**RFT 7.9 vs. Leading Gravity Theories: A Comparative Analysis**

**1. Statistical Model Performance Assessment**

**Galaxy Rotation Curves (SPARC)** – RFT 7.9 must contend with the wealth of high-quality galaxy rotation curve data (e.g. the SPARC database). Recent Bayesian fits of SPARC rotation curves strongly favor dark matter halo models over MOND-like modified gravity. For example, using Bayesian model comparison, **cored dark matter halos (Burkert profiles)** are preferred with large Bayes factors in many galaxies, whereas MOND fits tend to succeed only in cases with large data uncertainties​

[arxiv.org](https://arxiv.org/html/2401.10202v1#:~:text=this%2C%20we%20represent%20DM%20by,in%20favor%20of%20dark%20matter)

. Overall, rotation curve evidence “comes out in favor of dark matter” under rigorous Bayesian analysis​

[arxiv.org](https://arxiv.org/html/2401.10202v1#:~:text=this%2C%20we%20represent%20DM%20by,in%20favor%20of%20dark%20matter)

. If RFT 7.9 is to compete, it must either replicate this success or offer comparable fit quality without dark matter. Its performance can be quantified via Akaike (AIC) and Bayesian (BIC) information criteria on rotation curves: an **AIC/BIC difference > 10** in favor of one model is considered strong evidence. Any RFT 7.9 model that introduces extra parameters (e.g. a scalar field profile) is penalized by BIC, so it must achieve a significantly better likelihood to be favored over the simpler $\Lambda$CDM halo model​

[arxiv.org](https://arxiv.org/html/2401.10202v1#:~:text=would%20be%20a%20product%20of,be%20strongly%20favoured%20over%20MOND)

. As a benchmark, combining Bayes factors across the SPARC sample yields an overwhelming preference for the dark matter paradigm​

[arxiv.org](https://arxiv.org/html/2401.10202v1#:~:text=match%20at%20L257%20would%20be,be%20strongly%20favoured%20over%20MOND)

. Thus, **RFT 7.9 needs to match the flexibility of halo models (which fit the diverse rotation curve shapes) without overfitting**. Specific strengths of RFT may lie in reproducing the tight Radial Acceleration Relation (RAR) between baryonic and total acceleration observed in galaxies – something MOND naturally explains but $\Lambda$CDM struggles with. If RFT 7.9 incorporates this correlation (e.g. via an emergent relation from its field equations), it could provide a statistical improvement for rotation curves. Conversely, a weakness would be if RFT 7.9 cannot accommodate galaxies with declining outer rotation curves or the observed scatter in the RAR without fine-tuning. Robust Bayesian model comparison on SPARC (and upcoming high-resolution rotation curves from e.g. **Rubin Observatory**) will be a critical test: **RFT 7.9 must achieve comparable likelihoods to $\Lambda$CDM while using fewer or similar number of parameters**, to avoid being disfavored by AIC/BIC penalties.

**Cluster Mergers (Bullet Cluster, Abell 520, El Gordo)** – The gravitating mass in merging galaxy clusters provides a stringent, multi-faceted test for any gravity theory. The famous **Bullet Cluster** collision (1E 0657–56) is often cited as *“empirical proof”* of dark matter that modified gravity alone has difficulty explaining​

[bigthink.com](https://bigthink.com/starts-with-a-bang/galaxy-cluster-broke-modified-gravity/#:~:text=The%20galaxy%20cluster%20that%20broke,modified%20gravity)

. In this system, a smaller subcluster passed through a larger cluster, stripping the normal matter (hot gas) via ram pressure, while the inferred gravitating mass (from weak lensing) remained with the collisionless component (galaxies). The result is a **spatial offset between the gas and the mass**: gravitational lensing maps show the mass peaks (inferred to be dominated by dark matter) displaced from the X-ray luminous gas clouds​

[esa.int](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=The%20optical%20image%20from%20the,properties%20compared%20to%20normal%20matter)

. **Figure: The Bullet Cluster collision.** Hot gas (pink, Chandra X-ray) lies between two galaxy clumps, while the total mass (blue lensing map) is centered on the galaxies, indicating a dominant collisionless mass component​

[esa.int](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=The%20optical%20image%20from%20the,properties%20compared%20to%20normal%20matter)

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*Composite image of the Bullet Cluster. X-ray emitting gas (pink) lags behind the galaxy clusters, whereas the mass distribution from gravitational lensing (blue) stays with the galaxies​*

[*esa.int*](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=The%20optical%20image%20from%20the,properties%20compared%20to%20normal%20matter)

*. This separation is viewed as direct evidence of dark matter not explicable by modifying gravity alone.* RFT 7.9 must reproduce this phenomenon. Traditional MOND/TeVeS alone struggle because gravity in those theories is tightly coupled to the baryonic distribution; **without an unseen mass component, a pure modified gravity can’t easily produce two distinct gravitational potential centers**. Indeed, the Bullet Cluster provided the *first clear separation* of normal vs. dark matter in observations​

[esa.int](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=of%20background%20images%20by%20mass,properties%20compared%20to%20normal%20matter)

, which any viable theory must address. Some modified gravity advocates have attempted explanations: e.g. Moffat’s Scalar–Tensor–Vector Gravity (STVG or “MOG”) claimed that an enhanced gravity plus a residual **bound baryonic component** could shift the lensing peaks and mimic the observed separation​

[arxiv.org](https://arxiv.org/abs/1606.09128#:~:text=et%20al,cluster%20dynamics%20without%20dark%20matter)

. However, even these require additional assumptions (like hidden baryonic mass or neutrinos). RFT 7.9 would need to incorporate a mechanism (perhaps an “entropy-coupled” hidden mass proxy or a special scalar field configuration) to explain why lensing mass can be offset from gas. **Bayesian model comparison for the Bullet Cluster** would likely pit RFT’s explanation (with whatever additional fields it posits) against $\Lambda$CDM (with collisionless dark matter particles). Observationally, the **surface density profile** from lensing and the **X-ray gas profile** can be simultaneously fit; any extra degrees of freedom in RFT must be justified by a significantly better fit to these maps. If RFT 7.9 can naturally produce a separation of mass from baryons (say, via an “effective dark mass” in regions of high entropy or rapid relative motion), it might achieve a marginal likelihood comparable to $\Lambda$CDM. If not, it will be strongly disfavored by Bayes factors.

Notably, other cluster mergers provide additional tests. **Abell 520 (“Train Wreck” cluster)** presents an opposite puzzle: a *“dark core”* rich in inferred mass but **devoid of galaxies**, with the galaxies having been flung aside in the collision​

[science.nasa.gov](https://science.nasa.gov/missions/hubble/dark-matter-core-defies-explanation/#:~:text=This%20technique%20revealed%20the%20dark,far%20away%20from%20the%20collision)

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[science.nasa.gov](https://science.nasa.gov/missions/hubble/dark-matter-core-defies-explanation/#:~:text=match%20at%20L394%20Studies%20of,ray)

. In Abell 520, the cores of the clusters appear to have left behind a concentration of gravitating mass (detected via lensing) coincident with hot gas, rather than staying with the galaxies. This is difficult even for standard $\Lambda$CDM (it might hint at self-interacting dark matter), but it’s also problematic for any theory – the Bullet Cluster showed mass stays with galaxies, while Abell 520 shows mass with gas, and **“no single theory explains the different behavior of dark matter in those two collisions”​**

[**science.nasa.gov**](https://science.nasa.gov/missions/hubble/dark-matter-core-defies-explanation/#:~:text=match%20at%20L409%20dark%20matter,We%20need%20more%20examples)

. For RFT 7.9, this means it must be flexible: perhaps by an environment-dependent effect or an entropy-triggered mass redistribution that could account for both outcomes. **Statistical analyses on cluster mergers** will use metrics like the Bayes factor comparing how well each theory explains the full set of mergers. If RFT 7.9 excels in one (e.g. Bullet) but fails in another (Abell 520), its overall evidence will be weak. On the other hand, $\Lambda$CDM currently also faces tension (Abell 520, and the extreme high-velocity merger **El Gordo**). El Gordo (ACT-CL J0102–4915) is a massive high-redshift cluster merger that is difficult to reconcile with the expected collision speeds and rarity in $\Lambda$CDM​

[darkmattercrisis.wordpress.com](https://darkmattercrisis.wordpress.com/2021/01/16/54-the-interacting-galaxy-cluster-el-gordo-a-massive-blow-to-%CE%BBcdm-cosmology/#:~:text=,with%20more%20than%206sigma%20confidence)

. Some analyses claim the Bullet and El Gordo clusters *“falsify the standard dark matter cosmology at >6σ”* due to their unexpected properties​

[darkmattercrisis.wordpress.com](https://darkmattercrisis.wordpress.com/2021/01/16/54-the-interacting-galaxy-cluster-el-gordo-a-massive-blow-to-%CE%BBcdm-cosmology/#:~:text=54,with%20more%20than%206sigma%20confidence)

. RFT 7.9 could potentially shine here if its modified gravitational dynamics make such energetic collisions more probable (e.g. MOND can allow higher infall speeds in voids​

[darkmattercrisis.wordpress.com](https://darkmattercrisis.wordpress.com/2010/08/11/the-train-wreck-cluster-an-anti-bullet-cluster-disproof-of-cold-or-warm-dark-matter/#:~:text=7,Weck%20Clusters)

). Statistical model comparison would involve cluster collision velocity distributions: RFT 7.9 might predict a different tail of high-speed mergers than $\Lambda$CDM. **Bayes factors incorporating cluster dynamics** (like the required infall velocity to form El Gordo) could favor RFT if it naturally produces massive mergers more frequently. In summary, RFT 7.9 needs to demonstrate **at least as good a fit to multi-modal cluster data (lensing + X-ray + dynamics)** as $\Lambda$CDM. Its strengths might be in explaining one of the cluster anomalies (perhaps El Gordo’s existence or Bullet’s high speed​

[darkmattercrisis.wordpress.com](https://darkmattercrisis.wordpress.com/2010/08/11/the-train-wreck-cluster-an-anti-bullet-cluster-disproof-of-cold-or-warm-dark-matter/#:~:text=7,Weck%20Clusters)

), but a key weakness to watch is whether it can simultaneously account for the Bullet-type and Abell 520-type observations without fine-tuning.

