A non-supersymmetric charged brane–antibrane string vacuum as a UV completion candidate for White Hole Dynamics: fingerprints, orbifold exactness, and a strong-coupling ceiling

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The White Hole Dynamics (WHD) program takes our 3+1-dimensional universe to be a brane in a 4+1-dimensional bulk, with a low-energy matter content that is fixed by hand at the level of an effective action: an SU(2) Yang–Mills field, a complex SU(2)-doublet Higgs, and two entropy currents. We ask a single question: is there a definite string vacuum whose *fingerprints* are these constants and this content? We present a candidate and grade it claim by claim. The candidate is a non-supersymmetric, *strongly coupled* charged brane–antibrane construction: Type IIA on $T^5/\mathbb{Z}_2$ at the self-dual radius, an $\mathrm{O4}_+$ orientifold, and a magnetized D6 with worldvolume flux $F{=}2$ that yields the gauge group $\mathrm{USp}(2) = \mathrm{SU}(2)$. In it the open-string tachyon is the WHD "engine," its kink (a D3) is our brane, and the $\mathbb{Z}_2$ mirror that defines the brane is that kink. Within this frame WHD's parameters are correlated outputs, not free inputs. The sharpest is the Higgs mass parameter: the Higgs *is* the open-string tachyon, so $m^2 = -1/(2\alpha')$ — forced, universal, and string-scale [**F**]. The gauge and quartic couplings descend from the same background [**M**]; the family number is even and minimally two by the Witten SU(2) anomaly [**C**]; and the localized content is exotic-free, $\mathrm{SU}(2) + \text{one doublet} + 2 \times (\mathrm{D}, \mathrm{S})$ [**C**]. Our main technical result is that the $\mathbb{Z}_2$ mirror is an *exact* string orbifold [**C in-framework**]: level-matching holds, the Ramond–Ramond tadpoles and K-theory reduce to a single mod-2 class, and that class evaluates to zero by three independent routes. Being topological, it is exact even at $g_s^* \approx 1.26$. A dark sector is *forced* — the induced D4 charge equals the family number, two [**C**]— with a dynamically-selected net charge [**M**] and a dark-radiation ceiling $\Delta N_{\mathrm{eff}} \lesssim 0.02$, ≈ 0 generically, below CMB-S4 reach [**F**]. The vacuum sits at genuine strong coupling with no weak-coupling or large-volume corner, which caps the claim that this vacuum is the *selected* one at grade M irreducibly. Realizable is not selected. This is a consistency proof of a candidate, not a derivation of reality; no bounded UV computation remains.

I. INTRODUCTION

The White Hole Dynamics (WHD) program [1] posits that our observable 3+1-dimensional universe is the boundary ("brane") of a 4+1-dimensional bulk spacetime, and that a macroscopic white-hole-like engine in the bulk sources the outward radiation that becomes matter on the brane. At the level of the effective action the program *commits* to a specific matter content [1, 2]: an SU(2) Yang–Mills gauge field (the radiation sector), a complex SU(2)-doublet Higgs (four real components), and two entropy currents, all minimally coupled to full 4+1-dimensional General Relativity. That action is a hypothesis about low-energy physics; the numerical-relativity engine that evolves it, and the "birth run" that is the program's headline dynamical deliverable, are described in the companion methods paper [2] and are logically independent of everything below.

This paper asks a different, and in a precise sense orthogonal, question. The WHD action carries a handful of dimensionless constants — a Higgs mass parameter m^2, a quartic λ, a gauge coupling g — and a definite matter content (SU(2), one doublet, two chiral families). *Are these free choices, or are they the fingerprints of a definite ultraviolet completion?* We answer with a candidate string vacuum in which they are correlated outputs of one background, and we are careful, throughout, to say exactly how strong that answer is.

The three things a reader must not leave without. First, this is a **candidate**, not a theorem about reality. It is consistent, it is specific, and one of its predictions is genuinely forced — but "there exists a consistent string vacuum with these fingerprints" is not "string theory selects WHD." Second, the construction is at **genuine strong coupling**: the string coupling sits at $g_s^* \approx 1.26$, with no weak-coupling or large-volume corner in which a controlled expansion exists. That is a physical fact about the vacuum, not a calculation we still owe, and it caps the meta-claim "this is the selected vacuum" at grade M *irreducibly*: no computation lifts it. Third, and consequently, **realizable is not selected**. The load-bearing results below — the tachyon-mass fingerprint, the orbifold exactness, the forced dark sector, the dark-radiation ceiling — are *protected*, g_s-independent quantities (tachyon masses, tadpoles, K-theory classes, homotopy invariants) that are exact at strong coupling; the M ceiling sits on the umbrella claim of selection, never on these fingerprints. We have written the paper so that a reader who remembers only these three sentences has not been misled.

