Indirect detection of dark matter

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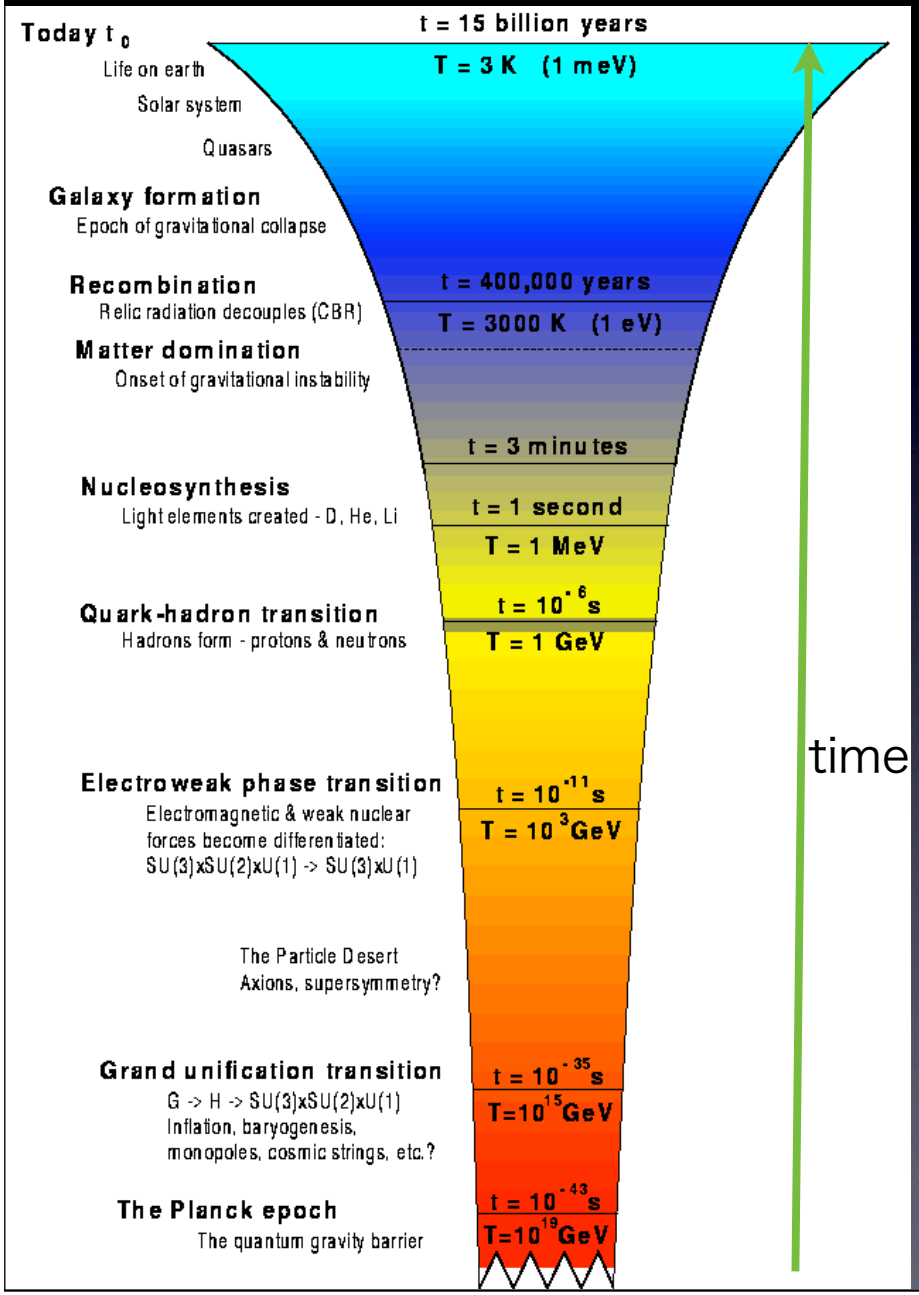
What's dark matter (DM) ?

