

19 – The Radial Acceleration Relation at the Edge of Galaxy Formation: A Geometric Reading

A second supplement to the Time-Symmetric Parity Constraint papers

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Abstract

Recent analysis by Júlio et al. (2025) examines the radial-acceleration relation (RAR) in extremely low-mass dwarf galaxies, extending to the threshold of galaxy formation. They report a systematic elevation of observed dynamical accelerations above the canonical baryonic relation, accompanied by increased scatter and multi-valued behaviour. This Second Supplement reviews those findings within the framework of the Time-Symmetric Parity Constraint (TSPC). It proposes that the excess arises

not from hidden mass but from residual curvature generated by the parity-enforcing tensor field that defines the constraint. At very low baryonic densities, the geometric term dominates the stress-energy balance, producing an apparent dark-matter signal while preserving global symmetry. The result marks the natural boundary where baryonic structure yields to geometry, and where the RAR ceases to be universal.

1 Context and Purpose

The radial-acceleration relation (RAR) remains one of the most striking empirical discoveries in galactic dynamics. Across spiral and lenticular systems of widely differing size and luminosity, a tight correlation links the radial acceleration inferred from orbital motion with that predicted from the visible distribution of baryonic matter. Expressed in logarithmic form, the relation spans more than four orders of magnitude in acceleration, with scatter so small that it rivals photometric error. It is, in effect, an observational law of galactic structure.

Its interpretation has divided the field. Within the Λ CDM framework the RAR is regarded as an emergent by-product of the coupling between baryonic feedback and dark-halo concentration. Modified-gravity approaches treat it as a primary law, expressing a direct mapping between baryons and total gravitational acceleration without recourse to hidden mass. In both readings, the remarkable regularity of the relation has suggested an underlying order, either dynamical or geometric, that extends across the diversity of galaxies.

The recent study by Júlio et al. (2025)¹ pushes this relation into a regime where order might fail: the faintest and least massive galaxies known, at the very threshold of formation. Their results show that the correlation weakens, its slope and scatter depart

¹ Júlio M. P. et al. (2025) *The radial acceleration relation at the EDGE of galaxy formation: testing its universality in low-mass dwarf galaxies*. arXiv:2510.06905 (astro-ph).

from the canonical form, and the apparent acceleration systematically exceeds the value predicted from baryons alone. This is the regime that marks the physical “edge” of galaxy formation, where stellar systems barely retain coherence against external tides and internal feedback.

For the TSPC framework, such departures are of immediate interest. The TSPC hypothesis regards curvature, rather than unseen matter, as the primary source of these anomalies. It therefore invites a re-examination of any empirical breakdown that might delineate the limits of baryonic control and the onset of geometric dominance. The purpose of this supplement is to review the findings of Júlio *et al.* within that geometric context, to test whether the observed excess can be interpreted as a manifestation of residual curvature rather than missing mass, and to define the observational priorities that could discriminate between the two.

2 Summary of the Júlio *et al.* Findings

The study by Júlio *et al.* (2025) extends the empirical investigation of the radial-acceleration relation into a domain rarely explored: dwarf galaxies of baryonic mass between 10^4 and 10^7 solar masses. These systems inhabit the lower limit of stable galaxy formation, where internal gravity competes with stellar feedback and external tides. Their small size and low luminosity make them critical laboratories for testing whether the RAR remains universal.

The authors assembled a sample of twelve nearby dwarfs with high-quality stellar-velocity data. Using the *GravSphere* code, they reconstructed the radial mass profiles through spherical Jeans modelling, thereby deriving the total gravitational acceleration at each radius. Baryonic accelerations were computed from the distribution of visible matter, principally stars with gas included where detected, and the two quantities were compared directly in log–log space.

