The missing matter problem: from the dark matter search to alternative hypotheses

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Dark matter is among the most important open problems in both astrophysics and particle physics. Recently, hints of anomalous cosmic-ray spectra found by astroparticle experiments, such as PAMELA, have motivated interesting interpretations in terms of DM annihilation and/or decay. Even if these signatures also have standard astrophysical interpretations, Fermi-LAT electron spectral measurements indicated the presence of an additional positron source, which could be DM annihilation or decay. Searches by the Fermi-LAT for gamma-ray signals have also been performed, along with measurements of the diffuse Galactic and extragalactic gamma-ray emission, providing unprecedented high quality data and statistics which makes crucial to investigate DM in gamma rays. In addition, Imaging Air Cherenkov Telescopes like HESS, MAGIC, and VERITAS have reported on searches for gamma-ray emission from dwarf galaxies. Moreover, CMS and ATLAS experiments at the Large Hadron Collider (LHC) currently in operation at CERN, are giving their first results for supersymmetry searches and for discovering DM in colliders. Concerning direct search of DM, the most stringent limits on the elastic spin-independent WIMP-nucleon cross-section are coming from CDMS-II, EDELWEISS-II and , in particular, XENON100, whereas, recently, the CoGeNT collaboration reported the WIMP candidate signal events exceeding the known backgrounds and results obtained by the DAMA/LIBRA set-up show the model independent annual modulation signature for DM particles. On the other hand, DM and Dark Energy (DE) could be nothing else but the signal that General relativity is not working at large scales (infrared scales) and alternative theories of gravity should be considered in order to fit observations. The issues of Òmissing matterÓ and Òaccelerating universeÓ could be addressed by taking account extensions of General Relativity (e.g. Extended Theories of Gravity) where gravitational interaction works in different ways at different scales. From this point of view, the gravitational sector should be revised without invoking the presence of new ingredients that, up to now, have not been detected at a fundamental level. At ultraviolet scales, the production of massive gravitons would be a test-bed for the theory. This review presents many aspects, from astrophysical observations to particle physics candidates and describes the theoretical and experimental aspects of the DM problem (or missing matter, considering the alternative approaches) in particle physics, astrophysics and cosmology. A brief overview is given of the phenomenology of several dark matter candidates and their expected production mechanisms, basic properties, and implications for direct and indirect detection, particle colliders, and astrophysical observations. A summary of the experimental status is given and the possible scenarios opening with the upcoming are discussed in the context of an approach which combines information from high-energy particle physics with cosmic-ray and traditional astronomical data.

I. INTRODUCTION

The nature of dark matter (DM) is one of the greatest today challenges in cosmology and particle physics: on one side it would have a significant impact on the large scale structure in the Universe and, on the other hand, it should lead to the empirical evidence of new unknown particles. The difficulties arise from the fact that DM could be composed by multiple components behaving in different ways depending on the scale. Besides, DM dynamics should be connected to that of dark energy (DE), the other unknown, unclustered form of energy that recent observations pointed out in the last decade. This further ingredient should constitute almost 75 % of cosmic matter-energy budget, turning out that the so-called *"dark side"* problem is dramatic and urgent to be solved.

The DM problem was finally set in the 1970s after several evidences accumulated in the past decades. In 1933 Fritz Zwicky measured the velocity dispersion of galaxies in the Coma cluster and found out that it was about a factor ten larger than expected from the estimated total mass of the cluster [Zwicky 1933]. It is interesting that Zwicky defined such a shortcoming as *the missing matter problem*. These preliminary observations have been confirmed in the 1970s, when data collected on the galactic rotational curves of spiral galaxies, proved the presence of large amounts of mass on scales much larger than the optical size of galactic disks.

Later on, the evidence of DM at various cosmological and astrophysical scales has been established by a wide number of observations, especially the very precise measurements of the cosmic microwave background radiation in the Wilkinson Microwave Anisotropy Probe (WMAP) experiment [Dunkley et al. 2009]. Data from weak [Refregier 2003] and strong [Tyson 1998] lensing, hot gas in clusters [Lewis et al. 2003], the Bullet Cluster [Clowe et al. 2006], Big Bang nucleosynthesis (BBN) [Fields & Sarkar 2008], further constraints from large scale structure [Allen 2003], distant supernovae [Riess et al. 1998, Perlmutter et al. 1999], and the cosmic microwave background (CMB) [Komatsu et al. 2011] also support the evidence for non-luminous matter.

The ensemble of these data provides a strong evidence for a non luminous and non absorbing matter interacting only gravitationally, which is five times more prevalent than ordinary matter and accounts for about a quarter of the Universe. More precisely, current data constrain the energy densities of the Universe in a baryonic component, mostly known ($\Omega_B \lesssim 0.0456 \pm 0.0016$), a DM (CDM) component ($\Omega_{CDM} \simeq 0.227 \pm 0.014$) still unknown, and a DE component ($\Omega_\Lambda \simeq 0.728 \pm 0.015$ with a great uncertainty on the generating mechanisms). The luminous matter in the Universe is less than 1% of the total composition of the Universe. The current most precise estimation of the density of non-baryonic DM Ω_{DM} is obtained combining the measurements of the CMB anisotropy and of the spatial distribution of the galaxies and has found to be $\Omega_{DM} h^2 = 0.110 \pm 0.006$. The "local" DM present in the Galactic disk has an average density of [Kamionkowski & Kinkhabwala 1998]: $\rho_{DM}^{local} \simeq 0.3 \frac{GeV}{cm^3}$.

An alternative, intriguing approach is to consider DM, as well as DE, as the manifestation of the break-down of General Relativity (GR) on large scales. A large literature is devoted to the possible modifications of the laws of gravitation, as Extended Theories of Gravity (ETGs), in particular $f(R)$-theories, by introducing into the Lagrangian , physically motivated higher-order curvature invariants and non-minimally coupled scalar fields [Capozziello & De Laurentis 2011]. The interest on such an approach, in early epoch cosmology, is due to the fact that it can "naturally" reproduce inflationary behaviours able to overcome the shortcomings of Standard Cosmological Model and, in late epoch cosmology, it seems capable of matching with several observations overcoming DM and DE problems related to the issue of detection.

In this review paper, we illustrate the experimental status of art to detect DM particles with direct and indirect methods, trying to interpretate and discuss the results obtained so far (Secs. 2,3,4). A possible alternative approach to the DM problem is presented in terms of gravitational effects at astrophysical and cosmological scales (Sec.5). Specifically, corrected gravitational potentials offer the possibility to fit galaxy rotation curves and galaxy clusters haloes without DM. The same approach allows to fit the apparent accelerated Hubble fluid without invoking DE. Conclusions are drawn in Sec. 6.

II. A SURVEY OF DARK MATTER CANDIDATES

Candidates for non-baryonic DM must satisfy several conditions: *i*) they should be neutral, (otherwise they would interact electromagnetically); *ii*) they should not have color charge (otherwise they could form anomalous nuclear states); *iii*) they should be stable on cosmological time scales (otherwise they would have decayed by now); *iv*) they should interact very weakly with ordinary matter (otherwise they would not be dark), and, finally, *v*) they should have a suitable relic density. If we consider the Standard Model (SM) of Particles, neutrinos seem to be the prominent DM candidate as they interact only weakly and have an extremely low mass (the exact value of neutrinos' mass has yet to be measured, but it is clear, from neutrino oscillation measurements, that their mass is non-zero). There are many sources of neutrinos in the Universe, nevertheless they can account only a small fraction of DM. First of all, they are "hot" since they move at relativistic velocities. Thus they should have had a strong effect on the instabilities that generated the primordial cosmological objects during the earliest Universe, in the sense that galaxy clusters would have formed before galaxies and stars. This is in contrast with most theories and measurements, which are, instead, supported by a model based on cold DM, consisting of particles which move at non-relativistic energies. Thus small-scale perturbations are not suppressed, allowing an early start of structure formation. Secondly, we know that neutrino mass is rather small. The most recent upper bound on electron neutrino mass is $m_{\nu_e} < 2$ eV (95% c.l.) while the experimental limits on the muon and tau neutrino are even weaker. So neutrinos cannot explain the gravitational effects DM is responsible for. However, extremely, high energetic neutrinos are of interest for DM search as they are among the secondary particles created in the annihilation of other DM candidates.

The most popular hypothesis is that non-baryonic DM consists of some neutral massive weakly interacting particles (WIMPs), which were created in the hot early Universe, decoupled early from ordinary matter in order to seed structure formation, and survived until today. They are supposed (from theoretical considerations and from the fact that they have not been detected yet) to be heavy respect to SM particles, with mass roughly between 10 GeV and few TeV. They interact via weak force and gravity only and are stable with a lifetime at least equal to the age of the Universe. Their relic density can be correctly calculated assuming that WIMPs were in thermal equilibrium with the SM particles in the early Universe. At the early stages, Universe was dense and hot. As the temperature T of the Universe cools, the density of more massive DM particles, with mass greater than T, become Boltzmann exponentially suppressed. When the expansion rate of the Universe, H, exceeds the particle annihilation/creation rate, the WIMPs drop out of thermal equilibrium, and the number density becomes "frozen". Presently the relic density of these particles is approximately given by

$$\frac{\Omega_{DM}h^2}{0.110} \approx \frac{3 \times 10^{-26} cm^3/sec}{\langle \sigma_A v \rangle_{ann}}, \tag{1}$$

where σ_A is the total annihilation cross section, v is the relative velocity of WIMPs and the term in brackets is an average over the thermal distribution of WIMPs velocities. From a cosmological point of view, it is worth noticing that the proper value of $\Omega_{DM}h^2$ density comes out from an annihilation cross section on the electroweak scale. This coincidence, obtained numerically, represents the main reason for believing that WIMPs give the largest contribution to the matter density in the Universe.

The freeze out happens at temperature $T_F \simeq m_{DM}/20$ almost independently of the properties of the WIMPs. This means they are already non-relativistic at the decoupling.

If we search beyond SM, well-motivated scenarios suggest good candidates. As neutralinos and Kaluza-Klein particles on which we are going to focus our discussion.

