STRING THEORY & INFLATION

TCC NETWORK MEETING, AUSTIN, OCT. 09

MELANIE BECKER (TEXAS A&M)

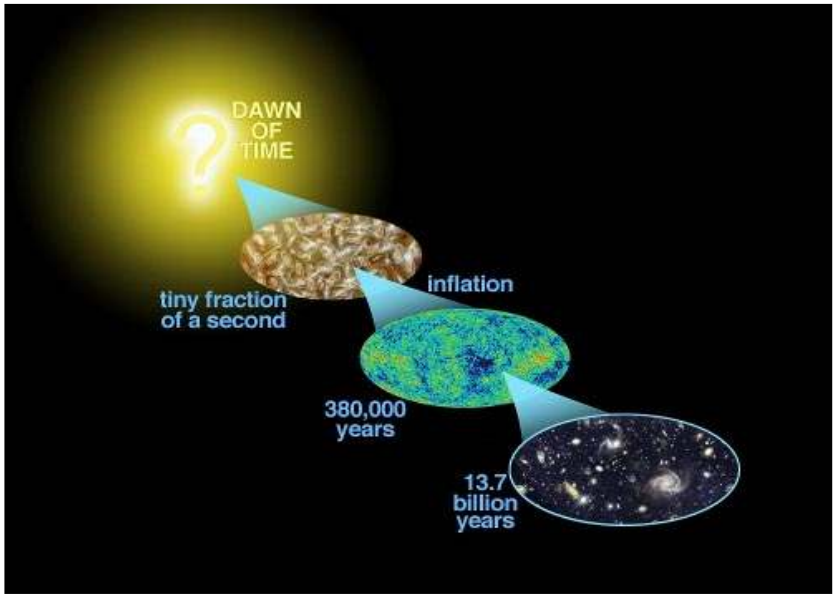
OVERVIEW

1. WHY STRING THEORY ?
2. INFLATION IN QFT
3. DENSITY PERTURBATIONS & GRAVITATIONAL WAVES
4. CHALLENGES FOR INFLATION IN STRING THEORY
5. MODELS FOR STRINGY INFLATION

① WHY STRING THEORY ?

* EXPANSION OF UNIVERSE BACKWARD IN TIME

* EVIDENCE FOR STRING THEORY FROM THE SKY



② INFLATION IN QFT

GOAL: DESCRIBE SOME ELEMENTS ABOUT INFLATION NEEDED LATER

CONSIDER THE GENERAL ACTION:

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2} M_p^2 R + \mathcal{L}(X^{IJ}, \phi^J) \right]$$

ϕ^J: scalars & inflaton

$$X^{IJ} = -\frac{1}{2} \partial\phi^I \partial\phi^J$$

$$\mathcal{L}_{\text{slow-roll}} = -(\partial\phi)^2 - V(\phi)$$

$$\mathcal{L}_{\text{DBI}} = -f^{-1}(\phi)\sqrt{1 - f(\phi)(\partial\phi)^2} + f^{-1}(\phi) - V(\phi)$$

$\mathcal{L}_{\text{DBI}} = \mathcal{L}_{\text{slow-roll}}$ for $\dot{\phi}^2$ small

CONSIDER ISOTROPIC & HOMOGENEOUS SOLUTIONS

$$ds^2 = -dt^2 + a^2(t)\, dx_3^2 \qquad \text{FRW METRIC}$$

$\ddot{a}(t) > 0$ inflation ; $H = \dfrac{\dot{a}(t)}{a(t)}$

SOLVING EOM IS DIFFICULT

SLOW ROLL APPROXIMATION

$$\varepsilon(\phi) = \frac{1}{2} M_P^2 \left(\frac{V'}{V}\right)^2 \ll 1$$

$$\eta(\phi) = M_P^2 \left|\frac{V''}{V}\right| \ll 1$$

END OF INFLATION

$$\varepsilon(\phi) = 1$$

HYBRID INFLATION (D-$\bar{D}$ SYSTEM)

