# Using Standard Candles Data to Analyse the $\lambda CDM$ Model

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## Introduction

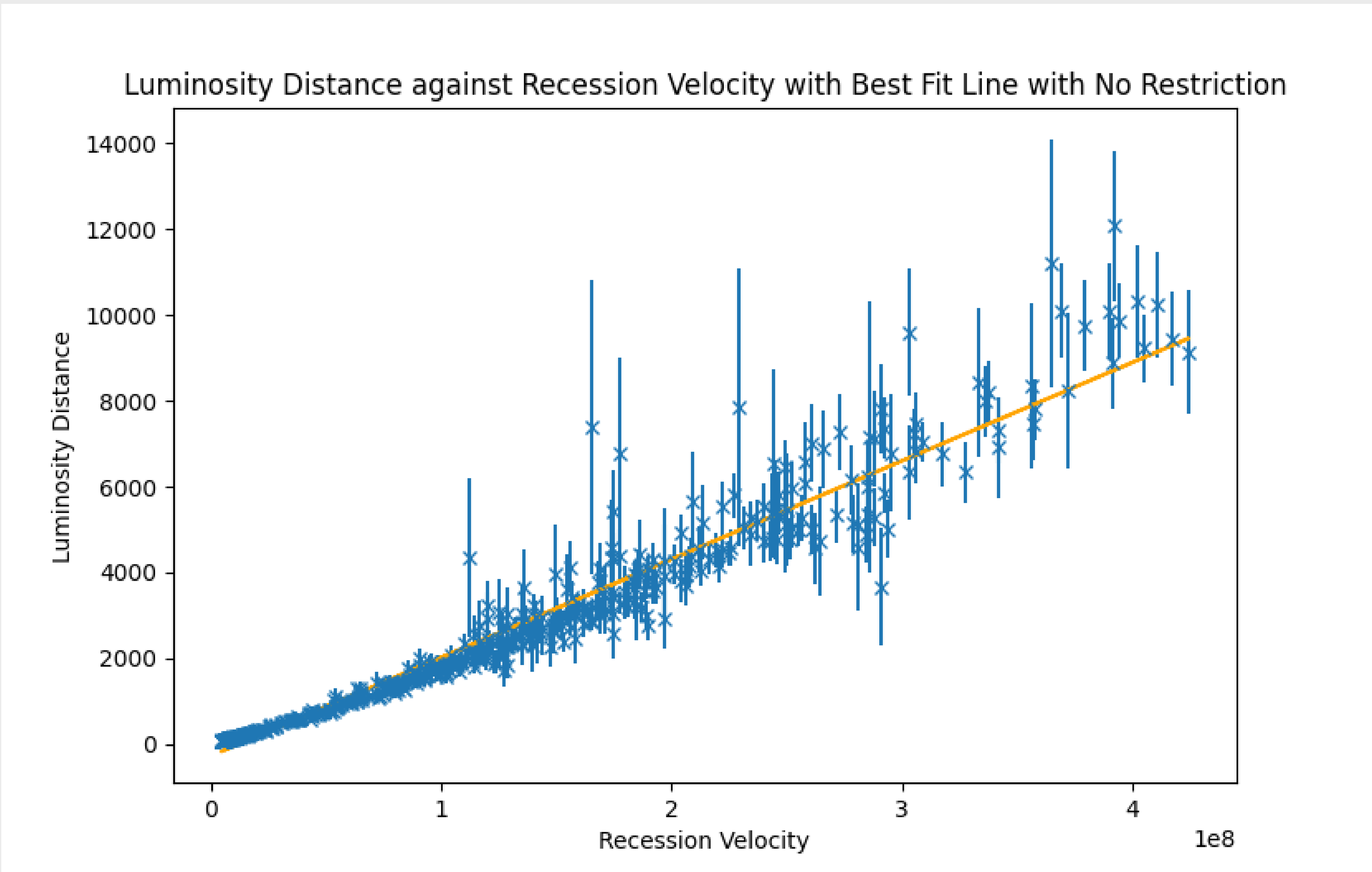
This project has the objective of serving as an introduction to cosmology and all its aspects. This will be achieved by retracing the steps that Hubble used to conclude that the universe was expanding using recent data sets and then build, from this analysis, more complex approaches that will allow us to test different cosmological models that exist nowadays.This poster presents the results of the first part of the project where we use the data from Supernova Type 1A from the Supernova Cosmology Project [1] to analyse the rate of expansion of the universe and conclude that universe is expanding at an accelerating rate.

