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# Is the CMB cold spot a gate to extra dimensions?

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# *ON THIS TALK...*

## I. COLD SPOT IN WMAP RESULTS

## II. PREVIOUS APPROACHES

Textures in Non Linear Sigma Model

## III. OUR APPROACH: BRANE WORLDS

Low energy brane dynamics

Some calculations

Conclusions

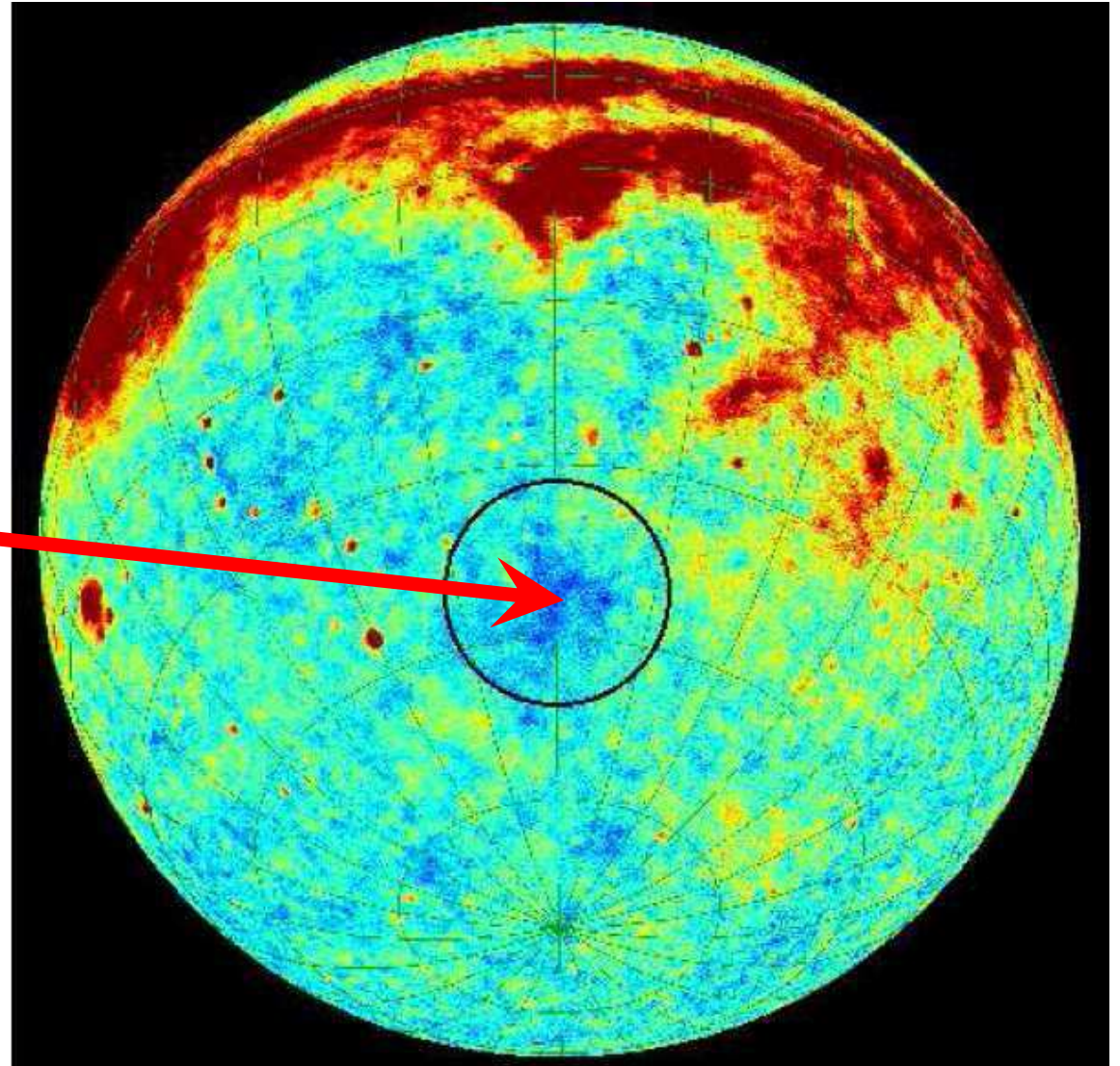
# I. COLD SPOT IN WMAP RESULTS

- Measurements of the **CMB** temperature anisotropies have been studied thoroughly in recent years by **WMAP**.
- Such anisotropies have been found to be approximately **Gaussian** as expected in standard cosmological scenarios corresponding to inflationary density fluctuations of one part in a hundred thousand in the early universe.



