SuperWIMP dark matter and the prospects for future colliders

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Dark matter is one of the best evidence for new physics

WMAP DATA

$\Omega_{DM} = 0.23 \pm 0.04$

$\Omega_{Total} = 1.02 \pm 0.02$

$\Omega_{baryon} = 0.044 \pm 0.004$

More than 90 % is dark in our universe

What is the dark matter ? Why is the relic $\Omega \sim O(0.1)$?

Stable, Nonbaryonic....

Dark matter and a connection to New TeV scale physics

SUSY / Extra Dimension

~ hierarchy problem

The extension introduces a partner/partners of SM particles and graviton
Super-partner / KK towers

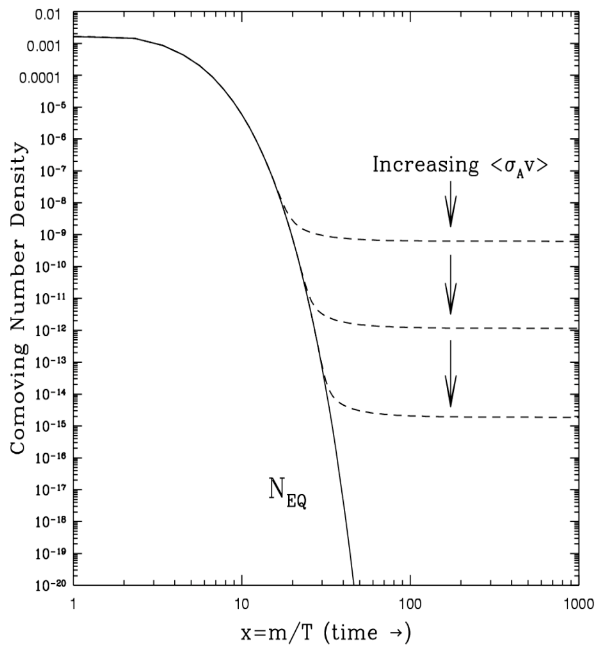
The stability of the lightest partner is ensured by Z_2 parity.

SUSY: R parity (forbid dim4 B, L violating terms)
ED : KK parity (a remnant of translational invariance for Extra Dims)

→ The lightest partner is a candidate of dark matter.

Neutralino/1st KK B gauge boson: candidates of WIMP dark matter

Weakly Interacting Massive Particle



$$\Omega \sim O(\ 0.1\ )\ (\ x_F\ /\ 20\ )(\ 10^{-9}\,\mathrm{GeV}^{-2}\ /\ \langle\sigma\ v\rangle\ )$$

$$x_F = m/T \sim 6/v^2$$

$$\langle\sigma\ v\rangle\ \sim\ O(\alpha^2/m^2\,)\ v^{2J} + \ldots.$$

For EW interaction

(Neutralino, charged slepton, sneutrino)

m ~ O(0.1-1TeV) ⇔ $\Omega\ \sim O(0.1)$

For colored interaction

(squark, gluino)

m ~ O(10-100TeV) ⇔ $\Omega \sim O(0.1)$

SUSY/Extra Dim

→ a connection between Gravitational and Particle Physics

Partner of graviton = superWIMP

Weak scale Gravitino/ 1st KK graviton could be the lightest partner.

Only gravitational interaction with SM particles and the partners

Recent analysis for gravitino LSP: J.L.Feng, A.Rajaraman, F.T (2003),
J.Ellis, K.Olive, Y.Santoso, V.Spanos (2003)
L.Roszkowski, R.R. de Austri (2004)
($1/Mpl^2$ not $1/F$ approximation)

