

# Universal Extra Dimensions on (Projective) Sphere

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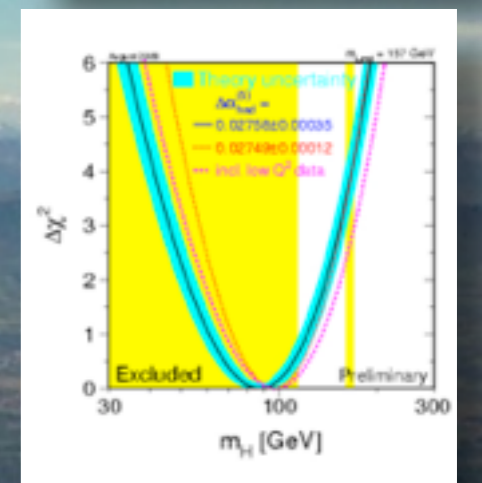
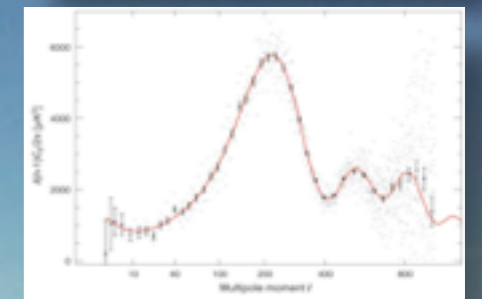
**H. Dohi**

Phys. Lett. B692 (2010) 114



# We Expect New Physics at LHC

- Certainly there exists dark matter.
- There's small tension within EW data:
  - ★ Best fit value  $m_H \sim 90\text{GeV}$  is already excluded by direct search:  $m_H > 114\text{GeV}$ .



※ all above three from web.

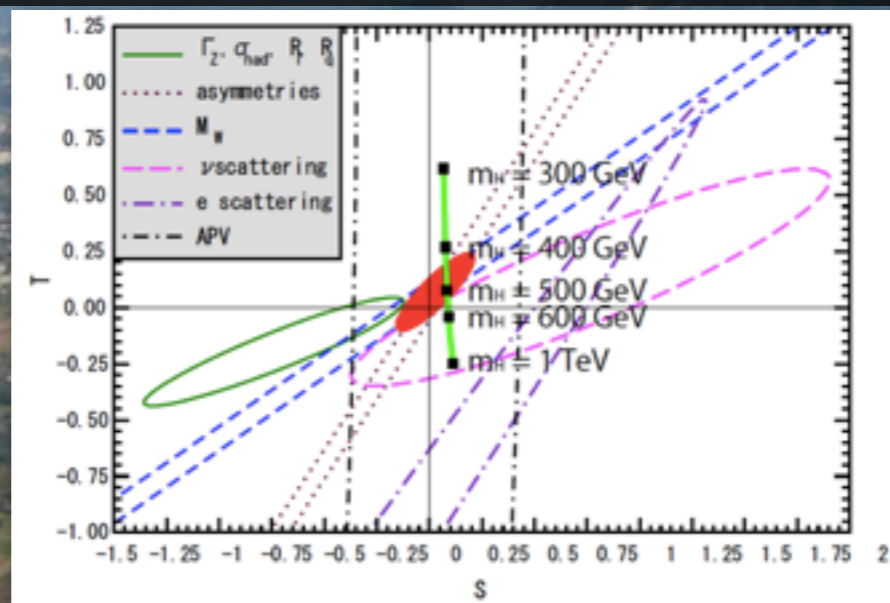


# UED Does the Job!

1. LKP DM stable by extra dimensional momentum/parity conservation by construction.

★ In our model, there is no orbifold fixed point.

2. EW data fit with few # (new parameters).





# Three Generations from 6D UED

Dobrescu, Poppitz (2001)

- ✿ 6D theory is chiral:  $Q_+$ ,  $U_-$ ,  $D_-$ ,  $L_+$ ,  $E_-$ ,  $N_-$ .
- ✿  $SU(2)_W$  global gauge anomaly canceled only when:
  - ✿  $\#(2_+) - \#(2_-) = 0 \pmod{6}$ .
  - ✿ **Three generations required!**



# To Summarize,

- 6D UED gives:
  - ★ stable DM as LKP,
  - ★ three generations.
- Fine, but UED need TeV scale comp'n radius.
  - ★ How can we fix radius at all?



