The de Sitter Problem in the String Swampland: A Verified Literature Map

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This document is a literature map, not original research. It surveys an active and contested debate in string/M-theory and represents the field's disagreements; it does not adjudicate them or advance a physics position of its own. It was produced through human-directed AI synthesis: the agentic instrument assembled the structure, camps, and candidate citations under the architect's direction, and a second AI instrument verified citations against arXiv, INSPIRE-HEP, and primary literature, correcting attributions whose provenance failed. Provenance tags mark the verification status of every cited work (see below). Open items are listed in the Verification Ledger.

Provenance tags

– [VERIFIED] the arXiv identifier was independently resolved against arxiv.org or INSPIRE-HEP, and its title, authorship, and placement in the correct camp were confirmed during this map's production.

– [SOURCED] the work is real and standard in the literature and is cited in good faith, but its identifier was not independently re-resolved in this pass; treat as high-confidence-but-unaudited.

– [FOUNDATIONAL] a pre-arXiv or field-defining work cited by its journal reference.

Revision note (what changed, and why it is documented)

The production of this map is itself an instance of the AI-failure-mode pattern this research program tracks, so its corrections are disclosed:

– Verification was executed before publication, not asserted after. The synthesis instrument's draft labeled its citation list "key verified papers" while verification was still pending the exact move that lets fabricated identifiers pass. Verification was then performed across two passes covering nineteen arXiv identifiers spanning all seven problems; every identifier checked resolved to a real paper correctly placed in its camp. Two author attributions initially flagged as suspect (Marsh on the LVS side; the KKLT-skeptic 10D papers) were confirmed correct on checking, and two Dark-Dimension attributions were corrected during synthesis and then confirmed against the literature.

– The Trans-Planckian Censorship Conjecture was promoted to its own thread. The draft folded TCC under another problem; it is central enough to the post-2019 debate to stand as Problem 7.

– The overlap among Problems 1, 2, and 6 is made explicit. KKLT control, LVS control, and the Dine-Seiberg problem are three angles on a single question whether any dS construction is under EFT control and the dependency map now shows that rather than presenting them as independent.

A. State of the Field

Whether string/M-theory admits stable or metastable de Sitter vacua remains one of the most contested open questions in the subject, and this map takes no side on it. Proponents of the string "landscape" hold that non-perturbative effects and anti-brane uplifting can stabilize moduli into a vast set of metastable dS vacua compatible with the observed accelerating universe. Advocates of the "swampland" program conjecture that consistent quantum gravity forbids metastable dS entirely, placing all candidate constructions in the swampland of effective theories with no UV completion. The disagreement is technical and genuine it turns on the validity of 4D effective actions, the control of higher-dimensional backreaction, and the trustworthiness of asymptotic regimes and both camps maintain mathematically sophisticated positions. There is no community consensus.

B. Open-Problems Table

| Problem (as a question) | Why it is hard | Competing camps | |---|---|---| | 1. Is the KKLT anti-brane uplift under parametric 10D supergravity control? | Matching a 4D non-perturbative EFT to a singular 10D backreaction. | KKLT defenders vs. 10D supergravity skeptics | | 2. Can the Large Volume Scenario build metastable dS under rigorous control? | Curvature, warping, and gs corrections can spoil a shallow minimum. | LVS proponents vs. control skeptics | | 3. Does the de Sitter Swampland Conjecture hold as a quantum-gravity constraint? | Rests on asymptotic and thermodynamic arguments, not a 10D proof. | Conjecture advocates vs. landscape defenders | | 4. Is the Dark Dimension scenario consistent with all bounds? | Balances a mesoscopic extra dimension against gravity and astrophysics limits. | Proponents vs. phenomenological skeptics | | 5. Can quintessence explain dark energy consistently with quantum gravity? | Observations push the dS-slope parameter small, straining the conjecture. | Swampland-quintessence advocates vs. observational skeptics | | 6. Does the Dine-Seiberg problem force all dS into the swampland? | Stabilization sits at finite coupling/volume, where control is contested. | Landscape proponents vs. asymptotic-swampland advocates | | 7. Does the Trans-Planckian Censorship Conjecture constrain the dS lifetime? | Forbids long-lived dS, demanding low-scale inflation and fine-tuning. | TCC proponents vs. cosmological/landscape skeptics |

C. Per-Problem Detail

1. KKLT anti-brane uplift and 10D control

KKLT stabilizes moduli in a supersymmetric AdS vacuum via fluxes and non-perturbative effects, then uplifts to dS with an anti-D3 brane. Critics argue the anti-brane backreaction is singular in 10D and destabilizes the geometry; defenders argue stringy resolutions (brane polarization) keep the 4D EFT valid.

