Violation of cosmic censorship in dynamical p-brane systems

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[1] Introduction

- ❖ String theory :
- ♠ This is the only viable unified fundamental theories at present.
- ♣ String theory contains p-branes as well as strings.

What is "p-brane" ?

(Gary T. Horowitz, Andrew Strominger, Nucl.Phys. B360 (1991) 197-209)

★ Classical membrane solution of Einstein equation

$X^1, X^2, \cdots, X^p$

- This is extended in p direction.
- p-brane has p spacelike translational Killing vectors.

❁ An innumerable number of static brane solutions have been discovered so far.

But …

☺ Cosmological brane solutions may also exist !

☞ Dynamical brane background

▶ "Dynamical" means time-dependent.

✦ Dynamical brane may be related to

- brane collision
  (Gibbons & Lu & Pope, Phys.Rev.Lett. 94 (2005) 131602)
- cosmic Big-Bang of our universe
  (Chen, et al., Nucl.Phys. B732 (2006) 118-135)
- black hole in expanding universe
  (Maeda & Ohta & Uzawa, JHEP 0906 (2009) 051)
  (Maeda & Nozawa, Phys.Rev. D81 (2010) 044017)

☀ It is of great significance to understand the cosmological backgrounds profoundly.

☠ There is a naked singularity in the dynamical brane background due to …

(i) the divergence of non-trivial dilaton (This also appears in the static brane).

(ii) the time-dependence in the theory.

✍ The naked singularity in the 4-dim Einstein-Maxwell-dilaton theory with cosmological constant gives the violation of cosmic censorship.

(Horne & Horowitz, Phys.Rev. D48 (1993) 5457-5462)

☆ Question

Does the smooth initial data in the dynamical brane background evolve into the naked singularity?

☀ Cosmic censorship conjecture

(Penrose, Riv. Nuovo Cim. 1 (1969) 252-276)
(Penrose, "Singularities and time-asymmetry", (1979) 617-629)

- **Weak :**

  "Singularities have to be hidden by the event horizon of a black hole."

- **Strong :**

  "For smooth initial data with suitable matter systems, the maximal Cauchy development is not extendible."

★Outline my talk

* Geometry of dynamical brane background
* Cosmic censorship in dynamical M5-brane
* Summary and comments

[2] Geometry of dynamical brane background

(Gibbons & Lu & Pope, Phys.Rev.Lett. 94 (2005) 131602)
(Chen, et al., Nucl.Phys. B 732 (2006) 118-135)

◆ Background

(1) The background has gravity,
field strength, dilaton.
⇒ Einstein-Maxwell-dilaton theory

(2) This is a part of SUGRA.
ex) M-brane, D-brane

● The characteristics of M-brane :

- Classical solution of 11-dim SUGRA
- Static limit of M-brane : Black brane
- M-brane on time-dependent background
  ⇒ Black hole in expanding universe

(Maeda & Ohta & Uzawa, JHEP 0906 (2009) 051)
(Maeda & Nozawa, Phys.Rev. D81 (2010) 044017)

❑ Our results:

❀ The cosmic censorship is violated in dynamical M-brane background.

☞ This is similar to the result which has been obtained in Einstein-Maxwell-dilaton theory (with cosmological constant).

(Horne & Horowitz, Phys.Rev. D48 (1993) 5457-5462)

[3] Cosmic censorship in dynamical M5-brane

☆ Logic :

- We can set a regular and smooth initial data for the M5-brane.
- These initial data in the far past evolve into the curvature singularity.
- The cosmic censorship is violated.

✿ M5-brane

(Duff & Stelle, Phys.Lett. B253 (1991) 113-118)
(Güven, Phys.Lett. B276 (1992) 49-55)

✏ matter (bosonic) :

gravity, 4-form field strength

	0	1	2	3	4	5	6	7	8	9	10
M5	○	○	○	○	○	○					
x^N	t	x^1	x^2	x^3	x^4	x^5	r	y^1	y^2	y^3	y^4

◆ Dynamical M5-brane background

(Binetruy & Sasaki & Uzawa, Phys.Rev. D80 (2009) 026001)
(Maeda & Ohta & Uzawa, JHEP 0906 (2009) 051)

(1+5)-dim worldvolume spacetime

$$ds^2 = \left(a\,t + b + \frac{M}{r^3}\right)^{-1/3} \eta_{\mu\nu} dx^\mu dx^\nu + \left(a\,t + b + \frac{M}{r^3}\right)^{2/3} \left(dr^2 + r^2 d\Omega_{(4)}\right)$$