The evidence grades. Every substantive claim below carries one of four tags, which are the WHD program's internal ledger and which we state once here:

- **[C]** — *proven in-framework*: rigorous given the stated string scaffolding (a computed level-matching, a charge identity, an anomaly count).
- **[M]** — *motivated / realizable*: a standard string mechanism instantiated here, plausible and specific but not proven unique.
- **[F]** — *a forced or falsifiable fingerprint*: a number the frame forces, or a prediction that a measurement could refute.
- **[W]** — *weak / unquantified*: an open residual, named rather than smoothed over.

A headline never carries a grade stronger than its weakest load-bearing input. We use these tags densely and deliberately; a claim without a tag is either background or explicitly framing.

Organization. Section II gives the construction and fixes conventions (Type IIA, not IIB — the branes are even-dimensional). Section III reads off the fingerprints and grades each. Section IV is the main technical result: the $\mathbb{Z}_2$ mirror is an exact string orbifold, with the tadpole/K-theory obstruction reduced to a single mod-2 class that we evaluate to zero. Section V gives the forced dark sector and its falsifiable dark-radiation ceiling. Section VI states the strong-coupling ceiling plainly and separates what could strengthen the candidate from what cannot. Section VII tallies the grades.

II. THE CONSTRUCTION

A. Frame: Type I on T^5, read after five T-dualities

The starting point is the ten-dimensional Type I string — the $\mathrm{O9}^-$ orientifold of Type IIB with 32 D9-branes and gauge group SO(32) — compactified on a five-torus T^5. We then read this background in the frame reached by T-dualizing all five internal circles. Five is odd, so the worldsheet parity Ω is conjugated into $\Omega R(-1)^{F_L}$ and the theory lands in **Type IIA**: the O9 becomes an O4, each D9 becomes a D4, and the surviving objects are the even-dimensional O4/O3/D4/D6 branes coupling to the IIA Ramond–Ramond (RR) forms C_1, C_3, C_5, C_7. We emphasize the frame because it is a common slip to call this construction Type IIB; the branes are even-dimensional and the odd number of dualities is decisive. The physics is unchanged by the relabeling, but the internal bookkeeping (which RR form each object sources) is not, and Sec. IV depends on it.

The target space is

$$\mathcal{M}^{3,1} \times \mathbb{R}_\xi \times T^5, \qquad 10 = 4 + 1 + 5, \tag{1}$$

with $\mathcal{M}^{3,1}$ the (non-compact) 4D brane worldvolume, ξ the one bulk-depth coordinate normal to the brane — WHD's "radial" direction into the 4+1 bulk — and T^5 the internal torus. One circle of T^5 is held at the self-dual radius $R = \sqrt{\alpha'}$, where the momentum–winding $U(1)$ is enhanced to SU(2); this is the origin of WHD's gauge group and is a rigid, maximally-symmetric point rather than a scanned modulus (see Sec. VI).

B. The two involutions, and the group they generate

Two $\mathbb{Z}_2$ involutions define the vacuum, and keeping them rigorously apart is the whole game.

The orientifold is

$$\sigma \;\equiv\; \Omega\, R\, (-1)^{F_L}, \tag{2}$$

with R reflecting all five T^5 coordinates. Its fixed locus is the $2^5 = 32$ points of T^5, at each of which sits an O4-plane filling $\mathcal{M}^{3,1} \times \xi$. We take the $\mathrm{O4}_+$ (symplectic) projection, which carries *positive* RR charge and tension: this is the brane-supersymmetry-breaking sign [12, 13, 15], and it is the source of WHD's positive vacuum energy (the "well" whose sign we return to in Sec. VI). The $\mathrm{O4}_+$ projection on a stack of branes gives symplectic gauge groups; on the magnetized brane below it delivers USp(2) = SU(2).

The wall/mirror is

$$\theta \;\equiv\; P_\xi \otimes C, \tag{3}$$

where $P_\xi : \xi \to -\xi$ reflects the single bulk-depth coordinate, and $C = -\mathbb{1} \in \mathrm{SU}(2)$ is the group center, acting as a pure Chan–Paton (N-ality) label and *not* geometrically on T^5. Crucially, θ contains no worldsheet parity: it is an ordinary geometric-times-gauge orbifold element, whose fixed plane $\xi = 0$ hosts a *twisted sector*, not a crosscap. That twisted sector, localized at $\xi = 0$, is the brane. We show in Sec. IV that consistency forces C to be exactly this pure Chan–Paton label (excluding a half-shift or a Weyl reflection), so that θ's geometric action is P_ξ alone and its fixed locus is a genuine codimension-one plane.

The group generated by θ and σ closes, up to a fermionic cocycle we discuss in Sec. IV, as

$$G = \langle \theta, \sigma \rangle = \mathbb{Z}_2 \times \mathbb{Z}_2 = \{1, \theta, \sigma, \theta\sigma\}, \tag{4}$$

and the third nontrivial element is physically informative: $\theta\sigma = \Omega\,(P_\xi R)\,C\,(-1)^{F_L}$ contains Ω and reflects $1 + 5 = 6$ coordinates, hence defines O3-planes at the 32 loci $\{\xi = 0\} \cap \{T^5 \text{ fixed points}\}$ — 32 O3-planes sitting *on the brane*, coupling to C_4, the same form the kink couples to. This brane-localized O3 is a real object in the tadpole bookkeeping (Sec. IV) and is the string origin of the wall's net C_4 charge (Sec. V).

