

Anderson, Lara B.; Gray, James; Lukas, Andre; Palti, Eran
Heterotic line bundle standard models. (English) Zbl 1397.81406
J. High Energy Phys. 2012, No. 6, Paper No. 113, 57 p. (2012).

Summary: In a previous publication, [*J. Gray et al.*, *Comput. Phys. Commun.* 180, No. 1, 107–119 (2009; [Zbl 1198.81156](#))], we have found 200 models from heterotic Calabi-Yau compactifications with line bundles, which lead to standard models after taking appropriate quotients by a discrete symmetry and introducing Wilson lines. In this paper, we construct the resulting standard models explicitly, compute their spectrum including Higgs multiplets, and analyze some of their basic properties. After removing redundancies we find about 400 downstairs models, each with the precise matter spectrum of the supersymmetric standard model, with one, two or three pairs of Higgs doublets and no exotics of any kind. In addition to the standard model gauge group, up to four Green-Schwarz anomalous $U(1)$ symmetries are present in these models, which constrain the allowed operators in the four-dimensional effective supergravity. The vector bosons associated to these anomalous $U(1)$ symmetries are massive. We explicitly compute the spectrum of allowed operators for each model and present the results, together with the defining data of the models, in a database of standard models accessible here. Based on these results we analyze elementary phenomenological properties. For example, for about 200 models all dimension four and five proton decay violating operators are forbidden by the additional $U(1)$ symmetries.

MSC:

[81T70](#) Quantization in field theory; cohomological methods
[81T30](#) String and superstring theories; other extended objects (e.g., branes)
in quantum field theory

Cited in **54** Documents

Keywords:

[superstrings and heterotic strings; superstring vacua](#)

Software:

[STRINGVACUA](#)

Full Text: [DOI](#) [arXiv](#)

References:

- [1] Candelas, P.; Horowitz, GT; Strominger, A.; Witten, E., Vacuum configurations for superstrings, *Nucl. Phys.*, B 258, 46, (1985) · [doi:10.1016/0550-3213\(85\)90602-9](#)
- [2] M.B. Green, J.H. Schwarz and E. Witten, *Superstring theory. Vol. 2: Loop amplitudes, anomalies and phenomenology*, *Cambridge Monographs On Mathematical Physics*, Cambridge University Press, Cambridge U.K. (1987), pg. 596.
- [3] Greene, BR; Kirklin, KH; Miron, PJ; Ross, GG, A three generation superstring model. 1. compactification and discrete symmetries, *Nucl. Phys.*, B 278, 667, (1986) · [doi:10.1016/0550-3213\(86\)90057-X](#)
- [4] Greene, BR; Kirklin, KH; Miron, PJ; Ross, GG, A three generation superstring model. 2. symmetry breaking and the low-energy theory, *Nucl. Phys.*, B 292, 606, (1987) · [doi:10.1016/0550-3213\(87\)90662-6](#)
- [5] Braun, V.; Candelas, P.; Davies, R.; Donagi, R., The MSSM spectrum from (0,2)-deformations of the heterotic standard embedding, *JHEP*, 05, 127, (2012) · [Zbl 1348.81435](#) · [doi:10.1007/JHEP05\(2012\)127](#)
- [6] Braun, V.; He, Y-H; Ovrut, BA; Pantev, T., A heterotic standard model, *Phys. Lett.*, B 618, 252, (2005) · [Zbl 1247.81349](#)
- [7] Braun, V.; He, Y-H; Ovrut, BA; Pantev, T., A standard model from the $E_{-}\{8\} \times E_{-}\{8\}$ heterotic superstring, *JHEP*, 06, 039, (2005) · [doi:10.1088/1126-6708/2005/06/039](#)
- [8] Braun, V.; He, Y-H; Ovrut, BA; Pantev, T., Vector bundle extensions, sheaf cohomology and the heterotic standard model, *Adv. Theor. Math. Phys.*, 10, 4, (2006) · [Zbl 1101.81086](#) · [doi:10.4310/ATMP.2006.v10.n4.a3](#)
- [9] Distler, J.; Greene, BR, Aspects of (2,0) string compactifications, *Nucl. Phys.*, B 304, 1, (1988) · [doi:10.1016/0550-3213\(88\)90619-0](#)
- [10] Kachru, S., Some three generation (0,2) Calabi-Yau models, *Phys. Lett.*, B 349, 76, (1995)
- [11] Bouchard, V.; Donagi, R., An $SU(5)$ heterotic standard model, *Phys. Lett.*, B 633, 783, (2006) · [Zbl 1247.81348](#)

