ET activities at UIB and plans

Alicia M. Sintes & David Keitel

ET-Spain Meeting, Barcelona, 2026-11-04

Universitat de les Illes Balears

IAC3 Institut d'Aplicacions Computacionals de Codi Comunitari

EINSTEIN TELESCOPE

GRAVITY research group at UIB

GRAVITY - Gravitational Physics: Theory and Observation (www.uib.eu/research/structures/structure/GRAVITY/),
>40 members (13 faculty, 13 postdocs, 16 PhD students)
part of the IAC3 research institute (iac3.uib.es)
and of LaGAC - Gravitational Physics, Astrophysics & Computation Lab
(www.uib.eu/research/structures/structure/LaGAC/)

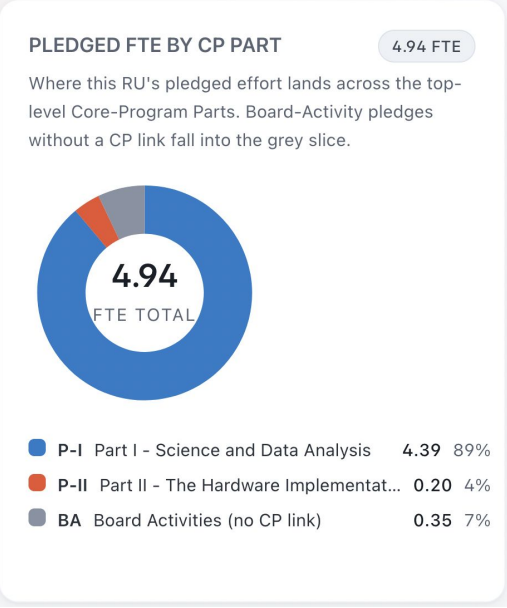


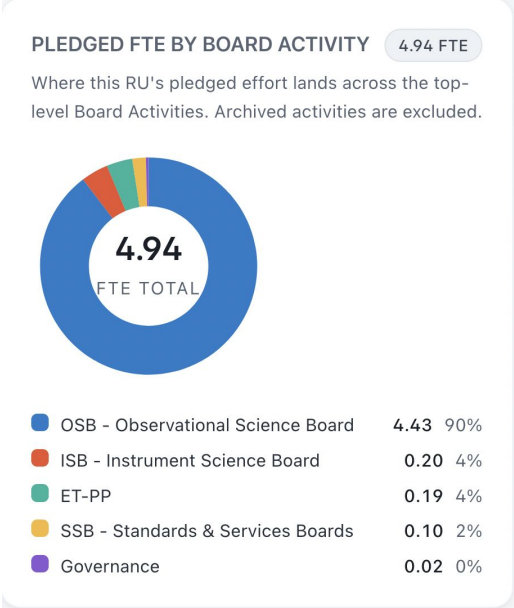
Einstein Telescope GRAVITY-UIB Research Unit

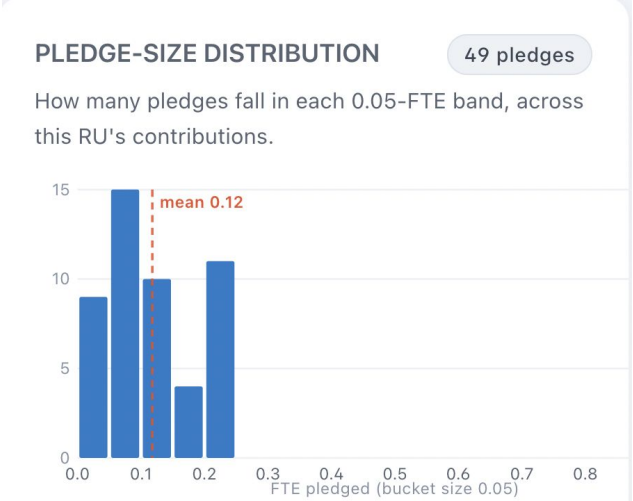
https://apps.et-gw.eu/etmd/research-unit.php?ru=43

RU Leader Alicia M Sintes **Outreach Responsible** Alicia M Sintes
25 members (8 faculty, 9 postdocs, 8 PhD students); 21 core members; 4.94 FTE Total
+ Sascha Husa RU: CSIC; Institution(s): GRAVITY-UIB, ICE-CSIC & IEEC; Role: chair of OSB Div 8: Waveforms

Alicia M. Sintes is member of ET Data Access Policy Committee; ET Collaboration Board; ET Editorial Committee







GRAVITY-UIB Research Unit pledges (2026-09-01 to 2027-08-31)

Our participation in the Einstein Telescope (ET) collaboration covers the following:

Divisions

- DIV 01 – Fundamental Physics
- DIV 02 – Cosmology
- DIV 03 – Population Studies
- DIV 04 – Multimessenger Observations
- DIV 05 – Synergies with Other GW Observatories
- DIV 07 – Stellar Collapse and Isolated Neutron Stars
- DIV 08 – Waveforms
- DIV 10 – Data Analysis Platform

Work Packages

- WP II.6 – Wavefront Sensing and Control
- WP10 – Education, Outreach and Citizen Engagement

Our **main contributions** are concentrated in

- DIV 07 (Stellar Collapse and Isolated Neutron Stars)
- DIV 08 (Waveforms)
- DIV 10 (Data Analysis Platform)

with additional participation in fundamental physics, cosmology, population studies, multimessenger astronomy, and synergies with other gravitational-wave observatories (ET, LISA and LVK).

Some more highlights:

- **Andrea Begnoni:** Responsible for the Coordination with Mock Data Challenges & Waveforms Development. Liaison activities between DIV 8 and 10.

- **Lorenzo Mirasola:** Wavefront sensing and control (WP II.6): Contributing to phase-camera simulations for the system under study at the University of Cagliari.

