Results from the DAMA/LIBRA experiment

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Abstract. The DAMA project is an observatory for rare processes and it is operative deep underground at the Gran Sasso National Laboratory of the I.N.F.N. In particular, the DAMA/LIBRA (Large sodium Iodide Bulk for RARe processes) set-up consists of highly radiopure NaI(Tl) detectors for a total sensitive exposed mass of \(\simeq 250\) kg. The results, obtained by this set-up by exploiting the model independent annual modulation signature of Dark Matter (DM) particles, have confirmed and improved those obtained by the former DAMA/NaI experiment. A model independent evidence for the presence of Dark Matter particles in the galactic halo is cumulatively obtained at 8.2 \(\sigma\) C.L.. No systematics or side reactions able to account for the measured modulation amplitude and to contemporaneously satisfy all the many specific requirements of the signature have been found or suggested by anyone over more than a decade. Future perspectives are shortly addressed.

1. Introduction

With the present technology the only reliable signature able to point out – in a model independent way – the presence of Dark Matter (DM) particles in the galactic halo is the DM annual modulation signature. This signature – originally suggested in the middle of ’80 in ref. [1] – exploits the effect of the Earth revolution around the Sun on the number of events induced by the Dark Matter particles in a suitable low-background set-up placed deep underground. In fact, as a consequence of its annual revolution, the Earth should be crossed by a larger flux of Dark Matter particles around \(\sim 2\) June (when its rotational velocity is summed to the one of the solar system with respect to the Galaxy) and by a smaller one around \(\sim 2\) December (when the two velocities are subtracted). In fact, the expected differential rate as a function of the energy (see also ref. [2, 3, 4, 5, 6, 7, 8, 9, 10] for some discussions) also depends on the DM particle velocity distribution and on the Earth’s velocity in the galactic frame. This offers an efficient model independent signature, able to test a large interval of cross sections and of halo densities. Thus, the contribution of the signal to the counting rate in the \(k\)-th energy interval
can be written as $S_k = S_{0,k} + S_{m,k} \cos \omega (t - t_0)$, where: i) $S_{0,k}$ is the constant part of the signal; ii) $S_{m,k}$ is the modulation amplitude; iii) $\omega = \frac{2\pi}{T}$ with period $T$; iv) $t_0$ is the phase.

The DM annual modulation signature is very distinctive since the DM signal 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 around $\simeq 2^{nd}$ 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 7% for usually adopted halo distributions (6), but it can be larger in case of some possible scenarios such as e.g. those in refs. [11, 12]. Only systematic effects or side reactions able to fulfil these requirements and to account for the whole observed modulation amplitude could mimic this signature; thus, no other effect investigated so far in the field of rare processes offers a so stringent and unambiguous signature. It is worth noting that the DM annual modulation is not – as often naively said – a "seasonal" variation and it is not a "winter-summer" effect. In fact, the DM annual modulation is not related to the relative Sun position, but it is related to the Earth velocity in the galactic frame. Moreover, the phase of the DM annual modulation (roughly $2^{nd}$ June) is well different than those of physical quantities (such as temperature of atmosphere, pressure, other meteorological parameters, cosmic rays flux, ...) instead correlated with seasons.

In the following, we will summarize just some of the main aspects of the first results obtained by DAMA/LIBRA exploiting over four annual cycles (exposure: $0.53 \text{ ton} \times \text{yr}$) the model independent DM annual modulation signature. These data and those previously collected by DAMA/NaI over 7 annual cycles ($0.29 \text{ ton} \times \text{yr}$) correspond to 11 annual cycles for a total exposure of $0.82 \text{ ton} \times \text{yr}$. All details can be found in ref. [13, 14] and references therein.

2. The DAMA project

The DAMA project is mainly based on the development and use of low background scintillators [2, 3, 4, 5, 6, 7, 8, 9, 13, 14, 15, 16, 17, 18, 19]; the main aim is the direct detection of DM particles in the galactic halo by investigating the DM model independent annual modulation signature. Profiting from the low background features of these set-ups, other rare processes are also investigated obtaining often competitive results.

