

Odd Radio Circles as Local Tracers of Residual Production in Galactic-Scale Events

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Abstract

We propose that Odd Radio Circles (ORCs), the giant ring-like radio structures discovered by ASKAP [8], can be interpreted as local, observable manifestations of rheological activation within the Cosmological Dissipative Residual (CDR) framework developed across Papers I–IV. In this picture, major galactic mergers or intense starbursts release rest-mass energy through Einstein’s mass-energy equivalence ($E = \epsilon M_{\text{event}} c^2$), inflating an expanding plasma bubble. As this bubble expands into the surrounding cosmological residual medium ($w_{\text{res}} \approx -1$), a sharp velocity and density gradient develops at the interface, generating significant shear ($\sigma \sim 10^{-14}–10^{-13} \text{ s}^{-1}$).

This shear activates the pseudoplastic (shear-thinning) rheological response of the residual (Paper II), producing anisotropic stress π^{ij} that dissipates energy through turbulent processes. Part of this dissipated energy is converted into the isotropic residual component, contributing locally to the cosmological residual density, while another fraction accelerates electrons to relativistic energies via second-order Fermi processes, powering the observed synchrotron emission that forms the bright radio ring.

Order-of-magnitude calculations using realistic astrophysical parameters demonstrate that modest conversion efficiencies are sufficient to sustain the observed radio luminosities ($10^{40}–10^{42} \text{ erg s}^{-1}$) and provide a concrete channel for the general production term $\beta_{\text{prod}}(z)$ introduced in Paper IV. ORCs thus function as natural, accessible laboratories where the transition from anisotropic stress to isotropic residual can be directly studied.

This interpretation unifies phenomena across vastly different scales — from late-time cosmic acceleration and emergent dark matter (Papers I and II) to strong-field jet launching (Paper III) and continuous residual production (Paper IV) — within a single effective medium. It makes clear, falsifiable predictions regarding polarization morphology, correlations with star formation history, and possible weak lensing shear excesses, offering a promising avenue for future multi-wavelength tests with ngEHT, Euclid, and the Roman Space Telescope.

Keywords: Odd Radio Circles, cosmological dissipative residual, rheological activation, anisotropic stress, galactic feedback, synchrotron emission

1 Odd Radio Circles and Residual Production in Galactic-Scale Events

The Cosmological Dissipative Residual (CDR) framework proposes that the residual component is continuously produced from high-energy cosmic events, ranging from the primordial Big Bang to ongoing galactic-scale processes such as mergers and starbursts (Paper IV [1]). In this section we explore whether Odd Radio Circles (ORCs), giant ring-like radio structures discovered by ASKAP [8], can be interpreted as local, observable manifestations of this production mechanism. Rather than claiming that ORCs dominate the global residual budget, we propose they serve as exemplified galactic-scale events where the injection, rheological activation, and dissipation of residual can be studied in detail.

1.1 Observational Context of ORCs

Odd Radio Circles (ORCs) are one of the most intriguing discoveries in radio astronomy in recent years. They were first identified in 2019–2020 during the EMU Pilot Survey conducted with the Australian Square Kilometre Array Pathfinder (ASKAP) and formally reported in 2021 [8]. Since then, systematic searches with ASKAP, MeerKAT, and citizen-science projects have increased the known sample to roughly a dozen confirmed objects, with several dozen candidates awaiting confirmation [9].

ORCs are defined by their striking morphology: nearly perfect circular or slightly elliptical rings of radio emission, with diameters ranging from approximately 300 kpc to over 1 Mpc — significantly larger than typical galaxies. They exhibit steep radio spectra ($\alpha \approx -1.1$ to -1.2), indicating synchrotron radiation from an aged population of relativistic electrons. Many show limb-brightened (edge-brightened) emission, meaning the radio intensity is higher at the periphery than in the interior, suggesting a shell-like structure. In several cases, linear polarization fractions reach 20–30%, implying ordered magnetic fields [4, 6].

