CAPA Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

Universidad Zaragoza
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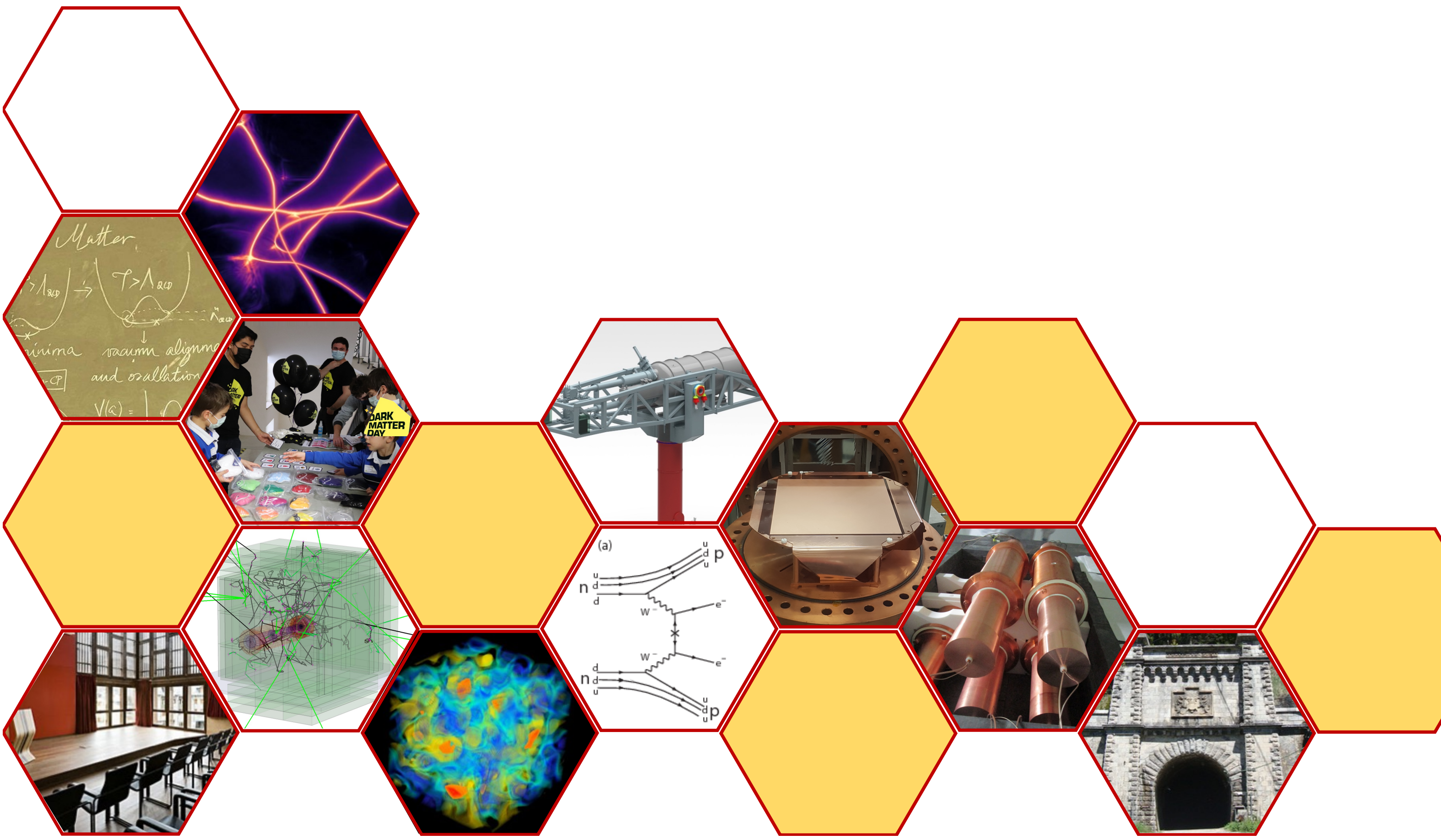
Annual Report 2024

Centro de Astropartículas y Altas Energías (CAPA)



Outline

Message from the Director

The past year has been an important one for the *Centro de Astropartículas y Física de Altas Energías* (CAPA). Our long-standing ambition to become a University Institute is now closer than ever. The administrative process has progressed smoothly through various evaluation and approval stages during 2024. As we write these words, we have just received final approval from the external evaluation agency. The official establishment of the new CAPA Institute is expected to take place very soon—this may well be the last report we write as a research center!

This milestone marks a significant achievement for CAPA, bringing new opportunities as well as new challenges. One of our first tasks as an Institute will be to develop a five-year Strategic Plan. Anticipating this transition, the CAPA community has already taken the initiative to incorporate a dedicated strategy chapter in this annual report. This section lays out the main guidelines that will shape the first Strategic Plan of the new CAPA Institute.

2024 has also been a successful year in further securing research funding. A particularly gratifying achievement has been CAPA's successful application to the National Research Agency (AEI) Scientific Equipment call, which will fund the acquisition of a cryogen-free dilution refrigerator valued at €400,000. This is the first time CAPA competes (and succeeds!) in this call that supports institutions in acquiring shared, cutting-edge research equipment. Another notable success is the approval of a COST Action (the third one in recent years) with strong CAPA participation. *BridgeQG*, launched in 2024, will explore potential signatures of quantum gravity by bridging both the high- and low-energy frontiers.

Additionally, this year marked the launch of the *DarkQuantum* ERC-SyG—an ambitious project set to enhance our work in axion dark matter detection and quantum sensor development. Another noteworthy success comes from CAPA's external member Diego Blas (IFAE), who secured another ERC-SyG project, *GravNet*. This project focuses on detecting high-frequency gravitational waves using experimental techniques similar to those employed in axion dark matter searches. The overlap between *GravNet* and *DarkQuantum* presents exciting opportunities for collaboration and synergy within CAPA.

CAPA has continued to expand, now boasting a total of 92 members—an increase of more than 50% since its founding. Encouragingly, this growth is not limited to temporary researchers but extends to permanent and tenure-track positions. This year, we welcomed three new permanent faculty members, Alejandro Vaquero (previously *Ramón y Cajal* researcher), Jacobo Asorey and Justo López Sarrión, who will further strengthen our astrophysics and theoretical research area. Additionally, Laura Seguí has joined the experimental division as a *Ramón y Cajal* researcher. However, not all news is without a bittersweet note. *Maria Zambrano* researchers Julia Vogel and Jaime Ruz are departing to establish a new research group in axion experimental physics at the University of Dortmund. While their departure is a loss for CAPA, we take pride in their achievements and remain connected, as they will continue to be CAPA external members, maintaining strong research ties with our institution.

As highlighted in this report, CAPA members have continued to produce high-quality research and maintain a strong presence at international conferences, scientific boards, and evaluation panels. Outreach remains a defining hallmark of CAPA, with a particular focus on promoting the role of women and girls in science and technology. This year has witnessed a notable expansion of CAPA's outreach on social networks, thanks to the efforts of our youngest members. CAPA is now present on *LinkedIn* and *TikTok*, in addition to *X*, *Instagram*, and *YouTube*, and enjoys more than 1600 followers across all those platforms.

A significant milestone this year was the release, in January 2024, of the documentary *Cazando lo Invisible* (Hunting the Invisible), directed by Mirella R. Abrisqueta. The documentary showcases some of CAPA's research and features the participation of several CAPA researchers. It premiered in Zaragoza and Huesca, followed by a screening in Teruel, and has also been broadcast on Aragonese television. The Zaragoza premiere completely packed a 300-seat cinema hall, demonstrating the public's strong interest in fundamental research on the Universe. It was a rewarding moment after all CAPA's outreach efforts.

CAPA's commitment to specialized training through the *Master in Physics of the Universe* at UNIZAR also marked a successful year in 2024. Despite undergoing a transition—from 90 to 60 ECTS credits to align with new national legislation—the program attracted the highest number of enrolled students since its launch in 2021.

We close a successful 2024 for CAPA. As we stand on the verge of becoming an institute, we look forward to the exciting developments and challenges that lie ahead. The strong foundation we have built over the years will serve as a platform for future growth, ensuring that CAPA remains at the forefront of astroparticle and high-energy physics research.

Igor G. Irastorza
CAPA Director

1

General description of CAPA

The *Centro de Astropartículas y Física de Altas Energías* (CAPA) of the University of Zaragoza, is a research center created in 2019 to foster the research in the fields of high energy physics, particle and nuclear physics, astrophysics, cosmology, astroparticle physics and theory, as well as in related technological developments. The center was built encompassing the research groups and lines already active in the University of Zaragoza in the aforementioned topics, some of them with a long and recognised trajectory.

1.1 | Main objectives

Apart from the general aim stated above, CAPA has the following specific objectives, as stated in its "memoria de creación":

1. Promote the presence of CAPA researchers in national and international scientific forums, increasing their specific weight in the mentioned fields of research.
2. Promote and support administratively new funding requests from the CAPA members, both in national programs (e.g. national R&D plans, María de Maeztu,...), as well as in international ones (European Research Council (ERC), European Innovation Council (EIC), European Cooperation in Science and Technology (COST), and others.)
3. Foster the creation of new synergies among the different research lines, especially between the theory and experimental areas.
4. Strengthen the participation of CAPA members in the Aragonese research centers related with the mentioned areas: the *Laboratorio Subterráneo de Canfranc* (LSC) and the *Centro de Ciencias de Benasque Pedro Pascual* (CCBPP), as well as to promote collaboration with the *Centro de Física del Cosmos de Aragón* (CEFCA).
5. Promote activites of specialized training and facilitate the incorporation of young scientist and technical manpower to the scientific community.
6. Ensure the corresponding transfer of the knowledge created in this field of research to the industrial sector.

7. Promote the scientific culture of the society through the realization of outreach activities addressed to the general public.

In order to better align the activities presented in this report to the aforementioned objectives, they will be referred to when appropriate in the following chapters.

1.2 | Organizative structure

CAPA was created as a *center* of the University of Zaragoza and as such it is regulated by the University's statutes. The CAPA organizative structure includes the center's *Council*, which is composed by all the PhDs of the center plus representatives of the PhD students and technical personnel. The Council is the body that, among other things, elects the *Director* of the center, and approves (after the Director's proposal) its *deputy Director* and its *Secretary*. The Director represents the CAPA and, among other things, organizes and leads the actions needed to better achieve the center's objectives. The center also counts with an external scientific advisory board, chaired by the Director and including at least other five scientists of recognized prestige. This board is in charge of evaluating the annual report of CAPA, and advising its governing bodies on the activities of the center and strategical matters. The name of the persons currently holding the mentioned uni-personal positions at CAPA, as well as the members of the advisory board, are listed in the attached table. The advisory board has been exceptionally running with four members in last times, but we finally welcomed Prof. Domènec Espriu as fifth member in February 2025.

Single-person governing positions:	
Director:	Igor G. Irastorza
Deputy Director:	Gloria Luzón
Secretary:	Eduardo Follana
Scientific advisory board:	
Inés Gil-Botella	CIEMAT, Madrid
Axel Lindner	DESY, Hamburg
Teresa Marrodán	MPIK, Heidelberg
Antonio Pich	IFIC, Valencia
Domènec Espriu	U. Barcelona

1.3 | Areas of activity and research groups

The CAPA community encompasses several research groups active in the fields mentioned above, both in theoretical and experimental aspects. Regarding experimental research, CAPA inherits from the long-standing trajectory of the Nuclear and Astroparticle Physics groups, responsible of the pioneering research on low background techniques and underground experimentation that were the seed of the current Laboratorio Subterráneo de Canfranc (LSC). These groups are nowadays involved in several of the experiments at LSC and in particular are the leaders of WIMP dark matter experiments like ANAIS or TREX-DM, as well as in axion searches like BabyIAXO and RADES. The CAPA researchers are also active in more transversal developments of novel detector concepts and low background know-how in general, and participates in several other international collaborations. The center counts with the LABAC, a laboratory performing environmental radioactivity monitoring, as a node of a network funded by the "Consejo de Seguridad Nuclear" (CSN, Spanish Nuclear Regulatory Commission). Regarding the theoretical research, CAPA members also inherit a long standing trajectory in Theoretical and Particle Physics. At present they are active in a number of frontier aspects of particle and astroparticle physics. The most relevant are: axion theory, astrophysics and cosmology; the phenomenology of beyond-SM particle physics models; quantum gravity phenomenology and lattice field theory. CAPA is an institution represented in the EuCAPT Council and participates in the COST Action

CA23130, "bridging high and low energies in search of quantum gravity", that started in September 2024. J. M. Carmona is one of the two Spanish Management Committee members. Detailed information of the research lines performed at CAPA is given in section 3.

2

Human resources

At the end of 2024, CAPA had a total of 91 members, a slight increase with respect the previous year. This tops up a growing trend, shown in Fig. 2.1 (right), that accumulates more than 50% increase since the creation of the center in 2019. The age distribution of CAPA members is shown in Fig. 2.1 (left).

Its gender gap is shown in Fig. 2.2. It has slightly decreased with respect to 2023, but not significantly. CAPA has been continuing carrying out specific activities addressed to female students to attract women to science, as described in Sec. 7.

CAPA members are distributed in the following personnel categories:

1. Teaching and research **permanent staff** of the University of Zaragoza.

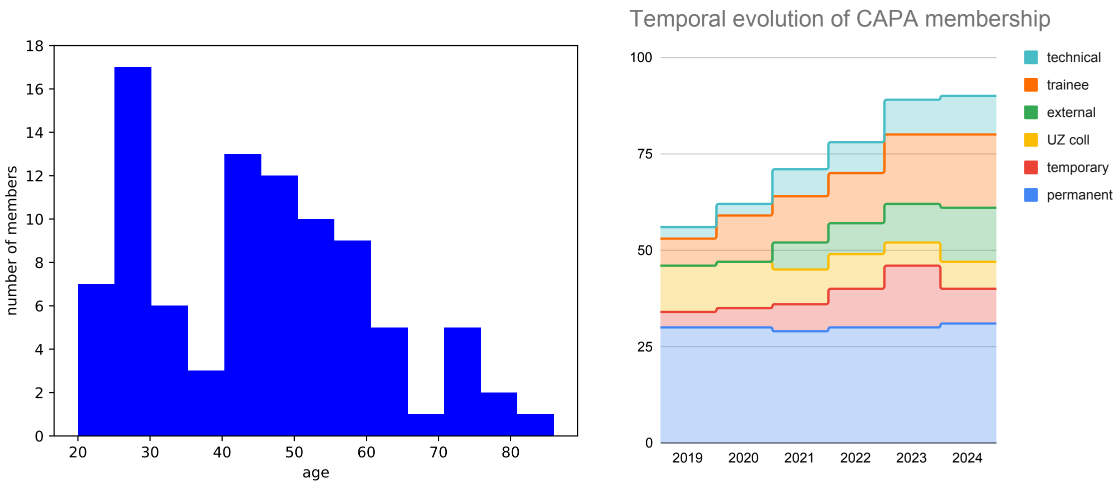


Figure 2.1: CAPA members current age distribution (left) and temporal evolution during the last years (the situation shown corresponds to the one a the end of the indicated year).

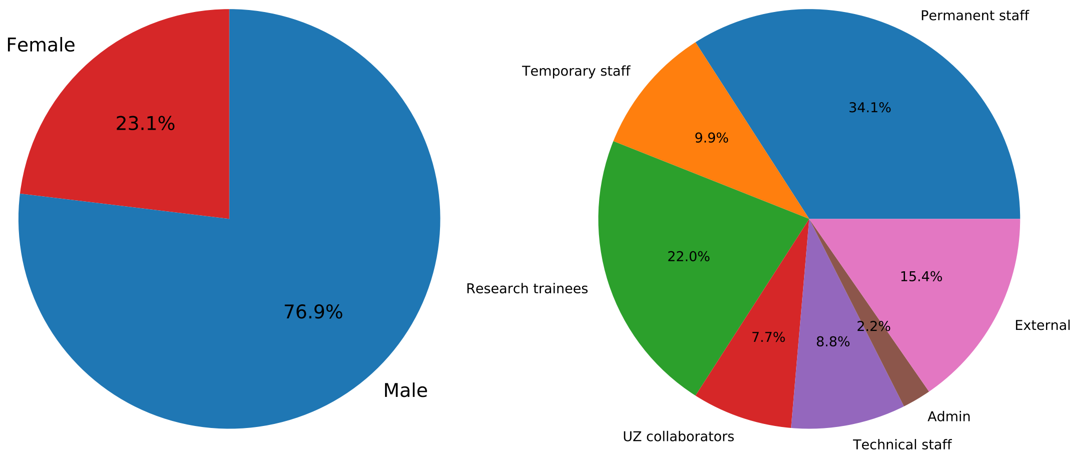


Figure 2.2: **Left**: CAPA gender gap. **Right**: Distribution of CAPA members in categories of personnel as percentage.

2. Teaching and research **temporary staff** of the University of Zaragoza, including here project-funded postdoctoral contracts, but also recipients of excellence postdoctoral programs (e.g. Ramón y Cajal, Beatriz Galindo, etc...)

3. **Research trainees**, which include early-stage researchers (PhD student level) normally enrolled in the doctoral program of the University.

4. **Collaborators** from the University of Zaragoza. This is a recognized category in the University including researchers from other institutions with recognized ascription to the University.

5. **Technologists** and technical staff, including project-based positions.

6. **Administration** staff.

7. Collaborators from **external** institutions.

The distribution in percentages is shown in Fig. 2.2 (Right). Compared with the situation at the end of 2023, CAPA has increased the proportion of permanent staff and considerably decreased the proportion of temporary staff. The increase in permanent staff is due to the hiring of new faculty members J. López Sarrión (new member of CAPA), J. Asorey (formerly an external collaborator), and A. Vaquero (formerly temporary staff, Ramón y Cajal contract). The strong decrease in temporary staff comes both from several members leaving CAPA for other institutions, some of which have become external collaborators (thus increasing their proportion), as well as from some of them entering the category of research trainees.

The list of members as of end of 2024is in appendix O.

3

Research lines & achievements

This section describes the various core research lines being pursued at CAPA, in the fields of cosmology, astrophysics, astroparticle and particle physics. It covers both theoretical and experimental aspects, emphasizing the achievements in 2024. It directly aligns with the main overarching objective of CAPA, as expressed in section 1. To the extent this research is conducted in international networks, or utilizes strategic regional infrastructure like the LSC, it also addresses specific objectives 1 and 4 (see section 1.1). Some of the lines simultaneously target similar objectives from both theoretical and experimental perspectives, thus addressing also objective 3, as explained below.

Several of these lines describe activities corresponding to well-defined funded projects (see annexes A and B). Others correspond to more specific research lines framed within larger projects (but of sufficient entity to deserve their own subsection here), research activity of more transversal character (e.g. R&D), or emerging activities or collaborations with external colleagues. Some CAPA members are also members of other "neighboring" research institutes like the BIFI (Biophysics and Complex Systems Institute) or the INMA (Nanotechnology and Materials Institute) and not all their research output can be ascribed to genuine CAPA research lines, something that can be seen in the automatically-produced list of publications in annex N. Furthermore, some of the newer members still enjoy scientific production from the previous projects in non-CAPA affiliations. In the following section we describe only the research lines fully considered within the CAPA scope. We divide them in experiment and theory research lines.

Experiment

The experimental research lines at CAPA largely inherit from the long-standing trajectory of the Nuclear and Astroparticle Physics group (GIFNA), responsible of the pioneering research on low background techniques and underground experimentation that were the seed of the current Laboratorio Subterráneo de Canfranc (LSC). Nowadays, GIFNA is an associated unit to the LSC, and its members participate actively in several of the approved experiments at the LSC. In particular they are the leaders of WIMP dark matter experiments like ANAIS (section 3.2) or TREX-DM (section 3.3), and participate in the DarkSide-20k project to be hosted at Gran Sasso Laboratory, but with a ancillary setup DART at the LSC (section 3.4). They play a leading role in axion experiments like BabyIAXO (section 3.1) and RADES (section 3.6), the former to be hosted at DESY, but with detector prototyping activity at the LSC, and funded by a prestigious ERC-AdG grant and, since last year, also by a ERC-SyG. The relation with LSC make CAPA a *de facto* gateway to LSC for many external collaborators that seek the collaboration of CAPA members when implementing their projects at LSC. In this respect there are more specific contributions to other current (or future) neutrino projects like CROSS, NEXT, Hyper-Kamiokande or others (section 3.5), mostly on radiopurity and low background detector expertise. The CAPA researchers are also active in more transversal developments of novel detector concepts for gaseous detectors (Micromegas) for low background in general (section 3.7). As we did in last year's report, we promote also the emerging activity on novel scintillator detector concepts within the LiquidO/CLOUD consortium (section 3.8). Finding ways to transfer the research knowledge to the society is also one of the goals of CAPA. In this respect, we count with he long-standing activity of the LABAC laboratory (section 3.9), which applies the expertise on low radioactivity techniques to the environmental radioactivity monitoring, contributing to the public health of the population within the net of the Spanish Nuclear Regulatory Commission.

3.1 | Axion searches with the International Axion Observatory (IAXO)

Responsible investigator(s) / coordinator(s):	
Igor G. Irastorza	staff
Gloria Luzón	staff
Researchers involved:	
Theopisti Dafni	staff
Susana Cebrián	staff
Javier Redondo	staff
Fernando Arteche	staff (ITA)
Javier Galán	postdoc
Juan A. García Pascual	postdoc (MC)
Jaime Ruz	postdoc (MZ)
Julia Vogel	postdoc (MZ)
Javier Galindo	postdoc (ITA)
Cristina Margalejo	predoc
Oscar Pérez	predoc
Luis Obis	predoc
David Díez Ibáñez	predoc
Ana Quintana	predoc
Alvaro Ezquerro	predoc
María Jiménez Puyuelo	predoc
Technical support:	
Alfonso Ortiz de Solórzano	engineer
Hector Mirallas	engineer
Juan Castel	engineer
Jorge Marqués	engineer
Javier Mena	technician
Angel de Mira	technician

The International Axion Observatory (IAXO) is the largest international collaboration in search for axions, with more than 125 scientists from more than 20 institutions. Axions are hypothetical particles appearing in extensions of the Standard Model (SM) of particle physics featuring the Peccei-Quinn (PQ) mechanism. This mechanism was postulated in the 1970s to solve the *strong CP problem*, a somewhat technical but fundamental problem of the SM, that regards why the *strong interactions do not seem to violate the time-reversal symmetry*, as the electroweak interaction does. In addition, axions are an excellent candidate to compose the Dark Matter (DM) of the Universe, and that is the reason why they are now among the most important goals of experimental searches of new physics beyond the SM. Axions (as well as their relatives, axion-like particles or ALPs) are sought in various ways [1], depending on the *origin* of these axions: cosmological, laboratory or astrophysical axions.

IAXO belongs to the latter category, as it follows the concept of an *axion helioscope*, whose main goal is to search for axions emitted from the Sun, although it could additionally host other setups targeting different sources of axions. A generic property of axions is that they couple with photons in a way that axion–photon conversion (and vice versa) can occur in the presence of strong magnetic or electric fields. This phenomenon is the basis of axion production in stars, as well as of most strategies for detecting axions. Magnets are therefore at the core of any axion experiment, as is the case for axion helioscopes. In these experiments, solar axions crossing the magnet may convert into x-rays that can be subsequently detected in devices placed at the end of the magnetic field region. This is the strategy followed by the CERN Axion Solar Telescope (CAST) that, using a decommissioned LHC magnet, has been the most powerful axion helioscope built so far. After almost two decades of operation, CAST has put the strongest limits yet on the axion–photon coupling across a range of axion masses [2] (see Fig. 3.2), surpassing previous astrophysical limits for the first time and probing relevant axion models of sub-electron-volt mass. IAXO was conceived as a new generation axion helioscope that builds on the CAST experience [3], and aims to provide a substantially improved sensitivity to go deep into unexplored axion parameter space [4].

The central component of IAXO is a purpose-built large-scale superconducting magnet similar to those used in large HEP detectors. It follows a toroidal configuration, and includes eight large “user” bores in which the solar axions can convert into x-rays. All of them are equipped with optics that concentrate the signal x-rays into small very sensitive low-background detectors. These x-ray optics are based on the reflection of x-rays by mirrors at grazing incident angle, technologies used in x-ray astronomy. The detectors will image the signal photons at the focal spot with very low level of background, achieved by means of techniques similar to that used in underground experiments: the use of radiopure detector components, passive and active shielding of environmental and cosmic radiation, and offline event discrimination techniques. The whole infrastructure is installed on a movable platform that allows tracking the Sun for about half the time. The baseline design of IAXO, shown in figure 3.1, is endowed with a sensitivity to solar axions of about 5 orders of magnitude better in signal-to-noise-ratio than CAST.

As a prior stage towards IAXO, the collaboration is planning the construction and operation of BabyIAXO, an intermediate scale version of IAXO. It is conceived to test all IAXO subsystems (magnet, optics and detectors) at a relevant scale for the final system and thus serve as a prototype for IAXO, but at the same time as a fully-fledged helioscope with relevant physics reach itself. The conceptual design of BabyIAXO [5] is shown in figure 3.3. The BabyIAXO magnet will feature two 10 m long, 70 cm diameter bores, and will host two detection lines (optics and detector) of dimensions similar to the final ones foreseen for IAXO.

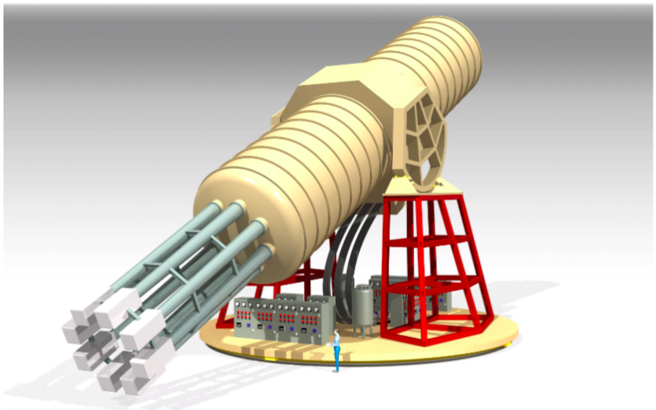


Figure 3.1: Sketch of the IAXO infrastructure as described in its conceptual design [3], showing the magnet and the eight detection lines including optics and detectors. The overall assembly is placed on a rotating platform to follow the Sun.

The project has been approved to be hosted by DESY, which offers an ideal environment to BabyIAXO as part of its emerging axion experimental program. The collaboration has been strengthened during the last years, and counts now 125 scientists, which make IAXO the largest collaboration in axion physics. In particular, the project relies on the superconducting magnet expertise from CERN. Indeed both the designs of the IAXO and BabyIAXO magnet have been carried out by CERN magnet experts.

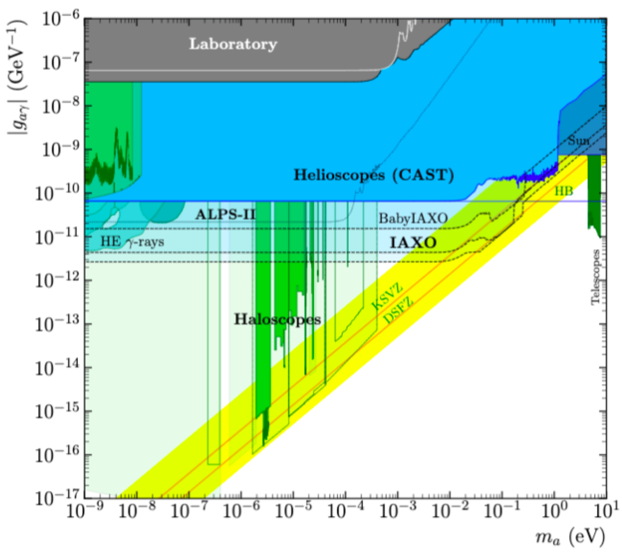


Figure 3.2: Sensitivity plot of IAXO and BabyIAXO in the primary axion-photon coupling versus axion mass parameter space, compared with the QCD axion (yellow) band and other current (solid) and future (dashed) experimental and observational limits

One of the two x-ray optics to be used in BabyIAXO is a flight spare module of the XMM-Newton mission that has been kindly lent to the collaboration by the European Space Agency (ESA). The second one will be built by the collaboration, as a prototype for the future IAXO optics. It will be the first large-scale optics specifically designed and built for axion physics. The baseline detectors to be placed at the focal point of the optics are small time projection chambers read with Micromegas readout planes of microbulk type. These detectors have achieved record background levels after many years of development especially within the CAST experiment. However, a portfolio of additional x-ray detection technologies is being developed in the collaboration, especially in view of IAXO, including Ingrid detectors, Magnetic Metallic Calorimeters, Silicon Drift Detectors or Transition Edge Sensors. These technologies could provide improved performance (e.g. in terms of energy threshold and resolution) that could be particularly important e.g. in case of a positive detection, to extract additional information from the data, like the mass or other couplings of the axion.

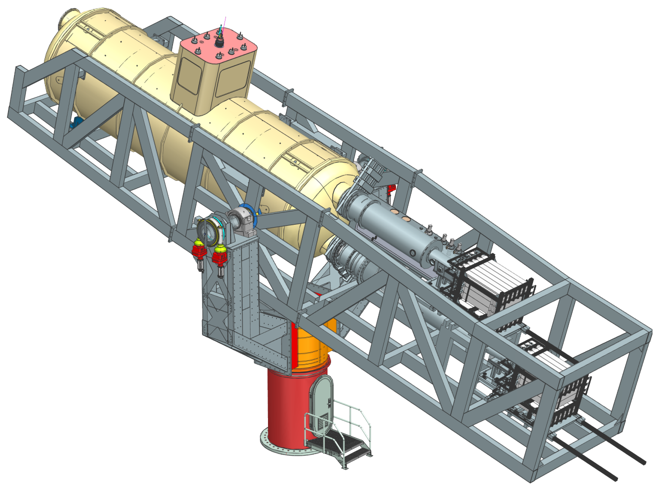


Figure 3.3: CAD design of the full BabyIAXO infrastructure, updated from the one described in its conceptual design [5], including the two-bore magnet, and the two detection lines, with x-ray telescopes and focal plane detectors, the latter surrounded by their shielding. All the assembly is placed on a support frame and positioner to keep the optical axis of the experiment pointing to the Sun. The overall system length is about 19 meters. The focal length is of 7.5 m for the line equipped with the XMM optics, and of 5 m for the custom-made optics.

BabyIAXO will detect or reject solar axions with axion-photon couplings down to $\sim 1.5 \times 10^{-11}$ GeV^{-1}, and masses up to $\sim$0.25 eV. BabyIAXO will offer additional opportunities for axion research in view of IAXO, like the tests of improved detectors such as the ones mentioned above, or the implementation of radiofrequency-cavity-based setups to search for dark matter axions, something being explored within the RADES project. The latter concept connects with quantum technologies, a connection that will be boosted by the DarkQuantum project, a ERC-SyG granted in 2023 (see section 3.6). Figure 3.2 shows the sensitivity prospects of both BabyIAXO and IAXO in their baseline configurations, within the current context of axion searches. BabyIAXO, and later on IAXO, will go well beyond current upper bounds on the axion-photon coupling from CAST and astrophysics, and venture deep into unexplored areas, in particular probing a large fraction of QCD axion models in the meV to eV mass band. This region encompasses the values invoked to solve the transparency anomaly, and the ones solving the stellar cooling anomalies, as well as a number of other possible hints. It also includes some of the axion models that can account to the totality of dark matter. Most of this region can only be reached realistically by using the helioscope technique, and therefore the BabyIAXO/IAXO program is unique in the wider landscape of experimental axion searches. In the case of a positive detection, (Baby)IAXO will permit high-precision measurements campaigns to determine axion parameters and getting further insight into the underlying axion models. In any case, IAXO is bound to play an important role in the future of axion and ALP research, with potential for a discovery, already at the BabyIAXO stage.

The CAPA group in IAXO plays a central role in the IAXO collaboration, as continuation of the long trajectory of research in the CAST experiment at CERN, that culminated with the IAXO pathfinder system that took data in CAST in the last data taking campaigns of the experiment. CAPA researcher and IAXO spokesperson Igor G. Irastorza was a recipient a ERC-AdG in 2019-2024 that has allowed to push BabyIAXO to construction phase. The CAPA group leads the conception, design and construction of the low background Micromegas detectors for the two BabyIAXO focal points. In this respect, IAXO-D1, the first prototype with form-factor fully compatible with the BabyIAXO geometry was finalized in 2022. Two replicas of such prototype are now taking data, one underground at the LSC, and the other one at the IAXOlab of CAPA, with the goal to provide insight on the background components. CAPA members are also leading the software and radiopurity working groups of the collaboration.

3.1.1 | Achievements in 2024

In 2024 the collaboration has continued preparing many of the experiment's subsystems for construction. Most importantly, substantial progress has been achieved clarifying the critical issues that were threatening the magnet construction timetable. On one side, a road-map to procure aluminum-stabilized superconducting cable is now established, and first productions are ongoing. On the other side, a roadmap for the full construction of the BabyIAXO is also getting established, and discussions are ongoing with CERN at this respect. The updated conceptual design of the BabyIAXO magnet, together with firm estimations of costs and schedule were successfully reviewed by a external panel of experts in April-2024. Other important achievements for 2024, particularly those involving work at CAPA, are the following.

1. In 2023, the new IAXO-D1 setup was installed underground at the LSC (a picture of it during installation is shown in Fig. 3.4, right). During the data taking campaign of 2023, the main conclusions were that running with Xe, a background level of $(5.5 \pm 1.0) \times 10^{-7}$ nfu[1] was measured, while running with Ar an even lower level of about $(1.7 \pm 0.5) \times 10^{-7}$ nfu was obtained. The unexpectedly high result with Xe, which a priori is preferred to avoid the ^{37}Ar present in natural Ar gas, suggested the presence of radon in Xe data, as the detector is operated in closed loop with moisture and oxygen filters, known to emanate ^{222}Rn. To investigate this issue, the data taking continued in 2024 using Ar with different circulation conditions and gain modes. When operating in closed loop, the measured background level is $(5.5 \pm 0.8) \times 10^{-7}$ nfu, whereas, in open-loop operation, it is $(1.8 \pm 0.3) \times 10^{-7}$ nfu. Additionally, when the detector was operated in low-gain mode, which involves reducing the amplification of the signal, alpha particle contamination levels of (10-20) Bq/m^3 were measured in closed loop, compared to an estimated activity < 1 Bq/m^3 in open-loop. These results confirm that the intrinsic background level of IAXO-D1 in Ar meets BabyIAXO's requirements and reinforce the

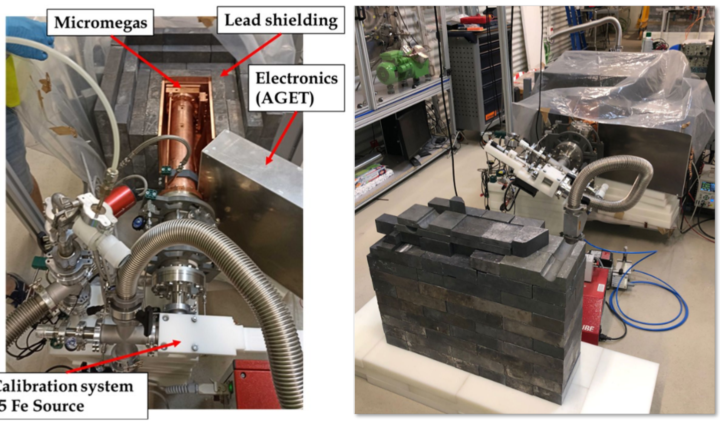


Figure 3.4: IAXO-D1 setup at the LSC. **Left:** Picture with the lead shielding opened. The different components of the experimental setup are labeled. **Right:** Picture of one of the shielding configurations tested, with a lead wall in front of the calibration system.

[1]nfu ≡ normalized flux units ≡ counts/keV/cm^2/s

hypothesis of ^{222}Rn contamination in recirculating gas. They also suggest that the intrinsic background level while operating with Xe remains unknown. Efforts are currently underway to mitigate radon contamination in the system during gas recirculation. Additionally, a publication detailing these findings is in preparation.

2. The IAXO-D0 setup at the CAPA IAXOlab, that included the neutron-tagging active shielding, was dismantled. A newer IAXO-D1 detector (like the one running at LSC) was installed and the shielding re-mounted around it (Fig. 3.5). Operations will soon resume to produce background runs, compare them with underground runs and get insight on the capability to remove cosmic-induced events.

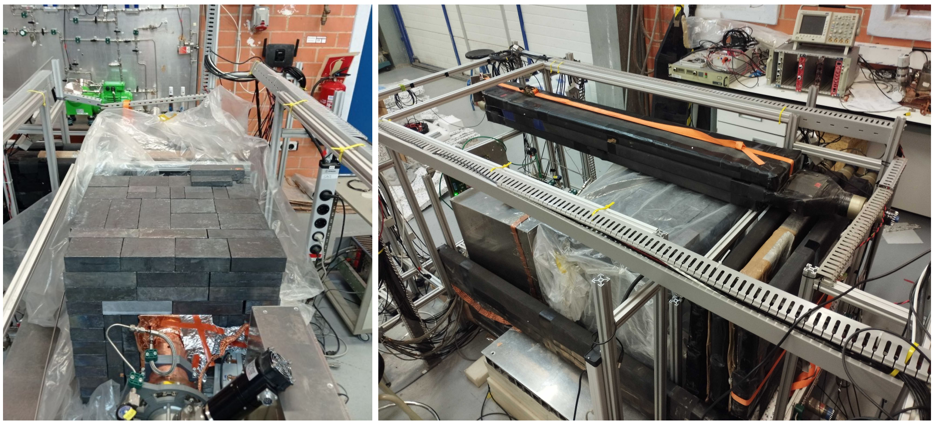


Figure 3.5: IAXO-D1 setup at the CAPA IAXOLab. **Left:** Picture showing the inner passive shielding composed by 20 cm of lead. **Right:** Picture with part of the active shielding composed of plastic scintillators installed.

3. The electromagnetic characterization of the environment where the detector is commissioned is being conducted. These studies aim at optimizing the integration of the DAQ system within the experiment ancillary systems. The analysis will help identifying potential noise sources requiring mitigation, sensitive areas and systems perturbing the DAQ. As part of this effort, conducted noise measurements have been carried out on the electrical installation at the CAPA IAXOlab, the collected data is currently under analysis The goal is to reduce the system's background noise level that is affected by the integration of the electronics. In parallel, the ARC acquisition system is being characterized, and a detailed study of its operation and control is being conducted. New functionalities are being analyzed to optimize its performance. The knowledge gained from this study will be applied in the first half of 2025 to perform an electromagnetic susceptibility characterization of the experiment in a semi-anechoic chamber. For this purpose, an *ad hoc* interface PCB has been developed to establish the lowest possible background level in terms of electromagnetic noise. A best practices guide/report is being developed for the integration of electronic equipment, considering electrical and electronic aspects.

4. The work to accurately determine the expected sensitivity in BabyIAXO, by MonteCarlo ray-tracing techniques in REST-for-Physics [6], was finished in 2024 and a draft for publication released recently [7]

5. Following the complete design of BabyIAXO's beamline at CAPA in 2023, the project has undergone an engineering review process at DESY this year. This review focused on refining and integrating the necessary elements for a comprehensive technical design. Specifically, the process involved defining the vacuum

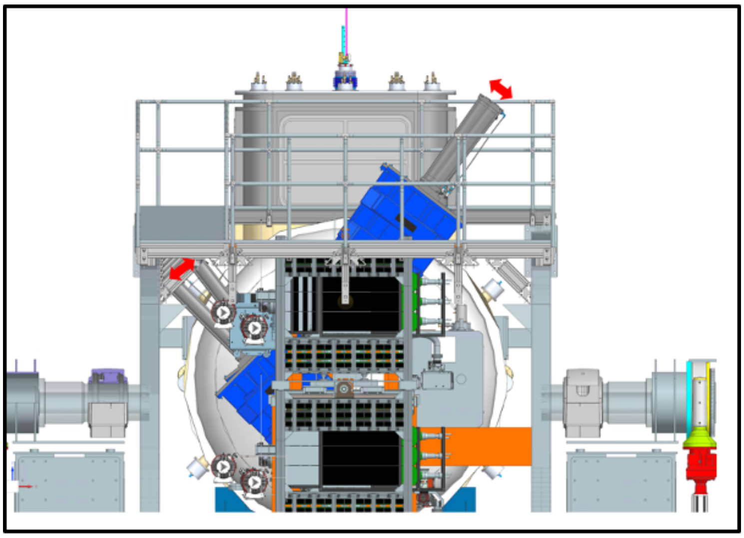


Figure 3.6: Perspective of BabyIAXO's beamline. The interface between the magnet and the beamline is envisioned by means of a DN 800 gatelve (blue). In order, the components of the line are: telescope vessel, Section 1, Section 2 and Detector section.

requirements for the X-ray optics in coordination with the magnet interface and detector groups, ensuring compatibility and optimal performance across all experimental components.

The finalized beamline design has received the approval from DESY engineering and has entered the tendering process for purchase of the different components of the line (see Fig 3.6). Moreover, the control system for the platform movement of BabyIAXO has also been defined and purchased.

