Enhancement of Line Gamma Ray Signature from Bino-like Dark Matter Annihilation due to CP Violation

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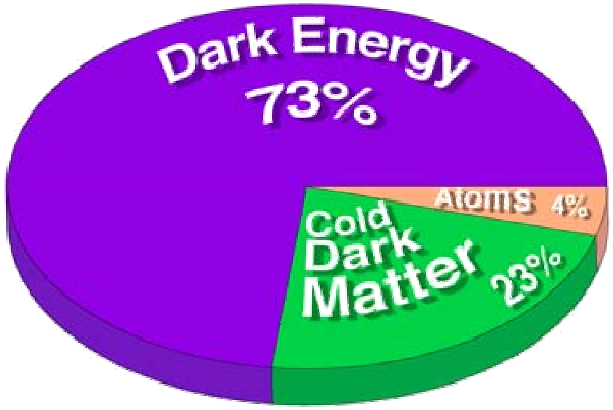
Introduction

- Many observation indicate the existence of Cold Dark Matter (CDM)
- Next question is what the composition of CDM is.
- In the standard model (SM), there is no candidate for CDM.
- A study of the beyond SM is mandatory.



WMAP
http://map.gsfc.nasa.gov

Candidate for Cold Dark Matter

- In the Minimal Supersymmetric Standard Model (MSSM), the lightest neutralino is a candidate for cold dark matter.

- Neutralino is a linear combination of SUSY particle.

$$\tilde{\chi}^0 = N_{\tilde{B}} \tilde{B} + N_{\tilde{W}} \tilde{W} + N_{\tilde{H}_1} \tilde{H}_1 + N_{\tilde{H}_2} \tilde{H}_2$$

- R-parity conservation ensures the stability of the Lightest Supersymmetric Particle (LSP).

In many SUSY breaking scenario, Bino-like neutralino predicted as the LSP.

Dark Matter Searches

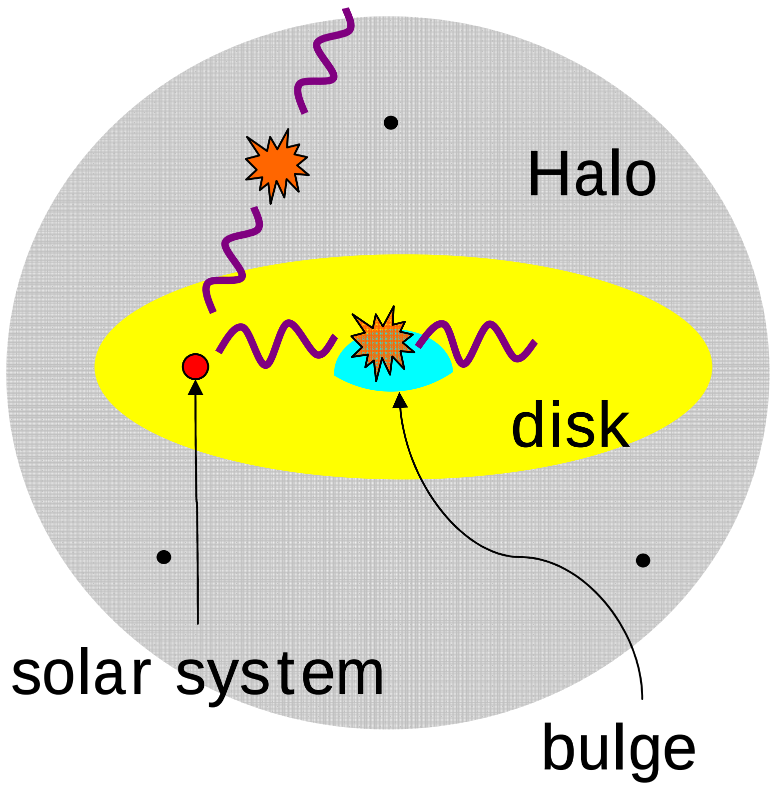
- Direct detection
- Indirect detection
  - Cosmic gamma rays
  - High energy neutrinos
  - Positron and anti-proton excess

Dark Matter (Halo) is associated with the galaxy, and distributes spherically.

