Problems of OHe dark matter

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1 Introduction

The dark matter, which corresponds to 25 % of total cosmological density, makes it possible to understand the creation of the large scale structures in the Big Bang. This matter is named like this because it is nonluminous. Indeed its existence is deduced by the observation of the speed of rotations of the galaxies, which are not the same to values obtain by the luminosity law. The non baryonic nature of the dark matter come from analysis of the nucleosynthesis of the Big Bang and the cosmic microwave background anisotropies.

The problem is that simulations of evolution of the Universe give different results according to the nature of the dark matter. To remove this ambiguity, astrophysicists try to determine the composition of this dark matter. The scientific investigation concluded the dark matter should be stable, saturate matter density and decouple from the plasma just before matter dominanted era ([1]). Results from recent searches can be interpreted by Weakly Interactive Massives Particles (WIMP), whereas this is not the unique solution for the dark matter scenario. The next step is to discover the physical composition of the WIMP.

It is presented here one of the propositions for the nature of the WIMP, the O-Helium dark matter, which corresponds to the composite dark matter model. I will explain in this report the research about it, the advantages of this model and finally the problems of this model.

2 The origin of the model

The particles in the composite dark matter model can be electrically charged, but they are hidden in atom-like states maintaining dark matter of the modern Universe. This is the origin of the name of this model, because the matter should be constituted not only by baryonic particles, but by a composition of baryonic and nonbaryonic elements.

This idea was proposed by Sheldon Glashow in his model ([2]) : it is based on million times heavier partners of normal quarks and leptons related by a strict simmetry. The lightest of them are the tera-electrons and tera-U-quark, can formed a tera-helium atom (UUU)EE, in which +2 charged quark cluster (UUU) is linked at 2 tera-electrons via electromagnetic interaction. Glashow proposed at the beginning of the Universe, the excess of U-quarks were been recombined by excess of tera-electrons to form tera-helium atom. As revealed in [3], there is an unrecoverable problem : binding of U-quarks and tera-electrons is uncomplete, that implies an overproduction +1 and +2 charged like (Uud), (UUu) hadrons or (UUU)E ions, which linked with ordinary electrons. To realize the dark atom scenario, we need to take in acompt all other model predicting stable +1 and −1 charged species.

Then, differents scenarios were proposed ([4, 5, 6, 7, 8, 9, 10, 11]), in which they mention the features of stable -2 charged species. They provided by : (a) stable antibaryons formed by 3 anti-U quarks of fourth generation ([12, 13, 14, 15]), (b) AC-leptons predicted in the extension of standard model ([16]) in the case of the almost-commutative geometry, (c) Technileptons and anti-baryons in the researchs of WTC ([17]), and finally (d) the stable charged clusters, composed by 3 anti-quarks of fifth family ([18]).

3 OHe atomic structure

An OHe atom is composed by a helium nucleus and and a heavy double charged particle O^{--} ([19]), which is a particle with strongly suppressed hadronic interaction. There are the mass M_O and M_{H_e}, and the charge $Z_O = 2e$. The potential interaction follows the laws below :

$$V(r \geq R_{H_e}) = -\frac{Z_O Z_{H_e} \alpha}{r} \tag{1}$$

$$V(r \leq R_{H_e}) = -\frac{Z_O Z_{H_e} \alpha}{r} \left(3 - \frac{r^2}{R_{H_e}^2}\right) \tag{2}$$

where $\alpha = e^2/4\pi$ is the fine structure constant and r the distance bewteen O^{--} and the center of the nucleus. Then, we put the expression of potential 1 in the radial time-independent Schrödinger equation, to obtain the eigenvalues of an OHe atom. At angular momentum $l = 0$, we applicate the non-modified WKB approximation as potential V ([20]). For states at $l \neq 0$, we replace $l(l+1)$ by $(l+\frac{1}{2})^2$ in the centrifugal term of the effective potential. For the first ten values of the quantum numbers n and l, the formula looks like pure hydrogen :

$$E_n^H = -\frac{1}{2} M_{He} \frac{(Z_O Z_{He} \alpha)^2}{n^2}$$

For the fundamental level, $E_1^H = 1.175 MeV$. In fact the potential is no longer $\propto 1/r$, so energy depends on both n and l, the energy of ground state increase with E_1^H.

