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Branon dark matter

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Outline

- Brane worlds: branons vs. KK gravitons
- Branon phenomenology in colliders
- Branons as dark matter
- Brane skyrmions and the CMB cold spot

Brane-worlds:
branons vs. KK gravitons

Introduction: brane worlds

M_D

fundamental scale of gravity in D = 4 + δ dimensions

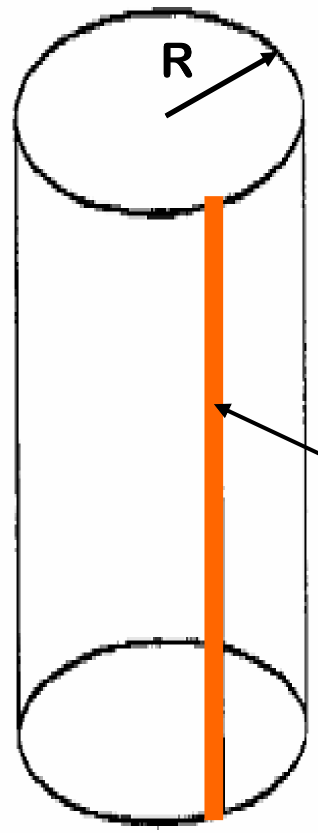
Brane hierarchy

$$M_P^2 = M_D^{2+\delta} R^\delta$$

$$M_D \simeq 1\,\mathrm{TeV}$$

$\delta = 2,\ R \simeq 1$ mm

$\delta = 7,\ R \simeq 10$ Fermi



f^4

brane tension

Brane universe

Antoniadis, et al. 98
ADD, 98

Kaluza-Klein gravitons

$$g_{\mu\nu}(x,\vec{y}) = \sum_{\vec{n}} g^{\vec{n}}_{\mu\nu}(x)\, e^{i\vec{n}\cdot\vec{y}/R}$$

3+1 coordinates

extra-dimensional coordinates

KK graviton tower

$$M_n = \frac{n}{R}$$

KK graviton mass (torus compactif.)

Linearizing the bulk gravitational field

$$G_{MN} = \eta_{MN} + \frac{h_{MN}}{M_D^{\delta/2+1}}$$

$$S_{KK} = -\frac{1}{M_D^{\delta/2+1}} \int d^4x\, d^\delta y\, h_{MN}(x,y)\, T^{MN}(x,y)$$

Branons (brane fluctuations)

Brane position

$$Y^M = (x^\mu, Y^m(x))$$

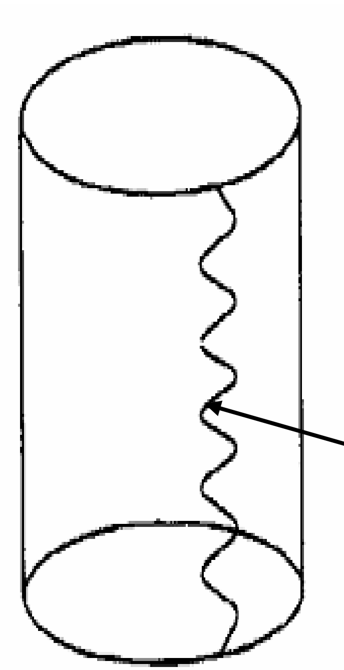
Brane ground state

$$Y^m(x) = Y_0^m$$

Coset space

$$K = G(B)/H(Y_0)$$

$$M_D = M_4 \times B$$



Isometry group of G_{MN}

$$G(M_D) = G(M_4) \times G(B)$$

Sundrum, '99
Dobado, A.L.M. '01

Branons $\pi^\alpha(x)$ GB fields
Spontaneous isometry breaking

$$Y^m(x) = Y^m(Y_0, \pi^\alpha(x)) = Y_0^m + \frac{1}{kf^2}\xi_\alpha^m(Y_0)\pi^\alpha(x) + \mathcal{O}(\pi^2)$$

Branons

- **Bulk metric:**

$$G_{MN} = \begin{pmatrix} \tilde{g}_{\mu\nu}(x)W(y) & 0 \\ 0 & g'_{mn}(y) \end{pmatrix}$$

- **Branon mass related to bulk curvature:**

$$M^2_{\alpha\beta} = \tilde{g}^{\mu\nu} R_{\mu\alpha\nu\beta}\big|_{y=0}$$

- **Induced metric on the brane:**

$$g_{\mu\nu}(x,\pi) = \tilde{g}_{\mu\nu}(x)\left(1 + \frac{M^2_{\alpha\beta}\pi^\alpha\pi^\beta}{4f^4}\right) - \frac{1}{f^4}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha + \mathcal{O}(\pi^4)$$

Branon dynamics

$$S_{Br} = -\int_{M_4} d^4x\sqrt{g}f^4 + \int_{M_4} d^4x\sqrt{g}\mathcal{L}_{SM}$$

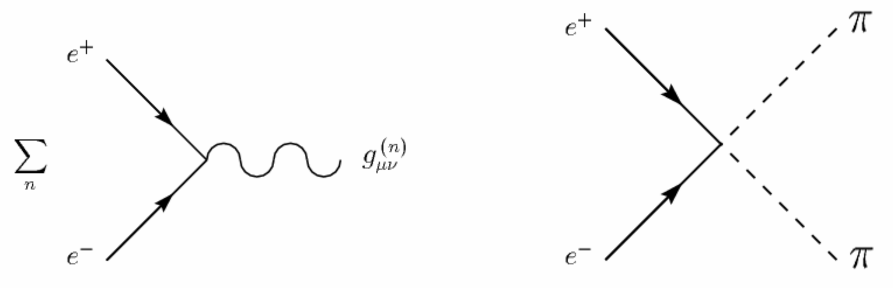
Dirac-Nambu-Goto

Induced metric

$$\begin{aligned} S_{Br} &= \int_{M_4} d^4x\sqrt{\tilde{g}}\left[\frac{1}{2}\left(\tilde{g}^{\mu\nu}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - M^2_{\alpha\beta}\pi^\alpha\pi^\beta\right)\right. \\ &+ \left.\frac{1}{8f^4}(4\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - M^2_{\alpha\beta}\pi^\alpha\pi^\beta\tilde{g}_{\mu\nu})T^{\mu\nu}_{SM}\right] \end{aligned}$$

