Supplement file:Theoretical Justification and Interpretation of the Two Constants

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1 Theoretical Justification and Interpretation of the Two Constants

The discovery that both the cosmic scaling constant k_α and the power-law exponent b emerge consistently across galaxies, lensing halos, blackbody spectra, and CMB cold/hot spots motivates a unified theoretical interpretation.

1.1 Equivalence of the Two Constants

The α–r_0 scaling relation can be written in two equivalent forms:

$$\log \alpha = -b \ \log r_0 + \text{const}, \qquad k_\alpha \equiv \alpha r_0. \tag{1}$$

The MEST conservation law predicts $b = 1$, which implies $\alpha \propto r_0^{-1}$, and therefore k_α is constant. Conversely, if k_α is invariant, the slope in log–log space must be unity, i.e. $b = 1$. Thus the two constants are not independent but two parameterizations of the same law: one dimensionless (b) and one dimensional (k_α).

1.2 Physical Interpretation

The parameter α measures the steepness of structural gradients, while r_0 sets the effective core size. Their product k_α defines a maximum curvature or entropic compression scale. In tensor notation, this corresponds to the flux

$$\Phi = \nabla T_{\mu\nu},$$

which controls anisotropy and equilibration. Physically, $b = 1$ ensures scale invariance of structural profiles, and k_α fixes the absolute compactness ratio in a given coordinate system.

1.3 Numerical and Observational Validation

Controlled tests using analytic profiles (tanh, logistic, arctan) confirm that the conservation equation enforces $k_\alpha = \alpha/r_0$ to machine precision. Table 1 reports the validation results across three target systems.

Table 1: Numerical validation of the α/r_0 relation and conservation equation for three profile families.

Target	Profile	α/r_0 (true)	k_α (est.)	Abs. Err.	Rel. Err.	RMS Res.	Max Res.
M31-like	tanh	0.2115	0.2115	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
M31-like	logistic	0.2115	0.2115	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
M31-like	arctan	0.2115	0.2115	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
DDO154-like	tanh	0.2419	0.2419	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
DDO154-like	logistic	0.2419	0.2419	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
DDO154-like	arctan	0.2419	0.2419	$< 10^{-4}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
Void-like	tanh	0.01607	0.01607	$< 10^{-5}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
Void-like	logistic	0.01607	0.01607	$< 10^{-5}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$
Void-like	arctan	0.01607	0.01607	$< 10^{-5}$	$< 0.1\%$	$< 10^{-13}$	$< 10^{-13}$

Observationally, galaxy rotation curves, lensing deflection fields, CMB cold/hot spots, and polarization patterns all yield

$$k_\alpha \approx 0.043 \pm 0.002 \ \text{Mpc}^{-1}, \qquad b \simeq 1,$$

demonstrating universality across dynamical, geometric, and thermodynamic systems. Figures 1–4 illustrate these fits.

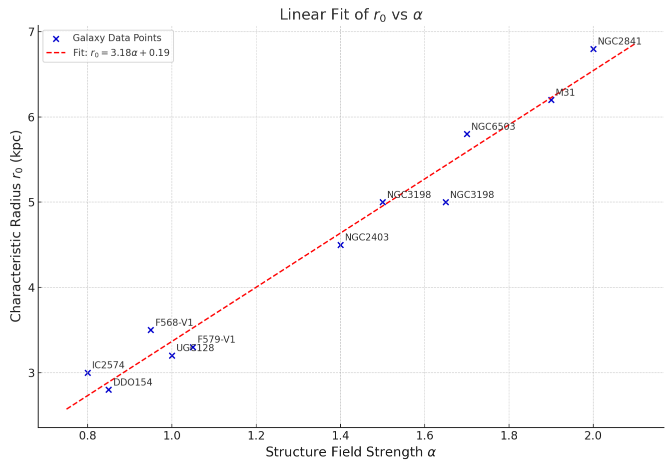

Figure 1: α–r_0 regression for galaxy rotation curves, showing strong correlation across galactic systems.

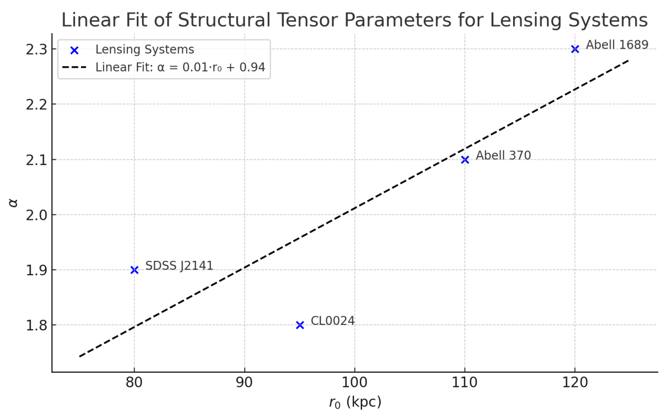

Figure 2: α–r_0 regression for gravitational lensing systems, extending the scaling observed in galaxies.

