The Mena Dominance Law of Operational Decay

A Fundamental Law of Bounded Viability for Constraint-Bearing Systems

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January 2026

Abstract

This paper states the *Mena Dominance Law of Operational Decay* (MDL) as a fundamental law of bounded viability for constraint-bearing systems. Its simplest form is

$$\Delta = Potential - Load,$$

where **Potential** is recoverable support and **Load** is imposed demand. In declared embodiments, the law is instantiated dynamically as

$$\Delta_X(t) = Potential_X(t) - Load_X(t),$$

with $Potential_X(t)$ and $Load_X(t)$ expressed in a single governing channel and a commensurate unit system. The law states that the operational state of X is governed by the trajectory of $\Delta_X(t)$ rather than by snapshot reserve alone. Four universal consequences follow. First, the sign and threshold position of $\Delta_X(t)$ determine viability regime. Second, warning, time-to-critical, and irreversibility are first-hitting-time outputs of the trace. Third, recoverability is finite and is exhausted when admissible intervention can no longer produce a reliable increase in $\Delta_X(t)$. Fourth, in deficit-sensitive embodiments, sustained negative dominance couples to accelerated loss of recoverable potential through *Reciprocal Decay.* The law is fundamental at the level of bounded viability: universal in operational form, embodiment-specific in mechanism, and physically instantiated when a declared embodiment provides a governing channel, commensurate units, a measurement or estimation pipeline, thresholds, uncertainty discipline, and a falsification hook. Representative embodiments in voltage, pressure, metabolic-power, and structural-demand channels illustrate how the same law can be instantiated for batteries, stars, plants, and civil systems once recoverable support and imposed demand are expressed in a single channel.

Keywords: dominance trace, bounded viability, recoverable potential, imposed load, Grace, Reciprocal Decay, deficit dose, boundary-crossing time, constraint-bearing systems.

Contents

1 Introduction

Bounded systems do not persist by threshold labels alone. They persist only while recoverable support remains ahead of imposed demand in the governing channel that decides continued structure or function. Engineering and risk practice have long used margins, reserves, safety factors, utilization bounds, and threshold checks to evaluate such systems. These constructs are useful, but they are usually static. They certify a state at an instant; they do not, by themselves, govern the trajectory of viability.

This paper states a law for that trajectory. In its simplest form, the *Mena Dominance Law of Operational Decay* (MDL) is

$$\Delta = Potential - Load,$$

where **Potential** is recoverable support and **Load** is imposed demand. In operational use, the law is instantiated as a measurable dominance trace

$$\Delta_X(t) = Potential_X(t) - Load_X(t),$$

with both terms expressed in the same governing channel and the same unit system. The law is not the subtraction alone. Its content is that once this trace is declared and measured in a valid embodiment, the trajectory of the trace determines regime, boundary crossing, recoverability, and, in deficit-sensitive embodiments, deterioration steepening.

The law is fundamental in the following sense. It identifies a primitive operational invariant for systems whose continued existence depends on recoverable support exceeding imposed demand. Other laws govern substrate and mechanism. The MDL governs bounded viability itself: whether dominance is preserved, eroded, restored, or irreversibly lost.

Scope, claim class, and falsifiability

Claim class. This paper advances a fundamental law of bounded viability for constraint-bearing systems. The law is fundamental at the level of bounded viability: it identifies a primitive trajectory variable, $\Delta_X(t)$, whose evolution determines regime, recoverability, and boundary approach in declared embodiments.

Universality. The law is universal in operational form. Its mechanism is embodiment-specific. Universality therefore lies in the dominance-trace structure and its derived operators, not in a claim that all embodiments share one substrate mechanism or one universal degradation equation.

Embodiment status. A declared embodiment may be physical or meta-operational. Physical embodiments use commensurate physical units and a replicable measurement or estimation pipeline. Meta-operational embodiments use tethered variables tied to measurable consequences. In either case, predictive use requires an explicit embodiment contract.

Falsifiability. The law is falsifiable through its embodiments. A declared embodiment fails if its boundary is violated while $\Delta_X(t)$ remains reliably positive beyond declared uncertainty, or if a deficit-sensitive embodiment fails to show the claimed deficit-coupled steepening after controlling known confounds.

