'EXCEPTIONAL' COMPOSITE DARK MATTER

BALLESTEROS, AC, CHALA, ARXIV:1704.05XXX

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PORTOROZ 2017 WORKSHOP

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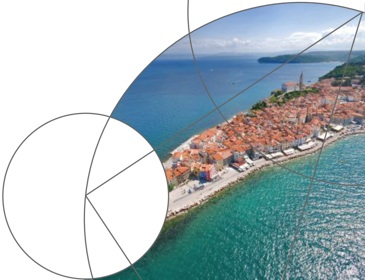
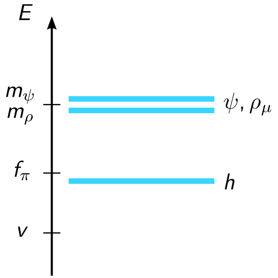
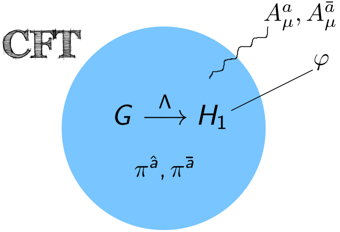


COMPOSITE HIGGS

- One interesting solution to the hierarchy problem is making the Higgs composite, the remnant of some new strong dynamics
  KAPLAN, GEORGI '84

- It is particularly compelling when the Higgs is the pNGB of some new strong interaction. Something like pions in QCD
  AGASHE, CONTINO, POMAROL '04





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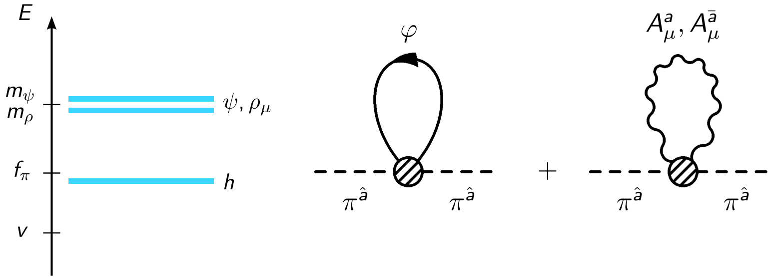

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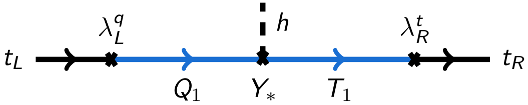
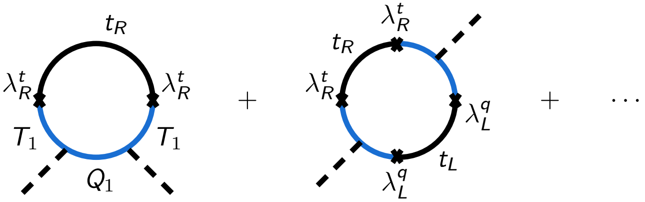
COMPOSITE HIGGS

- The gauge contribution is aligned in the direction that preserves the gauge symmetry WITTEN '83
- However, the linear mixings $\mathcal{L}_{\text{mix}} = \lambda_L^q \bar{q}_L \mathcal{O}_L^q + \lambda_R^t \bar{t}_R \mathcal{O}_R^t + \text{h.c.}$ needed to generate the fermion masses



break the NGB symmetry and will be also responsible for EWSB



THE QUESTION OF DM

- In order to have a DM candidate one needs to go beyond the minimal model
  0902.1483, 1105.5403, 1204.2808, 1409.7391, 1605.08663, ...

- One uses the fact that for a symmetric coset, $[X^a, X^b] = i f_{abk} T^k$ and therefore, if $U = \exp\left(i\Pi^a X^a/f\right)$ and $-iU^{-1}\partial_\mu U = d^a_\mu X^a + E^i_\mu T^i$,

$$d_\mu = \frac{1}{f}\partial_\mu\Pi - \frac{i}{2f^2}\left[\Pi, \partial_\mu\Pi\right]_X - \frac{1}{6f^3}\left[\Pi, \left[\Pi, \partial_\mu\Pi\right]\right]_X + \frac{1}{24f^4}\left[\Pi, \left[\Pi, \left[\Pi, \partial_\mu\Pi\right]\right]\right]_X + \ldots,$$

and

$$\mathcal{L}_\sigma = \frac{1}{2}f^2 \mathrm{Tr}\left(d_\mu d^\mu\right) + \mathcal{O}(\partial^4) \sim 1 + \frac{1}{f^2} + \frac{1}{f^4} + \ldots + \mathcal{O}(\partial^4)$$