**Wide Binary Dynamics (Gaia)** – In the ultra-weak acceleration regime ($g \sim 10^{-11}$ m/s$^2$), as probed by wide binary star orbits, modified gravity models often predict deviations from Newtonian $1/r^2$ forces. MOND, for instance, predicts that sufficiently wide binaries (separations $\gtrsim 5$ kAU) should orbit faster than Newton would allow, by on the order of ~20% at the largest separations, due to the external field effect of the Galaxy​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=,Milgromian%20predictions%20using%20the%20parameter)

. RFT 7.9, if it reduces to a MOND-like force law at low accelerations, would similarly predict an excess velocity dispersion for very wide binaries. However, recent analyses of **Gaia DR3** data on wide binaries have placed **stringent limits** on any such deviations. A detailed Bayesian study of ~8,600 wide binaries within 250 pc found that the data are **fully consistent with Newtonian gravity**, and strongly incompatible with the MONDian boost in orbital speeds​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

. The best-fit interpolation between Newton and MOND yielded a gravity normalization $\alpha\_{\rm grav} = -0.02^{+0.065}\_{-0.045}$ (consistent with pure GR = 0), effectively *excluding MOND at $16\sigma$* significance​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

. In other words, wide binaries **favor Newtonian/$\Lambda$CDM gravity by a huge Bayes factor**. For RFT 7.9, this is a crucial data point: unless RFT introduces a screening mechanism at these scales, it might also predict a deviation that Gaia does not see. One possible strength of RFT could be if its scalar field or entropy-coupling produces an **environment-dependent suppression** of modifications (so that within the Milky Way’s potential, wide binaries behave nearly Newtonian). Some $f(R)$ and scalar–tensor theories achieve this via the **chameleon mechanism**, wherein regions of higher ambient gravitational potential (like the Galactic disk) suppress the fifth force. If RFT 7.9 includes a similar effect, it could evade the Gaia wide-binary constraints, unlike vanilla MOND. On the statistical side, future Gaia data releases (DR4/5) will increase the sample and precision. **Model comparison using Bayes factors on wide-binary relative velocities** will decisively test RFT: if RFT predicts even a ~5% deviation in orbital velocity dispersion at 10 kAU separations, Gaia DR4’s improved precision might detect or rule out this at high confidence. To be viable, RFT 7.9 might need to predict deviations smaller than the $\sim 2%$ level (the expected eventual sensitivity). Thus, a *weakness* of many modified gravity theories – tension with precise stellar dynamics – must be addressed by RFT either through additional parameters or by effectively mimicking GR in this regime. Otherwise, the **AIC/BIC will heavily penalize RFT** for failing to fit the tight wide-binary constraints, giving $\Lambda$CDM a decisive edge in Bayesian evidence.

**Cosmic Voids & Weak Lensing (Large-Scale Structure)** – The low-density void regions of the universe provide another arena for model comparison. Voids are particularly useful because many modified gravity theories predict enhanced effects in underdense regions (where screening mechanisms like chameleon or Vainshtein are weak)​

[arxiv.org](https://arxiv.org/abs/1907.06657#:~:text=,voids%20to%20detect%20the%20signatures)

. RFT 7.9’s performance can be judged against data on void abundances, void lensing profiles, and expansion velocities of voids. Upcoming surveys (**Euclid, LSST**) will map thousands of voids and measure their properties with percent-level precision. Simulations have shown that certain $f(R)$ models produce noticeably “emptier” voids with denser surrounding walls compared to GR​

[aanda.org](https://www.aanda.org/articles/aa/full_html/2019/12/aa35949-19/aa35949-19.html#:~:text=f%28R%29%20and%20the%20symmetron%20theory,parameters%20that%20are%20derived%20independently)

. For instance, in Hu–Sawicki $f(R)$ gravity (a popular benchmark), void galaxies are more concentrated in walls and the void interiors are more underdense; as a result, the **void density profiles and lensing signals differ** from $\Lambda$CDM by a measurable amount​

[aanda.org](https://www.aanda.org/articles/aa/full_html/2019/12/aa35949-19/aa35949-19.html#:~:text=f%28R%29%20and%20the%20symmetron%20theory,parameters%20that%20are%20derived%20independently)

. Specifically, the **density contrast at void edges (“void walls”) is higher for stronger gravity modifications**​

[aanda.org](https://www.aanda.org/articles/aa/full_html/2019/12/aa35949-19/aa35949-19.html#:~:text=f%28R%29%20and%20the%20symmetron%20theory,parameters%20that%20are%20derived%20independently)

. If RFT 7.9 has a similar effect (perhaps due to its scalaron mediating an extra attraction in low-density regions), it would predict enhanced weak-lensing convergence at void boundaries and a higher void galaxy bias. These predictions can be statistically assessed with void catalogs: analysts will use likelihoods of void counts and lensing given each theory. Initial forecasts suggest that an LSST-like survey could distinguish GR from a modified gravity with parameter $|f\_{R0}| > 10^{-6}$ at high confidence​

[aanda.org](https://www.aanda.org/articles/aa/full_html/2019/12/aa35949-19/aa35949-19.html#:~:text=f%28R%29%20and%20the%20symmetron%20theory,parameters%20that%20are%20derived%20independently)

. In terms of Bayesian evidence, incorporating **void weak lensing data provides very high signal-to-noise (SNR)** for detecting deviations: one study finds SNR $\approx 50$ for void lensing profiles in an LSST-sized survey for a representative $f(R)$ model​

[arxiv.org](https://arxiv.org/abs/1907.06657#:~:text=this%20paper%2C%20we%20study%20the,like%20survey)

. In practice, this means if RFT 7.9 predicts even modest deviations in void lensing, the data will yield a Bayes factor overwhelmingly favoring whichever model (GR or RFT) is true. A *strength* of RFT could be if it naturally accounts for subtle void phenomena that $\Lambda$CDM struggles with – for example, the **very large local void (KBC void)** postulated by some to explain the Hubble tension. If RFT’s scalar field can mimic a locally underdense region effect, it might improve the global likelihood of cosmological data. However, a potential *weakness* is that any additional effect in voids must not upset the successful fit of $\Lambda$CDM to **weak lensing and galaxy clustering** on larger scales. The **Bayesian model comparison across all large-scale structure data** will penalize RFT if it over-predicts deviations that are not observed. Early results from DES, KiDS, etc., show no huge anomaly in void lensing – which implies RFT’s deviations must be at or below the current few-percent error bars. Euclid and LSST will reduce those error bars dramatically. Thus, RFT 7.9’s standing will rely on whether it can simultaneously **fit galaxies, clusters, and voids** consistently. Its overall Bayesian evidence will be high only if it **matches $\Lambda$CDM’s predictive power across these multiple scales**. If, for instance, RFT fits galaxies well but fails for voids, the joint likelihood will favor $\Lambda$CDM. Therefore, comprehensive Bayesian model selection (perhaps via Population Monte Carlo sampling of the entire parameter space​

[academic.oup.com](https://academic.oup.com/mnras/article/405/4/2381/1046327#:~:text=,was%20recently%20applied%20in)

) will be employed to weigh RFT 7.9 against $\Lambda$CDM, MOND, TeVeS, etc., using all these datasets together. Only if RFT 7.9 shows **no glaring likelihood deficit in any regime** will it survive with competitive AIC/BIC scores. The current evidence suggests $\Lambda$CDM remains a very tough benchmark – it provides a consistent (if empirical) fit from galaxies to cosmology, whereas modified theories often score wins on galaxy scales but losses on others. RFT 7.9 will need to **demonstrate all-around performance** to be statistically preferred.

**2. Theoretical Stability and Consistency Checks**

**Action in Jordan vs. Einstein Frame** – A crucial part of assessing RFT 7.9 is writing down its action and checking its consistency with known scalar–tensor frameworks. Let us assume RFT 7.9 is a relativistic field theory that modifies General Relativity by adding a function of the Ricci scalar ($R$) and possibly coupling to entropy or matter fields. In Jordan frame (the “physical” frame where matter sees the usual metric), one can postulate an action of the form:

SRFT=116πG∫d4x−g f(R,S)+Smatter[gμν,Ψ],S\_{\rm RFT} = \frac{1}{16\pi G}\int d^4x \sqrt{-g}\,f(R, S) + S\_{\rm matter}[g\_{\mu\nu}, \Psi],SRFT​=16πG1​∫d4x−g​f(R,S)+Smatter​[gμν​,Ψ],

where $f(R,S)$ is some function extending the Einstein–Hilbert action. (Here $S$ might denote an “entropy” related scalar, if RFT introduces an entropy coupling, see below.) By performing a conformal transformation $g\_{\mu\nu} \to \tilde{g}*{\mu\nu} = F(R,S),g*{\mu\nu}$ (with $F=\partial f/\partial R$ or a similar factor), one can move to the Einstein frame where the gravitational part is standard Einstein–Hilbert and the modifications appear as extra fields. In the case of pure $f(R)$ gravity (no explicit entropy term), it is well-known that one can define a **scalar field (scalaron) $\phi = F(R) = \partial f/\partial R$** that carries the additional degree of freedom​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=In%20case%20f,4)

. The Einstein-frame action then becomes that of GR plus a canonical scalar field $\phi$ with a self-interaction potential $V(\phi)$ determined by $f(R)$. RFT 7.9 likely follows this template: introducing a scalaron field $\phi$ ensures it is formally equivalent to a **Brans–Dicke-like theory** with $\omega\_{BD}=0$ (in the case of pure metric $f(R)$) or some generalized coupling if entropy is involved. Formally deriving the RFT action in both frames and showing their equivalence is vital to check there are no hidden inconsistencies. **Consistency with known scalar–tensor theory** means that RFT 7.9 should reduce to a subset of Horndeski theory or another stable theory if it involves a scalar. For instance, if RFT’s entropy coupling introduces a second field (say an “enthalpy” field that couples to matter entropy), one must examine if this can be re-written as a coupled scalar–tensor theory without higher than second-order derivatives (to avoid Ostrogradsky instabilities). The transformation to Einstein frame also makes it easier to identify how the scalaron couples to matter: typically $f(R)$ gravity in Jordan frame corresponds to a scalar $\phi$ that universally couples to matter (hence a “fifth force”). If RFT 7.9 is to be viable, in Einstein frame it likely includes a coupling of $\phi$ either minimal or with a coupling function $A(\phi)$ to matter fields. **Ensuring consistency** requires that any such coupling does not violate known bounds (for example, solar-system constraints demand either a very weak coupling or a screening mechanism).

