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Recent results in Dark Matter direct detection

A. D. Ferella
INFN, Laboratori Nazionali del Gran Sasso - Assergi (AQ), Italy

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Summary. — Finding a solution to the Dark Matter problem is surely one of the main challenges of modern cosmology. The existence of both Dark Matter and Dark Energy has been formulated on the basis of strong observational evidences, and constitutes the main success of the most accredited cosmological models. Yet none of them has been directly detected. In this review the Dark Matter problem will be discussed and the approaches to directly detect it, in the form of a special category of particles, *i.e.* the WIMPs (Weakly Interacting Massive Particles), will be presented and discussed.

PACS 14.80.-j – Other particles (including hypothetical).
PACS 95.35.+d – Dark matter (stellar, interstellar, galactic, and cosmological).
PACS 29.90.+r – Other topics in elementary-particle and nuclear physics experimental methods and instrumentation.
PACS 07.20.Mc – Cryogenics; refrigerators, low-temperature detectors, and other low-temperature equipment.

1. – Evidence for Dark Matter

The experimental evidence of Dark Matter comes from astronomical and astrophysical observations at different scales and with completely different techniques. From galactic to cosmological scales all evidences strongly suggest that more than 95% of the Universe is made of invisible and unknown types of matter and energy. In this section the observations pointing to the existence of a missing mass in the Universe will be briefly discussed.

Presence of non-luminous matter in galaxies is found in the observation of the so-called rotation curves, *i.e.* the graph of circular velocities of stars and gas around the galactic center as a function of their distance from the galactic center. The milestone in the study of such rotation curves was put by the pioneering work by V. Rubin and W.K. Ford in 1970 [1].

Assuming that Newtonian dynamics is applicable also at such scales, the circular velocity of the stars in a galaxy (and of the interstellar medium) is found to be approximately constant with the radius, while expected to decrease (based on the luminous matter) which points to the presence of a non-luminous matter extending far beyond the optical and gaseous disks.

The first experimental evidence of a missing mass in the structures of the Universe came from the observation of the velocity dispersion of galaxies in the Coma cluster (Fritz Zwicky [2] in 1933). By measuring the radial velocities of eight galaxies in this cluster Zwicky found an unexpectedly large velocity dispersion which would imply the existence of some kind of "Dark Matter".

The Inter-Cluster Medium (ICM) is a gas (mostly ionized hydrogen and helium) heated up by the gravitation-induced movement. For dispersion velocities above 300 km/s, the gas emits radiation in the X-ray region. Thus, the dynamics of a cluster can be inferred by analyzing its X-ray emission profile. The first systematic observations of X-ray dynamics of galaxy clusters were made by Forman *et al.* in 1985 [3].

One of the most convincing "direct proof[s] of Dark Matter" comes from this extra-galactic scale. In 2006, D. Clowe *et al.* [4] combined the observations in the visible (by the HST), the X-ray (by Chandra) and the weak lensing reconstruction (of the visible images) of two colliding clusters of galaxies, the so-called "Bullet cluster" or 1E 0657-558. They found that while the major baryonic component of the two clusters (the ICM, detected with the X-ray) interacts electromagnetically and thus gets slowed down by the collision, the largest fraction of the mass of the two clusters (detected by weak lensing) crosses undisturbed each other without interacting. Also the visible objects are not greatly affected by the collision, and most of them passed right through, given the relatively low density of stars in the clusters.

Another very stringent evidence of the existence of a non-baryonic component of matter in the Universe comes from the precision measurement of the Cosmic Microwave Background (CMB) radiation and especially of its anisotropies.

The CMB was predicted in 1948 by George Gamow [5], as a relic radiation from about 300000 years after the Big Bang. The power spectrum of the CMB depends on the value of the "cosmological parameters", *i.e.* a set of less than ten numbers (depending on the model) which usually describe the matter content of the Universe (baryons, Dark Matter, Dark Energy, neutrinos), its age (Hubble parameter), its global geometry (curvature parameter) and the properties of the initial fluctuations (amplitude and spectral index).

From the analysis of the WMAP experiment data [6], using the flat Λ-CDM model([1]) it is found that $\Omega_\chi h^2 = 0.1099 \pm 0.0062$, $\Omega_b h^2 = 0.02273 \pm 0.00062$ and $h = 0.719^{+0.026}_{-0.027}$, where Ω_χ is the Dark Matter density, Ω_b is the density of baryonic matter and h the Hubble parameter.

