SUPERSYMMETRY BREAKING AND SINGULARITY IN DYNAMICAL M-BRANE BACKGROUND

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Phys. Rev. D96 (2017) 084053
[arXiv:1705.01496 [hep-th]]
with Kengo Maeda

[1] Introduction

♦ Dynamical branes in string theory

- brane collision

(Gibbons & Lu & Pope, Phys.Rev.Lett. 94 (2005) 131602)
(Maeda & Minamitsuji & Ohta & Uzawa, Phys. Rev. D82 (2010)046007)
(Uzawa, Phys.Rev. D90 (2014) 025024)

- cosmic Big-Bang of our universe

(Chen, et al., Nucl.Phys. B732 (2006) 118-135)
(Minamitsuji & Ohta & Uzawa, Phys. Rev. D82 (2010)086002))

- black hole in expanding universe

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

- The cosmological scenario from the time dependent solution until the present have been much explored.

- However, the study of SUSY breaking in terms of dynamical solution is much less extensive.

- One motivation for the present work is to improve this situation.

- ✍ The dynamical D3-brane solution preserves ¼ SUSY in the conifold background.

  (H. Kodama & K. Uzawa, JHEP 0507 061 (2005))

- ☆ Question

  Do supersymmetries preserve in the dynamical M-brane background?

[2] Preserved supersymmetry (11d SUGRA)

The 11-dimensional action is invariant under local SUSY transformations :

$e^A{}_M$: graviton Ψ_M : gravitino,
A_{MNP} : 3-form gauge potential

$$\delta e^A{}_M = \bar{\varepsilon}\,\Gamma^A\,\Psi_M\,,$$

$$\delta A_{MNP} = -3\,\bar{\varepsilon}\,\Gamma_{[MN}\,\Psi_{P]}\,,$$

$$\begin{aligned}\delta\Psi_M &= D_M\,\varepsilon \\ &= \left[\nabla_M + \frac{1}{12\cdot 4!}\left(\Gamma_M\,F_{MNPQ}\Gamma^{MNPQ} - 12F_{MNPQ}\Gamma^{NPQ}\right)\right]\varepsilon\end{aligned}$$

Dynamical M2-brane solution :

(1+2)-dim worldvolume spacetime

$$ds^2 = \boxed{\left(c_\mu x^\mu + c + \frac{M}{r^6}\right)^{-2/3} \eta_{\mu\nu}(\mathrm{X}) dx^\mu dx^\nu}$$

$$+ \boxed{\left(c_\mu x^\mu + c + \frac{M}{r^6}\right)^{1/3} \left(dr^2 + r^2 d\Omega^2_{(7)}\right)}$$

8-dim transverse space to brane

$$F_{r\mu\nu\rho} = -\frac{6M}{r^7}\left(c_\mu x^\mu + c + \frac{M}{r^6}\right)^{-2} \varepsilon_{\mu\nu\rho}\,, \qquad \Psi_M = 0$$

- Solution for dynamical background

$$h^{-1/3}\, c_\mu \, \Gamma^\mu \varepsilon = 0\,, \qquad (1 \pm h\Gamma_0\Gamma_1\Gamma_2)\,\varepsilon = 0\,,$$