As a concrete exercise, one would derive the field equations of RFT 7.9. For pure $f(R)$, the trace of the modified Einstein equations yields:

3□F(R)+F(R)R−2f(R)=8πG T,3 \Box F(R) + F(R)R - 2f(R) = 8\pi G\,T,3□F(R)+F(R)R−2f(R)=8πGT,

where $F(R) = \partial f/\partial R$ and $T$ is the trace of the stress tensor​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=is%20given%20by%203%03F,we%20can%20find%20a)

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[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=In%20case%20f,4)

. The appearance of $F(R)$ in this equation signals the extra scalar DOF (since if $f(R)=R$, then $F=1$ and the extra terms vanish, recovering GR​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=2T%20,dynamics%20can%20be%20obtained%20by)

). For RFT with entropy coupling, an analogous equation would involve variations with respect to both $R$ and $S$: one might have a field equation for an entropy-related field. **It is essential that these field equations are internally consistent** (no contradictions or singular behavior for realistic initial conditions). One check is to look for the existence of well-behaved cosmological solutions (like a stable de Sitter solution for late-time acceleration). For $f(R)$ theories, a **de Sitter solution (with $T=0$)** exists if there is a root of $F(R)R - 2f(R)=0$​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=is%20a%20solution%2C%20so,R%29%20should%20satisfy)

. RFT 7.9 should similarly admit a solution that corresponds to our current $\Lambda$-like epoch (likely provided by the extra terms mimicking dark energy). Ensuring the solution is stable against perturbations leads to constraints on the functional form of $f$. In known $f(R)$ models, the condition

f′(R)>0andf′′(R)>0,f'(R) > 0 \quad \text{and} \quad f''(R) > 0,f′(R)>0andf′′(R)>0,

for $R$ in the regime of interest, is required for **avoidance of ghosts and tachyons**​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

. The first condition $f'(R)>0$ ensures that the effective Newton’s constant $G\_{\rm eff} = G/f'(R)$ is positive – equivalently it avoids a negative kinetic term for the scalaron which would signal a ghost instability​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

. The second condition $f''(R)>0$ ensures the scalaron mass squared ($m^2 \sim 1/(3f''(R))$ in vacuum) is positive, avoiding a tachyonic instability (exponential growth of the scalar)​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

. These are known as the **Dolgov–Kawasaki stability criteria** for $f(R)$ models. RFT 7.9 must satisfy analogous criteria. If RFT extends $f(R)$, one might have additional functions (e.g. $f(R,S)$ partial derivatives). We would require positivity of the kinetic matrix in the multi-field system (no eigenvalues with wrong sign) and positive effective masses. A formal linear stability analysis around vacuum and around relevant backgrounds (like a galaxy or the cosmological background) is necessary. This involves perturbing RFT’s field equations to second order and ensuring the kinetic term of each propagating mode is positive (no ghosts) and that dispersion relations yield real, positive frequency squared (no tachyons or gradient instabilities).

RFT 7.9 should be checked for **unitarity and causal propagation**. If the theory has higher-order derivatives (beyond second order in equations of motion), one worries about Ostrogradsky ghosts. However, if RFT is constructed within the Horndeski class or equivalent (which maintains second-order equations even if the action looks higher order), it can evade Ostrogradsky instabilities by design. We assume RFT 7.9’s designers took this into account. One specific check: after GW170817 (the neutron star merger with optical counterpart), modified gravity theories must ensure gravitational waves propagate at the speed of light (within $|c\_T - c|/c < 10^{-15}$). Many scalar–tensor theories were ruled out because they predicted $c\_T \neq c$ in vacuum​

[arxiv.org](https://arxiv.org/pdf/2011.15089#:~:text=context%20have%20been%20scalar,footprint%20on%20the%20in%02ternal%20kinematics)

. Thus, RFT 7.9 should be formulated such that the tensor perturbations remain exactly luminal (for example, $f(R)$ gravity automatically gives $c\_T=1$ in vacuum, whereas some Horndeski terms like $G\_5(\phi,X)$ would not). Ensuring **causality** likely means RFT does not include those terms or has parameters tuned to satisfy $c\_T=1$. We expect RFT passes this test by construction (otherwise it would already be excluded by gravitational wave timing). In summary, a **healthy RFT 7.9** in theoretical terms is one that in Einstein frame looks like: a scalar field $\phi$ (the scalaron or emergent gravity scalar) with a standard kinetic term (no ghosts), a well-behaved potential (mass$^2 >0$ around important backgrounds), and coupling to matter that does not break local Lorentz invariance or causality.

**Linear Stability and Ghost-Free Constraints** – The linear stability analysis involves perturbing the metric and any extra fields around a chosen background (Minkowski, de Sitter, etc.). For RFT 7.9, one would look at the scalaron perturbation $\delta \phi$ and metric perturbations (potentials $\Phi, \Psi$ in Newtonian gauge) to identify any pathological modes. In $f(R)$, the extra scalar has a **Compton wavelength** related to its mass $m$, which in turn depends on the local curvature. One finds that to satisfy solar-system tests, many viable $f(R)$ models give the scalaron a large mass in high-curvature environments (small Compton wavelength, i.e. short-range force that is hidden). At cosmological low-curvature, the mass can be small, yielding a long-range effect. RFT 7.9 likely has similar behavior: the **scalaron mass** $m\_\phi$ could depend on an “entropy” or environmental parameter, providing a kind of *entropy-based chameleon effect*. We must ensure no “ghost” appears – in a multi-field theory, ghosts could manifest if, say, the entropy coupling introduces higher-derivative interactions with the scalaron that are not properly constrained. If RFT includes a vector field (like TeVeS has a timelike vector field in addition to a scalar), one must check the **vector sector has no ghosts** (TeVeS avoids this by giving the vector a fixed norm constraint). For RFT, if an “entropy field” is actually a vector representing something like a background thermal flux, its kinetic term must be well-behaved (or it should be an auxiliary field without independent dynamics).

Ghost freedom can be checked by looking at the sign of the kinetic term in the quadratic action. For example, in $f(R)$ one can rewrite the action as $S = \int \sqrt{-g}[\frac{1}{2} (1+\varphi)R - U(\varphi) + \mathcal{L}*m]$ with $\varphi$ proportional to $\phi - 1$ (the deviation from GR) and $U(\varphi)$ a potential. Then one goes to Einstein frame via $g^\**{\mu\nu}=(1+\varphi) g\_{\mu\nu}$ and sees the scalar $\varphi$ has a kinetic term $\propto -3/(2(1+\varphi)^2) (\partial \varphi)^2$. Positivity of $f'(R)=1+\varphi$ ensures this kinetic term has the correct sign​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

. RFT’s entropy coupling may modify this condition slightly, but likely one gets analogous requirements (no sign flips in the kinetic matrix). We also check **tachyonic instabilities**: those occur if the second derivative of the potential at a critical point is negative, i.e. a local maximum when we need a minimum. For stable cosmic acceleration, the “scalaron” potential in RFT should have a minimum at the de Sitter value (so that small perturbations oscillate rather than run away). A criterion often quoted for $f(R)$ is that the effective equation of state $w\_{\rm eff}$ does not drop below $-1$ significantly, as $w < -1$ (phantom) signals a possible ghost or gradient instability. Ensuring $f''(R)>0$ helps avoid that (it prevents $w\_{\rm eff} < -1$ behavior in metric $f(R)$ models​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

). RFT’s extra coupling might complicate the $w\_{\rm eff}$ formula, so this should be studied via perturbations as well.

**Entropy Coupling Effects** – A notable feature of RFT 7.9 is the mention of “entropy coupling.” This suggests that the theory might couple the extra gravitational degree(s) of freedom to the entropy or information content of matter fields (or space). One possible interpretation is influenced by **entropic gravity** ideas (à la Verlinde), where gravity emerges from the thermodynamic tendency to maximize entropy. RFT 7.9 might embed Verlinde’s idea in a field theory: for example, the scalaron could couple to the matter Lagrangian in a way proportional to entropy or enthalpy. A concrete implementation could be adding a term like $\int d^4x \sqrt{-g}, \chi(R) S\_{\mu\nu}T^{\mu\nu}$, where $S\_{\mu\nu}$ is some entropy current. Stability-wise, any such coupling must be handled carefully. If the entropy coupling effectively introduces a **disformal coupling** (depending on derivatives of matter fields, temperature gradients, etc.), one must check it doesn’t lead to superluminal sound modes or violate the second law of thermodynamics. The second law requires entropy to never decrease, so if the scalar field can feedback into entropy, we need to ensure no exotic entropy-decreasing solutions arise. Likely, RFT treats the entropy coupling perturbatively, as a small correction for systems out of equilibrium (like during structure formation). **Stability criteria for scalaron parameters** in presence of entropy coupling would include: (i) The coupling constant (say $\alpha\_S$) that controls scalar–entropy interaction must be small enough to not spoil early-universe processes (e.g., Big Bang Nucleosynthesis, CMB decoupling, which are sensitive to any fifth force on entropy/temperature). (ii) The scalaron’s mass in high-entropy regions (like inside stars or the early universe plasma) might be shifted – one needs to ensure no tachyonic behavior in those regimes. It is plausible that **high entropy density environments screen the scalaron** (in analogy to high matter density screening in chameleon models). If so, one criterion might be a lower bound on the scalaron’s effective mass in such environments to avoid spurious long-range forces that aren’t observed (for instance, the Sun’s entropy profile has not shown deviations from Newton).

Finally, **causal propagation** must be ensured for all degrees of freedom. That means the characteristic speeds of perturbations (tensor, scalar, etc.) are all $\le c$. In most scalar–tensor theories that respect Lorentz symmetry, scalar perturbations travel at light speed or slightly below (depending on kinetic terms). RFT 7.9 should be checked for the propagation speed of its scalaron and any entropy-related mode. We expect it respects Lorentz invariance, so the scalar sound speed $c\_s$ should equal $1$ in vacuum. If the entropy coupling is akin to a fluid interaction, there could be an entropy perturbation mode – essentially a shift in temperature or chemical potential. That mode, if dynamic, should have a subluminal speed (likely related to the speed of sound in the medium). As long as the entropy coupling is through the stress-energy (which respects causality), RFT should remain causal. Another angle is checking **well-posedness** of the initial value problem: one wants the evolution equations to form a hyperbolic system. Ghosts or higher derivatives would typically spoil this, but assuming RFT avoids those, it should have a well-posed Cauchy problem like GR. Linear stability analysis around Minkowski spacetime (with some background entropy value) should reveal wave solutions for the graviton and scalaron. We would verify that no exponential runaway solutions exist (which would indicate an instability) and that the group velocity of wavepackets is not superluminal.

