Astrophysical Phenomenology of Light Colored Higgs Triplet

Anna Jankowsky

in collaboration with Gia Dvali & Manuel Ettengruber

PLANCK2024, 4th June

Astrophysical Phenomenology of Light Colored Higgs Triplet

- Introduction
- Mass Range of the Light Triplet
- Cosmological Production
  - Abundance
  - T-Mesons and DM candidates
  - *Td*-Mesons as heavy Neutrons
- Conclusions

Introduction: Who is T and why is it interesting

Triplet $(3, 1)_{+\frac{1}{3}}$

GUTs:

$$SM : SU(3) x SU(2) x U(1) \subset SU(5) \begin{cases} \subset SO10 \\ \subset SU6 \end{cases} \quad \ldots$$

Doublet**T**riplet**S**plitting **Problem**:

$$\begin{pmatrix} T^1 \\ T^2 \\ T^3 \\ H^- \\ H^0 \end{pmatrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{colored} \Rightarrow T - - - \begin{cases} q, q \\ q, l \end{cases} \Rightarrow \text{mediates proton decay} \Rightarrow \text{Yukawas} ⚡$$

Introduction: Who is T and why is it interesting

Solutions:

- **Standard approach:**

  $\Rightarrow m_H$ light and $m_T = \mathcal{O}(M_{GUT})$

- **Decoupled T**: m_H and m_T light, $\Gamma \sim m_T (\frac{m_{3/2}}{M_{GUT}})^2$

  $\Rightarrow \tau >$ seconds: Potentially interesting phenomenology Dvali 1992

$$H_u Q u^c + H_d Q d^c$$

by GUT-breaking couplings vanish $\qquad \downarrow \qquad \downarrow$

$$\cancel{T_u Q L} + \cancel{T_d d_c u^c}$$

Mass Range of the Light Triplet

$$m_T \sim [0.3, 7]\mathrm{TeV}$$

Mass calculated in $MSSM_T$: T included in MSSM $\Rightarrow$ modified RGEs

$$\mu \frac{\partial}{\partial \mu} g = -\frac{g^3}{(4\pi)^2} b_i$$

with adjusted coefficients b_i:

$$b_i^{MSSM_T} = b_i^{MSSM} - T_F(\mathrm{Triplet})$$

Reminder:

$$b_i^{MSSM} = (\frac{11}{3} - \frac{2}{3}) T_G - (\frac{2}{3} + \frac{1}{3}) T_F - (\frac{1}{3} + \frac{2}{3}) T_S$$

with $T_G = \begin{cases} 0 \text{ for } U(1) \\ N \text{ for } SU(N) \end{cases}$ and $T_{S,F} = \begin{cases} \frac{3}{5} Y_{\Phi_i}^2 \text{ for } U(1) \\ \frac{1}{2} \quad \text{ for } SU(N) \end{cases}$

Cosmological Production - Abundance

Thermal production with freeze-out at ($T_* = T_{QCD}$):

$$x_* = \frac{m_T}{T_*} \sim [10^3, 10^4]$$

$$\Omega_T = \frac{\tilde{g}_*^{\frac{1}{2}}}{g_* h_{75}^2} x_*^{\frac{3}{2}} \left(\frac{3 \times 10^{-38} cm^2}{\sigma_*} \right) \sim [10^{-7}, 10^{-6}]$$

- $\sigma_* = 10^{-26} cm^2$
- $\tilde{g}_* = 19.5$ and $g_* = 3$ are the total number of effectively massless d.o.f. for all particles and for the relic respectively
- $h_{75} \sim \mathcal{O}(1)$

Too small to constitute 100% of DM.. BUT...

SUSY: consider also boundstates with $\tilde{T}^c$ antiparticle of its superpartner

Cosmological Production - T-Mesons

T-Meson: boundstate of Triplet with another colored particle: Td, $T\tilde{T}^c$

- $T\tilde{T}^c$**-production:** cf. Redi et al. 2018

  At $T \sim T_{QCD}$:

  T and $\tilde{T}$ confine by picking up a d-quark ($\Omega_{Td} \sim 1$)

  or with each other (small abundance $\Omega_{T\tilde{T}^c} \sim 10^{-14}$).

  Later, at $T \lesssim T_{QCD}$:

  another process is taking place, yielding a much higher abundance of $T\tilde{T}^c$ ($\Omega_{T\tilde{T}^c} \sim 10^{-1} = \Omega_{DM}$):

  $Td + \tilde{T}^c d^c \longrightarrow T\tilde{T}^c + dd^c$

- $T\tilde{T}^c$**-decay:**

  $T\tilde{T}^c \longrightarrow TT^c + \tilde{\Phi}$ with $\tilde{\Phi}$: LSP (Lightest SUSY Particle)

Cosmological Production - T-Mesons

$\sigma_{T\tilde{T}^c} \sim R_{Bohr}^2$? $R_{Bohr} \sim \frac{1}{\alpha_{QCD} m_T}$ cf. Redi et al. 2018

here: both constituents charged $\longrightarrow$ el. dipole moment $\mathcal{D} = \frac{e}{m_T}$

