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FINAL MODEL-INDEPENDENT RESULTS OF DAMA/LIBRA-PHASE1 AND PERSPECTIVES OF PHASE2

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This paper shortly summarizes the results obtained with the total exposure of 1.04 $\mathrm{t \cdot y}$ collected by DAMA/LIBRA-phase1 deep underground at the Gran Sasso National Laboratory (LNGS) of the INFN during 7 annual cycles. The DAMA/LIBRA-phase1 and the former DAMA/NaI data (cumulative exposure 1.33 $\mathrm{t \cdot y}$, corresponding to 14 annual cycles) give evidence at 9.3σ C.L. for the presence of Dark Matter (DM) particles in the galactic halo, on the basis of the exploited model-independent DM annual modulation signature by using highly radiopure NaI(Tl) target. The modulation amplitude of the *single-hit* events in the 2–6 keV energy interval is: (0.0112 ± 0.0012) cpd/kg/keV; the measured phase is (144 ± 7) days and the measured period is (0.998 ± 0.002) y, the values well in agreement with those expected for DM particles. No systematic or side reaction able to mimic the exploited DM signature has been found or suggested by anyone over more than a decade. Some of the perspectives of the presently running DAMA/LIBRA-phase2 are outlined.

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INTRODUCTION

The presently running DAMA/LIBRA [1–12] experiment, as the former DAMA/NaI [13–25], has the main aim to investigate the presence of DM particles in the galactic halo by exploiting the model-independent DM annual modulation signature (originally suggested in [26]). Moreover, the developed highly radiopure NaI(Tl) target-detectors [1] assure as well sensitivity to a wide range of DM candidates, interaction types, and astrophysical scenarios.

As a consequence of the Earth revolution around the Sun, the Earth should be crossed by a larger flux of DM particles around $\simeq 2$ June and by a smaller one around $\simeq 2$ December. This DM annual modulation signature is very distinctive since the effect induced by DM particles must simultaneously satisfy all the following requirements: the rate must contain a component modulated according to a cosine function (1) with one year period (2) and a phase that peaks roughly $\simeq 2$ June (3); this modulation must only be found in a well-defined low energy range, where DM-particle induced events can be present (4); it must apply only to those events in which just one detector of many actually "fires" (*single-hit* events), since the DM particle multi-interaction probability is negligible (5); the modulation amplitude in the region of maximal sensitivity must be $\simeq 7\%$ for usually adopted halo distributions (6), but it can be larger (even up to $\simeq 30\%$) in case of some possible scenarios such as, e.g., those in [27, 28]. Thus, this signature is model-independent, very effective and, in addition, it allows the test of a large range of cross sections and of halo densities.

This DM signature might be mimiced only by systematic effects or side reactions able to account for the whole observed modulation amplitude and to simultaneously satisfy all the requirements given above. No one is available [1–4, 7, 8, 12, 15–17].

The full description of the DAMA/LIBRA setup during phase1 and other related arguments have been discussed in detail in [1–4, 8] and references therein. Here we just remind that the sensitive part of this setup is made of 25 highly radiopure NaI(Tl) crystal scintillators (5-rows by 5-columns matrix) having 9.70 kg mass each one. In each detector, two 10 cm long UV light guides (made of Suprasil B quartz) act also as optical windows on the two end faces of the crystal, and are coupled to two low background photomultipliers (PMTs) working in coincidence at a single photoelectron level. The low background 9265-B53/FL and 9302-A/FL PMTs, developed by EMI-Electron Tubes with dedicated R&Ds, were used in phase1; for details see [1, 14, 16] and references therein. The detectors are housed in a sealed low-radioactive copper box installed in the center of a low-radioactive Cu/Pb/Cd-foils/polyethylene/paraffin shield; moreover, about 1 m concrete (made from the Gran Sasso rock material) almost fully surrounds (mostly outside the barrack) this passive shield, acting as a further neutron moderator. A threefold-level sealing system prevents the detectors to be in contact with the environmental air of the underground laboratory [1]. The light response of the detectors during phase1 typically ranges from 5.5 to 7.5 photoelectrons/keV, depending on the detector. The hardware threshold of each PMT is at a single photoelectron, while a software energy threshold of 2 keV electron equivalent (hereafter keV) is used [1, 14]. Energy calibrations with X-rays/γ sources are regularly carried out in the same running condition down to few keV [1]; in particular, double coincidences due to internal X-rays from ^{40}K (which are at ppt levels in the crystals) provide (when summing the data over long periods) a calibration point at 3.2 keV close to the software energy threshold (for details see [1]). The radiopurity, the procedures, and details are discussed in [1–4, 8] and references therein.

