Title: A covariant entropy bound conjecture on dynamical horizon

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Abstract: After introduction and motivation, I will present a covariant entropy bound conjecture on dynamical horizon in a general sense. Then I will show its validity in black hole case and cosmological context. Especially its power in constraint on the cosmological constant is addressed. I will end up with the outlook of this conjecture.

From mechanics to thermodynamics for black holes

- *The four laws of black hole mechanics*

  J. M. Bardeen *et al.(1973)*
- *Black holes and entropy*

  J. D. Bekenstein(1973)
- *Generalized second law of thermodynamics in black-hole physics*

  J. D. Bekenstein(1974)
- *Particle creation by black holes*

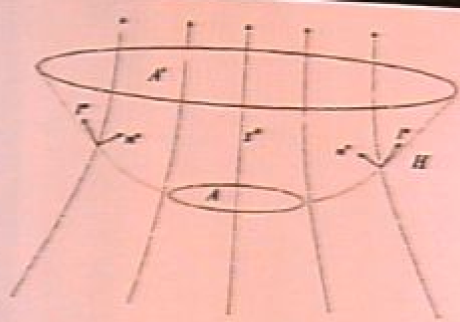
  S. W. Hawking(1975)

From event horizon to dynamical horizon for black holes

- *Event horizon is a global concept, which means we can locate it only if we know the whole spacetime, especially the null infinity*
- *Dynamical horizon is essentially a foliation of apparent horizon, which agrees with the boundary of black holes discussed in astrophysics*
- *The first and second law has been developed for dynamical horizon*

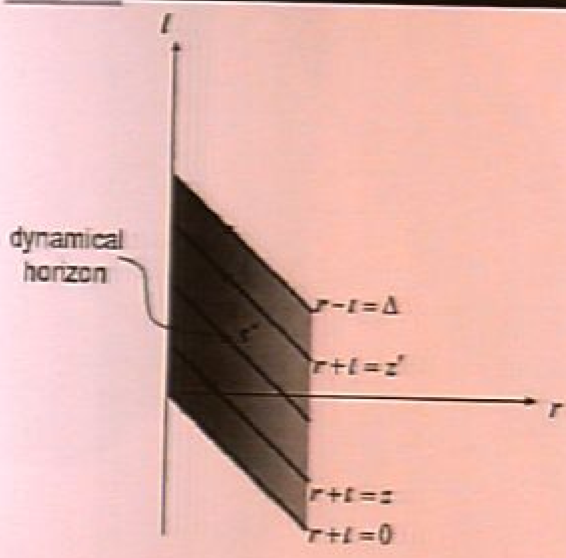
A. Ashtekar and B. Krishnan(2002,2003,2004)

CEB formulation of GSL for black hole dynamical horizon



S⩽(A'-A)/4, where Planck units have been used and dominant energy condition has been assumed.

CEBC tested in growing Vaidya black holes



$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega^2 + u(dt + dr)^2$$

$$u = \begin{cases} 0, & \text{Minkowski region,} \\ \frac{2m}{r} F(\frac{r+t}{\Delta}), & \text{within light shells,} \\ \frac{2m}{r}, & \text{Schwarzschild region.} \end{cases}$$

$$T_{ab} = \frac{mF'}{4\pi \Delta r^2} k_a k_b.$$

$$\delta A = 16\pi m^2 [F^2(\frac{z'}{\Delta}) - F^2(\frac{z}{\Delta})]$$

$$M_{eff} = m[F(\frac{z'}{\Delta}) - F(\frac{z}{\Delta})]$$

$$S \leq 4\pi m^2 [F(\frac{z'}{\Delta}) - F(\frac{z}{\Delta})]^2$$

CEB conjecture for general dynamical horizon

$\theta_l = 0$	$\theta_n > 0$	$\theta_n < 0$
$\mathcal{L}_n\theta_l > 0$, $\mathcal{L}_l\theta_l < 0$ (timelike)	expanding FRW universes with $-1 < w < \frac{1}{3}$	time reversal
	time reversal	growing Vaidya-De sitter black holes
$\mathcal{L}_n\theta_l > 0$, $\mathcal{L}_l\theta_l = 0$ (null generated by l^a)	expanding De sitter spacetime	time reversal
$\mathcal{L}_n\theta_l < 0$, $\mathcal{L}_l\theta_l < 0$ (spacelike)	time reversal	growing Vaidya black holes
	expanding FRW universes with $\frac{1}{3} < w \leq 1$	time reversal
$\mathcal{L}_n\theta_l < 0$, $\mathcal{L}_l\theta_l = 0$ (null generated by l^a)	time reversal	Schwarzchild black holes
$\mathcal{L}_n\theta_l = 0$, $\mathcal{L}_l\theta_l < 0$ (null generated by n^a)	expanding FRW universe with $w = \frac{1}{3}$	time reversal

