Cosmology project 2

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Abstract

In this project we explore how the CMB and matter power spectrum varies as function of the cosmological parameters, and what is the observational data available to compare with and qualitatively determine the best cosmological model. For doing this project, we use CLASS, which is a python based code that lets us vary the parameters to obtain data for the modified universe so that we can make graphs to see precisely how the power spectrums change because of the modifications.

1 Introduction

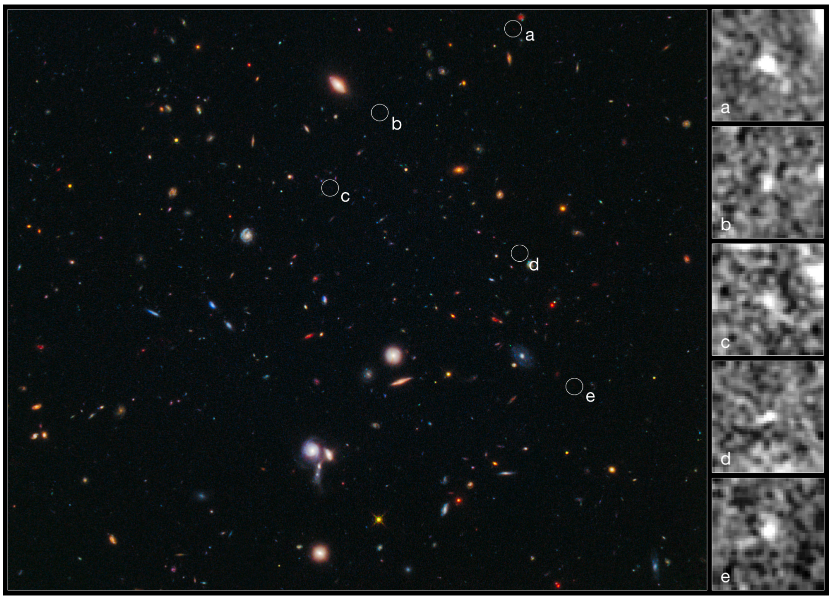
As we know from previous project, the CMB is the radiation that got left over from the beginning of the universe (Big Bang) [1]. This radiation is now known to accurately take on the form of a black-body with a temperature of T = 2.725 K. Cosmic Microwave Background photons last scattered off electrons at a redshift of z = 1100; since then they have traveled freely through space. [2] [3]

It is also important in cosmology that we study the power spectrum since it gives us a lot of information for various aspects that we need to study of the universe, we have the power spectrum for density fluctuations, this means it studies the formation of large scale structures in the universe that initially started as small fluctuations in density and that are amplified by gravity, with the power spectrum we can observe the amplitude of fluctuations on different length scales or equivalently on different mass scales. We get this by graphing k (wave number) vs P(k), remembering it is easier for us to transform our parameters to the Fourier space so that we can work more easily, that's why we are working with k. The shape and amplitude of the power spectrum of density fluctuations contains information about both the amount and nature of matter in the universe.

We can obtain power spectrum graphs or information to make this graphs from direct measurements of the dynamics of galaxies in surveys that cover the full sky or from the distortion of images of faint galaxies due to the gravitational lensing of their light by the intervening dark matter distribution. a way cosmologists constrain the power spectrum of mass fluctuations is to measure the power spectrum of galaxy clustering. See figure 6. [4]

To understand a bit more about what is happening, lets see a bit about the theory behind this, which is first-order perturbation theory. Perturbation theory is extremely successful in dealing with those cases that can be modelled as

Figure 1: Galaxy Clustering, image from NASA

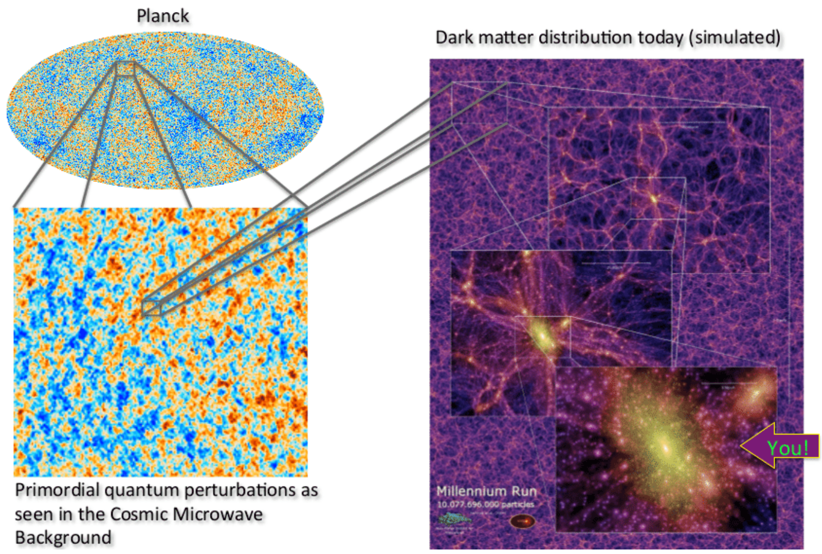


a "small deformation" of a system that we can solve exactly.