A comprehensive picture on the matter content of the Universe at cosmological scales comes from the combination of the results from CMB, Ia-type supernovae [7] and the REFLEX galaxy cluster survey [8], which can be summarized as follows:

$$\Omega_{Tot} = 1.02 \pm 0.02, \quad (1)$$

$$\Omega_\Lambda = 0.73 \pm 0.04, \quad (2)$$

$$\Omega_M = 0.27 \pm 0.04, \quad (3)$$

$$\Omega_b = 0.044 \pm 0.004, \quad (4)$$

$$\Omega_\chi = 0.22 \pm 0.04, \quad (5)$$

with Ω_M being the total mass density, $\Omega_M = \Omega_\chi + \Omega_b$.

([1]) We use here the convention of indicating with $\Omega_i \equiv \rho_i/\rho_c$ the density of each matter/energy component of the Universe related to the so-called "critical density", $\rho_c = 1.88\, h^2\, 10^{-29}$ g/cm^3, defined as the average total density corresponding to a flat Universe.

2. – The nature of Dark Matter

Once that the existence of Dark Matter has been assessed, we need to understand its characteristics and nature. Moving from experimental evidences and with the help of theoretical predictions we will now try to depict the "identikit" of a Dark Matter particle.

It has already been observed in the previous section that Dark Matter interacts gravitationally (*i.e.* is constituted by *massive* particles), is made of *non-baryonic* particles that, being invisible to any radiation sensitive device, have to be also *electrically neutral*.

In the frame of the Big Bang theory, we can assume that in the early stages of the Universe, Dark Matter particles were in thermal equilibrium with other particles. However, in order to provide the present significant abundance and to satisfy the cosmological requirements $\Omega_M \cong 0.3$, they had to have decoupled, before the present time [9]. Furthermore they have to be *stable* or at least have a lifetime much longer than the age of the Universe.

Dark Matter candidates may be classified as "hot" (relativistic) or "cold" (non-relativistic) according to their energy at the time when they de-coupled from the rest of the Universe. The observations on the present Universe suggest a Dark Matter being predominantly cold, *i.e. non-relativistic*. This is derived from the relation between the tiny fluctuations in the matter-density of the early Universe and the large scale structure we observe today: anisotropies in the cosmic microwave background radiation, cannot be created by the fluctuations in the baryonic matter density alone, and thus Dark Matter is required. Moreover, if Dark Matter were hot it would not be able to assemble in confined region and the Universe structures we observe nowadays would have been much more isotropic.

2˙1. *The WIMP miracle*. – The evolution of the number density of a particle χ over age of the Universe t follows the Boltzmann equation:

$$\frac{\mathrm{d}n_\chi}{\mathrm{d}t} + 3Hn_\chi = -\langle\sigma_A v\rangle(n_\chi^2 - (n_\chi^{eq})^2), \tag{6}$$

where H is the Hubble constant, n_χ is the number density, $\langle\sigma_A v\rangle$ is the thermally averaged annihilation cross section times the velocity of the species χ, and n_χ^{eq} is the number density in thermal equilibrium, so the term $3Hn_\chi$ is the term associated with the expansion of the Universe.

Following relatively simple considerations and calculations, we can find that the total density of χ particles (Ω_χ) is

$$\Omega_\chi = 1.66\ g^{1/2} \frac{T_0^3}{\rho_c m_{Pl}\langle\sigma_A|v\rangle}\,.$$

Substituting $T_0 = 2.35 \cdot 10^{-4}\,\mathrm{eV}$ (the current Universe temperature), $\rho_c = 1.05 \times 10^4\,h^2\,\mathrm{eV}\cdot\mathrm{cm}^{-3}$, $m_{Pl} = 1.22 \cdot 10^{28}\,\mathrm{eV}$ and $g^{1/2} \sim 1$, we obtain

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \simeq \frac{3 \cdot 10^{-27}\,\mathrm{cm}^3\,\mathrm{s}^{-1}}{\langle\sigma_a v\rangle}\,.$$

Therefore, in the case of Dark Matter particles we find that $\langle\sigma_a v\rangle \sim 10^{-26}{\div}10^{-25}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$, which is very close to the weak interaction cross section (of the order of

$\langle\sigma_a v\rangle \sim 10^{-25}\,\mathrm{cm^3\,s^{-1}}$). For this reason it is believed that a hypothetical "*Weakly Interacting* Massive Particle" (WIMP) could solve the Dark Matter puzzle and this concept defines the so called *WIMP miracle*.

