Strong coupling in string theory: physical irrelevance beyond low-energy supersymmetry

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Abstract

We examine the three principal strands of the strong-coupling program in string theory developed during the 1990s—S-duality, M-theory, and F-theory—and show that their most controlled formulations rely on supersymmetric regimes, typically involving unbroken supersymmetry at low energies. These results are obtained within narrow, highly constrained corners governed by supersymmetry. In the absence of experimental support for low-energy supersymmetry in the post-Large Hadron Collider era, the physical relevance of these regimes remains unsubstantiated. Without this structure, the computational control underlying the program is lost. It then follows that the central achievements of these frameworks lack a demonstrated connection to real-world physics.

Date: May 6, 2026

Contents

1 Introduction

The central theme of this paper is to assess the strong-coupling program in string theory. This program has three main strands. Strong coupling was investigated within the framework of string theory primarily during the 1990s, when major advancements were claimed, most notably in S-duality, M-theory [1, 2], and F-theory [3, 4, 5]. We focus on these three frameworks in this work.

The strong-coupling program in string theory relies crucially on supersymmetry: its explicit control is established only in regimes with supersymmetry. However, experimental results from the Large Hadron Collider (LHC) have placed strong constraints on low-energy supersymmetry, excluding it up to the TeV scale.

For the strong coupling program in string theory to be applicable to real-world physics, since no controlled extension is known once supersymmetry is broken beyond the accessible energy scale, supersymmetry is required to be present at low energies. Therefore, for the three frameworks to apply to real-world physics at accessible energy scales, they inherently rely on low-energy supersymmetry.

No controlled mechanism in these frameworks is known that connects supersymmetric regimes—where calculability is achieved—to non-supersymmetric regimes relevant for observed low-energy physics.

While control over strong coupling in S-duality, M-theory, and F-theory is restricted to narrow, highly constrained regimes defined by supersymmetry at low energies, these limited corners are not supported by experiment. This means that the regimes on which these frameworks inherently rely are not realized as descriptions of observed low-energy physics.

In the post-LHC era, these restricted corners defined by low-energy supersymmetry are experimentally disfavored as descriptions of observed low-energy physics. In this work, we clarify the physical implications of this fact for the strong-coupling program.

String theory does not provide a controlled definition of a non-supersymmetric, strongly coupled quantum gravitational theory in four dimensions. The non-detection of supersymmetry at the LHC therefore challenges the claimed control over strong coupling in string theory, a point that poses a serious challenge to this program.

While string dualities require supersymmetry, LHC results have effectively ruled out low-energy supersymmetric realizations, as viable descriptions of observed low-energy physics, of the string dualities emphasized in the 1990s. From an effective field theory viewpoint, they map physically irrelevant regimes—i.e., those not realized in experimentally accessible conditions and lacking empirical support—to one another. Control over strong coupling in string theory requires supersymmetry and is therefore not generic. M-theory has not been formulated as a complete, nonperturbative theory. F-theory has not provided a framework for computing dynamical observables.

Historically advertised "nonperturbative triumphs" collapse once supersymmetry is removed.

This paper does not dispute the correctness of the duality results in string theory developed during the 1990s. Rather, it disputes their interpretation as solutions to strong coupling in physically relevant regimes and their applicability to them. This work evaluates the physical relevance of nonperturbative results and strong-coupling claims in string theory from this period in light of the absence of supersymmetry at accessible energy scales.

This paper is structured as follows: In Section 2, we outline minimal standards for what it means for strong coupling to be under control. In Section 3, we assess strong-coupling control in the S-duality framework. The Seiberg–Witten (SW) curve [6, 7] is discussed in this section, as its inclusion strengthens the credibility of the argument. Sections 4 and 5 examine the M-theory and F-theory frameworks, respectively. Section 6 presents a summary of these assessments; however, it goes beyond a summary by identifying common patterns across the three frameworks. A brief comment on the anti-de Sitter/conformal field theory (AdS/CFT) correspondence [8] is included in Section 6 to clarify that the structural limitations identified here persist even in later developments. Structural issues in string theory have been identified in [9, 10]. The relation between those discussions and the present work is discussed in Section 7. The issues discussed in this paper are independent of those in [9, 10]. Our concluding remarks are presented in Section 8.