KK gravitons vs. branons

KK-production | **Branon production**

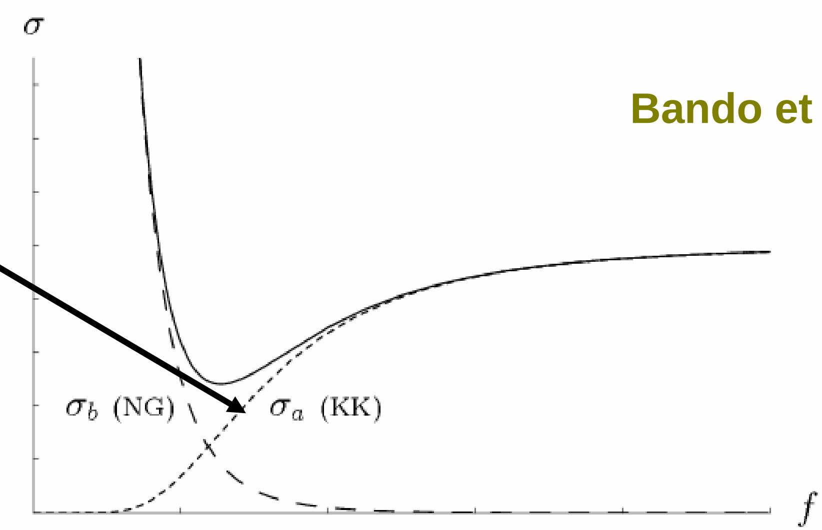


(a) (b)

$$\sigma_a = \frac{\pi^{1-\frac{\delta}{2}}}{2^{\delta+3}\Gamma(\frac{\delta}{2})}\frac{1}{M^{\delta+2}}\, s^{\frac{\delta}{2}}\, e^{-s\frac{M^2}{f^4}},$$

$$\sigma_b = \frac{\delta\pi^3}{1920}\frac{1}{f^8}\, s^3,$$

KK-SM coupling suppression



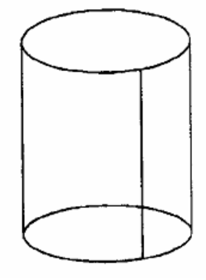
Bando et al. '99

KK gravitons vs. branons

Brane-world scenario

- **Rigid branes (f >> M_D)**

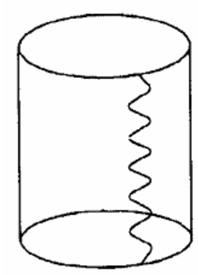
  Kaluza-Klein modes



- **Flexible branes (f << M_D)**

  Branon fields

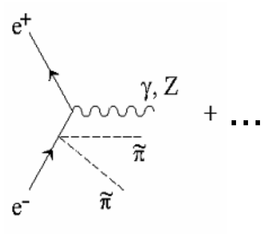
  (KK modes decouple from SM)



Branon phenomenology in colliders

Limits from colliders

LEP-II



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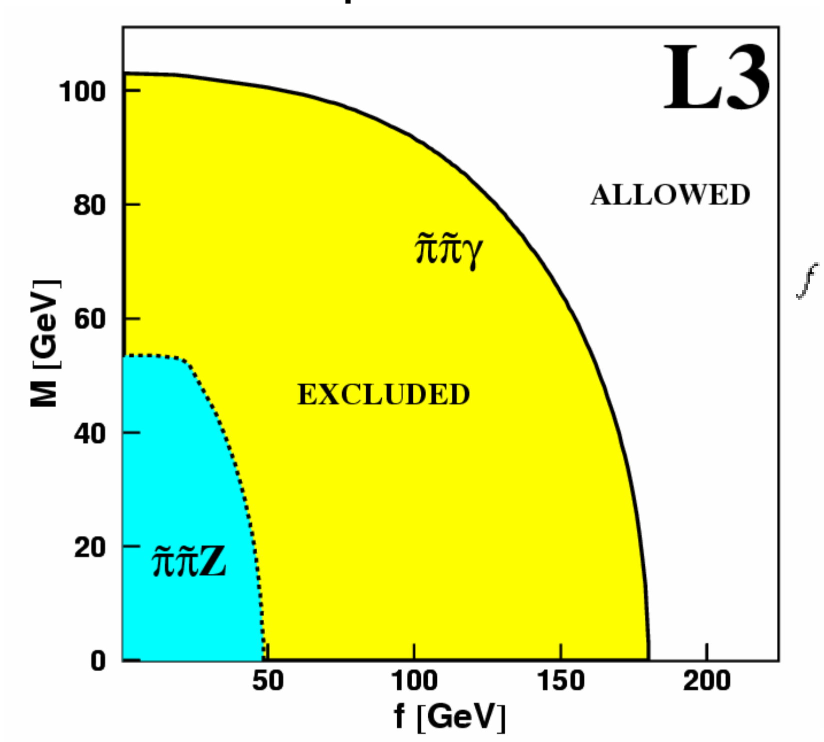
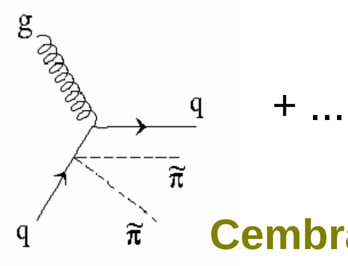
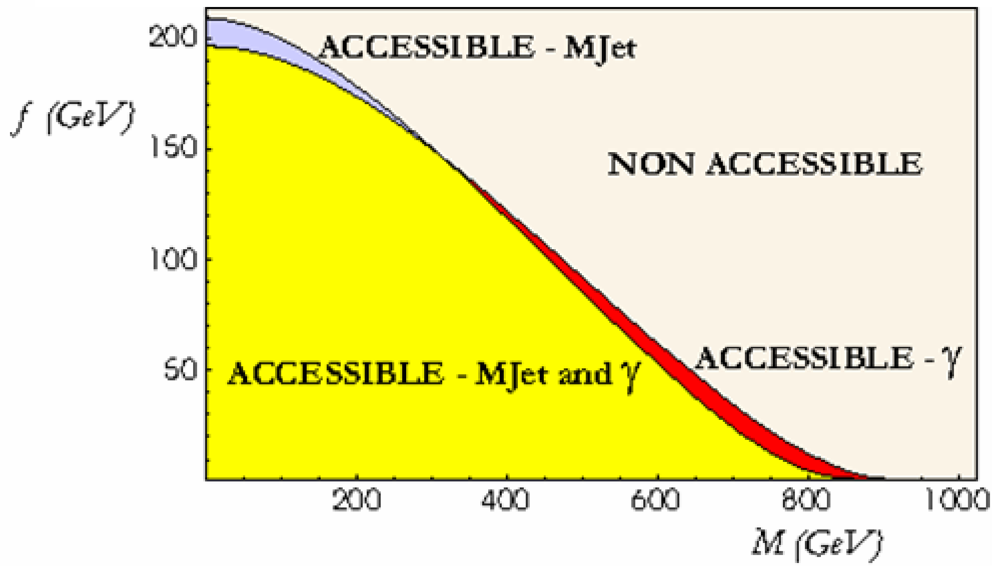


