INSTITUTE OF COSMOS SCIENCES
UNIVERSITY OF BARCELONA

# 2021 ANNUAL REPORT

Institute of Cosmos Sciences of the University of Barcelona.
Published in Barcelona, July 2023.
This report has been written and designed by the Scientific Office.

# CONTENTS

# FOREWORD

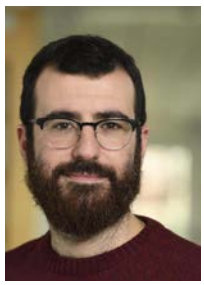
This year 2021, even if the activity of the institute has been still affected by the COVID-19 pandemics, we have started recovering from its effects. We have been able to resume face-to-face meetings, and even to do some travelling. And, more importantly, we can start to resume the social life of the institute and enjoy the irreplaceable interaction with our fellow members.

One more year, the groups at our institute have made significant scientific contributions in their areas; from Cosmology to Particle Physics, from Gravitation to Quantum technologies, the ICCUB activities have led to important results and achievements, that you can find summarized in this memory. And side to side with our scientific teams, our Technological Unit has supported these developments and has made its own contributions to instrumentation and data processing in many key missions and projects, thus making a virtuous duet of science and technology. We can be collectively proud of our work.

At a more personal level, the work of several members of the institute has been recognized through a variety of prices: Licia Verde has been granted the Rei Jaume I Award for Basic Research, Teresa Antoja has been awarded the Leonardo Grant for Basic Sciences and José Luís Bernal has been awarded the XXV Doctoral Senate Second Prize. Congratulations to all!

Licia Verde


Teresa Antoja


José Luís Bernal

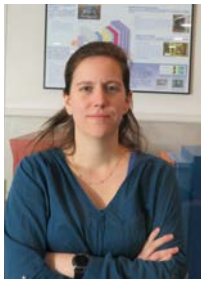
Furthermore, our member Prof. Domènec Espriu has been designated director of the Spanish State Research Agency. He will have in his hands the top-level management of the Spanish research and we wish him a good mandate and many successes in his endeavour.


Domènec Espriu

As you can see this year has brought good news and a lot of work. To share our achievements and activities with the society we have made a special effort on outreach; at the end of this report you can find a summary of these activities, and you can follow them in full detail through our renewed outreach pages serviastro and serviparticules.

Finally, to close this foreword, we want to welcome our new members, Juan Torres, Carla Marin Benito, Gemma Busquet, Chervin Laporte, Vincent Mathieu and Ricardo Vázquez.


Juan Torres


Carla Marín


Gemma Busquet


Chervin Laporte


Vincent Mathieu


Ricardo Vázquez

Looking forward to 2022 for more science and technology at ICCUB!

**Xavier Luri**

**Assumpta Parreño**

EXECUTIVE BOARD OF THE ICCUB

# GOVERNING BODIES

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Deputy Director: **Assumpta Parreño**

Secretary: **Federico Mescia**

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F. Mescia
J.M. Paredes
F. Figueras
B. Julià
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P. Garcia
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À. Ramos
L. Garrido
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D. Gascón
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M. Guilleumas

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J. Garriga
J. Casalderrey
B. Julià

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**Alan Heavens,** Imperial College, London

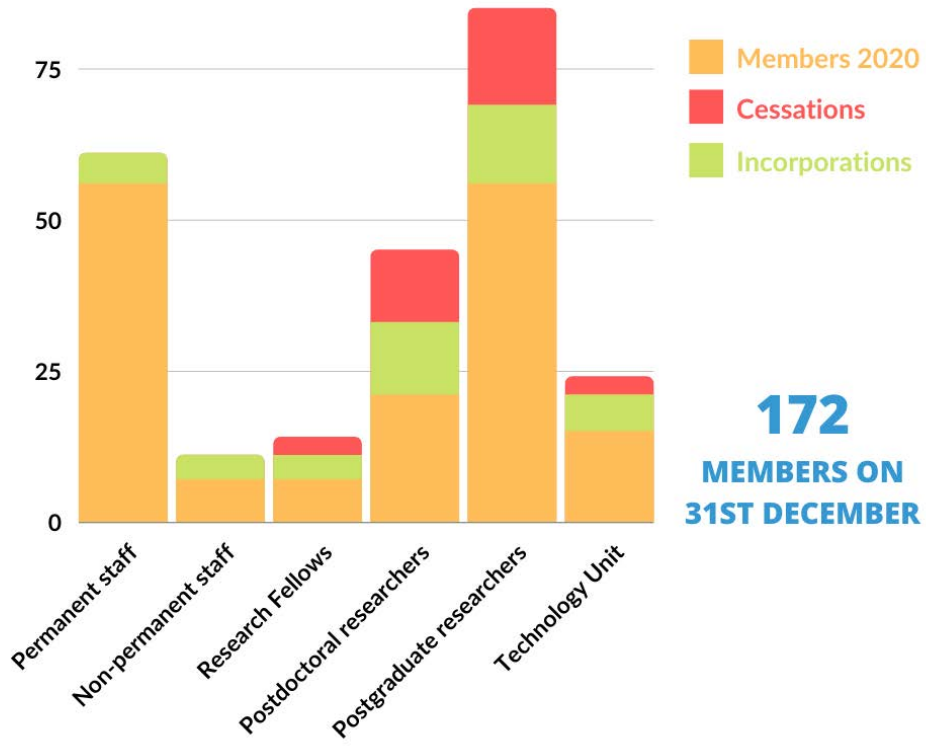
**Tatsuya Nakada,** École Polytechnique Féderale de Lausanne, Lausanne