In comparison with Bousso's covariant entropy conjecture

- Dominant energy condition
- Dynamical horizon versus light sheet

CEBC tested in expanding FRW universes

$$ds^2 = a^2(\eta)[-d\eta^2 + d\chi^2 + f^2(\chi)(d\theta^2 + \sin^2\theta d\phi^2)]$$

$$\theta_\pm = \frac{\dot{a}}{a} \pm \frac{f'}{f}$$

$$T_{ab} = a^2(\eta)\{\rho(\eta)(d\eta)_a(d\eta)_b + p(\eta)[(d\chi)_a d(\chi)_b + f^2(\chi)((d\theta)_a(d\theta)_b + \sin^2\theta(d\phi)_a(d\phi)_b)]\}$$

$$p = w\rho, \qquad a = f^q(\frac{\eta}{q}), \qquad \chi = \frac{\eta}{q} \qquad s^a = \frac{s}{a^3}(\frac{\partial}{\partial t})^a$$

$$q = \frac{2}{1+3w}$$

CEB conjecture for general dynamical horizon

$\theta_l = 0$	$\theta_n > 0$	$\theta_n < 0$
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CEBC tested in expanding FRW universes

$$ds^2 = a^2(\eta)[-d\eta^2 + d\chi^2 + f^2(\chi)(d\theta^2 + \sin^2\theta d\phi^2)]$$

$$\theta_\pm = \frac{\dot{a}}{a} \pm \frac{f'}{f}$$

$$T_{ab} = a^2(\eta)\{\rho(\eta)(d\eta)_a(d\eta)_b + p(\eta)[(d\chi)_a d(\chi)_b + f^2(\chi)((d\theta)_a(d\theta)_b + \sin^2\theta(d\phi)_a(d\phi)_b)]\}$$

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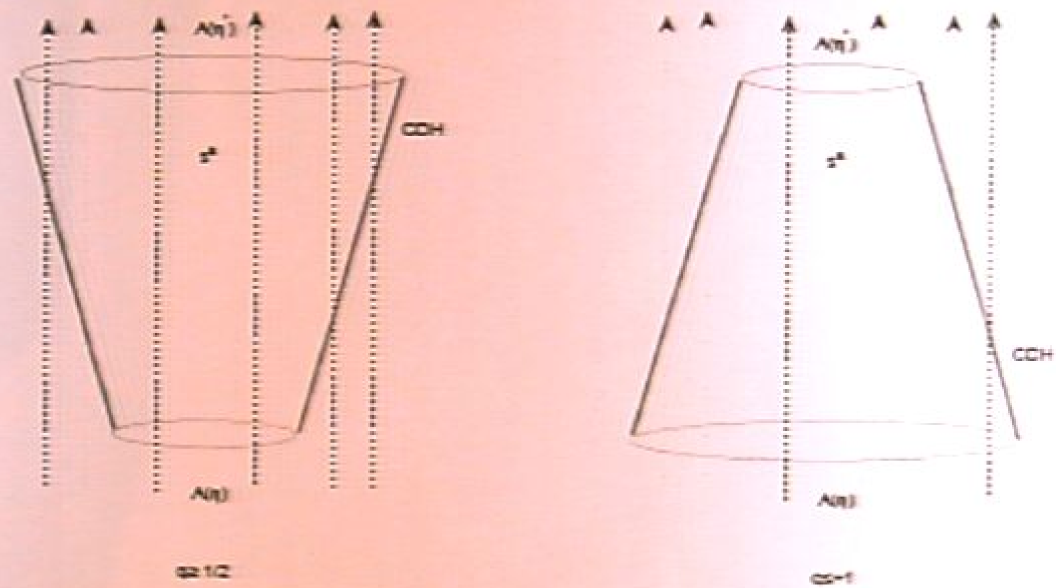
CEBC tested in expanding FRW universes