$\Rightarrow \sigma \sim 6.4 \times 10^{-32} Z^2 (\mathcal{D} \times 10^{17})^2 cm^2$ Sigurdson et al. 2004

equating this with the extrapolated linear $\sigma(m)$-function of:

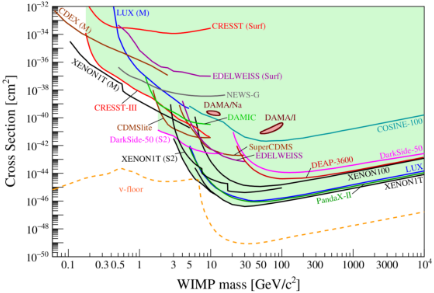

Fig.: Direct detection bounds on dark matter cross sections. Billard et al. 2022

Cosmological Production - T-Mesons

bound on Triplet-Mass: $m_T > 10^8$ GeV $\ll 10^{16}$ GeV

Larger than calculated in $MSSM_T$: We don't have to stick to the minimal case - mass is a free parameter

$\Longrightarrow$ Appropriate DM-candidate!

Cosmological Production - DM-candidate:

- not yet excluded by experimental bounds
- long-lived

- $T\tilde{T}^c$ stable?
  - **no** if $m_T \neq m_{\tilde{T}}$,
    i.e model-dependent LSP (e.g. Neutralino),
    T and $\tilde{T}$ are Next-to-LSP and NNLSP: LSP-DM
  - **yes** for $m_T = m_{\tilde{T}}$: $T\tilde{T}^c$-DM if $m_T > 10^8$ GeV
- Td stable?
  - T: yes (assumption in our project)
  - d: could decay via weak i.a.: $Td \longrightarrow Tu + e^- + \nu_e$
    lifetime: $\tau_T \sim 15min \sim 10^3 sec$

No DM but interesting collider phenomenology (another project..)

Td-Mesons as heavy Neutrons

Td-Meson: same quantennumbers as neutron but

$$\frac{10^2\text{GeV}}{1\text{GeV}} \lesssim \frac{m_{Td}}{m_{neutron}} \lesssim \frac{10^{16}\text{GeV}}{1\text{GeV}}$$

Td is a BBN-particle cf. Kusakabe et al. 2009

⟶ if it exists around us - can it be inside the atoms?
Or will it be stuck inside center of the stars/planets

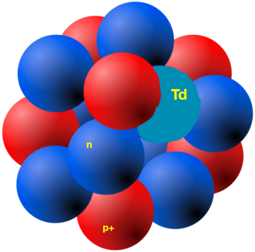

Fig.: Nucleus with Td

Conclusions

- Colored Higgs Triplet is universally predicted by Grand Unification
- This particle can be long-lived and therefore has an interesting phenomenology and cosmology

  cf. Dvali 1992; Dvali 1995; Dvali,Shifman 1997; Dvali,AJ 2020

- Colored Higgs Triplet is not yet excluded by experimental bounds - lead to serious Dark Matter candidates (T-Meson or LSP-DM)
- Open questions: Td-Meson is BBN particle. Can the Td-Meson hide inside our daily life matter? Or accumulate inside the core of our planet?


THANKS

BackUp: Abundance of Td- vs. $T\tilde{T}^c$-Meson

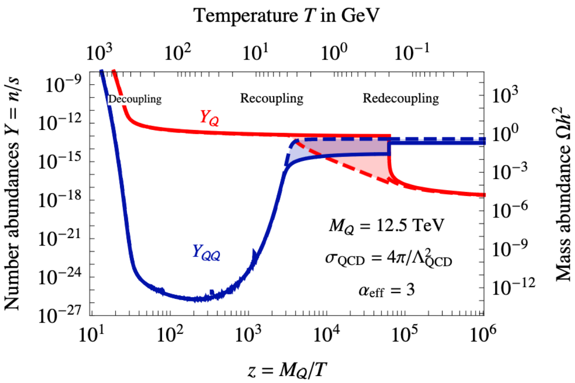

Fig.: Cosmological evolution of the abundances of Q states and of QQ DM states for $MQ = 12.5$ TeV. The uncertain phase at $T \geq \Lambda_{QCD}$ negligibly affects the final relic abundances: the dashed curves assume non-perturbative effects before confinement estimated as $\sigma = \sigma_{QCD} \frac{\Lambda_{QCD}}{T}^2$; the solid curves neglect such effects. The mass abundance on the right axis is computed assuming QQ particles with mass 2MQ. Redi et al. 2018

BackUp: SO(10)-example for Decoupled Triplet Dvali 1992

To generate quark and lepton masses:

- standard version of SO(10): $g10 \otimes 16 \otimes 16$ ↯
- pair of hypothetical heavy supermultiplets $144 + \overline{144}$ which couple to 45, 10 and 16:

  $$W = g16\gamma_i \overline{144}_k \otimes 45_{ik} + M_{144}\overline{144}_k \otimes 144_k + g' 16 \otimes 144_k \otimes 10_k$$

  with $M_{144} \sim M_{GUT}$

  Effective operator for energies below M_{GUT}:

  $\frac{gg'}{M_{144}} 45_{ik} 10_k \otimes 16\gamma_i 16 \Rightarrow$ Yukawa with Higgs Triplet suppressed