Definition of the Radial-Acceleration Relation

The relation links the observed radial acceleration

$$a_{\text{obs}}(r) = \frac{v_c^2(r)}{r}$$

to the baryonic acceleration

$$a_{\text{bar}}(r) = \frac{G M_{\text{bar}}(r)}{r^2},$$

where $v_c(r)$ is the circular velocity and $M_{\text{bar}}(r)$ the enclosed baryonic mass. In massive disc galaxies these obey a nearly one-to-one mapping

$$\log a_{\text{obs}} \approx f(\log a_{\text{bar}}),$$

with a characteristic turnover at $a_{\text{bar}} \sim 10^{-10} \text{ms}^{-2}$.

In this low-mass regime Júlio *et al.* found three key departures from that canonical behaviour:

2.1 Systematic elevation.

For a given a_{bar} the dwarfs display higher a_{obs} than predicted by the established relation, lying above its extrapolated curve by as much as 0.5 dex at the faintest end.

2.2 Increased scatter.

The dispersion about the mean trend rises sharply, well beyond the formal observational errors, suggesting that a single functional form can no longer describe all systems.

2.3 Non-monotonic profiles.

Several galaxies exhibit “hook-shaped” loci in the $a_{\text{bar}}-a_{\text{obs}}$ plane: multiple dynamical accelerations corresponding to the same baryonic acceleration, implying internal structural complexity or departures from equilibrium.

To test whether such behaviour might arise naturally within Λ CDM, the team analysed simulated dwarfs from the EDGE suite (*Engineering Dwarfs at Galaxy Formation’s Edge*). The simulations reproduced both the systematic offset and the enhanced scatter. This agreement led the authors to interpret the deviations as evidence for dark-matter domination in the smallest galaxies rather than as a failure of the standard cosmological model. They concluded that the RAR is not strictly universal, and that any baryon-based or modified-gravity account must confront this breakdown at the threshold of galaxy formation.

3 Re-examination under the TSPC Framework

TSPC interprets such departures not as evidence of missing matter but as a shift in the balance between baryonic stress–energy and the geometric term enforced by the involutive tensor field Π_v^μ .² When baryonic density falls below a critical threshold, curvature ceases to be fully determined by matter and is instead governed by the constraint itself. The observed elevation of dynamical acceleration in the faintest dwarfs then becomes a signature of residual curvature rather than additional mass.

In this regime the metric solution satisfies the standard Einstein equation only approximately. The parity-enforcing tensor contributes a symmetric correction that modifies the relation between potential and enclosed baryonic mass. The resulting acceleration can be written schematically as

² For the formal definition of Π and proof of its Robertson–Walker admissibility, see Paper 3 – TSPC, Section 2.

$$a_{\text{obs}} = a_{\text{bar}} + a_{\text{geom}},$$

where a_{geom} is the curvature-residual term produced by Π_{ν}^{μ} . At high densities a_{geom} is negligible, and the canonical RAR holds. At very low densities, where the parity field dominates, a_{geom} becomes comparable to or greater than a_{bar} , displacing galaxies upward in the RAR plane.

Geometric Residual Term

Schematically, in the linearised weak-field limit of TSPC, the local acceleration may be expressed as

$$\nabla \cdot g = -4\pi G \rho_{\text{bar}} - \kappa \text{Tr}(\Pi_{\nu}^{\mu}),$$

where ρ_{bar} is the baryonic density and κ is a coupling constant determined by the parity constraint.

The second term represents curvature generated by the fixed involutive field rather than by matter.

Integrating over radius gives an effective acceleration

$$a_{\text{geom}}(r) = \kappa r \text{Tr}(\Pi_{\nu}^{\mu}),$$

which contributes positively to a_{obs} while preserving overall time-symmetry. At high ρ_{bar} the trace term is suppressed; at low ρ_{bar} it dominates.

Within this picture, the increased scatter reported by Júlio *et al.* follows naturally. If the involutive field couples weakly to anisotropy or tidal curvature, then systems of similar baryonic mass but differing geometry will display distinct values of a_{geom} . The “hook-shaped” loci in the RAR plane may correspond to local reversals in the sign or magnitude of this term where parity changes orientation within the potential well. Such effects would appear stochastic in a purely dynamical analysis but are deterministic under a geometric one.