2 Standards on the control of strong coupling

2.1 Minimal criteria for strong-coupling control

For strong coupling to be considered *controlled* within the framework of string theory, at a minimum the following conditions must be satisfied:

- Access to non-Bogomol'nyi–Prasad–Sommerfield (non-BPS) observables.
- Dynamical mass scales.
- A vacuum selection mechanism.
- Stability under supersymmetry breaking.

In particular, there must exist a theoretical description of supersymmetry breaking and its consequences for observables previously protected by supersymmetry. Moreover, string theory admits a vast multiplicity of vacua—the so-called string theoretic landscape. Absent a physical vacuum selection mechanism, strong coupling is merely distributed across an ensemble of possibilities; in that case, it is not controlled in any meaningful sense.

2.2 Supersymmetry-protected quantities vs. dynamics

BPS states, supersymmetric indices, and holomorphic quantities are protected by supersymmetry. The exact results obtained in string theory overwhelmingly concern such protected quantities. As such, they fail to satisfy the minimal criteria listed in Section 2.1. Therefore, exact results restricted to supersymmetry-protected sectors do not constitute control over strong-coupling dynamics.

The criteria listed in Section 2.1 make explicit that control restricted to supersymmetry-protected sectors does not constitute control over strong-coupling dynamics in any physically relevant sense. In particular, any framework whose computational basis depends on low-energy supersymmetry is, by construction, confined to a highly restricted, nongeneric corner. It will be shown in subsequent sections that the principal nonperturbative frameworks in string theory—S-duality, M-theory, and F-theory—operate precisely within such restricted regimes.

3 S-duality

The "strong coupling" program pursued in string theory in the 1990s was, in reality, sharply restricted in scope. Its principal outputs include S-duality in maximally supersymmetric theories, exact results primarily for $\mathcal{N} = 4$ Super Yang–Mills (SYM) theory, BPS-protected quantities, certain supersymmetric black hole entropies, and highly constrained supersymmetric vacua. These results are computational achievements enabled by symmetry—specifically, cancellations enforced by extended supersymmetry. They are not solutions to dynamical strong-coupling problems.

What these computations demonstrate is that certain observables are coupling-independent. What they do *not* provide is a method for computing generic strongly coupled dynamics, nor do they provide a framework for treating supersymmetry breaking. They also do not provide a controlled or direct description of real-world quantum field theory (QFT).

All such results rely on BPS protection, holomorphy, and non-renormalization theorems. Once supersymmetry is absent—whether fundamentally or through breaking—duality lacks a controlled realization and becomes conjectural in practice, moduli spaces are typically lifted, removing the structures that enable exact control, and previously controlled computations lose computational control and become conjectural. The LHC did not merely fail to detect supersymmetry; it removed empirical support for treating the regime in which these results are calculationally controlled, as a description of observed low-energy physics.

Strong-coupling control has not been established beyond supersymmetry-protected sectors. The loss of experimental support for low-energy supersymmetry eliminates the calculability that was advertised in the 1990s.

The strong-coupling control in the S-duality framework is indeed a projection onto a supersymmetry-protected subsector, identifying invariants that are preserved by the symmetry.

Moreover, duality is not a solution to dynamical problems; it is a structural equivalence. A theory must be defined independently of such equivalence. Without supersymmetry, S-duality does not yield computable observables or dynamical information. Duality provides equivalences between descriptions but does not, by itself, yield access to generic dynamical observables.

S-duality probes only highly constrained corners in which supersymmetry is present and operative. Outside these narrow domains, it does not provide a general computational or predictive framework for strongly coupled dynamics. These corners are precisely those rendered physically irrelevant by experimental constraints: either they do not exist in nature as descriptions of observed low-energy physics, or they are inaccessible in any meaningful sense.

The celebrated "duality miracles" depend on symmetries not realized in nature.

The absence of low-energy supersymmetry removes empirical support for their claimed physical relevance to observed low-energy physics.

What was presented as a solution to strong coupling in string theory applies only to artificially restricted corners in which dynamical complexity is suppressed by symmetry.

In the post-LHC context, where low-energy supersymmetry is, for all practical purposes, no longer a viable description of observed low-energy physics, results based on S-duality and Seiberg–Witten theory must be regarded as mathematical structures rather than physically applicable frameworks.

What was advertised as solving strong coupling does not provide a controlled description of physically realized QFT.

The essential limitation is therefore structural: S-duality provides control over strong coupling only within a narrow corner defined by unbroken low-energy supersymmetry. Outside this regime, it does not provide computable dynamics. The regime in which it functions is precisely the one that lacks experimental support as a description of real physics.