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THE QUESTION OF DM

- We can then promote the accidental $\mathbb{Z}_2$ symmetry of $\mathrm{Tr}(d_\mu d^\mu)$ to a symmetry of the strong sector under which some pNGBs will be odd

$$H \to H \qquad \Phi \to -\Phi$$

- One needs to be sure that this symmetry is respected by the fermion linear mixings $\lambda \bar{q} \mathcal{O}$ and is therefore respected by the scalar potential

$$V \sim m_*^4 \frac{N_c}{16\pi^2} \left[\left(\frac{\lambda}{g_*} \right)^2 V_2(c_1, \ldots, c_N) + \left(\frac{\lambda}{g_*} \right)^4 V_4(c'_1, \ldots, c'_{N'}) \right] + \ldots$$

- Then the lightest $\mathbb{Z}_2$-odd scalar will be a DM candidate!

THE CASE OF SO7/G2

FIRST CONSIDERED IN 1210.6208

- It delivers a $\mathbf{7}$ of G_2, that decomposes under $SU(2) \times SU(2) \subset G_2$ as

$$\mathbf{7} = (\mathbf{2}, \mathbf{2}) \oplus (\mathbf{3}, \mathbf{1})$$

- Depending on which $SU(2)$ is weakly gauged, it means that

$$\mathbf{7} = \mathbf{2}_{\pm 1/2} + \mathbf{3}_0 \quad \text{or} \quad \mathbf{7} = \mathbf{2}_{\pm 1/2} + \mathbf{1}_{\pm 1} + \mathbf{1}_0$$

  under the EW group

- If the $\mathbb{Z}_2$ is succesfully enforced it will provide a natural version of Higgs portal DM or the Inert Triplet Model

- The group is non-anomalous but $SO(7)/G_2$ is not symmetric!

The case of SO7/G2

Even though the coset is not symmetric, $f^2\mathrm{Tr}(d_\mu d^\mu)$ only features even powers of $1/f$

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We make

$$q_L \sim \mathbf{35} = \mathbf{1}\oplus\mathbf{7}\oplus\mathbf{27}, \quad t_R \sim \mathbf{1}$$

leading to

$$V(\Pi) \approx m_*^2 f^2 \frac{N_c}{16\pi^2} y_t^2 \left[c_1 V_1(\Pi) + c_2 V_2(\Pi)\right],$$

with $c_{1,2} \lesssim 1$ numbers encoding the details of the UV dynamics

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A NATURAL INERT TRIPLET MODEL

- We consider first the case where the additional pNGBs span a triplet
- At the renormalizable level

$$V(H,\Phi) = \mu_H^2|H|^2 + \lambda_H|H|^4 + \frac{1}{2}\mu_\Phi^2|\Phi|^2 + \frac{1}{4}\lambda_\Phi|\Phi|^4 + \lambda_{H\Phi}|H|^2|\Phi|^2$$

with $H \sim \mathbf{2}_{1/2}$ and $\Phi \sim \mathbf{3}_0$ and

μ_H^2	μ_Φ^2	λ_Φ	$\lambda_{H\Phi}$
$-v^2\lambda_H$	$\frac{2}{3}f^2\lambda_H\left(1-\frac{8}{3}\frac{v^2}{f^2}\right)$	$-\frac{4}{9}\lambda_H\left(1-\frac{8}{3}\frac{v^2}{f^2}\right)$	$\frac{5}{18}\lambda_H\left(1+\frac{32}{15}\frac{v^2}{f^2}\right)$

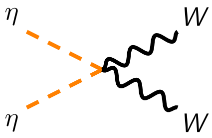
- Extremely predictive, only one free parameter f !
- $\mu_\Phi^2 > 0$ as well as $m_\Phi^2 = \mu_\Phi^2 + \lambda_{H\Phi}v^2 > 0$ so $\langle\Phi\rangle = 0$

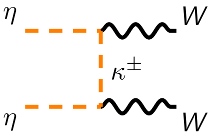
COANNIHILATIONS

- EW gauge bosons induce a radiative splitting between the neutral and the charged components

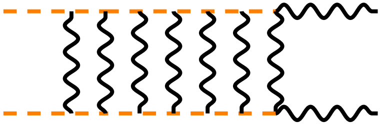
$$\Delta m_\Phi = g m_W \sin^2\theta_W/2 \sim 166\,\text{MeV}$$

