Inflation and string theory

Stephan Steinfurt (MPP)

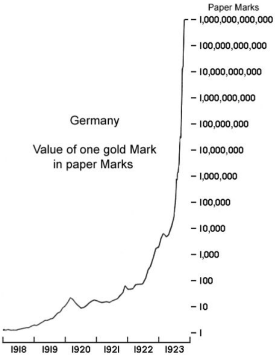
Wildbad Kreuth, 26.7.2011

Inflation (Economics)

Hyperinflation in the Weimar Republic 1921-1923:

30th June: 100 RM
23rd August: 1000 RM
9th October: 2 Million RM
12nd November: 10 Billion RM

Inflation (Economics)



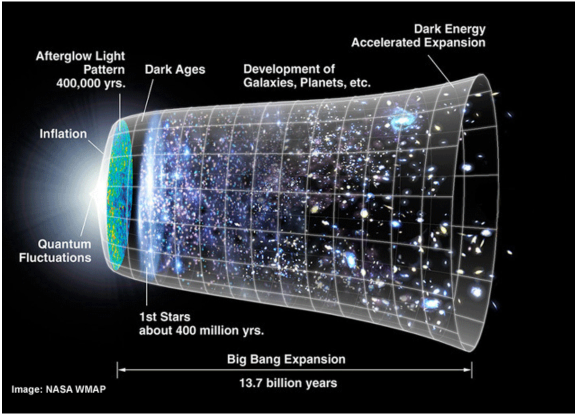
Increase by 10^{12} in 5 years...

Quotation

"All science is either physics or stamp collecting."

Ernest Rutherford

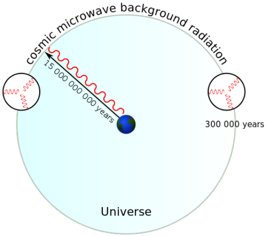
Timeline of the Universe



Increase by $e^{60} \approx 10^{26}$ in $\sim 10^{-32}$ seconds...

Horizon problem

CMBR: almost perfect isotropic black body rad. with T=2,725 K,
but in big bang cosmology (without inflation) very mysterious:



Different patches seem to have never been in causal contact, but show almost exactly the same T - implausible!
$\Rightarrow$ Solution: period of cosmological inflation after causal contact

Slow-roll inflation

Cosmology described by Friedmann-Robertson-Walker metric

$$ds^2 = -dt^2 + a(t)^2(dx^2 + dy^2 + dz^2).$$

We can get an accelerated expansion of $a(t)$

$$\boxed{\frac{d^2}{dt^2}a(t) > 0} \quad \leftrightarrow \quad \frac{d}{dt}(aH)^{-1} < 0 \quad \text{for} \quad \boxed{H = \frac{\dot{a}}{a}} \approx \text{const.}$$

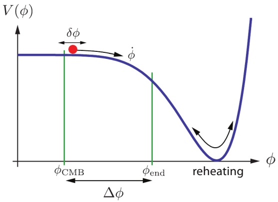
by introducing a scalar field ϕ

$$S = \int d^4x\sqrt{-g}\left(\frac{M_P^2}{2}R - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right)$$

with a "slow-roll potential" $V(\phi)$.

Slow-roll inflation

What is a “slow-roll potential” $V(\phi)$?



Potential energy dominates $\leftrightarrow$ quasi de Sitter $a(t) \sim e^{Ht}$.

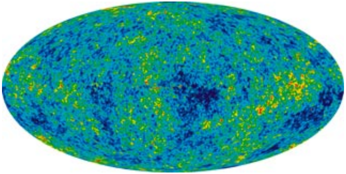
$$\dot{\phi}^2 \ll V(\phi) \;, \qquad \ddot{\phi} \ll 3H\dot{\phi} \;,\; V(\phi)'$$

for a sufficiently long time.

$$\text{Inflation} \;\Leftrightarrow\; \boxed{\epsilon = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1 \;, \quad \eta = M_P^2 \left(\frac{V''}{V}\right) \ll 1}$$

Summary inflation

- The slow-rolling scalar field induces a period of cosmological inflation, which ends when $\epsilon \sim 1$.
- This solves the puzzles of big bang theory (Horizon, Flatness, Monopole,. . .).
- Cosmological perturbation theory even correctly predicts the $\sim 10^{-5}$ density perturbations observed in the CMB!!



- Quantum mechanical inflationary fluctuations are seeds for large scale structure of the universe!!

Quotation

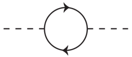
"According to inflation, the more than 100 billion galaxies, sparkling throughout space like heavenly diamonds, are nothing but quantum mechanics writ large across the sky. To me, this realization is one of the greatest wonders of the modern scientific age."

Brian R. Greene

Inflation in string theory

Why study inflation within the context of string theory?

- Embed it into consistent theory of quantum gravity and find out which particle the inflaton is!