**Meghan Urry,** Yale Center for Astronomy and Astrophysics, EE.UU.

# ICCUB IN FIGURES

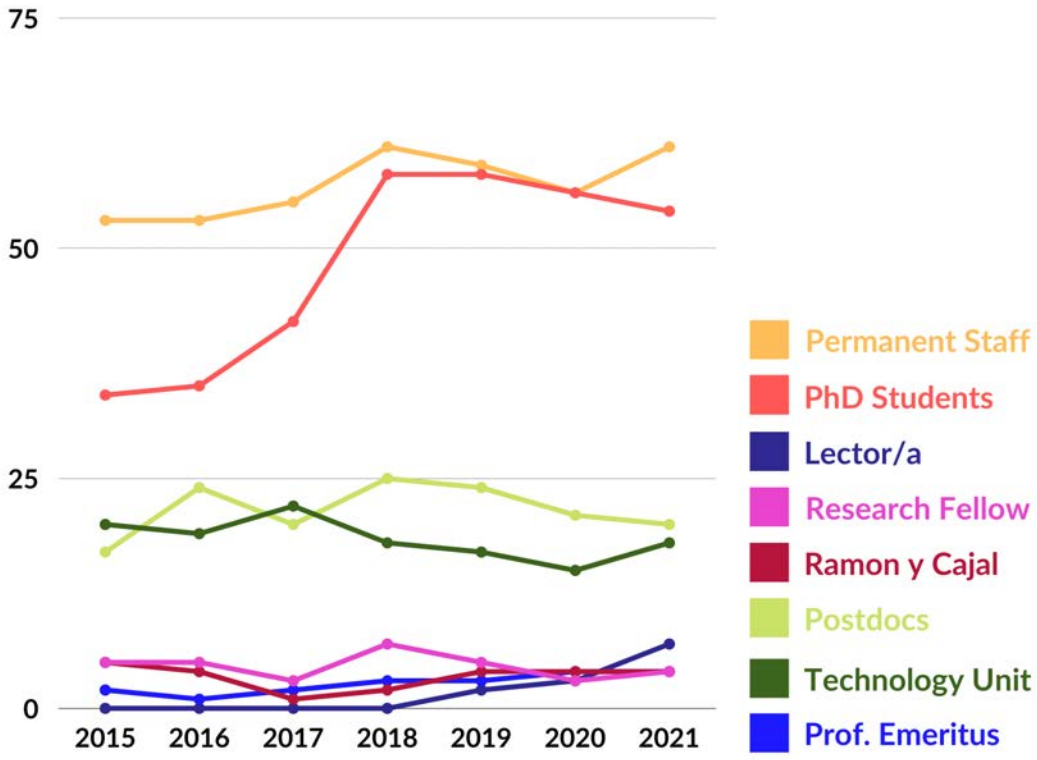
## STAFF

### Number of ICCUB members

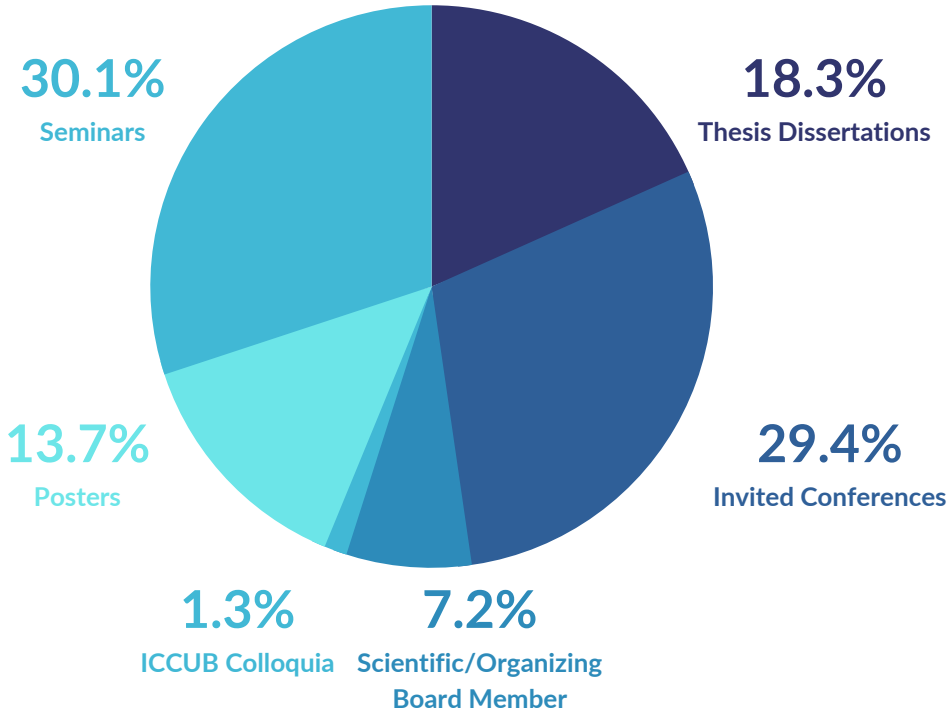


# GENDER

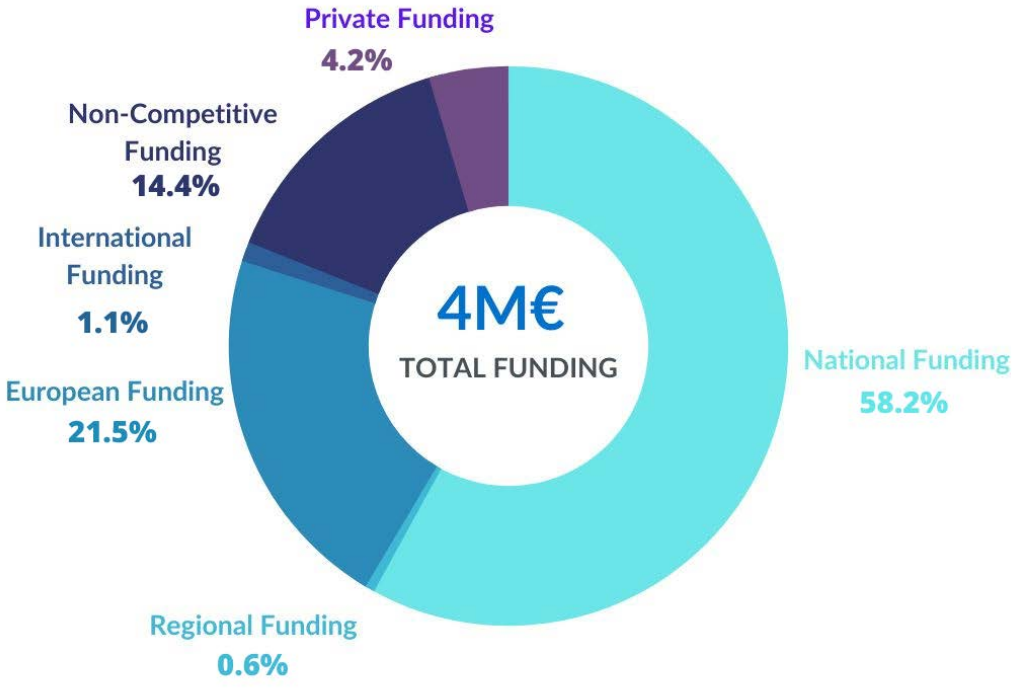

# EVOLUTION STAFF



# ACTIVITIES

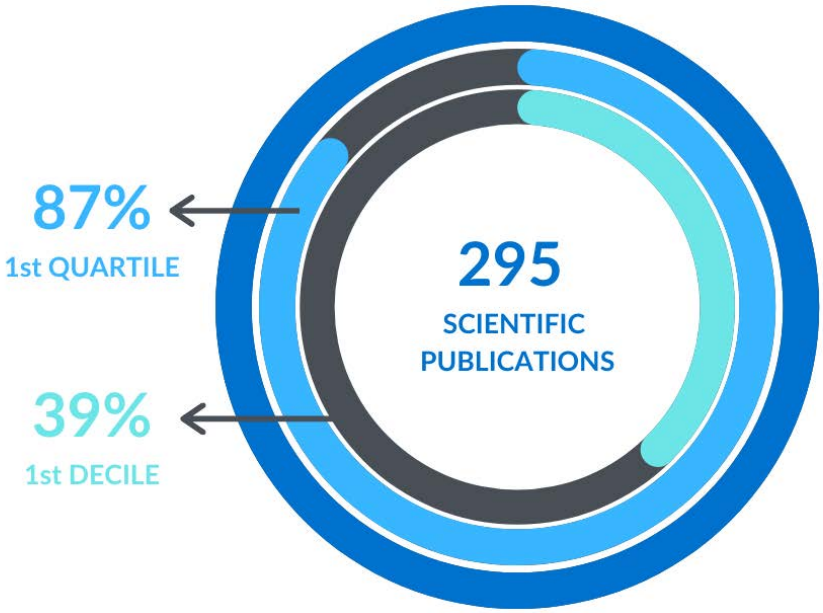



# FUNDING SOURCES



# RESEARCH HIGHLIGHTS

## PUBLICATIONS



# COSMOLOGY AND LARGE SCALE STRUCTURE

We have continued our effort in optimizing the analysis and interpretation of galaxy redshift surveys to constrain cosmology . In particular, we have presented an extension to the standard (classic) analysis of the clustering of galaxy redshift surveys that, while remaining model-independent and of transparent physical interpretation, matches the statistical power of direct fitting (full modeling) approaches which are highly model-dependent. This is being adopted by DESI to produce constraints on the nature of dark energy.

We have further investigated the Hubble tension also in the context of the age of the Universe, proposing a new way to put it into the big picture context and it implications for the cosmological model.

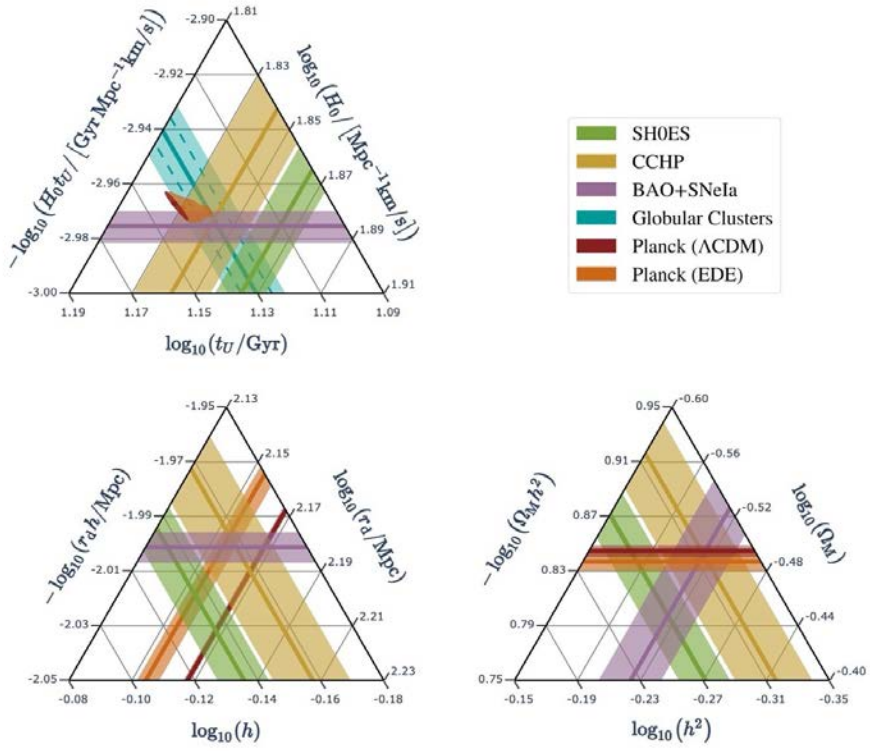
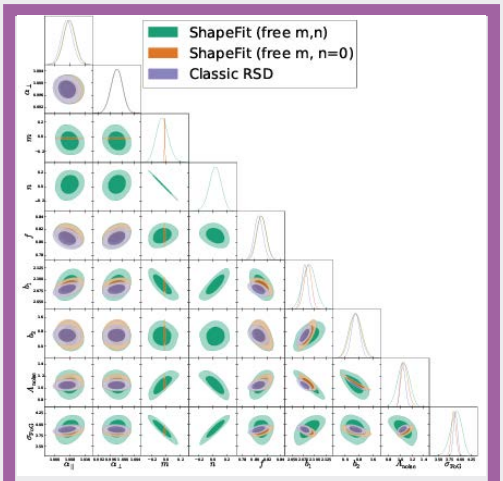


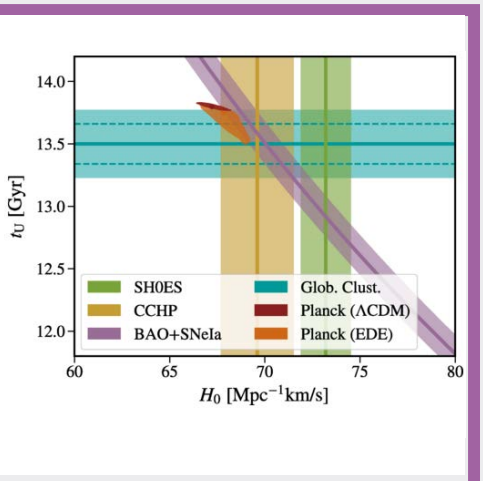

**Figure 1.** The new cosmic triangles (Bernal et al 2021). The H0 tension was reframed as a consistency test between triads of tow cosmological parameters and their product. These three different quantities which can be measured directly from observation but, of these,only two are independent if the model is the correct theory of the Universe. These are: {tU, H0, H0tU}, {rd, h, rdh} {ΩM, h , ΩMh }. The cosmo- logical model(s) yielding agreement of all these triads are favored by the data

# COSMOLOGY AND LARGE SCALE STRUCTURE

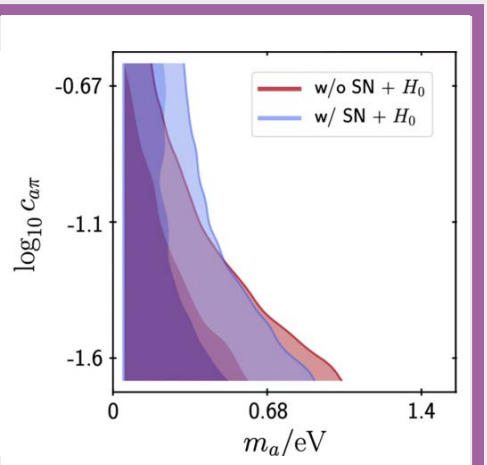
## Main scientific results:



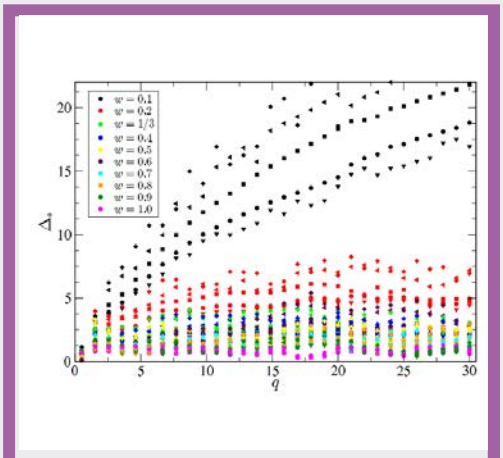

ShapeFit: extracting the power spectrum shape information in galaxy surveys beyond BAO and RSD



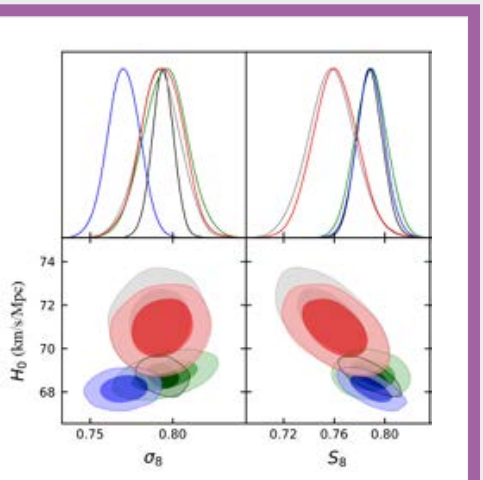

The trouble beyond H0 and the new cosmic triangles



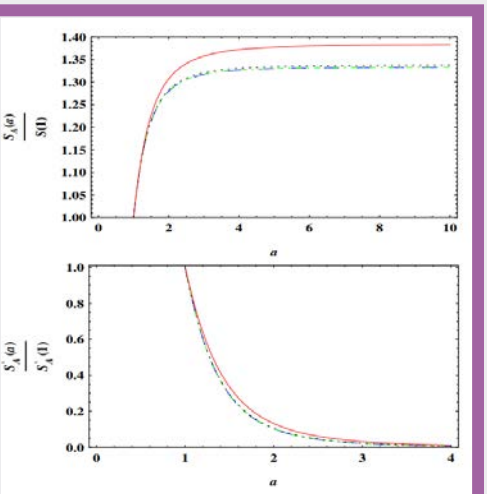

Dine-Fischler-Srednicki-Zhitnitsky axion in the CMB



Analytical thresholds for black hole formation in general cosmological backgrounds




Running vacuum against the $H_0$ and $\sigma_8$ tensions



Stringy-running-vacuum-model inflation: from primordial gravitational waves and stiff axion matter to dynamical dark energy

# EXPERIMENTAL PARTICLE PHYSICS

The ICCUB participation in the LHCb experiment has resulted in important scientific results in 2021. Those with highest impact are related to new decay observations, with new discovered states and in the search of new physics beyond the Standard Model (SM) of particles and fields in rare b-quark decays. Namely,

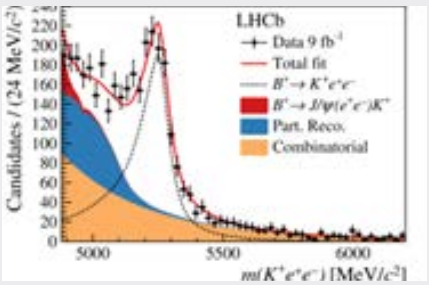
a) Test of lepton universality in the decay B+→K+l+l- where l indicates muon or electrons. The ratio of the branching fractions of these decays is expected to be one in the Standard Model and a deviation of 3σ is observed. Read the article here.

b) An improved measurement of the decay B s →μμ and searches for the decays B 0 →μμ and B s →μμγ. The branching fractions and effective lifetime are measured to be consistent with the Standard Model predictions. Read the article here.

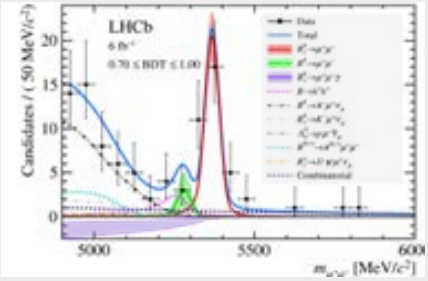
c) Observation of an exotic narrow doubly charmed tetraquark in the D 0 D 0 π mass spectrum with a mass of approximately 3875 MeV/c 2 . The near-threshold mass together with the narrow width reveals the resonance nature of the state. Read the article here.

