Introduction to Plack Stars

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November 6, 2015

Overwiew

Preliminaries

Einstein Field Equations

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi T_{\mu\nu} \tag{1}$$

Minkowski metric

$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega^2 \tag{2}$$

Black hole solutions

Classification of Black holes

	Non-rotating ($J = 0$)	Rotating ($J \neq 0$)
Uncharged ($Q = 0$)	Schwarzschild	Kerr
Charged ($Q \neq 0$)	Reissner-Nordström	Kerr-Newman

Schwarzschild Black hole

Schwarzschild metric

$$ds^2 = -\left(1 - \frac{2m}{r}\right) dt^2 + \left(1 - \frac{2m}{r}\right)^{-1} dr^2 + r^2 d\Omega^2 \qquad (3)$$

Kretschmann invariant

$$\kappa = R^{\alpha\beta\gamma\delta} R_{\alpha\beta\gamma\delta} = \frac{48m^2}{r^6} \qquad (4)$$

Regularized Schwarzschild metric

According to [1], we cand find metrics that are:

- Spherically symmetric.
- Static.
- Asymptotically flat (minkowski).
- **Have regular center.**

The resulting stress-energy tensor is physically reasonable, satisfies the weak energy condition and has components that are bounded and fall off appropriately at large distance.

Regularized Schwarchild metric

Consider a static, spherically symmetric metric of the form:

$$ds^2 = -F(r)dt^2 + \frac{1}{F(r)}dr^2 + r^2 d\Omega^2 \tag{5}$$

We demand

$$F(r) \sim 1 - \frac{2m}{r} \quad as \quad r \to \infty \tag{6}$$

$$F(r) \sim 1 - \frac{r^2}{l^2} \quad as \quad r \to 0 \tag{7}$$

Hayward metric

The so called Hayward metric [1] satisfies all the required properties and is given by:

$$F(r) = 1 - \frac{2mr^2}{r^3 + 2ml^2} \tag{8}$$

For this metric, the Kretschmann invariant is

$$OJO \tag{9}$$

Hayward metric

Analyzing the zeros of $F(r)$, we get a critical mass $m_* = \frac{3\sqrt{3}}{4}l$ and a radius $r_* = \sqrt{3}l$.

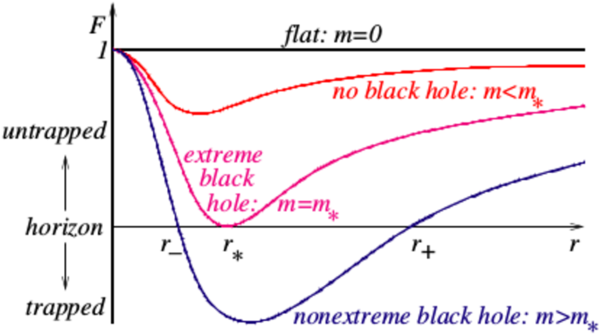

Figure : Behavior[1] of $g_{tt} = F(r)$ for different values of the parameter m.

[1]Image taken from [1].

Quantum Field Theory

Spacetime metric describing 'non-singular' black holes are commonly studied in the literature [2, 3] as effective modification to the Schwarzschild solution that mimic quantum gravity effects removing the central singuarity.

To begin with, two insights from quantum cosmology [4]:

- The onset of quantum gravitational effects is when energy density reaches the Plank scale ($\sim 5.155 \cdot 10^{96}\ \frac{kg}{m^3}$).
- The dominant quantum effect at high density is a strong pressure, sufficient to counterbalance weight and reverse gravitational collapse.

Quantum Field theory

For a black hole, the previous arguments imply that matter's collapse can be stopped before the central singularity is formed, yielding the formation of a central core, called a **Planck star**.

References

- Hayward, S.A.: Formation and Evaporation of regular black holes. Phys. Rev. Lett. **96**, 31103 (2006).
- De Lorenzo, T., Pacilio, C., Rovelli, C., Speziale, S.: On the effective metric of a Planck star. Gen. Relativ. Gravit. **47**, 41 (2015).
- Rovelli, C., Vidotto, F.: Planck Stars. Int. J. Mod. Phys. D. **23**, 1142026, (2014).
- Ashtekar, A., Pawlowski, T., Singh, P., Vandersloot, K.: Loop quantum cosmology of k=1 FRW models. Phys. Rev. D **75**,24035 (2007).

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