However, by means of wavelet analysis an anomalous **COLD SPOT**, apparently inconsistent with Gaussian, fluctuations was found.

It was centered at position  
 $b = -57^\circ$ ,  $l = 209^\circ$   
in galactic coordinates with a  
characteristic scale of about  $10^\circ$ .



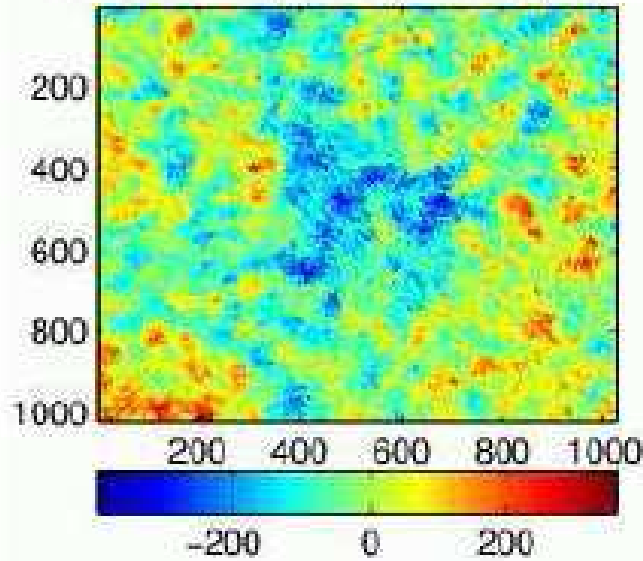
*“A Cosmic Microwave Background Feature Consistent with a Cosmic Texture”*

