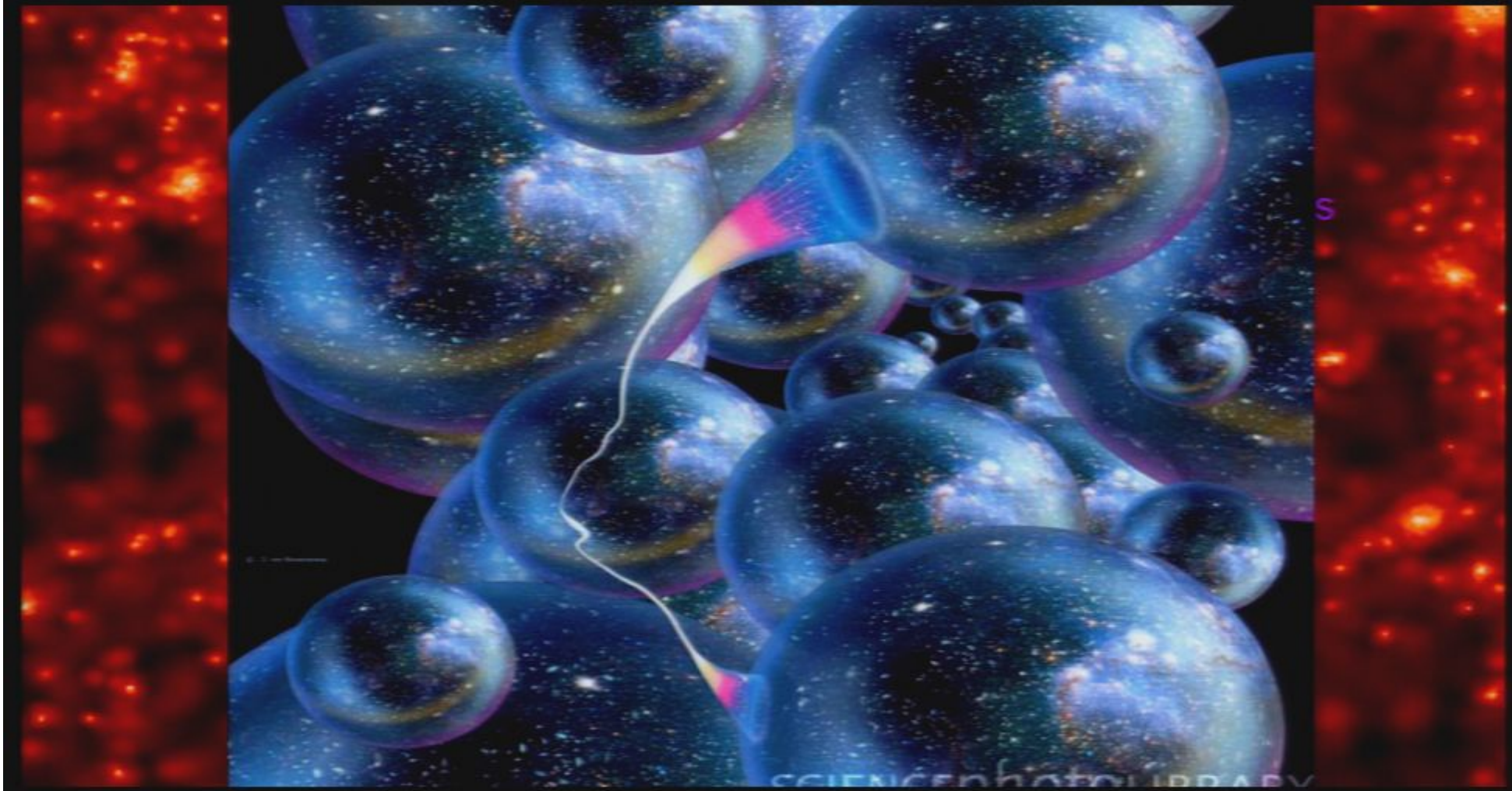
Title: What is the Multiverse?

Date: Sep 02, 2008 02:00 PM

URL: http://pirsa.org/08090043

Abstract:

What is the Multiverse?



Laura Mersini-Houghton, UNC-Chapel Hill

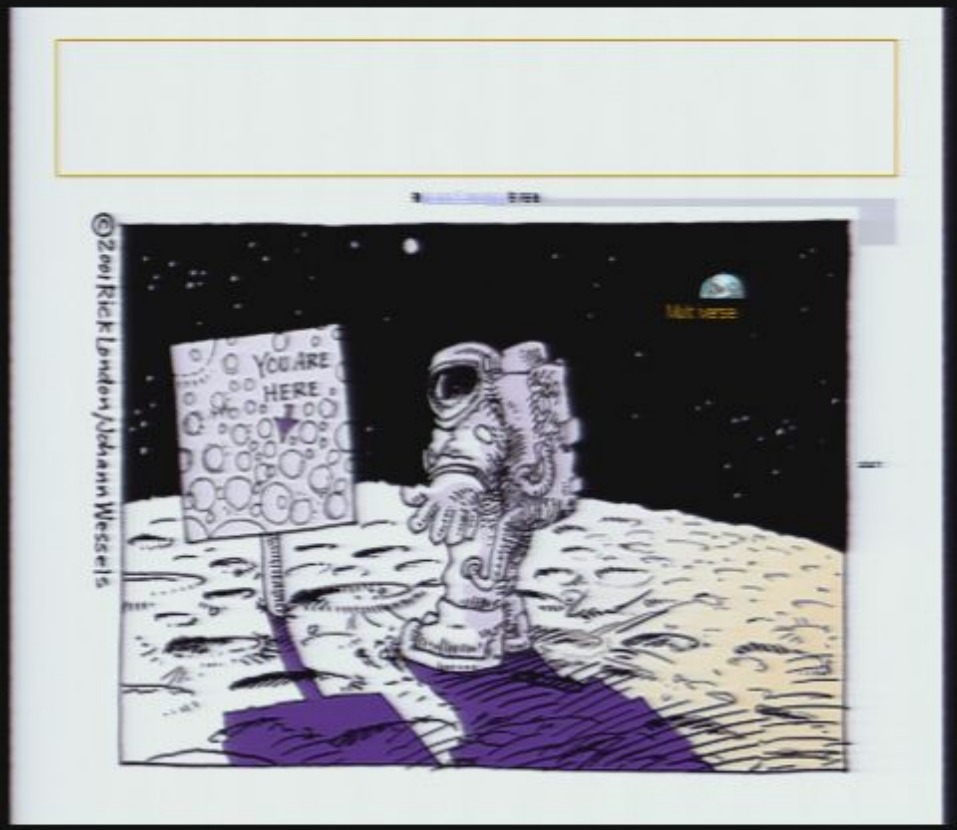
'A Debate in Cosmology: The Multiverse' PI, 2008

But why this ‘change of heart’ ?

- **By Necessity**

  and,

- **By Experience**



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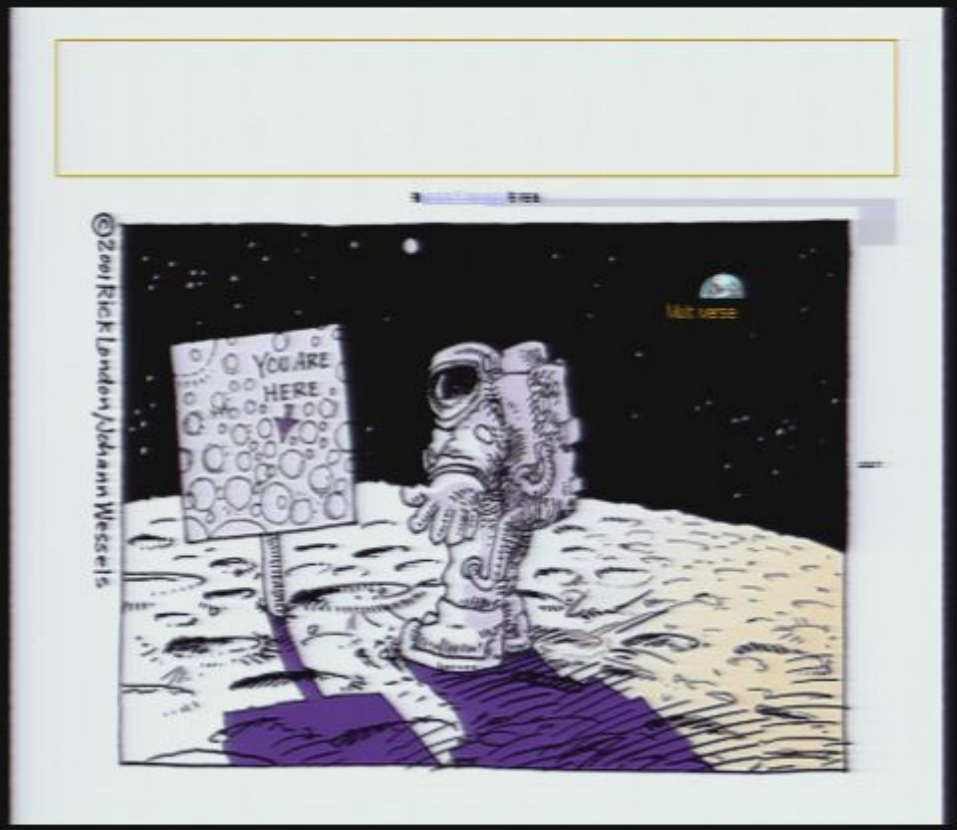


A Necessary Extension of Physics

1. Mystery of the Initial Conditions of our universe needs a multiverse:

How else can we ask the question: why did we start with these I.C./Universe –without implying – as compared to what other choices?

(long list of such questions, why these values for: Lambda, G, e).

Fundamental Questions about our Universe Do imply the Existence of a Phase Space for the Initial Conditions, a.k.a, a Landscape

A Necessary Extension of Physics, ctd...

2. A 'black box' model creates huge discrepancies with what's known of our observable universe:

* Boltzmann Brains? Arrow of Time? Inflation? 'Anthropics'

3. Inflationary Big Bang Theory already predicts a universe much larger than the observable one:

* there is no good reason to why stop there. After all, Big Bang is only a local process in the neighborhood of our I.C. .

* there is no indication or criterion that a local theory is cohesive and self-consistent.

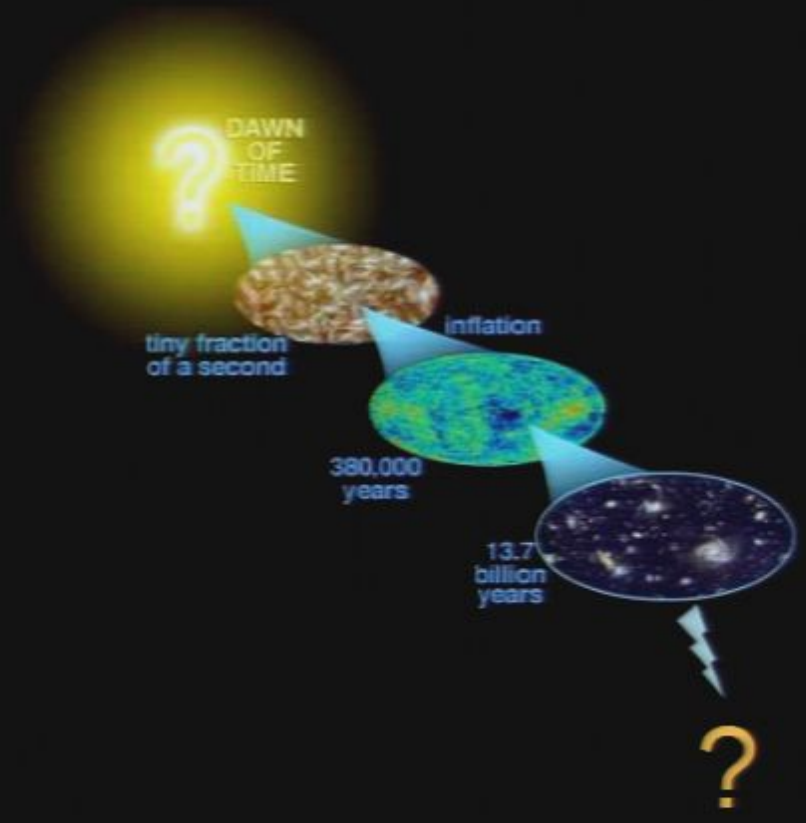
Inflation: Such Extraordinary Unlikely Initial Conditions!

