

SUPER CHALLENGES

Chaos, Cosmology and Strings

Paulo Vargas Moniz

UBI & CENTRA-IST



Problems for the Millenium!...

- How can quantum gravity help explain the origin of the universe?
- What physics explains the enormous disparity between the gravitational scale and the typical mass scale of the elementary particles?
- What are the fundamental degrees of freedom of M-theory and does the theory describe Nature?
- Why does the cosmological constant have the value that it has, is it zero and is it really constant?
- Why does the universe appear to have one time and three space dimensions?
- ... <http://www.claymath.org/millennium/> (\$1 million prize fund for the solution to *these* problems!)

Introduction	
● Cosmo '06	
● What's on for the XXlist?	
● ...For the XXlist!	
● 'Great Expectations'	
● Strings 'R' us	
● This Talk	
String Landscape	
Chaos-Order transition	
Semiclassical SQC	
Other Horizons	



String Landscape Problem

Introduction

String Landscape

- A View...
- **The Problem**
- Framework
- Quantization
- DeWitt's argument

Chaos-Order transition

Semiclassical SQC

Other Horizons



Portuguese perspective (circa. 1502!)



Introduction



String Landscape



Chaos-Order transition



Semiclassical SQC



- It's SUPER

- SQC

- Hamilton-Jacobi

- Matter Fields

- Corrections



Other *Horizons*

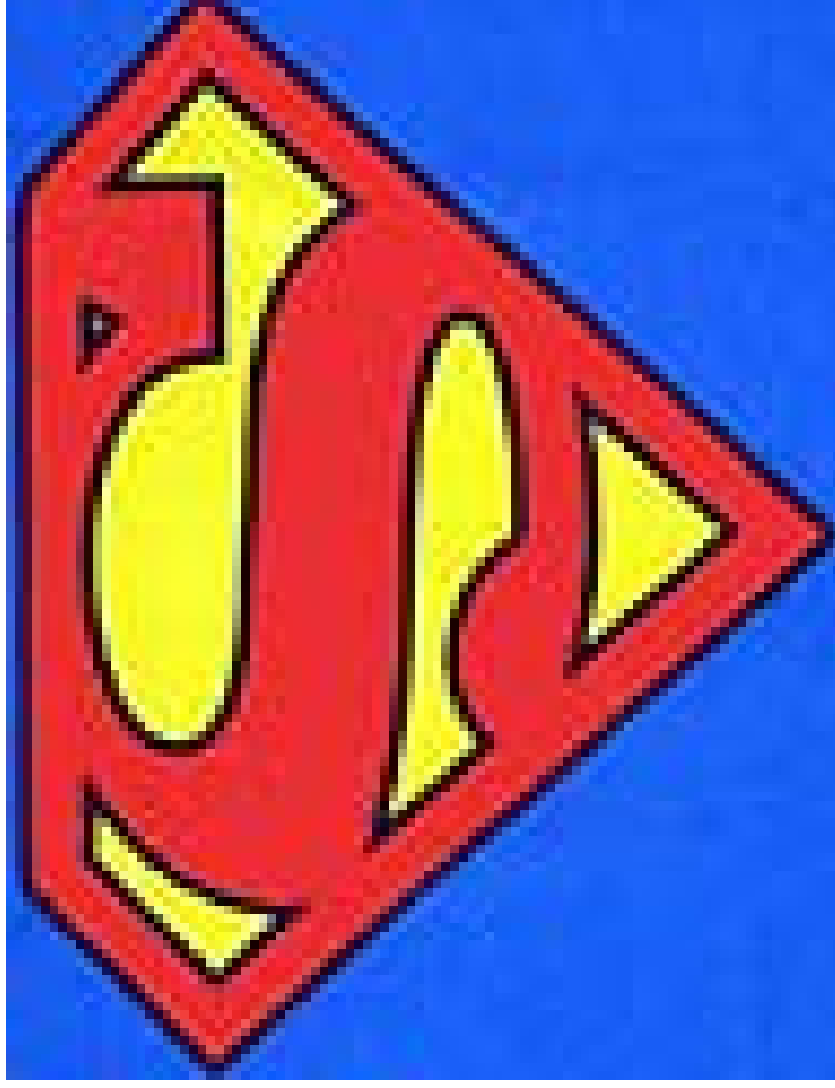


Semiclassical SQC



Supersymmetry!