The main experimental set-ups are: i) DAMA/NaI ($\simeq 100 \text{ kg}$ of highly radiopure NaI(Tl)) which completed its data taking on July 2002 [2, 3, 4, 5, 6, 7, 8, 9, 15, 17]; ii) DAMA/LXe ($\simeq 6.5 \text{ kg}$ liquid Kr-free Xenon enriched either in $^{129}\text{Xe}$ or in $^{136}\text{Xe}$) [20, 21] (which is again in operation since december 2007 after an upgrading and the waiting for the restoring of the underground laboratory water plant, necessary for the compressor refrigeration); iii) DAMA/R&D, devoted to tests on prototypes and to small scale experiments [22]; iv) the new second generation DAMA/LIBRA set-up ($\simeq 250 \text{ kg}$ highly radiopure NaI(Tl)) in operation since March 2003 [13, 14, 19] and firstly upgraded in fall 2008. Moreover, in the framework of devoted R&D for radiopure detectors and photomultipliers, sample measurements are carried out by means of the low background DAMA/Ge detector (installed deep underground since more than $\simeq 15$ years); this detector is also used for small scale experiments [23].

The DAMA/NaI set up and its performances are described in ref.[2, 3, 16, 24], while DAMA/LIBRA set-up and its performances in ref. [14]. Here we just summarized that: i) the detectors’ responses range from 5.5 to 7.5 photoelectrons/keV; ii) the hardware threshold of each photomultiplier (PMT) is at single photoelectron (each detector is equipped with two low background PMTs working in coincidence); iii) energy calibration with X-rays/$\gamma$ sources are regularly carried out down to few keV; iv) the software energy threshold of the experiment is 2 keV [14]. The DAMA/NaI experiment collected an exposure of $0.29 \text{ ton} \times \text{yr}$ over 7 annual
cycles [2, 3, 4, 5, 6, 7, 8, 9], while DAMA/LIBRA [13, 14, 19] has released so far an exposure of 0.53 ton×yr collected over 4 annual cycles [13]. Thus, the total exposure of the two experiments is 0.82 ton×yr, which is orders of magnitude larger than the exposures typically collected in the field.

3. The model independent DM annual modulation results

Several analyses on the model-independent investigation of the DM annual modulation signature have been performed (see ref. [13] and references therein); here just few arguments are reminded.

Fig. 1 shows the time behaviour of the experimental residual rates of the single-hit events collected by DAMA/NaI and by DAMA/LIBRA in the (2–6) keV energy interval. The superimposed curve represents the cosinusoidal function behavior $A \cos \omega(t - t_0)$ with a period $T = \frac{2\pi}{\omega} = 1$ yr and with a phase $t_0 = 152.5$ day (June 2$^{nd}$), while the modulation amplitude, $A$, has been obtained by best fit over the DAMA/NaI and DAMA/LIBRA data. When the period and the phase parameters are released in the fit, values well compatible with those expected for a DM particle induced effect are obtained [13]. In particular, the cumulative analysis of the single-hit residual rate favours the presence of a modulated cosine-like behaviour with the proper features at 8.2 $\sigma$ C.L.[13].

![Figure 1](image.jpg)

**Figure 1.** Experimental model-independent residual rate of the single-hit scintillation events, measured by DAMA/NaI and DAMA/LIBRA in the (2 – 6) keV energy interval as a function of the time. The zero of the time scale is January 1$^{st}$ of the first year of data taking of DAMA/NaI. The experimental points present the errors as vertical bars and the associated time bin width as horizontal bars. The superimposed curve is the cosinusoidal function behavior $A \cos \omega(t - t_0)$ with a period $T = \frac{2\pi}{\omega} = 1$ yr, with a phase $t_0 = 152.5$ day (June 2$^{nd}$), and with modulation amplitude, $A$, equal to the central value obtained by best fit over the whole data, that is (0.0129 ± 0.0016) cpd/kg/keV. The dashed vertical lines correspond to the expected maximum of the signal (June 2$^{nd}$), while the dotted vertical lines correspond to the expected minimum. The total exposure is 0.82 ton × yr [13].

