Lorentz violation and vacuum structure in string theories

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String can break CPT, but inevitability is obscure

String theory = A quantum gravity

Tiny string vibrates,

→ Many kinds of particles

Graviton, scalar fields, tensor fields, …

- Can determine the spacetime dimensions … 10 dim!
- Reduces to ordinary quantum field theory at low energy
- Complete definition not found yet

String supports antimatter feeling different gravity?

- Answer 1 : Broken CPT

  Matter and antimatter have different mass eigenstates

- Answer 2 : “Fifth force”

  Highly supersymmetrized hypothetical world has cancellation of gravity by scalar/tensor forces, called “BPS”

  Scalar (axion, dilaton,…), tensor (RR-field, NSNS field,…)

  These particles can be light, after moduli stabilization

  But It is unlikely that these couple to baryon charge.

String can break CPT, but inevitability is obscure

Cause of difficulty

CPT theorem cannot be applied

Current status

Standard scenario is “made” to be CPT invariant

Directions

Spontaneous compactification scenarios may evaluate possible Lorentz-breaking constants

String can break CPT, but inevitability is obscure

1

Cause of difficulty

CPT theorem cannot be applied

3 pages

2

Current status

Standard scenario is “made” to be CPT invariant

2 pages

3

Directions

Spontaneous compactification scenarios may evaluate possible Lorentz-breaking constants

6 pages

1

CPT theorem cannot be applied

CPT theorem (for 4d quantum field theory)

Local interaction + Lorentz invariance → CPT invariance

[Luders `54] [Pauli `55]

In string theory?

Locality : subtle

Lorentz : by hand!

1

CPT theorem cannot be applied

Locality : subtle

String = extended object
= non-local ?

String interaction is local, but action looks non-local

$$S = \int d^d x \ \left[(\partial_\mu \phi(x))^2 \ + \ (\exp(\partial_\nu \partial^\nu) \phi(x))^3 \right] + \cdots$$

1

CPT theorem cannot be applied

Lorentz : by hand!

Superstring needs Lorentz violation, because…….

Consistently formulated in 10 spacetime dimensions

→ Reconciled only by "Space compactification" 10 = 4 + 6

→ Inevitable breaking of 10 dim. Lorentz symmetry!
But 4d Lorentz is kept by hand!

Question : Why 4+6 ? Why not 1+1+1+1+1+…+1 ?

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2 Standard scenario is “made” to be CPT invariant

Normally string phenomenology keeps 4d Lorentz by hand.

- 6d Calabi-Yau compactification in heterotic string theory.
- D-brane wrapping 6d torus in type II superstring theory.
- F-theory compactifications.

Reason : simpler, and
we do not know spontaneous breaking mechanism

Question : Why 4+6 ? Why not 1+1+1+1+1+…+1 ?

2

Standard scenario is “made” to be CPT invariant

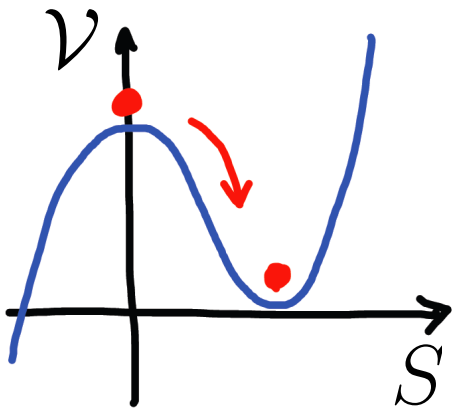
Look back: A historical side of String and Lorentz breaking

CPT breaking by a constant vector

- Standard Model Extension [Colladay, Kostelecky `97] [Myers,Pospelov `02]

$$\mathcal{L}'_a \equiv a_\mu \overline{\psi} \gamma^\mu \psi$$

Vector condensation in string theory [Kostelecky, Samuel `89]



$$\mathcal{V}(S, A_\mu) = -S^2 + S^3 - S A_\mu A^\mu$$

This seems not the case in string theory

If present, vector would be Planck scale

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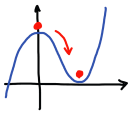
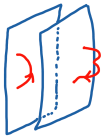
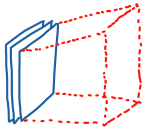
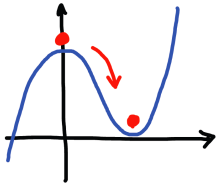
3 Spontaneous compactification scenarios