In summary, RFT 7.9 must clear the standard theoretical consistency hurdles: **no ghosts (positive kinetic energy for all modes)**, **no tachyons (positive mass squared or stable potential minima)**, and **no acausal propagation**. The conditions $f'*R>0, f''*{RR}>0$​

[arxiv.org](https://arxiv.org/pdf/2212.14563#:~:text=An%20f,the%20appearance%20of%20the%20ghost)

(and analogous ones if entropy is involved) provide a guide for tuning RFT’s parameters. Successfully demonstrating these properties builds confidence that RFT 7.9 is a theoretically viable modification of gravity, rather than an ad-hoc empirical fix. This theoretical soundness is essential if RFT is to be taken as a serious competitor to $\Lambda$CDM; many previous modified gravity ideas have failed one of these checks (e.g. some $f(R)$ models had tachyonic regimes, some bimetric theories had ghosts, etc.). The **consistency with scalar–tensor gravity frameworks** means RFT can leverage the rich literature of those theories for its stability analysis, which strengthens its standing if it indeed fits within a known stable category (perhaps a special case of Horndeski or DHOST theories tuned to $c\_T=1$). So far, we assume RFT passes these tests, enabling us to proceed to its **observable predictions**.

**3. Observational Predictive Benchmarking**

To establish RFT 7.9 as a credible theory, it must not only **fit existing data** (as addressed in section 1) but also make **clear predictions for forthcoming observations**. Here we outline explicit predictions RFT 7.9 offers for several upcoming missions and surveys, and what precision would be required to confirm or falsify those predictions:

* **X-ray Cluster Dynamics (XRISM, Athena)**: Space telescopes like JAXA/NASA’s **XRISM** (launched 2023) and ESA’s upcoming **Athena** (2030s) will provide high-resolution X-ray spectroscopy of galaxy clusters. This enables new tests of gravity in clusters via **two main observables**: (1) **Gas dynamics** – Athena’s XIFU instrument will measure the **line-of-sight velocities and turbulence** of the intracluster medium (ICM) with unprecedented precision (a few tens of km/s). Under $\Lambda$CDM/GR, hydrostatic equilibrium in clusters implies a balance between gas pressure gradients and the gravitational potential. RFT 7.9 might predict a different depth or shape of that potential due to its modified gravity (especially if less dark matter is present). For instance, if RFT enhances gravity, clusters might hold gas in a deeper potential well than the visible mass alone would produce, altering the gas pressure profile. Conversely, if RFT partly “replaces” dark matter, the effective potential might be shallower than in $\Lambda$CDM for the same gas distribution. **Athena will be able to map the gravitational potential via gas pressure profiles and the slight gravitational redshift of emitted X-ray lines**​

[the-athena-x-ray-observatory.eu](https://www.the-athena-x-ray-observatory.eu/en/node/822#:~:text=The%20high%20spectral%20and%20spatial,IFU)

. A predicted signature of RFT could be a small deviation in the **gravitational redshift profile** of clusters – e.g. gas at the cluster center might show a few km/s more redshift (towards the cluster’s edge) in RFT vs. GR if gravity is stronger. Athena’s ability to measure this gravitational redshift has been studied, showing it can be used as a probe of cluster mass profiles to high accuracy​

[the-athena-x-ray-observatory.eu](https://www.the-athena-x-ray-observatory.eu/en/node/822#:~:text=shifts%20in%20the%20X,IFU)

. RFT 7.9 should quantify how much difference (in km/s) it expects relative to GR. If the difference is, say, 5–10 km/s in the line shift, Athena could detect it. If it’s <1 km/s, it might remain below detection.

(2) **Mass profiles from combined X-ray + Lensing** – A powerful upcoming test is to compare cluster mass inferred from X-ray (assuming hydrostatic equilibrium) to that inferred from gravitational lensing (which directly probes the gravitational field via bending of light). In GR, cluster surveys have found some discrepancies (so-called “hydrostatic mass bias”, where X-ray mass can be ~10–20% lower than lensing mass, partly due to non-thermal pressure). RFT 7.9 might either exacerbate or reduce this tension. If RFT has an extra force, lensing (which in GR depends on mass) might not equal dynamical mass. Some modified gravity (like certain **chameleon $f(R)$ models) predict lensing is less affected by the scalar fifth-force (since lensing depends on the sum $\Phi+\Psi$ metric potentials, and some MG produce $\Phi \neq \Psi$)**. RFT might thus predict a specific ratio of lensing mass to X-ray mass. For example, an RFT model could predict that X-ray hydrostatic mass underestimates true mass by 30% because the gas does not feel the full modified gravity (if some effect like pressure support from entropy coupling exists), whereas lensing sees the full “effective mass”. **XRISM and Athena will measure gas pressure profiles with a few percent precision**, and upcoming wide-field optical surveys (LSST, Euclid) will provide precise weak lensing maps for many clusters. A concrete prediction could be: *In RFT 7.9, the hydrostatic mass bias is a function of the scalaron field value in the cluster, say, bias = 1/(1+\alpha\phi). Thus clusters in dense environments have $\phi \to 0$ (GR limit) and little bias, while isolated clusters have $\phi$ active and show larger mass bias.* If Athena finds a systematic trend in X-ray vs. lensing mass with environment or redshift that matches RFT’s functional form (and differs from $\Lambda$CDM’s approximately constant $\sim10%$ bias), that would be a win for RFT. On the flip side, if observations continue to align with $\Lambda$CDM (mass bias around 10% with no exotic trends), RFT’s parameter $\alpha$ might be constrained to near zero. **Required precision:** Athena aims for ~5% accuracy on cluster mass profiles. If RFT’s deviation is, say, 15%, it will be clearly detectable; if only 5%, it could be borderline. With a large sample of clusters, statistical combination could detect even a 5% effect. Thus, to *validate* RFT, it should predict at least a few-percent level signature in cluster X-ray dynamics. To *falsify* RFT, observers would demonstrate that no such signature exists down to <1–2% level, thereby ruling out the parameter values RFT needs.

Another test: **Velocity dispersion of galaxies vs. gas** in clusters. In some modified gravity scenarios, galaxies (being mostly collisionless) respond to gravity differently than the pressure-supported gas. RFT might predict a subtle difference in the profile of galaxy velocity dispersion vs. the gas temperature profile. Upcoming surveys like **DESI** will provide galaxy velocities in clusters, which can be compared to X-ray gas temperatures (which trace the potential depth). Any mismatch could be a clue. RFT’s prediction should be quantified (e.g. galaxies might experience an extra acceleration from scalar field that gas does not, if the scalar couples to galaxies differently due to entropy differences – galaxies have low entropy, hot gas has high entropy). If RFT expects, say, **galaxy velocities to fall off less steeply with radius than gas temperature**, then measuring those with DESI + Athena can test it. Achieving <5% errors on velocity dispersion profiles will likely require stacking many clusters, which could be done by the mid-2020s.

Overall, RFT 7.9 will be strongly tested by X-ray and lensing observations of clusters: **any deviation in the relation between mass, gravitational potential, and hot gas observable** is a potential “smoking gun” for modified gravity. As one study emphasizes, combining internal kinematics (like X-ray or galaxy dynamics) with lensing is a powerful way to constrain MG screening mechanisms​

[arxiv.org](https://arxiv.org/pdf/2011.15089#:~:text=surveys,Vainshtein%02screened%20theories%20improve%20through%20the)

. By 2030, if Athena and lensing surveys show a consistent GR picture to high precision, RFT would be forced into a very narrow parameter space (or ruled out). If instead slight discrepancies appear (beyond the capability of $\Lambda$CDM with reasonable baryonic physics to explain), RFT could gain support.

* **Void Lensing Profiles & Density Contrasts (Euclid, LSST)**: As discussed, cosmic voids are a prime testing ground for modifications. **Euclid** (launch ~$2025$) will map the 3D distribution of galaxies up to $z\sim1$–2, identifying thousands of voids, and measure weak gravitational lensing shapes of background galaxies behind those voids. **LSST** (Rubin Observatory, starting full survey ~$2024$) will do similarly with an even larger area. RFT 7.9 should put forward clear predictions for how voids behave. For instance, in RFT the presence of the scalaron might make gravity *less* effective inside voids (if an unscreened fifth force pushes matter out of voids more strongly), resulting in emptier void centers compared to $\Lambda$CDM. Quantitatively, RFT might predict that **voids of radius >30 Mpc have density contrast $\Delta \approx -0.95$ (5% of mean density) instead of $\Delta \approx -0.85$ in $\Lambda$CDM**. It might also predict a different evolution of void size with redshift, since structure formation dynamics change. These are measurable: Euclid will measure void density profiles via galaxy tracers, and the lensing signal (tangential shear) around voids. A benchmark prediction could be: *The average tangential shear signal for voids of radius 20–30 Mpc at $z\sim0.5$ is 10% higher in RFT than in $\Lambda$CDM.* According to simulations, LSST could detect such differences with high SNR​

[arxiv.org](https://arxiv.org/abs/1907.06657#:~:text=this%20paper%2C%20we%20study%20the,like%20survey)

. Indeed, forecasts show void abundances and void lensing could distinguish an $f(R)$ model (with parameter $|f\_{R0}| \sim 10^{-5}$) at $>8\sigma$ confidence with LSST data​

[arxiv.org](https://arxiv.org/abs/1907.06657#:~:text=we%20find%20that%20both%20statistics,like%20survey)

. RFT’s unique twist might be the entropy coupling – perhaps voids with different environments (near cluster superclusters vs in sparse regions) might show different lensing, if the scalaron’s behavior depends on entropy of surrounding matter. That is an exotic prediction: e.g. *voids near large clusters are less emptiness-enhanced because the cluster’s entropy environment suppresses the fifth force*. If Euclid/LSST were to find an environmental dependence of void profiles, it would be hard to explain in $\Lambda$CDM and could support RFT.

**Precision requirements:** Euclid aims for percent-level precision on the void lensing profile by combining many voids. If RFT’s effect is at the 5% level, it will be evident. To falsify RFT, Euclid/LSST would need to show void lensing that matches GR to within uncertainties ~1–2%. If, after Euclid’s survey (say ~2027), the void results are completely consistent with $\Lambda$CDM, then RFT models that predicted a larger effect (like 5–10%) are ruled out. Alternatively, if a void lensing anomaly is found, one will compute the Bayes factor comparing RFT vs. $\Lambda$CDM models for that data. Given the high SNR, even a modest anomaly could yield **Bayes factors $\gg 100$** in favor of whichever model fits.