The same data of Fig.1 have also been investigated by a Fourier analysis, obtaining a clear peak corresponding to a period of 1 year [13]; the same analysis in other energy regions shows instead only aliasing peaks. Similar result is obtained when comparing the single-hit residuals in the (2–6) keV with those in other energy interval; in fact, a clear modulation is present in the lowest energy interval, while it is absent just above [13]. In particular, in order to verify absence of annual modulation in other energy regions and, thus, to also verify the absence of any significant background modulation, the energy distribution measured during the data taking periods in energy regions not of interest for DM detection has also been investigated. In fact, the background in the lowest energy region is essentially due to “Compton” electrons, X-rays and/or Auger electrons, muon induced events, etc., which are strictly correlated with the events in the higher energy part of the spectrum. Thus, if a modulation detected in the lowest energy region would be due to a modulation of the background (rather than to a signal), an equal
or larger modulation in the higher energy regions should be present. The data analyses have allowed to exclude the presence of a background modulation in the whole energy spectrum at a level much lower than the effect found in the lowest energy region for the single-hit events [13].

A further relevant investigation has been done by applying the same hardware and software procedures, used to acquire and to analyse the single-hit events, to the multiple-hits ones. 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, this allows the study of the background behaviour in the same energy interval of the observed positive effect. In particular, while a clear modulation with proper features is present in the (2–6) keV single-hit events, the modulation amplitude of the multiple-hits ones in the same energy interval is well compatible with zero [13] (see Fig. 2). Similar results were previously obtained also for the DAMA/NaI case [3]. Thus, again evidence of annual modulation with the proper features required by the DM annual modulation signature, is present in the single-hit residuals (events class to which the DM particle induced events belong), while it is absent in the multiple-hits residual rate (event class to which only background events belong). Since the same identical hardware and the same identical software procedures have been used to analyse the two classes of events, the obtained result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background.

The annual modulation present at low energy has also been shown by depicting the differential modulation amplitudes, $S_{m,k}$, as a function of the energy, as obtained by maximum likelihood method over the data, considering $T = 1$ yr and $t_0 = 152.5$ day; positive signal is present in the (2–6) keV energy interval, while $S_{m,k}$ values compatible with zero are present just above. It has also been verified that the measured modulation amplitudes are statistically well distributed in all the crystals, in all the annual cycles and in the energy bins; these and other discussions can be found in ref. [13].

The data have also been analysed [13] releasing in the maximum likelihood procedure the assumption of a phase $t_0 = 152.5$ day, that is considering: $S_k = S_{0,k} + S_{m,k} \cos \omega(t - t_0) + Z_{m,k} \sin \omega(t - t_0) = S_{0,k} + Y_{m,k} \cos \omega(t - t^*)$. Obviously, DM induced signal requires: i) $Z_{m,k} \approx 0$ (because of the orthogonality between the cosine and the sine functions); ii) $S_{m,k} \approx Y_{m,k}$; iii) $t^* \approx t_0 = 152.5$ day. The obtained results (see Fig. 3) further confirm those already achieved by other kinds of analyses. In particular, a modulation amplitude is present in the single-hit events

![Figure 2. Experimental model-independent residual rates of the (2 – 6) keV single-hit events (open circles) (class of events to which DM events belong) and of the (2 – 6) keV multiple-hits events (filled triangles) (class of events to which DM events do not belong), measured in the four DAMA/LIBRA annual cycles (as collected in a single annual cycle; the initial time of the scale is taken on August 7th). The same identical hardware and the same identical software procedures have been applied in both cases. The experimental points present the errors as vertical bars and the associated time bin width as horizontal bars. For details see ref. [13].](image-url)
in the lower energy intervals and the period and the phase agree with those expected for DM induced signals. For more discussions see ref. [13].