# Outline

- I. Sphere with  $U(1)_X$  flux spontaneously stabilizes comp'n radius.
- II. Projective sphere removes unwanted long-range  $U(1)_X$  force.
- III. 4D-chiral theory from non-orientable manifold.



# Spontaneous Compactification

Randjbar-Daemi, Salam, Strathdee (1983)

- $M^4 \times S^2$  metric ansatz:

$$ds^2 = dx_4^2 + R^2 (d\theta^2 + \sin^2 \theta d\phi^2)$$

- Put monopole-like configuration for bulk  $U(1)_X$  gauge field:

$$A_\phi \sim (n/g_X) \cos\theta.$$

- Then Einstein equation automatically fixes radius

$$R = n/2g_X$$

(in a 6D-Planck unit)



# UED on $S^2$

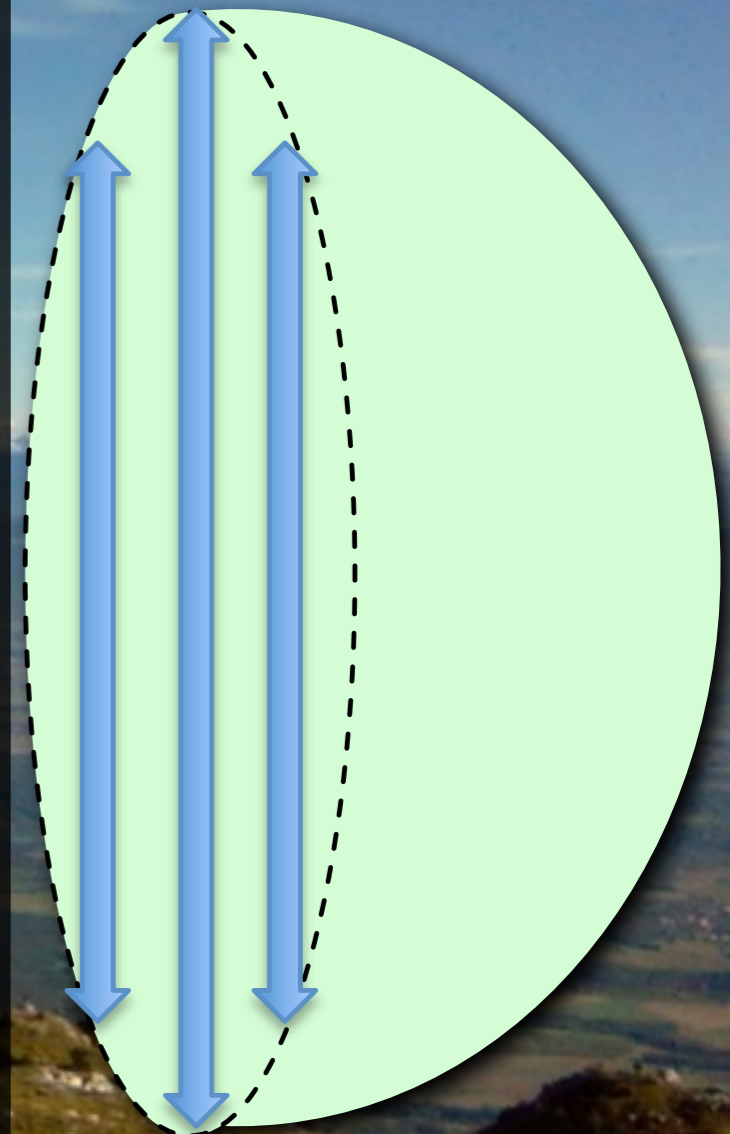
Dohi, KO (2010)

- To get TeV scale comp'n, we need:
  - ★ 6D Planck scale  $\sim 10^7 \text{TeV}$  (in any 6D UED)
  - ★ Very small  $U(1)_X$  coupling:  
$$g_{X4} \sim g_X/R \sim 10^{-15}n$$
- Bonus: on sphere, 4D massless spinor (KK zero modes) become automatically chiral!
  - ★  $U(1)_X$ -flux cancels  $S^2$ -curvature contribution.
- Yukawa's OK. EWSB fine. LKP stable.



