Cosmic Censorship Violation in String Theory.

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Outline

1/ The Cosmic Censorship Conjecture.

2/ Violation for some theories in AdS.

3/ Violation in low energy limit string theory.

4/ Understanding Cosmological Singularities ??

Our work : further restrict the nature of a possible cosmic censorship theorem.

Claim: There exist field theories that admit a positive energy theorem (in AdS), but violate cosmic censorship.

Positive Energy Theorem :

The total energy of all nonsingular initial data is positive and vanishes iff the metric is perfect AdS.

Easier in AdS because

1) Black holes harder to form,

$$ds^2 = -f(r)\,dt^2 + f(r)^{-1}dr^2 + r^2 d\Omega_2$$

$$f(r) = 1 - \frac{2M}{r} + \frac{r^2}{\ell^2}$$

If $R_{EH} > \ell_{AdS}$, then $M \sim R_{EH}^3$.

$\Rightarrow$ Black holes in AdS have much larger mass than Schwarzschild black holes of the same size.

The singularity theorems do not prove that gravitational collapse produces a black hole and not a naked singularity that is visible for a distant observer.

Cosmic Censorship.

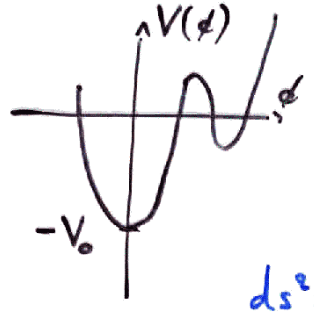
(Penrose '69)

> Generic smooth initial data with reasonable matter cannot form naked singularities.

We are far from a proof of this, but over the years the statement has been refined.

2) There is a qualitatively different way to form singularities.

Consider



ϕ homogeneous,

$$ds^2 = -dt^2 + a^2(t)\, dH_3^2$$

($k=-1$ RW universe)

* $\phi = 0$, at $t=0$ $\Rightarrow \begin{cases} \phi(t) = 0 \\ a(t) \sim \cos(\sqrt{V_0}\, t) \end{cases}$

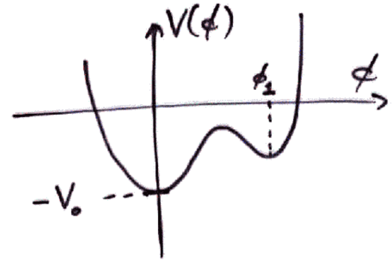
Pure AdS : coordinate singularity at $a=0$.

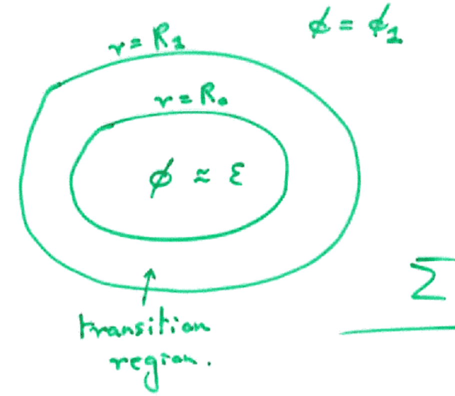
• $\phi = \varepsilon \neq 0$, at $t=0$, in some region

$\Rightarrow$ curvature singularity at $a=0$.

(cfr. vacuum decay)

Consider, $R - \frac{1}{2}(\nabla\phi)^2 - V(\phi)$





$\dot\phi = 0$ on Σ.

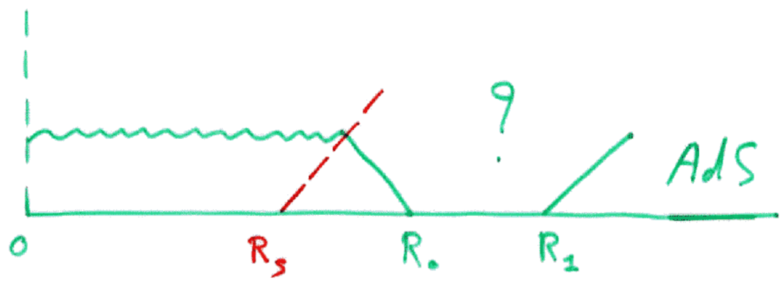
$$ds^2_\Sigma = \left(1 - \frac{2m(r)}{r} + \frac{r^2}{l^2}\right)^{-1} dr^2 + r^2\, d\Omega_2$$

Tuning $V(\phi)$: $M = \lim_{r\to\infty} m(r) > 0$, $\forall\, \phi(r)$.

- Central region $r < R_0$ develops spacelike singularity in time $T \sim V_0^{-1/2}$.
- For $V(\phi)$ at transition point, $\min_{\{\phi\}} M \sim R_1$, and optimal $\phi(r)$ like above.

Is there enough mass to form a B.H.?

Evolution :



The black hole area theorem still holds if $V(\phi) < 0$, so if a black hole forms then $R_{BH} > R_s$.

