The Shapeshifting Universe

Anisotropic Cosmologies from Gravitational Tunneling and their Observational Signatures

based on work with D. Campo and J.C. Niemeyer,
arXiv-eprint:1003.3204

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Outline

- Anisotropic Cosmologies from Gravitational Tunneling
  - Compact Extra Dimensions, Flux Compactification
  - “Shapeshifting” Process, Geometry of the Bubble Universe
- Signatures in the CMB
  - Distortion of the CMB Temperature Map
  - The WMAP Measurement
  - Constraint on Anisotropic Curvature

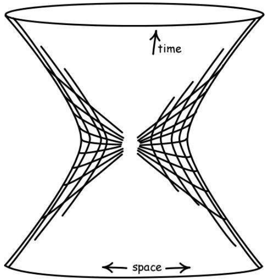
Anisotropic Cosmologies from Grav. Tunneling

Compact Extra Dimensions

Anisotropic Cosmologies from Grav. Tunneling

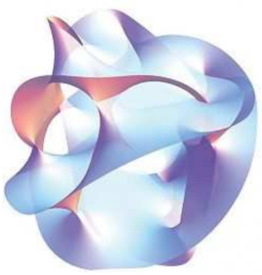
A “Landscape” of Compactification Vacua

In theories with extra dimensions there exists a multitude of vacuum solutions of the type



“macroscopic spacetime”

$\times$



“microscopic compact manifold”

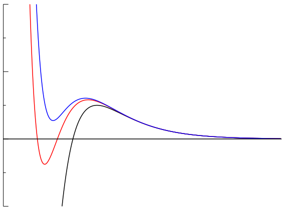
Anisotropic Cosmologies from Grav. Tunneling

Flux Compactification

Simple example: Einstein-Maxwell theory in higher dimensions

$$\mathcal{S} = \frac{1}{16\pi} \int d^D x \sqrt{-g} \left[\mathcal{R} - 2\Lambda - F^2\right]$$

F: q-form flux $\rightarrow$ compactification of q dimensions on a q-sphere.



Anisotropic Cosmologies from Grav. Tunneling

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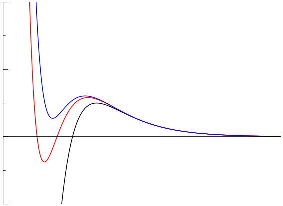

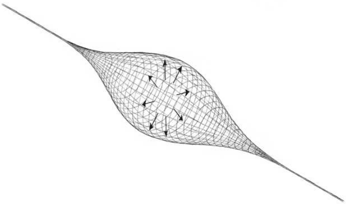

Elementary process: spontaneous (de)compactification.

Giddings & Myers (2004),

Blanco-Pillado, Schwartz-Perlov & Vilenkin (2009),

Carroll, Johnson & Randall (2009)

Flux Compactification

Shapeshifting process:

$$\begin{pmatrix}\text{pre-transition}\\ \text{macroscopic}\\ \text{universe}\end{pmatrix}_D \times \begin{pmatrix}\text{microscopic}\\ \text{compact}\\ \text{manifold}\end{pmatrix}_d \rightarrow \begin{pmatrix}\text{bubble}\\ \text{macroscopic}\\ \text{universe}\end{pmatrix}_{D'} \times \begin{pmatrix}\text{microscopic}\\ \text{compact}\\ \text{manifold}\end{pmatrix}_{D+d-D'}$$

Flux Compactification

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Anisotropic Cosmologies from Grav. Tunneling

Flux Compactification

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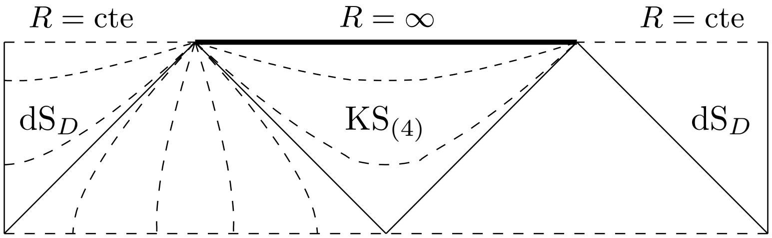
Examples:

compact manifold	cosmological model	curved directions
S_1 (Circle)	Bianchi III	$2 \times$ open $1 \times$ flat
$S_1 \times S_1$ (Torus)	Bianchi I	$3 \times$ flat
S_2 (Sphere)	Kantowski-Sachs	$2 \times$ closed $1 \times$ flat