M. Cruz et al.

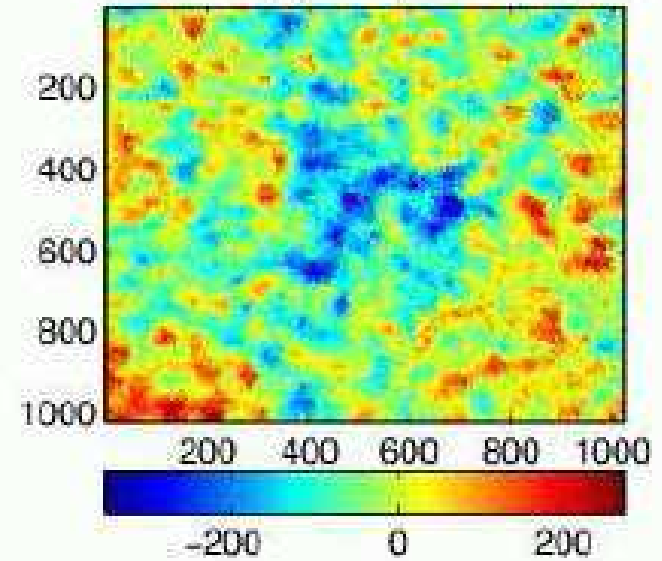
**SCIENCE**

7 December 2007:  
Vol. 318. no. 5856, pp.  
1612 - 1614.

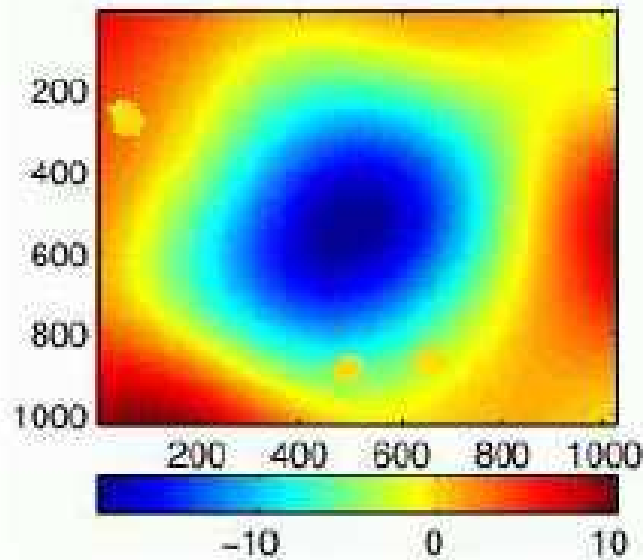
WCM 1- year, real space



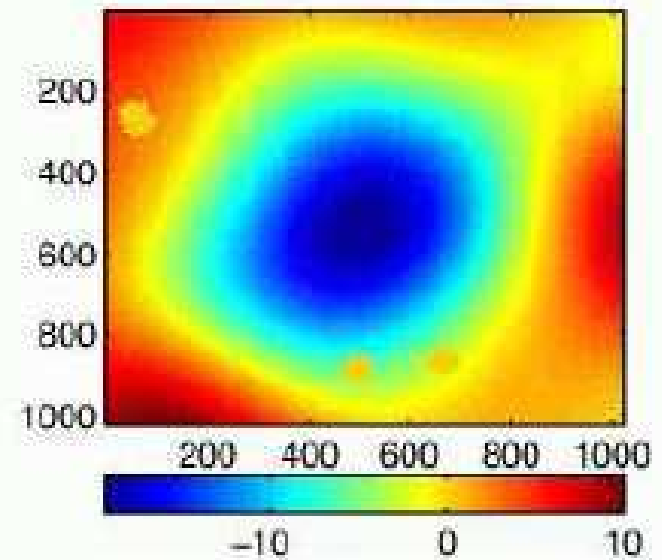
WCM 3- year, real space



WCM 1- year, scale  $R_9$



WCM 3- year, scale  $R_9$



➤ The non-gaussian cold spot in the 3-year wmap data.

M. Cruz et al. Published in **Astrophys. J. 655: 11-20, 2007.**

# II. WHERE DOES THIS COLD SPOT COME FROM?

- Some theories of **HEP** predict the formation of **Topological defects** → Cosmic textures → Photons traversing the texture region → **Hot/Cold spots** in the **CMB**.
- **Textures** would be remnants of **Symmetry breaking phase transition** in **early universe** and can produce a concentration of energy density.
- In order to produce textures the cosmic phase transition must be related to a global symmetry breaking pattern from one group  $G$  to a subgroup  $H$  so that the coset group  $K = G/H$  has a non trivial third homotopy group.

**If symmetry breaking would be local it could be gauged away**

- Textures can be understood as localized wrapped field configurations which collapse and unwind.

# A POSSIBLE EXPLANATION...

**SU(2) Non linear Sigma Model**, fractional distortion in the temperature is given by

$$\frac{\Delta T}{T}(\theta) = \pm \epsilon \frac{1}{\sqrt{1 + 4(\theta/\theta_c)^2}} \quad \epsilon = 7.7 \times 10^{-5} \equiv 8\pi^2 G \Phi_0$$
$$\theta_c = 5.1^\circ$$

$\Phi_0$  is the fundamental symmetry breaking scale that has to be set to:

$$\Phi_0 \simeq 8.7 \times 10^{15} \text{ GeV}$$



- But in **GUT's** is a **local symmetry** which is **broken** therefore cosmological defects would be destroyed.

VALOR ESPERADO EN EL VACÍO

$$\langle \hat{O} \rangle = \frac{\int \psi^* \hat{O} \psi dx}{\int \psi^* \psi dx}$$

$$\langle \hat{O} \rangle = \int \psi^* \hat{O} \psi dx$$

ANY OTHER IDEA....?