Another void observable is the **velocity flow out of voids**: Euclid will measure galaxy peculiar velocities/statistics (via redshift-space distortions). RFT might predict slightly faster outflows from void centers if gravity is modified. This could be seen in the void RSD profile (the $\alpha$ parameter of void elongation in redshift space). A difference of a few percent in outflow velocity at 10 Mpc from center might be detectable by combining many voids. Achieving ~5 km/s precision in average outflow speed would be needed – challenging but perhaps possible with upcoming data. If RFT’s entropy coupling affects void interiors (which have very low entropy), it might produce a distinct signature here.

* **Stellar Orbital Dynamics at Ultra-Weak Fields (Gaia DR4/5)**: Extending the wide binary tests, we consider other ultra-weak gravity scenarios that Gaia and future astrometric missions can probe. One is the motion of stars at the outskirts of the Milky Way and in dwarf galaxies. **Gaia DR4** (expected ~2025) and DR5 (~2028) will provide more distant hyper-velocity stars and satellite galaxy dynamics. RFT 7.9 could predict, for instance, that the outer rotation curve of the Milky Way will not fall off as fast as Newtonian expectation without dark matter – essentially a MOND-like boost beyond the baryonic mass edge. If RFT intends to eliminate dark matter, it must *predict the same flat rotation curves that dark matter would*, but via modified dynamics. By DR4, Gaia will have measured the 3D kinematics of halo stars out to perhaps 100 kpc. **If RFT is correct, the Milky Way’s gravitational field at 50–100 kpc (where $g \sim 10^{-11}$ m/s$^2$) might show a measurable departure from the Keplerian decline expected from visible mass alone.** MOND would predict needing an extra acceleration of order $a\_0 \sim 1.2\times10^{-10}$ m/s$^2$, but the wide-binary result suggests if such an extra acceleration exists, it is heavily suppressed in our Galactic environment​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

. RFT might incorporate that suppression. A concrete prediction could be: *The Milky Way’s circular velocity at 50 kpc is 200 km/s in RFT 7.9 (flat from the inner disk), whereas in a no-DM Newtonian scenario it would drop to ~150 km/s.* Dark matter of course also predicts ~200 km/s, so distinguishing RFT from DM in the Milky Way might require looking at the **detailed shape of the gravitational potential** (which could be probed by tidal streams or precession of orbits). RFT could cause, for example, a different precession rate of the Magellanic Clouds’ orbit than Newtonian DM would. Upcoming measurements of proper motions by Gaia and the **Roman Space Telescope** (which will do precision astrometry in the 2030s) can pin down the orbits of dwarf galaxies. If RFT fails to mimic dark matter perfectly, subtle discrepancies in orbital dynamics might emerge – e.g. the timing of the pericenter of the Large Magellanic Cloud might disagree.

Another laboratory is **tiny dwarf galaxies and wide binaries within them**. Gaia can observe stars in nearby dwarfs (like Carina, Draco) to see if their outer velocity dispersions adhere to Newtonian predictions given their baryon content. MOND famously predicted dwarfs should exhibit a “external field effect” (EFE) – their internal gravity is reduced if the galaxy is in a strong external field (like the Milky Way’s). RFT with entropy coupling might have an analogous prediction: dwarfs in high entropy environment (near a big galaxy) might behave closer to Newtonian (losing the modified effects). Gaia DR4 may not fully address this, but 30-m class telescopes could provide proper motions to test it. RFT should lay out whether it expects an EFE. If yes, one could test two dwarfs at different external field levels for differences in dynamics.

The **required precision** for stellar tests is high because often systematics (like non-equilibrium dynamics, binary contamination in dispersion measurements) limit us. However, wide binaries remain a clean test – Gaia DR4 will enlarge the sample and possibly directly measure accelerations for some wide pairs. A standout future mission concept, **THEIA**, could measure accelerations of stars at $10^{-11}$ m/s$^2$ over a few years. RFT 7.9 could be definitively falsified if such a mission detects no deviation where one is predicted. For now, the goal would be that Gaia can tighten the relative velocity constraints such that if RFT predicted even a 10% deviation in the relative velocity distribution at separations ~20 kAU, it would be evident. Given Gaia DR3 already excluded MOND’s 20% effect at 16$\sigma$​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

, DR4 might improve that to say 30$\sigma$ or allow even smaller effects (perhaps 5–10%) to be probed.

In summary, **Gaia and stellar dynamics** will continue to either bolster RFT 7.9 (if slight discrepancies with $\Lambda$CDM appear) or corner it. If RFT has a screening mechanism that mimics GR in these regimes, it may survive by being indistinguishable from $\Lambda$CDM at the precision of Gaia – but that also makes it harder to ever confirm (since it only deviates in regimes we haven’t probed yet). The **decisive test** might have to wait for specialized missions or the combination of many subtle effects.

* **Early-Galaxy Formation and Entropy Distributions (JWST)**: One of the exciting developments is that the **James Webb Space Telescope (JWST)** has observed surprisingly massive, bright galaxies at very high redshifts ($z \sim 10$), much earlier in cosmic history than standard $\Lambda$CDM predicted. This has opened a window for modified gravity: maybe structure grew faster without needing dark matter. Indeed, researchers have noted that **MOND (a modified gravity paradigm) predicted as early as 1998 that structure formation would be faster in the absence of DM**, whereas $\Lambda$CDM expected a slower build-up​

[techexplorist.com](https://www.techexplorist.com/oldest-galaxies-large-bright-supporting-alternative-gravity-theory/92531/#:~:text=Case%20Western%20Reserve%20astrophysicist%20Stacy,%E2%80%9D)

. JWST’s discovery of big galaxies at $z>10$ *“contradicts the popular hypothesis that dark matter played a key role… and instead supports an alternative theory of gravity”*​

[techexplorist.com](https://www.techexplorist.com/oldest-galaxies-large-bright-supporting-alternative-gravity-theory/92531/#:~:text=This%20finding%20contradicts%20the%20popular,understanding%20of%20the%20early%20universe)

. RFT 7.9, if it posits stronger effective gravity on large scales or different initial conditions, should quantitatively address this. For example, RFT might imply that small density fluctuations grow more efficiently, allowing galaxies of $10^{10} M\_\odot$ by $z=10$ without massive halos of dark matter. A concrete prediction: *the abundance of $M\_* > 10^{9} M\_\odot$ galaxies at $z=10$ in RFT is 10 times higher than in $\Lambda$CDM.\* JWST is already counting such objects, and indeed finds more than expected by $\Lambda$CDM. RFT could claim that’s natural in their framework. To bolster this, RFT should also predict differences in the **internal properties** of early galaxies. If there is no dark matter halo, high-$z$ galaxies might be more compact (since baryons had to collapse on their own) or perhaps have higher velocity dispersion relative to their rotation speed (since no halo to stabilize them). JWST and upcoming observatories can measure velocity dispersions via rest-frame optical emission lines. A prediction could be: *Disk galaxies at $z=6$ in RFT have a mass-to-size relation distinct from $\Lambda$CDM – e.g. they are smaller for a given mass because gravity was more effective in pulling matter in.* If observations find early galaxies are indeed unusually compact or have high surface densities, that might align with RFT.

Another aspect is the **entropy distribution** in early structures. In galaxy formation, “entropy” often refers to the thermodynamic entropy of gas (or a proxy like $K=T/n^{2/3}$). If RFT involves entropy coupling, it might affect how gas cools and collapses into the first galaxies. Possibly, RFT could imply that regions of high entropy (like ionized bubbles or shock-heated regions) create different gravitational feedback. One might translate this into an observable: e.g. the **intracluster medium entropy profile** at high redshift clusters (though JWST looks more at galaxies than clusters at high-$z$). For galaxies, it could mean that gas in proto-galaxies had a different equation of state. One way to test this is via the **stellar initial mass function (IMF)** or supernova feedback signatures in early galaxies. If gravity was different, the ability of gas clouds to fragment could change, leading to a different IMF (perhaps more top-heavy if collapse is easier). JWST can infer IMF from spectral features of early galaxies. RFT might predict, for example, more high-mass stars early on due to faster collapse – an “entropy” effect because high mass stars generate lots of entropy when they explode. While speculative, it shows the range of predictions RFT could make.

Coming back to straightforward predictions: **JWST observed a UV luminosity function of galaxies at $z=9-10$** higher than expected. RFT should provide a modeled luminosity function. If RFT is to be taken seriously, it should not only qualitatively say “galaxies form faster” but produce numbers. If RFT fails to reproduce the **precision JWST luminosity function or galaxy stellar mass function**, then it might be just as challenged as $\Lambda$CDM. On the other hand, if it does well there, that’s a point in its favor. The required precision is basically comparing to JWST uncertainties: currently those high-$z$ counts are based on small fields and subject to cosmic variance, but over coming years JWST will firm up the statistics. If RFT’s predicted counts are significantly off, that could falsify it in the realm of early structure. Conversely, if $\Lambda$CDM continues to struggle (some argue we need exotic feedback or even “dark stars” to reconcile), RFT can claim a more natural explanation.

Additionally, **upcoming JWST deep fields and surveys (like JADES, CEERS)** will push to even earlier epochs ($z \sim 12-15$). RFT might predict a cutoff or behavior of galaxy formation at some epoch distinct from $\Lambda$CDM. For instance, without dark matter, perhaps structure formation could stall at some point due to the universe becoming too homogeneous at very early times (just speculating). If $\Lambda$CDM predicts almost no galaxies at $z>12$ and RFT predicts some, then a single discovery of a well-formed galaxy at $z=14$ could be a game-changer.

As for **entropy distributions**, one concrete measurable is the **metallicity and chemical abundance patterns** in early galaxies. These trace the star formation and supernova history. If RFT led to more rapid star formation, one might see higher metallicities at a given age than in $\Lambda$CDM. JWST can measure metallicity via rest-UV spectra (oxygen lines, etc.). If RFT predicted, say, that a $z=8$ galaxy of mass $10^9 M\_\odot$ has $Z \approx 0.5 Z\_\odot$ (half-solar metallicity) whereas $\Lambda$CDM would predict $0.2 Z\_\odot$ due to less prior star formation, that’s testable.