6. The analysis of the last solar axion data taking campaign in CAST, with the IAXO pathfinder system during 2019-21, has been completed and published. The new data, which doubled the previous exposure time, combined with an improved detection efficiency and the novel use of a xenon-based gas mixture in the Micromegas detector, has led to the most restrictive experimental upper limit on the axion-photon coupling of $g_{a\gamma} < 5.8 \times 10^{-11}\,\mathrm{GeV}^{-1}$ at 95% C.L. (for $m_a < 0.02\,\mathrm{eV}$) [2]. This new limit is shown in Figure 3.7. This result serves as CAST's legacy measurement on solar axions, as the experiment concluded operations in 2021, and will remain the leading experimental bound until BabyIAXO helioscope begins data collection. Additional analyses exploring other solar axion production channels are ongoing, including the search for axion-electron coupling through the ABC solar axions, and new bounds on solar chameleons.

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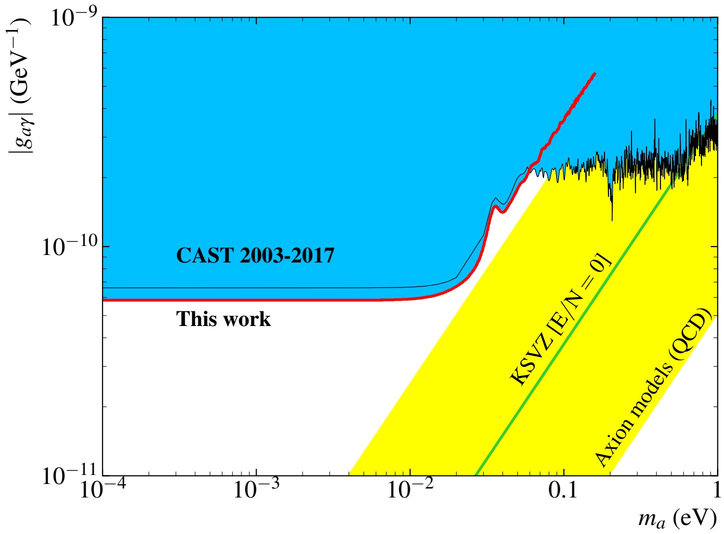

Figure 3.7: Parameter space for axions and ALPs showing the constraints on the axion-photon coupling $g_{a\gamma}$ versus axion mass m_a. The red line indicates the new limit from the most recent work, improving upon the previous CAST limit (black line). The yellow band represents the region favored by QCD axion models, with the green line showing a specific benchmark model (KSVZ with E/N = 0).

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3.2 | ANAIS Experiment

Responsible investigator(s) / coordinator(s):	
María Luisa Sarsa	Permanent staff
María Martínez	Permanent staff
Researchers involved:	
Susana Cebrián	Permanent staff
Eduardo García	Permanent staff
Jorge Puimedón	Permanent staff
Ysrael Ortigoza	Permanent staff
Iván Coarasa	Temporary staff
Tamara Pardo	Research trainee
Jaime Apilluelo	Research trainee
Carmen Seoane	Research trainee
Julio Amaré	UZ collaborator
David Cintas	External collaborator
Technical support:	
Alfonso Ortiz de Solórzano	Engineer
Francisco Javier Mena	Technician

Sodium Iodide Thallium doped (NaI(Tl)) scintillation detectors are a convenient choice for detecting radiation in many applications. In particular, they have been applied to the direct searches for dark matter since the 1990s and have produced one of the most challenging results in the field: the observation by the DAMA/LIBRA collaboration of an annual modulation in the detection rate for more than twenty years [1].

After more than three decades of DM direct searches [2], most experimental results are compatible with the estimated backgrounds, although some event excesses have been observed, indicating the necessity for further understanding of the backgrounds at or below 1 keVee [3]. However, the DAMA/LIBRA result persists: it cannot be explained by any known background and shares all the expected features of a dark matter signal [1].

The annual modulation effect in the DM interaction rate results from the Earth's orbital motion around the Sun throughout the year [4, 5]. The variation in the relative velocity of the DM particles with respect to the target nuclei induces a modulation in the DM interaction rate with a one-year period and peaking around June 2^{nd}, for the standard halo model. Backgrounds capable of mimicking this signal have been proposed and dismissed by the DAMA/LIBRA collaboration. However, the DAMA/LIBRA result is difficult to reconcile with the negative results from other experiments using a large variety of target materials and detection techniques. Although the DAMA/LIBRA result is incompatible with the rest of the experiments searching for DM in most of the analyzed scenarios, this comparison is model-dependent and the nature of DM remains unknown. Solving this experimental puzzle is important, as it could lead to new physics, and a model-independent test is needed. Recent reviews of the current experimental situation regarding direct dark matter detection searches and the testing of the DAMA/LIBRA puzzle can be found in [2, 3, 6, 7].

A model-independent test of the DAMA/LIBRA result requires an experiment using the same target material, with similar or better background and threshold energy as DAMA/LIBRA in the region of interest (ROI), large exposure (product of mass and measurement time) and stability. This is the goal of the ANAIS-112 experiment, which has been in data-taking phase at the Canfranc Underground Laboratory (LSC), in Spain, since August 2017. The ANAIS-112 design and operation rely on expertise acquired at the University of Zaragoza using NaI(Tl) scintillation detectors for about thirty years [8].

The ANAIS-112 experiment consists of 112.5 kg of NaI(Tl), distributed in 9 modules, 12.5 kg each, arranged in a 3 x 3 configuration (see figure 3.8). Among the most relevant features of the ANAIS-112 modules is their remarkable optical quality, which combined with high quantum efficiency Hamamatsu photomultipliers (PMTs), results in a very high light collection, at the level of 15 photoelectrons (phe) per keV, significantly larger and more homogeneous than that achieved by DAMA/LIBRA modules in the improved phase 2 of the experiment. Another interesting feature is a Mylar window in the middle of one of the lateral faces of the detectors, allowing calibration of the modules with external sources at energies just a few keV above the ROI ([1–6] keV). The ANAIS-112 experiment is installed inside a shielding consisting of an inner layer of 10 cm of archaeological lead and an outer layer of 20 cm of low-activity lead. This lead shielding is encased into an anti-radon box, tightly closed and kept under overpressure with radon-free nitrogen gas. The external layer of the shielding, the neutron shielding, consists of 40 cm of a combination of water tanks and polyethylene bricks. An active veto made up of 16 plastic scintillators is placed between the anti-radon box and the neutron shielding, covering the top and sides of the setup (see figure 3.8) allowing for effective tagging of the residual muon flux.

The signals from the two PMTs coupled to each module are digitized at 2 GS/s with high resolution. The trigger requires the coincidence of the two PMT trigger signals in a 200 ns window, while the PMT individual trigger is set at the single photo-electron level. The stability of the experiment is ensured by calibrating with ^{109}Cd sources every two weeks, allowing for the correction of small gain drifts. The energy calibration is performed with the ^{109}Cd lines plus the energy depositions at very low energy (3.2 and 0.87 keV) associated with the decay of ^{40}K and ^{22}Na crystal contaminations, respectively, that can be tagged by coincidences with high energy gammas in a different module. This procedure allows to perform a reliable energy calibration of the ANAIS-112 data down to 1 keV, while identifying events from ^{22}Na confirms the highly efficient triggering below 1 keV. The residuals of the energy associated with the ^{40}K and ^{22}Na peaks with respect to their nominal energy, gathering data every 90 days for the first year of data, are 0.01 keV at the 3.2 keV line and 0.04 keV at the 0.87 keV line [9].

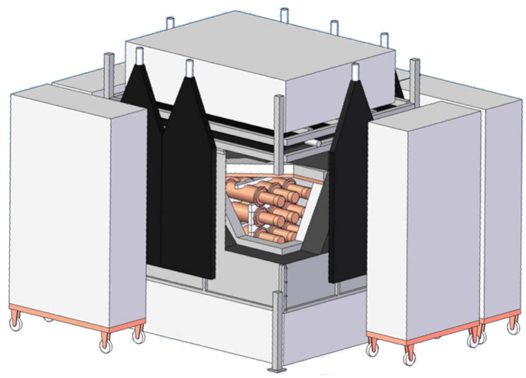
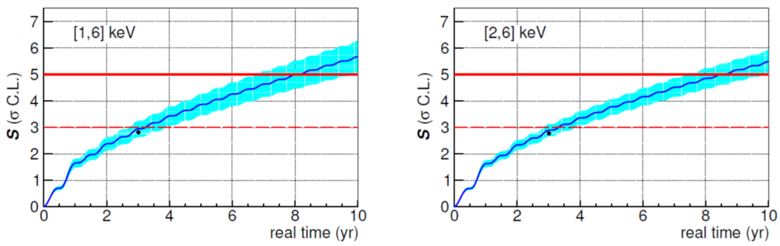


Figure 3.8: ANAIS-112 setup at the LSC.

The background in the ROI is dominated by non-bulk scintillation events, so strong filtering protocols based on the pulse shape and light sharing among the two PMTs have been developed. The efficiency of the event selection criteria is calculated with scintillation populations (^{109}Cd, ^{40}K, ^{22}Na) and is very close to 100% down to 2 keV, but then decreases steeply to about 15% at 1 keV, where we set the analysis threshold [9]. A careful background model of the ANAIS-112 experiment has been developed over the years, by combining inputs from different analysis techniques: HPGe screening of different materials used in the setup and in the detector building, measurements in coincidence of the modules before ANAIS-112 commissioning, determination of alpha rate by using PSD, estimates of cosmogenic activation rates in NaI, and so forth [11].



(a) (b)

Figure 3.9: Sensitivity projections of the ANAIS-112 experiment on the DAMA/LIBRA annual modulation signal after including the new filtering procedure (BDT cut) in the two energy regions, [1-6] and [2-6] keV [10].

A full description of the experiment's performance after the first year, a detailed background model and the analysis of the corresponding sensitivity to the DAMA/LIBRA signal were published in 2019 [11, 12] and shortly after, a preliminary annual modulation analysis corresponding to 1.5 years of data [13]. These initial results were fully compatible with the absence of modulation and in slight tension (2σ level) with the positive result of DAMA/LIBRA. In 2021, results corresponding to three-year exposure were published [14], supporting that ANAIS-112 results are leading the worldwide efforts to test DAMA/LIBRA result.

Strong efforts to improve the analysis procedure in the last years resulted in the development of a new machine-learning filtering for bulk scintillation events based on boosted decision trees (BDT), which allowed to improve the ANAIS-112 sensitivity [10], as shown in figure 3.9. Moreover, the consistency of the annual modulation analysis results has been significantly enhanced by further improvements in the data analysis. This new analysis procedure was preliminarily applied to the three-year exposure [15]. The ANAIS-112 experiment was scheduled to operate until the end of 2025, in order to approach 5σ sensitivity to DAMA/LIBRA result (See figure 3.9).

In the second half of the data-taking, a neutron calibration program has been developed, a new DAQ system was commissioned and a R&D program using SiPMs for the optical readout of NaI crystals cooled down to 100 K is in progress, ANAIS+. A new cryogenic facility at the University of Zaragoza was commissioned in order to test prototypes consisting of NaI crystals coupled to SiPMs to evaluate the feasibility of a DM search. A good-performing prototype of only 1 kg has a competitive sensitivity for low mass Spin-Dependent interacting dark matter candidates, as it is shown in figure 3.10.

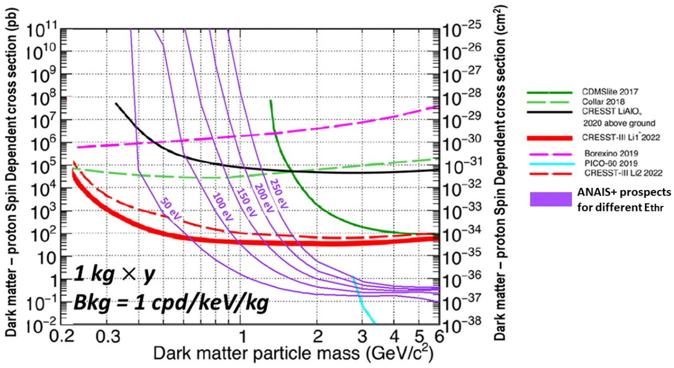


Figure 3.10: Sensitivity projections of ANAIS+ experiment for light WIMPs with Spin-Dependent coupling to nucleons for 1 kg x y with a background of 1 counts/keV/kg/day for different energy thresholds.

3.2.1 | Achievements in 2024

1. Data taking of the experiment at LSC progresses smoothly with same quality parameters as in previous years, accumulating more than seven years of data with more than 95% live time.

2. The reanalysis of the three-year exposure using the improved analysis procedure has been published in 2024 in Communications Physics [16]. For an exposure of 312.53 kg×year, the best fit for the modulation amplitude in [1-6] ([2-6]) keV energy regions is S_m=–1.3 ± 3.7 c/keVee/ton/d (3.1 ± 3.7 c/keVee/ton/d) with p-values of 0.40 (0.64). The corresponding result, shown in figure 3.11, is incompatible with DAMA/LIBRA at 3.2 (1.9) σ C.L. in the two energy regions analysed, [1-6] keV and [2-6] keV, for a sensitivity at (2.8 ± 0.3) σ in [1–6] keV and (2.8 ± 0.2) σ in [2–6] keV, where the uncertainty corresponds to the 68% C.L. DAMA/LIBRA uncertainty), confirming the sensitivity projections. This publication has also considered the effect of different scintillation quenching factors for nuclear recoils in DAMA/LIBRA and ANAIS-112 crystals by studying a region from 6.7 to 20 keV_{NR} for sodium and from 22.2 to 66.7 keV_{NR} for iodine, equivalent to the [2-6] keV_{ee}

region from DAMA/LIBRA, obtaining as best limit in the modulation hypothesis S_m=3.3 ± 5.0 c/keVee/ton/d. This publication was selected as highlight in October 2024 in the webpage of the journal (Communications Physics).

3. The analysis of six-year exposure was completed in 2024 and the article has been released in arXiv and sent for publication at the beginning of 2025 [17].

4. We are collaborating with COSINE-100 for the combination of our results. Sophia Hollick, PhD student at Yale University under supervision from Reina Maruyama, and member of the COSINE-100 collaboration has been in a research stay at the CAPA since September 2023 with this goal. Preliminary results of the combined analysis of COSINE-100 and ANAIS-112 three-year exposure were presented at IDM conference, in July 2024, at LNGS. The analysis is ready and a publication is under internal review by the collaborations, and it is expected to appear in 2025.

5. The new DAQ system for ANAIS-112 has been installed for all the modules within 2024 and it is taking data. This new DAQ (ANOD) is free from dead time and has a configurable digitizing window, now set to 8 microseconds (to be compared with 1.2 microseconds of the standard ANAIS DAQ system). ANOD is providing useful information to understand some anomalous events identified in ANAIS-112 data and to develop procedures to reject them. Work is ongoing.

6. Our program of calibration of the experiment onsite using neutrons produced by a ^{252}Cf source is ongoing. These calibrations provide a population of nuclear recoils in the NaI crystals at very low energy very similar to those DM particles should produce in the detectors. They are helping to improve our knowledge on the response function of the ANAIS-112 detectors. In particular, we have monitored the evolution of the event selection efficiencies in time with this population. Along 2024 we have strongly progressed in the simulation of these calibrations. We have found some mismatch in the cross-sections used by Geant4 versions and we are able to reproduce our measurements in single and multiple hits events both qualitative and quantitatively, while deriving information about the sodium and iodine quenching factors. This work, within the PhD of Tamara Pardo, is expected to be completed in 2025.

7. We continue publishing ANAIS data in open access. In collaboration with the Dark Matter Data Center, funded by the ORIGINS Excellence Cluster: https://www.origins-cluster.de/odsl/dark-matter-data-center. ANAIS data can be found at: https://www.origins-cluster.de/odsl/dark-matter-data-center/available-datasets/anais.

8. We continue collaborating within the HENSA-ANAIS effort to measure the possible seasonal variations in the neutron flux at the Hall B of the LSC and improving the estimates of the neutron contributions to the ANAIS background.

9. The analysis of the data corresponding to the measurements of the quenching factors for the scintillation produced by Na and I recoils in NaI(Tl) carried out at Triangle Universities Laboratory (USA) has been published in 2024 in [18].

10. The new cryocooler commissioning for the operation of the prototypes down to 100 K was due at the beginning of 2024 and it has been fully operative since then in the ANAIS+-lab at the Science Faculty in Zaragoza

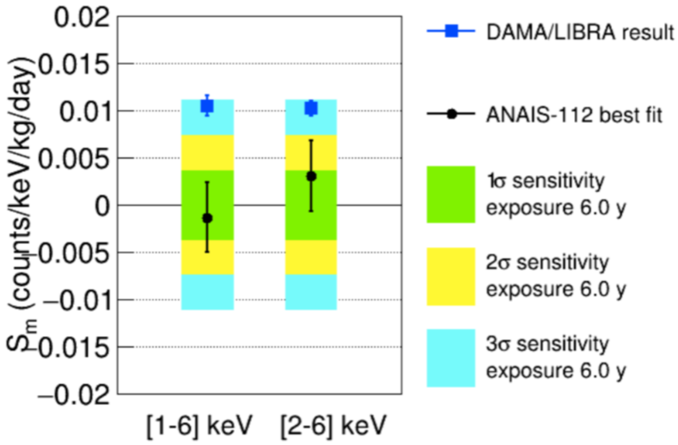


Figure 3.11: Comparison between ANAIS-112 results on annual modulation using three years of data reanalysed using machine-learning techniques [16], and DAMA/LIBRA modulation best fit [1]. Estimated sensitivity is shown at different confidence levels as colored bands: green at 1σ, yellow at 2σ, and cyan at 3σ.

University facilities. It has been used for the characterization of SiPMs at different temperatures and for checking the response of small crystals to several thermal cycles. Currently, there is functional DAQ system for the readout of four SiPM tiles, a calibration system based on low energy radioactive sources and a LED, both placed inside the cryocooler.

11. The collaboration with the LNGS (via Dr. A. Razeto) for the building of specifically designed SiPMs (integrating first steps of the readout front-end electronics) with outstanding performance at low temperature for the readout of NaI(Tl)/NaI scintillation at low temperature has continued along 2024. We have received new SiPMs to be tested. The first ANAIS+ prototype with NaI inside a tight housing is still under design phase, but a CsI crystal has been already operated in the ANAIS+-lab. First tests underground will be planned within 2025. A new PhD student joined the group in 2024 to work within the ANAIS+ research line.

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3.3 | Search for low-mass WIMPs with the TREX-DM experiment

Responsible investigator(s) / coordinator(s):	
Igor G. Irastorza	staff
Theopisti Dafni	staff
Researchers involved:	
Gloria Luzón	staff
Susana Cebrián	staff
Fernando Arteche	staff (ITA)
Javier Galán	postdoc
Juan A. García Pascual	postdoc (MC)
Cristina Margalejo	predoc
Oscar Pérez	predoc
Luis Obis	predoc
David Díez Ibáñez	predoc
Álvaro Ezquerro	predoc
María Jiménez Puyuelo	predoc
Javier Galindo	postdoc (ITA)
Technical support:	
Alfonso Ortiz de Solórzano	engineer
Hector Mirallas	engineer
Juan Castel	engineer
Javier Mena	technician

The TREX-DM experiment at the Canfranc Underground Laboratory, led by CAPA researchers, targets the detection of WIMPs with particularly low masses (below $\sim$ 10 GeV), which would have gone unnoticed in mainstream WIMPs experiments. For this purpose, it follows a novel technology, based on temporal projection chambers (TPC) with gases composed by low-atomic-number species (e.g. neon plus isobutane) at high pressure [1], which promises operation with an energy threshold and background noise lower than that obtained by other detectors to date [2]. If these projections are confirmed, TREX-DM could enjoy highly competitive sensitivity to low-mass WIMPs, even with discovery potential.

The core of the TREX-DM TPC are the readout planes, based on novel Micromegas readouts of a particular type, known as *microbulk*, developed mostly at CAPA within the T-REX project [3, 4], an ERC-StG grant carried out from 2009 to 2015. Moreover, many of the technical advantages exploited in the development of the detectors for axion research (see section 3.1) are of direct application also in this case; namely, the possibility to build Micromegas readouts with very radiopure materials and with a signal extraction scheme of extreme radiopurity or the capability to use topological discrimination techniques based on the highly granular readout. In addition, the way event detection happens in gas (i.e. drift of charge and signal amplification confined in the Micromegas structure) allows, in principle, to reach very low energy threshold even in relatively large size detectors [5]. Another aspect, very important for application to WIMP searches, are the scaling-up prospects. Technical solutions for scaling-up via tessellation of identical microbulk detectors have been defined.

The TREX-DM TPC has been designed to host 0.3 kg of argon mass at 10 bar (or, alternatively, 0.16 kg of neon). It is composed of a cylindrical vessel made of radiopure copper, with an inner diameter of 0.5 m, a length of 0.5 m and a wall thickness of 6 cm. These dimensions are set by the requirements that the vessel holds up to 10 bar of pressure, while at the same time constitutes the innermost part of the shielding. The vessel is divided into two active volumes by a central mylar cathode, which is connected to high voltage by a tailor-made feedthrough. At each side there is a 19 cm long field cage defined by a series of copper strips imprinted on a kapton substrate supported by four teflon walls.

Various TREX-DM sensitivity scenarios have been projected and are shown in Figure 3.13. Scenario A represents the sensitivity projection assuming a threshold (E_{th} = 50 eVee) as would be expected once the GEM preamplification is implemented in TREX-DM (see below), a nominal background of 10 dru and 1 year of exposure. Scenario B assumes an improved background (b = 1 dru) and the expected improved threshold (E_{th} = 50 eVee). To illustrate the effect of potential future experiment improvements, scenarios CAr10 and CNe10 are included, which represent a ten-fold improvement in background level beyond current nominal, as well as in exposure. However, this scenario would require a new detector design with a larger sensitive volume.

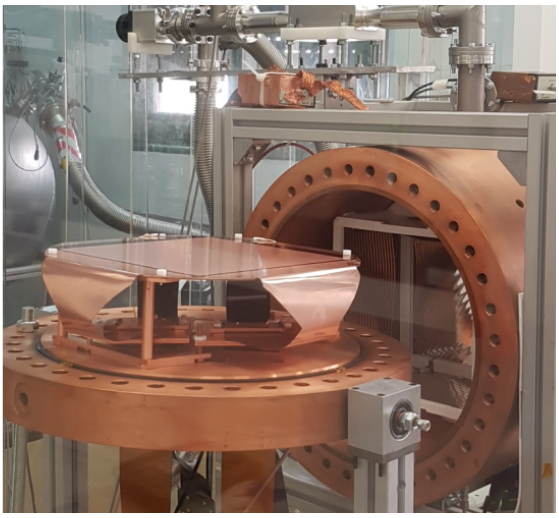

Figure 3.12: Picture of the TREX-DM detector with one of the endcaps open, showing the microbulk Micromegas readout plane, the largest ever built in this technology, and the flaps carrying out the signals via radiopure feedthroughs out of the vessel.

The installation of the TREX-DM detector at LSC was completed in 2018 (with the exception of the external neutron shielding) and the experiment went though its commissioning and first engineering runs in 2019. By then a full simulation-based background model of the experiment was finished and published. In 2020, the experiment started its first physics runs with Ne + Isobutane at a nominal pressure of 4 bar. The first data revealed an unanticipated background population at low energy, coming both from radon emanated into the detector gas, and decaying in the active volume, as well as from Rn progeny contamination of the inner surfaces of the detector. The 2021 runs were focused on the study and mitigation of these populations. In 2022, the detector underwent a major upgrade with the replacement of both Micromegas readout planes and part of the associated mechanics, with several improvements implemented, in particular a new type of home-made radiopure contact connector. In October 2022, after a few weeks of operation with the upgraded detector, the experiment had to be dismantled from Hall A as per request of LSC management, due to the assignment of a new site for the experiment in a different hall (Lab2500). Due to the unpreparedness of the new site, the recommissioning of the experiment did not happen until summer 2023. In 2024, a novel preamplification stage has been implemented, allowing for a substantial reduction of the threshold. An article on the achievements of the project and challenges that it faces was published [6].

3.3.1 | Achievements in 2024

During 2024, the experiment fulfilled one of its goals, demonstrating its ability to lower the energy threshold to values close to single-electron levels. This was possible employing a GEM foil suspended some mm above the Micromegas plane (more details given below), combined with the production of a low-energy calibration source in gas form (^{37}Ar). The GEM was installed during an intervention to fix leaks and electrical connection problems that had arisen months before (see report of 2023). Other measurements performed include the drift velocity (important for the topological reconstruction of the events collected) and gain curves for higher isobutane concentrations of the base gas mixture (of interest both for lower-mass WIMP detection and the operation stability of the detector). In parallel, the AlphaCAMM detector has started to measure thin samples of materials of interest to be used in TREX-DM.

1. Calibrations at low energies are mandatory for TREX-DM in order to monitor the performance of the detector in the region of interest (up to 10 keV). A source in gaseous form would allow for the homogeneous illumination of the detector volume and therefore readout plane: ^{37}Ar covers these two requirements, a gas that emits x-rays at 0.27 keV and 2.82 keV. In collaboration with researchers from the Centro Nacional de Aceleradores (CNA), Sevilla, CaO powder was irradiated with neutrons for the procurement of ^{37}Ar gas. In April 2024, the first irradiation attempt of the powder was successful, as evidenced by the measurement of ^{42}K gammas shortly after

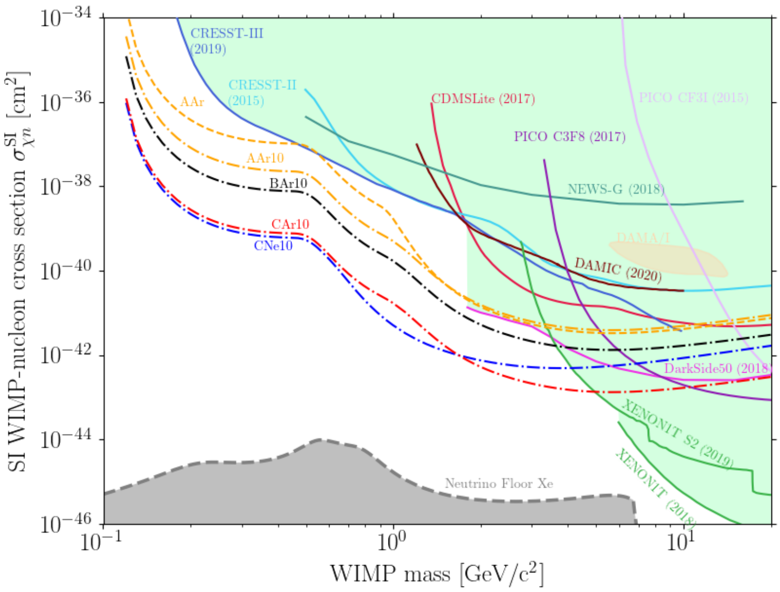

Figure 3.13: TREX-DM projected sensitivity in the WIMP-nucleon cross-section versus WIMP mass parameter space. Different TREX-DM scenarios, together with current bounds from leading light-WIMP DM experiments are shown. Scenario A represents nominal TREX-DM background and an improved threshold that can be reached with on-going developments, while AAr10 assume an enriched Hydrogen gas mixture. Scenario BAr10 assumes an improved background. Scenarios CAr10 and CNe10, assume a ten-fold improvement in background and exposure, that would require a larger sensitive volume.

the irradiation; however, because of limitation of operations at the LSC, the source was able to be tested at the TREX-DM detector several weeks after, and in non- optimal conditions of noise. Even so, the 2.82 keV peak was observed. It was in October 2024, after the second irradiation and with one of the detector readout planes equipped with the GEM-MM system, that the full ^{37}Ar spectrum was registered, as shown in Figure 3.14. This is an exceptional result, as it proves sensitivity down to $O(10)$ eV events, a necessary condition to explore the low-energy region of the WIMP parameter space.

2. The installation of a new clean room in LAB2500 at LSC in June 2024 made possible the first *in situ* intervention, in which the damaged GEM that was suspended approximately 1 cm above the Micromegas plane was replaced with a new one, among other repairs. With this system in place, the achievable gain is several tens of times higher than the nominal gain only with the Micromegas plane (at 1 bar), in line with the results obtained with the test GEM+MM set-up (see 2023 report). The low-energy region of the spectra obtained with the ^{37}Ar source (right part of Figure 3.14) clearly shows the peak at 270 eV, and exhibits an energy threshold around 20 eV, of the order of single-electron ionization energies for argon. This spectrum was taken with gains higher than the stable operating point. Nonetheless, even at a more conservative operating gain of the GEM-MM system, the energy threshold is better than 300 eV. This achievement constitutes an important milestone of the experiment, combining the R&D results from the GEM+MM set-up with a reliable method to obtain a low-energy calibration source.

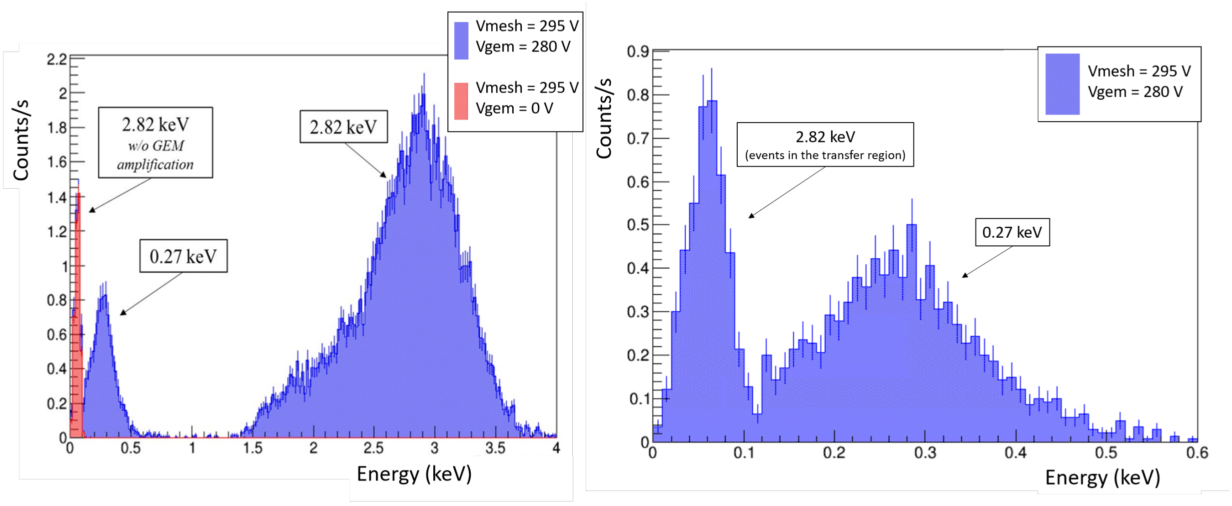

Figure 3.14: Left: spectra of the ^{37}Ar calibration. In blue, the spectrum with the GEM on; in red, the spectrum without the preamplification of the GEM. The red peak, present in both spectra, corresponds to the 2.8 keV events absorbed in the transfer region (between the GEM and the Micromegas), which are not preamplified by the GEM. The second and third peaks are the 0.27 keV and 2.82 keV peaks of the ^{37}Ar source absorbed in the drift region (between the GEM and the cathode), and therefore they do not appear in the red spectrum. The asymmetric tail of the third peak is due to saturation in the amplitude of the pulses with this high gain. Right: zoomed view of the low-energy region, showing an $O(10)$ eV energy threshold.

3. AlphaCAMM is a high-sensitivity alpha surface detector (see section 8.3) conceived to accurately screen ^{210}Po surface contamination, especially motivated by TREX-DM needs: it is a Micromegas-read TPC with a cathode that is transparent to alpha particles. The sensitivity of the detector was improved by one order of magnitude with respect to the one of 2023, however it still remains a factor 5 higher than the one needed for the sensitivity level imposed by the TREX-DM background model. In spite of this, first measurements of thin foils began in late 2024, starting with the aluminized Mylar sheet used as cathode in TREX-DM for two years, which was identified as the source of alpha background inside the detector and the kapton-copper foil that is planned to be used for the field cage.

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3.4 | The DarkSide-20k project

Responsible investigator(s) / coordinator(s):	
María Martínez Pérez	staff
Researchers involved:	
Susana Cebrián Guajardo	staff
Technical support:	
Alfonso Ortiz de Solórzano Aurusa	engineer

The DarkSide-20k project is intended to directly detect galactic dark matter particles using a two-phase liquid argon (LAr) TPC (see Fig. 3.15, left) filled with 20.2 tonnes (fiducial mass) of Underground Argon (UAr) depleted in ^{39}Ar at the Laboratori Nazionali del Gran Sasso (LNGS) [1]. Liquid argon offers important advantages for radiation detection, like a high scintillation yield and easy purification for non-noble contaminants; in addition, very efficient discrimination between electron recoils (ER) and nuclear recoils (NR) typically expected from WIMPs can be implemented based on Pulse Shape Discrimination techniques and on the measurement of both the primary scintillation and the electroluminescence from electrons multiplied in a gaseous region above the liquid. DarkSide-20k is the successor of the successful DarkSide-50 experiment and the first project of the Global Argon Dark Matter Collaboration (GADMC) collecting all the community working on dark matter searches using liquid argon. Data taking is expected to start from 2027; the goal of DarkSide-20k is to explore regions of WIMPs down to the level where coherent scatters from atmospheric neutrinos becomes a limiting background [2, 3]. Sensitivity to directionality of nuclear recoils is being explored too [4].

One of the goals of GADMC is the procurement of large amounts of low-radioactivity UAr as detector target [5, 6]. The content of ^{39}Ar in atmospheric argon, at a level of 1 Bq/kg, is unacceptable; DarkSide-50 produced the first WIMP search results using UAr with a reduced content of ^{39}Ar by a factor 1400±200. The Urania plant, in Colorado (US), is being built to extract UAr from the same underground source. The Aria facility, in Sardinia (Italy), will chemically purify the UAr and could allow an additional 10-fold suppression of ^{39}Ar per pass based on cryogenic

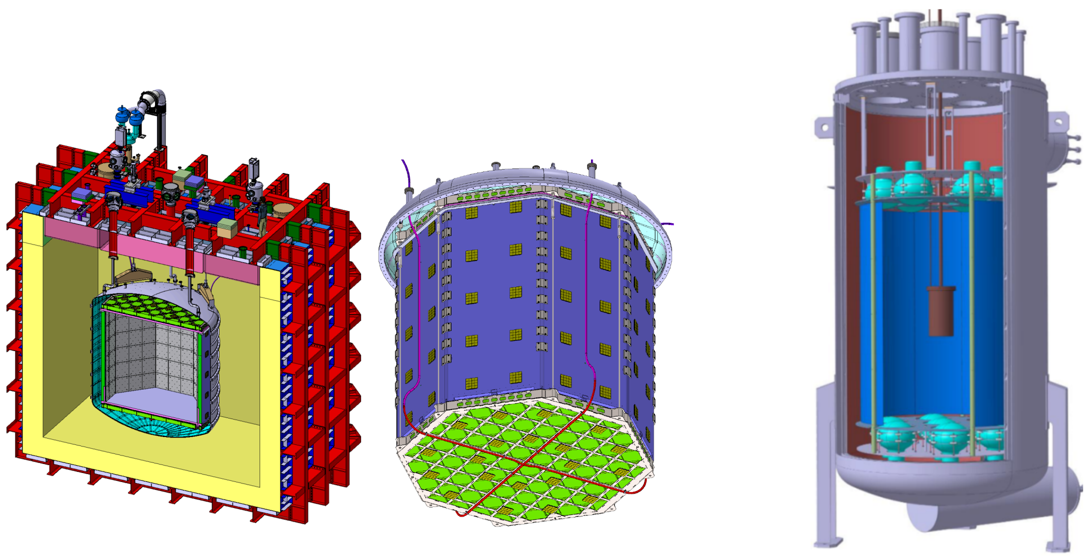

Figure 3.15: Left: cross section showing the detector system of the DarkSide-20k experiment to be installed in the Hall C of LNGS, with the TPC walls made of Gd-acrylic in green and the vessel in gray. Rigth: artistic view of the DArT chamber inside the LAr tank of the ArDM experiment at LSC.

distillation [7]. The assessment of the ultra-low levels expected of ^{39}Ar is the goal of the DArTinArDM experiment, in the Canfranc Underground Laboratory [8]. The interest in obtaining radiopure Argon goes beyond GADMC (see the Letter of Intent signed by GADMC, COHERENT, DUNE, and LEGEND experiments [9].

DArTinArDM consists on a small radiopure chamber with capacity for $\sim$1 liter of UAr (DArT) placed at the centre of the 1 ton LAr tank of the Argon Dark Matter (ArDM) detector, operated at the LSC several years ago, that will act as active veto (see Fig. 3.15, right). The scope of DArT is to measure ^{39}Ar depletion factors of the order of 1000 with a precision better than 10% in one week of running [8]. The ^{39}Ar isotope decays via β emission with an end-point of 565 keV. The absence of other γ or X-ray emission makes this measurement very challenging and requires a powerful veto system, whose role will be played by the ArDM detector. The scintillation light of the DArT chamber is read by the so-called DArTEyes, using SiPMs of the same manufacturer as DarkSide-20k [10], while the veto readout is performed with 13 photomultipliers (PMTs) installed in the top and bottom flanges of the ArDM tank. While preparing the assembly of the final detector, tests and first measurements have been carried out with a DArT detector in a test cryostat (DArTinTestCryo) installed in the hall A of LSC in order to tune some detectors parameters and characterize the radioactive background (see Fig. 3.16). The commissioning of DArTinArDM is ongoing and a measurement of ^{39}Ar activity in the UAr used in the DarkSide-50 experiment has been carried out in 2024. A Memorandum of Understanding between LSC and GADMC has been signed to develop the UAr measurements. CAPA is responsible for the data acquisition system for DArT and the veto (ArDM) and the design and construction of the shielding underground and participates in the SiPM characterization.

DarkSide-20k is being designed to operate with all sources of instrumental background reduced to $<$0.1 events over a 200 tonnes$\cdot$year exposure, thanks to the powerful ER background discrimination and the neutron veto capabilities. This imposes the consideration and study of all possible background sources, including a very thorough control of the radioactivity in all the components of the set-up to minimize the effect of direct emissions as well as of the neutrons induced by (α,n) reactions. This effort for the selection of proper materials involves different laboratories all over the world applying a combination of different sensitive techniques for radioassays, like HPGe gamma spectroscopy, Inductively Coupled Plasma Mass Spectrometry (ICPMS) and alpha spectroscopy combined with chemical separation techniques. CAPA is collaborating in the quantification of the cosmogenic activation of materials produced due to the exposure to cosmic rays above ground as well as in the radioassays performed at LSC.

3.4.1 | Achievements in 2024

1. DArTinTestCryo, with a lead shielding and an anti-Rn system, has been operated along 2024 to complete the studies on the light yield of SiPMs and Pulse Shape Discrimination techniques. From data runs taken with both AAr and UAr from DarkSide-50, the first analysis to derive the ^{39}Ar activity in AAr (by fitting the data after the subtraction of the UAr contribution to the theoretical beta spectrum) points to results in agreement with expectations.

2. The preparation of DArTinArDM has significanty advanced, completing the ArDM refurbishment, PMTs characterization and tests of photoelectronics. A new DArT2 detector has been built intended to improve light yield and radiopurity; new DArTEyes have been characterized in a dedicated test bench and special cleaning

of copper, stainless steel, plastic pieces has been developed. First samples of UAr from the Urania facility are expected to be received and measured in DArTinArDM during 2025.

3. Calculations of the cosmogenic activity of relevant long-lived radioisotopes induced in the argon and the corresponding background rates in DarkSide-20k have been updated taking into consideration the changes in transportation of UAr from US to Europe. Production of ^{39}Ar in the UAr has been checked to be tolerable in the foreseen conditions for extraction, purification and transport [11].

Figure 3.16: Hall A at LSC with DArTinTestCryo on the left and DArTinArDM on the right.

3.4.2 | References

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3.5 | Support to experiments at the LSC

Responsible investigator(s) / coordinator(s):	
Susana Cebrián Guajardo	staff
María Martínez Pérez	staff
Researchers involved:	
David Cintas González	postdoc
Víctor Pérez Sánchez	predoc
Technical support:	
Alfonso Ortiz de Solórzano Aurusa	engineer

Given the extensive experience of CAPA members and their status as an associated group of the LSC, the collaboration of CAPA members is frequently required in experiments conducted at the LSC. While the role in these experiments is not a leading one, it is nonetheless significant for specific tasks, such as studies of radioactive backgrounds, radiopurity measurements, or contributions to diverse activities related to the underground setup (acquisition system, quality control procedures, active veto systems...)

In 2024, CAPA contributions were particularly notable in two experiments currently under development at the LSC and looking for neutrinoless double beta decay ($0\nu\beta\beta$). This is a rare nuclear process that could occur if neutrinos are their own antiparticles, thus Majorana fermions. The detection of this decay, which violates lepton number conservation by two units, would serve as compelling evidence for physics beyond the Standard Model of particle physics and simultaneously yield a measurement of the neutrino mass scale.

