PLANES COMPLEMENTARIOS

Astrofísica y física de altas energías

Línea 3. Experimentos de ondas gravitacionales y astronomía de multi-mensajeros

Line 3. Gravitational wave experiments and multi-messenger astronomy.

Overview + status LIGO-Virgo-KAGRA

Alicia M. Sintes. Universitat de les Illes Balears

Financiado por la Unión Europea NextGenerationEU

Gobierno de España · Ministerio de Ciencia, Innovación y Universidades

Plan de Recuperación, Transformación y Resiliencia

Generalitat de Catalunya · Junta de Andalucía · Gobierno de Cantabria · Generalitat Valenciana · Gobierno de Aragón · Govern Illes Balears

Objectives

The objectives of this line include aspects of instrumentation, computation and methodologies of analysis and scientific exploitation of data from ground-based and space-based gravitational wave experiments, as well as the combination with data from telescopes at different frequencies of the electromagnetic spectrum and neutrino telescopes (multi-messenger astrophysics).

The Autonomous Communities involved are Catalonia (CAT), Valencia (CV) and the Balearic Islands (IB)

- *The groups involved are aiming for leadership in their participation in LIGO-Virgo-KAGRA, ESA's LISA mission and the Einstein Telescope (ET) observatory, included in the European ESFRI-2021 roadmap.*
- *The groups are embarking on the development of advanced computing techniques for simulations and data mining, including artificial intelligence aspects; on the development and optimization of Advanced LIGO (aLIGO) and Advanced Virgo (AdV) data processing and data flow; and on the definition of the future data processing and management system and distribution of ET alerts.*
- *In parallel, new instrumentation technologies are being developed for the AdV, ET and LISA interferometers.*

Contributions and synergies

- CAT, CV and IB share interests in areas related to the participation in the commissioning and observations of LIGO-Virgo-KAGRA, and in the characterization, analysis and scientific exploitation of the data from the detector network. Synergies have also been identified in areas related to the development of advanced computational techniques and artificial intelligence.
- CAT, CV and IB participate in activities of the Observational Science Board and Instrument Science Board of ET.
- CV and IB are involved in searches for electromagnetic counterparts of gravitational signals.
- CV and IB develop advanced computing techniques for numerical simulations and machine learning and data mining.
- CAT and IB are involved in the definition of the data processing and management system and distribution of ET alerts; studies in cosmology, search for dark matter and tests of general relativity using gravitational waves.
- CAT contributes to instrumentation, including the development of:
  - instrumented deflectors with silicon sensors in ultra-vacuum for AdV and ET main mirrors,
  - high precision temperature and metrology sensors, including optical frequency combs, for LISA, ET and ELGAR.
- CV participates in the acquisition of new pumping stations for AdV's vacuum tubes.
- CV and IB develop R&D activities in computational astrophysics focused on the numerical modeling of various waveforms.

Cataluña

ICE (CSIC)
ICC-UB
IFAE

ICE contribution to LIA3

The main objectives of the Institute of Space Sciences (ICE, CSIC) contribution to LIA3 are:

1. **Development of the LISA SDS**
   - The Gravitational Astronomy group at the leads the Spanish contribution to the LISA. This contribution is the Scientific Diagnostics Subsystem (SDS), one of the three main payload subsystems.
   - The SDS is the set of precision temperature sensors, magnetometers and radiation monitors monitoring the environment of the LISA constellation.
   - LISA (and SDS) successfully passed the Mission Adoption milestone (Jan. 2024). Currently undergoing phase B1, next milestone for SDS is PDR (Q2 2025).

2. **Development of opto-mechanical precision measurement techniques**
   - Opto-mechanical resonators are used in a wide variety of fields to achieve
   - Our group is pushing forward a research line to develop high precision metrology techniques in the framework of GW detection
   - In this context, we are developing an opto-mechanical based temperature sensor to reach ground-breaking sensitivity, reaching the fundamental thermal noise limit of the sensor itself and achieving 50 nK/sqrt(Hz) in the millihertz band.
   - First milestone of purchasing, implementing and characterisation of the optical setup is already done. Next step is moving to vacuum operations and low frequency performance.

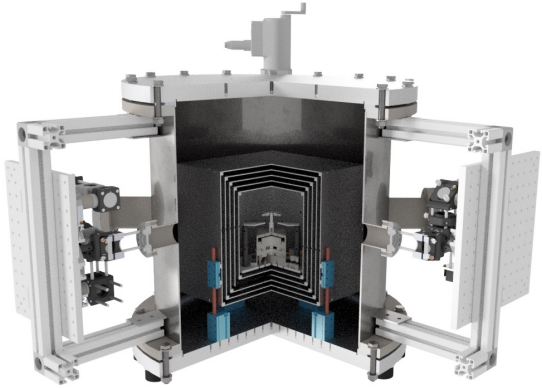
ICE contribution to LIA3

Personnel: Currently two people hired through LIA3 funding:

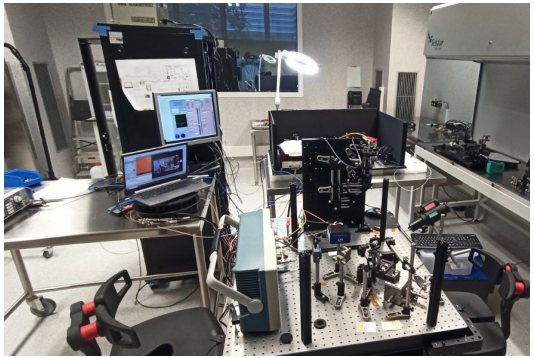
- Dr. D. Roma – Elec. Engineer, SDS system engineer
- Ivan Martín – PhD student, LISA data analysis

Equipment: Funding (200k€) dedicated to:

1. Development the LISA SDS
   - Acquisition of magnetic shielding unit and degaussing unit – done
   - Acquisition of impedance analyser – done
   - Temperature control subsystem – purchase on-going
2. Development of novel precision
   - Vacuum chamber and isolation structure – assembly on-going
   - Acquisition of opto-mechanical resonators – done
   - Acquisition of optical elements and optical equipment – done



Rendered sketch of the vacuum chamber, coupling boards, thermal shields and WGMR/prism mounts



Assembly work at the ICE clean room

ICCUB contributions to GW experiments

- ICCUB (Institut de Ciències del Cosmos, Universitat de Barcelona)
- LIA3 budget for ICCUB: 470k€
  - 100k€ reserved for Virgo fees
- Personnel involved: 9
  - 5 part-time seniors, as supervisors
  - 1 post-doc (P. Barneo), hired Feb'24
  - 1 PhD researcher (G. Skorobogatov), hired Aug'23
  - 1 non-PhD researcher (J. Trenado), hired Oct'23
  - 1 engineer / pre-doc (P. Jasal), hired Jan'24
- Investment: 4 part-time seniors

- Objectives:
  - **Transfer the know-how** of the ICCUB Technology Unit to ongoing and future GW projects
  - Better usage and monitoring of **LVK computing** resources
  - Improve **sensitivity and accuracy** of O4 and O5 LVK runs
  - Bootstrap the **computational and data analysis approaches** for ET and LISA
- Tasks and activities:
  - Computing and software engineering (LVK, ET, LISA)
  - Data analysis - denoising techniques (LVK)
  - Data analysis - GW templates (LVK, ET)
  - Data analysis - GlobalFit pipeline (LISA)
  - Space instrumentation - LISA radiation monitor (LIA2 engineer supporting LIA3 developments)
- Milestones:
  - Q3'24: PoC of better data formats and processing for Virgo in HPC environments
  - Q2'25: First computing and data model for ET
  - Q3'25: First design of DDPC-Barcelona hardware+software for LISA
- Main collaborations:
  - Univ. Valencia (coordinated project, national grant), mainly for Virgo/LVK
  - PIC, for ET
  - ICE/CSIC, for LISA

ICCUB Contributions to Virgo (and LVK in general)

- PPCC-funded personnel: 2 FTE/year
- Activities on data analysis, computing and outreach

- Tasks done:
  - Analysis of **glitches** in the GW strain data from LVK, creation of a **glitch templates** bank, and implementation of a **glitch removal** algorithm (instead of vetoing).
  - Revision of the irROF **denoising** algorithm and its integration in the **cWB** pipeline.
  - Support **O4a LVK analysis of GRBs** using the X-pipeline.
  - Improvements in the generation of **high-eccentricity GW templates** for LVK and ET by means of TEOBResumS-Dali model calibrations using NR-based simulations from massive Einstein Toolkit runs at the BSC.
  - Contributions to updates in the **Identity and Access Management (IAM) services** in LVK (migration to SciToken).
  - Improvements in the usage and centralised monitoring of **LVK computing resources** with HTCondor, including ElasticSearch and resolving Conda, Rucio and CVMFS issues.
  - Setup of a small HTCondor computing service at the ICCUB for local tests and small runs.
  - **Outreach** activities collaborating with the **Virgo visibility project** and the science summary review team.