UIB Participation in ET-PP:
Preparatory Phase for the Einstein Telescope Gravitational Wave Observatory

ET-PP - Refs: European Commission Framework Programme Horizon Europe. Coordination and Support action under grant agreement 101079696. HORIZON-INFRA-2021-DEV-02, https://etpp.ifae.es/

PI: Mario Martinez, (UIB coordination: Alicia Sintes) 01/09/2022 - 30/11/2026; 3.450.000 €

The Letter of Commitment (8 November 2022) establishes UIB's participation in the ET-PP project as a third party to IFAE, providing in-kind contributions free of charge.

- Contribution: 14.4 person-months, equivalent to 0.3 FTE. Financial valuation: €42,000 in seconded personnel costs.
- Main activities:
  - WP8 – Data Analysis Model: Contributions to gravitational-wave modelling and optimisation of computational implementations.
  - WP10 – Dissemination: Major contributions to the dissemination of ET results, building on UIB's experience with LIGO and LISA.

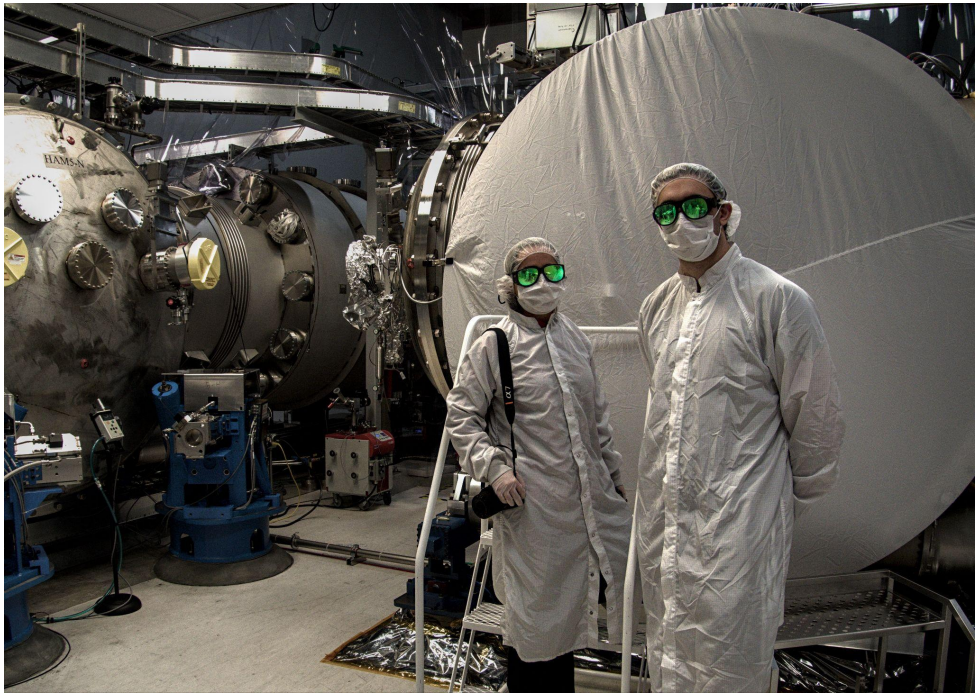
Alicia Sintes active member of:

- Et-isb-anm: Active Noise Mitigation division
- Et-eib-all - Einstein Telescope e-Infrastructure Board (Computing and Data Access)
- WP10 – Education, Outreach and Citizen Engagement

Coauthors of:

- ***Site-selection criteria for the Einstein Telescope***
  Florian Amann, Fabio Bonsignorio, Tomasz Bulik, Henk Jan Bulten, Stefano Cuccuru, Alain Dassargues, Riccardo DeSalvo, Edit Fenyvesi, Francesco Fidecaro, Irene Fiori, Carlo Giunchi, Aniello Grado, Jan Harms, Soumen Koley, László Kovács, Giovanni Losurdo, Vuk Mandic, Patrick Meyers, Luca Naticchioni, Frédéric Nguyen, Giacomo Oggiano, Marco Olivieri, Federico Paoletti, Andrea Paoli, Wolfango Plastino, Massimiliano Razzano, Paolo Ruggi, Gilberto Saccorotti, Alicia M. Sintes, László Somlai, Peter Ván, and Matyas Vasúth
  DOI: https://doi.org/10.1063/5.0018414, Rev. Sci. Instrum. 91, 094504 (2020)
- ***The Science of the Einstein Telescope***
  Einstein Telescope collaboration (including Sascha Husa, Alicia M. Sintes and Antoni Ramos Buades)
  DOI:https://doi.org/10.1088/1475-7516/2026/03/081, JCAP03(2026)081 (2026)

Detector Characterization: Current LVK activities



Research stays at LIGO Hanford – Key contributions
(most recently Mérou & Calafat*):

- identified the source of a persistent **30 Hz spectral comb** and proposed a mitigation strategy.
- Investigated **intermodulation products** to characterize nonlinearities in the detector readout chain.
- Analyzed **fast-shutter transients during lock losses** to assess photodiode protection.
- Contributed to **photon calibrator measurements** and environmental monitoring.
- Supported rapid **data-quality follow-up** of gravitational-wave candidates.

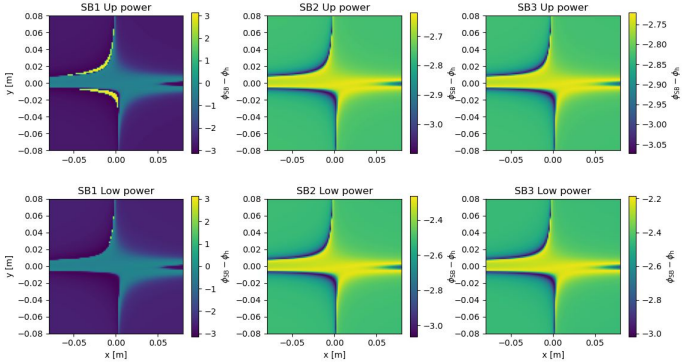
Other activities and contributions
(Ball, Mérou, Calafat, Mirasola, Keitel, Sintes):