3.5.1 | The CROSS experiment

CROSS (Cryogenic Rare-event Observatory with Surface Sensitivity) is an experiment utilizing the bolometric technique, installed in the LSC, to investigate $0\nu\beta\beta$ decay in two promising isotopes (^{100}Mo and ^{130}Te). The primary objective of CROSS is to develop innovative technology capable of discriminating events caused by surface radioactive impurities using pulse-shape discrimination (PSD) and test it in a year-scale experiment (CROSS demonstrator). Initially proposed under an ERC Advanced Grant project that commenced on January 1st, 2018, the CROSS technology involves modifying the pulse shape through a thin metallic or superconductive film deposited on the crystal surface, with a thickness of a few micrometers. The coating alters the phonon energy down-conversion cascade following particle interaction, resulting in a distinct signal shape for events close to the film. The efficacy of discriminating between internal and surface alpha and beta events has been demonstrated using Pd normal-metal film (10 nm thick) and Al–Pd superconductive bi-layers, either continuous or in grid form [1]. Furthermore, highly sensitive light detectors are essential for detecting the faint Cherenkov light emitted by poorly scintillating crystals, as in the case of TeO_2, or for enhancing the pile-up rejection capability in LMO [2]. The Neganov–Trofimov-Luke (NTL) effect leads to an increase in heat deposited by an ionizing particle in a bolometer at low temperatures when induced charges are collected by an applied voltage. CROSS utilizes NTL-effect-assisted cryogenic light detectors developed at the CSNSM laboratory in Orsay [3]. In July 2022 a muon veto was installed in the underground site with the participation of the UZ. During 2024, a calibration campain was performed to optimaze the veto performance.

Since 2021, several test runs have been carried out at Canfranc with crystals of TeO_2 and $Li2MO_4$ (LMO) and $CdWO_4$ (CWO) [4–6]. The last of these runs, RUN9, commenced in February 2023 and concluded in November 2023. This was a Mini demonstrator of the CROSS technology with 6 LMO and 4 TeO_2 crystals enhanced with NTL technology. RUN9 plays a crucial role in refining the design of the CROSS demonstrator, particularly in terms of optimizing the suspension system and the copper holding structure, testing crystals from different producers and validating the NTL amplification for light detectors on a large scale. The analysis of the TeO_2 crystals has been carried out during 2024 and is part of the phD thesis of Victor Perez.

After RUN9, a leak was detectected in the dilution unit, and several runs were perfored in order to solve this. This has delayed the installation of the CROSS demonstrator, that now is foreseen for mid 2025.

3.5.2 | The NEXT experiment

The "Neutrino Experiment with a Xenon Time-Projection Chamber" (NEXT) is intended to study the nature of neutrinos searching for the neutrinoless double beta decay of ^{136}Xe using a TPC with electroluminescent amplification filled with high-pressure gaseous xenon in the Canfranc Underground Laboratory. NEXT has been highlighted as one of the most competitive projects, together with LEGEND and CUPID, by the Double Beta Decay APPEC Committee. It is an international collaboration with more than twenty institutions mainly from Spain and US. The first phase of the program included the construction and operation of various prototypes with masses of around 1 kg which demonstrated the technology. The NEXT-White demonstrator, deploying 5 kg of xenon and operated in Canfranc, confirmed the required energy resolution at the transition energy of ^{136}Xe and established the topological signature of electrons for background discrimination [7, 8]. NEXT-100 construction [9], being a radiopure detector with 100 kg of xenon, has been completed in 2024. In the longer term, different approaches are being considered for a tonne-scale detector, exploiting to the limit the distinctive capabilities of the NEXT technology (NEXT-HD) and also considering the daughter Barium ion detection (NEXT-BOLD) [10]; the goal is to explore half-lives for the neutrinoless channel larger than 10^{27} y.

The expertise of the Zaragoza group for the control of the radiopurity of materials and components was requested and a contribution to the extensive radioassay program of NEXT-100, mainly based on HPGe gamma spectroscopy performed underground combined with other techniques like Inductively Coupled Plasma Mass Spectrometry (ICPMS) or Glow Discharge Mass Spectrometry (GDMS), has been made over several years. Results from activity measurements are useful for the selection of materials but also for inputs to background models based on Monte Carlo simulation to evaluate sensitivity.

3.5.3 | Achievements in 2024

1. The leak that appeared in the CROSS refrigerator during RUN10 has been successfully repaired. This required the replacement of the "fast injection line," identified by Cryoconcept as the most likely source of the leak. A flexible replacement was fabricated and successfully inserted into the cryostat, and its performance was verified in a cryogenic run, reaching and maintaining base temperature without issues.

2. The CROSS demonstrator preparation is ongoing and remains on schedule. Key tasks performed include polishing crystals to remove surface films, preparing NTD Ge thermistors, depositing Al electrodes for light detectors, cleaning and verifying copper components, 3D printing PLA holders, and gluing NTDs and heaters.

3. The CROSS muon veto has been significantly improved thanks to a calibration campaign using ^{60}Co sources on some elements of the system, including both lateral and bottom sections. This calibration allowed us to

carefully set thresholds in all elements, aiming for a compromise between total rate (which affects live time) and background level.

4. NEXT-100 construction at LSC has been completed in 2024 and first calibration and commissioning data have been taken at different pressures with Argon and since October with Xenon.

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3.6 | New search strategies for relic axion detection (RADES)

Responsible investigator(s) / coordinator(s):	
Igor G. Irastorza	staff UNIZAR
Researchers involved:	
Javier Redondo	staff UNIZAR
Laura Seguí	postdoc (RyC)
Yikun Gu	postdoc
David Díez	predoc
Javier Galindo	postdoc (ITA)

The most important strategy to search for axions that might compose our Dark Matter (DM) halo is the Sikivie's "axion haloscope", which uses a resonant microwave cavity inside a strong magnet to convert the DM axions into a small electromagnetic signal that can be amplified and detected. The signal is detectable only when the resonant frequency of the cavity matches the (unknown) axion mass, and therefore the haloscope must be tuned over a certain (limited) range of mass values. The concept has been implemented with sufficient sensitivity to reach viable axion models in the ballpark of few μeV by the pioneer ADMX collaboration. However, to push the sensitivity of axion haloscopes to other (higher or lower) axion masses is challenging. In particular, to go to higher frequencies, smaller cavities are required (to keep the resonance condition) which means also lower sensitivity. The RADES consortium, initiated by CAPA researchers but now grown to a large international one, with participation e.g. of CERN or MPP-Munich, performs various developments to extend the haloscope concept to other axion mass ranges.

RADES was born with the first goal of developing novel cavity geometries that allow to optimally use large-aspect ratio magnet like the one of CAST. These early efforts yielded the concept of the array of unit cavities interconnected by irises [1], which was fully implemented in the CAST magnet and took physics data in 2018 and 2019, without tuning, i.e., at a single axion mass point. Physics results were obtained and published with this data [2]. The RADES group is also exploring novel inner coatings using high temperature superconductor (HTS) tape, in order to improve the quality factor of these cavities. This is done in collaboration with experts in HTS coatings, also of interest for accelerator physics, in particular CERN and ICMAB-Barcelona. The RADES groups are also exploring the capabilities that the large magnetic volume of BabyIAXO magnet could have for these type of searches. In particular, the concept of one or several large-size cavity systems that could effectively use the BabyIAXO volume is being studied [3]. The concept shows promise of very good sensitivity in the axion mass range aroung 1 μeV, see Fig. 3.17. In this task, most RADES colleagues form part of the IAXO collaboration.

More recently, contacts with quantum technology experts have been established, with the goal of implementing new quantum sensing concepts in RADES-like setups. One of the most evident is the development of single photon counters based on superconducting qubits. Such a device, assuming it can be implemented in the magnetic environment of an axion haloscope and with sufficiently low dark count rate, could improve the sensitivity of the experiment enormously, suppressing the effective noise figure well beyond the standard quantum limit. This efforts have reached in 2023 a very important milestone: a very prestigious ERC-SyG, DarkQuantum, was granted, and has formally started in October 2024. Led by CAPA RADES PI, DarkQuantum counts also with the participation of T. Kontos (ENS-Paris), S. Paraoanu (Aalto U.) and W. Wernsdorfer (KIT), as well as four other RADES partners (DESY, MPP-Munich, ICMAB and UPCT). With a total budget of 13 M€, DarkQuantum will boost the development and implementation of quantum sensing for the detection of the axion in RADES and BabyIAXO.

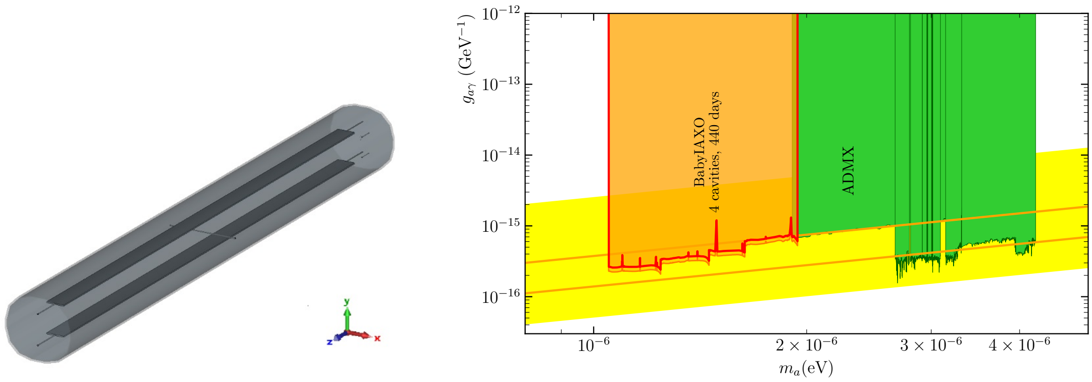

Figure 3.17: Left: sketch of a 5 m long cavity with movable slabs for BabyIAXO. Right: BabyIAXO sensitivity (defined as the average 90% CL upper limit obtained from a background-only data run) using the four 5-m cavities described in the text (orange region), for a total effective exposure time of 440 days. Two scenarios are plotted, one in which two similar cavities are coupled coherently (thin orange line), halving the acquisition time for each data taking configuration, and another one with parallel acquisition with different sized cavities (thick red line), yielding slightly less sensitivity. Also shown are the axion models band (yellow band and orange straigh lines) and the region explored by AMDX (green).

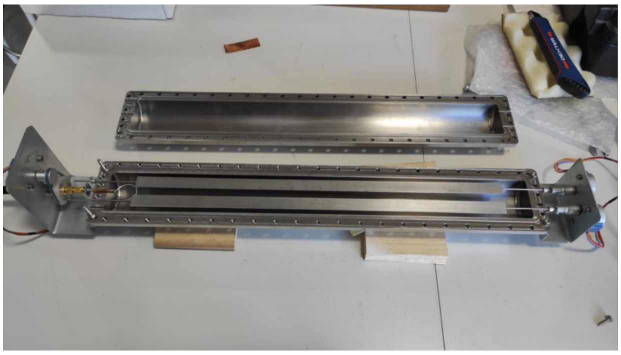

Figure 3.18: Picture of the 10× scaled-down prototype of BabyIAXO cavity, just manufactured and tested in 2023.

3.6.1 | Achievements in 2024

1. A double cavity was designed to develop a single photon counter, and its electrostatic behavior was simulated prior to manufacture. At the same time, qubit geometry was designed for this double cavity and a full batch of 64 transmons was produced in NIST, Boulder, Colorado. With these two items a working single photon counter for microwave photons was installed at a dilution refrigerator, reaching 10 mk, placed in Aalto university (see next item). This setup allows to test the measurement protocol that we want to implement in RADES-HF experiment and to improve further qubit and cavity designs foreseeing a physics run during 2025.

2. Measurements of the single-photon counter at Aalto University were carried out, with data analysis currently being carried out in Zaragoza. The cavity-qubit system has been tested in a 10 mK dilution refrigerator at Aalto University. This initial data campaign has fostered a productive collaboration among various actors, with CAPA members contributing to the cavity design and data analysis. Preliminary results have been obtained, showing a background level consistent with recent literature, though with room for improvement. This campaign has been

Figure 3.19: Picture of the 10× scaled-down prototype of BabyIAXO cavity made on copper, just manufactured and tested in 2024.

instrumental in defining the analysis procedure, refining data collection methods, and initiating improvements in cavity design. A new cavity is currently under development, and a second data-taking campaign is planned both at IFAE and CAPA.

3. Since the summer of 2024, the group has had access to a dilution refrigerator for transmon measurements. Equipment for RF generation and qubit manipulation has been acquired, and the characterization of the first qubit in a single cavity is currently underway. In parallel, efforts are being made to acquire control and readout electronics for quantum circuits. With this equipment, we expect to perform parity measurements before the end of 2025.

4. In November 2024 a new data campaign was carried out by the RADES collaboration. Two HTS coated cavities with new readout system were tested at the CERN SM18 facility with a maximum 12 Teslas magnet. Results from previous campaign were released recently [4]and currently under review for publication. The new data-taking lasted for 10 days, and the data analysis starts at the beginning of 2025.

5. The 10× scaled-down BabyIAXO cavity prototype in copper (1 m length by 50 cm diameter, 3.19) has been successfully tested under cryogenic conditions, achieving a quality factor (Q_0) close to theoretical predictions. Additionally, the tuning system was tested, confirming its functionality. Currently, a larger cavity measuring 50 cm in diameter and 1 m in length is being designed. CERN experts were also involved in the development of the manufacturing design and construction plan. Once completed, the new cavity will undergo measurements in a dilution refrigerator, which is being prepared at KIT.

6. Initial studies have been conducted to explore the detection of high-frequency gravitational waves (HFGWs) using the RADES cavity. So far, the gravitational waves detected have frequencies of maximum about 10 kHz. However, analogous to the electromagnetic spectrum, higher-frequency gravitational waves may also exist. Our goal is to detect these waves through the inverse Gertsenshtein effect, which is similar to the inverse Primakoff effect in axion searches. Techniques and methodologies developed for dark matter axion detection can be adapted to the search for HFGWs [5]. A first study specifically for the RADES/BabyIAXO geometry has been completed this year [6]. This setup has the potential to distinguish the cosmological origin of the detected signal, identifying whether it originates from axions or HFGWs. However, the approach is still far from reaching the theoretical sensitivity required for detection.

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3.7 | Generic R&D on novel low-background time projection chambers (TPC) concepts

Responsible investigator(s) / coordinator(s):	
Theopisti Dafni	staff
Javier Galán	postdoc
Researchers involved:	
Igor G. Irastorza	staff
Juan A. García Pascual	postdoc (MC)
Laura Seguí Iglesia	postdoc (RyC)
David Díez Ibáñez	predoc
Óscar Pérez Lázaro	predoc
María Jiménez Puyuelo	predoc
Technical support:	
Héctor Mirallas	engineer
Juan F. Castel Pablo	engineer

The development of gaseous Time Projection Chambers equipped with Micromegas detectors and their application to low-background experiments is a major activity of CAPA. With an R&D consolidated through and EU-funded project (T-REX StG-ERC, 2009-2015) [1, 2], and two major research lines that are the direct result of these developments (IAXO, TREX-DM), sections 3.1 and 3.3, CAPA is a recognised group in this field.

CAPA plays a significant role in the development of micropattern detectors of the Micromegas family, with emphasis to the microbulk flavour [3]. The microbulk Micromegas are quite suitable detectors because of their excellent performance, the versatility of readout configurations they allow and, very importantly, because of the low radioactivity levels it presents.

A good part of the R&D has been performed within the RD-51 collaboration at CERN in the past 17 years. Although RD-51 has officially reached its end, the community has moved forward towards the creation of the DRD1 R&D Collaboration. DRD1 serves as the continuation and in fact extension of the RD-51 effort, aiming at promoting the development, diffusion and applications of gaseous detectors. It is organised following the General Strategic Recommendations outlined in the ECFA Detector R&D Roadmap Document, in which the importance and richness of gaseous detectors in fundamental research is recognised. CAPA is part of the Collaboration, as explained below.

For CAPA, generic R&D activities are of great importance: resources are kept for a continuous R&D aiming both at improving the current state-of-the-art on the major activities and at looking for wider applications of the new ideas.

3.7.1 | Achievements in 2024

1. GEM+MM setup: A publication has been submitted on the studies that were carried out with an Ar-1%Isobutane mixture (see section 3.3 for more details on the implementation in the TREX-DM experiment) [4]. Those studies will be extended to mixtures with a higher quencher concentration up to 10%Isobutane. The interest in these mixtures is that higher voltages can be reached in the presence of more quencher, what would lead to a better stability of the setup. Other reasons include the increase of sensitivity of the TREX-DM experiment to lower masses due to the higher presence of H atoms. The first characterisations in the small set-up have been performed with an only-Micromegas configuration. More data will be taken during 2025, including the GEM stage.

2. Calibration system: a variable calibration source was developed with a UV LED and a photocathode and tested in a setup with a single-anode Micromegas of 2 cm-diametre. Two types of LED were tested, with wavelengths of 255 nm and 265 nm, and photocathodes were developed from a fused silica wafer with a deposition of a thin layer of 30 nm aluminium on one and with 20 nm copper on another. The aim was to use the LED system

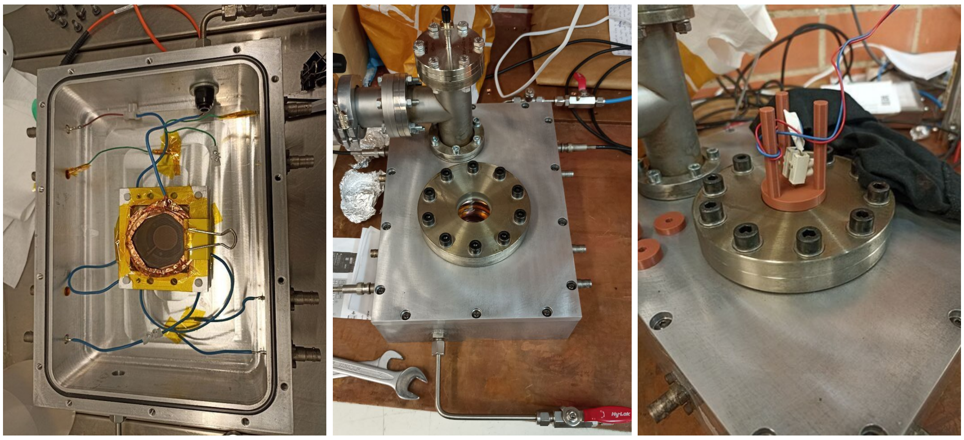

Figure 3.20: Pictures of the setup with the GEM-MM setup: On the left, the aluminium photocathode installed on top of a small Micromegas readout inside the chamber; in the middle, the window towards the gas chamber where the LED was coupled (on the right)

to extract electrons from the photocathode that would be detected at the Micromegas. The best configuration seems to be the most energetic LED, 255 nm, with the aluminium photocathode, which has the lowest work function (4.1 eV as opposed to 4.7 eV of copper). The lowest threshold measured in this setup, limited by the noise at the time of the measurements, was 0.6 keV in Argon + 1%Isobutane.

3. Radiopurity measurements of the resistive Micromegas planes: A first radioassay of a sample of resistive Micromegas produced at CERN was made using a germanium detector at the Canfranc Underground Laboratory; all the usual radioactive contaminants from 232Th, 238U and 40K have been quantified at a level of 1 Bq/kg, higher than expected. The origin of this activity is being investigated, with emphasis on the special glue used for this type of Micromegas.

4. DRD1 Collaboration: The Collaboration was officially formed in January 2024, with meetings that helped bring together the communities of the micro-pattern detectors (already organised in RD-51) with groups developing other gaseous structures like the Drift Chambers and Resistive Plate Chambers (RPC). The Collaboration has been advancing in administrative matters and it is expected that an MoU will be able to be signed before the end of 2025 [5].

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3.8 | Studies on the application of opaque scintillators in rare event searches

Responsible investigator(s) / coordinator(s):	
María Luisa Sarsa Sarsa	staff
María Martínez Pérez	staff
Researchers involved:	
Jaime Apilluelo Allué	predoc
Juan Antonio García Pascual	postdoc
Igor García Irastorza	staff
Gloria Luzón Marco	staff
María Jiménez Puyuelo	predoc
Technical support:	
María Rodríguez	engineer

The LiquidO technology, still in R&D phase, has recently emerged in the context of neutrino oscillation experiments using liquid scintillators [1]. The main idea is to use an opaque scintillator instead of a transparent one, in such a way that the light is strongly scattered but not absorbed, being confined locally around the interaction position. The light is collected by a network of optical fibers read by SiPM at each fiber end, enabling the 3D reconstruction of energy deposits with excellent temporal resolution.

This novel technology has clear synergies with the expertise of CAPA researchers who were asked to join the LiquidO and CLOUD collaborations. The long term goal is to study the feasibility of the application of opaque scintillators for double beta decay searches proposed in Ref. [2]. We expect to participate in European funding calls in the near future, aiming at the setting-up of a large prototype at LSC. In the meantime, many other very interesting applications of the technology are under consideration, profiting from the strong ability of the detector to identify positrons, as for instance shown in [3]. In particular, the technology is being explored as an efficient high-energy neutron and gamma detector, with an interesting application in IAXO, as both active shielding against cosmic neutrons (working in anticoindicence with the Micromegas x-ray detectors), and as a potential detector of high-energy gammas from axions from a potential galactic supernova explosion. This work is followed as part of the efforts to extend the physics case of IAXO. This synergy is being exploited and the construction of a LiquidO demonstrator has started at CAPA. This demonstrator will be used as a test-bench for the different R&D lines at CAPA.

The LiquidO collaboration is conducting R&D in various applications, testing different scintillators, and collaborating with companies building SiPM light sensors and WLS scintillating fibers. The first collaboration paper including the UNIZAR group has been published in 2024 [4] and a few others are under internal review by the collaboration.

3.8.1 | Achievements in 2024

1. We have started to simulate the response of a LiquidO system in terms of the light collected following different particle interactions and to develop analysis tools with the focus on the feasibility study of neutrinoless double beta decay searches. This work is being carried out within the PhD project of J. Apilluelo and a Bachelor Thesis (to be defended in February 2025).

2. First preliminary simulations on the capability of a lead-doped LiquidO scintillator to tag neutron-induced high-multiplicity events have been carried out.

3. The design of the LiquidO demonstrator at CAPA has been finalized and is shown in Fig. 3.21. It consist of a 150 litre chamber filled with a paraffin-scintillator mixture equipped with WLS fibres installed in two

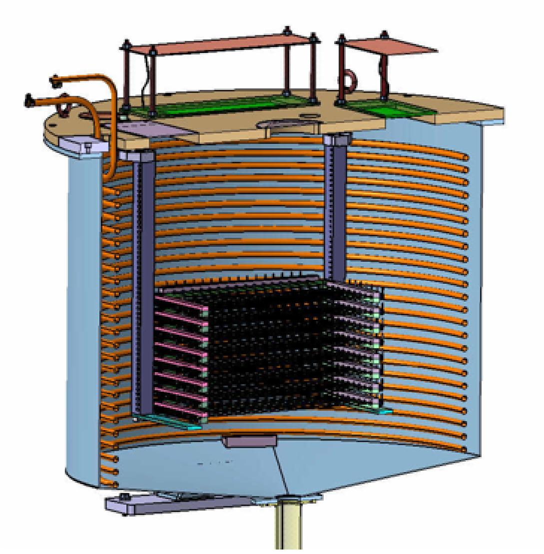

Figure 3.21: Design of the LiquidO demonstrator currently under construction at CAPA.

orthogonal directions. Several key aspects of the different R&D lines will be tested in the LiquidO demonstrator, which is currently under construction at CAPA.

3.8.2 | References

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3.9 | LABAC

Responsible investigator(s) / coordinator(s):	
Jorge Puimedón Santolaria	staff
Researchers involved:	
Susana Cebrián Guajardo	staff
Eduardo García Abancéns	staff
Ysrael Ortigoza Paredes	collaborator
Carmen Pérez Marín	staff, chemist
Technical support:	
Alfonso Ortiz de Solórzano	engineer

The main activity of the "Laboratorio de Bajas Actividades" (LABAC) of the University of Zaragoza[2] is the application of low radioactivity techniques to the environmental monitoring. LABAC measures the environmental parameters according to its agreement with the "Consejo de Seguridad Nuclear" (CSN, Spanish Nuclear Regulatory Commission). It is member of the REVIRA dense net ("Red de Vigilancia Radiológica Ambiental") of the CSN for more than 20 years. REVIRA is composed presently by 21 Spanish laboratories taking continuously data on environmental radioactivity; LABAC has assigned a program of sampling and analysis that controls the evolution of the quality radiological environmental in air, drinking water, diet and soil. LABAC is registered in the national control system for drinking water ("Sistema de Información Nacional de Agua de Consumo", SINAC) and makes regular analyses of water and food for the Government of Aragón since 2010. For the "Laboratorio Subterráneo de Canfranc" (LSC), LABAC performs periodic radiological controls of water and air, radon monitoring and dosimetry. Additionally, LABAC works also for research groups and public or private companies in order to quantify the concentrations of radioisotopes in environmental, industrial or suitable samples for human consumption (water, vegetables, food); in particular, the services currently offered include the determination of gross alpha and beta activity indexes, beta activity of ^{90}Sr, activity of gamma emitters like ^{131}I, ^{137}Cs, ^{60}Co and naturally occurring radioactive material (NORM).

The LABAC facilities are briefly described at Sec. 8.7. Since February 2019, LABAC has ENAC certification (number 1324/LE2490) for total alpha and beta activity assessment in drinking and continental water under rule UNE-EN ISO/IEC 17025. The laboratory takes part regularly in interlaboratory proficiency tests promoted by national (CSN) and international organizations (IAEA, International Atomic Energy Agency).

3.9.1 | Achievements in 2024

1. LABAC has successfully passed in July the follow-up audit for ENAC certification held this year. Next audit is scheduled in January 2026.

2. Members of LABAC are co-authors of the article "A combined study of gamma spectrometry and inductively coupled plasma spectroscopy reveals persistent anthropogenic radioactive pollution on Deception Island, Antarctica" published at Microchemical Journal [1].

3. Members of LABAC have collaborated with the Zaragoza section of the Spanish Geological Survey ("Instituto Geológico y Minero de España") in a study of the radioactivity of and around Gallocanta Lagoon.

4. The different types of assessments on different samples required by the REVIRA dense net of CSN, the Government of Aragón ("Servicio de Seguridad Alimentaria y Salud Ambiental"), the Zaragoza town Council ("Servicio de Salud Pública del Ayuntamiento de Zaragoza") and LSC have been successfully performed, as in previous years.

[2] https://gifna.unizar.es/labac/

5. The LABAC has successfully participated in two intercomparison exercises for radioactivity measurement in water, one of them promoted by the CSN/CIEMAT and the other by IAEA-TERC.

6. The LABAC has successfully participated in one intercomparison exercise for radon measurement in continental water, promoted by LaRUC.

7. Members of LABAC have attended the “29ª Jornada anual sobre vigilancia radiológica ambiental” at CSN and the "XII Jornadas de Calidad en el Control de la Radiactividad Ambiental" workshop held in Palma de Mallorca.

8. Members of LABAC have attended the “Workshop I+D+i en Radón” at LSC and are co-authors of the oral presentation “Medidas de la concentración de ^{222}Rn en el Laboratorio Subterráneo de Canfranc (2013-2023)”.

3.9.2 | References

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Theory

The Standard Model (SM) of particle physics is one of the great achievements of twentieth century physics. It describes all known particles and their interactions with the exception of gravity, and allows us to calculate many processes that have been tested in accelerators to unprecedented precision. The discovery in 2012 of the Higgs Boson completed the last missing piece of the model.

It seems however unlikely that the SM is the final description of fundamental physics. It does not describe the hypothetical quantum effects of gravity, which are expected to appear at high enough energies. But also as a theory it leaves many unanswered questions: it does not account for neutrino masses, does not explain the replication of families and the patterns of masses and mixings, or the absence of CP violation in the strong interactions. From the experimental side, the strong evidence for the existence of non-baryonic dark matter and dark energy points to a gap in our understanding of the fundamental building blocks of nature.

The various research lines of the theory side of CAPA aim to shed light on some of the unexplained features of the SM, as well as trying to go beyond. This is achieved both by building and testing other possibilities, by testing the SM itself by high precision calculations, as well as by obtaining a better understanding of the intricate features of the SM.

3.10 | Axion Physics

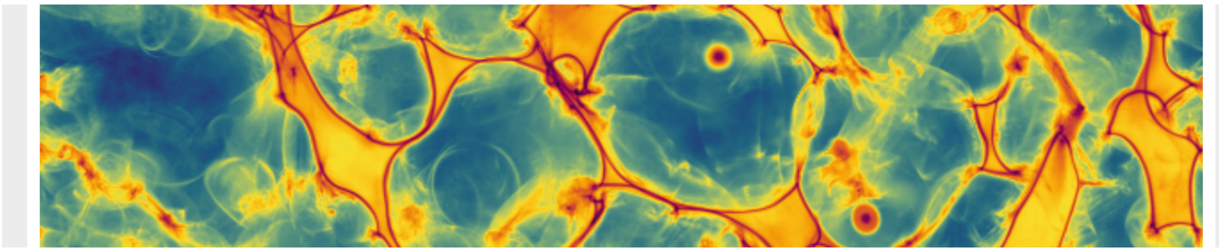

Figure 3.22: Energy projection map from one of our *jaxions* simulations of cosmic strings, domain walls and axitons close to the QCD phase transition. See text for details and references.

Responsible investigator(s) / coordinator(s):	
Javier Redondo	staff
Researchers involved:	
Maurizio Giannotti	B. Galindo
Alejandro Vaquero	staff
Ivan Rybak	postdoc
Mathieu Kaltschmidt	predoc

The QCD axion is a hypothetical 0^- boson, extremely light and weakly interacting, predicted by the Peccei-Quinn-Weinberg-Wilzcek mechanism that could explain the absence of CP violation in QCD. Non-thermally produced relic Axions could be the cold dark matter (CDM) observed in the Universe. Vacuum realignment and the decay of topological defects: cosmic strings and domain walls being usually the main production mechanisms. Axion CDM in our halo can be sought after by *haloscope* experiments (such as MADMAX or RADES), and axions in general by their impact on stellar evolution or by directly detecting stellar axion fluxes with *helioscopes* such as IAXO.

In this landscape, our group aims to solve the key theoretical issues slowing down the discovery (or refutation) of the axion and other axion-like particles (ALPs). In the DM frontline, we mainly focus on understanding axion CDM in the Post-Inflationary scenario (POSI). Here, a precision calculation of the DM yield dependence with axion mass will provide a clean target for the haloscope detection accelerating enormously its discovery. To this end, we study axion radiation from global cosmic strings with analytical and HPC numerical techniques. We also study the resulting small scale structure (miniclusters) and its challenges for detection. We maintain an open-source massively parallel code *jaxions* [3]. and develop a dedicated adaptive-mesh-refinement code and other HPC codes. Beyond the POSI, we plan to extend our simulations to other scenarios, such as large-angle, kinetic misalignment, etc.

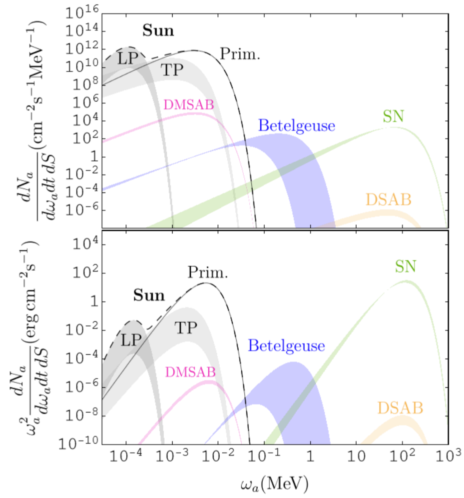

Figure 3.23: Astrophysical fluxes of Axions from our recent review [1].

The direct detection of axion dark matter is the ultimate goal of this program. We work by giving theoretical support and analysing data for optimising detection schemes for DM axions as well as for solar axions (IAXO, babyIAXO). In particular we participate in the MADMAX collaboration to build a dielectric haloscope in DESY, Hamburg (MADMAX collaboration) and the RADES initiative to build haloscopes.

Axions and other ALPs can have a noticeable impact on stellar evolution and produce a detectable flux by helioscopes. In our group we work on the theory of stellar ALP emission and use astronomical data to constrain the properties of axions and ALPs with the aim of detecting anomalies that can lead to a discovery and restricting parameter spaces to guide the experimental search.

3.10.1 | Achievements in 2024

1. We have completed a 100+ pages-long Physics Report on Axion Astrophysics [1].
2. We have explored the conversion of axion DM on radio waves in the large magnetic fields of the Solar surface and identified the relevant parameter space where this could trigger a discovery, see [2].
3. We have showed how a spectral measurement of gamma-rays from SN axion conversion in the galactiv B-field can be used to provide information about the composition of the protoneutron star, in particular of the pion abundance, see [3].
4. We have identified novel channels for the identification of solar chameleons with helioscopes and set a very strong limit in their parameter space, [4].
5. We have studied the imprints of current carrying cosmic strings in the CMB and compare them with the mere Nambu-Goto predictions, showing that the two could be distinguished by future CMB probes [5].

[3] https://veintemillas.github.io/jaxions/

6. We have completed a white paper for identifying gravitational waves from cosmic strings with LISA [6].
7. We have used the absence of features in NuSTAR X-ray data to produce a very strong helioscope constraint on ALPs [7].
8. We have made public the 1st results of the prototype MADMAX searches for axions and hidden photons[8, 9].
9. We have completed a study on the stochastic cosmic gravitational wave background produced from chiral superconducting cosmic strings and shown that the coupling to the vector field can suppress the radiation enough to be compatible with the latest pulsar time array data [10].
10. We have showed that finite density effects do not spoil the relaxation of SN bounds in nucleophobic axion models [11].
11. We have revisited the axion-induced $e^{\pm}$-pair production via the axion-electron coupling [12] and used it to study the 5.5 MeV solar pp-chain axion line and axions from a next galactic SN [12].
12. We have publish a study of the effect of gravitational radiation on the classicality of gravity [13].

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3.11 | Quantum gravity phenomenology

Responsible investigator(s) / coordinator(s):	
Jose Luis Cortés Azcoiti	permanent staff
Jose M. Carmona Martínez	permanent staff
Researchers involved:	
Justo López Sarrión	permanent staff
Maykoll A. Reyes Hung	postdoc
Filip Reščić	predoc
José J. Relancio Martínez	colaborator

The aim of this line of research is to explore deviations from special relativity (SR) from both theoretical and phenomenological perspectives. This is a central topic in the research program of the rather young field of quantum gravity phenomenology, whose development has been significantly driven at the international level by the COST Action CA18108, *Quantum gravity phenomenology in the multi-messenger approach*, a 4-year project that concluded in September 2023 and was coordinated by the Zaragoza group, with JMC serving as the Action Chair.

In September 2024, the COST Action CA23130, *Bridging high and low energies in search of quantum gravity*, commenced, in which the Zaragoza group plays a significant role, with JMC being one of the two Spanish Management Committee members.

From a theoretical perspective, one main motivation in the consideration of possible departures from SR comes from the difficulties to incorporate the quantum effects of the gravitational interaction in the framework of relativistic quantum field theory (RQFT), which is probably due to the relation at the classical level between the gravitational interaction and the structure of spacetime. More generically, the understanding of the origin of the matter-antimatter asymmetry, of the different flavors of elementary particles, of dark matter and dark energy might require to go beyond the RQFT framework.

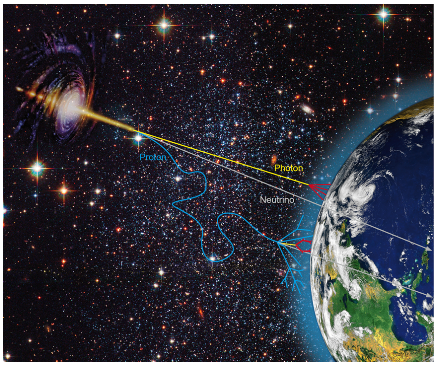

Figure 3.24: Multi-messenger astronomy involves the detection of different cosmic messengers: photons, neutrinos, cosmic rays and gravitational waves.

From a phenomenological perspective, there are new windows of observations in very high-energy astroparticle physics which could show us the first signals of a deviation from SR if we find the appropriate ways to look for them. This has been the main objective of the COST Action CA18108, joining together theorists with experimental physicists which are experts in the detection of the so-called "cosmic messengers": gamma rays, neutrinos, cosmic rays and gravitational waves. Similarly, the new COST Action CA23130 aims to bring together scientists from both high-energy astrophysics and high-precision tabletop experiments, with the objective of forming a joint effort in the search for effects of a quantum theory of gravity. Our position in both networks allow the Zaragoza group to be in close contact with the main ideas and results in the field, as well as to quickly and effectively disseminate our results in the relevant scientific community.

3.11.1 | Achievements in 2024

1. JL joined the group as a Senior Lecturer. After completing his PhD, MAR began a postdoctoral position within the group. FR spent January and February, as well as the first two weeks of September, at the University of Zaragoza as part of the *cotutelle* agreement.

2. FR participated in the MPIK-CDY School on the Future of Gamma-Ray Astronomy, held from June 25 to

July 3, 2024, in Heidelberg, Germany. He also conducted a research visit to the Department of Physics and Astronomy Galileo Galilei at the University of Padova through the Croatian Science Foundation Outbound Mobility project MOBDOK-2023, from September to December.

3. We joined the new COST Action *Bridging high and low energies in search of quantum gravity*. JM is currently a Management Committee member for Spain, while the rest of the group are members of various Working Groups. Through our participation in this research network, we can sustain our existing international collaborations and maintain visibility in the field.

4. During 2024, we concluded our coordination efforts for the white paper on quantum gravity phenomenology, leading to its finalization and subsequent publication in early 2025 [1]. As the outcome of the COST Action CA18108, this document now serves as a roadmap for future research in the field.

5. In collaboration with the gamma-ray experimental group at Rijeka University, we published a new expression for the cross section of the pair creation process relevant to the study of the transparency of the Universe to gamma rays within a Lorentz Invariance Violation (LIV) framework [2]. This new formulation overcomes limitations of previous approaches and refines existing constraints for the LIV scale.

6. We did a first study of the interplay between interaction and time-of-flight anomalies in a LIV theory, showing that the compatibility between both types of effects imposes stringent constraints, which should be accounted for in experimental searches that often study these phenomena separately [3].

7. We developed a new formulation of a QFT in DSR theories [4, 5]. Since infinite derivatives act on the field, nonlocal effects appear.

8. We conducted a pioneering study on the transparency of the universe to gamma rays within a DSR scenario with a sub-Planckian scale of new physics. The results were presented by MAR at the *Fifth Annual Conference on Quantum Gravity Phenomenology in the Multi-Messenger Approach (QGMM24)* in Madrid and are scheduled for publication in the coming months. At the same conference, JM, FR and JR delivered the talks *A New Perspective on Doubly Special Relativity*, *Approaches to Photon Absorption in a Lorentz Invariance Violation Scenario*, and *Non-local quantum field theory from Doubly Special Relativity*, respectively.

9. We continue collaborating with Denise Boncioli of L'Aquila University on studying the effects of Lorentz Invariance Violation (LIV) on superluminal neutrino decays. Domenico Fratulillo from Naples University visited the group from the end of May to the end of July 2024, contributing to the advancement of the implementation of DSR in an expanding universe. This visit laid the groundwork for a future collaboration.

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3.12 | Beyond the Standard Model Phenomenology

Responsible investigator(s) / coordinator(s):	
Siannah Peñaranda	staff
Researchers involved:	
Jorge Alda Gallo	postdoc (INFN)
Alejandro Mir Ramos	predoc (UNIZAR)

After the discovery of the Higgs boson at the LHC, all the basic building blocks of the Standard Model (SM) of particle physics have been unveiled. However, in spite of the enormous successes of the SM, there are some reasons to believe that the it is incomplete as fundamental theory of nature. From the theoretical point of view, the SM does not describe quantum gravity, does not account for neutrino masses and does not offer satisfactory explanations for some of its ingredients and parameters: the replication of families and the patterns of masses and mixings (flavour problem), the hierarchy of the Higgs and Planck masses (hierarchy problem) and the absence of CP-violation in the strong interactions and the strong CP problem. On the other side, there are experimental measurements of flavor violating processes at LHCb, Babar and Belle that show interesting deviations from the SM predictions, making them excellent probes of New Physics (NP) beyond the SM. Some of the flavour transition processes relevant to constrain NP at the LHC are the leptonic, semileptonic, baryon and radiative exclusive decays. In this context, both Effective Field Theory analysis and specific NP models (leptoquarks, W' and Z' bosons, axion-like particles, etc.) are mandatory to attack the flavour problem and flavour anomalies. Naturally, it is necessary to follow the updates of any of the new experimental results from high energy colliders.

Furthermore, particle physics phenomenology requires the analysis of a large number of experimental data and parameter spaces of high dimensionality. In addition, the number of competing NP theories poses a problem of model classification and selection. Traditional computational approaches may fall short in these kinds of settings. It is precisely in these conditions where Machine Learning and Deep Learning techniques are most useful [1, 2]. This is a pioneering approach and a very fruitful field of research.

