The Attractor Framework in Astrophysics: Persistence, Entropy, and Gravitational Systems; Robert Galida (July 2026) [A]

Abstract

The attractor framework provides a domain-general vocabulary for describing persistence and change across physical, biological, cognitive, and social systems. This paper extends the framework to astrophysical dissipative systems. We distinguish between conservative gravitational dynamics — which define families of stable invariant solutions — and dissipative processes — which select and can stabilize particular configurations within those families.

The central thesis is:

> ***Gravity defines the landscape. Dissipation selects the configuration.***

We provide an operational definition of the excess entropy production functional σ_{excess} for gravitational systems, grounding the persistence functional $D_\infty = \int \sigma_{excess}\, dt$ in physical dissipation rates above steady-state baselines. We show that:

- Orbital circularization is a dissipative process driven by gravitational radiation and tidal friction
- Tidal locking is an asymptotically stable state reached through dissipative evolution

- Planetary systems settle into metastable low-dissipation configurations through dissipative processes in protoplanetary disks
- Binary inspirals provide a natural setting for the framework's persistence functional

The framework's contribution is not a new mechanism of orbital evolution, but a unifying description of persistence across disparate dissipative systems using a common mathematical quantity: the persistence functional.

Keywords: attractor framework, astrophysics, gravitational radiation, tidal locking, orbital circularization, dissipative structures, Hamiltonian dynamics, planetary systems, binary inspirals, excess entropy production

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1. Introduction

The attractor framework has been developed to describe persistence and change across physical, biological, cognitive, and social systems. The core claim is that every dissipative system maintains its attractor through continuous reconfiguration, and that reconfiguration generates excess entropy.

This paper extends the framework to astrophysical dissipative systems. The key insight is a distinction that is often blurred in the literature:

Concept	Role
Conservative gravitational dynamics	Defines the landscape of possible configurations (orbits, resonances, stable solutions)

Concept	Role
Dissipative processes	Select and can stabilize particular configurations within that landscape

Gravity does not provide attractors in the dynamical systems sense — Hamiltonian systems conserve phase-space volume and do not have attractors. However, when dissipative processes are added, the system evolves toward particular asymptotically stable configurations within the family of invariant solutions. The circular orbit is not a dynamical attractor of pure Newtonian gravity; it is the endpoint of dissipative evolution (tidal friction, gravitational radiation, gas drag).

This distinction is central to the paper. Gravity defines the landscape; dissipation determines which configuration is reached.

What is new: Existing astrophysical theory explains *how* dissipative mechanisms drive orbital evolution. The attractor framework proposes a common mathematical quantity — the persistence functional — that measures the cumulative irreversible cost of approaching an asymptotically stable configuration. The novelty is therefore not a new mechanism of orbital evolution, but a unifying description of persistence across disparate dissipative systems.

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2. Conservative vs. Dissipative Systems

2.1 Hamiltonian Dynamics

A conservative Hamiltonian system preserves phase-space volume (Liouville’s theorem). It does not have attractors in the dynamical systems sense. Orbits are determined by initial conditions and remain on their invariant tori (Arnold, 1989).

Property	Implication
No phase-space contraction	No attractors
Time-reversible	No arrow of time
Energy conserved	No dissipation

2.2 Dissipative Dynamics

When dissipative processes are added, the system loses energy and angular momentum. Phase-space volume contracts, and asymptotically stable states can emerge. For foundational treatments of irreversible thermodynamics, see Onsager (1931) and Prigogine (1947).

Property	Implication
Phase-space contraction	Asymptotically stable states appear
Time-irreversible	Arrow of time
Energy lost	Entropy generated

2.3 The Framework's Position

The framework treats gravity as defining the landscape of possible configurations. Dissipation determines which of those configurations are actually reached.

> ***Gravity defines the landscape. Dissipation selects the configuration.***

This is the core insight of the paper.

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3. The Gravitational Persistence

Functional

3.1 Excess Entropy Production

Following Galida (2026c), the excess entropy production rate is defined as: $\sigma_{excess}(x)=\sigma(x)-\sigma_{ss}(x)$

where $\sigma(x)$ is the total entropy production rate and $\sigma_{ss}(x)$ is the steady-state baseline rate at the attractor.