Most confirmed ORCs lie at redshifts $0.3 < z < 0.6$, corresponding to look-back times of roughly 3–6 Gyr, although more distant candidates ($z \approx 0.9$) have been reported [10]. A significant fraction is spatially coincident with a central galaxy that often displays disturbed morphology, enhanced star formation, or signs of recent AGN activity. However, some ORCs appear relatively "hostless" or only weakly associated with visible galaxies, adding to their mystery.

Despite intensive follow-up, ORCs remain largely invisible in optical, infrared, and X-ray bands. This "radio-only" nature suggests that the emitting plasma is relatively tenuous, evolved, and possibly heated or accelerated by non-thermal processes. The combination of enormous size, circular symmetry, steep spectrum, and lack of strong multi-wavelength counterparts makes

ORCs difficult to explain with conventional mechanisms such as supernova remnants, AGN lobes, or cluster shocks alone.

These observational characteristics position ORCs as excellent testbeds for the Cosmological Dissipative Residual (CDR) framework. Their association with energetic galactic events and their large-scale, transient nature make them natural candidates for studying local rheological activation and residual production processes.

1.2 Expansion and Interface Dynamics

We interpret an ORC as an expanding bubble of hot, magnetized plasma generated by a major galactic merger or an intense starburst event. Such events inject large amounts of kinetic and thermal energy into the interstellar and intergalactic medium, inflating a bubble that expands supersonically relative to the ambient gas. As the bubble grows, it sweeps up and compresses surrounding material, creating a leading shock front.

Crucially, this expanding bubble does not propagate into a vacuum. It interacts with the pervasive cosmological residual medium, which has an effective equation of state $w_{\text{res}} \approx -1$ and exerts a negative pressure on large scales. At the contact surface (interface) between the overpressured bubble interior and the external residual, a strong velocity and density gradient naturally develops. The inner side of the interface moves outward at hundreds of km s^{-1} , while the outer side is embedded in the smoother Hubble flow of the residual.

This differential motion produces a sharp transition layer where the characteristic shear rate is given by

$$\sigma \approx \frac{\Delta v}{\Delta r}, \quad (1)$$

where $\Delta v \approx 200\text{--}500 \text{ km s}^{-1}$ represents the relative expansion velocity of the bubble with respect to the ambient medium, and $\Delta r \approx 5\text{--}10 \text{ kpc}$ is the estimated thickness of the interaction zone. The resulting shear rates ($\sigma \sim 10^{-14}\text{--}10^{-13} \text{ s}^{-1}$) are orders of magnitude larger than the typical cosmological expansion shear ($\sim H_0 \approx 2 \times 10^{-18} \text{ s}^{-1}$ at the present epoch).

Physically, this interface behaves as a dynamic boundary layer. The expanding bubble continuously "shears" against the residual medium, generating vorticity, turbulence, and magnetic field amplification through stretching and compression. This is analogous to the contact discontinuities observed in supernova remnants or AGN-driven bubbles, but here occurring on much larger scales and in the presence of the cosmological residual. The strong shear in this layer is the key trigger that drives the residual out of its isotropic, negative-pressure state and into the activated rheological regime described in Paper II.

This picture naturally explains the limb-brightened (edge-brightened) morphology of ORCs: the radio emission is concentrated where the shear — and therefore the rheological activation — is strongest.

1.3 Rheological Activation and Anisotropic Stress

According to the rheological description developed in Paper II [2], the residual behaves as a pseudoplastic (shear-thinning) fluid. In regions of low shear, it remains in an isotropic state with effective negative pressure ($w_{\text{res}} \approx -1$), consistent with the observed cosmological acceleration. However, when the shear rate exceeds a critical threshold, the residual undergoes a transition to an activated rheological phase.

This transition is characterized by the generation of a significant traceless anisotropic stress tensor:

$$\pi^{ij} \propto \eta_{\text{eff}} \sigma^{ij}, \quad (2)$$

where η_{eff} is the effective shear viscosity, which decreases with increasing shear rate due to the shear-thinning property. In the context of an ORC, the strong shear at the bubble-residual interface ($\sigma \sim 10^{-14}$ – 10^{-13} s $^{-1}$) is well above the expected cosmological background value, triggering this activation.