A. WIMPs in supersymmetric extensions of the Standard Model

This class contains a large amount of DM candidates, which are not predicted in the realm of the SM. In supersymmetric (SUSY) theories, each SM particle has a new yet-undiscovered partner whose spin differs by 1/2 with respect to the supersymmetric partner. In comparison to the mass eigenvalues in the SM, SUSY particles occur in linear combinations. The lightest possible combination (LSP) is the neutralino χ formed by the Bino $\tilde{\mathrm{B}}$, Wino $\tilde{\mathrm{W}}$ and two Higgsino $\tilde{\mathrm{H}}$ states, with a mass range $m_\chi \sim 10$ GeV-TeV. The main ingredient necessary to provide a natural WIMP candidate in the SUSY models is the R-parity conservation defining the R-parity as:

$$R = (-1)^{3(B-L)+2S} \,,$$

where B is the baryon number, L the lepton number and S the spin of the particle. $R = +1$ for ordinary particles and $R = -1$ for SUSY particles. This means that SUSY particles can only be created or annihilated in pairs. By imposing the R-parity conservation, a selection rule on the SUSY particle decays prevents the LSP to decay to an ordinary particle guaranteeing the stability in terms of cosmological abundances. However, this straightforward mechanism has to be experimentally probed. Several indications at Large Hadron Collider (LHC), CERN, seem to exclude minimal SUSY models, so the search of these candidates is, up to now, completely open.

B. Extra dimensions and Kaluza-Klein Dark Matter

An alternative possibility for new weak-scale physics is to search for universal extra dimensions (UED). The motivation to consider UED models is that they provide an interesting and qualitatively different alternative to supersymmetry. The idea of the existence of extra spatial dimensions was introduced, for the first time, by Kaluza and Klein in the

1920's. Such theories attempt to unify the two fundamental forces of gravitation and electromagnetism at the weak scales. Some models assume that all fields of SM propagate in "universal" extradimension. As a consequence, observers in the four-dimensional world see a tower of Kaluza Klein (KK) states for each SM particle [Kolb & Turner 1990]. The SM particles make up the first level of this tower and are referred to as the zero-th KK mode.

Momentum conservation in the extra dimension leads, in the four dimensional world, to a conservation of KK number (N_{KK}), where the KK number of a particle is given by its mode number. All SM particles have $N_{KK} = 0$ while the next most massive set of states have $N_{KK} = 1$. Such KK excitations appear as particles with masses near the TeV scale. Due to conservation of momentum in the higher dimensions, a symmetry called KK parity can arise which can, in some cases, make the lightest KK particle (LKP) stable, in a way which is analogous to R-parity of SUSY models, making it possible for the LKP to be a viable DM candidate. Since DM particles are expected to be neutral, non-baryonic and without color, the first mode KK partners of the neutral gauge bosons or neutrinos are likely choices for the lightest Kaluza-Klein particle (LKP). The identity of the LKP depends on the mass spectrum of the first KK level. The LKP is, most naturally, the first KK excitation of the B_1, the level 1 partner of the hypercharge gauge boson. It has been found that the appropriate relic density is predicted when the mass is moderately heavy, between 600 and 1200 GeV, somewhat heavier than the range favoured by supersymmetry. This range of LKP mass depends on the details of the co-annihilations of LKPs with heavier KK particles. Another difference between DM particles in universal extra dimensions and supersymmetry is that, unlike of LSP neutralino, the bosonic nature of the LKP means there is no chirality suppression of the annihilation signal in fermions. The annihilation rate of the LKP is therefore roughly proportional to the hypercharge of the final state, leading to a large rate in leptons, including neutrinos. The annihilation and co-annihilation cross-sections are determined by SM couplings and the mass spectrum of the first KK level. In contrast to supersymmetry, particles in UED have the same spin of the SM partners. As a result, the couplings become large and non-perturbative at energies far below the Planck scale. The detection of these kind of particles is also expected at LHC.

III. METHODS OF DETECTION AND EXPERIMENTAL STATUS

There are three main strategies to search for DM particles. Assuming that DM consists of WIMPs i.e. particles which froze out from thermal equilibrium when they were no more relativistic, one would expect that due to the gravitational interaction, they should have clustered with ordinary matter to form an almost spherical halo around the galaxies. Measurements of rotation curves of a large number of spiral galaxies have suggested the existence of a dark halo more extended than the visible disk. Despite the measurement in case of Milky Way is more difficult and suffers of larger uncertainties, the presence of a halo has been confirmed [Merrifield 1992]. Thus, if DM exists, it should be present also in the Milky Way and a consistent flux of WIMPs is expected to cross the Earth surface. The WIMPs of the dark halo, although with a very low cross section, interact with ordinary matter inducing atomic recoils. The measurement of these rare recoils through their energy deposit, carefully discriminated from the background, is performed by direct techniques.

Another method for DM detection is carried out by indirect techniques, which aims to observe the products of WIMPs annihilation process, as gamma rays, neutrinos, anti-matter cosmic rays occurring mainly inside astrophysical objects.

A third possibility is at particle colliders: here DM may be produced through the SM SM $\rightarrow$ XX process where SM denotes a standard model particle and X represents the WIMP. Such events are, in general, undetectable but are typically accompanied by related production mechanisms, such as SM SM $\rightarrow$ XX + "SM" , where "SM" indicates one or more standard model particles. These events are instead observable and should provide signatures of DM at colliders as LHC.

A. WIMPs Direct Detection

When a WIMP of a certain mass m_X scatters elastically a nucleus of mass m_N, the nuclear recoil occurs at an angle θ with respect to the WIMP initial velocity, with $\cos\theta$ uniformly distributed between -1 and 1 for the isotropic scattering that occurs with zero-momentum transfer. If the WIMP initial energy in the lab frame is $E_i = M_X v^2/2$, the the nucleus recoils (in the lab frame) with energy $E_R = E_i r \frac{(1-\cos\theta)}{2}$ where $r \equiv \frac{4\mu^2}{M_X M_A} = \frac{4 M_X M_A}{(M_X + M_A)^2}$. Note that $r \leq 1$, with $r = 1$ only if $M_X = M_A$. For this isotropic scattering, the recoil energy is therefore uniformly distributed between $0 - E_i r$.

Since typically the mean WIMP velocity is $v \simeq 220 km/s$ [Bernabei et al. 1998b], we can easily estimate that the maximum energy transfer from a WIMP to an electron, initially at rest, is at most in the eV range, while the energy transfer to an atomic nucleus would typically be in the range of tens of keV. This requires to use low threshold detectors, which are sensitive to individual energy deposits of this order of magnitude. In order to compute the WIMP-nucleon interaction rate, one needs the cross-section and the local density of WIMP. Details of this calculations can be found in e.g. [**?** Lewin & Smith 1996]. We report here only the final expression

$$\frac{dN}{dE_R} = \frac{\sigma_0 \rho_{DM}^{local}}{2\mu^2 m_X} F^2(q) \int_{v_1}^{v_2} \frac{f(v)}{v} dv$$

where ρ_{DM}^{local} is the local WIMP density, μ is the reduced mass of the WIMP nucleus system and $f(v)$ accounts the velocity distribution of WIMPs in the galactic halo. The lower and upper limit of the integral represent respectively the minimum WIMP velocity to produce a recoil of energy E_r, and the maximum WIMP velocity set by the escape velocity of the halo model. $F(q)$ is a dimensionless factor form and σ_0 is the WIMP-nucleus interaction cross-section. This cross section depends strongly on the form of the interactions of the DM particles. It may happen that the WIMP-nucleus cross-section is not sensitive to the spin of the nucleus; in such a case we refer to spin-independent interactions; otherwise, WIMPs couple dominantly to the nucleus spin and this is the case of a spin-dependent interaction. The WIMP-nucleus cross section, may be written in terms of a spin-independent (mostly scalar) and a spin-dependent (mostly axial vector) component. For the former, the interaction will be coherent across the nucleons in the nucleus, while the latter term will only be present for nucleons with nuclear spin 29 or 82 or 83). In most cases, the coherent term is dominant since it is proportional to A^2 where A is the atomic number of nucleus, which favours heavy nuclei. Nevertheless, for very heavy nuclei, as the recoil energy increases, account must also be taken of the nuclear form factor, which may suppress the differential scattering rate significantly as shown in Fig.1. The curves are obtained assuming the spin independent coupling dominant, a standard halo model and choosing a WIMP mass of 100 GeV [Baudis 2007].

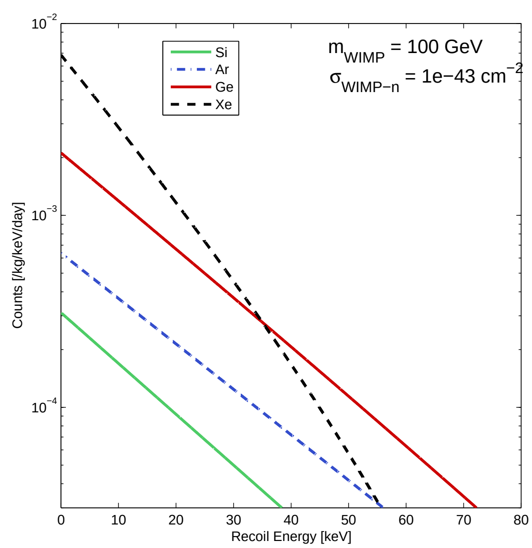

Figure 1. Differential WIMP recoil spectrum for a WIMP mass of 100 GeV and a WIMP-nucleon cross section $\sigma = 10^{-43}$ cm^2. The spectrum was calculated for Si (light solid), Ar (light dot-dashed), Ge (dark solid), Xe (dark dashed) [Baudis 2007].

The differential WIMP event rate versus the recoil energy expected for single isotope targets of ^{131}Xe (similar for ^{129}I), ^{73}Ge, ^{28}Si and ^{40}Ar is shown. It can be noticed that for a given cross section for WIMP-nucleon interactions, the interaction rate decreases for smaller nuclei because of a combination of smaller coherence enhancement ($\sim A^2$) and the less effective transfer of recoil energy to a target that is lighter than the WIMP. It is also evident that the recoil spectrum for the heavier Xe nucleus is suppressed significantly by the loss of coherence for higher q^2 scattering events (form factor suppression). A low analysis threshold is therefore important to maximise the effective search sensitivity of a given detector mass. The influence of threshold energy is even greater for lower-mass WIMPs, where the recoil spectrum slope becomes steeper because of the reduction in typical kinetic energy of the WIMPs. The interaction rate can be calculated within the Minimal SUSY models, but the predicted WIMP-nucleon interaction cross section spans many orders of magnitude. Typical values for the spin-independent cross section are between 10^{-6} pb and 10^{-11} pb [de Austri et al. 2006].