Besides, the members of the ICCUB group were responsible for the reconstruction algorithms of the muons and electrons for the Upgrade LHCb detector which is planned to start in 2022. The full LHCb reconstruction software was also coordinated by members of the ICCUB group

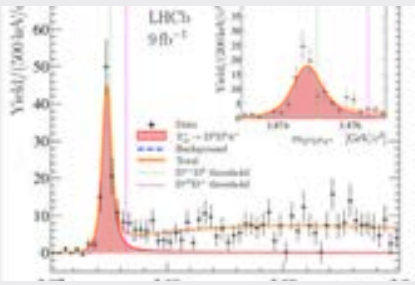
**a) Test of lepton universality in beauty-quark decays**



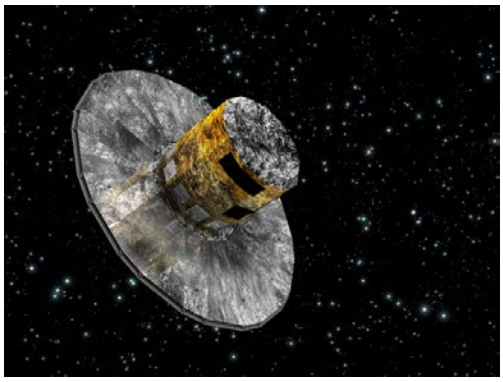

**b) Observation of an exotic narrow doubly charmed tetraquark**




**c) Observation of an exotic narrow doubly charmed tetraquark**



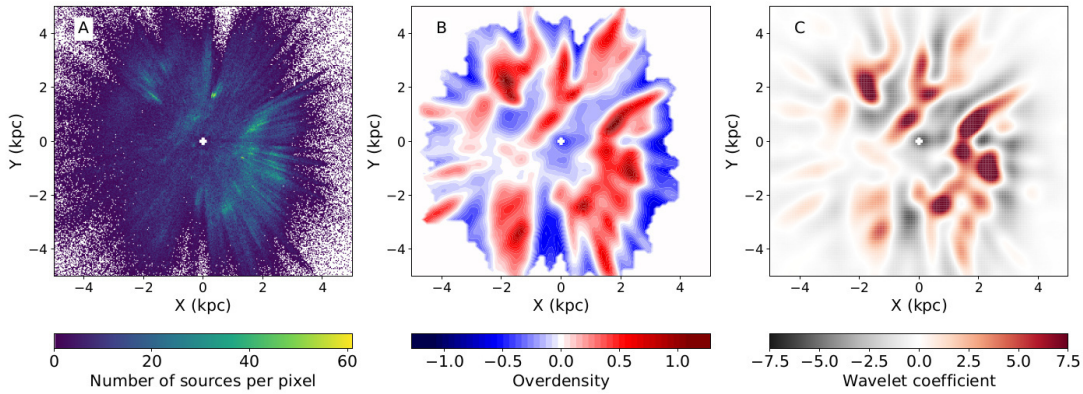
# GALAXY STRUCTURE AND EVOLUTION



The Gaia mission is revolutionizing astrophysics, and 2021 has been another key year for the production of the full third Data Release (DR3), that will be released in June 2022, and for the first steps in the processing of the fourth data release to be published around 2025. The ICCUB has a first-line participation in these achievements through its leading roles in the Data Processing and Analysis Consortium. The ICCUB has led the modelling of the low-resolution spectra (to be included for the first time in DR3), the validation of the full DR3 and has participated in two key articles illustrating its impact and its potentiality: the mapping of the symmetric disc of the Milky Way with several tracers and the use of the spectra to derive synthetic photometry. Additionally, our scientific exploitation of the previously delivered Early third Data Release (EDR3) has yielded

(a) the characterization of stellar streams of accreted galaxies, in particular Monoceros and ACS streams and the full Sagittarius stream,

(b) the analysis of the nature and evolution of the spiral arms, including the far Carina arm [link],

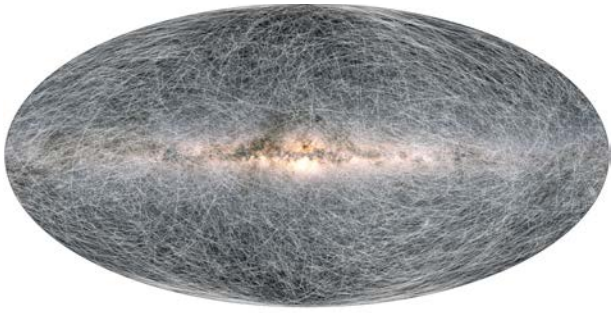



Spiral arms of the Milky Way mapped by *Gaia*
(Poggio, E., et al., 2021, A&A, 651, A104)

(c) the mapping of the bar and bulge with complementary APOGEE data,

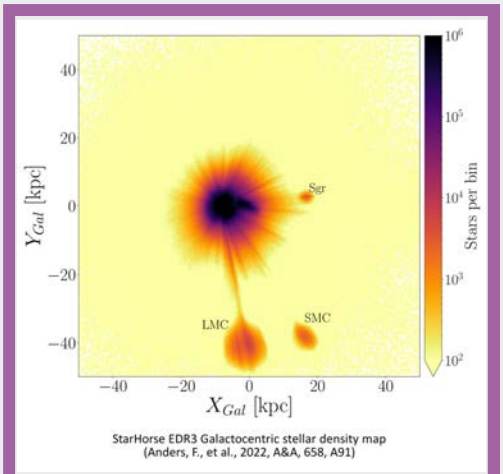
(d) the unveiling of hundreds of new open clusters enlarging the spatial volume covered by more than 1 kpc, and € the determination of astrophysical

parameters for more than 300 million stars, the largest sample to date combining Gaia and external data. To acquire complementary spectroscopic data our OCCASO project has completed 10 more open clusters; we have continued the preparation of the commissioning and scientific verification phases of the WEAVE spectrograph for first light in 2022, and our clusters project for the future 4MOST spectrograph has been approved.



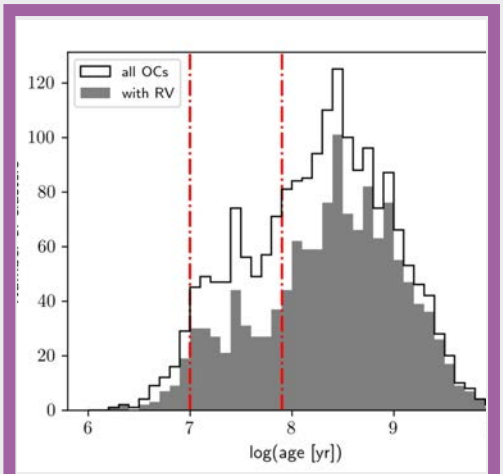
Trails showing the displacement of stars on the sky 400 thousand years into the future, based on *Gaia* Early Data Release 3 (Credit: ESA/Gaia/DPAC) ("*Gaia* Early Data Release 3" Special Issue, 2021, A&A, 649)

## Main scientific results:

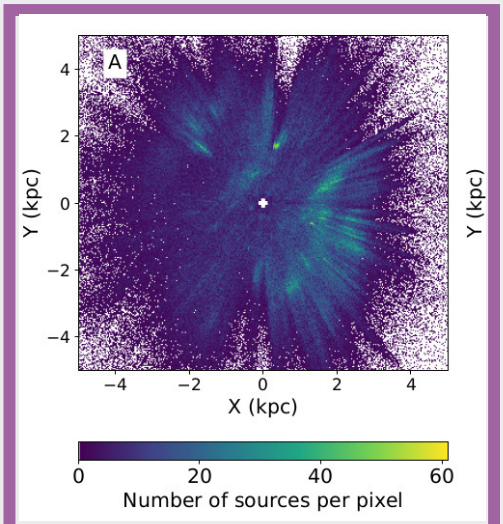



StarHorse EDR3 Galactocentric stellar density map (Anders, F., et al., 2022, A&A, 658, A91)

Photo-astrometric distances, extinctions, and astrophysical parameters for Gaia EDR3 stars brighter than G = 18.5




Milky Way spiral arms from open clusters in Gaia EDR3




Galactic spiral structure revealed by Gaia EDR3

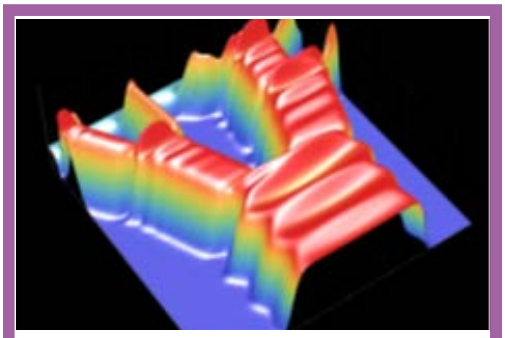
Besides the Gaia activities, we have continued studying the properties of the population of S0 galaxies in the local Universe (z < 0.1). Our baseline data are both single fiber (SDSS) and spatially resolved (MaNGA) spectra retrieved from the Sloan survey. We have carried out a comprehensive comparison of the most important activity diagnostics in the literature over different waveband including our own based on the principal component analysis (PCA) of the optical spectrum and its projections onto the first eigenvectors, and explored the connections between them and with parameters related to star formation and black hole accretion. Analysis of the spatially resolved spectra have revealed that present-day S0s with a passive global spectrum often exhibit star-forming rings visible in the nebular component (Ha), and sometimes in the stellar one (D4000) too, as found in recent cosmological simulations when S0 are formed through mergers.

# GRAVITATION AND COSMOLOGY

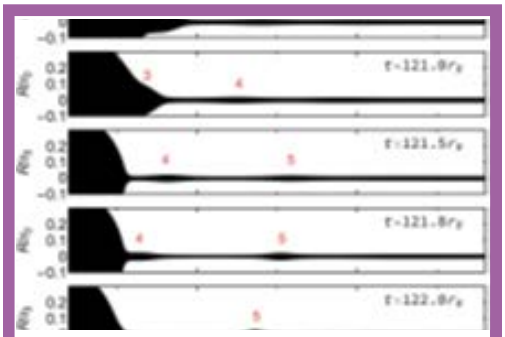
- *Quantum Black Holes*: Emparan and collaborators have used braneworld holography to study quantum black holes fully taking into account the exact backreaction from quantum matter fields.
- *Holographic study of Cosmological phase transitions*: Mateos and collaborators have applied holography to the study of cosmological phase transitions, deriving from first principles the bubble wall velocity, and uncovering new mechanisms of gravitational wave production.
- *Black hole instabilities*. Andrade and collaborators have used state-of-the-art methods in numerical relativity to investigate in unprecedented detail the endpoint of black string instabilities.
- *Higher-curvature gravities*: Bueno, Hennigar and collaborators have performed an extensive study of Generalized quasi-topological gravities, which are higher-curvature extensions of Einstein gravity in D-dimensions with specific appealing properties.
- *Primordial Black Holes*: Germani and collaborators have made significant contributions to the study of primordial black hole production due to cosmological fluctuations. Specifically, they have characterized more precisely the threshold for such production.

## Main scientific results:

Black holes in dS3



**Domain Collisions**



Endpoint of the Gregory-Laflamme instability of black strings revisited

Generalized quasi-topological gravities: the whole shebang

Analytical thresholds for black hole formation in general cosmological backgrounds

# HADRONIC, NUCLEAR AND ATOMIC PHYSICS

**Low-energy scattering and effective interactions of two baryons from lattice quantum chromodynamics**

Nuclear and hypernuclear interactions are key inputs into investigations of the properties of matter, such that one encountered in neutron stars. We have studied interactions between two-baryon systems with strangeness S=0 (NN) to S=-4 (ΞΞ) by direct calculations, on a lattice, of the underlying theory of the strong interactions (LQCD) and employing a pion mass of mπ∼450 MeV. An extrapolation of the binding energies to the physical point is performed. The SU(6)-symmetric Effective Field Theory (EFT) constrained by these LQCD calculations is used to make predictions for two-baryon systems, demonstrating the predictive power of two-baryon EFTs matched to LQCD

***Marc Illa, Assumpta Parreño, et al. (NPLQCD Collaboration), Phys.Rev.D 103 5, 054508 (2021)***

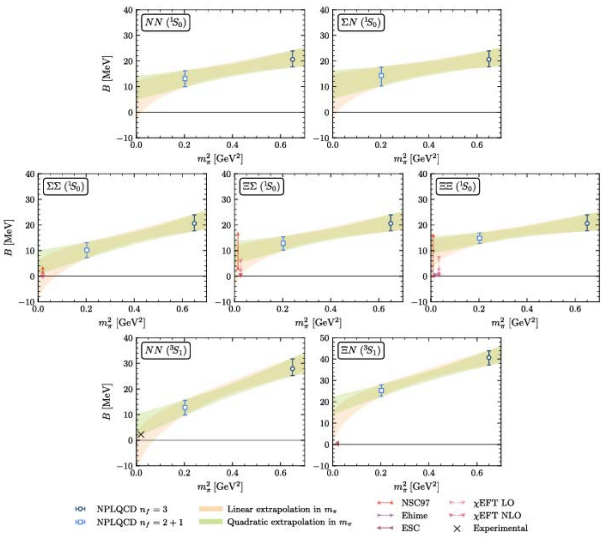



**Figure 1.** Extrapolation of the binding energies of different two-baryon systems, using the results obtained in this work at mπ∼450 MeV and those at mπ∼806 MeV.