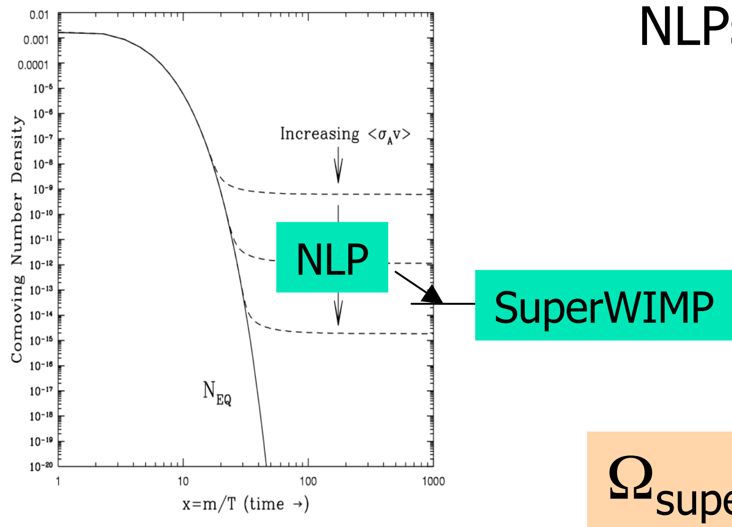
Next Lightest Partner(NLP) can decay into only the lightest partner.
→ long-lived due to the smallness of the coupling with superWIMPs

(New particle: Z_2 odd, SM particles: Z_2 even)

No natural explanation for $\Omega_{DM}=O(0.1)$?

SuperWIMPs naturally inherit the virtue of parent particles, NLPs..

J.Feng, A.Rajaraman, F.T (2003)



NLPs (=WIMP) obtain the desired relic density through the decoupling from thermal bath.

↓ After decoupling of NLPs

NLP → superWIMP+SM

$$\Omega_{\rm superWIMP} \sim (m_{\rm superWIMP}/m_{\rm NLP})\Omega_{\rm NLP} \sim \Omega_{\rm NLP}$$

$(m_{\rm WIMP} \sim m_{\rm superWIMP})$

(This feature may be also shared by axino DM in SUSY model etc)

The relic is insensitive to the detail of the Early Universe before decoupling of NLPs from thermal bath.

SuperWIMP dark matter scenario

Lifetime of NLP, τ_{NLP}

Gravitino LSP, KK Graviton

$$\tau_{NLP} \sim O(M_{pl}^2/(m_{NLP}-m_{superWIMP})^3\ ) \sim 10^{(4\text{-}8)}\text{sec}$$

Mass of NLP and superWIMP

Energy release $E \sim (\ m_{NLP}^2 - m_{superWIMP}^2\ )\ /\ 2m_{NLP} \sim \Delta\, m \sim O(\ m_{EW})$

(2 body decay case)

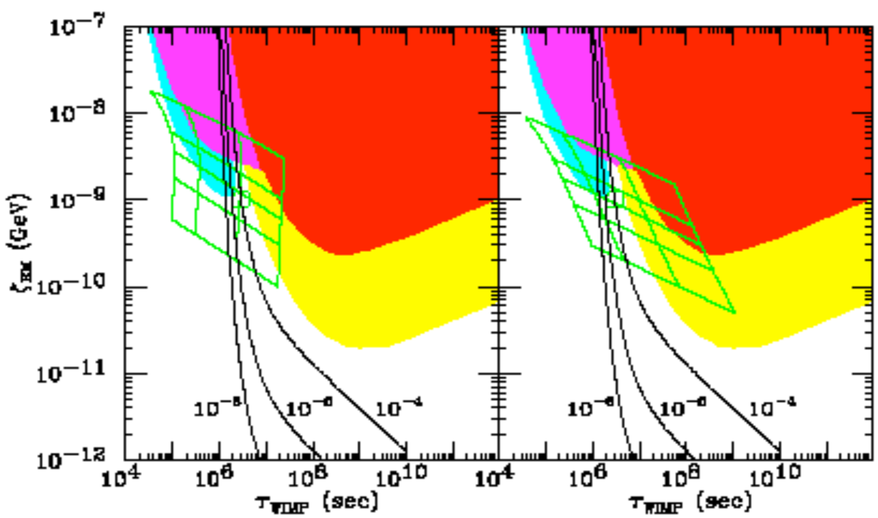
Relic abundance of NLP, n_{NLP}

A Kind of NLP

Neutral/Charged/Colored Scalar/Fermion.....

