ROSEBUD

Final report

November 2014

ROSEBUD (acronym of **R**are **O**bjects **SE**arch with **B**olometers **U**nderground**D**) is a collaboration, between the Institut d'Astrophysique Spatiale (IAS, France) and the University of Zaragoza (UNIZAR, Spain), which started in 1998. It was dedicated to the development, optimization and characterization at LSC of scintillating bolometers to be used in nuclear and astroparticle physics experiments. Since 2006, both institutions are also members of the EURECA collaboration, a large European effort in dark matter search whose main goal is to combine different detection techniques and target materials with a modular design in a unique low background cryogenic set-up scalable up to 1 ton total target mass.

ROSEBUD has carried out experimental runs in LAB2500 of the LSC since 1999 to 2007 and then moved the experimental set-up to Hall B of Lab2400 where it was upgraded. It continued its activities, completed the programme in 2012 and proceeded with the decommissioning of the experimental set-up at LSC in 2013.

In this report, we briefly describe the collaboration, the detection technique, the experimental set-up installed at the LSC, the scientific goals and the main results obtained. It also includes a list of the scientific production of ROSEBUB (papers, talks, posters and Ph.D. theses).

Full information of the collaboration is available in http://www.unizar.es/lfnae/rosebud/

The collaboration

Participants

- Group of Spectrométrie Thermique pour l'Astrophysique et la Physique (STAP)
  Institut d'Astrophysique Spatiale (IAS)
  Bâtiment 121, Université Paris-Sud 11 and CNRS (UMR 8617), 91405 Orsay Cedex, France

- Group of Nuclear and Astroparticle Physics (GIFNA)
  University of Zaragoza (UNIZAR)
  C/Pedro Cerbuna 12, 50009 Zaragoza, Spain

Collaboration size (in 2012): 2 institutions, 13 people.

4 people from Istitut d'Astrophysique Spatiale (IAS; Orsay, France).

9 people from University of Zaragoza (UZ, Spain).

The LSC staff has assisted us to the installation of the metallic structures, Faraday cage, gas handling and pumping system, and has provided logistical support during the move from the LAB2500 to the LAB2400 Canfranc laboratory.

Funding

French CNRS/INSU (MANOLIA and BOLERO projects)

Programme National de Cosmologie (PNC)

Spanish Commission for Science and Technology (MEC, MINECO)

Gobierno de Aragón (Group in Nuclear and Astroparticle Physics)

EU Project ILIAS Contract No. RII3-CT-2004-506222, project P2007-08-LSC

LSC support: installation of the hut to contain the Faraday cage

The detection technique

ROSEBUD uses the so-called cryogenic calorimeters or bolometers, which are operated near zero absolute temperature to profit from the very low heat capacity of dielectric and diamagnetic materials at such temperature, and hence, very low energy depositions are able to produce measurable temperature increases. The collaboration has been a pioneer in the development of scintillating bolometers (a cryogenic hybrid detection technique with an excellent particle discrimination power).

The bolometer

A bolometer is a particle detector that consists of a crystal (absorber), thermally coupled to a thermal bath, and a thermal sensor glued on it (see figure 1-left). It measures the energy ΔE deposited by the interaction of a particle in the absorber through the temperature increase ΔT

produced in it. This temperature increase is so small that it becomes measurable only at extremely low temperatures (near absolute zero). That requires the use of a complex cryogenic system: a dilution refrigerator (DR) which is a device that reaches temperatures down to approx 10-20 mK profiting from the special thermodynamic properties of a mixture of ^{3}He and ^{4}He (see figure 1-right).

