Neutralino Dark Matter in Mirage Mediation

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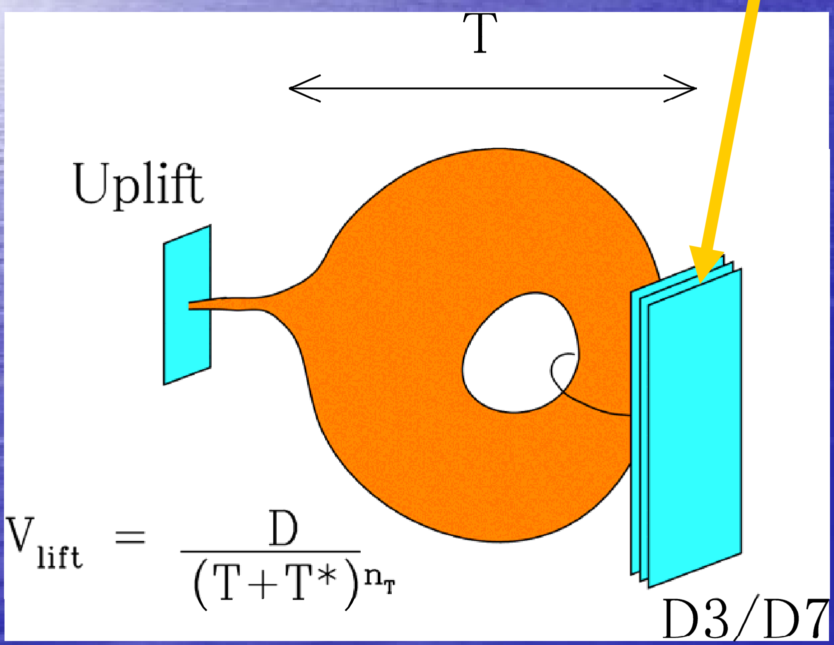
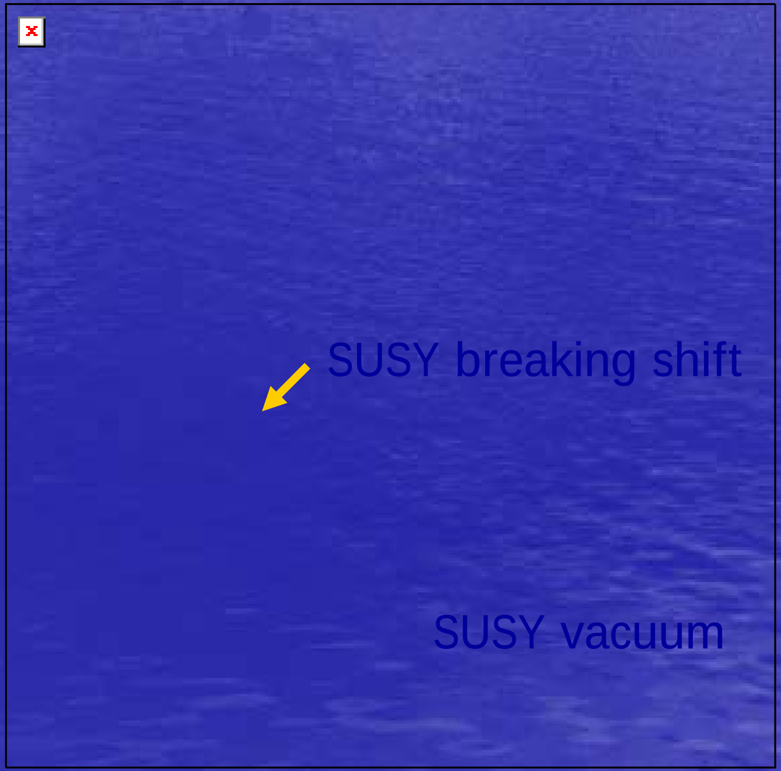
Mirage mediation in KKLT scenario

Compactified string theory predicts massless moduli in 4D.
KKLT stabilized all of them with tunable cosmological constant.

S, Z^{α} : *flux* $\qquad K = -3\ln(T + T^*), W = w_0 - Ae^{-aT}$





S.Kachru, R.Kallosh, A.Linde, S.P.Trivedi (2003)

$F^T/(T+T^*)$ is suppressed relative to $m_{3/2}$

by $\ln\left(M_{Pl}/m_{3/2}\right) \approx 4\pi^2$

$$\text{Modulus mediation} \approx \text{Anomaly mediation}$$

K.Choi, A.Falkowski, H.P.Nilles, M.Olechowski, S.Pokorski (2004)
K.Choi, A.Falkowski, H.P.Nilles, M.Olechowski (2005)

$$= \text{Mirage mediation}$$

$$\alpha = \frac{\text{Anomaly mediation}}{\text{Modulus mediation}} = \frac{\frac{1}{\ln\left(M_{Pl}/m_{3/2}\right)} m_{3/2}}{M_0} \approx \frac{2}{n_T}.$$

$$M_0 \equiv \frac{F^T}{T+T^*}.$$

Relative significance α is determined by the shape of uplifting potential (n_T).

KKLT predicts $n_T = 2\ (\alpha = 1)$ "Minimal case"

We assume that all gauge/matter fields are living on D7 brane.

$$\mathcal{L}_{Soft} = -\frac{1}{2} M_a \overline{\lambda^a} \lambda^a - m_i^2 Q_i^* Q_i - \frac{1}{6} \left(A_{ijk} y_{ijk} Q_i Q_j Q_k + \text{h.c.} \right)$$

Anomaly mediation

$$M_a = M_0 + \frac{\beta_a}{g_a} m_{3/2}$$

$$A_{ijk} = 3M_0 - \frac{1}{16\pi^2} (\gamma_i + \gamma_j + \gamma_k) m_{3/2}$$

$$m_i^2 = |M_0|^2 - \frac{1}{32\pi^2} \frac{d\gamma_i}{d \ln \mu} |m_{3/2}|^2 + \frac{1}{8\pi^2} \left(T \frac{\partial \gamma_i}{\partial T} m_{3/2} M_0 + h.c. \right)$$

