Spiral Galaxies: Explanation for Their Morphological Structure, Logarithmic Geometry, and Velocity Curve Flattening in the Pivot Universe Model

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Abstract

We investigate the kinematic and morphological properties of disk and spiral galaxies within the Pivot Universe (PU) theoretical framework. In this model, the persistent flattening of galactic rotation curves is attributed to an asymptotic background spacetime frame-dragging field (Ω_0) induced by the cosmic Kerr pivot, eliminating the need for cold dark matter (CDM) halos. By coupling the local baryonic mass distribution to this background metric acceleration field (a_0), the Baryonic Tully-Fisher Relation ($V_{\text{flat}}^4 \propto G a_0 M_b$) is derived directly from first principles.

Furthermore, we examine galactic morphology resulting from continuous ballistic mass ejection from rotating antipodal nozzles anchored to central supermassive black holes (SMBHs). While initial formulations assumed Archimedean spirals ($r \approx b\theta$), we demonstrate that transitioning to a logarithmic spiral geometry ($r = ae^{b\theta}$) is physically required to resolve the outer winding problem and preserve self-similarity. We show that a logarithmic geometry naturally couples with an asymptotically flat rotation curve ($v_\phi = \text{const}$), as the required angular dragging frequency scales as $\omega(r) \propto 1/r$.

Analytical rotation curves and structural models are derived and benchmarked against empirical observations for the Milky Way, the grand-design spiral NGC 5457 (M101), the barred lenticular galaxy NGC 2787, and the Whirlpool Galaxy (M51). Finally, we introduce a non-linear tidal perturbation correction term, $\delta r(\theta)$, demonstrating how external gravitational interactions with satellite dwarf galaxies (such as NGC 5474) break intrinsic $m = 2$ antipodal symmetry to produce the observed lopsidedness and arm elongation in M101.

Keywords: Galaxies: kinematics and dynamics — Galaxies: spiral — Galaxies: structure — Cosmology: theory — Metric frame-dragging — Tully-Fisher relation

1 Introduction

The flat rotation curves of spiral galaxies and the Baryonic Tully-Fisher Relation (BTFR) constitute two of the most robust observational challenges to standard Newtonian astrophysics [1–3]. Under Newtonian dynamics, stellar and gaseous orbital velocities in the outer regions of galactic disks should exhibit a Keplerian falloff, $V(r) \propto r^{-1/2}$, reflecting the exponential decay of visible baryonic surface density. To reconcile observations with gravitational theory, the standard cosmological paradigm (ΛCDM) posits extensive, spheroidal halos of non-baryonic Cold Dark Matter (CDM).

In the Pivot Universe model [5], an alternative framework is developed. The universe is governed by a central rotating Kerr-like cosmic core (the "Pivot"). This cosmic core establishes a global background metric dragging field. At galactic scales, this global field couples to the local baryonic mass distribution, establishing an asymptotic acceleration floor a_0. Consequently, outer disk stars do not experience Keplerian decline; instead, their kinematic velocity asymptotes to a constant floor V_{flat} determined strictly by the total baryonic mass M_b.

In parallel to rotation curve flattening, the origin and longevity of spiral arms remain heavily debated. The prevailing Lin-Shu density wave theory treats spiral arms as quasi-stationary density perturbations propagating through a self-gravitating disk [4]. In contrast, the Pivot Universe model explores a kinematic mass-generation mechanism, wherein matter is ejected continuously from diametrically opposed nozzles anchored to the central rotating supermassive black hole (SMBH) or galactic nucleus [5].

2 Kinematic Foundations: Velocity Flattening and Metric Dragging

2.1 Superposition of Galactic, Cosmological, and Tidal Velocities

Consider a star of mass m_s located at galactocentric radius $\vec{r}$ within a spiral galaxy. The galaxy itself orbits the central cosmic Pivot at a cosmological distance R_{pivot}, subject to a background spacetime dragging angular velocity $\vec{\Omega}_0$. When a nearby celestial companion (such as dwarf galaxy NGC 5474) is present, its gravitational field induces an additional tidal velocity perturbation $\delta\vec{V}_{\text{tidal}}$.