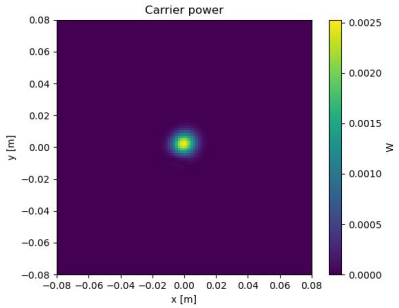
- **Noise studies:** Investigation of spectral artifacts in IR1 and O4 data.
- **Spectral line investigations:** Identification and characterization of instrumental lines in IR1 data, supporting all-sky continuous-wave (CW) searches.
- **Environmental coupling studies:** Analysis of magnetic-field transients associated with lightning as a potential source of correlated noise.
- **Rapid Response Team:** Human vetting of low-latency public alerts during IR1.
- **CW hardware injections:** Contribution to the IR1 hardware injection parameters & revision.

[*] previous site fellows: M. Oliver, P. Covas, R. Tenorio, R. Jaume

Developing a pixelated phase camera for ET

Lorenzo Mirasola (UIB) in collaboration with the Cagliari group





- **Phase camera (PC) aim**:
  - study **phase and power profiles** of laser circulating in the interferometer
  - link Higher Order Modes (HOMs) to defects/aberrations/misalign of mirrors
- **Status**:
  - current PC setups scan the laser profile **one "pixel" at a time**
  - **INFN Cagliari** group currently developing a **pixelated PC for ET**
  - the new approach should **improve the performance** of PCs in terms of **spatial and timing accuracy**
- **Status and contributions**:
  - throughout 2026, several previously missing elements have been added to the lab
    - work ongoing and experimental setup not yet "frozen"
  - simulations of optical setup implemented in Cagliari in finesse **(LM)**
  - effort to update code infrastructure from Finesse 2 → 3 and be ready to simulate final setup **(LM)**
- **Future aims**:
  - direct comparison between simulations and experimental results
  - induce deformations in optical elements (e.g. warming up a mirror) and study effects on phase maps

Potential Collaboration with the UIB Meteorology Group – LIDAR (*Light Detection and Ranging*) for Einstein Telescope



- **Atmospheric monitoring:** Interest in deploying a LIDAR system, potentially complemented by a cloud camera, to monitor atmospheric conditions at the ET site.
- **Turbulence characterization:** Measurement and modelling of atmospheric turbulence to estimate its impact on telescope performance and derive correction strategies.
- **Data analysis and interpretation:** The UIB Meteorology Group brings experience in LIDAR data analysis, atmospheric boundary-layer dynamics, wind measurements and aerosol characterization.
- **Long-term monitoring:** Ideally, LIDAR should be operational from the early construction phase to characterize site-specific turbulence and identify seasonal and daily patterns.
- **Scientific collaboration:** Joint analysis of atmospheric measurements, including potential contributions to the modelling and mitigation of atmospheric Newtonian noise.

BSAI: Balearic Islands Center for Supercomputing and Artificial Intelligence

Centre de Supercomputació i Intel·ligència Artificial de les Illes Balears



BSAI provides strategic computing infrastructure at the University of the Balearic Islands (UIB), supporting scientific research and innovation through high-performance computing (HPC), data storage, Artificial Intelligence (AI) and Big Data.

Funding and infrastructure development:
Supported by the Government of the Balearic Islands, the Spanish Ministry of Science and Innovation, the UIB and the European Union (NextGenerationEU).

Key initiatives with IAC3-Gravity group funds include:

- **SINCO 2022/18146 – HiTech-IAC3-BIO**
- **SINCO 2022/6719 – Advanced Technologies for Exploring the Universe and its Components:** Computing resources for gravitational waves physics, within the Complementary Plan for Astrophysics and High-Energy Physics.
- **AI and Big Data infrastructure:** Specialized computing resources for artificial intelligence and large-scale data analysis.

TalaIA @ BSAI is also part of RES (Red Española de Supercomputación), contributing to the Spanish network of advanced research computing infrastructures.

Centre de Supercomputació
i Intel·ligència Artificial
de les Illes Balears

TalaIA @ Balearic Islands Center for Supercomputing and Artificial Intelligence

Infraestructura	Avaluació	% recurs (temps de càlcul)		Descripció	Protocol d'Accés
Supercomputació	Exante	45%	15%	UIB	Comitè d'Accés BSAI
			10%	Ecosistema CTI-IB i Teixit productiu de les Illes Balears	
			20%	Red Española de Supercomputación	RES
	Expost	55%	40%	Projectes Estratègics Recerca en Astrofísica i Física d'Altes Energies	Consell Rector
			10%	Projectes de l'Administració de la CAIB, les seves entitats del sector públic instrumental i EELL	
			5%	Projectes estratègics discrecionals direcció	Direcció BSAI
GPU	Exante	55%	25%	UIB	Comitè d'Accés BSAI
			30%	Teixit productiu de les Illes Balears i Ecosistema CTI-IB	
	Expost	45%	40%	Projectes de l'Administració de la CAIB, les seves entitats del sector públic instrumental i EELL	Consell Rector
			5%	Projectes estratègics discrecionals direcció	Direcció BSAI

Section Break (Next Page)

TalaIA – Technical Specifications

- Peak performance: 2 PFLOPS (FP64) / 4.38 PFLOPS (FP32).
- CPU: 52 compute nodes, featuring AMD EPYC 9655 processors (192 cores per node), including 4 high-memory nodes (1.5 TB RAM).
- GPU: 9 nodes with 42 NVIDIA GPUs (B200, H200 and L40S), optimized for AI and accelerated computing.
- Storage: Over 2 PB of high-performance shared storage (NVMe + HDD).
- Networking: High-speed, low-latency InfiniBand interconnect (200 Gbps per node).
- Software: Rocky Linux 9, Slurm workload manager and standard HPC/AI libraries and compilers.

TalaIA is a versatile, high-performance supercomputer designed to support scientific computing, large-scale simulations, AI and data-intensive research.