# Cf. UED on $S^2/Z_2$ orbifold

- Our UED on  $S^2$  shares all the virtues of  $S^2/Z_2$  orbifold UED by Maru, Nomura, Sato, Yamanaka (2010).
- $S^2/Z_2$  orbifold = half sphere with its boundary orbifolded as  $S^1/Z_2$ .





# So far so good, but...

- There remains massless  $U(1)_X$  vector.
  - ★ SM fields must be charged under it.
  - ★ Torsion balance experiment constrain:  
 $g_{X4} < 10^{-24}$ . (Recall we need  $g_{X4} \sim 10^{-15} n$ ).
  - ★ Naive  $S^2$  UED is excluded.  
(Along with the  $S^2/Z_2$  orbifold UED.)
- We want projection to kill  $U(1)_X$ , while preserving monopole  $U(1)_X$  configuration.
  - ★ Cf. Another cure: put tiny Stueckelberg mass.



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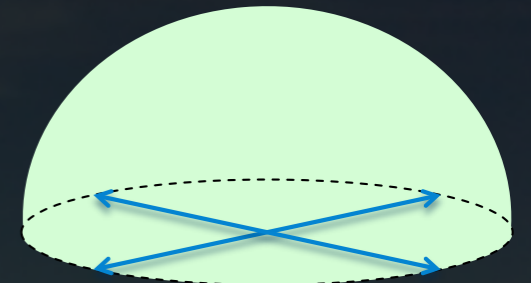
III. 4D-chiral theory from non-orientable manifold.



# Real Projective Plane

- $\mathbb{R}P^2$  obtained from  $S^2$   
by antipodal projection:

$$(\pi - \theta, \phi + \pi) \sim (\theta, \phi)$$



- $U(1)_X$  monopole configuration preserved  
if we twist gauge fields by  
a 6D-CP transformation:

$$A(\pi - \theta, \phi + \pi) = A^{\text{CP}}(\theta, \phi)$$



# Standard Lore:

- ✿ **Non-orientable** space (like our  $RP^2$ ) must preserve either P or CP,
- ✿ because there always be a **closed circuit** whose circulation gives you a parity transformation,

✿ E.g. look down from north:



- ✿ So how can we get a chiral theory at all?



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# Chiral 4D Theory from Non-Orientable Mfd

- Key idea:

- ★ 6D chiral fields  $\Psi_+$  and  $\Psi_-$  are independent irreps of 6D-Lorentz group.

- ★ SM gauge interaction can be 6D-chiral by:

$$\overline{\Psi_+} \Gamma^M \mathcal{A}_M \Psi_+ - \overline{\Psi_-} \Gamma^M \mathcal{A}_M^* \Psi_-$$

- ★ Note: For each  $\Psi_+(-)$ , we add a mirror  $\Psi_-(+)$  and identify:

$$\Psi_+(\pi-\theta, \varphi+\pi) = (\Psi_-)^{\text{CP}}(\theta, \varphi)$$

- ★ How about CP-violating chiral Yukawa?

