Five golden rules for superstring phenomenology

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Outline

- String Theory

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- Physics

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- Lessons from Physics

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- Five Rules

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- How to connect to explixit string constructions
- Discussion and Outlook

What does string theory give us?

- All we need
  - gravity
  - gauge interactions
  - matter fields

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  - gravity
  - gauge interactions
  - matter fields
- and even more
  - extra dimensions
  - supersymmetry
  - (potential) restrictions on gauge groups

Does this ressemble the real world?

Not really!

- we see $d = 4$ instead of $d = 10$
- we observe $N = 0$ or 1 SUSY instead of $N = 8$
- gauge group much smaller than e.g. $E_8 \times E_8$

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The world we see:

- $SU(3) \times SU(2) \times U(1)$ gauge bosons
- 3 families of quarks and leptons
- a Higgs boson???

The world we imagine

Theoretical arguments lead us to

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GUT picture has changed our view of the world ...

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- Educated guess of unified picture (bottom up)
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will lead to rules for selection of models.....

Rule 1: Spinor of $SO(10)$

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Chiral matter repr. of dimension $\bar{5} + 10$, 16, 27 ....

$SO(10)$ clearly singled out

- incorporates all the success of SU(5), Pati-Salam...
- family in a single irreducible representation
- includes right handed neutrinos
- no exotics

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Does this imply that gauge group $SO(10)$ is realized?

Rule 2: Incomplete multiplets

Complete $SO(10)$ representation is appropriate for fermions, but not for gauge bosons and Higgs

- only $SU(3) \times SU(2) \times U(1)$ gauge bosons
- just Higgs doublets
- doublet-triplet splitting problem of GUTS

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Split multiplets for gauge bosons and Higgses

Where are the other states?

How is the GUT gauge symmetry broken?

Rule 2: Incomplete multiplets ...

String theory in extra dimensions can help here!

- solution of doublet-triplet splitting in orbifolds (Ibanez, Kim, HPN, Quevedo 1987)
- GUT group not realized in d=4 but only in higher dimensions
- concept of "GUTs without GUTs"

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There could be even larger gauge groups in $d > 4$!

- $E_8 \times E_8$ in heterotic string theory
- 16-dimensional spinor of $SO(10)$ could be incomplete as well

Rule 3: Repetition of families?

Number of families needs an explanation

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- 3 families in single GUT representation requires many exotic states

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Again, extra dimension could help here

- toplogical numbers in Calabi-Yau compactification
- geometrical explanation from orbifolds
- could solve flavour problem through symmetries in extra dimensions

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Some arguments for SUSY

- evolution of gauge couplings in MSSM
- light Higgs boson
- grand desert (neutrino see-saw)

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Remaining problems

- SUSY breakdown and "μ-problem"
- Proton decay (via $d = 5$ operators)

Rule 5: R-parity needed

Discrete symmetries important!

- Avoid proton decay (via $d = 4$ operators)
- Need stable particle for cold dark matter
- Textures of Yukawa couplings
- The flavour problem
- The μ problem
- Axions

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Again, $SO(10)$ with the 16-dimensional spinor representation might be perfect.

R-parity is automatic!

Intermediate conclusion

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We need supersymmetry

Some group theory

Chirality in $d = 4$ requires gauge groups A_n, D_n or E_n

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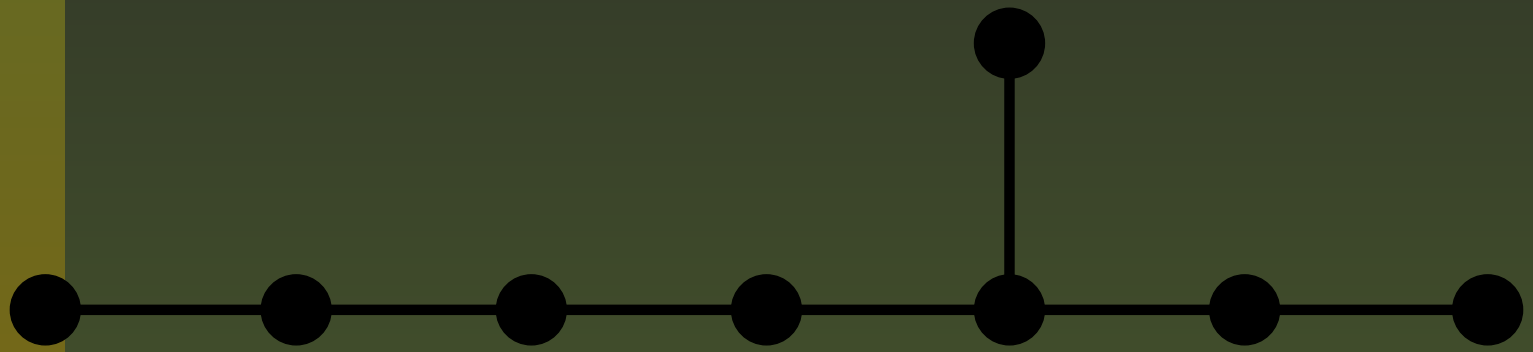
This suggests the E_n-series:

$E_8 \to E_7 \to E_6 \to E_5 = S(10) \to E_4 = SU(5) \to$
$E_3 = SU(3) \times SU(2) \times U(1)$

The conjectured E_n Series



The Dynkin diagram of E_8 ...