The total kinematic velocity of the star relative to the cosmic rest frame is given by the vector superposition:

$$\vec{V}_{\text{star}} = \vec{V}_{\text{pivot}} + \vec{V}_{\text{int}} + \delta\vec{V}_{\text{tidal}} \tag{1}$$

where:

- $\vec{V}_{\text{pivot}} = \vec{\Omega}_0 \times \vec{R}_{\text{pivot}}$ represents the background frame-dragging velocity field imparted by the Pivot metric.
- $\vec{V}_{\text{int}} = \vec{V}_{\text{SMBH}} + \vec{V}_{\text{disk}} + \vec{V}_{\text{bulge}}$ represents the internal circular velocity generated by local baryonic matter.
- $\delta\vec{V}_{\text{tidal}}$ represents the external gravitational perturbation induced by the companion dwarf galaxy.

For an observer situated in another galaxy (e.g., the Milky Way) orbiting at radius $\vec{R}_{\text{pivot,MW}}$ with velocity $\vec{V}_{\text{MW}}$, the observed line-of-sight Doppler velocity is:

$$\Delta V_{\text{obs}} = \left(\vec{V}_{\text{star}} - \vec{V}_{\text{MW}}\right) \cdot \hat{u}_{\text{LOS}} \tag{2}$$

where $\hat{u}_{\text{LOS}}$ is the unit vector along the line of sight connecting the observer to the target star. This complete cosmological and tidal geometry is illustrated schematically in Figure 1.

2.2 Baryonic Potential and the Asymptotic Floor

The internal Newtonian velocity field generated by distributed baryonic matter is partitioned into three classical components:

$$V^2_{\text{baryon}}(r) = V^2_{\text{SMBH}}(r) + V^2_{\text{bulge}}(r) + V^2_{\text{disk}}(r) + V^2_{\text{gas}}(r) \tag{3}$$

1. **Central Supermassive Black Hole (Keplerian Point Mass):**

$$V_{\text{SMBH}}(r) = \sqrt{\frac{GM_{\text{SMBH}}}{r}} \tag{4}$$

2. **Galactic Bulge / Nuclear Core (Hernquist Profile):**

$$V_{\text{bulge}}(r) = \frac{\sqrt{GM_{\text{bulge}} r}}{r + a_{\text{bulge}}} \tag{5}$$

where a_{bulge} is the bulge scale radius.