# ... BRANE WORLD MODELS

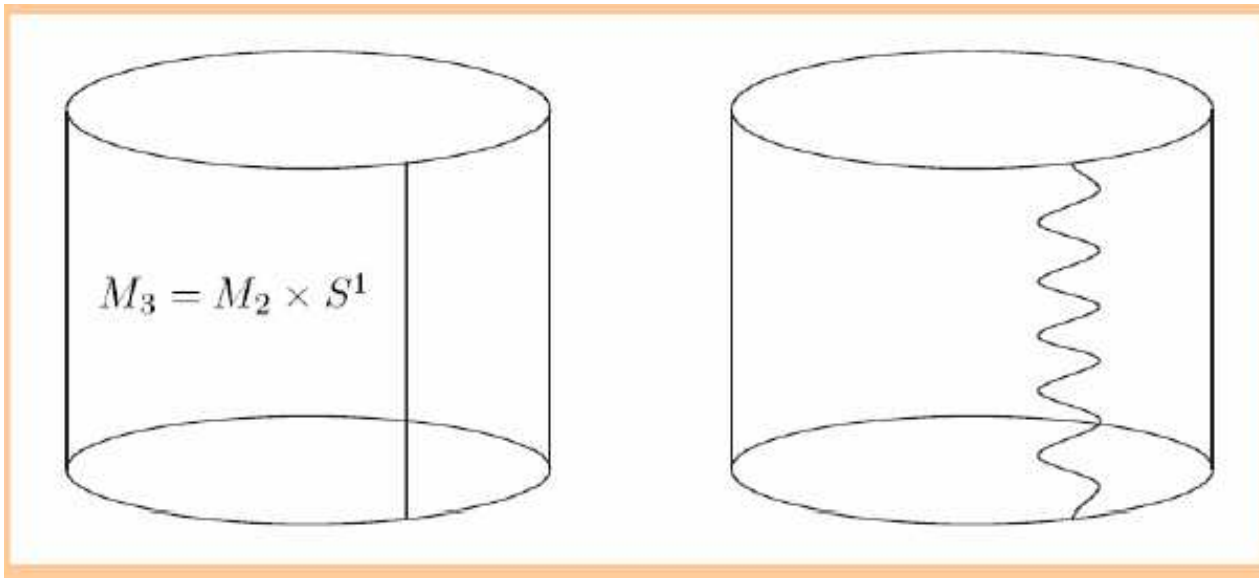
- In Brane World models, textures appear in a natural way.
- These textures, called **brane-skyrmions**, can be understood as holes in the brane which make possible to pass through them along the extra-dimensional space.
- Typical scales for the proposed **skyrmion** to explain Cold Spot can be as low as **electroweak scale**.

➤ Advantage: Provide global symmetries by assuming proper boundary conditions.

- See “**Brane skyrmions and wrapped states**”  
by Cembranos, Dobado and Maroto, **PRD 65: 026005, 2002.**  
e-Print: **hep-ph/0106322**

# ... but why a brane?

- ✓ Universe is a 3-dimensional brane, tension  $\tau = f^4$ , living in a higher  $D = 4+N$  dimensional space (bulk space).
- ✓ **BRANONS**: Topologically trivial vibrations of the brane