$$h = c_\mu x^\mu + c + \frac{M}{r^6}\,.$$

- Integrability condition $[\nabla_M, \nabla_N]\,\varepsilon = 0$ gives

$$c_\mu \, c^\mu = 0$$

Dynamical spacetime

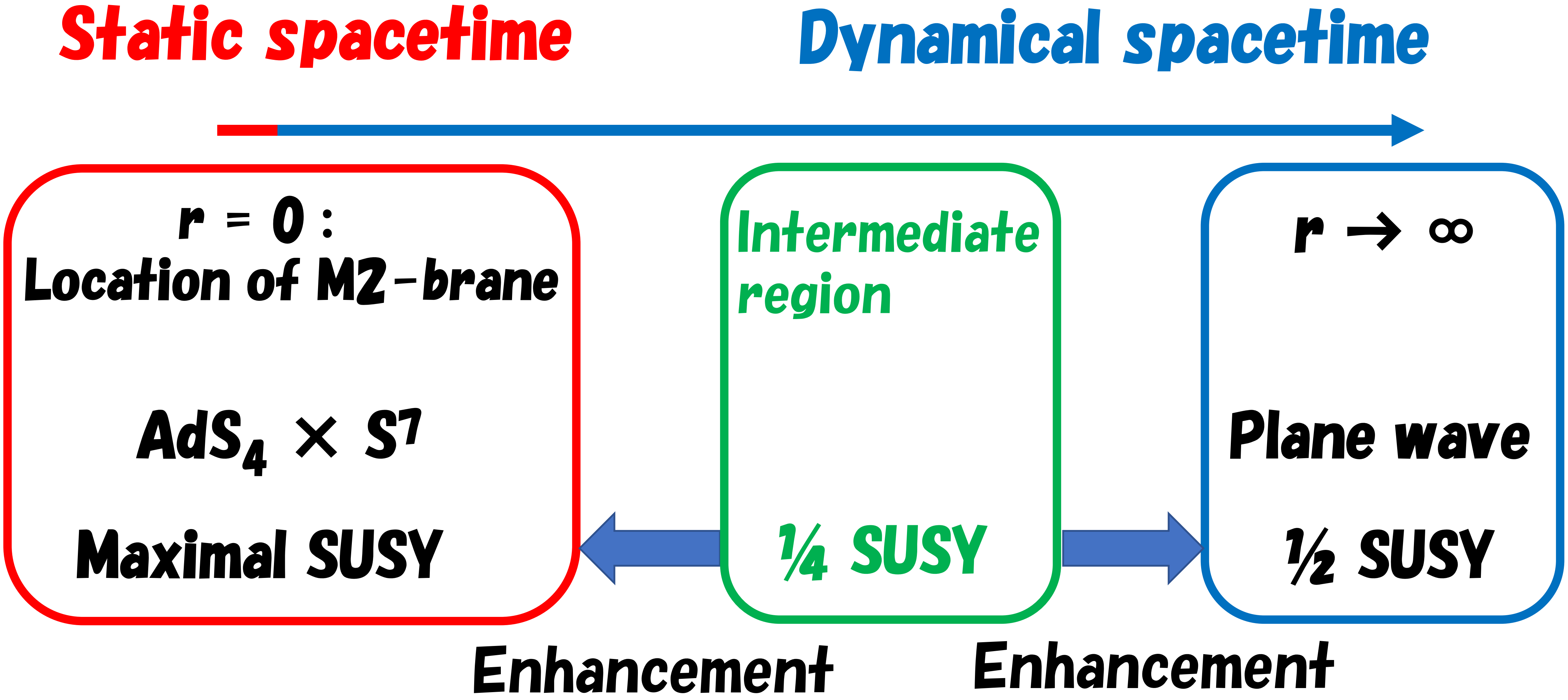
(1) $M \neq 0$, $c_\mu c^\mu = 0$, $c_0 \neq 0$, $c_1 \neq 0$, $c_2^2 = c_0^2 - c_1^2$: ¼ SUSY

(2) $M = 0$ (or $r \to \infty$), $c_\mu c^\mu = 0$, $c_0 \neq 0$, $c_1 \neq 0$, $c_2^2 = c_0^2 - c_1^2$: ½ SUSY, plane wave

(3) $M \neq 0$, $c_0 \neq 0$, $c_1 = 0$, $c_2 = 0$: Non SUSY

(4) $c_\mu = 0$, $c = 0$: Static, Maximal SUSY

Dynamical M2-brane background ($c_\mu c^\mu = 0$)



