meeting, University of the Balearic Islands, Palma, Spain	2018
(Oral) Calibration of a multi-mode phenomenological waveform model to Numerical Relativity, LIGO Virgo Collaboration meeting, Sonoma State University	2018
(Oral) Toward calibrating phenomenological waveform models with subdominant harmonics to Numerical Relativity, 7th Iberian Gravitational Wave Meeting, University of the Basque Country, Bilbao, Spain	2017
LIGO-Virgo-Kagra Collaboration Meeting, Online	2021
'XIV Reunión Científica de la SEA', Online	2020
LISA Consortium meeting, Online	2020
LIGO-Virgo Collaboration Meeting, Maastricht, Netherlands	2018
2nd face-to-face meeting of LIGO's and Virgo's Waveform Research and Development Team, Mallorca, Spain	2018
European Einstein Toolkit Workshop, University of Balearic Islands, Spain	2017
LIGO-Virgo Collaboration Meeting, LIGO Caltech Pasadena, California, USA	2017
Dublin School on Gravitational Wave Source Modelling, University College Dublin, Ireland	2018
School on Gravitational Waves for Cosmology and Astrophysics, Centro de Ciencias Pedro Pascual, Benasque, Spain	2017
Communication skills in English: Oral and Written Expression, University of Balearic Islands, Palma, Spain	2017
XVI School of Mathematics 'Lluis Santaló', International University Menéndez Pelayo, Santander, Spain	2015
Summer School in Particle and Astroparticle Physics, Laboratoire d'Annecy de Physique des Particules, Annecy, France	2014