5-dim transverse space to brane

$$\left(a\,t + b + \frac{M}{r^3}\right) = 0 \ : \quad \text{curvature singularity}$$

❃ The behavior of background

(i) Asymptotic region ($r \to \infty$): Kasner

$\Rightarrow$ Time dependent vacuum spacetime

(ii) Near horizon limit :

$t \to t/\varepsilon, \quad r \to \varepsilon r, \quad \varepsilon \to 0$

$\Rightarrow AdS_7 \times S^4$

- Geodesic equation :

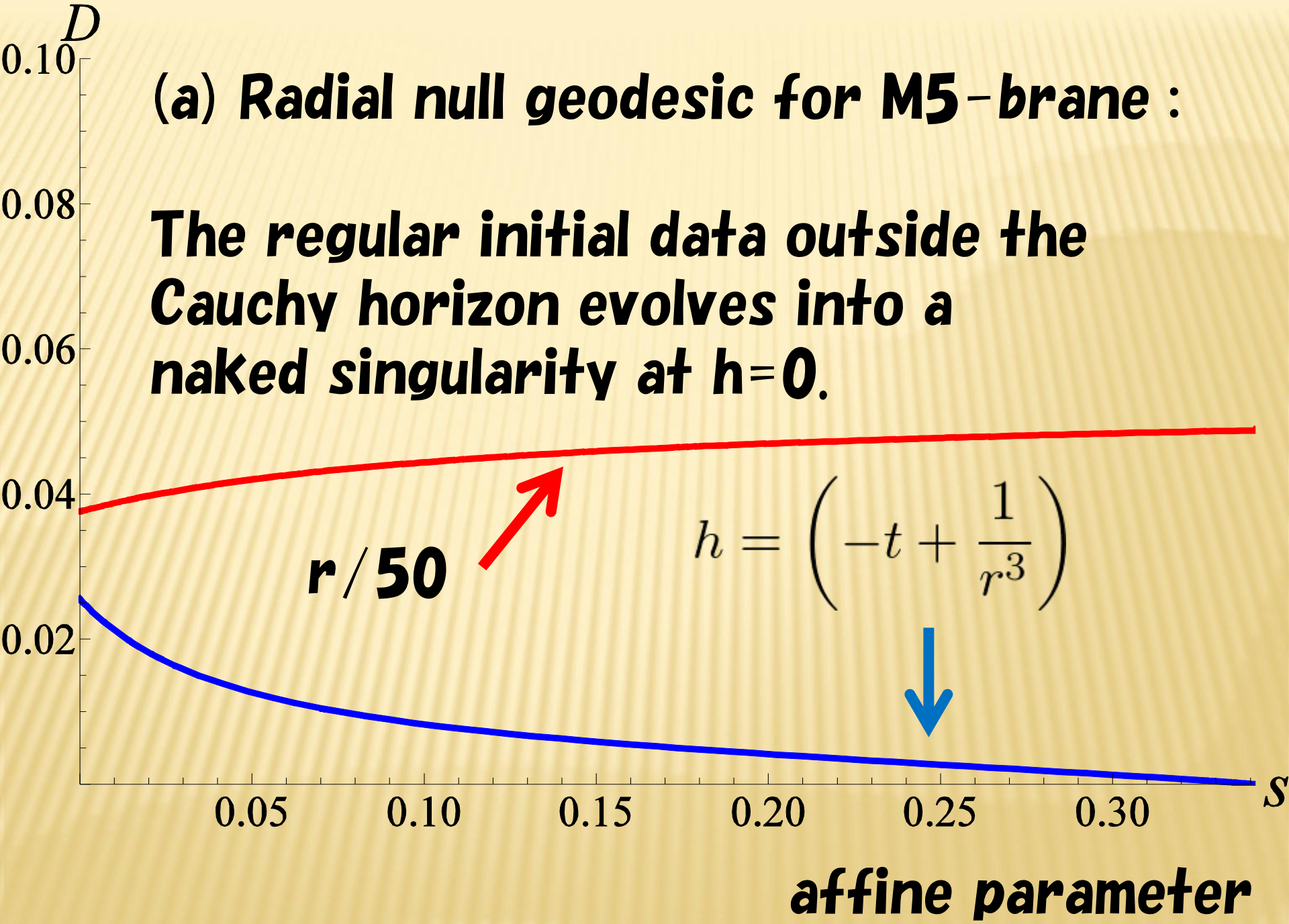
$$\frac{d^2 r}{ds^2} + \Gamma^r_{MN} \frac{dx^M}{ds} \frac{dx^N}{ds} = 0$$

- We can set a regular and smooth initial data for the M5-brane.

