Brane World scenarios:quasar luminocity

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PLAN

- Why brane world scenarios are important
- The field equations in 5D and 4D
- The idea and purpose (expansion of metric)
- CFP solutions
- Quasars and their luminosities

The talk is based on

- **Casadio–Fabbri–Mazzacurati black strings and braneworld-induced quasars luminosity corrections**

Roldão da Rocha, A Piloyan, A M Kuerten and C H Coimbra-Araújo

Roldão da Rocha *et al* 2013 *Class. Quantum Grav.* **30** 045014 doi:10.1088/0264-9381/30/4/045014

- http://arxiv.org/abs/1301.4483

- More quantitatively:

$$F_{\text{EM}} = \frac{q_1 q_2}{r^2} \qquad\qquad F_{\text{gravity}} = G_N \frac{m_1 m_2}{r^2}$$

Even for the heaviest elementary particles (e.g., *W* bosons, top quarks)

$$F_{\text{gravity}} \sim 10^{-32} F_{\text{EM}}$$

- The Hierarchy Problem: Why is gravity so weak? Maybe it isn't…

Extra Dimensions

- Suppose photons are confined to D=4, but gravity propagates in n extra dims of size L.

$r \ll L,\ F_{gravity} \sim 1/r^{2+n}$ $\quad$ $r \gg L,\ F_{gravity} \sim 1/r^2$

PROJECTED 4D EQUATIONS

$$ {}^{(5)}G_{AB} = -\Lambda_5\, {}^{(5)}g_{AB} + \kappa_5^2\, {}^{(5)}T_{AB} $$

$$ R_{ABCD} = {}^{(5)}R_{EFGH}\, g_A{}^E g_B{}^F g_C{}^G g_D{}^H + 2K_{A[C}K_{D]B}, $$

$$ K_{\mu\nu} = -\frac{1}{2}\kappa_5^2 \left(T_{\mu\nu} + \frac{1}{3}(\lambda - T)\, g_{\mu\nu} \right) $$

$$ G_{\mu\nu} = -\Lambda g_{\mu\nu} + \kappa^2 T_{\mu\nu} + 6\frac{\kappa^2}{\lambda}\mathcal{S}_{\mu\nu} - \mathcal{E}_{\mu\nu} + 4\frac{\kappa^2}{\lambda}\mathcal{F}_{\mu\nu} $$

JUNCTION CONDITION

- Lets define

$$T^{\text{brane}}_{\mu\nu} = T_{\mu\nu} - \lambda g_{\mu\nu}$$

$$\boxed{\begin{aligned} g^{+}_{\mu\nu} - g^{-}_{\mu\nu} &= 0, \\ K^{+}_{\mu\nu} - K^{-}_{\mu\nu} &= -\kappa_5^2 \left[T^{\text{brane}}_{\mu\nu} - \frac{1}{3} T^{\text{brane}} g_{\mu\nu} \right] \end{aligned}}$$

- Junction cond.

$$K_{\mu\nu} = -\frac{1}{2}\kappa_5^2 \left[T_{\mu\nu} + \frac{1}{3}(\lambda - T)\, g_{\mu\nu} \right]$$

EACH MEMBER IN THE EQUATION

- High energy correction

$$\boxed{\frac{|\kappa^2 \mathcal{S}_{\mu\nu}/\lambda|}{|\kappa^2 T_{\mu\nu}|} \sim \frac{|T_{\mu\nu}|}{\lambda} \sim \frac{\rho}{\lambda}.}$$

$$\mathcal{S}_{\mu\nu} = \frac{1}{12} T T_{\mu\nu} - \frac{1}{4} T_{\mu\alpha} T^{\alpha}{}_{\nu} + \frac{1}{24} g_{\mu\nu} \left[3 T_{\alpha\beta} T^{\alpha\beta} - T^2 \right]$$

- Vanishing if there is no brane-bulk energy exchange

$$\mathcal{F}_{\mu\nu} = {}^{(5)}T_{AB} g_{\mu}{}^{A} g_{\nu}{}^{B} + \left[{}^{(5)}T_{AB} n^A n^B - \frac{1}{4} {}^{(5)}T \right] g_{\mu\nu}$$