**Figure 3.** 2σ contours in the plane \((S_m, Z_m)\) (left) and in the plane \((Y_m, t^*)\) (right) for the (2–6) keV and (6–14) keV energy intervals. The contours have been obtained by the maximum likelihood method, considering the seven annual cycles of DAMA/NaI and the four annual cycles of DAMA/LIBRA all together. A modulation amplitude is present in the lower energy intervals and the period and the phase agree with those expected for DM induced signals. For details see ref. [13].

As previously done for DAMA/NaI [2, 3, 24], careful investigations on absence of any significant systematics or side reaction effect in DAMA/LIBRA have been quantitatively carried out and reported in details in ref. [13]. In order to continuously monitor the running conditions, several pieces of information are acquired with the production data and quantitatively analyzed. No systematics or side reactions able to account for the measured modulation amplitude and to simultaneously satisfy all the requirements of the signature have been found or suggested by anyone over more than a decade. For all details and for discussions see ref. [13] and references therein.

Just as an example we remind here the case of muons, whose flux has been reported by the MACRO experiment to have a 2% modulation with phase around mid–July (that is different than expected for the DM annual modulation signature and measured by the DAMA experiments). In particular, it has been shown [13] that not only this effect would give rise in the DAMA set-ups to a quantitatively negligible contribution, but some of the six requirements necessary to mimic the annual modulation signature – namely e.g. the conditions of presence of modulation just in the single-hit event rate and of the phase value – would also fail. Moreover, even the pessimistic assumption of whatever hypothetical (even exotic) cosmogenic product – whose decay or de-excitation or whatever else (with mean-life \(\tau\)) might produce: i) only events at low energy; ii) only single-hit events; iii) no sizeable effect in the multiple-hits counting rate – cannot give rise to any side process able to mimic the investigated DM signature. In fact, not only this latter hypothetical process would be quantitatively negligible, but in addition e.g. its phase – as it can be easily derived – would be even (much) larger than July 15th, and therefore again well different from the one measured by the DAMA experiments and expected from the DM annual modulation signature (\(\simeq\) June 2nd). Thus, also any possible effect from muons can be safely excluded.

Summarizing, DAMA/LIBRA has confirmed the presence of an annual modulation satisfying all the requirements of the DM annual modulation signature, as previously pointed out by DAMA/NaI; in particular, the evidence for the presence of DM particles in the galactic halo is cumulatively supported at 8.2 \(\sigma\) C.L..

It is worth noting that no other experiment exists, whose result can be directly compared in a
model-independent way with those by DAMA/NaI and DAMA/LIBRA. In particular, let us also point out that results obtained with different target materials and/or different approaches cannot intrinsically be directly compared among them even when considering the same kind of candidate and of coupling, although apparently all the presentations generally refer to cross sections on nucleon. Therefore, claims for contradictions made by experiments insensitive to the DM annual modulation signature, using different target materials and approaches, having well different sensitivities to various DM candidate and interactions, etc. have by the fact no impact even in the single arbitrary scenario they usually consider without accounting for experimental and theoretical uncertainties, using often crude approximation in the calculation, etc. Moreover, (see for example [2, 25, 26]), some critical points exist in those activities, claiming for exclusion, on important experimental aspects (energy threshold, energy scale, multiple selection procedures, stabilities, etc.). A relevant argument is also the methodological robustness [27]. Thus, the long-standing claims for controversy are arbitrary and have no serious scientific basis. Finally, the boost effect of DAMA activities and results in the field of direct Dark Matter investigation can be easily derived.

It is also worth noting that, whenever an experiment using the same identical target material and methodological approach would be available in future, as usual in whatever field of Physics a serious comparison would require – in every case – e.g. a deep investigation of the radiopurity of all the part of the different set-ups, of their specific performances in all the aspects, of the detailed procedures used by each one, of the used exposures, of the stability parameters, etc. Finally, as regards the indirect detection searches, let us note that also no direct model-independent comparison can be performed between the results obtained in direct and indirect activities, since it does not exist a biunivocal correspondence between the observables in the two kinds of experiments. Anyhow, if possible excesses in the positron to electron flux ratio and in the $\gamma$ rays flux with respect to an assumed simulation of the hypothesized contribution, which has to be expected from standard sources, might be interpreted in terms of Dark Matter (but huge and still unjustified boost factor and new interaction types are required), this would be not in conflict with the effect observed by DAMA experiments, as also discussed in literature at some extent.