It's possible if:

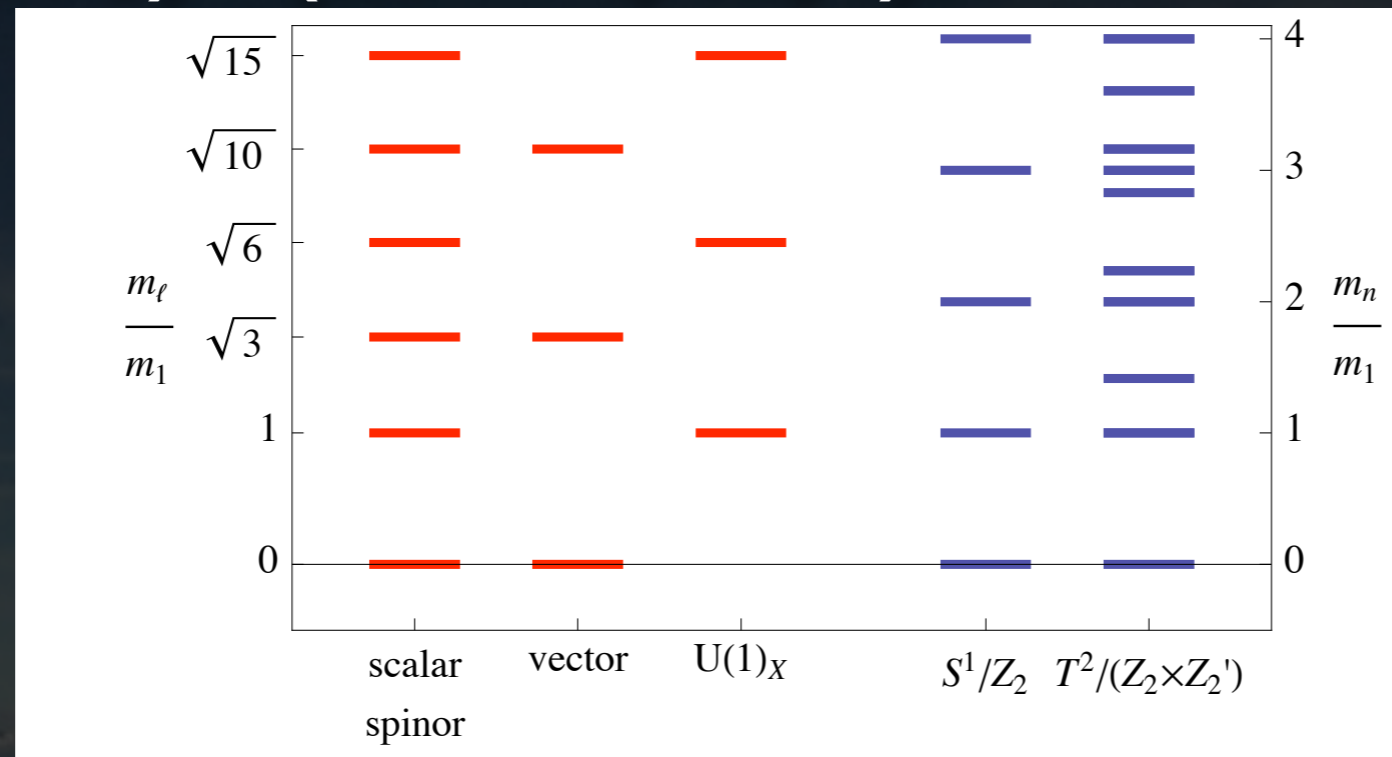
$\Psi$  by 6D-CP      ( $U(1)_X$  charged)

$\Phi$  by 6D-P      ( $U(1)_X$  neutral)



# KK Mass Spectra

- $M^2 \sim l(l+1)$  ( $m = -l, \dots, l$ ).



- Distinctive from ordinary UED (right).
- LKP is not KK photon. (No  $l=1$  mode for SM gauge.)
- ★ When  $U(1)_X$  gauge field is LKP, NLKP DMs annihilate via SM interactions; Survived ones decay to LKP while/after BBN.



# Summary & Discussions

- 6D UED gives 3 families and DM.
  - I.  $S^2$  with  $U(1)_X$ -flux spontaneously stabilizes radius.
  - II. Projective sphere removes unwanted  $U(1)_X$  force.
  - III. 4D-chiral theory from non-orientable manifold.
- DM study and LHC phenomenology being done. Join!!
  - IV. NLKP DMs annihilate via SM interactions; Survived ones decay to LKP while/after BBN.