No solution to the Dark Matter problem can be found in the framework of the Standard Model of Particle Physics, but on the other hand WIMPs are predicted in many supersymmetric extensions of this Model, with largely different masses and interaction cross-sections.

3. – Direct detection of WIMPs

3·1. *The rate.* – If WIMPs exist and are really the dominant constituent of Dark Matter, they must be present also in the Milky Way [10] and, though they only very rarely interact with conventional matter, should nonetheless be detectable in sufficiently sensitive experiments on Earth. The WIMP flux on Earth is of the order of $10^5\,\mathrm{cm^{-2}\,s^{-1}}$, large enough to allow the detection of the nuclear recoils caused by their elastic scattering off target nuclei of Earth based detectors [11]. Direct Dark Matter search experiments, indeed, aim to detect the interactions of WIMPs in dedicated low background detectors, by measuring the rate, R, and energy, E_R, of the induced nuclear recoils and possibly, in directional experiments, the direction. Since the WIMP-nucleon relative velocity v is non-relativistic, the recoil energy E_R can be expressed in terms of the scattering angle in the center of mass frame, θ as

$$E_R = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu_{\chi N}^2 v^2}{m_N}(1-\cos\theta),$$

where m_N and m_χ are the masses of the target nucleus and of the WIMP, $|\vec{q}\,| = \sqrt{2m_N E_R}$ is the momentum transfer and $\mu_{\chi-N} = \frac{m_\chi m_N}{m_\chi + m_N}$ is the WIMP-nucleus reduced mass. The differential nuclear recoil rate induced by the WIMPs can be written as

$$R = \int_{E_{th}}^{\infty} \mathrm{d}E_R \frac{\rho_0 \sigma_0}{m_N m_\chi} F^2(E_R) \int_{v_{min}}^{v_{esc}} v f(v)\mathrm{d}v.$$

Here E_{th} is the energy threshold of the detector, ρ_0 is the local Dark Matter density, σ_0 is the cross section at zero momentum transfer, $f(v)$ is the WIMP velocity distribution in the galactic halo, v_{min} is the minimum velocity required for the WIMP to generate the recoil energy E_R and v_{esc} is the galactic escape velocity. $F^2(E_R)$ is the nuclear form factor, which accounts for the fact that the de Broglie wavelength associated with the momentum transfer is of the same order as the nuclear dimensions; thus the bigger the nucleus the stronger this effect becomes.

The main astrophysical uncertainties lie in the velocity distribution $f(v)$ (commonly assumed to be Maxwellian) and in the density ρ_0 (usually assumed equal to $0.3\,\mathrm{GeVc^{-2}\,cm^{-3}}$). Detecting the direction of the WIMPs would provide a viable solution to the velocity distribution function problem.

3·2. *The cross section.* – If WIMPs are neutralinos, *i.e.* Majorana fermions, they can have only scalar or axial coupling with quarks, which, in this specific non-relativistic regime, translates into a spin-independent coupling and a coupling between the neutralino spin and the nucleon spin. In the spin-independent case, the full coherence results in a cross section $\sigma_0 \propto A^2$, for a target nucleus of mass number A, while in the spin-dependent case the cross section is dominated by the total net spin of the nucleus. In most cases, the coherent term will dominate because of the A^2 enhancement. However, neutralinos with dominantly gaugino or higgsino states may only couple through the spin-dependent term.

3·3. *The modulation of the rate.* – As a result of the Earth motion relative to the WIMP halo, the event rate is expected to modulate with a period of one year with the maximum on the 2nd of June. To detect this characteristic modulation signature, large masses are required, since the effect is of the order of 2% with respect to the total event rate. A stronger diurnal direction modulation of the WIMP signal is also expected. The Earth rotation about its axis, oriented at an angle with respect to the WIMP "wind", changes the signal direction by 90 degrees every 12 hours, with a resulting 30% modulation on respect to the total rate.

