Axion Astronomy: Searching for Dark Matter Particles

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Abstract

The basic methods of searching for dark matter candidates are discussed. The main topics of this talk are: (a) ground - based cavity experiments with searching for galactic axions; (b) searching for hadronic axion decay line into galactic and extragalactic light; (c) experimental search for solar and stellar axions; (d) basic methods of searching for WIMPs as candidates into dark matter; (e) limits on axion and WIMP masses and their coupling constants to photons and ordinary matter; (f) novels of searching for nonbaryonic dark matter.

1 Introduction

Our present results of cosmology and astronomical observations allow us to determine the densities of various components matter and energy in our Universe. According to [1] the densities of its component are related to

$$\Omega(a) = 1 + \frac{\Omega_{tot} - 1}{1 - \Omega_{tot} + \Omega_\Lambda a^2 + \Omega_{mat} a^{-1} + \Omega_{rel} a^{-2}} \tag{1}$$

where a is the scale factor. The current experimental results suggest a flat Universe with the following parameters (see [2]):

the cosmological constant: $\Omega_\Lambda = 0.7 \pm 0.1$;
the total density of matter: $\Omega_{mat} = 0.3 \pm 0.1$, including
baryonic matter: $\Omega_b = 0.04 \pm 0.01$ and
visual matter: $\Omega_{vis} \leq 0.01$;
cold dark matter: $\Omega_{DM} = 0.26 \pm 1$;
relativistic component: $0.01 \leq \Omega_{rel} \leq 0.05$ including
neutrinos $0.01 \leq \Omega_\nu \leq 0.05$ and
photons: $\Omega_\gamma = \left(4.8^{+1.5}_{-0.9}\right) \times 10^{-6}$.

The final results from HST Key Project give the following data on Hubble's constant (see [3]):

$H_0 = 71 \pm 2$(random)± 6(syst.) from Type Ia supernovae;
$H_0 = 71 \pm 3 \pm 7$ (Tully- Fisher relation);

$H_0 = 70 \pm 5 \pm 6$ (surface brightness fluctuation);
$H_0 = 72 \pm 9 \pm 7$ (Type II supernovae);
$H_0 = 82 \pm 6 \pm 9$ (fundamental plane).
Freedman et al. [3] combine these results and find good agreement and consistency with

$$H_0 = (72 \pm 8)\frac{km}{sMpc} \tag{2}$$

2 Basic Candidates into Dark Matter (DM)

Thus, a large fraction of the matter in the Universe (~30%) is nonluminous, or "dark". However, the origin of dark matter remain unknown up to now, providing a central problem for astronomy and cosmology.

Table 1 presents a list of basic candidates of DM.

All candidates can be divided on two large groups: baryonic and nonbaryonic (particle) DM. From baryonic candidates brown dwarfs were expected as most popular ones.

From nonbaryonic matter axions and WIMPs are the most preferable candidates. At present the axion has has consistently remained one of the leading candidates for DM in the Universe. Unlike many other exotic particles the axion is presented as a result of a minimal extension of the Standard QCD model and is a consequence of the Peccei-Quin (PQ) mechanism to solve one of the key difficulties of modern QCD - the strong CP problem.

The numerical value of the standard axion mass is given by Turner [4]:

$$m_a = \frac{0.6 \times 10^7 GeV}{f_{PQ}} eV \tag{3}$$

where f_{PQ} is the value of PQ symmetry breaking scale.

The axion has properties similar to those of a light neutral pion, but much weaker couplings to photon and ordinary matter.

There are two generic types of axions. The hadronic or KSVZ axions only couple to heavy quarks, not to leptons or light quarks ([5], [6]). The other DFS axions only couple to electrons and light quarks ([7]). Recently new types of exotic bosons like axions have been suggested. Anselm [8] has showed the possibility of the existence of massless boson which is very similar to an axion and named it an arion: $m_a = 0$. Bezezhiani et al. [9] have developed a model with broken symmetry of quarks and lepton generation that produced the new Goldstone boson, which was called an "archion". It is similar to a hadronic axion with a strong depression of its coupling to leptons.

Another popular candidate to nonbaryonic DM was claimed by supersymmetric (SUSY) particle physics. SUSY particle physics models provide a natural candidate for DM: the light's superpartner, usually taken to be a neutralino with with typical mass about $\sim 100\frac{GeV}{c^2}$ (see the review [10]). More generically, one can consider a class of, so-called, Weakly Interacting Massive Particles, or WIMPs, that were once in thermal equilibrium in early Universe, but were "cold", i.e. moving non-relativistically at the time of structure formation.