In summary, "strong coupling" in string theory was never generic. The results of the 1990s are exact only in maximally supersymmetric settings, within BPS-protected or topological sectors. They provide no control over dynamical mass generation, confinement without supersymmetry, chiral symmetry breaking, or vacuum selection. The term itself is therefore misleading: it refers to strong coupling under maximal symmetry protection, not strong coupling in realistic QFT.

Supersymmetry is not a technical detail—it is the entire mechanism enabling these results. All nonperturbative claims in string theory from this period depend on holomorphy, BPS saturation, non-renormalization theorems, or flat moduli spaces. Once supersymmetry is absent at low energies, dualities lose computational meaning and moduli stabilization becomes intractable. The experimental non-detection of supersymmetry does not merely constrain models; the applicability of these strong-coupling claims as descriptions of observed low-energy physics is no longer credible.

Historically, S-duality emerged as an extension of Montonen–Olive duality [11], where representative works include [6, 7, 12]. Its central claims included access to nonperturbative information, control over confinement, mass gaps, or infrared (IR) physics, and a paradigm for strong coupling. In practice, all such claims depend indispensably on extended supersymmetry. The results compute protected invariants, not dynamics.

They do not realize confinement without supersymmetry, nor do they address scattering amplitudes, real-time observables, and chiral gauge theories. They do not provide a controlled connection to real-world QFT.

SW theory does not compute strong-coupling dynamics; it determines exact moduli-space geometry that is protected from dynamical corrections.

While duality formally maps strong to weak coupling, its formulation requires supersymmetry on both sides. Without it, the dual description lacks a controlled or well-defined formulation. Thus, the duality framework itself ceases to provide known computational control without low-energy supersymmetry.

S-duality is therefore confined to a narrow corner requiring low-energy supersymmetry. This regime has been excluded as a description of observed low-energy physics in minimal low-energy realizations probed to date, while the remaining non-minimal possibilities lack empirical support. In the post-LHC context, the claim that S-duality has direct physical applicability to observed low-energy physics is no longer credible.

The Seiberg–Witten solution is frequently presented as a realization of strong coupling control via duality. Even this case already exhibits the limitation: the construction achieves exact results only by restricting to the holomorphic, supersymmetric, BPS-protected infrared sector, leaving generic observables inaccessible and providing no non-BPS sector. Thus, what is controlled is not strong coupling itself, but a projection onto nongeneric subsectors that are insensitive to it.

Analogous duality statements in extended supersymmetric gauge theories, such as BPS monopoles and dyons, likewise rely on BPS-protected spectra, reinforcing that strong coupling control is restricted to special sectors.

4 M-theory

M-theory is often described as the strong-coupling limit of type IIA superstring theory, unifying all string theories and providing a nonperturbative definition "in principle."

In practice, it lacks a defining structure: no action, no Hilbert space, no well-defined observables, and crucially, no formulation beyond its low-energy limit. It is not a fully defined theory in any conventional sense; rather, it is a conjectural framework lacking a nonperturbative definition. In this sense, it has not been formulated as a fully defined nonperturbative theory.

What is controlled is only eleven-dimensional (11D) supergravity at low energies, along with BPS states and index-like quantities. The full quantum theory remains undefined. Strong-coupling dynamics, particularly in non-supersymmetric backgrounds, are not under control.

M-theory lacks a complete nonperturbative definition, and where partial control is available, it is confined to supersymmetric low-energy regimes.

Taking a strong-coupling limit that eliminates the expansion parameter does not solve the problem of strong coupling—it removes the computational framework altogether.

Even where speculative constructions exist, calculability is confined to supersymmetric, low-energy corners. Brane-based computations do not escape this limitation. These are precisely the regimes excluded as, for all practical purposes, viable descriptions of observed low-energy physics, by experiment.

As in the case of S-duality as discussed in Section 3, the region where computational control exists is limited to highly restricted corners characterized by unbroken supersymmetry at low energies. Outside these regimes, neither a definition of the theory nor control over its dynamics is available. Therefore, the apparent access to strong coupling arises only within these narrow and nongeneric corners.

These analyses leave no choice but to conclude that the domain in which M-theory is computationally controlled is physically irrelevant as a description of observed low-energy physics.