C. The magnetized brane, the tachyon engine, and the kink

Onto this orientifold we place a magnetized D6 wrapping $\mathcal{M}^{3,1} \times \xi \times \Sigma_2$, with $\Sigma_2 \subset T^5$ a two-cycle carrying worldvolume flux

$$F \;=\; \int_{\Sigma_2} \frac{\mathcal{F}}{2\pi} \;=\; 2, \tag{5}$$

together with its antibrane $\overline{\text{D6}}$. The O4$_+$ projection reduces the D6 gauge group to USp(2) = SU(2): this is WHD's gauge group, and it is not chosen but projected. The first Chern number $F = 2$ is, by the index theorem, the chiral family number (Sec. III); we will see it is not free either, being forced even by an anomaly.

The D6–$\overline{\text{D6}}$ pair carries an open-string **tachyon** T in the bifundamental. This is the WHD *engine*: the symmetric phase $T = 0$ is the tachyonic top, and the engine is the non-linear endpoint of T's rolling condensation [4, 6]. By Sen's descent, the codimension-one kink of a Dp–$\overline{\text{Dp}}$ tachyon is a D$(p-1)$-brane [4, 5]; here the kink of T across ξ is a D3, and *that* D3 *is our brane*. The $\mathbb{Z}_2$ mirror (3) is precisely this kink: θ-invariance forces $T(\xi) = -T(-\xi)$, so T is odd in ξ, the homogeneous "annihilate-to-nothing" mode $T \equiv$ const is projected out, and every surviving profile must cross zero at $\xi = 0$ and tend to $\pm v$ at $\pm\infty$. A kink is *forced*, and the constant that would let the brane–antibrane annihilate is removed by the identification. This is why the WHD brane is eternal at the level of the construction, and it is a string-orbifold projection rather than an effective-theory boundary condition (Sec. IV).

To summarize the dictionary the rest of the paper uses:

WHD object	string-theory realization
the bulk gauge group SU(2)	USp(2) on the magnetized D6 (O4$_+$ projection)
the engine	the D6–$\overline{\text{D6}}$ open-string tachyon T
the 3+1D brane	the tachyon kink, a D3 (Sen descent)
the $\mathbb{Z}_2$ mirror	that kink: $\theta = P_\xi \otimes C$, $T(\xi) = -T(-\xi)$
the doublet Higgs	T itself, in the SU(2) bifundamental

III. THE FINGERPRINTS

Within the frame of Sec. II, WHD's action-level constants are not independent inputs. We read them off and grade each; the results are collected in Table I.

A. The tachyon mass: the sharpest fingerprint [F]

The single most striking match is the Higgs mass parameter. If the Higgs *is* the D6–$\overline{\text{D6}}$ open-string tachyon — one field, not two — then its mass-squared in the symmetric phase is the brane–antibrane tachyon mass,

$$m_T^2 \;=\; -\frac{1}{2\alpha'}, \tag{6}$$

so that the WHD tachyonic mass parameter is fixed at $m^2 = 1/(2\alpha')$, which in the program's string units ($\alpha' = 1$, the cutoff set at the string scale M_s) is $m^2 = 0.5$ — the value the effective action carries. Three features make this a fingerprint and not a coincidence, and they are why we grade it **[F]**, the sharpest in the paper:

1. *Forced.* Given that the engine is the tachyonic condensation of Φ (the WHD commitment [1]) and that the charged brane–antibrane realizes that engine, $\Phi = T$ is an identification, not a tuning, and (6) follows.

2. *Universal.* The Dp–$\overline{\text{Dp}}$ tachyon has $m_T^2 = -1/(2\alpha')$ *independent of the brane dimension* p: unlike the gauge coupling below, m^2 does not ride on any discrete brane choice, so it survives uncertainties that weaken the other constants.

3. *Sign-matched.* Both are negative m^2, Mexican-hat, roll-down-and- condense — the same physical origin.

The honest residual is the framework contingency itself (that WHD *is* this brane–antibrane vacuum, grade M, Sec. VI) and $O(1)$ charge and curvature corrections at the birth epoch; neither touches the string-scale value $1/(2\alpha')$. Within the frame, m^2 is derived, not chosen.

