A4: Dark matter in Randall-Sundrum brane cosmology

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1. Overview

• The Randall-Sundrum model explains the gauge hierarchy by two branes in a curved 5-dimensional space (AdS_5) which are stabilized in such a way that one of them defines the scale of gravity (Planck brane) while the other defines the Fermi scale (TeV brane). These models arise naturally in string-theory, where they correspond to the strongly warped regions ("throats") of 10d flux compactifications.

• In this project, it is planned to develop our understanding of the early cosmology in realistic Randall-Sundrum models. We will focus on the identification of dark matter candidates and the understanding of the high-temperature dynamics determining their abundance. In this context, it will be crucial to bring together the 5d Randall-Sundrum language and the language of the 10d warped geometries, the latter being presumably most relevant at the high energy scales governing the early universe.

• From a broader perspective, throat geometries are a generic feature of the string theory landscape. Thus, they have to be analysed in the context of the ongoing effort to understand the origin of the universe and early cosmology within this new paradigm.

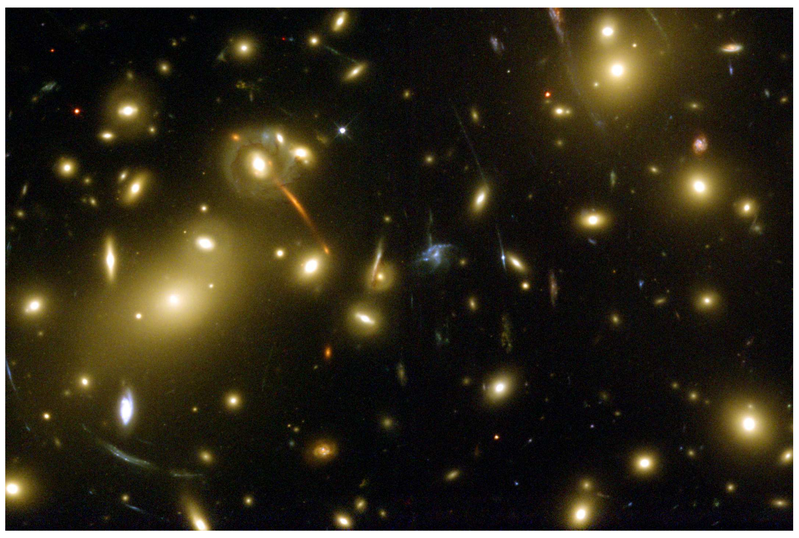

FIGURE 1: *Gravitational lensing is a direct test of dark matter (©NASA, ESA, R. Ellis and J.-P. Kneib)*

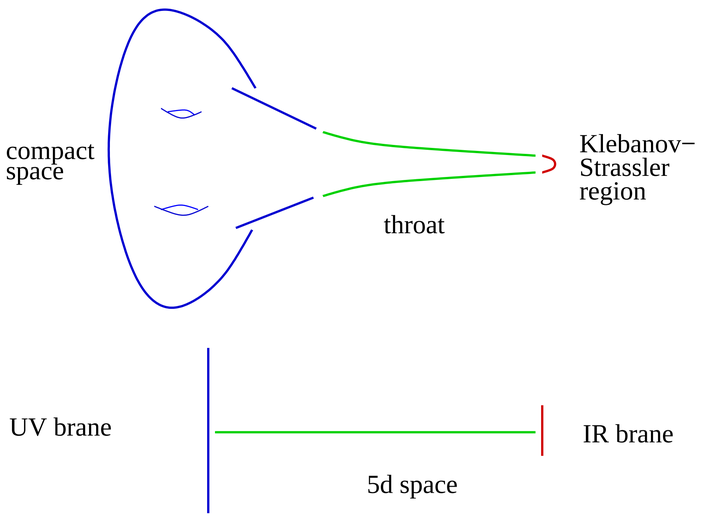

FIGURE 2: *Type IIB throat geometries and their 5d interpretation*

2. State of the art

• Modern Randall-Sundrum models includes bulk fermions and a Higgs particle that is a Pseudo-Goldstone-Boson, accommodate Grand Unification, and naturally solve flavour problems (see, e.g., [K. Agashe et al., JHEP **0308** (2003) 050]). On this basis, detailed cosmological questions, including in particular dark matter features, can now be addressed [K. Agashe and G. Servant, JCAP **0502** (2005) 002].

• The high scale cosmology is very unusual since, at non-zero temperature, the Planck brane radiates gravitons leading to the formation of a bulk black hole [A. Hebecker and J. March-Russell, Nucl. Phys. B **608** (2001) 375]. A first-order phase transition is expected in the process of the cooling and expansion of the universe during which the TeV brane would have to be 're-created' and replace the black hole horizon [P. Creminelli, A. Nicolis and R. Rattazzi, JHEP **0203** (2002) 051].

• During the past year, our main interest was the relation between the throat region of flux compactifications and the stabilized 5d Randall-Sundrum model. It has been understood that the throats can be viewed, from the 5d perspective, as Randall-Sundrum models with Goldberger-Wise stabilization [F. Brümmer, A. Hebecker and E. Trincherini, hep-th/0510113, to appear in Nucl. Phys. B.]