- Projection Weyl tensor, KK

$$\boxed{\nabla^{\mu} \mathcal{E}_{\mu\nu} = \frac{6\kappa^2}{\lambda} \nabla^{\mu} \mathcal{S}_{\mu\nu}}$$

$$\mathcal{E}_{\mu\nu} = {}^{(5)}C_{ACBD}\, n^C n^D g_{\mu}{}^{A} g_{\nu}{}^{B}$$

CORRECTIONS TO THE KK

- Note

$$V(r) = \frac{GM}{c^2 r}\left(1 + \frac{2\ell^2}{3r^2} + \cdots\right)$$

- and

$$K_{\mu\nu} = \frac{1}{2}\pounds_{\mathbf{n}} g_{\mu\nu} \qquad \Lambda_4 = \frac{\kappa_5^2}{2}\left(\frac{1}{6}\kappa_5^2\lambda^2 + \Lambda\right)$$

$$G_5 = G\ell_{\text{Planck}} \qquad \ell_{\text{Planck}} = \sqrt{G\hbar/c^3}$$

$$\kappa_4^2 = \frac{1}{6}\lambda\kappa_5^4$$

THE MAIN IDEA OF THE WORK

- Suppresing of Hawking radiation
- Teylor expansion of the metric along the extra dimension by using extrinsic curvature

$$\pounds_{\mathbf{n}} K_{\mu\nu} = K_{\mu\alpha} K^{\alpha}{}_{\nu} - \mathcal{E}_{\mu\nu} - \frac{1}{6} \Lambda_5 g_{\mu\nu}$$

- The calculation of the Black Hole horizon

$$\sqrt{g_{\theta\theta}(x,0)} = R,$$

$$g_{rr}^{-1} = 0$$

- The analysis of the luminosity corrections

$$L(\ell) = \eta(\ell) \dot{M} c^2$$

$$\eta = \frac{GM}{6c^2 R_S}$$

Teylor expansion of vacum on the brane (I am sorry☺)

$$
\begin{aligned}
g_{\mu\nu}(x,y) \;=\; & g_{\mu\nu} - \frac{1}{3}\kappa_5^2\lambda g_{\mu\nu}\,|y| \;\; + \left[\frac{1}{6}\left(\frac{1}{6}\kappa_5^4\lambda^2 - \Lambda_5\right) g_{\mu\nu} - \mathcal{E}_{\mu\nu}\right] y^2 \\
& - \frac{1}{6}\left(\left(\frac{193}{36}\lambda^3\kappa_5^6 + \frac{5}{3}\Lambda_5\kappa_5^2\lambda\right) g_{\mu\nu} + \kappa_5^2 R_{\mu\nu}\right)\frac{|y|^3}{3!} + \\
+ & \left[\frac{1}{6}\Lambda_5\left(\left(R - \frac{1}{3}\Lambda_5 - \frac{1}{18}\lambda^2\kappa_5^4\right) + \frac{7}{324}\lambda^4\kappa_5^8\right) g_{\mu\nu} + \left(R - \Lambda_5 + \frac{19}{36}\lambda^2\kappa_5^4\right)\mathcal{E}_{\mu\nu}\right. \\
& \left. + \frac{1}{6}\left(\frac{37}{36}\lambda^2\kappa_5^4 - \Lambda_5\right) R_{\mu\nu} + \mathcal{E}^{\alpha\beta} R_{\mu\alpha\nu\beta}\right]\frac{y^4}{4!} + \cdots
\end{aligned}
$$

WHAT ARE WE DEPARTING FROM

$$g_{\mu\nu}dx^{\mu}dx^{\nu} = -N(r)dt^2 + A(r)dr^2 + r^2 d\Omega^2$$

- Schwarzschild?

$$H(r) = 1 - \frac{2GM}{c^2 r} + \psi(r) \qquad \psi(r) \approx -\frac{4GM\ell^2}{3c^2 r^3}$$