The first basic question arises how it is possible to distinguish these so different popualtions of DM, i.e. baryonic and nonbaryonic DM candidates. The MACHO project LMC microlensing was appeared as a first very promised method for searching DM in the form of massive compact halo objects (MACHOs). Photometric monitoring of millions of stars in the Large Magellanic Cloud (LMC), Small Magellanic Cloud (SMC), and Galactic Bulge was used to search for gravitational microlensing events caused by these otherwise invisible objects. Analysis of the first $\sim$ 2 years of photometry of 8.5 million stars in the LMC allows to find 8 real microlensing events. Alcock et al [11] estimated the total microlensing optical depth towards the LMC from 8 events with $2 < \Delta t < 200$ days to be:

$$\tau_2^{200} = 2.9^{+1.4}_{-0.9} \times 10^{-7} \tag{4}$$

This estimation exceeds the optical depth predicted for a "standard" halo. It gives a fairly model independent estimate of the halo mass in MACHOs within 50 kpc of $2.0^{+1.2}_{-0.7} \times 10^{-11} M_{\odot}$, which is about half of the "standard halo" value. The most probable MACHO mass of $0.5^{0.3}_{-0.2} M_{\odot}$ was estimated in [11]. The absence of short duration events placed stringent upper limits on the contribution of low-mass MACHOs: objects from $10^{-4} M_{\odot}$ to $0.03 M_{\odot}$ contribute $\leq 20\%$ of the "standard" dark halo. These data show that the population of baryonic matter objects in our halo provides not more $\sim 50\%$ of all DM quantity.

As far as the detection of nonbaryonic DM the basic methods for axions are due to their couplings to photons and ordinary matter. As far as WIMPs their density today is mainly determined by their decay and annihilation rate with weak-scale interactions. One of the possible detection way is searching for unusual annihilation or decay line in the GeV spectral range. Recently Overduin and Wesson [12] have made the review of experimental limits on the intensity of cosmic background radiation in the microwave, infrared, optical, ultraviolet, X-ray and γ-ray bands that put strong limits on axions, WIMPs and primary black holes. The best possibility for direct detection of WIMPs lies in elastic scattering from nuclei that produces recoil nuclei. The nuclear-recoil energy is typically a few KeV since WIMPs should have velocities typical for Galactic objects.

Now I start to consider in detail methods of nonbaryonic DM matter and their results.

3 Searching for Axions Dark Matter by Astronomical Methods

Axions can be detected through their coupling to photons. They can decay into two photons. This $a \to 2\gamma$ coupling arises due two different decay mechanisms: through axion-pion mixing and via the electromagnetic (EM) anomaly of PQ symmetry.

The axion decay time is ([13]):

$$\tau_a(a \to 2\gamma) \cong 6.8 \times 10^{24} \xi^{-2} \left(\frac{m_a}{1eV}\right)^{-5} s \tag{5}$$

where

$$\xi = \frac{|E/N - 1.95|}{0.72} \tag{6}$$

E and N are the values of EM and color anomalies of PQ symmetry, respectively.

The free axion lifetime (6) is sufficiently large to allow for observations of decay of axions with mass much less than 1 eV. However, axion interaction with magnetic fields can provide photon production with energy comparable to the total axion energy (the Primakoff effect).

The probability of axion conversion into a photon and of the inverse process of a photon conversion into an axion ([8], [14]):

$$P_{||}(\gamma \leftrightarrow a) = \frac{1}{1+x^2}\sin^2(\frac{1}{2}B_{\perp}g_{a\gamma}L\sqrt{1+x^2}) \tag{7}$$

where

$$x = \frac{(\varepsilon - 1)\omega}{2Bg_{a\gamma}} \tag{8}$$

ω is the radiation frequency, ε is the dielectric constant permittivity of the medium in that the radiation is propagating, the effect of vacuum polarization in a strong magnetic field being included. Only one polarization state when the electric vector oscillates into the plane of the directions of the magnetic field and the photon propagation is subject to conversion. $B_{\perp} = B\sin\theta$ where θ is the angle between the photon propagation and magnetic field directions. A commonly accepted system of units is used here for which $\hbar = c = 1$. The probability has an oscillatory manner, the phase being depended on the product of the magnetic field strength B and the size L.