Novelty and relation to prior work

Margin, reserve, and capacity–demand constructs are widely used across engineering and risk practice, often as static or snapshot criteria such as safety factors, reserve capacity, and reliability margins [1]. The contribution of this work is not the arithmetic form

$$\Delta = Potential - Load,$$

itself, but the elevation of that relation to a measurable dominance trace with explicit trajectory structure. The law formalizes: (i) dominance as a time-dependent viability observable, (ii) finite recoverability through Grace, including both state-based thresholds and response-based control sensitivity, and (iii) a conditional deficit-coupled deterioration structure, Reciprocal Decay, for embodiments in which sustained deficit exposure accelerates loss of recoverable potential. In this respect, the law extends static margin reasoning into a trajectory-based law of bounded viability [3, 2].

2 Admissible System Class

A system belongs to the admissible class of the law if all of the following hold:

1. it possesses a governing operational channel in which continued structure or function is decided;
2. recoverable support and imposed demand can be expressed in a commensurate representation within that channel;
3. boundary violation has an operational consequence;
4. the system evolves over time under changing support, load, or both.

We call such a system a *bounded, constraint-bearing system.* Examples include stellar cores, batteries, plants, and structures, among other bounded, constraint-bearing systems once a valid governing channel is declared.

For control-relevant embodiments, an additional condition is required: at least one admissible intervention must exist that can alter effective support, effective load, or the governing architecture on the relevant decision timescale. This additional condition is required for response-based Grace and control claims, but not for the basic statement of the law itself.

3 Canonical Statement of the Law

Mena Dominance Law of Operational Decay. For any bounded, constraint-bearing system, define the simple law form

$$\Delta = Potential - Load.$$

For any declared embodiment X with a governing channel and commensurate measurable quantities $Potential_X(t)$ and $Load_X(t)$, instantiate the law dynamically as

$$\Delta_X(t) = Potential_X(t) - Load_X(t).$$

The operational viability of X is governed by the trajectory of $\Delta_X(t)$.

Boundary law.

$$\Delta_X(t) > 0 \Rightarrow \text{viable}, \qquad \Delta_X(t) = 0 \Rightarrow \text{critical boundary}, \qquad \Delta_X(t) < 0 \Rightarrow \text{deficit}.$$

Trajectory law. Warning, time-to-critical, and irreversibility are first-hitting-time outputs of the dominance trace.

Recoverability law. Recoverability is finite. Grace exists only while admissible intervention can still produce a reliable increase in $\Delta_X(t)$.

Reciprocal Decay law. In deficit-sensitive embodiments, sustained negative dominance couples to accelerated loss of recoverable potential unless admissible intervention restores dominance.

4 Primitive Quantities

For any admissible embodiment:

- **Potential** is recoverable support available to sustain structure or function in the governing channel.
- **Load** is imposed demand, required support, or opposing burden in the same channel.
- **Dominance trace** is
$$\Delta_X(t) = Potential_X(t) - Load_X(t).$$
- **Normalized stress ratio** is
$$\Delta D_X(t) = \frac{Load_X(t)}{Potential_X(t)},$$
defined when the denominator is well posed, with an ϵ-floor if needed for numerical stability.

The law is universal in operational form. Its physical content appears only through embodiment. Once a domain supplies a governing channel, commensurate definitions, a measurement or estimation pipeline, thresholds, uncertainty, and—where relevant—admissible interventions, $\Delta_X(t)$ becomes a measurable viability trace in that domain.

5 Core Law Statement

The simple form of the law is

$$\Delta = Potential - Load. \tag{1}$$

For any declared embodiment X, the law is applied dynamically as

$$\Delta_X(t) = Potential_X(t) - Load_X(t). \tag{2}$$

In physical embodiments, $\Delta_X(t)$ may be interpreted as the governing viability margin in the chosen channel. When useful, one may write

$$\mathcal{F}_{V,X}(t) := \Delta_X(t)$$

as a notation layer for that governing margin.

