**Introduction**

**RFT 7.5** is a new modified gravity framework featuring an *entropy-driven scalaron* – a scalar field that activates in low-acceleration regimes to alter gravity. This concept builds on ideas from entropic gravity, where gravity emerges from thermodynamic principles, generalized here using **Tsallis entropy** instead of the usual Boltzmann–Gibbs entropy​

[arxiv.org](https://arxiv.org/abs/1403.2688#:~:text=,new%20value%20for%20the%20Tsallis)

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[arxiv.org](https://arxiv.org/abs/1403.2688#:~:text=parameter%20via%20Mach%27s%20principle,entanglement%20in%20the%20holographic%20screen)

. By introducing a Tsallis-based entropy term, RFT 7.5 predicts deviations from Newtonian $1/r^2$ gravity in weak-field environments, similar in spirit to MOdified Newtonian Dynamics (MOND) but derived from first-principle entropy considerations. The scalaron remains dormant in high-gravity conditions (ensuring consistency with general relativity near Earth) and “activates” in low-density, high-entropy environments – increasing the effective gravitational attraction (or modifying inertia) without invoking dark matter. The goal of this study is to empirically **test RFT 7.5** in regimes where such weak-field effects should be most pronounced, and compare its predictions against those of Newtonian gravity and MOND.

Two promising testbeds for ultra-weak gravity are **cosmic voids** and **wide binary star systems**. Cosmic voids are immense underdense regions spanning tens of Mpc, where gravitational potentials are extremely low and screening effects (which hide scalar fields in dense regions) should fade​

[arxiv.org](https://arxiv.org/abs/1905.12450#:~:text=appear%20to%20be%20a%20suitable,mean%7D%7D%20density%20given)

. This makes voids natural laboratories for any “activated” scalaron – modified gravity theories like $f(R)$ gravity or symmetron predict distinct signatures such as denser void walls and enhanced outflows​

[arxiv.org](https://arxiv.org/abs/1905.12450#:~:text=voids,as%20an%20important%20consistency%20check)

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[roman.gsfc.nasa.gov](https://roman.gsfc.nasa.gov/science/Astro2020/PisaniAlice.pdf?version=1&modificationDate=1628623867637&api=v2#:~:text=modified%20gravity%20causes%20a%20faster,modified%20gravity%20results%20in%20environmental)

. Meanwhile, wide binaries (pairs of stars separated by >5000 AU) provide a **local** weak-field test: their orbital accelerations drop to $10^{-10}\text{m/s}^2$, comparable to the MOND regime. Recent Gaia observations of wide binaries have yielded intriguing, albeit debated, results: one analysis finds their relative velocities consistent with Newton/GR (with no significant MOND effect)​

[astro.theoj.org](https://astro.theoj.org/article/70171-wide-binaries-from-gaia-edr3-preference-for-gr-over-mond#:~:text=distribution%20of%20pairwise%20relative%20projected,full%20parameter%20space%20of%20triple)

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[astro.theoj.org](https://astro.theoj.org/article/70171-wide-binaries-from-gaia-edr3-preference-for-gr-over-mond#:~:text=population%20models%20and%20MOND%20versions,vs%20MOND%20in%20the%20future)

, while another reports a **$5\sigma$ detection** of excess acceleration (~30–40% above Newtonian predictions) at separations corresponding to $a < 10^{-10}$ m/s²​

[phys.org](https://phys.org/news/2023-08-smoking-gun-evidence-gravity-gaia-wide.html#:~:text=For%20accelerations%20lower%20than%20about,20%2C000%20wide%20binaries%20within%20a)

. In fact, the latter study’s observed boost (factor ~1.4) matches the classic MOND prediction (AQUAL with the Milky Way’s external field)​

[phys.org](https://phys.org/news/2023-08-smoking-gun-evidence-gravity-gaia-wide.html#:~:text=Moreover%2C%20the%20boost%20factor%20of,galaxy%20that%20is%20a%20unique)

. These conflicting findings underscore the need for new theoretical models to be confronted with data. **RFT 7.4 offers a fresh mechanism (entropy-driven gravity) that we aim to validate against these phenomena**, checking if it can reproducibly explain void dynamics and wide-binary orbits as well as (or better than) MOND and Newtonian gravity.

