Constraints on the Dark Matter Annihilations by Neutrinos with Substructure Effects Included

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Based on
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Outline

- Indirect DM detection and High energy neutrino
- Galactic DM distribution and substructure
- Constraint on the dark matter annihilation cross section by atmospheric neutrino
- Summary

Indirect detection

Dark matter annihilates in ________________ to

a place

__________ , which are detected by___________ .

particles an experiment

From the talk of J. L. Feng, BILCW07

Neutrinos from the DM annihilations

- High energy Neutrinos (MeV~TeV) can be produced by dark matter annihilations.
- **Advantage**: hardly energy loss and trajectory deflection during the propagation.

  preserve the information of the nature and distribution of the DM.
- **Disadvantage**: hard to detect such neutrinos in this energy range and with low flux.
- Detect these neutrinos by large volume Cerenkov detectors, such as **Super-kamiokande**, **IceCube**, **ANTARES**…

Strategies of detecting neutrinos

- One strategy : explore the location close to us such as the **Sun** and **Earth**.

- Other strategies :

  explore the neutrinos from the **extra-galactic**

  J. F. Beacom et al. , Phys. Rev. Lett. 99, 231301 (2007) .

  explore the neutrinos from the **galactic center (GC)**

  H. Yuksel et al. , Phys. Rev. D. 76, 123506 (2007).

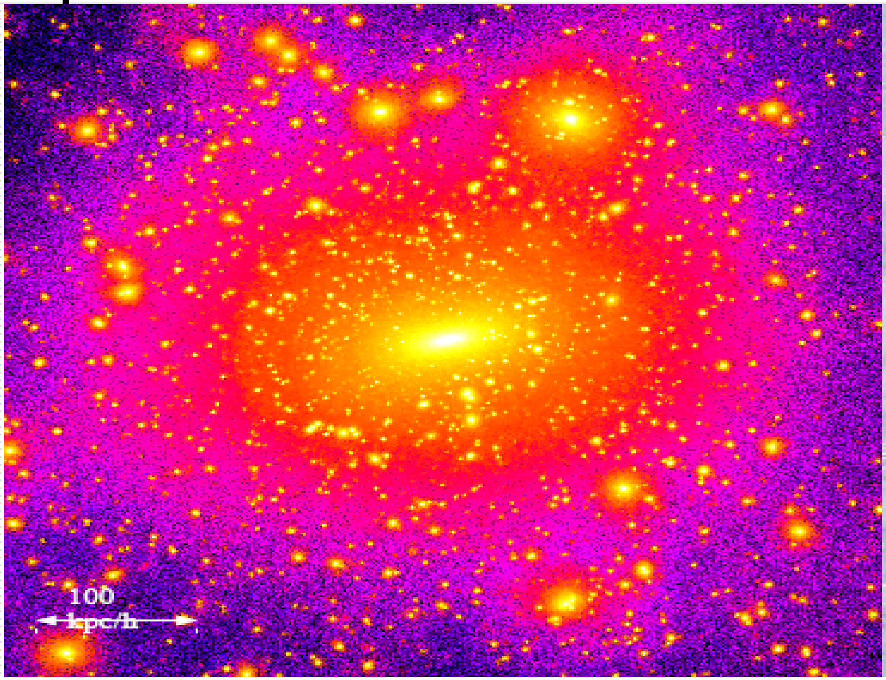
- Our strategy : explore the neutrinos from the **substructures in the Galaxy**.

- The **null** results can be used to set the **upper bound** of the DM annihilation cross sections.

Our strategy

Dark matter annihilates in _____subhalos_____ to
a place

neutrinos , which are detected by __IceCube__.
particles
an experiment



Power et al 2002

From the talk of F. Halzen, DM Workshop 07

The neutrino flux from the DM annihilations

- **Neutrino flux from the DM annihilations**

$$\phi(E,\psi) = C \times W(E) \times J(\psi)$$

$$= \rho^2 R \times \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_D^2} \frac{dN}{dE} \times \frac{1}{\rho^2 R} \int_{LOS} \rho^2(l)dl$$

local DM density $\rho = 0.34 GeV cm^{-3}$

distance of the Sun from the GC $R = 8.5 kpc$

- $W(E)$ **(energy dependent): the particle property.** $J(\psi)$ **(spatial dependent): the spatial distribution of DM.**

