PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 76, No. 5
May 2011
pp. 693–698

Working group report: Cosmology and astroparticle physics

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Abstract. This is the report of the cosmology and astroparticle physics working group at WHEPP-XI. We present the discussions carried out during the workshop on selected topics in the above fields. The problems discussed concerned axions, infrared divergences in inflationary theories, supersonic bubbles in a first-order electroweak phase transition, dark matter, MOND, interacting dark energy, composite Higgs models and statistical anisotropy of the Universe.

Keywords. Axions; infrared divergence; electroweak phase transition; Sommerfeld effect; CP violation; dark energy; statistical anisotropy; Higgs inflation; SUGRA; warm inflation.

PACS Nos 14.80.Va; 98.80.Cq; 64.60.Q-; 95.36.+x; 11.30.Er; 04.65.+e

There were several talks on cosmology and astroparticle physics during WHEPP-XI which raised issues that were subsequently discussed in the working group. The talks were on *Recent developments in dark matter* by A Berera, *Inflation and CMB* by M Bastero-Gil, *The origin of the accelerating Universe: Dark energy and particle cosmology* by Y-Y Keum, *The physics of the electroweak scale* by T Prokopec, *Evidence for large scale anisotropy in the Universe* by P Jain and *Axions in the laboratory and in cosmology* by E Masso.

We present below a brief description of the topics discussed at WHEPP-XI by the working group. The names indicate those who participated in the discussion.

1. Axions and resonance

M Bastero-Gil, J Bhatt, U Gupta, E Masso, T Prokopec, R Rangarajan, P Saumia and A Srivastava

Several resonant phenomena arising in the coupling between axions and photons, and their relevance both for cosmology and for axion detection were considered. Axions are pseudo-Nambu–Goldstone bosons that interact with two photons or electromagnetic fields. The Lagrangian for the axion–photon system is given by

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m^2 a^2 - \frac{g}{4} a F\tilde{F}. \tag{1}$$

Our metric is $(1, -1, -1, -1)$. The last term can be rewritten as

$$\mathcal{L}_{\text{int}} = gaE{\cdot}B. \tag{2}$$

The axion–photon interaction comes from a one-loop diagram with quarks or charged leptons in the loop.

There are five scenarios of particle production involving resonance due to an oscillating axion or EM background that we can consider:

1. $a_{\text{bgnd}} \to \gamma + \gamma$,
2. $a_{\text{bgnd}} + E/B \to \gamma$,
3. $a + E/B \to \gamma$,
4. $E + B \to a$,
5. $E/B(t) \to a + a$,

where E and B are background electric and magnetic fields.

The issue to be investigated was whether coherent oscillations of the axion field or of an electromagnetic field could enhance the axion–photon/EM field interaction. We obtained the equations of motion for the axion and the photon fields (A^μ in the Coulomb gauge). The first process namely, $a_{\text{bgnd}} \to \gamma + \gamma$ was considered in greater detail. Here we considered whether the oscillating background axion field can produce photons. Either these photons can be detected, or we can study depletion of the axion background due to photon production. The photon field is governed by Mathieu's equation which has bands of unstable regions which would correspond to exponentially growing photon fields, i.e. enhanced photon production. However, we found it difficult to obtain a sufficiently large resonance. Other processes were also considered, in particular, with high intensity oscillating electric and magnetic fields produced by lasers.

2. Quantum backreaction and the infrared problem in cosmology

M Bastero-Gil, K Bhattacharya, S Das, M Das, A Nautiyal, T Prokopec and R Rangarajan

Positively curved spatial sections ($\kappa > 0$) regulate the infrared correlators of massless fields in cosmology in a Bunch–Davies vacuum, such that all observables are infrared finite. Of interest are the correlators of massless scalar fields (a notable example being the inflaton) and the graviton. The discussion during the workshop focussed on obtaining the two-point correlators of a massless scalar field in a class of cosmological space-times with constant equation of state parameter $w_{\text{b}} = p_{\text{b}}/\rho_{\text{b}}$, where p_{b} and ρ_{b} denote the background pressure and energy density, respectively. During the workshop, the Klein–Gordon operator for a massless, nonminimally coupled scalar field in D space-time dimensions was obtained. Subsequently, the Klein–Gordon equation was written in an invariant form and solved for a pure de Sitter space, in a manner analogous to earlier work in the literature. What remains to be done is to redo the calculation in quasi-de Sitter space.