Need to extend to Multiverse?

- **What selected these Initial Conditions?**

Chances: 1/10^{10^122} !

- **What Banged? Where did this come from?**



Puzzle of Initial Conditions and the Multiverse

BUT: GRAVITY IS TRICKY!

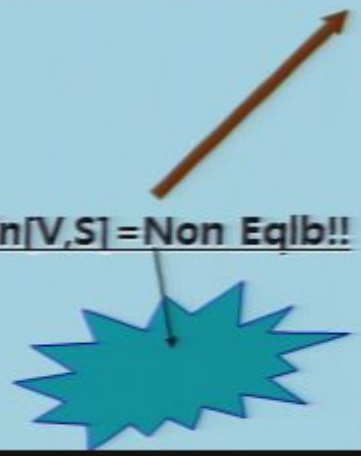
" REALLY SPECIAL " OR JUST "OUT OF EQUILIBRIUM"

RARE FLUCTUATION? DYNAMIC SELECTION?

Max[V, S]= Eqlb!

S = Log[V]

Min[V,S] =Non Eqlb!!



The Trouble with I.C.

Probability to start with Big Bang,

P = Exp [S], Entropy S = 1/Lambda.

Extraordinarly Unlikely Event I Anything Else More Likely !

mmediate Troubles:

"Too Special" , "Arrow of Time" , "Boltzman Brains" }

A Computational View of the Multiverse: Information

- Information is contained in Correlations.
- Entropy parameterizes Information.
- We know Exactly how to calculate Correlations.
- Then: why don't we understand the Entropy of the Universe?
- Because: It is not clear which correlations to include?

Experience with Multiverses?

The 3 Major Theories in Modern Physics Have Led to a Multiverse Prediction !!

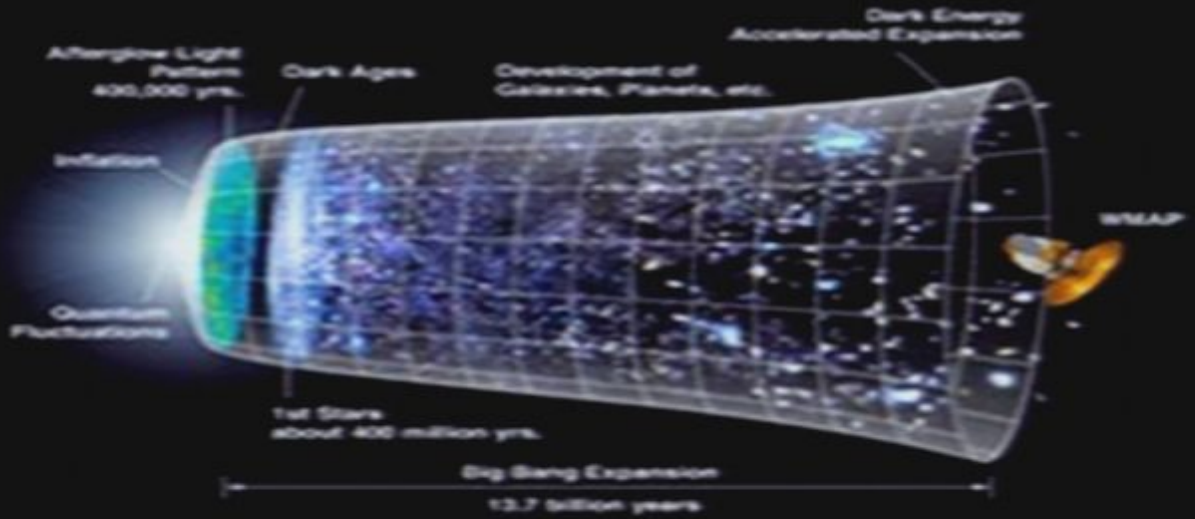
They are :

- Quantum Mechanics, (Many-World Interpretation)
- Inflation, (Almost Generically of Eternal Nature)
- String Theory, (the Landscape)

They cannot all correspond to Reality unless Identical

Inflation: Simple and in Agreement with Observations. BUT:

- Big Bang Inflation: Universe Bangs into Accelerated Expansion
- But once Inflation Starts, almost generically it never stops – Eternally producing New Bubbles – the Inflationary Multiverse
- Inflationary Universe already much larger than its observable subdomain



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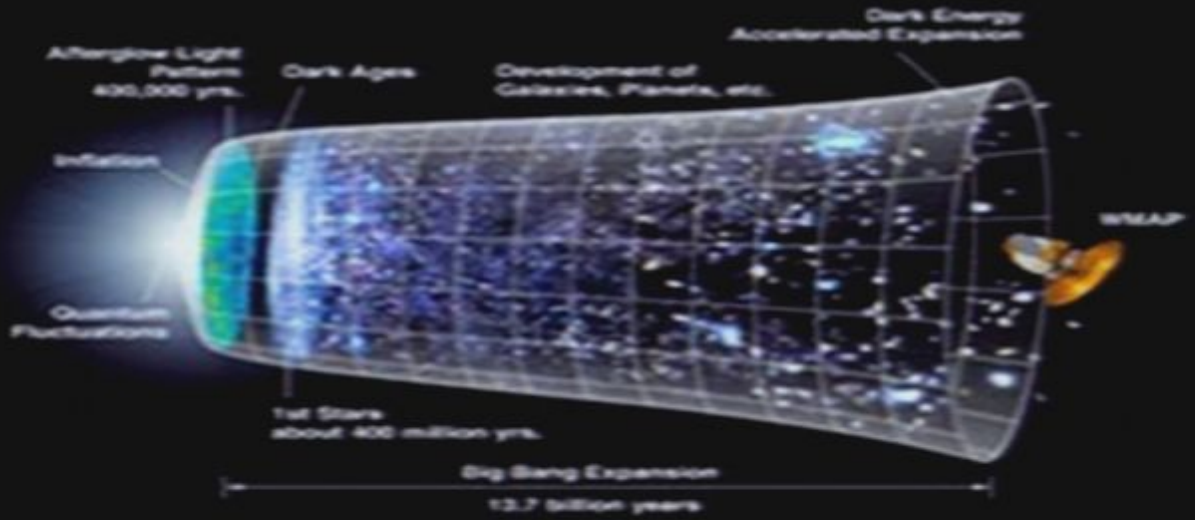
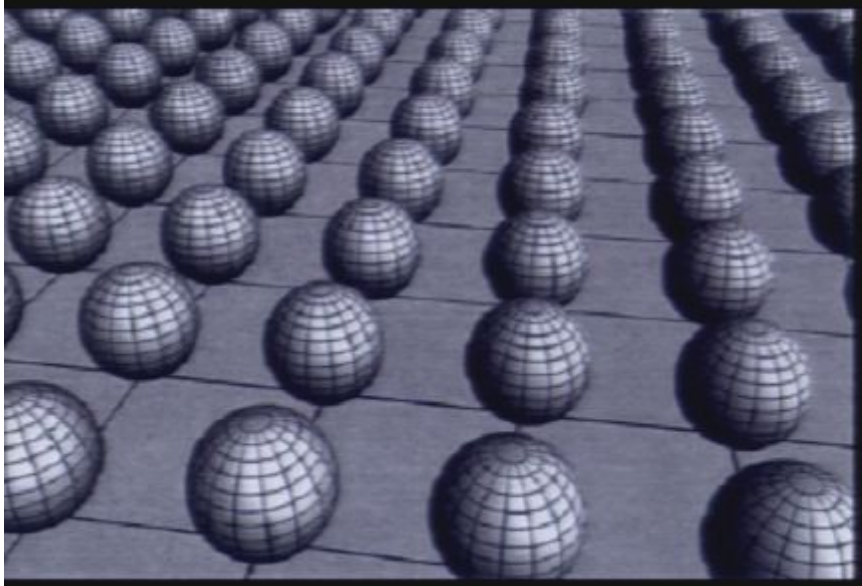
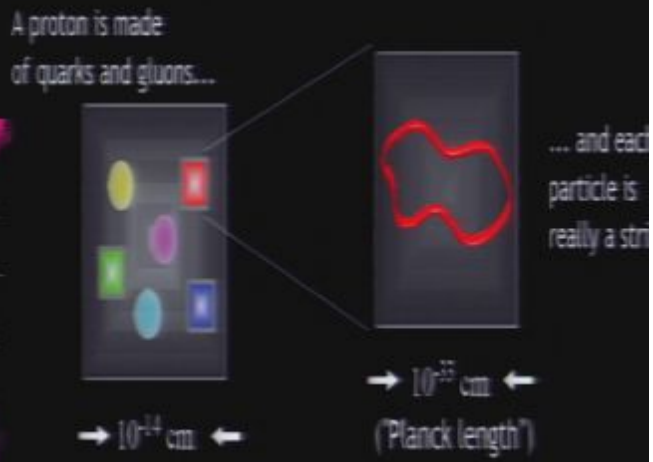


String Theory Landscape

Circa 2002: Advances in String Theory Result in Not Just 1 vacua for A Universe Like Ours. More Like 10^500 of Them?!

((oined the 'Landscape' By L. Susskind)



