Constraining Hořava-Lifshitz gravity by black hole accretion

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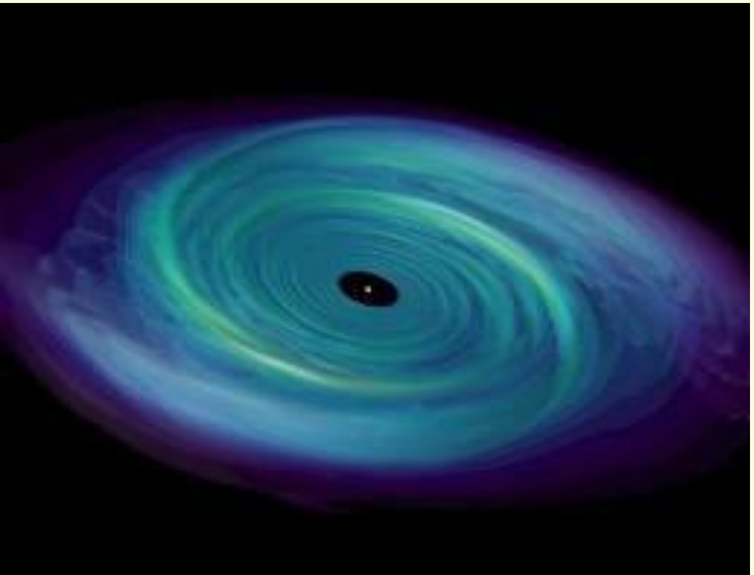
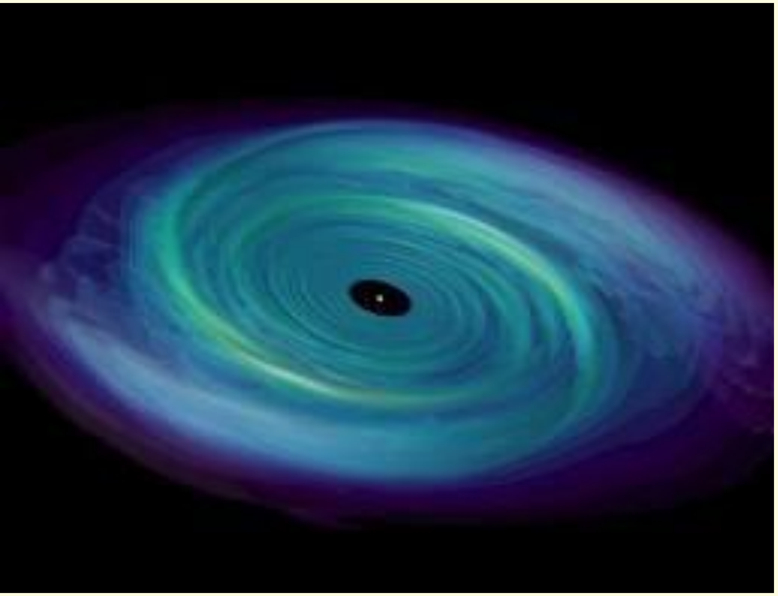




- Accretion process can be a useful tool to study different gravity theories.
- We can also test gravity in the strong field regime.