For gravitational systems, we propose: $\sigma_{excess}=\frac{\dot{E}_{irrev}-\dot{E}_{ss}}{T_{eff}}$

where $\dot{E}_{irrev}$ is the total irreversible energy loss rate, $\dot{E}_{ss}$ is the steady-state baseline loss rate at the attractor, and T_{eff} is an effective temperature.

This decomposition ensures $\sigma_{excess}\to 0$ at the attractor, avoiding the divergence problem that would arise from integrating raw dissipation rates over infinite time. Systems that continue to dissipate at a steady baseline (e.g., a circular binary emitting GWs, a tidally locked moon with residual eccentricity-driven heating) contribute only their *excess* above baseline to the persistence cost.

3.2 Domain-Specific Definitions

Process	Total $\dot{E}$	Baseline $\dot{E}_{ss}$	σ_{excess}
Orbital circularization	$L_{GW}(e)$	$L_{GW}(e=0)$	$[L_{GW}(e)-L_{GW}(0)]/T_{eff}$
Tidal locking	$P_{tide}(\Omega,e)$	$P_{tide}(\Omega=n,e)$	$[P_{tide}(\Omega,e)-P_{tide}(n,e)]/T_{eff}$
Disk dissipation	L_{disk}	$L_{disk,\ steady}$	$[L_{disk}-L_{disk,\ ss}]/T_{eff}$

3.3 The Persistence Functional

Definition 1 (Gravitational Persistence Functional): For a finite horizon $T>0$: $D_T(x)=\int_0^T \sigma_{excess}(\phi_t(x))\,dt$

$\sigma_{\text{excess}}(\phi_t(x))\,dt$

For trajectories that converge to the attractor: $D_\infty(x) = \int_0^\infty \sigma_{\text{excess}}(\phi_t(x))\,dt$

Interpretation: $D_\infty(x)$ measures the total *excess* entropy generated during the approach to an asymptotically stable configuration — the cumulative cost of reconfiguration above the steady-state baseline.

Note on gravitational wave entropy: Classical gravitational waves are coherent radiation and do not automatically carry large thermodynamic entropy. The entropy associated with gravitational wave emission arises from coarse-graining the wave's phase space or from the generalized entropy increase of the sources (e.g., black hole horizons). The proposed definition $\sigma_{\text{excess}} = [L_{\text{GW}}(e) - L_{\text{GW}}(0)]/T_{\text{eff}}$ isolates the eccentricity-specific excess above the circular-orbit baseline. Constructing an explicit entropy functional for gravitational radiation remains an open problem.

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4. Orbital Circularization

4.1 The Phenomenon

Binary systems (stars, black holes, planets) often have elliptical orbits. Over time, these orbits tend to **circularize** — the eccentricity decreases and the orbit becomes more circular.

This is a dissipative process. The system loses energy and angular momentum through:

- **Gravitational radiation** (for compact objects)
- **Tidal friction** (for fluid bodies)
- **Gas drag** (for protoplanetary disks)

4.2 Framework Interpretation

Component	Role
The landscape	Family of Keplerian orbits (all ellipses)
Asymptotically stable state	Circular orbit (endpoint of dissipative evolution)
The dissipation	Gravitational radiation, tidal friction, gas drag
The cost	$\sigma_{excess} = [L_{GW}(e) - L_{GW}(0)]/T_{eff}$

The framework proposes: $\kappa \propto \frac{1}{D_\infty}$

where κ is the circularization rate and $D_\infty = \int \sigma_{excess}\, dt$ is the cumulative excess entropy production during circularization.

4.3 The Peters & Mathews Formula

The foundational computation of the gravitational-wave power from a Keplerian orbit was given by Peters & Mathews (1963). The secular decay of semi-major axis and eccentricity was derived by Peters (1964): $\frac{da}{dt} = -\frac{64}{5}\frac{G^3 m_1 m_2 (m_1+m_2)}{c^5 a^3 (1-e^2)^{7/2}}\left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right)$ $\frac{de}{dt} = -\frac{304}{15}\frac{G^3 m_1 m_2 (m_1+m_2)}{c^5 a^4 (1-e^2)^{5/2}}\, e\left(1 + \frac{121}{304}e^2\right)$

Framework Interpretation: The decay of eccentricity $e \to 0$ is the approach to the asymptotically stable state. The excess entropy production is the eccentricity-dependent component of the gravitational wave luminosity: $\sigma_{excess} = \frac{L_{GW}(e) - L_{GW}(0)}{T_{eff}}$

(0)

This quantity vanishes as $e \to 0$, consistent with the e-proportionality of the de/dt equation. Orbital eccentricity may serve as an experimentally accessible proxy for the cumulative excess entropy production.

