Strings - Species and UV - completeness of Gravity.

Work done with
Gia Dvali

hep-th 1004 3744
hep-th 1005 3497

Gravity + N species →

The existence of an UV cutoff (The species scale L_N) below which Einsteinian Gravity should be modified.

For large enough N:

$$L_N \gg l_{pe}.$$

Questions:

- What is the physical meaning of L_N?
- What is the natural UV completion of a theory of gravity with species?
- What happens to a BH when it reaches the species scale?

The conjecture:

Theory of species:

$$\boxed{\begin{array}{ccc} l_{pe} , & N , & L_N \\ \text{Planck length} & \text{\# of species} & \text{Species scale} \end{array}}$$

naturally fits into String Theory:

$$\boxed{\begin{array}{ccc} l_{pe} , & g_s , & L_s \\ \text{Planck length} & \text{String coupling} & \text{string length.} \end{array}}$$

under the correspondence:

$$L_N \longrightarrow L_s$$

$$N \longrightarrow g_s^2 \sim \frac{1}{N}$$

How universal Gravity knows about species?

- Black Hole evaporation
- Holographic bounds on Information storage.

- Black Hole Evaporation Argument.

For Einstenian semi classical BHs the evaporation time is

$$\tau \sim \frac{M^3}{M_{pe}^4}$$

(assuming the BH is a perfect quantum emitter)

The change of temperature by particle emision is:

$$\frac{1}{T}\frac{dT}{dt} \sim \Gamma_{tot}$$

Γ_{tot} the total rate of particle emision

$\tau \sim \frac{M^3}{M_{pe}^4} \Longleftrightarrow$ pure graviton emission

$$\Gamma_{gr} \sim T\left(\frac{T}{M}\right)^2$$

We can define # of species N by

$$\Gamma_{tot} = N \, \Gamma_{gr.}$$

Semi classical BHs require

$$\Gamma_{tot} \leq T \quad (\text{or equivalently } \tau \geq R)$$

i.e

$$\boxed{\frac{1}{T^2} \frac{dT}{dt} \leq 1}$$

The bound is saturated by

$$M_{BH}^2 = M_{pe}^2 N$$

leading to a minimal size for s.c BHs

$$\boxed{L_N = \sqrt{N} \, \ell_{pe}}$$

and consequently a "maximum" temperature:

$$\boxed{T_N = \frac{1}{L_N}}$$

and to a minimum entropy:

$$\boxed{S \geq N}$$

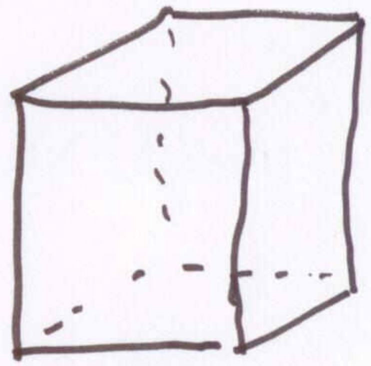
The previous argument leads to the BH definition of <u>species scale</u>. In $4+d$ dimensions:

$$\boxed{L_N = (N)^{1/2+d}\, l_{pe}}$$

- What is the holographic meaning of this length scale?

The answer is quite straightforward.

Imagine a box of size L and let us compute the maximum # of information bits that can be stored inside.



$$R_{gr} = l_{pe} \left[\frac{N}{L} l_{pe} \right]^{1/1+d} \leq L$$

$$\Rightarrow \quad L \geq l_{pe} (N)^{1/2+d} = L_N$$ species scale.

In other words: Physical resolution of species requires at least equal # of bits as # of species.

L_N = minimal size of the "species detector".

A marginal Comment:

In 10D:

$$L_N = N^{1/8}\, l_{pe}$$

This is the familiar AdS/CFT correspondence:

$$R_{AdS} = (N_c)^{1/4}\, l_{pe}$$

If $\quad N = \#\text{ species} = N_c^2.$

Other Faces of the Species Scale.

KK-reduction and KK-species.