3·4. *The detection approaches.* – Nuclear recoils induced by WIMPs are detected exploiting the three basic phenomena associated with the energy loss of charged particles in target media: scintillation, ionization and heat. All the detectors used to perform this rare event search are also sensitive to the environmental radiation associated with cosmic rays and radioactivity in construction materials and the environment. At the current limits [12, 13] the expected WIMP rate is less than 1 event per kg per year and significant SUSY parameter space exists down to 10^{-3} event per kg per year. Exploring this parameter space requires ton-scale detectors with nearly vanishing backgrounds.

Dark matter search experiments are located in deep-underground sites, to attenuate the cosmic muons flux by a factor 10^5 to 10^7. In addition, the detectors are typically enclosed by thick layers of absorbing materials (lead for γ's and hydrogen-rich compounds for neutrons), in order to reduce also the contribution due to the environmental radioactivity. Moreover shielding and detector components have to be as well selected to have low radioactivity, to allow significant background reduction. Since the mean free path of a high energy γ-ray or a neutron is of the order of centimeters, while the mean free path of a WIMP is of the order of light-years, the identification of multi-site events constitutes a powerful background rejection tool. Finally in many Dark Matter direct search experiments background discrimination mechanisms are used, based on the fact that nuclear recoils (signals) and electron recoils (backgrounds) generate different signals in the detectors, due to their different nature.

4. – WIMPs direct detection experiments: a selection

A large variety of underground experiments all over the world aim at the direct detection of the Milky Way halo's WIMPs. Only a limited selection of them is presented in this review.

4·1. *DAMA/LIBRA – A possible evidence?* – The DAMA/LIBRA experiment started its operation in 1990 at Gran Sasso underground laboratory (LNGS). The detector (DAMA) was initially based on nine 9.7 kg highly radio-pure NaI(Tl) scintillators shielded from radioactive background. The collaboration has then upgraded the detector to a sensitive mass of 250 kg of NaI(Tl). This new experiment, called LIBRA, is running since March 2003. The threshold for both experiments is 2 keV.

The DAMA experiment belongs to the first generation of Dark Matter direct detection experiments requiring a large detector exposure. Although the NaI(Tl) scintillator provides some discrimination between nuclear recoils and electronic recoils based on pulse shape, the collaboration published its data without any background reduction. The

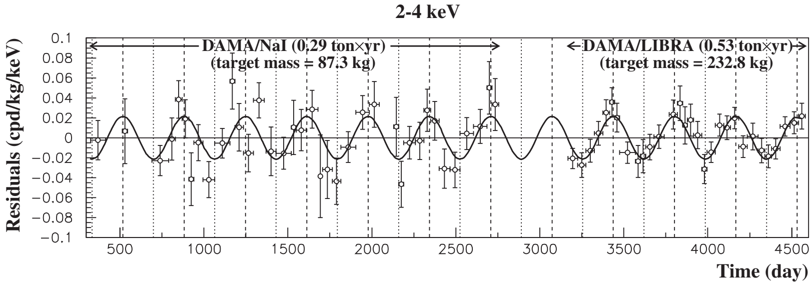

Fig. 1. – DAMA annual modulation signal from a model independent fit with the cosine function, showing a period of oscillation of 1.00 ± 0.01 year and offset t_0 equal to 140 ± 22 days [14].

DAMA/LIBRA Collaboration combined the 290 kg × year exposure of DAMA with the with the 530 ton × year exposure of LIBRA (total 820 kg × year), confirming in both cases a consistent modulation signal [14] (as reported in fig. 1). The total significance of the signal is 8.2σ.

4˙2. *CoGeNT – Hint for light WIMPs?* – The CoGeNT experiment is based on a 440 g, low-threshold (~ 0.4 keV) P-type Point Contact (PPC) germanium detector. The PPC technology employed allows an effective surface background events rejection, thanks to the good position sensitivity. The detector is installed in the Soudan Underground Laboratory (SUL) and was operated from December 2009 to March 2011; it acquired 442 live-days of data for a total exposure of about 146 kg × day. Also the CoGeNT Collaboration reports an annual modulation signal [15] (see fig. 2) with a statistical significance of 2.8σ, with a modulation amplitude of $16.6 \pm 3.8\%$ mDRU, a period of 347 ± 29 days and the minimum occurring on Oct. 16 ± 12d.

