THE CASE OF 1.5 EV NEUTRINO HOT DARK MATTER

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The lensing data of the galaxy cluster Abell 1689 can be explained by an isothermal fermion model with a mass of 1-2 eV. The best candidate is the 1.5 eV neutrino; its mass will be searched down to 0.2 eV in KATRIN 2015. If its righthanded (sterile) modes were created too, there is 20% neutrino hot dark matter. Their condensation on clusters explains the reionization of the intercluster gas without Pop. III stars. Baryonic structure formation is achieved by gravitational hydrodynamics alone, without dark matter trigger.

Keywords: Hot dark matter, neutrino mass, Majorana mass, double beta decay

1. Introduction

It is presently understood that the mass density of the universe is (nearly) equal to the critical density, with a fraction \( \Omega_B \approx 4.5\% \) in baryons, \( \Omega_D = 20 - 25\% \) in dark matter and the rest in dark energy. In the standard view, dark matter is cold, that is, a mass in the TeV regime, or at least warm, keV or more. Well over 40 searches have been performed, which failed to detect the dark matter particle, or came with claims that are not broadly accepted: the annual variation of the signal recorded in DAMA or the “two hints or background events” of CDMS-II.

In Ref. 1 the present author takes a “blind” approach to describe the lensing data of the galaxy cluster Abell 1689. The assumptions are: the dark matter is a non-interaction (quantum) gas; the cluster is stationary; it may be approximated as spherically symmetrical; the mass distribution is isothermal for each of its components: Galaxies, X-ray gas and dark matter; all three components are subject to the common gravitational potential. While galaxies and gas are so dilute that a classical isothermal model applies, the dark matter may in principle be quantum degenerate, having a Bose-Einstein or Fermi-Dirac distribution. If the mass comes out large and thus the density low, either case will reduce to a Maxwell-Boltzmann.

2. Thermal fermion model

The mass density of fermions with mass \( m, \bar{g} \) degrees of freedom at a temperature \( T \) in a gravitational potential \( U(r) \) and chemical potential \( \mu = \alpha k_B T \) reads

\[
\rho_D = \int \frac{d^3p}{(2\pi\hbar)^3} \frac{\bar{g}m}{\exp[(p^2/2m + mU(r) - \mu)/k_B T] + 1}.
\]

In dimensionless variables \( x = r/R_*, \phi = mU/k_B T \), with thermal length \( \lambda_T = (2\pi\hbar^2/mk_B T)^{1/2} \) and characteristic scale \( R_* \) in terms of \( \lambda_T \), the Poisson
equation has a polylogarithm $\text{Li}_\gamma(z) = \sum_{k=1}^{\infty} z^k / k^\gamma$ for the dark matter component, and Boltzmann terms for the galaxies (G) and the X-ray gas (g),

$$\phi'' + \frac{2}{x} \phi' = -\text{Li}_{3/2} \left( -e^{\alpha - \phi} \right) + e^{\alpha G - \beta G} + e^{\alpha s - \beta s} \phi.$$  \hfill (2)

This model is applied to lensing data of the galaxy cluster Abell 1689. The plotted quantity is the 2D density contrast between the inner disc with radius $r$ and the disc between $r$ and some fixed $r_m$, $\Delta \Sigma(r) = \Sigma(r) - \Sigma(r_m)/(1 - r^2/r_m^2)$. Here $\Sigma(r) = M_{2D}(r)/\pi r^2$ is the average projected mass profile,

$$\Sigma(r) = A \Phi \left( \frac{r}{R_s} \right), \quad \Phi(x) = \int_0^\infty ds \phi'(x \cosh s), \quad A \equiv \frac{h^6}{2g^2 G^3 m^8 R_s^5}.$$  \hfill (3)