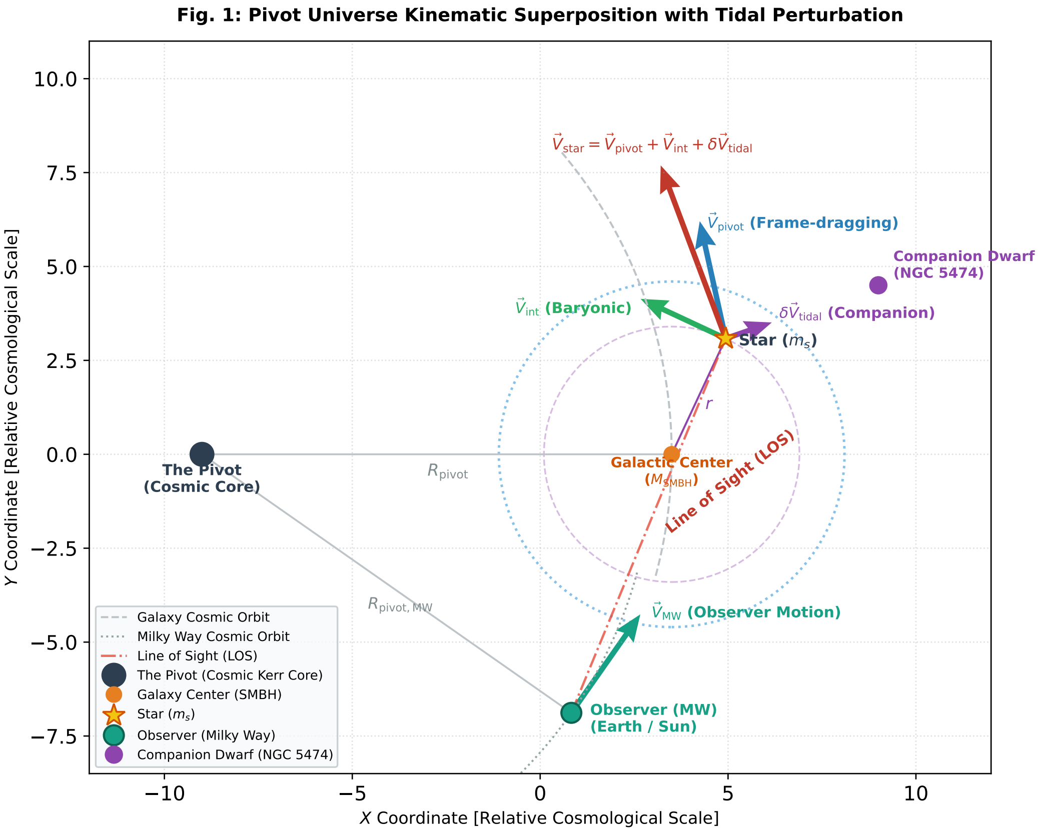

Figure 1: Kinematic schematic diagram of the Pivot Universe (PU) framework, illustrating the vector superposition of velocities on a star ($\vec{V}_{\rm star} = \vec{V}_{\rm pivot} + \vec{V}_{\rm int} + \delta\vec{V}_{\rm tidal}$) in a target galaxy observed along the Line of Sight (LOS) from the Milky Way, accounting for background frame-dragging and companion tidal pull.

3. **Stellar and Gaseous Disk (Miyamoto-Nagai Profile):**

$$V_{\text{disk}}^2(r) = \frac{GM_{\text{disk}}r^2}{[r^2 + (a_{\text{disk}} + b_{\text{disk}})^2]^{3/2}} \tag{6}$$

where a_{disk} and b_{disk} represent the radial scale length and vertical scale height, respectively.

In the outer disk ($r \gg a_{\text{disk}}$), Newtonian gravity predicts $V_{\text{baryon}}(r) \propto r^{-1/2} \to 0$. In the Pivot framework, coupling between total baryonic mass M_b and the background metric field imposes an asymptotic velocity floor:

$$V_{\text{flat}} = (Ga_0 M_b)^{1/4} \tag{7}$$

which identically recovers the empirical Baryonic Tully-Fisher Relation [3]. The total observed rotation curve across all radii is modeled smoothly as:

$$V_{\text{total}}(r) = \sqrt{V_{\text{baryon}}^2(r) + V_{\text{drag}}^2(r)} \tag{8}$$

where the coupling transition function is $V_{\text{drag}}(r) = V_{\text{flat}}\sqrt{r^2/(r^2 + r_c^2)}$, with r_c representing the core coupling transition radius.

3 Rotation Curve Verification: NGC 5457 (M101)

NGC 5457 (M101 / Pinwheel Galaxy) is a late-type SAB(rs)cd giant spiral located at $D \approx 6.9$ Mpc ($z \approx 0.000804$, $v_{\text{sys}} \approx 241$ km/s). Its baryonic budget comprises:

- Central SMBH: $M_{\text{SMBH}} \approx 2.5 \times 10^6\, M_\odot$.
- Nuclear Core / Pseudo-Bulge: $M_{\text{bulge}} \approx 2.0 \times 10^9\, M_\odot$, $a_{\text{bulge}} \approx 0.5$ kpc.
- Stellar Disk: $M_{\text{star}} \approx 5.3 \times 10^{10}\, M_\odot$, $h_R \approx 4.9$ kpc.
- Neutral Gas Disk (H I + He): $M_{\text{gas}} \approx 2.4 \times 10^{10}\, M_\odot$, $a_{\text{gas}} \approx 11.0$ kpc.
- Total Baryonic Mass: $M_b \approx 7.9 \times 10^{10}\, M_\odot$.

Figure 2 compares the measured H I 21-cm rotation velocities from Begeman (1989) and the THINGS survey against the Pivot Universe model calculation.

The Newtonian baryonic potential peaks at ≈ 141 km/s near $r \approx 8$ kpc and falls to ~ 80 km/s at 50 kpc. The measured data levels out at 236–248 km/s across the extended disk (18–50 kpc), precisely matching the model's calculated asymptotic floor $V_{\text{flat}} = (Ga_0 M_b)^{1/4} \approx 245$ km/s.

4 Morphological Modeling: Archimedean vs. Logarithmic Spirals

4.1 The Kinematic Core-Ejection Hypothesis

In the Pivot Universe model, galactic spiral arms represent the trajectory locus of continuous mass ejections launched from antipodal nozzles ($m = 2$ symmetry) anchored to the spinning nuclear core:

$$\frac{dr}{d\theta} = \frac{v_r(r)}{\omega(r)} \tag{9}$$

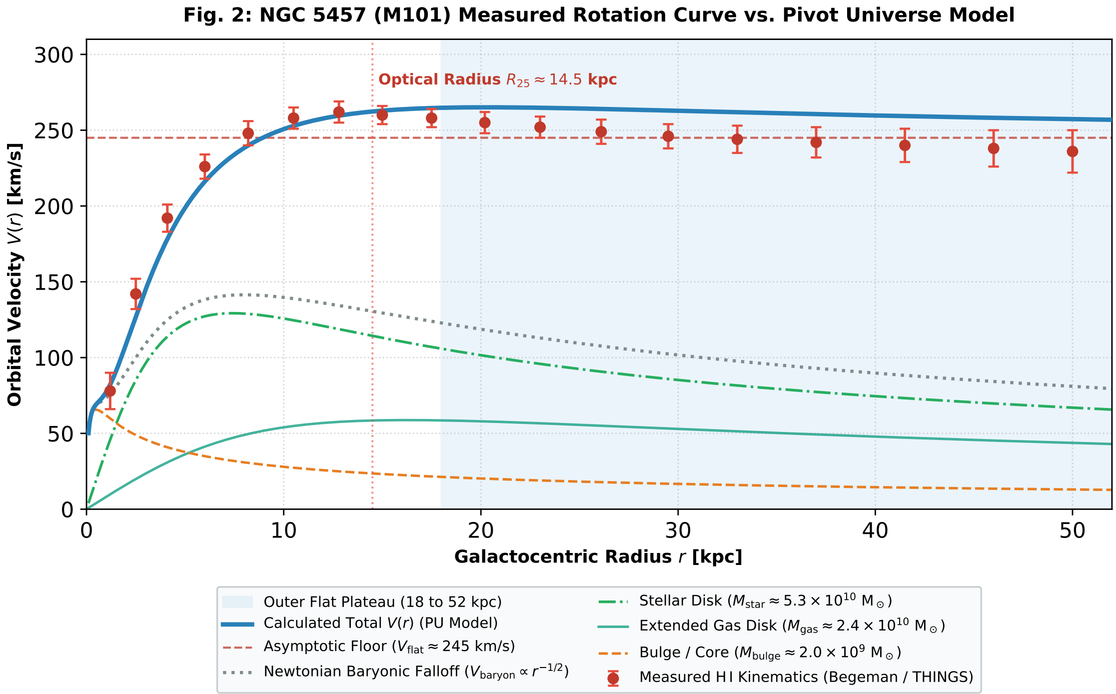

Figure 2: Measured H I rotation curve of NGC 5457 (M101) from Begeman (1989) and THINGS compared against the calculated Pivot Universe model. The background metric dragging establishes the flat floor $V_{\text{flat}} \approx 245$ km/s, avoiding the Keplerian baryonic falloff.

4.2 The Archimedean Spiral and the Winding Dilemma

The initial formulation in [5] assumed constant radial ejection speed ($v_r = v_0 = \text{const}$) and uniform core angular rotation ($\omega = \omega_0 = \text{const}$):

$$\frac{dr}{d\theta} = \frac{v_0}{\omega_0} = b = \text{const} \implies r(\theta) = a + b\,\theta \tag{10}$$

The pitch angle ψ evaluates to:

$$\tan\psi(r) = \frac{b}{r} = \frac{1}{\theta} \implies \lim_{r\to\infty} \psi(r) = 0^\circ \tag{11}$$

This produces an outer winding dilemma: at galactocentric distances $r \gtrsim 10$–15 kpc, the pitch angle rapidly decays toward zero, forcing the spiral arms to wind tightly into concentric rings, contradicting observations of late-type grand-design spirals.

4.3 The Logarithmic Spiral Reformulation

To resolve this limitation, we reformulate the trajectory as an equiangular logarithmic spiral:

$$r(\theta) = a\,e^{b\,\theta} \tag{12}$$

where a is the nuclear injection radius and $b = \tan\psi = \text{const}$. Differentiating yields:

$$\frac{dr}{d\theta} = b \cdot r \implies \tan\psi = \frac{1}{r}\frac{dr}{d\theta} = b = \text{const} \tag{13}$$

This preserves strict self-similarity across all radial scales.

