Light neutralino DM with a very light Higgs for CoGeNT and DAMA/LIBRA data

Seodong Shin

Seoul National University, Seoul, Korea

Identification of Dark Matter 2010

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arXiv:1005.5131 with K.J. Bae and H.D. Kim

Outline

- Introduction : Light DM
  CoGeNT and DAMA/LIBRA
- Light DM in SUSY models.
  - Heavy Higgs mediation scenario
  - Light Higgs mediation scenario
- Light Higgs in the MSSM
- Light Higgs in the BMSSM
- Right relic abundance
- Conclusions

Light DM from CoGeNT

- arXiv:1002.4703
- Coherent Germanium Neutrino Technology
- Soudan, Minnesota
- Ultra-low noise Ge detector of 330g
- The recoil of the nuclei by the scattering off WIMP induces ionizations inside the detector.
- After 8 week exposure, CoGeNT announced the DM candidate signal of mass 7 - 11 GeV and $\sigma_{\rm SI} \sim 10^{-41}{\rm cm}^2$

Light DM from CoGeNT

- arXiv:1002.4703
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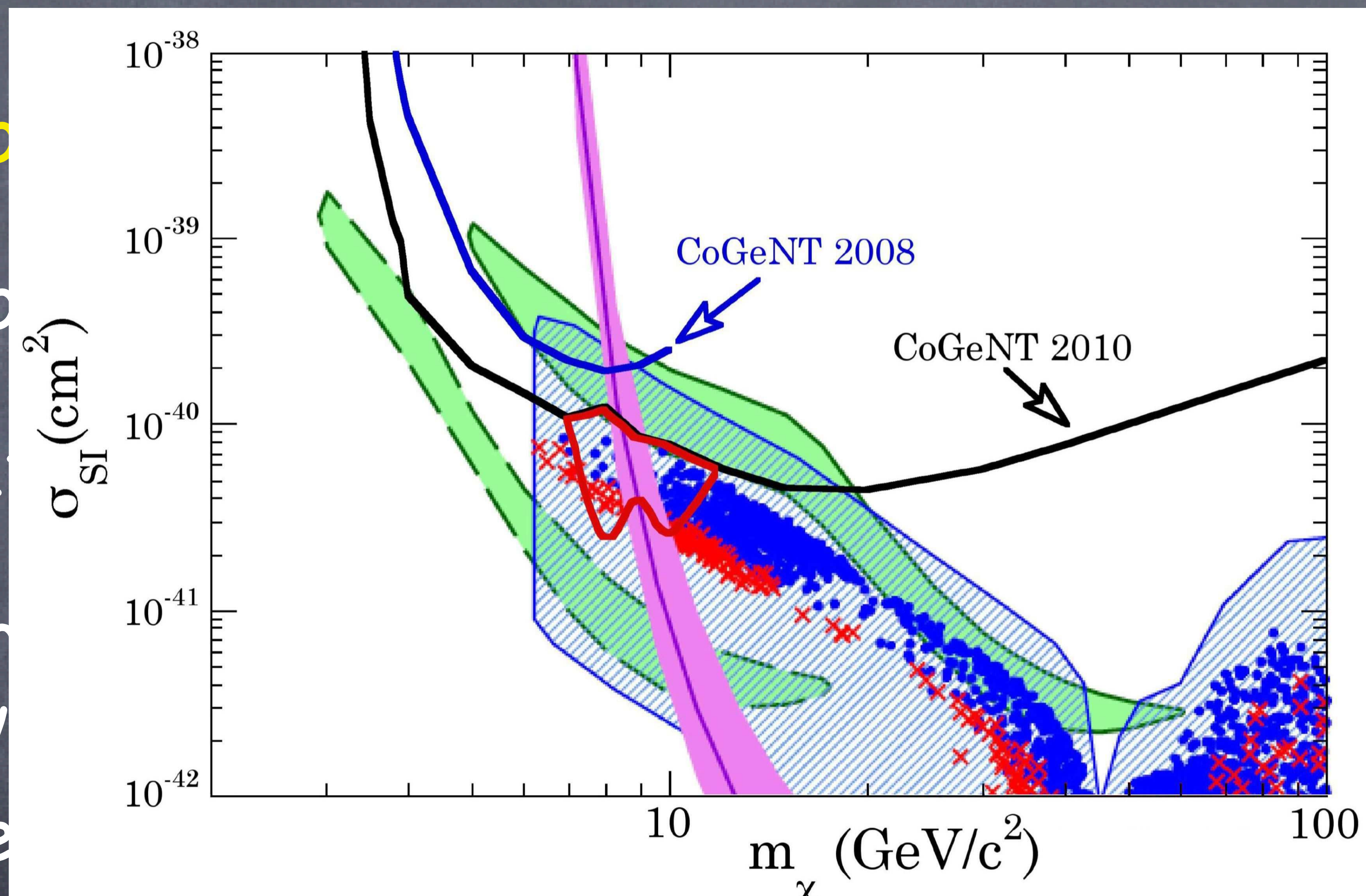

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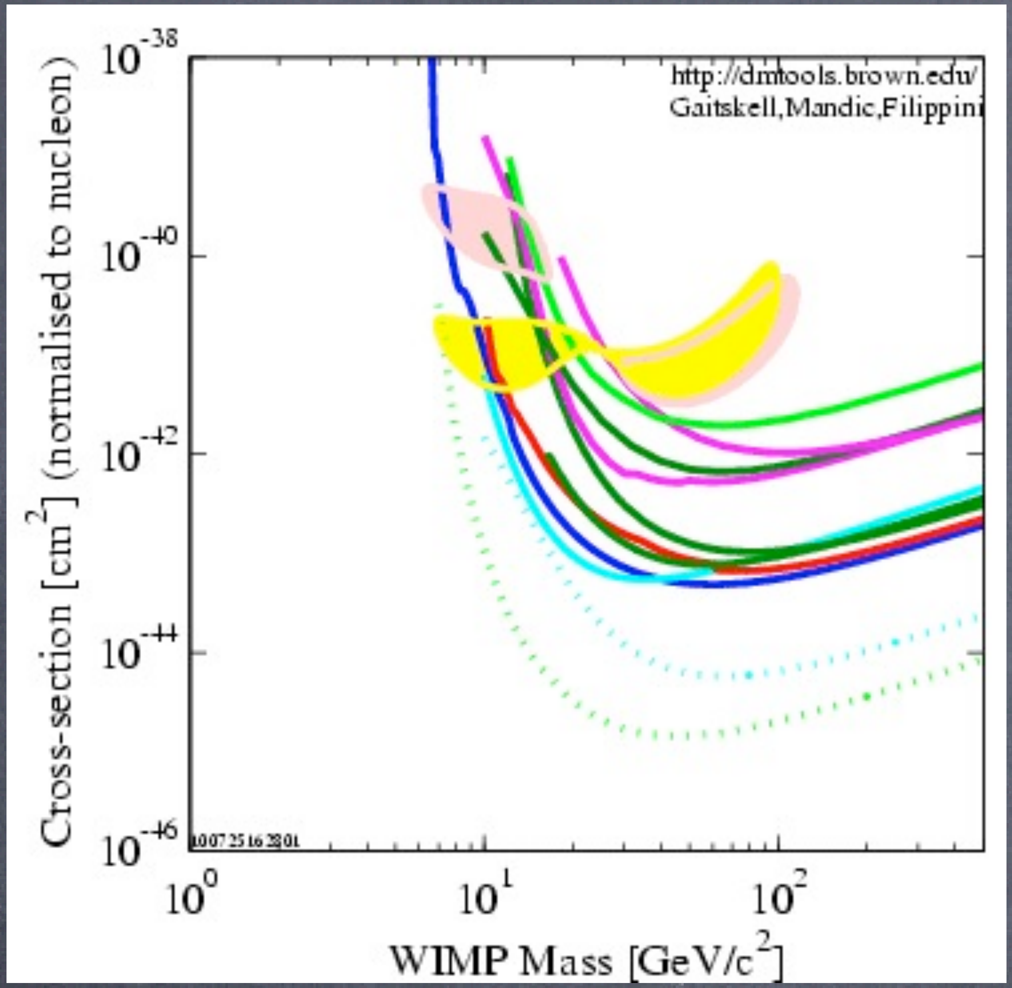

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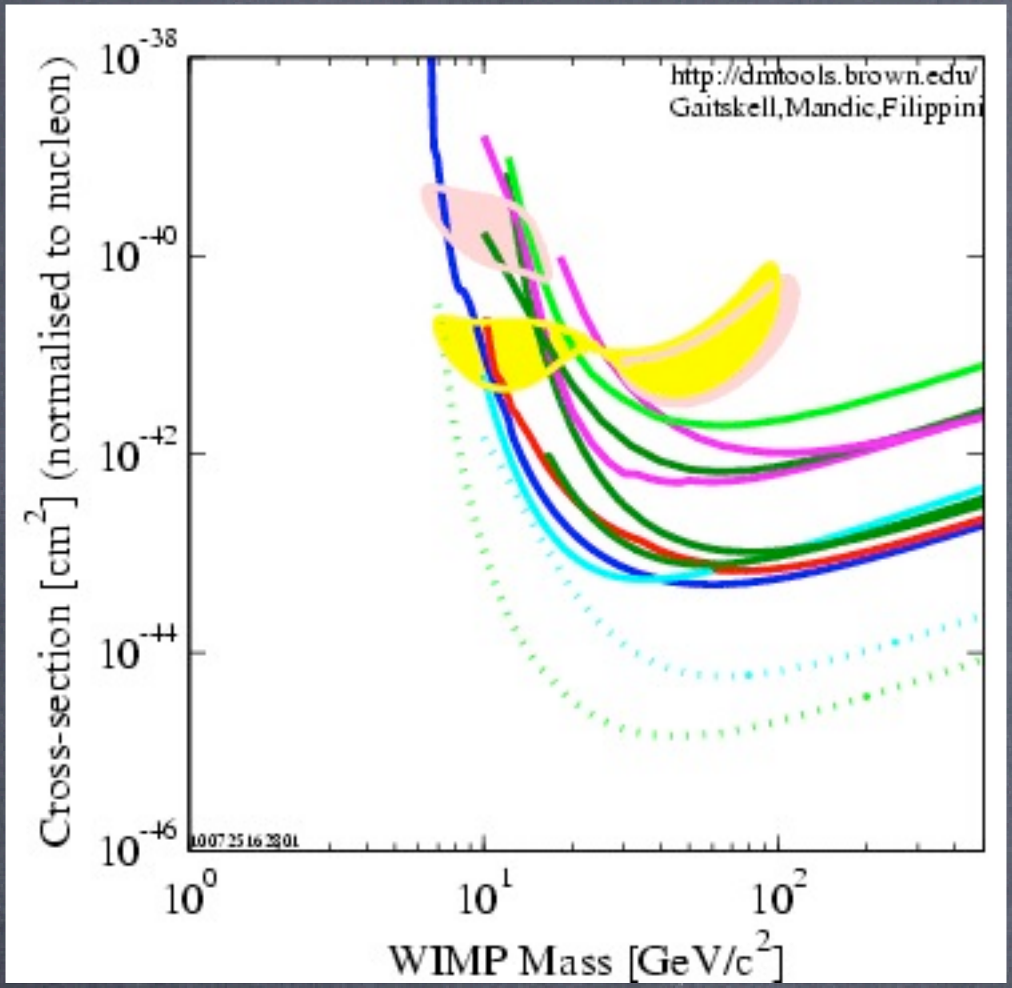
Light DM from DAMA



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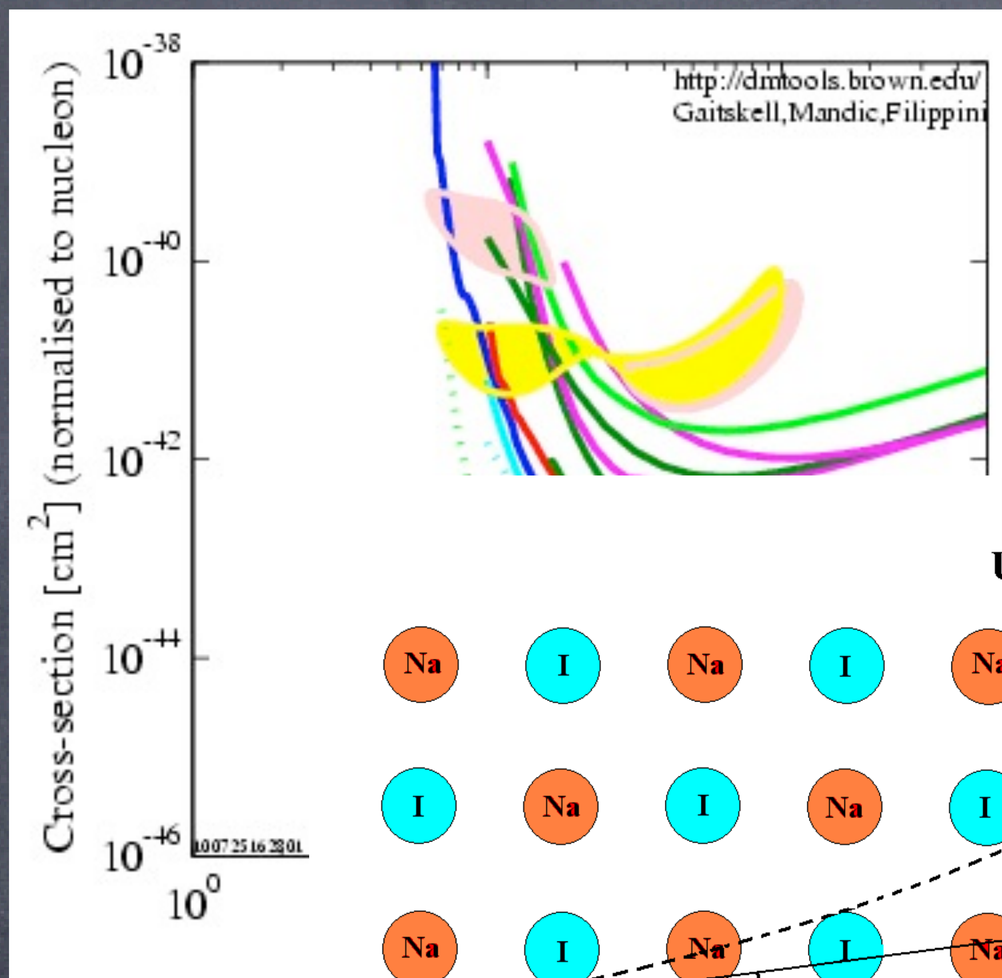
- To reconcile the DAMA and the other null experiments, channeling or inelastic DM.