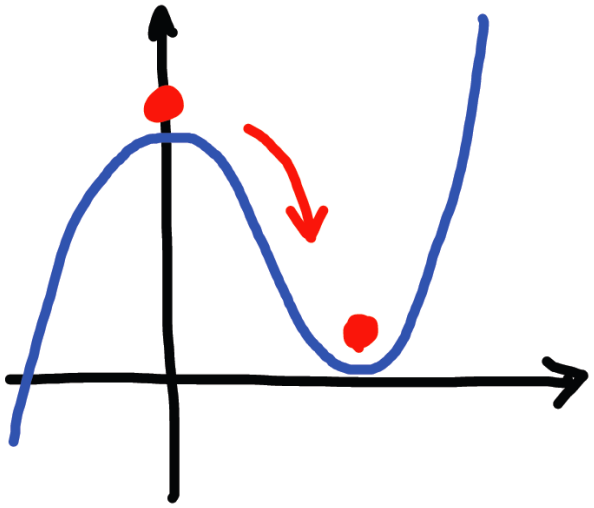
		Scenario	4d Lorentz breaking	Evaluation
1.		Vacuum condensation	Spontaneous	?
2.		Winding string	Explicit	△
3.		Braneworld	?	?
4.		Matrix universe	Spontaneous	△
5.		Emergent spacetime	Explicit	?

1. 

Vacuum condensation

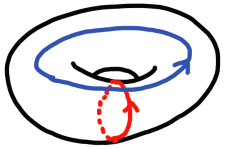
Lorentz breaking: Spontaneous, Evaluation: ?

Tachyon condensation [Kostelecky, Samuel, ’89] [Sen ‘98]



Bosonic string has tachyonic instability

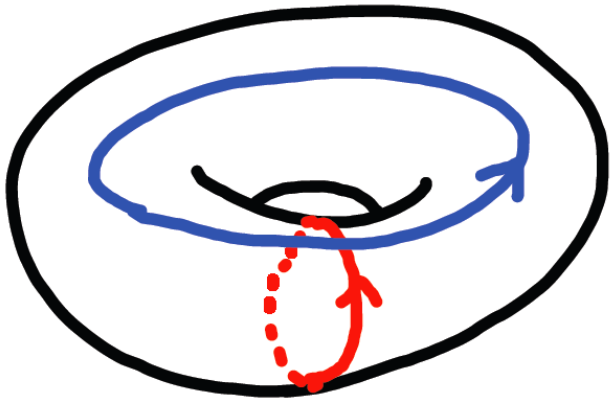
→ Spontaneous disappearance of spatial dimensions

2. 

Winding string

Lorentz breaking: Explicit, Evaluation: △

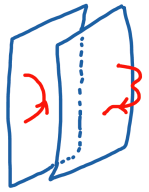
Brandenberger-Vafa scenario [Brandenberger, Vafa, '88]



Early hot universe
compactified on 10-dim. torus

Winding strings reconnected
→ Only 4 dim. are freed

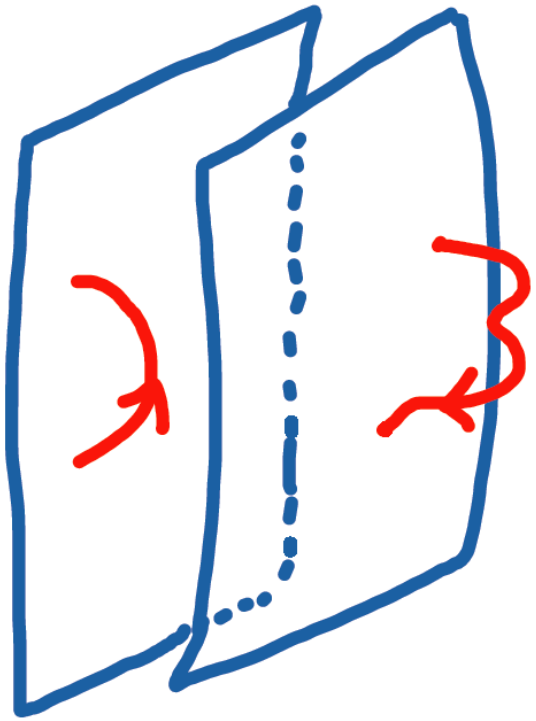
Our universe is a torus = 4d Lorentz breaking

3. 