KK-reduction 5D → 4D

$$M_{pl(4)}^2 = M_{pl(5)}^3 R$$

# of KK species in 4D: $N = R\, M_{pl(5)}$

$$\boxed{M_{pl(4)}^2 = M_{pl(5)}^2 N}$$

i.e $\frac{1}{M_{pl(5)}}$ is the species scale for "KK-species".

Induced Gravity.

Λ = UV cutoff of the Q.F.T:

$$M_{pl(4)}^2 = N \Lambda^2$$

i.e the species scale for the "induced gravity" is the UV cutoff of the underlying Q.F.T.

In summary:

In a theory with GRAVITY and SPECIES we have:

- Two natural length scales L_N, l_{pe}
- A bound on BH'S
  - size
  - Temperature
  - Entropy.
- A relation between L_N and l_p

$$L_N = (N)^{1/d+2}\, l_{pe}$$

This structure strongly reminds weakly coupled string theory

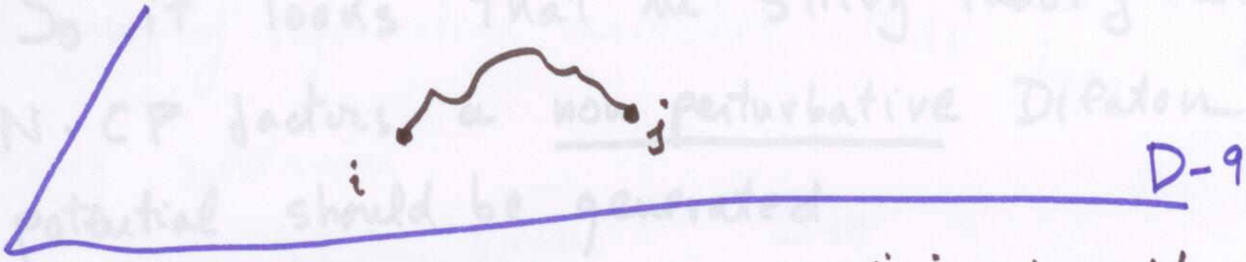
$$l_{pe} = g_s^{1/4} L_s$$

with

$$L_s \leftrightarrow L_N$$

$$g_s^2 \leftrightarrow 1/N$$

The simplest toy model where we can consistently put together species and gravity is open string Theory with Chan-Paton factors i.e D_9 branes.



$\#$ species $= N^2$ $\qquad$ $i, j = 1 \dots N$

For a given value of g_s the smaller BH in the gravity sector of this theory is a BH of: size $: L_s$

entropy $: 1/g_s^2$

Mass $= \dfrac{1}{g_s^2 L_s}$

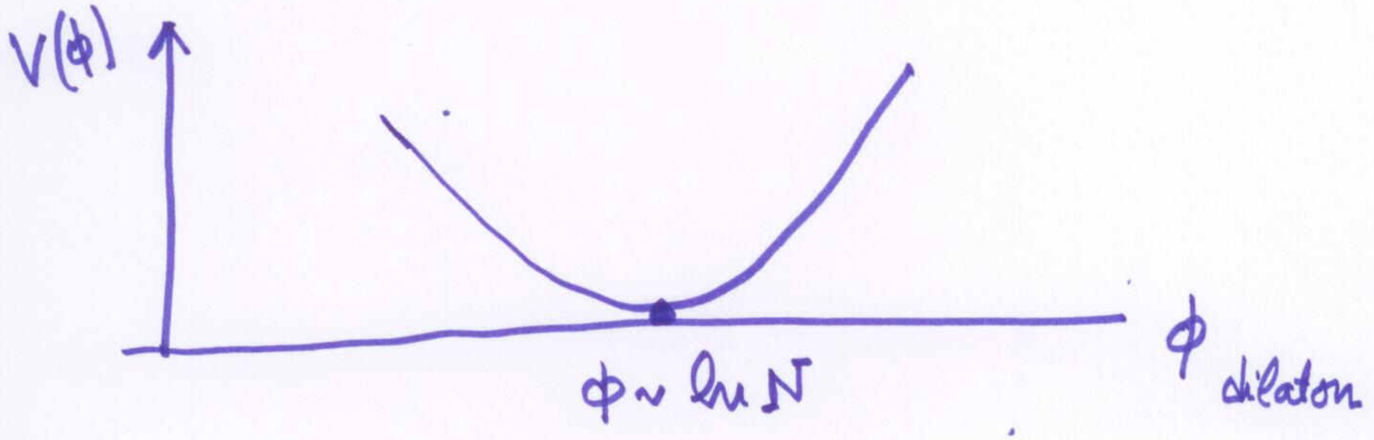
But the gravity sector of this theory is Gravity with N^2 species so:

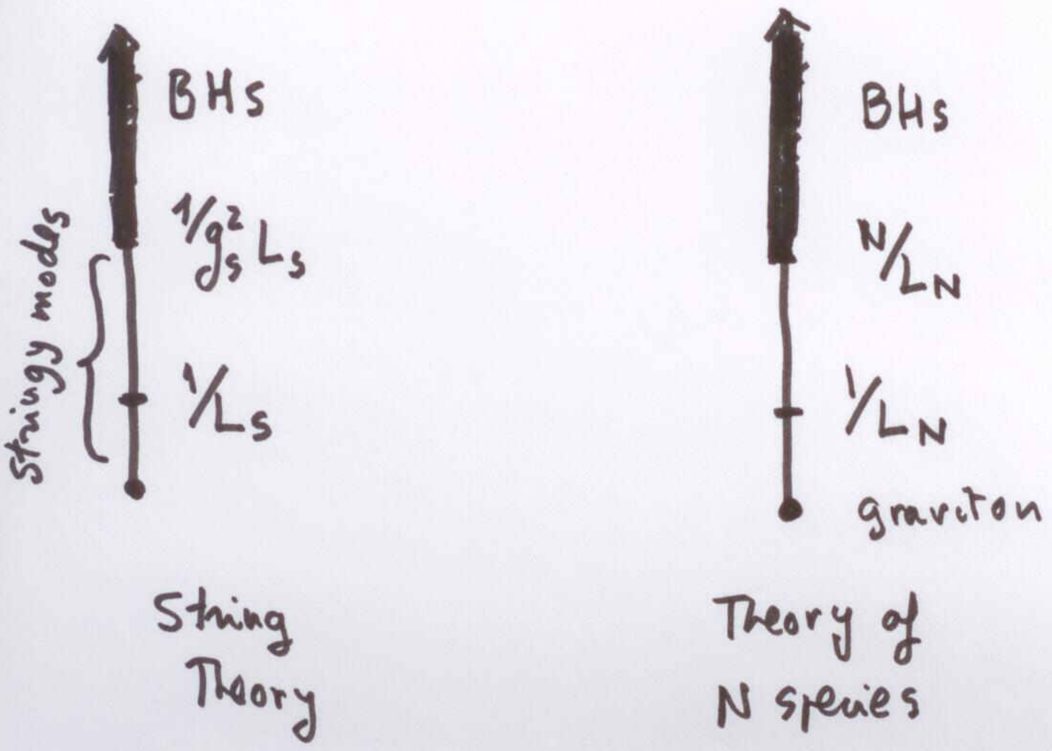
$$L_s \geq L_N$$

$$1/g_s^2 \geq N^2$$

Thus string Theory with N-CP factors is only consistent for $\boxed{g_s \lesssim \frac{1}{N}}$

So it looks that in string theory with N-CP factors a <u>non perturbative</u> Dilaton potential should be generated





Species Scale and String-BH correspondence.

BH mass spectrum:

$$M_{BH} = \frac{S_{BH}}{R}$$

In terms of "information" variables: $M_{BH} = \frac{\sqrt{S_{BH}}}{L_{pe}} = \frac{\sqrt{N}}{L_{pe}}.$

