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Massive hadronic candidates to dark matter

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A new family of equilibrium configurations for galactic halos is introduced, taking into account the possibility to identify strange particles conglomerates with masses larger than 8 GeV as components of the dark matter. This possibility may have important consequences on the formation of massive particles during the Big Bang in the framework of the Standard Model. The obtained results are in agreement with the values in mass and radius requested to be consistent with the rotational velocity curve observed in our Galaxy. In addition, the average density of such strange dark matter halos is similar to one for halos of dwarf spheroidal galaxies, suggesting a common origin of the two families of cosmic structures.

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1. Introduction

Dark matter (DM) is one of the current challenges for modern astrophysics. The hypothesis of his existence was initially introduced in order to explain the big difference between the virial and visible mass in several clusters of galaxies [1], but DM is also required as a fundamental component ($\sim 30\%$; see e.g. [2] and references therein) of the Universe's energy content. Several efforts have been made in order to identify plausible DM candidates, in particular on the side of elementary particles (see e.g. [3] for a review), however, without any direct hint about DM physics, the parameter space covered by the families of plausible DM candidates extends over many orders of magnitude of masses.

The possibility that DM is composed by conglomerate of matter with strange quark content is also challenging. The properties and the stability of strange quark matter (SQM) are still debated in literature. Nevertheless favourable conditions for the formation of such conglomerates could be achieved in the early Universe after the Big Bang. Despite the problem of the stability with respect to the strong, weak and electromagnetic interactions is an open problem, it is worth investigating the gravitational properties of galactic halos composed by SQM conglomerates, not explored so far.

Here, we analyze the the gravitational properties of SQM galactic halos in Milky Way-sized spiral galaxies. Conglomerates of SQM with mass larger than about 8 GeV are considered as components of the DM. The validity of the obtained results, depending only on the mass of DM components, is not affected by the nature of conglomerates.

We then compare the average properties of halos with the corresponding quantities derived from recent *Fermi-LAT* observations at 3σ confidence level of γ-rays from the dwarf spheroidal galaxy (dSph) Reticulum II (RetII; [4]), under the assumption that the γ-ray emission is due to DM self-interaction.

Finally we extend the analysis to other nine dSphs in order to compare the obtained results.

2. Massive particles as dark matter candidates

Besides the most commonly investigated dark matter candidates (e.g. Weakly-Interacting Massive Particles (WIMPs), or axions), for which no compelling observational or experimental evidence still exists, nor any proved beyond-the-Standard-Model production mechanism, other dark matter candidates were theorized (ranging from heavy stable particles to new states of matter) including ones which might arise within in the Standard Model.

The stability of SQM conglomerates, containing roughly the same numbers of u, d and s quarks, was conjectured long time ago (see e.g. [5, 6]). It is argued that, despite the big mass of the s quark, compared to the u and d quarks, this is smaller than the chemical potential due to the Pauli exclusion principle in bulk quark matter, making such a mixture energetically favoured. The only way for standard baryonic matter to make the transition to an SQM phase would be u and d quarks conversions into s quarks via weak interactions, stabilized by the chemical potential release. Such a process is astronomically disadvantaged. The SQM lumps formation could have found favourable conditions in the early Universe. In particular, if the Quantum Chromodynamics (QCD) phase transition is first order, the dynamics of bubble nucleation are such that quark matter