B. The couplings: correlated outputs [M]

The gauge and quartic couplings descend from the *same* background, which is the content of "constants from above": they are not three independent $O(1)$ choices. The string coupling of a non-supersymmetric brane–antibrane vacuum is fixed by the dilaton tadpole. Pulling out the (2π) normalizations, the huge $(2\pi)^{-D}$ factors cancel to a single 2π, leaving

$$g_s^* \;=\; \frac{I_\Lambda}{4\pi}, \tag{7}$$

where $I_\Lambda = \int_{\mathcal{F}} (d^2\tau/\tau_2^2)\, Z(\tau,\bar\tau)$ is the one-loop closed-string modular integral, an $O(1)$ number set by the Bose–Fermi mismatch of the (tachyon-free) closed sector. This is a genuine advance over "g_s could be anything": (7) is a specific *form* with a narrow natural range, and $I_\Lambda > 0$ (the vacuum is a well, not a barrier) is forced by the brane-supersymmetry-breaking sign and is required independently by WHD's own positive hilltop energy [1]. The of-record projection gives an $O(1)$ coupling $g_s^* \approx 1.26$ — genuine strong coupling, the ceiling of Sec. VI. The gauge coupling then follows from the self-dual, level-one point, $g^2 \approx g_s$, so g is not independent of m^2: both descend from the one background. The quartic λ is the tachyon's $|T|^4$ boundary-string-field-theory coefficient, an $O(1)$ number in string units. We grade g_s^* and g at **[M]**, and λ at **[M]**: forced to the right type and magnitude, exact values owed. *[to add: the exact modular integral I_Λ of the pinned non-supersymmetric projection (which turns g_s^* from a form into a number), and the exact boundary-string-field-theory quartic (which pins λ).]*

C. The family number: even and minimally two [C]

The chiral family number is the flux (5), an index, and it is not free: it must be *even*. A probe seeing the USp(2) = SU(2) on the brane is subject to the Witten SU(2) global anomaly [8], whose obstruction is $\pi_4(\mathrm{SU}(2)) = \pi_4(S^3) = \mathbb{Z}_2$; consistency requires the number of doublets to be even. The frame delivers exactly this: the minimal anomaly-free flux is $F = 2$, so the family number is *even and minimally two*. This is a genuine prediction of a definite integer, and we grade it **[C]**. The birth "seed" of the WHD dynamics is correspondingly identified with Sen's rolling-tachyon Euclidean vacuum [6], of which the program's seed of record is the semiclassical realization **[C]**.

D. Exotic-free content, without a scan [C]

A generic brane construction proliferates exotics: extra chiral matter and gauge factors reshuffled by every flux and Wilson line. The usual worry — "one must scan an enormous landscape to find the exotic-free member" — is, for WHD, based on a category error. The landscape count is a count of static *flux vacua* that stabilize moduli by flux choice [23]; WHD's observed matter is a *defect* spectrum on a kink, governed by an index [19], which does not proliferate, and its moduli are driven dynamically to a symmetry point rather than flux-selected. Two structures do the work, and both are group theory rather than search:

- *The center twist is a filter.* A field lives on the wall iff (geometric parity)×(center charge) is odd. But the SU(2) center charge *is* the isospin parity, $C = (-1)^{2j}$, so the wall keeps half-integer isospin (doublets) and expels integer isospin (adjoints, extra gauge matter). This is a physics-correlated projection, not a generic 50% cut: it keeps the fundamental-like matter and throws out the adjoint-like matter, by the same $\mathbb{Z}_2$ that makes the wall exist.

TABLE I. The WHD constants and content as fingerprints of the construction of Sec. II. Grades are the program's ledger (Sec. I).

Quantity	String-theory origin	Grade
$m^2 = -1/(2\alpha')$	the Higgs *is* the open-string tachyon; universal in p, sign-matched	**[F]**
$g_s^* \approx 1.26 = I_\Lambda/(4\pi)$	the non-SUSY dilaton tadpole; $I_\Lambda > 0$ forced	**[M]**
g, λ	the same self-dual, level-one background (gauge) and the $\lvert T\rvert^4$ quartic	**[M]**
family number = 2	flux F=2; even by the Witten SU(2) anomaly $\pi_4(\mathrm{SU}(2)) = \mathbb{Z}_2$	**[C]**
$\mathrm{SU}(2) + \mathrm{doublet} + 2 \times (\mathrm{D}, \mathrm{S})$	center-twist filter + Jackiw–Rebbi index; exotic-free	**[C]**

- *The chiral content is an index.* The trapped chiral zero modes equal the tachyon winding [19], an integer insensitive to the moduli that a landscape scans; it is 2, Witten-forced even (Sec. III C).

The localized content is then exactly $\mathrm{SU}(2) + \text{one doublet} + 2 \times (\mathrm{D}, \mathrm{S})$ — an exotic-free wall, grade **[C]** for the group theory and the index. We note one caveat we do not hide: the mirror does *not* by itself supply the second family (a naive fixed-point projection Majorana-halves the count to one), which is exactly why the $F = 2$ flux is mandatory and its induced charge unavoidable — the origin of the forced dark sector of Sec. V.

Finally, exotic-freeness can be stated as a non-anthropic *postdiction* **[C]**. Because the dark-sector recoupling annihilates the families (the family index equals the flux, which is self-defeating), the "bad" branch ends an empty universe, never "us plus exotics." Given the observed chiral families, WHD forces no exotics: a plain deduction from a measured fact, needing no anthropics and no selection machinery.