Astrophysical factor of the DM annihilation

- ☐ To account for the contribution of substructures

$$\rho^2 = \rho^2_{smooth} + \left\langle \rho^2_{sub} \right\rangle$$

$$\left\langle \rho^2_{sub} \right\rangle = \int dM_{sub} \frac{dN}{dM_{sub} 4\pi r^2 dr} \left(\int_{V_{sub}} \rho^2_{sub} dV \right)$$

Smooth distribution of DM is **NFW** profile

- ☐ Average astrophysical factor

$$J_{\Delta\Omega} = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} J(\psi) d\Omega \qquad \Delta\Omega = 2\pi(1 - \cos\Delta\Theta)$$

$\Delta\Theta$:the half angle of the cone centered at the direction of the GC

DM distribution profile

- ☐ A general DM distribution profile :

$$\rho(r)=\frac{\rho_s}{(r/r_s)^{\gamma}[1+(r/r_s)^{\alpha}]^{(\beta-\gamma)/\alpha}}$$

- ☐ (α,β,γ) denote different profiles.

  NFW profile: **1.5, 3.0, 1.5**

  Moore profile: **1.0, 3.0, 1.0**

- ☐ Virial mass: Virial radius:

$$M_v=\int\rho(r)dV \qquad r_v=\left(\frac{M_v}{(4\pi/3)\Delta\rho_c}\right)^{1/3}$$

Concentration parameter: $c_v=r_v/r_{-2}$ $\quad d(\rho r^2)/dr\big|_{r=r_{-2}}=0$

J. S. Bullock et al. , Mon. Not. Roy. Astron. Soc. 321, 559 (2001)

Determination of the profile parameters

- Use the fitted polynomial form and extrapolate to low masses

$$In(c_v) = \sum_{i=0}^{4} C_i \times [In \frac{M_v}{M_{sun}}]^i$$

- **ENS01** V. R. Eke et al., Astrophys. J. 554, 114 (2001).

$$C_i^{ENS01} = \{3.14, -0.018, -4.06 \times 10^{-4}, 0, 0\}$$

- **B01** J. S. Bullock et al. , Mon. Not. Roy. Astron. Soc. 321, 559 (2001).

$$C_i^{B01} = \{4.34, -0.0384, -3.91 \times 10^{-4}, -2.2 \times 10^{-6}, -5.5 \times 10^{-7}\}$$

- The above models are from the simulations which generate sub-halos within a distinct halo.