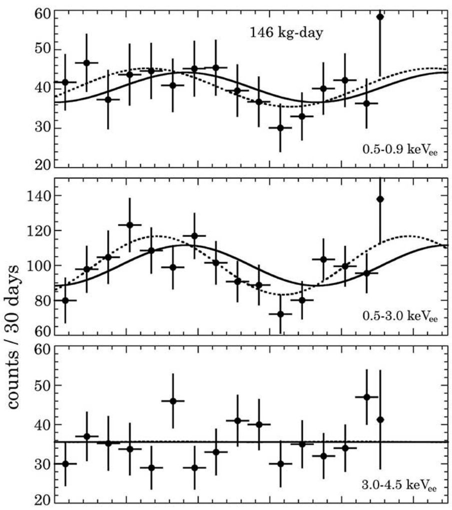

Fig. 2. – CoGeNT data [15]: rate *versus* time in several energy regions. The best-fit modulation is shown as a dashed line. The solid line indicates a prediction for a 7 GeV/c^2 WIMP in the galactic halo with a Maxwellian velocity distribution. The period of the modulation is compatible with the expected value from WIMPs in the galactic halo. No indication of a modulation is observed for the surface background events.

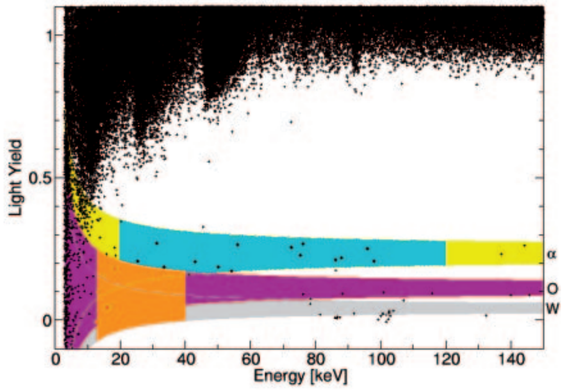

Fig. 3. – CRESST-II data of one crystal ("detector module"): light yield *versus* recoil energy. Electronic recoil events occur at high light yield (~ 1). The shaded areas represent the alpha, oxygen, and tungsten recoil bands, as indicated in the figure. The acceptance region, the reference region in the α-band, and the events observed are also shown.

4·3. *CRESST-II—Evidence, but background?* – The CRESST-II (Cryogenic Rare Event Search with Superconducting Thermometers) experiment is also located at the LNGS. The experiment is based on 9 scintillating $CaWO_4$ crystals of cylindrical shape, each with a mass of about 300 g. The crystals are operated as cryogenic calorimeters at temperatures of about 10 mK. The energy deposited by an interacting particle is mainly converted into phonons, which are then detected with a Transition Edge Sensor (TES). A small fraction of the energy deposited in the crystal goes into scintillation light, which is detected by a cryogenic light detector. According to the different phonon to light yields ratio particles can be identified and background rejected (see fig. 3).

The collaboration has published [16] the results from the analysis of the data collected between 2009 and 2011 (total net exposure of 730 kg $\times$ d), where the region of interest was defined in the energy interval 12$\div$40 keV. In [16] is stated that "Sixty-seven events are found in the acceptance region where a WIMP signal in the form of low energy nuclear recoils would be expected". With a maximum likelihood analysis they found that all the background sources are not sufficient to account for such a big excess of events.

4·4. *XENON100—No evidence.* – The XENON100 experiment is the most sensitive of the WIMP direct detection experiment in operation to date. This experiment exploits the time projection chamber (TPC) technology based on Liquid Xenon (LXe), with simultaneous detection of the ionization (via proportional scintillation) and the direct scintillation signals. The amplitude and timing of the signals, as well as the 3-dimensional event localization capability, enables these TPCs to effectively reject background.

The XENON Collaboration is following a phased approach to the direct detection of WIMPs in liquid Xe, with a series of detectors of increasingly larger mass and lower background. The goal is to build within 2014 an experiment with a ton scale fiducial target (XENON1T) to search for WIMPs with almost two orders of magnitude better sensitivity with respect to the current best limit. After the successful results of the first 10 kg scale prototype, XENON10 [17, 18], the XENON Collaboration has designed and built a second generation experiment with a mass increase of a factor 10 and a background reduction of a factor 100, in order to achieve the sensitivity goal of a factor 50 improvement with respect to XENON10.