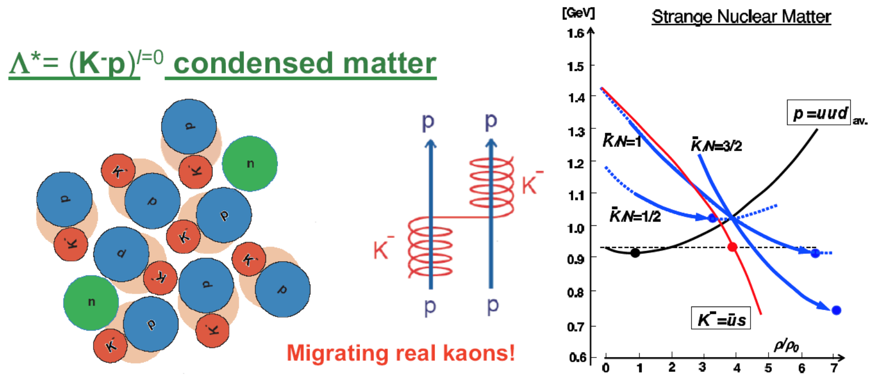

Figure 1: *Left:* speculated $K^-p = \Lambda^*$ matter with a quasi-Λ^* as an *atomic* constituent, where K^- migrate among protons, producing high-density kaonic matter. *Right:* speculated diagrams for the density dependency of the bound-state energies of various nuclear composite systems $(pK^-)^m n^n$. Both the $\bar{K}N$ energy (*red curve*) and the nuclear compression (*black curve*) are shown. The total energies for representative fractions of K^-/N $(= 1/2, 1, 3/2)$ are depicted by respective blue curves, showing minima at high density and low energy. Density-dependent enhanced $\bar{K}N$ interactions are assumed (figure and caption by Akaishi & Yamazaki [8]).

lumps would form at that stage and shrink and cool, moving on the Equation-of-State diagram from a high temperature to a zero temperature, high chemical potential configuration.

In [7] it is argued that stable lumps of matter with strange quark content could be obtained with the $\Lambda(1405)$ resonance, also indicated as Λ^*, through the introduction of $\Lambda(1405)$ conglomerates, whose formation may be conceived during the Big-Bang Quark Gluon Plasma (QGP) period in the early universe. The argument exposed is based on the attractive isospin $I = 0$ antikaon-nucleon ($\bar{\mathrm{K}}$N) strong interaction at energies below the $\bar{\mathrm{K}}$N mass threshold, which appears to be strong enough to form a $\bar{\mathrm{K}}$N bound state. For Λ^* conglomerates with baryon multiplicity $A > 8$, the absolute stability with respect to both the strong and the weak interactions is obtained. This condition reflects on the lower mass of stable conglomerates which can be expressed by the relation [7]

$$m^* \equiv m\,[(\Lambda^*)_A]\,c^2 \sim A \cdot 1405_{[MeV]} + \frac{A(A-1)}{2}\langle \Delta U \rangle_{av} \,, \tag{2.1}$$

where $\langle \Delta U \rangle_{av} = -135$ MeV. For $A > 8$, this implies that $m^* > 7.46$ GeV.

While the baryon density of the conglomerate increases, the mass per baryon decreases until it drops below the in-medium mass of the nucleon and the decay $\Lambda^* \to n$ is closed. This happens at baryon densities of about $3\rho_0$, where $\rho_0 = 0.17\,\mathrm{fm}^{-3}$ is the normal nuclear density (see Fig. 1).

Although the large densities in the central regions of the neutron stars may suggest the production of processes $\bar{K}^0 n \to K^- p$ for the formation of hyperon cores, due to the value of the required critical density (of the order of $10^{19}\,\mathrm{g\,cm}^{-3}$), we stress that this hypothesis could be more favourable in the cosmological field, where the possibility to have arbitrarily high values of density and temperature are not precluded. In this framework, the formation of ultra-dense kaonic nuclear states as a partial constituent of DM could be considered more realistic. We can thus hypothesize that during the first phase of the Big Bang, at sufficiently high density (and temperature), the conditions for the formation of stable conglomerates could be set. Since then, such conglomerates - with a mass m^* ranging around $8 \div 15$ GeV - should be a very low probability to interact with baryonic matter.

Besides the problem of the stability of SQM conglomerates with respect to the strong, weak and electromagnetic interactions, is currently debated in literature [9], it is worth investigating the gravitational stability of SQM halos in Milky Way-size spiral galaxies. We then explore the gravitational stability of halos composed of SQM conglomerates, considering the lower mass limit $m^* > 7.46$ GeV for the DM candidate. It is important to stress that the results we shall obtain are not dependent on the nature of the DM particle and can be applied also to other DM candidates having mass of the same order of magnitude.

3. The Milky Way halo modelling

Analyzing the rotation velocity curve by observative data, a flat behavior around 200 km/s is clearly shown, evidencing a significant difference from the expected theoric trend. The existence of a Galactic halo composed by DM, like the one first introduced by [1], can explain the observative behavior. More accurate observations have been performed and the flat behavior has been confirmed (see Fig. 2), resulting in agreement with the existence of a halo of mass $M_{halo} \sim 10 M_{gal}$ and radius $R_{halo} \sim 10 R_{gal}$.