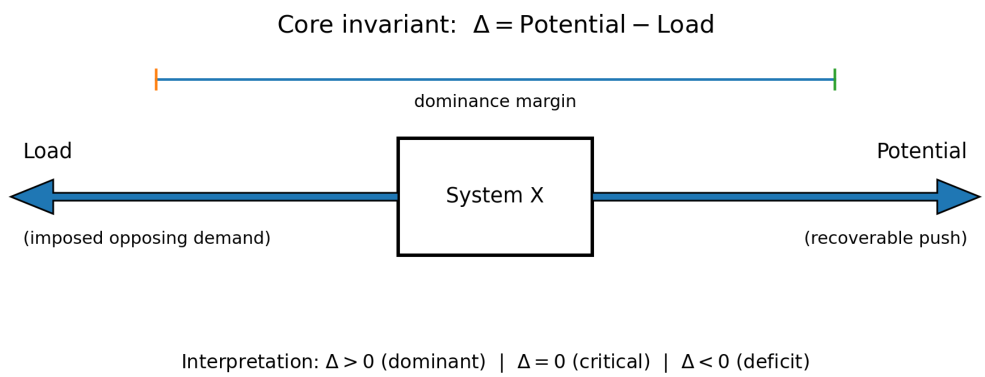

Figure 1: Physical schematic of the MDL core invariant. A bounded system experiences recoverable operational support (Potential) opposed by imposed demand (Load). The law is first stated in simple form as $\Delta = Potential - Load$ and then tracked dynamically as $\Delta_X(t) = Potential_X(t) - Load_X(t)$.

5.1 Dynamic form and trajectory outputs

In any declared embodiment,

$$Potential_X(t_k), \qquad Load_X(t_k), \qquad \Delta_X(t_k) = Potential_X(t_k) - Load_X(t_k),$$

are sampled or estimated on a declared time grid $\{t_k\}$.

The predictive outputs of the law are computed from the measured or estimated dominance trace. In particular, warning, time-to-critical, and irreversibility are defined as first-hitting-time outputs in Section 6.

No smoothness assumption is required. For sampled data, these outputs are computed as the first indices at which the stated inequalities hold. We refer to t_{critical} as the time-to-critical operator.

5.2 Commensurate forms

Two recurrent forms of the law appear across embodiments.

Rate form. When support and demand are naturally expressed as matched rates,

$$\Delta_{R,X}(t) = P_{R,X}(t) - L_{R,X}(t).$$

Budget–dose form. When the embodiment is governed by a stored budget depleted by a load rate,

$$\Delta_{E,X}(t) = E_X(t) - \int_{t_0}^{t} \dot{E}_{\text{load},X}(\tau)\, d\tau,$$

where the integral shares units with $E_X(t)$.

Under locally constant load rate,

$$T_{M,X}(t) \approx \frac{\Delta_{E,X}(t)}{\dot{E}_{0,X}}.$$

Under locally linear load rate with $\alpha_X > 0$,

$$T_{M,X}(t) = \frac{-\dot{E}_{0,X} + \sqrt{\dot{E}_{0,X}^2 + 2\alpha_X \Delta_{E,X}(t)}}{\alpha_X}.$$

These are conditional countdowns in a declared local model. They do not replace the primary first-hitting-time outputs when a direct dominance trace is available.

6 Regimes and Boundary-Crossing Operators

6.1 Regimes

Let $\tau_{w,X}$ denote a warning threshold and $\tau_{r,X}$ an irreversibility threshold, with

$$\tau_{r,X} < 0 < \tau_{w,X}.$$

The law yields the following regime structure:

$$\Delta_X(t) > \tau_{w,X} \Rightarrow \text{surplus},$$

$$\tau_{r,X} < \Delta_X(t) \le \tau_{w,X} \Rightarrow \text{Grace},$$

$$\Delta_X(t) = 0 \Rightarrow \text{critical boundary},$$

$$\Delta_X(t) < 0 \Rightarrow \text{deficit},$$

$$\Delta_X(t) \le \tau_{r,X} \Rightarrow \text{irreversibility threshold crossed}.$$

In normalized form,

$$\Delta D_X(t) < 1 \Rightarrow \text{viable}, \qquad \Delta D_X(t) = 1 \Rightarrow \text{critical boundary}, \qquad \Delta D_X(t) > 1 \Rightarrow \text{deficit}.$$

Grace is a recoverability interval, not a mutually exclusive sign regime. In many embodiments it spans both late positive-margin states and the recoverable portion of deficit above $\tau_{r,X}$.

