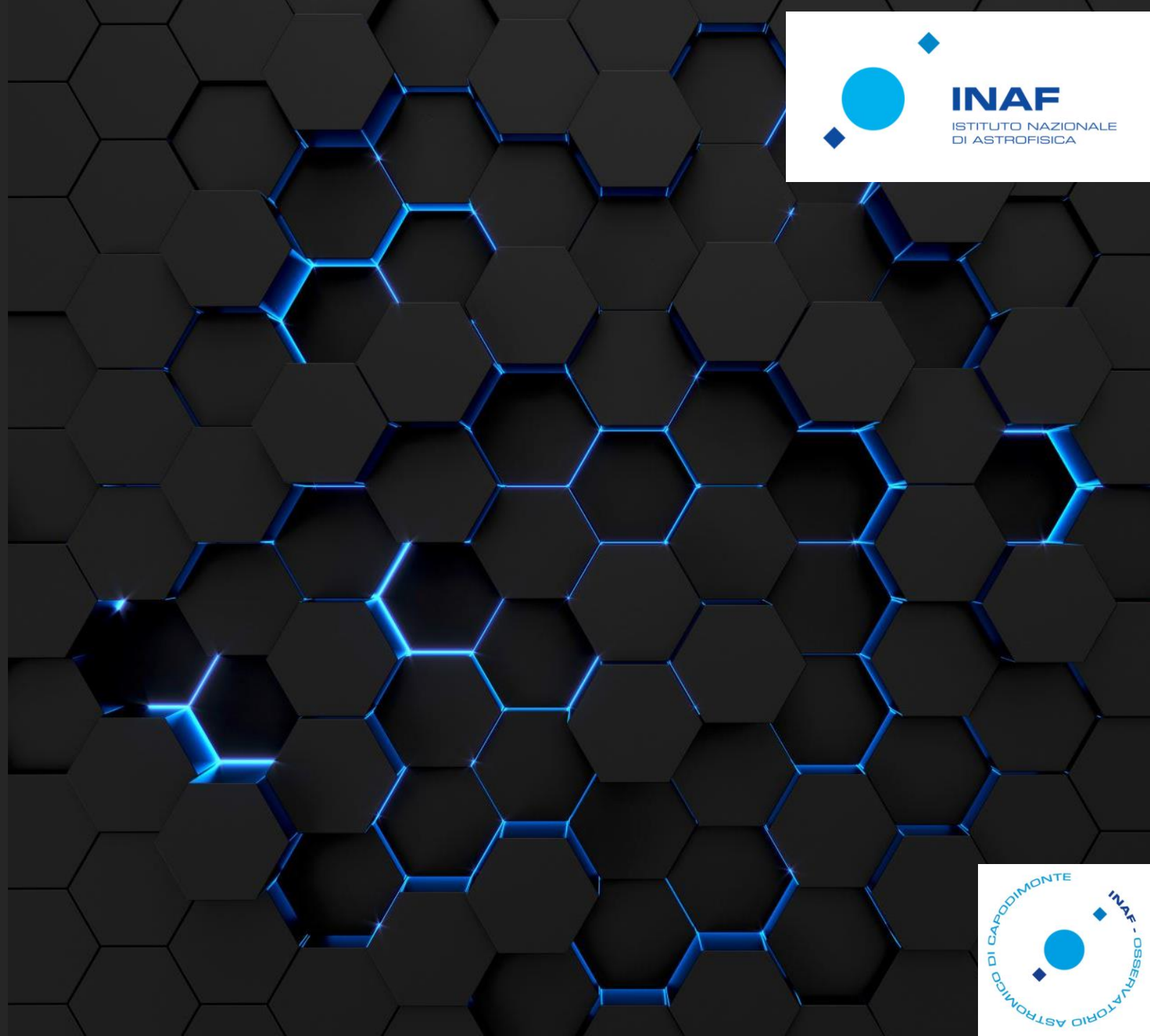
A quantum genetic algorithm to optimize cosmological parameters

BAO, CMB, SNE IA, FINDING THE BEST VALUES FOR H0 AND Ω_M

Giuseppe Sarracino et al.,
USCVIII meeting 15/10/2024



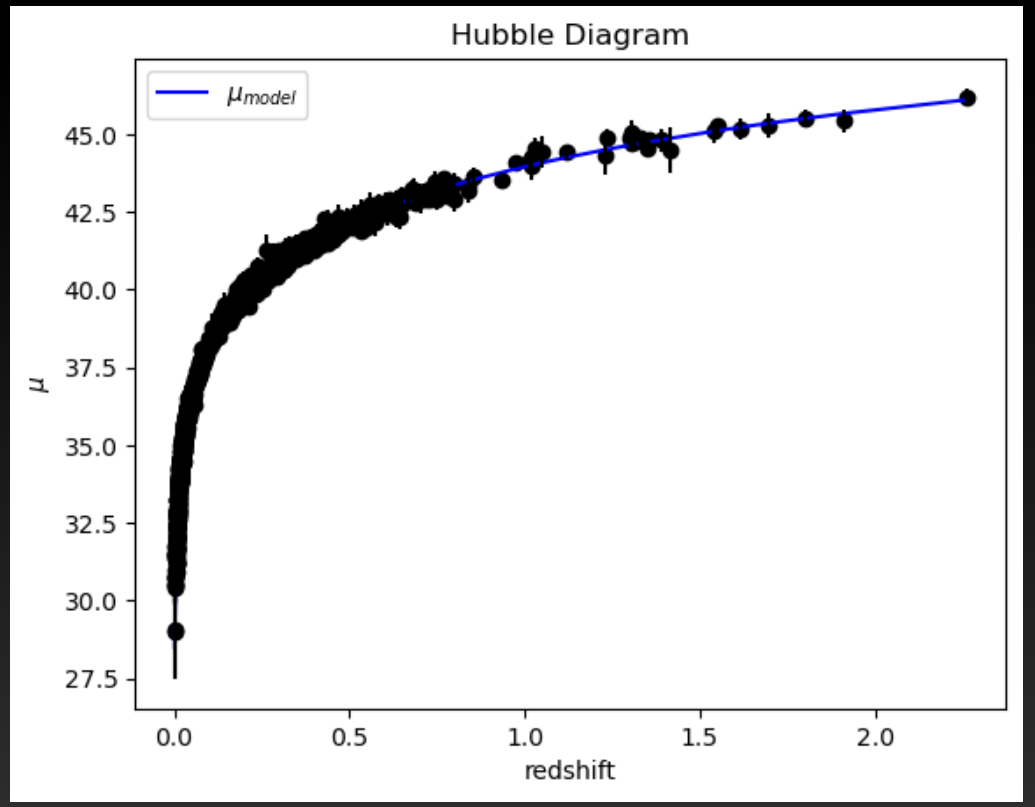
Objective: the Pantheon+ sample of SNe IA

$$\chi^2 = \Delta\vec{D}^T \; C^{-1}_{\text{stat+syst}} \; \Delta\vec{D},$$

$$\mu_{\text{model}}(z_i) = 5\log(d_L(z_i)/10\,\text{pc}),$$

$$d_L(z) = (1+z)c\int_0^z \frac{dz'}{H(z')},$$

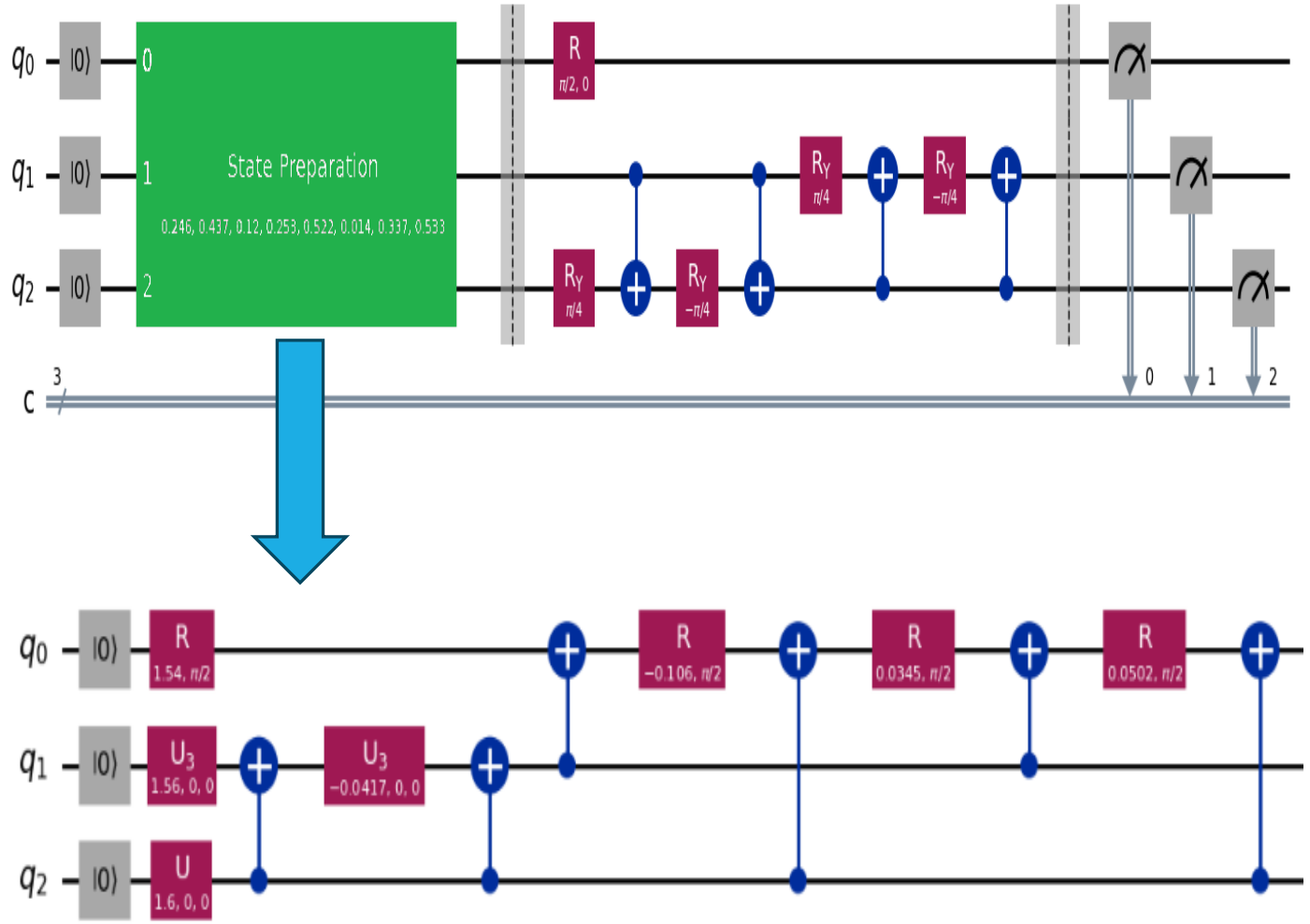
$$H(z) = \text{H}_0\sqrt{\Omega_M(1+z)^3 + \Omega_\Lambda(1+z)^{3(1+w)}}.$$