**Impact of the short-range nuclear matrix element on the neutrinoless double-beta decay of nuclei**

The leading-order short-range nuclear matrix element (NME) for the neutrinoless double-beta decay of the nuclei most relevant for experiments, including 76Ge, 100Mo, 130Te and 136Xe, has been evaluated. The results, performed with the nuclear shell model (NSM) and proton-neutron quasiparticle random-phase approximation (pnQRPA) methods, suggest a significant impact of the short-range matrix element. Combining the full matrix elements with the results from current $0\nu\beta\beta$-decay experiments it is found that, if both matrix elements carry the same sign, these searches move notably toward probing the inverted mass ordering of neutrino masses.

***Lotta Jokiniemi, Pablo Soriano, Javier Menéndez, Phys. Lett. B 823, 136720 (2021)***

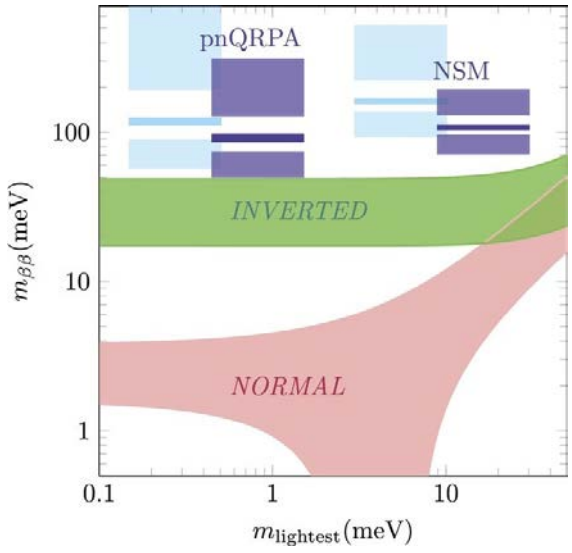



**Figure 2.**Effective Majorana mass mββ in terms of the lightest neutrino mass mlightest assuming the normal (pink) or inverted (green) ordering of neutrino masses, compared to the exclusion (blue) bands which combine data from 0νββ-decay experiments and the present pnQRPA or NSM NMEs.

# HIGH ENERGY ASTROPHYSICS

**Observational astrophysics of high-energy gamma-ray sources.** We have contributed to the identification of discrete high-energy (HE) and very-high-energy (VHE) sources in the Cygnus region by means of deep radio images obtained using the Giant Metrewave Radio Telescope at 610 and 325 MHz. A detailed exploration of the γ Cygni SNR led to the discovery of the Roman Squid source, which shows a rather peculiar extended morphology whose nature is completely unknown. We have also started an observational campaign at radio wavelengths to search for the radio counterpart of the variable HE source Fermi J1913+0515 associated with SS433/W50 with the ESA's DSA3 Antenna. We have characterized the companion star in the gamma-ray binary system HESS J1832-093 as an O-type star through observations in the infrared with the VLT X-Shooter spectrometer. We have continued our optical photometric monitoring of gamma-ray binaries with the Telescope Fabra ROA Montsec. We have searched for runaway massive galactic stars within the Gaia EDR3 catalogue with the goal to find gamma-ray binary candidates after a further cross-correlation with multi-wavelength catalogues. The refined list of sources could be targets for future MAGIC and CTA/LST observations.

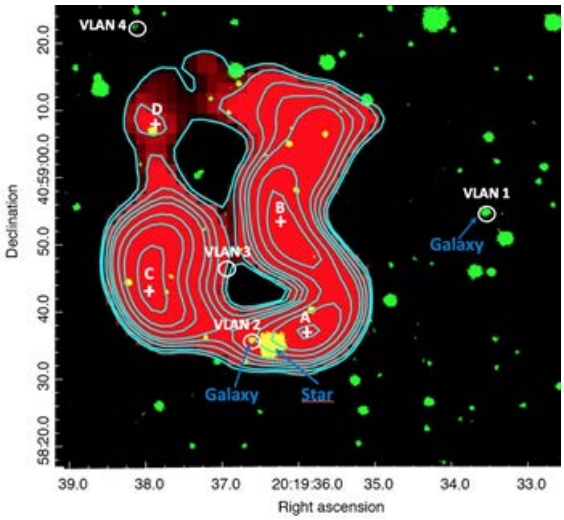



**Figure 1:** GMRT 610 MHz radio image of the Roman Squid source, in red. The peak position of each of the four components A, B, C and D is marked with a white cross. In green we show an infrared K-band image of the region from the UKIDSS catalogue.

**Active galaxies and other jet sources at low and high redshift.** We started a detailed X-ray study of the nearby starburst galaxy M82 and our systematic search found seven X-ray supernova remnants. They are all young, most likely less than 100 yr old and include the radio supernova SN2008iz, from which X-ray detection was reported for the first time. The search for the most distant quasars, using the Subaru HSC survey, continued and the number of our newly discovered quasars at z=5.7-7.1 now reached 162.

**CTA Consortium and LST Collaboration.** We have been deeply involved in the scientific exploitation of LST1 observations through the analysis of the obtained data. This includes analysis of the Crab data as well as the outburst of the RS Ophiuchi. To this end, we have also contributed to the test and improvement of the pipelines lstchain and lstMCpipe and the software Gammapy. We have regularly participated in analysis meetings and reported results in the LST General meeting. We have also conducted an observation shift to the LST1. We have continued the studies of simulations of transient sources to be observed with CTA in general and LST1 in particular. Finally, in close collaboration with members of the Technological Unit, we have also continued our developments in electronics for CTA and have continued working on the production of ASICs to build the cameras of LST2-LST4.

**Figure 2:** Large Size Telescope (LST1) at ORM observatory, La Palma.

**MAGIC Collaboration.** In 2021 we have led the writing of the paper reporting the MAGIC observations at VHE of the 2018 outburst of the black hole X-ray binary MAXI J1820+070, which we analysed in 2020. This paper also includes data from HESS and VERITAS and the global effort has been led by the ICCUB group. We have led the observation campaigns of the X-ray binary Cygnus X-3 and participated in the ones of the soft gamma-ray repeater and FRB galactic source SGR 1935+2154. We have analysed data on the X-ray binaries SS 433 and 1A 0535+026. We have been internal referees on the papers related to the millisecond pulsar PSR J0218+4232 and the Boomerang complex. An interesting discovery that took place in 2021 was the detection at TeV energies of the recurrent symbiotic nova RS Ophiuchi during an outburst. MAGIC conducted observations of this outburst under the galactic transient proposal that we lead, and we participated in the discussion of the results and the activation of the optical follow-up with the Joan Oró Telescope at the Montsec Observatory. A member of the group has been deputy physics coordinator and participated in the Time Allocation Committee.

# HIGH ENERGY ASTROPHYSICS

**Investigation of particle acceleration and transport at low energies.** Owing to the in-situ and remote sensing measurements from Solar Orbiter, we showed that the 50 – 800 keV proton event observed on 19 June 2020 at 0.52 au from the Sun was the result of a local second-order Fermi acceleration process in a corotating interaction region (CIR), identified by a recurrent galactic cosmic ray depression. We performed the first 3D simulation of a multi-spacecraft CIR ion event. We reproduced both the plasma and 30 – 1800 keV proton measurements from PSP (at 0.56 au) and STEREO-A (at 0.95 au) during the event on 18 – 24 September 2019. In contrast to the former case, we showed that acceleration is due to the CIR compressional waves, even within 1 au, for < 500 KeV protons.

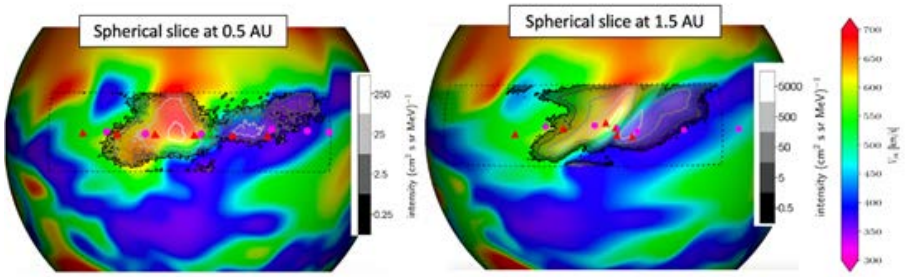



**Figure 3:** Simulated 84.1–92.7 keV ion intensities and solar wind speed at 0.5 au (left) and 1.5 au (right) for the 18 – 24 September 2019 particle event. Daily magnetic connections of PSP (triangles) and STEREO-A (circles) are indicated. Adapted from Wijsen et al. (2021, ApJ Lett., 908, L26).

**Theoretical Astrophysics**. We have carried out thorough 3D simulations of the impact of mechanical feedback in the accretion processes of isolated and primordial black holes. We have also computed and predicted the radio emission expected from the Lighthouse Nebula as its pulsar propagates in the ISM. A systematic numerical study has been performed to characterise the stellar-pulsar wind interaction in binaries with different eccentricities, and constraints have been derived from observations on the properties of the putative pulsar wind in the gamma-ray binary LS 5039.

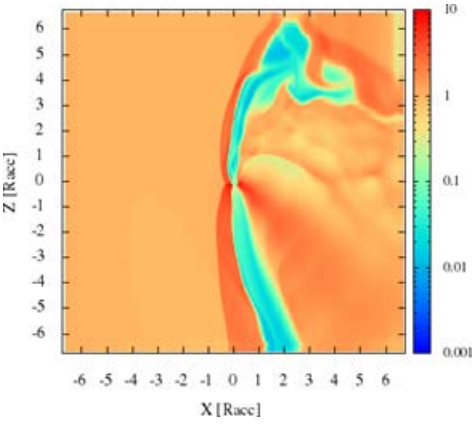



**Figure 3:** Density maps of an outflow from an isolated black hole interacting obliquely with the surrounding medium.

# PARTICLE PHYSICS PHENOMENOLOGY

In  arXiv:2109.10368, JCAP 02 (2022) 035, F. Mescia and collaborators have studies axion production from astrophysical bodies, thanks to theoretical progress in the estimate of stellar emission rates and, especially, because of improved stellar observations. We carry out a comprehensive analysis of the most informative astrophysics data, revisiting the bounds on axion couplings to photons, nucleons and electrons, and reassessing the significance of various hints of anomalous stellar energy losses. Finally, we scrutinize the discovery potential for such models at upcoming helioscopes, namely IAXO and its scaled versions.

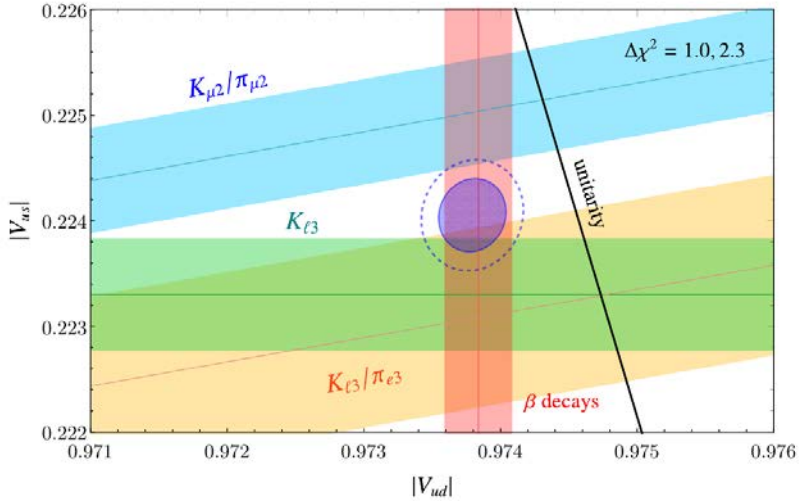
In arXiv:2212.06862, JHEP03(2023)234,  F Mescia and his postdoc have studied the tensions in the CKM matrix. These discrepancies, known as the Cabibbo Angle anomaly, can in principle be solved by modifications of W boson couplings to quarks.  In order to consistently assess the agreement of a new physics hypothesis with data, we perform a combined analysis for all dimension-six Standard Model Effective Field Theory operators that generate modified W couplings to first and second generation quarks.

In arXiv:2204.03011, JHEP 07 (2022) 138, Concha and collaborators has presented a detailed analysis of the spectral data of Borexino Phase II, with the aim of exploiting its full potential to constrain scenarios beyond the Standard Model. In particular, we quantify the constraints imposed on neutrino magnetic moments, neutrino non-standard interactions, and several simplified models with light scalar, pseudoscalar or vector mediators. Our analysis shows perfect agreement with those performed by the collaboration on neutrino magnetic moments and neutrino non-standard interactions in the same restricted cases and expands beyond those, stressing the interplay between flavour oscillations and flavour non-diagonal interaction effects for the correct evaluation of the event rates.