Table I. Underground laboratories housing DM experiments. The approximate effective shielding depth is mesured in meters of water equivalent (mwe).

Laboratory	Depth (m.w.e.)	Experiment
Soudan, US	2000	CDMS/SuperCDMS, CoGeNT
Yangyang, Korea	2000	KIMS
Kamioka, Japan	2700	XMASS,SuperKamiomkande
Bulby, UK	3200	ZEPLIN
LNGS, Italy	3500	DAMA, CRESST, WARP, XENON100
Modane, France	4800	EDELWEISS
SNOLab, Canada	6000	PICASSO, DEAP/CLEAN

In the recent years, an inelastic dark matter (iDM) model has been proposed as a modification of the elastic WIMP model. iDM model assumes that WIMPs scatter off baryonic matter by simultaneously transitioning to an excited state at an energy δ above the ground state ($\chi N \to \chi^* N$), while elastic scattering is forbidden or highly suppressed. This fact introduces a minimum velocity for WIMPs to scatter in a detector with a deposited energy E_{nr}.

1. *A Review of Experiments*

The nature of WIMPs makes their detection a hard task. A typical WIMP mass ranges between 10 GeV and few TeV according to the model chosen and the signal, to be detected in terms of deposit energy of the nuclear recoil, is of the order of tens keV. Within the MSSM models, the cross section interaction rates induce at most 1 evt day$^{-1}kg^{-1}$ in the detector, so large target masses and low background detectors are required. Typical background from environmental radioactivity and cosmic radiation are much higher with respect to these low expected rates and experimental purposes need underground laboratories to shield cosmic ray induced backgrounds, and for the selection of extremely radio-pure materials.

Worldwide, a large number of underground laboratories exists, many of them house present and/or future DM experiments (see Tab. I).

Three different detection principles are at the basis of most particle detectors:

- **ionizing effect of a particle interaction**;
- **scintillation light from electronic excitation**;
- **thermal signal from lattice vibrations**.

A great number of experiments performing one or a combination of the mentioned techniques have been realised throughout the years, mainly divided into two categories: single and double modality. Concerning the former, such experiments must work in ultra-low background conditions because they are not able to perform background rejection. Each event, which falls in the acceptance window of the detector is accepted as a DM candidate with its own deposit energy measurement. For instance CREEST I and CoGeNT belongs to this class of experiments. CRESST I was the first phase of the CRESST experiment and consisted of a cryogenic bolometer based on saphire crystals as target material operating below 10 mK. This technique provides a threshold energy on nuclear recoils of the order of 0.5-0.6 keV, much lower than the minimum thresholds set by other experimental methods. Anyway the reduced target mass (262 g) limit its sensitivity. The CoGeNT experiment uses a single, 440g, high-purity germanium crystal cooled to liquid nitrogen temperatures in its measurements. The detector has the advantage of a very low energy threshold (<0.5 keV) which allows it to search for nuclear recoil events due to DM particles of relatively low mass ($> GeV/c^2$). In addition to a low-background configuration, the detector is able to distinguish and reject background events from the surface by measuring the risetime of the detector's signals. The CoGeNT detector is sensitive only to the ionisation charge from nuclear recoils and sets limits on the mass and interaction cross-section of DM particles by excluding any candidate mass and cross-section pair that would result in a signal above the background of the detector.

The CoGeNT collaboration has recently announced their results on 15 months of data, including the measurement of the spectrum of nuclear recoil candidate events, and the time variation of those events [Aalseth et al. 2011a]. These results appear consistent with the signal anticipated from a relatively light DM particle scattering elastically with nuclei. The observed spectrum and rate is consistent with originating from DM particles with a mass in the range of 4.5-12 GeV and an elastic scattering cross section with nucleons of approximately $\sim 10^{-40} cm^2$ [Hooper & Kelso 2011]. In early 2010, the CoGeNT collaboration reported the observation of ∼100 events above expected backgrounds over a period of 56 days, with ionisation energies in the range of approximately 0.4 to 1.0 keV [Aalseth et al. 2011b]. Concerning the double modality, all the experiments able perform energy measurements and background discrimination of the electron recoils, belong to this category. The most important results come from CDMS and EDELWEISS. The Cryogenic DM Search (CDMS in the Soudan Underground Laboratory) has developed a ionisation/phonon technique which allows a high efficient event by event discrimination between electron and nuclear recoils, based on the simultaneous record of inciting and phonon signal in the Ge and Si detectors packed in towers, operating at 40 mK. The recoil energy threshold is 10 keV. Recently, results have been presented from a re-analysis of the entire five-tower data set acquired with an exposure of 969 kg-days [Ahmed et al. 2011] with a recoil energy extended to 150 keV and an increased sensitivity of the experiment to the inelastic DM (iDM) model. Three DM candidates were found between 25 keV and 150 keV where the probability to observe three or more background events in this energy range is 11%. The CDMS program goes on with a future installation of the SuperCDMS setup at the new deep SNOLab laboratory, with 100 kg of detectors. EDELWEISS experiment (in the Modane Underground Laboratory) is conceptually based on the same idea as CDMS, with 300g germanium monocrystals as target. The typical recoil energy ranges from a few keV to few tens of keV. This recoil is measured at the same time with a heat channel, and a ionisation channel. The energy threshold reaches 10 keV. The EDELWEISS-II experiment has carried out a direct WIMP search with an array of ten 400 g Inter-Digit detectors, achieving an effective exposure of 322 $kg\,days$. The best sensitivity achieved in the elastic spin-independent WIMP-nucleon cross-section is $5 \times 10^{?8} pb$ for a WIMP mass of 80 GeV . The results are detailed in [Armengaud 2010].

Exploiting the noble gas properties at low temperatures, both scintillation and ionisation signal can be detected by noble liquid detectors. Argon and Xenon at below 88K and 165K respectively behave as dense liquids with good scintillation yield of about $40{\times}10^3$ photons/MeV and good electron mobility. The particle interaction in the liquids ionises the medium and produces excited states of the gas atoms, which generate a luminescence signal. There are two excited states both for Ar and Xe (a singlet and a triplet) which differ in lifetime, quite enough to be measured by using a pulse shape discrimination analysis. The noble liquid detectors operate in a dual phase mode: the noble element (in the form of liquid and gas state) is saved in a vessel equipped with an array of photomultiplier. The interaction within the liquid phase produces a first direct scintillation signal, called S1, while, the produced ionisation electrons are drifted toward the liquid-gas interface, by means of a strong electric field applied in the volume. A second light signal S2 is emitted due to the difference of amplitude of the electric fields in both phases. By measuring the relative timings of the different signals, the position of the primary interaction may be reconstructed. Furthermore, since the ionisation yield is smaller for nuclear recoils, the S2/S1 ratio is used to distinguish nuclear from electron recoils.

The XENON10 experiment uses this technology, with PMT arrays both in the gas and liquid phase. The nuclear recoil energy threshold is 4.5 keV and the effective event rate in region of interest (4.5-29.6 keV) after all fiducial cuts is around 2×10^{-3} /keV/kg/day [Angle et al. 2008].

Xenon10 Collaboration has reported results of a search for light DM particle ($\lesssim$ 10 GeV) with a sensitivity threshold of 1.4 keV. Considering spin-independent dark matter- nucleon scattering, a cross sections $\sigma_n > 3.5 \times 10^{-42} cm^2$ is excluded, for a dark matter particle mass m_χ= 8 GeV [Angleet al. 2011].

XENON100 is one of the successor projects of XENON10. The experimental setup has been enlarged and much care has been taken to reduce the background. The XENON100 experiment has recently completed a DM run with 100.9 live-days of data, taken from January to June 2010. A total of three events have been found in the fiducial volume analyzed, compatible with the background prediction of (1.8 ± 0.6) events [Aprile et al. 2011].

The WARP collaboration has built a dual-phase prototype liquid Argon with a fiducial mass of 1.8 kg which achieved a good discrimination of the ^{39}Ar background and reached a background rate of 2×10^{-3} /keV/kg/day after discrimination in the 20-40 keVee [1] range. The WARP collaboration has also produced a large (order of 100 kg) detector at Gran Sasso with a massive active liquid argon shield, but unforeseen technical difficulties seem to prohibit a timely start of the experiment. In the dual phase detectors the major part of the discrimination power comes from the pulse shape. On this basis, a single phase liquid Argon project has been proposed and two detectors, DEAP 3600 and MiniClean with fiducial masses of 1000 kg and 100 kg respectively are under construction at SNOLAB. The pulse-shape based discrimination is expected to provide a sufficient electron recoil background reduction to completely suppress the intrinsic radioactivity, but it is also being considered to fill the detector with argon extracted from underground sources which are depleted in ^{39}Ar by a factor of 20 or more.

In the last years a new experiment, called DarkSide [A. Wright] has been proposed by a Chinese, Italian, Russian and US Collaboration. It consists of a large depleted argon TPCs for direct DM searches at LNGS. The innovations proposed make DarkSide a detector of unprecedent background-free performance. The mechanical design is in progress.

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[1] keV electron-equivalent.

The installation will start in summer 2012. The detector will reach, in 3 years background free operation, a cross-section sensitivity of 1.5×10^{-45} cm^2 for WIMP-nucleon scattering, competitive with the projected sensitivity of other present experiments.

Other projects are based on superheated liquids, used in particle detectors early on in the form of bubble chambers. The PICASSO project is based on this technology, but instead of a monolithic bubble chamber, the detectors consist of tiny droplets immersed in a gel matrix. In appropriate temperature and pressure conditions, the interacting particle creates a bubble in the target volume. The operation conditions can be tuned in a way that the detector is sensitive only for nuclear recoils while is essentially blind to gamma rays and cosmic muon induced events with small energy deposit. The advantage of this technology are the relatively low costs and simple detector production, while a clear disadvantage is that there is no energy information available. PICASSO has operated several of these detectors with a total volume of 4.5 l, containing of order of 70 g of the main WIMP target fluorine each. With this target the experiment is mainly sensitive to spin-dependent WIMP-nucleon interactions. PICASSO reported results on the limits obtained on the spin-dependent cross section for WIMP scattering on ^{19}F, setting a limit for WIMP interactions on protons of 0.16 pb (90% CL).