TEVATRON-II

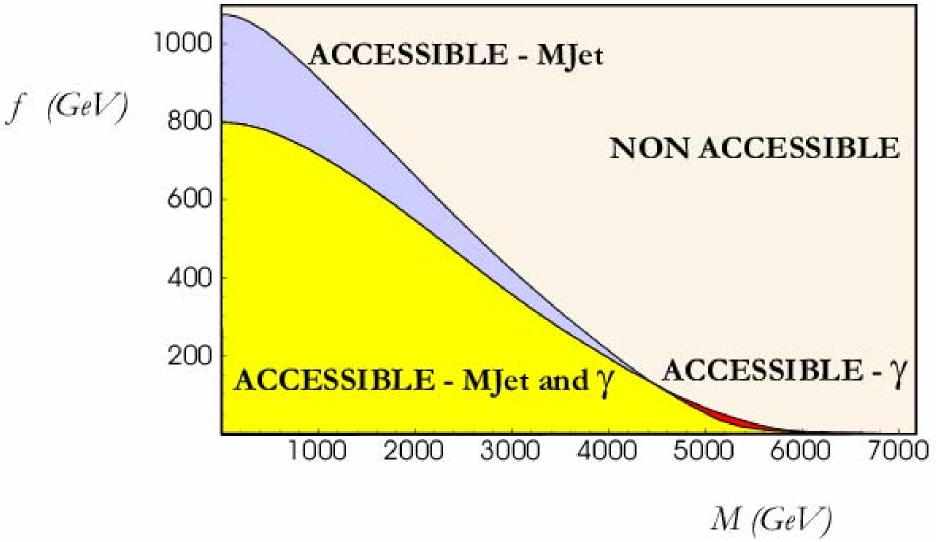


Cembranos, Dobado, A.L.M, ’03

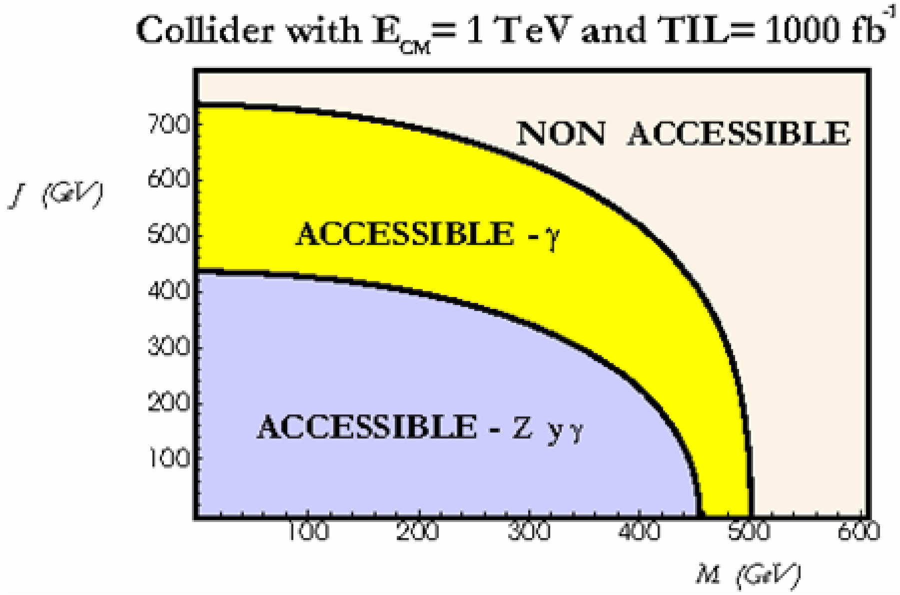


Prospects for future colliders

LHC



ILC



Cembranos, Dobado, A.L.M, ’04

Branons as dark matter

A new dark matter candidate

- 3-brane orientation ⟹ branons are pseudoscalar particles

- Parity on the brane ⟹ branons couple by pairs to SM (stable particles)

Branons are:

stable, massive and weakly interacting particles

NATURAL DARK MATTER CANDIDATES

Cembranos, Dobado, A.L.M, ’03

Branon cosmic abundance

Freeze-out in an expanding universe:

$$\frac{dn_\alpha}{dt} = -3Hn_\alpha - \langle \sigma_A v \rangle \left(n_\alpha^2 - (n_\alpha^{eq})^2\right)$$

Annihilation into all SM pairs *X* : $\sigma_A = \sum_X \sigma(\pi^\alpha \pi^\alpha \rightarrow X)$ **,**

e.g. annihilation into photons, $\boxed{\pi\,\pi \longrightarrow \gamma\,\gamma}$ **:**

Cold branons (M >> T)

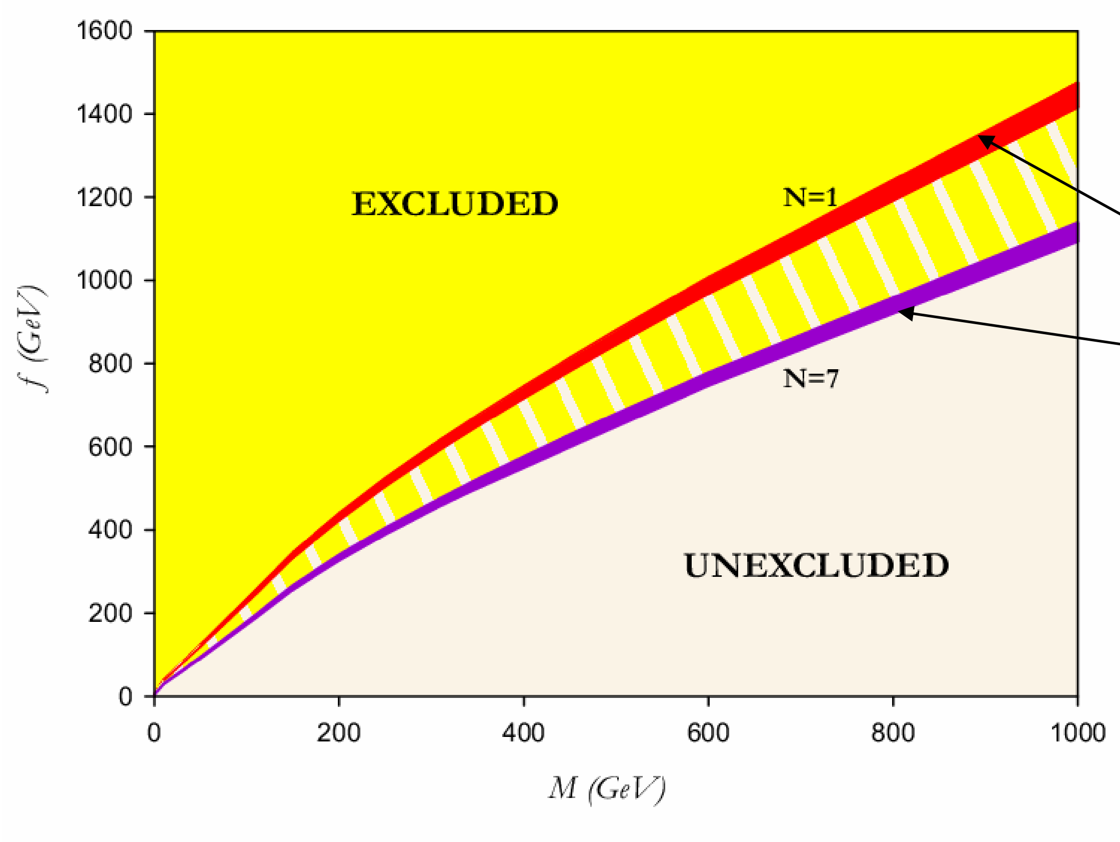
$$\langle \sigma_{\gamma\gamma} v \rangle \simeq \frac{68 M^4 T^2}{15 \pi^2 f^8}$$