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5. Binary Inspirals

5.1 The Phenomenon

Binary systems of compact objects (neutron stars, black holes) lose energy through gravitational radiation. The orbit shrinks and the binary inspirals.

This is one of the most direct applications of the framework. The inspiral is a dissipative process driven by gravitational wave emission. For general relativistic treatments of binary dynamics and the geometry of spacetime, see Carroll (2004), Schutz (2009), Wald (1984), and Misner, Thorne & Wheeler (1973).

5.2 Framework Interpretation

Component	Role
The landscape	Family of binary orbits
Asymptotically stable state	Quasi-circular orbit (endpoint of circularization)
The dissipation	Gravitational radiation
The cost	$\sigma_{excess} = [L_{GW}(e) - L_{GW}(0)]/T_{eff}$

5.3 The Persistence Functional

The persistence functional for a binary inspiral is:

$$D_\infty = \int_0^\infty \sigma_{excess}(t)\,dt = \int_0^\infty \frac{L_{GW}(e(t)) - L_{GW}(0)}{T_{eff}}\,dt$$

Note on circularization: For compact-object binaries, eccentricity damps on a much shorter timescale than the inspiral itself. Gravitational radiation circularizes the orbit well before merger, so the system reaches a quasi-circular state as a near-asymptotic limit before the final coalescence.

Hypothesis: The inspiral time τ is inversely proportional to D_∞:

$$\kappa = \frac{1}{\tau} \propto \frac{1}{D_\infty}$$

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6. Tidal Locking

6.1 The Phenomenon

Tidal locking occurs when a body's rotational period equals its orbital period. The Moon is tidally locked to Earth. Many exoplanets in the habitable zone are expected to be tidally locked.

Tidal locking is a dissipative process. Tidal friction converts rotational energy into heat, gradually slowing the body's rotation until it matches its orbital period.

6.2 Framework Interpretation

Component	Role
The landscape	Family of rotational states
Asymptotically stable state	Tidal lock (rotational period = orbital period)

Component	Role
The dissipation	Tidal friction (heat generation)
The cost	$\sigma_{excess} = [P_{tide}(\Omega, e) - P_{tide}(\Omega = n, e)] / T_{eff}$

Hypothesis: The tidally locked state is a low-dissipation configuration for the system. Once locked, tidal dissipation approaches a minimum. The excess entropy production is the despinning-specific component above whatever baseline eccentricity-driven heating persists after lock.

6.3 The Tidal Locking Timescale

The timescale for tidal locking is commonly given as (see, e.g., Murray & Dermott, 1999): $\tau_{lock} \approx \frac{2}{21} \frac{Q}{k_2} \frac{m}{M} \left(\frac{a}{R}\right)^6 \frac{1}{\Omega}$

where:

- Q is the tidal dissipation factor
- k_2 is the Love number
- m is the mass of the body
- M is the mass of the primary
- a is the semi-major axis
- R is the radius of the body
- Ω is the rotation rate

(Different derivations use different prefactors depending on the assumed dissipation model; the $(a/R)^6$ scaling is robust.)

Hypothesis: $\kappa = 1/\tau_{lock}$. The recovery rate is the inverse of the locking timescale. The cumulative excess entropy production is the total tidal heat dissipated during despinning above the post-lock baseline.

7. Planetary Systems

7.1 Formation and Evolution

Planetary systems form from protoplanetary disks. The disk is a dissipative structure: it loses energy through radiation, viscosity, and accretion.

Over time, the system approaches a stable configuration:

- Planets on nearly circular orbits
- Resonances between orbits
- Stable spin-orbit states

For a comprehensive treatment of solar system dynamics and tidal evolution, see Murray & Dermott (1999).

7.2 Framework Interpretation

Component	Role
The landscape	Family of possible planetary configurations
Metastable configuration	Low-dissipation planetary system
The dissipation	Disk viscosity, radiation, accretion
The cost	$\sigma_{excess}=[L_{disk}-L_{disk,\,ss}]/T_{disk}$

Hypothesis: Mature planetary systems approach metastable low-dissipation configurations. The cumulative excess entropy production is the total disk dissipation above the steady-state baseline integrated over the formation epoch.

