A

Presentation

on

Effects of Quantum Gravity in the Kerr Black Hole Paradigm

17TH INTERNATIONAL CONFERENCE ON INTERCONNECTIONS BETWEEN PARTICLE PHYSICS AND COSMOLOGY

PPC 2024

14 -18 October 2024, Hyderabad, India

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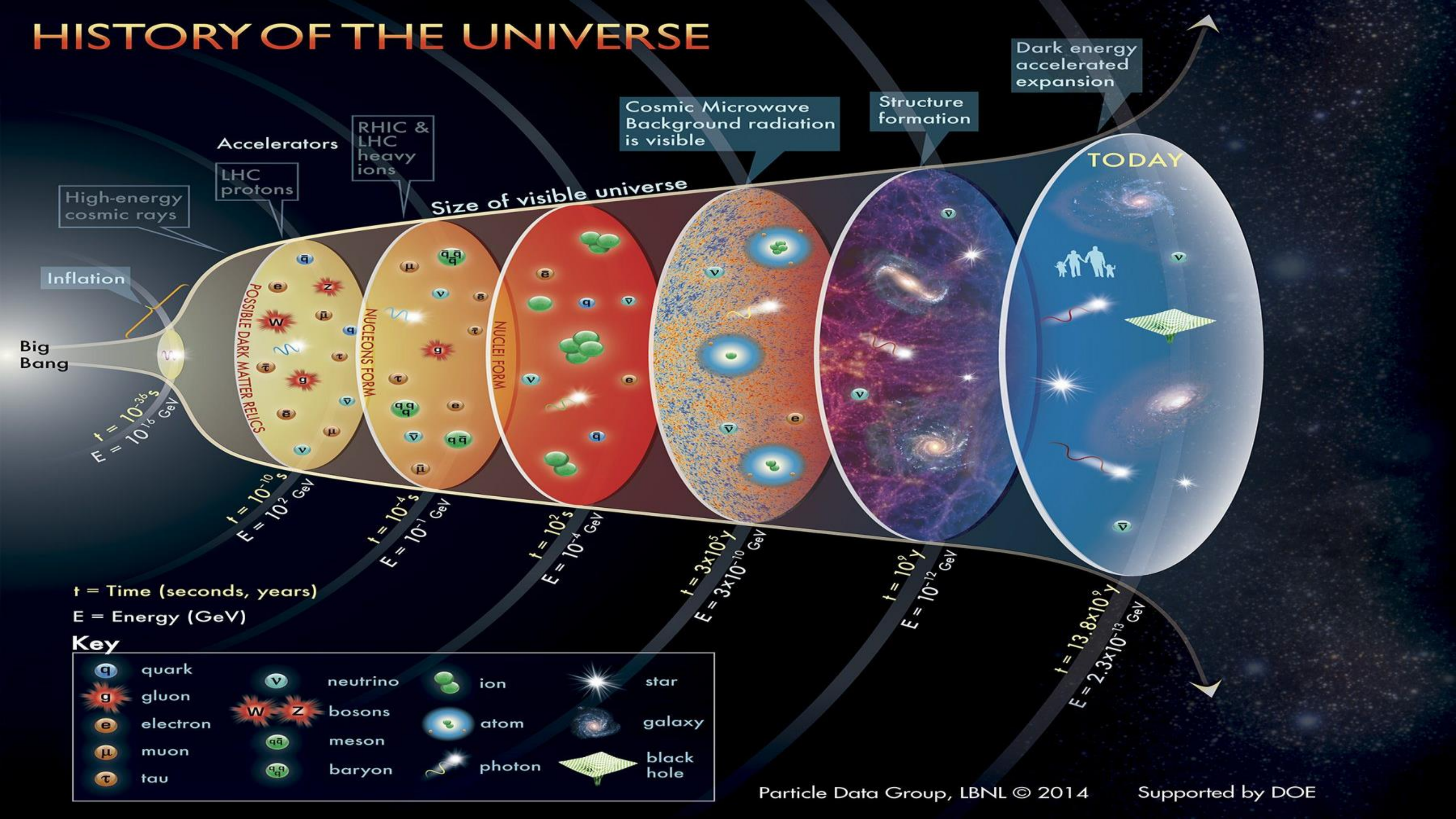
16th OCT, 2024