3.12.1 | Achievements in 2024

1. An updated analysis of the anomalies observed in the semileptonic decays of B mesons have been performed, by using an effective field theory approach and assuming that new physics affects only one generation in the interaction basis and non-universal mixing effects are generated by the rotation to the mass basis. A global fit to experimental measurements with improved precision is performed, focusing on Lepton Flavour Universality (LFU) ratios $R_{D^{(*)}}$ and $R_{J/\psi}$ and branching ratios that exhibit tensions with Standard Model predictions on $B \to K^{(*)}\nu\bar{\nu}$ decays [3]. For the numerical calculations, we use Machine Learning tools such as regression trees and SHAP (SHAPley Additive exPlanation) values.
   Our results show that, comparing three different scenarios, the one that introduces only mixing between the second and third quark generations and no mixing in the lepton sector, as well as independent coefficients for the singlet and triplet four fermion effective operators, provides the best fit to experimental data. Furthermore, it improves the predicted branching ratio for $\mathrm{BR}(B^+ \to K^+\nu\bar{\nu})$ although it does not fully explain $\mathrm{BR}(B^0 \to K^{*0}\nu\bar{\nu})$. The results are pointing in the direction of NP that interacts mainly with the third generation of leptons, reminiscent of the $U(2)$ flavour symmetry hypothesis [4, 5]. The situation would be clarified further with measurements of $R_{J/\psi}$ achieving a resolution similar to that of $R_{D^{(*)}}$, and with additional τ observables,

for example the longitudinal polarisation in $B_c \to J/\psi\tau\nu$ or the branching ratio of $B \to K^{(*)}\tau^+\tau^-$.

2. Besides, it is known that NP scenarios addressing the flavor puzzle and the hierarchy problem generally predict dominant new physics couplings with fermions of the third generation. In [3, 6], they explore the collider and astrophysical signatures of new light scalar and pseudoscalar particles dominantly coupled to the $\tau-$lepton. They found that the astrophysics bounds, mainly from core-collapse supernovae and neutron star mergers, are particularly effective and complementary to collider bounds. This program has been carried out in the well-motivated context of axion-like particles as well as generic CP-even and CP-odd particles, highlighting possible ways to discriminate among them.

3. Finally, the time modulation of weak nuclear decays as a method to probe axion dark matter have been studied in [7]. To this end, a theoretical framework to compute the θ-dependence of weak nuclear decays, including electron capture and β decay, is developed, enabling us to predict the time variation of weak radioactivity in response to an oscillating axion dark matter background. This work have been done in collaboration with scientists working at the underground Gran Sasso Laboratory.

   Phenomenology is an area of physics that lives in the balance between theory and experiment, and therefore, any new development in either can have a large impact in our results. This is specially true in the phenomenology of Flavour Physics, which is in rapid evolution caused by the plethora of experimental measurements and the renewed theoretical interest. We have experienced this evolution during the elaboration of our works, then redoing some of our analyses and even re-evaluating previous conclusions.

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3.13 | Lattice field theory

Responsible investigator(s) / coordinator(s):	
Eduardo Follana Adín	staff
Researchers involved:	
Vicente Azcoiti Pérez	staff
Alejandro Vaquero Avilés-Casco	staff
Eduardo Royo Amondarain	staff
Pietro Butti	postdoc
Adrián del Pino Rubio	predoc
Fernando Ezquerro Sastre	predoc

The lattice group in CAPA pursues two main lines of research: the calculation of quantities of phenomenological relevance, in particular in the search for physics beyond the Standard Model, and the study of systems with a strong sign problem.

The Standard Model (SM) is currently the best theory we have to describe nature, but it is not complete and it is currently regarded as an Effective Field Theory (EFT). We expect to find physics Beyond the SM (BSM) at some large energy scale. BSM physics can be accommodated in the SM by the addition of new operators in our EFT description. Experiments are of paramount importance to find constraints for the coefficients of these new operators, but experimental results must be matched with theory to find discrepancies indicative of BSM physics. This research line is devoted to the high precision testing of the SM, looking for small deviations between theory and experiment that can lead to new physics. Most of this high precision physics is done in the intensity frontier. By calculating to very high precision observables that can be influenced by the addition of new operators to the SM, one can test whether the experimental results match the current theory or not. In particular, A. Vaquero collaborates in a calculation of the hadronic contributions to observables and processes using Lattice QCD and supercomputers, and there is a close communication with experimentalist to decide which new quantities to calculate and how to orient future experiments.

The second main research line of our group is the study of systems with a strong sign problem. Such systems have an euclidean action that cannot be interpreted as the Boltzmann weight of a partition function, and therefore cannot be simulated using standard Montecarlo algorithms. Several models of great physical interest fall into this category, for example QCD at finite density, QCD with a θ term, or the Hubbard model. Our group has been working for a long time developing new algorithms that can, at least in some cases, evade the sign problem.

3.13.1 | Achievements in 2024

1. Members of the Lattice Field Theory group were invited to workshops involving experimentalists, theorists and phenomenologists, to discuss current B anomalies and the future ahead (Challenges B semileptonic decays in Vienna, DISCRETE 2024 in Ljubliana).

2. Further progress was made in the analysis of several B decays, and partial results were shown at the Lattice conference 2024 in Liverpool [1]

3. Two papers on g-2 have been published in the arXiv, awaiting referee clearance to be published in scientific journals [2, 3]. One concerns the short and intermediate distance windows, and the other one is about the pervasive long distance window. Together they constitute a new world-class determination of the hadronic vacuum polarization (HVP) contribution to the anomalous magnetic moment of the muon.

4. A new FLAG review as been published, with one of the members of the Lattice group being a contributor to the section on bottom and charm decays [4].

5. A PhD student (A. del Pino) started work on the HVP contribution to the running of the electromagnetic coupling constant, a hot topic right now, closely related to the calculation of g-2. He is expected to finish the calculation as his PhD thesis.

6. F. Ezquerro has started the calculation of the Casimir energy in non-abelian gauge theories with different boundary conditions on the lattice.

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3.14 | Beyond General Relativity

Responsible investigator:	
Manuel Asorey	staff
Researchers involved:	
Eduardo Follana Adín	staff
José Gracia Bondía	staff
Jesús Clemente Gallardo	staff
Justo Lopez Sarrión	staff
Carlos Bouthelier Madre	postdoc
Yisely Martínez Pérez	predoc
Fernando Ezquerro Sastre	predoc
David Martínez Crespo	predoc
Miguel Pardina García	predoc
José Manuel Silva Morales	predoc

A fundamental component of the physical universe which is beyond the Standard Model is the gravitational interaction which in fact was the first discovered interaction. So far Einstein's theory of General Relativity describes quite successfully the gravitational interactions in a wide range of physical scales from the millimeter to intergalactic scales.

However, there are few reasons to expect a modification of the theory at very short and very large scales. At large scales the apparent failure in the explanation of the rotating curves of galactic halos is actually solved by adding a dark matter component which also helps in fitting the current cosmological data.

The inflationary model which best fits the observational data is the Starobinsky model which involves a modification of Einstein theory by means of an R^2 term (see Figure 3.25 where the dependence of the ratio of the tensor-scalar fluctuations on the primordial tilt n_s is analyzed according to Planck results).

On the other hand the emergence of infrared quantum effects generated by the long-range quantum correlations dues the conformal anomaly amounts to a well-defined modification of Einstein's theory of gravitation (GR). These effects can be encoded in an Effective Field Theory (EFT) and their role can be especially relevant in two research fields: near-horizon physics of Black Holes (BHs) and standard ΛCDM cosmology.

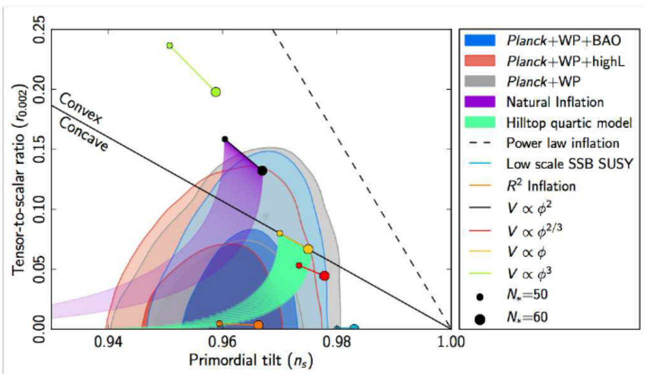

Figure 3.25: Ratio of the tensor-scalar fluctuations versus the primordial tilt, according to Planck results and predictions of different cosmological models.

The increasing amount of data coming from cosmological observations and multi-messenger astrophysics of black hole (BH) mergers provide new sources of information that make possible tests of the relevance of these quantum effects in gravity.

Another argument that leads to consider Einstein's theory as an effective theory of a more fundamental one is its non-renormalizability as a quantum field theory.

This problem can be cured by introducing high derivative terms generalizing Starobinsky model or even non-local terms. All these theories theories are renormalizable but most of them present consistency problems related to violations of causality and unitarity. Another effect of these theories is that in spite of the fact that they do not have ultraviolet divergences they present Black Hole solutions with peculiar properties and a dynamics quite different from Einstein theory Black Holes.

The research line of CAPA to approach this problem has the following fundamental goals:

- Complete Einstein's theory with higher derivative terms to achieve a consistent theory of quantum gravity.
- Explore the behaviour of the different theories of gravity at scales below the millimeter scale to find possible deviations from General Relativity.
- Analyse the black hole physics of higher derivative theories of gravitation and its implications for binary black hole mergers.

3.14.1 | Achievements in 2024

1. In the last years we have seen an intense development of extensions of the Einstein–Hilbert action containing non-local terms claiming to overcome inconsistencies (unitarity, absence of ghosts and conservation of probability) and at the same time removing all classical singularities of General Relativity. We have shown that most of these theories fail to admit a Källen-Lehmann decomposition, which raises a serious problem leading to inconsistency of the theories.
2. We have shown that in six derivatives quantum gravity there is a ghost condensation which confines de pathological ghosts [1]. We have also shown the relevant observables that admit a Källen-Lehmann decomposition. Open a new perspective for the consistency of higher derivative superrenormalizable quantum gravity.
3. A new cosmological solution without singularities has been discovered in higher derivative gravity. The solution avoids the critical conditions of Hawking and Penrose which lead to singularities [2]. The absence of Big-Bang and/or Big Crunch is very interesting and opens new cosmological scenarios which can being in agreement with the current data provide new frameworks for cosmological inflation.
4. We have been able to define a consistent hybrid quantum-classical theory describing a classical gravitational field which evolves coupled to a quantum scalar matter field. The resulting theory is nonlinear, but it is able to preserve the probability of the quantum degrees of freedom. [3]

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3.15 | Astrophysical and cosmological probes of the dark sector

Responsible investigator(s) / coordinator(s):	
Jacobo Asorey Barreiro	staff
Researchers involved:	
Maurizio Giannotti	Beatriz Galindo Senior Fellow
Justo Lopez Sarrión	staff
Miguel Pardina García	predoc

The majority of probes of the existence of a dark sector of the Universe (dark matter, dark energy) come from astrophysical and cosmological probes such as the determination of distances to extragalactic objects or the study of the inhomogeneities in the distribution of matter in the Universe.

Among other things, we need to understand if the current standard model of cosmology ΛCDM, based on general relativity and copernican principle, the cosmological constant Λ and the initial phase called Inflation, survives the different anomalies and tensions within results from different datasets. Even within this framework, we also need to understand which inflationary theory better predicts all datasets and probe which dark matter candidate can explain the cold dark matter (CDM) part of the model.

Regarding the ΛCDM tests, the group at CAPA participates in some collaborations like the Australian Dark Energy Survey (OzDES), Euclid and, in the radio sector, the SKA Observatory (SKAO) precursor the Evolutionary Map of the Universe (EMU). Within this collaborations, we plan to study the high redshift end of the galaxy realm and use them to test the different alternatives to dark energy and . Another research the group focuses on is on using re-analysis of cosmological probes of the early and late Universe to do thorough check on systematics to test ΛCDM.

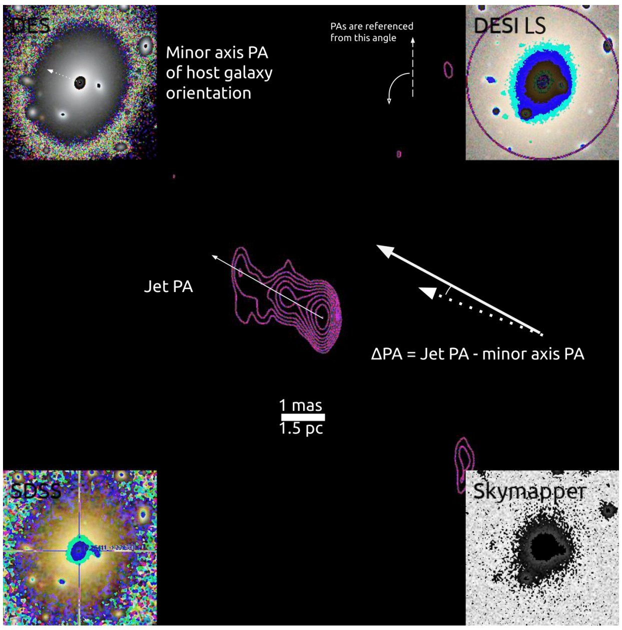

Figure 3.26: Alignment of VLBI jets with the minor axis of optical galaxies with 4 different images from different surveys.

Within this line, CAPA research is also focused on the using stars and other astrophysical objects as a probe for axions or similar light dark matter candidates. For example, the research can predict the axion production from supernovae and the implication for astronomical observations in several wavelenght ranges so we can perform the relevant observational tests about this candidate or similar axion-like particles in the near future, helping other CAPA research lines on dark matter direct detection experiments on the way.

Finally, the group is also interested in observationally exploring the range of gravity in the scale of black holes by study active galaxies with supermassive black holes in the center. Using radio observations with Very Large Baseline Interferometry (VLBI) we can study the core of this galaxies and understand how the galaxy became active and how black holes influenced galaxy creation and evolution. We can also use this astronomical objects to derive cosmological distances and therefore develop an alternative method to other cosmological distance estimators so we can compare with recent observations showing hints of dynamical dark energy or Hubble constant measurements.

To sum up, the main research goals within this line at CAPA are:

- Use of extragalactic galaxy surveys to understand the nature of the dark sector, general relativity and inflationary theories
- The use of radio Very Large Baseline Interferometry (VLBI) observations to probe the dark sector, black holes and the evolution of galaxies.
- The use of stars or astronomical objects as laboratories to probe axions or light dark matter candidates, using multi-messenger astrophysics.

3.15.1 | Achievements in 2024

1. We detected an an alignment between the direction of the ultra-relativistic jets nearby the supermassive black hole in the center of active elliptical galaxies and the minor axis of these galaxies as seen in Fig 3.26. This surprising connection over three orders of magnitude in scale, between the central supermassive black hole and the shape of the galaxy as a whole was published in Nature Astronomy [1] and featured as CAPA achievement in media such as Heraldo de Aragón or Radio Nacional de España. The result opens a new research line in which we can try to understand the evolution of galaxies, from spirals to elliptical through merges.

2. Another area of investigation focuses on the use of stars and other astrophysical environments as laboratories to probe axions and other light dark matter candidates. The research at CAPA has significantly improved our understanding of axion production in core-collapse supernovae, incorporating previously overlooked channels and refining theoretical predictions. In addition, we have studied the potential of current and next generation astrophysical observations, in x-ray and gamma-ray telescopes, as well as in radio, which can provide important information on the properties of weakly interacting particles such as axions, chameleons, hidden photons, and non-standard neutrinos. The experimental potential of astrophysical probes continues to grow, offering new opportunities to explore the dark universe and test fundamental aspects of particle physics beyond the Standard Model. [2–4]

3. In the last year, we published two of the main four key cosmological papers using the whole 6 year observations data for the Dark Energy Survey (DES) [5, 6]. One of the lines involves the measurement of the 2D baryonic acoustic oscillations (BAO) scale. The other key paper used 5 year observations of type Ia supernovae with DES and OzDES. Both papers showed the robustness of ΛCDM but the supernova sample seems to prefer a dynamical dark energy model when we allow these parameters to vary. This same sample is one of the main drivers that help the recent Dark Energy Spectroscopic Instrument results to emphasize that maybe an scalar field or similar theories should be added to the current model to explain a dark energy time evolution.

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3.16 | Quantum Mathematical Physics

Responsible investigator(s) / coordinator(s):	
Jesús Clemente-Gallardo	staff
Researchers involved:	
Manuel Asorey	staff
Inés Cavero-Peláez	staff
José F. Cariñena	staff
Fernando Falceto	staff
José V. García-Esteve	staff
Justo López-Sarrión	staff
Carlos Bouthelier-Madre	colab
Fernando Ezquerro	predoc
David Martínez-Crespo	predoc
Yisely Martínez	predoc

Properties of most realistic models for gravity and/or gauge interactions at a cosmological level are highly dependent on their mathematical properties. Furthermore, modern approaches to the developments of detectors require of a profound knowledge of the properties of quantum systems and their interactions with classical ones. This research line focuses on this type of problems, that we can divide in three blocks:

Many body quantum systems This line of research covers the study of emerging properties of Kitaev chains or other related many body quantum systems. We plan to discuss some of these properties as for instance:

Quantum Zeno effect (QZE) in a large quantum computer: we show that the multiple measurements that characterizes the QZE can be mimicked by the coupling of the system with many conditional gates. We consider that conditional gates couple the systems to multiple ancillas or that they all couple to a single one. We compare the dynamics of both situations and show similitudes and differences with the standard QZE [1]. We plan to continue this research implementing this ideas in real quantum computers and exploring the possible applications to stabilize qubits in quantum computers.

Leaning in heterogeneous Kitaev chains: here we discuss the distribution of the probability of presence of a particle in the two sides of a heterogeneous Kitaev chain. We have shown a remarkable pattern that shares properties with chaotic systems [2]. We plan to pursue this study to obtain a more accurate description of the phenomenon in terms of probability distributions and its universal properties

Topological insulators in Kitaev chains with a defect: We study a fermionic chain with insulating behavior in the bulk. When it contains a defect, localized states may appear whose energy form a discrete spectrum between the valence and conduction bands. Modifying the couplings in the defect the states can migrate from a band to the other, imitating the properties of topological insulators that can transport charge or spin through states localize at the boundary [3]. The robustness of this mechanism is currently under study using topological invariants like the Berry curvature and others.

Boundary effects in quantum field theories Different aspects of fluctuations of quantum fields in the vacuum are studied. When these fluctuations are modified due to the presence of some external conditions, they give rise to a net energy that could develop in a macroscopic measurable effect. The so-called vacuum energy or Casimir effect could play an important role at the micro and nanoscale but at the same time could also contribute to the dark energy. The second type of contributions leads to a too large effective cosmological constant which generates one of the fundamental problems of the compatibility of the Standard Model of particles and the current cosmological model LCDM.

We also ultimately expect that the analysis of the reaction of the vacuum to the presence of boundaries will shed some light on the non-perturbative behavior of confining theories like QCD.

We focus on the study of the Casimir self-energy of compact objects as spheres or cylinders with different boundary conditions on their surfaces and considering both fluctuating scalar and vector fields. We study the divergences arising from this kind of calculations and identify the origin of some divergent terms. Unlike divergences found in quantum field theories, those coming from quantum vacuum energies cannot be treated with standard methods and new regularization methods have to be employed for each particular case. Interacting Casimir energy between bodies usually gives finite effects, meaning it is easier to extract the finite part, contrary to the study of self-energies, one more reason to assure that a full understanding of this effect requires that we take a close look at the divergences in order to understand its meaning.

Hybrid quantum-classical systems: Quantum field theories depending on classical fields or magnitudes Hybrid quantum-classical systems are dynamical systems where classical and quantum degrees of freedom evolve coupled to each other. Usually, they are approximations to full quantum models where some of the degrees of freedom correspond to particles with mass much higher than others and which therefore evolve with much longer characteristic times. The best known example for this type of dynamical system are molecular systems where nuclei and inner electrons can be described as a classical subsystem which interacts with the valence electrons. In these approaches, the extension to statistical mechanical models based on hybrid dynamics is a natural requirement because of the macroscopic nature of the classical domains.

But we can find a similar situation when considering field theoretical models. Indeed, we can also consider a model where a quantum field theory interacts with a classical field. Several interesting examples fit in this framework, the most remarkable one being a quantum field theory which evolves in a given gravitational background. In this situation, models based on Minkowski-backgrounds field theories fail and all ingredients in our model must be reconsidered. Our approach is based on Malliavin stochastic calculus which provides rigorous mathematical tools to operate on spaces of fields modeled as Hida functions or distributions defined on the space of classical fields. These sets admit rigorously defined Gaussian measures and therefore square integrable functionals depending on classical degrees of freedom become meaningful. States become sections of suitable bundles defined on the space of classical objects and such dependence requires of the definition of a suitable connection to capture the effect on the quantum state of a change in the classical parameters.

3.16.1 | Achievements in 2024

1. We have been able to define a consistent hybrid quantum-classical theory describing a classical gravitational field which evolves coupled to a quantum scalar matter field. The resulting theory is nonlinear, but it is able to preserve the probability of the quantum degrees of freedom. [4]

2. We have defined a rigorous mathematical description based on Gaussian analysis of a Hamiltonian picture of a scalar quantum field theory in a curved space-time. In particular, we are able to prove the existence of a well-defined Gaussian measure on the manifold of fields and a consistent definition of a probability-preserving dynamics [5, 6]

3. We have introduced the notion of a control hybrid quantum-classical system, defined the notion of hybrid controllability and considered several interesting applications [7].

4. We have explored the dependence of vacuum energy on spacetimes the boundary conditions for massive scalar fields in (2 + 1)-dimensional. We consider the simplest geometrical setup given by a two-dimensional space bounded by two homogeneous parallel wires in order to compare it with the non-perturbative behavior of the

Casimir energy for non-Abelian gauge theories in (2 + 1) dimensions. Our results show the existence of two types of boundary conditions which give rise to two different asymptotic exponential decay regimes of the Casimir energy at large distances. [8]

5. We have considered the canonical quantization of the electromagnetic field in the ξ–gauge. We also discuss BRST quantization and investigate the apparent singularities present in the theory when the gauge parameter takes the value -1 [9].

3.16.2 | References

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4

Scientific Publications in 2024

The publications of CAPA members during 2024 are listed in annex N. The present section contains some plots which try to give an overview of the scientific production of CAPA in 2024.

Fig. 4.1 shows how the number of publications per year from present CAPA members have evolved in the last ten years. Fig. 4.2 indicates the evolution of the number of citations per year of these publications. Finally, Fig. 4.3 gives a graphical picture of how the 2024 CAPA publications are distributed in the different journals. The complete list of publications is presented in annex N.

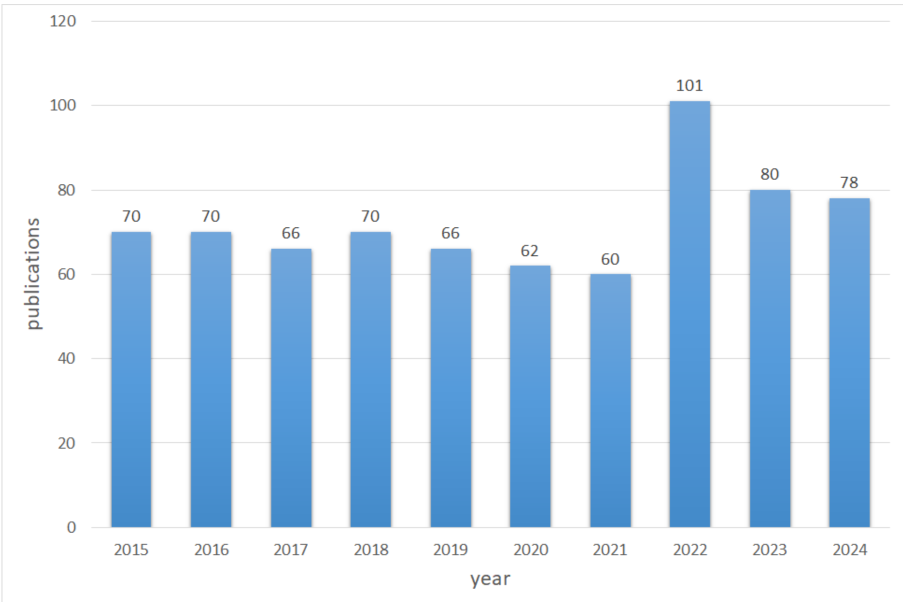

Figure 4.1: Evolution of the number of publications per year.

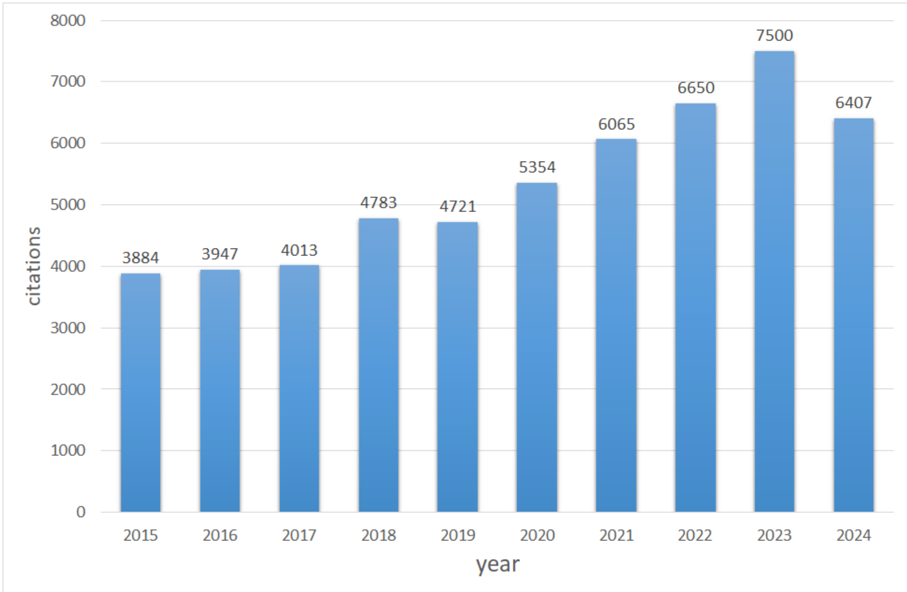

Figure 4.2: Evolution of the number of citations per year.

Figure 4.3: Journal distribution of CAPA publications in 2024.

5

Organization of conferences and seminars

5.1 | Conferences

The first meeting on national level on projects in Astrophysics and High Energy Physics financed with National and regional funds *1ª Reunión Nacional de Planes Complementarios de Astrofísica y Altas Energías (AstroHEP PPCC2024)* was organised by CAPA and took place in Zaragoza early June 2024. These funds were oriented towards the development of cutting-edge scientific instrumentation to ensure the progress on the acquisition of frontier knowledge. In this meeting, there were reports on the status and progress of the various lines that have been funded and in which participate 36 spanish scientific institutions from 6 different regions.

The *Saturnalia* meeting, in collaboration with the Department of Theoretical Physics of the University of Zaragoza constitutes already a tradition. It is a scientific meeting, organized every December, where new and ex-members of the department, along with invited researchers, discuss their current work. Information on the 2024 edition can be found in this link: (https://indico.capa.unizar.es/event/38/

The members of CAPA continue to be active in the organization of events of scientific interest at a national and international level, like the Organization of the *LI - International Meeting on Fundamental Physics*, the *Joint meeting of RENATA and Multidark* focussed on the Spanish input to the ESPP update, or *the International Workshop on High Energy Physics (TAE2024)* in the Centro de Ciencias Pedro Pascual in Benasque. In annex C a list of conferences and workshops where, although not directly organized by CAPA, several CAPA members were involved can be found.

5.2 | Seminars

A number of research seminars is also in the agenda of CAPA, announced at the website and at the Department and Faculty level https://capa.unizar.es/. The subjects treated are connected to the current or potential research topics of CAPA, and with activities of the Master on Physics of the Universe. The seminars and colloquia are broadcasted live and stored in the CAPA YouTube channel, https://www.youtube.com/channel/UC8gheC8DEgTmiwyA1kqs8_Q

Seminars and colloquia are listed in annex D.

6

Training and teaching activities

Training and teaching activities are integral to the objective 5 of CAPA, which aims to "promote activities of specialized training and facilitate the incorporation of young scientist and technical manpower to the scientific community" (see section 1.1). However, they are also important to "foster the creation of new synergies among the different research lines, especially between the theory and experimental area" (objetive 3), and to "strengthen the participation of CAPA members in the Aragonese research centers related with the mentioned areas: the *Laboratorio Subterráneo de Canfranc* (LSC) and the *Centro de Ciencias de Benasque Pedro Pascual* (CCBPP), as well as to promote collaboration with the *Centro de Física del Cosmos de Aragón* (CEFCA)" (objective 4).

6.1 | Master on Physics of the Universe at UNIZAR

CAPA is responsible for the **Master on Physics of the Universe: Cosmology, Astrophysics, Particles and Astroparticles** (whose web page is here). This Master offers a theoretical-phenomenological or/and experimental-technological formation learning in leading research centers and in an international research environment. The training offered by the Master's degree is framed in a privileged area of unique and excellent research. In the national and international context, Aragon stands out in this research area: the Centre of Astroparticles and High Energy Physics (CAPA), the Canfranc Underground Laboratory (LSC), and the Centre of Physics of the Cosmos of Aragon (CEFCA) have researchers and leading technologists in the lines of study of the title. A high-quality knowledge is offered, distinct from other national and international master titles. The University of Zaragoza, and CAPA as the Center coordinator of the Master could become a reference center for training in high-energy physics, cosmology, astronomy, astrophysics and astroparticles.

For three academic years, this Master's program has been offered by CAPA as a 90 ECTS program. but Royal Decree 822/21 required adapting current studies, though most requirements were already met. However, Royal Decree 576/2023 introduced a major change: a full Master's degree became mandatory for doctoral studies, replacing the previous requirement of 60 ECTS at the Master's level. Since many students in this program aim to pursue research careers, the current 90 ECTS format delays their doctoral studies and predoctoral contract applications by a year. To align with most Master's programs at Unizar and other Spanish universities, a new 60 ECTS program was discussed and proposed in 2024.

Figure 6.1: Master students visits and activities at the Laboratorio Subterráneo de Canfranc (left) and the Observatorio Astrofísico de Javalambre (right).

The main objectives of the program remain unchanged:

1. Train competent individuals to integrate as researchers or qualified technicians in research teams in the fields of Cosmology, Astrophysics, Particles, and Astroparticles.

2. Provide specialized training in Cosmology, Astrophysics, Astronomy, Astroparticles, and Particle Physics, with both theoretical-phenomenological and experimental-technological orientations. This training enables students to begin a doctoral thesis, prepare for the Resident Physicist (FIR) exam, or access technical positions in companies and research centers.

3. Offer students an active learning environment to develop skills in: understanding physical theories, solving theoretical problems, and discussing results; instrumentation and laboratory techniques; using methods and tools for modeling, simulation, data analysis, and interpretation; communication skills for presenting scientific work; teamwork and collaboration in multidisciplinary research groups; continuous learning ability; and the social and ethical responsibility of scientific work.

4. The mandatory courses aim to provide students with essential knowledge and tools to approach research in the Master's proposed fields. The elective courses introduce them to cutting-edge research areas guided by renowned experts in topics such as gravitation, cosmology, dark matter and energy, neutrinos, Standard Model

phenomenology, galaxy formation and evolution, stellar physics, observational astrophysics, instrumentation, etc. The goal of the Master's Thesis is to offer students real immersion in research.

The Master's program also offers a blended learning approach, combining traditional in-person training with online resources to accommodate students' needs at any time. For the same reason, all courses are delivered in a bilingual English/Spanish format.

The student profile is highly diverse, including physicists, mathematicians, and engineers from the University of Zaragoza, other universities, and Erasmus programs, with both full-time and part-time students. As a result, instructors must adapt their teaching to this variety. Overall, student satisfaction is very high.

Many CAPA researchers actively participate in teaching, requiring significant effort and coordination with researchers from LSC and CEFCA. Courses have covered topics such as Cosmology, Particle Physics, Astroparticles, and Astrophysics, with leading researchers delivering lectures. Additionally, visits to LSC and CEFCA have provided hands-on training in Astroparticle physics, Cosmology, and Astrophysics.

6.2 | Participation in schools

Researchers of CAPA participated in the organization and as teachers of the TAE 2024 - International Workshop on High Energy Physics. The TAE (Workshop on High Energy Physics) is an international workshop/school for first and second-year graduate students entering the fields of experimental or theoretical High Energy Physics, Astroparticles, and Cosmology.

This and other schools, as the 2nd Training School COST Action COSMIC WISPers (CA21106) or a Minicourse on perturbative and nonperturbative treatment of quantum gravity problems, are listed together with other conferences and workshops organized or co-organized by CAPA in Annex C.

7

Outreach activities

CAPA is fully committed, as stated in objective 7, to "promote the scientific culture of the society through the realization of outreach activities addressed to the general public". Thus, its members participate in and organize numerous activities in this direction. Some of the most relevant are described in the following.

7.1 | Dark Matter Day

Dark Matter Day is a globally recognized celebration sponsored by the Interactions Collaboration, an international community of particle physics communication specialists. CAPA has joined this celebration since its appearance in 2017.

This year, the activity "Hands on Dark Matter" was held on October 29^{th} (see figure 7.1). This day 45 high school students attended different talks on the subject and participated in activities in GIFNA laboratories.

Coinciding with Halloween, on October 31^{st}, CAPA researchers organized, as every year, a gymkhana at the Faculty of Sciences. Stalls with activities around particle physics, astroparticles and astrophysics are set up. Families with children, and other interested people, willing to learn and have fun, attend the activity. About 250 people attend this activity each year (see figure 7.1).

7.2 | Hands on Particle Physics

This activity has been organized by researchers of CAPA for more than a decade in the framework of the International Particle Physics Outreach Group. The 20^{th} edition of this master class was held on March 25^{th}, in Zaragoza, and on March 22^{nd}, in Benasque.

In the morning, high school students attended lectures on particle physics, accelerators, detectors and methods of basic research at the foundations of matter and forces. That enables the students to perform measurements on real data from particle physics experiments themselves. After the Higgs discovery in the LHC, Zaragoza and Huesca students analyze ATLAS data regarding the *Z-path*. In the afternoon, as any international research collaboration does, the participants joined students from other institutions in a video conference led by CERN researchers for discussion and combination of their results.

Figure 7.1: Images of some outreach activities carried out in 2024: *Hands on Dark Matter* and Science Immersion Week (top), European researchers' Night (middle) and *Hello, we are scientist*, LSC Open Day and Dark Matter Day gymkhana (bottom).

7.3 | Open Days of the Faculty of Sciences and Science Immersion Week (physics)

The Faculty of Science organizes every year different activities for high school students. Several Open Days are held throughout the year as well as one Science Immersion Week. Once again, members of CAPA collaborated at both activities. In the Open Days, CAPA researchers welcomed high school students to talk to them about astroparticles and show them the activities carried out in the GIFNA laboratories. In the context of the Science Immersion Week, CAPA is involved, offering activities on cosmology and astrophysics, particle physics, astroparticles and cosmic rays to students interested in Physics (see figure 7.1).

7.4 | European researchers' night

The University of Zaragoza held the European Night of Researchers on September 27^{th}, 2024. CAPA researchers collaborated with two "experiments" ("Bajo los rayos cósmicos" and "Un mundo radioactivo"), offering activities for all audiences in the *Paraninfo* building (see figure 7.1) and in the activity "Café con científicas".

Connected to this international celebration, and as an pre-event, some activities were offered to primary school students in June in the *Rincón de la Ciencia* of the *Mercado agroalimentario* of the Campus.

7.5 | Activities with Women's Names

At CAPA, it is considered important to highlight the work done by its female scientists. Therefore, participation in various activities aimed at raising the visibility of female scientists and promoting future vocations among girls and female teenagers is encouraged.

The activities of this year include: talks on the occasion of *11F*, participation in the project of the Faculty of Sciences *Hello, we are Scientists* (see figure 7.1), and appearances in the fourth edition of the photographic campaign *I am a Scientist. I live in your neighborhood*, organized by the Scientific Culture Unit of UNIZAR in collaboration with the Zaragoza City Council; in 2024, Siannah Peñaranda from CAPA was selected to take part in the campaign.

7.6 | Open Day at LSC

The Canfranc Underground Laboratory holds every year an Open Day; in 2024, it took place on October, 27^{th} and researchers from CAPA collaborated in some of the activities developed, as in previous editions (see figure 7.1).

7.7 | Documentary "Cazando lo invisible"

Carlos Pobes, María Luisa Sarsa and Igor G. Irastorza, members of CAPA, together with other researchers from the LSC, CEFCA and international facilities, were invited to take part in the documentary "Cazando lo invisible" (Hunting the invisible), produced by the company "Sintregua" ; it premiered in January at cinemas in Zaragoza (figure 7.2) , Huesca and Teruel with open colloquia and was emitted by the local TV network "Aragón TV". In addition, during the Science week in November it was shown also in several high schools with the attendance of members of CAPA.

Figure 7.2: Images of the premier of the documentary with the director of CAPA (Igor G. Irastorza), the film director (Mirella R. Abrisqueta), the research vice-rector of unizar (Rosa Bolea), researchers of CAPA (Maria Luisa Sarsa y Carlos Pobes), and the CEFCA director (Javier Cenarro).

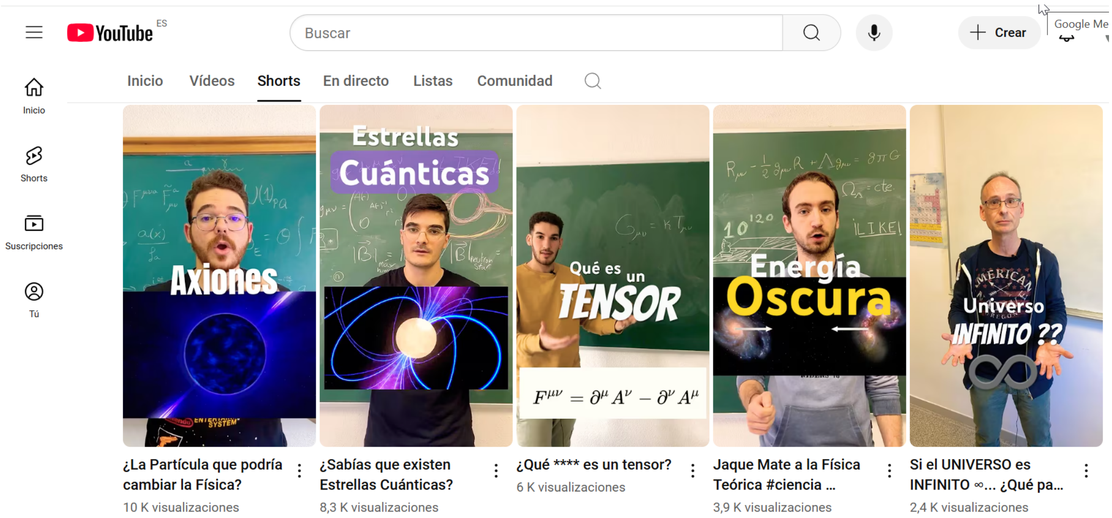

Figure 7.3: Screenshot of short outreach videos at the CAPA YouTube channel

7.8 | Social media

The presence of CAPA on social networks has been boosted thanks to the collaboration of some master's students. There are more than 500 followers on X (`@CAPA_unizar`), 400 on Instagram (`capaunizar`), 100 on TikTok (`capaunizar`), 100 on Linkedin and more than 500 subscribers on the YouTube channel. It can be highlihted that 17 short videos on topics related to CAPA research have been published, having several thousands of views many of them (see figure 7.3).

7.9 | Other activities

Further activities, mainly talks and different interventions in the media, have been collected in the annex I.

8

Equipment and facilities

As it is typical from frontier particle physics research, the activity at CAPA is performed using very specialized infrastructure available in international research facilities and centers like CERN, DESY or LSC. The latter is particularly relevant to the research trajectory of CAPA, as it hosts unique infrastructure associated with underground physics and low-background techniques that are central in CAPA expertise and activity. In the following we describe only the particular equipment or facilities that have been developed mostly by CAPA researchers (or acquired as part of CAPA projects) and are currently being used for particular projects or more transversally to provide service to more than one project. Some of the described infrastructure is at the CAPA premises at the University of Zaragoza, but other is physically at the LSC.

8.1 | Ge detectors

Several close-end, coaxial, High Purity germanium detectors owned by the University of Zaragoza are operated at the Canfranc Underground Laboratory to carry out gamma spectroscopy measurements to quantify the radioactivity of materials used in experiments with participation of members of GIFNA ("Grupo de Investigación en Física Nuclear y Astropartículas") like ANAIS, IAXO and TREX-DM. Sensitivities at the level of mBq/kg for ^{232}U and ^{238}Th natural chains and ^{40}K are typically obtained with these detectors. All of them have copper cryostats, shieldings made of copper and/or low activity lead from 20 to 30 cm and are enclosed in a plastic bag or box continuously flushed with boil-off nitrogen or radon-free air to avoid radon intrusion. The electronic chains for the data acquisition include linear amplifiers and Analog-to-Digital-Converter modules to get energy spectra.

