Constraining Einstein-Maxwell-dilaton-axion gravity from the observed quasi-periodic oscillations in black holes

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1 Abstract

The general theory of relativity (GR) plays the the key role to understand cosmology and gravity.GR has been successful to demonstrate the fundamental characteristics of gravity through its appreciable originality and mathematical magnificence.But,despite of its vast applications,GR is incomplete because of the presence of singularity where all the laws of physics breaks down,it's inconsistency with quantum mechanism,failure to explain dark matter and dark energy.Under this scenario,it is important to search for alternate theories those are able to solve most of the issues of GR.Einstein Maxwell Dilaton Axion (EMDA) gravity is an alternate theory of gravity which originates from compactifying 10 dimensional heterotic string theory on a 6 dimensional torus.It is therefore necessary to examine this theory whether it agrees with the astrophysical observations.Quasi periodic oscillation, observed in the power spectrum of few black holes can be our tool.Kerr-Sen black hole is the solution of EMDA gravity which represents stationary,axisymmetric,charged ,rotating black holes.There are several models those try to explain the QPOs observed from black hole like GRO J1655-40,XTE J1550-564,GRS 1915+105,H 143+322,Sgr A*.We have analysed these models in the background of Kerr-Sen spacetime and tried to see the effectiveness of EMDA gravity by constraining the dilaton charge which is indispensable part of Kerr-Sen spacetime.

CONSTRAINING EMDA GRAVITY FROM THE OBSERVED QPOs IN BLACK HOLES

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MOTIVATION

- ❑ Limitations of GR
  - ➢ It can not explain singularity where the all law of physics break down.
  - ➢ It is unable to explain the dark sector of the universe sufficiently.
- ❑ The String Inspired EMDA gravity
  - ➢ It can explain inflationary cosmology better than GR.
  - ➢ This theory is compatible with quantum mechanics.
- ❑ We study the role of EMDA gravity in explaining QPOs in black hole power density spectrum.

QPO MODELS

- Relativistic Presession Model

$f_1=f_\phi$, $f_2=f_\phi-f_r$, $f_3=f_\phi-f_\Theta$

- Parametric Resonance Model

$f_1=f_\Theta$, $f_2=f_r$

- Keplerian Resonance Model 2

$f_1=f_\phi$, $f_2=2f_r$

CONCLUSIONS

- r_2~0(kerr scenario) is most favored for Relativistic Precession Model and Parametric Resonance Model.
- Large values of r_2 are ruled out outside 3-σ.
- For Keplerian Resonance Model 2,r_2~0.2 is the most favored case. Here EMDA gravity is more applicable.
- Here also ,large values of r_2 are ruled out by 3-σ .
- Results need to be verified with more precise future data.

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Kerr-Sen Black Hole as a Solution of EMDA Gravity

❖ The four dimensional action of EMDA gravity is given by,

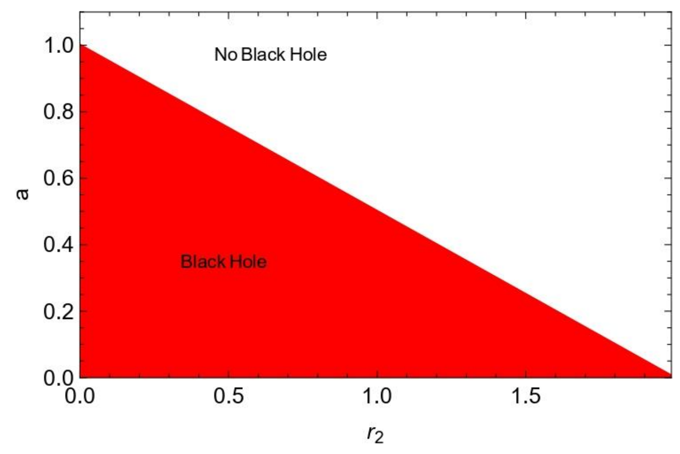
$$S=\frac{1}{16\pi}\int\sqrt{-g}\,d^4x\left(R-2\partial_\nu\chi\partial^\nu\chi-e^{4\chi}\partial_\nu\psi\partial^\nu\psi+e^{-2\chi}F_{\rho\sigma}F^{\rho\sigma}+\psi F_{\rho\sigma}F^{*\rho\sigma}\right)$$

