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. Different combinations of parameters have been taken into account, and collated with observed values.

Repulsive gravity due to sterile neutrinos and FLRW Model

In the matter dominated universe, two cases have been considered, light sterile neutrinos and massive sterile neutrinos. The Einstein Field Equation can be modified to:

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

where, $(T_{\mu\nu})_{s\nu}$ is the stress-energy tensor associated with sterile neutrinos. The corresponding negative gravitational constant is denoted by $-G'(G' > 0)$. We solve the pair of modified FLRW equations, from which an important condition is derived:

$$H^2 = \frac{8\pi G}{3}\rho_m\left[1 - \frac{G'\rho_{s\nu}}{G\,\rho_m}\right] - \frac{kc^2}{a^2} > 0 \Longrightarrow k = -1 \tag{2}$$

For an accelerating universe, the first term on the RHS will be negative. Therefore, in order to keep the LHS positive, an open universe ($k = -1$) is necessary.
Solving for a(t), we obtain the following two relations for the radial distance, r as a function of the redshift z:

(i) Very light (radiation-like) Sterile Neutrinos:

$$r(z) = \sinh\left[\cosh^{-1}\left(\frac{1+\frac{K_0}{2}}{\sqrt{K_1+\frac{K_0^2}{4}}}\right) - \cosh^{-1}\left(\frac{\frac{1}{1+z}+\frac{K_0}{2}}{\sqrt{K_1+\frac{K_0^2}{4}}}\right)\right] \tag{3}$$

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:

$$r(z) = \sinh\left[\frac{c}{a_0H_0}\frac{1}{\sqrt{K_3}}\left(\ln\left|\frac{\sqrt{K_2(1+z)+K_3}-\sqrt{K_3}}{\sqrt{K_2(1+z)+K_3}+\sqrt{K_3}}\right| - \ln\left|\frac{\sqrt{K_2+K_3}-\sqrt{K_3}}{\sqrt{K_2+K_3}+\sqrt{K_3}}\right|\right)\right] \tag{4}$$

With,

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

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

Results

To test the consistency 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]. 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

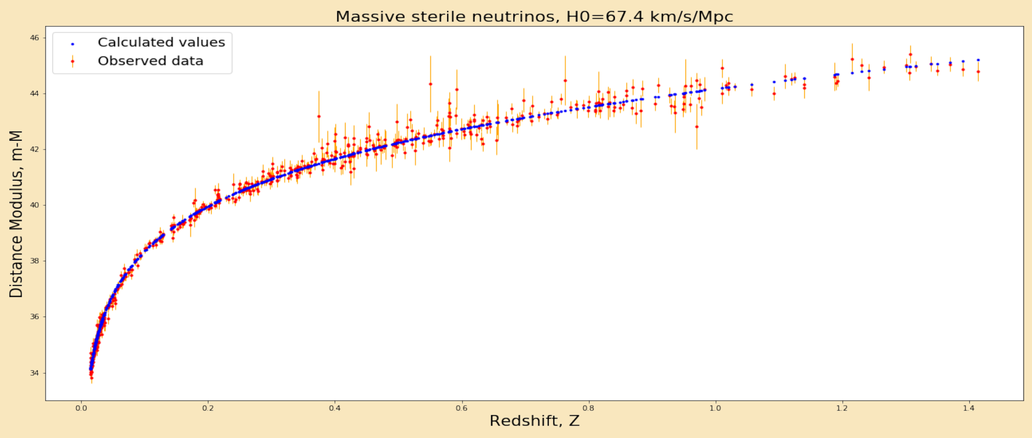

Figure 1: Massive Sterile Neutrinos, $H_0 = 67.4$, $(G'/G)\Omega_{s\nu,0} = 0.3579$

