Observational Constraints on the Possibility that Sterile Neutrinos cause Anti-gravity

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Introduction

The origin of neutrino masses heralds new physics. Some theories that explain small neutrino masses, predict the existence of sterile neutrinos. Observationally, there is no evidence that neutrinos cause attractive gravity. Exploring a new idea, we study constraints posed by data as to what if sterile neutrinos cause repulsive gravity. We use an effective negative gravitational constant for the sterile neutrinos to constrain the extent of anti-gravity sourced by them. The case of an open universe is explored (in accordance with the positive value of H_0^2), taking into account different combinations of parameters, and collating with observed values.

Repulsive gravity due to sterile neutrinos and FLRW Model

In the matter dominated universe, we consider two cases, very light (radiation-like) sterile neutrinos, and massive sterile neutrinos, that cause repulsive gravity. The Einstein Field Equation can be modified to:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu} - \frac{8\pi G'}{c^4}(T_{\mu\nu})_{s\nu} \quad (1)$$

where, $(T_{\mu\nu})_{s\nu}$ is the stress-energy tensor associated with the sterile neutrinos. The corresponding negative gravitational constant is denoted by $-G'(G' > 0)$. We solve the modified FLRW equations taking into consideration $-G'$ for the sterile neutrino. The FLRW equations can represented as:

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3}\left[\rho_m + \rho_r - \frac{G'}{G}\rho_{s\nu}\right] - \frac{kc^2}{a^2} \quad (2)$$

$$\frac{2\ddot{a}}{a} + \frac{\dot{a}^2 + kc^2}{a^2} = -\frac{8\pi G}{c^2}\left[p_m + p_r - \frac{G'}{G}p_{s\nu}\right] \quad (3)$$

Solving for a(t), and substituting in the following relation

$$\int_t^{t_0} \frac{cdt}{a(t)} = -\int_r^0 \frac{dr}{\sqrt{1-kr^2}} \quad (4)$$

one obtains the following two relations for the radial distance, r as a function of the redshift z: (i) Very light (radiation-like) Sterile Neutrinos:

$$r(z) = \sinh\left[\left(\frac{1+\frac{K_0}{2}}{\sqrt{K_1+\frac{K_0^2}{4}}}\right) - \left(\frac{\frac{1}{1+z}+\frac{K_0}{2}}{\sqrt{K_1+\frac{K_0^2}{4}}}\right)\right] \quad (5)$$

With,

$$K_0 = \frac{H_0^2 a_0^2 \Omega_{m,0}}{c^2}, \qquad K_1 = K_0 \frac{G' \Omega_{s\nu,0}}{G\,\Omega_{m,0}}$$

(ii) Massive Sterile Neutrinos:

$$r(z) = \frac{c}{a_0 H_0}\left[\ln\left(\frac{\sqrt{K_2(1+z)+K_3}-\sqrt{K_3}}{\sqrt{K_2(1+z)+K_3}+\sqrt{K_3}}\right) - \ln\left(\frac{\sqrt{K_2+K_3}-\sqrt{K_3}}{\sqrt{K_2+K_3}+\sqrt{K_3}}\right)\right] \quad (6)$$

With,

$$K_2 = \Omega_{m,0} - \frac{G'}{G'}\Omega_{s\nu,0}, \qquad K_3 = \frac{c^2}{a_0^2 H_0^2}$$

Here, $\Omega_{s\nu,0}$ = Density parameter associated with sterile neutrinos. Other symbols carry their usual meanings.

To test the efficiency of the theory, we plot the calculated values of distance modulus $\left[m - M = 5\log_{10}\frac{dL(z)}{10pc}\right]$ against observed values from the Supernova Cosmology Project Union Catalog [1].

Results

Different datasets have been computed for separate values of Hubble parameter H_0 and the free constant parameter $(G'/G)\Omega_{s\nu,0}$. Using weighted least-squared minimization technique, extent of fit has also been evaluated.