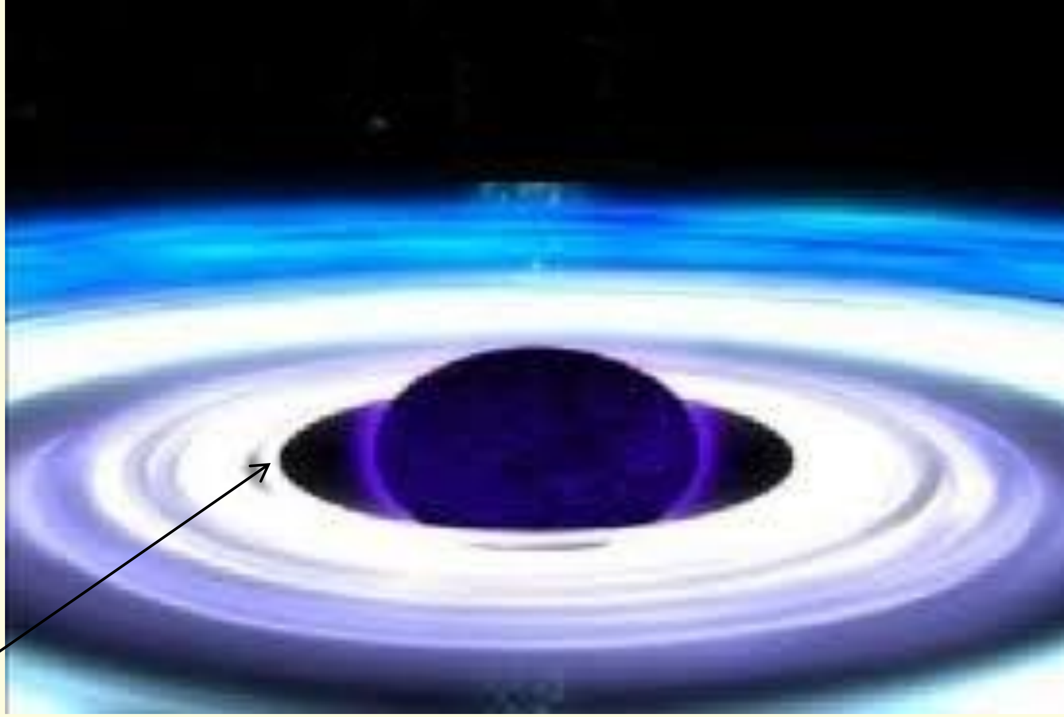
The simplest theoretical model of the accretion disks is the steady-state thin disk model → several simplifying assumptions.

Because of the negligible thickness of the disk, the heat generated by the dynamic friction can dissipate.

↓ constant accretion rate

→ hydrodinamical equilibrium

For large accretion disk luminosities, there is no unique inner edge and different definitions can be applied (Abramowicz et al. (2010))



For accretion disk with moderate luminosity, the inner edge of the disk is located at ISCO

- The infrared-modified Hořava-Lishitz gravity is one of the most recent promising alternative of GR.
- In the low energy limit the theory reduces to GR.
- It seems to be consistent with the current observational data (additional tests are needed).

- In this theory a spherically symmetric, static black hole solution was found by A. Kehagias and K. Sfetsos (KS).

$$ds^2 = g_{tt}(r)\,dt^2 + g_{rr}(r)dr^2 + r^2\left(d\Theta^2 + \sin^2\Theta d\varphi^2\right)$$

where the metric functions are provided by

$$-g_{tt}(r) = 1/g_{rr}(r) = 1 + \omega r^2\left[1 - \left(1 + \frac{4GM}{c^2\omega r^3}\right)^{1/2}\right]$$

beyond mass this is characterised by another parameter

- When omega tends to infinitiy, GR is recovered.
- We can write $\omega = \frac{16\mu^2}{k^2}$ where μ and k are constant parameters.
- When $\omega k^2 m^2 > 1/2$ there exist two event horizons at

$$r_\pm = k^2 m \left(1 \pm \sqrt{1 - \frac{1}{2\omega k^2 m^2}}\right)$$

- The two event horizons coincide for $\omega k^2 m^2 = 1/2$ and there is a naked singularity when $\omega k^2 m^2 < 1/2$

Approximations in the weak-field regime I.

- Introduce $\omega_0 = \omega m^2$ and the small $\varepsilon = \frac{m}{r} \ll 1$

- First, we assume that $\omega_0^{-1}\varepsilon^3 \ll 1 \longrightarrow \omega_0 \gg \varepsilon^3$
  with this assumption the KS metric become

$$-g_{tt} = \frac{1}{g_{rr}} = 1+\omega_0\left(\frac{r}{m}\right)^2\left[1-\left(1+\frac{4m^3}{\omega_0 r^3}\right)^{1/2}\right] = 1+\omega_0\varepsilon^{-2}\left[1-\underbrace{\left(1+\frac{4}{\omega_0}\varepsilon^3\right)^{1/2}}_{1+\frac{2}{\omega_0}\varepsilon^3}\right]$$

$$\simeq 1-2\varepsilon$$

Approximations in the weak-field regime II.