4. Already performed and planned upgradings

During September 2008 a first upgrade of the DAMA/LIBRA set-up has been realized and the shield has been opened in HP Nitrogen atmosphere. This has allowed the increase of the exposed mass since one detector has been recovered by replacing a broken PMT [13]. Moreover, a new optimization of some PMTs and HVs has been done. Finally, a total replacement of the used transient digitizers with new ones, having better performances, has been realized and a new DAQ with optical fibers has been installed and put in operation. The data taking has been restarted on October 2008. Moreover, in order to further increase the experimental sensitivity, it has been pointed out the relevance to lower the software energy threshold of the experiment and to improve some other aspects; thus, the replacement of all the PMTs with new ones with higher quantum efficiency has been planned.

A larger exposure collected by DAMA/LIBRA (or possibly by DAMA/1ton) and the lowering of the 2 keV energy threshold in the data analysis will improve the sensitivity of the experiment and the corollary information on the nature of the DM candidate particle(s) and on the various related astrophysical, nuclear and particle Physics scenarios. In addition, it is worth noting that ultra low background NaI(Tl) scintillators can also offer the possibility to achieve significant results on several other rare processes as already done e.g. by the former DAMA/NaI apparatus [17] and by DAMA/LIBRA so far [19].

Finally, we also mention that a third generation R&D effort towards a possible NaI(Tl) ton set-up, DAMA proposed in 1996, has been funded by I.N.F.N. and is in progress. Let us point
out that large exposed target masses is a key point for the investigation of the DM particles in the galactic halo with higher sensitivities, but it is not sufficient. In fact, a competitive DM experiment studying the annual modulation signature must also have a high duty cycle, long exposure time and very high stability for the long time of data taking, etc. Many of these requirements are not satisfied by proposed and planned experiments in this field (see e.g. for some cases [25, 26]).