The largest operating experiment for DM direct search is DAMA [Bernabei et al. 2004] which is based on about 10 kg of scintillating radiopure NaI(Tl) crystals readout by photomultiplier's in a well shielded and controlled environment. Although the scintillation light is detected, a signal shape discrimination can be performed at a reasonable level so the energy evaluation can be coupled to a discrimination method. The large mass and low background allow to investigate the presence of DM exploiting the model independent annual modulation signature.

Since NaI does not provide a strong event-by-event discrimination of electron recoil background, DAMA follows a unique strategy to still get a handle on the background: the Sun orbits our galaxy with a velocity of $\sim$ 220 km/s, while the earth rotates around the sun with $\sim$ 30 km/s. Assuming the DM halo around our galaxy has no net angular momentum, the relative velocity of WIMPs respect to the detector changes over the course of the year. For a given energy threshold this would lead to an annual modulation of the interaction rate with a known phase. DM particles from the Galactic halo are hence expected to show an annual modulation of the event rate induced by the Earth's motion around the Sun [Drukier et al. 1986]. DAMA reported an effect of annual modulation of the count rate at low energies, which attributes to a WIMP signal at 6.3σ. This annual fluctuation in the background rates occurs near threshold, in the 2-6 keV region where the pulse shape discrimination start to fail. The variation is well fitted by the cosine function expected for the WIMP signal with a period $T = 0.999 \pm 0.002$ year, i.e. very close to one year, with a phase $t_0 = 146 \pm 7$ days, which is very close to the signal modulation expected for WIMPs (152.5 days or 2nd of June), and with an amplitude of 0.0131 ev/kg/keV/day. The observed modulation amplitude is (0.0200 $\pm$ 0.0032) cev/kg/keV/day with a phase of t_0 = (140$\pm$22) days and a period of (1.00$\pm$0.01) year. In the meanwhile, the DAMA collaboration has upgraded the detector to 250 kg NaI(Tl) called DAMA/LIBRA which started the operations in 2003. The combination of all DAMA/NaI and DAMA/LIBRA data shows a statistically compelling (8σ) modulation signal at low energies (2-4 keV), compatible with a WIMP interpretation. The DAMA group has not found any modulation effect in the region of energies above 90 keV. If the effect is caused by variation of the Compton background in the $2 \div 6$ keV energy bin it must reveal itself also for the gammas with energies >90 keV. However, other experiments have excluded the region of the allowed parameters M_W and σ_p derived by DAMA from the modulation effect.

The experiments on WIMP search over the last years have put the limits on the spin-independent cross-section already below 10^{-7} pb. The ultimate goal of DM search experiments is to reach sensitivities down to 10^{-12} pb. This will allow to probe the whole M_W and σ_p parameter space of SUSY predictions. This goal can be achieved only with the use of next-generation detectors of the ton scale and ultimately of the multi-ton scale.

B. Indirect Detection

After freeze out, DM pair annihilation becomes largely suppressed. However, even if its impact on the DM relic density is negligible, DM annihilation continues and may be observable. Thus, DM particle are expected to either annihilate or decay into SM particles like γ-rays, neutrinos and matter-antimatter particles in the final state and the detection of annihilation products is usually referred to as indirect DM detection.

Indirect searches look for the excesses of annihilation products in the diffuse background or from point sources. In particular, concerning charged products, the search is devoted to the antimatter component due to the large amount of primary matter component in the cosmic rays.

There are several methods for DM indirect detection. Their relative sensitivities are highly dependent on what WIMP candidate is being considered, and the systematic uncertainties and difficulties in determining backgrounds also vary greatly from one method to another.

High WIMP density regions, e.g. the centers of galaxies, but also the core of astrophysical objects such as Sun and Earth, are expected to accumulated large amount of WIMPs. When WIMPs pass through the Sun or the Earth or the

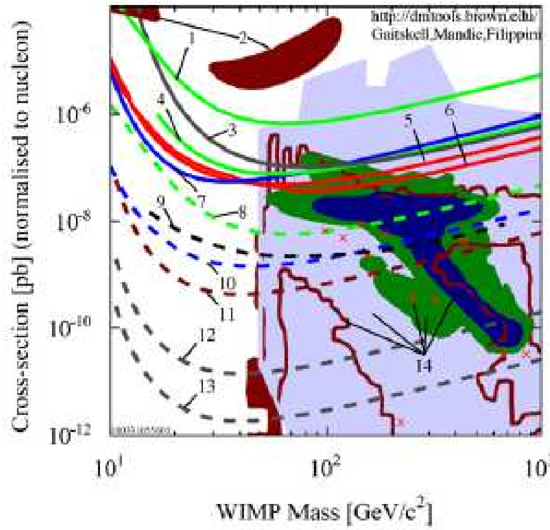

Figure 2. Experimental results and SUSY predictions for WIMP nucleon cross sections versus WIMP mass 1-ZEPLIN-II, 2-DAMA/LIBRA, 3-EDELWEISS, 4-ZEPLIN-III 1st phase, 5-CDMS, 6-CDMS, 7-Xenon10, 8-ZEPLIN-III 2D phase, 9-XMASS , 10-Xenon100 , 11-LUX, 12-Xenon1t , LZS , MAXG2LXe, 13-LZD, MAXG3LXe and 14-SUSY predictions.

galactic center, they may scatter and be slowed below escape velocity. In this way, they may become gravitationally bound in these gravitational wells. Over the age of the solar system, their densities and annihilation rates are greatly enhanced.

Although γ-rays, positrons and anti-protons produced in these annihilations do not escape the Sun or the Earth, neutrinos would be able in this because of their high penetration ability.

These neutrinos can travel to the surface of the Earth, where they may convert to charged leptons through $\nu q \rightarrow l q'$ and the charged leptons may be detected. The resulting neutrino flux could be detectable as a localised emission with earth-based neutrino telescopes by exploiting the Cherenkov light produced by the charged lepton.

Searches for neutrinos are unique among indirect searches since they are, under certain assumptions, probes of scattering cross sections, not annihilation cross sections, and so are competitive with the direct detection searches.

In the Sun both spin-independent as well as spin-dependent scattering can lead to the capture of DM. Among nuclei with a net spin, hydrogen is the only one present in the Sun in significant proportions. Other trace elements in the Sun generally have no net spin, and even when they do, there is no A^2 enhancement in the cross section coherent term because of their low density fraction. Therefore, the only relevant quantity for spin-dependent capture is the WIMP-proton cross section. Spin-independent capture, on the other hand, receives contributions from several elements. In fact, the cross section for spin-independent WIMP-nucleus scattering is strongly enhanced by large A. Therefore, even though the heavier elements in the Sun are rarer, this enhancement makes their contribution to the capture rate significant. In particular, oxygen plays the most important role in spin-independent capture of WIMPs in the Sun.

Neutrino telescopes could probe direct search observation. In fact, the signals observed at the direct detection experiments DAMA, CoGeNT and CRESST could be explained by light WIMPs with sizeable spin-independent cross sections with nucleons. The capture and subsequent annihilation of such particles in the Sun would induce neutrino signals in the GeV range which may be observed at Super-Kamiokande[Superkamiokande website].

Actually, detection of these neutrinos in the range $10GeV < E_\nu < 1TeV$ by large neutrino detectors such as SuperKamiokande , AMANDA [AMANDA website] and IceCube [IceCube website] so far provides only upper limits on the high energy neutrino flux from the center of the Sun or the Earth (see [Kundu & Bhattacharjee 2011]).

Future neutrino searches at Super-Kamiokande may have lower thresholds and so provide leading bounds on low mass WIMPs. In this way, Super-Kamiokande may test the DAMA and CoGeNT signal regions at high σ_{SI} and $m_X \sim 1$ - 10 GeV [Hooper et al. 2009, Feng et al. 2009, Kumar et al. 2009].

Moreover installing DeepCore, also IceCube significantly lowers its energy threshold and enhances the ability of detecting neutrinos from light WIMP annihilation.

Unlike other indirect DM searches this method does not depend strongly on our galaxy's DM halo profile or on the distribution of DM substructure.

The event rate depends on the DM density in the Sun, which in turn is dictated by the cross section of WIMPs with nucleons. This is constrained by direct detection experiments. The neutrino flux depends on the WIMP density, which is determined by the competing processes of capture, that is from the scattering cross section, and annihilation. Moreover the differential neutrino flux depends also on the way in which neutrinos are produced. Assuming that WIMPs annihilate to $b\bar{b}$ or W^+W^- which decay to neutrinos, as in many neutralino models, the neutrino signal is completely determined by the scattering cross section. For the majority of particle physics models considered (e.g., supersymmetry or KK models), the WIMP capture and annihilation rates reach or nearly reach equilibrium in the Sun. This is often not the case for the Earth. First, the Earth is less massive than the Sun and, therefore, provides fewer targets for WIMP scattering and a less deep gravitational well for capture. Secondly, in the Earth spin-independent interactions may occur. For these reasons, it is unlikely that the Earth will provide any observable neutrino signals from WIMP annihilations in any planned experiments.

If the annihilation occurs in free space, other types of radiation can be detected. The DM particles annihilating within the halo, can arise production of SM particles associated with the emission of γ ray with energies of the order of the DM particle mass. Thus, the γ-ray emission associated with such annihilation provides a chance for DM particles detection. The most striking gamma ray signal would be mono-energetic photons from $\chi\chi \to \gamma\gamma$, but since WIMPs cannot be charged, these processes are typically loop-induced or otherwise highly suppressed. More commonly, gamma rays are produced when WIMPs annihilate to other particles, which then radiate photons, leading to a smooth distribution of gamma ray energies. If gammas arise together with other particles, we only would expect some enhancement of the spectrum below the WIMP mass. The main difficulty in the extraction of information about DM from the annihilation photons is the presence of large and uncertain gamma-ray backgrounds. On the other hand, photons point back to their source, providing a powerful diagnostic. Possible targets for gamma ray searches are the center of the Galaxy, where signal rates are high but backgrounds are also high and potentially hard to estimate, and dwarf galaxies, where signal rates are lower, but backgrounds are also expected to be low. Moreover, for most particle DM candidates, γ-rays would be accompanied by neutrinos, thus neutrino experiments could help to confirm whether the γ flux originates from DM annihilations or from other astrophysical sources.

