Title: Cosmology 7

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Abstract:

THE FADING OF GRAVITY AND SELF-INFLATION

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WORK TO APPEAR SOON ...

PROPAGANDA :

- KEY LESSON FROM STRING THEORY :

  EARLY-UNIVERSE COSMOLOGY LIKELY TO BE VERY DIFFERENT THAN STANDARD BIG BANG STORY.

  - EXTRA DIMENSIONS OPEN UP
  - BRANES FLOAT AROUND (& CAN COLLIDE)

- COMMON FEATURE : STRONGER GRAVITY AT SHORT DISTANCES

1) $\mathbb{R}^{3,1} \times S^1$

THEN $F_{grav} \sim \dfrac{G_N m_1 m_2}{r^2} \longrightarrow \dfrac{G_N R m_1 m_2}{r^3}$

$(r \gg R)$ $(r \ll R)$

2) EXTRA DIM'NS + BRANES $\Longrightarrow$ EXTRA φ's OR MODULI IN 4d EFFECTIVE THEORY

THESE MODULI MEDIATE ATTRACTIVE 5^{th} FORCES $\Longrightarrow$ STRONGER EFFECTIVE GRAVITY

BUT WHAT IF GRAVITY BECOMES WEAKER
OR SHUTS OFF AT SHORT DISTANCES ?

→ NON-PERTURBATIVE EFFECTS IN STRING THEORY } TSEYTLIN, '95

→ MODELS INSPIRED FROM OPEN STRING FIELD THEORY } SIEGEL, '03; BISWAS, MAZUMDAR, SIEGEL '05

→ FAT GRAVITY } SUNDRUM, '97

⋮

OUR INTEREST : COSMOLOGICAL IMPLICATIONS

- CAN ONE GET INF'N IF GRAVITY IS WEAKER ?

- DO YOU NEED INF'N ?

- ALTERNATIVE MODELS OF EARLY-UNIVERSE COSMOLOGY ?

BASIC IDEA: MODIFY GRAVITON PROPAGATOR

$$\frac{1}{\Box} \longrightarrow \frac{G(\Box L^2)}{\Box} \qquad (\Box = \nabla^\mu \nabla_\mu)$$

SUCH THAT $G \longrightarrow 1$ FOR $\Box L^2 \ll 1$

$\longrightarrow 0$ FOR $\Box L^2 \gg 1$

GHOST STORIES: NO NEW POLES IN PROPAGATOR

$\therefore$ G ANALYTIC, e.g. $\boxed{G(\Box L^2) = e^{-\Box^2 L^4}}$

SURPRISE: GET INFLATIONARY SOL'N WITHOUT SCALAR FIELD NOR OTHER MATTER.

- KNOW A LOT ABOUT SCALAR-DRIVEN INF'N (GENERIC PREDICTIONS)
- BUT THIS IS A TOTALLY NEW WAY OF GETTING INF'N (NO KNOWN WAY TO REWRITE AS SCALAR-TENSOR THEORY)
- NEW PREDICTIONS!

FROM MODIFIED PROPAGATOR TO MODIFIED THEORY

$$S = \int d^4x \sqrt{-g} \left\{ R + G^{\mu\nu} \underbrace{\left(\frac{\mathcal{G}^{-1}(\square L^2) - 1}{\square} \right)}_{\alpha L^4 + \frac{\square^2 L^6}{2} + \dots} R_{\mu\nu} \right\} + S_{matter}[g]$$

IGNORE IN THIS TALK

(NOTE: JUST A TOY-MODEL. AS EFFECTIVE THEORY, CAN'T IGNORE $\mathcal{O}(R^3)$ TERMS ETC.)

WEAK-FIELD: $\quad g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$

$$\therefore R_{\mu\nu} = -\frac{\square}{2} h_{\mu\nu} + \mathcal{O}(h^2)$$

$$\Longrightarrow S_{quad} = \int \frac{1}{4} h^{\mu\nu} \underbrace{\mathcal{G}^{-1}(\square L^2)\, \square}_{\frac{\mathcal{G}}{\square}\ \text{SPIN-2 PROPAGATOR}} \left(h_{\mu\nu} - \frac{1}{2} \eta_{\mu\nu} h \right)$$

✓

EOM: $\quad \underbrace{\mathcal{G}^{-1}(\square L^2)}_{\mathcal{G} = G_N^{*}(\square L^2)} G_{\mu\nu} + \mathcal{O}(R^2) = 0$

SOLVE THIS HORRIFIC EQN, ASSUMING HOMOG., ISOTROPY, & SPATIAL FLATNESS.

SELF-INFLATION : A BRIEF SKETCH

2 OBSERVATIONS :

1. $R^{dS}_{\mu\nu} = \lambda g_{\mu\nu} \Longrightarrow \Box R^{dS}_{\mu\nu} = 0$

$$\longrightarrow \mathcal{G}^{-1}(\Box L^2) R^{dS}_{\mu\nu} = e^{\Box^2 L^4} R^{dS}_{\mu\nu}$$
$$= R^{dS}_{\mu\nu}$$

∴ PURE dS DOESN'T CARE ABOUT $\mathcal{G}(\Box L^2)$, NO MATTER HOW SMALL DE SITTER RADIUS IS.