1. THE RESULTS OF DAMA/LIBRA-PHASE1 AND DAMA/NaI

The total exposure of DAMA/LIBRA-phase1 is: 1.04 t · y in seven annual cycles; when including also that of the first generation DAMA/NaI experiment it is 1.33 t · y, corresponding to 14 annual cycles. The variance of the cosine during the DAMA/LIBRA-phase1 data taking is 0.518, showing that the setup has been operational evenly throughout the years [2–4, 8].

Figure 1 shows the time behaviour of the experimental residual rates of the *single-hit* scintillation events for DAMA/LIBRA-phase1 in the 2–6 keV energy

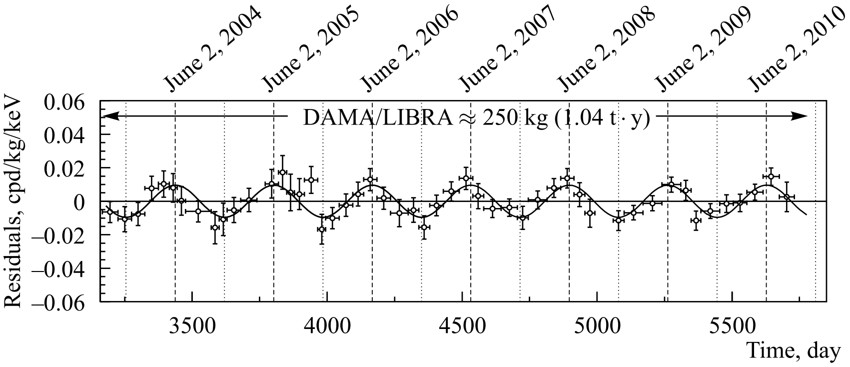

Fig. 1. Experimental residual rate of the *single-hit* scintillation events measured by DAMA/LIBRA-phase1 in the 2–6 keV energy interval as a function of the time. The data points present the experimental errors as vertical bars and the associated time bin width as horizontal bars. The superimposed curves are the cosinusoidal functions behaviours $A\cos\omega(t - t_0)$ with a period $T = 2\pi/\omega = 1$ y, a phase $t_0 = 152.5$ day (June 2nd) and modulation amplitudes, A, equal to the central values obtained by the best fit on the data points of the entire DAMA/LIBRA-phase1. The dashed vertical lines correspond to the maximum expected for the DM signal (June 2nd), while the dotted vertical lines correspond to the minimum

interval. The residuals of the DAMA/NaI data (0.29 $\mathrm{t} \cdot \mathrm{y}$) are given in [2,8,16,17]. We remind that these residual rates are calculated from the measured rate of the *single-hit* events after subtracting the constant part: $\langle r_{ijk} - \mathrm{flat}_{jk} \rangle_{jk}$. Here r_{ijk} is the rate in the considered ith time interval for the jth detector in the kth energy bin, while flat_{jk} is the rate of the jth detector in the kth energy bin averaged over the cycles. The average is made on all the detectors (j index) and on all the energy bins (k index) which constitute the considered energy interval. The weighted mean of the residuals must obviously be zero over one cycle.

The χ^2 test excludes the hypothesis of absence of modulation in the data: $\chi^2/\mathrm{d.o.f.} = 83.1/50$ and the P-value is $P = 2.2 \cdot 10^{-3}$ for the 2–6 keV energy interval. When fitting the *single-hit* residual rate of DAMA/LIBRA-phase1 together with the DAMA/NaI ones, with the function: $A \cos \omega (t - t_0)$, considering a period $T = 2\pi/\omega = 1$ y and a phase $t_0 = 152.5$ day (June 2nd) as expected by the DM annual modulation signature, the following modulation amplitude is obtained: $A = (0.0110 \pm 0.0012)$ cpd/kg/keV corresponding to 9.2σ C.L. (the χ^2 of the fit is 70.4 over 86 d.o.f.).