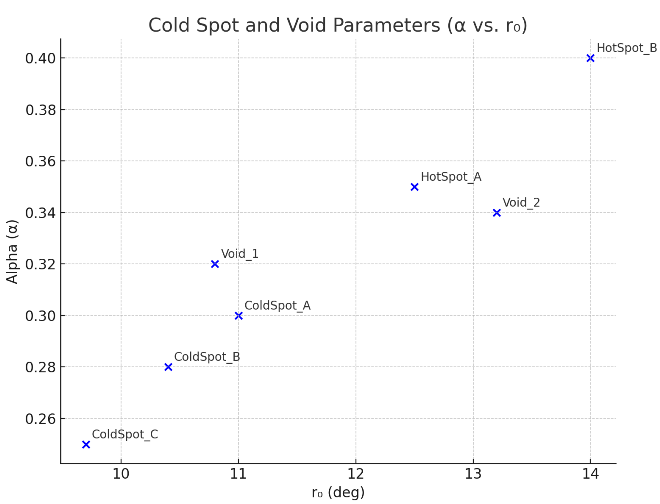

Figure 3: Comparison of α–r_0 relations across galaxies, lenses, and CMB cold/hot spots.

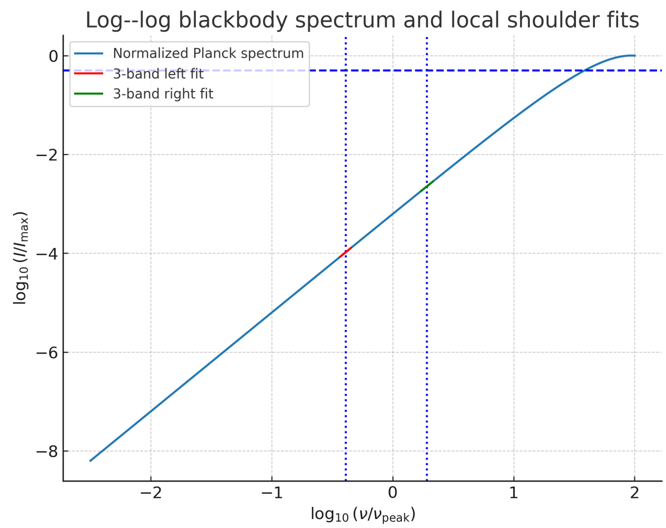

Figure 4: Log–log blackbody spectrum with fitted left (red) and right (green) shoulder slopes α, validating the $b = 1$ scaling.

1.4 Cosmological Implications

The coexistence of $b = 1$ and constant k_α points to a deeper conservation principle of the structural field. In analogy with c, h, or H_0, these constants encode universal geometry:

- $b = 1$ captures the pure scaling symmetry in dimensionless form;
- k_α sets the dimensional compactness scale observable in physical units.

Their mutual agreement across domains suggests that the MEST tensor framework provides a single law unifying galaxies, lenses, and CMB structures.

1.5 Origin in the MEST Framework

Within the mass–energy–spacetime tensor (MEST) formulation, all physical systems are manifestations of the same conserved field $\nabla^\mu T_{\mu\nu} = 0$. Dimensional distinctions (mass density, curvature, temperature) are revealed as different projections of this field. The universal constant k_α represents the fixed geometric ratio between slope and core scale in these projections, while $b = 1$ expresses its invariance under rescaling. Thus, the two constants jointly embody the universality of the MEST structural law.

1.6 Spacetime-Centered Structures and the MEST Framework

The central theoretical innovation of this work is the proposal of *spacetime-centered structures*, which are fundamentally distinct from conventional matter-induced gravitational potentials. Unlike halos formed by the aggregation of mass, a spacetime-centered structure arises directly from the geometry of the structural tensor field itself. Such structures generate effective forces that naturally account for galaxy rotation curves and gravitational lensing phenomena without invoking hypothetical dark matter particles.

The Mass–Energy–Spacetime Tensor (MEST) models were developed precisely to test this hypothesis. Different formulations—MEST_2, MEST_{2n}, and MEST_{n2}—capture different regimes of the relationship between spacetime-centered structures and embedded matter. MEST_2 describes mass-centered configurations, MEST_{2n} applies to spacetime-dominated cases, and MEST_{n2} represents mixed-coordinate systems. The explicit derivations for these three families clarify how the same underlying tensor law can generate distinct types of spacetime-centered structures, depending on whether matter or curvature dominates.