❖ The Einstein's equation assume the form

$$G_{\mu\nu}=T_{\mu\nu}(\mathcal{F},\chi,\psi)$$

❖ The energy momentum tensor is given by,,

$$T_{\mu\nu}(\mathcal{F},\chi,\psi)=\frac{-2}{\sqrt{-g}}\frac{\delta S(\mathcal{F},\chi,\psi)}{\delta g^{\mu\nu}}$$



❖ The Kerr-Sen metric in the boyer-Lindquist co-ordinate has the following form

$$ds^2=-\frac{1-2Mr/\rho}{\Delta}dt^2+\frac{\rho}{\Delta}dr^2+\rho d\theta^2+\frac{\Sigma}{\rho}\sin^2\theta(d\phi-\omega dt)^2$$

where $\rho=r(r+r_2)+a^2\cos^2\theta$, $\Delta=r(r+r_2)-2Mr+a^2$, $\Sigma=(r^2+a^2)^2-a^2\Delta\sin^2\theta$, and $\omega=\frac{2aMr}{\rho}$.

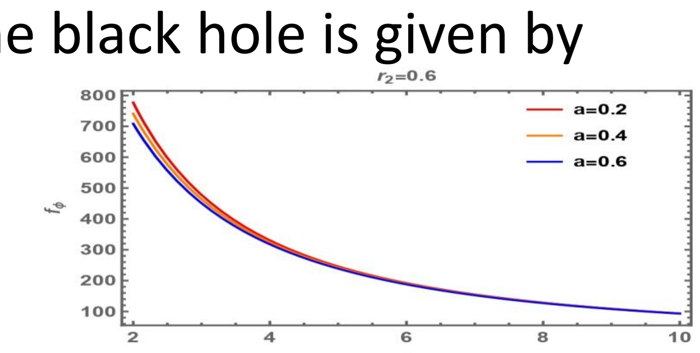
Here, the symbol r_2 symbolizes the dilaton parameter.

Orbital and Epicyclic Frequencies of Test Particle

❑ We study motion of massive test particles in circular, equatorial geodesics

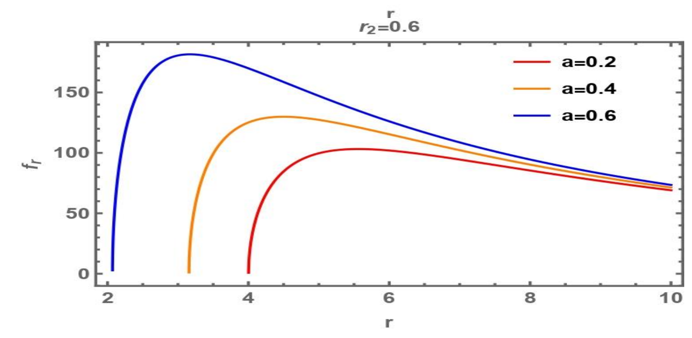
❑ The orbital frequency of a test particle revolving around the black hole is given by

$$\Omega=\frac{-\partial_r g_{t\phi}\pm\sqrt{(\partial_r g_{t\phi})^2-(\partial_r g_{\phi\phi})(\partial_r g_{tt})}}{\partial_r g_{\phi\phi}}=2\pi f_\phi$$



❑ Consider radial perturbation to the circular orbit,
The frequency of the radial oscillation is

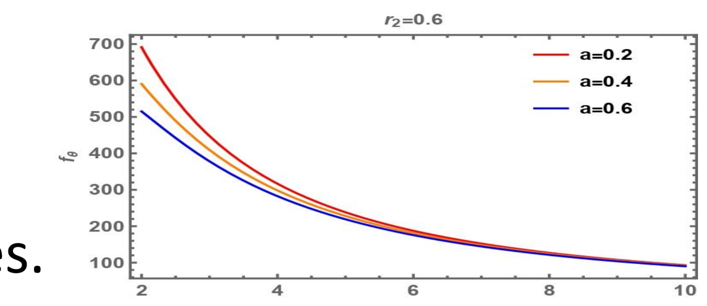
$$f_r^2=\frac{c^6}{G^2M^2}\left[\frac{(g_{tt}+g_{t\phi}\Omega)^2}{2(2\pi)^2 g_{rr}}\left(\frac{\partial^2 U}{\partial r^2}\right)_{r_c,\frac{\pi}{2}}\right]$$



❑ Consider vertical perturbation of the circular orbit,
The frequency of the vertical oscillation is

$$f_\theta^2=\frac{c^6}{G^2M^2}\left[\frac{(g_{tt}+g_{t\phi}\Omega)^2}{2(2\pi)^2 g_{\theta\theta}}\left(\frac{\partial^2 U}{\partial \theta^2}\right)_{r_c,\frac{\pi}{2}}\right]$$