- Future activities:
  - Analysis of all O3 and O4a data from LVK to **identify new glitches** and build a glitch database.
  - Optimization and improvement of the irROF **denoising** algorithm and of its integration in the cWB pipeline; analysis of O3 and O4 data to evaluate the improvement achieved in **sensitivity**.
  - Support O4a LVK routine data analysis.
  - Study more efficient **data handling and distribution** options for LVK O5+, including alternative data formats (such as HDF5) and compression algorithms.
  - Study the use of **HPC** environments for LVK data analysis.
  - Support to ICCUB scientists and engineers working on GW data analysis, including the use of Docker, Kubernetes, Conda and HTCondor.

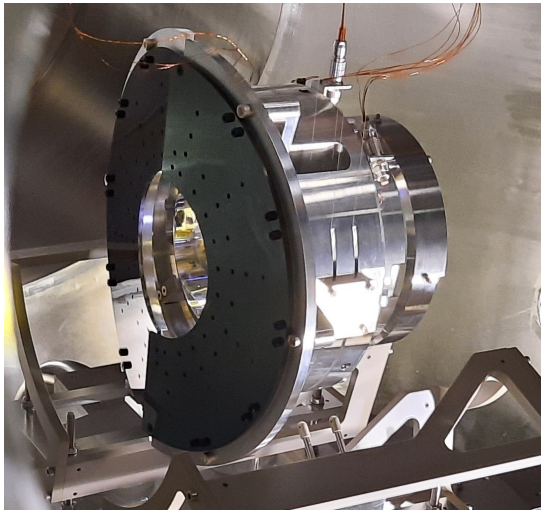
ICCUB Contributions to ET

- PPCC-funded personnel: 1.2 FTE/year
- Activities on computing, software engineering and data analysis
- Tasks done:
  - Test **data access** on ESCAPE data lake using Rucio.
  - Tests of **Stochastic pipeline** (**PyGWB-based workflows**) on ET mock data using **Rucio data lake** and **REANA** at the VRE/ESCAPE infrastructure, implementing WF definitions with CWL, Yadage and Snakemake, creating guides on how to run them on REANA.
  - Interface prototyping of **Rucio extension for JupyterLab**, adding functionality to filter datasets by metadata. Prototype implemented with Typescript and React.
  - Preparation for PyCBC-based workflow **benchmarking on GPUs** with HEPiX Benchmarking WG.
  - Improvements in the generation of **high-eccentricity GW templates** for LVK and ET by means of TEOBResumS-Dali model calibrations using NR-based simulations from massive Einstein Toolkit runs at the BSC.
- Future activities:
  - Work on **ET e-Infrastructure Board (eIB)** WP1: Development of a tool to translate HTCondor to Yadage, Snakemake workflow language.
  - Validate correctness of **CWL-based workflows** on REANA.
  - Incorporate the interface prototype into the **Rucio JupyterLab extension**.
  - Create and submit **PyCBC-based workflow** to HEPiX repository.
  - **Web form to submit workflows** to REANA without users requiring knowledge of workflow-definition languages.

ICCUB Contributions to LISA

- PPCC-funded personnel: 0.7 FTE/year
- Activities on computing, software engineering and hardware
- Tasks done:
  - Provide technical support to **LISA GlobalFit** implementation, rewriting the GBGPU library (to generate galactic binary waveforms) to JAX, simplifying its implementation and allowing it to run in Docker containers with GPU support.
  - Development of a radiation monitor for the LISA spacecrafts (LIA2 engineer partly supporting LIA3)
- Future activities:
  - Design of the hardware and software architecture of the **Barcelona DDPC for LISA** (Distributed Data Processing Center) to run a GlobalFit pipeline therein, identifying the optimal high-performance computing environment, the associated software framework and tools, and the necessary human resources to operate it.

- IFAE@Virgo
  - IFAE Operations & Hardware
  - Physics Analysis Program
- IFAE @ ET
  - Contribution to ET design and R&D



- At IFAE PC had a strong impact in the GW activities
  - Personnel (Engineers, PhD students and Postdocs)
  - Instrumentation (construction of new instrumented baffles)
  - Simulations for both Virgo and ET related to stray light control
  - R&D efforts at ET pathfinders
  - Catalysed our participation in dedicated workshops related to ET Design and R&D
- Most of the PC funds devoted to GWs have already been executed / compromised

Operations and Commissioning

IFAE took an energetic approach for the involvement in VIRGO operations since 2019

ITF commissioning /Noise hunting

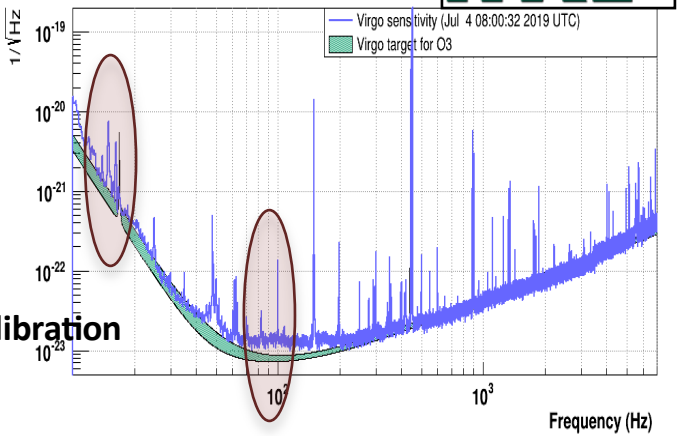
2021 + 2023 → 3+1 people @ EGO

- **IMC baffle operations**
- **ITF commissioning & h(t) calibration**
- **Magnetic Injections**

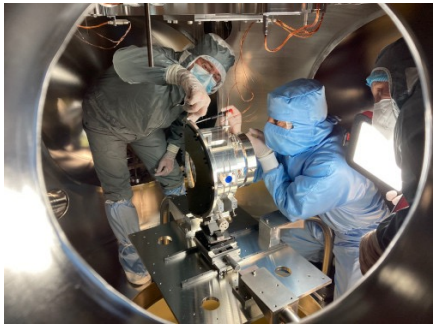
PC has been used to fund commissioning work and R&D and tests at EGO

2024 —> 2 +1 people @ EGO

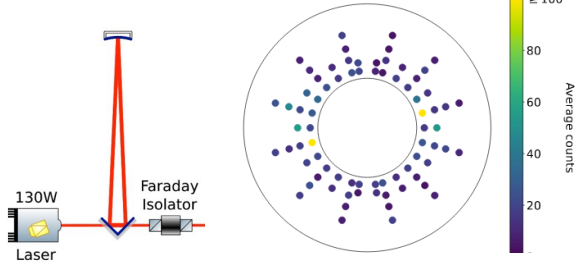
- **IMC baffle operations**
- **ITF commissioning & h(t) calibration**
- **Magnetic Injections**



Instrumented baffle @ Virgo (2021 - now)