- If $\omega_0^{-1}\varepsilon^3 = \mathcal{O}(1) \longrightarrow \omega_0 \approx \varepsilon^3$

$$-g_{tt} = \frac{1}{g_{rr}} = 1 + \varepsilon \underbrace{\left[\omega_0\varepsilon^{-3} - \left(\left(\omega_0\varepsilon^{-3}\right) + 4\left(\omega_0\varepsilon^{-3}\right)\right)^{1/2}\right]}_{-2\mathcal{O}(1)}$$

$$\simeq 1 - 2\varepsilon\mathcal{O}(1)$$

it is a correction of the Minkowski case

Approximations in the weak-field regime III.

- When $\omega_0^{-1}\varepsilon^3 \gg 1 \longrightarrow \omega_0 \ll \varepsilon^3$

$$-g_{tt} = \frac{1}{g_{rr}} = 1 + \left(\omega_0\varepsilon^{-3}\right)\varepsilon\left[1 - \left(1 + \frac{4}{\omega_0}\varepsilon^3\right)^{1/2}\right] \simeq 1 - 2\varepsilon\underbrace{\left(\omega_0\varepsilon^{-3}\right)^{1/2}}_{\ll 1}$$

<u>In summary:</u>

$$-g_{tt} = \frac{1}{g_{rr}} = 1 - 2\varepsilon y \qquad y = \begin{cases} 1 & \omega_0 \gg \varepsilon^3 \\ \lesssim 1 & \omega_0 \approx \varepsilon^3 \\ \ll 1 & \omega_0 \ll \varepsilon^3 \end{cases}$$

<u>Conclusions:</u> for $\varepsilon \ll 1$ gravity always weaker then predicted by GR (independently of the values of ω_0).

We can introduce the „effective mass" of the black hole as

$$m_{eff} = ym$$

In the strong-field regime I.

from contraints

$$\omega_{0\,\min} = 8 \times 10^{-10}$$

- Near the black hole $\varepsilon = \frac{m}{r} = \mathcal{O}(1)$

$$-g_{tt} = \frac{1}{g_{rr}} = 1 + \omega_0 \varepsilon^{-2} \left[1 - (1 + \frac{4}{\omega_0} \varepsilon^3)^{1/2} \right]$$

- $\omega_0 \ll 1$ ⇒ $-g_{tt} = \frac{1}{g_{rr}} = 1 + \omega_0 \varepsilon^{-2} \left[1 - (1 + \frac{4}{\omega_0} \varepsilon^3)^{1/2} \right] \simeq$

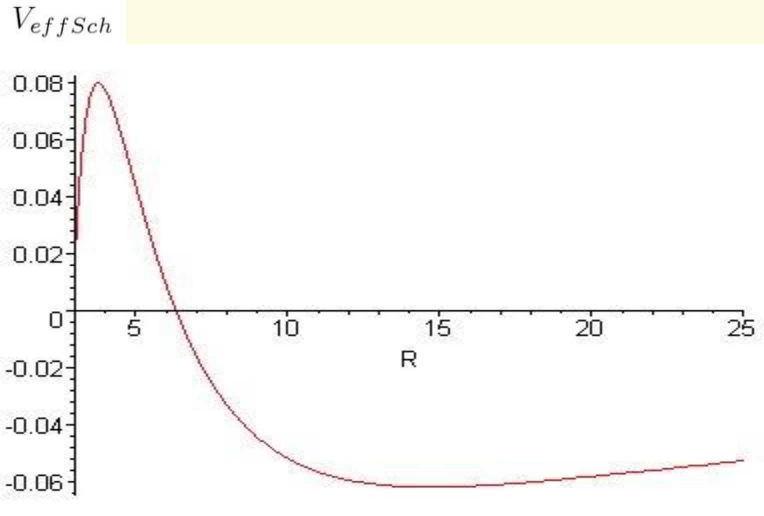
$$\simeq 1 - 2\varepsilon^{-1/2} \omega_0^{1/2} = 1 - 2 \left(\frac{\omega_0}{m} \right)^{1/2} r^{1/2}$$

approach towards the black hole, gravity decreases unlike the prediction in GR.