The resemblance between the observed offsets and those in the EDGE simulations is also explicable. Numerical solvers in Λ CDM codes enforce potential symmetry at each timestep, effectively embedding parity conservation within the algorithm. The simulated “dark-matter” response may mimic some of the same phenomenology that a fixed geometric would produce, without implying that the codes implement such a constraint explicitly. In both real and simulated dwarfs, the elevated acceleration signals the onset of curvature dominance.

4 Observational and Modelling Priorities

If the apparent elevation of acceleration in dwarf galaxies reflects curvature rather than mass, the distinction must be made empirically. The test is not subtle: it requires measurements that separate the geometry of the potential from its baryonic content. Several lines of enquiry follow naturally from the TSPC interpretation.

4.1 *Extend the sample to the ultra-faint regime.*

The parity-dominated domain is predicted to emerge below baryonic surface densities of roughly $10 M_{\odot} \text{ pc}^{-2}$. Galaxies of even lower density, some newly identified by LSST precursors, should therefore exhibit the largest geometric residuals. Accurate stellar-velocity dispersions in these systems will be decisive.

4.2 *Map anisotropy and environmental curvature.*

The scatter in the Júlio *et al.* sample suggests that local geometry, not mass alone, governs the offset. Measuring the spatial orientation and tidal environment of each dwarf may reveal whether a_{geom} relates with triaxiality or proximity to a larger host. A parity-linked dependence on orientation would be strong evidence for geometric control.

4.3 *Combine lensing and internal dynamics.*

Where dwarfs act as weak lenses either alone or within groups, the deflection field offers an independent probe of curvature.³ Comparing lensing-derived and dynamical accelerations within the same object can distinguish residual curvature from dark-mass hypotheses. A joint analysis of such systems should therefore be prioritised.

4.4 *Express residuals in curvature units.*

Reporting RAR departures in s^{-2} , rather than as logarithmic accelerations, would align the data directly with the geometric framework and allow comparison with the expected amplitude of the Π_{ν}^{μ} term. This simple change of units would greatly aid cross-disciplinary interpretation.

4.5 *Model parity fields explicitly in simulations.*

Hydrodynamical codes could be modified to include a fixed, divergence-free tensor field with the symmetries of Π_{ν}^{μ} . Its influence on dwarf-galaxy stability and on the emergent RAR would test whether curvature residuals of realistic

³ Ian Salisbury (2025) *See Paper 13 ante.*

amplitude can reproduce the observed offsets without invoking additional matter.

Collectively, these directions define a clear empirical programme: to observe where and how the baryonic description of gravity gives way to geometry. The faintest galaxies, rather than the most massive, now offer the strongest discriminant between matter-based and constraint-based cosmologies.

5 Concluding Remarks

The study by Júlio *et al.* draws the radial-acceleration relation into the smallest and faintest of galaxies and finds it beginning to unravel. Where baryons grow sparse, curvature persists. Within TSPC, that persistence is expected: the involutive tensor field that enforces time symmetry also sustains curvature when the material source term falls away. The apparent excess of acceleration is therefore a geometric residue, not an inventory of unseen mass.

At high densities the baryonic and geometric contributions are locked together, producing the near-perfect correlation that defines the classical RAR. As density declines, the two components decouple, and the mapping from light to gravity loses precision. The result is the “edge” of galaxy formation in both observational and theoretical senses; the threshold where matter yields to the governing geometry of spacetime.

In that light, the breakdown reported by Júlio *et al.* is not an anomaly but a boundary condition. It marks the transition from baryonic control to geometric constraint. Whether this interpretation prevails will depend on further observation, but its falsification lies within reach. If the geometry speaks, the evidence will decide.

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