The status of M-theory as a nonperturbative completion is concrete and explicit in restricted formulations such as matrix theory [13], where a nonperturbative definition exists only in specific limits relying crucially on supersymmetry. Outside these restricted corners, M-theory is primarily characterized by a web of dualities rather than by an intrinsic formulation. M-theory defines strong coupling only in restricted regimes even in its most explicit formulation: strong coupling is accessed only indirectly through relations between special limits, rather than by a standalone complete dynamical definition. There is no controlled access to generic strongly coupled dynamics within the M-theory framework.

5 F-theory

F-theory was proposed as a nonperturbative extension of type IIB superstring theory incorporating S-duality geometrically. However, it lacks a defining structure: no action, no path integral, no amplitudes, and no Hilbert space.

Its central construction, where the theory is compactified on an elliptic fibration, identifies axiodilaton $C_0 + ie^{-\phi}$ with the modular parameter of an elliptic fiber. This replaces the problem of strong coupling with a geometric encoding of coupling variation. This is not a solution—it is a reformulation that halts at the geometric level.

This construction depends critically on supersymmetry. The identification of the axiodilaton with the modular parameter of an elliptic fiber holds only in supersymmetric backgrounds. Holomorphicity enables the compactification space to be viewed as a complex manifold and algebro-geometric methods applied to F-theory; without supersymmetry, this structure ceases to apply. The physical interpretation of the underlying complex and algebro-geometric structures relies on supersymmetry. Without it, the use of holomorphicity and complex analytic structure loses its physical justification and computational control. The compactification space can no longer be treated as a complex manifold and the algebro-geometric framework loses applicability to physics.

The central phenomenological claims of F-theory rely on a geometry-physics correspondence: elliptic fibrations encoding gauge groups, matter representations, and Yukawa couplings. This correspondence is meaningful only within supersymmetric low-energy effective theories.

Outside this narrow corner, F-theory loses interpretative control.

Since this regime is experimentally excluded as viable descriptions of observed low-energy physics, given the absence of a controlled extension to non-supersymmetric regimes, this leaves us no choice but to conclude that the framework's claimed connection to real physics at observable low energies effectively fails.

F-theory does not provide dynamical control over strong coupling. It renders it tractable by restricting to non-dynamical backgrounds. Without supersymmetry, there is no BPS protection, no justification for the axiodilaton identification with an elliptic fiber, and no physically controlled derivation or protection of the geometric dictionary relating ADE singularities to gauge structures.

What remains is nonperturbative silence.

The pattern of structural issues is essentially identical to those in S-duality and M-theory as discussed in Sections 3 and 4: apparent control of the framework is achieved only within a narrow corner of backgrounds with unbroken supersymmetry at low energies where holomorphic structures in the geometry remain intact and the geometry-physics correspondence is available. Outside this restricted regime, the correspondence between physics and geometry breaks down and any claim to control over strong coupling collapses. Thus, F-theory does not extend strong-coupling control beyond the limited corner of the same type as those in S-duality and M-theory.

F-theory functions as a geometric bookkeeping device, assigning physical labels to geometric structures within a restricted supersymmetric corner at low energies. That regime is physically irrelevant.

Calling F-theory "nonperturbative" in the sense of providing dynamical control is therefore a category error.

F-theory construction via S-folds led to four-dimensional (4D) $\mathcal{N} = 3$ superconformal field theories (SCFTs) [14]. The resulting 4D $\mathcal{N} = 3$ SCFTs are intrinsically strongly coupled by construction, typically lacking a Lagrangian description. The field theories are defined by duality and rigid consistency constraints, i.e., they exist without an explicit and concrete construction. The coupling is encoded in the underlying geometry, not derived. In this sense, the F-theoretic geometry replaces the dynamics of strong coupling. Furthermore, $\mathcal{N} = 3$ supersymmetry in four dimensions is extremely rigid. The theory is controllable because it is highly constrained by algebraic constraints, and not because strong coupling is understood.

The 4D $\mathcal{N} = 3$ constraints expose the endpoint of the F-theory program: strong coupling is rendered inaccessible except through imposed symmetry and resulting consistency constraints rather than being addressed in its full dynamical generality. This example demonstrates that the issue discussed here is structural, not accidental.

6 The collapse of applicability under experimental constraints

In string theory, supersymmetry is not derived; it is imposed to enable calculability. It is a structural assumption.

Without supersymmetry, protected quantities disappear, moduli spaces are lifted, and dual descriptions break down. The nonperturbative results of the 1990s—S-duality, M-theory, and F-theory—depend entirely on supersymmetry at low energies.