Modulus mediation

Anomaly mediation effectively shifts the modulus mediation scale

Degenerate weak scale spectrum

Mirage mediation scale

$$M_{Mirage} \approx M_{Pl} \left(\frac{m_{3/2}}{M_{Pl}} \right)^{\alpha/2}$$

Similar for m_i^2
if Yukawa coupling
is vanishing

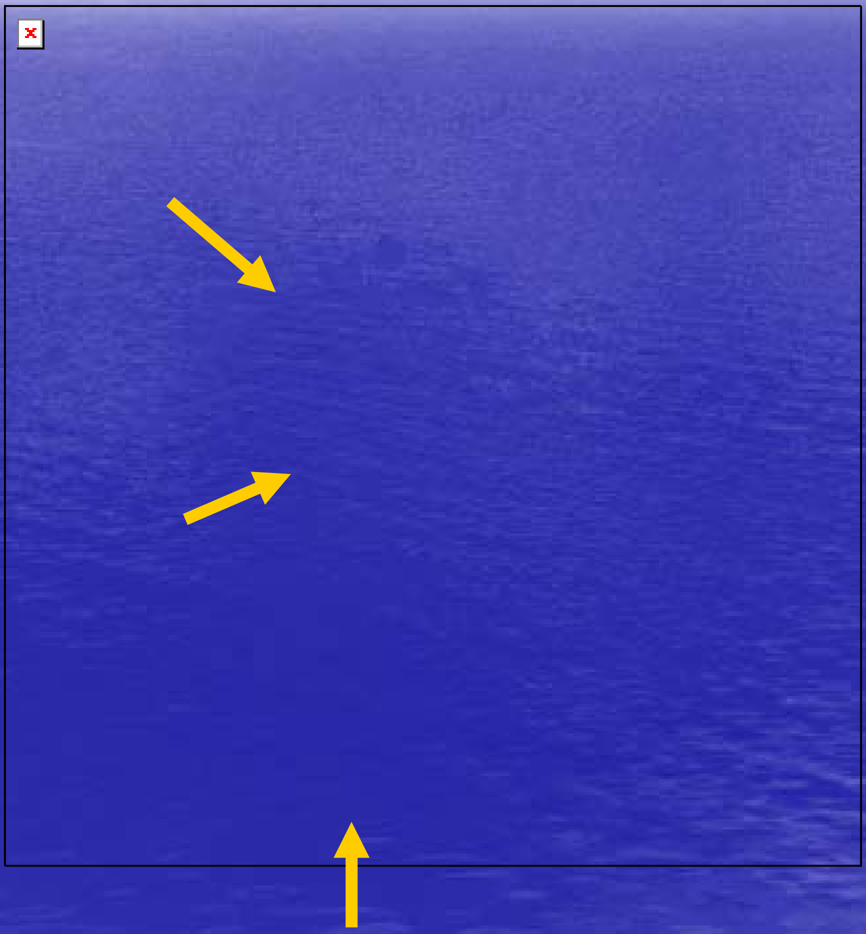
K.Choi, K-S. Jeong, KO.(2005)

$$M_{Mirage} \longleftarrow M_{GUT}$$

KKLT scenario predicts light higgsino

K.Choi, K-S Jeong, KO (2005)
M.Endo, K.Yoshioka, M.Yamaguchi (2005)

- Due to reduced mediation scale, EW symmetry breaking is weaken (smallμ) and B-ino becomes heavy.
- Higgsino component in the lightest neutralino is enhanced.
- If α is large enough, even higgsino LSP is possible.
- Dark matter relic abundance can be considerably different from B-ino LSP.



KKLT(Minimal)

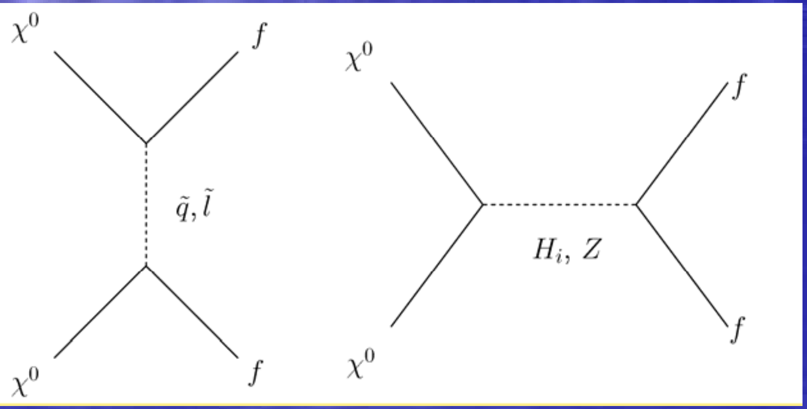
Neutralino relic aboundance in KKLT scenario.

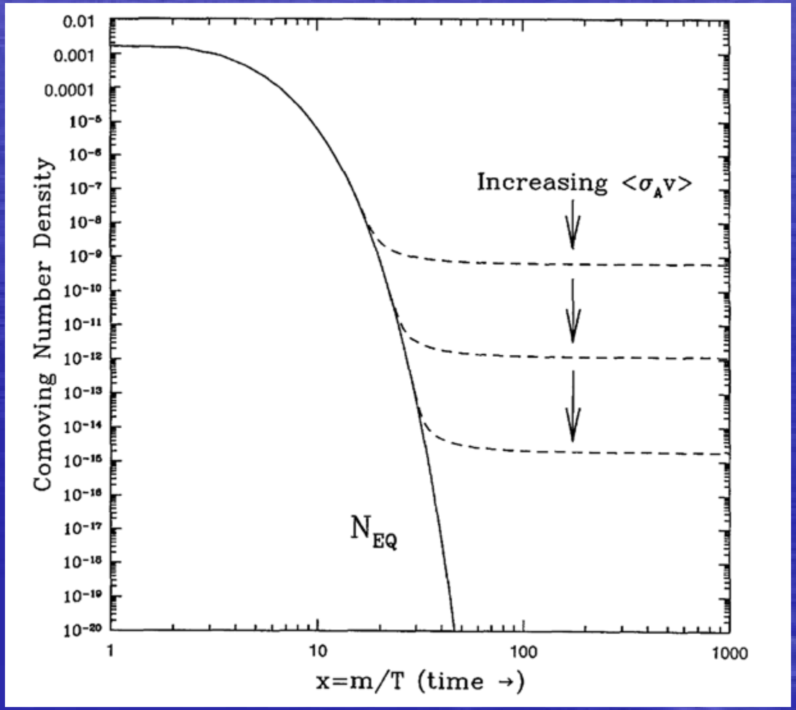
Assuming R-Parity, LSP is stable and neutralino is good candidate of cold dark matter

