# Higgs (and XENON1T excess) emerging from the Dark

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Virtual TeraScale Meeting

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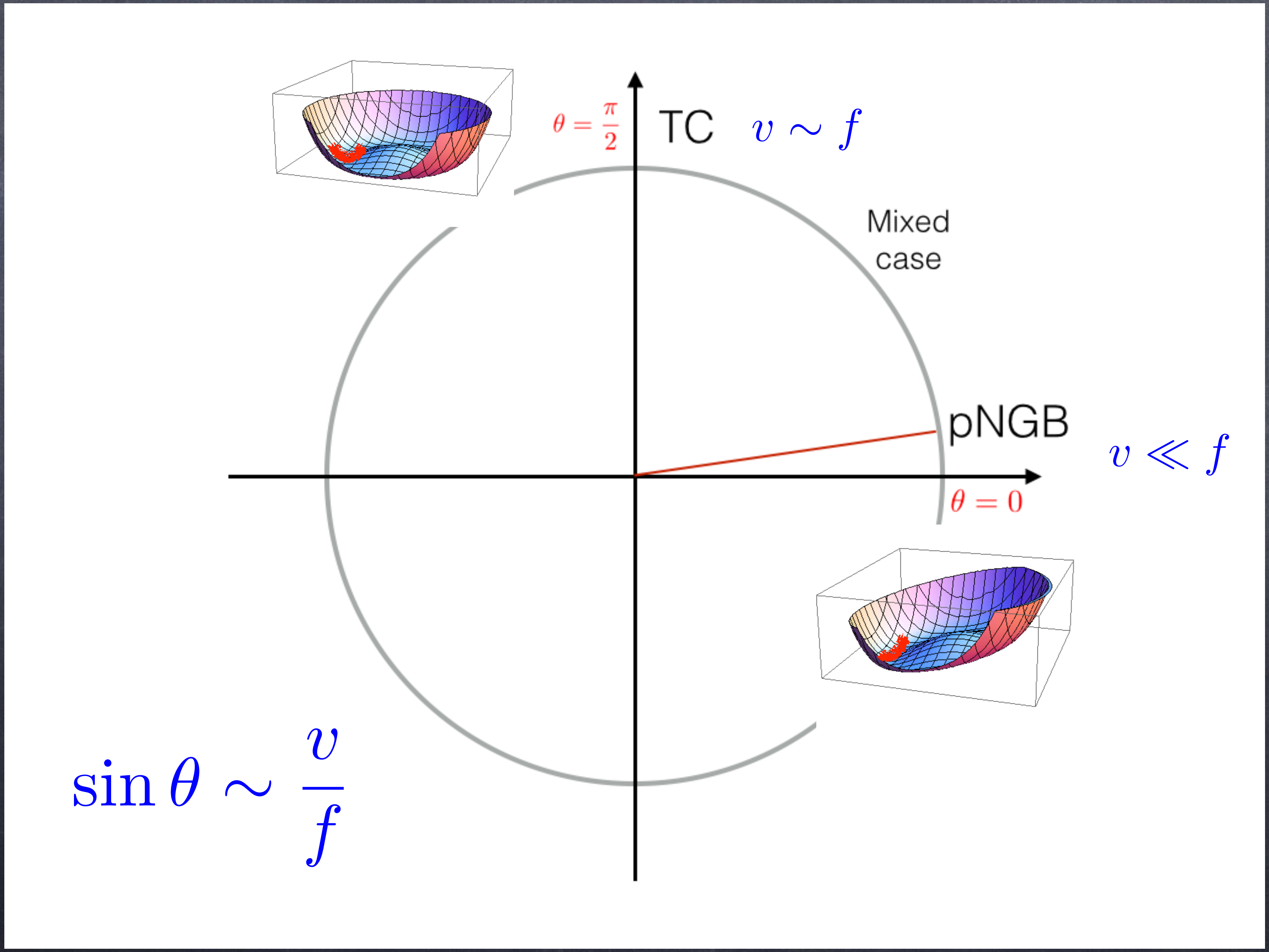
# EWSB by vacuum misalignment



