Gravitation, Relativistic Astrophysics and Cosmology
Second Argentinian-Brazilian Meeting, 2014
G. S. Vila, F. L. Vieyro and J. Fabris, eds.

Comparison of predictions from alternative cosmologies with Cosmic Microwave Background data

María Pía Piccirilli,[1] Gabriel León,[2] and Susana J. Landau[2]

[1]*Grupo de Astrofísica, Relatividad y Cosmología, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque S/N, (1900) La Plata, Provincia de Buenos Aires, Argentina*
[2]*Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria - PabI, (1428) Buenos Aires, Argentina*

Abstract. The emergence of the seeds of cosmic structure from a perfect isotropic and homogeneous Universe has not been clearly explained by the standard version of inflationary models. We consider alternative scenarios where the emergence of an anisotropic and inhomogeneous Universe from an initial isotropic and homogeneous state can be explained by the of introduction the “self-induced collapse hypothesis”, a scheme in which an internally induced collapse of the wave function of the inflaton field is the mechanism by which inhomogeneities and anisotropies arise at each particular length scale. Our aim is to test these models through statistical analysis comparing them with recent data of the Cosmic Microwave Background and galaxy surveys. This procedure will restrict the value of free parameters and test the viability of each scheme using the results of latest observational experiments.

1. Introduction

Observations of the Cosmic Microwave Background (CMB) radiation are the most powerful tools to study the early Universe and establish the value of cosmological parameters. In the last decade, there have been great advances concerning the CMB data due to a remarkable increase in the accuracy of observational techniques. Furthermore, the agreement between theory and observations has strengthened the theoretical status of inflationary scenarios among cosmologists.

In the standard inflationary paradigm the emergence of all structures in our Universe like galaxies and galaxy clusters is described by a featureless stage represented by a background Friedmann-Robertson-Walker (FRW) cosmology with a nearly exponential expansion driven by the potential of a single scalar field and from its quantum fluctuations characterized by a simple vacuum state. However, when the scenario is considered more carefully, a conceptual problem emerges regarding a change in the initial symmetries of the Universe. Indeed, the dynamics of quantum unitary evolution cannot explain how an inhomogeneous and anisotropic Universe originates from a completely homogeneous and isotropic initial situation. Dr. Sudarsky and collaborators have developed one proposal to handle these shortcomings (Sudarsky, 2011). To deal with the problem a new ingredient is introduced into the inflationary account of the origin of cosmic seeds: *“the self-induced collapse hypothesis”*. In this scheme an internally induced collapse of the wave function of the inflaton field is the mechanism by which inhomogeneities and anisotropies arise at each particular length scale. We do not know exactly what kind of physical mechanism would lie behind what looks like a spontaneous collapse of the wave function, as there is no "observer" who can possible "measure" the Universe. We assume that the effect is caused by an unknown quantum aspect of gravitation.

2. Collapse models

We consider the action of a scalar field minimally coupled to gravity:

$$S[\phi, g_{ab}] = \int \mathrm{d}^4 x\sqrt{-g}\Big(\frac{1}{16\pi G}R[g_{ab}] - \frac{1}{2}\nabla_a\phi\nabla_b\phi g^{ab} - V(\phi)\Big), \tag{1}$$

where ϕ is the inflaton field and g_{ab} is the metric. Fields are separated into their homogeneous ("background") part and the perturbations ("fluctuations"). Conformal Newton gauge is the most appropriate choice for this scheme.

Einstein's equations are followed up to the first order and scalar field perturbations are quantized in the framework of a semi-classical gravitation theory (Wald, 1994) $G_{ab} = 8\pi G < \hat{T}_{ab} >_\phi$. Hypothesis are: (i) given a value η_k^c of conformal time the state collapses to a different one ($\vec{k}$ is not longer in its vacuum state), (ii) the inflaton's wave function is initially the vacuum state, this implies that the metric perturbations are null before the collapse, (iii) each collapse mode represents beginning of inhomogeneities and anisotropies at the characteristic scale of that mode, and (iv) it is possible to describe the state of the system if collapse modes at each time and previous collapse state are known. Primordial power spectrum can be expressed:

$$P(k) = C(k)A_s\left(\frac{k}{k_0}\right)^{n_s-1}, \tag{2}$$

where $C(k)$ is a function that depends on the scheme under which the collapse hypothesis is taking place. In this work we will show results from three different collapse models depending on which variable changes as result of collapse: inflaton field, canonical conjugate momentum or both. It follows from Unánue & Sudarsky (2008) and Landau et al. (2012) that the primordial power spectrum is nearly scale invariant if the time of collapse of each mode can be expressed as:

$$\eta_k^c = \frac{A}{k} + B, \tag{3}$$

where A and B are constants (which value must be constrained). The case where $B = 0$ reduces $P(k)$ to a constant, giving a perfectly scale invariant primordial power spectrum ($n_s = 1$ for the standard model, see De Unáue & Sudarsky, 2008 for $C(k)$ expressions). Therefore, we take this expression for the collapse time in order to start with a scale invariant power spectrum and study small deviations with respect to the standard model. Let us now define a fiducial model, which will be taken just as a reference to discuss the results we obtain for the collapse models. The fiducial model is a ΛCDM model with the following cosmological parameters: $\Omega_b h^2 = 0.021$, $\Omega_c h^2 = 0.119$, $H_0 = 70$, $\tau = 0.084$, $n_s = 0.96$. The temperature anisotropy for the collapse models together with the prediction for the fiducial model is shown in Figs. 1 and 2.