In cosmology we use this theory to describe the universe since it is not really homogeneous (only can be seen this way in large scales), in reality some places of the universe are more dense than others see figure 2, so to solve this we use the first-order perturbation theory applied to the Boltzmann equation and we now have a different way of seeing this equation that describes the universe and its more realistic than the view of an homogeneous universe. For this theory it is simpler to transform to the Fourier Space so that it is easier for us to work with these equations. See ref chapter 4 [3]

Linear perturbation theory uses general relativity to compute the gravitational forces causing small perturbations (δ) to grow and eventually contribute to the formation of stars, quasars, galaxies and clusters. It only applies to situations in which the universe is predominantly homogeneous, such as during cosmic inflation and large parts of the Big Bang. The theory is a good approximation on large scales, but on smaller scales we need more techniques, some of which are the N-body simulations.
Since our perturbations (δ) are so small ($\delta << 1$) we use the linear theory in which as it indicates, quadratic or larger terms can be ignored since the value is very small. Besides all this, cosmologists are still working on larger order Perturbation Theories since they can still give us some data that may be useful to understand the universe better. Related to this we have superclusters, which we use to study the power spectrum and these are structures that are often flattened or elongated. [5]

Figure 2: Perturbations but viewed with some images that help us understand better what we refer to when we say this.



2 Methods

For this project and with the intention to observe the CMB and power spectrum of matter, we used CLASS which has "the purpose of CLASS is to simulate the evolution of linear perturbations in the universe and to compute CMB and large scale structure observables." You can download class from the page https://github.com/lesgourg/class_public.

Once we have CLASS, which in my case I had to install in colab Notebooks's "terminal" to work with this library so I downloaded all the documents required to work with this in drive. Once we have all of this, we are going to work with the file named "default.ini" from which I made a copy so I didn't have to edit and lose the original value of our parameters, in this file we have a section called Cosmological Parameters were we have Omegas, Redshift an h (all the parametrs we have worked with before). When we run the code for the first time, some files are generated (remembering to save Background data), these files are defaultCOPIA00_pk.dat and defaultCOPIA00_cl.dat from the first one we generated a graph for the power spectrum of matter, graphing K vs P that we obtain from the file and making the plot a log plot, and from the second one we graph the first and second column which are z and T which gives us the graph of the CMB.

For the other part of this project we had to "play" with the library and modify the parameters we have worked with before, we must note that certain combination of parameters don't work and will not generate graphs, which was the case for me, I was modifying parameters with a difference of 0.01 and in almost all the cases I got an error in the Thermodynamics part of CLASS.

The parameter I could modify the best was T_{CMB} the cosmic radiation background temperature, we can observe from the graphs of all the times I ran CLASS and obtained a new file, the difference from the spectrums, which for a small difference in value seems like a big difference from the present day graph. When I modified the Omegas, with the same difference of 0.01, I got a error in Thermodynamics which again is surprising but for the opposite reason, this time its surprising that such a small difference can cause the whole universe to "collapse", I then tried with a difference or increment of 0.1 and I still got the same errors.

It is important to note that I had to change the parameters manually because I couldn't make the code edit the file "default" because I got an error while reading strings and floats with numpy at the same time in the file. For this I changed or incremented the parameters 10 times for each, getting 10 files for pk and for cl (power spectrum of matter and CMB) again for each change. Another thing that happened while doing this project, is that every time I continued later the project and I had to run the cells again in colab, the permissions got removed and I had to delete the folder where CLASS and the files were and download and upload again the library CLASS, making me unable to run again with the information I had already got or taking a while to do it again.

3 Conclusions

The project can be found in https://github.com/l-cabal/CosmologyProject2_DCI_LCCP.

In this project we were able to view a bit more of how the universe works and also the importance of knowing how to work with data to obtain what we want to know about the universe.
From the plots we got from modifying the parameters it amazes me how with such a small change big things happen, the power spectrum varies a lot from a small change or the whole behaviour of the universe just doesn't work with the other properties and parameters, like the thermodynamics part just doesn't make sense and isn't able to get a power spectrum with that change.