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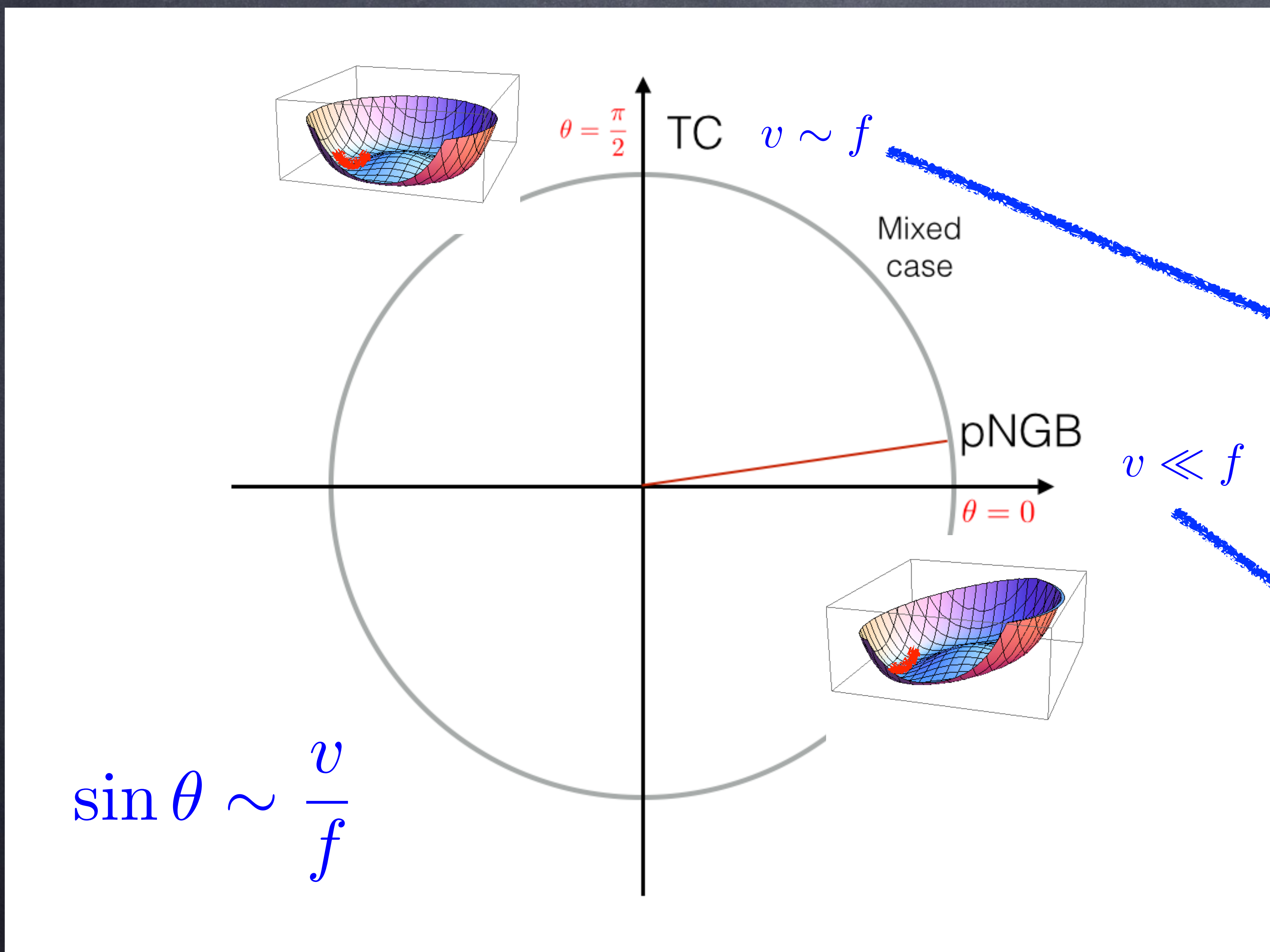



Example:

$SU(4)/Sp(4)$

TC (Higgsless) vacuum:

$Sp(4) \supset U(1)_{\rm em} \times U(1)_X$

Higgs vacuum:

$Sp(4) \supset SU(2)_L \times U(1)_Y$

# EWSB by vacuum misalignment

Extending the model: $SU(6)/Sp(6)$

(to include Dark Matter)