$$\chi_i^0 = N_{i1}\tilde{B} + N_{i2}\tilde{W}^3 + N_{i3}\tilde{H}_1^0 + N_{i3}\tilde{H}_2^0$$

$$\frac{dn}{dt} = -3Hn - \langle\sigma_{eff}v\rangle(n^2 - n_{eq}^2)$$

Once the expansion of universe dominates over the annihilation, neutralino decouples from equilibrium →thermal relic abundance.

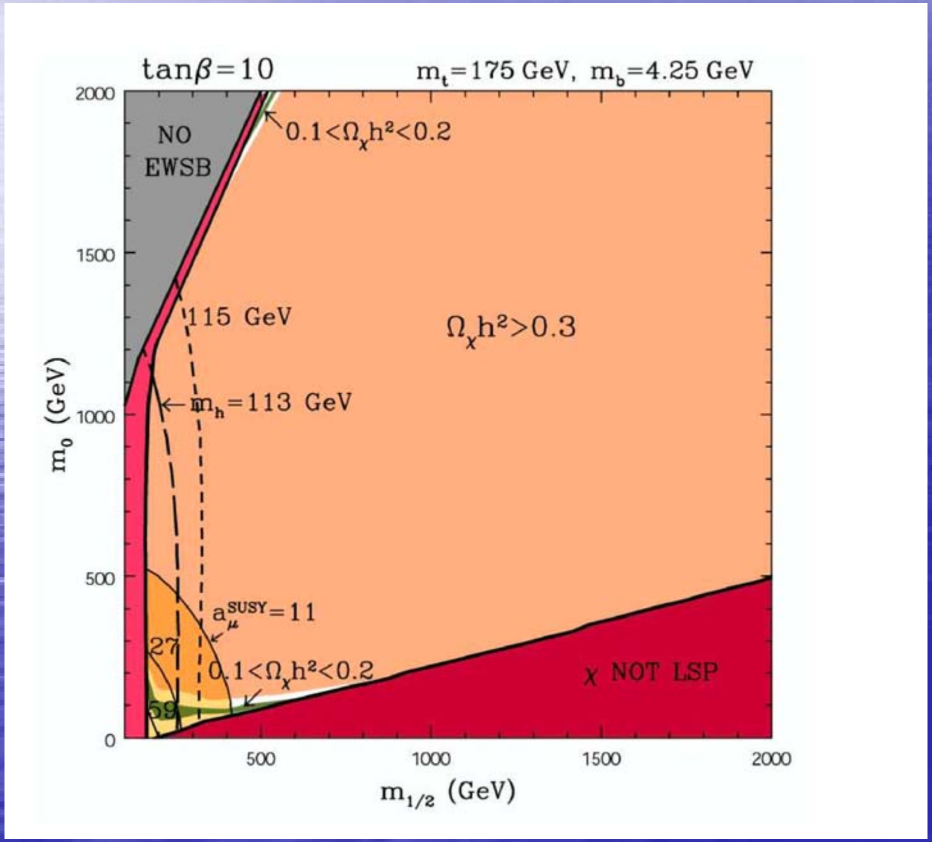




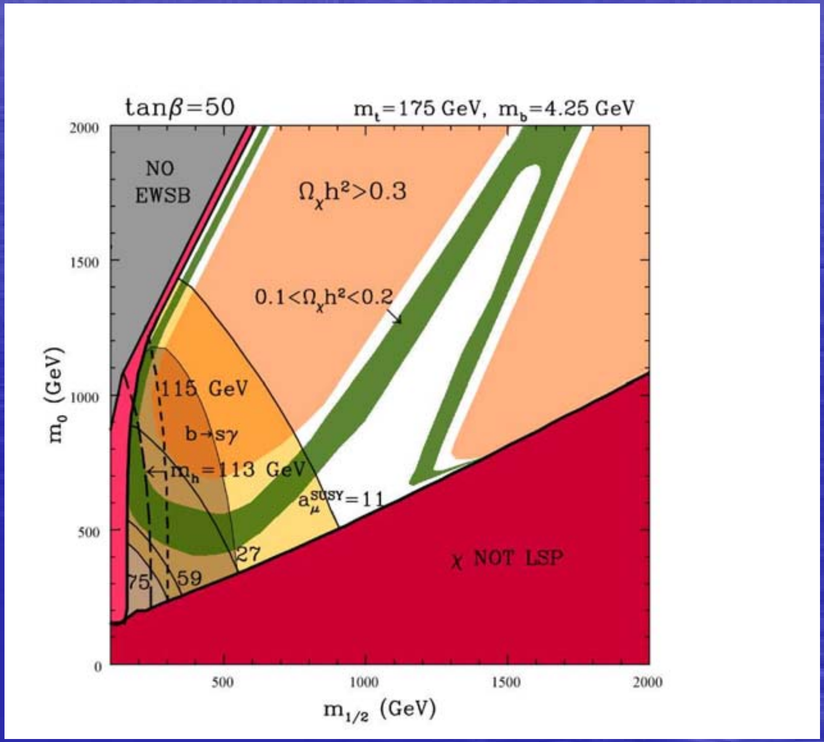
E.W.Kolb, M.S.Turner, The Early Universe

Example in CMSSM　(B-ino LSP)

B-ino interacts too weak and has tendency to remain too much.
→ requires light SUSY spectrum or degeneracy (coannihilation).