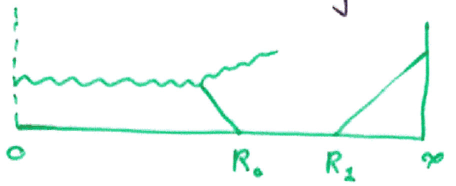
Since M is conserved, this requires an initial mass $M \sim R_s^3$.

But $R_s \sim R_1$ and some initial data have $M \sim R_1$, so endpoint must be naked. Hence there exists an open set of initial data that produce naked singularities.

Comments.

1) Hairy B.H.'s are more massive.

2) To avoid a contradiction with the Raychaudhuri eq., the singularity must be metrically a sphere, and not a point.

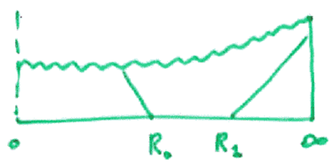


So it becomes weaker as it goes out.

3) Does it really end ?

Why not become timelike or extend to the boundary ?

→ classically not possible to distinguish.



→ We have no proof, but don't expect the collapse of a finite mass configuration with compact support to destroy the whole space.

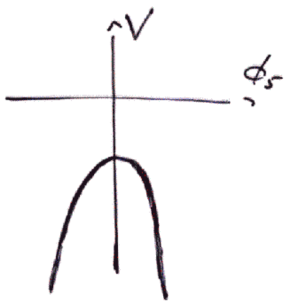
Does Cosmic Censorship hold in the low energy limit of string theory with AdS boundary conditions?

Low energy limit of string theory with $AdS_5 \times S^5$ boundary conditions is $D = 5$, $\mathcal{N} = 8$ SUGRA.

Spectrum contains 5 scalars with $m^2 = -\frac{d^2}{4} = -4$, saturating the BF bound, which ensures stability of the AdS_{d+1} state.

Configurations involving these scalars good candidates to violate cosmic censorship.

ϕ_s ~~decouples~~ does not act as source, non perturbatively from others, so consider



$$V(\phi_s) = -2e^{2\phi_s/\sqrt{3}} - 4e^{-\phi_s/\sqrt{3}}$$
$$\approx -6 - 2\phi^2 + \dots$$

$$\boxed{\phi_s(r)}$$

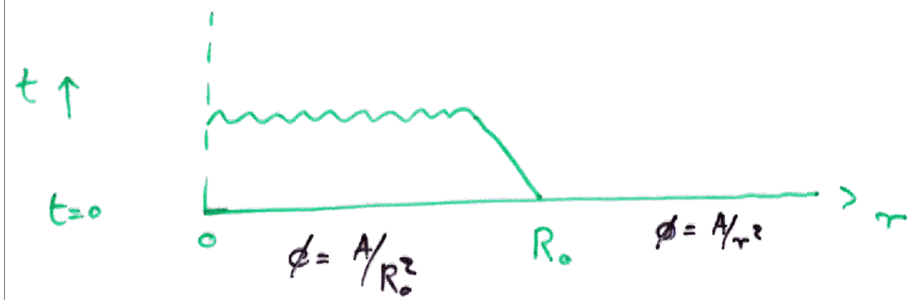
Because $m^2 < 0$ now, if $\phi_s(r)$ goes slowly to the top, this decreases the total M.

Slowest asympt. falloff that gives finite mass:

$$\phi_s(r) \sim 1/r^2 .$$

(cfr. ind. modes free wave eq. corresponding to CPT states)

Natural choice, $\phi(r)$ at $t=0$.



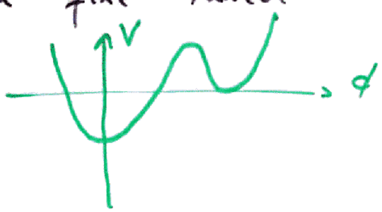
Not enough mass to enclose singular region by an event horizon.

Generic cosmic censorship violation in $D=5$ $\mathcal{N}=8$ SUGRA.

Note: Lifting our solutions to 10 D shows S^5 and AdS_5 part of metric become singular at the same time.

1) What about cosmic censorship in asymptotically flat space?

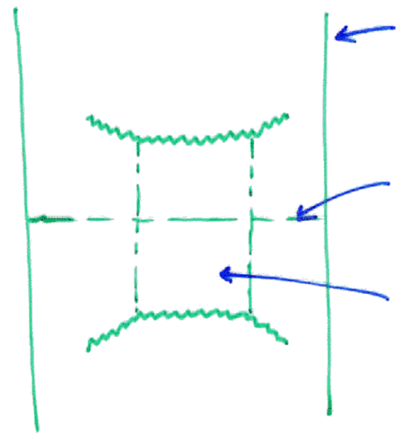
More delicate since $M_{BH} \sim R_{BH}$, but perhaps possible in fine-tuned theories with negative energy density.



Is only requiring P.E.T. "reasonable"?

Yes, because many CY compactifications contain fields with potentials that have negative regions.

2) Resolving Cosmological Singularities?



asympt. AdS

time symm. initial data

part of a cosmology with Big Bang and Big Crunch.

What is the dual field theory description?

- Are singularities resolved in full string theory?
- If so, how? Does the universe bounce?
- Should we expect a unique answer in a quantum theory?
- ...