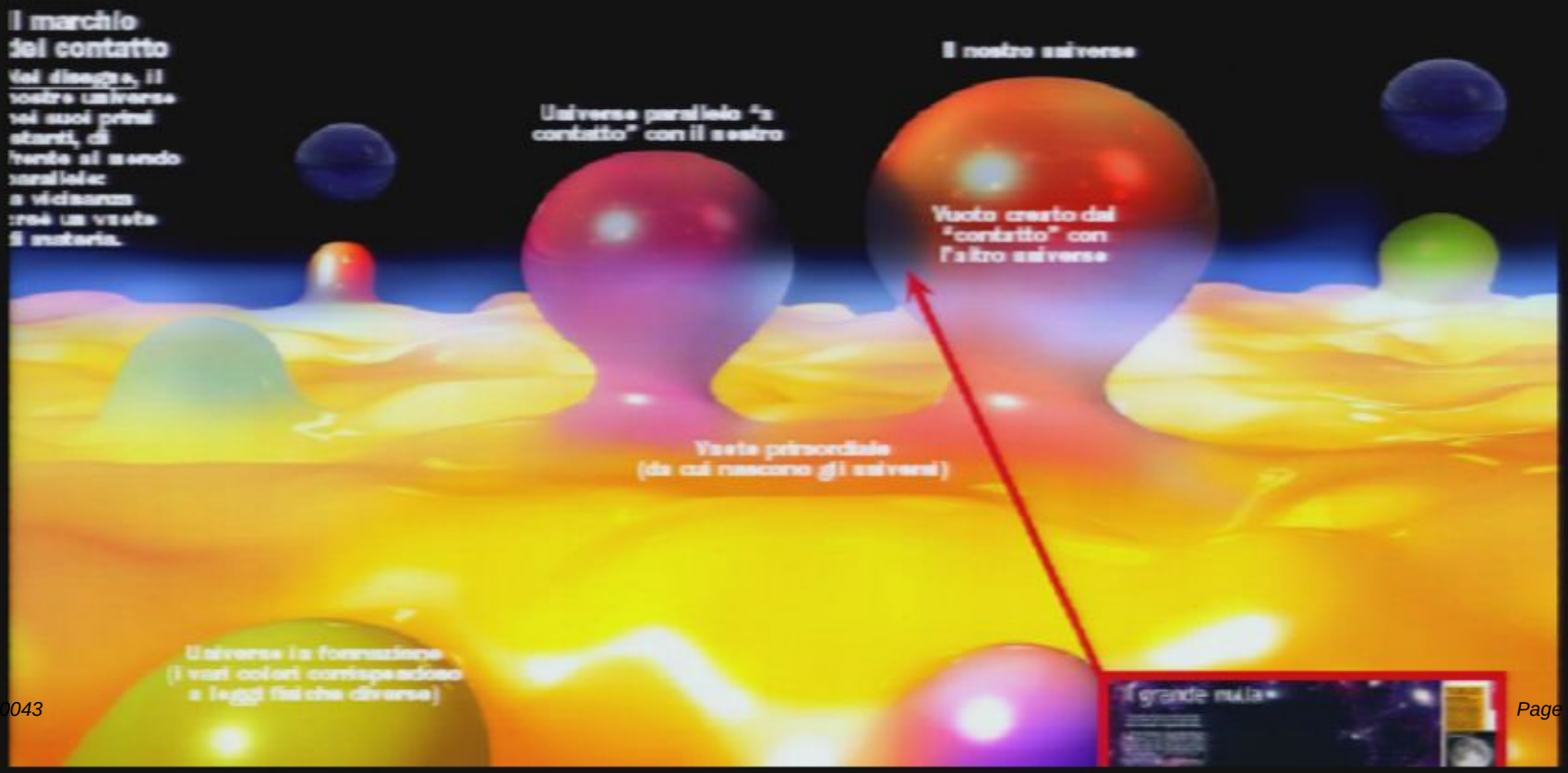


CRISIS: **A whole LANDSCAPE of Universes… but:**

How do we select our Universe in this multitude?

Landscape Discovery Considered a Crisis because we hoped STH would produce 1 unique solution for a (3+1)-D world that was like ours

- Reason: We had embraced a REDUCTIONIST view. But instead …



String Theory Multiverse

Advocating a *MERITOCRATIC* view

It's applied to the STH Landscape, by suggesting :

* to view the Landscape as the Phase Space if Initial Conditions

* and allow the Wavefunction of theuniverse to propagate on the Landscape, while including Decoherence mechanism

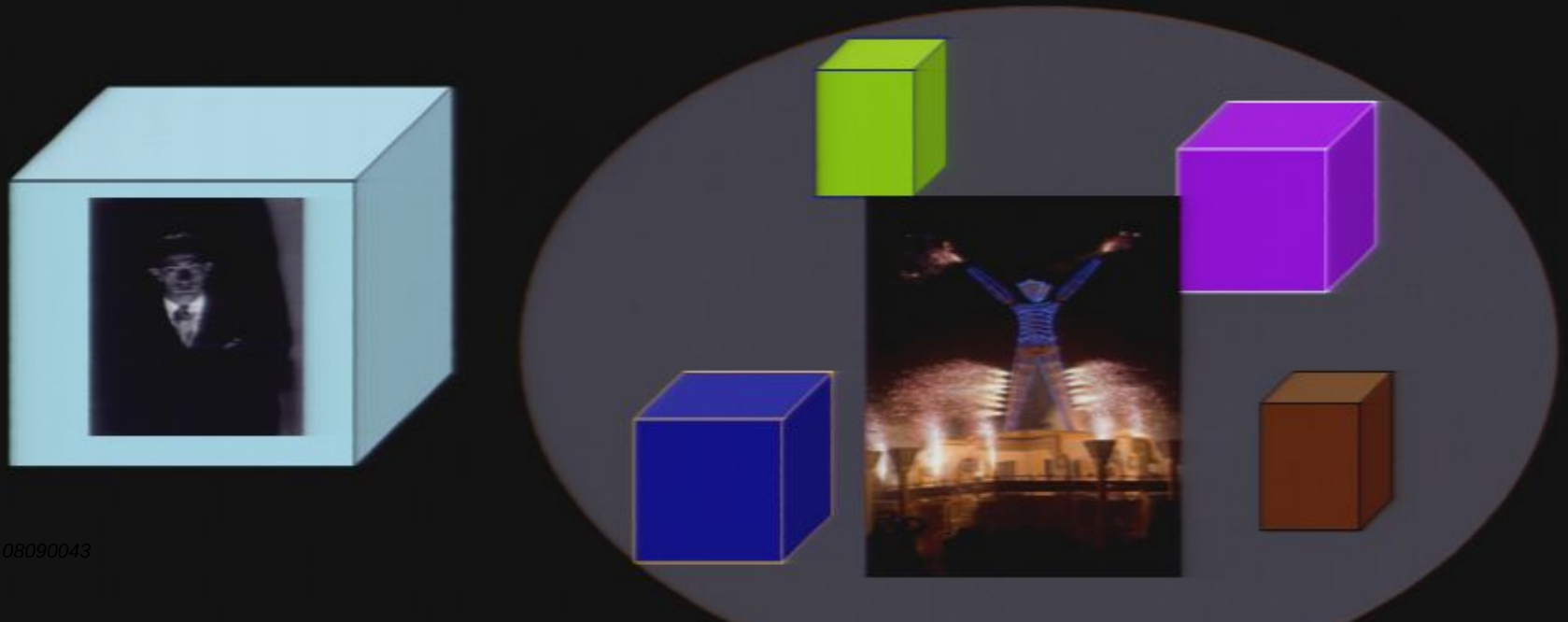
* Selection of 'Survivor Universes' , such as ours, based on the dynamics of gravitational and matter degrees of freedom – a 'tug of war'.

In this view, the STH Landscape has to be expected as a STH Multiverse Prediction

It Embeds the Landscape of String Theory into the Quantum Mechanics Multiverse

2 Views For TOE

- **"Reductionist":** TOE must yield 1 unique universe
- **"Meritocratic":** TOE must provide an ensemble of possible universes



Features of a Generic Multiverse

Perhaps some new theory of Quantum Gravity will be conceived in the future...

- *I believe, it has to contain a Multiverse Prediction, part of which will survive deconstruction in the low energy limit.*
- *The Multiverse of any theory will likely have two phases: quantum and classical, since our universe has to be part of it.*
- *Ultimately, Only One Multiverse can correspond to Physical Reality !*

Consensus on Definitions:

- *Multiverse :*

  The ensemble of all possible universes predicted by the underlying theory, i.e. all there is.

- *Universe :*

  Domain of Spacetime in which points were causally connected at some timeslice 't=0' of their past lightcone.

Multiverse Types and Hierarchy:

With current limited knowledge, we can expect these types and hierarchy of multiverses:

- ***TYPE A***: Different Laws Across the Multiverse
- ***TYPE B:*** Same Laws but Different Constants
- ***TYPE C:*** Varying Dimensionality 'D' Across the Multiverse, which can further subdivide into above Types - **A^D**, **B^D**.

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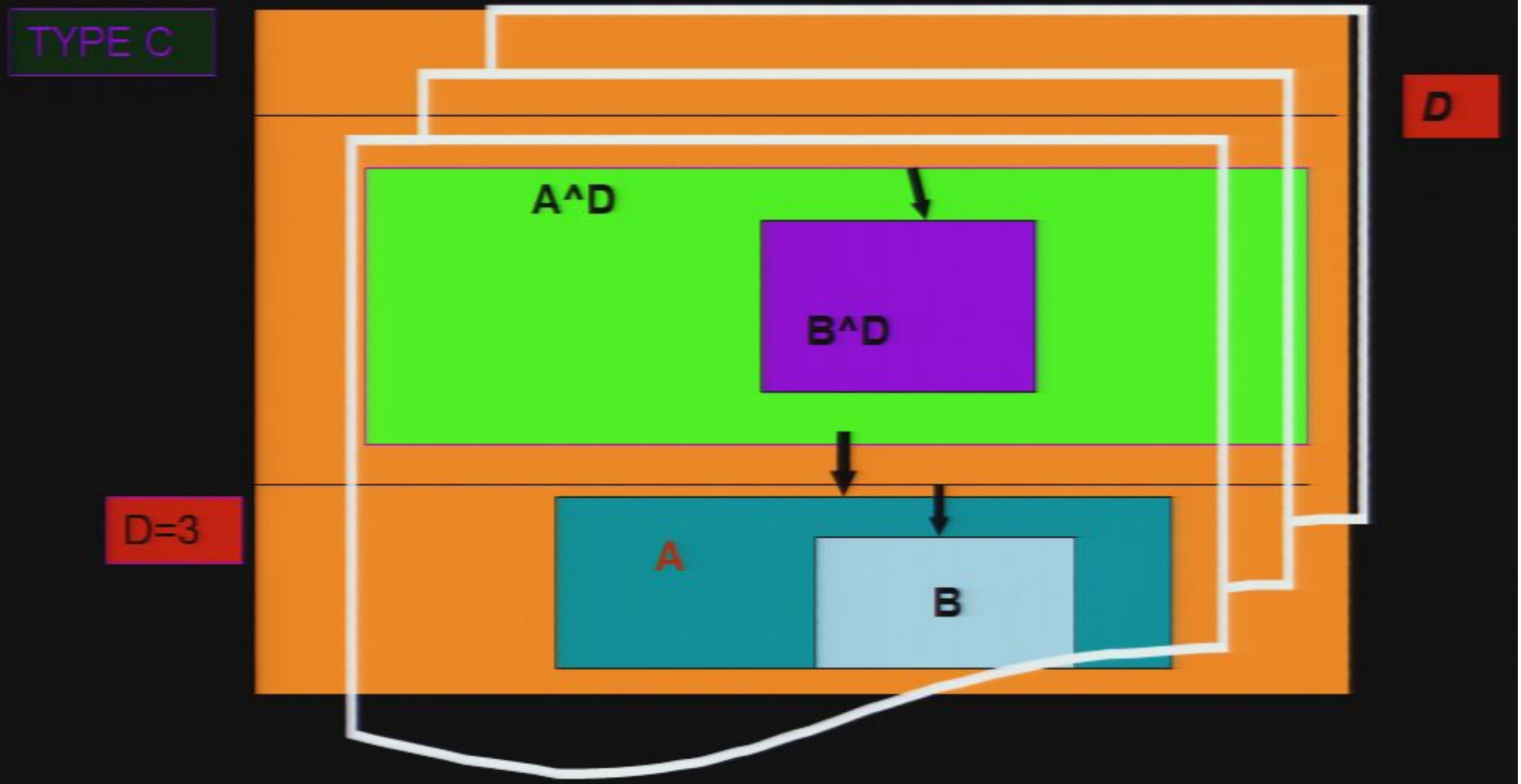
'Russian Dolls' Hierarchy



Corresponds to Tegmark's level 4

Differences in the Interpretation

MULTIVERSE : A Mathematical or a Physical Entity?

Only 1 Multiverse can Correspond to Physical Reality

- I do share Tegmark's view to allow all mathematical solutions on equal footing of existence, as candidates for correspondence to reality

- But : I take them as equal contenders only up to the Inclusion of Dynamics. I would suggest we include dynamics for determining the probability of their physical existence and correspondence.

(Not quite a Platonic view) .

But Dynamical Description Demands Space and Time

A Very Simple Question, (50 years after Everett..) : In what Space and Time do the Multiverse (s) Exist ? How can we decide this?

I Would like to Postulate 2 Principles:

- **SPACE**: The Principle of 'Domains Correlations'

If correlations exist, then multiverse embedded in One Bckg Spacetime (Connected)

Connected | Disconnected

- **TIME**: Principle of No 'Perpetual Motion', based on Time-Translation Symmetry

Energy cant be created and destroyed in/across domains. Then only one time parameter in common for all domains.

