The Festina Lente Bound from charged Black Hole Evaporation in de Sitter

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Overview

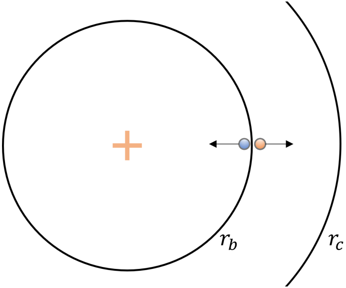
1. The Festina Lente Bound (Montero et al. '20)

Semiclassical decay of large $U(1)$ charged RNdS black holes:

$$S = \int d^4x\sqrt{-g}\left(\frac{1}{16\pi G_N}(R-2\Lambda) - \frac{1}{4g^2}F_{\mu\nu}F^{\mu\nu}\right)$$

$$ds^2 = -U(r)dt^2 + U(r)^{-1}dr^2 + r^2 d\Omega^2,$$

$$U(r) = 1 - \frac{2GM}{r} + \frac{Gg^2Q^2}{4\pi r^2} - \frac{\Lambda r^2}{3}$$



Schwinger pair production

$$\Gamma \sim e^{-\pi\frac{m^2}{qE}}$$

1. The Festina Lente Bound

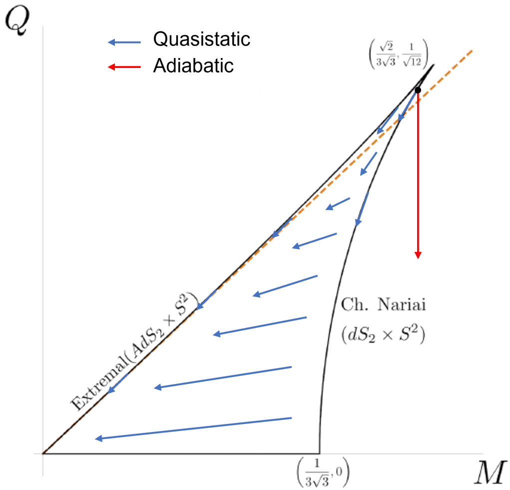


Figure: RNdS Phase Space (Montero et al. '20)

Semiclassical Nariai BHs

- $qE \gg \Lambda = 3H^2 > 0$
- $T_b = T_c = 0$

Quasistatic decay

$$m^2 \gg qE$$

Adiabatic decay

$$m^2 \ll qE$$

1. The Festina Lente Bound

Adiabatic decay: $m^2 \ll qE$ (Montero et al. '20)

Assuming traceless, perfect fluid $T_{\mu\nu}^{matter}$ and $\mathbb{R}^2 \times S^2$ Ansatz

$$ds^2 = e^{-\phi}(-d\tau^2 + a^2 dx^2) + e^{2\phi} d\Omega^2,$$

with $s = r^2 \equiv e^{2\phi}$ we get equations of motion

$$\ddot{s} = 3\sqrt{s} - \frac{1}{\sqrt{s}}\left(1 + \frac{\rho_0}{a^{4/3}}\right),$$

$$\frac{\ddot{a}}{a} = \frac{1}{2s^{3/2}}\left(1 - \frac{\rho_0}{a^{4/3}} + 3s\right)$$

$\rightarrow$ Crunch of spacetime

1. The Festina Lente Bound

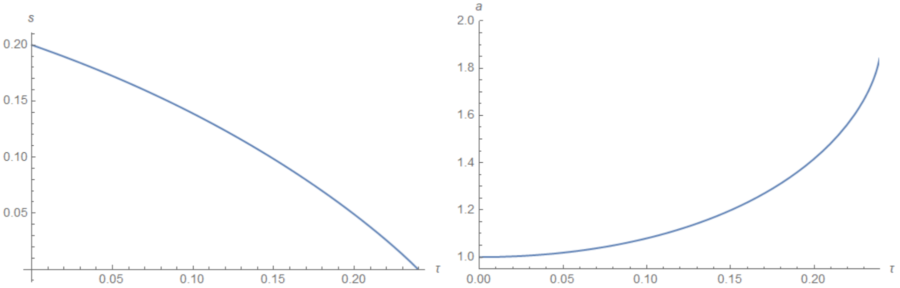


Figure: **Crunch**: S^2-sphere volume $s(\tau)$ and scale factor $a(\tau)$ for $H = 1$, $s_0 = 0.2$, $\rho_0 = 0.5$ and $\dot{s}_0 = -0.5$

FL bound on all $U(1)$ charged particles (Montero et al. '20)

$$m^2 \geq \sqrt{6} g q M_p H = qE|_{UC,Nariai}$$

2. FL in Gauß-Bonnet Gravity

Consider 5d Gauß-Bonnet-dS model (Cai, Li, Sun '22)

$$S = \int d^5x\sqrt{-g}\left(\frac{1}{16\pi G}\left(R - 2\Lambda + \alpha\mathcal{L}_{GB}\right) - \frac{1}{4g^2}F_{\mu\nu}F^{\mu\nu}\right),$$

$$\mathcal{L}_{GB} = R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} - 4R_{\mu\nu}R^{\mu\nu} + R^2$$

with analytic $U(1)$ charged black hole solution

$$\boxed{\begin{gathered} ds^2 = -W(r)dt^2 + W(r)^{-1}dr^2 + r^2 d\Omega_3^2, \\ W(r) = 1 + \frac{r^2}{4\alpha}\left(1 - \sqrt{1 + 8\alpha\left(\frac{2M}{r^4} - \frac{Q^2}{r^6} + H^2\right)}\right) \end{gathered}}$$