Light DM from DAMA



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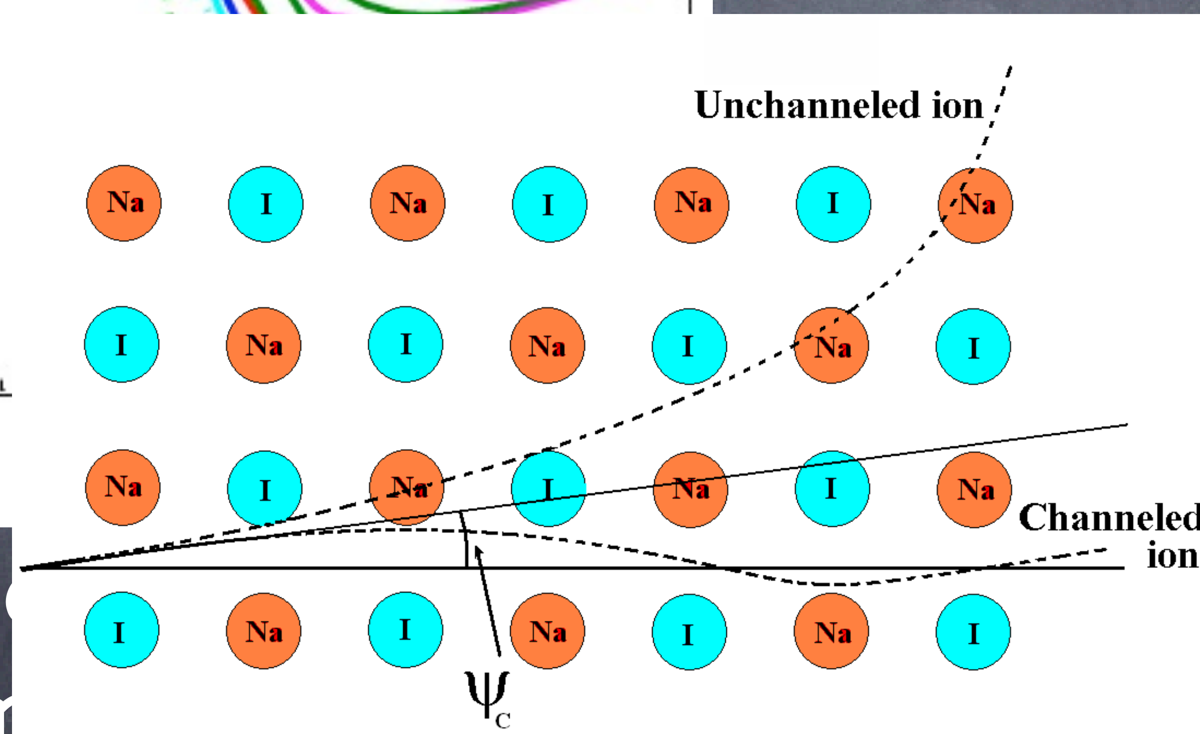
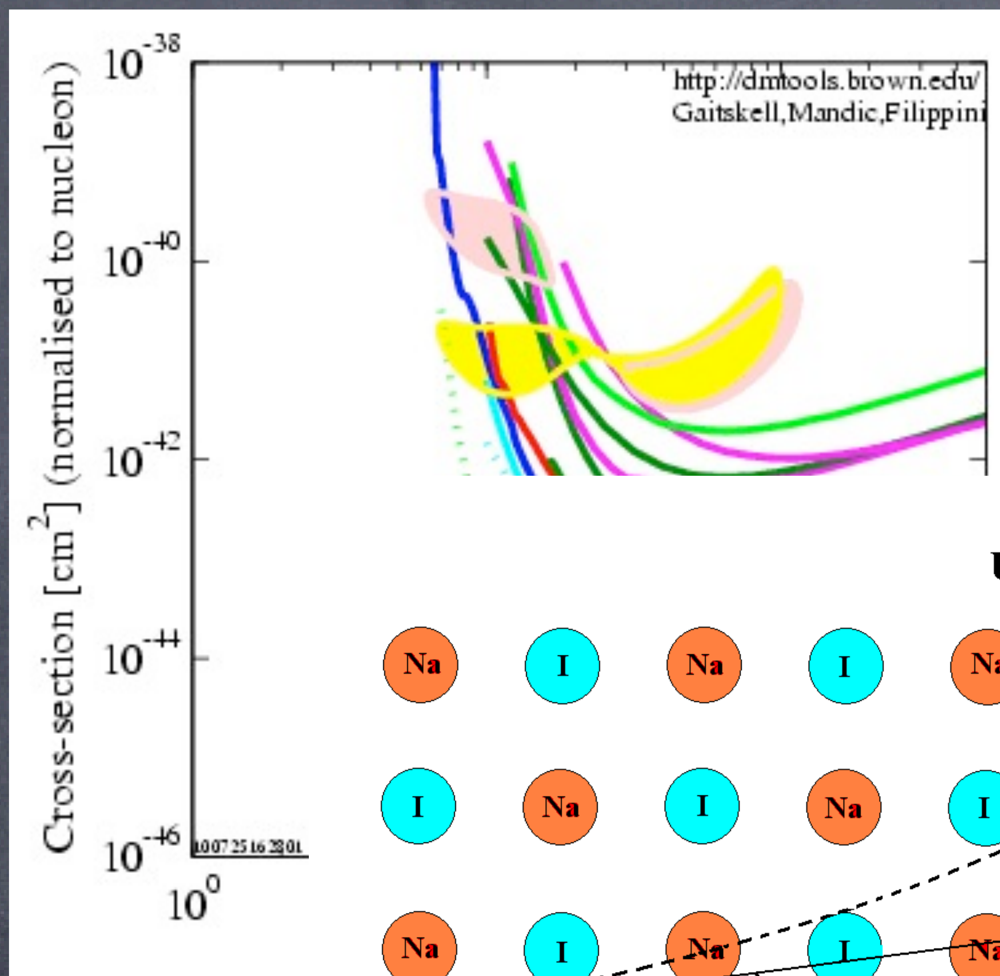


- To re... other null exper... stic DM.

Light DM from DAMA



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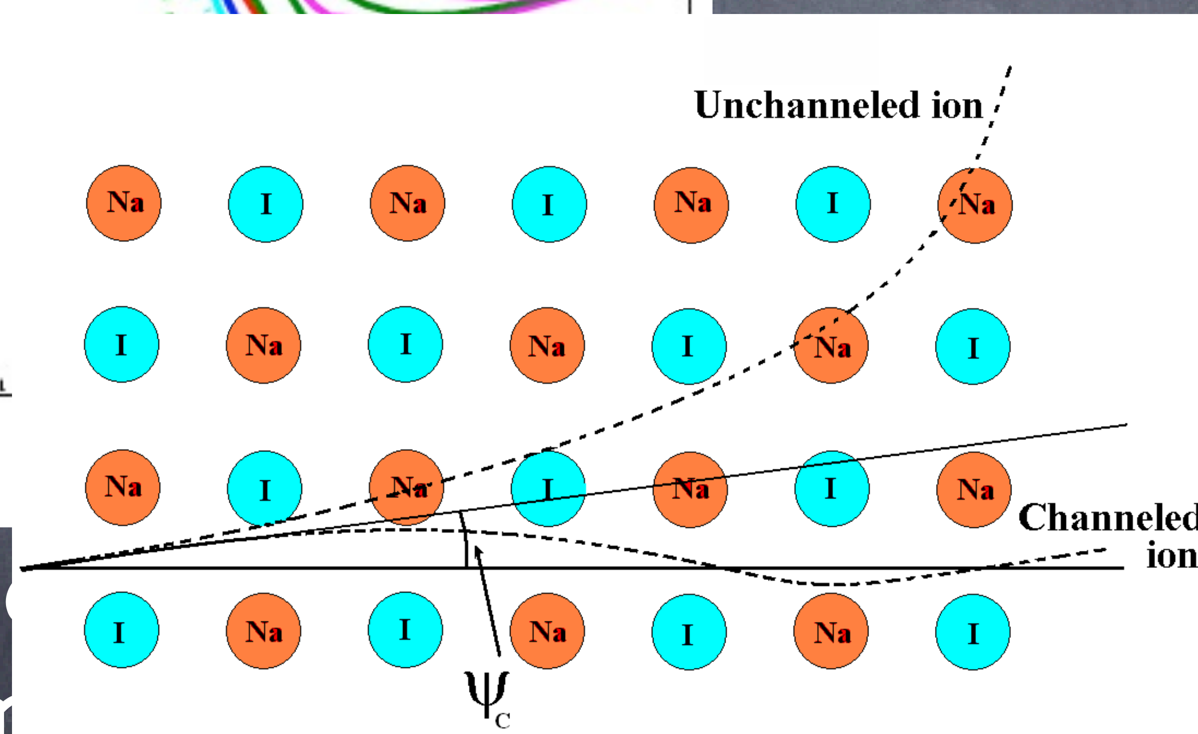
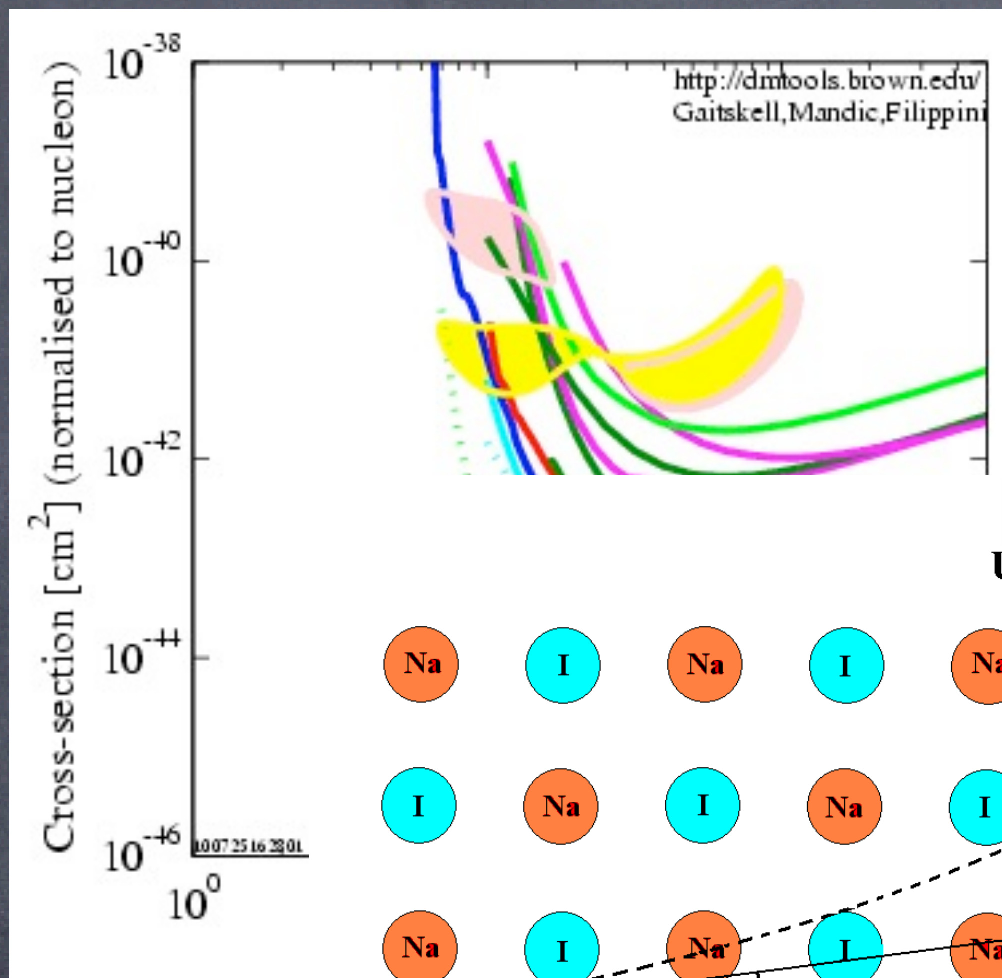


- To re… other null exper… stic DM.
- Channeling effect : Light DM can be survived.