– Defenders' strongest argument. SUSY breaking is localized on the anti-D3 brane (nilpotent-superfield in the 4D EFT), and an explicit 10D analysis reproduces the 4D result. Key works: KKLT [FOUNDATIONAL: hep-th/0301240], "Remarks on brane and antibrane dynamics" [VERIFIED: arXiv:1412.5702, Michel et al.], "dS Vacua and the Swampland" [VERIFIED: arXiv:1901.02022, Kallosh-Linde-McDonough-Scalisi], "de Sitter Vacua from Ten Dimensions" [VERIFIED: arXiv:1908.04788, Kachru-Kim-McAllister-Zimet]. Lead figures: Kallosh, Linde, Kachru, McAllister (Stanford, Cornell).

– Skeptics' strongest argument. Explicit 10D backreaction shows IR singularities that cannot be cloaked; the integrated 10D equations are argued to obstruct the uplift. Key works: "Anti-D3's Singular to the Bitter End" [VERIFIED: arXiv:1206.6369, Bena et al.], "Toward de Sitter space from ten dimensions" [VERIFIED: arXiv:1707.08678, Moritz-Retolaza-Westphal], "What if string theory has no de Sitter vacua?" [VERIFIED: arXiv:1804.01120, Danielsson-Van Riet]. Lead figures: Bena, Grana (IPhT Saclay); Moritz, Westphal (DESY); Danielsson (Uppsala); Van Riet (KU Leuven).

2. Large Volume Scenario and parametric control

LVS stabilizes Kahler moduli at exponentially large volume, nominally suppressing corrections. Proponents argue this secures control of the uplift; skeptics argue subleading corrections are not parametrically suppressed.

– Proponents. Large volume suppresses and loop corrections; uplift via F-terms of blow-up modes avoids singular anti-branes. Key works: LVS [FOUNDATIONAL: hep-th/0502058], "A New Class of de Sitter Vacua in Type IIB Large Volume Compactifications" [VERIFIED: arXiv:1707.01095, Gallego-Marsh-Vercnocke-Wrase], and dilaton-dependent uplift work [SOURCED: arXiv:1203.1750]. Lead figures: Conlon (Oxford), Quevedo (Cambridge), Cicoli (Bologna), Marsh, Wrase.

– Skeptics. Warp/loop corrections violate the expected scaling, and maintaining control requires a negative D3-tadpole exceeding known Calabi-Yau bounds. Key works: "LVS de Sitter Vacua are probably in the Swampland" [VERIFIED: arXiv:2201.03572, Junghans], "The LVS parametric tadpole constraint" [VERIFIED: arXiv:2202.04087, Gao-Hebecker-Schreyer-Venken]. Lead figures: Junghans, Hebecker, Gao, Schreyer, Venken (Heidelberg). [Note: the tadpole paper's author is Gerben Venken; confirm first-name rendering before any citation export.]

3. The de Sitter Swampland Conjecture

The conjecture asserts the scalar potential obeys |V|/V c (refined versions constrain the Hessian). Advocates motivate it from the distance conjecture and dS thermodynamics; skeptics argue it is phenomenologically strained and lacks a rigorous derivation.

– Advocates. Original conjecture [VERIFIED: arXiv:1806.08362, Obied-Ooguri-Spodyneiko-Vafa], refined form [VERIFIED: arXiv:1810.05506, Ooguri-Palti-Shiu-Vafa], slow-roll bound [VERIFIED: arXiv:1807.05193, Garg-Krishnan]. Lead figures: Vafa (Harvard), Ooguri (Caltech/IPMU), Palti (Ben-Gurion), Shiu (Wisconsin).

– Landscape defenders. c O(1) is in tension with inflation and the observed ; the conjecture over-generalizes tree-level no-go theorems. Cosmological critique [VERIFIED: arXiv:1808.09440, Akrami-Kallosh-Linde-Vardanyan]. Lead figures: Linde, Kallosh (Stanford).

4. The Dark Dimension

Ties the dark-energy scale to a Kaluza-Klein scale via the AdS distance conjecture, predicting a single micron-scale extra dimension. Proponents see a hierarchy-and-dark-matter payoff; skeptics cite short-range-gravity and astrophysical bounds.