6.2 First-hitting-time outputs

Given a measured or estimated dominance trace, define

$$t_{\text{warning}} := \inf\{t : \Delta_X(t) \le \tau_{w,X}\},$$

$$t_{\text{critical}} := \inf\{t : \Delta_X(t) \le 0\},$$

$$t_{\text{irreversible}} := \inf\{t : \Delta_X(t) \le \tau_{r,X}\}.$$

No smoothness assumption is required. For sampled data, these are the first indices at which the stated inequalities hold.

7 Grace: The Law of Finite Recoverability

Viability is not binary. Between comfortable dominance and irreversible loss lies a finite recoverable interval. The law names that interval *Grace*.

7.1 State-based Grace

State-based Grace is the region

$$\tau_{r,X} < \Delta_X(t) < \tau_{w,X}.$$

A system in Grace remains recoverable but no longer possesses comfortable viability margin. Depending on the embodiment, Grace may include the recoverable portion of deficit after the critical boundary has been crossed but before irreversibility is reached. Grace is exhausted when

$$\Delta_X(t) \le \tau_{r,X}.$$

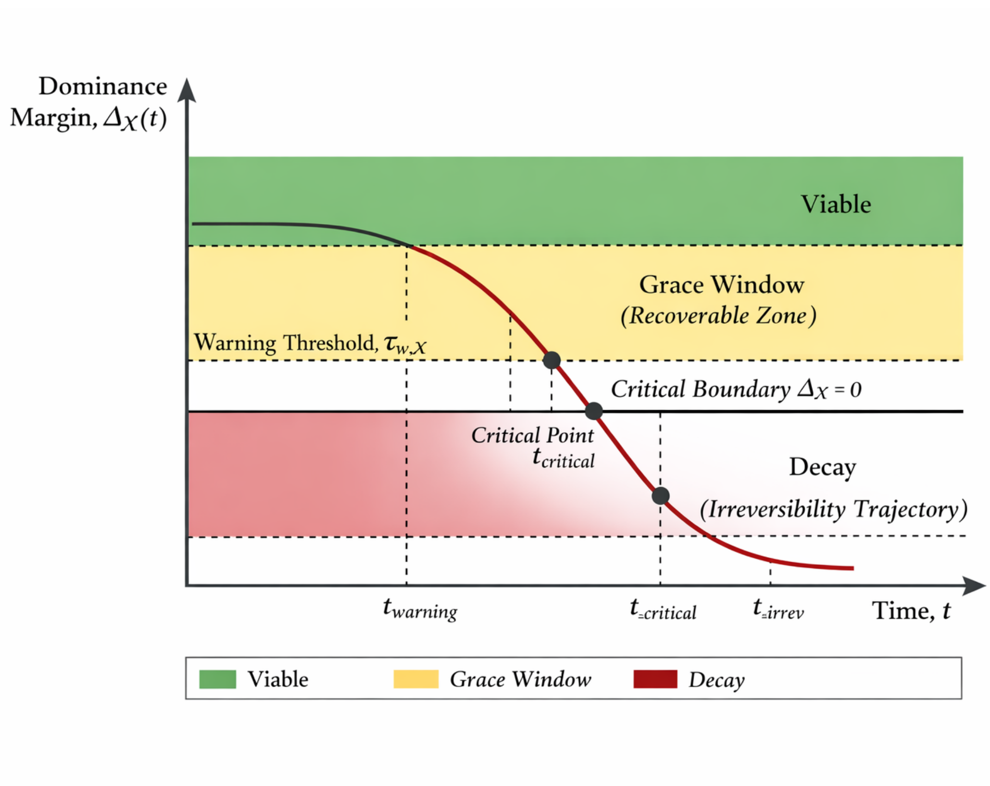

Figure 2: Dominance regimes and the Grace window. The dominance trace $\Delta_X(t)$ crosses the warning threshold $\tau_{w,X}$, the critical boundary $\Delta_X = 0$, and the irreversibility threshold $\tau_{r,X}$, defining a finite recoverable interval and the associated boundary-crossing times.

7.2 Response-based Grace

State tells where the system stands. Response tells whether the system can still be pulled back.