$SU(4)/Sp(4)$

$$\left( \begin{array}{c|c} \mathcal{G}_0/\mathcal{H}_0 & \begin{array}{c}\mathbb{Z}_2\text{–odd} \\ \text{pNGBs}\end{array} \\ \hline \begin{array}{c}\mathbb{Z}_2\text{–odd} \\ \text{pNGBs}\end{array} & \begin{array}{c}\mathbb{Z}_2\text{–even} \\ \text{pNGBs}\end{array} \end{array} \right)$$

| | Higgs vacuum $\theta \sim 0$ | HL vacuum $\theta = \pi/2$ | $q_X$ |
|---|---|---|---|
| $\frac{\mathcal{G}_0}{\mathcal{H}_0}$ | $H_1 = 2_{1/2}$<br>$\eta = 1_0$ | $\phi_X = (h + i\eta)/\sqrt{2}$<br>$\omega^\pm, \; z^0$ | 1<br>0 |
| $\mathbb{Z}_2$–odd pNGBs | $H_2 = 2_{1/2}$<br>$\Delta = 3_0$<br>$\varphi = 1_0$ | $\Theta_1 = -H_2^0 + \frac{\Delta_0 + i\varphi_0}{\sqrt{2}}$<br>$\Theta_2 = (H_2^0)^* + \frac{\Delta_0 - i\varphi_0}{\sqrt{2}}$<br>$\Theta_1^- = \Delta^- - H^-$<br>$\Theta_2^+ = \Delta^+ + H^+$<br>+c.c. | $\frac{1}{2}$ |
| $\mathbb{Z}_2$–even pNGBs | $\eta' = 1_0$ | $\eta'$ | 0 |

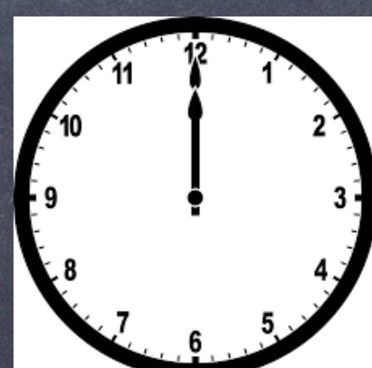
# Higgs emerging from the Dark

G.C., C.Cai, et al: 1911.12130

T

Thermal history of the Universe

$T_{\rm HL} \approx 10$ TeV




The strong interactions confine

The vacuum of the theory sits in the Higgsless vacuum.

An asymmetry in baryon and U(1)X charges is generated!

| $\phi_X$ | $\Theta_i$ |
|---|---|
| (even) | (odd) |

# Higgs emerging from the Dark

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T

Thermal history of the Universe

$T_{\mathrm{HL}} \approx 10\ \mathrm{TeV}$

Higgsless vacuum

$T_*$

The vacuum drifts away from the Higgsless towards the Higgs alignment

The asymmetry stored in the Z2-odd states remains, while...

$$\phi_X \to \frac{h + i\eta}{\sqrt{2}}$$

# Higgs emerging from the Dark

G.C., C.Cai, et al: 1911.12130

Thermal history of the Universe

T

$T_{\rm HL} \approx 10$ TeV

Higgsless vacuum

$T_*$

$$\phi_X \to \frac{h + i\eta}{\sqrt{2}}$$

$T \approx 0$

Vacuum settles on the Higgs vacuum. h is the Higgs!

Relic asymmetry in $\Theta$ , saturates DM.

# What else emerges from the Dark?

$$\phi_X \to \frac{h + i\eta}{\sqrt{2}}$$

$\eta$ is a pNGB associated to U(1)X

As U(1)X is softly broken, this pNGB must remain very light (sub-GeV).

Light axion-like particle (ALP) predicted!

# What else emerges from the Dark?

The light ALP is a perfect candidate for solar axion explanation!

In a composite model:

$$\mathcal{L}_{\rm WZW} = \frac{C_{\rm WZW}}{\Lambda}\eta\left(g^2 W^a_{\mu\nu}\tilde{W}^{a,\mu\nu} - g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu}\right)$$

$$\frac{C_{\rm WZW}}{\Lambda} = \frac{d_\psi \cos\theta}{64\sqrt{2}\pi^2 f}\,,$$

$d_\psi = 4$

$\cos\theta \approx 1$

$f =$ Higgs decay constant

# What else emerges from the Dark?

$$\mathcal{L}_\eta \supset \frac{\partial^\mu \eta}{2} \sum_{\mathrm{f}} \frac{C_{\mathrm{ff}}}{\Lambda}\, \bar{\psi}_{\mathrm{f}} \gamma_\mu \gamma^5 \psi_{\mathrm{f}} + e^2 \frac{C_{\gamma\gamma}}{\Lambda}\, \eta F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{2e^2}{s_W c_W} \frac{C_{\gamma Z}}{\Lambda}\, \eta F_{\mu\nu} \tilde{Z}^{\mu\nu} + \dots$$