- $\omega_0 \approx 1$ in this case, only numerical results are available.

- $\omega_0 \gg 1$ this is the Schwarzschild case.

In the strong-field regime II. (effective potentials)



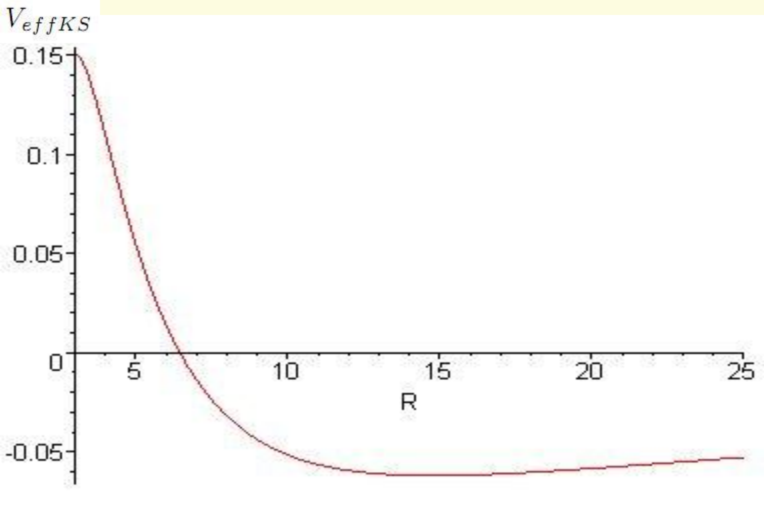
The general relativistic effective potential for L=4.3

$$V_{effSch}(R, L) = -\frac{1}{R} + \frac{L^2}{2R^2} - \frac{L^2}{R^3}$$

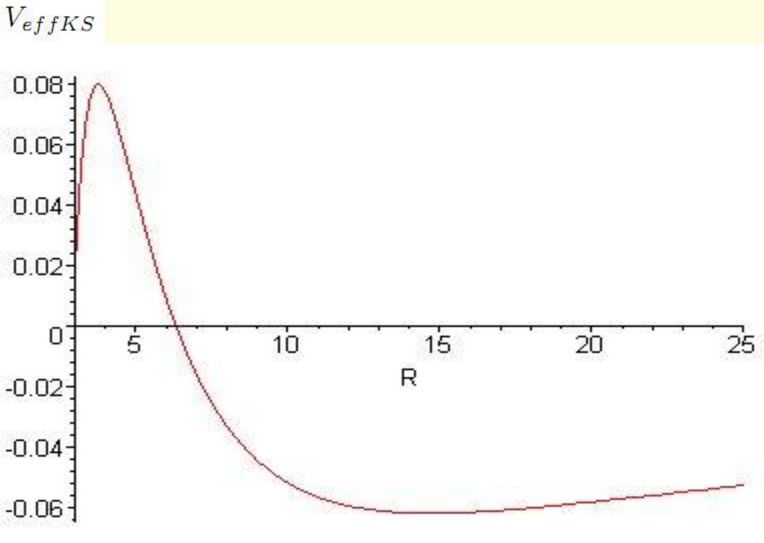
L is the normalized angular momentum and

$$R = \frac{r}{m}$$

$$V_{effKS}(R, L, \omega_0) = -\frac{\left(-1 - \omega_0 R^2 + \sqrt{R\omega_0\left(\omega_0 R^3 + 4\right)}\right)\left(L^2 + R^2\right)}{R^2}$$