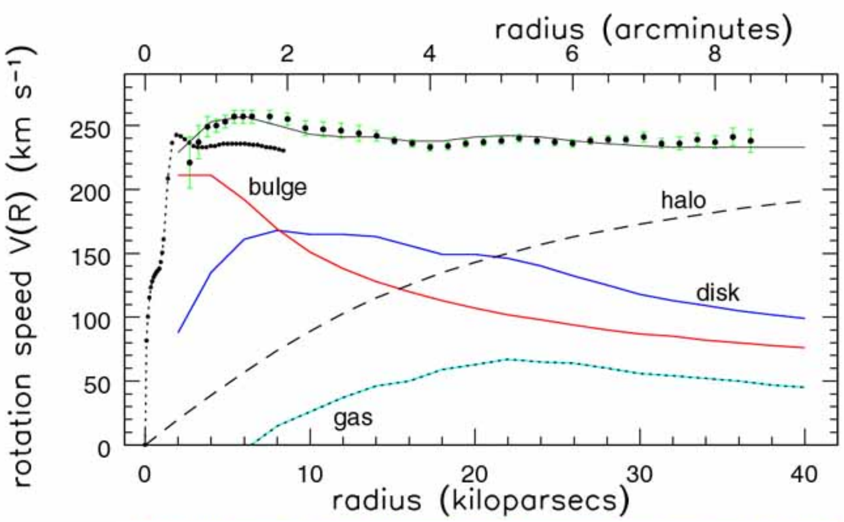

Figure 2: Different components in our Galaxy (spiral) and contribution to the rotation curve (figure by K. Begeman & Y. Sofue in [10]).

The question about the nature of the DM and the particle composition of halos was widely discussed since 1970s, and the construction of DM halos models has experienced a significant development, with the hypothesis of a massive neutrino (with a mass of the order of few tens of eV), generically named weakly-interacting massive particle (WIMP), as a diffuse component, due to the importance of beta decay in the stellar evolution (e.g. [11, 12, 13]).

The equilibrium of such a self-gravitating halo can be solved by considering a degenerate Fermi gas of neutrinos, and using a polytropic model with $n = 3/2$. The halo mass and radius are straightforward to obtain, their expressions given by

$$M = \frac{3}{2}\left(\frac{\pi}{2}\right)^{3/2}(2.71406)\,\frac{\hbar^3}{G^{3/2}m_\nu^4}\,\rho_0^{1/2}, \tag{3.1}$$

$$R = \frac{(9\pi)^{1/6}}{2\sqrt{2}}(3.65375)\,\frac{\hbar}{G^{1/2}m_\nu^{4/3}}\,\rho_0^{-1/6}, \tag{3.2}$$

where m_ν is the neutrino rest mass and ρ_0 the central density. Introducing the above conditions $M_{halo} \sim 10\,M_{gal}$ and $R_{halo} \sim 10\,R_{gal}$ implies a central density $\rho_0 \sim 10^{-25}\,\mathrm{g\,cm^{-3}}$ for a neutrino rest mass $m_\nu \sim 10\,\mathrm{eV}$. Moreover, combining Eqs. (3.1) and (3.2) leads to a simple relation between mass and radius of our Galaxy

$$R \simeq 90\left(\frac{M}{10^{12}M_\odot}\right)^{-1/3}\mathrm{kpc}\ . \tag{3.3}$$

A non-relativistic treatment of the halo equilibrium is clearly the most appropriate given that both the critical density ρ_{cr} and the general relativity factor GM/Rc^2 are small, i.e.

$$\rho_{cr} = \frac{m_\nu^4 c^3}{3\pi^2\hbar^3} = 7.8\cdot 10^{-17}\ \mathrm{g\ cm^{-3}} \gg \rho_0 \tag{3.4}$$

and

$$\frac{GM}{Rc^2} = 4.8\cdot 10^{-7} \ll 1\ . \tag{3.5}$$

4. Strange massive particles as component of dark matter halos

The WIMP hypothesis is not unique in the framework of possible dark matter particle candidates. There are in fact a lot more candidates (fuzzy DM, hidden photons, ultra-light axions...) discussed in the literature (e.g. [3]), with m_{DM} in principle anywhere between 10^{-31} GeV and 10^{18} GeV.

Furthermore, the possibility to have non-WIMP DM canditates can be taken into account. This alternative and fascinating hypothesis involves strange massive particles (SMP) directly produced in the framework of the Big Bang standard model. Such a scenario arises by the simple consideration that the interaction rate between baryons and DM particles may be suppressed if DM particles are produced with large mass and consequently low number density. In fact, this rate is proportional to $n\sigma v$, with n the number density, σ the cross section and v the particle velocity. Therefore, DM particles with low effective interaction rate (even for large cross sections) should evolve independently as massive Big-Bang relics, constituting a useful background in the formation of galactic halos. Among different possible candidates for DM, particles with strangeness may play a very interesting role, in particular, the SQM conglomerates discussed in Section II, with masses ranging around $8 \div 15$ GeV. These Big Bang relics particles could form galactic halos.