In summary, **JWST and early universe observations** provide an opportunity for RFT 7.9 to excel where $\Lambda$CDM faces challenges. Already, JWST’s findings *“bolster predictions made by… MOND”* according to some scientists​

[livescience.com](https://www.livescience.com/space/cosmology/the-bottom-line-is-i-told-you-so-jwst-observations-upend-standard-model-of-how-galaxies-form-new-study-claims#:~:text=%27The%20bottom%20line%20is%2C%20I,MOND)

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[techexplorist.com](https://www.techexplorist.com/oldest-galaxies-large-bright-supporting-alternative-gravity-theory/92531/#:~:text=Case%20Western%20Reserve%20astrophysicist%20Stacy,%E2%80%9D)

. RFT 7.9 can differentiate itself by giving a fuller cosmological model that matches these early galaxy results *without* introducing tensions elsewhere (like CMB, which we address next). The most decisive tests here will be **quantitative**: RFT’s success will be measured by comparing model predictions to observed galaxy statistics (stellar mass functions, sizes, metallicities) from $z\sim 5$–15. A cross-check will be that those early galaxies grow into realistic present-day galaxies, which requires consistency with observations at lower redshifts too.

**Required Observational Precision to Validate/Falsify RFT 7.9:** We have interspersed the precision needs above, but to summarize clearly:

* *Galaxy Rotation Curves:* a comprehensive fit to SPARC with RFT. If RFT can fit all 175 SPARC galaxies with residuals comparable to a dark matter fit and with fewer parameters, that would validate it. If there exist **rotation curve shapes RFT cannot reproduce (say, declining curves or wrong shape in the inner regions)**, high-quality data will expose that. The SPARC data is already precise (few km/s uncertainty); improving on that won’t be the limiting factor – it’s the model flexibility. So here, it’s more about *model adequacy* than observational precision.
* *Cluster Mergers:* next-gen optical and X-ray observations (JWST can observe shock fronts, Athena will map gas) will pin down the mass–baryon offsets in bullet-like systems to a few kpc accuracy. If RFT predicts *no* separation between lensing mass and gas, it’s already falsified by existing Bullet Cluster data (separation is clearly seen​

[esa.int](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=The%20optical%20image%20from%20the,properties%20compared%20to%20normal%20matter)

). If it predicts some separation, the exact offset and relative masses must match observations; future detailed lensing maps (e.g. with JWST or ELTs) will get error bars on the mass–gas offset to maybe 1–2%. That level will either continue to align with collisionless DM or reveal oddities – if the latter, RFT might get a point.

* *Wide Binaries:* Gaia DR4 will roughly double the sample and refine systematics. If DR3 gave Newton favored at 16σ​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

, DR4 could push that to >20σ or detect smaller deviations. A definitive falsification of a MOND-like RFT portion is arguably **already** in hand (the 16σ exclusion of MOND​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

). To validate RFT on the other hand, one would need Gaia to have found a deviation – which it did not. So RFT must differentiate itself by not predicting that particular deviation (perhaps via screening). In that sense, RFT survives where MOND didn’t by threading the needle of predictions. Future missions might shrink error bars such that even 5% modifications are excluded, which would really constrain any modified gravity.

* *Void lensing:* Euclid+LSST will measure void lensing to ~2% precision. If RFT predicts, say, a 10% effect, that’s an easy validation – a clear signal will appear with $>5\sigma$. If RFT predicts a 2% effect, that’s at the edge of detectability; absence of detection would falsify it. So ideally RFT should give a comfortably detectable signature or else be so close to GR that it’s indistinguishable (which then begs the question of its necessity).
* *CMB/BAO/LSS:* (transitioning to next section) experiments like **CMB-S4** will measure CMB anisotropies to cosmic-variance limits, BAO to sub-percent, etc. RFT will need to match those with similar precision as $\Lambda$CDM. A tiny hint of discrepancy might be tolerable, but big ones will kill the theory. CMB-S4 can detect an extra relativistic species or a change in the lensing potential at many sigma – if RFT inadvertently behaves like one of those, it could be falsified. Conversely, if RFT can slightly better explain any current anomalies (like the lensing amplitude $A\_L$ or $S\_8$ tension between lensing and CMB), that would raise its credence.

In conclusion for this section, the **most decisive observational tests for RFT 7.9 in the near future** will likely be:

* The **weak-field dynamical tests** (wide binaries, galaxy outskirts) which are tightening the noose on deviations.
* The **void and large-scale structure tests** from Euclid/LSST, offering new regimes to check for the fifth force.
* The **early universe galaxy formation tests** from JWST, which already hint at departures from standard expectations (where RFT might shine if it naturally accounts for them).

Each of these will either uncover a mismatch that calls for new physics (potentially validating RFT 7.9’s approach), or they will reinforce the standard model and further constrain RFT’s parameter space to the point of irrelevance.

**4. Cosmological Tests**

Beyond galaxy-scale and cluster tests, RFT 7.9 must prove itself in the arena of **precision cosmology**. This means integrating the effects of RFT’s scalaron (and any other new components) into the equations governing the expansion of the Universe and the growth of structure, then comparing to data from the cosmic microwave background (CMB), baryon acoustic oscillations (BAO), and large-scale structure (LSS).

**Background Expansion (Hubble curve & BAO)** – First, RFT’s modified Friedmann equations need to reproduce the observed expansion history of the Universe. In $\Lambda$CDM, the Friedmann equation (in a flat universe) is $H^2(a) = \frac{8\pi G}{3}(\rho\_m + \rho\_r + \rho\_\Lambda)$, and the presence of $\rho\_\Lambda$ (constant dark energy) drives an accelerated expansion at late times. RFT 7.9 might generate acceleration without a literal cosmological constant – e.g. in $f(R)$ gravity, the extra scalar can act like a time-varying effective $\Lambda$. We would integrate the **scalaron field equation** along with the Friedmann equation. Many $f(R)$ models are built to closely mimic $\Lambda$CDM expansion (for viability), differing only at late times by a few percent in $H(z)$. RFT likely does the same to avoid conflict with distances to supernovae and BAO measurements. So one test is: does RFT predict any difference in the distance–redshift relation measurable by upcoming surveys? For example, Euclid and DESI will measure BAO scale to ~1% across $z=0.5$–2. If RFT had a different expansion (say due to less matter or an evolving DE), it could shift the BAO peak. A specific prediction might be: *RFT 7.9 predicts a slightly lower matter fraction $\Omega\_m$ (since some “missing mass” is attributed to modified gravity rather than gravitating mass), leading to a ~2% larger sound horizon $r\_d$ and thus BAO scale.* That would mean comoving BAO scale maybe 150 Mpc in RFT vs 147 Mpc in Planck $\Lambda$CDM, for instance. Upcoming BAO measurements can detect such a difference. However, RFT can likely be parametrized in terms of an effective equation of state $w\_{\rm eff}(z)$ for dark energy. Matching the observed BAO and supernova distances essentially constrains $w\_{\rm eff}(z)$ to be near -1 in the recent universe. So RFT must either *predict* $w \approx -1$ (like $f(R)$ models tend to, at least at $z<1$), or be fine-tuned to it. Any deviation, like $w\_{\rm eff}(z)$ not equal -1, would manifest in next-gen data. CMB-S4 and DESI will determine the matter density $\Omega\_m$ and $H\_0$ combination to within a percent or so; RFT’s background needs to fit within those error bars. Thus, cosmologically, one likely finds RFT’s parameters chosen such that the background expansion is virtually indistinguishable from $\Lambda$CDM, to survive current tests. The room for improvement might be in the *Hubble tension* (the mismatch between local $H\_0$ and Planck inferred $H\_0$). If RFT can raise $H\_0$ a bit by altering late-time expansion (e.g. an effective $w(z)$ > -1 at $z\sim0.5$), it might better accommodate the local measurements. This is a delicate game because changing $H\_0$ often screws up the fit to CMB. But some modified gravity models (early dark energy, etc.) have been invoked to address the Hubble tension. RFT’s scalaron could potentially play a similar role if it contributes a bit of energy density at early times (to reduce the sound horizon and hence allow higher $H\_0$). That’s an avenue where RFT could be tested: *does it naturally lead to a different inference of $H\_0$ from cosmological data?* If yes, upcoming observations (SH0ES, CMB-S4) will scrutinize if that helps or hurts the tension.

**Perturbation Growth (CMB and LSS)** – The more distinctive signatures of RFT will appear in the **growth of cosmological perturbations**. We must integrate the linear perturbation equations for RFT. In $\Lambda$CDM, the metric perturbations $\Phi$ and $\Psi$ (Newtonian potentials) are equal (since no anisotropic stress except neutrinos) and are sourced by matter density perturbations. In modified gravity, often $\Phi \neq \Psi$ because the scalar field contributes an effective anisotropic stress. RFT 7.9 likely introduces a **scale-dependent growth rate**: on smaller scales (inside the scalar’s Compton wavelength) gravity is boosted by the fifth force, while on larger scales it might revert to GR. This would affect the matter power spectrum $P(k)$ and the CMB. For example, in $f(R)$ models, the growth of structure is enhanced at late times for scales below a certain $k$ (depending on $f\_{R0}$), leading to a higher $\sigma\_8$ (rms fluctuation) if unconstrained​

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. RFT might similarly predict a higher or lower $\sigma\_8$ or a different shape of the power spectrum. Cosmological surveys measure $\sigma\_8$ via weak lensing and cluster counts; currently there’s a slight tension (lensing prefers a lower $\sigma\_8$ than Planck $\Lambda$CDM predicts). If RFT by chance yields a slightly lower growth (maybe due to an environment effect or an effective drag on structure formation from entropy coupling), it could alleviate the $S\_8$ tension (where $S\_8 = \sigma\_8(\Omega\_m/0.3)^{0.5}$). Conversely, many simple MG models predict *higher* $\sigma\_8$ (because extra gravity clusters matter more), which would worsen the tension. So this is a critical test: **the sign of RFT’s effect on structure growth**. If RFT 7.9 claims to solve the missing mass without cold dark matter, presumably it relies on enhanced gravity to form structures – that likely means a higher growth rate, which might overshoot observations. Next-generation lensing surveys (LSST, Euclid) will measure the clustering amplitude and growth rate as function of $z$ to a few percent. They will essentially map out the **growth index $\gamma$** (defined by $f \approx \Omega\_m(z)^\gamma$ where $f=d\ln\delta/d\ln a$ is growth rate). $\Lambda$CDM with GR yields $\gamma \approx 0.55$ for $f \sim \Omega\_m^{0.55}$. Many modified gravities yield $\gamma$ in the range $0.3$–$0.7$​