PLAN OF TALK

- OBJECTIVE
- INTRODUCTION
- SETTING THE STAGE
- CALCULATION
- CONCLUSION
- REFFERENCES


HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Cosmic Microwave Background radiation is visible
Structure formation
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Size of visible universe
TODAY
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^{-36} s
E = 10^{16} GeV
t = 10^{-10} s
E = 10^{2} GeV
t = 10^{-4} s
E = 10^{-1} GeV
t = 10^{2} s
E = 10^{-4} GeV
t = $3x10^{5}$ y
E = $3x10^{-10}$ GeV
t = 10^{9} y
E = 10^{-12} GeV
t = $13.8x10^{9}$ y
E = $2.3x10^{-13}$ GeV
t = Time (seconds, years)
E = Energy (GeV)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL © 2014
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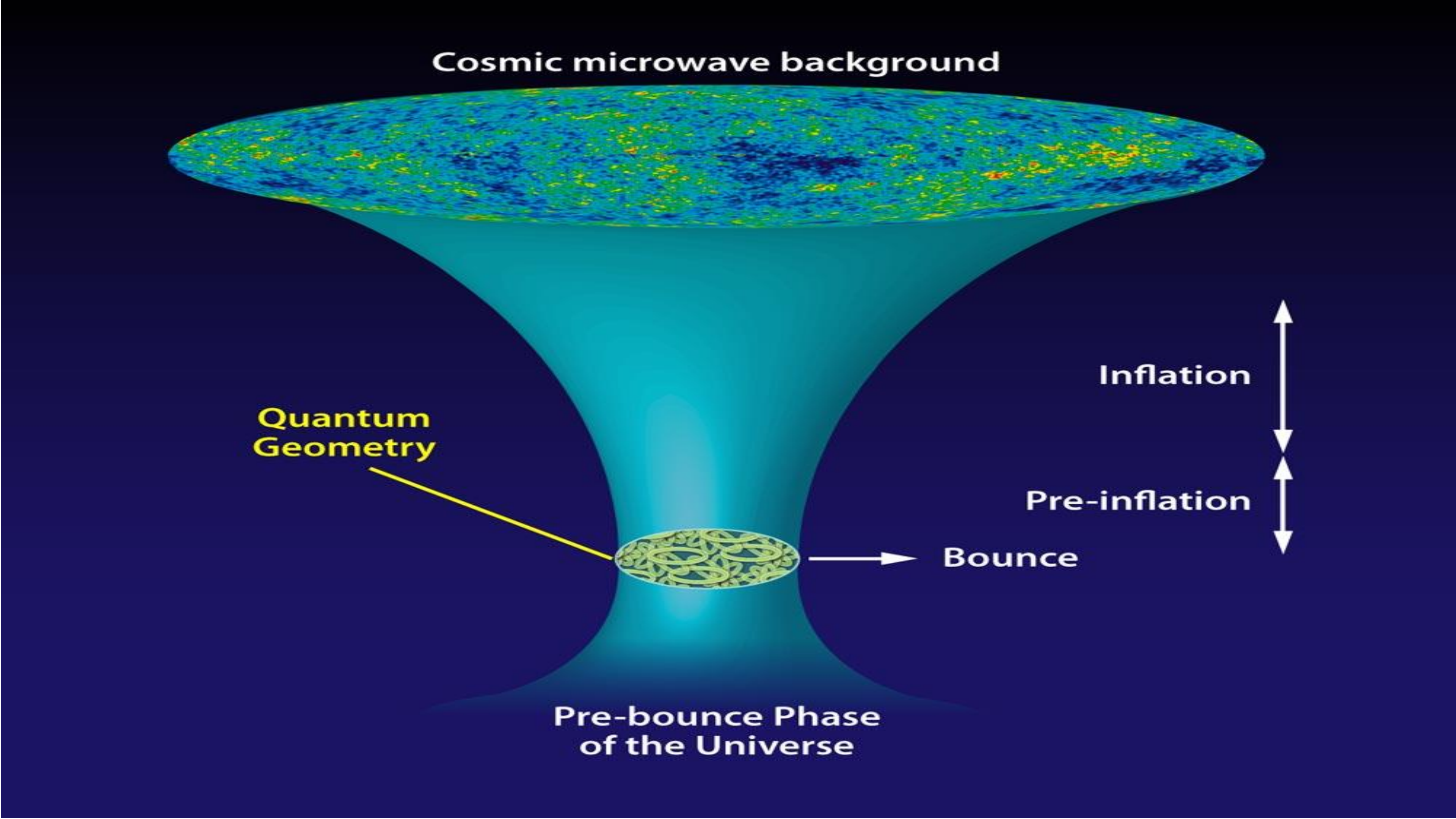
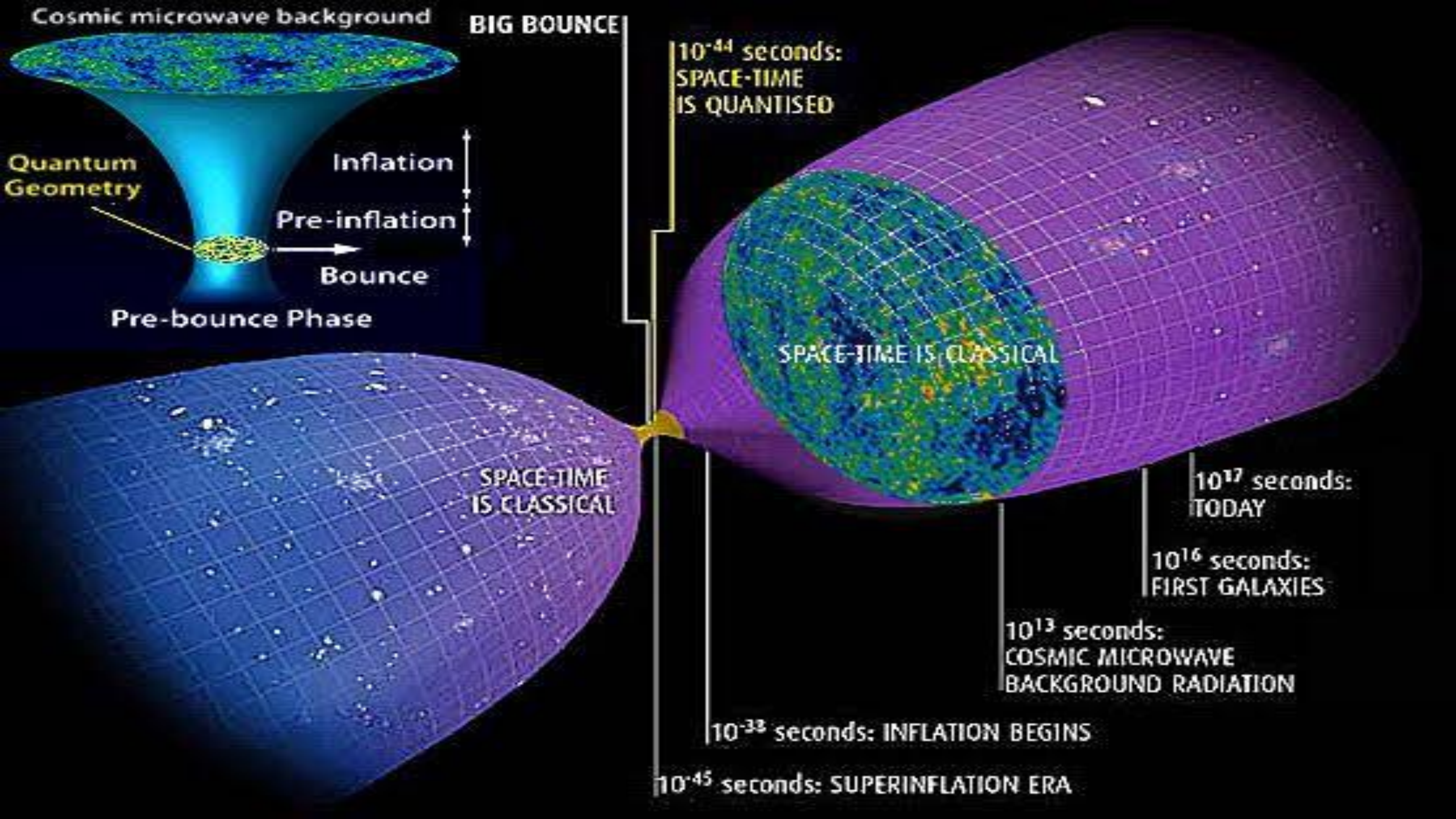
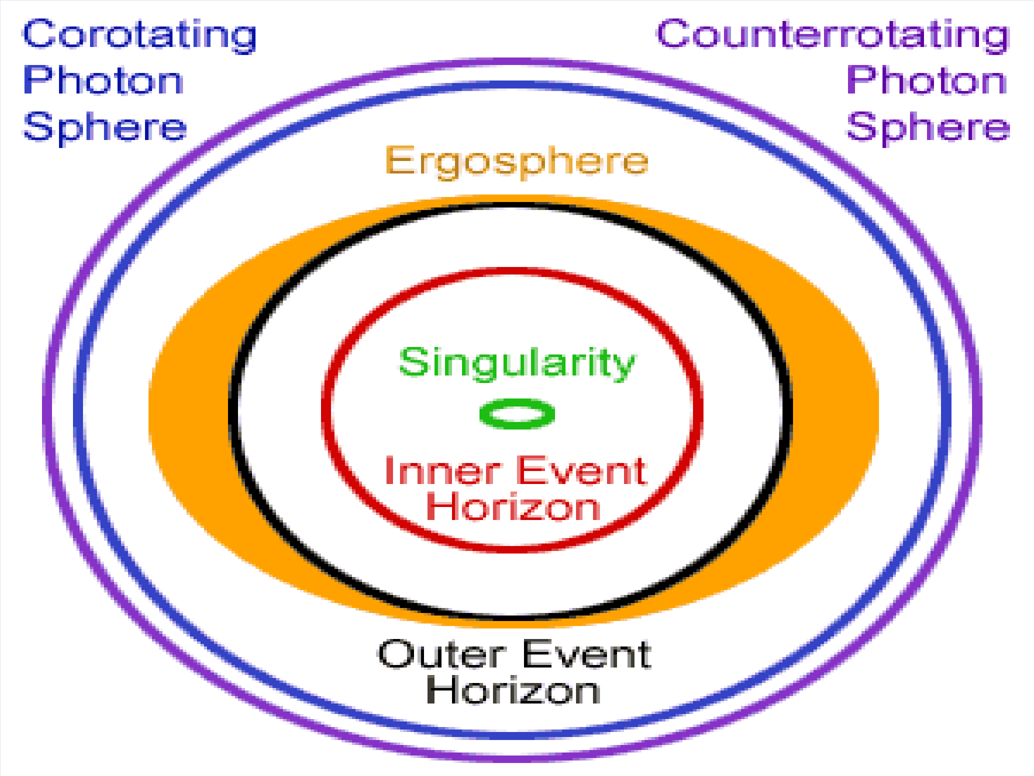