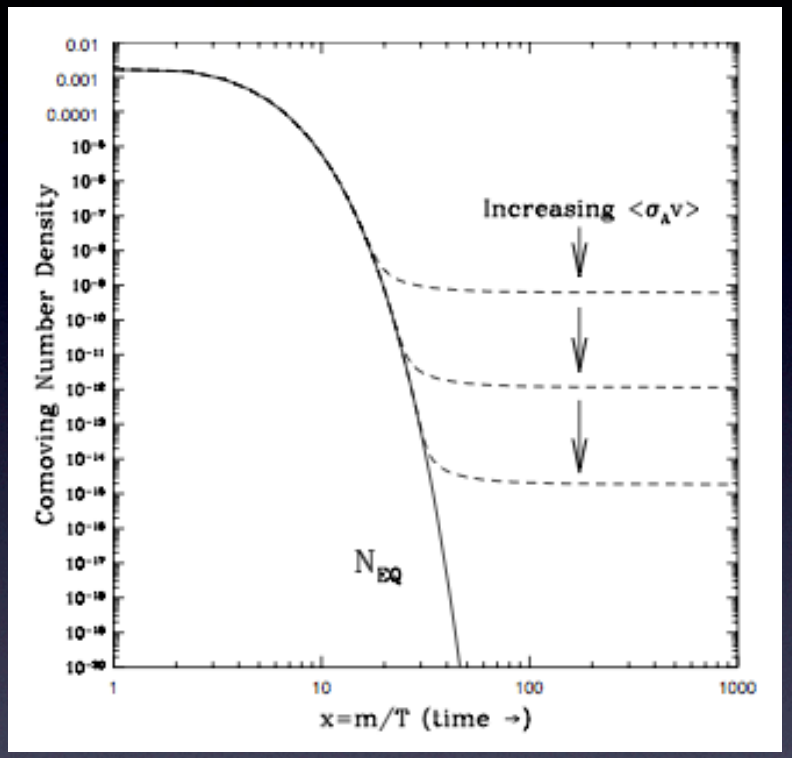
DM feature

- non-baryonic
- electrically neutral
- stable
- weakly interacting
- produced in the early universe
- particle beyond the standard model