The physical picture is as follows: the expanding bubble creates a sharp velocity gradient at the interface. This gradient induces differential motion between adjacent fluid elements, stretching and aligning magnetic field lines and generating anisotropic pressure. The resulting stress tensor π^{ij} represents a departure from perfect isotropy and leads to local energy dissipation. Part of this dissipated energy is converted into the isotropic residual component (contributing to ρ_{res}), while another fraction is transferred to relativistic electrons, powering the synchrotron emission observed as the bright radio ring.

This mechanism is directly analogous to the stress-driven jet production described in Paper III [3], but here operating at galactic scales rather than near black hole horizons. The shear-thinning behavior ensures that the viscosity drops in regions of high deformation rate, allowing efficient energy dissipation without requiring extreme parameters. This self-regulating property is a key feature of the CDR framework, linking local galactic phenomena to the global cosmological role of the residual.

1.4 Energy Conversion via $E = mc^2$ and Residual Production

The ultimate energy source powering the ORC phenomenon is the release of rest-mass energy during the galactic-scale cataclysmic event. According to Einstein’s mass-energy equivalence,

$$E_{\text{total}} = \epsilon M_{\text{event}} c^2, \quad (3)$$

where $M_{\text{event}} \sim 5 \times 10^9\text{--}10^{10} M_{\odot}$ represents the typical mass involved in a major galactic merger or intense starburst, and $\epsilon \approx 0.001\text{--}0.01$ is the overall conversion efficiency into usable forms of energy (kinetic, thermal, and magnetic). These efficiency values are consistent with observational and simulation studies of supernova feedback and AGN-driven outflows, where only a small but significant fraction of the available rest-mass energy is transformed into mechanical and radiative output [5, 7].

Not all of this energy is immediately available for residual production. A fraction is used to drive the expansion of the plasma bubble, heat the surrounding gas, and generate turbulent motions. However, at the critical interface between the overpressured bubble and the cosmological residual medium, a portion of this energy is transferred through dissipative processes. We denote by $\eta \approx 0.01\text{--}0.1$ the fraction of E_{total} that is ultimately converted into the residual component via rheological dissipation.

The local production rate of residual can then be expressed as

$$\dot{\rho}_{\text{res,local}} \approx \frac{\eta \epsilon M_{\text{event}} c^2}{V_{\text{interface}} \tau}, \quad (4)$$

where $V_{\text{interface}} \approx 4\pi R^2 \Delta r$ is the volume of the interaction shell and $\tau \sim 3 \times 10^8\text{--}10^9$ yr is the characteristic evolutionary timescale of the ORC. This expression provides a concrete, astrophysically grounded realization of the general production term $\beta_{\text{prod}}(z)$ introduced in Paper IV, demonstrating how discrete galactic-scale energetic events contribute to the continuous accumulation of the cosmological residual.

Physically, the conversion occurs as follows: the expanding bubble compresses and shears the ambient residual medium at the interface. This shear activates the pseudoplastic response of the residual (Paper II), generating anisotropic stress that dissipates irreversibly. Part of the dissipated energy increases the local isotropic residual density (ρ_{res}), while another fraction is channeled into accelerating electrons to relativistic energies, producing the observed synchrotron emission. This dual outcome (residual production + observable radio emission) makes ORCs particularly valuable as direct tracers of the energy conversion processes central to the CDR framework.

1.5 Order-of-Magnitude Consistency and Re-acceleration Mechanism

To assess the viability of the proposed mechanism, we perform order-of-magnitude calculations using realistic astrophysical parameters.

Consider a typical ORC with radius $R \approx 250$ kpc and an interaction shell thickness $\Delta r \approx 5\text{--}10$ kpc. The expanding bubble is driven by a galactic-scale

event involving a mass $M_{\text{event}} \sim 5 \times 10^9\text{--}10^{10} M_{\odot}$. Using Einstein's mass-energy equivalence,

$$E_{\text{total}} = \epsilon M_{\text{event}} c^2, \quad (5)$$

with a conservative conversion efficiency $\epsilon \approx 0.005$, we obtain $E_{\text{total}} \approx 2.25 \times 10^{61}$ erg. Assuming a fraction $\eta \approx 0.05$ of this energy is channeled into the residual over the evolutionary timescale $\tau \approx 5 \times 10^8$ yr ($\approx 1.6 \times 10^{16}$ s), the average power injected into the residual is

$$P_{\text{res}} \approx \frac{\eta E_{\text{total}}}{\tau} \approx 7 \times 10^{44} \text{ erg s}^{-1}.$$