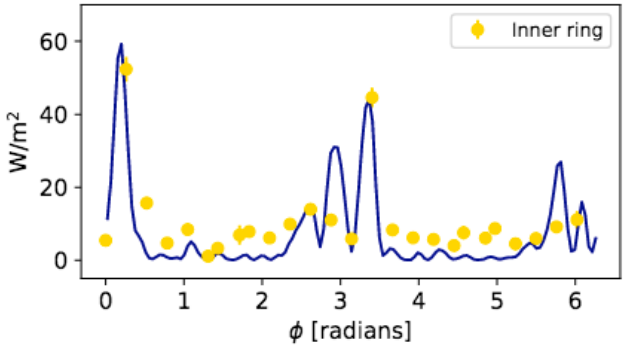


Instrumented baffle from IFAE @ Virgo —> almost 3 years of stable operation with no degradation of cavity observed

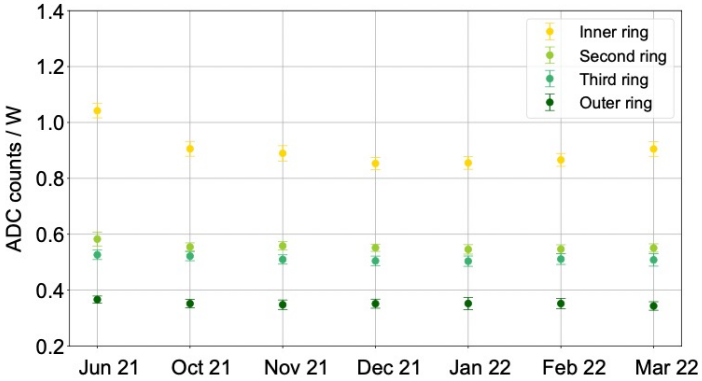


The installation of the first instrumented baffle in Virgo has demonstrated that the active monitoring of the stray light at the core optics of interferometers is feasible

O. Ballester et al., CQG 39 (2022) 115011



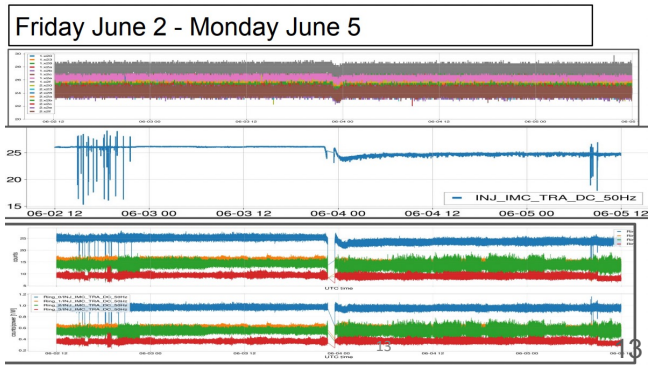
PC has been used to fund Engineers working on Virgo's new baffles



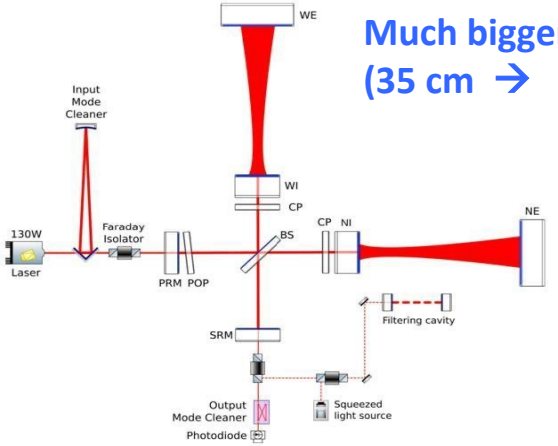
Comparison with SIS simulations of IMC

Confirmed sensitivity to mirror maps

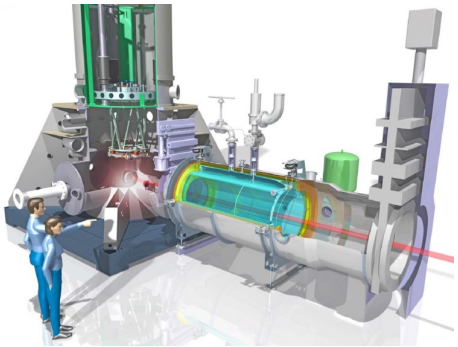
Running 24/7 stable

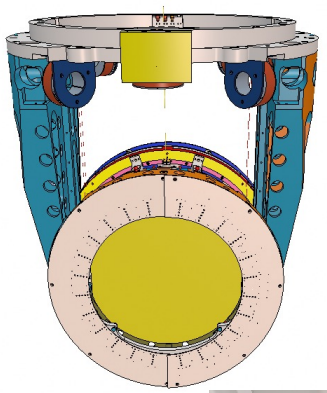


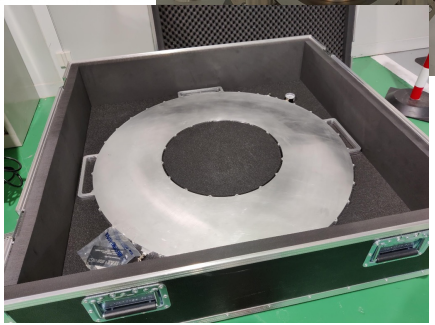
End Mirror Baffles



Much bigger than IMC (35 cm → 80 cm)

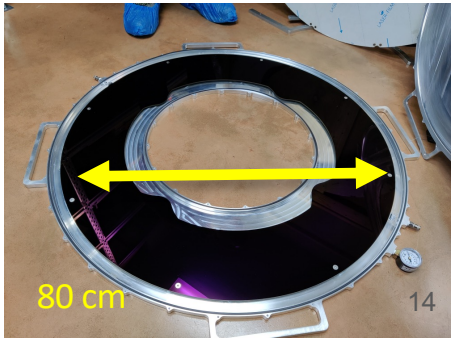






PC is instrumental to complete the construction of the baffles Both hardware and personnel

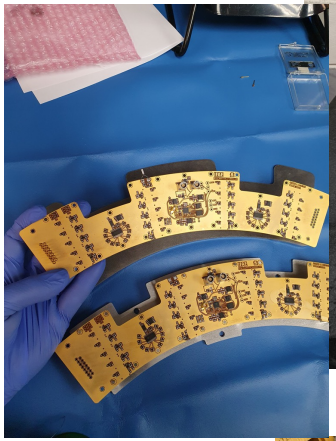
- **New instrumented baffles being produced**
  - 120 sensors distributed in 5 rings
  - New DAQ at 1kHz / serial + wireless readout
  - Further Improvements on material (starting from 316L super #10 polished)
  - Encapsulation of the FE electronics [no line of view between FE and mirror]
  - Further steps adopted in cleaning process (in house and also in industry)
  - Non-instrumented backside baffles produced and stored in coffins with N2
- **Virgo is now planning for installing the instrumented baffles at the entrance of the main tower —> this will make the project independent of potential delays in Virgo large mirrors.**

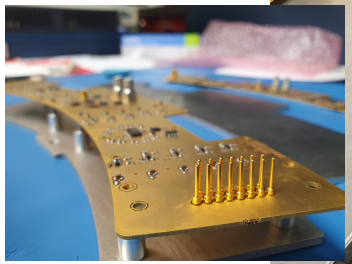


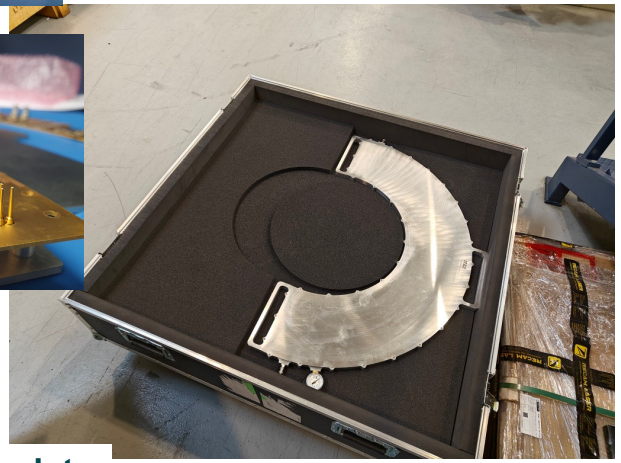
Production readiness

Decided to produce only one….

