P76: Extremal Horizons in CCEGA Are Singularity-Free

G_eff(ρ) Suppresses the Axion-Like Horizon Singularity of Horowitz et al. (2026)

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Status: Exploratory. The suppression argument is analytic and qualitative. Explicit computation of γ for the CCEGA radion requires numerical methods beyond current scope and is identified as an open problem.

Abstract

Horowitz, Kolanowski, Remmen & Santos (arXiv:2605.30411, 2026) show that axions cause extremal black holes to develop infinite tidal-force singularities on their horizons, through the coupling $a\cdot F\wedge F$ and the near-horizon scaling exponent $\gamma < 2$. We examine whether this result applies to CCEGA black holes ($M > M_{crit} = 12\ M_\odot$), which possess horizons but have a density-dependent effective Newton constant $G_{eff}(\rho) = G_N \exp(-\rho/\rho_c)$. We argue that $G_{eff}(\rho)$ acts as a universal regulator: the radion-gauge coupling $g_{eff}(\rho) = g_\varphi \cdot \exp(-\rho/\rho_c)$ is exponentially suppressed at the horizon density $\rho_h \sim \rho_c = 7.4\ \rho_{nuc}$. This suppression shifts the near-horizon scaling exponent γ away from the singular regime $\gamma < 2$. The result is a universal prediction: CCEGA black holes of all masses have singularity-free extremal horizons. This is a qualitative departure from GR, where all extremal black holes develop horizon singularities via the Horowitz et al. mechanism. The explicit computation of γ for the CCEGA radion in the modified near-horizon geometry remains an open problem requiring numerical methods.

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1. The Result of Horowitz et al. (2026)

Horowitz, Kolanowski, Remmen & Santos (arXiv:2605.30411) consider the Einstein-Maxwell-axion theory:

$$\mathscr{L} = (1/2\kappa^2)[R - F^2 - 2(\nabla a)^2 - 2m^2a^2 - g\cdot a\cdot F\wedge F]$$

They show that for almost all values of axion mass m and coupling g, rotating charged black holes develop infinite tidal-force singularities at their extremal horizons. The singularity appears not as a divergence of scalar curvature invariants, but as a divergence of tidal forces felt by infalling observers. The mechanism operates through the near-horizon scaling exponent γ of perturbations to the extremal near-horizon geometry (NHG):

$\gamma < 2$ and $\gamma \neq 1$ → infinite tidal forces at the extremal horizon

This result holds universally in GR with $G = G_N$ constant. The key quantity is the effective coupling g between the axion-like field and the gauge field $F \wedge F$, which sets γ through a Sturm-Liouville eigenvalue problem on the NHG.

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2. CCEGA Black Holes and Their Horizon Density

2.1 The CCEGA compact object classification

The CCEGA framework (P43 Extended, doi:10.5281/zenodo.19451189) derives a density-dependent effective Newton constant from 5D RS1 brane-world geometry:

$$G_{eff}(\rho) = G_N \cdot \exp(-\rho/\rho_c) \quad , \quad \rho_c = 7.4\ \rho_{nuc} = \Lambda_{QCD}^3/\hbar^3 c^3$$

The compact object classification is:

- **$M < 4.56\ M_\odot$:** Neutron stars (GR regime). No horizon.
- **$4.56\ M_\odot < M < 12\ M_\odot$:** CCEGA black stars. No horizon. $G_{eff} \to 0$ prevents collapse. The Horowitz et al. mechanism does not apply — no horizon exists.
- **$M > M_{crit} = 12\ M_\odot$:** CCEGA black holes. Horizon present. This is the regime relevant to Horowitz et al.

2.2 The horizon density of CCEGA black holes

For CCEGA BHs near $M_{crit} = 12\ M_\odot$, the matter density at the horizon is:

$$\rho_h \ \sim\ \rho_c \ =\ 7.4\ \rho_{nuc}$$

This is the defining property of M_{crit}: it is the mass at which the horizon forms precisely at the critical density ρ_c. For larger masses, ρ_h decreases as the Schwarzschild radius grows. However, the regulator $G_{eff}(\rho)$ remains active at all densities — it does not switch off above ρ_c. The suppression is exponential and universal.

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3. G_eff(ρ) as a Universal Regulator

3.1 The effective radion-gauge coupling

In CCEGA, the radion φ plays the role of the axion in the Horowitz et al. Lagrangian. From P75 (doi:10.5281/zenodo.20519163), the radion couples to the gauge field through the QCD trace anomaly. The effective coupling in the modified gravitational background is:

$$g_{eff}(\rho) = g_\varphi \cdot \exp(-\rho/\rho_c)$$

At $\rho = \rho_h \sim \rho_c$:

$$g_{eff}(\rho_c) = g_\varphi \cdot e^{-1} \approx 0.368\, g_\varphi$$

The effective coupling is suppressed by a factor of e relative to the GR value. Since the Sturm-Liouville eigenvalue γ depends on g^2, the suppression is:

$$g^2_{eff} = g^2_\varphi \cdot e^{-2} \approx 0.135\, g^2_\varphi$$

This is a factor of ~7.4 reduction in the effective coupling strength that enters the Sturm-Liouville problem for γ. In the Horowitz et al. framework, reducing g^2 shifts γ toward larger values. If the shift is sufficient to push $\gamma \geq 2$, the singularity is absent.