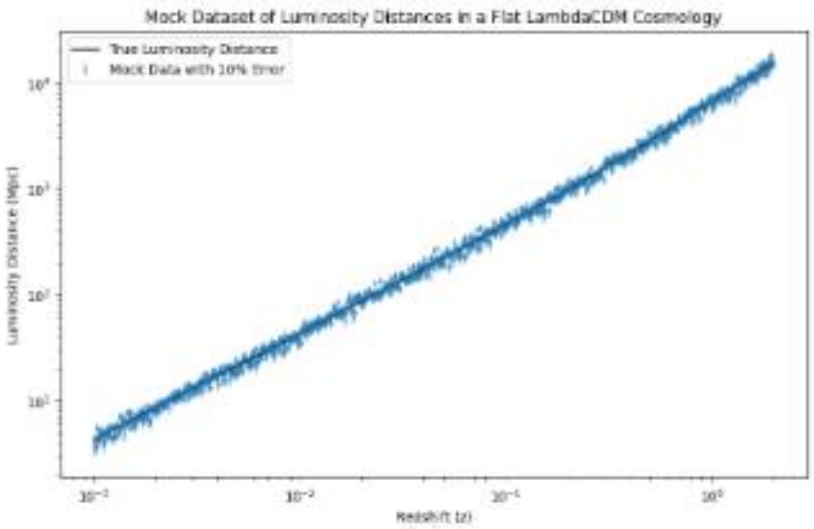


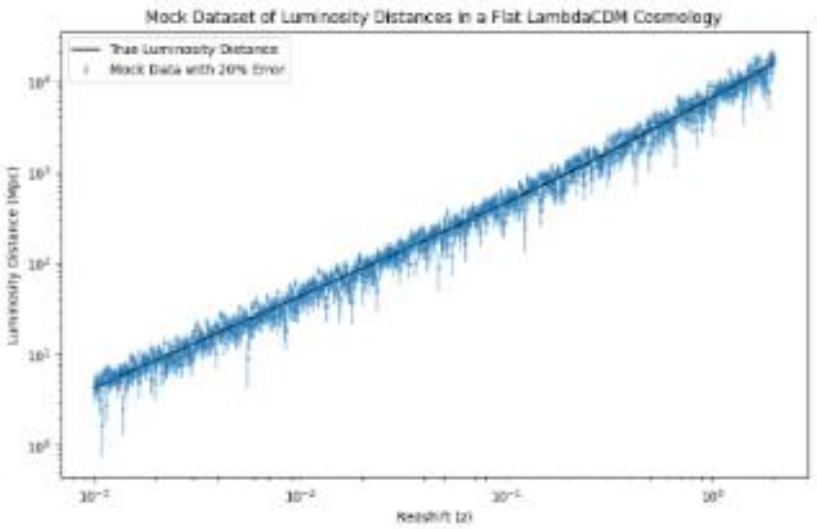
Quantum Genetic Algorithm: Workflow

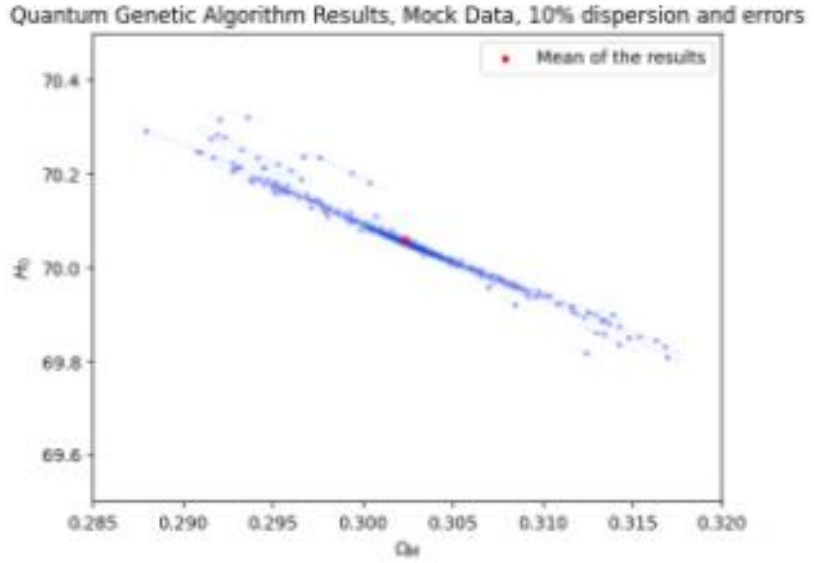
	Fitness Evaluation (Classical), evaluation of the chi-squared functions for the cosmological functions to find the minimization parameters
	Individual Selection and Repopulation (Classical, duplication of the selected individuals)
	2 quantum circuits, one for the duplicated best data and the other for the rest of the population (random), while keeping the best individuals. Quantum Encoding
	Quantum Superposition (already implemented in the encoding)
	Quantum Crossover + Mutation
	Quantum Decoding

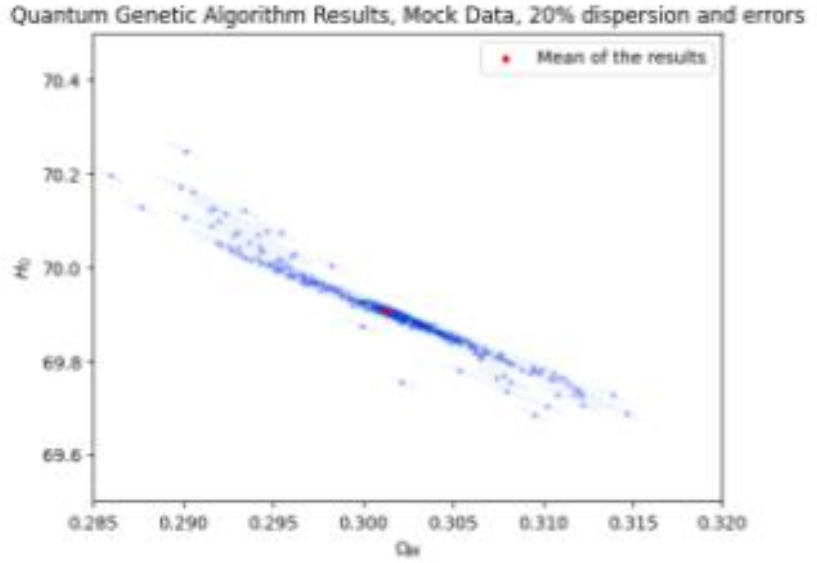
formulation for the quantum circuit for 3 qubits