Another method to regulate infrared divergences in an inflationary Universe is by invoking a radiation-dominated era prior to inflation. It was proposed to study the role of an early radiation era on the low multipoles of the CMB temperature fluctuations.

3. Supersonic bubble walls at the electroweak phase transition

J Bhatt, A P Mishra, T Prokopec, R Rangarajan and A Sarkar

Symmetry breaking phase transitions lead to a number of cosmological effects such as topological defects, baryon asymmetry and gravitational waves. A first-order phase transition proceeds via bubble nucleation and all these effects are inherently dependent on the motion of the bubble wall. Slow bubbles allow for diffusion outside the bubble wall which enhances the baryon asymmetry generated in baryogenesis at the electroweak phase transition. Bubbles that are fast and thin will lead to inefficient baryogenesis. However, colliding fast moving bubble walls are a source of gravitational waves.

The motion of the bubble wall has been studied by many authors. However, the current literature may not sufficiently address the case when the bubbles are near supersonic speed. During the workshop, a discussion of the existing litereature was carried out with a focus on understanding the shock front in front of the bubble, the interaction of the bubble wall with the plasma and the friction arising from such interactions.

4. Enhancement of WIMP annihilation cross-section with Sommerfeld effect

High energy electron and positron signals have been observed in satellite-based experiments like PAMELA and FermiLAT. If one wishes to explain the excess flux of e^+ and e^- by dark matter annihilation, then the annihilation cross-section of dark matter that is required is three or four orders of magnitude larger than the weak interaction cross-sections that give the correct relic density. However, a nonperturbative process called Sommerfeld effect can enhance the annihilation cross-section due to the long-range force of a ladder of exchanged 'light' particles.

Two problems were discussed during the workshop.

1. It was proposed that TeV scale winos may explain both the relic density and the PAMELA signal if the Sommerfeld effect is taken into account both in the annihilation of dark matter in the galaxy now and in the early Universe freeze-out calculation (*S Mohanty, S Rao, D P Roy*)
2. The Sommerfeld enhancement works for TeV scale particles as the exchanged light gauge bosons are the W's and Z's with mass of order 100 GeV. It was proposed that

one can get a long-range interaction in the initial particles by the exchange of a pair of fermions. It is known that a neutrino pair exchange gives rise to a $1/r^5$ long-range potential. It is planned to use a fermion pair exchange mechanism to get a Sommerfeld enhancement in the annihilaton of 100 GeV mass dark matter particles (*A Berera, S Mohanty, N Sahu*)

5. CP violation studies in composite Higgs models and electroweak baryogenesis

K Bhattacharya, D Ghosh, S Mohanty, T Prokopec and A Shivaji

Composite Higgs theories like walking technicolour can have a source of CP violation analogous to the strong CP term. It was proposed to study the effect of the analogous θ vacuum in the technopion sector and in turn in the longitudinal W couplings. The finite temperature calculation of one-loop potential and the study of the order of the electroweak symmetry breaking phase transition will be studied in composite Higgs models. Future extension to baryogenesis in such models is envisaged.

6. Coupled dark energy models

Several topics related to coupled dark energy models were considered.

6.1 *The inclusion of mass varying neutrinos within k-essence models*

A Bandyopadhyay, A Basak, S Chakraborty, Y-Y Keum, D Majumdar,
A Nautiyal and A Sen

Issues such as checking the possibility of the positive sound speed of mass varying neutrinos within the coupled k-essence model, studying the dynamics of mass varying neutrinos with perturbative equations with the COSMOMC program, and obtaining constraints from cosmological observations (WMAP, SDSS, BAO) were discussed.