The detectors named Paco and Paquito were produced in the US and have a mass of about 1 kg and 40% relative efficiency. They are operated at the LAB2500 of LSC (see Fig. 8.1); Paco is underground in Canfranc for more than thirty years. Other two detectors, having a mass of about 2 kg and 100% relative efficiency, were acquired to Canberra (model GC9571, serial numbers b 07074 and b 07084) in 2006. They are operated together with the germanium detectors of the Ultra Low Background Service of LSC at the LAB2400. The use and maintenance of these two detectors, named Asterix and Obelix, and their shieldings have been transferred to LSC as a part of the collaboration agreement between LSC and GIFNA, guaranteeing the preferential access to GIFNA for radiopurity measurements using these or equivalent detectors. In 2024, Asterix and Obelix were not in operation due to repair and maintenance works; the former has been checked to recover nominal operational conditions regarding energy resolution and efficiency, while further tests are underway for the latter.

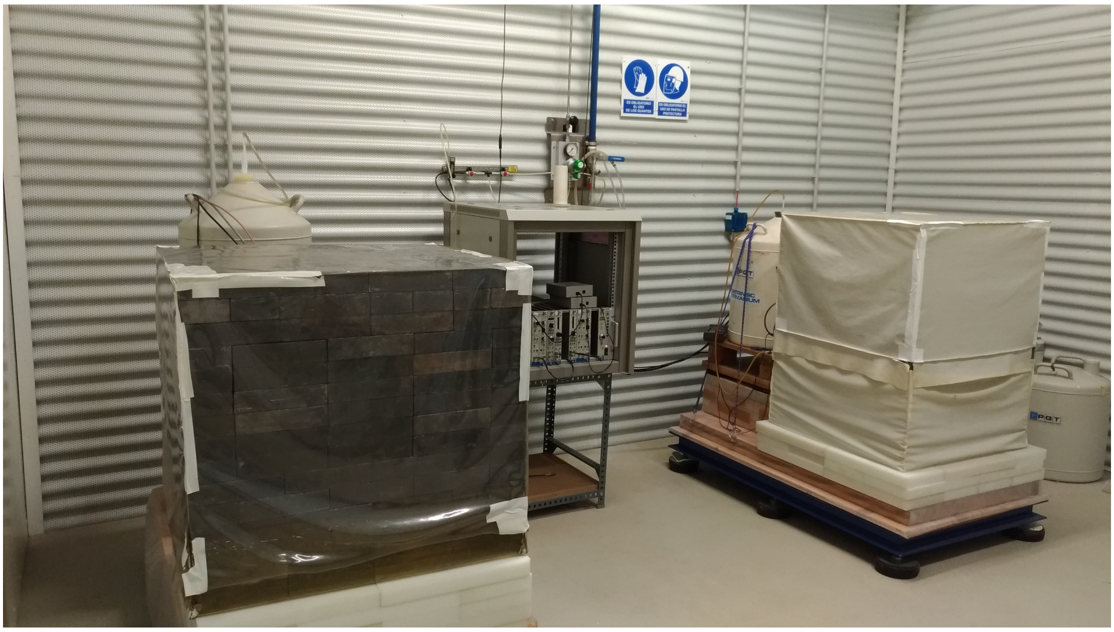

Figure 8.1: LAB2500 at the Canfranc Underground Laboratory where Paco and Paquito detectors are operated.

8.2 | IAXOlab

The new IAXOlab (figure 8.2) is a 160 m^2 laboratory space in the CIRCE building of the Rio Ebro campus of the Universidad de Zaragoza. It was set up mainly to host the activities of the IAXO project (see section 3.1), just after the AdG-ERC was granted in 2019. However it inherits from, and expands on, the previous T-REX laboratory space that was previously set up by the group, for the development, construction and characterization of novel particle detectors based on time projection chambers (TPCs) and micro-pattern gas detectors (MPGDs), with a special focus on low background applications. As such, the laboratory counts with various gas working points and the needed circuitry from the outdoor gas storage space. It also includes equipment associated with high purity gas systems and ultrahigh vacuum vessels, like pressure sensors, flowmeters, back-pressure controllers, filters gas mixers, turbo molecular and primary pumps, leak detectors and a mass spectrometer, as well as different vacuum and high-pressure vessels. In addition, it includes two laminar flow cabinets, various oscilloscopes, a set of nuclear electronics modules and racks. A very important asset to equip TPC-like setups are the specific electronic TPC DAQ cards based on specialized chips like AFTER, AGET and more recently, the newest STAGE.

Recently, two additional spaces of 35 m^2 and 30 m^2 have been incorporated into the CAPA facilities within the CIRCE building. The first space is currently being adapted (see Figure 8.3) to accommodate the activities of the LiquidO collaboration (see Section 3.8). The second space will be dedicated to a new setup designed to study the

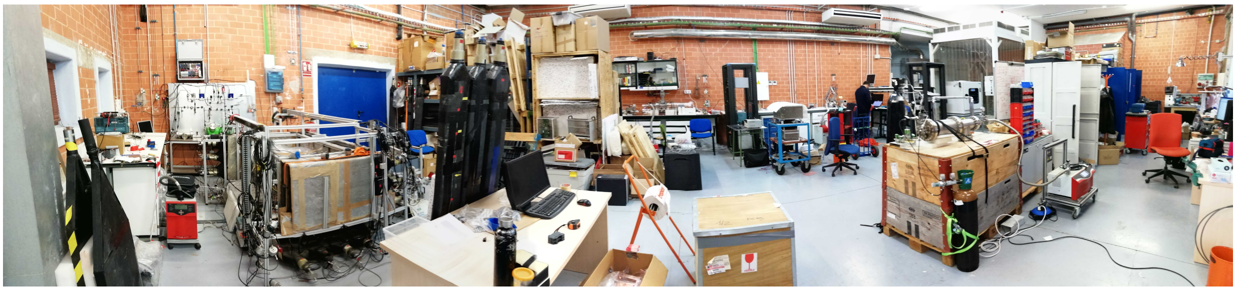

Figure 8.2: Picture of the IAXOlab at the CIRCE building in Rio Ebro Campus of the University of Zaragoza

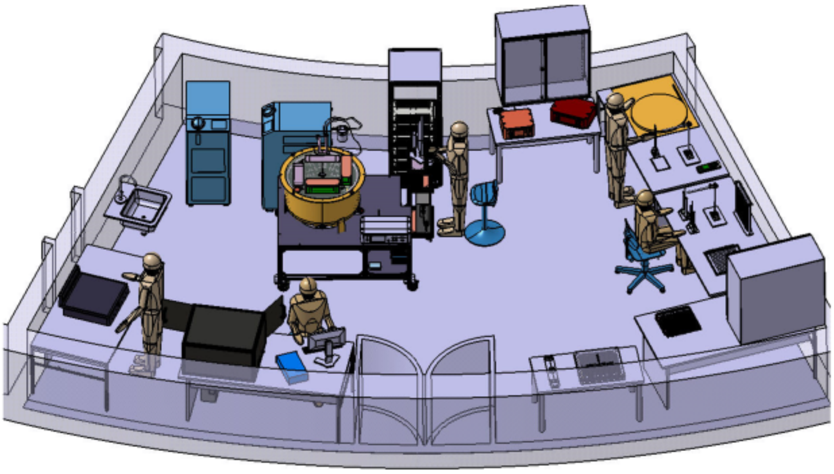

Figure 8.3: 3D drawing of the space at the CIRCE building, in Rio Ebro Campus of the University of Zaragoza, under adaptation to hold the laboratory for LiquidO R&D.

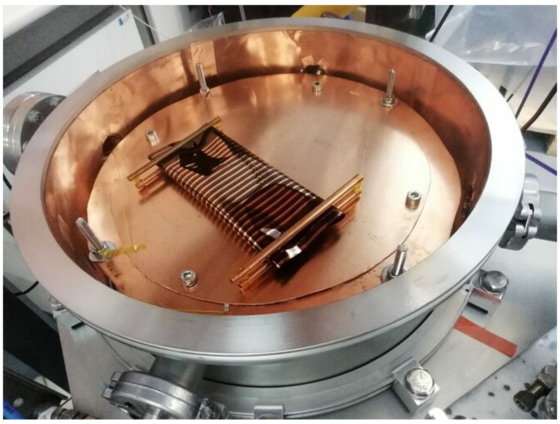

Figure 8.4: Cu-Kapton-Cu foil sample, which is intended to be used as a cathode in the TREX-DM, measured in AlphaCAMM.

response of low-threshold TPCs to single primary electrons, contributing to the TREX-DM experiment's search for low-mass WIMPs.

8.3 | AlphaCAMM

AlphaCAMM (Alpha CAMera Micromegas) is a new proposed detector for high-sensitivity screening of ^{210}Po surface contamination in material samples. AlphaCAMM was developed at CAPA and exploits the readout capabilities of the Micromegas detectors to identify alpha particle tracks and thereby increase the signal to background ratio. A new radiopure AlphaCAMM prototype was developed and commissioned at IAXOLab during 2023, however the background of the radiopure prototype was found to be around 1 order of magnitude larger than expected. To understand the source of the background, an intensive program to determine the source of the background was carried out during 2024. After completely covering the walls of the AlphaCAMM chamber with copper, the background level was reduced by a factor of 3, but still above the target sensitivity (1 μBq/cm^2 vs. 100 nBq/cm^2). With this sensitivity, the screening of material samples has already started, initially with different components to be used as cathodes in TREX-DM (see Fig. 8.4). In parallel, the program to understand and eventually eliminate the background source is still on-going.

8.4 | ANAIS

8.4.1 | ANAIS-112 experiment at LSC

The ANAIS-112 experiment consists of 112.5 kg of NaI(Tl), distributed in 9 modules, 12.5 kg each and built by Alpha Spectra Inc. Among the most relevant features of ANAIS-112 modules we can mention a remarkable optical quality, which combined to using high quantum efficiency Hamamatsu photomultipliers (PMTs) results in a very high light collection, at the level of 15 photoelectrons (phe) per keV in all the nine modules. Another interesting feature is a Mylar window in the middle of one of the lateral faces of the detectors, which allows to calibrate the modules with external sources at low energies.

Figure 8.5: Picture of the ANAIS glove box, continuously keeping a dry atmosphere to preserve and work with sodium iodide crystals.

The ANAIS-112 experiment is installed at the Canfranc Underground Laboratory, inside a shielding consisting of an inner layer of 10 cm of archaeological lead and an outer layer of 20 cm of low activity lead. This lead shielding is encased into an anti-radon box, tightly closed and kept under overpressure with radon-free nitrogen gas. The external layer of the shielding (the neutron shielding) consists of 40 cm of a combination of water tanks and polyethylene bricks. An active veto made up of 16 plastic scintillators is placed between the anti-radon box and the neutron shielding, covering the top and sides of the set-up (see Figure 3.8) allowing to effectively tag the residual muon flux.

Concerning radioactive backgrounds, a careful background model of the whole ANAIS-112 experiment has been developed, by combining inputs from different analysis techniques: HPGe screening of different materials used in the set-up and in the detector building, measurements in coincidence of the modules before ANAIS-112 commissioning, determination of alpha rate by using PSD, estimates of cosmogenic activation rates in NaI, etc. Considering altogether the nine ANAIS-112 modules the average background in the ROI (from 1 to 6 keV) is 3.6 cpd/kg/keV after three years of data taking, while DAMA/LIBRAphase2 background is below 0.80 cpd/kg/keV in the [1–2] keV energy interval, below 0.24 cpd/kg/keV in the [2–3] keV energy interval, and below 0.12 cpd/kg/keV in the [3–4] keV energy interval.

ANAIS-112 experiment operation at the LSC facilities has been granted until 2025. This will allow to accumulate enough statistics to test the DAMA/LIBRA result at about 5 sigma level.

8.4.2 | ANAIS laboratory at UNIZAR

At Zaragoza University there is a laboratory equipped to mount and test scintillating detectors. Figure 8.6, top panel, shows a general view of the ANAIS laboratory at the Zaragoza University facilities. A large size glove box keeping a very low humidity atmosphere, shown in Figure 8.5, allows handling bare highly hygroscopic materials, as NaI and NaI(Tl) crystals, and coupling them to different light sensors, as PMTs or SiPMs.

Along 2022, a new test bench was developed to allow cooling scintillation detector prototypes using SiPMs as light sensors down to -40ºC, and in 2023 a cryocooler was acquired and commissioning started. By the beginning of 2024 the facility was fully operative. This new equipment enables to extend the tests under temperature controlled conditions down to 100 K (see Figure 8.6, bottom panel). In addition, the laboratory disposes of all the hardware and software components required for implementing the corresponding electronic chain and data acquisition system.

Figure 8.6: Top: general view of the ANAIS laboratory at Zaragoza University facilities. Bottom: View of the new cryocooler facility for ANAIS+ prototype testing at Zaragoza University.

8.5 | TREX-DM

TREX-DM is a high pressure time projection chamber conceived for the search of low-mass WIMPs (see section 3.3). The detector (Fig. 8.7) has been designed to host 0.3 kg of argon mass at 10 bar (or, alternatively, 0.16 kg of neon). In some aspects, it is a scaled-up version of CAST Micromegas x-ray detectors but with a 10^3 larger active mass. It is composed of a copper vessel, with an inner diameter of 0.5 m, a length of 0.5 m and a wall thickness of 6 cm. The vessel is divided in two active volumes by a central aluminized mylar cathode, which is connected to high voltage by a tailor-made feedthrough. At each side there is a 19 cm long field cage, composed of a copper-kapton printed circuit screwed to four teflon walls. At each vessel endcap, one Micromegas readout plane (Fig. 3.12) is screwed to a copper base, which is then attached to the endcap. The readout has an active surface of 25×25 cm^2 and has been built with the microbulk technology, out of kapton and copper. It is patterned with ~ 1 mm side pixels, which are linked together in x and y directions, amounting to a total of 250 x and 250 y channels each of the 2 planes. The signals are extracted from the vessel by flat cables coming out through a slit at the endcap and a feedthrough screwed at the external side. The outer end of the cable is connected to the front-end electronics, an auto-triggering multichannel digitized board based on the AGET chip developed at CEA/Saclay.

The detector is surrounded by a 20 cm thick passive shielding against environmental gammas, made of low-radiactivity lead. The 6-cm thickness of the copper vessel serves, in addition to hold the high pressure gas, as the innermost layer of passive shielding to stop the emissions of the innermost lead layers (e.g. Pb^{210}). The lead shielding is further surrounded by an additional 40 cm of polyethylene (at the top and bottom) or water tanks (at the sides) as neutron shielding (the water tanks are foreseen but not yet installed). Finally, the inside of the shielding is intended to be flushed with radon-free air to remove the radon from the space close to the detector.

Since mid-2023,the detector is sitting at the LAB2500 of the Canfranc Underground Laboratory.

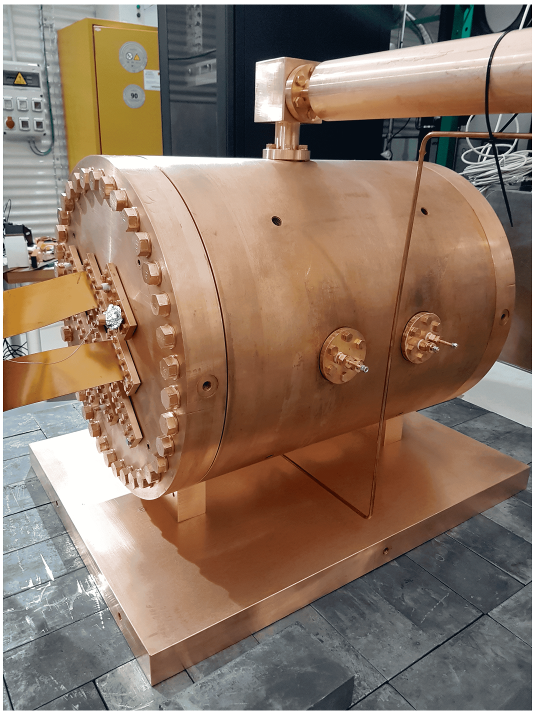

Figure 8.7: Picture of the TREX-DM detector, during its installation at the LSC, previous to the installation of the shielding.

8.6 | IAXO-D1

The IAXO-D1 set-up represents the current state-of-the-art for the development of ultra-low background Micromegas detectors for BabyIAXO and IAXO. The experimental set-up reproduces realistic data taking conditions, where the signal x-rays are focused into a few-mm-wide signal spot and enter the detector through a small thin mylar window. The Micromegas detector consists of a small gaseous time projection chamber with a drift distance of 3 cm and a microbulk readout plane with an area of about 6×6 cm^2, with a pixelated anode readout with a pitch of 0.5 mm. The detector chamber is built with the highest standards of radiopurity (electroformed copper for the detector body, copper and teflon for the field cage, kapton and copper for the microbulk readout and the routing of the signals out of the detector). Two different IAXO-D1 set-ups have been developed at CAPA: one is installed underground at the LSC to assess the intrinsic background level of the detector and another is installed at IAXOLab to measure current background levels under realistic conditions.

8.6.1 | IAXO-D1 at LSC

IAXO-D1 was installed and commissioned at the LSC during 2022 and has been continuously taking data in different configurations since 2023. The experimental set-up is shown in Fig. 3.4 and consists of a new Micromegas detector design surrounded by 20 cm of lead shielding. In this configuration, the lowest intrinsic background of about 1-2 $\times$ 10^{-7} counts cm^{-2} s^{-1} has been achieved. In addition, several studies have been carried out on the contribution of ^{222}Rn contamination in the gas volume, with similar background levels obtained using Ar and a Xe-Ne mixture as conversion gas in the Micromegas. Current efforts are focused on measuring the intrinsic background in a Xe+Ne mixture by reducing the ^{222}Rn contamination in the gas recirculation system. It is also planned to install new radiopure electronics to assess the background level in this configuration.

8.6.2 | IAXO-D1 at IAXOLab

IAXO-D1 has replaced the former IAXO-D0 set-up at the IAXOLab. This set-up is equipped with an active shielding consisting of three layers of plastic scintillators (see figure 3.5). The aim of this setup is to demonstrate that the intrinsic background level of the Micromegas detectors can be achieved with an efficient active veto. During 2024, this setup was in a commissioning phase where several items such as the Micromegas detector, the gas system and the plastic scintillators were commissioned. In addition, this facility will be used as a test bed for the Micromegas detector operating at the LSC. Short-term plans include assessing the surface background of IAXO-D1 and understanding the efficiency of the plastic scintillators as an active veto.

8.7 | LABAC

The LABAC facilities, located at the Faculty of Science (see Fig. 8.8), include a radiochemistry laboratory fully equipped for the preparation of samples. In some cases physical-chemical treatments are required to set up the original samples in shape and size according to the different requirements of the equipment. In other cases, as in the determination of certain radioisotopes, it is necessary to perform a radiochemical separation of a specific element. There is also appropriate equipment for sampling (aerosols and radioiodine, tap or rain water, soil, food) in accordance with standard operating procedures. In the radiophysics laboratory the determination of ambient equivalent doses or alpha, beta and gamma activities is performed using different detection systems, which include two low background germanium detectors (GR3520 and GX4018 Canberra), two gas flow proportional counters (HT-1000 Canberra and Berthold 770-2), a solid scintillation counter, an integrated alpha spectrometer (Alpha Analyst 7401 VR Canberra) and a thermoluminescent dosimeter reader (Panasonic UD-716AGL).

8.8 | Computing infrastructure

CAPA undertakes a wide range of research, from studying dark matter particles to investigating quantum gravity signals. These pursuits demand high-performance computational resources for advanced calculations, simulations, and efficient data storage.

Historically, CAPA members have used various means of computation, from personal computers to supercomputers. Although they have accessed supercomputing clusters for large-scale calculations, it is important to have medium-sized equipment at CAPA, which allows greater flexibility in program development and testing.

Thus, CAPA's activities require significant resources, such as servers and a robust storage infrastructure. Although research groups had servers and storage units obtained with their own resources, the demand for data processing

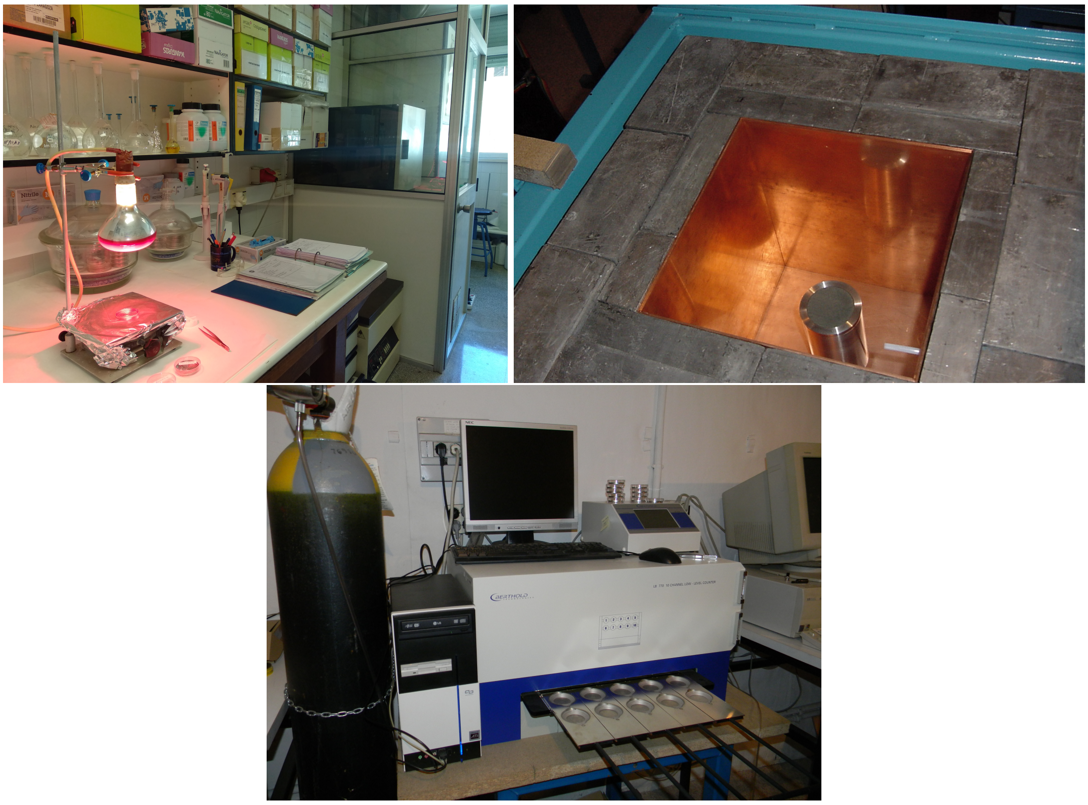

Figure 8.8: Pictures of some LABAC facilities: radiochemistry (top-left) and radiophysics laboratories, showing one germanium detector inside a shielding (top-right) and gas proportional counters (bottom).

and storage is constantly increasing due to the growing number of detectors, the increasing complexity of analyses, more precise simulations, and the expanding number of users at CAPA. Therefore, greater storage capacity is crucial to support these research activities. Thus, in 2023 CAPA participated in a call for the acquisition of research infrastructures at UNIZAR, requesting a server and storage units, and thanks to this 2023 funding call, CAPA was able to acquire an HP server, the HPE ProLiant DL385 Gen10 Plus V2, and a Synology NAS RS2421RP+ storage system. This server consists of two AMD EPYC 7763 CPUs, 1024 GB of RAM, two 480 GB SATA SSDs, and two NVIDIA A16 64 GB GPUs. This resource enhanced CAPA's computing and storage capacity, but it was still insufficient, so they participated in the 2024 call. Again, the request was granted and CAPA increased the storage capacity by acquiring a Synology RS4021xs+ NAS storage system from the manufacturer Synology. This system includes 24 Synology 18 TB SATA M drives, reaching a total of 432 TB, which has multiplied the current resources by 4.5.

This new equipment (Fig. 8.9) represents a significant augmentation of CAPA's computational and data management capabilities. Thus, having a powerful computing infrastructure at CAPA will strengthen research and analysis capabilities, facilitating the exploration of complex physical phenomena and contributing to the advancement of knowledge in the field of astroparticle and high-energy physics.

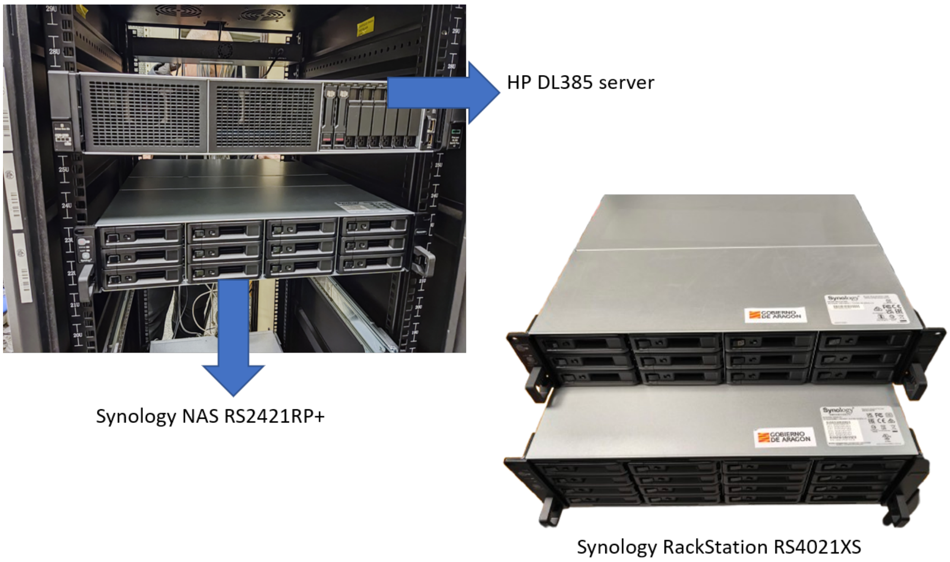

Figure 8.9: New computing infrastructure and storage units of CAPA acquired in 2023 (left) and 2024 (right)

8.9 | Dilution refrigerator

A vital infrastructure for the implementation of several of the actual and future activities, in particular for quantum sensors 3.6, is a dilution refrigerator capable of cooling samples to temperatures of the order of 10 mK. In fact, in 2024 CAPA successfully competed in the ministry's call for scientific equipment and secured funding for this acquisition, the bidding process for which is currently being prepared.

The CAPA dilution refrigerator is a state-of-the-art cryogen-free system, based on a $^3He/^4He$ mixture and cooled by cryocoolers, eliminating the need for cryogenic liquids. This reduces operating costs, improves sustainability, and enables continuous operation without interruption. The technical advancement of these coolers, driven primarily by cryogen-free technology, has overcome the traditional complexity associated with their use, allowing for more robust, efficient and economical operation, facilitating their management.

The equipment will reach temperatures of 10 mK in a mixing chamber (MXC) of approximately 300 mm in diameter, allowing the cooling of medium-sized samples and the simultaneous testing of several devices. Initially, it will feature four semi-rigid coaxial lines (two input and two output) capable of operating up to 18 GHz.

In a second phase, the system will be complemented with more 18 GHz lines and an anti-vibration platform to enable more sensitive measurements. In addition, additional lines (input and output) to explore frequencies up to 40 GHz can be added and the cooler can also be equipped with a magnet, thus expanding its capabilities and aligning it with ongoing strategic projects.

9

Strategic plan

Once established as an institute and in accordance with the regulations of the University of Zaragoza for university institutes, CAPA must periodically develop strategic plans (generally every five years). The first of these plans should be prepared shortly after its establishment as an institute. In anticipation of this, the process of defining the institute's strategy is already underway.

This chapter summarizes the main lines of the strategic plan for the institute's first five years of existence, which will be further developed in the initial months following its establishment.

9.1 | General approach and justification

The objectives and scientific and strategic research activities proposed for CAPA's first strategic plan can be divided into three categories.

The first category consists of actions fully aligned with CAPA's main research areas, labeled L1 to L5. These represent the primary scientific objectives of the plan and include research activities directly aimed at strengthening the areas where CAPA is already producing top-tier research.

The second category encompasses actions that identify innovative research initiatives. These may be byproducts or potential extensions of current areas, emerging synergies between them, and/or opportunities arising from recent collaborations within CAPA. These actions, labeled E1 to E4, include activities that will enrich and expand CAPA's research portfolio and could potentially evolve into entirely new research lines in the future, depending on the attraction of suitable young talent.

The third category consists of cross-cutting actions, labeled T1 to T4, related to the creation and consolidation of CAPA's Technology Unit, which is one of the main strategic objectives proposed for the first five years of the new institute.

This approach is justified by the opportunities and challenges CAPA faces during this transitional period as it becomes a university institute. In particular, we wish to highlight the following considerations:

- CAPA is a modestly sized research center, yet it has achieved outstanding research results in specific areas. This success stems from the unique research trajectory and accumulated expertise of CAPA scientists, the presence of a unique research infrastructure in the region (LSC), and proactive, long-term collaborations with key international partners. This distinctive character must be preserved, strengthened, and further leveraged to ensure scientific impact in the future.

- The close collaboration and coherence between CAPA groups, particularly between theoretical and experimental areas, have been a key ingredient of its success, especially in recent years. It is essential to maintain and further foster this potential for synergy in the future.
- The presence of unique scientific infrastructures in the "local" environment, particularly the LSC, which has a strong relationship with CAPA, is a defining characteristic that provides distinctive capabilities and opportunities compared to other national and international centers. It is necessary to further strengthen and capitalize on the relationship and synergies with the LSC, as well as with other Aragonese infrastructures such as the OAJ (CEFCA, Teruel) and the CCPPB (Benasque).
- Attracting new research talent—especially international postdocs, particularly with long-term retention strategies—has historically been a significant challenge. However, in recent years, there has been a strong shift in this trend (see section 2). This positive trend must be maintained and reinforced in the future. CAPA researchers' strong international connections should be effectively leveraged to foster internationalization across all dimensions of CAPA.
- As a research center (i.e., with a structure and transversal resources that are either absent or very limited), all existing technical infrastructure, technical staff, or technological developments at CAPA have been established in the past as project-based or opportunistic initiatives. Following the practices of similar institutions in the field, it is imperative to consolidate and expand these shared resources by creating a CAPA Technology Unit to integrate and organize them. This unit should take into account CAPA's unique character and the specific needs of its research lines and technologies to provide proper support, increase CAPA's attractiveness to new researchers, and maximize its scientific and social impact.
- CAPA has significant opportunities in the areas of education and outreach. This is due, among other factors, to the recent creation of a new master's program at UNIZAR and the extensive portfolio of outreach activities carried out by CAPA researchers. It is essential to continue strengthening these dimensions and to explore and capitalize on new synergies between them, as well as with research activities and infrastructure.

9.2 | Actions aligned with CAPA's main research lines

L1. Experimental Search for Axions

Over the next few years, the international IAXO collaboration, led by CAPA, is expected to complete the construction of the BabyIAXO superconducting magnet by 2028. This will allow the experiment to be completed and the first data collection to begin in 2029 at DESY, Hamburg. Most of the other components should be ready much earlier, and in fact, there are plans to initiate *magnet-less* operations, conducting a preliminary search for dark photons while the magnet is being finalized.

During this critical phase, CAPA aims to maintain its leadership role in IAXO by engaging in multiple key areas: physics motivation, coordination, X-ray detectors, detection lines, radiopurity, data analysis, and software development. In parallel, once BabyIAXO's construction is on track, feasibility studies for upgrading the design of the final IAXO helioscope should be carried out within the next five years. CAPA will continue to collaborate closely with international institutions such as CERN and DESY, whose involvement in IAXO is crucial.

On the other hand, the RADES project for dark matter axion searches faces significant challenges in the coming years. The first haloscope, cooled to 10 mK, is currently under construction at the Max Planck Institute for Physics (MPP) in Munich, with an initial physics phase expected soon, targeting axion masses around 30–40 μeV. The ERC-SyG DarkQuantum project, launched in October 2024 and led by CAPA, will develop quantum sensors to significantly enhance RADES' sensitivity to axions and expand its mass range. A quantum-enhanced RADES setup is expected to be installed at LSC, further improving detection sensitivity.

Additionally, the RADES/DarkQuantum collaboration is designing a larger haloscope intended to be placed inside the BabyIAXO magnet, which will be sensitive to lower-mass axions (1–2 μeV).

Overall, CAPA aims to continue playing a leading role in these initiatives, maximizing their scientific impact and international visibility.

L2. Experimental Search for WIMPs at the LSC

This research line includes three major projects in which CAPA researchers are involved: ANAIS, TREX-DM, and DarkSide. CAPA leads the first two projects. The specific actions for each of these projects are detailed below.

ANAIS and ANAIS+: Over the next few years, the ANAIS-112 experiment will complete data collection (expected by the end of 2025) and finalize various pending analyses, the most critical being the annual modulation analysis aimed at refuting the DAMA/LIBRA result with the full dataset. This phase will focus on maximizing scientific output from over 15 years of experimental effort, extending for approximately the next five years with gradually decreasing activity.

Meanwhile, the ANAIS+ project is under development, aiming to achieve energy thresholds as low as 0.1 keV using a detection technology also based on scintillating materials but with light readout via SiPMs, operating at temperatures around 100 K. This novel technology would also allow the use of a liquid argon or xenon bath as a cooling system, which could simultaneously function as an active veto. Currently, ANAIS+ is in the R&D phase using sodium iodide and cesium iodide crystals, and in the coming months, the first prototypes will be tested, including underground measurements.

Over the next two years, a feasibility study will be conducted to assess the potential for a dark matter experiment based on this new detection technology. If successful, funding sources will be sought to implement the project at LSC. ANAIS+ is now establishing itself as an international collaboration, currently including researchers from CAPA (leading), CIEMAT, and LNGS (Italy), with the potential to attract additional partners in the near future. Depending on the achieved energy threshold and background levels, ANAIS+ could lead WIMP searches in specific parameter space regions, even with relatively modest exposure times.

TREX-DM: The TREX-DM experiment searches for low-mass WIMPs at LSC using a time projection chamber (TPC) read out with Micromegas planes, a technology in which CAPA is a leader. Over the past year, a novel improvement in the readout plane has been implemented, lowering the detection threshold to nearly the equivalent of a single primary electron, allowing the search for extremely low-mass WIMPs.

The next objectives are to consolidate this improvement and study and mitigate background noise in this low-energy window. This will require completing an exhaustive study of surface contaminations, for which the AlphaCAMM system has been developed (see section 9.2). If these objectives are met, TREX-DM could achieve record sensitivity in the search for these dark matter candidates.

DarkSide: CAPA researchers are increasing their involvement in the DarkSide collaboration, which is currently installing the DarkSide-20k experiment at LNGS. This is one of the leading international efforts aiming to push the sensitivity of direct WIMP detection to the neutrino floor for WIMP masses above 10 GeV.

A critical factor for DarkSide-20k's success is the radiopurity control of the argon target, which will be monitored at the DArT facility at LSC. Over the next few years, CAPA researchers plan to actively participate in DArT's operation and data analysis, strengthening their role within the collaboration. Specifically, they aim to play a key role in the radiopurity and background studies group within the experiment.

L3. Low background techniques and "underground physics"

The application of low-background radiation techniques is essential in experiments searching for rare events. The sensitivity requirements of these experiments demand a continuous reduction in background levels, necessitating new developments that push the limits of activity quantification techniques and the removal of radioactive impurities from the surface or volume of materials.

The GIFNA group at CAPA and the LSC already have a collaboration agreement that includes measuring the radiopurity of materials using gamma spectroscopy with germanium detectors and the joint development of electroforming techniques with ultrapure copper, as well as the fabrication of components using this technique. Other areas of collaboration of interest to both CAPA and LSC will be explored, such as measuring radon emissions or determining activity in materials using alternative techniques.

Furthermore, CAPA members are already involved in the development and operation of the AlphaCAMM detector (to measure surface contamination) and the DArT detector (to quantify extremely low activities of ^{39}Ar), within the framework of the TREX-DM and DarkSide-20k experiments, respectively. Their broader use beyond these experiments will be encouraged.

The development of innovative detection technologies is crucial to tackling the challenges of the next generation of rare event searches (ultra-low radioactive background, lower energy detection thresholds, stability, track recording, etc.). CAPA is already involved in ongoing developments related to the TREX-DM experiment and the ANAIS+ and LiquidO projects.

Furthermore, in 2024, specific funding has been secured for the coming years, including the prestigious ERC Synergy Grant for the DarkQuantum project, which is based on quantum sensors, as well as funding for a new dilution refrigerator at CAPA through a scientific-technical equipment grant from the Ministry of Science, Innovation, and Universities (see section 8.9). These resources will help enhance ongoing developments and assess their potential applications in other contexts.

L4. Astrophysical and cosmological phenomenology of dark matter particles

Dark matter remains one of the great mysteries in astrophysics and cosmology. In the coming years, CAPA aims to consolidate its leadership in this field by advancing both theoretical and observational studies of dark matter candidates and their astrophysical signatures.

One of the key goals is to refine detection strategies by leveraging high-energy astrophysical observations, including those from Fermi LAT, NuSTAR, and future telescopes, as well as optical and radio studies from the Javalambre Astrophysical Observatory (OAJ) and the SKA Observatory (SKAO). These studies will focus on indirect detection methods, looking for potential signals such as deviations in gamma-ray spectra, neutrino interactions, and anomalies in cosmic ray propagation. The combination of observational and theoretical approaches will be essential to constrain the properties of dark matter and identify potential interactions.

In parallel, CAPA will continue to develop theoretical models that link particle physics with cosmology, focusing on weakly interacting massive particles (WIMPs), axions, and axion-like particles (ALPs). The group's advances in numerical simulations are providing new insights into the behavior of dark matter in galactic and extragalactic environments, helping to predict and analyze effects such as the inhomogeneous distribution of dark matter (clumpiness), gravitational lensing signatures, and enhanced indirect detection signals. These efforts will be crucial in guiding future observations and optimizing the search for dark matter.

CAPA will also expand its work on light and weakly interacting particles, such as axions, dark photons, and chameleons, which could leave observable traces in stellar evolution and cosmic structure formation. By optimizing the use of next-generation observatories, the group aims to maximize its potential to detect these elusive particles.

Through its participation in international collaborations and access to cutting-edge instrumentation, CAPA is strategically positioned to drive progress in the search for dark matter and weakly interacting particles. The coming years will be crucial for testing new theoretical models, refining observational techniques, and pushing the boundaries of dark matter detection.

L5. Theories beyond the Standard Model of Particle Physics and Gravitation

The study of theories beyond the Standard Model of particles and relativistic theories of gravitation, including both modifications to General Relativity and Special Relativity, is one of CAPA's strategic lines, with a particular emphasis on phenomenological predictions that could be detectable in high-energy experiments and multi-messenger observations of the cosmos. The CAPA community has been a pioneer in exploring the effects of quantum gravity on the propagation of cosmic messengers, leading the COST Action CA18108 on quantum gravity phenomenology, which brought together more than three hundred researchers from 38 countries between 2019 and 2023. CAPA is currently also participating as the Spanish representative in the Management Committee of the new COST Action CA23130, strengthening its leadership in the search for signals of new physics in the high-energy regime. Furthermore, our research covers models of physics beyond the Standard Model, including extensions of the gauge sector and the study of vacuum energy, both in its relationship with the quantum vacuum structure and its potential implications in cosmology and quantum field theory in curved spaces.

Research plans in this line include the development of theoretical models and their contrast with experimental observations in different areas. In the context of quantum gravity phenomenology, scenarios involving the violation and deformation of Lorentz symmetry will be explored in detail, evaluating their theoretical consistency and potential manifestations in astrophysical and laboratory data. On the other hand, in the framework of physics beyond the Standard Model, extensions of the gauge sector will be studied, with a particular focus on symmetry-breaking mechanisms and the origin of the mass of elementary particles, as well as on the structure of the quantum vacuum and its connection to the cosmological constant. Possible signals will be analyzed at the LHC and other high-energy experiments, including future colliders such as the ILC or the FCC. These lines of work will contribute to the design of experimental strategies and strengthen the institute's participation in key international collaborations.

In the coming years, CAPA will consolidate its leadership in quantum gravity phenomenology and physics beyond the Standard Model through its participation in strategic international projects and the attraction of young talent. Collaboration with key experimental infrastructures will be reinforced to identify and analyze signals of deviations from current models, thus expanding the institute's impact on the exploration of the fundamental laws of nature.

9.3 | Actions focused on emerging/synergistic topics.

