Primordial Loop Black Hole Dark Matter:

The Cosmological Implications

In collaboration with Leonardo Modesto

Outline

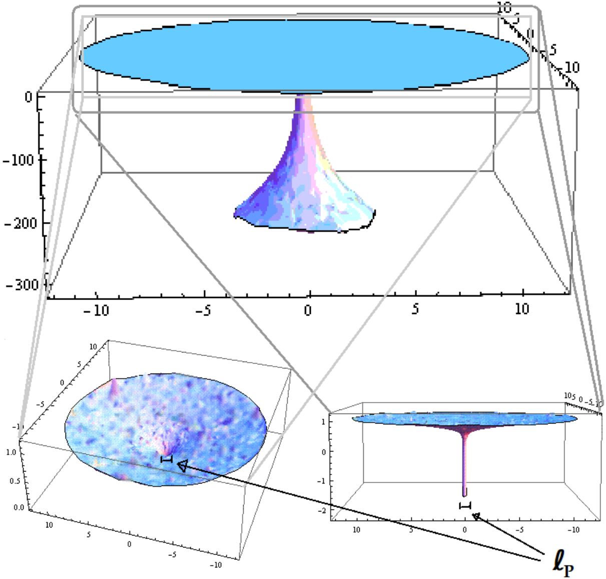
- Description of the Loop Black Holes:
  - Shape and Metric
  - Thermodynamic properties
- Cosmological Implications:
  - Creation Process
  - Constraints on Inflation

Loop Quantum Cosmology Applied to Black Holes

The space time inside a black hole is homogeneous: apply LQC techniques and extend analytically outside.

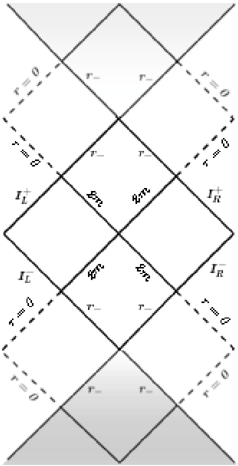
[Abhay Ashtekar, Martin Bojowald, Leonardo Modesto, Parampreet Singh,etc.]

Shape of Ultra Light Loop Black Holes



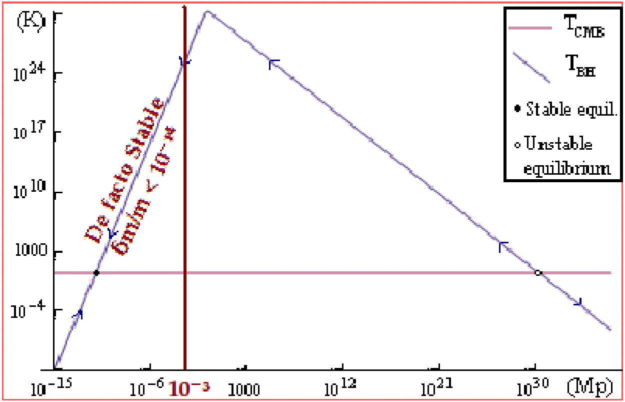
The Metric

$$ds^2 = -\frac{(r-r_+)(r-r_-)(r+r_\star)^2}{r^4+a_0^2}dt^2$$
$$+\frac{dr^2}{\frac{(r-r_+)(r-r_-)r^4}{(r+r_\star^d)^2(r^4+a_0^2)}}+\left(\frac{a_0^2}{r^2}+r^2\right)d\Omega^2,$$