String spectrum:

$$M_{st} = \frac{\sqrt{N_{osc}}}{L_{st}} \approx \frac{S_{st}}{L_{st}}.$$

The string becomes a BH if:

$$L_{st} = \sqrt{S_{st}}\, L_{pe} \qquad \sqrt{S_{st}} = \frac{1}{g_s}$$

Equivalently the smallest BH entropy in string theory is

$$\sqrt{S} = \frac{L_{st}}{L_{pe}}.$$

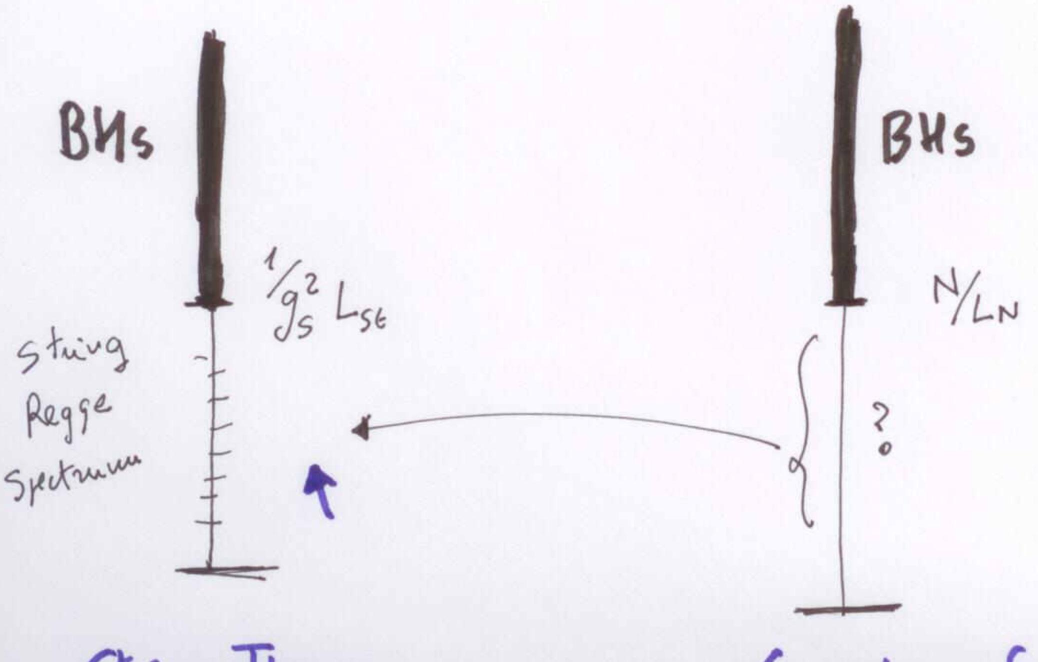
In presence of N species the smallest BH entropy is $\sqrt{S} = N$ $\Rightarrow$ L_{st} = species scale.

i.e

$$\boxed{\text{When the BH reaches the species scale becomes a string state with } N_{osc} = N^2}$$

In summary:

Gravity + Species	String Theory
minimal BH size L_N	minimal BH size L_{st}
Entropy bound:	Entropy bound:
$S_{BH} \geq N_{species}$	$S_{BH} \geq 1/g_s^2$
maximal temperature:	Hagedorn temperature
$T = \frac{1}{L_N}$	$T_H = \frac{1}{L_{st.}}$



String Theory

Gravity + Species

What happens at strong (string) coupling?

We should expect some form of <u>duality</u>:

$$g_s \to g_s^{(D)}$$

with

$$\hat{N} = \frac{1}{g_s^{(D)2}}$$

The effective # of species of the dual description. and with

$$\hat{L}_N = (\hat{N})^{1/8} l_{pe}$$

The species scale for the dual description.

Let us see how this picture fits with M-theory as the strong coupling version of II_A string Theory.

In M-theory we have

$$\hat{N} = \frac{R}{l_{11}} \quad \text{D-0 species}$$

So

$$L_{11} = (\hat{N})^{1/8} l_{10} \quad \text{is the species scale } \hat{L}_N$$

If $\hat{L}_N = \left(\frac{1}{g_s^D}\right)^{1/4} l_{pe}$ $\rightarrow$

$$\boxed{g_s^D \equiv \frac{1}{g_s^{1/3}}} \qquad \boxed{\hat{N} = \frac{1}{g_s^{D\,2}}}$$

Why $g_s^D = \frac{1}{g_s^{1/3}}$?