Key constructions, such as the identification of the axiodilaton with an elliptic fiber and the geometry-physics correspondence, such as the dictionary between ADE singularities and (non-Abelian) gauge groups, are valid only in supersymmetric settings. Without supersymmetry at low energies, these frameworks in F-theory collapse.

All three frameworks—S-duality, M-theory, and F-theory—share the identical structural limitation: their computational control over strong coupling is limited to narrow corners defined by low-energy supersymmetry, and does not extend beyond these limited corners.

All nonperturbative results operate within narrow, highly constrained supersymmetric corners. These regimes have been excluded as, for all practical purposes, viable descriptions of observed low-energy physics by LHC experiments. In the post-LHC era, these corners are "cut down" as unphysical, unrealistic.

The consequence is direct: the experimental absence of low-energy supersymmetry rules out the applicability of string theory's strong-coupling results to observed low-energy physics.

Strong-coupling control never extended beyond supersymmetry-protected sectors. Those sectors are now experimentally disfavored.

The loss of exact nonperturbative control provided by supersymmetry entails the loss of calculability in nonperturbative aspects.

Moreover, it must be emphasized that across all three frameworks, S-duality, M-theory, and F-theory, strong-coupling control means control of quantities that are themselves highly constrained in nature so they do not provide fully generic features of strong coupling.

What is controlled in these frameworks is: BPS invariants in S-duality, supersymmetric sectors in M-theory, and holomorphic and geometric data in F-theory. In each framework, strong coupling is not directly controlled; rather, it is rendered tractable by restricting to sectors where its effects are either invariant, suppressed, or encoded. More general quantities such as generic spectra, thermal physics, and nonequilibrium behaviors are not controlled.

Therefore, the strong-coupling program in string theory is rendered tractable by systematically restricting to protected sectors rather than being addressed in its full dynamical generality.

One might attempt to evade this conclusion by appealing to the AdS/CFT correspondence, which provides a nonperturbative definition of certain strongly coupled QFTs. However, this framework does not escape the structural limitation identified here. Its formulation relies on highly constrained settings—typically involving exact conformal symmetry, large N limits, and, in its most controlled realizations, supersymmetry.

Outside these restricted regimes, no controlled extension is known that maintains calculability while relaxing these assumptions. In particular, once supersymmetry or exact conformal symmetry is broken, the correspondence ceases to provide a framework with established computational control over generic strongly coupled dynamics relevant to observed low-energy physics.

Moreover, in the absence of such control, the framework does not constrain potential pathologies in the bulk gravitational description, including instabilities, singular geometries, or uncontrolled real-time dynamics. Whether these are resolved or merely reformulated within the correspondence in the absence of such control remains unknown. Thus, even in its most powerful form, the holographic approach does not provide a controlled description of generic strong coupling in physically realized QFTs.

7 Relations to other structural issues in string theory

The F-theory landscape overwhelmingly predicts vacua without gauge groups [9], rendering it incompatible with the observed universe. This is a failure of physical prediction, not merely a limitation.

Bosonic string theory is unstable owing to tachyons. Supersymmetry stabilizes the vacuum, but requires ten dimensions, forcing compactification assumptions that face serious tensions at multiple points with the inflationary imprints in the early universe [10].

The critique developed here is independent of these issues. Independently of those problems, the failure of strong-coupling control under loss of supersymmetry remains. We clarified in this work that the strong-coupling results in string theory are confined to the highly restricted corners where supersymmetry is present at low energies, which are excluded, for all practical purposes, viable descriptions of observed low-energy physics.

8 Concluding remarks

The strong-coupling program in string theory succeeded only in regimes where strong coupling is protected and trivialized by supersymmetry. It requires supersymmetry at low energies to function. Once this condition is removed—as demanded by experiment—the program ceases to provide controlled results.

The results on strong coupling in string theory of the 1990s were presented as a "second revolution." In retrospect, they relied entirely on supersymmetry as a computational crutch and applied only within narrow, symmetry-protected corners. When viewed from the current perspective, the results at the time of the revolution functioned within that corner, effectively waiting to be excluded as viable descriptions of nature at low energies by LHC experimental results.

Those regimes have now been excluded as, for all practical purposes, viable descriptions of observed low-energy physics.

The labels "nonperturbative" and "strong coupling" refer only to these excluded domains. They do not apply to observed low-energy physics.