- Possibly Fundamental in TYPE B?!
- Emergent in TYPE A ?

Is Time Fundamental or Emergent? I will now assume QM is valid and fundamental

(IF QM Survives)

And, if Nature is Economic, then:

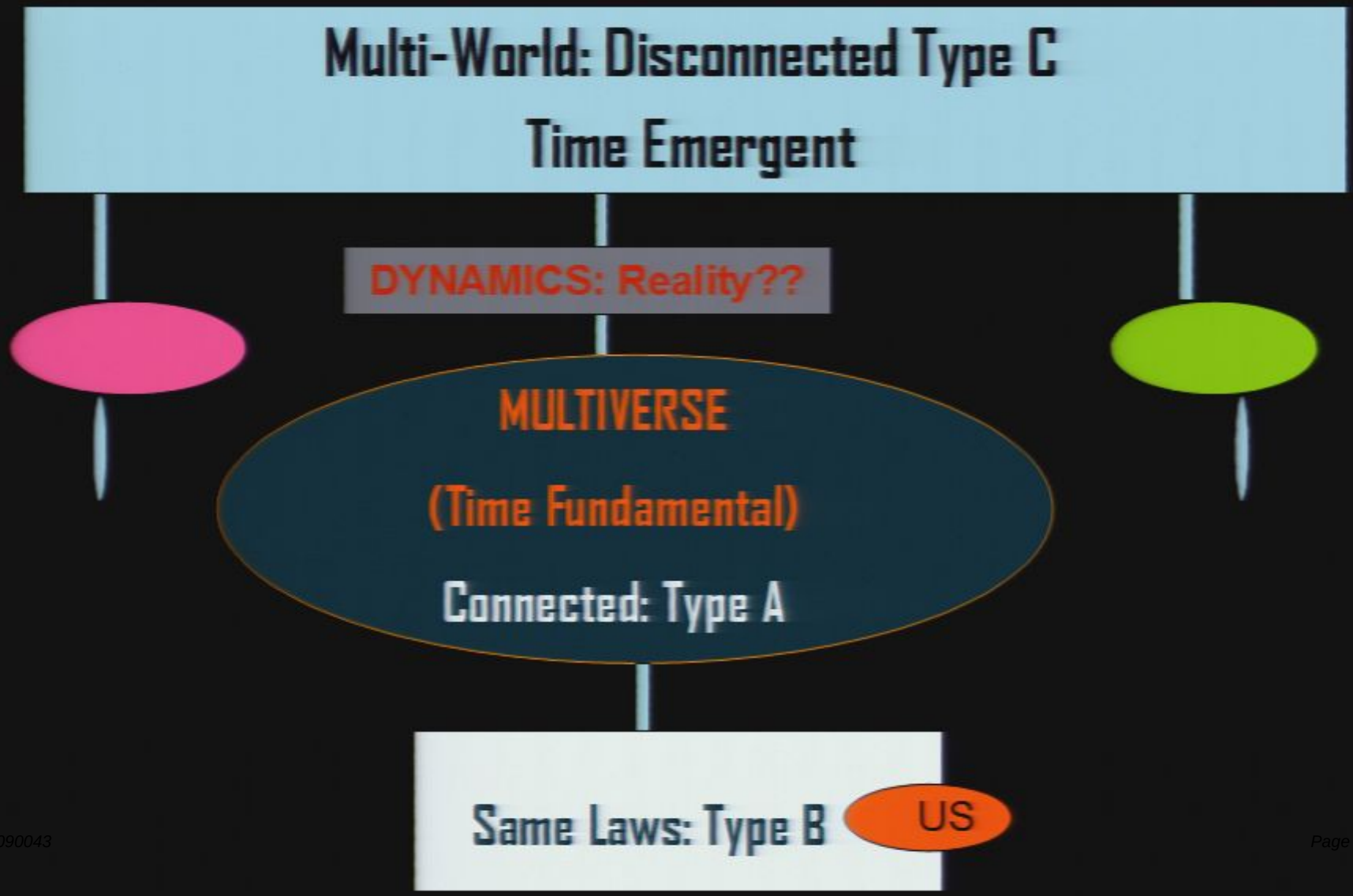
** Time-Translation Symmetry + Domain Correlation Reduce the Class of Multiverses corresponding to Physical Reality, to :

* Only the Connected Multiverse where Time is Fundamental *

i) The Multiverse does not need have same Dim. as its domains: correlations can exist in higher Dim.

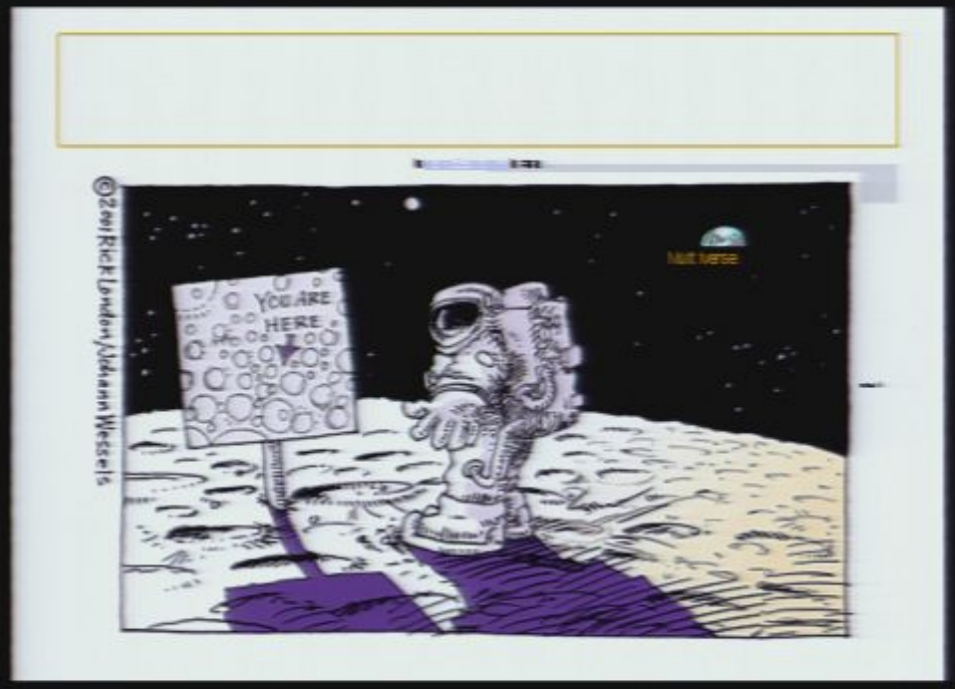
ii) We could distimguish Disconnected Type as Multi-world instead of Multiverse.

Hierarchy: Dynamics+ Quantum Mechanics



Contemplating Observational Imprints

?



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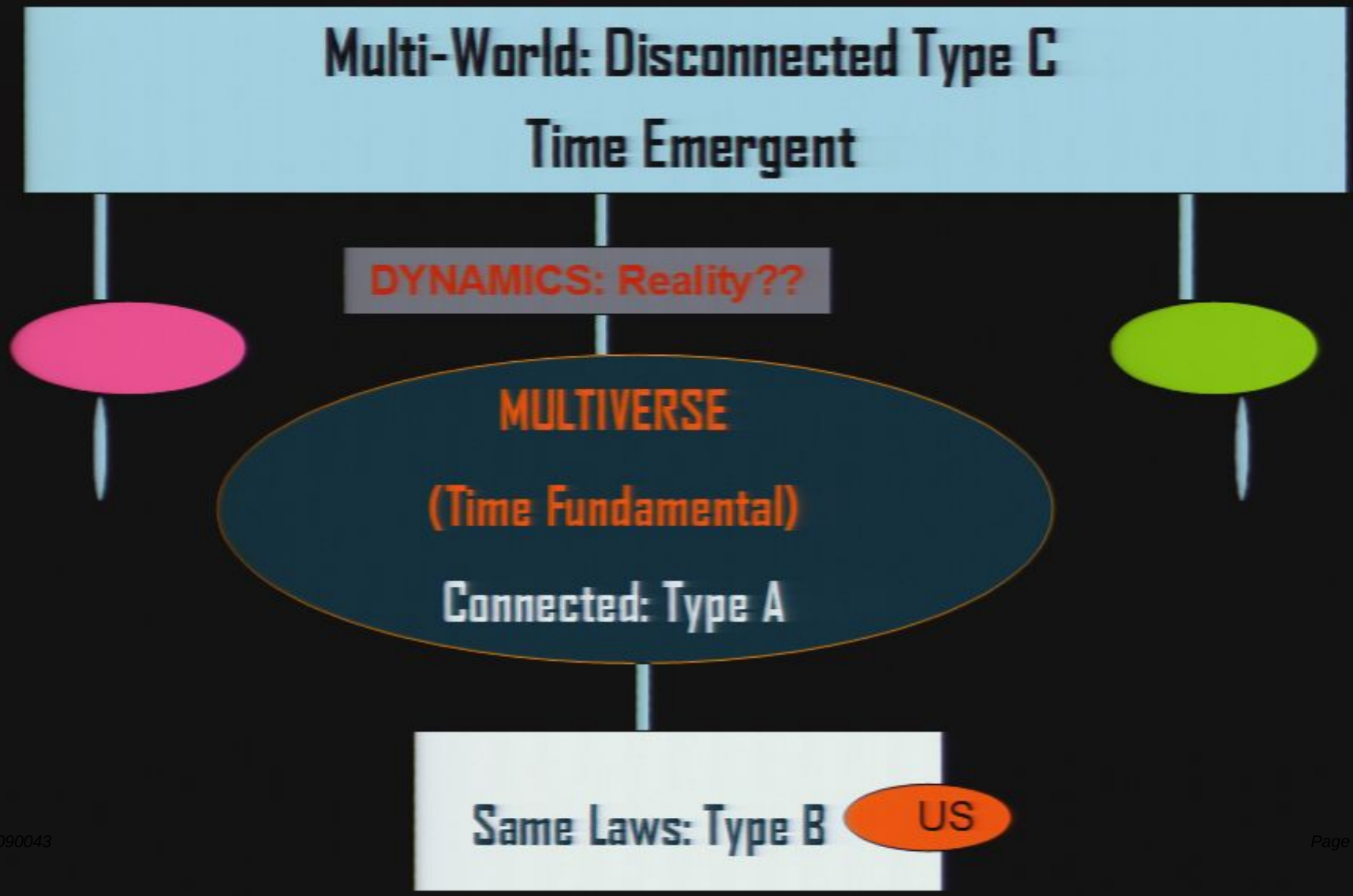

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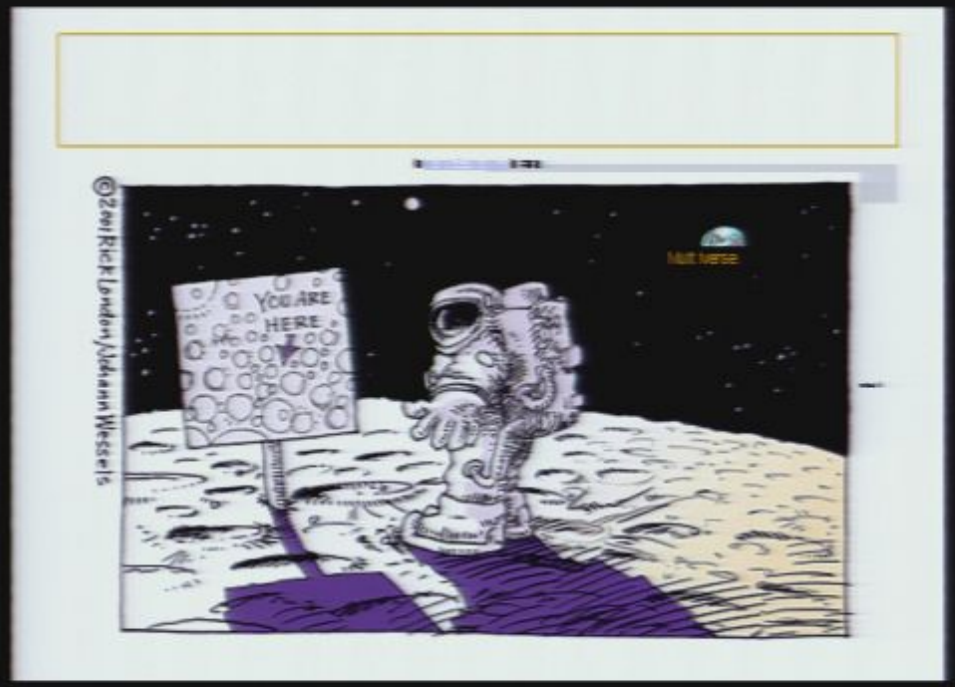


Selection Of Our Initial Patch: Why Pick One with Such an Extraordinarly Low Entropy?