This scenario must clearly be considered as only a possible hypothesis of formation of DM, and its further investigation is needed, especially from the quantitative point of view. One of the

PoS(MULTIF2019)011

problems is related to the expansion rate of the Universe: if cooling rate and decrease of density are in fact faster than the stabilization rate of conglomerates, the process is not implemented. Another problem is connected with the collisions among conglomerates: fluctuations of density with respect to the average value may increase the collision rate and thus create the conditions for instability of such systems. These particular conditions can also be reached in the central regions of a single galactic halo, if the central density of visible matter (galaxy) and the gravitational field are high enough to increase the probability of collision among conglomerates. During the collisions, kinetic energy can give the particles of a single conglomerate enough energy to reach a new instability, and then decay in standard model pairs that subsequently annihilate in γ-ray photons. Therefore, it is important to look into high-density regions, where the collisions are more probable, in order to obtain evidences of DM existence through the indirect detection of gamma rays from DM self-interaction.

In order to calculate self-gravitating equilibrium configurations of DM halos, we now explore the possibility of having halos composed by stable SQM conglomerates. Despite we expect a high density $\rho > 10^{15}\,\mathrm{g\,cm^{-3}}$ in the internal structure of the conglomerate, it is not relevant for our purposes. Therefore, we consider the single conglomerate like a massive particle of mass m^* interacting only gravitationally with the other conglomerates composing the halo.

First, we consider a semi-degenerate gas of conglomerates with a rest mass $m^* = 8 \div 15\,\mathrm{GeV}$. We look for halos with mass $M \sim 10^{12}\,M_\odot$ and radius $R \sim 100\,\mathrm{kpc}$, with a mean density $\bar{\rho}$ of the order of $10^{-26}\,\mathrm{g\,cm^{-3}}$. For $m^* = 10\,\mathrm{GeV}$ we obtain

$$\rho_{cr} = \frac{m^{*4}c^3}{3\pi^2\hbar^3} = 7.8\cdot 10^{19}\,\mathrm{g\,cm^{-3}} \gg \bar{\rho}\ , \tag{4.1}$$

and

$$\frac{GM}{Rc^2} = 4.8\cdot 10^{-7} \ll 1\ . \tag{4.2}$$

This indicates that also strange DM halos are non-relativistic and Newtonian.

For the equilibrium configuration, we consider a semi-degenerate Fermi distribution function with a cutoff in energy given by the following expression [14]

$$\begin{cases} f(\varepsilon) = \dfrac{g}{h^3}\left[\dfrac{1-e^{(\varepsilon-\varepsilon_c)/kT}}{e^{(\varepsilon-\mu)/kT}+1}\right] & \text{for } \varepsilon \le \varepsilon_c \\ f(\varepsilon) = 0 & \text{for } \varepsilon > \varepsilon_c\ , \end{cases} \tag{4.3}$$

where $\varepsilon_c = m(\varphi_R - \varphi)$ is the cutoff energy, φ is the gravitational potential, μ is the chemical potential and $g = 2s+1$ is the multiplicity of quantum states. For the gravitational equilibrium, we use the Poisson equation

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d\varphi}{dr}\right) = 4\pi G\rho \ \ \text{with} \ \ \varphi'(0) = 0;\ \varphi(0) = \varphi_0\ . \tag{4.4}$$

By integrating Eq. (4.4), we obtain different equilibrium configurations at different values of W_0 and θ_R, where W_0 is the value of $W = \varepsilon_c/kT$ at the center of the configuration and θ_R is the value of $\theta = \mu/kT$ at the border of the configuration. These quantities are related through the relation $\theta_R = \theta - W \le 0$ [15, 16]. The solutions also depend on m (mass of the particle) and σ (surface