RELEVANT FOR STRINGY INFLATION

$$V(\phi,\psi) = a(\psi^2-1)\phi^2 + b\phi^4 + c$$

inflaton tachyon $a,b,c>0$

$\psi^2 > 1 \Rightarrow \phi$ massive

$\psi^2 = 1 \Rightarrow \phi$ massless

$\psi^2 < 1 \Rightarrow \phi$ tachyonic $m_\phi^2 < 0$

TACHYON SIGNALS INSTABILITY WHERE A PHASE TRANSITION TAKES PLACE (TOPOLOGICAL DEFECTS)

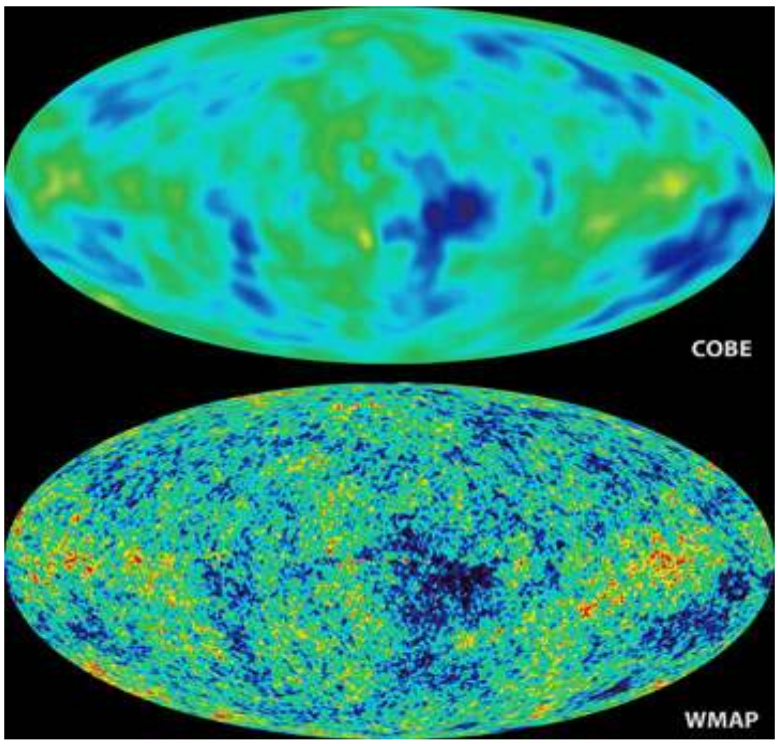
③ TENSOR & DENSITY PERTURBATIONS

INFLATION CLAIMS THAT SUCH PERTURBATIONS ORIGINATE FROM QUANTUM FLUCTUATIONS OF THE INFLATON

$$\delta_H(k) \approx \frac{V^{2/3}}{M_P^3 V'} \qquad A_G(k) \approx \frac{V^{1/2}}{M_P^2}$$