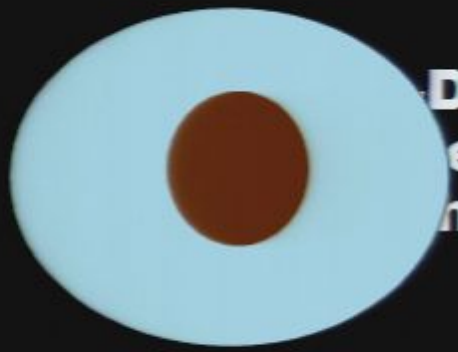
EXAMPLE : String Theory

- Non-Equilibrium: "Super Selection"

'SURVIVOR'
=Expand

Take the Landscape as the Theory of the Initial Conditions

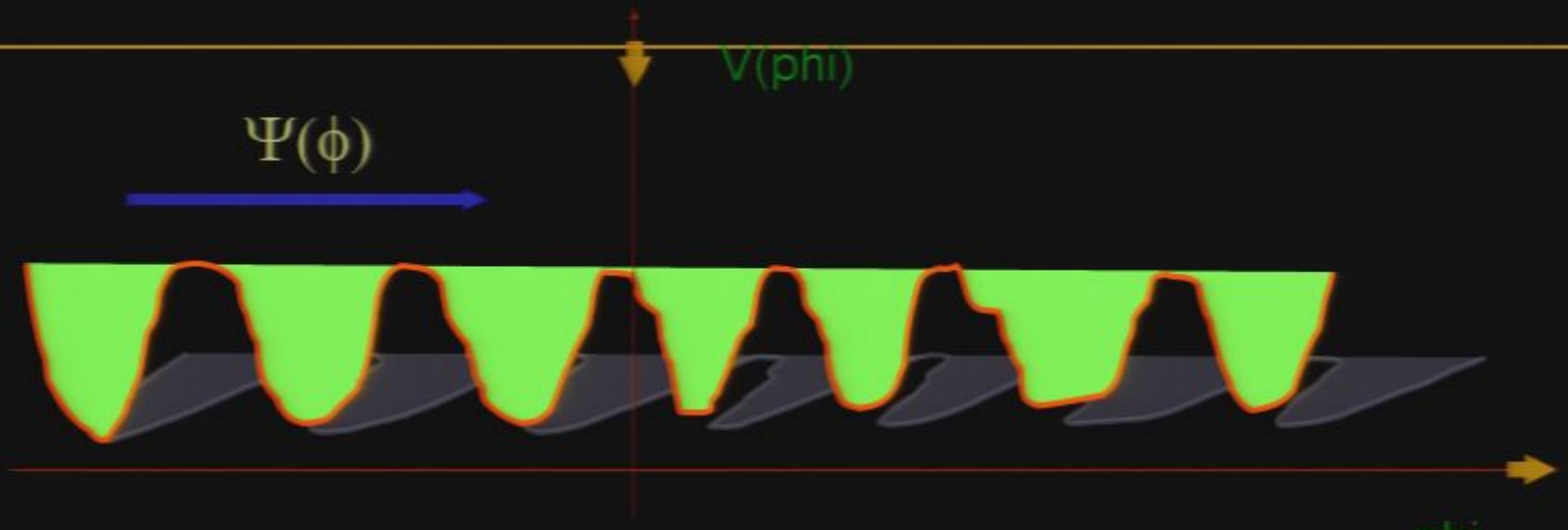
'TERMINAL'
=Collapse



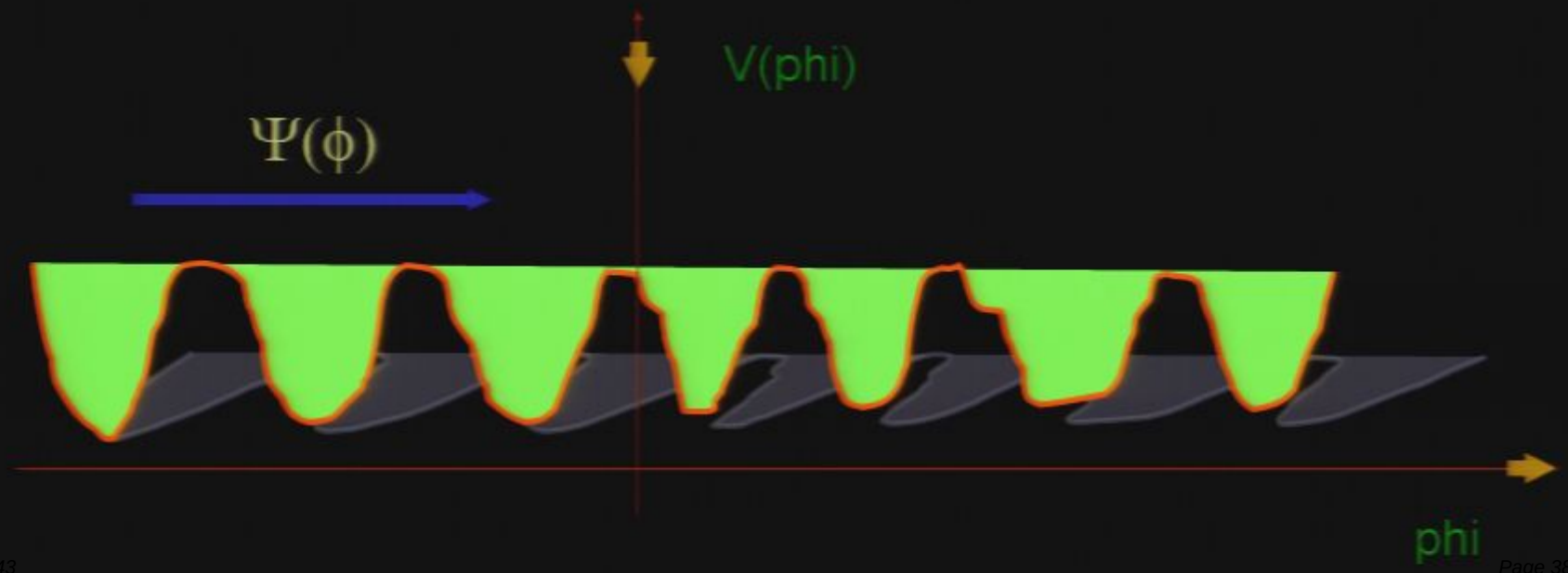
Dynamics of gravity ersus matter determines ne superselection rule.

The Universe on the Landscape

Multiverse

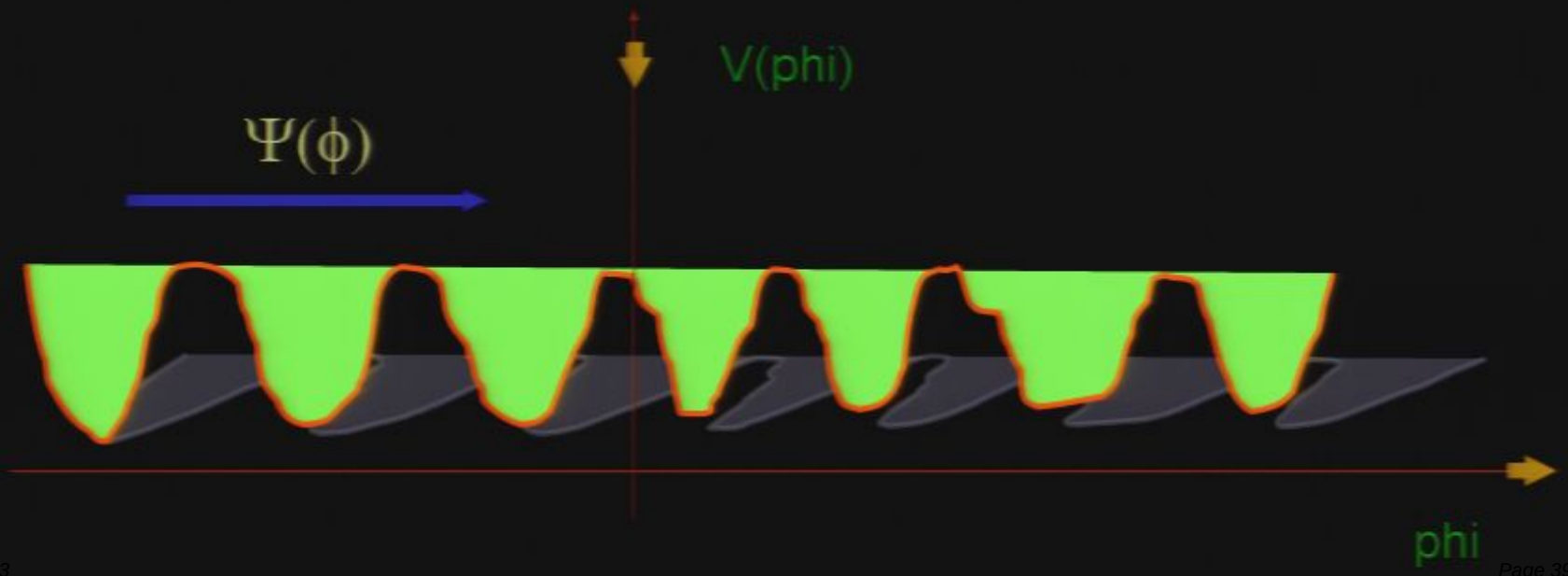


The Universe on the Landscape Multiverse



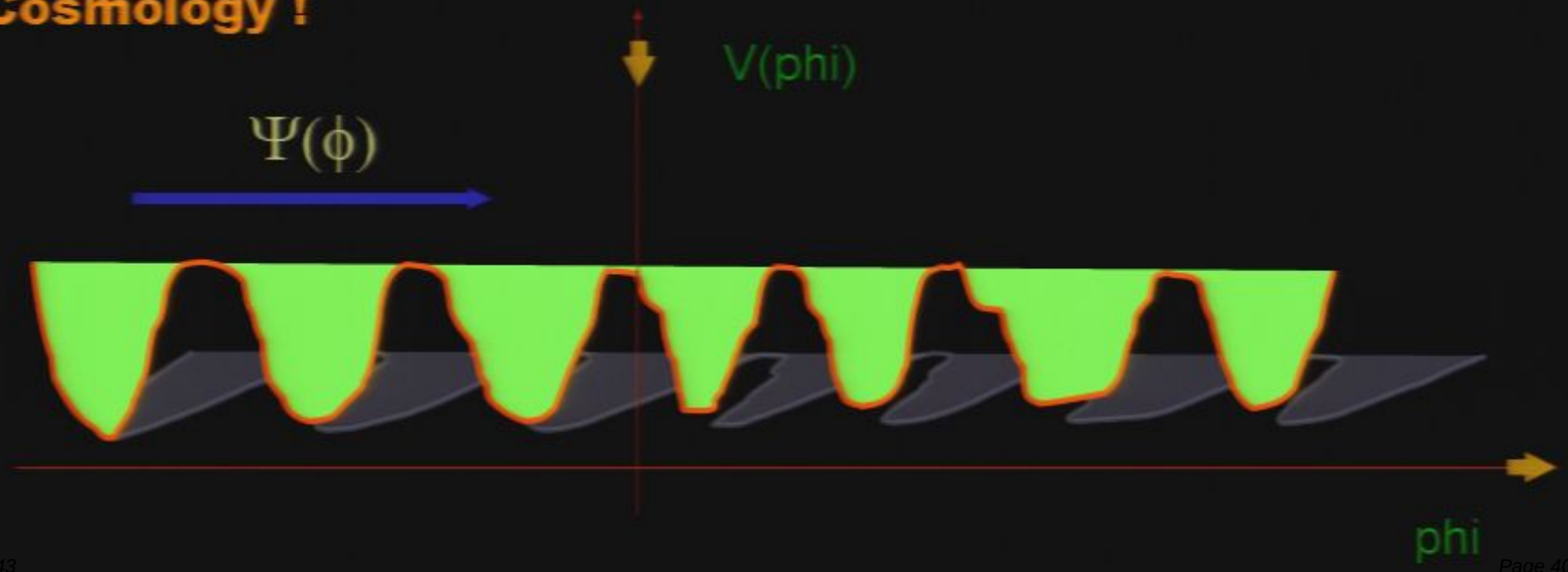
The Universe on the Landscape Multiverse