The pure vacuum solution of Eq.(8) transforms to

$$P_{||}(\gamma \leftrightarrow a) = \sin^2(\frac{1}{2}B_{\perp}Lg_{a\gamma}) \approx B_{\perp}^2L^2g_{a\gamma}^2/4 \tag{9}$$

(in the the case of a weak effect of conversion).

In real situations, the value of $\varepsilon - 1$ is frequently not so small. For instance, in the case of totally ionized plasma $\varepsilon - 1 \approx \omega_p^2/\omega^2$ where $\omega_p^2 = 4\pi e^2N/m_e$ is the square of the plasma frequency and N is the electron concentration. Therefore, in many astrophysical situations, the probability of magnetic conversion is sufficiently small, but nevertheless provides a noticeable amount of polarization (for details, see [15], [16]).

4 Searching for Axion Decay Line into Galactic and Extragalactic Light

An axion should be detected through its decay into two photons. There are the astrophysical and cosmological limits that define a window of probable axion mass between 2 eV and 8 eV. An upper bound to axion mass of $m_a < 8eV$ is derived by searching for the effect of decaying axions upon the diffuse extragalactic background radiation and the brightness of the night sky due to axions in the halo of our Galaxy. The intergalactic light of clusters of galaxies seems to be a very good place to search an emission line at the wavelength:

$$\lambda_a(z) = 24800\text{Å}\left(\frac{1eV}{m_a}\right)(1+z) \tag{10}$$

where z is the cluster redshift. This line is arising from the radiative decay of axions concentrated into the gravitational well of a cluster.

The results of observations of spectra of galaxy cluster A2256 and A2218 obtained at Kitt Peak Observatory have no shown the existence of axion lines [13].

Fig.2 from the paper [17] shows the results of observations of spectra of the galaxy cluster A2256 made at Russian 6-m telescope with Multi-Pupil Field Spectrograph (MPFS) which is intended for objects with moderate spectral resolution. The observational data show that standard and nonstandard hadronic axion masses lying between 3 and 6 eV are definitely excluded.

Blout et al [18] presented results from a radio telescope search for axion decay photons of mass m_a = 298 to $363\mu eV$ in Local Group dwarf galaxies. Observations were made at Haystack Observatory (Westfold, MA) on the 37-meter radio telescope at frequencies from 35.92 to 44.08 GHz. Power spectra were collected at the Haystack Observatory on 21 April 99, 15 October 99, 29-31 December 99, and 21 March 2000. Their search ruled out axions of mass 298 to $363\mu eV$ with axion-to-photon coupling of $g_{a\gamma} > 1.0 \times 10^{-9} GeV^{-1}$ at 96% confidence level. Their search was the first when the radio telescope was used to search for cold dark matter axions in the allowed mass window and from other galaxies (Local Group dwarf galaxies).

5 Axion Dark Matter Halo Density: Experimental Constraints

Most of the mass of the Milky Way Galaxy can be contributed by its halo, presumably in the form of axions. The maximum likelihood density for the CDM component of our galactic halo is $\rho_{CDM} = 7.5 \times 10^{-25} g/cm^3 (450 MeV/cm^3)$. Sikivie [19] has shown that halo axions may be detected by their resonant conversion into a quasi-monochromatic microwave signal in a high-Q cavity permeated by a strong magnetic field. The search for relic halo axions through the conversion process (8) was performed with superconducting resonant cavities ([20] - [23]). Semertzides et al [21] has suggested to use CERN's SMC polarized target. The signature for axions is a narrow peak at frequency ν, resulting via its resonant conversion into a photon at $h\nu = m_a c^2$.

The limit to sensitivity [19], [22]:

$$P_{a\to\gamma} = 8 \times 10^{-22} w \left(\frac{V}{10^5 cm^3}\right)\left(\frac{B}{10T}\right)^2\left(\frac{Q}{10^5}\right)\left(\frac{\rho_a}{\rho_h}\right)\left(\frac{m_a}{1.2 \times 10^{-5} eV}\right) \tag{11}$$

where V is the cavity volume, Q is the loaded quality form factor, ρ_a is the real axion density, ρ_h is the model halo axion density, $\rho_h = \rho_{CDM}$. The corresponding brightness temperature is determined by

$$T_B = 0.75K \left(\frac{B}{10T}\right)^2\left(\frac{V}{10^6 cm^3}\right)\left(\frac{Q}{10^6}\right) \tag{12}$$

The exposition time for $S/N = 3$ is

$$t_{exp} = 8.3 \times 10^4 c \left(\frac{T}{4K}\right)^2\left(\frac{2.3Hz}{\nu}\right) \tag{13}$$

The last axion search experiment has recently conducted in [23]. The previous large-scale experiment ($B \sim 7.5T$, $V \sim 200 liter$) has achieved sensitivity to KSVZ axions over a narrow mass range $2.77 < m_a < 3.3\mu eV$. The exclusion regions of this experiment, normalized to the best-fit CDM density $\rho_{CDM} = 7.5 \times 10^{-25} g/cm^3$ present constraints at the level $g_{a\gamma} < 2.4 \times 10^{-14} (GeV)^{-1}$.

