Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 815 (2009) 1–94
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

GUTs in type IIB orientifold compactifications

Ralph Blumenhagen [a], Volker Braun [b], Thomas W. Grimm [c], Timo Weigand [d,*]

[a] *Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany*
[b] *Dublin Institute for Advanced Studies, 10 Burlington Road, Dublin 4, Ireland*
[c] *Bethe Center for Theoretical Physics and Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn, Germany*
[d] *SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Road, Menlo Park, CA 94025, USA*

Received 5 January 2009; accepted 11 February 2009

Available online 14 February 2009

Abstract

We systematically analyse globally consistent $SU(5)$ GUT models on intersecting D7-branes in genuine Calabi–Yau orientifolds with O3- and O7-planes. Beyond the well-known tadpole and K-theory cancellation conditions there exist a number of additional subtle but quite restrictive constraints. For the realisation of $SU(5)$ GUTs with gauge symmetry breaking via $U(1)_Y$ flux we present two classes of suitable Calabi–Yau manifolds defined via del Pezzo transitions of the elliptically fibred hypersurface $\mathbb{P}_{1,1,1,6,9}[18]$ and of the Quintic $\mathbb{P}_{1,1,1,1,1}[5]$, respectively. To define an orientifold projection we classify all involutions on del Pezzo surfaces. We work out the model building prospects of these geometries and present five globally consistent string GUT models in detail, including a 3-generation $SU(5)$ model with no exotics whatsoever. We also realise other phenomenological features such as the $\mathbf{10}\,\mathbf{10}\,\mathbf{5}_H$ Yukawa coupling and comment on the possibility of moduli stabilisation, where we find an entire new set of so-called swiss-cheese type Calabi–Yau manifolds. It is expected that both the general constrained structure and the concrete models lift to F-theory vacua on compact Calabi–Yau fourfolds.
Published by Elsevier B.V.

* Corresponding author.
E-mail addresses: blumenha@mppmu.mpg.de (R. Blumenhagen), vbraun@stp.dias.ie (V. Braun), grimm@th.physik.uni-bonn.de (T.W. Grimm), timo@slac.stanford.edu (T. Weigand).

0550-3213/$ – see front matter Published by Elsevier B.V.
doi:10.1016/j.nuclphysb.2009.02.011

1. Introduction

The LHC experiment is widely expected not only to confirm the existence of the Higgs particle as the last missing ingredient of the Standard Model of Particle Physics, but also to reveal new structures going far beyond. As experiments are proceeding into this hitherto unexplored energy regime, string theory, with its claim to represent the unified theory of all interactions, will have to render an account of its predictions for physics beyond the Standard Model. Clearly, these depend largely on the value of the string scale M_s, the most dramatic outcome corresponding to M_s close to the TeV scale. While this is indeed a fascinating possibility, in concrete string models it often leads to severe cosmological issues such as the cosmological moduli problem. In this light it might be fair to say that a more natural (but also more conservative) scenario involves a value of M_s at the GUT, Planck or intermediate scale.

During the last years, various classes of four-dimensional string compactifications with $\mathcal{N}=1$ spacetime supersymmetry have been studied in quite some detail (see the reviews [1–5] for references). From the viewpoint of realising the Minimal Supersymmetric Standard Model (MSSM) and some extension thereof the best understood such constructions are certainly the perturbative heterotic string and type IIA orientifolds with intersecting D6-branes. On the contrary, as far as moduli stabilisation is concerned type IIB orientifolds with O7- and O3-planes look very promising. The combination of three-form fluxes and D3-brane instantons can stabilise all closed string moduli [6] even within the solid framework of (conformal) Calabi–Yau manifolds where reliable computations can be performed. Moreover, supersymmetry breaking via Kähler moduli mediation and the resulting structure of soft terms bear some attractive features and have been studied both for the LARGE volume scenario [7,8] with an intermediate string scale and for a GUT scenario with the string scale at the GUT scale [9,10].

These considerations are reason enough to seriously pursue model building within type IIB orientifolds. The observation that the MSSM gauge couplings appear to meet at the GUT scale furthermore suggests the existence of some GUT theory at high energies. GUT gauge groups such as $SU(5)$ and $SO(10)$ appear naturally in string theories based on gauge group E_8 like the heterotic string. On the other hand, it has become clear that for perturbative orientifolds with D-branes, exceptional gauge groups and features like the spinor representations of $SO(10)$ do not emerge. For $SU(5)$ D-brane models, by contrast, the gauge symmetry and the desired chiral matter spectrum can be realised, a fact welcome in view of the described progress in type IIB moduli stabilisation. Still, at first sight there appears a serious problem in the Yukawa coupling sector. The $\mathbf{10}\,\mathbf{10}\,\mathbf{5}_H$ Yukawa coupling violates global perturbative $U(1)$ symmetries which are the remnants of former $U(1)$ symmetries rendered massive by the Stückelberg mechanism [11]. As a consequence of these considerations it is sometimes argued that the natural context for type II GUT model building is the strong coupling limit, where the crucial couplings in question are not "perturbatively" forbidden. The strongly coupled duals of type IIA and type IIB orientifolds are given by singular M-theory compactifications on G_2 manifolds and, respectively, by F-theory compactifications on elliptically fibred Calabi–Yau fourfolds [12]. The local model building rules for such F-theory compactifications have been worked out recently in [13–19]; For recent studies of 7-branes from the F-theory perspective see [20–24].

On the other hand, investigations of non-perturbative corrections for type II orientifold models [25–27] have revealed that the $\mathbf{10}\,\mathbf{10}\,\mathbf{5}_H$ Yukawa coupling can be generated by Euclidean D-brane instantons wrapping suitable cycles Γ in the internal manifold with the right zero mode