When the period and the phase are kept free in the fitting procedure, the modulation amplitude is (0.0112 ± 0.0012) cpd/kg/keV (9.3σ C.L.), the period $T = (0.998 \pm 0.002)$ y, and the phase $t_0 = (144 \pm 7)$ day. The period and the phase are well compatible with expectations for a DM annual modulation signal. In particular, the phase is consistent with about June 2nd and is fully consistent with the value independently determined by the Maximum Likelihood analysis (see later). For completeness, we recall that a slight energy dependence of the phase could be expected in case of possible contributions of nonthermalized DM components to the galactic halo, such as, e.g., the SagDEG stream [19, 29, 30] and the caustics [31]. For more details see [4].

The modulation amplitudes singularly calculated for each annual cycle of DAMA/NaI and DAMA/LIBRA-phase1 are compatible among them and are normally fluctuating around their best fit values [2–4]. In particular, for the 2–6 keV energy interval the χ^2 is 10.8 over 13 d.o.f. corresponding to an upper tail probability of 63%, while the *run test* yields a lower tail probabilities of 23%. This analysis confirms that the data collected in all the annual cycles with DAMA/NaI and DAMA/LIBRA-phase1 are statistically compatible and can be considered together, on the contrary of the statements in [32].

The DAMA/LIBRA-phase1 *single-hit* residuals of Fig. 1 and those of DAMA/NaI have also been investigated by a Fourier analysis. The data analysis procedure has been described in detail in [8]. A clear peak corresponding to a period of 1 y (see Fig. 2, *a*) is evident for the 2–6 keV energy interval; the same analysis in the 6–14 keV energy region shows instead only aliasing peaks. Neither other structure at different frequencies has been observed (see also [8]).

Absence of any other significant background modulation in the energy spectrum has been verified in energy regions not of interest for DM; e.g., the measured

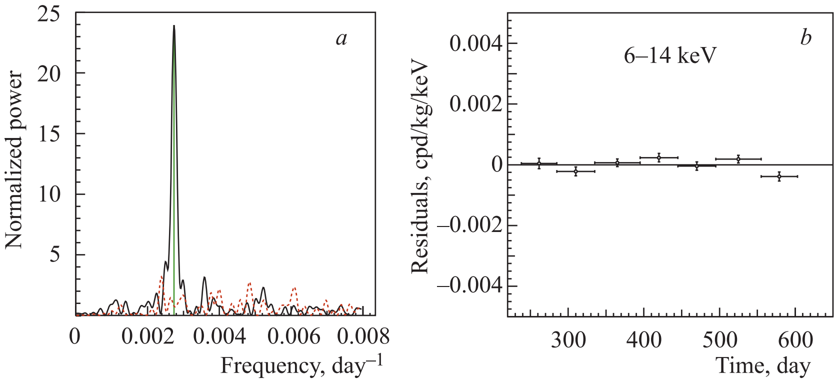

Fig. 2. *a*) Power spectrum of the measured *single-hit* residuals in the 2–6 keV (solid lines) and 6–14 keV (dotted lines) energy intervals calculated according to [8], including also the treatment of the experimental errors and of the time binning. The data refer to DAMA/NaI and DAMA/LIBRA-phase1. As can be seen, the principal mode present in the 2–6 keV energy interval corresponds to a frequency of $2.737 \cdot 10^{-3}$ day^{-1} (vertical lines), corresponding to a period of $\simeq 1$ y. A similar peak is not present in the 6–14 keV energy interval. *b*) Experimental *single-hit* residuals in the 6–14 keV energy region for the entire DAMA/LIBRA-phase1 data as if they were collected in a single annual cycle (i.e., binning in the variable time from January 1st of each annual cycle). The data points present the experimental errors as vertical bars and the associated time bin width as horizontal bars. The initial time of the figures is taken on August 7th. The amplitude is well compatible with zero: $A = (0.00032 \pm 0.00076)$ cpd/kg/keV

rate integrated above 90 keV, R_{90}, as a function of the time has been analyzed [4]. Similar result is obtained in other energy intervals; for example, Fig. 2, *b* shows the *single-hit* residuals in the 6–14 keV energy region for the entire DAMA/LIBRA-phase1 data as if they were collected in a single annual cycle (i.e., binning in the variable time from January 1st of each annual cycle). It is worth noting that the obtained results account of whatever kind of background and, in addition, no background process able to mimic the DM annual modulation signature (that is, able to simultaneously satisfy all the peculiarities of the signature and to account for the measured modulation amplitude) is available (see also discussions, e.g., in [1–4, 7, 8, 12, 33–39]).

