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. We explore the case of an open universe (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:

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

where, $(T_{\mu\nu})_{sv}$ 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:

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

$$\frac{2\ddot{a}}{a} + \frac{\dot{a}^2 + kc^2}{a^2} = -\frac{8\pi G}{c^2}\left[p_m + p_r - \frac{G'}{G} p_{sv}\right]$$

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

$$\int_t^{t_0} \frac{c\,dt}{a(t)} = -\int_r^0 \frac{dr}{\sqrt{1-kr^2}}$$

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:

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

With, $K_0 = \frac{H_0^2 a_0^2 \Omega_{m,0}}{c^2}$ and $K_1 = K_0 \frac{G'}{G}\frac{\Omega_{sv,0}}{\Omega_{m,0}}$

(ii) Massive Sterile Neutrinos:

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

With, $K_2 = \Omega_{m,0} - \frac{G'}{G}\Omega_{sv,0}$ and $K_3 = \frac{c^2}{a_0^2 H_0^2}$

Here, $\Omega_{sv,0}$ = 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 [m–M=5log$_{10}$(d$_L$(z)/10pc)] 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, total matter density parameter, $\Omega_{m,0}$ and the free constant parameter $(G'/G)\Omega_{sv,0}$. Using χ^2-minimization technique, extent of fit has also been evaluated. (Ideal value of best fit is χ^2 =1).

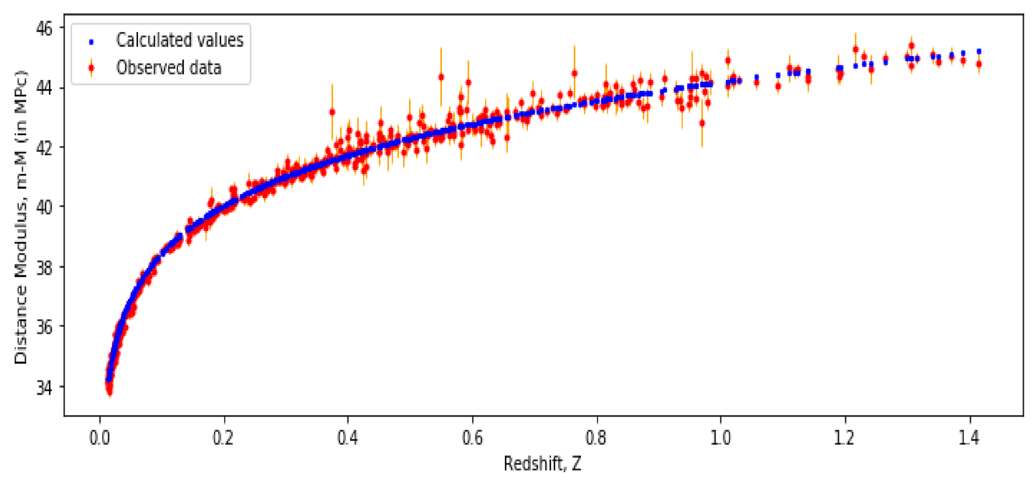

Figure 1: Very Light Sterile Neutrinos
$H_0 = 65$,
$(G'/G)\Omega_{sv,0} = 0.105$,
$\chi^2 = 1.09171$
$\Omega_{m,0} = 0.3$

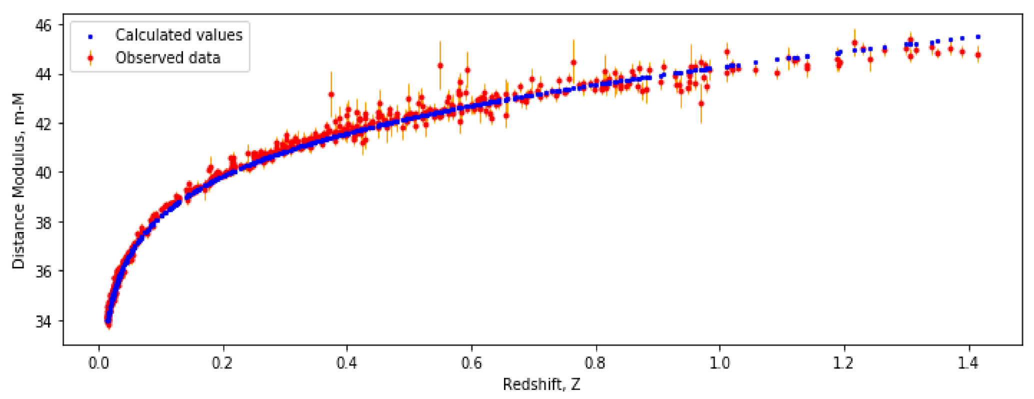

Figure 2: Massive Sterile Neutrinos
$H_0 = 73$,
$(G'/G)\Omega_{sv,0} = 0.678$,
$\chi^2 = 1.28124$
$\Omega_{m,0} = 0.31$

H_0	$\Omega_{m,0}$	$(G'/G)\Omega_{sv,0}$	χ^2
65	0.3	0.105	1.09171
65	0.31	0.11	1.09179
72	0.28	0.242	1.26263
72	0.29	0.246	1.26392

Table 1: Various cases for radiation-like sterile neutrinos

H_0	Ω_{m0}	$(G'/G)\Omega_{sv,0}$	χ^2
73	0.3	0.668	1.28124
73	0.31	0.678	1.28124
73.5	0.3	0.687	1.32706
73.5	0.31	0.697	1.32706

Table 2: Various cases for massive sterile neutrinos

Conclusion

Several theoretical models have been proposed to explain neutrino masses; See-Saw model is one among them. We modeled the sterile neutrino's repulsive gravity by assuming that the gravitational constant associated with this species of neutrino is negative (-G'). Different cosmological models were then studied by comparing them against observational data pertaining to Type Ia supernovae in order to obtain the best chi-square fit. The sterile neutrino-repulsive gravity theory appears to be doing marginally better, with chi-square values being very close to the ideal number. The massive sterile neutrino case gives a satisfactory fit even with recent findings [2] of H_0~73. The factor of –G' replaces the cosmological constant in order to explain late time accelerated expansion of the universe. Improved sensitivity and augmented sample of observed data in the future would lead to further refinement of constraints on the negative gravitational constant as well as other cosmological parameters.

References

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