The typical velocity of DM

$$v \sim \mathcal{O}(10^{-3})c$$

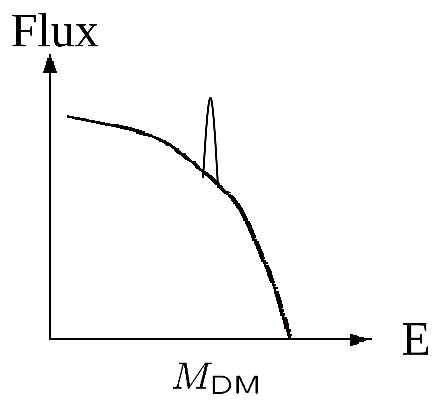
The Milky Way (Our Galaxy)



Gamma Ray Signature from Dark Matter Annihilation

- Gamma ray from dark matter pair annihilation have a line spectrum.

- The diffused gamma ray background induced from astrophysical sources has a continuum spectrum.

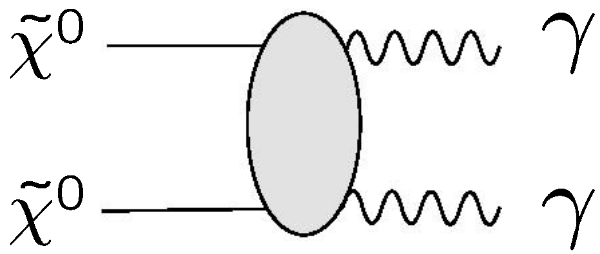


The line spectrum is a distinct signature against the diffused gamma ray background.

The line gamma ray is “ smoking gun ” signal of particle dark matter !

Dark Matter pair annihilation (CP conserving case)

- Dark matter pair annihilation to two gammas is radiative process.



- The full one-loop calculations have been performed.

Bergstrom and Ullio (1997)

In particular, when $\tilde{\chi}^0$ is Bino-like neutralino ($\tilde{B}$),

$$\sigma v \leq 10^{-30} \mathrm{cm}^3 \mathrm{s}^{-1}$$

The detection of the line gamma ray originating from Bino-like neutralino pair annihilation was difficult.

We calculate the line gamma ray flux from Bino-like dark matter pair annihilation in the Galactic Center.

We consider the case that

i) dark matter is Bino-like neutralino.

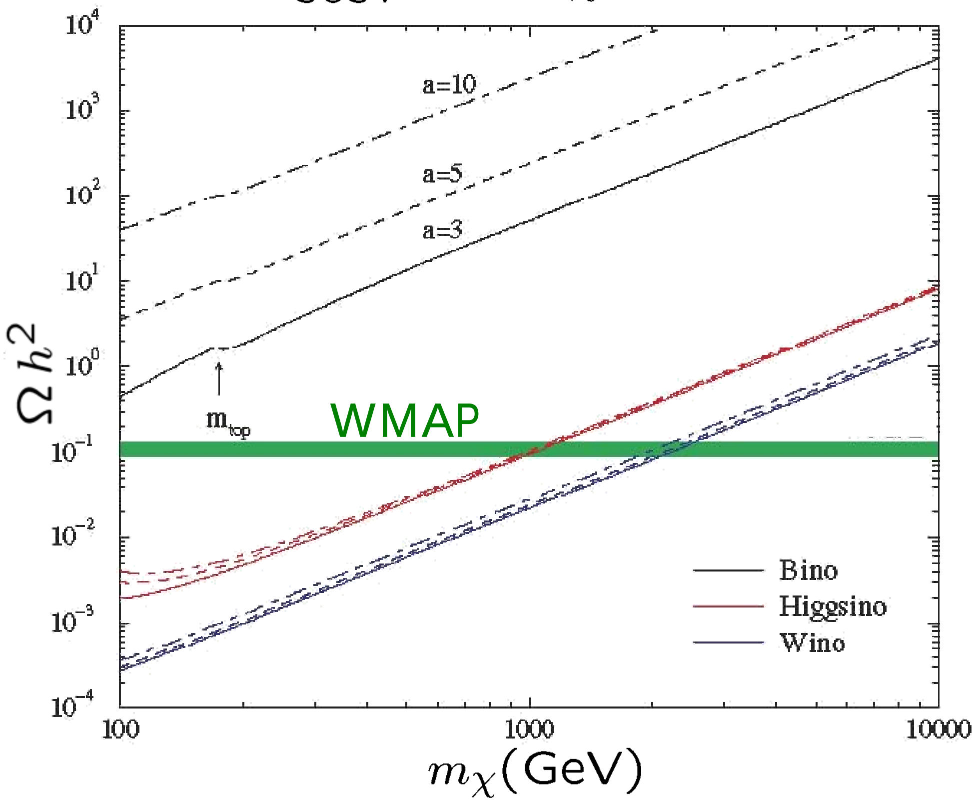
ii) Bino-like neutralino is nearly degenerate with sfermion (stau or stop) in mass.