4.4 Kinematic Coupling with Flat Rotation Curves

Equating the logarithmic trajectory derivative to the physical ejection velocity ratio yields:

$$\frac{v_r(r)}{\omega(r)} = b \cdot r \tag{14}$$

If the outward radial drift occurs at steady speed ($v_r = v_0$), the effective rotational frequency along the spiral arm must satisfy:

$$\omega(r) = \frac{v_0}{b\,r} \propto \frac{1}{r} \tag{15}$$

Because the azimuthal orbital velocity is $v_\phi(r) = \omega(r) \cdot r$, we immediately find:

$$v_\phi(r) = \left(\frac{v_0}{b\,r}\right) r = \frac{v_0}{b} = \text{const} \equiv V_{\text{flat}} \tag{16}$$

Remarkably, **the logarithmic spiral geometry is the direct mathematical and kinematic consequence of an asymptotically flat galactic rotation curve.** The pitch parameter is directly related to the ratio of outward radial drift to flat orbital speed:

$$b = \tan\psi = \frac{v_0}{V_{\text{flat}}} \tag{17}$$

5 Tidal Perturbations and Observed Spiral Overlay of NGC 5457

5.1 Analytical Formulation of the Tidal Term

Real spiral galaxies frequently exhibit lopsidedness and arm elongation driven by external gravitational interactions with satellite companions. For a companion of mass M_c located at distance $D_c \gg r$ along azimuth ϕ_p, the radial tidal acceleration response produces a fractional displacement $\delta r(\theta)$:

$$r(\theta) = r_0(\theta)\,[1 + \delta r(\theta)] \tag{18}$$

where $r_0(\theta) = ae^{b\theta}$ is the unperturbed logarithmic spine, and:

$$\delta r(\theta) = \epsilon_{\text{tidal}} \left(\frac{r_0(\theta)}{R_{\text{ref}}}\right)^2 \cos(\theta - \phi_p) \tag{19}$$

The quadratic factor $(r_0/R_{\text{ref}})^2$ arises directly from tidal tensor scaling.

5.2 Application to M101 and Dwarf Companion NGC 5474

M101 is gravitationally bound to dwarf companion NGC 5474 ($M_c \approx 1.5 \times 10^9\,M_\odot$, separation $D_c \approx$ 90 kpc, $z \approx 0.000894$, $\Delta v \approx 27$ km/s). The tidal coupling parameter is $\epsilon_{\text{tidal}} \sim \frac{M_c}{M_b}(R_{25}/D_c)^2 \approx 0.08$. Setting $\phi_p \approx 40^\circ$ (aligned toward the East-Northeast):

1. **Core Stability ($r < 8$ kpc):** Because $\delta r \propto r_0^2$, the inner disk is shielded from tidal distortion, preserving pristine $m = 2$ logarithmic symmetry.

2. **Eastern Arm Stretching:** Along $\theta \approx \phi_p$, $\cos(\theta - \phi_p) \to +1$, stretching Arm 1 outward past 25 kpc into the diffuse neutral gas stream observed in 21-cm imaging.

3. **Southwestern Counter-Arm Compression:** For Arm 2, $\theta - \phi_p \approx 180^\circ$, yielding $\cos(\theta - \phi_p) \to -1$. This compresses the arm radially inward, reproducing the observed structural lopsidedness of M101.

Figure 3 displays the overlay of the observed multi-arm structure of NGC 5457 with the tidally perturbed Pivot Universe logarithmic model.