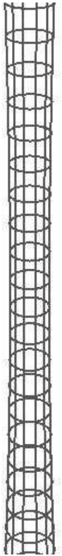
Spacetime Diagram of a Bubble Universe

Shapeshifting process (example):

$$\mathrm{dS}_D \times \mathrm{S}_2 \to \mathrm{KS}_{(4)} \times \mathcal{M}_{D-2}$$



A Shapeshifting Process (Illustration)



Anisotropic Cosmologies from Grav. Tunneling

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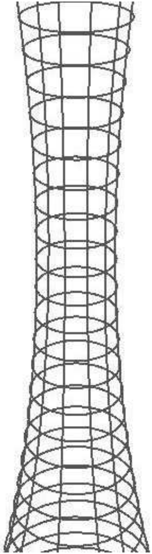

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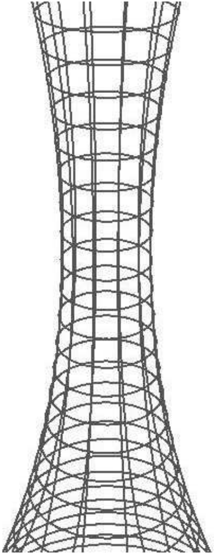

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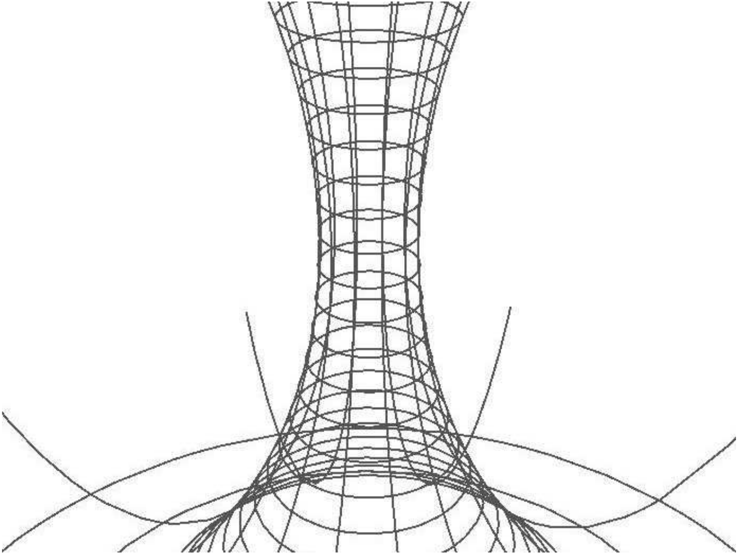

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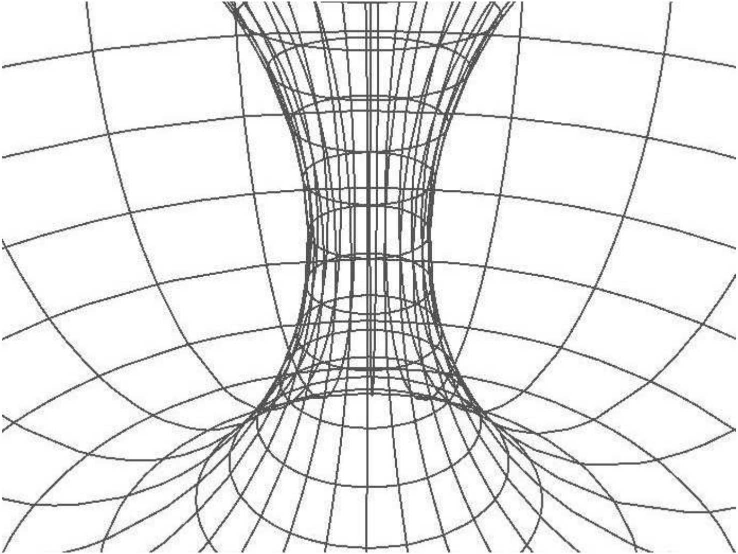