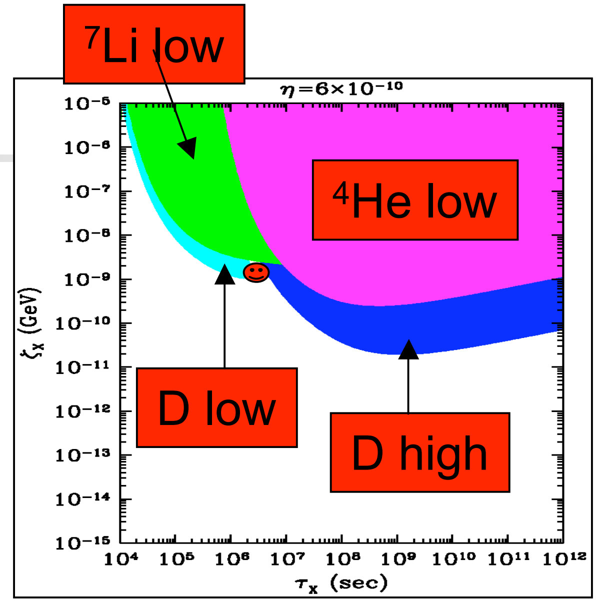
The Diffuse Microwave Emission Survey(DMIES) will be able to cover the interesting region to explain low ^{7}Li.

Gravitino LSP



Neutralino→G+γ

Stau→G+τ



R.Cyburt,J.Ellis,B.Field,K.Olive (2002)
(For EM energy injection)

Current limit
$\mu < 9\ 10^{-5}$

DIMES
$\mu < 2\ 10^{-6}$

J.Feng, A.Rajrararaman, F.Takayama, Phys.Rev.D68 (2003) 063504

Energy Injection after BBN era
: Effect of EM cascade after SBBN era (100sec)

J.Ellis,K.Olive,Field AstroPhys,
M.Kawasaki、K.Kohri, T.Moroi Phys.Rev.D
....

Injected high energy γ quickly thermalize
...BBN constrains total energy release

$$\zeta = \varepsilon\gamma\ n_{SWIMP}/n\gamma = \varepsilon\gamma\ Y_{SWIMP}$$

$$\gamma + \gamma_{BG} \rightarrow e^{+} + e^{-} \quad :E > E_{th}=m_e^{2}/22T$$

Constraints are weak for earlier decay .

Suppression of photon spectrum at $E > E_{th}$
above nuclear threshold.

CMB Blackbody Spectrum Distortion

Thermailization process

$e^- \gamma \rightarrow e^- \gamma$

$e^- X \rightarrow e^- X \gamma$

$e^- \gamma \rightarrow e^- \gamma \gamma$

μ distortion

(t < 10^6 sec)

Double Compton:

non conservation of photon number

…..relax the constraint

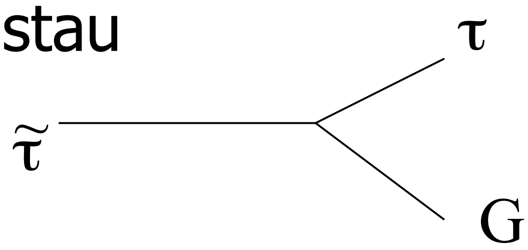
$$\mu = 8.0 \times 10^{-4} \left[\frac{\tau}{10^6\ \mathrm{s}}\right]^{\frac{1}{2}} \left[\frac{\zeta_{\mathrm{EM}}}{10^{-9}\ \mathrm{GeV}}\right] e^{-(\tau_{\mathrm{dC}}/\tau)^{5/4}} ,$$

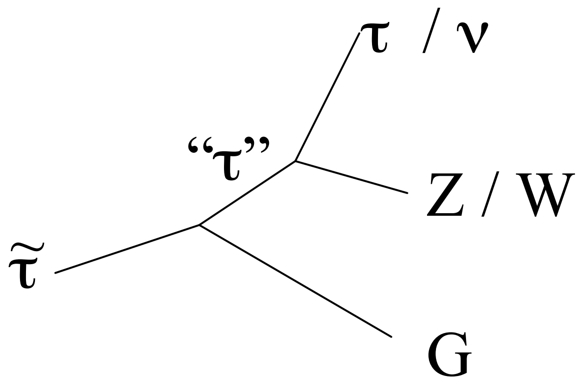
$$\tau_{\mathrm{dC}} = 6.1 \times 10^6\ \mathrm{s} \left[\frac{T_0}{2.725\ \mathrm{K}}\right]^{-\frac{12}{5}} \left[\frac{\Omega_B h^2}{0.022}\right]^{\frac{4}{5}} \left[\frac{1 - \frac{1}{2} Y_p}{0.88}\right]^{\frac{4}{5}} .$$