3. Goals and methods

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• Firstly, given that the generic presence of strongly warped regions (throats) in flux compactifications is an important fundamental reason to take Randall-Sundrum models seriously, it is crucial to establish Randall-Sundrum dark matter predictions in this more fundamental context.

• Secondly, given such a more fundamental underpinning, it is necessary to revisit the preliminary analysis of the high-temperature phase of such models and to analyse the influence of the corresponding phase transition on late cosmology and, in particular, dark matter abundance.

• The methods are those of string- and field-theoretic model building as well as the more recently developed techniques of analysing the phenomenology of throat compactifications (see e.g. [S. B. Giddings and A. Maharana, arXiv:hep-th/0507158]). In particular, we will include warped models without standard model gauge fields in the bulk (since those may be preferred from the string-theoretic perspective) into the analysis. Furthermore, recently raised fundamental objections to warped cosmological models (possible overclosure by Kaluza-Klein modes, cf. [L. Kofman and P. Yi, arXiv:hep-th/0507257]) will have to be addressed.

• A further goal is an embedding of the late phase in a more complete framework, including the (phenomenologically-preferred) post-inflationary reheating to a high temperature, the cooling through the first-order phase transition and the subsequent relaxation to a more conventional late-time cosmology. The most important challenge of the corresponding research program is the development of a qualitative and quantitative understanding of the phase transition process, including in particular the radion dynamics in the strongly-coupled, non-linear regime. Almost certainly, the full 10d warped dynamics will be relevant in the high-temperature phase of the Randall-Sundrum model and during the corresponding phase transition.

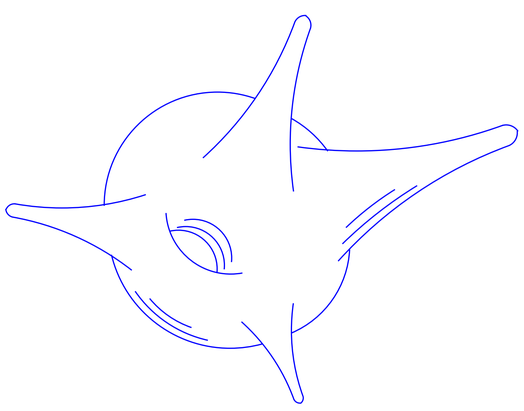

FIGURE 3: *Multi-throat geometries may be generic*

4. Further ideas

• The claim that throat geometries are generically present in the string-theory landsape has to be put on a firm quantiative basis. This may require a statistical analysis of the presence of throats in Calabi-Yau compactifications with many 3-cycles. There is good reason to believe that multi-throat situations are common.

• Furthermore, even if the Planck-scale weak-scale hierarchy is not related to strong warping, throat geometries may be important for and experimentally testable by cosmology. Even if the standard model is realized in the 'compact space' (i.e. on the UV brane), light particles originating from throat regions can be produced in the early universe and may, for example, provide natural dark matter candidates.

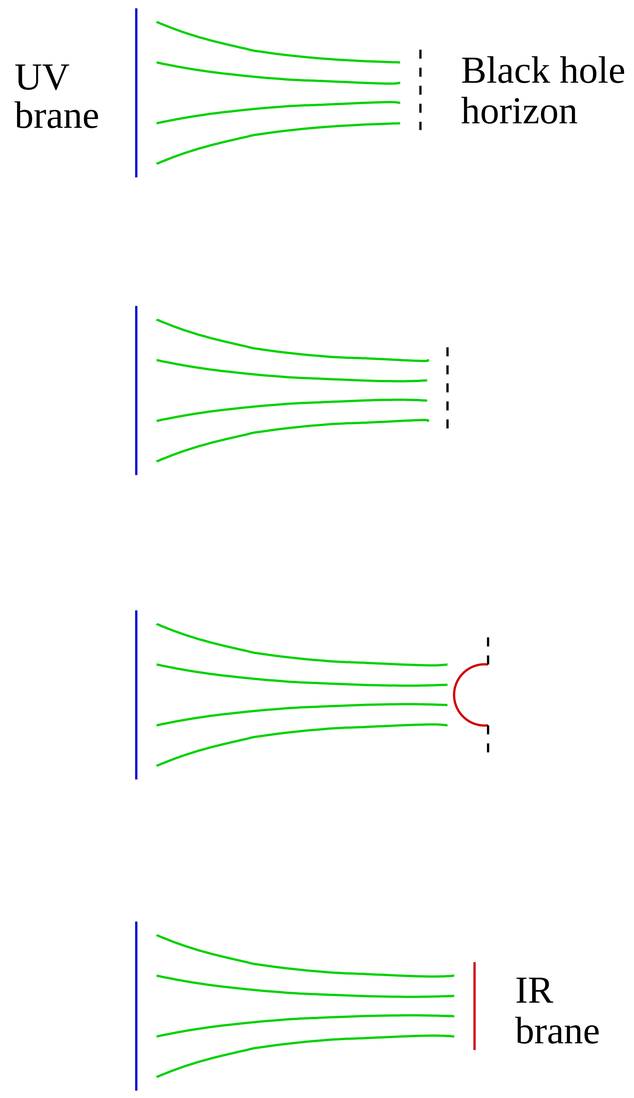

FIGURE 4: *Phase transition*