Static spacetime

Dynamical spacetime

$r = 0$:
Location of M2-brane

$AdS_4 \times S^7$

Maximal SUSY

Intermediate region

¼ SUSY

$r \to \infty$

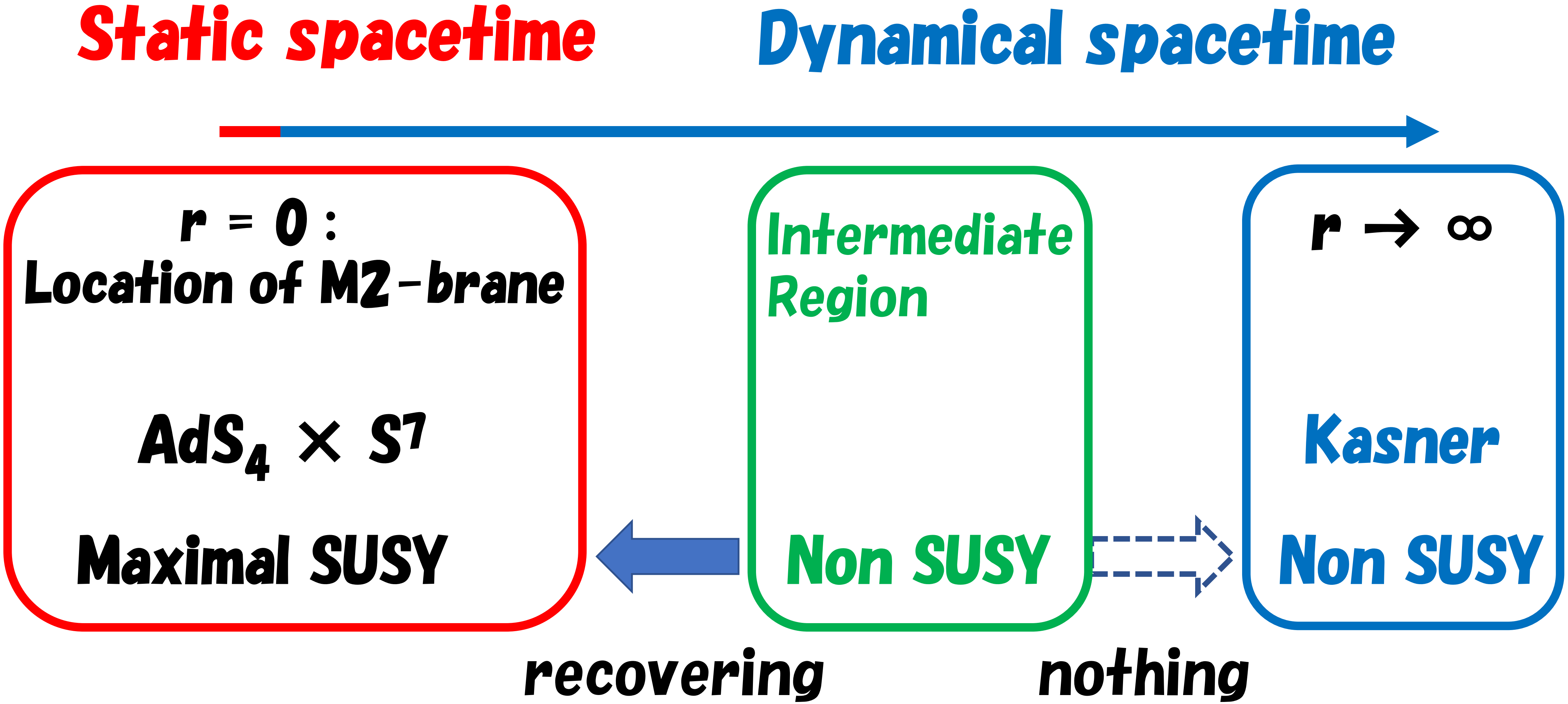
Plane wave

½ SUSY

Enhancement

Enhancement

Dynamical M2-brane background ($c_1=c_2=0$)



Static spacetime

Dynamical spacetime

$r = 0$:

Location of M2-brane

$AdS_4 \times S^7$

Maximal SUSY

Intermediate Region

Non SUSY

$r \to \infty$

Kasner

Non SUSY

recovering

nothing

[3] SUSY breaking and enhancement of SUSY

(1) SUSY solution: $h=h(\tau, x^i, r)$, $\tau/\tau_0=(ct)^{2/3}$

$$-\left(c\,t+c_i x^i+\frac{M}{r^6}\right)^{-\frac{2}{3}}dt^2+\cdots$$

$$=-\left[1+\left(\frac{\tau}{\tau_0}\right)^{-\frac{3}{2}}\left(c_i x^i+\frac{M}{r^6}\right)\right]^{-\frac{2}{3}}d\tau^2+\cdots$$

(2) As time increases (for $c_i x^i \ll M/r^6$),

$$1+\left(\frac{\tau}{\tau_0}\right)^{-\frac{3}{2}}\left(c_i x^i+\frac{M}{r^6}\right) \to 1+\left(\frac{\tau}{\tau_0}\right)^{-\frac{3}{2}}\frac{M}{r^6}$$

(3) $h(\tau, x^i, r)$ (SUSY) → $h(\tau, r)$ (Non SUSY)

Time evolution (But toy model !!)