Light DM from DAMA



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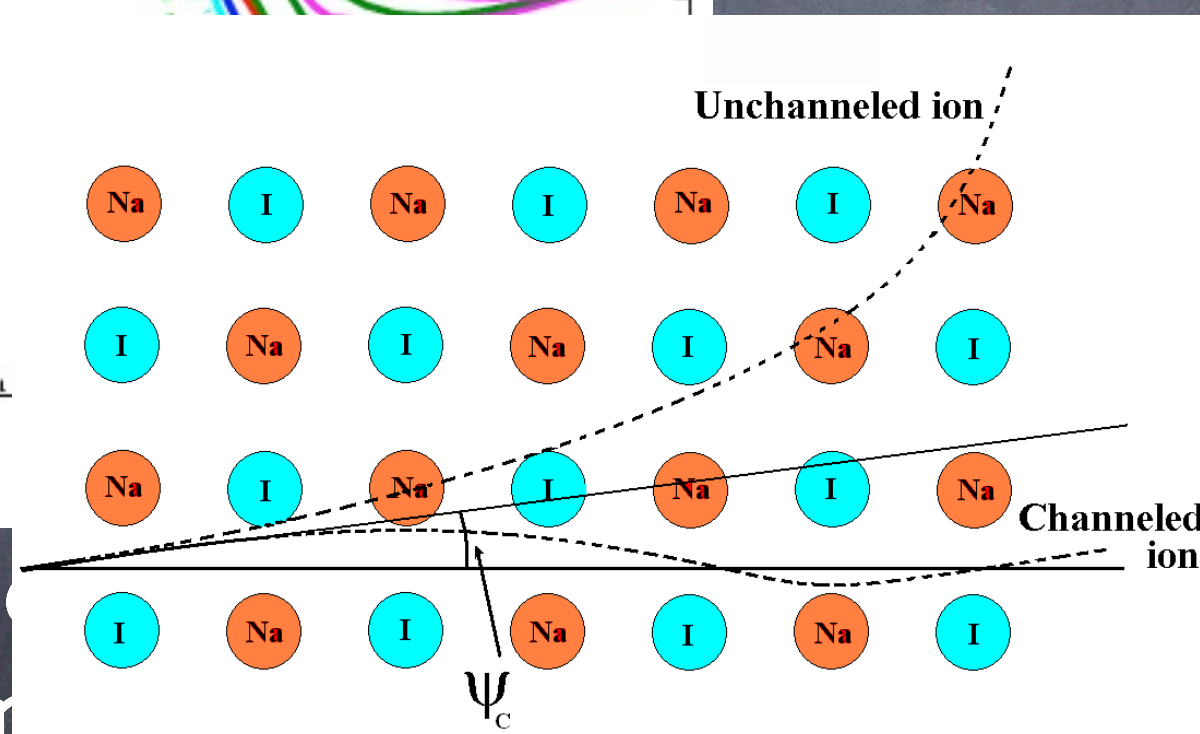

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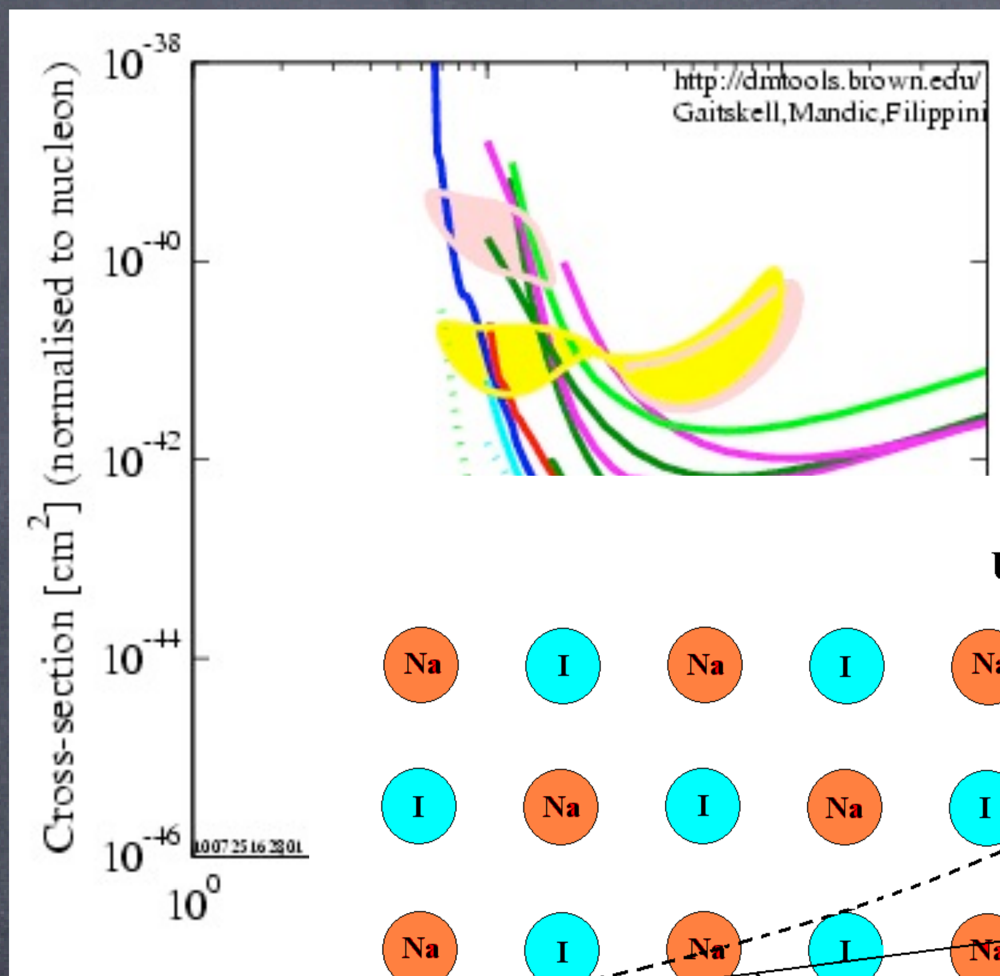
$$m_\chi \lesssim 10\ \mathrm{GeV}$$

Light DM from DAMA



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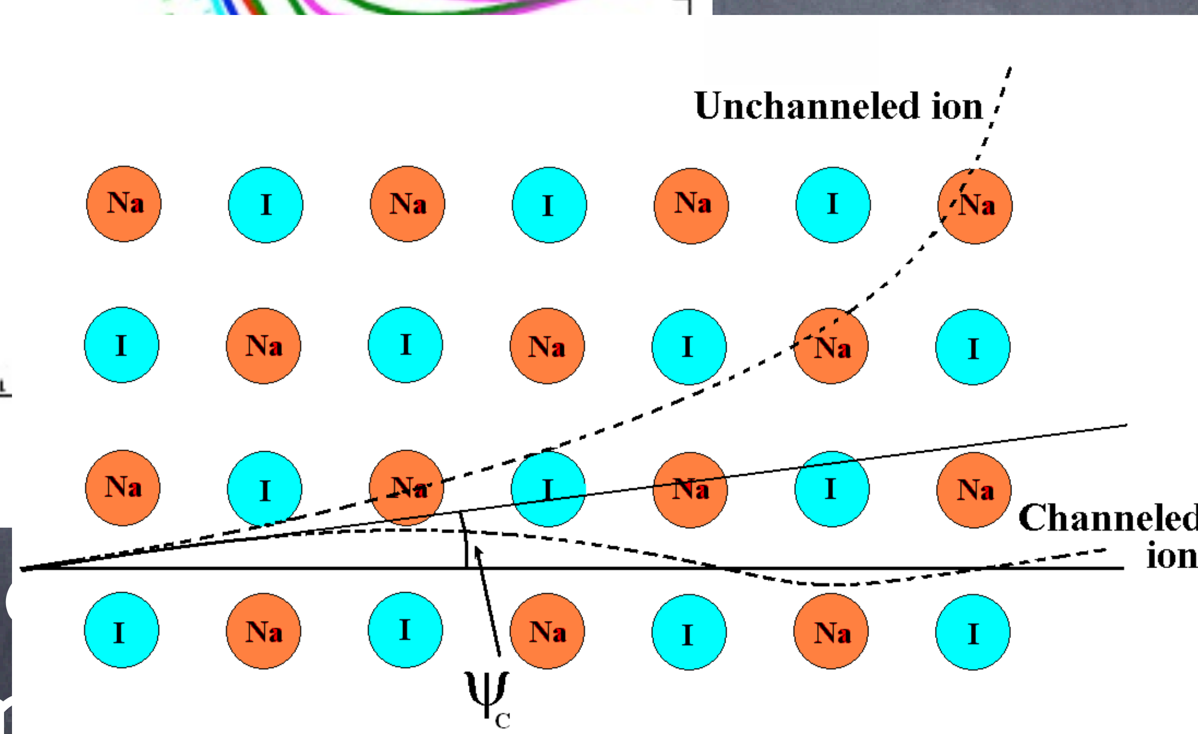


- To re... ...other null exper... ...stic DM.
- Channeling effect : Light DM can be survived.

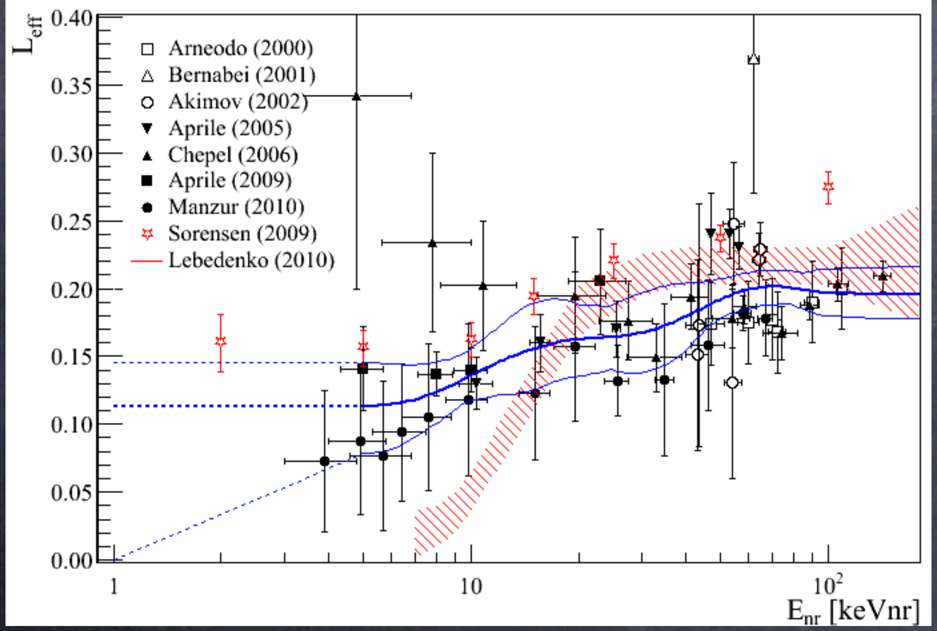
$$m_\chi \lesssim 10\ \mathrm{GeV} \qquad \sigma_{SI} \gtrsim 10^{-42}\mathrm{cm}^2$$

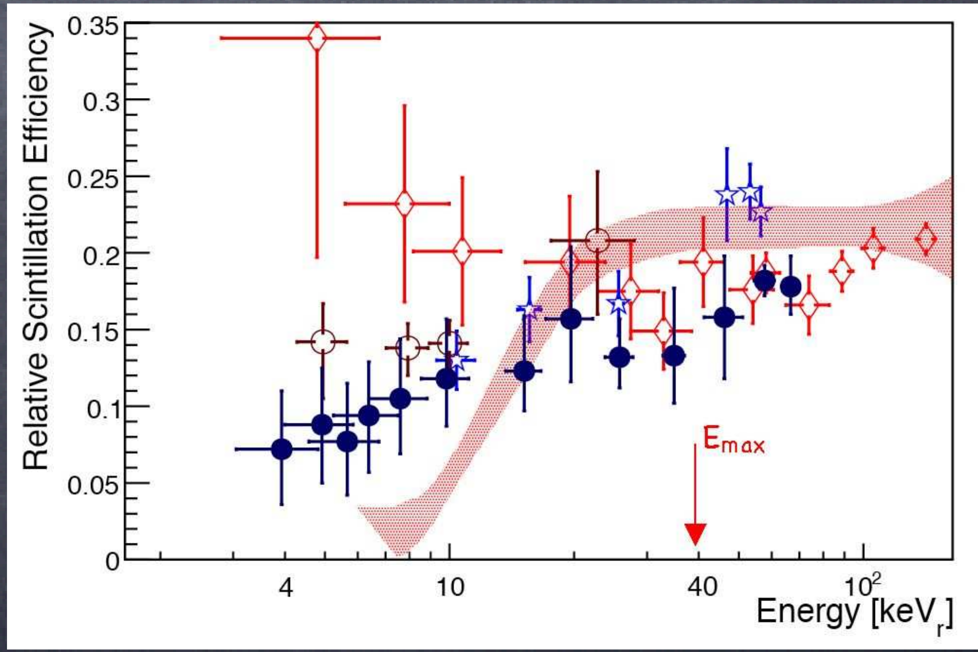
Light DM from DAMA

- Light SM gauge singlet fermionic DM
  Y.G. Kim and SS, JHEP 0905, 036 (2009)
- Light SM gauge singlet scalar DM
  S. Andreas, T. Hambye, M.H.G. Tytgat, JCAP 0810, 034
- WIMPless model
  J. Feng and J. Kumar, PRL 101, 231301 (2008)
- Light neutralino in an effective MSSM
  A. Bottino, F. Donato, N. Fornengo, S. Scopel
- Right handed sneutrino in the $\mu\nu$-SSM
  D. Cerdeno, C. Munoz, O. Seto, PRD 79, 023510 (2009)

Still, Tension with exp.