Cosmic microwave background
Inflation
Quantum
Geometry
Pre-inflation
Bounce
Pre-bounce Phase
of the Universe



Cosmic microwave background
BIG BOUNCE
10^{-44} seconds:
SPACE-TIME
IS QUANTISED
Quantum
Geometry
Inflation
Pre-inflation
Bounce
Pre-bounce Phase
SPACE-TIME IS CLASSICAL
SPACE-TIME
IS CLASSICAL
10^{17} seconds:
TODAY
10^{16} seconds:
FIRST GALAXIES
10^{13} seconds:
COSMIC MICROWAVE
BACKGROUND RADIATION
10^{-33} seconds: INFLATION BEGINS
10^{-45} seconds: SUPERINFLATION ERA

Schematic Diagram For Rotating Black hole



OBJECTIVE

- To study the accretion and evaporation of the rotating black holes using Loop Quantum Cosmology (LQC).
- To examine the nature of supermassive rotating black hole in the background of LQC.

Introduction

- Loop Quantum Gravity (LQG) is one of the special features of quantum gravity theories which is completely non-perturbative, explicit background independent approach to quantum gravity.

- Generally the implication of LQG on cosmology for the study of our universe is called as loop quantum cosmology (LQC).

- Kerr explains successfully regarding the geometry of uncharged black holes. As we know from the no hair theorem, a spinning uncharged black hole is only described by its two quantities. One is its mass (M) and another is respective angular momentum (J).

- Depending upon these various quantities such as mass, angular momentum, accretion efficiency (f), energy density (ρ) and dark energy parameter (ω), we can calculate the evolution of the rotating Kerr black hole.

SETTING THE STAGE

- For a spatially flat FRW universe (k=0) filled with dust and dark energy, the Friedmann equation, Raychaudhuri's equation and energy conservation equation in loop quantum cosmology respectively take the form

$$\boldsymbol{H^2 = \frac{8\pi G}{3}\left(\rho_\phi + \rho_m\right)\left\{1 - \frac{\left(\rho_\phi+\rho_m\right)}{\rho_c}\right\}} \qquad \textbf{(1)}$$

$$\boldsymbol{\dot{H} = -4\pi G(\rho_\phi + \rho_m + p_\phi)\left\{1 - \frac{2\left(\rho_\phi+\rho_m\right)}{\rho_c}\right\}} \qquad \textbf{(2)}$$

And

$$\boldsymbol{\left(\dot{\rho_\phi} + \dot{\rho_m}\right) + 3H\left(\rho_\phi + \rho_m + p_\phi\right) = 0} \qquad \textbf{(3)}$$

- The expression for density $\boldsymbol{\rho(t)}$ in radiation and matter dominated era can be calculated as

$$\boldsymbol{\rho(t)_{t<t_e} = \rho_0 \left[\frac{\rho_0}{\rho_c} + \left\{ 2\sqrt{\frac{8\pi G}{3}} \rho_0^{\frac{1}{2}} (t - t_e) + \frac{3}{2}\sqrt{\frac{8\pi G}{3}} \rho_0^{\frac{1}{2}} (t_e - t_o) + \left(1 - \frac{\rho_0}{\rho_c}\right)^{\frac{1}{2}} \right\}^2 \right]^{-1}} \quad \textbf{(4)}$$

$$\boldsymbol{\rho(t)_{t>t_e} = \rho_0 \left[\frac{\rho_0}{\rho_c} + \left\{ \frac{3}{2}\sqrt{\frac{8\pi G}{3}} \rho_0^{\frac{1}{2}} (t - t_o) + \left(1 - \frac{\rho_0}{\rho_c}\right)^{\frac{1}{2}} \right\}^2 \right]^{-1}} \quad \textbf{(5)}$$

- The space time around a rotating black hole with mass M and angular momentum J can be explained by the line element (c=G=1 units)

$$ds^2 = -\left(1 - \frac{2Mr}{\rho^2}\right)dt^2 - \frac{4M{a^*}^2 r \sin^2\theta}{\rho^2} d\phi dt + \frac{\rho^2}{\Delta}dr^2 + \rho^2 d\theta^2 + \left(r^2 + {a^*}^2 + \frac{2Mr{a^*}^2\sin^2\theta}{\rho^2}\right)\sin^2\theta d\phi^2$$