4 The OHe model of the Universe

During the radiation dominance (RD) era, O-Helium, plasma and radiation are in thermal equilibrium, while the plasma transfers the energy to it ([1]). The radiation pressure in the plasma is transferred to density fluctuations to the OHe gas and transforms them in acoustic waves at scales up to the size of the horizon. To explain the next step of the scenario, we use the following relations :

$$v = \sqrt{\frac{2T}{m_p}} \tag{3}$$

$$\sigma \approx \sigma_0 \sim \pi R_0^2 \approx 10^{-25} cm^2 \tag{4}$$

The formula 3 is the baryon thermal velocity, with T the tempareture of the plasma and m_p the mass of the proton. The relation 4 is the cross section of OHe. These formulas are included in the relation below :

$$n_B \langle \sigma v \rangle (m_p/m_0) t \leq 1$$

We deduce from this relation at temperature $T \leq T_{od} \approx 200 S_3^{2/3} eV$ the energy transfer from baryons to OHe is not effective (with $S_3 = m_0/(1TeV)$, and m_0 the mass of the OHe atom). After OHe gas decoupled from plasma, it started to become dominant after $t \sim 10^{12} s$ at $T \approx 1eV$ and OHe atoms have the main role in the development of gravitationnal perturbations, and the development of large scale structure. The nature of OHe determines the features of the composite dark matter scenario. At $T \geq T_{RM}$, the density of OHe gas is $\rho_d = (T_{RM}/T)\rho_{tot}$. After we deduce the total mass of OHe gas :

$$M = \frac{4\pi}{3} \rho_d t^3 = \frac{4\pi}{3} \frac{T_{RM}}{T} m_{Pl} (\frac{m_{Pl}}{T})^2$$

During the period of decoupling $T = T_{od}$ the total mass of OHe become :

$$M_{od} = \frac{T_R M}{T_{od}} m_{Pl} (\frac{m_{Pl}}{T_{od}})^2 \approx 2 \times 10^{44} S_3^{-2} g$$

At $T = T_0$ the OHe forms and at the time of the cosmological horizon $t = l_h$ the total mass is $M_0 = M_{od}(T_{od}/T_0)^3 = 10^{37} g$.

During the radiation dominance era, just before the decoupling, the propagation of the sound waves in the plasma is limited the Jeans length λ_J of the OHe gas. The relativistic equation of state is $p = \epsilon/3$, at the cosmological horizon the Jeans length is at the same order $\lambda_J = l_h/\sqrt{3} = t/\sqrt{3}$. After decoupling it decreases to $\lambda_J \sim v_0 t$, with $v_0 = \sqrt{2T_{od}/m_0}$, and the Jeans mass decreases to :

$$M_J \sim v_0^3 M_{od} \sim 3 \times 10^{-14} M_{od}$$

we expect, at scales $M \leq M_0$ a rough suppression of fluctuations, and an adiabatic damping of sound waves in the plasma at the radiation dominance era for scales $M_0 \leq M \leq M_{od}$. This suppression has not the same effect as the free streaming suppression in the Warm Dark Matter model, this model is called the Warmer than Cold Dark Matter model.

After the separation with the baryonic matter, the OHe gas does not follow the formation of baryonic astrophysical objects (stars, planets, molecular clouds...) and forms the dark matter halos of galaxies.

5 Signatures of OHe

5.1 The solution for puzzles of direct dark matter searches

The detection of dark matter is based on the interactions between OHe nucleus and the baryonic matter. The observations could come from the radiative capture of thermalized OHe, and could depend on some physical parameters of the detector like it composition and and it temperature. The concentration of OHe in the detector is determined by the equilibrium between the infalling cosmic OHe flux and its diffusion to the center of Earth. The problem is the infalling flux which changes every year because the Earth's rotation around the Sun modifies the OHe concentration, so the experiments have to change too.

Two experiments have been done ([21]) : DAMA/NaI and DAMA/LIBRA. They are based on the idea that OHe, slowed down in the matter of detector, can form a few keV bound state with sodium nucleus, if OHe is situated beyond the nucleus. The positive result of these experiments is explained by annual modulation in reaction of radiative capture in the detector :

$$A + ({}^4He^{++}O^{--}) \rightarrow [A({}^4He^{++}O^{--})] + \gamma$$

The low energy OHe-nucleus bound states is possible only for intermediate-mass nuclei : this explain the negative results of LUX experiments. To calculate the rate of this capture, we use an analogy with the radiative capture of neutron by proton, without the M1 transition from conservation of orbital momentum, and suppression of E1 transition in the case of OHe. The rate of OHE radiative capture with atomic number A and Z to energy level E at temperature T is given by the relation below :

$$\sigma v = \frac{f\pi\alpha 3T}{m_p^2\sqrt{2Am_pE}}\left(\frac{Z}{A}\right)^2$$

The capture rate is proportional to the temperature at the thermal equilibrium : this leads to a suppression of this effect in cryogenic detectors.