Early universe

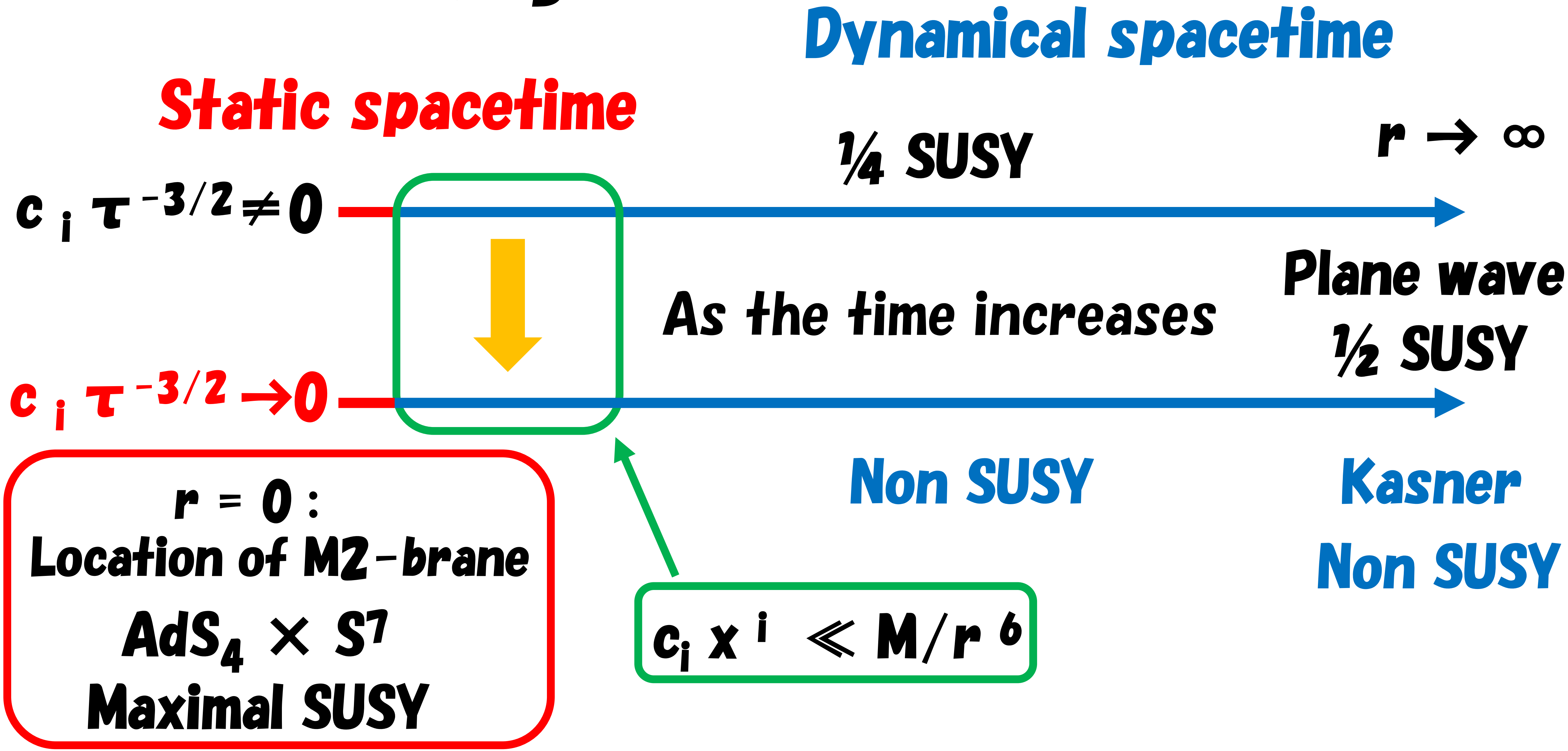
- inhomogeneous M-brane
- Preserved SUSY

