Adjoint Dark Matter

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Outline

- *Technicolor model & dark matter (WIMP)*
- *The WIMP density and mass mixing*
- *Model results*
- *Conclusion*

Basic idea of Technicolor (TC)

- New gauge interaction TC which only technifermions feel
- Left and right handed fermions (massless) have SU(2) chiral symmetry

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Technifermion condensate = a composite Higgs
(+ (pseudo) Goldstone bosons)

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- **<u>Spontaneus symmetry breaking dynamically</u>**
  - ➢Electroweak symmetry breaking
  - ➢Right mass ratio for EW gauge bosons

Early Universe
High Temperature
T > TeV

Universe expands,
T drops

$T_{EW} \approx 100\ GeV$

Minimal Walking TC (MWTC)

- **Model**: Two techniquarks(flavors) in two index symmetric (= adjoint) presentation of an SU(2) TC gauge group. $\begin{pmatrix} U^{\{c_1,c_2\}} \\ D^{\{c_1,c_2\}} \end{pmatrix}_L$ $\left(U_R^{\{c_1,c_2\}}, D_R^{\{c_1,c_2\}}\right)$
- Witten anomaly ➡ cured by introducing a new heavy lepton family $\begin{pmatrix} E^- \\ N \end{pmatrix}_L$
- Model is consistent with electroweak precision measurements (e.g. Antipin, Heikinheimo,Tuominen arXiv:09050622)

• Near conformal (=walking) → FCNC's suppressed.

(Sannino & Tuominen, hep-ph/0405209)

MWTC & SM-unification

- **Model**: Three additional Weyl fermions (TC singlets):
  One, $\tilde{g}$ in adjoint representation of QCD color (”gluino”)
  One, ω in adjoint representation of $SU(2)_L$ (”wino”)
  One, β singlet under all SM charges (”bino”)

- No fundamental scalars (Higgs) = No hierarchy problem

- MSSM like SM coupling constants unification (one loop)

(Gudnason, Ryttov & Sannino , hep-ph/0612230)

Unification motivated WIMP

- Assume $\tilde{g}$ "gluino" is heavy and decoupled
- The ω "wino" is $SU(2)_L$ triplet state (hypercharge singlet) $\omega = \begin{pmatrix} \omega^+ \\ \omega^0 \\ \omega^- \end{pmatrix}$
- The β "bino" (SM singlet) effects only by mass mixing
- Implement Z_2 symmetry $(\omega^a \to -\omega^a, \beta \to -\beta)$ (R-parity SUSY)

- ω^0 neutral "wino" and β "bino" mass mix and form two Majorana particles χ_1, χ_2 ➡ the lighter is stable (Z_2) and good candidate for dark matter: χ_2 the WIMP

Relic density from Lee-Weinberg equation

- Biggest effects to final abundance of the Adjoint DM particles comes from the **cross section** and **Hubble parameter**

Our mass mixing case and SUSY

$$\frac{\partial f(x)}{\partial x} = \frac{\langle v\sigma \rangle m_N x^2}{H}\left(f^2(x) - f_{eq}^2(x)\right)$$

Our earlier Model

$$H = \sqrt{\frac{8\pi G_N}{3}\rho_{rad,0}\left[h\left(\frac{a_0}{a}\right)^4 + r\left(\frac{a_0}{a}\right)^6\right]}$$