Thermal history



number density



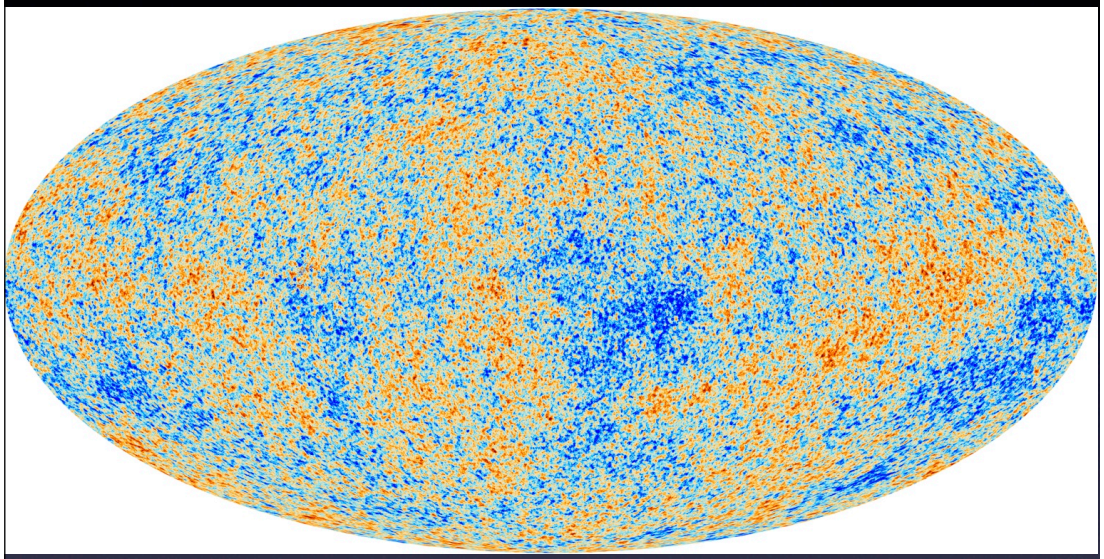
low temperature

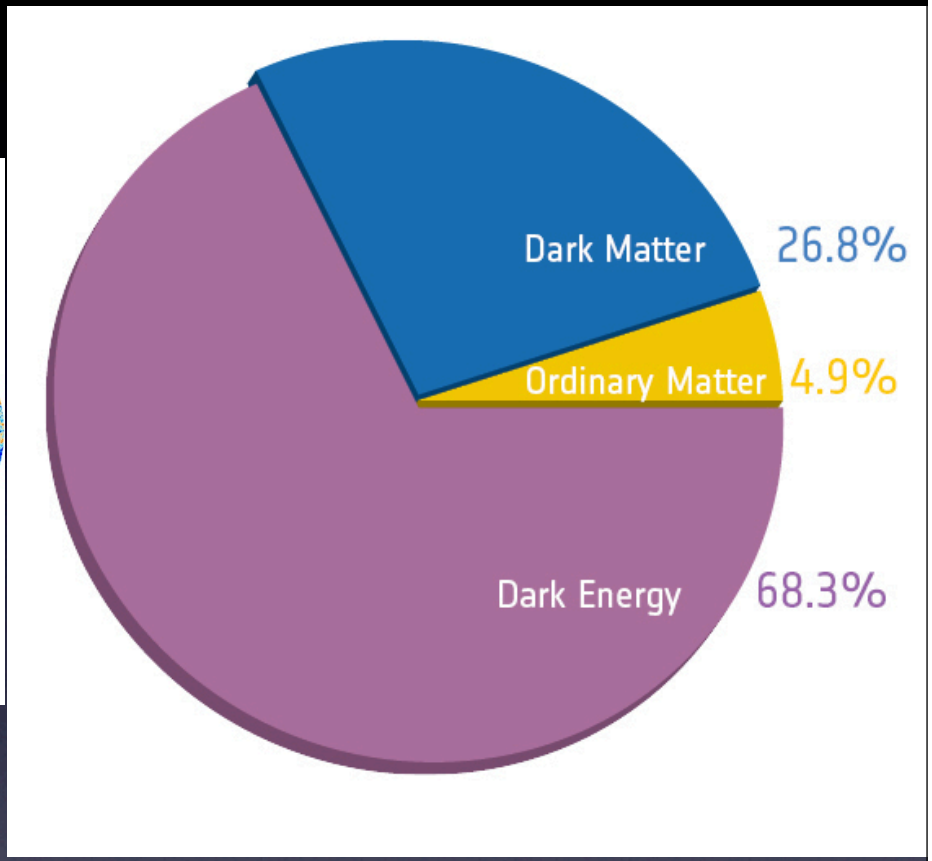
⟶ interaction is finished and balanced

hight temperature

⟶ it is off equilibrium and remains

Evidence : CMB





- Planck satellite

measurement of CMB fluctuation
(Cosmic Microwave Background)

the analysis of CMB anisotropies enable accurate testing of cosmological models and puts stringent constrains on cosmological parameter.