- 4D solutions with corrected 1/r^3 term

1. Cassadio-Fabbri-Mazzacurati I?
2. Cassadio-Fabbri-Mazzacurati II?

Metric on brane

- Cassadio-Fabbri-Mazzacurati I ($\beta = 5/4$)

$$N(r) = 1 - \frac{2GM}{c^2 r}$$

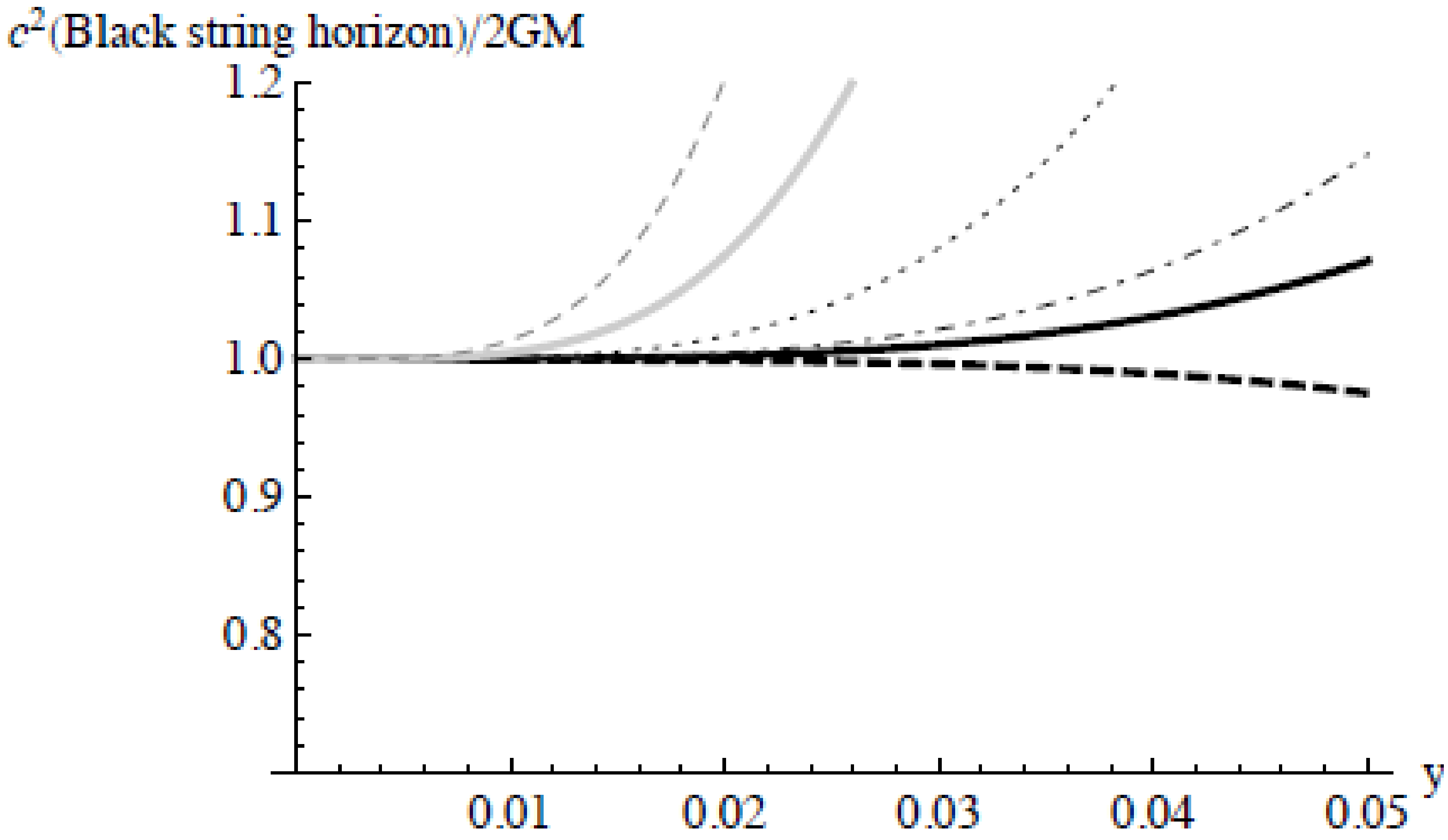
$$A(r) = \frac{1 - \frac{3GM}{2c^2 r}}{\left(1 - \frac{2GM}{c^2 r}\right)\left(1 - \frac{GM}{2c^2 r}(4\beta - 1)\right)}$$

- Cassadio-Fabbri-Mazzacurati II ($\beta = 3/2$)