Recently Asztalos et al [23] reported results from new search which probed the local galactic halo axion density using the Sikivie RF cavity technique. They use the magnetic field strength at the level of $B = 8.5T$ and the volume $V = 0.22m^3$. Candidates over the frequency range $550 \leq \nu \leq 810 MHz (2.3\mu eV \leq m_a \leq 3.4\mu eV)$ were investigated. The lack of a persistent signal allows them to exclude the axions from contributing more than $450 MeV/cm^3$ to the halo DM mass density over the mass range of $2.3 \times 10^{-6} \leq m_a \leq 3.4 \times 10^{-6} eV$.

Recent developments in amplifiers technique and Rydberg atom single-quantum detectors promise dramatic improvements in the level of noise temperature. These developments will enable rapid scanning of the axion mass range much below the existing limits.

6 Searching for Solar and Stellar Axions

Sun and stars are powerful sources for weakly interacting particles such as neutrons, gravitos and axions than can be produced by nuclear reactions or by thermal processes in the hot stellar interior. The comparison of this axion generation process with the standard energy loss mechanisms via neutrino and photon emission gives bounds of axion-to-photon and axion-to-matter coupling constants. The potential effect of axion emission on stars is evident: i.e., the acceleration of their evolution and shortening of their lifetimes.

The direct searching for axions by ground-based experiments can be made by using magnetic conversion process of solar axions. Axions can be produced in the Sun's interior through the scattering of thermal photons in the Coulomb field of nuclei (Promakoff effect). In a transverse magnetic field the Primakoff effect can work in reverse, coherently converting the solar axion back into X-ray photons of a few KeV.

Details of a theory for searching for axions with germanium detectors were recently given in [24], [25]. The average solar axion energy is $E_a = 4.2KeV$. The rate at which DFSZ axions should carry away energy generated at the centre of the Sun is

$$\frac{dE_c}{dt} \approx \left(\frac{T}{10^6 K}\right)^6 \left(\frac{m_a}{1eV}\right)^2 erg\, g^{-1} s^{-1} \tag{14}$$

The next important step of development of the solar axion experiment is connected with the use of coherency effects for an increase in the sensitivity level of these experiments.

Avignone III et al [24] have been reported the first results of an experimental search for the unique, rapidly varying temporal pattern of Solar axion coherently converting into photons via the Primakoff effect in a single crystal germanium detector. This conversion process exists when axions are incident at a Bragg angle with a crystalline plane. They have analyzed approximately 1.94 g.yr of data from the 1g DEMOS detector in Sierra Grande, Argentina and have given a new laboratory bound on axion-photon coupling of

$$g_{a\gamma} < 2.7 \times 10^{-9} GeV^{-1} (95\%\, c.l.) \tag{15}$$

independent of axion mass up to $\sim 1KeV$.

International group [25] have developed a new mode of solar axion experiment. They are going to use the 8.4 Tesla, 10 m long transverse magnetic field of CERN twin aperture

LHC bending magnet as a macroscopic coherent solar axion-to-photon converter. These authors have showed by numerical simulation that the integrated time of alignment with the Sun would be 33 days per year with the magnet on a tracking table capable of $\pm 5^\circ$ in the vertical direction and $\pm 40^\circ$ in the horizontal direction. Zioutas et al [25] estimated the probability of detecting a photon in the $\sim 1 \div 15 KeV$ region, per Solar axion as

$$P_{a\to\gamma} \approx 1.8 \times 10^{-17} \times \left[\left(\frac{B}{8.4T}\right)^2 \left(\frac{L}{10_m}\right)^2 \left(\frac{g_{a\gamma}}{10^{-10} GeV^{-1}}\right)^2 \right] \tag{16}$$

On the Earth, the expected total solar axion flux Φ_a is:

$$\Phi_a \approx 3.5 \times 10^{11} \left(\frac{g_{a\gamma}}{10^{-10}}\right)^2 1/cm^2 s \tag{17}$$

