Kaloian Dimitrov Lozanov

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EDUCATION

University of Cambridge **Cambridge, United Kingdom**
PhD Candidate 2013-present
Institute of Astronomy
Project title: Reheating after inflation
Key features of research:

- A simple result for the equation of state after inflation in all observationally consistent single-field models of inflation.
- A study of the nonlinear dynamics at the end of inflation and its impact on observables in physically motivated baryogenesis models with a complex inflaton field.
- Development of more realistic (post-)inflationary models including Abelian and non-Abelian gauge fields in addition to the more traditional scalar fields.
- Understanding the non-adiabatic particle production (preheating) in these models.
- Original algorithm to study numerically the subsequent nonlinear stage of reheating, taking advantage of high performance computing.

University of Cambridge **Cambridge, United Kingdom**
Masters of Science and BA in Natural Sciences 2009-2013
Theoretical and Experimental Physics

- Grades: 1^{st} Class in all 4 years.

National High School of Mathematics and Natural Sciences **Sofia, Bulgaria**
Advanced class for Physical sciences 2004-2009

- Grades: Obtained A in the overall diploma with A* in the Bulgarian A-Level equivalent in Physics.

SELECTED HONOURS

Awards

- 2011: Top of the Year for the Natural Sciences Tripos (ranked 1^{st} of 592 overall), University of Cambridge.
- 2010: Cavendish Part IA Prize (ranked 1^{st} in Physics overall), University of Cambridge.
- 2009: Silver Medal, participant at the International Physics Olympiad in Mexico.
- 2008: Bronze Medal, participant at the International Physics Olympiad in Vietnam.

Scholarships

- 2013: Graduate Scholar, Trinity College.
- 2012: Summer Research Studentship, Trinity College.
- 2011: Senior Scholar, Trinity College.

PUBLICATIONS

1. **K. D. Lozanov** and M. A. Amin: *The Equation of State After Inflation*, Manuscript in preparation.
2. **K. D. Lozanov** and M. A. Amin: *The charged inflaton and its gauge fields: preheating and initial conditions for reheating*, JCAP **1606**, 032 (2016) [arXiv:1603.05663].
3. **K. D. Lozanov** and M. A. Amin: *End of inflation, oscillons and matter-antimatter asymmetry*, Phys. Rev. D **90**, 083528 (2014) [arXiv:1408.1811].
4. A.C. Fabian, E. Kara, D. Walton, D. Wilkins, R.R. Ross, **K. Lozanov**, et. al.: *Long XMM observation of the Narrow-Line Seyfert 1 galaxy IRAS13224-3809: rapid variability, high spin and a soft lag*, MNRAS, **429**, 2917 (2013) [arXiv:1208.5898].

RECENT TALKS

- 08/2016: MIT, Density Perturbation Group (upcoming)
- 08/2016: The international cosmology conference, COSMO-16 (upcoming)
- 08/2016: Texas A & M, High Energy Physics Group (upcoming)
- 04/2016: Les Houches Physics School 'Cosmology after Planck: what is next?'
- 02/2015: University of Cambridge, IoA Wednesday Colloquium

TEACHING & OUTREACH

- 2013-present: Undergraduate supervisor at University of Cambridge. Courses: 3$^{\text{rd}}$ year Advanced Quantum Mechanics, Astrophysical Fluid Dynamics, Electrodynamics and Optics, Relativity; 1$^{\text{st}}$ year Physics.
- 2014: Participant at COSMOLOGY@KICC: outreach event at Kavli Institute for Cosmology Cambridge aimed at sixth form students to meet experts within the field of cosmology.
- 2010: Leader of the Bulgarian national team, International Young Physicist Tournament in Vienna, Austria.

INTERNSHIPS & WORK EXPERIENCE

- 2016-present: JHEP referee.
- 2012: Summer project with Prof. Andrew Fabian: 'Ray tracing around black holes', X-ray group Institute of Astronomy, University of Cambridge.
- 2011: Summer student of Dr. Jason Robinson at the Device Materials Group, Department of Materials Science & Metallurgy, University of Cambridge.

REFERENCES

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RESEARCH INTERESTS

My principle research lies in the field of Theoretical Cosmology. My PhD has been focused on one of the outstanding questions in contemporary cosmology: how exactly the Universe was populated with particles. According to the inflationary scenario nearly all elementary particles were produced towards the end of inflation: the epoch of reheating. This is a very exciting process which may include various non-pertubative out-of-equilibrium phenomena such as explosive particle production and non-linear dynamics. Whilst many questions have been answered in the context of scalar field dynamics, there are still gaps in our understanding of the late stages of reheating. It is not clear how the Universe made the transition to a radiation dominated state in thermal equilibrium, required as an initial condition for the successful big bang nucleosynthesis (BBN). We still do not know how to connect the hot big bang to inflation.