- **Baffle mechanics is essentially ready**
  - Final cleaning process taking place @ IFAE and in industry
  - Coffins for baffle preservation are being produced @ IFAE
  - Optical coating : Considering the possibility of Black-Nickel
- **Final version of PCBs are being produced**
  - Mounting Si-sensors @ IFAE
  - PCBs sent to CERN for extra cleaning
  - In parallel we are concluding the UHV certification @ CERN
  - In parallel a separate campaign for UHV certification @ EGO
  - EMI scan in industry @ IFAE campus
- **Final calibration campaign of photosensors is being launched**
  - Sensor by sensor calibration in optical setup @ IFAE
- **DAQ and Slow Control system is being finalised**





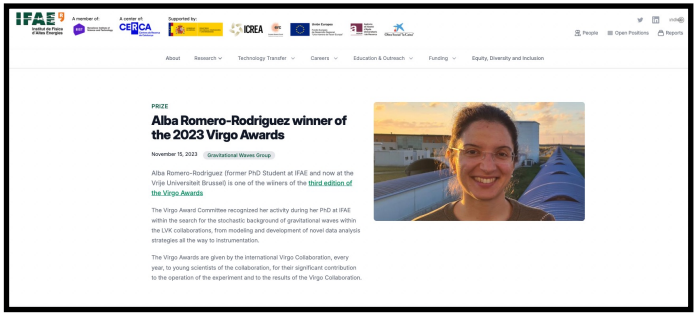


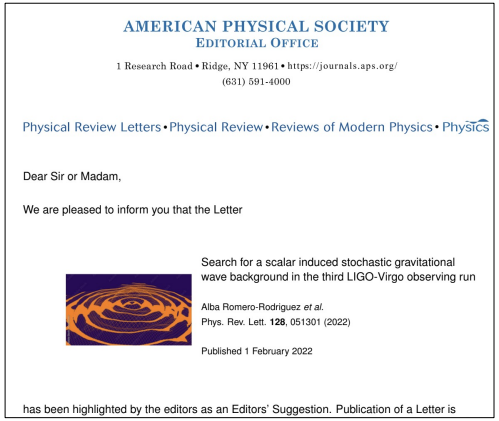
PC is instrumental to complete the construction of the baffles

IFAE Physics Analysis @ LVK & ET papers

- **A rich physics program using LVK data including a number of short-author list Q1 paper [not listing here LVK papers with many authors]**
  - **Stochastic GWs**
    - A. Romero et al., Phys. Rev. Lett. 126, 151301 (2021)
    - A. Romero et al., Phys. Rev. Lett., vol. 128, 051301 (2022)
  - **Test of GR & Cosmology using GWs**
    - G. Caneva et al., arXiv:2309.05061, accepted in PRL.
    - S. Mastrogiovanni et al., Annalen Phys. 536 (2024) 2, 2200180
    - R. Gray et al., JCAP 12 (2023) 023.
    - S. Mastrogiovanni et al., Phys.Rev.D 108 (2023) 4, 042002
  - **Search for CBC events using AI**
    - A. Menendez et al., arXiv:2401.12912, accepted in QCG.
    - M. Andres-Carcasona et al., Mon. Not. Roy. Astron.Soc. 527 (2023) 2, 2887-2894
    - A. Menéndez-Vázquez, et al., Phys. Rev. D 103, 062004 (2021).
  - **Search for Dark Matter and PBHs**
    - M. Andres-Carcasona et al., Phys.Rev.D 107 (2023) 8, 082003
    - M. Andrés-Carcasona et al., arXiv:2405.05732, submitted to PRD.
    - G. Morras et al., Phys.Dark Univ. 42 (2023) 101285

- **Also a number for Hardware and Simulations for both Virgo and ET**
  - M. Andres-Carcasona et al., Phys.Rev.D 107 (2023) 6, 062001
  - M. Andres-Carcasona et al., Phys.Rev.D 108 (2023) 10, 102001
  - A. Macquet et al., Class.Quant.Grav. 40 (2023) 7, 077001
  - O. Ballester et al., CQG 39 (2022) 115011
  - A. Romero-Rodríguez et al, 2021, Class. Quantum Grav. 38 045002
  - A. Romero-Rodríguez et al., Galaxies 10, 86 (2022)

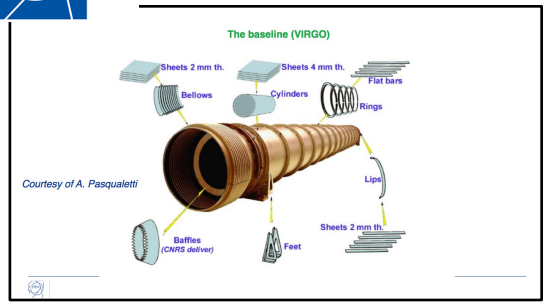


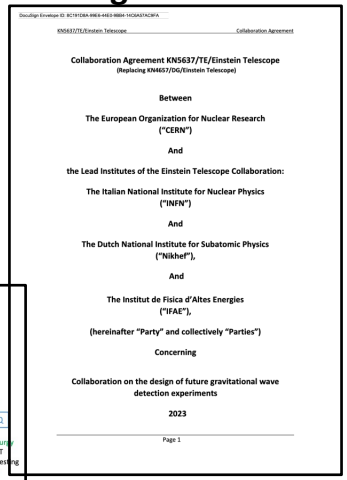


PC has been used to fund postdocs and PhD students working on GWs related aspects

ET & CE vacuum pipe design

MoU signed with CERN





Collaboration Agreement KN5637/TE/Einstein Telescope
(Replacing KN4657/DG/Einstein Telescope)

Between

The European Organization for Nuclear Research
("CERN")

And

the Lead Institutes of the Einstein Telescope Collaboration:

The Italian National Institute for Nuclear Physics
("INFN")

And

The Dutch National Institute for Subatomic Physics
("Nikhef"),

And

The Institut de Fisica d'Altes Energies
("IFAE"),

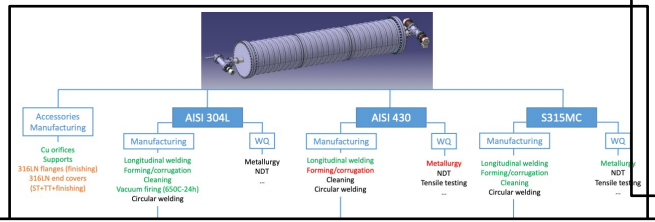
(hereinafter "Party" and collectively "Parties")

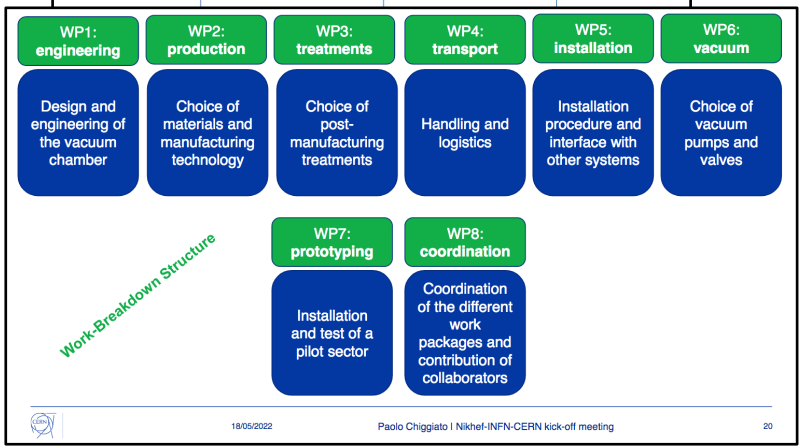
Concerning

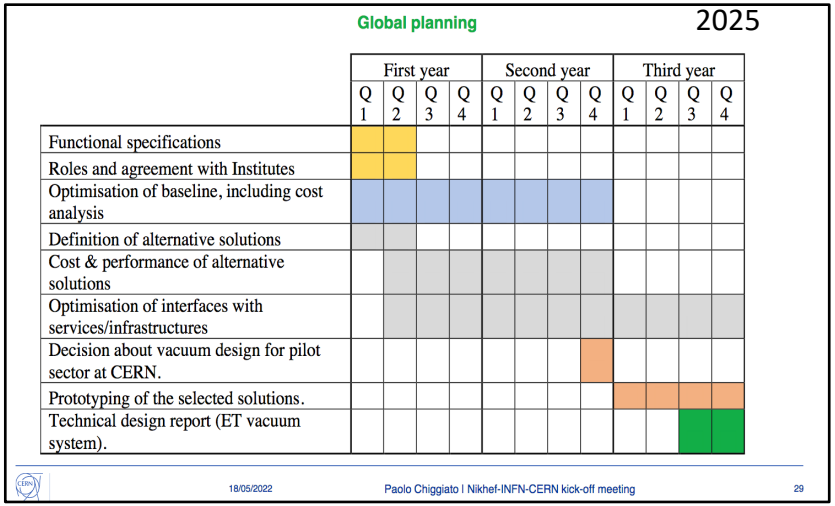
Collaboration on the design of future gravitational wave detection experiments