2. FL in Gauß-Bonnet Gravity

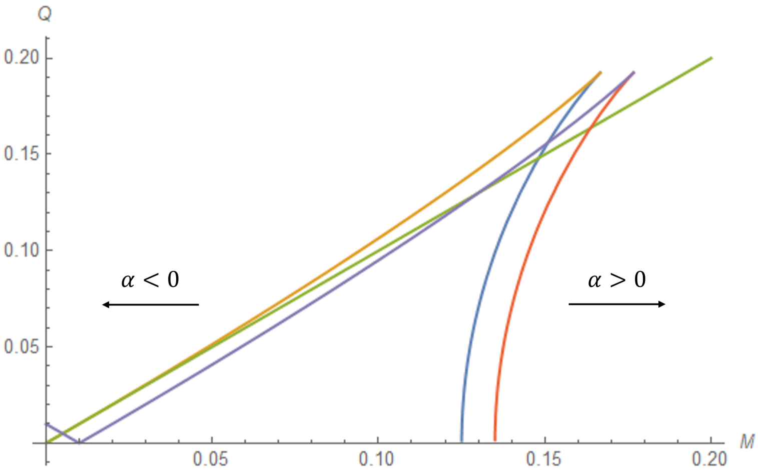


Figure: RNdS phase space (left) and GB-RNdS phase space (right) for $\alpha = 0.01$

2. FL in Gauß-Bonnet Gravity

Adiabatic decay

Assuming traceless, perfect fluid $T_{\mu\nu}^{matter}$ and $\mathbb{R}^2 \times S^3$ Ansatz

$$ds^2 = e^{-2\phi}(-d\tau^2 + a^2 dx^2) + e^{2\phi} d\Omega_3^2,$$

$$S = \int d^5x \sqrt{-g} \left(\frac{1}{16\pi G} (R - 2\Lambda + \alpha \mathcal{L}_{GB}) + \mathcal{L}_m \right)$$

with $s = r^3 \equiv e^{3\phi}$ we get equations of motion

$$\ddot{s} = f(a, s, \dot{s}, \ddot{s}; \alpha),$$

$$\ddot{a} = g(a, \dot{a}, s, \dot{s}, \ddot{s}; \alpha)$$

$\rightarrow$ Crunch of spacetime

2. FL in Gauß-Bonnet Gravity

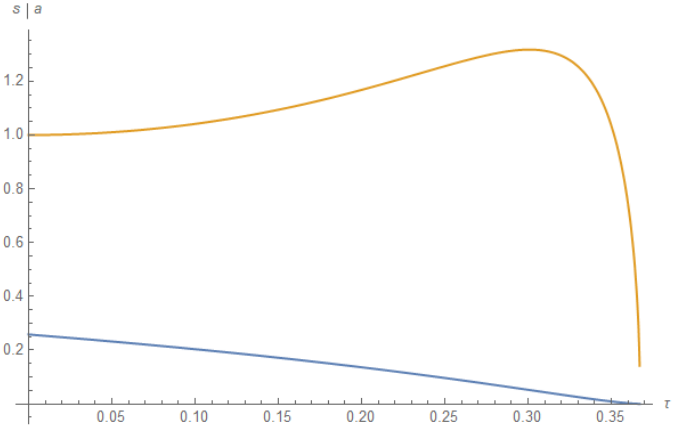


Figure: **Generic crunch**: S^3 volume $s(\tau)$ in blue and scale factor $a(\tau)$ in orange for $H = 1$, $\alpha = 0.01$, $s_0 = 1/\sqrt{15}$, $\rho_0 = 0.5$ and $\dot{s}_0 = -0.5$

2. FL in Gauß-Bonnet Gravity

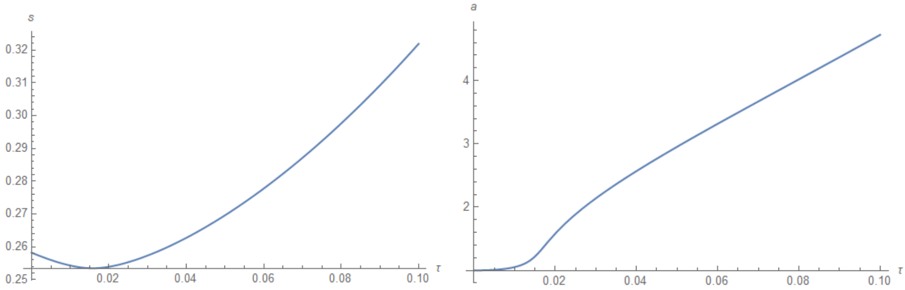


Figure: **No crunch scenario**: S^3 volume $s(\tau)$ and scale factor $a(\tau)$ for $H = 1$, $\alpha = -0.051$, $s_0 = 1/\sqrt{15}$, $\rho_0 = 0.5$ and $\dot{s}_0 = -0.5$

3. Summary and Outlook

Summary

- Avoid Nariai crunches by FL bound on all $U(1)$ charged particles:

$$m^2 \geq c_d g q \sqrt{V}$$

- FL bound holds for Gauß-Bonnet-RNdS models

Outlook

Test FL bound for general higher derivative theories and string theory related models

References

[1] Miguel Montero, Thomas Van Riet, and Gerben Venken (2020). Festina Lente: EFT Constraints from Charged Black Hole Evaporation in de Sitter. *JHEP*, 01:039.

[2] Miguel Montero, Cumrun Vafa, Thomas Van Riet, and Gerben Venken (2021). The FL bound and its phenomenological implications. *JHEP*, 10:009.

[3] Antonio De Felice and Shinji Tsujikawa (2010). f(R) theories. *Living Rev. Rel.*, 13:3.

[4] Rong-Gen Cai, Li Li, and Hao-Tian Sun (2022). Instability in charged Gauss–Bonnet–de Sitter black holes. *Phys. Rev. D*, 105(6):064032.