E1. Development of novel quantum sensors for the search of rare events

The development of quantum sensors has seen tremendous growth in recent years, driven by the ongoing quantum technologies revolution. This type of sensor leverages some quantum resource (quantization, entanglement, interferometry, etc.) to greatly enhance its sensitivity to a specific physical quantity. The applications of this immense potential to (astro)particle physics are just beginning to be explored. The CAPA is in a privileged position to contribute to this research for two reasons. On one hand, there is extensive experience in the development and operation of cryogenic detectors (bolometers), which have long attracted the attention of this community and require phonon-sensitive devices for their readout. Specifically, the CAPA has expertise in quantum sensors such as TES (transition edge sensors) and KIDs (Kinetic Inductance Detectors), whose superconductivity-based technology enables high sensitivity in detecting weak signals. Additionally, research has been conducted on the effect of radioactivity on superconducting qubits, contributing to the development of strategies to mitigate its impact on quantum coherence. On the other hand, axion physics, in which CAPA is a leader (see L1), is one of the current particle physics objectives where the impact of quantum technologies and the roadmap to achieve it is best defined. This is the goal of DarkQuantum, an ERC-SyG granted in 2023, led from CAPA (see L1).

Because of this, and taking advantage of the significant boost this ERC-SyG will give to quantum technologies at CAPA, a strategic objective has been identified: the creation of specialized resources, both infrastructure and expertise, in quantum technologies and related techniques (cryogenics, RF electronics, etc.). The goal is to prepare a suitable environment for undertaking more generic developments (beyond DarkQuantum) that could be of interest in the context of "rare event" searches or general (astro)particle physics. These developments could include the creation of superconducting qubits as sensors in general, low-mass dark matter detectors, neutrinos, gravitational waves, or new forces or phenomena in fundamental physics. These capabilities would further enhance CAPA's appeal as a destination for young talent and new research initiatives.

E2. New low-background scintillators based on the LiquidO technique

The LiquidO technology, although still in the R&D phase, offers great potential for application in the field of rare-event physics. The confinement of light in a medium that is strongly diffusive, but not absorbent, enables the spatial reconstruction of the topology of energy deposits on one hand, while the lack of need for transparency in the scintillating medium allows it to be doped with isotopes of interest to a much greater degree than conventional transparent liquid scintillators. This potential of the technology and its synergy with the research lines of CAPA have led to the recent incorporation of several of its researchers into the LiquidO collaboration.

Currently, work is being done on the simulation of detectors based on this technology, and efforts have begun to build a prototype that will be operated at the University of Zaragoza facilities to assess its performance in several areas: as active veto against cosmic neutrons (applicable in IAXO), as detector for high-energy gammas generated by axions from a possible supernova explosion in our galaxy (extending the scientific case of IAXO), and as a source-detector configuration, by doping with an isotope undergoing $\beta\beta$ decay and scalable to large masses (applicable to the search for neutrino-less $\beta\beta$ decay). In the coming years, feasibility studies will be conducted for these detector concepts, their scaling, and their potential implementation both in the underground environment of the LSC and in the design of the X-ray detectors' shielding for IAXO. If the results of these studies prove competitive, CAPA will consider more ambitious proposals based on this technology for those applications where it is most suitable.

E3. Novel numerical and analysis techniques

A strategic objective of CAPA as a new research institute is the consolidation of its computational capacity, developing and implementing new computational techniques with transversal applications in the search for new physics across the institute's different research lines. Advances in big data processing, high-performance numerical simulations, and methods based on artificial intelligence and machine learning are opening new possibilities in exploring subtle signals that may be due to weakly interacting particles and physics beyond the Standard Model.

To achieve these objectives, optimized methods will be developed for the analysis of large volumes of data in particle and astroparticle physics experiments, improving sensitivity in the search for deviations from current models. Work will focus on the implementation of advanced machine learning techniques and neural networks for pattern recognition in experimental data, as well as the optimization of simulation algorithms on high-performance computing infrastructures, including GPUs and hybrid architectures. Additionally, innovative approaches in the simulation of complex physical processes will be explored, with applications in the characterization of astrophysical signals and in phenomenological studies of quantum gravity. The combination of new numerical techniques with the phenomenology of new physics will enhance the interpretation of experimental data and optimize search strategies, strengthening the institute's contribution to major international collaborations.

E4. Research on gravitational waves

One of CAPA's strategic objectives is the progressive incorporation of gravitational wave research, thereby expanding its scope within astroparticle physics and fundamental physics. This field has experienced enormous development in recent years, with detections that have opened new windows to the universe and have solidified multi-messenger astronomy as a key tool for exploring astrophysical phenomena and new physics. The future integration of this research at CAPA will be carried out by exploiting synergies with the institute's current activities, while maintaining a distinctive approach that allows CAPA to stand out in the broader context of this research field. This distinctiveness can be achieved, on one hand, through the search for signals of new physics via cosmic messengers and the study of quantum gravity (in connection with L5), or, on the other hand, by exploring the emerging connections with axion physics (L1) or quantum sensors (E1).

On one hand, the development of this research line will focus on theoretical and phenomenological aspects of gravitational waves, exploring their potential to constrain theories beyond General Relativity and detect quantum effects in gravity. In particular, the implications of alternative theories to General Relativity and their observational predictions in both gravitational wave propagation and black hole mergers will be analyzed.

Moreover, advanced techniques for detecting gravitational waves will be studied, evaluating their possible connection with CAPA's experimental and technological capabilities. In this regard, recent proposals (in which CAPA is already involved) will be explored to use axion dark matter detection techniques (axion haloscopes) for the detection of high-frequency gravitational waves (above 10 kHz). This range offers a unique opportunity to explore physics beyond the Standard Model, including topological defects, black hole superradiance, primordial black holes, and phase transitions in the early universe. CAPA is well-positioned to contribute significantly, leveraging its experience in resonant cavity experiments such as IAXO and RADES. Similarly, as with axion experiments, the application of new quantum technologies promises significant advancements in the sensitivity of these strategies.

9.4 | Actions for the Consolidation of the Technological Unit (TU) at CAPA

CAPA currently possesses numerous resources that, in practice, operate informally as a technological unit, namely, much of the infrastructure that its researchers have acquired and developed over time and the core technical staff, which has mainly been formed through project contracts. As argued earlier, it is imperative to strengthen these resources and organize them in a way that allows optimization of their efficiency to support CAPA's various technical and technological needs. The new institute will have a Technological Unit that encompasses, expands, and coordinates all these resources, with the goal of 1) providing better service to CAPA researchers, 2) hosting projects with a higher technological development content, 3) enabling participation in new projects with technological contributions, and 4) enabling and fostering transfer activities.

This unit must have dedicated technical personnel capable of carrying out the defined tasks and handling the maintenance, operation, and potential expansion of various facilities, described in chapter 8, regarding CAPA's scientific equipment, such as germanium detectors for radiopurity measurements, the AlphaCAMM detector for quantifying surface radioactive contamination, the Low Activity Laboratory (LABAC), computational equipment, and all future infrastructure that is already being defined.

The specific objectives of the Technological Unit include the following:

- Promoting and enhancing ultra-low background techniques and the development of new particle detectors, in line with what is described in the strategic line L3.

- Managing CAPA's computing and computational resources, required for tasks such as simulation, data analysis, and offering open data, for both theoretical and experimental groups that require high computational power and data storage capacity. In this regard, it is essential to have specialized personnel who can exploit and update both hardware and software systems to facilitate the work of the scientific staff. CAPA has already received support for its computing equipment through funding from the University of Zaragoza's research infrastructure acquisition calls. Collaborations with other institutes like BIFI, which offer access to supercomputers, will be explored to optimize available resources.

- Consolidating LABAC as a radioassay service offered to the university community, other research centers, public entities, and companies, with facilities that allow radioactivity characterization of various sample types (air, water, food, etc.). The services include measurements of alpha, beta, and gamma emitters and radon monitoring, with ENAC accreditation for certain assays. Environmental radiation monitoring is carried out in collaboration with the Nuclear Safety Council ("Consejo de Seguridad Nuclear", CSN). The GIFNA group and LSC have a cooperation agreement with LABAC for environmental measurements and the determination of various physical and chemical parameters at LSC facilities. The possibility of connecting with the University of Zaragoza General Research Support Service ("Servicio General de Apoyo a la Investigación", SAI) will be explored.

To progress toward these objectives, the following actions are proposed as part of this strategic plan:

T1. Creation and Organization of the TU

Once the Technological Unit is defined in the institute's organizational structure, it will be headed by a subdirector at CAPA, and responsible persons for various areas will be appointed. The technical staff currently working at CAPA includes an engineer (PTGAS from the University of Zaragoza) and a computer technician, involved in all projects, and seven technicians or engineers with diverse training, hired under various projects for specific tasks. The Technological Unit, which will encompass this staff, will need to be supplemented with additional personnel through new contracts, providing transversal technical support in various areas (mechanical engineering, electronics, computing, chemistry, cryogenics, and gases), including new profiles such as a computer engineer. Applications will be made through the institute in support programs for Technical Support Personnel from the Ministry of Science, Innovation, and Universities, and options for hiring through the University of Zaragoza will be explored.

T2. Inventory and Regularization of Infrastructure

The Technological Unit will define an inventory of its general-use infrastructures based on the scientific equipment currently available or expected in the near future, listed in section 8. A program for access to these general infrastructures will be established for CAPA members and, eventually, for external personnel who could benefit from the available facilities. This program will define the requirements and conditions of use for each infrastructure.

T3. Reinforcement and Technologist Program

To achieve the objectives for the Technological Unit, it will be necessary to expand the technical personnel working on CAPA's projects, as described in action T1. Some of these objectives require cutting-edge technological developments, for which it will be crucial to have technologists in the institute who can lead these tasks. As much as possible, the incorporation of permanent personnel with advanced degrees (bachelor's or PhD) specializing in areas like computing or detection systems will be prioritized.

T4. Encouraging Transfer

CAPA's participation in transfer projects or contracts has traditionally been limited, given the nature of the research projects developed. However, LABAC already collaborates in projects related to radiological analysis, environmental radiation monitoring (through a network of sampling stations), and the measurement of ambient gamma radiation in Spain. In addition to consolidating this area of work as a service offered to society, the possibility of transferring developments in advanced detection technologies that could find applications in other fields will be explored. These actions will also include the possibility of seeking specific funding for transfer projects through calls like the EU Pathfinder or similar initiatives.

A

Research grants

In the following we list of research grants that are currently active at CAPA, including also the projects obtained in 2024 (first bullet-points), even if some will start in 2025.

1. TITLE: **GravNet: A Global Network for the Search for High Frequency Gravitational Waves (ERC-2024-SyG 101167211)**
   MAIN RESEARCHER(S): M. Schott (coord), Diego Blas, C. Gatti, D. Budker
   BUDGET: 1 598 488 €
   AGENCY: European Research Council
   YEARS: 2025-2031

2. TITLE: **QRADES: Quantum relic axion detection sensors (QuantERA Call 2023 - Quantum Phenomena and Resources (QPR))**
   MAIN RESEARCHER(S): T. Kontos (CNRS, coord), Igor G. Irastorza (CAPA PI)
   BUDGET: 100 000 €
   AGENCY: QuantERA
   YEARS: 2024-2027

3. TITLE: **Quantum Technologies for Axion Dark Matter Search (DarkQuantum) (ERC-2023-SyG 101118911)**
   MAIN RESEARCHER(S): Igor G. Irastorza (coord), T. Kontos, S. Paraoanu, W. Wernsdorfer
   BUDGET: 4 051 464 €
   AGENCY: European Research Council
   YEARS: 2024-2029

4. TITLE: **Adquisición de un refrigerador de dilución 3He-4He cryogen-free, con capacidad de enfriar a 10 mK un tamaño de muestra medio, para el Centro de Astropartículas y Física de Altas Energías (CAPA) (EQC2024-008314-P)**
   MAIN RESEARCHER(S): Igor G. Irastorza (as CAPA Director)
   BUDGET: 399.300 €

AGENCY: Ministerio de Ciencia, Innovación y Universidades - convocatoria de equipamiento científico
YEARS: 2024-2026

5. TITLE: **Sistema de almacenamiento SAN/NAS Synology RackStation RS4021XS+ (EQUZ2024-CAPA-01)**
   MAIN RESEARCHER(S): Igor G. Irastorza (as CAPA Director)
   BUDGET: 24.926 €
   AGENCY: Gobierno de Aragón - convocatoria de infraestructura
   YEARS: 2024-2024

6. TITLE: **Programa de vigilancia radiológica ambiental (red de estaciones de muestreo) (OTRI 2024/0439)**
   MAIN RESEARCHER(S): Jorge Puimedón
   BUDGET: 211.697,72 €
   AGENCY: Consejo de Seguridad Nuclear
   YEARS: 2024-2027

7. TITLE: **Física de Partículas, Gravitación y Cosmología en la Frontera (PID2023-146686NB-C31)**
   MAIN RESEARCHER(S): Diego Blas, A. Wulzer
   BUDGET: 431 000 €
   AGENCY: Agencia Estatal de Investigación
   YEARS: 2024-2027

8. TITLE: **Detección de ondas gravitacionales en la órbita lunar y en órbitas de satélites artificiales (Becas Leonardo)**
   MAIN RESEARCHER(S): Diego Blas
   BUDGET: 40 000 €
   AGENCY: BBVA
   YEARS: 2024-2026

9. TITLE: **UNDARK: Unravelling the Dark Universe from the Canary Islands Observatories (HORIZON-WIDERA-2023-ACCESS-02-01 101159929)**
   MAIN RESEARCHER(S): J. Camalich (coord), Diego Blas, K. Blum, F. Calore, V, Domcke, A. Sofia
   BUDGET: 101 250 €
   AGENCY: HORIZON EUROPE
   YEARS: 2024-2027

10. TITLE: **New detection windows of gravitational waves (NeWGrav) (CNS2023-143767)**
    MAIN RESEARCHER(S): Diego Blas
    BUDGET: 199 887 €
    AGENCY: Agencia Estatal de Investigación
    YEARS: 2024-2026

11. TITLE: **Un detector basado en *LiquidO* para búsqueda de axiones (EUR2023-143444)**
    MAIN RESEARCHER(S): Juan Antonio García Pascual

BUDGET: 100.000 €
AGENCY: MCIN/AEI/10.13039/501100011033 y por la Unión Europea «NextGenerationEU»/PRTR
YEARS: 2023-2025

12. TITLE: **ANAIS-112 Y ANAIS+: Detectores avanzados de ioduro de sodio para la búsqueda de materia oscura e I+D en otras técnicas basadas en centelleo (PID2022-138357NB-C21)**
MAIN RESEARCHER(S): María Luisa Sarsa Sarsa and María Martínez Pérez
BUDGET: 438.375 €
AGENCY: Agencia Estatal de Investigación
YEARS: 2023-2026

13. TITLE: **Actividades de coordinación hacia la construcción de BabyIAXO, implementación de los detectores de rayos-x de bajo fondo del experimento y otras contribuciones relacionadas (PID2022-137268NB-C51)**
MAIN RESEARCHER(S): Igor G. Irastorza y Gloria Luzón Marco
BUDGET: 589.625 €
AGENCY: Agencia Estatal de Investigación
YEARS: 2023-2026

14. TITLE: **Grupo de Investigación en Física Nuclear y Astropartículas (GIFNA) (Grupo de Referencia DGA-FSE, 225362 E27-23R)**
MAIN RESEARCHER(S): Susana Cebrián y Gloria Luzón
BUDGET: 60.389,79 €
AGENCY: Gobierno de Aragón
YEARS: 2023-2025

15. TITLE: **Grupo Teórico de Física de altas energías (E21-23R)**
MAIN RESEARCHER(S): Eduardo Follana
BUDGET: 41.174 €
AGENCY: Gobierno de Aragón
YEARS: 2023-2025

16. TITLE: **Análisis y Física Matemática (E48-23R)**
MAIN RESEARCHER(S): Luis Velázquez
BUDGET: 54.899,81 €
AGENCY: DGA-FSE
YEARS: 2023-2025

17. TITLE: **Low background techniques on particle detectors for Rare Event Searches (LOBRES) (MSCA 101026819)**
MAIN RESEARCHER(S): Theopisti Dafni, Juan Antonio García
BUDGET: 160 000 €

AGENCY: European Union (MSCA Horizon 2020)
YEARS: 2022-2024

18. TITLE: **ANAIS-112 experiment and new research lines for rare events detection at Canfranc Underground Laboratory (PID2019-104374GB-I00)**
MAIN RESEARCHER(S): María Luisa Sarsa Sarsa and María Martínez Pérez
BUDGET: 219.010 €
AGENCY: Agencia Estatal de Investigación
YEARS: 2020-2024

19. TITLE: **Actividades de coordinación de la construcción de BabyIAXO, construcción de los detectores de rayos-X del experimento, y otras contribuciones relacionadas. (PID2019-108122GB-C31)**
MAIN RESEARCHER(S): Igor G. Irastorza and Gloria Luzón
BUDGET: 340 736 €
AGENCY: Agencia Estatal de Investigación
YEARS: 2020-2024

20. TITLE: **Further beyond the standard models in dark matter, gravity and symmetry (PGC2021-126078NB-C2)**
MAIN RESEARCHER(S): Javier Redondo, Siannah Peñaranda
BUDGET: 387.200 €
AGENCY: Ministerio de Ciencia e Innovación
YEARS: 2022-2025

21. TITLE: **Quantum ENIA: creación de un ecosistema de computación cuántica para la Inteligencia Artificial (IA) (605851-C16.R1)**
MAIN RESEARCHER(S): Manuel Asorey
BUDGET: 250.000 €
AGENCY: Ministerio de Asuntos Económicos y Transformación Digital
YEARS: 2022-2025

22. TITLE: **Dinámica y control de sistemas cuánticos e híbridos clásico-cuánticos (PID2021-123251NB-I00)**
MAIN RESEARCHER(S): Jesús Clemente-Gallardo, Alberto Castro
BUDGET: 48.000 €
AGENCY: Agencia Estatal de Investigación-Unión europea
YEARS: 2022-2026

23. TITLE: **Búsquedas directas de materia oscura (Integración de la línea de detección de ultra-bajo fondo del heliscopio de axiones BabyIAXO, y estudio de la ampliación del caso de física a la detección de axiones de Materia Oscura), en el marco del Convenio de Colaboración entre el Gobierno de Aragón, la Fundación Centro de Estudios de Físicas del Cosmos de Aragón, la Universidad de Zaragoza y el Instituto Tecnológico de Aragón para la ejecución de líneas de actuación de I+D+i en el marco de los planes complementarios previstos en el Plan de Recuperación, transformación y Resiliencia-MRR**

(LA5.A1.)
MAIN RESEARCHER(S): Igor G. Irastorza and Gloria Luzón
BUDGET: 1.281.700 €
AGENCY: Ministerio de Ciencia e Innovación / Gobierno de Aragón
YEARS: 2022-2025

24. TITLE: **Búsquedas directas de materia oscura (Implementación de mejoras en umbral energético y ruido de fondo del experimento TREX-DM de búsqueda de WIMPs de baja masa en el LSC), en el marco del Convenio de Colaboración entre el Gobierno de Aragón, la Fundación Centro de Estudios de Físicas del Cosmos de Aragón, la Universidad de Zaragoza y el Instituto Tecnológico de Aragón para la ejecución de líneas de actuación de I+D+i en el marco de los planes complementarios previstos en el Plan de Recuperación, transformación y Resiliencia-MRR (LA5.A2.)**
MAIN RESEARCHER(S): Theopisti Dafni
BUDGET: 301.655 €
AGENCY: Ministerio de Ciencia e Innovación / Gobierno de Aragón
YEARS: 2022-2025

25. TITLE: **Búsquedas directas de materia oscura (ANAIS+: mejoras en la sensibilidad de ANAIS-112 usando aprendizaje automático y una nueva aproximación experimental), en el marco del Convenio de Colaboración entre el Gobierno de Aragón, la Fundación Centro de Estudios de Físicas del Cosmos de Aragón, la Universidad de Zaragoza y el Instituto Tecnológico de Aragón para la ejecución de líneas de actuación de I+D+i en el marco de los planes complementarios previstos en el Plan de Recuperación, transformación y Resiliencia-MRR (LA5.A3.)**
MAIN RESEARCHER(S): María Martínez
BUDGET: 327.296 €
AGENCY: Ministerio de Ciencia e Innovación / Gobierno de Aragón
YEARS: 2022-2025

26. TITLE: **Grup de Física Teòrica UAB/IFAE (2021 SGR 00649)**
MAIN RESEARCHER(S): Diego Blas
BUDGET: 40 000 €
AGENCY: Agència de Gestió d'Ajuts Universitaris i de Recerca, Generalitat de Catalunya
YEARS: 2021-2025

27. TITLE: **IAXO+: Towards the detection of the axion with the International Axion Observatory (ERC-AdG 788781)**
MAIN RESEARCHER(S): Igor G. Irastorza
BUDGET: 3 106 875 €
AGENCY: European Research Council
YEARS: 2018-2024

B

Networking grants

1. TITLE: **Bridging high and low energies in search of quantum gravity (BridgeQG) (COST Action CA23130)**
   MAIN RESEARCHER(S): Giulia Gubitosi (Federico II Naples University), Action Chair
   LOCAL NODE MAIN RESEARCHER(S): José Manuel Carmona (Spanish representative in Managing Committee), José Luis Cortés, Justo Lopez, Maykoll A. Reyes, Filip Rescic
   BUDGET: 1st Grant Period (2024-25): 129 995 €
   AGENCY: COST (European Cooperation in Science and Technology)
   YEARS: 2024-2028

2. TITLE: **COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments (COST Action CA21106)**
   MAIN RESEARCHER(S): Alessandro Mirizzi (Bari University), Action chair
   LOCAL NODE MAIN RESEARCHER(S): Igor G. Irastorza (Spanish representative in Managing Committee), Mathieu Kaltschmidt (Co-Leader of Working Group 2, Dark Matter & Cosmology), Julia Vogel, Maurizio Giannotti (Leader of Working Group 3, Astrophysics), Javier Redondo, Jaime Ruz Armendáriz
   AGENCY: COST (European Cooperation in Science and Technology)
   YEARS: 2022-2026

3. TITLE: **Red de Física de Partículas (RED2022-134487-T)**
   MAIN RESEARCHER(S): Igor G. Irastorza
   BUDGET: 20 300 €
   AGENCY: Agencia Estatal de Investigación
   YEARS: 2023-2025

4. TITLE: **Red Temática MultiDark (RED2022-134411-T)**
   MAIN RESEARCHER(S): Miguel Ángel Sánchez Conde (UAM)
   LOCAL NODE MAIN RESEARCHER(S): María Luisa Sarsa
   BUDGET: 20 300 €

AGENCY: Agencia Estatal de Investigación
YEARS: 2023-2025

5. TITLE: **Red española de Lattice Gauge Theory LATTICENET (RED2022-134428-T)**
   MAIN RESEARCHER(S): Eduardo Follana
   BUDGET: 20 300 €
   AGENCY: Agencia Estatal de Investigación
   YEARS: 2023-2025

C

Organization of conferences, workshops and schools

1. EVENT: **New Frontiers in Strong Gravity**
   PARTICIPANT(S): Diego Blas, P. Figueras, S. Nissanke, L. Stein, H. Witek
   TYPE OF PARTICIPATION: Local Organizing Committee
   VENUE: Benasque, Spain
   DATE: 07/07/24-19/07/24
   URL: https://www.benasque.org/2024relativity/

2. EVENT: **Kick-off meeting UNDARK**
   PARTICIPANT(S): J. Camalich (chair), Diego Blas, K. Blum, F. Calore, V, Domcke
   TYPE OF PARTICIPATION: Local Organizing Committee
   VENUE: La Laguna, Spain
   DATE: 08/10/24-11/10/24
   URL: https://indico.cern.ch/event/1443449/

3. EVENT: **LI - International Meeting on Fundamental Physics**
   PARTICIPANT(S): Diego Blas, T. Lux, I. Riu, R. Vázquez
   TYPE OF PARTICIPATION: Local Organizing Committee
   VENUE: Benasque, Spain
   DATE: 09/09/24-14/09/24
   URL: https://www.benasque.org/2024imfp/

4. EVENT: **Saturnalia 2024**
   PARTICIPANT(S): Mathieu Kaltschmidt, Javier Redondo, Siannah Peñaranda, Laura Seguí
   TYPE OF PARTICIPATION: Local Organizing Committee

VENUE: Zaragoza, Spain
DATE: 17/12/24-20/12/24
URL: https://indico.capa.unizar.es/event/38/

5. EVENT: **RENATA&21th Multidark Joint Meeting, special event for the Spanish input to the ESPP update**
PARTICIPANT(S): Maria Martinez
TYPE OF PARTICIPATION: Organizing Committee
VENUE: IFCA (Santander)
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

6. EVENT: **2nd General Meeting of the COST Action CA21106**
PARTICIPANT(S): Maurizio Giannotti
TYPE OF PARTICIPATION: Organizing Committee
VENUE: Istinye University, Istanbul (TR)
DATE: 03/09/24-06/09/24
URL: https://agenda.infn.it/event/39939/

7. EVENT: **Fifth annual conference on quantum gravity phenomenology in the multi-messenger era (QGMM24)**
PARTICIPANT(S): José Manuel Carmona
TYPE OF PARTICIPATION: Member of the Global Scientific Committee
VENUE: Faculty of Sciences of the Complutense University of Madrid
DATE: 15/07/24-19/07/24
URL: https://teorica.fis.ucm.es/QGMM24

8. EVENT: **TAE2024-International Workshop on High Energy Physics**
PARTICIPANT(S): Manuel Asorey, Maria Martínez
TYPE OF PARTICIPATION: Member of the Organizing Committee
PARTICIPANT(S): Theopisti Dafni
TYPE OF PARTICIPATION: Teachers
VENUE: Centro de Ciencias de Benasque Pedro Pascual
DATE: 01/09/24-14/09/24
URL: https://www.benasque.org/2024tae/

9. EVENT: **2nd Training School COST Action COSMIC WISPers (CA21106)**
PARTICIPANT(S): Maurizio Giannotti

TYPE OF PARTICIPATION: Organizing Committee
VENUE: Faculty of Mathematics and Physics, Ljubljana (Slovenia)
DATE: 10/06/24-13/06/24
URL: https://indico.ijs.si/event/1825/

10. EVENT: **Cosmology, Astrophysics, Theory and Collider Higgs 2024 (CATCH22+2)**
PARTICIPANT(S): Maria Martinez
TYPE OF PARTICIPATION: Member of the International Advisory Commeette
VENUE: DIAS, Dublin (Ireland)
DATE: 01/05/24-05/05/24
URL: https://indico.cern.ch/event/1291893/

11. EVENT: **Working Group Meeting of COST Action COSMIC WISPers (CA21106)**
PARTICIPANT(S): Maurizio Giannotti
TYPE OF PARTICIPATION: Organizing Committee
VENUE: DESY Hamburg, Germany
DATE: 01/02/24-02/02/24
URL: https://indico.desy.de/event/42137/overview

12. EVENT: **XI Jornada de Jóvenes Investigadores de Química y Física de Aragón**
PARTICIPANT(S): Susana Cebrián
TYPE OF PARTICIPATION: Member of the Organizing Committee
VENUE: Zaragoza
DATE: 21/11/24-21/11/24
URL: https://eventos.unizar.es/120120/detail/xi-jornada-de-jovenes-investigadores-de-quimica-y-fisica-de-aragon.html

13. EVENT: **1ª Reunión Nacional Planes Complementarios de Astrofísica y Altas Energías (AstroHEP PPCC2024)**
PARTICIPANT(S): Manuel Asorey, Susana Cebrián, Iván Coarasa Casas, Theopisti Dafni, Maurizio Giannotti, Igor G. Irastorza, Gloria Luzón, María Martínez, Jaime Ruz, María Luisa Sarsa, Julia Vogel
TYPE OF PARTICIPATION: Members of the Local Organizing Committee
VENUE: Zaragoza
DATE: 5/6/24-7/6/24
URL: https://indico.capa.unizar.es/event/36

14. EVENT: **Minicourse on perturbative and nonperturbative treatment of quantum gravity problems, ICTP-SAIFR-UNESP**
    PARTICIPANT(S): Manuel Asorey
    TYPE OF PARTICIPATION: Member of the Organizing Committee
    VENUE: Sao Paolo, Brasil
    DATE: 20/05/24-23/05/24
    URL: https://www.ictp-saifr.org/mqgp2024/

15. EVENT: **VI International Workshop on Information Geometry, Quantum Mechanics and Apps**
    PARTICIPANT(S): Manuel Asorey,
    TYPE OF PARTICIPATION: Member of Scientific Committee
    VENUE: UC3M, Madrid
    DATE: 20/02/24-22/02/24
    URL: http://www.q-math.es/conferences/IGQMA2024/

16. EVENT: **Workshop on the Quantum Future**
    PARTICIPANT(S): Manuel Asorey and Fernando Falceto
    TYPE OF PARTICIPATION: Members of the Organizing Committee
    VENUE: Facultad de Ciencias. Universidad de Zaragoza
    DATE: 13/03/24-14/03/24
    URL: https://ciencias.unizar.es/noticia/workshop-quantum-future-miercoles-13-de-marzo

D

Seminars and Colloquia at CAPA

1. TITLE: **Saturnalia 2024: Neutron-Capture Experiments and the Synthesis of Heavy Elements**
   SPEAKER: Jorge Lerendegui
   INSTITUTION: IFIC, Valencia
   DATE: 20/12/2024

2. TITLE: **Saturnalia 2024: Primordial Correlators: Opening a Window into the very early Universe**
   SPEAKER: Carlos Duaso Pueyo
   INSTITUTION: Scuola Normale Superiore, Pisa
   DATE: 20/12/2024

3. TITLE: **Saturnalia 2024: Doubly Special Relativity as a Nonlocal Quantum Field Theory**
   SPEAKER: Javier Relancio
   INSTITUTION: CAPA, Zaragoza
   DATE: 20/12/2024

4. TITLE: **Saturnalia 2024: Phenomenology of Theories of Gravitation beyond General Relativity**
   SPEAKER: Miguel Pardina
   INSTITUTION: CAPA, Zaragoza
   DATE: 19/12/2024

5. TITLE: **Saturnalia 2024:Dark Matter Detection with a Superconducting Qubit in the DarkQuantum Project**
   SPEAKER: Yikun Gu
   INSTITUTION: CAPA, Zaragoza

DATE: 19/12/2024

6. TITLE: **Saturnalia 2024: Searching for New Physics in Semileptonic B Decays using Lattice QCD**
SPEAKER: Alejandro Vaquero
INSTITUTION: CAPA, Zaragoza
DATE: 19/12/2024

7. TITLE: **Saturnalia 2024: Machine Learning Developments for 3D Muon Tomography of a Nuclear Reactor**
SPEAKER: Héctor Gómez
INSTITUTION: CEA, Saclay, Francia
DATE: 18/12/2024

8. TITLE: **Saturnalia 2024: A Cosmic Dance: How Supermassive Black Holes and their Host Galaxies are tangled up**
SPEAKER: Jacobo Asorey Barreiro
INSTITUTION: CAPA, Zaragoza
DATE: 18/12/2024

9. TITLE: **Saturnalia 2024: Spectrum of Global Strings and the Axion Dark Matter Mass**
SPEAKER: Mathieu Kaltschmidt
INSTITUTION: CAPA, Zaragoza
DATE: 18/12/2024

10. TITLE: **Saturnalia 2024:Enhancing $0\nu2\beta$ Detection with the CROSS Demonstrator**
SPEAKER: David Cintas
INSTITUTION: IJCLab, Saclay, Francia
DATE: 17/12/2024

11. TITLE: **Saturnalia 2024: Geometric Flavours of Quantum Field Theory: Applications to Cosmology**
SPEAKER: David Martínez
INSTITUTION: CAPA, Zaragoza
DATE: 17/12/2024

12. TITLE: **DESI 2024 Cosmological results and the modelling of galaxies**
SPEAKER: Violeta González Pérez

INSTITUTION: Departamento de Física Teórica, Universidad Autónoma de Madrid
DATE: 28/11/24

13. TITLE: **Axion Dark Matter and the Quality Problem**
SPEAKER: Giacomo Landini
INSTITUTION: IFIC, Valencia
DATE: 14/11/2024

14. TITLE: **Quasinormal modes and self-adjoint extensions of the Schrodinger operator**
SPEAKER: A. Saa
INSTITUTION: Universidad de Campinas, Sao Paolo, Brasil
DATE: 18/10/24

15. TITLE: **Amundsen-Scott Base and the IceCube Neutrino Telescope**
SPEAKER: Carlos Pobes
INSTITUTION: Instituto de Nanociencia y Materiales de Aragón (INMA, CSIC–UNIZAR)
DATE: 17/10/24

16. TITLE: **Cosmic strings and where to find them**
SPEAKER: Ivan Rybak
INSTITUTION: CAPA, Zaragoza
DATE: 12/09/2024

17. TITLE: **The solar axion quest**
SPEAKER: Jaime Ruz Armendáriz
INSTITUTION: CAPA, Zaragoza
DATE: 06/09/2024

18. TITLE: **Solar chameleon production**
SPEAKER: Tomas O´Shea
INSTITUTION: CAPA, Zaragoza
DATE: 20/06/2024

19. TITLE: **Neutrino Physics at Low Energy: Coherent Scattering and the CONUS Experiment**
SPEAKER: Kaixiang Ni
INSTITUTION: Max-Planck-Institut für Kernphysik -MPIK-, Heidelberg

DATE: 07/06/24

20. TITLE: **Hybrid geometrodynamics: A Hamiltonian description of QFT coupled to gravitation and foliation-dependent Hilbert space structures**
SPEAKER: Carlos Bouthelier
INSTITUTION: CAPA, Universidad de Zaragoza
DATE: 30/05/24

21. TITLE: **Phenomenology of DSR-relativistic in-vacuo dispersion in FLRW spacetime**
SPEAKER: Domenico Frattulillo
INSTITUTION: Universidad de Nápoles
DATE: 25/05/24

22. TITLE: **Core-collapse supernovae shining in axion-like particles**
SPEAKER: Alessandro Lella
INSTITUTION: Università degli Studi di Bari
DATE: 09/05/24

23. TITLE: **Neutrino mixing beyond Pontecorvo theory, entangled vacuum and all of that!**
SPEAKER: Giuseppe Gaetano Luciano
INSTITUTION: Univ. Lleida
DATE: 08/05/24

24. TITLE: **Multimessenger physics, gravitational waves and quantum gravity**
SPEAKER: Antonia Micol Frassino
INSTITUTION: University of Alcalá - ICC University of Barcelona)
DATE: 15/04/2024

25. TITLE: **How dark matter came to be: Experimental constraints on dark matter production mechanisms**
SPEAKER: David G. Cerdeño
INSTITUTION: UAM-IFT, Madrid
DATE: 01/02/2024

26. TITLE: **Relativistic properties of deformed lifetime phenomenology**
SPEAKER: Iarley Pereira Lobo
INSTITUTION: Universidade Federal da Paraíba UFPB

DATE: 24/01/24

E

PhD Theses

E.1 | Theses defended in 2024

1. TITLE: **Epistemología Política de la Ciencia Ciudadana. Una Aproximación desde la Teoría de los Bienes Comunes**
   STUDENT: Maite Pelacho López
   SUPERVISOR: Hannot Rogríguez Zabaleta and Jesús Clemente Gallardo
   DATE: 25/11/2024, Universidad del País Vasco, Doctorado en Filosofía, Ciencia y Valores

   TITLE: **Desarrollo de grandes planos de lectura Micromegas para experimentos de búsqueda de sucesos poco probables.**
   STUDENT: Hector Mirallas Sanchez
   SUPERVISOR: Theopisti Dafni and Igor G. Irastorza
   DATE: 15/07/2024

   TITLE: **Hybrid quantum-classical systems: Statistical mechanics, thermodynamics and field theory**
   STUDENT: Carlos Bouthelier Madre
   SUPERVISOR: Jesús Clemente Gallardo and Alberto Castro Barrigón
   DATE: 18/01/2024

E.2 | Theses ongoing in 2024

1. TITLE: **ANAIS-112 and ANAIS+: advanced NaI detector for dark matter searches and R&D in other detection techniques based on scintillation**
   STUDENT: Carmen Seoane Herce
   SUPERVISOR: María Martínez Pérez and Iván Coarasa Casas

DATE: 2024-2028

2. TITLE: **Higher Derivative Gravity**
   STUDENT: Miguel Pardina
   SUPERVISOR: Manuel Asorey
   DATE: 2024-2028

3. TITLE: **Flavour Physics and Machine Learning**
   STUDENT: Alejandro Mir Ramos
   SUPERVISOR: Siannah Peñaranda and Jose Alda Gallo
   DATE: 2024-2028

4. TITLE: **Muonic $g-2$ in the lattice**
   STUDENT: Adrián del Pino
   SUPERVISOR: Alejandro Vaquero Avilés-Casco
   DATE: 2024-2028

5. TITLE: **Sistemas de blindaje activo en detectores de axiones solares para BabyIAXO**
   STUDENT: Jorge Porrón Lafuente
   SUPERVISOR: Gloria Luzón and Jaime Ruz
   DATE: 2024-2028

6. TITLE: **Searching for ultra-light dark matter in AION**
   STUDENT: Dhruv Pathak
   SUPERVISOR: Diego Blas, C. McCabe
   DATE: 2024-2027

7. TITLE: **Condensed dark matter**
   STUDENT: Joel Barir
   SUPERVISOR: Diego Blas, T. Volansky
   DATE: 2024-2027

8. TITLE: **Beyond Einstein: Exploring the Universe's Transparency through Lorentz Invariance Violation and Doubly Special Relativity in Astrophysical Phenomena**
   STUDENT: Filip Rescic
   SUPERVISOR: José Manuel Carmona and Tomislav Terzić

DATE: 2023-2028

9. TITLE: **Desarrollo de nuevas técnicas de detección para búsqueda de materia oscura en la frontera de baja masa**
STUDENT: María Jiménez Puyuelo
SUPERVISOR: Theopisti Dafni y Juan Antonio García Pascual
DATE: 2023-2027

10. TITLE: **Millikelvin technologies for neutrino physics and quantum computing**
STUDENT: Victor Pérez Sánchez
SUPERVISOR: Andrea Giuliani and Maria Martínez
DATE: 2023-2026

11. TITLE: **Predicting the Properties of Axion Dark Matter with Supercomputers**
STUDENT: Mathieu Kaltschmidt
SUPERVISOR: Javier Redondo
DATE: 2022-2026

12. TITLE: **New experimental techniques for axion searches**
STUDENT: Cristian Cogollos
SUPERVISOR: Javier Redondo
DATE: 2022-2026

13. TITLE: **Design of advanced scintillators for rare event searches at the Canfranc Underground Laboratory.**
STUDENT: Jaime Apilluelo Allué
SUPERVISOR: María Martínez Pérez and María Luisa Sarsa Sarsa
DATE: 2022-2026

14. TITLE: **Nuevos desarrollos de bajo fondo para la detección de axiones solares en BabyIAXO.**
STUDENT: Ana Quintana García
SUPERVISOR: Susana Cebrián and Igor G. Irastorza
DATE: 2022-2026

15. TITLE: **Nuevas estrategias de reducción de fondo en experimentos para la búsqueda de Materia Oscura**
STUDENT: Álvaro Ezquerro Sastre

SUPERVISOR: Theopisti Dafni y Juan Antonio García Pascual
DATE: 2022-2026

16. TITLE: **New Physics with Gravitational Wave Observations**
STUDENT: Silvia Gasparotto
SUPERVISOR: Diego Blas
DATE: 2021-2025

17. TITLE: **New analytical insights into gravitational waveforms**
STUDENT: Marina de Amicis
SUPERVISOR: Diego Blas, V. Cardoso
DATE: 2021-2025

18. TITLE: **Geometric flavours of Quantum Field Theory on a Cauchy Hypersurface**
STUDENT: David Martínez Crespo
SUPERVISOR: Jesús Clemente-Gallardo
DATE: 2021-2025

19. TITLE: **Energía de Casimir en Teorías Gauge no Abelianas**
STUDENT: Fernando Ezquerro Sastre
SUPERVISOR: Manuel Asorey and Eduardo Follana
DATE: 2021-2025

20. TITLE: **Annual modulation and other rare processes searches using five-year exposure of ANAIS-112 and prospects of an upgraded experiment, ANAIS+.**
STUDENT: Tamara Pardo Yanguas
SUPERVISOR: María Martínez Pérez and María Luisa Sarsa Sarsa
DATE: 2021-2025

21. TITLE: **Búsqueda de Axiones solares con BabyIAXO**
STUDENT: Luis Antonio Obis Aparicio
SUPERVISOR: Gloria Luzón
DATE: 2020-2025

22. TITLE: **El experimento TREX-DM: fenomenología y búsqueda de WIMPs de baja masa.**
STUDENT: David Díez Ibáñez

SUPERVISOR: Theopisti Dafni
DATE: 2020-2025

23. TITLE: **Looking for low-mass WIMPs with the TREX-DM detector**
    STUDENT: Óscar Pérez Lázaro
    SUPERVISOR: Igor G. Irastorza
    DATE: 2020-2025

24. TITLE: **Estados de borde en materiales topológicos**
    STUDENT: Yisely Martinez Pérez
    SUPERVISOR: Manuel Asorey
    DATE: 2020-2025

25. TITLE: **Diseño y prueba de un detector Micromegas para BabyIAXO**
    STUDENT: Cristina Margalejo Blasco
    SUPERVISOR: Gloria Luzón and Theopisti Dafni
    DATE: 2019-2025