# PARTICLE PHYSICS PHENOMENOLOGY

In arXiv:2212.03889, Concha and J. Salvado, JHEP 04 (2023) 039, studied the a long-range force generating the exchange of a pair of neutrinos with Standard Model weak interactions. The associated potential is extremely feeble massless neutrinos, which renders it far from observable even in the most sensitive experiments testing fifth forces. By reevaluating the 2ν exchange potential in the presence of a neutrino background including finite width effects, we find that the background-induced enhancement is reduced by several orders of magnitude.

In arXiv:2108.00496, Phys. Rev. D 104, 074027 (2021), J. Soto studied nonrelativistic effective-field theory description of doubly heavy baryons. We propose a parametrization of these potentials with a minimal model dependence based on an interpolation of short- and long-distance descriptions. The short-distance description is obtained from weakly-coupled pNRQCD and the long-distance one is computed using an effective string theory.
The unknown parameters are obtained from heavy quark-diquark symmetry or fitted to the available lattice QCD determinations of the hyperfine splittings. Using these parameters we compute the double charm and bottom baryon spectrum including the hyperfine contributions. We compare our results with those of other approaches and find that our results are closer to lattice QCD determinations, in particular for the excited states.

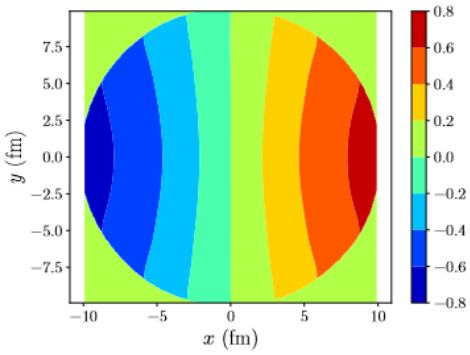



Global fit of all the available CKM determinations. Only the 1σ regions from β decays, Kl3 , Kμ2/πμ2 and Kl3 /πe3 observables are shown. The black line represents the unitarity condition, Vus^2+Vud^2 +Vub^2=1.

# QUANTUM FIELD THEORY AND STRING THEORY

A first-order phase transition in the Early Universe would have taken place via the nucleation of bubbles of the preferred phase. The subsequent dynamics would have produced gravitational waves that could potentially be discovered by future detectors like LISA. The most important parameter to determine the gravitational wave spectrum is the bubble wall velocity. Using holography we have determined this parameter at strong coupling for the first time. Link to the article.

We have explored how to improve the hybrid model description of the particles originating from the wake that a jet produced in a heavy ion collision leaves in the droplet of quark-gluon plasma (QGP) through which it propagates, using linearized hydrodynamics on a background Bjorken flow (Link).




(a) $v_{\mathrm{cell},x}$ profile.

**Figure 8.** Transverse flow velocities vcell at freezeout, Tf = 154 MeV, extracted from the calibrated 2 + 1D viscous hydrodynamics calculation

We have derived the planar limit of 2- and 3-point functions of single-trace chiral primary operators of N=2 SQCD on S4, to all orders in the 't Hooft coupling (link).

We have computed thermal 2-point correlation functions in the black brane AdS5 background dual to 4d CFT's at finite temperature for operators of large scaling dimension and found a formula that matches the expected structure of the operator product expansion (link).

We have constructed the non-relativistic and Carrollian versions of Jackiw-Teitelboim gravity (link).

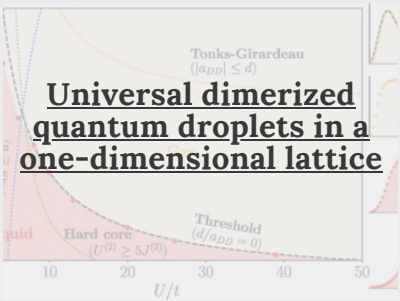
# QUANTUM TECHNOLOGIES

The group has contributed to several quantum pillars, Sensing, Simulation and Computation. In **Quantum simulation** we have: a) Obtained the phase diagram of binary mixtures of ultracold atomic gases loaded in optical lattices. Demonstrating the presence of quantum droplets, Morera et al PRL 2021. b) Studied the dynamics of a dark soliton in a two-component immiscible mixture analyzing the reflection and transmission of the dark soliton through the domain wall [Arazo, Mayol, Guilleumas PRA 2021], c) Studied the equiliabration and collisions of ultradilute quantum droplets, Cikojevic, et al, Phys. Rev. Research 2021, d) Proposed the combination of subwavelength, two-dimensional atomic arrays and Rydberg interactions as a powerful platform to realize strong, coherent interactions between individual photons with high fidelity, Moreno-Cardoner et al PRL 2021.

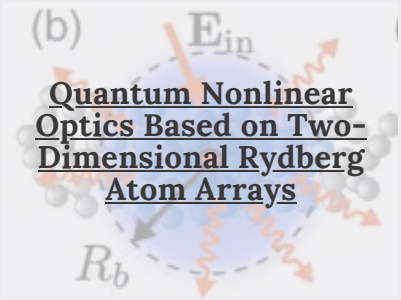
In **Quantum Sensing**, we have proposed a dipolar BEC in a shell-shaped potential as a preliminary setup for realizing a gravity sensor in space laboratories, Arazo et al New Journal of Phyisics (2021).

In **Quantum Algorithms**, we have worked on the development of a new class of Markov chains for strongly interacting systems using tensor networks. [M. Frías et al., https://arxiv.org/abs/2104.13264, accepted in SciPost.]

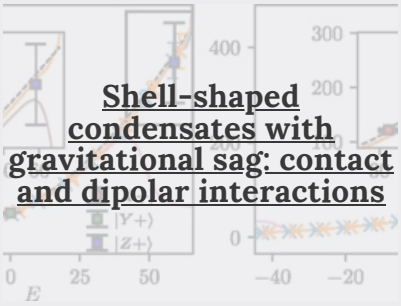
## Main scientific results:




**Universal dimerized quantum droplets in a one-dimensional lattice**




**Quantum Nonlinear Optics Based on Two-Dimensional Rydberg Atom Arrays**




**Shell-shaped condensates with gravitational sag: contact and dipolar interactions**

# STAR FORMATION

The star-formation group has been awarded 306 hours of observing time with the Karl G. Jansky Very Large Array (VLA) to conduct the Large Project "VOLS: The VLA Orion A Large Survey" (PI: G. Busquet). The goal of the VOLS project is to build a census of the stellar population to investigate how the mass accretion rate and mass-loss rate proceed with the protostellar evolution and how they depend on the birth environment and on the mass of the star. VOLS will cover 0.5 deg2 of the Orion A molecular cloud (see Figure 1) at two different radio frequency bands that will be confronted with state-of-the-art simulations of star formation. The observations will start in March 2022.

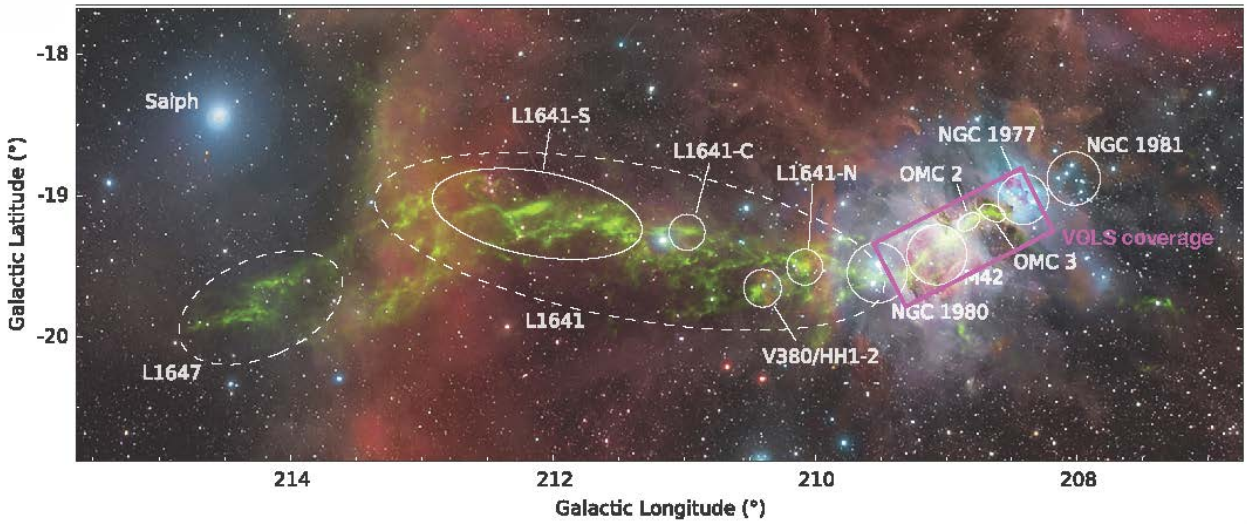



**Figure 1:** Composite of optical data overlayed with the Planck-Herschel column density map of Orion A in green. Positions of noteworthy objects and regions are marked and labeled. The pink rectangle depicts the area covered by the VOLS project. Figure adapted from Meingast et al. (2016).

The group has also been awarded the third year of a multi-year PRACE Tier-0 supercomputing grant, providing 23 million core hours, that has been used to carry out large-scale simulations of turbulent star-forming regions. The simulations have been used to study the dynamical importance of magnetic fields in the formation and evolution of molecular clouds. Using smaller-scale simulations, we have also demonstrated that the mass of stars is assembled over an extended period of time, with a large fraction of the

material originally located outside their progenitor cores (see Figure 2). These findings are in contradiction with previous star-formation models and shed new light on the origin of the mass distribution of stars.

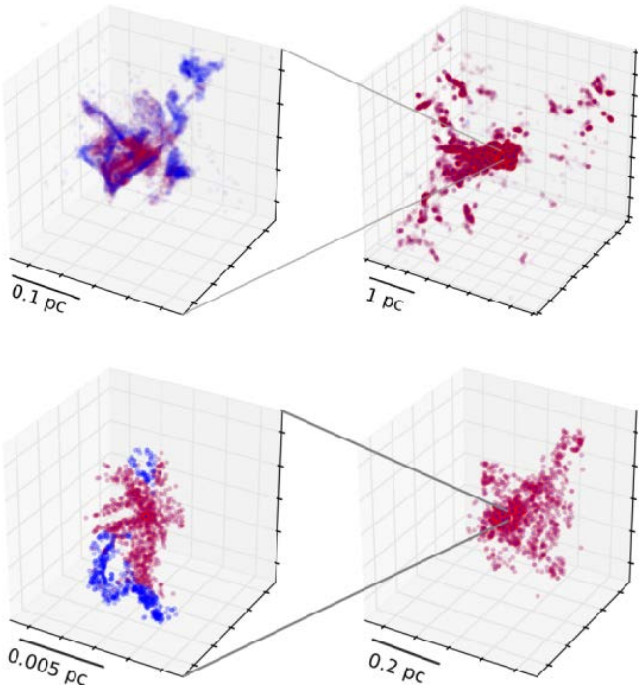



**Figure 2:** Examples of two progenitor cores that will form a high-mass star, Mstar = 28 M⊙ (upper panels), and a low-mass star, Mstar = 0.21 M⊙ (lower panels), visualized through their tracer particles. Left panels: The 0.25 pc (top) and 0.01 pc (bottom) central regions around the (red dots are tracers that will accrete onto the star, blue dots are the remaining tracers of the cores). Right panels: The whole 4 pc simulation box (top), and a 0.5 pc sub-cube (bottom) centered around the same star as in the left panels. The red dots are the locations of all the tracers that will accrete onto the stars by the end of the simulation. A significant fraction, ∼ 90% (top) and ∼ 60% (bottom), of the final stellar mass is found outside the progenitor core.

To investigate the role of the magnetic field in star formation, we have collaborated in a systematic observational study of a number of massive star-forming clumps. We have found that the fragmentation of star-forming clumps is affected by the magnetic field strength (see Figure 3).