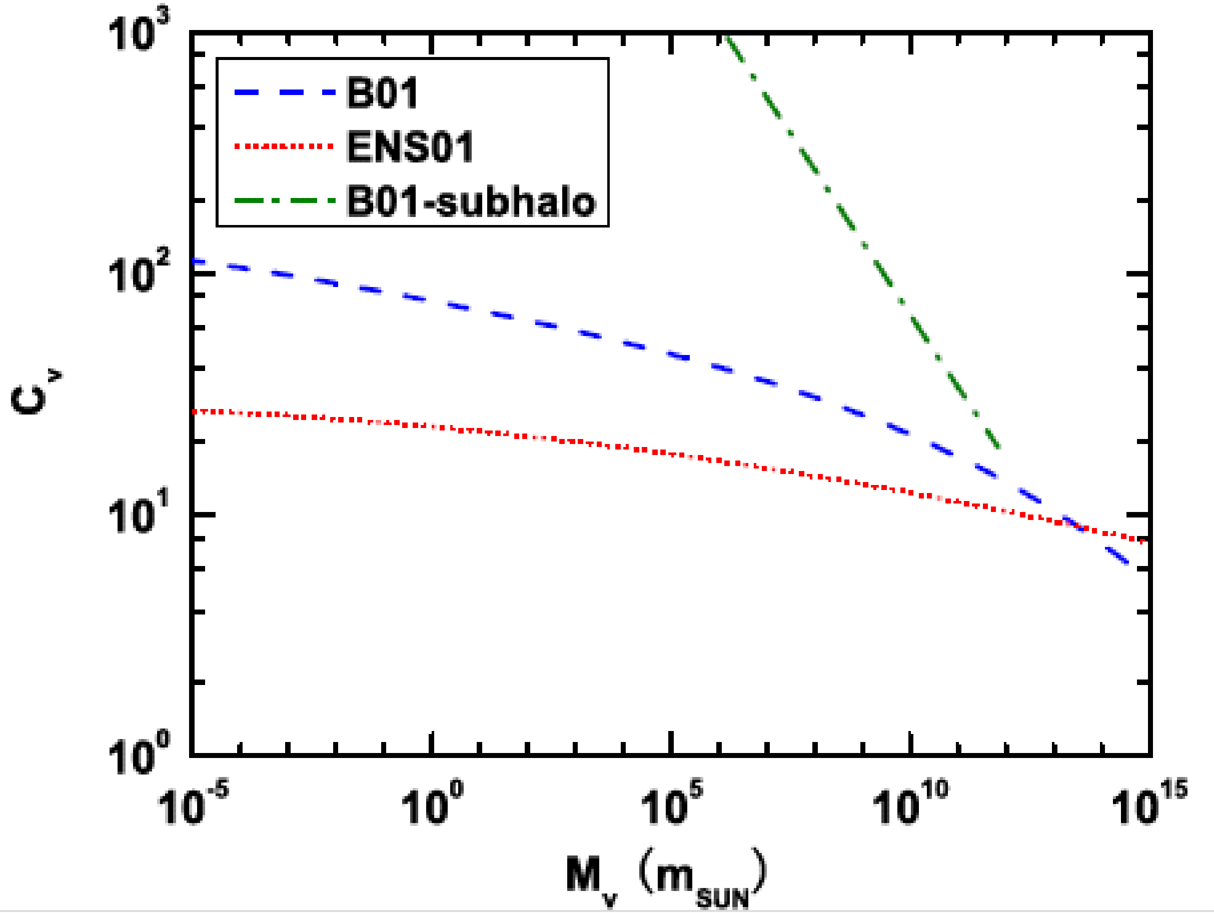
For the host ones,

B01-sub $C_v \sim M_v^{-0.3}$ or **B01X2** $C_v \sim 2C_v^{B01}$

J. S. Bullock et al. , Mon. Not. Roy. Astron. Soc. 321, 559 (2001).

S. Colafrancesco et al., Astron. Astrophys. 455, 21 (2006).

Determination of the profile parameters



- ☐ **The relation of $c_v - M_v$ at epoch Z=0**

The Galaxy halo and substructure

- Simulations give the number density of sub-halos an isothermal spatial distribution and a power-law function

$$\frac{dN}{dM_{sub}4\pi r^2 dr}=N_0\left(\frac{M_{sub}}{M_{host}}\right)^{-a}\frac{1}{1+(r/r_H)^2}$$

core radius $r_H=0.14r_v$, $a=1.9$

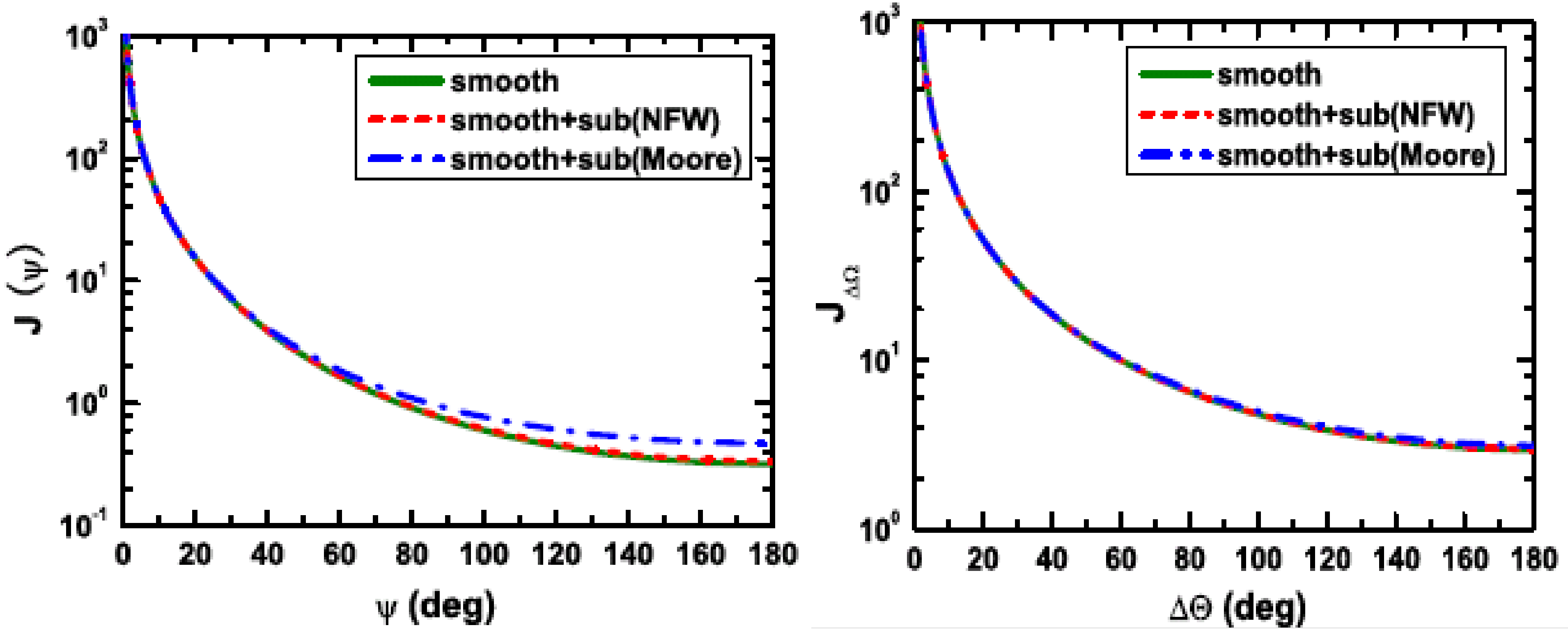
sub-halos mass range: $10^{-6}M_{sun}\sim 10^{12}M_{sun}$