A step towards the solution of this problem is improving our understanding of the rich non-linear dynamics after inflation. This is not a trivial task and requires a complex (numerical) analysis. One also needs to develop more realistic models including Abelian and non-Abelian gauge fields in addition to the more traditional scalar fields. However, this poses both theoretical and numerical challenges. The intricate gauge invariant couplings and gauge constraints lead to great technical complications, as yet unresolved in the literature. Ultimately, the impact on cosmological observables in different realistic scenarios has to be considered. This could be quite difficult, since reheating occurs after inflation and the complicated dynamics on small scales is concealed by the later nonlinear evolution of structure. The thermal state required for BBN also hides information about earlier times.

All of these theoretical, phenomenological and observational sides to reheating have been of main interest to my research. Otherwise my broader research interests include cosmological perturbation theory, solitons and cosmic defects, phase transitions in the early Universe, primordial gravitational waves, primordial black holes, magnetogenesis and baryogenesis.

Over the past year we have worked on the phenomenological aspects of all observationally consistent single-field models of inflation. We showed through a combination of semi-analytic calculations and classical lattice simulations how non-linear post-inflationary dynamics can affect the equation of state of the Universe during reheating – a very important quantity for connecting inflationary predictions and cosmic observations. In particular we found a very simple and general result: at sufficiently late times, the Universe reaches a radiation-like state of expansion with the inflaton field evolving in a turbulent manner. The only exception is when the inflaton has a non-zero bare mass. Then we observe the formation of soliton-like objects known as oscillons which behave as pressureless dust, giving rise to a matter-like equation of state. For more details see Publication 1. Our study also revealed the formation of transient objects in the cases of massless inflaton. They do not have an effect on the late equation of state. However, since this is the first time they have been reported in the literature, we intend to study their dynamics in a future work more carefully. We will also compare their observational implications to those of oscillons. For instance, the formation of oscillons after inflation can impact the predictions of baryogenesis models. In Publication 3 we show how the predicted difference in the amount of matter and antimatter in our universe can be suppressed. It will be interesting to see if that is the case when transients form.

We have also investigated the behaviour of gauge fields during inflation and the initial stages of reheating. The main focus of the studies has been the different mechanisms of gauge field production. We concentrated on models with charged scalar fields coupled to Abelian and non-Abelian gauge fields. These are well-motivated models, since such interactions appear in the Standard Model itself. A generic feature of these models is that the scalar fields attain large vacuum expectation values during slow-roll inflation and subsequently decay to gauge fields. For a very broad range of parameters the oscillating scalar condensates after inflation resonantly amplify gauge field modes. This period of non-adiabatic particle production, also known as preheating, ends when the resonantly excited gauge fields (or more generally the daughter fields) back-react on the condensate and eventually lead to its fragmentation. The ensuing non-linear stage of reheating can be studied only through lattice simulations within the classical approximation.

We first pursued the linear analysis of Abelian and non-Abelian gauge fields in a charged scalar field background. Accounting for the gauge constraints and the space-time curvature is a non-trivial task, not addressed clearly in the literature. In Publication 2 we describe in detail how to quantise consistently the gauge fields interacting with the perturbations in the scalar condensate and the metric during inflation and preheating. We provide initial conditions from inflation for lattice studies of reheating. We also show that the transverse and longitudinal modes of gauge fields can be resonantly produced during preheating, but at different rates – clarifying contradicting claims in the literature.

We spent a lot of effort over the past year in developing a lattice code to study the non-linear post-inflationary dynamics in models with a charged scalar field coupled to gauge fields. We have found a novel numerical scheme of unmatched precision for the integration of the equations of motion with the space-time curvature included at the background level. It is the only algorithm in existence allowing for self-consistent computation of the field dynamics in an expanding Universe while satisfying all consistency relations (gauge constraints) to machine precision. We have carried out multiple small scale simulations to verify the robustness of our scheme. We have observed the formation of cosmic strings after preheating as well as oscillons coupled to gauge fields. However, to study such physical phenomena properly, we will need to carry out larger and more expensive simulations in terms of computational resources. Currently, we are adapting the code for parallel computing. The aim of the first project in which we wish to use the lattice code is to answer the important question whether the coupling of oscillons to gauge fields delays or advances the onset of the epoch of radiation domination. Another immediate application of the code is to reheating after Higgs-inflation – the only cosmological model in which all parameters are known from experimental and observational measurements and in principle one should be able to compute the complete history of the universe. The only required improvement of the current version of the program is the addition of fermions fields which we are currently considering.

The main focus of the dissertation I intend to submit should I be short-listed will be the non-linear dynamics during reheating. I will first provide a connection between the epoch of inflation, when all matter fields are highly quantum, and the non-linear stage of reheating, when bosonic matter can be described classically to a very good approximation. This will include Publication 2 and parts of Publication 3. I will then concentrate on the various non-linear phenomena we have studied. I will start with the simplest models of inflation (Publication 1) and then consider the more complicated ones (Publication 3). I will also include a detailed discussion of the code I am developing and physical questions that can be addressed with it. I will conclude with a discussion on possible observational implications of reheating.

My future research plans are to build on the foundations of my PhD to further investigate the nonlinear period of reheating. The software that is currently being under construction will be an indispensable and my hope is to make it available to the cosmology community in the near future. I am also eager to expand the scope of my research to other areas of physics taking advantage of my background in field theory, general relativity, quantum mechanics and scientific computing.