– Proponents. AdS distance conjecture plus the observed predicts R 106 m; KK gravitons supply dark matter. Key works: "The Dark Dimension and the Swampland" [VERIFIED: arXiv:2205.12293, Montero-Vafa-Valenzuela], a warped-throat realization [VERIFIED: arXiv:2208.01057, Blumenhagen-Brinkmann-Makridou], decaying-dark-graviton constraints [SOURCED: arXiv:2307.11048, Law-Smith-Obied-Prabhu-Vafa]. Lead figures: Vafa, Obied (Harvard); Montero, Valenzuela; Anchordoqui (CUNY); Antoniadis; Lust (LMU/MPP). [Author attributions on the second and third papers were corrected during synthesis see Ledger.]

– Skeptics. Torsion-balance limits on inverse-square-law deviations and SN1987A/neutron-star cooling constrain the scenario. Key works: short-range-gravity tests [SOURCED: arXiv:2002.11761; hep-ph/0611184, Kapner et al.]. Lead figures: Adelberger, Heckel (Eot-Wash, U. Washington).

5. Quintessence as the dark-energy alternative

If dS is in the swampland, dark energy must roll. Proponents argue rolling-scalar potentials satisfy the swampland criteria; skeptics argue the fit to data demands fine-tuning.

– Advocates. Quintessence avoids the thermodynamic problems of stable dS and can satisfy |V|/V c. Key work: cosmological implications of the conjectures [VERIFIED: arXiv:1806.09718, Agrawal-Obied-Steinhardt-Vafa]. Lead figures: Steinhardt (Princeton), Agrawal, Vafa (Harvard).

– Skeptics. Bounds on the equation of state (w 1) push c 0.1, straining the O(1) requirement; DESI/Euclid will tighten this. Key works: [VERIFIED: arXiv:1808.02877, Heisenberg-Bartelmann-Brandenberger-Refregier; SOURCED: arXiv:2307.15060]. Lead figures: Heisenberg, Brandenberger (McGill).

6. The Dine-Seiberg problem

The 1985 observation that string compactifications are weakly coupled and large-volume only asymptotically, where the potential vanishes. Landscape proponents argue interior minima can be stabilized under control; asymptotic-swampland advocates argue the interior is outside control.

– Landscape proponents. Combining fluxes, instantons, and corrections yields trustworthy interior minima. Key works: KKLT [FOUNDATIONAL: hep-th/0301240], LVS [FOUNDATIONAL: hep-th/0502058]. Lead figures: Kachru, Quevedo, Conlon.

– Asymptotic-swampland advocates. The conjectures are sharp asymptotically; interior stabilization introduces unsuppressed corrections. Key works: Dine-Seiberg [FOUNDATIONAL: Phys. Lett. B 162 (1985) 299], refined dS conjecture [VERIFIED: arXiv:1810.05506], AdS distance conjecture [VERIFIED: arXiv:1906.05225, Lust-Palti-Vafa]. Lead figures: Vafa, Palti, Lust.

7. The Trans-Planckian Censorship Conjecture

TCC holds that sub-Planckian fluctuations must never cross the Hubble horizon and freeze, bounding the dS lifetime to H1 ln(M_Pl/H). Proponents derive swampland-like constraints from it; skeptics note the tension with inflation.

– Proponents. Frozen sub-Planckian modes would break the EFT; TCC yields a natural lifetime bound. Key work: TCC foundational [VERIFIED: arXiv:1909.11063, Bedroya-Vafa]. Lead figures: Bedroya, Vafa (Harvard).

– Skeptics. TCC forces V14 109 GeV, making the observed perturbation amplitude hard to generate without fine-tuning. Cosmological constraints [SOURCED: arXiv:1808.09440]. Lead figures: Linde, Kallosh (Stanford); Brandenberger (McGill).

D. Dependency Map

Problems 1, 2, and 6 are three angles on a single underlying question whether any dS construction is under EFT control and are grouped accordingly. The swampland conjectures (3, 7) feed on the failure of that control; the Dark Dimension (4) and quintessence (5) are downstream consequences of taking the swampland position seriously.

[Code block available in canonical web edition.]

The EFT Control Problem [6] Dine-Seiberg [1] KKLT control [2] LVS control if uncontrolled [Maldacena-Nunez no-go] (bypass required) [1],[2] [3] de Sitter Swampland Conjecture derived/refined by [7] TCC forbids stable dS constrains dS lifetime [5] Quintessence [AdS Distance Conjecture] [4] Dark Dimension constrained by Eot-Wash short-range gravity + SN1987A / neutron-star cooling

[Code block available in canonical web edition.]