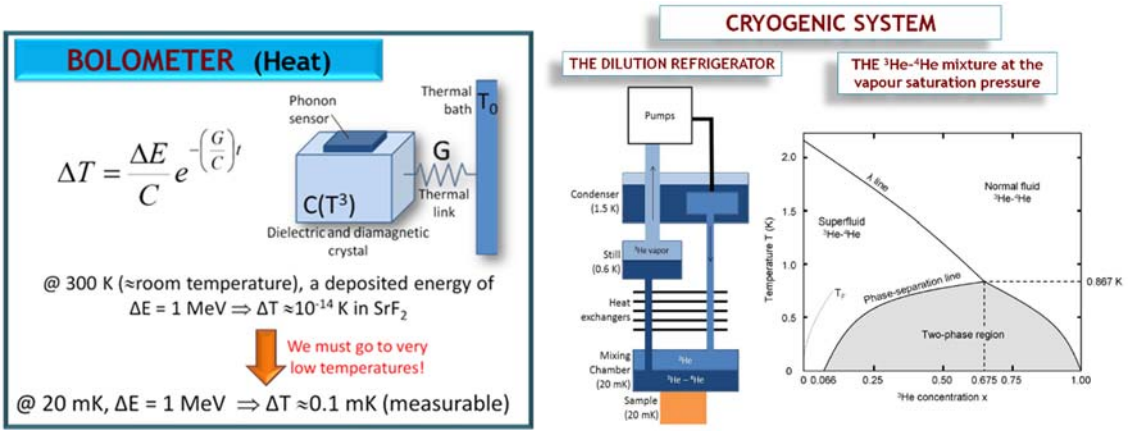

Fig. 1. ***Left:*** Schematic view of the bolometric detection technique. ***Right:*** Scheme of a dilution refrigerator (a cryogenic system operating near zero absolute temperature) and its operation principle.

Bolometers have many applications as particle detectors (dark matter detection, neutrino mass measurement, double beta decay and other rare event searches, etc.) because, apart from their excellent performances (good energy resolution and very low energy threshold), this detection technique also offers a wide absorber material choice.

The scintillating bolometer

Scintillating absorbers are mounted in a double bolometer configuration (see figure 2) to simultaneously measure the heat and light produced by the interaction of a particle. The second bolometer is a thin Ge disk (tens of μm in thickness) with the corresponding thermal sensor glued on it. Scintillation photons produced in the absorber and escaping from it are absorbed on the Ge disk, called optical detector.

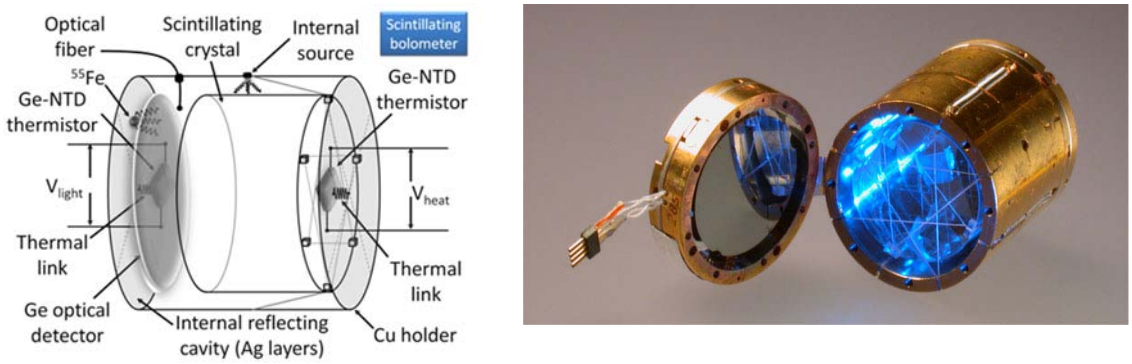

Fig. 2. Schematic view ***(left)*** and picture ***(right)*** of a scintillating bolometer. It is based on a double bolometer configuration in which the light produced in the scintillating crystal by a particle interaction is absorbed in the Ge disk.

Since scintillation yield strongly depends on the type of interacting particle, this simultaneous measurement allows event-by-event particle discrimination (see figure 3), increasing sensitivity of the detector to the searched signal.

