Non-supersymmetric strings and rank reduction

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Based on [B. Fraiman, HPF ‘22], [WIP]

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Introduction

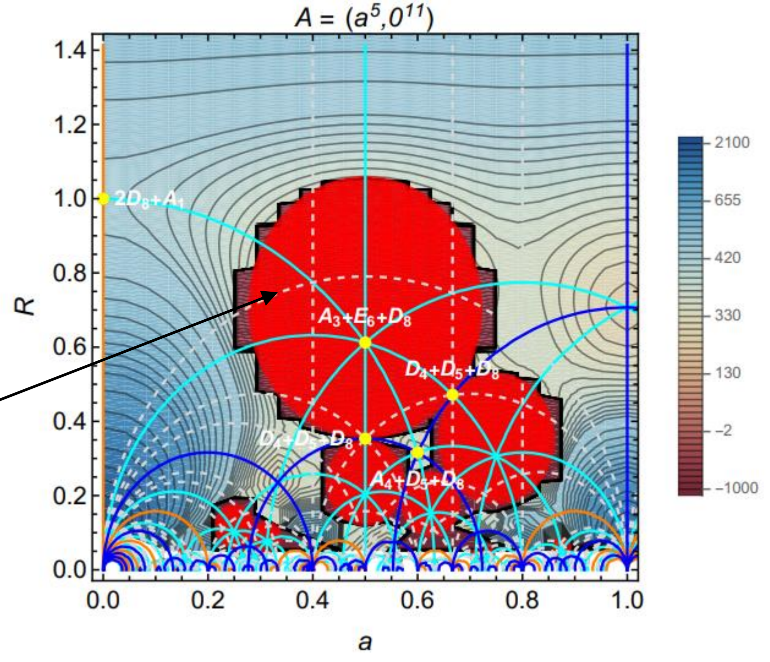
The question that I want to ask is how to get a handle on the salient properties of non-supersymmetric string theories in simple examples. These properties include:

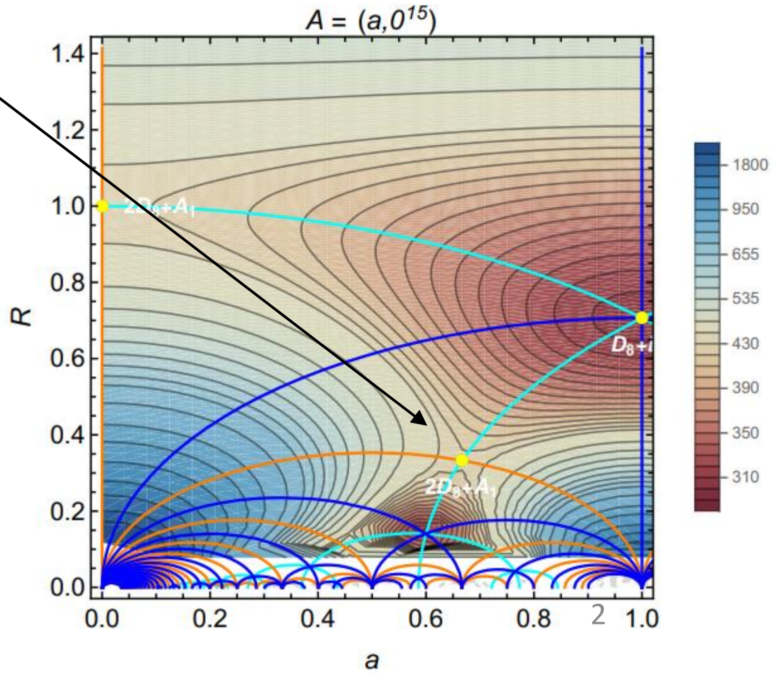
1. Enhancement of gauge symmetries, matter content and tachyons. (Maximal enhancements are critical points of the potential)

2. Relationships among them, for classification purposes.

3. Inherited properties from supersymmetric parents, like duality. (I consider mainly spontaneous supersymmetry breaking)

I will be considering theories descending from those with 16 supercharges.