- [12] Braun, V.; He, Y-H; Ovrut, BA; Pantev, T., The exact MSSM spectrum from string theory, *JHEP*, 05, 043, (2006) · [doi:10.1088/1126-6708/2006/05/043](https://doi.org/10.1088/1126-6708/2006/05/043)
- [13] Bouchard, V.; Cvetic, M.; Donagi, R., Tri-linear couplings in an heterotic minimal supersymmetric standard model, *Nucl. Phys.*, B 745, 62, (2006) · [Zbl 1214.81193](https://doi.org/10.1016/j.nuclphysb.2006.03.032) · [doi:10.1016/j.nuclphysb.2006.03.032](https://doi.org/10.1016/j.nuclphysb.2006.03.032)
- [14] Blumenhagen, R.; Moster, S.; Weigand, T., Heterotic GUT and standard model vacua from simply connected Calabi-Yau manifolds, *Nucl. Phys.*, B 751, 186, (2006) · [Zbl 1192.81257](https://doi.org/10.1016/j.nuclphysb.2006.06.005) · [doi:10.1016/j.nuclphysb.2006.06.005](https://doi.org/10.1016/j.nuclphysb.2006.06.005)
- [15] Blumenhagen, R.; Moster, S.; Reinbacher, R.; Weigand, T., Massless spectra of three generation $U(N)$ heterotic string vacua, *JHEP*, 05, 041, (2007) · [doi:10.1088/1126-6708/2007/05/041](https://doi.org/10.1088/1126-6708/2007/05/041)
- [16] Anderson, LB; He, Y-H; Lukas, A., Heterotic compactification, an algorithmic approach, *JHEP*, 07, 049, (2007) · [doi:10.1088/1126-6708/2007/07/049](https://doi.org/10.1088/1126-6708/2007/07/049)
- [17] Anderson, LB; He, Y-H; Lukas, A., Monad bundles in heterotic string compactifications, *JHEP*, 07, 104, (2008) · [doi:10.1088/1126-6708/2008/07/104](https://doi.org/10.1088/1126-6708/2008/07/104)
- [18] Anderson, LB; Gray, J.; He, Y-H; Lukas, A., Exploring positive monad bundles and a new heterotic standard model, *JHEP*, 02, 054, (2010) · [Zbl 1270.81146](https://doi.org/10.1007/JHEP02(2010)054) · [doi:10.1007/JHEP02\(2010\)054](https://doi.org/10.1007/JHEP02(2010)054)
- [19] Buchmüller, W.; Hamaguchi, K.; Lebedev, O.; Ratz, M., Supersymmetric standard model from the heterotic string, *Phys. Rev. Lett.*, 96, 121602, (2006) · [doi:10.1103/PhysRevLett.96.121602](https://doi.org/10.1103/PhysRevLett.96.121602)
- [20] Buchmüller, W.; Hamaguchi, K.; Lebedev, O.; Ratz, M., Supersymmetric standard model from the heterotic string (II), *Nucl. Phys.*, B 785, 149, (2007) · [Zbl 1149.81344](https://doi.org/10.1016/j.nuclphysb.2007.06.028) · [doi:10.1016/j.nuclphysb.2007.06.028](https://doi.org/10.1016/j.nuclphysb.2007.06.028)
- [21] Lebedev, O.; et al., A mini-landscape of exact MSSM spectra in heterotic orbifolds, *Phys. Lett.*, B 645, 88, (2007) · [Zbl 1256.81094](https://doi.org/10.1016/j.nuclphysb.2007.06.028)