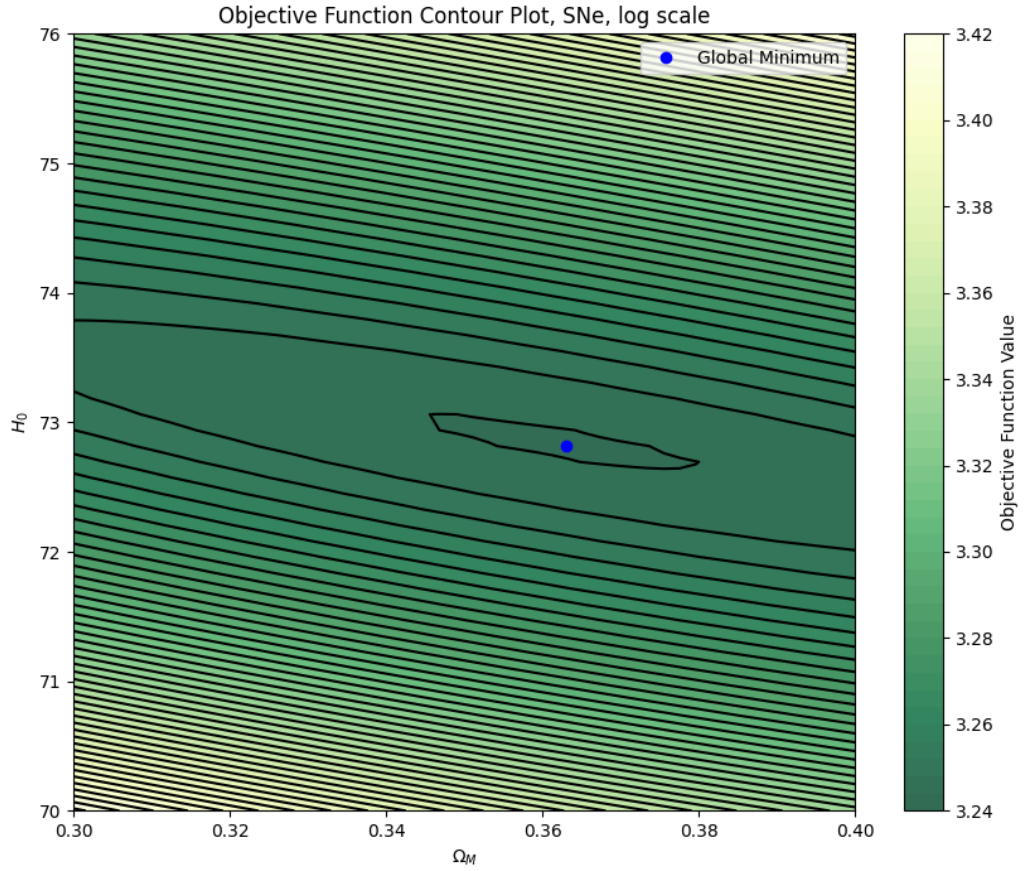


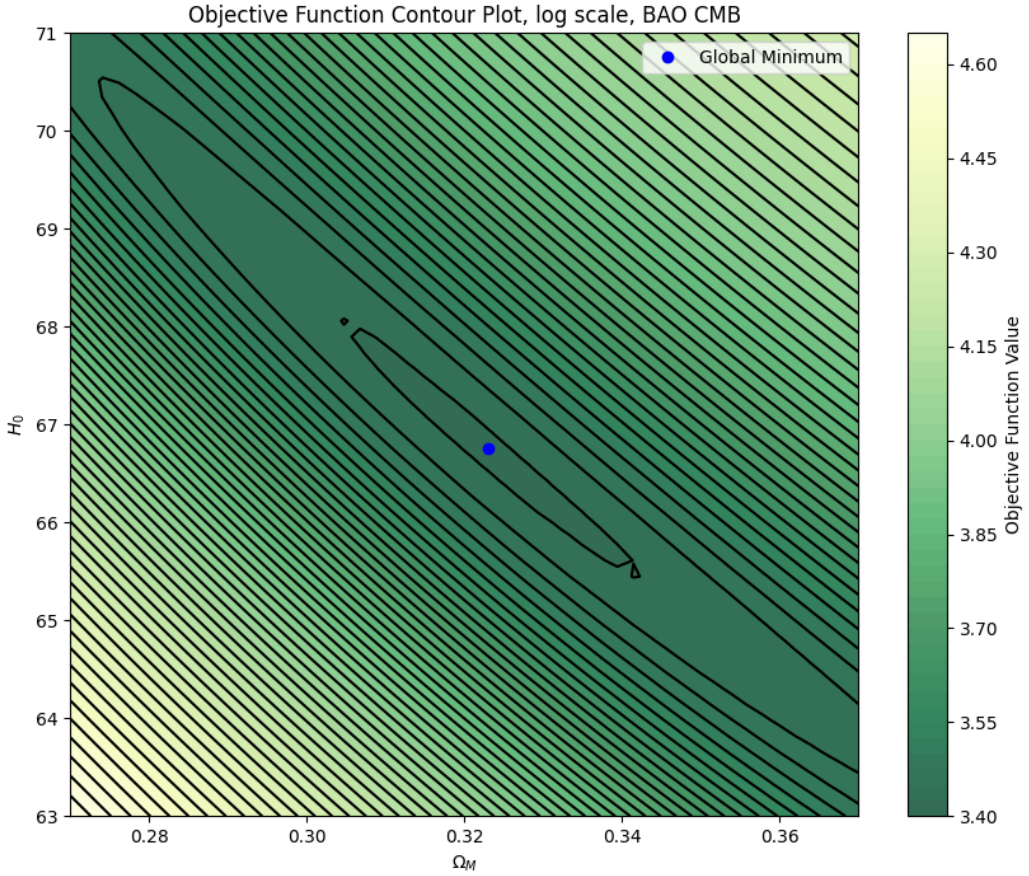


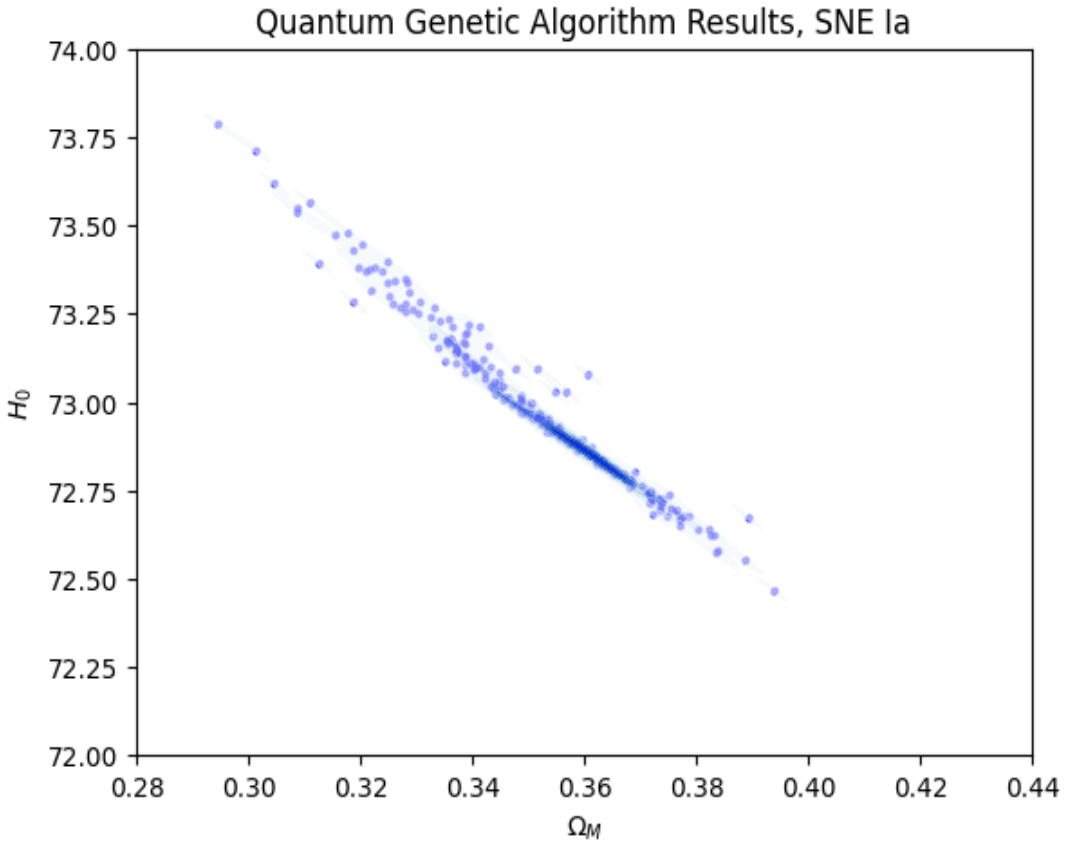


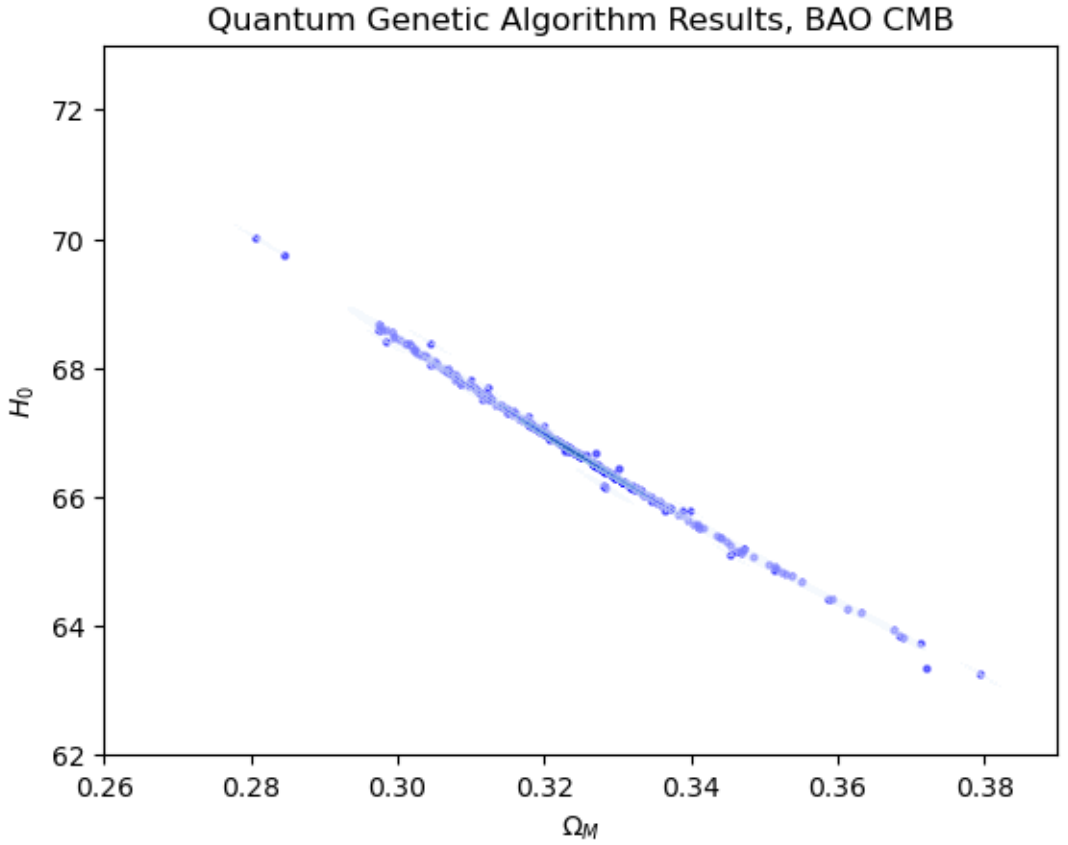
Mock Data results

