Phase III (and maybe IV) of the SIMPLE dark matter search experiment at the LSBB

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Abstract. with the recent conclusion of Phase II, SIMPLE has ended its use of Superheated Droplet Detectors (SDD) in the WIMP search effort. An in-progress Phase III comprises a transition to larger mass bubble chamber technology, using many of the lessons gained from the previous phase since the underlying physics is identical. We describe the progress of the activities, to include several $\sim$1 kg prototype chambers, each $4\times$ the total Phase II active mass, which are undergoing testing, prior to a rescaling to a 50 kg capacity within a Phase IV modular 1 ton detector for a definitive astroparticle search effort.

1. Introduction

Phase II of the LSBB-sited SIMPLE dark matter search program [1] consisted of two arrays of 15 SDDs each, each operated $\sim$100 day, which provided internationally competitive results comparable to its North American counterparts PICASSO [2] and COUPP [3] with significantly less exposure. In its duration, Phase II demonstrated the viability of high concentration, relatively inexpensive C_2ClF_5 SDD constructions in the search effort [4, 5], including the chemistry necessary to achieve detector fabrications with stable operation over extended periods at operating temperatures and pressures capable of providing low energy recoil threshold measurements [6, 7]. It further demonstrated the ability to construct similar SDDs with various superheated liquids (C_3F_8, C_4F_{10}, C_4F_8, CF_3I) towards eventually providing more restrictive results via different target comparisons [8], and the capacity of a refined, low frequency (LF) acoustic instrumentation to provide discrimination of nuclear recoil events from all gel-associated, environmental, and α-induced backgrounds [9, 10].

The difficulty with SDDs for dark matter detection is their low active-to-total mass ratio ($\sim$1–2%), and that each construct requires 2 day. Phase III comprises a transition to bubble chamber (BC) technology, with a significantly larger mass ratio, enroute to a final Phase IV search experiment with a one ton modular detector.

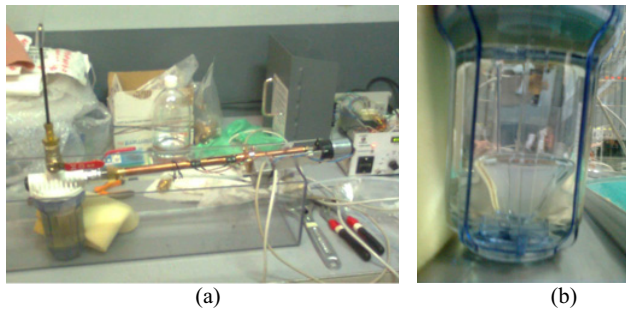[a] Corresponding author: `lcriodets@cii.fc.ul.pt`

(a)   (b)

Figure 1. Prototype BDC nº1 (∼0.3 kg active mass) with piston recompression; (b) the "big droplet" within the BC.
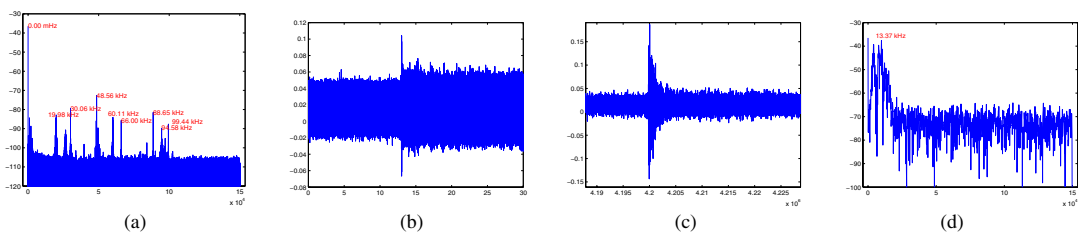

(a)   (b)   (c)   (d)

Figure 2. (a) Prototype HF signal acquisition; (b) correlation with pressure signal: (c) removal of the piston noise by filtering, (d) FFT of the filtered signal in (c). Note that the signal-recompression correlation obviates the need for recording intermediate acoustic data.

Figure 3. Recompression system.