Where, $U(r,\theta)=g^{tt}-2\left(\frac{L}{E}\right)g^{t\phi}+\left(\frac{L}{E}\right)^2 g^{\phi\phi}$



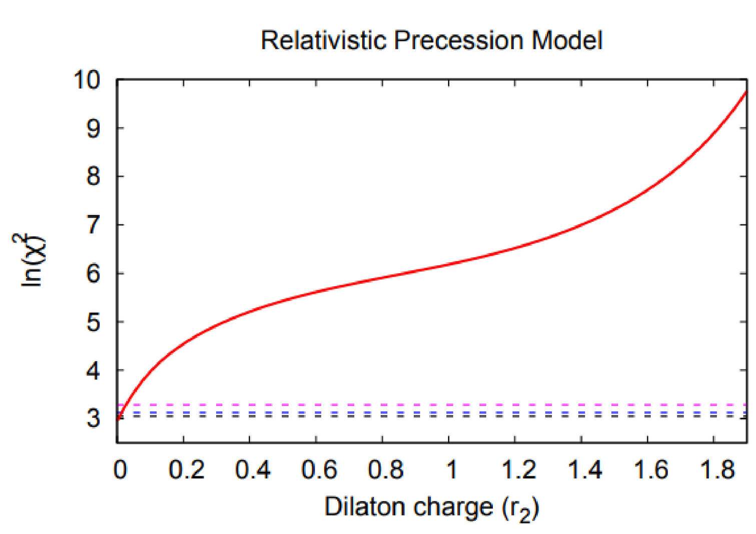
❑ U(r,Θ) is the effective potential in which the particle moves.