5.2 Positron annihilation in galaxy bubles

The satellite INTEGRAL observed a positron-annihilation line excess in the galactic bulge, and the number of collisions increases in the zones with higher gas density. It can explained by the presence of OHe ([19, 21]). The dark matter collision rate is higher in the bulge than the rest of the galaxy. The collision rate is estimated to ([22]):

$$\frac{dN}{dt} = n^2 \sigma v_h \frac{4\pi}{3} r_b^3 \approx 3 \times 10^{42} S_3^{-2} s^{-1}$$

At a velocity $v_h \sim 3 \times 10^{-3} cm/s$ energy transfer in the collisions is $\Delta E \sim 1 MevS_3$. The collisions excite the OHe gas, which de-excites by pair production, then the de-excitation in E0 transitions had been observed by excess of positron-annihilation line. However, calculated rate of collisions depends of the density of OHe, but the theoretical estimations for dark matter are uncertain because in the bulbe subdominant dark matter has a poorly density. The last analysis indicates a lower value of dark matter density, and deduce the mass of O^{--} near 1.0 TeV.

5.3 OHe de-excitation

The collisions excite the OHe gas at the first level with non-zero angular momentum, the E1 transition create gamma lines with principal quantum numbers n and m when n is higher than m, at the energies :

$$E_{nm} = \left(\frac{1}{m^2} - \frac{1}{n^2} \right) \times 1.5879 MeV$$

for the transitions more realistic in the case of OHe, see the section 3. The interest of this predictions is to analyse and compare the unidentified lines from the center of the Milk Way. In all line emissions from the Galaxy ([19]), there are some X-Ray and gamma ray, probably origines from OHe. The INTEGRAL and XMM-Newton data permit to compare the observations and the simulations to understand the unidentified lines. The comparison between the predictions and the observations provides an effective tool to test OHe dark matter model.

5.4 The LHC probes

To understand how constitutes the OHe, so the nature of WIMP, experiments have been done at LHC with massives stable doubly charged particles around 1 TeV ([21]). The objective is to compare the results with astroparticle data. The detector ATLAS and CMS give the lower value for double charged particle around 700 GeV ([23]), so this is a good way to find the explanation for the observed low and high energy positron express. We have to take in consideration the doubly charged particles composed by techniquarks needs very higher energy to reveal it intern structure, but the UUU 3 quarks need to find stable hadrons which containing single U or $\bar{U}$ like Uud $\bar{U}u/\bar{U}d$.

6 Some potential problems

6.1 Inelastic process

One of the most problem in the OHe dark matter scenario, there is a strong dipole Coulomb barrier in OHe-He interaction. We explain in this section the consequences of this effect. At the beginning of the Universe, inelastic diffusion between particles of OHe and between OHe and primordial He decreased the quantity of OHe ([24]). The nuclear reactions are :

$$OHe + OHe \rightarrow O_2Be \tag{5}$$

$$OHe + He \rightarrow OBe \tag{6}$$

where Be is the beryllium. The OHe forms at a temperature T_0 which depends of it binding energy, which is 1.175 MeV, that corresponds to $T_0 = 50$keV. The cosmological time is calculated with the temperature, the inelastic process start at a time :

$$t(s) \simeq \frac{1}{T^2(MeV)} \simeq \frac{1}{0.05^2} = 400s$$

after the Big Bang and continue until helium freezes out at $t_* \simeq 600s$.