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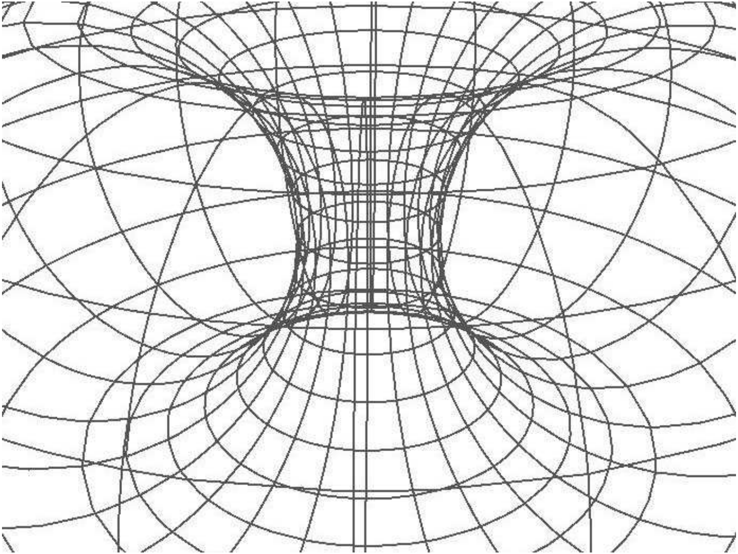

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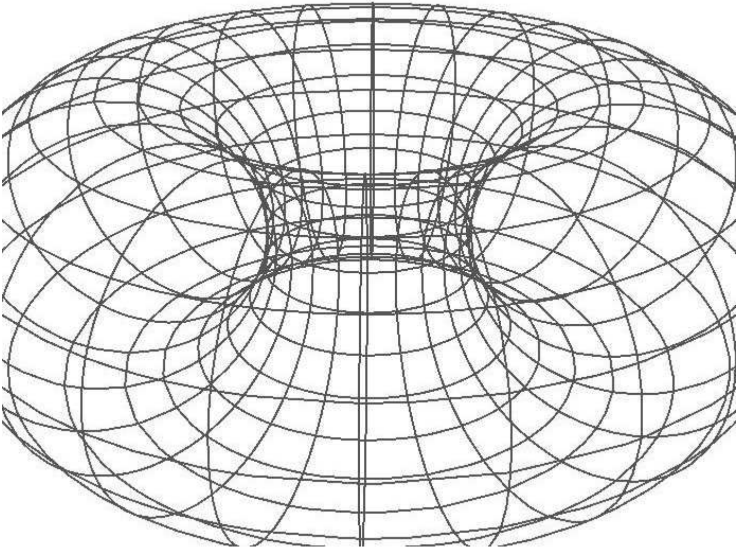

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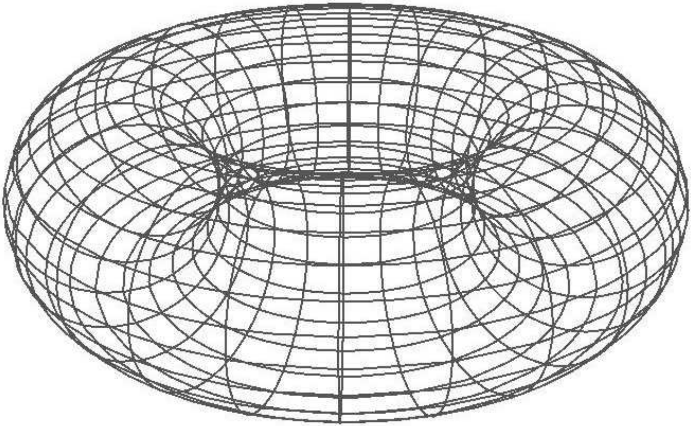

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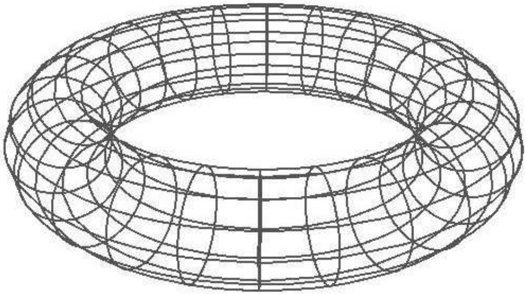

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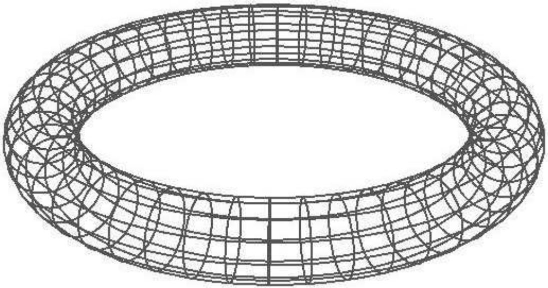