Education, Outreach and Citizen Engagement









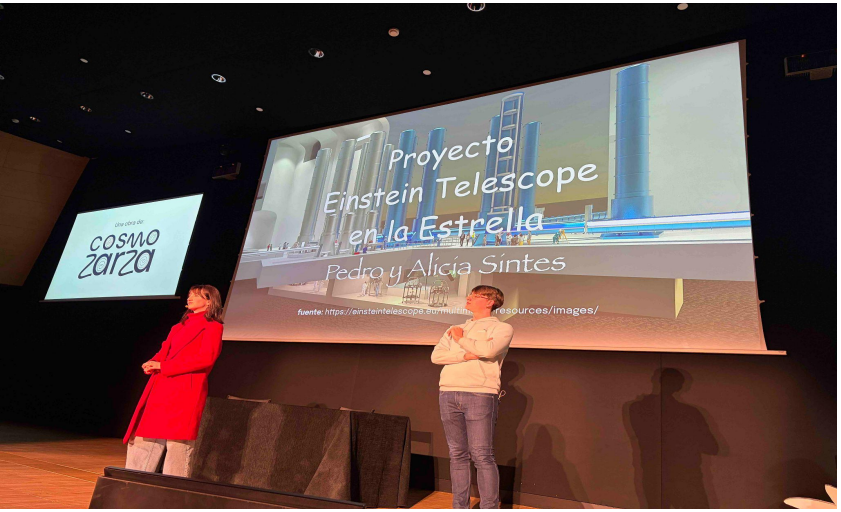


- 160+ outreach activities across 70 events in the past five years, reaching thousands of people locally, nationally and internationally.
- Participation in major science festivals, public lectures, school visits, hands-on workshops and educational initiatives.
- 400+ media appearances and numerous science communication publications.
- Close collaboration with the UIB Communication Office to produce press releases.
- Active group and institute websites, and social media presence.
- Production of audiovisual and graphic materials.

Education, Outreach and Citizen Engagement

- **“La medición de un sueño”** is a fascinating and rather unusual production: a scientific zarzuela promoting Einstein Telescope created by La CosmoZarza, with the support of Apadrina la Ciencia and Universidad Carlos III de Madrid.
- It premiered at the **CosmoCaixa Science Museum in Barcelona** on 7 March 2026, as part of the XXVII Exporecerca Jove Awards.
- In September 2026, it was also performed in Galicia during the European Researchers’ Night, reaching around 300 secondary-school students and members of the general public.









Education, Outreach and Citizen Engagement

Recent science communication articles:

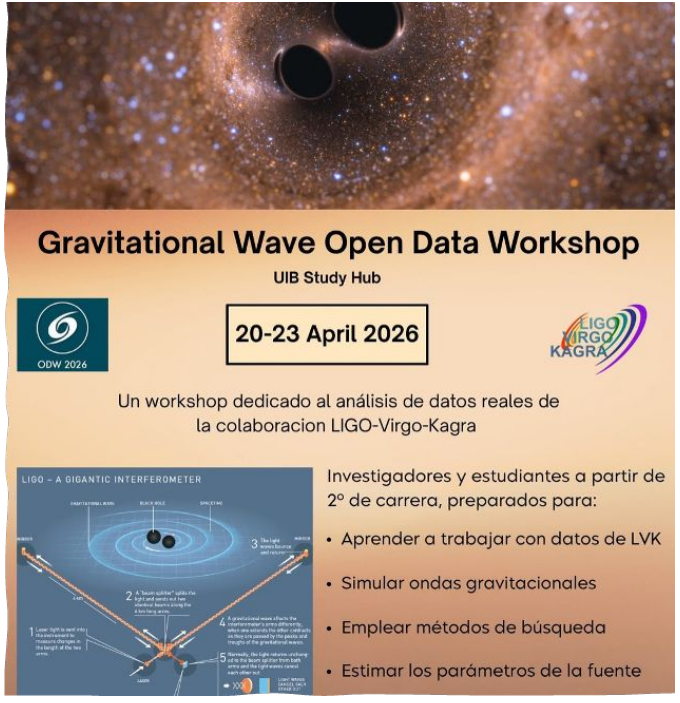
- **Calafat, A.; Mérou, J.-R.** *From Mallorca to LIGO Hanford: Three Months as LIGO Fellows.* **LIGO Magazine**, núm. 29. (Sep 2026)
- **Calafat, A.; Mérou, J.-R.** Article publicat al **núm. 129 de la revista TELOS**, 12/02/2026. [Article TELOS]
- **Mérou, J.-R.; Rosselló, M.; Valencia, J.; Sintes, A. M.** *El legado de una década de ondas gravitacionales.* **Boletín SEA**, núm. 53, hivern 2025, 19/12/2025. ISSN 1575-3476. [Boletín SEA2025]
- **Calafat, A.; Mérou, J.-R.** *De Mallorca a LIGO: descifrando el lenguaje del universo.* **The Conversation**, 24/11/2025. **Article premiat.** [Article https://theconversation.com/de-mallorca-a-ligo-descifrando-el-lenguaje-del-universo-269946]
- **Covas, P. B.; Keitel, D.** *Ondas gravitacionales: 10 años después de la primera detección directa.* **Revista Española de Física**, vol. 39, núm. 3, juliol–setembre 2025, p. 1–7. **Article premiat per la RSEF-BBVA.** https://revistadefisica.es/index.php/ref/article/view/3163
- **Sintes, A. M.** *El gran día de las ondas gravitacionales: una década escuchando señales invisibles del universo.* **The Conversation**, 11/09/2025. DOI: 10.64628/AAO.nujg5jqjp. ---
- **Ramos Buades, A.; Amengual, R. J.; Jiménez Forteza, X.** *Los ecos del espacio-tiempo.* **Astronomía Magazine**, 30/08/2025. Article complet publicat al número de setembre de 2025. [Article: https://www.globalastronomia.com/los-ecos-del-espacio-tiempo/]