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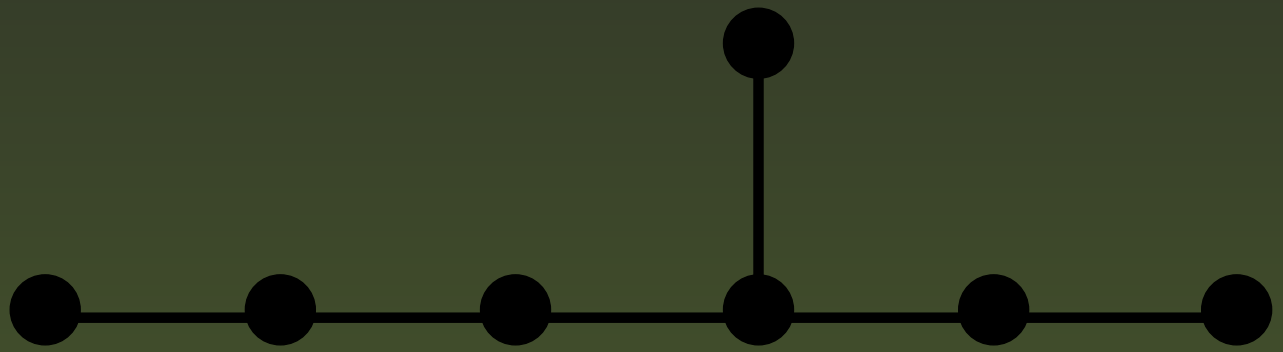
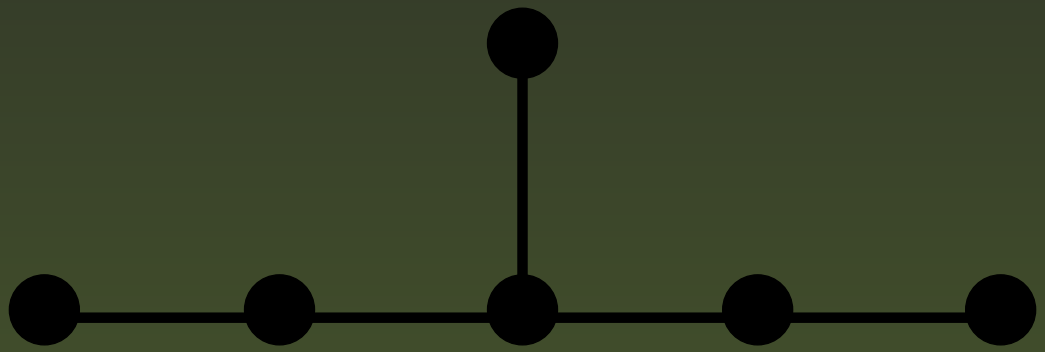


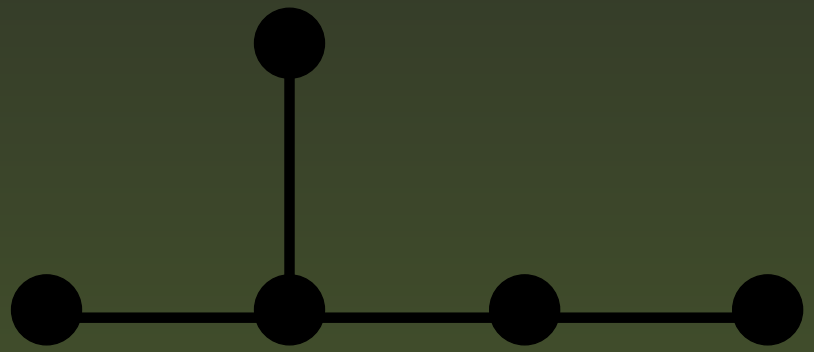
... leads to E_7 by removing a “dot” ...

The conjectured E_n Series



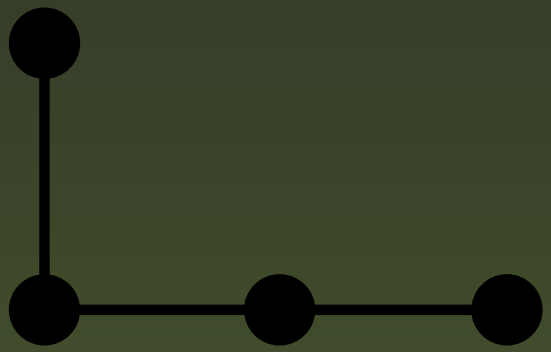
... and to E_6 by removing a second “dot” ...

The conjectured E_n Series



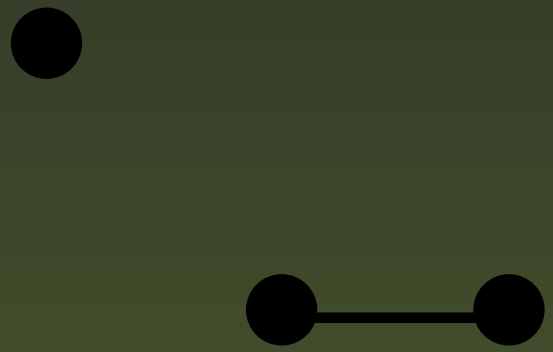
... $E_5 = D_5 = SO(10)$ connects to the D-series ...

The conjectured E_n Series



... and $E_4 = A_4 = SU(5)$ to the A-series ...

The conjectured E_n Series



... and finally $E_3 = SU(3) \times SU(2)(\times U(1))$

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- heterotic M-theory (Horava-Witten)

Conclusion

THE

HETEROTIC $E_8 \times E_8$ THEORY

SEEMS TO BE MOST PROMISING!

talks by Kim, Ovrut, Raby, Faraggi, Park, Zhang, Wingerter ...

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