## Supernova Type 1A as Standard Candles

To analyse the rate of expansion of the universe we need to be able to identify the position of different objects and its relative velocity towards us. For this we need a Standard Candle, an object that has an intrinsic brightness and that can be found along a wide range of distances[2]. The intrinsic brightness allows us to calculate the relative velocity of the objects. Since we know what brightness the objects are supposed to have, we can treat any difference in the wavelength of the radiation we receive as a Redshift and associate that with the velocity of expansion. Thus by using Redshift as a measure of velocity we can find a relationship between the velocity of expansion and the distance at which we find the galaxies, thus we can discover the rate of expansion of the universe (the Hubble parameter).
A Supernova type 1A occurs any time a star accretes enough mass to reach the critical mass density to cause a supernova. Since the luminosity of a supernova is directly related to the mass density of the star that originates it we can use this phenomena has a Standard Candle. This kind of phenomena is ideal since it happens in every galaxy making it perfect for long range surveys which are ideal when studying the evolution of the universe.

## Huble's Expansion of the Universe

By analysing the behaviour of the whole system we can get the average rate of expansion of the universe. This is what we call the Hubble parameter, which we find to be of approximately 44 km/s/MPc.




## Hubble's Accelerating Expansion

However if we isolate the supernova type 1A at smaller distances (with a Redshift smaller than 0.025) we get an Hubble Parameter of approximately 71 km/s/MPc.


This allows us to conclude that a linear fit is not adequate and that the universe is not only expanding but it's expansion is also accelerating. This goes accordingly with what was found by Hubble and its experiments.

## Friedman Equation and Cosmological Parameters

The next step of this project is to understand what factors affect the rate of of expansion of the Universe. The rate of expansion of the universe can be modelled by the Friedman equation(1).

$$H(z) = H_0\sqrt{\Omega_M(z+1)^3 + \Omega_R(z+1)^4 + \Omega_\Lambda} \tag{1}$$

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It is important to note that the Friedman equation assumes that the universe is both spatially homogeneous and isotropic, which has thus been supported by current observations. The Friedman equation, was developed upon Einstein's general theory of relativity and can provide information on the contents of the universe, which in their turn provide indicators as to the shape of the universe.
The constants in the Friedman equation are known as the cosmological parameters and include the baryon density – matter density ($\Omega_M$) , the radiation density ($\Omega_R$), and the cosmological constant ($\Omega_\Lambda$), whose origin is still unknown, but which is usually called dark energy. These parameters are defined by the fraction that they make up in the composition of the universe. We can see that these 3 parameters are what defines the rate of expansion of the universe, thus the variation of the rate of expansion of the universe we verified indicates that this values have varied through time.
The Hubble constant is also a cosmological parameter, defining the expansion rate of the universe in 'present day time' (we can only define the rate of expansion of the universe at a given time by having a point of reference). The value of these parameters can be varied to calculate the corresponding rates of expansion, and upon comparison with observational data can be used to verify the contents of the universe.
A quick analysis with a simplified model with only matter and dark energy indicates that our experimental values are consistent with a universe with a matter density of 30% and a dark energy density of 70%. However this approach is very superficial and a more statistically complex approach with a more complex model is necessary to take any serious conclusions.

## Next Steps

- Implement Likelihood analysis and account for relativistic effects in order to obtain realistic constrains to the values of the cosmological parameters
- Elaborate a Literature Review and find several models with alternative variations to the Friedman Equation (that present new relationships between the 3 cosmological parameters we've been studying) to test against the experimental values
- Include more data sets in order to find better constrains for the cosmological parameters

## References

[1] https://supernova.lbl.gov/Union/ (25/5/2023)
[2] Saul Perlmutter; Supernovae, Dark Energy, and the Accelerating Universe. Physics Today 1 April 2003; 56 (4): 53–60. https://doi.org/10.1063/1.1580050