E. Where an Outsider Could Realistically Engage

Most of this literature is formalism-bound, requiring Calabi-Yau geometry, flux compactification, and 10D/11D supergravity. A few corners are genuinely tractable for a computationally-oriented outsider, and they should be distinguished honestly from the ones that are not.

Genuinely tractable. Programmatic searching of the Kreuzer-Skarke database for Calabi-Yau manifolds meeting the LVS parametric-tadpole bounds (large Euler number, large negative D3-tadpole) is a database/algorithmic task that does not require solving supergravity equations. And constraining swampland-quintessence or TCC models against CMB/DESI data by modifying standard Boltzmann solvers (CLASS, CAMB) and running MCMC pipelines (Cobaya) is accessible to anyone with a cosmology-data background.

Accessible to reproduce, not to extend. Modeling Eot-Wash torsion-balance data to bound Dark Dimension parameters is straightforward to read and reproduce but harder to contribute novel limits to than "compute a Yukawa potential" suggests the micron-scale prediction sits at the current experimental frontier and the systematics modeling is the actual difficulty.

Effectively closed without an expert collaborator. The 10D supergravity backreaction calculations (polarized D3-branes in warped throats, KPV dynamics) and the non-perturbative moduli-stabilization computations (instanton contributions, gaugino condensation, Kahler corrections on orientifolds) are deep formal work in algebraic geometry and supergravity.

F. Verification Ledger

Verified (identifier resolved, authorship and camp placement confirmed): 1412.5702 (Michel et al.); 1901.02022 (Kallosh-Linde-McDonough-Scalisi); 1908.04788 (Kachru-Kim-McAllister-Zimet); 1206.6369 (Bena et al.); 1707.08678 (Moritz-Retolaza-Westphal); 1804.01120 (Danielsson-Van Riet); 1707.01095 (Gallego-Marsh-Vercnocke-Wrase); 2201.03572 (Junghans); 2202.04087 (Gao-Hebecker-Schreyer-Venken); 1806.08362 (Obied-Ooguri-Spodyneiko-Vafa); 1810.05506 (Ooguri-Palti-Shiu-Vafa); 1807.05193 (Garg-Krishnan); 1808.09440 (Akrami-Kallosh-Linde-Vardanyan); 2205.12293 (Montero-Vafa-Valenzuela); 2208.01057 (Blumenhagen-Brinkmann-Makridou); 1906.05225 (Lust-Palti-Vafa); 1806.09718 (Agrawal-Obied-Steinhardt-Vafa); 1808.02877 (Heisenberg-Bartelmann-Brandenberger-Refregier); 1909.11063 (Bedroya-Vafa, TCC). The OOSV-vs-OPSV distinction the prior ledger flagged is resolved: 1806.08362 is the four-author OOSV origin paper, 1810.05506 the OPSV refinement distinct papers, both correctly placed.

Author-attribution corrections made during synthesis (now confirmed against the literature): arXiv:2208.01057 reassigned from Obied-Ooguri-Vafa to Blumenhagen-Brinkmann-Makridou (confirmed); arXiv:2307.11048 reassigned to Law-Smith-Obied-Prabhu-Vafa.

Foundational, cited by journal reference (pre-arXiv or field-defining): hep-th/0301240 (KKLT); hep-th/0502058 (LVS); Phys. Lett. B 162 (1985) 299 (Dine-Seiberg).

Sourced but not independently re-resolved (high-confidence, standard works): 1203.1750; 2307.11048; 2002.11761; hep-ph/0611184; 2307.15060.

Remaining before publication:

– Resolve the five [SOURCED] identifiers above against arXiv/INSPIRE to complete the upgrade to [VERIFIED]. These are the short-range-gravity experimental papers (2002.11761, hep-ph/0611184) and three recent preprints; none is conjecture-defining, so the residual risk is low.

– Confirm the first-name rendering of G. Venken in the Problem 2 skeptic attribution.

– Spot-check affiliations (Marsh, Shiu), which drift over time and were not the focus of citation verification.

– Final human read.

Note on the use of this map

This is a non-peer-reviewed synthesis of a contested literature, produced to orient a reader in the structure of an active debate. It is reliable as a map of who argues what and where the fault lines run; it is not a substitute for the primary papers. Nearly all citations have been independently resolved against arXiv/INSPIRE-HEP (see Ledger); the remaining handful of [SOURCED] tags mark the five non-conjecture-defining identifiers a reader should resolve before relying on them in their own work.

Canonical web edition and structured metadata: https://research.mahastrategies.com/papers/de_sitter_swampland_map