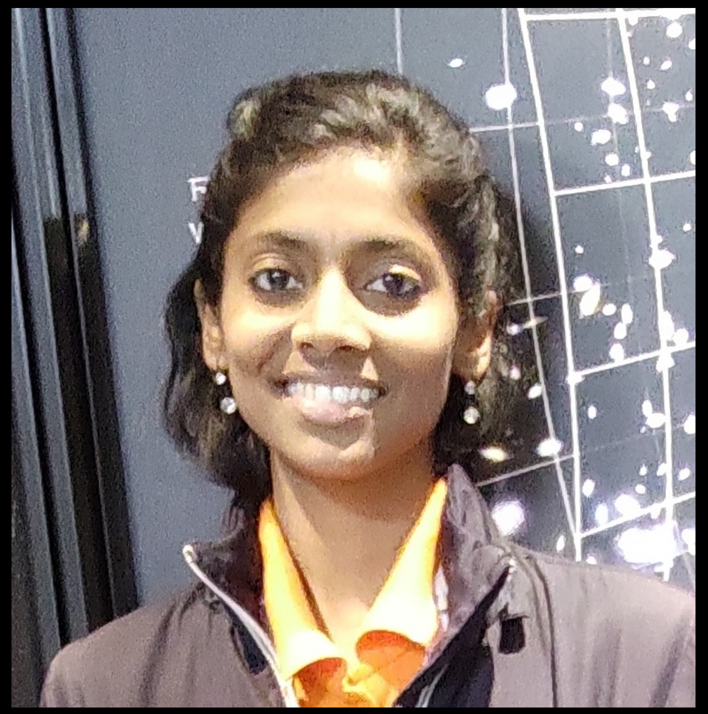
Cosmology From Home
2021



Observational constraints on the possibility that Sterile Neutrinos cause Anti-Gravity

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A novel idea:

Can the acceleration of the universe be due to repulsive gravity caused by sterile neutrinos?

Overview

- Motivation
- Theory
- Modified FLRW Equations
- Results

Motivation

- More number of stars formed late in the cosmic timeline, thus giving rise to more number of supernovae explosions.
- Stellar neutrinos thus produced copiously .
- IF sterile neutrinos do cause repulsive gravity, then:
- Greater flux of sterile neutrinos → accelerated expansion in late-time universe.

Modified Einstein Field Equation

- Introduce a negative gravitational constant, called $-G'$ $(G' > 0)$ associated with sterile neutrinos.

- Remove the cosmological constant term i.e. $\Lambda = 0$, and replace it with $(T_{\mu\nu})_{s\nu}$

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

- Now re-writing the modified FLRW Equations:

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3}\left[\rho_m + \rho_r - \frac{G'}{G}\rho_{s\nu}\right] - \frac{kc^2}{a^2} \quad \text{......................} \quad \textbf{(1)}$$

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

- Rearranging Eqn. (1), an important condition is obtained:

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

→ $k = -1$

- For an accelerating universe, 1st term of RHS is negative.

- This implies 2nd term of RHS *has* to be negative i.e. $k = -1$, for LHS to remain positive}.

Sterile Neutrinos - How Many?

Massive Sterile Neutrinos

Light Sterile Neutrinos

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

- Use this to obtain the radial distance as a function of redshift, z.

Very Light Sterile Neutrinos

- For very light sterile neutrinos, the energy density can be taken similar to that of radiation . The radial distance is given by the formula:

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

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

Massive Sterile Neutrinos

- For massive sterile neutrinos, the energy density is roughly similar to that of ordinary matter. The radial distance is given by the formula:

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

- With, $K_2 = \Omega_{m,0} - \alpha$ and $K_3 = \dfrac{c^2}{a_0^2 H_0^2}$

Comparing with Observations

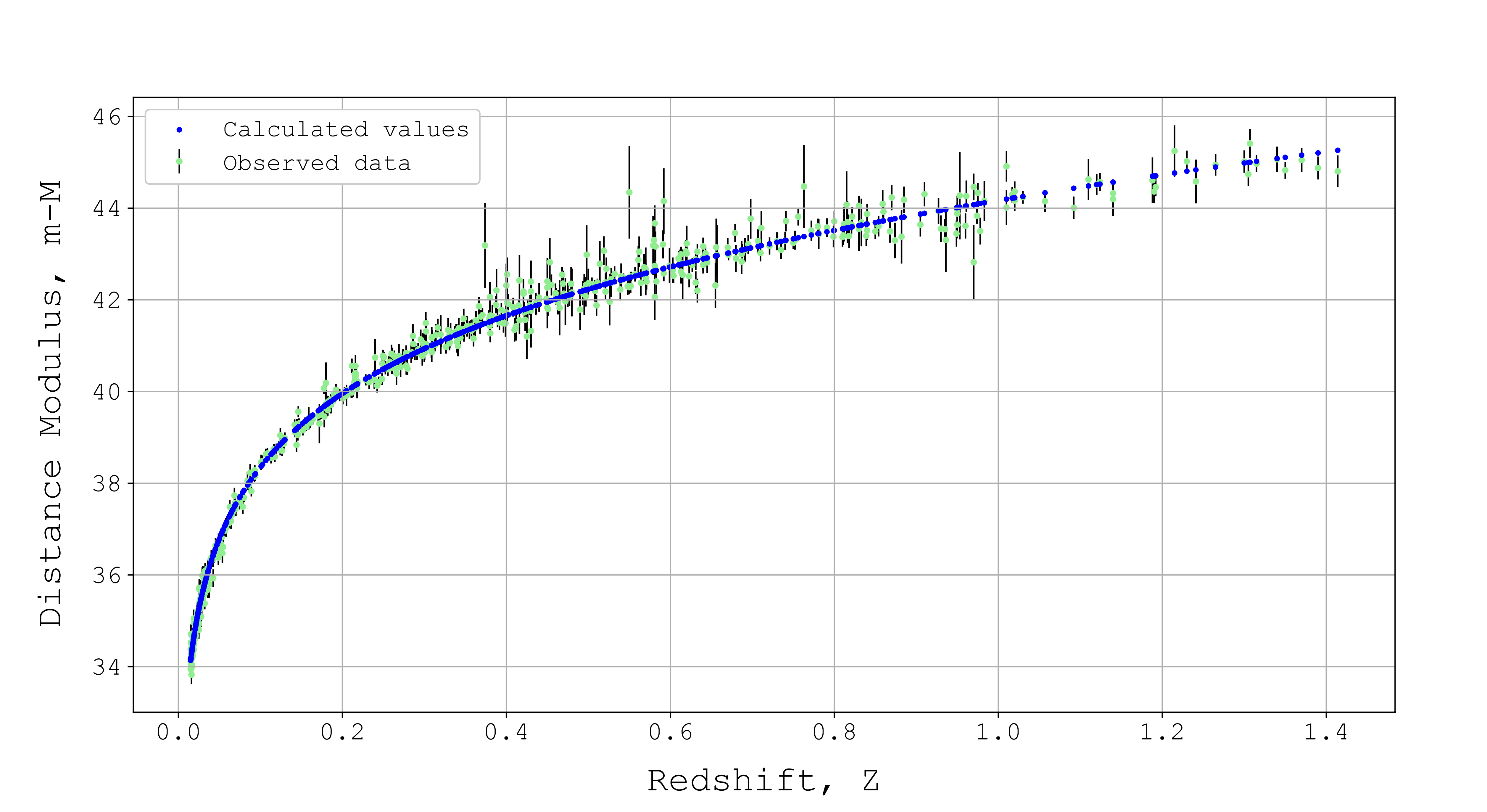
- Using the previously computed radial distances, calculate the distance modulus values:

$$m - M = 5\log_{10}\left(\frac{d_L(z)}{10pc}\right)$$

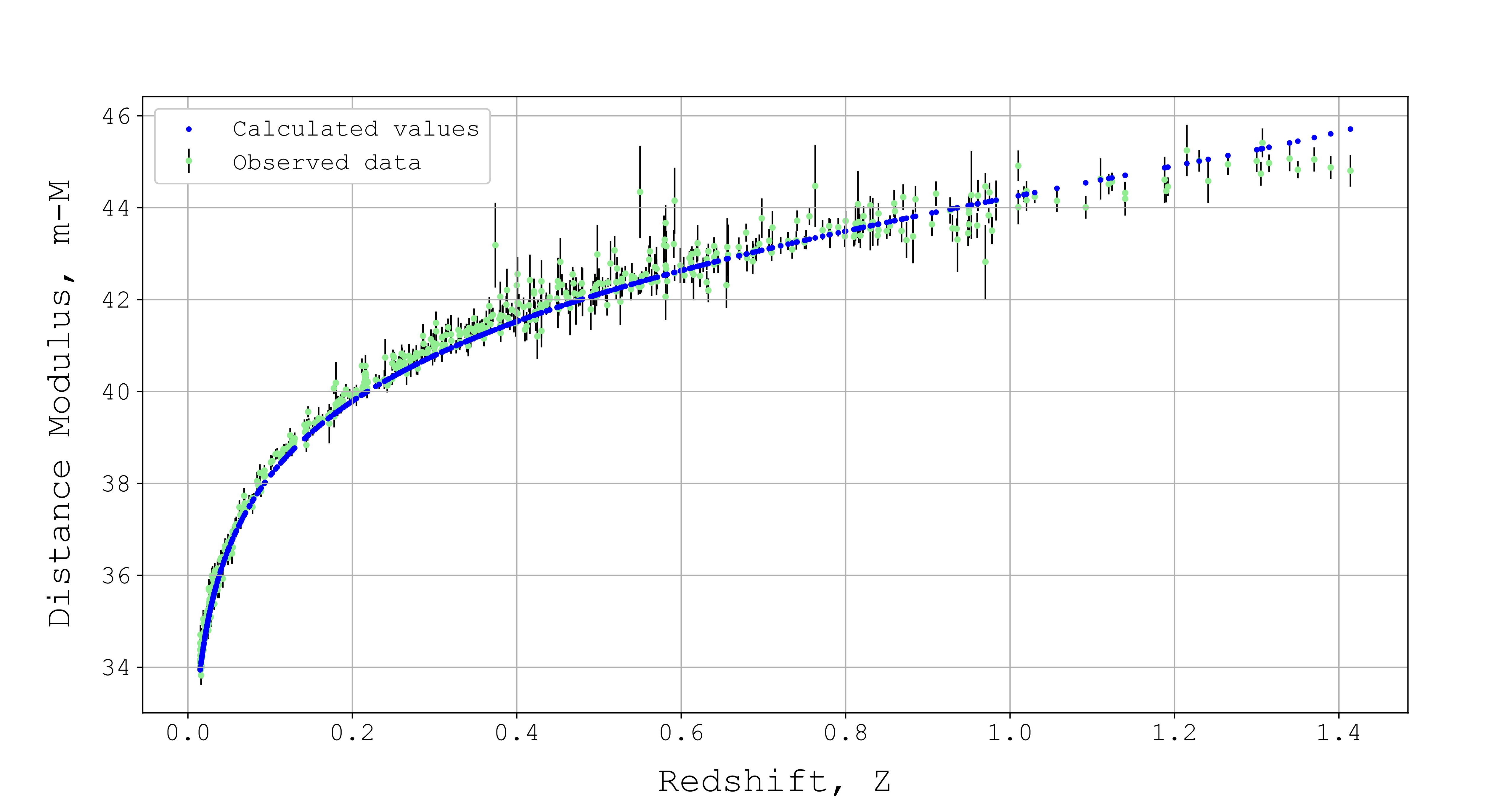
- Observational data used: Type Ia Supernovae data from the Union 2.1 Catalogue (Supernova Cosmology Project, Suzuki et al., 2012).

- Plot and compare the computed distance modulus values as a function of the redshift, with that obtained from SNIa observations.

