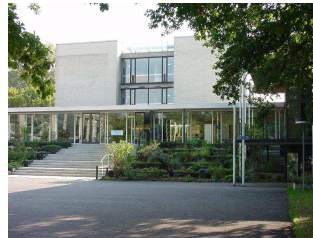


# The Landscape of String Vacua

Ralph Blumenhagen

Max-Planck-Institut für Physik, München



# New era of experiments

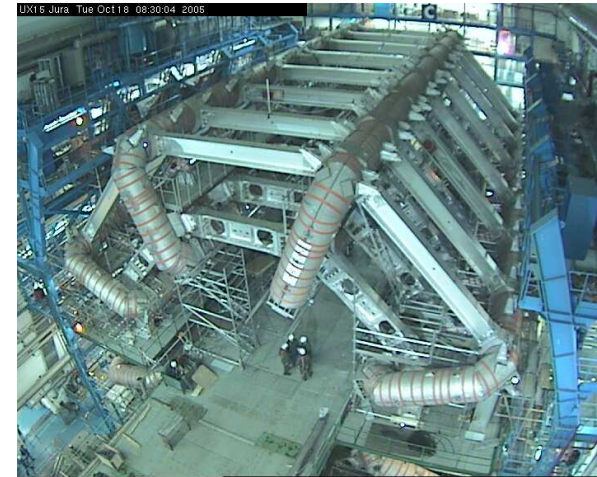
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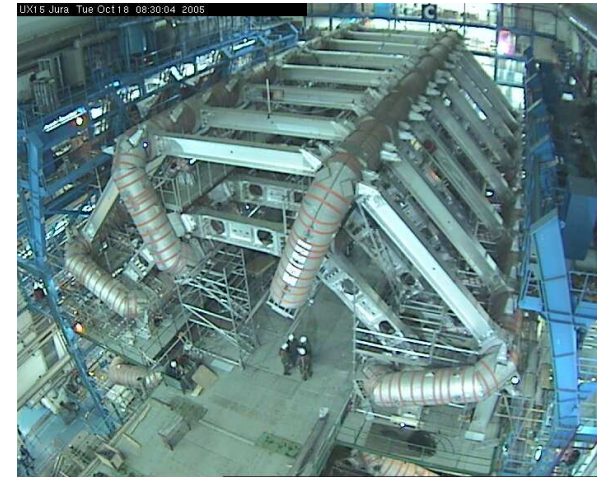
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- The **LHC** at CERN will start taking data and will probe pp-collisions at 14TeV  $\rightarrow$  Higgs particle, supersymmetry, more exotic theories
- The **Planck satellite** will be launched to measure the anisotropies in CMB with new precision  $\rightarrow$  discriminate among various inflationary scenarios



# New era of experiments

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- The **Glast** (Gamma-ray Large Area Space Telescope) will be launched into orbit to take a gamma-ray image of the sky → dark matter



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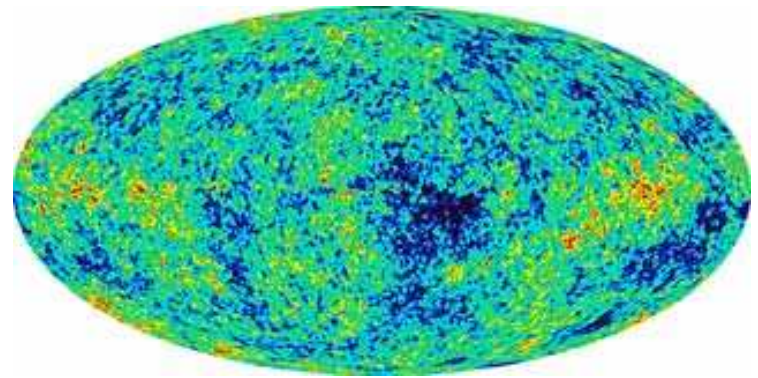
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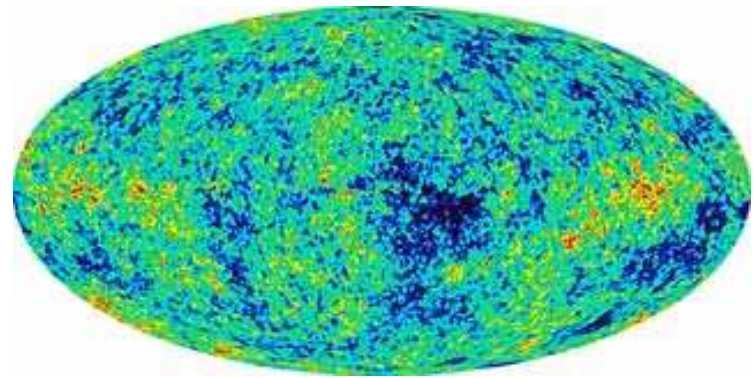