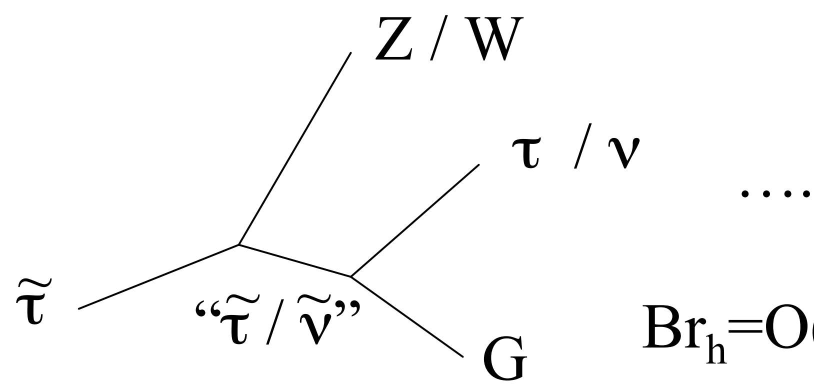
If a particle decays into SMs, hadronic decay modes always exist.
At least, @3-4 body level. (Model independent feature)

Charged slepton NLSP / Sneutrino=smaller hadronic activity

(1)stau

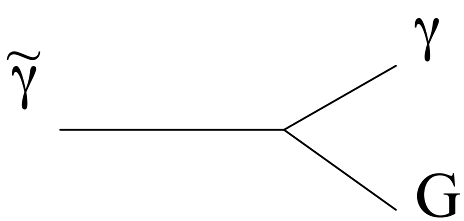


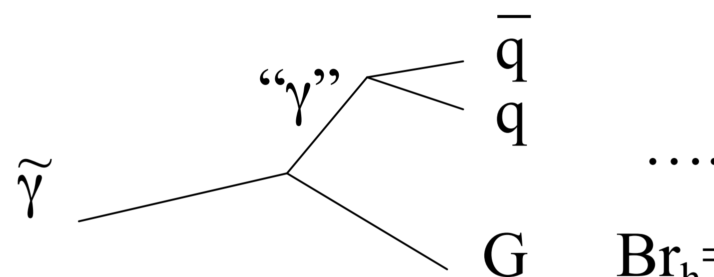




$Br_h = O(10^{-(3\text{-}5)})$

(2)photino

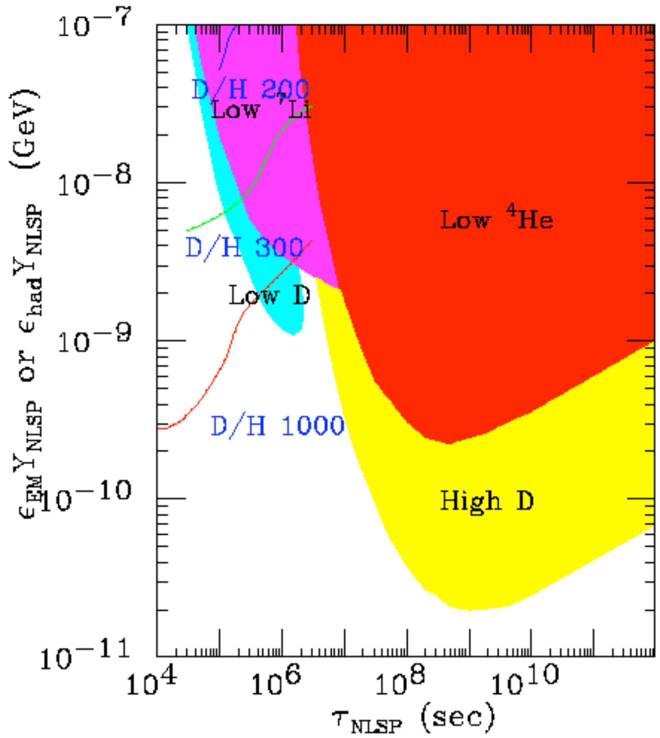




$Br_h = O(10^{-3})$

Hadronic contribution in slepton NLP

J.L.Feng, S.Su, F.T (2004)