Let R denote an admissible intervention or intervention policy applied from time t, and let R_0 denote the corresponding baseline no-intervention policy. Define the short-horizon response gain

$$G_X(t; R, \Delta t) = \Delta_X(t + \Delta t \mid R) - \Delta_X(t + \Delta t \mid R_0).$$

Response-based Grace exists at time t if there exists an admissible intervention R such that

$$G_X(t; R, \Delta t) \geq g_{\min,X},$$

where $g_{\min,X} > 0$ is the minimum detectable or operationally meaningful improvement, set above measurement resolution and ordinary noise.

Response-based Grace is exhausted when, across repeated decision instants, no admissible intervention can achieve

$$G_X(t; R, \Delta t) \geq g_{\min,X}.$$

7.3 Correction cost

Let $\mathcal{U}_X$ denote the set of admissible intervention policies over a planning horizon $H > 0$. Let $\mathrm{cost}_X(u; t, H) \geq 0$ denote the embodiment-defined resource cost of applying policy $u \in \mathcal{U}_X$ from t to $t + H$.

Define the minimum admissible recovery cost required to restore dominance above a target level θ after horizon H:

$$C_X(t; H, \theta) := \inf_{u \in \mathcal{U}_X} \ \mathrm{cost}_X(u; t, H) \quad \text{s.t.} \quad \Delta_X(t + H \mid u) \geq \theta.$$

If no admissible policy satisfies the constraint, define

$$C_X(t; H, \theta) = +\infty.$$

As irreversibility is approached, one expects $C_X(t; H, \theta)$ to increase and ultimately diverge.

8 Reciprocal Decay

8.1 Law statement

In deficit-sensitive embodiments, sustained dominance violation

$$\Delta_X(t) < 0$$

over a nontrivial operational interval induces a sign-coupled deterioration process: unless admissible intervention restores dominance, loss of recoverable potential tends to steepen with the magnitude and persistence of deficit.

8.2 Deficit dose

To capture both intensity and persistence, define a nonnegative deficit dose

$$D_X(t) = \int_0^t \phi\big(\max(0, -\Delta_X(\tau))\big)\, d\tau, \qquad \phi(\cdot) \geq 0.$$

The function ϕ is embodiment-defined, but it must be sign-consistent: larger and longer deficits produce larger dose. In deficit-sensitive embodiments, deterioration steepening is coupled to deficit dose rather than to elapsed time alone.

8.3 General coupling form

A general deficit-sensitive realization may be written as

$$\frac{d\,Potential_X(t)}{dt} = -\mathcal{D}_X\big(\text{state}, \text{environment}, \mathcal{C}_X(t)\big), \tag{3}$$

$$\mathcal{C}_X(t) \geq 0, \qquad \mathcal{C}_X(t) \text{ increases with sustained } \max\big(0, -\Delta_X(t)\big). \tag{4}$$

The law requires sign-consistent deficit coupling, not a single universal exponent or a single universal differential equation. Sustained negative dominance must worsen future recoverable potential or raise effective burden in the embodiment.

9 Falsification Criteria

The law is falsifiable within declared embodiments.

An embodiment fails if any of the following occurs:

1. a declared operational boundary is violated while the measured or estimated dominance trace remains reliably positive beyond stated uncertainty;
2. recoverability is repeatedly observed after the declared irreversibility threshold under unchanged admissible controls and unchanged measurement contract;
3. in a deficit-sensitive embodiment, sustained deficit dose fails to associate with nondecreasing deterioration burden after controlling known confounds.

These are embodiment-level falsifiers within the law's contract. A failed embodiment mapping does not, by itself, invalidate the law in other declared embodiments; it invalidates the stated mapping or deficit-sensitive claim for that embodiment.

10 Embodiment Contract

A physical embodiment is valid for predictive use when it provides:

1. a declared governing channel;
2. explicit definitions of $Potential_X(t)$ and $Load_X(t)$ in one commensurate unit;
3. measured observables and sampling cadence;
4. an estimator or pipeline from observables to $Potential_X(t)$, $Load_X(t)$, and $\Delta_X(t)$;

5. declared uncertainty sufficient to interpret thresholds and gains;
6. an admissible intervention class when response-based Grace or control claims are made;
7. an explicit falsification hook.

Embodiments without a direct physical unit channel may still instantiate the law meta-operationally when their variables are tethered to measurable consequences and their mapping is replicable. In such cases the claims are meta-operational rather than direct physical-embodiment claims.

Table 1: Embodiment definition template.