- The coannihilation is dominated by gauge interactions



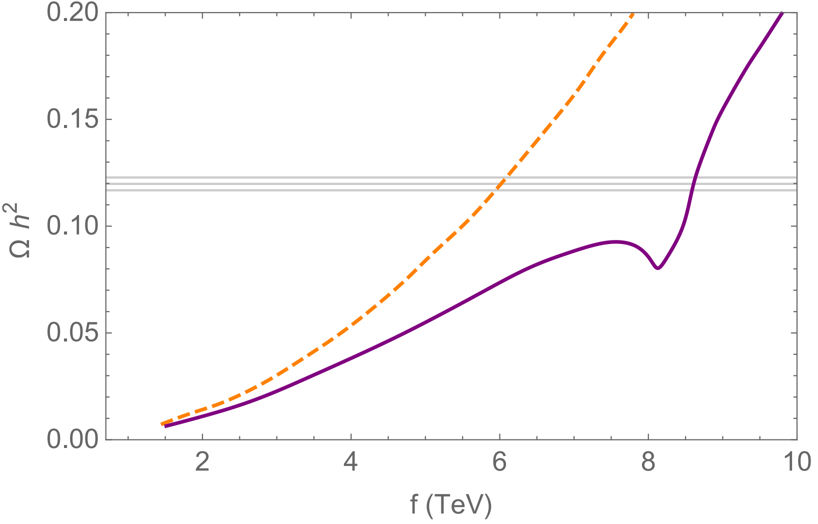


- Sommerfeld enhancement and bound state production are important! $g m_\Phi / m_W \gg 1$ 0706.4071



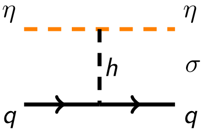
RELIC ABUNDANCE

RECAST OF 0706.4071



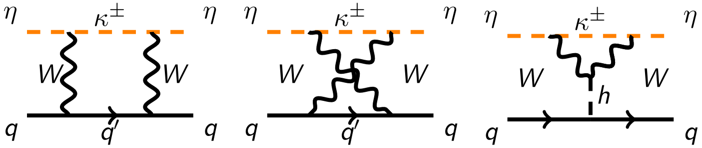
DIRECT DETECTION

- There is a m_Φ^2-suppressed tree-level contribution proportional to $\lambda_{H\Phi}$



$$\sigma = \lambda_{H\Phi}^2 m_N^4 f_N^2/(\pi m_h^4 m_\Phi^2), \quad f_N = \sum_q \langle N|\bar{q}q|N\rangle \approx 0.3$$

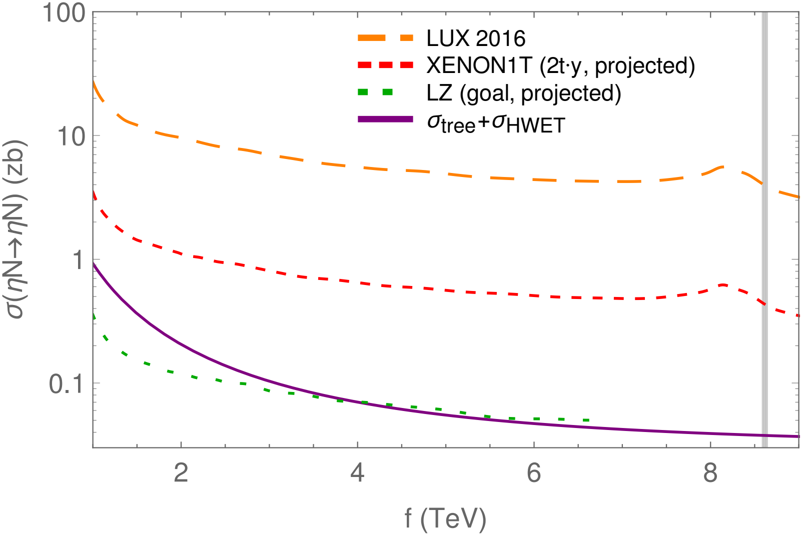
- But there are also m_Φ-independent loop induced contributions



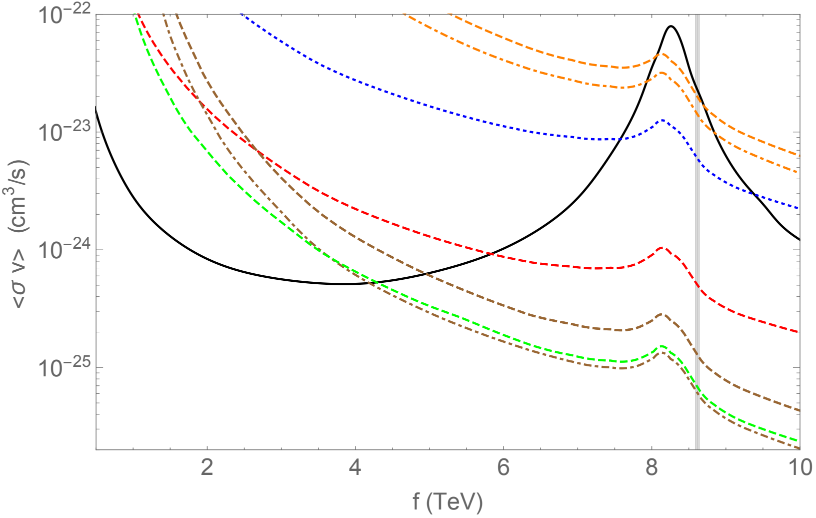
It has been computed in the heavy WIMP effective theory 1309.4092