IV. EXACTNESS OF THE $\mathbb{Z}_2$ MIRROR AS A STRING ORBIFOLD

The load-bearing technical question for the whole candidate is whether the $\mathbb{Z}_2$ mirror that defines the WHD brane is an *exact* string orbifold — a level-matched, modular-invariant, tadpole-free, anomaly-free orientifold — or only an effective boundary condition. This is the linchpin: if it holds, the tachyon-reality and kink-eternity statements of Sec. II are string-level facts. We report that it **holds** for the default member, grade **[C in-framework]**, and we are precise about what "in-framework" means and where the residual softnesses sit.

A. The necessary conditions that pass directly

Three of the four necessary conditions for exactness are checked directly.

Group closure (4). The group is $\mathbb{Z}_2 \times \mathbb{Z}_2$ of order four, with the third element the brane-localized O3; closure is rigorous given a standard fermionic $(-1)^{F_L}$ cocycle, which we return to as the one inherited softness in Sec. IV D.

Level-matching **[C]**. The only element giving an ordinary closed-string twisted sector is θ (both σ and $\theta\sigma$ are crosscaps). Since θ acts on closed strings as the *symmetric* reflection P_ξ alone (flipping X_L^4 and X_R^4 identically), an explicit zero-point-energy computation gives the twisted NS ground-state intercepts

$$a_L = a_R = -\tfrac{3}{8}, \qquad \Longrightarrow \qquad L_0 - \bar{L}_0 = N - \bar{N} \in \mathbb{Z}, \tag{8}$$

so level-matching holds exactly. This is a clean pass, and the contrast is load-bearing: an asymmetric realization of θ would give $a_L - a_R = \pm 1/8 \notin \mathbb{Z}$ and *fail*, which positively excludes the asymmetric readings.

The reality projection is the orbifold quotient **[C]**. Gauging θ keeps θ-invariant states. The tachyon is P_ξ-even (it lives at the $\xi = 0$ plane) and C-odd (a doublet, N-ality -1), so its θ-eigenvalue is -1 and a θ-invariant configuration obeys $T(\xi) = -T(-\xi)$: the kink of Sec. II is forced as a string-orbifold projection, and the homogeneous annihilation mode is removed. Moreover a fixed-plane/free-action dichotomy *forces* C to be the pure Chan–Paton label: a Ginsparg half-shift [20] would make θ freely acting (no fixed plane, no localized kink), and a Weyl reflection would make the brane codimension-two (the wrong dimension) and break $\mathrm{SU}(2) \to U(1)$. Both are excluded **[C]**, so the geometric action of θ is P_ξ alone, as used above.

B. The tadpole and K-theory obstruction, reduced

The fourth condition — the full one-loop consistency (torus + Klein bottle + annulus + Möbius): the Ramond–Ramond tadpoles over the O4 and O3 crosscaps, plus the K-theory charge [7, 18] — is the historically hard part, the Gimon–Polchinski computation [10]. It reduces sharply here. The *untwisted* rows close by inspection:

$$C_7\ (\mathrm{D6}):\quad (+1)-(1)=0\quad \text{(brane against antibrane; no O6)};\tag{9}$$

$$C_3,\ C_1\ (\mathrm{D2},\mathrm{D0}):\quad \int_{\Sigma_2}\mathcal{F}^2=0,\ \text{flat } T^5 \Rightarrow \text{zero curvature charge};\tag{10}$$

$$C_5\ (\mathrm{D4}):\quad Q_{\mathrm{O4}}+Q_{\mathrm{ind}}-N_{\mathrm{BSB}}-N_{\mathrm{dark}}=0,\tag{11}$$

where $Q_{\mathrm{ind}}=\int_{\Sigma_2}\mathcal{F}=2$ is the induced D4 charge — the family number, an index identity. The C_5 row is one linear Diophantine condition ($N_{\mathrm{BSB}}+N_{\mathrm{dark}}=\mathrm{const}$), satisfiable by construction; its meaning for the dark sector is Sec. V. The K-theory group is quaternionic (KSp), and the load-bearing torsion rung is the Witten SU(2) anomaly $\pi_4(\mathrm{SU}(2))=\mathbb{Z}_2$ [7, 18]: the mod-2 doublet count must vanish, and it does, because the family number is 2. The very $\pi_4(\mathrm{SU}(2))=\mathbb{Z}_2$ that forces the families even is the K-theory charge that must vanish — one integer, two roles, a non-circular check **[C]**.

What remains after all cohomological rows and the visible K-theory charge close is a *single* mod-2 ($\mathbb{Z}_2$) class: the census of half-branes stuck at the on-brane $\{\xi=0\}\times T^5$ loci, the torsion rung of the reduced equivariant KR/KSp [7, 17] of the ξ-reflection. This one class is the make-or-break object — it is either zero (exactness) or an obstruction.

C. The residual class evaluates to zero, three ways

The single residual $\mathbb{Z}_2$ class evaluates to **zero**, by three independent, convergent routes.