- [22] Kim, JE; Kim, J-H; Kyeae, B., Superstring standard model from $Z(12-I)$ orbifold compactification with and without exotics and effective R-parity, *JHEP*, 06, 034, (2007) · [doi:10.1088/1126-6708/2007/06/034](https://doi.org/10.1088/1126-6708/2007/06/034)
- [23] Lebedev, O.; et al., The heterotic road to the MSSM with R parity, *Phys. Rev.*, D 77, 046013, (2008)
- [24] Lebedev, O.; Nilles, HP; Ramos-Sanchez, S.; Ratz, M.; Vaudrevange, PK, Heterotic mini-landscape. (II). completing the search for MSSM vacua in a $Z(6)$ orbifold, *Phys. Lett.*, B 668, 331, (2008)
- [25] Nibbelink Groot, S.; Held, J.; Ruehle, F.; Trapletti, M.; Vaudrevange, PK, Heterotic $Z(6 - II)$ MSSM orbifolds in blowup, *JHEP*, 03, 005, (2009) · [doi:10.1088/1126-6708/2009/03/005](https://doi.org/10.1088/1126-6708/2009/03/005)
- [26] Blaszczyk, M.; et al., A $Z2 \times Z2$ standard model, *Phys. Lett.*, B 683, 340, (2010)
- [27] Blaszczyk, M.; Nibbelink Groot, S.; Ruehle, F.; Trapletti, M.; Vaudrevange, PK, Heterotic MSSM on a resolved orbifold, *JHEP*, 09, 065, (2010) · [Zbl 1291.81296](https://doi.org/10.1007/JHEP09(2010)065) · [doi:10.1007/JHEP09\(2010\)065](https://doi.org/10.1007/JHEP09(2010)065)
- [28] Kappl, R.; et al., String-derived MSSM vacua with residual R symmetries, *Nucl. Phys.*, B 847, 325, (2011) · [Zbl 1208.81164](https://doi.org/10.1016/j.nuclphysb.2011.01.032) · [doi:10.1016/j.nuclphysb.2011.01.032](https://doi.org/10.1016/j.nuclphysb.2011.01.032)
- [29] Assel, B.; Christodoulides, K.; Faraggi, AE; Kounnas, C.; Rizos, J., Exophobic quasi-realistic heterotic string vacua, *Phys. Lett.*, B 683, 306, (2010)
- [30] Christodoulides, K.; Faraggi, AE; Rizos, J., Top quark mass in exophobic Pati-Salam heterotic string model, *Phys. Lett.*, B 702, 81, (2011)
- [31] Cleaver, G.; et al., Investigation of quasi-realistic heterotic string models with reduced Higgs spectrum, *Eur. Phys. J.*, C 71, 1842, (2011) · [doi:10.1140/epjc/s10052-011-1842-8](https://doi.org/10.1140/epjc/s10052-011-1842-8)
- [32] Maio, M.; Schellekens, A., Permutation orbifolds of heterotic Gepner models, *Nucl. Phys.*, B 848, 594, (2011) · [Zbl 1215.81091](https://doi.org/10.1016/j.nuclphysb.2011.03.012) · [doi:10.1016/j.nuclphysb.2011.03.012](https://doi.org/10.1016/j.nuclphysb.2011.03.012)