Results: Figures

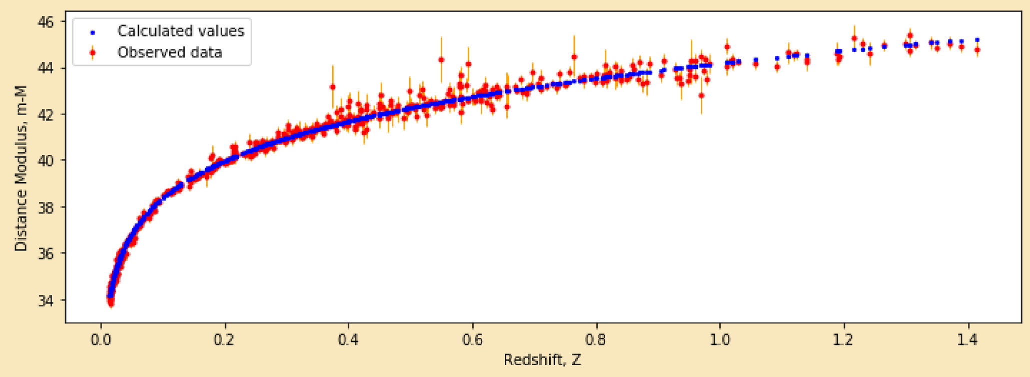

Figure 1:Massive Sterile Neutrinos, $H_0 = 67.4, (G'/G)\Omega_{s\nu,0} = 0.3579$

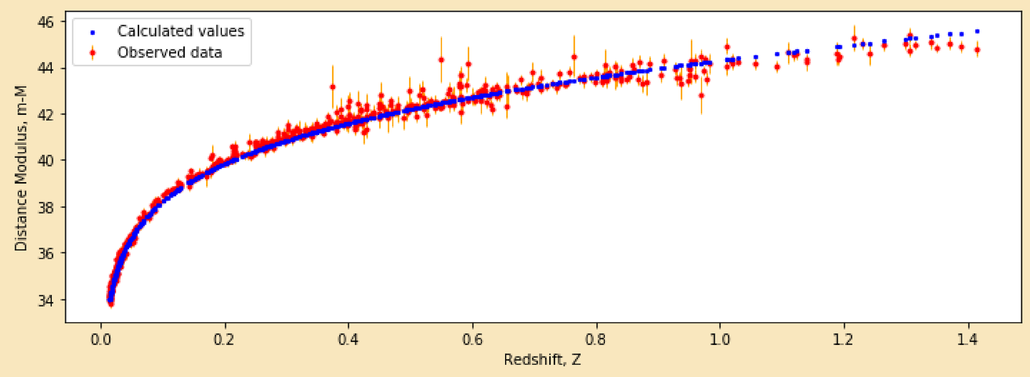

Figure 2:Massive Sterile Neutrinos, $H_0 = 73, (G'/G)\Omega_{s\nu,0} = 0.6904$

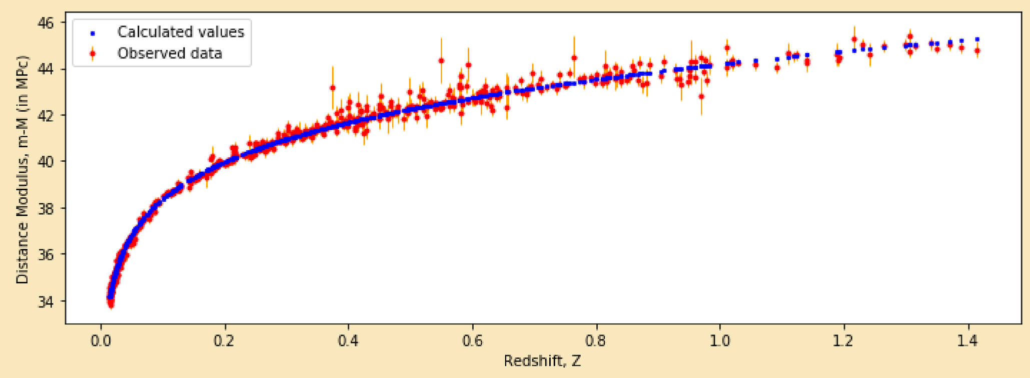

Figure 3:Very Light Sterile Neutrinos, $H_0 = 67.4, (G'/G)\Omega_{s\nu,0} = 0.1584$

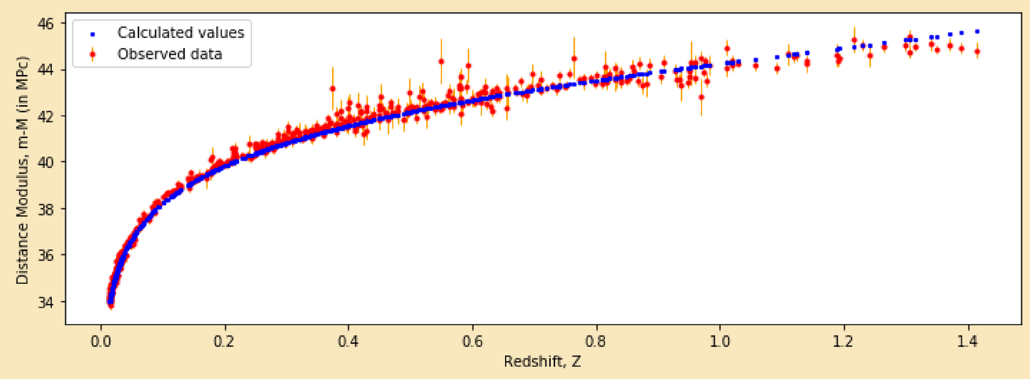

Figure 4:Very Light Sterile Neutrinos, $H_0 = 73, (G'/G)\Omega_{s\nu,0} = 0.2685$

Conclusion

We modelled the sterile neutrino's repulsive gravity by assuming that the gravitational constant associated with this species of neutrino is negative $(-G')$. Different combinations of involved parameters were then studied by comparing them against observational data pertaining to Type Ia supernovae in order to obtain the best weighted least-square fit. The sterile neutrino-repulsive gravity theory appears to be giving satisfactory fits, even with recent findings [2] of $H_0 \approx 73$. The factor of $-G'$ replaces the cosmological constant in order to explain late time accelerated expansion of the universe. Further fine-tuning of theory, improved sensitivity and augmented sample of observed data in the future would lead to refinement of constraints on the negative gravitational constant, as well as other cosmological parameters.

References

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