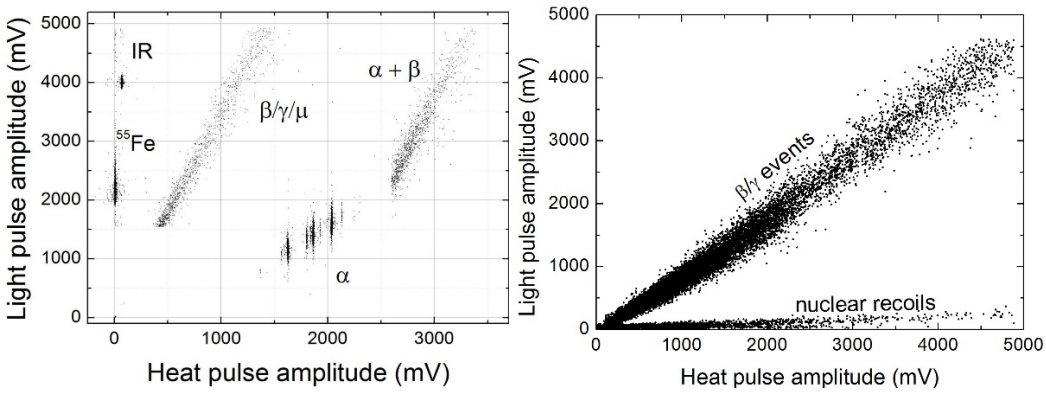

Fig. 3. Light versus heat scatter plot of a scintillating bolometer that shows its capability to distinguish β/γ particles from α particles ***(left)*** and from nuclear recoils ***(right)***.

The experimental set-up at LSC

The detectors (scintillating bolometers) are developed at IAS and mounted inside a copper frame thermally coupled to the mixing chamber of the DR (see figure 4-left). Preliminary tests are performed at IAS. Those detectors with best performances are moved and tested at Hall B of the LSC in an ultralow radioactive background environment. The external part consists of a 3x3x4.8 m^3 Faraday cage (acoustically isolated and vibrationally decoupled) used to avoid electromagnetic interferences (see figure 4-center), and the gas handling and pumping system for the DR (see figure 4-right).

Fig. 4. Experimental set-up at Hall B of the LSC. ***Left:*** Three scintillating bolometers mounted each inside a copper frame thermally coupled to the mixing chamber of the DR. ***Center:*** Acoustically isolated Faraday cage. ***Left:*** Gas handling and pumping system for the DR.

The DR is mounted inside the Faraday cage and surrounded by a shield (see figure 5) that, from inside to outside, consists of 25 cm of Pb bricks, a 1 mm μ-metal foil, a PVC box sealed and

flushed inside with boil-off LN_2 to remove airborne radioactive radon and 40 cm of polyethylene as neutron shielding.

Fig. 5. Pictures of the DR at Hall B of the LSC inside the Faraday cage with the shielding partially mounted.

Note: Until 2007, measurements were carried out at LAB2500 using a similar experimental set-up with a smaller Faraday cage

Scientific goals and main results

Scintillating bolometers have many applications in nuclear and astroparticle physics. We briefly summarize the main research fields tackled by ROSEBUD and the most relevant results obtained by the collaboration.

The dark matter problem

One of the most important challenges of the new century cosmology, astrophysics and particle physics is the nature of the ~85% of the matter of the universe that does not emit nor absorb radiation: the so-called dark matter. Scintillating bolometers are used in experiments for direct detection of this dark matter profiting from the wide absorber choice and background rejection capability.

- In the LSC, ROSEBUD has carried out the first underground light versus heat dark matter search with a $CaWO_4$ scintillating bolometer.
- ROSEBUD has developed and tested at LSC detector prototypes of Al_2O_3 and BGO obtaining excellent performances. These materials could be incorporated as targets in EURECA.
- It has also measured the light and heat response of several materials to nuclear recoils (the expected dark matter signal).

Neutron detection

Neutrons are relevant background in rare event physics.