WMAP: CMB anisotropies

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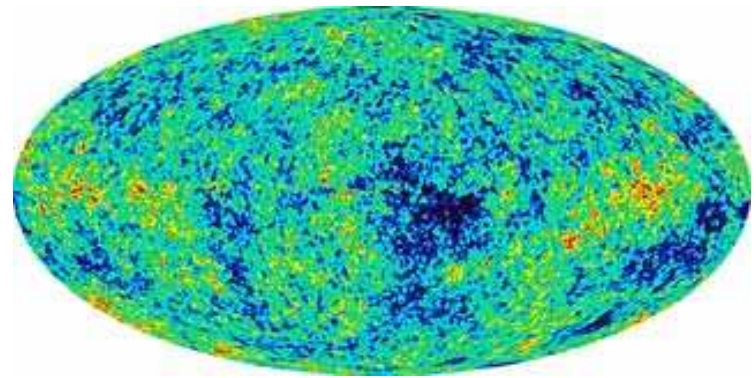


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The solutions of these problems seem to lie **beyond** the established theories of the Standard Model and General Relativity.

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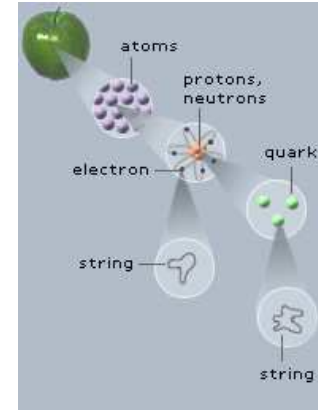
String Theory is a candidate solution to more ambitious theoretical questions like

- Ultraviolet finite quantisation of gravity, space-time at very short distances
- Statistical interpretation of black hole entropy
- Unification of gauge theories and gravity in one theoretical framework

# String Theory

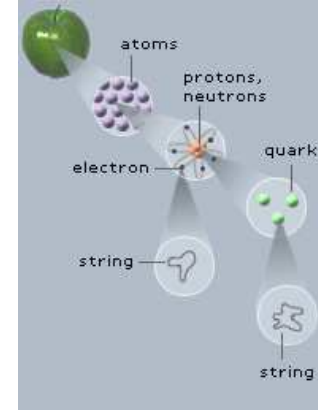
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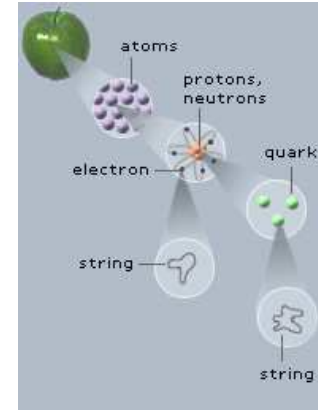
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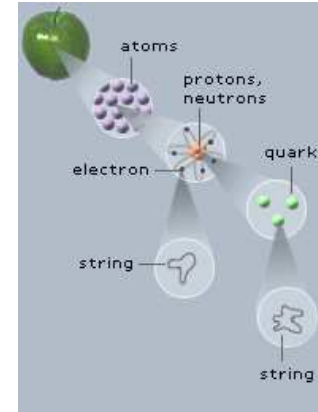
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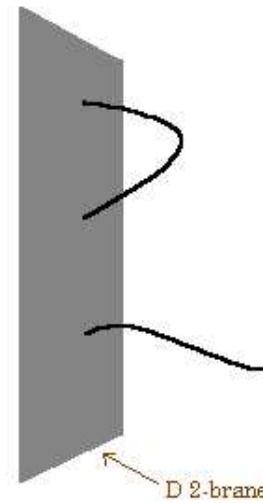
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non-perturbative, solitonic  
objects, fluctuations  $\rightarrow$  **open  
strings**