Contour Maps for the Cosmological Objective functions

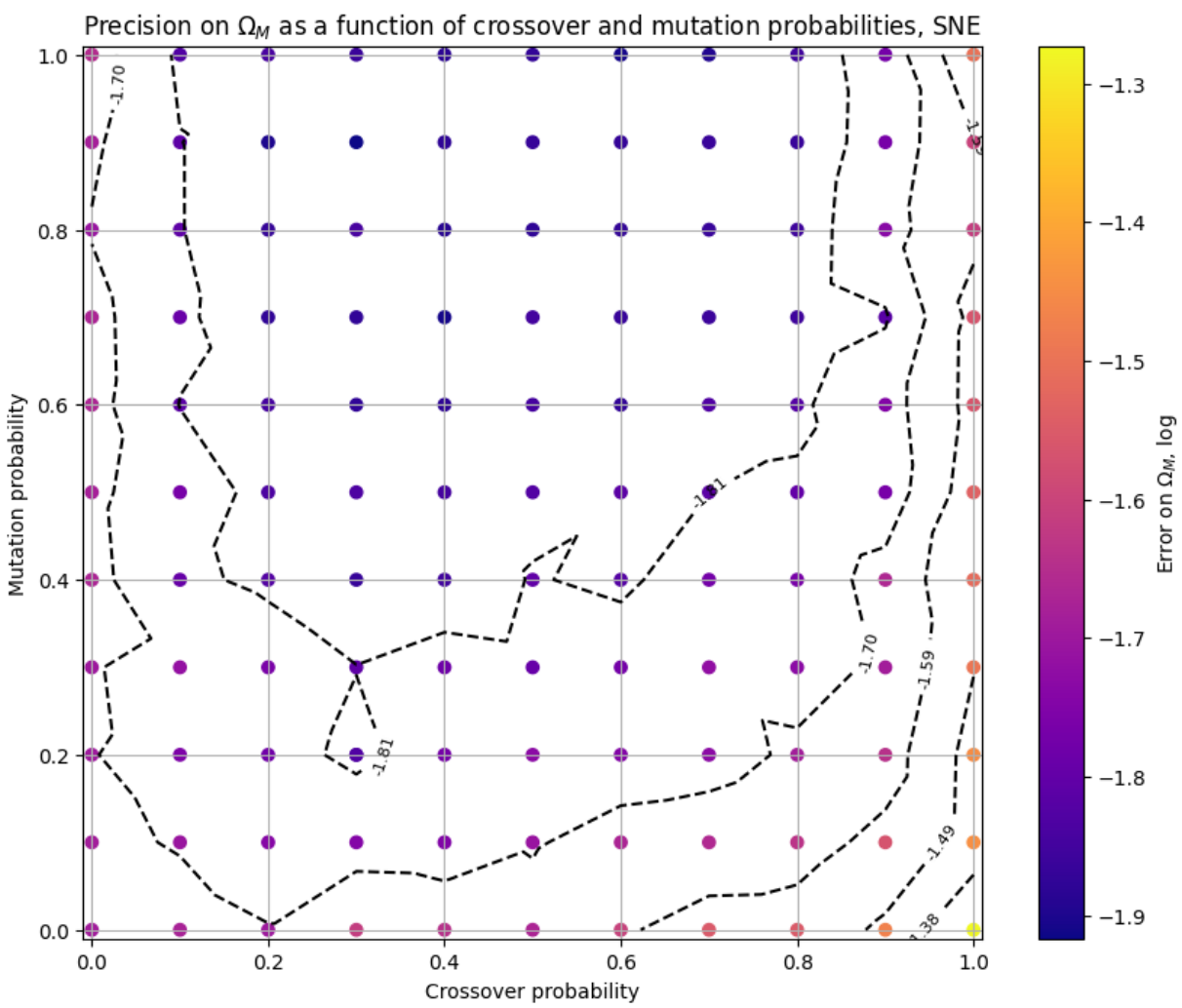


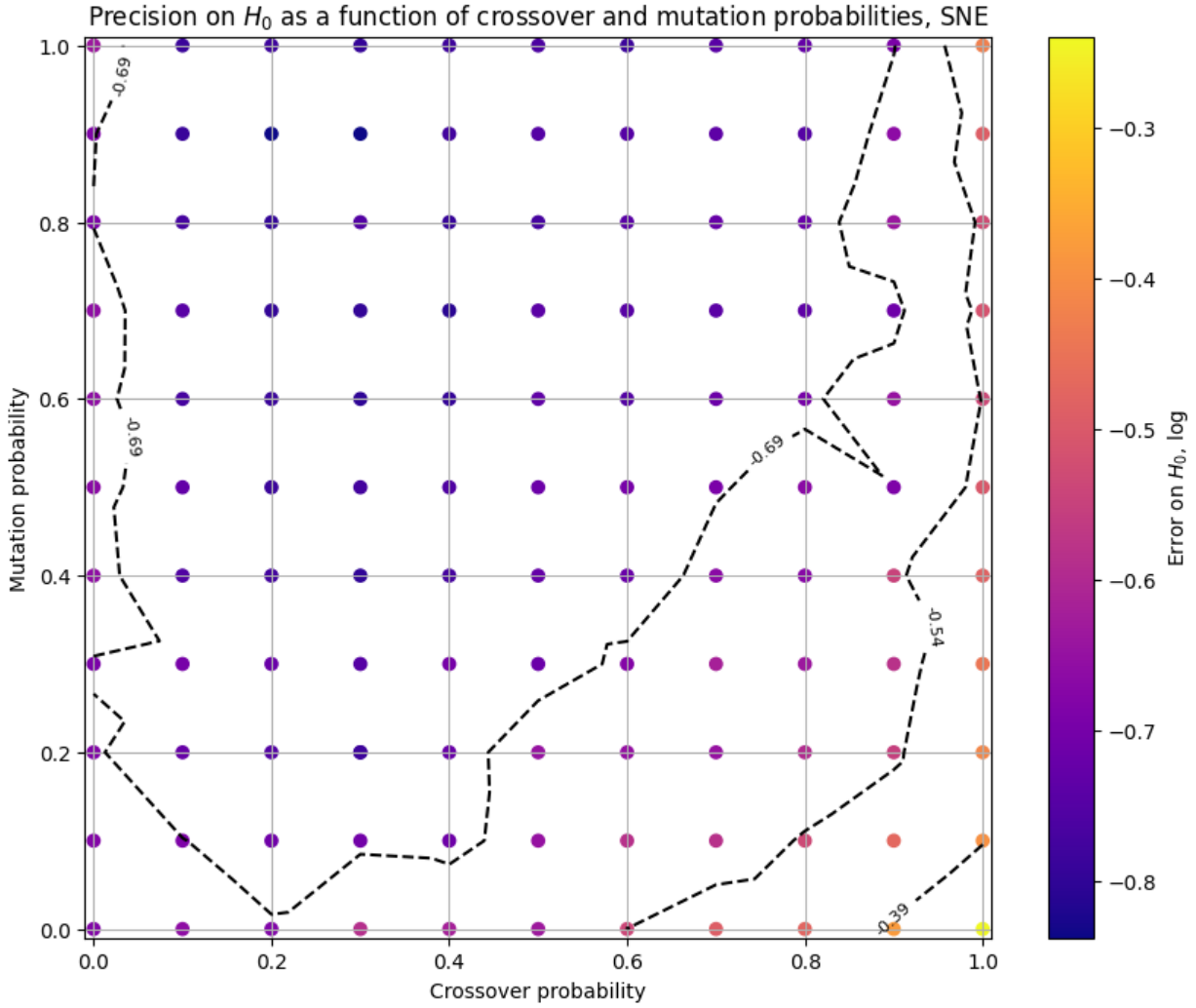






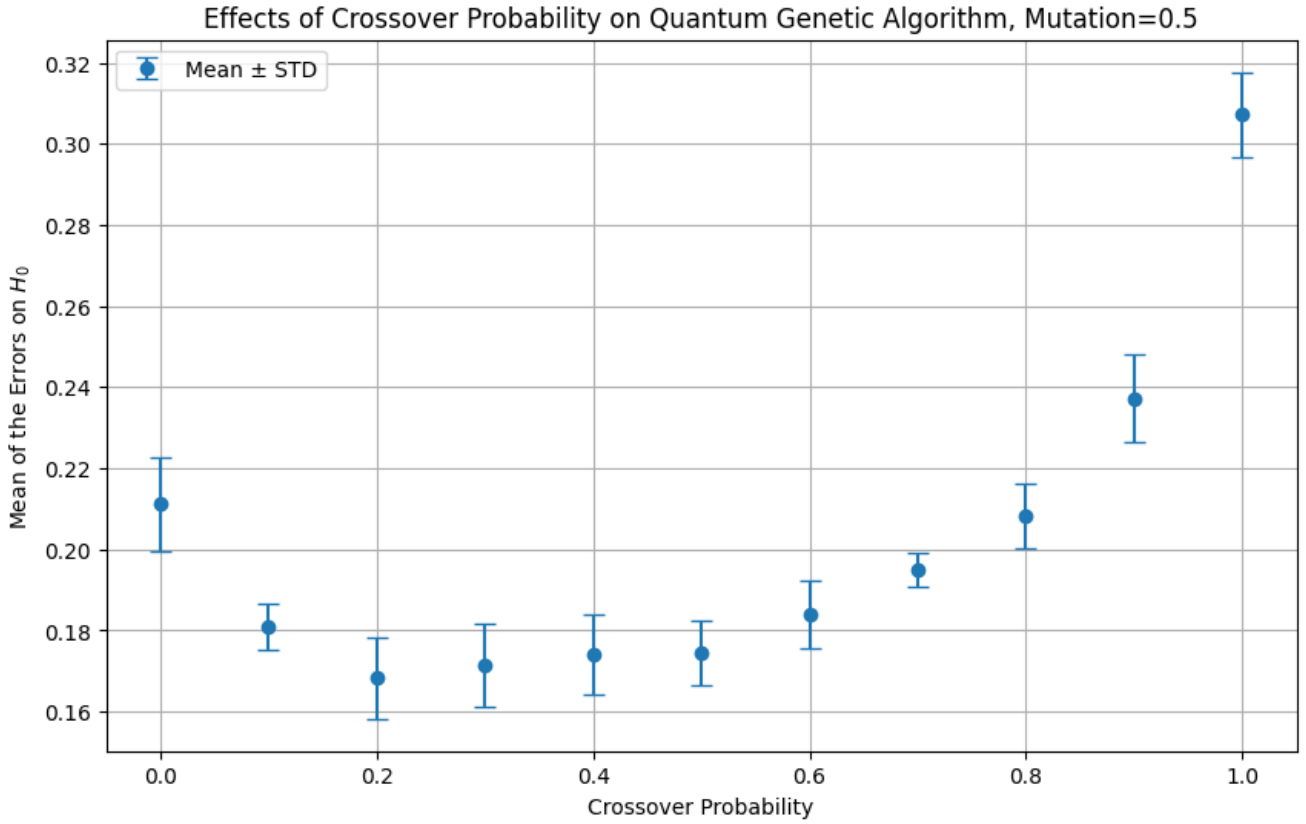
Results with real data (SNe IA left, CMB+BAO right)