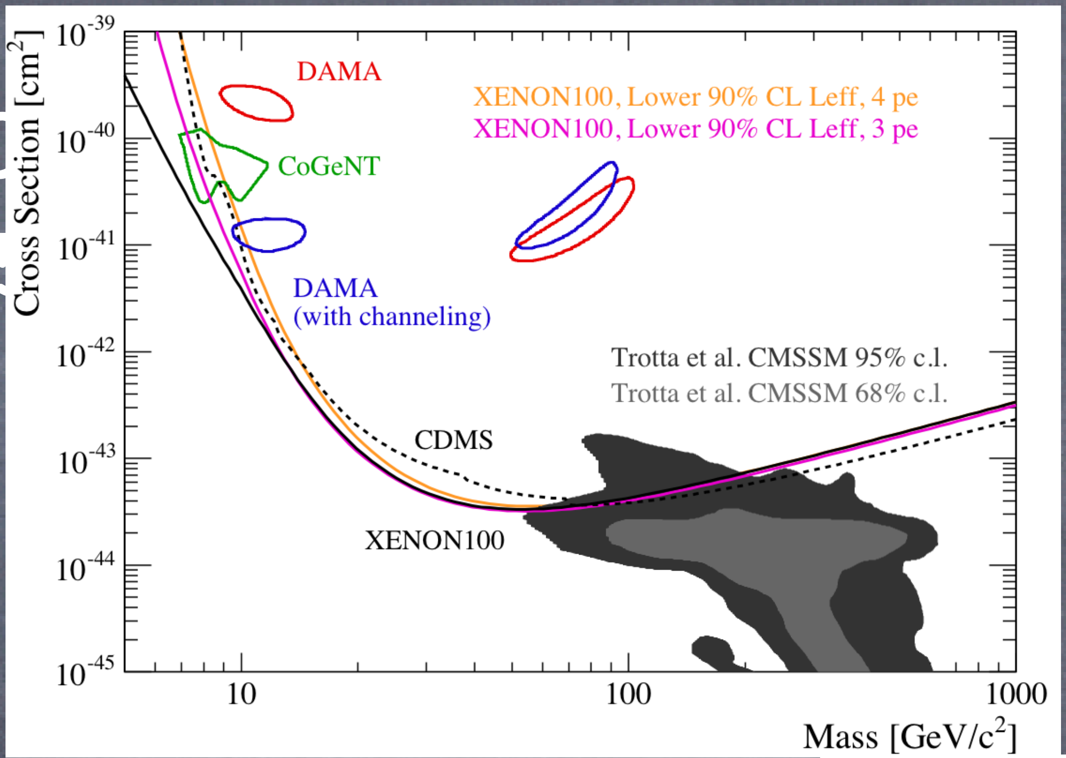
- Experiments are getting more and more improved.
- XENON 100 and CoGeNT arXiv:1005.0838, 1005.2615, 1005.3723
- Discussed in Prof. Mckinsey's talk

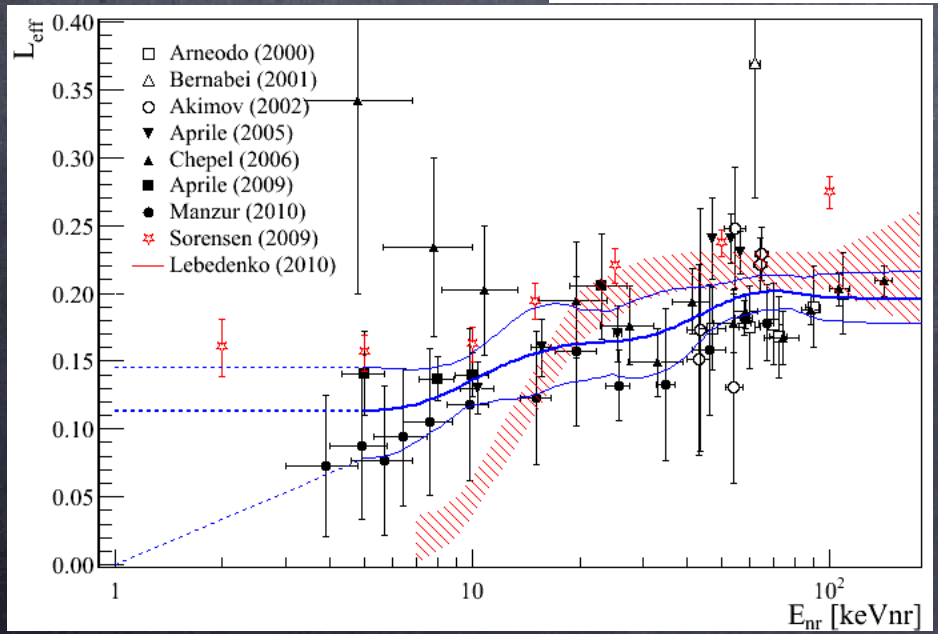


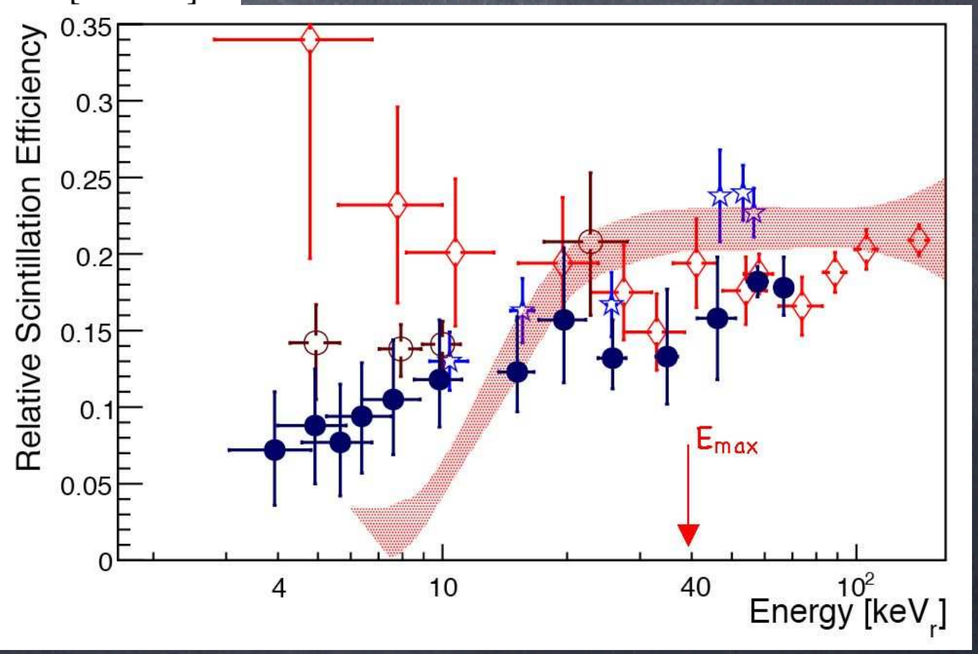


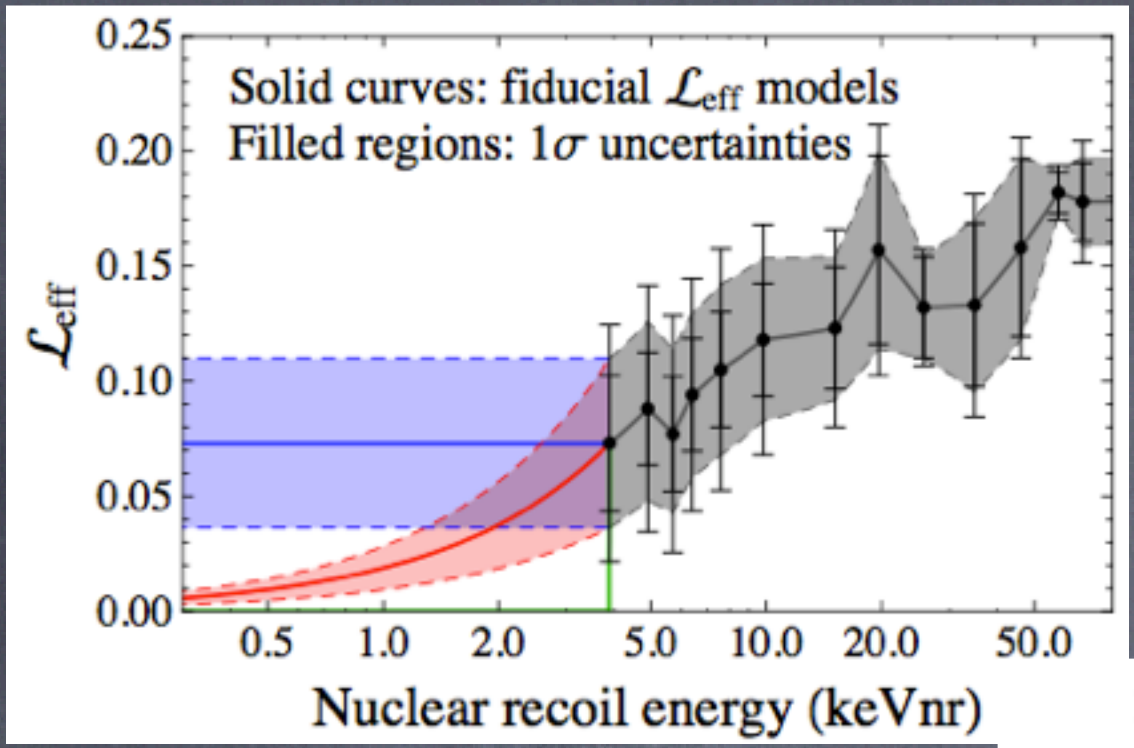
Still, Tension with exp.

- Experiments are getting more and more improved.
- XENON 10
  arXiv:100 3723
- Discussed







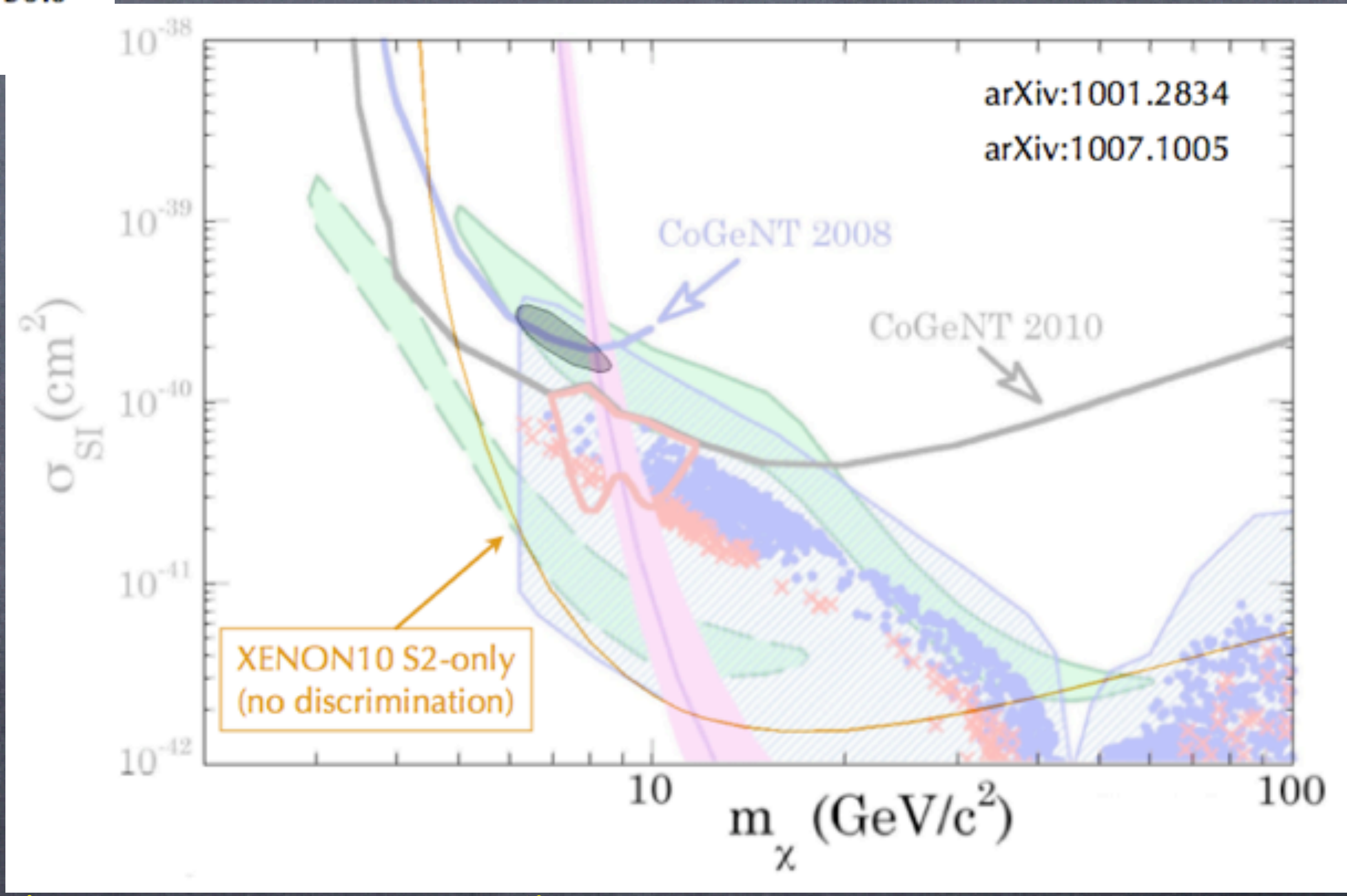


XENON 10 ?

arXiv:1006.0972

C. Savage, G. Gelmini, P. Gondolo, K.Freese

Channeling quite suppressed



Talk by Dr. Peter Sorensen arXiv:1007.3549

Aside from the scintillation efficiency, focus only S2

We can open up the allowed region.