- **Tidal effect**: In the inner region of the host halo, strong tidal force tends to destroy the sub-halo.
- The mass of the Galaxy halo: $M_v\sim 10^{12}M_{sun}$

  The mass fraction of substructure: **14%** .

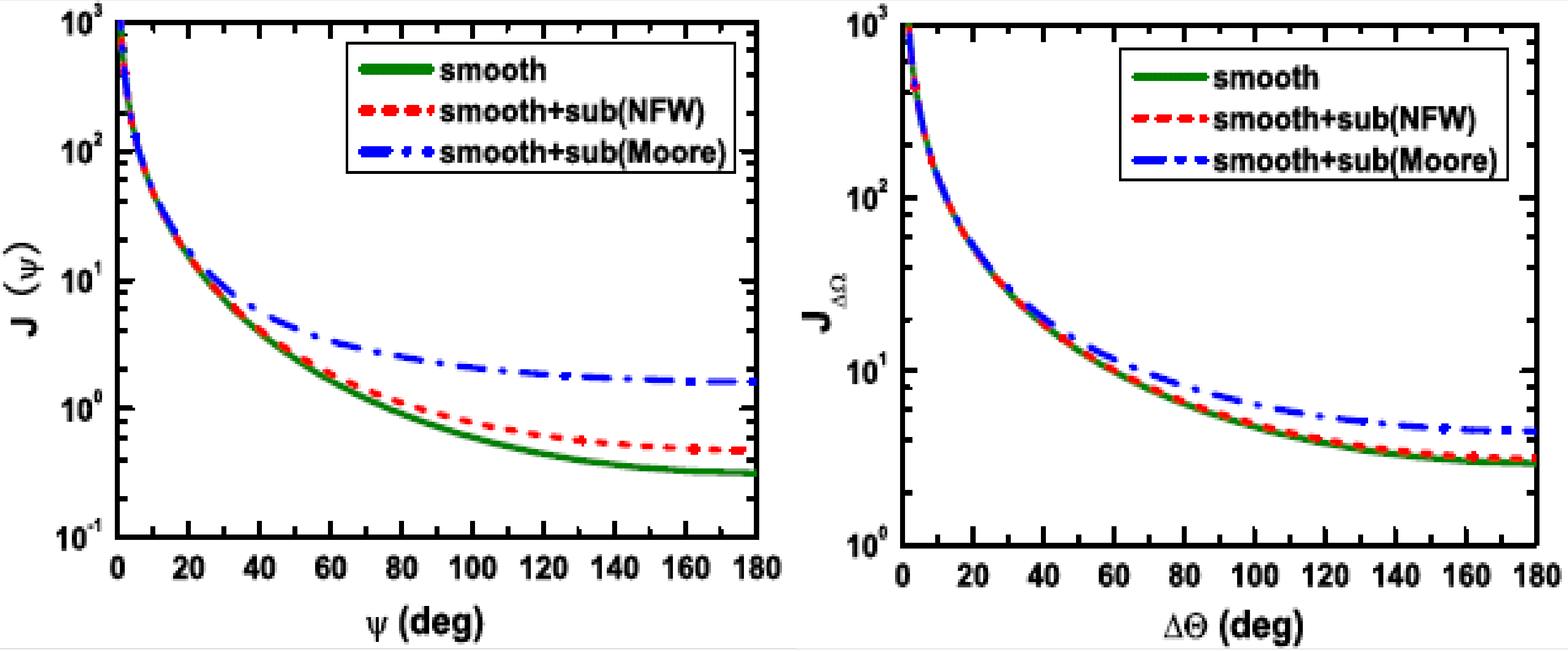
Astrophysical factor of the DM annihilation (ENS01)