This results got me thinking that it's like the universe could only evolution a certain way or certain ways that are very limited, there may be more combinations of parameter values that work in the universe but that since they are somewhat rare, I couldn't find another certain valid combination.
The universe is unique and the form it has with the formation of superclusters, galaxies, solar systems, planets seems to be the only way things could have formed in the universe, at least that's the way it seems and this is I think one of the objectives of doing this project.

4 Notes

- You can get starting code to run in Google colab in https://colab.research.google.com/drive/1vDw7t44Nx5VCka3UNtDKDoHIuR-uWfYi?usp=sharing

  (The second part of the notebook can also be run locally if you installed CLASS in your computer)

- You can get inspired on this page...
  http://background.uchicago.edu/~whu/animbut/anim2.html

- You will have to provide the code used to generate the plots, either in scripts, jupyter notebooks, or linking to a github page (preferable)

- Make a first submission on June 14 2022, or before, and final submission on June 17, 2022.

References

[1] Rita Tojeiro. Understanding the cosmic microwave background temperature power spectrum. *alm*, 2:6, 2006.

[2] B. Ryden. *Introduction to cosmology*. Cambridge University Press, 1970.

[3] Scott Dodelson. *Modern Cosmology*. Academic Press, Amsterdam, 2003.

[4] Carlton Baugh. Correlation function and power spectra in cosmology. In *Encyclopedia of Astronomy & Astrophysics*, pages 1–3. CRC Press, 2001.

[5] Andrew R. Liddle. *An introduction to modern cosmology*. 1998.

5 Annexes

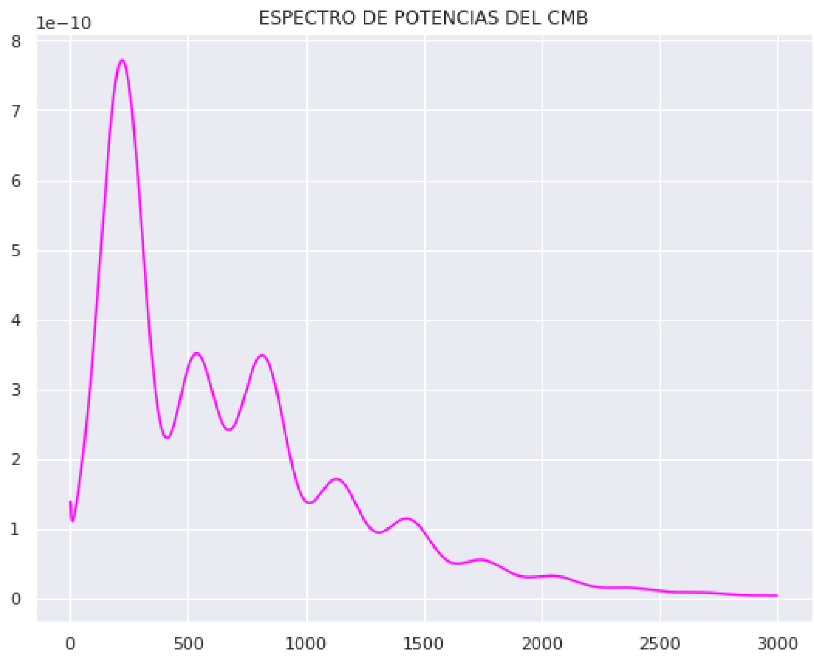


Figure 3: Power Spectrum CMB plot with the actual data registered in CLASS

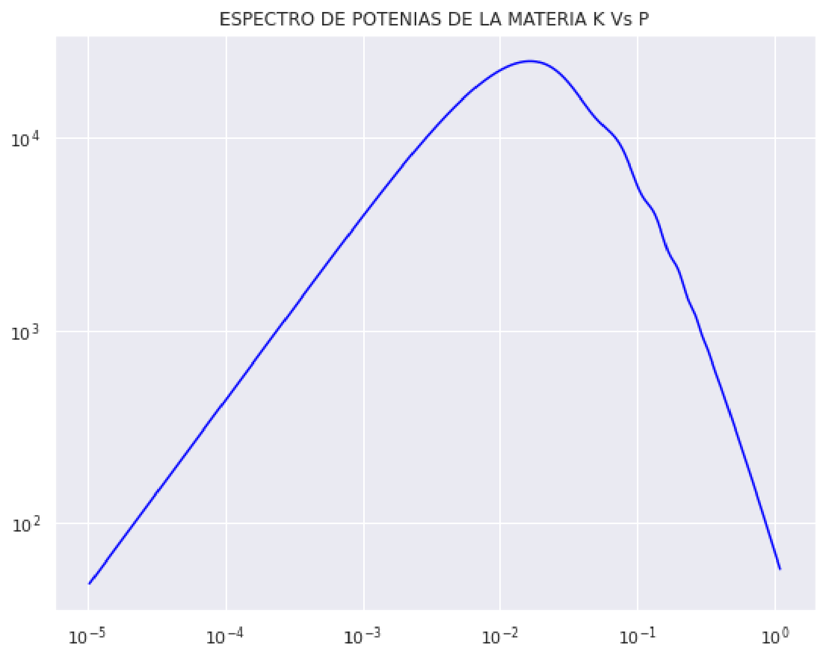


Figure 4: Power Spectrum of Matter, logarithmic plot with the actual data registered in CLASS