- Considering the low energy background
  First bin in DAMA
  Some exponential background in CoGeNT
  S. Chang, J. Liu, A. Pierce, N. Weiner, I. Yavin,
  arXiv:1004.0697

- Ambiguity in the experimental parameter
  or halo profile

- Changing the fraction of channeling in DAMA
  CoGeNT and DAMA compatible?
  Need more research on the channeling
  Prof. Gelmini's talk based on arXiv:1006.3110

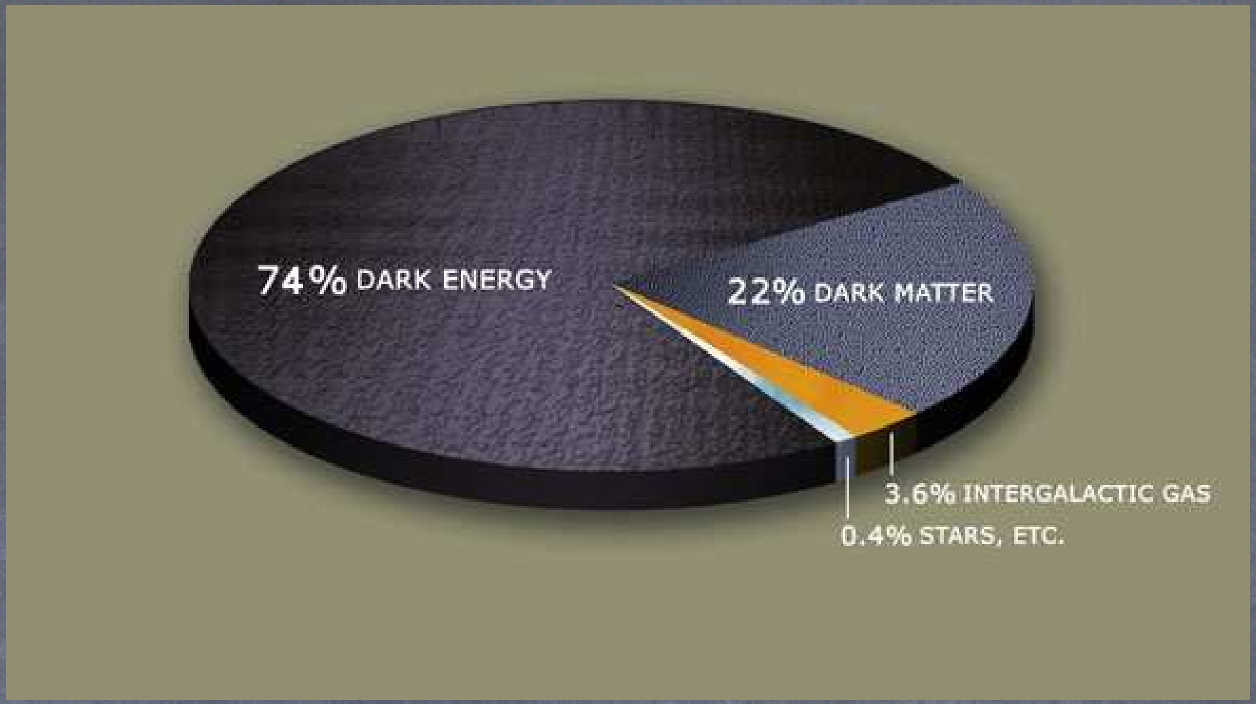
Light DM

- Focus on the optimistic side that the left signal region is from the DM scattering
- The channeling effect in DAMA/LIBRA is not so suppressed.
- DM of mass < 10 GeV
  (Conservatively, 4-7 GeV : <6 GeV is OK)
  $\sigma_{\rm SI} \sim 10^{-40} {\rm cm}^2$
  This region is interesting to be analyzed.
- So it is meaningful to investigate the model of light DM of this parameter region.

Light DM in SUSY

$\sigma_{\rm SI} \sim 10^{-40}{\rm cm}^2$

Light DM in SUSY



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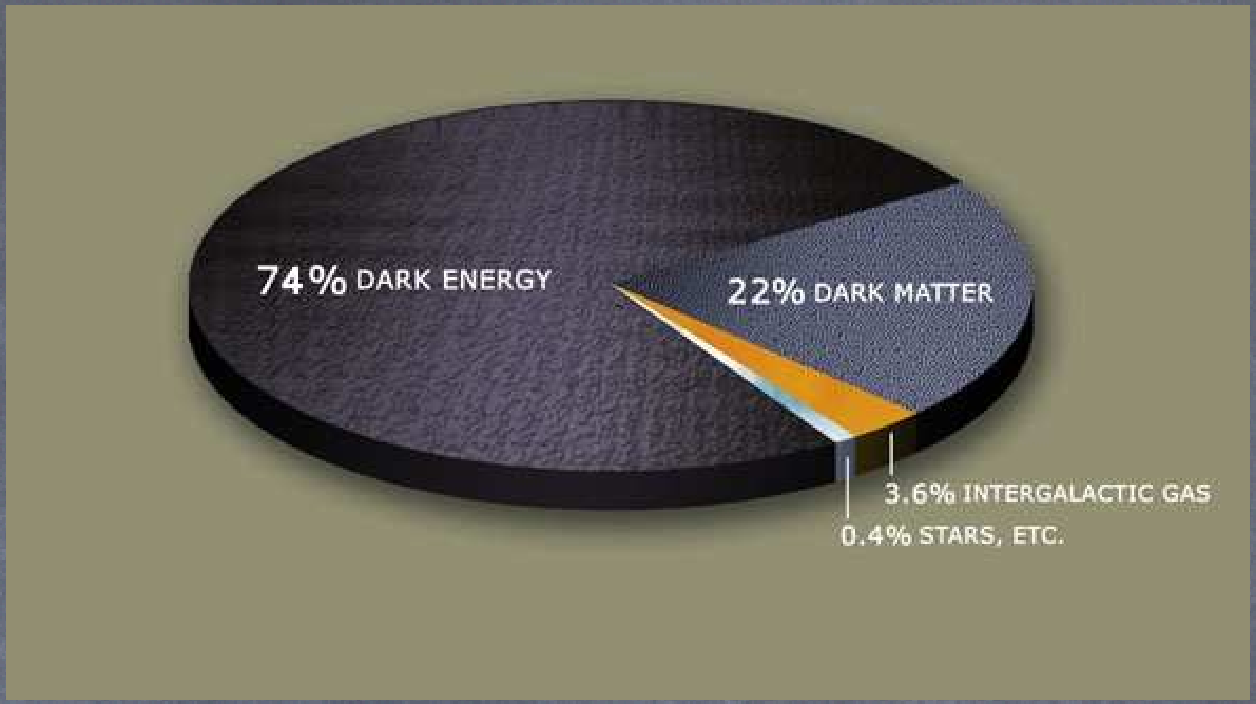
Light DM in SUSY



- SM matters not enough : The evidence of new physics beyond the SM
- We focus on SUSY which is one of the promising candidates of the new physics.
- So we search the viable parameter space to explain light DM of 4-7 GeV and $\sigma_{\rm SI} \sim 10^{-40}{\rm cm}^2$ in SUSY models with minimal d.o.f

Light DM in SUSY

- Two Higgs doublets (H_u, H_d realistically)
  Heavy CP-even neutral Higgs : H
  Light CP-even neutral Higgs : h
  (CP-odd Higgs A and two charged Higgs)

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} H_d^0 \\ H_u^0 \end{pmatrix}$$

$$-\frac{\pi}{2} \leq \alpha \leq \frac{\pi}{2}$$

- $\tan\beta = v_u/v_d$; $v^2 = v_u{}^2 + v_d{}^2$

Light DM in SUSY

$$\sigma_{\rm SI} = \frac{4m_r^2}{\pi} f_{p(n)}^2,$$

$$f_{p,n} = \sum_{q=u,d,s} f_{T_q}^{(p,n)} a_q \frac{m_{p,n}}{m_q} + \frac{2}{27} f_{TG}^{(p,n)} \sum_{q=c,b,t} a_q \frac{m_{p,n}}{m_q},$$

- The WIMP and **s**-quark coupling is dominant in WIMP-nucleon scattering due to large $f_{T_s}^{(p,n)}$
  J.R. Ellis, A. Ferstl, K.A. Olive, PLB481, 304 (2000)
- The *t*-channel exchange of H_d-like CP-even Higgs is dominant in the WIMP-nucleon scattering. (Neglected scalar quark exchange since scalar quarks are usually heavier than Higgs to satisfy the collider bounds)

Light DM in SUSY

- σ_{SI} : (Higgs - **s** quark)^2 (Higgs - WIMP)^2 / M^4
- Two cases to obtain the large σ_{SI}

(1) H_d-like Higgs : Heavy H, large tanβ

(H : Heavy Higgs mediation)

$(\tan\beta)^2\ (m_H)^{-4}$ term is dominant in σ_{SI}.

(2) H_d-like Higgs : Light h, small tanβ

(h : Light Higgs mediation)

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- Constraints from the other experiments must be considered.

Heavy Higgs mediation

- When H is not much heavier than h
  For large tanβ

$$\sigma_{\rm SI} \simeq 1.6 \times 10^{-40}\ {\rm cm}^2 \times \left(\frac{N_{13}}{0.4}\right)^2 \left(\frac{\tan\beta}{200}\right)^2 \left(\frac{100\ {\rm GeV}}{m_H}\right)^4$$

- H : as heavy as ≳ 100 GeV tanβ ≳ 200
- The parameter space with such large tanβ is highly constrained by the branching ratio of $B_s \to \mu^+\mu^-$
- Considering the upper limit in H/A $\to \tau^+\tau^-$, it is impossible to obtain such high $\sigma_{\rm SI} \sim 10^{-40}{\rm cm}^2$

  E. Kuflik, A. Pierce, K. Zurek, arXiv:1003.0682

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  E. Kuflik, A. Pierce, K. Zurek, arXiv:1003.0682
- Light Higgs mediation must be considered!

Light Higgs mediation

- h is H_d-like and $m_h \ll m_H$ with moderate tanβ

$$\sigma_{\rm SI} \simeq 1.9 \times 10^{-40}\ {\rm cm}^2 \times \left(\frac{N_{13}}{0.3}\right)^2 \left(\frac{\tan\beta}{3}\right)^2 \left(\frac{10\ {\rm GeV}}{m_h}\right)^4,$$

- This is obtained for $\alpha \simeq \beta$: LEP constraint.
- h : as light as O(10) GeV tanβ can be O(1)
- LEP constraints on the Higgs must be considered since h is lighter than 114.4 GeV.
  (1) Higgsstrahlung
  $$e^+e^- \to Z^* \to Zh$$
  (2) Associative production
  $$e^+e^- \to Z^* \to hA$$

Light Higgs mediation

$$R_{hZ} \equiv \frac{\sigma(e^+e^- \to Z^* \to Zh)_{\rm MSSM}}{\sigma(e^+e^- \to Z^* \to Zh)_{\rm SM}} = \sin^2(\alpha - \beta)$$

$$R_{hA} \equiv \frac{\sigma(e^+e^- \to Z^* \to hA)_{\rm SUSY}\mathcal{B}(h \to \bar{b}b)\mathcal{B}(A \to \bar{b}b)}{\sigma(e^+e^- \to Z^* \to hA)_{\rm ref}}$$
$$= \cos^2(\alpha - \beta)\mathcal{B}(h \to \bar{b}b)\mathcal{B}(A \to \bar{b}b)$$

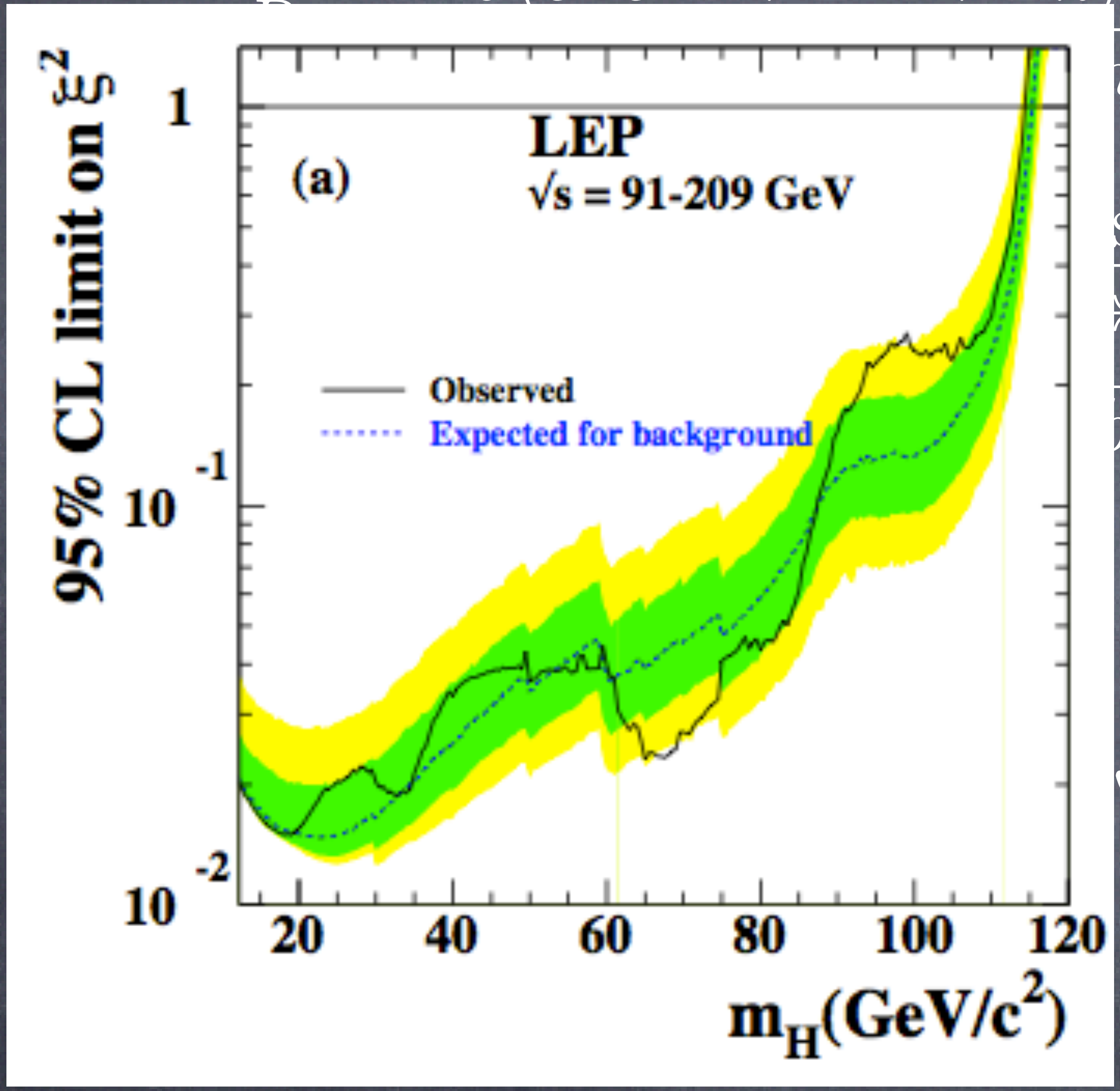
$${\rm ref} : g_{ZhA} = g_{ZZh}^{\rm SM}$$