- The asymptotic behavior of the null curves depends crucially on whether r is inside or outside the Cauchy horizon.

(a) Radial null geodesic for M5-brane :

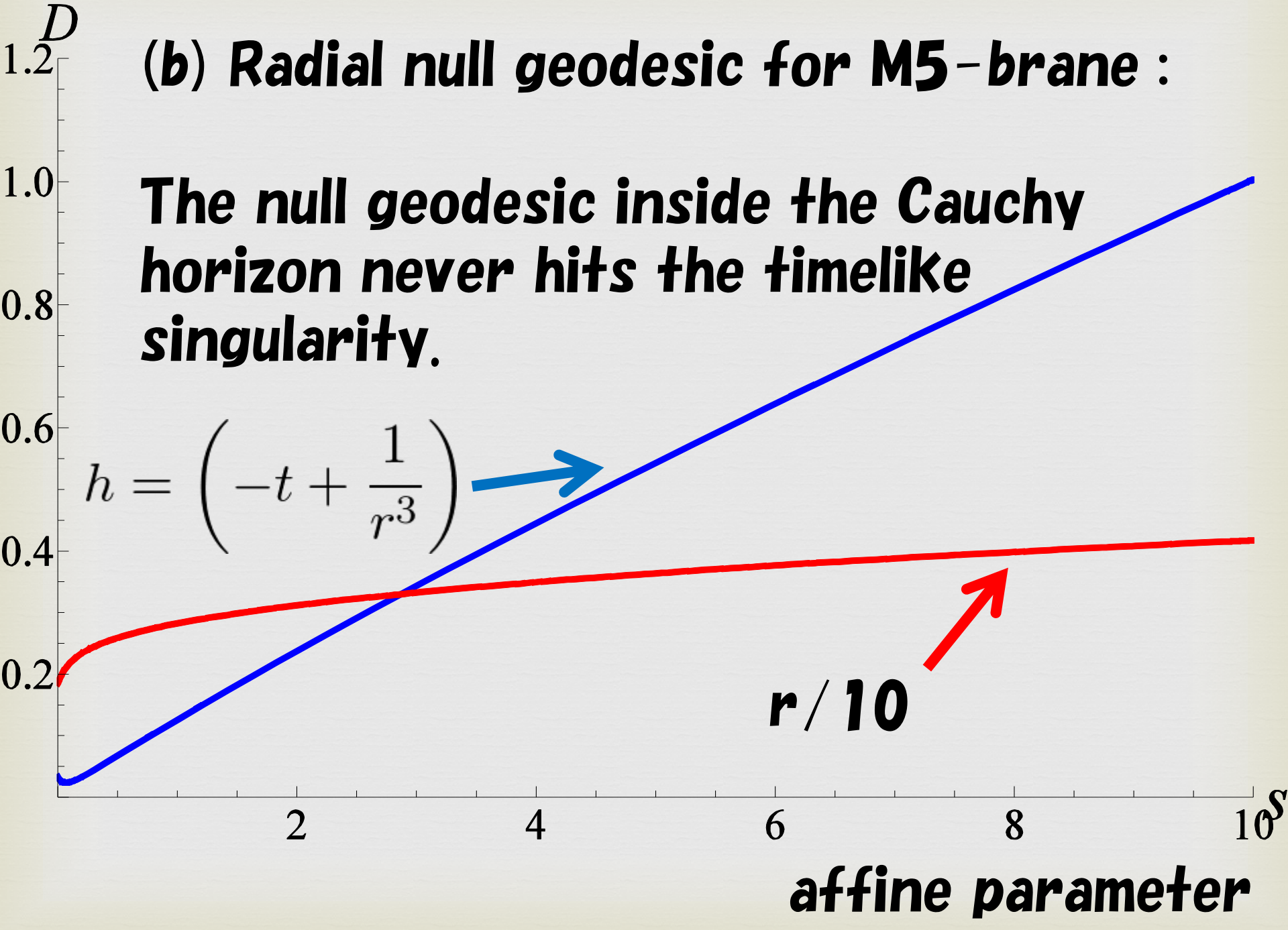
The regular initial data outside the Cauchy horizon evolves into a naked singularity at h=0.