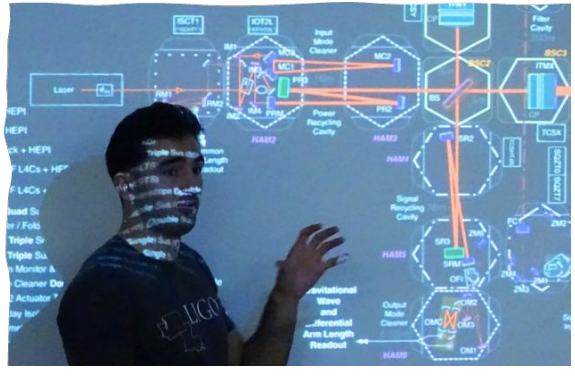
Other collaborations:

- **ProyectoSTEM (2023–2024):** Co-development of an educational game highlighting women in STEM. ProyectoSTEM – Investigadoras.
- **Natural Sciences Museum of Barcelona (2026):** Contribution to videos and podcasts for the exhibition *The Invention of Time,* curated by Ricard Solé and hosted at the Centre Martorell d'Exposicions.
- **International science outreach**: A Sintes served as an ambassador for the **Instituto Cervantes,** delivering talks and public engagement activities on gravitational waves
- **Territorio Gravedad (CSIC–IAA):** Participation in a documentary series co-produced by IAA-CSIC and Lipssync Medialab, exploring gravity and the universe. Alicia Sintes and Sascha Husa feature in episodes on gravitational waves, the first detection, and future missions such as LISA and Einstein Telescope (ET).

LVK activities:

- Panagiota Kolitsidou Co-Deputy Chief Editor of the LIGO Magazine,
- Organization of the UIB study Hub for the Gravitational Wave Open Data Workshop
- Science Summaries, translations, etc.





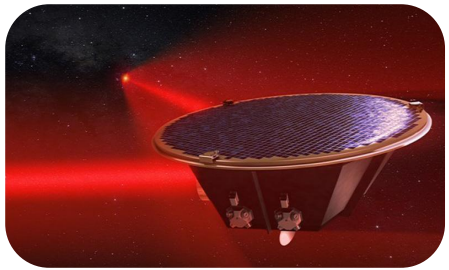
Some more highlights of UIB participation in ET

- **Editorial and scientific review:** Reviewing scientific talks, publications, and waveform models.
- **Waveform development (DIV 08):** Developing and improving IMRPhenom and JAX waveform models, including eccentricity and tidal effects, and computationally efficient templates for BNS and NSBH systems. Contributing to common waveform modelling, reviews, interfaces, and coordination with Mock Data Challenges (MDCs) across ET, LISA, and LVK.
- **Continuous gravitational waves and neutron stars (DIV 07):** Developing search and parameter-estimation pipelines for continuous gravitational waves and long-duration transients from isolated and binary neutron stars, glitches, magnetars, and supernovae. Conducting sensitivity studies, investigating neutron-star properties, gravitational lensing, and developing machine-learning methods.
- **Data analysis and Mock Data Challenges (DIV 10):** Developing and validating analysis software for continuous gravitational-wave searches, adapting LALPulsar-based codes to ET MDC formats, performing sensitivity studies, and supporting MDC data generation and validation.
- **Fundamental physics (DIV 01):** Searching for dark matter candidates and developing methods to detect gravitational-wave nonlinear memory and orphan memory signals.
- **Cosmology (DIV 02):** Developing data-analysis techniques for synergies between gravitational waves (GW) and large-scale structure (LSS).
- **Population studies (DIV 03):** Simulating isolated binary populations and providing catalogues for injection studies, merger-rate estimates, and electromagnetic counterpart predictions.
- **Multimessenger astronomy (DIV 04):** Developing unmodelled burst-search pipelines for targeted searches using electromagnetic and neutrino triggers.
- **Synergies with other gravitational-wave observatories (DIV 05):** Investigating synergies between LISA and ET.
- **Stellar collapse and neutron-star instrumentation (DIV 07):** Improving burst and continuous-wave search sensitivity and developing methods to study neutron-star signals.
- **Wavefront sensing and control (WP II.6):** Contributing to phase-camera simulations
- **Coordination and inter-division activities:** Coordinating with Mock Data Challenges and facilitating liaison activities between DIV 08 (Waveforms) and DIV 10 (Data Analysis).
- **Education, outreach and citizen engagement (WP10):** Participating in and organising gravitational-wave outreach activities in Spain.

UIB contributions so far: data analysis and astrophysics

- ET bluebook (arXiv:2503.12263):
  - O. Piccinni co-coordinator of chapter 7 (under previous affiliation)
  - 4 UIB co-authors (Gonzales, Husa, Ramos-Buades, Sintes)
    The Science of the Einstein Telescope
- Leadership in phenomenological waveforms project.
- Leadership of several key LVK software packages that can transition seamlessly to ET applications.

- Significant overlap in science requirements for ET and LISA,
  with substantial UIB contributions also to LISA:
  - science team member and several WG chairs
  - 2 co-authors of the redbook (arXiv:2402.07571)
  - 4 co-authors of waveforms white paper (LRR28, 9 (2025)).