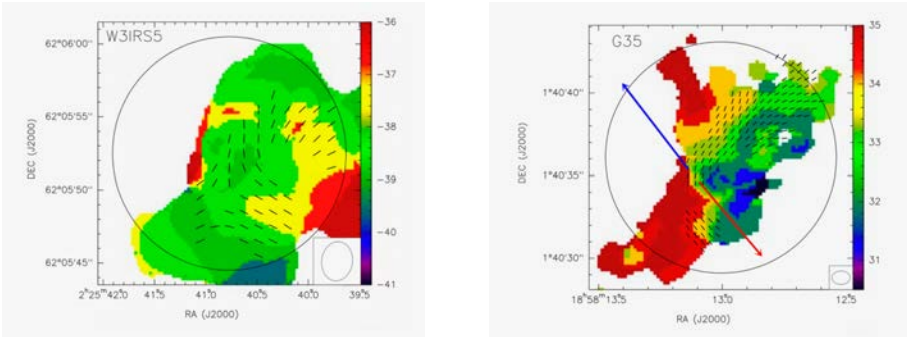
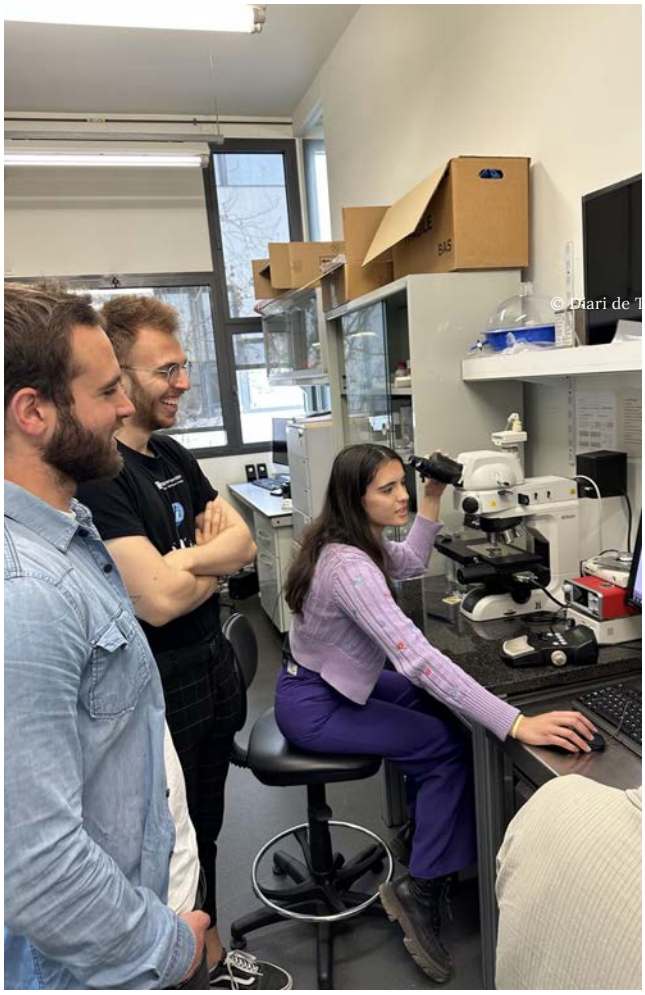



**Figure 3:** Examples of two massive clumps with a stronger magnetic field (relative to self-gravity) and lower level of fragmentation (left panel) and weaker magnetic field and higher level of fragmentation (right panel). The colour scale indicates velocity in km/s and the black segments show the magnetic field orientation.

# LIFE AT THE ICCUB

## Launch of new Master in Quantum Science and Technology in Barcelona

The Technological Unit of the Institute of Cosmos Sciences is one of the research groups that has joined the initiative of the Fab-LabUB of the University of Barcelona, where researchers from the Faculties of Physics, Chemistry, Medicine and Fine Arts also participate.



The Fab-Lab UB group was organized

during the month of March, when the authorities and the professionals of the sanitary facilities warned of the need to increase the stock of protective material for

# WELCOME

## Juan Torres

Juan Torres-Rincon joined the Institute of Cosmos Sciences in December 2021 after several postdoctoral experiences in Frankfurt (Germany), Stony Brook (NY, USA), Nantes (France) and Barcelona. He is Lecturer Professor at the University of Barcelona and works in the theory of relativistic heavy-ion collisions. In particular, he has experience in the application of effective field theories and many-body techniques to describe the low-energy domain of QCD, the theory of strong interactions. Juan is interested in relativistic kinetic theory, transport phenomena, and in anomalous properties of chiral plasmas. He looks forward to a better understanding of the different phases of QCD and the transitions among them, by analyzing the experimental outcome of heavy-ion colliders.

## Carla Marín Benito

Carla Marin joined the ICCUB in September 2021 as a Lecturer Professor, following two postdoctoral fellowships at Laboratoire de l'Accélérateur Linéaire (Orsay, France) and CERN. Her research in the field of experimental high energy physics focuses on the study of rare b hadron decays within the LHCb experiment at CERN, with the goal of testing the Standard Model of Particle Physics.
Carla's expertise lies in the acquisition, reconstruction, calibration and analysis of particle physics data and she is currently responsible for the real time acquisition and processing of the upcoming LHCb Run 3 data.

ORCID number: 0000-0003-0529-6982

## Gemma Busquet

Gemma Busquet joined the ICCUB in 2021 as a Lecturer Professor through the Serra Hunter program. Her postdoctoral career includes a research contract at the Istituto di Astrofisica e Planetologia Spaziali (Italy), at the Instituto de Astrofísica de Andalucía (Spain), at the Institut de Ciències de l'Espai (Spain), and at the Université Grenoble Alpes (France). She is a radio astronomer working in the field of star and planet formation. She is particularly interested in the early stages of stellar cluster formation in high-mass star-forming complexes using a multi-scale approach. Her work also focuses on the physical and chemical properties of protostellar shocks and on the chemical complexity of protostellar cores.

ORCID number: 0000-0002-2189-6278

## Chervin Laporte

Chervin Laporte joined the ICCUB in November 2021 as a distinguished researcher and ERC Group Leader. Before his appointment at the UB, he held three independent postdoctoral fellowships as a Junior Fellow of the Simons Society of Fellows at Columbia University (2014-2017), a CITA National Fellow at the University of Victoria (2017-2019) and a Kavli Fellow at the Kavli Institute for the Physics and Mathematics of the Universe (2020-2021). His research interests are in galaxy formation, Galactic dynamics, Galactic Archaeology and astrophysical tests of dark matter. His research combines both numerical simulations of galaxy formation and observations of the Galaxy through data mining of large photometric, spectroscopic and astrometric surveys to study the formation of the Milky Way and dynamical processes shaping galaxies as well as the distribution of dark matter in them.

ORCID number: 0000-0003-3922-7336

## Vincent Mathieu

Vincent Mathieu has joined the ICCUB in February 2021 as a Serra Húnter Lector. He obtained his PhD in 2009 from University of Mons. His postdoctoral career includes research contracts at University of Valencia, ECT*-Trento, Indiana University and the Jefferson national Laboratory (JLab). He returned to Spain at the Complutense University of Madrid in 2019 with the 'programa de atracción de talento'. Vincent's research interests lie in particle/hadronic physics, in particular in the search and study of exotic hadrons (resonances that don't fall into the traditional quark model). He's working closely with experimental collaborations such as GlueX and CLAS (at JLab), and, COMPASS and LHCb (at CERN). His expertises consists in developing formalisms to extract observables from specific reactions, developing theoretical models and extract resonance properties from experimental data.

ORCID number: 0000-0003-4955-3311

## Ricardo Vázquez

Ricardo Vazquez Gomez joined the ICCUB in February 2021. His postdoctoral career includes a 4-year contract at the Laboratori Nazionali di Frascati, a CERN Fellowship and an associated researcher at Universidade de Santiago de Compostela. His research focuses on the study of flavour physics with the LHCb detector. In particular he is interested in measurement of the Lepton Flavour Universality in semileptonic Bs decays as they can offer complementary information on the already exisiting anomalies measured by the B-factories.

## Licia Verde is granted the 2021 Rei Jaume I Award for Basic Research

The prize was awarded to Dr. Gil-Marín as one of the most brilliant researchers of his generation in the field of cosmology and for his outstanding contributions to the analysis and interpretation of galaxy mapping, which allowed advancing in our understanding of the accelerated Universe.

Dr. Gil-Marín is taking part in the mapping project Dark Energy Spectroscopic Instrument (DESI), to measure the effects of dark energy in the expansion of the Universe.


## Teresa Antoja awarded the Leonardo Grant for Basic Sciences

Teresa Antoja, a Ramón y Cajal Researcher from the Institute of Cosmos Sciences of the University of Barcelona, has been awarded one the six Leonardo Grants for Basic Sciences by the BBVA Foundation.

This distinction is bestowed upon researchers between the ages of 35 and 40 who have remarkable scientific production levels. The grant consists of 40.000€ that will support the realization of Antoja's research project "Analysis of the shake that our Galaxy suffered in the recent past" in the field of Galaxy formation and evolution.

## Prof. Domènec Espriu designated director of the State Research Agency

The prize was awarded to Dr. Gil-Marín as one of the most brilliant researchers of his generation in the field of cosmology and for his outstanding contributions to the analysis and interpretation of galaxy mapping, which allowed advancing in our understanding of the accelerated Universe.

Dr. Gil-Marín is taking part in the mapping project Dark Energy Spectroscopic Instrument (DESI), to measure the effects of dark energy in the expansion of the Universe.

## José Luís Bernal awarded the XXV Doctoral Senate Second Prize

Our former PhD student José Luis Bernal wins the XVI Prize for the Spanish Doctoral Thesis in Astronomy and Astrophysics with his work "Cosmology on the Edge of the Λ-Cold Dark Matter".

Supervised by the cosmologist Licia Verde, José Luis Bernal defended his thesis last September, 13th, and is currently doing a postdoctoral stay at Johns Hopkins University (JHU,Baltimore, United States).

# TECHNOLOGICAL UNIT

## Gaia

After the publication of EDR3 in December 2020, our team has actively worked on the validation of the new data products that will be published in DR3 (announced for June 13th, 2022), remarkably, the BP/RP and RVS spectra. Meanwhile, the complete cross-matching of observations to sources for DR4 was executed in MareNostrum, processing 142 billion detections from the 5.5 years of nominal operations (see figure), and resolving close pairs of sources for the first time - leading to a more complete and consistent catalogue. The team also supported the first runs of the new pipeline for crowded fields.

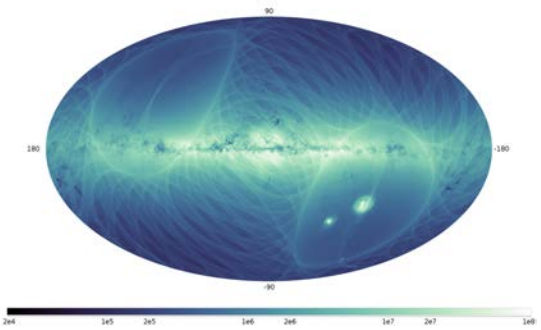


Figure X: Credits: ESA/Gaia/DPAC, F. Torra, J. Portell, J. Castañeda, M. Bernet, S. Bartolomé and CU3-IDU/DPCB team

## Ariel

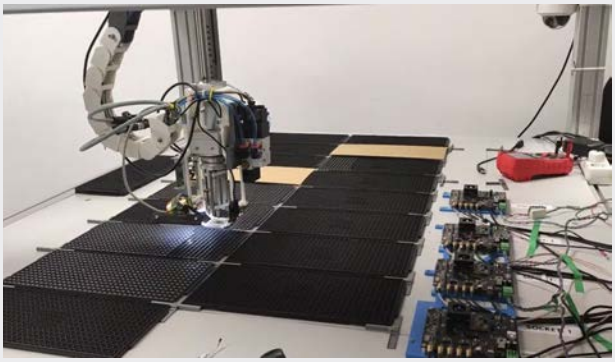
The ICCUB participates through the IEEC in the Ariel ESA mission led by RAL. Its main task is the development of the Telescope Control Unit which includes the control of the mechanisms and the measurement of the telescope cryogenic temperature.

## PLATO

In collaboration with other teams at IEEC (mostly from ICE), our team has revised the work packages and development tasks definition of the Ground-based Observation Programme for the Ground Segment Requirements Review of the mission.

## HERD

The group implemented the 16-channel BETA ASIC developed in a 130 nm technology developed for the SiPM readout of the Scintillating Fiber Tracker (FIT) at the HERD facility. The ASIC is the main candidate to be employed in the Plastic Scintillator (PSD) as a trigger also in the HERD. Initial characterization of the ASIC showed that it's main functionalities are working, but still more tests will be performed during 2022. The ASIc will be distributed to other institutions to also evaluate it. A revised version will be submitted during 2022 including new functionalities to better adapt to the PSD requirements. This work was successfully presented at the NSS 2021 conference.



## CTA

The technological unit submitted for production a new ACTA ASIC version based on AMS CMOS 0.35um technology, in order to implement a "test pulse" functionality to be able to perform electrical tests at the front end level. Additionally, the technological unit managed the production of 50 wafers to equip the 9 MST NectarCAM for the CTA-north observatory in La palma, and 4 LST for the CTA-south observatory.