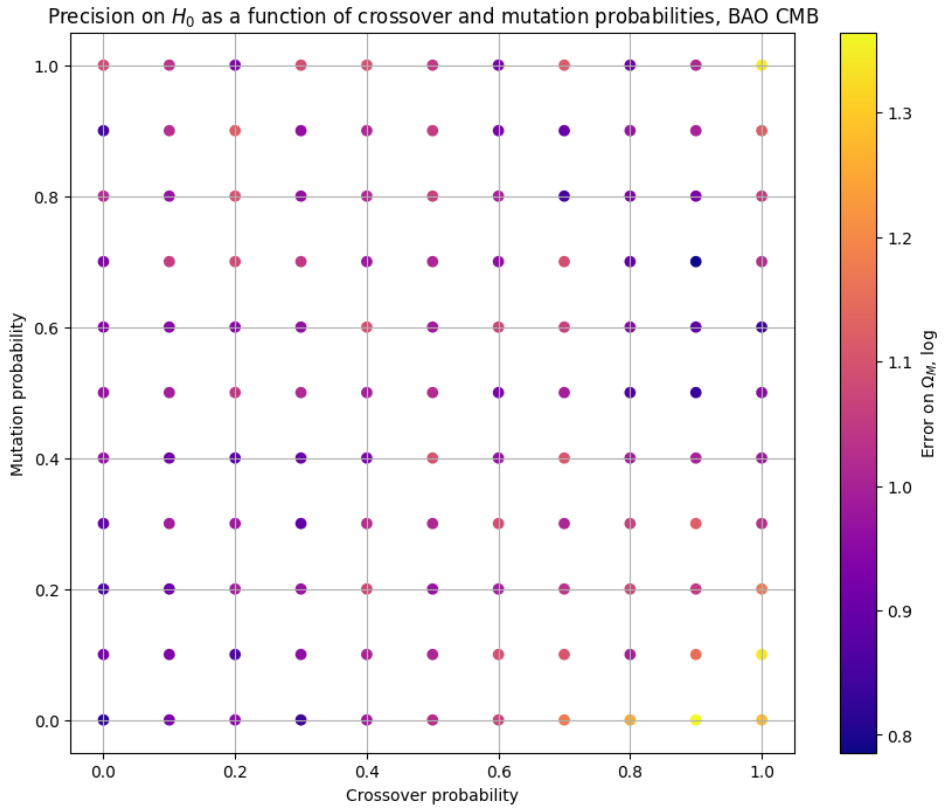


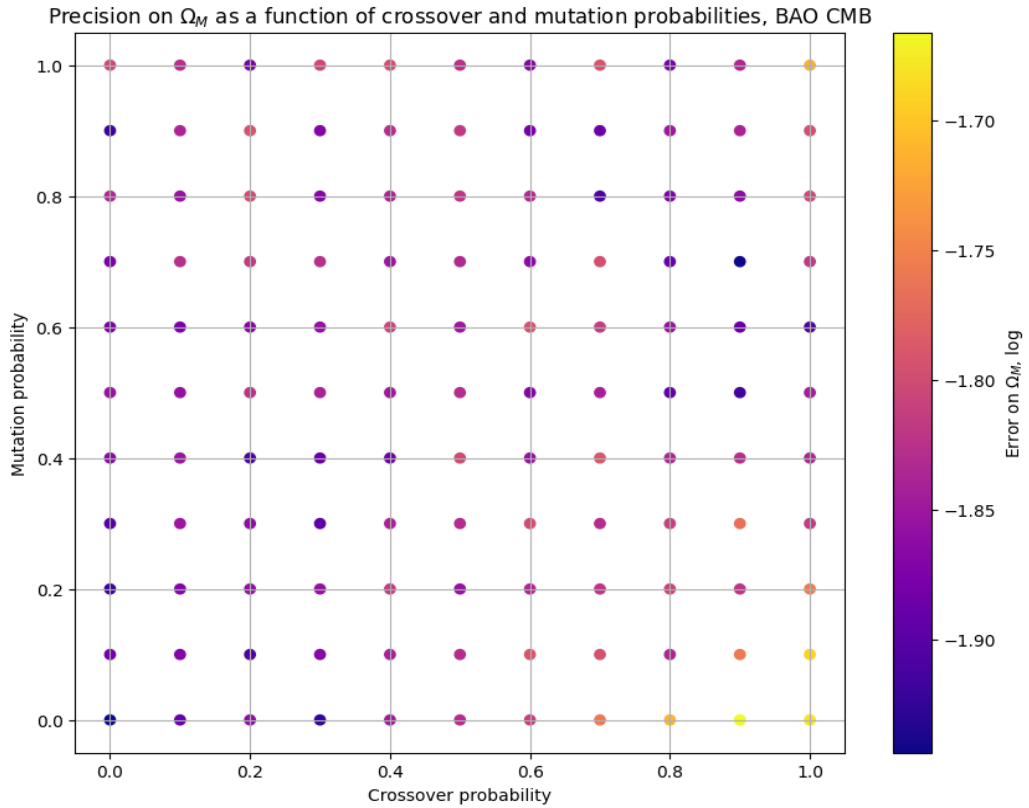


Testing the crossover and mutation effects for the SNe results

Studying the stability of the Algorithm, SNe la

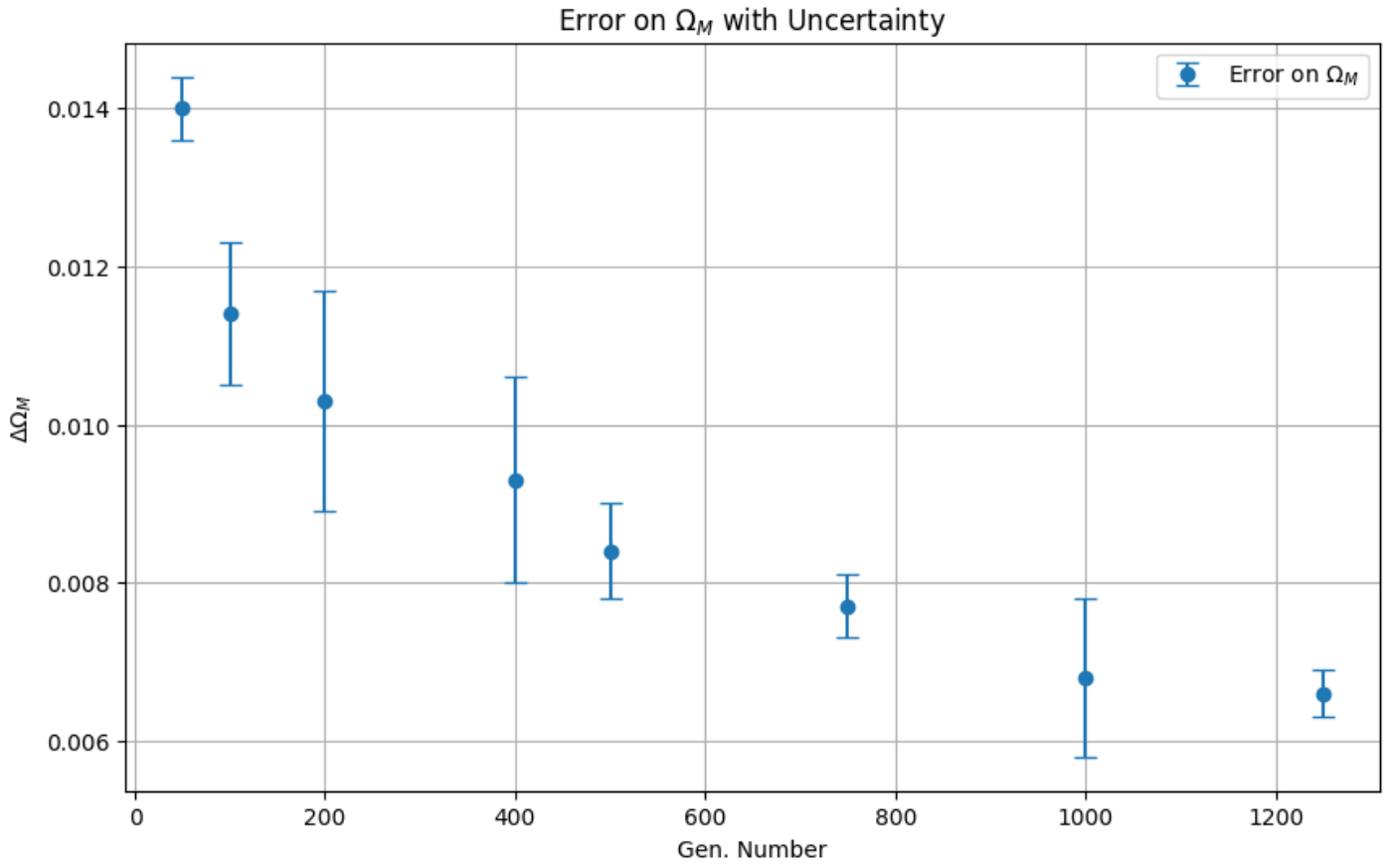


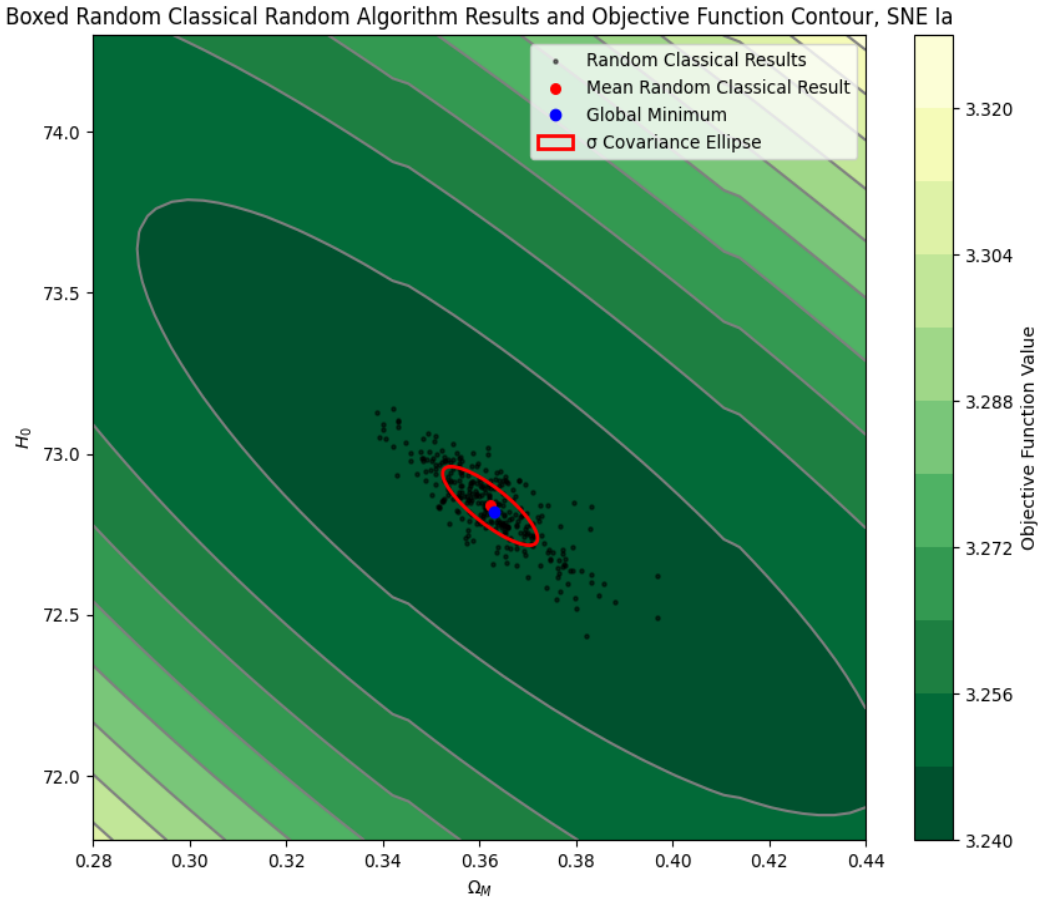