$\delta_H = 1.91\ 10^{-5}$

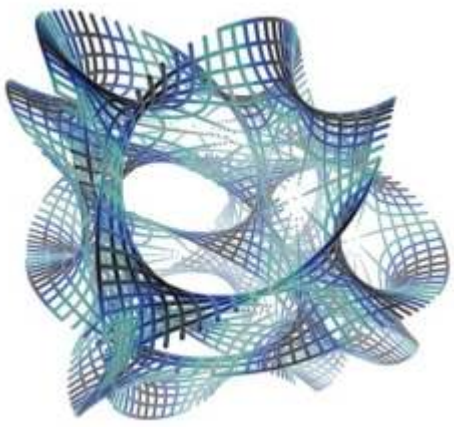
$(A_G \ll \delta_H)$



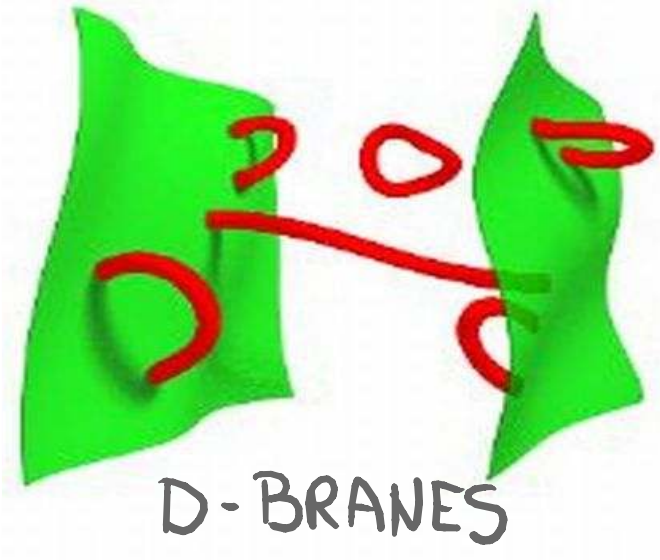
④ CHALLENGES FOR STRINGY INFLATION

THE EMBEDDING OF INFLATION IN STRING THEORY IS DIFFICULT IN CONVENTIONAL CALABI-YAU COMPACTIFICATIONS (MODULI-FIELDS)

D-BRANES & FLUX COMPACTIFICATIONS (90s) PUT THINGS INTO A NEW PERSPECTIVE!

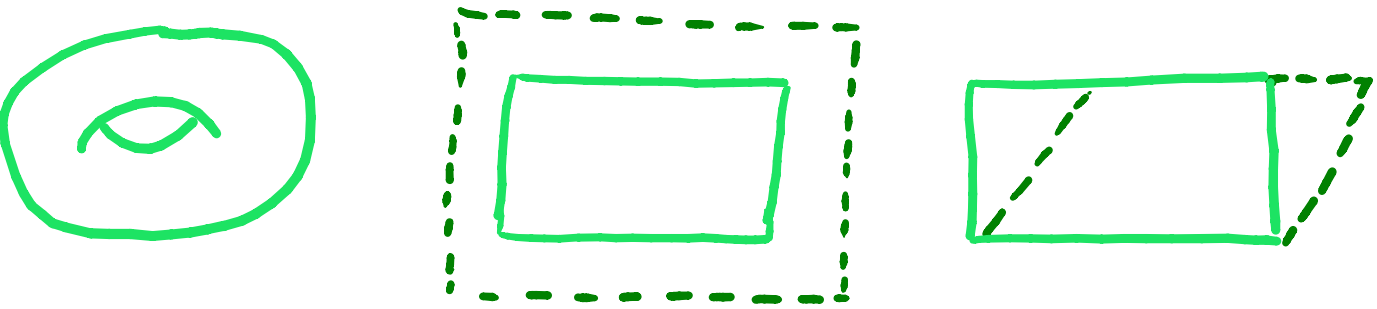


CALABI-YAU



D-BRANES

MODULI FIELDS ARE SCALARS DESCRIBING THE DEFORMATION OF THE SHAPE & SIZE OF THE INTERNAL GEOMETRY



THESE FIELDS ARE MASSLESS IN CALABI-YAU COMPACTIFICATIONS $\Rightarrow$ FLUXES !

OBSERVATION DEMANDS $m \sim H$

$$m_\varphi^2 = \frac{V}{M_{Pl}^2}\eta = 3H^2\eta \Rightarrow \eta \sim 1$$

ETA PROBLEM !