## LHCb

The calorimeter Front End Boards (FEB) and 3CU (control boards) were installed at the LHCb Pit in the Calorimeter sub-detector crates. Cabling works were performed which included all the optical links to be used for the electronics control and data transmission to the data analysis farm. Commissioning on the electronics has started and many activities on electronics control and monitoring software have been adapted and developed when needed to. Additionally, the calorimeter sub-detector has participated in data taking activities used for LHCb global detector commissioning such as Beam Test (proton beam collisions) and cosmic runs.

## Virgo

The ICCUB-Virgo group has significantly grown during 2021, including one full-time software engineer to support several collaboration-wide developments. Our work on rROF-based denoising for Virgo achieved successful results, reaching significant SNR improvements on real GW events.

The Technological Unit delivered the PSD electronics units for the SQB1 and SQB2 detectors at the SIN subsystem of the interferometer, with the respective calibrations in vacuum and light environments.

## IAXO

The ICCUB has been debugging the radiopure readout electronics for the Micromegas sensor in order to get ready for final production. Detailed meetings have been useful to adapt the electronics design to the final mechanical dimensions of the Baby IAXO detector. Detailed Monte Carlo simulation studies of their effect on the noise have been reproduced with the new detector topology

## LISA

A study of the feasibility of an integrated approach for MELISA electronics (MEMS-based compact magnetometer for LISA). Two different IC technologies were studied in terms of noise and dynamic range in order to find the most suitable one for this application. In addition, simulations were performed to evaluate the net charging rate induced in the LISA test masses by background particles like cosmic rays. This information was used to study the possibility of using the Next Generation Radiation Monitor (NGRM) to monitor the charging of the test masses.

## FASTIC

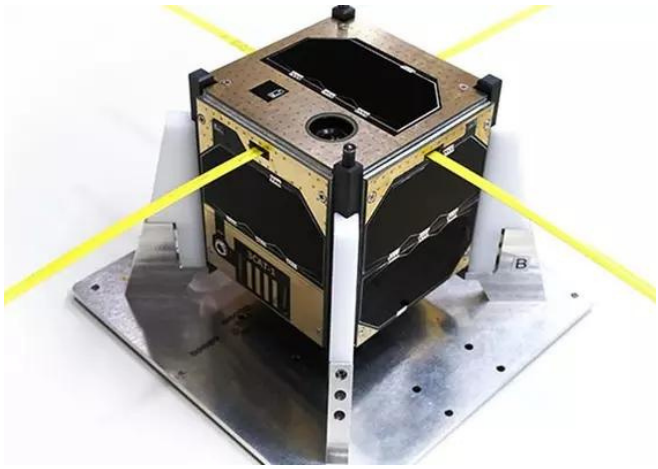
The ASIC connected to Multi-anode PMTs was studied for the future upgrade of the Ring-Imaging Cherenkov (RICH) detectors to capture the time of arrival of Cherenkov photons. This work was successfully presented at the NSS 2021 conference and TWEPP 2021.

## MATRIX16

The instrumentation division published the MATRIX developments in MDPI Electronics. “MATRIX16: A 16-Channel Low-Power TDC ASIC with 8 ps Time Resolution”. Electronics 2021, 10, 1816. https://doi.org/10.3390/electronics10151816

## Nanosatellites

The NewSpace strategy for Catalonia, where members of the IEEC are participating actively, has launched the Enxaneta satellite. In parallel, the Dawn Dusk Debris Detection Cubesat (4DCube) mission has been presented as an idea to ESA. The concept has been selected as a possible action for future Space Situational Awareness activities. Also, a payload for Earth Observation is under development. Finally, a future Photometric mission is under study.



## ET

The Einstein Telescope was approved for the ESFRI roadmap 2021 (European Strategy Forum on Research Infrastructures). Our team will contribute to its e-Infrastructure Board (eIB), specially on the definition of the overall computing and massive data handling.

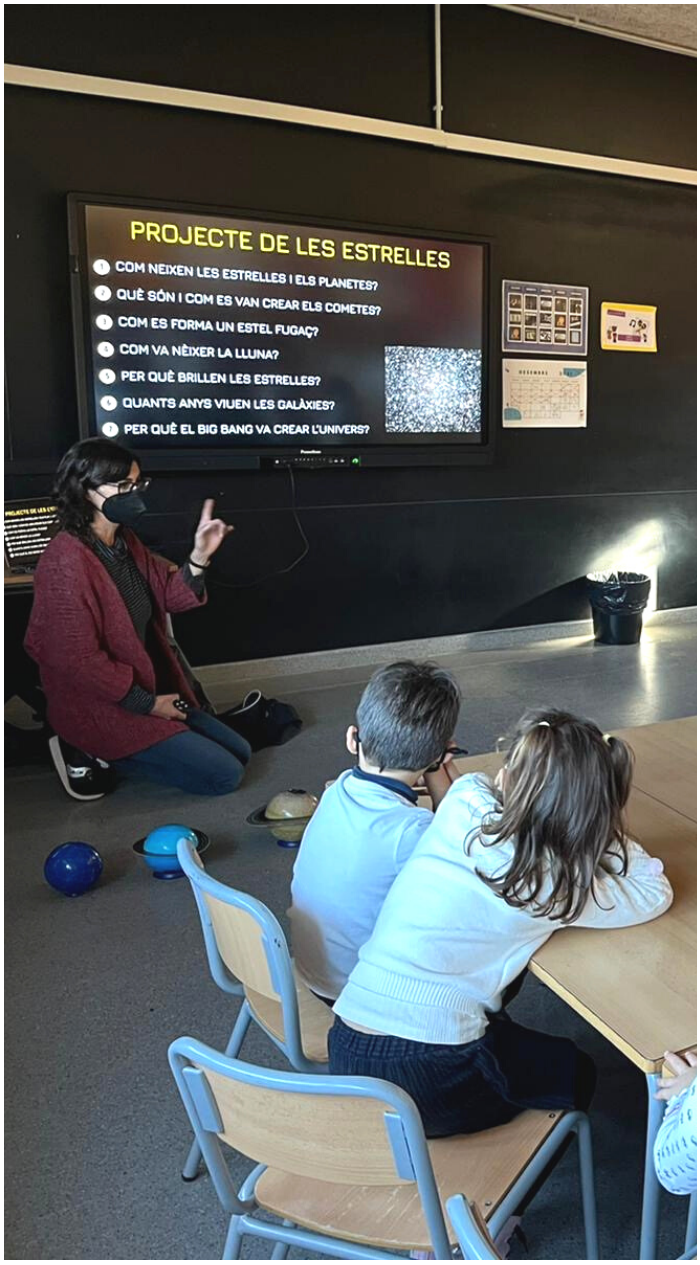
## GRANTECAN

The algorithms for the collision detection and trajectory planning for the MIRADAS instrument have been improved. They have been tested, confirming their proper performance, and integrated in the instrument software

# OUTREACH

The ICCUB research groups are very active in the dissemination of their activity in schools and public centers, and since its establishment, the Institute has provided economic and human support to the extent possible. Thanks to the María de Maeztu award, the Institute has been able to significantly expand this support. The Institute's main outreach activities are:

- Publication of outreach articles
- Astronomy sessions, courses and public talks
- "Taller de Física de Partícules" organization
- Fabrication and management of itinerant exhibitions.
- Astronomic events follow-up

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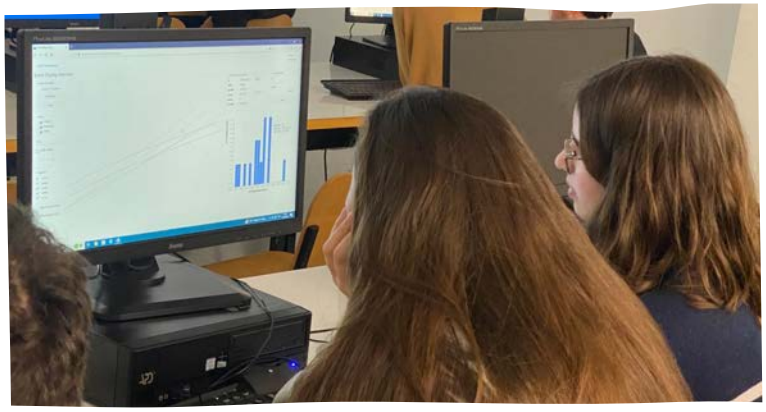
ACTIVITIES
IN 2021

# MASTERCLASS ON PARTICLE PHYSICS 2021

The Masterclass on Particle Physics is an activity addressed to high school students in their final year, as part of the international activity Hands on Particle Physics. The workshop has taken place at the UB since 2005 and lasts one day, during which students attend talks about Physics and study real data from LHC. The students also visit the laboratories and attend a presentation about the courses offered at the Faculty of Physics.



In 2021 the Masterclass held a single edition on the 12th of March because of the COVID-19 pandemic at the Faculty of Physics.


**107** STUDENTS — ATTENDANCE

**93** — HIGH SCHOOLS

# TRAVELLING EXHIBITIONS



The ICCUB owns nine travelling exhitibions. These exhibitions have different printed versions that are displayed annually in different external centers, like high schools, libraries or community centers. All the exhibitions also have online versions, some of them translated in several languages.

In 2021, the ICCUB launched the presentation of the new travelling exhibition **AstrónomAs** , which counted with several ICCUB members as part of the comissionary committee.

# Exhibitions

- **AstrónomAs**
- **Dones i Física**
- **De la Terra a l'Univers**
- **Amb A d'AstrònomA**
- **Les distàncies còsmiques**
- **Mil milions d'ulls per a mil milions d'estrelles**
- **Viatge cap a l'univers fosc**
- **Telescopi Assumpció Català**
- **Investigadores en Física Nuclear**

11 DESTINATIONS

9 TRAVELLING EXHIBITIONS

# OTHER OUTREACH ACTIVITIES

ICCUB members give outreach talks addressed both to students and general public; they also give courses and participate in workshops, science festivals or students fairs. They assist high school students on their final projects, organize astronomical observations, and give coverage to remarkable astronomical ephemeris.

## REMARKABLE OUTREACH ACTIVITIES

### Art&Science: Dibuixa el teu Asteroide!

To celebrate the **2021 International Asteroid Day**, the ICCUB organized the drawing contest "Dibuixa el teu asteroide!" aimed at children from Catalonia's primary schools to foster their interest on the topic, learn more abou asteroids and put their artistic skills to the test.
The winning work was "impactes a la Terra" by Valèria Endrino Lainz.

# Barcelona's Science Fest 2021

The ICCUB participated in the 2021 edition of the Barcelona's Science Fest, an outreach event held in the context of the second City and Science Biennal of Barcelona.
This event offered a wide array of activities to reflect and debate about scientific knowledge to face the challenges of our century, including activities of all shapes and sizes: debates, talks, round tables, workshops, conferences, etc.
Our members participated with three workshops:

- 3D Constellations and Virtual Reality walk through the Milky Way
- Quarks, the building blocks of Matter
- Physics Simulations


# Solar Observation: Science Week 2021

ICCUB researchers participated in a Solar Observation in Sant Joan Despí to celebrate Science Week 2021.
They used an H-Alpha filter to observe the the emission spectrum of our Sun in the 6562,8 Å wavelenght with the junior students of the Sant Joan Despí Highschool.

## Dark Matter Day 2021

In 2021, we celebrated Dark Matter Day with a disseminative round table around this mysterious gravitational phenomenon with the participation of Héctor Gil and Mercè Romero from the ICCUB.


They, together with other experts on the area, discussed what knowledge we have about dark matter and the latests results obtained around it from different perspectives.

## 11F Round table "Actions to improve the visibilty of the work of female scientists

On occasion of the **International Day of Women and Girls in Science**, the ICCUB along with several other UB institutes organized a joint event.

- "Modeling COVID19 from a perspective of complex systems"

- Round table: "Actions to improve the visibility of the work of female scientists"


ICCUB researcher Jordi Miralda also offered a conference to highlight the contributions of women to astrophysics.

# Quantum Mechanics Simulations 2021

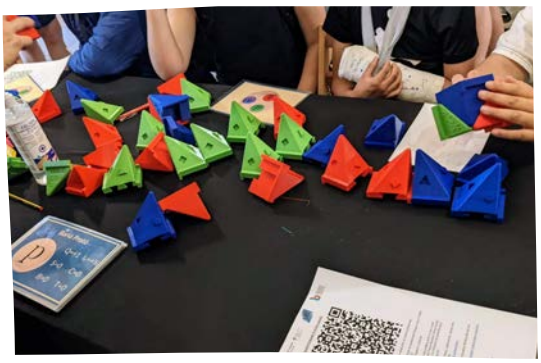

During 2021, the Physics Simulations project, coordinated by ICCUB researchers Bruno Juliá and Muntsa Guilleumas, held the presentation of the new phone App "**Saved by the Paradox**" which was the result of one of the internships of students in the project.