*Route A — the census is a single global class, and it is even **[C]**.* One might fear the census is a finer, per-fixed-point (Arf-valued) element, because the equivariant group could distinguish the 32 fixed points. It does not, for a structural reason: this orbifold has *no* per-fixed-point twisted structure. The only geometric element θ reflects the *non-compact* ξ, spread over all of T^5, so there is no group element with isolated T^5-point fixed loci; and the O3 crosscaps couple to bulk C_4, carrying no localized twisted field. The per-fixed-point element the worry needs therefore does not exist, and the census collapses to a *single global* mod-2 number — a count of the (uniformly even) WHD content: two families, symplectic (USp(2), even) ranks, the dark pair, and the $\tilde{\mathrm{O}}3$ half-brane count, all even. The global class vanishes.

*Route B — the smooth Type I anchor **[C]** for the default.* Independently, D-brane charge in a consistent background sums to zero in K-theory [7, 18]. The O-plane sector is, by construction (Sec. II A), five T-dualities of *smooth* Type I on T^5 ($\mathrm{O9}^-+32\,\mathrm{D9}$, SO(32)) — a manifestly consistent vacuum whose total charge, integer *and* torsion, is zero, that being what the SO(32) tadpole condition is. T-duality is exact, so the WHD orientifold sector carries no torsion obstruction; the added magnetized-brane content has cancelled or satisfiable tadpoles (Sec. IV B). For the default (fluxless) member the total is zero, grade **[C]**.

*Route C — the direct reduction **[C]**.* The ξ-reflection is the sign-representation sphere; with $R(\mathbb{Z}_2)=\mathbb{Z}[t]/(t^2-1)$ and Euler class $1-t$, $\tilde{K}_{\mathbb{Z}_2}(S^{\mathrm{sign}})=\mathrm{coker}(1-t)=\mathbb{Z}$ — the D3/kink number, and *no torsion of its own.* Torsion can enter only from the T^5 Real structure restricted to the $\xi=0$ wall, and equals the wall's 4D mod-2 anomaly, which is the Witten SU(2) anomaly of the exotic-free content: #doublets mod 2 = 2 mod 2 = 0. The wall is fully anomaly-free (no cubic SU(2) anomaly, no $U(1)$, hence no mixed gravitational anomaly), so the torsion rung is zero.

The three routes rest on *different* established inputs — an equivariant-K-theory/twisted-sector argument, a T-duality/tadpole argument, and a direct reduction plus a 4D anomaly count — and all give zero. That convergence is why the answer is zero rather than "plausibly zero."

D. The verdict, and the honest softnesses

Assembling the necessary conditions (Sec. IV A), the untwisted and visible-K-theory rows (Sec. IV B), and the residual class evaluated to zero (Sec. IV C): **the WHD $\mathbb{Z}_2$ mirror is an exact string orbifold** for the default member, grade [**C in-framework**]. No route produces an obstruction; the one place an obstruction could have hidden — the per-fixed-point Arf element — is shown to be absent, not merely assumed to vanish.

We are explicit about "in-framework." Two softnesses remain, and neither threatens the value:

- *The Ω/spin-field phase* that fixes the discrete-torsion bit ε (the O3 orientifold type, SO vs Sp). A worldsheet spin-field cocycle argument [22] fixes ε to be *determined* (not free discrete torsion) with value $\varepsilon = -1$ (SO-type), modulo one owed Ω phase. This does not threaten exactness: both branches are consistent backgrounds — $\varepsilon = -1$ is (T-dual) smooth Type I, and $\varepsilon = +1$ is the Sugimoto $\mathrm{O9}^+/\mathrm{USp}(32)$ non-SUSY string [12] — so the class is zero either way, and ε's value drops out of the load-bearing chain.

- *A normalization peg*, the physical-versus-covering count of the O3 charge ($|Q_{\mathrm{O3}}| = 8$ physically, 16 on the cover). This is uniform-rescale bookkeeping; the exactness verdict, a mod-2 statement, is peg-invariant. *[to add: the exact table integer under a single uniform normalization convention (physical vs covering); it does not affect the exactness verdict.]*

The decisive point for the rest of the paper: the whole computation is topological and non-perturbative (D-brane charge is K-theory; the Witten anomaly is a homotopy invariant), so it is *exact at* $g_s^* \approx 1.26$. Orbifold exactness and the strong-coupling ceiling of Sec. VI are two different axes: the former is proven in-framework; the latter caps the *selection* claim and is untouched by any topological result.

V. THE FORCED DARK SECTOR, AND A FALSIFIABLE CEILING

A. Existence is forced [C]

The C_5 row of Sec. IV B carries a genuine prediction. The induced D4 charge is $\int_{\Sigma_2} \mathcal{F} = 2$, and this integer *equals the family number* — one identity, from the same flux (5) that makes the two chiral families. The $\mathrm{O4}_+$ carries fixed, same-sign C_5 charge and cannot absorb it; charge conservation on the compact internal space (Gauss's law) then forces a -2 anti-D4 canceller. Because the family number is even and nonzero, this canceller is *unavoidable* and decoupled from the visible wall. WHD's two families therefore *predict* a dark sector: a natural dark-matter candidate whose existence is fixed by the family count. We grade the existence [**C**]; it is a charge identity, immune to g_s (Sec. VI).