The shear rate in the interface is

$$\sigma \approx \frac{\Delta v}{\Delta r} \sim 10^{-14}\text{--}10^{-13} \text{ s}^{-1}.$$

To remain consistent with the available power budget over the interaction volume $V_{\text{interface}} \approx 1.2 \times 10^{71} \text{ cm}^3$, the required volumetric dissipation rate is $\dot{\epsilon}_{\text{diss}} \sim 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}$. Using the relation $\dot{\epsilon}_{\text{diss}} \approx \eta_{\text{eff}} \sigma^2$, this implies an effective viscosity

$$\eta_{\text{eff}} \sim 10^1\text{--}10^2 \text{ g cm}^{-1} \text{ s}^{-1}.$$

This dramatically reduced viscosity compared to the unperturbed cosmological background is a direct signature of the shear-thinning rheological transition proposed in Paper II. Only a small fraction ($\sim 10^{-3}$ to 10^{-2}) of the dissipated power needs to be converted into relativistic electrons to reproduce the observed synchrotron luminosity ($10^{40}\text{--}10^{42} \text{ erg s}^{-1}$).

****Re-acceleration mechanism****: In the turbulent, sheared interface, electrons can be re-accelerated via second-order Fermi processes. Turbulent magnetic fields generated by Kelvin-Helmholtz instabilities scatter relativistic electrons, leading to a net energy gain. This stochastic acceleration operates continuously as long as the shear is maintained by the expanding bubble, naturally explaining the persistence of synchrotron emission over hundreds of millions of years.

1.6 Testable Predictions

The interpretation presented here generates several distinctive, falsifiable predictions that can be tested with current and near-future observational facilities. These predictions arise directly from the proposed shear-driven rheological activation of the residual at the bubble interface.

1. ****Polarization Morphology and Magnetic Field Structure**** If the radio emission is powered by shear-induced anisotropic stress, the magnetic field lines in the bright ring should be predominantly stretched and

aligned tangentially to the circumference. High-resolution polarimetric observations are expected to reveal ordered linear polarization vectors following the ring's curvature, with polarization fractions potentially reaching 20–40% in the brightest regions. This pattern would differ from the more radial or chaotic configurations expected in purely shock-compressed or turbulent models without rheological activation. Instruments such as ngEHT, MeerKAT, and the future SKA will be capable of resolving this morphology at arcsecond scales, providing a strong test of the shear-driven mechanism proposed in Papers II and III.

2. ****Correlation with Star Formation History and Merger Activity**** Since residual production is linked to energetic galactic events (Paper IV), the luminosity, size, and occurrence rate of ORCs should correlate statistically with the recent star formation rate (SFR) and merger history of the host galaxy. Specifically, brighter and more numerous ORCs are expected around galaxies that experienced intense starbursts or major mergers within the last $\sim 1\text{--}4$ Gyr. This correlation can be tested by cross-matching ORC catalogs with multi-wavelength data on stellar populations, AGN activity, and morphological disturbances from surveys such as DESI, Euclid, and Roman. A positive correlation would support the idea that ORCs trace localized residual injection triggered by galactic-scale cataclysms.

3. ****Weak Lensing Shear Excess ("Shadow Effect")**** The presence of activated anisotropic stress π^{ij} at the interface may produce a subtle but detectable excess in weak gravitational lensing shear across the bright radio ring, compared to what is expected from the visible baryonic mass alone. This "shadow effect" would manifest as a localized enhancement in the lensing convergence or shear field aligned with the radio emission. Although challenging due to noise and foreground contamination, this prediction could be searched for using deep weak-lensing data from Euclid, the Roman Space Telescope, or LSST. A statistically significant excess at the location of the ORC ring would constitute direct gravitational evidence of the rheological activation of the residual, providing a powerful link between radio morphology and the predictions of Paper III.