Couplings to fermions and photons are loop-generated:

$$\frac{C_{\gamma Z}}{\Lambda} = \frac{C_{\mathrm{WZW}}}{\Lambda}$$

$$\begin{aligned} \frac{C_{\gamma Z}}{\Lambda} &= 0.9 \cdot 10^{-7}\,\mathrm{GeV}^{-1}\,, \\ \frac{C_{ee}}{\Lambda} &= -0.55 \cdot 10^{-8}\,\mathrm{GeV}^{-1}\,, \\ \frac{C_{uu}}{\Lambda} &= -0.60 \cdot 10^{-8}\,\mathrm{GeV}^{-1}\,, \\ \frac{C_{dd}}{\Lambda} &= -0.63 \cdot 10^{-8}\,\mathrm{GeV}^{-1}\,. \end{aligned}$$

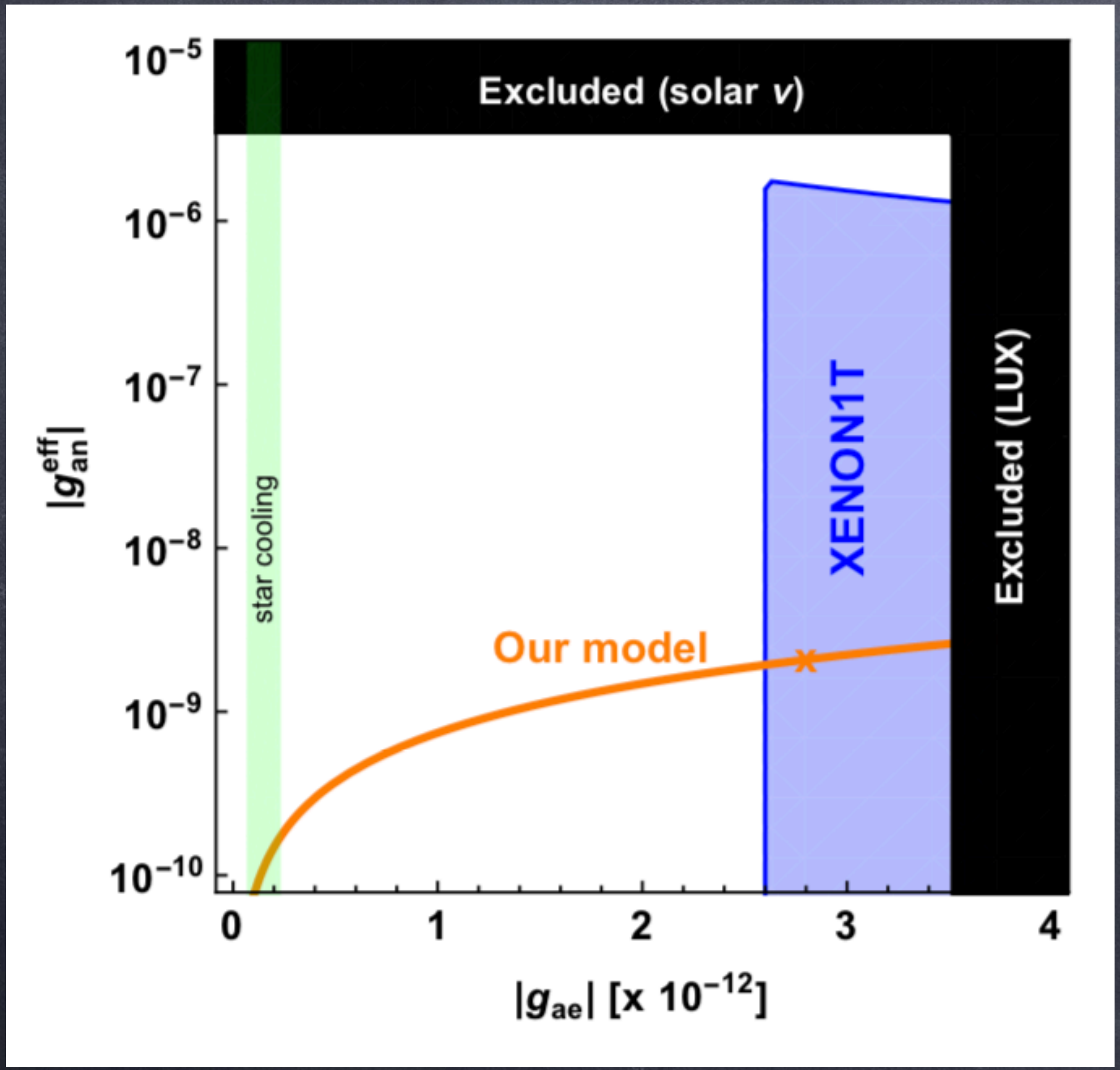
Benchmark:

$f = 50$ TeV

M.Bauer, M.Neubert, A.Thamm: 1708.00443

# XENON1T excess

G.C., C.Cai, et al: 2006.16267




Benchmark:

$$g_{ae} = \frac{m_e C_{ee}}{\Lambda} = -2.80 \cdot 10^{-12}$$

$$f = 36 \div 55 \text{ TeV}$$

Can we make any predictions?

0) very high compositeness scale -> no hope for LHC nor 100 TeV Colliders!

# Prediction 1)

G.C., C.Cai, et al: 2006.16267

Dark Matter mass: $M_{\rm DM} \approx f \approx 50\ {\rm TeV}$

No Direct Detection!

Strong phase transition at $T_{\rm HL} \approx f$

$$\omega_{\rm peak} \approx 1\ {\rm Hz}\ \frac{1}{v_{\rm w}} \left(\frac{\beta/H_*}{1000}\right) \left(\frac{T_{\rm HL}}{100\ {\rm TeV}}\right)$$

Detectable at BBO, Einstein Telescope, Voyager!

# Prediction 2)

G.C., C.Cai, et al: 2006.16267

Z decays into the ALP:

$$\Gamma(Z \to \gamma\eta) = \frac{8\pi\alpha^2(m_Z)}{3s_W^2 c_W^2}\left(\frac{C_{\gamma Z}}{\Lambda}\right)^2 m_Z^3 ,$$

$$6 < \frac{\mathrm{BR}(Z \to \gamma\eta)}{10^{-12}} < 14 .$$

10^-11 reachable at a future TeraZ!

M. Cobal, C. de Dominicis, et al: 2006.15945

# Prediction 3)

G.C., C.Cai, et al: 2006.16267

Top loop generated FC coupling of the ALP to down-type quarks:

$$\mathrm{BR}(K_L \to \pi^0 + \mathrm{inv.}) = 0.5 \div 1.2 \cdot 10^{-11}\,,$$
$$\mathrm{BR}(K^+ \to \pi^+ + \mathrm{inv.}) = 0.12 \div 0.29 \cdot 10^{-11}\,.$$

$$\mathrm{BR}(K_L \to \pi^0 \mathrm{inv})\big|_{\mathrm{KOTO}} = 2.1^{+4.1}_{-1.7} \cdot 10^{-9}\,,$$
$$\mathrm{BR}(K_L \to \pi^0 \mathrm{inv})\big|_{\mathrm{SM}} = 3.0 \pm 0.3 \cdot 10^{-11}\,,$$

Effect in KL up to 40% of the SM prediction.

# Prediction 3b)

G.C., C.Cai, et al: 2006.16267

Top loop generated FC coupling of the ALP to down-type quarks:

$$\mathrm{BR}(B \to K + \mathrm{inv.}) = 3.4 \div 8.0 \cdot 10^{-9}\,,$$
$$\mathrm{BR}(B \to \pi + \mathrm{inv.}) = 1.5 \div 3.4 \cdot 10^{-10}\,,$$

SM predictions:

$$\mathrm{BR}(B \to K\nu\nu) = 4.0 \pm 0.5 \cdot 10^{-6}\,,$$
$$\mathrm{BR}(B^+ \to \pi^+\nu\nu) = 2.4 \pm 0.3 \cdot 10^{-7}\,,$$
$$\mathrm{BR}(B^0 \to \pi^0\nu\nu) = 1.2 \pm 0.15 \cdot 10^{-7}\,.$$