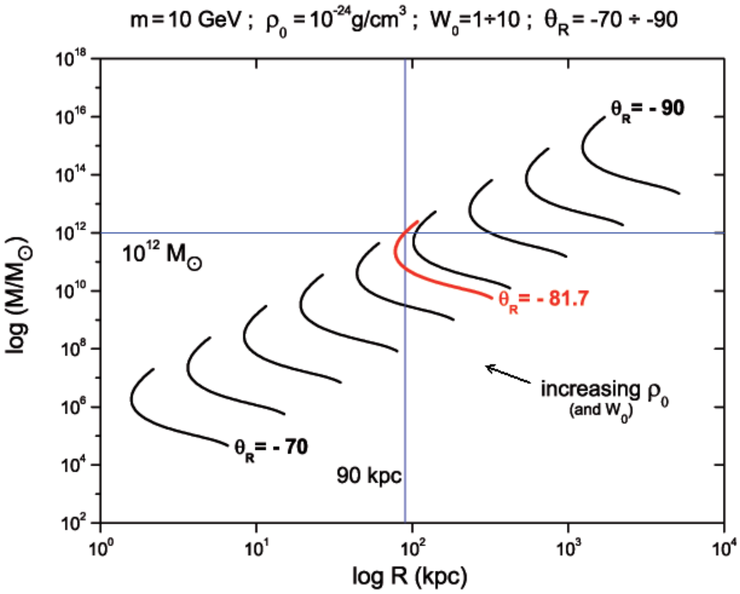

Figure 3: Individuation of the value of θ_R compatible with the requested values of mass and radius for spiral-galaxy halos. The position of a MW-sized halo (*blue axes*) is highlighted, along with the relevant value of θ_R (*red curve*).

velocity dispersion) through scaling laws. The results are summarized in diagrams of M versus ρ_0 and R versus ρ_0 for $m = 10\,\mathrm{GeV}$ and $\sigma = 400\,\mathrm{km\,s^{-1}}$.

It is clear that the particle mass value $m^* = 10\,\mathrm{GeV}$ does not allow to obtain the expected values of central density, mass and radius for a galactic halo. In fact, we have $\rho_0 \propto \sigma^3 m^4$, $M \propto \sigma^{3/2} m^{-2}$ and $R \propto \sigma^{-1/2} m^{-2}$. This results in too large densities, and too small masses and radii, implying that the semi-degenerate regime is not appropriate to describe strange DM halos. We need much more negative values of θ_R, typical of a classical regime well described by the Boltzmann (King) distribution function with cutoff in energy. Therefore, strange DM halos are non-relativistic, Newtonian and do not follow quantum statistics.

In order to obtain halos with appropriate densities, masses and radii, we calculate equilibrium configurations at fixed central density ($\rho_0 = 10^{-24}\,\mathrm{g\,cm^{-3}}$) and particle mass ($m^* = 10\,\mathrm{GeV}$), while increasing the value of $-\theta_R$ until we reach $M \sim 10^{12}\,M_\odot$ and $R \sim 100\,\mathrm{kpc}$ (see Fig. 3). We compute solutions in the range $W_0 = 1 \div 10$ (for globular clusters, the most significant values are between 4 and 8; for galactic halos we expect even less). In this regime, the dependence on θ_R becomes a scaling law. It is possible to make a tuning by varying the central density ρ_0 and the parameter θ_R in order to match the requested values in M and R, also at different values of W_0. The obtained results for $m^* = 10$ GeV and $\rho_0 = 10^{-24}\,\mathrm{g/cm^3}$ are very satisfying: we obtain $\theta_R = -81.7$ and $W_0 = 1.8$, implying a halo mass $M = 9.98 \cdot 10^{11}\,M_\odot$, a halo radius $R = 89.41\,\mathrm{kpc}$, a mean halo density $\bar{\rho} = 3M/4\pi R^3 = 2.16 \cdot 10^{-26}\,\mathrm{g\,cm^{-3}}$ and a velocity dispersion $\sigma_v = 405\,\mathrm{km\,s^{-1}}$. The other