[Fraiman, Graña, HPF, Sethi '23]

Supersymmetric Case

Supersymmetric case

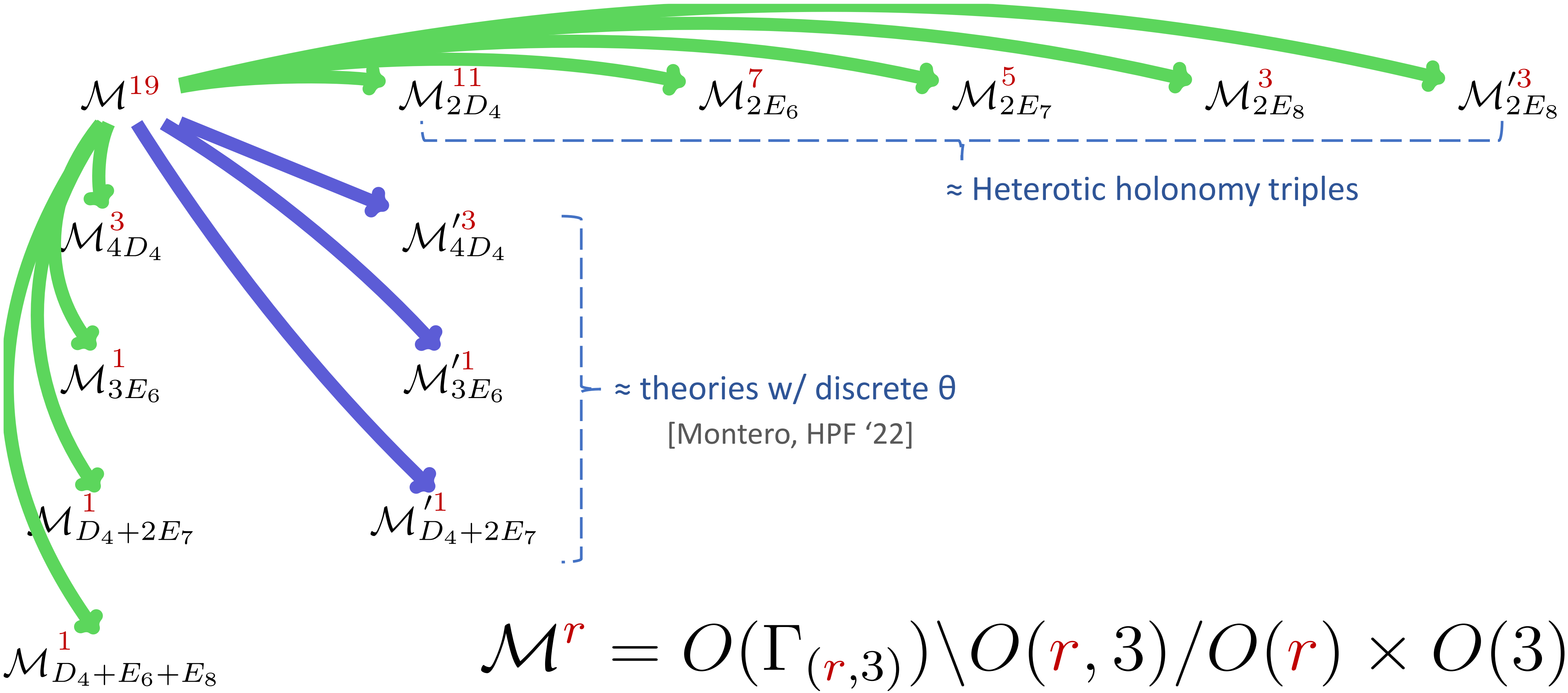
- The supersymmetric landscape (16 supercharges) in high dimensions exhibits many structures which allow to study it in a controlled manner.

- These vacua include heterotic strings compactified on tori and their asymmetric orbifolds, as well as asymmetric orbifolds of type II strings. Each different construction lies on an disconnected component of the moduli space.