**Ground state**

**Excited state**

**Branons are natural candidates for dark matter.**

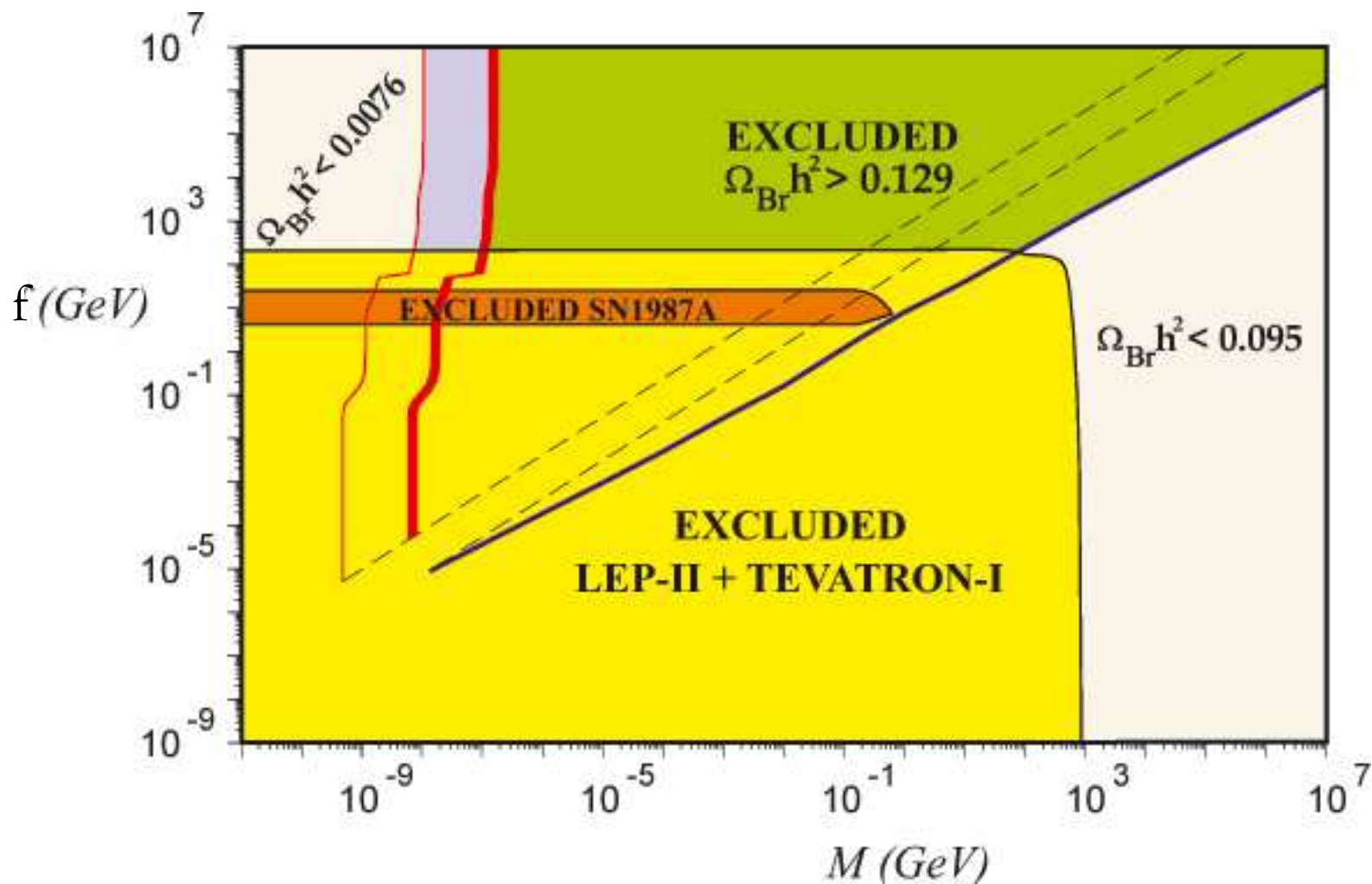
$$M_{\text{P}}^2 = (R_{\text{B}})^N (M_{\text{D}})^{2+N}$$

$M_{\text{P}}$  is the Planck scale.

$M_{\text{D}}$  is the fundamental gravity scale in  $D$  dimensions.

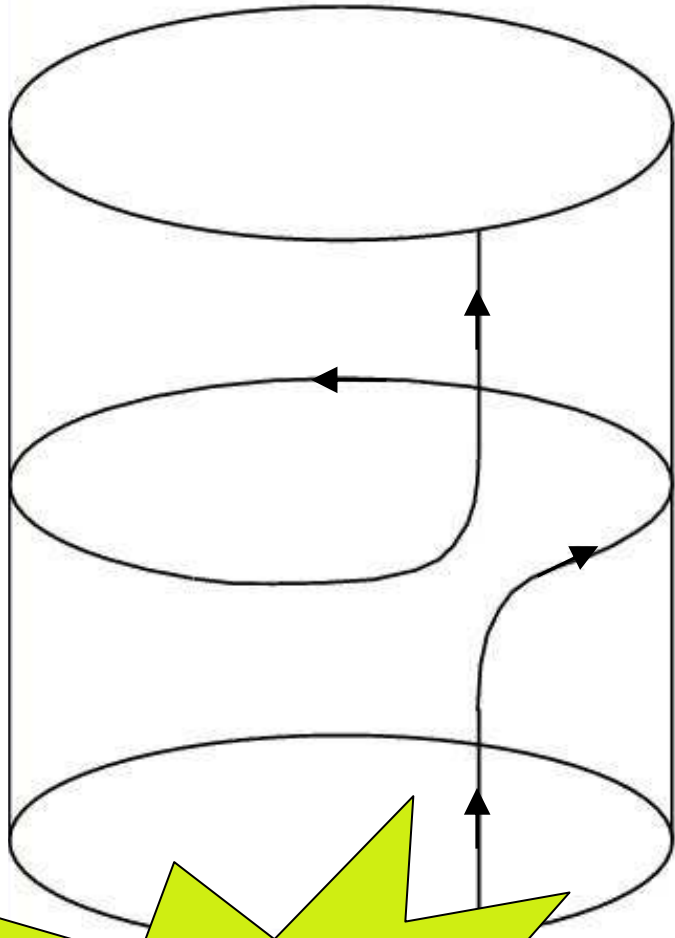
$N$  extra dimensions compactified to some manifold with volume  $(R_{\text{B}})^N$ .