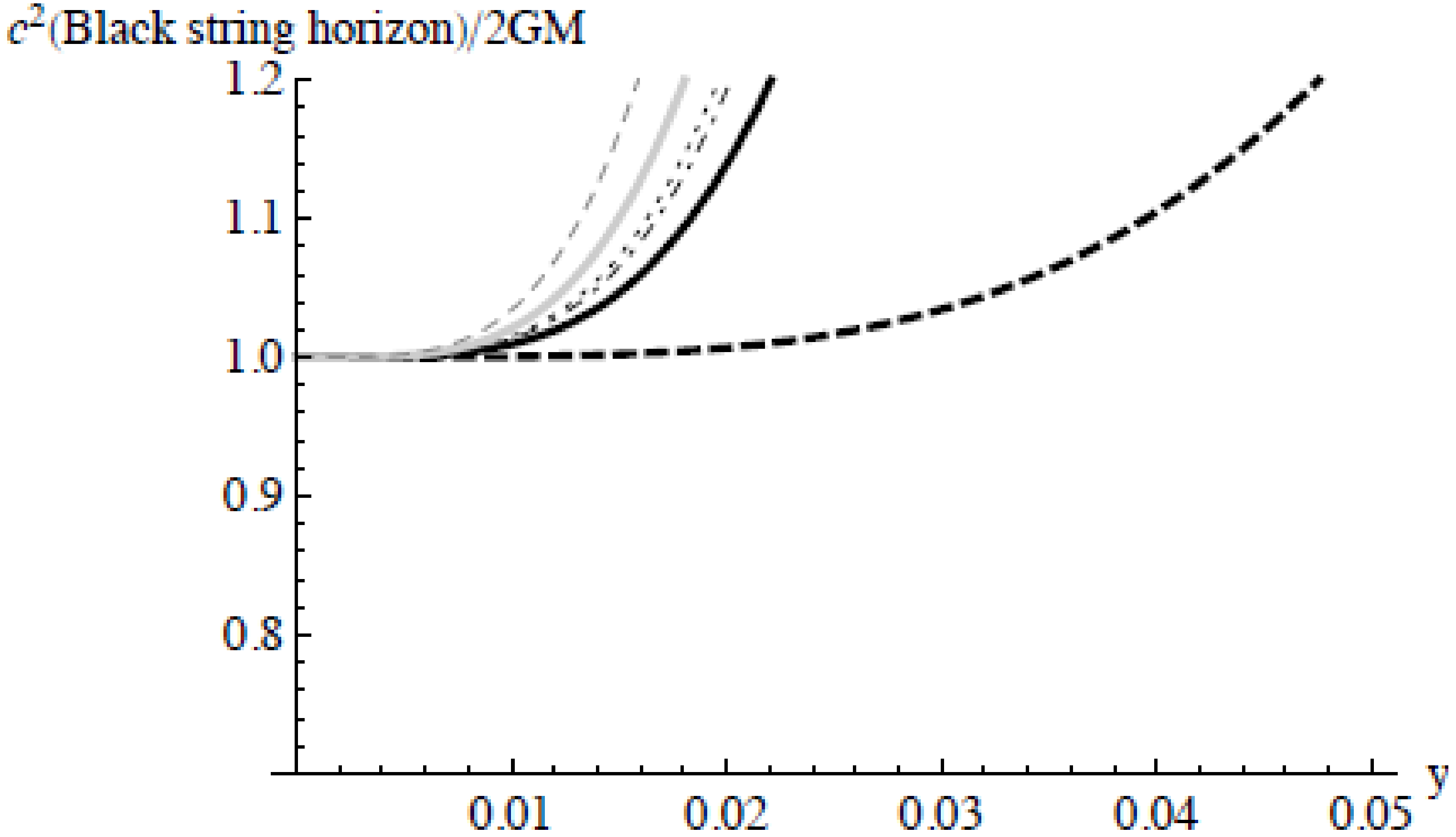
$$N(r) = 1 - \frac{2GM}{c^2 r} + \frac{2G^2 M^2}{c^4 r^2}(\beta - 1)$$

$$A(r) = \frac{1 - 3GM/2c^2 r}{\left(1 - \frac{2GM}{c^2 r}\right)\left(1 - \frac{GM}{2c^2 r}(4\beta - 1)\right)}$$

Cassadio-Fabbri-Mazzacurati I (Horizon corrections)



Cassadio-Fabbri-Mazzacurati II (Horizon corrections)



Luminosity corrections

- As mentioned above:

$$\Delta L = \frac{GM}{6c^2}\left(R_{\rm brane}^{-1} - R_S^{-1}\right)\dot{M}c^2 = \frac{1}{12}\left(\frac{R_S}{R_{\rm brane}} - 1\right)\dot{M}c^2$$