⑤ MODELS FOR STRINGY INFLATION

CLASSIFY MODELS ACCORDING TO THE ORIGIN OF THE INFLATON :

* OPEN STRING MODELS (BRANE INFLATION)

  INFLATON IS RELATED TO THE POSITION OF D-BRANES

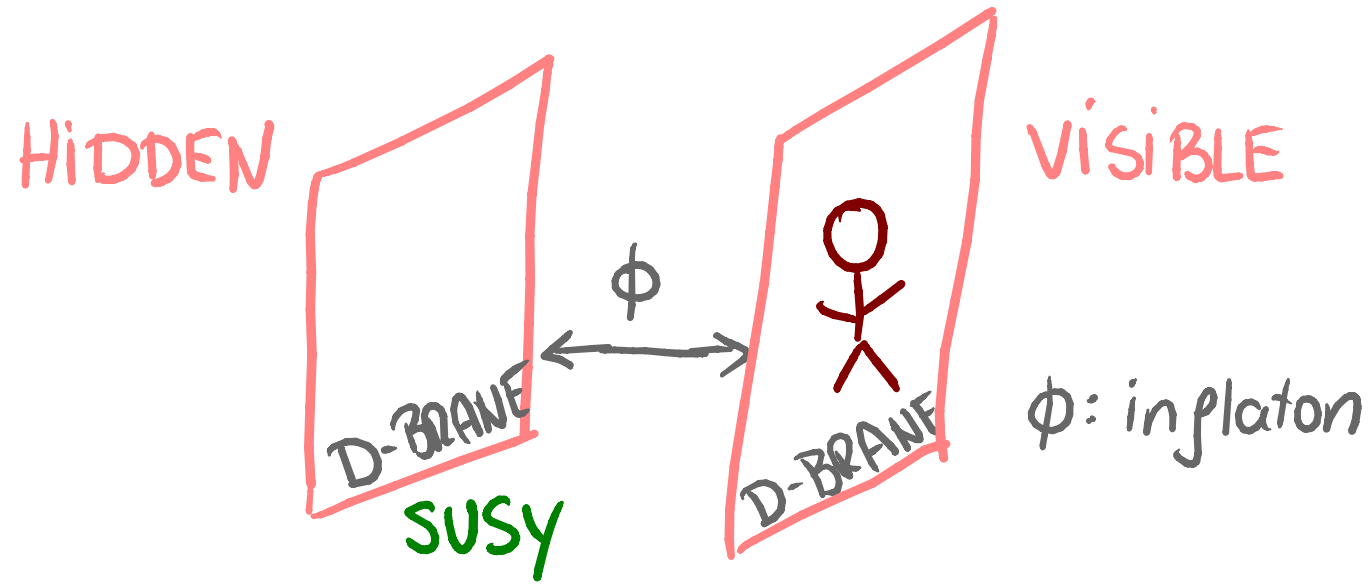
* CLOSED STRING MODELS (MODULI INFLATION)

