The Swampland Distance Conjecture

Subjects: Physics, Particles & Fields

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The Swampland Distance Conjecture (SDC) is one of the most studied and well-established Swampland Conjetures, and it introduces an omnipresent feature in effective field theories (EFTs) of quantum gravity, namely the appearance of infinite towers of states that become light an imply a breakdown of the EFT in the infinite distance limits in moduli space. In this entry we present the conjecture, a simple example and some comments on relations to other conjectures.

Keywords: quantum gravity ; low energy effective theories ; particle physics

1. Introduction

Recent years have seen the emergence of a new picture, or rather, a new paradigm, of quantum gravity. It has become clear that certain low energy theories that seem consistent from several points of view (such as e.g. anomaly cancellation) cannot be coupled to quantum gravity in a consistent way. The low-energy theories that cannot be consistently coupled to gravity are said to belong to the swampland[1] (see also the reviews [2][3][4][5]). The general conditions that low energy theories that do not belong to the swampland (i.e. that can be consistently completed to quantum gravity) must fulfil are often formulated in terms of conjectures, which are usually referred to as Swampland Conjectures. One of the most studied and well-stablished Swampland Conjectures is the Swampland Distance Conjecture, which states the following:

2. The Swampland Conjectures

The Swampland Distance Conjecture (SDC):[6] Consider a gravitational effective theory with a moduli space (i.e. a space parameterized by the massless scalar fields in the theory) and whose metric is given by the kinetic terms of the scalar fields. Starting from a point P in moduli space and moving towards a point Q an infinite geodesic distance away (i.e. $d(P,Q)\to\infty$), one encounters an infinite tower of states which become exponentially massless with the geodesic distance, i.e.

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with α an order one constant in Planck units.

To give some intuition about the Swampland Distance Conjecture, let us consider the canonical example, namely a theory compactified on a circle of size R. It is well known that the Kaluza-Klein (KK) modes in such a circle compactification have a mass that scales with the internal radius as

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After dimensional reduction of the gravitational piece of the action and the corresponding field redefinition to go to the Einstein-frame, the kinetic term for the radion field R takes the form $\mathcal{L}_{\text{kin}} \sim \frac{\partial_M R\,\partial^M R}{R^2}$. The distance between two points, R_i and R_f in field space is therefore measured by the field space metric, given by $1/R^2$, and it yields

$$d\left(R_i, R_f\right) = \int_{R_i}^{R_f} \sqrt{\tfrac{1}{R^2}}\, dR = \left|\log\left(R_f/R_i\right)\right|. \quad (3)$$

Therefore, starting at any finite radius, there are two points that lie at infinite proper distance, namely $R\to\infty$ and $R\to 0$. Approaching the former it is clear that rewriting the KK tower masses given by eq. (2) one obtains precisely the behaviour predicted by the Swampland Distance Conjecture, namely

$$m_n \sim e^{-d(R_i, R_f\to\infty)}\,. \quad (4)$$

On the other hand, approaching the infinite distance point $R \to 0$, one could be tempted to say that the Swampland Distance Conjecture is violated. However, this is not the case in string theory, which includes an infinite tower of winding states with masses given by

$$m_w^2 = \frac{w^2 R^2}{(\alpha')^2}\,. \quad (5)$$

These become exponentially light in terms of the field-space distance d as $R \to 0$ limit. Hence, string theory provides a natural candidate for the tower in the two possible infinite distance limits, as required by the SDC. In fact, this also suggests a fundamental connection between the SDC and the existence of extended objects in quantum gravity, as the winding states only appear when strings are considered.