(1) h and A mainly decay to $b\bar{b}$

m_h > 10 GeV

Light Higgs mediation

$$\frac{\sigma(e^+e^- \to Z^* \to Zh)_{\rm MSSM}}{\quad h)_{\rm SM}} = \sin^2(\alpha - \beta)$$



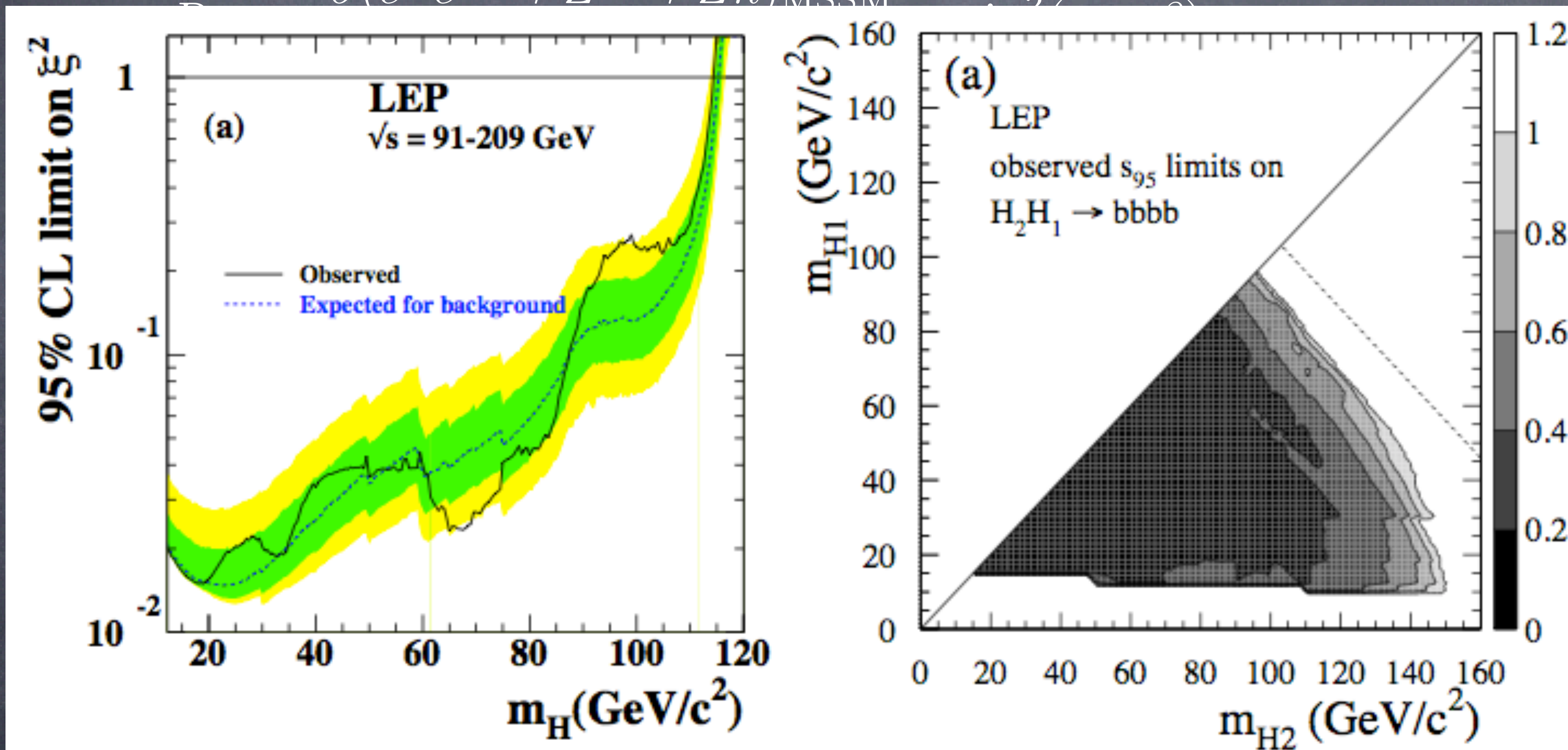
$$\frac{\quad_{\rm SUSY}\mathcal{B}(h \to \bar{b}b)\mathcal{B}(A \to \bar{b}b)}{\to Z^* \to hA)_{\rm ref}}$$

$$\bar{b}b)\mathcal{B}(A \to \bar{b}b)$$

y to $b\bar{b}$

Light Higgs mediation

$\sigma(e^+e^- \to Z^* \to Zh)_{\mathrm{MSSM}}$



Light Higgs mediation

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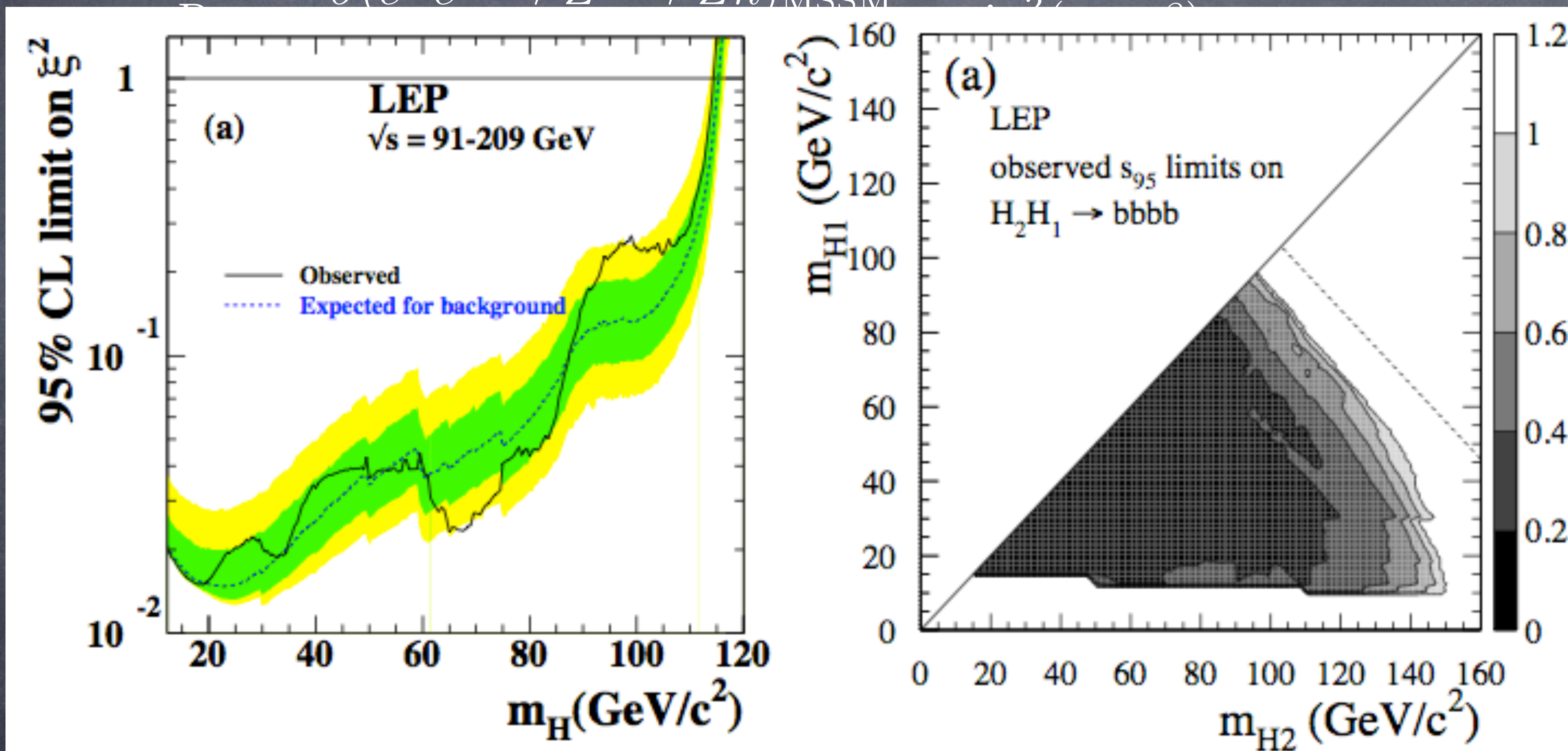

- $R_{hZ} \lesssim 0.01$ and $R_{hA} \lesssim 0.2$
  for $m_h \lesssim 20$ GeV, $m_A \leq 110$ GeV

LEP Higgs Working Group LHWG-Note-2005-01

Light Higgs mediation

- $\alpha \simeq \beta$ to satisfy the Higgsstrahlung constraint.
- Then, $\cos(\alpha-\beta) \simeq 1$ in the associative production.

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$$\chi\bar{\chi}$$

- $m_h \gtrsim 2\, m_\chi$ ($\sim$ 20 GeV) and low $\tan\beta \lesssim 3$ may provide plausible parameter space.

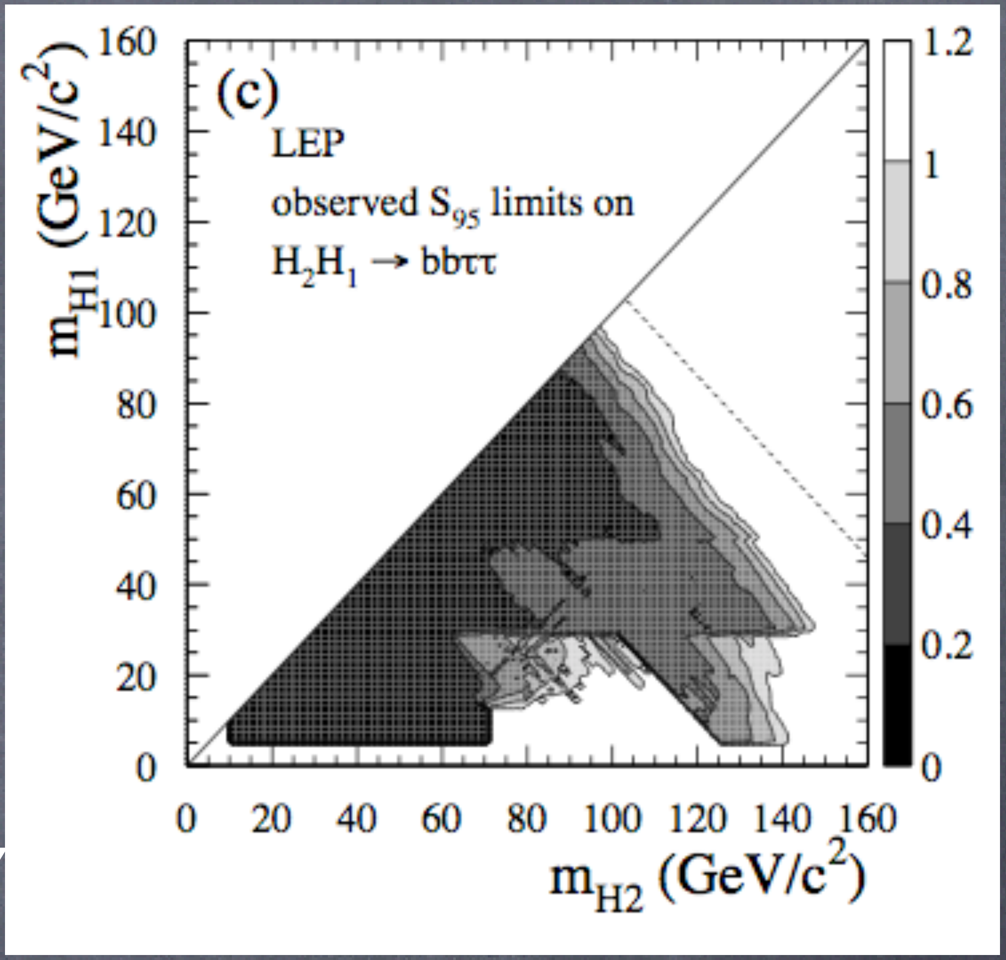
  ($\tan\beta \lesssim 3$: C.E. Yaguna, PRD 76, 075017 (2007))

Light Higgs mediation

(2) h mainly decays to $\tau^+\tau^-$
$m_h < 10$ GeV

- No constraint from the associative production for mA ≤ 120 GeV.

- Instead, the constraint from the radiative Υ decay $\Upsilon \to h\gamma$ is on rise as well as the Higgsstrahlung $\sin(\alpha-\beta) \simeq 0$.