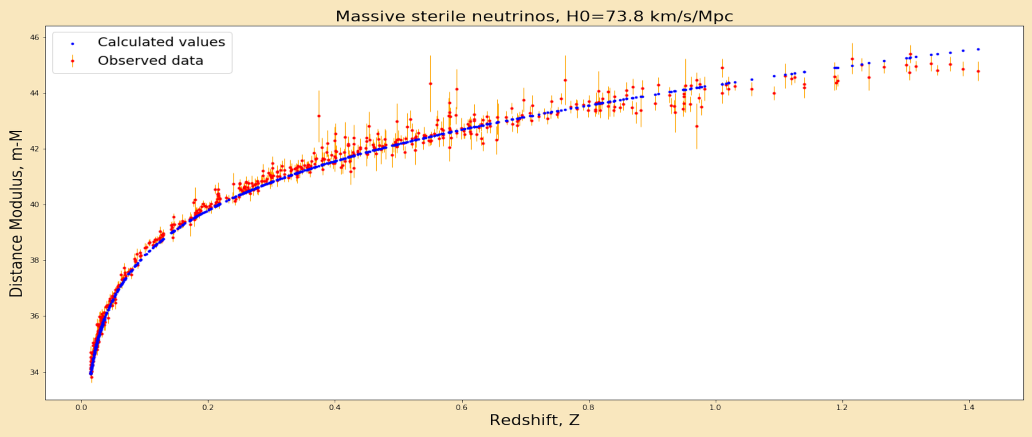

Figure 2: Massive Sterile Neutrinos, $H_0 = 73.8$, $(G'/G)\Omega_{s\nu,0} = 0.7238$

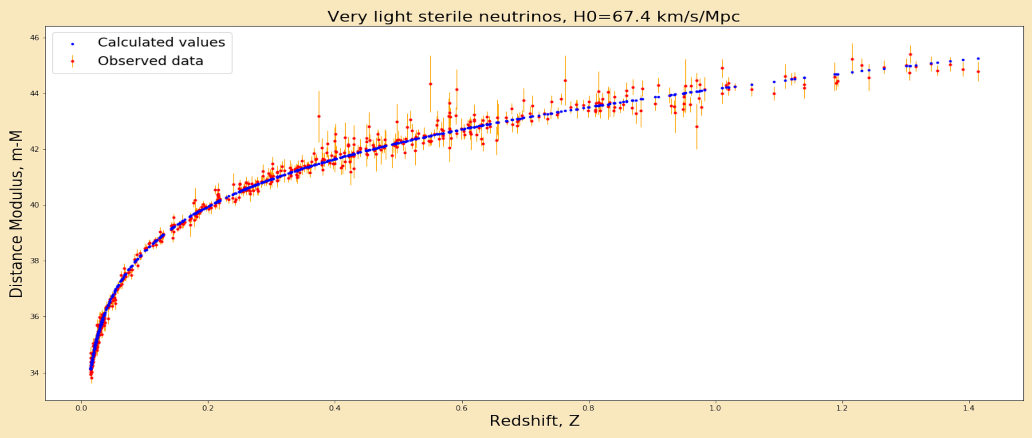

Figure 3: Very Light Sterile Neutrinos, $H_0 = 67.4$, $(G'/G)\Omega_{s\nu,0} = 0.1584$

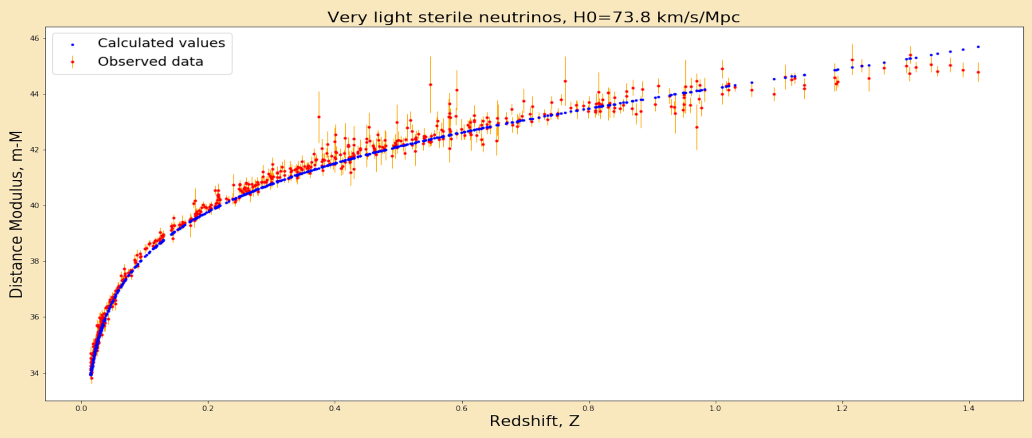

Figure 4: Very Light Sterile Neutrinos, $H_0 = 73.8$, $(G'/G)\Omega_{s\nu,0} = 0.2759$

Conclusion

We modeled the sterile neutrino's repulsive gravity by assuming a negative gravitational constant associated with it ($-G'$). 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 $H_0 \approx 74$. The factor of $-G'$ replaces the Λ term in order to explain late time accelerated expansion of the universe. Further fine-tuning of theory and larger 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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