Our observational program demonstrates that the MEST formalism successfully fits data across four regimes:

1. **Galaxy rotation curves:** fitted with MEST_2, confirming that observed flat curves can be explained by spacetime-centered gradients rather than unseen mass halos.
2. **Strong gravitational lensing:** modeled with MEST_{2n}, where the observed deflections follow directly from curvature-induced forces.
3. **CMB cold and hot spots:** analyzed with MEST_{n2}, which reproduces the observed α–r_0 scaling and confirms that such anisotropies reflect intrinsic spacetime-centered structures.

4. **CMB blackbody spectrum:** shoulder-fitting in log–log coordinates validates both the $b = 1$ power-law constant and the k_α linear scaling, while also revealing new peaklike structures unique to MEST_{n2}.

In particular, the CMB analysis provides decisive evidence. First, the verification of the two constants in the radiation spectrum establishes the universality of the structural scaling law beyond matter-based systems. Second, both cold and hot spot fits reproduce the same constants found in galaxies and lensing, despite the absence of mass-based explanations. Third, the discovery of sharp spectral peaks in the blackbody spectrum, predicted and fitted by MEST_{n2}, represents a novel structural signature that not readily explained by standard dark matter models, suggesting the need for additional structural effects such as spacetime-centered fields.

Because all four systems yield the same pair of constants—$b = 1$ and $k_\alpha \approx 0.043$ Mpc^{-1}—we conclude that the MEST framework identifies a universal property of spacetime-centered structures. This unification demonstrates the *reasonableness* and *irreplaceability* of the hypothesis: dark matter profiles can mimic lensing and rotation curves, but they cannot account for the tensorial symmetries evident in CMB anisotropies and thermodynamic spectra.

Finally, the success of MEST_2, MEST_{2n}, and MEST_{n2} across different domains shows that while spacetime-centered structures may take different forms depending on their interaction with matter, they are governed by the same conservation law and share the same constants. Thus, the existence of spacetime-centered structures is strongly supported by both theory and observation. Although the ultimate physical origin of such structures remains unknown—much as the fundamental origin of matter itself remains open—the MEST equations provide a concrete definition, predictive framework, and testable path forward.

1.7 Irreplaceability of Spacetime-Centered Structures

The introduction of spacetime-centered structures represents a conceptual advance that cannot be substituted by conventional models of dark matter or empirical halo fitting. Unlike mass-centered profiles—such as Navarro–Frenk–White (NFW) or Einasto models—which attribute structural phenomena to unseen matter distributions, the spacetime-centered hypothesis posits that geometry itself can generate the observed dynamical and lensing effects. This approach establishes a new category of structures: those arising not from mass aggregation but from intrinsic properties of the spacetime field.

Several lines of evidence underscore the irreplaceability of this concept:

1. **Galaxy rotation curves and gravitational lensing:** MEST_2 and MEST_{2n} models reproduce observed phenomena with high fidelity, while avoiding the degeneracies inherent in dark-matter-based profiles. Although dark matter can mimic these effects, its interpretation is model-dependent, whereas spacetime-centered structures emerge directly from tensor conservation laws.

2. **CMB cold and hot spots:** The successful fits to anisotropy profiles, including both cold and hot regions, confirm that the same constants ($b = 1$, k_α) extend naturally to thermodynamic fluctuations. Such results cannot be explained within the dark matter paradigm, since CMB anisotropies are decoupled from local mass distributions at recombination.

3. **Blackbody spectrum shoulders and peak structures:** The discovery of systematic deviations in the CMB blackbody spectrum and their successful MEST_{n2} fits highlight structures of purely spacetime origin, irreducible to baryonic physics or dark matter halos. This provides an observational signature uniquely tied to the spacetime-centered hypothesis.

4. **Universality of the two constants:** The consistency of $b = 1$ and k_α across four independent systems—galactic dynamics, lensing geometries, CMB anisotropies, and blackbody radiation—shows that the spacetime-centered framework delivers a unification that no dark matter model has achieved. These constants are not empirical fitting parameters but conserved quantities dictated by the geometry of the structural tensor field.

For these reasons, the spacetime-centered structure hypothesis is not merely an alternative explanation to dark matter, but an irreplaceable theoretical framework. Its predictive power extends across dynamical, geometric, and thermodynamic domains, providing a unified description that links galactic scales to cosmological observables. Whereas dark matter remains a hypothetical substance inferred from missing mass, spacetime-centered structures arise as a necessary consequence of conservation and symmetry, offering a deeper physical interpretation of cosmic phenomena.