Results

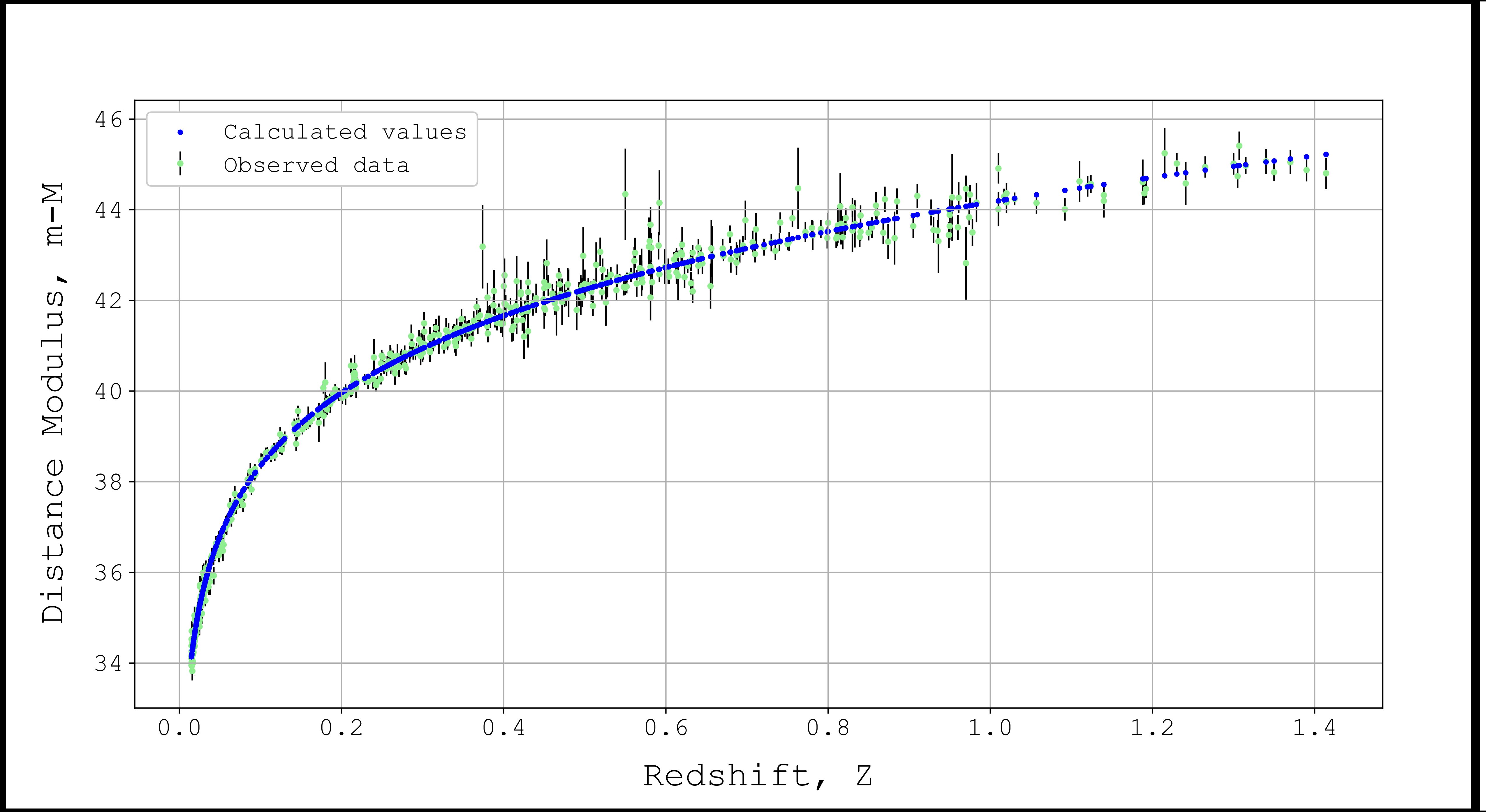


Light sterile Neutrinos, $H_0 = 67.4$ $(G'/G)\Omega_{s\nu 0} = 0.1584$

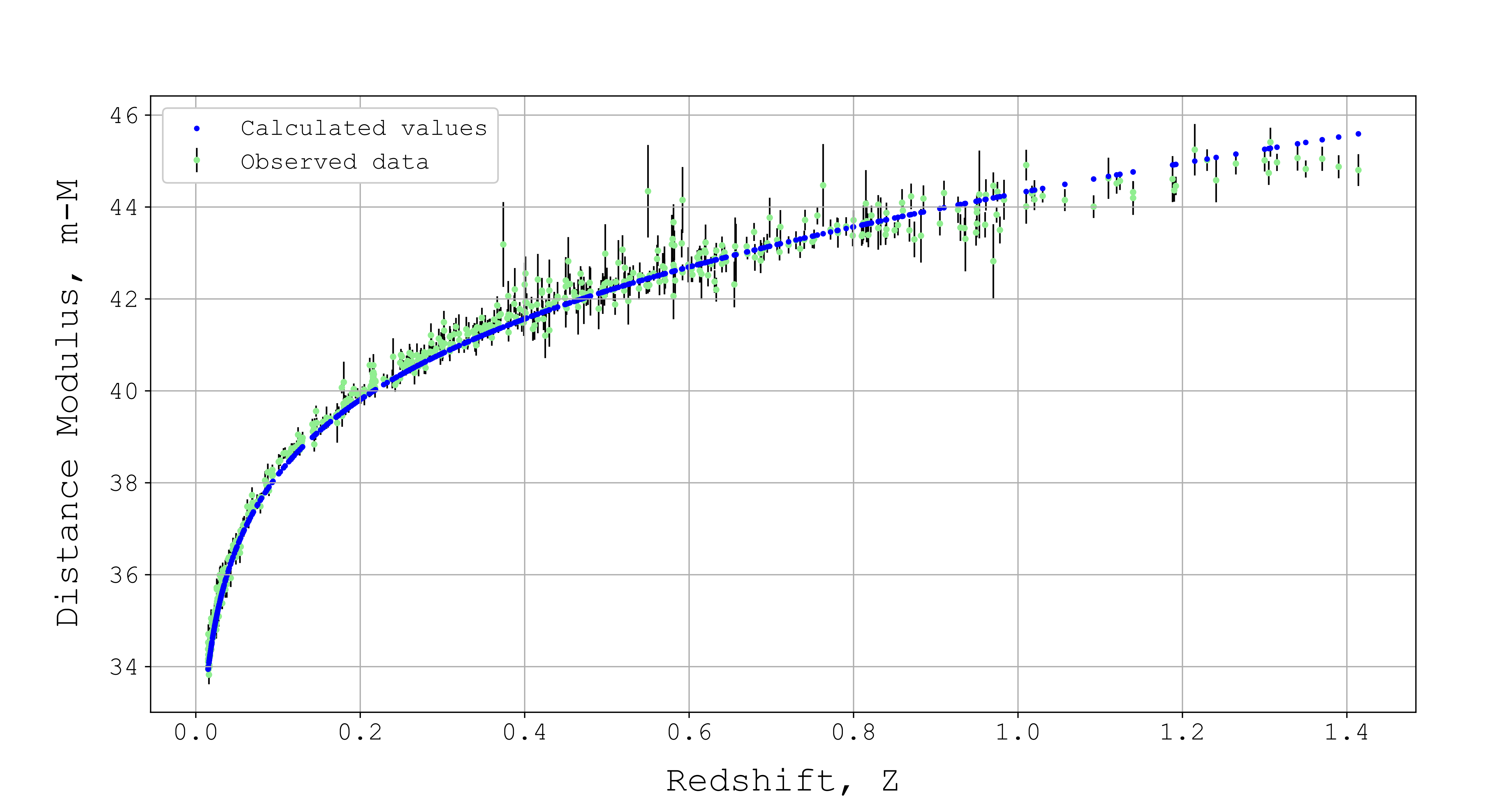


Light sterile Neutrinos, $H_0 = 73.8$ $(G'/G)\Omega_{s\nu 0} = 0.2759$

Results



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



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

Summary Table

- A summary of the various combinations used and the best fit parameter values:

H0	$\frac{G'}{G}\Omega_{s\nu}$	
	Massive Case	Light Case
67.4	0.3579	0.1584
69.8	0.5243	0.2199
73	0.6904	0.2685
73.8	0.7238	0.2759

Analysis

- The theoretically computed values of (m-M) were plotted and compared with the observed values, according to best fit of the free parameter, $\frac{G'}{G}\Omega_{s\nu}$.
- Different combinations of H_0 and $\frac{G'}{G}\Omega_{s\nu}$ were studied. Goodness of fit estimated using weighted least squares minimization.
- Values of H_0 ranging from 67.4 to 73.8.
- Satisfactory fits even with recent findings of $H_0 \sim 74$ (Pesce et al., 2020)

Future Prospect

- The theory needs to be refined further to include the time dependent contribution of sterile neutrinos.
- A preliminary calculation shows the addition of the -G′ term and repulsive gravity does not affect the present scenario of early universe.
- The theory can hold a wide number of applications in cosmology and structure formation.

Thank you!