- ☐ **Astrophysical factor with concentration models as ENS01**



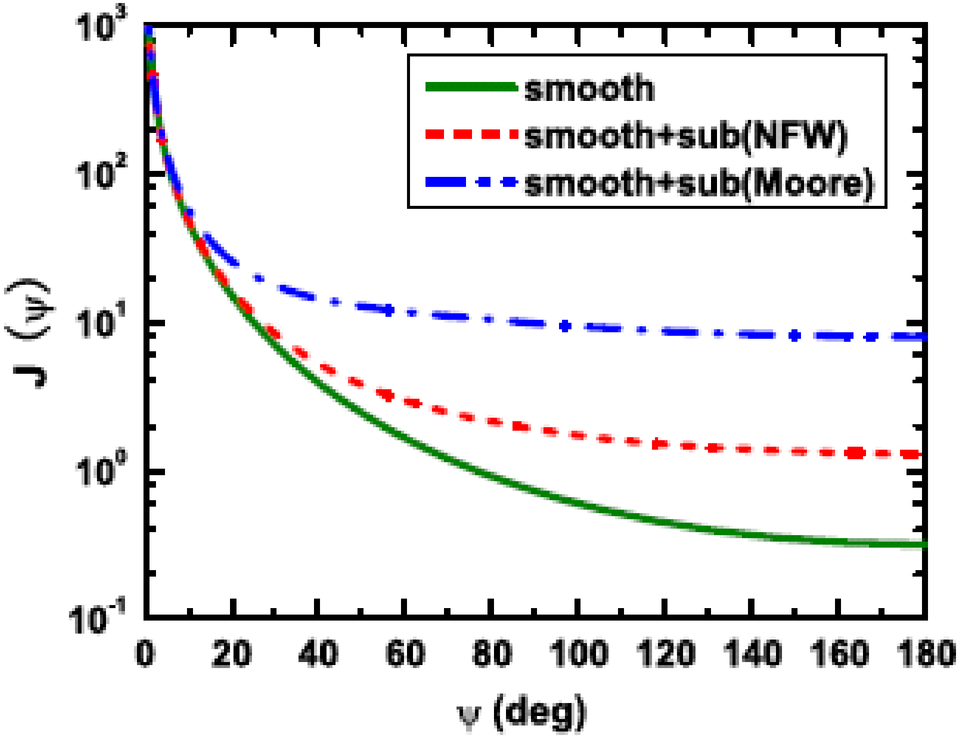
Astrophysical factor of the DM annihilation (B01)