[academic.oup.com](https://academic.oup.com/mnras/article/423/4/3761/1749191#:~:text=The%20growth%20index%20of%20matter,2dFGRS%29%2C)

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[academic.oup.com](https://academic.oup.com/mnras/article-pdf/423/4/3761/4916952/mnras0423-3761.pdf#:~:text=The%20growth%20index%20of%20matter,observational%20growth%20rate%20data)

. If RFT yields, say, $\gamma=0.45$, that’s a detectable difference. Current data already constrain an effective $\gamma$; future data will map $\gamma(z)$. A success for RFT would be if data prefer a $\gamma$ different from 0.55 in the direction RFT predicts. For example, if RFT’s scalaron is active at late times, one might get **scale-dependent $\gamma$: maybe $\gamma \approx 0.4$ on small scales (due to enhanced growth) and $\gamma \approx 0.55$ on large scales (still GR-like)**. Euclid’s combination of lensing and redshift-space distortions will be able to measure growth rate as a function of scale and compare to lensing (which measures $\Phi+\Psi$). Any discrepancy between the two (often parameterized by $E\_G$ or by $\Sigma$ and $\mu$ functions) would signal modified gravity. RFT predictions could be formulated in terms of the Poisson equations: $\nabla^2 \Psi = 4\pi G\_{\rm eff}(a,k)\rho \Delta$ and $\Psi - \Phi = \Pi(a,k)$ (an anisotropic stress term). RFT might predict $G\_{\rm eff} > G$ for certain $k$ and $\Pi \neq 0$. Observables like the **ISW effect** in the CMB (late-time decay of potentials) are sensitive to $\Phi'$ and $\Psi'$. If RFT enhances late-time growth, potentials decay less (or more slowly) causing a smaller ISW effect. The CMB late-time ISW is detected as the correlation between CMB and large-scale structure; future surveys can measure it better. A reduced ISW correlation could support a model with less dark energy or modified gravity. Planck’s ISW data is not very constraining, but LSST might improve it.

Another major signature: **CMB lensing**. Planck measured the CMB lensing power spectrum and found it slightly higher than expected (the $A\_L$ anomaly). If RFT has more structure (higher $\sigma\_8$), it could potentially explain that high lensing amplitude without invoking an arbitrary $A\_L$ parameter. CMB-S4 will nail down CMB lensing to high precision (few percent). RFT must be able to reproduce whatever that result is. If CMB-S4 finds $A\_L$ back to 1 (no anomaly), then RFT should not predict too high lensing. If an anomaly persists, RFT might latch onto it as evidence of extra clustering.

**Scalaron-induced CMB deviations** – Because RFT presumably has no actual cold dark matter, one wonders how it explains the CMB acoustic peaks that strongly evidence the presence of DM at $z\sim1100$. In $\Lambda$CDM, dark matter’s gravity enhances the odd-numbered acoustic peaks (by providing extra gravitational restoring force) and shifts the peak positions. MOND-like theories alone had trouble with the CMB: they often require invoking sterile neutrinos or some proxy for DM to fit the CMB power spectrum. RFT 7.9 might have to do similarly – perhaps the scalaron plays the role of an effective neutrino/dark component in the early universe. If the scalar-mediated force wasn’t active at early times (maybe the scalaron was heavy in the high-density early universe, thus suppressing modifications), then early-universe behaves like GR with just baryons and radiation – which does *not* fit the observed CMB peaks (it would produce much smaller second peak, etc.). Thus, likely RFT still needs some form of effective dark matter in the early universe or initial conditions that differ. Maybe RFT assumes a different initial power spectrum (some theories like “primeval baryon isocurvature” tried to fit CMB without DM by adjusting initial conditions). Either way, the **CMB anisotropies are a critical test**. Next-gen CMB (like CMB-S4) will measure the small-scale anisotropies and polarization even better, which could reveal any subtle deviations. For instance, if RFT’s scalaron was lightly active around recombination, it could cause an unusual Integrated Sachs-Wolfe effect during that era or alter polarization E-mode peaks. CMB-S4 will also constrain relativistic species and recombination physics. If RFT introduced something like an “early entropy perturbation”, it must not spoil the exquisite fit of $\Lambda$CDM to Planck data (which currently is a success of $\Lambda$CDM). So one of two things must happen: RFT 7.9 in its full cosmological implementation *includes additional effective components to emulate DM in the early universe* (in which case it’s more a DM substitute than a true no-DM theory), or if it truly has no equivalent to DM, it would likely be in conflict with CMB data unless some other new effect intervenes (which would itself have to be fine-tuned).

That said, some modified gravity advocates have suggested that perhaps the discrepancy between early and late universe (like the $S\_8$ or $H\_0$ tensions) hint that GR+$\Lambda$CDM is failing at either early or late times. RFT might aim to be the single theory that addresses both: e.g. maybe it behaves like GR (with something effectively playing DM) at recombination, but by today it alters how matter clusters (reducing $S\_8$ tension or explaining MOND-like galaxy phenomenology). If it pulls that off, it would represent a unification that is arguably RFT’s greatest strength. To test that, **next-gen combined analyses** (Planck + CMB-S4 + BAO + supernova + lensing, etc.) will do global fits. They will output Bayesian evidences for $\Lambda$CDM vs. various extensions. If RFT 7.9 (with whatever parameters it introduces) doesn’t significantly improve the fit or if it overfits, the Bayes factor will not favor it given Occam’s razor. Typically, $\Lambda$CDM is hard to beat unless there’s a clear discrepancy in the data. So far, tensions exist (Hubble, $S\_8$), but none are universally confirmed as new physics. RFT’s fate may hinge on whether these tensions persist and grow with upcoming data. For instance, if LSST finds $S\_8$ is indeed 5% lower than Planck’s prediction at high significance, then $\Lambda$CDM might be in trouble and modified gravity like RFT could gain ground by explaining it (perhaps via a slightly slower growth due to an effect of the scalaron at late times). Or if JWST’s high-$z$ galaxies cannot be reconciled with $\Lambda$CDM, again RFT wins by offering a mechanism.

**Potential Observational Signatures for Next-Gen Experiments**:

* **CMB-S4 (and LiteBIRD, etc.)**: These will improve constraints on any extra energy components in both early and late universe. A signature for RFT could be a specific **scale-dependent shift in CMB power**. For example, if the scalaron is light enough to mediate a force at recombination, it might alter the damping tail of the CMB (small-scale power) due to an early ISW or metric perturbation effect. Or it might leave **non-standard lensing on the CMB**: if structure at $z\sim2$–3 was different, the CMB lensing B-modes could differ. CMB-S4 will measure lensing B-modes to high precision. A prediction could be: *RFT yields a ~10% lower lensing B-mode power at $\ell=1000$ compared to $\Lambda$CDM.* This could be due to less integrated mass along the line-of-sight if, say, scalaron suppressed some clustering at intermediate redshifts. If CMB-S4 finds no such deviation, that part of parameter space is out.
* **Euclid/LSST (galaxy clustering & lensing)**: As mentioned, these will map the growth. One signature to look for is a **sale-scale dependent growth**. LSST can do tomography: measure $f\sigma\_8(z)$ from RSD and compare with lensing $G(z)$ (growth inferred from lensing). A discrepancy between the two is a smoking gun for MG. RFT could be specifically probed by looking at the **shape of the matter power spectrum**: if no cold DM, the matter power at small scales would be suppressed (baryon-radiation pressure cut-off, aka Silk damping scale ~ Mpc). But we see halos down to much smaller scales, implying power on small scales – something that CDM provides. If RFT has no CDM, it needs an alternative way to produce small-scale power (maybe through some phase of faster growth or different inflationary spectrum). LSST will measure the matter power via weak lensing down to scales of a few hundred kpc (with systematic challenges). If they find the small-scale power consistent with CDM, a no-CDM theory would be hard pressed. Conversely, any deviation (like a cutoff in power) could signal something interesting like ultra-light axion DM or MG. RFT might mimic a cutoff if not properly seeded. So that’s an important signature: **subgalactic scale matter power**.
* **Next-generation Spectroscopic Surveys (DESI, Euclid spectro, SKA)**: These will nail down structure growth via redshift-space distortion (RSD) parameters to ~1%. For RFT, a telling sign would be a **scale-dependent RSD** signal – e.g. measuring $f\sigma\_8$ in Fourier bins: if shorter waves (like $k=0.2$–0.3 h/Mpc) have higher growth than longer waves ($k=0.05$), that could indicate the transition scale of the scalar force. DESI might not have the volume for such fine-scale division, but combining with Euclid or SKA (21cm surveys) might. If RFT scalaron has Compton wavelength ~ several Mpc, one might detect that imprint.
* **Gravitational Waves (GW) from binary mergers** as a probe: In the future, GW observatories (LISA, Einstein Telescope) might test gravity in the radiative regime. If RFT’s scalaron couples to neutron star or black hole binaries, it could induce dipole radiation (like in scalar-tensor theories) or affect the inspiral waveform. The absence of deviations in observed GW waveforms can put constraints on RFT’s coupling to compact objects. This is a bit farther out, but worth noting: if RFT is a scalar-tensor with a coupling $\beta$, binary pulsar timing and LIGO/Virgo events constrain $\beta$ strongly. RFT might avoid that by having the scalar decouple in strong fields (a screening like Damour-Esposito-Farèse “spontaneous scalarization” might be absent until certain masses). But say LIGO at design sensitivity or ET could detect a -1PN (dipole) term in the waveform if present. If none is found, RFT must adhere to that.

In conclusion, the cosmological tests will either solidify RFT 7.9 as a viable alternative that matches the precise shape of the CMB power spectrum, the expansion history, and the growth of structure – or they will expose inconsistencies. Given the tight coupling between early-universe behavior and late-universe predictions, RFT’s scalaron and entropy effects need to be carefully tuned to “turn on” at the right times and scales. The upcoming experiments like CMB-S4, Euclid, LSST, DESI, SKA will all provide data that can be jointly fitted under RFT vs. $\Lambda$CDM hypotheses. We will know RFT 7.9 is on the right track if those fits consistently show **equal or better likelihood** for RFT *and* a Bayes factor that justifies the extra complexity. Conversely, if any one of these pillars (CMB, expansion, growth) significantly prefers $\Lambda$CDM, it would highlight where RFT needs refinement – perhaps indicating the necessity of incorporating a form of dark matter after all, or adjusting the coupling functions.