$$\sigma(\eta N \to \eta N)_{\text{HWET}} = 1.3^{+0.4+0.4}_{-0.5-0.3} \times 10^{-2}\,\text{zb}$$

DIRECT DETECTION



INDIRECT DETECTION



COLLIDER SIGNATURES AND OTHER CONSTRAINTS

- EWPT: modification of hVV coupling $\Rightarrow f \gtrsim 900$ GeV   1511.08235
- Modification of Higgs production and decay

$$R_\gamma = \frac{\sigma(gg \to h) \times BR(h \to \gamma\gamma)}{\sigma_{\rm SM}(gg \to h) \times BR_{\rm SM}(h \to \gamma\gamma)} \sim 1 + \mathcal{O}\left(\frac{v^2}{f^2}\right) \Rightarrow f \gtrsim 800 \text{ GeV}$$

- Searches for dissapearing tracks: κ^+ has a decay length of a few cm

$f \gtrsim 650$ GeV   RECAST OF AN ATLAS 8 TEV ANALYSIS   1310.3675

- Monojet searches are not competitive to the previous ones

THE SINGLET CASE

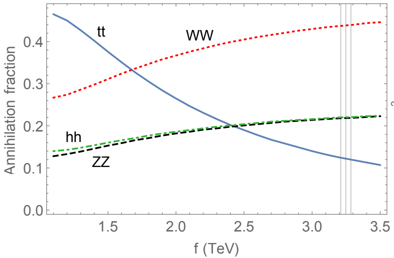
THE SCALAR POTENTIAL

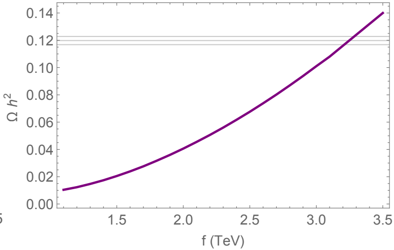
The leading contribution to the scalar potential remains the same but there are subleading contributions

- Breaking the degeneracy of κ^+ and η (coming mostly from B_μ)
- Making $\kappa^\pm$ decay into $t_L b_R$ (coming from the b_R)

RELIC ABUNDANCE

- Sommerfeld effects and bound state production no longer relevant
- $|H|^2(\partial_\mu \eta)^2/f^2$ dominates over $\lambda_{H\Phi}|H|^2\eta^2$





THE SINGLET CASE

DIRECT DETECTION

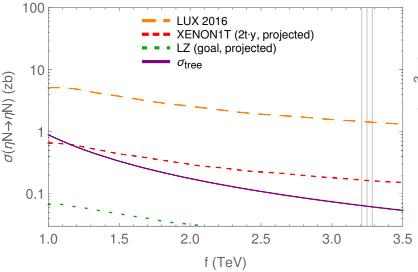
- No m_Φ-independent contribution but the bounds rescale differently

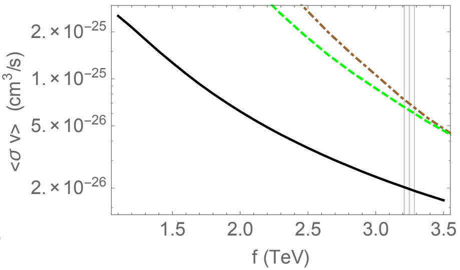
INDIRECT DETECTION

- Now it is possible to accommodate the whole DM abundance

COLLIDER SEARCHES

- Dissapearing tracks are no longer relevant





CONCLUSIONS

- Scalar WIMPs can naturally arise in (a limited number of) non-minimal composite Higgs models.

- Non symmetric cosets can also work

- In particular, the coset $SO(7)/G_2$ leads to natural versions of Higgs portal DM and the Inert Triplet Model

- The model is extremely predictive, having only one free parameter f

$$0.9 \text{ TeV} \lesssim f \lesssim 6\,(3) \text{ TeV} \quad \text{for the triplet (singlet) case}$$

THANKS!