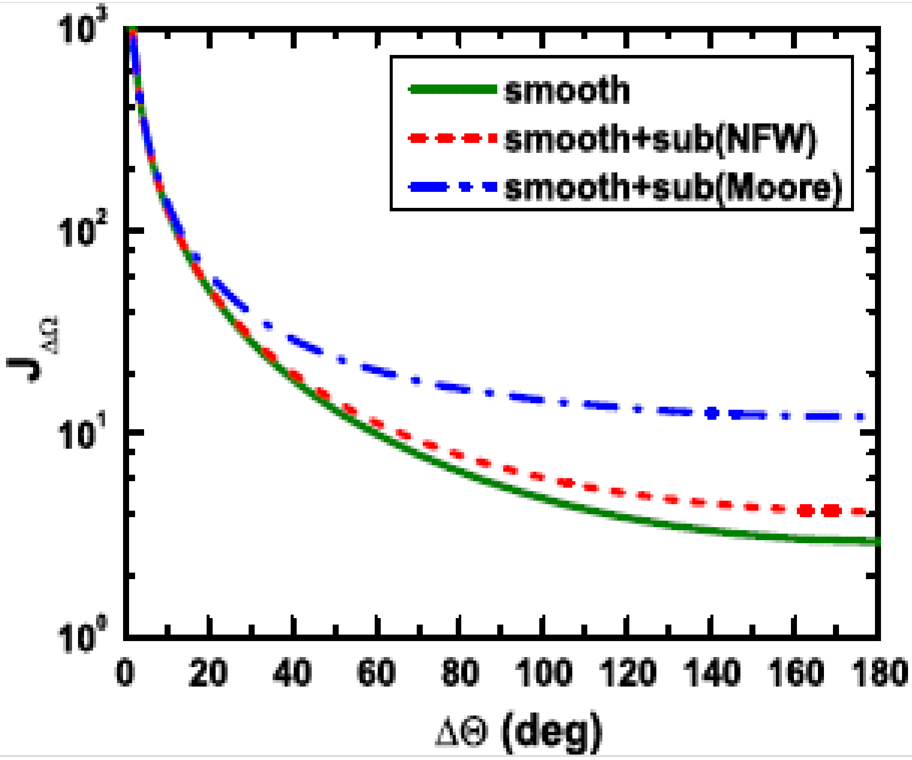
- ☐ **Astrophysical factor with concentration models as B01**



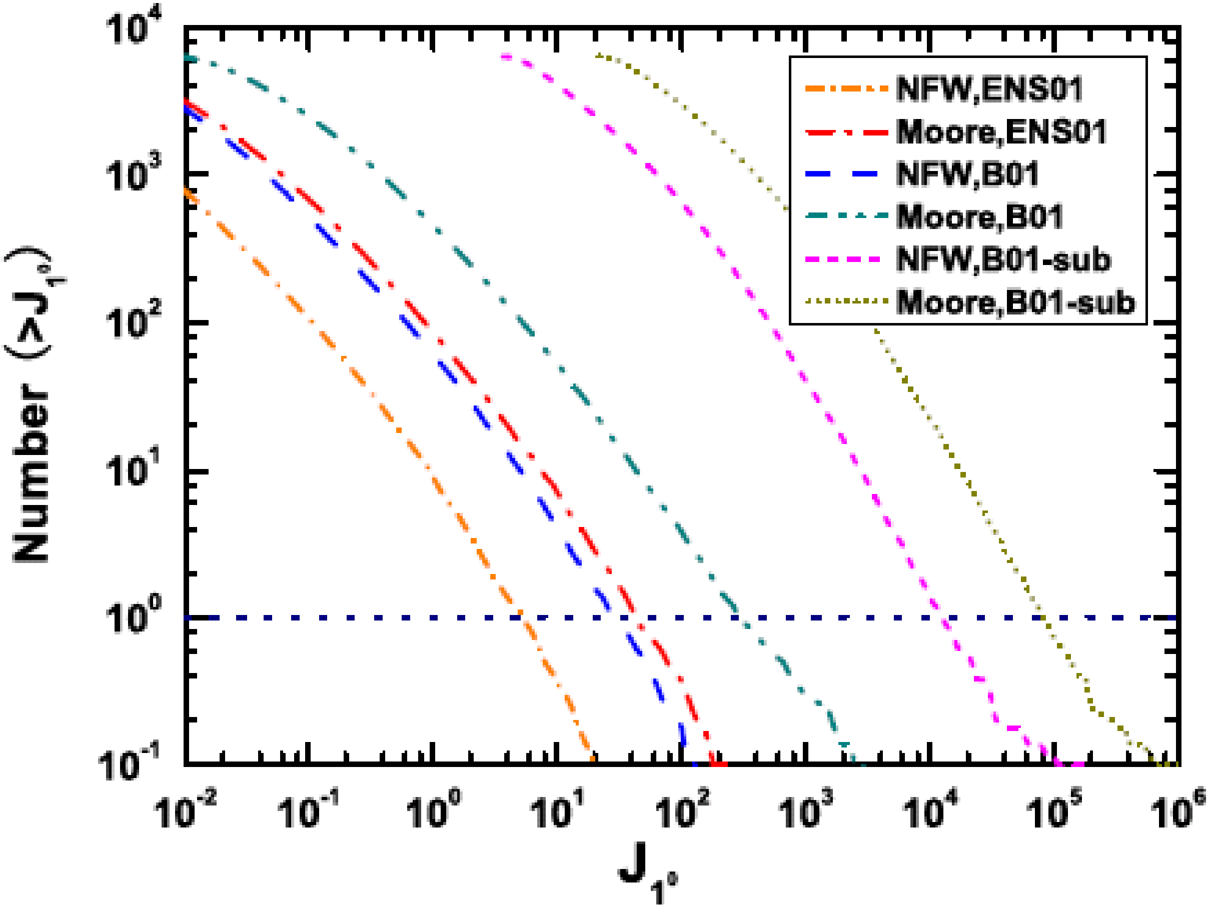
Astrophysical factor of the DM annihilation (B01X2)