**Methods**

**Cosmic Void Simulations**

We will perform high-resolution N-body simulations of cosmic void regions using codes like **GIZMO** (for hydrodynamics + N-body) or **RAMSES** (for adaptive-mesh N-body). The RFT 7.4 modifications will be implemented in the gravity solvers: effectively, an additional scalaron-mediated force term that becomes significant at low densities/large scales. This term will be derived from Tsallis entropy formalisms (e.g. altering the Poisson equation or particle forces to mimic the entropy-gradient driven acceleration). We will simulate a cosmological volume and identify voids (under-densities with $\delta \sim -0.9$). For each void, we will analyze:

* **Galaxy Density Profiles** – the radial density of matter (or galaxies) from void center to boundary. RFT 7.4 predicts that scalaron activation will pull more matter toward void edges (since inside the void the scalar fifth-force is unscreened), leading to **denser void walls** than in $\Lambda$CDM/GR. Prior studies of $f(R)$ gravity show void walls can indeed become overdense when gravity is enhanced​

[arxiv.org](https://arxiv.org/abs/1905.12450#:~:text=voids,as%20an%20important%20consistency%20check)

. We will quantify the void’s central density, wall density, and thickness under RFT 7.4 and compare to standard simulations and observations.

* **Peculiar Velocities & Void Expansion** – Galaxy peculiar velocities around voids will be examined to see if RFT 7.4 causes enhanced outflows. Modified gravity generally causes faster void expansion (galaxies accelerating outward more strongly) which can be detected via redshift-space distortions (RSD)​

[roman.gsfc.nasa.gov](https://roman.gsfc.nasa.gov/science/Astro2020/PisaniAlice.pdf?version=1&modificationDate=1628623867637&api=v2#:~:text=modified%20gravity%20causes%20a%20faster,modified%20gravity%20results%20in%20environmental)

. Using simulation outputs, we’ll measure velocity dispersion and radial flow profiles at void boundaries. We will also track void size evolution over time (void radius growth rates). These results will be confronted with observational metrics: e.g. **DESI** and **Euclid** survey data can provide galaxy peculiar velocity statistics and void-galaxy RSD signals, and **LSST** (Rubin Observatory) will map thousands of voids in 3D. Any systematic increase in outflow velocity or faster void growth predicted by RFT 7.4 can be checked against such data. For instance, if RFT’s scalaron yields a ~5–10% faster expansion of voids relative to $\Lambda$CDM, this should be evident in RSD measurements (void-centric galaxy clustering anisotropy) from upcoming surveys.

* **Comparison to Observations** – Simulated **void catalogs** from RFT 7.4 will be directly compared with real void observations (from DESI, Euclid, LSST). Key observables include void abundance as a function of size, void ellipticity, and lensing signals through voids. Since voids “feel” less gravity in standard models, an entropy-boosted gravity could leave an imprint (e.g. more large voids or slightly different void-galaxy correlation functions). We will use data like DESI’s low-$z$ void catalog and **Dark Energy Survey (DES) Year 3** void lensing results as a baseline. A chi-square or likelihood will be computed for how well RFT 7.4 matches the distribution of void sizes and densities. Particular attention will be on void **edges**: RFT’s scalaron may create a shallow potential well at the void boundary due to entropy gradients, which could be detectable via slight gravitational lensing or temperature perturbations of CMB (integrated Sachs-Wolfe effect) across voids. Any such novel signature will be a clear prediction to test with Euclid and LSST data releases.

Throughout these simulations, we will vary the **entropy-driven scalaron parameters** (for example, the Tsallis non-extensivity $q$ or a coupling strength $\beta$ that controls when the scalaron kicks in). This will let us create a suite of void predictions to be statistically compared to observations, as discussed below.

**Wide Binary Orbital Analysis**

For stellar tests, we will use the **REBOUND** N-body integrator to simulate the dynamics of wide binary star systems under RFT 7.4. In Newtonian gravity, wide binaries follow Kepler’s laws to high precision; MONDian gravity would modify their effective force at low accelerations (potentially yielding tighter or faster orbits than expected). RFT 7.4 introduces a similar departure in the form of an entropy-driven extra acceleration. We will incorporate the RFT 7.4 gravitational potential into REBOUND – effectively modifying the pairwise force law for star-star interactions beyond a certain separation or below a critical acceleration $a\_c$. This could be done via a parametric potential $U(r) = -\frac{G M\_1 M\_2}{r}[1 + \Phi\_{\text{scalar}}(r)]$, where $\Phi\_{\text{scalar}}(r)$ is a small correction term derived from the scalaron field (likely a function that grows as acceleration drops, tuned by Tsallis’ $q$ parameter).

