De Sitter solutions in the higher-dimensional gravity

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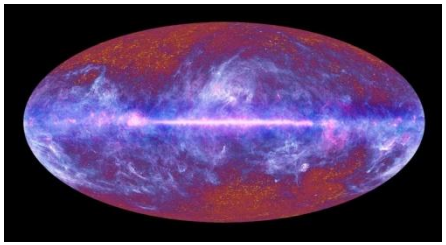
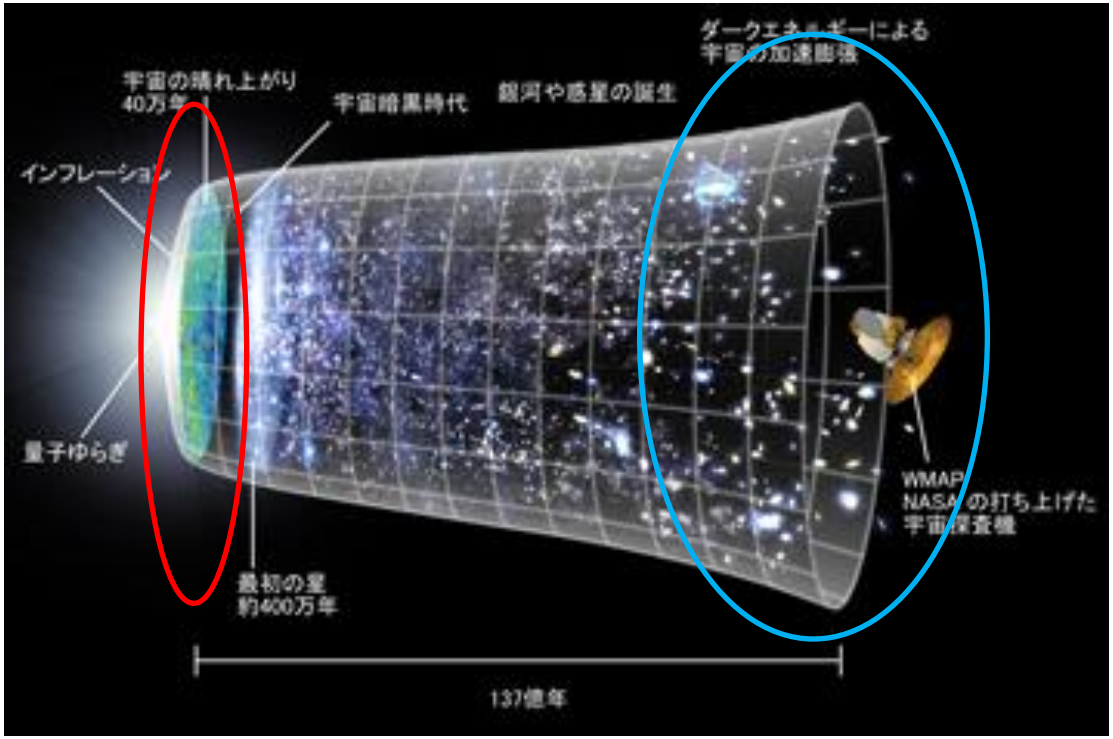
Accelerating solutions play the important roles in recent cosmology.

Inflation

✓explaining the flatness, homogeneity and isotropy of the universe

✓generating seed of cosmic structures.



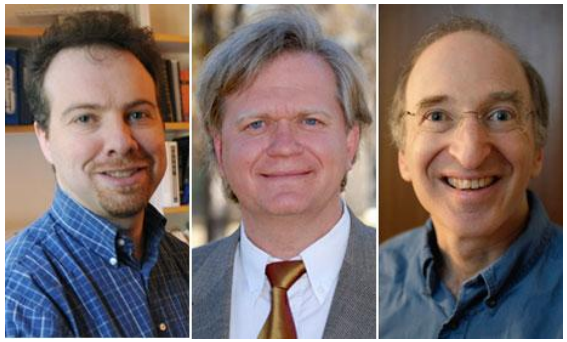


Dark Energy

✓Occupying 70 % of the present cosmic energy, assuming GR is hold on all distance scales.

✓Modified gravity?

2011 Nobel Prize in Physics



A. Riess B. Schmidt S. Perlmutter

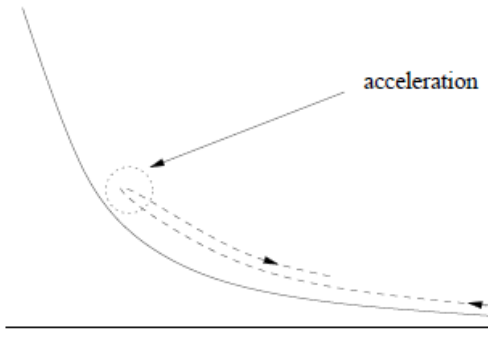
➢ Superstring/ M-theory suggests that our universe is higher-dimensional.

