Recent developments on scintillating bolometers for WIMP searches: ROSEBUD status

J Amaré, B Beltrán, J M Carmona, S Cebrián, N Coron, G Dambier, E García, I G Irastorza, H Gómez, J Leblanc, G Luzón, P de Marcillac, M Martínez, J Morales, A Ortiz de Solórzano, C Pobes, J Puimedón, T Redón, A Rodríguez, J Ruiz, M L Saras, L Torres, and J A Villar

1 Laboratorio de Física Nuclear y Altas Energías, Universidad de Zaragoza, Spain
2 Institut d’Astrophysique Spatiale (IAS), Bâtiment 121, 91405 Orsay Cedex, France
* Paper presented at the conference by L Torres
E-mail: Lidia.Torres@unizar.es

Abstract. The particle discrimination capability of various scintillating bolometers has been tested, proving their suitability for dark matter searches. In particular, BGO and undoped sapphire have shown low particle discrimination energy threshold (down to around 20 and 10 keV, respectively). We report on the present status of the ROSEBUD (Rare Objects SEarch with Bolometers UnDerground) Experiment and its prospects.

1. Introduction

Direct WIMP searches rely on the possibility to detect the interaction of galactic halo WIMPs through the nuclear recoil they produce when scattered off target nuclei. The low event rate and the low energy of the signal expected compel this type of experiments to fulfill the requirements of ultralow radioactive background and low energy threshold. In particular, bolometric experiments are regarded as being among the most suitable for dark matter searches, since they use very efficiently the energy released by a nuclear recoil (relative efficiency factor close to 1) and permit to tune for the most favored nuclei as far as WIMP interaction is concerned.

In recent years, improvement of sensitivity has been achieved by using active background suppression techniques: the simultaneous measurement of two physical quantities related to the deposited energy, heat and charge [1, 2], or heat and light [3, 4], for instance, has permitted the identification of nuclear recoil events down to energies of a few keV.

The ROSEBUD experiment uses scintillating bolometers as detectors, making use of the above-mentioned background suppression technique: the energy of the interacting particle is measured via the dominating fraction of energy released through the heat channel, which subsequently allows to directly compare the energy of all types of events. The fraction of energy going to the light channel depends strongly on the interaction occurring at the electronic or

3 Present address: CEA, Saclay, France
4 CEE fellow in the Network on Cryodetectors, under contract HPRN-CT-2002-00322, presently at the Dipartimento di Fisica dell’Università di Milano-Bicocca, Italy.
nuclear level. As a result, $\gamma$ and $\beta$ particles show a higher light yield than recoiling nuclei induced by neutrons and expected from WIMPs. Part of this collaboration has lead the search for new scintillating materials [5] showing that a wide choice of targets is allowed.

2. Simultaneous measurement of light and heat: The double bolometer technique

The simultaneous measurement of the heat and light produced in an interaction is achieved by the use of a double bolometer assembly (see figure 1). It consists of a scintillating crystal and a germanium disk (25 mm, 100 $\mu$m thickness) inside an Ag-coated reflecting cavity. The heat produced in the scintillating crystal is directly seen as a temperature increase and the emitted light escaping from it is eventually absorbed in the Ge crystal where it is also converted into heat. Both heat signals are measured by NTD Ge thermistors glued onto each crystal for this purpose. Calibration is done through inner and outer sources and absolute calibration of the light channel is achieved with an inner $^{55}$Fe source. See reference [4] for more details on the double bolometer configuration and read-out system and reference [6] for information on design and performance of the optical detector.

![Figure 1. Scheme of a double bolometer for light and heat simultaneous measurement.](image)

3. Results

The light response under particle excitation and the discrimination capability of several bolometers of BGO (46 and 92 g) and undoped sapphire (50 and 25 g) have been studied.

We present in table 1 the results obtained for BGO and sapphire (Russian origin grown by the Kyropoulus method) in terms of collected light output in interactions with $\beta/\gamma$ and $\alpha$ particles and relative light output factors ─ normalized to the one for neutrons─ after calibrations with gamma ($^{60}$Co, $^{57}$Co, $^{137}$Cs), alpha ($^{241}$Am, $^{210}$Po) and neutron ($^{252}$Cf) sources. For BGO (sapphire) we find threshold energies of 23 keV and 51 keV (10 keV and 23 keV) for 90% and 99.99% efficiency of particle discrimination (see figures 2 and 3).

A remarkable feature of sapphire is the negative correlation found between heat and light amplitude signals in gamma events of the same energy. The reason for this behavior is being studied at the moment [7].

We have also tested sapphire of French origin grown by the Verneuil method and, although the results are preliminary, we can say that it shows, compared to the Russian origin one, a similar light yield under alpha particle and neutron excitation but a lower light yield (roughly a factor 5 lower) for $\beta/\gamma$ particle excitation.

4. Conclusion and prospects

The good performance shown by BGO and sapphire (Russian origin) in terms of particle discrimination capability justifies their mounting in the Canfranc Underground Laboratory.
Table 1. Collected light output and relative light output factors for BGO and Russian origin sapphire.

| Material | Light output ($\beta/\gamma$) | Light output ($\alpha$) | Relative factors ($\beta/\gamma:\alpha:n$) |
|----------|-------------------------------|-------------------------|------------------------------------------|
| BGO      | 7.5 keV/MeV                   | 1.3 keV/MeV             | 15 : 2.6 : 1                             |
| Sapphire | 13.5 keV/MeV                  | 1.3 keV/MeV             | 20 : 2 : 1                               |

Figure 2. Discrimination plot for a background measurement with a 46 g BGO bolometer. The confidence bands have been evaluated after $^{60}$Co and $^{252}$Cf calibration runs. The lines at energies 15 and 88 keV are due to the internal contamination of the EC decaying nucleus $^{207}$Bi.

Figure 3. Discrimination plot for a gamma calibration measurement ($^{57}$Co and $^{241}$Am) with a 50 g Russian origin sapphire bolometer. The confidence bands have been evaluated after $^{57}$Co + $^{241}$Am and $^{252}$Cf calibration runs. The line at 1200 mV is the 59.5 keV gamma line of $^{241}$Am.

for the next dark matter run of the ROSEBUD experiment. BGO, apart from the excellent discrimination properties shown above, is an interesting material for WIMP searches due to its high content in $^{209}$Bi, a favored nucleus both in spin independent and spin dependent interactions. On the other hand, the particle discrimination ability of sapphire is efficient for energies down to 10 keV. The assembly of two double bolometers of BGO and sapphire in the same experimental set-up will permit us to compare their pure nuclear recoil spectra and, possibly, to look for a WIMP signature exploiting the signal dependence on the type of material.

Acknowledgments
This work has been supported by the Spanish Ministry of Sciences and Technology (MCyT, contract FPA2004-0974), by the French CNRS/INSU (MANOLIA and BOLERO projects) and the EU Network Contract HPRN-CT-2002-00322.

References
[1] Akerib D S et al 2005 Phys. Rev. D 72 052009
[2] Sanglard V et al 2005 Phys. Rev. D 71 122002
[3] Angloher G et al 2005 Astropart. Phys. 23 325-39
[4] Cebrián S et al 2004 Astropart. Phys. 21 23-34
[5] Coron N et al 2004 Nucl. Inst. and Meth. A 520 159-62
[6] Coron N et al 2004 Opt. Eng. 43 1568-70
[7] Amaré J et al 2005 Appl. Phys. Lett. 87 264102