2. Phase III

The BC is essentially a single large droplet SDD, with the same physics base. To avoid the early problems of inhomogeneous nucleation events experienced by COUPP in its developmental phase, the "big droplet" chamber design of Puibasset [11] was resurrected: this consists of a smooth gel sheathing of the inner chamber surface, and creation of a cavity into which glycerol is introduced, followed by the freon. The use of a bulk liquid requires a recompression system capable of rapidly restoring the initial metastable condition of the liquid, preventing its full transition to the gas phase.
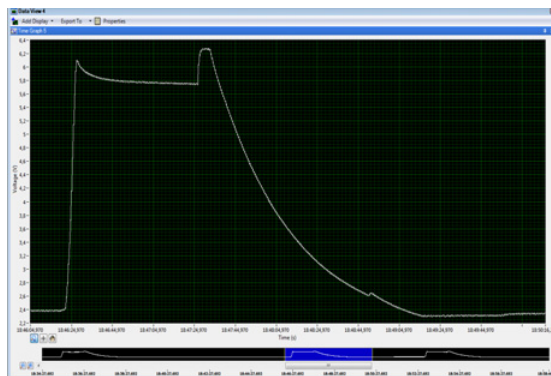
Figure 4. (a) Overall recompression profile, with prototype BDC nº3 (recomp distance = 5 m, trigger threshold = 100 mbar).
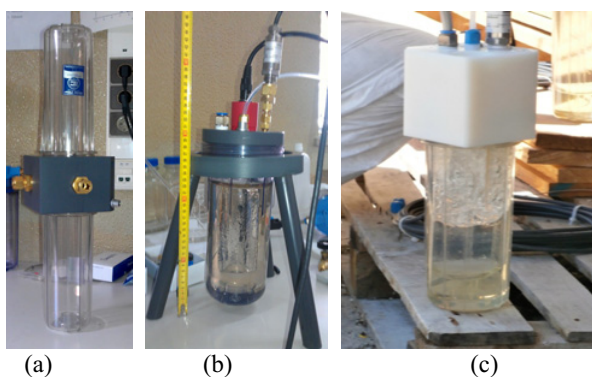

(a)　　　　　(b)　　　　　(c)

Figure 5. BC evolution (a) 2-chamber BC for bubble drift studies; (b) mono-chamber with PVC capping, (c) production model with high density PE cap replacement; the PE cap is internally domed to minimize its mass.

Prototyping of the new detector began in 2011, using a low cost "quick & dirty" home water filter (to permit observation) and N_2 re-pressurization, which was quickly replaced by a piston-based system (shown in Fig. 1 during its testing in early 2012) to isolate the freon from the gas. An initial concern of the early testing was the effect of the technique change on the previous particle discrimination capability, which was in part based on the size distribution of the SDD droplets. Given that both PICASSO and COUPP employ high frequency (HF) acoustic instrumentation, signal acquisition was tested with a CM16/CMPA40-5V, 10-250 kHz condenser microphone, and substitution of the current I/O board with the faster NI PCI-6251 1MS/s. As seen in Fig. 2a, although the raw record contained signal events reaching to 100 kHz, noise filtering eliminated all but the lower frequencies to leave true nucleation events in a 10-16 kHz window, well within the range of the previous LF system [1]. As seen in Fig. 2b, onset of the piston movement partially masks the event signal, which is recovered by the filtering (Fig. 2c) to yield the FFT of a true nucleation event (Fig. 2d) as observed with the Phase II instrumentation.
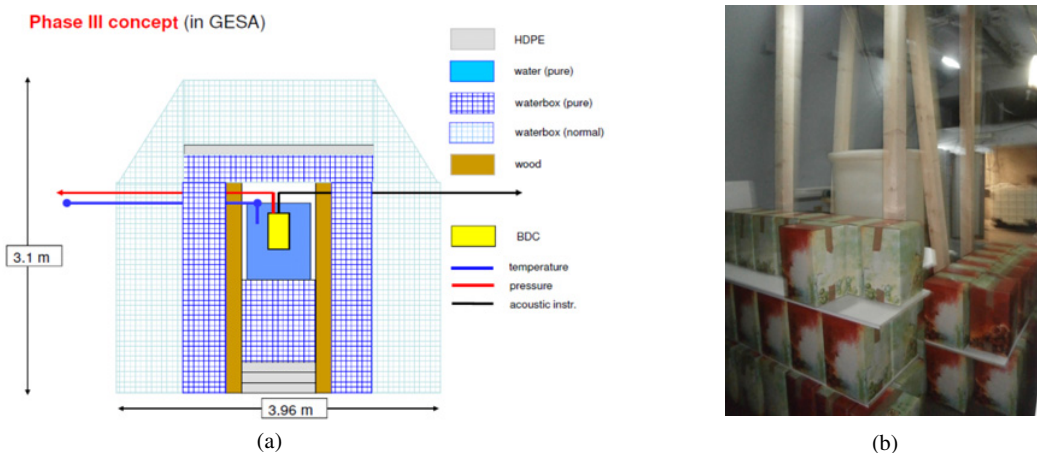
Following the 2012 tests, a new "industrial" piston-based recompression system was prototyped, shown completed in Fig. 3. The unit comprises two separate piston subsystems, each capable of driving one BC and both controlled by a single "automaton" based on ladder logic. The overall performance of