- **LANDSCAPE: Each vacua can potentially host a universe. Include decoherence among solutions.**



The Universe on the Landscape Multiverse

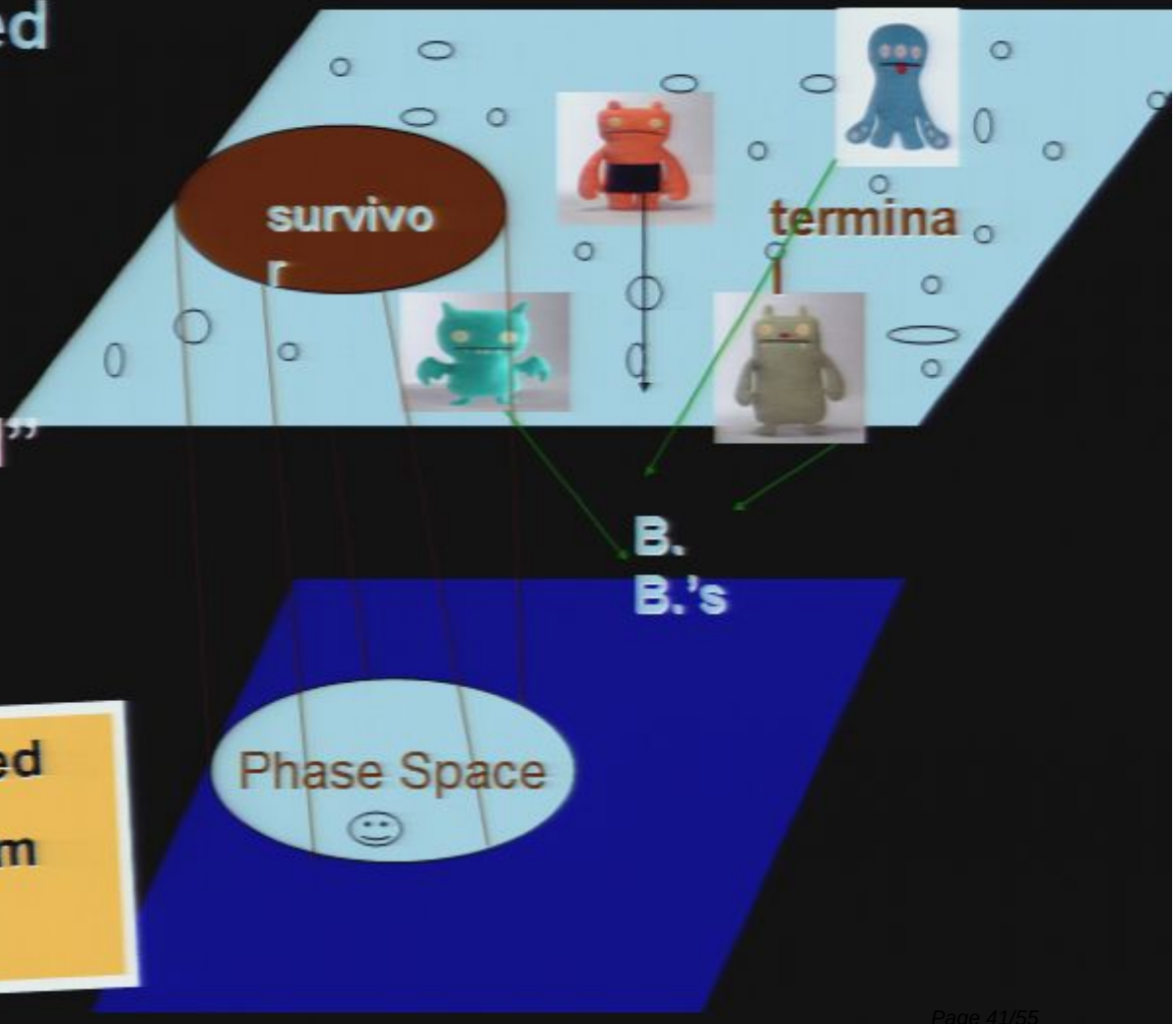
- **LANDSCAPE: Each vacua can potentially host a universe. Include decoherence among solutions.**
- **WaveFn. Of Universe: Quantum Mechanics – not Quantum Cosmology !**



What Happens to Phase Space

Dynamically Cleansed
Out of Low Energy
Inflationary Patches
From Gravitational
Instabilities!

"Survivor and Terminal"
Universes!

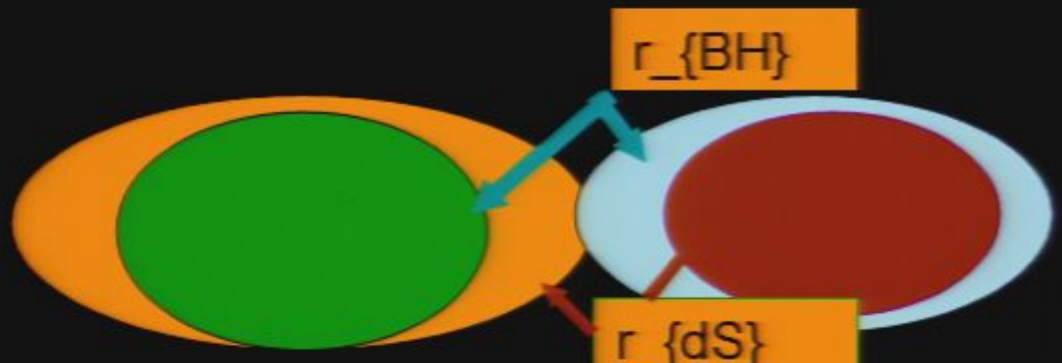


S = Log [V] : Dynamically Reduced
"Special" I. C. == Out-of-Equilibrum
Universe is Not Ergodic.

A Radical Proposal But Does it Make Predictions that can be Tested?

Yes, Mixing Remains by Unitarity !!

An Entangled State Can Not Evolve into a Pure State



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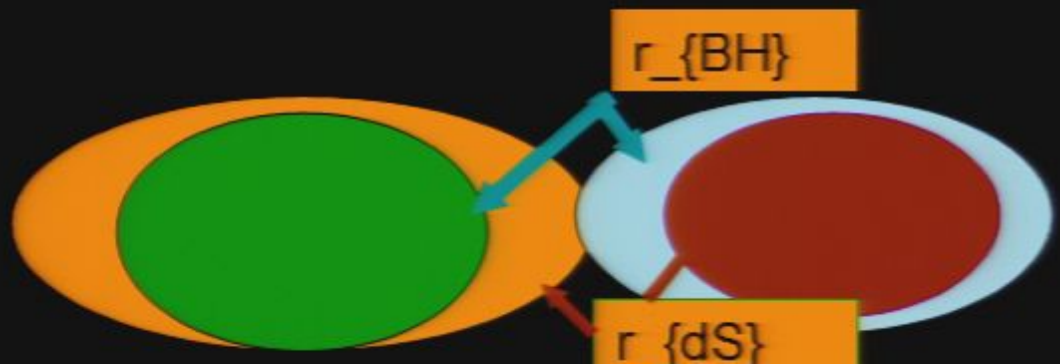

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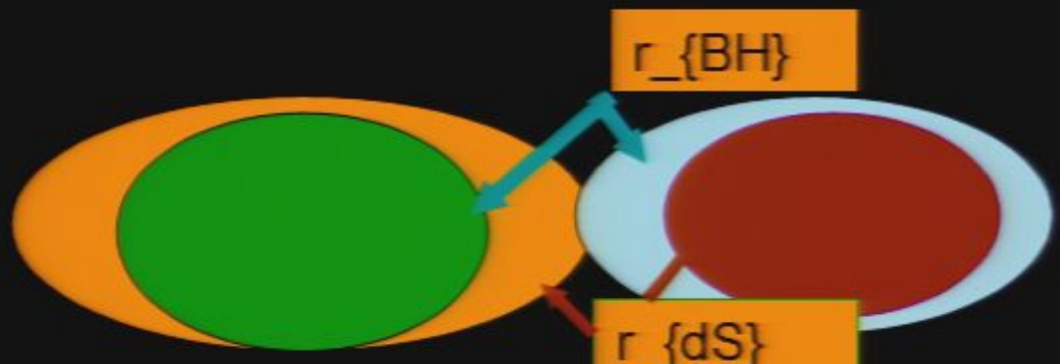

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An Entangled State Can Not Evolve into a Pure State

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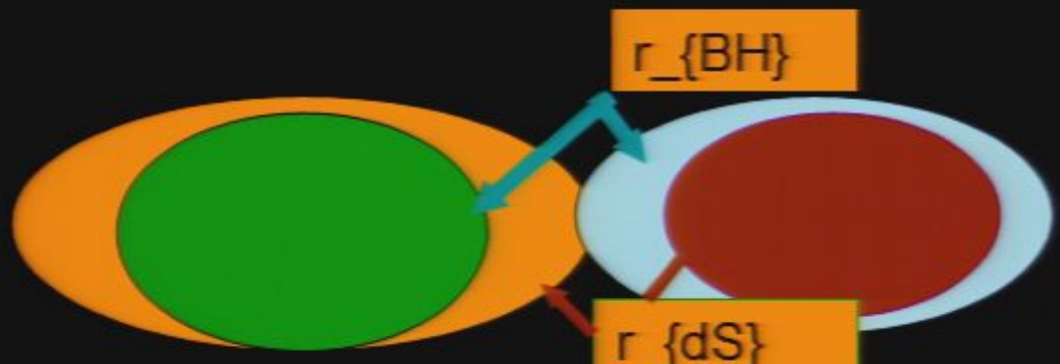
2. **Bounds on M_{susy} as local fundamental scale to be tested by LHC.**



Astrophysical Tests:

Entanglement Imprints on Friedman Equation

$$H^2 = \frac{1}{3M_P^2}\left[V(\phi) + \frac{1}{2}\left(\frac{V(\phi)}{3M_P^2}\right)^2 F(b,V)\right] \equiv \frac{V_{\text{eff}}}{3M_P^2} \qquad (4.2)$$

where

$$F(b,V) = \frac{3}{2}\left(2 + \frac{m^2 M_P^2}{V}\right)\log\left(\frac{b^2 M_P^2}{V}\right) - \frac{1}{2}\left(1 + \frac{m^2}{b^2}\right)\exp\left(-3\frac{b^2 M_P^2}{V}\right). \qquad (4.3)$$

Constrain SUSY Scale from Flatness and CMB Conditions

$$(\nabla T/T)_{\text{quad}} \approx r_H^2 \nabla^2 \delta\phi$$
$$= (ck_1/H_0)^2 \delta\phi \approx 0.5 (r_H/L_1)^2 (\delta\rho/\rho)_1.$$

$$\Delta V/(\Delta\phi)^4 \leq O(10^{-7})$$

$$10^{-10} M_P < b < 10^{-8} M_P$$

Modified Newtonian Potential.