M-atrix model: $\frac{1}{g_s}\int dt \,\mathrm{Tr}\, FF \rightarrow$

$$\frac{1}{g_s}|\phi \times \phi|^2 \longrightarrow \frac{1}{g_s^D}|\hat{\phi}\times\hat{\phi}|^2$$

$$g_s^D = \frac{1}{g_s^{1/3}} \qquad \phi = g_s^{1/3}\hat{\phi}$$

(String - M-theory transformation)

i.e

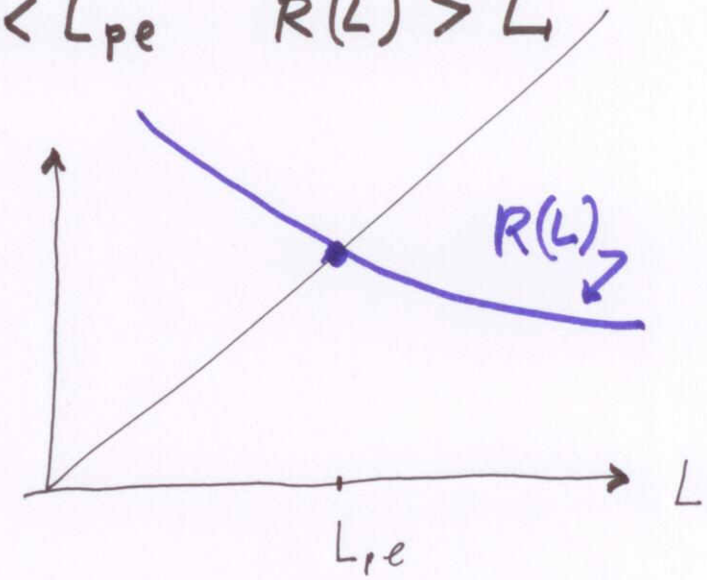
type II_A at strong coupling = theory of D-0 brane species with l_{11} as the species scale.

Is Einstenian Gravity UV-complete?

- L_{pe} is the minimal length we can resolve.
  Localization of a probe in L → Gravitational generation of a BH of size:

$$R(L) = \frac{L_{pe}^2}{L}$$

So for $L < L_{pe}$ $R(L) > L$



• No "hard" Trans-Planckian modification of graviton propagator:

$$\underset{\substack{T_{\mu\nu} \qquad t_{\alpha\beta} \\ \langle h_{\mu\nu} h_{\alpha\beta} \rangle}}{\otimes\!\sim\!\sim\!\sim\!\otimes} = \frac{1}{M_{pl}^2}\left(\frac{T_{\mu\nu} t^{\mu\nu} - \frac{1}{2} T_\mu^\mu t_\nu^\nu}{p^2} + \frac{a T_{\mu\nu} t^{\mu\nu} - s \frac{1}{3} t_\nu^\nu T_\mu^\mu}{p^2 + \left(\frac{1}{L}\right)^2} \right)$$

T.P - new pole.
$M \sim 1/L$

$$= \underset{\text{graviton}}{\otimes\!\sim\!\sim\!\otimes} + \underset{\phi}{\otimes - - - \otimes}$$

$$\phi_{\mu\nu} T^{\mu\nu} : \qquad \phi \longrightarrow q + \bar{q}$$

$\begin{cases} L > L_{pl} & \text{quantum decay} \\ L < L_{pl} & \text{BH - evaporation} \end{cases}$

(suppressed by Boltzman factor $e^{-1/LT}$)