- In F/M-theory on K3 surfaces (i.e. 8D and 7D), every known component of the moduli space is realized through frozen singularities, which generalize the "geometric" uplift of positive orientifold-planes. [de Boer et al '01] [HPF '22]

- One can then formally map regions of the standard Narain component (heterotic on tori) to every other component at the level of the spectrum, namely gauge groups (as there is no matter). The resulting theories always have reduced gauge group rank, and exhibit interesting properties such non-simply-laced gauge symmetries. [Cvetic, Dierigl, Lin, Zhang '21], [Fraiman, HPF '21]

All moduli spaces connect to the Narain moduli space in D = 7

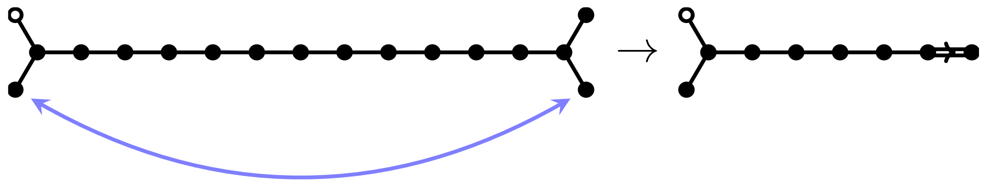


$$\mathcal{M}^r = O(\Gamma_{(r,3)})\backslash O(r,3)/O(r)\times O(3)$$

Supersymmetric case

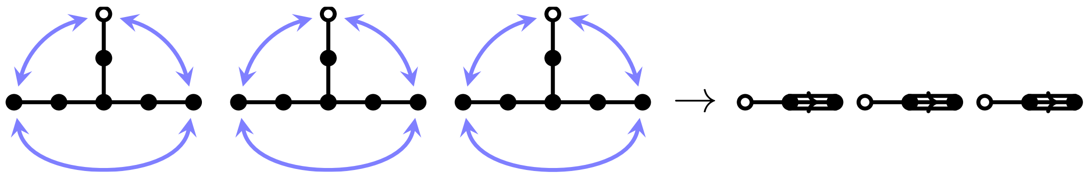
In D = 6, map acts on vacua at the level of gauge groups, only if they have nontrivial topology. This map acts on (affine) Dynkin diagrams by folding them: [Fraiman, HPF '21]

$$\frac{Spin(32)}{\mathbb{Z}_2} \rightarrow Spin(17)$$



(Rank reduced by 8)
CHL String

$$\frac{E_6 \times E_6 \times E_6}{\mathbb{Z}_3} \rightarrow G_2 \times G_2 \times G_2$$



(Rank reduced by 12)
Z3-triple

Supersymmetric case

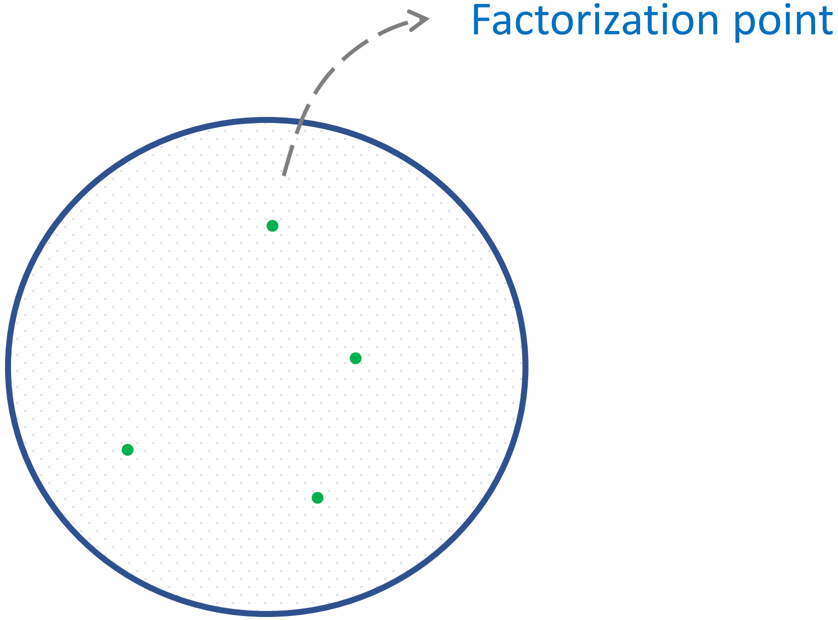
By folding in every posible way, one recovers every known theory in 6D with 16 supercharges and predicts a few more (here I restrict to *cyclic* orbifolds; non-cyclic are not well explored). [Fraiman, HPF '22]

Moreover, all of these theories have worldsheets which factorize holomorphically in 2D (after T^4 compactification) at various points:

$$Z(\tau, \bar{\tau}) = Z_L(\tau) \times Z_R(\bar{\tau})$$

For heterotic strings, the left-moving chiral bosonic CFT with c = 24 belongs to Schellekens list [Schellekens '92].
For type II strings, it is a theory with 24 real fermions and a choice of current algebra. [Harrison, Paquette, Persson, Volpato '20]

Sprectral data of the 6D theories is encoded in these chiral CFTs. [Fraiman, HPF '22]



D = 2 Moduli space

Non-Supersymmetric Case

Non-supersymmetric case

Question: is there an analogous story for non-supersymmetric strings?