We make a $\chi^2$ fit of $\Delta \Sigma$ to the 19 data points of Ref. 2, combined with 13 core points constructed from $M_{2D}(r)$ of Ref. 3. As seen in Fig. 1a, the relative errors increase strongly with $r$, and become more equal if we consider the $\chi^2$ of $\sqrt{\Delta \Sigma}$. We take $\beta_g = 0.153$ and $\alpha_g = 2.36$ at $\beta_G = 1$. There is a minimum $\chi^2 = 13.645$. With $h \equiv 0.70 h_{70}$, the correlation matrix for the upper errors yields $A = 59.4 \pm 9.6 h_{70} M_{\odot} \text{pc}^{-2}$, $\alpha = 38.4 \pm 3.1$, $R_s = 297 \pm 10 h_{70}^4 \text{kpc}$, $\alpha_G = 8.26 \pm 0.32$. We present its fit in Figure 1a. The WIMP mass comes out as

$$m = \frac{1}{2^{1/8} g^{1/4} \frac{h^{3/4}}{G^{5/8} A^{1/8} R_s^{7/8}}} = h_{70}^{1/2} \left( \frac{12}{g} \right)^{1/4} \frac{0.1455 \pm 0.030}{\text{eV}}.$$  \hfill (4)

This is much below the keV or TeV regime of the supposed warm or cold dark matter, so the approach rules them out. In Fig. 1b we neglect the Galaxies and the gas, and plot the curves for a Bose-Einstein distribution in the limit $\alpha \to 0^-$, for a classical isothermal model and for an NFW profile with $\bar{\rho} = \rho_c (1+z)^3$ at $z = 0.183$: $\rho_D = \bar\rho_0 c^2 \rho_c |r(r+r_s)|^2$, $\delta_c = 200 c^2 / 3 [\ln(1+c) - c/(1+c)]$ with $c = 4.684$. None of them fits the data globally.

While $\bar{g}$ is the number of states that can be filled in the cluster formation process, $g$ is the filling factor in the dark matter genesis. The global mass fraction thus reads

$$\Omega_D = \frac{n_F \rho}{\rho_c} = g \left( \frac{12}{g} \right)^{1/4} h_{70}^{-3/2} 0.1893 \pm 0.0039.$$  \hfill (5)

3. Neutrino: return of the first dark matter candidate

They can occupy in the cluster formation process all $\bar{g} = 12$ left and righthanded states, which gives $m = 1.445(30) h_{70}^{1/2}$ eV, below the Mainz-Troitsk bound of 2 eV. Neutrinos oscillate, so their masses differ, but the effect is only in the meV regime. The mass of the electron anti neutrino will be searched down to 0.2 eV in the KATRIN tritium decay experiment (Karlsruhe, 2015). So this will confirm or
Fig. 1. Left: The mass contrast $\Delta\Sigma$ as function of radius $r$. Large data points from Ref. 2, small ones (at radii $5^{2n/3}h_{70}^{-1}$ kpc with $n = 0, \ldots, 12$) from Fig. 6 of Ref. 3. Full line: The theoretical profile. Right: 1) Isothermal Bose-Einstein model with $\alpha \to 0$; 2) Classical isothermal model; 3) NFW profile. The first two do not fit for $r < 200$ kpc, NFW not for $r > 200 - 500$ kpc.

rule out our theory. If the mass is indeed around 1.5 eV, it will have a 0.6% error, so our approach will offer a new, sharp way to determine Hubble’s constant.

With $g = 6$ for active neutrinos, $\Omega_\nu \approx 10\%$. If righthanded (and lefthanded anti-) neutrinos (sterile neutrinos) are created in the early Universe, then $g \approx 12$ and $\Omega_\nu \approx 20\%$. This may happen if there is a meV valued Majorana mass matrix, that by itself leads to neutrinoless double beta decay, be it a rather weak one, the present upper bound is $\sim 0.5$ eV. With the Dirac mass matrix at the 1.5 eV scale, the meV Majorana mass matrix presents an anti-see-saw mechanism.

Neutrinos are free streaming at the decoupling and condense on the galaxy cluster fairly late, at $z \sim 7$. The theory of violent relaxation predicts a Fermi-Dirac distribution. Since the cosmic baryonic voids are till then filled with neutrinos, the metric is then quite homogeneous. It is intriguing to see whether the present inhomogeneity can explain the cosmological constant of the concordance model.

The region in Abell 1689 where the neutrinos are quantum degenerate is millions of light years wide, a truly large scale for quantum behavior.

Gravitational hydrodynamics explains baryonic structure formation without cold dark matter trigger, because viscosity is more important than often realized. Galactic dark matter is observed as MACHOs of earth weight and in other ways. Therefore neutrino free streaming is not ruled out by structure formation arguments.

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