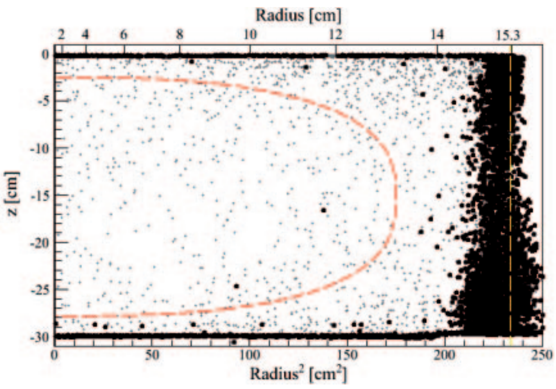

Fig. 4. – XENON100 data: 3D distribution of all the events (gray) and of the events below the 99.75% rejection (black dots) in the energy region of interest (6.6÷30.5) keV$_{nr}$. The dashed line indicates the boundary of the 34 kg fiducial volume, while the gray line indicate the TPC dimensions. The two thicker dots falling inside the 34 kg fiducial volume indicate the two events found in the region of interest that pass all the analysis cuts.

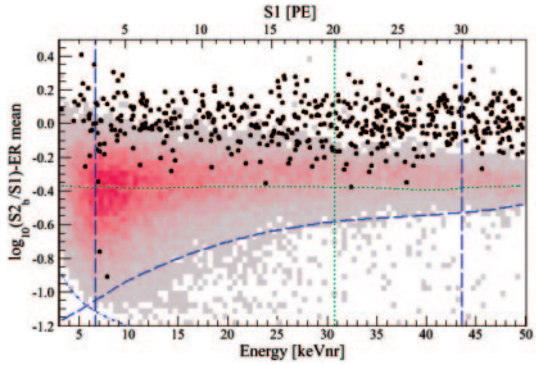

Fig. 5. – XENON100 data: flattened $\log_{10}(S2_{bottom}/S1)$ versus nuclear recoil energy for all the events passing all the analysis cuts. The gray points indicate the nuclear recoil event distribution from a ^{241}AmBe calibration run. The dashed lines indicate the energy region selected for the final analysis, the software threshold S2 > 300 p.e, the 99.75% rejection line and the 3σ lower bound of the nuclear recoil band.

The XENON100 experiment is installed at LNGS. The TPC sensitive volume is surrounded by an active liquid xenon veto. The total mass of Xe required to fill the detector is 161 kg, of which approximately 62 kg are in the target volume. By looking at the different light to charge yield ratio background events can be rejected. Moreover the double phase technique allows to further reduce the background by applying fiducial volume cuts (exploiting the efficient self-shielding features of the LXe) and by single scatter selection criteria.

The collaboration has recently published the results of the analysis on a 224.6 live-days data sample acquired between February 2011 and March 2012 [13] using a fiducial mass of 34 kg. Two candidate events were found in the signal region, where 1.0 ± 0.2

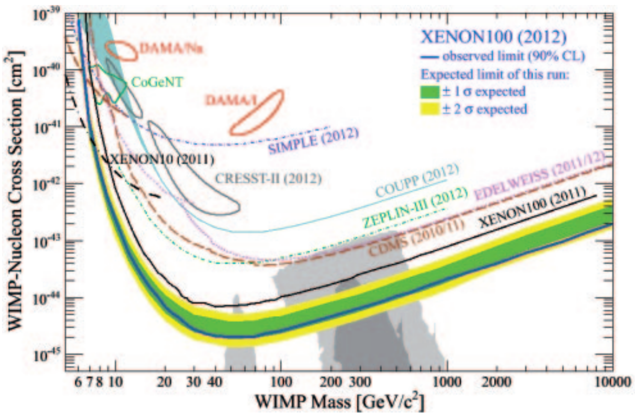

Fig. 6. – Spin independent elastic WIMP-nucleon cross section as a function of the WIMP mass. Exclusion limits from the most sensitive experiments are shown, as well as 90% favored regions from DAMA/LIBRA, CoGeNT and CRESST-II.

background events were expected, as shown in figs. 4 and 5. This results in the most stringent limit to date on the WIMP-nucleon spin-independent cross-section as shown in fig. 6, with a minimum of $2\times10^{-45}\,\mathrm{cm}^2$ for a WIMP mass of $55\,\mathrm{GeV/c}^2$ at 90% confidence level. XENON10 and XENON100 results exclude the parameter space associated with the signals of the DAMA/LIBRA, CoGeNT and CRESST-II experiments.