**Conclusion: RFT 7.9’s Standing in the Landscape of Gravity Theories**

Bringing together the above strands, we can summarize where **RFT 7.9** excels relative to $\Lambda$CDM and other modified gravity theories, where it needs refinement, and which upcoming observations will be most decisive for its fate:

* **Strengths and Potential Advantages:** RFT 7.9 appears designed to unify the successes of different approaches: like MOND/TeVeS, it aims to explain well the galaxy-scale dynamical phenomenology (flat rotation curves, the baryon–acceleration relation) without invoking unseen matter; like $f(R)$ or scalar–tensor models, it provides a relativistic framework with a scalaron that can also drive cosmic acceleration; and by including an “entropy coupling” (inspired by emergent gravity ideas), it attempts to incorporate environment-dependent effects that could solve puzzles such as the external field effect and perhaps rapid early structure formation. If RFT 7.9 can indeed **simultaneously fit galaxy rotation curves and gravitational lensing (as MOND and TeVeS struggle with lensing), explain cluster dynamics (where MOND failed without neutrinos)​**

[**bigthink.com**](https://bigthink.com/starts-with-a-bang/galaxy-cluster-broke-modified-gravity/#:~:text=The%20galaxy%20cluster%20that%20broke,modified%20gravity)

**, and produce a reasonable expansion history and structure growth (which pure MOND cannot do, but $f(R)$ can approximate)**, then it holds a unique position. Preliminary comparisons suggest RFT can naturally account for observations that individually favor different theories. For example, **JWST’s early galaxy observations**, which challenge $\Lambda$CDM, align qualitatively with RFT/modified gravity expectations of faster early growth​

[techexplorist.com](https://www.techexplorist.com/oldest-galaxies-large-bright-supporting-alternative-gravity-theory/92531/#:~:text=Case%20Western%20Reserve%20astrophysicist%20Stacy,%E2%80%9D)

. **Galaxy-scale predictive power** (like the RAR) could be a strong point – RFT might derive the RAR from first principles of its scalar field equations, turning what is an empirical MOND law into a consequence of RFT dynamics. Additionally, RFT’s scalaron, if tuned appropriately, might address the $H\_0$ or $S\_8$ cosmological tensions by slight adjustments in early/late-time gravity. Another strength is theoretical – by working within a scalar–tensor framework, RFT piggybacks on the stability of well-explored $f(R)$ models, meaning it can be ghost-free and causal, avoiding the obvious pitfalls that rule out many alternative theories.

* **Weaknesses and Needed Refinements:** RFT 7.9 is undoubtedly more complex than $\Lambda$CDM. It introduces a scalar degree of freedom (and possibly an entropy-related component), which means extra parameters (mass of scalaron, coupling strengths, potential shape, etc.). This makes it vulnerable to **Occam’s razor** unless it significantly improves fits to data. For instance, the **Bullet Cluster** remains a stiff test: does RFT truly solve it or just shift the missing mass problem into the “entropy sector”? If RFT still effectively needs unseen mass in that context, it undermines its purpose. As of now, no modified gravity theory has provided as straightforward an explanation for Bullet-like systems as collisionless dark matter does​

[esa.int](https://www.esa.int/ESA_Multimedia/Images/2007/07/The_Bullet_Cluster2#:~:text=The%20optical%20image%20from%20the,properties%20compared%20to%20normal%20matter)

– RFT will need either a convincing simulation showing it can reproduce the lensing/X-ray map, or it must concede that some form of dark component (maybe baryonic clumps or neutrinos) is present. **Cosmologically, fitting the CMB** without cold dark matter is a huge challenge – RFT might have to invoke initial conditions or fields that mimic DM, which is a weakness as it diminishes the elegance of the theory. If RFT ends up requiring a shadow component for early times, it becomes a modified gravity + dark matter hybrid, which may solve everything but at the cost of simplicity. Additionally, the **wide binary null result**​

[arxiv.org](https://arxiv.org/abs/2311.03436#:~:text=Directly%20comparing%20the%20best%20Newtonian,a%20considerable%20range%20of%20variations)

is a glaring issue for any theory that acted like MOND at low acceleration – RFT must incorporate a screening mechanism to survive, but that raises questions: how exactly does the entropy coupling produce screening, and is that falsifiable? If it’s just tuned in, it may appear contrived.

Another area needing refinement is the **mathematical clarity of the entropy coupling**. Emergent gravity concepts are still heuristic; embedding them in a Lagrangian (as RFT attempts) might lead to ambiguities or new interactions that haven’t been fully thought out. RFT 7.9 will have to undergo peer scrutiny on whether the “entropy term” in the action is well-defined and doesn’t cause violations of thermodynamic or quantum principles. In terms of computational work, RFT should be developed into N-body simulations and Boltzmann codes (like how $f(R)$ was implemented in MG codes). If it’s too complex to simulate, that’s a drawback. But assuming it can, any mismatch with structure formation details will quickly show up.

* **Comparative Standing:** Right now, **$\Lambda$CDM** remains the empirically successful standard, with decades of cross-verified predictions (Big Bang Nucleosynthesis, CMB, structure formation) – but it leaves the dark matter and dark energy unexplained in particle physics terms. **MOND/TeVeS** excel at galaxy scales (naturally explaining the Tully-Fisher relation and RAR) but falter on clusters and cosmology. **$f(R)$ and general scalar–tensor theories** can explain cosmic acceleration and pass solar system tests via screening, and even affect structure formation in testable ways, but by themselves don’t solve the missing mass in galaxies without still requiring dark matter halos (just slightly different clustering). **Emergent gravity** (Verlinde’s theory) offers an innovative principle (gravity from entropy and information) and did surprisingly well in lensing of galaxies without DM​

[arxiv.org](https://arxiv.org/abs/1612.03034#:~:text=predicted%20by%20EG%20based%20on,developed%20and%20solidly%20tested%20theory)

, but it’s not yet a full theory for cosmology or dynamics. **RFT 7.9 attempts to synthesize these**: it can be thought of as an “augmented $f(R)$ theory” that aims to reproduce MONDian behavior on galactic scales (perhaps through the entropy coupling) while retaining consistency with cosmology. In the landscape, this positions RFT as a **comprehensive theory** if it works – one that could potentially eliminate the need for particle dark matter and a fundamental cosmological constant by attributing those effects to modified gravity and an additional field.

At present, however, RFT 7.9 would likely be viewed with healthy skepticism. It has many promises to keep: *Can it quantitatively fit the CMB power spectrum? Can it match the exact lensing and dynamics of clusters? Will it avoid all current experimental constraints (laboratory, solar system, binary pulsars)?* The answers to these are not yet fully demonstrated in the literature. Thus, **the next few years of data will be pivotal**. Key decisive tests include:

* **Precise Galactic Dynamics:** If future wide binary studies or precise galactic outer rotation curves continue to uphold GR to high precision, any theory requiring a general 10% deviation in 10^-11 m/s^2 regime (as many modified gravities do) will be essentially ruled out. RFT must show that it can reduce to GR in those regimes (perhaps via entropy screening). If it fails, that’s decisive against it.
* **Galaxy Clusters (mass vs. light):** With upcoming multi-wavelength data, if every cluster, including extreme mergers, neatly maps onto a collisionless dark matter picture (with maybe some self-interactions but nothing like a modification of $G$ needed), then RFT’s alternative explanation will lose credibility. However, if even one cluster shows an odd behavior that is hard for DM but fits an RFT pattern (like a gravitational potential that seems too deep or shallow in a way MG could explain), that would be a foothold for RFT.
* **Large-Scale Structure & Voids:** As Euclid/LSST results roll in (late 2020s), they will likely either find consistency with GR or hint at new effects (maybe a discrepancy in lensing vs. galaxy clustering on large scales). Since $f(R)$ models predict a specific scale-dependent signature, non-detection of that at high precision will rule out a broad class of MG. RFT’s entropy twist might produce a different signature – but if nothing is found, then gravity is just GR to those levels, and RFT’s modifications (if any) must be extremely small, making it questionable what problem it’s solving.
* **Cosmological Parameter Tests:** Next-gen surveys will constrain the sum of neutrino masses, number of relativistic species, etc. If RFT inadvertently acts like an extra $\Delta N\_{\rm eff}$ or some hidden component, it could be pinned down. Similarly, if it cannot match the precise phase and amplitude of all CMB peaks, it will be in trouble. Conversely, if a subtle anomaly is confirmed (like a small early ISW signal or an odd lensing amplitude), and RFT predicted it, that could elevate its status significantly.

In the end, **RFT 7.9’s standing** will be determined by whether it can **match $\Lambda$CDM’s explanatory breadth while addressing its shortcomings (dark matter particles, etc.)**. If it does so, it could represent the next paradigm, integrating gravity and thermodynamics in a novel way. In that scenario, RFT’s entropy coupling idea might herald a shift in how we view gravity – not just as geometry or a quantum field, but as linked to information content of space. On the other hand, if RFT falls short on any major front, it will join the long list of interesting but ultimately unsupported modified gravity proposals. The next decade of observations – from Gaia’s Milky Way mapping to JWST’s early-universe views, from Euclid/LSST’s cosmic web surveys to CMB-S4’s polarization maps – will provide a **comprehensive crucible for RFT 7.9**. Either a coherent picture will emerge in which RFT 7.9 consistently passes each test (and perhaps even predicts new phenomena that are observed), or the $\Lambda$CDM paradigm will further cement its place as the preferred model, leaving RFT to either evolve in response or be discarded.

In summary, RFT 7.9 strives to be a **true alternative to $\Lambda$CDM**, incorporating the insights of MOND and emergent gravity into a relativistic, cosmologically viable framework. It **excels in potentially explaining galaxy-scale relations and maybe some cosmic anomalies** with a single underlying mechanism (the scalaron with entropy coupling). It **needs refinement** in ensuring agreement with precision data (clusters, CMB) and in fully specifying the entropy coupling without ambiguity. The coming observational tests – especially those by **Athena, Euclid, LSST, Gaia DR4/5, JWST, and CMB-S4** – will be most decisive. Each will probe a different scale of RFT’s predictions, and together they will either **validate RFT 7.9 as a competitive theory of modified gravity** or pinpoint exactly where it fails, thus informing the next iteration of gravity theories in our ongoing quest to understand the true nature of dark matter and dark energy.