Table 1. Materials' U/Th radio-assays, and background contribution estimates based on the Fig. 6a shield design.

	rock	concrete	metal	water (tap)	water (pure)	Wood	PE	plastics	paraffin
^{232}Th	0.16	7.7	1.3×10^{-2}	5.0×10^{-5}	5.0×10^{-5}	3.0×10^{-3}	2×10^{-1}	1.27	<0.41
^{238}U	5.0	10.5	$3.6\ a\ 10^{-3}$	3.2×10^{-3}	3×10^{-6}	1.1×10^{-1}	4×10^{-1}	2.74	<0.25
Contribution	-	2.9×10^{-4}	- 0	2.5×10^{-3}	2.6×10^{-5}	6.7×10^{-6}	5.3×10^{-5}	3.2×10^{-3}	8.4×10^{-5}

Table 2. Plastics radio-assays, and background contribution estimate.

	"SIMONA"	"PET"	"TANK"	"BARRA"	"Acrilico"
O origin	(unused)	cap PVC	watertank	shield HDPE	chamber
content (mg/kg)	0.024 ± 0.004	<0.35	<0.054	0.032 ± 0.001	<0.034
background(evt(/kgd)	3.1×10^{-2}	5.3×10^{-1}	8.1×10^{-2}	4.8×10^{-2}	5.0×10^{-2}

Figure 6. (a) Schematic of 2m thick neutron shield using both normal and purified water, (b) GESA shielding reconstruction (in progress).

the recompression system is shown in Fig. 4, comprising a response time of 2 s, 6 s condensation period, and overall recompression cycle of 163 s.

Testing of the system proceeded throughout 2012–2013, with the BC design evolution shown in Fig. 5. The initial design (Fig. 5a), two centrally-coupled waterfilters with the upper serving as a "drift chamber", was intended to study bubble evolution following observation that it separated from the bulk under its gas buoyancy and rose in the glycerin. Optimization of the recompression timing reduced the drift to within 1 cm of the bulk droplet, leading to the single filter design of Fig. 5b.

Another concern in the Phase III development was minimization of the background contributions from the U/Th impurities of the experiment construction. Radio-assays of all materials, shown in Table 1, were used to estimate the overall contribution to a measurement based on the preliminary shield design of Fig. 6, which identified the principle contribution to be the containment as in Phase II, and that use of resin-purified water yielded a 10^2 reduction in the background contribution.

A series of assays was made (Table 2) on a variety of plastics, from which the replacement of the PVC by high density PE was suggested given its estimated almost factor 10 lower background contribution (4.8×10^{-2} evts/kgd). The final prototype construction shown in Fig. 5c.