As the time increases

Late time

- homogeneous M-brane
- Non SUSY

SUSY breaking



Dynamical spacetime

Static spacetime

¼ SUSY

$r \rightarrow \infty$

$c_i \, \tau^{-3/2} \neq 0$

As the time increases

Plane wave

½ SUSY

$c_i \, \tau^{-3/2} \rightarrow 0$

Non SUSY

Kasner

Non SUSY

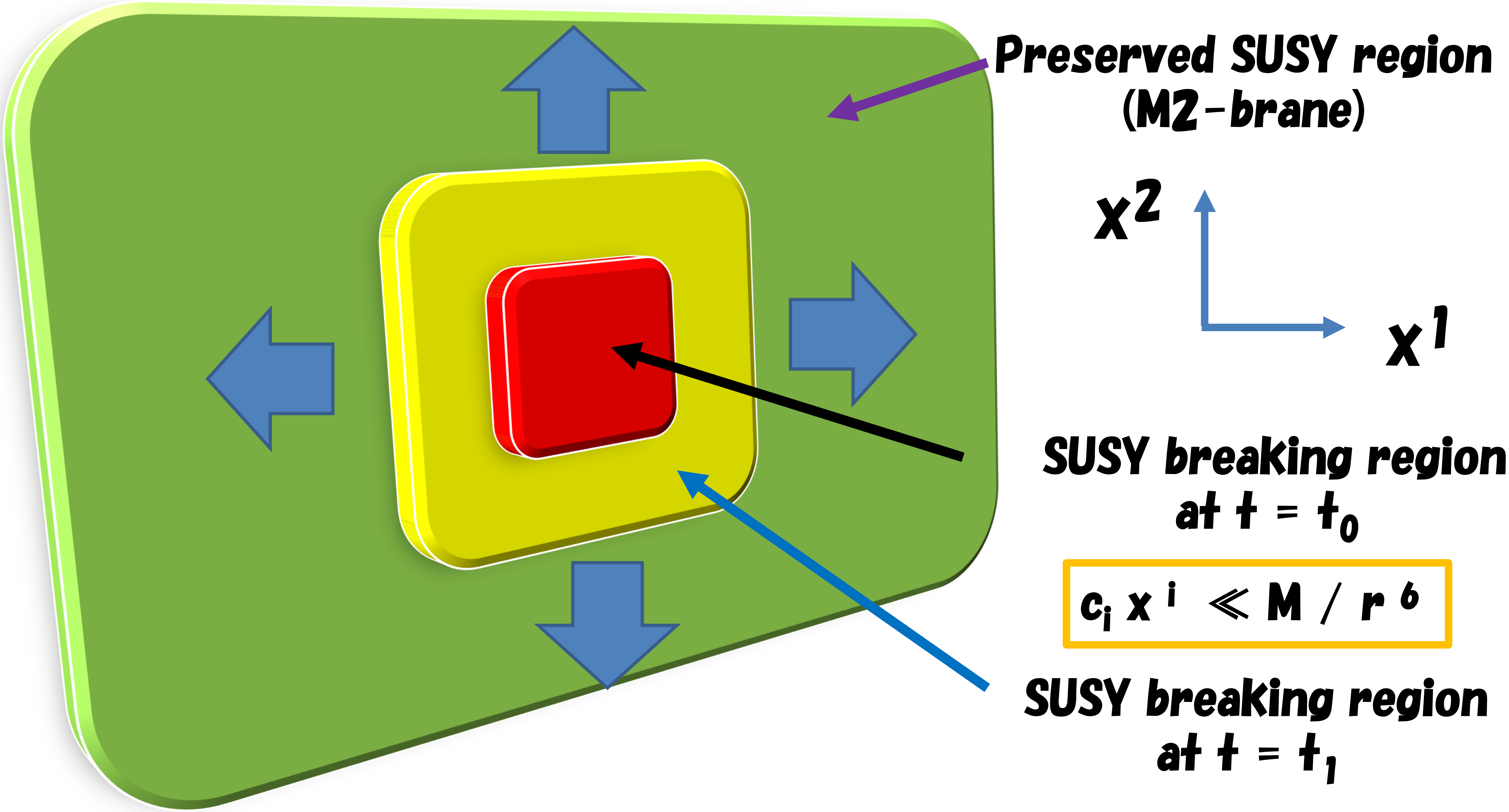
$r = 0$:

Location of M2-brane

$AdS_4 \times S^7$

Maximal SUSY

$c_i \, x^i \ll M/r^6$



Preserved SUSY region
(M2-brane)

SUSY breaking region
at $t = t_0$

$$\boxed{c_i x^i \ll M / r^6}$$

SUSY breaking region
at $t = t_1$

[4] Summary and comments

(1) The dynamical M2-brane background preserves the ¼ supersymmetry. For vanishing M2-brane charge, we also find ½ SUSY solution.

(2) The solutions of field equations cannot give a homogeneous expansion at constant r unless supersymmetries are completely broken.

(3) Although the solution itself is by no means realistic, its interesting behavior suggests a possibility that the Universe preserved originally SUSY and begin to evolve toward a Universe without SUSY.