During these 200 s, the rate of the quantity of OHe decreases like this :

$$\frac{dn_{OHe}}{dt} = -3Hn_{OHe} - n_{OHe}^2\sigma_1 v_1 - n_{OHe}n_{He}\sigma_2 v_2 \tag{7}$$

with n_{OHe} and n_{He} are the densities of OHe and He, $H = 1/2t$ the expansion rate of the Universe during the radiation dominance era, σ_1, σ_2, v_1 and v_2 are respectivly the cross section and the relative velocity of the reaction (5) and (6). The only factor which affect n_{He} is the expansion :

$$\frac{dn_{He}}{dt} = -3Hn_{He} \iff n_{He}(t) = n_{He}^0\left(\frac{t_0}{t}\right)^{3/2} \tag{8}$$

where n_{He}^0 is the number density of He at $t = t_0$. We calculate the fraction of free OHe atoms due to their inelastic reactions, with the ratio f of the number density of OHe and He nuclei, $f = \frac{n_{OHe}}{n_{He}}$. The expressions (7) and (8) give the relation of evolution :

$$\frac{df}{dt} = -n_{He}f(\sigma_1 v_1 f + \sigma_2 v_2) \tag{9}$$

The cross sections σ_1 and σ_2 depend of the size of the nucleus :

$$\sigma_1 \approx 4\pi(2r_{OHe})^2 \tag{10}$$

$$\sigma_2 \approx 4\pi(r_{OHe} + r_{He})^2 \tag{11}$$

where r are the radius of respectively the OHe nucleus and the He nucleus. The both are approximately equal to 2 fm, $\sigma_1 \approx \sigma_2 \approx 64\pi 10^{-26} cm^2$. The mean relative velocities v_1 and v_2 are obtained by the Maxwell-Boltzmann velocity distributions, because the species are in thermal equilibrium with the plasma :

$$v_1 = \sqrt{\frac{8T}{\pi\mu_1}} \tag{12}$$

$$v_2 = \sqrt{\frac{8T}{\pi\mu_2}} \tag{13}$$

with $\mu_1 = \frac{m_{OHe}}{2}$ the reduced mass of OHe-OHe and $\mu_2 \simeq m_{He}$ the reduced mass of OHe-He. During the radiation-dominated era, the relation between time and temperature is : $Tt^{1/2} = T_0 t_0^{1/2}$, we insert it in the expression of velocities, and use the relation (9) to obtain :

$$\frac{df}{dt} = -\gamma \frac{1}{t^{7/4}} f(\alpha f + \beta) \tag{14}$$

with

$$\alpha = \frac{\sigma_1}{\sqrt{\mu_1}} \tag{15}$$

$$\beta = \frac{\sigma_2}{\sqrt{\mu_2}} \tag{16}$$

$$\gamma = n_{He}^0 t_0^{7/4} \sqrt{\frac{8T_0}{\pi}} \tag{17}$$

The initial condition is $f(t_0) = f_0$, the solution of (14) is :

$$f(t) = \frac{\beta f_0}{exp(\frac{4}{3}\beta\gamma(t_0^{-3/4} - t^{-3/4}))(\alpha f_0 + \beta) - \alpha} \tag{18}$$

We can deduce the number density of He at the biginning of the baryon nucleosynthesis from its actual value. It corresponds today about 10% of all baryons, with a present critical density measured is to :

$$\rho_c^1 = 5.67 \times 10^{-6} m_p/cm^3 \iff n_{He}^1 \simeq 2.8 \times 10^{-8} cm^{-3} \tag{19}$$

Then, we have to add the effect of the expansion, which is proportionnal at the temperature of the CMB $n^0_{He} = n^1_{He}\left(\frac{T_0}{T_1}\right)^3 \simeq 2.8 \times 10^{-17} cm^{-3}$. At the biginning of the Universe the quantity of O^{--} particles was the same that OHe particles. Today the quantity of particles hasn't been change, but the size of the Universe increases so the density of particles has been diluted. The fraction of OHe hasn't been change, almost 25% of the critical density, so we can calculate the parameter $f_0 \simeq 0.05$. Now we can insert this value in the equation (18) and calculate the fraction at the freeze-out time :

$$f(t_*) \simeq 5 \times 10^{-6133} \ll f_0 \tag{20}$$

this results means the OBe creation by the reaction 1 decreases rapidly. To be more clearly, the reaction (6) is majoritary, so the dark matter is now in form of OBe. The suppression instant arrive when the exponential term has the value e^{14127}. This value represents the number N_2 of reactions that happened between t_0 and t_* :

$$\begin{aligned}
N_2 &= \int_{t_0}^{t_*} n_{He}(t)\sigma_2 v_2(t) dt \\
&= n^0_{He} t_0^{3/2} \sigma_2 \sqrt{\frac{8T_0 t_0^{1/2}}{\pi\mu_2}} \int_{t_0}^{t_*} \frac{1}{t^{7/4}} dt \\
&= n^0_{He} t_0^{7/4} \sqrt{\frac{8T_0}{\pi}} \frac{\sigma_2}{\sqrt{\mu_2}} \left(-\frac{4}{3}\right)\left(\frac{1}{t_*^{3/4}} - \frac{1}{t_0^{3/4}}\right) \\
&= \frac{4}{3}\beta\gamma\left(\frac{1}{t_0^{3/4}} - \frac{1}{t_*^{3/4}}\right)
\end{aligned}$$