- [33] Gato-Rivera, B.; Schellekens, A., Heterotic weight lifting, *Nucl. Phys.*, B 828, 375, (2010) · [Zbl 1203.81147](https://doi.org/10.1016/j.nuclphysb.2009.12.001) · [doi:10.1016/j.nuclphysb.2009.12.001](https://doi.org/10.1016/j.nuclphysb.2009.12.001)
- [34] Gato-Rivera, B.; Schellekens, A., Asymmetric Gepner models II. heterotic weight lifting, *Nucl. Phys.*, B 846, 429, (2011) · [Zbl 1208.81161](https://doi.org/10.1016/j.nuclphysb.2011.01.011) · [doi:10.1016/j.nuclphysb.2011.01.011](https://doi.org/10.1016/j.nuclphysb.2011.01.011)
- [35] Anderson, LB; Gray, J.; Lukas, A.; Palti, E., Two hundred heterotic standard models on smooth Calabi-Yau threefolds, *Phys. Rev.*, D 84, 106005, (2011)
- [36] Gray, J.; He, Y-H; Ilderton, A.; Lukas, A., STRINGVACUA: A Mathematica package for studying vacuum configurations in string phenomenology, *Comput. Phys. Commun.*, 180, 107, (2009) · [Zbl 1198.81156](https://doi.org/10.1016/j.cpc.2008.08.009) · [doi:10.1016/j.cpc.2008.08.009](https://doi.org/10.1016/j.cpc.2008.08.009)
- [37] Anderson, LB; Gray, J.; He, Y-H; Lukas, A., Exploring positive monad bundles and a new heterotic standard model, *JHEP*, 02, 054, (2010) · [Zbl 1270.81146](https://doi.org/10.1007/JHEP02(2010)054) · [doi:10.1007/JHEP02\(2010\)054](https://doi.org/10.1007/JHEP02(2010)054)
- [38] He, Y-H; Lee, S-J; Lukas, A., Heterotic models from vector bundles on toric Calabi-Yau manifolds, *JHEP*, 05, 071, (2010) · [Zbl 1287.81094](https://doi.org/10.1007/JHEP05(2010)071) · [doi:10.1007/JHEP05\(2010\)071](https://doi.org/10.1007/JHEP05(2010)071)
- [39] Anderson, LB; He, Y-H; Lukas, A., Monad bundles in heterotic string compactifications, *JHEP*, 07, 104, (2008) · [doi:10.1088/1126-6708/2008/07/104](https://doi.org/10.1088/1126-6708/2008/07/104)
- [40] Gray, J.; He, Y-H; Ilderton, A.; Lukas, A., A new method for finding vacua in string phenomenology, *JHEP*, 07, 023, (2007) · [doi:10.1088/1126-6708/2007/07/023](https://doi.org/10.1088/1126-6708/2007/07/023)
- [41] Anderson, LB; He, Y-H; Lukas, A., Heterotic compactification, an algorithmic approach, *JHEP*, 07, 049, (2007) · [doi:10.1088/1126-6708/2007/07/049](https://doi.org/10.1088/1126-6708/2007/07/049)
- [42] Anderson, LB; Gray, J.; Grayson, D.; He, Y-H; Lukas, A., Yukawa couplings in heterotic compactification, *Commun. Math. Phys.*, 297, 95, (2010) · [Zbl 1203.81130](https://doi.org/10.1007/s00220-010-1033-8) · [doi:10.1007/s00220-010-1033-8](https://doi.org/10.1007/s00220-010-1033-8)