For 2 years of measuring time, $\pm 40^\circ$ horizontal and $\pm 5^\circ$ vertical tracking and 33 days of integrated solar-alignment time per year the estimated number R of X-rays due to the converted axion gives:

$$R \approx 195 \left(\frac{g_{a\gamma}}{6.6 \times 10^{-11} GeV^{-1}}\right) \; events/66\, days\, in\, 2\, years \tag{18}$$

This is an improvement by a factor ~ 55 compare to previous results. Zioutas et al [25] hope with using single 14 m bending magnet or two 10 m magnets in series to improve the expected limits for the coupling constant $g_{a\gamma}$ up to $5.2 \times 10^{-11}\, GeV^{-1}$ and $4.6 \times 10^{-11}\, Gev^{-1}$, respectively.

Recent results have been obtained from the Tokyo axion helioscope experiments [26]. A search for solar axions has been performed using an axion helioscope which was equipped with a 2.3m long 4T superconducting magnet, PIN-photodiode X-ray detectors, and a telescope mount mechanism to track the Sun. A gas container to hold dispersion-matching gas has been developed and a mass region up to $m_a = 0.26\, eV$ was newly explored. Preliminary analysis sets a limit on axion-photon coupling constant to be $g_{a\gamma} < 6.8 \div 10.9 \times 10^{-10}\, GeV^{-1}$ for the axion mass of $0.05 < m_a < 0.27\, eV$ at 95% confidence level. This result is more stringent than the limit inferred from the solar-age consideration.

The most recent axion search project is developed in CERN. The conceptual design of this new axion telescope CAST was described in details in [27]. The CERN team uses the recently decommissioned straight-bore LHC test magnets, having $B \sim 9.6T$, $L \sim 9.5m$ and $\sim 10\, mrad$ angular resolution. In a result, the new project provides a rare opportunity for the construction of a high-sensitivity axion telescope. A single one of these magnets with the product $B \times L = 9.2\, T \times m$ is ~ 100 times more efficient as an axion-to-photon converter than one, presently in operation at the University of Tokyo, and mentioned above. For two such magnets in series, a special combination provides the efficiency factor ~ 400. This new experiment allows to achieve the record ground-based experimental constraint on the coupling constant:

$$g_{a\gamma} < 1.4 \times 10^{-9} (GeV^{-1}) \frac{b^{1/8}}{t^{1/8} B^{1/2}(T) L^{1/2}(m) A^{1/4}} \tag{19}$$

where b is the X-ray detector background in counts/day in energy region $\sim 1 \div 10\, KeV$, $t[days]$ is the time of alignment of the magnet bore with the Sun and $A[cm^2]$ is the bore opening area. The last one is suggested to be $A = 19.6\, cm^2$. CAST's LHC magnet will be mounted on a moving platform with X-ray detectors on either end, allowing it to observe the Sun for half an hour at sunrise and half an hour at sunset. The rest of the day will be devoted to background measurements and, through the Earth's motion, observations of a large portion of sky [27].

On the main sequence and in red giant stars the primary axion emission is to be via the Compton-like process and axion bremsstrahlung, both of that are proportional to $g_{ae}^2 \sim m_a^2$. Another very important process is the photoproduction of axions or the Primakoff process. In the very-low-mass stars ($M < 0.2M_{\odot}$) emission through the axion-electric effect (an analogue to the photo-electric effect) is very important [28].

Axion bremsstrahlung in red giants and white dwarfs has been calculated by many authors. Burrows et al [29] have calculated axion emission that would have significantly affected the cooling of the proto-neutron star associated with 1987A. They have computed the axion opacities due to inverse nucleon-nucleon, axion bremsstrahlung and then used these numerical models to calculate the integrated axion luminosity, the temperature of the axion sphere, and the effect of axion emission on the neutrino bursts detected by the Kamiokande II and Irvine-Michigan-Brookhaven water-Cherenkov detectors.

The last results in this field of research is the calculation of pion processes that can produce axion due to many-body effects. As a result axion-photon coupling and correspondingly to axion mass decreasing:

$$m_a < 0.5 \times 10^{-3}\, eV \tag{20}$$

Recently the process of axion cyclotron emissivity of magnetized white dwarfs and neutron stars has been investigated in [30].