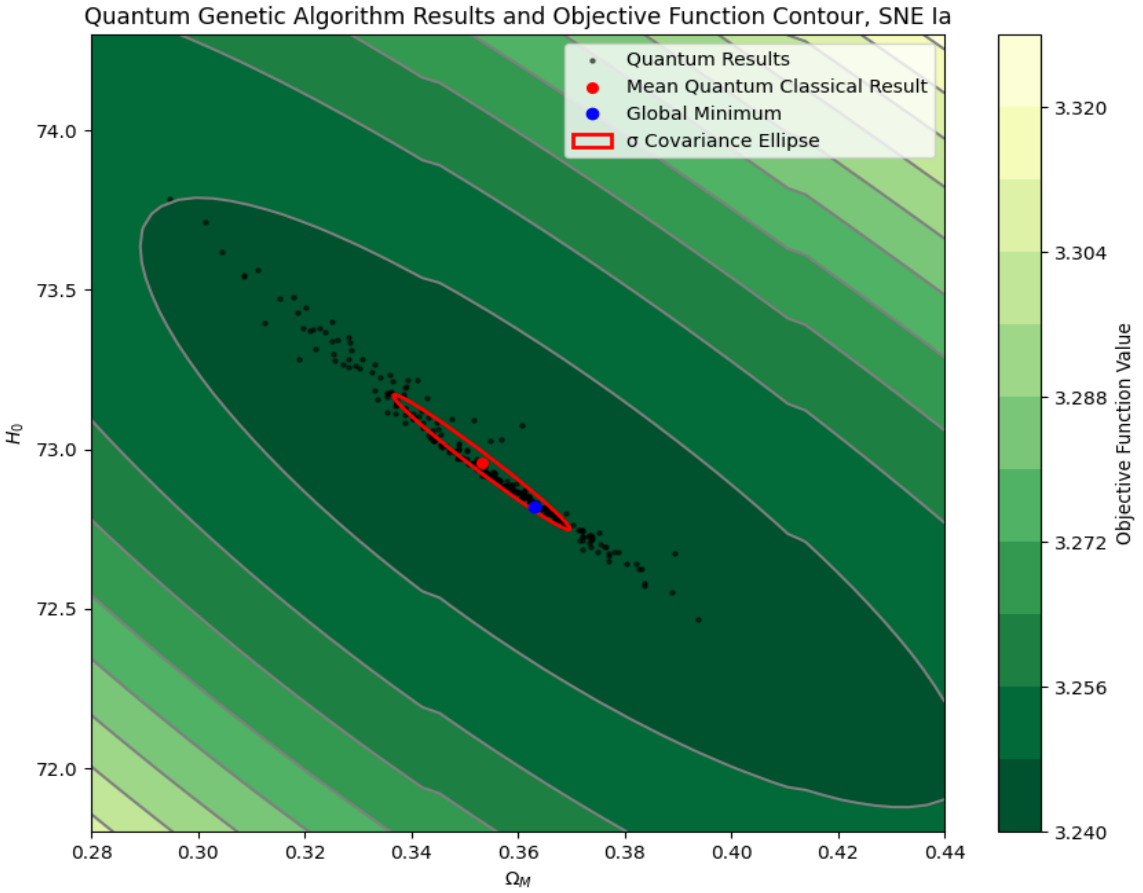


Testing the crossover and mutation effects for the CMB+BAO results

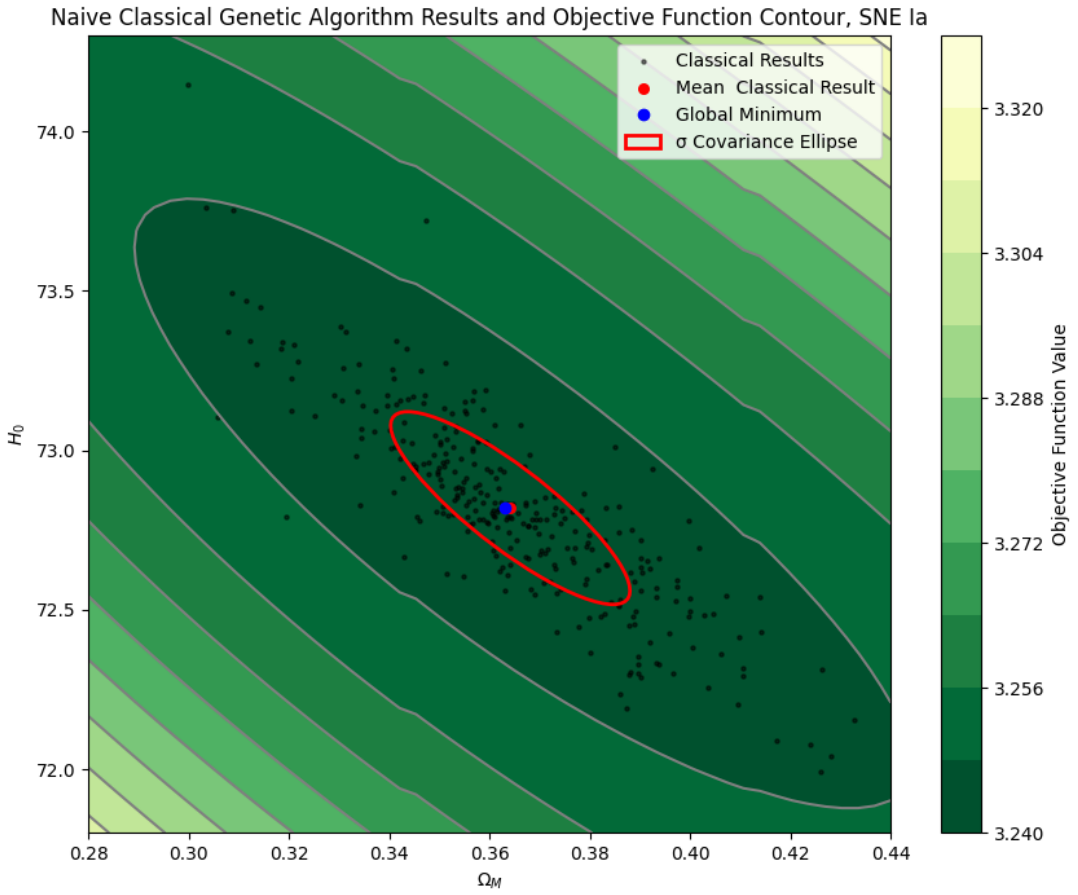
Precision and number of generations, SNE

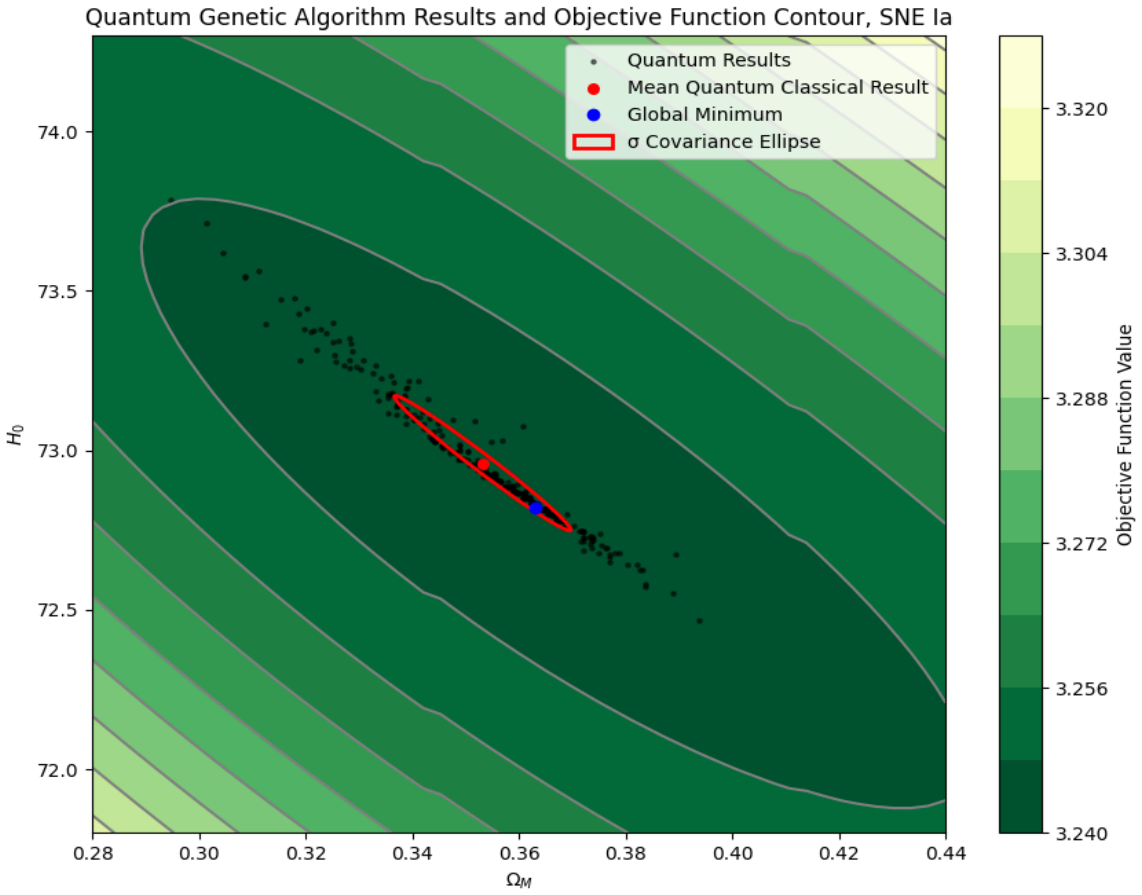






Comparison with classical algorithms (1)