Funnel region　$m_{A^0} = 2m_{\chi_1^0}$



L.Roszkowski, R.R.Austri, T.Nihei (2001)

Comment on the moduli induced gravitino problem

- After inflation, coherent oscillation of modulus dominates energy density of the universe and its decay reheats the universe again.
- Branching ratio of modulus to gravitino is found to be larger than ~ 0.01 witch is 10^4 larger than previous estimate.
- Non-thermal LSP from the decay of gravitino is too much.
- We assume gravitino is diluted after the reheating by e.g. thermal inflation and after that the universe reaches the neutralino decouple temperature.

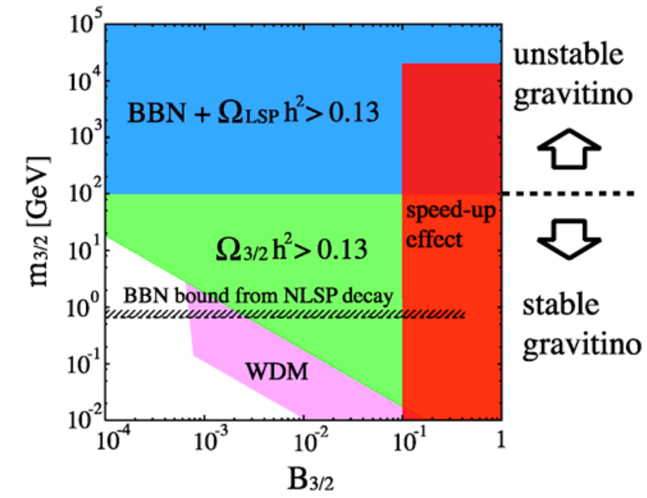


FIG. 1: The cosmological bounds on $m_{3/2}$ and $B_{3/2}$. Shaded regions are excluded by cosmological arguments. See the text for details. The horizontal dashed line denotes the BBN bound from the stau NLSP decay into gravitinos for $m_{\rm NLSP} = 100$ GeV. We have chosen $m_X = 10^3$ TeV and $c = 1$. The bounds become severer for larger m_X.

M.Endo, K.Hamaguchi, F.Takahashi (2006)

S.Nakamura,　M.Yamaguchi （2006）

Calculation of neuralino thermal relic abundance

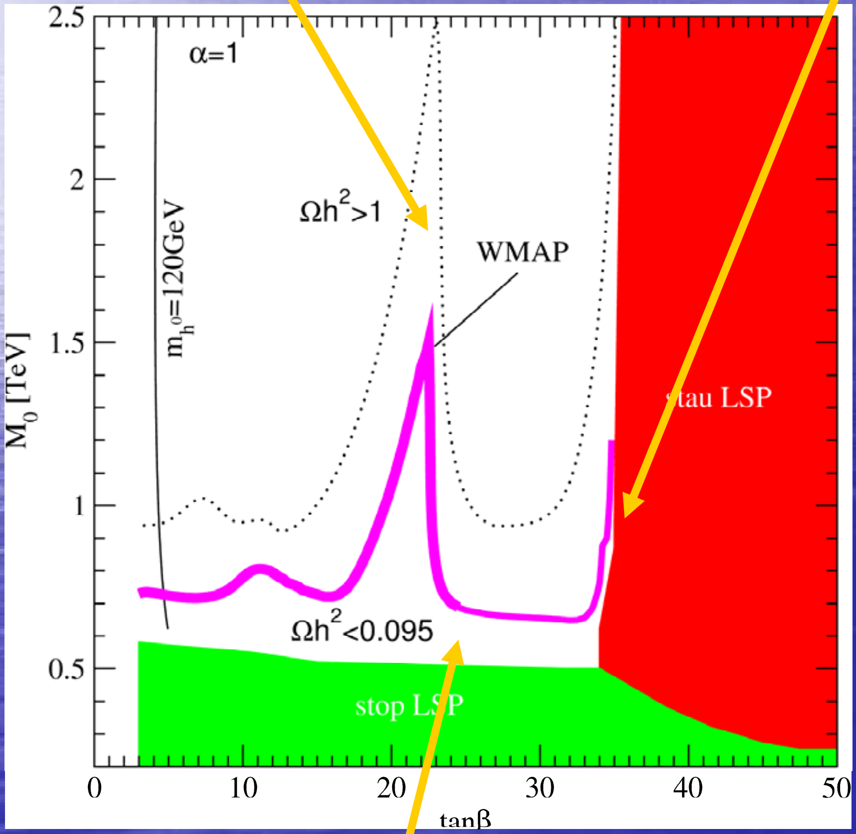
We fully exploit Dark SUSY 4.1 for calculation of relic abundance, direct and indirect search prospects in the KKLT scenario.
Thanks for the authors

P.Gondolo, J.Edsjö, P.Ullio, L.Bergström, M.Schelke and E.A.Baltz

Minimal case (α=1)