$$r_+ = 2m, \quad r_\star = 2mP, \quad r_- = 2mP^2; \quad 0 < P < 1.$$

Loop Black Hole Temperature

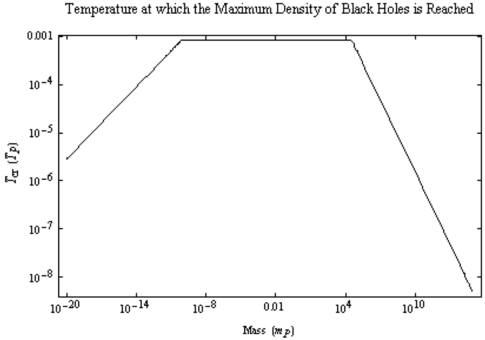


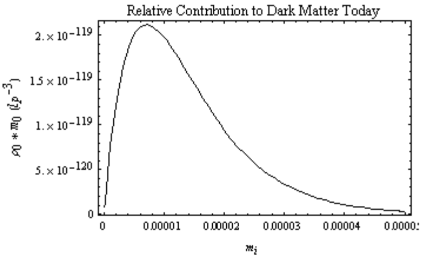
$$T(m) = \approx \frac{(2m)^3}{4\pi[(2m)^4 + a_0^2]}.$$

Creation

$$\rho(m) \approx \frac{1}{\pi^3} \exp(-\Delta F/T) \text{ where } \Delta F = F_{BH} - F_R.$$

Validity of thermodynamics: local equilibrium:
$t_{reaction} < t_{exp} \approx H^{-1} \Rightarrow T < 10^{15} - 10^{17} GeV.$





Inflation

$$\int_0^\infty \frac{(a(t_i))^3 m_0(m_i)\rho_i(m_i)}{(a(t_0))^3} dm_i = 0.22\rho_{crit} = \rho_{DM}$$

$$\Rightarrow \frac{a(t_0)}{a(t_i)} = e^{85}$$

- 60 e-folds ago, was the end of inflation which lasted for at least 60 e-folds.

$T_{inflation} \approx 10^{14} GeV \Rightarrow \frac{a(t_0)}{a(t_i)} = e^{85}$

Conclusion

- Light Loop Black Holes: small cross-section, stable, heavy. Possible Dark matter.
- Would be created during Inflation.
- Constrains at least 2-stage inflation.

Deriving the Loop Quantum Black Hole

- Restrict consideration to Kantowski-Sachs space-time inside BH.

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

- Introduce polymerisation and Ashtekar variables.
- Use holonomies and density triads as fundamental variables.
- Semiclassical evolution: using Poisson brackets.
- Resulting metric exhibits a minimum in area.
- Fix minimum area, simplest way: minimum area of full LQG.
- Extend metric analytically outside (the two) Horizons.

Deriving the Loop Quantum Black Hole

- Restrict consideration to Kantowski-Sachs space-time inside BH.

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

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Deriving the Loop Quantum Black Hole

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$$ds^2 = -\frac{dt^2}{\frac{2m}{t} - 1} + (\frac{2m}{t} - 1)dr^2 + t^2 d\Omega^2$$

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The GZK Cutoff

Figure: Modification of a figure by Angela V. Olinto (U. Chicago).

- distance > 50Mpc ⇒ $E_{\text{cosmic ray}} < 6 \times 10^{19}$eV
- we observe $E_{\text{cosmic ray}} > 6 \times 10^{19}$eV
- @ distance < 50Mpc, no observed sources

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Radiation Emitted by Ultra Light LQBH

In the Universe at Large:

$$R_{BH}(\nu) = \int_{m_0=0}^{\sqrt{a_0}/2} \rho_0(m_0) \frac{2A_{min}}{\pi} \frac{\nu^2}{e^{\frac{\nu}{T_{BH}(m_0)}} - 1} dm_0$$

In the vicinity of the Solar System:

$$R_{SSBH}(\nu) = \int_{m_0=0}^{\sqrt{a_0}/2} \rho_L(m_0) \frac{2A_{min}}{\pi} \frac{\nu^2}{e^{\frac{\nu}{T_{BH}(m_0)}} - 1} dm_0 \ ; \rho_L(m_0) = \frac{\rho_{DM}\, \rho_i(m_0)}{\int_{m=0}^{\infty} \rho_i(m)\, m\, dm}$$