- ROSEBUD has developed and tested scintillating bolometers of LiF and ^{6}LiF that could be applied to monitor the neutron flux inside the experimental shielding of a cryogenic dark matter experiment like EURECA through the resonance of the ^{6}Li(n,α) reaction (see figure 6).
- With the simultaneous use of a LiF and a Al_2O_3 scintillating bolometer ROSEBUD has measured the neutron flux (E>0.1 MeV) for moderated neutrons coming from a ^{252}Cf source placed outside the lead shielding.

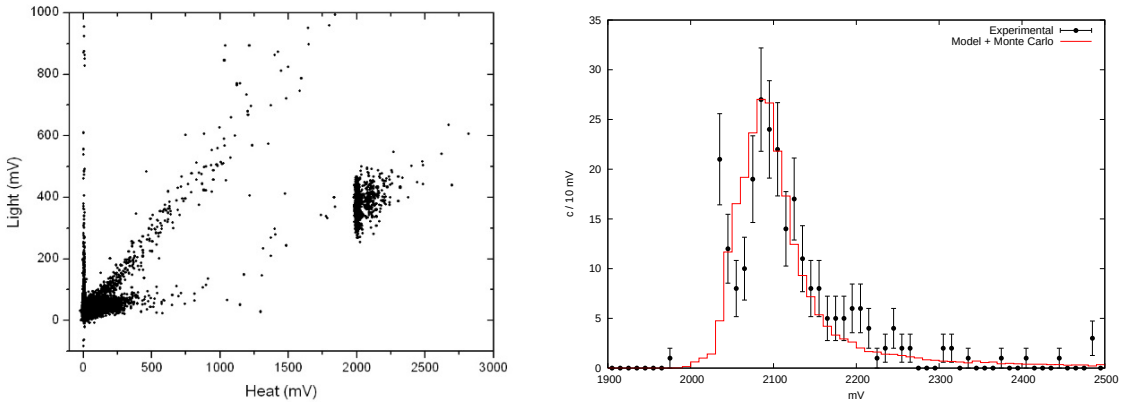

Fig. 6. ***Left:*** Light versus heat scatter plot of LiF irradiated with ^{252}Cf neutrons coming from outside the lead shielding. ***Right:*** Experimental and simulated spectra of absorbed fast neutrons in LiF.

Nuclear and fundamental physics

Scintillating bolometers can also be used in nuclear and multidisciplinary physics experiments. Among the ROSEBUD applications and relevant results one can cite:

- it has designed and constructed an ultralow background cryogenic facility
- with a $CaWO_4$ detector it has given improved limits to natural α radioactivity of tungsten
- it has measured the light and thermal yield of several materials for different particles
- with a BGO detector it has measured the L/K electron capture ratio of ^{207}Bi
- it has studied and measured the energy partition among heat, light and traps produced in the interaction of radiation with matter in several materials

Publications

2014

- **Neutron spectrometry with scintillating bolometers of LiF and sapphire.**
  N. Coron et al. Submitted to IEEE Transactions on Nuclear Science.
- **Response of parylene-coated NaI(Tl) scintillators at low temperature.**
  N. Coron et al., in "Proceedings of the RPSCINT 2013 – International Workshop on Radiopure Scintillators", The European Physical Journal (EPJ): EPJ WEB of Conferences 65:02001 (2014).

2013

- **Development of scintillating bolometers for dark matter searches.**
  M. Martínez et al., in "Proceedings of the 3rd Galileo-Xu Guangqi Meeting", International Journal of Modern Physics: Conference Series 23 (2013) 324.
- **Light Relative Efficiency Factors for ions in BGO and Al_2O_3 at 20 mK.**
  Y. Ortigoza et al., Astroparticle Physics 50-52 (2013) 11.
- **Study of parylene-coated NaI(Tl) at low temperatures for bolometric applications.**
  N. Coron et al., Astroparticle Physics 47 (2013) 31.