A further relevant investigation in the DAMA/LIBRA-phase1 data has been performed by applying the same hardware and software procedures, used to acquire and to analyse the *single-hit* residual rate, to the *multiple-hit* one. In fact, since the probability that a DM particle interacts in more than one detector is negligible, a DM signal can be present just in the *single-hit* residual rate. Thus, the comparison of the results of the *single-hit* events with those

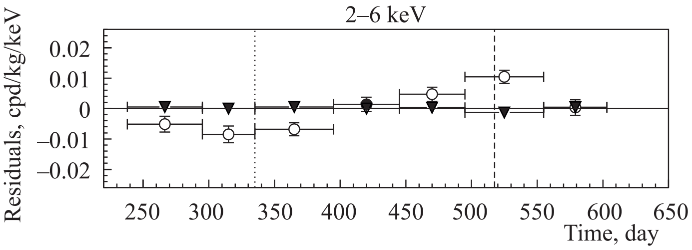

Fig. 3. Experimental residual rates of DAMA/LIBRA-phase1 *single-hit* events (open circles), the class of events to which DM events belong, and for *multiple-hit* events (filled triangles), the class of events to which DM events do not belong. They have been obtained by considering for each class of events the data as collected in a single annual cycle and by using in both cases the same identical hardware and the same identical software procedures. The initial time of the figure is taken on August 7th. The experimental points present the errors as vertical bars and the associated time bin width as horizontal bars. Analogous results were obtained for the DAMA/NaI data [17]

of the *multiple-hit* ones corresponds practically to compare between them the cases of DM particles beam-on and beam-off. This procedure also allows an additional test of the background behaviour in the same energy interval where the positive effect is observed. In particular, in Fig. 3 the residual rates of the *single-hit* events measured over the DAMA/LIBRA-phase1 annual cycles are reported, as collected in a single cycle, together with the residual rates of the *multiple-hit* events, in the 2–6 keV energy interval. While, as already observed, a clear modulation, satisfying all the peculiarities of the DM annual modulation signature, is present in the *single-hit* events, the fitted modulation amplitude for the *multiple-hit* residual rate is well compatible with zero: $-(0.0005 \pm 0.0004)$ cpd/kg/keV in the energy region of 2–6 keV. Thus, again evidence of annual modulation with the features required by the DM annual modulation signature is present in the *single-hit* residuals (event class to which the DM particle induced events belong), while it is absent in the *multiple-hit* residual rate (event class to which only background events belong). Similar results were also obtained for the last two annual cycles of the DAMA/NaI experiment [17]. Since the same identical hardware and the same identical software procedures have been used to analyze the two classes of events, the obtained result offers an additional strong support for the presence of a DM particle component in the galactic halo.

The annual modulation present at low energy can also be pointed out by depicting — as a function of the energy — the modulation amplitude, $S_{m,k}$, obtained by maximum likelihood method considering $T = 1$ y and $t_0 = 152.5$ day. For such a purpose, the likelihood function of the *single-hit* experimental data in the kth energy bin is defined as: $\mathbf{L}_k = \mathbf{\Pi}_{ij}\,\mathrm{e}^{-\mu_{ijk}}\dfrac{\mu_{ijk}^{N_{ijk}}}{N_{ijk}!}$, where N_{ijk} is the number of events collected in the ith time interval (hereafter 1 day), by the jth detector and in the kth energy bin. N_{ijk} follows Poisson's distribution with expectation value $\mu_{ijk} = [b_{jk} + S_{ik}]M_j\Delta t_i \Delta E \epsilon_{jk}$. The b_{jk} are the background contributions, M_j is the mass of the jth detector, Δt_i is the detector running time during the ith time interval, ΔE is the chosen energy bin, ϵ_{jk} is the overall efficiency. Moreover, the signal can be written as $S_{ik} = S_{0,k}+S_{m,k}\cos\omega(t_i-t_0)$, where $S_{0,k}$ is the constant part of the signal and $S_{m,k}$ is the modulation amplitude. The usual procedure is to minimize the function $y_k = -2\ln(\mathbf{L}_k) - \mathrm{const}$ for each energy bin; the free parameters of the fit are the $(b_{jk} + S_{0,k})$ contributions and the $S_{m,k}$ parameter. Hereafter, the index k is omitted for simplicity.