$m_{\chi^0} = m_{A^0}/2$

$m_{\chi^0} \approx m_{\tilde{\tau}_R}$



$m_{\chi^0} \approx m_{\tilde{t}_1}$

$$0.095 < \Omega h^2 < 0.13$$

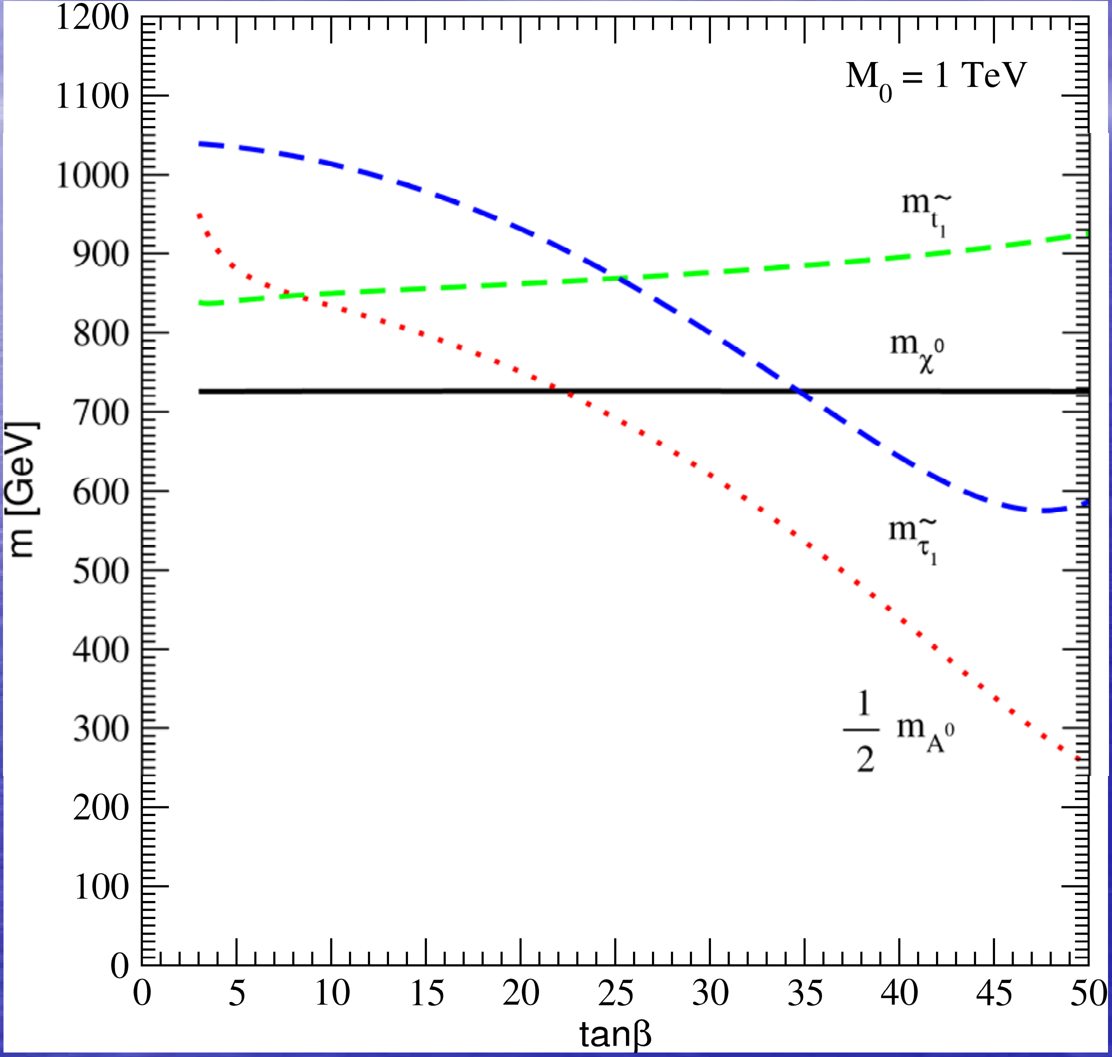
Still B-ino dominates

Higgs resonance, stop/stau coannihilation at work

Reasonable thermal abundance with heavy enough squarks and sleptons (~ TeV) to satisfy indirect constraints

(Higgs mass, b → s,γ).

Mass spectrum for $M_0 = 1$ TeV



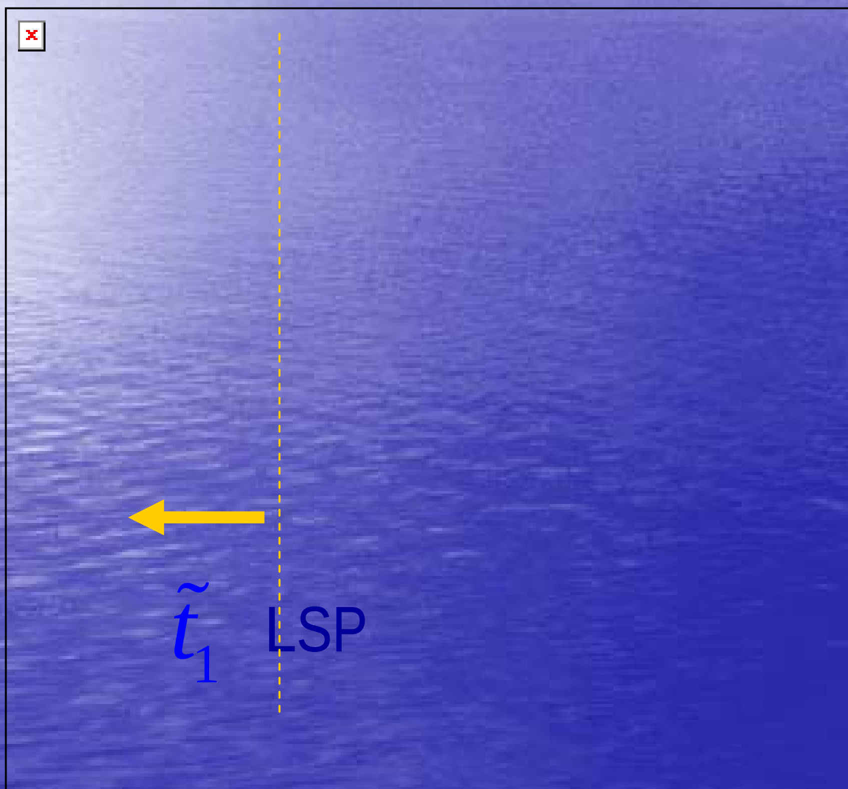
Ωh^2 vs Higgs resonance

w/o coannihilation

w/ coannihilation

Direct detection (α=1)