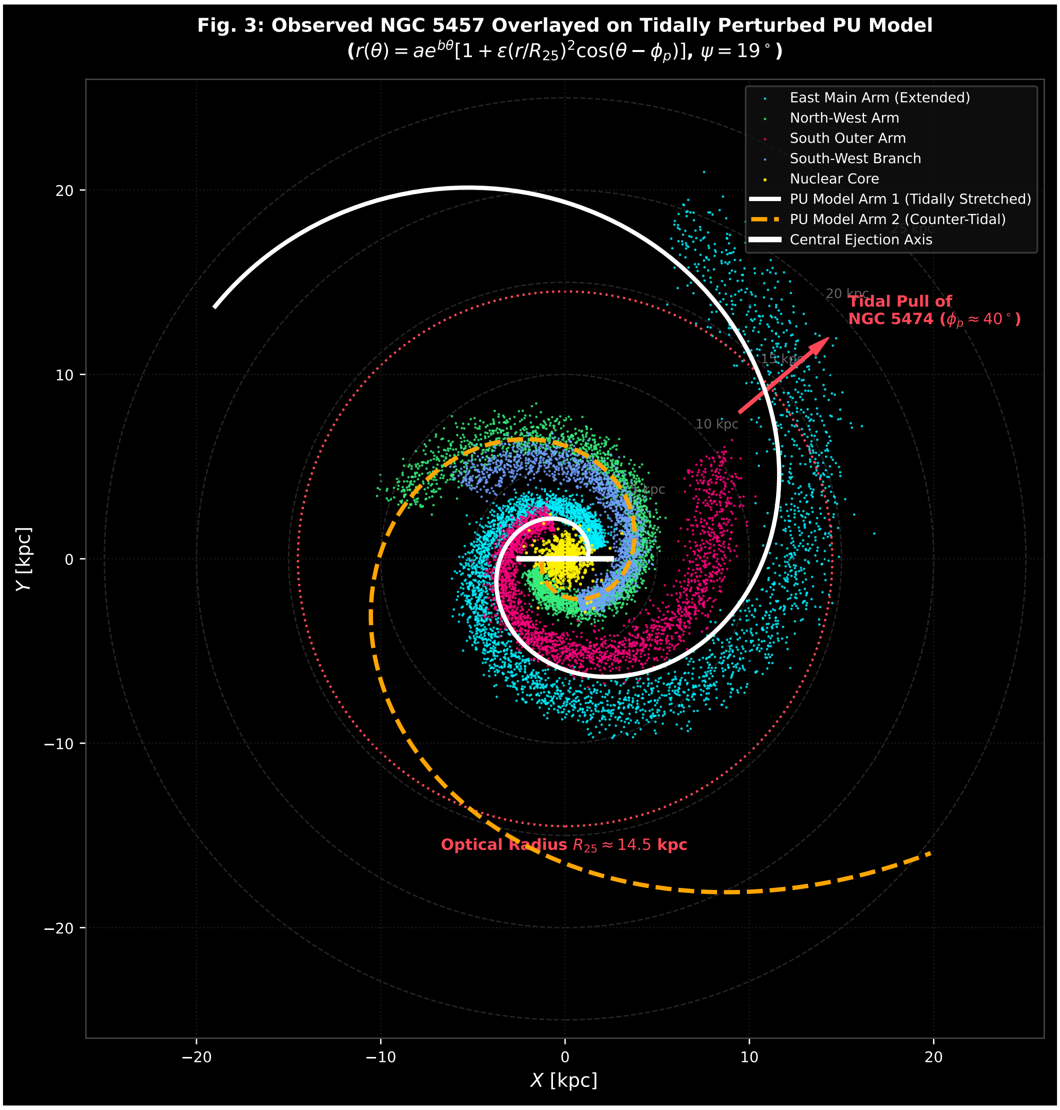

Figure 3: Observed multi-arm morphology of NGC 5457 (M101) overlayed on the tidally perturbed Pivot Universe logarithmic spiral model ($r(\theta) = ae^{b\theta}[1 + \epsilon(r/R_{25})^2\cos(\theta - \phi_p)]$, $\psi = 19^\circ$). The tidal vector to companion NGC 5474 breaks $m = 2$ symmetry, reproducing the extended eastern arm.

Table 1: Calibrated Baryonic Masses, Kinematics, and Spiral Parameters

Galaxy	**Type**	$\mathbf{M_b}$ [10^{10} $M_\odot$]	$\mathbf{V}_{\text{flat}}$ [km/s]	$\mathbf{R_{25}}$ /$\mathbf{R_e}$ [kpc]	**Pitch** ψ	**Geometry**
Milky Way	SBbc	5.5	225	11.5	13.0°	Logarithmic ($m = 2$)
NGC 5457 (M101)	SABcd	7.9	245	14.5	19.0°	Logarithmic (Tidally Perturbe
NGC 2787	$SB0^+$	4.0	195	2.1	7.5°	Tight Logarithmic Dust Ring
NGC 5194 (M51)	SAcd	8.2	220	11.0	18.5°	Interacting Logarithmic Strea

6 Conclusions

The Pivot Universe model provides an integrated theoretical architecture addressing both the kinematic and morphological properties of spiral galaxies:

1. **Velocity Flattening:** The persistent asymptotic plateau observed in galactic rotation curves arises naturally from coupling local baryonic mass to a background cosmological metric frame-dragging field (a_0), recovering the Baryonic Tully-Fisher Relation without requiring non-baryonic dark matter halos.

2. **Logarithmic Spiral Geometry:** Transitioning from Archimedean ($r \approx b\theta$) to logarithmic spirals ($r = ae^{b\theta}$) is physically required by flat rotation curves ($v_\phi = \text{const}$), ensuring self-similarity and constant pitch angles across all radii.

3. **Tidal Symmetry Breaking:** While continuous core nozzle ejection generates an intrinsic $m = 2$ grand-design skeleton, external tidal quadrupole fields $\delta r(\theta) \propto (r/R_{\text{ref}})^2 \cos(\theta - \phi_p)$ break this symmetry in the outer disk, explaining observed lopsidedness in interacting systems like M101 and M51.

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