2023

Page 1







On-going effort led by CERN on the design of ET vacuum pipe

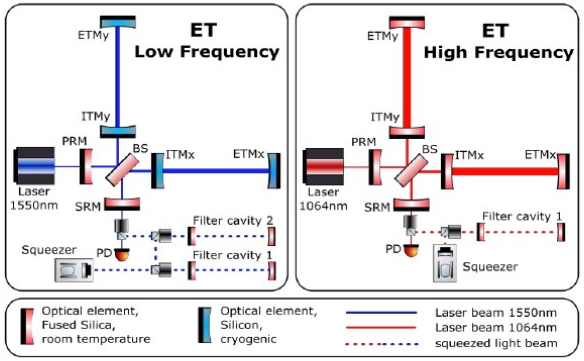
(1/3 of the total ET cost) —> Will deliver a TDR in 2 years

- Physics requirements
- Vacuum / Cryo Technology
- Civil Infra-structure
- Cost Reduction/Optimization
- Prototyping

PC will cover partially the cost of baffling strategy for the CERN prototype plus related simulation work

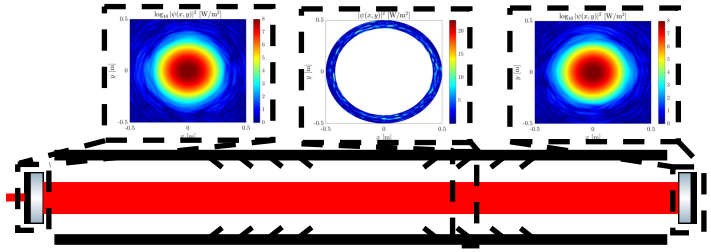
ETO is putting in place other agreements with CERN's engineering department to assist with : **civil engineering costing and review (ending 2026)** ; safety; project management tools..

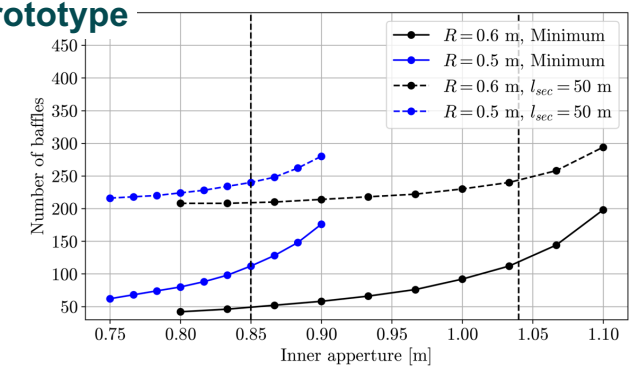
ET stray light simulations



IFO	λ	mode	mirror ⌀	R_C	w_0	z_0	w	g–factor
ET-HF	1064 nm	TEM_{00}	62 cm	5070 m	1.42 cm	5000 m	12.0 cm	0.95
ET-LF	1550 nm	TEM_{00}	45 cm	5580 m	2.9 cm	5000 m	9.0 cm	0.63

PC covered the cost of simulations for baffling strategy for the CERN prototype

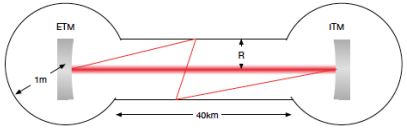


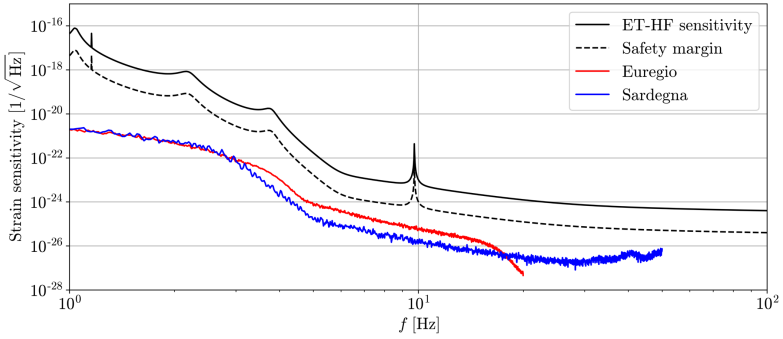


Running optical simulations to determine the best strategy for stray light mitigation in ET

—> Desire to extend it to CE

—> Running common ET/CE meetings





A joint effort with CERN on the very details of the vacuum pipe design and the baffling integration strategy, eventually including active monitoring inside the cavity

—> IFAE will build baffle prototypes

M. Andrés-Carcasona et al., Phys. Rev. D 108, 102001 (2023)

ETpathfinder(s)

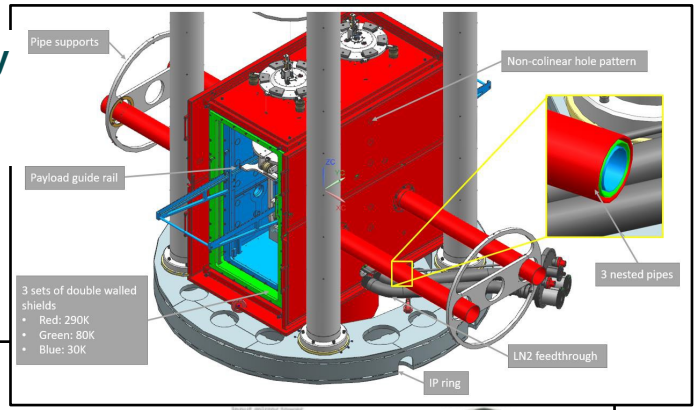
A collaboration established with Etpathfinder @ Maastricht

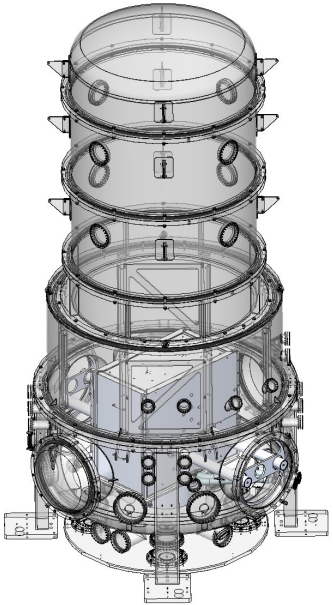
- **IFAE redesigned the cryo-shielding [paid by Nikhef]**
- **IFAE will contribute to its installation in 2024**

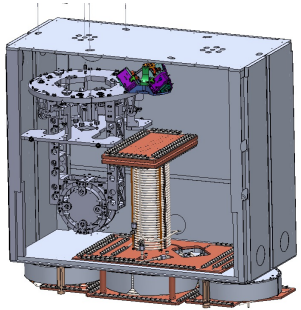
PC will cover partially the hardware cost at ETparthfinder

- **Pre-alignment & monitoring of the mirror surface at 80 - 290 K**
- **(instrumented baffle with sensors for λ = 1550 nm)**