Another difficulty for DM search with γ arises from the fact that the DM gamma ray emission is expected to be a function of the DM density profile, which is not experimentally known. The most adopted density profile models are the Navarro-Frenk-White profile for which:

$$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}(1+\frac{r}{R_s})^2} \tag{2}$$

where ρ_0 and R_s, are parameters which vary from halo to halo, and the Einasto profile for which:

$$\rho(r) \propto exp(-Ar^{\alpha}) \tag{3}$$

The parameter α controls the degree of curvature of the profile.

The expected energy integrated γ-ray flux from a region of volume V at a distance D with DM density ρ is:

$$\phi_\gamma = N_\gamma \frac{\langle \sigma v \rangle}{m^2} \frac{1}{4\pi D^2} \int_V dV \frac{\rho^2}{2}, \tag{4}$$

where N_γ is the number of γ-rays per collision, m is the DM particle mass and $\langle \sigma v \rangle$ is the velocity-weighted annihilation cross-section. The current cosmological DM density is set by their annihilation rate in the early Universe. This provides a natural value for the annihilation cross-section of $\langle \sigma v \rangle \sim 3 \times 10^{-26} cm^3 s^{-1}$.

Obviously, the higher ρ the better, so that the annihilation radiation is searched for in the most dense regions of the Milky Way (MW).

The improvement of the Galactic diffuse model as well as the potential contribution from other astrophysical sources could provide a better description of the data.

γ-ray observations, in particular, at very high energies where DM masses of a few 100 GeV and above are probed, are a promising way to detect DM by space-based experiments, such as Fermi and AMS, and by ground-based atmospheric Cherenkov telescopes.

H.E.S.S. is an array of four Imaging Atmospheric Cherenkov Telecopes (IACTs) that uses the atmosphere as a calorimeter and images electromagnetic showers induced by TeV γ-rays [Hofmannetal 2004].

H.E.S.S. Collaboration performed searches for a very-high-energy (VHE; $\geq$ 100 GeV) γ-ray signal from annihilation of DM particles, towards the Galactic center, the Sagittarius Dwarf galaxy and hypothetical DM spikes that could have formed around Intermediate Mass Black Holes (IMBHs).

The γ-ray energy spectrum in the range between 300 GeV and 30 TeV after the background suppression shows no any convincing evidence for γ-ray emission from self-annihilating DM. Limits on annihilating cross section for χ and B_1 have been found constraining some models.

For instance, limits on $\langle\sigma v\rangle$ are derived as a function of the DM particle mass assuming Navarro-Frenk-White and Einasto density profiles. In particular, for the DM particle mass of $\sim$ 1 TeV, values for $\langle\sigma v\rangle$ above 3 $\times 10^{-25} cm^3 s^{-1}$ are excluded for the Einasto density profile [Abramowski et al. 2011].

The Galactic center (GC) region is the main target for DM search, because of its proximity and its expected large DM concentration. However, the search for DM induced γ rays in the GC is affected by a strong astrophysical background. In fact, in the GC there is the compact γ-ray source HESS J1745-290 [Abramowski et al. 2011], coincident with the position of the supermassive black hole Sgr A* and a nearby pulsar wind nebula, which represents other sources of VHE γ-rays in the observed region, thus complicating the detection of γ-ray emission from DM annihilation.

VERITAS is a ground based Cherenkov telescope for gamma ray astronomy and has among other things searched for an enhancement of gamma rays from the center of neighboring dwarf galaxies without a positive signal so far [Weinstein et al. 2008].

Data from the EGRET satellite in the energy range 20 MeV - 30 GeV, interpreted as evidence for DM [de Boer 2005], are not confirmed by recent data from Fermi satellite [Abdo et al. 2010].

The new precise data from the FERMI satellite on the diffuse gamma ray data are well-described at intermediate latitudes by standard CR physics assuming isotropic propagation models , but towards the Galactic center a 20%-30% excess has been observed in the 2-4 GeV range or even more significantly, within $\approx 1^\circ$ from the Galactic Center (GC), that could be interpreted as a signal of DM annihilation (DMA) for a very light neutralino of about 8 GeV [de Boer 2011].

Other products of DM annihilation are pairs of particles-antiparticles, like e^+e^-, $p\bar{p}$ and $d\bar{d}$ pairs.

Since anti-matter is a very rare product of conventional sources of cosmic radiation, is suitable as possible indicator for DM annihilation.

Actually, unlike neutrinos and γ, positrons and anti-protons do not point back to their sources making an unambiguous separation from backgrounds very difficult.

In contrast to direct detection, many anomalies have been reported in the indirect search with anti-matter, and some of these have been interpreted as possible evidence for DM. The most prominent recent example is the detection of positrons and electrons with energies between 10 GeV and 1 TeV by the PAMELA, ATIC, and Fermi LAT Collaborations [Adriani et al. 2009, ATIC website, FERMILAT website].

PAMELA [Picozza et al. 2007], a satellite based instrument specifically designed to search for anti-particles in cosmic radiation, has reported an enhancement of positrons around 100 GeV over the standard expectation from diffuse galactic cosmic ray secondary models, in which positrons result from inelastic collisions of primary protons on the intergalactic gas nuclei.

Since DM annihilation produces as many positrons as electrons, with particles of energies close to the DM particle mass (in the range 10 GeV - 100 GeV for best motivated particle models), the positron fraction is enhanced.

If such enhancement originates from DM annihilation, also a respective enhancement of anti-protons would be expected, but is not observed. Special DM models could avoid hadron production, but also astrophysical explanations exist as well, such as nearby pulsars.

Additionally, the ATIC balloon-borne experiment also reported an anomalous "bump" in the total flux of e^+e^-, at energies of $\sim$ 600 GeV [Panov et al. 2011] which also has been interpreted as possible evidence for DM annihilation. It would imply a large mass and a very large pair annihilation cross section for DM.

Recently the experimental information available on the Cosmic Ray Electron (CRE) spectrum has been dramatically expanded as the Fermi-LAT Collaboration has reported a high precision measurement of the electron spectrum from 7 GeV to 1 TeV performed with its Large Area Telescope (LAT) [Fermi LAT collaboration 2010].

The Fermi experiment, like also ATIC, is unable to distinguish positrons from electrons, and so constrain the total $e^+ + e^-$ flux.

The ATIC "bump" is not confirmed by the Fermi LAT data. The Fermi-LAT spectrum shows no prominent spectral features and the spectral index of the cosmic ray background is significantly harder than that inferred from several previous experiments: depending on the diffusion model, best fit injection spectral indexes range between 2.3 and 2.4, as opposed to previous models with 2.54. These data together with the PAMELA data on the rise above 10 GeV of the positron fraction are quite difficult to explain with just secondary production . An additional primary positron source is required to match the high-energy positron fraction, but other astrophysical explanations could be considered.

Additional data from, for example, Fermi and the Alpha Magnetic Spectrometer (AMS) [Pohl et al. 2010], an anti-matter detector placed on the International Space Station, may be able to distinguish the various proposed explanations for the positron excesses, as well as be sensitive to canonical WIMP models, but it remains to be seen whether the astrophysical backgrounds may be sufficiently well understood for these experiments to realize their DM search potential.

Other promising indirect detection search strategies are based on anti-protons and anti-deuterons from WIMP annihilation in the galactic halo. This searches are sensitive to DM candidates that annihilate primarily to quarks, but, until now, no result is reported [D.Casadei 2006, Adriani et al. 2009].

C. Particle Colliders

Contributions to solve the mystery of the DM will come also from colliders. Collider experiments can access interactions not probed by direct detection searches. A suitable room to search for DM is SUSY search and presently LHC data and analyzes are advancing very quickly, and possible signal for direct detection of supersymmetry are strictly related to the DM discussion.

The LHC is a $p-p$ collider, designed to operate at a center of mass energy up to $\sqrt{s}=14$ TeV [LHC website]. Two main general purpose detectors are installed at the LHC: ATLAS and CMS. They are designed to perform precision measurements of photons, electrons, muons and hadrons. At this writing the LHC is colliding p-p at $\sqrt{s}=7$ TeV and analyzes of about 1 fb^{-1} has already excluded squarks with mass up to 1 TeV about, in many models, superseding results from Fermilab-Tevatron $p\bar{p}$ collider with $\sqrt{s}=1.96$ TeV (CDF [CDF website] and D0 [D0 website] experiments). At hadron colliders heavy particles can be produced via quark-antiquark collisions, as at Tevatron, or via gluon-gluon and quark-gluon collision as at the LHC: the signals are an inclusive combination of all these processes. At Tevatron valence quark annihilation into virtual weak bosons give up to chargino and neutralino production with a large cross-section, unless squarks or gluino were lighter then 300 GeV, value ruled out by LHC. At LHC production of gluinos and squarks by gluon-gluon and gluon-quark fusion should be dominant. At hadron colliders, independently of whether it is a pp or $p\bar{p}$ kind, one can also have associated production of a chargino or neutralino together with a sqaurk or gluino, but most models predict diverse cross-section for several processes: slepton pair production was quite small at Tevatron, but might be observable eventually at the LHC.

Produced sparticles decay in final states with two neutralino LSPs, which escape the detectors, carrying away a part of the missing energy which is at least two times the mass of neutralinos. At hadron colliders only the component of the missing energy that is manifest as momenta transverse to the colliding beams is observable, so generally the observable signals for supersymmetry are: N leptons and M jets with a missing transverse energy, where N or M might be zero.

The main problem is that significant backgrounds to these signal come from Standard Model particle, in particular processes involving production of W and Z which decays into neutrinos, providing missing transverse energy.