2012

- **Measurement of the differential neutron flux inside a lead shielding in a cryogenic experiment.**
  N. Coron et al., Journal of Physics: Conference Series 375 (2012) 012018.
- **Measurement of the L/K electron capture ratio of the ^{207}Bi decay to the 1633 keV level of ^{207}Pb with a BGO scintillating bolometer.**
  N. Coron et al., The European Physical Journal A 48:89 (2012).
- **Characterization of a SrF_2 Scintillating Bolometer.**
  C. Ginestra et al., in the issue entitled "Low Temperature Detectors (LTD-14): Part II" Journal of Low Temperature Physics 167 (2012) 973.

2011

- **Energy partition in sapphire and BGO scintillating bolometers.**
  Y. Ortigoza et al., Astroparticle Physics 34 (2011) 603.
- **2010 update on the ROSEBUD project.**
  N. Coron et al., in proceedings of "Identification of Dark Matter 2010", PoS(IDM2010)054.

2010

- **BGO scintillating bolometer: Its application in dark matter experiments.**
  N. Coron et al., in proceedings of "Topics in Astroparticle and Underground Physics (TAUP2009)", Journal of Physics: Conference Series 203 (2010) 012038.

- **Detection of fast neutrons with LiF and Al_2O_3 scintillating bolometers.**
  N. Coron et al., in proceedings of "Topics in Astroparticle and Underground Physics (TAUP2009)", Journal of Physics: Conference Series 203 (2010) 012139.

2009

- **Neutron spectroscopy with ^{6}LiF bolometers.**
  J. Gironnet et al., in proceedings of "The Thirteenth International Workshop on Low Temperature Detectors - LTD13", AIP Conference Proceedings 1185 (2009) 751.
- **A BGO scintillating bolometer as dark matter detector prototype.**
  N. Coron et al., Optical Materials 31 (2009) 1393.

2008

- **Our short experience at IAS and within ROSEBUD with radioactive contaminations in scintillating bolometers: uses and needs.**
  N. Coron et al., in proceedings of "The 1st International Workshop on Radiopure Scintillators for EURECA (RPScint'2008)", arXiv:0903.1539v2 [nucl-ex] (2008) 12.
- **Sapphire, BGO and LiF scintillating bolometers developed for dark matter experiments.**
  N. Coron et al., in proceedings of "Identification of Dark Matter 2008", PoS(IDM2008)007.
- **Thermal relative efficiency factor for recoiling ^{206}Pb nuclei in a sapphire bolometer.**
  N. Coron et al., Physics Letters B 659 (2008) 113.
- **Measurement of the Nuclear Recoil Thermal Relative Efficiency Factor with an Undoped Sapphire Scintillating Bolometer.**
  N. Coron et al., in proceedings of "The 12th International Workshop on Low Temperature Dectectors (LTD12)- Part II", Journal of Low Temperature Physics 151 (2008) 865.
- **Recent Performance of Scintillating Bolometers Developed for Dark Matter Searches.**
  A. Calleja et al., in proceedings of "The 12th International Workshop on Low Temperature Dectectors (LTD12) - Part II", Journal of Low Temperature Physics 151 (2008) 848.

2006

- **High performance scintillating bolometers in the search for WIMPs: ROSEBUD experiment.**
  E. García et al., in proceedings of "The Sixth International Workshop on The Identification of Dark Matter", World Scientific Publishing Co., edited by M. Axenides, G. Fanourakis and J. Vergados, (2006) 302.
- **Recent developments on scintillating bolometers for WIMP searches: ROSEBUD status.**
  J. Amaré et al., in proceedings of "The Ninth International Conference on Topics in Astroparticle and Underground Physics (TAUP2005)", Journal of Physics: Conference Series 39 (2006) 133.

- **UZ dark matter searches at Canfranc.**
  J. Amaré et al., in proceedings of "The Dark Side of the Universe, 2nd International Conference on the Dark Side of the Universe, DSU 2006", edited by C. Muñoz and G. Yepes. AIP Conference Proceedings 878 (2006) 99.