  MODULI ARE MOST PROMINENT OPEN STRING MODES

Dvali & Tye

BRANE-BRANE INFLATION

IS ONE OF THE FIRST ATTEMPTS TO EMBED INFLATION INTO OPEN STRING THEORY



* NO NET ATTRACTIVE FORCE $V(\phi) = 0$

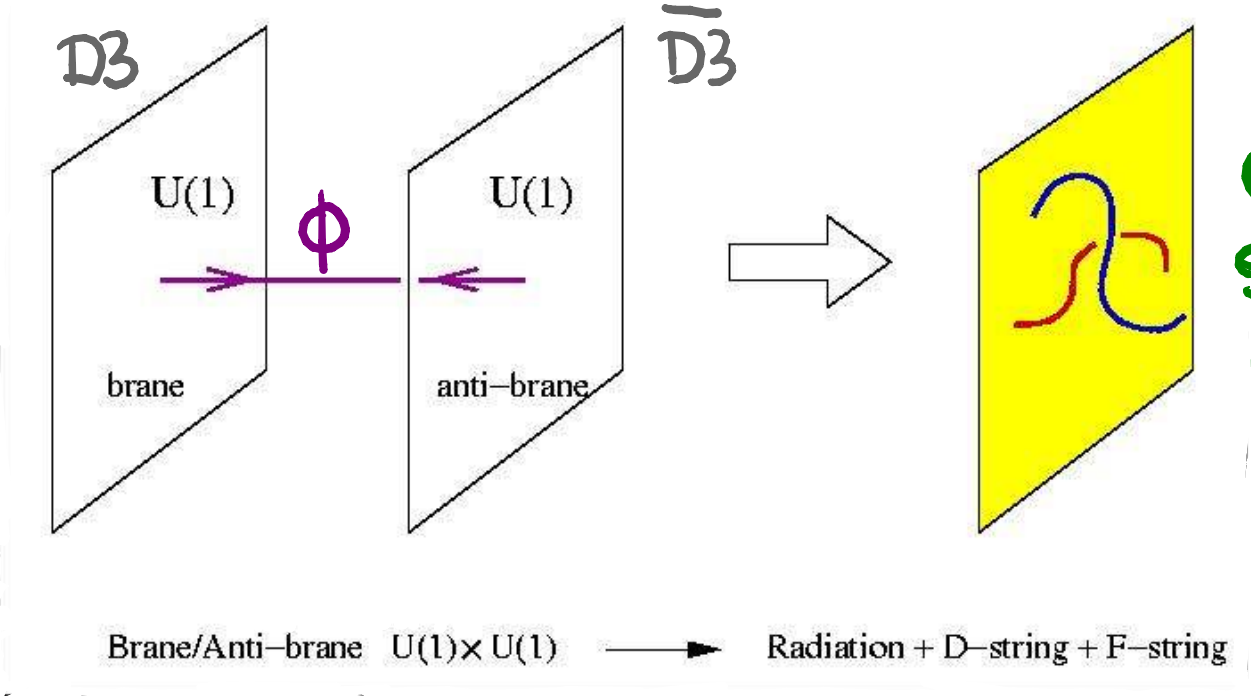
$F_{grav} + F_{coul} = 0$

* SUSY BREAKING EFFECT NEEDED

* END OF INFLATION ?

* FINE TUNING

BRANE-ANTI-BRANE INFLATION



COSMIC STRINGS

$T \sim M_p$

SUPERSYMMETRY IS BROKEN

THERE IS A NET ATTRACTIVE FORCE BETWEEN THE BRANES

D3-brane tension ↓ 10D Planck mass : M_{10}

$$V(\phi) = 2T_3\left(1 - \frac{1}{2\pi^3}\,\frac{T_3^3}{M_{10}^8\,\phi^4}\right)$$

$$V(\phi) = 2T_3 \left(1 - \frac{1}{2\pi^3} \frac{T_3^3}{M_{10}^8 \phi^4}\right)$$

$$\varepsilon = \frac{1}{2} M_p^2 \left(\frac{V'}{V}\right) \sim \frac{L^6}{\phi^{10}}$$

$\text{VOL}(CY3)$

$M_p^2 = L^6 M_{10}^8$

$$\eta = M_p^2 \left(\frac{V''}{V}\right) \sim \frac{L^6}{\phi^6} > 1$$

ETA PROBLEM !

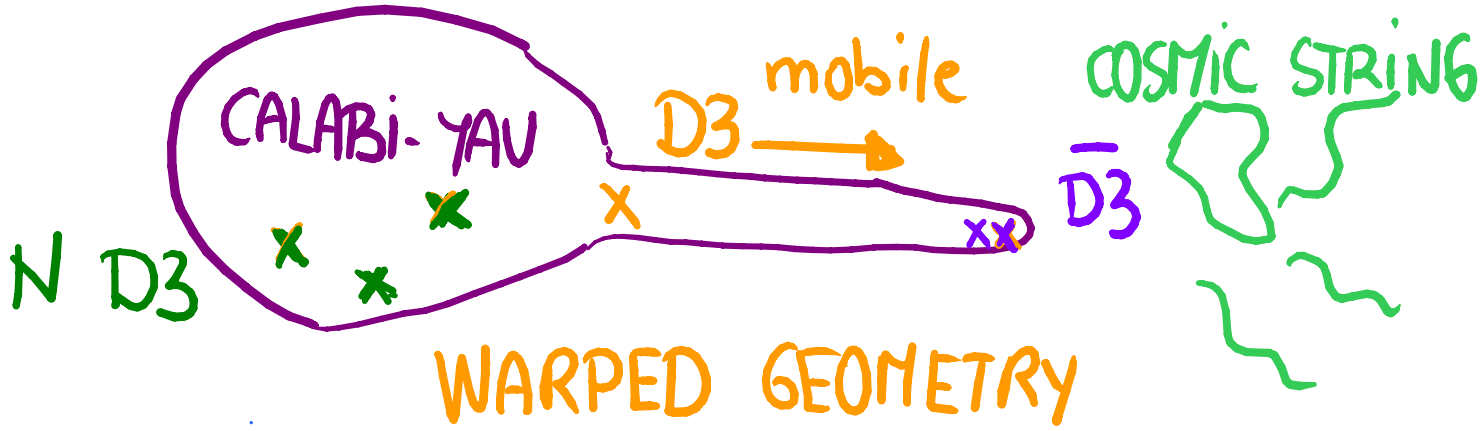
$\phi < L$ BRANES ARE LOCALIZED AT POINTS OF CY3