The Swampland Distance Conjecture can be understood as a restriction on the range of validity of any effective field theory (EFT) coupled to gravity, in the sense that an EFT defined at a point in moduli space cannot be extended to a point which is at an arbitrarily large distance from the initial one. If one tried to do so, an infinite number of light degrees of freedom would become light and break the aforementioned EFT description. As in all swampland conjectures, this is to be compared to the situation in which gravity is not present, in which no obstruction to the extension of an EFT to an arbitrary point in moduli space appears. A neat microscopic interpretation for the Swampland Distance Conjecture is not fully clear at the moment, but it is strongly inspired by dualities in string theory. In the KK example above this picture is indeed realized by T-duality. Along these lines, it has also been conjectured that every infinite distance limit actually corresponds to either a decompactification limit or a string becoming tensionless.[7][8]

The aforementioned towers, whose energy scale is related to the breaking of the EFT, fit very naturally with the picture presented by the Weak Gravity Conjecture,[9] particularly with its magnetic version. This is the case because weak coupling points are generally at infinite distance in moduli space. The lower and lower cutoff scale predicted by the magnetic Weak Gravity Conjecture as we approach those limits may then be associated with the presence of a tower of states, which actually motivated the proposal of the so-called tower versions of the Weak Gravity Conjecture. These are the (Sub)lattice Weak Gravity Conjecture,[10][11] which requires the existence of a superextremal particle at every point in a (sub)lattice of the lattice of charges, and the Tower Weak Gravity Conjecture,[12] which predicts the existence of an infinite number of superextremal particles, not necessarily populating a sublattice. In fact, It is well known that in many examples in string theory, the states in the tower that satisfy the Swampland Distance Conjecture are also the states that satisfy tower versions of the Weak Gravity Conjecture. The possibility of this being a result of the restoration of a global symmetry at every infinite distance point has also been suggested.[13][14] This is indeed the case in the circle compactification example presented above, where the tower of KK states are charged under the U(1) graviphoton and saturate the Weak Gravity Conjecture bound. Moreover, the winding modes are charged under the 1-form coming from the reduction of the B-field along the circle, and they also saturate the Weak Gravity Conjecture inequality.

References

1. Vafa, C. The String landscape and the swampland. arXiv 2005, arXiv:hep-th/0509212.
2. Brennan, T.D.; Carta, F.; Vafa, C. The String Landscape, the Swampland, and the Missing Corner. PoS 2017, TASI2017, 15.
3. Palti, E. The Swampland: Introduction and Review. Fortsch. Phys. 2019, 67, 1900037.
4. Van Beest, M.; Calderón-Infante, J.; Mirfendereski, D.; Valenzuela, I. Lectures on the Swampland Program in String Compactifications. arXiv 2021, arXiv:2102.01111.
5. Graña, M.; Herraez, A. The Swampland Conjectures: A bridge from Quantum Gravity to Particle Physics. Universe. 2021; 7(8):273. arXiv:2107.00087
6. Ooguri, H.; Vafa, C. On the Geometry of the String Landscape and the Swampland. Nucl. Phys. B 2007, 766, 21–33.
7. Lee, S.-J.; Lerche, W.; Weigand, T. Emergent Strings, Duality and Weak Coupling Limits for Two-Form Fields.arXiv:1904.06344
8. Lee, S.-J.; Lerche, W.; Weigand, T. Emergent Strings from Infinite Distance Limits. arXiv:1910.01135
9. Arkani-Hamed, N.; Motl, L.; Nicolis, A.; Vafa, C. The String landscape, black holes and gravity as the weakest force. J. High Energy Phys. 2007, 6, 60.

10. Heidenreich, B.; Reece, M.; Rudelius, T. Sharpening the Weak Gravity Conjecture with Dimensional Reduction.JHEP 02 (2016) 140.arXiv:1509.06374
11. Heidenreich, B.; Reece, M.; Rudelius, T. Evidence for a sublattice weak gravityconjecture.JHEP 08 (2017) 025.arXiv:1606.08437
12. Andriolo, S.; Junghans, D.; Noumi, T.; Shiu, G. A Tower Weak Gravity Conjecture from Infrared Consistency. Fortschritte der Physik 2018, 66
13. Grimm, T. W.; Palti, E.; Valenzuela, I. Infinite distances in field space and massless towers of states. Journal of High Energy Physics 2018, 143.
14. Gendler, N.; Valenzuela, I.Merging the weak gravity and distance conjectures using BPS extremal black holes. Journal of High Energy Physics 2021, 2021, 1