- **Scintillation of Sapphire under particle excitation at low temperature.**
  J. Amaré et al., in proceedings of "The Ninth International Conference on Topics in Astroparticle and Underground Physics (TAUP2005)", Journal of Physics: Conference Series 39 (2006) 200.

2005

- **Light yield of undoped sapphire at low temperature under particle excitation.**
  J. Amaré et al., Applied Physics Letters 87 (2005) 264102.

- **ROSEBUD-II. Light-heat discrimination with scintillating bolometers underground.**
  S. Cebrián et al., Nuclear Physics B (Proc. Suppl.) 138 (2005) 519.

2004

- **Bolometric WIMP search at Canfranc with different absorbers.**
  S. Cebrián et al., Astroparticle Physics 21 (2004) 23.

- **Performance of a scintillating sapphire bolometer for the ROSEBUD experiment.**
  J. Amaré et al., in proceedings of "The Fifth International Workshop on The Identification of Dark Matter", World Scientific Publishing Co., edited by Neil J. C. Spooner and Vitaly Kudryavtsev, (2004) 384.

2003

- **Cryogenic Detection Techniques at the Canfranc Underground Laboratory: The ROSEBUD Experiment.**
  S. Cebrián et al., Nuclear Physics B (Proc. Suppl.) 118 (2003) 523.

- **First underground light versus heat discrimination for dark matter search.**
  S. Cebrián et al., Physics Letters B 563 (2003) 48.

- **Improved limits for natural α radioactivity of tungsten with $CaWO_4$ scintillating bolometer.**
  S. Cebrián et al., Physics Letters B 556 (2003) 14.

2002

- **The ROSEBUD experiment at Canfranc: 2001 report.**
  S. Cebrián et al., Nuclear Physics B (Proc. Suppl.) 110 (2002) 97.

2001

- **First results of the ROSEBUD dark matter experiment.**
  S. Cebrián et al., Astroparticle Physics 15 (2001) 79.

2000

- **Status of the ROSEBUD Dark Matter search experiment.**
  S. Cebrián et al., Nuclear Instruments and Methods in Physics Research A 444 (2000) 315.
- **Status of the ROSEBUD Dark Matter Experiment in 1999.**
  S. Cebrián et al., Nuclear Physics B (Proc. Suppl.) 87 (2000) 500.
- **Cold dark matter searches at the Canfranc Underground Laboratory.**
  S. Cebrián et al., New Journal of Physics 2 (2000) 13.
- **Status report on the ROSEBUD dark matter experiment.**
  S. Cebrián et al., in proceedings of "The Third International Workshop on The Identification of Dark Matter", World Scientific Publishing Co., edited by Neil J. C. Spooner and Vitaly Kudryavtsev, (2000) 361.

1999

- **Performances and prospects of the "ROSEBUD" dark matter search experiment.**
  S. Cebrián et al., Astropatticle Physics 10 (1999) 361
- **Towards measurements of recoils below 4 keV with the "ROSEBUD" experiment.**
  C. Bobin et al., Nuclear Physics B (Proc. Suppl.) 70 (1999) 90.

Conference talks

2013

- **Parylene-coated NaI(Tl) scintillators at low temperature.**
  9th MULTIDARK Consolider Workshop, Universidad de Alcalá (UAH), Alcalá de Henares, Spain, 6 - 8 November, 2013.
- **Response of parylene-coated NaI(Tl) scintillators at low temperature.**
  International Workshop on Radiopure Scintillators RPSCINT 2013, Institute for Nuclear Research, Kiev, Ukraine, 17 - 20 September, 2013.

2012

- **Cryogenic efforts in the University of Zaragoza and the Canfranc Underground Laboratory.**
  First Topical Workshop of the HAP Dark Universe: Workshop on Data Analysis and Detector Technologies, Burg Liebenzell, Bad Liebenzell, Germany, 18 - 23 November, 2012.
- **Rare event searches at Canfranc: ANAIS and ROSEBUD experiments.**
  "Thirteenth Marcel Grossmann Meeting" on Recent Developments in Theoretical and Experimental General Relativity, Gravitation, and Relativistic Field Theory, Stockholm University, Stockholm, Sweden, 1 - 7 July, 2012.