- Astrophysical factor with concentration models as **B01X2**





DM substructure as point-like source



- The massive sub-halo can be treated as point-like source and may be identified by high angular resolution detector.

- Use a Monte-Carlo method to generate $N(>10^6 M_{sun}) \approx 6400$ average $J(\psi)$ within the cone with half angle of 1^0

Particle Physics factor of the DM annihilation

- Assumption : the productions of DM annihilation are **only** neutrinos.

  J. F. Beacom et al. , Phys. Rev. Lett. 99, 231301 (2007) ; H. Yuksel et al. , Phys. Rev. D. 76, 123506 (2007).

- DM may annihilation into final states other than neutrinos.

  High energy neutrinos from the DM annihilation will lead to gauge bosons bremsstrahlung.

  M. Kachelriess, P.D. Serpico, Phys. Rev. D 76, 063516 (2007) ; N. F. Bell et al., arXiv: 0805.3423;

  J. B. Dent et al, Phys. Rev. D 78, 063509 (2008).

- The spectrum of neutrinos per flavor is a monochromatic line

  $$dN_\nu / dE_\nu = \frac{2}{3}\delta(E_\nu - m_{DM})$$

  average neutrino flux within the energy bin $\Delta\log_{10} E = 0.3$ around $E_\nu = m_{DM}$

Atmospheric neutrino

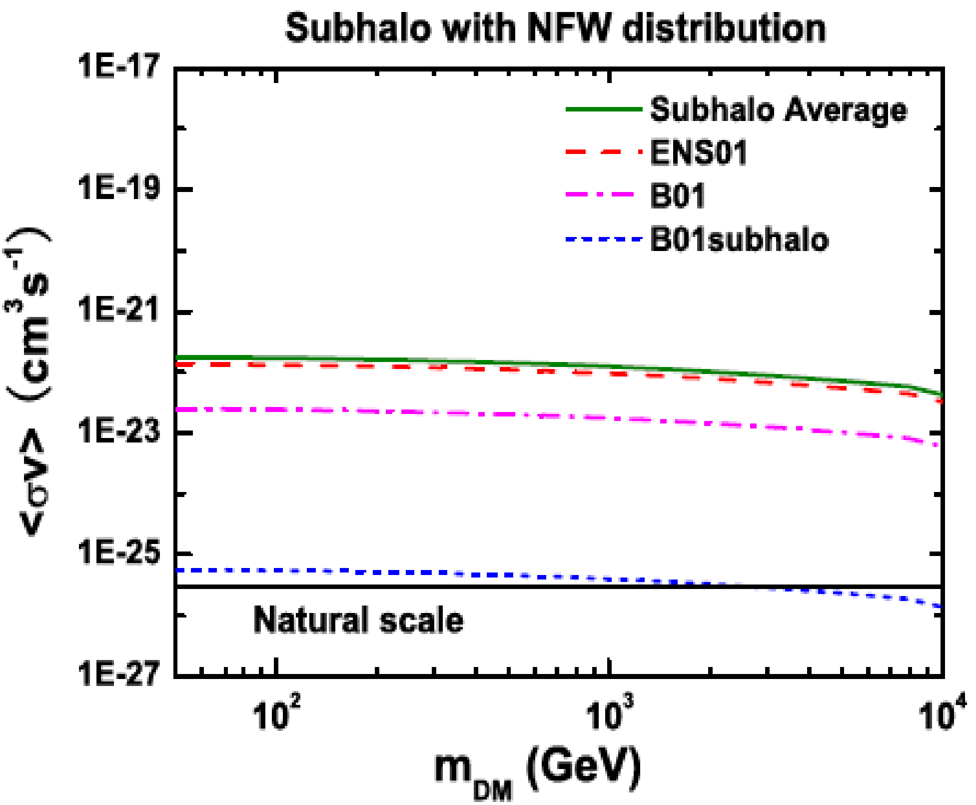
- The backgrounds detected by Cerenkov detectors
  - Neutrinos from cosmic ray interacting with particles in the Sun’s corona.
  - Muons from cosmic ray interacting with the atmosphere of the earth.
  - Neutrinos from cosmic ray interacting with the atmosphere of the earth.
- The main background is the third one due to large flux and no special direction.
- No excess beyond the theoretical prediction of the atmospheric neutrino.