i.e T-P effects are SOFT

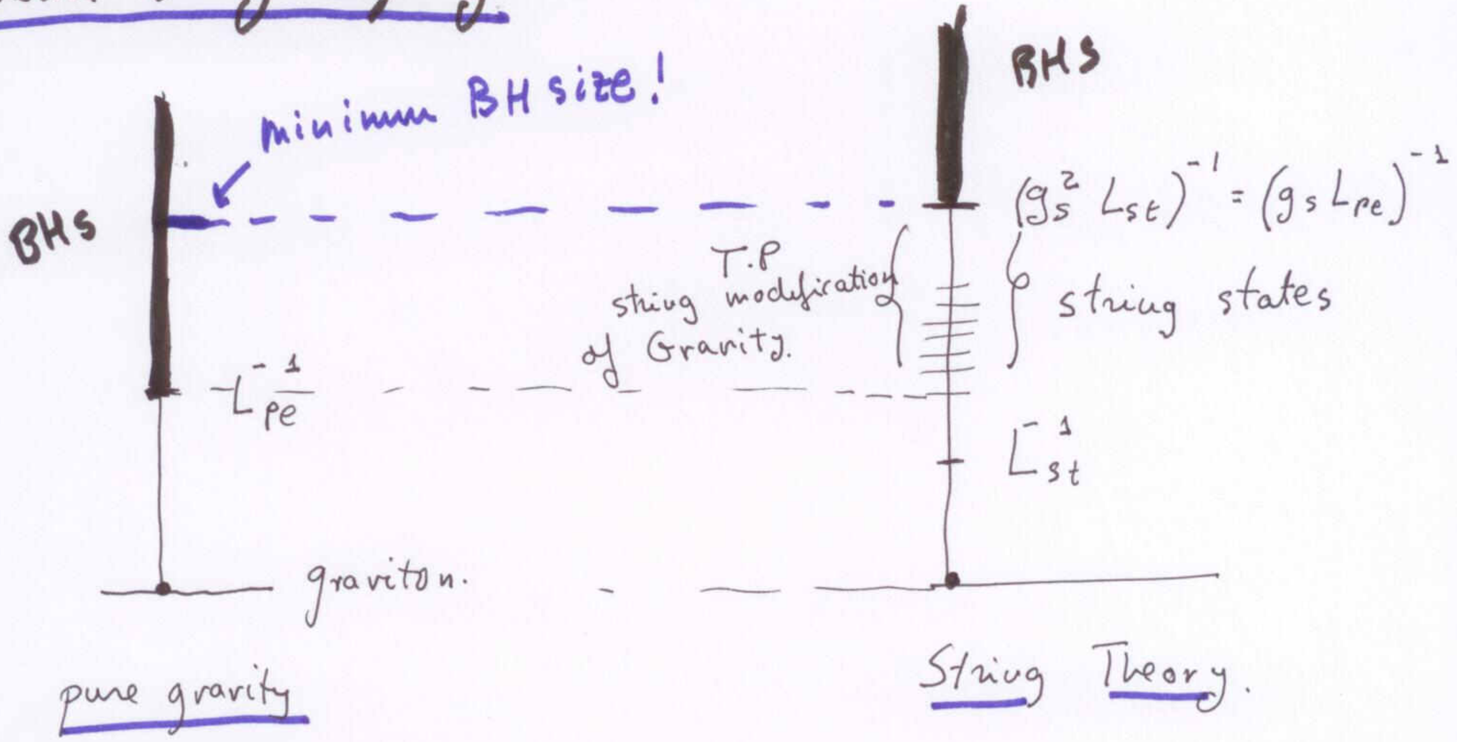
$$e^{-\left(L_P/L\right)^2} \sim e^{-S_{BH}}.$$