Evidence :Rotation curve of galaxy

The balance of centrifugal force and gravitation gives

$$v(r) = \sqrt{\frac{GM(r)}{r}}$$

v :velocity G :gravitational constant

r :radius from galactic center

M :total mass in radius r from galactic center

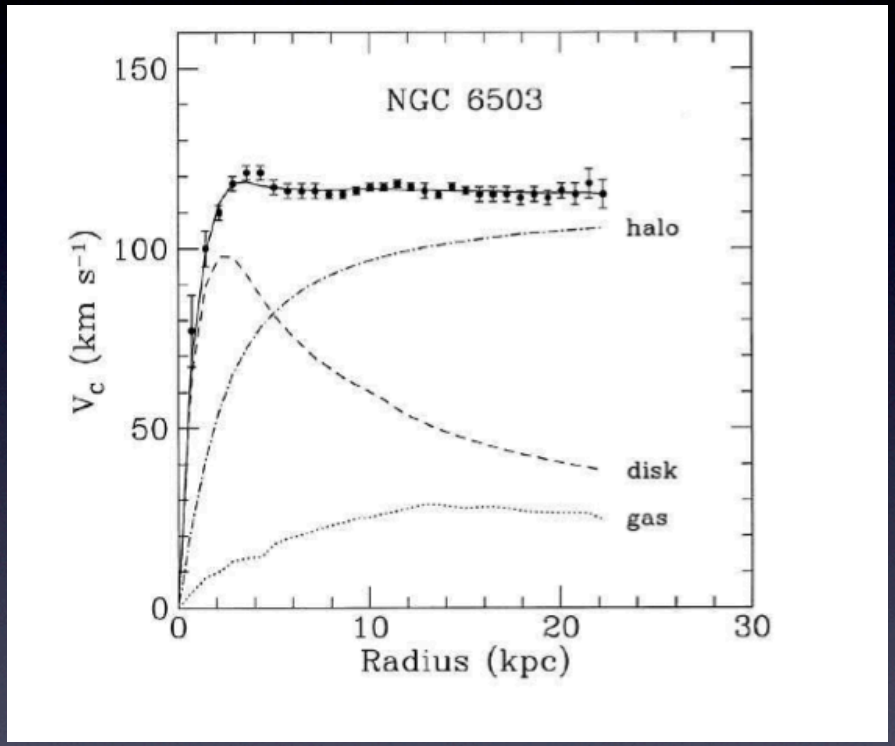
$$v(r) \propto r^{-1/2}$$

On the other hand, observation

$$v(r) = const$$

The distribution

$$M(r) \propto r$$



Dark Matter

$$M(r) = 4\pi \int \rho(r) r^2 dr$$

$$\propto r$$

density $\rho(r)$

$$\rho(r) \propto \frac{1}{r^2}$$

Smooth density profile

- density spike (innermost region)
- $\propto \frac{1}{r^2}$ (outer region)

- Example :NFW profile

$$\rho^{NFW} = (0.4 \pm 0.1 GeV\, cm^{-3}) \left(\frac{8.5kpc}{r}\right) \left[\frac{1 + (8.5kpc/20kpc)}{1 + (r/20kpc)}\right]^2$$

- Candidates

Two popular candidates

- neutralino(SUSY)
- Kaluza-Klein particle

Other candidates

- Axion
- Gravitino etc.

Detection of DM

- Detection of annihilation products from DM sources

indirect detection

- Nuclear recoils in underground experiments
- DM production in collider experiments

direct detection

Indirect detection

Observation of photon produced from DM annihilations

The flux of radiation is proportional to the annihilation rate, Γ_A

$$\Gamma_A \propto \sigma v n^2 = \sigma v \frac{\rho_{DM}^2}{m_{DM}^2}$$

σv :annihilation cross section multiplied by velocity

n :DM number density

ρ_{DM} :DM density

m_{DM} :DM mass

- Sources

the galactic center(GC), the sun, the earth, etc.