If LHC discovers signatures which seems like R-parity conserving SUSY signatures, a SUSY mass scale has to be derived from the deviation from SM. Early LHC data had excluded a SUSY mass scale in the sub-TeV range [Martin 2011]. SUSY contribution to DM from excess above the SM, observed in observables, should be characterized by the decay chains isolated to disentangle this contribution. The amount of LSP relic density of the Universe today is determined by the efficiency of LSP annihilation before freeze-out, that is by the cross section for $\chi\chi \rightarrow f\bar{f}/W^+W^-/ZZ$ [Di Ciaccio 2011]. ATLAS/CMS data can determine the LSP relic density, once one have estimated the SUSY parameters which enter the dominating annihilation process/processes. In mSUGRA model [A. H. Chamseddine et al. 1982] the LSP is usually most bino and in this case the basic annihilation process $\chi\chi \rightarrow f\bar{f}$ proceed via exchange of a slepton or squark and has a too low cross-section. To determine the LSP composition, the mass of additional neutralinos are important, being SUSY models dependent from many parameters as mass of LSP, sleptons/quarks and ,whether they are superpartners of left-handed or right-handed SM particles, the neutral Higgs masses. Up to now no deviation from SM has been observed

IV. DISCUSSION OF EXPERIMENTAL RESULTS

As we have shortly reported, during the last years, several experiments have performed direct and indirect search investigating the possibility of DM presence.

Concerning the direct DM detection, recently, the CRESST-II and CoGeNT collaborations have reported the observation of low-energy events in excess over known backgrounds. This result has encouraged the hypothesis that such signals in addition to the long standing DAMA annual modulation signal might arise from the scattering of a light ($\lesssim$10 GeV) DM particle.

The rate of DM elastic scattering events as a result of Earth's motion around the Sun and relative to the rest frame of the DM halo, is predicted to vary with an annual cycle. The only experiment reporting the observations of an annual modulation is DAMA/LIBRA which detected with high significance ($\sim 8\sigma$) with a phase and period consistent with elastically scattering DM.

The spectrum of the signals reported by DAMA/LIBRA and CoGeNT seem to point toward a similar range of DM parameter space. Moreover, the range of DM mass implied by CoGeNT and DAMA/LIBRA is very similar to that required to explain the spectrum of gamma rays observed by the Fermi Gamma Ray Space Telescope from the the inner 0.5° around the Galactic Center [Hooper & Goodenough 2011], and for the observed synchrotron emission known as the WMAP Haze [Hooper & Linder et al. 2011]. Anyway much care must be taken for this interpretation since CoGeNT experiment does not discriminate between electron and nucleon recoils [Chang et al. 2010].

Against to the positive signals of DAMA and CoGeNT, several other experiments find no evidence for DM. In particular, the CDMS, Xenon10 and Xenon100 collaborations disfavor the parameter space indicated by DAMA and CoGeNT.

One remarkable difference between DAMA/CoGeNT and these experiments, is that the latter reject electronic interactions attempting to collect only nuclear recoil events. In fact, it would be possible that the anomalous signals arise from such electronic recoils, a possibility that would explain away the existing tension. A model of this type was considered in prior to the recent CoGeNT measurement and it remains to be seen whether this possibility is theoretically feasible. Concerning the inelastic DM interpretation the spin independent fit to the DAMA modulated rate allows two qualitatively different best-fit regions: one around $M_{DM} \approx 80GeV$ with $\sigma \approx 10^{-41}cm^2$ due to scattering on iodine (A = 127, Z = 53) and one around $M_{DM} \approx 10GeV$ with $\sigma \approx 10^{-40}cm^2$ due to scattering on sodium (A = 23, Z = 11). The first region is firmly excluded by many other experiments, such XENON100 and CDMS. The second region, while still disfavoured by other null searches, is not completely excluded due to many experimental uncertainties and due to the general difficulty of direct detection searches to deal with low recoil energy scatterings. A possibility to make the DAMA results consistent with other experiments is to include an effect called "channelling" which will be present only the NaI crystals with DAMA uses. Anyway though inclusion of this effect the situation does not improve significantly. For a WIMP mass close to $10GeV$ with the help of NaI channelling it is possible to explain the DAMA results in terms of spin independent inelastic DM nucleon scattering. In that case some relevant parameters as DM mass and splitting should be fine tuned, and also the WIMP velocity distribution in the Galaxy should be close to the escape velocity. Inelastic spin-dependent interpretation would be a possibility which do not receive significant constraints from other experiments. Anyway both interpretations make difficult to reconciling DAMA and CoGeNT results [Chang et al. 2010].

A possibility to avoid the conflict between DAMA results and other experiments is proposed in terms of different but not irrelevant DM candidates. Stable particles with charge -2, bound with primordial helium would represent a kind of nuclear interacting form of DM. Such particles cannot be detected using nuclear recoils by direct search experiments , but their low energy binding with Na nuclei can the annual variations of energy release from their radiative capture, in the energy range 2-4 KeV corresponding to the signal observed in DAMA and DAMA/LIBRA [Khlopov 2010a, Khlopov et al. 2010b, Khlopov et al. 2010c].

Regarding indirect detection four experiments on DM search have generated great excitement in the astroparticle community. Their results are briefly summarized below:

- the PAMELA experiment measured with high statistics the positron component in the cosmic ray flux in the energy range between 10 and 100 GeV, observing a positrons excess above 10 GeV claimed also by earlier experiments as HEAT and AMS whose experimental data extend up to 40 GeV but with larger uncertainties. Anyway the rise up to 20 GeV can be explained by solar modulation which depends on the charge sign of a particle affecting positrons and electrons in a different way [Adriani et al. 2009]. No excess in the antiproton/proton fraction has been observed by PAMELA [Adriani et al. 2009]. The positron excess cannot be explained by a purely secondary production (due to primary protons and He nuclei interacting with the interstellar medium), which is characterized by a not so hard spectrum suggesting the existence of other primary sources.

- The ATIC ballon born experiment has measured the total $e^+ + e^-$ spectrum in the energy range 3 GeV-2.5 TeV, finding an increase of the flux from 100 GeV up to 600 GeV where they observed a peak followed by a sharp fall to about 800 GeV. The rest of the data agree with the GALPROP theoretical predictions within the errors.

- The FERMI experiment is able to measure with high resolution and statistics γ-rays in the energy range 20 MeV-300 GeV and primary cosmic ray $e^+ + e^-$ spectrum between 20 GeV and 1 TeV. Recent results on a data sample of 6 months confirmed the excess in the total $e^+ + e^-$ flux seen by ATIC, even though with a flatter trend.

- The large array telescope HESS measured γ-rays up to 5 TeV. HESS's results do not confirm ATIC peak as well as the sharp fall around 800 GeV, but a suitable HESS data normalization leaves a room for an agreement with ATIC results within the uncertainties.

Several interpretations came out invoking different sources: from those purely astrophysical like nearby pulsars or SNR to more exotic such as DM annihilation or decay in the halo of our Galaxy, arising from annihilation or decay of DM particles. Presently we are not able to say which interpretation assumes more validity. Nearby pulsars have been proposed as accelerating mechanism of energetic particles to explain the observed positron excess. Primary electrons should be accelerated in the pulsar magnetosphere, emitting gamma rays by synchrotron radiation. In the high magnetic fields of the pulsar, such gammas induce and electromagnetic cascade. The electron-positron pairs are then accelerated and confined in the pulsar nebula before escaping into the interstellar medium, so enhancing the CR electron and positron components. The energy spectrum of such particles is expected to be harder than that of the positrons of secondary production , thus the positrons originated by pulsars may dominate the high energy end of the CR positron spectrum. Two nearby pulsars could enhance significantly the high energy electron and positron flux reaching the Earth: Monogem at a distance of 290 pc and Geminga at a distance of 160 pc. This because electrons and positrons, during their propagation loose energy mainly by inverse Compton scattering and synchrotron radiation so only sources at distance less than 1 kpc can give a significant contribute to the energy spectrum. The interpretation of the FERMI, PAMELA and HESS excesses in terms of DM signature is quite suggestive but encounters some difficulties arising from the PAMELA data which show an asymmetry between the hadronic (antiprotons) and leptonic (positrons) component.

A first source of disappointment for the neutralino devotees is, in this case, due to the fact that, assuming the usual local DM density $\rho = 0.3 GeV/cm^3$, the annihilation cross section needed to explain the signal is about $\sigma v \simeq 1 \times 10^{-24} cm^3 s^{-1}$, while the value $\sigma v \simeq 3 \times 10^{-26} cm^3 s^{-1}$, is needed in the early universe for a thermal WIMP in order to provide the correct relic abundance.

In conclusion, it seems that we are on the track to find evidences for DM but no *experimentum crucis* has given final probes. A main challenge comes from cosmology since it seems that DM behaves in different ways depending on the astrophysical structures and cosmological scales. For example, DM dynamics is very different in the various self-gravitating systems as elliptical, spiral and dwarf galaxies. Besides, it seems that different DM components have to be considered to address local systems (galaxies) and large scale structures (clusters of galaxies and super clusters of galaxies). An alternative view, could be that the problem of missing matter does not require the introduction of new ingredient but a modification or an extension of GR. The point is that gravity could not work in the same way at any scale. This issue will be faced in the next section.