- where

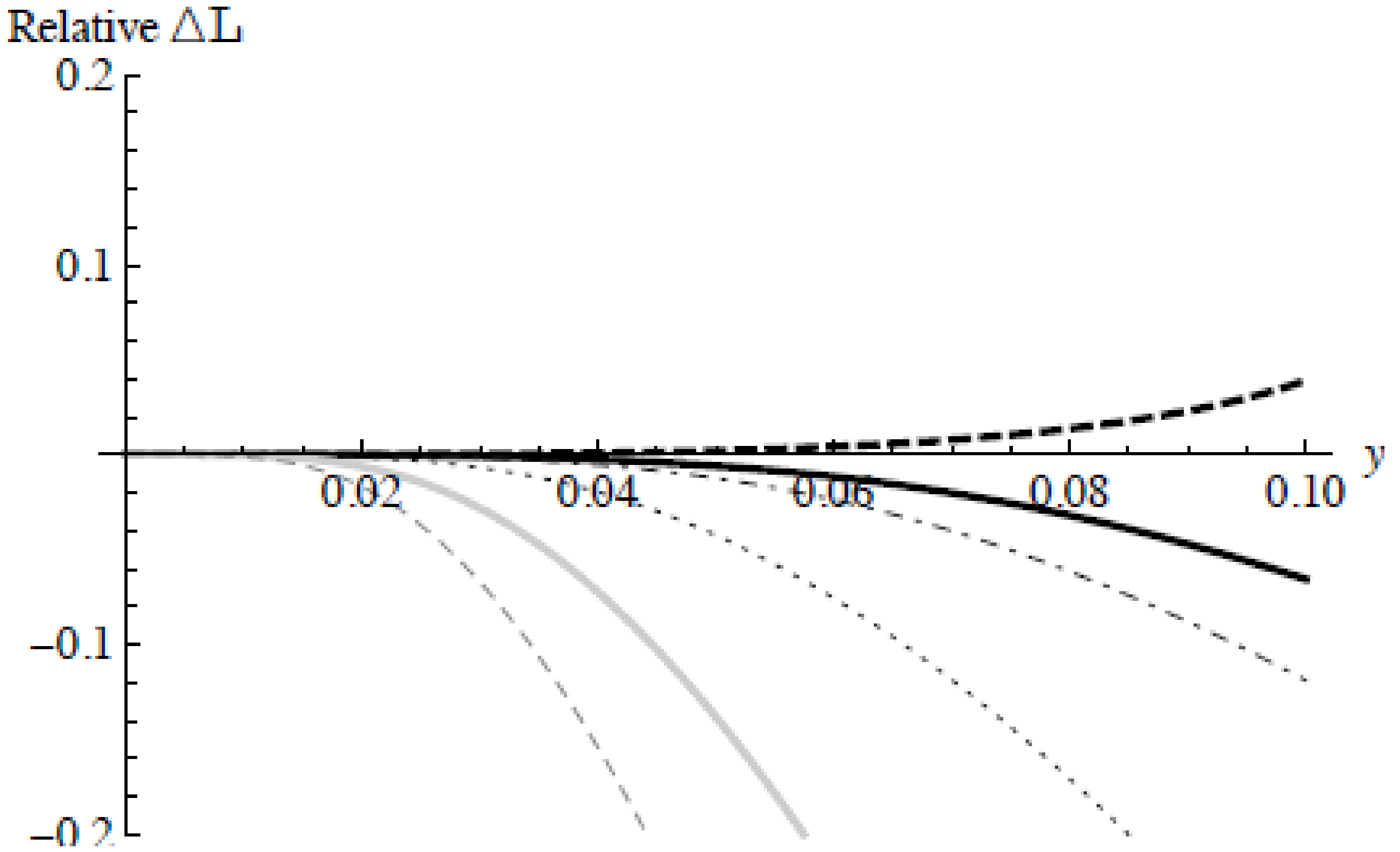
$$R_{\rm brane} = \sqrt{g_{\theta\theta}(r = R_S, y)}$$