Item	**Definition**	**Unit**	**Measurement**
$Potential_X(t)$	recoverable support	declared unit	sensor + estimator
$Load_X(t)$	imposed demand	same unit	sensor + estimator
$\Delta_X(t)$	$Potential_X(t) - Load_X(t)$	same unit	computed
Observables	declared signals	mixed	instruments / data sources
Cadence	T_s	time	logging procedure
Noise / uncertainty	ϵ_X or CI	unit of Δ	resolution / estimator error
Thresholds	$\tau_{w,X}, \tau_{r,X}$	unit of Δ	physical or meta-operational basis

11 Representative Embodiment Map

Table 2: Representative governing channels and dominance variables used in this paper.

Field	**Governing Channel (Unit)**	**Potential**	**Load**
Batteries	Voltage (V)	Estimated rest-equivalent voltage support	Cutoff voltage plus load-induced voltage drop
Stars	Pressure (Pa)	Local support pressure in the governing region	Pressure required to balance gravitational compression
Plants	Metabolic power (W)	Recoverable metabolic power available to sustain function	Metabolic power demand for maintenance, repair, and stress response
Bridges (Appendix A)	Structural demand ($kN \cdot m$)	Recoverable resistance of the governing limit state	Traffic plus environmental demand on that limit state

12 Battery Embodiment: Voltage-Margin Basis

Let X = batt be a Li-ion battery pack treated as a bounded, constraint-bearing system whose function is to maintain terminal voltage support against imposed discharge demand.

12.1 Operational quantities

Table 3: Battery embodiment definition table.

Item	Definition	Unit	Measurement
$Potential_{\text{batt}}(t)$	$V_{\text{rest}}(t)$	V	rest proxy or inferred rest-equivalent voltage
$Load_{\text{batt}}(t)$	$V_{\text{cut}} + I(t)R_{\text{eff}}(t)$	V	cutoff plus measured current times estimated effective resistance
$\Delta_{\text{batt}}(t)$	$Potential_{\text{batt}}(t) - Load_{\text{batt}}(t)$	V	computed; equivalently $V_{\text{term}}(t) - V_{\text{cut}}$
Observables	$V_{\text{term}}(t), I(t)$, optional $T(t)$	V, A, °C	logger / load readout
Cadence	T_s	s	logger cadence
Noise / resolution	ϵ_V	V	effective voltage uncertainty

Choose a voltage-margin channel. Let

$$V_{\text{term}}(t) = V_{\text{rest}}(t) - I(t)R_{\text{eff}}(t). \tag{5}$$

Let the enforced cutoff condition be

$$V_{\text{term}}(t) \geq V_{\text{cut}}.$$

Define

$$\begin{aligned} Potential_{\text{batt}}(t) &:= V_{\text{rest}}(t), \\ Load_{\text{batt}}(t) &:= V_{\text{cut}} + I(t)R_{\text{eff}}(t), \\ \Delta_{\text{batt}}(t) &:= V_{\text{rest}}(t) - \big(V_{\text{cut}} + I(t)R_{\text{eff}}(t)\big). \end{aligned}$$

By substitution from (5),

$$\Delta_{\text{batt}}(t) = V_{\text{term}}(t) - V_{\text{cut}}.$$

Hence

$$\Delta_{\text{batt}}(t) \geq 0 \iff V_{\text{term}}(t) \geq V_{\text{cut}}.$$

12.2 Admissible current headroom

At cadence-level, define the maximum cutoff-respecting discharge current

$$I_{\max}[k] := \max\left(0, \frac{V_{\text{rest}}[k] - V_{\text{cut}}}{\widehat{R}_{\text{use}}[k]}\right).$$

Then

$$I[k] \le I_{\max}[k] \Longrightarrow V_{\text{term}}[k] \ge V_{\text{cut}}.$$

This yields an embodiment-level control implication of the law: the dominance margin determines admissible current headroom under the declared estimator.

12.3 Embodiment-specific falsification

The embodiment fails if cutoff occurs while the estimator-based margin remains reliably positive beyond ϵ_V, or if repeated sustained near-boundary operation does not associate with any measurable deficit-sensitive steepening such as increased sag or growth in effective resistance under controlled comparison.

13 Star Embodiment: Pressure-Margin Basis

Let $X = \star$ be a massive star core treated as a bounded, constraint-bearing system whose function is to maintain pressure support against gravitational compression.