8. Entropy Generation in Gravitational Systems

8.1 The Subtlety of Gravitational Entropy

Gravitational waves carry energy. Whether they carry entropy is a more subtle question. Classical gravitational waves are coherent radiation; coherent radiation is not obviously high-entropy. Binary mergers ultimately increase the generalized entropy of spacetime, but the bookkeeping is subtle.

Note: Throughout this paper, entropy generation refers to the irreversible processes associated with tidal heating, viscous dissipation, and the generalized entropy increase accompanying gravitational-wave emission. The precise entropy carried by gravitational radiation remains an active topic.

8.2 Operational Definition of σ_{excess}

For the purposes of this framework, we propose the following operational definition: $\sigma_{excess} = \frac{\dot{E}_{irrev} - \dot{E}_{ss}}{T_{eff}}$

where:

- $\dot{E}_{irrev}$ is the total irreversible energy loss rate
- $\dot{E}_{ss}$ is the steady-state baseline loss rate at the attractor
- T_{eff} is an effective temperature for the dissipative process

This definition ensures $\sigma_{excess} \geq 0$ and vanishes when the system reaches its attractor. For specific astrophysical contexts:

Context	$\dot{E}_{irrev}$	$\dot{E}_{ss}$	T_{eff}
Orbital circularization	$L_{GW}(e)$	$L_{GW}(0)$	Effective GW temperature
Tidal locking	$P_{tide}(\Omega, e)$	$P_{tide}(\Omega = n, e)$	Effective body temperature
Disk dissipation	L_{disk}	$L_{disk,\ ss}$	Disk temperature
Black hole mergers	L_{GW}	0	Hawking temperature of final black hole

Note: This is a working hypothesis. Constructing an explicit entropy functional for relativistic gravitational systems remains an open problem. The effective temperature T_{eff} is the primary underdetermined quantity in the framework; its derivation from first principles is a priority for future work.

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9. The Boundary

The framework’s boundary is not absolute zero. It is the **absence of irreversible processes**. At the boundary, the system becomes conservative and no entropy is generated. Hamiltonian systems exist at nonzero temperature; the boundary is dynamical, not thermal.

10. Testable Predictions

10.1 Core Prediction

Prediction: The circularization rate κ is inversely proportional to the cumulative excess entropy production during circularization.

$$\kappa \propto \frac{1}{D_\infty}$$

10.2 Specific Predictions

Prediction	Falsification
Tidal locking timescale correlates with total tidal heat dissipated above baseline	If no correlation, the prediction is falsified
Circularization rate correlates with total eccentricity-dependent GW energy emitted	If no correlation, the prediction is falsified
Planetary system stability correlates with total disk dissipation above steady state	If no correlation, the prediction is falsified

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11. Open Questions

Question	Status
Q1: Gravitational entropy	What is the entropy of a gravitational system? (Penrose, 1965; Hawking & Ellis, 1973)
Q2: Black hole entropy	How does black hole entropy fit into the framework?

Question	Status
Q3: Entropy of gravitational radiation	Does gravitational radiation carry entropy, and if so, how is it defined? (Zeldovich, 1972)
Q4: Cosmological stability	Do cosmological models admit asymptotically stable late-time solutions?
Q5: Effective temperature for GWs	What is the correct T_{eff} for gravitational wave entropy production? (Galida, 2026d)
Q6: Coarse-graining	What coarse-graining scheme defines the entropy of classical gravitational waves? (Galida, 2026d)

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12. Conclusion

The attractor framework extends naturally to astrophysical dissipative systems. The key insight is a distinction that is often blurred:

> ***Gravity defines the landscape. Dissipation selects the configuration.***

Conservative gravitational dynamics define families of stable invariant solutions. Dissipative processes — gravitational radiation, tidal friction, gas drag — select and can stabilize particular configurations within those families.

The framework does not claim that gravity provides attractors. It claims that the combination of conservative dynamics and dissipative processes produces asymptotically stable states. This is a more accurate and defensible position.

The contribution is not a new mechanism of orbital evolution, but a unifying description of persistence across disparate dissipative systems using a common mathematical quantity: the persistence functional $D_\infty = \int \sigma_{excess}\, dt$, with σ_{excess} operationally defined as the rate of irreversible energy loss above steady-state baseline divided by an effective temperature.

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