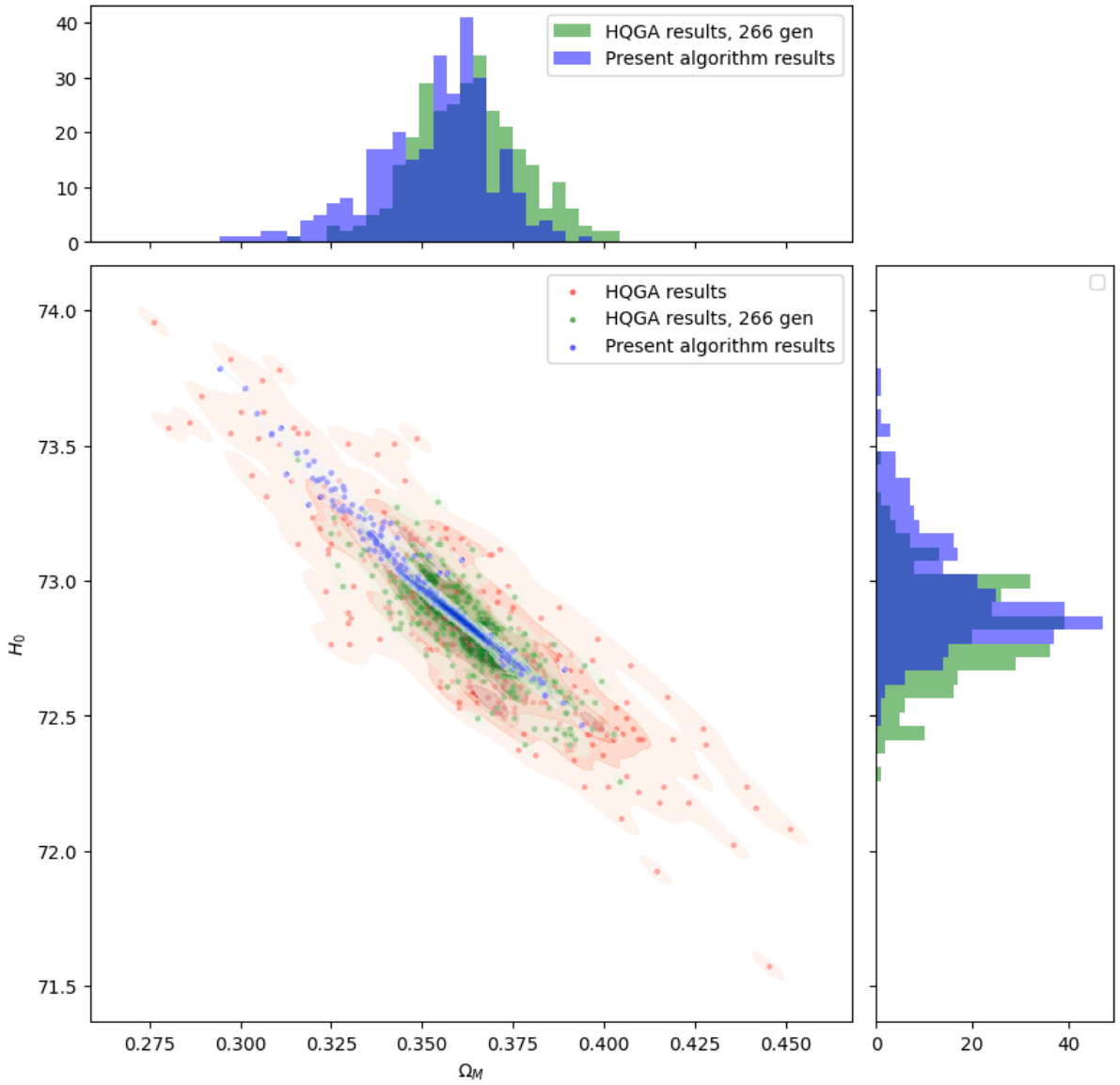




Comparison with classical algorithms (2)

Comparison with HQGA

Hybrid Quantum Genetic Algorithm (HQGA, Acampora et al. 2021) is a quantum genetic algorithm following a different philosophy from ours, but even so the results are comparable if the number of merit evaluation is similar.



Conclusions

1)The algorithm works.

2) An interesting dependence on the crossover and mutation probabilities has been found.

3) The first comparisons with classical results give precisions which are comparable (or even better for a naive application for the classical genetic algorithm), similar conclusion also with another quantum genetic algorithm found in the literature.

4) Tests on the other hyperparameters (number of population and generation) have also been performed.

5) The speed of the algorithm cannot be significantly better than the classical counterparts given the classical fitness evaluation.

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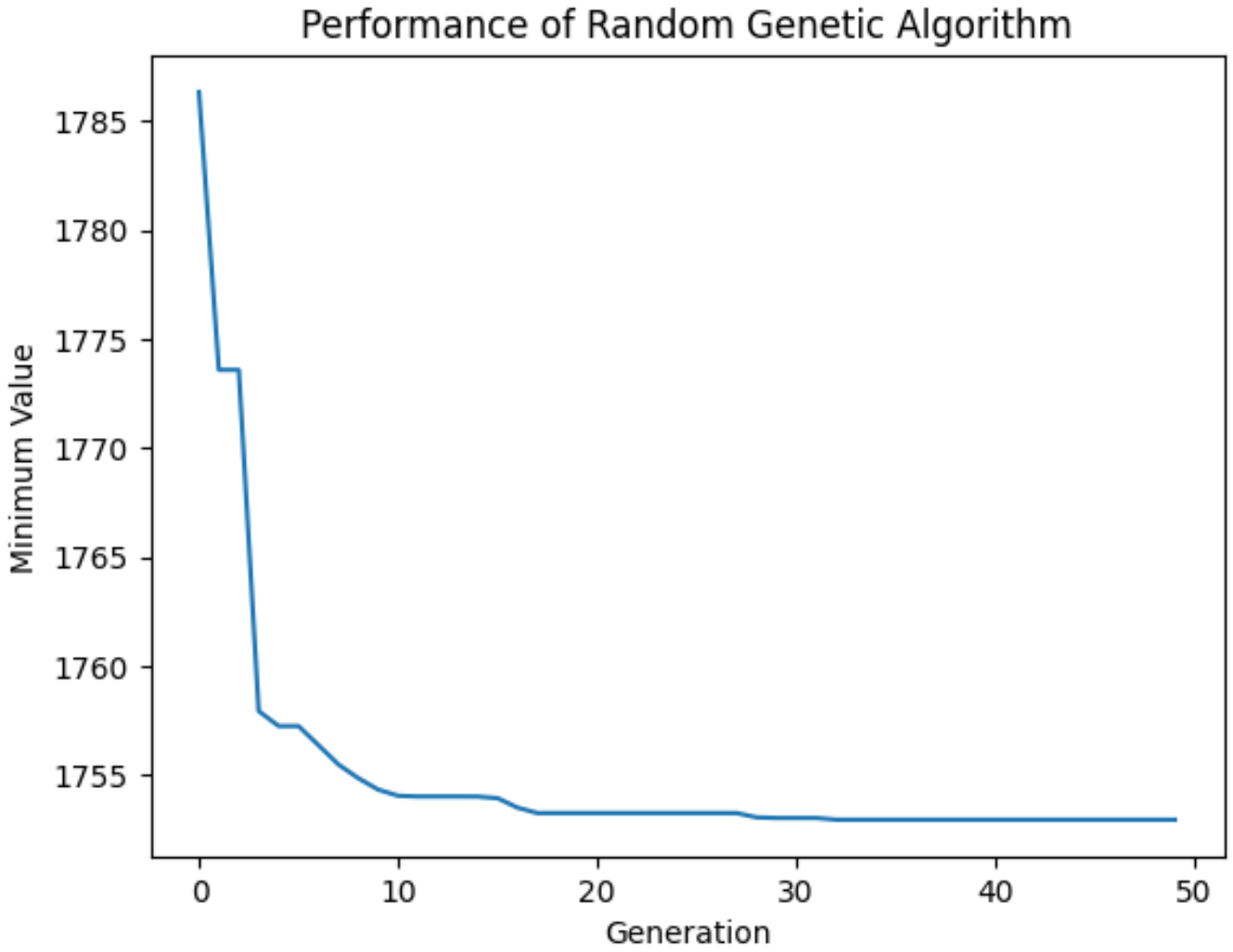
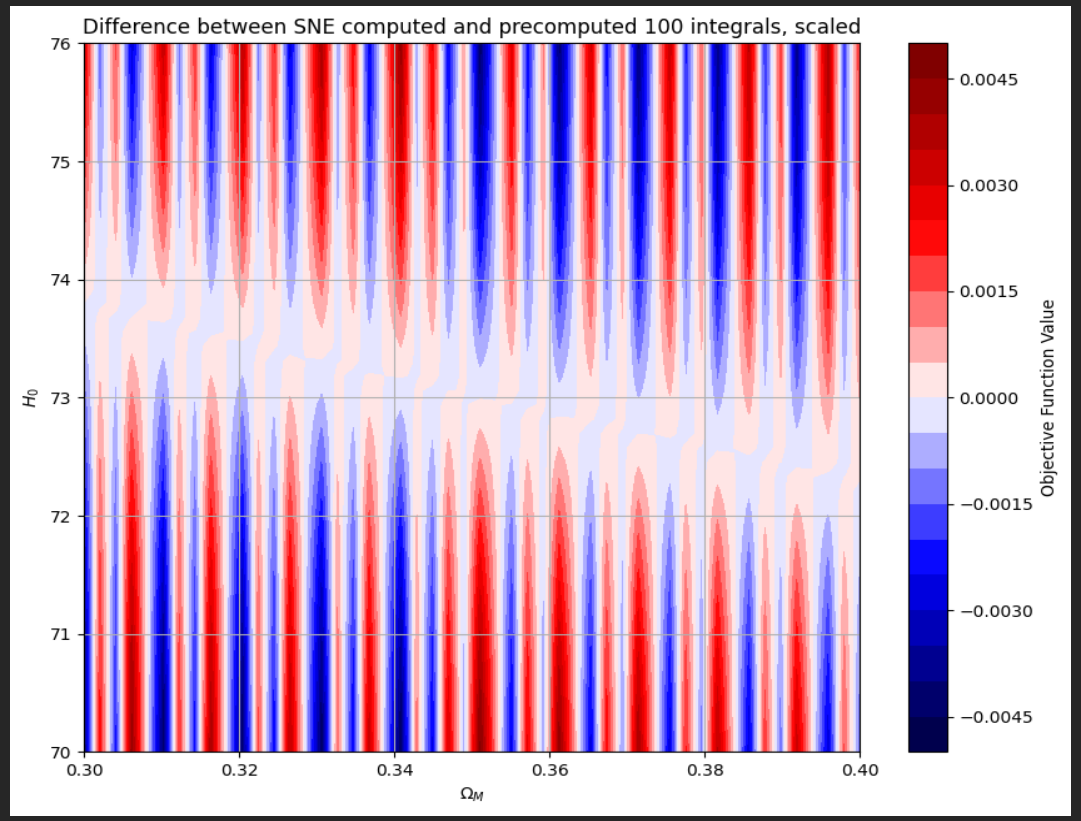
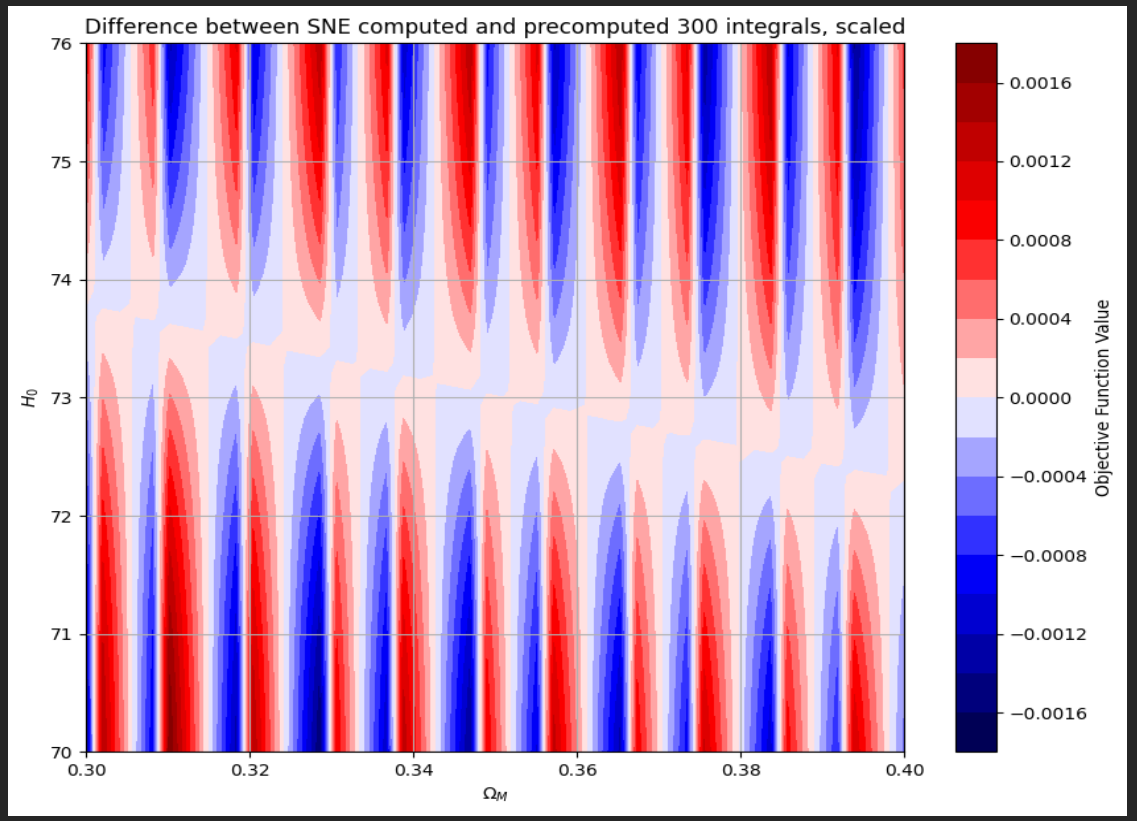