6.2 *Growth factor of clustering structures in models with mass varying neutrinos*

A Basak and Y-Y Keum

The kinetic term contributions to the growth factor was considered.

6.3 *Tests of the coupled dark energy models with observations*

S Chakraborty, S Goswami, Y-Y Keum and D Majumdar

Neutrino oscillations with two and three mass varying supernova neutrinos with dominant collective neutrinos effects were discussed. Time dilation effects between photons and neutrinos for a short γ-ray burst was considered.

6.4 *Contribution of mass varying neutrinos to primordial gravitational waves*

A Basak and Y-Y Keum

Free streaming neutrinos contribute dominantly to the tensor component of matter anisotropic stress, which was discussed during the workshop.

7. Constraints on anisotropy using CMB *B* modes

P Jain and P Saumia

There has been some observations of statistical anisotropy in the Universe. Radiowave anisotropy may be explained by frequency-independent rotation in polarization

$$\Delta\theta = \vec{\lambda} \cdot \hat{n}, \tag{3}$$

where $\Delta\theta$ is the rotation in polarization, $\vec{\lambda}$ is the preferred axis, and $\hat{n}$ is the unit vector towards the source. Assuming that the preferred axis points towards Virgo, this introduces the magnitude of $\vec{\lambda}$ as a new parameter. How to put constraints on this parameter by making a global fit to WMAP and other cosmological data was discussed at the workshop.

8. Constraints on anisotropy and inhomogeneity using high *z* supernovae

P Jain and R Mohapatra

An anisotropic or inhomogeneous model, invoked to explain statistical violation in CMB data, could be

$$d_{\mathrm{L}} = d_{\mathrm{L}}(z, \hat{n}), \tag{4}$$

where d_{L} is the luminosity distance and $\hat{n}$ is the unit vector towards the source. However, such an anisotropy has not been observed. Hence, using the supernova data to impose limits on such models was considered.

9. Higgs as an inflaton

The standard model Higgs potential with Einstein gravity is not suitable for inflation. The Higgs self-coupling is too large to produce the primordial density perturbations deduced from the CMB. But recently it has been pointed out that the standard model Higgs potential with some nonminimal coupling with the Ricci scalar can provide inflation consistent with all observations. Two topics related to Higgs inflation were discussed in the working group.

9.1 *Inclusion of radiative corrections*

M Bastero-Gil, K Dutta and T Prokopec

Different authors [1,2] have obtained different behaviour for the spectral index as a function of the Higgs mass. It was proposed to redo the calculation of the spectral index using the approach of Barvinsky *et al* [1] at two loops.

9.2 *Initial condition problem*

M Bastero-Gil, K Dutta, T Prokopec and R Rangarajan

The low probability of quantum creation of a Universe in models where the inflaton is the Higgs was discussed. Quantification of the underlying arguments and inclusion of a prior matter era were considered.

10. SUGRA models and inflation

M Bastero-Gill and K Dutta

In general, one needs to fine-tune supergravity models to obtain a successful model of inflation. Hybrid inflation has been realized in the context of supergravity. It was proposed to work towards a successful chaotic inflation model.

11. MSSM and warm inflation

M Bastero-Gil, A Berera, S Das, K Dutta and A Nautiyal

MSSM provides flat directions that one may consider for inflation. However, the parameter space is constrained and therefore fine-tuned. There were discussions on how dissipation in models of warm inflation can relax the constraints. It was proposed to explore the possible interactions for dissipation and the modified parameter space in the context of warm inflation and MSSM flat directions. Possibilities of enhanced nongaussianities were also suggested.

References

[1] A O Barvinsky, A Yu Kamenshchik, C Kiefer, A A Starobinsky and C Steinwachs, *J. Cosmol. Astropart. Phys.* **0912**, 003 (2009)
[2] A D Simone, M P Hertzberg and F Wilczek, *Phys. Lett.* **B678**, 1 (2009)