26. TITLE: **Valoración del impacto dosimétrico producido por la variación de los parámetros de entrada de un sistema de cálculo de dosis absorbida por el método de Monte Carlo en tratamientos de radioterapia.**
    STUDENT: Francisco Javier Jiménez Albericio
    SUPERVISOR: Jorge Mario Puimedón Santolaria
    DATE: 2014-2025

F

Bachelor and Master Theses

F.1 | Bachelor Theses presented in academic year 2023-24

1. TITLE: **Quantum Spin Dynamics in Magnon Gravitational Wave Detectors**
   STUDENT: Wenjing Zhou
   SUPERVISOR: Diego Blas
   ACADEMIC YEAR: 2023-2024

2. TITLE: **Cosmología con cartografíados extragalácticos**
   STUDENT: Álvaro Fernández Madrid
   SUPERVISOR: Jacobo Asorey
   ACADEMIC YEAR: 2023-2024

3. TITLE: **Cosmología con cartografíados extragalácticos**
   STUDENT: Santiago Herraiz Ortiz
   SUPERVISOR: Jacobo Asorey
   ACADEMIC YEAR: 2023-2024

4. TITLE: **Fenomenología de violación de invariancia Lorentz en la física de neutrinos de muy alta energía**
   STUDENT: Guillermo Pascua Ramón
   SUPERVISOR: José Manuel Carmona and Maykoll A. Reyes
   ACADEMIC YEAR: 2023-2024

5. TITLE: **Modificaciones en la transparencia del universo a fotones de muy alta energía en deformaciones de la relatividad especial**
   STUDENT: Cristina Santa Eugenia Mercado
   SUPERVISOR: José Manuel Carmona and Maykoll A. Reyes
   ACADEMIC YEAR: 2023-2024

6. TITLE: **Análisis de datos del experimento ANAIS-112 con un sistema de adquisición de datos mejorado**
   STUDENT: Diego Miguel Pascual
   SUPERVISOR: María Martínez Pérez and Iván Coarasa Casas
   ACADEMIC YEAR: 2023-2024

7. TITLE: **Optimización de la respuesta de prototipos de ANAIS+ (centelleadores de NaI+SiPM) mediante simulaciones ópticas por el método de Monte Carlo**
   STUDENT: Manuel Lozano Deirós
   SUPERVISOR: María Martínez Pérez and Jaime Apilluelo Allué
   ACADEMIC YEAR: 2023-2024

8. TITLE: **Dinámicas no lineales de sistemas híbridos clásico-cuánticos**
   STUDENT: Acher Alias Saura
   SUPERVISOR: Jesús Clemente Gallardo
   ACADEMIC YEAR: 2023-2024

9. TITLE: **El formalismo de Koopman en la dinámica de sistemas híbridos clásico-cuánticos**
   STUDENT: Carmen García Muñoz
   SUPERVISOR: Jesús Clemente Gallardo
   ACADEMIC YEAR: 2023-2024

10. TITLE: **Formalismo de Koopman y cuantización**
    STUDENT: Paul Rosa Ruiz
    SUPERVISOR: Jesús Clemente Gallardo and David Martínez Crespo
    ACADEMIC YEAR: 2023-2024

11. TITLE: **Física del Sabor en el Modelo Estándar de la física de partículas**
    STUDENT: Gabriel López Pinar
    SUPERVISOR: Siannah Peñaranda
    ACADEMIC YEAR: 2023-2024

12. TITLE: **Introducción a las teorías de Gran Unificación**
    STUDENT: Adrián Fernández Duro
    SUPERVISOR: Siannah Peñaranda
    ACADEMIC YEAR: 2023-2024

13. TITLE: **El boson de Higgs y la ruptura espontánea de simetría**
    STUDENT: Juan Prado Ardanuy
    SUPERVISOR: Siannah Peñaranda
    ACADEMIC YEAR: 2023-2024

14. TITLE: **Realineamiento del vacío y materia oscura axiónica**
    STUDENT: Lorenzo Izuel Lumbierres
    SUPERVISOR: Javier Redondo Martín
    ACADEMIC YEAR: 2023-2024

15. TITLE: **Simulación del modelo cuántico de Ising unidimensional en un ordenador cuántico**
    STUDENT: Pedro José Álvarez Terraz
    SUPERVISOR: José V. García Esteve
    ACADEMIC YEAR: 2023-2024

16. TITLE: **Diseño y caracterización por medio de machine learning de sistemas de medida no-destructiva de pines y ensamblajes nucleares usados en reactores nucleares**
    STUDENT: Jorge Paz-Peñuelas Oliván
    SUPERVISOR: Jaime Ruz Armendariz
    ACADEMIC YEAR: 2023-2024

17. TITLE: **Planificación del tratamiento por radioembolización hepática con microesferas de itrio-90**
    STUDENT: Rocío García Carnicero
    SUPERVISOR: F. Javier Jiménez Albericio, Nuria Gómez González and Eduardo García Abancéns
    ACADEMIC YEAR: 2023-2024

18. TITLE: **Revisión de las ideas envueltas en los intentos de formular una teoría de gravedad cuántica**
    STUDENT: Diego Morales
    SUPERVISOR: José Luis Cortés, Maykoll A. Reyes and Eduardo Follana Adín
    ACADEMIC YEAR: 2023-2024

19. TITLE: **Precesión del perihelio para órbitas alrededor de agujeros negros en la aproximación postnewtoniana en relatividad general**
    STUDENT: Pablo Florencio Díaz Navarrete
    SUPERVISOR: Eduardo Follana Adín
    ACADEMIC YEAR: 2023-2024

20. TITLE: **Deflexión de la luz por agujeros negros de Kerr**
    STUDENT: Javier Ramos Ortega
    SUPERVISOR: Eduardo Follana Adín
    ACADEMIC YEAR: 2023-2024

21. TITLE: **Cosmología en teorías de gravitación no Einstenianas**
    STUDENT: Diego Muñoz Zorrilla
    SUPERVISOR: Manuel Asorey and Fernando Ezquerro Sastre
    ACADEMIC YEAR: 2023-2024

22. TITLE: **Agujeros negros en teorías de gravitación no Einstenianas**
    STUDENT: Elena Margalejo Hernández
    SUPERVISOR: Manuel Asorey
    ACADEMIC YEAR: 2023-2024

23. TITLE: **Reconocimiento de trazas en detectores basados en una nueva tecnología: LiquidO**
    STUDENT: Isabel Lobera Fortea
    SUPERVISOR: Gloria Luzón Marco and Luis Antonio Obis Aparicio
    ACADEMIC YEAR: 2023-2024

24. TITLE: **Estudios de RBE (eficacia biológica relativa) en hadronterapia**
    STUDENT: César Hernández Forguet
    SUPERVISOR: Gloria Luzón Marco and Valentina Zambrano
    ACADEMIC YEAR: 2023-2024

25. TITLE: **Análisis del impacto del movimiento de los órganos, la remisión del tumor, la pérdida de peso, en tratamientos radioterápicos**
    STUDENT: Eduardo Cativiela Domingo
    SUPERVISOR: Gloria Luzón Marco and Valentina Zambrano
    ACADEMIC YEAR: 2023-2024

26. TITLE: **Estudio comparativo de radioterapia en el cerebro**
    STUDENT: Lidia Domínguez Gajate
    SUPERVISOR: Gloria Luzón Marco and Valentina Zambrano
    ACADEMIC YEAR: 2020-2021

27. TITLE: **Implementación de mejoras en la simulación óptica de la respuesta de los módulos de ANAIS-112**
    STUDENT: Marta Herraiz Forcano
    SUPERVISOR: Marisa Sarsa Sarsa and Tamara Pardo Yanguas
    ACADEMIC YEAR: 2023-2024

28. TITLE: **Estudio de generación señal en helioscopios de axiones mediante el trazado de rayos**
    STUDENT: Raúl Ena Callejero
    SUPERVISOR: Javier Galán Lacarra and Igor Irastorza
    ACADEMIC YEAR: 2023-2024

29. TITLE: **Explorando nuevos modelos de materia oscura en el Sistema Solar a través de simulaciones de N-cuerpos**
    STUDENT: María Rubio Miana
    SUPERVISOR: Javier Galán Lacarra and Theopisti Dafni
    ACADEMIC YEAR: 2023-2024

30. TITLE: **Entrenamiento de un algoritmo de machine learning con pulsos simulados mediante la función respuesta de los detectores de ANAIS-112**
STUDENT: Marcos Bueta Mata
SUPERVISOR: Iván Coarasa Casas and Marisa Sarsa Sarsa
ACADEMIC YEAR: 2023-2024

31. TITLE: **Energía de Casimir en sistemas definidos con potencial delta de Dirac**
STUDENT: Ariadna Salazar Mendieta
SUPERVISOR: Inés Cavero Peláez
ACADEMIC YEAR: 2023-2024

32. TITLE: **Efectos del Radón y su descendencia en experimentos de búsqueda de Materia Oscura con detectores Gaseosos**
STUDENT: Daniel Martínez Miravete
SUPERVISOR: David Díez Ibáñez and Igor G. Irastorza
ACADEMIC YEAR: 2023-2024

33. TITLE: **Medida de contaminación de Pb210 en huesos y tejidos vivos**
STUDENT: Naroa Cubillas Murguia
SUPERVISOR: Gloria Luzón and Theopisti Dafni
ACADEMIC YEAR: 2023-2024

34. TITLE: **Realineamiento del Vacío y Materia Oscura Axiónica**
STUDENT: Lorenzo Yzuel Lumbierres
SUPERVISOR: Javier Redondo Martín
ACADEMIC YEAR: 2023-2024

35. TITLE: **Vacios de Materia Oscura**
STUDENT: Marc Gras Sanz
SUPERVISOR: Javier Redondo Martín
ACADEMIC YEAR: 2023-2024

36. TITLE: **Simulando la evolución de la materia oscura**
STUDENT: Víctor Martínez Pérez
SUPERVISOR: Javier Redondo Martín
ACADEMIC YEAR: 2023-2024

F.2 | Master Theses presented in academic year 2023-2024

1. TITLE: **Primordial black holes overproduction bounds on LISA phase transition target sources**
STUDENT: Daniel Lozano Larque
SUPERVISOR: Diego Blas
ACADEMIC YEAR: 2023-2024

2. TITLE: **On probing cosmological models through the absorption of gravitational waves**
   STUDENT: Victor Fonoll i Rubio
   SUPERVISOR: Diego Blas
   ACADEMIC YEAR: 2023-2024

3. TITLE: **Unraveling Neutron Star Secrets: Magnetar Studies using X-ray Telescopes**
   STUDENT: Francisco Rodríguez Cadón
   SUPERVISOR: Julia Katharina Vogel
   ACADEMIC YEAR: 2023-2024

4. TITLE: **Estudio y caracterizacion de detectores micromegas de ultra-bajo fondo para su instalacion y uso en el Observatorio Internacional de axiones (IAXO)**
   STUDENT: Itxaso Beatriz Antolín Rojo
   SUPERVISOR: Jaime Ruz
   ACADEMIC YEAR: 2023-2024

5. TITLE: **Formulación geométrica de la Mecánica Cuántica sobre espacios métricos generales**
   STUDENT: Miguel Martínez Martínez
   SUPERVISOR: Jesús Clemente Gallardo
   ACADEMIC YEAR: 2023-2024

6. TITLE: **Desintegraciones semileptónicas de mesones pesados y el elemento de matriz CKM** V_{cb}
   STUDENT: Pablo Javier Trujillo Vázquez
   SUPERVISOR: Alejandro Vaquero Avilés-Casco
   ACADEMIC YEAR: 2023-2024

7. TITLE: **Problemas de las Teorías Cuánticas de Campos en Espacios-Tiempos Curvos**
   STUDENT: Alejandro Cano Jones
   SUPERVISOR: Manuel Asorey
   ACADEMIC YEAR: 2023-2024

8. TITLE: **Fenomenología de las anomalías de sabor**
   STUDENT: Alejandro Mir Ramos
   SUPERVISOR: Siannah Peñaranda and Jorge Alda
   ACADEMIC YEAR: 2023-2024

9. TITLE: **La contribución de la polarización hadrónica del vacío al momento magnético anómalo del muón en el retículo**
   STUDENT: Adrián Del Pino Rubio
   SUPERVISOR: Alejandro Vaquero Avilés-Casco
   ACADEMIC YEAR: 2023-2024

G

Presentations in conferences, workshops and schools

1. TITLE: **Massive gravity in Lorentz violating theories**
   SPEAKER: Diego Blas
   EVENT: **Lorentz Violations in Gravity: Part II**
   VENUE: Benasque, Spain
   DATE: 09/12/24-13/12/24
   URL: https://www.benasque.org/2024lorentz/

2. TITLE: **Results from six years of ANAIS-112 and future prospects**
   SPEAKER: Tamara Pardo
   EVENT: **XVI CPAN days**
   VENUE: Madrid, Spain
   DATE: 19/11/24-21/11/24
   URL: https://indico.ific.uv.es/event/7664/

3. TITLE: **IAXO: Simulations, detector shielding and first results of the IAXO-D1 detector for the Baby-IAXO intermediate step at Zaragoza**
   SPEAKER: Jorge Porrón Lafuente
   EVENT: **XVI CPAN Days**
   VENUE: Madrid, Spain
   DATE: 19/11/24-19/11/24
   URL: https://indico.ific.uv.es/event/7664/

4. TITLE: **Results from six years of ANAIS-112 and future prospects**
   SPEAKER: María Martínez

EVENT: **Dark World to Swampland 2024: the 9th IBS-IFT Workshop**
VENUE: Daejeon, Corea
DATE: 05/11/24-14/11/24
URL: https://indico.cern.ch/event/1424560/contributions/6185576/attachments/2963497/5212982/IBS24_MMartinez.pdf

5. TITLE: **New ideas to find ultralight dark matter in astrophysical data**
   SPEAKER: Diego Blas
   EVENT: **Dark World to Swampland 2024: the 9th IBS-IFT Workshop**
   VENUE: Daejeon, Corea
   DATE: 05/11/24-14/11/24
   URL: https://indico.cern.ch/event/1424560/

6. TITLE: **TREX-DM Status Report**
   SPEAKER: Hector Mirallas
   EVENT: **35th LSC Scientific Committee**
   VENUE: Canfranc, Spain
   DATE: 05/11/24-06/11/24
   URL: https://lsc-canfranc.es/wp-content/uploads/2024/10/35_SC_Agenda_vF.pdf

7. TITLE: **Detecting gravitational waves with SLR**
   SPEAKER: Diego Blas
   EVENT: **23rd International Workshop on Laser Ranging**
   VENUE: Kunming, China (online)
   DATE: 20/10/24-26/10/24
   URL: https://23rdworkshop.casconf.cn/

8. TITLE: **Update on cosmological tensions from the most recent datasets from early and late Universe probes**
   SPEAKER: Jacobo Asorey
   EVENT: **X Meeting on Fundamental Cosmology**
   VENUE: Sevilla, Spain
   DATE: 16/10/24-18/10/24
   URL: https://gestioneventos.us.es/x-meeting-fundamental-cosmology/conference-programme

9. TITLE: **LISA binaries to detect ultra-light dark matter**
   SPEAKER: Diego Blas

EVENT: **LISA Spain Meeting 2024**
VENUE: ICE, Cerdanyola del Vallès, Spain
DATE: 15/10/24-16/10/24
URL: https://indico.ice.csic.es/event/42/

10. TITLE: **Axion Review A: Theory/Astro/Cosmo**
SPEAKER: Maurizio Giannnotti
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

11. TITLE: **Axion Review B: Experiments**
SPEAKER: Maurizio Giannnotti
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

12. TITLE: **The DAMA/LIBRA puzzle**
SPEAKER: María Luisa Sarsa
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

13. TITLE: **Results from six years of ANAIS-112 and future prospects.**
SPEAKER: María Martínez
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

14. TITLE: **A combined search for dark matter with COSINE-100 and ANAIS-112.**
SPEAKER: Sophia Hollick
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain

DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

15. TITLE: **Aspects of ultralight dark matter for astrophysical observations**
SPEAKER: Diego Blas
EVENT: **UNDARK Kick-off meeting**
VENUE: Instituto de Astrofísica de Canarias, La Laguna, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.cern.ch/event/1443449/

16. TITLE: **The ANAIS+ project: increasing the sensitivity of direct detection experiments based on NaI**
SPEAKER: Jaime Apilluelo
EVENT: **RENATA & 21st MultiDark joint meeting**
VENUE: Santander, Spain
DATE: 08/10/24-11/10/24
URL: https://indico.ifca.es/event/3186/

17. TITLE: **Updated background studies for the ANAIS dark matter experiment**
SPEAKER: Susana Cebrián
EVENT: **IX Workshop on Low Radioactivity Techniques (LRT2024)**
VENUE: Krakow, Poland
DATE: 1/10/24-4/10/24
URL: https://indico.fais.uj.edu.pl/event/1/

18. TITLE: **Cosmogenic activation in materials used in low background experiments**
SPEAKER: Susana Cebrián
EVENT: **IX Workshop on Low Radioactivity Techniques (LRT2024)**
VENUE: Krakow, Poland
DATE: 1/10/24-4/10/24
URL: https://indico.fais.uj.edu.pl/event/1/

19. TITLE: **Hidden Sector Waters**
SPEAKER: Javier Redondo
EVENT: **DESY Theory Workshop, Andreas Rinwald Fest**
VENUE: Hamburg, Germany
DATE: 24/09/24-27/09/24
URL: https://indico.desy.de/event/43923/sessions/18243/#20240927

20. TITLE: **Application of machine learning techniques to search dark matter with ANAIS-112**
    SPEAKER: Iván Coarasa
    EVENT: **Fourth MODE Workshop**
    VENUE: Valencia, Spain
    DATE: 23/09/24-25/09/24
    URL: https://indico.cern.ch/event/1380163/contributions/6013465/attachments/2933190/5151416/

21. TITLE: **Detecting (high frequency) gravitational waves in the lab**
    SPEAKER: Diego Blas
    EVENT: **Precision Atomic Physics Experiments to Probe for New Physics. 817. WE-Heraeus-Seminar**
    VENUE: Wilhelm und Else Heraeus-Stiftung, Bad Honnef, Germany.
    DATE: 23/09/24-27/09/24
    URL: https://www.we-heraeus-stiftung.de/veranstaltungen/precision-atomic-physics-experiments-to-probe-for-new-physics

22. TITLE: **Status and perspectives on axion searches**
    SPEAKER: Maurizio Giannnotti
    EVENT: **2nd General Meeting of the COST Action CA21106**
    VENUE: Istanbul, Turkey
    DATE: 03/09/24-06/09/24
    URL: https://agenda.infn.it/event/39939/

23. TITLE: **Spectrum of global string networks and the axion dark matter mass**
    SPEAKER: Mathieu Kaltschmidt
    EVENT: **2nd General Meeting of the COST Action CA21106**
    VENUE: Istanbul, Turkey
    DATE: 03/09/24-06/09/24
    URL: https://agenda.infn.it/event/39939/

24. TITLE: **Recent Progress on Axion Searches**
    SPEAKER: Igor G. Irastorza
    EVENT: **LI International Meeting on Fundamental Physics, 6-11 September, 2021.**
    VENUE: Benasque, Spain
    DATE: 6/9/24-11/9/24
    URL: https://www.benasque.org/2024imfp/

25. TITLE: **Cosmology (Lecture)**
    SPEAKER: Jacobo Asorey

EVENT: **TAE 2024 - International Workshop on High Energy Physics**
VENUE: Centro de Ciencias de Benasque "Pedro Pascual", Benasque (Spain)
DATE: 01/09/23-14/09/23
URL: https://www.benasque.org/2024tae/

26. TITLE: **ANAIS-112 updated results on dark matter annual modulation**
    SPEAKER: María Martínez
    EVENT: **42nd International Conference on High Energy Physics ICHEP2024**
    VENUE: Prague, Czech Republic
    DATE: 17/7/24-24/7/24
    URL: https://indico.cern.ch/event/1291157/contributions/5879754/

27. TITLE: **Updated results on anual modulation from the ANAIS-112 dark matter experiment**
    SPEAKER: Susana Cebrián
    EVENT: **XXXIX Reunión Bienal de la Real Sociedad Española de Física**
    VENUE: San Sebastián, Spain
    DATE: 15/7/24-19/7/24
    URL: https://bienalfisica.org/en/symposia

28. TITLE: **Micromegas detectors for rare event searches in CAPA**
    SPEAKER: Susana Cebrián
    EVENT: **XXXIX Reunión Bienal de la Real Sociedad Española de Física**
    VENUE: San Sebastián, Spain
    DATE: 15/7/24-19/7/24
    URL: https://bienalfisica.org/en/symposia

29. TITLE: **ANAIS-112: the most sensitive experiment to test the DAMA/LIBRA signal in a model independent way.**
    SPEAKER: Iván Coarasa
    EVENT: **15th International Workshop on the Identification of Dark Matter 2024**
    VENUE: L'Aquila, Italy
    DATE: 15/7/24-18/7/24
    URL: https://agenda.infn.it/event/39713/contributions/234147/

30. TITLE: **A combined search for dark matter with COSINE-100 and ANAIS-112.**
    SPEAKER: Sophia Hollick
    EVENT: **15th International Workshop on the Identification of Dark Matter 2024**

VENUE: L'Aquila, Italy
DATE: 15/7/24-18/7/24
URL: https://agenda.infn.it/event/39713/contributions/234125/

31. TITLE: **Dark matter search opportunities with NaI scintillating crystals using SiPMs at cryogenic temperatures**
SPEAKER: Jaime Apilluelo
EVENT: **15th International Workshop on the Identification of Dark Matter 2024**
VENUE: L'Aquila, Italy
DATE: 15/7/24-18/7/24
URL: https://agenda.infn.it/event/39713/contributions/234157/

32. TITLE: **A new upper limit on the axion-photon coupling with an extended CAST run with a Xe-based Micromegas detector**
SPEAKER: Cristina Margalejo
EVENT: **15th International Workshop on the Identification of Dark Matter 2024**
VENUE: L'Aquila, Italy
DATE: 15/7/24-18/7/24
URL: https://www.idm2024.eu/

33. TITLE: **Experimental search of Dark Matter Axions (Invited Plenary)**
SPEAKER: Julia K. Vogel
EVENT: **15th International Workshop on the Identification of Dark Matter 2024**
VENUE: L'Aquila, Italy
DATE: 15/7/24-18/7/24
URL: https://www.idm2024.eu/

34. TITLE: **Searches of Axion/ALPs with (Baby)IAXO**
SPEAKER: Julia K. Vogel
EVENT: **15th International Workshop on the Identification of Dark Matter 2024**
VENUE: L'Aquila, Italy
DATE: 15/7/24-18/7/24
URL: https://www.idm2024.eu/

35. TITLE: **A new perspective on Doubly Special Relativity**
SPEAKER: José Manuel Carmona
EVENT: **Fifth annual conference on quantum gravity phenomenology in the multi-messenger approach**

(QGMM24)
VENUE: Madrid, Spain
DATE: 15/7/24-19/7/24
URL: https://teorica.fis.ucm.es/QGMM24/

36. TITLE: **Non-local quantum field theory from doubly special relativity**
SPEAKER: José Javier Relancio
EVENT: **Fifth annual conference on quantum gravity phenomenology in the multi-messenger approach (QGMM24)**
VENUE: Madrid, Spain
DATE: 15/7/24-19/7/24
URL: https://teorica.fis.ucm.es/QGMM24/

37. TITLE: **Dark Matter Direct Detection**
SPEAKER: Julia K. Vogel
EVENT: **GraSPA 2024, Summer School on Particle and Astroparticle Physics**
VENUE: Annecy, France
DATE: 16/7/24-23/7/24
URL: https://indico.in2p3.fr/event/32120/

38. TITLE: **Generalized Hamilton spaces: new developments and applications**
SPEAKER: José Javier Relancio
EVENT: **XXXII International Fall Workshop on Geometry and Physics**
VENUE: Coimbra, Portugal
DATE: 2/9/24-5/9/24
URL: https://www.uc.pt/events/ifwgp2024/

39. TITLE: **Doubly Special Relativity from cotangent bundle geometries**
SPEAKER: José Javier Relancio
EVENT: **DICE2024**
VENUE: Castiglioncello, Italy
DATE: 16/9/24-20/9/24
URL: https://osiris.df.unipi.it/~elze/DICE2024.html

40. TITLE: **Mathematical Aspects of Topological Insulators**
SPEAKER: Manuel Asorey
EVENT: **X International Workshop on Mathematical Foundations of Quantum Mechanics and its applications (DFTP)**

VENUE: San Sebastian, Spain
DATE: 15/7/24-18/7/24
URL: https://bienalfisica.org/en/symposia

41. TITLE: **Approaches to photon absorption in a Lorentz invariance violation scenario**
SPEAKER: Filip Resic
EVENT: **Fifth annual conference on quantum gravity phenomenology in the multi-messenger approach (QGMM24)**
VENUE: Madrid, Spain
DATE: 15/7/24-19/7/24
URL: https://teorica.fis.ucm.es/QGMM24/

42. TITLE: **Photon absorption in a DSR scenario**
SPEAKER: Maykoll A. Reyes
EVENT: **Fifth annual conference on quantum gravity phenomenology in the multi-messenger approach (QGMM24)**
VENUE: Madrid, Spain
DATE: 15/7/24-19/7/24
URL: https://teorica.fis.ucm.es/QGMM24/

43. TITLE: **Cosmology with wide extra-galactic ASKAP radio surveys.**
SPEAKER: Jacobo Asorey
EVENT: **XVI Scientific Meeting of the Spanish Astronomical Society (SEA)**
VENUE: Granada, Spain
DATE: 15/07/24-19/07/24
URL: https://www.granadacongresos.com/sea2024

44. TITLE: **Updating cosmological tensions using the most recent datasets from early and late Universe probes.**
SPEAKER: Jacobo Asorey
EVENT: **CosmoVerse @ Krakow 2024**
VENUE: Krakow, Poland
DATE: 9/07/24-11/07/24
URL: https://indico.oa.uj.edu.pl/event/3/overview

45. TITLE: **Hybrid quantum-classical equilibrium ensembles?**
SPEAKER: Jesús Clemente Gallardo

EVENT: **New trends in Quantum Thermodynamics**
VENUE: Surrey, UK
DATE: 08/07/2024-08/07/2024
URL: https://www.surrey.ac.uk/events/20240708-new-trends-quantum-thermodynamics

46. TITLE: **Bridging the microHz gap in the GWs spectrum**
SPEAKER: Diego Blas
EVENT: **New horizons for Psi**
VENUE: Lisbon, Portugal
DATE: 01/07/24-05/07/24
URL: https://strong-gr.com/new-horizons-for-psi/

47. TITLE: **Good and bad ghosts in super-renormalizable theories**
SPEAKER: Manuel Asorey
EVENT: **Quantum Gravity and Cosmology 2024**
VENUE: ShanghaiTech University, Shanghai, China
DATE: 1/7/24-5/7/24
URL: https://qgc2024.shanghaitech.edu.cn/index.php

48. TITLE: **Axions from the Sky: Perspectives on the Detection of Solar and other Stellar Axions**
SPEAKER: Maurizio Giannnotti
EVENT: **Neutrino Frontiers**
VENUE: Galileo Galilei Institute, Italy
DATE: 25/06/24-19/07/24
URL: https://www.ggi.infn.it/showevent.pl?id=482

49. TITLE: **Cosmic strings parameter reconstruction**
SPEAKER: Ivan Rybak
EVENT: **11th LISA Cosmology Working Group Workshop**
VENUE: Porto, Portugal
DATE: 17/06/24-21/06/24
URL: https://indico.cern.ch/event/1399649/

50. TITLE: **Cosmology from SKA Observatory precursors.**
SPEAKER: Jacobo Asorey
EVENT: **ATHEXIS - Athens Symposium on Exploring the Universe 2024**
VENUE: Athens, Greece

DATE: 10/06/24-14/06/24
URL: https://indico.cern.ch/event/1368116/

51. TITLE: **Direct searches for Dark Matter: status and prospects. Down to the neutrino floor while solving the DAMA/LIBRA puzzle.**
SPEAKER: María Luisa Sarsa
EVENT: **SUSY2024: theory meets experiment**
VENUE: Madrid, Spain
DATE: 10/06/24-14/06/24
URL: https://indico.cern.ch/event/1354279/contributions/5947050/

52. TITLE: **Updated results on annual modulation with three years of data from ANAIS-112, present status and prospects**
SPEAKER: Iván Coarasa
EVENT: **SUSY2024: theory meets experiment**
VENUE: Madrid, Spain
DATE: 10/06/24-14/06/24
URL: https://indico.cern.ch/event/1354279/contributions/5961407/

53. TITLE: **Cosmic String Dynamics: An Effective Description Approach**
SPEAKER: Ivan Rybak
EVENT: **Topological Defects in Cosmology**
VENUE: Manchester, United Kingdom
DATE: 10/06/24-13/06/24
URL: https://inspirehep.net/conferences/2781996?ui-citation-summary=true

54. TITLE: **Axion Searches**
SPEAKER: Igor G. Irastorza
EVENT: **International School on Astroparticle Physics (ISAPP 2024): Particle Candidates for Dark Matter. 25-june to 5-july 2024,**
VENUE: Padova, Italy.
DATE: 25/6/24-5/7/24
URL: https://indico.dfa.unipd.it/event/864/

55. TITLE: **Testing ultra-light dark matter and degenerate dark matter with galactic dynamics**
SPEAKER: Diego Blas
EVENT: **SynCRETism 2024. Particle physicists dining with Astrophysicists**

VENUE: Rethymno, Greece
DATE: 17/06/24-21/06/24
URL: https://syncretism.physics.uoc.gr/

56. TITLE: **Photon emission from ALPs in the Sun**
SPEAKER: Jaime Ruz
EVENT: **2024 Axions in the Sky! Barolo Astroparticle Meeting**
VENUE: Barolo, Italy
DATE: 12/06/2024-15/06/2024
URL: https://agenda.infn.it/event/39100/

57. TITLE: **Quantum technologies for fundamental physics**
SPEAKER: Diego Blas
EVENT: **ALPS-DM**
VENUE: SUSY24: The 31st International Conference on Supersymmetry and Unification of Fundamental Interactions
DATE: 10/06/24-14/06/24
URL: https://indico.cern.ch/event/1354279/

58. TITLE: **Cosmology from SKA Observatory precursors**
SPEAKER: Jacobo Asorey
EVENT: **First National Meeting of the "Planes Complementarios" on astrophysics and high energy physics. AstroHEP-PPCC24**
VENUE: Zaragoza, Spain
DATE: 5/6/24-7/6/24
URL: https://indico.capa.unizar.es/event/36/

59. TITLE: **Axion Searches**
SPEAKER: Igor G. Irastorza
EVENT: **First National Meeting of the "Planes Complementarios" on astrophysics and high energy physics, Zaragoza, 5-7 June 2024.**
VENUE: Zaragoza, Spain
DATE: 5/6/24-7/6/24
URL: https://indico.capa.unizar.es/event/36/

60. TITLE: **Improving ANAIS-112 sensitivity to the DAMA/LIBRA dark matter signal**
SPEAKER: Iván Coarasa

EVENT: **1ª reunión nacional de los Planes Complementarios de Astrofísica y Altas Energías, AstroHEP-PPCC24**
VENUE: Zaragoza, Spain
DATE: 05/06/24-07/06/24
URL: https://indico.capa.unizar.es/event/36/contributions/611/

61. TITLE: **WIMP searches**
SPEAKER: Maria Martinez
EVENT: **1ª reunión nacional de los Planes Complementarios de Astrofísica y Altas Energías, AstroHEP-PPCC24**
VENUE: Zaragoza, Spain
DATE: 05/06/24-07/06/24
URL: https://indico.capa.unizar.es/event/36/contributions/583/

62. TITLE: **Using Micromegas detectors for direct dark matter searches: challenges and perspectives**
SPEAKER: Gloria Luzón
EVENT: **CPAN Network on Instrumentation and Detectors (CNID), Valencia**
DATE: 08/05/24-10/05/24
URL: https://indico.ific.uv.es/event/7477/

63. TITLE: **X-ray optics for Particle, Astroparticle and Nuclear Physics**
SPEAKER: Jaime Ruz
EVENT: **CPAN Network on Instrumentation and Detectors (CNID), Valencia**
DATE: 08/05/24-10/05/24
URL: https://indico.ific.uv.es/event/7477/

64. TITLE: **ANAIS-112 experiment and the testing of the DAMA/LIBRA result**
SPEAKER: María Luisa Sarsa
EVENT: **Invisibles Data Days**
VENUE: Munich, Germany
DATE: 06/05/24-07/05/24
URL: https://indico.ph.tum.de/event/7592/contributions/9091/

65. TITLE: **Introduction to Quantum Gravity**
SPEAKER: Manuel Asorey
EVENT: **Minicourse on perturbative and nonperturbative treatment of quantum gravity problems**
VENUE: ICTP-SAIFR, Sao Paolo, Brasil

DATE: 20/05/24-24/05/24
URL: https://www.ictp-saifr.org/mqgp2024/

66. TITLE: **Status and Future Prospects of the search for Dark Matter Annual Modulation in NaI**
SPEAKER: María Martínez
EVENT: **Cosmology, Astrophysics, Theory and Collider Higgs 2024 conference (CATCH22+2)**
VENUE: Dublin, Ireland
DATE: 01/05/24-05/05/24
URL: https://indico.cern.ch/event/1291893/contributions/5858378/

67. TITLE: **GEANT4 simulations within the ANAIS-112 experiment data analysis procedures**
SPEAKER: Tamara Pardo
EVENT: **Vienna Workshop on Simulations (VIEWS24)**
VENUE: Vienna, Austria
DATE: 25/04/24-27/04/24
URL: https://indico.cern.ch/event/1275551/contributions/5836884/

68. TITLE: **Stato e prospettive delle ricerche sugli assioni**
SPEAKER: Maurizio Giannnotti
EVENT: **INFN Commissione 2**
VENUE: Foligno, Italy
DATE: 10/04/24-12/04/24
URL: https://agenda.infn.it/login/?next=/event/40232/

69. TITLE: **Detecting GWs in the microHz: the Solar system as a GW detector**
SPEAKER: Diego Blas
EVENT: **ALPS-DM**
VENUE: Obergurgl, Austria
DATE: 01/04/24-06/04/24
URL: https://indico.cern.ch/event/1294886/

70. TITLE: **Bridging gaps in the GW spectrum**
SPEAKER: Diego Blas
EVENT: **Dark Matter Beyond the Weak Scale II**
VENUE: Durham, UK
DATE: 25/03/24-28/03/24
URL: https://conference.ippp.dur.ac.uk/event/1289/

71. TITLE: **ANAIS-112: First direct test of DAMA/LIBRA beyond three sigma**
SPEAKER: María Martínez
EVENT: **Lake Louise Winter Institute 2024**
VENUE: Chateau Lake Louise, Canada
DATE: 18/02/24-24/02/24
URL: https://indico.cern.ch/event/1205625/contributions/5754582/

72. TITLE: **Vacuum structure of Yang-Mills theory in 2+1 dimensions**
SPEAKER: Manuel Asorey
EVENT: **VII International Workshop on Information Geometry, Quantum Mechanics and Applications**
VENUE: Universidad Carlos III,Madrid, Spain
DATE: 20/02/24-22/02/24
URL: http://www.q-math.es/conferences/IGQMA2024/

73. TITLE: **Closing gaps in the GW spectrum: new physics with ?Hz GWs and ideas to detect them**
SPEAKER: Diego Blas
EVENT: **Bottom-Up Cross-Cutting Workshop "JENAS Initiative: Gravitational Wave Probes of Fundamental Physics"**
VENUE: Rome, Italy
DATE: 12/02/24-16/02/24
URL: https://agenda.infn.it/event/37487/https://indico.gssi.it/event/603/

74. TITLE: **Sistemas en grandes instalaciones**
SPEAKER: María Martínez
EVENT: **second Vacuum Course of the ASEVA society 2023-2024**
VENUE: online
DATE: 08/02/24-
URL: https://aseva.es/ii-curso-de-vacio-otono-2023/

75. TITLE: **Developments of Micromegas detectors for the BabyIAXO experiment**
SPEAKER: Ana Quintana García
EVENT: **X-ray DEtector Technologies for Physics (X-DEP) workshop**
VENUE: Saint Aubin, France
DATE: 05/02/24-06/02/24
URL: https://indico.synchrotron-soleil.fr/event/

76. TITLE: **Status of IAXO and BabyIAXO**
SPEAKER: Jaime Ruz

EVENT: **2024 X-ray Detector Technology for Physics**
VENUE: SOLEIL, Saint-Aubin, France
DATE: 05/02/2024-06/02/2024
URL: https://indico.synchrotron-soleil.fr/event/

77. TITLE: **The IAXO experiment**
    SPEAKER: Jaime Ruz
    EVENT: **Working Wroup Meeting of COST Action COSMIC WISPers (CA21106)**
    VENUE: DESY, Hamburg, Germany
    DATE: 01/02/2024-02/02/2024
    URL: https://indico.desy.de/event/42137/

78. TITLE: **Axion Beyond Discoveries: Measuring Axion Couplings**
    SPEAKER: Maurizio Giannnotti
    EVENT: **Axions beyond DM Paradigm**
    VENUE: DESY, Hamburg, Germany
    DATE: 28/01/24-31/01/24
    URL: https://indico.desy.de/event/42124/

79. TITLE: **BabyIAXO**
    SPEAKER: Jaime Ruz
    EVENT: **2024 Axions beyond the dark matter paradigm**
    VENUE: DESY, Hamburg, Germany
    DATE: 29/01/2024-31/01/2024
    URL: https://indico.desy.de/event/42124/

80. TITLE: **LIV and DSR formulas for time delays: assumptions, misconceptions and challenges**
    SPEAKER: Jose Manuel Carmona
    EVENT: **Astrophysical searches for quantum-gravity-induced time delays (IFPU Focus Week)**
    VENUE: IFPU, Trieste, Italy
    DATE: 15/01/24-19/01/24
    URL: https://www.ifpu.it/focus-week-time-delays/

81. TITLE: **Perspectives on the Detection on Solar and other Stellar Axions**
    SPEAKER: Maurizio Giannnotti
    EVENT: **AxionOrigins**
    VENUE: INFN-LNF, Frascati, Italy

DATE: 25/01/24-26/01/24
URL: https://agenda.infn.it/event/39135/

82. TITLE: **Have we observed Lorentz invariance violation in very high-energy cosmic messengers?**
    SPEAKER: Jose Manuel Carmona
    EVENT: **The New Era of Multi-Messenger Astroparticle Physics (IFPU Focus Week)**
    VENUE: IFPU, Trieste, Italy
    DATE: 19/02/24-23/02/24
    URL: https://indico.gssi.it/event/603/

83. TITLE: **ITA activities in DRD7: Power efficiency & Timing**
    SPEAKER: Fernando Arteche
    EVENT: **CPAN Network on Instrumentation and Detectors (CNID), Valencia**
    VENUE: Valencia, Spain
    DATE: 08/05/24-10/05/24
    URL: https://indico.ific.uv.es/event/7477/

84. TITLE: **Novel Timing and Synchronization Trends for Particle Detectors: Experience with White Rabbit-Based Distributed System Spanning from Accelerators to Future Detectors**
    SPEAKER: Javier Galindo
    EVENT: **XVI CPAN days**
    VENUE: Madrid, Spain
    DATE: 19/11/24-21/11/24
    URL: https://indico.ific.uv.es/event/7664/

H

Seminars by CAPA members

1. TITLE: **Gravitational wave detection through their absorption by binaries**
   SPEAKER: Diego Blas
   VENUE: Pulsar SGW SKA meeting (virtual)
   DATE: 05/10/2024

2. TITLE: **Gravitational wave detection with orbital motion of satellites**
   SPEAKER: Diego Blas
   VENUE: Advanced Concepts Team, European Space Agency, Virtual
   DATE: 06/09/2024

3. TITLE: **Quantum Sensors for Gravitational Waves**
   SPEAKER: Diego Blas
   VENUE: QIT-TH Forum, CERN. Switzerland
   DATE: 12/08/2024

4. TITLE: **High frequency gravitational waves**
   SPEAKER: Diego Blas
   VENUE: Budker Group Meeting, Mainz, Virtual.
   DATE: 12/09/2024

5. TITLE: **The solar axion quest**
   SPEAKER: Jaime Ruz Armendáriz
   VENUE: Technical University of Dortmund, Germany
   DATE: 26/06/2024

6. TITLE: **Gravitational wave detection with orbital motion of Moon and artificial satellites**
SPEAKER: Diego Blas
VENUE: Science Coffee, Advanced Concepts Team, European Space Agency, Virtual
DATE: 06/06/2024

7. TITLE: **Detecting GWs in the microHz: natural and artificial satellites as GW detectors**
SPEAKER: Diego Blas
VENUE: Instituto de Astrofísica de Canarias, La Laguna, Spain
DATE: 02/05/2024

8. TITLE: **Detecting gravitational waves, dark matter and neutrinos in the precision lab**
SPEAKER: Diego Blas
VENUE: Institut de Ciències Fotòniques, Castelldefels, Spain
DATE: 29/04/2024