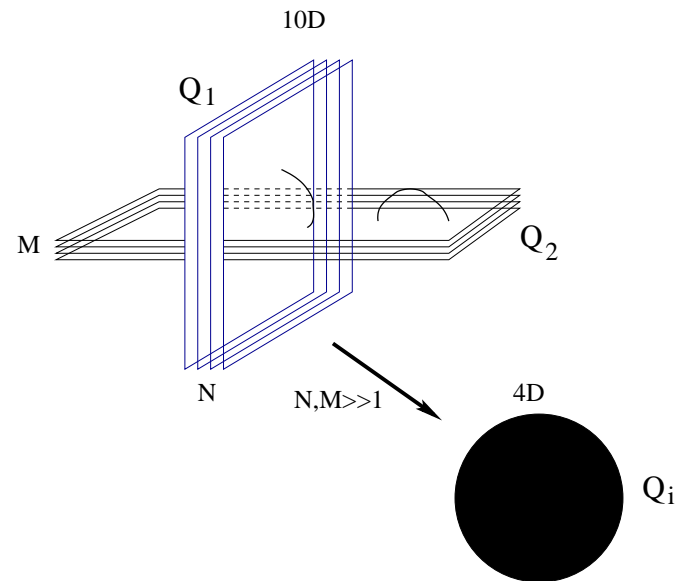
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entropy of black holes:  $S = A/4$



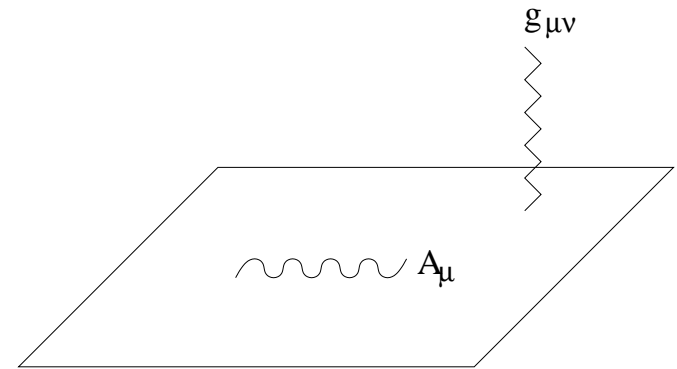
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**gauge fields** propagate on  
D-branes:  $U(N)$ ,  $SO(2N)$ ,  
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- Does there exist (a so far unknown) dynamical process which (uniquely) selects this vacuum? (vacuum selection principle)

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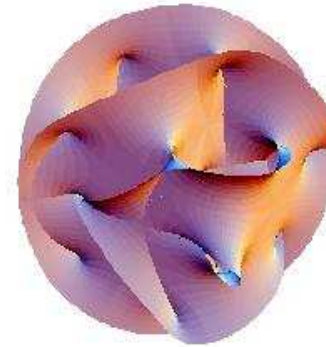


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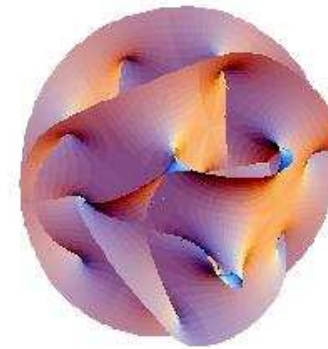


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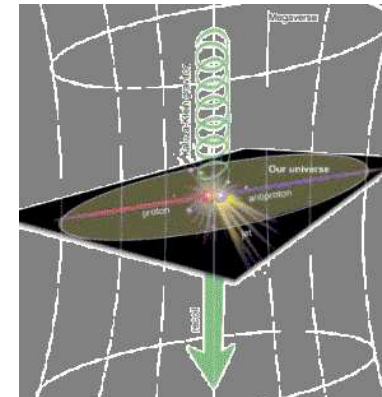
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Scenario II:

The gauge interactions are **confined** on 4D hypersurface (Brane) in 10D. Only **gravity** in 10D.



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Supersymmetry breaking: Dynamical supersymmetry breaking on hidden  $E_8^H$  mediated gravitationally to observable  $E_8$ .

# Compactifications



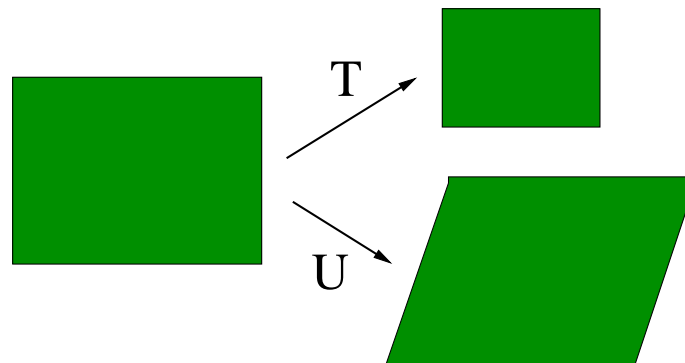
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Details of **MSSM physics** depend on geometry of  $(X, V)$ , i.e. the details of **moduli stabilisation** and the details of **susy breaking** + generated **soft susy breaking terms**.