There should be in one way or another, since non-supersymmetric heterotic strings exist. At the classical level, these theories behave just like their supersymmetric partners with respect to symmetry enhancements, suggesting that many aspects of the supersymmetric theories have non-supersymmetric equivalents/analogs.

Clue: Non-supersymmetric heterotic strings in 10D are in correspondence with *fermionic* CFTs with c = 16, as opposed to bosonic CFTs (see e.g. [Boyle Smith, Tachikawa, Zheng '23]). To get lower dimensional theories, need to classify fermionic CFTs with c = 24.

This was achieved in [Höhn, Möller '23]. There are 969 such CFTs, arranged into 33 families.
We can then associated each family to a non-SUSY heterotic string moduli space in 2D.

Non-supersymmetric case

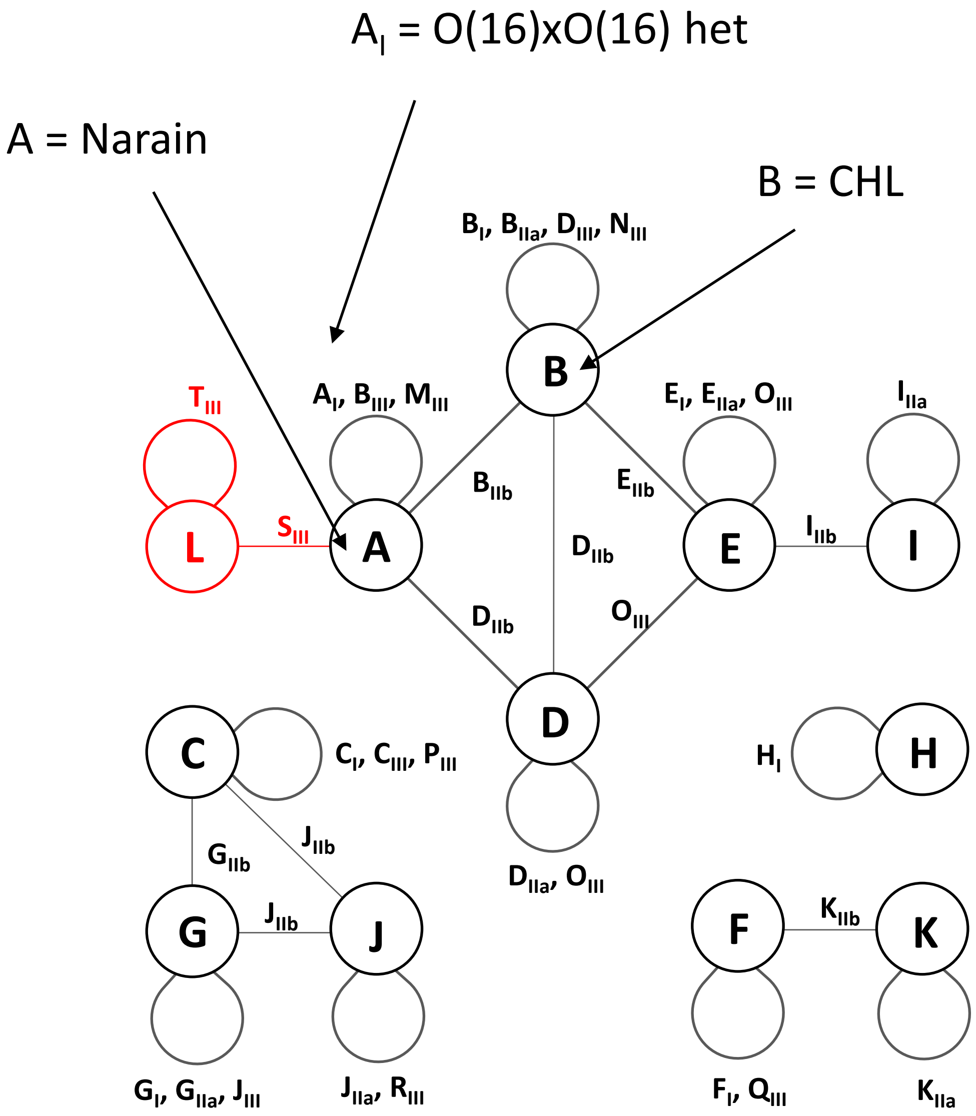
Each node (A,B,…) is a family of bosonic CFTs, i.e. a moduli space of supersymmetric heterotic strings.

