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WHEPP-X: Report of the working group on cosmology

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Abstract. This is a summary of the activities of the working group on cosmology at WHEPP-X. The three main problems that were discussed at some length by the group during the course of the workshop were (i) canceling a 'large' cosmological constant, (ii) non-Gaussianities in inflationary models and (iii) stability of interacting models of dark energy and dark matter. We have briefly outlined these problems and have indicated the progress made.

Keywords. Inflationary cosmology; physics of the early universe; cosmic microwave background radiation.

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1. Beyond plain vanilla cosmology

The concordant cosmological model – *viz.* the Λ CDM model and a Gaussian, adiabatic and a nearly scale invariant inflationary perturbation spectrum – fits the various observations quite well (see, for instance, ref. [1] and references therein; see, however, refs [2]). The aim of the working group on cosmology was to focus on signatures of deviations from such a vanilla cosmology and discuss their importance

and implications. With this goal in mind, Manoj Kaplinghat and Jerome Martin had given two plenary talks titled *Beyond standard cosmology* and *Non-vanilla cosmological models*, respectively. In addition, Arjun Berera had highlighted the recent *Developments in inflationary cosmology* in his working group talk.

A variety of topics were initially considered for discussion. The different topics that were proposed include: (a) non-Gaussianities in inflationary models, (b) evolution of perturbations in bouncing universes, (c) pre-inflationary models and features in the primordial spectrum and (d) warm inflationary scenarios.

After the preliminary discussion, the following three problems were discussed at length and worked upon to some extent during the period of the meeting: (a) canceling a ‘large’ cosmological constant, (b) non-Gaussianities in Dirac–Born–Infeld (DBI) models and warm inflationary scenarios and (c) stabilizing interacting models of dark energy and dark matter. We have described these three problems below.

2. Cancelling a ‘large’ cosmological constant with scalar fields

M Kaplinghat, J Martin, R Rangarajan, V H S Kumar and L Sriramkumar

Consider a Friedmann universe driven by the cosmological constant Λ and a scalar field, say, ϕ , that is coupled non-minimally to gravity through the following action:

$$S[g_{\mu\nu}, \phi] = \int d^4x \sqrt{-g} \left[\left(\frac{R}{16\pi G} \right) - \Lambda + \left(\frac{1}{2} \right) \partial_\mu \phi \partial^\mu \phi - \xi R \phi^2 \right]. \quad (1)$$

The equations of motion satisfied by the system are given by

$$H^2 = \left(\frac{1}{8\pi G} \right) (\Lambda + \rho_\phi) \quad (2)$$

and

$$(\square + \xi R) \phi = 0, \quad (3)$$

where H is the Hubble parameter and ρ_ϕ denotes the energy density associated with the scalar field. Based on the above Friedmann equation, an effective gravitational constant can be defined as

$$\left(\frac{1}{16\pi G_{\text{eff}}} \right) = \left(\frac{1}{16\pi G} \right) - \xi \phi^2. \quad (4)$$

The goal is to reduce the value of the cosmological constant to an acceptable level with the aid of the scalar field. For $\xi < 0$, asymptotically, ϕ increases with time and, hence, the effective value of Λ proves to be small, but G_{eff} turns out to be small as well [3]. In other words, attempting to kill the cosmological constant seems to kill gravity.

An example wherein it seems to be possible to arrive at such a cancellation is the case of a scalar field that is described by the following action [4]:

$$S[g_{\mu\nu}, \phi] = \int d^4x \sqrt{-g} \left[\left(\frac{R}{16\pi G} \right) - \Lambda + \left(\frac{c^2}{2R^2} \right) \partial_\mu \phi \partial^\mu \phi + \alpha \phi \right], \quad (5)$$

where c and α are constants. In such a case, it is found that the $(\alpha\phi)$ term effectively reduces the value of the cosmological constant without killing gravity.

The discussion was aimed at constructing more realistic models (with a coupling such as, say, $[f(R)\phi^2]$), which allow a cancellation of the cosmological constant while satisfying the current bounds on the variation of the gravitational constant [5].

3. Non-Gaussianities in DBI models and warm inflationary scenarios

A Berera, P Chingangbam, R K Jain, M Joy, M Kaplinghat, J Martin,
S Mohanty, A Nautiyal, S Ray and L Sriramkumar

3.1 The non-Gaussianity parameter

The local form of non-Gaussianity is often expressed in real space in terms of the Bardeen potential Φ as follows (see, for instance, refs [6,7]):

$$\Phi(\mathbf{r}) = \Phi_G(\mathbf{r}) + f_{\text{NL}} [\Phi_G^2(\mathbf{r}) - \langle \Phi_G^2(\mathbf{r}) \rangle], \quad (6)$$

where the parameter f_{NL} characterizes the extent of primordial non-Gaussianity. The quantity Φ_G is the strictly Gaussian distribution that arises from the first-order field perturbations [8,9].