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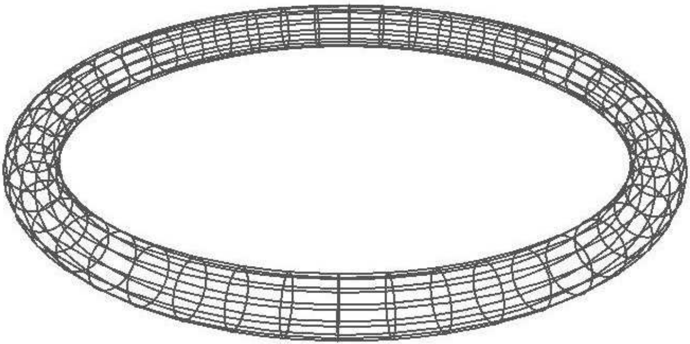

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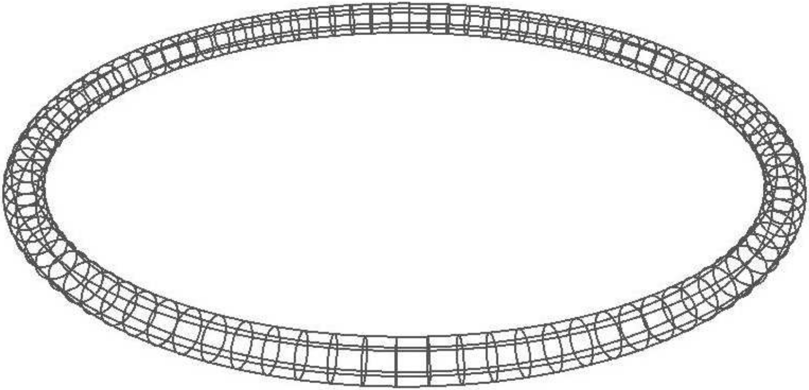

Signatures in the CMB

Anisotropic Curvature

$$\Omega_{\mathrm{curv}} \sim \frac{K}{H^2} \sim \left(\frac{\text{“horizon size”}}{\text{“curvature radius”}}\right)^2$$

cosmological model	curved directions	Ω_{curv}
Bianchi III	$2 \times$ open $1 \times$ flat	< 0
Bianchi I	$3 \times$ flat	$= 0$
Kantowski-Sachs	$2 \times$ closed $1 \times$ flat	> 0

Signatures in the CMB

Distortion of the CMB Temperature Map

Corrections come in at two places:

- Primordial power spectrum
  - Kantowski-Sachs JA, Campo & Niemeyer (2010)
  - Bianchi III Blanco-Pillado & Salem (2010)
- Late universe (photon propagation)
  - Sachs-Wolfe effect Graham, Harnik & Rajendran (2010)

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All modifications are found to have a generic form:

$$T(\theta,\phi) = [1 + c\,\Omega_{\mathrm{curv}} Y_{20}(\theta,\phi) + d\,\Omega_{\mathrm{curv}} \partial_\theta Y_{20}(\theta,\phi)\partial_\theta]\, T_0(\theta,\phi)$$

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Stated in terms of a_{lm}'s one finds:

- at fixed l, a non-uniform redistribution of power among m
- correlations between a_{lm} and $a_{l'm}$ for $l' = l \pm 2$

Signatures in the CMB

The Bipolar Coefficients

It is useful to represent the two-point correlation function $\mathcal{C}(\mathbf{n}, \mathbf{n}')$ in the basis of the total angular momentum with eigenvalues L and M:

$$\langle \mathbf{n}, \mathbf{n}' | \mathcal{C} \rangle = \sum_{l, l', L, M} N^{L}_{ll'} A^{LM}_{ll'} \langle \mathbf{n}, \mathbf{n}' | ll'; LM \rangle$$

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Statistical isotropy $\Leftrightarrow$ zero total angular momentum:

$$\begin{aligned} & \mathcal{C}(\mathcal{R}\mathbf{n}, \mathcal{R}\mathbf{n}') = \mathcal{C}(\mathbf{n}, \mathbf{n}') \quad \forall \quad \mathcal{R} \in SO(3) \\ \Leftrightarrow \quad & A_{ll'}^{LM} = 0 \quad \forall \quad L > 0 \end{aligned}$$

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In this case, $A_{ll}^{00} = C_l$.