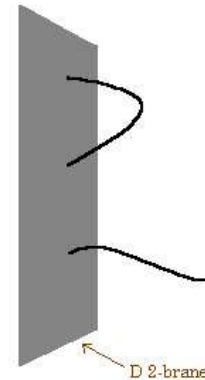


Also  $g_s = \exp(\phi)$  is a modulus.

# Brane Worlds

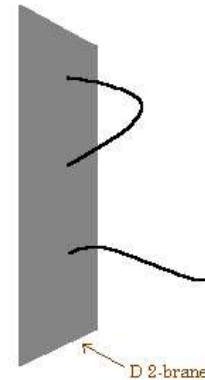
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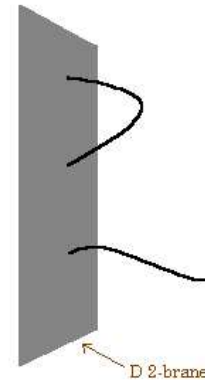
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A small  $M_s$  can be traded for a large transversal dimension  $V_t$ !

Three cases:  $M_s = 1 \text{ TeV}$ ,  $M_s = 10^{11} \text{ GeV}$ ,  $M_s = 10^{17} \text{ GeV}$ .

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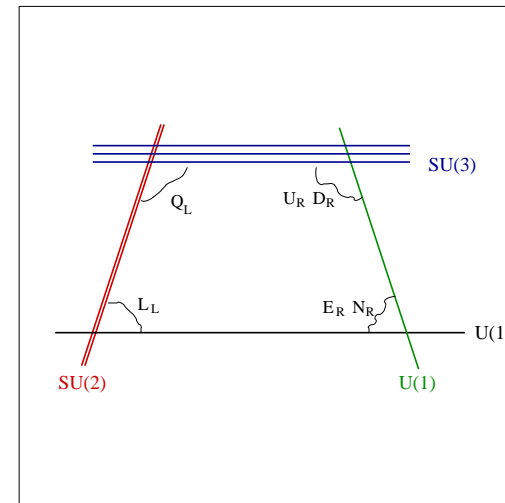
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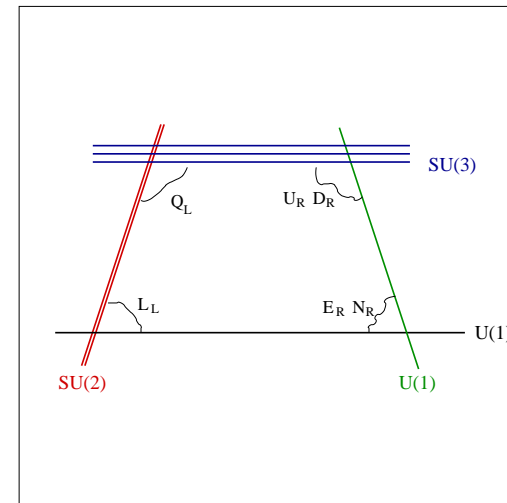
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Possible string compactifications, mechanisms for **moduli stabilisation** and the determination of the **4D effective action** for the light  $m < M_s$  modes are under investigation (string phenomenology).