Using this custom force law, we will simulate binaries with separations 5,000–20,000 AU (characteristic orbital periods of millions of years). Direct $N$-body integration over full orbits is infeasible (too long), so instead we will utilize **semi-analytical solutions**: for instance, derive the modified Kepler’s third law in RFT 7.4 or the perihelion advance for elliptical orbits under the scalaron force. This analytical approach can highlight how orbit shapes or periods deviate from Newtonian expectations. We expect RFT 7.4 to produce a subtle but measurable effect: perhaps an increase in orbital velocity at large separation (mimicking MOND’s prediction of faster motion in low gravity). We will specifically look for deviations like: **excess pericenter precession**, changes in the velocity vs separation relation, or an anomalous decline of relative velocity dispersion with separation. These theoretical predictions will be plotted against empirical trends from **Gaia DR3** (and future DR4) data: Gaia’s catalog of wide binaries provides relative velocities and separations for thousands of pairs out to ~1 kpc distances​

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Our analysis will mirror what observers have done, enabling direct comparison. For example, we will generate the distribution of **relative velocity ratios** (observed velocity divided by the Newtonian circular velocity for that separation) for a mock population of wide binaries under RFT 7.4. If RFT’s scalaron is active, we might see a broader high-velocity “tail” in this distribution, similar to what has been observed​

[astro.theoj.org](https://astro.theoj.org/article/70171-wide-binaries-from-gaia-edr3-preference-for-gr-over-mond#:~:text=before%2C%20these%20distributions%20show%20a,data%20from%20future%20GAIA%20releases)

. We will then statistically compare RFT’s predicted distribution to the Gaia **observed** distribution (accounting for measurement errors, unseen third stars, etc.). Any improvement in reproducing features like the tentative 30% velocity excess at low accelerations​

[phys.org](https://phys.org/news/2023-08-smoking-gun-evidence-gravity-gaia-wide.html#:~:text=For%20accelerations%20lower%20than%20about,20%2C000%20wide%20binaries%20within%20a)

will be noted. Conversely, if RFT predicts no such excess, it should align with the more conservative analyses that favor GR​

[astro.theoj.org](https://astro.theoj.org/article/70171-wide-binaries-from-gaia-edr3-preference-for-gr-over-mond#:~:text=mixture%20of%20binary%2C%20triple%20and,vs%20MOND%20in%20the%20future)

– in either case, providing a testable outcome.

Additionally, we’ll incorporate external influences: MOND theories require the *external field effect* (gravity from the Galaxy) to explain wide binary motions​

[phys.org](https://phys.org/news/2023-08-smoking-gun-evidence-gravity-gaia-wide.html#:~:text=Moreover%2C%20the%20boost%20factor%20of,galaxy%20that%20is%20a%20unique)

. RFT 7.4’s framework might naturally include or exclude such effects depending on how the entropy scalaron couples to ambient fields. We will test both scenarios in simulations (e.g. adding a constant external acceleration background to see if the wide binary behavior changes). By fitting the RFT model to the data, we will **extract best-fit model parameters** (like the Tsallis $q$ value that yields the observed boost). For example, if Gaia data indeed show a 1.4× acceleration boost at ~$10^{-10}$ m/s², we’ll adjust RFT 7.4’s parameters until the simulations reproduce ~40% higher acceleration at those separations. That parameter set can then be cross-checked against the cosmic void results (ensuring one set of parameters explains both galactic and cosmological weak-field phenomena). This consistency check is crucial for RFT 7.4 to be viable as a universal theory.

**Statistical Model Comparisons**

To rigorously quantify RFT 7.4’s performance, we will employ **Bayesian inference and model selection** techniques across our void and binary analyses. For each domain, an appropriate likelihood function $\mathcal{L}(\text{data}|\text{model, params})$ will be constructed based on established modified gravity frameworks. For cosmic voids, likelihoods can be built from void statistics – e.g. the probability of observing a set of void radii and densities given a model’s predictions. For wide binaries, the likelihood might derive from the distribution of relative velocities: similar to how Pittordis & Sutherland (2023) fit mixtures of binary populations to Gaia data​

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, we will fit RFT 7.4’s predicted velocity distribution to the observed one. In both cases, we will sample the posterior probability of model parameters (using MCMC or nested sampling) to find the best-fit values and uncertainties for RFT 7.4’s parameters.