INFLATION EXIT : HYBRID INFLATION

TACHYON & COSMIC STRINGS

KKLMMT

WARPED D3-BRANE INFLATION

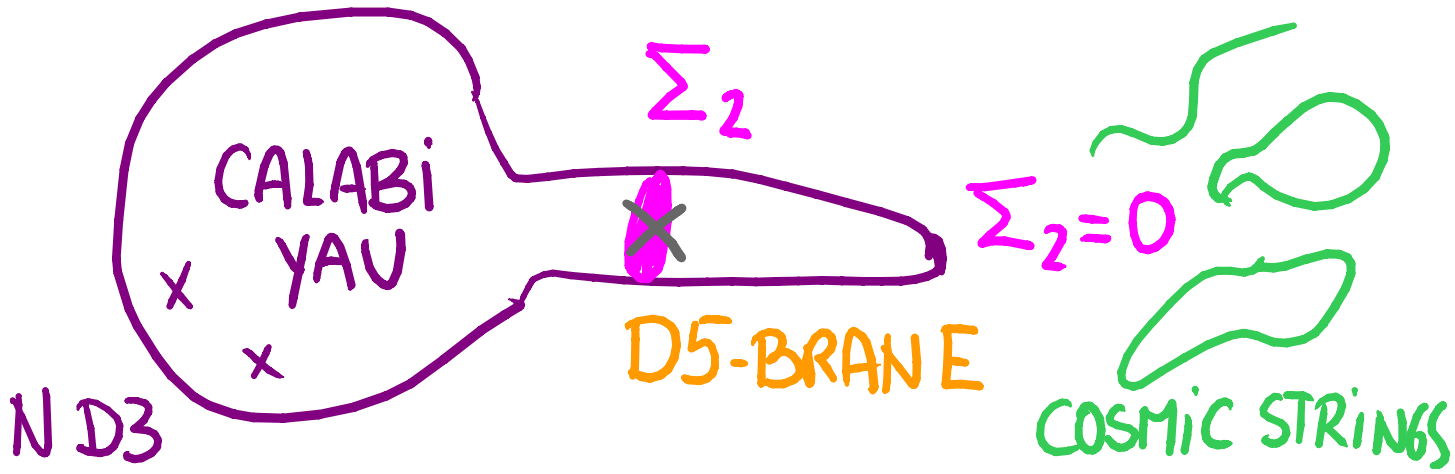


ADDED BONUS : COSMIC STRING TENSION

$$\left(\frac{\Delta\phi}{M_P}\right)^2 < \frac{4}{N} \quad ; \quad N > 10^4$$ Baumann & Mc Allister

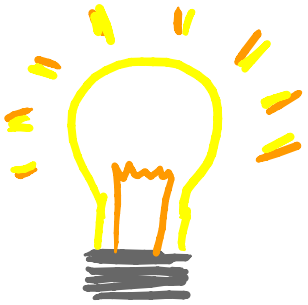
$$r \lesssim \frac{8}{30^2}\left(\frac{\Delta\phi}{M_P}\right)^2 \Rightarrow \frac{r}{0.009} \lesssim \frac{4}{N}$$ LYTH BOUND