# TeV scale Brane Worlds

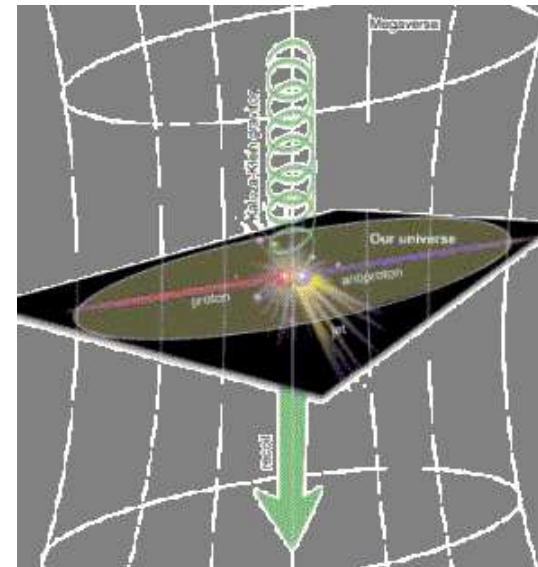
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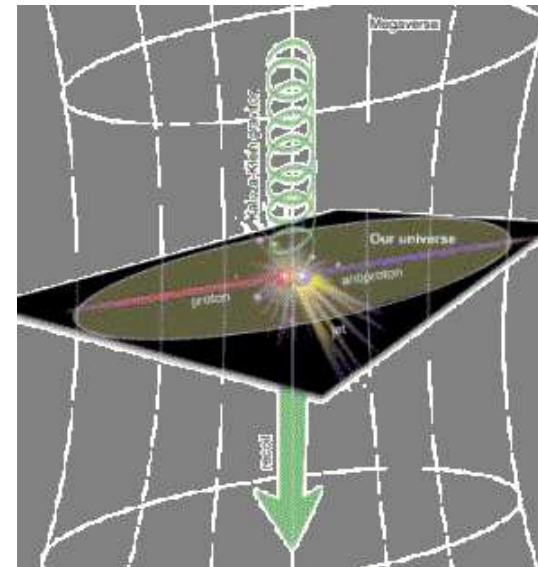
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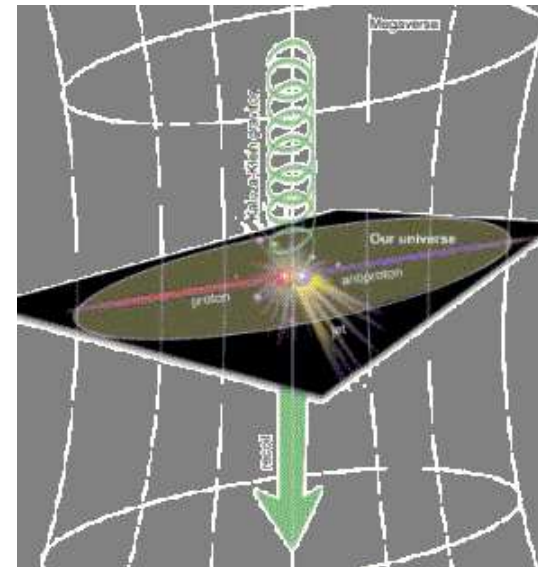
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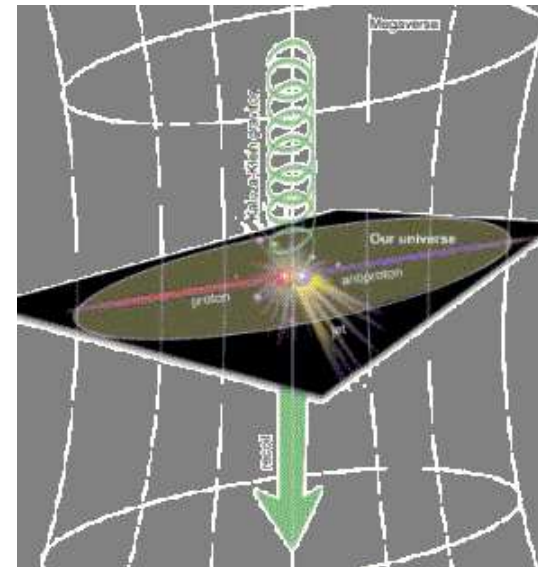
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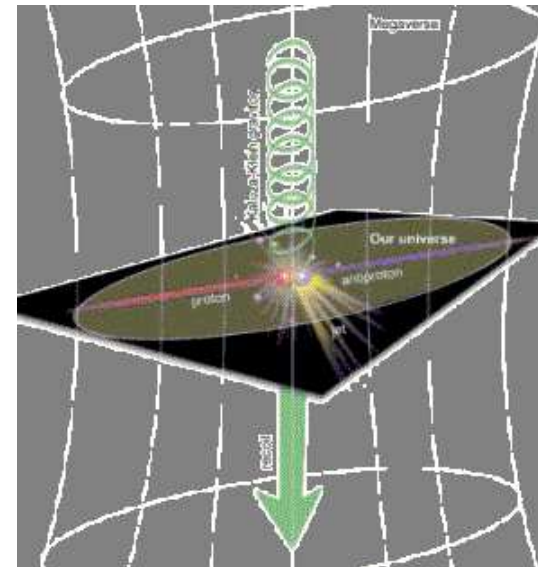




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Gauge **hierarchy** problem: Shifted towards explaining the hierarchy of compactification scales  $l_t \gg l_{pl}$ !

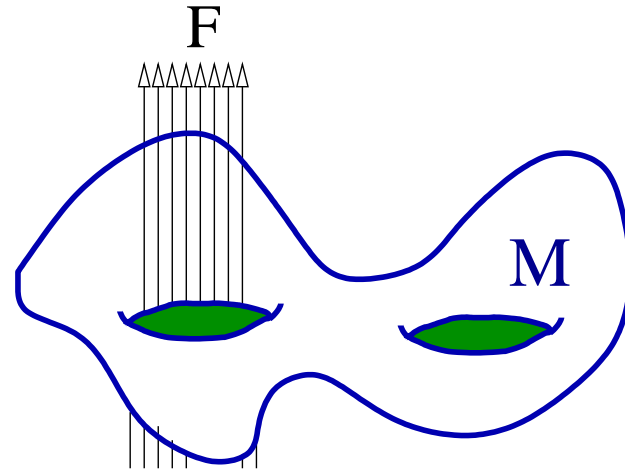
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I. Background **fluxes** of the 10D String Theory  $F_{p+1} = dC_p$ :