Structure formation (small scale vs large scale)

Dark matter power spectrum $< \delta\rho/\rho \; \delta\rho/\rho >$

$V \sim \Delta m / m_{superWIMP}$

M.Kaplinghat astro-ph/0507300

J.Cembranos, J.Feng,A.Rajaraman,F.T hep-ph/0507150

Free streaming

$$\lambda_{FS} \sim \lambda_{EQ} (p/m_{superWIMP})(t / t_{EQ})^{1/2} \sim (0.01\text{-}0.1)\text{Mpc}$$

Coupling with photon-baryon fluid

CHAMP: M.Kamionkowski, K.Sigurdson (2003)

$$\lambda_{Damping} \sim \lambda_{EQ} (t / t_{EQ})^{1/2} < 0.3 \text{ Mpc} \quad (t < 10^8 \text{ sec})$$

SuperWIMP is not thermaly produced warm dark matter(=gauge mediation) which demands diluation by late time entropy production to obtain desired relic.

(recent ref, Jedamzik, Lemoine, Moultaka hep-ph/0506129)

Cosmic ray

Stau production and detection at south pole (IceCube)

I. Albuquerque, G.Burdman, Z.Chacko(2003)

X.Bi, J.Wang, C.Zhang, X.Zhang(2004)

Stau storage in earth (sea water)

J.L.Feng, J.Cembranos, F.T (in progress)

$n(\mathrm{CHAMP})/n(\mathrm{H}) < 10^{-28}$

$\tau(\mathrm{CHAMP}) > 10^{9}$ year

Search for superWIMPs scenario with charged NLP

W.Buchmuller, K.Hamaguchi, M. Ratz, T. Yanagida (2004)

J.L.Feng, A.Rajaraman, F.T (2004)

CHAMP → superWIMP+SM

Observable : E(SM), τ(CHAMP), m(CHAMP)

→Test of BBN

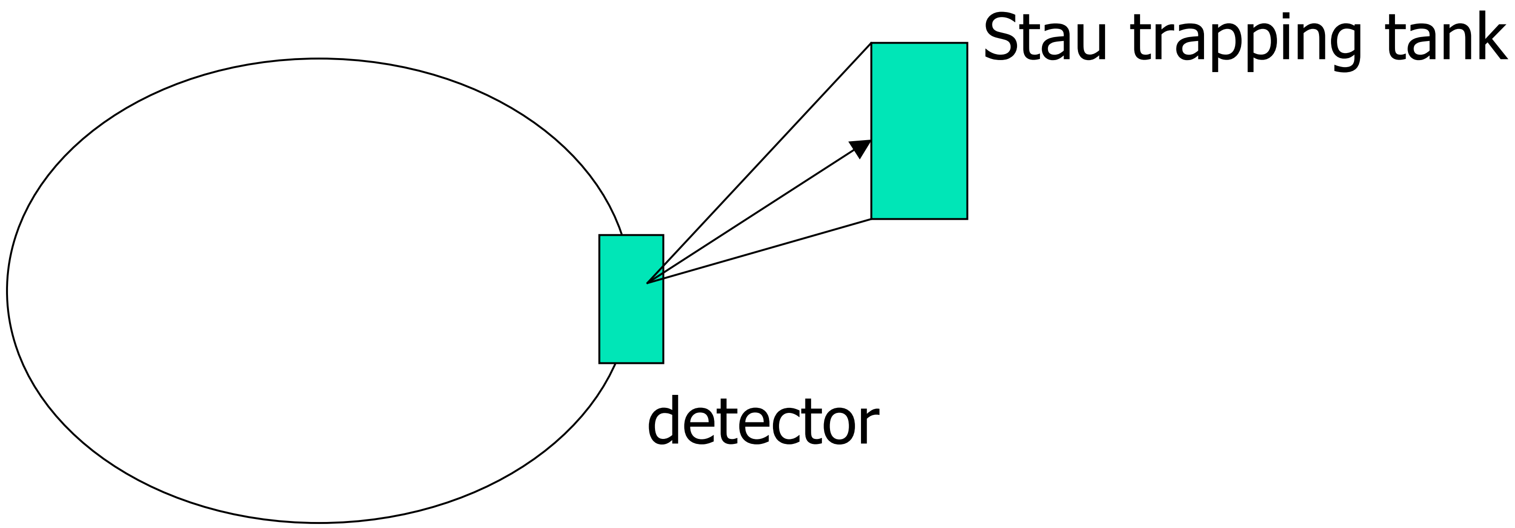
Model(SUSY)
coupling(CHAMP-superWIMP-SM) ~ Mpl or F or ....