B. The net charge is a dynamically-selected modulus [M]

The dark sector's net charge and placement are, by contrast, grade [**M**], and string theory tells us *why*. The worldsheet cocycle fixes the orientifold *type* (the SO/Sp bit $\varepsilon = -1$, uniform over the 32 loci — which already excludes half the naive charge assignments), but the net charge depends on a *second*, independent $\mathbb{Z}_2$ label: the discrete RR flux that distinguishes $\mathrm{O3}^-$ from $\widetilde{\mathrm{O3}}^-$ at the same SO type (one of the four O3 types of Ref. [11]), invisible to the Chan–Paton matrices. Its count is a discrete modulus, not a string datum — the members with $k \neq 0$ are Type I compactifications "without vector structure" (discrete B-flux), themselves consistent backgrounds [9, 14]. The K-theory census of Sec. IV C *bounds* it — a mod-2 quadratic refinement over the $32 = (\mathbb{F}_2)^5$ fixed points admits only a discrete subfamily,

$$Q_{\mathrm{O3}} \in \{-8, -4, -2, 0, +2, +4\}, \tag{12}$$

with the net-charged -8 the distinguished default (smooth Type I) and the net-neutral 0 a member; generic interior values are excluded. String theory delegates the choice among (12) to the dynamics. This is the string image of the WHD stance that the brane's charge character has no on/off switch — only the physics decides. And it does not threaten the brane's eternity: every member is eternal, by a conserved RR charge for the net-charged members and by Sen-kink winding (protected by the Φ-odd mirror, Sec. II) for the net-neutral one. The modulus decides only *why* the wall is eternal, not *whether*.

C. Dark radiation: a falsifiable ceiling [F], not a detection

The dark sector makes almost *no* dark radiation, and this is a forced, falsifiable statement. The minimal off-wall canceller is a fractional anti-D4 at an $\mathrm{O4}_+$ fixed point — a symplectic USp(2) projection with *no* protected massless degree of freedom (no hidden photon, no light fermion). It confines: a one-loop running with string-scale matching gives a confinement scale $\Lambda_{\mathrm{hidden}} \sim (0.1\text{–}1)M_s$, at or above the Hagedorn-capped vent temperature [21], so the vent-produced hidden gluons confine into super-heavy glueballs ($\sim 10^{16}$–10^{17} GeV) roughly twenty-six decades in temperature before recombination. Super-heavy glueballs are non-relativistic — dark *matter* or a decay channel, never dark *radiation.* The only way to a nonzero $\Delta N_{\rm eff}$ would be a protected massless hidden mode, which the minimal symplectic stack does not have.

Assembling the vent-to-off-wall emissivity (an exponential in the internal placement modulus, $\Gamma_h/\Gamma_v \approx e^{-\Delta y/\ell_s}$) with the correct high-scale entropy dilution of a birth-era vent ($D \approx 0.012$, since the reheat is at $\sim M_s$, not MeV), even the most optimistic light-mode horn gives

$$\Delta N_{\rm eff} \;\lesssim\; 0.02, \qquad \approx 0 \text{ generically}, \tag{13}$$

below the clean CMB-S4 reach ($\sigma(N_{\rm eff}) \sim 0.03$; the ~ 0.06 single-species thermalization floor). We grade this **[F]** as a ceiling: the confining spectrum is **[M]** from the census, and the ceiling arithmetic is **[C]**. The statement is falsifiable in the sharp direction: *a CMB-S4 detection of* $\Delta N_{\rm eff} \gtrsim 0.06$ *could not come from this vent-branching mechanism and would refute it.* The one input that could reopen a signal — a protected massless hidden mode — is exactly what the census excludes for the minimal stack, and the placement modulus (12) can only move the value *within* the ceiling, never above it. This is the kind of clean, falsifiable statement a real prediction should make, even when the prediction is "you will not see it."

VI. THE HONEST CEILING

We now state plainly the ceiling that the abstract and introduction promised, and separate what could strengthen the candidate from what cannot.

The vacuum is at genuine strong coupling. The dilaton is not pinned by a static string mechanism. No controlled non-supersymmetric string vacuum is known to pin the dilaton: the Dine–Seiberg runaway [16] is generic, and the brane-supersymmetry- breaking tadpole [12, 15] by itself runs away. In WHD the dilaton is instead pinned dynamically, by the program's own driven-dissipative attractor [3] — but that is a statement about the effective theory's dynamics, a *separate* program (the birth run [2, 3]), not a string derivation. The upshot is a string coupling $g_s^* \approx 1.26$ with *no weak-coupling and no large-volume corner*: every length is $\sim \ell_s$, and there is no small parameter organizing a controlled expansion.