- For quasars $\dot{M} \approx 2.1 \times 10^{19} {\rm kg\,s^{-1}}$

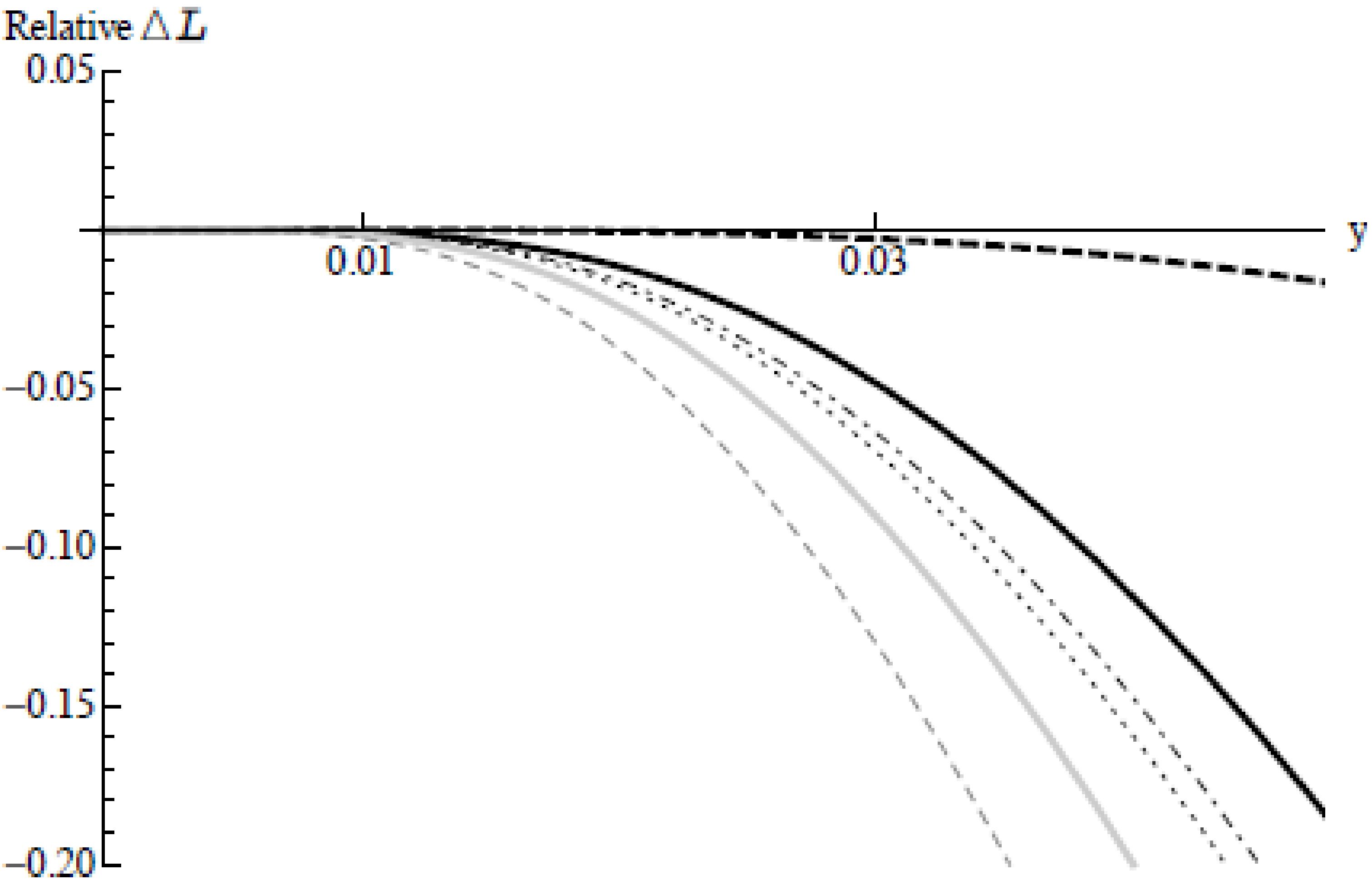
$$L = L_{\rm Edd} \sim 1.2 \times 10^{45} \left(\frac{M}{10^7 M_\odot}\right) {\rm erg\,s^{-1}}$$

$$L \sim 10^{47}\,{\rm erg\,s^{-1}}$$

Cassadio-Fabbri-Mazzacurati I (Luminosity corrections)



CASSADIO-FABBRI-MAZZACURATI II (LUMINOSITY CORRECTIONS)



CONCLUSION

- It is shown how the horizon vary due to the extra dimension
- Thus, Illustrated Luminosity variation only by extra dimensional effects

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