Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 897 (2015) 500–554

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

A flux-scaling scenario for high-scale moduli stabilization in string theory

Ralph Blumenhagen [a], Anamaría Font [a,b,1], Michael Fuchs [a], Daniela Herschmann [a,*], Erik Plauschinn [c,d], Yuta Sekiguchi [a,b], Florian Wolf [a,b]

[a] *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany*
[b] *Arnold Sommerfeld Center for Theoretical Physics, LMU, Theresienstr. 37, 80333 München, Germany*
[c] *Dipartimento di Fisica e Astronomia "Galileo Galilei", Università di Padova, Via Marzolo 8, 35131 Padova, Italy*
[d] *INFN, Sezione di Padova, Via Marzolo 8, 35131 Padova, Italy*

Received 28 April 2015; accepted 2 June 2015

Available online 4 June 2015

Editor: Stephan Stieberger

Abstract

Tree-level moduli stabilization via geometric and non-geometric fluxes in type IIB orientifolds on Calabi–Yau manifolds is investigated. The focus is on stable non-supersymmetric minima, where all moduli are fixed except for some massless axions. The scenario includes the purely axionic orientifold-odd moduli. A set of vacua allowing for parametric control over the moduli vacuum expectation values and their masses is presented, featuring a specific scaling with the fluxes. Uplift mechanisms and supersymmetry breaking soft masses on MSSM-like D7-branes are discussed as well. This scenario provides a complete effective framework for realizing the idea of F-term axion monodromy inflation in string theory. It is argued that, with all masses close to the Planck and GUT scales, one is confronted with working at the threshold of controlling all mass hierarchies.

* Corresponding author.
E-mail address: herschma@mpp.mpg.de (D. Herschmann).

1 On leave from Departamento de Física, Facultad de Ciencias, Universidad Central de Venezuela.

http://dx.doi.org/10.1016/j.nuclphysb.2015.06.003

1. Introduction

The central element in relating string theory to the real world is moduli stabilization, i.e. a dynamical mechanism that gives a mass to the ubiquitous massless scalar fields. Most of the more detailed questions about string phenomenology and string cosmology can only be answered in a framework of moduli stabilization. Of course, it would be a big advance to isolate generic but specific predictions of string theory derived models, but so far there are only very general predictions, such as the existence of supersymmetry at a high scale, the existence of axions, gauge interactions with chiral fermions and the existence of inflaton candidates.

The usual approach to moduli stabilization [1–6] is to start with an $\mathcal{N} = 1$ supersymmetric compactification to four dimensions of one of the ten-dimensional superstring theories, and then generate a scalar potential for the many moduli by taking into account additional ingredients. These are tree-level background fluxes as well as perturbative and non-perturbative corrections to the Kähler potential and the superpotential. Once these data are specified, one can compute the resulting scalar potential for the moduli and search for minima, which can either preserve supersymmetry or break it spontaneously. A *scenario* of moduli stabilization is a restricted set-up, where a certain type of minima is guaranteed to exist and where one has parametric control over the emerging scales of the vacuum expectation values and masses of the moduli. It is fair to say that in view of the vast landscape, so far there only exist few such scenarios. The most studied ones are the racetrack, the KKLT [7] the large volume scenario (LVS) [8,9], and variations thereof.

The aim of this paper is to propose a scenario of moduli stabilization, which is entirely based on the tree-level flux induced scalar potential. The motivation for this study is two-fold, and to appreciate our approach and its historical embedding let us elucidate this point further.

In the first run of LHC no direct indication of supersymmetry has been found, so that naturalness as a guiding principle is under pressure, and fine-tuning of the Higgs mass (in the string landscape) might eventually be something we have to face. In most approaches to string phenomenology, a supersymmetry breaking scale of the order $M_{\rm susy} \sim 1$ TeV was used as an input to fix the stringy scales. Due to $M_{\rm Pl}/M_{\rm susy} \sim 10^{15}$, a moduli stabilization scenario, dynamically generating exponential hierarchies, seemed very natural. This is precisely what the LVS achieves. However, if $M_{\rm susy}$ is indeed much larger or even close to the GUT scale, then scenarios generating only polynomial hierarchies might also be interesting to consider.

Furthermore, the BICEP2 claim [10] to have measured primordial B-modes with a large tensor-to-scalar ratio of $r \sim 0.2$ has triggered quite some activity in realizing large-field inflation models in string theory. Although by now there is agreement between the PLANCK and the BICEP2 Collaborations that the main component of the B-modes is due to dust in the foreground [11–13], BICEP2's initial results have led to a number of developments in string cosmology. Invoking string theory is motivated because inflation is UV sensitive. For instance, for chaotic inflation with a quadratic potential, the mass scale of inflation is at $M_{\rm inf} \sim 10^{16}$ GeV, the Hubble scale of inflation at $H_{\rm inf} \sim 10^{14}$ GeV and the mass of the inflaton is $m_\theta \sim 10^{13}$ GeV. Therefore, a mechanism such as the shift symmetry of an axion is necessary to gain control over higher-order Planck-suppressed operators.[2] Various scenarios for axion inflation have been proposed, such as natural inflation [15], N-flation [16], or aligned inflation [17]. During the last year, it was analyzed how these scenarios can be embedded into string theory [18–32].

[2] For other symmetry-based mechanisms to suppress higher-order corrections, see [14].