Scale transformations and the dynamics of string theory

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The progress of theoretical physics

c. 100
Ptolemaic system
(heavenly bodies move in perfect circles)

1687
Newton’s theory of gravity
(No exact solution to three-body problem)
The progress of theoretical physics

1915
General Relativity
(no exact solution to two-body problem)

1940s
Quantum field theory
(no exact solution to one-body problem)
The progress of theoretical physics

1970s
String theory
What is the vacuum???

Colloquium plot:
- basics of string theory
- particles with strange masses
- things we don’t understand about string theory
- beginnings of a solution
String Theory 101

String theory combines particle physics with General Relativity.

To accomplish this, it postulates changes to both theories at very small scales ($10^{-20}$ to $10^{-33}$ cm).
Each point of our 3D space hides a tiny 6D space.

The equations that determine the shape of this space:
1. are not completely known
2. are complicated
3. have many solutions

“vacuum problem”

MH, Wiseman (2005)
Every particle is a tiny vibrating string

Kinds of particles you see depends on topology & geometry of hidden space

ALWAYS have a graviton $\Rightarrow$ gravity

Can also get all the kinds of particles of Standard Model:

- gauge bosons (abelian & non-abelian)
- chiral fermions
- scalars (Higgs boson, ...)

$\Rightarrow$ unification

Devil is in the details ...
String Theory 101

Can we get this:
Calculations in string theory are easiest when you assume **SUPERSYMMETRY**

Sadly, this beautiful symmetry is not a property of the **real world**

In non-supersymmetric backgrounds, string theory (generically) predicts particles with:

$$m^2 < 0$$

Huh?
An odd result

Actually, not so odd: Higgs field in Standard Model

Scalar field with potential

\[ V(\phi) \]

Particle with mass

\[ m^2 = V''(0) \]

massive particle

massless particle

\[ m^2 < 0 \]

(instability)
An odd result

Potential for Higgs field:

\[ \phi \text{ will roll down to minimum of } V \]

\[ \ddot{\phi} = -V'(\phi) - \mu \dot{\phi} \]
String theory’s dark secrets

Let’s do the same for strings with $m^2 < 0$

Two fundamental obstacles:

1) **Background independence:**
   No (obvious) field picture

2) **Time dependence:**
   Equations of motion? Initial data?

Our understanding of string theory is mostly limited to fixed, static backgrounds
Progress

(Freedman, MH, Lawrence, PRD 2006)

Assume \(|m^2| \ll m_{\text{string}}^2\)

**Step 1:** Shape (etc) of hidden space can be deformed

**Step 2:** \(\phi\) is a field; it corresponds to a string particle
Step 3: Look at the world through the eyes of a string

1D physicist living on the string sees 1D laws of physics

- 3 scalar fields $x, y, z$
  (our familiar dimensions)
- other fields for hidden dimensions

$\phi$ is 1D “fundamental constant of nature”
Progress

3 interpretations for $\phi$
- parameter describing shape of hidden space
- scalar field of 3D physics
- coupling constant of 1D physics

Coupling “constants” run: depend on size or momentum of probe
Progress

We showed:

1) equation of motion:

\[ \ddot{\phi} = -\beta(\phi) - \mu \dot{\phi} \]

2) potential energy:

\[ \beta(\phi) = V'(\phi) \]

scalar field (1D coupling constant) \( D \) controls string splitting/joining

\[
\mu = -\dot{D} \quad V(\phi) = \beta_D(\phi)
\]
Real-world application?

Stringy effects in time-dependent situations: black hole singularity & very early universe
Conclusions

By taking a 1D viewpoint, we’ve made some progress on the problems of background independence and time dependence in string theory. This may lead to insights about black hole singularities, the early universe, and possibly vacuum selection.