Ex: 6D fluxes  $F_p \neq 0$ , yield a **po-  
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$$V(R) = -\frac{(2 - 2g)}{R^4} + \frac{n^2}{R^6}$$

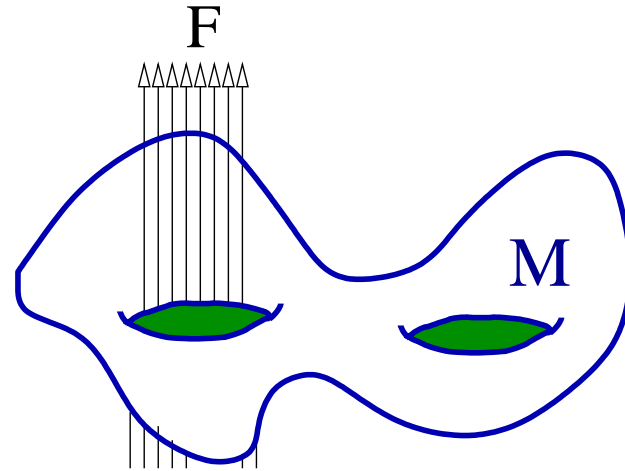


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II. **Non-perturbative effects:**

- String instantons generate terms of the form  $V(R) = \exp(-R/g_s)$ .
- Corrections to **MSSM couplings** like Majorana masses, Yukawa couplings,  $\mu$ -terms

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The later estimate is **based** on the tree level GVW flux superpotential

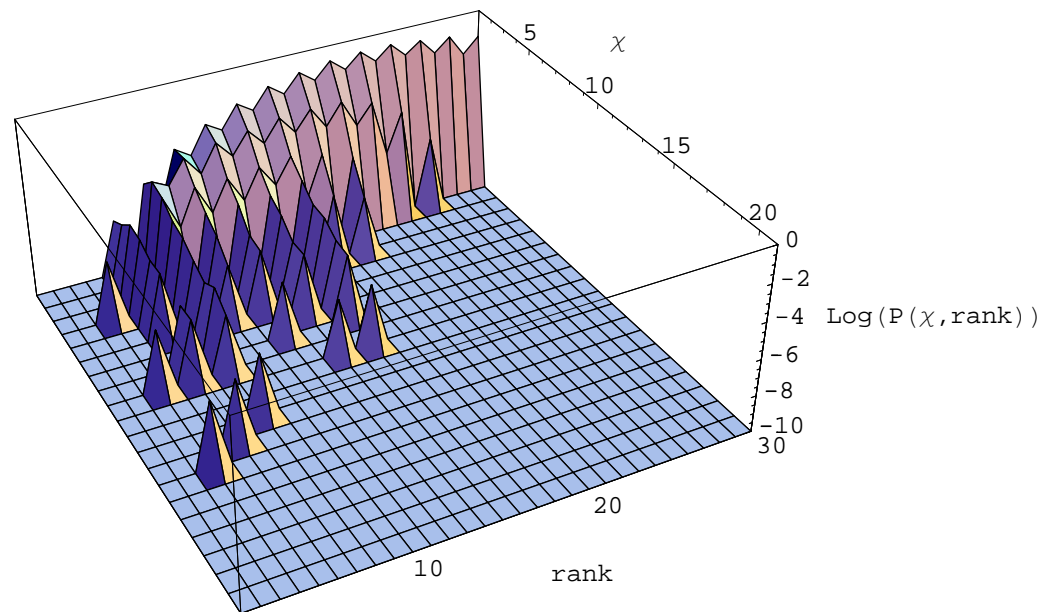
$$W = \int \Omega \wedge G$$

and  $G$  is expanded in  $H^3(X)$  so that  $N = L^{b_3}/b_3!$  for  $L \gg b_3..$