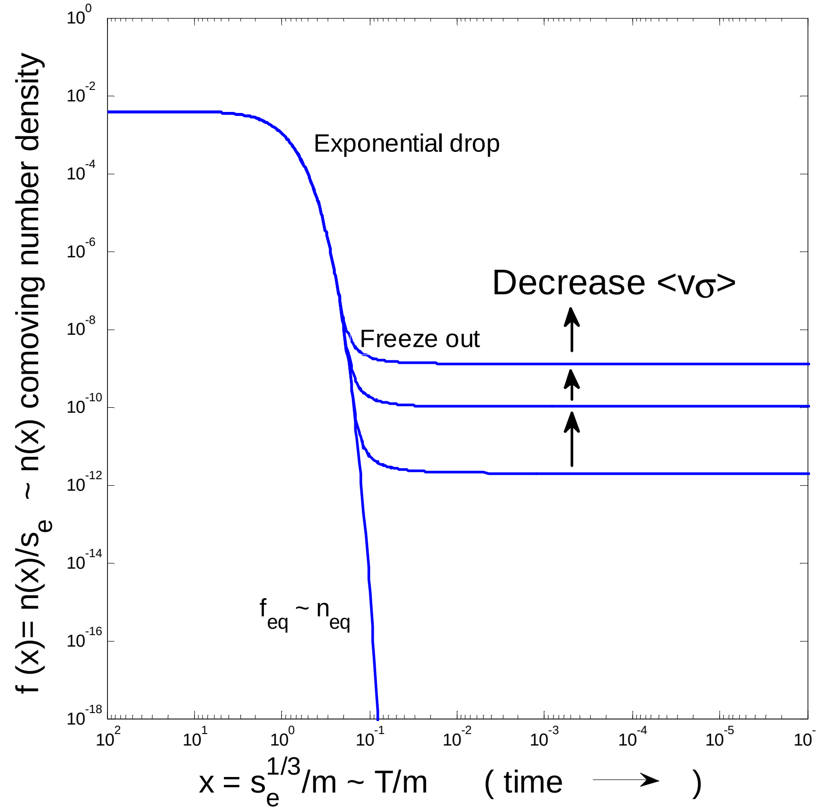
$$r = \frac{\rho_{Q,0}}{\rho_{rad,0}}$$

"0" means T = 1 MeV

$\rho_{rad} \propto a^{-4}$ — **Standard model**

$\rho_Q \propto a^{-6}$ — **Dynamical dark energy**

(Kainulainen, Tuominen, Virkajärvi, hep-ph:0612247)



Effective Mass Lagrangian

Non-renormalizable operators: dimension five

$$L_{Mass} = \frac{\lambda_L}{\Lambda}(H^\dagger \overline{\omega}\omega H) + \frac{\lambda_D}{\Lambda}(\overline{\beta}H^\dagger \omega H) + h.c + \frac{\lambda_R}{\Lambda}(\overline{\beta}\beta H^\dagger H) + \ h.c \quad or \quad y_R S\ \overline{\beta}\beta + \ h.c$$

Scenario1 — Scenario 2

Triplet "wino": $\omega = \omega^a \tau^a$
SU(2) generators: $\tau^a = \sigma^a / 2$

Singlet "bino": β
Composite Higgs doublet: H
Composite singlet: S

Spontaneus symmetry breaking: Composite Higgs gets VEV

$$H \to \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ h+\upsilon \end{pmatrix}$$

Most general mass term for the Adjoint dark matter:

$$-2L_{mass} = \begin{pmatrix} \overline{\omega}_L{}^C & \overline{\beta}_R \end{pmatrix} \begin{pmatrix} M_L & m_D \\ m_D & M_R \end{pmatrix} \begin{pmatrix} \omega^0{}_L \\ \beta_R{}^C \end{pmatrix} + h.c.$$

$M_{L,R} = 4\lambda_{L,R}\upsilon^2 / \Lambda$
or $M_R = 4 y_R \upsilon_S$
$m_D = -2\lambda_D \upsilon^2 / \Lambda$

Mass mixing and Ann. Cross section

- **Diagonalize mass matrix:**

  Two **MAJORANA** particles: χ_1 and χ_2

  Three parameters: m_1, m_2, θ , *and* $m_1 > m_2$

  - $If\ m_D^2 < M_L M_R\ then\ m_1, m_2 > 0\ (\rho_2 = +1).$
  - $If\ m_D^2 \geq M_L M_R\ then\ extra\ phase\ \rho_2 = -1$,

  $so\ that\ m_2 = \rho_2 \lambda_2 > 0,\ m_1 > 0.$

- **Couplings to gauge bosons:**

  $$W_\mu^- \overline{\omega}^- \gamma^\mu \omega^0 = W_\mu^- \left[\sin\theta\, \overline{\omega}_L^- \gamma^\mu \chi_{2L} + \rho_2 \sin\theta\, \overline{\omega}_R^- \gamma^\mu \chi_{2R}\right] + \ldots$$

  $\omega^0\ doesn't\ couple\ to\ Z - boson$

- **Couplings to composite Higgs**

- **Thermally averaged annihilation cross section**:

$$\chi_2 \overline{\chi}_2 \to f_i \bar{f}_i (via\ h^0)$$
$$\chi_2 \overline{\chi}_2 \to W^+ W^-$$
$$\chi_2 \overline{\chi}_2 \to Z^0 Z^0 (via\ h^0)$$
$$\chi_2 \overline{\chi}_2 \to h^0 h^0$$

$$< \sigma v >_{\chi_2} \sim \quad f(\sin\theta) < \sigma v >_{USUAL\ WIMP(heavy\ majorana\ neutrino)}$$

Things effecting to results

- **Two β mass scenarios:** Scenario 1 / Scenario 2 — **different Higgs couplings**

- **Phase factor ρ_2 choice in Mass matrix diagonalization:** $\rho_2 = \pm 1$, $m_2, \theta,$ $(\rho_1 = +1, m_1 = 2m_2)$

