

**Zwischenbericht (Sachbericht)**

Fördermaßnahme: Helmholtz-Nachwuchsgruppe	
Förder-Nr.: HZ-NG-603	Titel des Vorhabens: Strings and Cosmology – an interface for testing fundamental theories
Federführender Wissenschaftler: Dr. Alexander Westphal	
Berichtszeitraum: 01.10.2010 bis 22.04.2010	

**Sachbericht** (bitte möglichst max. 2 Seiten)

- a) The first part of this project concerns the prevalence and possible statistical predictions of string inflation across the landscape of string vacua. This is necessary to have a better understanding of the range of likely theoretical predictions from the landscape for the inflationary observables ready at a time when the first rounds of future precision cosmological data, e.g. from the PLANCK satellite, or the ground- or balloon-based experiments like BICEP 2, Keck-array, QUIET or SPIDER, may become available.

The understanding of the number frequency prevalence of, say, large-field models of string inflation versus small-field models, using F-theory methods eventually, has very recently seen a significant extension of the scope of monodromy based large-field models of string inflation, as as a whole new class of axion monodromy inflation models based on monodromy in the potential energy induced by higher-dimensional p-form fluxes type IIB string theory was uncovered [Dong,Horn,Silverstein,Westphal 2010]. In certain limits of moduli space these new models are related to the known 5-brane axion monodromy models [McAllister,Silverstein,Westphal 2008] by a string theoretic duality called geometric transition. This duality allows for a connection of the two axion monodromy model classes by passing through a curvature singularity of the internal Calabi-Yau space rendered calculable by string theory (which shows its true power as a quantum theory of gravity here). At the same time, the enriched perspective on axion monodromy opened up by the flux-based models and their duality to the 5-brane constructions gave the first concrete hints why the string theoretic large-field models seem to consistently deviate compared to naive simple field-theoretic large-field models towards smaller powers of the scalar potential ('flattening') [Dong,Horn,Silverstein, Westphal 2010]. The consequences of these developments are under further study with the project's postdoc, Pascal Vaudrevange. A sufficient grasp of these consequences is essential before the F-theory based task of counting number frequencies of these large-field axion monodromy string inflation models can be addressed in earnest.

On the the other front of the first part of the project, we have developed in collaboration with Pascal Vaudrevange and Koushik Dutta, also a DESY postdoc, an approximate analytical solution of Coleman-de Luccia tunneling of a scalar field in a meta-stable vacuum into a vacuum of lower potential energy, where the shape of the scalar potential is given as a simple combination of linear and quadratic terms [Dutta,Vaudrevange, Westphal 2011]. Such a scalar potential is suitable to give a leading-order approximation to a generic string theory landscape moduli potentials with built-in regions of slow-roll inflation. The analytical approximate tunneling solution is valid for a wide range of shape parameters of the potential (such as barrier height and width), including regions where both the known thin-wall approximation by Coleman & deLuccia [Coleman,deLuccia 1972], and the description in terms of purely linear potentials by Duncan & Jensen [Duncan,Jensen 1992] break down. As tunneling from a higher-lying metastable vacuum in the string landscape is the typical mechanism for initiating and populating the known slow-roll string inflation models, this new result comprises the first necessary step

towards describing the number frequency bias between large-field and small-field inflation models which is introduced by the dynamics of populating the models and their initial condition phase space volumina, as opposed to the pure number frequency counts discussed before. The next step, which is ongoing right now, consists in analyzing the phase space volumina of initial conditions of slow-roll inflation for large-field and small-field models in connection with their seeding via the tunneling solution.

Note, that from the start there was close collaboration with the DFG Collaborative Research Center SFB 676, C6, of which I have been made PI. Through the collaboration with the SFB 676 this project's group unexpectedly grew, because Koushik Dutta from the SFB 676 effectively joined my group as a 2nd postdoc, as well as Markus Rummel who joined the group as my PhD student from the SFB 676. Both group members are funded by the SFB 676. With Markus Rummel we embarked on the task to find sufficient criterion for the existence of metastable de Sitter (dS) vacua in string theory, which already led to successful results, and a publication is in preparation. Metastable dS vacua are a prerequisite for any successful model of inflation in string theory. A sufficient dS criterion would move the search for dS vacua in string theory qualitatively beyond the current state of the art. This is, because the existing dS constructions (e.g. KKLT or the Large Volume Scenario) are more a kind of 'lamp post' (covering only small sets of string compactifications), and so far only a necessary criterion for the existence of metastable dS vacua has been derived from supergravity [Covi et al. 2008].

Finally, in collaboration with Andrei Linde and Mahdiyar Noorbala (Stanford U.) we analyzed [Linde,Noorbala,Westphal 2011] the effects of higher-order couplings of the inflaton to curvature (a la "Higgs inflation" by Bezrukhov & Shaposhnikov [Bezrukhov,Shaposhnikov 2006]) on the inflationary observable, as the tilt of the primordial power spectrum of density fluctuation, and the power in primordial gravitational waves generated during inflation. This may well be relevant for the discriminatory power when separating small-field from large-field models in string theory, as the higher-order couplings between the inflaton and curvature can sometimes interpolate quite efficiently between originally small-field or large-field models.