Crucially, we will compute **Bayesian evidence** values (or use information criteria like AIC/BIC) to compare the overall fit quality of RFT 7.4 against Newtonian (with dark matter where relevant) and MOND models. This will tell us which framework is most favored by the data. For example, in a cosmological context, a previous analysis of a Tsallis-modified gravity (TMG) model found a slight preference for $\Lambda$CDM over TMG (∆AIC ≈ 3.7) but not enough to rule TMG out​

[arxiv.org](https://arxiv.org/pdf/2106.15551#:~:text=is%20the%20number%20of%20free,2021)

. We will perform a similar analysis: if RFT 7.4 significantly improves the fit to wide binary accelerations or void profiles, it will show up as a lower AIC or higher Bayes factor compared to Newtonian/MOND. We will report these statistics with careful attention to uncertainties and prior assumptions.

For the cosmic void simulations, we’ll use a modified gravity likelihood already developed for void lensing and clustering (e.g. leveraging software from void cosmology analyses). For the wide binaries, we may develop a custom likelihood that incorporates uncertainties in binary orbit inclinations, line-of-sight projection (since Gaia measures projected separation and velocity), and contamination by unresolved multiples​

[astro.theoj.org](https://astro.theoj.org/article/70171-wide-binaries-from-gaia-edr3-preference-for-gr-over-mond#:~:text=mixture%20of%20binary%2C%20triple%20and,vs%20MOND%20in%20the%20future)

. **Bayesian model averaging** will be used to marginalize over nuisance parameters (like the fraction of unseen triple systems in the binary sample). This ensures that the inferred gravity model likelihood is robust.

Finally, we will combine the two arenas (voids and binaries) in a joint likelihood, under the assumption that RFT 7.4’s parameters are universal. This joint analysis is powerful: for instance, void data alone might permit a range of scalaron strengths, and binary data another range – the overlap of these posteriors will pinpoint the **consistent parameter set** (if one exists) that works for both. If no single parameter set fits both, that will reveal tension needing resolution (or potential failure of RFT 7.4). On the other hand, finding a consistent fit will strengthen RFT 7.4’s case as a **unified weak-field theory**. All analysis will be done within a Bayesian framework, providing not just best-fits but also credible intervals for parameters and **Bayes factors** for model comparison (e.g. how strongly does wide binary data favor RFT 7.4 over MOND?). These quantitative metrics will form a core part of the deliverables.