# Frequency distributions

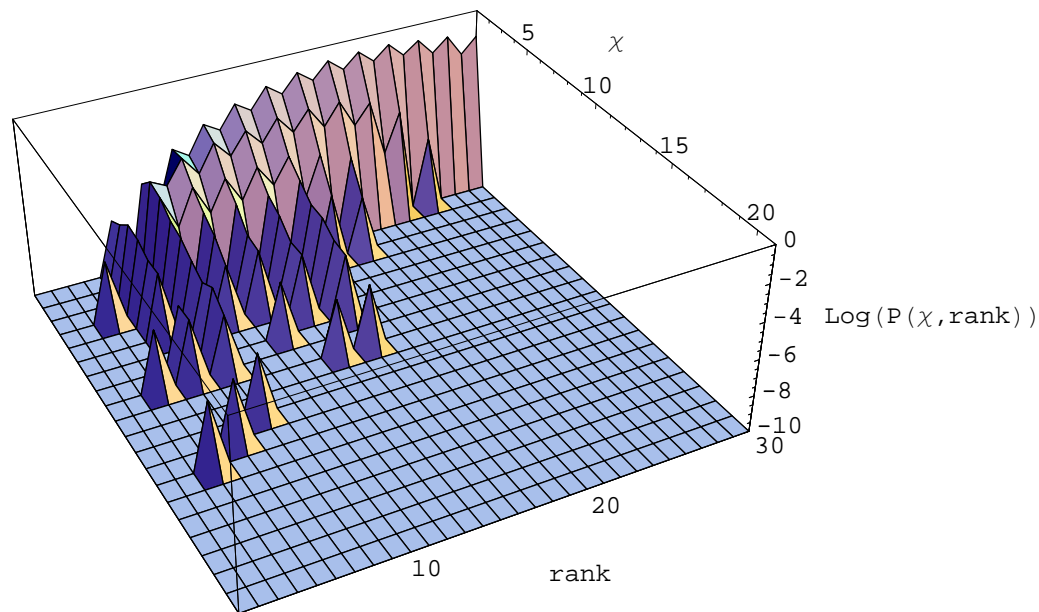
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Correlations on the landscape?

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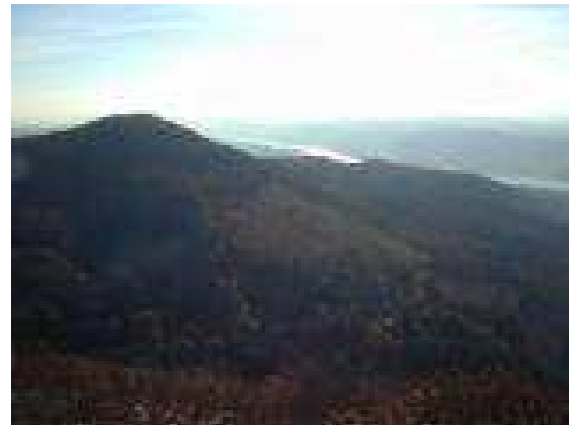
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If there is really such a vast number of string vacua with **different** physical features in 4D, then this leads to a new view on **fine tuning** problems



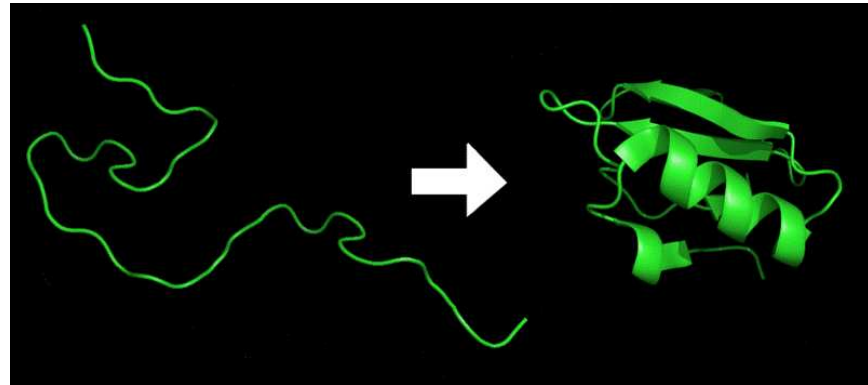
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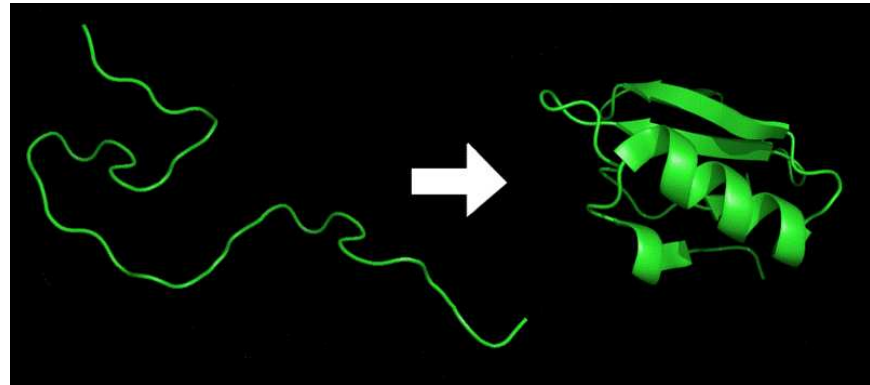
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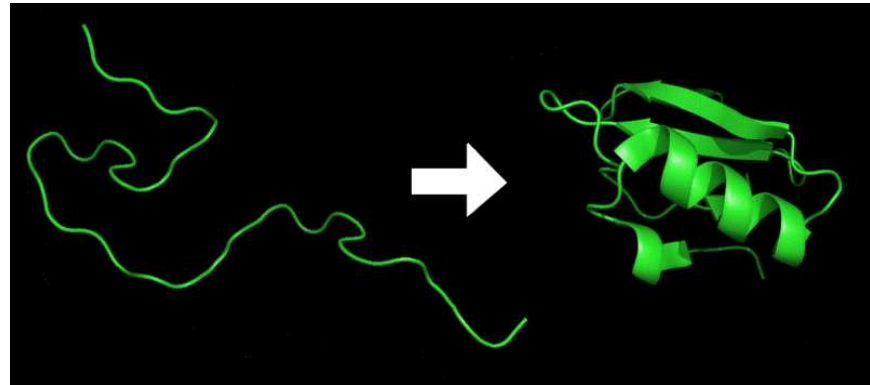