In 2013, two chambers and a recompression system were transferred to the LSBB for final testing during the GESA shield reconstruction, with a 30 day preliminary search measurement intended to
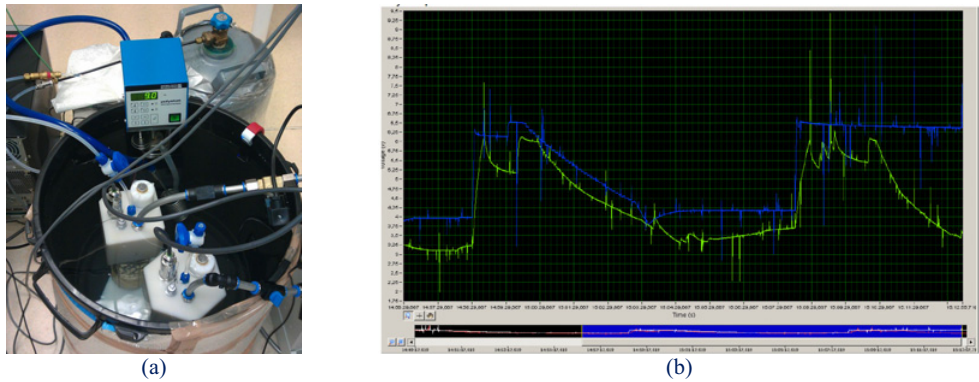
(a)   (b)

Figure 7. (a) Two BCs undergoing testing in the LSBB "Salle Blanche"; (b) typical May/June 2013 recompression record, the traces indicating the numerous voltage spikes and inability of the system to return to 2 bar.
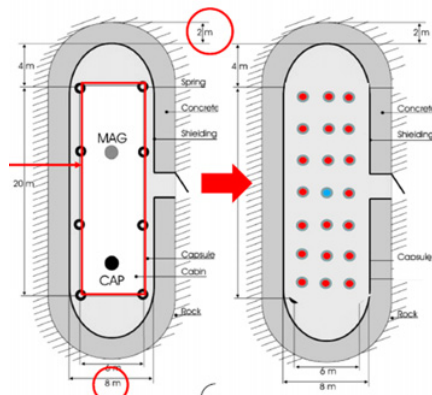

Figure 8. Left: current Capsule configuration, Right: projected SIMPLE reconfiguration, showing the "box" removal and a twenty detector installation in a water-flooded Capsule.

follow. Almost immediately, however, problems developed with the chamber performance, in particular the inability of the recompression system to restore the initial device metastability as seen in Fig. 7.

After 6 weeks of unsuccessful trouble-shooting, the equipment was packed and returned to Lisbon for more detailed diagnostics. The problems have since been identified and rectified, the repressurization problem in fact resulting from an instability in the LSBB "Salle Blanche" power supply, and a return to GESA is imminent.

3. A possible Phase IV

To achieve the Phase IV 1 ton detector, the design concept consists of a modular, twenty $\times$ 50 kg chamber array, with 2 m surrounding purified water for neutron shielding. Although the estimated necessary 1200 m^3 is large, several underground siting possibilities exist and are currently being explored, including the LSBB, Canfranc Underground Laboratory in the Spanish Pyrénées, and JinPing Laboratory in China (see talk J. Wang, these Proceedings).

Figure 8 shows a possible experiment configuration for siting in the LSBB Capsule, which entails only a removal of the "box" of the former missile launch control, and flooding of the cavern to a depth of

4.5 m. Of the 10 recompression systems required, 2 already exist; similarly, all acoustic instrumentation and the temperature control units are in readiness.

4. Summary

SIMPLE Phase III has working BCs, with 4 to be installed underground in GESA with a new shielding construct (1.5 m water thickness 4π, inner 2 ton resin-purified). Expected turn-on now depends on financial support and team strength, both of which have been decimated by current science policies in Portugal.

A SIMPLE Phase IV is being organized, based on a modular array of twenty 50 liter chambers surrounded 4π by 2 m purified water, with an initial objective of a 4×10^5 kgd exposure (with anticipated significant intermediate results). Apart from funding and underground siting still to be negotiated, the goal implies the need for an overall background level of $\sim 10^{-6}$ evt/kgd, which as evident from Table 2 will require significant further chamber R&D to achieve the necessary 10^4 reduction in containment background.

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