CEBC tested in expanding FRW universes

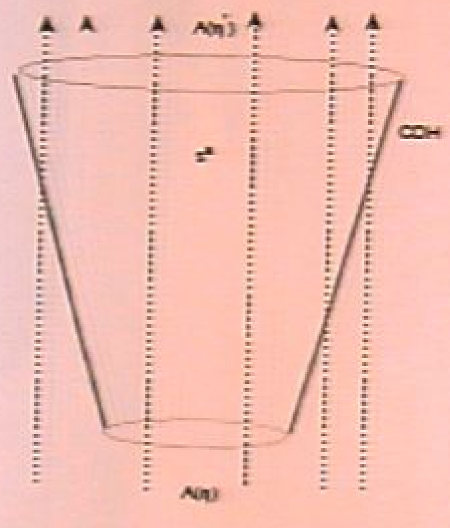
$$\frac{A(\eta')}{4} - S(\eta') \geq \frac{A(\eta)}{4} - S(\eta) \qquad (q+1)f^{2q-1}(\frac{\eta}{q}) - 2s \geq 0$$

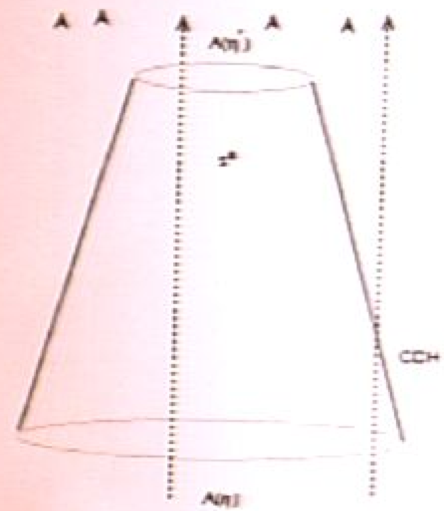
$$\frac{A(\eta')}{4} + S(\eta') \geq \frac{A(\eta)}{4} + S(\eta) \qquad (q+1)f^{2q-1}(\frac{\eta}{q}) + 2s \leq 0$$

$$A(\eta) = 4\pi f^{2(q+1)}(\frac{\eta}{q})$$

$$S(\eta) = 4\pi s \int_0^{\frac{\eta}{q}} d\chi f^2(\chi).$$

CEBC tested in expanding FRW universes





CEBC tested in expanding FRW universes

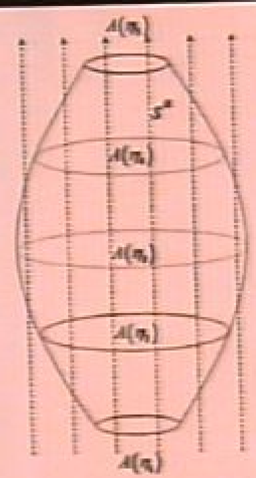
$$\frac{A(\eta')}{4} - S(\eta') \geq \frac{A(\eta)}{4} - S(\eta) \qquad (q+1)f^{2q-1}(\frac{\eta}{q}) - 2s \geq 0$$

$$\frac{A(\eta')}{4} + S(\eta') \geq \frac{A(\eta)}{4} + S(\eta) \qquad (q+1)f^{2q-1}(\frac{\eta}{q}) + 2s \leq 0$$

$$A(\eta) = 4\pi f^{2(q+1)}(\frac{\eta}{q})$$

$$S(\eta) = 4\pi s \int_0^{\frac{\eta}{q}} d\chi f^2(\chi).$$

As a Theoretical Constraint to Cosmological Physics



$$s \leq \frac{\sqrt{3(8\pi\rho a^2 + \Lambda a^2)}(1+w)\rho a^2}{2[\Lambda - (1+3w)\rho]}$$

$$\rho = \frac{\rho_r^0 a_0^4}{a^4} + \frac{\rho_m^0 a_0^3}{a^3}$$

$$s\sqrt{\Lambda} \leq 2\sqrt{3}\pi\rho_m^0$$

Conclusions

- Our CEBC has been formulated to general cases and confirmed by various examples
- Our CEBC implies a noval but profound relation between cosmological constant and dust matter, which provides an alternative macroscopic approach to shed light on the longstanding cosmological constant problem

Outlook

- To investigate our CEBC in more realistic grativational collapse
- To investigate our CEBC in universes with negative cosmological constant
- To investigate our CEBC in the inhomogeneous universes such as LTB universe
- To investigate our CEBC in the regime where quantum gravity effect becomes dominant such as loop quantum cosmology
- More importantly, the microscopic origin of our CEBC