Each link (I, IIa, IIb, III) is a family of fermionic CFTs constructed from a family of bosonic CFTs using shifts, outer automorphisms and $(-1)^F$ (in the worldsheet).

Red node and links involve the monster CFT and the associated heterotic strings have no moduli.

Conjecture: the associated theories will also uplift to 6 or more dimensions.

Intuition: outer automorphisms uplift to 6D, where they can be used to construct the theories.
Rank reduced theories admit three types of shifts.



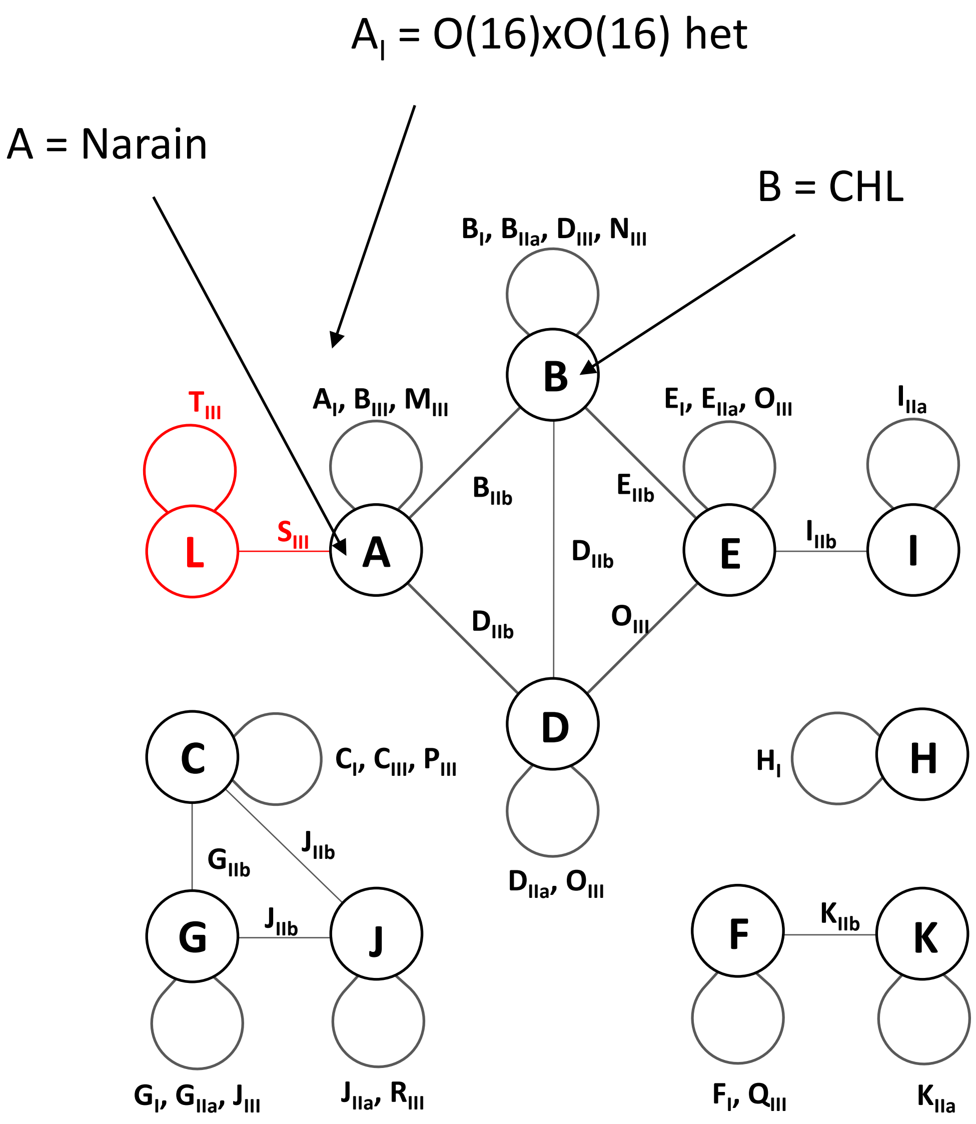
Non-supersymmetric case

Class I theories are Scherk-Schwarz reductions of supersymmetric theories, so they are straight-forward to construct.