- The equation of state parameter ω which we calculated as

$$\omega = 0.01971\left(\frac{t}{t_0}\right)^2 - 1.0442\left(\frac{t}{t_0}\right) \quad \textbf{(6)}$$

- The accretion of black hole mass with the rate is given by

$$\dot{M}_{acc} = 4\pi f R_{BH}^2 \rho_R \quad \textbf{(7)}$$

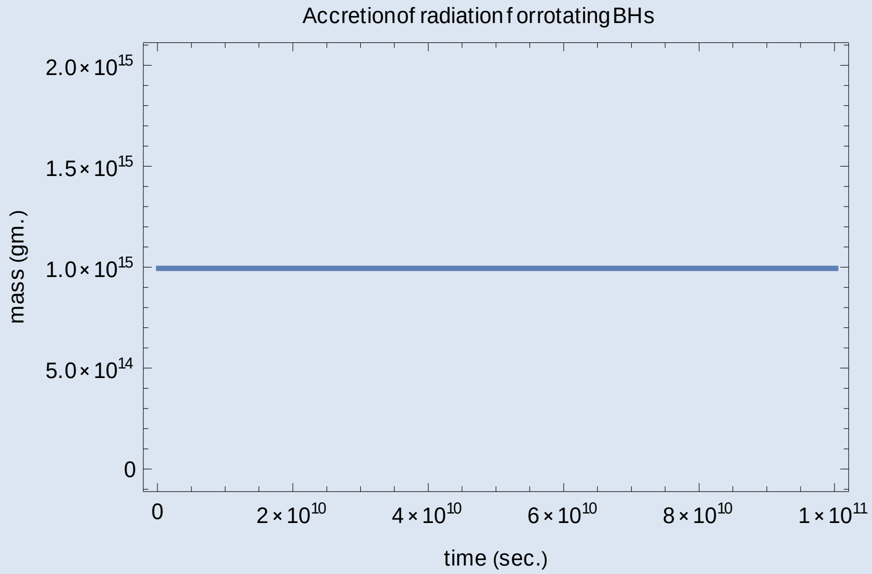
- The evaporation of black hole mass with the rate is given by

$$\dot{M}_{evp} = -4\pi R_{BH}^2 \sigma_H T_{BH}^4 \quad \textbf{(8)}$$

Calculation

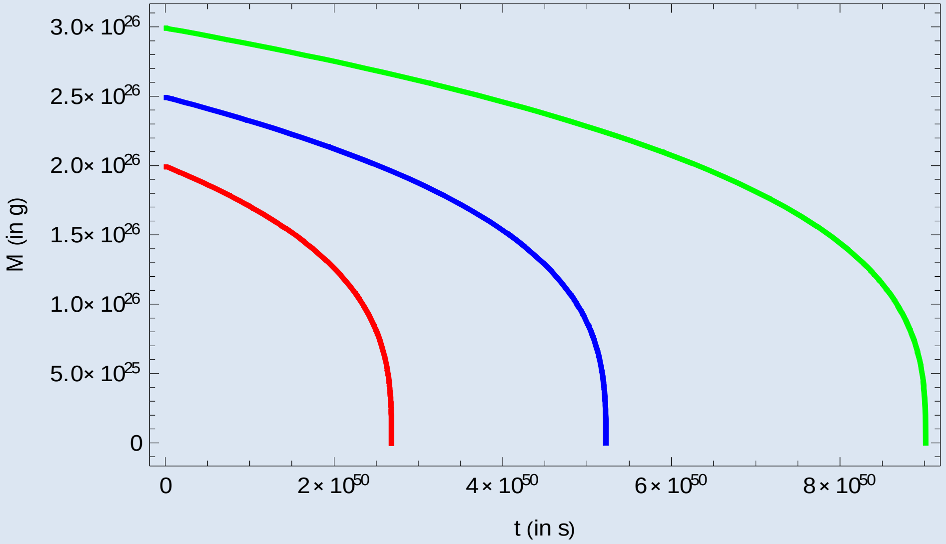
- Now the modified accretion of black hole mass in the radiation dominated era is