Signatures in the CMB

The Bipolar Coefficients (continued)

$$T(\theta, \phi) = [1 + c\,\Omega_{\mathrm{curv}} Y_{20}(\theta, \phi) + d\,\Omega_{\mathrm{curv}} \partial_\theta Y_{20}(\theta, \phi) \partial_\theta]\, T_0(\theta, \phi)$$

T_0: statisically isotropic, angular power spectrum C_l (scale invariant)

Signatures in the CMB

The Bipolar Coefficients (continued)

$$T(\theta,\phi) = \left[1 + c\,\Omega_{\rm curv} Y_{20}(\theta,\phi) + d\,\Omega_{\rm curv} \partial_\theta Y_{20}(\theta,\phi)\partial_\theta\right] T_0(\theta,\phi)$$

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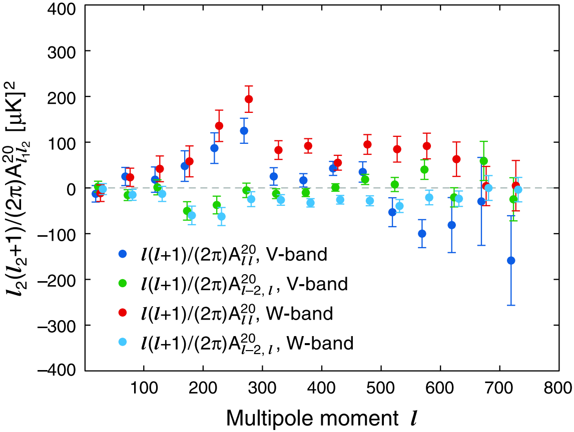
Non-zero bipolar coefficients for T:

$$\begin{aligned} A^{00}_{ll} &= C_l + \mathcal{O}(\Omega^2_{\rm curv}) \\ A^{20}_{ll} &= C_l \frac{c + 3d}{\sqrt{\pi}} \Omega_{\rm curv} + \mathcal{O}(\Omega^2_{\rm curv}) \\ A^{20}_{l-2,l} &= C_l \frac{c\left(l^2 - l + 1\right) - d\left(l^2 - l - 2\right)}{\sqrt{\pi}\left(l^2 - 3l + 2\right)} \Omega_{\rm curv} + \mathcal{O}(\Omega^2_{\rm curv}) \end{aligned}$$

Signatures in the CMB

WMAP Measurement



WMAP 7yr data Bennett *et al.* (2010)
arXiv:1001.4758 [astro-ph.CO]

Signatures in the CMB

The CMB Quadrupole Constraint

$$T(\theta, \phi) = [1 + c\,\Omega_{\mathrm{curv}} Y_{20}(\theta, \phi) + d\,\Omega_{\mathrm{curv}} \partial_\theta Y_{20}(\theta, \phi) \partial_\theta]\, T_0(\theta, \phi)$$

- The term $\propto c$ induces a contribution to the quadrupole from the CMB monopole

Signatures in the CMB

The CMB Quadrupole Constraint

$$T(\theta, \phi) = \left[1 + {\color{red}c}\,\Omega_{\mathrm{curv}} Y_{20}(\theta, \phi) + {\color{blue}d}\,\Omega_{\mathrm{curv}} \partial_\theta Y_{20}(\theta, \phi) \partial_\theta\right] T_0(\theta, \phi)$$

- The term $\propto {\color{red}c}$ induces a contribution to the quadrupole from the CMB monopole
- The observed quadrupole of only $\sim 14\mu K$ therefore constrains $|{\color{red}c}\,\Omega_{\mathrm{curv}}| \lesssim 10^{-4}$, even taking into account “cosmic variance”
- The term $\propto {\color{blue}d}$ is much less constrained, $|{\color{blue}d}\,\Omega_{\mathrm{curv}}| \lesssim 10^{-2}$

Summary

- **Shapeshifting** (= tunneling between compactification vacua) generically leads to homogeneous but *anisotropic* bubble universes.
- **Anisotropic curvature** produces distinct signatures in the CMB.
- **CMB quadrupole** puts strong constraints on the simplest of such models.

For further reference, see also **arXiv-eprint:1003.3204**