# The dark matter research

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# 1 Introduction

The dark matter, which corresponds to 25 % of total cosmologic density, makes it possible to understand the creation of the big structures in the Big Bang. This matter is named like this because it does not emit rays. Indeed it existence is deduce 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. Recent searches indicates that a combinaison between nucleus of He and 2 leptons, namned OHe, possibly satisfy the caractéristic of the dark matter.

The O-Helium dark matter is named composite dark matter model. I will explain in this report the research who had permit to discover it, the advantages of this model and finally the problems of this model.

# 2 OHe atomic structure

An OHe atom is composed by a helium nucleus and and an heavy double charged particule $O^{--}$ (references [1]), maybe a lepton. There are the mass $M_O$ and $M_{H_e}$, and the charge $Z_O = 2e$. The potential interaction follows the laws below :

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

where $\alpha$ is the fine structure constant and $r$ the distance bewteen the leptons and the center of the nucleus.

# 3 Signatures of OHe

## 3.1 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 high gas density zone. It can explained by the presence of OHe (references [1, 2]). The dark matter is more concentrated in the bulge than the rest of the galaxy, and this gas is collisionless. The collisions excites the OHe gas in creating a 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 and baryonic are uncertain. The last analysis indicates a little value of dark matter density, and deduce the mass of $O^{--}$ near 1.0 TeV.

### 3.2 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 energies :

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

In all line emissions from the Galaxy (references [1]), there are some X-Ray and gamma ray, probebly origines from OHe. The INTEGRAL and XMM-Newton data permit to compare the observations and the simulations to understand the unidentified lines.

### 3.3 The LHC probes

To understand how constitutes the OHe, so the nature of $O^{--}$, scientist at LHC done experiences with massives stable charged particules around 1 TeV (references [2]). The detector ATLAS and CMS detected particules around 700 GeV, so this is a good way to find the particule which correspond to composite dark matter.

## 4 Some potential problems

### 4.1 Inelastic process

During the young age of the Universe, inelastic diffusion between particules of OHe and between OHe and primordial He decreased the quantity of OHe (references [3]). The nuclear reactions are :

$$OHe + OHe \rightarrow O_2Be \tag{1}$$

$$OHe + He \rightarrow OBe \tag{2}$$

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 diminution rate of the quantity of OHe is :

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

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, $\sigma_1$, $\sigma_2$, $v_1$ and $v_2$ are respectivly the cross section and the relative velocity of the reaction (1) and (2). The only factor which affect $n_{He}$ is the expansion :

$$\frac{dn_{He}}{dt} = -3Hn_{He} \iff n_{He}(t) = n_{He}^0\left(\frac{t_0}{t}\right)^{3/2} \tag{4}$$

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 (3) and (4) give the relation of evolution :

$$\frac{df}{dt} = -n_{He}f(\sigma_1 v_1 f + \sigma_2 v_2) \tag{5}$$

The cross sections $\sigma_1$ and $\sigma_2$ depends of the size of the nucleus :

$$\sigma_1 \approx 4\pi(2r_{OHe})^2 \tag{6}$$

$$\sigma_2 \approx 4\pi(r_{OHe} + r_{He})^2 \tag{7}$$

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 :

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

$$v_2 = \sqrt{\frac{8T}{\pi\mu_2}} \tag{9}$$

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 (5) to obtain :

$$\frac{df}{dt} = -\gamma\frac{1}{t^{7/4}}f(\alpha f + \beta) \tag{10}$$

with

$$\alpha = \frac{\sigma_1}{\sqrt{\mu_1}} \tag{11}$$

$$\beta = \frac{\sigma_2}{\sqrt{\mu_2}} \tag{12}$$

$$\gamma = n_{He}^0 t_0^{7/4} \sqrt{\frac{8T_0}{\pi}} \tag{13}$$

The initial condition is $f(t_0) = f_0$, the solution of (10) is :

$$f(t) = \frac{\beta f_0}{exp(\frac{4}{3}\beta\gamma(t_0^{-3/4} - t^{-3/4}))(\alpha f_0 + \beta) - \alpha} \tag{14}$$

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

$$\rho_c^1 = 5.67 \times 10^{-6} m_p/cm^3 \iff n_{He}^1 \simeq 2.8 \times 10^{-8} cm^{-3} \tag{15}$$

Then, we have to add the effect of the expansion, which is proportionnal at the temperature of the CMB $n_{He}^0 = n_{He}^1 \left(\frac{T_0}{T_1}\right)^3 \simeq 2.8 \times 10^{-17} cm^{-3}$. At the biginning of the Universe the quantity of $O^{--}$ particules was the same that OHe particules. Today the quantity of particules hasn't been change, but the size of the Universe increase so the density of particules 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 (14) and calculate the fraction at the freeze-out time :

$$f(t_*) \simeq 5 \times 10^{-6133} \ll f_0 \tag{16}$$

this results means the OHe reactions don't during. To be more clearly, the reaction (2) 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 $t_*$ :

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

This relation means the realization of the OHe dark matter model implies a very strong suppression of the reaction (2), 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.

## 4.2 Problems of OBe dark matter

Due to the Coulomb barrier, the particule of OBe can't capture leptons, and it recombines with electrons during the radiation dominante era (references [3]). 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. We know there is some OBe in the stars, but the thermonuclear process in the stars interects 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 particules are ionized by the radiation and neutralized by electron capture.

# 5 Conclusion

The O-Helium, this particule composed by helium nuclei and a doubled charged lepton $O^{--}$, is good hypothesis for explain the nature of the dark matter, and it existence has been desmonstrated in the LHC, and the physicals caracteristics too.

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.

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

# 6 References

## References

[1] J-R.Cudell, M.Yu Khlopov, and Q. Wallemacq. Effects of dark atoms excitations. *Mod.Phys.Lett*, 2014.

[2] M.Yu Khlopov. 10 years of dark atoms of composite dark matter. *Mod.Phys.Lett*, 2015.

[3] J-R.Cudell, M.Yu Khlopov, and Q. Wallemacq. Some potential problems of ohe composite dark matter. *Bled Workshops in Physics 15*, 2014.