In Fig. 4, the obtained S_m are shown in each considered energy bin (there $\Delta E = 0.5$ keV), when the data of DAMA/NaI and DAMA/LIBRA-phase1 are considered. It can be inferred that positive signal is present in the 2–6 keV energy interval, while S_m values compatible with zero are present just above. In fact, the S_m values in the 6–20 keV energy interval have random fluctuations around zero with χ^2 equal to 35.8 for 28 degrees of freedom (upper tail probability of 15%). All this confirms the previous analyses.

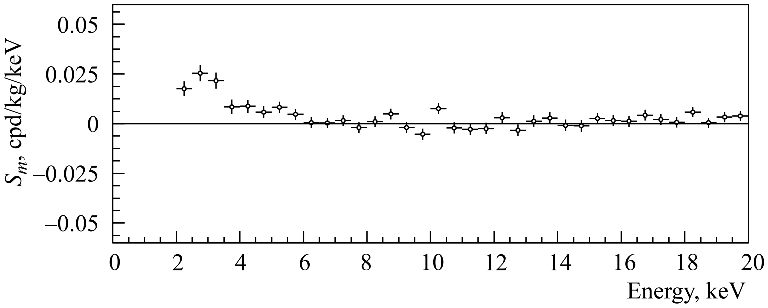

Fig. 4. Energy distribution of the S_m variable for the total cumulative exposure 1.33 t · y. The energy bin is 0.5 keV. A clear modulation is present in the lowest energy region, while S_m values compatible with zero are present just above. In fact, the S_m values in the 6–20 keV energy interval have random fluctuations around zero with χ^2 equal to 35.8 for 28 degrees of freedom (upper tail probability of 15%)

As described in [2–4, 8], the observed annual modulation effect is well distributed in all the 25 detectors at 95% C.L.

Among further additional tests, the analysis of the modulation amplitudes as a function of the energy separately for the nine inner detectors and the remaining external ones has been carried out for the entire DAMA/LIBRA-phase1. The obtained values are fully in agreement; in fact, the hypothesis that the two sets of modulation amplitudes as a function of the energy belong to the same distribution has been verified by χ^2 test, obtaining: $\chi^2/\text{d.o.f.} = 3.9/4$ and 8.9/8 for the energy intervals 2–4 and 2–6 keV, respectively ($\Delta E = 0.5$ keV). This shows that the effect is also well shared between inner and outer detectors.

Let us, finally, release the assumption of a phase $t_0 = 152.5$ day in the procedure to evaluate the modulation amplitudes. In this case the signal can be written as

$$\begin{aligned} S_{ik} &= S_{0,k} + S_{m,k}\cos\omega(t_i - t_0) + Z_{m,k}\sin\omega(t_i - t_0), \\ &= S_{0,k} + Y_{m,k}\cos\omega(t_i - t^*). \end{aligned} \tag{1}$$

For signals induced by DM particles one should expect: i) $Z_{m,k} \sim 0$ (because of the orthogonality between the cosine and the sine functions); ii) $S_{m,k} \simeq Y_{m,k}$; iii) $t^* \simeq t_0 = 152.5$ day. In fact, these conditions hold for most of the dark halo models; however, as mentioned above, slight differences can be expected in case of possible contributions from nonthermalized DM components, such as, e.g., the SagDEG stream [19, 29, 30] and the caustics [31].

Considering cumulatively the data of DAMA/NaI and DAMA/LIBRA-phase1, the obtained 2σ contours in the plane (S_m, Z_m) for the 2–6 keV and 6–14 keV energy intervals are shown in Fig. 5, *a*, while in Fig. 5, *b*, the obtained 2σ contours in the plane (Y_m, t^*) are depicted. The best fit values for the 2–6 and 6–14 keV energy intervals (1σ errors) for S_m versus Z_m and Y_m versus t^* are reported in Table 1.

Finally, setting S_m in Eq. (1) to zero, the Z_m values as a function of the energy have also been determined by using the same procedure. The values of Z_m are well compatible with zero, as expected [2–4].