Hot branons (M << T)

$$\langle \sigma_{\gamma\gamma} v \rangle \simeq \frac{16 \pi^7 T^6}{297675 f^8}$$

Branon cosmic abundance

Cold branons



WMAP limits

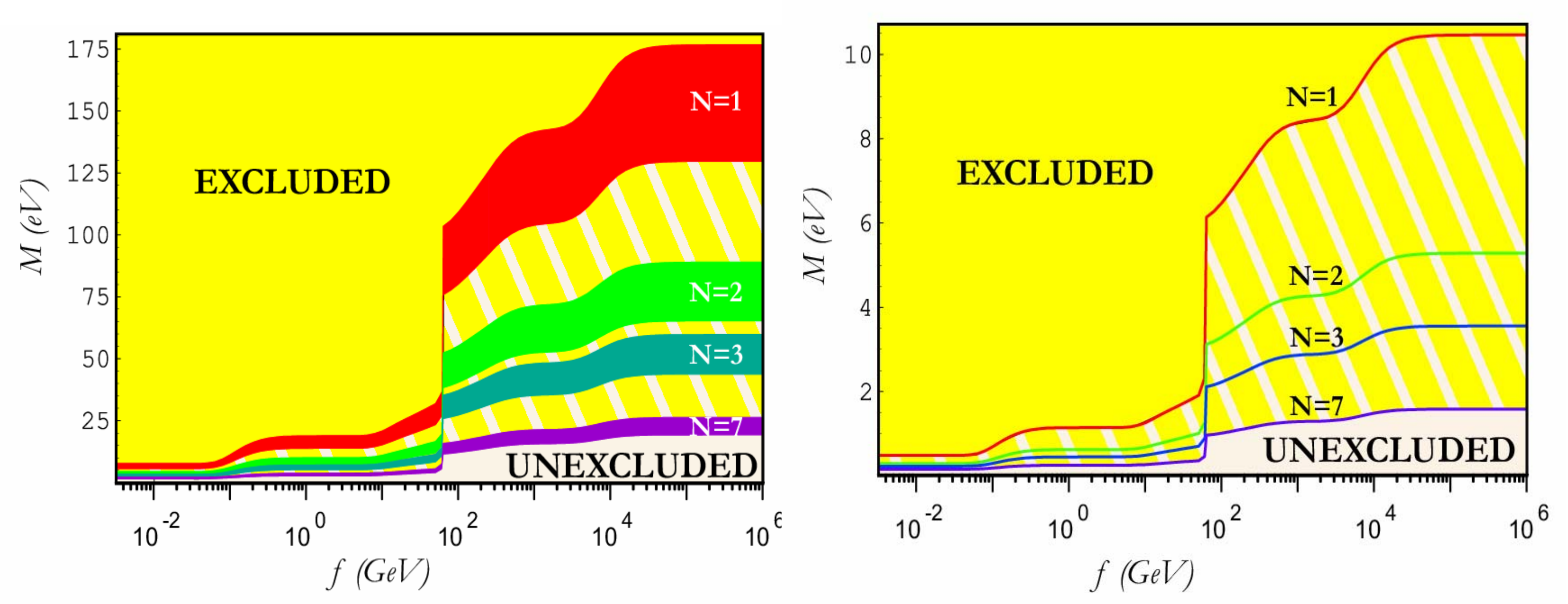
$$\Omega_{Br}h^2 = 0.129 - 0.095$$

Branon cosmic abundance

Hot branons

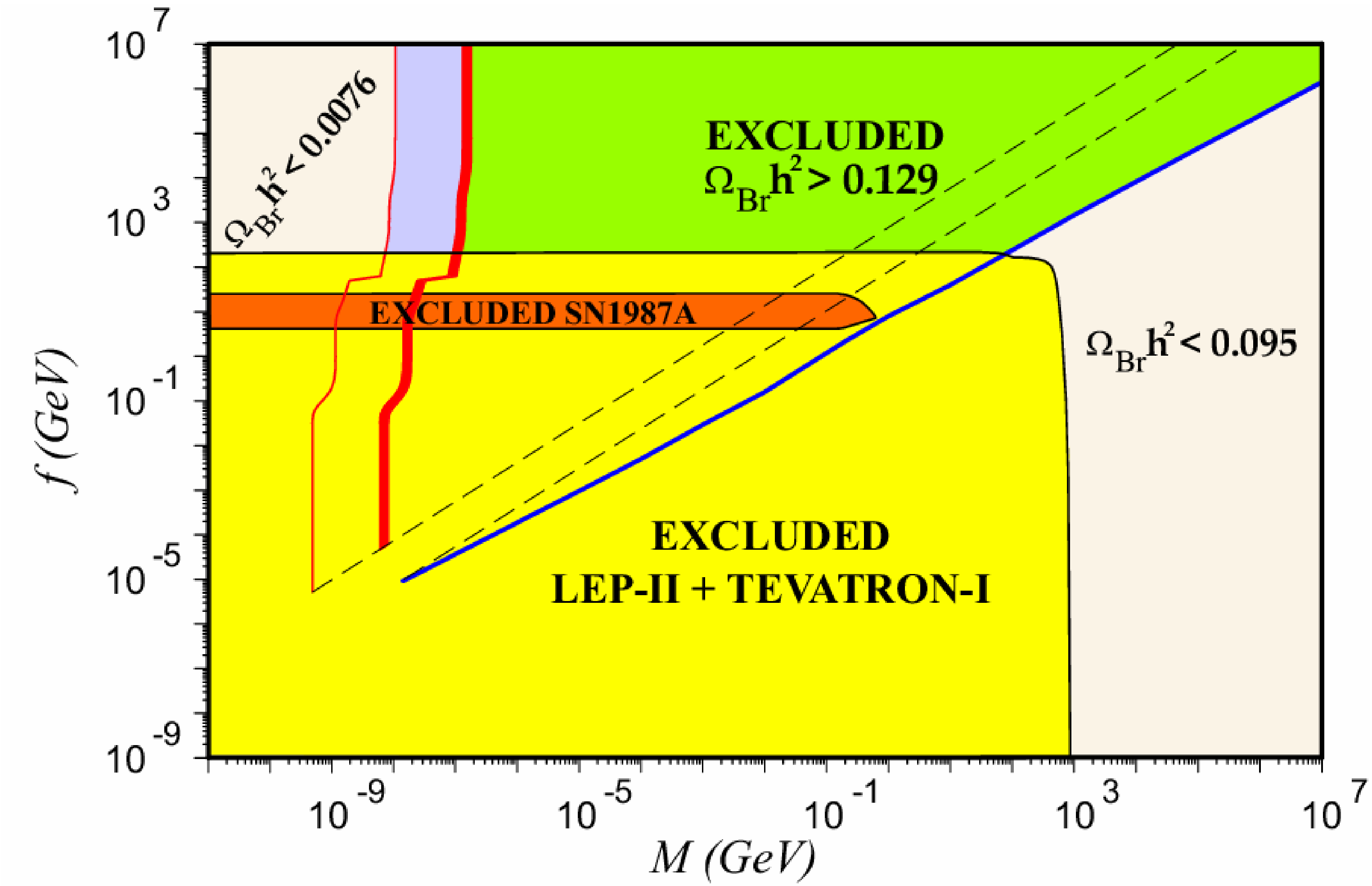
WMAP $\Omega_{Br}h^2 = 0.129 - 0.095$

WMAP-CBI-ACBAR-2dF-Ly-α $\Omega_{Br}h^2 = 0.0076$

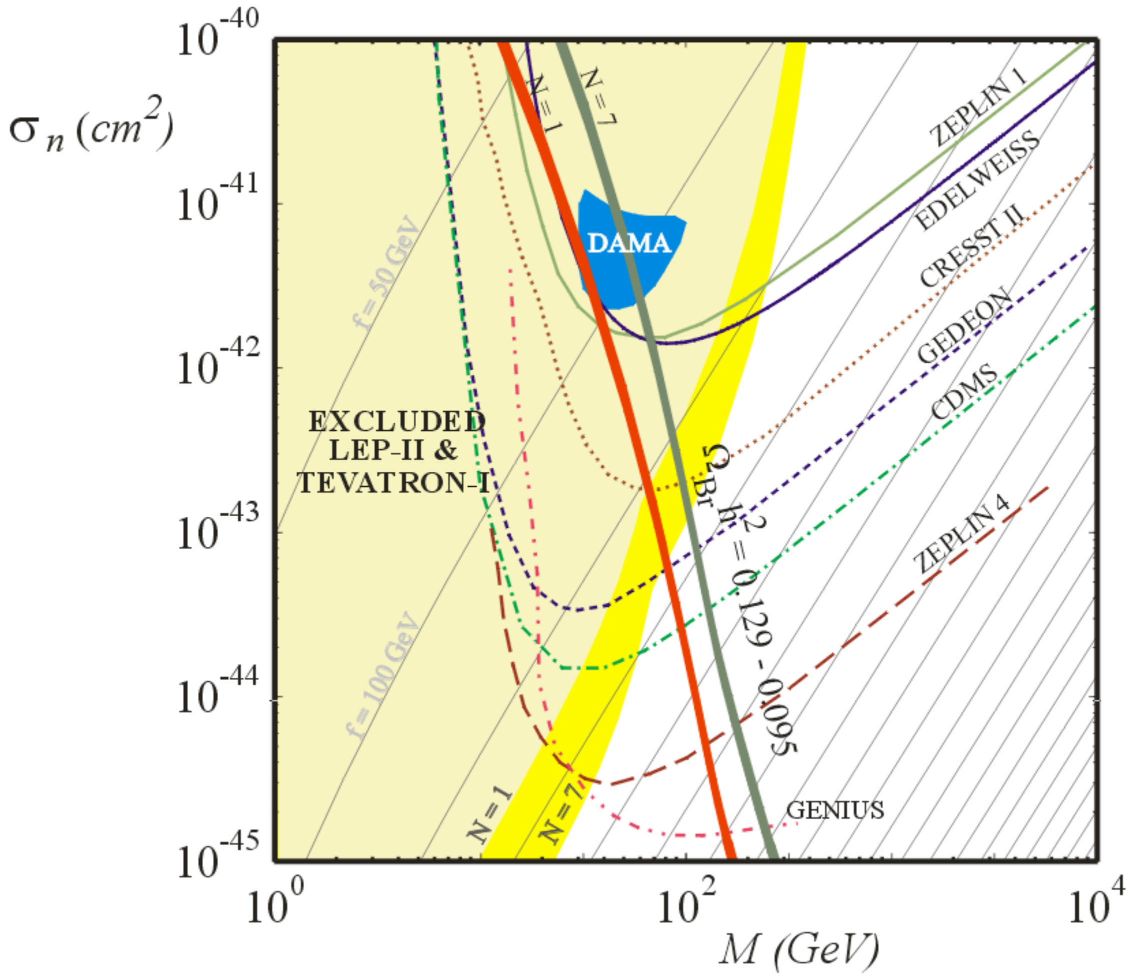