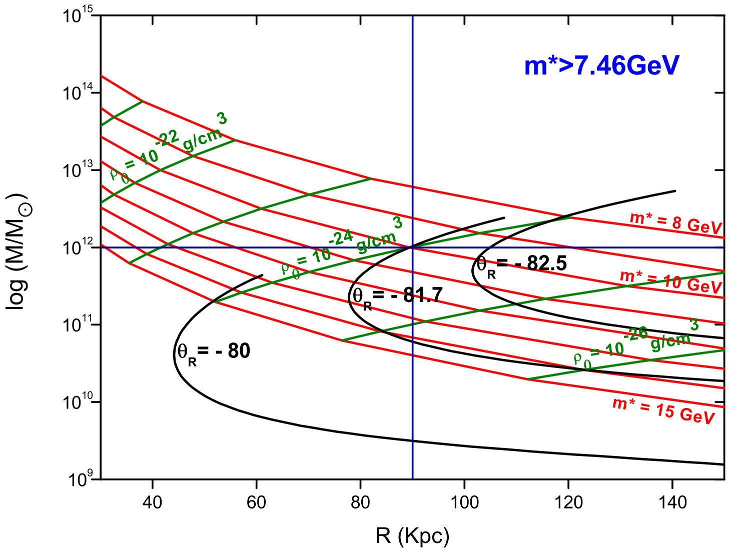

Figure 4: Solutions for MW-sized DM halos obtained through scaling laws between halo physical parameters and conglomerate masses. The relations between halo mass and size for different conglomerate masses (*red curves*), central DM densities (*green curves*) and concentration parameters (*black curves*) are plotted. The position of the MW-sized halo for $m^* = 10\,\mathrm{GeV}$ (*crossing of the blue axes*) is also marked.

solutions can be obtained from scaling laws involving the total mass M and the radius R. We obtain

$$M = 9.98 \cdot 10^{11} \left(\frac{\rho_0}{10^{-24}\,\mathrm{g\,cm^{-3}}} \right)^{-1/2} \left(\frac{m^*}{10\,\mathrm{GeV}} \right)^{-4} \mathrm{M}_\odot \,, \tag{4.5}$$

$$R = 89.41 \left(\frac{\rho_0}{10^{-24}\,\mathrm{g\,cm^{-3}}} \right)^{-1/6} \left(\frac{m^*}{10\,\mathrm{GeV}} \right)^{-4/3} \mathrm{kpc}\,. \tag{4.6}$$

These results are summarized in a visual way in Fig. 4.

5. Comparison with dwarf galaxy halo properties

The theoretical scenario presented in Section 4, though fascinating, is deeply related to the existence of unobserved strange conglomerates; furthermore, the derived physical parameters of the DM halo hold in principle only for MW-sized spiral galaxies. In this section, we show how the average density of a strange DM halo is (possibly) common also to halos of different size like those surrounding the dSphs, probably the most DM dominated objects in the local Universe, and that such halos can be obtained by scaling down the typical masses and radii for halos around normal galaxies. In order to do so, we derive the amount of DM in the dSph RetII by analyzing the kinematics of its member stars.

Discovered in 2015 by [17] in first-year Dark Energy Survey (DES) data, RetII is a faint MW satellite from which *Fermi-LAT* has detected an excess of gamma rays between ~ 3 and $\sim 10\,\mathrm{GeV}$ [4]. Such an excess is compatible with a flux coming from DM annihilation of particles with

$m_\chi \sim 25\,\mathrm{GeV}$ at 3σ confidence level. In the case of SQM conglomerates the mass increases with the baryon multiplicity A thus any value for the mass is allowed whether the stability conditions are fulfilled, in particular, in the model of [7] the stability is achieved for $A > 8$ which correspond to $m^* > 7.46\,\mathrm{GeV}$. Under this hypothesis, this signal can therefore be used to constrain the amount of DM in RetII, i.e. its astrophysical factor for DM annihilation J (e.g., [18]). We get

$$J = \int_{\Delta\Omega} d\Omega \int_{los} \rho^2(s,\Omega)\, ds \,. \tag{5.1}$$

Assuming an appropriate value for the velocity-averaged cross section of the annihilation process $\langle\sigma v\rangle \lesssim 2.2\cdot 10^{-26}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$ [19], one gets $J \gtrsim 4\cdot 10^{19}\ \mathrm{GeV}^2\,\mathrm{cm}^{-5}$ over a region of interest (ROI) of 0.5 deg around RetII center.

Since the astrophysical factor for DM annihilation is defined as the integral of the squared DM density in the ROI along the line of sight, one can derive the rms value ρ_{rms} of this density from the measurement of J. We obtain

$$J = \frac{\int_{\Delta\Omega} d\Omega \int_{los} \rho^2(s,\Omega) ds}{\int_{los} ds} \int_{los} ds = \langle\rho^2\rangle_{\Delta\Omega}\, D_\odot \,, \tag{5.2}$$

giving a mean density $\rho_{rms} = \sqrt{J/D_\odot}$. From Eq. (5.2), with $D_\odot = 30 \pm 2\,\mathrm{kpc}$ [17, 19] one obtains $\rho_{rms} = \left(3.7^{+8.4}_{-2.1}\right)\cdot 10^{-26}\,\mathrm{g\,cm}^{-3}$ as an estimate of the mean DM density of RetII halo, in excellent agreement with the theoretical value derived in Section 4 for MW-sized halos. One can argue that the belonging of RetII to the MW system naturally implies similar mean DM densities among gravitationally bound halos in (approximate) dynamical equilibrium; nonetheless, this is not necessarily true, if for instance the original distribution of DM halo parameters had implied very different scale densities for halos of different size.