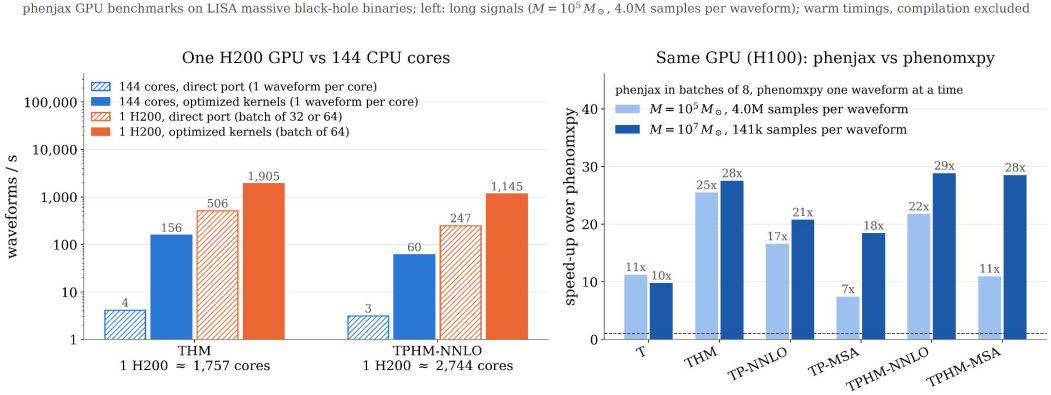


UIB contributions: waveform modeling

- LISA and ET both require efficient and precise long-duration waveforms → data analysis challenges:
  - overlapping signals (LISA global fit problem)
  - long signals, cannot neglect detector motion: learn from experience with CW signals
- Contributions to OSB Div-8 (waveforms)
  - 9 contributors with 1.62 FTE (0.18/contributor)
  - IMRPhenomXPHM is the standard waveform model for explorations of observability and comparison of detector designs within the ET collaboration.
  - Synergies with contributions to LISA DDPC, LISA Consortium, LVK (IGWN)
  - Contributions pledged to “integration” activities:
    - Common tools between ET, LISA and LVK for waveform systematics
    - Common waveform reviews
    - Common waveform interface for ET, LISA and LVK
    - Coordination with Mock Data Challenges (MDCs)
- Close collaboration with ICE-CSIC group (Husa, Estellés; Brandoli on systematics)

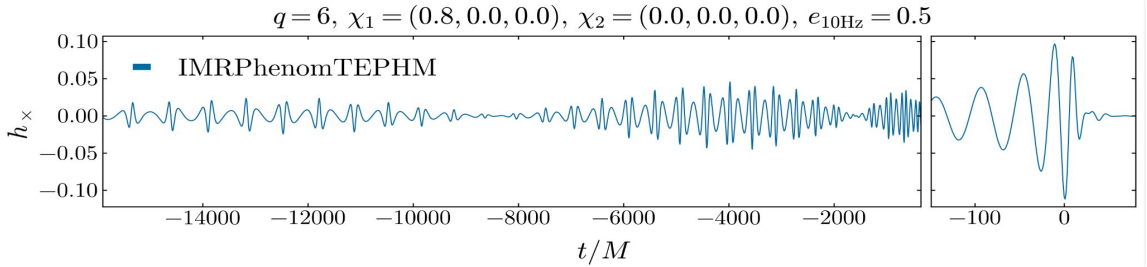
Waveform modeling progress at UIB: BBHs I

- **Frequency domain: IMRPhenomX* - unparalleled computational efficiency**
  - IMRPhenomXPHM [Pratten+ PRD103,104056 (2021)] - LVK workhorse since O3.
  - **State of the art: IMRPhenomXPNR** [Hamilton+ arXiv:2507.02604] from O4b on:
    NR-calibration + accurate PN inspiral from IMRPhenomXPHM-SpinTaylor [Colleoni+ PRD111,104019 (2025), Estellés+arXiv:2609.10345].
  - "Fast eccentricity" for long WFs: IMRPhenomX**E** [Ramos+PRD113,083044(2026)]
- **Time domain versions facilitate incorporation of new physics**: Next slide!
- **New code base: phenomxpy, GPU support**
  - https://gitlab.com/imrphenom-dev
  - Even faster JAX versions in development: Andrea Begnoni

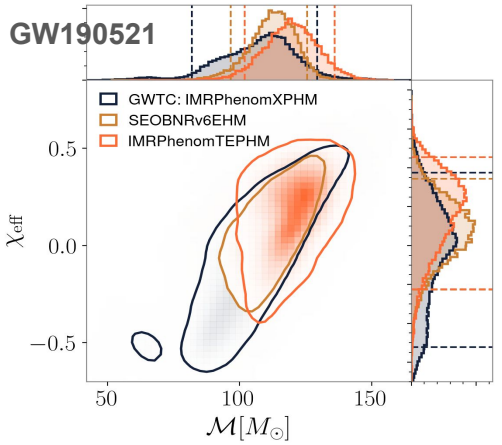


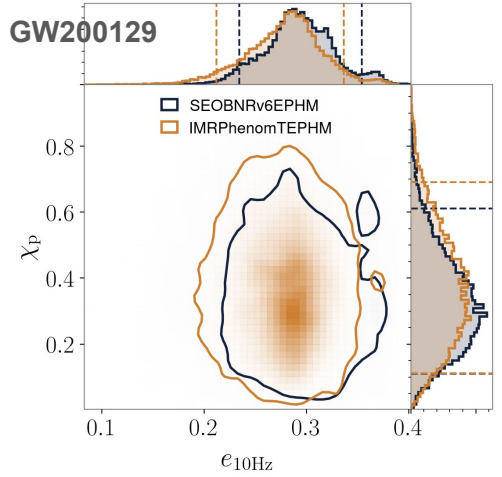
BBHs II: time-domain Phenom models facilitate modeling of complex physics

- **Eccentric BBHs:** IMRPhenomT**E**HM [Planas+ arXiv:2503.13062] (already used in analysis of O3 & O4 BBH & NSBH events: Planas+ arXiv:504.15833, arXiv:2506.01760, more in progress) Eccentric precessing model IMRPhenomT**EP**HM [Valencia+]



- To be published jointly with upgrades to precession treatment this month: Estellés+, Kolitsidou+, Hamilton+.
- Including GW memory: IMRPhenomTHM**_20** [Rosselló+ arXiv:2405.17302, Valencia+ arXiv:2406.16636, Rosselló+ arXiv:2506.05859, Rosselló+ arXiv:2506.08888]