BBN limits (light branons): $N \lesssim 18$ **for** $f \gtrsim 60\ \mathrm{GeV}$

Combined limits



Direct detection

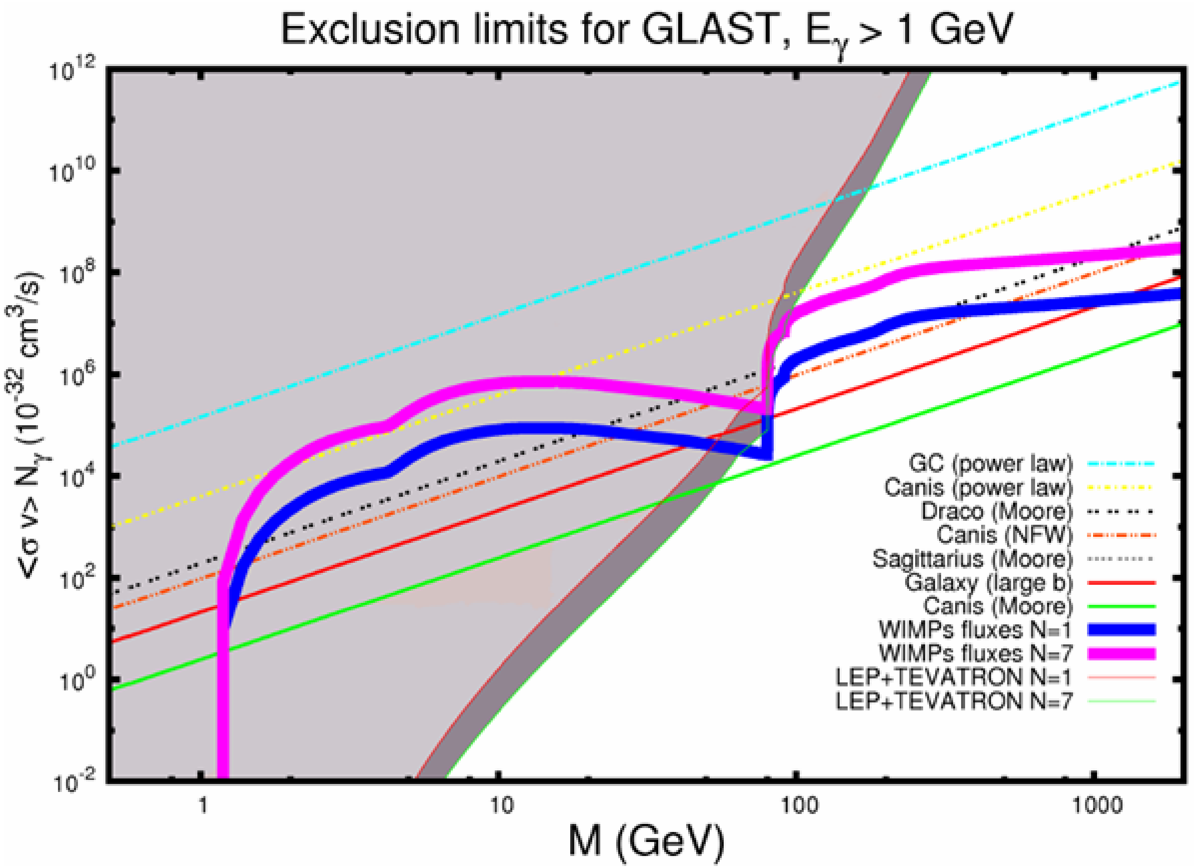


Elastic branon-nucleon cross section (spin independent)

$$\frac{d\sigma}{d|q|^2} = \frac{\sigma_n A^2\, F^2(|q|)}{4v^2\mu^2}$$

$$\sigma_n = \frac{9M^2 m^2 \mu^2}{64\pi f^8}$$

Indirect detection



Cembranos, de la Cruz Dombriz, Dobado, Maroto, PRELIMINARY

Non-thermal branon production