- b) We are about a third towards milestone ii) (analysis of the phase space volumina of initial conditions of slow-roll inflation for large-field and small-field models in connection with their seeding via the newly found tunneling solution [Dutta,Vaudrevange,Westphal 2011]) of the first part of the project, while milestone i) (number frequency estimates for small-field vs large-field string inflation from F-theory) has made its first significant progress with the realization of flux monodromy models dual to the 5-brane axion monodromy construction [Dong,Horn,Silverstein,Westphal 2010], which considerably enlargens the space of construction to be analyzed now in terms of counting within F-theory.
- c) The budget proves so far fully sufficient for the research activities undertaken. The postdoc position of the project has been filled by Pascal Vaudrevange. The search for a 2nd PhD student is underway, as the group unexpectedly grew by collaboration with the SFB 676, and as the typical start date for hep-th positions is October, which in 2010 was not realizable for obtaining student funded directly by the project. The project is on track to reach the first milestones at the end of 2011 and in 2012.
- d) Publications:

K. Dutta, P. M. Vaudrevange, A. Westphal, "An Exact Tunneling Solution in a Simple Realistic Landscape," [arXiv:1102.4742 [hep-th]].

M. C. March, R. Trotta, P. Berkes, G.D. Starkman, P. M. Vaudrevange, "Improved constraints on cosmological parameters from SNIa data," [arXiv:1102.3237 [hep-th]].

A. Linde, M. Noorbala, A. Westphal, "Observational consequences of chaotic inflation with non- minimal coupling to gravity," JCAP 1103, 013 (2011). [arXiv:1101.2652 [hep-th]].

E. Greenwood, P. M. Vaudrevange, "Gravity waves from the non-renormalizable Electroweak Vacua phase transition," [arXiv:1011.5881 [hep-th]].

X. Dong, B. Horn, E. Silverstein, A. Westphal, "Simple exercises to flatten your potential," [arXiv:1011.4521 [hep-th]].

#### Talks:

Invited keynote review at PONT 2011 (Progress on Old and New Themes in cosmology), Avignon, France, (Apr. 2011)

A. Westphal: "Inflation in String Theory";

<http://indico.cern.ch/conferenceDisplay.py?confId=114928> .

Invited seminar at Perimeter Institute, Waterloo, Canada (Apr 2011)

K. Dutta, P. M. Vaudrevange, A. Westphal: " "An Exact Tunneling Solution in a Simple Realistic Landscape".

Invited seminar at Case Western Reserve University, Cleveland, OH, USA (Apr 2011)

K. Dutta, P. M. Vaudrevange, A. Westphal: " "An Exact Tunneling Solution in a Simple Realistic Landscape".

Invited seminar at Arizona State University, Tempe, AZ, USA (Apr 2011)

K. Dutta, P. M. Vaudrevange, A. Westphal: " "An Exact Tunneling Solution in a Simple Realistic Landscape".

Seminar at the XXIII workshop "Beyond the Standard Model", Bad Honnef, Germany (Mar 2011)

K. Dutta, P. M. Vaudrevange, A. Westphal: " "An Exact Tunneling Solution in a Simple Realistic Landscape";

<http://www.desy.de/uni-th/stringth/bad-honnef/2011/>

Seminar at the XXIII workshop "Beyond the Standard Model", Bad Honnef, Germany (Mar 2011)

A. Linde, M. Noorbala & A. Westphal: "Observational consequences of chaotic inflation with non- minimal coupling to gravity";

[http://www.desy.de/uni-th/stringth/bad-honnef/2011/Alexander\\_Westphal.pdf](http://www.desy.de/uni-th/stringth/bad-honnef/2011/Alexander_Westphal.pdf)

Invited seminar at Utrecht University, Utrecht, Netherlands (Mar. 2011)

A. Linde, M. Noorbala & A. Westphal: "Observational consequences of chaotic inflation with non-minimal coupling to gravity".

Invited seminar at the workshop "Foundational Aspects of Cosmology", Hamburg, Germany (Feb 2011)

A. Linde, M. Noorbala & A. Westphal: "Observational consequences of chaotic inflation with non- minimal coupling to gravity";

[http://www.foundationalcosmology.com/talks/Friday/1\\_Westphal.pdf](http://www.foundationalcosmology.com/talks/Friday/1_Westphal.pdf) .

Invited seminar at the workshop "Theoretical Cosmology Meetings", Leiden, Netherlands

(Feb. 2011)

X. Dong, B. Horn, E. Silverstein & A. Westphal: "Simple exercises to flatten your potential";

<http://www.cosmology.nl/> .

Invited seminar at Technical University of Munich, Munich, Germany (Nov. 2010)

R. Flauger, T. He, S. Kachru, L. McAllister, E. Pajer, E. Silverstein, A. Westphal & G. Xu:  
"Large-Field Inflation & Gravity Waves in String Theory".

Invited seminar at Technical University of Munich, Munich, Germany (Nov. 2010)

X. Dong, B. Horn, E. Silverstein & A. Westphal:

"Simple exercises to flatten your potential".

Invited seminar at the 2nd Bethe Center workshop "Cosmology meets Particle Physics",  
Bad Honnef, Germany (Oct. 2010)

R. Flauger, T. He, S. Kachru, L. McAllister, E. Pajer, E. Silverstein, A. Westphal & G. Xu:  
"Large- Field Inflation & Gravity Waves in String Theory";

<http://www.bctp.uni-bonn.de/workshop2010/talks/Westphal BCTP2010.pdf> .