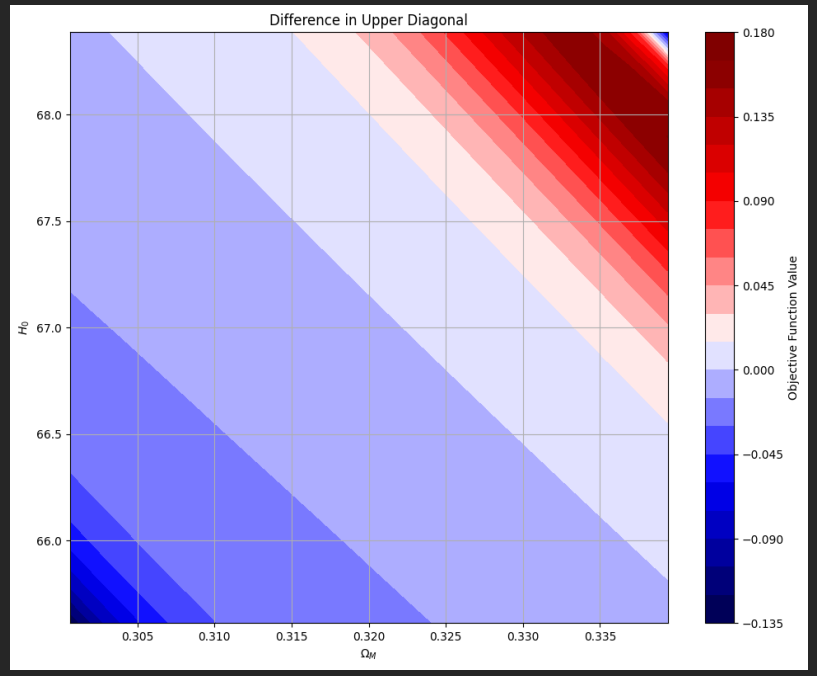
A single iteration of the algorithm for the SNe Ia

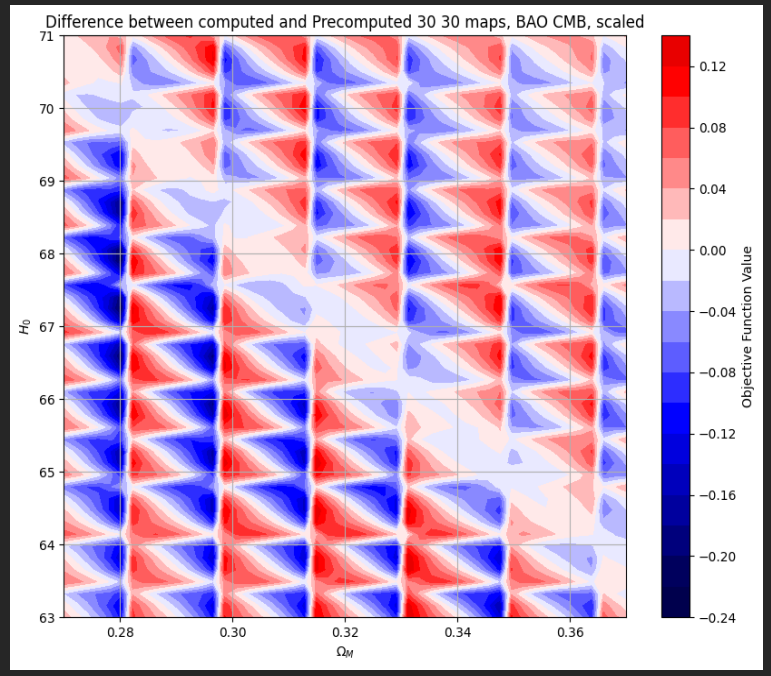
Precomputed Integrals,SNE, confronting the Maps

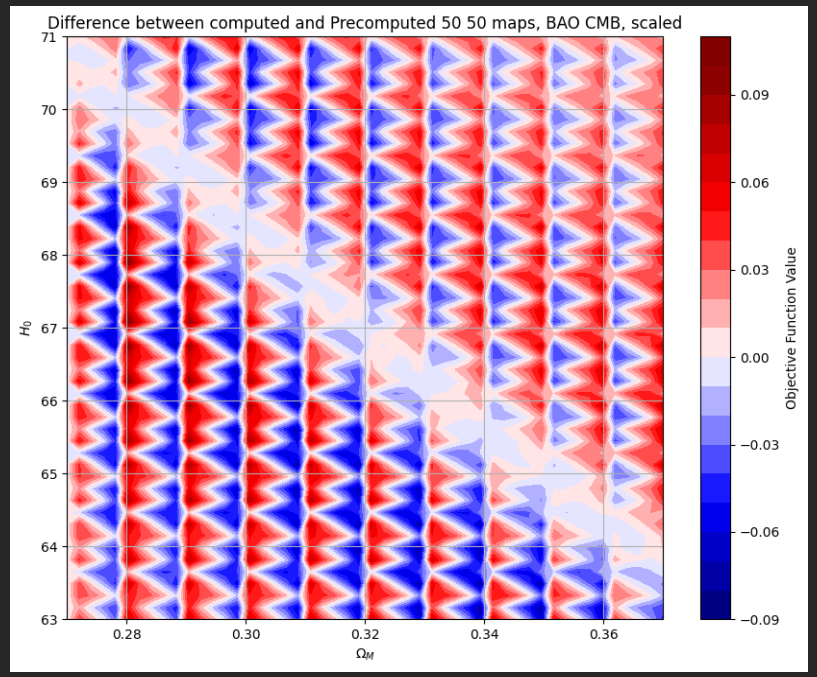
We note the remarkable precision for both the precomputations in the region around the minimum

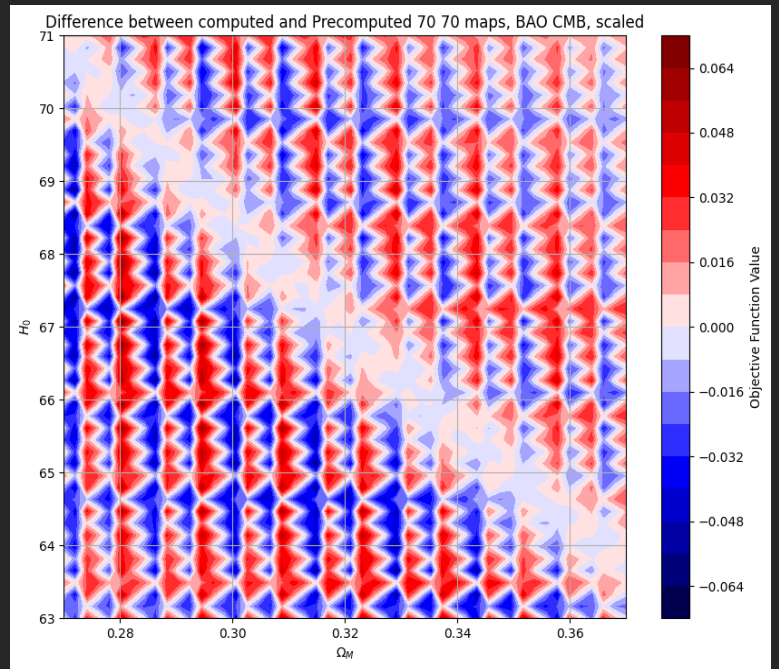












PICO and precomputed maps, BAO+CMB

Note how the PICO map is more consistent in the region around the minimum of the objective function, while loses accuracy in other zones of the parameter space, which are not represented in the PICO plot