- [43] Gray, J., A simple introduction to grobner basis methods in string phenomenology, *Adv. High Energy Phys.*, 2011, 217035, (2011) · [Zbl 1234.81112](#)
- [44] Blumenhagen, R.; Jurke, B.; Rahn, T.; Roschy, H., Cohomology of line bundles: A computational algorithm, *J. Math. Phys.*, 51, 103525, (2010) · [Zbl 1314.55012](#) · [doi:10.1063/1.3501132](#)
- [45] T. Rahn, [\textit{Target Space Dualities of Heterotic Grand Unified Theories}](#), arXiv:1111.0491 [INSPIRE].
- [46] The database of 400 heterotic line bundle standard models can be accessed at <http://www-thphys.physics.ox.ac.uk/projects/CalabiYau/linebundles>
- [47] Dine, M.; Seiberg, N.; Witten, E., Fayet-Iliopoulos terms in string theory, *Nucl. Phys.*, B 289, 589, (1987) · [doi:10.1016/0550-3213\(87\)90395-6](#)
- [48] Lukas, A.; Stelle, K., Heterotic anomaly cancellation in five-dimensions, *JHEP*, 01, 010, (2000) · [Zbl 0989.81595](#) · [doi:10.1088/1126-6708/2000/01/010](#)
- [49] Blumenhagen, R.; Honecker, G.; Weigand, T., Loop-corrected compactifications of the heterotic string with line bundles, *JHEP*, 06, 020, (2005) · [doi:10.1088/1126-6708/2005/06/020](#)
- [50] Anderson, LB; Gray, J.; Lukas, A.; Ovrut, B., Stability walls in heterotic theories, *JHEP*, 09, 026, (2009) · [doi:10.1088/1126-6708/2009/09/026](#)
- [51] Anderson, LB; Gray, J.; Lukas, A.; Ovrut, B., The edge of supersymmetry: stability walls in heterotic theory, *Phys. Lett.*, B 677, 190, (2009)
- [52] Anderson, LB; Gray, J.; Ovrut, BA, Transitions in the web of heterotic vacua, *Fortsch. Phys.*, 59, 327, (2011) · [Zbl 1215.81076](#) · [doi:10.1002/prop.201000100](#)
- [53] Witten, E., Strong coupling expansion of Calabi-Yau compactification, *Nucl. Phys.*, B 471, 135, (1996) · [Zbl 1003.81536](#) · [doi:10.1016/0550-3213\(96\)00190-3](#)
- [54] Lukas, A.; Ovrut, BA; Waldram, D., Nonstandard embedding and five-branes in heterotic M-theory, *Phys. Rev.*, D 59, 106005, (1999)
- [55] Anderson, LB; Gray, J.; Lukas, A.; Ovrut, B., Stabilizing all geometric moduli in heterotic Calabi-Yau vacua, *Phys. Rev.*, D 83, 106011, (2011)
- [56] Candelas, P.; Ossa, X., Moduli space of Calabi-Yau manifolds, *Nucl. Phys.*, B 355, 455, (1991) · [Zbl 0732.53056](#) · [doi:10.1016/0550-3213\(91\)90122-E](#)
- [57] J. Wess and J. Bagger, [\textit{Supersymmetry and supergravity}](#), Princeton University Press, Princeton U.S.A. (1992), pg. 259.
- [58] Barbier, R.; et al., R-parity violating supersymmetry, *Phys. Rept.*, 420, 1, (2005) · [doi:10.1016/j.physrep.2005.08.006](#)
- [59] Arkani-Hamed, N.; Hall, LJ; Murayama, H.; Tucker-Smith, D.; Weiner, N., Small neutrino masses from supersymmetry breaking, *Phys. Rev.*, D 64, 115011, (2001)
- [60] Giudice, G.; Masiero, A., A natural solution to the mu problem in supergravity theories, *Phys. Lett.*, B 206, 480, (1988)
- [61] S. Kobayashi, [\textit{Mathematical Society of Japan Publications. Vol. 15: Differential geometry of complex vector bundles}](#), Princeton University Press, Princeton U.S.A. (1987). · [Zbl 0708.53002](#)
- [62] Sharpe, ER, Kähler cone substructure, *Adv. Theor. Math. Phys.*, 2, 1441, (1999) · [Zbl 1059.14500](#)