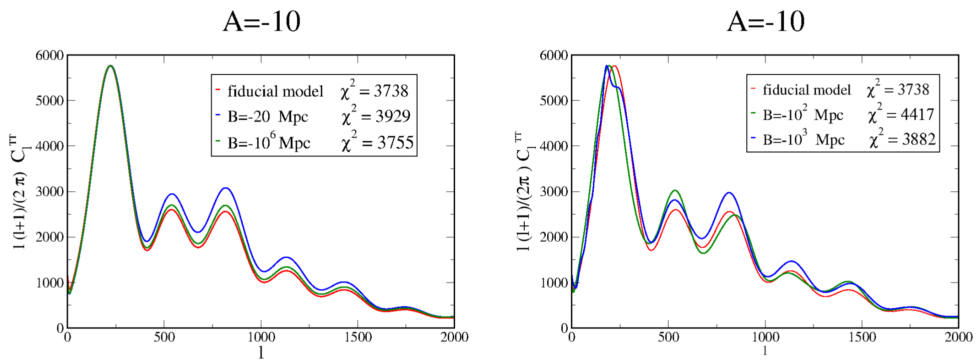

Figure 1. **Model I (left)**: Both expectation values for the field and its canonical conjugate momentum collapse. This plot compares the temperature anisotropy predictions for different values of the collapse conformal time with the fiducial model. For values $|A| > 20$, collapse model I is indistinguishable from the standard one. **Model II (right)**: Only the conjugate momentum changes its expectation value after the collapse. A comparison of the temperature anisotropy predictions for different values of the collapse conformal time is shown. Landau et al. (2012). Reprinted with permission from Physical Review D85, 123001 (2012). Copyright(2012) by the American Physical Society.

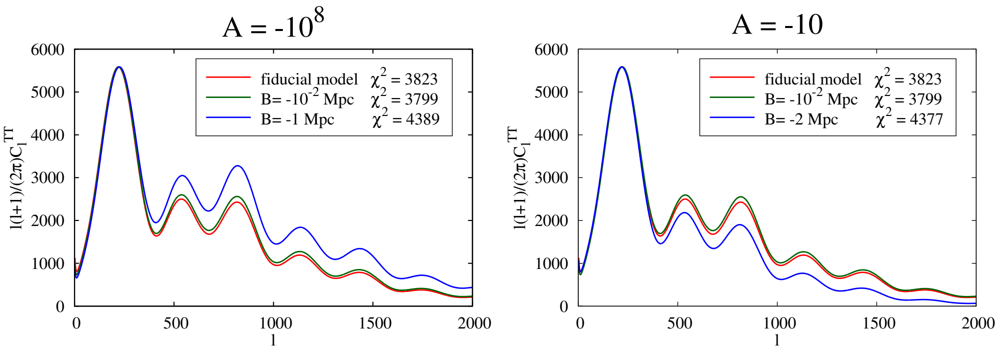

Figure 2. **Model III**. Both field and its canonical conjugate momentum are affected by the collapse following a correlation described by a *Wigner's distribution function*. Both plots compare the temperature anisotropy predictions for different values of the collapse parameters with the fiducial model.

It follows from Fig. 2 that not every value of η_k^c gives a good fit to the observational data (represented by the fiducial model). This gives predictability to the model, as not every pair of values for A and B will do. However, there are certain values for the collapse conformal time that fit observational data just as well as the standard paradigm. Once our free parameters are constrained with CMB observations, we will end up with a cosmological model that can explain in a more feasible way the origin of cosmic structures.

3. Conclusions

The emergence of the seeds of cosmic structure, from a perfect isotropic and homogeneous Universe, has not been clearly explained by the standard version of inflationary models as the dynamics involved is not capable of breaking the initial symmetries of the system. The *self induced collapse hypothesis* attempts to deal with this problem. The proposal incorporates two free parameters which are to be constrained using the latest CMB data available. Figs. 1 and 2 show that not all the values are viable and some of them must be ruled out. In order to constrain the values of the free parameters A and B we need to perform a statistical analysis with the latest CMB data.

Previous works show that collapse models I and II can explain with enough accuracy the observations provided by WMAP 7-year release. Our aim now is to compare models I, II and III with WMAP 9-year release and Planck data. We are working on different schemes for collapse and also some cutting edge modifications to previous models, such as the possibility of collapse occurring during the radiation era.

Acknowledgments. This research is developed in the framework of a CONICET doctoral fellowship, and supported by CONICET PIP 0152/10 and UNLP project 11/G119 grants. We thank Federico Bareilles for computational support.

References

de Unánue, A. & Sudarsky, D. 2008, Phys. Rev. D, 78, 043510

Landau, S. J., Scóccola, C. G. & Sudarsky, D. 2012, Phys. Rev. D, 85, 123001

Landau, S. J., León, G. & Sudarsky, D. 2013, Phys. Rev. D, 88, 023526

León, G., de Unánue, A. & Sudarsky, D. 2011, Classical and Quantum Gravity, 28, 155010

Perez, A., Sahlmann, H. & Sudarsky, D. 2006, Classical and Quantum Gravity, 23, 2317

Sudarsky, D. 2011, International Journal of Modern Physics D, 20, 509

Wald, R. M. 1994, "Quantum field theory in curved spacetime and black hole thermodynamics", Chap. 4, The University of Chicago Press