→ **R&D on InGaAs photosensors with AR-coatings will start soon**





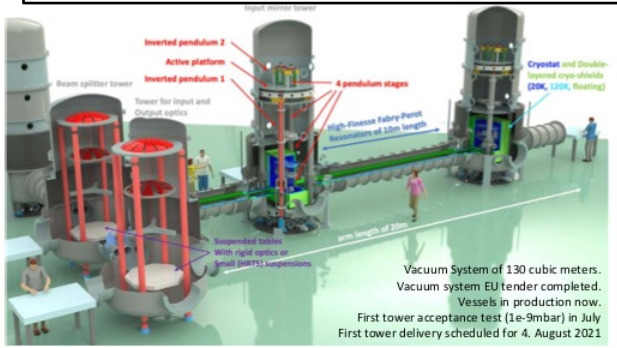


ETpathfinder

- **New facility for testing 3G technology in a low-noise, full-interferometer setup.**
- Key aspects: **Silicon mirrors** (3 to 100+kg), **cryogenics** (cryogenic liquids and sorption coolers, water/ice management), **"new" wavelengths** (1550 and 2090nm), new coatings …
- Start with 2 FPMI, one 120K and one 15K.
- **16 official partners from NL/B/G/FR** + a few more involved, but not yet official partners (like AEI, KIT, Bham, Cardiff, Barcelona etc).
- **Initial capital funding of 14.5 Meuro (no personpower).**
- Detailed **Design Report** available at apps.et-gw.eu/tds/?content=3&r=17177
- **Open for everyone interested to join.**
- **www.etpathfinder.eu**

Nikhef SAC, 2021-05-26

[S.Hild]



Slide from Nikhef SAC Meeting

Comunidad Valenciana

Procurement and commissioning of new ultra-high vacuum ion pumps for the Advanced Virgo+ detector arms.

ASFAE/2022/003

Adquisición y puesta en marcha de nuevas bombas de iones de ultra alto vacío para los brazos del detector Advanced Virgo +

Investigadores principal: José Antonio Font.

Entidades participantes: Universitat de València.

Equipo de investigación: Isabel Cordero Carrión, Pablo Cerdá Durán, Alejandro Torres Forné, Nicolás Sanchis Gual.

El grupo de investigación que avala esta Expresión de Interés es el Grupo Virgo de la Universitat de València (Valencia Virgo Group, VVG, www.uv.es/virgogroup), coordinado por el Prof. José A. Font.

En la actualidad, el VVG cuenta con ocho miembros con vinculación permanente a la universidad, un investigador post-doctoral de excelencia (contrato Ramón y Cajal) y cinco estudiantes de doctorado.

The ASFAE's research projects acknowledge the financial support from the MCIN with funding from the European Union NextGenerationEU and Generalitat Valenciana.

Financiado por la Unión Europea NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

GENERALITAT VALENCIANA

Procurement and commissioning of new ultra-high vacuum ion pumps for the Advanced Virgo+ detector arms.

- It is intended to perform an intervention on the ultra-vacuum system of the Advanced Virgo+ detector, in order to reach the vacuum level proposed in the original design of the experiment, 2.5 10-9 mbar. Currently, the residual pressure along the two arms of the detector is about 5 10-9 mbar.

- The objective will be achieved through the acquisition and installation of 10 new ion pumping stations. The current residual pressure level will be improved by a factor of almost 10. The new stations will provide a “noise” level about three times lower than the minimum of the Advanced Virgo+ sensitivity curve during O5 (from 2026 onwards).

- The implementation of the proposed objectives will be carried out in coordination with the group of Dr. Antonio Pasqualetti (European Gravitational Observatory, EGO, Advanced Virgo headquarters), head of the Advanced Virgo+ vacuum system.

Procurement and commissioning of new ultra-high vacuum ion pumps for the Advanced Virgo+ detector arms

- The bidding process for the pumping stations has begun. Negotiated procedure without advertising and by exclusivity with the company Agilent.

  [Agilent Technologies Italia S.p.A.Vacuum Products Division, Leini (Torino), Italia.]

- The features of the vacuum pumps and controllers supplied by Agilent are not available in any other ion pump or controller on the market. Standardization and complementarity with the current pumps installed at Advanced Virgo, supplied by Agilent.

- The new pump stations will be installed at Advanced Virgo during the next detector upgrade between the end of the O4 observing campaign (mid-2025) and the start of the O5 campaign

- VVG intends to participate in future upgrades of the Advanced Virgo detector equipment (Virgo_nEXT project). The continuity of the PC-ASFAE program would provide the possibility to continue developing cutting-edge research in the field of Gravitational Wave Astronomy.

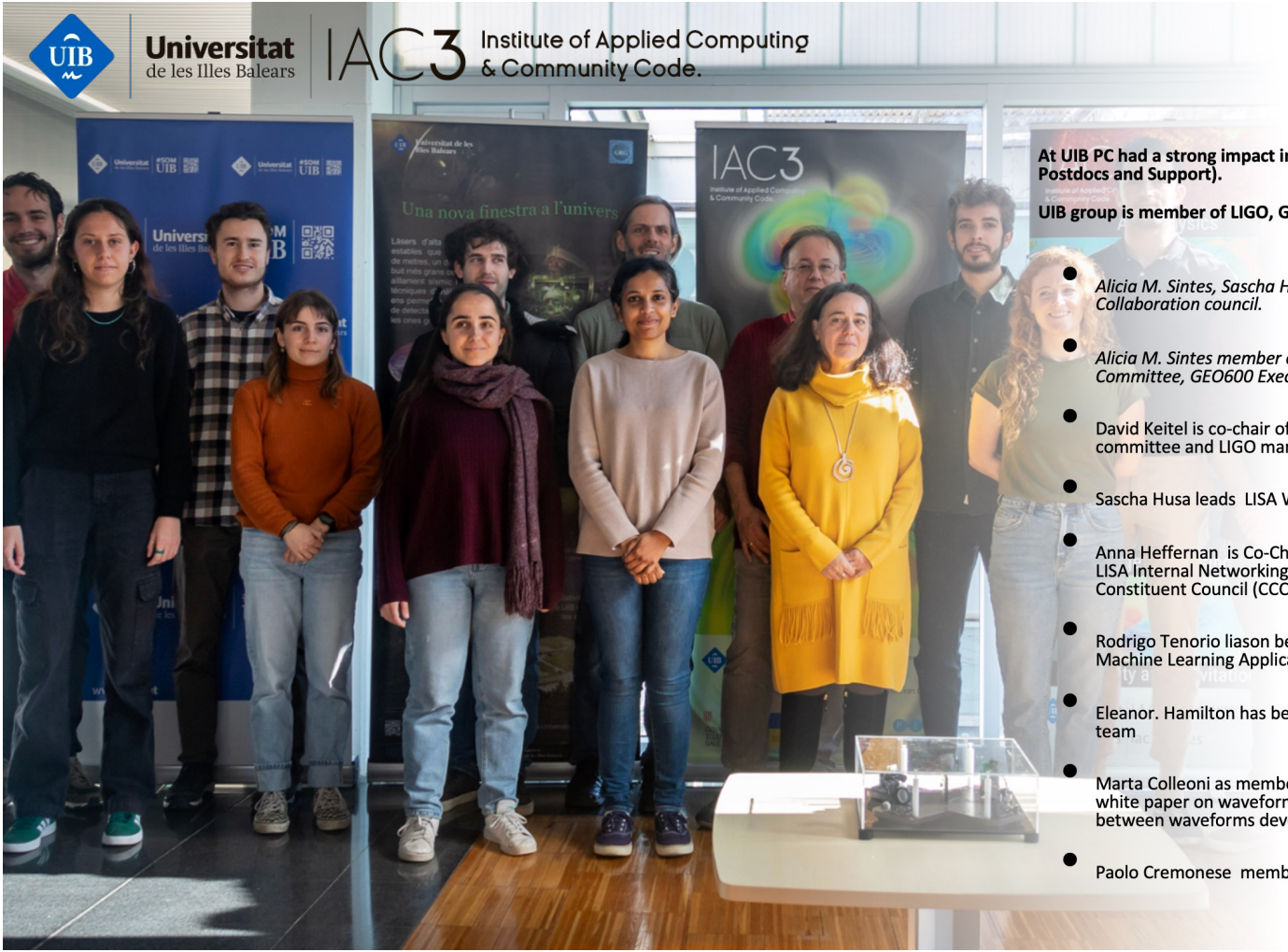
Islas Baleares

The main contributions of the Universitat de les Illes Balears (UIB) to LIA3 are:

Collaborations have been established among UIB and the other groups to have more impact on the LIGO-Virgo collaborations, LISA space mission and Einstein Telescope

- CBC **waveform development** – IMRPhenom
  - Parameter estimation of special events; **fast PE for LVK**.
  - Lead **LISA work package** on efficient waveform models
- **Numerical Relativity** for BBH – largest catalog of eccentric waveforms.
- Leading **all-sky CW searchers** for spinning neutron starts in isolated and binary systems based on Hough transform.
- Leading **long transient searches** for BNS merger remnants
- **Lensing** of GWs – preparing for first detection.
- **GW Cosmology** analysis of events
- **Noise modelling**: Line noise investigation and mitigation
- **EPO** efforts

Baleares



At UIB PC had a strong impact in the GW activities with hiring personnel (PhD students, Postdocs and Support).