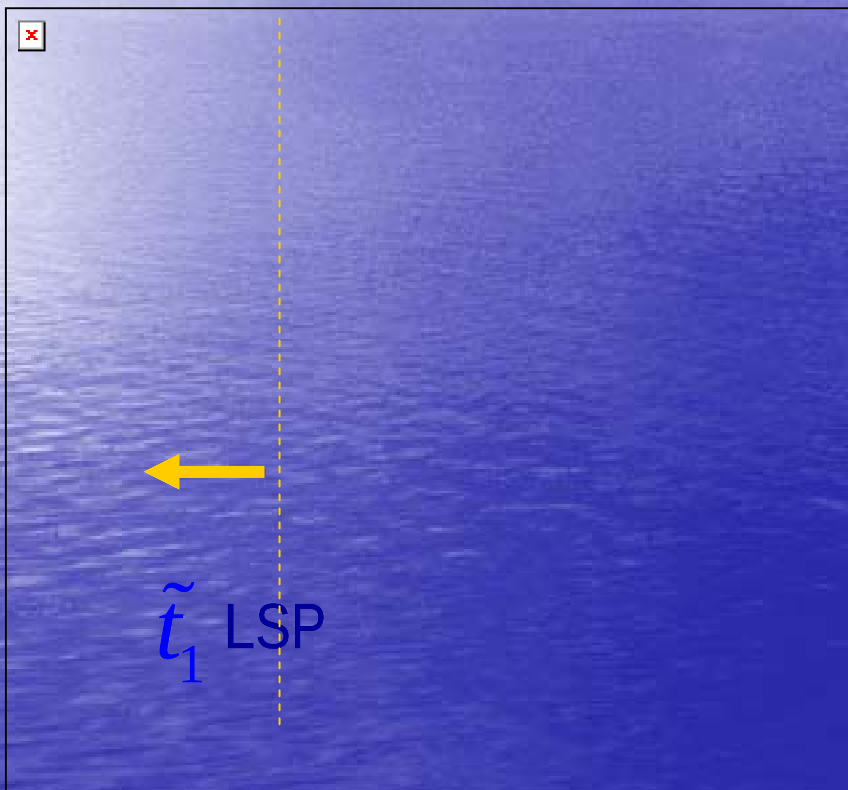
Spin independent (SI) crossection



- Red points saturate the WMAP result.
- The SI crossection can not be large enough due to small higgsino component and heavy CP odd Higgs mass ($\leftarrow \chi^0$ LSP) .

Direct detection (α=1) cont'd

Spin dependent (SD) crossection

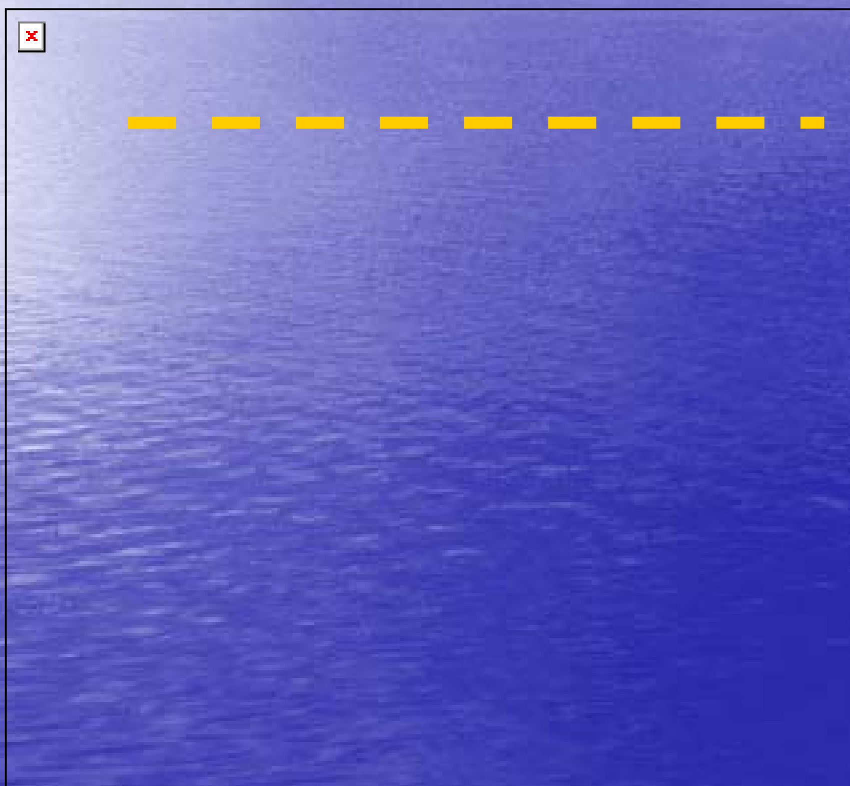


- Red points saturate the WMAP result.
- Suppressed Z exchange due to small higgsino component → SD crossection is smaller than $10^{-6}[pb]$

$(\square\ 10^{-1}[pb])$

Indirect detection (α=1)

Gamma ray flux from the galactic center



- We use isothermal halo density profile.
- $(\bar{J} \sim 30, \Delta\Omega = 10^{-3}, E_{th} = 1 GeV)$
- Allowed region barely touches the GLAST expeccted reach