In this game, the user controls a door that separates two chambers with a gas. As the individual gas particles approach the door, the player has to open and close it quickly to allow only fast particles to pass in one direction and only those that move slowly in the other. In doing so, the player creates a temperature imbalance between the two chambers (and a decrease in gas entropy!).
This imbalance is then used as a source of energy to drive a car that has to flee before the Monster catches it!

The Quantum Simulations project aims to introduce basic concepts of quantum mechanics and the physics of ultracold gases to the students of baccalaureate and degree. They are based on the development of computer programs created by students under the supervision of professors.

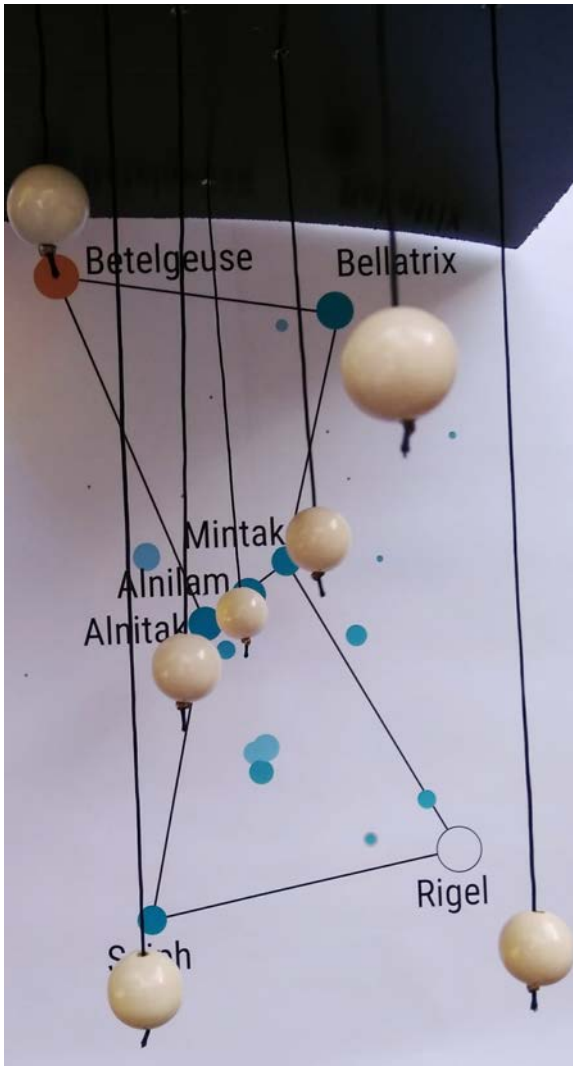
In the workshops, students are able to of make simulations with computers of several experiments in which the quantum properties of matter are revealed.

# Quarks: the building blocks of matter



Have you ever wondered what the Universe is made of? With the workshop "**Quarks, the building blocks of matter**" you will learn about the particles that make up all matter in our Universe using a three-dimensional puzzle designed at CERN, the European Centre of Nuclear Research. With this activity, we will approach the fundamental laws that determine how these particles come together to form protons and neutrons and how they interact among each other. This workshop is the creation of several members of the Hadronic Physics Group of the University of Barcelona.

# 3D Constellations




In the project Constellations in 3D you will find a virtual tour of the galaxy by Gaia, and how to buil the Orion constellation in three dimensions.

**Gaia: The Galaxy in 3D**

It is a virtual tour where visitors will be able to see various materials related to the mapping of the sky and the measurement of stellar distances. The highlight of the workshop will be Gaia's virtual reality program that will allow us to virtually travel through our Galaxy.

**3D Constellations: Orion**

We will build the Orion constellation in three dimensions, taking into account both the position and the distance of the stars that form it.

# PUBLICATIONS, PRESS & MEDIA

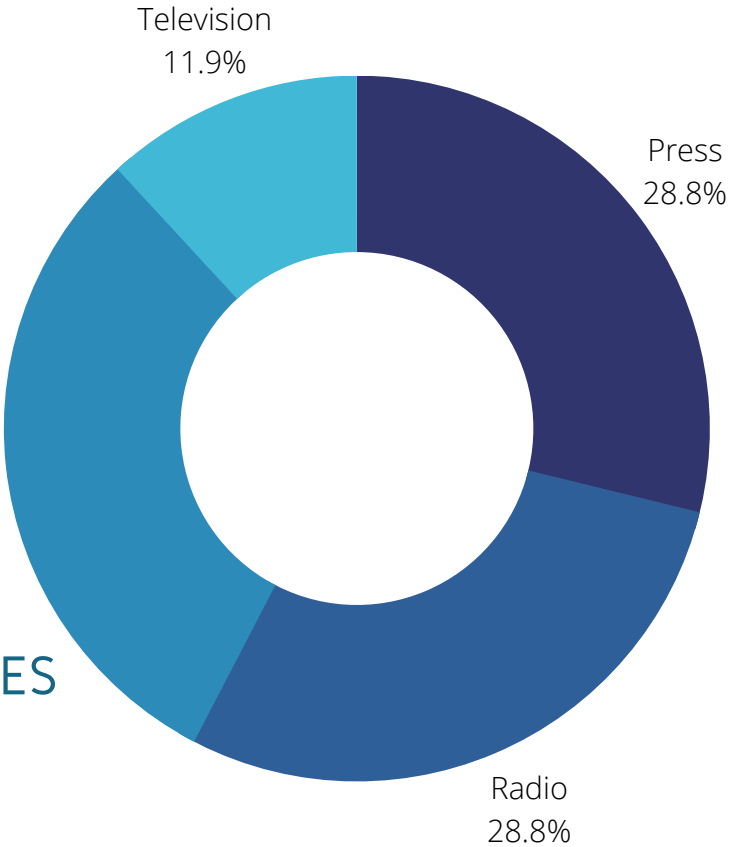
During 2021 the Institute's members have actively participated in the dissemination of science, through the publication of popular science books and articles in journals and magazines; giving interviews about their groups' scientific publications to press and television; commenting about discoveries or remarkable achievements as experts, and participating in roundtables and debates in radio shows.

The astrophysicist **Mark Gieles** discusses the results of his new publication in Nature Astronomy on the swarm of black holes found in the globular cluster Palomar 5 in RTVE.

The astrophycist **Chervin Laporte** comments on his discovery of fossil spiral arms on the edge of the Milky Way in an interview with EuropaPress .

## Media appearances

Our researchers gave written statements and comments about scientific articles and discoveries in their appearances in the media.




452 APPEARANCES

+300% THAN 2020

## TELEVISION

The cosmologist **Licia Verde** receives the Rey Jaume I award for basic research for her work on theoretical cosmology life in Telemadrid.


## ONLINE MEDIA

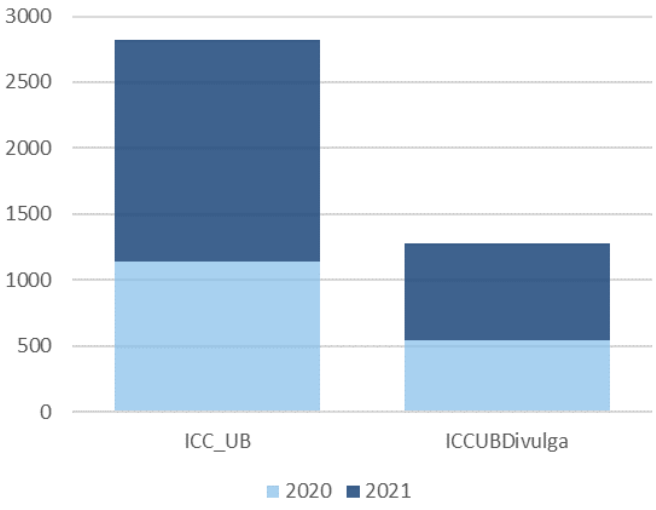
Online media Europapress covers the designation of professor Domènec Espriu as the new director of the State Research Agency

## PRESS

**Teresa Antoja** is interviewed by the newspaper El País on her work on galaxy evolution, that rendered her the Leonardo Grant for basic research.

# Social Media appearances

Our social media strategy has been to increase the Institute's visibility among the scientific community and to reach a more global audience through the outreach twitter account.




1679
+526 IN 2021

FOLLOWERS
@ICC_UB

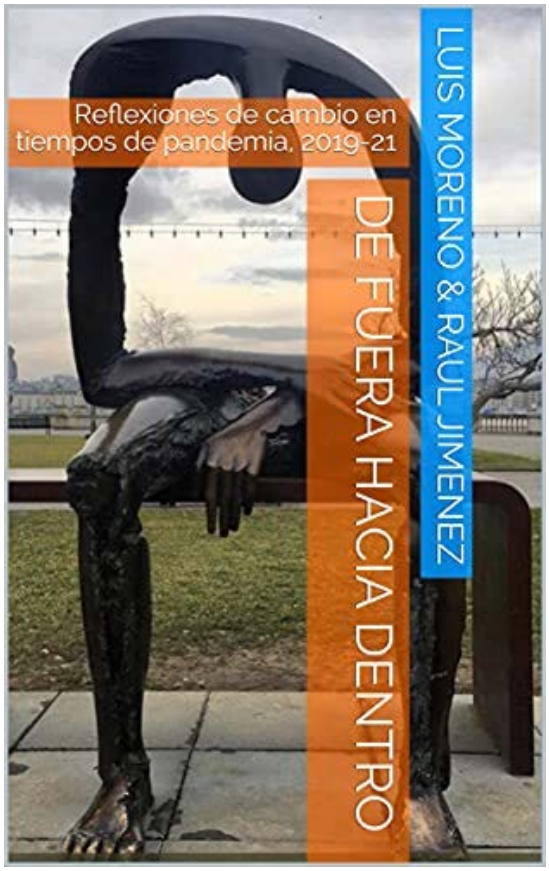
728
+174 IN 2021

FOLLOWERS
@ICCUBDIVULGA

# Books and didactic materials

Our researchers are also active in the editorial field. In 2021, we highlight the following publications:

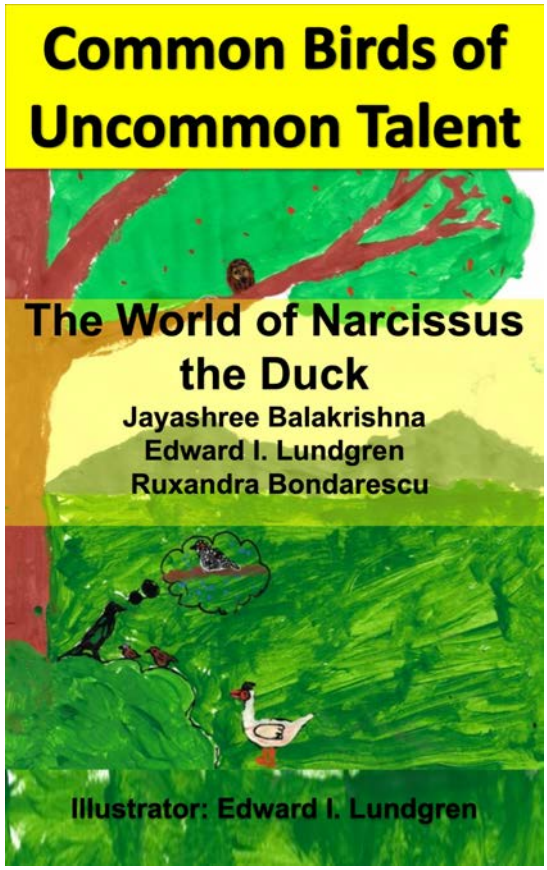
## "De fuera hacia dentro: Reflexiones de cambio en tiempos de pandemia, 2019-21"




This new book collects several articles where the impact of the exponential robotization that is seen in society is discussed. The themes of these essays span from the lack of human interaction in an article called "Where is the Agora?", to extreme robotization, and to what kind of society we are building for the future.

By ICCUB-ICREA researcher **Raúl Jiménez**.

## "Common Birds of Uncommon Talent: The World of Narcissus the Duck"




Their book introduces readers to conservation through birds that can easily be observed in every neighbourhood. Biodiversity is a good indicator of environmental health. The disappearance of common birds raises alarm bells. The dwindling numbers of city sparrows around the world is particularly worrisome. It shows that cities are becoming increasingly unhealthy.

By ICCUB researcher **Ruxandra Bondarescu**.