- **Higgs mass** m_{Higgs}

- M_L **is related to charged states mass (LEP limits)**

$$-2L_{mass} = \begin{pmatrix} \overline{\omega}_R^{\,-} & \overline{\omega}_R^{\,+} & \overline{\omega}_R^{\,0} & \overline{\beta}_R \end{pmatrix} \begin{pmatrix} 0 & M_L & 0 & 0 \\ M_L & 0 & 0 & 0 \\ 0 & 0 & M_L & m_D \\ 0 & 0 & m_D & M_R \end{pmatrix} \begin{pmatrix} \omega^{+}{}_L \\ \omega^{-}{}_L \\ \omega^{0}{}_L \\ \beta_R{}^C \end{pmatrix} + h.c.$$

Model results

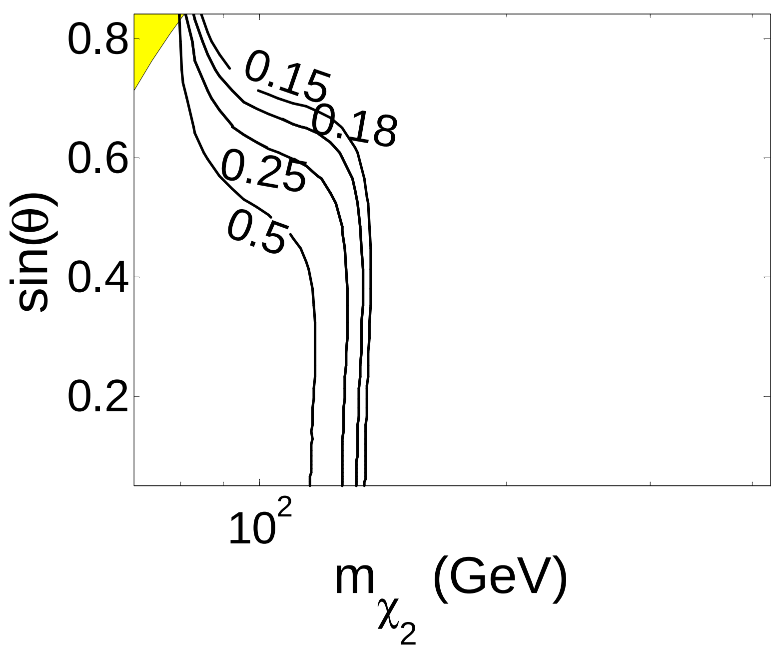
From Lee-Weinberg equation

$$\Omega_{\chi_2} = 1.09\times10^6 \tfrac{1}{2} m_{\chi_2} f(0)$$

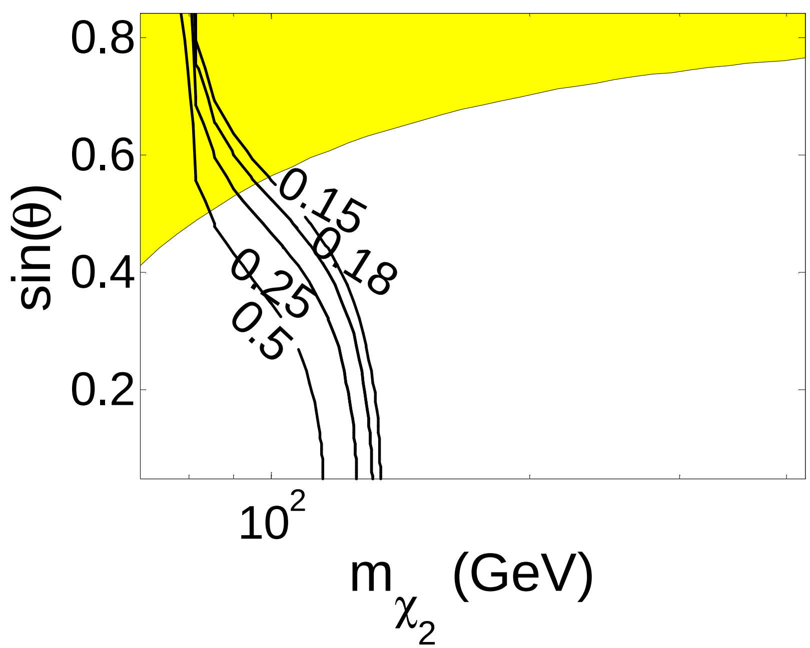
Area between 0.18 - 0.25 contours compatible with WMAP results