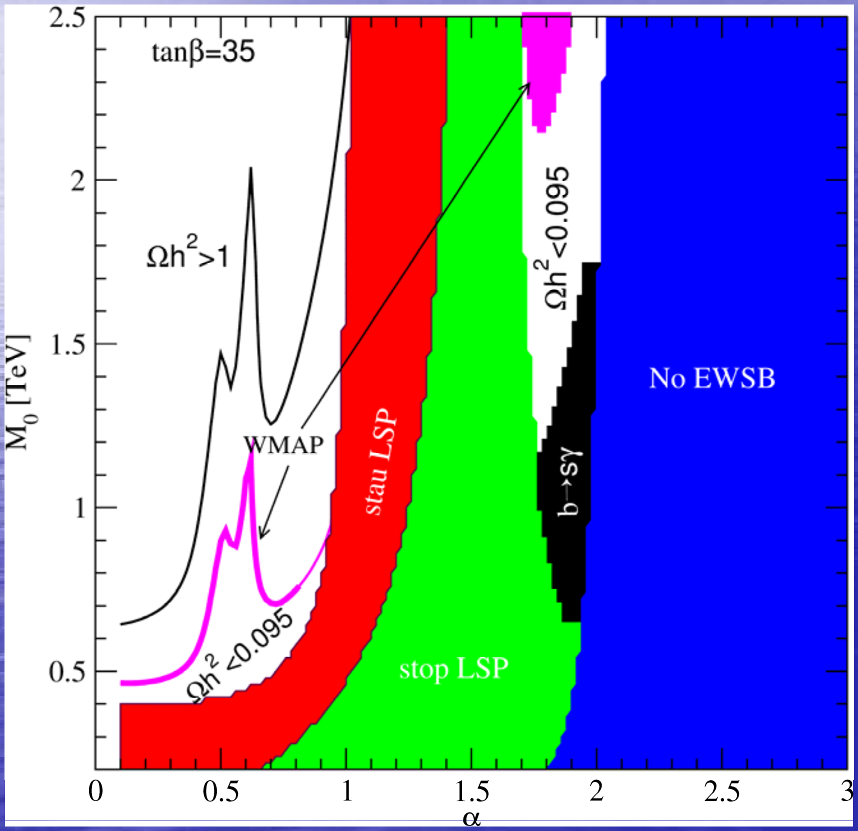
$$\sim 10^{-10} cm^{-2} s^{-1}$$

Note that the density profile is conservative.

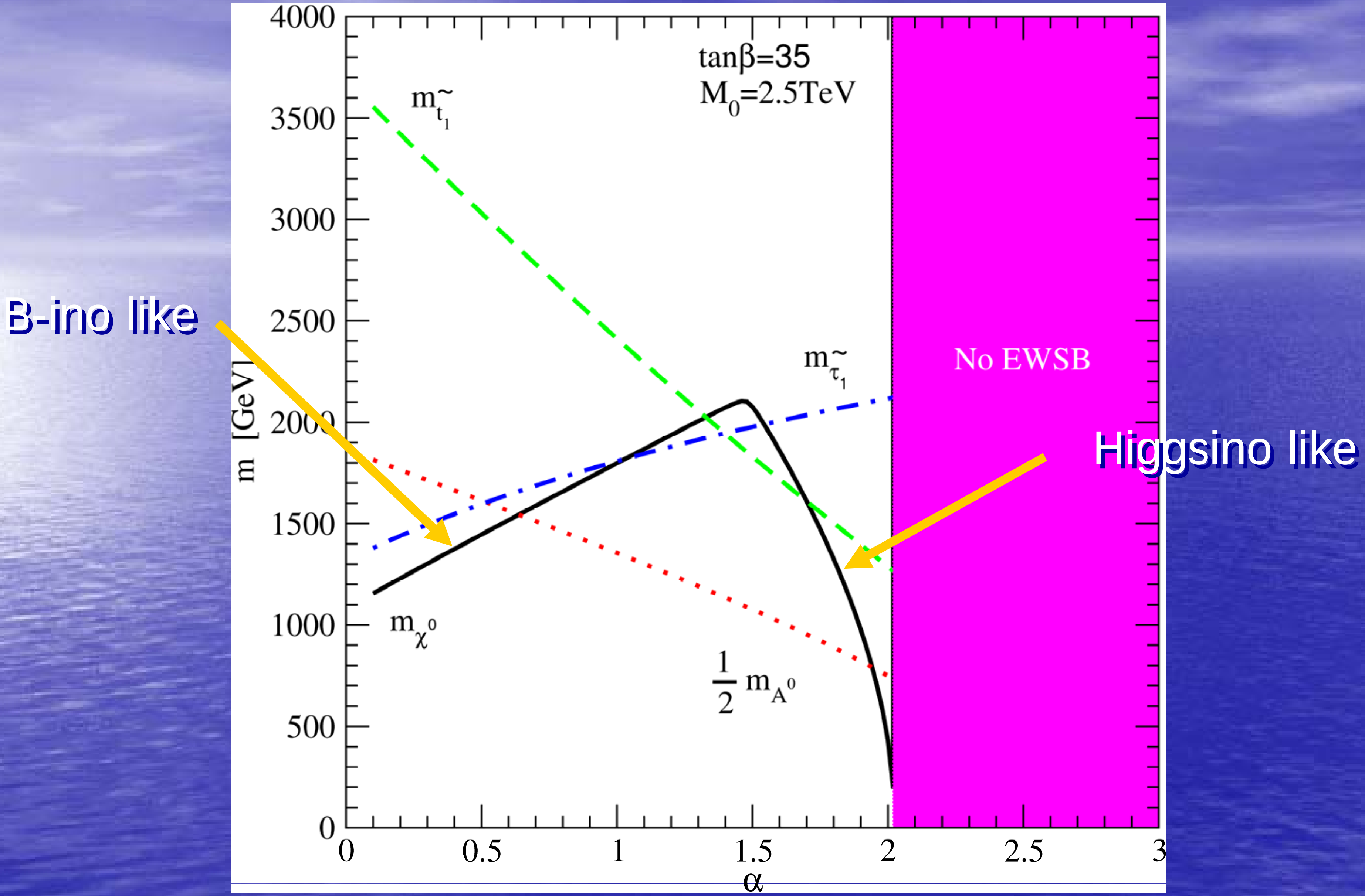
Enhancement of the gamma ray flux due to Higgs resonance

Higgs boson →Heavy quarks→ hadronization, γ

Non-minimal case ($\alpha \neq 1$)