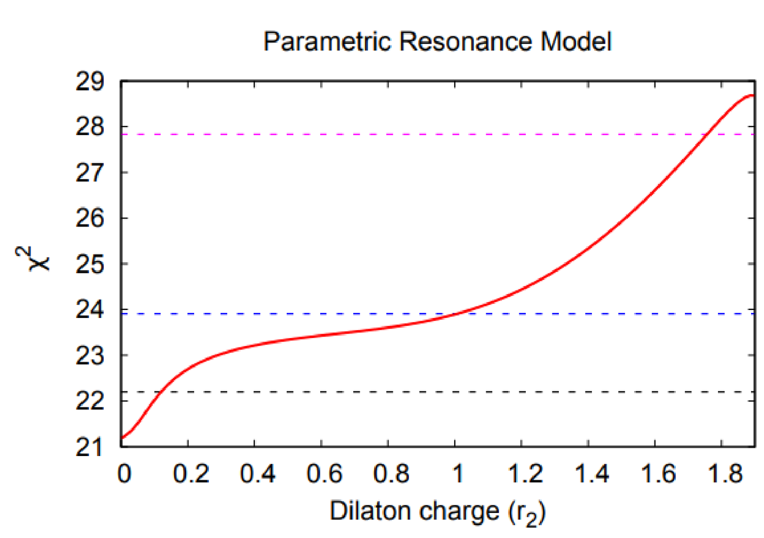
Results Based on Chi-Square Analysis

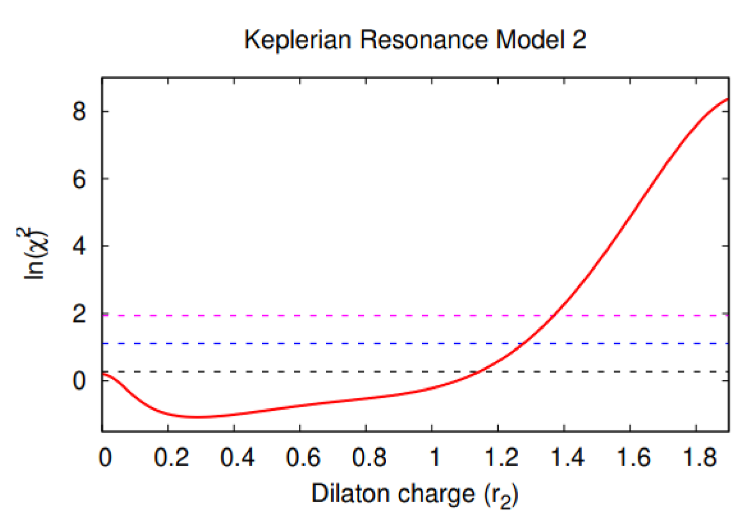
- Observation of QPOs from black holes

Source	$M_\odot$	$f_{up1}\pm\Delta f_{up1}$ (Hz)	$f_{up2}\pm\Delta f_{up2}$ (Hz)	$f_{up3}\pm\Delta f_{up3}$ (Hz)
GRO J1655-40	5.4 ± 0.3	441 ± 2	298 ± 4	17.3 ± 0.1
XTE J1550-564	9.1 ± 0.61	276 ± 3	184 ± 5	-
GRS 1915+105	$12.4^{+2.0}_{-1.8}$	168 ± 3	113 ± 5	-
H 1743+322	$8.0-14.07$	242 ± 3	166 ± 5	-
Sgr A*	$(3.5-4.9)\times10^6$	$(1.445\pm0.16)\times10^{-3}$	$(0.886\pm0.04)\times10^{-3}$	-

- Now we apply chi-square analysis test to different models to constrain the value of r_2







$$\mathcal{X}^2(r_2)=\sum_i\frac{[f_{up1,i}-f_1(r_2,a_{min},M_{min},r_{min})]^2}{\sigma^2_{f_{up1,i}}}+\sum_i\frac{[f_{up2,i}-f_2(r_2,a_{min},M_{min},r_{min})]^2}{\sigma^2_{f_{up2,i}}}$$

Comparison of mass estimates (in $M_\odot$)	GRO J1655-40	XTE J1550-564	GRS 1915+105	H 1743+322	Sgr A*
Previous constraints	5.4 ± 0.3	9.1 ± 0.61	$12.4^{+2.0}_{-1.8}$	8.0-14.07	$(3.5\text{-}4.9)\times10^{-3}$
RPM	$5.1\ (r_{2,min}\sim0)$	$9.31\ (r_{2,min}\sim0)$	$11\ (r_{2,min}\sim0)$	$12.07\ (r_{2,min}\sim0)$	$3.5\times10^6\ (r_{2,min}\sim0)$
PRM	$5.17\ (r_{2,min}\sim0)$	$9.63\ (r_{2,min}\sim0)$	$13.75\ (r_{2,min}\sim0)$	$9.39\ (r_{2,min}\sim0)$	$3.5\times10^6\ (r_{2,min}\sim0)$
KRM2	$5.7\ (r_{2,min}\sim0.2)$ $5.3\ (r_2\sim0)$	$9.11\ (r_{2,min}\sim0.2)$ $9.31\ (r_2\sim0)$	$12.5\ (r_{2,min}\sim0.2)$ $12.7\ (r_2\sim0)$	$12.87\ (r_{2,min}\sim0.2)$ $10.47\ (r_2\sim0)$	$3.8\times10^6\ (r_{2,min}\sim0.2)$ $4.1\times10^6\ (r_2\sim0)$

Comparison of spin estimates	GRO J1655-40	XTE J1550-564	GRS 1915+105	H 1743+322	Sgr A*
Previous constraints	$a\sim0.65-0.75$ $a\sim0.94-0.98$ $a=0.29\pm0.003$	$-0.11<a<0.71$ $a=0.55^{+0.15}_{-0.22}$	$a\sim0.98$ $a\sim0.7$ $a\sim0.6-0.98$ $a\sim0.4-0.98$	$a=0.2\pm0.3$	$a\sim0.92$ $a\sim0.5$ $a=0.9959\pm0.0005$ $a\sim0.1$
RPM	$0.3(r_{2,min}\sim0)$	$0.4(r_{2,min}\sim0)$	$0(r_{2,min}\sim0)$	$0.5(r_{2,min}\sim0)$	$0.92(r_{2,min}\sim0)$
PRM	$0.9(r_{2,min}\sim0)$	$0.95(r_{2,min}\sim0)$	$0.9(r_{2,min}\sim0)$	$0.92(r_{2,min}\sim0)$	$0.99(r_{2,min}\sim0)$
KRM2	$0.3(r_{2,min}\sim0.2)$ $0.3(r_2\sim0)$	$0.3(r_{2,min}\sim0.2)$ $0.4(r_2\sim0)$	$0.1(r_{2,min}\sim0.2)$ $0.2(r_2\sim0)$	$0.5(r_{2,min}\sim0.2)$ $0.4(r_2\sim0)$	$0.8(r_{2,min}\sim0.2)$ $0.92(r_2\sim0)$