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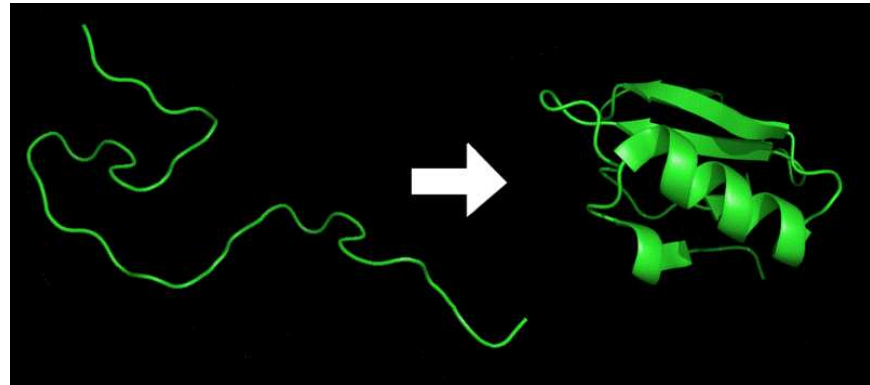
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Evolution, which might be called the *A-(mino) principle*

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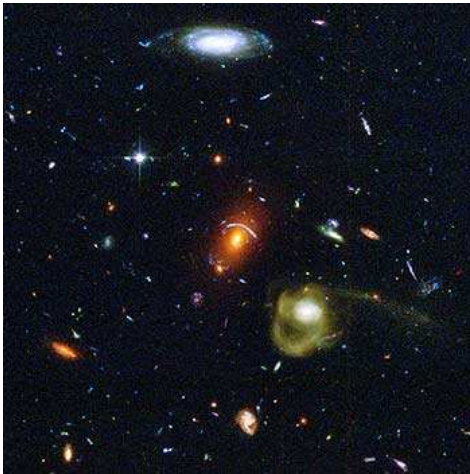
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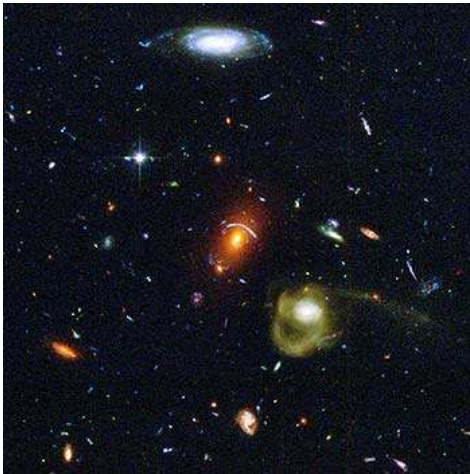
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Inflation

Cosmological constant problem

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = 8\pi G T_{\mu\nu}$$

No **dynamical** explanation yet

# String Multiverse

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environmentally

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If the string landscape provides vacua with **uniformly** distributed vacuum energies, then with **enough models** in the ensemble some of them will have the **cosmological constant** we observe.

However, given the **accuracy** with which SM parameters are measured, one can estimate that we might even get too many, like  $10^{100}$ , vacua with acceptable 4D parameters  $\rightarrow$  **predictivity?!?**



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## LHC results!