iii) The trilinear coupling between $\tilde{B}$-$\tilde{f}$-f violates CP;

CP violating phase comes from the sfermion (stau or stop) mass term.

Bino-like Dark Matter

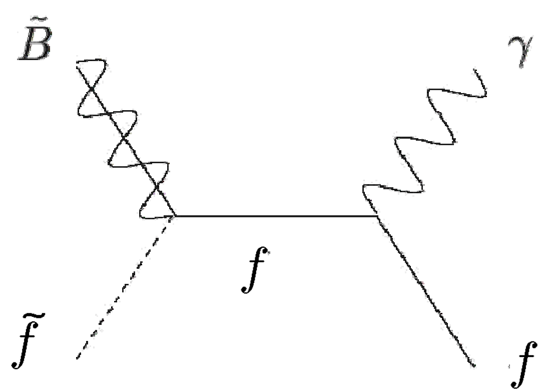
$m_{\mathrm{SUSY}} \sim \mathrm{a}\ m_\chi$



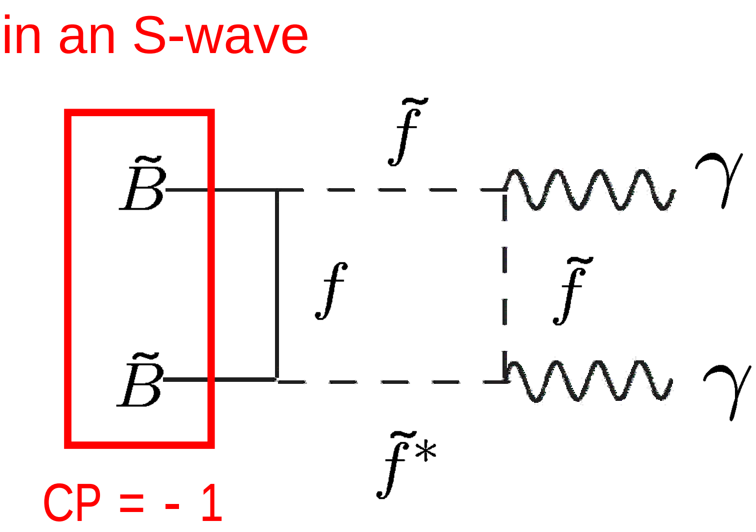
Profumo and Yaguna (2004)

- The viable models with Bino-like dark matter require the presence of mechanisms which suppress the density.

"coanihilation"



CP of two-body state



CP of Bino two-body state

J^{PC}	$l=0$	$l=1$
$s=0$	0^{-+}	$\times$
$s=1$	$\times$	$0^{++}, 1^{++}, 2^{++}$

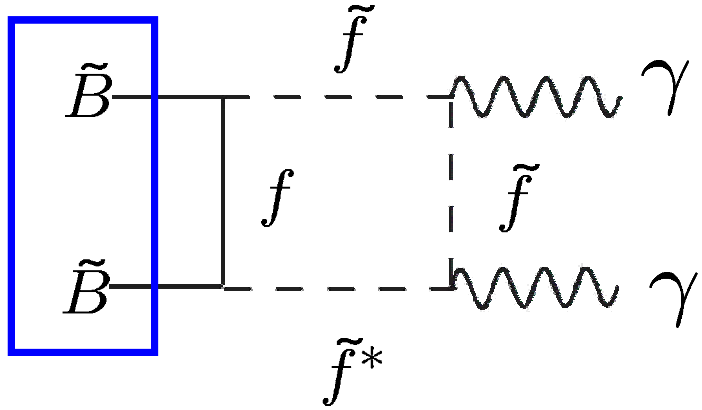
CP of sfermion two-body state

J^{PC}	$l=0$	$l=1$
$s=0$	0^{++}	1^{++}

This process is forbidden in the CP conserving case.