A more reliable estimate of the DM halo parameters for RetII can be performed by repeating the Jeans analysis presented in [20], i.e. integrating the moments of the phase-space distribution function for a steady-state, spherically symmetric and negligibly rotating collisionless system to obtain the second-order Jeans equation [21]

$$\frac{1}{n(r)}\left[\frac{d}{dr}\left(n\bar{v}_r^2\right)\right] + 2\,\frac{\beta_{ani}(r)}{r}\,\bar{v}_r^2(r) = -\frac{4\pi G}{r^2}\int_0^r \rho_{DM}(s)\, s^2\, ds \,. \tag{5.3}$$

Here, $n(r)$, $\bar{v}_r^2(r)$ and $\beta_{ani}(r)$ are the stellar number density, velocity dispersion and velocity anisotropy respectively. For the case of dSphs, the solution to Eq. (5.3) relates the internal proper motions of stars to the amount of DM in the dSph halo, although only line-of-sight observables like the projected radius R, the surface brightness $\Sigma(R)$ and the projected stellar velocity dispersion $\sigma_p(R)$ can be used, namely

$$\sigma_p^2(R) = \frac{2}{\Sigma(R)}\int_R^{+\infty}\left[1 - \beta_{ani}(r)\left(\frac{R}{r}\right)^2\right]\frac{n(r)\,\bar{v}_r^2(r)}{\sqrt{r^2 - R^2}}\, dr \,. \tag{5.4}$$

In order to determine the parameters that best reproduce the observed properties of RetII, we run a simulation of $8\cdot 10^4$ MCMC points with the CLUMPY [1] software [22, 23] on the member

[1] Available at `https://lpsc.in2p3.fr/clumpy/`.

stars of RetII [24], according to the prescriptions listed in [25, 20] and assuming an Einasto profile [26] for the DM distribution

$$\rho(r) = \rho_s \, e^{-\frac{2}{\alpha}\left[(r/r_s)^{\alpha}-1\right]} \; . \tag{5.5}$$

The stellar number density $n(r)$ is preventively calculated by fitting a 3D Zhao-Hernquist profile [27, 28] to publicly available 2D photometric data of RetII [29], and the resulting parameters are used as a fixed input for CLUMPY. We take the stellar-kinematics data from [30], estimating the membership probability P_i of the i-th star with an estimation-of-membership (EM) algorithm [31] and keeping only stars for which $P_i \geq 0.95$. In doing so, we find that an astrophysical factor $\log J = 19.3^{+1.1}_{-0.7}$ at an integration angle of 0.5 deg, compatible at 1σ level with the upper limit estimated by [4], is obtained from the assumed DM density profile with

$$\begin{cases} \rho_s = \left(5.9^{+21.0}_{-4.8}\right) \cdot 10^7 \, \mathrm{M}_\odot \, \mathrm{kpc}^{-3} \\ r_s = 0.52^{+3.29}_{-0.50} \, \mathrm{kpc} \\ \alpha = 0.51^{+0.35}_{-0.26} \; . \end{cases} \tag{5.6}$$

For the purposes of calculating (i) the astrophysical factor for DM annihilation over a ROI of 0.5 deg diameter, and (ii) the average DM density in RetII halo, we integrate the DM density profile obtained from the MCMC run up to the tidal radius of the dSph halo. Using Eq. 18 of [20] we compute a value of 3.2 kpc for r_t. Thus, the mean DM density $\langle \rho_{DM} \rangle$ over the volume enclosed within r_t around the dSph center is given by

$$\langle \rho_{DM} \rangle = \frac{4\pi}{\mathscr{V}} \int_0^{r_t} \rho_{DM}(r) \, r^2 \, dr \; , \tag{5.7}$$

with $\mathscr{V} = 4\pi r_t^3/3$ (note that we are here neglecting any effect of a halo triaxiality; see e.g. [32]).