UIB group is member of LIGO, GEO600, LISA and ET collaborations.

- *Alicia M. Sintes, Sascha Husa and David Keitel. Members of the LIGO Scientific Collaboration council.*
- *Alicia M. Sintes member of the LSC Speakers and Awards Committee, Virgo Award Committee, GEO600 Executive Committee.*
- David Keitel is co-chair of LVK Continuous waves WG, member of LIGO program committee and LIGO management team.
- Sascha Husa leads LISA WP 1.8: "Efficient massive black hole models"
- Anna Heffernan is Co-Chair of LISA Waveform Work Package Team. Member of the LISA Internal Networking Committee for Science".Co-chair of the LISA Consortium Constituent Council (CCC) and CCC steering committee member.
- Rodrigo Tenorio liason between LIGO-Virgo-KAGRA continuous gravitational waves & Machine Learning Applications WGs
- Eleanor. Hamilton has been serving as the Waveforms liaison for the LVK O4a Catalog team
- Marta Colleoni as member of the LISA Waveforms group has coordinated parts of the white paper on waveform modelling , (LVK) testing GR paper and working as a liaison between waveforms developers and the spin-induced quadrupole moment analysis
- Paolo Cremonese member of LIGO climate change committee.

Baleares LIA3 ← → LIA8

- Numerical simulations of black hole mergers.
- Development and optimization of data analysis tools to perform searchers for gravitational wave signals.
- Contributed to many LIGO-Virgo-KAGRA publications derived from the third observing run O3.
- Parameter estimation for all LVK CBC GW events detected.
- Acceleration of blind continuous gravitational wave searches using GPUs,
- Launch of a Kaggle competition for the analysis of continuous gravitational signal data using artificial intelligence techniques: https://www.kaggle.com/competitions/g2net-detecting-continuous-gravitational-waves
- Development of machine learning methods and new implementations of classical algorithms to obtain results with greater robustness and efficiency with respect to previous implementations.

Software

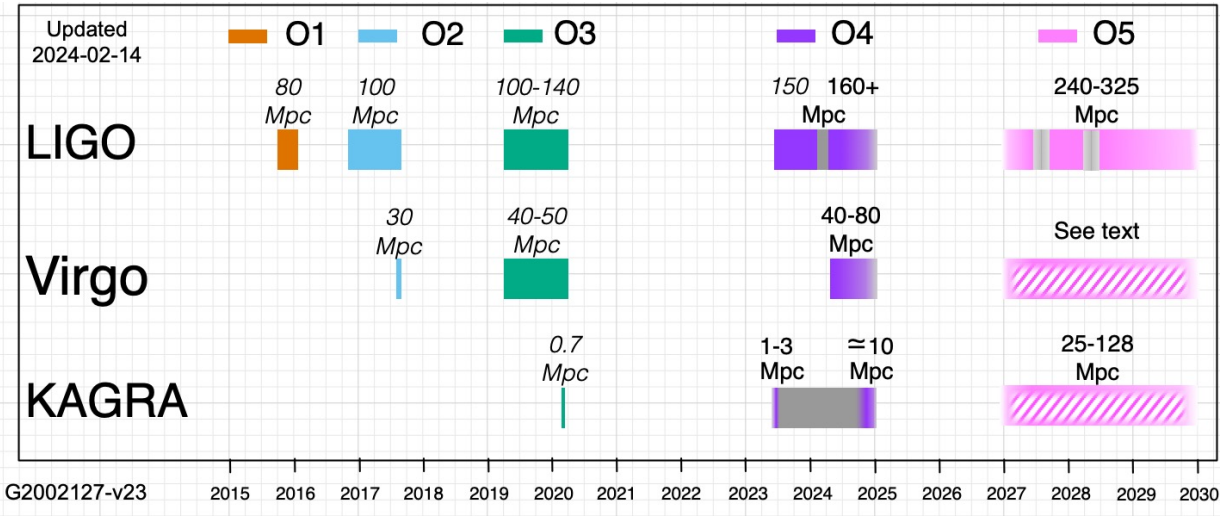
- David Keitel maintainer of the continuous wave data analysis ("LALPulsar") codes in the public open source LALSuite package [doi:10.7935/GT1W-FZ16].
- Anna Heffernan. Self-Force Regularisation Parameters Package (Mathematica). DOI: https://doi.org/10.5281/zenodo.6282572
- Tenorio, Rodrigo; Modafferi, Luana M.; Keitel, David; Sintes, Alicia M. distromax. DOI: https://doi.org/10.5281/zenodo.5763765 A Python package to empirically estimate the loudest candidate from a gravitational-wave search.
- Ashton, Gregory; Keitel, David; Prix, Reinhard; Tenorio, Rodrigo, PyFstat. DOI: https://doi.org/10.5281/zenodo.3967045 A python package for gravitational wave analysis with the F-statistic.
- Alicia M. Sintes, S. Husa, D. Keitel, M. Colleoni, H. Estellés, C. García-Quirós, A. Ramos-Buades, R. Tenorio and others (contributors). LALSuite - LSC Algorithm Library Suite. DOI: https://doi.org/10.7935/GT1W-FZ16

Observing runs:

Important detector improvements between O3 and O4

- Higher laser power
- Frequency-dependent squeezing
- Noise reduction & duty cycle improvements
- + Improvements to processing of data for use by searches

Not comprehensive! These are just some highlights.