Introduction	
String Landscape	
Chaos-Order transition	
Semiclassical SQC	
● It's SUPER	
● SQC	
● Hamilton-Jacobi	
● Matter Fields	
● Corrections	
Other <i>Horizons</i>	





Supersymmetric Quantum Cosmology

Introduction	III
String Landscape	III
Chaos-Order transition	III
Semiclassical SQC	III
● It's SUPER	III
● SQC	III
● Hamilton-Jacobi	III
● Matter Fields	III
● Corrections	III
Other Horizons	III

- SQC essential feature....
- ...Quantum gravity **and** SUSY effects as dominant!
- Improved description of the universe:
 - ◆ Creation;
 - ◆ Immediate subsequent stages.
- In spite of all the progress achieved so far...
- ... further efforts are required:
 - ◆ Find *new* states;
 - ◆ Determine consistent path from SQC to a classical universe
 - ... Develop a semiclassical scheme;
 - 'New' (Constraint) Equations;
 - ... E.g., Born–Oppenheimer expansion.



Recovery the Hamilton-Jacobi eq.

Introduction	
String Landscape	
Chaos-Order transition	
Semiclassical SQC	
• It's SUPER	
• SQC	
• Hamilton-Jacobi	
• Matter Fields	
• Corrections	
Other <i>Horizons</i>	

■ ... Use

$$\Psi[e, \psi, \Phi] = \exp \left(\frac{i}{\hbar} \sum_{n=0}^{\infty} S_n[e, \psi, \Phi] G^{n-1} \right)$$

■ Use

$$\mathcal{H}_{\perp} = \dots \text{Phys.Rev.D72(2005)045006}$$



Recovery the Hamilton-Jacobi eq.

- Introduction |||
- String Landscape |||
- Chaos-Order transition |||
- Semiclassical SQC
 - It's SUPER
 - SQC
 - **Hamilton-Jacobi**
 - Matter Fields
 - Corrections
- Other Horizons |||

- At order G^{-1} :

$$0 = 4\pi i \left(\psi_i^B \frac{\delta S_0}{\delta e_j^{AB'}} E_{Bjk}^{CAB'i} \frac{\delta S_0}{\delta \psi_k^C} - n^{AA'} D_{ij}^{BB'} \frac{\delta S_0}{\delta e_j^{AB'}} \frac{\delta S_0}{\delta e_i^{BA'}} \right) + \frac{i}{\sqrt{h}} \epsilon^{ijk} e_i^{BC'} e^A_{C'l} ({}^{3s}D_j \psi_{Ak}) \frac{\delta S_0}{\delta \psi_l^B} - n^{AA'} {}^{3s}D_i \frac{\delta S_0}{\delta e_i^{AA'}} - V.$$

- Background spacetime *involves* gravitino;
- Purely bosonic and ... fermionic sectors.



Corrections to the Schrödinger eq.

- Introduction
- String Landscape
- Chaos-Order transition
- Semiclassical SQC
 - It's SUPER
 - SQC
 - Hamilton-Jacobi
 - Matter Fields
 - Corrections
- Other Horizons

- At the order G^1 : $\Theta \equiv \chi \exp\left(\frac{i}{\hbar}\eta G\right)$
- ◆ Decomposition into a 'normal' and a 'tangential' part
- ◆ 'Super-DeWitt metric' \mathcal{G} on *SuperRiem* Σ :

$$\mathcal{G}_{ab} = \begin{pmatrix} B & S_1 \\ S_2 & \mathcal{F} \end{pmatrix}.$$

- ◆ 'normal' part

$$i\hbar \frac{\delta \Theta}{\delta \tau} = \mathcal{H}_{\perp}^m \Theta + \frac{4\pi G}{\sqrt{\hbar}^{3s} R} \left[(\mathcal{H}_{\perp}^m)^2 + i\hbar \frac{\delta \mathcal{H}_{\perp}^m}{\delta \tau} - \frac{i\hbar}{\sqrt{\hbar}^{3s} R} \frac{\delta(\sqrt{\hbar}^{3s} R)}{\delta \tau} \mathcal{H}_{\perp}^m \right]$$



Corrections to the Schrödinger eq.

- At the order G^1 :
- ◆ For a Friedmann universe with scale factor a
$$\frac{\hbar}{(\mathcal{H}_\perp^m)^2} \frac{\delta \mathcal{H}_\perp^m}{\delta \tau} \sim \frac{\hbar \dot{a}}{(\mathcal{H}_\perp^m)^2} \frac{d\mathcal{H}_\perp^m}{da} \sim \frac{\hbar H_0}{E} \sim 10^{-44}$$
- ◆ SQC ... establishing predictions;
- ◆ It can be improved (... in progress).