13.1 Operational quantities

Table 4: Star embodiment definition table.

Item	**Definition**	**Unit**	**Measurement**
$Potential_\star(r,t)$	$P_\star(r,t)$	Pa	inferred from stellar structure / EOS model constrained by observables
$Load_\star(r,t)$	$P_{\text{req}}(r,t)$	Pa	computed hydrostatic requirement from inferred profiles
$\Delta_\star(t)$	$\min_{r\in[0,r_{\text{core}}]}\big(P_\star - P_{\text{req}}\big)$	Pa	computed per time step
Observables	M, R, L, T_{eff}, composition, optional modes	mixed	photometry / spectroscopy / asteroseismology
Cadence	Δt	s/yr	assimilation cadence
Noise / resolution	$\epsilon_\star$	Pa	propagated inference uncertainty

Define

$$\begin{aligned} Potential_\star(r,t) &:= P_\star(r,t), \\ Load_\star(r,t) &:= P_{\text{req}}(r,t), \\ \Delta_\star(r,t) &:= P_\star(r,t) - P_{\text{req}}(r,t). \end{aligned}$$

The gravity-required pressure is

$$\frac{dP_{\text{req}}}{dr}(r,t) = -\frac{Gm(r,t)\rho(r,t)}{r^2}, \qquad P_{\text{req}}(R,t) = 0,$$

equivalently,

$$P_{\text{req}}(r,t) = \int_r^R \frac{Gm(r',t)\rho(r',t)}{r'^2}\,dr'.$$

A conservative scalar dominance trace is the minimum core margin

$$\Delta_\star(t) := \min_{r\in[0,r_{\text{core}}]} \Delta_\star(r,t).$$

13.2 Local countdown

On any local window where $\Delta_\star(t)$ is approximately monotone, define the local margin-loss rate

$$\kappa_\star(t) := -\frac{d\Delta_\star}{dt}(t).$$

When $\kappa_\star(t) > 0$,

$$T_{w,\star}(t) \approx \frac{\Delta_\star(t) - \tau_{w,\star}}{\kappa_\star(t)}, \qquad T_{r,\star}(t) \approx \frac{\Delta_\star(t) - \tau_{r,\star}}{\kappa_\star(t)}.$$

As support erodes and $\kappa_\star$ rises, the countdowns shrink: that is the star-form of dominance collapse.

13.3 Reciprocal Decay in the star embodiment

Under sustained negative pressure margin, contraction raises density and steepens the required pressure profile. Once restoring support cannot recover dominance quickly enough, deficit deepens the conditions that generate more deficit. A minimal collapse proxy is

$$\frac{dr_c}{dt} = -a_{\text{base}} - a_{\text{dom}}\max(0, -\Delta_\star(t)), \qquad a_{\text{dom}} \geq 0,$$

where $r_c(t)$ is a representative core-contraction variable.

13.4 Embodiment-specific falsification

The embodiment fails if collapse is inferred while $\Delta_\star(t)$ remains reliably positive under the declared inference contract, or if sustained negative pressure margin does not associate with accelerating collapse indicators under correct estimation.

14 Plant Embodiment: Metabolic-Power Basis

Let $X = \text{plant}$ be a living plant treated as a bounded, constraint-bearing system whose function is to maintain viable metabolism and structural integrity against environmental demand.

14.1 Operational quantities

Table 5: Plant embodiment definition table.

Item	Definition	Unit	Measurement
$Potential_{\text{plant}}(t)$	$P_{\text{met}}(t)$	W	estimated from gas exchange and hydraulic state
$Load_{\text{plant}}(t)$	$P_{\text{dem}}(t)$	W	estimated from maintenance, repair, and stress demand
$\Delta_{\text{plant}}(t)$	$P_{\text{met}}(t) - P_{\text{dem}}(t)$	W	computed
Observables	$A_n, R_d, g_s, T_\ell, \Psi_\ell$, soil moisture, fluorescence	mixed	instrument suite
Cadence	T_s	time	logger / sampling cadence
Noise / resolution	ϵ_{plant}	W	estimator uncertainty

Choose a metabolic-power channel. Define

$$\begin{aligned} Potential_{\text{plant}}(t) &:= P_{\text{met}}(t), \\ Load_{\text{plant}}(t) &:= P_{\text{dem}}(t), \\ \Delta_{\text{plant}}(t) &:= P_{\text{met}}(t) - P_{\text{dem}}(t). \end{aligned}$$

Here $P_{\text{met}}(t)$ is recoverable metabolic power available to sustain function, and $P_{\text{dem}}(t)$ is metabolic power demand for maintenance, repair, and stress response.