9. TITLE: **Detecting (high frequency) gravitational waves in a cavity**
SPEAKER: Diego Blas
VENUE: IAXO Collaboration Meeting, Virtual
DATE: 13/03/2024

10. TITLE: **Closing gaps in the GW spectrum: Ideas to detect microHz and high frequency GWs**
SPEAKER: Diego Blas
VENUE: INFN Pisa, Pisa, Italy
DATE: 29/02/2024

11. TITLE: **Detecting (high frequency) gravitational waves in a box**
SPEAKER: Diego Blas
VENUE: Madrid Polygonal Gravity Seminars, Complutense University, Madrid, Spain
DATE: 24/01/2024

12. TITLE: **Closing gaps in the GW spectrum: ideas to detect microHz and high frequency GWs**
SPEAKER: Diego Blas
VENUE: Niels Bohr Institut, Copenhagen, Denmark
DATE: 16/01/2024

13. TITLE: **About the geometric phase**
SPEAKER: Inés Cavero Peláez

VENUE: School of Physics and Applied Physics, Southern Illinois University, Carbondale, IL, USA
DATE: 05/12/2024

14. TITLE: **ANAIS-112: el experimento más sensible para comprobar la señal de DAMA/LIBRA**
    SPEAKER: Iván Coarasa
    VENUE: Autumn Season, Seminarios LSC, Laboratorio Subterráneo de Canfranc
    DATE: 15/10/24

15. TITLE: **Haciendo visible lo invisible**
    SPEAKER: María Luisa Sarsa
    VENUE: Discurso de Ingreso en la Real Academia de Ciencias Exactas, Físicas, Químicas y Naturales de Zaragoza, Facultad de Ciencias
    DATE: 18/09/24

16. TITLE: **Quantification and control of the cosmogenic activation of materials**
    SPEAKER: Susana Cebrián
    VENUE: Laboratorio Subterráneo de Canfranc
    DATE: 15/5/24

17. TITLE: **The Spectrum of Global Axion Strings**
    SPEAKER: Mathieu Kaltschmidt
    VENUE: Cosmology Seminar, DAMTP, University of Cambridge, UK
    DATE: 09/05/24

18. TITLE: **The New Gravitational Landscape**
    SPEAKER: Manuel Asorey
    VENUE: ICTP-SAIFR & IFT-UNESP Colloquium, Sao Paolo
    DATE: 22/05/24
    URL: https://www.ictp-saifr.org/mqgp2024/

19. TITLE: **QGMM network: theoretical and experimental challenges and opportunities for research in quantum gravity phenomenology**
    SPEAKER: José Manuel Carmona
    VENUE: IFPU Colloquia, Institute for Fundamental Physics of the Universe, Trieste (Italia)
    DATE: 19/01/24

20. TITLE: **A la caza de la Materia Oscura**
    SPEAKER: Maria Martinez
    VENUE: Escuela de Verano de la Universidad del Bio-Bio, Chillán (Chile)
    DATE: 19/01/24

21. TITLE: **Algoritmos de cálculo en haces clínicos de rayos X de alta energía**
    SPEAKER: Francisco Javier Jiménez Albericio
    VENUE: Curso Experto Universitario en Fundamentos de Física Médica, Universidad Internacional de Andalucía, Baeza (Spain)
    DATE: 21/02/24

22. TITLE: **Métodos de Monte Carlo en el cálculo de dosis en radioterapia**
    SPEAKER: Francisco Javier Jiménez Albericio
    VENUE: Curso Experto Universitario en Fundamentos de Física Médica, Universidad Internacional de Andalucía, Baeza (Spain)
    DATE: 22/02/24

23. TITLE: **Verificación dosimétrica de tratamientos de radioterapia externa: EPID y matrices de detectores**
    SPEAKER: Francisco Javier Jiménez Albericio
    VENUE: Curso Experto Universitario en Fundamentos de Física Médica, Universidad Internacional de Andalucía, Baeza (Spain)
    DATE: 22/02/24

I

Outreach activities

1. NAME OF ACTIVITY: **Interview about the detection of a connection between super massive black holes and their host galaxies in RNE**
   PARTICIPANTS: Jacobo Asorey
   DATE: 15/12/2024
   PLACE: Fallo de sistema - Radio Nacional de España

2. NAME OF ACTIVITY: **Interview about the detection of a connection between super massive black holes and their host galaxies in Onda Cero Zaragoza**
   PARTICIPANTS: Jacobo Asorey
   DATE: 11/12/2024
   PLACE: Más de uno Zaragoza - Onda Cero Zaragoza

3. NAME OF ACTIVITY: **Round table. Sky Readings II, Tabita Rezaire**
   PARTICIPANTS: Diego Blas
   DATE: 27/11/2024
   PLACE: TBA21, Madrid, Spain

4. NAME OF ACTIVITY: **Einstein: 50 horas en Zaragoza y un legado universal**
   PARTICIPANTS: María Luisa Sarsa
   DATE: 11/2024
   PLACE: Revista conCIENCIAS digital nº 33, Facultad de Ciencias, Universidad de Zaragoza.
   https://divulgacionciencias.unizar.es/revista-conCIENCIAS/uploads/files/33_05.pdf

5. NAME OF ACTIVITY: **Outreach article in The Conversation Spain: "Hallados indicios de conexión entre agujeros negros y sus galaxias"**
   PARTICIPANTS: Jacobo Asorey

DATE: 14/11/2024
PLACE: The Conversation Spain

6. NAME OF ACTIVITY: **Science Week activity related to documentary “Cazando lo invisible”**
   PARTICIPANTS: Inés Cavero Peláez
   DATE: 13/11/2024
   PLACE: IES Goya, Zaragoza

7. NAME OF ACTIVITY: **Science Week activity related to documentary “Cazando lo invisible”**
   PARTICIPANTS: Susana Cebrián
   DATE: 07/11/2024
   PLACE: Colegio Sagrado Corazón de Jesús, Zaragoza

8. NAME OF ACTIVITY: **¿Qué sabemos de lo que hay más allá de la tierra?**
   PARTICIPANTS: Manuel Asorey
   DATE: 12/11/2024
   PLACE: Paraninfo, Aula Magna, Universidad de Zaragoza

9. NAME OF ACTIVITY: **Science Week activity related to documentary “Cazando lo invisible”**
   PARTICIPANTS: María Luisa Sarsa
   DATE: 08/11/2024
   PLACE: IES Luis Buñuel, Zaragoza

10. NAME OF ACTIVITY: **Día de la materia oscura: yincana Descubre la materia oscura**
    PARTICIPANTS: Jaime Apilluelo, Jacobo Asorey, Susana Cebrián, Iván Coarasa, Theopisti Dafni, David Díez, Fernando Ezquerro, Álvaro Ezquerro, Maurizio Giannotti, María Jiménez, Gloria Luzón, Cristina Margalejo, María Martínez, Yisely Martinez, Alejandro Mir Ramos, Manuel Membrado, Luis Obis, Miguel Pardina, Siannah Peñaranda, David Martínez Crespo, Francisco Javier Gómez Fauro, Carlos Aguilar Abad, Tamara Pardo, Carmen Pérez, Jorge Porrón, Maykoll Reyes, Francisco Rodríguez, María Luisa Sarsa
    DATE: 31/10/2024
    PLACE: Facultad de Ciencias, Zaragoza

11. NAME OF ACTIVITY: **Pizza seminar for the RSEF students of UAB**
    PARTICIPANTS: Diego Blas
    DATE: 30/10/2024
    PLACE: Universitat Autònoma de Barcelona, Spain

12. NAME OF ACTIVITY: **Día de la materia oscura: taller Hands on Dark Matter**
    PARTICIPANTS: Jaime Apilluelo, Susana Cebrián, Iván Coarasa, Álvaro Ezquerro, María Jiménez, Gloria Luzón, Cristina Margalejo, María Martínez, Manuel Membrado, Tamara Pardo, Jorge Porrón, María Luisa Sarsa
    DATE: 29/10/2024
    PLACE: Facultad de Ciencias, Zaragoza

13. NAME OF ACTIVITY: **Jornada de Puertas Abiertas del Laboratorio Subterráneo de Canfranc 2024**
    PARTICIPANTS: Susana Cebrián, María Luisa Sarsa, Theopisti Dafni, Gloria Luzón, Tamara Pardo, Jorge Porrón, Francisco Rodríguez Candón
    DATE: 27/10/2024
    PLACE: Laboratorio Subterráneo de Canfranc, Canfranc, Huesca

14. NAME OF ACTIVITY: **“Artículos científicos para todos"**
    PARTICIPANTS: María Luisa Sarsa
    DATE: 10/2024 - 09/2025
    PLACE: Proyecto financiado por FECYT. Ref.: FCT-23-19323 (Programa de Cultura Científica y de la Innovación). INVESTIGADOR PRINCIPAL: María Eugenia Dies Álvarez (Facultad de Educación, Universidad de Zaragoza).

15. NAME OF ACTIVITY: **Round table “Los límites de la ciencia ” with Javier Argüello**
    PARTICIPANTS: Diego Blas
    DATE: 15/10/2024
    PLACE: Finestres Bookshop, Barcelona, Spain

16. NAME OF ACTIVITY: **Noche europea de los investigadores e investigadoras: Café con científicas**
    PARTICIPANTS: Siannah Peñaranda
    DATE: 27/09/2024
    PLACE: Paraninfo, Universidad de Zaragoza

17. NAME OF ACTIVITY: **Noche europea de los investigadores e investigadoras. Experimentos: Bajo los rayos cósmicos y la radiactividad que nos rodea**
    PARTICIPANTS: Jaime Apilluelo, Susana Cebrián, Francisco R. Candón, María Jiménez Puyuelo, Álvaro Ezquerro, Laura Seguí, Gloria Luzón, Tamara Pardo, Jorge Porrón
    DATE: 27/09/2024
    PLACE: Paraninfo, Universidad de Zaragoza https://ucc.unizar.es/noche-investigadores-2024/programa-zaragoza

18. NAME OF ACTIVITY: **Semana de Inmersión en Ciencias 2024**
PARTICIPANTS: Jaime Apilluelo, Susana Cebrián, Iván Coarasa, Theopisti Dafni, David Díez, Álvaro Ezquerro, Fernando Falceto, José García-Esteve, María Jiménez, Gloria Luzón, Cristina Margalejo, María Martínez, Yisely Martínez, Cristina Margalejo, Manuel Membrado, Alejandro Mir, Luis Obis, Tamara Pardo, Siannah Peñaranda, Jorge Porrón, María Luisa Sarsa
DATE: 10-14/06/2024
PLACE: Facultad de Ciencias, Zaragoza

19. NAME OF ACTIVITY: **Rincón de la Ciencia 2024**
PARTICIPANTS: María Jiménez, David Díez, Álvaro Ezquerro, Gloria Luzón, Jorge Porrón
DATE: 10-14/06/2024
PLACE: Facultad de Ciencias, Zaragoza

20. NAME OF ACTIVITY: **PINT OF SCIENCE**
PARTICIPANTS: Diego Blas
DATE: 13/05/2024
PLACE: Barcelona, Spain

21. NAME OF ACTIVITY: **Seminario Permanente de Ciencias y Humanidades 'Blas Cabrera-Felipe'**
PARTICIPANTS: Diego Blas
DATE: 02/05/2024
PLACE: La Laguna, Spain

22. NAME OF ACTIVITY: **CIENCIA, y otras "Easy Pieces"- Miremos al pájaro**
PARTICIPANTS: Inés Cavero Peláez
DATE: 29/05/2024
PLACE: Capítulo en el libro de divulgación homenaje a las Lectures de Feynman y a la "mano" que nos ha guiado a través de lo desconocido. https://cienciayotraseasypieces.blogspot.com

23. NAME OF ACTIVITY: **CIENCIA, y otras "Easy Pieces"- ¿De qué está hecho el Universo?**
PARTICIPANTS: Gloria Luzón
DATE: 29/05/2024
PLACE: Capítulo en el libro de divulgación homenaje a las Lectures de Feynman y a la "mano" que nos ha guiado a través de lo desconocido. https://cienciayotraseasypieces.blogspot.com

24. NAME OF ACTIVITY: **Ética e Inteligencia Artificial**
PARTICIPANTS: Manuel Asorey

DATE: 30/04/2024
PLACE: Universiad de la Experiencia, UNED, Calatayud

25. NAME OF ACTIVITY: **Ética e Inteligencia Artificial**
PARTICIPANTS: Manuel Asorey
DATE: 25/04/2024
PLACE: Universiad de la Experiencia, Facultad de Medicina, Universidad de Zaragoza

26. NAME OF ACTIVITY: **Un universo de radiaciones**
PARTICIPANTS: Gloria Luzón
DATE: 11/04/2024
PLACE: Club Cultural 33, Colegio La Salle-Gran Vía,Zaragoza

27. NAME OF ACTIVITY: **Program Biblio Steam**
PARTICIPANTS: Diego Blas
DATE: 19/04/2024
PLACE: Sarrià de Ter, Spain

28. NAME OF ACTIVITY: **Program Biblio Steam**
PARTICIPANTS: Diego Blas
DATE: 22/03/2024
PLACE: Tossa de Mar, Spain

29. NAME OF ACTIVITY: **Mesa Redonda: EXPOSICIÓN "Soy científica, vivo en tu Barrio"**
PARTICIPANTS: Siannah Peñaranda
DATE: 13/03/2024
PLACE: Asociación Vecinal Delicias «Manuel Viola», Zaragoza

30. NAME OF ACTIVITY: **Recorrido interactivo Exposición "Soy científica, vivo en tu Barrio"**
PARTICIPANTS: Siannah Peñaranda
DATE: 02/03/2024
PLACE: Parque Grande «José Antonio Labordeta», Zaragoza

31. NAME OF ACTIVITY: **Hands on particle physics**
PARTICIPANTS: Manuel Asorey, José García-Esteve, Fernando Falceto, Gloria Luzón, Yisely Martinez
DATE: 22/03/2024

PLACE: Centro de Ciencias de Benasque Pedro Pascual

32. NAME OF ACTIVITY: **Hands on particle physics**
PARTICIPANTS: Siannah Peñaranda, José García-Esteve, Fernando Falceto, Gloria Luzón, Yisely Martinez, Alejandro Mir Ramos, Alejandro Cano
DATE: 25/03/2024
PLACE: Facultad de Ciencias, Zaragoza

33. NAME OF ACTIVITY: **Tertulia sobre el 11F, Día de la Mujer y de la Niña en la Ciencia**
PARTICIPANTS: Siannah Peñaranda
DATE: 09/02/2024
PLACE: Aragón radio, Zaragoza

34. NAME OF ACTIVITY: **Actuación RISARCHERs en la IV Gala de la Nanotecnología**
PARTICIPANTS: María Luisa Sarsa
DATE: 24/02/2024
PLACE: El show de los monólogos científicos, Ciclo solidario de artes escénicas 2024, centro cívico Teodoro Sánchez Punter, Zaragoza

35. NAME OF ACTIVITY: **Collaborator of Lydia Ourahmane. 108 Días**
PARTICIPANTS: Diego Blas
DATE: 18/02/2024
PLACE: MACBA, Barcelona, Spain

36. NAME OF ACTIVITY: **Program Biblio Steam**
PARTICIPANTS: Diego Blas
DATE: 07/02/2024
PLACE: Figueres, Spain

37. NAME OF ACTIVITY: **Hola! somos científicas**
PARTICIPANTS: Tamara Pardo, María Luisa Sarsa
DATE: 10/02/2023
PLACE: Actividad organizada con motivo del 11F en el Hall de la Facultad de Ciencias, Universidad de Zaragoza.

38. NAME OF ACTIVITY: **Panelist of *Panel III: Scientific Imaginations*, at the *Unveiling the Universe: Art and Science Summit & 70 years of discoveries at CERN***

PARTICIPANTS: Diego Blas
DATE: 30/01/2024
PLACE: CERN, Geneva, Switzerland

39. NAME OF ACTIVITY: **Premiere of the documentary "Cazando lo invisible"**
PARTICIPANTS: Participants in the colloquium: Igor G. Irastorza, M.L. Sarsa
DATE: 25/01/2024
PLACE: Cines Gran Casa, Zaragoza

40. NAME OF ACTIVITY: **Ética e Inteligencia Artificial**
PARTICIPANTS: Manuel Asorey
DATE: 23/01/2024
PLACE: Paraninfo, Aula Magna, Universidad de Zaragoza

41. NAME OF ACTIVITY: **Jornadas de Puertas Abiertas de la Facultad de Ciencias**
PARTICIPANTS: Jaime Apilluelo, Susana Cebrián, Iván Coarasa, María Jiménez,María Martínez, Theopisti Dafni, David Díez, Álvaro Ezquerro, Gloria Luzón, Cristina Margalejo, María Martínez, Luis Obis, Tamara Pardo, Jorge Porrón, María Luisa Sarsa
DATE: 2024
PLACE: Facultad de Ciencias, Zaragoza

J

Research stays by CAPA members

1. INSTITUTION: **School of Physics and Applied Physics, Southern Illinois University, IL, USA**
   PERIOD: 04/12/2024-10/12/2024
   RESEARCHER: Inés Cavero Peláez
   REASON OF STAY: Research visit

2. INSTITUTION: **Department of Physics and Astronomy "Galileo Galilei", University of Padova, Italy**
   PERIOD: 16/09/2024-31/12/2024
   RESEARCHER: Filip Resic
   REASON OF STAY: Predoctoral research

3. INSTITUTION: **Department of Theoretical Physics, CERN, Switzerland**
   PERIOD: 22/07/2024-22/08/2024
   RESEARCHER: Diego Blas
   REASON OF STAY: Research visit

4. INSTITUTION: **ShanghaiTech University, Shanghai, China**
   PERIOD: 01/07/24
   –12/07/24 RESEARCHER: Manuel Asorey
   REASON OF STAY: Research stay in Research Program

5. INSTITUTION: **INFN-LNF – Laboratori Nazionali di Frascati**
   PERIOD: 17/06/2024-28/06/2024
   RESEARCHER: Maurizio Giannotti
   REASON OF STAY: Research visit

6. INSTITUTION: **ICTP-SAIFR, Sao Paolo, Brasil**
   PERIOD: 20/05/24
   –30/05/24 URL: https://www.ictp-saifr.org/mqgp2024/
   RESEARCHER: Manuel Asorey
   REASON OF STAY: Research stay in Research Program

7. INSTITUTION: **Max Planck Institute for Physics, Munich, Germany**
   PERIOD: 02/04/2024-01/07/2024
   RESEARCHER: Tamara Pardo Yanguas
   REASON OF STAY: Predoctoral research

8. INSTITUTION: **Centre for Theoretical Cosmology, DAMTP, University of Cambridge, UK**
   PERIOD: 29/04/2024-10/05/2024
   RESEARCHER: Mathieu Kaltschmidt
   REASON OF STAY: COST Action COSMIC WISPers - Short Term Scientific Mission

9. INSTITUTION: **Laboratori Nazionali del Gran Sasso, Assergi L'Aquila, Italy**
   PERIOD: 23/03/2024-7/04/2024
   RESEARCHER: Eduardo Follana
   REASON OF STAY: Research visit

10. INSTITUTION: **Astronomical Institute of the Romanian Academy, Bucharest, Romania**
    PERIOD: 29/01/2024-03/02/2024
    RESEARCHER: Jacobo Asorey
    REASON OF STAY: Research visit

11. INSTITUTION: **University of Surrey, Faculty of Engineering and Physical Sciences**
    PERIOD: 03/01/2024-04/04/2024
    RESEARCHER: David Martínez Crespo
    REASON OF STAY: Predoctoral research

K

Guest researchers visiting CAPA

1. RESEARCHER: Violeta González Pérez
   INSTITUTION: **Departamento de Física Teórica, Universidad Autónoma de Madrid**
   PERIOD: 26 - 28 November, 2024

2. RESEARCHER: Giacomo Landini
   INSTITUTION: **Instituto de Física Corpuscular, Universitat de València**
   PERIOD: 13 - 16 November, 2024

3. RESEARCHER: Alberto Saa
   INSTITUTION: **Universidad de Campinas, Brasil**
   PERIOD: 17/10/2024 - 25/10/2024

4. RESEARCHER: Domenico Fratulillo
   INSTITUTION: **University of Naples**
   PERIOD: 22 May - 31 July, 2024

5. RESEARCHER: Alessandro Lella
   INSTITUTION: **Università degli Studi di Bari**
   PERIOD: May 6 - 15 2024

6. RESEARCHER: Publio Rwany Batista Ribeiro do Vale
   INSTITUTION: **UFJF, Brasil**
   PERIOD: 1/05/2024 - 30/08/2024

7. RESEARCHER: Antonia Frassino
   INSTITUTION: **Universidad de Barcelona**
   PERIOD: 15 April, 2024

8. RESEARCHER: Giuseppe Marmo
   INSTITUTION: **Universidad de Napoles**
   PERIOD: 1/02/2024, 30/04/2024

9. RESEARCHER: Sophia Hollick
   INSTITUTION: **Yale University, US**
   PERIOD: September 2023 -

L

Memberships of editorial boards

1. JOURNAL: **Frontiers of Mathematical Physics, Frontiers in Physics**
   MEMBER: Manuel Asorey
   PERIOD: 2010-
   LINK: https://www.frontiersin.org/journals/physics/sections/statistical-and-computational-physics

2. JOURNAL: **International Journal of Modern Physics A, World Scientific Co.**
   MEMBER: Manuel Asorey
   PERIOD: 2019-
   LINK: https://www.worldscientific.com/page/ijmpa/editorial-board

3. JOURNAL: **Modern Physics Letters A, World Scientific Co.**
   MEMBER: Manuel Asorey
   PERIOD: 2019-
   LINK: https://www.worldscientific.com/page/mpla/editorial-board

4. JOURNAL: **International Journal of Modern Physics D, World Scientific Co.**
   MEMBER: José Manuel Carmona
   PERIOD: 2024-
   LINK: https://www.worldscientific.com/page/ijmpd/editorial-board

5. JOURNAL: **Classical and Quantum Gravity**
   MEMBER: José Manuel Carmona
   PERIOD: 2023-2024
   LINK: Focus Issue on Quantum Gravity Phenomenology in the Multi-Messenger Era: Challenges and Per-

spectives

6. JOURNAL: **Frontiers in Physics**
   MEMBER: Igor G. Irastorza
   PERIOD: 2023-2024
   LINK: Research Topic: New Developments In The Quest For Discovering Axions And Axion-like Particles.

7. JOURNAL: **European Physical Journal Plus - EPJ+**
   MEMBER: M.L. Sarsa
   PERIOD: 2024-2025
   LINK: Focus Point issue on Best doctoral theses from the Spanish Royal Physics Society (RSEF) in 2023-24.

M

Scientific evaluation and committees

1. NAME OF COMMITTEE: **Management Committee of COST Action CA23130**
   TASK: Coordination and organization of the activities of the COST Action CA23130
   MEMBER: José Manuel Carmona
   PERIOD: 2024-2028

2. NAME OF COMMITTEE: **Leadership of COST Action CA21106 *CosmicWispers***
   TASK: Coordinator of the astrophysics section of the COST Action CA21106
   MEMBER: Maurizio Giannotti
   PERIOD: 2023-2027

3. NAME OF COMMITTEE: **Management Committee of COST Action CA21106 *CosmicWispers***
   TASK: Spanish representative in the committee
   MEMBER: Igor G. Irastorza
   PERIOD: 2023-2027

4. NAME OF COMMITTEE: **International Scientific Advisory Committee of S. Korean's IBS Center for Axion and Precision Physics (CAPP)**
   TASK: Providing scientific guidance to the center, periodic evaluations, reports
   MEMBER: Javier Redondo
   PERIOD: 2017-

5. NAME OF COMMITTEE: **IAXO Collaboration Board**
   TASK: Institutional representation of the Zaragoza node in the board
   MEMBER: Igor G. Irastorza and Gloria Luzón

PERIOD: indefinite

6. NAME OF COMMITTEE: **IAXO Steering Committee**
TASK: Chair of committee
MEMBER: Igor G. Irastorza
PERIOD: indefinite

7. NAME OF COMMITTEE: **IAXO Steering Committee**
TASK: Coordinator of IAXO Physics
MEMBER: Maurizio Giannotti
PERIOD: From Mar-15-2023

8. NAME OF COMMITTEE: **IAXO Steering Committee**
TASK: Coordinator of IAXO Optics and Deputy Spokes person IAXO
MEMBER: Julia K. Vogel
PERIOD: Since 2018

9. NAME OF COMMITTEE: **CPAN Network on Instrumentation and Detectors (CNID)**
TASK: Convener of WG5 (quantum sensors)
MEMBER: Igor G. Irastorza
PERIOD: Since October-2024

10. NAME OF COMMITTEE: **TVLBAI International Collaboration Board**
TASK: Member
MEMBER: Diego Blas Temiño
PERIOD: From 12/2024

11. NAME OF COMMITTEE: **Executive Committee of C-PAN (Centro Nacional de Física de Partículas, Astropartículas y Nuclear)**
TASK: Member
MEMBER: Diego Blas Temiño
PERIOD: From 02/2024

12. NAME OF COMMITTEE: **LISA Consortium Constitutional Committee**
TASK: Member
MEMBER: Diego Blas Temiño

PERIOD: From 12/2023

13. NAME OF COMMITTEE: **AION Collaboration**
    TASK: Manager of Work Package
    MEMBER: Diego Blas Temiño
    PERIOD: From 01/2021-

14. NAME OF COMMITTEE: **Scientific Committee, Benasque Center for Science**
    TASK: Member
    MEMBER: Diego Blas Temiño
    PERIOD: From 01/2022-

15. NAME OF COMMITTEE: **CUPID Collaboration Institutional Board**
    TASK: Institutional representation of Zaragoza University group in the board
    MEMBER: María Martínez
    PERIOD: From 06/2020-

16. NAME OF COMMITTEE: **ASEVA (Spanish Vacuum Society) Scientific Committee**
    TASK: Member of the Committee
    MEMBER: María Martínez
    PERIOD: From 07/2021-

17. NAME OF COMMITTEE: **Comité Ejecutivo del Centro Nacional de física de Partículas, Astropartículas y Nuclear (CPAN)**
    TASK: Member
    MEMBER: María Martínez
    PERIOD: From 01/2023-31/2024

18. NAME OF COMMITTEE: **National Science Center Poland research projects**
    TASK: External Reviewer
    MEMBER: José Manuel Carmona
    PERIOD: December 2024

19. NAME OF COMMITTEE: **National Science Centre Poland research projects**
    TASK: External Reviewer
    MEMBER: María Martínez

PERIOD: April 2024

20. NAME OF COMMITTEE: **French National Research Agency (ANR)**
    TASK: External Reviewer
    MEMBER: Diego Blas Temiño
    PERIOD: May 2023

21. NAME OF COMMITTEE: **French National Research Agency (ANR)**
    TASK: External Reviewer
    MEMBER: Diego Blas Temiño
    PERIOD: May 2023

22. NAME OF COMMITTEE: **STFC Ernest Rutherford Fellowship (UK)**
    TASK: External Reviewer
    MEMBER: Diego Blas Temiño
    PERIOD: December 2024

23. NAME OF COMMITTEE: **UNESCO Science**
    TASK: Consultant
    MEMBER: Diego Blas Temiño
    PERIOD: 2024

24. NAME OF COMMITTEE: **STFC Ernest Rutherford Fellowship (UK)**
    TASK: External Reviewer
    MEMBER: Diego Blas Temiño
    PERIOD: December 2023

25. NAME OF COMMITTEE: **FONDECYT-CHILE**
    TASK: External Reviewer
    MEMBER: Diego Blas Temiño
    PERIOD: December 2023

26. NAME OF COMMITTEE: **RD51 Institutional Board**
    TASK: Institutional representation of the Zaragoza node in the board
    MEMBER: Igor G. Irastorza
    PERIOD: indefinite

27. NAME OF COMMITTEE: **FIP (Feebly Interacting Particle) Physics Center Steering Group - CERN**
TASK: Member of the committee
MEMBER: Igor G. Irastorza
PERIOD: since 2021

28. NAME OF COMMITTEE: **FIP (Feebly Interacting Particle) Physics Center Steering Group - CERN**
TASK: Member of the committee
MEMBER: Maurizio Giannotti
PERIOD: since 2021

29. NAME OF COMMITTEE: **European Innovation Council and SMEs Executive Agency (EISMEA) - Evaluation panel of FET-OPEN Action**
TASK: External expert acting as "monitor"
MEMBER: Igor G. Irastorza
PERIOD: December 2022 - March 2024

30. NAME OF COMMITTEE: **University of Stockholm - evaluation committee for a tenure-track position**
TASK: External expert
MEMBER: Igor G. Irastorza
PERIOD: Oct 2023 - Jan 2024

31. NAME OF COMMITTEE: **State Research Agency (AEI)/Agencia Estatal de Investigación (AEI).**
TASK: Evaluator// Programa Prometeo, G. Valenciana
MEMBER: E. Follana
PERIOD: 2023

32. NAME OF COMMITTEE: **Agència Valenciana d'Avaluació i Prospectiva (AVAP)**
TASK: Evaluator
MEMBER: Gloria Luzón
PERIOD: From 08/2024

33. NAME OF COMMITTEE: **Patronato del Centro de Estudios de Física del Cosmos de Aragón**
TASK: Member of the Scientific Committee
MEMBER: Gloria Luzón
PERIOD: From 01/2022

34. NAME OF COMMITTEE: **Ministero dell'Università e della Ricerca (MUR)**
TASK: External Evaluator of PRIN (Progetti di ricerca di Rilevante Interesse Nazionale)
MEMBER: Manuel Asorey
PERIOD: 2023-2026

35. NAME OF COMMITTEE: **Fondo para la Investigación Científica y Tecnológica (FONCYT) Argentina**
TASK: Evaluador Externo
MEMBER: Manuel Asorey
PERIOD: indefinite

36. NAME OF COMMITTEE: **Programa Nacional de Investigación Científica y Estudios Avanzados, CONCYTEC–PROCIENCIA (Perú)**
TASK: Evaluador Externo
MEMBER: Manuel Asorey
PERIOD: indefinite

37. NAME OF COMMITTEE: **Miembro del Banco de Evaluadores/as de la Agencia I+D+i (FONCYT) Argentina**
TASK: Evaluador Externo
MEMBER: Manuel Asorey
PERIOD: indefinite

38. NAME OF COMMITTEE: **Division de Física Teórica y de Partículas de la Real Sociedad Española de Física**
TASK: Vicepresidente
MEMBER: Manuel Asorey
PERIOD: 2018-2026

39. NAME OF COMMITTEE: **DarkSide-20k Collaboration Institutional Board**
TASK: Institutional representation of Zaragoza University group in the board
MEMBER: Susana Cebrián
PERIOD: Since September 2018

40. NAME OF COMMITTEE: **Sección Local de Aragón de la Real Sociedad Española de Física**
TASK: Vicepresident
MEMBER: Susana Cebrián

PERIOD: November 2020 to December 2024

41. NAME OF COMMITTEE: **Faculty of Science, Outreach and Communication**
    TASK: Vice-dean
    MEMBER: Susana Cebrián
    PERIOD: Since January 2023

42. NAME OF COMMITTEE: **Agencia para la Calidad del Sistema Universitario de Castilla y León**
    TASK: Evaluation of postdoctoral contracts for University of Valladolid
    MEMBER: Susana Cebrián
    PERIOD: 2024

43. NAME OF COMMITTEE: **Czech Science Foundation**
    TASK: Evaluation of basic research grant projects for Standard Projects
    MEMBER: Susana Cebrián
    PERIOD: 2024

44. NAME OF COMMITTEE: **Swiss National Science Foundation**
    TASK: Evaluation of research grant projects
    MEMBER: Susana Cebrián
    PERIOD: 2024

45. NAME OF COMMITTEE: **Austrian Science Fund (FWF)**
    TASK: External evaluator for research grants
    MEMBER: M.L. Sarsa
    PERIOD: November 2024

46. NAME OF COMMITTEE: **European Research Council - "ERC Synergy Grant - 2024" call**
    TASK: External Evaluator
    MEMBER: M.L. Sarsa
    PERIOD: 2024

47. NAME OF COMMITTEE: **Agencia Estatal de Investigación - Jornada de seguimiento de proyectos de Convocatoria de Proyectos de I+D+i 2020, 2021 - Subárea FPN**
    TASK: External Evaluator
    MEMBER: M.L. Sarsa

PERIOD: Noviembre 2024

48. NAME OF COMMITTEE: **European Research Council - "ERC Synergy Grant - 2024" call**
TASK: External Evaluator
MEMBER: Theopisti Dafni
PERIOD: 2024

49. NAME OF COMMITTEE: **Comité de Estrategia Científica del Centro Nacional de física de Partículas, Astropartículas y Nuclear (CPAN)**
TASK: Member
MEMBER: Theopisti Dafni
PERIOD: Since 01/2023

50. NAME OF COMMITTEE: **Comité de Estrategia Científica del Centro Nacional de física de Partículas, Astropartículas y Nuclear (CPAN)**
TASK: Member
MEMBER: Fernando Arteche
PERIOD: Since

51. NAME OF COMMITTEE: **CPAN Network on Instrumentation and Detectors (CNID)**
TASK: Convener
MEMBER: Fernando Arteche
PERIOD: Since

N

List of publications in 2024

In the following we list all the publications with CAPA authors appeared in 2024. Most of them have also been referenced in the corresponding sections in chapter 3. Table N.1 shows the distribution of such publications per research line in a compact way.

Research line	Publications	References	Comments
3.1	4	[13, 14, 51, 56]	+ 1 preprint (eventually published in 02/2025), Ref. [56] is shared with 3.10
3.2	3	[34, 33, 70]	
3.3	1	[31]	+1 preprint (published in 03/2025)
3.4	12	[4, 5, 8, 9, 32, 35, 41, 59, 60, 64, 77, 78]	
3.5	8	[15, 17–19, 22, 45, 54, 71]	
3.6	0	-	+ 2 preprints (one eventually published on 01/2025)
3.7	0	-	+1 preprint (published in 03/2025)
3.8	0	-	1 preprint (eventually published in 02/2025)
3.9	1	[1]	
3.10	10	[56, 68, 49, 57, 25, 23, 26, 48, 72, 66]	+ various preprints, Ref. [56] is shared with 3.1, [25] with 3.15
3.11	3	[29, 30, 63]	+ 1 preprint (eventually published in 2025)
3.12	0	-	+ 3 preprints (one eventually published on 02/2025)
3.13	0	-	3 preprints
3.14	2	[16, 10]	+ 2 preprints (one eventually published in 01/2025), Refs. [16, 10] shared with 3.16
3.15	11	[25, 2, 3, 6, 7, 43, 52, 61, 69, 74, 76]	[43] printed in 02/2025, Ref. [25] is shared with 3.10.
3.16	8	[16, 10, 21, 11, 12, 40, 27, 28]	Refs. [16, 10] shared with 3.14
Other	19	[20, 24, 36–39, 42, 44, 46, 47, 50, 53, 55, 58, 62, 65, 67, 73, 75]	

Table N.1: CAPA publications in 2024 per research line. The first column indicates the research line according to the numbering in chapter 3. The second column indicates the number of publications and unpublished released preprint, per each of the research lines. The latter are normally intended for publication next year. The third column provides the references of those articles, in the bibliography at the end of the report.

1. Abás, E., Marina-Montes, C., Pérez-Marín, C., Puimedón, J. & Anzano, J. A combined study of gamma spectrometry and inductively coupled plasma spectroscopy reveals persistent anthropogenic radioactive pollution on Deception Island, Antarctica. *Microchemical Journal* **196,** 109575 (2024).
2. Abbott, T. M. C. *et al.* Dark Energy Survey: A 2.1% measurement of the angular baryonic acoustic oscillation scale at redshift zeff=0.85 from the final dataset. *PHYSICAL REVIEW D* **110,** 063515 (2024).
3. Abbott, T. M. C. *et al.* The Dark Energy Survey: Cosmology Results with $\sim$1500 New High-redshift Type Ia Supernovae Using the Full 5 yr Data Set. *ASTROPHYSICAL JOURNAL LETTERS* **973,** L14 (2024).

4. Acerbi, F. *et al.* A new hybrid gadolinium nanoparticles-loaded polymeric material for neutron detection in rare event searches. *JOURNAL OF INSTRUMENTATION* **19,** P09021 (2024).
5. Acerbi, F. *et al.* DarkSide-20k sensitivity to light dark matter particles. *COMMUNICATIONS PHYSICS* **7,** 422 (2024).
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7. Adame, A. G. *et al.* Validation of the Scientific Program for the Dark Energy Spectroscopic Instrument. *ASTRONOMICAL JOURNAL* **167,** 62 (2024).
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O

Members of CAPA

In the following list we include all the members of CAPA as of the end of 2024, including personnel category (see section 2).

Name	**Personnel category**
Jacobo Asorey Barreiro	Permanent staff
Manuel Asorey Carballeira	Permanent staff
Agustín Camón Lasheras	Permanent staff
José Manuel Carmona Martínez	Permanent staff
Inés Cavero Peláez	Permanent staff
Susana Cebrián Guajardo	Permanent staff
Jesús Clemente Gallardo	Permanent staff
Theopisti Dafní	Permanent staff
Pablo Díaz Benito	Permanent staff
Fernando Falceto Blecua	Permanent staff
Eduardo Follana Adin	Permanent staff
Eduardo García Abancéns	Permanent staff
José Vicente García Esteve	Permanent staff
Igor García Irastorza	Permanent staff
Jesús Gómez Gardeñes	Permanent staff
Justo López Sarrión	Permanent staff
Gloria Luzón	Permanent staff
María Martínez Pérez	Permanent staff

Manuel Clemente Membrado Ibáñez	Permanent staff
Yamir Moreno Vega	Permanent staff
Ysrael Richard Ortigoza Paredes	Permanent staff
Siannah Peñaranda Rivas	Permanent staff
Sergio Pérez Gaviro	Permanent staff
Carlos Pobes Aranda	Permanent staff
Jorge Puimedón Santolaria	Permanent staff
Javier Redondo Martín	Permanent staff
Ana Maria Salinas Baldellou	Permanent staff
María Luisa Sarsa Sarsa	Permanent staff
Alfonso Tarancon Lafita	Permanent staff
Alejandro Vaquero Avilés-Casco	Permanent staff
Luis Fernando Velázquez Campoy	Permanent staff
David Cintas González	Temporary staff
Iván Coarasa Casas	Temporary staff
Juan Antonio García Pascual	Temporary staff
Maurizio Giannotti	Temporary staff
Yikun Gu	Temporary staff
Francisco Javier Jiménez Albericio	Temporary staff
Maykoll Anthonny Reyes Hung	Temporary staff
Eduardo Royo Amondarain	Temporary staff
Laura Seguí Iglesia	Temporary staff
Itxaso Beatriz Antolín Rojo	Research trainees
Jaime Apilluelo Allué	Research trainees
David Díez Ibáñez	Research trainees
Álvaro Ezquerro Sastre	Research trainees
Fernando Ezquerro Sastre	Research trainees
María Jiménez Puyuelo	Research trainees
Mathieu Kaltschmidt	Research trainees
Cristina Margalejo Blasco	Research trainees

David Martínez Crespo	Research trainees
Yiseli Martínez Pérez	Research trainees
Alejandro Mir Ramos	Research trainees
Luis Antonio Obis Aparicio	Research trainees
Miguel Pardina García	Research trainees
Tamara Pardo Yanguas	Research trainees
Óscar Pérez Lázaro	Research trainees
Jorge Porrón Lafuente	Research trainees
Ana Quintana García	Research trainees
Filip Rescic	Research trainees
Francisco Rodríguez Candón	Research trainees
Carmen Seoane Herce	Research trainees
José Luis Alonso Buj	UZ collaborators
Julio César Amaré Tafalla	UZ collaborators
César Asensio Chaves	UZ collaborators
Vicente Azcoiti Pérez	UZ collaborators
José Fernando Cariñena Marzo	UZ collaborators
José Luis Cortés Azcoiti	UZ collaborators
José Mariano Gracia Bondía	UZ collaborators
Juan Francisco Castel Pablo	Technical staff
Jorge Marqués García	Technical staff
Francisco Javier Mena Alastuey	Technical staff
Ángel de Mira Bartolomé	Technical staff
Héctor Mirallas Sánchez	Technical staff
Alfonso Ortiz de Solórzano Aurusa	Technical staff
María del Carmen Pérez Marín	Technical staff
María Rodríguez Sierra	Technical staff
Pedro José Justes Aizpún	Admin
Virginia Rodríguez Romeo	Admin
Jorge Alda Gallo	External collaborators

Fernando Arteche González	External collaborators
Diego Blas Temiño	External collaborators
Carlos Bouthelier Madre	External collaborators
Javier Galán Lacarra	External collaborators
Francisco Javier Galindo Guarch	External collaborators
Héctor Gómez Maluenda	External collaborators
Sven Heinemeyer	External collaborators
Sophia Hollick	External collaborators
Ciaran O'Hare	External collaborators
José Javier Relancio Martínez	External collaborators
Jaime Ruz Armendáriz	External collaborators
Tomas O'Shea	External collaborators
Julia Katharina Vogel	External collaborators