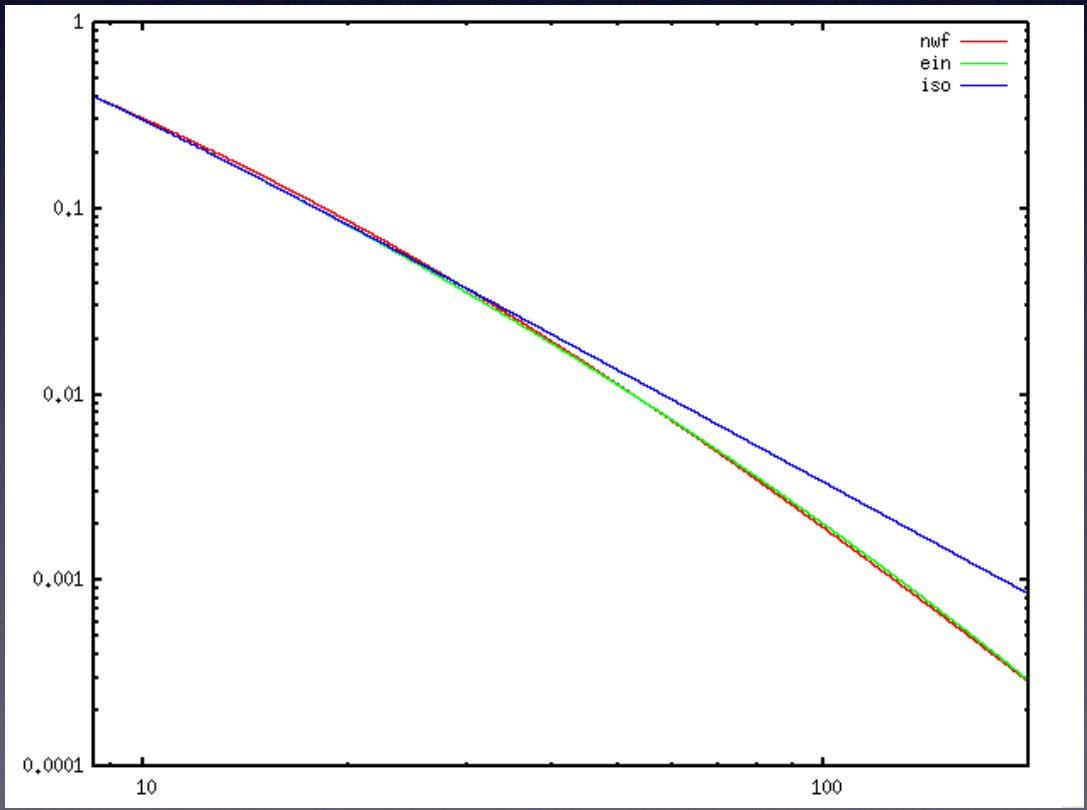
Indirect detection from cosmic ray

- photon(gamma-ray)
- neutrino
- electron and positron

Gamma-ray from the galactic center

In the Milky Way(MW), with the Fermi Gamma-Ray Space Telescope

The smooth DM density distribution in the MW



The gamma-ray number flux intensity due to the Galactic Halo DM self annihilation, $I_\gamma^G(E_0)$

$$I_\gamma^G(E_0) = \frac{dN_\gamma}{dAdtd\Omega dE_0} = \frac{\sigma v}{8\pi}\frac{r_\odot \rho_\odot^2}{m_{DM}^2} J(\psi)\frac{dN_\gamma}{dE_0}$$

$\frac{dN_\gamma}{dE_0}$:the photon energy spectrum per annihilation

E_0 :the observed photon energy

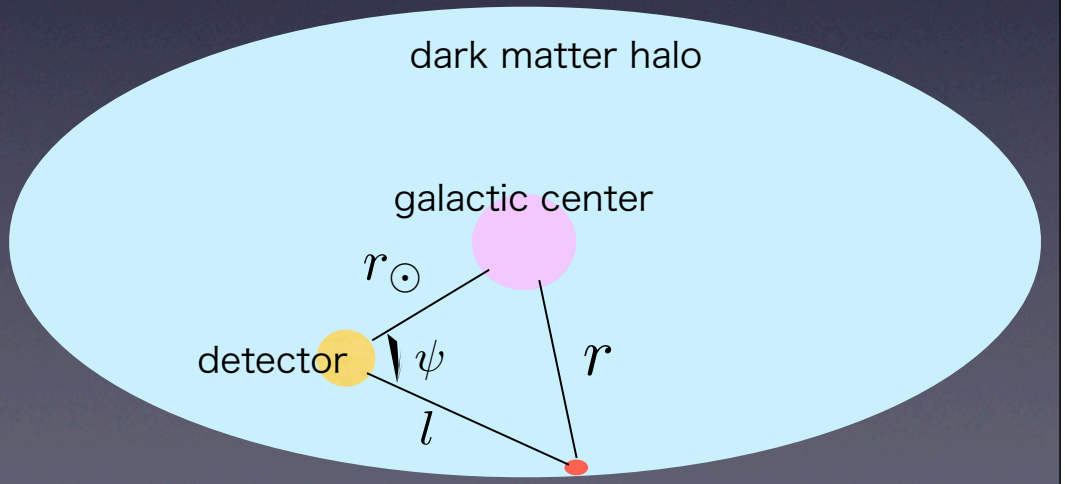
$r_\odot = 8.5kpc$:the solar distance to the GC