CP of two-body state

in a P-wave



CP = + 1

CP of Bino two-body state

J^{PC}	$l=0$	$l=1$
$s=0$	0^{-+}	$\times$
$s=1$	$\times$	$0^{++}, 1^{++}, 2^{++}$

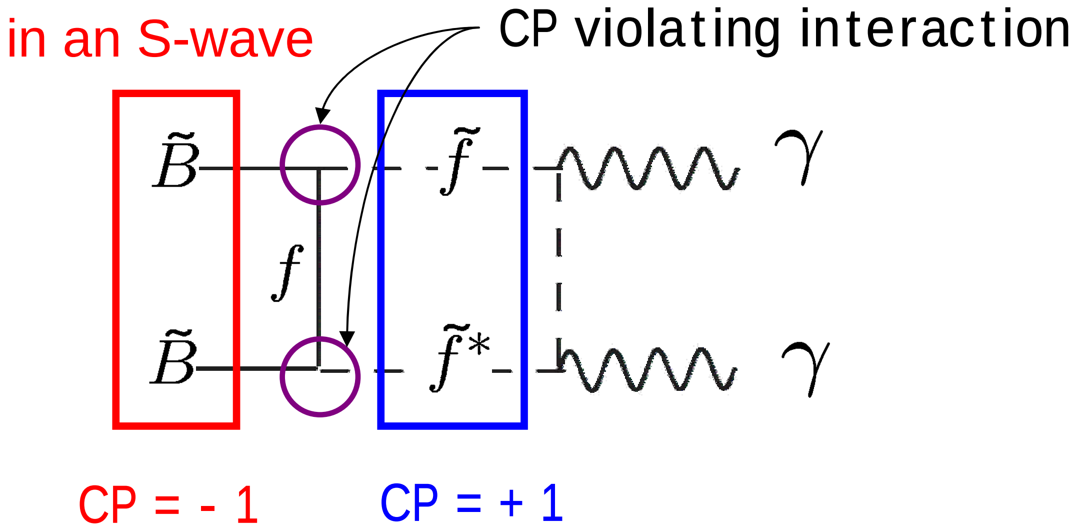
CP of sfermion two-body state

J^{PC}	$l=0$	$l=1$
$s=0$	0^{++}	1^{++}

However, the cross section of this process is suppressed by initial relative velocity square; $\sim \mathcal{O}(10^{-6})$

CP Violating Interaction

If $\tilde{B}$-$\tilde{f}$-f coupling has CP violating phase, the transition between Bino pair and sfermion pair can take place.



This process does not suffer velocity suppression.

What is the origin of CP violation ?

Sfermion Mass Term

sfermion mass matrix (weak base) : $M^2_{sf} = \begin{pmatrix} M^2_{\mathrm{LL}} & M^2_{\mathrm{LR}} \\ M^{2*}_{\mathrm{LR}} & M^2_{\mathrm{RR}} \end{pmatrix}$

where

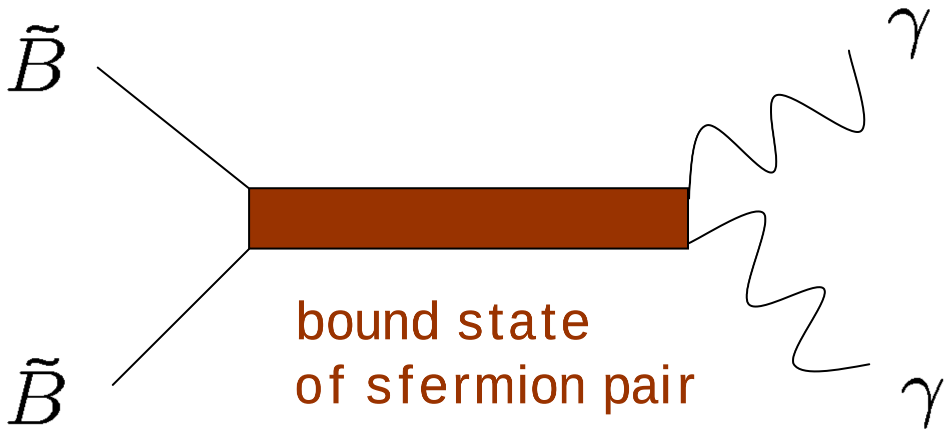
$$\begin{aligned} M^2_{\mathrm{LL}} &= M^2_{\mathrm{L}} + m_f^2 + M_Z^2 \cos 2\beta \; (T_3 - Q \sin^2 \theta_W) \\ M^2_{\mathrm{RR}} &= M^2_{\mathrm{R}} + m_f^2 + M_Z^2 \cos 2\beta \; Q \sin^2 \theta_W \end{aligned}$$