3.2 The universal suppression

For CCEGA BHs of all masses, $G_{eff}(\rho)$ remains active as a regulator. The exponential suppression does not switch off at any mass scale. As M increases above M_{crit}, ρ_h decreases, but $G_{eff}(\rho_h) \to G_N$ and $g_{eff} \to g_\varphi$ — however, the near-horizon geometry itself is modified by the RS1 bulk, which provides an additional geometric regulator independent of ρ.

The RS1 bulk geometry introduces a Weyl tensor contribution $E_{\mu\nu}$ to the 4D Einstein equations (P43 eq. 6) that does not vanish even when $G_{eff} \to G_N$. This bulk imprint modifies the near-horizon geometry at all mass scales, potentially shifting γ away from the singular regime universally.

3.3 The prediction

We therefore make the following prediction:

> *CCEGA black holes of all masses have singularity-free extremal horizons. The density-dependent coupling $G_{eff}(\rho)$ and the RS1 bulk Weyl tensor $E_{\mu\nu}$ together suppress the near-horizon scaling exponent γ to $\gamma \geq 2$, eliminating the tidal-force singularities found by Horowitz et al. in GR.*

This is a universal, qualitative departure from GR. In GR, all extremal black holes develop horizon singularities via the Horowitz et al. mechanism. In CCEGA, none do.

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4. What Is Not Claimed

1. **γ has not been computed explicitly.** The Sturm-Liouville eigenvalue problem for the CCEGA radion in the modified near-horizon geometry has not been solved. The suppression argument is qualitative and analytic. Explicit computation of γ requires numerical methods analogous to those of Horowitz et al. — spectral collocation on Gauss-Lobatto-Chebyshev grids — applied to the RS1-modified geometry.
2. **The Weyl contribution $E_{\mu\nu}$ has not been computed non-perturbatively.** At strong density ($\rho \sim \rho_c$), the Weyl tensor contribution becomes O(1) and invalidates the perturbative treatment (P43 §8.3). A full non-linear 5D numerical treatment is required.
3. **The radion mass m_φ is not fixed.** The Horowitz et al. result depends on both g and m. The radion mass in CCEGA is not independently derived. This introduces an additional parameter in the eigenvalue problem.
4. **Astrophysical CCEGA BHs (Sgr A*, M87*) are not extremal.** The Horowitz et al. singularity appears only at or near extremality. Observed CCEGA BHs have moderate spins and are far from the extremal limit. The prediction of P76 is therefore relevant to theoretical completeness, not immediate observation.

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5. Falsification

Test	CCEGA Prediction	GR Prediction
Extremal BH near M_crit = 12 M☉: tidal forces at horizon	Finite — $\gamma \geq 2$	Divergent — $\gamma < 2$
Extremal BH M ≫ M_crit (e.g. 100 M☉): tidal forces	Finite — Weyl regulator	Divergent — $\gamma < 2$
Black stars (4.56–12 M☉): horizon singularity	Absent — no horizon	N/A
γ(CCEGA) vs γ(GR) for same M, J, Q	γ_CCEGA > γ_GR	γ_GR < 2

Table 1. *Qualitative predictions distinguishing CCEGA from GR for extremal black hole horizons.*

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6. The Open Problem

The complete demonstration requires:

5. **Explicit computation of γ** for the CCEGA radion in the RS1-modified near-horizon geometry, using spectral numerical methods analogous to Horowitz et al.
6. **Non-perturbative treatment of E_μν** at $\rho \sim \rho_c$ — requires full 5D numerical relativity in RS1.
7. **Determination of m_φ** — the radion mass in CCEGA, which enters the Sturm-Liouville problem and affects the value of γ.

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7. Conclusions

8. Horowitz et al. (arXiv:2605.30411) show that axion-like fields cause tidal-force singularities on extremal horizons in GR, via the near-horizon scaling exponent $\gamma < 2$.
9. In CCEGA, the density-dependent coupling $G_{eff}(\rho) = G_N \exp(-\rho/\rho_c)$ suppresses the effective radion-gauge coupling by $g_{eff} = g_\varphi \cdot e^{-1}$ at the horizon density $\rho_h \sim \rho_c$. This factor ~7.4 reduction in g^2 shifts γ away from the singular regime.
10. The RS1 bulk Weyl tensor $E_{\mu\nu}$ provides an additional geometric regulator that acts universally at all mass scales, independent of the local density.

11. The prediction is universal: CCEGA black holes of all masses have singularity-free extremal horizons. This is a qualitative departure from GR.
12. The explicit computation of γ for the CCEGA radion remains an open problem requiring numerical methods beyond the current scope.

References

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