NEAR FUTURE CMB POLARIZATION EXPERIMENTS WILL PROBE $r \gtrsim \mathcal{O}(10^{-2})$



M.B, L.LEBLOND & S.SHANDERA

INFLATON NORMALIZATION DEPENDS ON THE BRANE



$$\left(\frac{\Delta\phi}{M_P}\right)_{D5} < 2\,p^{1/2}\left(\frac{g_s}{N}\right)^{\frac{1}{4}}$$

$$\left(\frac{\Delta\phi}{M_P}\right)_{D7} < p\,g_s^{1/2}$$

GRAVITATIONAL WAVES & NON-GAUSSIANITY

DBI INFLATION

SILVERSTEIN & TONG

$$S_{DBI} = -\int f^{-1}(\phi)\sqrt{1 - f(\phi)(\partial\phi)^2} - V(\phi)$$

THIS IMPOSES A SPEED LIMIT ON ϕ INDEPENDENTY OF $V(\phi)$

$$f(\phi)\,\dot{\phi}^2 \leq 1$$

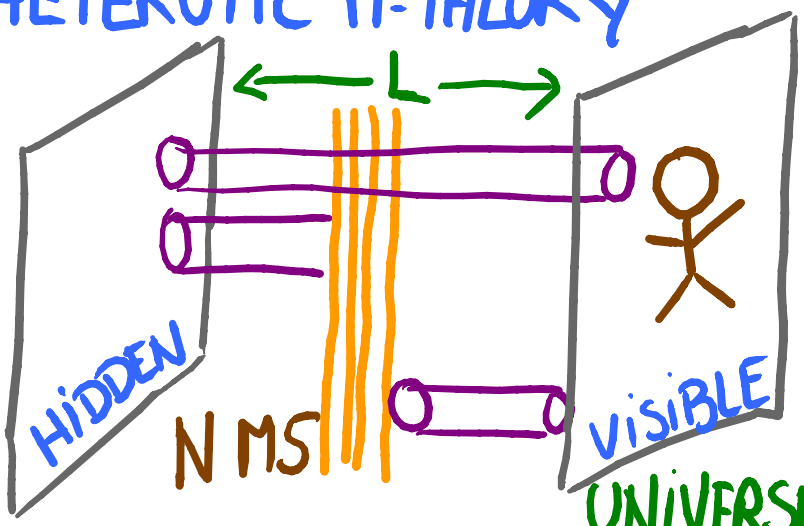
PARTICULAR $f(\phi), V(\phi)$ GIVE INFLATION WITH ENOUGH E-FOLDS EVEN FOR STEEP $V(\phi)$

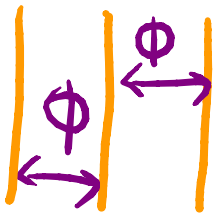
PHENOMENOLOGY IS SIMILAR AS FOR SLOW-ROLL INFLATION

M-THEORY INFLATION

BECKER[2] & KRAUSE

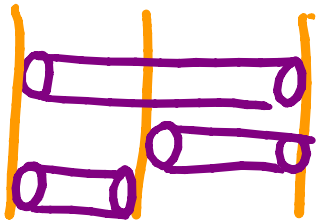
HETEROTIC M-THEORY





INFLATON

UNIVERSE HAS 2 BOUNDARIES



OPEN MEMBRANES

EXPONENTIAL POTENTIAL

* Φ GROWS DURING INFLATION

$$\varepsilon \sim \frac{1}{N4} \qquad \eta \sim \frac{1}{N4}$$

* $\Phi \sim L$ REHEATING

CONCLUSION

IT IS AN EXCITING TIME TO WORK IN ASTRONOMY & COSMOLOGY

EVIDENCE FOR STRING THEORY MAY COME FROM THE SKY