$$\dot{M}_{acc} = 4\pi f R_{BH}^{2}\boldsymbol{\rho_0}(\boldsymbol{1}+\boldsymbol{\omega})\left[\frac{\boldsymbol{\rho_0}}{\boldsymbol{\rho_c}} + \left\{\boldsymbol{2}\sqrt{\frac{\boldsymbol{8\pi G}}{\boldsymbol{3}}}\boldsymbol{\rho_0}^{\frac{1}{2}}(\boldsymbol{t}-\boldsymbol{t_e}) + \frac{\boldsymbol{3}}{\boldsymbol{2}}\sqrt{\frac{\boldsymbol{8\pi G}}{\boldsymbol{3}}}\boldsymbol{\rho_0}^{\frac{1}{2}}(\boldsymbol{t_e}-\boldsymbol{t_o}) + \left(\boldsymbol{1}-\frac{\boldsymbol{\rho_0}}{\boldsymbol{\rho_c}}\right)^{\frac{1}{2}}\right\}^{2}\right]^{-1} \quad \textbf{(9)}$$



❖ Now the evolution of rotating black hole mass in the matter dominated era is

$$\dot{M}_{evo} = \dot{M}_{acc} + \dot{M}_{evp} = 4\pi f R_{BH}^2 \boldsymbol{\rho_0}(\mathbf{1}+\boldsymbol{\omega}) \left[\frac{\boldsymbol{\rho_0}}{\boldsymbol{\rho_c}} + \left\{\frac{\mathbf{3}}{\mathbf{2}}\sqrt{\frac{\mathbf{8\pi G}}{\mathbf{3}}}\boldsymbol{\rho_0}^{\frac{1}{2}}(\boldsymbol{t}-\boldsymbol{t_o}) + \left(\mathbf{1}-\frac{\boldsymbol{\rho_0}}{\boldsymbol{\rho_c}}\right)^{\frac{1}{2}}\right\}^{2}\right]^{-1} - 4\pi R_{BH}^2 \sigma_H T_{BH}^4 \quad (10)$$



- In this research work, we have checked the effect of rotating parameter on the evaporation of rotating black holes

Table 2: Variation of the evaporation time with rotating parameter (a^*) for fixed value of RBH mass and time, and accretion efficiency (f).

$t_i = 10^{-13}$s, $M_i = 10^{25}$g, $f = 0.4$	
$(a^*)^2$	t_{evp} (in 10^{18} s)
$10^{-12} m_i^2$	33333.32124
$10^{-11} m_i^2$	33333.32124
$10^{-10} m_i^2$	33333.32126
$10^{-9} m_i^2$	33333.32192
$10^{-8} m_i^2$	33333.32274