Class IIb theories are "non-supersymmetric versions" of the rank reduced theories, involving an extra $(-1)^F$ operation in the supersymmetric orbifold. The CHL case was studied in [Nakajima '23].

Class III theories do not involve shifts, e.g. B_{III} is the E_8 string. **Class IIa** theories are so far unexplored; B_{IIa} can be realized as an SS reduction of the E_8 string.

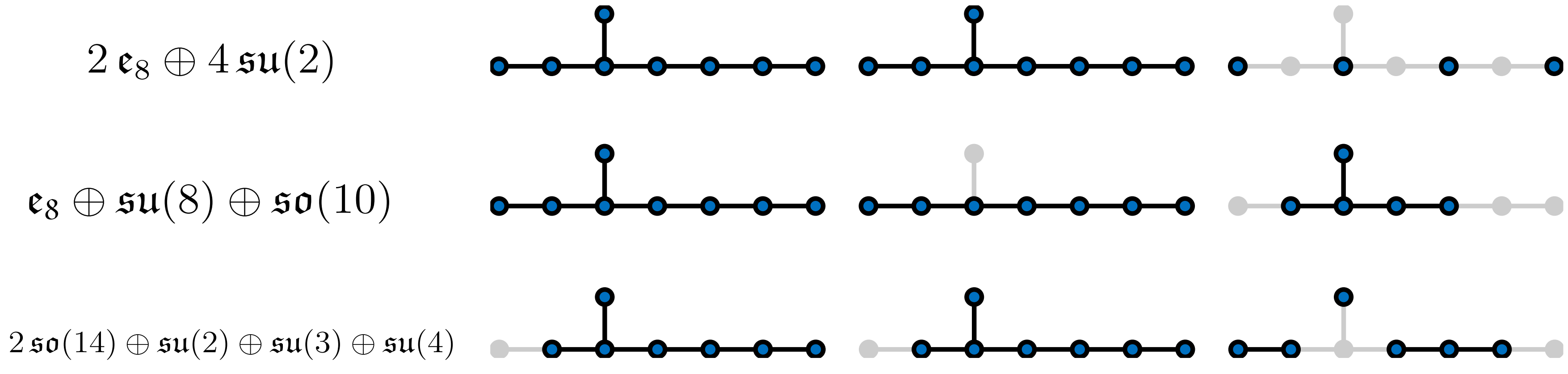
The connection between these orbifolds and the 2D CFTs can be established by checking that the partition functions factorize appropriately for certain values of the moduli (done explicitly for all of class B).



Spectral data

The classification of (a family of) non-supersymmetric heterotic theories seems to work correctly.
What can we infer from the associated 2D CFTs?

For heterotic strings on T4 (equivalently type IIA on K3), every gauge symmetry is encoded in the 24 Niemeier lattices (which underlie the associated 2D CFTs). E.g. for 3 E_8: [Fraiman, HPF '22]



For the O(16)xO(16), there are 273 associated lattices, and they also encode spectral data. They give every posible symmetry enhancement in 6D and the associated massless matter content, as well as certain tachyons. This helps classifying tachyon-free extrema of the potential. For other theories a proof is lacking but seems feasible.

Rank reduction and Duality

Rank reduction and duality

It would be good to have maps from which we can produce the spectral data of the theories with rank reduction. This would show a non-trivial link between the different theories with some physical meaning.

At the formal level, the main challenge is that the spectrum is split into different classes yielding the gauge bosons, matter content and tachyons, each associated to a different subset of the charge lattice. Embedding the charge lattice of one theory into another does not seem to make sense.

In the supersymmetric case, the rank reduction maps are meaningful e.g. as singularity freezing in M/F-theory. But here we do not have such duals so far. In general very little is known about non-supersymmetric string dualities. [Blum, Dienes '97], [Bergman, Gaberdiel '99], [Blumenhagen, Kumar '99]

A first step in this direction is to find a Type II orientifold dual to a non-supersymmetric heterotic string.