Shown $\Omega_{\chi_2}(m_{\chi_2}, \sin\theta)$ constant contours

$Scenario = 1,\ \rho_2 = +1,\ m_{Higgs} = 500\ GeV$

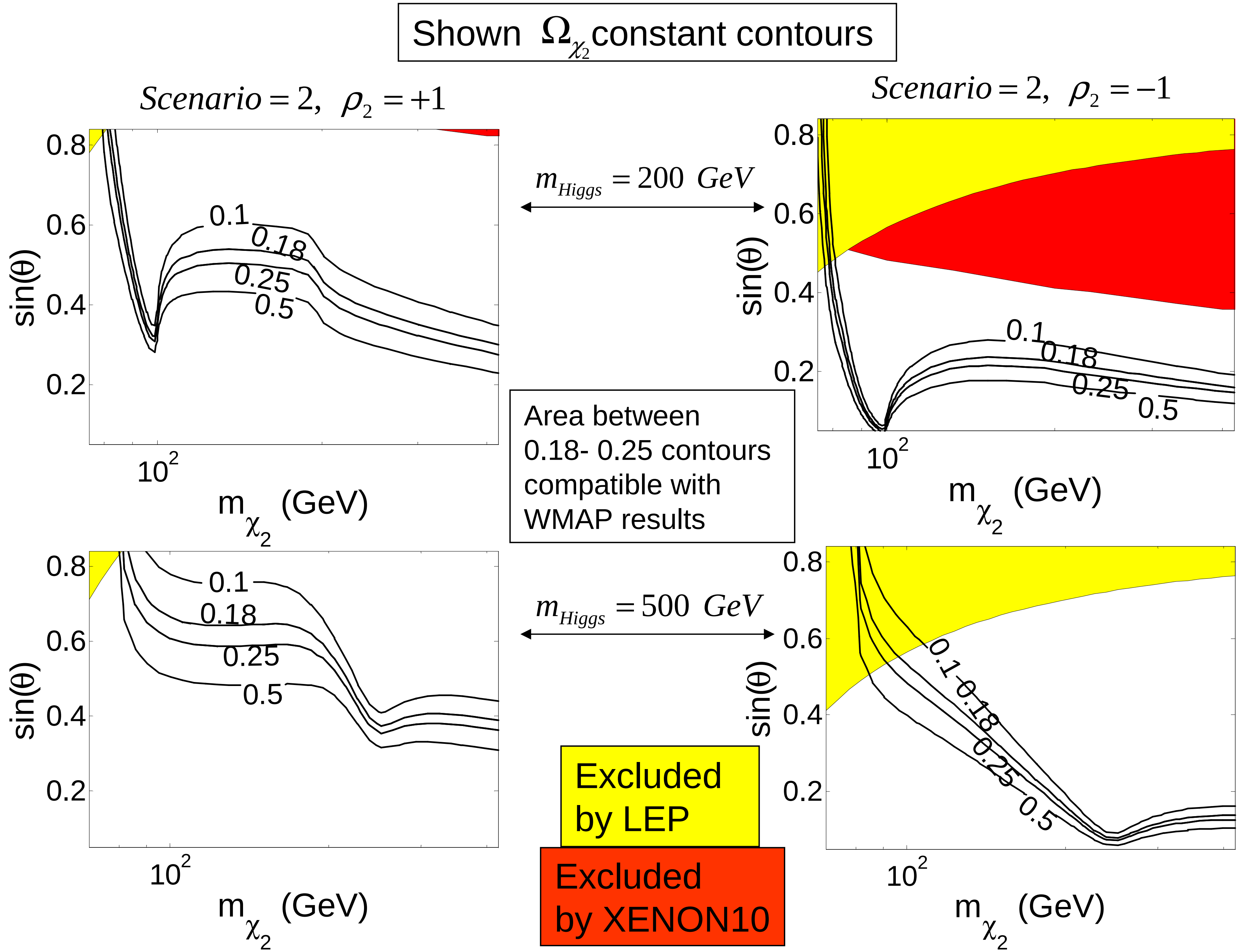


$Scenario = 1,\ \rho_2 = -1,\ m_{Higgs} = 500\ GeV$



Yellow area Excluded by LEP: $\sqrt{s} \le 209\ GeV$ *i.e.* $M_L \equiv m_{\omega^\pm} \le 104.5\ GeV$

Red area Excluded by XENON10 experiment results 2008



Shown Ω_{χ_2} constant contours
$Scenario = 2, \ \rho_2 = +1$
$Scenario = 2, \ \rho_2 = -1$
$m_{Higgs} = 200 \ GeV$
$m_{Higgs} = 500 \ GeV$
sin(θ)
0.8
0.6
0.4
0.2
0.1
0.18
0.25
0.5
10^2
m_{χ_2} (GeV)
Area between 0.18- 0.25 contours compatible with WMAP results
Excluded by LEP
Excluded by XENON10

Conclusion

- In **standard expansion** case from mixed Dirac-Majorana mass term:
  - Annihilation cross section smaller ($f(\sin\theta)$) than in the case of usual WIMP (for example heavy Majorana neutrino).
  - Mainly right handed Adjoint fermion with m > 80 GeV candidate for dark matter: not excluded by LEP or cryogenic direct searches.
- Model gives (in Non-SUSY framework)
  - Solution for hierarchy problem
  - SM-coupling constants unification
  - A natural dark matter candidate

With modest new matter content