Daniel Panizo | Statement of Purpose

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Recent research activity: Blowing bubbles to escape from the swamp

The swamp is a cold place, fill with mud, mosquitos and dangers everywhere you step on. Unfortunately, it seems that our understanding of cosmology from a string theory perspective lies in a sludgy puddle of these lands. Is there any way we can make that knowledge escape to better grounds? Unraveling around this question has been my main interest during my Ph.D. studies.

Although the last decade has resulted in great progress towards the construction of realistic models of cosmology from string theory, there are some major issues that remain. To build models where all moduli are stabilised, equipped with scale separation and a small and possitive cosmological constant (CC) is still an unsolved problem [1]. Concurrently, based on the evidence pointing to the fact that less than expected low dimensional effective field theories (EFT) could be obtained from quantum gravity, the **swampland** program was created [2]. One of the most striking conclusions that may be drawn from this criteria is that de Sitter (dS) cosmology may belong to the swampland.

At this point, one question has to be raised: Is there any way to scape from the swampland? An alternative mechanism to **flux compactification** is **braneworld** cosmology. My Ph.D. research has been devoted to develop a braneworld model, which makes use of swampland constrains, i.e. the Weak Gravity Conjecture (WGC), as its foundation. This model is known as **dark bubble** cosmology [3].

In simple grounds, this model is the realisation of an **induced** four dimensional dS cosmology living on a three spatial dimension brane. This mediates the decay of a five dimensional true vacuum that has **nucleated** inside a false one. The region of vacuum emcompased by the brane is colloquially called **bubble**, which will nucleate at rest and finite size, as a **Brown-Teitelboim** instanton. If the bubble nucleates with a subcritical tension, it will then start to expand. The value disagreement between the tensions of the bounce solution (i.e. critical) and the nucleated bubble can be interpreted as a positive CC on the induced cosmology, giving name to the model; Four dimensional **dark energy** is no more than a dynamical property of a higher dimensional expanding bubble. Together with my supervisor, Ulf Danielsson, Thomas van Riet and other collaborators, I have also explored how the brane **backreacts** on the bulk geometry, which in turn affects the induced effective gravity and energy-momentum tensor on the first, resulting in familiar energy densities decorating the induced cosmology, such as gravitational and electromagnetic radiation [4, 5]. **Gauss-Codazzi** equations are the dictionary to understand how gravity, extending along the bulk, dictates how the aforementioned and brane relate one another.

The derivation of a complete **top-down** construction of the dark bubble model from string theory has been the greatest achievement of my Ph.D. scientific production [6]. In this set-up, the ten dimensional background consists of a stack of D3 branes with angular momentum and **near horizon** limit description as $AdS_5 \times S^5$. **Supersymmetry** is broken due to non-zero temperature and a large chemical potential in the $\mathcal{N} = 4$ Yang-Mills dual description, pointing to an instability that will eventually cause the nucleation of a bubble (which can be identified with the creation event in Vilenkin **quantum cosmology** [7]). This corresponds to the creation of an induced four dimensional cosmology as the brane emerges after tunneling through the potential barrier and begins to expand. Corrections to the DBI action governing the motion of the expanding brane will yield an effective positive, yet small CC in the induced cosmology. This whole construction comes also equipped with a novel energy scale hierarchy [8], where **scale separation** is implemented via tension-to-charge ratio of the expanding brane, rather than small extra dimensions.

Future research

In the near future, I would like to continue researching on phenomenological implications on low dimensional EFT's that can be obtained from string theory. There are two main research territories that I would like to immediately adventure in after obtaining my Ph.D.

The dark bubble formalism is a compelling novel alternative framework that can evade the most prominent issues discussed above when constructing realistic models of cosmology from string theory. This model provides a new paradigm for string phenomenology, with plenty of puzzles still to delve into. For example, one of the most important tasks within dark bubble cosmology would be to understand the uplift of the **standard model** of particle physics into the higher dimensions. This is a highly non-trivial task, which would involve a rigorous study on the dynamics of branes in the compact dimensions of S^5 and strings stretching between them, giving rise to massive sectors in the expanding cosmology. Another bubble aspect that I would like to study is the embedding of the dark bubble in different **supergravity** backgrounds. This analysis would provide further insights about the key features of the model and enhance our understanding towards a more general top-down construction for it.

It is remarkable that, althought the swampland program started as a formal identification of universality properties of consistent quantum gravitational theories, it has spread towards phenomenological aspects in contact with observations over the years. These consistency requirements are challenging our **Naturalness** concept, pointing to the need of constructing EFT's that are sensitive to changes in its ultraviolet (UV) completion. An area that I would like to potentially investigate is how the Swampland Distance Conjecture (SDC) and the WGC affect the inflation mechanism, imposing severe constraints in its derivation from quantum gravity. These restrictions, together with enhanced observational data, may provide insights about the unknown early universe. It is also worth considering the interplay between dark energy, dark matter and the extra mesoscopic **dark dimension** proposed in [9]. This new scenario can shed some light on our comprehension of the dark sector, given the suggested relation between fundamental interactions in our brane and its embedding in bulk space.

References

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