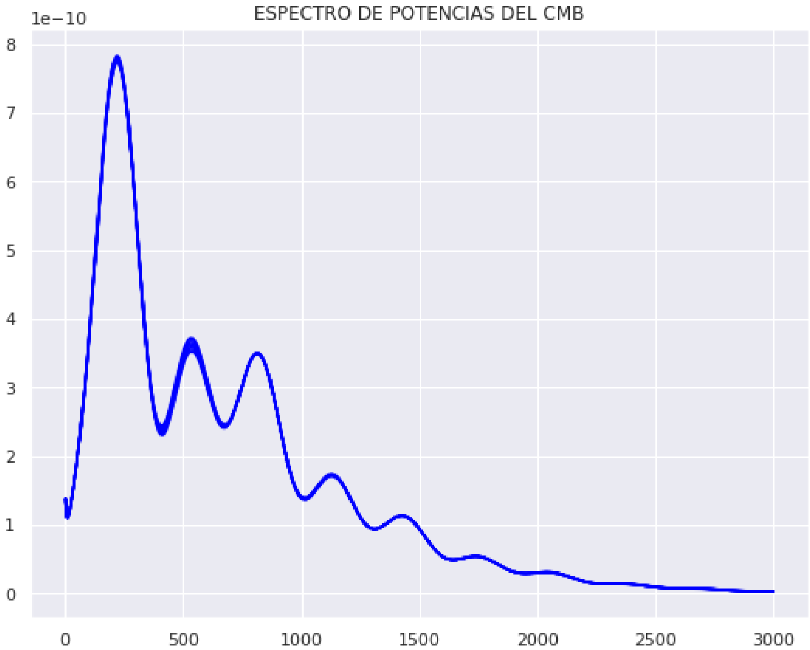


Figure 5: Power Spectrum CMB plot with a variation of TCMB in increments of 0.01, there are 10 different plots of the spectrum, but since the variation is small, it looks thicker were there is a difference from the graph of Figure 3.

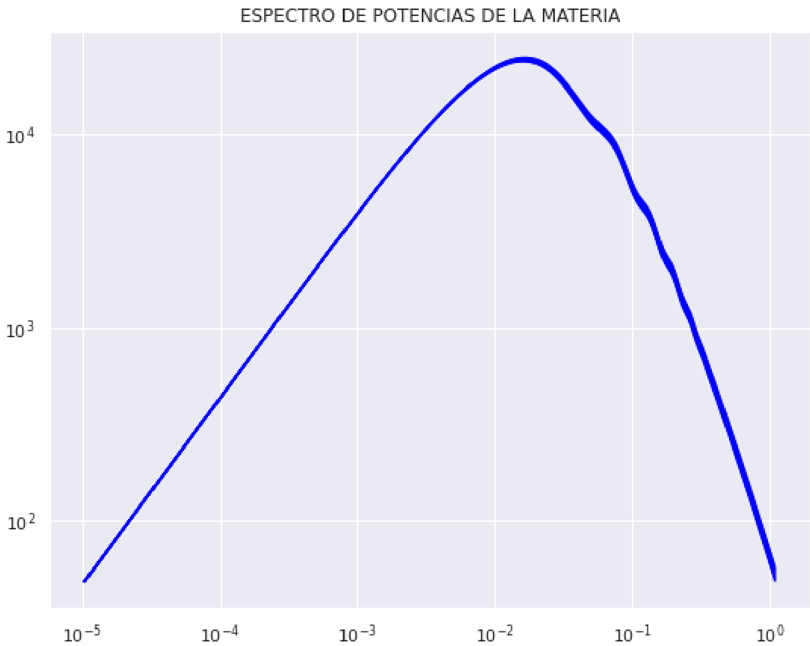


Figure 6: Power Spectrum of Matter, logarithmic plot with a variation of TCMB in increments of 0.01, there are 10 different plots of the spectrum, but since the variation is small, it looks thicker were there is a difference from the graph of Figure 4