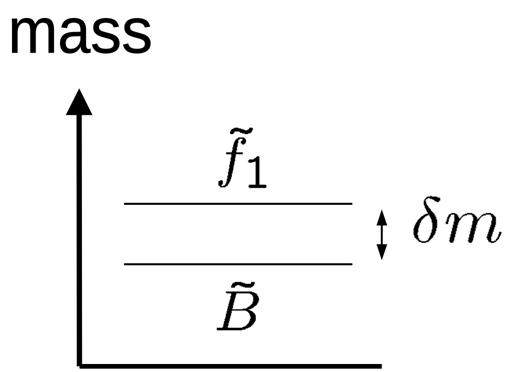
$$M^2_{\mathrm{LR}} = \begin{cases} -m_\tau \;\; (A^*_\tau + \mu \tan \beta) & \text{for stau} \\ -m_t \;\; (A^*_t + \mu \cot \beta) & \text{for stop} \end{cases}$$

This matrix is diagonalized by $U = \begin{pmatrix} \cos \theta_f & \sin \theta_f \; e^{i\gamma_f} \\ -\sin \theta_f \; e^{-i\gamma_f} & \cos \theta_f \end{pmatrix}$

We assume that only A_τ or A_t has CP phase.

Quasi Stable Bound State





Condition that sfermion pair forms bound state

$$\frac{md^2}{4n^2} = 2\delta m - \frac{mv^2}{4} \quad \text{where} \quad d = \begin{cases} \alpha & \text{for stau} \\ 4\alpha_s/3 & \text{for stop} \end{cases}$$

When sfermion pair forms bound state,
the cross section can be enhanced.

Outline of Calculation

i) MSSM action

↓ *integrate out all fields except for Bino and sfermion*

ii) Effective action for Bino and sfermion

↓ *non-relativistic limit*

iii) Non-relativistic Lagrangian

↓ *introduce the auxiliary fields for two-body state*

iv) Two-body states effective Lagrangian

↓

v) Equation of motion (Schroedinger equation)

↓

vi) Annihilation cross section

Line Gamma Ray Flux from the Galactic Center

$$F_{\rm line} = 1.9 \times 10^{-11}\ {\rm cm}^{-2}{\rm s}^{-1} \Delta\Omega \left(\frac{100{\rm GeV}}{m_{\tilde{B}}}\right)^2 \left(\frac{<\sigma v>}{10^{-27}{\rm cm}^3\ {\rm s}^{-1}}\right) \bar{J}$$

where,

$$\bar{J}(\Delta\Omega) \equiv \int_{\Delta\Omega} \frac{d\Omega}{\Delta\Omega} \int_{\rm line\ of\ site} \frac{dl}{8.5\ {\rm kpc}} \left(\frac{\rho}{0.3\ {\rm GeV\ cm}^{-3}}\right)^2$$