14.2 Physical regime thresholds

Let $\tau_{w,\text{plant}}$ denote onset of protective regime restriction and let $\tau_{r,\text{plant}} < \tau_{w,\text{plant}}$ denote the hydraulic-failure boundary beyond which admissible interventions cannot restore dominance on the relevant time scale.

Then

$$\tau_{r,\text{plant}} < \Delta_{\text{plant}}(t) < \tau_{w,\text{plant}} \Rightarrow \text{Grace window.}$$

14.3 Reciprocal Decay in the plant embodiment

Under sustained negative dominance, reserves are consumed, hydraulic capacity is lost, and future recoverable power falls. A minimal structural-capacity proxy is

$$\frac{dS}{dt} = -a_{\text{base}} - a_{\text{dom}} \max(0, -\Delta_{\text{plant}}(t)), \qquad a_{\text{dom}} \geq 0,$$

with $P_{\text{met}}(t)$ increasing in $S(t)$ on the time scale of interest.

14.4 Embodiment-specific falsification

The embodiment fails if irreversible physiological failure is observed while the power-margin trace remains reliably positive under the declared estimator, or if sustained deficit does not associate with measurable steepening in hydraulic or metabolic collapse under controlled comparison.

15 Control Consequence of the Law

Because recoverable support cannot be increased without time, cost, or risk, a system under dominance erosion survives only by one or more of the following:

1. reducing effective load,
2. increasing recoverable potential through admissible intervention,
3. changing the architecture that maps load into the governing channel.

This is the control consequence of the law: viability is not saved by label but by restoring positive dominance before Grace is exhausted.

16 Conclusion

The MDL states a fundamental law of bounded viability. It is first stated in simple form as

$$\Delta = Potential - Load,$$

and then instantiated dynamically as

$$\Delta_X(t) = Potential_X(t) - Load_X(t).$$

From that trace follow regime, boundary crossing, finite Grace, and, in deficit-sensitive embodiments, Reciprocal Decay. The law is universal in operational form and embodiment-specific in mechanism. It does not replace substrate physics. It governs whether recoverable support remains ahead of imposed demand over time in a bounded system. Once a governing channel, a commensurate measurement contract, and—where relevant—an admissible intervention class are declared, the law becomes measurable, predictive, and falsifiable.

The battery embodiment instantiates the law in a voltage-margin channel, the star embodiment in a pressure-margin channel, and the plant embodiment in a metabolic-power channel. Appendix A shows the same structure in a structural-demand channel for a selected bridge limit state. In each case the same primitive structure governs the same operational question: whether dominance is being preserved, eroded, restored, or irreversibly lost.

A Appendix A: Bridge Physical Instantiation (Selected Limit State)

Choose a governing limit state in a bridge, such as flexural demand in a critical girder, and express all terms in the same physical unit, for example $\mathrm{kN \cdot m}$:

$$\begin{aligned} Potential_B(t) &:= R_B(t), \\ Load_B(t) &:= D_B(t), \\ \Delta_B(t) &:= R_B(t) - D_B(t). \end{aligned}$$

Consider

$$R_B(t) = 12000 - 240t, \qquad D_B(t) = 8500 + 150t,$$

where t is in years. Then

$$\Delta_B(t) = 3500 - 390t.$$

The critical boundary occurs at

$$t_{\text{critical}} = \frac{3500}{390} \approx 8.97 \text{ years.}$$

Let $\tau_{w,B} = 500$ and $\tau_{r,B} = -500$. Then

$$t_{\text{warning}} = \frac{3500 - 500}{390} \approx 7.69 \text{ years,} \qquad t_{\text{irreversible}} = \frac{3500 - (-500)}{390} \approx 10.26 \text{ years.}$$

Thus the bridge enters a finite Grace interval of

$$10.26 - 7.69 \approx 2.57 \text{ years.}$$

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