- **Scintillating bolometers: at the forefront of particle detection.**
  Cantabria Campus Nobel 2012, Palacio de la Magdalena, Santander (Cantabria), Spain, 11 - 15 June, 2012.

- **ROSEBUD experiment and the UZ participation in EURECA.**
  6th Multidark Consolider Workshop & RENATA meeting, Canfranc Underground Laboratory, Canfranc (Huesca), Spain, 12 - 15 April, 2012.

2011

- **Bolometric experiments at the Canfranc Underground Laboratory.**
  Reunión de la Red Temática Nacional de Astropartículas (RENATA), Hotel Catalonia Barcelona Plaza, Barcelona, Spain, 02 - 04 November, 2011.

- **Development of Scintillating Bolometers for Dark Matter Searches.**
  3rd Galileo-Xu Guangqi meeting, National Astronomical Observatories, Beijing, China, 11 - 15 October, 2011.

- **Cryogenic particle detection at the Canfranc Underground Laboratory.**
  First International Workshop for the Design of the ANDES Underground Laboratory, Centro Atómico Constituyentes, Buenos Aires, Argentina, 11 - 14 April, 2011.

2010

- **ROSEBUD: recent results.**
  3rd MULTIDARK Consolider Workshop, Centro Extremeño de Tecnologías Avanzadas CETA-CIEMAT, Trujillo (Cáceres), Spain, 15 - 16 November, 2010.

- **2010 update on the ROSEBUD Project.**
  8th International Workshop on Identification of Dark Matter 2010 (IDM2010), University of Montpellier II, Montpellier, France, 26 - 30 July, 2010.

- **Cryogenic direct search for dark matter: ROSEBUD-EURECA.**
  1st MULTIDARK Consolider Workshop, Universidad Autónoma de Madrid, Madrid, Spain, 25 - 27 January, 2010.

2009

- **BGO scintillating bolometer: its application in dark matter experiments.**
  Eleventh International Conference on Topics in Astroparticle and Underground Physics (TAUP2009), Pontifical University of Saint Thomas Aquinas, Rome, Italy, 1 - 5 July, 2009.

2008

- **Our short experience at IAS and within ROSEBUD with radioactive contaminations in scintillating bolometers: uses and needs.**
  1st International Workshop on Radiopure Scintillators for EURECA (RPScint'2008), Institute for Nuclear Research, Kyiv, Ukraine, 9 - 10 September, 2008.

- **Sapphire, BGO and LiF scintillating bolometers developed for dark matter experiments.**
  7th International Workshop on Identification of Dark Matter 2008 (IDM2008), AlbaNova University Centre, Stockholm, Sweden, 18 - 22 August, 2008.

- **BGO scintillating bolometer as a dark matter detector prototype.**
  4th Workshop on Cryogenic Scintillation (CryoScint'08), Institut de Physique Nucléaire de Lyon, Lyon, France, 6 June, 2008.
- **WIMP search with scintillating bolometers at LSC within TA-DUSL (P2004-05-LSC).**
  The ILIAS 5th Annual Meeting, Excmo. Ayuntamiento de Jaca, Jaca, Spain, 18 - 21 February, 2008.

2007

- **Sapphire and BGO performance as scintillating bolometers developed for dark matter searches.**
  EURECA meeting, Max Planck Institute for Physics of the Technical University of Munich, Garching, Germany, 24 October, 2007.
- **Recent performance of scintillating bolometers developed for dark matter searches.**
  12th International Workshop on Low Temperature Detectors (LTD12), Conservatoire National des Arts et Métiers, Paris, France, 22 - 27 July, 2007.
- **Status of the ROSEBUD experiment.**
  4th Workshop on Cryogenic Scintillation (CryoScint 2007), Institut de Physique Nucléaire de Lyon, Lyon, France, 23 April, 2007.
- **Status of the ROSEBUD experiment.**
  4th Applied Cryodetectors Network Meeting, Max Planck Institute for Physics of the Technical University of Munich, Garching, Germany, 30 March, 2007.