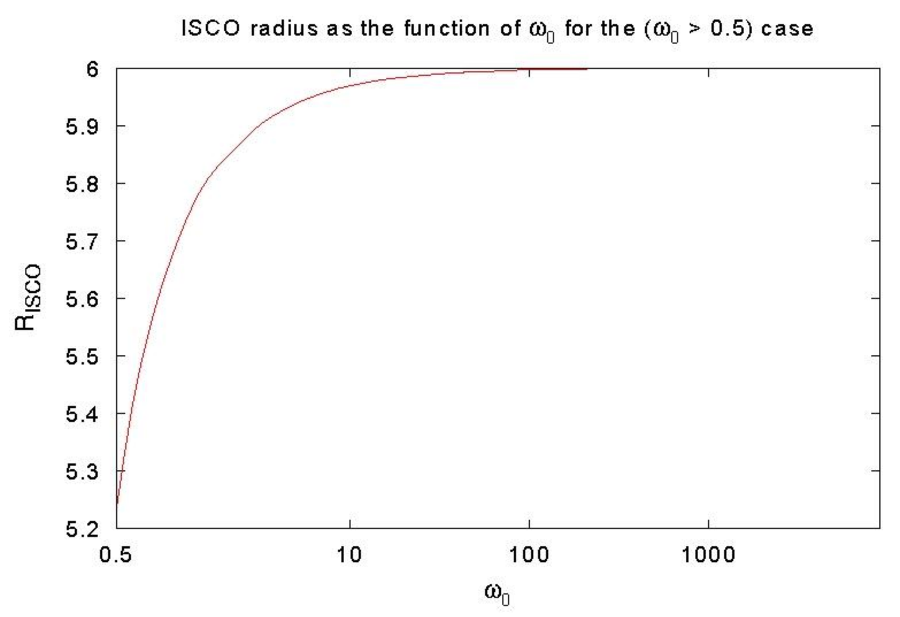


The effective potential of the KS black hole solution for L=4.3 and Omega=0.5

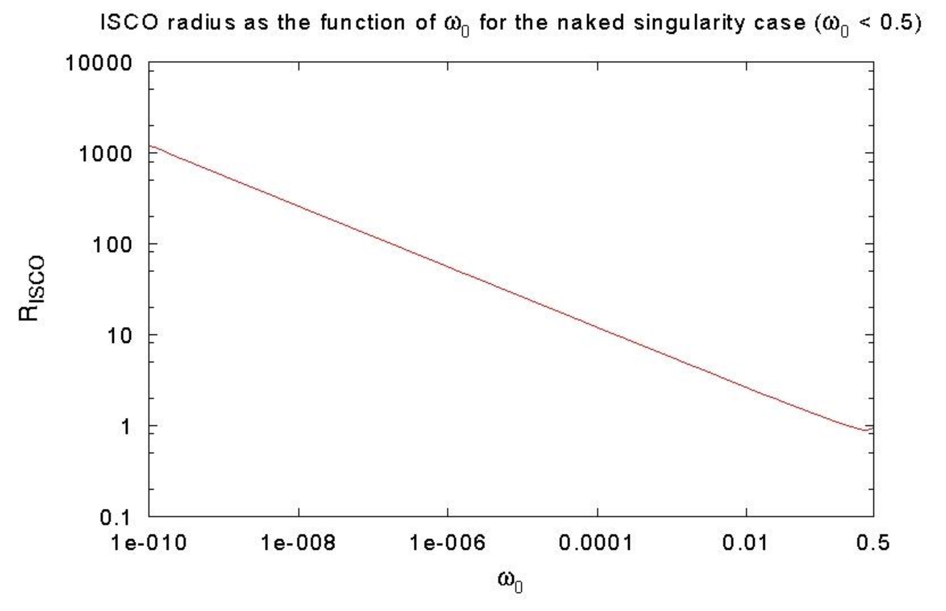


The effective potential of the KS black hole solution for L=4.3 and Omega=1000

The innermost stable circular orbit (ISCO) in Kehagias-Sfetsos geometry



ISCO radius as the function of ω_0 for the ($\omega_0 > 0.5$) case



ISCO radius as the function of ω_0 for the naked singularity case ($\omega_0 < 0.5$)

Thank you for your attention!