Void Predicted at z<1 with size ~200Mpc Observed: Sigma_8 predicted <1, in agreement w. WMAP.

$$\Phi = \Phi^0 + \delta\Phi \simeq \Phi^0 \left[1 + \frac{f(b,V)}{\rho} \left(\frac{r}{L_1(k,b)} \right)^2 \right].$$

CMB: Running n_s. Suppressed sigma_8.

LSS: Power Enhanced at Cluster Scales.

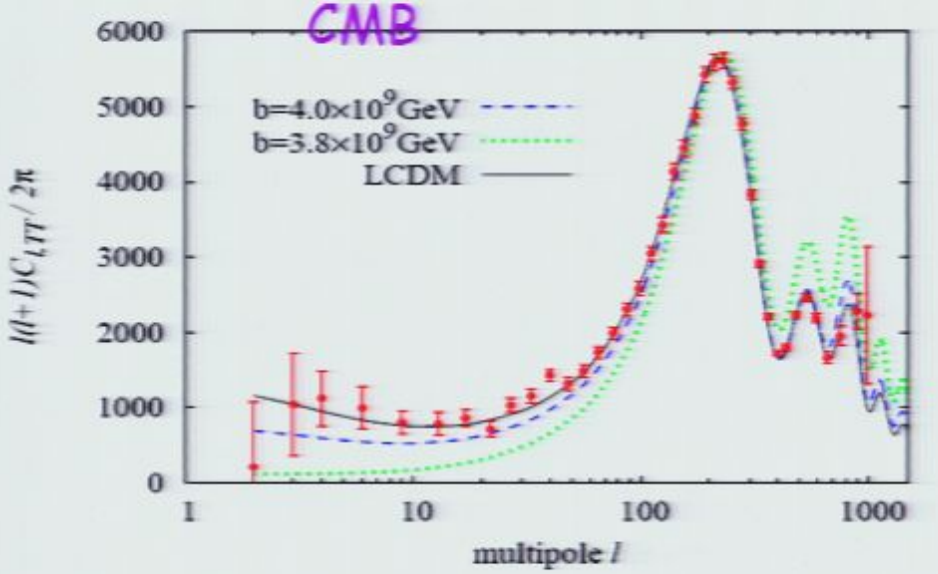
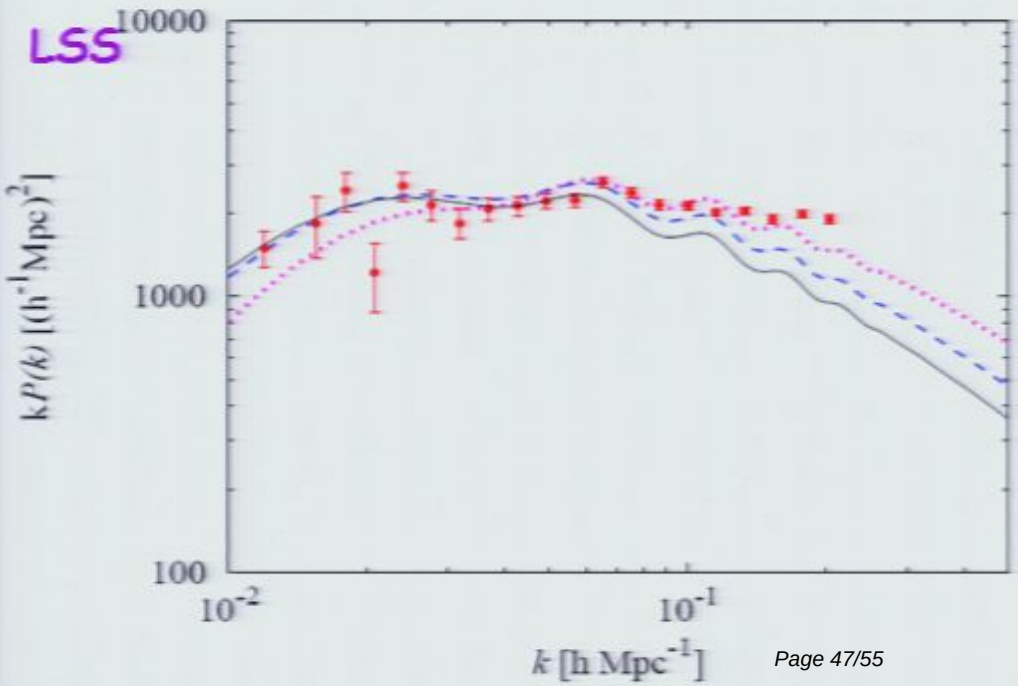


FIG. 1: CMB TT power spectra for the cases with $b = 4.0 \times 10^9$ GeV (dash-line) and 3.8×10^9 GeV (dot-line). For reference, the spectrum for the ΛCDM case (solid-line) and the data from WMAP3 are also



Ontology of Multiverse

- **But so many types of Multiverse already. Only one can correspond to physical reality. Have we just shifted the trouble of I.C. to Multiverse selection?**

- **Propose 2 principles to identify the Multiverse:**

  1) No 'Perpetual Motion' on Multiverse. (TIME)

  2) 'Domains Correlation' on Multiverse.(SPACE)

These principles ensure one background spacetime for the Multiverse.

- Who would have thought that Nature would lead us to a situation where a deeper understanding of its mysteries, at the smallest and largest scales, would guide the extension of our physical theories to the realm of the Multiverse ?

Microsoft PowerPoint - [multiversepi08]

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Outline Slides

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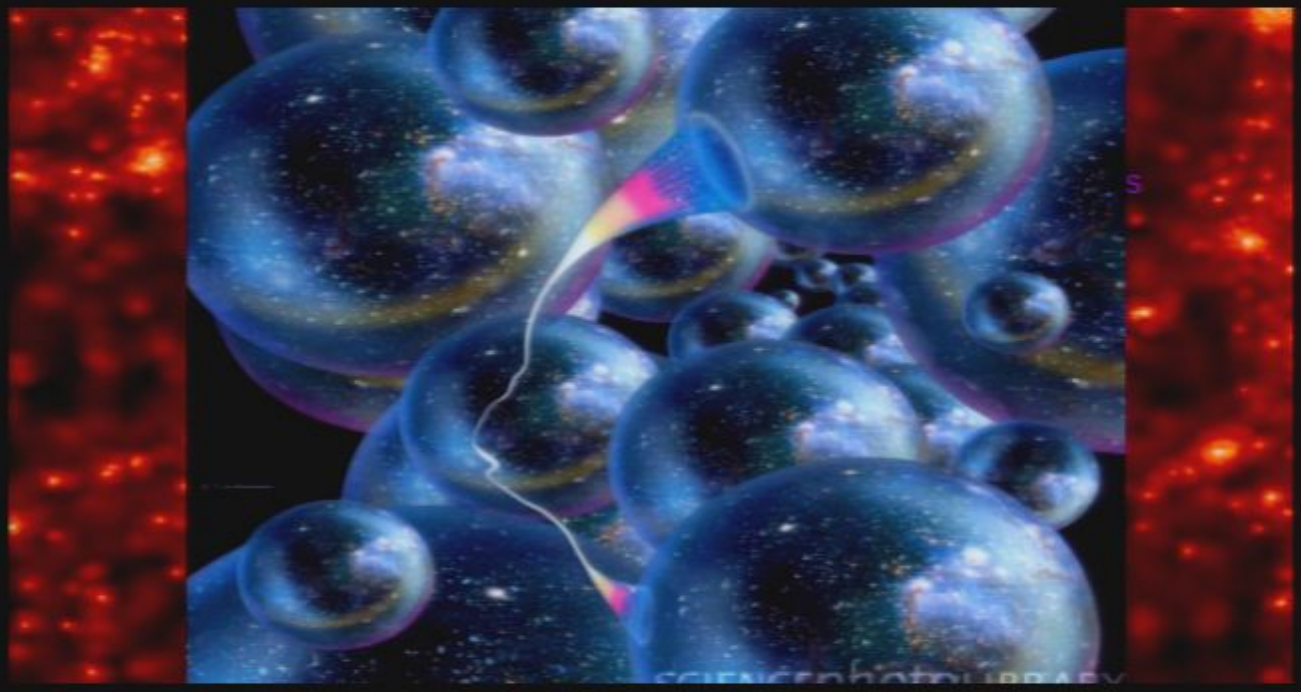