From a present perspective, these results were oversold.

They must be reclassified accordingly: as mathematical structures, not solutions to physical strong-coupling problems.

Strong-coupling results in string theory, centrally developed during the 1990s, constitute an accumulation of results that function only with low-scale supersymmetry. Strong-coupling results in string theory have not provided a controlled description of the dynamics of physically relevant QFT—and, in light of experimental constraints, they cannot. In the post-LHC era, experiments revealed that these strong-coupling results in string theory do not—and never did—provide a solution to strong coupling in physically relevant, real QFT.

Whether supersymmetry persists at higher scales is immaterial to the issues presented in this work: no controlled framework is known that connects the supersymmetric regimes where computational control is achieved to the non-supersymmetric regimes relevant for observed low-energy physics.

In summary, the strong-coupling program in string theory never achieved control over generic strongly coupled dynamics. It achieved exact results only within narrow, highly constrained corners defined by low-energy supersymmetry. These regimes lack experimental support as descriptions of physical reality. Consequently, string theory's strong-coupling program does not apply to physically relevant, observed low-energy QFT and must be regarded as restricted to potentially mathematically consistent but physically unsubstantiated sectors.

Acknowledgments

Y.K. acknowledges Hakubi projects of RIKEN. This work was supported by the JSPS Grant-in-Aid for Scientific Research, No. JP24K06909.

References

[1] E. Witten, "String theory dynamics in various dimensions," *Nucl. Phys.* **B443**, 85–126 (1995) [arXiv:hep-th/9503124 [hep-th]].

[2] P. K. Townsend, "The eleven-dimensional supermembrane revisited," *Phys. Lett.* **B350**, 184–187 (1995) [arXiv:hep-th/9501068 [hep-th]].

[3] C. Vafa, "Evidence for F theory," *Nucl. Phys.* **B469**, 403–418 (1996) [arXiv:hep-th/9602022 [hep-th]].

[4] D. R. Morrison and C. Vafa, "Compactifications of F theory on Calabi-Yau threefolds. 1," *Nucl. Phys.* **B473**, 74–92 (1996) [arXiv:hep-th/9602114 [hep-th]].

[5] D. R. Morrison and C. Vafa, "Compactifications of F theory on Calabi-Yau threefolds. 2.," *Nucl. Phys.* **B476**, 437–469 (1996) [arXiv:hep-th/9603161 [hep-th]].

[6] N. Seiberg and E. Witten, "Electric - magnetic duality, monopole condensation, and confinement in N=2 supersymmetric Yang-Mills theory," *Nucl. Phys.* **B426**, 19–52 (1994) [erratum: *Nucl. Phys.* **B430**, 485–486 (1994)] [arXiv:hep-th/9407087 [hep-th]].

[7] N. Seiberg and E. Witten, "Monopoles, duality and chiral symmetry breaking in N=2 supersymmetric QCD," *Nucl. Phys.* **B431**, 484–550 (1994) [arXiv:hep-th/9408099 [hep-th]].

[8] J. M. Maldacena, "The Large N limit of superconformal field theories and supergravity," *Adv. Theor. Math. Phys.* **2**, 231–252 (1998) [arXiv:hep-th/9711200 [hep-th]].

[9] Y. Kimura, "On the Mathematical Limitations and Physical Relevance of the F-theory Landscape," Zenodo, https://doi.org/10.5281/zenodo.20053073.

[10] Y. Kimura, "On the Physical Viability of String Compactification under Inflationary Imprints," Zenodo, https://doi.org/10.5281/zenodo.20053896.

[11] C. Montonen and D. I. Olive, "Magnetic Monopoles as Gauge Particles?," *Phys. Lett.* **B72**, 117–120 (1977).

[12] A. Sen, "Strong - weak coupling duality in four-dimensional string theory," *Int. J. Mod. Phys.* **A9**, 3707–3750 (1994) [arXiv:hep-th/9402002 [hep-th]].

[13] T. Banks, W. Fischler, S. H. Shenker and L. Susskind, "M theory as a matrix model: A conjecture," *Phys. Rev.* **D55**, 5112–5128 (1997) [arXiv:hep-th/9610043 [hep-th]].

[14] I. García-Etxebarria and D. Regalado, "$\mathcal{N} = 3$ four dimensional field theories," *JHEP* **03**, 083 (2016) [arXiv:1512.06434 [hep-th]].