2. ANSATZ $R_{\mu\nu} = R^{dS}_{\mu\nu} + r_{\mu\nu}$; $r_{\mu\nu} \ll R_{\mu\nu}$

$O(H^2)$ $O(\dot{H})$ (i.e. $\frac{\dot{H}}{H^2} \ll 1$)

THEN $\mathcal{G}^{-1}(\Box L^2)\, r_{\mu\nu} \approx \mathcal{G}^{-1}(H^2 L^2)\, r_{\mu\nu}$

$$= e^{\# H^4 L^4}\, r_{\mu\nu} \gg r_{\mu\nu}$$

if $H \gtrsim L^{-1}$.

∴ DEVIATION FROM dS CARE A LOT ABOUT $\mathcal{G}(\Box L^2)$

SELF-INFLATING SOL'N:

1. $R_{\mu\nu} = 3H^2 g_{\mu\nu} + \underbrace{r_{\mu\nu}}_{O(\dot{H})}$ ANSATZ

2. PLUG INTO EOM & NEGLECT TERMS OF ORDER $\ddot{H}, \dot{H}^2, \dddot{H} \ldots$

(CONTROLLED EXPANSION IN DEVIATION FROM PURE dS)

3. FIND

$$H^2 + \frac{3}{8} \zeta^{-1}(8H^2L^2)\, \dot{H} \approx 0$$

$$\Longrightarrow \boxed{\frac{\dot{H}}{H^2} \approx -\frac{8}{3}\zeta(8H^2L^2) \ll 1}$$

FOR $HL \gtrsim 1$

REHEATING :

- $\frac{\dot{H}}{H^2} < 0 \longrightarrow$ EVENTUALLY $\dot{H}/H^2 \sim O(1)$
  $\longrightarrow$ infl'n STOPS

- REHEAT THROUGH GRAVITATIONAL PARTICLE PRODUCTION

  Ford '87
  Grishchuk & Sidorov '90
  Spokoiny '93

$$T_{\rm reheat} \sim H \sim L^{-1}$$

- BBN CONSTRAINT :

$$L < 1 \text{ fm}$$

REHEATING :

SELF-INFLATING SOL'N : $\frac{\dot{H}}{H^2} < 0 \Longrightarrow$ EVENTUALLY $\dot{H}/H^2 \sim O(1)$ ANSATZ

1. $R_{\mu\nu} = 3H^2 g_{\mu\nu} \longrightarrow$ INFL'N STOPS $\Gamma \sim O(H)$
   - REHEAT THROUGH GRAVITATIONAL PARTICLE PRODUCTION

2. PLUG INTO EOM, NEGLECT TERMS OF ORDER $\ddot{H}, \dot{H}^2, \dddot{H}$

   $T_{\mu\nu} \sim H \sim L^{-1}$

   (CONTROLLED EXPANSION IN DEVIATION FROM PURE dS)

   FORD '87
   GRISHCHUK & SIDOROV '90
   SPOKOINY '93

   - BBN CONSTRAINT :

3. FIND $L < 1\ \mathrm{fm}$

$$H^2 + \frac{3}{8}\, G^{-1}(8H^2L^2)\,\dot{H} \approx 0$$

$$\Longrightarrow \boxed{\frac{\dot{H}}{H^2} \approx -\frac{8}{3}G\,(8H^2L^2) \ll 1 \quad \text{FOR } HL \gtrsim 1}$$

REHEATING :

- $\frac{\dot{H}}{H^2} < 0 \Longrightarrow$ EVENTUALLY $\dot{H}/H^2 \sim O(1)$

  $\Longrightarrow$ INFLN STOPS

- REHEAT THROUGH GRAVITATIONAL PARTICLE PRODUCTION

  FORD '87
  GRISHCHUK & SIDOROV '90
  SPOKOINY '93

$$T_{rh} \sim H \sim L^{-1}$$

- BBN CONSTRAINT :

$$L < 1\ fm$$

DENSITY PERTURBATIONS :

- HERE NEWTONIAN POT. Φ PLAYS THE ROLE OF INFLATON IN SOME SENSE

$$\Longrightarrow \quad \frac{\delta\rho}{\rho} \sim \frac{H}{\varepsilon} \qquad \left(\varepsilon \equiv -\dot{H}/H^2\right)$$

(COMPARE WITH $\delta\rho/\rho \sim H/\varepsilon^{1/2}$ IN SCALAR-DRIVEN INFLATION)

- FIXING $\delta\rho/\rho \sim 10^{-5}$ FROM OBSERVATIONS

$$\Longrightarrow \boxed{L^{-1} = 10^{9}\,\mathrm{GeV} \quad \text{OR} \quad L = 10^{-22}\,\mathrm{cm}}$$

- SPECTRAL TILT: $n_s - 1 \simeq 8\varepsilon \ln\left(\frac{3}{8}\varepsilon\right)$

$$\simeq -0.05$$

(& NO SIGNIFICANT RUNNING)

GRAVITY WAVES:

- HERE $h_k \sim a^{2/3}$ FOR $k \to 0$
  (COMPARED TO $h_k \sim$ const. IN INF'N)

$$\therefore \quad \boxed{\Delta h_k \sim \frac{H}{M_{Pl}} \left(\frac{H}{k}\right)^{2/3}}$$

(COMPARED TO $\Delta h_k \sim H/M_{Pl}$ IN SCALAR INF'N)

- VERY RED SPECTRUM OF GW's
- FIXING $\left.\frac{\delta\rho}{\rho}\right|_s \sim 10^{-5}$, GET TOO LARGE GW POWER ON LARGE SCALES

→ DIFFERENT CHOICE OF $G(\Box L^2)$?

→ CAN WE GET SOME LARGE BUT OBSERVATIONALLY-ACCEPTABLE RED TILT?

→ CAN WE GET BLUE TILT?