If $\Lambda << T_{RH} << T_f$

($\Lambda = (M f^2 R_B)^{1/2}$ explicit symmetry breaking scale).

Branons are very light particles and decoupled from SM.

$\Downarrow$

Brane initial position: $Y_0 = \mathcal{O}(R_B)$ and $\pi_0 = f^2 R_B$

Dark matter as coherent brane oscillations (similar to axions)

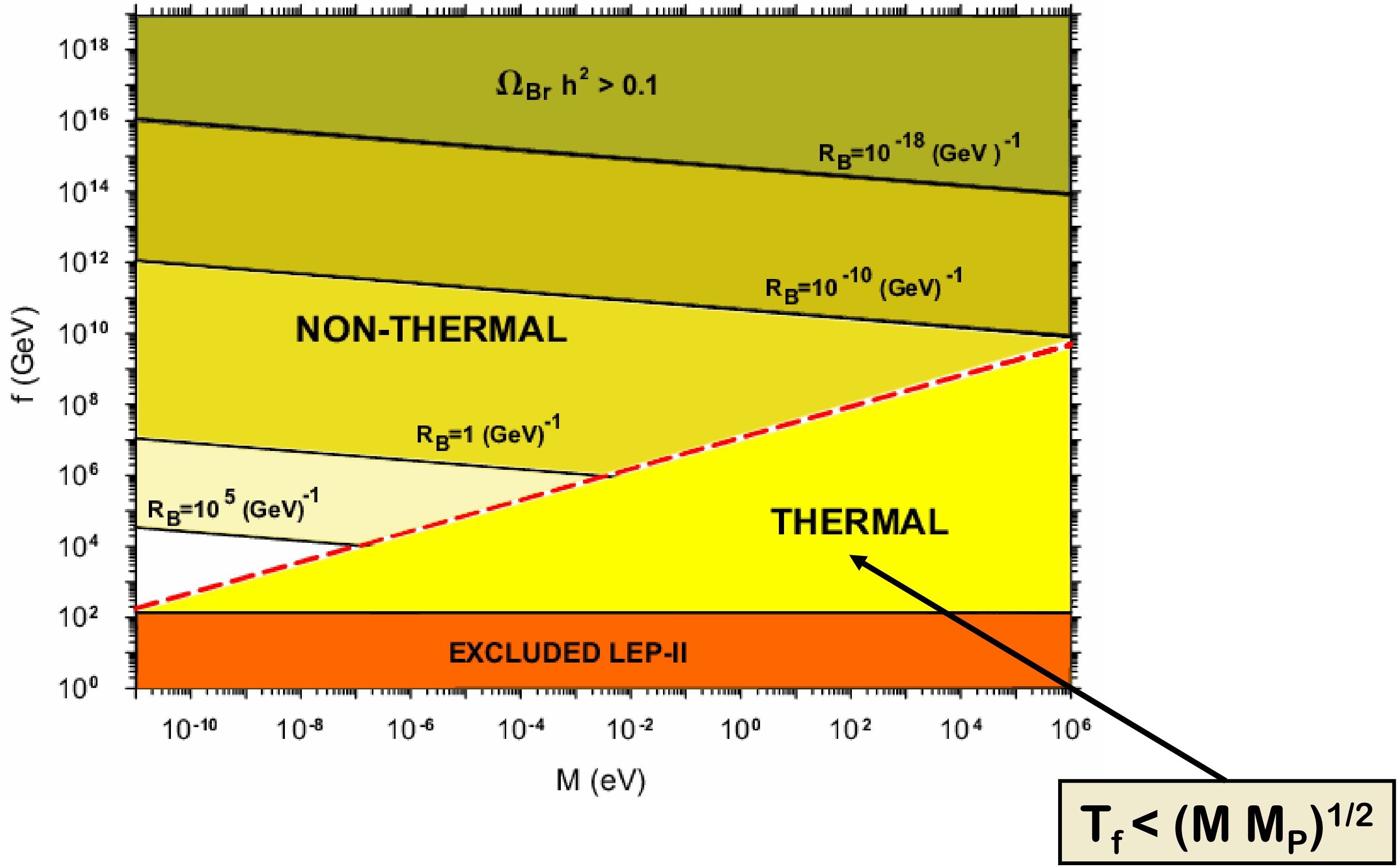
If H(T) > G(T) for T < T_{RH} brane oscillations only diluted by Hubble expansion.