V. AN ALTERNATIVE VIEW

Both cosmic speed up (DE) and DM, instead of being related to the search of new ingredients, could be the signal of a breakdown in our understanding of the laws of gravitation at large (infra-red) scales. From this point of view, one should consider the possibility that the Hilbert - Einstein Lagrangian, on which GR relies and linear in the Ricci scalar R, should be generalized. Following this approach, the choice of the effective theory of gravity could be derived by means of the data and the "economic" requirement that no exotic ingredients have to be added. This is the underlying philosophy of what is referred to as Extended Theories of Gravity consisting in enlarging the geometric sector of GR and assuming the possibility that other curvature invariants could contribute to the dynamics [Capozziello & Faraoni 2010, Capozziello & De Laurentis 2011]. From a theoretical standpoint, several issues from fundamental physics (quantum field theory on curved spacetimes, M-theory etc.) suggest that higher order terms must necessarily enter the gravity Lagrangian. On the other side, Solar System experiments show the validity of Einstein's theory at local scales so the problems could come out at galactic scales and beyond. The simplest extension of Einstein theory is the possibility to take into account actions of the form $f(R)$ where f is a function of the Ricci scalar R not necessarily linear in R as in the Hilbert case. This kind of theories have recently received much attention in cosmology, since they are naturally able to give rise to accelerating expansions (both in the late and the early Universe). However, it is possible to demonstrate that $f(R)$ theories can also play a major role at astrophysical scales [Capozziello & Faraoni 2010]. In fact, modifying the gravitational Lagrangian can affect the gravitational potential in the low energy limit, provided that the modified potential reduces to the Newtonian one at the Solar System scales. In fact, a corrected gravitational potential could offer the possibility to fit galaxy rotation curves without the need of DM. In addition, one could work out a formal analogy between the corrections to the Newtonian potential and the usually adopted DM models. The choice of an analytic function in term of Ricci scalar is physically corroborated by the Ostrogradski theorem, which states that this kind of Lagrangian is the only viable one which can be considered among the several that can be constructed by means of curvature tensor and possibly its covariant derivatives. The field equations of this approach can be recast in the Einstein form, that is:

$$G_{\alpha\beta} = R_{\alpha\beta} - \frac{1}{2} g_{\alpha\beta} R = T^{curv}_{\alpha\beta} + T^{M}_{\alpha\beta}/f'(R) \tag{5}$$

where the prime denotes derivative with respect to R, $T^{M}_{\alpha\beta}$ is the standard matter stress - energy tensor and

$$T^{curv}_{\alpha\beta} = \frac{1}{f'(R)}\left\{\frac{1}{2}g_{\alpha\beta}\left[f(R) - Rf'(R)\right] + f'(R)^{;\mu\nu}(g_{\alpha\mu}g_{\beta\nu} - g_{\alpha\beta}g_{\mu\nu})\right\}, \tag{6}$$

defines a *curvature stress - energy tensor*. The presence of the terms $f'(R)_{;\mu\nu}$ renders the equations of fourth order, while, for $f(R) = R$, Eqs.(5) reduce to the standard second - order Einstein field equations. As it is clear from Eq.(5), the curvature stress - energy tensor formally plays the role of a further source term in the field equations which effect is the same as that of an effective fluid of purely geometrical origin. Depending on the scales, it is such a curvature fluid which can play the role of DM and DE. From the cosmological viewpoint, in the standard framework of a spatially flat homogeneous and isotropic Universe, the cosmological dynamics is determined by its energy budget through the Friedmann equations. In particular, the cosmic acceleration is achieved when the r.h.s. of the acceleration equation remains positive. In physical units, we have $\ddot{a}/a = -(1/6)(\rho_{tot} + 3p_{tot})$, where a is the cosmic scale factor, $H = \dot{a}/a$ the Hubble parameter, the dot denotes derivative with respect to cosmic time, and the subscript *tot* denotes the sum of the curvature fluid and the matter contribution to the energy density and pressure. From the above relation, the acceleration condition, for a dust dominated model, leads to: $\rho_{curv} + \rho_M + 3p_{curv} < 0 \rightarrow w_{curv} < -\frac{\rho_{tot}}{3\rho_{curv}}$ so that a key role is played by the effective quantities:

$$\rho_{curv} = \frac{1}{f'(R)}\left\{\frac{1}{2}\left[f(R) - Rf'(R)\right] - 3H\dot{R}f''(R)\right\} , \tag{7}$$

$$w_{curv} = -1 + \frac{\ddot{R}f''(R) + \dot{R}\left[\dot{R}f'''(R) - Hf''(R)\right]}{\left[f(R) - Rf'(R)\right]/2 - 3H\dot{R}f''(R)} . \tag{8}$$

As a direct simplest choice, one may assume a power - law form $f(R) = f_0 R^n$, with n a real number, which represents a straightforward generalization of the Einstein General Relativity in the limit $n = 1$. One can find power - law solutions for $a(t)$ providing a satisfactory fit to the SNeIa data and a good agreement with the estimated age of the Universe in the range $1.366 < n < 1.376$ [Capozziello & Faraoni 2010]. It is worth noticing, that even an inverse approach for the choice of $f(R)$ is in order. Cosmological equations derived from (5) can be reduced to a linear third order differential equation for the function $f(R(z))$, where z is the redshift. The Hubble parameter $H(z)$ inferred from the data and the relation between z and R can be used to finally work out $f(R)$. In addition, one may consider the expression for $H(z)$ in a given DE model as the input for the above reconstruction of $f(R)$ and thus work out a $f(R)$ theory giving rise to the same dynamics as the input model. This suggests the intriguing possibility to consider observationally viable DM models (such as ΛCDM and quintessence) only as effective parameterizations of the curvature fluid [Capozziello et al. 2008].

The successful results obtained at cosmological scales motivates the investigation of $f(R)$ theories even at astrophysical scales. In the low energy limit, higher order gravity implies a modified gravitational potential. Now, by considering the case of a pointlike mass m and solving the vacuum field equations for a Schwarzschild - like metric, one gets from a theory $f(R) = f_0 R^n$ the modified gravitational potential:

$$\Phi(r) = -\frac{Gm}{r}\left[1 + \left(\frac{r}{r_c}\right)^{\beta}\right] \tag{9}$$

where

$$\beta = \frac{12n^2 - 7n - 1 - \sqrt{36n^4 + 12n^3 - 83n^2 + 50n + 1}}{6n^2 + 4n - 2} \tag{10}$$

which corrects the ordinary Newtonian potential by a power - law term. In particular, this correction sets in on scales larger than r_c which value depends essentially on the mass of the system. The corrected potential (9) reduces to the standard $\Phi \propto 1/r$ for $n = 1$ as it can be seen from the relation (10). The generalization of Eq.(9) to extended systems is straightforward. We simply divide the system in infinitesimal mass elements and sum up the potentials generated by each single element. In the continuum limit, we replace the sum with an integral over the mass density of the system taking care of eventual symmetries of the mass distribution. Once the gravitational potential has been computed, one may evaluate the rotation curve $v_c^2(r)$ and compare it with the data. For the pointlike case we have:

$$v_c^2(r) = \frac{Gm}{r}\left[1 + (1-\beta)\left(\frac{r}{r_c}\right)^{\beta}\right] . \tag{11}$$

Table II. Best fit values of the model parameters from maximizing the joint likelihood function $\mathcal{L}(\beta, \log r_c, f_g)$. We also report the value of $\Upsilon_\star$, the χ^2/dof for the best fit parameters (with $dof = N-3$ and N the number of datapoints) and the root mean square σ_{rms} of the fit residuals. See also Fig.3 [Capozziello et al. 2007].

Id	β	$\log r_c$	f_g	$\Upsilon_\star$	χ^2/dof	σ_{rms}
UGC 1230	0.608	-0.24	0.26	7.78	3.24/8	0.54
UGC 1281	0.485	-2.46	0.57	0.88	3.98/21	0.41
UGC 3137	0.572	-1.97	0.77	5.54	49.4/26	1.31
UGC 3371	0.588	-1.74	0.49	2.44	0.97/15	0.23
UGC 4173	0.532	-0.17	0.49	5.01	0.07/10	0.07
UGC 4325	0.588	-3.04	0.75	0.37	0.20/13	0.11
NGC 2366	0.532	0.99	0.32	6.67	30.6/25	1.04
IC 2233	0.807	-1.68	0.62	1.38	16.29/22	0.81
NGC 3274	0.519	-2.65	0.72	1.12	19.62/20	0.92
NGC 4395	0.578	0.35	0.17	6.17	34.81/52	0.80
NGC 4455	0.775	-2.04	0.88	0.29	3.71/17	0.43
NGC 5023	0.714	-2.34	0.61	0.72	13.06/30	0.63
DDO 185	0.674	-2.37	0.90	0.21	6.04/5	0.87
DDO 189	0.526	-1.87	0.69	3.14	0.47/8	0.21
UGC 10310	0.608	-1.61	0.65	1.04	3.93/13	0.50

Compared with the Newtonian result $v_c^2 = Gm/r$, the corrected rotation curve is modified by the addition of the second term in the r.h.s. of Eq.(11). For $0 < \beta < 1$, the corrected rotation curve is higher than the Newtonian one. Since measurements of spiral galaxies rotation curves signals a circular velocity higher than what is predicted on the basis of the observed luminous mass and the Newtonian potential, the above result suggests the possibility that our modified gravitational potential may fill the gap between theory and observations without the need of additional DM. It is worth noting that the corrected rotation curve is asymptotically vanishing as in the Newtonian case, while it is usually claimed that observed rotation curves are flat. Actually, observations do not probe v_c up to infinity, but only show that the rotation curve is flat within the measurement uncertainties up to the last measured point. This fact by no way excludes the possibility that v_c goes to zero at infinity. In order to observationally check the above result, we have considered a sample of LSB galaxies with well measured HI + Hα rotation curves extending far beyond the visible edge of the system. LSB galaxies are known to be ideal candidates to test DM models since, because of their high gas content, the rotation curves can be well measured and corrected for possible systematic errors by comparing 21 - cm HI line emission with optical Hα and [NII] data. Moreover, they are supposed to be DM dominated so that fitting their rotation curves without this elusive component is a strong evidence in favour of any successful alternative theory of gravity. Our sample contains 15 LSB galaxies with data on both the rotation curve, the surface mass density of the gas component and R - band disk photometry extracted from a larger sample selected by [de Blok & Bosma 2002]. We assume the stars are distributed in an infinitely thin and circularly symmetric disk with surface density $\Sigma(R) = \Upsilon_\star I_0 exp(-R/R_d)$ where the central surface luminosity I_0 and the disk scalelength R_d are obtained from fitting to the stellar photometry. The gas surface density has been obtained by interpolating the data over the range probed by HI measurements and extrapolated outside this range.

When fitting to the theoretical rotation curve, there are three quantities to be determined, namely the stellar mass - to - light (M/L) ratio, $\Upsilon_\star$ and the theory parameters (β, r_c). It is worth stressing that, while fit results for different galaxies should give the same β, r_c must be set on a galaxy - by - galaxy basis. However, it is expected that galaxies having similar properties in terms of mass distribution have similar values of r_c so that the scatter in r_c must reflect somewhat that on the terminal circular velocities. In order to match the model with the data, we perform a likelihood analyzis determining for each galaxy using as fitting parameters β, $\log r_c$ (with r_c in kpc) and the gas mass fraction[2] f_g. Considering the results summarized in Table II, the experimental data are successfully fitted by the model. In particular, for the best fit range of β ($\beta = 0.58 \pm 0.15$), one can conclude that R^n gravity with $1.34 < n < 2.41$ (which well overlaps the above mentioned range of n interesting in cosmology) can be a good candidate to solve the missing matter problem in LSB galaxies without any DM [Capozziello et al. 2007]. At this point, it is worth wondering

[2] This is related to the M/L ratio as $\Upsilon_\star = [(1-f_g)M_g]/(f_g L_d)$ with $M_g = 1.4 M_{HI}$ the gas (HI + He) mass, $M_d = \Upsilon_\star L_d$ and $L_d = 2\pi I_0 R_d^2$ the disk total mass and luminosity.