These predictions are falsifiable: the absence of tangential polarization, lack of correlation with star formation history, or no detectable lensing excess would require significant revision or rejection of the proposed mechanism. Conversely, confirmation of these signatures would strongly support the CDR framework as a unified description connecting galactic-scale feedback to cosmological residual production.

1.7 Discussion and Consistency with Previous Papers

This interpretation of Odd Radio Circles as sites of local rheological activation provides a natural bridge between the different scales addressed in the CDR series. In Paper I, the residual was introduced as a late-time dis-

sipative component capable of resolving the H_0 and S_8 tensions through a single parameter $\Gamma(t)$. Paper II extended this to galactic scales, showing that the same residual behaves as a shear-thinning fluid, producing anisotropic stresses that mimic emergent dark matter phenomenology. Paper III demonstrated that in the strong-field regime near rotating black holes, accumulated stress can lead to jet launching through a phenomenological conversion process. Finally, Paper IV proposed that the residual is continuously produced from high-energy events, acting as an adaptive regulator of cosmic expansion.

The current work unifies these pieces by identifying ORCs as observable, intermediate-scale laboratories where the same physical processes operate. The expanding bubble generated by a galactic merger or starburst creates precisely the high-shear environment required to activate the rheological transition (Paper II). The resulting anisotropic stress dissipates in a manner analogous to the near-horizon stress conversion of Paper III, while simultaneously contributing to the local production of isotropic residual as described in Paper IV. Thus, ORCs offer a direct, multi-scale testbed for the CDR framework: from the global cosmological role (acceleration and tensions) down to localized, observable radio structures.

This picture has several conceptual strengths. First, it maintains minimality — no new fields or modifications to general relativity are required. Second, it provides a unified energy flow: rest-mass energy from galactic events is partially converted into residual, with synchrotron emission serving as a visible byproduct of the dissipation. Third, it naturally explains why ORCs are rare and transient: they represent short-lived phases where the shear is sufficiently strong to produce detectable emission before the structure expands, weakens, and merges into the background residual.

Nevertheless, important uncertainties remain. The exact efficiency of energy transfer from the galactic event to the residual, the detailed microphysics of electron re-acceleration in the shear layer, and the long-term evolution of these structures require further theoretical and observational work. Future high-resolution observations — particularly polarimetric imaging with ngEHT and MeerKAT, combined with deep weak-lensing data from Euclid and Roman — will be critical to test whether the predicted tangential magnetic field alignment, shear-induced lensing excesses, and correlations with star formation history hold.

By linking giant radio structures to the same effective medium responsible for dark energy, emergent dark matter, and jet launching, this work reinforces the internal consistency and predictive power of the CDR framework across vastly different astrophysical scales.

2 Conclusions

In this work we have proposed that Odd Radio Circles (ORCs) can be interpreted as local, observable laboratories of the Cosmological Dissipative Residual (CDR) framework developed across Papers I–IV. We suggest that major galactic mergers or intense starbursts release rest-mass energy that inflates expanding plasma bubbles. At the interface between these bubbles and the surrounding cosmological residual, strong shear activates the rheological phase of the residual, generating anisotropic stress whose dissipation contributes simultaneously to the observed synchrotron radio emission and to the local production of residual.

This interpretation unifies several previously disconnected pieces of the CDR model. Paper I introduced the residual as a late-time dissipative component capable of resolving the H_0 and S_8 tensions. Paper II demonstrated its shear-thinning rheological behavior at galactic scales, producing emergent dark matter phenomenology. Paper III showed how accumulated anisotropic stress can drive jet launching in the strong-field regime. Paper IV proposed that the residual is continuously generated from high-energy cosmic events and functions as an adaptive regulator of cosmic expansion. The current analysis shows that ORCs naturally emerge as intermediate-scale phenomena where these mechanisms operate together: energetic events inject energy, shear activates the residual, anisotropic stress dissipates into both radiation and new residual, and the process contributes to the global cosmological budget.

Order-of-magnitude calculations demonstrate that realistic astrophysical efficiencies are sufficient to explain the observed radio luminosities while producing a measurable local injection of residual. The model does not require extreme parameters and remains fully consistent with known feedback processes in galaxies. ORCs thus provide a valuable observational window into the microphysics of residual production and activation — a window that was previously inaccessible at cosmological scales.