Introduction

String Landscape

Chaos-Order transition

Semiclassical SQC

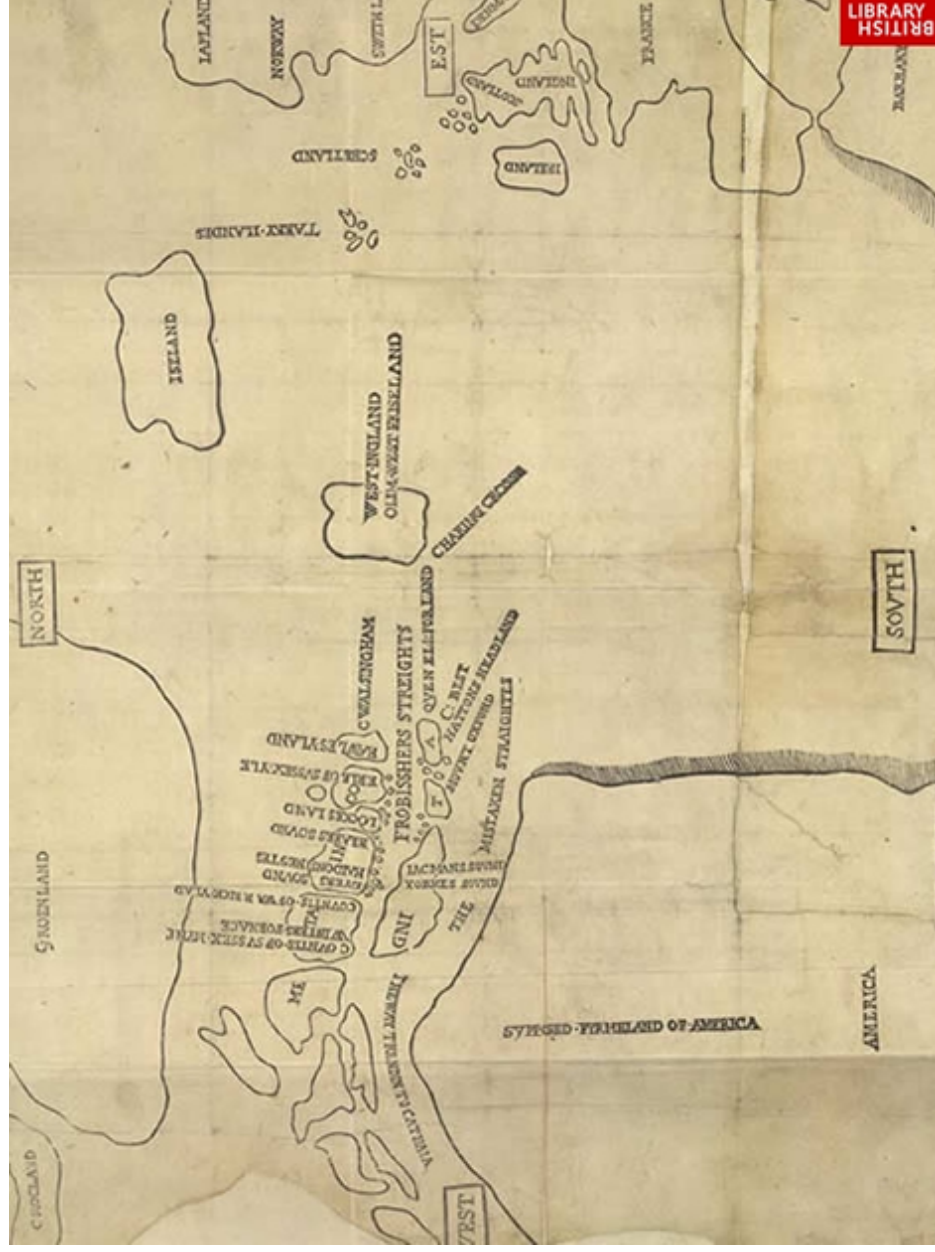
- It's SUPER
- SQC
- Hamilton-Jacobi
- Matter Fields
- Corrections

Other Horizons



'What' is the Landscape?

- Introduction
- String Landscape
- Chaos-Order transition
- Semiclassical SQC
- Other Horizons
- 'The' Frontier
- **'What' is the Landscape?**
- 'Where' is the chaos?
- 'When' is it SUSY?
- Borderline...





'When' is it SUSY?

Introduction	1
String Landscape	1
Chaos-Order transition	1
Semiclassical SQC	1
Other Horizons	1
• 'The' Frontier	1
• 'What' is the Landscape?	1
• 'Where' is the chaos?	1
• 'When' is it SUSY?	1
• Borderline...	1

- Quantum gravitational corrections;
- Applying it to minisuperspaces:
 - ◆ Determine which type of "effective" QFT
 - ◆ Any shift in $\langle E \rangle \Leftarrow$ SQC?
- Breakdown of the classical background picture
 - ◆ Probing superspace \Leftarrow classical solution
 - ◆ Revealing the back reaction effects (graviton and gravitino loops and vertices)



Borderline...

Introduction	
String Landscape	
Chaos-Order transition	
Semiclassical SQC	
Other <i>Horizons</i>	
● 'The' Frontier	
● 'What' is the Landscape?	
● 'Where' is the chaos?	
● 'When' is it SUSY?	
● Borderline...	

“In order to draw a limit to thinking, we should have to think both sides of this limit.”

Ludwig Wittgenstein