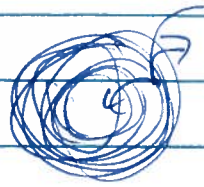
11/30/2016. Black hole thermodynamics.



$$T = \frac{1}{2\pi} \cdot \kappa = \frac{1}{2\pi} \cdot \frac{GM}{(2GM/c^2)^2} \cdot \frac{\hbar}{k_B c}$$

$$T = \frac{1}{8\pi} \frac{\hbar c^3}{k_B G M}$$

$M_\odot = 2 \times 10^{33}$ g $\longrightarrow$ 0.0617 μK.

$$\frac{dE}{dA} = \sigma T^4 = \frac{1}{4} \left(\frac{g\pi^2}{30}\right) \left(\frac{kT}{\hbar c}\right)^3 (kT) \cdot c$$

$$\frac{dM}{dt} = -(T^4)(A) \propto -\frac{1}{M^4} \cdot M^2 = -\frac{1}{M^2}$$

$$M^3 = M_0^3 - t$$

$$\tau = M_0^3 \cdot \left(\frac{t_{pl}}{M_{pl}^3}\right)$$

$$\frac{GM_{pl}^2}{\hbar c} = 1$$

$$t_{pl} = \frac{\hbar}{M_{pl} c^2}$$

$$\tau = M_0^3 \cdot \frac{\hbar}{M_{pl}^4 c^2} = M_0^3 \cdot \frac{\hbar}{c^2} \cdot \left(\frac{G}{\hbar c}\right)^2$$

$\tau = 14$ Gy $\rightarrow$ $M = (4) \times 10^{15}$ g

$T > 1\,\text{MeV} \rightarrow m < 10^{-17} \cdot 10^{15}\,\text{g} = 10^{-2}\,\text{g}$

$:= 10^{10}\,\text{K}$

$\tau(10^{-2}\,\text{g}) = (14\,\text{Gy})\left(\frac{10^{-2}}{10^{15}}\right)^3 = (10^{8}\,\text{s})(10^{-51}) = 10^{-33}\,\text{s}$

$r_H(10^{-2}\,\text{g}) = \left(\frac{10^{-2}}{10^{33}}\right)(3\times10^{5}\,\text{cm}) = 10^{-28}\,\text{cm}$

$\Delta p = \frac{\hbar}{\Delta r} = \frac{10^{21} \cdot 0.2\,\text{GeV}\cdot\text{fm}}{(10^{-13}\,\text{fm})} = 10^{21}\,\text{GeV}$

most comes out as γ

last 1 sec

$m \sim (10^{15}\,\text{g})\left(\frac{1\,\text{s}}{10^{18}\,\text{s}}\right)^{1/3} = 10^{9}\,\text{g}$

$\text{power} = \frac{(10^{9}\,\text{g})(3\times10^{10}\,\text{cm/s})^2}{1\,\text{s}} = 10^{30}\,\frac{\text{erg}}{\text{s}}\;(10^{-3}\,L_\odot)$

$r \sim (3\,\text{km})\left(\frac{10^{9}}{10^{33}}\right) = 10^{-19}\,\text{cm}$

$T = 10^{-7}\,\text{K}\cdot\left(\frac{10^{15}}{10^{9}}\right) \simeq 0.1\,\text{K}$

out vs In — Asymptotically flat

$$ds^2 \simeq -\left(1 - \frac{2m}{r} + \frac{2(\beta)m}{r^2} + \cdots\right) dt^2$$

$$- \left(4 \frac{\vec{S} \times \vec{x}}{r^3} + \cdots\right) dt\, d\vec{x}$$

$$+ \left[\left(1 + 2(\delta)\frac{m}{r} + \cdots\right)(\delta_{ij}) + \frac{h^{TT}_{ij}}{r}\right] dx^i dx^j$$

$$m = \int d^3x\, T^{00} \qquad \vec{S}_i = \int d^3x\, \varepsilon_{jkm} x^k T^{m0}$$

Gaussian integrals — $m, 0, 1$ — $\vec{S}$.

"Black Hole Has no Hair" . JTW

Comoving → $v \to 0$ in finite proper time (πm)

Extremal → $(2m)$ as $e^{-t/m}$. never crosses.

$$S = \frac{1}{16\pi G} \int d^4x \sqrt{g} \cdot R = m_{pl}^2 \cdot \int d^4x \, R$$

$$\rightarrow M^{n-2} \int d^n x \cdot R \rightarrow M^{n-2} \cdot L^{n-4} \cdot \int d^4x \, R^{(4)}$$

"Compact" extra dimensions.

$$ds^2 = \overset{(4)}{g}_{\mu\nu} dy^\mu dx^\nu + \overset{(n-4)}{G}_{mn} dy^m dy^n$$

$$L$$

$$m_{pl}^2 = M^{n-2} \cdot L^{n-4} = M^2 \cdot (LM)^{n-4}$$

$$L > M^{-1} \rightarrow m_{pl,4} > M$$

observable at LHC. $M \simeq 10^{10}$ TeV $L \leq 1$ cm

$$\left(\frac{10^{19}\,\text{GeV}}{10\,\text{TeV}}\right)^2 = \left(\frac{10^{28}\,\text{eV}}{10^{13}\,\text{eV}}\right)^2 = 10^{30}$$

$$(LM)^{n-4} = \left(\frac{1\,\text{cm} \cdot 10\,\text{TeV}}{0.1\,\text{GeV} \cdot \text{fm}}\right)^{n-4} = \left(10^{13} \cdot 10^{4}\right)^{n-4} = \left(10^{17}\right)^{n-4}$$

$n-4 \geq 2$ $\quad$ $n \geq 6$

String Theory: (10, 11, 26)