Non-thermal branon abundance:

$$\Omega_{Br} h^2 \simeq \frac{6.5 \cdot 10^{-20} N}{\mathrm{GeV}^{5/2}} f^4 R_B^2 M^{1/2}$$

A.L.M, '04

Non-thermal branon production



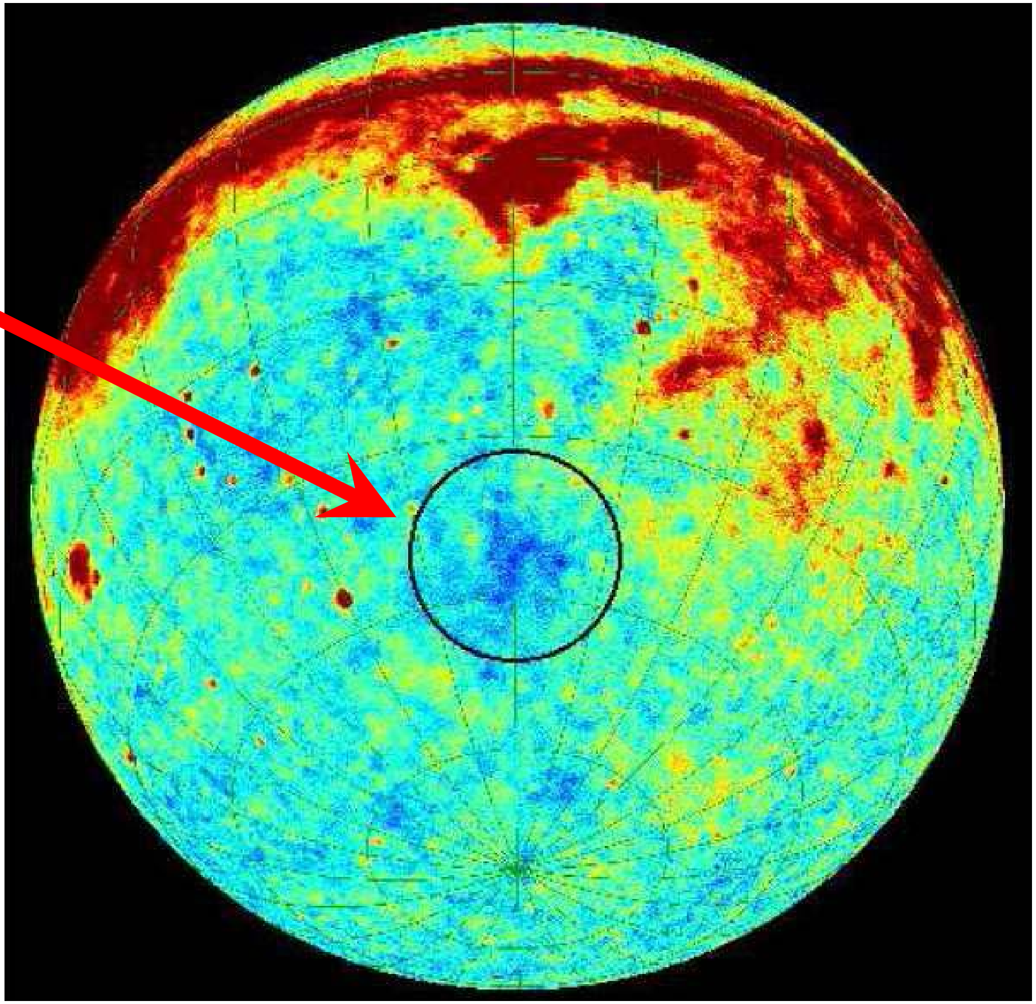
Brane skyrmions and the CMB cold spot

The CMB cold spot

Anomalous **COLD SPOT**, inconsistent with Gaussian fluctuations at position:

b = - 57º , l = 209º

Caracteristic scale ~ 10º.



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

GUT texture or EW-scale brane skyrmion?

SU(2) Non linear Sigma Model texture.
Fractional distortion in the temperature given by:

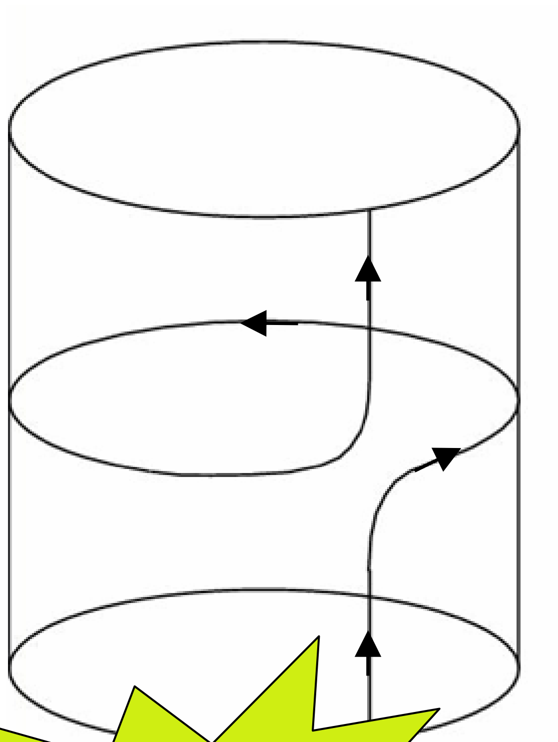
$$\frac{\Delta T}{T}(\theta) = \pm\epsilon\frac{1}{\sqrt{1+4(\theta/\theta_c)^2}} \qquad \begin{aligned}\epsilon &= 7.7\times 10^{-5} \equiv 8\pi^2 G\Phi_0\\ \theta_c &= 5.1^\circ\end{aligned}$$

M. Cruz et *al*. **SCIENCE** 318, no 5856, 1612 (2007).

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

→ **GUT scale**

GUT texture or EW-scale brane skyrmion?



Brane skyrmions: Topologically non-trivial brane configurations

Cembranos, de la Cruz Dombriz, Dobado, Maroto, 2008

Coset space: K = G(B)/H ~ S^3

$$\pi^\alpha : S^3 \rightarrow S^3,\ \pi_3(S^3) = Z$$

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

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

A gate to extra dimensions?