- Strongest experimental bound $B(\Upsilon \to h\gamma) < 10^{-5}$
→ Most conservative Higgs mass bound

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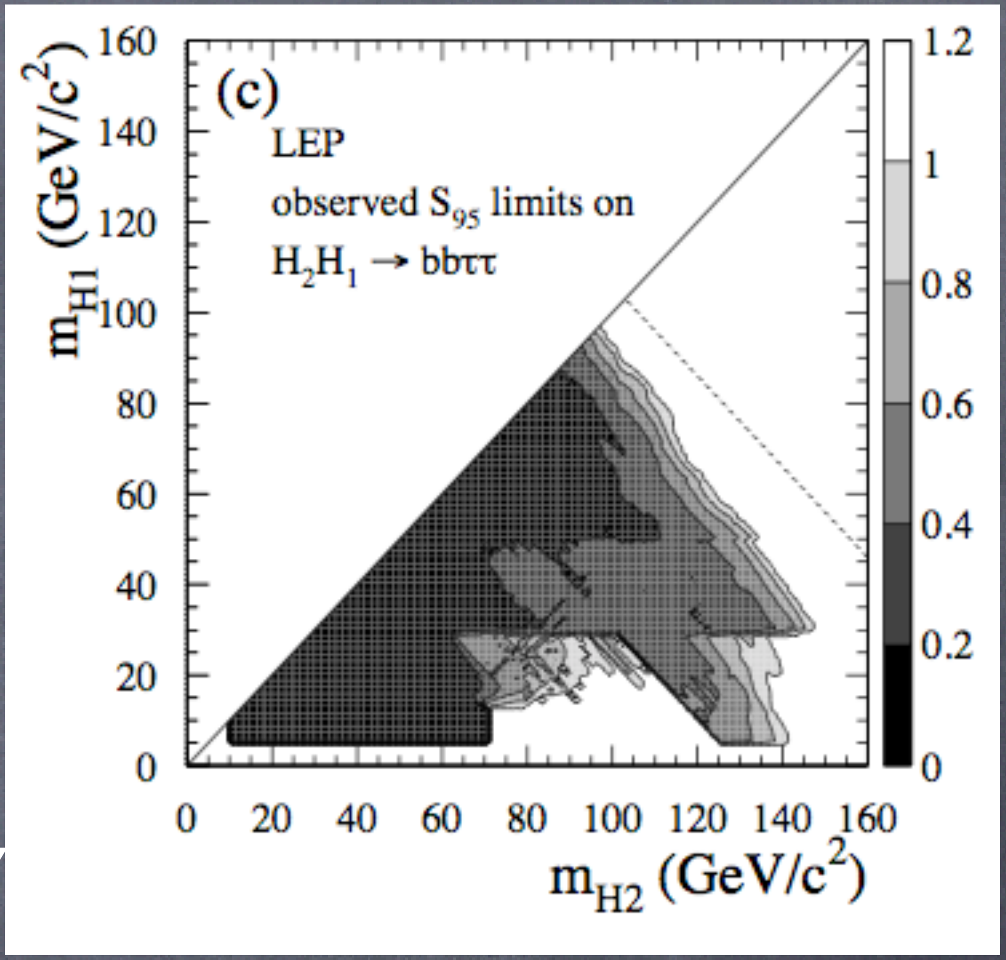

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→ Most conservative Higgs mass bound

$$m_h \gtrsim 8.9\text{GeV}$$

Light Higgs in the MSSM

- Plausible light Higgs 9 GeV $\lesssim m_h \lesssim$ 20 GeV
- Tree level Higgs mass matrix in the MSSM

$$\begin{pmatrix} M_Z^2 c_\beta^2 + m_A^2 s_\beta^2 & -(M_Z^2 + m_A^2) s_\beta c_\beta \\ -(M_Z^2 + m_A^2) s_\beta c_\beta & M_Z^2 s_\beta^2 + m_A^2 c_\beta^2 \end{pmatrix}$$

$$c\beta = \cos\beta, \quad s\beta = \sin\beta \quad (H_d^0, H_u^0)\text{basis}$$

- $\tan\beta \lesssim 5$: β is near to $\pi/2$
- To obtain such light Higgs, $m_A < M_Z$ since M_Z is fixed as $\sim$ 90 GeV

Light Higgs in the MSSM

- $m_A \ll M_Z$: h is mostly down-type $\alpha \simeq \pi/2$
  Not favored by invisible Z-width $Z \to hA$
- $m_A \lesssim M_Z$: Maximal mixing $\alpha \simeq -\pi/4$
  Not favored by the Higgsstrahlung
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  Not favored by invisible Z-width $Z \to hA$
- $m_A \lesssim M_Z$: Maximal mixing $\alpha \simeq -\pi/4$
  Not favored by the Higgsstrahlung
  since β is positive
- Light Higgs mediation scenario cannot be realized in the MSSM!

Light Higgs in the BMSSM

- We consider additional correction to the tree level Higgs mass : BMSSM

  M.Dine, N. Seiberg, S. Thomas, PRD 76, 095004 (2007)

$$\begin{pmatrix} M_Z^2 c_\beta^2 + m_A^2 s_\beta^2 + 4v^2\epsilon_1 s_{2\beta} + 4v^2\epsilon_2 s_\beta^2 & -(M_Z^2 + m_A^2)s_\beta c_\beta + 4v^2\epsilon_1 \\ -(M_Z^2 + m_A^2)s_\beta c_\beta + 4v^2\epsilon_1 & M_Z^2 s_\beta^2 + m_A^2 c_\beta^2 + 4v^2\epsilon_1 s_{2\beta} + 4v^2\epsilon_2 c_\beta^2 \end{pmatrix}$$

- We consider the BMSSM to realize the light Higgs mediation scenario with minimal contents. (without additional light d.o.f. such as NMSSM

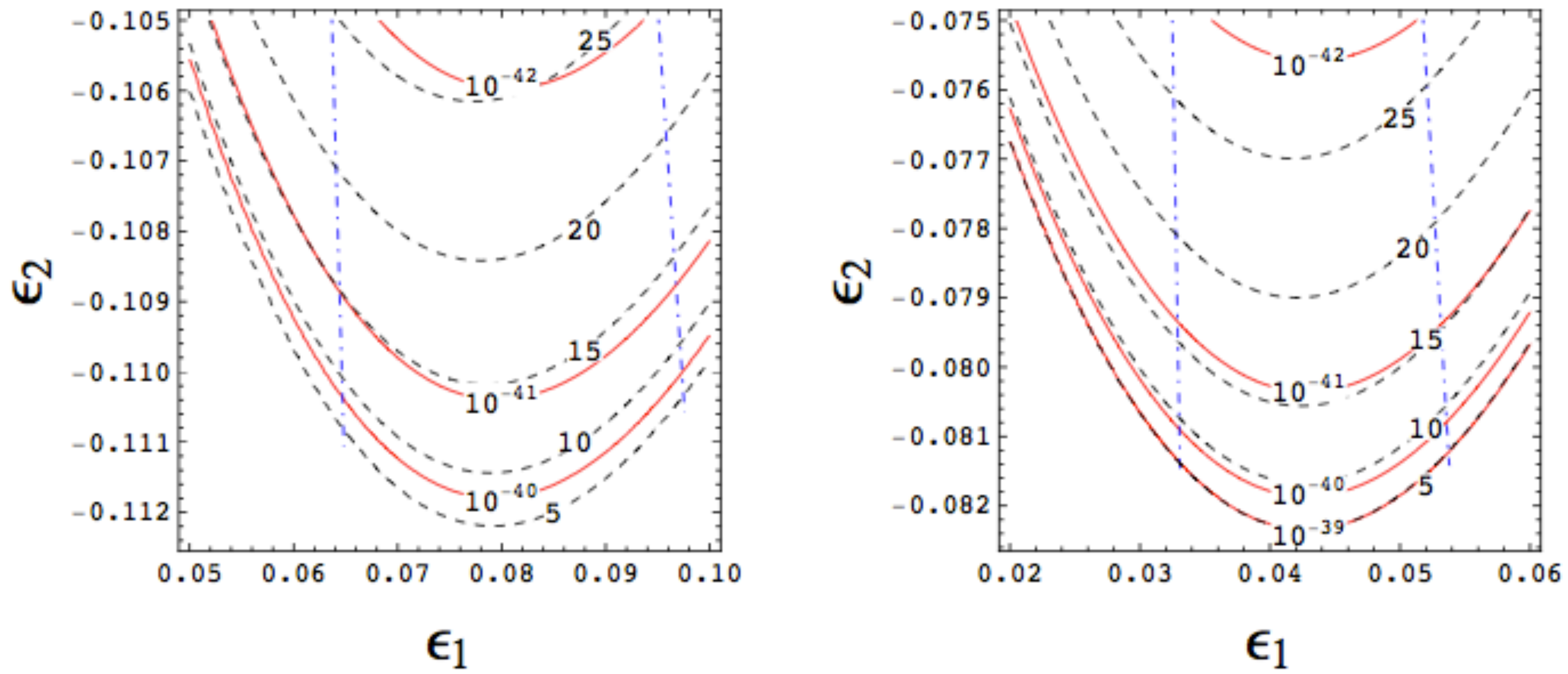
  J.F. Gunion, D. Hooper, B. McElrath, PRD 73, 015011 (2006))

Light Higgs in the BMSSM

- Negative ε_2 correction effectively reduces m_A^2 in the MSSM to $m_A^2+4v^2\varepsilon_2$ so that very light h scenario can be realized without introducing light CP-odd Higgs.

- Positive ε_1 correction can reduce the off-diagonal Higgs mixing.
  When $4v^2\varepsilon_1 \gtrsim (M_Z^2+m_A^2)\, s\beta c\beta$, we achieve $\alpha \lesssim \pi/2$ so that the Higgsstrahlung bound can be avoided.

Light Higgs in the BMSSM



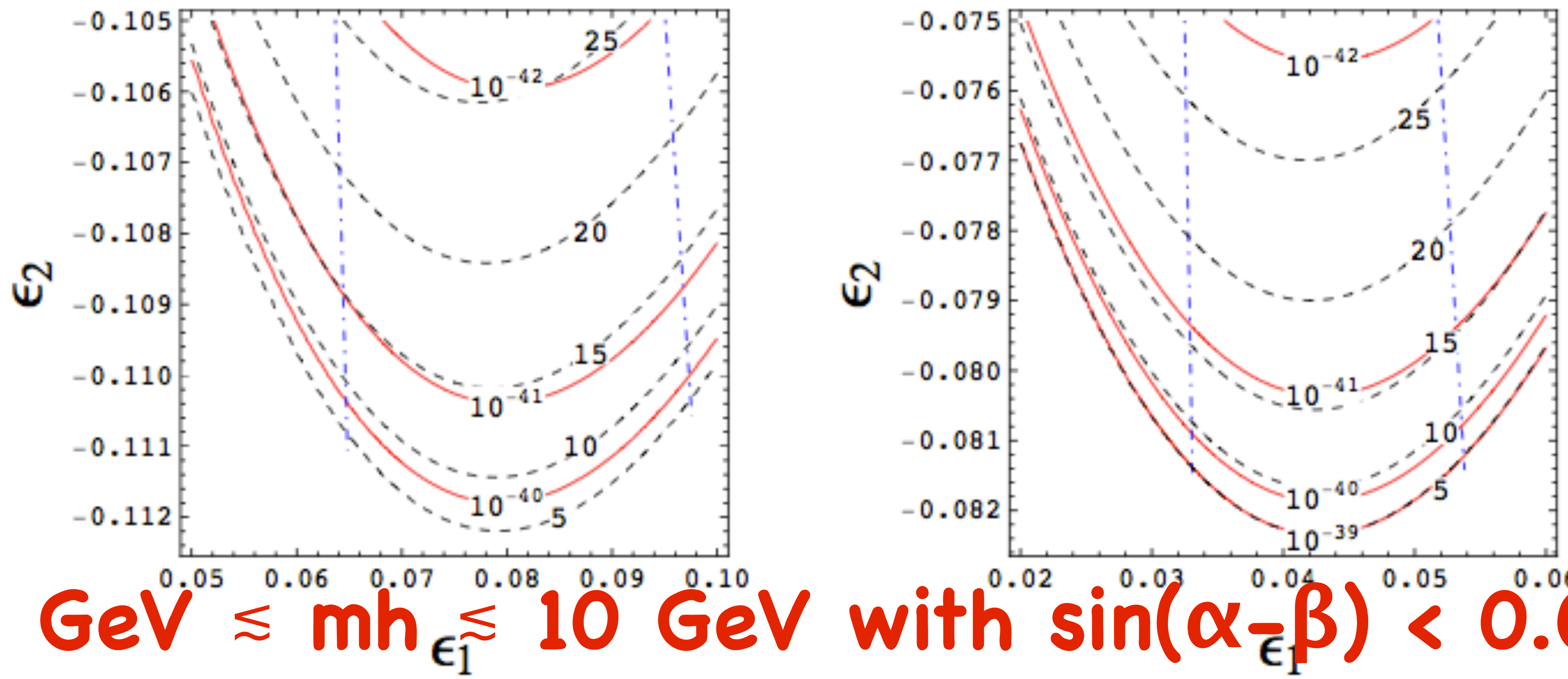
(a) $\tan\beta = 3$, $m_A = 90$ GeV

(b) $\tan\beta = 5$, $m_A = 90$ GeV

FIG. 2. Numerical results of neutralino-nucleon scattering cross section in $\epsilon_1 - \epsilon_2$ plane. Solid(red) curves stand for scattering cross section, $\sigma = 10^{-40}$-10^{-42} cm^2 for left panel and $\sigma = 10^{-39}$-10^{-42} cm^2 for right panel from the bottom to the top. Dashed(black) curves stand for light Higgs mass, $m_h = 5$-25 GeV from the bottom to the top. Dot-dashed(blue) lines stand for $\sin^2(\alpha - \beta) = 0.01$, the region between the lines is safe from the Higgsstrahlung constraint. Neutralino mass is 4 GeV$\lesssim m_\chi \lesssim$ 7 GeV depending on parameters.

- m_h larger than 10 GeV may demand smaller $\tan\beta < 3$ to satisfy the constraint from R_{hA}
  Large $\varepsilon_{1,2}$ to satisfy $\sigma_{\rm SI} \sim 10^{-40}{\rm cm}^2$ (>10%)

Light Higgs in the BMSSM



9 GeV ≲ mh ≲ 10 GeV with sin(α-β) < 0.01 is favored in the BMSSM

(a)tan $\beta = 3$, $m_A = 90$ GeV (b)tan $\beta = 5$, $m_A = 90$ GeV

FIG. 2. Numerical results of neutralino-nucleon scattering cross section in $\epsilon_1 - \epsilon_2$ plane. Solid(red) curves stand for scattering cross section, $\sigma = 10^{-40}$-10^{-42} cm^2 for left panel and $\sigma = 10^{-39}$-10^{-42} cm^2 for right panel from the bottom to the top. Dashed(black) curves stand for light Higgs mass, m_h = 5-25 GeV from the bottom to the top. Dot-dashed(blue) lines stand for $\sin^2(\alpha - \beta) = 0.01$, the region between the lines is safe from the Higgsstrahlung constraint. Neutralino mass is 4 GeV$\lesssim m_\chi \lesssim$7 GeV depending on parameters.