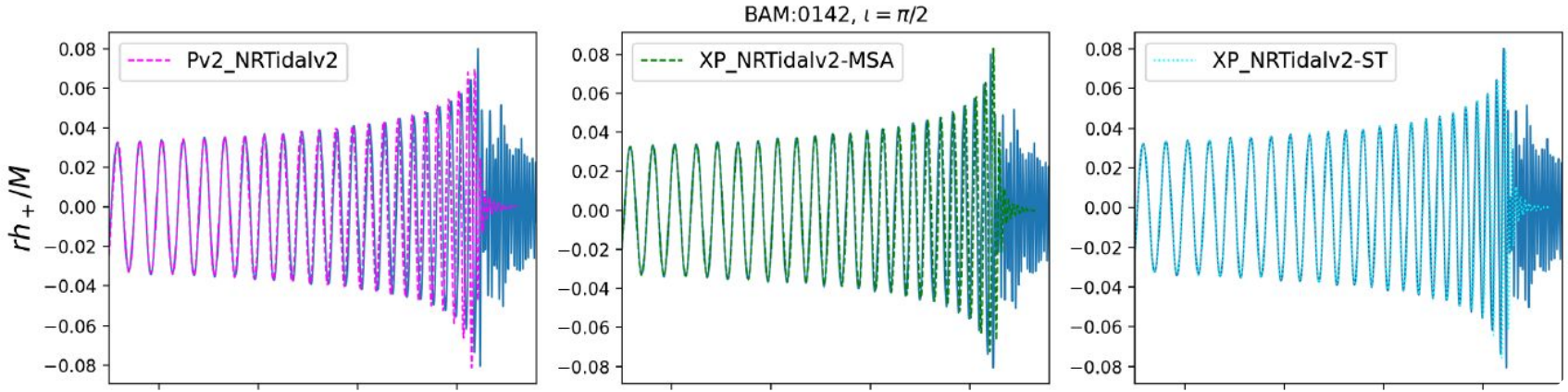




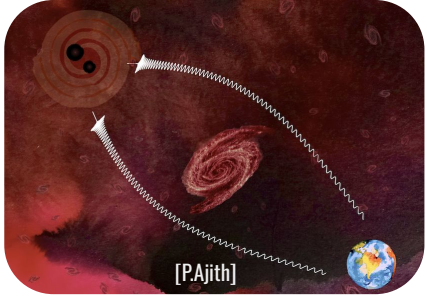
Waveform modelling progress at UIB: BNS/NSBH



- Mergers including neutron stars are of highest interest for multi-messenger astronomy.
- But more difficult to model than BBHs due to matter effects.
- Latest models:
  - BNS: IMRPhenomXP_NRTidalv2/3 [Colleoni+PRD111,064025 (2025),Abbac,Ramis+PRD112,104026(2025)] including tidal corrections and precessing spins.
  - NSBH: IMRPhenomXPHM_NSBH [Ramis+PRD**114**,064044(2026)] highly efficient precessing-spin neutron-star black-hole model.



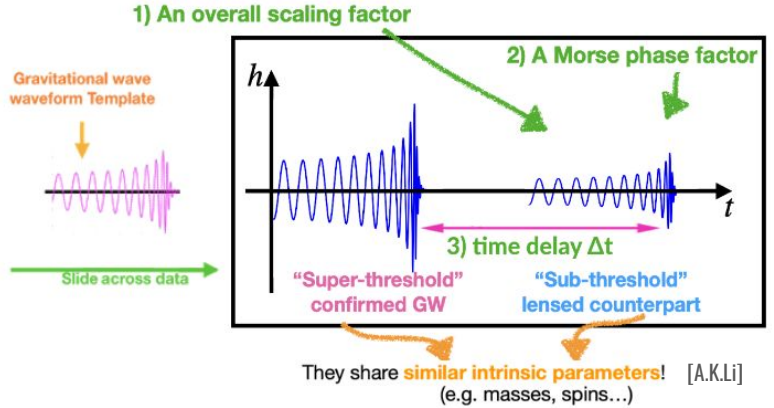
UIB contributions: gravitational lensing



- ET will enable sufficient event rates for regular and high-confidence lensing observations.
- Work at UIB so far focused on short-term LVK applications, but all developed methods translate naturally to ET.
- Migration of pledged effort from LVK to ET will be progressive over the coming cycles.

Results so far:

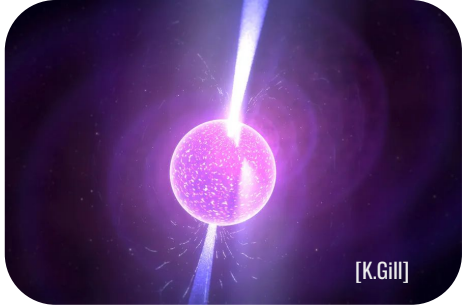
- waveform systematics in lensed candidate identification [CQG 41, 015005 (2023)]
- breaking the mass-sheet degeneracy with wave-optics lensing [PRD 110, 123015 (2024)]
- GW230529 as possible lensed BNS [MNRAS 537, 1001–1014 (2025)]
- multi-messenger lensing science cases [PTRSA 383, 2295, 2024.0134 (2025)]
- lensing false alarm rates [PRTSA 383, 2295, 20240128 (2025)]
- lensing rate simulations [JOSS11(124),7420 (2026)]
- PyCBC sub-threshold search for faint lensed counterparts to GWTC-4.0 events [arXiv:2512.16347]



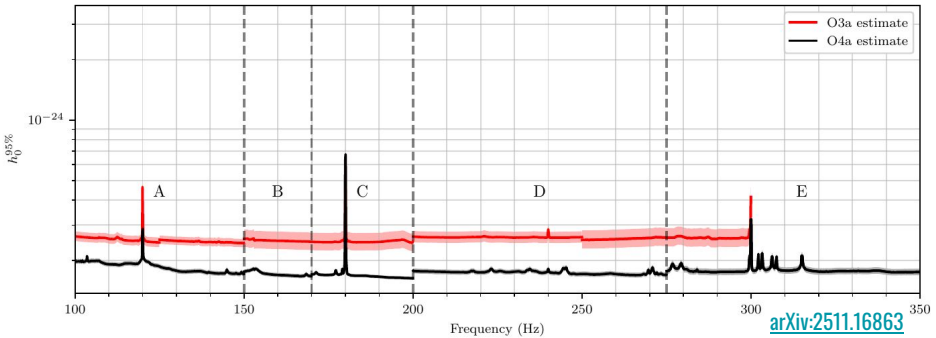
Ongoing / near-future work:

- fully coherent sub-threshold searches
- accelerated multi-image joint inference with GMMs and sequential MCMC
- low-latency joint sky localisation
- DINGO-lensing (neural posterior estimation)
- lensed continuous waves

UIB contributions: continuous waves (with LVK)



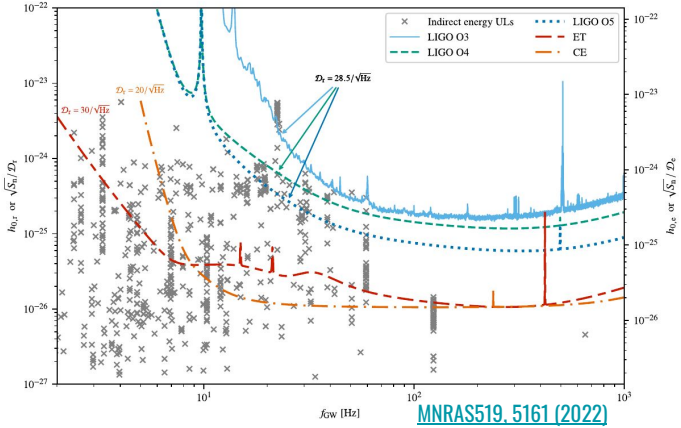
- Long-term leadership in the LVK CW working group
  (A.M. Sintes co-chair 2016-2018, D. Keitel since 2022, O. Piccinni since 2026).
- D. Keitel lalpulsar co-maintainer, O. Piccinni BSD/SNAG core developer
- Blind all-sky searches for neutron stars in binaries
  (the computationally hardest possible search type!):
  - O3a data [LVC PRD 103, 064017 (2021)]
  - O4a (LVK) [arXiv:2511.16863]
  - using GPUs at MareNostrum
    w. FastTracks pipeline [PRD111, 104002 (2025)]



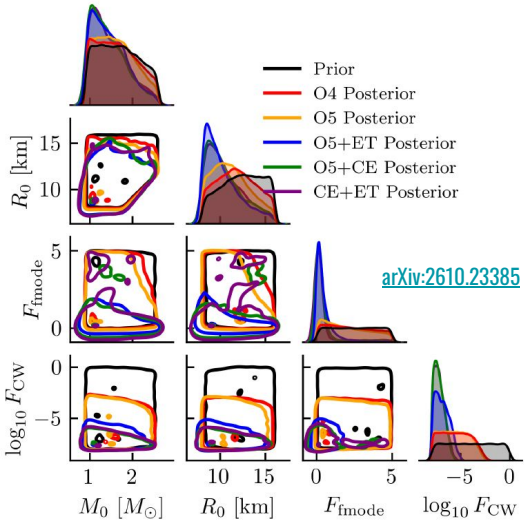
- PyFstat: package for Bayesian follow-ups, GPU-accelerated transient searches, etc:
  github.com/PyFstat/PyFstat/ [JOSS 6(60), 3000 (2021)]
- Known pulsars and pulsar glitches
  [Astrophys. J. 1005, 221 (2026) led by L. Mirasola, Astrophys. J. 1005, 12 (2026) led by D. Keitel]
- Directed NS searches [Astrophys. J. 1004, 204 (2026)], dark matter and PBH searches (O. Piccinni)

UIB contributions: continuous waves (with ET)

- Detection and astrophysical inference prospects for glitching pulsars: Lopez+ PRD106, 103037 (2022), Moragues+ MNRAS519, 5161 (2022), Ball&Keitel arXiv:2610.23385 and for quiescent NSs (ongoing work with Strozyk, Bulik)



MNRAS519, 5161 (2022)

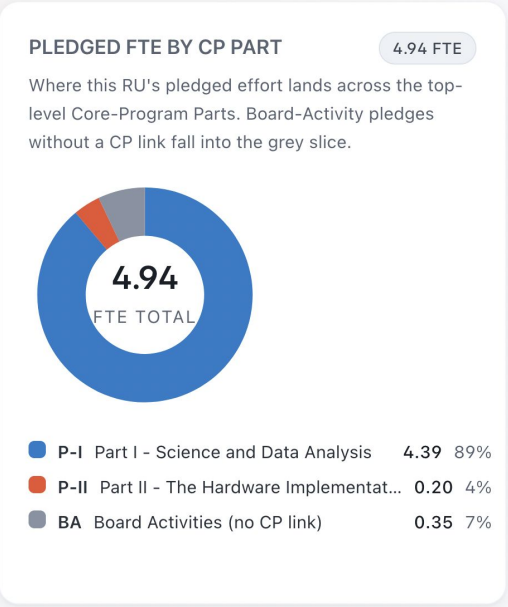


arXiv:2610.23385

- Committing to review of CW implementation in ripple and gwmock for 2nd ET MDC (Covas, Rodriguez & Keitel with Strozyk, Wong) → also a great opportunity for ET–IGWN synergies
- Planning to participate in MDC analysis with at least one pipeline.

Summary and outlook

- GRAVITY-UIB RU: 25 members (8 faculty, 9 postdocs, 8 PhD students); 21 core; 4.94 FTE Total



- Contributions in waveform modelling, data analysis, detchar, hardware, computing, outreach, management
- Many synergies between ET, IGWN, and LISA projects at UIB and potential for migrating additional IGWN development work to ET over future pledge cycles.
- We want to ensure alignment of overall strategic priorities and funding strategies across the Spanish community.

Acknowledgments

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