References

[1] K.A. Drukier et al., Phys. Rev. D 33 (1986) 3495; K. Freese et al., Phys. Rev. D 37 (1988) 3388.
[2] R. Bernabei et al., La Rivista del Nuovo Cimento 26 n.1 (2003) 1-73.
[3] R. Bernabei et al., Int. J. Mod. Phys. D 13 (2004) 2127.
[4] R. Bernabei et al., Eur. Phys. J. C 47 (2006) 263.
[5] R. Bernabei et al., Int. J. Mod. Phys. A 21 (2006) 1445.
[6] R. Bernabei et al., Int. J. Mod. Phys. A 22 (2007) 3155.
[7] R. Bernabei et al., Eur. Phys. J. C 53 (2008) 205.
[8] R. Bernabei et al., Phys. Rev. D 77 (2008) 023506.
[9] R. Bernabei et al., Mod. Phys. Lett. A 23 (2008) 2125.
[10] P. Belli et al., Phys. Rev. D 61 (2000) 023512.
[11] D. Smith and N. Weiner, Phys. Rev. D 64 (2001) 043502; D. Tucker-Smith and N. Weiner, Phys. Rev. D 72 (2005) 063509.
[12] K. Freese et al., Phys. Rev. D 71 (2005), 043516; Phys. Rev. Lett. 92 (2004) 11301.
[13] R. Bernabei et al., Eur. Phys. J. C 56 (2008) 333.
[14] R. Bernabei et al., Nucl. Instr. & Meth. A 592 (2008) 297.
[15] R. Bernabei et al., Phys. Lett. B 389 (1996) 757; R. Bernabei et al., Phys. Lett. B 424 (1998) 195; R. Bernabei et al., Phys. Lett. B 450 (1999) 448; R. Bernabei et al., Il Nuovo Cim. A 112 (1999) 545; P. Belli et al., Phys. Rev. D 61 (2000) 023512; R. Bernabei et al., Phys. Lett. B 480 (2000) 23; R. Bernabei et al., Eur. Phys. J. C 18 (2000) 283. R. Bernabei et al., Phys. Lett. B 509 (2001) 197; R. Bernabei et al., Eur. Phys. J. C 23 (2002) 61; P. Belli et al., Phys. Rev. D 66 (2002) 043503.
[16] R. Bernabei et al., Il Nuovo Cim. A 112 (1999) 545.
[17] R. Bernabei et al., Phys. Rev. Lett. 83 (1999) 439; P. Belli et al., Phys. Rev. Lett. B 460 (1999) 236; R. Bernabei et al., Phys. Rev. Lett. 83 (1999) 4918; P. Belli et al., Phys. Rev. C 60 (1999) 065501; R. Bernabei et al., Il Nuovo Cimento A112 (1999) 1541; R. Bernabei et al., Phys. Lett. B 515 (2001) 6; F. Cappella et al., Eur. Phys. J. -direct C14 (2002) 1; R. Bernabei et al., Eur. Phys. J. A 23 (2005) 51.
[18] R. Bernabei et al., Astrop. Phys. 4 (1995) 45; R. Bernabei, in the volume ”The identification of Dark Matter”, World Sc. Pub. (1997) 574.
[19] R. Bernabei et al., Eur. Phys. J. C 62 (2009) 327.
[20] P. Belli et al., Astropart. Phys. 5 (1996) 217; P. Belli et al., Nuovo Cim. C 19 (1996) 537; P. Belli et al., Phys. Lett. B 387 (1996) 222; P. Belli et al., Phys. Lett. B 389 (1996) 783 (err.); P. Belli et al., Phys. Lett. B 465 (1999) 315; P. Belli et al., Phys. Rev. D 61 (2000) 117301; R. Bernabei et al., New J. of Phys. 2 (2000) 15.1; R. Bernabei et al., Phys. Lett. B 493 (2000) 12; R. Bernabei et al., Eur. Phys. J. direct C11 (2001) 1; R. Bernabei et al., Nucl. Instr. & Meth A 482 (2002) 728; R. Bernabei et al., Phys. Lett. B 527 (2002) 182; R. Bernabei et al., Phys. Lett. B 546 (2002) 23; R. Bernabei et al., in the volume Beyond the Desert 2003, Springer, Berlin (2003) 365; R. Bernabei et al., Eur. Phys. J. A 27, s01 (2006) 35.
[21] R. Bernabei et al., Phys. Lett. B 436 (1998) 379.
[22] R. Bernabei et al., Astropart. Phys. 1 (1996) 73; R. Bernabei et al., Nuovo Cim. A 110 (1997) 189; P. Belli et al., Astropart. Phys. 10 (1999) 115; P. Belli et al., Nucl. Phys. B 563 (1999) 97; R. Bernabei et al., Nucl. Phys. A 705 (2002) 29; P. Belli et al., Nucl. Instr. & Meth A 498 (2003) 352; R. Cerulli et al., Nucl. Instr. & Meth A 525 (2004) 535; R. Bernabei et al., Nucl. Instr. & Meth A 555 (2005) 270; R. Bernabei et al., Ukr. J. Phys. 51 (2006) 1037; P. Belli et al., Nucl. Phys. A 789 (2007) 15; P. Belli et al., Phys. Rev. C 76 (2007) 064603; P. Belli et al., Phys. Lett. B 688 (2008) 193; P. Belli et al., Nucl. Phys. A 789 (2007) 15; P. Belli et al., Nucl. Phys. A 826 (2009) 256.
[23] P. Belli et al., Nucl. Instr. & Meth. A 572 (2007) 734; Nucl. Phys. A 806 (2008) 388; Nucl. Phys. A 824 (2009) 101.
[24] R. Bernabei et al., Eur. Phys. J. C 18 (2000) 283.
[25] R. Bernabei et al., ISBN 978-88-95688-12-1, pages 1-53 (2009) Exorma ed. (arXiv:0806.0011[astro-ph]).
[26] A. Benoit et al., Phys. Lett. B 637 (2006) 156.
[27] R. Hudson, Found. Phys. 39 (2009) 174-193.