Low-energy branon dynamics is described by the brane tension scale  $f$  and the branon mass  $M$ .



- ✓ Cosmological, astrophysical and collider limits on branon physics in the  $f$ - $M$  plane. Right full line corresponds to the limit of cold dark matter. Lines on the left are related to hot dark matter being the widest that to total dark matter  $\Omega_{\text{Br}} h^2 = 0.129 - 0.095$ . Thinnest one is referred to the limit  $\Omega_{\text{Br}} h^2 = 0.0076$  for hot dark matter.

✓ **SKYRMIONS:** Topologically non-trivial vibrations of the brane



Brane configurations with  $n_W = 1$  for the same  $M_3$ .

We have plotted a 1-brane-skyrmion.

A brane skyrmion can be seen as a hole in the brane towards extra dimensions.

✓ Eg. :  $M_4$  and coset  $K = G(B)/H$  isomorphic to  $S^3$

**From now on!**

# SOME CALCULATIONS...

- ✓ Low energy brane dynamics can be described by **Nambu-Goto action**

- ✓ **Metric** :  $g_{\mu\nu} = \tilde{g}_{\mu\nu} - \frac{1}{f^4} \partial_\mu \pi^\alpha \partial_\nu \pi^\beta h_{\alpha\beta}$

$$S = -f^4 \int d^4x \sqrt{-g}$$

- ✓ Spherical coordinates on  $K(S^3)$   $\longleftrightarrow$  Physical branon fields

$$\{\chi_K, \theta_K, \phi_K\} \left\{ \begin{array}{l} \pi_1 = v \sin \chi_K \sin \theta_K \cos \phi_K, \\ \pi_2 = v \sin \chi_K \sin \theta_K \sin \phi_K, \\ \pi_3 = v \sin \chi_K \cos \theta_K. \end{array} \right. \left\{ \begin{array}{l} \pi_1 \\ \pi_2 \\ \pi_3 \end{array} \right.$$

Coset metric in spherical coordinates,  $v = f^2 R_B$   
(size of the coset space)

$$h_{\alpha\beta} = \begin{pmatrix} v^2 & & \\ & v^2 \sin^2(\chi_K) & \\ & & v^2 \sin^2(\chi_K) \sin^2(\theta_K) \end{pmatrix}$$

- ✓ Non trivial mapping with winding number  $n_W$ ,  $\pi^\alpha : S^3 \rightarrow S^3$  defined from

$$\phi_K = \phi, \quad \theta_K = \theta, \quad \chi_K = F(t, r) \quad \text{where} \quad F(t, \infty) - F(t, 0) = n_W \pi$$

✓ **Equation of motion :**

$$\sin(2F) - 2rF' + \left(r^2 + \frac{v^2}{f^4} \sin^2 F\right) \frac{\ddot{F} - F'' + \frac{v^2}{f^4} (\ddot{F} F'^2 + F'' \dot{F}^2 - 2F' \dot{F} \dot{F}')}{1 - \frac{v^2}{f^4} (\dot{F}^2 - F'^2)} = 0$$

For brane-skyrmion within the Hubble radius  $r^2 \gg R_B^2 = v^2 / f^4$

$$r^2 (\ddot{F}_0 - F_0'') + \sin(2F_0) - 2rF_0' = 0$$

**Simplified equation of motion**

For winding number  $\mathbf{n}_W = 1$

$$F_0(t, r) = 2 \arctan(-r/t)$$

# ✓ SCALAR PERTURBATIONS IN MINKOWSKI METRIC

$$ds^2 = (1 + 2\Phi) dt^2 - (1 - 2\Psi)\delta_{ij} dx^i dx^j$$

$$\delta\mathcal{G}_0^0 = 2\nabla^2\Psi$$

$$\delta\mathcal{G}_i^j = [-2\ddot{\Psi} - \nabla^2(\Phi - \Psi)]\delta_i^j + \partial_i\partial^j[\Phi - \Psi]$$