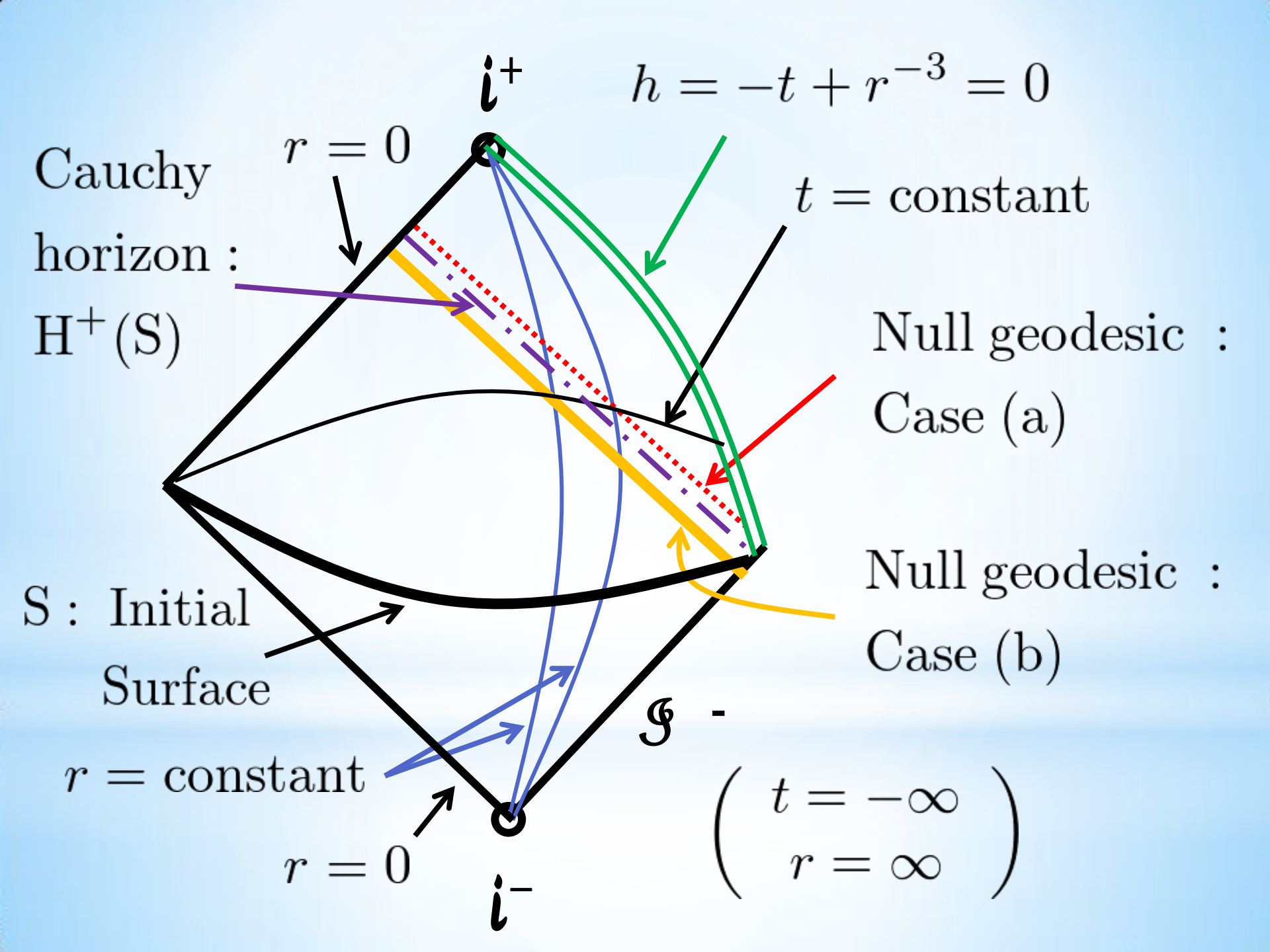


(b) Radial null geodesic for M5-brane :

The null geodesic inside the Cauchy horizon never hits the timelike singularity.

$$h = \left(-t + \frac{1}{r^3}\right)$$




i^+
$h = -t + r^{-3} = 0$
$r = 0$
Cauchy horizon : $H^+(S)$
$t =$ constant
Null geodesic : Case (a)
Null geodesic : Case (b)
S : Initial Surface
$\mathcal{I}^-$
$r =$ constant
$r = 0$
i^-
$\begin{pmatrix} t = -\infty \\ r = \infty \end{pmatrix}$

[4] Summary and comments

(1) There is a singularity due to the time dependence in Einstein-Maxwell-dilaton theory.

(2) For dynamical M5-brane, we can set smooth initial data evolving into a timelike curvature singularity.

(3) For dynamical p-brane, the cosmic censorship is not violated by the non-trivial dilaton.