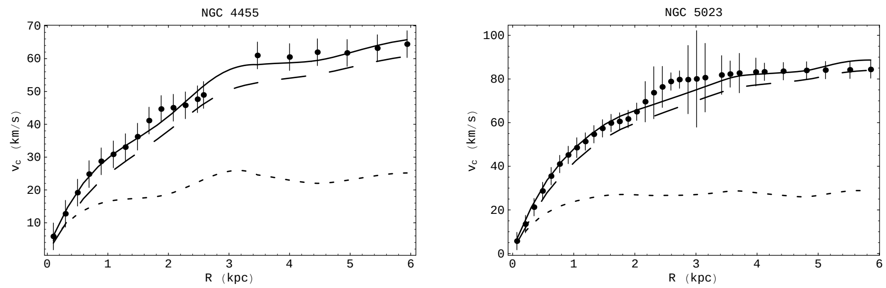

Figure 3. Best fit theoretical rotation curve superimposed to the data for the LSB galaxy NGC 4455 (left) and NGC 5023 (right). To better show the effect of the correction to the Newtonian gravitational potential, we report the total rotation curve $v_c(R)$ (solid line), the Newtonian one (short dashed) and the corrected term (long dashed).

whether a link may be found between R^n gravity and the standard approach based on dark matter haloes since both theories fit equally well the same data. As a matter of fact, it is possible to define an *effective DM halo* by imposing that its rotation curve equals the correction term to the Newtonian curve induced by R^n gravity. Mathematically, one can split the total rotation curve derived from R^n gravity as $v_c^2(r) = v_{c,N}^2(r) + v_{c,corr}^2(r)$ where the second term is the correction one. Considering, for simplicity a spherical halo embedding an infinitely thin exponential disk, we may also write the total rotation curve as $v_c^2(r) = v_{c,disk}^2(r) + v_{c,DM}^2(r)$ with $v_{c,disk}^2(r)$ the Newtonian disk rotation curve and $v_{c,DM}^2(r) = GM_{DM}(r)/r$ the DM one, $M_{DM}(r)$ being its mass distribution. Equating the two expressions, we get :

$$M_{DM}(\eta) = 2^{\beta-5}\eta_c^{-\beta}\pi(1-\beta)\Sigma_0 R_d^2 \eta^{\frac{\beta+1}{2}} \mathcal{I}_0(\eta,\beta) \ . \tag{12}$$

with $\eta = r/R_d$, $\Sigma_0 = \Upsilon_\star I_0$ and :

$$\mathcal{I}_0(\eta,\beta) = \int_0^\infty \mathcal{F}_0(\eta,\eta',\beta) k^{3-\beta} \eta'^{\frac{\beta-1}{2}} \mathrm{e}^{-\eta'} d\eta' \tag{13}$$

with $\mathcal{F}_0$ only depending on the geometry of the system. Eq.(12) defines the mass profile of an effective spherically symmetric DM halo whose ordinary rotation curve provides the part of the corrected disk rotation curve due to the addition of the curvature corrective term to the gravitational potential. It is evident that, from an observational viewpoint, there is no way to discriminate between this dark halo model and R^n gravity. Having assumed spherical symmetry for the mass distribution, it is immediate to compute the mass density for the effective dark halo as $\rho_{DM}(r) = (1/4\pi r^2) dM_{DM}/dr$. The most interesting features of the density profile are its asymptotic behaviours that may be quantified by the logarithmic slope $\alpha_{DM} = d\ln\rho_{DM}/d\ln r$ which can be computed only numerically as function of η for fixed values of β (or n). The asymptotic values at the center and at infinity denoted as α_0 and α_∞ result particularly interesting. It turns out that α_0 almost vanishes so that in the innermost regions the density is approximately constant. Indeed, $\alpha_0 = 0$ is the value corresponding to models having an inner core such as the cored isothermal sphere and the Burkert model [Burkert 1995]. Moreover, it is well known that galactic rotation curves are typically best fitted by cored dark halo models [Gentile & Salucci 2004]. On the other hand, the outer asymptotic slope is between -3 and -2, that are values typical of most dark halo models in literature. In particular, for $\beta = 0.58$ one finds $(\alpha_0, \alpha_\infty) = (-0.002, -2.41)$, which are quite similar to the value for the Burkert model $(0, -3)$, that has been empirically proposed to provide a good fit to the LSB and dwarf galaxies rotation curves. The values of $(\alpha_0, \alpha_\infty)$ we find for our best fit effective dark halo therefore suggest a possible theoretical motivation for the Burkert-like models. Now, due to the construction, the properties of the effective DM halo are closely related to the disk one. As such, we do expect some correlation between the dark halo and the disk parameters. To this aim, exploiting the relation between the virial mass and the disk parameters , one can obtain a relation for the Newtonian virial velocity $V_{vir} = GM_{vir}/R_{vir}$:

$$M_d = \frac{(3/4\pi\delta_{th}\Omega_m\rho_{crit})^{\frac{1-\beta}{4}} R_d^{\frac{1+\beta}{2}} \eta_c^\beta}{2^{\beta-6}(1-\beta)G^{\frac{5-\beta}{4}}} \frac{V_{vir}^{\frac{5-\beta}{2}}}{\mathcal{I}_0(V_{vir},\beta)} \ . \tag{14}$$

We have numerically checked that Eq.(14) may be well approximated as $M_d \propto V_{vir}^a$ which has the same formal structure as the baryonic Tully-Fisher (BTF) relation $M_b \propto V_{flat}^a$ with M_b the total (gas + stars) baryonic mass and V_{flat} the

circular velocity on the flat part of the observed rotation curve. In order to test whether the BTF can be explained thanks to the effective DM halo we are proposing, we should look for a relation between V_{vir} and V_{flat}. This is not analytically possible since the estimate of V_{flat} depends on the peculiarities of the observed rotation curve such as how far it extends and the uncertainties on the outermost points. For given values of the disk parameters, we therefore simulate theoretical rotation curves for some values of r_c and measure V_{flat} finally choosing the fiducial value for r_c that gives a value of V_{flat} as similar as possible to the measured one. Inserting the relation thus found between V_{flat} and V_{vir} into Eq.(14) and averaging over different simulations, we finally get : $\log M_b = (2.88 \pm 0.04) \log V_{flat} + (4.14 \pm 0.09)$ while observational data give : $\log M_b = (2.98 \pm 0.29) \log V_{flat} + (3.37 \pm 0.13)$. The slope of the predicted and observed BTF are in good agreement thus leading further support to our approach. The zeropoint is markedly different with the predicted one being significantly larger than the observed one, but it is worth stressing, however, that both relations fit the data with similar scatter. A discrepancy in the zeropoint may be due to our approximate treatment of the effective halo which does not take into account the gas component. Neglecting this term, we should increase the effective halo mass and hence V_{vir} which affects the relation with V_{flat} leading to a higher than observed zeropoint. Indeed, the larger is M_g/M_d, the more the point deviate from our predicted BTF thus confirming our hypothesis. Given this caveat, we may therefore conclude with confidence that R^n gravity offers a theoretical foundation even for the empirically found BTF relation.
These results are referred to a simple choice of $f(R)$, while it is likely that a more complicated Lagrangian is needed to reproduce the whole dark sector phenomenology at all scales. Nevertheless, although not definitive, these achievements represent an intriguing matter for future more exhaustive investigations. In particular, exploiting such models can reveal a useful approach to motivate a more careful search for a single fundamental theory of gravity able to explain the full cosmic dynamics with the only two ingredients we can directly experience, namely the background gravity and the baryonic matter [S. Capozziello et al. 2006].

VI. CONCLUSIONS

DM and DE can be considered among the biggest puzzles of modern physics. While their effects are evident from galactic to cosmological scales, their detection, at fundamental level, is a cumbersome task that, up to now, has no definitive answer. From a macroscopic viewpoint, DM is related to the clustering of astrophysical structures and DE is an unclustered form of energy (e.g. the cosmological constant Λ) which should be the source of cosmic speed up, detected by SNeIa and other cosmological indicators in the Hubble flow. Following the standard approach in physics, such *missing matter problem* and *cosmic acceleration* should be related to some fundamental ingredient (e.g. particles). Specifically, such particles should be not electromagnetically interacting (and then they are "dark") and, a part a few percent of further baryons, should be out of SM. In the case of DE, instead, they should be scalar fields that do not give rise to clustered structures.

Essentially, the DM (and DE) problem consists of three issues: *i*) the existence, *ii*) the detection, *iii*) the possible alternatives. In this review paper, we have tried to summarize the status of art with no claim to completeness.

After a discussion of the need of DM to address astrophysical and cosmological dynamics, we have reviewed the possible candidates. as SUSY, WIMP and extra dimension particles. The big issue is the detection of such particles that can be faced in three ways.

The direct detection (e.g. of WIMPs) consists, essentially, in identifying a certain mass m_X from scattering processes. Several underground experiments (e.g. DAMA) are running or have to start with this purpose. The approach is that standard interacting particles have to be shielded by some layer of rocks so then the weak interacting particles could be identified.

Indirect searches look for the excesses of annihilation products that should be DM remnants. Such experiments, like PAMELA and FERMI, are based on spacecrafts and are devoted to reconstruct the signature of DM.

Finally, DM evidences could come from particle colliders like LHC or Tevatron. In this case, DM should result from high-energy colliding processes where particles out of SM should be produced.

A radically alternative view is that DM (and DE) do not exist at all. Missing matter problem and cosmic speed up could be addressed by revising and extending the gravitational sector. Specifically, Einstein's GR should be a theory working only at local scale that should be revised at infrared (large scale structure and cosmology) and ultraviolet regimes (quantum gravity).

In conclusion, it seems that DM problem will be open until incontrovertible evidences (signatures) will be available at fundamental level. Very likely, the today working space- and ground-based experiments are going to reach the requested energy and precision levels in order to confirm or rule out the DM issue.

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