$$\delta\mathcal{G}_i^0 = 2\partial_i\dot{\Psi}$$

$$T_{00} = \frac{2v^2(r^2 + 3t^2)}{(t^2 + r^2)^2}; \quad T_{rr} = \frac{2v^2(r^2 - t^2)}{(t^2 + r^2)^2}$$

$$T_{0r} = -\frac{4v^2rt}{(t^2 + r^2)^2}; \quad T_{\theta\theta} = \frac{2v^2r^2(r^2 - t^2)}{(t^2 + r^2)^2}$$

$$T_{\phi\phi} = \sin^2\theta T_{\theta\theta}$$

**Einstein  
equations**

$$\Psi \equiv \Phi = 4\pi G v^2 \log \frac{r^2 + t^2}{t^2}$$

# Integrated Sachs Wolfe effect

$$\left(\frac{\Delta T}{T}\right)_{SW} = -[\Phi]_{\tau_i}^{\tau_f} + \int_{\tau_i}^{\tau_f} (\dot{\Psi} + \dot{\Phi}) d\tau = -[\Phi]_{\tau_i}^{\tau_f} + \int_{\tau_i}^{\tau_f} 2\dot{\Phi} d\tau$$

$$z_f \rightarrow \infty$$

$$r^2 = z^2 + R^2$$

$$z = t - t_0$$

$\gamma$

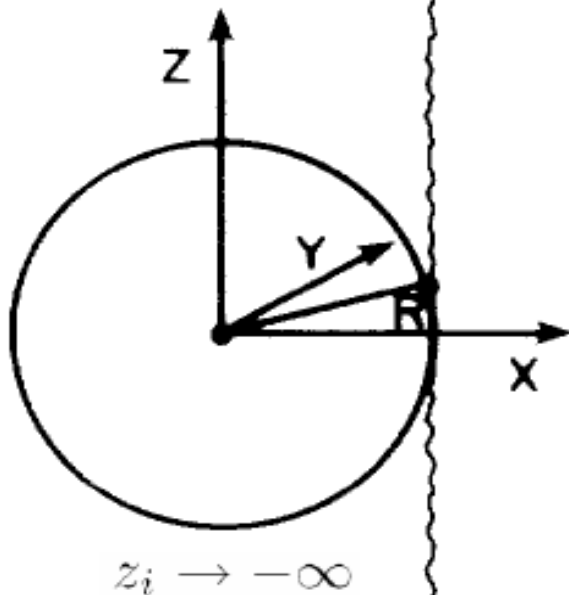
$$\left(\frac{\Delta T}{T}\right)_{SW} = \epsilon \frac{t_0}{\sqrt{2R^2 + t_0^2}}$$

$$\epsilon = 8\pi^2 G v^2$$

to be compared with **NLSM** solution...

$$\frac{\Delta T}{T}(\theta) = \pm \epsilon \frac{1}{\sqrt{1 + 4(\theta/\theta_c)^2}}$$

- ✓ Same solution but with completely different physical origins.



## ✓ What are therefore the involved scales?

For the minimal model supporting brane-skyrmions with  $N = 3$  extra dimensions we will have

$$R_B \simeq \left( \frac{M_P^2}{M_D^5} \right)^{1/3} \quad \text{and therefore} \quad v^2 \equiv f^4 R_B^2 \simeq f^4 \left( \frac{M_P^2}{M_D^5} \right)^{2/3}$$

- Since  $\epsilon \sim 10^{-5}$  then  $M_D \sim f \sim 1 \text{ TeV}$   
(natural values for branon matter as Dark Matter).
- In this case  $R_B$  is around  $10^{-8} \text{ m}$  and approximations are completely justified.
- In other words, brane-skyrmions provide an accurate description for the Cold Spot with **no need of introducing very high energy (GUT) scales**, since correct temperature fluctuation amplitude can be obtained with natural values around **electroweak scale**.

# CONCLUSIONS

- Brane-skyrmions provide an alternative explanation to the CMB Cold Spot.
- Natural scales can be as low as Electro-weak.
- For those scales branons are natural candidates for Dark Matter.
- Since fundamental scales of the theory are of order TeV, future experiments could confirm the studied model (virtual or real branons productions and KK-gravitons).

Thank you & have a look to [astro-ph/0803.0694](https://arxiv.org/abs/astro-ph/0803.0694)

Published in JCAP 0810: 039, 2008.