$\varepsilon \sim 7.7 \times 10^{-5}$ → $M_D \sim f \sim 1$ TeV

Conclusions and future perspectives

Low-energy branon dynamics universally described by effective action depending on 3 parameters (M,f,N)

For $f \ll M_D$ only branons and SM particles relevant degrees of freedom.

Limits on (M,f) from present and future colliders

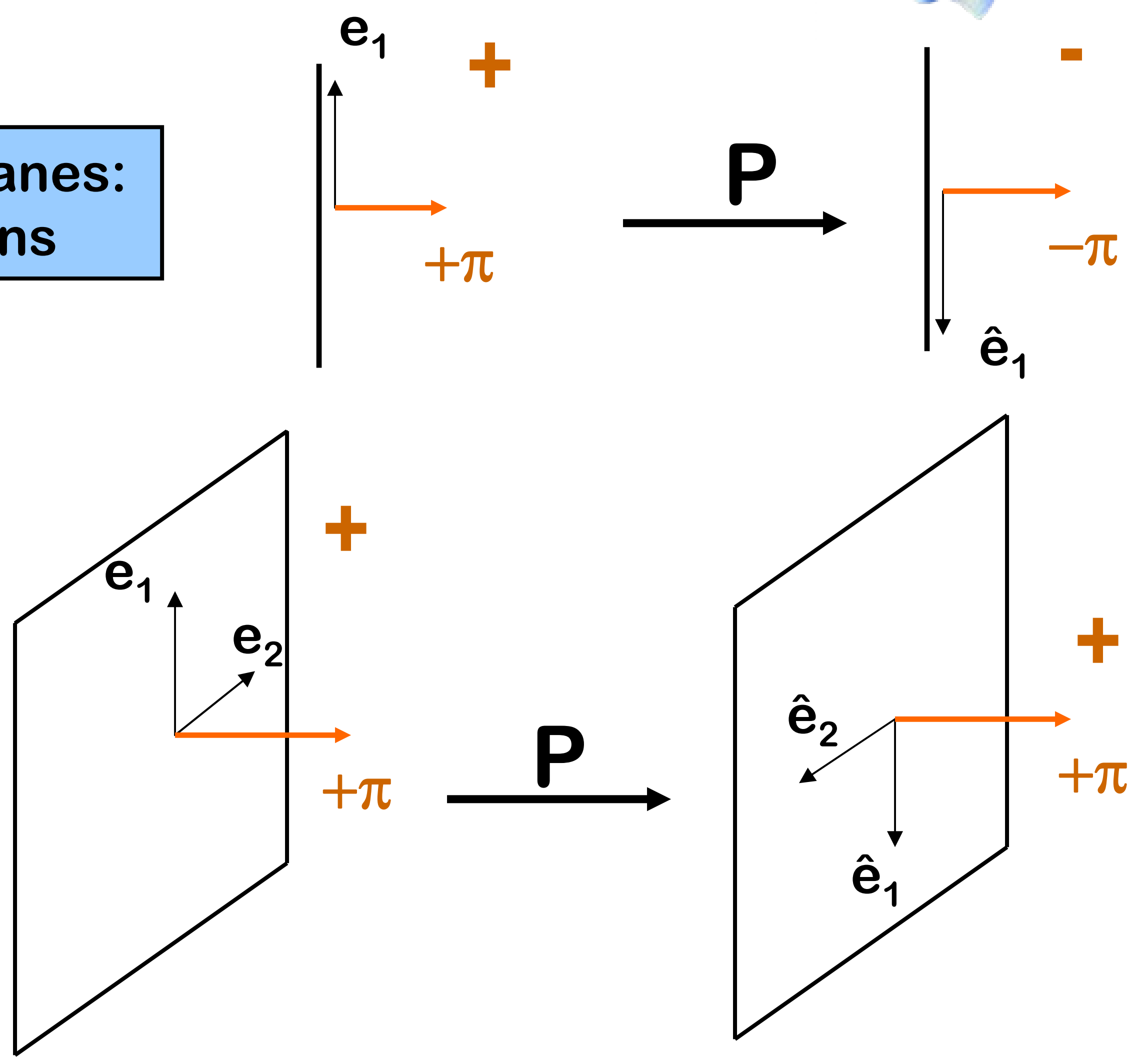
Branons are natural dark matter candidates (either as thermal or non- thermal relics)

Future detection in direct or indirect experiments (or as CMB cold spots?)

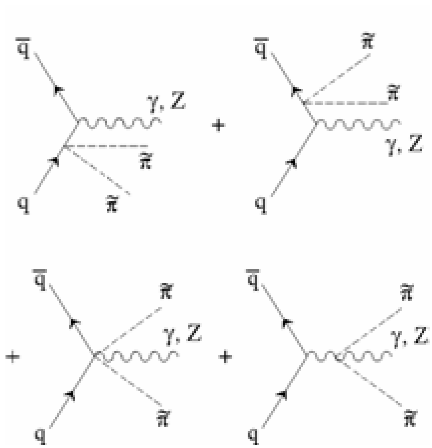
Parity on the brane

Odd-dimensional branes: pseudoscalar branons

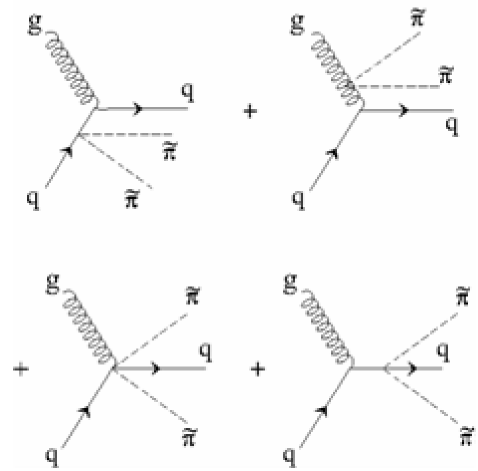
Even-dimensional branes: scalar branons



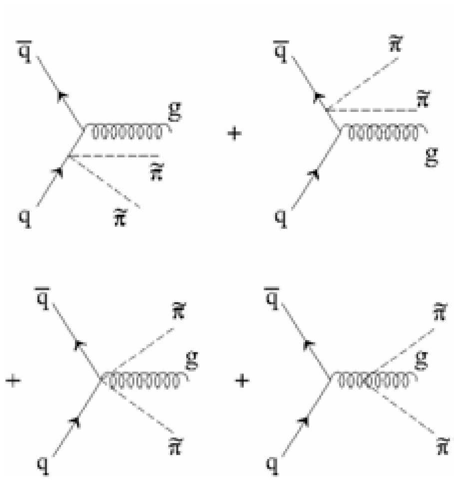
Prospects for future colliders



Single photon-Z



Monojet (quark production)



Monojet (gluon prod.)