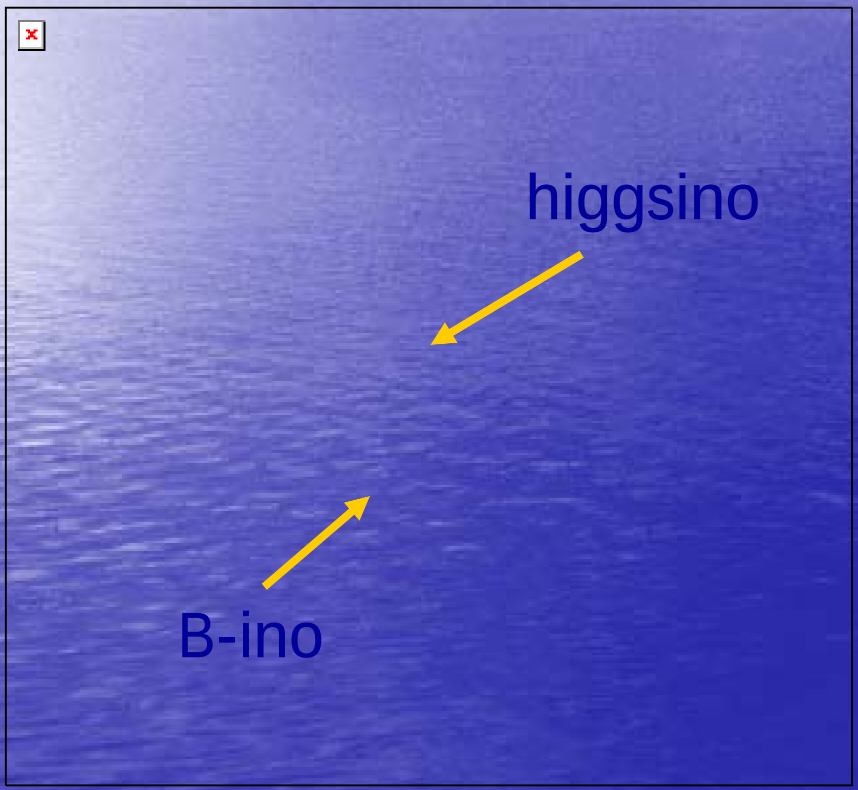
- Two allowed regions
  - B-ino like ($\alpha < 1$)
  - Higgsino like ($\alpha \sim 2$)



B-ino like
Higgsino like
tanβ=35
M0=2.5TeV
No EWSB
m [GeV]
α
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3

Direct detection ($\alpha \neq 1$)

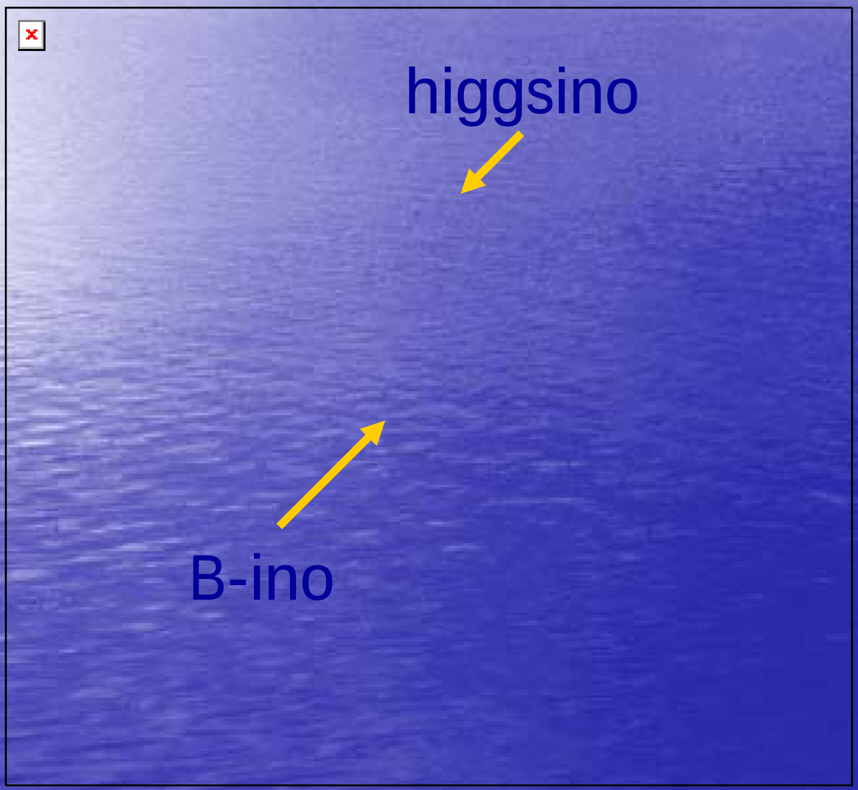
Spin independent (SI) crosssection



- Red points saturate the WMAP result.
- Two branches (B-ino, higgsino)
- Higgs exchange is suppressed due to small mixing.
- SI crossection is smaller than $10^{-9}[pb]$

Direct detection ($\alpha \neq 1$) cont'd

Spin dependent (SD) crossection



- Red points saturate the WMAP result.
- Z exchange enhances the SD crossection in higgsino LSP case.
- The SD crossection reaches $10^{-6}[pb]$.

Indirect detection ($\alpha \neq 1$)

Gamma ray flux from the galactic center (continuum)

- Isothermal halo density profile (conservative).
- Higgsino LSP leads to enhanced γ due to unsuppressed WW (ZZ) decay.
- B-ino case is more enhanced due to the Higgs resonance.

Indirect detection ($\alpha \neq 1$) cont'd

Gamma ray flux from the galactic center (monochromatic)

- Monochromatic gamma provides background free smoking gun signal.
- The flux reaches $10^{-16} \sim 10^{-15} cm^{-2} s^{-1}$ for higgsino case and measurable with cuspy halo profile.

(HESS $\sim 10^{-14} cm^{-2} s^{-1}$)

Conclusion

- Mirage mediation in KKLT opens new avenue for SUSY spectrum ($\neq$ CMSSM, AMSB).
- Obserbed $\Omega_{CDM} h^2$ can be saturated with reasonable SUSY mass scale ($\sim$ 1TeV). (Higgs resonance/coannihilation/higgsino LSP)
- Direct detection crossections are too small for near future experiments. $(\sigma_{SI} \leq 10^{-9}\, pb, \sigma_{SD} \leq 10^{-6}\, pb)$
- Indirect detection (γfrom the galactic center)

  might be promising with cuspy halo density profile.

  $$(\Phi^{\gamma}{}_{cont} = 10^{-10--12} cm^{-2} s^{-1}, \Phi^{\gamma}{}_{mono} = 10^{-14--15} cm^{-2} s^{-1})$$