$\Delta\Omega$:Angular acceptence of the detector

Typical value for Air Cherencov Telescope detector $\Delta\Omega = 10^{-3}$

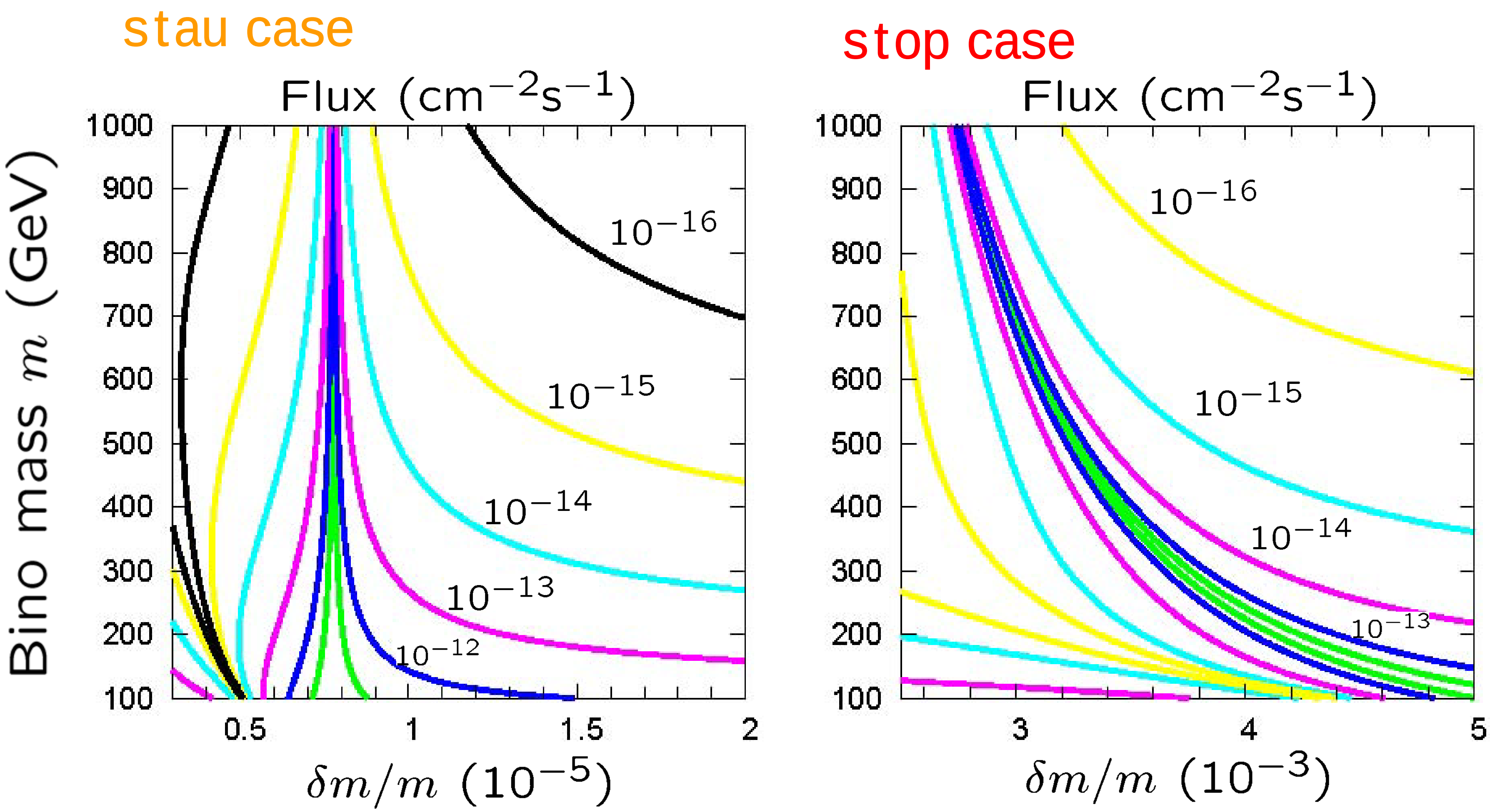
Dark matter density profile is still controversial.

$$10 < \bar{J}(10^{-3}) < 10^6$$

We use moderate value: $\bar{J}(10^{-3}) = 1352$ for NFW profile

Numerical Result of the Line Gamma Ray Flux

parameter $\theta_f = \pi/4\,,\ \gamma_f = \pi/2\,,\ \Delta\Omega = 10^{-3}\,,\ \bar{J} = 1352(\mathrm{NFW})$



c.f. Flux at one-loop in the CP conserving case $\leq 10^{-14}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$

Summary

- When CP is violating and sfermion is degenerate with Bino-like neutralino so as to form bound state, the line gamma ray flux is enormously enhanced.

- Our result is maintained as long as the sfermion mixing is not so small and CP violating phase is $\mathcal{O}(1)$.

- We expect that our predicted flux may be detected or excluded by the Air Cherencov Telescope detectors in the near future.