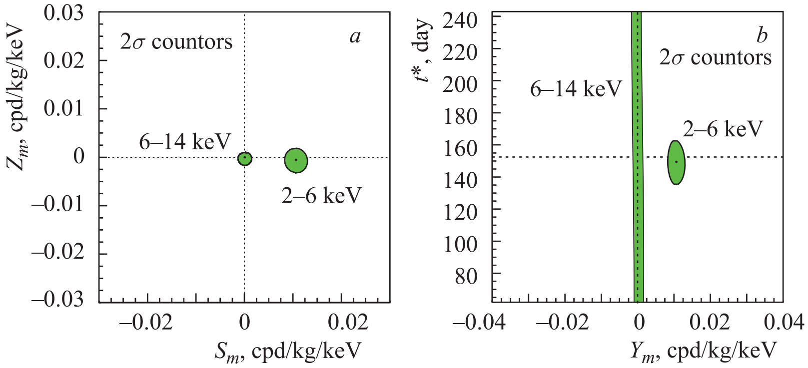

Fig. 5. 2σ contours in the plane (S_m, Z_m) (*a*) and in the plane (Y_m, t^*) (*b*) for the 2–6 keV and 6–14 keV energy intervals. The contours have been obtained by the maximum likelihood method, considering the cumulative exposure of DAMA/NaI and DAMA/LIBRA-phase1. A modulation amplitude is present in the lower energy intervals and the phase agrees with that expected for DM induced signals. See the text

Table 1. **Best fit values for the 2–6 and 6–14 keV energy intervals (1σ errors) for S_m versus Z_m and Y_m versus t^*, considering the cumulative exposure of DAMA/NaI and DAMA/LIBRA-phase1. See also Fig. 5**

E, keV	S_m, cpd/kg/keV	Z_m, cpd/kg/keV	Y_m, cpd/kg/keV	t^*, day
2–6	0.0106 ± 0.0012	-0.0006 ± 0.0012	0.0107 ± 0.0012	149.5 ± 7.0
6–14	0.0001 ± 0.0007	0.0000 ± 0.0005	0.0001 ± 0.0008	Undefined

Sometimes naive statements were put forwards as the fact that in nature several phenomena may show some kind of periodicity. The point is whether they might mimic the annual modulation signature in DAMA/LIBRA (and former DAMA/NaI), i.e., whether they might be not only quantitatively able to account for the observed modulation amplitude but also able to contemporaneously satisfy all the requirements of the DM annual modulation signature. The same is also for side reactions. This has already been deeply investigated in [1–4] and references therein; the arguments and the quantitative conclusions, presented there, also apply to the entire DAMA/LIBRA-phase1 data. Additional arguments can be found in [7, 8, 12, 33–39].

In order to continuously monitor the running conditions, several pieces of information are acquired with the production data and quantitatively analyzed. In particular, all the time behaviours of the running parameters, acquired with the production data, have been investigated: the modulation amplitudes obtained for each annual cycle when fitting the time behaviours of the parameters including a cosine modulation with the same phase and period as for DM particles are well compatible with zero.

No modulation has been found in any possible source of systematics or side reactions; thus, cautious upper limits (90% C.L.) on possible contributions to the DAMA/LIBRA measured modulation amplitude are summarized in Table 2 (also see [2–4]). It is worth noting that they do not quantitatively account for the measured modulation amplitudes, and also are not able to simultaneously satisfy all the many requirements of the signature. Similar analyses have also been done for the seven annual cycles of DAMA/NaI [16, 17].

In conclusion, the model-independent DAMA results give evidence (at 9.3σ C.L. over 14 independent annual cycles) for the presence of DM particles in the galactic halo.

In order to perform corollary investigations on the nature of the DM particles, model-dependent analyses are necessary; thus, many theoretical and experimental parameters and models are possible and many hypotheses must also be exploited.

In particular, the obtained DAMA model-independent evidence is compatible with a wide set of scenarios regarding the nature of the DM candidate and

Table 2. **Summary of the results obtained by investigating possible sources of systematics or side processes [1–4, 7, 8, 12, 33–39]. None able to give a modulation amplitude different from zero has been found; thus cautious upper limits (90% C.L.) on the possible contributions to the measured modulation amplitude have been calculated and shown here**

Source	Main comment	Cautious upper limit, cpd/kg/keV (90% C.L.)
Radon	Sealed Cu Box in HP Nitrogen atmosphere, 3-level of sealing	$< 2.5 \cdot 10^{-6}$
Temperature	Air conditioning + huge heat capacity	$< 10^{-4}$
Noise	Efficient rejection	$< 10^{-4}$
Energy scale	Routine + intrinsic calibrations	$< (1{-}2) \cdot 10^{-4}$
Efficiencies	Regularly measured	$< 10^{-4}$
Background	No modulation above 6 keV; no modulation in the 2–6 keV *multiple-hit* events; this limit includes all possible sources of background	$< 10^{-4}$
Side reactions	From muon flux variation measured by MACRO	$< 3 \cdot 10^{-5}$
In addition: no effect can mimic the signature.		