Braneworld

Lorentz breaking : ? Evaluation: ?

Brane gas cosmology [Alexander, '01],[Brandenberger,et.al]



D-branes: hypersurfaces on which strings can end

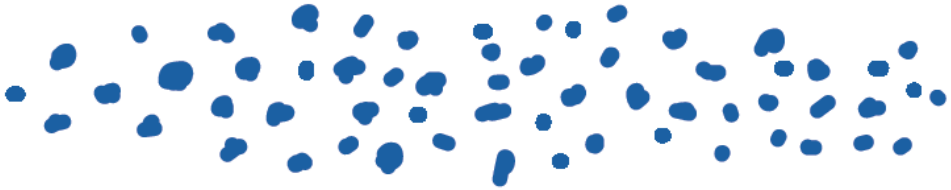
Braneworld: We live on D3-branes

Dp-Dpbar annihilation in 10 dim.
→ creation of D(p-2) brane
"D9→D7→D5→D3."

4. Matrix universe

Lorentz breaking: Spontaneous, Evaluation: △

IIB Matrix Model [Ishibashi, Kawai, Kitazawa, Tsuchiya '96]

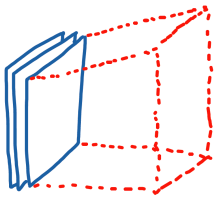


Small D-branes forming a bound state

→ 4 large dimensions + 6 compact dimensions

Our space is non-commutative, CPT can be broken

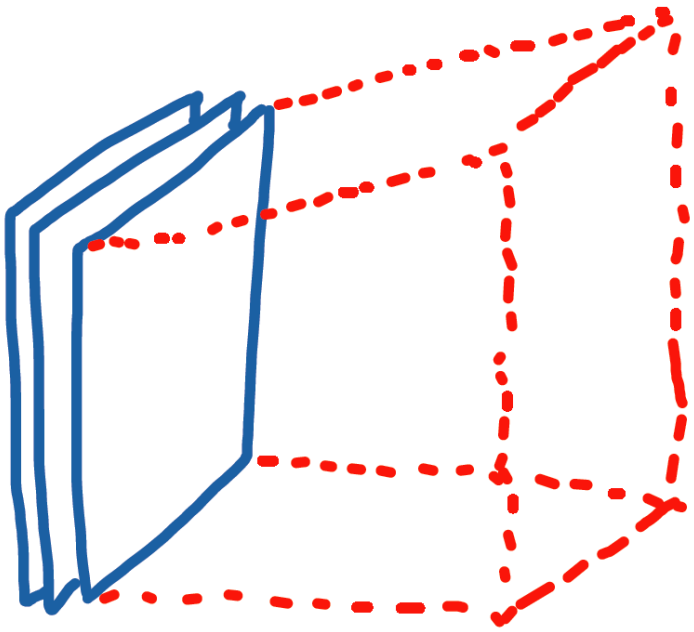
[Mocioiu, Pospelov, Roiban '01]

5. 

Emergent spacetime

Lorentz breaking: Explicit, Evaluation: ?

AdS/CFT correspondence [Maldacena '98]
M-theory [Witten '95]



Gauge theory at strong coupling
→ Additional emergent dimension
without Lorentz symmetry

3 Spontaneous compactification scenarios

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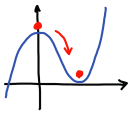
1.		Vacuum condensation	Spontaneous	?
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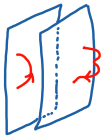
3.		Braneworld	?	?
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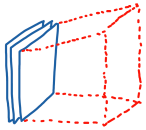
5.		Emergent spacetime	Explicit	?

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