7 WIMPs and Kaluza-Klein Particles as the Candidates into Cold Dark Matter (CDM)

The experimental effort in the search for CDM in the form of Weakly Interacting Massive Particles (WIMPs) have recently increased. The most well-known WIMP is the neutralino that was predicted by the Minimal Supersymmetric extension of the Standard Model (MSSM) of particle physics. It is the Lightest Supersymmetric Particle (LSP) with a mass in the range of several tens of GeV up to a TeV. Advantage of this candidate in DM is a fact that neutralino is compatible with all the available accelerator constraints, including searches for supersymmetric particles at LEP, HERA and the Tevatron Colliders [10].

The best previous cryogenic technique experiments were DAMA [31] and EDELWEISS [32]. The experiment DAMA has reported an annual modulation signal in NaI detector at the level $\sim 4\sigma$. This result have been interpretated as an evidence for WIMP mass $M_W = 44GeV/c^2$ and cross section $\sigma = 5.4 \times 10^{-6}\, pb$, respectively. The EDELWEISS experiment, located in a 4800 m.w.e. deep underground site was able to reject the values $M_W = 52\, GeV/c^2$ and $\sigma = 7.2 \times 10^{-6}\, pb$. The improved exclusion limits from the EDELWEISS excluded at more than 99.8% Cl the DAMA result. This experiment excluded also at 90% Cl a first sample of SUSY models.

The best experiment to search for WIMPs is the Cryogenic Dark Matter Search (CDMS) with use cryogenic Ge and Si detectors capable of active rejection of backgrounds within a carefully-shielded environment [33].

The second probability of WIMPs detection is connected with measuring the contribution to the extragalactic gamma-ray radiation, induced by WIMP pair annihilations into high-energy photons [34].

The last promising idea is that CDM is made of Kaluza-Klein particles. The possible candidates are the axion-like Kaluza-Klein particles [35] or Kaluza-Klein gauge bosons [36]. Various methods of their detection have been suggested. Csaki et al [35] have recently proposed a mechanism of photon-axion oscillations as a way of rendering supernovae dimmer without cosmic acceleration. Gnedin [37] has considered the situation where the coupling between electromagnetic and axion-like Kaluza-Klein particles affects the polarization state of light rays when they propagate through a magnetic field. Therefore polarimetric observations may yield strong constraints on pseudoscalar-photon coupling constant (see polarimetric observation in [38]).

8 The Novel of Cold Dark Matter Problem (Instead of Conclusions)

The last news from the theater of Dark Matter situation are very exciting. Zioutas and his team [39] have studied published data from the Yohkoh solar X-ray mission, with the purpose of searching for signals from radiative decays of new massive neutral particles. The base of this search is that solar axions of the Kaluza-Klein type should result in the emission of X-rays from the Sun direction beyond the limb with a special radial distribution. These X-rays were easily observed during periods of quiet Sun. An additional signature was the observed hard X-ray emission by SMM, NEAR and RHESSI. Zioutas et al. [39] have shown that the recent observations made by RHESSI of a continuous emission from the quiet Sun in the 3 to $\sim$ 15 keV range are quite well fitted by the generic axion scenario (see Fig.). One can expect that such measurements bring more progress during the forthcoming solar cycle minimum with an increased number of quiet Sun periods.

The CAST experiment using a decommissioned LHC test magnet during was been running for 6 months during 2003. The first results from the analysis of these data are presented in [40]. No signal above background was observed. In a result an upper limit to axion-photon coupling $g(\alpha) < 1.16 \times 10^{-10} Gev^{-1}$ at 95% confidence level and $ma < 0.02$ eV.

The last results of the EDELWEISS experiment are presented in [41]. This experiment itself is dedicated to the search for non-baryonic cold dark matter in the form WIMPs. The direct detection principle consists in the measurements of energy released by nuclear recoils produced in a target by elastic collisions of WIMPs from the galactic halo. The EDELWEISS detectors are cryogenic Ge bolometers with simultaneous measurement of phonon and ionization signals. The experiment is located in the Modane Underground Laboratory in the tunnel connecting France and Italy under 1800 m of rock. During three last years 62 kg.day of data have been accumulated with five 320 g Ge detectors. The overall shape of the experimental spectrum seems to be incompatible with WIMP masses above $20 GeV/c^2$. Data taking in the new setup is scheduled for end 2005.

My final conclusion is that the last experimental results appeared to be incompatible with the traditional DM models considering axions and WIMPs (neutralinos) as the best candidates into dark matter. It means that the problem of the identity of DM is currently among the most profound mysteries in particle physics, astrophysics and cosmology.

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