**Deliverables and Expected Outcomes**

* **Predicted Scalaron Signatures** – We will deliver clear, testable predictions for how RFT 7.4’s scalaron manifests in weak-field environments. This includes: *Cosmic void indicators* (e.g. an excess density at void boundaries, distinctive void density profiles, and faster void expansion observable via galaxy peculiar velocities) and *Wide binary orbital effects* (e.g. a specific deviation curve for relative velocity vs separation, or a shift in the wide binary kinetic temperature profile). These signatures will be contrasted against baseline Newtonian and MOND predictions, highlighting where RFT 7.4 diverges. For example, if RFT 7.4 predicts a slight increase in galaxy velocities leaving voids, we will quantify that (say, +10% higher outflow velocity at void radius) and show how surveys like Euclid or DESI could detect it. Likewise, for binaries, we might predict a particular range of separations (e.g. 5,000–10,000 AU) where the orbital period or velocity dispersion deviates measurably from Keplerian, due to entropy-driven extra gravity. These concrete predictions are designed to enable **observational falsification or confirmation** of RFT 7.4.
* **Statistical Performance Analysis** – A detailed comparison of how well RFT 7.4 fits the data **relative to Newtonian gravity and MOND**. This will be presented in terms of goodness-of-fit metrics and model selection statistics. For instance, we will provide log-likelihood values, $\chi^2$/dof, and Bayesian evidence (or $\Delta$AIC/$\Delta$BIC) for each model across the void and binary tests. We anticipate results such as: “RFT 7.4 provides a **better fit to wide binary velocity distributions** than Newtonian gravity with dark matter, with $\Delta\text{AIC} \approx -5$ (favoring RFT) compared to MOND” or conversely if RFT underperforms, we will document that. If available, we will also include **Bayes factor** values (e.g. $B\_{RFT,MOND}$) to quantify the likelihood of RFT 7.4 vs MOND given the data. The analysis will also highlight any remaining discrepancies – for example, if RFT 7.4 fits void data well but still struggles with some aspect of binary motions, this will be transparently discussed. Overall, this deliverable serves as a scorecard of RFT 7.4’s predictive accuracy, demonstrating whether the entropy-driven approach can match real-world weak-field phenomena as closely as existing theories do (or better).
* **Parameter Constraints for Scalaron Activation** – Using the Bayesian inference results, we will report the **best-fit parameters** and **credible ranges** for RFT 7.4’s key parameters that drive the scalaron activation. This could include the Tsallis entropy index $q$ (e.g. $q=1+$ε indicating how much it deviates from standard entropy), any length/acceleration scale parameters (analogous to MOND’s $a\_0$), and coupling strengths. For example, we might constrain the critical acceleration $a\_c$ at which the scalaron significantly boosts gravity (perhaps finding $a\_c \sim 1\times10^{-10}$ m/s² consistent with the MOND scale), or set limits on the scalaron’s coupling $\beta$ such that void profiles aren’t over-modified. If the data favor RFT 7.4, we will provide a **consistent parameter set** that explains both cosmic void and wide binary observations. If not, we will indicate the tension (e.g. “Void data require a weaker scalaron effect than wide binaries do, suggesting either model refinement or systematic issues”). These constraints are valuable for refining the theory: they effectively tell us how strong the entropy-driven forces are allowed to be in reality. We will also compare these to any previous constraints on entropic gravity models – for instance, ensuring that our parameters don’t conflict with solar system tests if extrapolated, or with cosmological fits from other studies of Tsallis gravity​

[arxiv.org](https://arxiv.org/pdf/2106.15551#:~:text=is%20the%20number%20of%20free,2021)

. This deliverable thus translates observations into concrete limits, sharpening RFT 7.4 into a predictive framework.

* **Observational Validation Recommendations** – Finally, we will provide guidance for future observations and experiments to further test RFT 7.4’s distinctive predictions. This includes identifying *which observables* are most promising and *which upcoming surveys* can capture them. For cosmic voids, we might recommend targeted analysis of the **largest voids** (where RFT’s effects are maximized) using **LSST** and **Euclid** data – for example, looking at voids >100 Mpc across for anomalous dynamics​

[arxiv.org](https://arxiv.org/pdf/2206.06480#:~:text=related%20to%20the%20depth%20and,for%20significantly%20higher%20acceleration%20ratios)

. We will suggest measuring void-galaxy cross-correlation functions and void lensing signals as diagnostics. For wide binaries, we will encourage deeper use of **Gaia** (DR4 and DR5 in coming years) to improve sample statistics, and perhaps **follow-up observations** (e.g. high-precision radial velocities for long-period binaries) to verify true orbital motions. If RFT 7.4 predicts subtle timing effects (like a period change over decades due to scalaron influence), we’ll note that as a potential long-term test. Additionally, we will highlight synergies: e.g. using **DESI** and **Rubin Observatory** together to map voids with spectroscopy (for accurate distances) and photometry (for volume) to reduce uncertainties in void measurements, which could tighten the tests of RFT. Our recommendations will serve as a roadmap for the community to either confirm RFT 7.4’s predictions or find where it breaks, thereby guiding the development of the next iteration (RFT 7.5).

By pursuing these methods and deliverables, this study will effectively **refine RFT 7.4 into a fully vetted weak-field gravity model**. We will either validate that an entropy-driven scalaron can indeed reproduce observed cosmic void dynamics and wide binary orbits, or pinpoint adjustments needed. In doing so, we set the stage for **RFT 7.5**, using the empirical insights gained to inform what modifications or tuning the next version will require. Ultimately, this research pushes RFT toward a comprehensive theory that bridges the gap between general relativity and the persistent gravity anomalies in the weak-field regime, paving the way for a deeper understanding of gravity inspired by the principles of entropy and information.