i.e They contribute to the amplitude as "classical" IR configurations

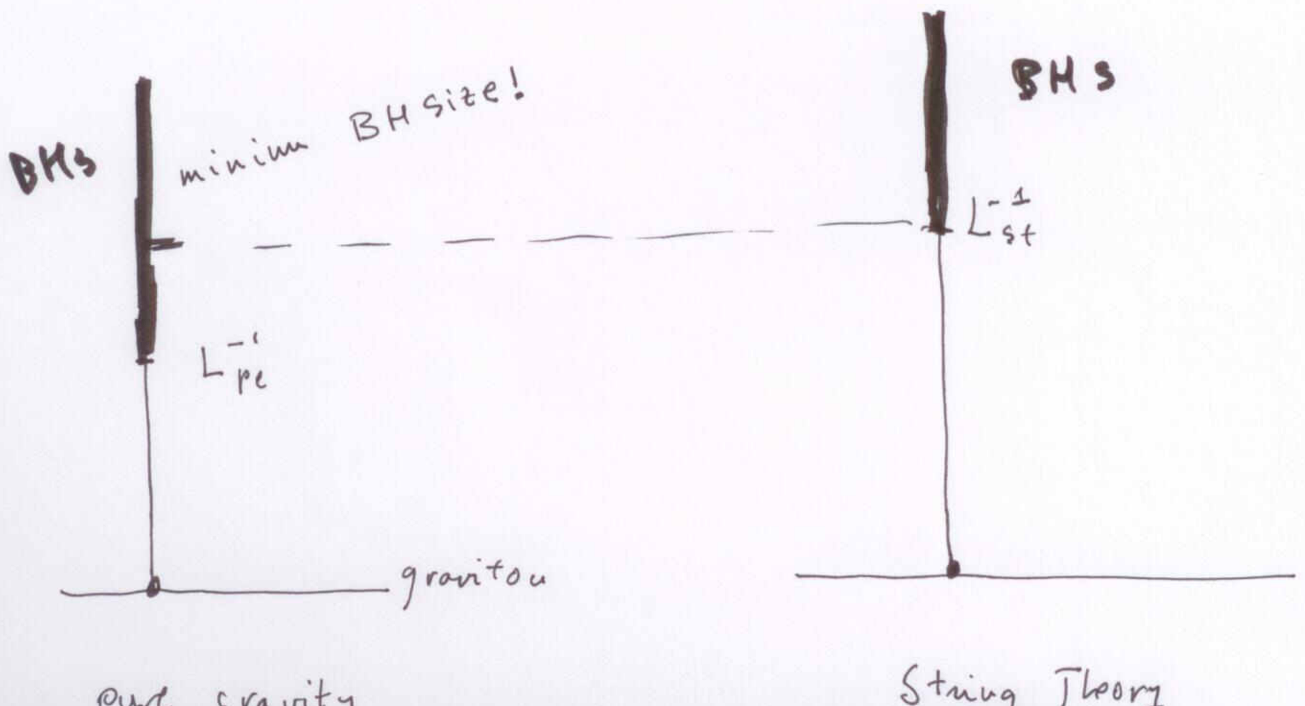
$$UV \longleftrightarrow IR.$$

Stringy Trans-Planckian modifications of Gravity?

weak string Coupling:



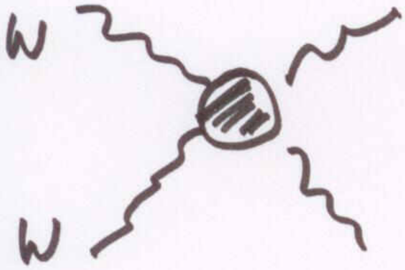
strong string Coupling:



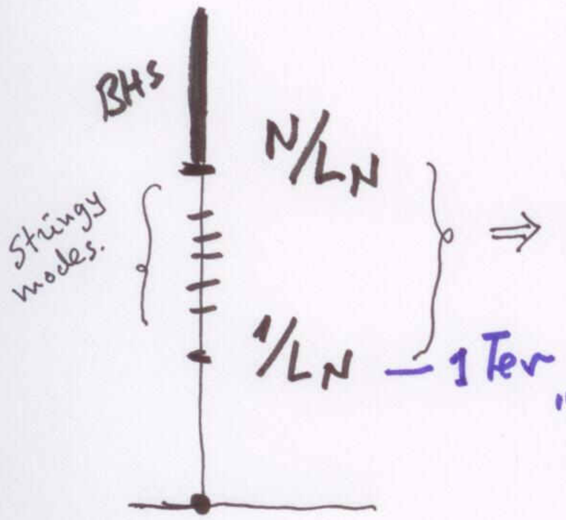
$$\boxed{\text{T-Planckian modifications of Gravity} \rightarrow \text{Species.}}$$

Higgless Scenario

Use species to push $L_N \sim (1\,\mathrm{TeV})^{-1}$.



unitarity problems for WW Scattering $\sim$ 1 TeV.



gravitational spectrum.

$\Rightarrow$ UV-gravitational completion

Effective Higgs.

"String Regge Trajectory"

$$M_H \sim \frac{\sqrt{n}}{L_N} \qquad N^2 \geq n \geq 1$$

$$\boxed{\text{Higgs } \underbrace{\wedge}_{\text{(stringy)}} \text{ Resonances at the LHC ?}}$$