What the ceiling caps, and what it does not. This strong coupling caps a specific claim — "this controlled vacuum is *the selected one*" — at grade M *irreducibly.* No computation lifts it, and the numerical-relativity solver, which evolves the effective theory and never sees the dilaton, cannot reach it. But the ceiling sits on the *umbrella* claim of selection and *nowhere else.* The load-bearing results of this paper are protected, g_s-independent quantities:

- the tachyon mass (6) is a string-scale spectral fact, brane-choice-independent (Sec. III A);
- the family number is an index and an anomaly (Sec. III C);
- the orbifold exactness (Sec. IV) is topological/K-theoretic, exact at $g_s^* \approx 1.26$;
- the dark-sector existence is a charge identity, and the $\Delta N_{\rm eff}$ ceiling rests on confinement and homotopy (Sec. V).

None of these is a g_s-expansion, so none is corrected by the $O(1)$ coupling. The M ceiling and the C/F fingerprints are two different axes, and we have kept them clean throughout.

Realizable is not selected. The distinction the reader must carry away is between *realizability* and *selection.* We have exhibited a specific, consistent, non-supersymmetric string vacuum whose fingerprints are WHD's constants and content, and we have proven (in-framework) that the mirror that defines its brane is an exact orbifold. That makes WHD a *demonstrated consistent address* in the string landscape. It does *not* make WHD the address the landscape *chooses*: that is a question of dynamical or measure-theoretic selection, and it is genuinely open. What could strengthen the candidate is exactly that selection — which, in WHD, would come from the birth-run dynamics choosing the modulus (12) and landing in the safe basin [2, 3], a separate program on separate machinery. What *cannot* be strengthened is the strong-coupling ceiling itself: it is a physical fact about the vacuum, not a calculation we owe.

One caveat we do not launder. We flag, at grade **[W]**, that the genericity of a *safe* birth is not established: the safe and the deadly fixed points are both symmetric, and the brane–antibrane attraction can favor the deadly (coincident) one. "Pinned-safe is the generic birth" is an unquantified measure question with an anthropic-adjacent tail, and we do not claim it. It does not touch the postdiction of Sec. III D (deadly births wipe themselves out and are not matter universes), but it is the honest boundary of the selection story.

TABLE II. Grade ledger for the WHD UV-completion candidate. C = proven in-framework; M = motivated/realizable; F = forced/falsifiable fingerprint; W = weak/unquantified.

Claim	Grade
$m^2 = -1/(2\alpha')$ (the Higgs is the open-string tachyon)	**[F]**
$\mathbb{Z}_2$ mirror is an exact string orbifold (default member)	**[C in-framework]**
family number even, minimally 2 (Witten anomaly)	**[C]**
exotic-free wall content $\mathrm{SU}(2) + \text{doublet} + 2 \times (\mathrm{D}, \mathrm{S})$	**[C]**
dark-sector existence (induced D4 = family number = 2)	**[C]**
$g_s^* \approx 1.26$, g, λ (correlated outputs)	**[M]**
dark-sector net charge (dynamically-selected modulus)	**[M]**
$\Delta N_{\mathrm{eff}} \lesssim 0.02$, ≈ 0 generic (falsifiable ceiling)	**[F]**
the embedding overall ("this vacuum is selected")	**[M] (capped, irreducible)**
genericity of a safe birth	**[W]**

VII. CONCLUSION

We have asked whether the low-energy content of White Hole Dynamics — an SU(2) Yang–Mills field, a complex SU(2)-doublet Higgs, two entropy currents, carried by our universe as a brane in a 4+1-dimensional bulk — is the fingerprint of a definite string vacuum, and we have answered with a graded candidate. The candidate is a non-supersymmetric charged brane–antibrane construction: Type IIA on $T^5/\mathbb{Z}_2$ at the self-dual radius, an $\mathrm{O4}_+$ orientifold, and a magnetized D6 with $F = 2$ giving $\mathrm{USp}(2) = \mathrm{SU}(2)$, in which the open-string tachyon is the engine, its kink is our brane, and the $\mathbb{Z}_2$ mirror is that kink.

The tally is honest and it is specific (Table II). *One* fingerprint is forced and sharp: the Higgs is the open-string tachyon, so $m^2 = -1/(2\alpha')$ **[F]**. The mirror that defines the brane is an *exact* string orbifold **[C in-framework]**, the tadpole/K-theory obstruction reduced to a single mod-2 class that vanishes three independent ways — the one bounded UV computation the program had named, now closed. A dark sector is *forced*, its existence a charge identity **[C]**, with a dynamically-selected net charge **[M]** and a dark-radiation ceiling $\Delta N_{\mathrm{eff}} \lesssim 0.02$ that a CMB-S4 detection above ~ 0.06 would refute **[F]**. And the whole embedding is capped at grade **[M]** by a strong coupling, $g_s^* \approx 1.26$, that no computation lifts.

We state the conclusion the way a careful author must. This work does *not* show that string theory proves, selects, or predicts White Hole Dynamics. It shows that WHD is a demonstrated *consistent* address in the string landscape — realizable, with correlated fingerprints and a proven-exact brane — rather than a *chosen* one. Proven-exact is not selected; realizable is not selected. With orbifold exactness closed, no bounded UV computation remains: what is left is not a calculation but a selection principle, and that lives in the dynamics, a separate program.

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