➢ In context of the higher-dimensional gravity, much attention has been paid to *compactifications to de Sitter or accelerating universe*, since it could provide a fairly direct explanation of these issues.

➢ An initial clue was the time-dependence of a hyperbolic internal space.

Townsend & Wohlfarth (03), Ohta (03)

$$V_{eff} \approx -R_H > 0$$



Emparan & Garriga (03)

➢ Since many familiar solutions in the higher-dimensional gravity such as brane solutions have warped structures, it is very interesting to investigate the warped solutions which could lead to 4D de Sitter universe.

$$ds_D^2 = A(y)^2\left(-dt^2 + e^{2Ht}\delta_{ij}dx^i dx^j\right) + w_{ab}(Y)dy^a dy^b$$

Warp factor

4-dimensional de Sitter spacetime

(D-4)-dimensional internal space

➢ Among the warped solutions, time-dependent generalizations of static p-branes could not provide accelerating solutions.

Gibbons, Lu & Pope (05), 1007.1762,1011.2376, 1109. 1415

We now turn to more explicit constructions of warped de Sitter solutions.

De Sitter solutions

1103.5326, 1110.2843

$$L = \frac{1}{2\kappa^2}\sqrt{-g}\left(R - \frac{1}{2}(\partial\phi)^2 - \sum_I \frac{1}{2\cdot p_I!} e^{c_I\phi} F^2_{(p_I)} \right)$$

gravity scalar form field strength

c_I : coupling constant to each form field strength.

Warped noncompactifications to de Sitter spacetime

1103.5326 See also Neupane (10), Chemissany, Janssen & Van Riet (11)

✓ warped de Sitter solutions with a noncompact internal direction.

$$ds_D^2 = A(y)^2\left[q_{\mu\nu}(X)dx^\mu dx^\nu + dy^2 + u_{ab}(Z)dz^a dz^b\right]$$

4-dim de Sitter space — infinite — (D-5) dim compact space

Exponential warp

$$F_{D-5} = f\,\Omega(Z)$$

✓ (D-5)-form field strength has nonvanishing components along Z

✓de Sitter solutions can be obtained for $c_{D-5}^2 > \dfrac{2(D-6)^2}{D-2}$

✓ Warped product of $dS_4 \times R \times S^{D-5}$

✓ Cosmological model

$$A \sim \exp(-|y|)$$

Our universe is located at the boundary with matter $y = 0$

Warped compactifications to de Sitter spacetime

1110.2843

✓ Warped de Sitter solutions with compact internal space and 0-form.

$$D = 4 + 1 + \sum_I L_I$$

$$ds_D^2 = A(\theta)^2 \left[q_{\mu\nu}(X) dx^\mu dx^\nu + d\theta^2 + \sum_I u_{a_I b_I}(Z_I) dz^{a_I} dz^{b_I} \right]$$

S^1

4-dim de Sitter

A product of compact spaces

Periodic warp

✓ form fields : $F_{(4)} = f_4 \Omega(X)$ $F_{(L_I)} = \ell_I \, \omega_I$ $F_{(0)} = m$

✓ coupling constant: $c_4 = -3c_0$ $c_I = (-L_I + 1)c_0$ $\boxed{c_0 = \left(\frac{2}{(D-1)(D-2)} \right)^{\frac{1}{2}}}$

✓ De Sitter solutions are realized if there is the 0-form field strength.

$$m^2 > (D-4) f_4^2 + \sum_I (L_I - 1) \ell_I^2$$

See Maldacena & Nunez (00) for general arguments

✓ $R(Z_I) > 0 \longrightarrow$ Warped product of $dS_4 \times S^1 \times \prod_I S^{L_I}$

Thank you

NO-GO theorem

Gibbons (84) Maldacena & Nunez (00)

Under assumptions

1) There is no higher curvature /derivative correction in gravity action.

$R + \alpha R^2$ higher-dimensional general relativity

2) All massless fields have kinetic terms with correct sign.

$-(\partial\phi)^2$ $-F_{A_1\cdots A_p}F^{A_1\cdots A_p}$

3) The scalar potential /cosmological constant is non-positive

$V \leq 0$

4) The internal space is compact with a finite volume and no boundary.

⇒De Sitter solutions are forbidden.