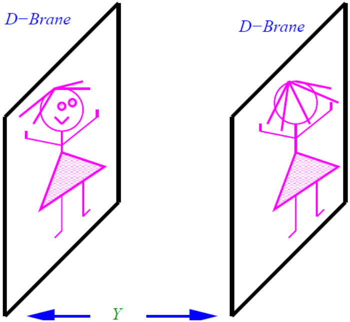
- $|\eta| \ll 1$ is sensitive to Planck scale physics due to effective operators, which come from loop diagrams

$$\frac{\mathcal{O}_6}{M_P^2} \sim V_0 \frac{\phi^2}{M_P^2}$$

$$V \sim V_0 \left(1 + \frac{\phi^2}{M_P^2}\right) \quad \Rightarrow \quad \eta = M_P^2 \left(\frac{V''}{V}\right) \sim \mathcal{O}(1)$$

- Task: Need to understand these operators from string theory!

Brane Inflation



- nice visualisation
- natural end of inflation when branes collide

Problem in brane inflation

- Inflationary potential

$$\mathcal{L} \quad \sim \quad (\partial r)^2 - \left(A - B \, \frac{1}{r^{d_\perp - 2}} \right)$$

- energy density of branes + Coulomb / Newtonian potential
- Slow roll conditions are $\epsilon \ll 1$ (easily) and

$$\eta = M_P^2 \left(\frac{V''}{V} \right) \propto \frac{B}{A} \left(\frac{L}{r} \right)^{d_\perp} \ll 1 \, ,$$

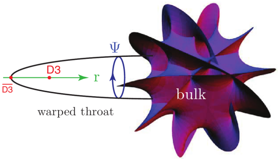
but that requires $r \gg L$, impossible due to compactification!

D3 brane in warped geometry

- D3 in AdS_5 background $\quad ds^2 = \frac{r^2}{R^2}\left(-dt^2 + d\vec{x}^2\right) + \frac{R^2}{r^2}dr^2$
- with an additional $\overline{D3}$ at r_0, the potential is

$$V = V_0\left(1 - \frac{1}{N}\frac{r_0^4}{r^4}\right) \quad \Rightarrow \quad \frac{B}{A} \sim \frac{1}{N} \ll 1 \,, \quad \eta \ll 1 \text{ possible}$$

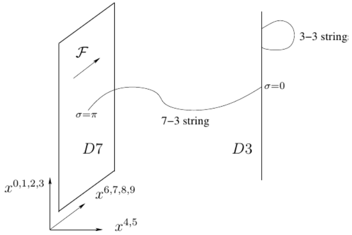
- actually use Klebanov-Strassler throat



- Moduli stabilization well understood, can calculate!
  $\rightarrow$ however: fine-tuning

D3-D7 on $K3 \times T_2/Z_2$

- Look at interaction of a D3 and a D7 brane with flux $\mathcal{F}$



- D7 brane has effective $\overline{D3}$ charge $q = \int \mathcal{F} \wedge \mathcal{F}$
- Inflaton features (shift) symmetry :-),
  broken by quantum corrections :-(

D7-D7 $\mathbb{F}$luxbrane inflation

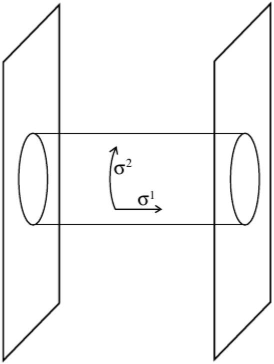
- Both D7 branes carry fluxes $\mathcal{F}_i$
- we get interaction terms resulting from D3 charges $\int \mathcal{F} \wedge \mathcal{F}$, D5 charges $\int \mathcal{F}$ and D7 charges
- Inflationary potential:

$$V = A + B\, g_s \log\left(\frac{r}{R}\right) \text{ with } A \propto |\mathcal{F}|^2\ ,\ B \propto |\mathcal{F}|^4$$
$$\Rightarrow \quad \eta \propto |\mathcal{F}|^2 \left(\frac{L}{r}\right)^2 \ll 1$$

- conceptually similar to D3/D7, moduli stabilization in IIB !?
- long term goal: implementation into F-theory

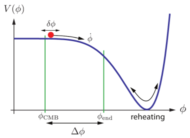
String calculation

- Evaluate open string 1-loop annulus diagram (flux boundary) $\leftrightarrow$ Coleman-Weinberg potential

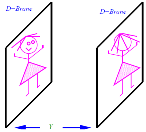


Summary - things to remember

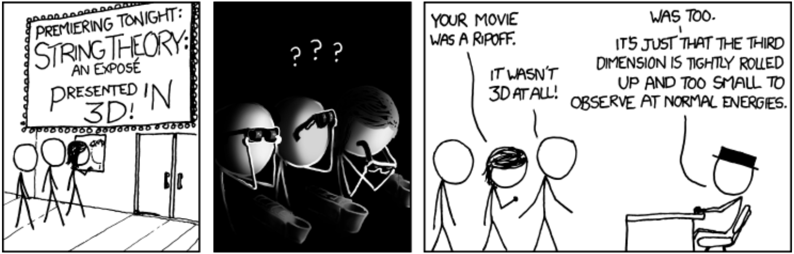
- Inflation describes vast accelerated expansion after the big bang, solves several puzzles of the standard big bang theory and predicts anisotropies observed in the CMB.
- The easiest models need a "slow roll potential" $(\epsilon, \eta \ll 1)$ for a single inflaton.



- In string theory this inflaton could be the distance between branes.



Questions



(XKCD 848)

Thank you for your attention!

Any questions?