- m_h larger than 10 GeV may demand smaller $\tan\beta < 3$ to satisfy the constraint from R_{hA} Large $\varepsilon_{1,2}$ to satisfy $\sigma_{\rm SI} \sim 10^{-40}{\rm cm}^2$ (>10%)

Relic abundance

- Since the neutralinos are very light $\lesssim$ 7 GeV, they annihilate only to light fermions at the freeze-out.
- The neutralino is much lighter than A, scalar quarks, and Z-boson so that the dominant annihilation process is mediated by the CP-even Higgs h which is a P-wave process.
- Small $\tan\beta \sim 3$ constrains the interaction of h to the SM fermions.
- Therefore, the resonant annihilation is the only possible process to obtain the right relic abundance.

Relic abundance

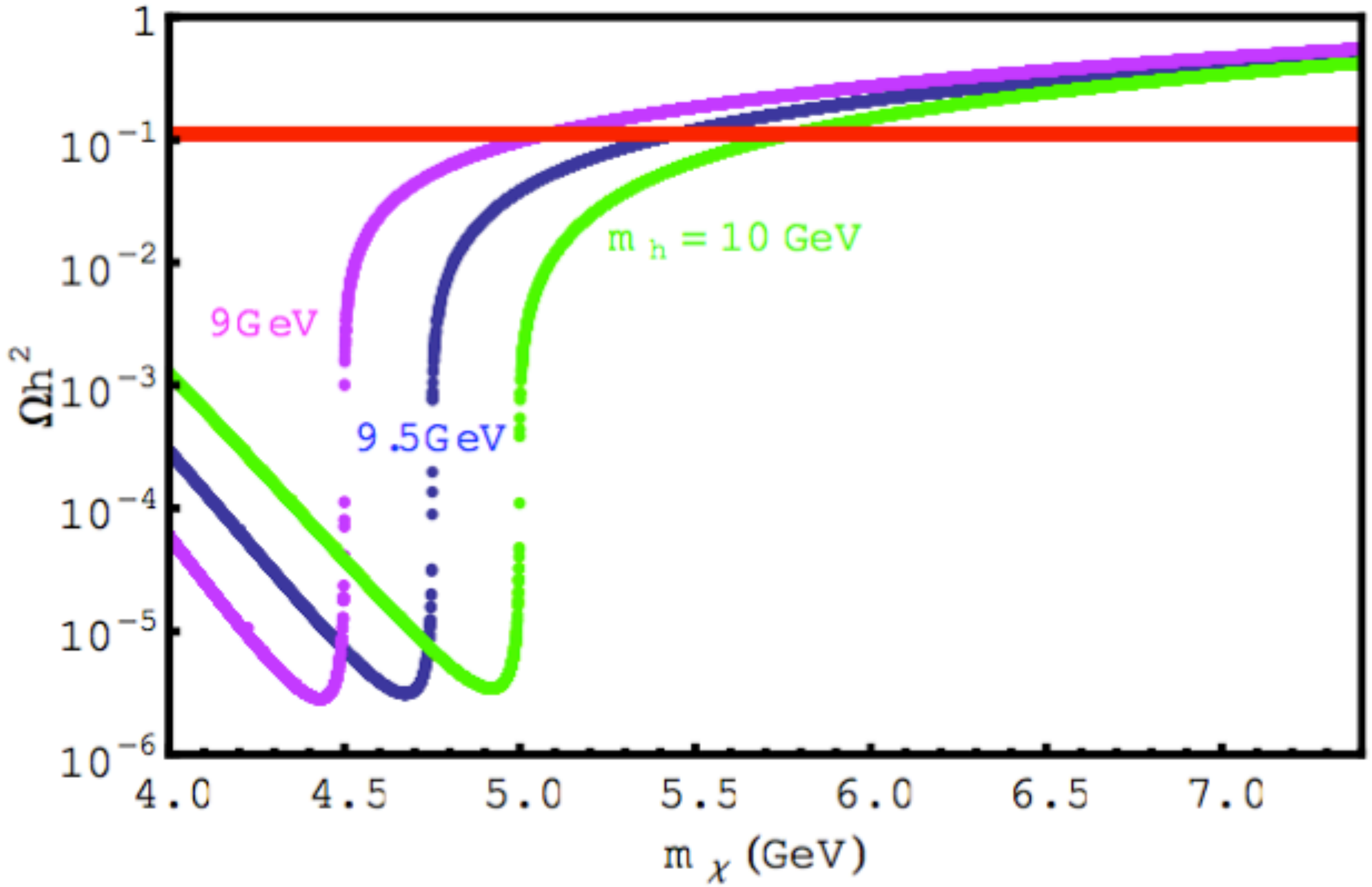


FIG. 3. Ωh^2 to m_χ with fixed $\tan\beta = 3$ and $N_{13} = 0.3$ values. The allowed mass of the light CP-even Higgs is 9 GeV $\lesssim m_h \lesssim$ 10 GeV. The magenta, blue, green lines denote the case $m_h = 9$ GeV, 9.5 GeV, 10 GeV respectively. The parameters are given to avoid the LEP or Υ decay constraints. The red region denotes the observed relic abundance satisfying (1). Therefore, we conclude that the physically consistent mass of our light WIMP is determined as 5 GeV$\lesssim m_\chi \lesssim$ 6 GeV here.

Conclusions

- Light DM of < 10 GeV and 10^{-40} cm^2 is being focussed on these days.
- We searched such reliable parameter space within SUSY models which is one of the promising candidates of the new physics beyond the SM (with the minimal number of contents)
- We found that light H_d like Higgs mediation with low $\tan\beta$ is viable
- MSSM is not suitable for the light mediation : BMSSM is considered.

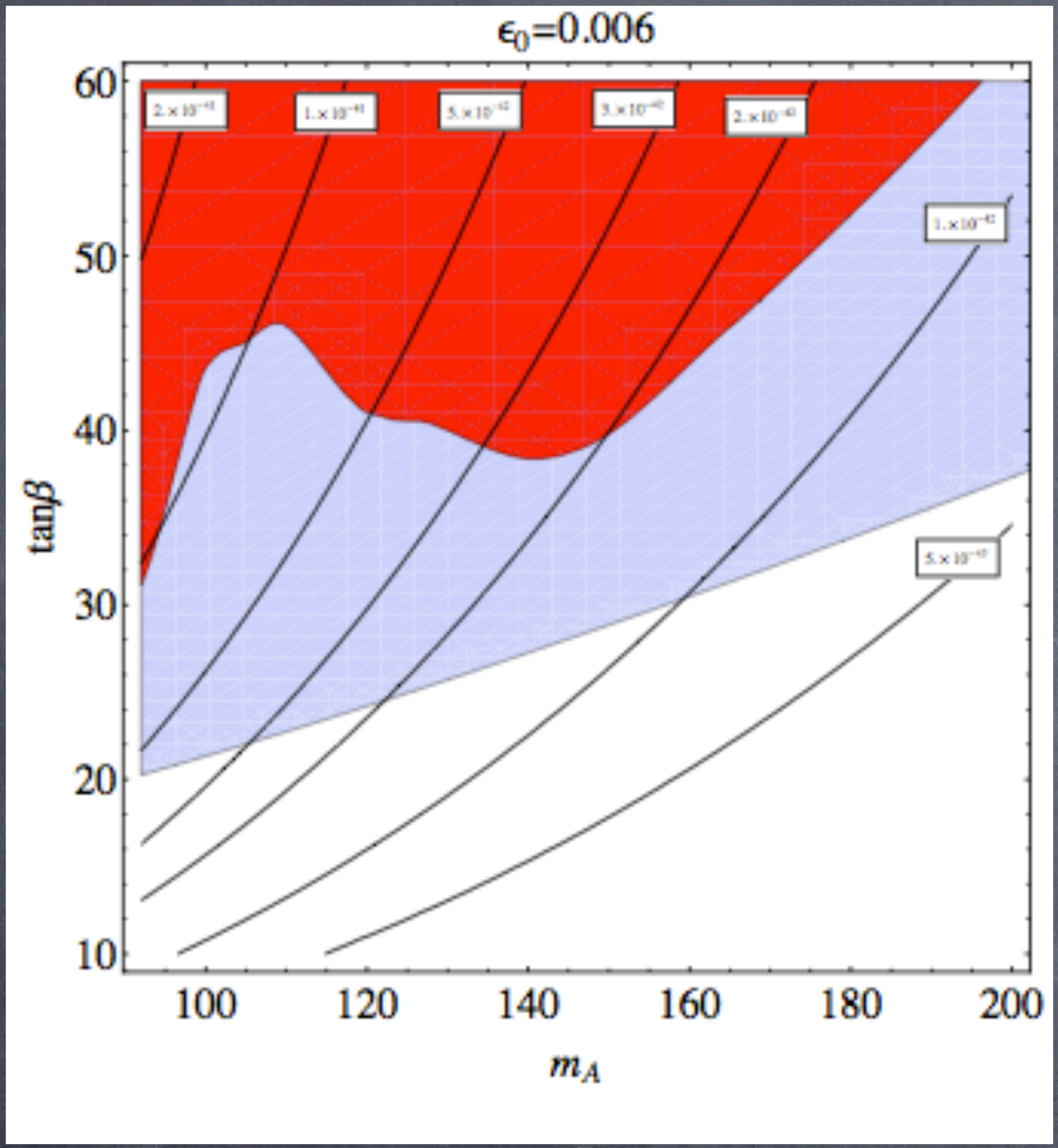
- From the constraints by other experiments such as LEP, Upsilon decay, we found reliable range for the mass of the light Higgs 9-10 GeV within the plausible parameter space of BMSSM.

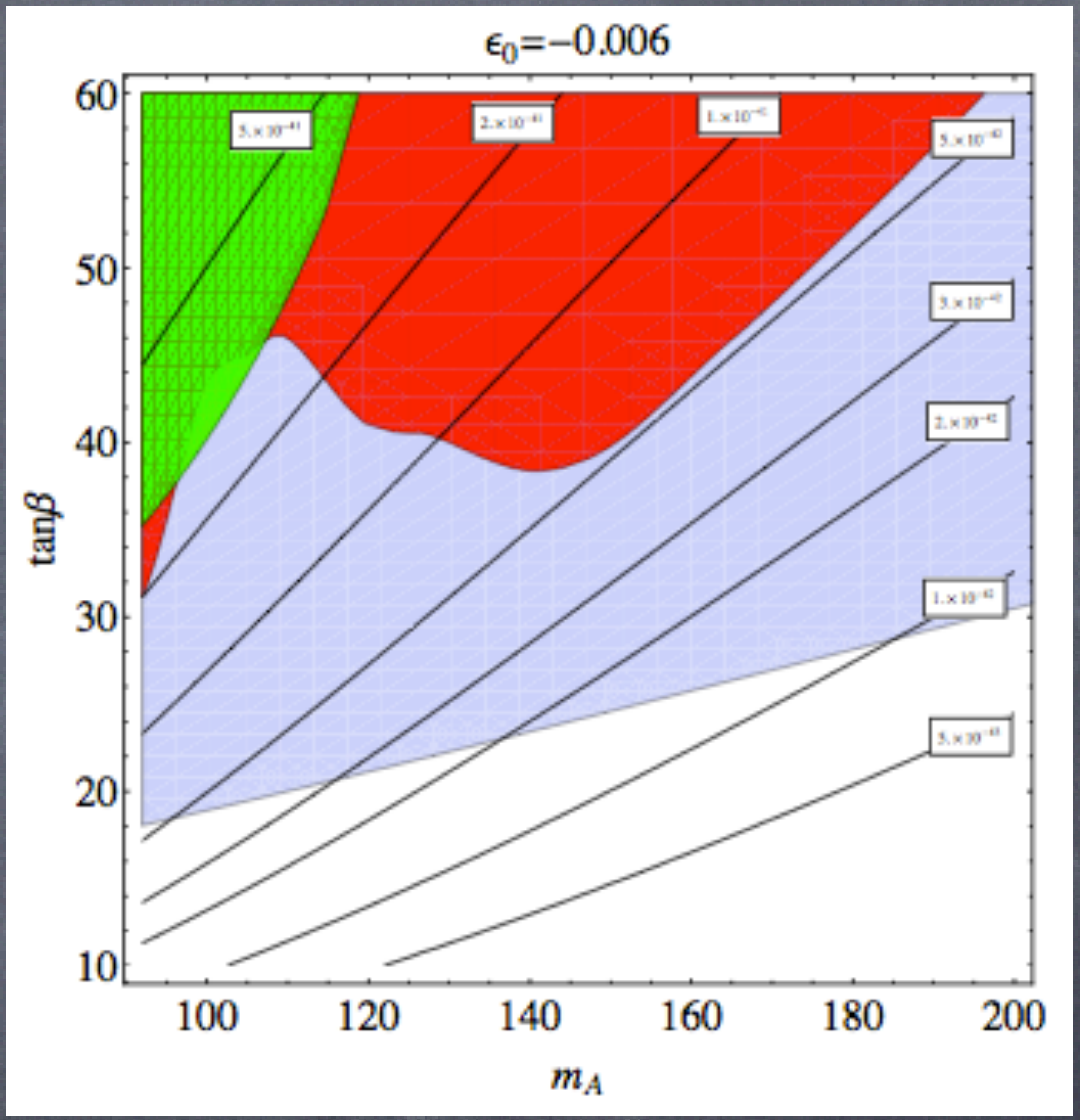
- The relic abundance of the light neutralino is obtained by the resonant process in the pair annihilation to give the right value observed by WMAP. Therefore, WIMP mass 5-6 GeV is viable. (Anyway survived : Dr. Sorensen's result)

- Consequently, we succeeded to obtain the reliable parameter space for light DM consistent with CoGeNT and DAMA/LIBRA, without introducing additional light d.o.f.

Merci beaucoup!

Back-up slides





- Grey : $B \to \tau\nu$
- Below the red region : $\varphi \to \tau\tau$

Back-up slide

- Upsilon decay

$$\mathcal{B}(\Upsilon \to h\gamma) \approx 1.59 \times 10^{-4} \times z(0.928 - 0.302 z^{-1/2}) \tan^2 \beta$$

$$z = 1 - m_h^2/m_\Upsilon^2$$