This relation means the realization of the OHe dark matter model implies a very strong suppression of the reaction (6), which corresponding to $N_2 \ll 1$. This particular case needs the development of a strong dipole Coulomb barrier in OHe-He interaction. This one of the most important problem in this scenario.

6.2 Problems of OBe dark matter

Due to the Coulomb barrier, the particle of OBe can't capture helium nucleus, and it recombines with electrons during the radiation dominante era ([24]) at the temperature $T_{od} = 2eV$. Without this barrier there will be no suppression of inelastic reactions, in which O^{--} binds with nuclei. After recombination the OBe gas will undergo a decoupling with the plasma and the radiation, after that there is an adiabatic damping separation which remove the density fluctuation at smaller scale than the horizon of events. This is the Warmer than cold dark matter model. The total mass of OBe is similary at OHe at the time before the horizon. This dark matter is mixed with ordinary matter in the process of galaxy formation, and become collisional on the scale of the galaxies. So there is some OBe in the stars, but the thermonuclear reaction in the stars interect with it and create anomalous isotopes. OBe can be ionized, but the more part of it is neutral. In the atmosphere, OBe atoms are the most part of the dark matter, in the ionosphere the particles are ionized by the radiation and neutralized by electron capture. When OBe arrive on the Earth there are many collisions which decrease the velocity of OBe. The cross section of OBe is in the order of $\sigma \approx 10^{-15} - 10^{-14} cm^{-2}$, in take in account the number density of terrestrial matter $n = 0.27 \times 10^{23} molecules/cm$ we calculate the OBe atoms velocity inside the Earth at :

$$V = \frac{g}{n\sigma v} \leq 2.7 \times 10^{-11} cm/s \approx 270 fm/s \tag{21}$$

To determine the OBe abundance in the Earth we need to know the equilibrium between the in-falling and down-drifting fluxes. The flux of O-Helium in-falling from dark matter halo is given by :

$$F = \frac{n_0}{8\pi} \times \mid \bar{V_h} + \bar{V_E} \mid \tag{22}$$

with $V_h = 220 km/s$ the speed of the Solar System, $V_E = 29.5 km/s$ the speed of the Earth and $n_0 = 3 \times 10^{-4} cm^{-3}$ is the assumed local density of OBe dark matter. To simplify the calculation, we didn't take in account the annual modualtion of the incoming flux and take $\mid \bar{V_h} + \bar{V_E} \mid = u \approx 300 km/s$. The equilibrium concentration of OBe is obtained by :

$$n_{0E} = \frac{2\pi \times F}{V} \tag{23}$$

and the ratio of anomalous isotopes to the total amount of the Earth matter is given by :

$$r_{0E} = \frac{n_{0E}}{n} = \frac{2\pi \times F\sigma v}{g} \geq 3.1 \times 10^{-9} \tag{24}$$

The upper limits on the anomalous helium abundance are very stringent ([25]) $r_{0E} \leq 10^{-19}$, and the hard estimate is ten orders of magnitude too large. Today with the other problems of OBe Universe explained before, this ban the OBe scenario.

7 Conclusion

The O-Helium is a good hypothesis for explain the nature of the dark matter, is composed by helium nuclei and a doubled charged O^{--}. Now the scientist work to discover it physcial nature, but the scientist have many propositions about it.

The warmer than cold dark matter scenario has the advantage to have a few parameters for explain the Universe, and the scenario is not very different than the cold dark matter scenario. The OHe dark matter can explain the observations from the center of the galaxies, with the positron line excess and the OHe de-excitation, but the experiments done at LHC didn't give confirmation of its nature.

The problem is this model run successfully only if there is a strong Coulomb barrier in the OHe particle. To confirm it existence, this needs a new research in atomics physics, astrophysics and simulation.

8 References

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