Several testable predictions arise from this framework, including tangential magnetic field alignment in the rings, statistical correlations between ORC properties and the star formation or merger history of their host galaxies, and possible subtle excesses in weak gravitational lensing shear at the location of the bright radio emission. Future observations with ngEHT, MeerKAT, Euclid, and the Roman Space Telescope will be crucial to confront these predictions.

If supported by data, this picture would significantly strengthen the CDR framework as one of the most economical and unified descriptions of the dark sector currently available. It connects phenomena ranging from the accelerated expansion of the universe to localized radio structures through a single effective medium governed by rheological and dissipative physics. While important uncertainties remain — particularly regarding the exact

microphysical efficiencies and the long-term evolution of these structures — the model offers a coherent, falsifiable, and observationally motivated path forward.

Ultimately, the Cosmological Dissipative Residual framework suggests that what we call "dark energy" and "dark matter" may not be separate substances, but different dynamical phases of the same underlying medium — one that is continuously produced, activated, and dissipated by the energetic processes that shape the evolution of galaxies and the cosmos as a whole.

A Explanation of Key Equations

This appendix provides a detailed explanation of the main equations used in this work, their physical meaning, and their connection to the Cosmological Dissipative Residual (CDR) framework.

A.1 Shear Rate at the Interface

$$\sigma \approx \frac{\Delta v}{\Delta r} \quad (6)$$

The shear rate σ quantifies the velocity gradient in the transition zone between the expanding bubble and the surrounding cosmological residual. Here, Δv is the relative expansion velocity (typically 200–500 km s⁻¹) and Δr is the thickness of the interaction layer (5–10 kpc). This shear is significantly higher than the average cosmological value and is responsible for activating the rheological regime of the residual, as described in Paper II.

A.2 Anisotropic Stress Tensor

$$\pi^{ij} \propto \eta_{\text{eff}} \sigma^{ij} \quad (7)$$

When the shear rate exceeds a critical threshold, the residual enters an activated rheological phase. The traceless anisotropic stress tensor π^{ij} is proportional to the effective shear viscosity η_{eff} and the shear tensor σ^{ij} . This equation, central to Papers II and III, describes how shear generates anisotropic pressure that can dissipate energy locally, contributing both to synchrotron emission and to the production of isotropic residual.

A.3 Mass-Energy Conversion

$$E_{\text{total}} = \epsilon M_{\text{event}} c^2 \quad (8)$$

This is Einstein's mass-energy equivalence applied to the galactic-scale cataclysmic event. M_{event} is the mass involved in the merger or starburst ($\sim 5 \times 10^9$ – $10^{10} M_{\odot}$), and $\epsilon \approx 0.001$ – 0.01 is the conversion efficiency into kinetic, thermal, and magnetic energy. This term provides the ultimate energy

budget for the entire process, including bubble expansion, shear generation, and residual production.

A.4 Local Residual Production Rate

$$\dot{\rho}_{\text{res,local}} \approx \frac{\eta \epsilon M_{\text{event}} c^2}{V_{\text{interface}} \tau} \quad (9)$$

This equation gives the local production rate of residual. η is the fraction of the total energy converted into residual, $V_{\text{interface}}$ is the volume of the interaction shell, and τ is the evolutionary timescale of the ORC ($\sim 3 \times 10^8$ – 10^9 yr). It represents a concrete realization of the general production term $\beta_{\text{prod}}(z)$ introduced in Paper IV, showing how galactic-scale events contribute locally to the residual density.

A.5 Physical Interpretation

The sequence of equations describes a continuous energy flow: rest-mass energy from a galactic event ($E = mc^2$) drives an expanding bubble, which generates strong shear at the interface with the cosmological residual. This shear activates the rheological response of the residual, producing anisotropic stress that dissipates into both isotropic residual and relativistic electrons responsible for the observed synchrotron emission.

This mechanism does not require new free parameters and is fully consistent with the CDR framework across scales. It positions ORCs as possible natural, observable testbeds for the production and activation processes proposed in Papers I–IV.

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