Did you say scintillating bolometers? 

Scintillating bolometers are a powerful technique to identify signals and reject backgrounds in the rarest astroparticle physics events searches. They are for instance a key element in the race for dark matter...

Single crystals of some hundred grams cooled at cryogenic temperatures (<100mK) are now at the heart of many experiments of fundamental physics looking for very rare events in the 1keV-10MeV energy range. Low temperatures here help a lot: the lower the temperature is, the bigger the mass that can be used, for an equal sensitivity. (Astro-) Particle Physics beyond the Standard Model can then be addressed. Is the dark matter (DM) of the Universe really made of supersymmetric particles? Are the properties of the neutrino such that it can annihilate with itself in the so called double beta decay (DBD) of selected nuclides?

Supersymmetric particles – with neutralinos being the favoured candidates– are looked for through their rare elastic scattering off nuclei, and a measurement of the recoiling nuclei, with an energy expected in the keV range, while the observation of the neutrinoless double beta decay would be found through the detection of a single energetic line, at the energy foreseen by nuclear masses, in the MeV range. The energetics of the events searched for, modulated by the nature of the crystal, will sign the interaction. They are retrieved by calorimetry, in a “bolometer” set up: a simple thermistor – a resistor with a temperature dependence - is glued on the crystal under study, and its value is continuously monitored. The heat escapes through a well defined thermal link, that couples the crystal to the refrigerator, with time constants of the order of a few tens of milliseconds.

Massive bolometers have been proved in the 1990s to be sensitive enough for the foreseen scopes, but all teams had to go deep underground to avoid the permanent cosmic rays flux that makes these detectors blind at surface level.

It was then realised that the natural radioactive background from the rocks, the material used..., even in the cleanest experiments, would impede any significant exploration of the new physics. Mixed techniques were then developed for semiconducting targets (Ge, Si crystals), where both the heat and the charge signals created in the crystal by the interaction are measured. The combination of both signals reveals the nature of the particles detected through their ionizing power and allows to reject most of the background. Among the most advanced experiments looking for a direct detection of dark matter underground, CDMS & EDELWEISS are indeed based on this mixed technique using Germanium bolometers. But neutralinos are expected to scatter off all nuclei, with a strength that depends on the mass of the nucleus, on its spin contents. Why should we restrict ourselves to Germanium, while a modulation of the signal according to the theoretical predictions would give a much stronger base to a claim of positive detection, and help to better identify the dark matter candidate?

These reflections motivated at the end of the 1990s the development of a new class of detectors, scintillating bolometers, which realise at very low temperature the simultaneous measurement of the heat release and the light emission following a particle interaction in transparent crystals. Two bolometers are used in the most retained scheme, a “heat” one, which incorporates the transparent scintillating target, and an “optical” one, dark, which absorbs the light emitted, in a common reflective
h Housing. A strong discrimination power among particles has been proved so far in all targets tested by the CRESST or ROSEBUD collaborations (CaWO₄, sapphire Al₂O₃, BGO Bi₄Ge₃O₁₂), confirming that a broad range of nuclei are now available for DM searches. In these experiments, the availability of different materials sharing the same site and set-up is very helpful to reduce systematic effects at low event rates, which can spoil the interest of a whole experiment, in case of a wrong identification.

The use of scintillating bolometers allows for relaxing somewhat the radioactivity level in experiments looking for events at high energy, where the different particles are well-separated. The recent discovery in 2002 of the natural alpha decay of bismuth-209 in BGO crystals, which is the longest alpha emitter ever measured (with a half life 2.10¹⁹ years, and an energy release of Q=3137keV), in a common laboratory at surface level, was a spectacular experimental proof of the discrimination power of this technique.

Bolometers are ideal detectors for neutrinoless DBD searches: crystals can be grown with different interesting DBD-emitters and, which is fundamental for next generation experiments, they show an excellent energy resolution.

The CUORICINO experiment, constituted by an array of 62 T eO₂ crystal bolometers, demonstrated not only the power of this technique but also that the main source of background for these detectors arises from surface contaminations of radioactive α-emitters. Scintillating bolometers represent the ideal way to overcome this problem, that will represent the major source of background for the CUORE experiment.

The main technical advantage with respect to DM searches is due in the energy of the event; a few keV’s for DM, about 3 MeV in case of DBD. This simply means that the light signal is rather large resulting in a simplified, less complicated, light detector. This last point has to be taken seriously into account when projecting this technique on a very large mass experiment. Several interesting DBD-scintillating bolometers have been tested so far, based on “golden isotopes” whose decay energy is above 2.6 MeV, one of the most intense natural background lines.

The LUCIFER Project, funded by ERC will be constituted by an array of enriched ZnSe scintillating bolometers. The total ⁸²Se isotope mass will be about 15 kg. The experiment is planned to start in 2014 in the facility that housed CUORICINO. The expected background in the region of interest (2995 keV) is expected to be about 30 times less with respect to CUORICINO, making Lucifer competitive with the next world wide planned DBD Experiments.

Submitted by Pierre de Marsillac (IAS-Orsay / France) and Stefano Pirro (INFN Milano Bicocca / Italy)