Heart of the Milky way

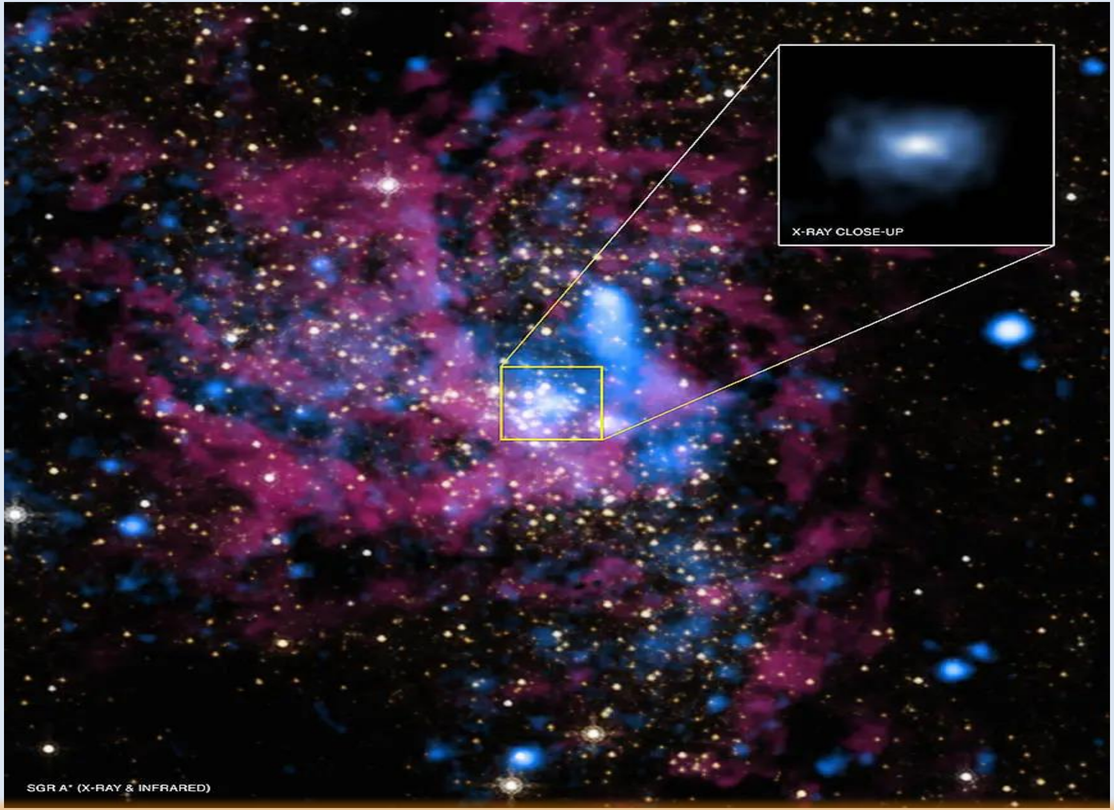
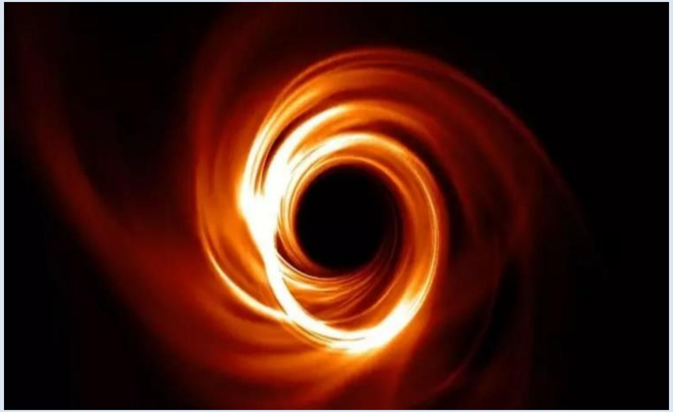


Image credit: X-ray: NASA/UMass/D.Wang et al., IR: NASA/STScI



$\approx 10^6 \, M_\odot$

Quasar J0313-1806

Image credit: NASA/ESA/ESO/Wolfram Freudling et al. (STECF)

$\approx 10^9\ M_\odot$

$\geq 10^{48}$ gm

Swain, S., Sahoo, G. & Nayak, B. Unveiling the evolution of rotating black holes in loop quantum cosmology. *Sci Rep* **14**, 16928 (2024). https://doi.org/10.1038/s41598-024-68000-x

Conclusion

- Accretion of radiation does not affect significantly on the evolution of RBH in loop quantum cosmology.
- Here we found that RBHs formed in the early radiation dominated era evaporated quickly than the RBHs formed in the later time period.
- Also, we examined that rotating parameter does not affect vitally on the evaporation of RBHs.
- we also successfully investigated that those RBHs having mass greater than equal to 10^{48} gm. they all would have been evaporated by the present time due to the accretion of dark energy.

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