5. – Summary

In fig. 6 the parameter space associated with the DAMA/LIBRA, CoGeNT and CRESST-II signals and the exclusion limits from the most significant experiments (including the ones presented in this short review) are shown. Many more experiments are either taking data, in commissioning runs, in construction phase or being designed with the precise aim of solving the Dark Matter puzzle. The tensions between the experiments claiming and those rejecting light WIMPs will hopefully be solved, or at least relaxed by the upcoming experiments. In order to improve the reliability of the results, CoGeNT is going to start a new run (after a forced shut off due to fire in SUL), CRESST is expected to start a new run with reduced background and XENON100 is taking data with reduced background and lower energy threshold.

It is interesting to notice that in the last five years the sensitivity of the experiments improved by two or three orders of magnitude. The detectors based on noble liquids seem to have the best sensitivity and are the most promising technologies, thanks to their easy scalability with respect to cryogenic crystals, for example.

Finally it is important to notice that other WIMP detection approaches, like indirect detection and production at high energy particle colliders, are already being used to answer the pressing question on the real nature of Dark Matter particles.

REFERENCES

[1] Rubin V. C. and Ford W. K. Jr., *Astrophys. J.*, **159** (1970) 379.
[2] Zwicky F., *Helv. Phys. Acta*, **6** (1933) 110.
[3] Forman W., Jones C. and Tucker W., *Astrophys. J.*, **293** (1985) 102.
[4] Clowe D., Bradac M., Gonzalez A. H., Markevitch M., Randall S. W., Jones C. and Zaritsky D., *Astrophys. J.*, **648** (2006) L109 [astro-ph/0608407].
[5] Gamow G., *Phys. Rev.*, **74** (1948) 505.
[6] Dunkley J. *et al.* (WMAP Collaboration), *Astrophys. J. Suppl.*, **180** (2009) 306 [arXiv:0803.0586 [astro-ph]].
[7] Riess A. G. *et al.* (Supernova Search Team Collaboration), *Astrophys. J.*, **607** (2004) 665 [astro-ph/0402512].
[8] Schuecker P., Bohringer H., Collins C. A. and Guzzo L., *Astron. Astrophys.*, **398** (2003) 867 [astro-ph/0208251].
[9] Turner M. S. and Kolb E. W., *The early Universe (Frontiers in Physics)* (Addison-Wesley, U.S.) 1990.
[10] Merrifield M. R., *Astron. J.*, **103** (1992) 1552.
[11] Goodman M. W. and Witten E., *Phys. Rev. D*, **31** (1985) 3059.
[12] Ahmed Z. *et al.* (CDMS-II Collaboration), *Science*, **327** (2010) 1619 (arXiv:0912.3592 [astro-ph.CO]).
[13] Aprile E. *et al.* (XENON100 Collaboration), *Phys. Rev. Lett.*, **109** (2012) 181301 (arXiv:1207.5988 [astro-ph.CO]).
[14] Bernabei R. *et al.* (DAMA Collaboration), *Eur. Phys. J. C*, **56** (2008) 333 (arXiv:0804.2741 [astro-ph]).
[15] Aalseth C. E. *et al.*, *Phys. Rev. Lett.*, **107** (2011) 141301 (arXiv:1106.0650 [astro-ph.CO]).
[16] Angloher G. *et al.* (CRESST Collaboration), *Eur. Phys. J. C*, **72** (2012) 1971 (arXiv:1109.0702 [astro-ph.CO]).
[17] Angle J. *et al.* (XENON10 Collaboration), *Phys. Rev. Lett.*, **100** (2008) 021303.
[18] Angle J. *et al.* (XENON10 Collaboration), *Phys. Rev. Lett.*, **101** (2008) 091301.