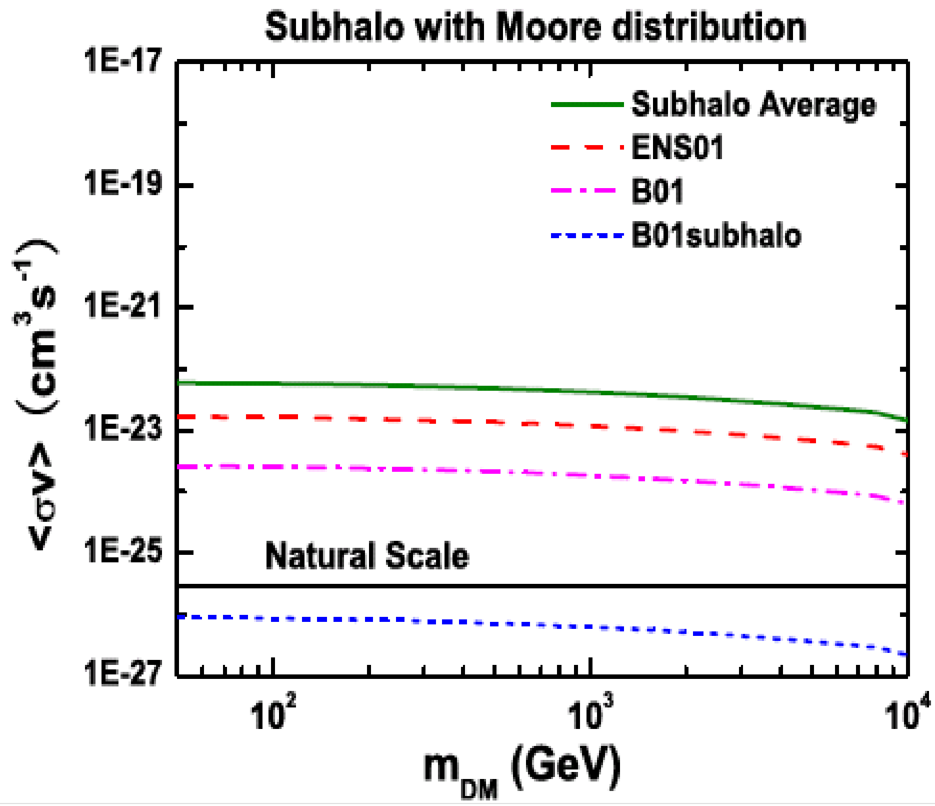
  The null results can be used to set the upper bound of the DM annihilation cross sections.
- Flux of atmospheric neutrino from

  M. Honda et al. Phys. Rev. D 75, 043006 (2007).

Results

- Upper bound to the DM annihilation cross section by requiring the neutrino flux does not exceed the atmospheric neutrino flux .


Subhalo with NFW distribution


Subhalo with Moore distribution

Summary

- By requiring the DM induced neutrino flux less than the measured ones, we give the improved upper bounds on the DM annihilation cross section.

- Considering substructure average contribution over all directions, the bound are improved by several times.

- Considering single massive sub-halo as point source, the bound can be improved by 10~10000 utilizing the angular resolution of IceCube. In some model, IceCube can achieve the sensitivity of DM annihilation cross section as $10^{-26} cm^{-3} s^{-1}$.

Thank you!