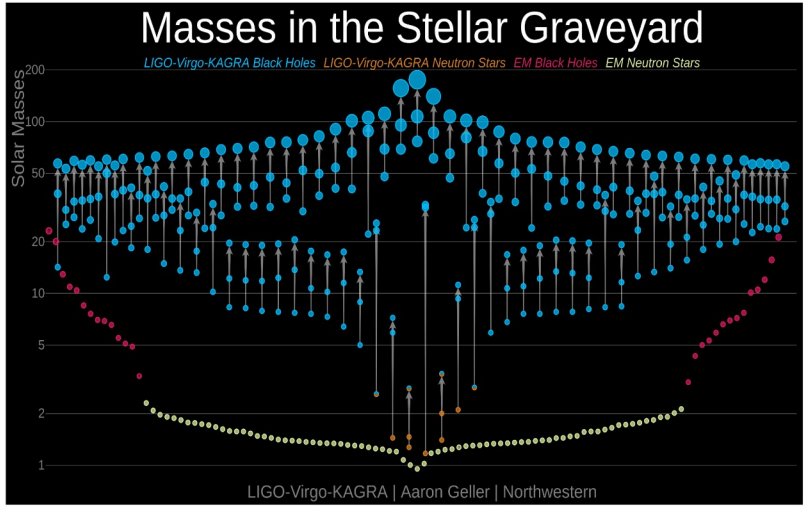


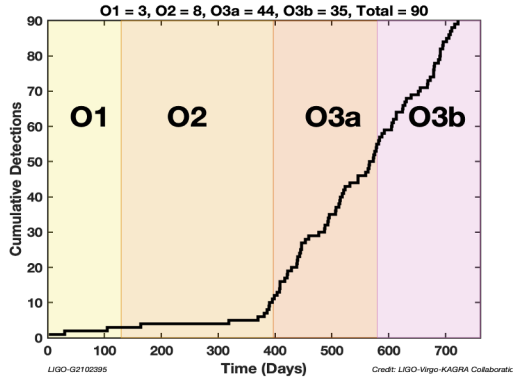
https://observing.docs.ligo.org/plan/

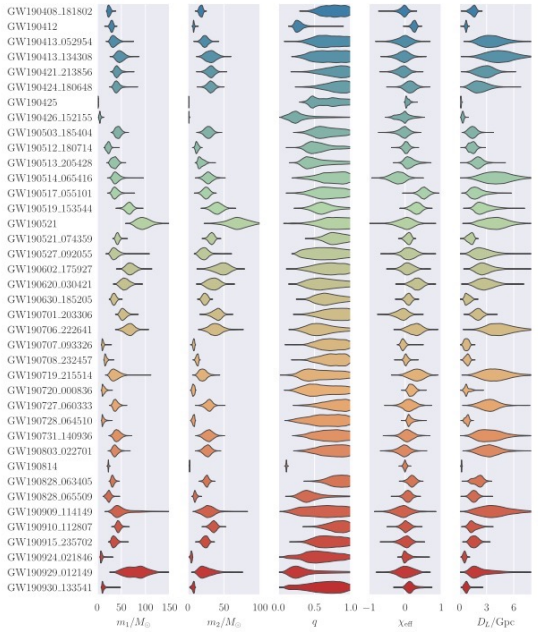
O4 observing run:

04a: May 24th 2023- January 16th 2024
O4b: April 10th 2024- February 2025

KAGRA delayed due to 7.6 magnitude earthquake on Jan 1, 2024







- Wide range of masses
- most events: binary black holes
- redshifts up to ~0.8
- Spins:
  - Key signatures to discriminate BH populations: shed light on formation mechanism
  - Some events with clear indication of a net positive X_{eff}

O3 Exceptional Detections

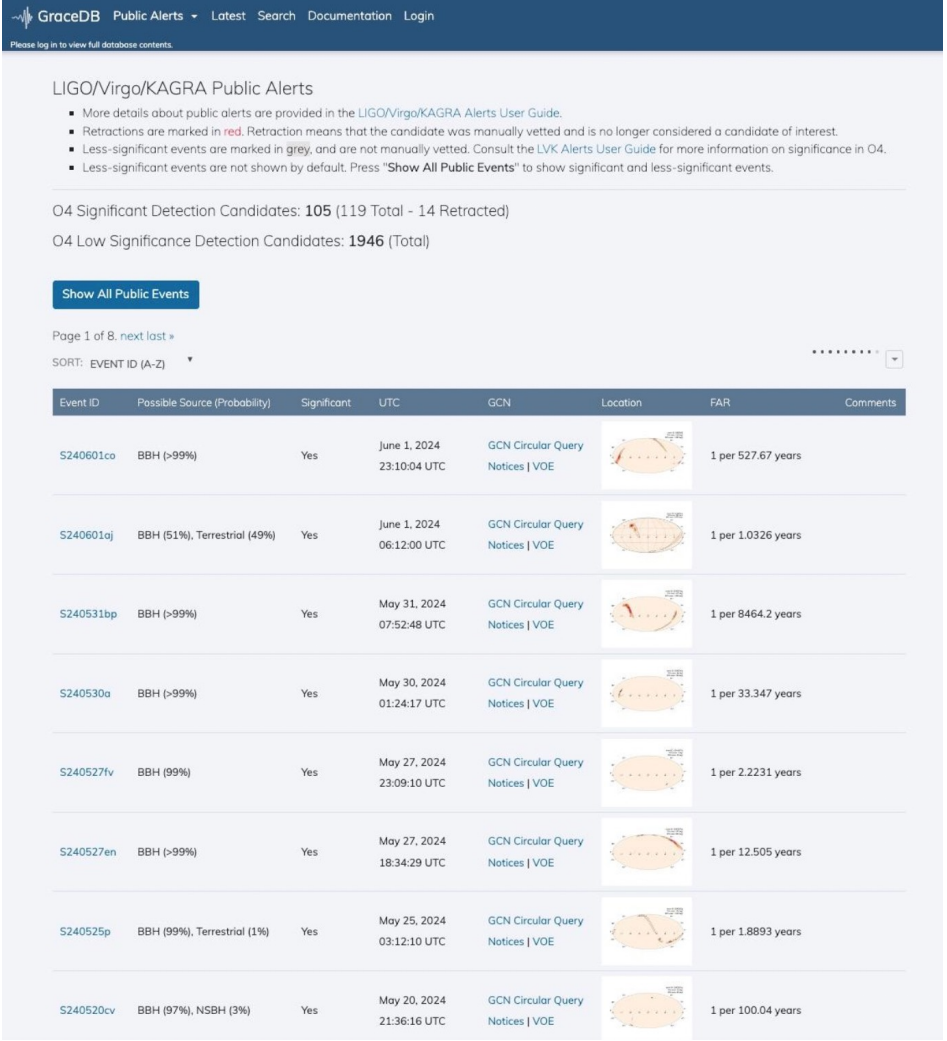
GW190412: first observed BBH possessing unequal mass ratio
- Masses: ~3, ~8 Msun
- [Abbott et al. (LIGO/Virgo Coll.), Phys. Rev. D 102, 043015]

GW190814: the most asymmetric mass ratio merger ever observed
- (m1/m2 = 9)
- The secondary mass of 2.6 Msun lies in the lower 'mass gap' either the lightest BH or the heaviest NS ever observed
- [Abbott et al (LIGO/Virgo Coll.), ApJL 896 L44]

GW190425: BNS merger of total mass of ~3.4 Msun
- Significantly larger than any other known BNS system
- [Abbott et al (LIGO/Virgo Coll.) ApJL 892 L3]

GW190521: BBH with component masses ~66 and 85 Msun
- First observation of an intermediate mass BH (Mf > 100).
- First observation of a BH in the (pulsational) pair instability upper mass gap 65 - 120 Msun .
- Farthest source so far (z ~ 0.8)
- [Abbott et al (LIGO/Virgo Coll.) Phys. Rev. Lett. 125, 101102]

GW200105-GW200115: 1st unambiguous detection of NSBH (2 events)
- [Abbott et al (LIGO/Virgo/KAGRA Coll.) ApJL 915 L5]



LVK- O4:
It's Been A Year!

1) Observing Run #4 (O4) started on May 24, 2023.
2) The LIGO Virgo KAGRA collaborations had our 100th O4 gravitational wave candidate a week ago on May 27th. (Named S240527en observed on Memorial Day).
You can always follow along with O4 Public Alerts here: https://gracedb.ligo.org/superevents/public/O4/

--As of today, there have been 105 gravitational wave candidates (119 total, with 14 retracted).
--Our first exceptional O4 gravitational wave detection (GW230529) was announced on April 5, 2024 (more info here: https://www.ligo.org/detections/GW230529.php).
--O4a went from May 24, 2023 to Jan 16, 2024.
--O4b started on April 12, 2024 and will tentatively end in early 2025.
--The O4 break + Engineering Run 16 (ER16) was from Jan 16 - April 12 this year.

Acknowledgments

This work was supported by the Universitat de les Illes Balears (UIB); the Spanish Agencia Estatal de Investigación grants PID2022-138626NB-I00, RED2022-134204-E, RED2022-134411-T, funded by MICIU/AEI/10.13039/501100011033 and ERDF/EU; the MICIU with funding from the European Union NextGenerationEU/PRTR (PRTR-C17.I1); the Comunitat Autonòma de les Illes Balears through the Direcció General de Recerca, Innovació I Transformació Digital with funds from the Tourist Stay Tax Law (PDR2020/11 - ITS2017-006), the Conselleria d'Economia, Hisenda i Innovació grant numbers SINCO2022/18146 and SINCO2022/6719, co-financed by the European Union and FEDER Operational Program 2021-2027 of the Balearic Islands.