Using the parameters listed in Eq. (5.6), we get $\langle \rho_{DM} \rangle = \left(22.6^{+9.6}_{-2.4}\right) \cdot 10^{-26} \, \mathrm{g\,cm}^{-3}$. This value is a factor of ~ 6 larger than the estimate of ρ_{rms} obtained from J, and an order of magnitude larger than the value for MW-sized DM halos constructed with strange conglomerates; however, the impact of stellar feedback, triaxiality and tidal interactions on the dynamical status of dSph DM halos is still largely unknown, meaning that at least the RetII mean density is overestimated. Therefore, a difference of roughly an order of magnitude between the mean densities of MW-sized and dSph-sized halos is acceptable in this framework to stress anyway a common origin for the two families of galactic structures.

Similar calculations are made for other nine dSph-sized halos, showing very interesting results. The fact that different halos associated to morphologically very different galaxies, dominated in different way by the dark matter component (dSph mass-luminosity ratio very high with respect to common galaxies) have mean densities compatible among them, encourages the continuation of studies on their common origin. Therefore, if the hypothesis claiming SQM conglomerates constitute galaxy halos is valid, the dark matter particles composing such halos must have formed immediately after the Big Bang, when the density was low enough to allow their formation and, subsequently, ensure their stability. Decoupled from ordinary matter, they would have been able to gravitationally aggregate, forming the potential wells where proto-galaxies began to collapse.

In Fig. 5 we show the scaling relation of ten dSph halo parameters obtained from the Jeans analysis and the MW parameters for the theoretical SMP halo in a graphical way. The dSphs taken

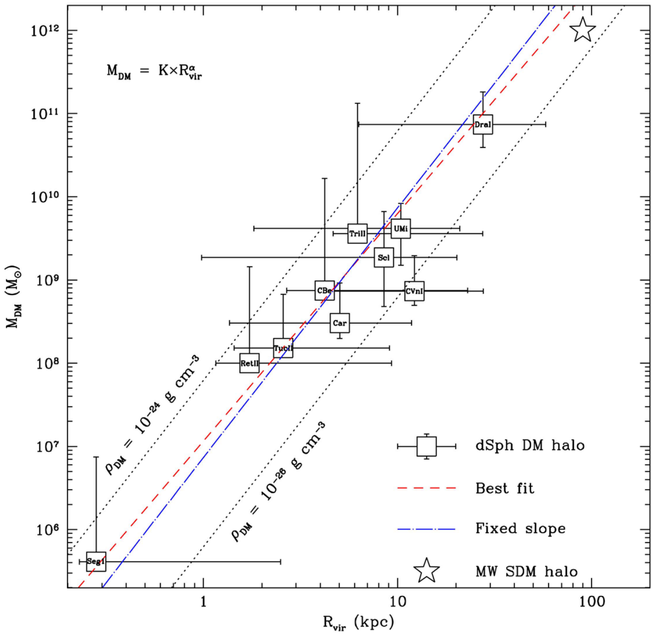

Figure 5: Scaling relation for ten dSph DM halo parameters obtained from the Jeans analysis performed with the CLUMPY software (*open squares*) and MW parameters for the theoretical DM halo constructed with SMPs (*open star*). The errors at 68% confidence level are associated to the measurements of halo masses and virial radii. For comparison, the relation $M_{DM} \propto r_{halo}^3$ at constant density $\rho_{DM} = 2.2 \cdot 10^{-26}$ g cm^{-3} (*blue dash-dotted line*) is reported, along with the same relation scaled at 10^{-24} and 10^{-26} g cm^{-3} (*dotted lines*).

into account are: Carina (Car), Coma Berenices (CBe), Canes Venatici I (CVnI), Draco I (DraI), Reticulum II (RetII), Sculptor (Scl), Segue 1 (Seg1), Triangulum II (TriII), Tucana II (TucII), and Ursa Minor (UMi). A more detailed discussion on these calculations can be found in [33].

6. Conclusions

In this paper, we proposed a possible scenario for DM origin in the Universe based on conglomerates made of strange quark matter. These conglomerates form in the very early phases after the Big Bang, when the conditions of extreme density ($\rho \gg 10^{19}$ g cm^{-3}) and temperature may favor the aggregation of strange baryonic matter in stable structures that interact only gravitationally with ordinary matter; subsequently, when the Universe expands and cools down, the conglomerates formed in this way settle into galactic halos as “relic” DM.

We showed how the assumption of conglomerates with mass of 10 GeV can lead to a good reproduction of the physical properties (mass, radius, concentration) of a typical MW-sized DM halo. Performing a Jeans analysis on the kinematical properties of ten dSph member stars, we also showed how the average DM density in halos of very different size is approximately maintained, hinting for a common origin of both families of structures.

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