Let's put forward a proposal…

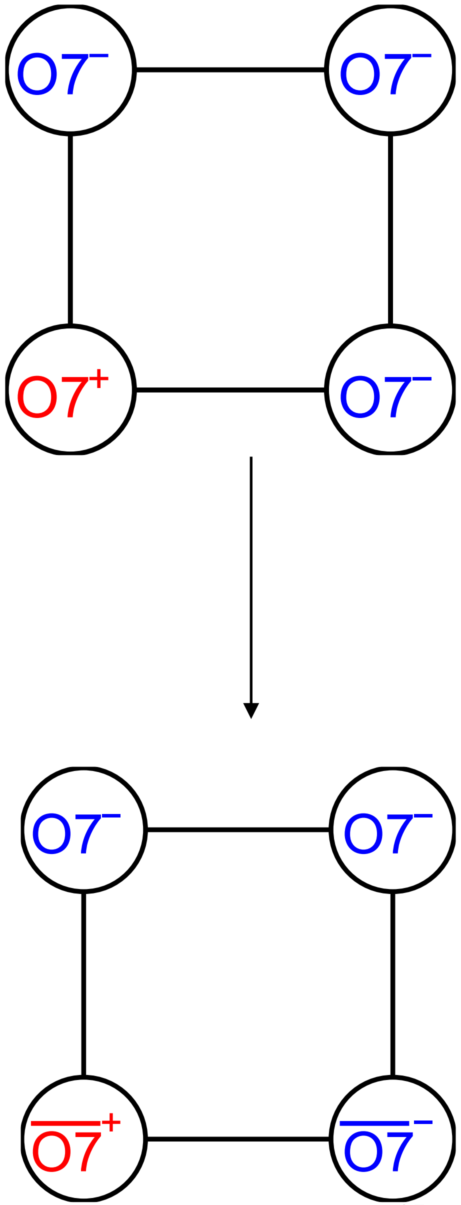
Rank reduction and duality

The CHL string has an orientifold dual in eight dimensions with three O7-'s and positive O7+, with eight D7 branes.

In this special setup, supersymmetry can be broken by switching a pair O7- /O7+ by anti-orientifolds, i.e. by changing the sign of Their RR coupling. They are no longer mutually BPS with the D7 branes. Note that the theory does not have NSNS tadpole.
[Coudarchet, Dudas, Partouche]

The spectrum of gauge bosons is not altered, but the fermions do change. For stacks of D7 branes on anti-o-planes, there are spinors in the symmetric (antisymmetic) representation of SO(2n) (Sp(n)).

It turns out that the same behavior is reproduced by going from the CHL string to its non-supersymmetric version given by the orbifold RT(-1)^F , (Class BIIb), With one caveat: the trace of the fermionic representations (a fermion singlet) is not present.



Rank reduction and duality

It is likely that these two theories with reduced rank **are strong-weak dual.** If so, much but not all of the massless spectrum is preserved. Any proposed map connecting different theories will depend on the duality frame.

On the other hand, this duality helps us extend the non-supersymmetric heterotic string classification to type II strings. A stack $O7^- + 8\ D7$ can be traded by an $O7^+$, reducing the gauge group rank from 10 to 2. This theory would then be dual to the non-supersymmetric version of various type II theories with rank 2.

Moreover this indicates that strong-weak duality makes sense more generally for non-supersymmetric strings, at least in the case of freely acting orbifolds.

Finally, duality means that we have access to the potential both at weak and strong coupling, which could impose important constraints on the full potential.

Main points:

- Classification of 6D heterotic strings with 16 supercharges extends naturally to non-supersymmetric strings. The type II case is not clear but progress seems feasible.

- 2D fermionic CFTs with c = 24 encode a great deal of the spectra in the associated 6D theories, including the presence of tachyons.

- Rank reduction maps in SUSY case are independent of the stringy details; they are fully non-perturbative. In the non-SUSY case, it seems very difficult to construct them.

- We propose a non-supersymmetric heterotic-type II duality which implies the lack of such a map, but a more intrincate structure may yet exist.

- The simple examples considered here are worth studying further. Having a handle on their spectra would help in finding more dualities, or other surprising structures.

Thanks for your attention!