In the standard slow roll inflationary scenario involving the canonical scalar field, f_{NL} turns out to be much smaller than unity (see, for example, ref. [10]). However, an analysis of the three-year WMAP data seems to indicate sufficiently large non-Gaussianities with $23 < f_{\text{NL}} < 75$ at 95% confidence level [11]. Another recent analysis of the data suggests the value of $27 < f_{\text{NL}} < 147$ at 95% confidence level [12]. (In this context, also see the discussions involving the most recent, i.e. five-year, WMAP data [13].)

The discussions of the group were aimed at identifying and working upon models that ‘naturally’ lead to a sufficiently large non-Gaussianity. Two cases that were considered were the DBI inflationary models and the warm inflationary scenarios.

3.2 Studying non-Gaussianity in DBI models through the stochastic inflation approach

The stochastic inflation approach provides a method to calculate the non-Gaussianities in a particular model [6,14]. In this approach, the evolution of the coarse-grained inflaton (say, the canonical scalar field) is assumed to be governed by a first-order differential equation of the following Langevin form in the slow-roll approximation [15]:

$$\dot{\phi} + \left(\frac{1}{3H}\right) \left(\frac{dV}{d\phi}\right) \simeq \left(\frac{H^{3/2}}{2\pi}\right) \xi(t). \tag{7}$$

The quantity $\xi(t)$ is a stochastic noise field that has been introduced by hand. Its mean value is assumed to vanish, and its two-point correlation function is assumed to be given by the following relation:

$$\langle \xi(t)\xi(t') \rangle = \delta(t - t'). \tag{8}$$

The DBI scalar field, say, ϕ , is described by the action [16,17]

$$S[\phi] = \int d^4x \sqrt{-g} \left[\left(\frac{1}{f(\phi)}\right) ([1 - f(\phi) \partial_\mu \phi \partial^\mu \phi]^{1/2} - 1) - V(\phi) \right]. \tag{9}$$

The equation of motion describing the DBI field is given by

$$\ddot{\phi} + \left(\frac{3f'}{2f}\right) \dot{\phi}^2 - \left(\frac{f'}{f^2}\right) + \left(\frac{3H\dot{\phi}}{\gamma^2}\right) + \left(V' + \frac{f'}{f^2}\right) \left(\frac{1}{\gamma^3}\right) = 0, \tag{10}$$

where the quantity γ is defined as

$$\gamma = \left(\frac{1}{\sqrt{1 - f\dot{\phi}^2}}\right). \tag{11}$$

There are indications that such models can ‘naturally’ lead to large non-Gaussianities [18].

The aim was to follow the stochastic inflation approach in the context of DBI inflationary models and compute the three-point and the four-point functions for the gravitational potential. The stochastic equation for the DBI case, equivalent to eq. (7) for the canonical scalar field, was constructed.

3.3 *Non-Gaussianities in warm inflationary scenarios*

Preliminary calculations seem to indicate that, in the warm inflationary scenario, the thermal effects can indeed lead to large non-Gaussianities [19,20].

During the course of the discussion, it was recognized that, with suitable modifications to the correlation functions for the noise $\xi(t)$, the stochastic inflation approach can be utilized to evaluate the three- and four-point functions of the gravitational potential at a finite temperature in the warm inflationary scenario.

4. **Stabilizing interacting models of dark energy and dark matter**

P Chingangbam, M Joy, M Kaplinghat, J Martin, S Mohanty,
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There has been a recent interest in the literature to study interacting models of dark energy and dark matter [21,22]. However, certain models, such as, for example, the one described by a potential of the following form [21]:

$$V(\chi, \psi) = V(\chi) + g(\chi)(\bar{\psi}\psi), \quad (12)$$

where χ describes the dark energy component while ψ represents the dark matter, seems to lead to an instability.

The aim was to study models that are non-linear in $(\bar{\psi}\psi)$ which can possibly help in avoiding the instability. Another possibility that was discussed was to take into account the decay of the dark matter particles into the particles constituting the dark energy.

5. Summary

In this report, we have briefly outlined the various problems that were discussed by the working group on cosmology at WHEPP-X.

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