Reheating temperature

Spin 3/2 observation by use of three body decay (BHRY(2004))

Stau → tau+photon+gravitino

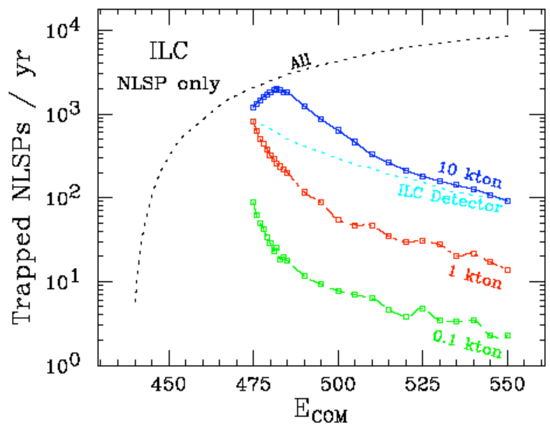
CHAMP(NLP) trapping and decay of CHAMP into superWIMP

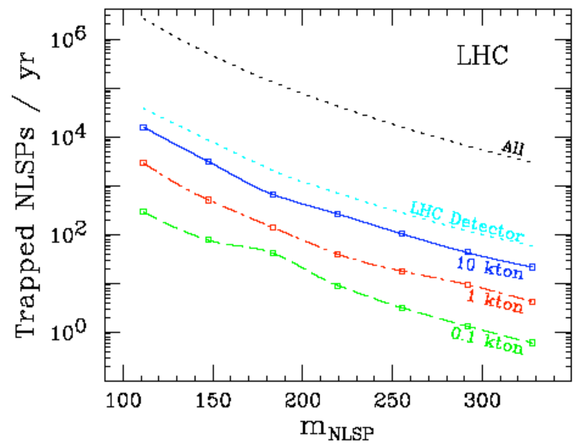


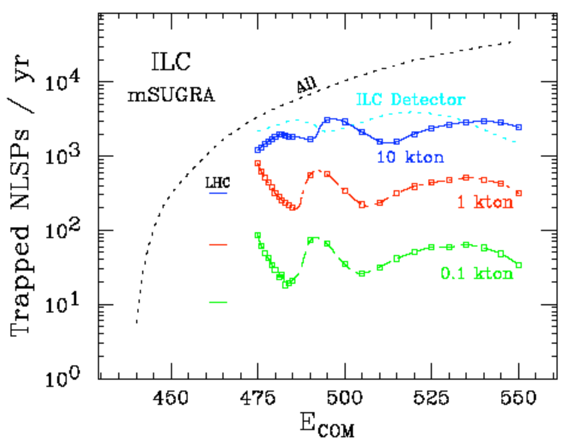
Trapping longlived CHAMPs (in SUSY model)

J.L.Feng, B.Smith (2004)

K.Hamaguchi, Y.Kuno, T. Nakaya, M. Nojiri(2004)







$10^{3\text{-}5}$ staus

J.L.Feng, B.Smith hep-ph/0409278

Summary

$(1/M)^n\ \psi\ (\widetilde{SM}\ \text{SMs})$

ψ = superWIMP

$\widetilde{SM}$ = NLP (WIMP)

Near future cosmological and collider experments may find signals from NLP/superWIMP dark matter.

The role of NLP/superWIMP in cosmology may be also understood by collider expermeints.