$\rho_\odot = 0.4 \pm 0.1 GeV cm^{-3}$
:the DM density in the solar neighborhood

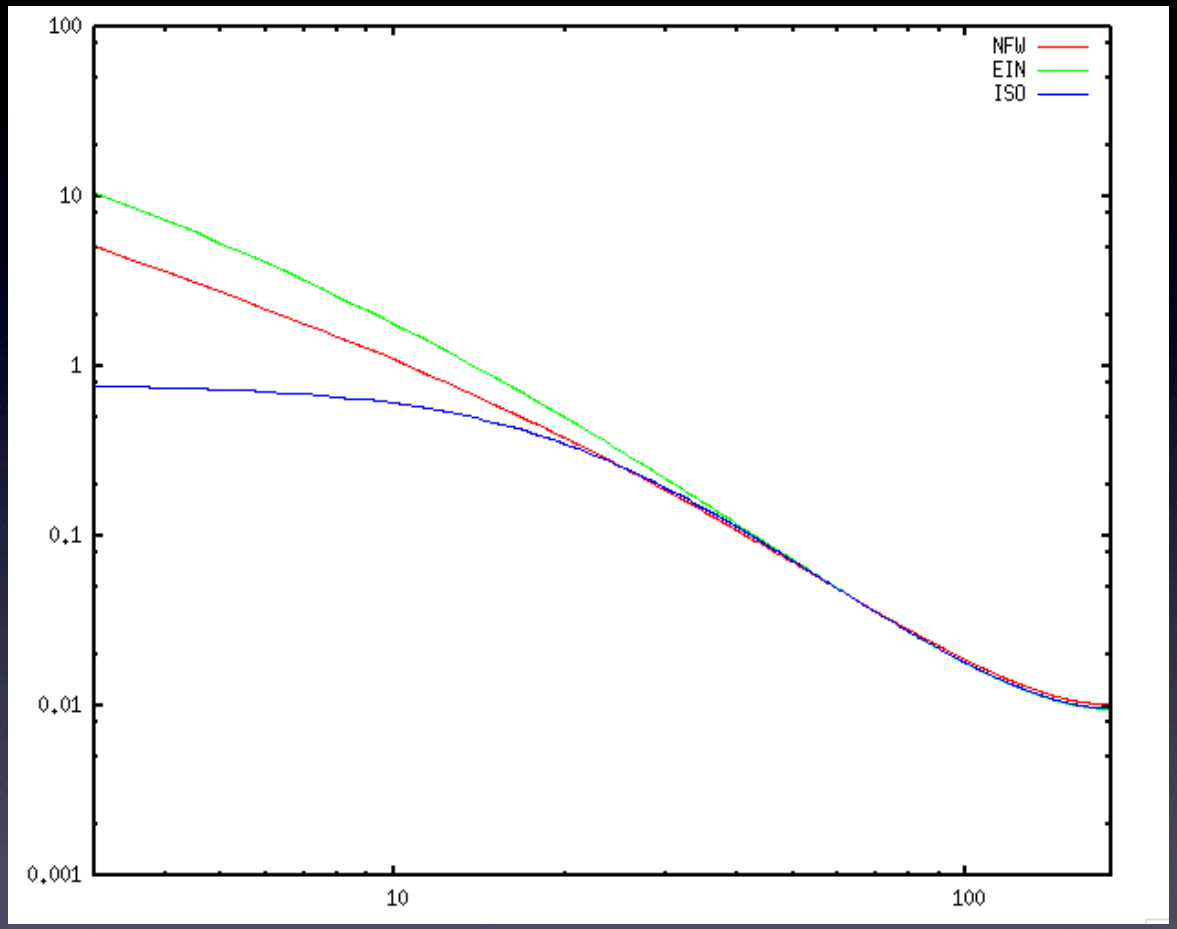
$$J(\psi) = \frac{1}{r_\odot \rho^2 \odot}\int_0^{l_{max}} \rho_{DM}^2(r(\psi,l))dl$$