2006

- **High performance scintillating calorimeters in the search for WIMPs: ROSEBUD experiment.**
  6th International Workshop on The Identification of Dark Matter, The Island of Rhodes, Greece, 11 - 16 September, 2006.
- **Recent progress on R&D activities for the ROSEBUD experiment.**
  2nd Workshop on the development and characterization of Cryogenic Scintillation Detectors for low background experiments (CryoScint), Oxford, United Kingdom, 7 March, 2006.
- **Light and heat for direct dark matter detection: R&D + ROSEBUD status.**
  The ILIAS 3rd Annual Meeting, LNGS, Assergi, Italy, 27 February - 3 March, 2006.

2005

- **Recent developments on scintillating bolometers for WIMP searches: ROSEBUD status.**
  9th International Conference on Topics in Astroparticle and Underground Physics (TAUP2005), University of Zaragoza, Zaragoza, Spain, 10 - 14 September, 2005.

Posters

2011

- **Measurement of the differential neutron flux inside a lead shielding in a cryogenic experiment.**
  12th International Conference on Topics in Astroparticle and Underground Physics (TAUP2011), Münchner Künstlerhaus (Munich House of Artists), Munich, Germany, 5 – 9 September, 2011.
- **Characterization of a SrF_2 scintillating bolometer.**
  14th International Workshop on Low Temperature Detectors (LTD-14), Heidelberg University, Heidelberg, Germany, 1 - 5 August, 2011.

2009

- **Detection of fast neutrons with LiF and Al_2O_3scintillating bolometers.**
  Eleventh International Conference on Topics in Astroparticle and Underground Physics TAUP2009, Pontifical University of Saint Thomas Aquinas, Rome, Italy, 1 - 5 July, 2009.

2007

- **Measurement of the nuclear recoil thermal relative efficiency factor with an undoped sapphire scintillating bolometer.**
  12th International Workshop on Low Temperature Detectors, Conservatoire National des Arts et Métiers, Paris, France, 22 - 27 July, 2007.

2005

- **Scintillation of Sapphire under particle excitation at low temperature.**
  12th International Conference on Topics in Astroparticle and Underground Physics (TAUP2005), University of Zaragoza, Zaragoza, Spain, 10 - 14 September, 2005.

Ph. D. Theses

2013

- **Characterization of scintillating bolometers for particle detection and installation of a bolometric test facility in the University of Zaragoza.**
  Carlos Ginetra Díaz. Tesis Doctoral. Laboratorio de Física Nuclear y Astropartículas. Facultad de Ciencias. Universidad de Zaragoza. September 2013.
- **Detección de neutrones con bolómetros centelleantes de fluoruro de litio y zafiro y su aplicación en experimentos de búsqueda de materia oscura.**
  Tomás Alberto Rolón Cabrera. Tesis Doctoral. Laboratorio de Física Nuclear y Astropartículas. Facultad de Ciencias. Universidad de Zaragoza. May 2013.

2010

- **Caracterización de un bolómetro centelleador de BGO ($Bi_4Ge_3O_{12}$) para su aplicación en la búsqueda directa de Materia Oscura.**
  Ysrael Richard Ortigoza Paredes. Tesis Doctoral. Laboratorio de Física Nuclear y Astropartículas. Facultad de Ciencias. Universidad de Zaragoza. February 2010.

2008

- **Bolómetros centelleadores para búsqueda de materia oscura.**
  Lidia C. Torres Ferrández. Tesis Doctoral. Laboratorio de Física Nuclear y Astropartículas. Facultad de Ciencias. Universidad de Zaragoza. May 2008.