- [63] Anderson, LB; Gray, J.; Ovrut, B., Yukawa textures from heterotic stability walls, *JHEP*, 05, 086, (2010) · [Zbl 1287.81087](#) · [doi:10.1007/JHEP05\(2010\)086](#)
- [64] Kuriyama, M.; Nakajima, H.; Watari, T., Theoretical framework for R-parity violation, *Phys. Rev.*, D 79, 075002, (2009)
- [65] J. Li and S.-T. Yau, [\textit{The existence of supersymmetric string theory with torsion}](#), hep-th/0411136 [INSPIRE].
- [66] Berglund, P.; et al., On the instanton contributions to the masses and couplings of E_6 singlets, *Nucl. Phys.*, B 454, 127, (1995) · [Zbl 0925.81153](#) · [doi:10.1016/0550-3213\(95\)00403-F](#)
- [67] Anderson, LB; Gray, J.; Lukas, A.; Ovrut, B., Stabilizing the complex structure in heterotic Calabi-Yau vacua, *JHEP*, 02, 088, (2011) · [Zbl 1294.81153](#) · [doi:10.1007/JHEP02\(2011\)088](#)
- [68] Anderson, LB; Gray, J.; Lukas, A.; Ovrut, B., The Atiyah class and complex structure stabilization in heterotic Calabi-Yau compactifications, *JHEP*, 10, 032, (2011) · [Zbl 1303.81139](#) · [doi:10.1007/JHEP10\(2011\)032](#)
- [69] Candelas, P.; Dale, A.; Lütken, C.; Schimmrigk, R., Complete intersection Calabi-Yau manifolds, *Nucl. Phys.*, B 298, 493, (1988) · [doi:10.1016/0550-3213\(88\)90352-5](#)
- [70] Gagnon, M.; Ho-Kim, Q., An exhaustive List of complete intersection Calabi-Yau manifolds, *Mod. Phys. Lett.*, A 9, 2235, (1994) · [Zbl 1020.14501](#)
- [71] The CALABI-YAU Home Page, <http://www.th.physik.uni-bonn.de/th/Supplements/cy.html>.
- [72] Braun, V., On free quotients of complete intersection Calabi-Yau manifolds, *JHEP*, 04, 005, (2011) · [Zbl 1250.14026](#) · [doi:10.1007/JHEP04\(2011\)005](#)
- [73] L.B. Anderson, [\textit{Heterotic and M-theory compactifications for string phenomenology}](#), arXiv:0808.3621 [INSPIRE].
- [74] R. Friedman, [\textit{Algebraic Surfaces and Holomorphic Vector Bundles}](#), Springer-Verlag, Heidelberg Germany (1998). · [Zbl 0902.14029](#) · [doi:10.1007/978-1-4612-1688-9](#)
- [75] Donagi, R.; Ovrut, BA; Pantev, T.; Reinbacher, R., $SU(4)$ instantons on Calabi-Yau threefolds with $Z(2) \times Z(2)$ fundamental group, *JHEP*, 01, 022, (2004) · [Zbl 1243.14034](#) · [doi:10.1088/1126-6708/2004/01/022](#)
- [76] R. Hartshorne, [\textit{GTM 52: Algebraic Geometry}](#), Springer Verlag, Heidelberg Germany (1977). · [doi:10.1007/978-1-4757-](#)

- [77] P. Griffith and J. Harris, *Principles of algebraic geometry*, (1978).
- [78] T. Hubsch, *Calabi-Yau manifolds: A Bestiary for physicists*, first edition World Scientific, Singapore (1992), pg. 362 [second edition, World Scientific, Singapore (1994), pg. 374]. · [Zbl 0771.53002](#)
- [79] Dudas, E.; Palti, E., On hypercharge flux and exotics in F-theory guts, *JHEP*, 09, 013, (2010) · [Zbl 1291.81443](#) · [doi:10.1007/JHEP09\(2010\)013](#)
- [80] Marsano, J., Hypercharge flux, exotics and anomaly cancellation in F-theory guts, *Phys. Rev. Lett.*, 106, 081601, (2011) · [doi:10.1103/PhysRevLett.106.081601](#)
- [81] Dolan, MJ; Marsano, J.; Schäfer-Nameki, S., Unification and phenomenology of F-theory GUTs with $U(1)_{PQ}$, *JHEP*, 12, 032, (2011) · [Zbl 1306.81215](#) · [doi:10.1007/JHEP12\(2011\)032](#)
- [82] Nir, Y.; Seiberg, N., Should squarks be degenerate?, *Phys. Lett.*, B 309, 337, (1993)

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.