$$r(\psi,l) = \sqrt{r_\odot^2 - 2lr_\odot \cos\psi + l^2}$$

$$l_{max} = (\sqrt{R^2 - r_\odot^2 \sin^2\psi} + r_\odot \cos\psi)$$



J-factor $J(\psi)$



y axis: $J(\psi)$

x axis: ψ

$0^\circ \leq \psi \leq 180^\circ$

J-factor becomes maximum in GC and becomes small as it goes away from GC

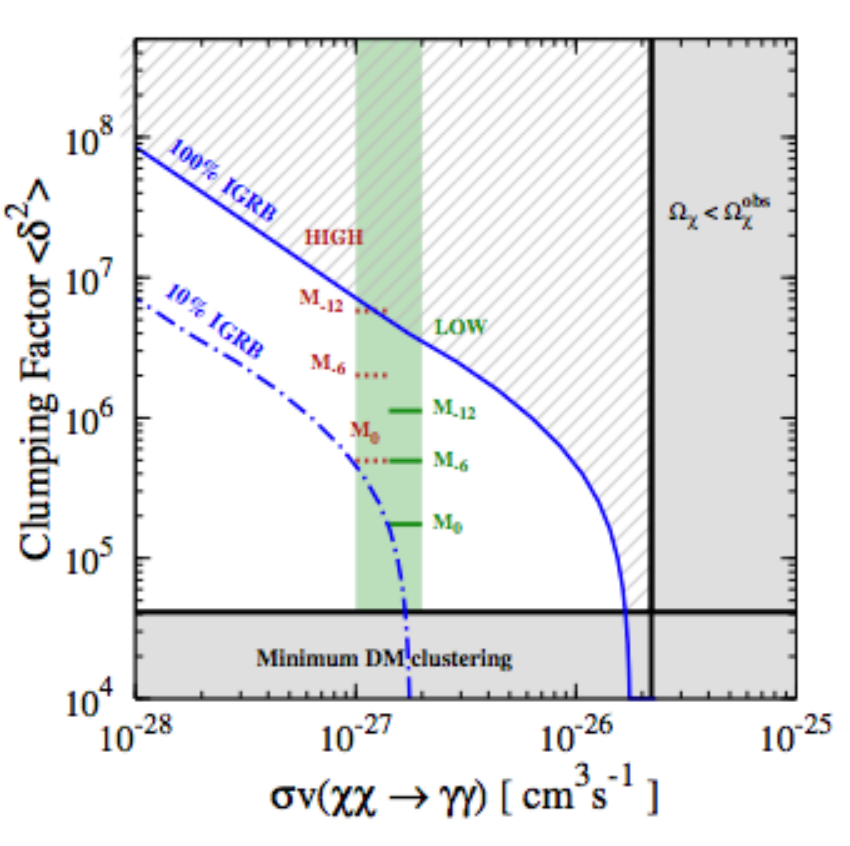
Recent measurement

IGRB(isotropic Gamma Ray Background)

IGRB includes isotropic galactic and extragalactic components.

in extragalactic,
we use clumping factor $< \delta^2 >$
instead of J-factor.

$$< \delta^2 >= \frac{< \rho_{DM}^2 >}{\bar{\rho}_{DM}^2}$$



Because IGRB does not have the peak thought to be the thing of the dark matter, it can constrain mass and cross section of the dark matter.

Summary

- It is sure that DM exists from various experiments.
- Observation of DM includes direct detection and indirect detection(cosmic ray).
- Cosmic ray measurement can probe DM.