related astrophysical, nuclear and particle physics. For examples, some given scenarios and parameters are discussed, e.g., in [2, 8, 13, 15, 16, 19]. Further, large literature is available on the topics (see, for example, in [8]). Moreover, both the negative results and all the possible positive hints, achieved so-far in the field, are largely compatible with the DAMA model-independent DM annual modulation results in many scenarios considering also the existing experimental and theoretical uncertainties; the same holds for indirect approaches; see, e.g., arguments in [8] and references therein.

2. DAMA/LIBRA-PHASE2 AND PERSPECTIVES

After the first upgrade of the DAMA/LIBRA setup in September 2008, a more important upgrade has been performed at the end of 2010, when all the PMTs have been replaced with new ones having higher Quantum Efficiency (QE), realized with a special dedicated development by HAMAMATSU co.. Details on the developments and on the reached performances in the operative conditions are reported in [6]. We remind that up to October 2010, low background PMTs, developed by EMI-Electron Tubes with dedicated R&D, were used; the light yield and other response features already allowed in DAMA/NaI and DAMA/LIBRA-phase1 a software energy threshold of 2 keV in the data analysis. The feasibility to decrease the software energy threshold below 2 keV in the new configuration has been demonstrated [6].

Since the fulfillment of this upgrade, DAMA/LIBRA-phase2 — after optimization periods — is continuously running in order: 1) to increase the experimental sensitivity lowering the software energy threshold of the experiment; 2) to improve the corollary investigation on the nature of the DM particle and related astrophysical, nuclear, and particle physics arguments; 3) to investigate other signal features. This requires long and heavy full time dedicated work for reliable collection and analysis of very large exposures.

Another upgrade at the end of 2012 was successfully concluded: new-concept preamplifiers were installed, with suitable operative and electronic features; in particular, they allow the direct connection of the signal to the relative channel of the Transient Digitizer (TD). Moreover, further improvements are planned; in particular, new trigger modules have been prepared and ready to be installed.

In the future, DAMA/LIBRA will also continue its study on several other rare processes [9–11] as also the former DAMA/NaI apparatus did [24].

Finally, further improvements to increase the sensitivity of the setup can be considered; in particular, the use of high QE and ultra-low background PMTs directly coupled to the NaI(Tl) crystals is an interesting possibility*. This possible configuration can allow a further large improvement in the light collection and a further lowering of the software energy threshold. Moreover, efforts towards a possible highly radiopure NaI(Tl) "general purpose" experiment (DAMA/1 t) having full sensitive mass of 1 t (we already proposed in 1996 as a general purpose setup) have been continued in various aspects.

CONCLUSIONS

The data of DAMA/LIBRA-phase1 have further confirmed the presence of a peculiar annual modulation of the *single-hit* events in the 2–6 keV energy region satisfying all the many requirements of the DM annual modulation signature; the cumulative exposure by the former DAMA/NaI and DAMA/LIBRA-phase1 is 1.33 $t \cdot y$.

In fact, as required by the DM annual modulation signature: 1) the *single-hit* events show a clear cosine-like modulation as expected for the DM signal; 2) the measured period is equal to (0.998 ± 0.002) y well compatible with the 1 y period

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*However, this would require the disassembling of the detectors since the light guides act at present also as optical windows.

as expected for the DM signal; 3) the measured phase (144 ± 7) days is compatible with $\simeq$ 152.5 days as expected for the DM signal; 4) the modulation is present only in the low energy 2–6 keV interval and not in other higher energy regions, consistently with expectation for the DM signal; 5) the modulation is present only in the *single-hit* events, while it is absent in the *multiple-hit* ones as expected for the DM signal; 6) the measured modulation amplitude in NaI(Tl) of the *single-hit* events in the 2–6 keV energy interval is: (0.0112 ± 0.0012) cpd/kg/keV (9.3σ C.L.). No systematic or side processes able to simultaneously satisfy all the many peculiarities of the signature and to account for the whole measured modulation amplitude are available.

DAMA/LIBRA is continuously running in its new configuration (named DAMA/LIBRA-phase2) with a lower software energy threshold aiming to improve the knowledge on corollary aspects regarding the signal and on second order effects as discussed, e.g., in [8, 12].

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