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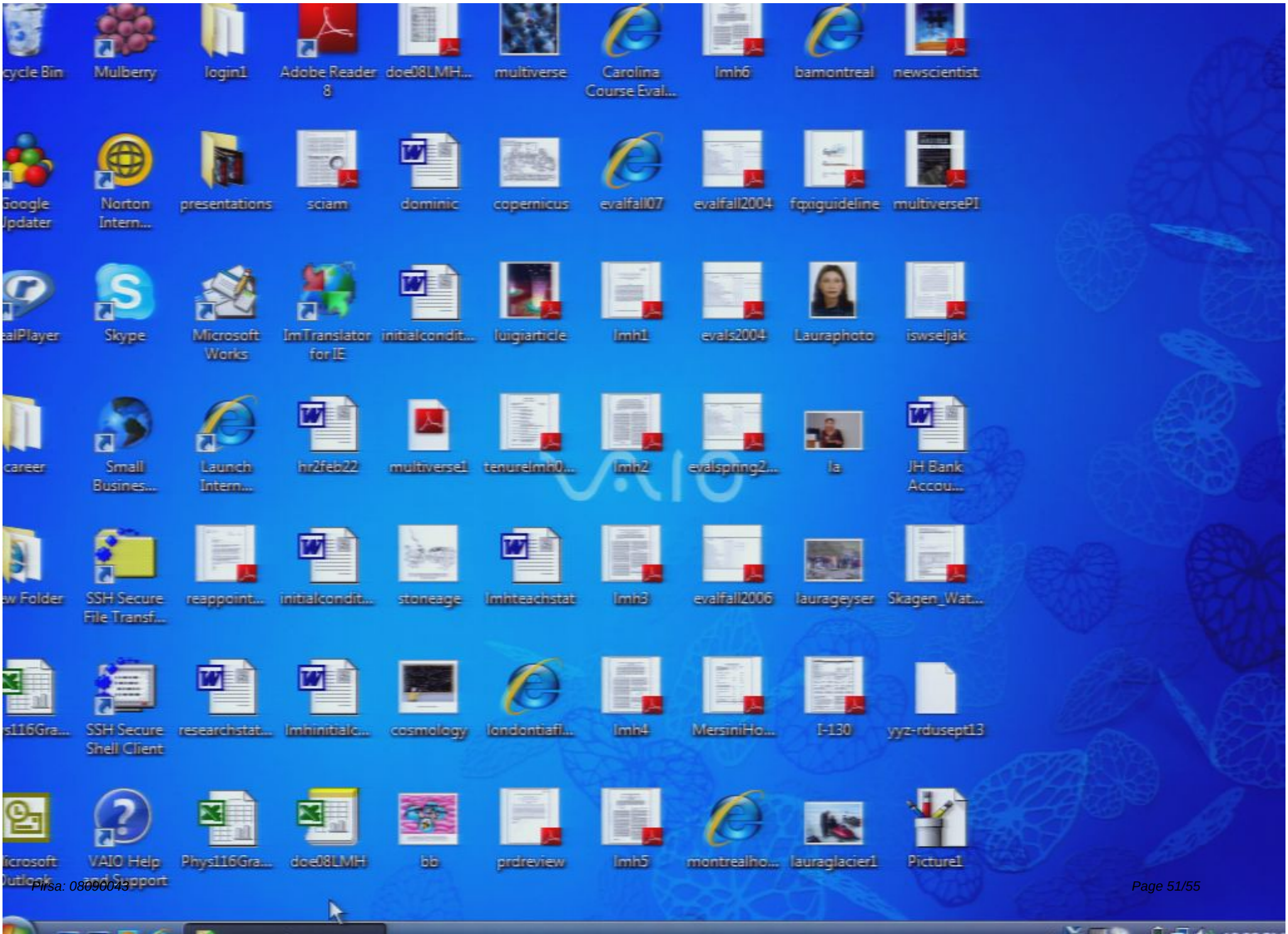
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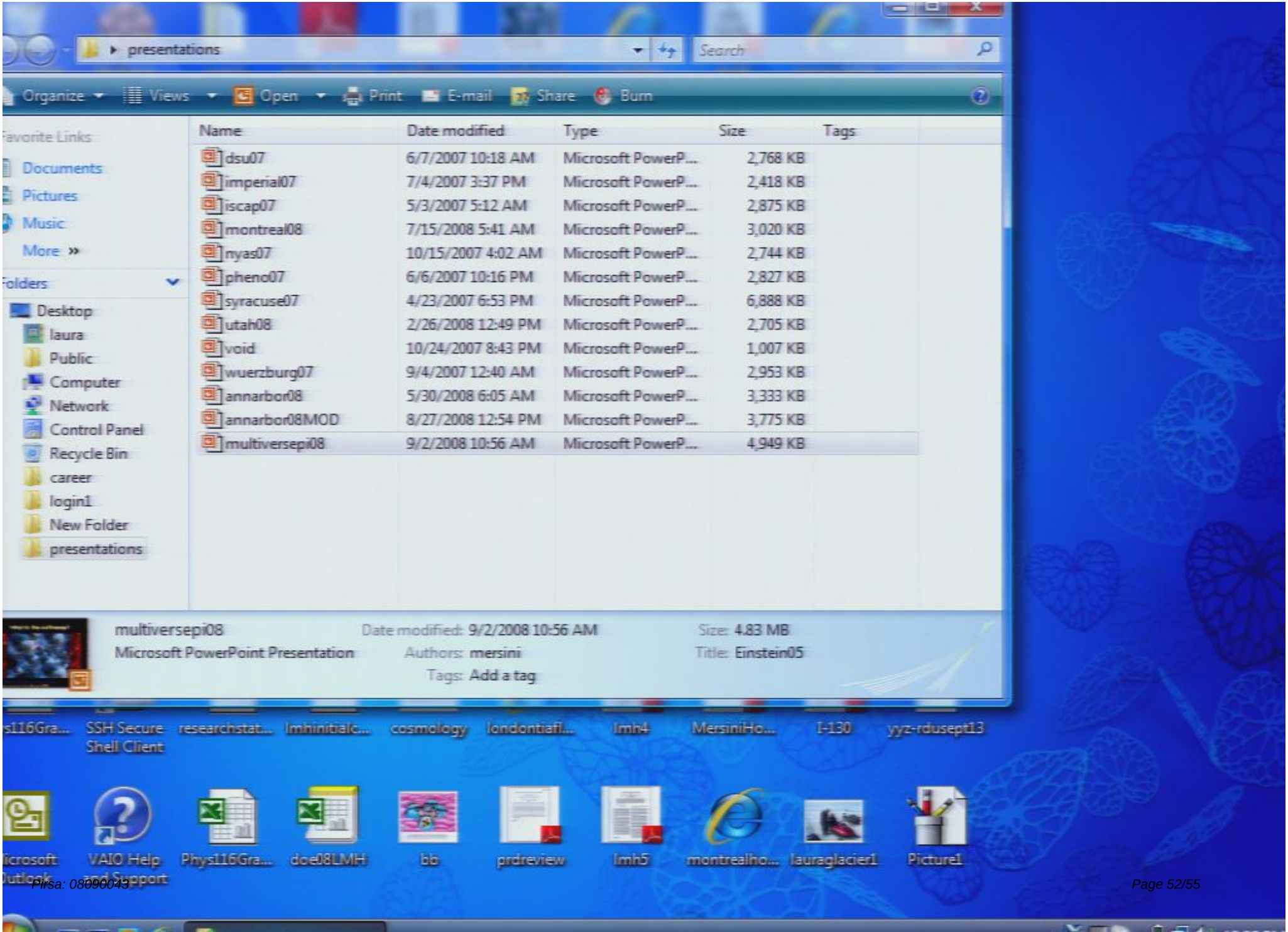
Picture1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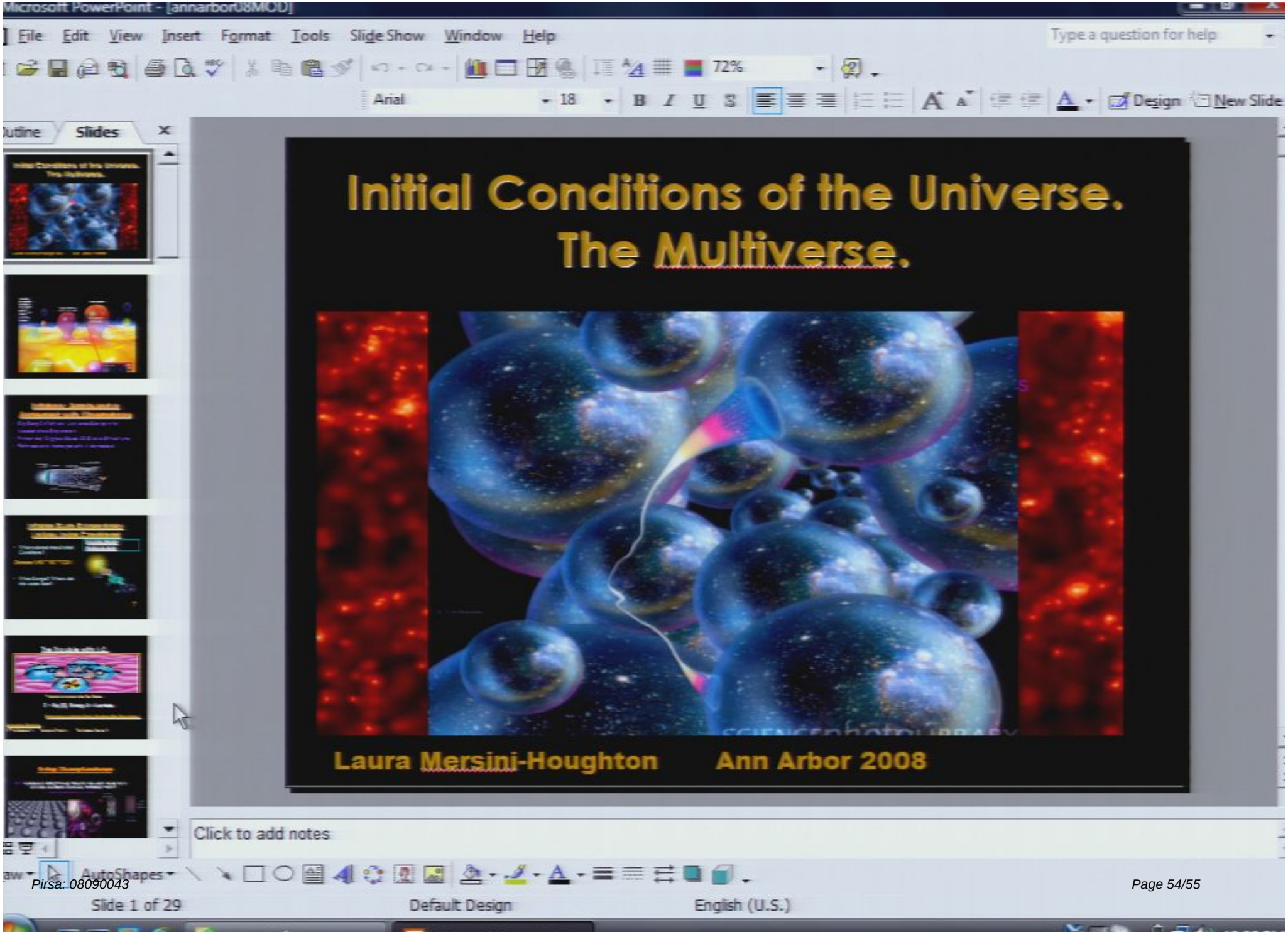
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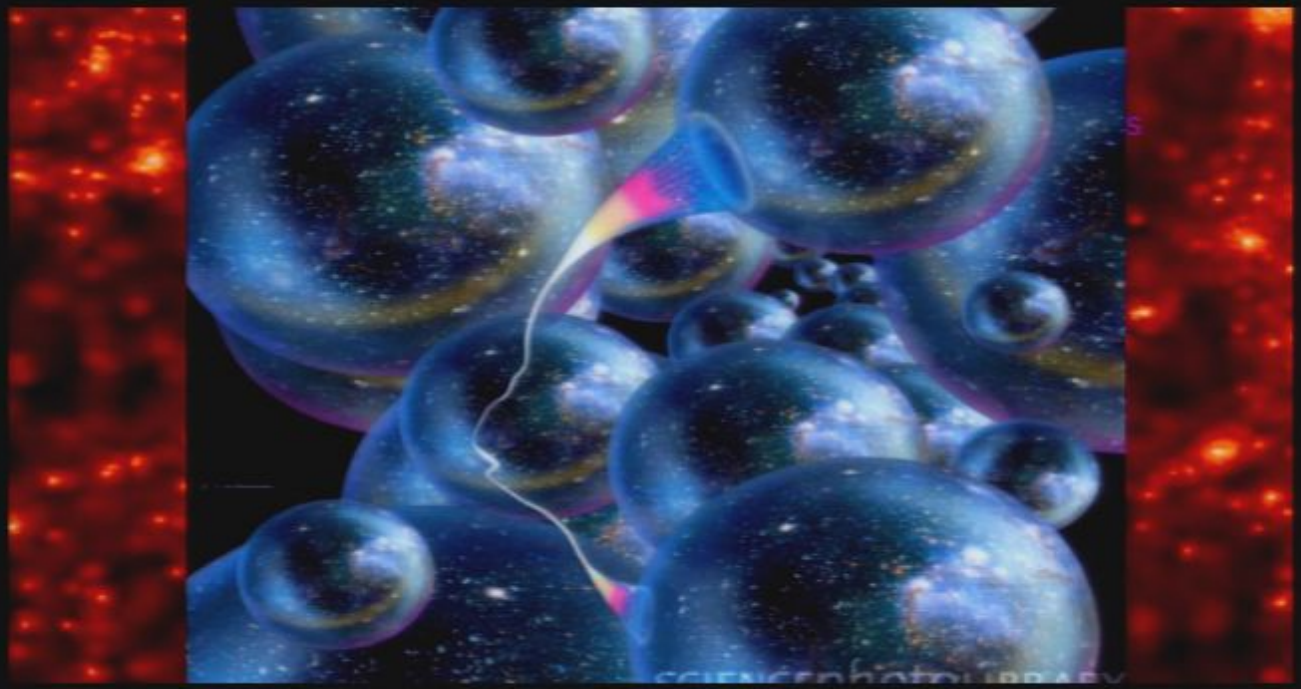
Outline Slides

Initial Conditions of the Universe. The Multiverse.



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